Kreative Techniken zur Ideenfindung

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Es gibt für viele geniale Einfälle schon zahlreiche Patente. Was viele nicht wissen ist, dass man durch Verbesserungen bestehender Patente recht leicht an ein eigenes Patent gelangen kann. Es lohnt sich ebenfalls etwas Neues zu entwickeln (so bekommt man statt ein paar Krümeln vielleicht sogar eine ganze Torte). Falls ein genialer Einfall nach erster Abschätzung und Prüfung nicht umsetzbar sein, so muss man ihn nicht zwangsläufig verwerfen. Mit geeigneten Problemlösungsstrategien und Kreativtechniken ist manchmal trotzdem eine Umsetzung möglich, wenngleich diese Techniken oft zu völlig anderen Ansätzen führen.

Welche Kreativtechniken können hier Anwendung finden?

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- Denkhüte und Denkstühle
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Brainstorming

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Das Brainstorming ist eine der beliebtesten Kreativitätstechniken. Es ist geeignet für Gruppen zwischen vier und acht Teilnehmern. Obwohl mehrere Studien die Effektivität dieser Methode kritisieren, wird dieser Klassiker dennoch in zahlreichen Unternehmen eingesetzt.

Was kann Brainstorming?

Durch die Technik des Brainstormings wird innerhalb kurzer Zeit eine Vielzahl von Ideen produziert. Sie führt sowohl zu zahlreichen Denkanstößen als auch zu sehr originellen Lösungen, die sich effektiv weiterverarbeiten lassen. Dies trifft insbesondere dann zu, wenn sie noch am Anfang stehen und noch sehr viele Ideen benötigen, um eine konkrete Fragestellung zu beantworten. Das Brainstorming ist insbesondere für jene Bereiche geeignet, in denen die Art der Lösungsvorschläge eine breite Streuung zeigen soll. Beispiele hierfür sind Bereiche, die die Gruppe selbst betreffen, wie bei der Frage: „Wie kann ich effektiver arbeiten? Auch wenn Experten aus unterschiedlichen Bereichen zusammenarbeiten müssen, ist das Brainstorming die Methode der Wahl.

Weniger geeignet ist das Brainstorming, um komplexe Probleme zu lösen oder wenn ein bestimmtes Spezialwissen erforderlich ist, welches die Gruppe nicht besitzt. Diese Technik funktioniert nur dann effektiv, wenn alle Teilnehmer in der Gruppe gleichrangig sind.

Um eine Brainstorming Sitzung durchzuführen benötigen sie eine Gruppe mit 4 bis 8, maximal 15 Teilnehmern. Weiterhin bedarf es eines Moderators, der die Vorschläge auf einem Flipchart, einer Tafel oder Moderationswand aufzeichnet bzw. protokolliert. Eine solche Sitzung dauert ca. 15 bis 20 Minuten in der Ideenfindungsphase und 30 bis 40 Minuten in der Bewertungsphase.

Brainstorming zeichnet sich durch seine ungemein hohe Flexibilität aus, welche in fast allen Bereichen Anwendung findet, in denen kreativ gedacht werden soll.

Ablauf einer Brainstorming Sitzung

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Ein Moderator präsentiert das Thema und erläutert die Regeln, sofern sie den Teilnehmern noch nicht bekannt sind. Die Einhaltung der Regeln wird vom Moderator überwacht. Die Teilnehmer sollen spontan Vorschläge äußern, welche vom Moderator dokumentiert werden.

Die vier Grundregeln

- Solange nicht alle Vorschläge geäußert wurden, darf nicht beurteilt werden. Jede Kritik ist untersagt.
- Jeder Vorschlag ist willkommen, und sei er auch noch so ungewöhnlich. Der Grund ist: es ist leichter, ungewöhnliche Ideen durch die anschließende Bewertungsphase abzuschwächen, als sie zu entwickeln.
- Die Quantität geht vor Qualität, das heißt es sollen so viele Vorschläge wie möglich entwickelt werden.
- Es ist gestattet die Ideen anderer aufzugreifen, sie weiterzuentwickeln oder neu zu kombinieren.

Ideen Sturm mit zwei Wellen

Es ist ein interessantes Phänomens das nach fünf bis zehn Minuten den Teilnehmern die Ideen ausgehen. Sie sollten jedoch die Sitzung auf keinen Fall abbrechen, auch wenn es so aussieht, als wenn keinem mehr etwas einfiele. Wenn sie weitermachen, werden sie feststellen, dass den meisten Teilnehmern nach kurzer Zeit weitere Vorschläge einfallen; zwar nicht mehr so viele, aber häufig wesentlich originellere. Es lohnt sich in jedem Fall die zweite Welle der Ideen abzuwarten. Es kommt bei manchen Gruppen vor, dass sie auch noch eine dritte Welle der Ideenproduktion erfolgreich abschließen.

Bewertung

Nach der Ideenproduktion folgt die Bewertungsphase. Nach der Phase der Ideenproduktion haben sich alle Teilnehmer der Gruppe eine Pause verdient. Oftmals ist es sinnvoll mit der Bewertungsphase erst am darauf folgenden Tag zu beginnen. Die Teilnehmer müssen für die Bewertung von der flexiblen Kreativität zur Objektivität wechseln. an dieser Stelle ist die zuvor verbotene sachliche Kritik durchaus erwünscht, und so manche ungewöhnliche Idee muss eine Prüfung auf Brauchbarkeit über sich ergehen lassen.

Von den Teilnehmern werden alle Vorschläge bewertet. Die Kriterien sind Praktikabilität und Gefühlsmäßiger Anspruch. Es sollte eine Rangfolge der Ideen festgelegt werden, in der sie bearbeitet werden. Oder sie wählen nur einzelne Ideen aus, die weiter ausgearbeitet werden. Die restlichen Ideen können anhand der Osborn-Checkliste (kommt später) weiterbearbeitet werden.

Welche Rolle hat der Moderator?

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Das Gelingen des Brainstormings hängt entscheidend von der guten Moderation ab. Es ist dem Moderator nicht erlaubt sich einzumischen oder gar in den Vordergrund zu spielen und auf keinen Fall dürfen Vorschläge von ihm gemacht werden. Seine Aufgaben sind die folgenden: Er soll

- für eine vertrauensvolle Atmosphäre sorgen
- alle Teilnehmer ermutigen, mitzumachen.
- auf die Einhaltung der Regeln achten und verhindern, dass in der Phase der Ideenfindung schon Bewertungen vorgenommen werden
- alle Vorschläge dokumentieren, ohne selbst zu kommentieren oder sie abzuändern.
- die Bewertung leiten, ohne selbst Stellung zu nehmen.
- die Sachlichkeit der Bewertung gewährleisten.

Wie sollte die Gruppe zusammengesetzt sein?

Am günstigsten sind die Voraussetzungen, wenn es sich um ein eingespieltes Team in der Gruppe handelt. Sehr hinderlich ist, wenn es innerhalb der Gruppe zu einem ausgeprägten Konkurrenzneid oder zu Statuskämpfen kommt. Es ist weiterhin umstritten, ob es sinnvoll ist ein Brainstorming mit zufällig zusammengestellten Teilnehmern durchzuführen. Manche halten die doch genau dies für die besten Voraussetzungen dafür viele Anregungen aus unterschiedlichen Blickwinkeln zu bekommen.

Ist Brainstorming ein kreatives Allheilmittel?

Die Hochzeit des Brainstormings waren die sechziger und siebziger Jahre. In der Zwischenzeit jedoch, haben mehrere Studien Zweifel an der Wirksamkeit dieser Methode aufgebracht. In diesen Studien wird in Frage gestellt, ob Brainstorming zwangsläufig zu mehr und besseren Ergebnissen führt, als wenn jeder Teilnehmer separat nach einer Lösung sucht. Man ist sich heute einig, dass Brainstorming eine der wichtigsten Kreativitätstechniken ist, die auch von ihren Kritikern als eine höchst effiziente Technik zur Stimulierung des kreativen Denkens dargestellt wird. Es lässt sich anhand vieler Beispiele belegen, dass sie zu brauchbaren Ergebnissen führt.

Es gibt einige Varianten des Brainstormings. Ein populäres Beispiel ist das Destruktiv-Konstruktiv-Brainstorming. Hierbei ist die Phase der Ideenfindung zweigeteilt: negative Ideen, die eine Lösung verhindern können, sollen zunächst gesammelt werden. In der anschließenden Phase dürfen die Teilnehmer konstruktive Vorschläge äußern. Auf diese Weise sind reichere und originellere Ideen zu erwarten.

Im Kontrast zum Gruppen Brainstorming gibt es noch das Einzel Brainstorming. In diesem Fall sind Ihr eigener Moderator, durchlaufen wie bereits beschrieben ein Ideenfindungsphase, in der sie in jedem Fall noch keine Bewertung vornehmen sollten, und werden diese Ideen hinterher kritisch bewerten. Bei diesem Verfahren müssen sie sehr diszipliniert sein, was sich jedoch mit ein wenig Übung bewerkstelligen lässt. Auch hier ist es anzuraten, nicht gleich nach der Ideenfindungsphase mit der Bewertungsphase fortzusetzen, sondern vielleicht ein oder zwei Tage verstreichen zu lassen.

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Brainwriting

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Brainwriting

Das Brainwriting funktioniert ganz ähnlich wie das Brainstorming, der Hauptunterschied ist der, dass alle Einfälle schriftlich festgehalten werden. Man unterscheidet zwischen zwei sehr unterschiedlichen Varianten:

- Die bekanntere, die Methode 635, welche auf die Kreativität fördernde Wirkung von akutem Stress setzt. Diese Methode produziert wesentlich mehr Ideen als beim Brainstorming, die zudem noch durch die Originalität spontaner Antworten geprägt sind.
- Die Collective-Notebook-Methode, welche langwieriger aber auch wesentlich gründlicher, sowie zeitlich und räumlich flexibler ist.

- **Was kann Brainwriting leisten?**

Neben den Vorteil, dass beim Brainwriting wesentlich mehr Ideen produziert werden als beim Brainstorming, gesellen sich noch weitere, wie die Tatsachen:

- dass gruppendynamische Prozesse kaum eine Rolle spielen
- die Zahl der Teilnehmer theoretisch unbegrenzt ist
- kein Moderator benötigt wird, der manchmal Kreativität eher verhindert, als sie zu fördern.

Brainwriting ist besonders geeignet, wenn:

- einfache und klar strukturierten Frage vorliegen (Methode 635), aber auch komplexere Probleme (collective Notebook)
- Teilnehmer schwer verfügbar sind (collektive Notebook)
- es in der Gruppe Kommunikation Probleme gibt oder aber keinen Moderator zur Verfügung steht

-

Brainwriting ist dagegen weniger geeignet:

- Zur Lösung komplexer Fragen (Methode 635)
- Wenn starke Unterschiede im Erfahrungs- und Wissenshorizont der einzelnen Teilnehmer bestehen
- Wenn die Zahl Lösungen *a priori* stark eingeschränkt ist.

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Was wird für ein Brainwriting benötigt?

Was wird für ein Brainwriting benöti

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Was wird für ein Brainwriting benötigt?

- Eine Gruppe, die im Idealfall aus sechs Teilnehmern besteht (Methode 635), die Teilnehmeranzahl kann jedoch auch variabel sein.
- Schreibwerkzeug und Papier (im Idealfall dafür vorbereitete Vordrucke) oder ein vernetztes Computersystem.

-

Wie ist Ablauf beim Brainwriting?

Methode 635

Ein Blatt auf dem die Fragestellung vorformuliert ist, wird jedem Teilnehmer ausgehändigt. In den nächsten fünf Minuten sollen drei Lösungsvorschläge auf dem Blatt notiert werden. Danach reicht der Teilnehmer das Blatt an seinen Nachbarn weiter. Im Gegenzug bekommt er dessen Blatt. Auf dieses Blatt soll er in den folgenden fünf Minuten drei neue Ideen hinzufügen, wobei er sich idealerweise von den bereits bestehenden Vorschlägen inspirieren lässt. Danach wird auch dieses Blatt wieder weitergegeben.

Wenn jeder Teilnehmer jedes Blatt gehabt hat ist die Sitzung beendet. Bei sechs Teilnehmern sollte also nach einer guten halben Stunde ein Pool von 108 Lösungsvorschlägen bereitliegen. Die Auswertung verläuft wie beim Brainstorming.

Auch diese Methode lässt sich nach der bereits beschrieben Collective-Notebook-Methode durchführen. Hierbei erhält jeder Teilnehmer ein Notizbuch mit der Problemstellung. Innerhalb einer bestimmten Frist soll er das Problem analysieren und die Vorschläge darin notieren. Der Austausch dieser Notizbücher geschieht analog nach der Methode 635.

Wenn man sich zwischen den zwei oberen vorgestellten Methoden entscheiden muss, sollte man sich vor Augen halten, dass die erste Methode die Teilnehmer sehr unter Druck setzt. Sie müssen innerhalb kürzester Zeit eine Vielzahl von Ideen produzieren, was nicht selten ein Grund für eine Denkblockade ist. Der Vorteil dieses Stresses ist allerdings auch, dass die Teilnehmer gezwungen sind, sich zu konzentrieren und sich nicht in der Gruppe verstecken können. Im Vergleich zum Brainstorming kommen auf diese Weise nicht nur wesentlich mehr Ideen zustande, sondern der gesamte Ablauf führt dazu, dass die Teilnehmer gedanklich neue Wege einschlagen müssen.

Der Effekt ist, dass erstaunlich viele Entdeckungen zu machen sind. Es wird von vielen als angenehmer Nebeneffekt empfunden, wie kreativ und produktiv sie eigentlich sein können.

Die Collective-Notebook-Methode dagegen erfordert ein hohes Maß an Selbstdisziplin. Der Vorteil ist sicher, dass die Teilnehmer sich ihre Zeit frei einteilen können. Dadurch fällt allerdings auch der vorgenannte Stress mit seinen positiven Effekten weg. Außerdem dauert das Verfahren natürlich wesentlich länger.

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Mindmapping

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Mind Mapping

Diese Technik ist sehr schnell zu lernen, universell und fast überall einsetzbar, und es ist sehr wahrscheinlich, dass immer etwas dabei herauskommt. Diese Technik wurde von Tony Buzan entwickelt und erfreut sich außerordentlicher Beliebtheit.

Um ein Mind Mapping durchzuführen bedarf es nicht viele Werkzeuge, es schafft Übersicht und bringt sie mit einfachen Mitteln auf neue Ideen.

Was leistet Mind Mapping?

Mit den Mind Mapping wird unser bildlich-räumliches Denken stimuliert und eine neue Sichtweise wird ermöglicht. Da durch, dass wir unser Thema oder unser Problem im wörtlichen Sinne verbildlichen, können wir es neu strukturieren. Wesentliche Punkte können herausgearbeitet werden, es können leicht neue Verbindungen hergestellt werden und Nebenaspekte miteinbezogen werden. Die offene Struktur der Mind Maps hat den Vorteil, dass sie später ergänzt werden können.

Für folgende Bereiche ist das Mind Mapping besonders geeignet:

- Problemanalyse
- Überblick über komplexe Themen
- Vorbereitung von Vorträgen und Aufsätzen
- Planung und Strategie

Dass Mind Mapping hat allerdings auch seine Schwächen:

- Durch einen Mind Map entsteht leicht der Eindruck, ein Problem zu überblicken, selbst wenn dies nicht der Fall ist.
- Die entstandenen Bilder können suggestiv wirken und Ihr Denken in die falsche Richtung lenken
- Komplexe Sachverhalte werden stark verkürzt dargestellt

Was benötigt man für einen Mind Mapping?

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Dies benötigt man für einen Mind Map

- Ein mindestens DIN-A4 großes Blatt Papier
- Schreibwerkzeug, möglichst in verschiedenen Farben

-

Zeitbedarf: 20 bis 30 Minuten

Neben dem strategischen Vorteil die das Erstellen eines Mind Maps hat, funktioniert es auch sehr gut als Erinnerungstütze und versetzt Sie in der Lage auch später noch ein Thema wieder aufzugreifen und schnell die Orientierung zu finden.

Wie er stellt man einen Mind Map?

Man beginnt in der Mitte des Blattes. Dort sollte der zentrale Begriff, um den es geht, stehen. Es steht ihnen frei diesen zentralen Begriff auch bildlich darzustellen. Von diesem zentralen Bild oder Begriff beginnt man nun mehrere Linien abzweigen zu lassen. Auf jede diese Linien wird ein Begriff geschrieben, den man aus dem vorgegebenen Thema ableiten kann. Dabei sollte man nicht zu lang überlegen, sondern einfach, was einem in den Sinn kommt, niederschreiben.

Nehmen wir als Beispiel das Thema Effektivität. Hier lassen sich Begriffe ableiten wie etwa:

- Zeit sparen
- Schnelligkeit
- Ökonomie
- Gewinnbringend
- Hilfsmittel.

- Von diesen Begriffen ausgehend fallen einem wieder Andere ein, die auf neue Linien beschrieben werden. Nach und nach werden Zusammenhänge erkennbar, die es ermöglichen, auch abseitige Aspekte zu betrachten. Zunehmend füllt sich ihr Blatt. Sobald man das Gefühl hat, man hat das Wichtigste notiert, ist das Mind Map vorläufig fertig. Ein Beispiel für ein Mind Map ist auf der nebenstehenden Abbildung dargestellt.

Die sieben Grundregeln des Mindmapping

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Tony Buzan, der Erfinder des Mind Maps hat sieben Grundregeln formuliert, nach denen ein Mind Map zu gestalten ist:

- Beginnen sie mit einem farbigen Bild in der Mitte
- Schreiben Sie alle Wörter in Großbuchstaben, das fördert die Übersichtlichkeit.
- Die Wörter sollen auf Linien stehen, wobei jede Linie mit anderen Linien verbunden ist
- Verwenden Sie nach Möglichkeit nur ein Stichwort pro Linie
- Benutzen sie möglichst viele Farben
- Ignorieren sie kontrolliertes denken und halten Sie möglichst alles fest, was ihnen im Zusammenhang mit der Zentralidee in den Sinn kommt.

- Beispiel

Um Mind Maps noch übersichtlicher zu gestalten, steht es Ihnen frei individuelle Symbole zu verwenden. Sie verwenden diese Symbole einheitlich, um beispielsweise Fragen, Ziele oder Wünsche gegeneinander abzugrenzen.

Wie kann man Mind Maps effektiv nutzen?

Wenn sie gerade damit anfangen sich mit einem Thema zu beschäftigen, ist es sehr sinnvoll ein Mind Map zu erstellen.

Schreiben Sie alles auf, was ihnen einfällt, und sie werden sich wundern, wie viel sie bereits über dieses Thema wissen, selbst wenn sie geglaubt haben noch gar nichts zu wissen.

Wenn sie beginnen ein Mind Maps in die Praxis umzusetzen, so sollten sie das Mind Map kontinuierlich ergänzen, um es den gegenwärtigen Umständen anzupassen. Irgendwann kann es natürlich passieren, dass ein Mind Map unübersichtlich wird. Dies ist der beste Zeitpunkt ein neues anzufangen. Denn ein aktuelles Mind Map lässt sich auch am besten nutzen.

Sobald dann meint man fertig ist, sollten sie es sich sehr genau anschauen und vielleicht mit jemand anderem darüber reden. Möglicherweise ergeben sich neue Zusammenhänge die sie dazu verleiten neue Prioritäten zu setzen.

Seien Sie jedoch vorsichtig, obwohl ein Mind Map fast immer sehr strukturiert aussieht, muss das nicht bedeuten, dass damit das Problem auch strukturiert gelöst ist. Machen Sie sich die Grenzen dieser Technik genau bewusst. Nur dann können sie Mind Mapping wirklich effektiv und zielführend einsetzen.

Die Individualität der Mind Maps macht es schwierig die, von fremden Personen Erstellten zu verstehen. Sie sollten sich diese, so Sie daran interessiert sind, genau erklären lassen. Nur so lassen sich Missverständnisse der individuellen Schreibweise verhindern.

Es gibt eine Variante des Mind Mapping die bei komplexen Problemen zielführend ist.

Sie notieren die einzelnen Schlüsselbegriffe und Ideen nicht direkt in das Mind Map, sondern zunächst auf Kartei Karten oder Haft Notizen. Diese können dann leicht auf dem zu erstellenden Mind Map verschoben, weggenommen oder neu kombiniert werden. Obwohl mit dieser Technik die Gestaltungsmöglichkeiten nicht so groß sind, sind sie doch wesentlich flexibler. Sind sie mit ihrem Ergebnis zufrieden, sollten Sie daraus möglichst bald ein „echtes Mind Map herstellen, ansonsten ist das Ergebnis äußerst flüchtig.

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Bei der Frage „Woher kreative Leistungen kommen stößt man relativ schnell auf das Prinzip der Bisoziation. Bei dieser Technik wird in zwei, vorher unverbundenen Denkdimensionen gedacht. Ein sehr schönes Beispiel ist Johannes Gutenberg. Als er die Merkmale der Weinpresse mit denen des Münzprägestempels verband, erfand er die Druckpresse mit beweglichen Lettern.

Was leistet die Bisoziation?

Hier handelt sich um eine sehr vielseitige Technik. Ihre Effektivität hängt sehr stark von der Wahl der beiden Denkdimensionen ab. Das Prinzip der Bisoziation liegt auch anderen Kreativitätstechniken zugrunde, die später noch beschrieben werden. Bei diesen wird Ihnen die Wahl der zweiten Denkdimension jedoch abgenommen.

Für die folgenden Bereiche ist die Technik der Bisoziation besonders geeignet:

- Technische Probleme und Erfindungen
- Im künstlerischen Bereich
- Gut strukturiertes Fragen und Probleme

Die Technik hat aber auch ihre Schwächen:

- Es ist besser vorher zu wissen, wo sie suchen müssen
- Sie kann sehr langwierig sein
- Brauchbarer Analogien sind relativ selten, prüfen Sie daher jeder Einzelne sorgfältig.

Die folgenden Dinge benötigen Sie für die Technik der Bisoziation:

- Beobachtungsgabe
- Fantasie
- Zeit
- Neugier
- Glück
- fachliche Kompetenz
- strukturelle Intelligenz

Je nach Fragestellung, benötigen sie von diesen Dingen mehr oder weniger.

Dauer: diese Technik kann sehr zeitaufwendig sein, daher empfiehlt sich eine zeitliche Begrenzung für diese Gruppen Sitzung anzusetzen (zwei bis vier Stunden). Die Technik der Bisoziation ist eine äußerst flexible Denktechnik, die sich auf viele Fragestellungen anwenden lässt.

Auf welche Weise lassen sich nun geeignete Bisoziation und finden?

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Bei der Lösungssuche werden vier Phasen durchlaufen:

- Problemdefinition
- Auffinden der zweiten den Denkimension
- Erkennen von Analogien
- Transfer der Lösung

Das Problem definieren

Das Problem sollte zu Beginn klipp und klar definiert werden. Beispiel: Sie möchten ein Werkzeug konstruieren, dass sehr vielseitig ist und trotzdem in jede Hosentasche passt.

Sie sollten sich fragen: „worum geht es hier eigentlich? Die beste Taktik ist, das Problem von möglichst vielen Seiten einzukreisen. Erstellen Sie eine Liste, welche die Anforderungen ihre Lösung erfüllen muss.

Finden sie den Einstieg in die zweite Denk Dimension.

An dieser Stelle fängt die Sache an, kreative Leistung zu fordern: es ist nicht leicht die zweite Denkdimension aufzuspüren, die geeignet ist, Ihr Problem zu lösen.

Der beste Einstieg ist die Überlegung, was ist so ähnlich, was sie erreichen möchten. Warum funktioniert etwas in einem Bereich, welches bei ihnen nicht funktioniert. Dabei ist es unerheblich, wie weit sie sich von ihrem Ausgangspunkt entfernen. Ob sie sich bei der Entwicklung ihres Werkzeugs, welches in jede Hosentasche passen soll, von Insekten, Regenschirmen oder anderen Dingen, die es vielleicht schon gibt anregen lassen, ist völlig unerheblich solange die Sache funktioniert.

Analogien erkennen

Dies ist eine der wichtigsten Teile dieser Technik: sie sollten sehr aufmerksam sein, nach Analogien und gemeinsame Prinzipien suchen. Am besten ist es wenn sie die Gesetzmäßigkeiten erkennen und prüfen ob sich diese in ihrem Bereich übertragen lassen.

Das heißt nicht, dass sie in diesem fremden Bereich zum Experten werden müssen. Dies wäre unter Umständen sogar nachteilig. Das heißt, dass ein Flugzeugkonstrukteur, der die Flügel eines Vogels untersucht, nicht zum Vogelkundler werden muss. Aber oftmals ist es hilfreich einen solchen Experten zu befragen.

Bei der Suche nach Analogien sollten sie auch nahe liegende Bereiche berücksichtigen. Denn nicht immer ist die Entfernteste auch die beste Lösung: wenn Sie ein Werkzeug entwerfen wollen müssen Sie also nicht unbedingt ein Vorbild in der Natur suchen, manchmal reicht es auch aus ein wenig bei anderen Herstellern zu spionieren. Dies klingt natürlich sehr naheliegend und wenig kreativ, doch in vielen Fällen kommen so nicht nur gute sondern auch äußerst kreative Ideen zustande. Damit sind wir noch nicht am Ende angekommen, denn der entscheidende Schritt steht ihnen noch bevor: sie müssen die Lösung auf ihren Bereich übertragen.

Der Transfer

Eine gute Idee aus anderen Bereichen einfach zu übernehmen klingt vielleicht einfach, ist jedoch nicht ausreichend. Sie muss in dem neuen Bereich, den sie anstreben, auch funktionieren. Das heißt, es müssen in der Regel noch einige Dinge verändert werden. Wie Sie sich sicher vorstellen können, fliegt ein Flugzeug eben nicht genauso wie ein Vogel, weshalb zwei Elemente des Flügels übernommen werden können, andere jedoch möglicherweise abgeändert werden müssen. Dann heißt es, dass sie die Idee ihrer Routine anpassen müssen. Denn erst dann zeigt sich, ob sie wirklich brauchbar, und damit kreativ ist.

Die oben vorgestellte Strategie erinnert uns berechtigterweise an den Forschungsbereich der **Bionik**. In einem Bereich werden viele Erfinder und Konstruktor fündig: der Natur. Sie kennen sicher die geniale Erfindung des Klettverschluss, welche sich von ihrem Vorbild den eher lästigen Kletten ableitet. Die Hautoberfläche von Delphinen und Haien inspirierte Konstrukteure, die Fortbewegung von U-Boten zu optimieren. Die Übertragung von Vorbildern aus der Natur in den Bereich der Technik heißt Bionik und gilt als außerordentlich leistungsfähige Methode.

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Hierbei handelt sich um einen Klassiker der Kreativitätstechniken, der Anfang der sechziger Jahre von dem Amerikaner William Gordon entwickelt wurde. Es handelt sich hier um eine recht anspruchsvolle Verfremdungsmethode die auch von zahlreichen namhaften Unternehmen eingesetzt wird. In abgewandelter Form lässt sie sich auch von Einzelpersonen nutzen. Im Prinzip arbeitet die Synektik ähnlich wie die Bisoziation. Jedoch weicht sie in einem entscheidenden Punkt wesentlich ab: Sie suchen sich nicht irgendeinen selbst gewählten fremden Bereich, in dem sie nach Anregungen für ihre Lösung forschen, sondern sie entfernen sich über drei bis vier Verfremdungsschritte immer weiter von ihrem Problem.

Was leistet Synektik?

Dadurch, dass sie ihren Problemkreis gedanklichen weit verlassen, ermöglicht diese Technik, dass Sie unvoreingenommen und ohne Scheu oder Betriebsblindheit an ihr Problem heran gehen und es lösen.

Die Synektik ist für folgende Bereiche besonders geeignet:

- Ausgesprochen schwierige Probleme
- Neue Entwicklungen oder Produkte
- Versierte Problemlöser als Teilnehmer

Auch die Synektik hat ihre Schwächen, denn sie ist **für Anfänger grundsätzlich ungeeignet.**

Die folgenden Dinge benötigen Sie für eine Synektik Sitzung:

- Vier bis acht Teilnehmer
- Einem Moderator
- Einen Protokollanten (das kann auch vom Moderator übernommen werden)
- Eine Tafel, Flipchart- oder Moderationswand zum Aufzeichnen der Vorschläge

Dauer: 4 bis 8 Stunden

Diese Technik ist nicht nur außerordentlich aufwändig, sie ist auch sehr anspruchsvoll und fordert viel von Teilnehmern und Moderator.

Ablauf einer Synektik Sitzung

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1. Das Problem wird formuliert

Diese Phase dauert ungefähr 15 bis 30 Minuten. Zu Beginn informiert der Moderator die Teilnehmer über den zeitlichen Ablauf der Sitzung und erklärt das Problem. Zu diesem Zeitpunkt können auch noch Verständnisfragen geklärt werden. Alle notwendigen Informationen müssen zu diesem Zeitpunkt verstanden sein. Sollte einer der Teilnehmer ergänzende Information und bereit haben, so sollte er sie der Gruppe nicht vorenthalten.

2. Brainstorming

Dauer dieser Phase ist 10 Minuten. In einem kurzen Brainstorming werden spontane Lösungsvorschläge gesammelt. Dies hat den Vorteil, dass die Teilnehmer unbelastet in den eigentlichen Synektik Prozess eintreten können. Die Ideen werden formuliert und z.B. auf den Flipchart notiert, zu diesem Zeitpunkt jedoch noch nicht ausgewertet.

3. Formulieren sie das Problem neu

Dauer: 5 bis 10 Minuten. Meistens ergeben sich durch das Brainstorming neue Aspekte. Dann kann es sinnvoll sein das Problem um zu formulieren mit dem Hintergrund, dass alle Teilnehmer von der gleichen Fragestellung ausgehen. Ob das nötig ist wird vom Moderator entschieden.

4. Bilden sie eine so genannte direkte Analogie

Dauer dieser Phase:20 Minuten.

Nach den Regeln der Bisoziation wird versucht eine Entsprechung des Problems aus einem anderen Bereich zu finden. Dieser Bereich wird in der Regel vom Moderator vorgegeben und ist in den meisten Fällen aus dem Bereich der Natur. Auch hier ist die Natur wieder so beliebt, weil fast jedes Problem auf dieses Gebiet projiziert werden kann. Nun werden die Antworten gesammelt und am Ende wählt die Gruppe eine Antwort aus.

5. Bilden sie eine persönliche Analogie

Dauer:20 Minuten.

Die Antwort aus der letzten Phase bildet den Ausgangspunkt für ihre persönliche Analogie. Jeder Teilnehmer versucht sich in den Gegenstand hinein zu versetzen und stellt sich die Frage " Wie fühle ich mich/verhalte ich mich als...?" Auch hier wird von der Gruppe ein Vorschlag ausgewählt.

6. Finden Sie eine symbolische Analogie

Dauer:10 Minuten.

Wieder wird ausgehend vom Vorschlag aus dem Vorhergehenden Schritt von den Teilnehmern nach ungewöhnlichen Vergleichen gesucht. Hier jedoch kommen die Vergleiche aus dem Bereich der Formen, Bilder oder Klänge. Es geht hierbei um die Verdichtung des Gefühls. Dabei können auch recht widersprüchliche Vergleiche und Paradoxa wie "Strahlende Dunkelheit" gebildet werden. Am Ende entscheidet wieder die Gruppe mit welcher Lösung weiter gearbeitet wird

7. Bilden sie eine zweite direkte Analogie

Dauer:20 Minuten.

Hier sollte die Lösung denkbar weit von der Ursprungsfrage entfernt sein. Es soll noch einmal auf einen bestimmten Bereich projiziert werden. Wurde im Schritt vier der Bereich Natur ausgewählt, so ist es nun häufig der Bereich Technik, der zum Einsatz kommt. Alle stellen sich auch hier wieder die Teilnehmer eine Frage: " auf welche technischen Geräte oder Verfahren könnte die Antwort des vorhergehenden Schrittees zutreffen?" Hier können ebenfalls eine bis drei Lösungen ausgewählt werden

8. Analysieren Sie die Analogien

Dauer dieser Phase:20 Minuten.

Ziel ist es eine Liste der Merkmale und Funktionsprinzipien der ausgewählten Analogien aufzuzeichnen. Was zeichnet die gefundenen Geräte oder Verfahren aus?

9. Force fit

Dauer:30 Minuten.

Dies ist die entscheidende Phase: die zuvor aufgestellte Merkmalsliste wird nun auf die Ausgangsfrage zurückbezogen. Welche Bedeutung haben die Merkmale dieser Liste in Hinsicht auf unser Problem?

Wurde zuvor in vier Schritten ein großer Abstand zur Ausgangsfrage erzielt, so müssen nun die Teilnehmer nun mit einem Riesensatz zurückspringen und brauchbare Ideen finden. Wichtig ist jedoch, dass sie sich auf eine Lösung einigen müssen, wie auch immer diese aussieht, denn dieser Schritt heißt nicht ohne Grund „force fit oder übersetzt: "erzwungene Einigung".

Die Methode der Synektik ist nicht ganz unproblematisch, denn der Zwang zu kreativen Ideen kann eine sog. kreative Denkfalle öffnen, mit dem Ergebnis, dass die Teilnehmer die abwegigsten Ideen produzieren, die sich nie in die Praxis umsetzen lassen. Aus diesem Grund ist das „Force Fit ein unbedingter Bestandteil dieser Methode, die er sowohl von den Teilnehmern als auch vom Moderator ein Höchstmaß an Fantasie und Konzentration abverlangt. Es empfiehlt sich daher vor diesem Schritt eine Pause einzulegen.

10. Formulieren sie Lösungsansätze

Dauer:20 Minuten.

Ausgehend von den Ideen aus der letzten Phase, formuliert die Gruppe ihre Lösungsansätze. Dabei ist weniger die Anzahl der Lösungsansätze wichtig, als dass diese auch weiter ausgearbeitet werden können. Damit ist das Ziel der synektischen Sitzung erreicht.

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Es gibt Kreativitätstechniken die darauf beruhen, dass sich der Anwender in eine Situation oder gar in einer Person oder Rolle hinein versetzt. Stellen Sie sich die Frage: " was würde ein zehnjähriges Kind dazu sagen?" Obwohl diese Techniken vielfach als unseriös angesehen werden, sind sie oft erstaunlich effektiv; flexibel und auch sehr erfolgreich. Obwohl Sie sich prinzipiell in jede Rolle hinein versetzen könnten, gibt es Technikern die es nicht bei unverbindlichen Vorgaben belassen. Auf diese Art und Weise sind die "6 Denkhüte" von De Bono oder die " drei Denkstühle " von Walt Disney entstanden.

Was leisten solche Techniken?

Diese Techniken versetzen Sie in der Lage, ihr Problem aus unterschiedlichen Perspektiven zu durchdenken. Dabei werden alle Aspekte erfasst, und zwar wesentlich effizienter, als wenn sie " direkt " darüber nachdenken. Sie können wesentlich spielerischer und „rücksichtsloser vorgehen, wenn sie sich in bestimmte Rollen oder Standpunkte projizieren. Dies erweitert ihren Ideenradius erheblich.

Die Stärken dieser Techniken:

- Ermöglicht eine Distanz zu ihrem Problem
- Betrachtet das Problem aus mehreren Perspektiven
- Kann bei Gruppensitzungen Spannungen lösten

Aber auch hier gibt es Schwächen:

Die Technik bleibt verhältnismäßig nah an ihrem gewohnten Denken; wenn sie kreativer sein möchten, sollten Sie auf andere Techniken zurückgreifen.

Die Technik wirkt zunächst etwas unnatürlich; ihre Wirksamkeit entfaltet sich erst nach einiger Übung

Im Folgenden werden diese Techniken am Beispiel von Disney´s Denkstühlen erklärt.

Von Walt Disney wird berichtet, dass es sich bei seiner kreativen Arbeit nacheinander in verschiedenen Rollen versetzt hat:

- Die des Träumers
- Des Realisten
- Des Kritikers

Disney habe diese Rollen zuvor ist so gut wie möglich getrennt. Dies tat er daher durch, dass er beim Wechsel der Rolle auch seinen Platz in seiner Firma wechselte. So soll er zunächst drei unterschiedliche Denkstühle gehabt haben, später sogar drei unterschiedliche Räume für seine unterschiedlichen Denkhaltungen.

So setzen Sie diese Strategie für sich ein

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So setzen Sie diese Strategie für sich ein:

- Sie nehmen nacheinander verschiedene Denkhaltungen ein
- Diese Denkhaltungen verknüpfen sie mit bestimmten Ort zum „Verankern
-

Es ist ganz normal, dass sie zu Beginn etwas Mühe haben werden, sich in die entsprechende Denkhaltung hinein zu finden. Dies wird durch die Verbindung mit einem festen Platz erleichtert.

Der Stuhl des Träumers

Auf diesem Stuhl produzieren sie die fantastischsten Einfälle und spielen mit verschiedenen Möglichkeiten und auch Unmöglichkeiten. Sie dürfen fast alles, nur eines sollten sie tunlichst unterlassen: ernsthaft über das Problem nachzudenken. Spinnen sie ihre Ideen und Vorstellungen und bringen sie sie zu Papier.

Der Stuhl des Kritikers

Unterziehen sie ihre Ideen einer schonungslosen Kritik. Sie sollten prüfen, was sich umsetzen lässt und was nicht. Sie sollten sich die Frage stellen, ob sich die Sache lohnt und ob sie sie überhaupt wollen. Was überflüssig ist, sollte jetzt gestrichen werden.

Der Stuhl des Realisten

An diesem Platz kommen sie wieder zur " Normalität " zurück. Sie versuchen die verrückten Ideen des Träumers weiterzuentwickeln, greifen Anregungen auf und suchen schon jetzt nach neuen Lösungen. Weiterhin wählen Sie den kürzesten und zweckmäßigsten Weg aus. Dabei sollten sie sehr pragmatisch vorgehen.

Der Wechsel der Stühle

Sie sollten nicht zu lange auf einer bestimmten Stufe verweilen. Auch während der Fragestellung können sie mehrmals die Stühle wechseln. Wenn sie das Projekt abschließen wollen, sollten sie im Idealfall auf dem Stuhl des Realisten sitzen.

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Alex Osborn, der Erfinder des Brainstorming, hat noch weitere Kreativtechniken entwickelt. Die Bekannteste ist die nach ihm benannte Checkliste, mit der Sie aus bereits existierenden Ideen neue Lösungen kreieren können.

Was leistet die Osborn- Checkliste?

Sollte die Lösung für ein vorhandenes Problem nur konventioneller oder unbefriedigender Natur sein, so können Sie anhand der Checkliste überprüfen, wo etwas verändert werden kann, um eine kreativere Lösungen zu finden.

Die Osborn- Checkliste ist besonders geeignet:

- Bei bereits vorliegenden Ideen oder Produkten
- Die Nachbearbeitung einer Brainstorming Sitzung
- Zum Auffinden origineller Produktideen

Diese Technik ist weniger geeignet:

- Wenn man erst am Anfang ganz Projektes steht
- Texte und Verfahren
- Wenn Originalität nicht gefragt ist

Es was benötigen sie um diese Technik durchzuführen?

- Eine existierende Idee oder ein Produkt, welches sie verbessern möchten
- Die hier vorliegende Checkliste

Dauer: etwa eine Stunde; Unterbrechungen sind möglich.

Mit der Osborn Checkliste lassen sich schwache Ideen oder Produkte mit Kreativität "aufpeppen".

Wie wird mit der Osborn Checkliste gearbeitet?

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Für jede Idee oder jedes Produkt welches Sie bearbeiten möchten, sollten Sie die Checkliste komplett durchgehen. Sie sollten sich genügend Zeit für jeden einzelnen Punkt einräumen und zu jedem Punkt mindestens eine Ideen notieren.

- **Anderes verwenden!** - Gibt es eine andere Möglichkeit das Produkt zu gebrauchen? Können Sie die Idee woanders einsetzen?
- **Anpassen!** - Gibt es etwas, was dieser Idee ähnelt? Existieren Parallelen? Was könnten Sie nachahmen?
- **Ändern!** - Können sie die Größe, Form, Farbe, Bewegung etc. verändern?
- **Vergrößern!** - Können sie ist größer machen? Etwas hinzufügen? Die Stärke, die Höhe, den Wert, die Länge, oder den Abstand ferneren? Können Sie es duplizieren? Oder gar übertreiben, vielleicht vergröbern?
- **Verkleinern!** - Kann man es kleiner machen? Etwas wegnehmen oder tiefer machen? Geht es kürzer, dünner oder leichter? Was ist wenn sie es heller, von einer oder gar aufspalten? Kann man es als Miniatur verwenden?
- **Ersetzen!** - Was kann an dieser Idee ausgetauscht werden? Kann der Prozess anderes gestaltet werden? Lassen sich die Positionen, Tonlagen, oder Elemente durch andere ersetzen?
- **Umstellen!** - Können Teile oder Abschnitte ausgetauscht werden? Was ist mit der Reihenfolge, kann man Ursache und Wirkung umdrehen?
- **Umkehren!** - Kann man aus der Idee das Gegenteil machen? Wie sieht Idee spiegelverkehrt aus? Oder lässt sich die Idee gar um 180 Grad drehen?
- **Kombinieren!** - Lassen sich andere Ideen mit der bestehenden Idee verbinden oder kombinieren? Oder lässt sich die Idee in ein bestehendes größeres Ganzes einfügen, in Module oder Bausteine zerlegen?
- **Transformieren!** - Kann man die Eigenschaften der Idee verändern? Kann man die Idee ausdehnen, transparent machen, verhärten oder verflüssigen?

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[Bisoziation] [Synektik] [Denkhüte und Denkstühle] [Die Osborn- Checkliste]
[Wie wird mit der Osborn Checkliste gearbeitet?]
[Konzeptfächer und progressive Abstraktion]

Konzeptfächer und progressive Abstr

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Brainwriting
Mindmapping
Bisoziation
Synektik
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Konzeptfächer un
Wie geht man

Manchmal hat man sich bei einem Problem festgefahren und kommt nicht mehr weiter. Dann es ist oft sehr hilfreich, wenn sie die Betrachtungsebene ändern. Das heißt in den meisten Fällen: die Frage muss grundsätzlicher formuliert werden. Mit diesen Techniken lässt sich das Problem oft überraschend einfach lösen.

Die folgenden zwei Techniken greifen auf genau dieses Prinzip zurück. Diese Methoden wurden von Edward de Bono (Konzeptfächer) und von H. Geschka (progressive Abstraktion) entworfen.

Beide Techniken helfen systematisch eine Vielzahl von Lösungsmethoden zu entwickeln und dabei die beste Alternative zu finden.

Für folgende Fälle sind die Techniken besonders geeignet:

- Wenn man sich an einer Frage festgefahren hat
- Bei strategischen Fragen
- Wenn eine bestehende Lösung verbessert werden soll
-

Weniger geeignet sind diese Technik und für:

- Den Fall, dass sie keine Lösung oder Belegung haben, von der sie ausgehen können
- Wilde Ideen und kreative Sprünge
-

Was benötigen Sie für diese Techniken?

Wenn sie diese Techniken in Einzelarbeit durchführen benötigen sie Schreibzeug und Papier. Bei Gruppenarbeit (vier bis sechs Teilnehmer) benötigen sie einen Moderator, der auch Protokollieren kann, sowie eine Tafel oder Flipchart.

Dauer: sehr unterschiedlich und abhängig von der Aufgabenstellung; oft kommt man ganz schnell zu einer Lösung.

Die progressive Abstraktion bzw. die Konzeptfächer ermöglichen es ihnen systematisch dem Grundsätzlichen ihrer Idee auf die Spur zu kommen. Sie können, ohne die bereits geleistete Arbeit zu verwerfen, den Denkprozess noch einmal von vorne beginnen.

Wie geht man bei der Arbeit mit dem Konzeptfächern und der progressiven Abstraktion vor?

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[Konzeptfächer und progressive Abstraktion]
[Wie geht man bei der Arbeit mit dem Konzeptfächern und der prog ressiven Abstraktion vor?]

Wie geht man bei der Arbeit mit der

Das Prinzip ist simpel, einfach und einleuchtend: als Ausgangspunkt nehmen Sie die unzulängliche Lösung des Problems und versuchen es auf eine allgemeine Ebene zurückzuführen (= Abstraktion). Sie können sich auch fragen, welches Konzept hinter dieser Lösung steht. Im Folgenden werden die drei Schritte beschrieben, mit denen sie zu einer besseren Lösung kommen. Diese Abfolge ist beliebig wiederholbar.

- Worum geht es eigentlich? Legen Sie dies bitte fest.
- Sie erschließen sich Handlungsalternativen
- Sie entscheiden sich für eine Lösung

-

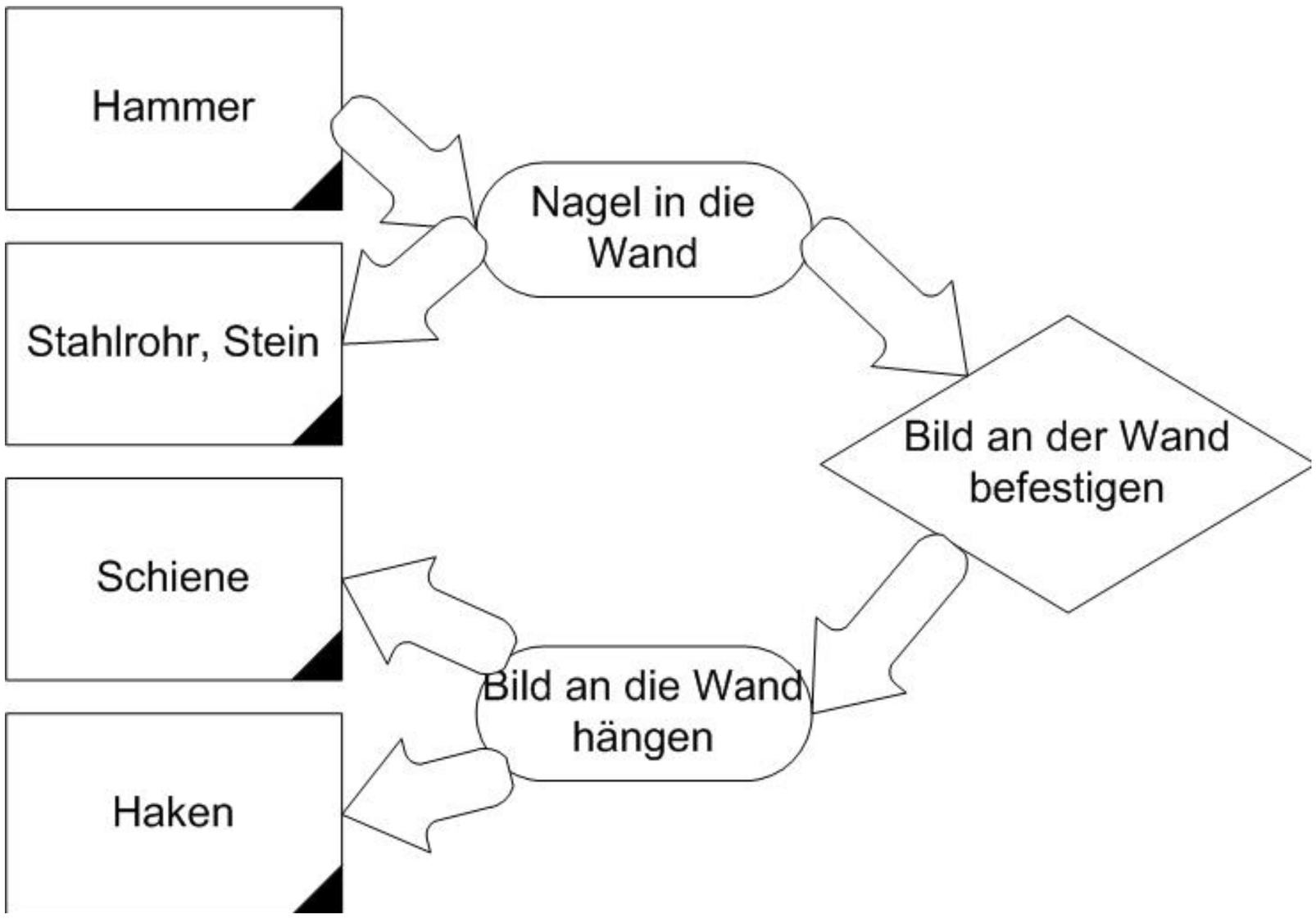
Worum geht es?

Durch Abstraktion verlagern Sie das Problem auf die nächst höhere Ebene. Hierbei sollten Sie nicht zu übertrieben vorgehen.

- Welche Alternativen gibt es?
- Mit welchen Möglichkeiten kann man dieses Konzept realisieren?
- Für welche Lösung entscheiden Sie sich?

-

Sie prüfen die Alternativen auf ihre Brauchbarkeit und entscheiden sich für eine von ihnen. Haben sie eine passende Lösung gefunden, ist Ihr Problem gelöst. In dem Fall, dass sie nicht zufrieden sind sollten Sie auf keinen Fall aufhören. Abstrahieren sie einfach weiter! Der nächste Schritt entspricht dann wieder dem Ersten, nur arbeiten sie jetzt auf einer noch allgemeineren Ebene und können noch mehr Alternativen in Betracht ziehen. Das wiederholte abstrahieren führt zu einer fächerförmigen Struktur. Je weiter sie sich von ihrem Ausgangspunkt wegbewegen, also stärker abstrahieren, umso mehr Optionen ergeben sich auf der unteren Ebene. Allerdings müssen diese Optionen zunächst aus den übergeordneten Konzepten abgeleitet werden. Im folgenden Schaubild ist dargestellt wie solche Konzeptfächer aussehen können. Das Beispiel ist natürlich banal, aber die Methode lässt sich auch auf komplexere Fragestellungen anwenden.



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[Wie geht man bei der Arbeit mit dem Konzeptfächern und der prog
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Beispiel Effektivität

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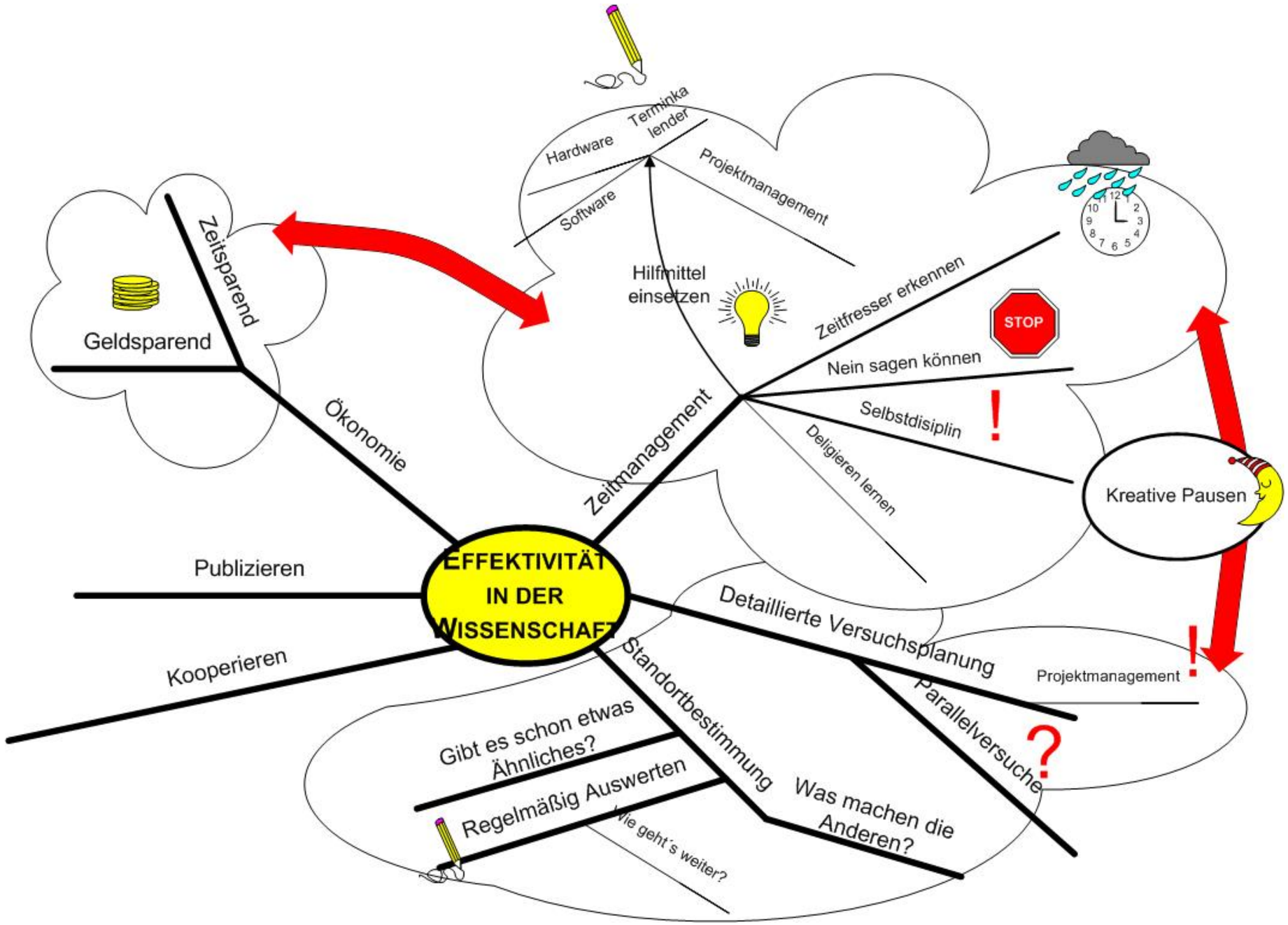
Was benötigt
Die sieben Gr
Bisoziation
Synektik
Denkhüte und Denk
Die Osborn- Checkl
Konzeptfächer und



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[Kreative Techniken zur Ideenfindung] [Copyright]
[Kreativtechniken Kompakt] [Brainstorming] [Brainwriting] [Mindmapping]
[Was benötigt man für einen Mind Map?]
[Die sieben Grundregeln des Mindmapping] [Bisoziation] [Synektik]
[Denkhüte und Denkstühle] [Die Osborn- Checkliste]
[Konzeptfächer und progressive Abstraktion]

6810083 Method and system for estimating objective quality of compressed video data
6801492 Solid immersion mirror type objective lens and optical pickup device adopting the same
6761454 Apparatus and method for determining objective refraction using wavefront sensing
6717742 Objective for a movie camera
6607274 Method for computing visual performance from objective ocular aberration measurements
6606125 Shutter, in particular for an objective, and a CCD-camera
6600552 Microlithography reduction objective and projection exposure apparatus
6578963 Wavefront sensor for objective measurement of an optical system and associated methods
6577443 Reduction objective for extreme ultraviolet lithography
6552806 Automated minimization of optical path difference and reference mirror focus in white-light interference microscope objective
6519098 Objective lens system
6497483 Apparatus and method for objective measurement of optical systems using wavefront analysis
6495839 Microlithography projection objective and projection exposure apparatus
6460997 Apparatus and method for objective measurements of optical systems using wavefront analysis
6450651 Anti-glare device for objective lenses
6423969 Dual infrared band objective lens
6392680 Image formation on objective bodies
6271915 Objective measurement and correction of optical systems using wavefront analysis
6271914 Objective measurement and correction of optical systems using wavefront analysis
6256155 Objective optical system
6244717 Reduction objective for extreme ultraviolet lithography
6243217 Objective lens system
6239922 Objective lens
6236521 Objective lens and image pickup device using the same
6219182 Multiple magnification stereo video telescope objective lens system
6148151 Control system for an objective of a camera
6142934 Objective lens system for imaging instrument
6126334 Camera having interchangeable objective lens
6101046 Cylindrical mount for optical components of a variable-power objective
6072634 Compact digital camera objective with interdigitated element alignment, stray light suppression, and anti-aliasing features
6040943 Digital camera objective with diffractive optical surface
6038079 Sapphire objective system
6023379 Method and apparatus for aligning an objective lens
5999327 Objective lens system
5978159 Hybrid photographic objective
5978155 Adapters for correcting spherical aberrations of objective lens
5978086 Method and apparatus for correcting shifts between a reference focal point and a reference surface as a result of thermal effects in an interferometric optical objective
5956124 Automated threshold-related objective perimetry
5940111 Image formation on objective bodies
5916148 Objective optical system for endoscopes
5912774 Lens moving mechanism for finely moving a portion of an objective lens by rotating a holding member
5907400 Folded low-power interference microscope objective
5880879 Objective lens system utilizing diffractive optical element
5878017 Title Not Available.

5867592 Method of utilizing edge images of a circular surface for detecting the position, posture, and shape of a three-dimensional objective having the circular surface part
5859727 Objective unit
5828498 Objective lens of endoscope
5828453 Lens designing method and objective lens apparatus with two lenses
5815293 Compound objective lens having two focal points
5809349 Camera with adjusting device for objective lens and image carrier and a focusing process
5797049 Focus detection device for objective lens
5768035 Method and apparatus for aligning an objective lens
5757552 Microscope objective lens and a microscope incorporating same
5743846 Stereoscopic endoscope objective lens system having a plurality of front lens groups and one common rear lens group
5742441 Method and apparatus for aligning an objective lens
5742439 Apochromatic wide-angle objective
5734511 Wide angle objective system
5708532 Double-sided telecentric measurement objective
5707925 Image formation on objective bodies
5696634 Objective lens for image pickup apparatus with size of image pickup surface changeable between aspect ratios
5692061 Method of utilizing a two-dimensional image for detecting the position, posture, and shape of a three-dimensional objective
5682269 Objective lens device
5673147 Stereo video endoscope objective lens systems
5668669 Compact wide-angle objective lens
5659425 Immersion microscope objective
5657158 Microscope having an objective corrected to infinity
5640270 Orthogonal-scanning microscope objective for vertical-scanning and phase-shifting interferometry
5638215 Objective lens system
5636058 Microscope objective lens and microscope using the same
5632718 Non-flexible endoscope with objective lens system and relay lens system
5630771 Coarse and fine drives for an objective
5629259 Image formation on objective bodies
5589989 Compact objective lens system
5583690 Faraday microscope with magneto-optical indicator as terminating element of objective lens
5553052 Inclination of an objective lens in an optical information system
5528428 Compact wide-angle objective lens
5491528 Real image mode finder optical system having an objective lens integrated as a prism with a reflective surface
5451560 Image formation on objective bodies
5446565 Compound objective lens having two focal points
5396063 Objective replacing apparatus having objective position, displacement and address detecting means and microscope using it
5367153 Apparatus for detecting the focus adjusting state of an objective lens by performing filter processing
5329347 Multifunction coaxial objective system for a rangefinder
5327291 Compact objective lens
5321555 Compact photographic objective of the triplet type having improved chromatic and monochromatic characteristics
5306892 Mirror objective arrangement
5305035 Panoramic camera with objective drum
5258791 Spatially resolved objective autorefractometer
5257136 Reverse telephoto agron objective lens

5251068 Objective lens having a filter
5249012 Auto-focusing system for cameras with in interchangeable objective lens
5243468 Wide angle objective lens
5218445 System for focusing a television camera objective lens
5214455 Objective eye alignment measurement method and system
5191203 Stereo video endoscope objective lens system
5175650 Objective lens system for endoscopes
5157427 Objective refractor
5138359 Focus detecting apparatus in which matching with the image performance of an objective lens is achieved
5122650 Stereo video endoscope objective lens system
5056901 Wide-angle objective
5051833 Camera apparatus capable of freely setting objective area within viewed subject
5018832 Device for preventing generation of harmful light in objective lens assembly
4959676 Control device for use in a camera having an objective lens
4948984 Optical scanning head with objective position measuring and mirrors
4927254 Scanning confocal optical microscope including an angled apertured rotating disc placed between a pinhole and an objective lens
4923848 Image formation on objective bodies
4912498 Camera system capable of interchanging its objective lens
4907866 Objective of variable focal length
4892398 Triplet type objective with a diaphragm arranged behind the lens system
4876732 System for detecting rotational angle of objective pattern
4867547 Mirror objective and optical arrangement comprising two mirror objectives
4855777 Apparatus for detecting the focus adjusted state of an objective lens
4854685 Variable-focus objective-lens device and a method for the control of said device
4842386 Variable focal length objective
4841326 Apparatus for detecting the focus adjusted state of an objective optical system
4836665 Objective lens
4831396 Objective for photographic cameras
4800409 Control device for use in a camera having an objective lens
4800261 Apparatus for detecting focusing state of objective lens
4799077 Common drive for shutter blades and objective lens assembly
4792668 Apparatus for detecting focusing state of objective lens
4787724 Triplet type objective with a diaphragm arranged behind the lens system
4783673 Holding apparatus for an image frame or objective frame of a professional camera
4779967 Objective lens assembly
4773745 Compact wide-angle objective
4767202 Objective lens system for optical recording type disks
4765723 Objective lens system for optical reading device
4764001 Retrofocus-type objective for an endoscope
4755759 Temperature compensating method in automatic diaphragm control amplifier used with objective for CCTV camera
4752798 Swingable holder for anterior accessories of an objective lens
4750812 Objective observation optical material
4741606 Objective lens system for optical recording and reading device
4741605 Multifocal objective

4737855 Automatic diaphragm control device for TV camera objective
4717960 Automatic diaphragm control device of variable photometry type used in objective for television camera
4708444 Photographic objective
4679913 Vari-focal objective lens of short total length
4647160 Small-sized wide angle zoom objective
4639112 Camera system capable of interchanging its objective lens
4601550 Stereo-microscope with a common objective lens system
4572612 Photographic objective with a fastening device
4547808 Photometric circuit incorporated in objective provided with automatic diaphragm for closed circuit television (CCTV) camera
4545661 Folding camera with movable member mounting an objective lens and reflex mirror
4542410 Automatic diaphragm control device of objective provided with automatic diaphragm for closed circuit television (CCTV) camera
4529288 Camera system with interchangeable objective lens
4525039 Objective lens
4525037 Objective lens assembly of variable focal length having a diaphragm mechanism with adjustable aperture
4518238 Rotation control mechanism for diaphragm-operating ring in interchangeable objective for photographic camera
4514052 High speed objective lens system with an aspheric surface
4509842 Camera system capable of focus detection through an interchangeable objective lens
4508433 Telephoto objective
4505564 Rotation control mechanism for diaphram-operating ring in interchangeable objective for photographic camera
4504134 Photographic objective with automatic diaphragm
4494829 Curved field photographic objective
4483602 Apparatus for detecting a focusing condition of an objective lens
4477153 Ultrawide angle zoom objective
4467188 Device for splitting light from an objective lens
4443079 Method and apparatus for detecting focus condition of objective lens
4437735 Inverted telephoto type wide angle objective of large relative aperture
4425577 Television camera equipped with a color-separating arrangement disposed behind the objective
4416518 Objective comprising aspherical surfaces, whose focal length is variable over a wide range
4416513 Automatic and manual focus control for objective lens assembly
4413888 Compact photographic objective
4411510 Apparatus for compensating for the rebounding of an automatic diaphragm in a photographic objective
4407568 Large aperture objective with behind the lens diaphragm
4381888 Retrofocus type large aperture wide angle objective
4380376 Zoom objective
4376571 Photographic small size objective
4373786 Photographic objective of reduced size
4368956 Compact photographic objective
4368955 Variable-focal-length objective
4365884 Still camera with retracting objective
4364644 Gauss type large aperture photographic objective
4360835 Television camera objective having driving mechanism for adjusting components of its optical system
4354753 Reflex camera having a focal plane shutter and an interchangeable variable shutter objective
4353634 Focusing mechanism for camera objective
4350423 Still camera with a retractable objective

4336996 Variable-focal-length objective and an optical system equipped with objectives of this type for the production of special effects on film
4336986 Camera having an independently focused retractable objective lens
4326783 Interchangeable objective lens single-lens reflex camera focusing device
4324458 Tele-objective lens with a movable sub-group for focusing
4322150 Mechanical mounting system for zoom objective
4307941 Adjustable objective holder
4293185 Optical conversion assembly for objective camera lenses
RE30708 Telephoto objective
4281908 Tesser type objective lens system having a rear aperture stop
4280762 Camera having an independently focused retractable objective lens
4274725 Depth of field objective
4274720 Automatic focus control device for objective lens exchangeable cameras
4273415 Optical objective
4266865 Diaphragm correcting means of an objective lens mounted on a single lens reflex camera of the TTL full aperture exposure measurement type
4258998 Still camera with an objective which can be retracted into the camera housing for dimensional compactness
4255023 Objective retinal response recorder
4240705 Five element photographic objective
4239339 Varifocal objective for photographic camera
4235519 Compact retrofocus type wide angle objective
4229094 Camera with transversely displaceable objective
4226518 Photographic camera having long focal length objective
4219261 Photographic camera with a means for coordinating and indicating depth of field focusing and objective setting values
4217033 Camera objective of variable focal length
4214815 Semi-wide angle objective lens
4213686 Closeup focusing mechanism for an objective of long focal length
4211472 Wide angle objective lens system
4206973 Retrofocus type wide-angle objective
4200377 Focusing mechanism for camera objective
4196970 Optical objective with extended varifocal range
4188092 Retrofocus type wide-angle objective lens
4183625 Wide-angle photographic objective
4182565 Light-ray deviator for camera objective
4179191 Adjusting mechanism for optical objective with lost-motion zone
4176920 Ophthalmoscopic system with a wide angle objective lens
4176914 Compact retrofocus wide angle objective
4174153 Varifocal objective with focal length adjustment
4168884 Varifocal objective with mechanism for closeup focusing
4165916 Objective lens system with close object focusing aberration correction
4162827 Wide angle objective for ophthalmoscopic instrument
4161756 Control system for varifocal objective
4160263 Dual or multiple objective video microscope for superimposing spaced images
4117325 Optical objective focus indicator and display
4110769 Coupling mechanism for the alternate manual and automatic adjustment of a varifocal objective
4110008 Cushioned objective lens

4110005 Wide-angle attachment for varifocal objective
4104663 Multiple objective lens camera
4101202 Varifocal camera objective with adjustment-range selection
4099849 Wide angle objective
4095247 Interchangeable objective for cameras
4087160 Camera objective of variable focal length
4081811 Diaphragm preselector for camera objective
4079401 Diaphragm preselector for camera objective
4072396 Focussing objective mechanism for telescopic rifle sights
4070686 Camera with adjustable objective
4063801 Telephoto type objective
4059348 Objective plotting of visual fields by eye movement monitoring
4054372 Focusing mechanism for varifocal objective
4046459 Retrofocus wide angle objective lens system
4045128 Telephoto objective
4037935 High-speed adjustable focus telephoto objective lens
4025170 Retro-focus type wide angle objective lens
4025169 High speed wide angle objective lens system
4009386 Method and arrangement for automatically focussing an objective onto a subject, using autocollimation
4005263 Device for adjusting the distance between the objective and the pick-up tube in a television camera
3999840 Wide angle objective having a non-spherical surface
3994576 Objective lens system with five elements
3994558 Binocular microscope with improved monocular photographic and measuring capability using movable objective
3984156 Objective plotting of visual fields by eye movement monitoring
3982823 Retrofocus wide-angle objective lens system of large relative aperture
3975090 Wide angle objective
3969018 Objective system with zoom lens for photographic apparatus
3967884 Three element objective lens
3961347 Interchangeable objective lens diaphragm exposure control coupling mechanism
3957355 Objective system with zoom lens for motion picture cameras
3953863 Method and apparatus for focusing an objective
3944339 Large aperture photographic objective
3938882 High numerical aperture intermediate wide angle objective
3936153 Retrofocus type objective lens system

US006810083B2

(12) **United States Patent**
Chen et al.

(10) **Patent No.: US 6,810,083 B2**
(45) **Date of Patent: Oct. 26, 2004**

(54) **METHOD AND SYSTEM FOR ESTIMATING OBJECTIVE QUALITY OF COMPRESSED VIDEO DATA**

(75) Inventors: **Yingwei Chen**, Briarcliff Manor, NY (US); **Jorge Caviedes**, Yorktown Hts, NY (US)

(73) Assignee: **Koninklijke Philips Electronics N.V.**, Eindhoven (NL)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 539 days.

(21) Appl. No.: **09/996,003**

(22) Filed: **Nov. 16, 2001**

(65) **Prior Publication Data**

US 2003/0112333 A1 Jun. 19, 2003

(51) **Int. Cl.**[7] **H04N 7/12**

(52) **U.S. Cl.** **375/240.25**; 375/240.26; 375/240.03

(58) **Field of Search** 375/240.12, 240.13, 375/240.18, 240.19, 240.24, 240.25, 240.26, 240.27, 240.29, 243, 240.03; 348/420.1, 425.1, 425.2, 408.1, 671; 382/235, 237, 268, 276, 251; 725/107, 130, 150

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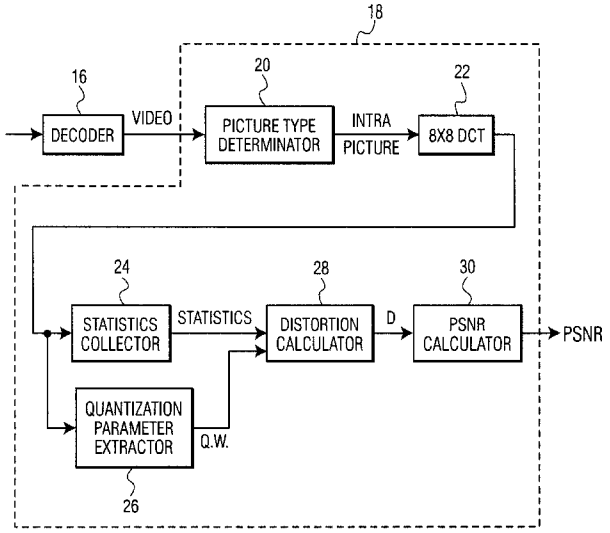
* cited by examiner

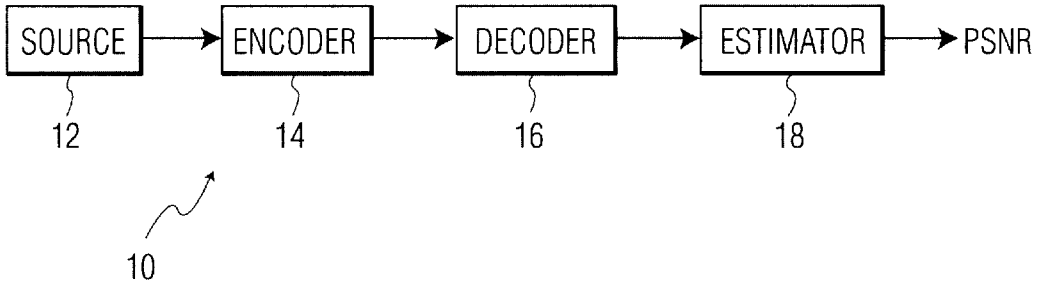
Primary Examiner—Vu Le

(57) **ABSTRACT**

The present invention relates to a method and system for evaluating the quality of encoded video data without gaining access to the source data or the compressed video bitstream. The system is configured to decode compressed video data using an MPEG decoder to produce decompressed video data. The decoded data is analyzed to determine whether the decompressed video data is intra-coded. If so, a discrete cosine transform (DCT) is performed to produce a set of DCT coefficients for at least one AC frequency band in the decompressed video data. At the same time, quantization matrix data of a frame of the decompressed video data as well as a quantizer scale for each block of the decompressed video data are extracted. Thereafter, the variance of the converted DCT coefficients is obtained, and then an average quantization error for each set of said DCT coefficients is determined based on the variance, the quantization matrix, and the quantizer scale. Lastly, a peak signal to noise ratio (PSNR) is calculated based on the resultant average quantization error.

27 Claims, 6 Drawing Sheets




SOURCE
ENCODER
DECODER
ESTIMATOR
PSNR
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14
16
18
10

FIG. 1

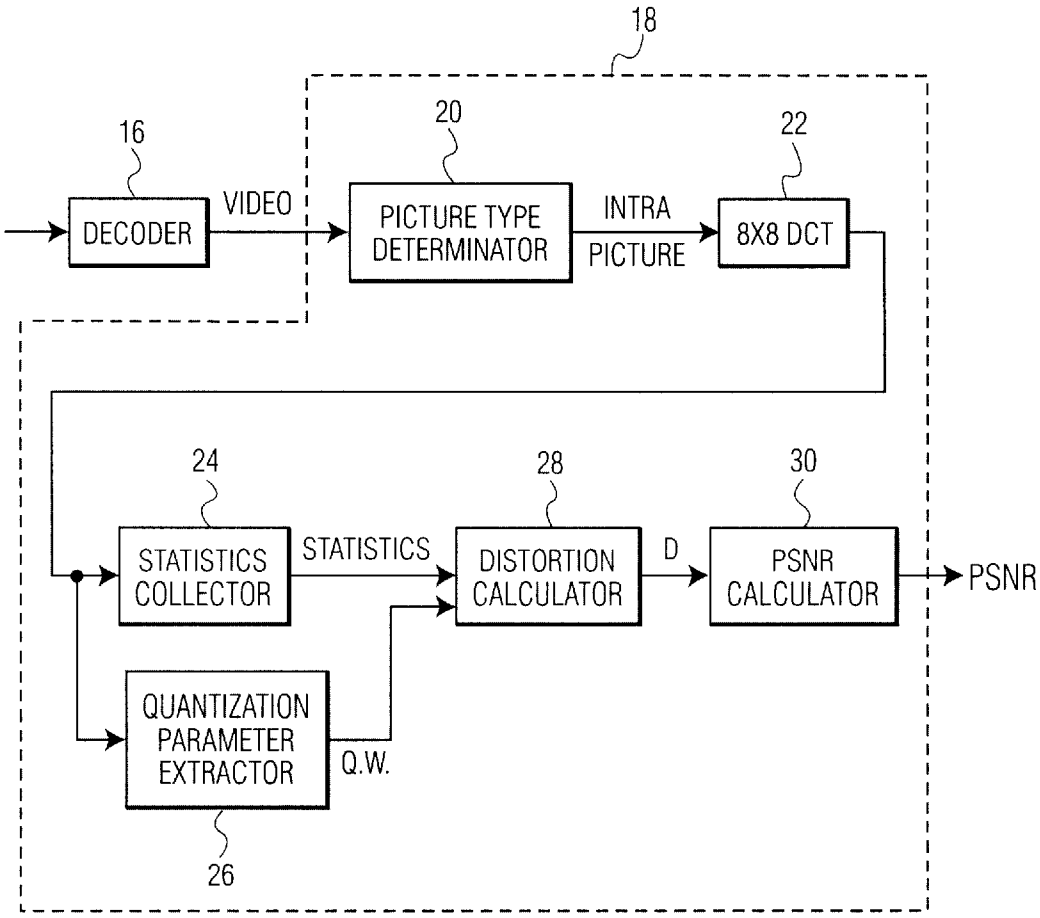
18
16
20
22
DECODER
VIDEO
PICTURE TYPE DETERMINATOR
INTRA PICTURE
8X8 DCT
24
28
30
STATISTICS COLLECTOR
STATISTICS
DISTORTION CALCULATOR
D
PSNR CALCULATOR
PSNR
QUANTIZATION PARAMETER EXTRACTOR
Q.W.
26

FIG. 2

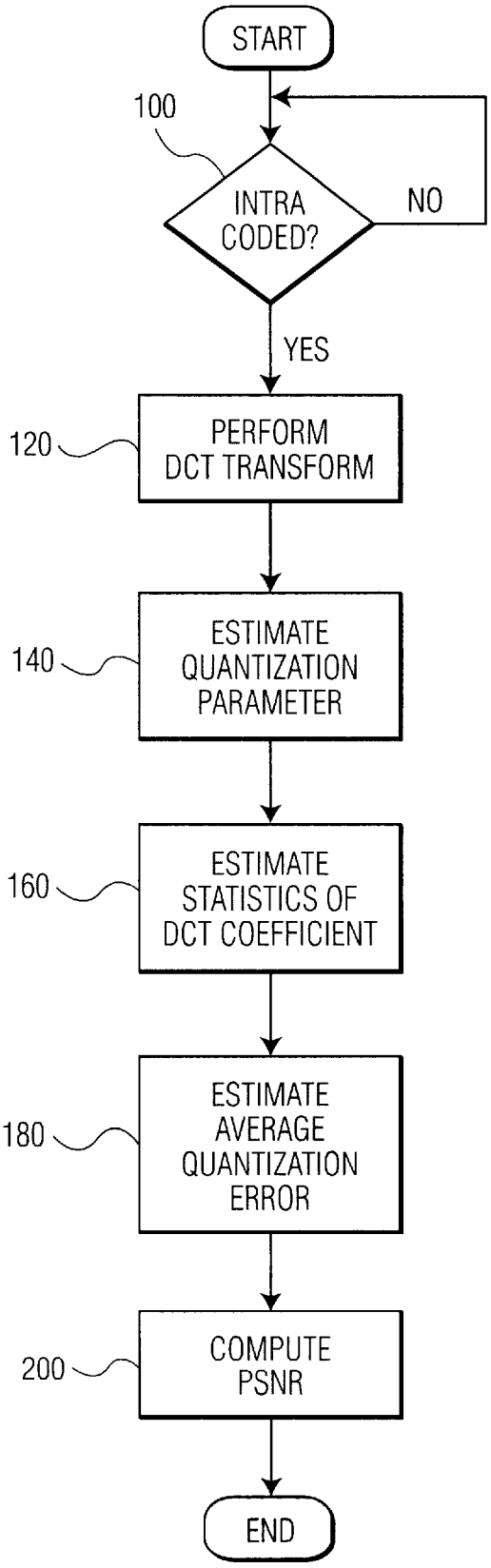
START
100
INTRA CODED?
NO
YES
120
PERFORM DCT TRANSFORM
140
ESTIMATE QUANTIZATION PARAMETER
160
ESTIMATE STATISTICS OF DCT COEFFICIENT
180
ESTIMATE AVERAGE QUANTIZATION ERROR
200
COMPUTE PSNR
END

FIG. 3

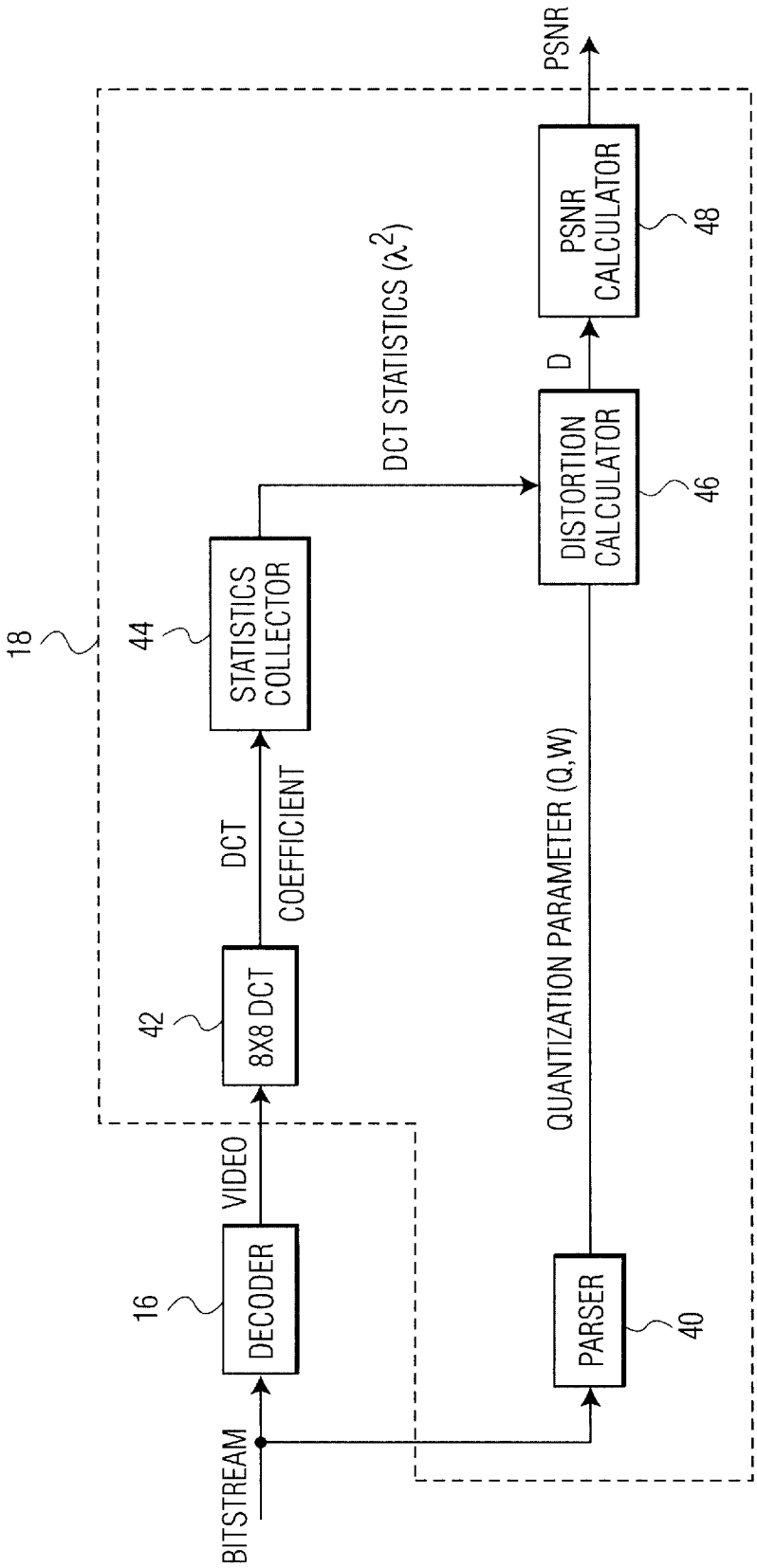
BITSTREAM
16
DECODER
VIDEO
42
8X8 DCT
DCT
COEFFICIENT
18
44
STATISTICS
COLLECTOR
DCT STATISTICS (λ^2)
PARSER
40
QUANTIZATION PARAMETER (Q,W)
DISTORTION
CALCULATOR
46
D
PSNR
CALCULATOR
48
PSNR

FIG. 4

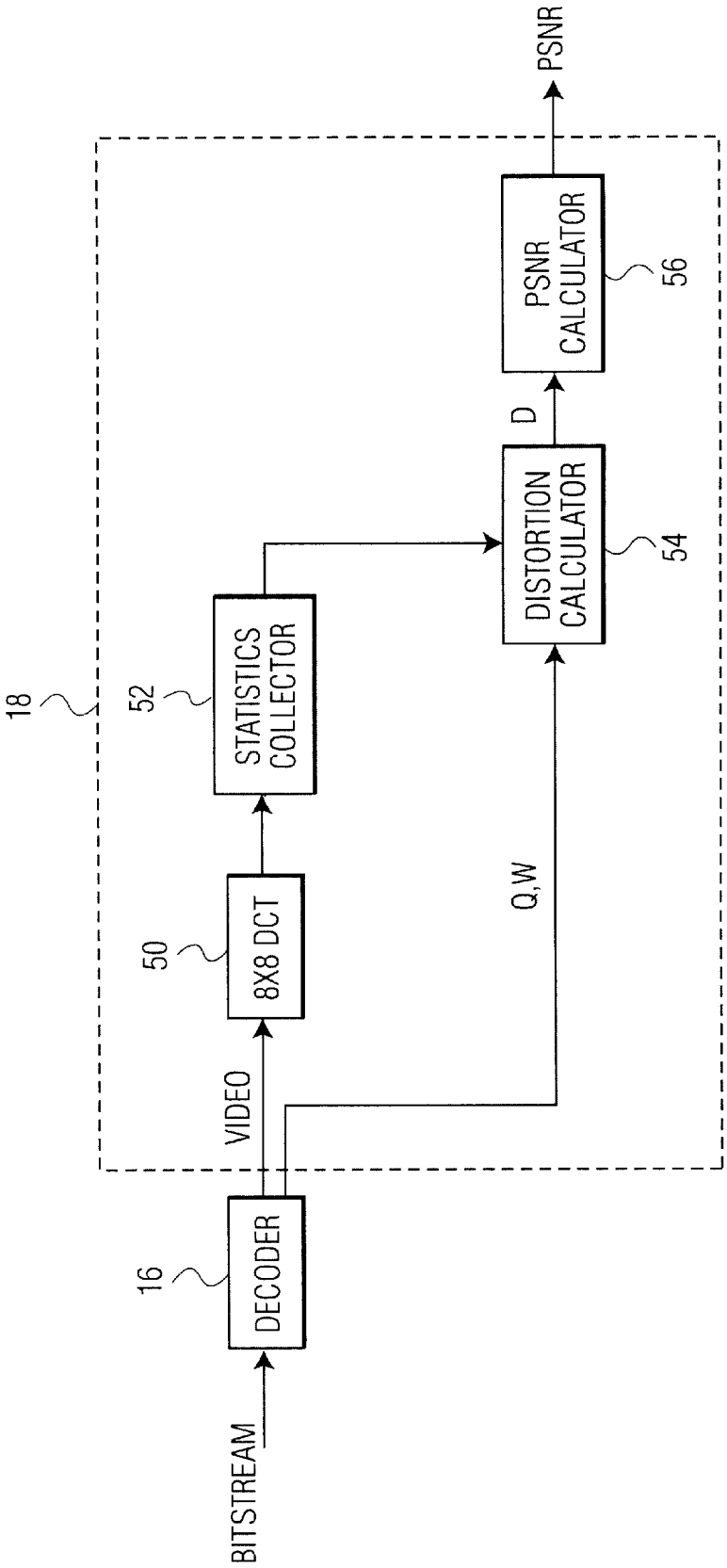
BITSTREAM
16
DECODER
VIDEO
50
8X8 DCT
52
STATISTICS COLLECTOR
18
Q,W
DISTORTION CALCULATOR
54
D
PSNR CALCULATOR
56
PSNR

FIG. 5

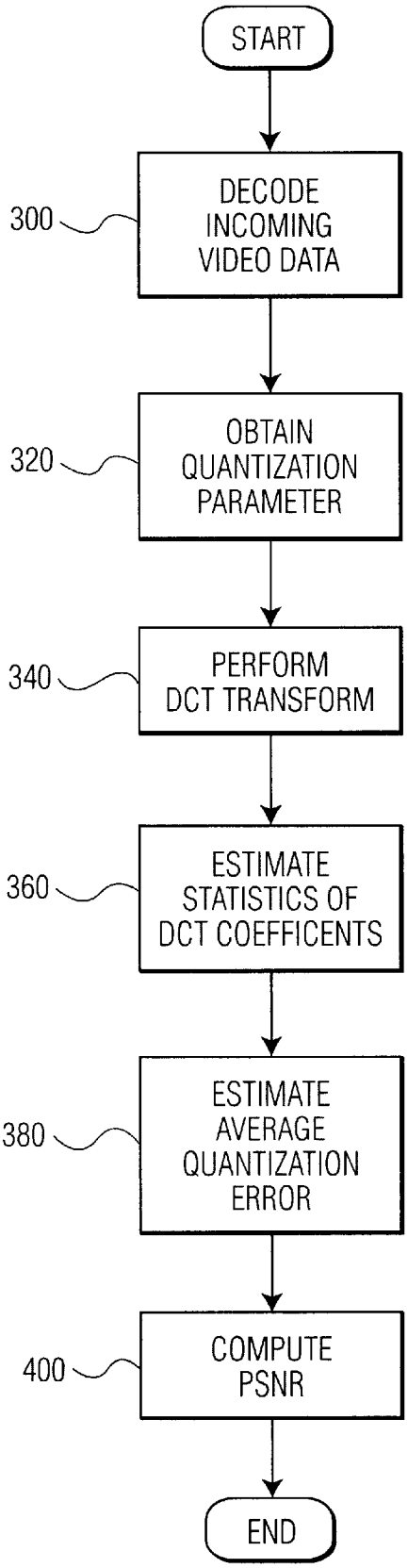
START
300
DECODE INCOMING VIDEO DATA
320
OBTAIN QUANTIZATION PARAMETER
340
PERFORM DCT TRANSFORM
360
ESTIMATE STATISTICS OF DCT COEFFICENTS
380
ESTIMATE AVERAGE QUANTIZATION ERROR
400
COMPUTE PSNR
END

FIG. 6

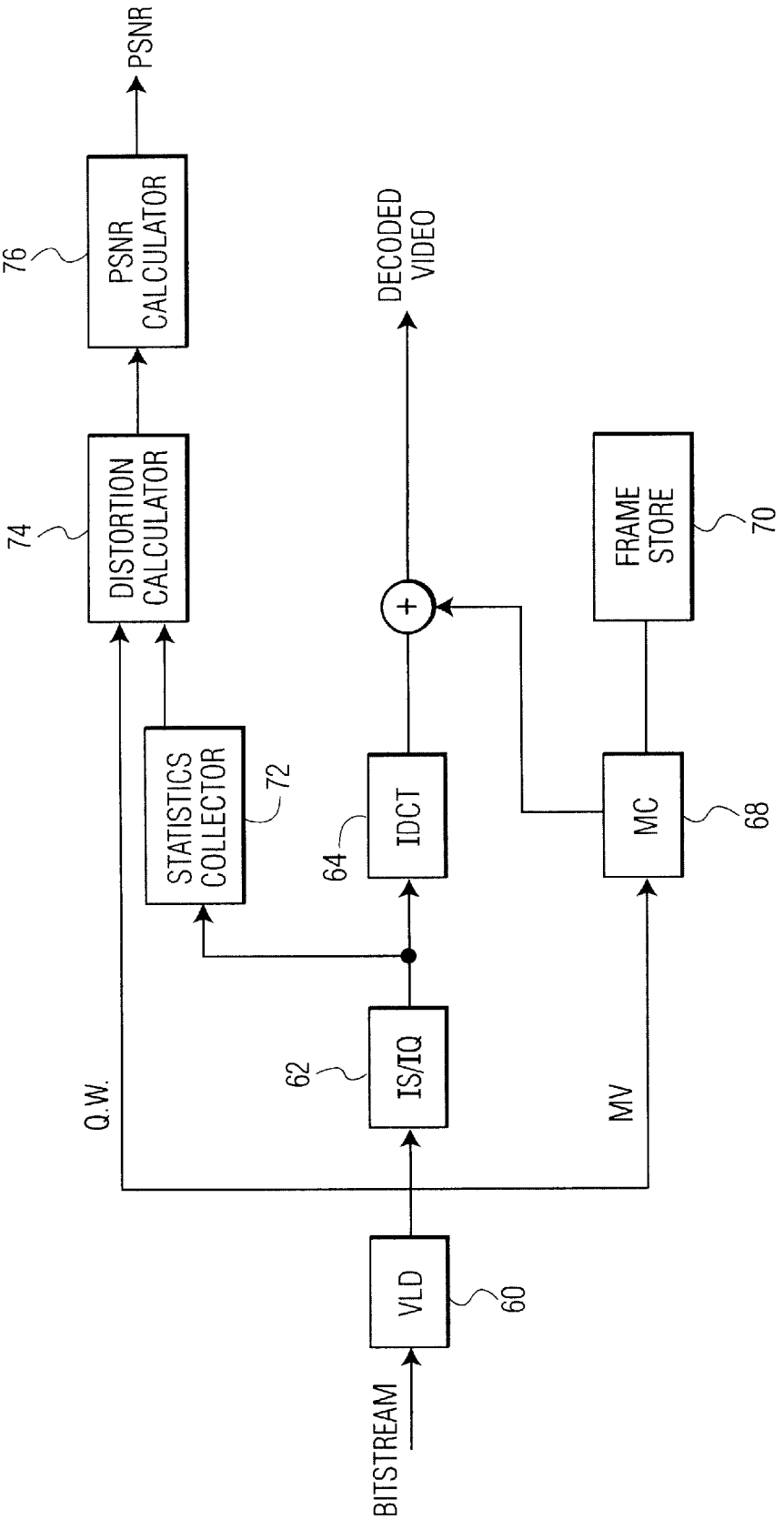
PSNR
76
PSNR CALCULATOR
74
DISTORTION CALCULATOR
STATISTICS COLLECTOR
72
DECODED VIDEO
64
IDCT
FRAME STORE
70
MC
68
62
IS/IQ
Q.W.
MV
VLD
60
BITSTREAM

FIG. 7

METHOD AND SYSTEM FOR ESTIMATING OBJECTIVE QUALITY OF COMPRESSED VIDEO DATA

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a method and system for measuring the quality of compressed video data and, in particular, to a method and system for assessing the objective quality of compressed pictures, namely Peak-Signal to Noise-Ratio (PSNR), without referring to the source video data.

2. Description of the Related Art

It is the ultimate goal of the video experts to provide most perceptually appealing video images to viewers. One way to determine whether the resulting image quality is good or poor is to ask a panel of viewers to watch certain video sequences to provide their opinions. Another way to analyze video sequences is to provide an automated mechanism to evaluate the excellence or the degradation of the video quality. This type of procedure is known as "objective video quality assessment."

A common approach for measuring the picture quality of a compression process is to make a comparison between the processed image and the unprocessed source images (hereinafter referred to as "double-ended measurement"). Various metrics are used, i.e., Block Artifact Metric (BAM), PSNR, Perceptually Weighted PSNR, etc., to evaluate an objective picture quality measure. In particular, the PSNR is most commonly used parameter for measuring any picture quality, especially in evaluating MPEG-2 video bitstream. However, the double-ended measurement has some drawbacks in that access to both the processed picture and the source picture is not feasible if the source data or the alignment between the source and processed pictures are unavailable. In order to overcome this problem, a "single-ended measurement" has been proposed to monitor the video quality when the source is neither available nor controllable. Unlike the double-ended measurement, the single-ended measurement technique operates on the compressed picture without access to the source picture when evaluating video quality. Although there are various single-ended methods that have been proposed, no single-ended measurement uses the PSNR metric in evaluating the compressed pictures alone without access to the source picture or the compressed video bitstream. Accordingly, the present invention proposes an objective quality assessment using the PSNR metric to evaluate the objective quality of compressed pictures without utilizing the source data or the compressed video bitstream.

SUMMARY OF THE INVENTION

The present invention is directed to an apparatus and method for evaluating the quality of encoded video data without access to the source data or the compressed video bitstream, by utilizing quantization parameters estimated directly from the decompressed picture.

According to an aspect of the invention, the method of evaluating the picture quality includes the steps of: performing a discrete cosine transform (DCT) on at least a substantial portion of the decompressed video data to produce a set of DCT coefficients for at least one AC frequency band; simultaneously, extracting quantization matrix data for at least one AC frequency band and extracting a quantizer scale for each block of the decompressed video data; estimating a variance of the DCT coefficients; determining an average quantization error for each set of the DCT coefficients based on the resultant variance, quantization matrix, and quantizer scale; and, calculating a peak signal to noise ratio (PSNR) based on the average quantization error.

According to another aspect of the invention, the method includes the steps of: performing a DC computation operation to recover an intra-dc-precision level from the decompressed video data; and, if the intra-dc-precision level is less than a predefined threshold, classifying the decoded video data as an intra-coded; performing a discrete cosine transform (DCT) on the decompressed video data to produce a set of DCT coefficients for at least one AC frequency band; extracting quantization matrix data for the at least one AC frequency band; extracting a quantizer scale for each block of the decompressed video data; estimating a variance of the DCT coefficients; determining an average quantization error for each set of the DCT coefficients; and, calculating a peak signal to noise ratio (PSNR) based on the average quantization error.

According to anther aspect of the invention, the apparatus capable of evaluating the quality of encoded video data includes: a decoder for decoding at least a substantial portion of the encoded video data to produce decoded video data including a plurality of blocks; a discrete cosine transform (DCT) configured to transform the decompressed video data into a set of DCT coefficients for at least one AC frequency band; an extractor for extracting quantization matrix data for at least one AC frequency band and for extracting a quantizer scale for each block of the decompressed video data; a collector for estimating a variance of the DCT coefficients; a first calculator for determining an average quantization error for each set of the DCT coefficients based on the variance, the quantization matrix, and the quantizer scale; a second calculator for determining a peak signal to noise ratio (PSNR) based on the resultant average quantization error; and, a picture detector for detecting an intra-coded picture in each block of the decompressed video data. The picture detector further includes a means for performing a DC computation operation to recover intra-dc-precision level from the decompressed video data; and, a means for classifying the decoded video data as an intra-coded picture when the intra-dc-precision level is less than a predefined threshold.

According to another aspect of the invention, the apparatus includes: a decoder configured to decode compressed variable-length Huffman codes and for producing therefrom decoded data, and for extracting quantization matrix data and a quantizer scale for each block of the decoded video data; an inverse quantizer configured to perform inverse-quantizing of the decoded data output from the decoder to produce a set of DCT coefficients; an inverse DCT configured to transform values of pixels in blocks of signals output from the inverse quantizer to dequantize decoded data including the difference data; a motion compensation and adder for receiving reference data within the encoded video data and the difference data from said inverse DCT to form motion compensated pictures therefrom; a collector coupled to the output of the inverse quantizer for estimating a variance of the DCT coefficients; a first calculator for determining an average quantization error for each set of the DCT coefficients based on the variance, quantization matrix, and quantizer scale; and, a second calculator for determining a peak signal to noise ratio (PSNR) based on the resultant average quantization error. The apparatus further includes a video memory configured to store reproduced video data.

The foregoing and other features and advantages of the invention will be apparent from the following, more detailed description of preferred embodiments as illustrated in the accompanying drawings in which reference characters refer to the same parts throughout the various views. The drawings are not necessarily to scale; the emphasis instead is placed upon illustrating the principles of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a simplified block diagram illustrating the picture quality estimator according to an embodiment of the present invention;

FIG. **2** is a block diagram of the estimating apparatus according to an exemplary embodiment of the present invention;

FIG. **3** is a flow chart illustrating the operation steps of the estimating apparatus in accordance with the present invention;

FIG. **4** is a simplified block diagram of the estimating apparatus according to another exemplary embodiment of the present invention;

FIG. **5** is a simplified block diagram of the estimating apparatus according to another exemplary embodiment of the present invention;

FIG. **6** is a flow chart illustrating the operation steps of the estimating apparatus in accordance with the present invention; and,

FIG. **7** is a simplified block diagram of the estimating apparatus according to another exemplary embodiment of the present invention

DETAILED DESCRIPTION OF THE EMBODIMENTS

In the following description, for purposes of explanation rather than limitation, specific details are set forth such as the particular architecture, interfaces, techniques, etc., in order to provide a thorough understanding of the present invention. For purposes of simplicity and clarity, detailed descriptions of well-known devices, circuits, and methods are omitted so as not to obscure the description of the present invention with unnecessary detail.

In order to facilitate an understanding of this invention, background information relating to MPEG2 coding is explained. In general, the MPEG2 coding is performed on an image by dividing the image into macro-blocks of 16×16 pixels, each with a separate quantizer scale value associated therewith. The macro-blocks are further divided into individual blocks of 8×8 pixels. Each 8×8 pixel block is subjected to a discrete cosine transform (DCT) to generate DCT coefficients for each of the 64 frequency bands therein. The DCT coefficients in an 8×8 pixel block are then divided by a corresponding coding parameter, i.e., a quantization weight. The quantization weights for a given 8×8 pixel block are expressed in terms of an 8×8 quantization matrix. Thereafter, additional calculations are affected on the DCT coefficients to take into account, namely the quantizer scale value, among other things, and thereby complete MPEG2 coding. It should be noted that other coding techniques, such as JPEG or the like, may be used in the present invention.

FIG. **1** is a simplified circuit diagram whereto the embodiment of the present invention is applied. The inventive system **10** includes a video source **12**, an encoder **14**, a decoder **16**, and an estimator **18**. The source **12** may be any type of video generating device, such as a television camera or other video equipment that is capable of generating video data based on a particular image. The encoder **14** and decoder **16** may be any conventional encoder and decoder known in this art for encoding/decoding MPEG2 video data, respectively. The estimator **18** processes the decoded video data to evaluate the objective quality of compressed pictures without utilizing the source video data or the compressed video bitstream. To achieve this, the present invention relies on a statistical analysis to determine the quality of the picture that has been compressed in a previous coding operation. The statistics of pictures are gathered from the DCT coefficients either after the decompression stage or during the decompression stage, thereby eliminating the need for gaining access to the source picture in accordance with the present invention.

Now, a description will be made in detail regarding this invention with reference to FIGS. **2–7**.

FIG. **2** depicts a representative hardware of the decoder **16** and the estimator **18** illustrated in FIG. **1** according to a first embodiment of the present invention. In particular, the first embodiment provides a mechanism for estimating video quality after the coded video data has been decompressed via the decoder **16**. The estimator **18** includes a picture determinator **20**, a 8×8 DCT **22**, a statistics collector **24**, a quantization parameter extractor **26**, a distortion calculator **28**, and a PSNR calculator **30**. A key principle of the present invention relies on the fact that the quality of P and B pictures and hence the overall video is in general consistent with that of the intra pictures for the MPEG-2 coded video. Therefore, if the PSNR can be estimated only for intra-coded pictures, it serves as a quality metric for the overall video as a good video encoder strives to maintain a consistent quality from picture to picture.

In operation, the decoded video data, after being decoded by the decoder **16**, is forwarded to the picture determinator **20** of the estimator **18**. The picture determinator **20** then determines whether the decoded video data is intra-coded. In MPEG-2 video, intra_dc_precision controls the quantization coarseness of DC DCT coefficients in intra-coded macroblocks or intra-coded pictures and ranges from 8 to 11 bits, with 11 bits as the highest which results when no quantization error occurs in the intra DC coefficients. In most broadcast quality digital video, the lowest intra_DC_precision is typically set to 8. Accordingly, if the estimated intra_DC_precision less than 11, the current picture is determined to be intra-coded in the present invention. If intra-coded, the DCT block **22** subjects the decoded video data to DCT processing in order to generate DCT coefficients for AC frequency bands. Thereafter, the statistics collector **24** estimates the variance of the DCT coefficients, whereafter the estimated DCT variance is transmitted to the distortion calculator **28**. At the same time, the quantization extractor **26** extracts quantization matrices that correspond to those used in a previous coding operation. U.S. Pat. No. 6,101,278 entitled, "System for Extracting Coding Parameters from Video Data," assigned to the same assignee, explains how to extract the quantization matrices (W_{ij}), thereby incorporated herein as a reference. The distortion calculator **28** then uses the extracted quantization matrices, quantizer step size and the estimated DCT variance to determine the average quantization error. Thereafter, the PSNR calculator **26** determines the PSNR, using the average quantization error obtained by the distortion calculator block **28**. The value of PSNR is used to evaluate any degradation in the video quality.

FIG. **3** is a flow diagram depicting the operation steps of evaluating video quality in accordance with the first embodiment of the present invention. It should be noted that the processing and decision blocks may represent steps performed by functionally equivalent circuits, such as a digital signal processor circuit or an application-specific integrated circuit (ASIC). The flow diagrams do not depict the syntax of any particular programming language. Rather, the flow diagrams illustrate the functional information that a person of ordinary skill in the art requires to fabricate circuits or to generate computer software to perform the processing required of the particular apparatus.

Upon receiving the decoded video output from the decoder **14**, an 8×8 block DC precision computation is performed by the picture type determinator **20** to determine whether the decoded video is intra-coded for each macroblock in step **100**. It is noted that the intra-coded pictures

possess unique statistical properties from non-compressed pictures, or P and B coded pictures, and the number of bits used to represent intra DC coefficients is 11 bits before compression. Hence, if the intra DC precision is less than 11, the current picture being analyzed is classified as an intra-coded picture

In step **120**, the detected intra code picture is then subjected to a DCT transform by the DCT block **22** to generate DCT coefficients for AC frequency bands in the video data. In step **140**, quantization matrices (W_{ij}) and a quantizer step size for each macroblock (Q_m) for the whole picture are obtained. That is, after determining that the current picture being analyzed is an intra-coded picture, the quantization parameter extractor **26** operates to extract a quantization matrix for each frame that correspond to those used in a previous coding operation. A quantization matrix consists of sixty-four entries, each entry being designated with a weight. The sixty-four entries, each being an 8-bit integer ranging from 1 to 255, correspond to 8×8 DCT coefficients in a block. The weight and the quantizer scale-value determine the quantization step-sizes for a block of DCT coefficients. The process of extracting quantization matrices (W_{ij}) is explained in U.S. Pat. No. 6,101,278, entitled, "System for Extracting Coding Parameters from Video Data," assigned to the same assignee, thereby incorporated herein as a reference. The quantization parameter extractor **26** further operates to extract a quantizer step size/scale for each macroblock. In order to extract a quantizer step size/scale for each macroblock, the AC coefficients in the macroblock is averaged. In the case of MPEG-2, a quantization matrix is first extracted as discussed in U.S. Pat. No. 6,101,278 to obtain the weights W_{ij}, for i, j=0, 1 . . . 7 and i, j (0, 0). Each AC coefficient is then weighed according to the equation below:

$$\overline{C}_{i,j} = \frac{C_{i,j} \times 16}{W_{i,j}},$$

wherein $C_{i,j}$ represents the (i, j)th AC coefficient in the current macroblock, and $\overline{C}_{i,j}$ represents the weighted or normalized AC coefficient. In other DCT-based compression schemes where quantization matrix is not utilized, i.e., where all AC coefficients in the same macroblock are quantized with the same step size, this step may be skipped. After averaging the AC coefficients in the macroblock, the operation of finding a quantization scale and a DCT type is executed by finding the largest common divider for all normalized AC coefficients in the macroblock, or just for a selected set of coefficients, such as the first 4 AC coefficients in a zig-zag scanning order. For MPEG-2 video, this is performed on both the frame DCT data and field DCT data. Finding the largest common divider for all normalized AC coefficients in the macroblock can be processed as follows:

```
First for frame DCT block:
q=max_Q
d_max=large number
while (q>lowest_q_allowed)
{
    d=0
    for i,j = 0,. . .7 and i,j    (0,0)
    {
        quantize C̄i,j with q:    i,j = quantize(C̄i,j, q)
        d = d + abs(C̄i,j− i,j)
        if (abs(d_prev / d) > threshold) return current_DCT_Type
        and q
        q=next_lower_q
        d_prev=d
    }
}
```

In the above pseudo-code, abs( ) stands for "absolute value" operation. quantize( ) is the quantization procedure which is specified by the video coding scheme. A nominal value for threshold is 1.5.next_lower_q and determined according to different coding schemes. The above code essentially performs a search operation through possible quantization scale values and DCT types. When the search starts, the DCT type is initiated to frame DCT as the frame-based DCT is more likely used in MPEG-2 coded video. For other video coding standards, such as MPEG-1, MPEG-4 and H.263, or MPEG-2 field pictures, the DCT type will remain as frame based. The quantization scale is initiated to the highest value allowed by the standard. For example, in MPEG-2, this number is 62 or 112 depending on the coding scheme used for quantization scale. For each quantization scale value, the quantization distortion is computed for the current macroblock. The computed distortion is then compared with the previous computed and stored distortion. If the reduction in distortion in terms of ratio between the two exceeds a certain threshold (set to 1.5 above), then the current quantization scale is extracted and returned. If not, the current distortion is stored, and the search resumes with the next higher quantization scale as dictated by the standard or coding scheme. If a quantization scale is not extracted from frame DCT data, then the same search options are performed on the field DCT data. Alternatively, the search can start with the lowest possible quantization scale and proceeds up, or start with more likely quantization scales. For example, 10 for DVD video or DVB video, and higher than 10 for lower bit rate video. Accordingly, the largest common divider for all normalized AC coefficients calculated, as described in the preceding paragraphs, to determine the DCT type and the quantization scale per macroblock.

Meanwhile, in step **160**, estimating statistics of DCT coefficients is performed. For each AC location (i, j), the variance of the coefficients $\lambda^2_{i,j}$ is estimated according to the formula below:

$$\lambda^2_{i,j} = \frac{\sum_{b=1}^{N} (C^b_{i,j})^2}{2N}$$

wherein C^b_{ij} represents the (i, j)th AC coefficient in block b, and N represents the total number of blocks in the picture. It should be noted that step **140** and step **160** can be performed simultaneously in accordance with the present invention.

After determining the DCT statistics $\lambda^2_{i,j}$, in step **160**, the average quantization error is estimated in step **180**. This is performed for each set of DCT coefficients corresponding to the same DCT location. Calculating the quantization error is explained in the U.S. Pat. No. 6,067,118 entitled, "Method of Frame-By-Frame Calculation of Quantization Matrices," assigned to the same assignee, and herein incorporated by simple reference. For DC, the quantization error $D_{0,0}$ is estimated to be half that of the intra-DC quantization step size according to the table below.

Intra_DC_Precision	Average DC quantization error
8	4
9	2
10	1
11	0

Hence, the (i, j)th AC location, the quantization error $D_{i,j}$ is estimated as follows:

$$D_{i,j} = 2\lambda_{i,j}^2\left(1 - \frac{\beta_{i,j}}{e^{\beta_{i,j}/2} - e^{-\beta_{i,j}/2}}\right)$$

$$\text{where } \beta_{i,j} = \Delta_{i,j}/\lambda_{i,j} = \frac{W_{i,j}Q}{16\lambda_{i,j}}.$$

In the event that all coefficients corresponding to an AC location are zero, either because of coarse quantization during encoding or small magnitude of the coefficients, $\lambda_{i,j}$ may be estimated according to the following equation:

$$\frac{1}{\lambda_{i,j}} e^{-\frac{W_{i,j}Q/16}{2\lambda_{i,j}}} = \frac{1}{N},$$

wherein N represents the number of blocks in the picture. Alternatively, a look-up-table may be utilized to solve the equation quickly. The average quantization error or distortion for this AC location is then estimated as follows:

$$D_{i,j}=2\lambda^2_{i,j},$$

Here, it is assumed that the true distribution of the (i, j)th coefficients range from all 0 (with no quantization error) to the Laplacian distribution with parameter $\lambda_{i,j}$ (with quantization error $2\lambda^2_{i,j}$). Finally, the overall average distortion in the DCT domain is computed as follows:

$$D = \frac{\sum_{i=0,j=0}^{i=7,j=7} D_{i,j}}{64}.$$

Finally, in step **200**, the PSNR is calculated as follows:

$$PSNR = 10\log_{10}\frac{255\times 255}{D}$$

The peak signal-to-noise ratio (PSNR) obtained, as described in the preceding paragraph, can be used to evaluate the picture quality in accordance with the present invention.

FIG. **4** depicts a representative hardware of the decoder **16** and the estimator **18** illustrated in FIG. **1** according to a second embodiment of the present invention. The decoder **16** includes a parser **40**, DCT block **42**, a statistics collector **44**, a distortion calculator **46**, and a PSNR calculator **48**. In operation, an incoming bitstream is decoded by the decoder **16**, and the decoded video data is subjected to DCT processing by the DCT block **42** in order to generate DCT coefficients for AC frequency bands in the video data. The statistics collector **44** estimates variance of the DCT coefficients, whereafter the estimated DCT variance is transmitted to the distortion calculator **46**. Meanwhile, the parser **40** extracts quantization matrices from the incoming bitstream that correspond to those used in a previous coding operation. The distortion calculator block **46** uses the quantization matrices and the DCT variance to determine the average quantization error. Finally, the PSNR calculator block **48** determines the PSNR using the average quantization error obtained by the distortion calculator block **24**.

FIG. **5** depicts a representative hardware of the decoder **16** and estimator **18** illustrated in FIG. **1** according to a third embodiment of the present invention. The construction and operation of the second embodiment are essentially the same as that described above with respect to FIG. **2**(*a*). The only notable difference is that the function of the parser **40** is incorporated in the estimator **18** in the second embodiment. Hence, the discussion of similar components described in the preceding paragraphs is omitted to avoid redundancy, as they are described with respect to FIG. **4**.

FIG. **6** is a flow diagram depicting the operation steps of evaluating video quality in accordance with the second and third embodiments of the present invention. It should be noted that the processing and decision blocks may represent steps performed by functionally equivalent circuits such as a digital signal processor circuit or an application specific integrated circuit (ASIC). In addition, the flow diagrams illustrate the functional information that a person of ordinary skill in the art requires to fabricate circuits or to generate computer software to perform the processing required of the particular apparatus. Specifically, with reference to FIGS. **4** and **5**, the incoming video data is decoded in step **100**. From the decoded video data, the intra_DC_precision, quantization matrices (W_{ij}), and quantization step size for each macroblock Q_m for the whole picture are extracted in step **320**. A quantization matrix consists of sixty-four entries, each entry being designated with a weight. The sixty-four entries, each being an 8-bit integer ranging from 1 to 255, correspond to 8×8 DCT coefficients in a block. The weight and the quantizer scale-value determine quantization step-sizes for a block of DCT coefficients. Thereafter, in step **340**, the decoded video data is subjected to a DCT transform to generate DCT coefficients for AC frequency bands in the video data.

In step **360**, estimating statistics of DCT Coefficients is performed. For each AC location (i, j), the variance of the coefficients $\lambda^2_{i,j}$ is estimated according to the formula below:

$$\lambda^2_{i,j} = \frac{\sum_{b=1}^{N}(C^b_{i,j})^2}{2N}$$

wherein C^b_{ij} represents the (i, j)th AC coefficient in block b, and N represents the total number of blocks in the picture.

After determining the DCT statistics $\lambda^2_{i,j}$, in step **380**, the average quantization error is estimated. This is performed for each set of DCT coefficients corresponding to the same DCT location. Calculating the quantization error is explained in the U.S. Pat. No. 6,067,118 entitled, "Method of Frame-By-Frame Calculation of Quantization Matrices," assigned to the same assignee, and herein incorporated by simple reference. For DC, the quantization error $D_{0,0}$ is estimated to be half that of the intra-DC quantization step size according to the table below:

Intra_DC_Precision	Average DC quantization error
8	4
9	2

-continued

Intra_DC_Precision	Average DC quantization error
10	1
11	0

For the (i, j)th AC location, the quantization error $D_{i,j}$ is estimated as follows:

$$D_{i,j} = 2\lambda_{i,j}^2\left(1 - \frac{\beta_{i,j}}{e^{\beta_{i,j}/2} - e^{-\beta_{i,j}/2}}\right)$$

where $\beta_{i,j} = \Delta_{i,j}/\lambda_{i,j} = \frac{W_{i,j}Q}{16\lambda_{i,j}}$.

In the event that all coefficients corresponding to an AC location are zero either because of coarse quantization during encoding or a small magnitude of the coefficients, $\lambda_{i,j}$ may be estimated according to the following equation:

$$\frac{1}{\lambda_{i,j}} e^{\frac{W_{i,j}Q/16}{2\lambda_{i,j}}} = \frac{1}{N},$$

wherein N represents the number of blocks in the picture. Alternatively, a look-up-table may be utilized to solve the equation quickly. The average quantization error or distortion for this AC location is then estimated as follows:

$$D_{i,j} = 2\lambda^2_{i,j}.$$

Here, it is assumed that the true distribution of the (i, j)th coefficients range from all 0 (with no quantization error) to the Laplacian distribution with the parameter $\lambda_{i,j}$ (with quantization error $2\lambda^2_{i,j}$). The overall average distortion in DCT domain is computed as follows:

$$D = \frac{\sum_{i=0,j=0}^{i=7,j=7} D_{i,j}}{64}.$$

Finally, in step **400**, the PSNR is calculated as follows:

$$PSNR = 10\log_{10}\frac{255\times 255}{D}.$$

Accordingly, the peak signal-to-noise ratio (PSNR) necessary to evaluate the picture quality is obtained.

FIG. **7** illustrates a fourth embodiment of the present invention in which the hardware of the estimator is integrated into a conventional decoder. The decoder according to the present invention is a programmable video decoding system, which includes: a variable length decoder (VLD) **60** configured to receive and decode a stream of block-based data packets; an inverse quantizer **62** coupled to receive the output of the VLD **60** to operatively inverse quantize the quantized data received from the VLD **60**; an inverse discrete cosine transformer (IDCT) **61** coupled to the output of the inverse quantizer for transforming the dequantized data from a frequency domain to a spatial domain; a motion compensator (MC) **68** configured to receive motion vector data from the quantized data and to generate a reference signal based on motion-compensated block of a preceding frame stored in a preceding frame stage and a motion-compensated block of a succeeding frame stored from a frame storage **70**; an adder for receiving the reference signal and the spatial domain data from the IDCT **64** to form motion-compensated pictures; a statistics collector **72** for estimating the variance of the DCT coefficients; a distortion calculator block **74** for determining the average quantization error **74** based on the quantization matrices; and, a PSNR calculator **76** for determining the PSNR using the average quantization error obtained by the distortion calculator block **74**.

While the preferred embodiments of the present invention have been illustrated and described, it will be understood by those skilled in the art that various changes and modifications may be made, and equivalents may be substituted for elements thereof without departing from the true scope of the present invention. In addition, many modifications may be made to adapt to a particular situation and the teaching of the present invention without departing from the central scope. Therefore, it is intended that the present invention not be limited to the particular embodiment disclosed as the best mode contemplated for carrying out the present invention, but that the present invention include all embodiments falling within the scope of the appended claims.

What is claimed is:

1. A method for evaluating the quality of encoded video data, the method comprising the steps of:

decoding at least a substantial portion of said encoded video data to produce decompressed video data including a plurality of blocks;

performing a discrete cosine transform (DCT) on said decompressed video data to produce a set of DCT coefficients for at least one AC frequency band;

simultaneously, extracting quantization matrix data for the at least one AC frequency band and extracting a quantizer scale for each block of said decompressed video data;

estimating a variance of said DCT coefficients;

determining an average quantization error for each set of said DCT coefficients based on said variance, said quantization matrix, and said quantizer scale; and,

calculating a peak signal to noise ratio (PSNR) based on said average quantization error.

2. The method of claim **1**, wherein said quantizer step size is calculated by averaging the AC coefficients in each of said decompressed video data as follows:

$$\overline{C}_{i,j} = \frac{C_{i,j}\times 16}{W_{i,j}},$$

where $C_{i,j}$ represents the (i, j)th AC coefficient in the current block, $\overline{C}_{i,j}$ represents the normalized AC coefficient, and $W_{i,j}$ represents the (i, j)th quantization matrix.

3. The method of claim **2**, wherein the variance of the coefficients (λ^2_{ij}) is determined by the following equation:

$$\lambda^2_{i,j} = \frac{\sum_{b=1}^{N}(C^b_{i,j})^2}{2N},$$

where C^b_{ij} represents the (i, j)th AC coefficient in each block (b), and N represents the total number of blocks.

4. The method of claim **3**, wherein the average quantization error (D) is computed as follows:

$$D = \frac{\sum_{i=0,j=0}^{I=7,j=7} D_{i,j}}{64},$$

and $D_{i,j}=2\lambda^2_{i,j}$,

where λ^2_{ij} represents the variance of the coefficients (λ^2_{ij}), and $D_{i,j}$ represents the quantization error for the (i, j)th AC coefficient in each block.

5. The method of claim **4**, wherein said PSNR is calculated as follows:

$$PSNR = 10 \log_{10} \frac{255 \times 255}{D},$$

where D represents an average quantization error.

6. The method of claim **1**, wherein said quantization matrix and said quantizer scale correspond substantially to coding parameters used in a coding operation that was previously performed on said encoded video data.

7. The method of claim **1**, wherein said quantization matrix and said quantizer scale correspond substantially to coding parameters used in a coding operation that was previously performed on said encoded video data.

8. A method for evaluating the quality of encoded video data, the method comprising the steps of:

at least partially decompressing said encoded video data in an MPEG decoder and outputting a decompressed video data including a plurality of blocks;

detecting an intra-coded picture in each block of said decompressed video data;

if detected, performing a discrete cosine transform (DCT) on said decompressed video data to produce a set of DCT coefficients for at least one AC frequency band;

extracting quantization matrix data for the at least one AC frequency band;

extracting a quantizer scale for each block of said decompressed video data;

estimating a variance of said DCT coefficients;

determining an average quantization error for each set of said DCT coefficients; and,

calculating a peak signal to noise ratio (PSNR) based on said average quantization error.

9. The method of claim **8**, wherein said detecting step comprises the steps of:

performing a DC computation operation to recover the intra-dc-precision level from said decompressed video data; and,

if said intra-dc-precision level is less than a predefined threshold, classifying said decoded video data as an intra-coded picture.

10. The method of claim **8**, wherein said quantizer step size is calculated by averaging the AC coefficients in each of said decompressed video data as follows:

$$\overline{C}_{i,j} = \frac{C_{i,j} \times 16}{W_{i,j}},$$

where $C_{i,j}$ represents the (i, j)th AC coefficient in the current block, $\overline{C}_{i,j}$ represents the normalized AC coefficient, and $W_{i,j}$ represents the (i, j)th quantization matrix.

11. The method of claim **10**, wherein the variance of the coefficients (λ^2_{ij}) is determined by the following equation:

$$\lambda^2_{i,j} = \frac{\sum_{b=1}^{N} (C^b_{i,j})^2}{2N}$$

where C^b_{ij} represents the (i, j)th AC coefficient in each block (b), and N represents the total number of blocks.

12. The method of claim **11**, wherein the average quantization error (D) is computed as follows:

$$D = \frac{\sum_{i=0,j=0}^{I=7,j=7} D_{i,j}}{64},$$

and $D_{i,j}=2\lambda^2_{i,j}$,

where λ^2_{ij} represents the variance of the coefficients (λ^2_{ij}), and $D_{i,j}$ represents the quantization error for the (i, j)th AC coefficient in each block.

13. The method of claim **12**, wherein said PSNR is calculated as follows:

$$PSNR = 10 \log_{10} \frac{255 \times 255}{D}$$

where D represents an average quantization error.

14. An apparatus for evaluating the quality of encoded video data comprising:

a decoder for decoding at least a substantial portion of said encoded video data to produce decoded video data including a plurality of blocks;

a discrete cosine transform (DCT) configured to transform said decompressed video data into a set of DCT coefficients for at least one AC frequency band;

an extractor for extracting quantization matrix data for the at least one AC frequency band and for extracting a quantizer scale for each block of said decompressed video data;

a collector for estimating a variance of said DCT coefficients;

a first calculator for determining an average quantization error for each set of said DCT coefficients based on said variance, said quantization matrix, and said quantizer scale; and,

a second calculator for determining a peak signal to noise ratio (PSNR) based on said average quantization error.

15. The apparatus of claim **14**, further comprising a picture detector for detecting for an intra-coded picture in each block of said decompressed video data.

16. The apparatus of claim **15**, wherein said picture detector comprises:

means for performing a DC computation operation to recover an intra-dc-precision level from said decompressed video data; and,

means for classifying said decoded video data as an intra-coded picture when said intra-dc-precision level is less than a predefined threshold.

17. The apparatus of claim **14**, wherein said quantization matrix and said quantizer scale correspond substantially to coding parameters used in a coding operation that was previously performed on said encoded video data.

18. The apparatus of claim **14**, wherein said quantizer step size is calculated by averaging the AC coefficients in each of said decompressed video data as follows:

$$\overline{C}_{i,j} = \frac{C_{i,j} \times 16}{W_{i,j}},$$

where $C_{i,j}$ represents the (i, j)th AC coefficient in current block, $\overline{C}_{i,j}$ represents the normalized AC coefficient, and $W_{i,j}$ represents the (i, j)th quantization matrix.

19. The apparatus of claim **18**, wherein the variance of the coefficients (λ^2_{ij}) is determined by the following equation:

$$\lambda^2_{i,j} = \frac{\sum_{b=1}^{N} (C^b_{i,j})^2}{2N},$$

where C^b_{ij} represents the (i, j)th AC coefficient in each block (b), and N represents the total number of blocks.

20. The apparatus of claim **19**, wherein the average quantization error (D) is computed as follows:

$$D = \frac{\sum_{i=0,j=0}^{I=7,j=7} D_{i,j}}{64},$$

and $D_{i,j}=2\lambda^2_{i,j}$,

where λ^2_{ij} represents the variance of the coefficients (λ^2_{ij}), and $D_{i,j}$ represents the quantization error for the (i, j)th AC coefficient in each block.

21. The apparatus of claim **20**, wherein said PSNR is calculated as follows:

$$PSNR = 10 \log_{10} \frac{255 \times 255}{D},$$

where D represents an average quantization error.

22. An apparatus for evaluating the quality of encoded video data comprising:

a decoder configured to decode compressed variable-length Huffman codes and for producing therefrom decoded data, and for extracting quantization matrix data and a quantizer scale for each block of said decoded video data;

an inverse quantizer configured to perform inverse-quantizing of the decoded data output from said decoder to produce a set of DCT coefficients;

an inverse DCT configured to transform values of pixels in blocks of signals output from said inverse quantizer to dequantize decoded data including difference data;

a motion compensation and adder for receiving reference data within the encoded video data and said difference data from said inverse DCT to form motion-compensated pictures therefrom;

a collector coupled to the output of said inverse quantizer for estimating a variance of said DCT coefficients;

a first calculator for determining an average quantization error for each set of said DCT coefficients based on said variance, said quantization matrix, and said quantizer scale; and,

a second calculator for determining a peak signal to noise ratio (PSNR) based on said average quantization error.

23. The apparatus of claim **22**, further comprising a video memory configured to store reproduced video data.

24. The apparatus of claim **22**, wherein said quantization matrix and said quantizer scale correspond substantially to coding parameters used in a coding operation that was previously performed on said encoded video data.

25. A system for evaluating the quality of encoded video data comprising:

a memory for storing a computer-readable code; and,

a processor operatively coupled to said memory, said processor configured to:

decompress said encoded video data to produce a decompressed video data including a plurality of blocks;

detect an intra-coded picture in each block of said decompressed video data;

if detected, perform a discrete cosine transform (DCT) on said decompressed video data to produce a set of DCT coefficients for at least one AC frequency band;

extract quantization matrix data for the at least one AC frequency band;

extract a quantizer scale for each block of said decompressed video data;

estimate a variance of said DCT coefficients;

determine an average quantization error for each set of said DCT coefficients; and,

calculate a peak signal to noise ratio (PSNR) based on said average quantization error.

26. The system of claim **25**, wherein the detection of said intra-coded picture includes the steps of:

performing a DC computation operation to recover an intra-dc-precision level from said decompressed video data; and,

classifying said decoded video data as an intra-coded picture when said intra-dc-precision level is less than a predefined threshold.

27. The apparatus of claim **25**, wherein said quantization matrix and said quantizer scale correspond substantially to coding parameters used in a coding operation that was previously performed on said encoded video data.

* * * * *

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Lee et al.

(10) **Patent No.: US 6,801,492 B2**
(45) **Date of Patent: Oct. 5, 2004**

(54) **SOLID IMMERSION MIRROR TYPE OBJECTIVE LENS AND OPTICAL PICKUP DEVICE ADOPTING THE SAME**

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(73) Assignee: **Samsung Electronics Co., Ltd.**, Suwon-si (KR)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 477 days.

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(65) **Prior Publication Data**

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(30) **Foreign Application Priority Data**

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(51) **Int. Cl.**[7] **G11B 7/135**

(52) **U.S. Cl.** **369/112.26**; 369/112.25; 359/731

(58) **Field of Search** 369/112.26, 112.25, 369/13.33, 112.2; 359/731, 730, 719, 729

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Assistant Examiner—M. V. Battaglia
(74) *Attorney, Agent, or Firm*—Staas & Halsey LLP

(57) **ABSTRACT**

A solid immersion mirror (SIM) type objective lens and an optical pickup employing the same. The objective lens has a first curved surface which condenses incident light and a second curved surface surrounding the first curved surface which diverges incident light. A second transmission surface disposed to face the first transmission surface has an area which transmits incident light and a first reflection surface surrounding the second transmission surface which reflects incident light. A second reflection surface which surrounds the second curved reflects incident light. The objective lens realizes an NA of 0.7 or more with a single lens; has a working distance enabling far field recording/reproducing; has a smaller blocking area than that of the conventional SIM; and generates a smaller amount of side lobe. Where the objective lens is adopted in an optical pickup device, generation of jitter during reproduction or cross erasure during recording is minimized.

29 Claims, 5 Drawing Sheets

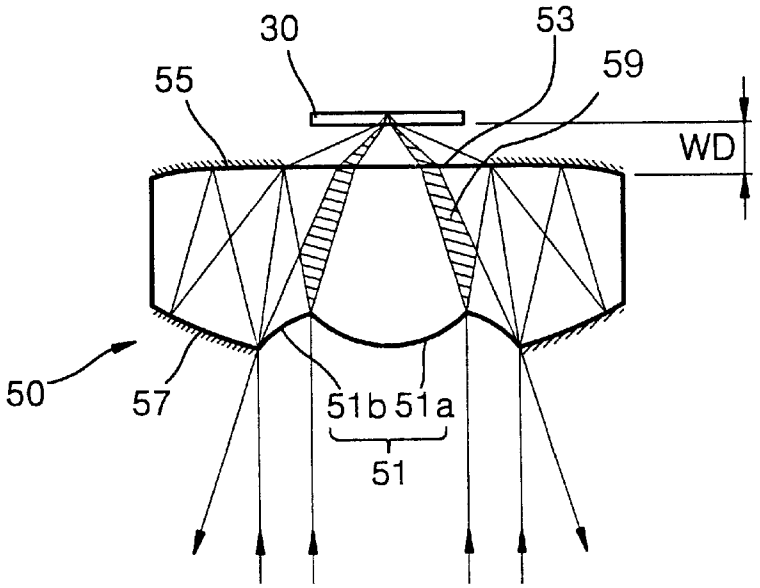


FIG. 1 (PRIOR ART)

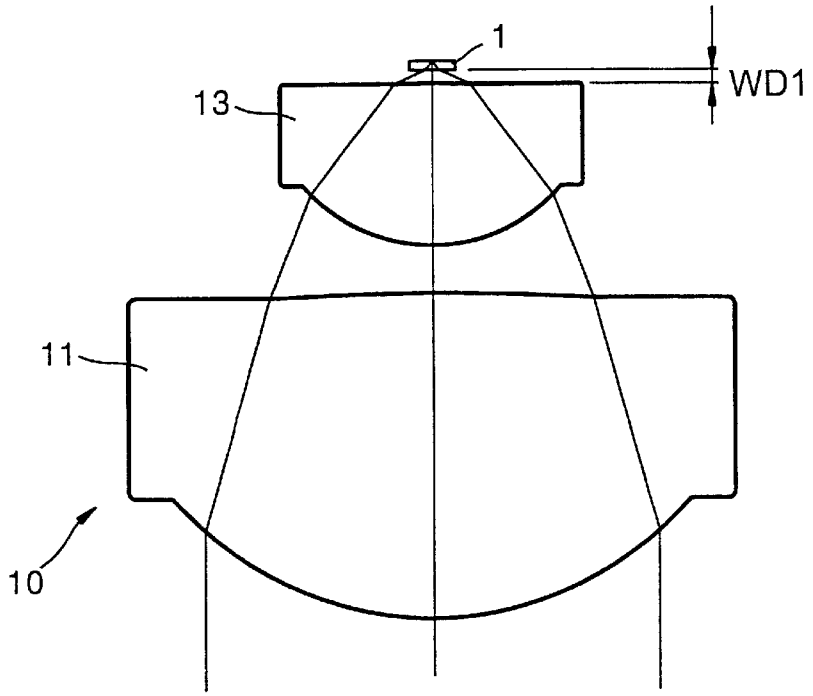


FIG. 2 (PRIOR ART)

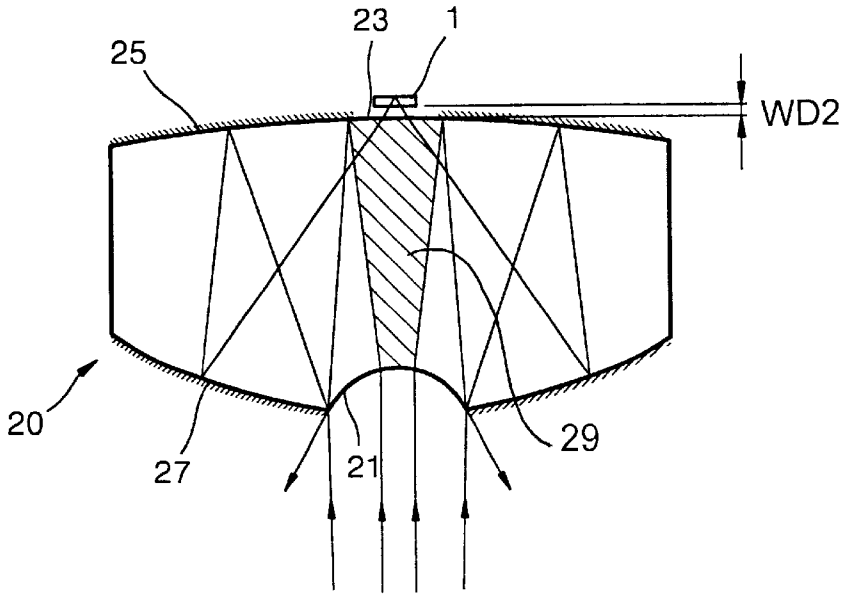


FIG. 3 (PRIOR ART)

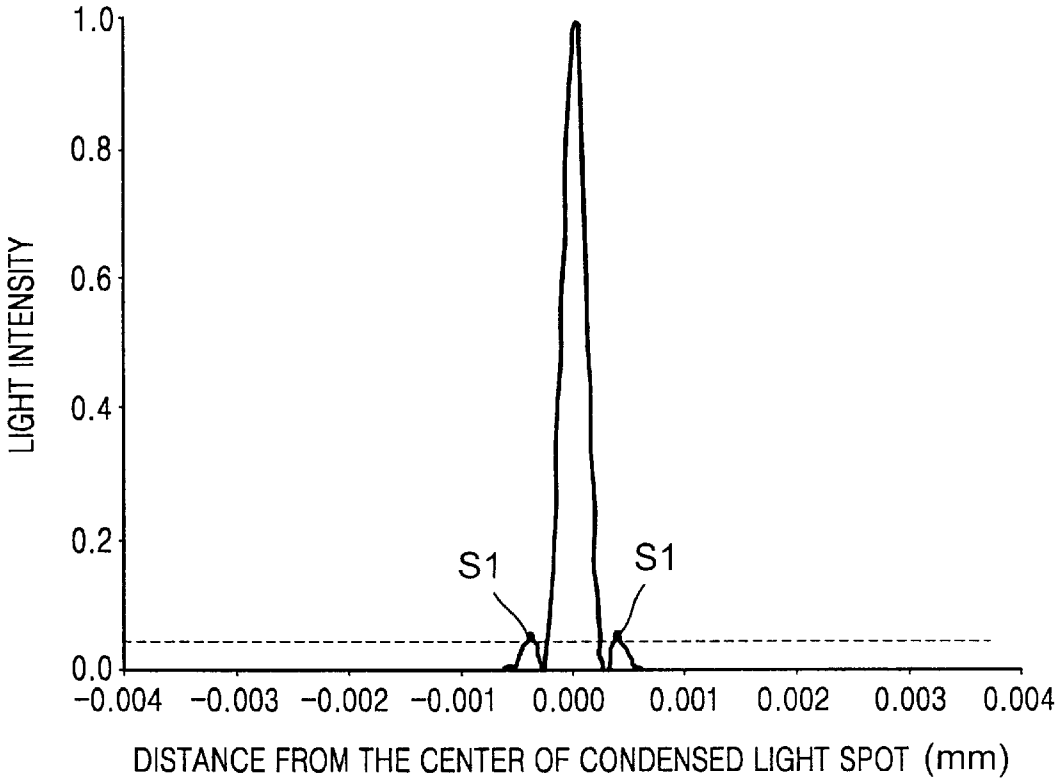


FIG. 4

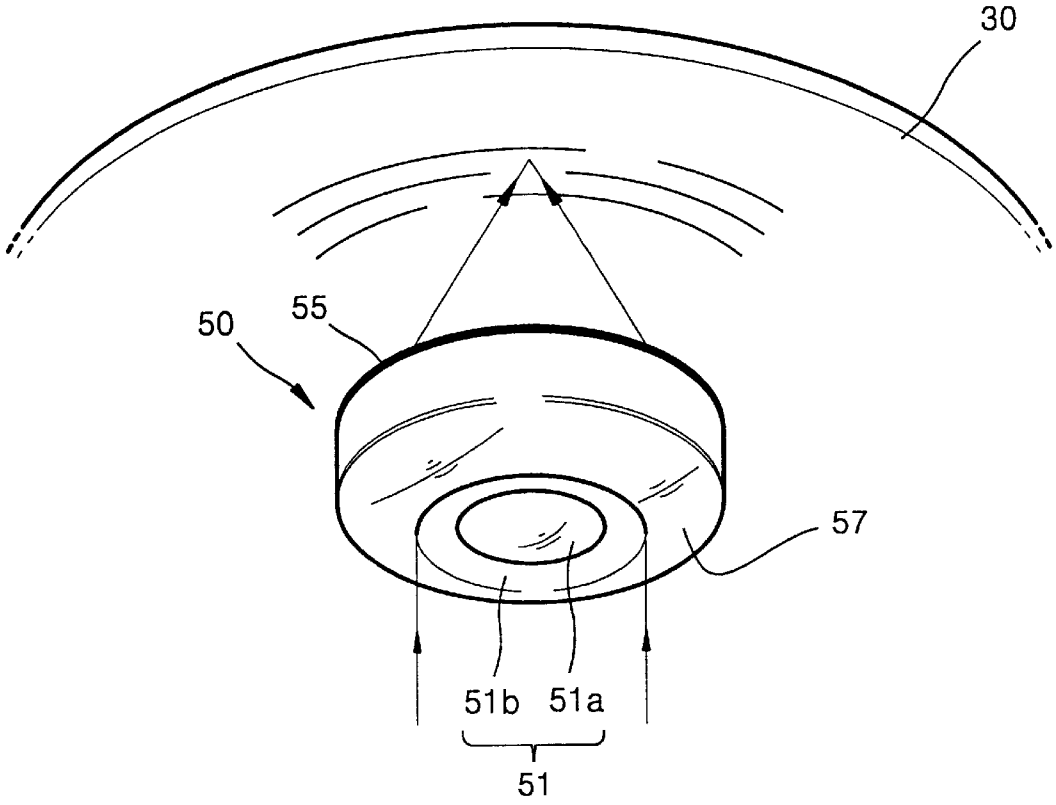


FIG. 5

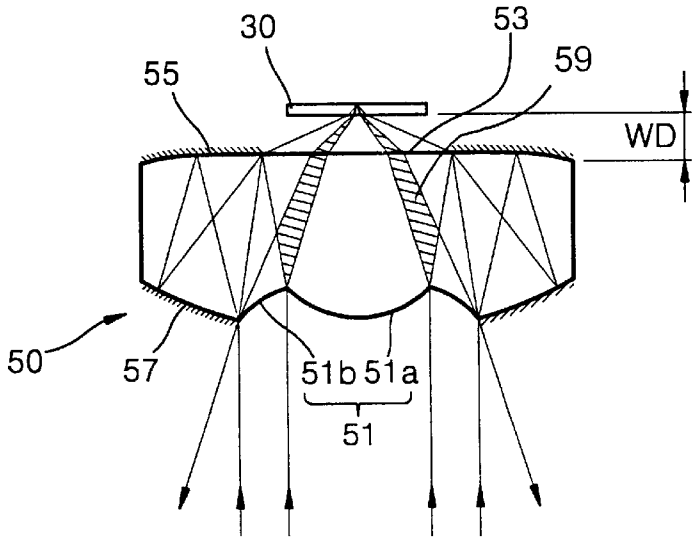


FIG. 6

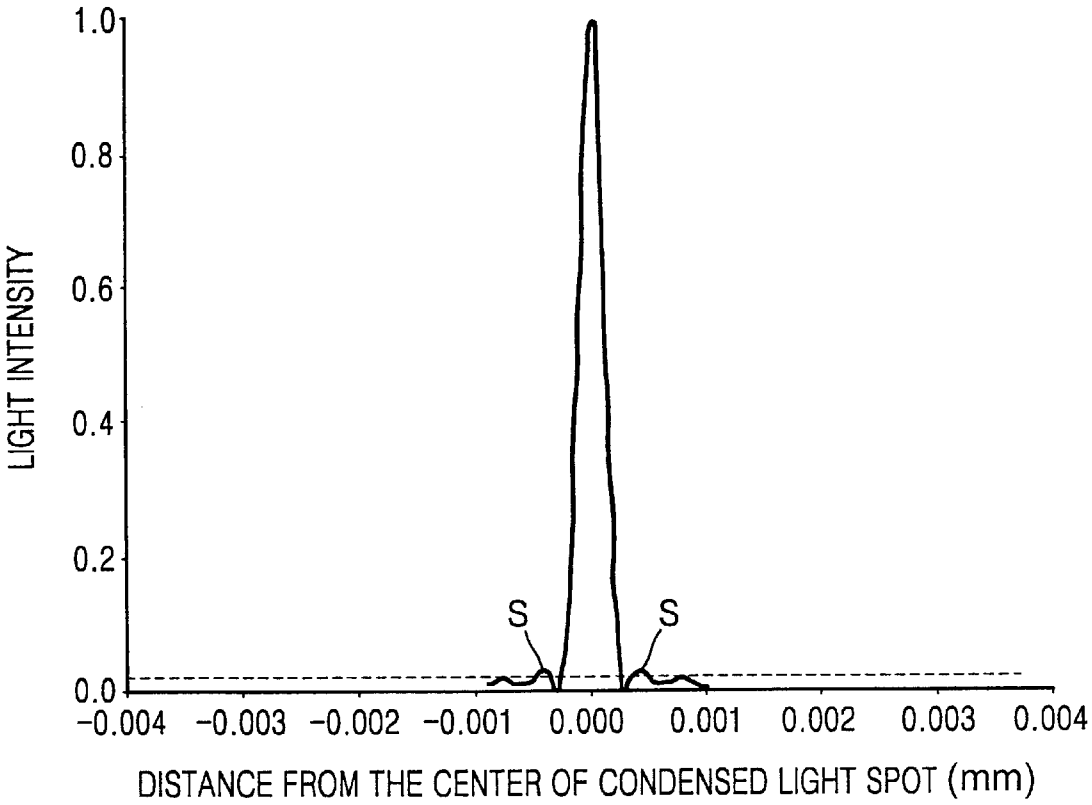
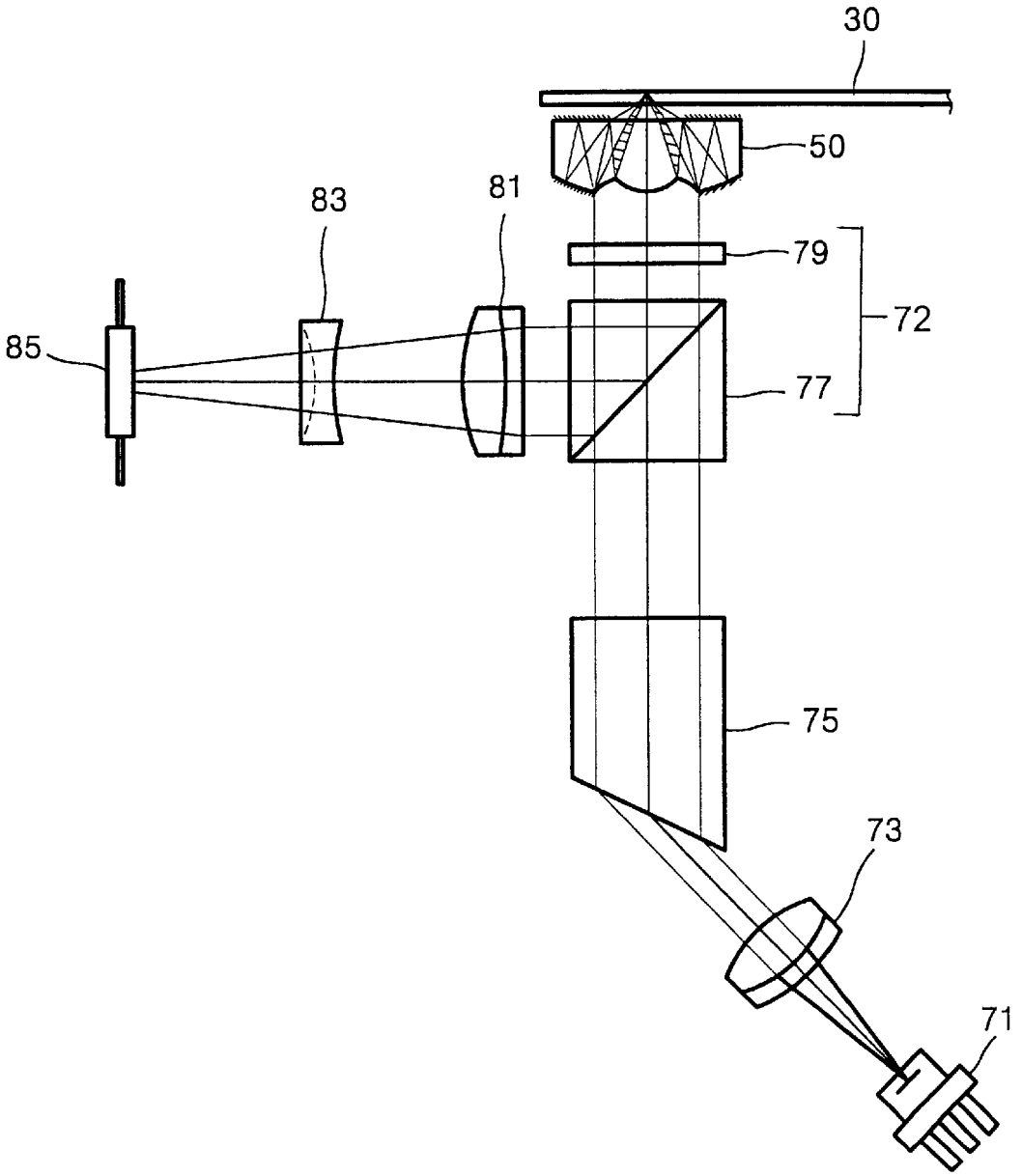

1.0
0.8
0.6
0.4
0.2
0.0
LIGHT INTENSITY
S
S
-0.004
-0.003
-0.002
-0.001
0.000
0.001
0.002
0.003
0.004
DISTANCE FROM THE CENTER OF CONDENSED LIGHT SPOT (mm)

FIG. 7



SOLID IMMERSION MIRROR TYPE OBJECTIVE LENS AND OPTICAL PICKUP DEVICE ADOPTING THE SAME

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of Korean Application No. 2000-76492 filed Dec. 14, 2000, in the Korean Patent Office, the disclosure of which is incorporated herein by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a solid immersion mirror (SIM) type objective lens and an optical pickup device adopting the same, and particularly, to a modified SIM type objective lens for far field recording/reproducing, and an optical pickup device adopting the same.

2. Description of the Related Art

In general, information recording/reproducing density increases as a size of a light spot formed on an optical disc by an optical pickup device is decreased. The size of a light spot decreases as a wavelength of a light beam in use becomes shorter and an NA of an objective lens which focuses the light spot becomes greater. A relationship of the size of a light spot to wavelength and NA is shown in equation (1).

$$\text{Size of light spot} \propto \lambda/\text{NA} \quad (1)$$

Thus, an optical pickup device for high density should adopt a light source emitting a light beam having a shorter wavelength and an objective lens having a high NA. To realize a stable system, the objective lens should have a working distance (a distance from a light exit surface of an objective lens to a light input surface of an optical disc) which is large. An optical pickup device for recoding/reproducing information on/from an optical disc of a next generation DVD family, or a so-called HD-DVD (high definition digital versatile disk) family, may adopt, for example, a light source for emitting a light beam having a wavelength of 405 nm and an objective lens having an NA of 0.85 and a large working distance.

However, due to a limit in manufacture, it is difficult to manufacture an objective lens formed of a single lens having an NA of 0.7 or more and satisfying an allowance condition of optical aberration. Thus, to realize an NA of 0.7 or more and satisfy an allowance condition of optical aberration, an objective lens **10** formed of two lenses as shown in FIG. **1** has been suggested.

Referring to FIG. **1**, a conventional objective lens **10** includes a first condensing lens **11** for condensing incident light and a second condensing lens **13** arranged between the first condensing lens **11** and an optical disc **1** for increasing an NA of the objective lens **10**. In the objective lens **10**, for example, where a 0.6 NA is secured by the first condensing lens **11**, the NA may be increased by the second condensing lens **13**. For the objective lens **10** to have a 0.85 NA, a light input surface of each of the first and/or second condensing lenses **11** and **13**, facing a light source (not shown), is formed to have a large curvature, or at least one of the first and second condensing lenses **11** and **13** is formed of a material exhibiting a high refractive index, to produce a sharp refraction of light.

Thus, the objective lens **10** as shown in FIG. **1** is sensitive to decenter, being off an optical axis, and coma is greatly

generated according to an amount of the decenter. Also, the objective lens **10** is difficult to manufacture because processing a lens surface having a large curvature is difficult.

Also, the working distance WD1 of the objective lens **10** is short, for example, about 0.15 mm due to a sharp refraction of light. It is difficult to design the objective lens **10** to have a working distance of 0.15 mm or more. For reference, the working distance of an objective lens in an optical pickup device for DVD is about 1.8 mm.

Since the objective lens **10** realizes a high NA by the structure of two lenses, where the first and second condensing lenses **11** and **13** are inclined to each other, it is impossible to maintain a small optical aberration. Thus, allowance of distance and inclination between the first and second condensing lenses **11** and **13** is very strictly obeyed.

Referring to FIG. **2**, a conventional solid immersion mirror **20** includes a first transmission surface **21** for diverging and transmitting incident light, a second transmission surface **23** disposed to face the first transmission surface **21**, a first reflection surface **25** formed around the second transmission surface **23**, for reflecting incident light passing through the first transmission surface **21** and a second reflection surface **27**, formed around the first transmission surface **21**, for reflecting incident light reflected by the first reflection surface **25** to proceed toward the second transmission surface **23**.

The solid immersion mirror **20** as described above may realize an NA of 0.7 or more with a single lens structure. In the solid immersion mirror **20**, since a blocking area, indicated by a hatched area **29** in FIG. **2**, exists where the light input to the first transmission surface **21** is relatively near the optical axis, some of the input light is not focused on a recording surface of the optical disc **1** and is lost. Here, the light lost by not being focused on the recording surface of the optical disc **1** is light directly input to the second transmission surface **23** from the first transmission surface **21**, and light which is lost at a boundary between the first transmission surface **21** and the second reflection surface **27** among the light from the fist transmission surface **21**, reflected by the first reflection surface **25**, and proceeding toward the second reflection surface **27**. In FIG. **2**, to show the blocking area, only a proceeding path of the light input to the first transmission surface **21** is shown. Light reflected by the recording surface of the optical disc **1** and input to the second transmission surface **23** proceeds in the reverse order along the light proceeding path shown in FIG. **2**.

The solid immersion mirror **20** can realize a high NA of 0.7 or more with a single lens. Since the solid immersion mirror **20** has a structure in which light is condensed after reflected from the two reflection surfaces **25** and **27**, curvature may be small so that the solid immersion mirror **20** may be insensitive to the decenter, exhibit relatively superior chromatism quality, and be manufactured easily.

However, since the blocking area exists due to the structure of the solid immersion mirror **20**, as shown in FIG. **2**, all of the incident light is not used, and the efficiency of light is reduced. About ⅓ of the incident light is blocked in the conventional solid immersion mirror **20**.

Also, since the quantity of the blocked light depends on the size of the first transmission surface **21**, the diameter of the first transmission surface **21** is made less than ¼ of an overall effective diameter of the solid immersion mirror **20** to minimize reducing the light efficiency. To maximize efficiency in an optical pickup device employing the solid immersion mirror **20** as an objective lens, an incident light beam having a diameter slightly greater than that of the first transmission surface **21** is input to the first transmission

surface **21**. Accordingly, the quantity of light input to the first transmission surface **21** is greatly affected by movement of the solid immersion mirror **20** for tracking in a radial direction perpendicular to the optical axis.

FIG. **3** shows a light beam intensity profile of light focused by the solid immersion mirror **20**. As can be seen from FIG. **3**, since a side lobe S1 which amounts to 5–6% of a peak value of the light intensity is relatively great, where the solid immersion mirror **20** is adopted as an objective lens of an optical pickup device, a great amount of jitter is generated during reproduction of information recorded on the optical disc **1** and a cross erasure problem of removing signals recorded on adjacent tracks may occur during recording. The conventional solid immersion mirror **20** used to generate the light intensity profile shown in FIG. **3** has an NA of 0.85, an overall effective diameter of 4.5 mm, and the first transmission surface **21** has a diameter of 1.0 mm. Thus, where about 33% of the quantity of light input to the first transmission surface **21** is blocked. FIG. **3** shows a light intensity profile of a beam having a 400 mm wavelength and focused by the conventional solid immersion mirror **20**. A side lobe is also produced in light focused by the objective lens **10** as shown in FIG. **1**. However, the side lobe produced in light focused by the objective lens **10** is about 2–3% or less of a peak value of the light intensity so that it does not cause a serious increase of jitter in a reproduction signal and cross erasure.

Further, since the conventional solid immersion mirror **20** having the structure shown in FIG. **2** has a short working distance WD2, the SIM **20** is usable as an objective lens for high density light condensation in a near field recording/reproducing needing a working distance of several tens to hundreds nano meters, but is not useable as an objective lens for far field recording/reproducing.

SUMMARY OF THE INVENTION

To solve the above-described and other problems, it is a first object of the present invention to provide a solid immersion mirror type objective lens formed of a single lens and having a high NA of 0.7 or more.

It is a second object of the invention to provide an optical pickup device which adopts the solid immersion mirror type lens formed of a single lens and having a high NA of 0.7 or more. The solid immersion mirror type objective lens of the present invention has a superior efficiency of light and a drastically reduced side lobe component compared with a conventional solid immersion mirror. Thus, where the solid immersion mirror type objective lens of the present invention is adopted in an optical pickup device, excess jitter is not generated during reproducing and cross erasure does not occur during recording. Also, since a relatively great working distance (compared with a conventional solid immersion mirror) is realizable, the solid immersion mirror type objective lens of the present invention is applicable to far field recording/reproducing.

Additional objects and advantages of the invention will be set forth in part in the description which follows, and, in part, will be obvious from the description, or may be learned by practice of the invention.

To achieve the first and other objects of the invention, there is provided an objective lens comprising a first transmission surface formed of a first curved surface which condenses incident light and a second curved surface formed around the first curved surface which diverges incident light, a second transmission surface disposed to face the first transmission surface and which transmits incident light, a first reflection surface formed around the second transmission surface which reflects incident light, and a second reflection surface formed around the first transmission surface which reflects incident light.

To achieve the second and other objects of the invention, there is provided an optical pickup device comprising a light source which generates and emits a laser beam, an optical path changer which changes a proceeding path of incident light, an objective lens arranged on an optical path between the optical path changer and a recording medium which condenses incident light emitted from the light source to form a light spot on the recording medium, and a photodetector which detects incident light reflected by the recording medium and passing through the objective lens and the optical path changer, wherein the objective lens comprises a first transmission surface comprising a first curved surface and which condenses incident light and a second curved surface formed around the first curved surface which diverges incident light, a second transmission surface disposed to face the first transmission surface which transmits incident light, a first reflection surface formed around the second transmission surface which reflects incident light, and a second reflection surface formed around the first transmission surface which reflects incident light.

BRIEF DESCRIPTION OF THE DRAWINGS

The above object and advantages of the present invention will become more apparent by describing in detail preferred embodiments thereof with reference to the attached drawings in which:

FIG. **1** is a view showing an example of a conventional objective lens formed of two lenses;

FIG. **2** is a view showing an example of a conventional solid immersion mirror;

FIG. **3** is a graph showing a beam profile of light condensed by the solid immersion mirror of FIG. **2**;

FIG. **4** is a perspective view of a solid immersion mirror type objective lens according to an embodiment of the present invention;

FIG. **5** is a side view of the solid immersion mirror type objective lens according to an embodiment of the present invention;

FIG. **6** is a graph showing a beam profile of light condensed by an objective lens according to the present invention; and

FIG. **7** is a view showing the optical arrangement of an optical pickup device adopting the objective lens according to the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Reference will now be made in detail to the present embodiments of the present invention, examples of which are illustrated in the accompanying drawings, wherein like reference numerals refer to like elements throughout.

Referring to FIGS. **4** and **5**, an objective lens **50** according to the present invention is a modified solid immersion mirror (SIM). The objective lens **50** comprises a first transmission surface **51** formed of a first curved surface, preferably, a convex surface **51***a*, disposed on an optical axis, and a second curved surface, preferably, a concave surface **51***b*, formed around the first curved surface, a second transmission surface **53** disposed to face the first transmission surface **51**, a first reflection surface **55** formed around the second transmission surface **53**, and a second reflection surface **57** formed around the first transmission surface **51**.

The convex curved surface **51***a* of the first transmission surface **51** condenses light from a light source which is input relatively near the optical axis. The concave surface **51***b* is formed around the convex curved surface **51***a* and diverges light input radially outward from the convex curved surface **51***a*.

Preferably, the first transmission surface **51** has a diameter within a range including ⅔ and ⅘ of an overall effective diameter of the objective lens **50**. Considering conditions such as minimization of a blocking area, realization of high NA and a great working distance, minimizing generation of coma due to decenter, and ease in manufacture, the convex surface **51***a* of the first transmission surface **51** preferably has a diameter within a range including ⅕ and ⅔ of the overall effective diameter of the objective lens **50**. The diameter is maximum on a plane perpendicular to the optical axis of the first transmission surface **51** or the convex surface **51***a*.

Where light is input to the first transmission surface **51** of the objective lens **50** according to the present invention, the light incident upon the convex surface **51***a* of the first transmission surface **51** is condensed by the convex surface **51***a*, directly proceeds toward the second transmission surface **53** and passes the second transmission surface **53**, and is focused on a recording surface of the recording medium **30**, for example, a disc of a next generation DVD family. The light incident upon the concave surface **51***b* of the first transmission surface **51** is diverged and most light proceeds toward the first reflection surface **55**. Then, the light which is incident on the first transmission surface **55** is sequentially reflected by the first and second reflection surfaces **55** and **57** and passes through the second transmission surface **53**. Like the light passing through the convex surface **51***a*, the light passing through the concave surface **51***b* is focused on the recording surface of the recording medium **30**.

Part of the light passing a boundary of the convex surface **51***a* and the concave surface **51***b* of the first transmission surface **51**, reflected by the first reflection surface **55**, and proceeding toward the second reflection surface **57**, for example, light incident upon a boundary between the first transmission surface **51** and the second reflection surface **57**, is lost and is not focused on the recording surface of the recording medium **30**. The area of light which is not focused on the recording surface of the recording medium **30** is a blocking area which is indicated by hatching **59** in FIG. **5**.

The modified SIM type objective lens **50** according to the present invention has all merits of the conventional SIM **20** and simultaneously exhibits superior decenter and chromatism features and a higher efficiency of light, compared with the conventional SIM **20**. As shown in FIG. **5**, the SIM type objective lens **50** according to the present invention has a great working distance (WD) and as shown in FIG. **6**, the SIM type objective lens **50** generates a smaller quantity of side lobe S which does not cause serious jitter of a reproduction signal or cause cross erasure of the recording medium.

Since the modified SIM type objective lens **50** having the structure according to the present invention focuses the light incident on the convex surface **51***a* of the first transmission surface **51**, the blocking area is drastically reduced, compared with the conventional SIM **20**. Thus, an efficiency of light is high and the side lobe S is reduced, compared with the conventional SIM **20** described with reference to FIG. **2**.

FIG. **6** shows a beam profile of light condensed by the objective lens **50** according to the present invention. Performance of the objective lens of the present invention and performance of the conventional SIM are compared by comparing the light intensity profile of FIG. **6** with the light intensity profile of FIG. **3**. Here, the light intensity profile of the objective lens **50** as shown in FIG. **6** is formed under the same conditions as the light intensity profile of the conventional SIM **20** as shown in FIG. **3**. The data shown in FIG. **6** corresponds to an objective lens **50** having a convex surface **51***a* of which a radius of curvature and a diameter are 1.67 mm and 0.34 mm, respectively. Comparing FIG. **3** with FIG. **6**, shows that the side lobe S of the SIM **50** of the present invention is reduced to 2% or less of a peak value of light intensity, compared with a peak of 5% to 6% in a case of the conventional SIM **20**.

Experiments with the SIM type objective lens **50** of the present invention have confirmed that a 0.6 mm working distance (WD) is obtainable where the modified SIM type objective lens **50** is made such that an overall effective diameter of the objective lens **50** is about 5.0 mm, a diameter of the first transmission surface **51** is about 3.0 mm, a diameter of the convex surface **51***a* of the first transmission surface **51** is about 1.5 mm, and a maximum thickness of the objective lens **50** is about 1.7 mm. According to the experiments, the modified SIM type objective lens **50** as shown in FIGS. **4** and **5** obtains a working distance within a range including 0.1 mm and 0.6 mm, and indicates that a longer working distance is obtainable by a more strict design.

Here, the working distance is not necessarily limited to the values obtained experimentally and the working distance is changeable depending on design conditions such as size and curvature of the first and second transmission surfaces **51** and **53**, and the first and second reflection surfaces **55** and **57**. Nevertheless, by forming the center portion of the first transmission surface **51** to be the convex surface **51***a*, a design having an NA of 0.7 or more, preferably, 0.85, and simultaneously having a working distance greater than that of the conventional objective lenses **10** and **20** described with reference to FIGS. **1** through **3** is obtainable.

Thus, since the objective lens **50** according to the present invention realizes a great working distance, the objective lens **50** is easily adopted as an objective lens of an optical pickup device for recording/reproducing a recording medium of a next generation DVD family for far field recording/reproducing.

Also, since a ratio of the diameter of the first transmission surface **51** and the overall effective diameter of the objective lens **50** is greater than a ratio of the diameter of the first transmission surface **21** and the overall effective diameter of the conventional SIM **20**, an input light beam having a greater diameter than the conventional technology may be used. Thus, the quantity of light input to the first transmission surface **51** is relatively less affected by movement for tracking in a radial direction perpendicular to the optical axis than a similar movement in the technology incorporating the conventional SIM **20**.

FIG. **7** shows the optical arrangement of an optical pickup device for recording/reproducing a recording medium of a next generation DVD family adopting the modified SIM type objective lens **50** according to the present invention.

Referring to FIG. **7**, an optical pickup device according to the present invention comprises a light source **71**, a optical path changer **72** which changes a proceeding path of incident light, an objective lens **50** according to the present invention which condenses light emitted from the light source **71** to form a light spot on a recording medium **30**, and a photodetector **85** which receives light reflected by the recording medium **30** and passing through the optical path changer **72**.

The light source **71** comprises blue semiconductor laser which emits light having a wavelength of about 400–420 nm, preferably, about 405 nm. The semiconductor laser may be, for example, an edge emitting laser or a vertical cavity surface emitting laser.

The optical path changer **72** is arranged on the optical path between the light source **71** and the objective lens **50** to change a proceeding path of incident light. Preferably, the optical path changer **72**, as shown in FIG. **7**, comprises a polarized beam splitter **77** which selectively transmits or reflects incident light according to a polarization thereof, and a quarter wave plate **79** which changes a phase of the incident light. Alternatively, a beam splitter (not shown) which transmits and reflects incident light at a predetermined ratio may be provided as the optical path changer.

The objective lens **50** has an NA of 0.7 or more, preferably, 0.85, so that a light spot which enables recording/reproducing of a high density recording medium **30** such as a next generation DVD, or a so-called an HD-DVD, is formed. The photodetector **85** receives the light reflected by the recording medium **30** and detects an information signal and an error signal.

Preferably, a collimating lens **73** is provided on the optical path between the light source **71** and the optical path changer **72**. The collimating lens **73** condenses the divergent light emitted from the light source **71** into a parallel light beam. As shown in FIG. **7**, where the collimating lens **73** is arranged on the optical path between the light source **71** and the optical path changer, a condensing lens **81** is provided between the optical path changer **72** and the photodetector **85**.

Where the edge emitting laser is adopted as the light source **71**, a beam shaping prism **75** is preferably provided on the optical path between the collimating lens **73** and the optical path changer **72**, so that information is recorded with a relatively low light power. The beam shaping prism **75** shapes an oval beam emitted from the edge emitting laser into a circular beam. Alternatively, the beam shaping prism **75** may be arranged between the light source **71** and the collimating lens **73**. Where a vertical cavity surface emitting laser which emits an approximately circular beam is adopted as the light source **71**, the beam shaping prism **75** is omitted from the optical arrangement shown in FIG. **7**.

A sensing lens **83** is interposed between the condensing lens **81** and the photodetector **85**. For example, where a focus error signal is detected by an astigmatism method, an astigmatism lens which causes astigmatism to the incident light may be provided as the sensing lens **83**.

Since the optical pickup device according to the present invention adopts the modified SIM type objective lens **50** formed of a single lens, the optical pickup device is adapted to record or reproduce information on or from the recording medium **30** of a next generation DVD family. Also, an increase of jitter during reproduction of a signal and cross erasure do not occur. Cross erasure refers to erasing a signal recorded in an adjacent track.

Also, since the objective lens **50** having two reflection surfaces **55** and **57** is insensitive to chromatism, chromatism produced with respect to a change in wavelength according to a change in the amount of light output during a switch between reproduction and recording modes and/or an increase in width of a line width of a wavelength because the light source **71** is driven by HF (high frequency), is within a scope of allowance. Thus, by using the optical pickup device according to the present invention, quality recording and/or reproduction signals are obtained. Light having a wavelength of 405 nm is emitted from the light source **71** during output of reproduction power and light having a longer wavelength, for example, a wavelength of 406 nm, is emitted from the light source **71** during output of recording power.

FIG. **7** shows an embodiment of the optical pickup device adopting the objective lens **50** of the present invention. However, the optical pickup device according to the present invention is not limited to the optical arrangement of FIG. **7**. Since the objective lens **50** according to the present invention secures an NA of 0.7 or more and a relatively great working distance by a structure using a single lens, the objective lens **50** may be adopted in various optical systems, in addition to the optical pickup device for recording/reproducing information on/from a recording medium of a next generation DVD family. For example, the objective lens **50** according to the present invention may be adopted to various optical systems needing a high NA and a relatively great working distance such as a microscopic apparatus, a microscopic apparatus with a CCD camera connected thereto, a semiconductor exposure apparatus having an objective lens, a light source, and a collimating lens to focus light on a semiconductor material. The objective lens **50** is also usable in an apparatus for exposing an optical mask pattern on a photosensitive medium and a mastering apparatus for manufacturing an optical disc by using an objective lens.

In FIGS. **4**, **5**, and **7**, only a proceeding path of the light input to the first transmission surface **51** of the objective lens **50** is shown. The light reflected by the recording medium **30** and input to the second transmission surface **53** proceeds in the reverse order along the path shown in the drawings.

As described above, according to the present invention, by forming a surface on the optical axis on the first transmission surface and a concave surface around the convex surface in the SIM structure, an objective lens which has superior performance and which realizes a high NA of 0.7 or more with a single lens is obtainable.

That is, in the objective lens according to the present invention, since the blocking area is smaller than that of the conventional SIM, an efficiency of light is high. Also, in the objective lens according to the present invention, since a very small amount of side lobe is generated compared to the conventional SIM, where the objective lens of the present invention is adopted in an optical pickup device, excess generation of jitter during reproduction or cross erasure during recording does not occur. Further, the objective lens according to the present invention has a working distance which enables far field recording/reproducing. Therefore, the objective lens according to the present invention is especially suitable for use in an optical pickup device for recording/reproducing information on/from a recording medium of a next generation DVD family.

Although a few embodiments of the present invention have been shown and described, it would be appreciated by those skilled in the art that changes may be made in these embodiments without departing from the principles and spirit of the invention, the scope of which is defined in the claims and their equivalents.

What is claimed is:

1. An objective lens comprising:

a first transmission surface which transmits incident light, the first transmission surface comrprising:

a first curved surface disposed on an optical axis which condenses a first portion of the incident light, and

a second curved surface formed around the first curved surface which diverges a second portion of the incident light;

a second transmission surface disposed to face the first transmission surface and which transmits the incident light;

a first reflection surface formed around the second transmission surface which reflects the second portion of the incident light; and

a second reflection surface formed around the first transmission surface which condenses the reflected second portion of the incident light.

2. The objective lens as claimed in claim **1**, wherein the first curved surface of the first transmission surface is convex and the second curved surface is concave.

3. The objective lens as claimed in claim **2**, wherein a ratio of a diameter of the first curved surface and an overall effective diameter of the objective lens is in a range including ⅕ and ⅖.

4. The objective lens as claimed in claim **1**, wherein a ratio of a diameter of the first transmission surface and an overall effective diameter of the objective lens is in a range including ⅖ and ⅘.

5. The objective lens as claimed in claim **4**, wherein a ratio of a diameter of the first curved surface and an overall effective diameter of the objective lens is in a range including ⅕ and ⅖.

6. The objective lens as claimed in claim **1**, wherein a ratio of a diameter of the first curved surface and an overall effective diameter of the objective lens is in a range including ⅕ and ⅖.

7. An optical pickup device comprising:

a light source which emits light;

an optical path changer which changes a proceeding path of incident light;

an objective lens arranged on an optical path between the optical path changer and a recording medium which condenses the emitted light to form a light spot on the recording medium; and

a photodetector which detects light reflected by the recording medium and passing through the objective lens and the optical path changer,

wherein the objective lens comprises:

a first transmission surface which transmits incident light, the first transmission surface comprising:

a first curved surface disposed on an optical axis which condenses a first portion of the incident light, and

a second curved surface formed around the first curved surface which diverges a second portion of the incident light;

a second transmission surface disposed to face the first transmission surface which transmits the incident light;

a first reflection surface formed around the second transmission surface which reflects the second portion of the incident light; and

a second reflection surface formed around the first transmission surface which condenses the reflected second portion of the incident light.

8. The optical pickup device as claimed in claim **7**, wherein the first curved surface of the first transmission surface is convex and the second curved surface is concave.

9. The optical pickup device as claimed in claim **8**, wherein a ratio of a diameter of the first curved surface and an overall effective diameter of the objective lens is in a range including ⅕ and ⅖.

10. The optical pickup device as claimed in claim **8**, wherein the objective lens has an NA of 0.7 or more.

11. The optical pickup device as claimed in claim **8**, wherein a working distance between the second transmission surface and the recording medium is in a range including 0.1 mm and 0.6 mm.

12. The optical pickup device as claimed in claim **7**, wherein a ratio of a diameter of the first transmission surface and an overall effective diameter of the objective lens is in a range including ⅖ and ⅘.

13. The optical pickup device as claimed in claim **12**, wherein a ratio of a diameter of the first curved surface and an overall effective diameter of the objective lens is in a range including ⅕ and ⅖.

14. The optical pickup device as claimed in claim **12**, wherein the objective lens has an NA of 0.7 or more.

15. The optical pickup device as claimed in claim **7**, wherein a ratio of a diameter of the first curved surface and an overall effective diameter of the objective lens is in a range including ⅕ and ⅖.

16. The optical pickup device as claimed in claim **7**, wherein the light source emits light having a wavelength in a range including 400 nm and 420 nm.

17. The optical pickup device as claimed in claim **16**, wherein the objective lens has an NA of 0.7 or more.

18. The optical pickup device as claimed in claim **7**, wherein the objective lens has an NA of 0.7 or more.

19. An apparatus comprising:

an objective lens which focuses light onto an object;

a light source which emits the light; and

an optical system which transmits the light to the objective lens;

wherein the objective lens comprises:

a first curved surface which condenses a first portion of the emitted light to form a light spot on the object,

a second curved surface formed around the first curved surface and which diverges a second portion of the emitted light;

a transmission area disposed adjacent the recording medium;

a first reflection surface disposed radially outward from the transmission area which reflects the diverged light; and

a second reflection surface formed around the second curved surface which condenses the reflected light toward the light spot.

20. The apparatus of claim **19**, wherein the object is an optical recording medium.

21. The apparatus of claim **19**, wherein the aparatus is an optical disc mastering apparatus.

22. The apparatus of claim **19**, wherein the apparatus exposes an optical mask pattern on a photosensitive medium.

23. The apparatus of claim **19**, wherein the apparatus is a semiconductor exposure apparatus and the object is a semiconductor material.

24. The optical head of claim **19**, wherein:

the objective lens has an NA of 0.7 or more, and

a working distance between the transmission area and the object is in a range including 0.1 mm and 0.6 mm.

25. An optical head comprising:

an objective lens which gathers light from an object;

a photodetector which converts the gathered light into an electrical signal;

an optical system which transmits the gathered light to the photodetector;

wherein the objective lens comprises:

a transmission area disposed adjacent the object which transmits the gathered light;

a first curved surface which converges a first portion of the gathered light;

a first reflection surface formed around the transmission area;

a second curved surface formed around the first curved surface; and

a second reflection surface formed around the second curved surface;

wherein a second portion of the gathered light is sequentially reflected by the second and first reflection surfaces and diverged by the second curved surface.

26. The optical head of claim **25**, wherein the photodetector is a CCD camera.

27. The optical head of claim **25**, wherein:

the photodetector is a CCD camera, and

the optical system is a microscope apparatus.

28. The optical head of claim **25**, wherein:

the objective lens has an NA of 0.7 or more, and

a working distance between the transmission area and the object is in a range including 0.1 mm and 0.6 mm.

29. The optical head of claim **25**, wherein the object is an optical recording medium.

* * * * *

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(12) **United States Patent**
Lai et al.

(10) **Patent No.: US 6,761,454 B2**
(45) **Date of Patent: Jul. 13, 2004**

(54) **APPARATUS AND METHOD FOR DETERMINING OBJECTIVE REFRACTION USING WAVEFRONT SENSING**

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(52) **U.S. Cl.** **351/216**; 351/221
(58) **Field of Search** 351/200, 205, 351/206, 211, 212, 216, 219, 221, 246, 247

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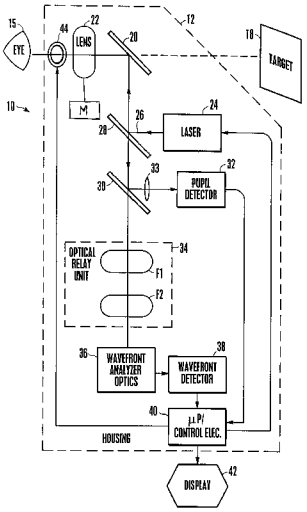
(57) **ABSTRACT**

An apparatus for determining the objective refraction of a patient's eye includes a transparent window and a wavefront measurement device that determines aberrations in a return beam from the patient's eye after the beam passes through a corrective test lens in the apparatus. The wavefront measurement device outputs an instant display representative of the quality of vision afforded the patient through the test lens. The display can be a representation of a Snellen chart, convoluted with the optical characteristics of the patient's vision, an overall quality of vision scale or the optical contrast function, all based on the wavefront measurements of the patient's eye. The examiner may use the display information to conduct a refraction examination and other vision tests without the subjective response from the patient.

27 Claims, 5 Drawing Sheets



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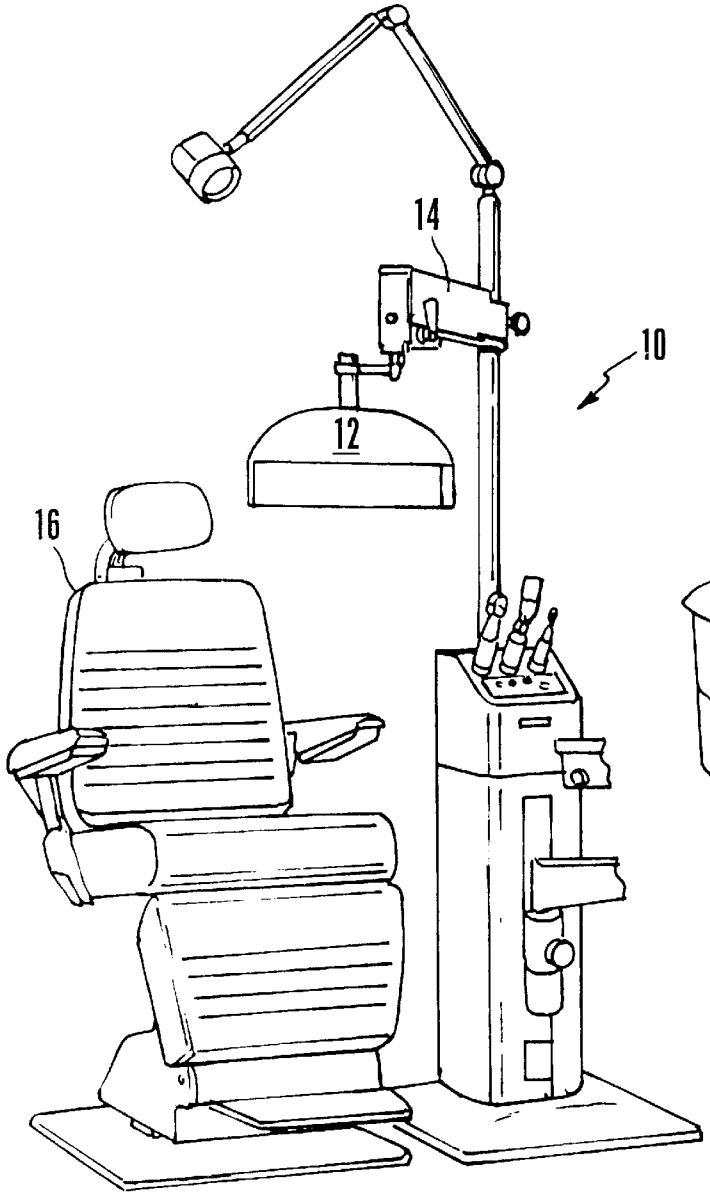


Fig. 1

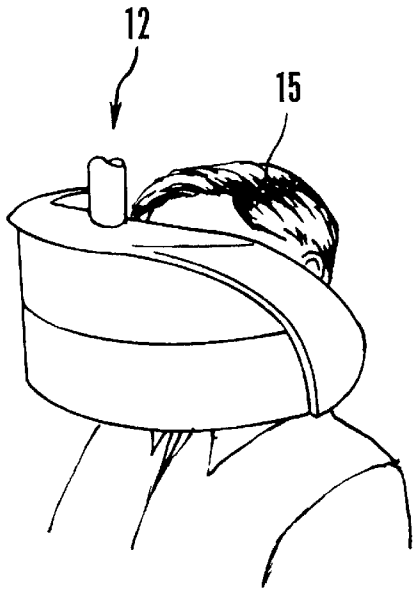
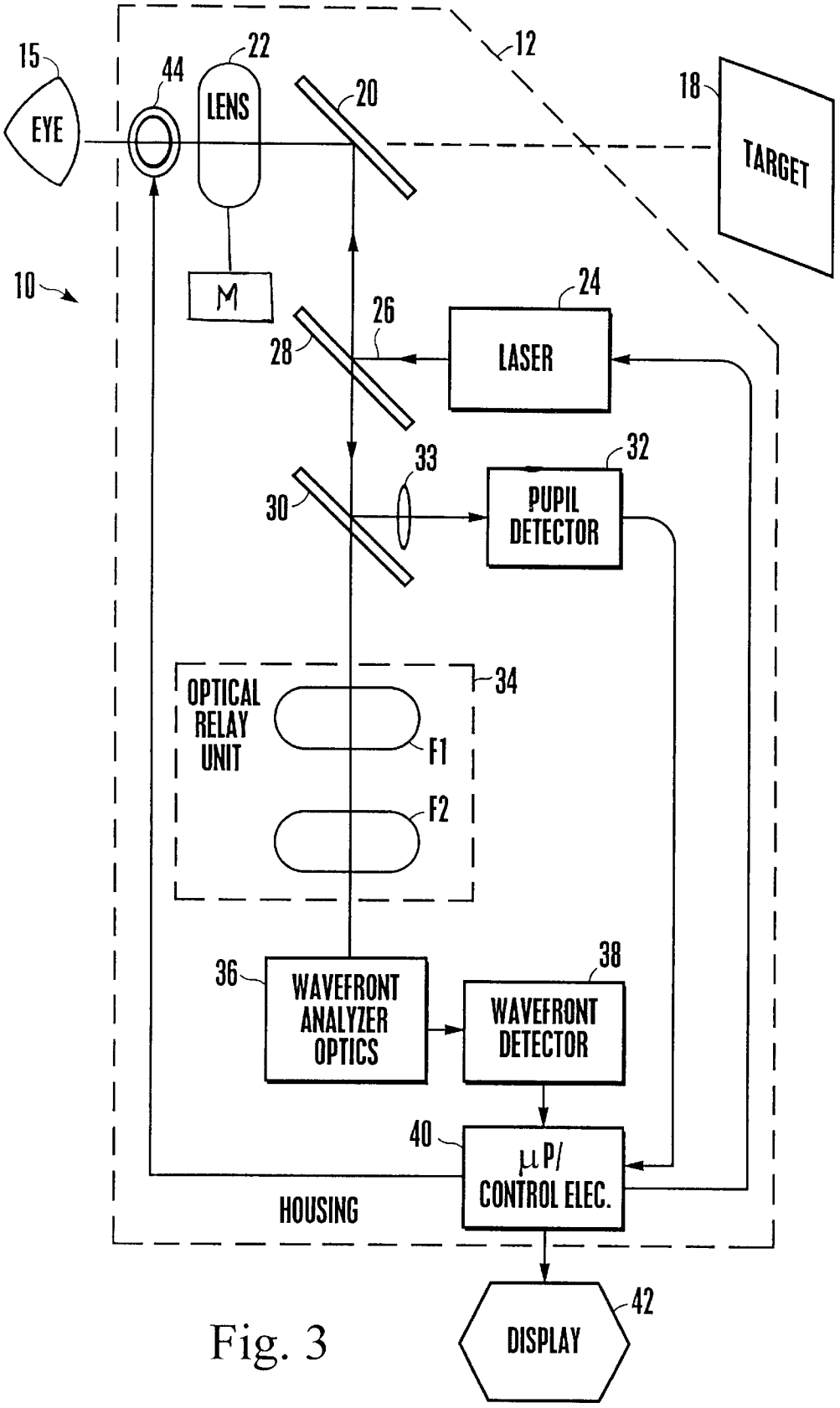


Fig. 2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TARGET
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M
24
LASER
26
28
33
32
30
PUPIL DETECTOR
OPTICAL RELAY UNIT
34
F1
F2
36
WAVEFRONT ANALYZER OPTICS
38
WAVEFRONT DETECTOR
40
μP/ CONTROL ELEC.
HOUSING
42
DISPLAY

Fig. 3

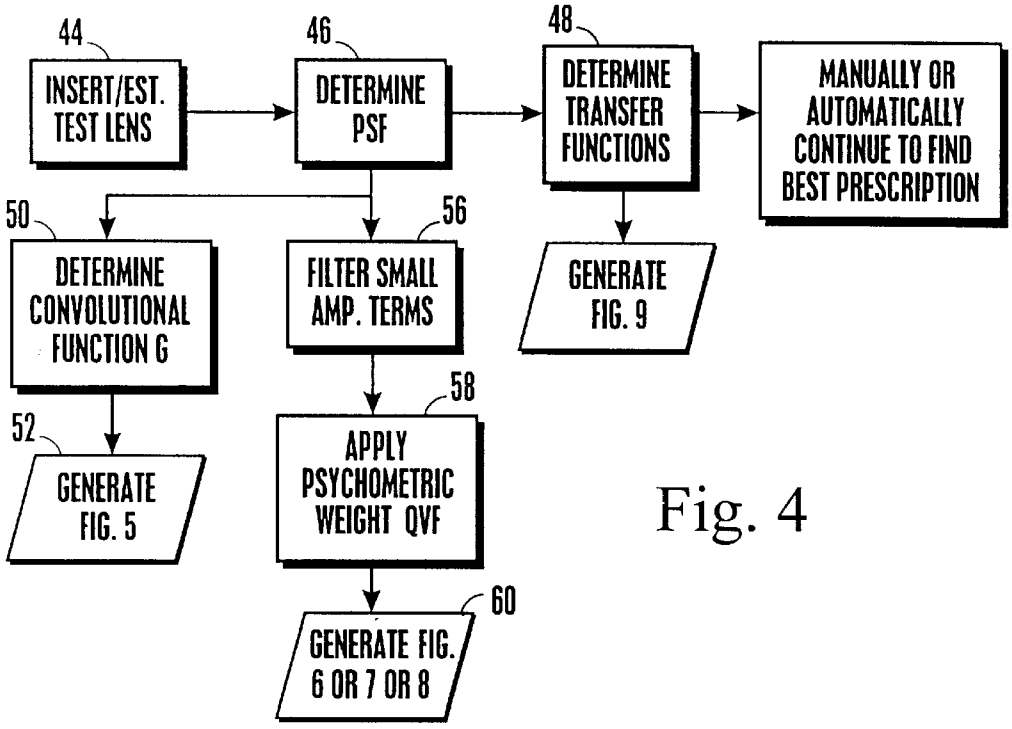


Fig. 4

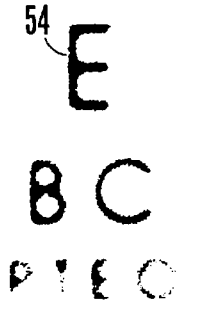
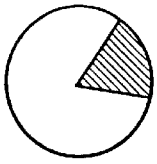


Fig. 5

Fig. 6

Fig. 7



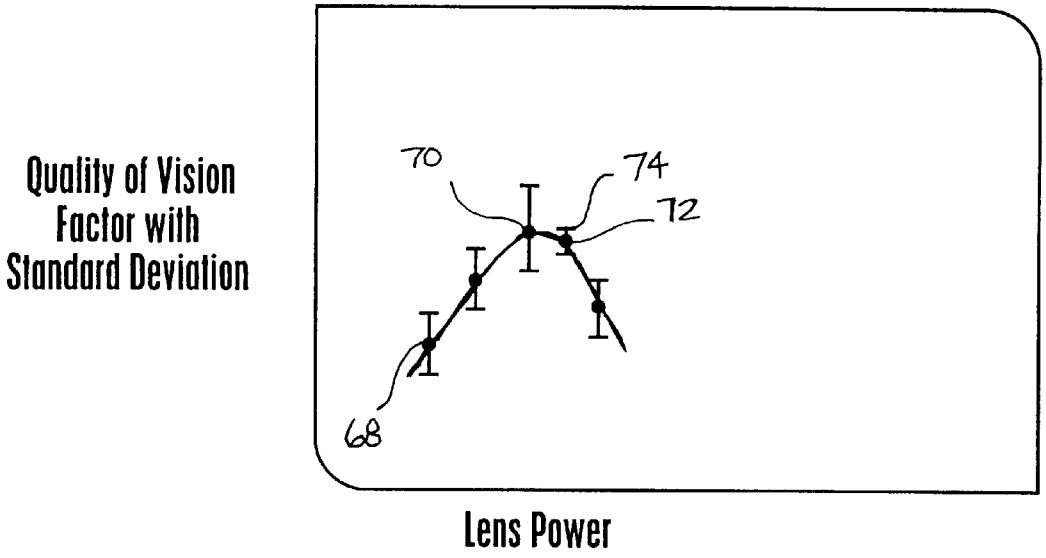

Quality of Vision
Factor with
Standard Deviation
70
74
72
68
Lens Power

Fig. 8

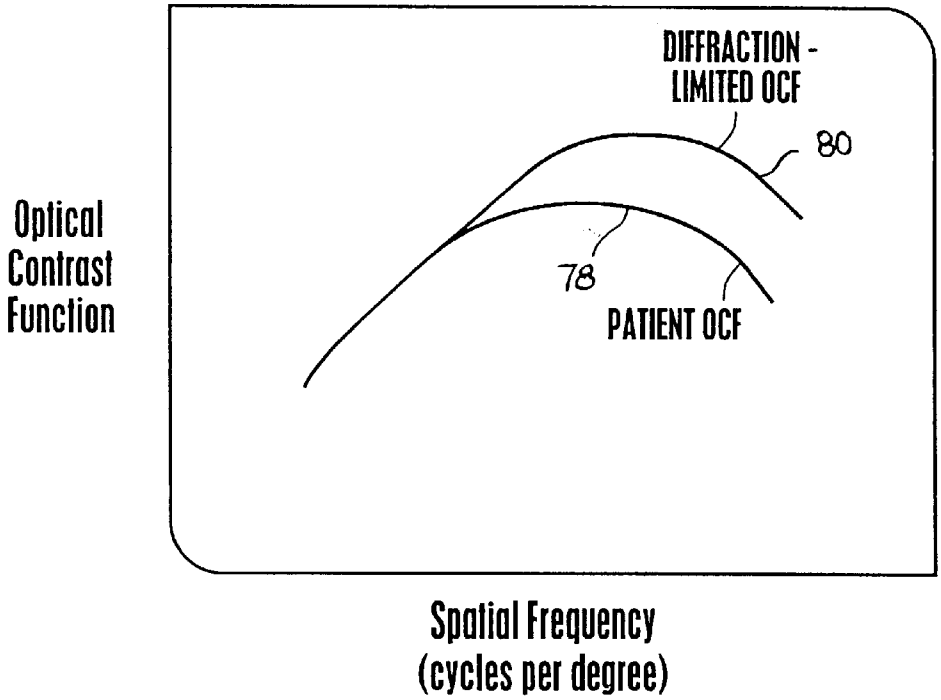

Optical
Contrast
Function
DIFFRACTION -
LIMITED OCF
80
78
PATIENT OCF
Spatial Frequency
(cycles per degree)

Fig. 9

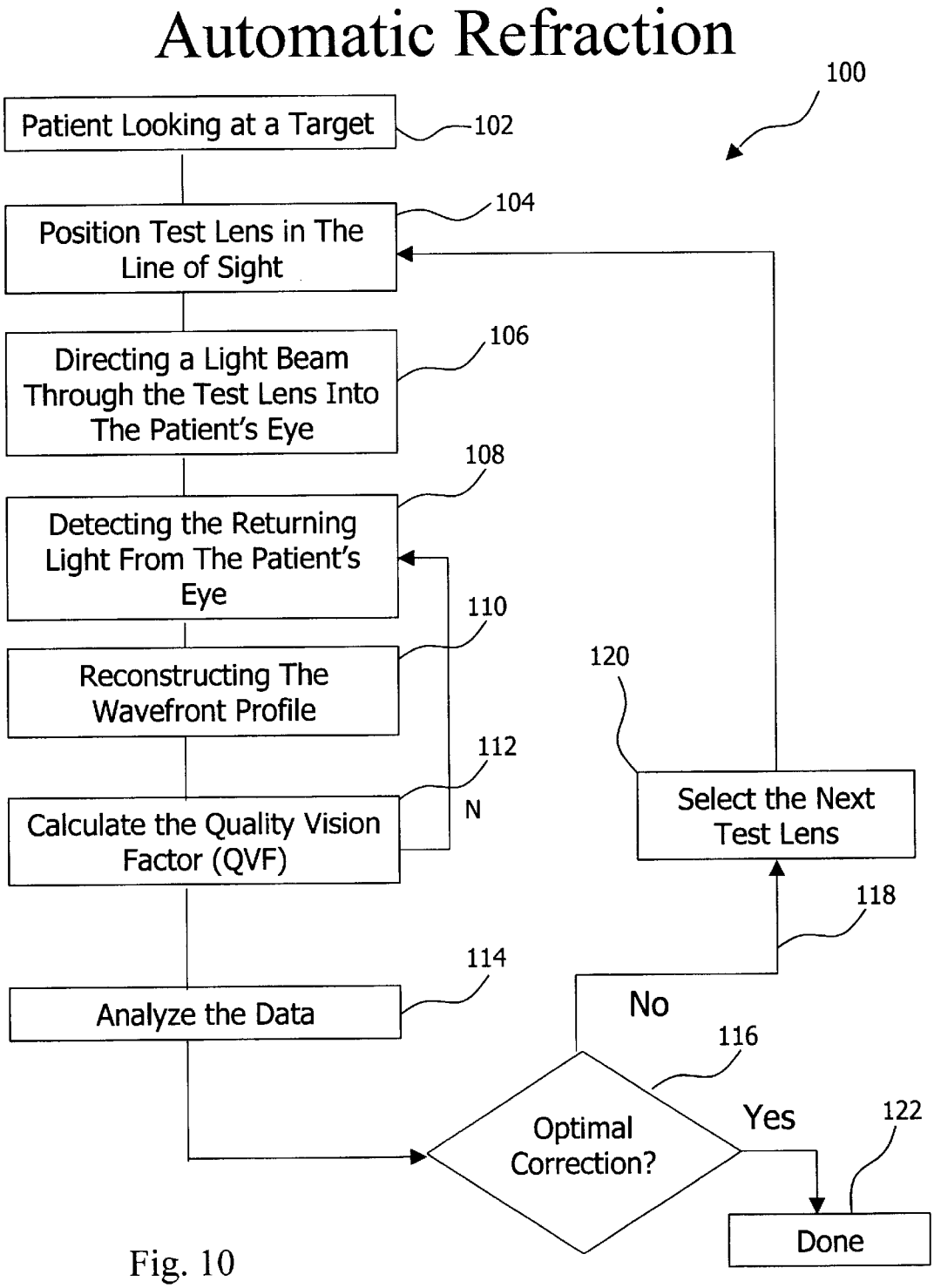

Automatic Refraction
100
Patient Looking at a Target
102
Position Test Lens in The Line of Sight
104
Directing a Light Beam Through the Test Lens Into The Patient's Eye
106
Detecting the Returning Light From The Patient's Eye
108
Reconstructing The Wavefront Profile
110
Calculate the Quality Vision Factor (QVF)
112
N
Analyze the Data
114
Optimal Correction?
116
No
Yes
Select the Next Test Lens
118
120
Done
122

Fig. 10

APPARATUS AND METHOD FOR DETERMINING OBJECTIVE REFRACTION USING WAVEFRONT SENSING

FIELD OF THE INVENTION

The present invention relates generally to methods and apparatus for determining a person's visual characteristics, and more particularly to apparatus for determining the refraction of the eye.

BACKGROUND

Phoropters are apparatus used by optometrists to determine a patient's visual characteristics, so that proper eye diagnoses can be made and eyewear can be prescribed. In conventional phoropters, a patient looks through the phoropter, in which various test lenses are disposed, at a target eye chart, referred to as a "Snellen chart", while an optometrist moves the test corrective lenses into the patient's field of view. In some applications, the target may be positioned at a predetermined distance from the patient. The patient is then asked to verbally compare the quality of the perceived image as afforded by one lens versus the prior lens presented. The optometrist takes note of either an improvement or a deterioration in the patient's vision through such lenses. Systematically, the test progresses towards the "best" test lens entirely based on the patient's responses. The lens parameters are then used as the basis for a prescription for eyewear.

Unfortunately, as recognized herein the patient can become fatigued during the process and/or misjudge the vision afforded by the various lenses. This can lead to the selection of a less than optimum prescription. Moreover, some patients, such as a very ill or a very young patient, might not be capable of articulating the quality of vision the various lenses afford the patient.

Objective methods of determining the patient's refraction errors have been proposed, but these other methods introduce further complications that are not present when using phoropters. In a retinoscopy method, for example, a streak of light is projected to a patient's retina, and the characteristics of the reflected light at the patient's corneal plane is analyzed to determine whether the patient is myopic, or hyperopic, and with or without astigmatism. However, the method does not provide sufficient accuracy for prescribing spectacle lenses. Consequently, its measurement results are typically used only as a starting point of a standard phoropter measurement.

Another objective measurement instrument for determining refractive errors is an autorefractor, which, owing to its speed of use, is more popular than retinoscopy. To use the autorefractor, a patient is asked to look inside an enclosed box that is part of the autorefractor. A target image is optically projected into patient's eye, and a series of lenses is automatically moved into position of the patient's line of sight to the target, to neutralize the patient's refractive errors (autorefraction). Unfortunately, the measurement outcome often differs from the patient's ideal prescription. Accordingly, like retinoscopy, autorefractor outcomes typically are used only as starting points for standard phoropter measurements.

Moreover, both retinoscopy and autorefraction fail to account for the accommodation effect of the patient, that is, for the propensity of a patient to alter his or her focus or sight to make the best of the vision test. An autorefractor measurement essentially is a snapshot of the patient's vision at a particular instant at which the autorefractor has identified a so-called neutralization point, and at this point if it happens that the patient focuses his vision for seeing an image at a distance other than what is intended, or if the patient is momentarily looking elsewhere other than the target, the output of the autorefractor is erroneous. Such deceptive focussing on the part of the patient can arise because the patient is conscious of the working distance inside the box, and when an image of an object presented to the patient which is modelled to be located at, e.g., twenty feet, the patient automatically focusses for an image at a much closer distance, knowing the actual size of the box. Examination results that include patient accommodation effects are inaccurate for prescribing spectacle lenses.

Another limitation of the autorefractor is that the examiner has no control over which lens is to be used in test. The result is that repeated measurements are likely to provide different results for the same eye from the same patient, which results in laborious and time consuming tests and retests when using the device to finalize a prescription. The present invention, having made the above-noted critical observations, provides the solutions disclosed herein.

SUMMARY OF THE INVENTION

A phoropter includes plural test lenses that can be disposed into a line of sight defined between a patient and a target, such that a patient looking at the target perceives light from the lens. A wavefront measurement apparatus is positioned to detect aberrations in light returning from the patient. The aberrations are caused by the eye of the patient.

In a preferred embodiment, the wavefront measurement apparatus includes a light source, such as a laser, for generating the light and a light detector that outputs a signal representative of the aberrations. Also, the apparatus includes a processor that receives the signal from the light detector and outputs a diagnostic signal representative thereof. The diagnostic signal is useful for generating an image representative of the test object, and/or for generating at least one visual display representative of an effectiveness of the lens in correcting a patient's vision. The visual display can include a bar chart, a pie chart, and/or a line chart, and it can be color coded.

In another aspect, a method for indicating the quality of a patient's vision includes providing a device through which a patient can look at a target. The method also includes directing a laser beam into the eye of a patient when the patient looks at the target, and then detecting aberrations in a wavefront of the light beam as the light beam returns from the patient's eye. Based on the wavefront, the method indicates a quality of a patient's vision.

In still another aspect, a method for indicating the quality of a patient's vision includes providing a device into which a patient can look, and that generates an instantaneous visual indication of a quality of a patient's vision.

In yet another aspect, a device for aiding a practitioner in knowing the integrated effect of a patient's eye and a test lens placed in front of the eye includes means for sensing a wavefront of light returning from the eye through the lens. Means are coupled to the wavefront sensing means for generating an indication of the integrated effect of the eye and the test lens.

In another aspect, a device for generating an indication of the quality of vision of a patient viewing a target includes a light beam generator directing light into the eye of the patient, and a wavefront sensing device detecting the wavefront in light returned from the eye of the patient while the

patient is looking at the target. A computing device receives input from the wavefront sensing device that is representative of the wavefront. The computing device outputs a continuous update of at least one of: a point spread function, and a modular transfer function, while the patient is looking at the target. A display device displays at least one of: a simulated image of the target at the patient's retina, a quality of vision indicator indicating the quality of vision, and a graph indicating a contrast function of the patient, based at least in part on at least one of the point spread function and the modular transfer function.

In yet another aspect, a vision quantifying device includes a beamsplitter through which a patient can look at a target. A source of light emits light into an eye of the patient, which reflects from the eye as a return beam. A processor receives a signal representative of a wavefront of the return beam and generates at least one signal in response thereto, and a display receives the signal and presents a visual indication of the patient's sight.

Another aspect of the device is to provide automatic refraction process. The patient looks at a target, a test lens is positioned between the target and the patient's eye, and in the line of sight of the patient. A light beam is directed through the test lens and into the patient's eye. Using a portion of that light reflected from the surfaces within the eye a wavefront profile is reconstructed. From the reconstructed wavefront profile, A quality vision factor ("QVF") may be calculated. In order to improve the accuracy of the measurements of the patient's eye, a number of measurements of the returning wavefront profile are taken, and the corresponding QVF values for each of the measurements for that particular test lens, is analyzed. The analysis of this data provides for a determination that the correction with that particular lens is optimal. If the correction is not optimal, a next test lens is selected, and the process is then repeated the next test lens after it is positioned by mechanical means in the patient's line of sight. On the other hand, if the correction with that particular lens is optimal, than the process ends and resulting in the proper refractive correction having been identified.

The details of the present invention, both as to its structure and operation, can best be understood in reference to the accompanying drawings, in which like reference numerals refer to like parts, and in which:

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a perspective view of the present apparatus, in one intended environment;

FIG. **2** is a perspective view of the apparatus, showing a patient in phantom;

FIG. **3** is a block diagram of the components of one preferred apparatus;

FIG. **4** is a flow chart of the presently preferred logic;

FIGS. **5–9** are exemplary non-limiting diagrams of quality of vision displays; and

FIG. **10** is a flow chart showing the automatic refraction method of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring initially to FIGS. **1** and **2**, an apparatus of the present invention is shown, generally designated **10**, and includes a housing **12** that can be mounted on a movable stand **14** for positioning the housing **12** in front of a patient **15** who might sit in an examination chair **16**. As can be appreciated in cross-reference to FIGS. **1** and **2**, the patient **15** can position his or her head against the housing **12**. Alternatively, the housing **12** can be supported on the head of the patient **15** and/or be suspended from a flexible overhanging arm which may be attached to a stand, to provide weight balance and to facilitate mounting and dismounting of the head mounted-apparatus. Or, the apparatus of the present invention can be co-mounted with a conventional phoropter (not shown), in which case the test lenses of the present invention can be established by the lenses of the conventional phoropter.

Now referring to FIG. **3**, the patient **15** can look through the housing **12** to a target **18**, such as but not limited to a Snellen chart. The target **18** can be positioned at any appropriate distance from the patient **15**, e.g., twenty feet or closer. Since the target **18** can be positioned at a distance that actually is the distance intended, the above-noted patient accommodation effects related to autorefractors, are reduced or eliminated.

FIG. **3** shows one exemplary implementation of the housing **12**. While FIG. **3** shows that various components are located inside the housing **12** and various other components such as the output display is located outside the housing **12**, it is to be understood that the principles advanced herein apply to phoropter systems having multiple housings, or a single housing.

In the embodiment shown, the patient looks at the target **18** through a transparent window within the housing **12**, such as can be established by a primary beamsplitter **20**. Interposed in the line of sight of the patient **15** are one or more movable test, or test lenses **22**. By "movable" is meant physically movable by hand or computer-controlled mechanism "M" as indicated as M in FIG. **3**, and more fully disclosed below to be selectively interposed within or without the line of sight of the patient **15**, or movable in the sense that a variable focal length lens can be used, with its optical characteristics being variable in accordance with principles known in the art, for example those utilized in various designs of autorefractors. That is, the test lens **22** can be, but not limited to, a single concave convex lens, or a combination of optical components, including a cylindrical lens and a prism.

As also shown, a light source such as but not limited to a laser **24** generates a light beam **26** that can be directed, in one preferred embodiment, toward a laser beamsplitter **28**. The laser beamsplitter **28** reflects the light beam **26** toward the primary beamsplitter **20**, which in turn reflects the beam through the test lens **22** and onto the eye of the patient.

The beam **26** is then reflected by the eye of the patient **15**, back through the lens **22**, and is reflected off the primary beamsplitter **20**. The beam passes through the laser beamsplitter **28**, and a portion of the beam is reflected off a pupil detection beamsplitter **30** toward a pupil light detector **32** through one or more focussing lenses **33**, for purposes to be shortly disclosed. A portion of the return beam passes through the pupil detection beamsplitter **30** and propagates through an optical relay unit **34**, which focusses the beam onto a wavefront analyzer optics **36**. The wavefront analyzer optics **36** generates a signal representative of the wavefront of the return beam, and a wavefront detector **38** transforms the signal into an electrical signal for analysis by a processor **40**. In one preferred embodiment, the processor **40** can be associated with control electronics known in the art for undertaking control of one or more components (e.g., the light source **24**) of the system **10** as more fully set forth below. Also, the processor **40** can generate the below-

described visual indications of the patient's vision as corrected by the test lens **22** and can cause the indications to be displayed on a display **42**, such as a video monitor, that can be mounted on the housing **12** or apart therefrom. Or, the display **42** can be a liquid crystal display that can be mounted on the housing **12** of the system **10**, or a standalone display unit conveniently located for the examiner's viewing. Suitable displays may include, but not be limited to, numerical and/or graphical representations indicative of the patient's quality of vision, more details are provided in the following.

If desired, an illumination light **44**, e.g., a ring-shaped fiber optic, can be mounted on the housing **12** and can be connected to the processor **40** to control the pupil size of the patient **15**. The illumination light **44** can be a source of diffused light. The light intensity of the illumination light **44** is controlled by the processor **40** in response to feedback from the pupil light detector **32**, which can comprise a CCD camera, or reticon detector arrays to monitor the size of the pupil, so that a predetermined pupil size can be maintained for the patient during the measurement. The locations of the pupil detection unit, including the components, beamsplitter **30**, lens **33**, and pupil light detector **32** can be in other appropriate locations along the optical path of the return light from the eye, including locations inside the optical relay unit **34**.

As a further improvement to the accuracy of the refraction measurement, the system also monitors the first Purkinge image, an image formed by reflection at the anterior surface of the cornea of the light beam **26**. The position of this image relative to the pupil boundary is an indication of gazing direction of the patient under examination. Unless the patient has strabismus in that eye, the relative position of the First Perkinge image is a well defined bright spot, and it is typically inside the pupil boundary. Therefore, in a preferred but non-limiting embodiment, the pupil detector **32** can also function as a patient gazing monitor. In this case, the relative position of the First Perkinge image to the pupil is determine by processing of the image data from the CCD camera, for example, using data filtering, contrast enhancement, and pupil boundary determination methods known in the art.

All software processing can be done in real time in a matter of a fraction of a second. The objective of this analysis is to determine whether the patient is looking at the target, or momentarily drifting off. The information is electromagnetically transmitted to the central control unit **40**. If the patient is not looking at the target, the data set from the wavefront detector unit **38** is rejected, and shall not be displayed or accumulated for data analysis.

The following comments are germane to implementation details of preferred, non-limiting embodiments. The light source **24** can be a diode laser that emits light at near infrared wavelengths. Moreover, the light detectors **32**, **38** can be implemented by CCD arrays or linear reticon arrays. Further, the primary beamsplitter **20** can be coated to transmit visible light and to reflect infrared light. On the other hand, the laser beamsplitter **28** can be a polarization dependent reflector, in which case the laser light is polarized, and a quarter wave plate (not shown) is disposed in the beam path to the patient **15** such that the return beam is rotated ninety degrees (90°) upon double passing the quarter wave plate for facilitating passage thereof through the laser beamsplitter **28** toward the wavefront analyzer optics **36**. Alternatively, the laser beamsplitter **28** can be plate coated for high transmission and low reflectivity at forty five degrees (45°) incident angle, such that only a small portion of the laser light is reflected into the eye, but a high percentage of the return light propagates through the laser beamsplitter **28**.

Continuing with the implementation details of a preferred, non-limiting embodiment, the optical relay unit **34** can include two convex lenses F1 and F2 that together establish a telescope. The lenses F1, F2 are separated from each other by a distance equal to the sum of their focal lengths, with the focal plane of the first lens F1 being located at the front surface of the test lens **22**, i.e., the surface facing the primary beamsplitter **20**. The focal plane of the second lens F2 is located at the image plane of the wavefront analyzer optics **36**. The purpose of the telescope structure of the relay unit **34** is to relay the wavefront at the exit surface of the test lens **22** to the image plane of the wavefront analyzer optics **36**. Alternative relay optics can be used to achieve the same purpose.

With respect to the non-limiting details of the wavefront analyzer optics **36**, the optics **36** can include an array of lenslets arranged as in a Shack-Hartmann wavefront sensor, an example of which can be found in page 37, "Customized Corneal Ablation The Quest for Super Vision" edited by MacRae, et. al. published by Slack Incorporated, 2001, incorporated herein by reference. Various Shack-Hartmann wavefront sensors and processors are available, for example, from commercial vendors such as Wavefront Sciences, in Albuquerque, N. Mex., Zeiss/Humphrey Instruments, in Dublin, Calif., or Bausch and Lomb, in Irvine, Calif. More preferably, the optics **36** can include ruled reticles such as those disclosed in co-pending application U.S. patent application Ser. No. 10/014,037, entitled "SYSTEM AND METHOD FOR WAVEFRONT MEASUREMENT", filed Dec. 10, 2001, incorporated herein by reference, which uses a self-imaging diffraction principle to detect the wavefront in the return beam.

Regardless of the type of wavefront analyzer optics **36** used, the processor **40** analyzes the profile of the wavefront of the light returned from the patient's eye, and quantifies the wavefront aberrations in two regimes: low order aberrations, including spherical refractive error, cylinder, and axis, and higher order aberrations, including coma, spherical aberrations and other higher order terms that can be described by Zernike polynomials. Quantitative data representing the patient's quality of vision are then graphically presented on the display **42**.

Now referring to FIG. **4**, an exemplary mode of operation of the present invention can be seen. The patient **15** views the target **18** through the phoropter system **10**, and in particular through the transparent window that is established by the primary beamsplitter **20**. At block **44** the examiner initiates the vision test by inserting a selected test lens **22** in the line of sight of the patient, or by configuring a variable focal length lens **22** to have a predetermined focal length. Inserting means either a manual positioning or positioning using a motorized means. Or, the processor **40** can select a particular lens **22** and cause it to be automatically moved in the line of sight, in accordance with disclosure below.

Proceeding to block **46**, the processor **40** determines the point spread function (PSF) that is derived from using, for instance, the terms of Zernicke polynomials, which is in turn derived from the wavefront passing through the wavefront analyzer optics **36** and transformed into an electrical signal by the wavefront detector **38** at the instant when the wavefront data is acquired. The processor **40** Fourier transforms the signal from the wavefront detector **38** using the following equation:

$$PSF(x, y)=FT(P(x, y))|^2$$

wherein FT designates a Fourier Transform calculation and P(x, y) is the spatial distribution of the wavefront profile of light with the same phase (phase front) returned at the corneal plane.

Proceeding to block **48**, if desired an Optical Transfer Function (OTF) can be calculated from an inverse operation of Fourier Transform as follows:

$$OTF(f_x, f_y)=FT^{-1}(PSF(x, y)),$$

wherein f_x, f_y are spatial frequencies in x and y directions, respectively, that are orthogonal to each other.

Moreover, a Modular Transfer Function (MTF) can be determined as the amplitude of the OTF:

$$MTF(f_x, f_y)=|OTF(f_x, f_y)|.$$

The above functions are used to generate visual indications of the quality of vision that is afforded by the test lens **22** currently being viewed by the patient **15**. For instance, once the PSF is determined at block **46**, the logic can flow to block **50** to determine a convolutional function G as follows:

$$G(x_{img}, y_{img})=\int\int PSF(x-x_{img}, y-y_{img})f(x_{img}, y_{img})dx\ dy,$$

wherein $f(x_{img}, y_{img})$ is the test target **18** (FIG. **3**), i.e., an ideal image function, $x-x_{img}$ is the difference in the x-dimension between each point in the PSF and the corresponding ideal point in the ideal image, and $y-y_{img}$ is the difference in the y-dimension between each point in the PSF and the corresponding ideal point in the ideal image.

The convolutional function G can be used at output state **52** to generate an appropriately blurred image, point by point, of an ideal image as affected by the imperfection of the patient's eye in combination with the lens **22**. For example, when the target **18** is a Snellen chart, the ideal image function can be the letter "E" or a series of other letters, e.g., of various physical sizes as conventionally used in the various lines in the Snellen chart. FIG. **5** shows one such blurred image at **54**, which can be presented on the display **42**. Alternatively, the target can be a picture, and the convoluted image $G(x_{img}, y_{img})$ of the picture is blurred point by point, according to the PSF, which represents an image of the target formed at the patient's retina.

Accordingly, the letters in the simulated blurred image have the same blurring as perceived by the patient **15**. In this way, the examiner can visualize the clarity and sharpness of the image as a result of the lens **22** as it is perceived by the patient **15**.

Alternatively or in addition to the image shown in FIG. **5**, the processor **40** can generate the displays shown in FIGS. **6–8** as follows. At block **56** the wavefront profile, as indicated by the above-mentioned linear combination of Zernike polynomials, is filtered to eliminate terms with coefficient below a threshold amplitude. Moving to block **58**, a psychometric weighting factor "P" is inserted for each of the remaining Zernike terms as shown in the following. This weighting factor "P" represents the effect of the brain to discriminate objects despite certain types of ocular aberrations. For example, most people can discern a letter in a Snellen chart with a certain amount of defocus while the same amplitude of aberration in coma would not allow the same patient to discern that letter. To compensate for this, a Quality of Vision Factor (QVF) is determined as follows:

$$QVF=exp(-(\Sigma_n P_n Z_n^2))$$

wherein P_n is the psychometric weight factors for the corresponding n^{th} term of the Zernike polynomials, and Z_n is the coefficient of the n^{th} term of the Zernike polynomials in the PSF.

The psychometric weighting factors "P" can be determined by presenting a particular aberration to a normative group of people, for example, between one hundred to four hundred people, depending on the accuracy level desired and the range of the scatter value of each type of aberration measurement. The patients are presented one at a time with particular types of aberrations selected from the Zernike polynomials, and then the patients are scored for the extent of success in discerning the target, for example, by the number of letters correctly read on the Snellen chart, or other standardized vision test chart. Other scoring methods base on contrast level, standardized letter size, sine or square wave patterns can also be used as targets.

The presenting means can be an aberration plate on which a selected type of aberration has been imprinted. For example, the aberration type can be a coma, or a trefoil, having the refractive index profile as specified by the corresponding Zernike polynomial.

The relative effect of each type of aberration is tabulated for the group and averaged to obtain statistically meaningful weight factors. For most practical purposes, Zernike coefficients for terms higher then the sixth order (term number twenty nine or higher) minimally contribute to the overall aberration profile of normal eyes. The method of producing various types of aberrations with desired amplitudes according to each of the Zernike terms is set forth in co-pending U.S. patent application Ser. No. 09/875,447 filed Jun. 4, 2001, incorporated herein by reference. In the event that no data for the psychometric weight factors are available, all weighting factors P_n can be set to unity.

Once the QVF has been determined, one or more of the displays shown in FIGS. **6–8** can be generated and displayed as indicated in block **60**. For example, as shown in FIG. **6**, a bar chart display can be generated to present an overall indication of the patient's quality of vision as afforded by the lens **22** under test. As shown, the indicator can be in the form of a graduated bar **62**, the height of which is proportional to the QVF determined at block **60**, with zero indicating poor vision and perfect vision being indicated by a bar extending from the bottom to the top **64** of the scale. If desired, the display scale can be a log scale, in which case the "best" is indicated by the bar **62** being at zero, and rising logarithmetrically with worse vision using a root-mean-square function of the QVF. Enhancements to the bar **62** such as color-coding can be used. For instance, the bar **62** can be colored red for poor vision and green for good vision, with other colors being used to indicate intermediate qualities of vision. In lieu of the bar chart of FIG. **6**, the QVF can be used to generate a pie chart as shown in FIG. **7**, with the size of a pie slice **66** relative to the entire circle being linearly or logarithmetrically proportional to the QVF.

The system **10** can continuously measure the wavefront profile of the light beam returned from the patient's eye. Accordingly, in one preferred, non-limiting embodiment, a sequence of QVF measurements (e.g., twenty) for a single test lens **22** can be made in a second or two and grouped together.

As described earlier, the measurement accuracy can be improved by monitoring the gazing direction of the patient, and the computing device in block **40** can reject the data points acquired when the patient was not looking at the designated target. Furthermore, the computing device can also accumulate data and perform calculations for average values and standard deviation for selected subsets of measurement.

FIG. **8** shows a resulting display. As can be appreciated from the exemplary embodiment shown, five lenses **22** have been tested and several QVF values obtained over a short period for each. Each group of QVF values is plotted as a respective vertical line **68** on a plot of QVF versus lens, with the length of each error bar line **68** representing the standard deviation of the measurements for that particular lens and the center of each line representing the mean QVF value. The prescription can be based not only on a high mean QVF value, as indicated at points **70** and **72**, but also on a small standard deviation, as indicated by bar **74**. That is, the lens corresponding to the bar **74** might be selected because its QVF values had a small standard deviation from each other and it had a high mean QVF value, even if not as high as the point **70**. This recognizes that some patients prefer a lens power which may not necessarily provide the sharpest image but which does result in more comfort, since a patient does relatively little searching for the "better focus" using lenses that exhibit smaller standard deviations in the QVF. For example, a patient did not have a vision check for an extended period of time, and the required correction is more than 1.5 diopters in cylinder, for example. The patient may feel uncomfortable with the full correction as afforded by the sharpest image, rather the patient prefers a smaller amount of correction which represents improvement in his vision, yet not causing dizziness or head strains. Therefore, the present invention provides objective data based on the subjective response of the patient to a test lens set **22** presented to the patient.

As recognized by the present invention, to diagnose a patient's contrast, the patient can be presented with a series of standardized patterns of sine wave gratings of increasing spatial frequency frequencies, with the patient offering subjective responses. The resulting examination report can be a curve that depicts a cutoff contrast intensity at various spatial frequencies. The present invention can provide a quantitative evaluation of a patient's contrast, which can be generated in addition to or in lieu of those displays disclosed above. Such a display can be generated at output state **76** in FIG. **4** and is shown in FIG. **9**, showing a curve **78** depicting actual patient optical contrast function (OCF) and a reference curve **80** depicting a diffraction-limited reference. To determine OCF, the following relation is used:

$$OCF=MTF\times M_{lat.}$$

wherein MTF is the modulation transfer function determined at block **48** and M_{lat} is a mathematical function accounting for the low frequency filtering of the neural system, the value of which linearly increases with spatial frequencies with a slope of unity in a log—log scale plot and reaching the maximum value of one at and above the spatial frequency of seven cycles per degree.

Accordingly, the OCF does not include the effect of the brain processing at frequencies higher than seven cycles per degree, but it does provide valuable information about the patient's ability to discern sine gratings of various spatial low frequencies based on a patient's optics.

The above process of measuring and displaying indications of the improvement in vision afforded by a particular test lens **22** to the patient **15** can be continued at block **82** until the "best" test lens is found. This can be done by the examiner manually swapping lenses **22** as in a conventional phoropter, or, as mentioned above, the positioning of test lenses **22** can be done automatically by the processor **40** controlling the moving mechanism "M", which can include a motor and coupling structure connecting the motor to one or more lenses **22**, such that the mechanism follows an instruction from the processor **40** to insert the particular lens in the line of sight of the patient, as requested by the processor.

When done by the processor **40**, the sequence of test lenses **22** to be used in an examination may be programmed into the processor **40** in accordance with examination strategy and routines known in the art. The starting lens can be selected based on the patient's current spectacle prescription or based on the wavefront measurement without any test lens **22** in the patient's line of sight. Consequently, in reconstructing the return beam wavefront without a test lens **22** being in the beam path, the processor **40** essentially models the uncorrected aberrations of the patient's eye in Zernike terms. Recall that the second order Zernike terms represent defocus, astigmatism and axis information. Based on the patient's pupil size and the uncorrected wavefront error amplitudes, the processor **40** can determine the equivalent diopter power in sphere and cylinder and its axis, and select the appropriate lens **22** being used to start the examination. In selecting test lenses **22**, the processor **40** can use the above-disclosed QVF values in lieu of subjective responses from the patient, and can then execute the examination strategy as if it is performed with the subjective response from the patient.

The automatic refraction process is depicted in FIG. **10**, and generally designated **100**. Process **100** begins with a first step **102** wherein the patient looks at a target. In step **104** a test lens is positioned between the target and the patient's eye, and in the line of sight of the patient. A light beam is directed through the test lens and into the patient's eye in step **106**. A portion of that light is reflected from the surfaces within the eye and returns along the line of sight of the patient.

In step **108**, the light returning from the patient's eye is detected. From this detected light, the wavefront profile may be reconstructed, as shown in step **110**. From the reconstructed wavefront profile, the quality vision factor ("QVF") may be calculated in step **112**. In order to improve the accuracy of the measurements of the patient's eye, "N" number of measurements are performed using the returning light. Thereby, "N" wavefront measurements are taken, thereby yielding N wavefront profiles and corresponding QVF values. These successive measurements are taken by returning from step **112** to step **108**, in which the returning light is again detected "N" times.

Once "N" measurements have been taken and the QVF for each measurement has been calculated, the QVF for that particular test lens, is analyzed in step **114**. The analysis of this data provides for a determination that the correction with that particular lens is optimal. This decision is made in step **116**, and if the correction is not optimal, a next test lens is selected in step **120**, and the process returns to step **104** where the next test lens is positioned in the patient's line of sight. On the other hand, if the correction with that particular lens is optimal, than the process ends in step **122** resulting in the proper refractive correction having been identified.

In a typical automatic refraction process, a series of lenses in ¼ diopters increments are used to determine the patient's optical correction. However, the present invention contemplates using more or less than the typical number of lenses, and the diopter increments can be in ⅛ instead of ¼, depending upon the magnitude of correction necessary. Also, as shown in FIG. **10**, a number ("N") of measurements of the returning light are taken in steps **108** through **112** to calculate the VQF for the particular test lens. Typically, "N" will equal for example, 10–20 separate measurements being taken to provide an accurate measurement of the VQF.

However, the present invention contemplates taking more or less than the typical number of measurements depending upon the particular wavefront sensor device used, and the magnitude of correction necessary.

The prescription can be determined by a person viewing the display of FIG. **8**, or automatically by the processor **40** based on a high QVF value and low standard deviation, as follows: The examiner, or the processor will examinate the curve shown in FIG. **9**, which connects the average values of the QVF's for various lens sets presented to the patient. An improvement may include the step of performing a best fit to the average values, suing a polynomial of up to 4 order, for example. The processor searches for the maximum value, of the "peak" of the curve. This can be accomplished by monitoring the peak value of the curve, or slope of the curve from decreasing lens power, from right to left, in FIG. **8**. When the curve reaches its maximum value, the slope changes sign, and the maximum is at the zero slope value. Now, the processor send the peak value of the QVF and the corresponding lens power to the display or a printer.

Additionally, the processor also searches for the minimum value among the standard deviation in the data set as shown in FIG. **8**. A figure similar to FIG. **8** showing standard deviations versus lens power can be useful (not shown) in determining the minimum value, suing the steps of a best fit curve, and search for the sign change of the slope as described above for determining the maximum QVF value. Again, this minimum standard deviation value and the corresponding lens power are sent to the display or a printer for record. For example, on the display or the printout the processor may indicate that lens power with the maximum QVF value provides for the sharpest image, while the lens power with the minimum standard deviation provides for the most comfortable prescription to the patient.

While FIG. **3** illustrates a system **10** wherein the return beam from the lens **22** is detected and analyzed and, hence, the integrated effect on the wavefront introduced by the eye and lens **22** is measured, it is to be understood that as mentioned above the return beam from the eye can also be analyzed without passing through the lens **22**. In such an embodiment, the effect of the lens **22**, which has a known deviation from spherical, can be accounted for by adding or subtracting the lens **22** effect as appropriate from the eye-only wavefront. To facilitate this, a sensor (not shown) can be provided that senses which lens **22** is moved into the patient's line of sight. The sensor sends a signal representative of the lens (and, hence, of the optical contribution of the lens) to the processor **40**.

In any case, it may now be appreciated that if desired, the examiner can use conventional tactics in the steps of selecting test lenses **22** as if the whole process were done using a conventional phoropter that requires subjective responses from the patient. For example, the examiner can use "fogging" in accordance with principles known in the art to form an artificial image before the retina of the patient to cause the patient to relax the above-mentioned accommodative power. However, owing the present display capability of the system **10**, the examiner can identify the test lens **22** with which the patient achieves good vision without accommodation, regardless of patient verbal cooperation or ability to judge and articulate which lens **22** is best. That is, by observing the present displays and continuing to decrease the focusing power of the test lenses being used and moving the image behind the patient's retina, the examiner can determine the range of accommodation of the patient.

Once the best lens **22** has been identified, the examiner may indicate this decision by pressing a "finish" button (not shown), and a printout of the examination result can be output using a printer or similar device (not shown) that is connected to the processor **40**. The processor **40** may also automatically transmit via modem, internet or other appropriate means, the prescription to a remote location for lens manufacturing. A prescription to correct low order aberrations including sphere, cylinder and axis, can be used for prescribing conventional ophthalmic lenses, or a "supervision" prescription to correct all orders of aberrations can be used to prescribe improved vision lenses, such as are described in co-pending U.S. patent application Ser. No. 10/044,304, filed Oct. 25, 2001 and incorporated herein by reference.

While the particular APPARATUS AND METHOD FOR DETERMINING OBJECTIVE REFRACTION USING WAVEFRONT SENSING as herein shown and described in detail is fully capable of attaining the above-described objects of the invention, it is to be understood that it is the presently preferred embodiment of the present invention and is thus representative of the subject matter which is broadly contemplated by the present invention, that the scope of the present invention fully encompasses other embodiments which may become obvious to those skilled in the art, and that the scope of the present invention is accordingly to be limited by nothing other than the appended claims, in which reference to an element in the singular is not intended to mean "one and only one" unless explicitly so stated, but rather "one or more". All structural and functional equivalents to the elements of the above-described preferred embodiment that are known or later come to be known to those of ordinary skill in the art are expressly incorporated herein by reference and are intended to be encompassed by the present claims. Moreover, it is not necessary for a device or method to address each and every problem sought to be solved by the present invention, for it to be encompassed by the present claims. Furthermore, no element, component, or method step in the present disclosure is intended to be dedicated to the public regardless of whether the element, component, or method step is explicitly recited in the claims. No claim element herein is to be construed under the provisions of 35 U.S.C. §112, sixth paragraph, unless the element is expressly recited using the phrase "means for" or, in the case of a method claim, the element is recited as a "step" instead of an "act".

What is claimed is:

1. An apparatus for determining the refraction and aberrations of a patient's eye focused on an external physical target, comprising:

a light source;

optics directing light from said light source to the patient's eye;

a test lens having an optical power, said test lens disposable in an optical path between the patient's eye and said external physical target, such that the patient'eye looking at said external physical target receives light from said light source through the lens;

at least one wavefront measurement device positioned to detect aberrations in light returning from the patient's eye;

a housing containing said optics and said test lens, said housing having an input port and an output port, said optical path between the patient's eye and said physical target passing through said input port into said housing and through said output port thereby exiting said housing, said target being external to said housing; and

processing electronics configured to compute variation in multiple wavefront measurements performed by said

wavefront measurement device using said test lens having said optical power to measure a patient's subjective response to said optical power.

2. The apparatus of claim **1**, wherein said housing further comprises a substantially transparent window in said optical path between the patient's eye and said external physical target through which the patient's eye views said external physical target, said window separating said optical path into a portion inside said housing and a portion of said optical path external to said housing.

3. The apparatus of claim **1**, wherein the light source includes a laser for generating the light and said laser is within said housing.

4. The apparatus of claim **1**, wherein the wavefront measurement device includes at least one light detector receiving a wavefront from the light returning from the patient's eye, and outputting a signal representative of the aberrations.

5. The apparatus of claim **4**, further comprising at least one visual display configured to receive input from said processing electronics generated substantially instantaneously by said processing electronics using the diagnostic signal from the light detector, said processing electronics and said display configured to generate at least one data representation selected from the group consisting of (1) an image generated by a convolution of the image of the target based on the wavefront returning from the patient's eye and through the test lens; (2) a numerical and/or graphic display representative of the effectiveness of the test lens; (3) a numerical and/or graphic display of the contrast function of the patient's vision.

6. The apparatus of claim **5**, wherein said processing electronics is configured to provide the visual display with representations selected from the group consisting of a bar chart, a pie chart, and a line chart.

7. The apparatus of claim **5**, wherein the visual display comprises a color display and said data representation is color coded, said processing electronics being configured to provide input to said color display to create said color coded data representation.

8. The apparatus of claim **4**, wherein the wavefront measurement device includes electronics that outputs a diagnostic signal substantially instantly, and wherein said diagnostic signal corresponds to the objective assessment of quality of vision.

9. The apparatus of claim **8**, wherein said processing electronics is configured to generate an image representative of the target as seen by the patient's eye.

10. The apparatus of claims **9**, wherein said processing electronics is configured to use said objective assessment of quality of vision to select a next lens to determine a successive objective measurement of quality of vision corresponding to said next lens.

11. The apparatus of claim **8**, wherein said processing electronics is configured to use the diagnostic of signal for generating at least one visual display representative of an effectiveness of the lens in correcting a patient's vision.

12. The apparatus of claim **8**, wherein said processing electronics is configured to compute the standard deviation of said objective measurement of quality of vision and one or more successive objective measurements of quality of vision and identifies an optimal vision correction lens for the patient.

13. The apparatus of claim **1**, wherein said processing electronics are configured to compute the standard deviation of multiple wavefront measurements performed using said test lens having said optical power to assess a patient's subjective refraction.

14. An apparatus for determining the refraction of a patient's eye focused on a physical target, said apparatus comprising:

a light source;

optics directing light from said light source to the patient's eye, said light reflecting from a surface of said eye, said reflected light comprising a plurality of wavefronts;

a wavefront measurement device positioned along a first optical path to said eye to measure the shape of said wavefronts reflected from the patient's eye;

at least one test lens disposable along a second optical path between the patient's eye and the physical target; and

processing electronics configured to determine the variation in multiple wavefront measurements that are performed by said wavefront measurement device for a fixed amount of refractive correction using said at least one test lens having said fixed refractive correction to quantify accommodation of the patient's eye,

wherein said optics and said at least one test lens are arranged such that when said patient looks at said physical target through said test lens, said light from said light source is directed through said eye so as to determine said refraction from said wavefronts returning from said eye.

15. The apparatus of claim **14**, further comprising a beamsplitter for merging said first optical path from said wavefront sensor to said eye and said second optical path from said eye to said physical target such that they overlap in a region between said beam splitter and said eye.

16. The apparatus of claim **15**, wherein said test lens is disposed in said region between said patient's eye and said beamsplitter where said first and second optical paths overlap.

17. The apparatus of claim **14**, wherein said test lens is positioned an optical path length of L from said physical target, said eye being adjusted to view said physical target said distance, L, away from said eye.

18. The apparatus of claim **17**, wherein said distance between said eye and said physical target is about 20 feet.

19. The apparatus of claim **14**, further comprising a housing containing said optics, said wavefront measurement device, and said at least one test lens, said housing having an input port and an output port, said second optical path between said patient's eye and said physical target passing through said input port into said housing and through said output port thereby exiting said housing, said physical target being external to said housing, wherein said housing includes a substantially transparent window disposed in said second optical path between said patient's eye and said physical target such said patient's eye can focus on said physical target, said window separating said second output path into a portion inside said housing and a portion of said second optical path external to said housing.

20. The apparatus of claim **19**, wherein said light source comprises a laser and said laser is within said housing.

21. The apparatus of claim **14**, wherein said wavefront measurement device includes at least one light detector receiving the light returning from the patient's eye and sending a signal to at least one processor, said at least one processor generating at least one diagnostic output based on said wavefront measurements.

22. The apparatus of claim **14**, wherein said processing electronics is configured to determine the standard deviation of said multiple wavefront measurements performed by said

wavefront measurement device for said fixed refractive correction to quantify accommodation of said patient's eye.

23. The apparatus of claim **14**, wherein said at least one lens comprises a plurality of test lens having different amounts of refractive correction, wherein said processing electronics are configured to determine variation in multiple wavefront measurements for each of said plurality of test lens so as to quantify accommodation of the patient's eye for each of said plurality of test lens.

24. The apparatus of claim **14**, wherein said at least one lens comprises an adjustable lens system having a plurality of settings that provide different amounts of refractive correction, wherein said processing electronics are configured to determine variation in multiple wavefront measurements for said different amounts of refractive correction provided by said adjustable lens system so as to quantify accommodation of the patient's eye for each of said different amounts of refractive correction.

25. The apparatus of claim **1**, further comprising a housing containing said optics and said test lens, said housing having an input port and an output port, said second optical path between said patient's eye and said physical target passing through said input port into said housing and through said output port thereby exiting said housing, said physical target being external to said housing.

26. An apparatus for determining the refraction and aberrations of a patient's eye focused on a target, comprising:

a light source;

optics directing light from said light source to the patient's eye;

a test lens having an optical power, said test lens disposed in an optical path between the patient's eye and said target, such that the patient's eye looking at said target receives light from said light source through the lens;

at least one wavefront measurement device positioned to detect aberrations in light returning from the patient's eye; and

processing electronics configured to determine variation in multiple wavefront measurements performed by said wavefront measurement device using said test lens having said optical power to measure a patient's subjective response to said optical power.

27. The apparatus of claim **26**, wherein said processing electronics are configured to determine the standard deviation of multiple wavefront measurements performed using the test lens having said optical power to assess a patient's subjective refraction.

* * * * *

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(12) **United States Patent**
Weber

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(45) **Date of Patent: Apr. 6, 2004**

(54) **OBJECTIVE FOR A MOVIE CAMERA**

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(52) **U.S. Cl.** **359/694**; 359/823; 359/696
(58) **Field of Search** 359/694, 696, 359/822, 823, 828, 738, 739, 740

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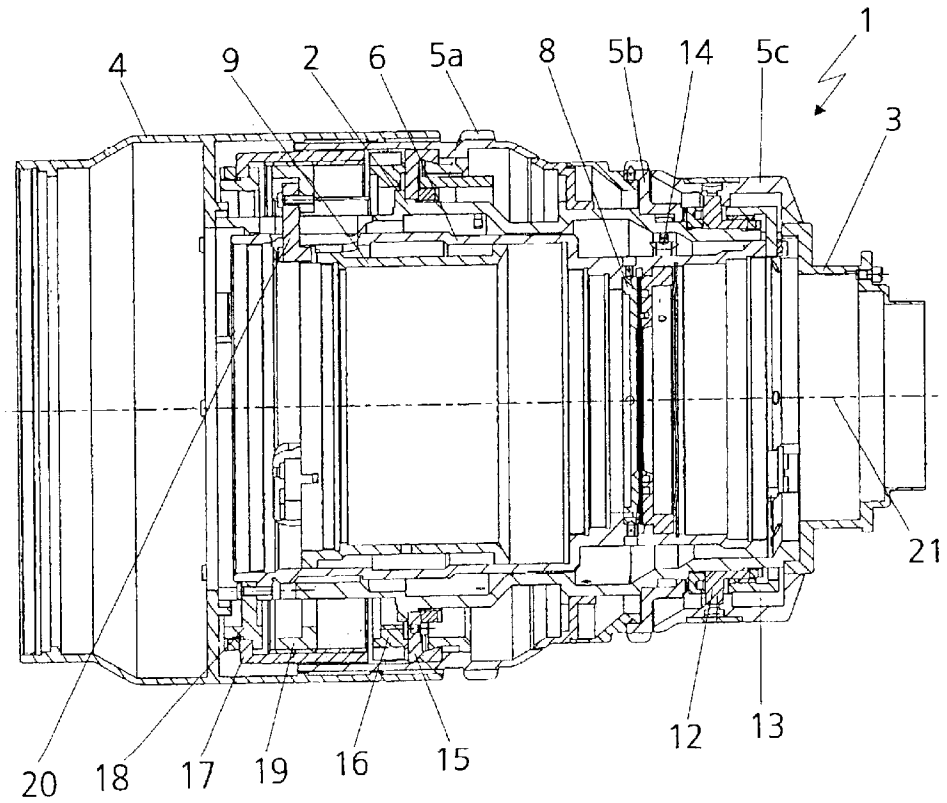
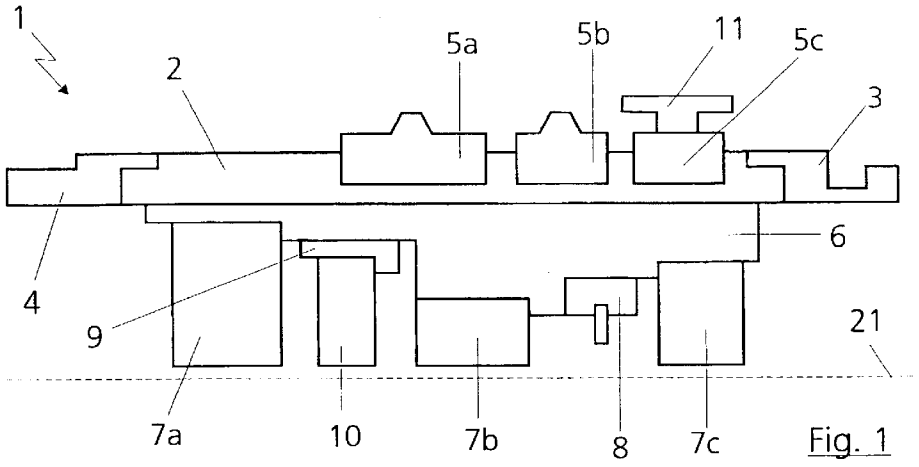
(57) **ABSTRACT**

An objective for a movie camera for digital cinematography comprises a cylindrical main barrel with a bayonet or K mount, an inner tube, fixed optical elements, adjustable optical sliding elements and drive rings with scales for adjusting the optical sliding elements that are mounted rotatably in the axial direction on the main barrel. The objective also comprises an iris diaphragm with a diaphragm ring rotating on the main barrel, an internal focusing system and a back focus correction device. The inner tube is mounted on the main barrel in a fashion displaceable along the optical axis for the purpose of back focus correction by means of the back focus correction device. The fixed optical elements, the iris diaphragm and sliding holders for holding the adjustable optical sliding elements are inserted into the inner tube.

15 Claims, 1 Drawing Sheet




1
2
5a
5b
11
5c
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6
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7a
10
7b
8
7c

Fig. 1

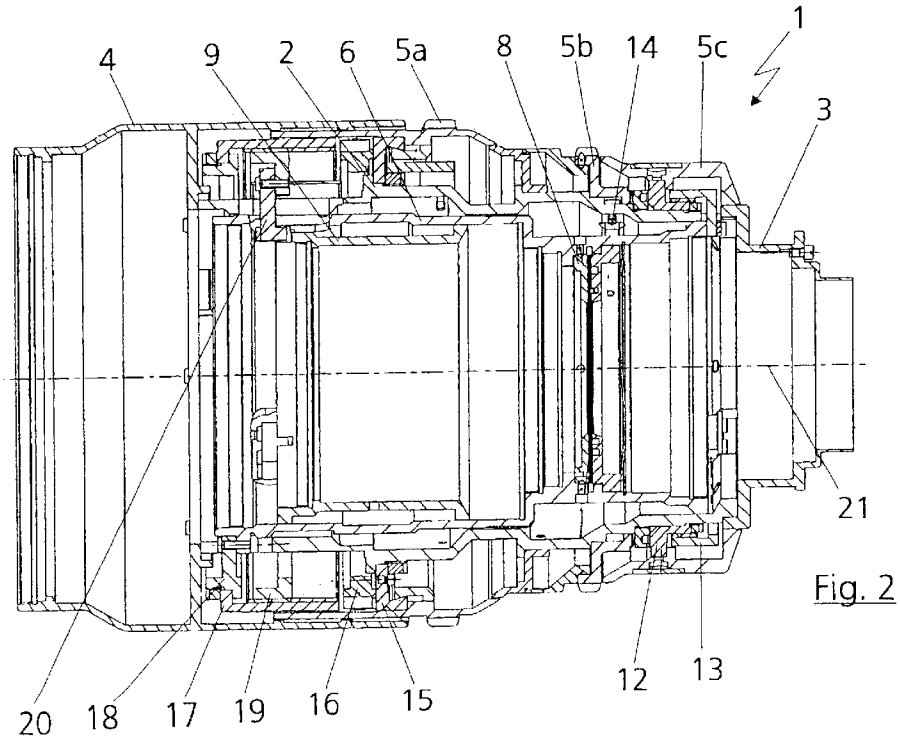
1
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Fig. 2

OBJECTIVE FOR A MOVIE CAMERA

BACKGROUND OF THE INVENTION

CROSS REFERENCE TO RELATED APPLICATION

This application relates to and claims priority to corresponding German Patent Application No. 102 15 140.7, which was filed on Apr. 5, 2002.

1. Field of the Invention

The invention relates to an objective for a movie camera for digital cinematography in accordance with the preamble of claim **1**, and to a set of objectives in accordance with the preamble of claim **15**.

2. Description of the Related Art

Apart from a rotating mirror that splits up the light in the viewfinder direction and the film direction, in conventional movie cameras only air is located between the bearing surface of the objective and the image plane, that is to say the film. The mirror is, as it were, the only mechanism that is always located between objective and film. This distance can therefore be kept very accurately and can likewise be produced exactly. Moreover, this distance is largely constant even at different temperatures, and so additional adjustment is not required here. The objective is therefore responsible only for the usual tasks, specifically the imaging optical system, the regulation of the diaphragm, the focusing and, if appropriate, a zoom mechanism. An additional mechanism is not required to compensate possible camera tolerances.

The situation is different from this in the case of digital movie cameras. Here, a plurality of optical elements affected by tolerance are located between the bearing surface of the objective and the image plane, which is represented by three CCDs. For example, complicated prismatic devices split up the images into the RGB color channels. Again, additional specific properties are further achieved with the aid of a complicated upstream filter system. A suitable compensation is required owing to this additional quantity of tolerance-affected optical elements, this also being due to the summation of the respective individual tolerances. It should therefore be possible to correct the mount-to-film distance. Movie cameras do not offer this possibility of correction, and this must therefore be integrated into the objectives. Moreover, it is further to be remarked that this correction must also be possible during normal operation, since, firstly, the tolerances can change permanently owing to the development of heat or similar and, secondly, for example, there is generally no use of zoom objectives in digital cinematography, that is to say depending on setting on a camera use is made of a plurality of objectives with different focal lengths in each case.

The necessity of correcting the mount-to-film distance, the so-called back focus correction, is sufficiently known. In the video field (for example newscasts or similar), it is customary to use zoom objectives and in this case the rear element thereof can be displaced for the purpose of back focus correction. It is very disadvantageous that in this operation there is a substantial change in the distance setting. The indication (normally the rings for distance setting/focusing of the objective) no longer corresponds exactly to the distance set, and this entails unsharpness of the image. However, viewfinders are used in the video field, and so the camera operators see when the image becomes unsharp and then immediately correct the distance setting. Here, the camera operators work less with the distance scale of the objective. It is disadvantageous, in addition, that each objective requires a different back focus traveling stroke, although the error in the mount-to-film distance is always the same.

Whereas in the case of the video technology described above, for example in order to record news or television reports, the setting and/or the accuracy of the distance scale plays a rather subordinate role, because any instances of unsharpness that occur can be detected by the camera operator in the viewfinder and corrected, this state of affairs is entirely different in cinematography, the production of movies or advertising films. Here, it is already fixed before shooting at which time actors or props are situated at which location. It is normal in cinematography for movie cameras to be operated by two camera operators, of whom one is responsible for viewing and the other, the so-called camera assistant, is responsible for image sharpness. The latter observes the scenes to be filmed and readjusts the distance without a camera viewfinder merely with the aid of the distance scale on the basis of his own estimate. This is necessary chiefly when actors may move faster or differently than was previously laid down. Since the camera assistant works only with the aid of the distance scale, the latter must be exactly correct because, by contrast with normal TV technology, in cinematography instances of unsharpness have substantial effects (size of the cinema screen, etc.).

Since the camera assistant regulates the sharpness only with the aid of the rotary distance ring with reference to the scale engraved on the objective, the latter must be very accurate. This was not much of a problem with conventional movie cameras (non-digital) since, as already mentioned above, there was no need for back focus correction. However, with digital cinematography there is a need to correct the back focus because of the tolerances of the digital movie camera. This correction of the back focus entails altering the distance scale to the effect that so-called scale spreading occurs. In the case of scale spreading, the distances of the scale marks on the rotary distance ring would actually have to change relative to one another, but said ring is a solid element that is unalterably engraved. Consequently, when correcting the back focus it is no longer possible to read off the scale accurately, as is required in cinematography.

In conjunction with fixed focal lengths, for the purpose of adjusting the back focus previous objectives for digital cinematography have an adjustable index mark for the distance scale of the rotary distance ring. By subsequently rotating this so-called index ring, the indicated value of the distance scale can be corrected for exactly one distance. Otherwise than in the case of conventional objectives, in which a rotatable scale and a fixed part with the index mark are always rotated. The sequence when shooting a movie then shapes up approximately as follows: for cameras and objectives there are so-called rental stocks that have a large number of different cameras and associated objectives. The movie people assemble their equipment for the respective set. This also includes, for example, lighting, stands, etc. Before filming is started, the optical system, that is to say camera and objective, is firstly checked and, if appropriate, corrected. This task is usually carried out by the camera assistant. The latter mounts the camera on a stand and sets up a so-called test image, with structures that can be focused with appropriate sharpness, at a specific prescribed distance (for example 3 meters). The prescribed distance is then set with the aid of the distance setting at the objective. This is followed by using the back focus correction for focusing with reference to the test image, something which can be accomplished with the aid of an HD monitor, for example.

Filming is started thereafter. This process naturally has to be repeated if appropriate when changing the camera or the objective (for example for other instances of viewing).

It is very disadvantageous in this case that when a different distance is being set the indicated scale value of the objective is no longer exactly correct, since the objectives have a so-called internal focusing in which only a portion of the optics in the system is moved and this is not in a linear relationship with the adjustment of the overall objective or with the correction to the back focus.

SUMMARY OF THE INVENTION

It is therefore the object of the present invention to provide an objective for a movie camera for digital cinematography of the type mentioned at the beginning, and a set of objectives by means of which the disadvantages of the prior art are eliminated, the aim being, in particular, for the scale values to be correct in every situation, a correction of the back focus having no influence on the calibration of the distance scale, and it is also intended that the external controls of the objective do not take part in any axial movement during back focus correction, and that all objectives are based on the same mechanism in the sense of a modular system.

This object is achieved according to the invention by virtue of the fact that the inner tube is mounted on the main barrel in a fashion displaceable along the optical axis for the purpose of back focus correction by means of the back focus correction device, the fixed optical elements, the iris diaphragm and sliding holders for holding the adjustable optical sliding elements being inserted into the inner tube.

The object is achieved with reference to the set of objectives wherein the arrangement of said optical elements in the sequence of fixed front element, sliding holders with associated adjustable optical sliding elements, fixed intermediate element, iris diaphragm and fixed rear element is constant, the focusing mounts of the respective objectives differing from one another only in the external lettering or engraving and in the pitches of the respective motion-transmitting threads of the internal focusing devices, and/or in the focal lengths of the objectives.

The measures named above result in a nested arrangement of functional elements which permits the movements required for back focus correction to be done in the objective without the need for the drive rings also to move axially on the outside, in particular electric drives, suppressors, compendiums etc., and without changing the accuracy with which the scales, in particular the distance scale, are read off. Since the back focus drive is always the same in a simple and advantageous way and the arrangement of the optical elements (fixed front element, moveable sliding elements, fixed intermediate element, iris diaphragm, fixed rear element) has also been kept constant for all objectives in the set, the focusing mounts differ only in the external lettering (engraving) and in the pitch of the motion-transmitting thread of the internal focusing system (different traveling strokes have to be produced here in conjunction with the same angle of rotation). As a result, there is, firstly, a reduction in the number of different parts of the objective, and secondly an increase in the number of items of same parts, and so the production of the focusing mount exhibits large economic advantages.

It is also advantageous when the back focus ring can be locked by the clamping element after the back focus correction, and the clamping element is designed as a clamping screw.

It can be ensured through these measures that the back focus correction mechanism is secured against accidental or undesired adjustment.

In an advantageous development of the invention, it can also be provided that the objective has a zoom setting system, at least one of the adjustable optical sliding elements being designed as a lens group for zoom setting, and at least one of the drive rings being designed as a zoom ring.

Zoom objectives can also be produced in a simple way by means of these measures. Provided to that end is a further sliding holder for holding a lens group for the zoom setting system. The optical sliding element for the zoom setting system is adjusted by an associated drive ring designed as a zoom ring.

Advantageous refinements and developments of the invention emerge from the further subclaims and from the exemplary embodiment described below in principle with the aid of the drawing, in which:

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** shows a schematic of the principle of the design of an objective according to the invention; and

FIG. **2** shows a longitudinal section through an objective according to the invention.

DETAILED DESCRIPTION

As may be seen from FIG. **1**, an objective **1** for a movie camera that is suitable for digital cinematography has a cylindrical main barrel **2** with a bayonet or K mount **3** for mounting the objective **1** onto a movie camera (not illustrated), and a compendium ring **4** for connecting a compendium objective (not illustrated). Rotating outside on the main barrel **2** are drive rings **5**, specifically a rotary distance ring **5***a*, a diaphragm ring **5***b* and a back focus ring **5***c*. These drive rings **5** partly have scales (not illustrated) for accurate setting by the user. The core of the objective **1** is the main barrel **2**, in which an inner tube **6** is mounted such that it can be displaced in the direction of an optical axis **21** indicated by dashes in FIGS. **1** and **2**. Fixed optical elements **7**, specifically a front element **7***a*, an intermediate element **7***b* and a rear element **7***c*, as well as an iris diaphragm **8** are fastened on the inner tube **6**. Moreover, a sliding holder **9** that for its part supports the adjustable optical sliding element **10** for internal focusing is displaceably mounted in the inner tube **6**. The adjustable optical sliding element is designed as a lens group **10**.

If the rotary distance ring **5***a* is now turned, a traveling stroke displaces only the sliding holder **9** with the adjustable optical sliding element **10**, all other elements remaining stationary. If the diaphragm ring **5***b* is rotated, the iris diaphragm **8** opens or closes. If the back focus ring **5***c* is rotated, the complete inner tube **6** with all elements contained is displaced for the purpose of back focus correction. The accuracy of the distance setting is retained by the overall displacement of the optical system when the back focus ring **5***c* is actuated.

In another exemplary embodiment, the objective **1** could additionally include a zoom setting system. It would be possible for this purpose to mount on the main barrel a zoom ring that resembles the rotary distance ring **5***a* and uses a further adjustable optical zoom element to adjust a further sliding holder arranged between the adjustable optical sliding element **10** and the front element **7***a*.

As may further be seen from FIG. **1**, the back focus ring can be locked by a clamping element that is designed as a

clamping screw **11**, in order to avoid undesired rotation after the setting of the back focus.

As may be seen from FIG. **2**, the back focus ring **5***c* is mounted on a back focus input drive part **12** that rotates on the main barrel **2** and produces a traveling stroke in the back focus output drive part **13** by means of a motion-transmitting thread (not illustrated in more detail). This traveling stroke is transmitted onto the inner tube **6** through the main barrel **2** via a through-passage (not illustrated). Consequently, when the back focus ring **5***c* is rotated a movement of the inner tube **6** relative to the fixed main barrel **2** is produced. In other words, the main barrel **2** with the drive rings **5** mounted thereupon remains in its position during the back focus correction.

The diaphragm ring **5***b* rotates on the main barrel **2**. The rotary movement of the diaphragm ring **5***b* is transmitted onto the iris diaphragm **8** via a driver **14** comprising groove and pin. Nothing changes at the iris diaphragm **8** during a movement for back focus correction. The rotary distance ring **5***a* is mounted on a bearing ring **15** that rotates on the main barrel **2** and transmits the rotary movement onto a distance input drive **17** via an Oldham coupling **16**. The Oldham coupling **16** in this case permits the back focus traveling stroke and transverse offsets between the bearing ring **15** and the distance input drive **17**. The distance input drive **17** rotates on a bearing ring **18** that is connected to the inner tube **6**, and produces a traveling stroke of the distance output drive **19** by means of a motion-transmitting thread (not illustrated in more detail). This traveling stroke is transmitted onto the sliding holder **9** by means of a web **20** via a through-passage through the main barrel **2** and the inner tube **3**. Thus, when the rotary distance ring **5***a* rotates a movement of the sliding holder **9** relative to the inner tube **6** is produced that is independent of the back focus.

There is in each case between the sliding holder **9** and the inner tube **6** and between the inner tube **6** and the main barrel **2** a rotation-prevention means (not illustrated) that permits traveling strokes of the elements relative to one another, but no rotary movements.

Owing to the nested arrangement of functional elements in the present exemplary embodiment, it becomes possible to produce the required movements in the objective **1** without the need for the drive rings **5** also to move axially on the outside, and without changing the accuracy with which the scales are read off. Since the back focus drive is always the same, and the arrangement of the optical elements (fixed front element **7***a*, moveable sliding element **10**, intermediate element **7***b*, iris diaphragm **8** and fixed rear element **7***c*) is also kept constant for all objectives **1** in a set, the focusing mounts differ from one another only in the external lettering (engraving) and the pitch of the motion-transmitting thread of the internal focusing system (different traveling strokes must be produced here for the same angle of rotation). Owing to these measures, on the one hand there is advantageously a reduction in the number of different parts, and on the other hand an increase in the number of items of the same parts, as a result of which the focusing mount has great economical advantages.

Objectives **1** in the set have between 14 and 19 lenses.

What is claimed is:

1. An objective for a movie camera for digital cinematography, comprising:

a cylindrical main barrel with a bayonet or K mount,

an inner tube,

fixed optical elements,

adjustable optical sliding elements,

drive rings with scales for adjusting the optical sliding elements, which are mounted rotatably in the axial direction on the main barrel,

an iris diaphragm with a diaphragm ring rotating on the main barrel,

an internal focusing system, and

a back focus correction device,

wherein said inner tube is mounted on said main barrel in a fashion displaceable along the optical axis for the purpose of back focus correction by means of said back focus correction device, said fixed optical elements, said iris diaphragm and sliding holders for holding said adjustable optical sliding elements being inserted into said inner tube.

2. The objective as claimed in claim **1**, wherein said back focus correction device has a back focus ring mounted on said main barrel, a back focus input drive part, a back focus output drive part, and a clamping element.

3. The objective as claimed in claim **2**, wherein said displacement of said inner tube is performed by axial rotation of said back focus ring rotatably mounted on said main barrel, without varying the setting or the calibration or the accuracy of said adjustable optical sliding elements or of their drive rings, in particular of said internal focusing system, without varying the diaphragm setting and without changing the position of said main barrel with said drive rings mounted thereupon.

4. The objective as claimed in claim **2**, wherein said back focus ring is mounted on said back focus input drive part.

5. The objective as claimed in claim **2**, wherein said back focus input drive part is mounted rotatably on said main barrel, and a motion-transmitting thread is provided for producing traveling stroke in the back focus output drive part, a through-passage being provided for transmitting the traveling stroke through said main barrel onto said inner tube.

6. The objective as claimed in claim **2**, wherein after back focus correction said back focus ring can be locked by said clamping element.

7. The objective as claimed in claim **2**, wherein said clamping element is designed as a clamping screw.

8. The objective as claimed in claim **1**, wherein a driver is provided for transmitting onto said iris diaphragm the rotary movement of said diaphragm ring mounted rotatably on said main barrel.

9. The objective as claimed in claim **1**, wherein at least one of said adjustable optical sliding elements is designed as a lens group for internal focusing, at least one of said drive rings being designed as rotary distance ring in order to set said focusing.

10. The objective as claimed in claim **9**, wherein said rotary distance ring is mounted on a bearing ring that rotates on said main barrel and an Oldham coupling is provided for transmitting this rotary movement onto a distance input drive, said Oldham coupling permitting the back focus traveling stroke and transverse offsets between said bearing ring and said distance input drive, said distance input drive likewise being mounted on a bearing ring, the latter being connected to said inner tube and a motion-transmitting thread being provided for producing a traveling stroke onto a distance output drive, a web being provided for transmitting the traveling stroke onto the sliding holder, in which the lens group for internal focusing is mounted, via a through-passage through said main barrel and said inner tube, and a movement of said sliding holder relative to said inner tube being performed, independently of the back focus setting.

11. The objective as claimed in claim 1, wherein a rotation-prevention means that permits traveling strokes of the elements relative to one another without rotary movements is arranged in each case between said sliding holders and said inner tube and between said inner tube and said main barrel.

12. The objective as claimed in claim 1, defined by a zoom setting system, at least one of said adjustable optical sliding elements being designed as a lens group for zoom setting, and at least one of said drive rings being designed as a zoom ring.

13. The objective as claimed in claim 1, wherein said fixed optical elements are designed as a front element, an intermediate element and a rear element.

14. The objective as claimed in claim 1, wherein said fixed optical elements are designed as lens groups.

15. A set of objectives as claimed in one of claims 1 to 15, wherein the arrangement of said optical elements in the sequence of fixed front element, sliding holders with associated adjustable optical sliding elements, fixed intermediate element, iris diaphragm and fixed rear element is constant, the focusing mounts of the respective objectives differing from one another only in the external lettering or engraving and in the pitches of the respective motion-transmitting threads of the internal focusing devices, and/or in the focal lengths of the objectives.

* * * * *

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Stantz et al.

(10) **Patent No.: US 6,607,274 B2**
(45) **Date of Patent: Aug. 19, 2003**

(54) **METHOD FOR COMPUTING VISUAL PERFORMANCE FROM OBJECTIVE OCULAR ABERRATION MEASUREMENTS**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **10/115,037**

(22) Filed: **Apr. 4, 2002**

(65) **Prior Publication Data**

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Related U.S. Application Data

(63) Continuation of application No. PCT/US01/32505, filed on Oct. 19, 2001.
(60) Provisional application No. 60/241,789, filed on Oct. 20, 2000.

(51) **Int. Cl.**[7] **A61B 3/10**
(52) **U.S. Cl.** **351/221**
(58) **Field of Search** 351/205, 206, 351/211, 212, 214, 221, 237, 239, 241, 242, 243; 348/607

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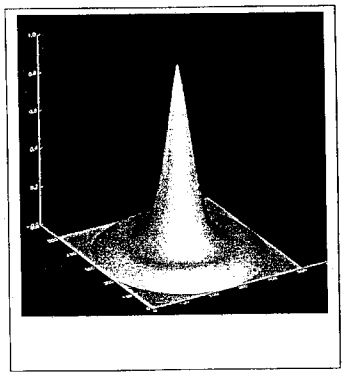
Primary Examiner—George Manuel

(57) **ABSTRACT**

A method for computing the visual performance of a human or animal subject based on objective measurements of visual refraction, including higher order aberrations, includes measuring wavefront aberrations of a subject ocular pupil, computing a point-spread-function from the measured pupil aberration, providing a test image, and convolving the test image with the point-spread-function. A simulated image may be produced from the convolution result of the test image with the point-spread-function. One or more specific terms of the point-spread-function may be subtracted therefrom prior to the convolving step to simulate an effect of a correcting means, such as spectacles lenses, contact lenses, or laser surgery. A best correction for a given subject may be determined by adjusting the terms that are subtracted to optimize the resultant image.

21 Claims, 4 Drawing Sheets



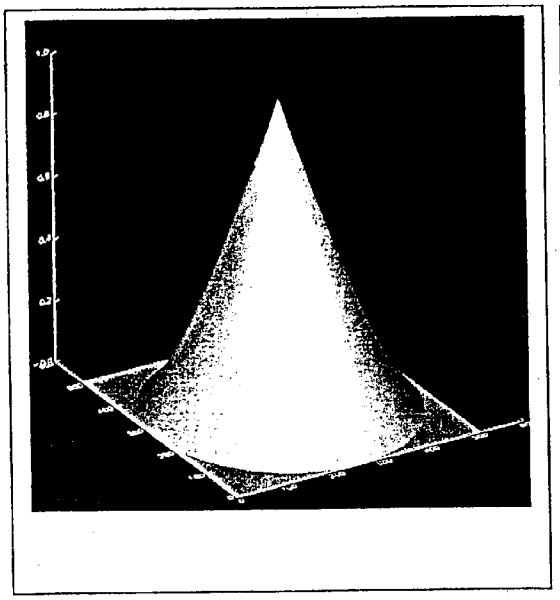


FIG. 1A

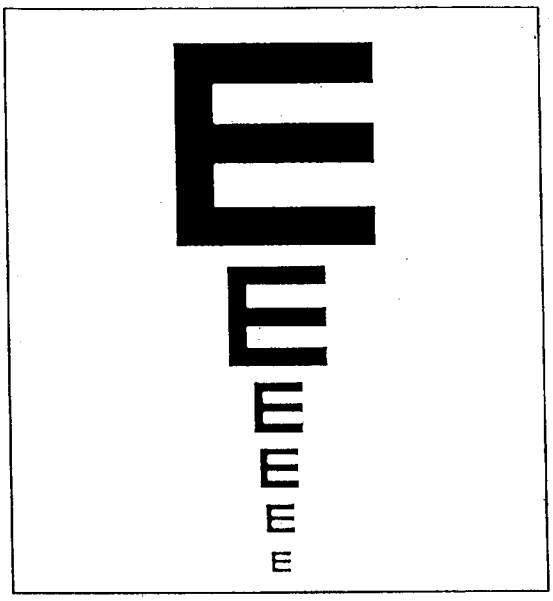


FIG. 1B

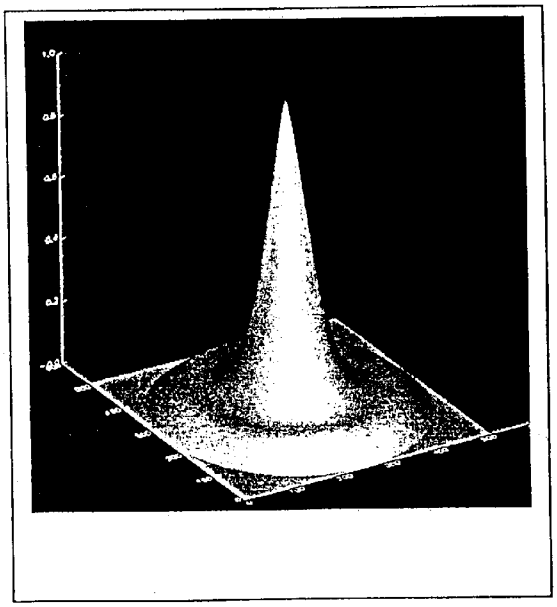


FIG. 2A

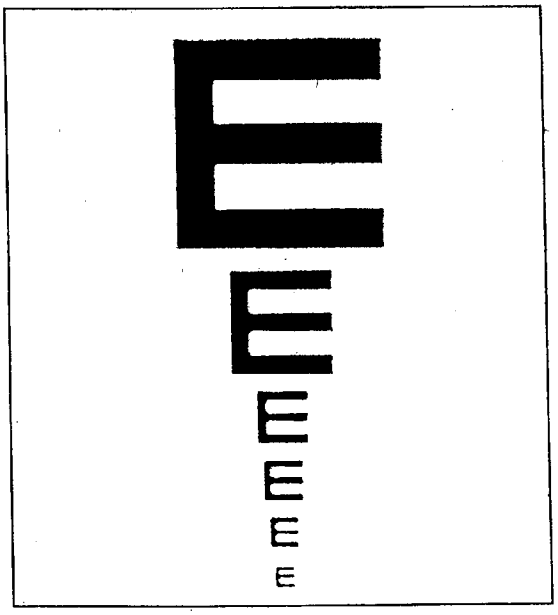


FIG. 2B

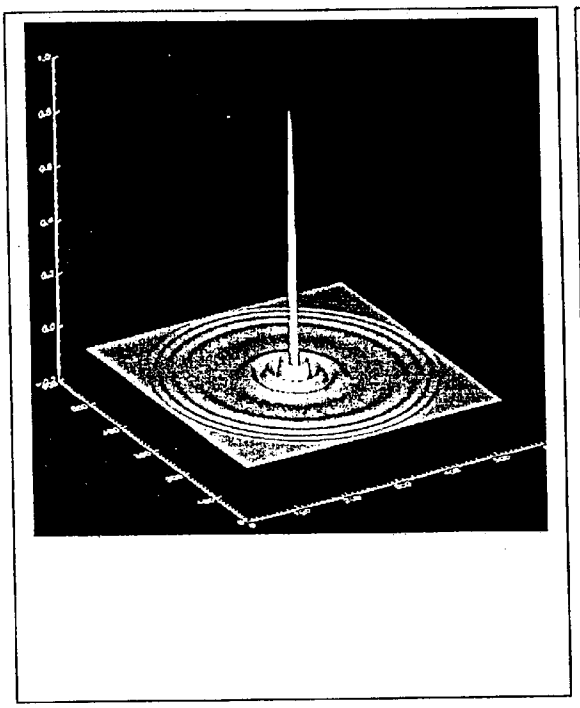


FIG. 3A

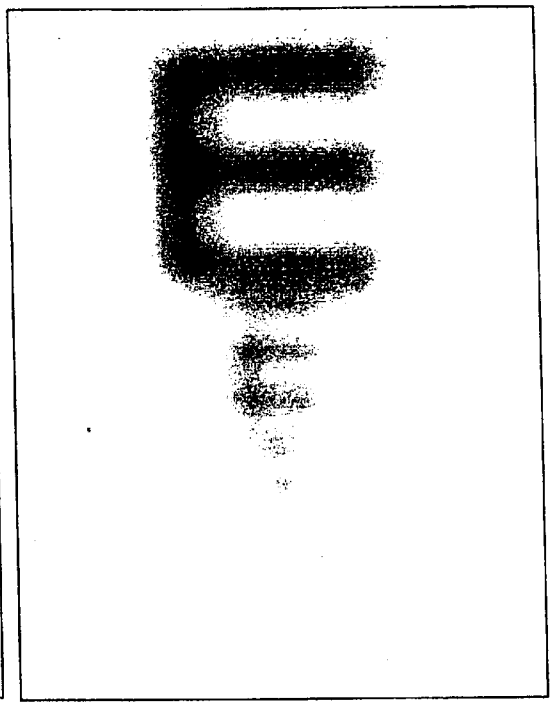


FIG. 3B

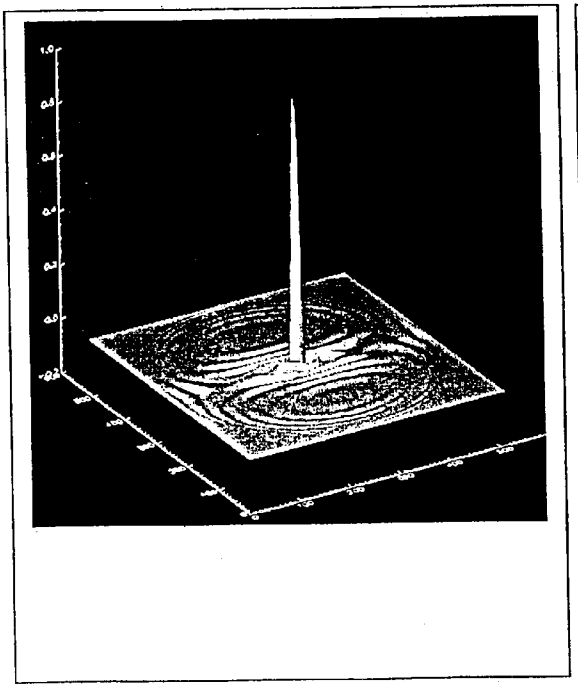


FIG. 4A

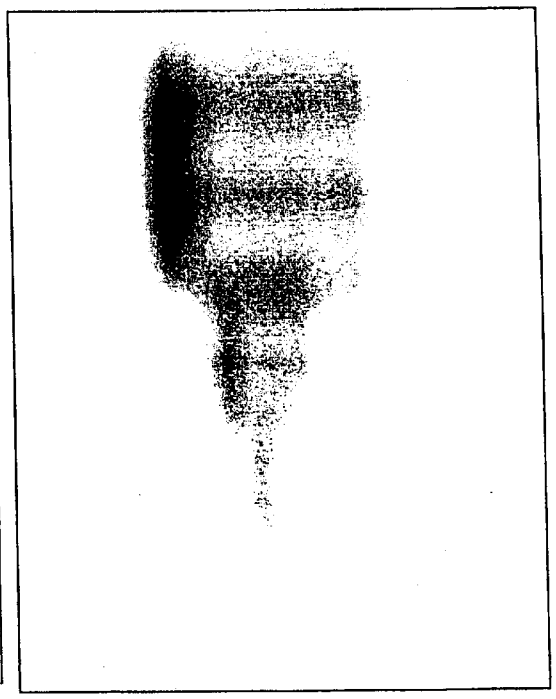


FIG. 4B

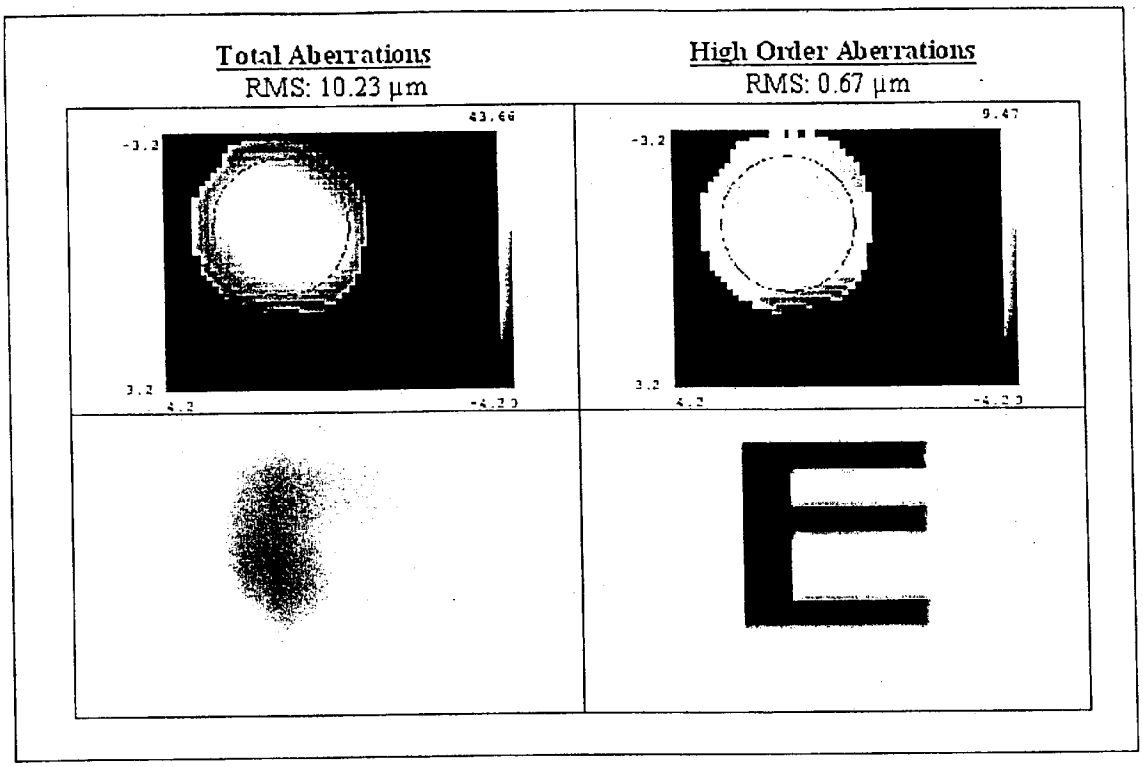

Total Aberrations
RMS: 10.23 µm
High Order Aberrations
RMS: 0.67 µm

FIG. 5

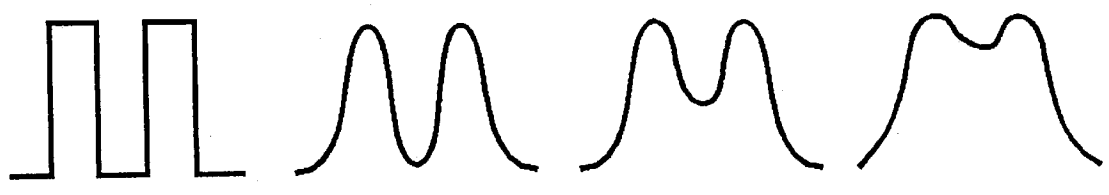

Target
Fully Resolved
Just Resolved
(Rayleigh)
Unresolved

FIG. 6

FIG. 7

METHOD FOR COMPUTING VISUAL PERFORMANCE FROM OBJECTIVE OCULAR ABERRATION MEASUREMENTS

CROSS REFERENCE TO RELATED APPLICATIONS

This is a continuation application claiming the priority benefit under 35 U.S.C. §119 of International Application Serial No. PCT/US01/32505 filed on Oct. 19, 2001, under 35 U.S.C. §119, and U.S. Provisional Patent Application No. 60/241,789 filed on Oct. 20, 2000, the entirety of each of which is hereby incorporated by reference for all purposes as if fully set forth herein.

BACKGROUND OF THE INVENTION

1) Field of the Invention

This invention pertains to the field of characterization and measurement of human and animal visual performance, and more particularly, to a method of performing objective measurement of human and animal visual performance.

2) Description of the Related Art

Traditional measures of human and animal visual performance have been limited by the need for subjective feedback from patients, or to examination of a limited number of parameters. The Snellen chart is often used to measure the visual acuity of the subject. The visual acuity is defined in terms of the ability to distinguish letters or shapes in a standard chart, the size of the letters that can be recognized being a measure of the optical system performance of the eye.

Unfortunately, the most common method for measuring visual performance, subjective refraction, cannot be applied to animal subjects used for research, for very young children, or those with learning or communication difficulties. New instruments have been developed in recent years to make objective measurements of the eye. These instruments include: autorefractors for measuring the basic refractive error; corneal topography instruments that can measure the corneal surface; and a variety of aberrometers that have recently been shown to be able to measure higher order aberrations. With each new advance, more information can be measured about the eye.

Auto-Refractor.

The auto-refractor is an instrument that uses one of a variety of methods to analyze the cornea and lens of an eye to determine the basic refractive error. This error is presented in terms of the spherical and cylindrical power of a lens that is needed for its correction. In the event that higher order irregularities are present, these are included only in the effect that they have on the overall visual performance.

Corneal Topography.

A corneal topography instrument uses one of a number of techniques to measure the shape of the cornea. Since this shape is, in many cases, the source of the aberrations, it provides a useful and more complete measure of the optical performance of the eye. The information can be used to predict the visual acuity and optical performance with greater accuracy than using the sphero-cylinder terms alone. However, assumptions about the interior structure of the eye must be made in inferring the visual performance from corneal topography measurements alone.

Aberrometer (Also Known as Wavefront Analyzer).

The aberrometer is a system for measuring the aberrations of the eye by projecting light onto the retina and thus

observing the effect of the entire ocular optical system. Using these methods both the basic refractive error (sphero-cylinder) and higher order aberrations may be determined. However, since this represents a measurement of the full optical path through the eye, a complete estimate of all the important optical effects can be obtained. It is not necessary to make assumptions about the internal or external structure of the eye since the aberrations can be measured directly. An objective aberrometer does not rely on subjective feedback, but measures the aberrations by projecting light into the eye and measuring it using objective means.

Given this new level of accurate information that can be determined about the eye, it remains an important task for the clinician to interpret the data in light of both the historical measures, and in terms that can be readily understood by patients. For example, Mrochen, Kaemmerer, Mierdel and Seiler used an objective aberrometer to measure the effect of laser refractive surgery on ocular aberrations. Mrochen, Kaemmerer, Mierdel and Seiler, 27 J. CATARACT REFRACT SURG. (March 2001). But while they were able to relate their results in terms of the optical aberrations of the eye, they were not able to make the connection to patient satisfaction or degradation in visual acuity in scotopic conditions. While the aberrometer is capable of providing a precise wavefront map of the aberrations of the optical system, unless the information can be interpreted by the clinician or researcher, it may have little value for diagnosis and treatment.

There are a number of methods currently used to measure performance of the ocular system. The most widely used and well established are psycho-physical methods, i.e., methods relying on subjective patient feedback. The oldest of the psycho-physical methods is the phoropter or trial lens method, which relies on trial and error to determine the required correction. There are psycho-physical methods for measuring visual acuity, ocular modulation transfer function, contrast sensitivity and other parameters of interest. While new advances in this field continue (see, e.g., PCT Publication No. WO 93/002614, European Patent Number 00600963/EP B1), they rely on subjective feedback and hence suffer from the limitations cited above.

In addition to these subjective methods, there are also objective methods for assessing the performance of the ocular system. Such objective methods include corneal topography, wavefront aberrometry, corneal interferometry, and auto-refraction. Many of these methods only measure the contribution of specific elements to the total refractive error. For example, much work has been directed to measuring the topography of the cornea and characterizing the corneal layer. However, the corneal shape only contributes about 30–40% of the total refractive error in most cases. In order to measure the bulk of the refractive error and to provide a complete mapping for diagnosis and correction, additional information and measurements are needed.

Another method for determining the refraction of the eye is auto-refraction, which uses a variety of techniques to automatically determine the required corrective prescription. These automated techniques include projecting one or more spots or patterns onto the retina, automatically adjusting optical elements in the auto-refractor until the desired response is achieved, and determining the required correction from this adjustment. However, auto-refractors are not considered especially reliable. Further, auto-refractors measure only lower order components of the aberrations, e.g., focus and astigmatic errors.

Recently, the eye has been considered an optical system, leading to the application of methods previously used for

other optical systems to the measurement of the eye. These methods include interferometry and Shack-Hartmann wavefront sensing. These techniques are of particular interest because they measure the complete aberrations of the eye. These include the low order aberrations such as defocus and astigmatism, as well as higher order aberrations such as coma, spherical aberration or other more rapidly varying components. This additional information allows measurement of non-uniform, asymmetric errors that may be affecting vision. Further, this information may be linked with any of the various corrective techniques to provide improved vision. For example, U.S. Pat. No. 5,777,719 to Williams describes the application of Shack-Hartmann wavefront sensing and adaptive optics for correcting ocular aberrations to make a super-resolution retina-scope. U.S. Pat. No. 5,949,521 to Williams et al. describes using this information to make better contacts, intra-ocular lenses and other optical elements. Several types of objective aberrometers have been developed which can provide the wavefront information. These include the Shack-Hartmann (or Hartmann-Shack), Moiré deflectometry, Tscheming aberrometer, scanning resolved refractometer (ray-tracing), and a variety of other wavefront aberrometer technologies.

Wavefront aberrometry measures the full, end-to-end aberrations through the entire optics of the eye. In these measurements, a spot is projected onto the retina, and the resulting returned light is measured with an optical system, thus obtaining a full, integrated, line-of-sight measurement of the eye's aberrations. U.S. patent application Ser. No. 09/692,483 describes a method for designing practical clinical instruments for measuring full, end-to-end aberrations through the entire optics of the eye.

Williams, and others, have been able to use a full adaptive optics system to present a corrected eye chart to a subject. However, this is still not useful for determining the objective visual acuity. While such a system can produce images with arbitrary effects included (up to the mechanical ability of the deformable mirror components), it introduces a significant additional cost and complexity.

Camp, McGuire, Cameron and Robb attempted to simulate the image quality and visual performance based on a model of the internal structure and measurements of the corneal surface. 109 AM. J. OPHTHALMOLOGY 4 (Apr. 15, 1990). Klonos, Pallikaris and Fitzke extended this work using an improved model of the internal structure. 12 J. REFRACT. SURG. 2 (February 1996). Barsky, Garcia, Klein, and Van De Pol reported a method for computing the visual acuity from the wavefront inferred from corneal topography measurements and a model of the interior structure of the eye in SPIE 3591, pp. 303–310 (1999). In these cases the internal structure of the eye was simulated based on a priori assumptions.

While ray-tracing and other techniques have attempted to predict visual acuity based on the refraction or corneal topography data, in all cases these relied on assumptions, rather than measurements, of the ocular optical system.

Accordingly, it would be advantageous to provide a method is needed to predict visual acuity and other ocular performance metrics from the aberrometry data. In particular, it would be advantageous to provide a method of evaluating of visual performance that relies on only measured values for the ocular aberrations. It would also be advantageous to provide a method for computing the ocular performance, predicting the appearance of images viewed by a subject, and determining the visual acuity in an objective fashion. Other and further objects and advantages will appear hereinafter.

SUMMARY OF THE INVENTION

The present invention comprises a method for computing the visual performance of a human or animal subject by using measurements of the subject's aberrations obtained from an aberrometer that measures the full aberrations through the ocular optical system.

In one aspect of the invention, a method for computing the visual performance of a human or animal subject based on objective measurements of visual refraction including higher order aberrations, includes measuring wavefront aberrations of a subject ocular pupil, computing a point-spread-function from the measured pupil aberration, providing a test image, and convolving the test image with the point-spread-function. Beneficially, a simulated image, that is similar to a subject's view, is produced from the convolution result of the test image with the point-spread-function. Also beneficially, the convolution of the test image with the point-spread-function includes performing an inverse Fourier transform of a modulus squared of the point-spread-function to compute an optical transfer function, computing a Fourier transform of the test image, and computing an inverse Fourier transform of a product of the optical transfer function and the test image Fourier transform.

Moreover, in another aspect of the invention, the subject's visual acuity and visual acuity number can be determined objectively from these computations. In that case, the test image may be a Snellen acuity chart.

In another aspect of the invention, a method for computing an image, includes measuring wavefront aberrations of a subject ocular pupil, computing a point-spread-function from the measured pupil aberration, providing a test image, convolving the test image with the point-spread-function, and producing a simulated image from a convolution result of convolving the test image with the point-spread-function, wherein at least one specific term of the point-spread-function is adjusted prior to the convolving step to simulate an effect of a correcting means. Beneficially, adjusting the specific term comprises subtracting or eliminating the specific term, e.g., by setting a high order Zernike coefficient in the pupil aberration function to zero.

In yet another aspect of the invention, a method for computing an effect of corrective means on a subject's visual acuity, includes measuring a subject pupil aberration function with an objective aberrometer, adjusting (e.g., adding or subtracting) terms to the measured subject pupil aberration function that correspond to specific corrective means, producing a modified pupil aberration function, computing a point-spread-function from the modified pupil aberration function, computing an optical transfer function (OTF) of the computed point-spread-function, multiplying a Fourier transform of a test image by the OTF to produce a Fourier result, and performing an inverse Fourier transform on the Fourier result. The corrective means may be spectacle lenses, contact lenses, laser refractive surgery, or Laser Thermal Keratotomy.

In still another aspect of the invention, a method of determining a best correction for a given subject, includes measuring a subject pupil aberration function with an objective aberrometer, subtracting terms from the pupil aberration function that correspond to specific corrective means, producing a modified pupil aberration function, computing a point-spread-function from the modified pupil aberration function, computing an optical transfer function (OTF) of the computed point-spread-function, multiplying a Fourier transform of a test image by the OTF to produce a Fourier result, performing an inverse Fourier transform on the

Fourier result, and adjusting the terms that are subtracted to optimize a resultant image.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1**A shows the Modulation Transfer Function (MTF) for an eye with perfect vision, and FIG. **1**B shows a corresponding visual acuity chart computed according to a preferred embodiment of the invention.

FIG. **2**A shows the MTF of an eye having a weak aberration, V_4 wave of defocus, and FIG. **2**B shows a corresponding visual acuity chart computed according to a preferred embodiment of the invention.

FIG. **3**A shows the MTF of an eye having a significant aberration, 2 waves of defocus, and FIG. **3**B shows a corresponding visual acuity chart computed according to a preferred embodiment of the invention.

FIG. **4**A shows the result of measuring the MTF of a human eye with an objective aberrometer, and FIG. **4**B shows a corresponding visual acuity chart computed according to a preferred embodiment of the invention.

FIG. **5** illustrates the effect of subtracting the lower order Zernike terms (focus and astigmatism) from a wavefront before computation of a simulated image.

FIG. **6** presents a cross section through a target. FIG. **6**A shows a cross section through the original target, FIG. **6**B shows a resolved image of the target, FIG. **6**C shows the target image that just meets the Rayleigh criterion, and FIG. **6**D shows an unresolved image.

FIG. **7** shows a simulated target that is used to determine a visual acuity number.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Embodiments and other aspects of the invention described herein, including the system embodiments described below, may be made or used in conjunction with inventions described, in whole or in part, in co-pending U.S. patent application Ser. No. 09/692,483, filed on Oct. 20, 2000, filed in the name of inventors Daniel R. Neal, Darrel Armstrong, James Gruetzner, and James Copland, entitled "Dynamic Range Extension Techniques for a Wavefront Sensor Including Use in Ophthalmic Measurement," the entirety of which is hereby incorporated herein by reference for all purposes as if fully set forth herein.

This invention relies on a measurement of the aberrations, including both the low and high orders to calculate the effect of these aberrations on an image. The aberrometer generates a measured map of the appropriate aberrations, which may be expressed either in terms of a wavefront error distribution, or in terms of a set of representative polynomials. This map, which may be called the pupil aberration function, can be analyzed to predict the effect of these aberrations on the image.

The method described herein consists of two basis steps:

1. Computation of the point-spread-function. That is, the response of the measured optical system to a single point source; and
2. Convolution of the point-spread-function with an appropriate image.

These steps are the minimum necessary to evaluate the effect of the aberrations on visual acuity. The point-spread-function may be computed from the aberration map alone, with no a priori assumptions about the internal structure of the eye. Any image can be used for the second, convolution, step. This can be a scene, a color or black and white image, a letter or series of letters, a Snellen acuity chart, or a pattern of geometric shapes that may be useful for determining other properties of vision.

It may be possible to perform both operations at once by taking advantage of certain properties of the Fourier transform. Both the point-spread-function and convolution operations may be performed using Fourier-transform techniques.

Some specific shapes can be used to determine the Snellen Acuity number, or objective visual acuity. The simplest such shape is a pair of points. When convolved with the point-spread-function, the visual acuity number may be related to the resolvable separation of the points. An absolute criterion, such as the Rayleigh criterion, may be used to determine this number from the data. Better targets, such as a series of bars at different separations may be more readily interpreted automatically.

It is also possible to compute the visual acuity directly from the point-spread-function by analyzing its spatial extent. Since the point-spread-function (by definition) is the response of the optical system to a point input, the spatial extent of this function contains all the information needed to compute the visual acuity number. An appropriate algorithm can be used to objectively determine the spatial extent, such as 2^{nd} moment, or fitting to a Gaussian profile or other a priori shapes.

Algorithm.

A wavefront aberrometer measures the full aberrations of the eye (e.g., cornea and lens) to provide the pupil aberration function $\phi(x,y)$. Beneficially, the wavefront aberrometer is an objective aberrometer that measures the low order aberrations such as defocus and astigmatism, as well as higher order aberrations such as coma, spherical aberration or other more rapidly varying components. With this information, it is possible to simulate how these aberrations reduce the fidelity of a subject's eyesight, i.e., to visualize a patient's lack of acuity. The procedure follows these steps:

(1) construct the impulse response function, or point-spread-function (PSF), of the cornea and lens using either the fitted Zernike coefficients from measured data or a measured wavefront map;

(2) perform the inverse Fourier transform of the intensity-PSF (modulus squared of the PSF) to produce the measured optical transfer function (OTF);

(3) multiply the OTF with the spectral distribution of an image (e.g., eye chart); and

(4) calculate the inverse Fourier transform to simulate how a patient's visual acuity affects his or her eyesight.

The first step is to form the generalized pupil aberration function, P, utilizing measured sensor data.

$$P(x,y)=P(x,y)\cdot e^{i\phi(x,y)}, \tag{1}$$

where P(x,y) is the pupil aberration function,

$$P(x,y)\equiv P(\rho,\theta)=circ(\rho), \tag{2}$$

and the wavefront may be represented by the phase function:.

$$\phi(\rho,\theta)=k\cdot\sum_{n=1}^{15} z_n\cdot P_n(\rho,\theta), \tag{3}$$

where z_n represents the coefficients for the Zernike polynomials P_n (see, e.g., MALACARA, OPTICAL SHOP TESTING, p. 455–499, John Wiley & Sons 1992) and k is

the wave-number of the laser source, $2\pi/k$. The pupil aberration function may be expressed as an expansion in terms of known polynomials, e.g. Zernike polynomials, or as a distribution map of wavefront values, determined numerically or analytically. From P the PSF is calculated by taking the Fourier transform F{ }:

$$PSF=F\{P(x,y)\}. \quad (4)$$

The next step solves for the OTF to be used for incoherent illumination. It is the normalized autocorrelation function of the intensity impulse response function, the magnitude squared of the PSF.

$$OTF = \frac{F^{-1}\{PSF^* \cdot PSF\}}{\pi \cdot r^2}, \quad (5)$$

where r is the pupil radius.

Convolution takes place in the frequency domain. The OTF is multiplied by the spectral content of an image, e.g., the Fourier transform of the eye chart input image. The final step performs the inverse Fourier transform on the above product to determine the form of the image on the retina (see FIGS. **1**B, **2**B, **3**B and **4**B).

$$\text{Retinal image}=|F^{-1}\{OTF \cdot F\{\text{image}\}\}| \quad (6)$$

Computational Considerations.

Two inter-related issues include how to sample the image and the sampling resolution of the above calculation. The resolution of an image on the retina (i.e., sampling rate) is defined by the minimal distance between rods or cones, which is 1.5–2.0 μm. Therefore, an image placed one focal length in front of the eye has a magnification of 1 and the same spatial resolution. Therefore, all eye charts represent letter sizes and line-widths with a specific number of pixels. This has been measured and tabulated in Table 1 below.

TABLE 1

Resolution requirements for simulating letters in an Eye Chart

Visual Acuity	Eye Chart	samples
20/200	E	185.2
20/100	F P	92.6
20/70	T O Z	64.8
20/50	L P E D	46.3
20/40	P E C F D	37.0
20/30	E D F C Z P	27.8
20/25	F E L O P Z D	23.2
20/20	D E F P O T E C	18.5

The Fourier transforms may advantageously be computed using Fast Fourier Transform (FFT) techniques.

The eye chart displays the letter E for the following levels of visual acuity: 20/200, 20/100, 20/50, 20/40, 20/30, and 20/20 (FIGS. **1**B, **2**B, **3**B and **4**B). Defining the retinal sample size to 2 μm, the number of samples is 512. This sample size ignores the diffractive effects of the pupil, only the effects of the aberrations on the object are simulated.

FIGS. **1**–**4** display the Modulation Transfer Function and visual acuity charts. (eye chart simulations) for the following cases: perfect visual acuity ($z_n 0$) (FIGS. **1**A–B); vision with slight defocus ($z_5 \sim \lambda/4$) (FIGS. **2**A–B); vision with a lot of defocus ($z_5 \sim 2\%$) (FIGS. **3**A–B); and the vision of a human subject (FIGS. **4**A–B). The Modulation Transfer Function (MTF) is the modulus of the Optical Transfer Function (OTF), which is a complex function.

FIG. **1**A shows the MTF for an eye with perfect vision, i.e., excellent visual acuity, no aberrations measured (i.e., Zernike coefficients approach zero). This produces an MTF having nearly a perfect cone shape. The degradation in acuity is only a result of the fact that the image was transmitted through a finite pupil. FIG. **1**B shows an eye chart simulation produced by the convolution of the OTF whose MTF is shown in FIG. **1**A, with an exemplary eye chart.

Aberrations distort the OTF and thus an image. Slowly increasing the defocus term (Zernike coefficient five) attenuates higher frequency acuity causing edges to appear "fuzzy."As an example, FIG. **2**A shows the MTF of an eye having a weak defocus term, ¼ wave of defocus, and FIG. **2**B shows the an eye chart simulation produced by convolution of the OTF whose MTF is shown in FIG. **2**A, with the exemplary eye chart of FIG. **1**B. A slice of the MTF cone through the origin appears "L-shaped." As this aberration becomes worse ($>\lambda/2$), the OTF can change sign, an indication of contrast reversal. FIG. **3**A shows the effect of a significant aberration, 2 waves of defocus, on the MTF, and FIG. **3**B shows the corresponding acuity chart (eye chart simulation) obtained by convolution of the OTF whose MTF is shown in FIG. **3**A, with the exemplary eye chart of FIG. **1**B. While the aberrations are still symmetric, a significant effect is evident. Oscillations in the MTF, reversals in contrast, and the loss of visual acuity (20/100) are noted.

FIGS. **4**A–B show the results of measuring a human eye with an objective aberrometer, and applying the method described above to the computation of the visual acuity of a human subject. It is noted that the aberrations produce an MTF and visual acuity chart which are no longer symmetric, but which represent the effects of focus, astigmatism, and other higher order aberrations. The strong difference between horizontal and vertical visual acuity is seen in the MTF of FIG. **4**A. The eye chart simulation of FIG. **4**B, produced by convolution of the OTF whose MTF is shown in FIG. **4**A, with the exemplary eye chart of FIG. **1**B, indicates weak visual acuity in the horizontal direction, and reasonable acuity in the vertical. This agrees well with testimonial description from the subject regarding the subject's vision without the use of corrective lenses.

Subtraction of Specific Terms.

One key advantage to the numerical technique of computing the visual acuity image is that the effect of specific types of aberration may be considered. For example, it is quite common for a post-Lasik patient to complain of poor night vision, especially while driving. The patient may describe star shapes or double images surrounding headlights. In this case it may be desirable to isolate the effects of the various aberration terms in order to identify which is the most significant. This can be done by adjusting (e.g., adding to, subtracting from, eliminating, etc.) the appropriate terms in the aberration distribution that is used as the input to the algorithm.

This technique is particularly powerful when used with correction means that may introduce higher order aberrations in the process of correcting low order effects. As an example, it is common for the Lasik procedure to introduce significant spherical aberration in the process of correcting low order terms. Using the invention described herein, these effects could be correctly simulated to determine the effect on the subject's vision, before performing the procedure.

As an example of this, consider FIG. **5**, which illustrates the effect of subtracting the lower order Zernike terms (focus and astigmatism) from the wavefront before computation of a simulated image. The left hand side of FIG. **5** shows the effect of all measured aberrations on a projected image, and right hand side of FIG. **5** shows the effect of only the higher

order aberrations. This case is particularly useful since it represents correction of the ocular system with the best-fit conventional glasses. The residual aberrations can be evaluated for the effectiveness of other corrective means, or for screening and diagnosis.

Computation of the Visual Acuity Number.

One of the key parameters used to describe visual performance is the visual acuity number. This describes the comparative visual performance relative to a standard. Thus a subject is described as having 20/20, or 20/40 visual acuity. An objective means for determining this numerical representation is needed to allow interpretation of the measured aberration information. To determine the visual acuity number from the computed image, a special set of images may be used. The visual acuity is related to the ability to resolve a pair of points or targets. To this end a special set of images that may be test targets may be used to advantage. These may be sets of bars similar to an Air Force test target, or may be as simple as a pair of points with known separation. If the target image is configured with a number of different spatial frequencies, the resulting image (after convolution) may be used to automatically determine the visual acuity number.

FIG. **7** shows a typical target that may be used to determine the visual acuity number. In this case a series of targets, each in different rows corresponding to a different visual acuity number (20/200, 20/50, 20/40, 20/20, etc.), is used as the input image to the convolution algorithm described herein. Each row contains targets with different spatial frequency information. By presenting several different targets for each line of a visual acuity number, the effect of non-symmetric aberrations may be included in the analysis. By determining the last line that may be distinguished, the visual acuity number may be measured. Each of these targets is analyzed using the Rayleigh or other criteria to determine if it meets the resolution requirements. The Rayleigh criteria states that two point or line sources may be considered distinguishable if the intensity distribution between the sources falls to ½ of the peak intensity, as shown in FIG. **6**. FIG. **6** shows a cross section through a target. Proceeding from left to right, the first graph on the left shows a cross section through the original target, the second graph shows a resolved image of the target, the third graph shows the target image that just meets the Rayleigh criterion, and the last graph shows an unresolved image.

To determine the visual acuity number an image with a number of targets arranged in rows, each row consisting of the same size target corresponding to a given visual acuity. The targets may have both horizontal and vertical features, as appropriate. A section through each of the targets, in either the horizontal or vertical direction, as appropriate, is analyzed to determine if the Rayleigh criterion has been met for that target. If all targets on one row meet this criterion, but none on the next successive rows meet this criteria, then the visual acuity is the number associated with the last successful row.

Partial or fractional visual acuity may be obtained by counting the number of targets that pass the criteria on a given row. Other means for determining the visual acuity number from this arrangement of targets will be apparent to those skilled in the art.

A method for using measured wavefront information from an objective aberrometer to compute a simulated image has been presented. This method allows wavefront information to be interpreted in terms of a subject's visual performance, and allows a clinician to ascertain the effect of various aberrations. The visual acuity of the subject can be computed, either by a view of the computed eye chart, or through objective calculation of standardized targets. The effect on the subject visual performance of corrective means, including the effect of increased aberrations, can be computed, allowing evaluation of candidate treatments.

Several potential benefits may be obtained.

For example, conventional objective methods for measuring optical quality of the eye require a subjective evaluation by the interpreter. Accordingly, these conventional methods are not useful for measuring optical qualities for non-communicative subjects (e.g., deceased subjects, animals, infants, etc.). However, the methods described herein maybe used to predict the acuity of animal eyes both in vivo and ex vivo. Consequently, the usefulness of animal and cadaver studies of corrective measures can be increased.

Also, the methods described herein open the possibility of studying the relative importance of certain aberrations (such as spherical aberrations) for visual perception. Such a study may involve the combination of the objective measurements provided by the disclosed methods, in combination with subjective measurements (e.g., having a patient evaluate simulated acuity against what they perceive from an actual eye chart). This knowledge can lead to improvements in the manufacture of spectacles and contact lenses and improvement in surgical prescription techniques.

Moreover, according to the disclosed methods, it is possible for doctors to provide correction techniques by allowing them to show a prospective patient the potential improvement in their sight.

While preferred embodiments are disclosed herein, many variations are possible which remain within the concept and scope of the invention. Such variations would become clear to one of ordinary skill in the art after inspection of the specification, drawings and claims herein. The invention therefore is not to be restricted except within the spirit and scope of the appended claims.

What is claimed is:

1. A method for computing the visual performance of a human or animal subject based on objective measurements of visual refraction including higher order aberrations, comprising the steps of:

measuring wavefront aberrations of a subject ocular pupil;

computing a point-spread-function from the measured pupil aberration;

providing a test image; and

convolving the test image with the point-spread-function.

2. The method of claim **1** wherein the wavefront aberrations are measured with an objective aberrometer.

3. The method of claim **1** wherein the wavefront aberrations are measured with one selected from a group consisting of a Shack-Hartmann wavefront sensor system, a Tscherning aberrometer, a scanning resolved refractometer, and a Moire deflectometer.

4. The method of claim **1** where the wavefront aberrations are measured objectively by projecting a beam of light onto a retina and analyzing resulting return images.

5. The method of claim **1**, further comprising producing a simulated image from a convolution result of convolving the test image with the point-spread-function.

6. The method of claim **1** wherein the test image is a Snellen acuity chart, and further comprising producing a simulated subject view of the Snellen acuity chart from a convolution result of convolving the Snellen acuity chart with the point-spread-function.

7. The method of claim **1** wherein convolving the test image with the point-spread-function comprises the steps of:

performing an inverse Fourier transform of a modulus squared of the point-spread-function to compute an optical transfer function;

computing a Fourier transform of the test image; and

computing an inverse Fourier transform of a product of the optical transfer function and the test image Fourier transform.

8. The method of claim **7**, wherein the Fourier transform and inverse Fourier transforms are computed with Fast Fourier Transforms.

9. A method for computing a point-spread-function of a human or animal ocular system from objective aberrometry measurements, comprising the steps of:

measuring a pupil aberration function with an objective aberrometer; arid

computing the point-spread-function as a modulus squared of a Fourier transform of the measured pupil aberration function.

10. A method for determining a visual acuity of an ocular optical system, comprising:

measuring a pupil aberration function with an objective aberrometer;

computing a point-spread-function as a modulus squared of a Fourier transform of the measured pupil aberration function; and

analyzing a spatial extent of the point-spread-function.

11. A method for determining Snellen acuity from evaluation of a double object when convolved with a point-spread-function, comprising the steps of:

measuring a subject pupil aberration function with an objective aberrometer;

computing a point-spread-function from the modified pupil aberration function;

computing an Optical Transfer Function (OTF) from the computed point-spread-function;

providing an input image which consists of appropriate targets coded so that known image features can be correlated to a visual acuity number; and

convolving the input image with the point-spread-function by multiplying a Fourier transform of the input image by the OTF and then performing an inverse Fourier transform.

12. The method of claim **11** where the double object is a series of bars with different orientations.

13. A method for computing an image, comprising the steps of:

measuring wavefront aberrations of a subject ocular pupil;

computing a point-spread-function from the measured pupil aberration;

providing a test image;

convolving the test image with the point-spread-function; and

producing a simulated image from a convolution result of convolving the test image with the point-spread-function,

wherein at least one specific term of the point-spread-function is adjusted prior to the convolving step to simulate an effect of a correcting means.

14. The method of claim **13**, wherein adjusting the specific term comprises subtracting the specific term from the point-spread-function.

15. A method for computing an effect of corrective means on a subject's visual acuity, comprising the steps of:

measuring a subject pupil aberration function with an objective aberrometer;

adjusting terms in the measured subject pupil aberration function that correspond to specific corrective means, producing a modified pupil aberration function;

computing a point-spread-function from the modified pupil aberration function;

computing an optical transfer function (OTF) of the computed point-spread-function;

multiplying a Fourier transform of a test image by the OTF to produce a Fourier result; and

performing an inverse Fourier transform on the Fourier result.

16. The method of claim **15** wherein the corrective means is spectacle lenses.

17. The method of claim **15** wherein the corrective means is contact lenses.

18. The method of claim **15** wherein the corrective means is laser refractive surgery.

19. The method of claim **15** wherein the corrective means is Laser Thermal Keratotomy.

20. The method of claim **15**, wherein the corrective means includes one selected from a group consisting of Interocular lenses, femto-second laser correction, and corneal implants.

21. A method of determining a best correction for a given subject, comprising the steps of:

measuring a subject pupil aberration function with an objective aberrometer;

subtracting terms from the pupil aberration function that correspond to specific corrective means, producing a modified pupil aberration function;

computing a point-spread-function from the modified pupil aberration function;

computing an optical transfer function (OTF) of the computed point-spread-function;

multiplying a Fourier transform of a test image by the OTF to produce a Fourier result;

performing an inverse Fourier transform on the Fourier result; and

adjusting the terms that are subtracted to optimize a resultant image.

* * * * *

US006606125B1

(12) **United States Patent**
Schulz et al.

(10) **Patent No.: US 6,606,125 B1**
(45) **Date of Patent: Aug. 12, 2003**

(54) **SHUTTER, IN PARTICULAR FOR AN OBJECTIVE, AND A CCD-CAMERA**

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(73) Assignee: **Henke-Sass, Wolf GmbH**, Tuttlingen (DE)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

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(22) Filed: **Jun. 10, 1999**

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(52) **U.S. Cl.** **348/362**; 348/341
(58) **Field of Search** 348/222.1, 241, 348/250, 362, 363, 76; 382/276, 293, 294, 300; 396/507, 505

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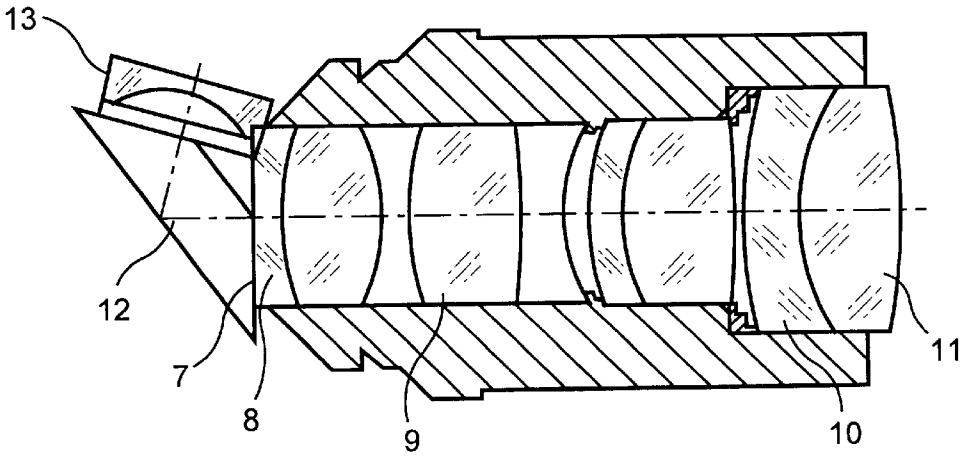
(57) **ABSTRACT**

A shutter for use as an objective for improving the depth of focus in a camera is disclosed. The shutter has, in a central area, a radially uniform transmission function averaged over the circumferential angle. The radial transmission function first drops off toward zero in a radial transition area which is a continuation of the central area and which has a quantity n of cutouts which extend toward the radial outside and are spaced apart from one another at equal angles 360°/n in the circumferential direction. The quantity n of cutouts has the value 5, 6 or 7.

22 Claims, 2 Drawing Sheets



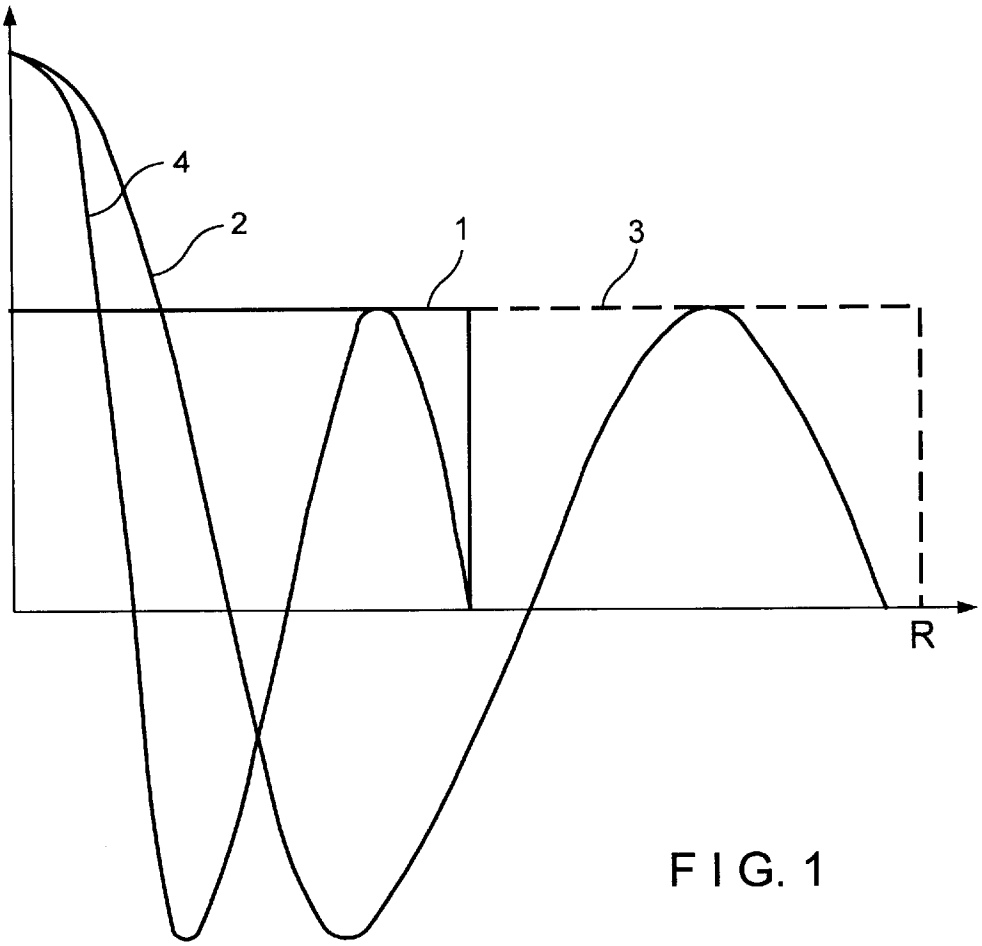


FIG. 1

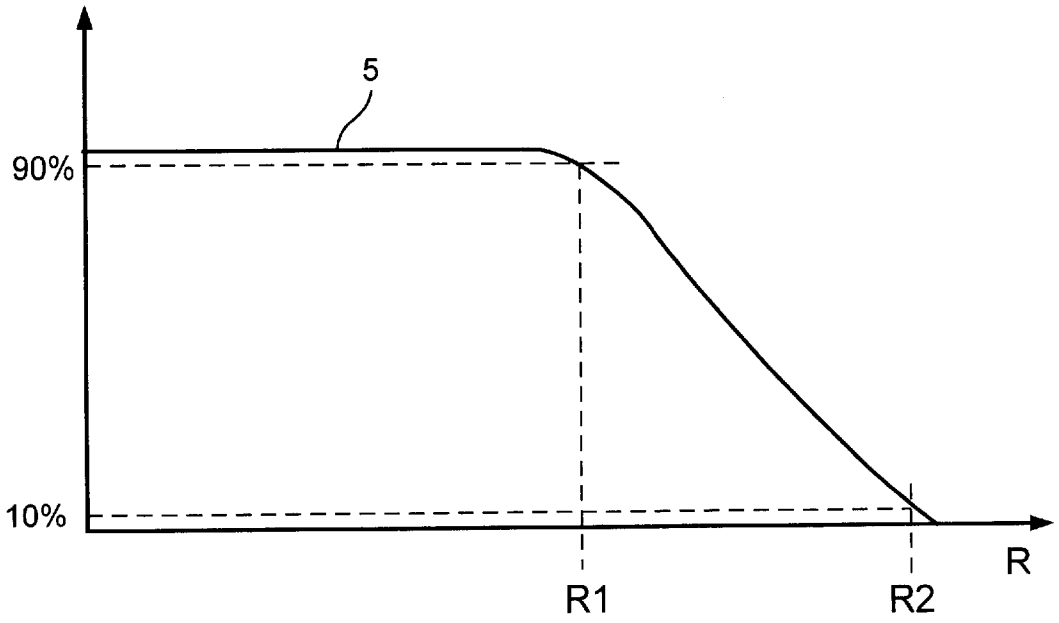


FIG. 2

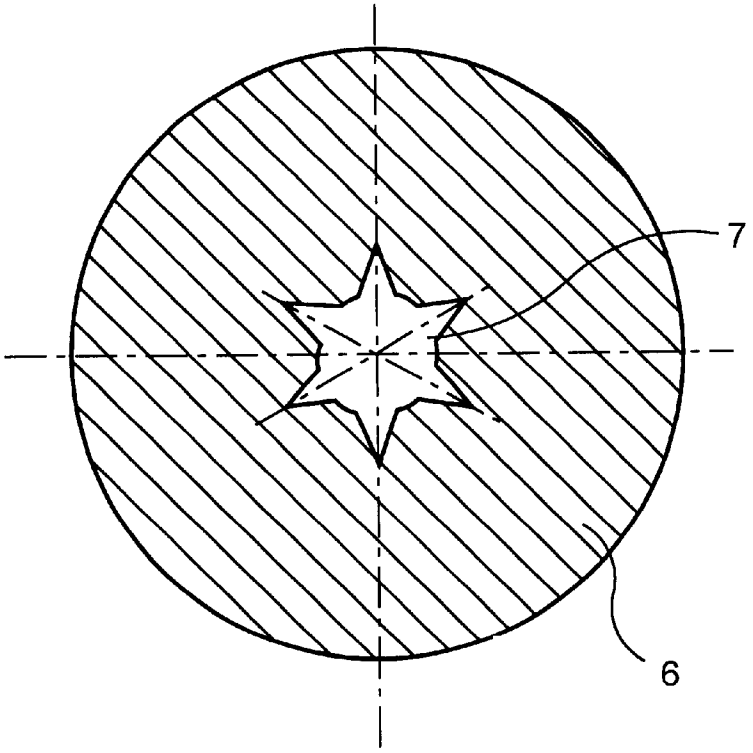


FIG. 3

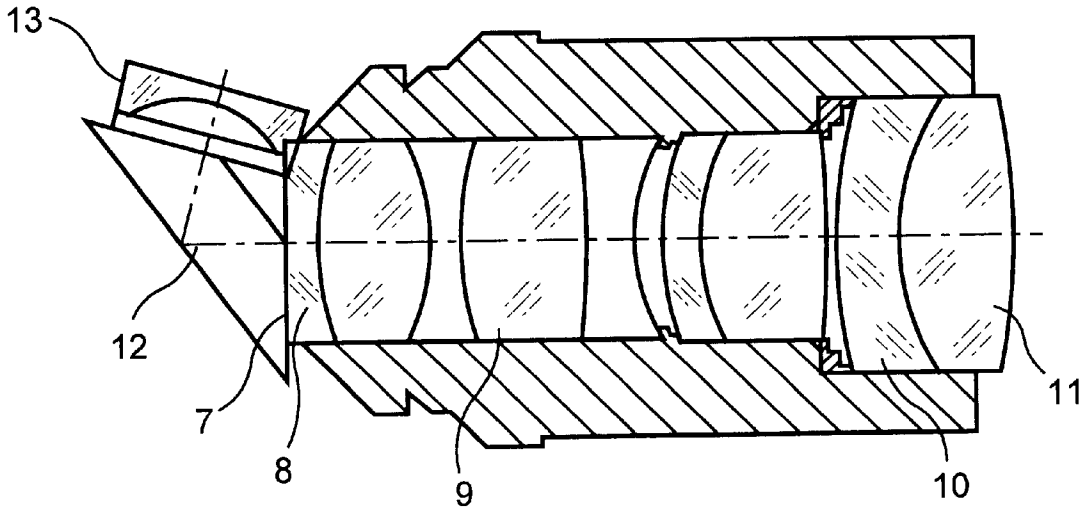


FIG. 4

SHUTTER, IN PARTICULAR FOR AN OBJECTIVE, AND A CCD-CAMERA

BACKGROUND OF THE INVENTION

a) Field of the Invention

The invention is directed to a shutter, in particular for an objective, for improving the depth of focus in a camera, wherein the shutter has, in a central area, a radially uniform transmission function averaged over the circumferential angle. The invention is further directed to a CCD-camera, especially for endoscopes, in which the shutter can advantageously be used together with the objective.

b) Description of the Related Art

Objectives are known from photographic cameras, for example. In order to limit the light intensity in the exposure of a photographic film, a shutter is normally provided in objectives of this type. While the shutter is usually adjustable in this application and, for that reason, does not appear completely round, this shutter still essentially constitutes a round hole optically, that is, it has a radially independent transmission function in the area of a hole.

However, this shutter has additional functions. First, by limiting the light to rays in the vicinity of the optical axis, the imaging characteristics of the objective are improved by stopping out the outer lens areas. On the other hand, an increased depth of focus is achieved as the shutter decreases in size.

However, the design of this shutter can be problematic particularly in small cameras, for example, CCD-cameras in endoscopes which often require small shutters because of miniaturized construction. A shutter which is too small also has worsened resolving capability for image presentation because, in view of the wavy nature of the light at the edge of the shutter, there is always a noticeable diffraction which limits the possible image resolution and predominates when the shutter is reduced in size below a certain lower limit.

Particularly in the case of CCD-cameras in which the individual elements for image presentation are usually in the order of magnitude of micrometers and with which diffraction effects can also be detected in the micrometer range, a clearly visible diffraction limitation occurs already in shutters in the order of magnitude of millimeters. Naturally, the shutters could be made larger; but there would be a loss in the depth of focus, which is completely unacceptable in the case of endoscopes when the image recording is carried out by means of a CCD-camera.

OBJECT AND SUMMARY OF THE INVENTION

It is the primary object of the invention to improve known shutters, especially in connection with objectives, so that they are suitable particularly for CCD-cameras and so that the depth of focus as well as the resolution for image presentation can be increased by means of them.

This object is met in a shutter of the type described above in that the transmission function determining the shutter first drops off toward zero in a radial transition area which is a continuation of the central area mentioned above and which has a quantity n of cutouts which extend toward the radial outside and are spaced apart from one another at equal angles 360°/n in the circumferential direction, and the quantity n of cutouts has the value 5, 6 or 7. It is possible to use a shutter of this kind, according to the invention, in any type of optical beam path, for example, in the beam path of a laser, etc., also without an objective. However, the preferred use of the shutter in connection with an objective is referred to hereinafter.

First of all, it is surprising in terms of physics that this object can be met at all, since the shutter diameter was previously regarded as an insurmountable barrier to improvement of resolution. Heretofore, there has been no suggestion whatsoever for straying from circular shutters with a radial rectangular transmission function, since these were believed to have the best depth of focus and the loss of resolution was always taken for granted with the smaller diameter of the shutter because all of the familiar physics textbooks attributed the maximum attainable resolving capability exclusively to the very small lens diameter or shutter diameter.

Shutters of the type mentioned above always have a sharp edge, so that the diffraction pattern limiting the resolution can be represented mathematically essentially by a zero-order Bessel function. In contrast to this, however, the diffraction pattern of the shutter, according to the invention, for the objective is still a sum of different Bessel functions as a result of the transition area provided according to the invention. Through the selection of the shape of the shutter and/or the configuration of the transmission function, for the purpose of displaying the diffraction pattern, contributions of higher Bessel functions can be added which, because of a different phase relationship, can narrow the broad maximum of the zero-order Bessel function in the neighborhood of small radii. Particularly also due to the area which is provided according to the invention for the diffraction and which is widened by the transition area, the zero-order Bessel function contribution dominating the resolution is also scaled to smaller radii, so that, as a result, the diffraction pattern limiting the resolution is even substantially sharper in the neighborhood of zero. However, because of the higher light intensity in the central area, the depth of focus is essentially entirely determined thereby. Accordingly, with an improved depth of focus, an improved resolution is also possible in particular.

Surprisingly, it has been shown that a camera which is outfitted with a shutter of this type for the objective of the camera is also substantially more sensitive to light. In fact, this could be expected because the central area is somewhat enlarged by the transition area with respect to the transmissivity of the shutter. But at the same time it would have to have been expected that the depth of focus would decrease. However, with a suitable design of the shutter according to the invention, it was observed that the depth of focus did not decrease in spite of increased-light sensitivity.

Due to the cutouts which extend on the radial outside and are spaced at equal angles 360°/n in the circumferential direction and because of the resulting symmetry, the Bessel functions which additionally contribute to the diffraction and whose solution, as is well known, runs in periodicity with the circumferential angle are selected. Accordingly, this further development forces the occurrence of higher-order Bessel functions than the zero order, especially of an order of the whole number n of 5, 6 or 7, which also enables the selection of a suitable phase position of these contributions based on a suitable shape for a particularly favorable increase in the resolving capability.

Surprisingly, it has proven particularly advantageous when the number n has the value 5, 6 or 7. Since these findings were made through experimentation, a plausible explanation was even found. These Bessel functions have a maximum in the neighborhood of the drop-off of the zero-order Bessel function. When it is made possible, as a result of appropriate shaping of the shutter, to generate these contributions in reverse phase position to the zero-order Bessel function, the total drop-off of the diffraction patterns

in the area of the diffraction maximum is substantially steeper and the possible resolution is thus improved in a substantially more effective manner. A shape of this kind is shown later in an embodiment example.

The desired transmission function of the shutter could also be achieved through arrangements of holes in the shutter material in the radial transition area. However, such holes can cause new diffraction effects, so that the resolution by means of the provided transition area remains far from optimum. Accordingly, based on these considerations, a preferable shutter will have no closed cutouts and, above all, no circular cutouts in the transition area forming a continuation of the central area.

Based on these considerations, the shutter was further optimized. According to an advantageous further development in this respect, it has proven particularly favorable when the shutter is formed with a star-shaped transition area around a circular central area.

In particular, the following further developments of the invention have proven especially favorable for the design of the shutter, according to the invention, for an objective. In a first further development of the invention, it is provided in this connection that the radial transmission function drops off to 90% of the central value at a radius R_1 and to 10% of the central value at a radius R_2, wherein R_2-R_1 is greater than 0.1 R_1.

In another advantageous further development of the invention in this connection, it is provided that the radial transmission function drops off to 90% of the central value at a radius R_1 and to 10% of the central value at a radius R_2, and $(R_2-R_1)<R_1$.

It has been determined in particular that the above-mentioned advantageous results can be achieved in a simple manner when R_2/R_1 is fixed at 0.8 ± 0.1.

Due to the fact that the radial area continuing the central area is set at the order of magnitude of 10% to 100% of the radius of the central area, the contribution of larger proportions to the increased resolution is not too small to be effective on the one hand and, on the other hand, the continuation of the area up to twice the central area also leads to an approximate doubling of the resolving capability, so that a noticeable increase in resolution can be seen without a substantial worsening of the depth of focus. In particular, the indicated value of $R_2/R_1-1=0.8\pm0.1$ has proven particularly suitable for practical applications.

Based on the ideas expressed above which were formed by means of mathematical considerations, such a simple shutter shape would not have been expected. In particular, a shutter of this type can be manufactured in a simple manner. With regard to the further improvement of the shutter according to the invention, this was an additional unexpected result which was particularly advantageous for the use of these shutters.

In another further development of the invention, the shutter is vacuum-deposited on a lens as an opaque layer, especially as a metal layer.

Initially, no special improvement was anticipated with respect to this embodiment form either. However, it has been shown that a substantial increase in resolution can be achieved in this way compared, for example, to an individual shutter which is placed in front of a lens. This is due primarily to the fact that the light passing through the shutter is immediately conducted into the glass of the following lens, so that deviations in the light propagation direction based on Snell's law of refraction, whereby every change in angle is reduced with respect to the surface normal, are compensated. Therefore, diffraction effects due to proximity to a glass surface resulting from said lens can be kept small.

This advantage becomes apparent above all when the surface normal remains constant in the area of the shutter opening or varies only slightly over the shutter area, namely, when this lens is plane or flat. The above-mentioned advantages can be achieved in an extremely simple manner, for example, in a commercially available CCD-camera, when the shutter is vacuum-deposited on the foremost lens of the objective. The fact that common CCD-cameras with a plane first lens surface are commercially available and the possibility of vacuum-depositing the metal layer on these lenses without completely disassembling the camera advantageously simplifies the required modification in which a shutter according to the invention is used on the objective that is already provided for the camera.

Due to the somewhat elongated optics, it is extremely advantageous for a favorable arrangement of the camera, for endoscopy in particular, to record images from areas which lie at an angle to the optical axis of the CCD-camera. For this purpose, it is provided that a prism and/or an achromat and/or a negative individual lens are/is arranged in front of the shutter located on the front lens. The prism allows a recording of images at an angle to the optical axis of the objective. The achromat is provided, for example, in order to correct for chromatic aberrations caused by the prism.

As stated above, cameras of the type mentioned above can be used in a particularly advantageous manner for endoscopy and the abovementioned embodiment forms for the shutters which will be better understood from the following embodiment forms were optimized especially for the field of endoscopy. However, it has also been shown that the objectives outfitted with a shutter of this kind are also particularly suitable for other CCD-cameras and other objectives which can be used for imaging.

The invention is described more fully in the following with reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings:

FIG. **1** illustrates the resolving capability as a function of the shutter diameter;

FIG. **2** illustrates the transmission function of a shutter according to the invention which can be used particularly advantageously in an objective;

FIG. **3** shows a particularly advantageous construction of a shutter; and

FIG. **4** shows an objective unit for a CCD-camera which is especially suitable for endoscopy and which is outfitted with the shutter according to the invention shown in FIG. **3**.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The known curve of a diffraction pattern in a shutter is shown schematically in FIG. **1** for purposes of illustration. In particular, FIG. **1** shows curves **1** and **3** of transmissions averaged about the circumference as a function of the radius R, the distance from the center of the shutter.

In a round shutter, the transmission function is essentially a box profile as is shown schematically, for example, in FIG. **1** by reference number **1**. Further, curve **2** shows schematically the amplitude of the associated diffraction pattern at a shutter as follows from the dimensions of the shutter and from the wavelength of the light passing through the objective. When the shutter diameter is increased as is shown in

dashed lines by curve **3**, the expected diffraction pattern is scaled based on the known law of diffraction with radius R and shifts within a narrow area as is shown schematically by curve **4**.

This means that the resolving capability improves as the size of the shutter in an objective increases. On the other hand, the depth of focus which depends in practice on the angular area comprehended by the objective decreases.

In comparison with the conventional circular shutter with the rectangular transmission function shown by curve **1**, a gentler transition from maximum to minimum transmission is suggested in this case as is shown by way of example by reference number **5** in FIG. **2**.

This function initially shows a flat area and then a gradual drop-off between R_1 and R_2 corresponding to 10% and 90% of the value in the central area.

Because of this smooth transition, even closer contributions in the diffraction pattern relative to the diffraction curve **2** expected in the box profile are added to the diffraction pattern of the shutter as can be seen, for example, in curve **4** in FIG. **1**, so that the resolution is already improved in this way.

Radii R_1 and R_2 which relate to the drop-off of 90% and 10% of the transmission curve are shown in FIG. **2** to define the desired transmission behavior. It has proven particularly advantageous for a shutter which limits the central beam path of an objective when $R_2-R_1>0.1\ R_1$, $R_2-R_1<R_1$ and $R_2/R_1-1=0.8\pm0.1$.

The transmission curve shown in FIG. **2** can be achieved, for example, with a round shutter which is formed by means of a darkened quartz plate which transmits in the central area and whose degree of darkness continuously increases toward the outside. However, it has been shown that it is also possible to realize this transmission function according to the invention by means of a nonuniform curve of the transmission function in the circumferential direction because the components contributing to the curve **2** which originate as a result of the transition area are essentially determined by a higher-order Bessel function which approaches zero in the neighborhood of R=0, but has a maximum which is offset from the zero point. With an appropriate phase position given by the shape of the shutter, this results in a path interference of a majority of the intensity in the wide flank of then diffraction curve and the resolution is further improved.

Accordingly, it is particularly advantageous for the resulting deviation from a uniform transmission in the circumferential direction when the shutter is constructed by means of an opaque material in which cutouts are provided in the transition area in the circumferential direction so as to be spaced apart at identical angles 360°/n. The chief effect brought about by this is that the lowest-order Bessel function which contributes to the increase in resolution through changed phases is of the nth kind. Particularly favorable increases in resolution have been shown in particular when n is set at a value 5, 6 or 7. In an embodiment form, the quantity n can be an integral multiple of the value 5, 6 or 7.

FIG. **3** shows a shutter **6** of the type mentioned above which is constructed as a star-shaped cutout **7** in an opaque material. This star-shaped shutter opening **7** has a six-sided symmetry, that is, it is constructed such that n=6.

This shutter was used in an objective according to FIG. **4**. The shutter structure **6** and **7** shown in FIG. **2** was vacuum-deposited on a plane surface of a front lens **8**. Aluminum has proven to be a particularly suitable material for this purpose as a metal layer.

The sectional view in FIG. **4** shows the front lens **8** in the objective followed by an expansion lens **9** which is followed in turn in the light propagation direction by a plurality of field lenses **10**, **11**. This type of objective is especially suited to CCD-cameras.

In order to be able to acquire CCD images at an angle to the optical axis, a prism **12** was used in the embodiment example, wherein an achromat **13** is provided in front of the prism to compensate for chromatic aberrations caused by the prism **12** in that its dispersion behavior is selected in such a way that it compensates for the dispersion given by the prism **12**. In this way, loss of resolution due to different wavelengths is limited to a great extent, so that an especially high resolution results on the whole with the shutter shown in FIG. **2** when this objective is used in a CCD-camera, wherein its diffraction propagation was less than the CCD-elements used for image recording. It is also possible to use a negative individual lens instead of a prism.

In the construction shown in FIG. **4**, the shutter **7** also limits to near-axis beams, so that the depth of focus in the objective according to FIG. **4** is also increased relative to shutters with a rectangular radial transmission function in which the shutter must always have a certain minimum size in order to prevent loss of resolution.

However, not only CCD-cameras can be outfitted with these objectives with the shutter shown in FIG. **3**, or also in general with a transmission characteristic such as that shown in FIG. **2**, but also photographic objectives, e.g., for microfilming, in which a high resolution is also wanted.

While the foregoing description and drawings represent the present invention, it will be obvious to those skilled in the art that various changes may be made therein without departing from the true spirit and scope of the present invention.

What is claimed is:

1. A shutter, for use on an objective, for improving the depth of focus in a camera, said shutter comprising:

in a central area, means for providing a radially uniform transmission function averaged over the circumferential angle, said radial transmission function first dropping off toward zero in a radial transition area which is a continuation of said central area and which has a quantity n of cutouts which extend toward the radial outside and are spaced apart from one another at equal angles 360°/n in the circumferential direction, and the quantity n of cutouts has the value 5, 6 or 7, and

wherein the radial transmission function drops off to 90% of the central value at a radius R_1 and to 10% of the central value at a radius R_2, wherein $(R_2-R_1)>0.1\ R_1$.

2. The shutter according to claim **1**, wherein the radial transmission function drops off to 90% of the central value at a radius R_1 and to 10% of the central value at a radius R_2, and $(R_2-R_1)<R_1$.

3. The shutter according to claim **1**, wherein $R_2/R_1-1=0.8\pm0.1$.

4. The shutter according to claim **1**, wherein the quantity n is a whole-number multiple of the value 5, 6 or 7.

5. The shutter according to claim **1**, wherein the shutter has a star-shaped transition area outside of a circular central area.

6. The shutter according to claim **1**, wherein the shutter is vacuum-deposited on a lens as an opaque layer.

7. The shutter of claim **6**, wherein the opaque layer is a metal.

8. The shutter according to claim **6**, wherein the shutter is vacuum-deposited on a front plane surface of the lens.

9. The shutter according to claim 6, wherein the shutter is arranged on the foremost lens of the objective.

10. The shutter according to claim 1, wherein the shutter is arranged behind a prism or an achromat or a negative individual lens.

11. A CCD-camera for an endoscope, having a shutter for use as an objective, for improving the depth of focus in a camera, said shutter comprising:

in a central area, means for providing a radially uniform transmission function averaged over the circumferential angle, said radial transmission function first dropping off toward zero in a radial transition area which is a continuation of said central area and which has a quantity n of cutouts which extend toward the radial outside and are spaced apart from one another at equal angles 360°/n in the circumferential direction, and the quantity n of cutouts has the value 5, 6 or 7, and

wherein the shutter is vacuum-deposited on a lens as an opaque layer.

12. A shutter, for use on an objective, for improving the depth of focus in a camera, said shutter comprising:

in a central area, means for providing a radially uniform transmission function averaged over the circumferential angle, said radial transmission function first dropping off toward zero in a radial transition area which is a continuation of said central area and which has a quantity n of cutouts which extend toward the radial outside and are spaced apart from one another at equal angles 360°/n in the circumferential direction, and the quantity n of cutouts has the value 5, 6 or 7, and

wherein the radial transmission function drops off to 90% of the central value at a radius R_1 and to 10% of the central value at a radius R_2, wherein $(R_2-R_1)<R_1$.

13. The shutter according to claim 12, wherein the radial transmission function drops off to 90% of the central value at a radius R_1 and to 10% of the central value at a radius R_2, wherein $(R_2-R_1)>0.1\ R_1$, and

wherein $R_2/R_1-1=0.8\pm0.1$.

14. The shutter according to claim 12, wherein the quantity n is a whole-number multiple of the value 5, 6 or 7.

15. The shutter according to claim 12, wherein the shutter has a star-shaped transition area outside of a circular central area.

16. The shutter according to claim 12, wherein the shutter is arranged behind a prism or an achromat or a negative individual lens.

17. A shutter, for use on an objective, for improving the depth of focus in a camera, said shutter comprising:

in a central area, means for providing a radially uniform transmission function averaged over the circumferential angle, said radial transmission function first dropping off toward zero in a radial transition area which is a continuation of said central area and which has a quantity n of cutouts which extend toward the radial outside and are spaced apart from one another at equal angles 360°/n in the circumferential direction, and the quantity n of cutouts has the value 5, 6 or 7, and

wherein the shutter is vacuum-deposited on a lens as an opaque layer.

18. The shutter of claim 17, wherein the opaque layer is a metal.

19. The shutter according to claim 17, wherein the shutter is a vacuum-deposited on a front plane surface of the lens.

20. The shutter according to claim 17, wherein the shutter is arranged on the foremost lens of the objective.

21. A CCD-camera for an endoscope, having a shutter for use as an objective, for improving the depth of focus in a camera, said shutter comprising:

in a central area, means for providing a radially uniform transmission function averaged over the circumferential angle, said radial transmission function first dropping off toward zero in a radial transition area which is a continuation of said central area and which has a quantity n of cutouts which extend toward the radial outside and are spaced apart from one another at equal angles 360°/n in the circumferential direction, and the quantity n of cutouts has the value 5, 6 or 7, and

wherein the radial transmission function drops off to 90% of the central value at a radius R_1 and to 10% of the central value at a radius R_2, wherein $(R_2-R_1)>0.1\ R_1$.

22. A CCD-camera for an endoscope, having a shutter for use as an objective, for improving the depth of focus in a camera, said shutter comprising:

in a central area, means for providing a radially uniform transmission function averaged over the circumferential angle, said radial transmission function first dropping off toward zero in a radial transition area which is a continuation of said central area and which has a quantity n of cutouts which extend toward the radial outside and are spaced apart from one another at equal angles 360°/n in the circumferential direction, and the quantity n of cutouts has the value 5, 6 or 7, and

wherein the radial transmission function drops off to 90% of the central value at a radius R_1 and to 10% of the central value at a radius R_2, wherein $(R_2-R_1)<R_1$.

* * * * *

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(12) **United States Patent**
Dinger

(10) **Patent No.: US 6,600,552 B2**
(45) **Date of Patent: Jul. 29, 2003**

(54) **MICROLITHOGRAPHY REDUCTION OBJECTIVE AND PROJECTION EXPOSURE APPARATUS**

(75) Inventor: **Udo Dinger**, Oberkochen (DE)

(73) Assignee: **Carl-Zeiss SMT AG**, Oberkochen (DE)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **10/004,674**

(22) Filed: **Dec. 3, 2001**

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(30) **Foreign Application Priority Data**

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Oct. 7, 1999 (DE) 199 48 240

(51) **Int. Cl.**[7] **G03B 27/54**; G03B 27/72; G02B 5/10

(52) **U.S. Cl.** **355/67**; 355/71; 359/859

(58) **Field of Search** 355/52–53, 55, 355/67–71, 77; 359/365, 631, 686, 859; 250/492.2

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Primary Examiner—Henry Hung Nguyen
(74) *Attorney, Agent, or Firm*—Marshall, Gerstein & Borun

(57) **ABSTRACT**

A microlithography reduction objective formed from six mirrors arranged in a light path between an object plane and an image plane is provided. The microlithography reduction objective is characterized by having an image-side numerical aperture NA≧0.15. In some embodiments, the mirror closest to the image plane, i.e., the fifth mirror is arranged such that an image-side optical free working distance is greater than or equal to a used diameter of a physical mirror surface of the fifth mirror, a physical mirror surface being the area of a mirror where light rays from the object impinge. The fifth mirror may be arranged such that an image-side optical free working distance is greater than or equal to the sum of one-third the used diameter of the physical mirror surface on the fifth mirror and a length between 20 mm and 30 mm. The fifth mirror may be arranged such that the image-side optical free working distance is at least 50 mm, as well. The image-side free working distance is the physical distance between the vertex of the surface of the fifth mirror and the image plane. Other embodiments are described.

14 Claims, 6 Drawing Sheets

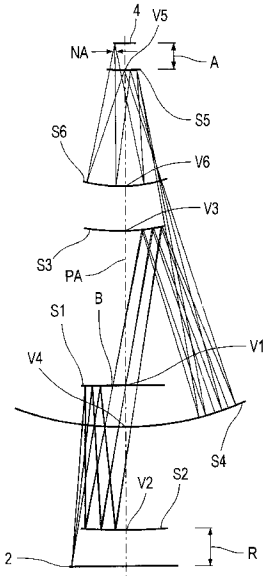
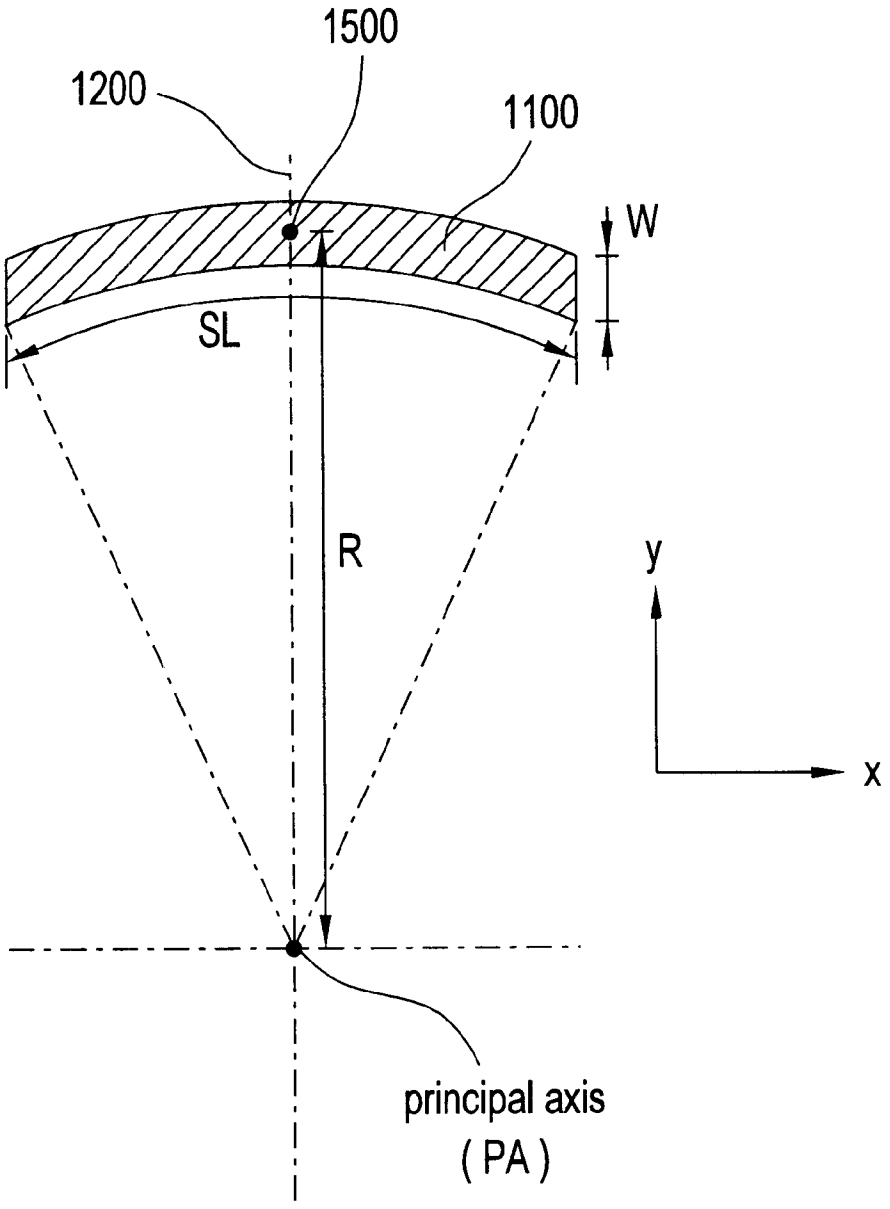


Fig.1



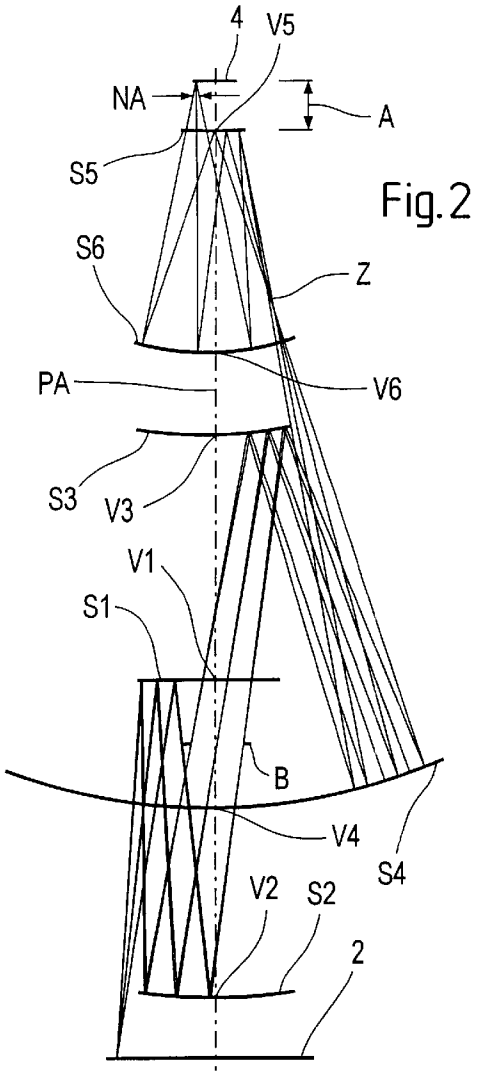


Fig.2

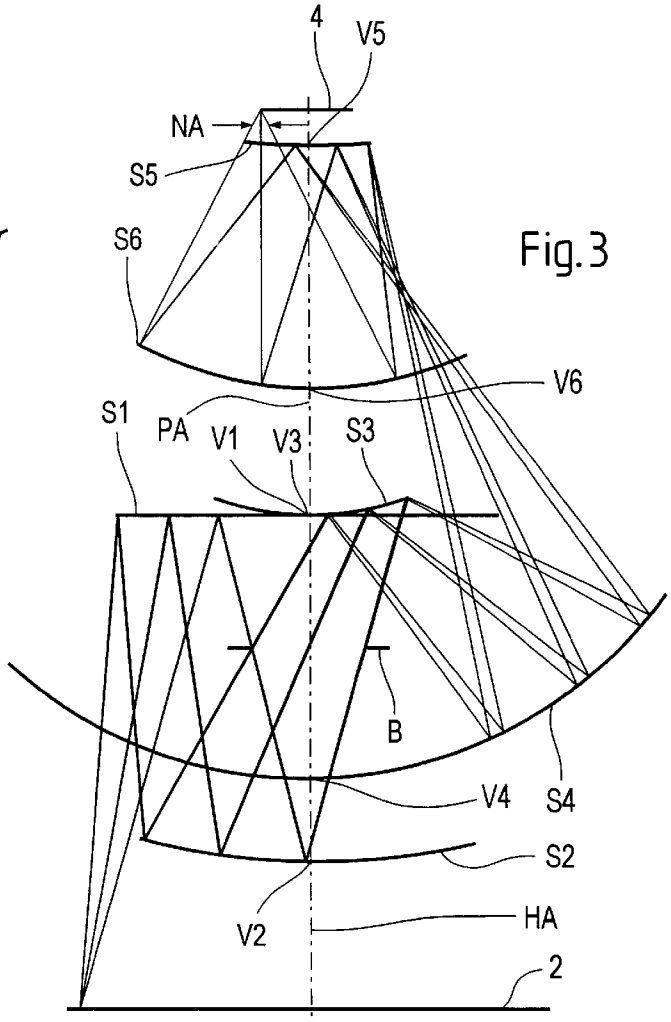
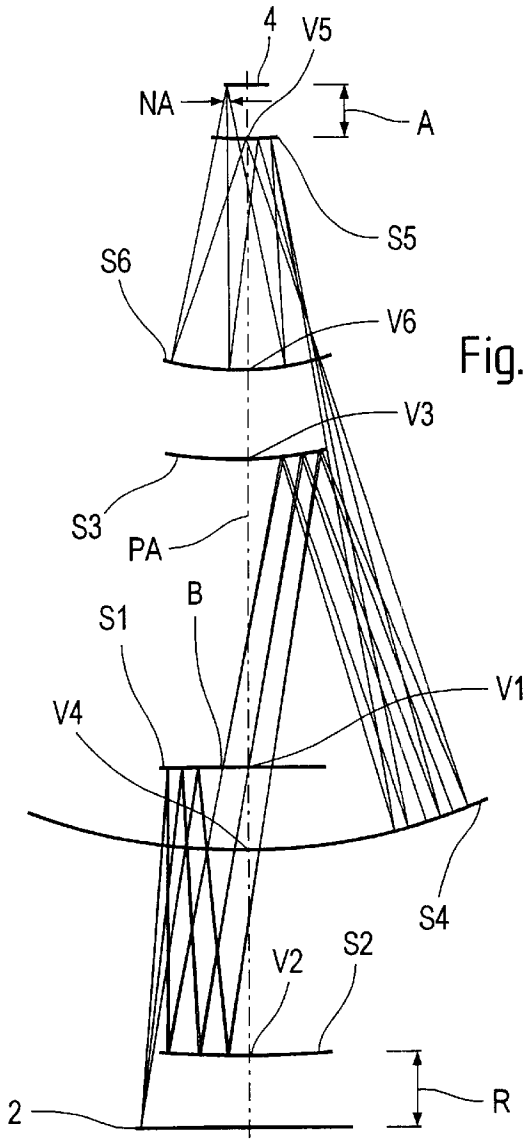


Fig.3

PRIOR ART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V5
NA
A
S5
S6
V6
V3
S3
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B
S1
V1
V4
S4
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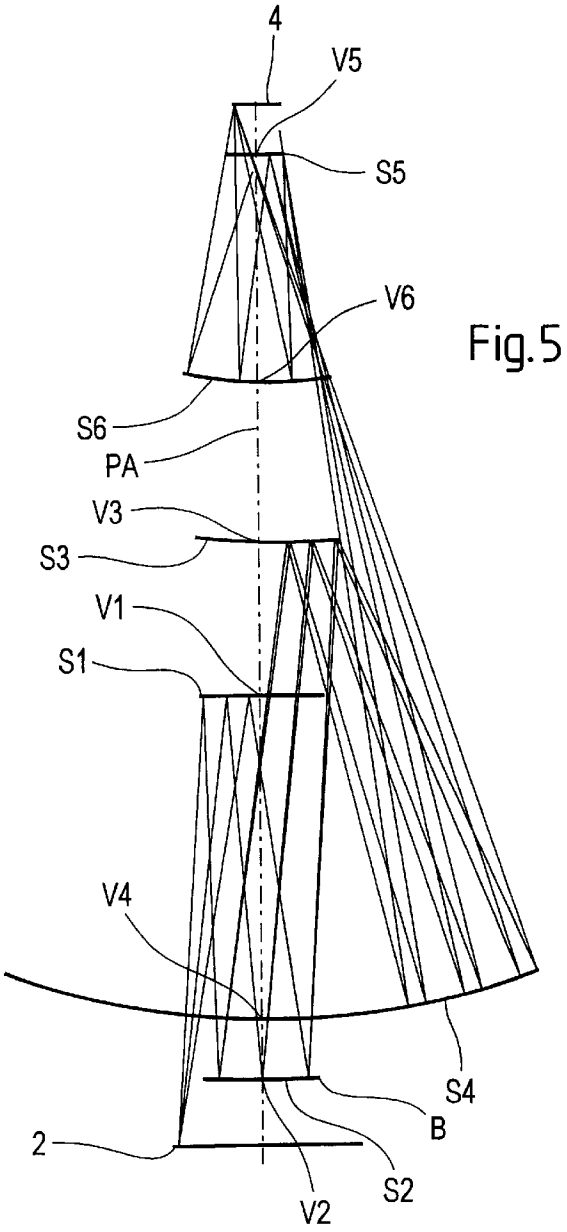
2
R

Fig. 4


4
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S4
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Fig. 5

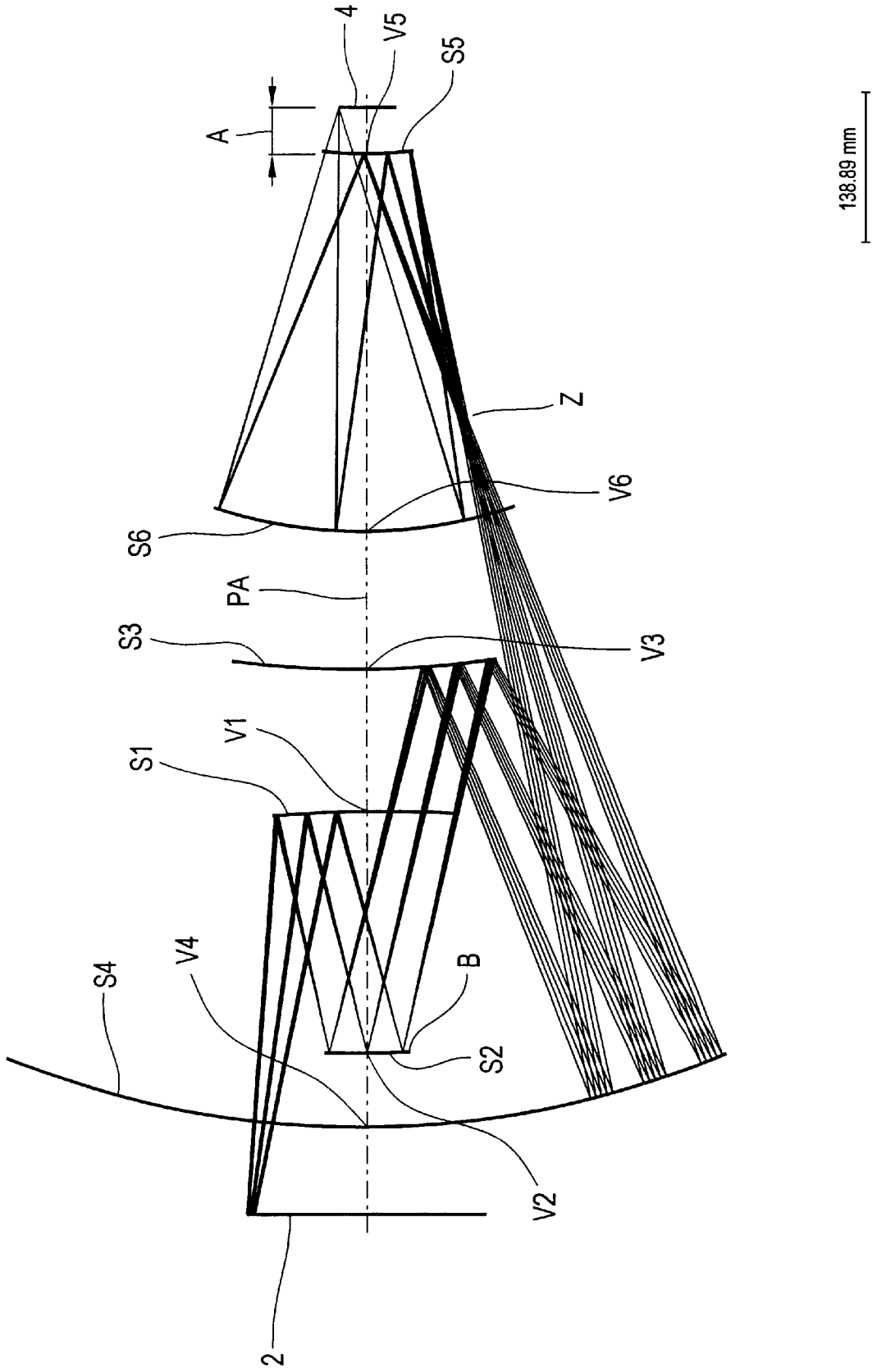


Fig.6

Fig. 7

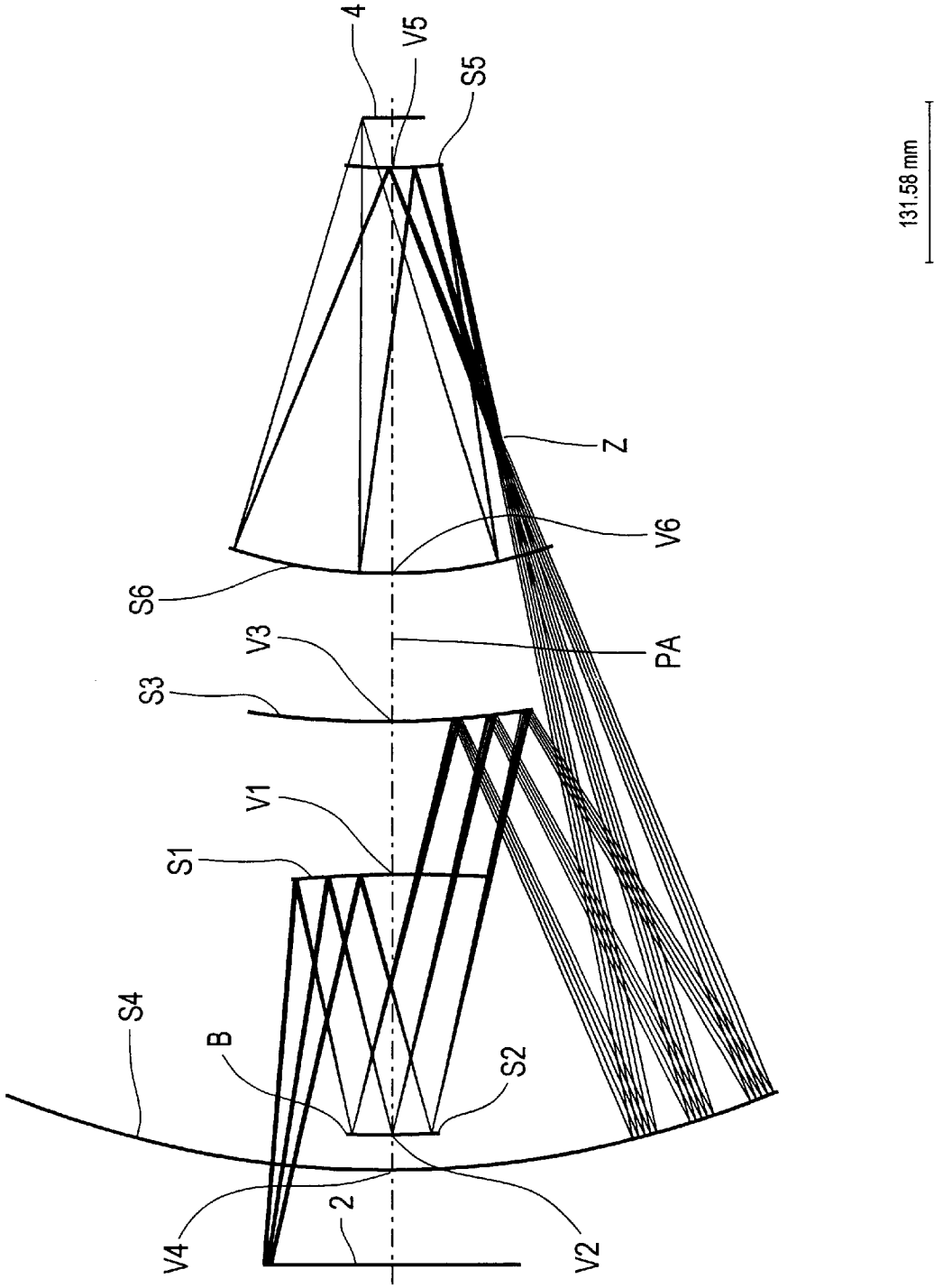


Fig. 8a

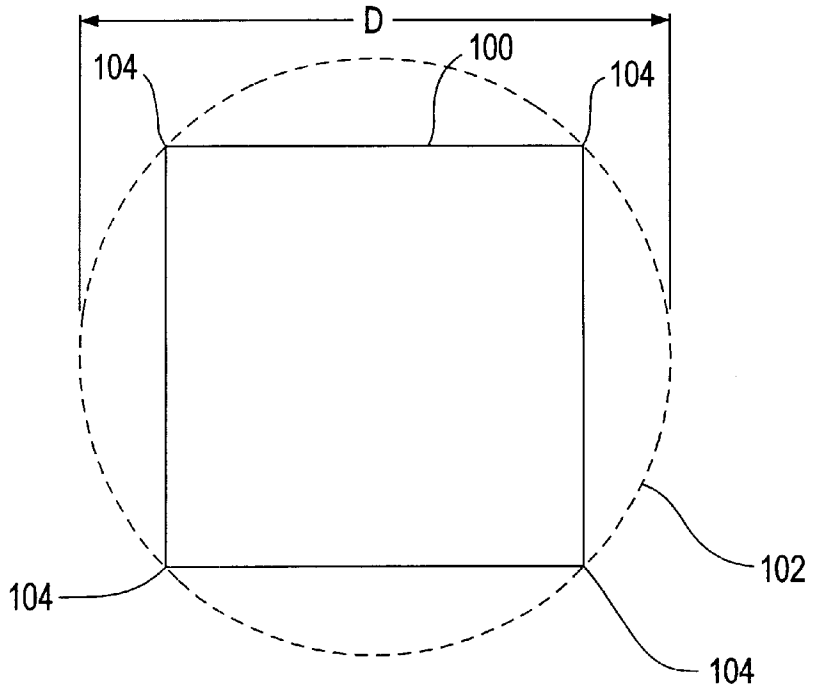
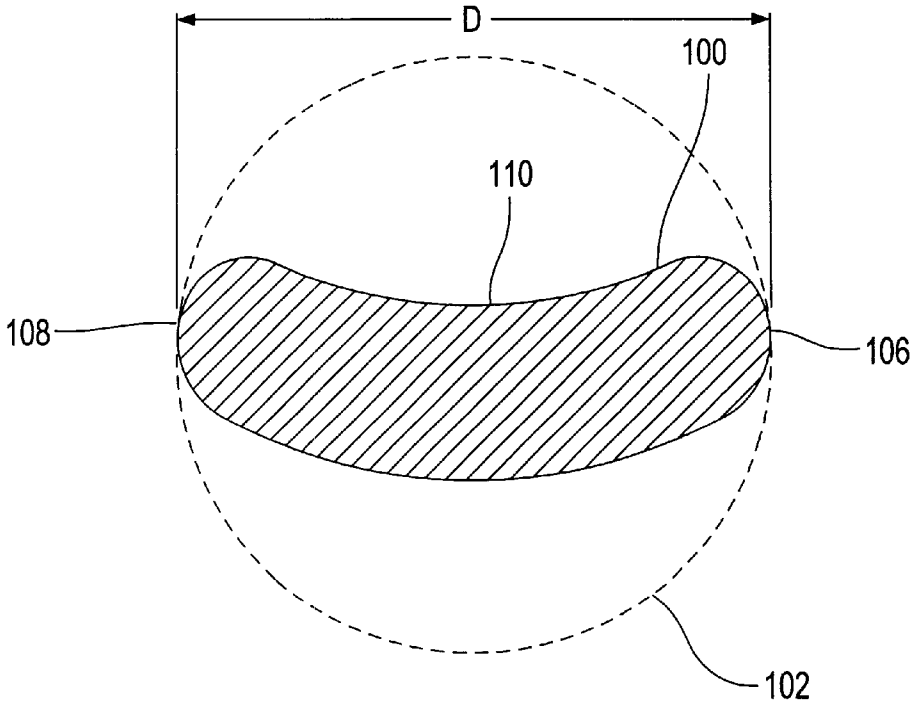


Fig. 8b



MICROLITHOGRAPHY REDUCTION OBJECTIVE AND PROJECTION EXPOSURE APPARATUS

This is a Continuation-In-Part of U.S. application Ser. No. 09/503,640, filed Feb. 14, 2000, now U.S. Pat. No. 6,353,470.

FIELD OF THE INVENTION

The invention relates to a microlithography objective, a projection exposure apparatus containing the objective, and a method of manufacturing an integrated circuit using the same.

BACKGROUND OF THE INVENTION

Using a lithography system operating with wavelengths below 193 nm for imaging structures of below 130 nm resolution has been proposed. In fact, such lithography systems have been suggested for the extreme ultraviolet (EUV) range with wavelengths of λ=11 nm or λ=13 nm producing structures of below 100 nm. The resolution of a lithographic system is described by the following equation:

$$RES=k_1\cdot\lambda/NA$$

where k_1 is a specific parameter of the lithographic process, λ is the wavelength of the incident light, and NA is the image-side numerical aperture of the system. For example, if one assumes a numerical aperture of 0.2, then the imaging of 50 nm structures with 13 nm radiation requires a process with k_1=0.77. With k_1=0.64, the imaging of 35 nm structures is possible with 11 nm radiation.

For imaging systems in the EUV region, substantially reflective systems with multilayer coatings are available as optical components. Preferably multilayers of Mo/Be are used as multilayer coating systems for systems operating at λ=11 nm, whereas Mo/Si systems are used for λ=13 mm. Since the reflectivity of the multilayer coatings is approximating 70%, it is desirable to use as few optical components as possible in e.g. an EUV projection microlithography objective to achieve sufficient light intensity. Specifically, to achieve high light intensity and to allow for the correction of imaging errors, systems with six mirrors and a image side numerical aperture (NA)=0.20 have been used.

Six-mirror systems for microlithography have become known from the publications U.S. Pat. No. 5,686,728, EP 779,528 and U.S. Pat. No. 5,815,310. The projection lithography system according to U.S. Pat. No. 5,686,728 has a projection objective with six mirrors, where each of the reflective mirror surfaces has an aspherical form. The mirrors are arranged along a common optical axis in such a way that an obscuration-free light path is achieved. Since the projection objective known from U.S. Pat. No. 5,686,728 is used only for UV light with a wavelength of 100–300 nm, the mirrors of this projection objective have a very high asphericity of approximately ±50 μm as well as very large angles of incidence of approximately 38°. Even after reducing the image side aperture to NA=0.2, an asphericity of 25 μm from peak to peak remains, with a barely reduced angle of incidence. Such asphericities and angles of incidence are not practicable in the EUV region due to the high requirements for surface quality and reflectivity of the mirrors.

Another disadvantage of the objectives disclosed in U.S. Pat. No. 5,686,728, which precludes their use with wavelengths below 100 nm such as the 11 nm and 13 nm wavelengths desirable for EUV microlithography, is the short distance between the wafer and the mirror arranged next to the wafer. In the case of U.S. Pat. No. 5,686,728, due to this short distance between the wafer and the mirror next to the wafer, the mirrors could be made only very thin. Due to the extreme layer stress in the multilayer systems discussed for 11 nm or 13 nm wavelengths, such thin mirrors are very unstable.

A projection objective with six mirrors for use in EUV lithography, particularly also for wavelengths of 13 nm and 11 nm, has become known from EP 779,528. This projection objective also has the disadvantage that at least two of the six mirrors have very high asphericities of 26 and 18.5 μm. However, even in the EP 779,528 arrangement, the optical free working distance between the mirror next to the wafer and the wafer itself is so small that either instabilities occur or the mechanical free working distance is negative.

Thus, it is desirable to provide a projection objective for lithography with short wavelengths, preferably smaller than 100 nm, which does not have the disadvantages of the state of the art described above.

SUMMARY OF THE INVENTION

According to one aspect of the invention, the shortcomings of the prior art are overcome by a projection objective having an object plane and an image plane and a light path for a bundle of light rays from the object plane to the image plane. The six mirrors of the objective are arranged in the light path from the object plane to the image plane. According to the invention the mirror closest to the image plane where e.g. an object to be illuminated such as a wafer is situated is arranged in such a way that an image-side numerical aperture is NA≧0.15. In this application the image-side numerical aperture is understood to be the numerical aperture of the bundle of light rays impinging onto the image plane. Furthermore, the mirror arranged closest to the image plane of the objective is arranged in such a way that the image-side free working distance corresponds at least to the used diameter of the mirror next to the wafer. In a preferred embodiment the image-side free working distance is at least the sum of one-third of the used diameter of the mirror next to the image plane and a length between 20 and 30 mm. In an alternative embodiment the image-side free working distance is at least 50 mm. In a particularly preferred embodiment, the image-side free working distance is 60 mm. In this application the free working distance is defined as the distance of the vertex of the surface of the mirror next to the image plane and the image plane. All surfaces of the six mirrors in this application are rotational-symmetric about a principal axis (PA). The vertex of a surface of a mirror is the intersection point of the surface of a mirror with the principal axis (PA). Each mirror has a mirror surface. The mirror surface is the physical mirror surface upon which the bundle of light rays traveling through the objective from the object plane to the image plane impinge. The physical mirror surface or the used area of a mirror can be an off-axis or an on-axis mirror segment relative to the principal axis (PA).

According to another aspect of the invention, a projection objective that comprises six mirrors is characterized by an image-side numerical aperture, NA, greater than 0.15 and an arc-shaped field width, W, at the wafer in the range 1.0 mm≦W. The peak-to-valley deviation, A, of the aspheres are limited with respect to the best fitting sphere of the physical mirror surface of all mirrors by:

$$A\leqq 19\ \mu m-102\ \mu m\ (0.25-NA)-0.7\ \mu m/mm\ (2\ mm-W).$$

In a preferred embodiment, the peak-to-valley distance A of the aspheres is limited with respect to the best fitting sphere of the off-axis segments of all mirrors by:

$$A\leqq 12\ \mu m-64\ \mu m\ (0.25-NA)-0.3\ \mu m/mm\ (2\ mm-W).$$

According to yet another aspect of the invention, a projection objective that includes six mirrors is characterized by an image-side numerical aperture NA≧0.15 and an image-side width of the arc-shaped field W≧1 mm, and the angles of incidence AOI are limited for all rays of the light bundle impinging a physical mirror surface on all six mirrors **S1**, **S2**, **S3**, **S4**, **S5**, **S6** by:

$$AOI \leqq 23° - 35°(0.25 - NA) - 0.2°/mm(2\ mm - W)$$

wherein the angles of incidence AOI refer to the angle between the incident ray and the normal to the physical mirror surface at the point of incidence. The largest angle of any incident bundle of light rays occurring on any of the mirrors is always given by the angle of a bundle-limiting ray.

Preferably, an embodiment of the invention would encompass all three of the above aspects, e.g., an embodiment in which the free optical working distance would be more than 50 mm at NA=0.20 and the peak-to-valley deviation of the aspheres, as well as the angles of incidence, would lie in the regions defined above.

The asphericities herein refer to the peak-to-valley (PV) deviation, A, of the aspherical surfaces with respect to the best fitting sphere of the physical mirror surface of an specific mirror. The physical mirror surface of a specific mirror is also denoted as the used area of this specific mirror. The aspherical surfaces are approximated in the examples by using a sphere. The sphere has a center on the figure axis vertex of the mirror. The sphere intersects the asphere in the upper and lower endpoint of the used area in the meridian section. The data regarding the angles of incidence always refer to the angle between the incident ray and the normal to the physical mirror surface at the point of incidence. The largest angle of any incident bundle of light rays occurring on any of the physical mirror surfaces is always given by the angle of a bundle-limiting ray. The used diameter or the diameter of the physical mirror surface will be defined here and below as the envelope circle diameter of the physical mirror surface or the used area of a mirror, which is generally not circular.

In a preferred embodiment, the free working distance is 60 mm.

The objective can be used not only in the EUV, but also at other wavelengths, without deviating from the scope of the invention. In any respect, however, to avoid degradation of image quality, especially degradation due to central shading, the mirrors of the projection objectives should be arranged so that the light path of the bundle of light rays traveling from the object plane to the image plane is obscuration-free. Furthermore, to provide easy mounting and adjusting of the system, the physical mirror surfaces have a rotational symmetry to a principal axis (PA). Moreover, to have a compact design with an accessible aperture and to establish an obscuration-free light path of the bundle of light rays traveling from the object plane to the image plane, the projection objective device is designed in such a way that an intermediate image of the object situated in the object plane is formed after the fourth mirror. In such systems, it is possible that the aperture stop is situated in the front, low-aperture objective part, with a pupil plane conjugated to the aperture stop imaged in the focal plane of the last mirror. Such a system ensures telecentricity in the image plane.

In a preferred embodiment of the invention, the aperture stop is freely accessible and arranged in the light path from the object plane to the image plane between the second and third mirror. Good accessibility of the aperture stop is ensured when the ratio of the distance between the first and third mirror to the distance between the first and second mirror lies in the range of:

$$0.5 < S1S3/S1S2 < 2.$$

As defined for the free working distance in general a distance between two mirrors is the distance of the vertices of the surfaces of these mirrors.

Furthermore, in order to prevent vignetting of the light running from the third to the fourth mirror, by the aperture stop arranged between the second and third mirror, the ratio of the distance between the second mirror and aperture stop to the distance between the third mirror and the aperture stop lies in the range:

$$0.5 < S2\ \text{aperture}/(S3\ \text{aperture}) < 2.$$

In such a system, the angles of incidence on the physical mirror surfaces in the front part of the objective are reduced.

An aperture stop which physically lies between the second mirror, **S2**, and the first mirror, **S1**, must be formed at least partially as a narrow ring in order to avoid clipping of light moving from **S1** to **S2**. In such a design, there is a danger that undesirable direct light or light reflected on **S1** and **S2**, will pass outside the aperture ring and reach the image plane and thus the wafer. However, if the aperture stop is placed in the light path between the second and third mirror and physically close to the first mirror (which can be easily achieved mechanically), an efficient masking of this undesired light is possible. The aperture stop can be designed both as an opening in the first mirror or an opening which is arranged behind the first mirror.

In another embodiment of the invention, the aperture stop is arranged on or near the second mirror. Arrangement of the aperture on a mirror has the advantage that it is easier to manufacture.

In order to ensure an obscuration-free ray path with simultaneously low angles of incidence, the ratio of the distance between the first and third mirrors **(S1S3)** to the distance between the first and second mirrors **(S1S2)** lies in the range:

$$0.3 \leqq S1S3/S1S2 \leqq 2.0,$$

while the ratio of the distance between the second and third mirrors **(S2S3)** to the distance between the third and fourth mirrors **(S3S4)** lies in the range:

$$0.7 \leqq S2S3/S3S4 \leqq 1.4.$$

In order to be able to make the necessary corrections of imaging errors in the six-mirror systems, in a preferred embodiment, all six mirrors are designed to be aspherical. However, an alternative embodiment whereby at most five mirrors are aspherical can simplify the manufacturing, because it is then possible to design one mirror, preferably the largest mirror, i.e., the quaternary mirror, in the form of a spherical mirror. Moreover, it is preferred that the second to sixth mirror be in a concave-convex-concave-convex-concave sequence.

In order to achieve a resolution of at least 50 nm, the design part of the rms wavefront section of the system should be at most 0.07λ and preferably 0.03 λ.

Advantageously, in the embodiments of the invention, the objectives are always telecentric on the image-side.

In projection systems, which are operated with a reflection mask, a telecentric light path on the object-side is not possible without illumination through a beam splitter, which reduces the transmission strongly. One such device is known from JP 95 28 31 16.

In systems with transmission mask, the projection objective can be telecentric on the object side. In these embodiments, the first mirror is preferably concave.

The telecentericity error in the image plane, where the wafer is situated should not exceed 10 mrad and is typically between 5 mrad and 2 mrad, with 2 mrad being preferred. This ensures that changes of the imaging ratio remain within tolerable limits over the depth of focus.

In an preferred embodiments of the invention, the six mirror objective may include a field mirror, a reducing three-mirror subsystem and a two-mirror subsystem.

In addition to the projection objective according to the invention, the invention also makes available a projection exposure apparatus that includes at least a projection objective device. In a first embodiment, the projection exposure apparatus has a reflection mask, while, in an alternative embodiment, it has a transmission mask. Preferably, the projection exposure apparatus includes an illumination device for illuminating an off-axis arc-shaped field and the system is designed as an arc-shaped field scanner. Furthermore, the secant length of the scan slit is at least 26 mm and the ring width is greater than 0.5 mm.

The invention will be described below with the aid of the drawings as examples.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** illustrates the ring field in the object plane of the objective.

FIG. **2** illustrates an embodiment of the invention with an intermediate image, a freely accessible aperture stop between a second and third mirror, and a image side numerical aperture of 0.2.

FIG. **3** illustrates a prior art six-mirror objective arrangement for wavelengths>100 nm as disclosed in U.S. Pat. No. 5,686,728.

FIG. **4** illustrates a second embodiment of the invention with an aperture stop between the second and third mirror at the first mirror.

FIG. **5** illustrates a third embodiment of the invention with an aperture stop on the second mirror and a working distance of 59 mm.

FIG. **6** illustrates a fourth embodiment of the invention with an intermediate image, a image side numerical aperture NA of 0.28 as well as a free working distance on the image-side which is at least the sum of one-third of the useful diameter of the mirror nearest to the wafer and a length which lies between 20 and 30 mm.

FIG. **7** illustrates a fifth embodiment of the invention of a system with an intermediate image and a image side numerical aperture NA of 0.30.

FIGS. **8**A and **8**B show the used diameter for different physical mirror surfaces or used areas of a mirror

DESCRIPTION OF THE PREFERRED EMBODIMENTS

In FIG. **1** the object field **1100** of a projection exposure apparatus in the object plane of the projection objective according to the invention is shown. The object plane is imaged by means of the projection objective in an image plane, in which a light sensitive object, for example a wafer with a light sensitive material is arranged. The image field in the image plane has the same shape as the object field. The object (or the image) field **1100** has the configuration of a segment of a ring field, and the ring field has an axis of symmetry **1200**.

In addition the axis **1200** extending to the object plane, the x-axis and the y-axis are depicted. As can be seen from FIG. **1**, the axis of symmetry **1200** of the ring field runs in the direction of the y-axis. At the same time the y-axis coincides with the scanning direction of an projection exposure apparatus, which is designed as a ring field scanner. The x-direction is thus the direction that stands perpendicular to the scanning direction, within the object plane. The ring field has a so called ring field radius R, which is defined by the distance of the central field point **1500** of the image field from the principal axis (PA) of the projection objective. The arc-shaped field in the object plane as well as in the image plane has a arc shaped field width W, which is the extension of the field in scanning or y-direction and a secant length SL.

In FIGS. **2**, **4** and **5**, arrangements of the six-mirror projection objectives according to the invention are shown. Each embodiment has a free working distance that corresponds at least to the used diameter of the physical mirror surface or mirror segment next to the wafer. In contrast, FIG. **3** shows a prior art system for use with wavelengths>100 nm, such as the system of U.S. Pat. No. 5,686,728. In all embodiments below, the same reference numbers will be used for the same components and the following nomenclature will be employed:

first mirror (**S1**), second mirror (**S2**), third mirror (**S3**), fourth mirror (**S4**),

fifth mirror (**S5**), and sixth mirror (**S6**).

In particular, FIG. **2** shows a six-mirror projection objective with a ray path from the object plane **2**, i.e. reticle plane to the image plane **4**, i.e. wafer plane. The embodiment includes a field mirror **S1**, which forms a virtual image of an object with an imaging ratio $\beta>0$. A three-mirror system formed from **S2**, **S3** and **S4** is also provided and produces a real, reduced image of the virtual image as the intermediate image, Z. Lastly, a two-mirror system **S5**, **S6**, images the intermediate image Z in the wafer plane **4** while maintaining the requirements of telecentricity. The aberrations of the three-mirror and two-mirror subsystems are balanced against one another so that the total system has a high optical quality sufficient for integrated circuit fabrication applications.

The physical aperture stop B is arranged between the second mirror **S2** and the third mirror **S3**. And, as is clear from FIG. **2**, the aperture stop is accessible in the ray path between the second mirror **S2** and the third mirror **S3**. Furthermore, the distance between the vertex **V5** of the surface of the mirror next to the wafer, i.e., the surface of the fifth mirror **S5** in the present embodiment, and the image plane is greater than the used diameter of the physical mirror surface of mirror **S5**. The used diameter of a physical mirror surface is explained in more detail in the description of FIGS. **8**A and **8**B. In other words, the following condition is fulfilled:

> the physical distance from the vertex **V5** of the surface of mirror **S5** to the image plane **4** is greater than the used diameter of mirror **S5**.

Other distance requirements are also possible and may be used, such as the physical distance is (1) greater than the sum of one-third of the used diameter of the mirror next to the wafer, **S5**, and 20 mm, or (2) greater than 50 mm. In the preferred embodiment, the physical distance is 60 mm.

Such a physical distance guarantees a sufficiently free working distance A, and allows the use of optical components compatible for use with wavelengths<100 nm, and preferably wavelengths of 11 to 13 nm. Optical components in this range include, for example, Mo/Si or Mo/Be multi-

layer systems, where the typical multilayer systems for λ=13 nm is Mo/Si layer pairs and for λ=11 nm, is Mo/Be systems, both of approximately 70 layer pairs. Reflectivities attainable in such systems are approximately 70%. In the multilayer layer systems, layer stresses of above 350 MPa may occur. Stresses of such values may induce surface deformation, especially in the edge regions of the mirror.

The systems according to the invention, as they are shown, for example, in FIG. **1**, have:

$$RES=k_1\lambda/NA.$$

This results in a nominal resolution of at least 50 nm and 35 nm at a minimum numerical aperture of NA=0.2 for k_1=0.77 and λ=13 nm, and for k_1=0.64 and λ=11 nm, respectively, where k_1 is a parameter specific for the lithographic process.

Furthermore, the light path for a bundle of light rays running from the object plane to the image plane of the objective shown in FIG. **2** is obscuration-free. For example, in order to provide image formats of 26×34 mm^2 or 26×52 mm^2, the projection objectives according to the invention are preferably used in an arc-shaped field scan projection exposure apparatus, wherein the secant length of the scan slit is at least 26 mm.

Numerous masks can be used in the projection exposure apparatus. The masks or reticle are arranged in the object plane of the projection objective. The masks include transmission masks, stencil masks and reflection masks. The projection objective, which is telecentric on the image side, i.e. in the image plane, can be telecentric or non-telecentric on the object side, i.e. in the object plane depending on which mask is used. For example, if the bundle of light rays is telecentric on the object-side when using a reflection mask, a transmission-reducing beam splitter must be employed. If the bundle of light rays is non-telecentric on the object-side, unevennesses of the mask leads to dimensional errors in the image. Therefore, the angle of incidence of the chief ray of the bundle of light rays through the central field point **1500** in the object plane is preferably below 10°, so that the requirements for reticle evenness lies in an achievable range. Moreover, the system of FIG. **2** which is telecentric on the image side has an image-side error of telecentry at the wafer level of 1 mrad for a image side numerical aperture of 0.2.

Due to the high image-side telecentricity, the entrance pupil of the last mirror **S6** is at or near the focal plane of this mirror. Therefore, in systems with an intermediate image as described before, the aperture, B, is in the front, low-aperture objective part preferably in the light path between the first and third mirror **S1**, **S3**. Thus the pupil plane conjugated with the aperture stop will be imaged in the focal plane of the last mirror.

All mirrors **S1**–**S6** of FIG. **2** are designed to be aspherical, with a maximum asphericity of approximately 7.3 μm. The low asphericity of the embodiment shown in FIG. **2** is advantageous from a manufacturing point of view, since the technological difficulties in processing the surfaces of the multilayer mirrors increases proportionally with aspherical deviation and gradient of the asphere.

The highest angle of incidence of a ray impinging a mirror surface in the six-mirror objective shown in FIG. **2** occur on the fifth mirror **S5** and is approximately 18.4°. The maximum variation of the angles of incidence of the rays within a bundle of light rays impinging onto a mirror surface occurs on mirror surface of mirror **S5** and is approximately 14.7°. The wavefront error at λ=13 nm is better than 0.032λ; the centroid distortion of the point spread function is <3 mm; and the static, dimension-corrected distortion lies at 4 nm.

A freely accessible aperture stop between the second and third mirror as well as no vignetting of the bundle of light rays running from **S3** to **S4** by the aperture stop is achieved with small angles of incidence of the rays impinging onto the mirror surfaces when the following distance conditions are fulfilled:

$$0.5<S1S3/S1S2<2$$

and

$$0.5<S2 \text{ aperture}/(S3 \text{ aperture})<2.$$

Here, the abbreviation **S1S3** means the mechanical distance or physical distance between the vertices **V1** and **V3** of the surface of the mirrors **S1** and **S3**. And, "**S2** aperture" means the mechanical distance between the vertex **V2** of the surface of mirror **S2** and the aperture. Furthermore, in order to reduce the angles of incidence on the mirrors in any of the embodiments of FIGS. **2**, **4**, and **5**, the distance from the object plane, where for example the reticle is situated to the vertex of the surface of the mirror **S1**, is made smaller than the mechanical distance from the vertex of the surface of mirror **S2** to the vertex of the surface of mirror **S3**, i.e., the following applies:

$$\text{reticle } S1<S2S3.$$

To ensure a sufficient free working distance A not only on the image side but also on the object side the reticle is situated sufficiently far in front of the first mirror next to the object plane, which is in the present case the surface of the second mirror **S2**. In the present case, for example, the physical distance between the reticle and the vertex **V2** of the surface of mirror **S2** is 80 mm.

Furthermore, in the embodiments of FIGS. **2** and **4** to **6**, the physical distance between the mirrors **S3** and **S6** is chosen so that mirrors of sufficient thickness can be used. Thicker mirrors have sufficient strength and stability properties that can withstand the high layer tensions described above. In these systems, the following relationship is preferred:

$$0.3 \text{ (used diameter } S3+\text{used diameter } S6)<S3S6.$$

Here **S3S6** denotes the physical distance between the vertex **V3** of the surface of mirror **S3** and the vertex **V6** of the surface of the mirror **S6**.

In the following table, the parameters of the system represented in FIG. **2** are exemplarily shown in Code V(™) nomenclature. The objective is a 5× system with a 26×2 mm^2 arc-shaped field in the image plane, wherein 26 mm is the secant length of the arc-shaped field and 2 mm is the width W of the arc shaped field. Furthermore the numerical aperture is 0.2 on the image side. The mean image side radius of the system is approximately 26 mm.

TABLE 1

element No.	radius	Thickness	diameter	Type
object	INF	80.9127		
			258.1723	
		413.0257		

TABLE 1-continued

S1	A(1)	−88.8251	197.5712	REFL
			195.6194	
		−324.2006		
			188.6170	
		0.0000		
S2	A(2)	324.2006	188.7078	REFL
		aperture	67.1796	
		423.6214		
			183.2180	
		0.0000		
S3	A(3)	−423.6214	184.7062	REFL
			519.0546	
		−74.9270		
S4	A(4)	498.5484	541.0453	REFL
			248.6244	
		109.8242		
			177.5488	
		281.5288		
S5	A(5)	−281.5288	65.0842	REFL
S6	A(6)	281.5288	187.9549	REFL
			78.3999	
image	image width	59.9202		
			53.9889	

aspherical constants:

$$Z = (CURV)\,Y^2/[1 + (1 - (1 + K)\,(CURV)^2\,Y^2)^{1/2}] + (A)Y^4 + (B)Y^6 + (C)Y^8 + (D)Y^{10}$$

asphere	CURV	K	A	B	C	D
A(1)	0.00031800	−27.686599	0.00000E+00	1.32694E−15	2.00546E−20	−8.49471E−25
A(2)	0.00094928	−3.998204	0.00000E +00	4.03849E−15	−6.15047E−20	2.73303E−25
A(3)	0.00126752	0.424198	0.00000E+00	1.58766E−15	−8.27965E−20	2.80328E−24
A(4)	0.00123850	0.023155	0.00000E+00	2.46048E−17	−1.08266E−22	3.75259E−28
A(5)	0.00329892	2.902916	0.00000E+00	1.55628E−12	−6.71619E−17	−5.30379E−21
A(6)	0.00277563	0.072942	0.00000E+00	2.96285E−16	3.99125E−21	4.55007E−26

Reference wavelength = 13 nm

FIG. **3** shows an arrangement of a projection objective for microlithography with a wavelength of $\lambda<100$ nm according to U.S. Pat. No. 5,686,728. By way of a simplified explanation and comparison only, components similar to those of FIG. **1** are provided with the same reference numbers. As is clear, the physical distance between the vertex **V5** of the surface of the mirror next to the image plane **S5** and the image plane, where the wafer is situated, is significantly smaller than the used diameter of the fifth mirror **S5**, lying mainly in the range of approximately 20 mm. This leads to strength and stability problems for the optics in the EUV region because of the extreme tensions in the layers. Furthermore, the system has very high asphericities of ±50 μm and a maximum angle of incidence of 38°. From a manufacturing and coating technology point of view, such asphericities and angles of incidence are incompatible for use in the EUV region.

FIG. **4** is an alternative embodiment of a six-mirror system in which the aperture stop is situated on the first mirror. The same components as in FIG. **2** again receive the same reference number in FIG. **4**. The free working distance A to the wafer is 60 mm in this embodiment, as it was in the embodiment of FIG. **2**, and thus it is greater than the used diameter of the mirror next to the wafer, **S5**. Similarly, as with FIG. **2**, the physical distance between the vertex **V2** of the surface of mirror **S2** and the vertex **V3** of the surface of mirror **S3** was increased significantly in comparison to that of U.S. Pat. No. 5,686,728, so that large angles of incidence can be avoided in the system.

One difference to the objective of FIG. **2**, is that in FIG. **4** the aperture stop B is placed on the first mirror **S1**. As a result of this position, a reduction in vignetting from the light reflected on **S2** is possible, whereas with the physical aperture stop positioned between **S1** and **S2** light of the bundle of light rays running thorough the objective could pass above the aperture stop which is designed as a narrow ring. In the embodiment shown in FIG. **4**, the aperture can be either an opening in the **S1** mirror or an aperture disposed behind SI close to this mirror.

Another advantage of this embodiment is the spherical design of mirror **S4**, which presents advantages especially from the point of view of manufacturing, because mirror **S4** is the largest mirror of the system. With such a design, the asphericity in the used range is increased slightly to 10.5 μm. The largest angle of incidence occurs on mirror **S5** and is approximately 18.6°. The wavefront error of the arrangement is 0.032 λ, within a 1.7 mm wide arc-shaped field at λ=13 nm. Furthermore, if the mirror **S4** is designed to be slightly aspherical with 0.4 μm, then the wavefront error can be kept to 0.031λ within a 1.8 mm wide arc-shaped field at λ=13 nm. Efficient masking of the undesirable light is obtained not only when the aperture stop is formed directly on mirror **S1**, but also when it is arranged behind, i.e., after, mirror **S1**. Preferably, the aperture stop is positioned such that the following relationship is obtained:

$$S2S1 \leq 0.9 \times S2 \text{ aperture.}$$

S2S1 denotes the mechanical distance of the vertex **V2** of the surface of mirror **S2** and the vertex **V1** of the surface of the mirror **S1**.

Table 2 shows the constructional data of the 5× objective according to FIG. **4** in Code V(™) nomenclature, where the fourth mirror **S4** is spherical. The mean radius of the 26×1.7 mm image field is approximately 26 mm.

TABLE 2

element No.	radius	Thickness	diameter	type
Object	INF	85.2401		
			256.1389	
		358.4668		
S1	A(1)	0.0024	203.8941	REFL
			203.8845	
		−358.4691		
			201.9677	
		0.0000		
S2	A(2)	358.4691	201.9942	REFL
		aperture	60.7572	
		390.5456		
			187.2498	
		0.0000		
S3	A(3)	−390.5456	188.9474	REFL
			505.8686	
		−104.1273		
S4	A(4)	494.6729	550.3686	REFL
			256.9217	
		114.3062		
			181.7337	
		281.6969		
S5	A(5)	−281.6969	64.4286	REFL
S6	A(6)	281.6969	187.8549	REFL
			78.1545	
image	image width	60.0041		
			53.6996	

aspherical constants:

$Z = (CURV)Y^2/[1 + (1 - (1 + K)\ (CURV)^2Y^2)^{1/2}] + (A)Y^4 + (B)Y^6 + (C)Y^8 + (D)Y^{10}$

asphere	CURV	K	A	B	C	D
A(1)	0.00035280	−58.238840	0.00000E + 00	2.14093E − 15	2.29498E − 20	0.00000E + 00
A(2)	0.00097971	−4.160335	0.00000E + 00	1.54696E − 15	8.15622E − 21	0.00000E + 00
A(3)	0.00117863	−2.136423	0.00000E + 00	−1.78563E − 16	3.45455E − 20	0.00000E + 00
A(4)	0.00124362	0.000000	0.00000E + 00	0.00000E + 00	0.00000E + 00	0 00000E + 00
A(5)	0.00338832	2.909987	0.00000E + 00	7.90123E − 13	7.04899E − 17	0.00000E + 00
A(6)	0.00278660	0.062534	0.00000E + 00	2.79526E − 16	7.00741E − 21	0.00000E + 00

Reference wavelength = 13 nm

Another embodiment is shown in FIG. **5**, where again the same reference numbers are used for the same components as in the previous figures. Here, the aperture stop B is placed optically and physically on the secondary mirror or second mirror **S2**. The ability to place the aperture stop on **S2** makes manufacturing easier. Therefore this arrangement is advantageous. The system of FIG. **5** is a 4× reduction system with a wavefront error of 0.021λ within a 2 mm wide image side arc-shaped field at λ=13 nm. The maximum asphericity in the used range lies at 11.2 μm, and the largest angle of incidence, which occurs at **S5**, is approximately 18.3°. The ring field radius R as defined in FIG. **1** of the arc-shaped field in the image plane is approximately 26 mm, as with the previous two embodiments. Furthermore, the distance between the image plane and the vertex **V5** of the surface of the mirror next to the image plane, **S5**, is greater than the used diameter of the mirror next to the wafer, **S5**, and lies at around 59 mm in this embodiment.

Table 3 shows the optical parameters of the embodiment of FIG. **5** in Code V(™) nomenclature.

TABLE 3

element No.	Radius	thickness	diameter	Type
object	INF	84.0595		
			205.6642	
		473.5521		
S1	A(1)	−145.8261	147.3830	REFL
			136.4700	
		−327.7260		
		aperture	112.0176	
		0.0000		
S2	A(2)	473.5521	112.1228	REFL
			163.5236	
		190.4830		
			184.4783	
		0.0000		
S3	A(3)	−190.4830	185.3828	REFL
			358.6720	
		−399.1713		

TABLE 3-continued

S4	A(4)	589.6560	654.5228	REFL
			310.1977	
		207.5220		
			175.3066	
		276.2668		
S5	A(5)	−276.2668	65.2138	REFL
S6	A(6)	276.2668	182.8159	REFL
			77.5085	
image	image width	59.0000		
			53.9968	

aspherical constants:

$Z = (CURV)Y^2/[1 + (1 - (1 + K)\ (CURV)^2Y^2)^{1/2}] + (A)Y^4 + (B)Y^6 + (C)Y^8 + (D)Y^{10}$

asphere	CURV	K	A	B	C	D
A(1)	0.00015851	441.008070	0.00000E + 00	−3.49916E − 16	1.27478E − 19	−3.37021E − 25
A(2)	0.00089932	−5.032907	0.00000E + 00	−6.95852E − 15	−7.53236E − 20	−2.74751E − 24
A(3)	0.00188578	0.913039	0.00000E + 00	−1.60100E − 15	−9.53850E − 20	1.30729E − 26
A(4)	0.00108147	0.038602	0.00000E + 00	2.48925E − 18	−5.29046E − 24	−4.37117E−31
A(5)	0.00269068	7.253316	0.00000E + 00	−5.70008E − 13	−9.32236E − 17	−6.09046E − 21
A(6)	0.00281036	0.150957	0.00000E + 00	1.30822E− 15	1.86627E − 20	5.08158E − 25

Reference wavelength = 13 nm

FIG. **6** shows an embodiment of the invention which includes a field mirror **S1**, a first subsystem with the second to fourth mirror **S2**–**S4** and a second subsystem with the fifth and sixth mirror, **S5**, **S6**. The field mirror **S1** with imaging ratio,β, β>0 produces a virtual image of the object in the object plane **2**. The virtual image is then imaged by the first subsystem consisting of the second, third and fourth mirrors, **S2**, **S3**, **S4**, which has β<0, producing a real intermediate image Z in a plane conjugate to the object plane **2**. The real intermediate image Z is imaged as a real image into image plane **4** by the second subsystem, which consists of the fifth and sixth mirrors, **S5**, **S6**. The image side numerical aperture of the system is NA=0.28. The optical free working distance,s A, between the vertex of the surface of the last mirror **S5** and the image plane **4** corresponds to at least the sum of one-third of the used diameter of the mirror nearest to the image plane and a length which lies between 20 and 30 mm. The aperture stop B is situated on the second mirror **S2**.

Table 4 shows the optical parameters of the embodiment of FIG. **6** in Code V(™) nomenclature.

TABLE 4

element No.	Radius	thickness	Diameter	Type
Object	INF	151.2625		
			194.7605	
		229.0820		
S1	A(1)	−39.4068	162.9862	REFL
			147.1426	
		−189 6752		
		aperture	65.0637	
		0.0000		
S2	A(2)	229.0820	65.1650	REFL
			168.3504	
		137.5708		
			230.5128	
		0.0000		
S3	A(3)	−137.5708	234.0072	REFL
			386.2567	
		−300.3445		
S4	A(4)	437.9153	630.7784	REFL
			343.1578	
		133.0981		
			257.0225	
		353.0840		
S5	A(5)	−353.0840	79.9521	REFL
S6	A(6)	353.0840	264.2853	REFL
			78.6376	
image	image width	44.0000		
			54.0051	

aspherical constants:

$Z = (CURV)Y^2/[1 + (1 + (1 + K)\ (CURV)^2Y^2)^{1/2}] + (A)Y^4 + (B)Y^6 + (C)Y^8 + (D)Y^{10} + (E)Y^{12} + (F)Y^{14} + (G)Y^{16} + (H)Y^{18} + (J)Y^{20}$

K	A	B	C	D

TABLE 4-continued

asphere	CURV	E	F	G	H	J
A(1)	−0.00080028	0.000000	−3.35378E − 09	5.36841E − 14	−7.86902E − 19	−5.07886E − 24
		0.00000E + 00	0.00000E + 60	0.00000E + 00	0.00000E + 00	0.00000E + 00
A(2)	0.00040002	0.000000	1.68187E − 08	2.05570E − 12	2.42710E − 16	5.69764E − 20
		0.00000E + 00	0.00000E + 00	0.00000E + 00	0.00000E + 00	0.00000E + 00
A(3)	0.00113964	−2.760663	0.00000E + 00	−3.55779E − 15	1.03888E − 19	−3.64996E − 24
		0.00000E + 00	0.00000E + 00	0.00000E + 00	0.00000E + 00	0.00000E + 00
A(4)	0.00128753	0.019273	0.00000E + 00	5.82746E − 18	−1.77496E − 22	1.64954E − 27
		−6.20361E − 33	0.00000E + 00	0.00000E + 00	0.00000E + 00	0.00000E + 00
A(5)	0.00373007	11.6888968	0.00000E + 00	−5.53902E − 12	−4.32712E − 16	−1.54425E − 19
		0.00000E + 00	0.00000E + 00	0.00000E + 00	0.00000E + 00	0.00000E + 00
A(6)	0.00240387	−0.002567	0.00000E + 00	−6.78955E − 16	−8.39621E − 21	−2.95854E − 25
		0.00000E + 00	0.00000E + 00	0.00000E + 00	0.00000E + 00	0.00000E + 00

Reference wavelength = 13 nm

FIG. **7** shows a similar, yet alternative, embodiment to that of FIG. **6** with a six-mirror objective with field mirror **S1** as well as first and second subsystems as shown in FIG. **6**. The embodiment shown in FIG. **7** comprises as the embodiment in FIG. **6** an intermediate image Z. Furthermore the aperture B is formed on the second mirror **S2** similar and the numerical aperture on the image side is NA=0.30. The optical parameters of this alternative embodiment are shown in Table 5 in Code V(™) nomenclature.

TABLE 5

element No.	radius	thickness	Diameter	type
object	INF	103.2808		
			197.1874	
		219.3042		
S1	A(1)	−39.2890	157.6222	REFL
			142.1492	
		−180.0152		
		aperture	67.2659	
		0.0000		
S2	A(2)	219.3042	67.4347	REFL
			167.6895	
		131.2051		
			228.0182	
		0.0000		
S3	A(3)	−131.2051	232.3162	REFL
			401.4441	
		−247.5850		
S4	A(4)	378.7901	613.5493	REFL
			355.7774	
		134.4001		
			268.3735	
		348.5086		
S5	A(5)	−348.5086	81.5255	REFL
S6	A(6)	348.5086	269.2435	REFL
			75.4983	
image	image width	36.1195		
			53.9942	

aspherical constants:

$Z = (CURV)\,Y^2/[1 + (1 - (1 + K)\,(CURV)^2Y^2)^{1/2}] + (A)Y^4 + (B)Y^6 + (C)Y^8 + (D)Y^{10} + (E)Y^{12} + (F)Y^{14} + (G)Y^{16} + (H)Y^{18} + (J)Y^{20}$

asphere	CURV	K E	A F	B G	C H	D J
A(1)	−0.00061615	0.000000	−5.19402E − 09	1.09614E − 13	−3.44621E − 18	1.58573E − 22
		−7.07209E − 27	0.00000E + 00	0.00000E + 00	0.00000E + 00	0.00000E + 00
A(2)	0.00066911	0.000000	1.69112E − 08	2.39908E − 12	2.89763E − 16	1.00572E − 19
		1.84514E − 29	0.00000E + 00	0.00000E + 00	0.00000E + 00	0.00000E + 00
A(3)	0.00140031	0.000000	−8.71271E − 10	−1.47622E − 15	−3.40869E − 20	4.32196E − 24
		−2.23484E − 28	0.00000E + 00	0.00000E + 00	0.00000E + 00	0.00000E + 00
A(4)	0.00143731	0.000000	2.18165E + 12	2.65405E − 17	−2.01757E − 22	1.14856E − 28
		1.49857E − 32	−8.61043E − 38	0.00000E + 00	0.00000E + 00	0.00000E + 00
A(5)	0.00378996	0.000000	8.54406E − 08	2.25929E − 12	3.36372E − 16	1.92565E − 20
		5.75469E − 24	0.00000E + 00	0.00000E + 00	0.00000E + 00	0.00000E + 00
A(6)	0.00246680	0.000000	−3.61754E − 12	−8.29704E − 16	−1.53440E − 20	−2.24433E − 25
		5.91279E − 30	0.00000E + 00	0.00000E + 00	0.00000E + 00	0.00000E + 00

Reference wavelength = 13 nm

FIGS. **8**A and **8**B define the used diameter D as used in the description of the above embodiments. As a first example, the illuminated field **100** on a mirror in FIG. **8**A is a rectangular field. The illuminated field corresponds to the area on a mirror onto which a bundle of light rays running through the objective from the object side to the image side impinge. The used diameter D according to FIG. **8**A is then the diameter of the envelope circle **102**, which encompasses the rectangle **100**, where the corners **104** of the rectangle **100** lie on the envelope circle **102**. A more realistic example is shown in FIG. **8**B. The illuminated field **100** has a kidney shape, which is expected for the physical mirror surfaces of the mirrors **S1**–**S6** or the so called used areas of the mirrors **S1**–**S6**, when the field in the image plane as well as the field in the object plane is an arc shaped field as depicted in FIG. **1**. The envelope circle **102** encompasses the kidney shape fully and it coincides with the edge **110** of the kidney shape at two points, **106**, **108**. The used diameter D of the physical mirror surface or the used area of the mirrors **S1**–**S6** is then given by the diameter of the envelope circle **102**.

Thus, the invention provides a six-mirror projection objective with an imaging scale of preferably 4×, 5× or 6× for use in an EUV projection system. Other uses may be employed, however. The six-mirror projection objective has the resolution required for the image field, which is e.g. arc-shaped and has a advantageous structural design, since the aspheres of the mirror surfaces are relatively low, the angles of incidence of the rays of the bundle of light rays impinging the mirror surfaces are small, and there is enough room for mounting the mirrors.

I claim:

1. A projection objective with an object plane and an image plane and a light path for a bundle of light rays from the object plane to the image plane for use in short wavelength microlithography, comprising;

six mirrors (a first mirror (**S1**), a second mirror (**S2**), a third mirror (**S3**), a fourth mirror (**S4**), a fifth mirror (**S5**) disposed closest to the image plane and a sixth mirror (**S6**)) arranged in the light path such that an image-side numerical aperture (NA) is NA≧0.15, wherein each mirror has a physical mirror surface and wherein said fifth mirror is positioned in the light path such that at least one of the following conditions is satisfied:

an image-side optical free working distance is greater than or equal to a used diameter D of a physical mirror surface of the fifth mirror;

the image-side optical free working distance is greater than or equal to a sum of one-third of the used diameter of the physical mirror surface of the fifth mirror and a length between 20 mm and 30 mm; and

the image-side optical free working distance is at least 50 mm;

wherein the image side free working distance is the physical distance between the vertex of the surface of the fifth mirror and the image plane and wherein the physical mirror surface of a mirror is the area of the surface of a mirror, where the rays of the bundle of light rays running from the object side to the image side impinge.

2. A projection objective with an object plane and an image plane and a light path for a bundle of light rays from the object plane to the image plane for use in short wavelength microlithography, comprising;

six mirrors (a first mirror (**S1**), a second mirror (**S2**), a third mirror (**S3**), a fourth mirror (**S4**), a fifth mirror (**S5**) disposed closest to the image plane, and a sixth mirror (**S6**)) arranged in the light path such that an image-side numerical aperture (NA) is NA≧0.15 and an image side arc-shaped field width (W) lies in the range of 1.0 mm≦W, and wherein each of said six mirrors has a physical mirror surface with a maximum aspherical peak-to-valley (PV) deviation (A) from a best-fitting sphere in the following range:

$$A \leqq 19\ \mu m - 102\ \mu m\ (0.25 - NA) - 0.7\ \mu m/mm\ (2\ mm - W)$$

wherein the physical mirror surface of a mirror is the area of the surface of a mirror where the rays of the bundle of light rays running from the object side to the image side impinge.

3. A projection objective with an object plane and an image plane and a light path for a bundle of light rays from the object plane to the image plane for use in short wavelength microlithography, comprising;

six mirrors (a first mirror (**S1**), a second mirror (**S2**), a third mirror (**S3**), a fourth mirror (**S4**), a fifth mirror (**S5**) disposed closest to the image plane, and a sixth mirror (**S6**)) arranged such that an image-side numerical aperture (NA) is NA≧0.15 and an image-side arc-shaped field width (W) lies in the range of 1.0 mm≦W, and wherein the rays of a bundle of light rays incident on each physical mirror surface of the six mirrors have angles of incidence (AOI) relative to the surface normal of said physical mirror surface that are lying in the range:

$$AOI \leqq 23° - 35°(0.25 - NA) - 0.2°/mm(2\ mm - W)$$

wherein the physical mirror surface of a mirror is the area of the surface of a mirror where the rays of the bundle of light rays running from the object side to the image side impinge.

4. A projection objective with an object plane and an image plane and a light path from the object plane to the image plane for use in short wavelength microlithography, comprising;

a field mirror (**S1**) with an imaging ratio $\beta_1 > 0$, wherein the field mirror produces a virtual image of an object in the object plane;

a first subsystem with a second mirror (**S2**), a third mirror (**S3**), and a fourth mirror (**S4**), wherein the first subsystem has an imaging ratio $\beta_2 < 0$, and wherein said first subsystem images the virtual image to a real intermediate image;

a second subsystem with a fifth mirror (**S5**) disposed closest to the image plane and a sixth mirror (**S6**), wherein the second subsystem images the intermediate image to a real image in the image plane; and

wherein the objective has an image-side numerical aperture (NA) and an arc-shaped field width (W) in the image plane, where an object to be illuminated is situated, and wherein each mirror has a physical mirror surface that is the area of the surface of the mirror where the rays of the bundle of light rays running from the object side to the image side impinge.

5. A projection objective according to any one of claims **1** to **4**, wherein the surface of the mirrors have a rotational symmetry with respect to a principal axis (PA).

6. A projection objective according to one of claims **1** to **4**, further comprising an aperture stop (B) in the light path positioned between the second mirror (**S2**) and the third mirror (**S3**).

7. A projection objective according to claim **6**, wherein a ratio of a physical distance between the vertex of the surface

of the first mirror and the vertex of the surface of the third mirror (S1S3) to a physical distance between the vertex of the surface of the first mirror and the vertex of the surface of the second mirror (S1S2) is in the range of:

$$0.5<S1S3/S1S2<2.$$

8. A projection objective according to claim **7**, wherein a ratio of a physical distance between the vertex of the surface of the second mirror and the vertex of the surface of the third mirror (S2S3) to a physical distance between the vertex of the surface of the third mirror and the vertex of the surface of the fourth mirror (S3S4) lies in the range:

$$0.7<S2S3/S3S4<1.4.$$

9. A projection objective according to any one of claims **1** to **4**, wherein all physical mirror surfaces are aspherical.

10. A projection objective according to any one of claims **1** to **4**, wherein at most five physical mirror surfaces are aspherical.

11. A projection objective according to any one of claims **1** to **4**, wherein the second mirror, third mirror, fourth mirror, fifth mirror, and sixth mirror are in a concave-convex-concave-convex-concave sequence.

12. A projection objective according to any one of claims **1** to **4**, wherein a physical distance between the vertex of the surface of the third mirror and the vertex of the surface of the sixth mirror (S3S6) satisfies the following relationship:

$$0.3\ (\text{used diameter of third mirror } S3+\text{used diameter of sixth mirror } S6)<S3S6.$$

13. A microlithography projection exposure apparatus comprising:

a projection objective according to one of the claims **1** to **4**; and

an illumination system comprising a radiation source providing a bundle of light rays illuminating an arc-shaped field in the object plane of the projection objective, wherein the projection objective images a mask located in the object plane into the image plane of the projection objective, where a light sensitive objective is situated.

14. A method for producing a microelectronic device with a microlithography exposure apparatus according to claim **13** wherein a mask with a structure in the object plane is illuminated and said mask is imaged onto a light sensitive object situated in the image plane.

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US006578963B2

(12) **United States Patent**
Pettit

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(45) **Date of Patent: Jun. 17, 2003**

(54) **WAVEFRONT SENSOR FOR OBJECTIVE MEASUREMENT OF AN OPTICAL SYSTEM AND ASSOCIATED METHODS**

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(52) **U.S. Cl.** **351/212**

(58) **Field of Search** 351/211, 212, 351/216, 220, 221; 359/1, 19, 20, 109, 115, 117

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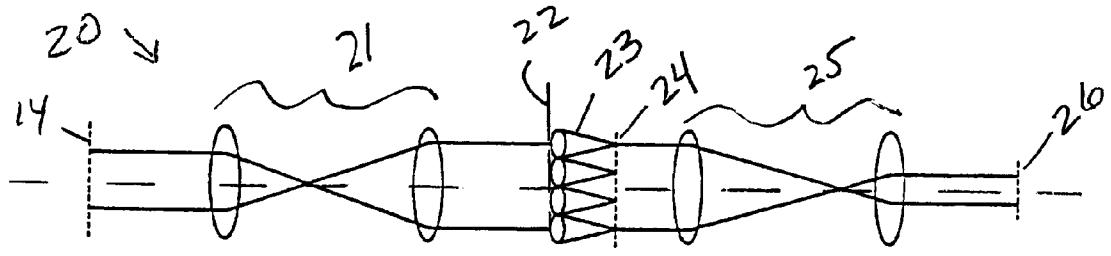
(57) **ABSTRACT**

A wavefront sensor includes an afocal relay stage for magnifying an incoming wavefront reflected from a source plane. In an exemplary application, a retina of an eye reflects an impinging light beam thereon to form a series of wavefronts. A lenslet array is positioned at a reference plane of the afocal relay stage to receive the magnified wavefront. Further downstream is positioned a means for imaging and demagnifying a focal plane image of the lenslet array at a final image plane. This demagnified image then serves as input to an analyzer, such as a charge-coupled-device (CCD) camera.

20 Claims, 1 Drawing Sheet



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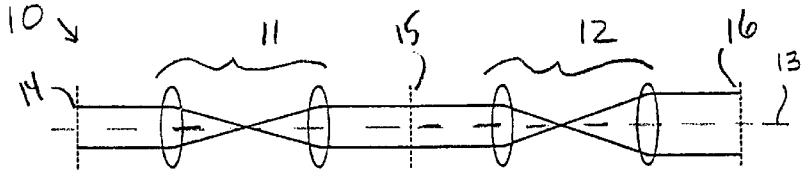


FIG. 1
(prior art)

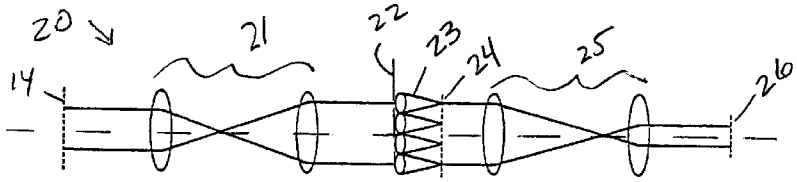


FIG. 2

WAVEFRONT SENSOR FOR OBJECTIVE MEASUREMENT OF AN OPTICAL SYSTEM AND ASSOCIATED METHODS

CROSS-REFERENCE TO RELATED APPLICATION

This application claims priority from provisional application Ser. No. 60/198,536, filed Apr. 19, 2000, "Wavefront Sensor with an Extended Dynamic Range and a Small-Format CCD Detector."

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to optical measurement systems and methods, and, more particularly, to such systems and methods for objective measurement of an eye.

2. Description of Related Art

Optical systems having a real image focus can receive collimated light and focus it at a point. Such optical systems can be found in nature, e.g., human and animal eyes, or can be manmade, e.g., laboratory systems, guidance systems, and the like. In either case, aberrations in the optical system can affect the system's performance. By way of example, the human eye will be used to explain this problem.

A perfect or ideal eye diffusely reflects an impinging light beam from its retina through the optics of the eye, which includes a lens and a cornea. For such an ideal eye in a relaxed state, i.e., not accommodating to provide near-field focus, reflected light exits the eye as a sequence of plane waves. However, an eye typically has aberrations that cause deformation or distortion of reflected light waves exiting the eye. An aberrated eye diffusely reflects an impinging light beam from its retina through its lens and cornea as a sequence of distorted wavefronts.

There are a number of technologies that attempt to provide the patient with improved visual acuity. Examples of such technologies include remodeling of the cornea using refractive laser surgery or intra-corneal implants, adding synthetic lenses to the optical system using intra-ocular lens implants, and precision-ground spectacles. In each case, the amount of corrective treatment is typically determined by placing spherical and/or cylindrical lenses of known refractive power at the spectacle plane (approximately 1.0–1.5 cms anterior to the cornea) and literally asking the patient which lens or lens combination provides the clearest vision. This is an imprecise measurement of true distortions in the reflected wavefront because (1) a single spherocylindrical compensation is applied across the entire wavefront; (2) vision is tested at discrete intervals (i.e., diopter units) of refractive correction; and (3) subjective determination by the patient is made in order to determine the optical correction. Thus conventional methodology for determining refractive errors in the eye is substantially less accurate than the techniques now available for correcting ocular aberrations.

One method of measuring ocular refractive errors is disclosed in U.S. Pat. No. 5,258,791 to Penney et al. for "Spatially Resolved Objective Autorefractometer," which teaches the use of an autorefractometer to measure the refraction of the eye at numerous discrete locations across the corneal surface. Penney '791 further teaches the use of autorefractometer measurements in determining an appropriate corneal surface reshaping to provide emmetropia, a condition of a normal eye when parallel beams or rays of light are focused exactly on the retina and vision is perfect.

By way of example, one method and system known in the art are disclosed by Junzhong Liang et al. in "Objective

Measurement Of Wave Aberrations of the Human Eye with the Use of a Hartmann-Shack Wave-Front Sensor"[*J. Opt. Soc. Am.* 11(7), July 1994, pp 1949–57]. Liang et al. teach the use of a Hartmann-Shack wavefront sensor to measure ocular aberrations by measuring the wavefront emerging from the eye by the retinal reflection of a focused laser light spot on the retina's fovea. The actual wavefront is reconstructed using wavefront estimation with Zernike polynomials. A parallel beam of laser light passes through beam splitters and a lens pair, which brings the beam to a focus point on the retina by the optics of the eye. Possible myopia or hyperopia of the tested eye is corrected by movement of a lens within the lens pair. The focused light on the fovea is then assumed to be diffusely reflected and acts as a point source located on the retina. The reflected light passes through the eye and forms a distorted wavefront in front of the eye that results from the ocular aberrations. The aberrated wavefront is then directed to the wavefront sensor.

The Hartmann-Shack wavefront sensor disclosed by Liang et al. includes two identical layers of cylindrical lenses with the layers arranged so that lenses in each layer are perpendicular to one another, as further disclosed in U.S. Pat. No. 5,062,702 to Bille. In this way, the two layers operate as a two-dimensional array of spherical lenslets that divide the incoming light wave into subapertures. The light through each subaperture is brought to focus in the focal plane of the lens array where a charge-coupled-device (CCD) image module resides.

The system of Liang et al. is calibrated by impinging an ideal plane wave of light on the lenslet array so that a reference or calibrating pattern of focus spots is imaged on the CCD. Since the ideal wavefront is planar, each spot related to the ideal wavefront is located on the optical axis of the corresponding lenslet. When a distorted wavefront passes through the lenslet array, the image spots on the CCD are shifted with respect to a reference pattern generated by the ideal wavefront. Each shift is proportional to a local slope, i.e., partial derivatives of the distorted wavefront, which partial derivatives are used to reconstruct the distorted wavefront, by means of modal wavefront estimation using Zernike polynomials.

However, the system disclosed by Liang et al. is effective only for eyes having fairly good vision. Eyes that exhibit considerable myopia (near-sightedness) cause the focus spots to overlap on the CCD, thereby making local slope determination practically impossible for eyes having this condition. Similarly, eyes that exhibit considerable hyperopia (farsightedness) deflect the focus spots such that they do not impinge on the CCD, thereby again making local slope determination practically impossible for eyes having this condition.

Various embodiments of a method and system for objectively measuring aberrations of optical systems by wavefront analysis have been disclosed in commonly owned application Ser. No. 09/566,668, "Apparatus and Method for Objective Measurement and Correction of Optical Systems Using Wavefront Analysis," filed May 8, 2000, which is hereby incorporated by reference herein. In this invention, an energy source generates a beam of radiation. Optics, disposed in the path of the beam, direct the beam through a focusing optical system (e.g., the eye) that has a rear portion (e.g., the retina) that provides a diffuse reflector. The beam is diffusely reflected back from the rear portion as a wavefront of radiation that passes through the focusing optical system to impinge on the optics. The optics project the wavefront to a wavefront analyzer in direct correspondence with the wavefront as it emerges from the focusing optical

system. A wavefront analyzer is disposed in the path of the wavefront projected from the optics and calculates distortions of the wavefront as an estimate of ocular aberrations of the focusing optical system. The wavefront analyzer includes a wavefront sensor coupled to a processor that analyzes the sensor data to reconstruct the wavefront to include the distortions thereof.

A perfectly collimated light beam (i.e., a bundle of parallel light rays, here a small-diameter, eye-safe laser beam) incident on a perfect, ideal emmetropic eye, focuses to a diffraction-limited small spot on the retina. This perfect focusing is true for all light rays passing through the entrance pupil, regardless of position. From the wavefront perspective, the collimated light represents a series of perfect plane waves striking the eye. The light emanates from an illuminated spot on the retina as wavefronts exiting as a series of perfect plane waves, which are directed onto a wavefront analyzer for measuring distortions from ideality.

In one embodiment, the radiation is optical radiation and the wavefront sensor is implemented using a plate and a planar array of light-sensitive cells. The plate is generally opaque but has an array of light-transmissive apertures that selectively let impinging light therethrough. The plate is disposed in the path of the wavefront so that portions of the wavefront pass through the light-transmissive apertures. The planar array of cells is arranged parallel to and spaced apart from the plate by a selected distance. Each portion of the wavefront passing through one of the light-transmissive apertures illuminates a geometric shape covering a unique plurality of cells.

The wavefront optical path relays the re-emitted wavefront from the corneal plane to an entrance face of a Hartman-Shack wavefront sensor. The wavefront incident on the sensor is received by a sensitive charged-coupled-device (CCD) camera and an optical plate containing an array of lenslets. The lenslet array is parallel to the CCD detector face, with a distance therebetween approximately equal to the focal length of each lens in the lenslet array. The lenslet array divides the incoming wavefront into a matching array of "wavelets," each of which focuses to a small spot on the CCD detector plane. The constellation of wavelet spots in the CCD is used to reconstruct the shape of the incident wavefront. Collimated light striking the lenslet at normal (perpendicular) incidence would focus to the spot on the CCD face where this optical axis intersects. The optics of the apparatus provides such collimated light to the wavefront sensor using a calibration optical path.

In the case of a reflected aberrated wavefront, light focuses to a spot displaced from the collimated reference point by a distance D_x. The distance from the lenslet face to the CCD surface, D_z, is precisely known. Therefore, dividing the measured displacement, D_x, by the known propagation distance, D_z, the slope of the wavefront at the location of this lens element is determined. The same calculation is applied in the y direction within the plane, and the entire process applied to every lenslet element irradiated by the wavefront. A mathematical algorithm is then applied to reconstruct the wavefront shape consistent with the calculated D_x/D_z and D_y/D_z slope data. Regardless of which wavefront sensor is used, the distance between the planar array of cells and the opaque plate, or the array of lenslets, can be varied to adjust the slope measurement gain of the wavefront sensor and thereby improve the dynamic range of the system.

Another measure of dynamic range enhancement is provided by the focusing optics. The focusing optics includes first and second lenses maintained in fixed positions in the path of the beam and wavefront. An arrangement of optical elements is disposed between the lenses in the path of the beam and the wavefront. The optical elements are adjustable to change the optical path length between the lenses. If an optical correction is desired, the distortions are converted to an optical correction, which, if placed in the path of the wavefront, causes the wavefront to appear approximately as a plane wave. The optical correction can be in the form of a lens or an amount of corneal material ablated from the eye.

One method for determining aberrations of an eye, herein described by way of example, includes directing a probe beam along a probe beam path toward an eye, directing a fixation image along a fixation image path toward the eye, directing a light source along a video image path toward the eye, generating a video image of the eye, directing a wavefront originating from the eye along a wavefront path, wherein the probe beam path, the fixation image path, the video image path, and the wavefront path are coincident at least along a portion of their respective paths, the probe beam path terminating at the retina of the eye and the probe beam reflecting from the retina of the eye as a wavefront, aligning the eye with the probe beam path based at least in part on the video image of the eye generated by the light source directed along the video image path, measuring the wavefront, and generating data representative of the aberrations of the eye based on the measurement of the wavefront. Further, the aligning of the eye with the probe beam path based at least in part on the video image of the eye generated by the light source directed along the video image path, may have the wavefront pass through a single microlens array.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a system and method for objectively measuring ocular aberrations using a wavefront analyzer of simple and inexpensive design.

It is a further object to provide such an apparatus and method that can employ a small-format camera.

It is an additional object to provide a method for constructing such a system.

These and other objects are achieved by the present invention, a wavefront sensor that comprises an afocal relay stage for magnifying an incoming wavefront reflected from a source plane. In an exemplary application, a retina of an eye reflects an impinging light beam thereon to form a series of wavefronts.

A lenslet array is positioned at a reference plane of the afocal relay stage to receive the magnified wavefront. Further downstream is positioned a means for imaging and demagnifying a focal plane image of the lenslet array at a final image plane. This demagnified image then serves as input to an analyzer, such as, but not intended to be limited to, a charge-coupled-device (CCD) camera.

The features that characterize the invention, both as to organization and method of operation, together with further objects and advantages thereof, will be better understood from the following description used in conjunction with the accompanying drawing. It is to be expressly understood that the drawing is for the purpose of illustration and description and is not intended as a definition of the limits of the invention. These and other objects attained, and advantages offered, by the present invention will become more fully apparent as the description that now follows is read in conjunction with the accompanying drawing.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** (prior art) is a schematic diagram of an apparatus for wavefront sensing.

FIG. **2** is a schematic diagram of the apparatus of the present invention for wavefront sensing.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

A description of the preferred embodiments of the present invention will now be presented with reference to FIGS. **1** and **2**.

The prior art apparatus **10** (FIG. **1**) includes a first **11** and a second **12** afocal relay stage within the optical axis **13**. The optical path through the first afocal relay stage **11** results in an image of the corneal plane **14** at a first image plane **15**, which serves as an insertion point for a spherical trial lens, as described in application Ser. No. 09/566,668.

The wavefront sensor comprises a microlens array plate and a charge-coupled-device (CCD) camera at the second image plane **16** separated by a fixed distance. The optical path **13** thus creates an image of the corneal plane **14** at the lenslet array, that is, at the entrance face of the actual wavefront sensor, which could be accomplished by a single afocal relay stage. Placing a spherical lens into the optical axis **13** at the first image plane **15**, in theory, could be used to remove the defocus wavefront error. This would potentially expand the dynamic range of the apparatus **10**. However, the trial lens approach is a moving mechanism that can position lenses at the first image plane **15** with tremendous accuracy and repeatability. It was therefore highly desirable that alternative means be developed to address dynamic range.

The present invention **20** (FIG. **2**) accomplishes this by magnifying the corneal plane **14** image with the first afocal stage **21**. Magnification of the wavefront reduces the wavefront slope, so that the displacement of the focused lights spots on the CCD is decreased. The prior art design **10** does include some magnification in the second afocal stage **12** for this reason. The chosen magnification factor used with that apparatus **10** at the second afocal stage **12** is approximately 1.2, which is insufficient to cover the desired range in refractive errors. A magnification factor in excess of 1.5 is desirable for expanding the use of the apparatus **10**. However, simply magnifying the corneal plane **14** has a drawback in that it necessitate a large-aperture wavefront sensor. That is, both the lens array and the CCD camera would preferably have large cross-sectional areas to encompass the magnified image of the point of plane. This is not a significant issue for the lens array plate; however, a large-format CCD camera is quite expensive, and such cameras are only available from a limited number of vendors.

The apparatus **20** of the present invention solves this difficulty. The corneal plane **14** is imaged at a reference plane **22** by the first afocal relay stage **21**. The first afocal relay stage **21** magnifies the corneal plane **14** by a predetermined amount. A lenslet array plate **23** is placed at reference plane **22**. Focused spots of light from an eye are produced at the lenslet array **23** focal plane **24**.

A second afocal relay stage **25** images the array focal plane **24** at a camera plane **26**, where the CCD is located. The second stage **25** may be other than an afocal design, but preferably should provide demagnification of the array focal plane **24**. This feature permits a small-active-area camera to be used as the light-recording element in the wavefront sensor. Specifics of the optical design are adjustable as desired to maximize performance for given camera and lenslet array specifications.

It may be appreciated by one skilled in the art that additional embodiments may be contemplated, including alternate optical elements to achieve similar functions.

In the foregoing description, certain terms have been used for brevity, clarity, and understanding, but no unnecessary limitations are to be implied therefrom beyond the requirements of the prior art, because such words are used for description purposes herein and are intended to be broadly construed. Moreover, the embodiments of the apparatus illustrated and described herein are by way of example, and the scope of the invention is not limited to the exact details of construction.

Having now described the invention, the construction, the operation and use of preferred embodiment thereof, and the advantageous new and useful results obtained thereby, the new and useful constructions, and reasonable mechanical equivalents thereof obvious to those skilled in the art, are set forth in the appended claims.

What is claimed is:

1. A wavefront sensor comprising:

an afocal relay stage for magnifying an incoming wavefront reflected from a source plane;

a lenslet array positioned at a reference plane of the afocal relay stage for receiving the magnified wavefront; and

means for imaging and demagnifying a focal plane image of the lenslet array at a final image plane, for serving as input to an analyzer.

2. The wavefront sensor recited in claim **1**, wherein the imaging and demagnifying means comprises a second afocal relay stage.

3. The wavefront sensor recited in claim **1**, wherein the source plane comprises a corneal plane.

4. The wavefront sensor recited in claim **1**, wherein the afocal relay stage comprises means for magnifying the incoming wavefront by a factor of at least 1.5.

5. The wavefront sensor recited in claim **1**, wherein the demagnifying means is adapted to reduce the lenslet array focal plane image to a dimension smaller than a dimension of the incoming wavefront.

6. A system for determining refractive aberrations of an eye comprising:

means for directing a beam of light onto a cornea of an eye;

an afocal relay stage for magnifying wavefronts of light reflected from a retina of the eye;

a lenslet array positioned at a reference plane of the afocal relay stage for receiving the magnified wavefront;

means for demagnifying a focal plane image of the lenslet array at a final image plane; and

means for imaging the final image plane for determining aberrations from planarity of the reflected wavefronts.

7. The system recited in claim **6**, wherein the directing means comprises a laser beam focused on a fovea of the eye.

8. The system recited in claim **6**, wherein the imaging and demagnifying means comprises a second afocal relay stage.

9. The system recited in claim **6**, wherein the afocal relay stage comprises means for magnifying the incoming wavefront by a factor of at least 1.5.

10. The system recited in claim **6**, wherein the demagnifying means is adapted to reduce the lenslet array focal plane image to a dimension smaller than a dimension of the incoming wavefront.

11. The system recited in claim 6, wherein the imaging means comprises a charge-coupled-device camera.

12. The system recited in claim 11, wherein the camera comprises a small active area camera.

13. A method of measuring refractive aberrations in an eye comprising the steps of:

directing a beam of light onto a cornea of an eye;

magnifying wavefronts of light reflected from a retina of the eye;

directing the magnified wavefronts to a lenslet array positioned at a reference plane of the magnified wavefronts;

demagnifying a focal plane image of the lenslet array at a final image plane; and

imaging the final image plane for determining aberrations from planarity of the reflected wavefronts.

14. The method recited in claim 13, wherein the directing step comprises focusing a laser beam on a fovea of the eye.

15. The method recited in claim 13, wherein the magnifying step comprises directing the reflected wavefronts to a first afocal relay stage.

16. The method recited in claim 13, wherein the demagnifying step comprises directing the focal plane image of the lenslet array to a second afocal relay stage.

17. The method recited in claim 13, wherein the first afocal relay stage comprises means for magnifying the reflected wavefronts by a factor of at least 1.5.

18. The method recited in claim 13, wherein the demagnifying step comprises reducing the lenslet array focal plane image to a dimension smaller than a dimension of the reflected wavefronts.

19. The method recited in claim 13, wherein the imaging step comprises using a charge-coupled-device camera to collect the final image plane.

20. A method for constructing a system for measuring refractive aberrations in an eye comprising the steps of:

providing means for directing a beam of light onto a cornea of an eye;

providing means for magnifying wavefronts of light reflected from a retina of the eye;

providing a lenslet array positioned at a reference plane of the magnified wavefronts;

providing means for demagnifying a focal plane image of the lenslet array at a final image plane; and

providing means for imaging the final image plane; and

providing means for determining aberrations from planarity of the reflected wavefronts.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

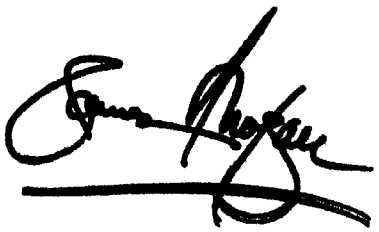
PATENT NO. : 6,578,963 B2
DATED : June 17, 2003
INVENTOR(S) : George H. Pettit

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

The Title page should be deleted and substitute therefore the attached Title page.

Signed and Sealed this

Twenty-third Day of September, 2003



JAMES E. ROGAN
Director of the United States Patent and Trademark Office

(12) **United States Patent**
Pettit

(10) **Patent No.: US 6,578,963 B2**
(45) **Date of Patent: Jun. 17, 2003**

(54) **WAVEFRONT SENSOR FOR OBJECTIVE MEASUREMENT OF AN OPTICAL SYSTEM AND ASSOCIATED METHODS**

(75) Inventor: **George H. Pettit**, Maitland, FL (US)

(73) Assignee: **Alcon Universal Ltd.**, Hunenberg (CH)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 134 days.

(21) Appl. No.: **09/838,669**

(22) Filed: **Apr. 19, 2001**

(65) **Prior Publication Data**

US 2002/0003606 A1 Jan. 10, 2002

Related U.S. Application Data

(60) Provisional application No. 60/198,536, filed on Apr. 19, 2000.

(51) **Int. Cl.**[7] **A61B 3/10**

(52) **U.S. Cl.** **351/212**

(58) **Field of Search** 351/211, 212, 351/216, 220, 221; 359/1, 19, 20, 109, 115, 117

(56) **References Cited**

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4,750,818	A		6/1988	Cochran
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4,838,679	A		6/1989	Bille
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JP	5-146409	6/1993
JP	6-327634	11/1994
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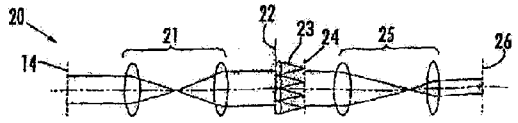
Primary Examiner—George Manuel
(74) *Attorney, Agent, or Firm*—Allen, Dyer, Doppelt, Milbrath & Gilchrist, P.A.

(57) **ABSTRACT**

A wavefront sensor includes an afocal relay stage for magnifying an incoming wavefront reflected from a source plane. In an exemplary application, a retina of an eye reflects an impinging light beam thereon to form a series of wavefronts. A lenslet array is positioned at a reference plane of the afocal relay stage to receive the magnified wavefront. Further downstream is positioned a means for imaging and demagnifying a focal plane image of the lenslet array at a final image plane. This demagnified image then serves as input to an analyzer, such as a charge-coupled-device (CCD) camera.

20 Claims, 1 Drawing Sheet



UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 6,578,963 B2
DATED : June 17, 2003
INVENTOR(S) : George H. Pettit

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

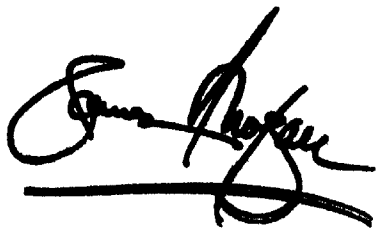
The Title page should be deleted and substitute therefore the attached Title page.

The attached drawing sheet 1 of 1 should be inserted.

This certificate supersedes Certificate of Correction issued September 23, 2003.

Signed and Sealed this

Ninth Day of December, 2003



JAMES E. ROGAN
Director of the United States Patent and Trademark Office

(12) **United States Patent**
Pettit

(10) **Patent No.: US 6,578,963 B2**
(45) **Date of Patent: Jun. 17, 2003**

(54) **WAVEFRONT SENSOR FOR OBJECTIVE MEASUREMENT OF AN OPTICAL SYSTEM AND ASSOCIATED METHODS**

(75) Inventor: **George H. Pettit**, Maitland, FL (US)

(73) Assignee: **Alcon Universal Ltd.**, Hunenberg (CH)

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(58) **Field of Search** 351/211, 212, 351/216, 220, 221; 359/1, 19, 20, 109, 115, 117

(56) **References Cited**

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4,688,941	A	8/1987	Philbert	
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4,721,379	A	1/1988	L'Esperance	
4,729,372	A	3/1988	L'Esperance, Jr.	
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4,764,930	A	8/1988	Bille et al.	
4,838,679	A	6/1989	Bille	
4,848,340	A	7/1989	Bille et al.	
4,881,808	A	11/1989	Bille et al.	

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WO	WO 95/28989	11/1995
WO	WO 98/27863	7/1998

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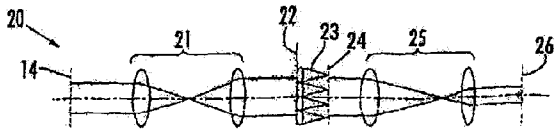
Reidy, et al., "Corneal Topography of Epikeratophakia," *Refractive & Corneal Surgery*, vol. 6, Jan./Feb. 1990, pp. 26–31.

Primary Examiner—George Manuel
(74) *Attorney, Agent, or Firm*—Allen, Dyer, Doppelt, Milbrath & Gilchrist, P.A.

(57) **ABSTRACT**

A wavefront sensor includes an afocal relay stage for magnifying an incoming wavefront reflected from a source plane. In an exemplary application, a retina of an eye reflects an impinging light beam thereon to form a series of wavefronts. A lenslet array is positioned at a reference plane of the afocal relay stage to receive the magnified wavefront. Further downstream is positioned a means for imaging and demagnifying a focal plane image of the lenslet array at a final image plane. This demagnified image then serves as input to an analyzer, such as a charge-coupled-device (CCD) camera.

20 Claims, 1 Drawing Sheet



U.S. Patent Jun. 17, 2003 Sheet 1 of 1 6,578,963 B2

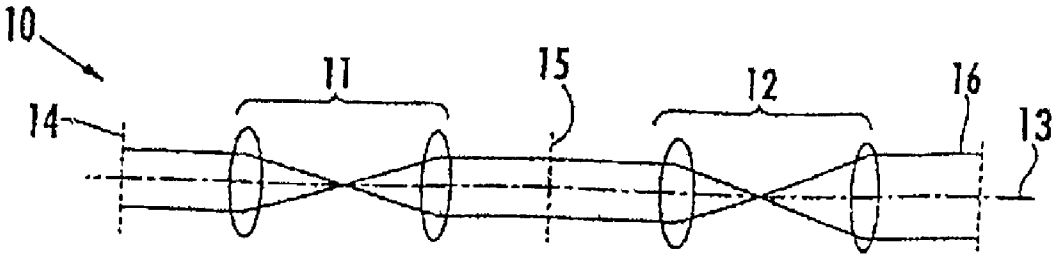


FIG. 1.
(PRIOR ART)

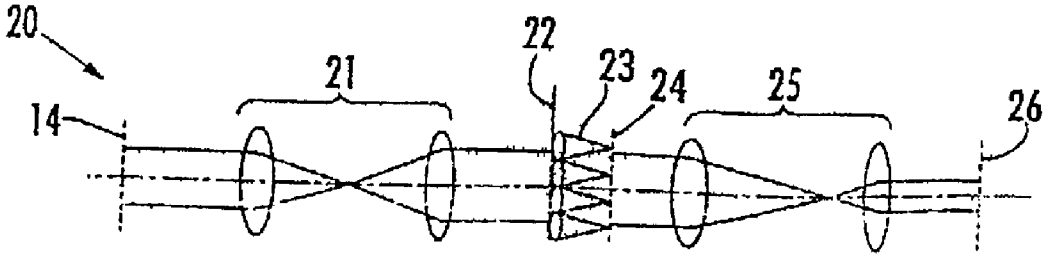


FIG. 2.

US006577443B2

(12) **United States Patent**
Dinger et al.

(10) **Patent No.: US 6,577,443 B2**
(45) **Date of Patent: Jun. 10, 2003**

(54) **REDUCTION OBJECTIVE FOR EXTREME ULTRAVIOLET LITHOGRAPHY**

(75) Inventors: **Udo Dinger**, Oberkochen (DE); **Hans-Jürgen Mann**, Oberkochen (DE)

(73) Assignee: **Carl-Zeiss Stiftung**, Heidenheim (DE)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/878,697**

(22) Filed: **Jun. 11, 2001**

(65) **Prior Publication Data**

US 2002/0114089 A1 Aug. 22, 2002

Related U.S. Application Data

(63) Continuation-in-part of application No. 09/322,813, filed on May 28, 1999, now Pat. No. 6,244,717.

(30) **Foreign Application Priority Data**

May 30, 1998 (DE) 193 24 442

(51) **Int. Cl.**[7] **G02B 5/10**; G02B 17/00; G03B 27/54; G21K 5/00

(52) **U.S. Cl.** **359/366**; 359/731; 359/859; 359/861; 359/900; 359/351; 359/359; 378/34; 378/35; 355/67

(58) **Field of Search** 359/365, 366, 359/730, 731, 859, 861, 900, 350, 351, 355, 359; 355/60, 67, 71; 378/34, 35

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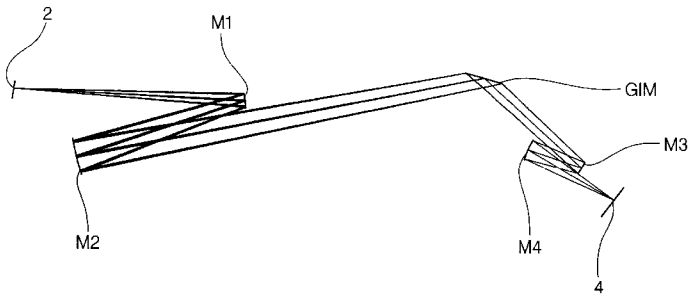
Primary Examiner—Ricky D. Shafer
(74) *Attorney, Agent, or Firm*—Marshall, Gerstein & Borun

(57) **ABSTRACT**

A reduction objective, a projection exposure apparatus with a reduction objective, and a method of use thereof are disclosed. The reduction objective has a first set of multilayer mirrors in centered arrangement with respect to a first optical axis, a second set of multilayer mirrors in centered arrangement with respect to a second optical axis, and an additional mirror disposed at grazing incidence, such that said additional mirror defines an angle between the first optical axis and said second optical axis. The reduction objective has an imaging reduction scale of approximately 4× for use in soft X-ray, i.e., EUV and UV, annular field projection applications, such as lithography

19 Claims, 8 Drawing Sheets



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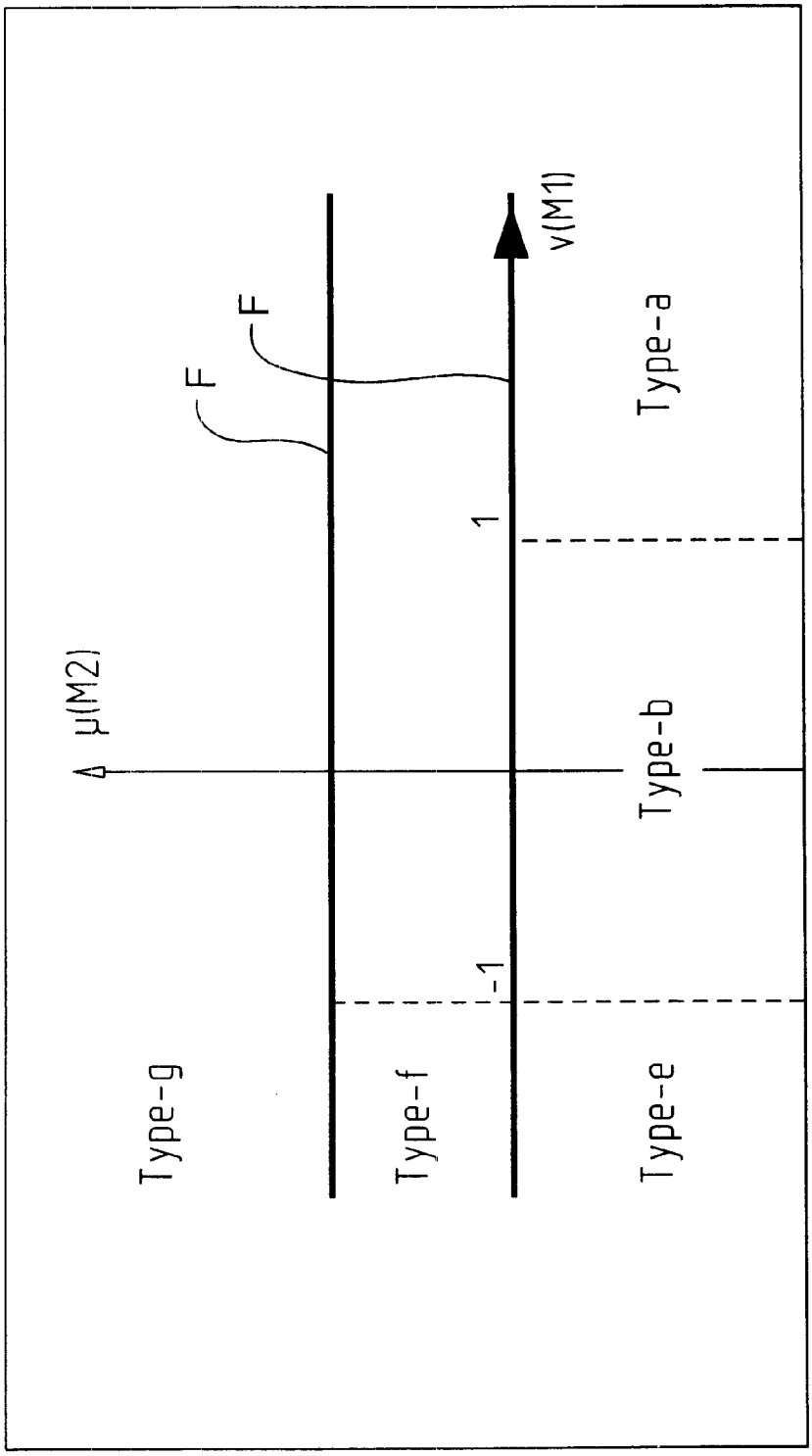


Fig.1

Fig.2

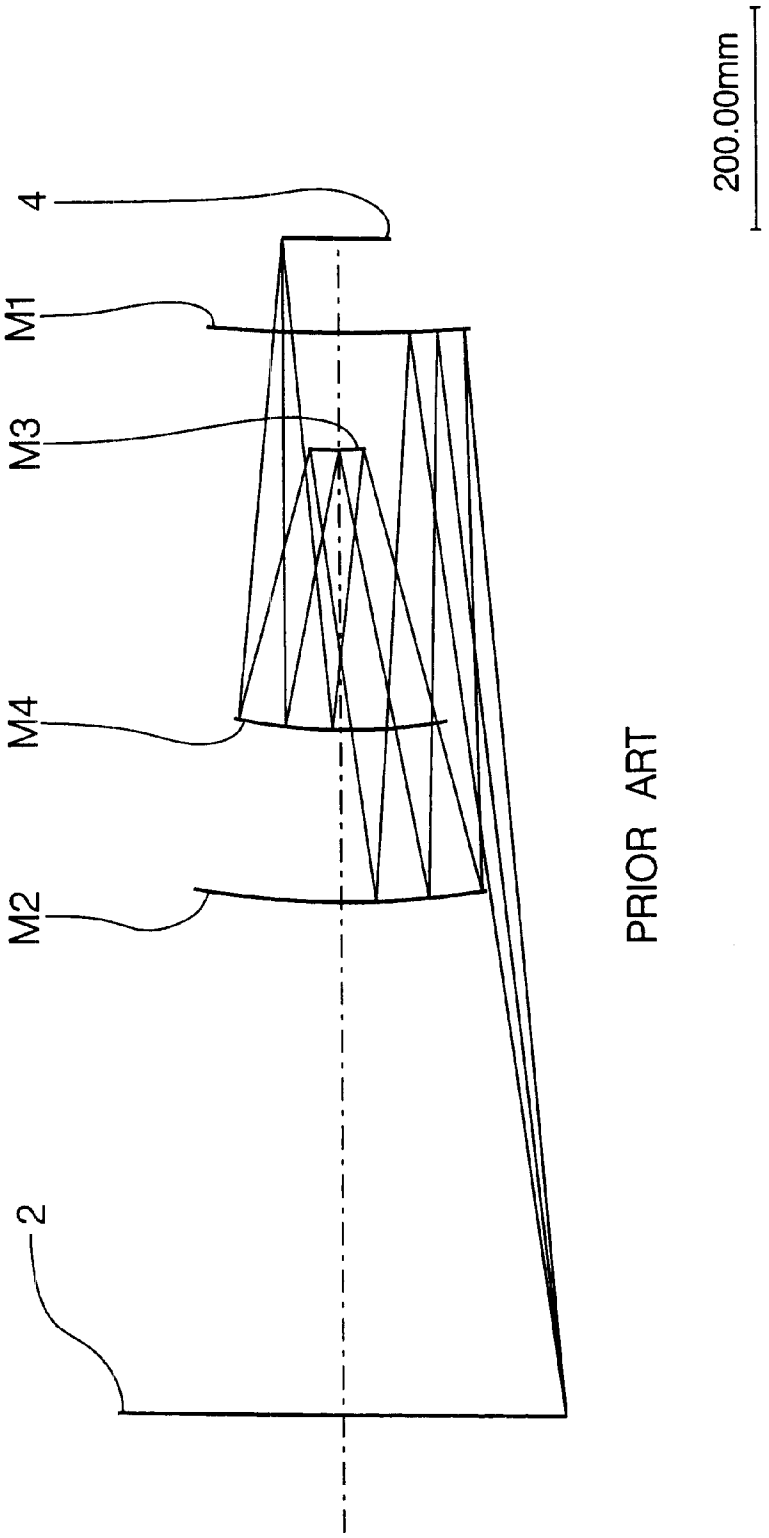


Fig.3

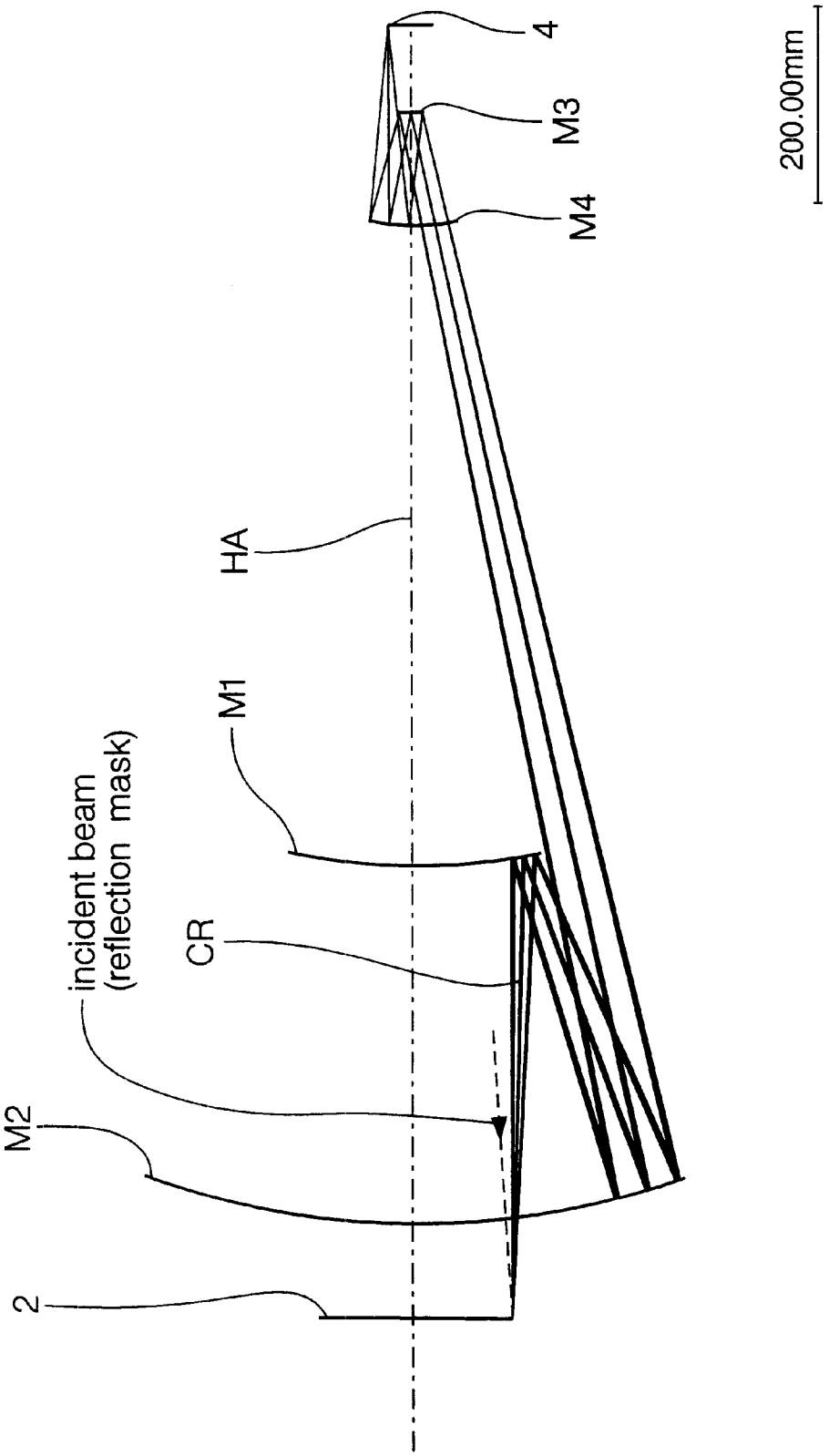
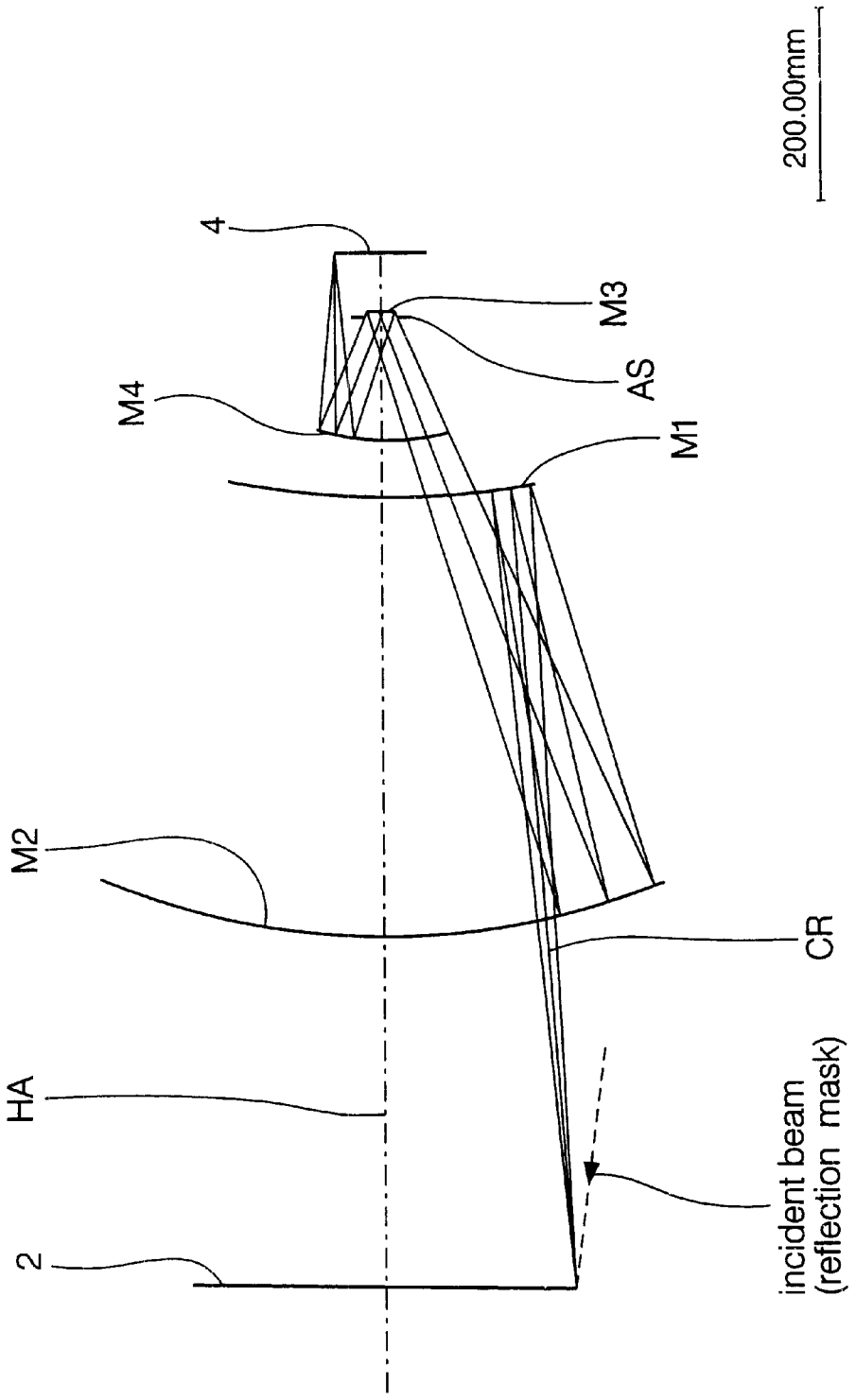


Fig.4



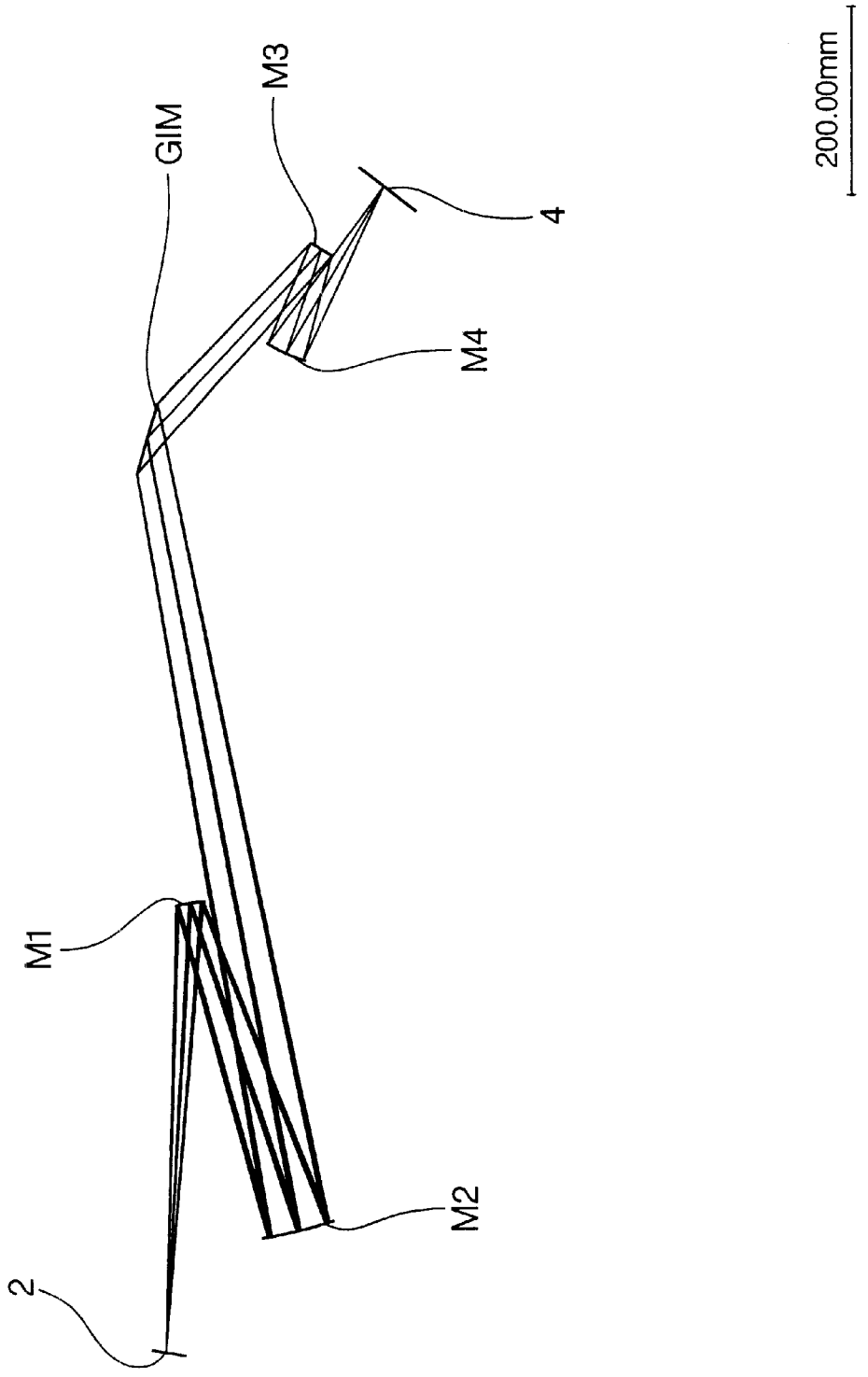


Fig.5

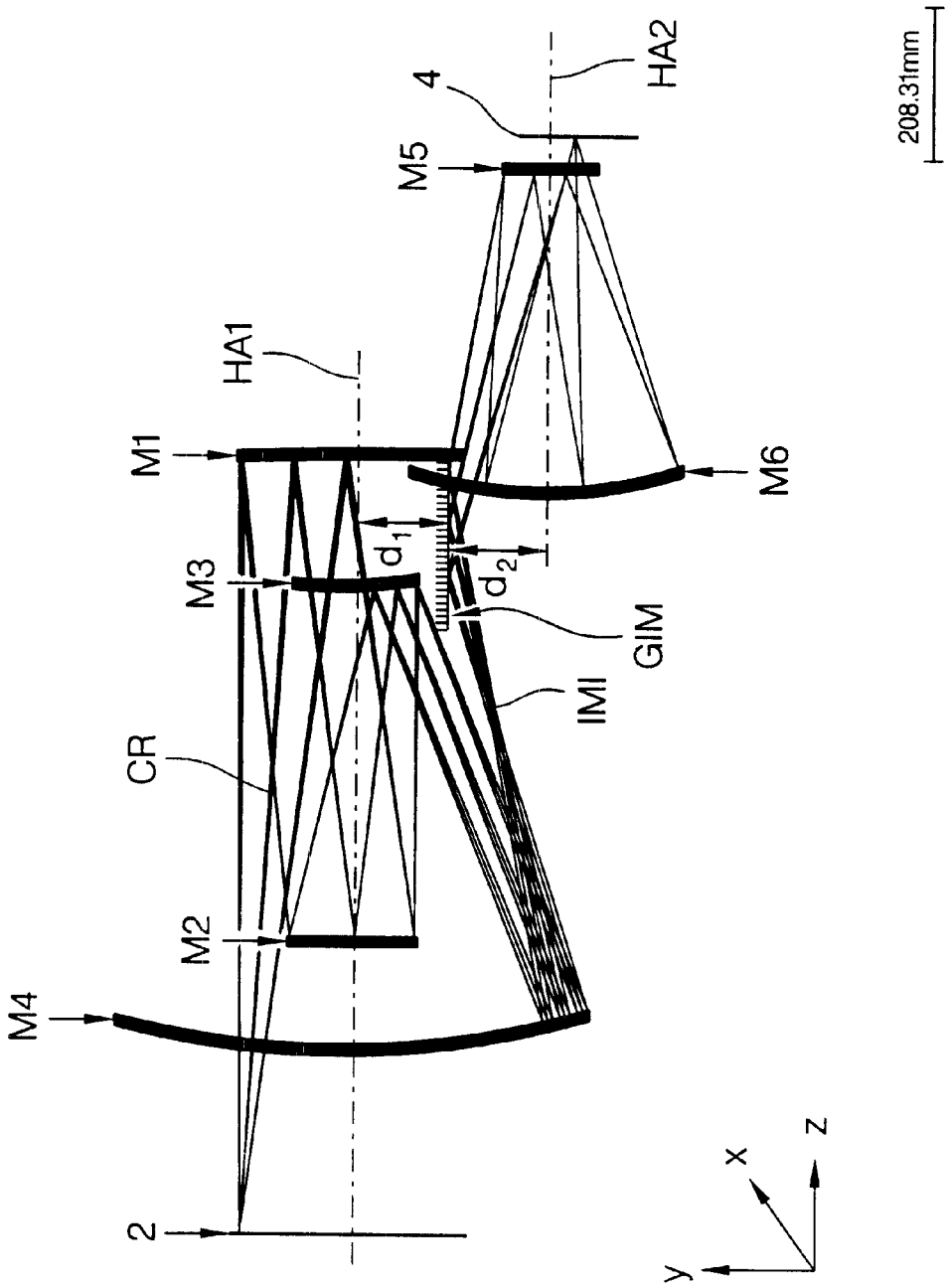


Fig.6

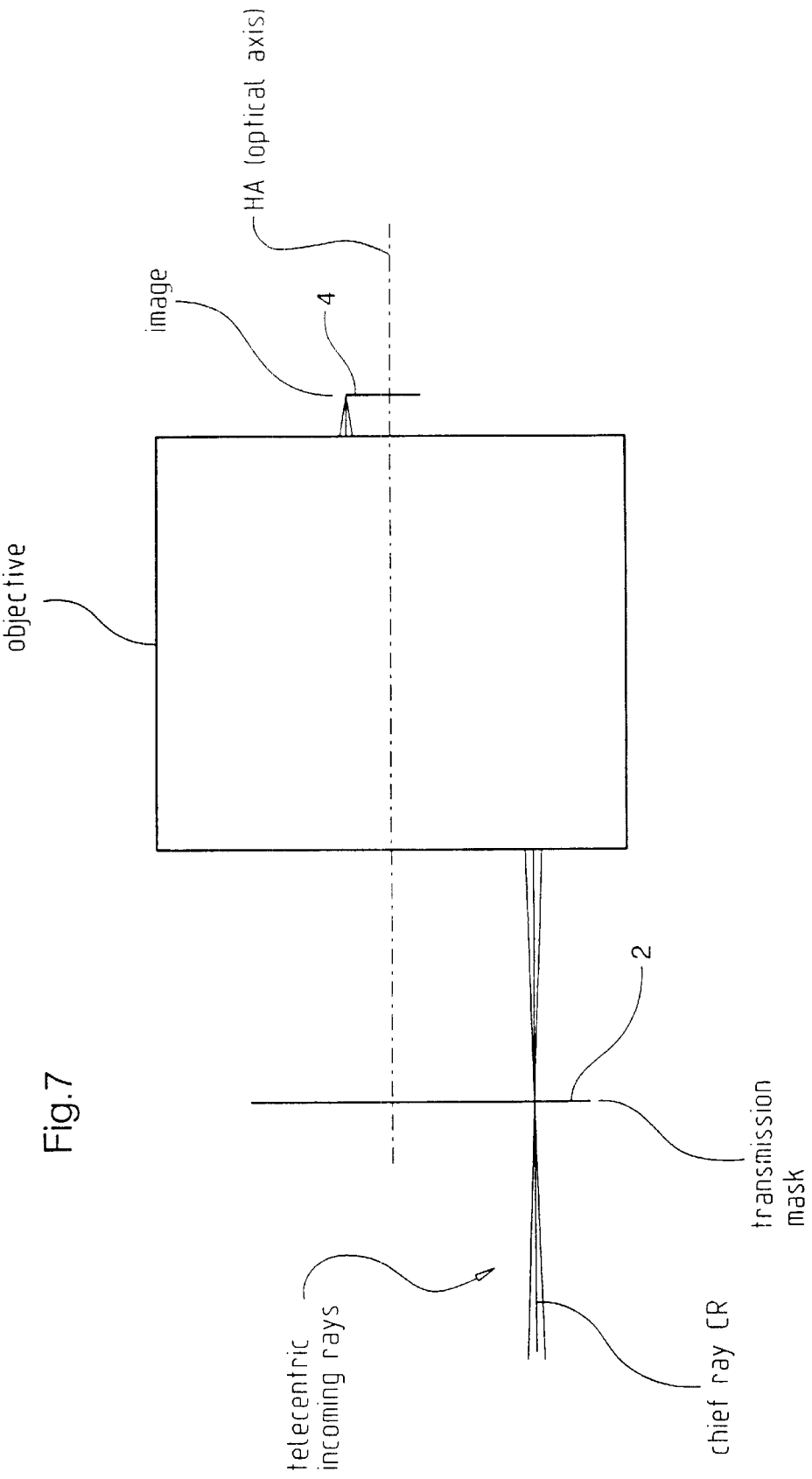

HA (optical axis)
image
4
objective
2
transmission mask
telecentric incoming rays
chief ray CR

Fig.7

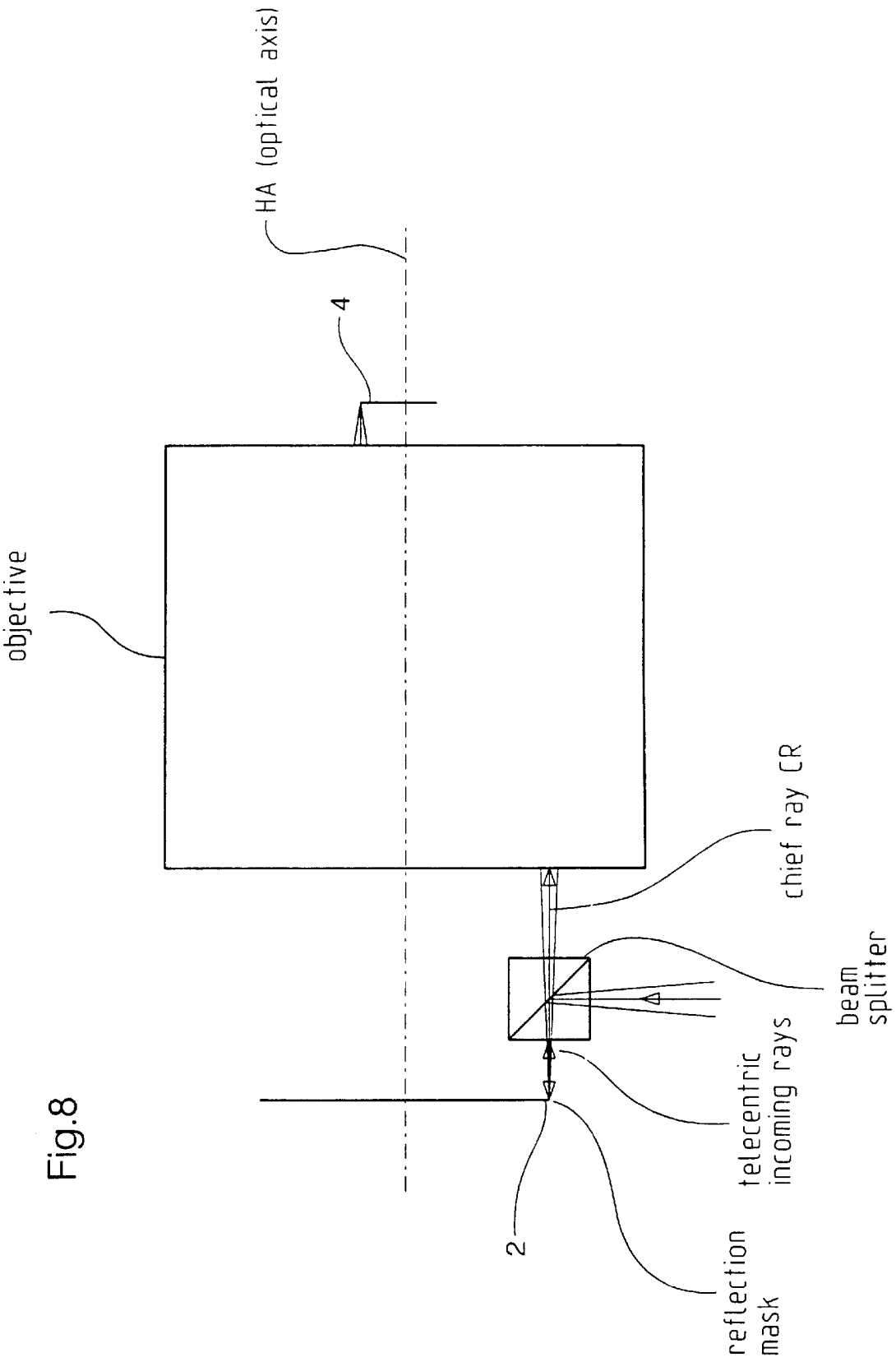

HA (optical axis)
4
objective
chief ray CR
beam splitter
telecentric incoming rays
2
reflection mask

Fig.8

REDUCTION OBJECTIVE FOR EXTREME ULTRAVIOLET LITHOGRAPHY

This is a continuation-in-part of U.S. application Ser. No. 09/322,813, filed May 28, 1999, now U.S. Pat. No. 6,244,717.

FIELD OF THE INVENTION

The invention relates to a reduction objective, a projection exposure apparatus, and method of use thereof for exposing patterned information onto a reduced image plane for use in lithography applications, such as integrated circuit fabrication.

BACKGROUND OF THE INVENTION

The desirability of creating lithography systems which operate with incident light wavelengths below 193 nm to achieve imaging structures or patterns with resolution below 130 nm has been established. In fact, there has been a need for lithography systems using soft X-ray, or so called extreme ultraviolet (EUV), wavelength incident light, such as λ=11 nm or λ=13 nm light, to obtain image resolution in the below 100 nm range. The resolution of a lithography system is described by the following equation:

$$RES=k_1 \cdot /NA$$

where k_1 is a specific parameter of the lithography process, λ is the wavelength of the incident light and NA is the numerical aperture of the system on the image side. This equation can be used to establish design criteria for soft X-ray lithography systems. Thus, for a numerical aperture of 0.10, the imaging of 100 rim structures with 13 nm radiation requires a process with k_1=0.77. Alternatively, with k_1=0.64, which occurs with 11 nm radiation, imaging of 70 nm structures is possible with a numerical aperture of 0.10.

For lithography imaging systems in the soft X-ray region, multilayer coated reflective systems, such as Distributed Bragg Reflectors (DBRs) and mirrors, are used as optical components. These multilayer systems employ alternating layers of different indices of refraction. The particular multilayer reflective system depends on the wavelength of incident light used. For example, with incident light of λ=11 nm alternating layers of Mo/Be are preferred and with incident light of λ=13 nm Mo/Si layers are used. In the case of projection objectives used in soft X-ray or EUV microlithography, the reflectivity of these multilayer systems is approximately 70%. It is, therefore, desirable to use as few optical components in the projection objective as possible to ensure sufficient light intensity at the image. With high intensity light, four-mirror projection objective systems were found to be useful in correcting imaging errors at NA=0.10.

Other requirements for soft X-ray projection objectives, in addition to using a limited number of multilayer reflectors, relate to obscuration, image field curvature, distortion, telecentricity on both the image and the object side, free working distance, and aperture stop positioning and accessibility. Obscurations, for example the central obscuration apparent in Schwarzschild systems, create intolerable degradation in image quality. If an obscuration-free light path is required, then, in the case of centered systems, an off-axis image field must be used. In order to provide

image formats of 26×34 mm^2 or 26×52 mm^2, it is advantageous to design the projection objective system as an annular field scanner. In such systems, the useful secant length of the scanning slit should be at least 26 mm, and the annular width should lie in the range of 0.5 mm to 2 mm in order to make uniform illumination and illumination-control and dose-control possible.

Regarding distortion, a distinction between static and dynamic or scan distortion is made. Scan distortion is the effective distortion which is obtained by integration of the static distortion over the scanning path. The limits for magnification-corrected, static distortion follow essentially from the specifications for contrast and CD variation.

Image-side telecentricity is also desired in soft X-ray lithography systems. Whether telecentricity is possible on the object side depends on the type of projection application used. If the projection system uses a reflection mask, then a telecentric optical path on the object side is not possible. If transmission masks, for example stencil masks, are used then a telecentric optical path on the object side can be realized.

In order to enable clean limitations of the beam, the aperture stop should be physically accessible. The image-side telecentricity requirement, referred to above, means that the entrance pupil of the last mirror would lie in or near its focal point. In order to obtain a compact design and maintain an accessible aperture stop, it is recommended that a beam-limiting element be placed before the last mirror. This, preferably, results in the place of the beam-limiting element at the third mirror.

Four-mirror projection or reduction objectives have become known from the following publications:

U.S. Pat No. 5,315,629

EP 480,617

U.S. Pat. No. 5,063,586

EP 422,853

Donald W. Sweeney, Russ Hudyma, Henry N. Chapman, David Shafer, EUV optical Design for a 100 mm CD Imaging System, 23rd International Symposium of microlithography, SPIE, Santa Clara, Calif., Feb. 22–27, 1998, SPIE Vol. 3331, p. 2ff.

In U.S. Pat. No. 5,315,629, a four-mirror projection objective with NA=0.1, 4×31.25×0.5 mm^2 is claimed. The mirror sequence is concave, convex, concave, concave. From EP 480,617, two NA=0.1, 5×, 25×2 mm^2 systems have become known. The mirror sequence is concave, convex, arbitrary/convex, concave.

The systems according to U.S. Pat. No. 5,063,586 and EP 422,853 have a rectangular image field, for example, at least 5×5 mm^2, and use a mirror sequence of convex, concave, convex, concave. These generally decentered systems exhibit very high distortion values. Therefore, the objectives can only be used in steppers with distortion correction on the reticle. However, the high level of distortion makes such objectives impractical in the structural resolution regions discussed here ($\leqq$130 nm).

From U.S. Pat. No. 5,153,898, overall arbitrary three to five-multilayer mirror systems have become known. However, the disclosed embodiments all describe three-mirror systems with a rectangular field and small numerical aperture (NA<0.04). Therefore, the systems described therein can only image structures above 0.25 μm in length.

Furthermore, reference is made to T. Jewell: "Optical system design issues in development of projection camera for EUV lithography", Proc. SPIE 2437 (1995) and the citations given there, the entire disclosure of which is incorporated by reference.

In the known systems according to EP 480,617 as well as U.S. Pat. No. 5,315,629 and according to Sweeney, cited above, it was found to be disadvantageous that the outside-axially used part of the primary mirror conflicts with the wafer-side sensor structures of a projection exposure installation when not very large free mechanical working distances greater than 100 mm are realized. By using mirror segments which are placed "near the image field", these conflicts occur only at significantly lower distances (≈10 mm).

Six mirror projection or reduction objectives with all multilayer mirrors in centered arrangement to an optical axis have become known, e.g., from U.S. Pat. No. 6,033,079. The system according to U.S. Pat. No. 6,033,079 is telecentric on the image side. To provide small reflection angles at the object side, i.e., at the reticle, a long distance between the primary multilayer mirror and the reticle according to U.S. Pat. No. 6,033,079 is chosen. A disadvantage of this reduction objective is the extension, or lengthening, of the projection objective in the direction of the optical axis.

Thus, it is desired to provide a projection objective which is suitable for lithography with short wavelengths (at least below 193 nm and, preferably below 100 nm) which does not have the disadvantages of the prior art mentioned above, uses as few optical elements as possible and, yet, has a sufficiently large aperture and fulfills the telecentricity requirements as well as all other requirements for a projection system operating with incident light of wavelengths below 193 nm.

SUMMARY OF THE INVENTION

According to an aspect of the invention, the shortcomings of the prior art are overcome by using a reduction objective that includes four-mirrors (primary, secondary, tertiary, and quaternary). Using this four-mirror system, high transmission efficiency is achieved at wavelengths in the soft x-ray and EUV region with a multilayer mirror system of 70% reflectivity and an aperture in the range of NA≈0.10. The four-mirror objective according to the invention is thus characterized by high resolution, low manufacturing costs and high throughput. In another embodiment a system using six multilayer mirrors is provided.

In both systems a first set of multilayer mirrors is in centered arrangement with respect to a first optical axis and a second set of multilayer mirrors is in centered arrangement with respect to a second optical axis. At least one additional mirror is disposed at grazing incidence between said first and said second set of multilayer mirrors, wherein said additional mirror defines an angle between said first optical axis and said second optical axis.

In a preferred embodiment of the invention, it is provided that an aperture stop lies on or near a mirror, especially on the tertiary mirror. In this embodiment, the aperture stop is physically accessible and the reduction objective is compact and free from vignetting.

In another embodiment of the reduction objective of the invention, the secondary mirror and the quaternary mirror are concave. In still a further embodiment of a four-mirror-system, the four mirrors are arranged in the convex-concave-convex-concave sequence.

The asphericities discussed herein refer to the peak-to-peak or peak-to-valley (PV) deviation A of the aspherical surfaces in comparison to the best fitting sphere in the used region of the mirrors. In the embodiments of the invention discussed herein, these are approximated by a sphere, the center of which lies on the figure-axis of the mirror and the meridional plane of the aspherical element intersects in the upper and lower and point of the used region. The data on the angles of incidence, as provided below in Table II, refer to the angle between the particular incident radiation and the normal to the surface at the point of incidence. The largest angle of incidence of a ray is established by a rim-ray at one of the mirrors.

Preferably, the optically free working distance on the wafer side is 60 mm and the free working distance on the reticle side is at least 100 mm.

As will be appreciated from this disclosure by persons of ordinary skill in the art, the objectives described above can be used not only for soft X-ray lithography, but for other wavelengths, both in the EUV range and outside of this range, without deviation from the invention. Nonetheless, the invention is preferably used at soft X-ray and EUV wavelengths in the region of 193 nm and below. Wavelengths within this range can be generated using excimer lasers.

In order to achieve a diffraction-limited system, it is preferred that the design part of the rms wave front section of the system is at most 0.07λ. It is further preferred that the reduction objective is designed so that it is telecentric on the image side. In systems with a transmission mask, the projection objective is also designed to be telecentric on the object side. In projection systems which are operated with a reflection mask, a telecentric beam path without illumination over a beam splitter which reduces transmission greatly, such as is shown in JP-A-95/28 31 16, is not possible on the object side. Therefore, the chief ray angle in the reticle is chosen so that shading-free illumination, that is no obscuration, is possible. Overall, the telecentricity error on the wafer should not exceed 10 mrad, and preferably is in the 5 mrad to below 2 mrad range. This ensures that the change in the image scale or distortion lies within tolerable limits in the depth of field.

In a preferred embodiment of the invention, the first set of multilayer mirrors comprises four mirrors and the second set of multilayer mirrors comprises two mirrors. The grazing-incidence mirror is arranged in such a way that the first and the second optical axis are parallel to each other. Such an embodiment provides for a short projection objective in axial direction and for small reflection angles at the object side.

According to another aspect of the invention, the reduction objective is used with a mask and a soft X-ray or EUV exposure source, for example, in a projection exposure apparatus, such as those used in lithography for integrated circuit fabrication. In the embodiment, the projection exposure apparatus has a reflection mask and, in an alternative embodiment, it has a transmission mask.

The projection exposure apparatus is preferably designed as an annular-field scanner illuminating an off-axis annular field. 10Advantageously, it is provided that the secant length of the scanning slit is at least 26 mm and that the annular width is greater than 0.5 mm, so that uniform illumination is made possible.

Another advantage of the objective of the invention, is that the asphericity of the aspherical optical elements is small enough so that the system requirements of being "diffraction-limited" and having high reflectivity multilayer mirrors can be achieved, such that the resulting accuracy requirements on these surfaces in all spatial frequency regions from the free diameter of the mirror to atomic dimensions can be obeyed.

According to another aspect of the invention, a method of integrated circuit fabrication using a projection exposure apparatus including a reduction objective is provided. The method comprises the steps of providing a mask, providing a soft X-ray or EUV, illumination source, and providing four mirrors (primary, secondary, tertiary, and quaternary) in centered arrangement with respect to an optical axis, wherein the primary mirror is a convex mirror and the secondary mirror has a positive angular magnification.

Traditionally, approximately 40 pairs of alternating Mo/Si DBR layers are used to create mirrors with high reflectivity of 13 nm wavelength incident light. Similarly, high reflectivity of 11 nm wavelength radiation, requires approximately 70 pairs of Mo/Be alternating layers. By using large numbers of DBR layers, the acceptance angle of mirrors and thus their objective systems is only a few degrees and decreases with increasing angle of incidence. Furthermore, with this increasing angle of incidence, detrimental phase effects can occur. If the test-point-related mean angle of incidence varies greatly over a system surface, then layer packets with changing thickness must be applied. These disadvantages of existing multilayer mirror objective systems are reduced in the present invention in which the objectives have a low mean angle of incidence and a low surface-specific variation around the mean angle of incidence.

The invention will be explained below with the aid of drawings depicting the preferred embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic representation of the system classification used in the invention.

FIG. **2** is a lens cross-section of a first four-mirror system (type-e system) according to the prior art.

FIG. **3** is a lens cross-section of a four-mirror system (type-f system) according to the invention.

FIG. **4** is a lens cross-section of another four-mirror system (type-g system) according to the invention.

FIG. **5** is a lens cross-section of type f with an introduced grazing incidence mirror according to the invention.

FIG. **6** is a lens cross-section of a system with six multilayer mirrors and a grazing incidence mirror.

FIG. **7** is a depiction of a four-mirror or six-mirror reduction objective that is telecentric on the object side and used with a transmission mask.

FIG. **8** is a depiction of a four-mirror or six-mirror reduction objective that is telecentric on the object side and used with a reflection mask.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The practical examples identified in FIGS. **2** to **5** are centered reduction systems, telecentric on the image side, with an aperture stop (indicated by AS in FIG. **4**, for example) at the third mirror **M3**. In all systems, the same reference numbers are used for the same components and the following nomenclature is employed:

first (primary) mirror (**M1**), second (secondary) mirror (**M2**), third (tertiary) mirror (**M3**), fourth (quaternary) mirror (**M4**).

Reduction objectives used in lithography are classified by their primary mirror magnification m(**M1**), or convergence ratio $\nu(M1)=-1/m(M1)$, and their secondary-mirror chief ray angular magnification $\mu(M2)$. This nomenclature is taken from Dietrich Korsch, Reflective optics, Academic Press, 1991, p. 41 ff, which is incorporated herein by reference. For the different types of primary mirrors Table 1, below, summarizes the different convergence ratio and angular magnification values obtainable.

TABLE I

	M1	$\nu(M1)$	$\mu(M2)$
type-a	concave	$\epsilon]1,\infty[$	$<-\epsilon_4$
type-b	plane, concave	$\epsilon[-1,1]$	$<-\epsilon_4$
type-e	convex	$\epsilon]-\infty,-1[$	$<-\epsilon_4$
type-f	convex	$\epsilon]-\infty,-1[$	$\epsilon]\epsilon_4,1-\epsilon_2[$
type-g	convex	$\epsilon]-\infty,-1[$	$\epsilon]1+\epsilon_3,\infty[$

The following is true for these systems: $\epsilon_i>0$ increases with the numerical i6, 1aperture NA of the system, that is, $\epsilon_i=0\rightarrow$ NA=0. A schematic representation of the system classification as used below is shown in FIG. **1**.

The concept of the chief ray angular magnification or angular magnification refers to the tangents of the chief ray (see Korsch, Reflective Optics, incorporated by reference above). A positive angular magnification means that the slopes of the straight lines identifiable with the incident and reflected chief rays to the optical axis have the same sign, that is, that the entrance and exit pupils of the respective mirror lie on the same physical side of the mirror.

As shown in FIG. **1**, type-a, type-b and type-e are topologically connected components of the two-dimensional parameter space. Therefore type-a, type-b, and type-e objectives can be transformed continuously into each other. In contrast, this is not possible between each of the two other classes of the three systems shown in FIG. **1**. The class including types-a, -b, and -e, can not be continuously transformed into the type-f class (system) or the type-g class (system). FIG. **1** indicates the forbidden regions F in which, in the case of a finite NA, obscuration of the light beam by the mirror will occur and therefore the objectives will fail to image properly.

The particular topologically-connected component region is determined by $\mu(M2)$. The annular field systems disclosed in U.S. Pat. No. 5,315,629 and EP 480,617 are type-a systems. Type-b systems provide continuous transition to the type-e system which also include the system known from Donald W. Sweeney et al., 23rd International Symposium of Microlithography. Type-a, type-b, and type-e systems are known in the prior art.

Systems of type-f and type-g are not known from any of the publications referred to above. The systems according to type-f and type-g differ from the systems of U.S. Pat. No. 5,315,629 and EP 480,617 by having a convex primary mirror. The system disclosed in Donald W. Sweeney et al., 23rd International Symposium of Microlithography, loc. cit., has a convex primary mirror but it also has a different angular magnification μ at **M2** and thus a different optical path in the system, which does not overcome the prior art problems described above.

Systems of type-f with ν(**M 1**) above approximately −1.5 lead to large chief ray angles on the reticle and to large system diameters. As a result, sensible system design with a concave **M1**, i.e. ν(**M1**)≧1, is difficult.

In the following Table II, typical functional data are given for some of the embodiments of the various system categories. The distortion values follow from the magnification correction through the annular field. Objective systems belonging to the individual system classes are shown in FIGS. **2–5**.

TABLE II

	type-f (94)	type-g (68)
M1	convex	convex
ν(M1)	−2.4	−2.9
μ(M2)	0.6	1.6
NA	0.1	0.1
Red	4x	4x
annular field [mm^2]	26.0 × 1.0	26.0 × 1.25
mean annular field radius [mm]	25	51
OO' [mm]	1368	1112
FWD [mm]	92	62
CRAO [mm]	ϵ[−2.1, −2.0]	ϵ[4.1, 4.2]
CRA [mrad]	ϵ[−0.35, −0.50]	ϵ[−0.2, 0.2]
max. asph. [μm]	19.6	8.3
AOI max. [deg]	14.1	22.0
ΔAOI max. [deg]	±2.5	±2.8
WFE max. [λrms]	0.029	0.025
distortion [nmPV]	7	30

Explanation of the abbreviations used in Table II are listed in Table III, below.

TABLE III

	Meaning
M1	form of the primary mirror
ν(M1)	"conversion ratio" according to Korsch
μ(M2)	"angular magnification" according to Korsch
NA	image-side numerical aperture
Red	reduction factor = −1/imaging scale
annular field [mm^2]	secant length × annular width in the image field
mean annular field radius [mm]	image field radius in the middle of the annular field
OO' [mm]	object-image distance
FWD [mm]	optically free working distance on the image side
CRAO [deg]	chief ray angle in the object space
CRA [mrad]	chief ray angle in the image space
max. asph. [μm]	maximum deviation of the asphere from the best fitting sphere with respect to the used region of the mirror
AOI max. [deg]	maximum angle of incidence
ΔAOI max. [deg]	variation of the angle of incidence over the mirror
WFE max. [λrms]	maximum rms wavefront error in units of λ
distortion [nmPV]	peak-to-peak value over the annular field scale-corrected chief ray distortion

Systems with a convex **M1**, i.e. primary mirror, show a significantly higher asphericity than the type-a designs with a concave **M1**.

FIG. **2** shows a cross-section of a type-e system from a reticle plane **2**, or mask, to a wafer plane **4**. The mirror nearest to the wafer is the first mirror **M1**. Type-e systems have the lowest AOI and ΔAOI on mirrors **M1**, **M2**, **M3**, **M4**, which favors the polarization-optical properties of the system. However, the high chief ray angles on the reticle plane **2** requires plane reticles. Conversely, type-g systems, as shown in cross-section in FIG. **4**, have relatively large AOI and ΔAOI on mirrors **M1**, **M2**, **M3**, **M4** with tolerable chief ray angles on the reticle.

As shown in FIG. **3**, type-f systems require the largest aspherical elements, but have favorable angular distributions on mirrors **M1**, **M2**, **M3**, **M4** and on the reticle **2**. The low distortion results in a relatively small image field. Although the constructional length, i.e. the physical length, of the system is larger than in the other systems, the long drift sections within the objective permit the optional use of additional components, such as an alignment system, deflecting mirror, etc. A chief ray CR and an optical axis HA are also shown in FIG. **3**.

The type-f and type-g systems, as shown in FIGS. **3** and **4**, respectively, can be realized with positive and negative chief ray angles on reticle **2**. Thus, an optimal geometry can be selected, especially a comparatively low free working distance to reticle **2**, for imaging the light when using a reflection mask. Furthermore, when using a transmission mask, a telecentric beam path can be realized.

The systems of type-a and type-f have relatively long "drift sections" before or within the actual image system. Therefore, it is possible to introduce grazing-incidence mirrors of high reflectivity as correction elements. These correction elements can include Schmidt corrector-type elements or an active optical correction system. Based on known values for molybdenum-coated mirrors; it is theoretically possible to achieve approximately 85% reflectivity of non-polarized incident light of wavelength 13.3 nm incident at an angle of 75°. Due to the grazing incidence of the beam, the illuminated part of the mirror can be made

very large in one direction, in comparison to that on the neighboring mirror, which facilitates the design of the correcting elements. Preferably, the individual mirrors are designed in a pair-wise manner with the normals to the surface being almost perpendicular to one another, in order to be able to manipulate the beams in all spatial directions with the same resolution. FIG. **5** shows such a design of type-f with an introduced grazing-incidence mirror GIM.

The parameters of the system according to FIG. **3** in the code V format are given in Table 1 below.

TABLE 1

Type-f (94) 4 ×/0.10 1.0 mm annular field

ELEMENT NUMBER	RADIUS	THICKNESS	DIAMETER	TYPE
OBJECT	INF	0.000	204.000	
		100.228	217.084	
		380.421		
M1	A(1)	−380.421	264.271	REFL.
M2	A(2)	380.421	563.054	REFL.
		796.185	390.422	
		APERTURE-STOP	23.764	
M3	A(3)	−117.68	23.764	REFL.
M4	A(4)	117.968	92.608	REFL.
		284.465	71.790	
			89.622	
IMAGE	IMAGE WIDTH = INF.	−192.945	50.989	

Aspherical Constants:

$$Z = \frac{(CURV)Y^2}{1 + (1 - (1 + K)(CURV)^2 Y^2)^{1/2}} + (A)Y^4 + (B)Y^6 + (C)Y^8 + (D)Y^{10}$$

Asphere	CURV	K	A	B	C	D
A(1)	0.0014137	−4.643893	0.00000E − 00	−6.97355E − 15	7.87388E − 20	0.00000E + 00
A(2)	0.0011339	−0.232793	0.00000E + 00	−5.35926E − 17	3.35875E − 23	0.00000E + 00
A(3)	0.0040246	6.006678	0.00000E − 00	3.76117E − 13	−1.43488E − 15	0.00000E + 00
A(4)	0.0042162	0.289323	0.00000E + 00	8.76473E − 15	−5.59142E − 19	0.00000E + 00

Reference wavelength = 13 nm

Similar to Table 1 above, the constructional data of the type-g system shown in FIG. **4** can be seen in the following Table 2:

TABLE 2

ELEMENT NUMBER	RADIUS	THICKNESS	DIAMETER	TYPE
OBJECT	INF	0.000		
			413.000	
		378.925		
			373.642	
		474.629		
M1	A(1)	−474.629	327.612	REFL.
M2	A(2)	474.629	600.624	REFL.
			206.075	
		196.627		
		APERTURE-STOP	28.266	
M3	A(3)	−136.037	28.266	REFL.
M4	A(4)	136.037	141.438	REFL.
			115.807	
		−196.627		
			155.535	
		160.000		
IMAGE	IMAGE WIDTH = INF.	98.781	103.302	

Aspherical Constants	CURV	K	A	B	C	D

TABLE 2-continued

A(1)	0.0010894	−0.738027	0.00000E+00	3.65218E−16	−1.37411E−20	0.00000E+00
A(2)	0.0012023	0.031851	0.00000E−00	1.38321E−17	−6.58953E−23	0.00000E+00
A(3)	0.0036931	1.579939	0.00000E+00	−1.26703E−13	3.53973E−16	0.00000E+00
A(4)	0.0035917	0.316575	0.00000E+00	3.15592E−15	1.74158E−19	0.00000E+00
Reference Wavelength	13.0 nm					

If a grazing incidence, deflecting mirror GIM is introduced between mirrors **M1**, **M2** and **M3**, **M4**, then one obtains the structure of type-f shown in FIG. **5**. The data for this embodiment can be seen in Table 3.

TABLE 3

Type-f(xx) 4x/0.10 1.0 mm annular field

ELEMENT NUMBER	RADIUS	THICKNESS	DIAMETER	TYPE
OBJECT	INF	0.000		
			204.000	
		100.000		
			217.065	
		380.407		
M1	A(1)	−380.407	264.287	REFL.
M2	A(2)	380.407	563.152	REFL.
			390.481	
		296. 123		
	DECENTER (1)			
GIM	INF	−499.995	536.341	REFL.
		APERTURE STOP	23.757	
M3	A(3)	117.968	23.757	REFL.
M4	A(4)	−117.968	92.614	REFL.
			69.580	
		−284.465		
	IMAGE WIDTH =	192.994		
IMAGE	INF.		51.000	

Aspherical Constant N	CURV	K	A	B	C	D
A(1)	0.0014140	−4.643296	0.00000E+00	−96.99186−15	7.89877E−20	0.00000E−00
A(2)	0.0012023	0.031851	0.00000E−00	1.38321E−17	−6.58953E−23	0.00000E+0
A(3)	0.0012023	1.579939	0.00000E+00	−1.26703E−13	3.5973E−16	0.00000E+0
A(4)	−0.0042169	0.289286	0.00000E+00	−8.76770E−15	5.47269E−19	0.00000E+00
DECENTER CONSTANTS DECENTER			Deflection Angle ALPHA AM GIM			
D(1) Wavelength 13 nm			75.00000 Degree			

In FIG. **6** another embodiment of the invention is shown. The projection objective comprises reticle **2** in the object plane. The system is telecentric in the image plane, i.e., the wafer plane **4**. A first set of multilayer mirrors comprises the mirrors **M1**, **M2**, **M3** and **M4** in centered arrangement to a first optical axis **HA1**, and a second set of multilayer mirrors comprises the mirrors **M4** and **M5** in centered arrangement to a second optical axis **HA2**. The mirror **M4** has a positive chief ray angular magnification. The grazing incidence mirror GIM is arranged such that the first optical axis **HA1** is parallel to the second optical axis **HA2**. The projection objective system comprises an intermediate image **IM1** between the fourth and fifth mirror.

The grazing incidence mirror GIM is disposed near the intermediate image. Since near the intermediate image the ray bundle has only a small extension, the grazing incidence mirror can be chosen small in size.

Preferably the grazing incidence mirror is arranged in the system, such that the distance d_1 from the first optical axis **HA1** to the grazing incidence mirror is equal to the distance d_2 from the second optical axis **HA2** to the grazing incidence mirror.

Furthermore in FIG. **6** a system of coordinates is shown. The z-direction is parallel to the optical axes **HA1**, **HA2**. The y-direction is perpendicular to the z-direction and lies in the plane of the figure. The x-direction is perpendicular to the z- and the y-direction. In such a coordinate system the projection objective according to FIG. **6** has a positive linear magnification in the x-direction, and due to the grazing incidence mirror GIM, the system has negative linear magnification in y-direction.

The projection objective according to FIG. **6** provides for a large distance between the object plane and the first mirror and thus for small reflection angles in the object plane. The

data of the system according to FIG. **6** in Code-V-format are apparent from Table 4:

TABLE 4

6 mirror-system with addition grazing incidence mirror

Element Number	Radius	Thickness	Diameter	Type
Object	INF	1060.0000		
1	A(1)	−652.9611	284.1884	REFL
		Aperture Stop 0.0000	155.8959	
2	A(2)	472.9611	156.3900	REFL
3	A(3)	−620.5240	159.1868	REFL
4	A(4)	680.4920	577.1214	REFL
	DECENTER(1)			
5	INF	−80.9306	232.9061	REFL
	DECENTER(2)	−427.9379	251.8960	
	DECENTER(3)			
6	A(5)	427.9379	107.6545	REFL
7	A(6)	−479.1014	333.2079	REFL
IMAGE	INF		70.9994	

Aspheric Constants

$$Z = \frac{(CURV)Y^2}{1+(1-(1+K)(CURV)^2Y^2)^{1/2}} + (A)Y^4 + (B)Y^6 + (C)Y^8 + (D)Y^{10}$$

Aspherical Constant N	CURV	K	A	B	C	D
A(1)	0.00034830	3.659681	0.00000E + 00	1.32325E − 15	6.23099E − 22	0.00000E − 00
A(2)	0.00081769	1.117921	0.00000E + 00	−5.02192E − 15	−4.822269E − 20	0.00000E + 00
A(3)	0.00208391	0.843622	0.00000E + 00	7.65748E − 14	−2.37306E − 19	0.00000E + 00
A(4)	0.00104477	−0.865338	0.00000E + 00	1.25916E − 15	−3.29529E − 21	0.00000E + 00
A(5)	−0.00186127	11.590049	0.00000E + 00	3.16061E − 13	1.45186E − 17	0.00000E + 00
A(6)	0.00184285	0.106589	0.00000E + 00	−2.10598E − 16	−1.32532E − 21	0.00000E + 00

DECENTERING CONSTANTS

Decenter	X	Y	Z	Alpha	Beta	Gamma
D(1)	0.0000	−120.000	0.0000	90.0000	0.0000	0.0000 (BEND)
D(2)	0.0000	120.000	0.0000	0.0000	0.0000	0.0000
D(3)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

DECENTERING CONSTANT KEY:

Type	Trailing Code	Order of Application
DECENTER		DISPLACE (X, Y, Z) TILT (ALPHA, BETA, GAMMA) REFRACT AT SURFACE THICKNESS TO NEXT SURFACE
DECENTER & BEND	BEND	DECENTER (X, Y, Z, ALPHA, BETA, GAMMA) REFLECT AT SURFACE BEND (ALPHA, BETA, GAMMA) THICKNESS TO NEXT SURFACE

REFERENCE WAVELENGTH = 13.5 NM

FIG. **7** shows the four-mirror or six-mirror reduction objective of FIGS. **3**, **4**, or **6** with the reticle plane **2** as a transmission mask. Thus, it can be seen from FIG. **6** that the reduction objective is telecentric on the object side of such a configuration.

Similarly, FIG. **8** shows the four-mirror or six mirror reduction objective of FIGS. **3**, **4**, or **6** with reticle plane **2** as a reflection mask. In such a configuration, a beam splitter may be used, for example, to ensure the reduction objective is also telecentric on the object side.

Thus, the invention provides for a reduction objective with an imaging reduction scale of approximately 4× for use in soft X-ray, i.e., EUV and UV, annular field projection applications, such as lithography. The reduction objection achieves the necessary resolution at the required image field and provides a structural design with optical elements of sufficiently mild asphericity, sufficiently small incident angles for the multilayered optics, and sufficiently large constructional space for the image carriers.

We claim:

1. A reduction objective with an image side and an object side, comprising:

a first set of multilayer mirrors in centered arrangement with respect to a first optical axis, and a second set of multilayer mirrors in centered arrangement with

respect to a second optical axis situated between the image side and the object side; and

an additional mirror disposed at grazing incidence such that said additional mirror defines an angle between said first optical axis and said second optical axis.

2. A reduction objective according to claim **1**, wherein the first set of multilayer mirrors comprises a primary multilayer mirror and a secondary multilayer mirror.

3. A reduction objective according to claim **2**, wherein the primary mirror is convex and the secondary mirror has positive chief ray angular magnification.

4. A reduction objective according to claim **2**, wherein the second set of multilayer mirrors comprises a tertiary multilayer mirror and a quaternary multilayer mirror.

5. A reduction objective according to claim **4**, wherein the primary mirror is convex and the secondary mirror has positive chief ray angular magnification.

6. A reduction objective according to claim **1**, wherein said angle is 75°.

7. A reduction objective according to claim **1**, wherein the first set of multilayer mirrors comprises a primary, a secondary, a tertiary and a quaternary multilayer mirror.

8. A reduction objective according to claim **7**, wherein the second set of multilayer mirrors comprise a fifth and a sixth multilayer mirror.

9. A reduction objective according to claim **8**, wherein the fifth mirror is convex and the sixth mirror is concave.

10. A reduction objective according to claim **8**, wherein the first and the second optical axis are parallel to each other and said angle is 0°.

11. A reduction objective according to claim **10**, wherein the grazing incidence mirror is disposed between the first optical axis and the second optical axis.

12. A reduction objective according to claim **10**, wherein the objective is telecentric at the object side.

13. A reduction objective according to claim **10**, wherein the objective is telecentric at the image side.

14. A reduction objective according to claim **8**, wherein the reduction objective comprises a plane conjugate to the object plane in which an intermediate image of the object lies.

15. A reduction objective according to claim **14**, wherein the grazing incidence mirror is disposed near the intermediate image of the object.

16. A reduction objective according to claim **8**, wherein the quaternary multilayer mirror has positive chief ray angular magnification.

17. A reduction objective according to claim **8**, wherein linear magnification of the reduction objective in an x-direction is positive and the linear magnification of the reduction objective in a y-direction is negative.

18. A projection exposure apparatus including a reduction objective with an image side and an object side for annular field scanning operation comprising:

a mask;

a first set of multilayer mirrors in centered arrangement with respect to a first optical axis and a second set of multilayer mirrors in centered arrangement with respect to a second optical axis situated between the image side and the object side; and

an additional mirror disposed at grazing incidence such that said additional mirror defines an angle between said first optical axis and said second optical axis.

19. A method for integrated circuit fabrication using a projection exposure apparatus including a reduction objective, with an image side and an object side, comprising the steps of:

providing a mask;

providing a first set of multilayer mirrors in centered arrangement with respect to a first optical axis and a second set of multilayer mirrors in centered arrangement with respect to a second optical axis situated between the image side and the object side; and

providing an additional mirror disposed at grazing incidence such that said additional mirror defines an angle between said first optical axis and said second optical axis.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 6,577,443 B2
DATED : June 10, 2003
INVENTOR(S) : Dinger et al.

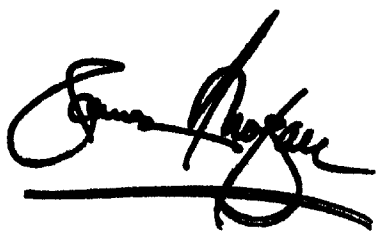
It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Title page,
Item [75], Inventors, please correct inventorship to include the following inventors:

-- **Udo Dinger**;
Hans-Jürgen Mann; and
Dr. Wolfgang Singer --
Item [30], please change the application number for the **Foreign Application Priority Data** from "19324442" to -- 19824442 --.

Signed and Sealed this

Twenty-third Day of December, 2003



JAMES E. ROGAN
Director of the United States Patent and Trademark Office

US006552806B1

(12) **United States Patent**
Swinford et al.

(10) **Patent No.: US 6,552,806 B1**
(45) **Date of Patent: Apr. 22, 2003**

(54) **AUTOMATED MINIMIZATION OF OPTICAL PATH DIFFERENCE AND REFERENCE MIRROR FOCUS IN WHITE-LIGHT INTERFERENCE MICROSCOPE OBJECTIVE**

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(73) Assignee: **Veeco Instruments Inc.**, Tucson, AZ (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/497,567**

(22) Filed: **Feb. 3, 2000**

(51) **Int. Cl.**[7] **G01B 9/02**
(52) **U.S. Cl.** **356/512**; 356/497
(58) **Field of Search** 356/497, 511, 356/512; 359/371

(56) **References Cited**

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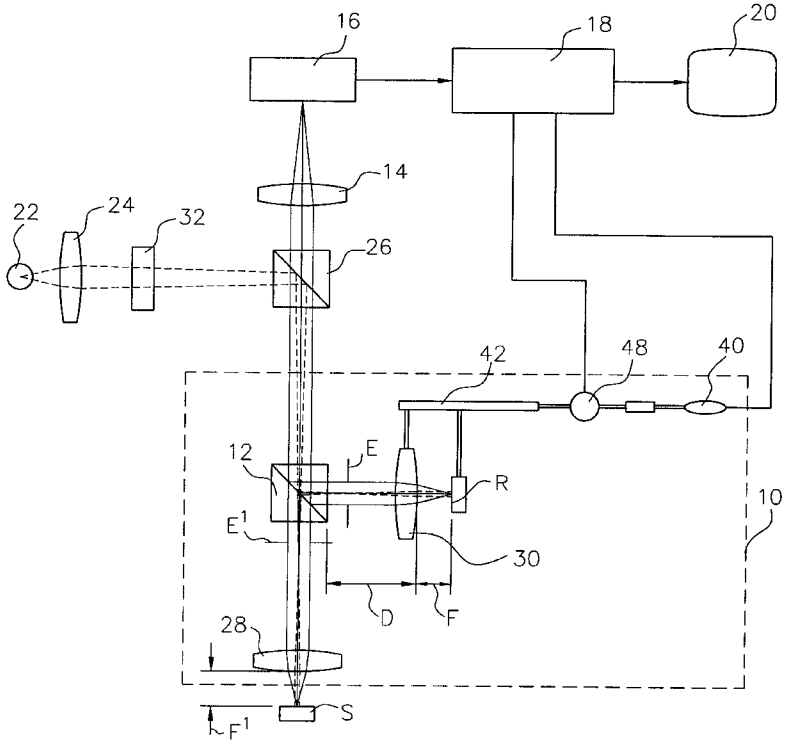
Primary Examiner—Samuel A. Turner
Assistant Examiner—Patrick Connolly
(74) *Attorney, Agent, or Firm*—Antonio R. Durando; Durando Birdwell & Janke, PLC

(57) **ABSTRACT**

Average fringe contrast is determined by PSI measurements at each step of relatively large translations of the reference optics and mirror of a white-light Linnik interference objective and the resulting data are used to minimize the OPD between the reference and test beam paths of the instrument. Utilizing the same algorithms used in the art to perform conventional vertical scanning interferometry, the position of minimum OPD is determined by finding the position of maximum average fringe contrast. Furthermore, by automating the system with a precise translation mechanism, operator-to-operator variations are completely eliminated and the precision of the process of OPD minimization is greatly improved. In another embodiment of the invention, the optimal focal position of the reference mirror is found at the same time by calculating the average lateral variation of fringe contrast as a function of OPD and focal position. The optimal OPD and focal position correspond to the maximum average lateral variation of fringe contrast in the resulting three-dimensional space.

25 Claims, 15 Drawing Sheets



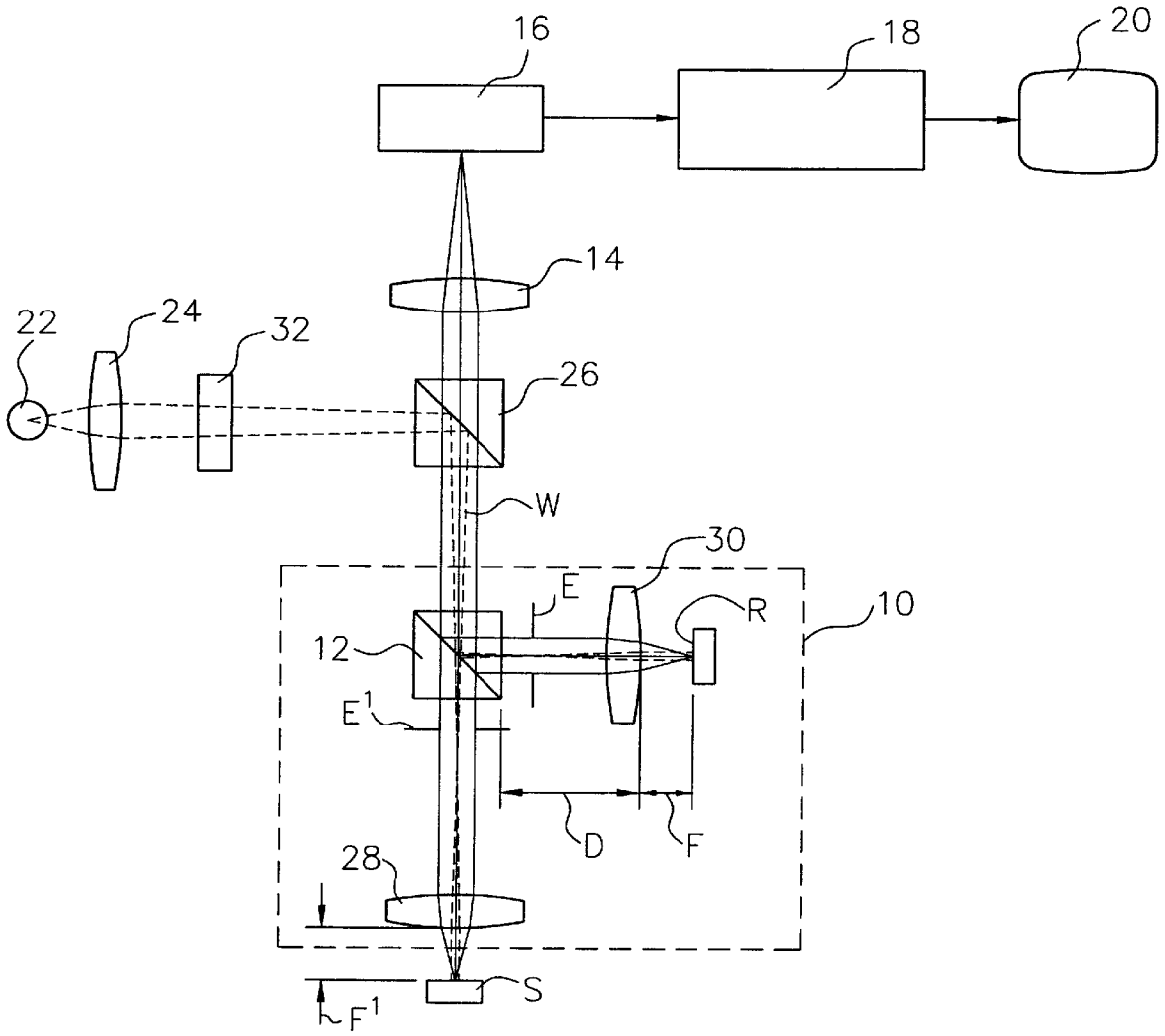


Fig. 1 (Prior Art)

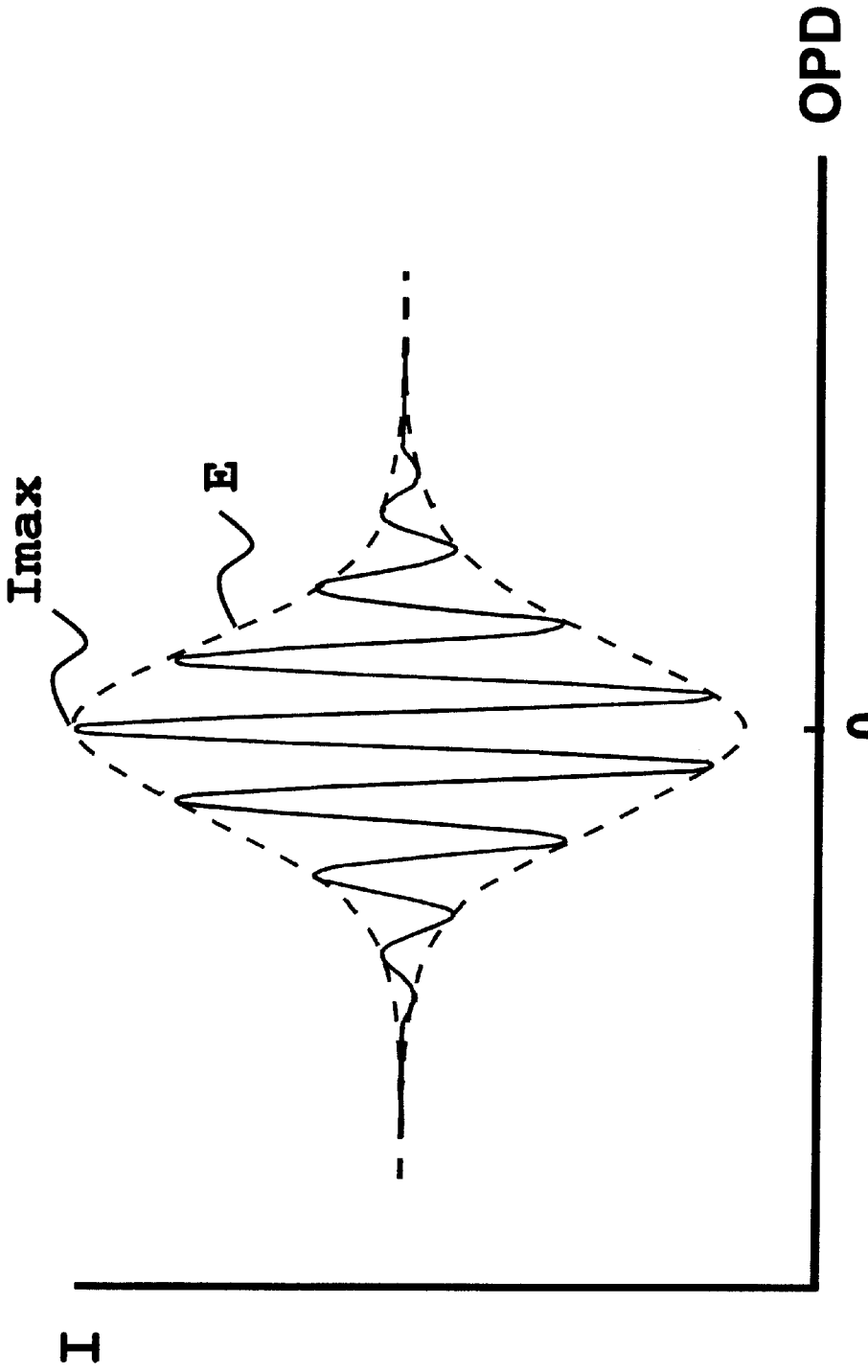


FIG. 2 (PRIOR ART)

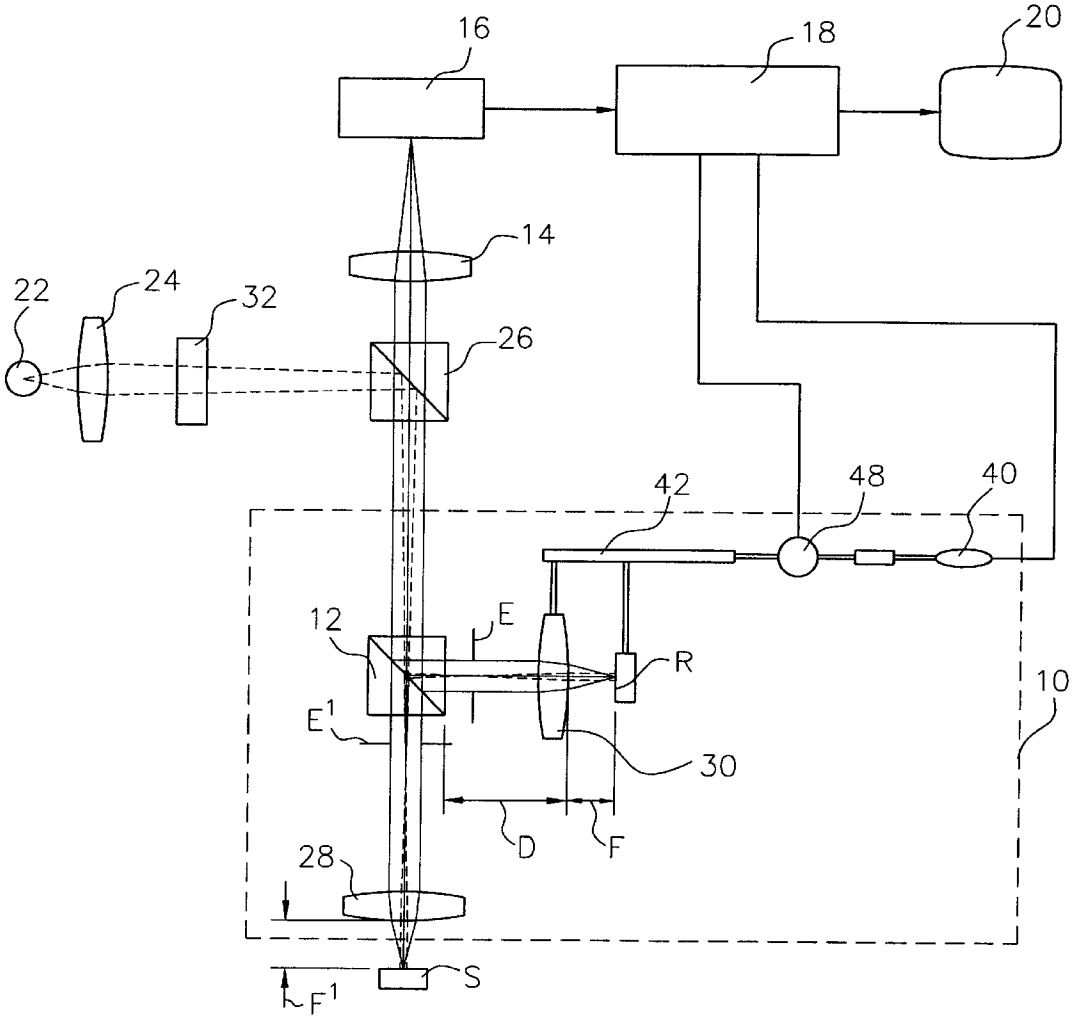


Fig. 3

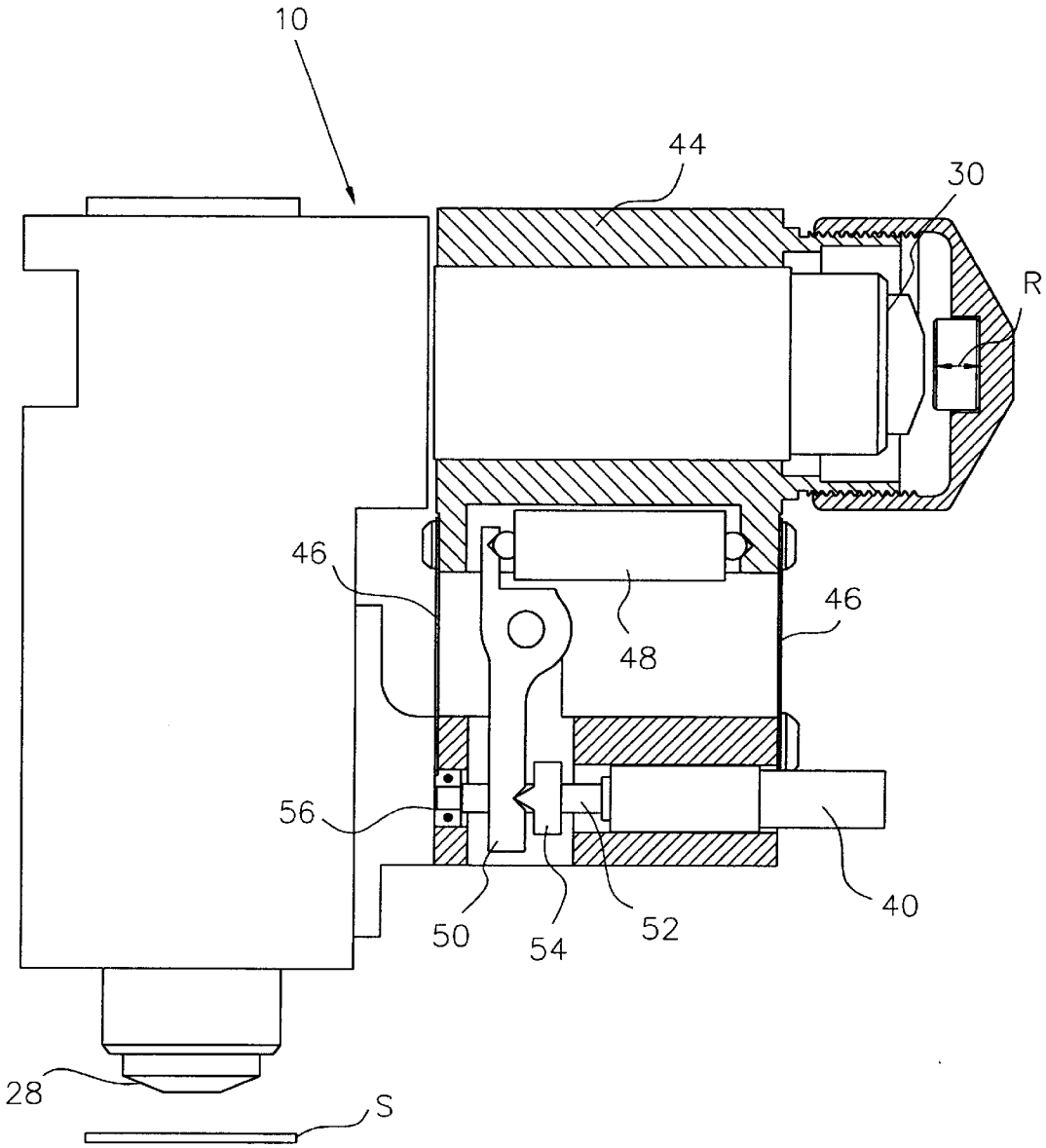
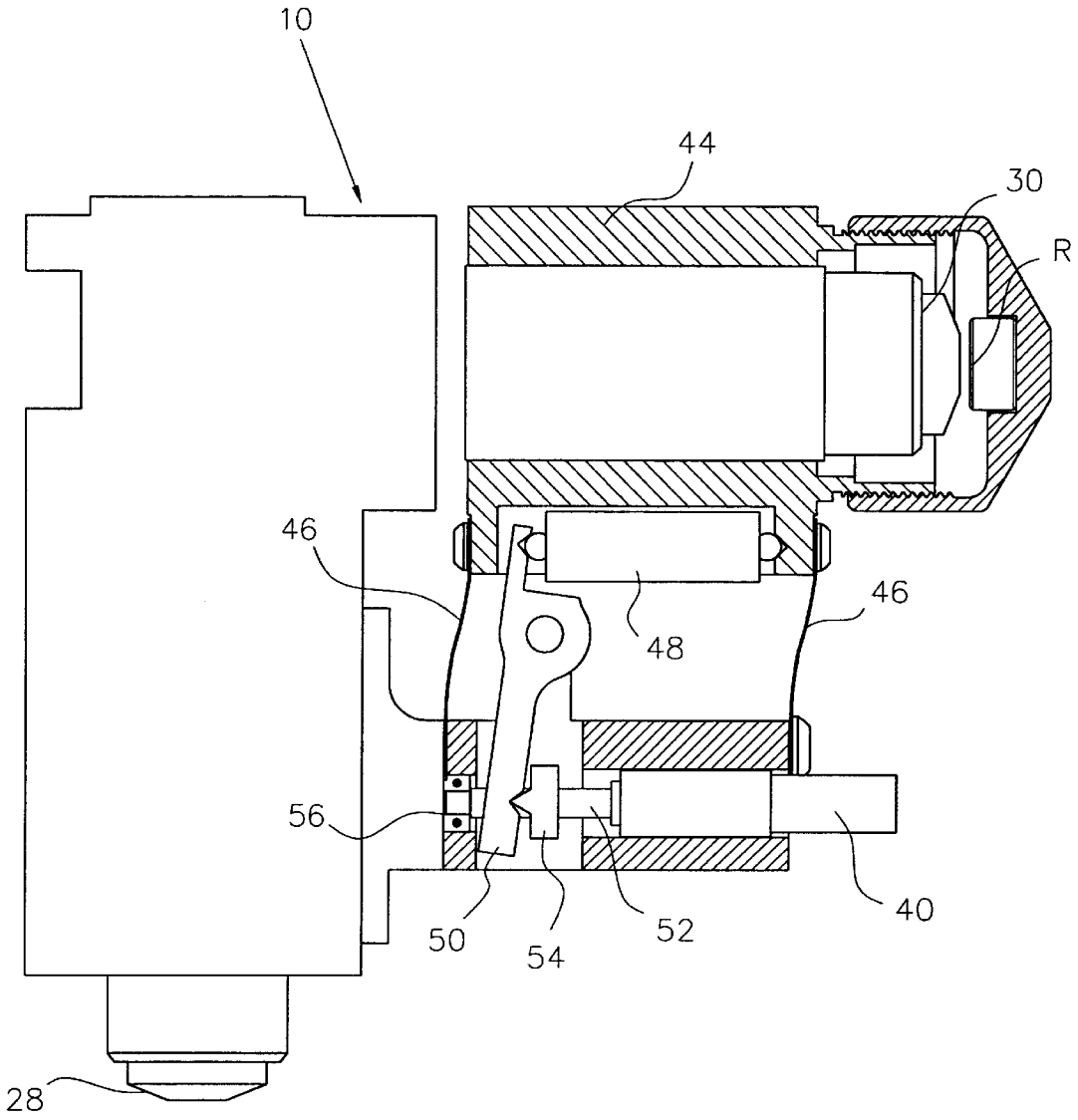


Fig. 4



EXTENDED POSITION
(EXAGGERATED FOR CLARITY)

Fig. 5

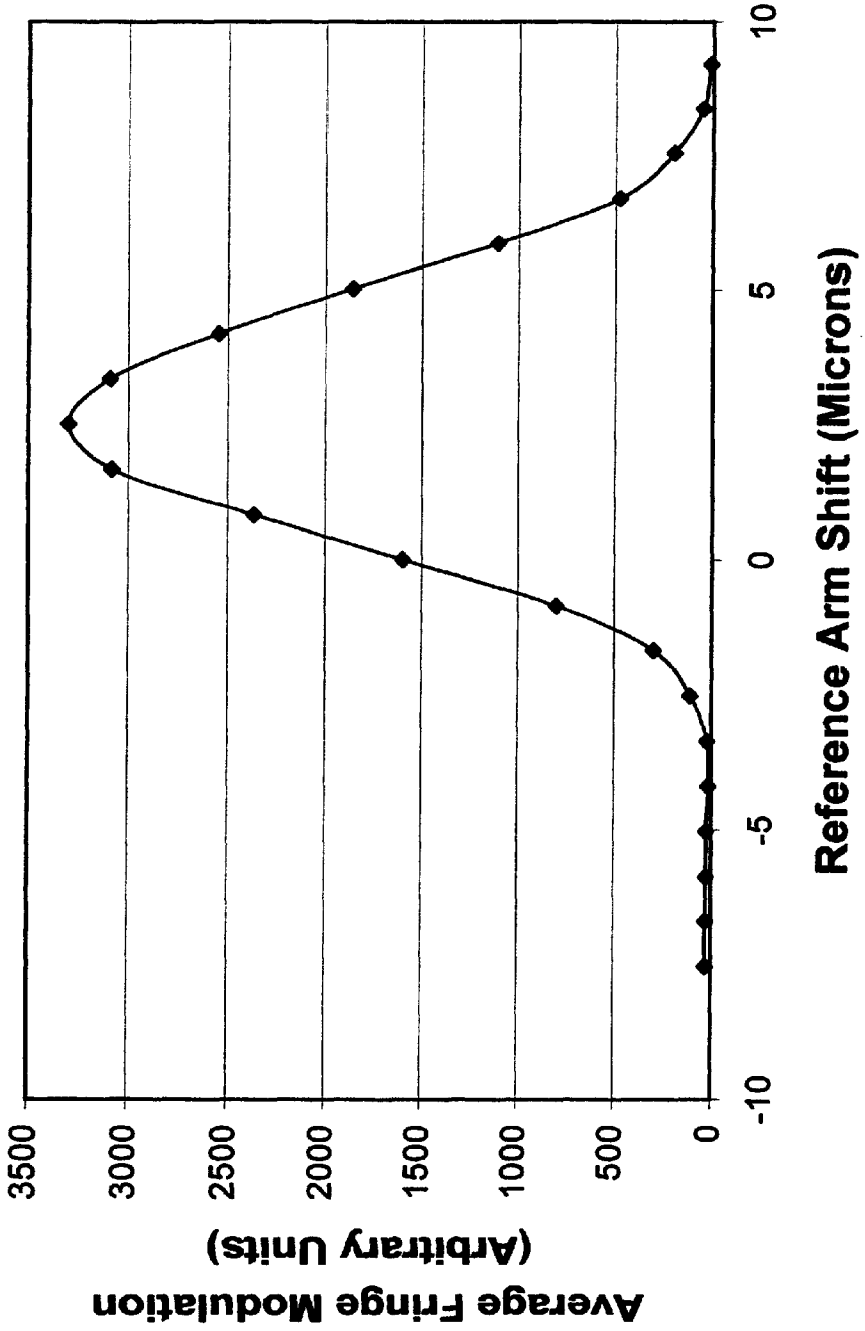

Average Fringe Modulation
(Arbitrary Units)
3500
3000
2500
2000
1500
1000
500
0
-10
-5
0
5
10
Reference Arm Shift (Microns)

Fig. 6

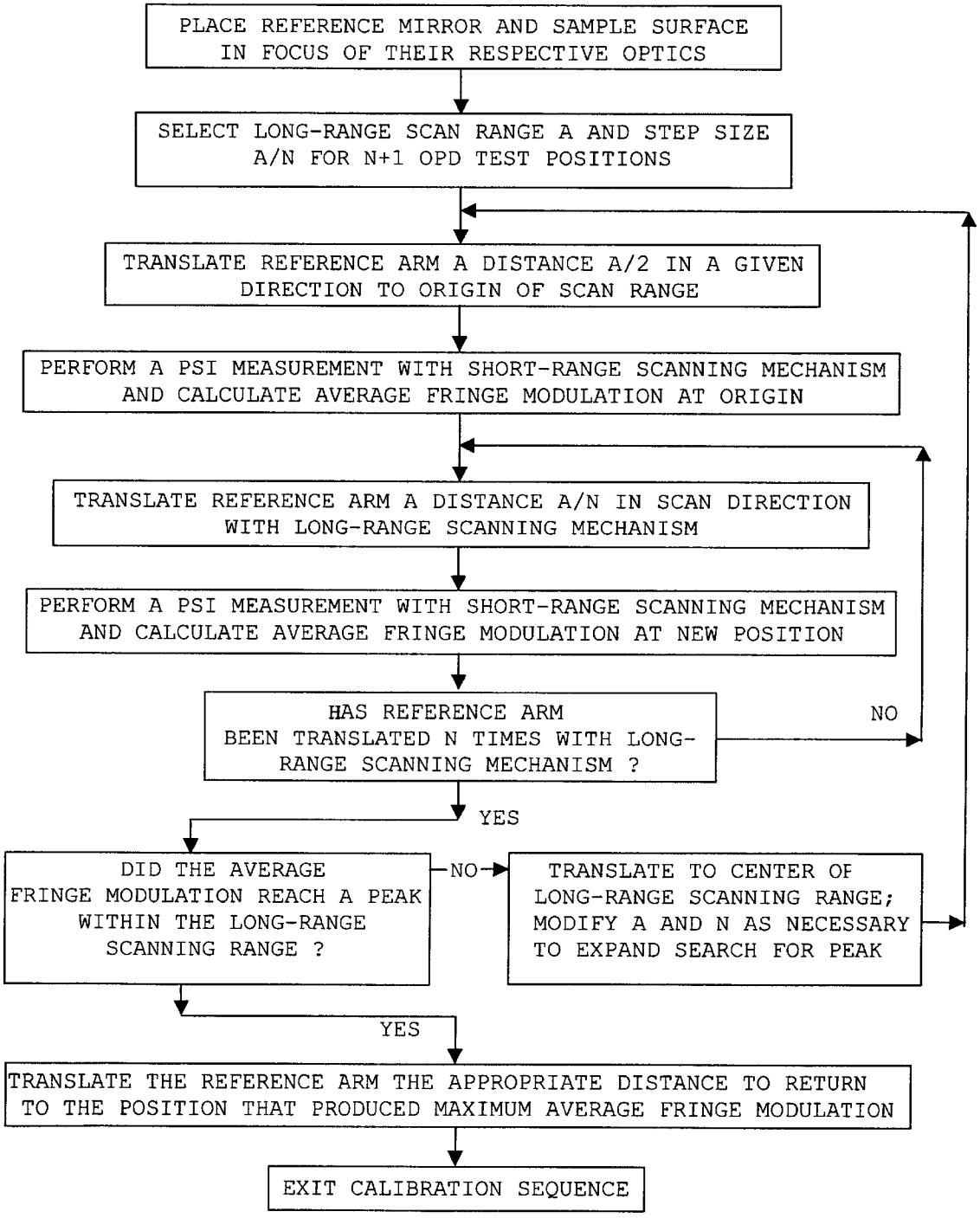

PLACE REFERENCE MIRROR AND SAMPLE SURFACE IN FOCUS OF THEIR RESPECTIVE OPTICS
SELECT LONG-RANGE SCAN RANGE A AND STEP SIZE A/N FOR N+1 OPD TEST POSITIONS
TRANSLATE REFERENCE ARM A DISTANCE A/2 IN A GIVEN DIRECTION TO ORIGIN OF SCAN RANGE
PERFORM A PSI MEASUREMENT WITH SHORT-RANGE SCANNING MECHANISM AND CALCULATE AVERAGE FRINGE MODULATION AT ORIGIN
TRANSLATE REFERENCE ARM A DISTANCE A/N IN SCAN DIRECTION WITH LONG-RANGE SCANNING MECHANISM
PERFORM A PSI MEASUREMENT WITH SHORT-RANGE SCANNING MECHANISM AND CALCULATE AVERAGE FRINGE MODULATION AT NEW POSITION
HAS REFERENCE ARM BEEN TRANSLATED N TIMES WITH LONG-RANGE SCANNING MECHANISM ?
NO
YES
DID THE AVERAGE FRINGE MODULATION REACH A PEAK WITHIN THE LONG-RANGE SCANNING RANGE ?
NO
TRANSLATE TO CENTER OF LONG-RANGE SCANNING RANGE; MODIFY A AND N AS NECESSARY TO EXPAND SEARCH FOR PEAK
YES
TRANSLATE THE REFERENCE ARM THE APPROPRIATE DISTANCE TO RETURN TO THE POSITION THAT PRODUCED MAXIMUM AVERAGE FRINGE MODULATION
EXIT CALIBRATION SEQUENCE

FIG. 7

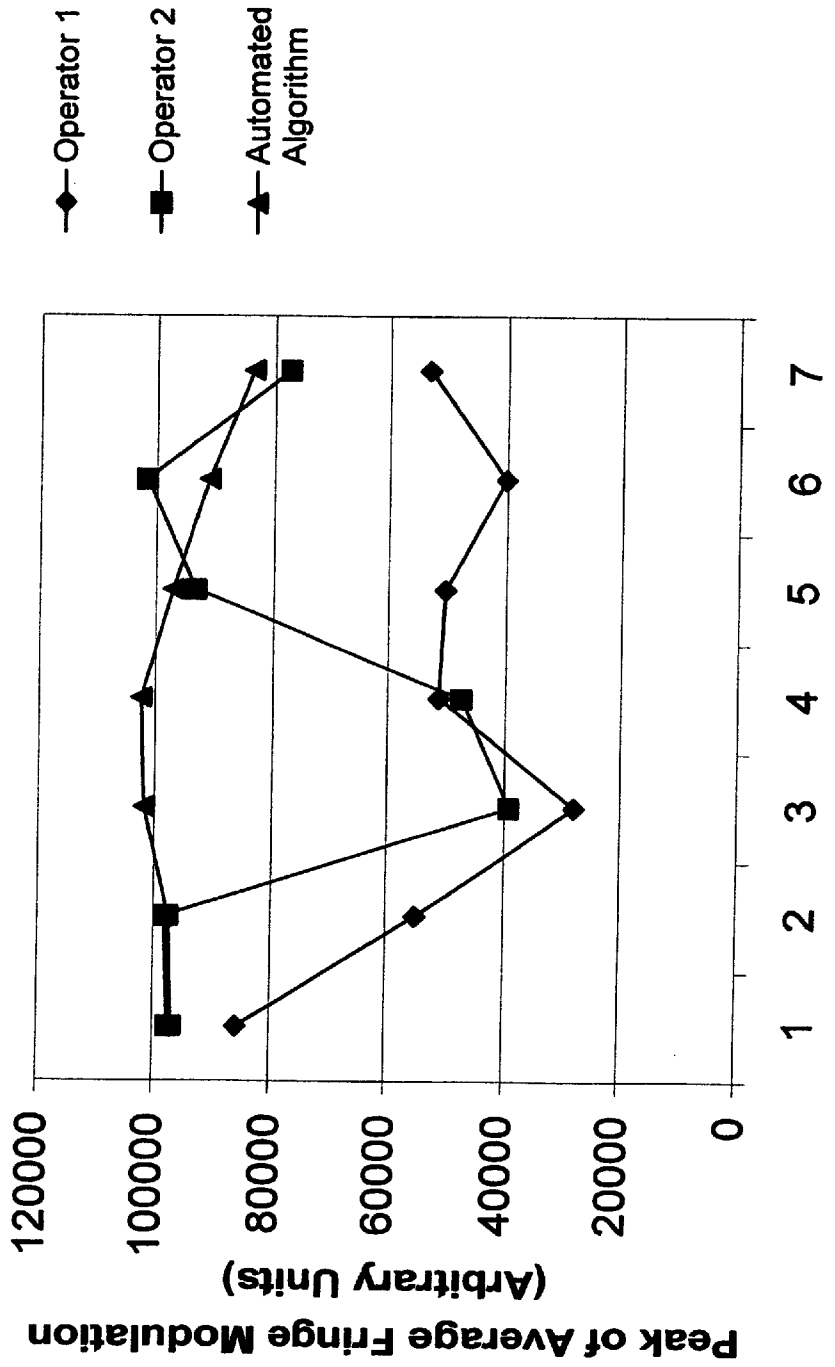

Operator 1
Operator 2
Automated Algorithm
Peak of Average Fringe Modulation
(Arbitrary Units)
120000
100000
80000
60000
40000
20000
0
1
2
3
4
5
6
7
Trial

Fig. 8

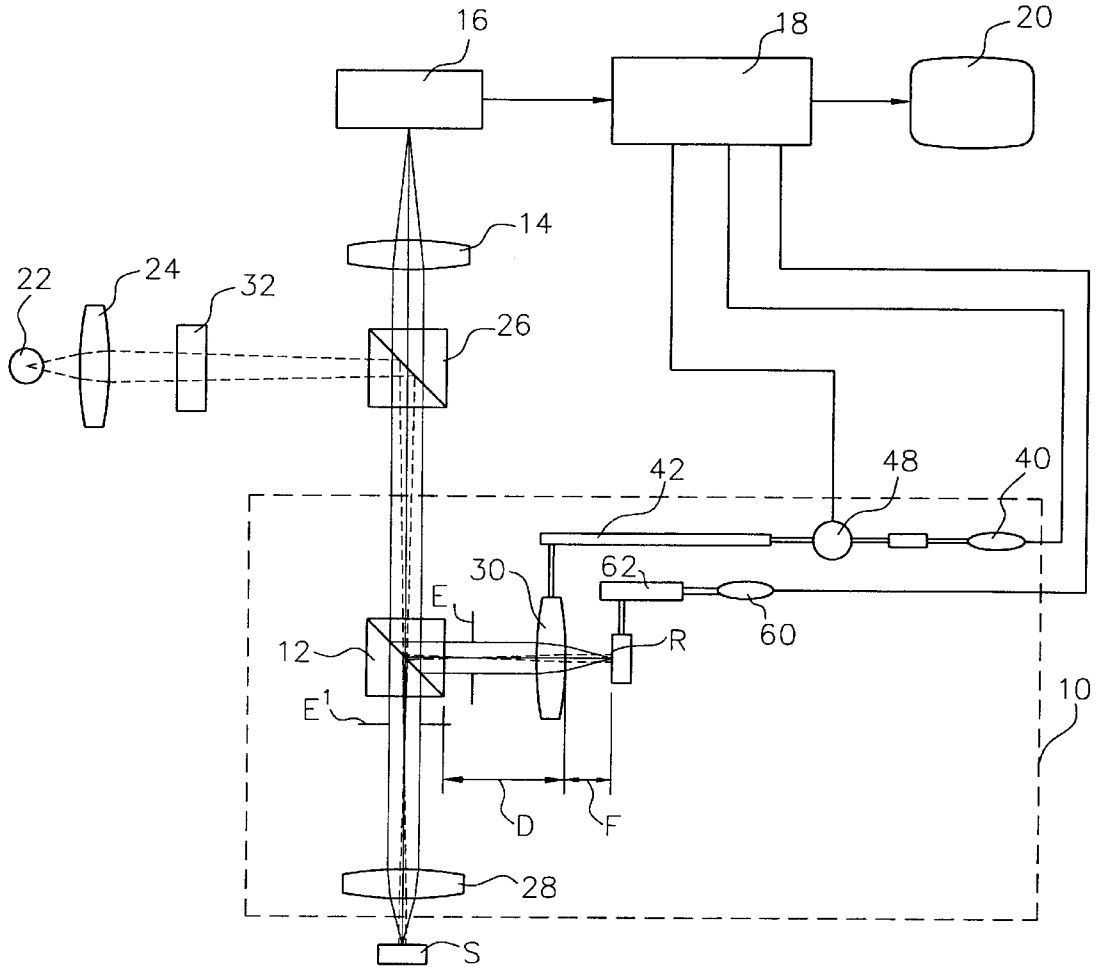


Fig. 9

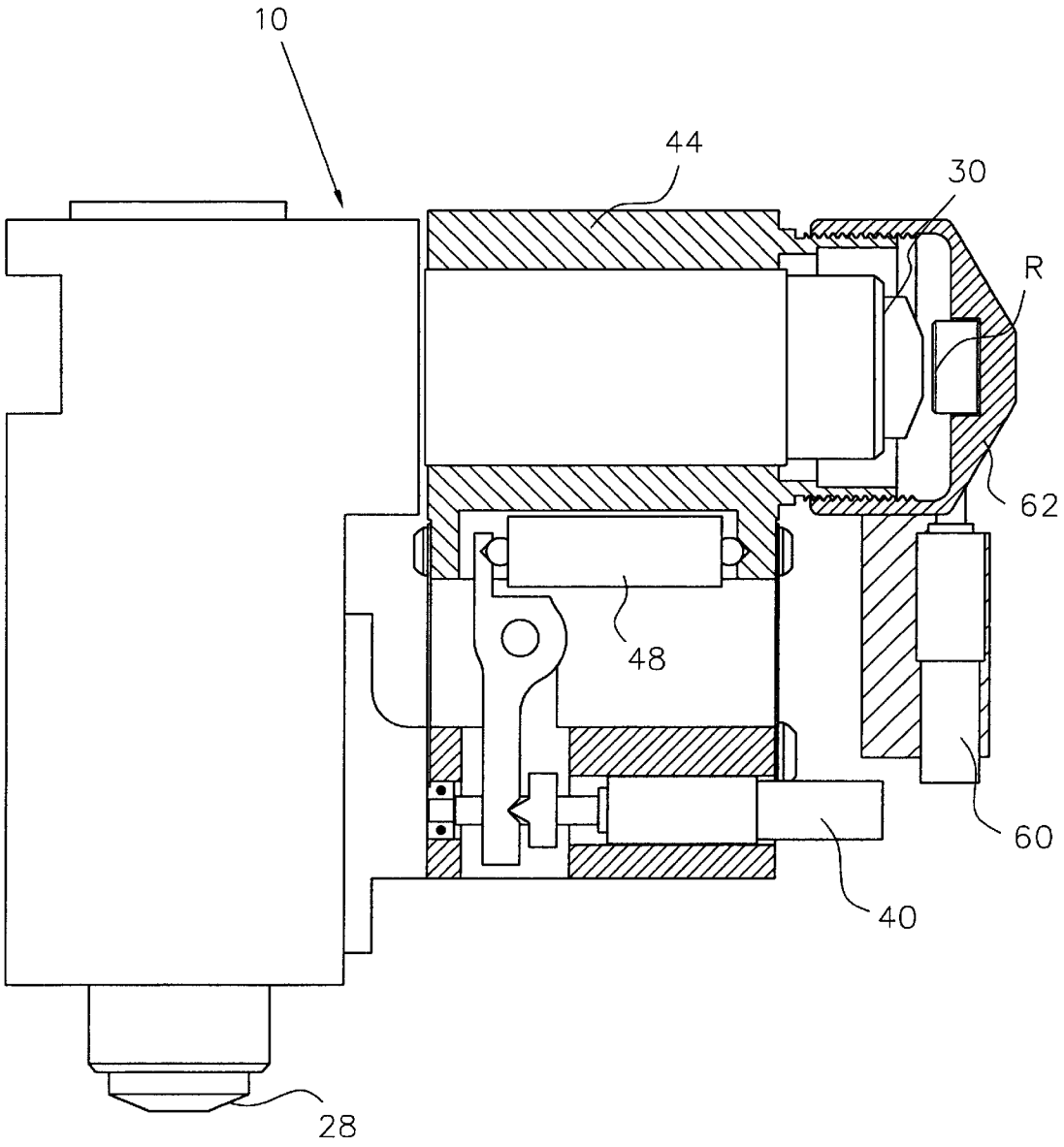


Fig. 10

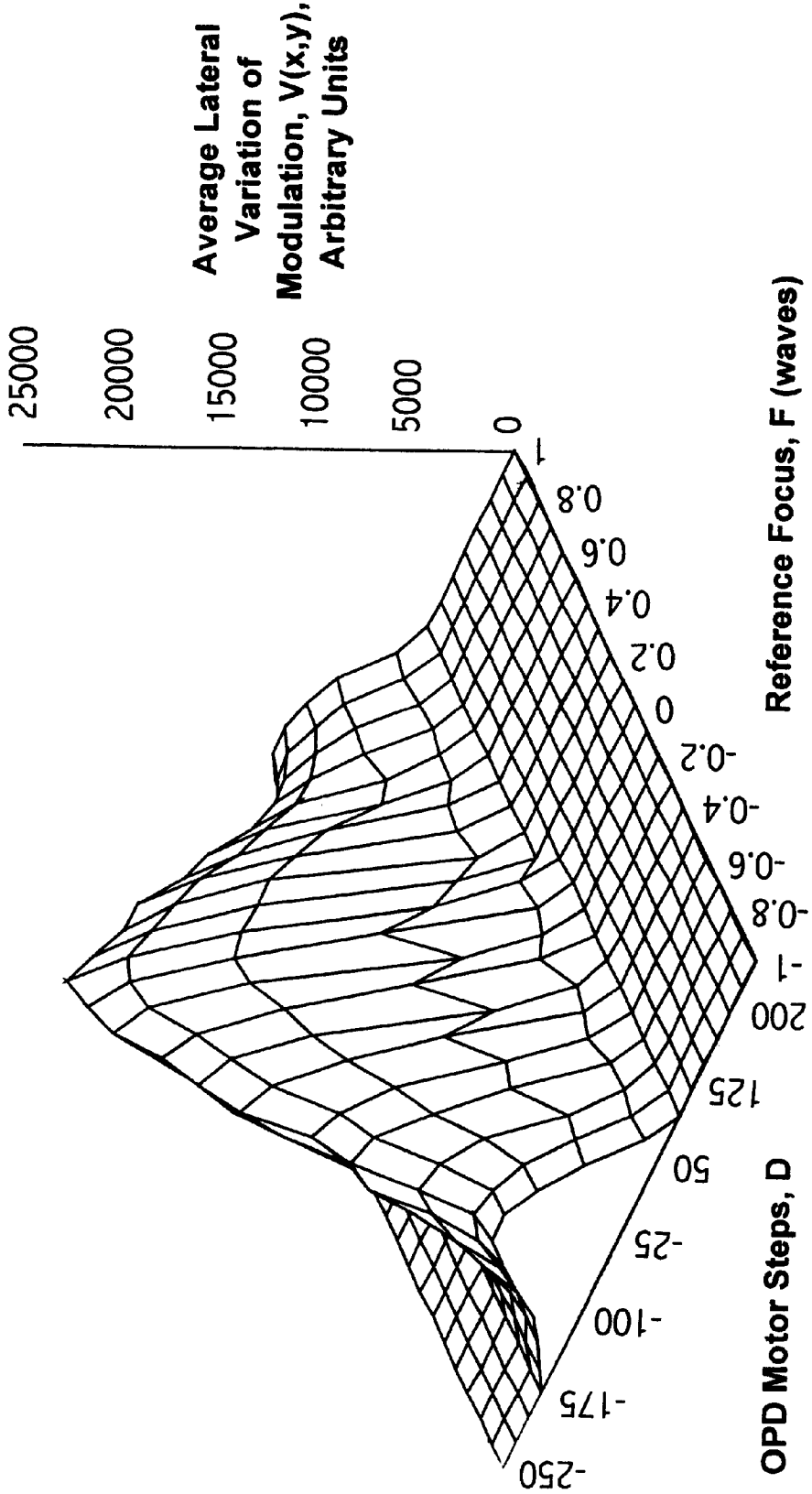

Average Lateral Variation of Modulation, V(x,y), Arbitrary Units
25000
20000
15000
10000
5000
0
Reference Focus, F (waves)
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
OPD Motor Steps, D
200
125
50
-25
-100
-175
-250

Fig. 11

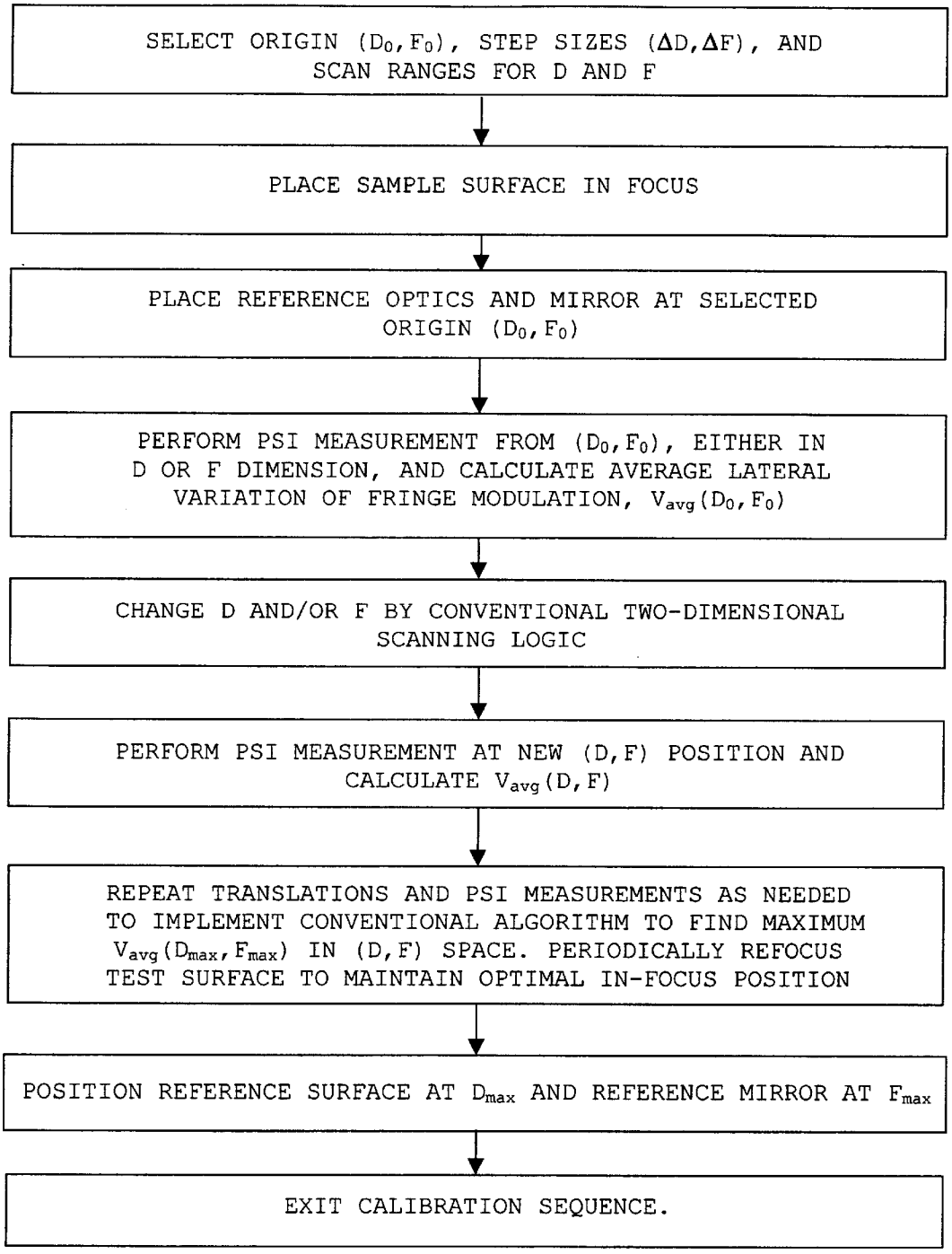

SELECT ORIGIN (D_0, F_0), STEP SIZES (ΔD, ΔF), AND SCAN RANGES FOR D AND F
PLACE SAMPLE SURFACE IN FOCUS
PLACE REFERENCE OPTICS AND MIRROR AT SELECTED ORIGIN (D_0, F_0)
PERFORM PSI MEASUREMENT FROM (D_0, F_0), EITHER IN D OR F DIMENSION, AND CALCULATE AVERAGE LATERAL VARIATION OF FRINGE MODULATION, $V_{avg}(D_0, F_0)$
CHANGE D AND/OR F BY CONVENTIONAL TWO-DIMENSIONAL SCANNING LOGIC
PERFORM PSI MEASUREMENT AT NEW (D,F) POSITION AND CALCULATE $V_{avg}(D, F)$
REPEAT TRANSLATIONS AND PSI MEASUREMENTS AS NEEDED TO IMPLEMENT CONVENTIONAL ALGORITHM TO FIND MAXIMUM $V_{avg}(D_{max}, F_{max})$ IN (D,F) SPACE. PERIODICALLY REFOCUS TEST SURFACE TO MAINTAIN OPTIMAL IN-FOCUS POSITION
POSITION REFERENCE SURFACE AT D_{max} AND REFERENCE MIRROR AT F_{max}
EXIT CALIBRATION SEQUENCE.

FIG. 12

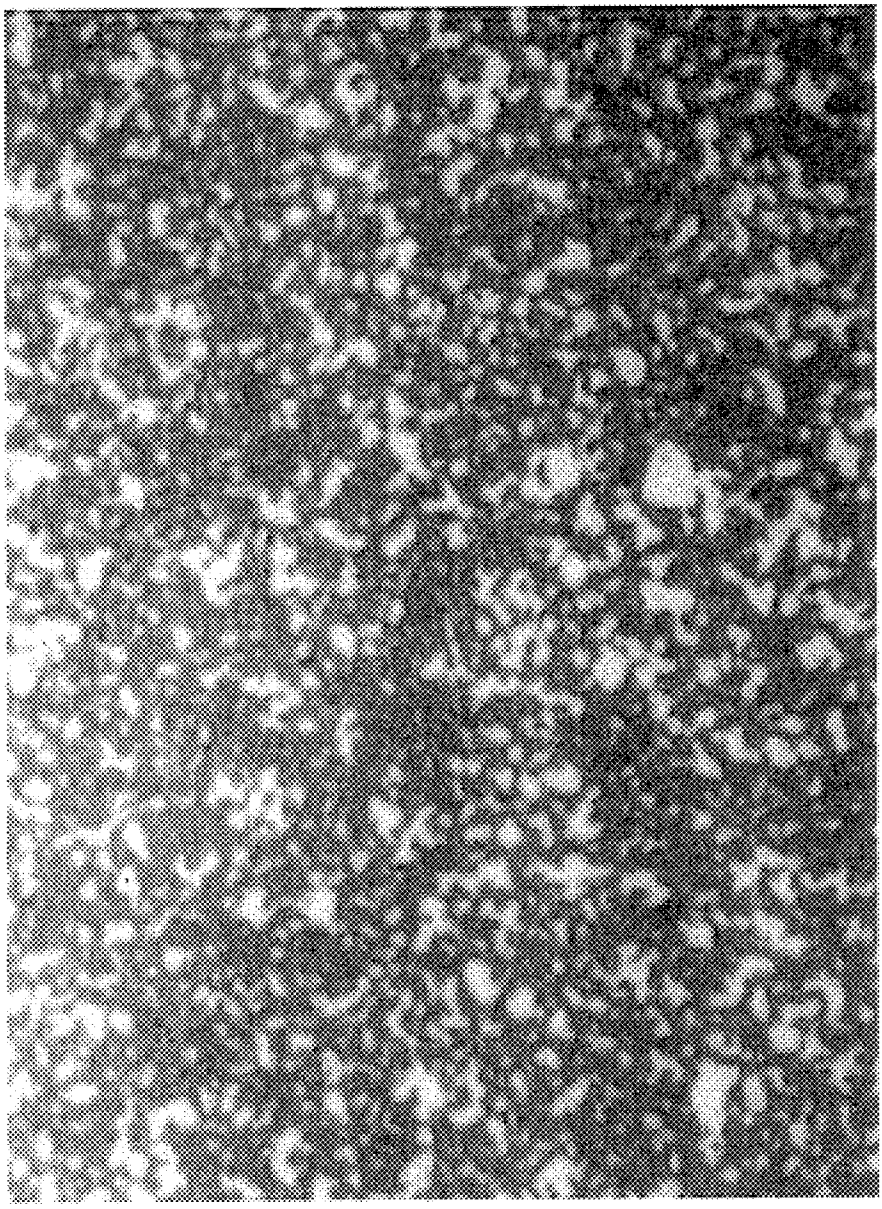


FIG. 13

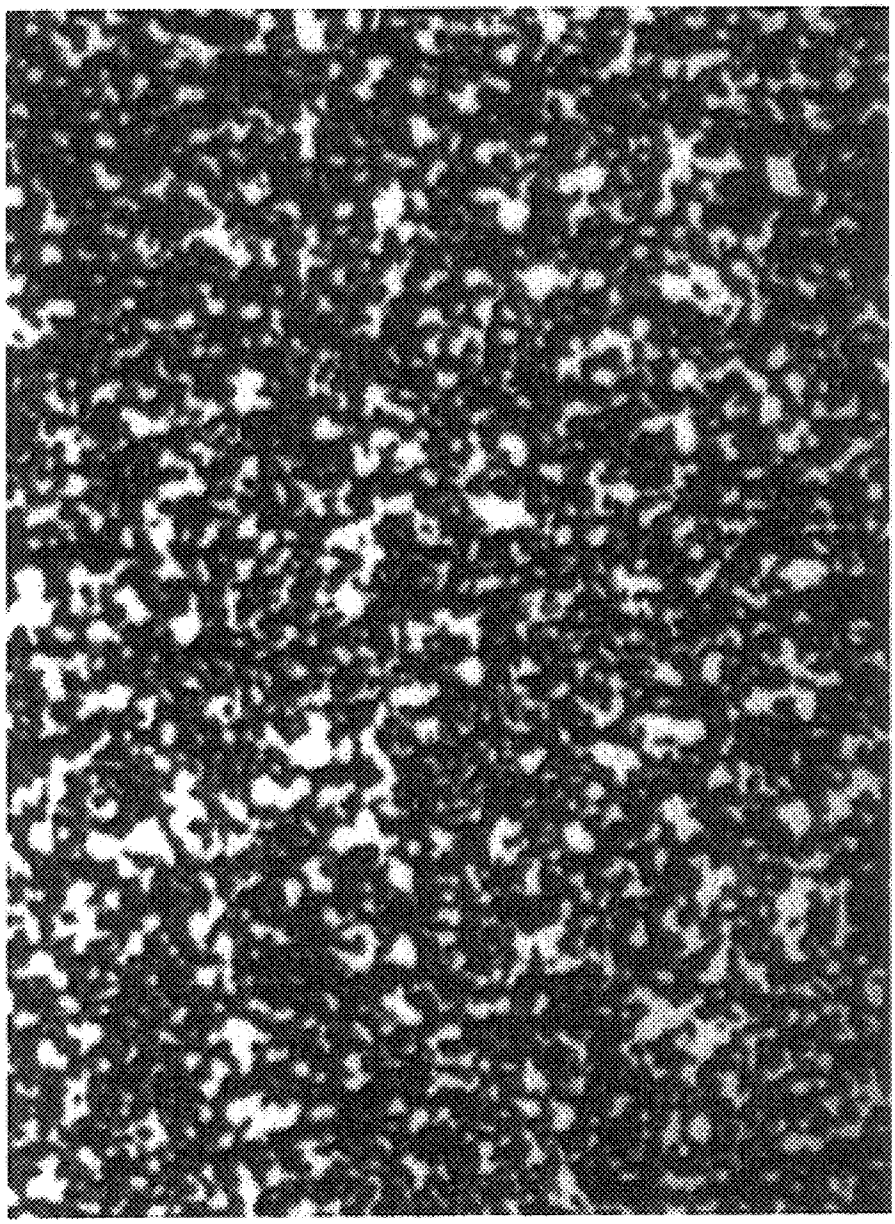


FIG. 14

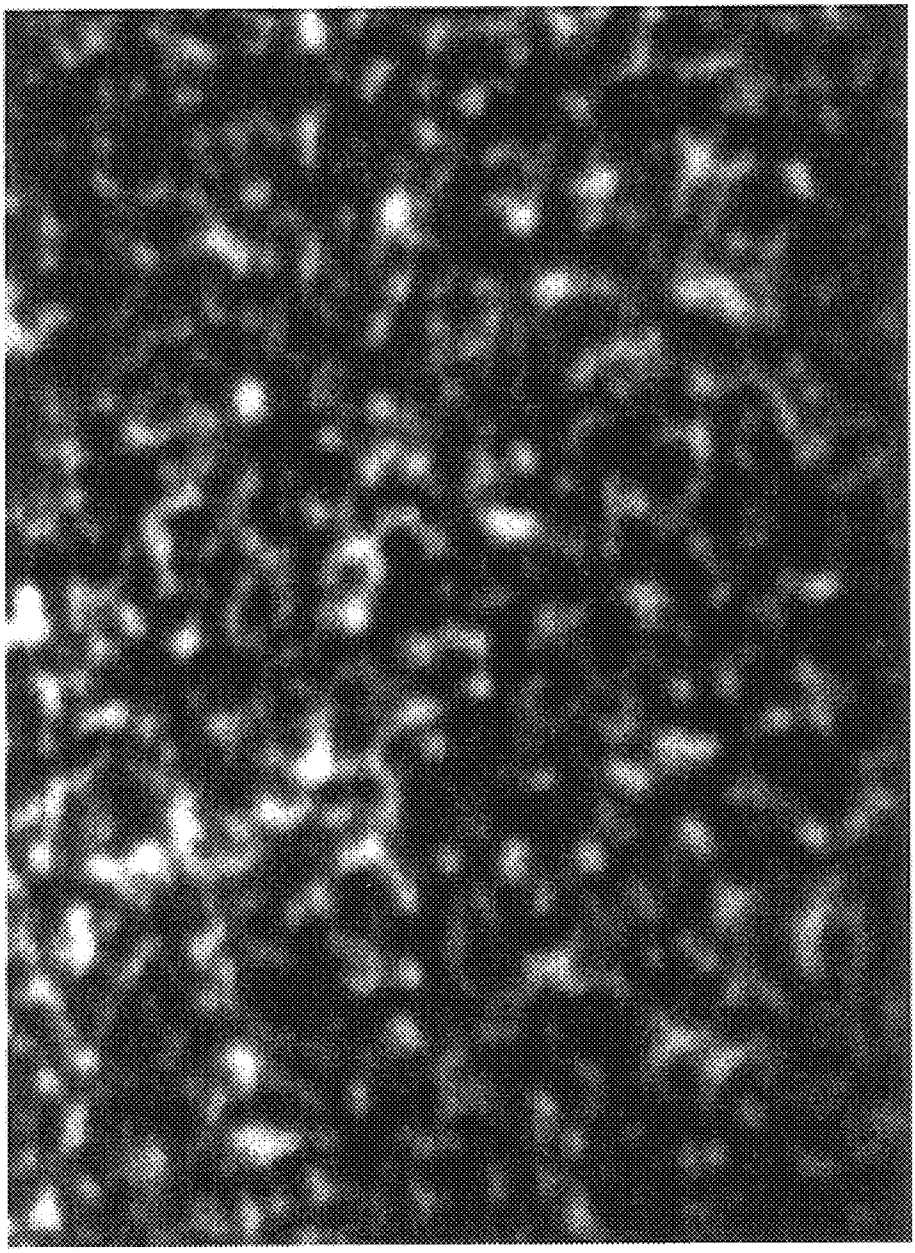


FIG. 15

AUTOMATED MINIMIZATION OF OPTICAL PATH DIFFERENCE AND REFERENCE MIRROR FOCUS IN WHITE-LIGHT INTERFERENCE MICROSCOPE OBJECTIVE

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention is related in general to the field of interferometry and, in particular, to an automated method and apparatus for minimizing the optical path difference between the reference and the test arms of a Linnik white-light interference objective.

2. Description of the Related Art

White-light interferometric devices typically utilize microscope objectives for simultaneously imaging a sample surface and a reference surface onto a detector in order to produce interference fringes representative of the height of the sample. As illustrated in simple schematic form in FIG. **1**, a typical Linnik interference microscope includes an objective **10** focused on a test surface S and incorporating an interferometer. The interferometer comprises a beam splitter **12** and a reference mirror R such that the light beam W directed to the sample surface S is split and also directed toward the reference mirror.

As is well understood by those skilled in the art, the light beams reflected from the reference mirror R and the test surface S (the reference and test beams, respectively) are combined to produce interference fringes as a result of the optical path difference (OPD) between the reference and test beams. The light reflected by the test surface S interferes with the light reflected at the reference mirror R and, according to the principle of superposition, bright interference fringes are produced corresponding to all points on the reference mirror where the optical path difference of the light is equal to a multiple of its wavelength. In order for discernible fringes to appear, the OPD must be within the coherence length of the light source. Spectral filtering may be used to increase the coherence length of the light.

The light from the reference and sample surfaces is typically passed back through the interferometric microscope **10** and appropriate imaging optics **14** toward an imaging array **16** positioned in a camera in coaxial alignment with the objective. The imaging array usually consists of individual charge-coupled-device (CCD) cells or other sensing apparatus adapted to record a two-dimensional array of signals corresponding to interference effects produced by the interferometer as a result of light reflected at individual x-y coordinates or pixels in the surface S and the reference mirror R and received at corresponding individual cells in the array. Appropriate electronic hardware (not shown) is also provided to process the signals generated by each cell and transmit them to a computer **18** for further processing. Thus, an interference-fringe map is generated by detecting the intensity of the light signal received in each cell of the array. The map may be displayed on a monitor **20** connected to the processing unit **18**. As mentioned, a filter **32** may be provided to optionally narrow the bandwidth of the light beam W to a predetermined value.

In a Linnik interferometer, a smooth test surface S is typically profiled by phase-shifting interferometry (PSI), typically by scanning the reference arm of the microscope objective **10**. A piezoelectric translator or equivalent device (not shown in FIG. **1**) is used in conventional manner to shift the reference optics **30** and mirror R together with respect to the sample surface S. Phase shifting is founded on the basic

concept of varying the phase difference between two interfering beams in some known manner, such as by changing the optical path difference in discrete steps or linearly with time. Under such conditions, three or more measurements of the light intensity at a pixel of a receiving sensor array can be used to determine the relative phase of the light reflected from the point on a test surface corresponding to that pixel, with respect to the other points on the test surface. Based on such measurements at each pixel of coordinates x and y, a phase distribution map $\Phi(x,y)$ can be determined for the test surface, from which very accurate height data $h(x,y)$ are calculated in relation to the wavelength λ of the light source used by the following general equation:

$$h(x, y) = \frac{\lambda}{4\pi}\Phi(x, y). \quad (1)$$

Phase-shifting interferometry provides a vertical resolution in the order of 1/100 of a wavelength or better. The technique is typically limited to measurements of smooth surfaces due to a height ambiguity encountered at phase steps greater than π.

Linnik interferometers are also used for vertical-scanning interferometry (VSI) of rough surfaces. VSI is a well-known technique where white light is used as the light source in an interferometer and the degree of modulation, or coherence, of interference fringes produced by the instrument is measured for various distances between the test surface and the reference surface of the interferometer (each corresponding to a different optical path difference) to determine surface height. The microscope objective is typically adapted for vertical movement (along the z coordinate). Thus, an interference-fringe map is generated by detecting the intensity of the light signal received in each cell of the light sensor as a function of the z-scan position. The position of the scanning mechanism corresponding to maximum interference at each pixel is determined and used, based on the distance from a reference point, to calculate the height of the surface at that pixel.

As shown in FIG. **1**, the Linnik configuration of a microscope objective includes a white light source **22** and imaging optics **24** providing an illumination beam W to the system through a beam splitter or equivalent device **26**. The illumination beam is then focused, ideally, in the entrance pupils E and E' of the reference and test imaging optics **30** and **28**, respectively. This is known as Kohler illumination, and produces approximately uniform illumination on the sample surface S and the reference surface R. By way of calibration, the reference mirror R is set at the focal point of the imaging optics **30** through a process based on a visual determination of best focus produced by axially shifting the reference mirror with respect to its imaging optics **30** along a distance F, as one skilled in the art would readily understand. This is often accomplished by the introduction of a field stop in the illuminator (not shown in FIG. **1**). When the diameter of the field stop is reduced sufficiently to bring its edges into the field of view, a sharp image of the edges is formed on the camera when the reference surface R is in focus. Copending application Ser. No. 09/452,334 discloses a mechanism for focusing the reference mirror R automatically, which provides an opportunity for periodic recalibration of the instrument.

Prior to carrying out surface profiling by PSI measurements, the distance between the sample surface S and its focusing optics **28** is also adjusted to produce a sharp, in-focus image of the sample. This is normally achieved by

moving the entire objective **10** vertically with respect to the sample stage (although the same result could obviously be achieved as well by moving the stage). The distance F' (FIG. **1**) between the lens **28** and the surface S is varied, either manually or automatically, until the sample surface is in focus. Typically, the optimal in-focus position of the sample surface is determined by visual observation of the best picture of the sample surface seen at the monitor **20**. Alternatively, an image of the field stop, as described above, can be used to set the optimal in-focus position. Similarly, for VSI measurements, fringes are present at a given scan position only for portions of the surface that are in focus.

When a light of short coherence length is used, such as produced by the white-light source **22**, interference between the return beams only occurs when the optical path difference between the test and the reference paths is within the coherence length of the system. The coherence length of a white-light source can be increased with spectral filtering. Therefore, it is necessary to minimize the OPD in order to obtain satisfactory fringe contrast for PSI and VSI measurements. In general, for optimum performance the OPD between the reference and test paths must be less than approximately one wavelength. If a 40 nm bandwidth red light source is used, the coherence length is about 9 μm and the OPD between the reference and test paths must be less than 0.6 μm.

If a narrower bandwidth is chosen to carry out the interferometric measurements, such as with the use of a laser light, the coherence length and hence the OPD can be much greater, but stricter operational requirements render the commercial use of this type of interferometer less desirable for many applications. Therefore, short coherence lengths are preferred in many cases and the sample and reference path length difference must then necessarily be placed within very close tolerances. Minute changes in the optical path difference between the reference and test surfaces are sufficient to cause degradation of the fringe quality seen at the sensor **16**.

Therefore, the quality of the phase-shifting and vertical-scanning measurements are also directly related to the degree to which the OPD is minimized.

A manual control is typically provided to adjust the length of the optical path of either the reference or the test beam. For example, a typical adjustment consists of manually translating the lens **30** and the reference mirror R together (thereby preserving the in-focus position of the reference mirror) with respect to the splitter **12** along a distance D (see FIG. **1**), so as to generate the best visual fringe contrast. This adjustment is performed prior to performing measurements of the test sample S. In phase-shifting, measurements are accomplished using a scanning mechanism, typically a piezoelectric element, that also shifts the lens **30** and mirror R together in the spatial dimension of the distance D, herein also referred to as the D direction. In vertical-scanning, measurements are made by varying the distance F', either by moving the objective **10** or the sample S. Obviously, the OPD adjustment is limited by the subjective nature of human measurements and by the relatively coarse ability of the human eye to discern degrees of contrast in an interferogram. This is particularly true in the case of nulled fringes, where a single, uniform fringe covers the entire field-of-view.

As interference microscopes have become standard quality-control tools in production environments, such as for testing the topography of magnetic heads, greater measurement precision and repeatability are required. Such interference microscopes are now capable of making measurements with sub-nanometer precision. Accordingly, the precise minimization of the OPD between the reference mirror and the test surface has become more and more critical. This is especially true with objectives of high numerical aperture and correspondingly short depth of focus. Even though it is possible to maximize the fringe contrast (minimum OPD) in the Linnik interferometer at a condition where the reference mirror is out of focus, this condition is known to degrade the measurement performance of interference microscopes, as detailed in U.S. Pat. No. 5,978,086.

It has therefore become necessary to obtain extremely tight levels of control over the length of the reference path with respect to the test path, encompassing distances D and F in FIG. **1**. In addition, it would be very desirable to have an automated method and apparatus for minimizing the OPD in white-light interference objectives in order to avoid the subjectivity and lack of precision of human measurements. The present invention is directed at improving the quality of the fringes generated by the interference between the reference and test beams by ensuring that the OPD between the two beams is optimally minimized. Two solutions are provided for optimizing the objective prior to performing phase-shifting or vertical-scanning interferometry. One solution is provided by maximizing the fringe contrast in the process of OPD minimization. It is suitable for general test surfaces, but requires separate optimization of reference mirror focus. The second solution entails maximizing the fringe modulation across the test surface. While it is suitable for a limited number of test surfaces with specific attributes, it allows for the simultaneous optimization of reference mirror focus and OPD, and can be employed in the critical measurement of magnetic heads.

BRIEF SUMMARY OF THE INVENTION

One primary object of this invention is a method for optimizing the process of minimization of the optical path difference between the reference and test beams of a white-light Linnik interferometer.

Another primary objective of the invention is a method for setting the in-focus position of the reference surface of an interferometric microscope objective.

Another object of the invention is a method that is suitable for automated implementation.

Still another objective is a method and corresponding implementing apparatus that are suitable for automated use while the interferometer is in service for quality control in an assembly line.

Another goal of the invention is a method and apparatus that are suitable for incorporation within existing instruments.

A final object is a procedure that can be implemented easily and economically according to the above stated criteria.

Therefore, according to these and other objectives, the present invention consists of incorporating a mechanism for producing relatively large translations of the reference optics and mirror in a white-light Linnik interference objective and carrying out PSI measurements while the OPD between the reference and test beams is varied. Utilizing the same algorithms used in the art to perform conventional phase shifting interferometry, the position of minimum OPD is determined by finding the corresponding position of maximum intensity contrast of the interference fringes resulting from the superposition of the reference and test beams as the OPD is varied. Alternatively, for a test surface with specific

characteristics, such as a magnetic head air bearing surface, the OPD is minimized and the reference mirror is simultaneously focused by maximizing the variation in fringe modulation across the test surface. By automating the system with a precise translation mechanism, operator-to-operator variations are completely eliminated and the precision of the process of OPD minimization and reference mirror focus are greatly improved.

Various other purposes and advantages of the invention will become clear from its description in the specification that follows and from the novel features particularly pointed out in the appended claims. Therefore, to the accomplishment of the objectives described above, this invention consists of the features hereinafter illustrated in the drawings, fully described in the detailed description of the preferred embodiment and particularly pointed out in the claims. However, such drawings and description disclose only one of the various ways in which the invention may be practiced.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a simplified schematic representation of a prior-art Linnik interferometric microscope.

FIG. **2** is a typical intensity signal obtained from a detector cell in the image plane of an interferometer as the OPD is varied by vertically scanning the objective or the test sample, or by varying the reference path length.

FIG. **3** is a schematic representation of the microscope objective of FIG. **1** incorporating a scanning mechanism for translating the reference optics and mirror with reference to the sample surface.

FIG. **4** is a partially cut-out view of an interference objective according to one preferred embodiment of the invention.

FIG. **5** is a view of the interference objective of FIG. **4** where the reference sleeve is shown in exaggerated extended position for clarity.

FIG. **6** shows the fringe modulation for an examplary PSI measurement as a function of optical path difference in a Linnik objective, where the spectral bandwidth of the light is approximately **40** nm with center wavelength of about 600 nm.

FIG. **7** is a diagram of the steps involved in the procedure of the invention for OPD minimization by fringe contrast maximization.

FIG. **8** shows the fringe modulation for a series of examplary trials, where the OPD was minimized with the automated algorithm of the invention and manually by two different operators.

FIG. **9** is a schematic representation of the microscope objective of FIG. **1** incorporating an alternative preferred embodiment of the invention, which includes a first scanning mechanism for translating the reference optics and mirror in relation to the sample surface as well as a second scanning mechanism for translating the reference mirror in relation to the reference optics.

FIG. **10** is a partially cut-out view of an interference objective according to the embodiment of FIG. **9**.

FIG. **11** is a three-dimensional plot of average fringe-modulation lateral variation as a function of both OPD and focal distance changes.

FIG. **12** is a diagram of the steps involved in producing minimum OPD and optimal reference-mirror focus by finding the peak of the average lateral variation of modulation as a function of OPD and focal position.

FIG. **13** shows an intensity image of an air bearing surface (ABS) found to be suitable for optimizing the OPD and focal position of an interferometric objective with the procedure outlined in FIG. **12**.

FIG. **14** is a modulation image of the air bearing surface of FIG. **13** produced at D and F positions optimized with the procedure outlined in FIG. **12**.

FIG. **15** is a modulation image of the air bearing surface of FIG. **13** produced at D and F positions that have not been optimized.

DESCRIPTION OF THE PREFERRED EMBODIMENT OF THE INVENTION

The present invention is based on the idea of maximizing fringe modulation or the spatial variation of fringe modulation in order to minimize the optical path difference between the reference path and the test path of a white-light interference objective in a white-light Linnik interferometer. The approach makes it possible to automate the process and optimize the quality of the resulting PSI or VSI profiling measurements. For the purposes of this disclosure, the term white light is intended to refer to any broad-bandwidth light such as produced by halogen lamps, arc lamps, and LEDs, which are often also filtered to reduce the bandwidth to a particular wavelength range of interest. In the examples described below, white light filtered to a 40-nm bandwidth with about 600-nm center wavelength was used. The reference symbols F, D, and F' are used to refer (as also defined above) to the distances between reference mirror and reference optics, reference optics and microscope splitter, and sample surface and microscope splitter, respectively, as well as to the spatial dimension or direction of these parameters.

The prior art discloses various ways by which VSI may be implemented to determine surface height by calculating the degree of fringe modulation, or coherence, of the interference fringes produced at the light detector for various OPDs between the test surface and the reference surface of the interferometer. These methods involve a determination of the scanning position corresponding to the peak of the modulation envelope of the intensity measurements collected during scanning. When white light is used as the source of illumination, the visibility of the fringes drops off rapidly from its maximum value at minimum OPD. FIG. **2** illustrates the modulation envelope E of a typical intensity signal I (irradiance) received at a detector cell in the image plane of the interferometer as the OPD is varied by vertically scanning the sample (or the objective). A measurement of relative surface height at the vertical-scanning point corresponding to the fringe-modulation peak Imax can thus be made. By simultaneously carrying out the procedure in parallel for each detector cell during vertical scanning, a three-dimensional height map can be obtained for the surface of the test sample. The point of maximum fringe visibility can be calculated from irradiance data using several known techniques. See, for example, the methods disclosed in U.S. Pat. No. 5,471,303 and U.S. Pat. No. 5,633,715.

According to the present invention, additional positioning mechanisms are incorporated into the conventional hardware of a Linnik interference objective. Referring to the drawings, wherein like parts are designated throughout with like numerals and symbols, FIG. **3** shows schematically a gear motor or equivalent device **40** rigidly coupled to a mounting structure **42** holding the lens **30** and the reference mirror R in fixed spatial relationship, so that the motor can translate both units together along the reference optical path of the objective **10**. The gear motor **40** is used to vary the distance D between the beam splitter **12** and the structure **42**

(i.e., the assembly containing the lens **30** and mirror R) in order to equalize the optical paths of the reference and test beams. Due to the relatively large adjustments that may be necessary to facilitate assembly of the objective **10** with typical mechanical components, the gear motor **40** is preferably selected with a range of about ½ mm, and in any event sufficient to translate the lens **30** and mirror R to a position in the D direction where the OPD is within the coherence length of the light source. Once adjusted to its nominal position, small, occasional motions in the position of lens **30** and mirror R to accommodate thermal, spectral, and other changes are required. A piezoelectric element **48**, also acting on the reference mirror R and lens **30** through the common support structure **42**, is provided to effect phase-shifting measurements after calibration.

In practice, the system of the invention is implemented by serially combining the gear motor or equivalent mechanism **40** used for minimizing OPD with the conventional piezoelectric mechanism used for conducting PSI profiling measurements. As illustrated in the partially cut-out view of FIG. **4**, the reference mirror R and lens **30** are fixedly assembled in an objective sleeve **44** mounted on the main body of the interference objective **10** by means of vertical flexures **46**. A piezoelectric actuator **48** causes the horizontal outward translation of the sleeve **44** against the flexures **46** that urge the sleeve toward the beam splitter **12** (not seen in FIG. **4**). The whole mechanism of the piezoelectric actuator **48** is coupled to the upper end of a pivoted lever arm **50**, and the lower end of the arm is coupled to the motor **40** of the invention. In the preferred embodiment of the invention, the output shaft of the motor **40** consists of a lead screw **52** threaded through a stationary lead nut **54** that engages the lever arm **50** by means of two lateral V-shaped ridges connected to conforming grooves in the lever arm. The screw **52** passes through the lever arm and is supported by a bearing **56** in the main body of the objective.

Thus, the series combination of the motor **40** and piezo actuator **48** provide a scanning mechanism capable of translating the objective sleeve **44** (and with it the reference optics **30** and mirror R) for the purpose of minimizing OPD as well as for performing phase-shifting measurements. FIG. **5** illustrates the extended position of the sleeve **44** with reference to the main body of the objective **10**. During OPD minimization, which may occur within the noted range of about ½ mm, the short-range actuator **48** functions as a coupling device to transmit the motion of the lever arm **50** to the sleeve **44** while the long-range motor **40** effects relatively large incremental steps. At each of these incremental positions during the long-range translation, the motor **40** is stopped and a measurement is made using the short-range piezoelectric actuator **48** and white light reduced in bandwidth and centered around an appropriate wavelength by the filter **32**. This measurement is referred herein as a PSI measurement because it is conducted in the same manner of conventional PSI measurements. Instead of measuring phase shift, though, the recorded frames of intensity data are used to produce average modulation data, which are then utilized as individual points to generate an average modulation curve tracking the long-range scan produced by the motor **40**. As well understood in the art, modulation (commonly also referred to as visibility or contrast) is defined as the ratio between the difference and the sum of the maximum and minimum intensities recorded over a predetermined scan range (i.e., modulation=$[I_{max}-I_{min}]/[I_{max}+I_{min}]$).

Each PSI measurement causes the signal at the detector to vary approximately sinusoidally, as illustrated in FIG. **2**. The average fringe modulation for the entire pixel array is recorded at each translation point by some averaging method (simple arithmetic averaging was used in testing the concept of the invention). Following long-range translation of the objective sleeve **44** through a predetermined range of motion, the translation location where the average fringe modulation is at a maximum is determined (i.e. the peak of the envelope, as illustrated in FIG. **6**, where incremental long-range steps of about ⅝ of a micron are shown for illustration), and the objective sleeve is returned to this position. If the peak fringe modulation is not found within the selected translation range, the range is increased and the procedure is repeated. Obviously, various known methods can be adopted to select the appropriate length of the long-range scan, its step size, and origin. For example, it may be advantageous to change the step size during a scan where modulation is measured for relatively large ranges, but the fundamental procedure is the same. The invention was tested by judiciously selecting initial values for these parameters, shifting the origin half the selected scan range in one direction from the current OPD position, and then scanning incrementally in the opposite direction over the selected range length.

When the point of minimum OPD is found, the calibration process is completed and normal PSI profilometric measurements may be carried out with white light (which may be appropriately filtered) in conventional manner using the piezoelectric actuator **48** while the motor **40** is inactive. It is noted that PSI measurements may also be carried out by varying the distance F or the distance F' (FIG. **3**), although this is generally inferior for PSI measurements at high numerical apertures because of the more non-collimated condition and corresponding error introduced by such lenses. During all phases of operation, the flexures **46** urge the objective sleeve **44** toward the splitter **12** (see FIG. **3**); that is, toward a direction of decreasing reference-beam path length.

In operation, the procedure of the invention is carried out advantageously in automatic fashion by first focusing the reference mirror R within the focal plane of the lens **30**; focusing the test surface S with respect to its optics **28**; and then minimizing the OPD between the reference and test optical paths by monitoring the average fringe modulation through short-range PSI measurements while scanning the reference arm of the objective with the long-range motorized mechanism, as described. These steps can be automated in relatively straightforward manner by adapting the same algorithms used for conventional VSI and PSI measurements. When the position of maximum average fringe modulation is found through the calibration process, the test surface S can be profiled by performing PSI after switching to the short-range piezoelectric scanner (illustrated by element **48**), or by VSI in the conventional manner (scanning the objective or the sample towards or away from each other). The procedure is outlined in FIG. **7**.

Thus, a new procedure and apparatus have been disclosed to improve the process of bringing the reference and test optical paths to within a small fraction of the coherence length of the light source. By utilizing a motorized implementation, the invention makes it possible to automate the procedure and optimize the process of minimization of the OPD between the test and reference beams. FIG. **8** illustrates the improvement provided by the invention in terms of consistency and repeatability in the process of OPD minimization. Over the course of seven trials conducted both automatically and manually by two separate operators, the range of peak average modulation corresponding to minimum OPD determined manually was three times as large, for both operators, as the range measured automatically.

As detailed in U.S. Pat. No. 5,978,086, it is critical to avoid shifts of the reference mirror R away from its best focus position. Therefore, it would be very advantageous if it were possible to reset the mirror's best-focus position as part of the same procedure by which the OPD is minimized. According to another aspect of the invention, we found that this can be accomplished if a test surface with specific characteristics is used.

In an effort to solve this problem, we investigated average fringe modulation as a function of changes of both the D and F distances (see FIG. **3**). We discovered that an average-modulation envelope such as shown in FIG. **2** can be observed and used advantageously from scanning in the OPD distance D even when the reference mirror R is away from its best focus position. That is, a poorly focused reference mirror still produces a significant peak in the average modulation curve obtained while scanning over the distance D (FIG. **3**) to minimize OPD. Therefore, the procedure outlined above to optimize OPD (FIG. **7**) is relatively insensitive to the focal position of the reference mirror. Unfortunately, this means that a single solution for maximum average fringe modulation as a function of D and F (i.e., in D,F space) does not exist.

In order to effectively determine both the D and F parameters at the same time, the functionality of the observed variable must provide a single-point peak in D,F space. We discovered that such an observable variable exists in the average lateral variation of modulation, rather than in the average modulation defined above. Average lateral variation of modulation is defined as the average change in modulation between proximate pixels, as further detailed below for the purposes of this disclosure. Accordingly, we selected a test surface S smooth enough for carrying out PSI measurements, but exhibiting sufficient nonuniformity in reflectivity to produce lateral variations in modulation. We found that we can use this fact, coupled with the physically smooth nature of the test surface, to optimize reference focus and OPD at the same time by noting that the average lateral variation in modulation will reach a maximum when both variables D and F are optimized.

Thus, there exists a three-dimensional solution space wherein the average lateral variation of fringe modulation can be plotted as a function of adjustment axes D and F. This is accomplished by varying both D and F and recording the average lateral variation of fringe modulation at each coordinate point in D,F space. The lateral variation of modulation V(x,y) is calculated at every detector-surface pixel location (x,y) by comparing the modulation M(x,y) at pixel (x,y) to its "lateral neighbors" as follows:

$$V(x,y)=abs(M(x,y)-[M(x+G_x,y)+M(x-G_x,y)+M(x,y+G_y)+M(x,y-G_y)]/4\}, \quad (2)$$

where G_x and G_y are the X and Y granularities, respectively. G_x and G_y represent the typical "grain size" in the modulation array, the grains being caused by dissimilar-material effects on the modulation, as well understood in standard image-processing techniques. For the purposes of the tests of the invention, we found that a G_x and a G_y equal to 10 (that is, comparing a pixel to neighbors ten steps removed) was optimal for the optical resolution provided by the system).

Thus, according to this aspect of the invention, an additional scanning mechanism **60** is required to translate the reference mirror R with respect to the lens **30**, as illustrated schematically in FIG. **9**. In practice, the mechanism **60** consists of a motor **60** adapted to rotate a collar **62** that supports the mirror R and is threaded onto the sleeve **44** holding the reference lens **30**, as shown in FIG. **10**. Therefore, as the collar **62** rotates, the distance F is varied (FIG. **9**).

An origin, two sets of scanning ranges, and related steps are selected, in similar manner as the procedure outlined above, to cover predetermined ranges for both D and F. At every point in (D,F) space, PSI measurements are conducted, by scanning preferably in the D dimension, but alternatively in the F (or F') dimension, to measure fringe modulation for every pixel in the detector array. The lateral variation of modulation is then calculated for each pixel using Equation (2) and an average V(x,y) for that D,F position, denoted by V_{avg}(D,F), is computed by some arbitrary criterion, such as simple arithmetic average. This average V(D,F) value represents a point on a three-dimensional (V_{avg},D,F) surface that we found to have a single maximum corresponding to optimal D and F values. Repeating the calculation of V_{avg}(D,F) at incremental D and F positions, this three-dimensional surface is generated and optimum focus and OPD positions are readily ascertained. As illustrated in FIG. **11**, the surface **64** is monotonic, which facilitates the process of finding its single maximum using conventional numerical methods. This occurs when the OPD is minimized and the reference mirror is simultaneously in best focus. It is noted that this procedure can be carried out advantageously using any known numerical algorithm for finding the maximum of a surface in three-dimensional space. During this scanning operation, the focal distance F' of the sample surface S may need adjustment to maintain the sample in the optimal in-focus position, as would be obvious to one skilled in the art. We found that automatic periodic refocusing of the surface S by conventional methods facilitates the process. The steps of the procedure are outlined in FIG. **12**.

We also discovered that a test surface S that is suitable for practicing this aspect of the invention is the air bearing surface (ABS) of a magnetic head. The ABS is a highly polished surface composed of multiple materials (typically aluminum oxide and titanium carbide). The reflectivity of these materials varies, such that, while the surface is smooth, an optical image of the surface exhibits bright and dark structural sections. This is illustrated in FIG. **13**, which is an intensity image of a region of an ABS.

A primary commercial application of interference microscopes is in the measurement of the topography of magnetic heads. Within these heads, the height of the poles and shields utilized in the process of writing and reading data is critical. These heights are typically measured with respect to the nearby air bearing surface. Thus, optimization of the properties of the interference objective used to measure these heights can be done very advantageously with the test surface itself, thereby eliminating the need for a separate calibration surface.

Those skilled in the art readily understand that theoretically the best conditions for performing a surface measurement by interferometry are achieved when maximum fringe contrast is produced, although practical considerations often warrant some additional adjustments. FIG. **14**, corresponding to the sample surface of FIG. **13**, is an example of the sharp fringe modulation produced when D and F are optimized according to the invention. In comparison, FIG. **15** is an example of the same modulation image produced when D and F have not been optimized.

Therefore, various changes in the details, steps and components that have been described may be made by those skilled in the art within the principles and scope of the

invention herein illustrated and defined in the appended claims. For example, various kinds of long-range, linear scanning mechanisms could be used with equivalent results. Similarly, various alternative VSI or PSI algorithms known in the art could be used to find the position of maximum fringe contrast and maximum variation of fringe contrast. Moreover, the invention has been described in terms of a white-light instrument used for conducting surface measurements by phase-shifting interferometry, but it should not be so limited because the same principles can be applied to any interferometer using broad-bandwidth light, whether for PSI or VSI measurements. Thus, while the present invention has been shown and described herein in what is believed to be the most practical and preferred embodiments, it is recognized that departures can be made therefrom within the scope of the invention, which is not to be limited to the details disclosed herein but is to be accorded the full scope of the claims so as to embrace any and all equivalent processes and products.

We claim:

1. A method for minimizing the optical path difference between a test beam path and a reference beam path produced in an interference microscope objective having a reference-arm assembly that comprises a reference lens and a reference mirror, and having first scanning means for carrying out interference measurements of a test surface, the method comprising the following steps:

(a) providing second scanning means for translating the reference-arm assembly along said reference beam path;

(b) translating the reference-arm assembly through a plurality of positions along the reference beam path using said second scanning means;

(c) measuring a fringe modulation at predetermined locations corresponding to said plurality of positions along the reference beam path;

(d) determining a location of the reference-arm assembly along the reference beam path corresponding to an optimal fringe modulation; and

(e) fixing said optimal-fringe-modulation location of the reference-arm assembly such that interferometric measurements of the test surface may be carried out by varying the optical path difference therefrom.

2. The method of claim **1**, wherein said step (c) is carried out by performing phase-shifting interferometric measurements at each of said plurality of positions.

3. The method of claim **1**, wherein said optimal fringe modulation is selected to correspond to a maximum fringe modulation and said step (d) is carried out by performing vertical-scanning interferometry analysis with the fringe modulation data produced by step (c) at each of said plurality of positions.

4. The method of claim **3**, wherein said fringe modulation at each of said plurality of positions along the reference beam path is an average of modulation components calculated for individual pixels of a light detector.

5. The method of claim **1**, wherein said second scanning means includes a gear motor.

6. The method of claim **1**, wherein said steps (b), (c), (d) and (e) are carried out automatically.

7. A method for minimizing the optical path difference between a test beam path and a reference beam path produced in an interference microscope objective having a reference-arm assembly that comprises a reference lens and a reference mirror, and for contemporaneously optimizing the focal position of the reference mirror, wherein the objective comprises first scanning means for carrying out interference measurements of a test surface, the method comprising the following steps:

(a) providing second scanning means for translating the reference-arm assembly in an OPD dimension along said reference beam path;

(b) providing third scanning means for translating the reference mirror with respect to the reference lens in a focal-distance dimension along said reference beam path;

(c) measuring a fringe modulation at predetermined locations corresponding to a plurality of OPD and focal-distance positions obtained using said second and third scanning means;

(d) calculating a lateral variation of fringe modulation for each of said predetermined locations;

(e) determining an optimal OPD position and an optimal focal-distance position corresponding to an optimal lateral variation of fringe modulation; and

(f) fixing the OPD and focal-distance positions at said optimal OPD and focal-distance positions such that interferometric measurements of the test surface may be carried out by varying the OPD therefrom.

8. The method of claim **7**, wherein said step (c) is carried out by performing phase-shifting interferometric measurements at each of said plurality of OPD and focal-distance positions.

9. The method of claim **7**, wherein said optimal lateral variation of fringe modulation is selected to correspond to a maximum lateral variation of fringe modulation and said step (e) is carried out by finding said maximum using the lateral variation of fringe modulation calculated for said predetermined locations.

10. The method of claim **9**, wherein said step (e) is carried out by performing vertical-scanning interferometry analysis with the later variation of fringe modulation data produced by step (d) at each of said plurality of positions.

11. The method of claim **9**, wherein said lateral variation of fringe modulation at each of said predetermined locations is an average of lateral variation of fringe modulation components calculated for individual pixels of a light detector.

12. The method of claim **7**, wherein each of said second and third scanning means includes a gear motor.

13. The method of claim **7**, wherein said steps (c), (d), (e) and (f) are carried out automatically.

14. An apparatus for minimizing the optical path difference between a test beam path and a reference beam path produced in an interference microscope objective having a reference-arm assembly that comprises a reference lens and a reference mirror and having first scanning means to carry out interference measurements of a test surface, comprising:

second scanning means to effect a translation of the reference-arm assembly along said reference beam path;

means for measuring a fringe modulation at a plurality of positions along the reference beam path scanned by said second scanning means;

means for determining a position of the reference-arm assembly along the reference beam path corresponding to an optimal fringe modulation; and

means for fixing said position of the reference-arm assembly such that interferometric measurements of the test surface may be carried out by translating the reference-arm assembly therefrom.

15. The apparatus of claim 14, wherein said optimal fringe modulation is selected to correspond substantially to maximum fringe modulation.

16. The apparatus of claim 15, wherein said means for determining a position of the reference-arm assembly along the reference beam path corresponding to maximum fringe modulation includes means for carrying out vertical-scanning interferometry analysis with the fringe modulation data measured at each of said plurality of positions.

17. The apparatus of claim 14, wherein said means for measuring a fringe modulation at a plurality of positions includes means for carrying out phase-shifting interferometric measurements at each of said plurality of positions.

18. The apparatus of claim 14, wherein said fringe modulation at each of said plurality of positions along the reference beam path is an average of fringe-modulation components calculated for individual pixels of a light detector.

19. The apparatus of claim 14, wherein said second scanning means includes a gear motor.

20. An apparatus for minimizing the optical path difference between a test beam path and a reference beam path produced in an interference microscope objective having a reference-arm assembly that comprises a reference lens and a reference mirror, and for contemporaneously optimizing the focal position of the reference mirror, the apparatus having first scanning means for carrying out interference measurements of a test surface, comprising:

second scanning means for translating the reference-arm assembly in an OPD dimension along said reference beam path;

third scanning means for translating the reference mirror with respect to the reference lens in a focal-distance dimension along said reference beam path;

means for measuring a fringe modulation at predetermined locations corresponding to a plurality of OPD and focal-distance positions obtained using said second and third scanning means;

means for calculating a lateral variation of fringe modulation for each of said predetermined locations;

means for determining an optimal OPD and focal-distance position corresponding to an optimal lateral variation of fringe modulation; and

means for fixing the OPD and focal-distance positions at said optimal OPD and focal-distance positions such that interferometric measurements of the test surface may be carried out by varying the OPD therefrom.

21. The apparatus of claim 20, wherein said optimal lateral variation of fringe modulation is selected to correspond substantially to a maximum lateral variation of fringe modulation.

22. The apparatus of claim 21, wherein said means for determining an optimal OPD and focal-distance position corresponding to a maximum lateral variation of fringe modulation includes means for carrying out vertical-scanning interferometry analysis with lateral variation of fringe modulation data calculated at said predetermined locations.

23. The apparatus of claim 20, wherein said means for measuring a fringe modulation at predetermined locations corresponding to a plurality of OPD and focal-distance positions includes means for carrying out phase-shifting interferometric measurements at each of said plurality of OPD and focal-distance positions.

24. The apparatus of claim 20, wherein said lateral variation of fringe modulation for each of said predetermined locations corresponding to said plurality of OPD and focal-distance positions is an average of lateral variation of fringe-modulation components calculated for individual pixels of a light detector.

25. The apparatus of claim 20, wherein each of said second and third scanning means include a gear motor.

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US006519098B2

(12) **United States Patent**
Nagaoka

(10) **Patent No.: US 6,519,098 B2**
(45) **Date of Patent: Feb. 11, 2003**

(54) **OBJECTIVE LENS SYSTEM**

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(73) Assignee: **Olympus Optical Co., Ltd.**, Tokyo (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

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Related U.S. Application Data

(62) Division of application No. 09/455,362, filed on Dec. 6, 1999, now Pat. No. 6,243,217, which is a division of application No. 08/713,069, filed on Sep. 12, 1996, now Pat. No. 5,999,327.

(30) **Foreign Application Priority Data**

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(52) **U.S. Cl.** **359/793**; 359/661; 348/552
(58) **Field of Search** 359/793, 784, 359/558, 656–661; 348/552; 345/168–169

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(57) **ABSTRACT**

A portable TV telephone has an objective lens system configured to form an image of an object and an antenna configured to transmit and receive at least one of an image signal representing the image of the object, a dial signal and a voice signal carried by radio waves. A display unit is configured to display at least a dial number and the image of the object and a switch is configured to operate responsive to at least the dial number. The objective lens system includes a diffractive optical element configured to at least correct chromatic aberration produced by the objective lens system. The objective lens system includes, in order from an object side, a first negative lens unit and a second positive lens unit.

6 Claims, 16 Drawing Sheets

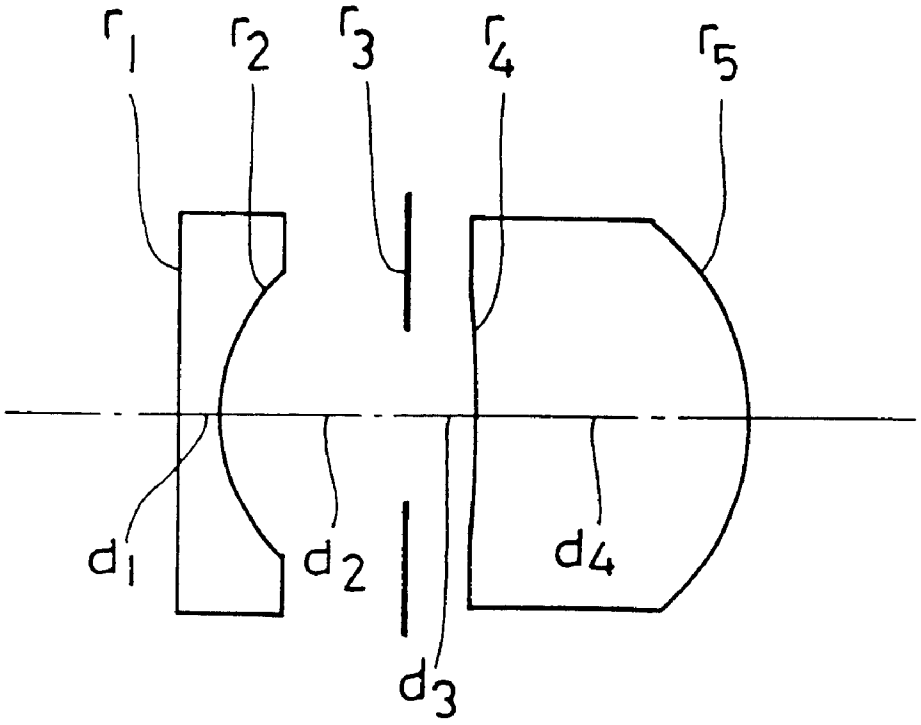

FIG. 1
PRIOR ART

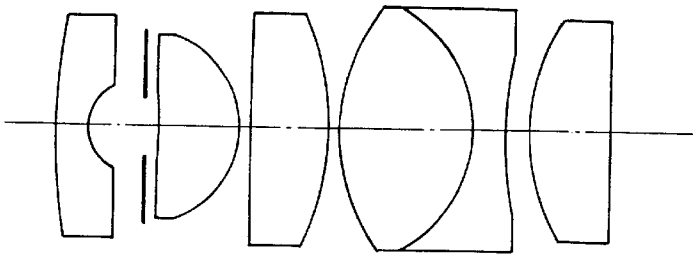

FIG. 2

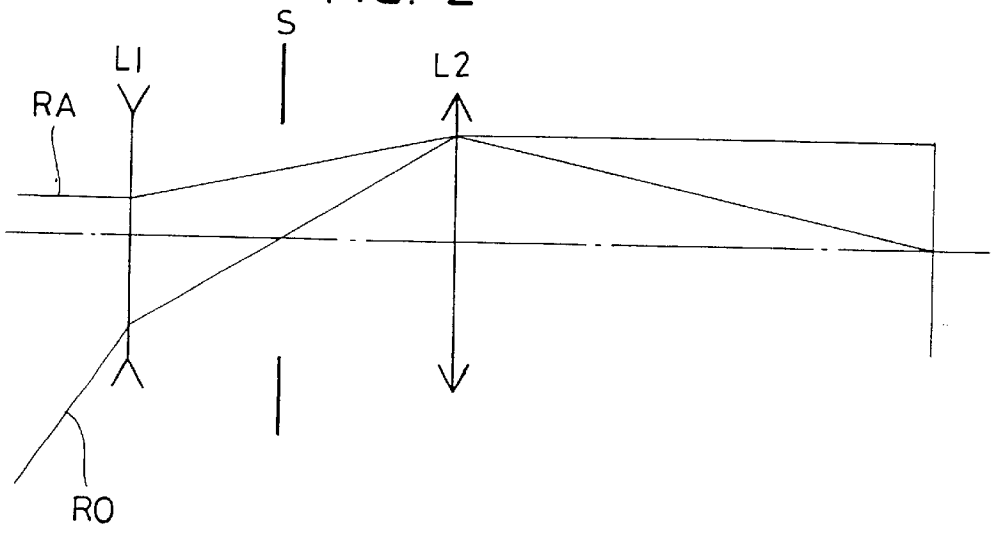

FIG. 3

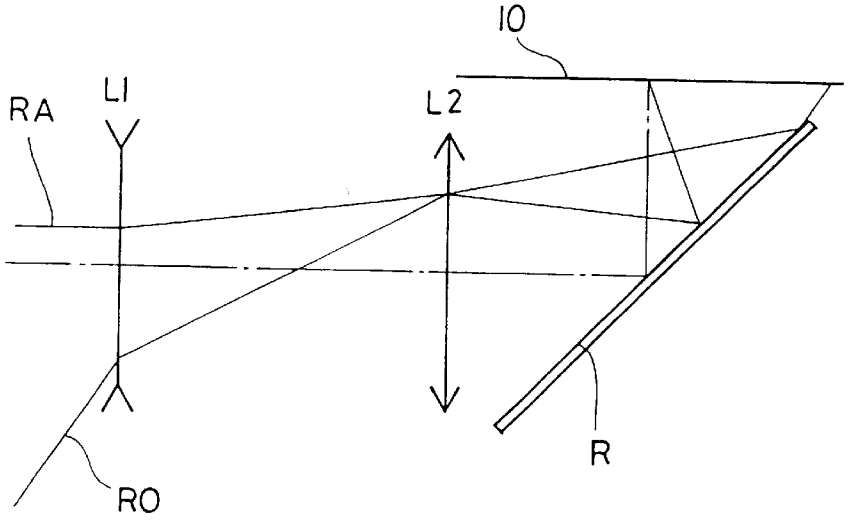

FIG. 4

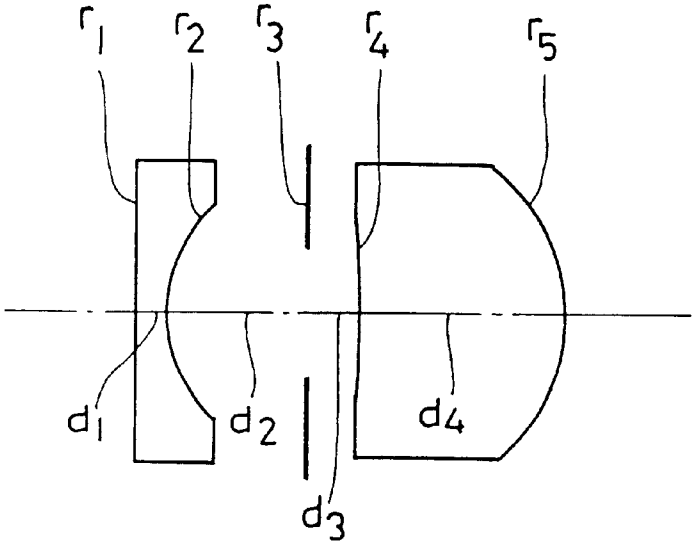

FIG. 5

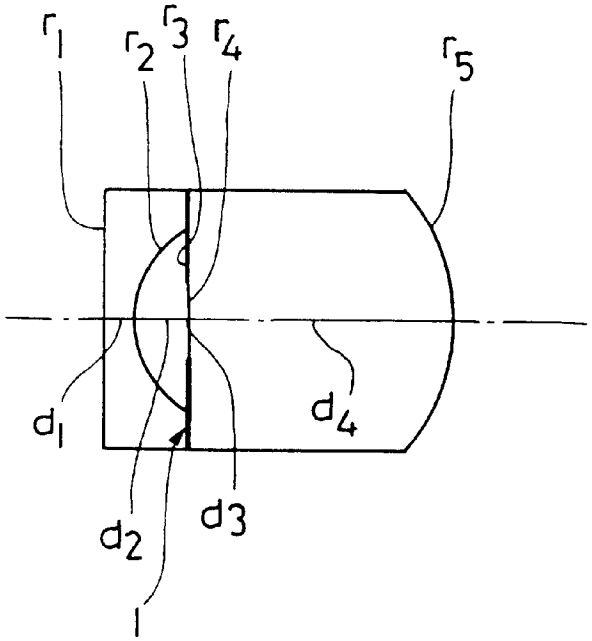

FIG. 6

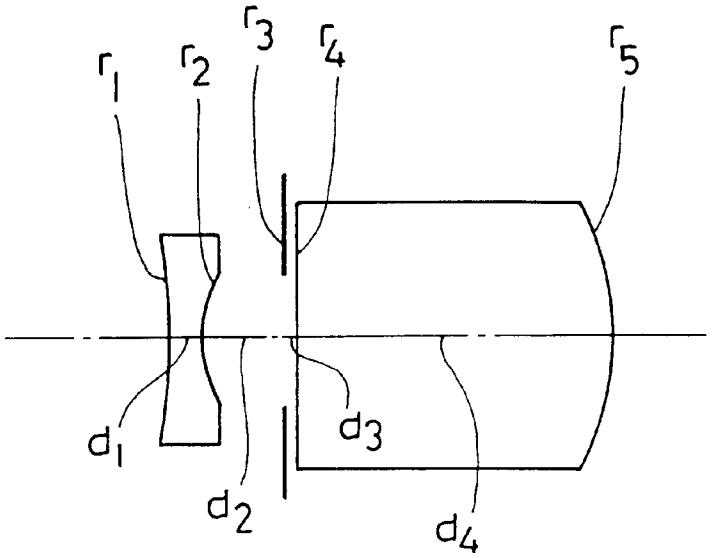

FIG. 7

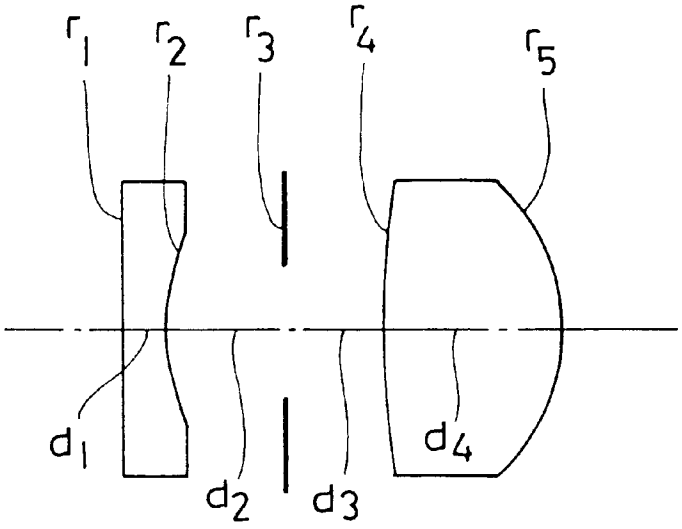

FIG. 8

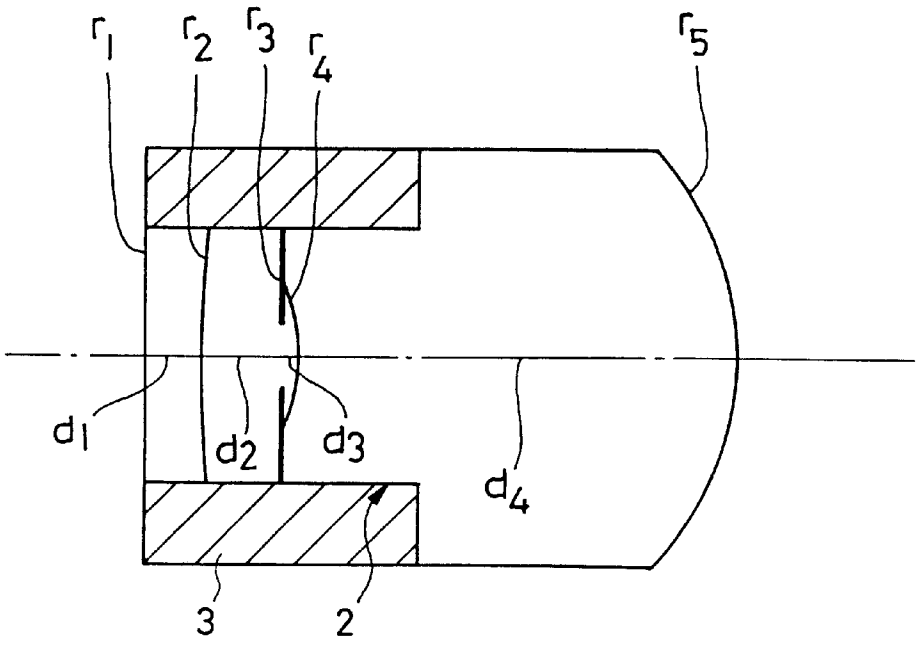

FIG. 9

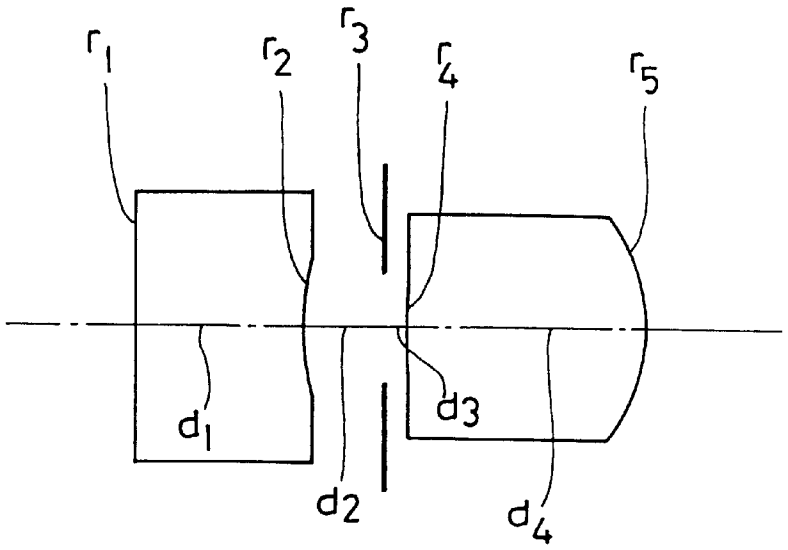

FIG. 10

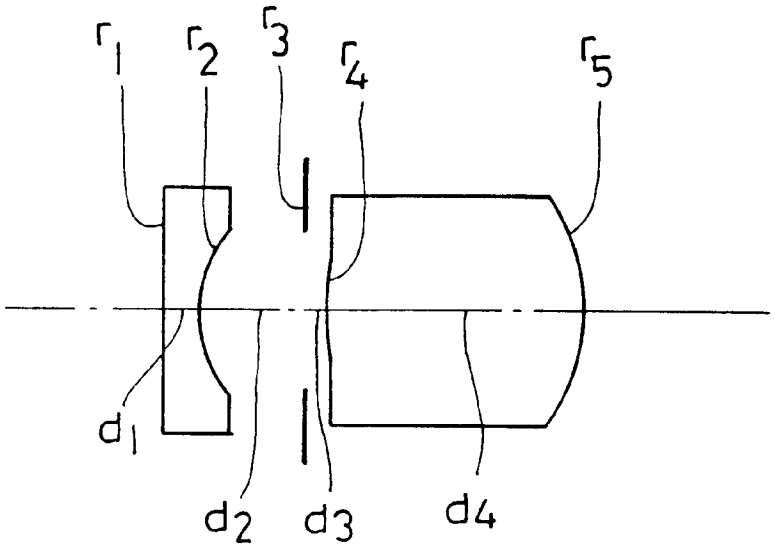

FIG. 11

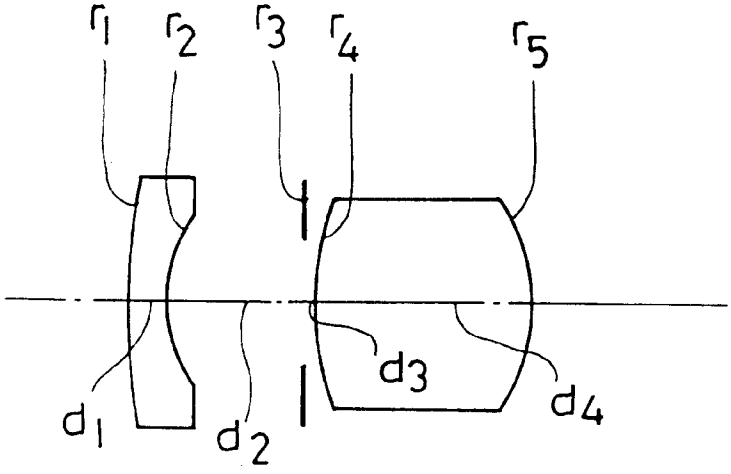

FIG. 12

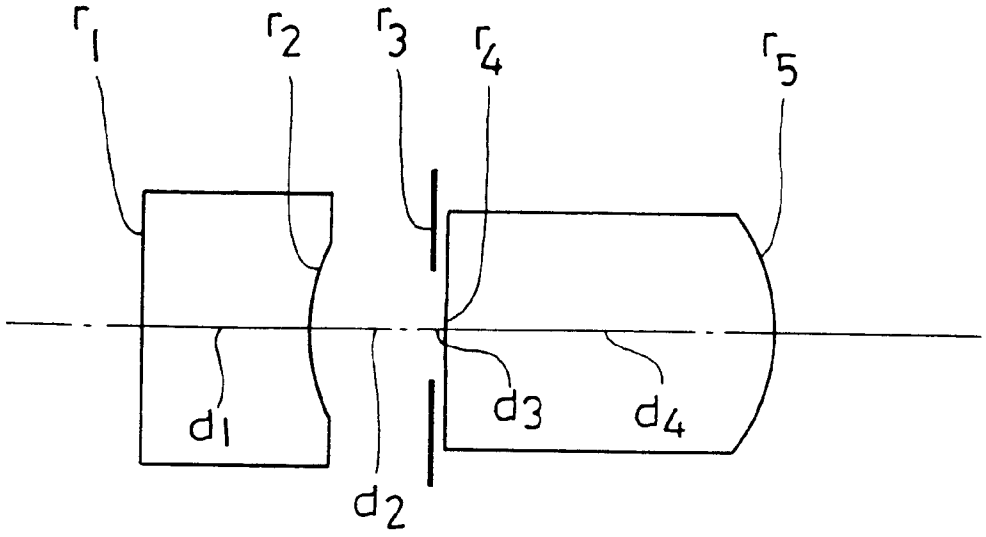

FIG. 13

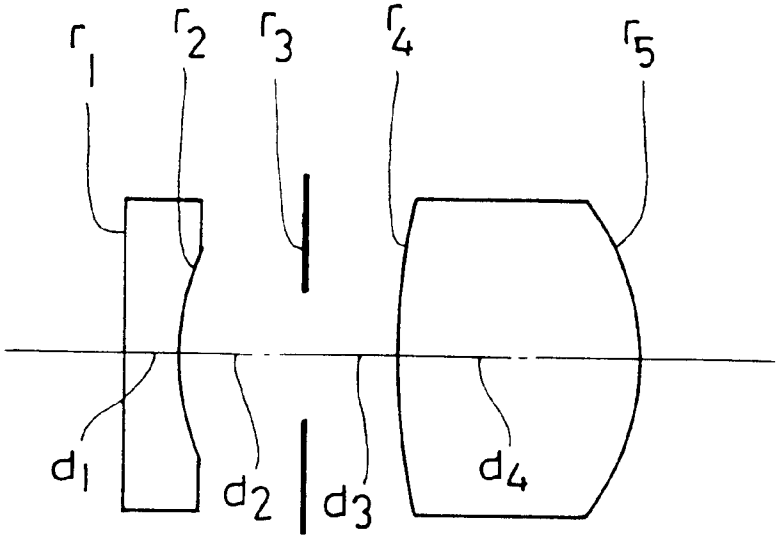

FIG. 14

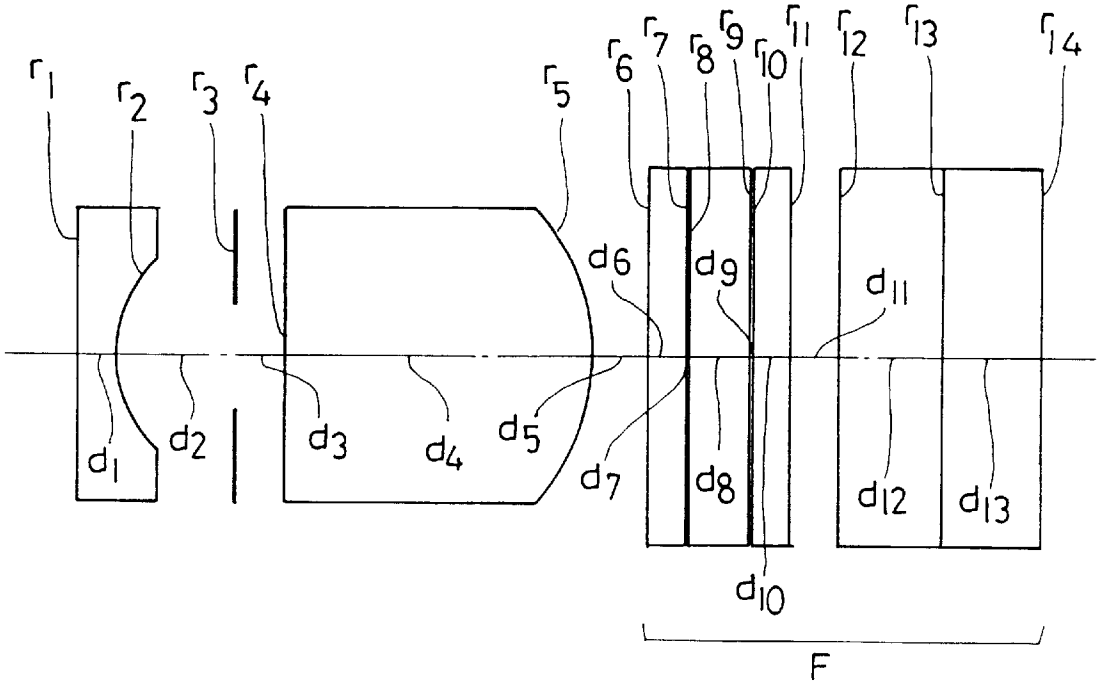
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FIG. 15

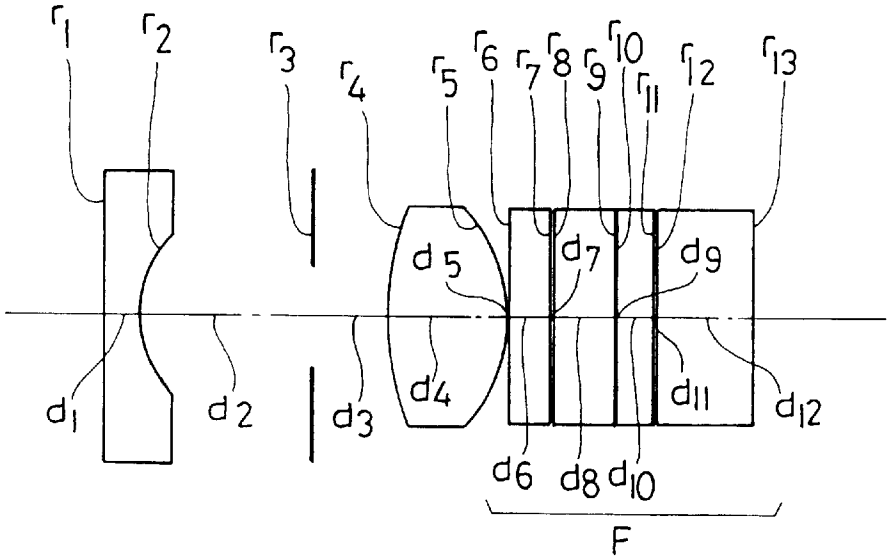
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FIG. 16A

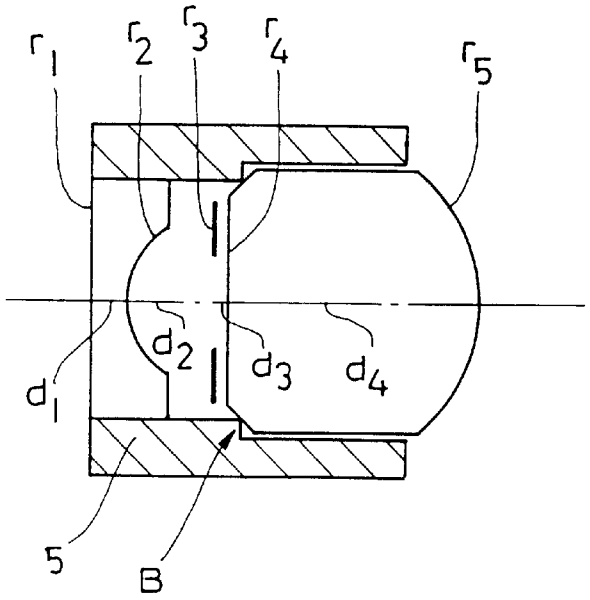

FIG. 16B

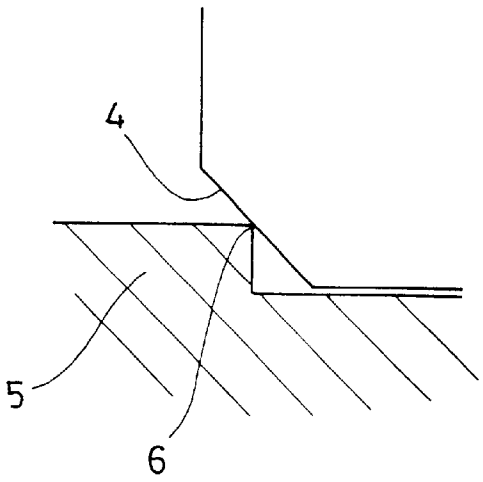

FIG. 17

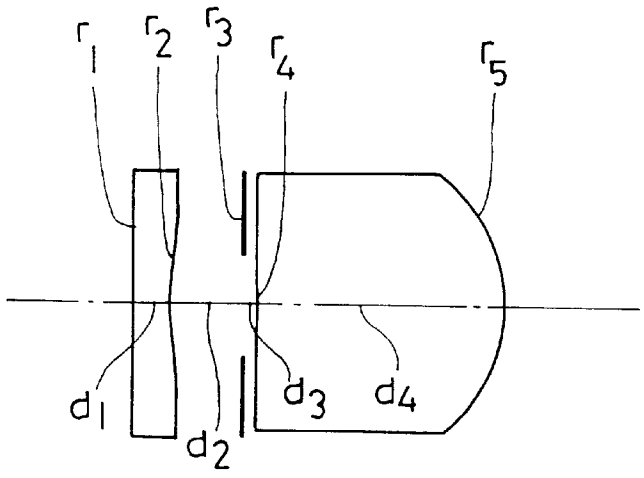

FIG. 18

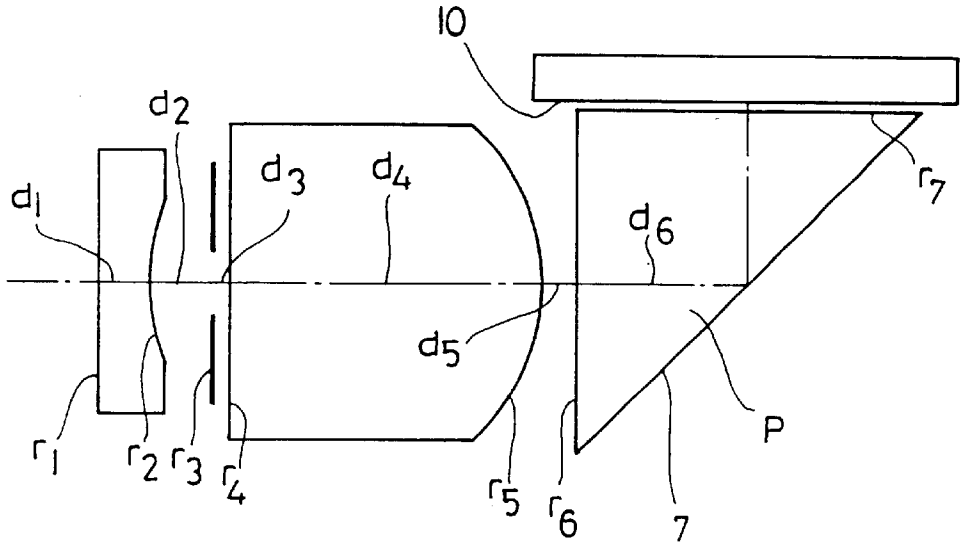

FIG. 19

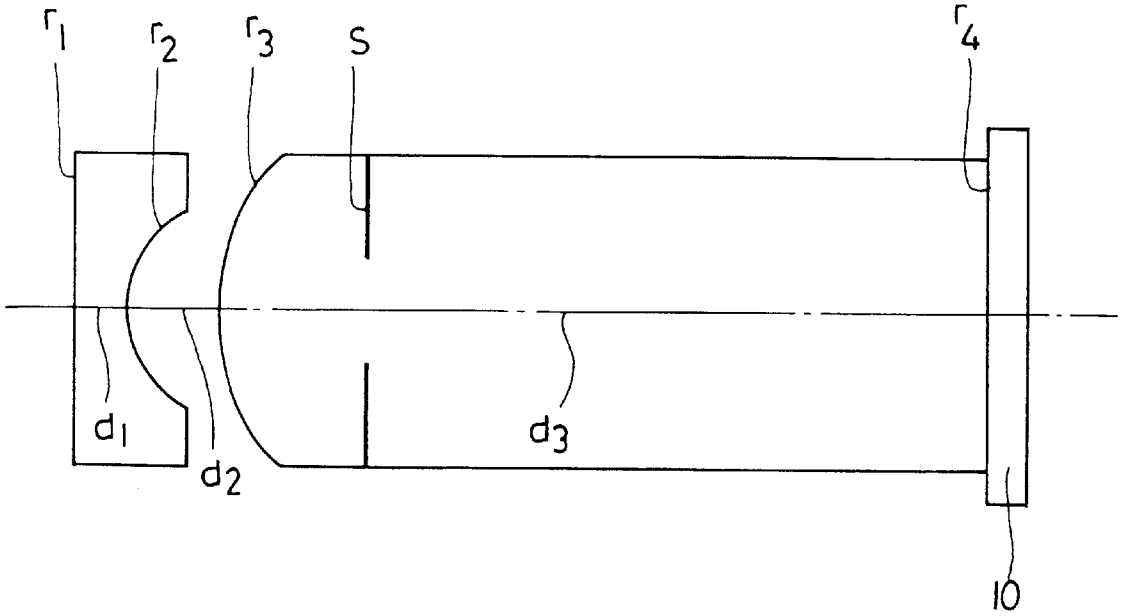

FIG. 20

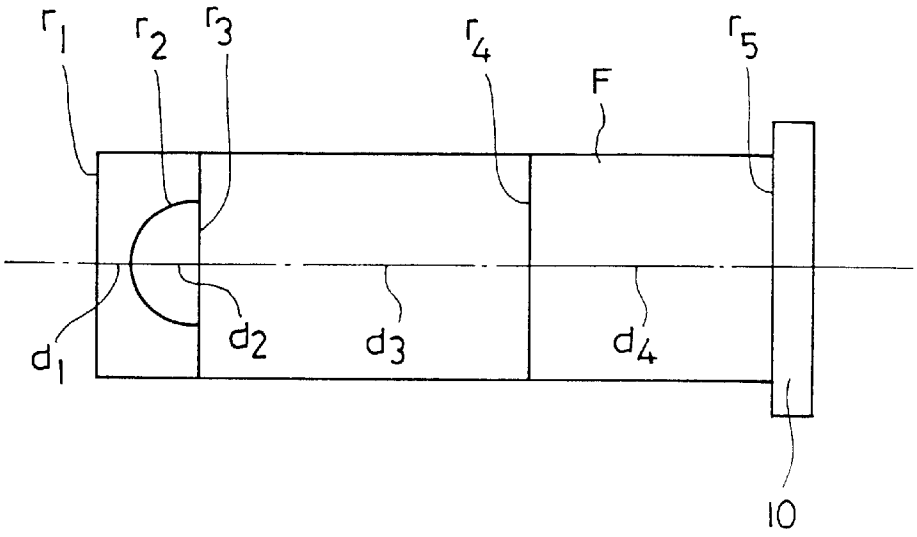

FIG. 21

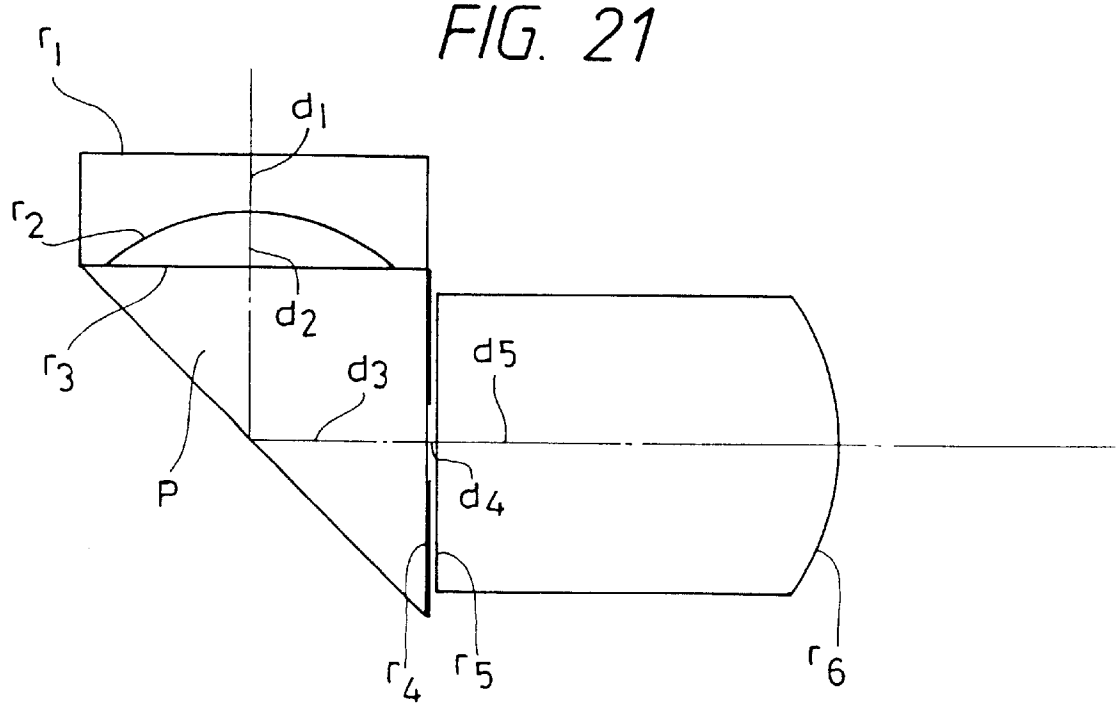

FIG. 22A

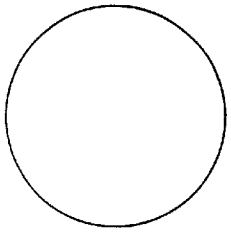

FIG. 22B

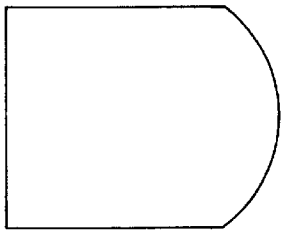

FIG. 22C

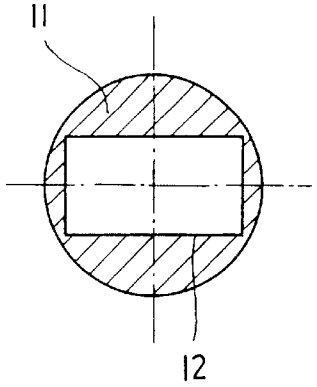

FIG. 23A

FIG. 23B

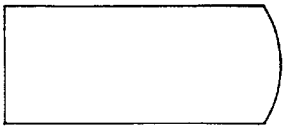

FIG. 23C

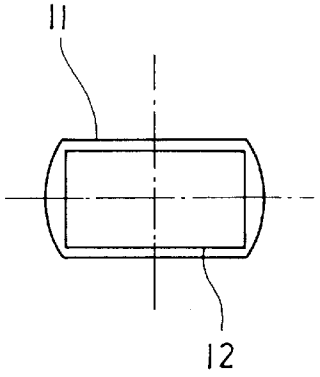

FIG. 24

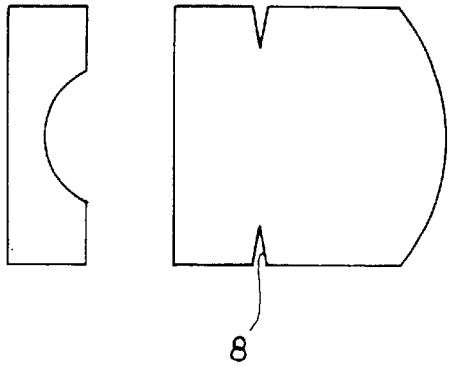

FIG. 25

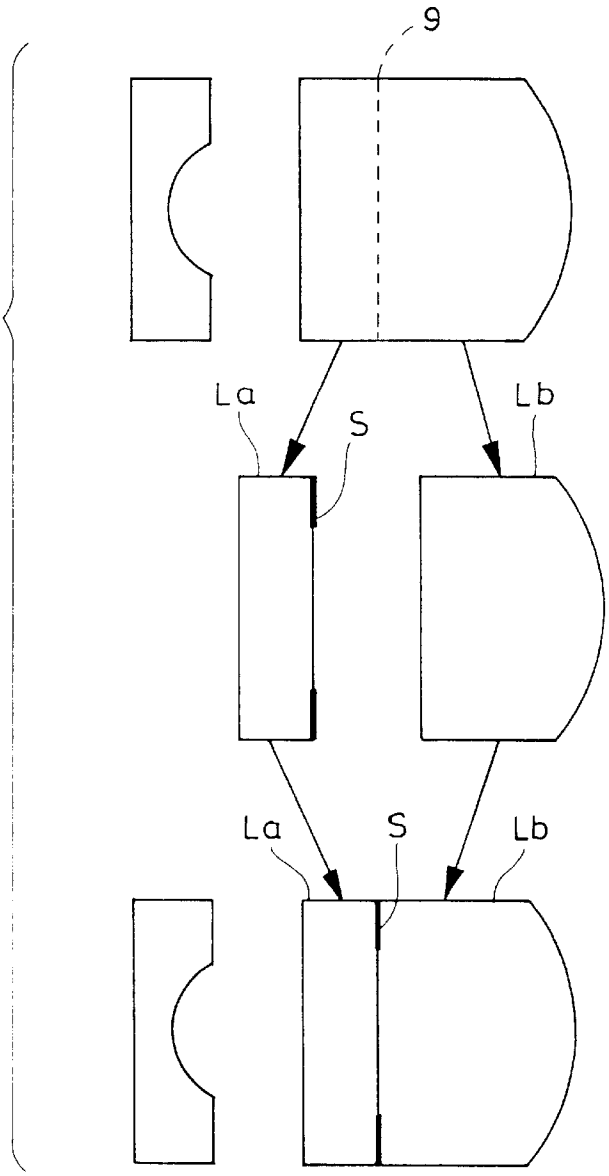

FIG. 26

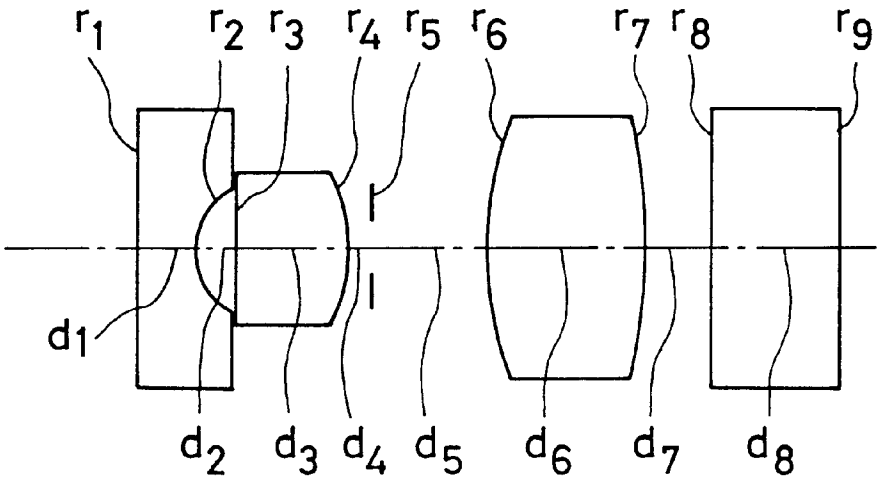
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FIG. 27

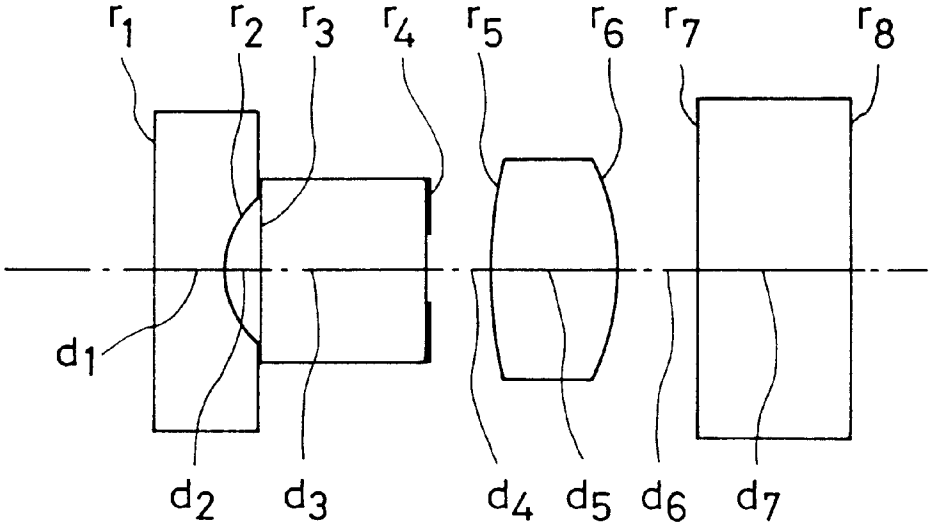
r1
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FIG. 28

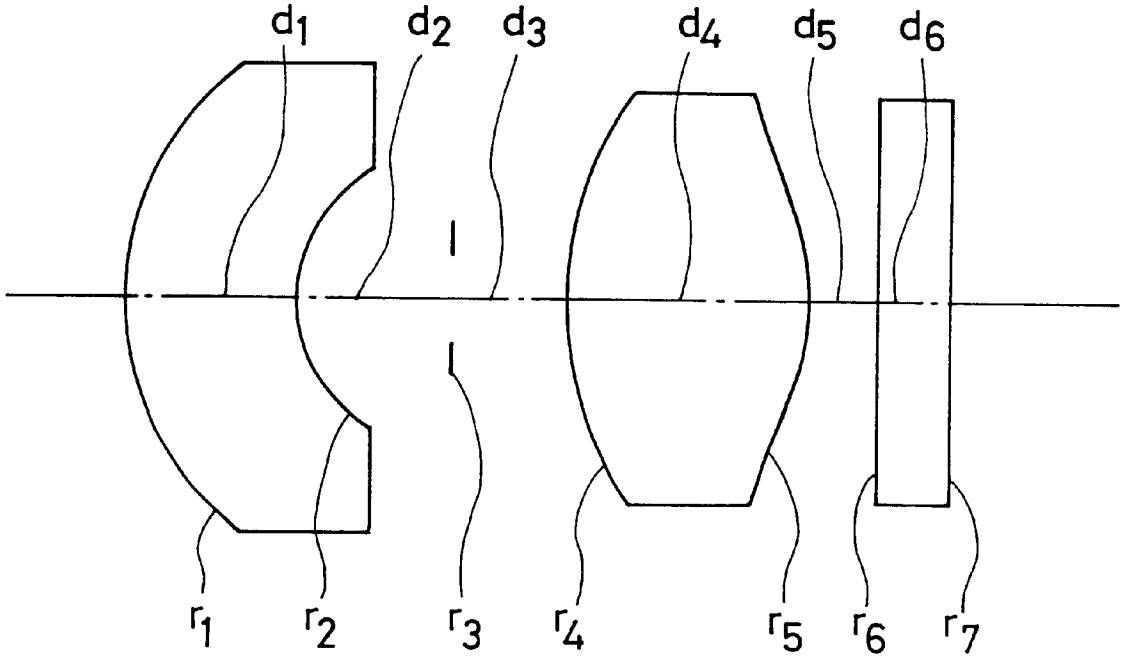


FIG. 29

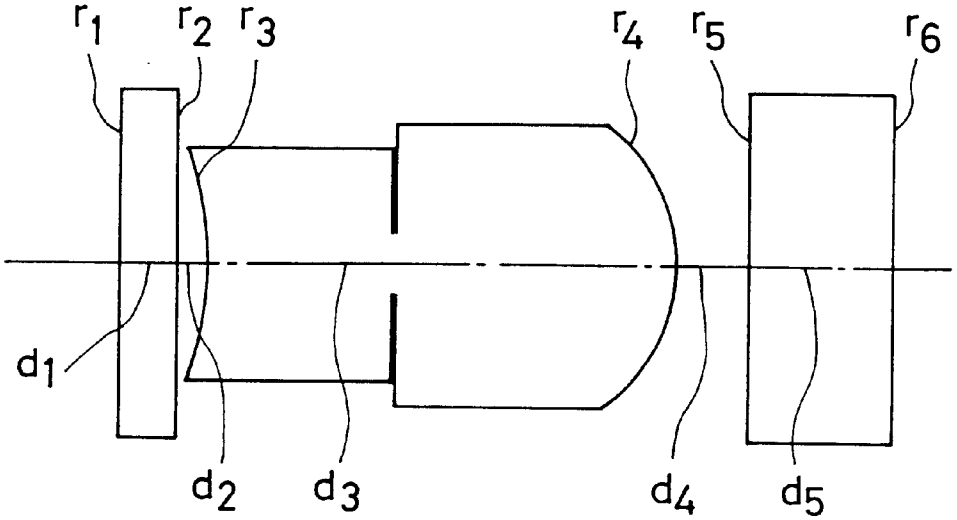
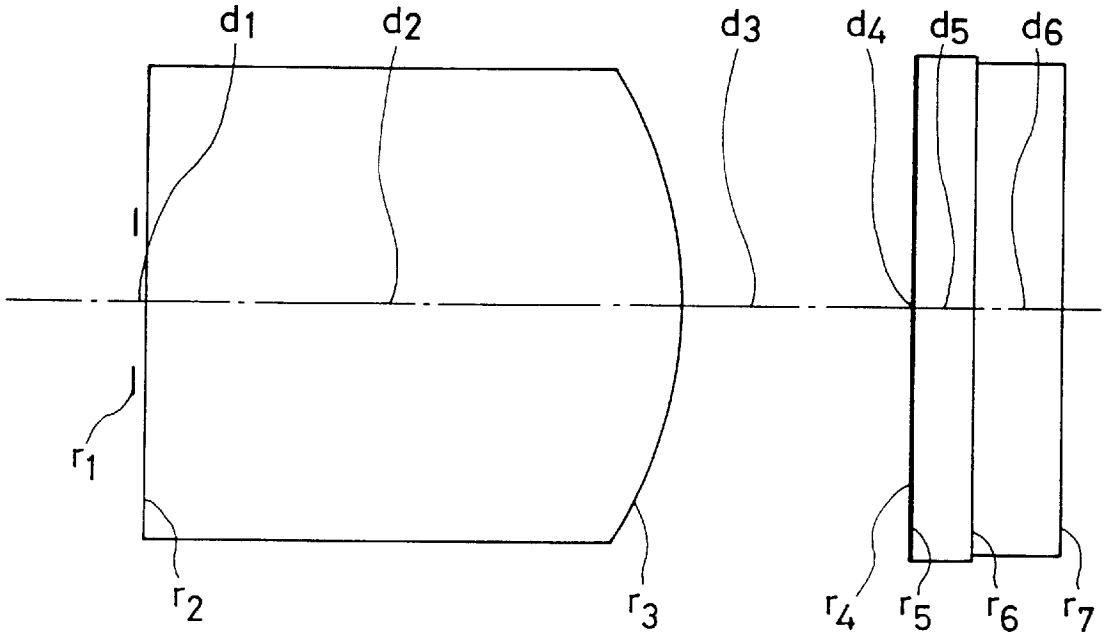


FIG. 30


d1
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r2
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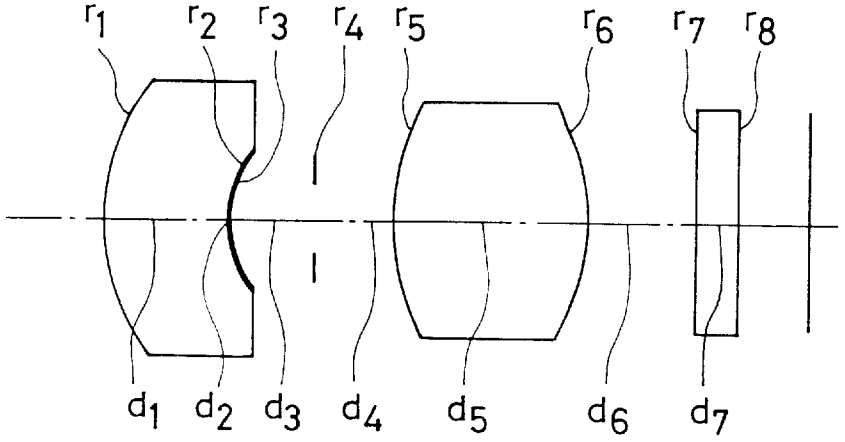
r7

FIG. 31


r1
r2
r3
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r6
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r8
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d5
d6
d7

FIG. 32

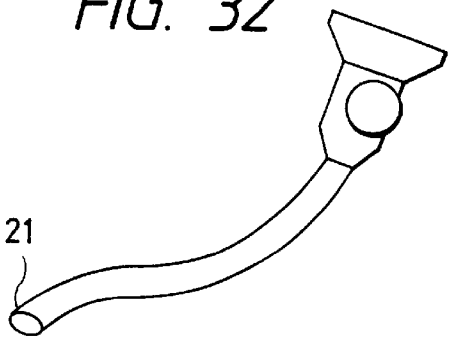


FIG. 33

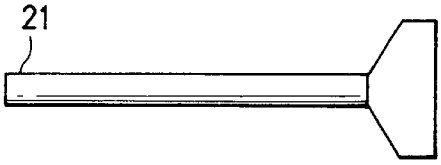


FIG. 34

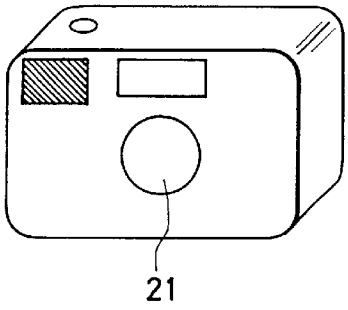


FIG. 35

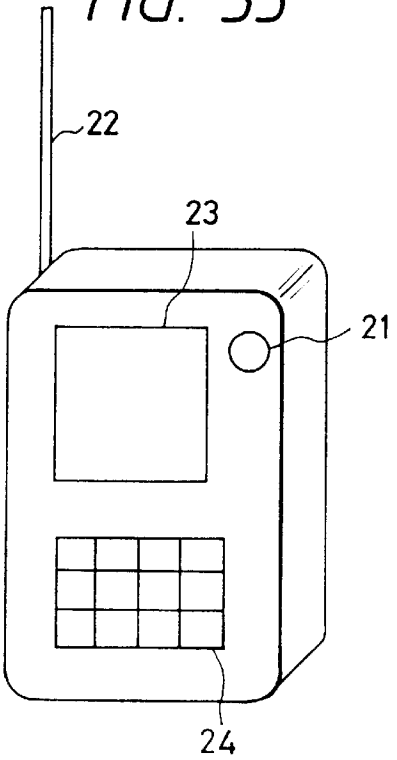
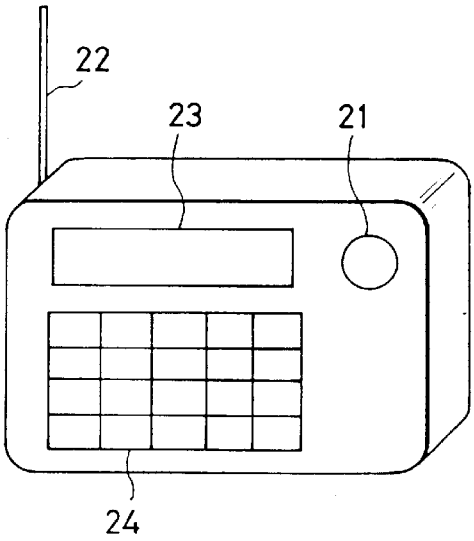


FIG. 36



OBJECTIVE LENS SYSTEM

This is a division of application Ser. No. 09/455,362 filed Dec. 6, 1999, now U.S. Pat. No. 6,243,217, which is a divisional of application Ser. No. 08/713,069 filed Sep. 12, 1996, now U.S. Pat. No. 5,999,327, the entire contents of each being incorporated by reference.

BACKGROUND OF THE INVENTION

a) Field of the Invention

The present invention relates to an objective lens system which uses a radial type gradient index lens element.

b) Description of the Prior Art

As conventional examples of lens systems having relatively wide field angle and high optical performance which are used, for example, as objective lens systems for endoscopes, there are known many lens systems such as a lens system disclosed by Japanese Patent Kokoku Publication No. Sho 60-46410 shown in FIG. **1**. A conventional example shown in FIG. **1** is a lens system of the so-called retrofocus type which is composed, in order from the object side, of a front lens unit having negative refractive power, a stop and a rear lens unit having a positive refractive power. In this lens system, the front lens unit has a function to widen a field angle and another function to correct curvature of field by reducing a Petzval's sum of the lens system as a whole, the rear lens unit serves for suppressing production of spherical aberration and coma by distributing refractive powers among three positive lens elements and a cemented lens component, and the cemented lens component corrects lateral chromatic aberration which poses a problem, in particular, in a lens system which has a wide field angle. Though this conventional example favorably corrects aberrations, it is composed of lens elements in a number as large as six, thereby posing a problem of low producibility or a high manufacturing cost. Accordingly, it is expected to develop a retrofocus type objective lens system for endoscopes which is composed of an extremely small number of lens elements and has a high producibility. However, a lens system which favorably corrects aberrations and has high optical performance can hardly be composed of two homogenous spherical lens elements.

Further, an endoscope is generally equipped with a system for illuminating a location to be observed since it is used frequently for observing and photographing dark locations such as interiors of human bodies, aircraft engines, pipings and so on. In addition, an objective lens system for endoscopes has an NA which is not so large for obtaining a large depth of field. Accordingly, axial aberrations do not pose a serious problem, but a wide field angle and a negative-positive asymmetrical composition as shown in FIG. **1** make it difficult to correct offaxial aberrations. When an objective lens system is to be composed of two negative and positive lens elements, it is impossible to use a cemented lens component as in the objective lens system disclosed by Japanese Patent Kokoku Publication No. Sho 60-46410 mentioned above as the conventional example, whereby lateral chromatic aberration can hardly be corrected and offaxial imaging performance is remarkably degraded. It is therefore difficult to favorably correct offaxial aberrations with two homogenous lens elements so as to obtain favorable offaxial imaging performance.

It is therefore conceivable to use a radial type gradient index lens element which is characterized in that it corrects chromatic aberration in particular more favorably than a homogenous lens element. As a conventional example of an objective lens system for endoscopes which uses a radial type gradient index lens element and is composed of two lens elements, there is known a lens system disclosed by Japanese Patent Kokai Publication No. Sho 52-29238. However, this conventional example has a field angle as narrow as 72° which is insufficient for use as an objective lens system for endoscopes.

Further, a lens system disclosed by Japanese Patent Kokai Publication No. Hei 5-107471, for example, is known as a conventional example of an objective lens system having a wide field angle obtained with two lens elements. Though this example uses a radial type gradient index lens element, it does not effectively make use of the chromatic aberration correcting capability of the radial type gradient index lens element and does not sufficiently correct lateral chromatic aberration which poses a problem in a lens system having a wide field angle in particular.

SUMMARY OF THE INVENTION

A primary object of the present invention is to provide an objective lens system which is composed of lens elements in a number on the order of 2, that favorably corrects aberrations and has a wide field angle.

The objective lens system according to the present invention is characterized in that it comprises, in order from the object side, a first lens unit having a negative refractive power and a second lens unit having a positive refractive power, that at least the first lens unit comprises a radial gradient index lens element which has a refractive index distribution in a radial direction of the lens element; and that the first lens unit satisfies that following condition (1):

$$1/V_{10}<1/V_{00} \tag{1}$$

wherein the reference symbols V_{00} and V_{10} represent parameters expressing a dispersing power of the radial type gradient index lens element which are given by the following formula (b) and (c) respectively:

$$V_{00}=(N_{00d}-1)/(N_{00F}-N_{00C}) \tag{b}$$

$$V_{10}=N_{10d}/(N_{10F}-N_{10C}) \tag{c}$$

wherein the reference symbols N_{00d}, N_{00F}, and N_{00C} represent refractive indices of the radial type gradient index lens element for the d-line, F-line and C-line respectively, and the reference symbols N_{10d}, N_{10F}, and N_{10C}) designate values of a coefficient of a term r^2 for the d-line, F-line and C-line respectively when a refractive indices of the radial type gradient index lens element is expressed in a form of a poly-nominal. In embodiments of the present invention which are to be described later, refractive indices of radial type gradient index lens element are given by the following formula (a):

$$n(r)=N_{00}+N_{10}r^2+N_{20}r^4+\ldots \tag{a}$$

wherein the reference symbol r represent a distance as measured from an optical axis in a radial direction of the radial type gradient index element and the reference symbol n(r) designates a refractive index of a portion of the radial type gradient index lens element located at the distance r.

Further, the objective lens system according to the present invention is characterized in: that it is composed, in order from the object side, of a first lens unit having a negative refractive power, and a second lens unit having a positive refractive power, that at least the second lens unit comprises a radial type gradient index lens element having a refractive

index distribution in a radial direction of the lens element, and that the second lens unit satisfies the following conditions (1) and (3):

$$1/V_{10}<1V_{00} \quad (1)$$

$$0.05<\phi_{2m}/\phi<1.0 \quad (3)$$

wherein the reference symbols ϕ_{2m} represents a refractive index of a medium of the radial type gradient lens element used in the second lens unit.

Further, it is desirable that the objective lens system according to the present invention described above satisfies the following condition (2):

$$-0.5<\phi_{1m}/\phi<-0.02 \quad (2)$$

wherein the reference symbol ϕ_{1m} represent a refractive power of a medium of the radial type gradient index lens element used in the first lens unit and the reference symbol ϕ designates a refractive power of the objective lens system as a whole.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** shows a sectional view illustrating a composition of a conventional objective lens system;

FIG. **2** shows a diagram schematically showing a fundamental composition of the objective lens system according to the present invention;

FIG. **3** shows a diagram schematically showing the fundamental composition of the objective lens system according to the present invention wherein an image surface is positioned in parallel with an optical axis;

FIGS. **4** through **15** show sectional views illustrating compositions of first through twelfth embodiments of the objective lens system according to the present invention;

FIGS. **16**A and **16**B show views illustrating a composition of a thirteenth embodiment of the objective lens system according to the present invention;

FIGS. **17** through **21** show sectional views illustrating composition of fourteenth through eighteenth embodiments of the objective lens system according to the present invention;

FIGS. **22**A, **22**B and **22**C show diagrams exemplifying a shape, before working, of a lens element which is to be used in the objective lens system according to the present invention;

FIGS. **23**A, **23**B and **23**C show diagrams exemplifying a shape, after working, of the lens system which is to be used in the objective lens system according to the present invention;

FIG. **24** is a diagram showing an example of a stop which is to be disposed in the objective lens system according to the present invention;

FIG. **25** is a diagram showing another example of a stop which is to be disposed in the objective lens system according to the present invention;

FIGS. **26** through **31** show sectional views illustrating compositions of nineteenth through twenty-fourth embodiments of the objective lens system according to the present invention;

FIG. **32** shows a perspective view illustrating an endoscope which uses the objective lens system according to the present invention;

FIG. **33** shows a side view of a non-flexible endoscope which uses the objective lens system according to the present invention;

FIG. **34** shows a perspective view illustrating a video camera which uses the objective lens system according to the present invention;

FIG. **35** shows a perspective view illustrating a portable TV telephone which uses the objective lens system according to the present invention; and

FIG. **36** shows a perspective view illustrating a portable data input unit which uses the objective lens system according to the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

It is desirable that an objective lens system which has a relatively wide field angle for use in endoscopes, for example, is configured as the so-called retrofocus type composed, in order from the object side, of a first lens unit having a negative refractive power and a second lens unit having a positive refractive power.

Further, it is desirable that endoscopes, for example, which are inserted into human bodies and pipings for observing interiors thereof use objective lens systems having small diameters. When the lens system according to the present invention is to be used as an objective lens system for endoscopes, it is desirable for reducing a diameter of the lens system to compose it by disposing a stop between a negative lens unit and a positive lens unit. By selecting such a composition, it is possible to lower heights of rays passing through a first lens unit or a second lens unit, thereby reducing the diameter of the lens system. When the lens system has an asymmetrical composition, or is composed of a positive lens unit and a negative lens unit disposed on both sides of a top, however, offaxial aberrations are apt to be produced in large amounts in the lens system as a whole, or it is difficult to favorably correct lateral chromatic aberration in particular. For favorably correcting lateral chromatic aberration, it is desirable to use a radial type gradient index lens element which has a more excellent characteristic for correcting chromatic aberration than a homogenous lens element.

It is known that lateral chromatic aberration LTC produced by a thin radial type gradient index lens element is expressed by the following formula (d):

$$LTD=K(\phi_s/V_{00}+\phi_m/V_{10}) \quad (d)$$

wherein the reference symbol K represents a constant determined dependently on a height of an offaxial ray and an angle of a final axial ray, the reference symbol (ϕ_s designates a refractive power of a surface of the radial type gradient index lens element and the reference symbol (ϕ_m denotes a refractive power of a medium of the radial type gradient index lens element which is known to be approximated by the following formula (e):

$$\phi_m=31\ 2N_{10}d_G \quad (e)$$

wherein the reference symbol d_G represents thickness of the radial type gradient index lens element.

As is apparent from the formula (d), it is possible to control an amount of chromatic aberration to a desired value by varying V_{10} in the second term of the formula.

Since the objective lens system according to the present invention has an asymmetrical composition, like the model of thin lens elements shown in FIG. **2**, wherein a first negative lens unit L_1 and a second positive lens unit L_2 are disposed in that order from the object side and on both side of a stop S, each of the lens units refracts a ray RO coming

from an offaxial object point, unlike a ray RA coming from an axial object point, in a direction which is the same as a refracted direction (downward in FIG. **2**) of an incident light bundle. Accordingly, lateral chromatic aberration is produced in a very large amount in the objective lens system according to the present invention, thereby making it difficult to compose the objective lens system, in order from the object side, of a negative lens unit and a positive lens unit which consist of two homogenous lens elements.

For solving this problem or favorably correcting lateral chromatic aberration by adopting a radial type gradient index lens element, it is conceivable to select either of two cases: one where the radial index lens element is used in the first negative lens unit and the other where the radial gradient lens element is used in the second positive lens unit.

Description will be made of a first composition of the objective lens system according to the present invention where a radial gradient index element is used in the first negative lens unit.

For allowing a radial type gradient index lens element to produce chromatic aberration in an amount smaller than that of chromatic aberration produced by a homogenous lens element which has the same refractive power as that of the radial type gradient index lens element, it is necessary to form the formula (d) to satisfy the following relationship:

$$\phi_s/V_{00}+\phi_m/V_{10}<\phi_1/V_{00}$$

wherein the reference symbol ϕ_t represents a refractive power of the homogenous lens element on an assumption that it has an Abbe's number which is equal to that on the optical axis of the radial type gradient index lens element.

Since the radial type gradient index lens element and the homogenous lens element which are compared with each other have the same refractive power, we obtain:

$$\phi_t=\phi_2+\phi_m$$

From the two formulae mentioned above, there establishes the following relationship:

$$\phi_2/V_{00}+\phi_m/V_{10}<\phi_s/V_{00}+\phi_m/V_{00}$$

The above-mentioned condition (1) is obtained from this formula.

For favorably correcting lateral chromatic aberration in the objective lens system according to the present invention, it is desirable to use a radial type gradient index lens element satisfying the condition (1) as the first lens unit which has the negative refractive power as described above. The condition (1) is required for allowing a radial type gradient index lens element to produce chromatic aberration in an amount smaller than that of chromatic aberration produced by a homogenous lens element which has the same refractive power as that of the radial type gradient index lens element. If the condition (1) is not satisfied, a radial type gradient index lens element cannot correct lateral chromatic aberration more favorably than a homogenous lens element which has the same refractive power as that of the radial type gradient index lens element.

When a radial type gradient index lens element is to be used for correcting lateral chromatic aberration, it is necessary, as apparent from the formula (d), to take into sufficient consideration not only a value of V_{10} but also refractive powers of a surface and a medium. For reducing an amount of lateral chromatic aberration to be produced by the first lens unit in the objective lens system according to the present invention, it is desirable from the formula (d) to meet the following equation:

$$\phi_s/V_{00}+\phi_m/V_{10}=0$$

By using a total refractive power of a surface and a medium ϕ_G ($=\phi_s+\phi_m$) in this formula and developing it, we obtain:

$$\phi_m=\phi_G\times V_{10}/(V_{10}-V_{00})$$

Since the Abbe's number V_{00} of a radial type gradient index lens element ordinarily has a value on the order of 30 to 80 on an optical axis and the first lens unit has the negative refractive power, the condition (1) required for correcting chromatic aberration can be transformed as follows:

$$\phi_G\times V_{10}/(V_{10}-V_{00})<0$$

It is desirable as understood from this formula that a medium has a negative refractive power. Taking into consideration this fact and the requirement to correct lateral chromatic aberration favorably in the objective lens system as a whole, it is desirable that a radial type gradient index lens element which is to be used in the objective optical system according to the present invention is made of a medium having a refractive power ϕ_{1m} satisfying the above-mentioned condition (2).

When a ratio of a refractive power of a medium of the first lens unit relative to a refractive power of the objective lens system satisfies the condition (2), it is possible to correct lateral chromatic aberration favorably in the objective lens system as a whole. If the upper limit of −0.02 of the condition (2) is exceeded, a medium of the radial type gradient index lens element will have a weak refractive power, thereby undesirably making it difficult to correct lateral chromatic aberration favorably in the objective lens system as a whole. If the lower limit of −0.5 of the condition (2) is not satisfied, in contrast, a medium will have too strong a refractive power, thereby overcorrecting lateral chromatic aberration.

The objective lens system according to the present invention which has a second composition is composed of a first lens unit having a negative refractive power and a second lens unit having a positive refractive power; a radial type gradient index lens element being used in the second lens unit having the positive refractive power; and the radial type gradient index lens element used in the second lens unit having a refractive index expressed by the above-mentioned formula (a) and satisfying the following conditions (1) and (3):

$$1/V_{10}<1/V_{00} \quad (1)$$

$$0.05<\phi_{2m}/\phi<1.0 \quad (3)$$

wherein the reference symbol ϕ_{2m} represents a refractive power of the gradient index lens element which is used in the second lens unit and the reference symbol ϕ designates a refractive power of the objective lens system as a whole.

Since lateral chromatic aberration is produced in a very large amount in the objective lens system as a whole as described above, it is difficult to compose the lens system, in order from the object side, of two negative and positive homogenous lens elements. When a radial type gradient index lens element is to be used in the second lens unit for solving this problem or favorably correcting lateral chromatic aberration, it is desirable to configure this lens element so as to satisfy the condition (1) mentioned above.

The condition (1) is required for allowing the radial type gradient index lens element to produce chromatic aberration in an amount smaller than that of chromatic aberration produced by a homogenous lens element which has the same refractive power as that of the radial type gradient index lens element.

If the condition (1) is not satisfied, the radial type gradient index lens element cannot correct chromatic aberration more favorably than the homogenous lens element having the same refractive power as that of the radial type gradient index lens element.

When a radial type gradient index lens element is to be used for correcting lateral chromatic aberration, it is necessary to take into consideration not only a value of V_{10} but also refractive powers of a surface and a medium as described above. When lateral chromatic aberration produced by the second lens unit is to be reduced in the objective lens system according to the present invention, the formula (d) is transformed, as in the case where a radial type gradient index lens element is used in the first lens unit, into the following formula:

$$\phi_m = \phi_G \times V_{10}/(V_{10}-V_{00})$$

Since the second lens unit has a positive refractive power, it is desirable that ϕ_m has a positive value. When a radial type gradient index lens element is to be used in the second lens unit for correcting lateral chromatic aberration favorably in the objective lens system as a whole, it is desirable that the refractive power ϕ_m of a medium satisfies the above-mentioned condition (3).

When a ratio of a refractive power of medium relative to a refractive power of the objective lens system as a whole satisfies the condition (3), it is possible to correct lateral chromatic aberration favorably in the objective lens system as a whole.

If the lower limit of 0.05 of the condition (3) is not satisfied, a medium of the radial type gradient index lens element will have a weak refractive power, thereby undesirably making it difficult to correct lateral chromatic aberration favorably in the objective lens system as a whole. If the upper limit of 1.0 of the condition (3) is exceeded, in contrast, a refractive power of medium will be too strong, thereby undesirably overcorrecting lateral chromatic aberration.

The condition (3) is required also for favorably correcting not only chromatic aberration but also the other aberrations.

The objective optical system according to the present invention which has a wide field angle produces a positive Petzval's sum in the lens system as a whole, thereby tending to tilt an image surface toward the object side. For favorably correcting this Petzval's sum, it is desirable to use a radial type gradient index lens element in the second lens unit which has a large positive Petzval'sum.

A Petzval's sum PTZ of a radial type gradient index lens element is expressed by the following formula (f):

$$PTZ = \phi_s/N_{00} + \phi_m/N_{00}^2 \quad (f)$$

As is apparent from the formula (f) in which the denominator of the second term on the right side is squared, it is possible to configure a radial type gradient index lens element so as to have a Petzval's sum which is smaller than of a homogenous lens element having the same refractive power as that of the radial type gradient index lens element.

For reducing a Petzval's sum of the objective lens system with a radial type gradient index lens element, it is desirable from the formula (f) that the radial type gradient index lens element satisfies the following formula:

$$\phi_s/N_{00} + \phi_m/N_{00}^2 = 0$$

The formula shown below can be derived by using a total refractive power of surface and medium ϕ_G ($=\phi_2+\phi_m$) in the above formula and developing it.

$$\phi_m = \phi_G \times N_{00}/(N_{00}-1$$

Since refractive indices N_{00} on an optical axis of radial gradient index lens elements ordinarily have values larger than 1, or on the order of 1.45 to 1.85, it is desirable for favorably correcting a Petzval's sum to use a radial type gradient index lens element which has a positive refractive power of medium when it is to be used in the second lens unit having the positive refractive power. If a radial type gradient index lens element which has a negative refractive power of medium is used in the second lens unit, the positive Petzval's sum will be further enlarged, hereby undesirably tilting an image surface toward the object side.

For correcting the Petzval's sum in the objective lens system according to the present invention, it is desirable from the formula (f) that a refractive power of medium is strong to a certain degree or refractive power of medium ϕ_m satisfies the condition (3). When a ratio of the refractive power of medium relative to a refractive power of the objective lens system as a whole satisfies the condition (3), it is possible to favorably correct the Petzval's sum in the objective lens system as a whole. If the lower limit of 0.05 of the condition (3) is not satisfied, a refractive power of medium will be weak, thereby making it difficult to correct the Petzval's sum favorably in the objective lens system as a whole. If the upper limit of 1.0 of the condition (3) is exceeded, in contrast, a refractive power of medium will be too strong and the Petzval's sum will be overcorrected, thereby undesirably tilting an image surface in a direction away from the object side.

As understood from the foregoing description, the condition (3) is required for favorably correcting lateral chromatic aberration and Petzval's sum at the same time in the objective lens system according to the present invention (which has the second composition).

Further, an objective lens system for endoscopes is generally used in combination with a solid-state image pickup device such as CCD or an end surface of the so-called image guide composed of an optical fiber bundle which is disposed on an image surface. When a objective lens system is to be combined not with a silver salt photographic film but with a solid-state image pickup device or an image guide, it is desirable for enhancing a light condensing efficiency to configure the objective lens system so as to be telecentric on the image side so that incident rays are as perpendicular as possible to an image surface. For configuring the objective lens system according to the present invention so as to meet this requirement, the second lens unit having the positive refractive power must have an image side surface which has a positive refractive power stronger than that of an object side surface thereof. When the image side surface of the second lens unit on which offaxial rays are relatively high has a strengthened refractive power in the objective lens system according to the present invention having a wide field angle, however, this surface will produce coma in a large amount and it will be difficult to correct this coma favorably with a homogenous lens element.

Accordingly, it was conceived to correct coma favorably in the objective lens system according to the present invention with a radial type gradient index lens element used in the second lens unit. For correcting this aberration, it is desirable that the radial type gradient index lens element has such a refractive index distribution as to progressively lower refractive indices from the optical axis toward a marginal portion. An amount of coma to be produced by the image side surface of the second lens unit can be reduced by configuring the radial type gradient index lens element to be used in the second lens unit so as to have such a refractive

index distribution. Therefore, the condition (3) serves for favorable correction of coma in addition to favorable correction of lateral chromatic aberration. When the condition (3) is satisfied, the radial type gradient index lens element has a refractive index distribution wherein refractive indices are progressively lowered from the optical axis toward the marginal portion, thereby being capable of favorably correcting coma. If the lower limit of 0.05 of the condition (3) is not satisfied, it will be difficult to favorably correct coma with the radial type gradient index lens element. If the upper limit of 1.0 of the condition (3) is exceeded, in contrast, coma will undesirably be overcorrected.

Since the objective lens system according to the present invention has a wide field angle and the asymmetrical composition which is negative-positive in order from the object side, it tends to produce remarkable barrel form distortion which can hardly be corrected favorably with two homogenous lens elements. For correcting the barrel form distortion favorably in the objective lens system according to the present invention, it is desirable to use, in the second lens unit having the positive refractive power, a radial type gradient index lens element which has a refractive index distribution wherein refractive indices are progressively lowered from the optical axis toward the marginal portion. Distortion to be produced by the second lens unit can be reduced by using a radial type gradient index lens element having such a refractive index distribution. Accordingly, the condition (3) serves for favorable correction of distortion in addition to favorable correction of lateral chromatic aberration. When the condition (3) is satisfied, refractive indices are progressively lowered from the optical axis toward the marginal portion, thereby enabling to favorably correct distortion. If the lower limit of 0.05 of the condition (3) is not satisfied, it will be difficult to favorably correct distortion with a radial type gradient index lens element. If the upper limit of 1.0 of the condition (3) is exceeded, in contrast, aberrations other than distortion will undesirably be overcorrected.

The objective lens system according to the present invention which has a third composition is characterized in: that it is composed, in order from the object side, of a first lens unit having a negative refractive power and a second lens unit having a positive refractive power; that it uses at least one radial type gradient index lens element having a refractive index distribution in a radial direction from an optical axis which is expressed by the formula (a); and that at least one the of surfaces of lens elements including the radial type gradient index lens element composing the lens system is configured as an aspherical surface which has such a shape as to weaken a refractive power of the lens element having the aspherical surface from the optical axis toward the marginal portion.

Since the objective lens system according to the present invention has a wide field angle and an asymmetrical composition which is negative-positive in order from the object side, it tends to produce remarkable distortion in addition to lateral chromatic aberration. Though distortion can be corrected to a certain degree by using a radial type gradient index lens element in the second lens unit as described above, it is desirable for correcting distortion more favorably to configure the objective optical system according to the present invention so as to comprise at least one surface of at least one lens element which is configured as an aspherical surface having such a shape as to weaken a refractive power of the lens element having the aspherical surface from the optical axis toward the marginal portion. In the objective lens system according to the present invention, barrel form distortion is produced by both the first lens unit having the negative refractive power and the second lens unit having the positive refractive power. When an aspherical surface is to be used in either of the lens units in the objective lens system, it is therefore desirable to configure the aspherical surface so as to have such a shape as to weaken a refractive power from the optical axis toward the marginal portion of the lens element using the aspherical surface. When the second lens unit uses a radial type gradient index lens element, for example, it is desirable to use an aspherical surface in the first lens unit having the negative refractive power and configure the aspherical surface so as to have such a shape as to weaken the negative refractive power from the optical axis toward the marginal portion. Though distortion produced by the second lens unit can be corrected to a certain degree by using a radial type gradient index lens element in the second lens unit as described above, distortion can be corrected more favorably by using an aspherical surface in the first lens unit.

When a radial type gradient index lens element is used in the first lens unit, it is desirable to use, in the second lens unit having a positive refractive power, an aspherical surface which has such a shape as to weaken the positive refractive power toward the optical axis to a marginal portion.

If an aspherical surface has such a shape as to strengthen the refractive power of a lens unit which comprises this aspherical surface, it will undesirably make barrel form distortion more remarkable in the objective lens system as a whole.

It is needless to say that an effect similar to that described above can be obtained by configuring a surface of a radial type gradient index lens element as an aspherical surface.

For correcting lateral chromatic aberration in the objective lens system according to the present invention which has the third composition, it is desirable to configure the radial type gradient index lens element so as to satisfy the condition (1). If the condition (1) is not satisfied, lateral chromatic aberration will undesirably be more remarkable in the objective lens system according to the present invention.

It is needless to say that lateral chromatic aberration can be corrected more favorably by using two radial type gradient index lens elements when the objective lens system according to the present invention is to be composed of two negative and positive lens elements.

It is also needless to say that distortion can be corrected more favorably by using an aspherical surface on each of the lens elements when the objective lens system is to be composed of two negative and positive lens elements.

The objective lens system according to the present invention which has a fourth composition is characterized in that it is composed, in order from the object side, of a first lens unit having a negative refractive power and a second lens unit having a positive refractive power. The second lens unit comprises at least one radial type gradient index lens element which has a refractive index distribution in a radial direction expressed by the formula (a), or wherein refractive indices are progressively lowered from an optical axis toward a marginal portion. The radial type gradient index lens element has a shape of a positive lens element. The radial type gradient index lens element satisfies the condition (1).

When a radial type gradient index lens element is to be used in the second lens unit, it is desirable for correcting lateral chromatic aberration to configure it so as to satisfy the condition (1) as described above, and it is desirable for correcting a Petzval's sum, coma or distortion that this lens element has a refractive index distribution wherein refrac-

tive indices are lowered from the optical axis toward the marginal portion. When not only correction of aberrations but also manufacturing facility are taken into consideration, it is desirable that the radial type gradient index lens element has a shape of a positive lens element.

Since the objective lens system according to the present invention has a wide field angle, it is necessary that the second lens unit has a strong positive refractive power. When a radial type gradient index lens element is to be used in the second lens unit, it is therefore desirable that the radial type gradient index lens element also has a strongly positive refractive power. However, it is undesirable that the radial type gradient index lens element has an extremely strong positive refractive power of medium for a reason described below. As apparent from the formula (e), it is sufficient for strengthening a refractive power of medium of a radial type gradient index lens element to enlarge an absolute value of the refractive index distribution coefficient of the second order N_{10} or thickness d_G of the radial type gradient index lens element. However, an absolute value of the refractive index distribution coefficient of the second order can be enlarged only within a range limited by preparation of materials and enlargement of thickness d_G makes it difficult to configure the objective lens system compactly, thereby making it unusable as an objective lens system for endoscopes, for example, which are desired to be compact. Accordingly, it is desirable not to impart an extremely strong positive refractive power to a medium but to impart refractive powers to both the medium and surfaces, or configure the radial type gradient index lens element so as to have a shape of a positive lens element.

The objective lens system according to the present invention which has a fifth composition is characterized in that it is composed, in order from the object side, of a first lens unit having a negative refractive power and a second lens unit having a positive refractive power; that it uses at least one lens element which is configured as a radial type gradient index lens element having a refractive index distribution in the radial direction from an optical axis expressed by the formula (a); and that a lens unit comprising the radial type gradient index lens element or at least one optical element disposed in the objective lens system has a function to shield components having specific wavelengths.

By using a radial type gradient index lens element, it is possible to obtain an objective lens system which favorably corrects chromatic aberration in particular and has high imaging performance. An objective lens system for endoscopes which comprises a solid-state image pickup device such as a CCD, for example, may use an infrared cut filter for cutting off rays in the infrared region since the image pickup device has high sensitivity at wavelengths in the infrared region. Further, such an optical system may use a low pass filter made, for example, of quartz for eliminating noise components produced due to moire. Furthermore, such an objective lens system may use a band cut filter for cutting off components having specific wavelengths since endoscopes may be used not only for observing interiors of human bodies but also for cutting off diseased portions of patients with laser knives. It is therefore desirable that the objective lens system according to the present invention uses not only a radial type gradient index lens element but also filters of the kinds mentioned above so that it can exhibit high imaging performance when it is used in optical systems for endoscopes which use, for example, solid-state image pickup devices such as CCD's.

It is desirable that these filters are disposed at locations between a lens element disposes on the image side and an image surface at which offaxial rays, in particular, are nearly in parallel with the optical axis. By disposing the filters as described above, it is possible to prepare approximately equal optical path lengths for axial and offaxial rays, thereby allowing the filters to exhibit their effects uniformly over the entire image pickup surface.

Endoscopes which are to be inserted into human bodies must be compact and require compacter optical systems. When importance is laid on compactness rather than optical performance, it is effective to dispose filters between the first lens unit and the second lens unit. Further, for obtaining an objective lens system which is compact and can be manufactured at a low cost, is is effective to impart filter functions to at least one of the lens elements including a radial type gradient index lens element.

The objective lens system according to the present invention which has a sixth embodiment is characterized in that it is composed, in order from the object side, of a first lens unit having a negative refractive power and a second lens unit having a positive refractive power, that it uses at least one radial type gradient index lens element which has a refractive index distribution in a radial direction expressed by the formula (a); and that it uses a reflecting surface for at least a single reflection disposed on the image side of the second lens unit.

Resolution of an optical system for endoscopes which uses a solid-state image pickup device such as a CCD, for example, can be enhanced by reducing the size of picture elements and arranging these picture elements in a larger number at a higher density on the image pickup device. However, the size of a picture element can be reduced only within a certain manufacturing limit and it is therefore conceivable to enhance resolution by enlarging an image pickup surface. However, it is desirable that endoscopes which may be inserted into human bodies have smaller diameters, or it is undesirable to enlarge image pickup surfaces, thereby enlarging diameters of endoscopes.

For allowing solid-state image pickup devices having larger image pickup surfaces to be used without enlarging diameters of endoscopes, the objective lens system according to the present invention uses a reflecting surface for at least one reflection on the image side of the second lens unit which makes it possible to dispose a solid-state image pickup device not in parallel with a radial direction of the endoscope but in a position inclined with regard thereto. FIG. **3** shows a conceptional diagram of the objective lens system according to the present invention which has the sixth composition. In FIG. **3**, the reference symbol L_1 represents the first negative lens unit, the reference symbol L_2designates the second positive lens unit, the reference symbol RA denotes an axial ray, the reference symbol RO represents an offaxial ray, the reference symbol R designates the reflecting surface and the reference numeral **10** denotes the image pickup device disposed on an image pickup plane. The reflecting surface R disposed on the image side of the second lens unit makes it possible to arrange the solid-state image pickup device which has a large image pickup surface nearly parallel to the optical axis. Though a system for a single reflection is illustrated in FIG. **3**, it is possible, needless to say, to obtain a similar effect by using a larger number of reflecting surfaces for a plurality of reflections.

When a solid-state image pickup device having a large image pickup surface is used, an image height can be enhanced in a lens system for obtaining a lens system having a wide field angle. However, it is desired for an objective lens system to correct aberrations more favorably over a range from a center to a marginal portion of an image plane.

For an objective lens system having a wide field angle in particular, it is desired to favorably correct lateral chromatic aberration.

An objective lens system which has high imaging performance for axial and offaxial rays can therefore be obtained by using a radial gradient index lens element which has high capability to correct chromatic aberration in particular. It is possible to obtain an objective lens system having higher performance by combining an objective lens system which uses a radial type gradient index lens element with a reflection system shown in FIG. **3** which permits enlarging an image pickup surface.

When a radial type gradient index lens element is used in the second lens unit in each of the compositions (first through sixth composition) of the objective lens system according to the present invention, it is desirable for more favorable correction of lateral chromatic aberration, coma and distortion to satisfy the following condition (4)

$$-0.5<N_{10p}\cdot f^2<-0.01 \tag{4}$$

wherein the reference symbol N_{10p} represents a refractive index distribution coefficient of the second order when a radial type gradient index lens element is used in the second lens unit and the reference symbol f designates a focal length of the objective lens system as a whole.

When the condition (4) is satisfied, a refractive power of medium of the radial type gradient index lens element has a sufficiently large value, thereby making it possible to correct lateral chromatic aberration favorably. Further, refractive indices are progressively lowered from the optical axis toward a marginal portion and a difference in refractive index (Δn) is large between the optical axis and the marginal portion, thereby making it possible to favorably correct coma produced by an image side surface of the second lens unit and barrel form distortion which poses a problem in the objective lens system as a whole.

If the upper limit of −0.01 of the condition (4) is exceeded, the radial type gradient index lens element will have a weak refractive power of medium, thereby making it difficult to correct lateral chromatic aberration favorably in the objective lens system as a whole, and the difference in refractive indices will be small between the optical axis and the marginal portion, thereby making it difficult to correct coma and distortion. If the lower limit of −0.5 of the condition (4) is not satisfied, in contrast, the radial type gradient index lens element will have a large refractive index difference Δn, thereby undesirably making it difficult to prepare a material for the radial type gradient index lens element.

When a radial type gradient index lens element is used in the first lens unit in the objective lens system according to the present invention which has one of the compositions described above, it is desirable for correcting lateral chromatic aberration more favorably to satisfy the following condition (5):

$$0.01<N_{10n}\cdot f^2<0.6 \tag{5}$$

wherein the reference symbol N_{10n} represents the refractive index distribution coefficient of the second order of a gradient index lens element when the radial type gradient index lens element is used in the first lens unit and the reference symbol f designates a focal length of the objective lens system as a whole.

When the condition (5) is satisfied, a refractive power of medium of the radial type gradient index lens element has a sufficiently large value, thereby making it possible to correct lateral chromatic aberration favorably.

If the lower limit of 0.01 of the condition (5) is not satisfied, the radial type gradient index lens element will have a weak refractive power of medium, thereby making it difficult to correct lateral chromatic aberration favorably in the objective lens system as a whole. If the upper limit of 0.6 of the condition (5) is exceeded, the radial type gradient index lens element will have a large refractive index difference Δn, thereby making it difficult to prepare a material for the radial type gradient index lens element.

When the radial type gradient index lens element is used in the first lens unit or the second lens unit of the objective lens system according to the present invention, it is desirable for correcting lateral chromatic aberration more favorably in the lens system to satisfy the following condition (6):

$$1/V10<0.01 \tag{6}$$

The objective lens system which satisfies the condition (6) can favorably correct lateral chromatic aberration. Since radial type gradient index lens elements have Abbe's numbers on the order of 30 to 80 as described above, it is desirable from the formula (d), for allowing a radial type gradient index lens element to exhibit a sufficient function for correction chromatic aberration to satisfy the condition (6). If the condition (6) is not satisfied, it will undesirably be impossible to sufficiently correct lateral chromatic aberration.

When a radial type gradient index lens element is used in the first lens unit of the objective lens system according to the present invention which has any one of the first through sixth compositions, it is desirable for correcting lateral chromatic aberration more favorably to satisfy the following condition (7):

$$0.05<d_{Gn}/f_{Gn}<1.2 \tag{7}$$

wherein the reference symbol d_{Gn} represents thickness of the radial type gradient index lens element used in the first lens unit and the reference symbol f_{Gn} designates a focal length of the radial type gradient index lens element used in the first lens unit.

A radial type gradient index lens element can exhibit its effect to connect chromatic aberration when it has refractive power of medium ϕ_m having a value which is large to a certain degree as described above. When a radial type gradient index lens element has extremely small thickness, for example, the refractive power of medium ϕ_m is weak as judged from the formula (e), thereby making it difficult to favorably correct chromatic aberration. It is therefore desirable that the objective lens system according to the present invention satisfies the condition (7) when a radial type gradient index lens element is used in the first lens unit.

If the lower limit of 0.05 of the condition (7) is not satisfied, the refractive power of medium will be weak, thereby undesirably making it difficult to favorably correct lateral chromatic aberration. If the upper limit of 1.2 of the condition (7) is exceeded, in contrast, the radial type gradient index lens element will have large thickness, thereby undesirably prolonging a total length of the objective lens system.

When a radial type gradient index lens element is used in the second lens unit of the objective lens system according to the present invention which has any one of the composition described above, it is desirable for correcting lateral

chromatic aberration more favorably to satisfy the following condition (8).

$$0.3<d_{Gp}/f_{Gp}<4.0 \quad (8)$$

wherein the reference symbol d_{Gp} represents the thickness of the radial type gradient index lens element used in the second lens unit and the reference symbol f_{Gp} designates a focal length of the radial type gradient index lens element used in the second lens unit.

When a radial type gradient index lens element has extremely small thickness as described above, for example, the refractive power of medium ϕ_m is weak, thereby making it difficult to correct chromatic aberration favorably. When a radial type gradient index lens element is to be used in the second lens unit of the objective lens system according to the present invention, the lens system is therefore configured so as to satisfy the condition (8).

If the lower limit of 0.3 of the condition (8) is exceeded, a refractive power of medium will be weak, thereby undesirably making it difficult to favorably correct lateral chromatic aberration. If the upper limit of 4.0 of the condition (8) is exceeded, a radial type gradient index lens element will have large thickness, thereby undesirably enlarging the objective lens system.

When the first lens unit is to be composed of a single negative lens element in the objective lens system according to the present invention which has any one of the compositions described above, it is desirable for favorably correcting aberrations to satisfy the following condition (9)

$$0.1<1H/r_2<1.7 \quad (9)$$

wherein the reference symbol 1H represents an image height and the reference symbol r_2 designates a radius of curvature on an image side surface of the first lens unit having the negative refractive power.

If the lower limit of 0.1 of the condition (9) is not satisfied, the image side surface of the first lens unit will have a weak refractive power and it will be necessary to strengthen a negative refractive power of an object side surface of the first lens unit on which off axial rays are relatively high, whereby the object side surface will undesirably produce distortion, astigmatism, etc. in larger amounts. If the upper limit of 1.7 of the condition (9) is exceeded, in contrast, the image side surface of the first lens unit will have a strong negative refractive power, thereby undesirably overcorrecting spherical aberration in the objective lens system as a whole.

When the second lens unit is to be composed of a single positive lens element in the objective lens system according to the present invention which has any one of the compositions described above, it is desirable for favorably correcting aberrations to satisfy the following condition (10)

$$-1.5<IH/r_3<0.8 \quad (10)$$

wherein the reference symbol IH represents an image height and the reference symbol r_3 designates a radius of curvature on an object side surface of the second lens unit having the positive refractive power.

If the lower limit of −1.5 of the condition (10) is not satisfied, the object side surface of the second lens unit will have a strong negative refractive power, thereby undesirably overcorrecting spherical aberration in the objective lens system as a whole. If the upper limit of 0.8 of the condition (10) is exceeded, in contrast, the object side surface will undesirably produce spherical aberration, etc. in larger amounts.

When the, second lens unit is to be composed of a single positive lens element in the objective lens system according to the present invention which has any one of the compositions described above, it is desirable for favorably correcting aberrations to satisfy the following condition (11):

$$-1.0<IH/r_4<-0.2 \quad (11)$$

wherein the reference symbol IH represents an image height and the reference symbol r_4 designates a radius of curvature on an image side surface of the second lens unit having the positive refractive power.

If the lower limit of −1.0 of the condition (11) is not satisfied, the image side surface of the second lens unit will have a strong positive refractive power, thereby undesirably aggravating astigmatism and distortion in the objective lens system as a whole. If the upper limit of −0.1 of the condition (11) is exceeded, in contrast, it will be necessary to strengthen a positive refractive power of the object side surface of the second lens unit, whereby the object side surface will undesirably produce astigmatism and distortion in large amounts.

When a radial type gradient index element is to be used in the first lens unit in the objective lens system according to the present invention which has any one of the compositions described above, it is desirable for correcting lateral chromatic aberration more favorably to satisfy the following condition (12):

$$0.05<N_{10n}\cdot f_{Gn}^{\ 2}<1.2 \quad (12)$$

wherein the reference symbol f_{Gn} represents a focal length of the radial type gradient index lens element to be used in the first lens unit.

When the condition (12) is satisfied, the refractive power of medium of the radial type gradient index lens element will have a value which is sufficiently large relative to its total refractive power and can favorably correct lateral chromatic aberration. If the lower limit of 0.05 of the condition (12) is not satisfied, the refractive power of medium will be weak, thereby undesirably making it difficult to correct lateral chromatic aberration favorably with the radial type gradient index lens element. IF the upper limit of 1.2 of the condition (12) is exceeded, refractive index difference Δn will be large, thereby undesirably making it difficult to prepare a material for the radial type gradient index lens element.

When a radial type gradient index lens element is to be used in the second lens element in the objective lens system according to the present invention which has any one of the compositions described above, it is desirable for correcting lateral chromatic aberration, a Petzval's sum, coma or distortion more favorably to satisfy the following condition (13):

$$-0.8<N_{10p}\cdot f_{Gp}^{\ 2}<-0.05 \quad (13)$$

wherein the reference symbol f_{Gp} d represents a focal length of the radial type gradient index lens element to be used in the second lens unit.

When the condition (13) is satisfied, the refractive power of medium of the radial type gradient index lens will have a value which is sufficiently large relative to its total refractive power and can favorably correct lateral chromatic aberration. If the upper limit of −0.05 of the condition (13) is exceeded, the refractive power of medium will be weak, thereby undesirably making it difficult to correct lateral

chromatic aberration favorably with the radial type gradient index lens element. If the lower limit of −0.8 of the condition (13) is not satisfied, in contrast, refractive index difference Δn will be large, thereby undesirably making it difficult to prepare a material for the radial type gradient index lens element.

When a radial type gradient index lens element is to be used in the second lens unit in the objective lens system according to the present invention which has any one of the compositions described above, it is desirable, for facilitating preparation of a material in addition to correction of lateral chromatic aberration, to satisfy the following condition (14):

$$0.1<\phi_{2m}/\phi<0.8 \quad (14)$$

When the condition (14) is satisfied, the radial type gradient index lens element will have a strong refractive power of medium and can correct lateral chromatic aberration favorably. If the lower limit of 0.1 of the condition (14) is not reached, the radial type gradient index lens element will have a weak refractive power of medium and can hardly correct lateral chromatic aberration favorably in the objective lens system as a whole, and a difference in refractive indices will be small between a portion of the radial type gradient index lens element located on the optical axis and a marginal portion thereof, thereby making it difficult to correct coma and distortion. If the upper limit of 0.8 of the condition (14) is exceeded, in contrast, the radial type gradient index lens element will have a large refractive index difference Δn or large thickness, thereby undesirably making it difficult to prepare a material for the radial type gradient index lens element in the former case or undesirably enhancing a manufacturing cost and prolonging a total length of the objective lens system in the latter case.

When a radial type index lens element is to be used in the first lens unit in the objective lens system according to the present invention which has any one of the compositions described above, it is desirable, for facilitating manufacturing of the radial type gradient index lens element in addition to correction of lateral chromatic aberration, to satisfy the following condition (15):

$$-0.25<\phi_{1m}/\phi<-0.05 \quad (15)$$

When the condition (15) is satisfied, the radial type gradient index lens element will have a strong refractive power of medium and can favorably correct lateral chromatic aberration. If the upper limit of −0.05 of the condition (15) is not reached, the radial type gradient index lens element will undesirably have a weak refractive power of medium and can hardly correct lateral chromatic aberration favorably. If the lower limit of −0.25 of the condition (15) is exceeded, the radial type gradient index lens element will undesirably have a large refractive index difference Δn, whereby it can hardly be manufactured or it will be thickner and more expensive to manufacture.

When a radial type gradient index lens element is to be used in the first lens unit in the objective lens system according to the present invention which has any one of the compositions described above, it is desirable, for facilitating manufacturing of the radial type gradient index lens element in addition to correction of lateral chromatic aberration, to satisfy the following condition (16)

$$0.02<N_{10n}\cdot f^2<0.4 \quad (16)$$

When the condition (16) is satisfied, a marginal portion of the radial type gradient index lens element used in the first lens unit may have a refractive index higher than that of a portion thereof on the optical axis, whereby the radial type gradient index lens element has a sufficiently strong refractive power of medium and can correct lateral chromatic aberration favorably.

If the lower limit of 0.02 of the condition (16) is not satisfied, the radial type gradient index lens element will have a weak refractive power of medium, thereby making it difficult to correct lateral chromatic aberration favorably in the objective lens system as a whole. If the upper limit of 0.4 of the condition (16) is exceeded, the radial type gradient index lens element will have a large refractive index difference Δn, thereby undesirable making it difficult to prepare a material therefor.

When a radial type gradient index lens element is to be used in the second lens unit of the objective lens system according to the present invention which has any one of the compositions described above, it is desirable, for facilitating manufacturing of the radial type gradient index lens element in addition to correction of lateral chromatic aberration, to satisfy the following condition (17):

$$-0.25<N_{10p}\cdot f2<-0.04 \quad (17)$$

When the condition (17) is satisfied, the radial type gradient index lens element has a sufficiently strong refractive power of medium and can favorably correct lateral chromatic aberration.

If the upper limit of −0.04 of the condition (17) is exceeded, the radial type gradient index lens element will have a weak refractive power of medium, thereby making it difficult to correct lateral chromatic aberration favorably in the objective lens system as a whole. If the lower limit of −0.25 of the condition (17) is not satisfied, in contrast, the radial type gradient index lens element will have a large refractive index difference Δn, thereby making it difficult to prepare a material therefor.

For correcting lateral chromatic aberration more favorably in the objective lens system according to the present invention which has any one of the compositions described above, it is desirable to configure a radial type gradient index lens element so as to satisfy the following condition (18):

$$1/V_{10}<0 \quad (18)$$

When the condition (18) is satisfied, the radial type gradient index lens element produces chromatic aberration in a direction opposite to that of chromatic aberration produced by a homogeneous lens element having a refractive power which is the same as that of the radial type gradient index lens element. That is to say, when a radial type gradient index lens element is used in the first lens unit or the second lens unit of the objective lens system according to the present invention satisfies the condition (18), lateral chromatic aberration is overcorrected independently by the radial type gradient index lens element, but this overcorrected chromatic aberration cancels lateral chromatic aberration produced by the other lens element, thereby correcting chromatic aberration favorably in the objective lens system as a whole.

When a radial type gradient index lens element is to be used in the first lens unit of the objective lens system according to the present invention which has any one of the compositions described above, it is desirable, for facilitating manufacturing of the radial type gradient index lens element

in addition to correction of lateral chromatic aberration, to satisfy the following condition (19)

$$0.1<d_{Gn}/f_{Gn}<0.9 \quad (19)$$

If the lower limit of 0.1 of the condition (19) is exceeded, the radial type gradient index lens element will undesirably have a weak refractive power of medium, thereby undesirably making it difficult to correct lateral chromatic aberration favorably. If the upper limit of 0.9 of the condition (19) is exceeded, in contrast, the radial type gradient index lens element will be thick, thereby undesirably increasing the manufacturing cost of the objective lens system.

When a radial type gradient index lens element is to be used in the first lens unit of the objective lens system according to the present invention which has any one of the composition described above, it is desirable, for facilitating manufacturing of the radial type gradient index lens element in addition to correction of lateral chromatic aberration, to satisfy the following condition (20)

$$0.7<d_{Gp}/f_{Gp}<2.8 \quad (20)$$

When a radial type gradient index lens element has extremely small thickness for example, it has a weak refractive power of medium ϕm and can hardly correct chromatic aberration favorably. When a radial type gradient index lens element is to be used in the second lens unit of the objective lens system according to the present invention, it is therefore desirable to configure the radial type gradient index lens element so as to satisfy the condition (20).

If the lower limit of 0.7 of the condition (20) is exceeded, the radial type gradient index lens element will undesirably have a weak refractive power of medium, thereby undesirably making it difficult to correct lateral chromatic aberration favorably. IF the upper limit of 2.8 of the condition (20) is exceeded, in contrast, the radial type gradient index lens element will have large thickness, thereby undesirably increasing the manufacturing cost of the objective lens system.

When the first lens unit is to be composed of a single negative lens element in the objective lens system according to the present invention which has any one of the compositions described above, it is desirable for more favorable correction of aberrations to configure it so as to satisfy the following condition (21):

$$0.25<IH/r_2<1.4 \quad (21)$$

If the lower limit of 0.25 of the condition (21) is not satisfied, an image side surface of the first lens unit will have a weak negative refractive power and it will be necessary to strengthen a negative refractive power of an object side surface of the first lens unit on which off axial rays are relatively high, whereby the object side surface will undesirably produce distortion, astigmatism, etc. in large amounts. If the upper limit of 1.4 of the condition (21) is exceeded, in contrast, the image side surface of the first lens unit will have a strong negative refractive power, thereby undesirably overcorrecting spherical aberration in the objective lens system as a whole.

When the second lens unit is to be composed of a single positive lens element in the objective lens system according to the present invention which has any one of the compositions described above, it is desirable for favorably correcting aberrations to satisfy the following condition (22):

$$-0.9<IH/r_3<0.6 \quad (22)$$

If the lower limit of −0.9 of the condition (22) is not reached, an object side surface of the second lens unit will have a strong negative refractive power, thereby undesirably overcorrecting spherical aberration in the objective lens system as a whole. IF the upper limit of 0.6 of the condition (22) is exceeded, in contrast, the object side surface will undesirably produce astigmatism, distortion, etc. in large amounts.

When the second lens unit is to be composed of a single positive lens element in the objective lens system according to the present invention which has any one of the compositions described above, it is desirable for favorable correction of aberrations to satisfy the following condition (23):

$$-0.8<IH/r_4<-0.2 \quad (23)$$

If the lower limit of −0.8 of the condition (23) is not reached, the image side surface of the second lens unit will have a strong negative refractive power, thereby undesirably aggravating astigmatism and distortion in the objective lens system as a whole. If the upper limit of −0.2 of the condition (23) is exceeded, in contrast, it will be necessary to strengthen the positive refractive power of the object side surface of the second lens unit, whereby the object side surface will undesirably produce spherical aberrations, etc. in large amounts.

When a radial type gradient index lens element is to be used as the first lens unit of the objective lens system according to the present invention which has any one of the compositions described above, it is desirable, for facilitating manufacturing of the radial type gradient index lens element in addition to correction of lateral chromatic aberration, to satisfy the following condition (24)

$$0.121N_{10n}\cdot f_{Gn}^2<0.85 \quad (24)$$

When the condition (24) is satisfied, a refractive power of medium of the radial type gradient index lens element has a value sufficiently large relative to a total refractive power thereof, thereby making it possible to correct lateral chromatic aberration favorably. If the lower limit of 0.1 of the condition (24) is exceeded, the radial type gradient index lens element will undesirably have a weak refractive power of medium and can hardly correct lateral chromatic aberration favorably. If the upper limit of 0.85 of the condition (24) is not satisfied, in contrast, a refractive index difference Δn will undesirably be large, thereby making it difficult to prepare a material for the radial type gradient index lens element.

When a radial type gradient index lens element is to be used as the second lens element of the objective lens system according to the present invention which has any one of the compositions described above, it is desirable, for facilitating manufacturing of the radial type gradient index lens element in addition to correction of lateral chromatic aberration, to satisfy the following condition (25):

$$-0.3<N_{10p}\cdot f_{Gp}^2<-0.1 \quad (25)$$

When the condition (25) is satisfied, a refractive power of medium of the radial type gradient index lens element has a

value sufficiently large relative to a total refractive power thereof, whereby the radial type gradient index lens element can correct lateral chromatic aberration favorably. If the upper limit of −0.1 of the condition (25) is not reached, the refractive power of medium will undesirably be weakened, thereby undesirably making it difficult to correct lateral chromatic aberration with the radial type gradient index lens element. If the lower limit of −0.3 of the condition (25) is exceeded, in contrast, the refractive index difference Δn will undesirably be large, thereby making it difficult to prepare a material for the radial type gradient index lens element.

Though it is desirable to satisfy the condition (18) for correcting lateral chromatic aberration more favorably in the objective lens system according to the present invention which has any one of the compositions described above, lateral chromatic aberration is overcorrected when $1/V_{10}$ has a negative value which is too large. Therefore, it is further desirable to satisfy the following condition (26):

$$-0.5<1/V_{10}<0 \quad (26)$$

When the condition (26) is satisfied, it is possible to correct lateral chromatic aberration favorably. If the upper limit of 0 of the condition (26) is exceeded, lateral chromatic aberration will undesirably be under-corrected. IF the lower limit of −0.5 of the condition (26) is not reached, lateral chromatic aberration will undesirably be over-corrected.

From a viewpoint of reducing a manufacturing cost of the objective lens system according to the present invention, it is desirable that a radial type gradient index lens element has a planar surface on one side or planar surfaces on both sides.

The objective lens system according to the present invention which has a seventh composition uses a diffraction type optical element as an optical element which is disposed in the lens system.

The objective lens system according to the present invention which has the seventh composition is composed, for example, of a first lens unit having a negative refractive power, a stop and a second lens unit having a positive refractive power: the first lens unit being composed of a diffractive optical element and the second lens unit being composed of a refractive optical element (lens).

Further, an objective lens system which can accomplish the object of the present invention can be obtained by composing a lens system of a positive lens unit and a positive lens unit: the positive lens unit disposed on the object side being composed of a radial type gradient index lens element and the lens unit disposed on the image side being composed of a diffractive optical element.

The objective lens system which has each of the compositions described above is composed of a small number of optical elements, has a compact size and exhibits favorable optical performance. It is therefore suited for use as an objective lens system for endoscopes, non-flexible endoscopes and video cameras.

Accordingly, endoscopes, non-flexible endoscopes, video cameras, portable TV telephones, portable data input units, etc. which use the objective lens system according to the present invention having the compositions described above are included within the scope of the present invention.

Now, embodiments of the objective lens system according to the present invention will be described below:

EMBODIMENT 1

focal length = 1.07 mm, object distance = 11.8 mm,
image height = 0.97 mm, NA = 0.0115, 2ω = 113.1°

r_1 =	∞	d_1 = 0.3000	n_1 = 1.48749	ν_1 = 70.21
r_2 =	1.2764	d_2 = 1.2646		
r_3 =	∞ (stop)	d_3 = 0.5196		
r_4 =	−11.2580	d_4 = 1.8811	n2 (radial type gradient index lens)	
r_5 =	1.6678			

radial type gradient index lens

	N_{00}	N_{10}	N_{20}	N_{30}
d line	1.72000,	-0.87464×10^{-1},	0.44719×10^{-2},	0.37403×10^{-2}
C line	1.71540,	-0.88776×10^{-1},	0.45390×10^{2},	0.37964×10^{-2}
F line	1.73072,	-0.84403×10^{-1},	0.43154×10^{-2}, ,	0.36094×10^{-2}

$1/V_{10}=-0.050$, $1V_{00}=0.021$, $\phi_{2m}/\phi=0.353$, $N_{10p}\cdot f^2=-0.100$, $IH/r_2=0.799$, $IH/r_3=-0.091$ $IH/r_4=-0.612$, $N_{10p}\cdot f_G{}^2=-0.213$, $d_{Gp}/f_G=1.207$

EMBODIMENT 2

focal length = 1.1 mm, object distance = 14 mm,
image height = 0.85 mm, NA = 0.01, 2ω = 96.4°

r_1 =	∞	d_1 = 0.3000	n_1 = 1.51633	ν_1 = 64.15
r_2 =	0.9785	d_2 = 0.3992		
r_3 =	∞ (stop)	d_3 = 0.1000		
r_4 =	−2.6225	d_4 = 2.4188	n_2 (radial type gradient index lens)	
r_5 =	−1.8297			

radial type gradient index lens

	N_{00}	N_{10}	N_{20}
d line	1.88300,	−0.11306,	0.10113×10^{-2}
C line	1.87656,	−0.11340,	0.10143×10^{-2}
F line	1.89821,	−0.11227,	0.10042×10^{-2}

$1/V_{10}=-0.010$, $1V_{00}=0.025$, $\phi_{2m}/\phi=0.603$, $N_{10p}\cdot f^2=-0.137$, $IH/r_2=0.869$, $IH/r_3=-0.324$, $IH/r_4=-0.465$, $N_{10p}\cdot f_G{}^2=-0.192$, $d_{Gp}/f_G=1.858$

EMBODIMENT 3

focal length = 1.1 mm, object distance = 11 mm,
image height = 0.85 mm, NA = 0.01, 2ω = 103.5°

r_1 =	−5.5224	d_1 = 0.3000	n_1 = 1.51633	ν_1 = 64.15
r_2 =	1.2132	d_2 = 0.7397		
r_3 =	∞ (stop)	d_3 = 0.1000		
r_4 =	−4.0638	d_4 = 2.8548	n_2 (radial type gradient index lens)	
r_5 =	−2.5042			

radial type gradient index lens

	N_{00}	N_{10}	N_{20}
d line	1.88300,	−0.10007,	0.17880×10^{-3}
C line	1.87656,	-0.99971×10^{-1},	0.17863×10^{-3}
F line	1.89821,	−0.10030,	0.17922×10^{-3}

$1/V_{10}=0.003$, $1/V_{00}=0.025$, $\phi_{2m}/\phi=0.627$, $N_{10p}\cdot f^2=-0.120$, $IH/r_2=0.701$, $IH/r_3=-0.209$, $IH/r_4=-0.339$, $N_{10p}\cdot f_G{}^2=-0.221$, $d_{Gp}/f_G=1.922$

EMBODIMENT 4

focal length = 1.02 mm, object distance = 13 mm, image height = 1.0 mm, NA = 0.012, 2ω = 99.1°

r_1 =	∞	d_1 = 0.3842	n_1 = 1.74100	ν_1 = 52.65
r_2 =	1.4937	(aspherical surface)		
		d_2 = 1.0970		
r_3 =	∞ (stop)	d_3 = 0.8723		
r_4 =	11.2798	d_4 = 1.6154	n_2 (radial type gradient index lens)	
r_5 =	−1.7612			

aspherical surface coefficients

P = 1, A_4 = −0.30311, A_6 = 0.20982

radial type gradient index lens

	N_{00}	N_{10}	N_{20}	N_{30}
d line	1.70000,	-0.79349×10^{-1},	0.34621×10^{-1},	-0.10102×10^{-1}
C line	1.69580,	-0.81730×10^{-1},	0.35660×10^{-1},	-0.10405×10^{-1}
F line	1.70960,	-0.73795×10^{-1},	0.32198×10^{-1},	-0.93948×10^{-2}

$1/V_{10}$=−0.100, $1/V_{00}$=0.020, ϕ_{2m}/ϕ=0.260, $N_{10p}\cdot f^2$=−0.082, IH/r_2=0.670, IH/r_3=0.089, IH/r_4=−0.568, $N_{10p}\cdot f_G{}^2$=−0.201, d_{Gp}/f_G=1.015

EMBODIMENT 5

focal length = 1.1 mm, object distance = 14 mm, image height = 0.85 mm, NA = 0.01, 2ω = 83.4°

r_1 =	∞	d_1 = 0.3000	n_1 = 1.51633	ν_1 = 64.15
r_2 =	2.9790	(aspherical surface)		
		d_2 = 0.4409		
r_3 =	∞ (stop)	d_3 = 0.1000		
r_4 =	−1.1911	d_4 = 2.4102	n_2 (radial type gradient index lens)	
r_5	−1.6277			

-continued

aspherical surface coefficients

P = 1, A_4 = −0.55346, A_6 = 0.76608

radial type gradient index lens

	N_{00}	N_{10}	N_{20}
d line	1.88300,	−0.12090,	0.11838×10^{-1}
C line	1.87656,	−0.12126,	0.11874×10^{-1}
F line	1.89821,	−0.12005,	0.11755×10^{-1}

$1/V_{10}$=−0.010, $1/V_{00}$=0.025, ϕ_{2m}/ϕ=0.641, $N_{10p}\cdot f^2$=−0.146, IH/r_2=0.336, IH/r_3=−0.840, IH/r_4=−0.614, $N_{10p}\cdot f_G{}^2$=−0.173, d_{Gp}/f_G=2.017

EMBODIMENT 6

focal length = 1.37 mm, object distance = 14 mm, image height = 0.85 mm, NA = 0.01, 2ω = 93.3°

r_1 =	∞	d_1 = 1.5026	n_1 (radial type gradient index lens)	
r_2 =	2.5886	d_2 = 0.8187		
r_3 =	∞ (stop)	d_3 = 0.1000		
r_4 =	3.7062	d_4 = 2.1446	n_2 = 1.88300	ν_2 = 40.78
r_5 =	−1.5967			

radial type gradient index lens

	N_{00}	N_{10}	N_{20}	N_{30}
d line	1.65000,	0.21000×10^{-1},	0.20240×10^{-1},	0.14372×10^{-1}
C line	1.64443,	0.21630×10^{-1},	0.20847×10^{-1},	0.14803×10^{-1}
F line	1.66300,	0.19530×10^{-1},	0.18823×10^{-1},	0.13366×10^{-1}

$1/V_{10}$=−0.100, $1/V_{00}$=0.029, ϕ_{1m}/ϕ=−0.086, $N_{10n}\cdot f_2$=0.041, IH/r_2=0.328, IH/r_3=0.229, IH/r_4=−0.532, $N_{10n}\cdot f_G^2$=0.203, d_{Gn}/f_G=0.484

EMBODIMENT 7

focal length = 1.11 mm, object distance = 14 mm, image height = 0.85 mm, NA = 0.01, 2ω = 104.8°

r_1 =	∞	d_1 = 0.2945	n_1 (radial type gradient index lens)	
r_2 =	1.0451	d_2 = 0.8845		
r_3 =	∞ (stop)	d_3 = 0.1000		
r_4 =	2.6882	d_4 = 2.0134	n_2 = 1.88300	ν_2 = 40.78
r_5 =	−1.5483			

radial type gradient index lens

	N_{00}	N_{10}	N_{20}
d line	1.51633,	0.26303,	−0.10874
C line	1.51385,	0.26382,	−0.10907
F line	1.52190,	0.26119,	−0.10798

$1/V_{10}$=−0.010, $1/V_{00}$=0.016, ϕ_{1m}/ϕ=−0.171, $N_{10n}\cdot f^2$=0.322, IH/r_2=0.708, IH/r_3=0.244, IH/r_4=−0.586, $N_{10n}\cdot f_G^2$=0.609, d_{Gn}/f_G=0.194

EMBODIMENT 8

focal length = 1.13 mm, object distance = 20 mm, image height = 0.8 mm, NA = 0.007, 2ω = 102.0°

r_1 =	5.5159	d_1 = 0.3200	n_1 (radial type gradient index lens)	
r_2 =	1.1306	d_2 = 1.0270		
r_3 =	∞ (stop)	d_3 = 0.1000		
r_4 =	3.2778	d_4 = 1.6805	n_2 = 1.81600	ν_2 = 46.62
r_5 =	−1.3650			

radial type gradient index lens

	N_{00}	N_{10}	N_{20}
d line	1.55000,	0.21140,	0.20293
C line	1.54633,	0.21119,	0.20273
F line	1.55856,	0.21190,	0.20340

$1/V_{10}$=0.003, $1/V_{00}$=0.022, ϕ_{1m}/ϕ=−0.153, $N_{10n}\cdot f^2$=0.269, IH/r_2=0.708, IH/r_3=0.244 IH/r_4=−0.586, $N_{10n}\cdot f_G^2$=0.787, d_{Gn}/f_G=0.166

EMBODIMENT 9

focal length = 1.11 mm, object distance = 14 mm, image height = 0.9 mm, NA = 0.01, 2ω = 98.3°

r_1 =	∞	d_1 = 1.3941	n_1 (radial type gradient index lens)	
r_2 =	1.7035	d_2 = 1.0045		
r_3 =	∞ (stop)	d_3 = 0.1000		
r_4 =	2.3343	(aspherical surface)		
		d_4 = 2.7508	n_2 = 1.72916	ν_2 = 54.68
r_5 =	−1.3745	(aspherical surface)		

aspherical surface coefficients

(4th surface)	P = 1,	A_4 = 0.60639 × 10^{-1},	A_6 = −0.86398
		A8 = −0.85186	
(5th surface)	P = 1,	A_4 = 0.33872 × 10^{-1},	A_6 = 0.71755 × 10^{-1},
		A_8 = −0.27664 × 10^{-1}	

radial type gradient index lens

	N_{00}	N_{10}	N_{20}	N_{30}
d line	1.70000,	0.53850 × 10^{-1},	−0.25175 × 10^{-4},	−0.19807 × 10^{-2}
C line	1.69300,	0.55466 × 10^{-1},	−0.25931 × 10^{-4},	−0.20401 × 10^{-2}
F line	1.71633,	0.50081 × 10^{-1},	−0.23413 × 10^{-4},	−0.18420 × 10^{-2}

$1/V_{10}$=−0.100, $1/V_{00}$=0.033, ϕ_{1m}/ϕ=−0.167, $N_{10n}\cdot f^2$=0.066, IH/r_2=0.528, IH/r_3=0.386, IH/r_4=−0.655, $N_{10n}\cdot f_G^2$=0.155, d_{Gn}/f_G=0.822

EMBODIMENT 10

focal length = 1.01 mm, object distance = 11.8 mm, image height = 0.97 mm, NA = 0.0115, 2ω = 115.2°

r_1 =	∞	d_1 = 0.4395	n_1 (radial type gradient index lens)
r_2 =	1.9633	d_2 = 1.1006	
r_3 =	∞ (stop)	d_3 = 0.7310	
r_4 =	7.6592	d_4 = 2.0532	n_2 (radial type gradient index lens 2)
r_4 =	−1.8838		

radial type gradient index lens 1

	N_{00}	N_{10}	N_{20}	N_{30}
d line	1.65000,	0.19087,	−0.20292,	0.10047
C line	1.64443,	0.19468,	−0.20698,	0.10248
F line	1.66300,	0.18196,	−0.19345,	0.95778×10^{-1}

radial type gradient index lens 2

	N_{00}	N_{10}	N_{20}	N_{30}
d line	1.72000,	-0.64751×10^{-1},	0.21345×10^{-1},	-0.39150×10^{-2}
C line	1.71568,	-0.66046×10^{-1},	0.21772×10^{-1},	-0.39933×10^{-2}
F line	1.73008,	-0.61729×10^{-1},	0.20349×10^{-1},	-0.37323×10^{-2}

1st lens

$1/V_{10}$=−0.067, $1/V_{00}$=0.029, ϕ_{2m}/ϕ=0.433, $N_{10p}\cdot f^2$=−0.066, IH/r_2=0.494, IH/r_3=0.127, IH/r_4=−0.515, $N_{10p}\cdot f_G^2$=−0.172, d_{Gp}/f_G=1.260

2st lens

$1/V_{10}$=−0.067, $1/V_{00}$=0.020, ϕ_{1m}/ϕ=−0.170, $N_{10n}\cdot f^2$=0.195, IH/r_2=0.494, IH/r_3=0.127, IH/r_4=−0.515, $N_{10n}\cdot f_G^2$=0.741, d_{Gn}/f_G=0.233

EMBODIMENT 11

focal length = 1.48 mm, object distance = 11.6 mm, image height = 1.54 mm, NA = 0.0082, 2ω = 140.3°

r_1 =	∞	d_1 = 0.3999	n_1 = 1.65160	ν_1 = 58.52
r_2 =	1.3620	d_2 = 1.2404		
r_3 =	∞ (stop)	d_3 = 0.4587		
r_4 =	27.7558	d_4 = 3.0744	n_2 (radial type gradient index lens)	
r_5 =	−2.1899	d_5 = 0.5724		
r_6 =	∞	d_6 = 0.4000	n_3 = 1.51633	ν_3 = 64.15
r_7 =	∞	d_7 = 0.0300		
r_8 =	∞	d_8 = 0.6200	n_4 = 1.52000	ν_4 = 74.00
r_9 =	∞	d_9 = 0.0300		
r_{10} =	∞	d_{10} = 0.4000	n_5 = 1.51633	ν_5 = 64.15
r_{11} =	∞	d_{11} = 0.4800		
r_{12} =	∞	d_{12} = 1.1000	n_6 = 1.51633	ν_6 = 64.15
r_{13} =	∞	d_{13} = 1.0000	n_7 = 1.51633	ν_7 = 64.15
r_{14} =	∞			

radial type gradient index lens

	N_{00}	N_{10}	N_{20}	N_{30}
d line	1.63300,	-0.37202×10^{-1},	0.26687×10^{-2},	0.94109×10^{-3}
C line	1.62841,	-0.37680×10^{-1},	0.21318×10^{-2},	0.11022×10^{-2}
F line	1.64370,	-0.36087×10^{-1},	0.39213×10^{-2},	0.56515×10^{-3}

$1/V_{10}=-0.043$, $1/V_{00}=0.024$, $\phi_{2m}/\phi=0.339$, $N_{10p}\cdot f^2=-0.082$, $IH/r_2=1.130$, $IH/r_3=0.055$, $IH/r_4=-0.703$, $N_{10p}\cdot f_G{}^2=-0.185$, $d_{Gp}/f_G=1.378$

EMBODIMENT 12

focal length = 0.83 mm, object distance = 9.3 mm, image height = 0.8 mm, NA = 0.0115, 2ω = 128.9°

r_1 =	∞	d_1 = 0.3700	n_1 = 1.51633	ν_1 = 64.15
r_2 =	1.1462	d_2 = 1.7257		
r_3 =	∞ (stop)	d_3 = 0.7547		
r_4 =	3.0329	d_4 = 1.2159	n_2 (radial type gradient index lens)	
r_5 =	−1.5583	d_5 = 0.0300		
r_6 =	∞	d_6 = 0.4000	n_3 = 1.52287	ν_4 = 59.89
r_7 =	∞	d_7 = 0.0300		
r_8 =	∞	d_8 = 0.6200	n_4 = 1.52000	ν_4 = 74.00
r_9 =	∞	d_9 = 0.0300		
r_{10} =	∞	d_{10} = 0.4000	n_5 = 1.51633	ν_5 = 64.15
r_{11} =	∞	d_{11} = 0.0300		
r_{12} =	∞	d_{12} = 1.0000	n_6 = 1.51633	ν_6 = 64.15
r_{13} =	∞			

radial type gradient index lens

	N_{00}	N_{10}	N_{20}	N_{30}
d line	1.63300,	-0.82149×10^{-1},	0.25774×10^{-1},	0.17638×10^{-1}
C line	1.62848,	-0.82067×10^{-1},	0.25748×10^{-1},	0.17621×10^{-1}
F line	1.64377,	-0.82341×10^{-1},	0.25834×10^{-1},	0.17679×10^{-1}
g line	1.65257,	-0.82452×10^{-1},	0.25869×10^{-1},	0.17703×10^{-1}

$1/V_{10}=0.003$, $1/V_{00}=0.024$, $\phi_{2m}/\phi=0.166$, $N_{10p}\cdot f^2=-0.057$, $IH/r_2=0.698$, $IH/r_3=0.264$, $IH/r_4=-0.513$, $N_{10p}\cdot f_G{}^2=-0.166$, $d_{Gp}/f_G=0.855$

EMBODIMENT 13

focal length = 1.04 mm, object distance = 13 mm, image height = 1.1 mm, NA = 0.01, 2ω = 140.5°

r_1 =	∞	d_1 = 0.3500	n_1 = 1.51633	ν_1 = 64.15
r_2 =	0.8824	d_2 = 0.8722		
r_3 =	∞ (stop)	d_3 = 0.1000		
r_4 =	∞	d_4 = 2.4666	n_2 (radial type gradient index lens)	
r_5 =	−1.6539			

radial type gradient index lens

	N_{00}	N_{10}	N_{20}
d line	1.70000,	-0.82964×10^{-1},	0.16995×10^{-1}
C line	1.69475,	-0.84814×10^{-1},	0.17477×10^{-1}
F line	1.71225,	-0.78645×10^{-1},	0.15871×10^{-1}

$1/V_{10}=-0.074$, $1/V_{00}=0.025$, $\phi_{2m}/\phi=0.426$, $N_{10p}\cdot f^2=-0.090$, $IH/r_2=1.245$, $IH/r_3=0.000$ $IH/r_4=-0.665$, $N_{10p}\cdot f_G{}^2=-0.183$, $d_{Gp}/f_G=1.661$

EMBODIMENT 14

focal length = 0.99 mm, object distance = 13 mm, image height = 1.1 mm, NA = 0.01, 2ω = 108.9°

r_1 =	∞	d_1 = 0.3500	n_1 = 1.53996	ν_1 = 59.57
r_2 =	2.3039	(aspherical surface)		
		d_2 = 0.7372		
r_3 =	∞ (stop)	d_3 = 0.1000		

-continued

r_4 =	−1.9109	d_4 = 2.4559	n_2 (radial type gradient index lens)
r_5 =	−1.5046		

-continued

aspherical surface coefficients

P = 1, A_4 = −0.28151, A_6 = 0.21002, $A_8=-0.73150\times10^{-1}$

radial type gradient index lens

	N_{00}	N_{10}	N_{20}	N_{30}
d line	1.70000,	−0.14024,	0.31859×10^{-1},	-0.54102×10^{-2}
C line	1.69475,	−0.14257,	0.32390×10^{-1},	-0.55004×10^{-2}
F line	1.71225,	−0.13478,	0.30620×10^{-1},	-0.51998×10^{-2}

$1/V_{10}=-0.056$, $1/V_{00}=0.025$, $\phi_{2m}/\phi=0.681$, $N_{10p}\cdot f^2=-0.137$, $IH/r_2=0.478$, $IH/r_3=-0.576$, $IH/r_4=-0.731$, $N_{10p}\cdot f_G{}^2=-0.198$, $d_{Gp}/f_G=2.066$

EMBODIMENT 15

focal length = 1.06 mm, object distance = 14 mm, image height = 0.85 mm, NA = 0.01, 2ω = 98.5°

r1 =	∞	d_1 = 0.3000	n_1 = 1.51633	ν_1 = 64.15
r_2 =	1.2020	d_2 = 0.4079		
r_3 =	∞ (stop)	d_3 = 0.0500		
r_4 =	∞	d_4 = 1.8037	n_2 (radial type gradient index lens)	
r_5 =	−1.1988	d_5 = 0.2000		
r_6 =	∞	d_6 = 2.0000	n_3 = 1.51633	ν_3 = 64.15
r_7 =	∞			

-continued

radial type gradient index lens			
	N_{00}	N_{10}	N_{20}
d line	1.75000,	−0.10566,	0.60988×10^{-1}
C line	1.74500,	−0.10598,	0.61170×10^{-1}
F line	1.76167,	−0.10492,	0.60561×10^{-1}

$1/V_{10}=-0.01$, $1/V_{00}=0.022$, $\phi_{2m}/\phi=0.404$, $N_{10p}\cdot f^2=-0.119$, $IH/r_2=0.707$, $IH/r_3=0$ $IH/r_4=-0.709$, $N_{10p}\cdot f_G^{\,2}=-0.142$, $d_{Gp}/f_G=1.558$

EMBODIMENT 16

focal length = 0.87 mm, object distance = 11 mm, image height = 0.8 mm, NA = 0.011, 2ω = 131.3°				
r_1 =	∞	d_1 = 0.3800	n_1 = 1.88300	ν_1 = 40.78
r_2 =	0.7400	d_2 = 0.6000		
r_3 =	1.6000	d_3 = 5.1250	n_2 (radial type gradient index lens)	
r_4 =	∞			

radial type gradient index lens				
	N_{00}	N_{10}	N_{20}	N_{30}
d line	1.70000,	−0.12580,	0.78000×10^{-2},	-0.47000×10^{-3}
C line	1.69475,	−0.12567,	0.77985×10^{-2},	-0.47001×10^{-3}
F line	1.71225,	−0.12609,	0.79935×10^{-2},	-0.48176×10^{-3}

$1/V_{10}=0.003$, $1/V_{00}=0.025$, $\phi_{2m}/\phi=0.499$, $N_{10p}\cdot f^2=-0.087$, $IH/r_2=1.081$, $IH/r_3=0.5$, $IH/r_4=0$, $N_{10p}\cdot f_G^{\,2}=-0.676$, $d_{Gp}/f_G=2.211$

EMBODIMENT 17

focal length = 0.84 mm, object distance = 11 mm, image height = 0.8 mm, NA = 0.011, 2ω = 129.2°				
r_1 =	∞	d_1 = 0.3600	n_1 = 1.88300	ν_1 = 40.78
r_2 =	0.6800	d_2 = 0.8000		
r_3 =	∞	d_3 = 3.6000	n_2 (radial type gradient index lens)	
r_4 =	∞	d_4 = 2.8000	n_3 = 1.51633	ν_3 = 64.15
r_5 =	∞			

radial type gradient index lens				
	N_{00}	N_{10}	N_{20}	N_{30}
d line	1.70000,	−0.12580,	0.78000×10^{-2},	-0.47000×10^{-3}
C line	1.69475,	−0.12567,	0.77985×10^{-2},	-0.47001×10^{-3}
F line	1.71225,	−0.12609,	0.79935×10^{-2},	-0.48176×10^{-3}

$1/V_{10}=0.003$, $1/V_{00}=0.025$, $\phi_{2m}/\phi=0.549$, $N_{10p}\cdot f^2=-0.090$, $IH/r_2=1.177$, $IH/r_3=0$, $IH/r_4=0$, $N_{10p}\cdot f_G^{\,2}=-0.298$, $d_{Gp}/f_G=2.471$

EMBODIMENT 18

focal length = 0.96 mm, object distance = 10 mm, image height = 0.85 mm, NA = 0.01, 2ω = 108.5°				
r_1 =	∞	d_1 = 0.3500	n_1 = 1.77250	ν_1 = 49.60
r_2 =	1.3385	d_2 = 0.3000		
r_3 =	∞	d_3 = 2.0000	n_2 = 1.51633	ν_2 = 64.15
r_4 =	∞ (stop)	d_4 = 0.0500		
r_5 =	∞	d_5 = 2.3091	n_3 (radial type gradient index lens)	
r_6 =	−1.4778			

-continued

radial type gradient index lens			
	N_{00}	N_{10}	N_{20}
d line	1.75000,	-0.33160×10^{-1},	0.27722×10^{-1}
C line	1.74500,	-0.33359×10^{-1},	0.27888×10^{-1}
F line	1.76167,	-0.32696×10^{-1},	0.27334×10^{-1}

$1/V_{10}=-0.02$, $1/V_{00}=0.022$, $\phi_{2m}/\phi=0.147$, $N_{10p}\cdot f^2=-0.031$, $IH/r_2=0.717$, $IH/r_3=0$, $IH/r_4=-0.650$, $N_{10p}\cdot f_G^{\,2}=-0.091$, $d_{Gp}/f_G=1.397$

EMBODIMENT 19

f = 0.77, F/4.7, 2ω = 113.3°				
r_1 =	∞	d_1 = 0.3200	n_1 = 1.51633	ν_1 = 64.15
r_2 =	0.4025	d_2 = 0.2229		
r_3 =	∞	d_3 = 0.6556	n_2 = 1.84666	ν_2 = 23.78
r_4 =	−0.9538	d_4 = 0.1230		
r_5 =	∞ (stop)	d_5 = 0.6316		
r_6 =	2.1852	d_6 = 0.8955	n_3 (radial type gradient index lens)	
r_7 =	−3.2816	d_7 = 0.3800		
r_8 =	∞	d_8 = 0.7500	n_4 = 1.53172	ν_4 = 48.91
r_9 =	∞			

radial type gradient index lens				
	N_{00}	N_{10}	N_{20}	N_{30}
d line	1.65000,	-1.5405×10^{-1},	1.5784×10^{-1},	2.9179×10^{-2}
C line	1.64512,	-1.5400×10^{-1},	1.5784×10^{-1},	2.9179×10^{-2}
F line	1.66138,	-1.5418×10^{-1},	1.5784×10^{-1},	2.9179×10^{-2}
g line	1.67088,	-1.5430×10^{-1},	1.5784×10^{-1},	2.9179×10^{-2}

EMBODIMENT 20

f = 0.65, F/4.25, 2ω = 113°				
r_1 =	∞	d_1 = 0.3200	n_1 = 1.51633	ν_1 = 64.15
r_2 =	0.4397	d_2 = 0.1672		
r_3 =	∞	d_3 = 0.7894	n_2 (radial type gradient index lens)	
r_4 =	(stop)	d_4 = 0.2910		
r_5 =	2.1800	d_5 = 0.5912	n_3 = 1.88300	ν_3 = 40.78
r_6 =	−1.2158	d_6 = 0.3800		
r_7 =	∞	d_7 = 0.7500	n_4 = 1.53172	ν_4 = 48.91
r_8 =	∞			

radial type gradient index lens				
	N_{00}	N_{10}	N_{20}	N_{30}
d line	1.65200,	-5.4253×10^{-1},	6.6408×10^{-1},	1.0097
C line	1.64616,	-5.3145×10^{-1},	6.5052×10^{-1},	9.8907×10^{-1}
F line	1.66562,	-5.6836×10^{-1},	6.9570×10^{-1},	1.0578
g line	1.67733,	-5.9247×10^{-1},	7.2632×10^{-1},	1.1002

EMBODIMENT 21

f = 2.74, F/2.8, 2ω = 68.1°				
r_1 =	3.0226	d_1 = 1.7507	n_1 (radial type gradient index lens)	
r_2 =	1.4700	d_2 = 1.6154		
r_3 =	∞ (stop)	d_3 = 1.1572		
r_4 =	3.7806	d_4 = 2.4588	n_2 = 1.69680	ν_2 = 55.53
r_5 =	−2.2830	(aspherical surface)		
		d_5 = 0.7143		
r_6 =	∞	d_6 = 0.7500	n_3 = 1.48749	ν_3 = 70.21
r_7 =	∞			

-continued

aspherical surface coefficients

P = 1, $A_4 = 3.1652 \times 10^{-2}$, $A_6 = 5.4023 \times 10^{-5}$, $A_8 = 5.2354 \times 10^{-4}$

radial type gradient index lens

	N_{00}	N_{10}	N_{20}
d line	1.60000,	-8.0063×10^{-3},	-2.4555×10^{-3}
C line	1.59400,	-7.7381×10^{-3},	-2.3621×10^{-3}
F line	1.61400,	-8.5860×10^{-3},	-2.6962×10^{-3}
g line	1.62646,	-8.8951×10^{-3},	-2.9391×10^{-3}

EMBODIMENT 22

f = 0.96, F/4.25, 2ω = 112.9°

r_1 =	∞	d_1 = 0.3000	n_1 = 1.51633	ν_1 = 64.15
r_2 =	∞	d_2 = 0.1500		
r_3 =	−1.7433	d_3 = 2.3691	n_2 (radial type gradient index lens)	
r_4 =	−0.9326	d_4 = 0.3800		
r_5 =	∞	d_5 = 0.7500	n_3 = 1.53172	ν_3 = 48.91
r_6 =	∞			

radial type gradient index lens

	N_{00}	N_{10}	N_{20}	N_{30}
d line	1.57000,	-1.8143×10^{-1},	9.8792×10^{-2},	-1.8066×10^{-1}
C line	1.56715,	-1.7983×10^{-1},	9.7920×10^{-2},	-1.7907×10^{-1}
F line	1.57665,	-1.8517×10^{-1},	1.0083×10^{-1},	-1.8438×10^{-1}
g line	1.58176,	-1.8795×10^{-1},	1.0115×10^{-1},	-1.8621×10^{-1}

EMBODIMENT 23

f = 3.1, F/2.8, 2ω = 65.4°

r_1 =	∞ (stop)	d_1 = 0.1000		
r_2 =	∞	d_2 = 4.6740	n_1 (radial type gradient index lens)	
r_3 =	−3.7203	d_3 = 1.9817		
r_4 =	7000.000	d_4 = 0.0010	n_2 = 1000	ν_2 = −3.45 (DOE)
r_5 =	∞	d_5 = 0.5000	n_3 = 1.45851	ν_3 = 66.75
r_6 =	∞	d_6 = 0.7500	n_4 = 1.53172	ν_4 = 48.91
r_7 =	∞			

aspherical surface coefficients
(diffraction type optical element)

P = 1, $A_4 = -2.1097 \times 10^{-5}$, $A_6 = 5.0147 \times 10^{-6}$, $A_8 = -3.0443 \times 10^{-7}$, $A_{10} = -1.3365 \times 10^{-8}$

radial type gradient index lens

	N_{00}	N_{10}	N_{20}	N_{30}
d line	1.70000,	-1.4314×10^{-2},	-7.4587×10^{-4},	3.4977×10^{-4}
C line	1.69580,	-1.4176×10^{-2},	-7.4587×10^{-4},	3.4977×10^{-4}
F line	1.70980,	-1.4636×10^{-2},	-7.4587×10^{-4},	3.4977×10^{-4}
g line	1.71757,	-1.4899×10^{-2},	-7.4587×10^{-4},	3.4977×10^{-4}

EMBODIMENT 24

f = 3.4, F/2.8, 2ω = 60.4°

r_1 =	3.9329	d_1 = 2.1359	n_1 = 1.58423	ν_1 = 30.49
r_2 =	1.9115	d_2 = 0	n_2 = 1000	ν_2 = −3.45 (DOE)
r_3 =	1.9114	d_3 = 1.5050		
r_4 =	∞ (stop)	d_4 = 1.3716		
r_5 =	4.6967	d_5 = 3.3378	n_3 = 1.69680	ν_3 = 55.53
r_6 =	−2.9928	(aspherical surface)		
		d_6 = 1.8296		
r_7 =	∞	d_7 = 0.7500	n_4 = 1.48749	ν_4 = 70.21
r_8 =	∞	d_8 = 1.2084		
r_9 =	∞ (image)			

aspherical surface coefficients
(diffraction type optical element)

P = 1, $A_4 = 9.1010 \times 10^{-6}$, $A_6 = -6.4422 \times 10^{-6}$, ($6^{th}$ surface)

P = 1, $A_4 = 1.1402 \times 10^{-2}$, $A_6 = -9.8667 \times 10^{-5}$, $A_8 = 1.5019 \times 10^{-5}$,

wherein the reference symbols r_1, r_2, . . . represent radii of curvature on surfaces of respective lens elements, the reference symbols d_1, d_2, . . . designate thicknesses of the respective lens elements and airspaces reserved therebetween, the reference symbols n_1 n_2, . . . denote refractive indices of the respective lens elements, and the reference symbols ν_1, ν_2, . . . represent Abbe's numbers of the respective lens elements.

The first embodiment of the objective lens system according to the present invention has a composition illustrated in FIG. **4**. Speaking concretely, it is composed of two lens units, i.e., in order from the object side, a first lens unit consisting of a negative lens element, a stop and a second lens unit consisting of a positive lens element. The second lens unit having the positive refractive power is configured as a radial type gradient index lens element. The first lens unit is composed of a homogenous lens element which has a planar surface on the object side and a concave surface on the image side, whereas the second lens unit is composed of a radial type gradient index lens element having a meniscus shape which has a concave surface on the object side.

Though it is ordinarily difficult to favorably correct lateral chromatic aberration in particular with two lens elements, the lens system preferred as the first embodiment is capable of favorably correcting lateral chromatic aberration by using the radial type gradient index lens element as the second lens unit.

Further, distortion and coma produced by the second lens unit are favorably corrected by the radial type gradient index lens element used as the second lens unit which has a refractive index distribution wherein refractive indices are progressively lowered from an optical axis toward a marginal portion.

In the first embodiment, lateral chromatic aberration in particular is corrected favorably by configuring the radial type gradient index lens element used as the second lens unit so as to satisfy the condition (18).

Furthermore, the object side planar surface of the first lens unit is effective for lowering a cost required for polishing the lens element.

Though the first embodiment is composed only of the two lens elements, it favorably corrects aberrations and has high optical performance.

The second embodiment of the present invention is an objective lens system which has a composition illustrated in

FIG. **5**. Speaking concretely, it is composed of two lens elements, i.e., in order from the object side, a first lens unit composed of a negative lens element, a stop and a second lens unit composed of a positive lens element. The second lens unit having the positive refractive power is configured as a radial type gradient index lens element.

The second embodiment is an example in which the objective lens system is configured so as to have a total length that is shorter than that of the first embodiment. In the second embodiment also, lateral chromatic aberration in particular is favorably corrected by using the radial type gradient index lens element as the second lens unit.

The radial type gradient index lens element has a meniscus shape which has a concave surface on the object side. When a radial type gradient index lens element has such a meniscus shape, its refractive power of surface and refractive power of medium which are weaker and stronger respectively than a refractive power of surface and a refractive power of medium of a radial type gradient index lens element having a biconvex shape and a refractive power which is the same as that of the radial type gradient index lens element. When a radial type gradient index lens element has a strong refractive power of medium, its effect for correcting chromatic aberration can be effectively utilized as seen from the formula (d). For effectively utilizing the effect of a radial type gradient index lens element, the second embodiment adopts the radial type gradient index lens element which has the meniscus shape. The meniscus shape which has the concave surface on the object side is effective in particular for preventing offaxial aberrations from being aggravated.

In the second embodiment, the outer circumferential portion located outside an effective diameter of the first lens unit and the second lens unit is configured as a nearly planar surfaces on which both the lens units are cemented or kept in contact with each other. By cementing these two lens units into an integrated part, it is possible to simplify a structure of a lens barrel and facilitate assembly of the objective lens system.

The second embodiment also has high optical performance though it is composed only of the two lens elements.

The third embodiment of the present invention is an objective lens system which has a composition illustrated in FIG. **6**. That is to say, the objective lens system is composed of two lens unit, in order from the object side, of a first lens unit composed of a negative lens element, a stop, and a second lens unit composed of a positive lens element. The second lens unit having the positive refractive power is configured as a radial type gradient index lens element. The first lens unit is composed of a homogenous lens element having a biconcave shape, whereas the second lens unit is composed of a radial type gradient index lens element having a meniscus shape which has a concave surface on the object side.

Though it is ordinarily difficult to favorably correct lateral chromatic aberration with two lens elements, the objective lens system according to the present invention is capable of favorably correcting lateral chromatic aberration by using the radial type gradient index lens element as the second lens unit.

The third embodiment is an example wherein amounts of aberrations to be produced by the first lens unit are reduced by selecting the biconcave surface for the first lens unit so that a power of this lens unit is shared between the surfaces.

Though $1/V_{10}$ of the radial type gradient index lens element has a positive value, lateral chromatic aberration is favorably corrected by satisfying the condition (1).

The objective lens system preferred as the third embodiment also has high optical performance though it is composed only of the two lens elements.

The fourth embodiment of the present invention is an objective lens system which has a composition shown in FIG. **7**. Concretely, it is composed of two lens units, in order from the object side, a first lens unit composed of a negative lens element, a stop and a second lens unit composed of a positive lens element. The second lens unit having the positive refractive power is configured as a radial type gradient index lens element. The first lens unit has a planar surface on the object side and a concave surface on the image side configured as an aspherical surface which weakens a negative refractive power as portions of the aspherical surface are farther from an optical axis toward a marginal portion. The second lens unit is composed of a radial type gradient index lens element which has a biconvex shape.

The aspherical surface used in this embodiment has a shape expressed by the following formula:

wherein a direction along the optical axis is taken as the x axis, a direction perpendicular to the optical axis is taken as the y axis, the reference symbol r represents a radius of curvature on the optical axis, the reference symbol p designates a conical constant and the reference symbol A_{2i} denotes an aspherical surface coefficient.

In the fourth embodiment, the aspherical surface used in the first lens unit is capable of favorably correcting mainly barrel form distortion produced in the lens system as a whole.

Though the first lens unit has the planar surface on the object side in the fourth embodiment, a similar effect can be obtained by using an aspherical surface as the object side surface of the first lens unit.

The fourth embodiment is an example wherein the second lens unit is configured as the biconvex radial type gradient index lens element which has a weakened refractive power of medium and a strengthened refractive power of surface. Accordingly, the radial type gradient index lens element can have a small refractive index difference Δn contributing to a refractive power of medium, thereby enhancing productibility or shortening a time required for imparting a refractive index distribution at a stage to prepare a material for the radial type gradient index lens element.

In spite of the fact that the fourth embodiment is composed only of the two lens elements, it has high optical performance.

It is possible to obtain a similar effect by using, in place of the aspherical surface disposed in the first lens unit, an axial type gradient index lens element having a refractive index continuously varying in the direction along the optical axis.

The fifth embodiment of the present invention is an objective lens system which has a composition illustrated in FIG. **8**. That is to say, it is composed of two lens elements, in order from the object side, a first lens unit composed of a negative lens element, a stop and a second lens unit composed of a positive lens element configured as a radial type gradient index lens element. The first lens unit has a planar surface on the object side and a concave surface on the image side which is configured as an aspherical surface which has such a shape as to weaken a negative refractive power as portions of the aspherical surface are farther from the optical axis toward a marginal portion, whereas the second lens unit is configured as a radial type gradient index lens element having a biconvex shape. The aspherical surface used in the first lens unit is capable of favorably

correcting barrel form distortion which is produced in the objective lens system as a whole as in the fourth embodiment.

For configuring compactly a tip of an endoscope which is to comprise the objective lens system according to the present invention, an outer circumferential portion of the radial type gradient index lens element used as the second lens unit is cut off as shown in FIG. **8**. A tip of the objective lens system can be made thinner since the lens barrel or the like can be disposed, for example, as a slashed location **3** on the cut portion **2**.

The fifth embodiment is an example wherein the objective lens system has a total length that is shorter than that of the fourth embodiment. Though the fifth embodiment is composed only of the two lens elements, it has high optical performance.

The sixth embodiment of the present invention has a composition shown in FIG. **9**. Speaking concretely, it is composed of two lens units, in order from the object side, a first lens unit composed of a negative lens element, a stop and a second lens unit composed of a positive lens element. The first lens unit having the negative refractive power is configured as a radial type gradient index lens element. The first lens unit is a radial type gradient index lens element which has a planar surface on the object side and a concave surface on the image side, whereas the second lens unit is a biconvex homogenous lens element.

Unlike the first through fifth embodiments, the sixth embodiment uses the radial type gradient index lens element as the first lens unit for favorably correcting lateral chromatic aberration which poses a problem in particular in the objective lens system according to the present invention.

The planar surface adopted as the object side surface of the first lens unit makes it possible to reduce the cost required for polishing the lens element.

Further, aberrations are reduced by selecting the biconvex shape for the second lens unit so that its power is shared between the two surfaces.

Furthermore, the image side surface of the second lens unit has a refractive power of surface which is stronger than that of the object side surface thereof so that offaxial rays are incident on an image surface nearly at telecentric angles.

The sixth embodiment also has high optical performance though it is composed only of the two lens elements.

The seventh embodiment of the present invention has a composition illustrated in FIG. **10**. That is to say, an objective lens system preferred as the seventh embodiment is composed of two lens units, in order from the object side, a first lens unit composed of a negative lens element, stop and a second lens unit composed of a positive lens element. The first lens unit having the positive refractive power is configured as a radial type gradient index lens element. The first lens unit is a radial type gradient index lens element which has a planar surface on the object side and a concave surface on the image side, whereas the second lens unit is a homogeneous lens element which has a biconvex shape.

This embodiment also has high optical performance though it is composed only of the two lens elements.

The eighth embodiment of the present invention is an objective lens system which has a composition shown in FIG. **11**. This lens system is composed of two lens units, in order from the object side, a first lens unit composed of a negative lens element, a stop and a second lens unit composed of a positive lens element. The first lens unit having the positive refractive power is configured as a radial type gradient index lens element. The first lens unit is a radial type gradient index lens element having a meniscus shape which has a concave surface on the image side, whereas the second lens unit is a homogeneous lens element which has a biconvex shape.

The composition of the eighth embodiment, in which the radial type gradient index lens element has the meniscus shape which has a concave surface on the image side is advantageous for correcting offaxial aberrations in particular.

The eighth embodiment also has high optical performance in spite of the face that it is composed only of the two lens elements.

The ninth embodiments of the present invention is an objective lens system which has a composition illustrated in FIG. **12**. Speaking concretely, this lens system is composed of two lens elements, in order from the object side, a first lens unit composed of a negative lens units, a stop and a second lens unit composed of a positive lens element. The first lens unit having the negative refractive power is configured as a radial type gradient index lens element. The first lens unit is a radial type gradient index lens element having a meniscus shape which has a planar surface on the object side and a concave surface on the image side, whereas the second lens unit has aspherical surfaces on both sides.

Owing to a fact that an image side surface of the second lens unit on which offaxial rays are relatively high is configured as an aspherical surface having such a shape as to weaken a positive refractive power as portions of the aspherical surface are farther from an optical axis toward a marginal portion, the ninth embodiment is capable of favorably correcting barrel form distortion produced in the lens system as a whole.

Though the ninth embodiment uses the aspherical surfaces on both sides of the second lens unit, a similar effect can be obtained by using an aspherical surface only on one side.

The ninth embodiment also exhibits high optical performance though it consists only of the two lens elements.

Further, a similar effect can be obtained by adopting, the place of the aspherical surfaces used in the second lens unit, an axial type gradient index lens element which continuously varies a refractive index in a direction along the optical axis.

The tenth embodiment of the present invention is an objective lens system which has a composition shown in FIG. **13**. This lens system consists of two lens units, in order from the object side, a first lens unit composed of negative lens element, a stop and a second lens unit composed of a positive lens element. The first lens unit having the negative refractive power and the second lens unit having the positive refractive power are configured as radial type gradient index lens elements. The first lens unit is a radial type gradient index lens element which has a planar surface on the object side and a concave surface on the image side, whereas the second lens unit is a radial type gradient index lens element which has a biconvex shape.

The tenth embodiment is an example wherein lateral chromatic aberration produced in the lens system as a whole is favorably corrected by using radial type gradient index lens elements in both the lens units. In other words, lateral chromatic aberration is favorably corrected by configuring the radial type gradient index lens element used in the first lens unit to satisfy the condition (1) and the condition (2), and designing the radial type gradient index lens element used in the second embodiment to satisfy the condition (1) and the condition (3).

Though the tenth embodiment consists only of the two lens elements, it has high optical performance.

Preferred as an eleventh embodiment of the present invention is an objective lens system which has a composition illustrated in FIG. **14**. This lens system comprises two lens units, or is composed, in order from the object side, a first lens unit composed of a negative lens element, a stop, a second lens unit composed of a positive lens element and filters F disposed on the image side of the second positive lens unit. The first lens unit is configured as a homogenous lens element which has a planar surface on the object side and a concave surface on the image side, whereas the second lens unit is configured as a biconcave radial type gradient index lens element which has an object side surface having a weak positive refractive power.

When the objective lens system according to the present invention is used in a video scope or the like which uses a solid-state image pickup device such as a CCD, a low pass filter and an infrared cut filter composed, for example, of quartz or diffraction gratings may be disposed on the object side of an image surface as exemplified in FIG. **14**. The eleventh embodiment is an example comprising such filters. In the objective lens system according to the present invention, the above-mentioned filters can be disposed between the negative lens element and the positive lens element.

Preferred as the twelfth embodiment of the present invention is an objective lens system which has a composition shown in FIG. **15**. Like the eleventh embodiment, the twelfth embodiment comprises two lens units, or is composed, in order from the object side, of a first lens unit composed of a negative lens element, a stop, a second lens unit composed of a positive lens element, and filters which are disposed between the two lens elements and on the image side of the positive lens element. The first lens unit is configured as a homogenous lens element which has a planar surface on the object side and a concave surface on the image side, whereas the second lens unit is configured as a radial type gradient index lens element which has a biconvex shape.

The thirteenth embodiment of the present invention has a composition illustrated in FIGS. **16**A and **16**B: FIG. **16**A being a sectional view showing the thirteenth embodiment as a whole and FIG. **16**B being a diagram illustrating only a portion B on an enlarged scale. The thirteenth embodiment is composed, in order from the object side, of a first lens unit composed of a negative lens element, a stop and a second lens unit composed of a positive lens element. A radial type gradient index lens element is used as the second lens unit. The first lens unit has a planar surface on the object side and a concave surface on the image side, whereas the second lens unit has a planar surface on the object side and a convex surface on the image side.

The thirteenth embodiment is an example wherein aberrations are favorably corrected by using a radial type gradient index lens element and a large number of planar surfaces are adopted for reducing a cost required for polishing lens elements, or the object side surface of the first lens unit and the object side surface of the second lens unit are configured to be planar.

Further, for preventing eccentricities of lens elements, in directions along an optical axis and perpendicular thereto in particular, which pose a problem at a stage of assembly, an outer circumferential portion **4** is obliquely chamfered as shown in FIG. **16**B so that a chamfered portion **4** is limited at a location **6** of a lens barrel **5**. Since a radial type gradient index lens element which has a refractive power of medium requires a manufacturing precision stricter than that for a homogenous lens element, the thirteenth embodiment provides effective assembling convenience. A similar effect can, needless to say, be obtained by assembling the first lens unit having the negative refractive power in a similar manner.

Though the thirteenth embodiment uses a large number of planar surfaces, it has high optical performance.

The fourteenth embodiment of the present invention is an objective lens system which has a composition illustrated in FIG. **17**. That is to say, the fourteenth embodiment is composed, in order from the object side, of a first lens unit consisting of a negative lens element, a stop and a second lens unit consisting of a positive lens element which is configured as a radial type gradient index lens element. The first lens unit has a planar surface on the object side and a concave surface on the image side, whereas the second lens unit has a meniscus shape which has a concave surface on the object side.

When a radial type gradient index lens element is used as the second lens unit, it is desirable for correcting aberrations such as spherical aberration that the term of the fourth order N_{20} of a refractive index distribution has a positive value.

The fifteenth embodiment of the present invention has a composition shown in FIG. **18**. Speaking concretely, the fifteenth embodiment is composed, in order from the object side, of a first lens unit consisting of a negative lens element, a second lens unit consisting of a positive lens element and a reflecting optical element. A radial type gradient index lens element is used as the second lens unit. In this embodiment, a light bundle emerging from the second lens unit is reflected by a reflecting surface **7** of a reflecting optical element P made, for example, of a mirror or a prism so that it is imaged onto a solid-state image pickup device **10** which is disposed nearly parallel to the optical axis. This reflecting surface makes it possible to dispose a solid-state image pickup device such as a CCD that is not parallel to a radial direction of the lens elements, but oblique. Though a solid-state image pickup device **10** is disposed nearly parallel to the optical axis in the fifteenth embodiment, the image pickup device can be disposed more obliquely by selecting an adequate inclination angle for the reflecting surface **7** relative to the optical axis. Though the fifteenth embodiment is configured to reflect the light bundle only once, it is possible to reflect the light bundle twice, three times or more times by adopting a larger number of reflecting surfaces.

The sixteenth embodiment of the present invention is an objective lens system which has a composition shown in FIG. **19**. That is to say, the sixteenth embodiment is composed, in order from the object side, of a first lens unit composed of a negative lens element, a second lens unit composed of a positive lens element and a solid-state image pickup device. A radial type gradient index lens element is used ass the second lens unit. In this embodiment, the radial type gradient index lens element has a nearly planar image side surface which is cemented or kept in close contact to or with a solid-state image pickup device **10** such as a CCD. Further, disposed in the second lens unit, is a member which extends from an outer circumference toward an optical axis for shielding a light bundle passing through the lens unit or functioning as an aperture stop of the objective lens system. Such a shielding member can be constituted, for example, by forming a cut **8** from the outer circumference toward the optical axis. For preventing the cut from producing flare, it is desirable to color the cut **8**. Further, it is possible to cut the second lens unit along a dashed line **9** shown in FIG. **25** into a front portion La and a rear portion Lb, attach a stop S to a cut surface of the front portion La and cementing the two portions to each other or bringing them into close contact with each other. A similar effect can be obtained by attaching

the stop S to the rear portion Lb in place of the front portion La. As means for attaching the stop, it is conceivable to utilize deposition, printing or bonding a stop plate. This means can be utilized for manufacturing not only an aperture stop but also a flare stop.

In the sixteenth embodiment, the aperture stop is disposed at a location 1 mm apart from an object side surface of the second lens unit toward an image surface.

It is needless to say that an aperture stop, a flare stop or the like can be manufactured by the means described above in each of the embodiments.

The seventeenth embodiment of the present invention has a composition illustrated in FIG. **20**. That is to say, the seventeenth embodiment is composed, in order from the object side, of a first lens unit composed of a negative lens element, a second lens unit composed of a positive lens element, an optical filter F and a solid-state image pickup device **10**. A radial type gradient index lens element is used as the second lens unit. In the seventeenth embodiment, the second lens unit has planar surfaces on both sides for reducing the cost for polishing the lens unit. The seventeenth embodiment is an example wherein the second lens unit is cemented to the optical filter F for simplifying a structure of a lens barrel and assembly of the objective lens system. Further, the optical filter F is cemented or kept in close contact to or with the solidstate image pickup device **10**. Furthermore, the first lens unit and the second lens unit are cemented or kept in close contact to or with each other on outer circumferences thereof outside an effective diameter thereof.

In the seventeenth embodiment, an aperture stop is disposed at a location 1 mm apart from an object side surface of the second lens unit toward an image surface.

The eighteenth embodiment of the present invention has a composition shown in FIG. **21**. That is to say, the eighteenth embodiment is composed, in order from the object side, of a first lens unit composed of a negative lens element, a regularly reflecting optical element and a second lens unit composed of a positive lens element. The second lens unit which is disposed on the image side is configured as a radial type gradient index lens element.

Certain endoscopes are specified for oblique observation in direction inclined relative to the optical axis. When the objective lens system according to the present invention is used in an endoscope for oblique observation, a reflecting optical element P composed of a mirror or a prism is disposed between the first lens unit and the second lens unit as shown in FIG. **21** so that a light bundle emerging from the first lens unit is reflecting by a reflecting surface **7** of the reflecting optical element and led to the second lens unit.

Though a lens element ordinarily has a circular sectional shape, it may have a different sectional shape. FIGS. **22**A, **22**B, **22**C, **23**A, **23**B and **23**C exemplify lens elements which have external shapes cut or worked in accordance with shapes of image pickup devices for configuring objective lens systems compactly. FIGS. **22**A, **22**B and **22**C schematically show the second lens unit which is used in the first through eighteenth embodiments before being shaped. FIG. **22**A shows a sectional view taken in a direction from an object, FIG. **22**B is a sectional view taken in a direction in parallel with the optical axis, and FIG. **22**C illustrates an image circle **11** of the objective lens system and an image pickup surface **12** of an image pickup device. FIGS. **23**A, **23**B and **23**C schematically show the lens element illustrated in FIGS. **22**A, **22**B and **22**C in another condition after it is shaped. Since a solid-state image pickup device such as CCD may have a rectangular shape and a lens element ordinarily has a circular shape as shown in FIG. **22**A, there is produced, as slashed in FIG. **22**C, a region which serves for image formation but is not used for image pickup. Since it is desired to configure an objective lens system for endoscopes compacter, it is conceivable to cut off the region of the lens element which is not used for image pickup. The eighteenth embodiment is an example wherein lens portion through which rays to be condensed outside an image pickup surface of an image pickup device are cut off as exemplified by FIGS. **23**A and **23**B so that an image formation range of the lens element is nearly coincident with the image pickup surface of the image pickup device. It is possible to obtain a compacter objective lens system or endoscopes by configuring a lens element so as to occupy a narrower space.

Though the second lens unit is worked for narrowing a lens space in the example descried above, it is needless to say that a similar effect can be obtained by working other lens element or optical element, for example, the first lens unit or the reflecting optical element.

The nineteenth embodiment has a composition illustrated in FIG. **26**. Speaking concretely, the nineteenth embodiment is a retrofocus type objective lens system which is composed, in order from the object side, of a first negative lens unit, a second positive lens unit and a third positive lens unit. A stop is disposed between the second lens unit and the third lens unit. The nineteenth embodiment is an objective lens system which has a wide field angle and is usable for endoscopes, video cameras, etc. Though the nineteenth embodiment has a wide field angle which makes it rather hard to contact lateral chromatic aberration, it corrects lateral chromatic aberration with a radial type gradient index lens element. In the nineteenth embodiment, the first lens unit has a plano-concave shape and a function to widen a field angle, the second lens unit has a plano-convex shape and a function to correct mainly lateral chromatic aberration produced by the first lens unit, and the third lens unit has a biconvex shape and a main imaging function, and is configured as a radial type gradient index lens element.

Though it is rather hard in the nineteenth embodiment to correct coma which is produced by the third lens unit disposed on the image side of a stop, coma is corrected by configuring the third lens unit as a radial type gradient index lens element which has such a characteristic as to progressively lower a refractive index in a radial direction from an optical axis. In other words, coma is corrected by imparting a positive refractive power to a medium of the radial type gradient index lens element. The composition described above is capable of correcting not only coma but also distortion.

For correcting coma with a medium of a radial type gradient index lens element, it is desirable that terms of high orders of a refractive index distribution satisfy the following condition (27):

$$-0.05 < \sum_{i=2}^{n} N_{iod} e^{2i} < 0.2 \tag{27}$$

wherein the reference symbol e represents an effective diameter of the lens element.

If the lower limit of −0.05 of the condition (27) is not reached, coma will be undercorrected. If the upper limit of 0.2 of the condition (27) is exceeded, in contrast, coma will be overcorrected.

It is desirable for more favorable correction of coma to satisfy the following condition (28):

$$0 < \sum_{i=2}^{n} N_{iod} e^{2i} < 0.1 \quad (28)$$

If the lower limit of 0 of the condition (28) is not reached, coma will be undercorrected. If the upper limit of 0.1 of the condition (28) is exceeded, in contrast, coma will be overcorrected. Either of these cases is undesirable for more favorable correction of coma.

Further, a planar surface used as an object side surface of the lens element disposed on the image side in the nineteenth embodiment has an effect for preventing adhesion of foreign matter such as dust.

In this embodiment, at least one lens element can have a function to cut off components having specific wavelengths, or a radial type gradient index lens element can have such a function.

When an image pickup device such as a CCD which has high sensitivity in the infrared wavelength region is to be disposed on an image pickup surface, for example, it is desirable to provide a function to cut off components having wavelengths in the infrared region. Accordingly, it is desirable that at least one lens element has a function to cut off components having specific wavelenghts such as those in the infrared region.

The function to cut off components having specific wavelengths can be obtained by forming, on a flat portion of a lens element or a flat plate, an interference film which cuts off the components having specific wavelengths.

A stop can be manufactured from a thin plate.

Further, amounts of aberrations produced can be reduced by configuring a radial type gradient index lens element so as to have a biconvex shape, thereby sharing a refractive power between the two surfaces.

Use of a radial type gradient index lens element makes it possible to obtain an optical system which is compact and composed of a small number of lens elements, and has a wide field angle and favorably corrected aberrations such as chromatic aberration and coma. Accordingly, it is effective to use an optical system such as an optical system for image input units for portable TV telephones and portable data input units such as those shown in FIGS. **35** and **36**.

The twentieth embodiment is an optical system which has a composition illustrated in FIG. **17**. It is a retrofocus type optical system which is composed, in order from the object side, of a first lens unit having a negative refractive power, a second lens unit having a positive refractive power and a third lens unit having a positive refractive power. A stop is disposed between the second lens unit and the third lens unit.

The twentieth embodiment is an optical system which has a wide field angle and is usable as an objective lens system for endoscopes or a lens system for video cameras, etc. Though the twentieth embodiment also has a wide field angle and hardly allows correction of lateral chromatic aberration in particular, aberrations are favorably corrected in this embodiment by using a radial type gradient index lens element.

In the twentieth embodiment, the first lens unit is a plano-concave lens element having a function to widen a field angle, the second lens unit is a radial type gradient index lens element having planar surfaces on both sides and a function to correct lateral chromatic aberration produced by the first lens unit, and the third lens unit has a biconvex shape and a main imaging function. The twentieth embodiment favorably corrects lateral chromatic aberration in particular by using, as the second lens unit disposed on the object side of the stop, a radial type gradient index lens element made of a medium which has a positive refractive power and a relatively strong dispersing power. The medium having the positive refractive power favorably corrects a Petzval's sum.

For correcting lateral chromatic aberration by disposing a radial type gradient index lens element on a stop, it is desirable to satisfy the following condition (29).

$$0.01<1V_{10}<0.5 \quad (29)$$

If the lower limit of 0.01 of the condition (29) is not reached, lateral chromatic aberration will be undercorrected. If the upper limit of 0.5 of the condition (29) is exceeded, in contrast, lateral chromatic aberration will be overcorrected.

For correcting lateral chromatic aberration more favorably by disposing a radial type gradient index lens element on the object side of the stop, it is desirable to satisfy the following condition (30):

$$0.015<1/V_{10}<0.1 \quad (30)$$

If the lower limit of 0.015 of the condition (30) is not reached, lateral chromatic aberration will be undercorrected. If the upper limit of 0.1 of the condition (30) is exceeded, lateral chromatic aberration will be overcorrected. Either of these cases is undesirable for correcting lateral chromatic aberration extremely favorably.

When preparation of a material for a radial type gradient index lens element is taken into consideration, it is desirable that $1/V_{10}$ has a value not exceeding 0.05. From viewpoints of manufacturing convenience and cost, it is desirable to configure a radial type gradient index lens element so as to have planar surfaces on both sides. When durability of a radial type gradient index lens element is taken into consideration, it is desirable to make it entirely of a glass material.

The twenty-first embodiment has a composition illustrated in FIG. **28**, or is a retrofocus type optical system which is composed, in order from the object side, of a first lens unit having a negative refractive power and a second lens unit having a positive refractive power. A stop is disposed between the first lens unit and the second lens unit. The twenty-first embodiment which is an optical system having a wide field angle is usable as an objective lens system for endoscopes or video cameras and so on. Though this optical system also has a wide field angle and hardly allows correction of lateral chromatic aberration in particular, lateral chromatic aberration is favorably corrected by using a radial type gradient index lens element.

In the optical system preferred as the twenty-first embodiment, the first lens unit has a negative meniscus shape which has a concave surface on the image side, and the second lens unit has a biconvex shape and a main imaging function. A radial type gradient index lens element is used as the first lens unit.

Offaxial aberrations can be corrected favorably by configuring the radial type gradient index lens element used as the first lens unit so as to have the meniscus shape which has the concave surface on the side of the stop. Lateral chromatic aberration is favorably corrected in particular owing to a fact that the radial type gradient index lens element has a positive refractive power of medium and is configured so as to satisfy the condition (29).

Further, coma is corrected favorably by using an aspherical surface on the lens element disposed on the object side of the stop. This aspherical surface has such a shape as to weaken a positive refractive power as portions of the aspherical surface are farther from an optical axis toward a marginal portion. Owing to this aspherical surface, the twenty-first embodiment is configured as an optical system which is compact and composed of a small number of lens elements, has a wide field angle and favorably corrects aberrations such as coma. It is therefore effective to apply the twenty-first embodiment as an optical system for image intake devices for portable TV telephones and portable date input units.

The twenty-second embodiment has a composition shown in FIG. **29**, or is an optical system composed of a single radial type gradient index lens element. The radial type gradient index lens element has a meniscus shape which has a concave surface on the object side and a positive power of medium. A stop is disposed at a location 0.9471 mm apart from an object side surface of the lens element toward the image side.

The twenty-second embodiment has a wide field angle, and is usable as an objective lens system for endoscopes or a lens system for video camera and so on. Though the twenty-second embodiment which has a wide field angle hardly allows correction of chromatic aberration, it is corrected with the radial type gradient index element. A flat glass plate is disposed on the object side as a cover glass plate. A stop is disposed in the radial type gradient index lens element for obtaining highly symmetrical refractive power of medium, thereby favorably correcting offaxial aberrations. The radial type gradient index lens element satisfies the condition (29) for correcting lateral chromatic aberration produced by an object side concave or convex surface with a medium located on the object side of the stop.

For reducing chromatic aberration to be produced by surfaces of the radial type gradient index lens element, it is desirable that V_{00} has a value of at least 30, or more desirably, at least 40. For reducing aberrations to be produced by the surfaces of the radial type gradient index lens element, it is desirable that N_{00} has a value of at least 1.55, or more desirably, at least 1.6.

The twenty-third embodiment has a composition shown in FIG. **30**, or is composed of two lens units, in order from the object side, a first positive lens unit and a second positive lens unit. The twenty-third embodiment is an example wherein aberrations are corrected favorably by composing an optical system of a radial type gradient index element and a diffraction type optical element (DOE). Speaking more concretely, the twenty-third embodiment is composed, in order from the object side, of a first lens unit composed of a radial type gradient index lens element and a second lens unit composed of a diffraction type optical element.

A diffraction type optical element is equivalent to a lens element which has a very high imaginary refractive index as described in literature SPIE, Vol. 126, P46 (1997). For this reason, the diffractive optical element is assumed to be a lens element which is optically equivalent to the optical element including aberrations to be produced thereby, and radii of curvature, thickness, a refractive index, an Abbe's number and aspherical surface coefficients of the lens element are described in the numerical data of the twenty-third embodiment. In the twenty-third embodiment, a stop is disposed on the object side of the optical system (the first lens unit).

In the twenty-third embodiment, the first lens unit composed of the radial type gradient index lens element has a main imaging function and the second lens unit composed of the diffraction type optical element favorably corrects lateral chromatic aberration. The twenty-third embodiment is an example of an optical system which is composed of a small number of optical elements and has a wide field angle, and favorably corrects lateral chromatic aberration with a diffractive optical element disposed on the image side of a stop. The diffraction type optical element has a positive refractive power, is disposed on the image side of the radial type gradient index lens element and has a function to favorably correct lateral chromatic aberration produced by a convex surface of the radial type gradient index lens element. Further, the radial type gradient index lens element has another function to favorably correct a Petzval's sum.

The twenty-third embodiment is usable as described above, as an objective lens system for endoscopes or an optical system for video cameras and so on. Since the twenty-third embodiment is an optical system which is compact and is composed of a small number of lens elements, and favorably corrects aberrations such as chromatic aberration owing to the fact that it uses the diffraction type optical element, it is effective to apply it as an optical system for image intake devices for portable TV telephones and portable data input units.

The twenty-fourth embodiment has a composition illustrated in FIG. **31**, or is composed, in order from the object side, of a first lens unit having a negative refractive power and a second lens unit having a positive refractive power. A stop is disposed between the first lens unit and the second lens unit. In the twenty-fourth embodiment, the first lens unit having the negative refractive power serves mainly for widening a field angle and the second lens unit having the positive refractive power functions mainly for imaging.

The twenty-fourth embodiment favorably corrects aberrations by using the diffraction type optical element in that place of the radial type gradient index lens element adopted for the twenty-first embodiment.

The twenty-fourth embodiment hardly allows correction of offaxial aberrations since it has an asymmetrical refractive power distribution wherein a negative refractive power is disposed on the object side of the stop and a positive refractive power is disposed on the image side of the stop. For this reason, lateral chromatic aberration is corrected favorably by disposing the diffraction type optical element on the object side of the stop an imparting a negative refractive power to this optical element. Coma and distortion in particular can be corrected favorably by using an aspherical surface on a positive lens unit disposed on the image side of the stop and configuring this aspherical surface so as to have such a shape as to weaken a positive refractive power in a radial direction from an optical axis. The negative lens unit has a meniscus shape which has a concave surface on the side of the stop for reducing amounts of offaxial aberrations in particular. Further, the positive lens unit has a biconvex shape so that amounts of aberrations are reduced by sharing a refractive power between two surfaces. Furthermore, the diffraction type optical element is disposed on a surface which is concave toward the stop so that differences between angles of incidence of paraxial rays and offaxial rays are reduced, thereby enhancing a diffraction efficiency.

FIG. **32** is a perspective view illustrating an endoscope according to the present invention which uses an objective lens system such as the embodiment described above. The reference numeral **21** represents the objective lens system.

FIG. **33** is a side view of a non-flexible endoscope according to the present invention which uses an objective lens system such as the embodiment described above. The reference numeral **21** represents the objective lens system.

FIG. **34** shows a video camera according to the present invention which uses an objective lens system such as the embodiment described above. The reference numeral **21** represents the objective lens system.

FIG. **35** shows a perspective view illustrating a portable TV telephone according to the present invention which uses an objective lens system such as the embodiment described above. The reference numeral **21** represents the objective lens system, the reference numeral **22** designates an antenna for transmission and reception, the reference numeral **23** denotes a display, and the reference numeral **24** represents switches.

Further, FIG. **36** shows a perspective view illustrating a portable data input unit according to the present invention which uses an objective lens system such as the embodiment described above. The reference numeral **21** represents the objective lens system, the reference numeral **22** **22** designates an antenna for transmission and reception, the reference numeral **23** denotes a display, and the reference numeral **24** represents switches.

As understood from the foregoing description, the objective lens system for endoscopes according to the present invention is composed of lens elements in a number on the order of 2, and is nevertheless an optical system which favorably corrects aberrations, lateral chromatic aberration in particular, and has high optical performance.

What is claimed is:

1. A portable TV telephone, comprising:

an objective lens constructed and arranged to form an image of an object;

an antenna constructed and arranged to transmit and receive at least one of an image signal representing said image of the object, a dial signal and a voice signal carried by radio waves;

a display unit which displays at least a dial number and said image of the object; and

a switch which operates responsive to at least the dial number,

wherein said objective lens system includes a diffractive optical element configured to at least correct chromatic aberration produced by said objective lens system,

wherein said objective lens system has a stop,

wherein said diffractive optical element has a negative refractive power and

wherein said diffractive optical element is disposed on an object side of said stop.

2. A portable TV telephone comprising:

an objective lens system arranged to form an image of an object;

an antenna constructed and arranged to transmit and receive at least one of an image signal representing said image of the object, a dial signal and a voice signal carried by radio waves;

a display unit constructed and arranged to display at least a dial number and said image of the object; and

a switch constructed and arranged to operate responsive to at least the dial number,

wherein said objective lens system includes a diffractive optical element configured to at least correct chromatic aberration produced by said objective lens system, wherein said objective lens system comprises, in order from an object side, a first negative lens unit and a second positive lens unit, and wherein said first lens unit consists only of a negative lens element and said second lens unit consists only of a positive lens element.

3. A portable TV telephone comprising:

an objective lens system arranged to form an image of an object;

an antenna constructed and arranged to transmit and receive at least one of an image signal representing said image of the object, a dial signal and a voice signal carried by radio waves;

a display unit constructed and arranged to display at least a dial number and said image of the object; and

a switch constructed and arranged to operate responsive to at least the dial number,

wherein said objective lens system includes a diffractive optical element configured to at least correct chromatic aberration produced by said objective lens system, wherein said objective lens system comprises, in order from an object side, a first negative lens unit and a second positive lens unit, and wherein said diffractive optical element is cemented to a surface of said first negative lens unit.

4. A portable TV telephone comprising:

an objective lens system arranged to form an image of an object;

an antenna constructed and arranged to transmit and receive at least one of an image signal representing said image of the object, a dial signal and a voice signal carried by radio waves;

a display unit constructed and arranged to display at least a dial number and said image of the object; and

a switch constructed and arranged to operate responsive to at least the dial number,

wherein said objective lens system includes a diffractive optical element configured to at least correct chromatic aberration produced by said objective lens system, wherein said objective lens system comprises, in order from an object side, a first negative lens unit and a second positive lens unit, wherein said objective optical system comprises a stop which is disposed between said first negative lens unit and said second positive lens unit, and wherein said diffractive optical element is disposed on the object side of said stop.

5. The portable TV telephone according to claim **1**, **2**, **3** or **4**, wherein said objective lens system is disposed on a surface on which said image display unit is disposed.

6. The portable TV telephone according to claim **1**, **2**, **3** or **4**, wherein said objective lens system is disposed on a surface on which said switch is disposed.

* * * * *

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Frey et al.

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(45) **Date of Patent: Dec. 24, 2002**

(54) **APPARATUS AND METHOD FOR OBJECTIVE MEASUREMENT OF OPTICAL SYSTEMS USING WAVEFRONT ANALYSIS**

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(52) **U.S. Cl.** **351/212**
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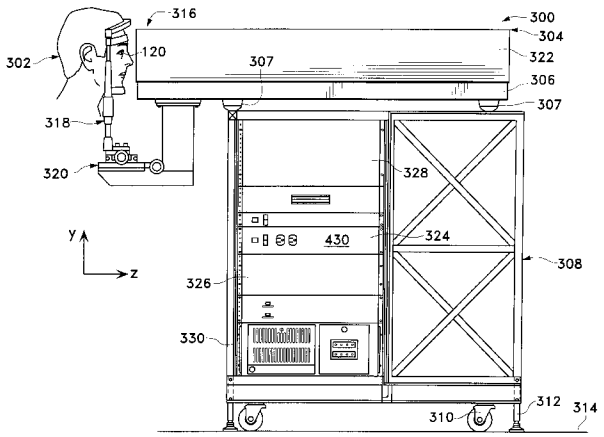
(57) **ABSTRACT**

An apparatus for determining aberrations of an eye includes a patient head rest allowing for positioning adjustment. The patient head rest is operable with an optical table having a base. The base includes a probe beam generating apparatus, probe beam directing optics which itself comprises a beam splitter; a mirror; and a lens. The probe beam directing optics is capable of directing a probe beam toward an eye of a patient positioned on the patient head rest. Video image components are provided and comprise a light source, a mirror; and a video camera. The video image components are capable of generating an image of an eye of a patient positioned on the patient head rest. Eye fixation components generate a target that the eye of a patient positioned on the patient head rest can view. The eye fixation components comprise a fixation target, a light source, a lens, and a mirror. Wavefront directing and analyzing components measure a wavefront emanating from the eye of a patient positioned on the patient head rest and determine aberrations of the eye that range from at least about + or −1 diopters to at least about + or −6 diopters. The wavefront directing and analyzing components include a lens; a mirror, a microlens array, a camera, and a data processor.

7 Claims, 28 Drawing Sheets



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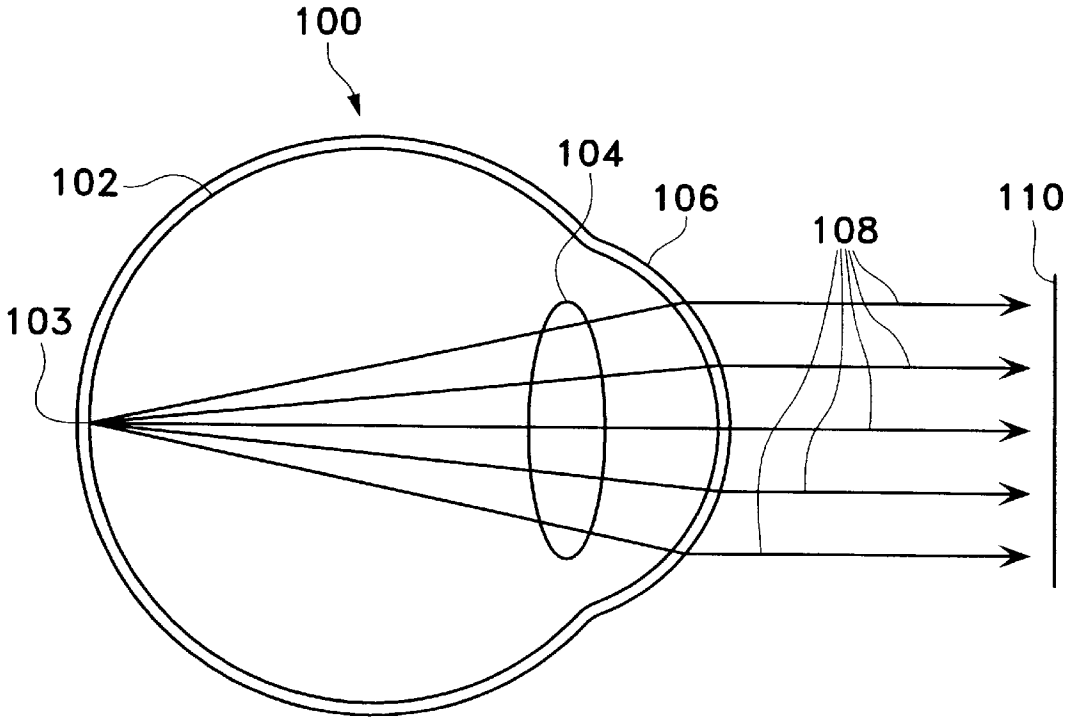


FIG. 1A

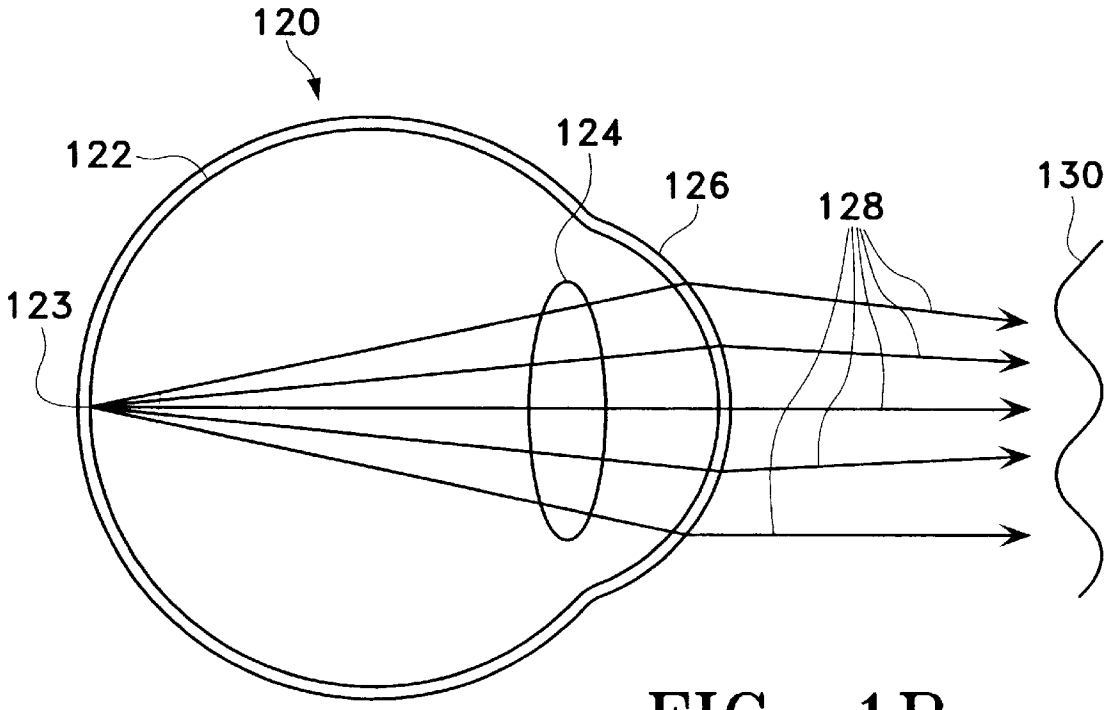


FIG. 1B

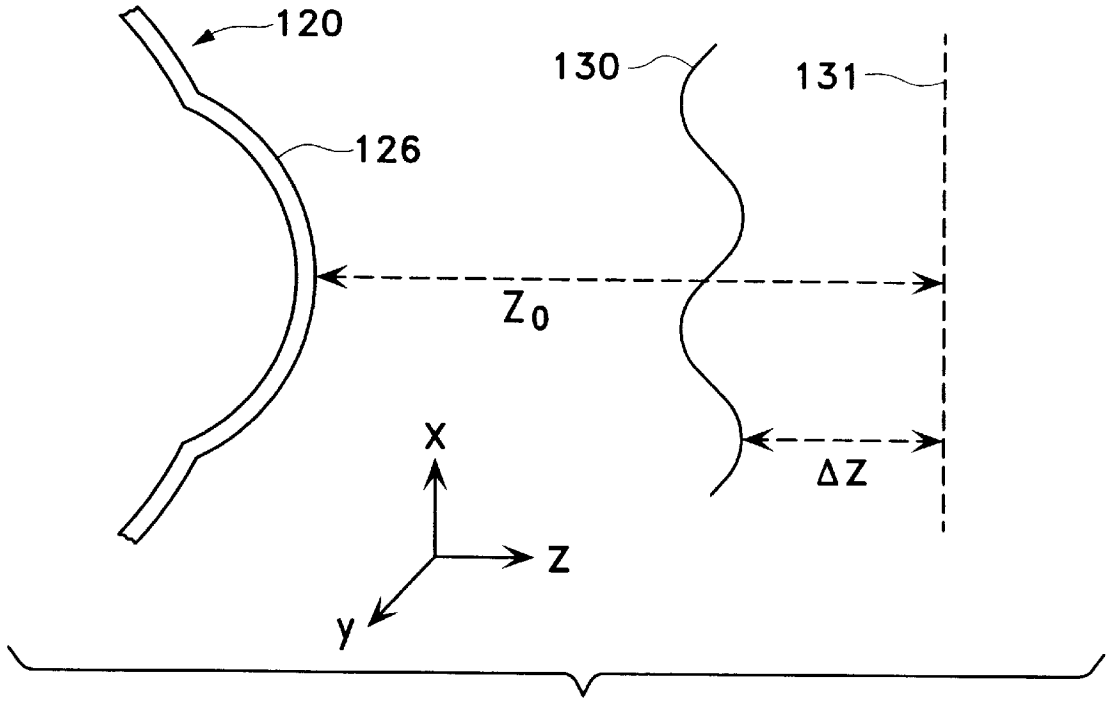

120
130
131
126
Z_0
X
Z
y
ΔZ

FIG. 1C

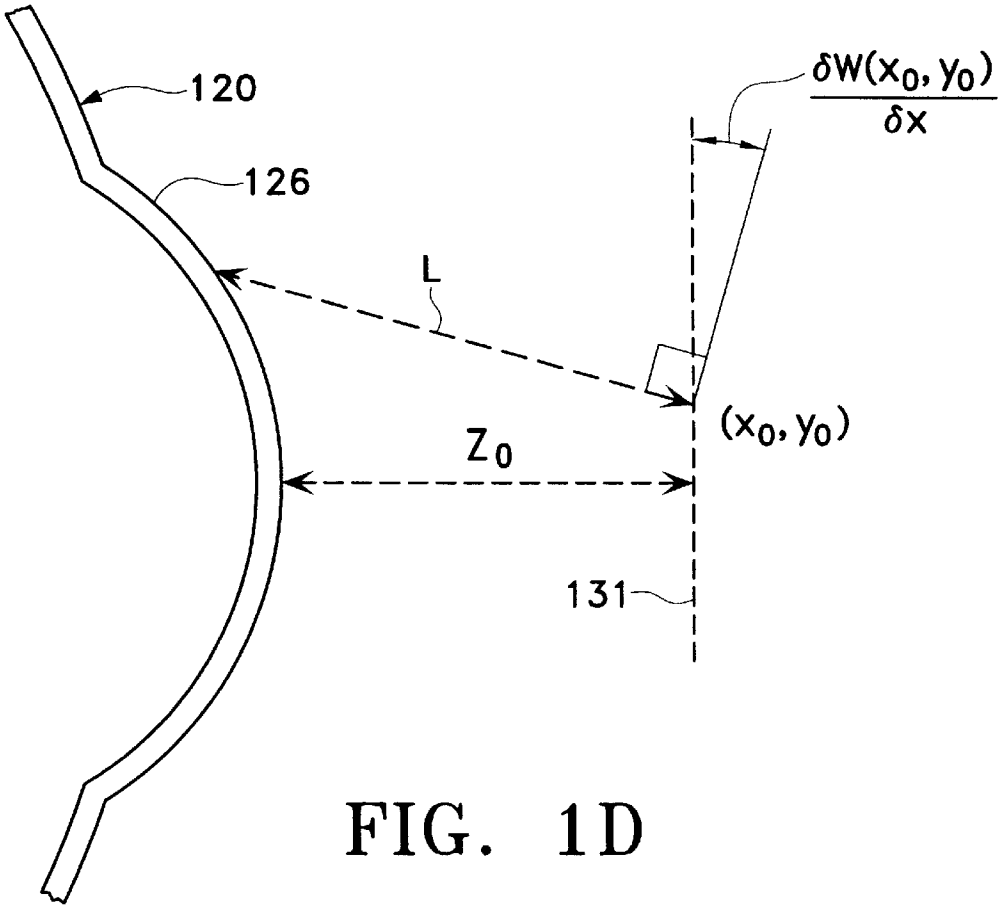
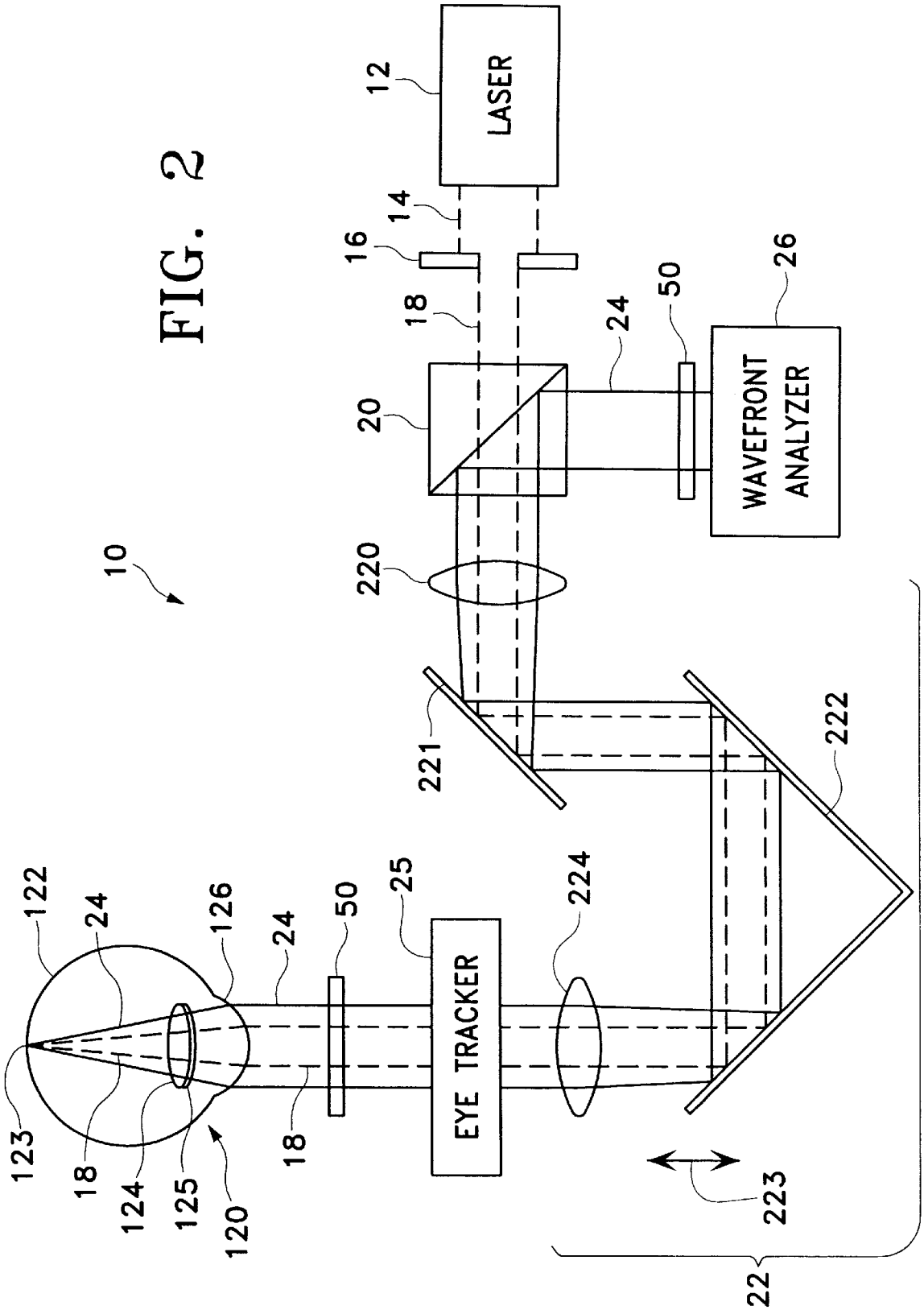

120
126
$\frac{\delta W(x_0, y_0)}{\delta x}$
L
(x_0, y_0)
Z_0
131

FIG. 1D

FIG. 2


10
12
LASER
14
16
18
20
24
50
26
WAVEFRONT ANALYZER
220
221
222
224
25
EYE TRACKER
223
22
122
24
126
24
50
18
123
18
124
125
120

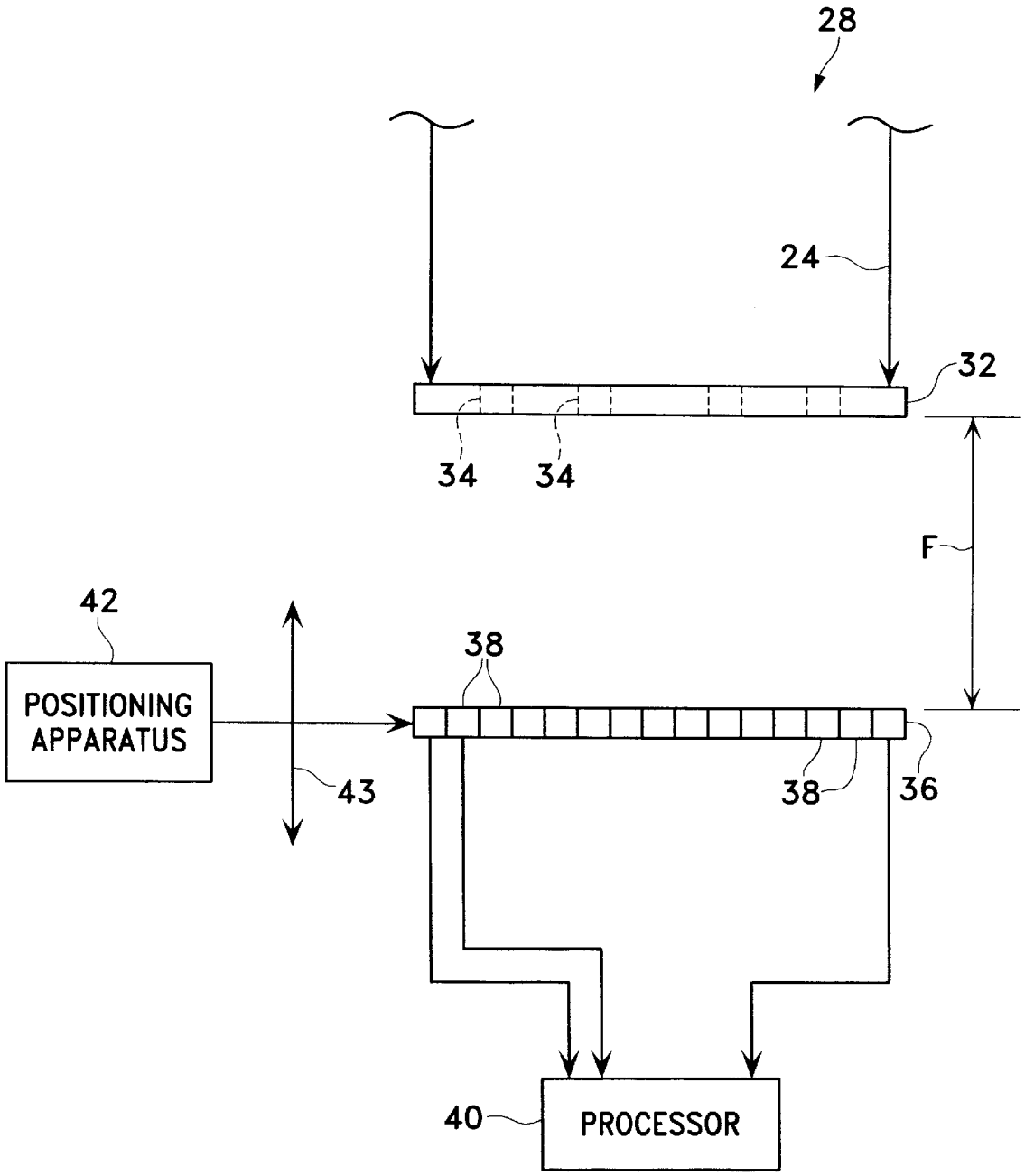

28
24
32
34
34
F
42
POSITIONING APPARATUS
38
43
38
36
40
PROCESSOR

FIG. 3

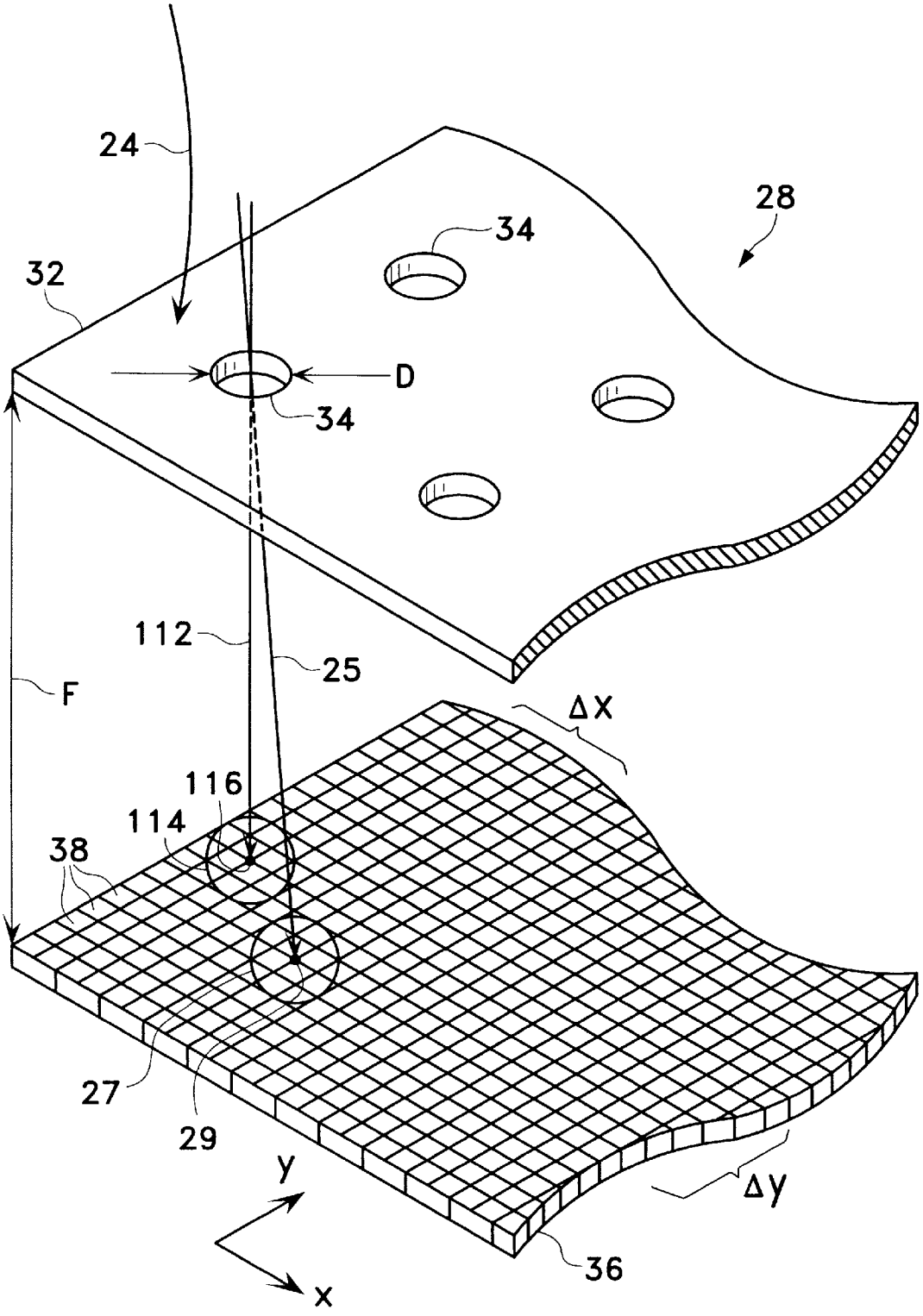


FIG. 4

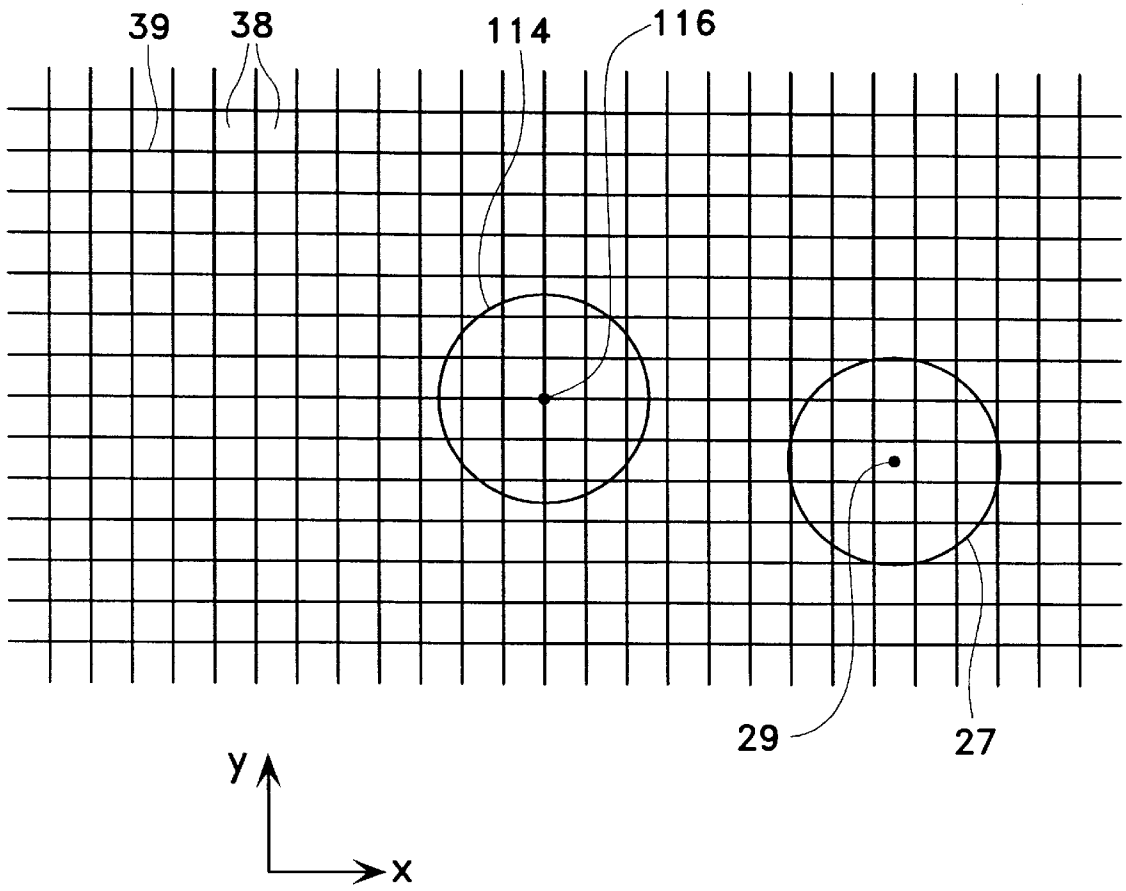
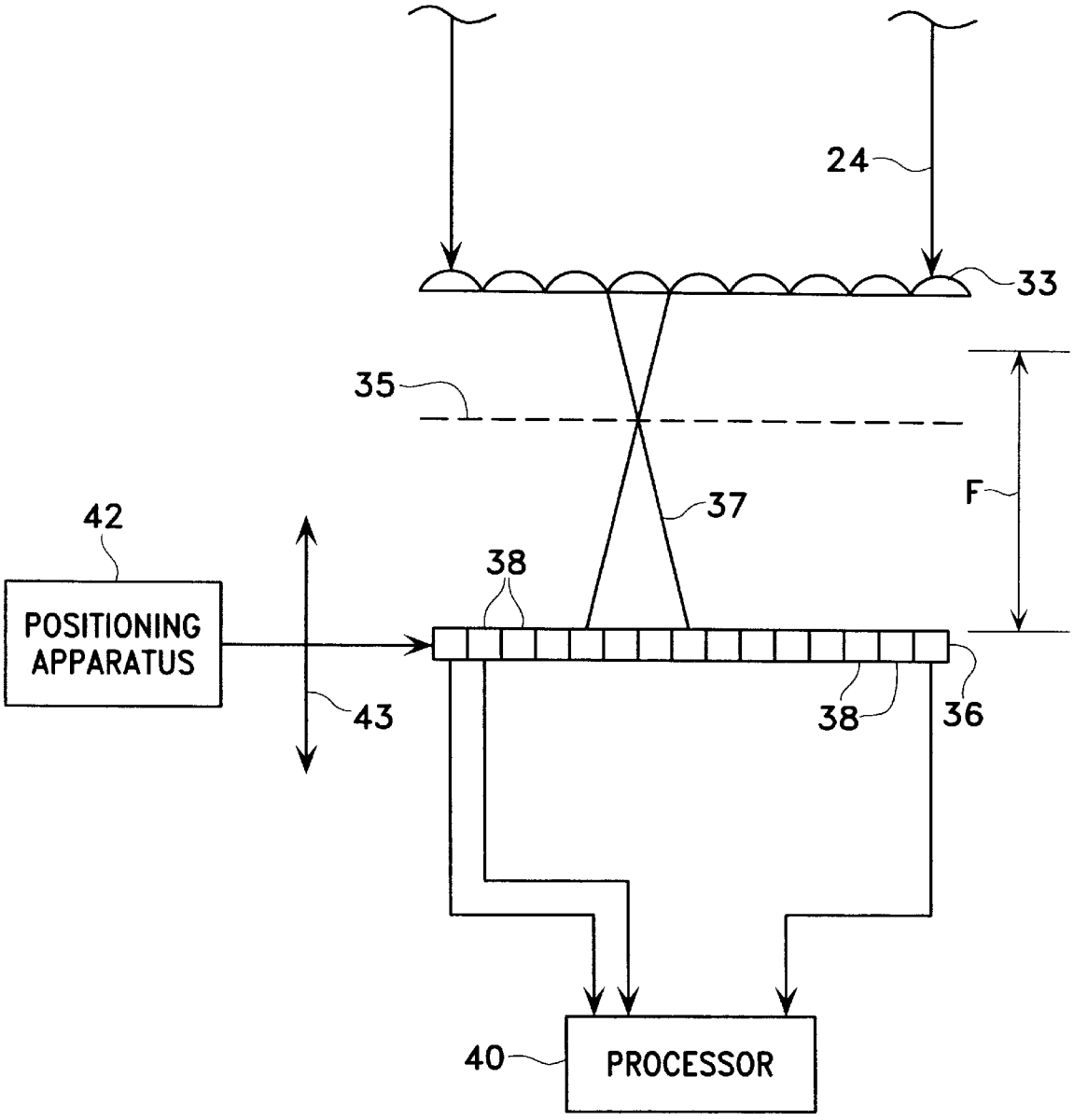


FIG. 5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38
POSITIONING APPARATUS
43
38
36
40
PROCESSOR

FIG. 6

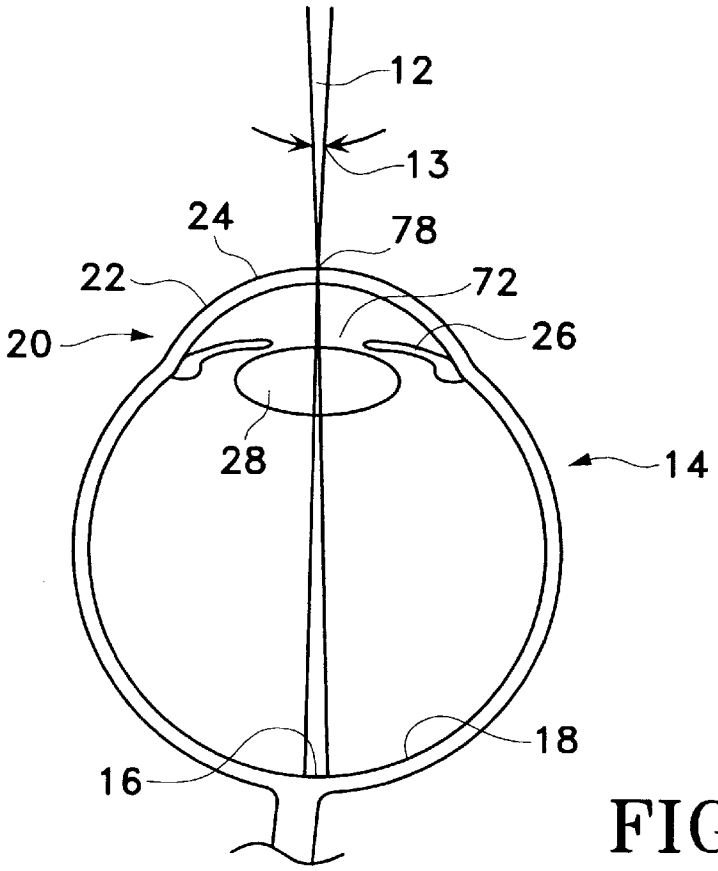


FIG. 7

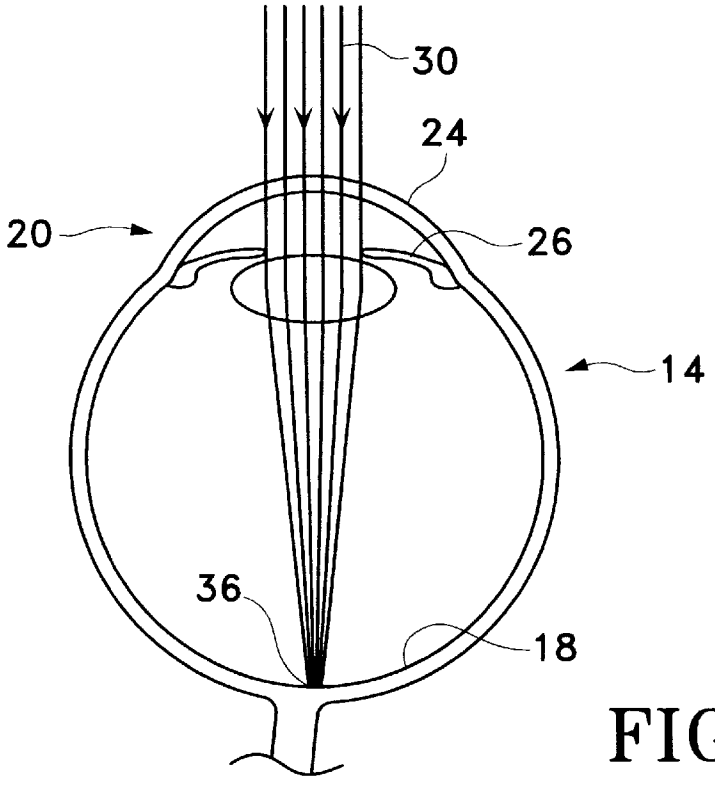
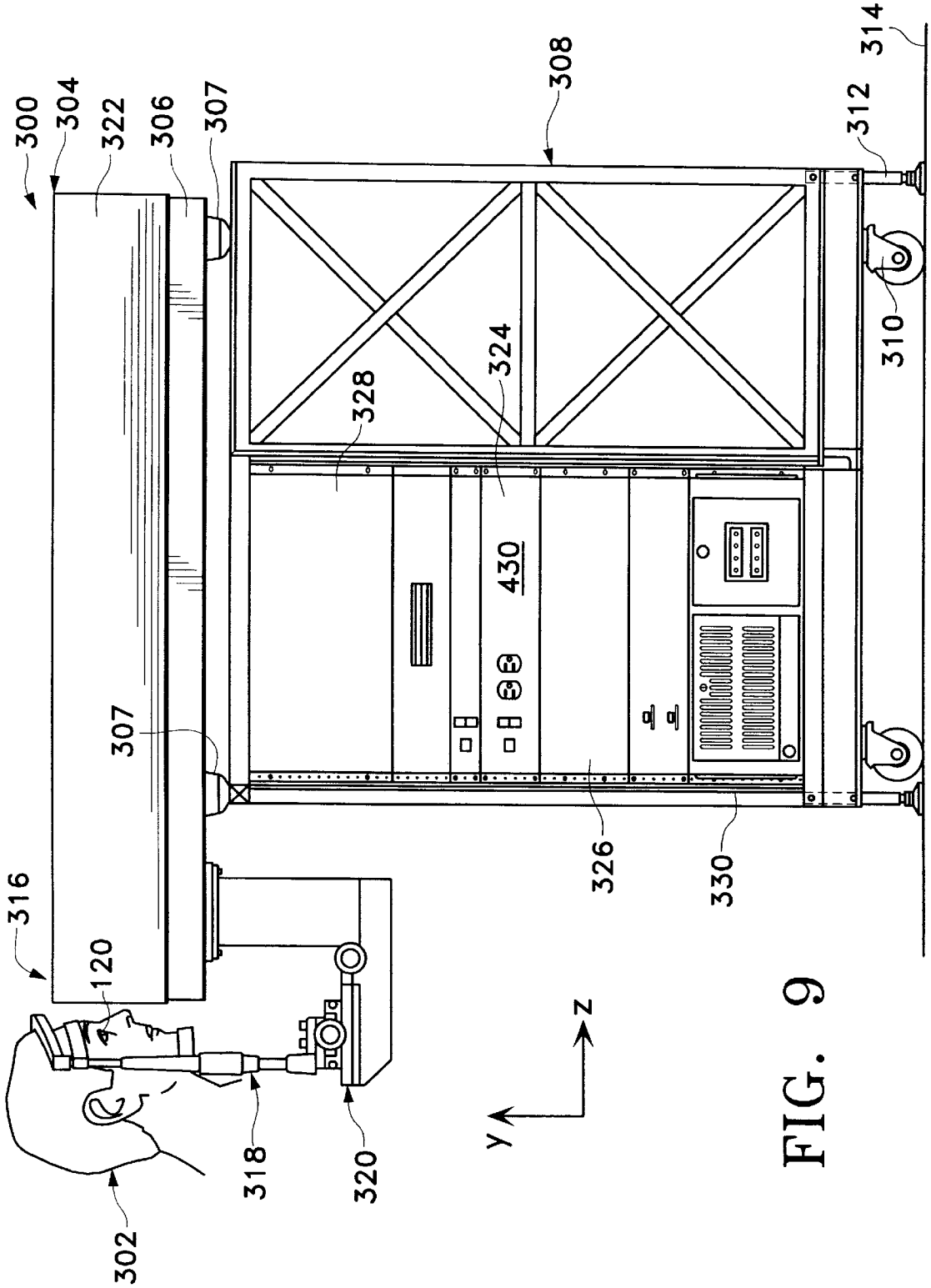


FIG. 8


300
304
322
306
307
308
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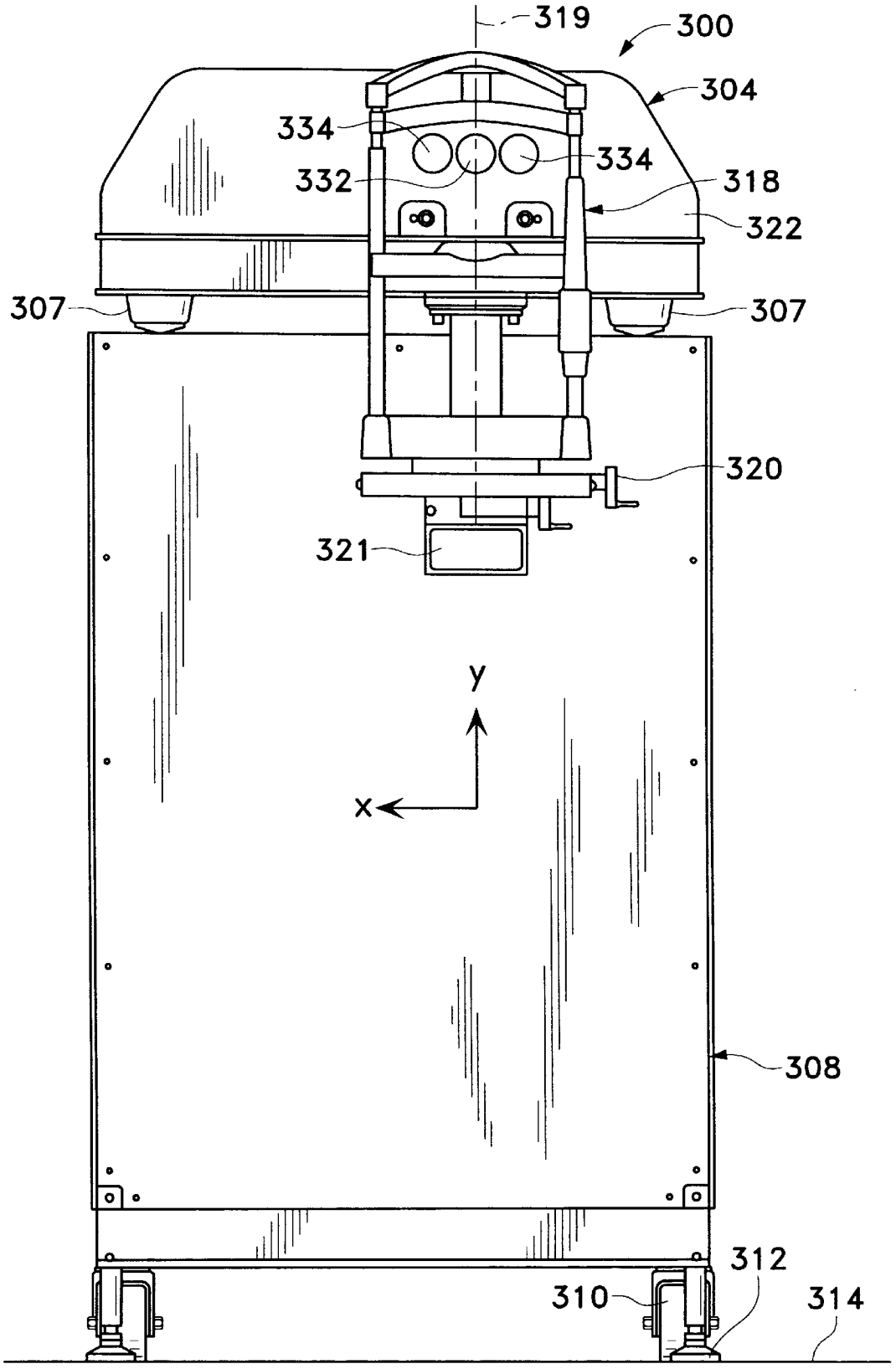
314
310
324
328
430
307
316
120
326
330
318
320
302
y
z

FIG. 9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332
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322
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321
y
x
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314

FIG. 10

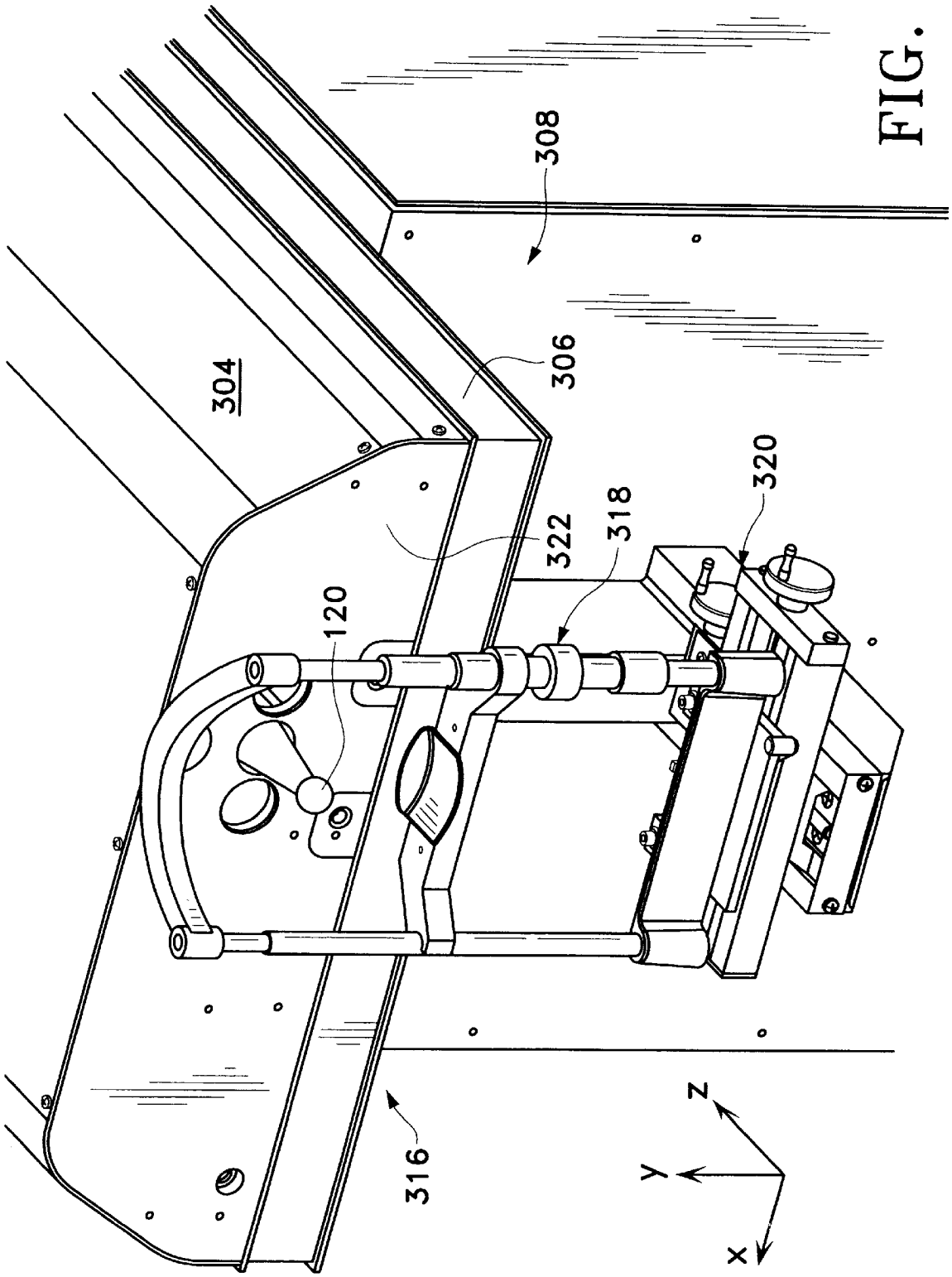
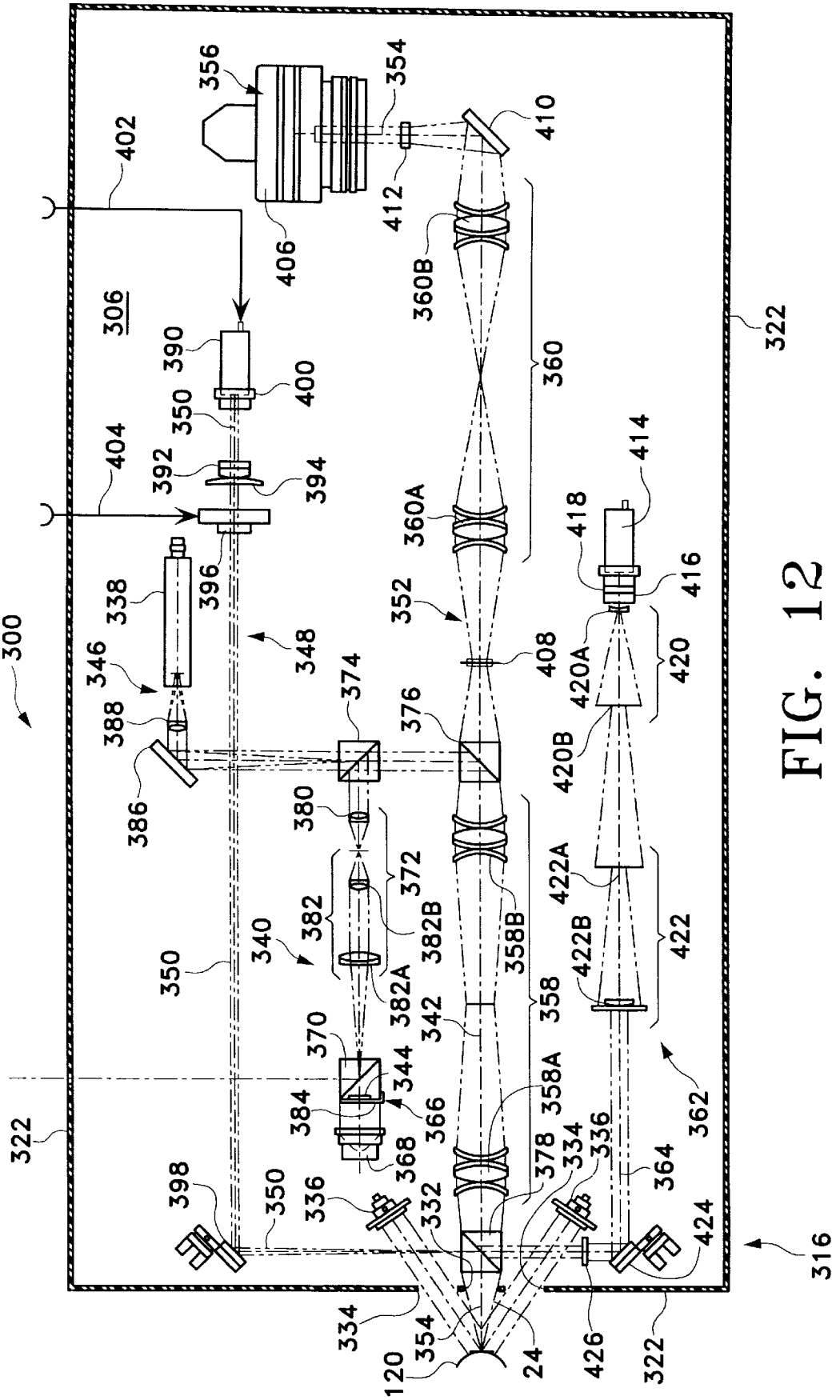


FIG. 11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322
322
322
322
334
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120
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426
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336
332
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384
368
366
370
344
358A
362
340
350
382
382A
382B
372
380
358B
342
358
422A
422B
422
374
376
386
388
346
338
396
348
352
408
420A
420B
420
360A
360B
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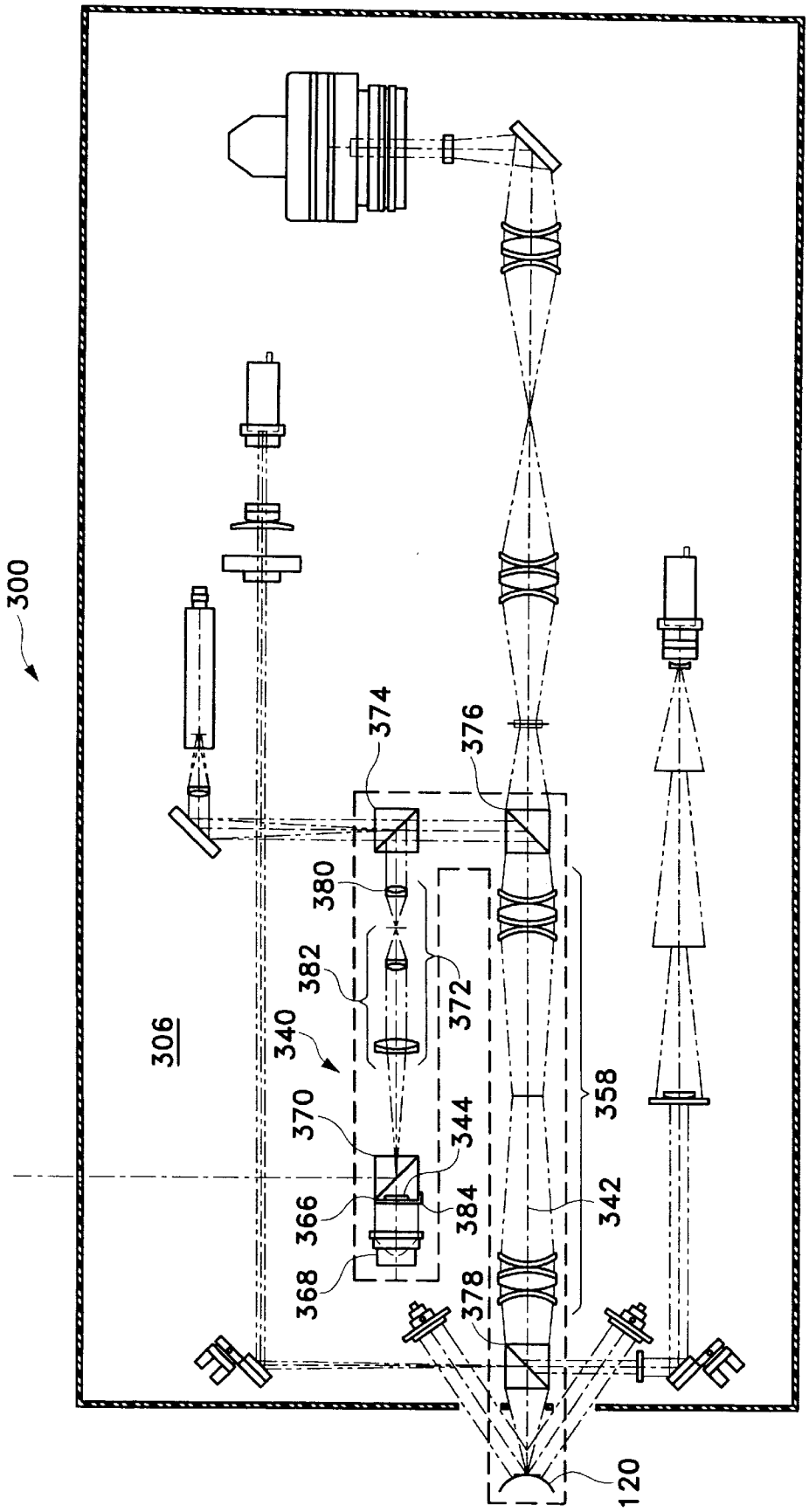
414
416

FIG. 12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378
380
382
384
120

FIG. 12A

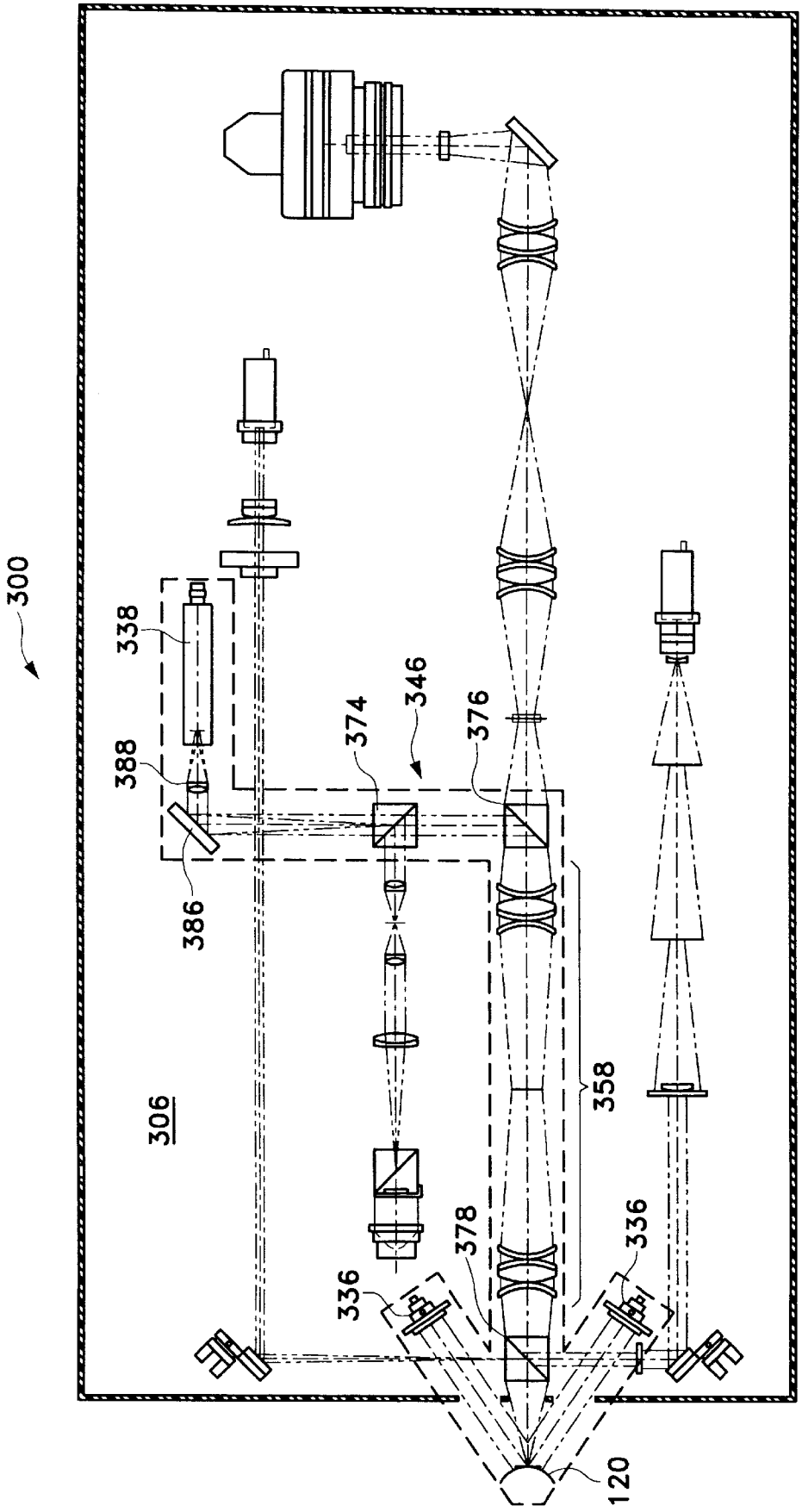


FIG. 12B

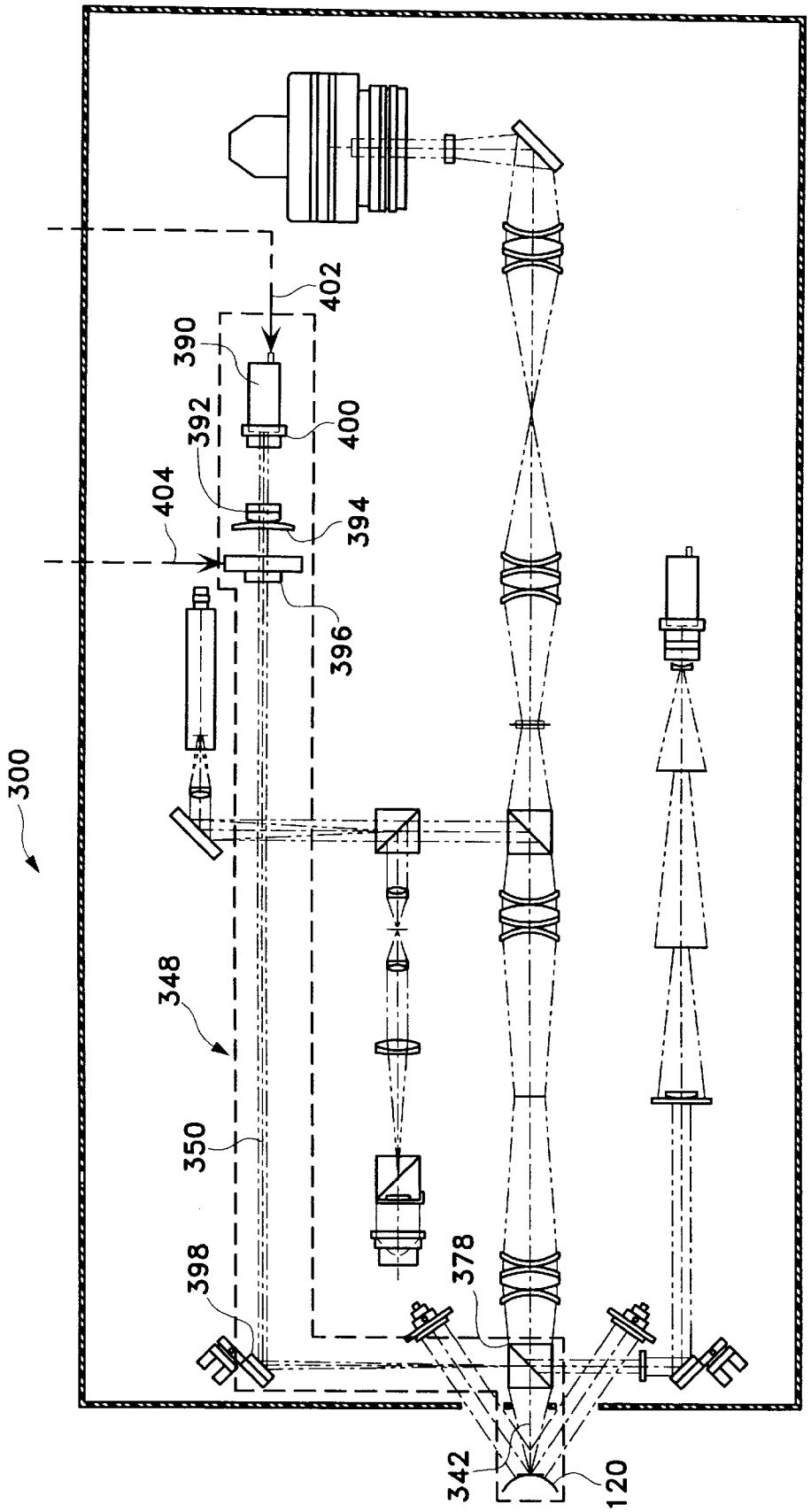


FIG. 12C

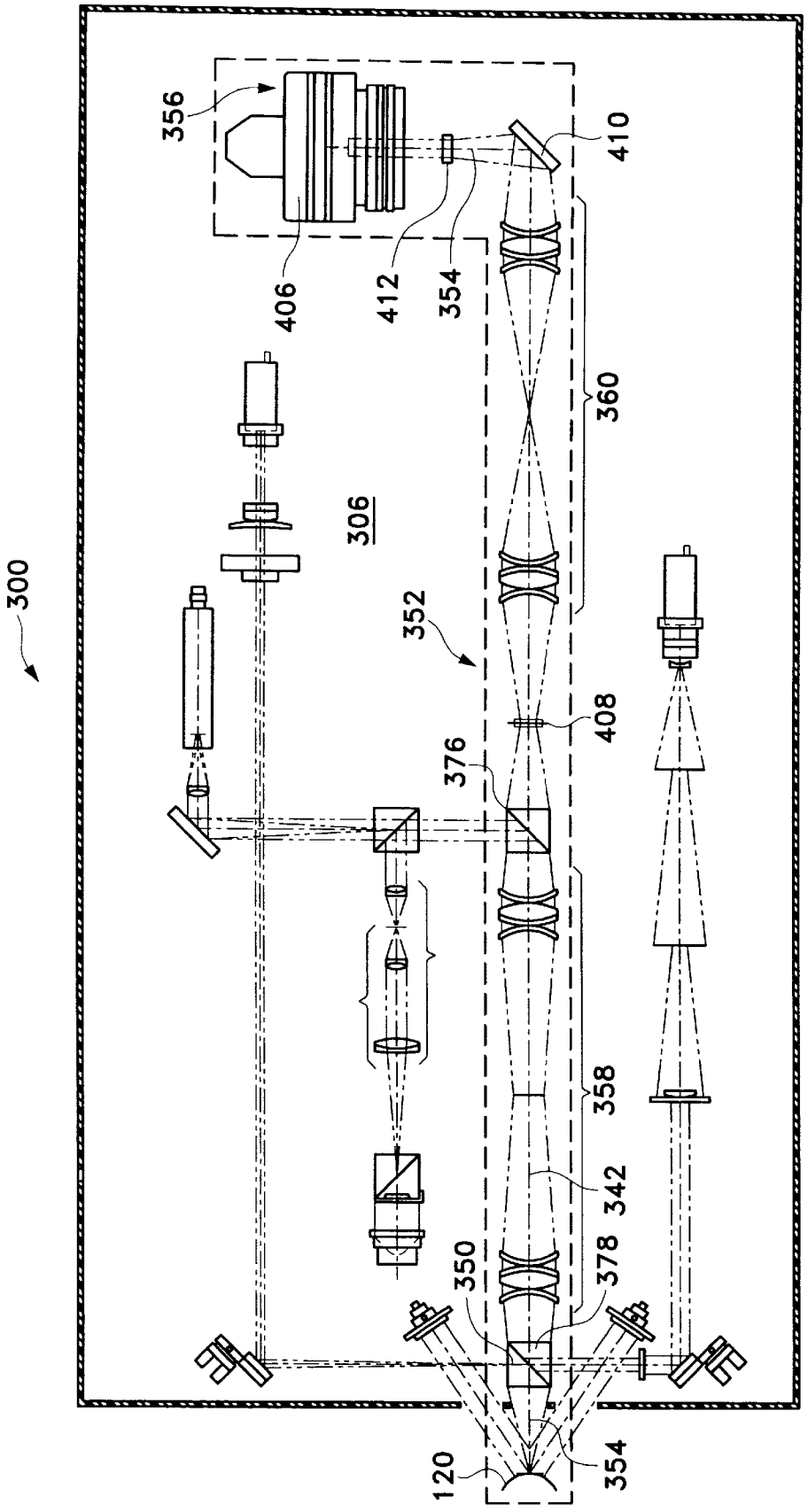
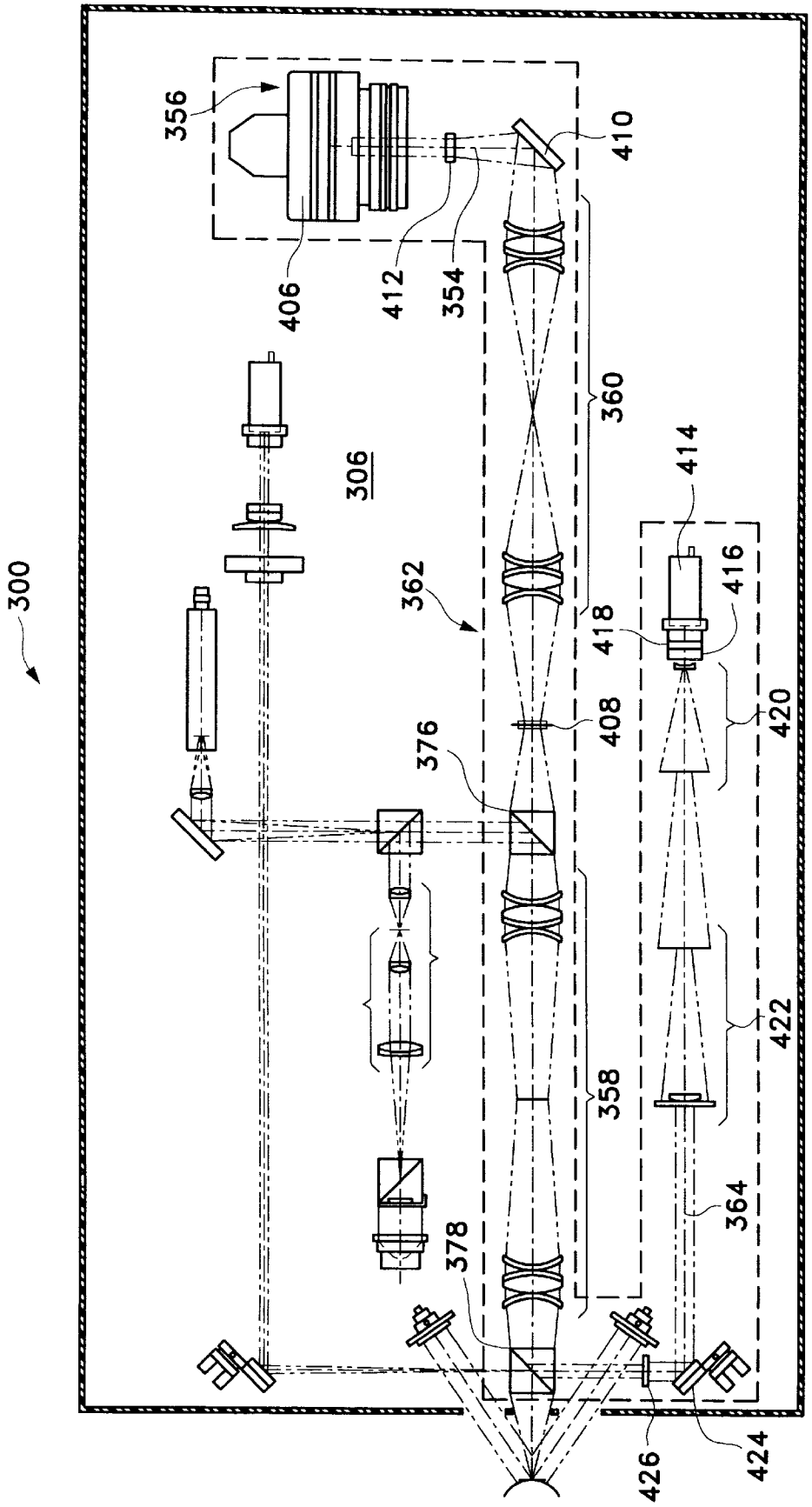

300
306
352
356
406
412
354
410
360
408
376
358
342
350
378
120
354

FIG. 12D


300
306
356
406
412
354
410
360
362
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416
418
408
376
420
422
358
364
378
426
424

FIG. 12E

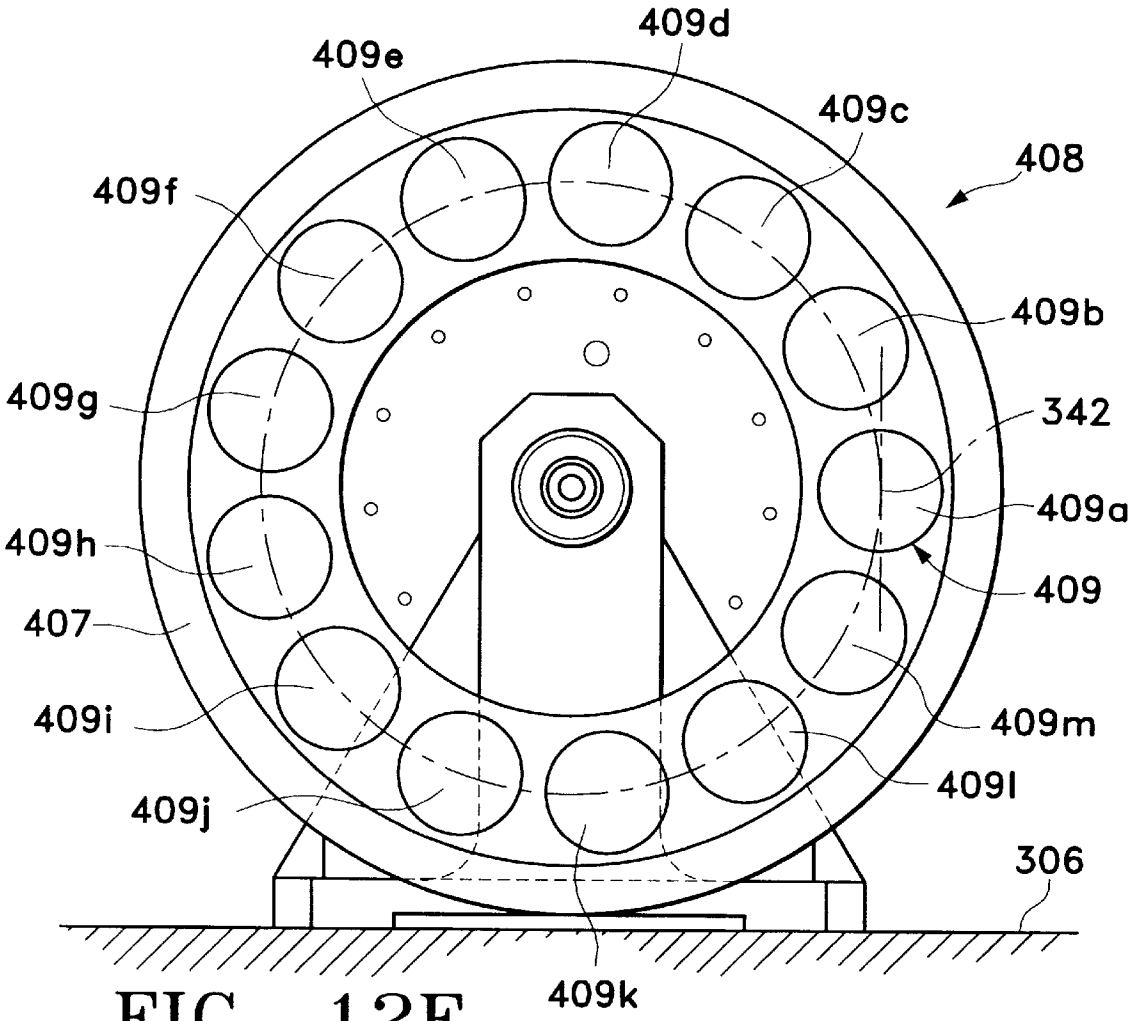

FIG. 12F

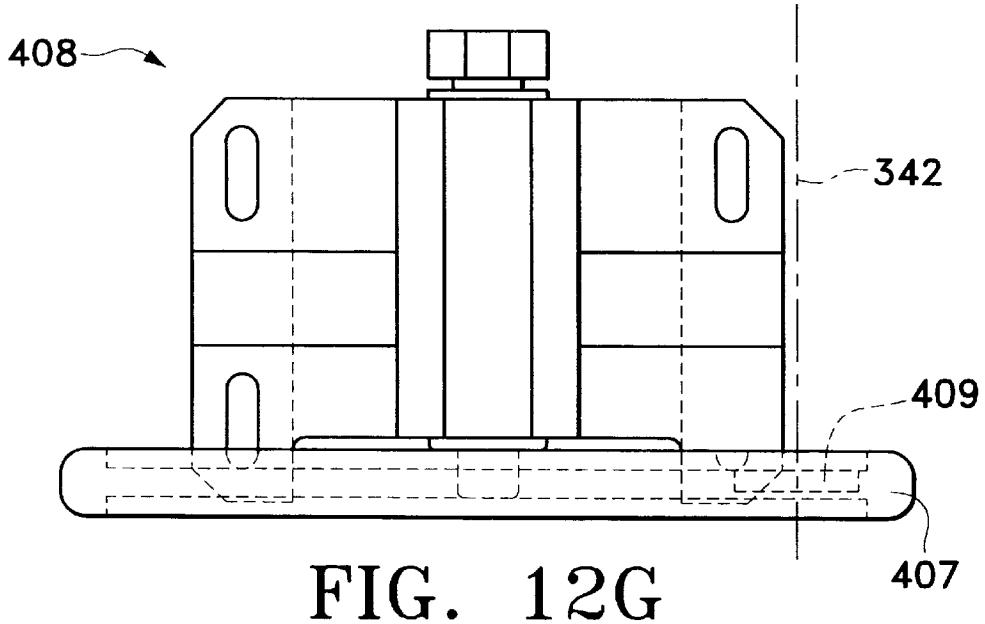

FIG. 12G

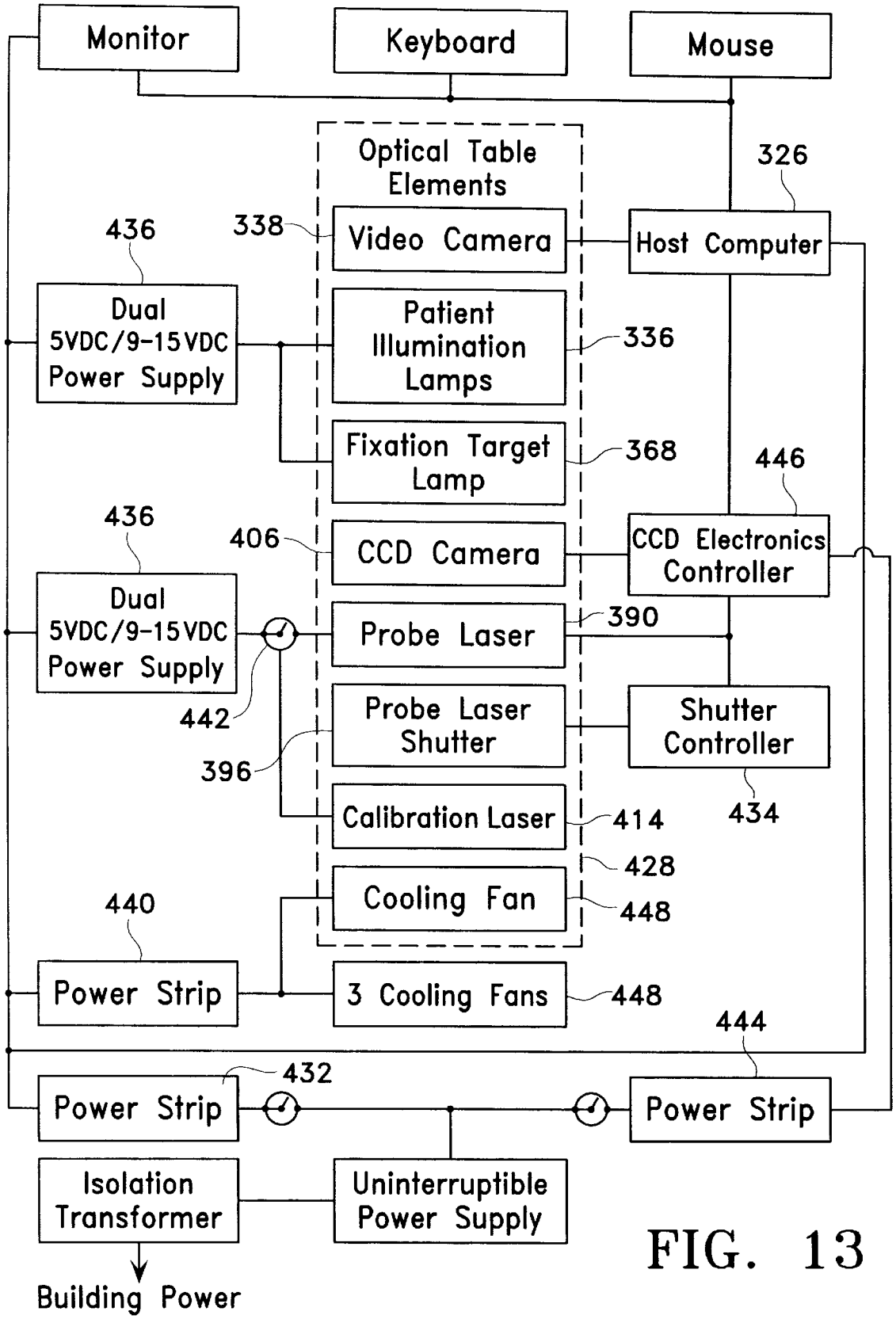
Monitor
Keyboard
Mouse
Optical Table Elements
326
436
338
Video Camera
Host Computer
Dual 5VDC/9-15VDC Power Supply
Patient Illumination Lamps
336
Fixation Target Lamp
368
446
436
406
CCD Camera
CCD Electronics Controller
Dual 5VDC/9-15VDC Power Supply
Probe Laser
390
442
Probe Laser Shutter
Shutter Controller
396
Calibration Laser
414
434
428
Cooling Fan
448
440
Power Strip
3 Cooling Fans
448
444
432
Power Strip
Power Strip
Isolation Transformer
Uninterruptible Power Supply
Building Power

FIG. 13

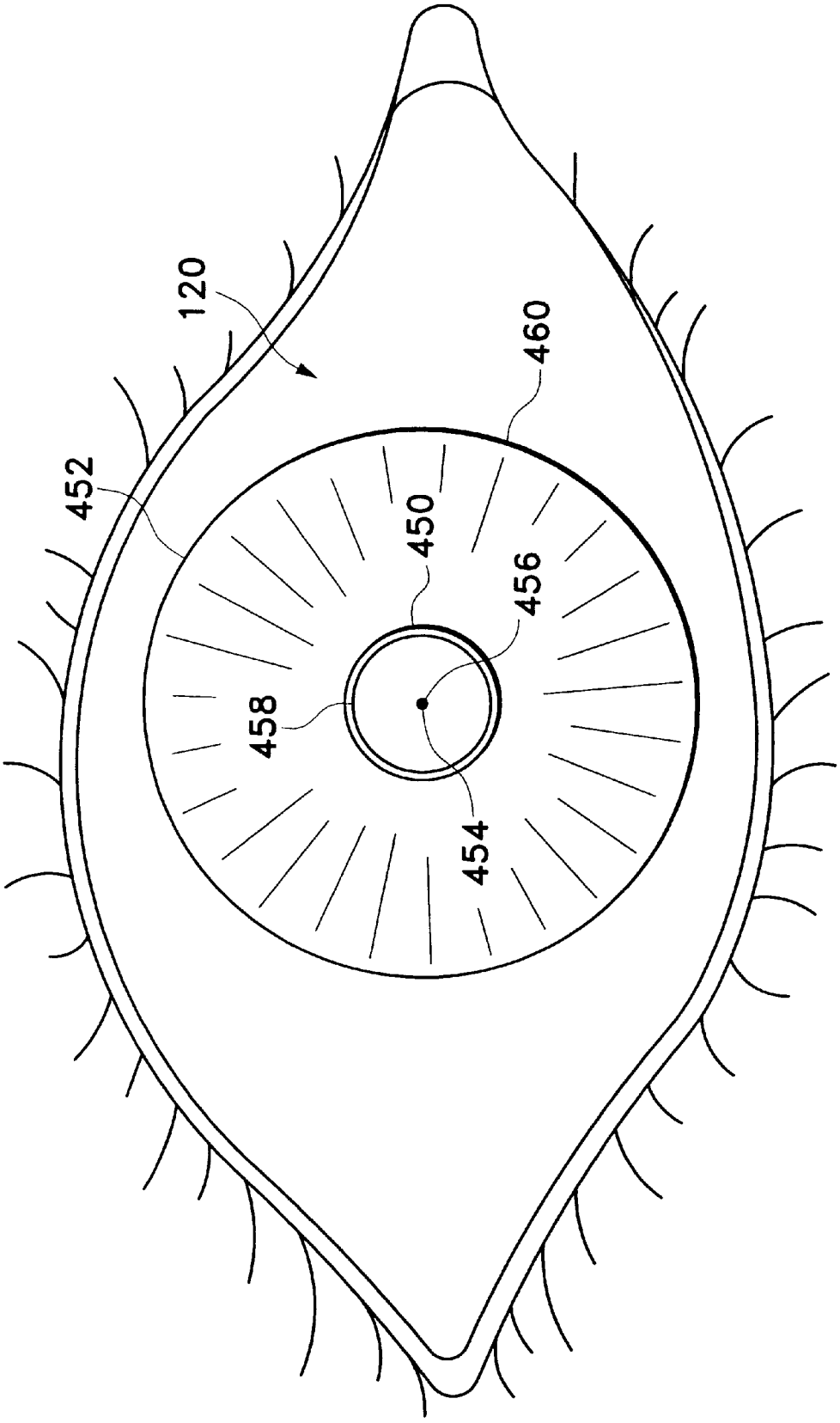

FIG. 14

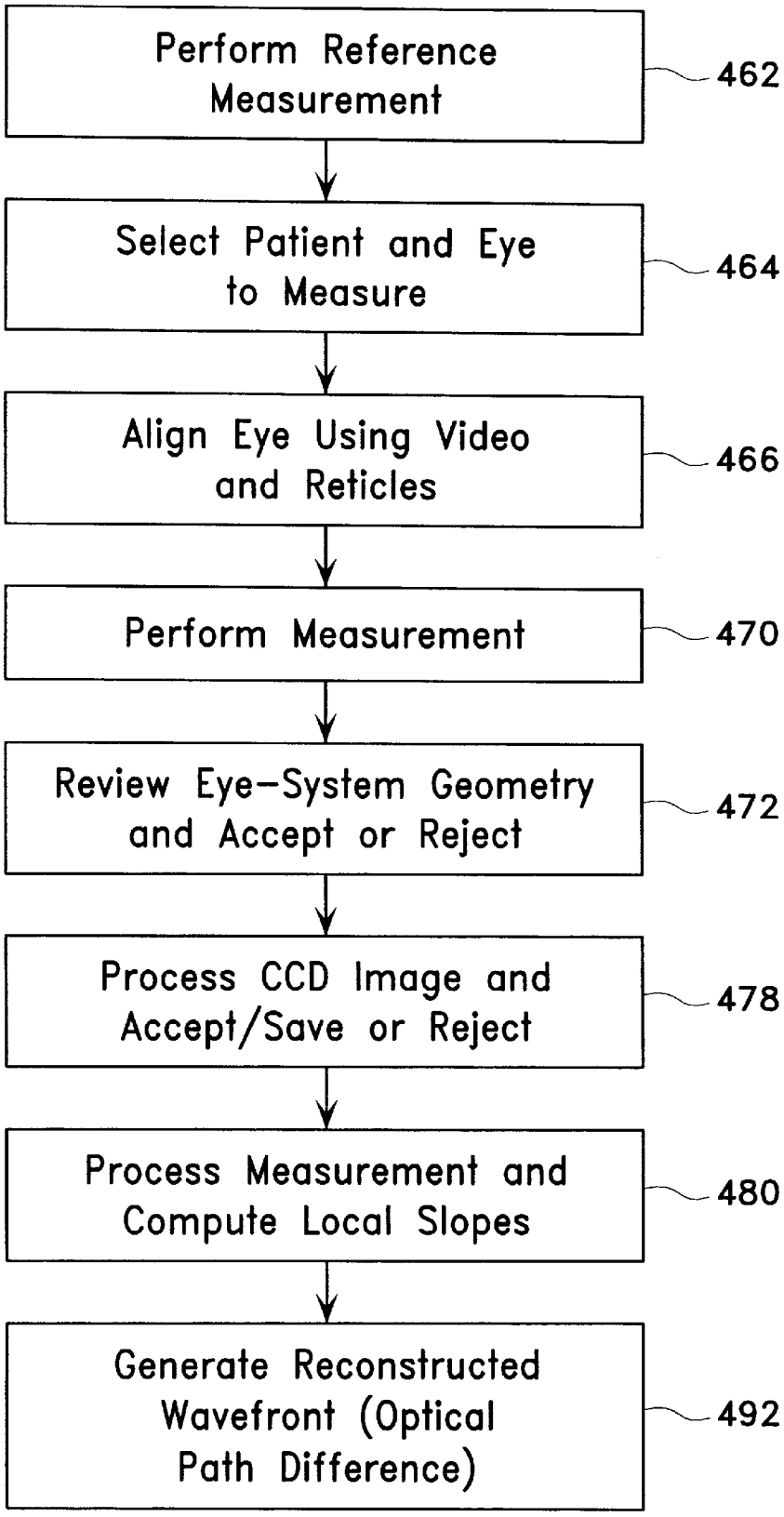
Perform Reference Measurement
462
Select Patient and Eye to Measure
464
Align Eye Using Video and Reticles
466
Perform Measurement
470
Review Eye-System Geometry and Accept or Reject
472
Process CCD Image and Accept/Save or Reject
478
Process Measurement and Compute Local Slopes
480
Generate Reconstructed Wavefront (Optical Path Difference)
492

FIG. 15

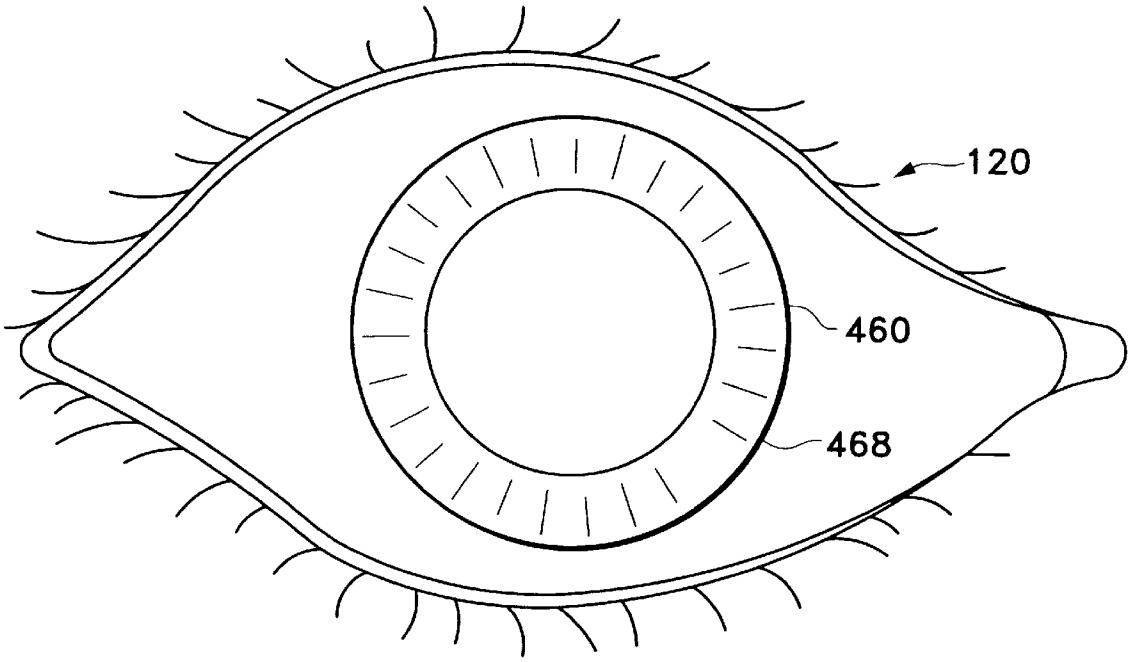

FIG. 16

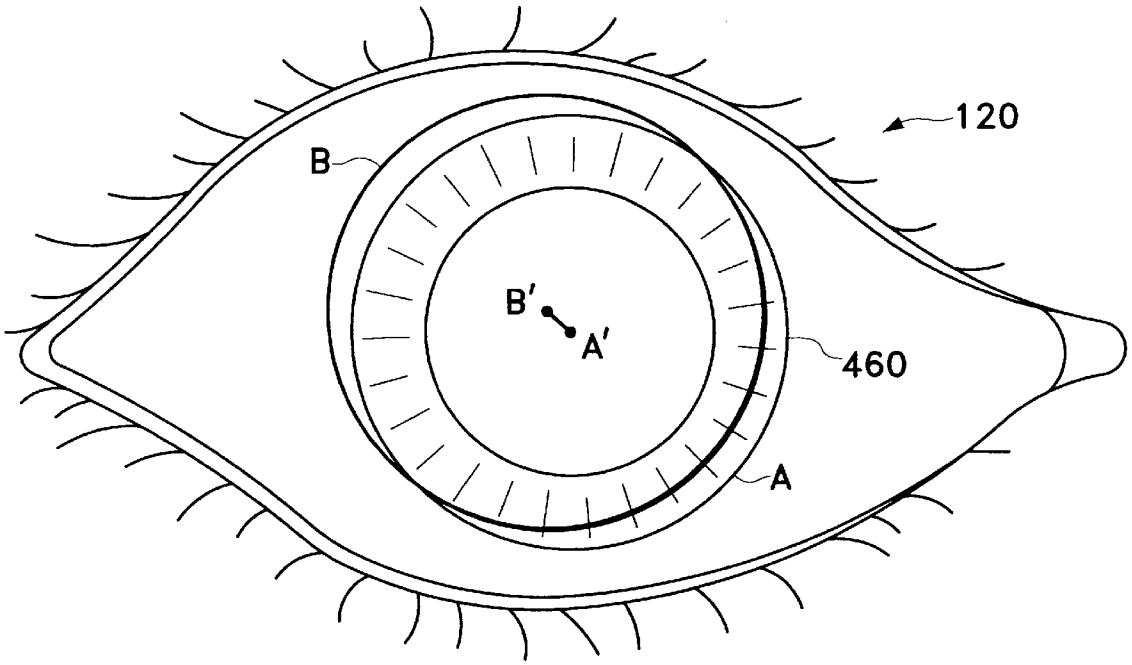

FIG. 17

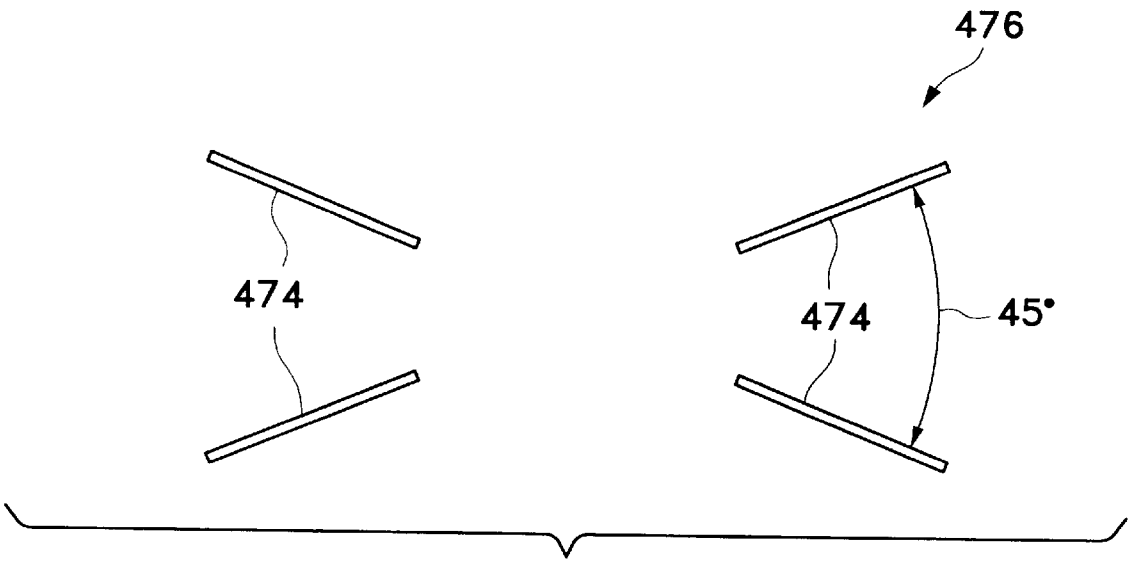

FIG. 18

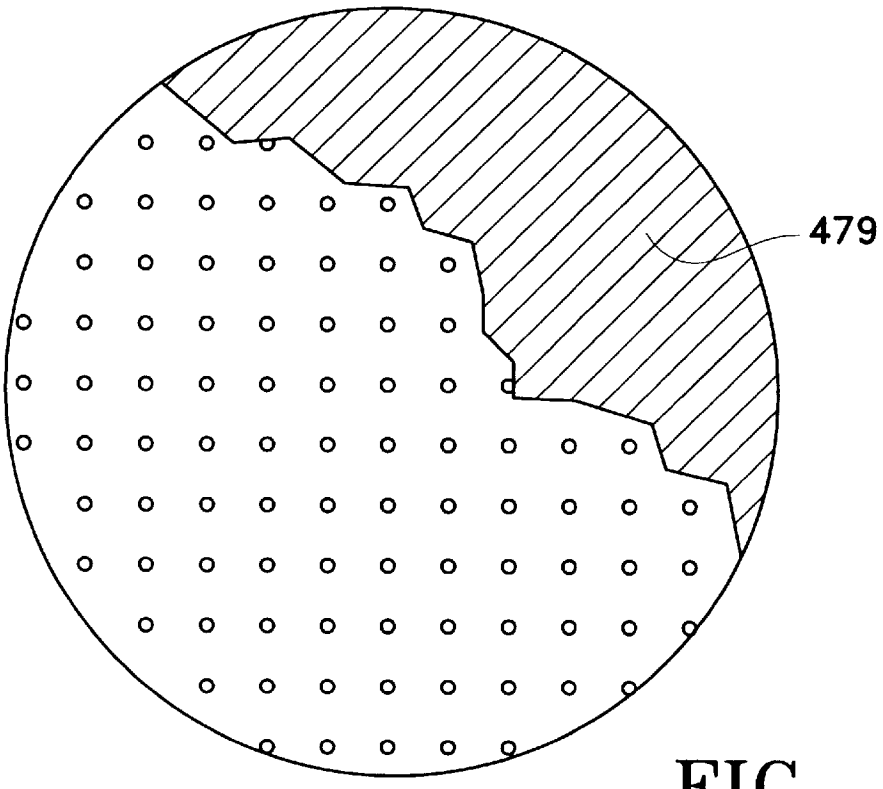

FIG. 19

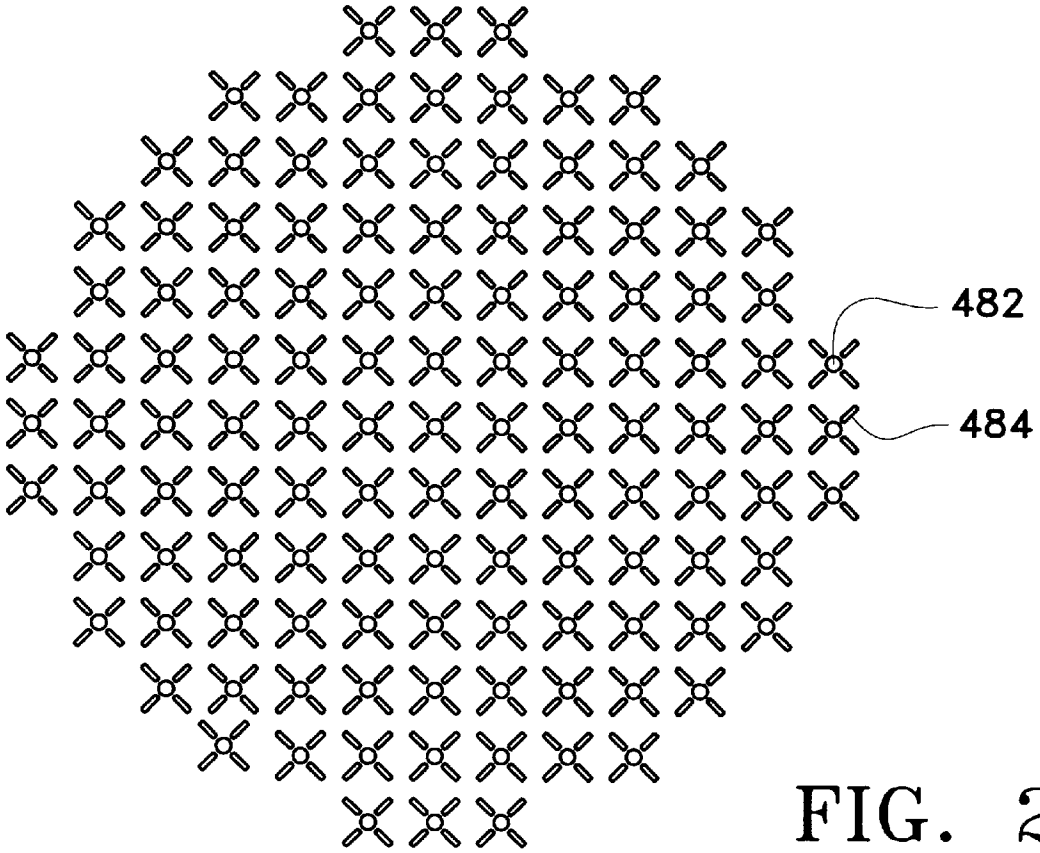

FIG. 20

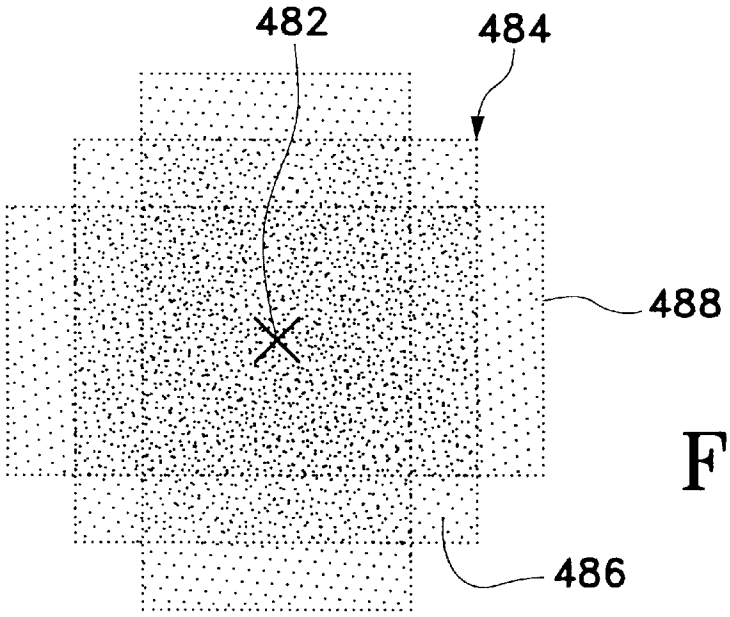

FIG. 21

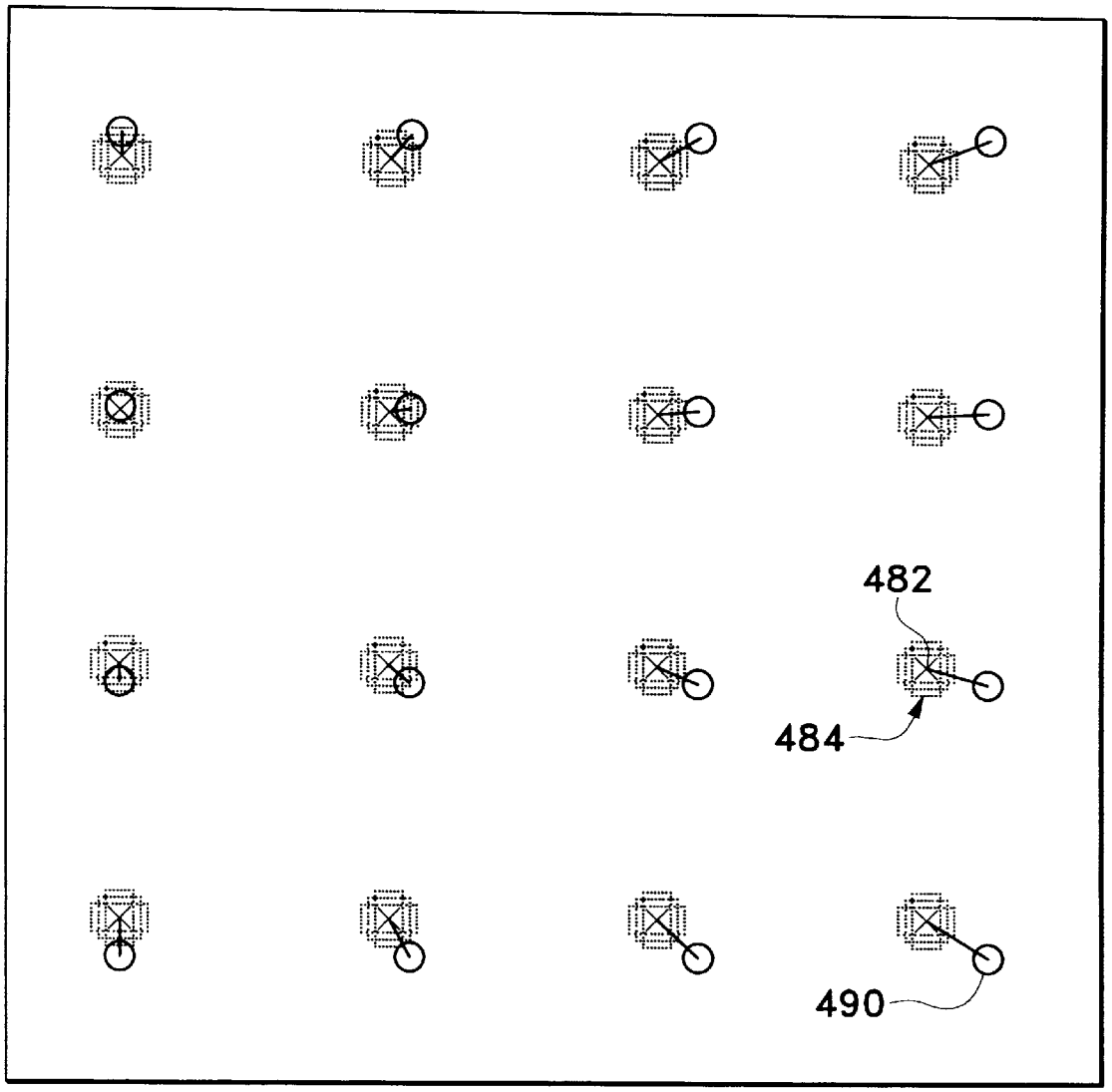

FIG. 22

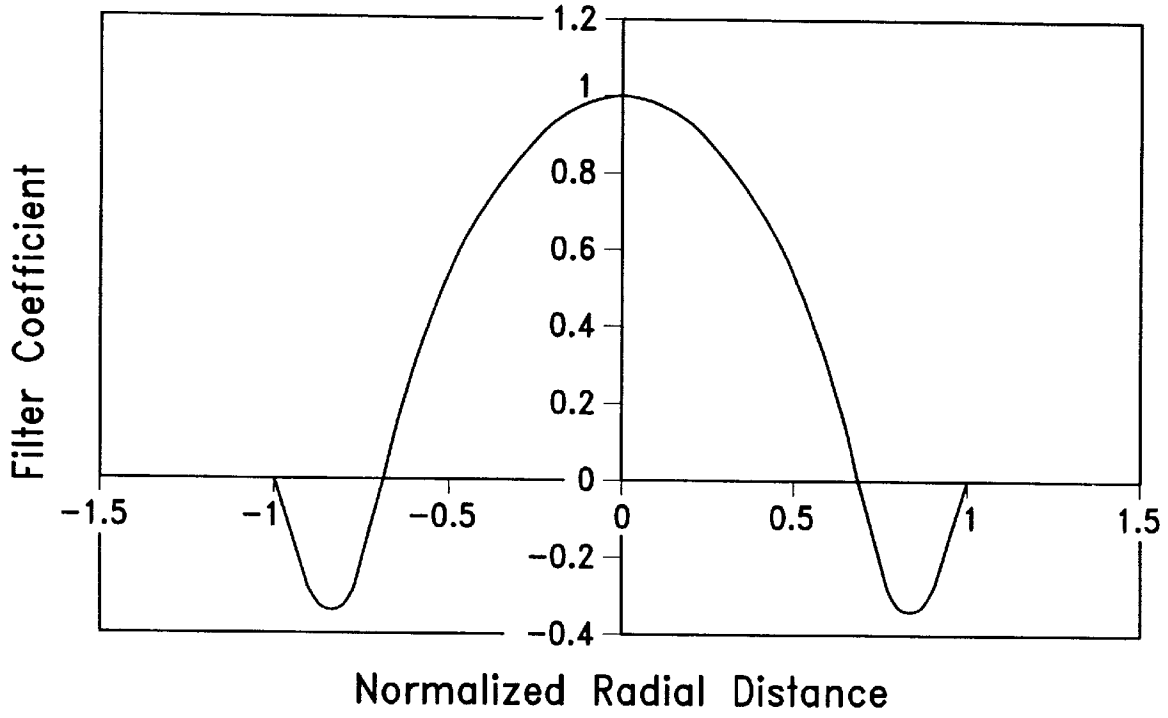

FIG. 23A

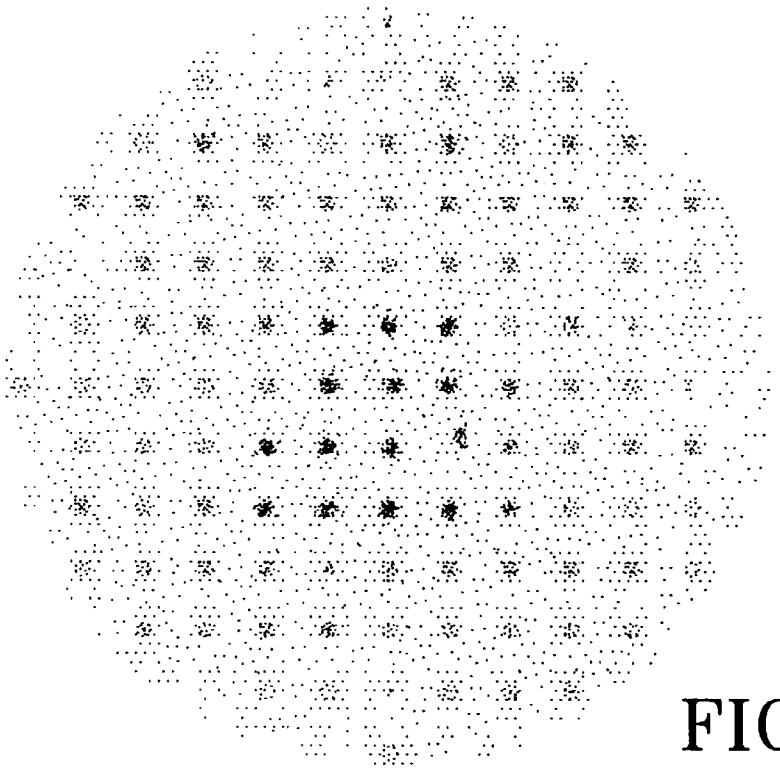

FIG. 23B

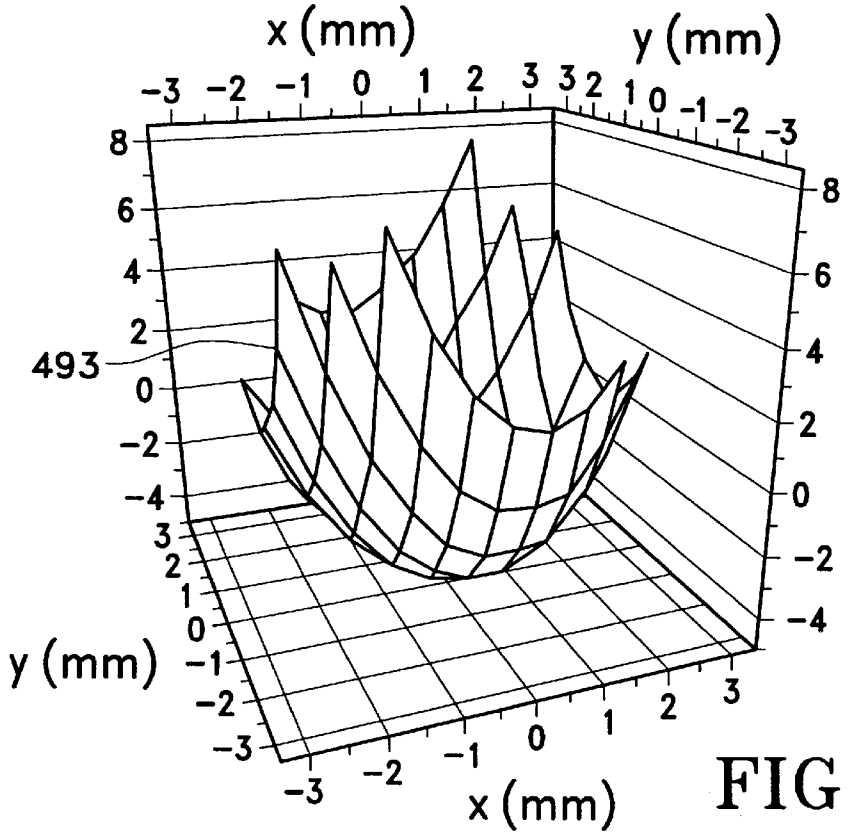

FIG. 24A

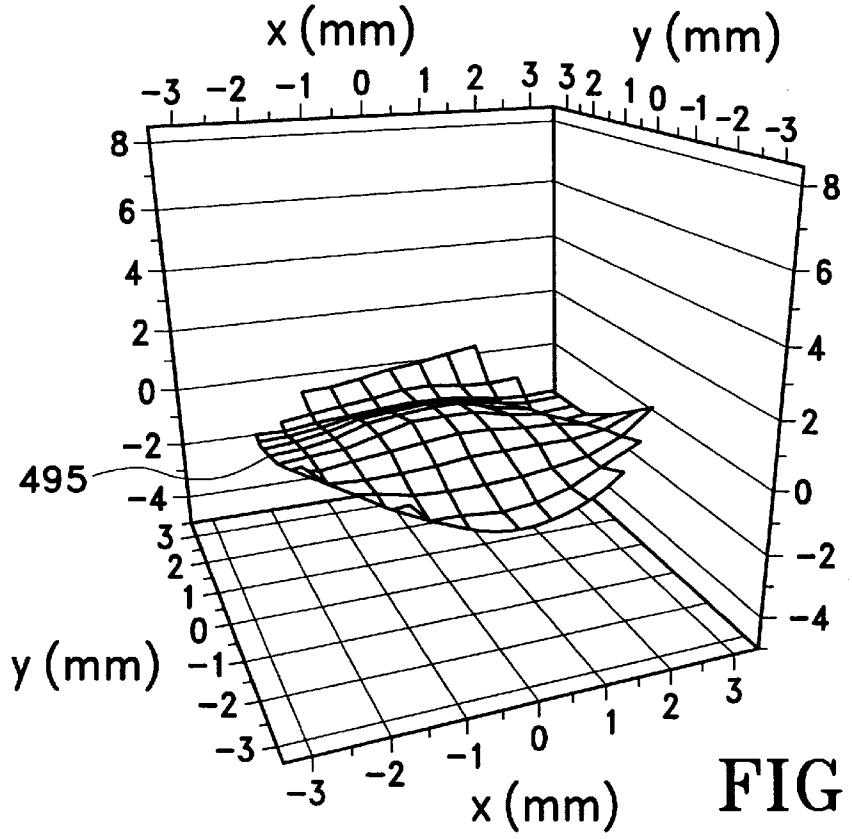

FIG. 24B

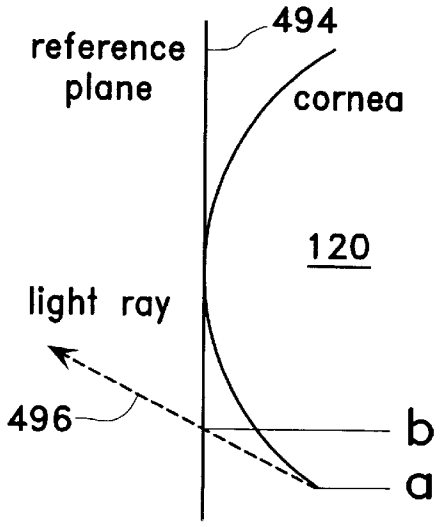

FIG. 25

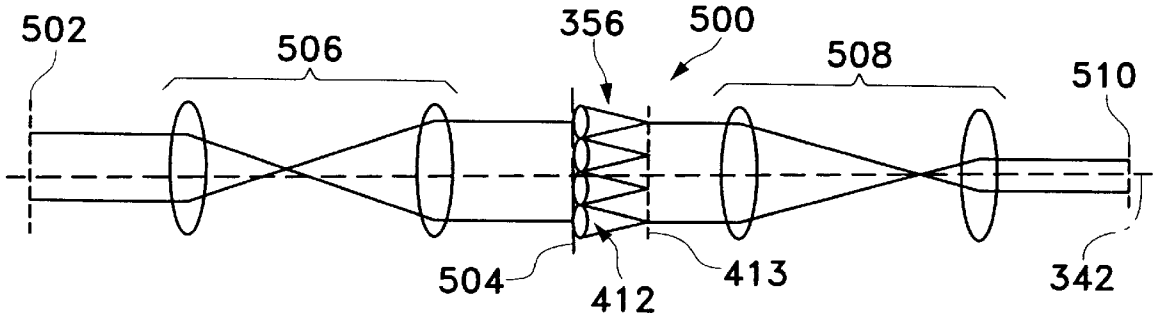

FIG. 26A

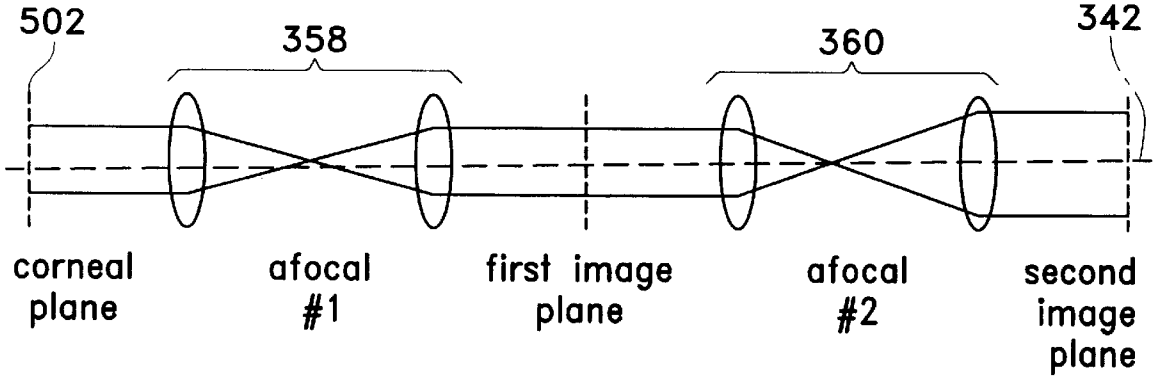

FIG. 26B

APPARATUS AND METHOD FOR OBJECTIVE MEASUREMENT OF OPTICAL SYSTEMS USING WAVEFRONT ANALYSIS

This application is a continuation of U.S. patent application Ser. No. 09/566,409, filed May 8, 2000 now U.S. Pat. No. 6,460,997.

FIELD OF THE INVENTION

The invention relates generally to optical aberration measurement and analysis, and more particularly to an objective measurement of optical systems, such as systems of a human eye.

BACKGROUND OF THE INVENTION

Optical systems having a real image focus can receive collimated light and focus it at a point. Such optical systems can be found in nature, e.g., human and animal eyes, or can be man-made, e.g., laboratory systems, guidance systems, and the like. In either case, aberrations in the optical system can affect the system's performance. By way of example, the human eye will be used to explain this problem.

A perfect or ideal eye diffusely reflects an impinging light beam from its retina through optics of the eye which includes a lens and a cornea. For such an ideal eye in a relaxed state, i.e., not accommodating to provide near-field focus, reflected light exits the eye as a sequence of plane waves. However, an eye typically has aberrations that cause deformation or distortion of reflected light waves exiting the eye. An aberrated eye diffusely reflects an impinging light beam from its retina through its lens and cornea as a sequence of distorted wavefronts.

There are a number of technologies that attempt to provide the patient with improved visual acuity. Typically, treatment is determined by placing spherical and/or cylindrical lenses of known refractive power at the spectacle plane (approximately 1.0–1.5 centimeters anterior to cornea) and literally asking the patient which lens or lens combination provides the clearest vision. This is an imprecise measurement of true distortions in the reflected wavefront because 1) a single spherocylindrical compensation is applied across the entire wavefront, 2) vision is tested at discrete intervals (i.e., diopter units) of refractive values, and 3) subjective determination by the patient is employed. Thus, conventional methodology for determining refractive errors in the eye is substantially less accurate than the techniques now available for measuring the ocular aberrations.

One method of measuring ocular refractive errors is disclosed in U.S. Pat. No. 5,258,791 to Penney et al. for "Spatially Resolved Objective Autorefractometer," which teaches the use of an autorefractometer to measure the refraction of the eye at numerous discrete locations across the corneal surface. The autorefractometer is designed to deliver a narrow beam of optical radiation to the surface of the eye, and to determine where that beam strikes the retina using a retinal imaging system. Both the angle of the beam's propagation direction with respect to the optical axis of the system and the approximate location at which the beam strikes the corneal surface of the eye are independently adjustable. However, a small uncertainty or error in the location of the beam's point of incidence on the cornea exists due to the curved corneal surface. For each point of incidence across the corneal surface, the refraction of the eye corresponding to that surface point can be determined by adjusting the angle at which the beam strikes the cornea until the beam refracted on to the iris strikes the fovea centralis. Adjustment of the beam angle of propagation can be accomplished either manually by the patient or automatically by the autorefractometer, if a feedback loop involving a retinal imaging component is incorporated.

Penney '791 further teaches the use of the autorefractometer measurements in determining the appropriate corneal surface reshaping to provide emmetropia, a condition of a normal eye when parallel beams or rays of light are focused exactly on the retina and vision is perfect. This is accomplished by first obtaining an accurate measurement of corneal surface topography using a separate commercially available device. A mathematical analysis is then performed using an initial corneal topography at each surface reference point, the measured refraction at each surface point, and Snell's law of refraction, to determine a desired change in surface contour at each reference point.

A major limitation to the approach described by Penney '791 is that a separate measurement of corneal topography is desired to perform the Snell's Law analysis of needed refraction change. This adds significantly to the time and cost of a complete and desirable diagnostic evaluation. Further, the accuracy of the refraction change analysis will be dependent upon the accuracy of the topographic measurement and the accuracy of the autorefractometer measurement. In addition, any error in the spatial orientation of a topography map with respect to a refraction map will degrade the accuracy of the measured profile. Yet another limitation to known approaches such as described in Penney '791, by way of example, is that test points on the corneal surface are examined sequentially. Eye motion during the examination, either voluntary or involuntary, could introduce substantial errors in the refraction measurement. Penney '791 teaches detection of such eye movement by deliberately including measurement points outside the pupil, i.e., in the corneal region overlying the iris, where the return from the retina will obviously be zero at specific intervals in the examination sequence. However, this approach may still allow substantial undetected eye movement error between such iris reference points.

By way of example, one method and system known in the art, are disclosed by Junzhong Liang et al. in "Objective Measurement Of Wave Aberrations Of The Human Eye With The Use Of A Hartmann-Shack Wave-Front Sensor," published in the Journal of the Optical Society of America, Volume 11, No. 7, July 1994, pages 1949–1957. Liang et al. teach the use of a Hartmann-Shack wavefront sensor to measure ocular aberrations by measuring the wavefront emerging from the eye by the retinal reflection of a focused laser light spot on the retina's fovea. The actual wavefront is reconstructed using wavefront-estimation with Zernike polynomials.

The imprecise measurement technique of placing lenses of known refractive power anterior to the cornea and asking a patient which lens or lens combination provides the clearest vision has been improved with the use of autorefractometers, as described in Penny '79, or with the use of wavefront sensors as described by Liang et al. Spatially resolved refraction data, in combination with measured existing surface contour of the anterior surface of the eye, enable a calculation of a detailed spatially resolved new contour. However, it would be an improvement in this art if such vision measurements could be made without the need for this contour data, and further without the need for feedback from the patient regarding an appropriate lens. Liang et al. discloses the use of a Hartmann-Shack wavefront sensor to measure ocular aberrations by measuring the

wavefront emerging from the eye by retinal reflection of a focused laser light spot on the retina's fovea. A parallel beam of laser light passes through beam splitters and a lens pair which brings the beam to a focus point on the retina by the optics of the eye. Possible myopia or hyperopia of the tested eye is determined by movement of a lens within the lens pair. The focused light on the fovea is then assumed to be diffusely reflected and acts as a point source located on the retina. The reflected light passes through the eye and forms a distorted wavefront in front of the eye that results from the ocular aberrations. The aberrated wavefront is then directed to the wavefront sensor.

A point source of radiation on the retina would be ideal for such measurements. However, when the perfect eye receives a collimated beam of light, the best possible image on the retina is a diffraction limited spot. As illustrated by way of example, with Penny et al. and Liang et al., discussed above, and typical for those of skill in the art, parallel or collimated beams are used with the optics of the eye being measured to achieve this diffraction limited spot for such objective measurements. To do so, a setup for each patient includes a lens or lens combination and adjustments thereto for accommodating that patient's specific visual acuity. Providing a lens combination, as well as setting up for their use becomes cumbersome, time consuming, and at an additional expense. Eliminating the need for such optics is desirable and eliminates a variable within optical measurement systems that typically include many variables. Further, there is a need for providing optical characteristics of an eye without requiring feedback from the patient. By way of example, the patient may be a wild or domestic animal, living or dead.

The Hartmann-Shack wavefront sensor disclosed by Liang et al. includes two identical layers of cylindrical lenses with the layers arranged so that lenses in each layer are perpendicular to one another, as further disclosed in U.S. Pat. No. 5,062,702 to Bille. In this way, the two layers operate as a two-dimensional array of spherical lenslets that divide the incoming light wave into sub-apertures. The light through each sub-aperture is brought to focus in the focal plane of the lens array where a charge coupled device (CCD) image module resides.

The system of Liang et al. is calibrated by impinging an ideal plane wave of light on the lenslet array so that a reference or calibrating pattern of focus spots is imaged on the CCD. Since the ideal wavefront is planar, each spot related to the ideal wavefront is located on the optical axis of the corresponding lenslet. When a distorted wavefront passes through the lenslet array, the image spots on the CCD are shifted with respect to a reference pattern generated by the ideal wavefront. Each shift is proportional a local slope, i.e., partial derivatives of the distorted wavefront, which partial derivatives are used to reconstruct the distorted wavefront, by means of modal wavefront estimation using Zernike polynomials.

However, the system disclosed by Liang et al. is effective only for eyes having fairly good vision. Eyes that exhibit considerable myopia (near-sightedness) would cause the focus spots to overlap on the CCD, thereby making local slope determination practically impossible for eyes having this condition. Similarly, eyes that exhibit considerable hyperopia (farsightedness) deflect the focus spots such that they do not impinge on the CCD thereby again making local slope determination practically impossible for eyes having this condition.

SUMMARY OF THE INVENTION

In general, an embodiment of the present invention provides a method and system for objectively measuring aberrations of optical systems by wavefront analysis. Another embodiment further provides for the objective measurement of ocular aberrations having a dynamic range that can cope with large amounts of such aberrations so as to be useful in practical applications. Still another embodiment of the present invention provides a method and system for objectively measuring ocular aberrations using a wavefront analyzer of simple and inexpensive design.

One embodiment of the present invention provides an apparatus and method for making objective and detailed measurements of aberrations present in human eyes. Aberrations measured by the apparatus include "higher order" phenomena, such as spherical aberration and coma, in addition to the traditional myopia/hyperopia and astigmatism.

In accordance with an embodiment of the present invention, an energy source generates a beam of radiation. Optics, disposed in the path of the beam, direct the beam through a focusing optical system that has a rear portion which provides a diffuse reflector. The beam is diffusely reflected back from the rear portion as a wavefront of radiation that passes through the focusing optical system to impinge on the optics. The optics project the wavefront to a wavefront analyzer in direct correspondence with the wavefront as it emerges from the focusing optical system. A wavefront analyzer is disposed in the path of the wavefront projected from the optics and calculates distortions of the wavefront as an estimate of ocular aberrations of the focusing optical system. The wavefront analyzer includes a wavefront sensor coupled to a processor that analyzes the sensor data to reconstruct the wavefront to include the distortions thereof.

One embodiment of the present invention, herein described by way of example, utilizes wavefront sensing to measure the aberrations of the eye. When one considers the perfect or ideal eye as earlier described, a perfectly collimated light beam (i.e., a bundle of parallel light rays) incident on the perfect, ideal emmetropic eye, focuses to a diffraction-limited small spot on the retina. This perfect focusing is true for all light rays passing through the entrance pupil, regardless of position. From the wavefront perspective, the collimated light represents a series of perfect plane waves striking the eye. Due to the reversible nature of light ray propagation, the light emanates from an illuminated spot created on the retina as wavefronts exiting the ideal eye as a series of perfect plane waves. The apparatus of the present invention achieves this ray reversal effect using a probe beam optical path for projecting a small diameter, eye-safe laser beam into the eye and onto the fovea. The light scattered from the irradiated retina serves as a secondary source for a re-emitted wavefront. The probe laser beam strikes the retina at an appropriate foveal location to illuminate a sufficiently small spot. A fixation optical path is provided which includes a reference target aligned to an optical axis. This allows a patient to fixate on a target. A video path provides a video image of the eye plane, centered on the optical axis. A video image of the eye allows a clinical operator to assist in orienting the eye for the wavefront measurement.

Embodiments of the present invention, herein described, provide a refraction measurement system that easily accommodates the measurement of vision characteristics of the eye, even in the presence of finite refractive errors. The time for a patient to be in a fixed position during examination is reduced, while at the same time providing a useful source of light on the retina of the eye to be measured regardless of the characteristics of the eye of that patient or other patients to

be examined. Desirably, measurements are made without requiring patient or operator feedback. One method aspect of the invention for measuring optical characteristics of an optical system, such as the eye, includes focusing an optical beam onto an anterior surface of the eye for providing a finite source of secondary radiation on the retina of the eye, which secondary radiation is emitted from the retina as a reflected wavefront of radiation that passes through the eye. The reflected wavefront is directed onto a wavefront analyzer for measuring distortions associated with the reflected wavefront.

In one embodiment, the radiation is optical radiation and the wavefront sensor is implemented using a plate and a planar array of light-sensitive cells. The plate is generally opaque but that has an array of light transmissive apertures that selectively let impinging light therethrough. The plate is disposed in the path of the wavefront so that portions of the wavefront pass through the light transmissive apertures. The planar array of cells is arranged parallel to and spaced apart from the plate by a selected distance. Each portion of the wavefront passing through one of the light transmissive apertures illuminates a geometric shape covering a unique plurality of cells.

As herein described, by way of example, the wavefront optical path of the present invention relays the re-emitted wavefront from the corneal plane to an entrance face of a Hartman-Shack wavefront sensor. The wavefront incident on the sensor is received by a sensitive charged-coupled device (CCD) camera and an optical plate containing an array of lenslets. The lenslet array is parallel to the CCD detector face with a distance therebetween approximately equal to the focal length of each lens in the lenslet array. The lenslet array divides the incoming wavefront into a matching array of "wavelets," each of which focuses to a small spot on the CCD detector plane. The constellation of wavelet spots in the CCD is used to reconstruct the shape of the incident wavefront. Collimated light striking the lenslet at normal (perpendicular) incidence would focus to the spot on the CCD face where this optical axis intersects. The optics of the apparatus provides such collimated light to the wavefront sensor using a calibration optical path. Collimated light CCD images are routinely obtained as part of a daily calibration process and used for reference in analyzing experimental data.

However, in the case of a reflected aberrated wave front, light focuses to a spot displaced from the collimated reference point by a distance Dx. The distance from the lenslet face to the CCD surface, Dz, is precisely known. Therefore, dividing the measured displacement, Dx, by the known propagation distance, Dz, the slope of the wavefront at the location of this lens element is determined. The same calculation is applied in the y direction within the plane, and the entire process applied to every lenslet element irradiated by the wavefront. A mathematical algorithm is then applied to reconstruct the wavefront shape consistent with the calculated Dx/Dz and Dy/Dz slope data. Regardless of which wavefront sensor is used, the distance between the planar array of cells and the opaque plate, or the array of lenslets, can be varied to adjust the slope measurement gain of the wavefront sensor and thereby improve the dynamic range of the system.

Another measure of dynamic range enhancement is provided by the focusing optics. The focusing optics includes first and second lenses maintained in fixed positions in the path of the beam and wavefront. An arrangement of optical elements is disposed between the lenses in the path of the beam and the wavefront. The optical elements are adjustable to change the optical path length between the lenses.

A method aspect of the present invention, as herein described, determines aberrations of an eye requiring greater than a + or −3 diopter change, and includes directing an optical beam onto a retina of an eye, reflecting the optical beam from the retina of the eye, determining characteristics of a wavefront in a reflected optical beam, and generating data based on the characteristics of the wavefront, which data quantifies the aberrations of the eye. The data may further be generated based on refractive indices of media through which the optical beam passes. Yet further, data based on the characteristics of the wavefront, which data quantifies the aberrations of the eye for a discrete section of the eye may also be generated.

One method for determining aberrations of an eye, herein described by way of example, includes directing a probe beam along a probe beam path toward an eye, directing a fixation image along a fixation image path toward the eye, directing a light source along a video image path toward the eye, generating a video image of the eye, directing a wavefront originating from the eye along a wavefront path, wherein the probe beam path, the fixation image path, the video image path, and the wavefront path are coincident at least along a portion of their respective paths, the probe beam path terminating at the retina of the eye and the probe beam reflecting from the retina of the eye as a wavefront, aligning the eye with the probe beam path based at least in part on the video image of the eye generated by the light source directed along the video image path, measuring the wavefront, and generating data representative of the aberrations of the eye based on the measurement of the wavefront. Further, the aligning of the eye with the probe beam path based at least in part on the video image of the eye generated by the light source directed along the video image path, may have the wavefront pass through a single microlens array.

One apparatus for determining the aberrations of an eye comprises a patient head rest comprising vertical adjustment, the patient head rest associated with an optical table having a base. The base carries a probe beam generating apparatus, probe beam directing optics, the probe beam directing optics comprising a beam splitter; a mirror; and a lens, the probe beam directing optics being capable of directing a probe beam toward an eye of a patient positioned on the patient head rest, video image components, the video image components comprising a light source, a mirror, and a video camera, the video image components being capable of generating an image of an eye of a patient positioned on the patient head rest, eye fixation components, the eye fixation component comprising a fixation target; a light source; a lens; and a mirror, the fixation components being capable of generating a target that the eye of a patient positioned on the patient head rest can view, and wavefront directing and analyzing components, the wavefront directing and analyzing components comprising a lens, a mirror, a microlens array, a camera, and a data processor. The wavefront directing and analyzing components are capable of measuring the wavefront emanating from the eye of a patient positioned on the patient head rest and determining aberrations of said eye that range from at least about + or −1 diopters to at least about + or −6 diopters.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the invention are described by way of example with reference to the accompanying drawings in which:

FIG. **1A** is a schematic view of the ideal eye reflecting light from its retina as a planar wavefront;

FIG. **1**B is a schematic view of an aberrated eye reflecting light from its retina as a deformed wavefront;

FIG. **1**C is a schematic view of the distorted wavefront relative to a reference plane to show the wavefront error or optical path difference as a function of transverse distance in the propagation direction;

FIG. **1**D is a schematic view illustrating use of a reference plane;

FIG. **2** is a simplified schematic of the system for determining ocular aberrations in accordance with the essential features of the present invention;

FIG. **3** is a schematic of one embodiment of a Hartmann-Shack wavefront analyzer used in the present invention;

FIG. **4** is a perspective view of a portion of the pinhole imaging plate and planar array of light-sensitive cells comprising the wavefront sensor from the embodiment of FIG. **3** where the deflection of a wavefront piece associated with an aberrated eye is shown in comparison with a wavefront piece associated with a calibration or planar wavefront;

FIG. **5** is a plan view of a designated area on the planar array of light-sensitive cells associated with a corresponding hole;

FIG. **6** is a schematic of another embodiment of a wavefront analyzer used in the present invention;

FIG. **7** is a schematic view of an eye to be measured by the present invention;

FIG. **8** is a schematic view of an eye to be measured by the present invention;

FIG. **9** is a side elevation view of one embodiment of the present invention illustrating a patient positioning for measurement;

FIG. **10** is an end elevation view of the embodiment of FIG. **9**;

FIG. **11** is an enlarged perspective view of an patient positioning portion of the embodiment of FIG. **9**;

FIG. **12** is a top plan view of optical elements of the embodiment of FIG. **9**;

FIG. **12**A illustrates a fixation target optical path of FIG. **12**;

FIG. **12**B illustrates a video image optical path of FIG. **12**;

FIG. **12**C illustrates a probe laser optical path of FIG. **12**;

FIG. **12**D illustrates a re-emitted wavefront optical path of FIG. **12**;

FIG. **12**E illustrates a calibration wavefront optical path of FIG. **12**;

FIGS. **12**F and **12**G are front elevation and top plan views of a trial lens holder useful with embodiments of the present invention herein described;

FIG. **13** is a block diagram illustrating electrical components of the embodiment of FIG. **9**;

FIG. **14** is an enlarged image of an eye illustrating a centration image;

FIG. **15** is a block diagram illustrating an operable flow of steps used in one embodiment of the present invention;

FIG. **16** is an enlarged image of an eye illustrating a pre-measurement eye alignment;

FIG. **17** is an enlarged image of an eye illustrating a pre-measurement eye alignment checking thereof;

FIG. **18** is a line diagram illustrating an eye registration pattern;

FIG. **19** illustrates a rejected CCD image;

FIG. **20** illustrates a CCD image including centroids;

FIG. **21** is an enlarged image of a centroid;

FIG. **22** illustrates an image available to an operator of a measured and reference centroid;

FIG. **23**A illustrates a spacial filter operable in one embodiment of the present invention;

FIG. **23**B illustrates a noisy CCD image before filtering to provide an image as illustrated with reference to FIG. **20**;

FIG. **24**A is a three dimensional plot of a wavefront reconstruction in accordance with the present invention;

FIG. **24**B illustrates a higher order aberration for the wavefront of FIG. **23**;

FIG. **25** illustrates a geometric effect of a curved corneal surface on a wavefront measurement;

FIG. **26**A is a pictorial line drawing illustrating magnification modification to the embodiment of FIG. **12**; and

FIG. **26**B is a pictorial line drawing illustrating optical elements of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

The present invention will now be described more fully hereinafter with reference to the accompanying drawings, in which embodiments of the present invention are shown by way of illustration and example. This invention may, however, be embodied in many forms and should not be construed as limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. Like numbers refer to like elements throughout.

By way of illustrative example, the present invention will be described with respect to diagnosing a human eye. However, it is to be understood that the teachings of the present invention are applicable to any optical system having a real image focus that can be, or can be adapted to diffusely reflect a focused spot of radiation from a rear portion of the optical system back through the optical system as a wavefront of radiation. Thus, the present invention can be used with human or animal eyes of patients that may be alive or dead, or any man-made optical system.

The method of using wavefront analysis will be introduced with reference to the eye example and the aid of the schematic drawings of FIGS. **1**A, **1**B, and **1**C. As earlier described with reference to an ideal eye, and with reference now to FIG. **1**A, the ideal emmetropic or perfect eye **100** diffusely reflects an impinging light beam (not shown for sake of clarity) from the back of its retina **102** (i.e., the fovea centralis **103**) through the eye's optics which includes lens **104** and cornea **106**. For such an ideal eye **100** in a relaxed state, i.e., not accommodating to provide near-field focus, the reflected light (represented by arrows **108**) exits the eye **100** as a sequence of plane waves, one of which is represented by straight line **110**. However, as illustrated with reference to FIG. **1**B, a typical eye **120** normally has aberrations that cause deformation or distortion of a reflected wave exiting the eye, where the aberrated eye **120** diffusely reflects an impinging light beam (again not shown for sake of clarity) from the back of its retina **122** of the fovea centralis **123** through lens **124** and cornea **126**. For the aberrated eye **120**, the reflected light **128** exits the eye **120** as a sequence of distorted wavefronts, one of which is represented by wavy line **130**.

With reference now to FIG. **1**C, a coordinate system is defined for convenience, where positive x is upward in the plane of the figure, positive y is outward from the plane of

the figure, and positive z is to the right along a propagation direction. The distorted wavefront **130** is herein described mathematically as W(x,y). One method of measuring distortions in the wavefront **130** is by determining a spatial separation Δz between a reference plane **131** (by way of example, a plane analogous to the ideal wavefront **110**) at a known distance Z_0 from the eye **120** at each (x,y) point of the distorted wavefront **130** as the leading edge of the wavefront **130** traverses the distance Z_0. This is described mathematically as:

$$\Delta z(x,y)=z_0-W(w,y) \tag{1}$$

These Δz measurements define optical path differences due to aberrations in the eye **120** being tested, by way of example.

Depending on the desired therapy (for example, synthetic lens addition), the material thickness at each (x, y) coordinate can be calculated directly if the refractive index of the material in question is known. For many procedures, such as intra-ocular lens implantation, a wavefront analysis may be performed repetitively during a procedure to provide feedback information as to the appropriate endpoint of the procedure.

In terms of the illustrative example, the differences Δz(x, y) between the distorted wavefront **130** and the ideal wavefront **110** are the consequence of the aberrations in the eye. Measuring these aberrations consists of introducing an optical path difference at the reference plane **131** of negative Δz(x,y). If the treatment approach, by way of example, consists of adding material to the cornea **126**, then one choice for the location of reference plane **131** is tangential to the surface of cornea **126** (i.e. at z=0). This is illustrated schematically with reference to FIG. **1**D, where the curvature of the cornea **126** is greatly exaggerated for clarity of illustration.

The appropriate corneal addition at any (x,y) transverse coordinate is, to within a small error, given by:

$$\Delta z(x,y)/(n_c-1) \tag{2}$$

where n_c is the refractive index of corneal tissue or 1.3775. The method described in detail below calculates Δz(x,y) by first measuring the local slopes in wavefront **130**, i.e. ∂W(x, y)/∂x and ∂W(x,y)/∂y, at a number of points in the transverse x and y directions in reference plane **131** and then generating a mathematical description of W(x,y) having slopes in best possible agreement with the experimentally determined values. One such slope ∂W(x, y)/∂x is illustrated with reference again to FIG. **1**D. In doing this, a small error is introduced due to the fact that distorted wavefront **130** is measured at the reference plane **131** while wavefront **130** emerged from a curved corneal surface just posterior to reference plane **131**. By way of example, an error $E_x(x,y)$ is the lateral displacement in the x-direction at each (x,y) location at the measurement plane (i.e., reference plane **131**) to the curved corneal surface. A similar error will be manifest for any measurements involving curved optical surfaces. The error will generally increase with both (x,y) displacement from the point of tangency and local wavefront error.

The magnitude of error $E_x(x,y)$ can be found for each measurement location (x,y) measured at an arbitrary coordinate, e.g., (x_0,y_0) by projecting that location back to the point of origin on the cornea **126**. This is explained mathematically with reference again to FIG. **1**D, where by way of example, it is assumed that the error is in the plane of the figure, i.e., the plane defined by $y=y_0$, although it is quite straightforward mathematically to extend the analysis to include errors in the y-dimension. The quantification of a line L tracing the propagation of the wavefront **131** measured at (x_0,y_0) in the z_0 reference plane from the corneal surface to the reference plane is:

$$L(x) = z_0 - \frac{(x - x_0)}{\partial W(x_0, y_0)/\partial x} \tag{3}$$

If the corneal surface in the plane of the figure is described by the expression $S(x_0,v_0)$, then the point of origin for the wavefront **131** in question can be found by finding the point of intersection between L(x) and S(x, y_0). Mathematically, one finds the value x', that satisfies $L(x')=S(x_0,y_0)$. The error $E_x(x_0,y_0)$ is then given as $Ex(x_0,Y_0)=x'-x_0$. Extending the analysis to consider errors in the y-direction would yield a similar expression for E_y where $E_y(x_0, y_0)=y'-y_0$. If significant, these transverse errors can be compensated for by laterally displacing the aberration calculated at each (x,y) coordinate by the amounts $E_x(x,y)$ and $E_y(x,y)$.

In the case of human corneas, the transverse error under most circumstances will be negligible. The error will be zero at the origin where the corneal tissue and reference plane **131** are tangent. For human corneas, the tissue is approximately spherical with a radius of curvature of approximately 7.5–8.0 mm. The treatment radius is typically no more than 3 mm, and local wavefront radius of curvature will almost never exceed 50 mm (a 20 diopter refractive error). The transverse error E at a 3 mm treatment radius for a local wavefront radius of curvature of 50 mm is less than 40 μm.

For certain ophthalmic procedures, wavefront analysis can also be used repetitively during the procedure to provide useful feedback information. One example of such use would be following placement of an intra-ocular lens implant (IOL). The analysis helps to identify whether the appropriate refractive power IOL has been inserted, or whether a different refractive power IOL should be used.

In order to perform wavefront analysis in a manner compatible with procedures such as those described above, the amount of spatial separation of component portions of wavefront **130** relative to the corresponding component portions of the planar or ideal wavefront **110** is measured. It is the system and method of the present invention that allows such separation to be objectively and accurately measured for even substantially aberrated eyes **120** including those exhibiting severe defects such as severe myopia or hyperopia.

For the evaluation or measurement portion of the present invention, the patient's pupil should ideally be dilated to approximately 6 mm or more, i.e., the typical size of a human pupil in low light. Smaller amounts of dilation or no dilation at all may also evaluated or measured. In this way, the eye is evaluated while it is using the greatest area of the cornea so that any measurement takes into account the largest usable corneal area of the patient's eye. A lesser amount of the cornea is used in daylight where the pupil is considerable smaller, e.g., on the order of 3 millimeters. Dilation can be brought about naturally by implementing the measurement portion of the present invention in a low light environment such as a dimly lit room. Dilation can also be induced through the use of pharmacologic agents.

Referring now to FIG. **2**, a simplified schematic of one exemplary embodiment of the apparatus **10** of the present invention is illustrated. The apparatus **10** includes a laser **12** for generating optical radiation used to produce a small-diameter laser beam **14**. The laser **12** generates a collimated laser light beam (represented by dashed lines for the beam **14**) of a wavelength and power that is eye safe. For oph-

thalmic applications, appropriate wavelengths would include the entire visible spectrum and the near infrared spectrum. By way of example, appropriate wavelengths may be in a range of from approximately 400 to 1000 nanometers, including 550, 650, 850 useful wavelengths. While operation in the visible spectrum is generally desired, since these are the conditions in which the eye operates, the near infrared spectrum may offer advantages in certain applications. For example, the patient's eye may be more relaxed if the patient does not know measurement is taking place. Regardless of the wavelength of the optical radiation, power should be restricted in ophthalmic applications to eye safe levels. For laser radiation, appropriate eye-safe exposure levels can be found in the U.S. Federal Performance Standard for Laser Products. If the analysis is to be performed on an optical system other than the eye, the examination wavelength range logically should incorporate the intended performance range of the system.

To select a small-diameter collimated core of laser light beam **14**, an iris diaphragm **16** is used to block all of laser light beam **14** except for the laser beam **18** of a size desired for use. In terms of the present invention, the laser beam **18** will have a diameter in the range of approximately 0.5–4.5 millimeters with 1–3 millimeters being typical, by way of example. A badly aberrated eye uses a smaller diameter beam while an eye with only slight aberrations can be evaluated with a larger diameter beam. Depending on the output divergence of the laser **12**, a lens, as will be later described, can be positioned in the beam path to optimize collimating of the beam.

Laser beam **18**, as herein described by way of example, is a polarized beam that is passed through a polarization sensitive beam splitter **20** for routing to a focusing optical train **22** which optical train operates to focus the laser beam **18** through the optics of the eye **120** (e.g., the cornea **126**, pupil **125** and the lens **124**) to the retina **122**. It is to be understood that the lens **124** may not be present for a patient that has undergone a cataract procedure. However, this does not affect the present invention. In the illustrated example of FIG. **2**, the optical train **22** images the laser beam **18** as a small spot of light at or near the eye's fovea centralis **123** where the eye's vision is most acute. Note that the small spot of light could be reflected off another portion of retina **122** in order to determine aberrations related to another aspect of one's vision. For example, if the spot of light were reflected off the area of the retina **122** surrounding the fovea centralis **123**, aberrations specifically related to one's peripheral vision could then be evaluated. In all cases, the spot of light may be sized to form a near-diffraction limited image on the retina **122**. Thus, the spot of light produced by laser beam **18** at fovea centralis **123** does not exceed approximately 100 micrometers in diameter and, typically, is on the order of 10 micrometers.

The diffuse reflection of the laser beam **18** back from the retina **122** is represented in FIG. **2** by solid lines **24** indicative of radiation that passes back through the eye **120**. The wavefront **24**, earlier described with reference to FIG. **1**B as distorted wavefront **130** impinges on and is passed through the optical train **22** and on to the polarization sensitive beam splitter **20**. The wavefront **24** is depolarized relative to the laser beam **18** due to reflection and refraction as the wavefront **24** emanates from the retina **122**. Accordingly, the wavefront **24** is turned at the polarization sensitive beam splitter **20** and directed to a wavefront analyzer **26** such as a Hartmann-Shack (H-S) wavefront analyzer. In general, the wavefront analyzer **26** measures the slopes of wavefront **24**, i.e., the partial derivatives with respect to x and y, at a number of (x,y) transverse coordinates, as earlier described with reference to FIGS. **1**C and **1**D. This partial derivative information is then used to reconstruct or approximate the original wavefront with a mathematical expression such as a weighted series of Zernike polynomials.

The polarization states for the incident laser beam **18** and the beam splitter **20** minimizes the amount of stray laser radiation reaching the sensor portion of the wavefront analyzer **26**. In some situations, stray radiation may be sufficiently small when compared to the radiation returning from the desired target (e.g., the retina **122**) so that the polarization specifications are unnecessary.

The present invention is able to adapt to a wide range of vision defects and as such achieves a new level of dynamic range in terms of measuring ocular aberrations. Dynamic range enhancement is accomplished with the optical train **22** and/or a wavefront sensor portion of the wavefront analyzer **26**. With continued reference to FIG. **2**, the optical train **22** includes a first lens **220**, a flat mirror **221**, a Porro mirror **222** and a second lens **224** all of which lie along the path of laser beam **18** and the wavefront **24**. The first lens **220** and the second lens **224** are identical lenses maintained in fixed positions. The Porro mirror **222** is capable of linear movement as indicated by arrow **223** to change the optical path length between the lenses **220** and **224**. However, it is to be understood that the present invention is not limited to the particular arrangement of the flat mirror **221** and the Porro mirror **222** and that other optical arrangements, as will herein be described by way of example, will be used without departing from the teachings and benefits of the present invention.

A "zero position" of the Porro mirror **222** is identified by replacing the eye **120** illustrated with reference again to FIG. **2**, by a calibration source, as will be described later by way of further example, of collimated light to provide a reference wavefront such as the perfect plane wave **110**, earlier described with reference to FIG. **1**A. Such a source could be realized by a laser beam expanded by a beam telescope to the diameter that will cover the imaging plane of wavefront analyzer **26** and adjustment of the Porro mirror **222** until the wavefront analyzer **26** detects the light as being collimated. Note that the changes in optical path length brought about by the Porro mirror **222** can be calibrated in diopters to provide an approximate spherical dioptric measurement, as will be explained further below.

The dynamic range of the apparatus **10** is further improved by providing an improved wavefront sensor arrangement **28** as illustrated with reference to FIGS. **3** and **4**. The wavefront analyzer **26** includes an opaque imaging plate **32** having an array of holes **34** passing therethrough, a planar array **36** of light-sensitive cells such as charge coupled device (CCD) cells **38**, and a processor **40** operable with the planar array **36** of the CCD cells **38**. The combination of the plate **32** and the planar array **36** provides one embodiment of the present invention. The plate **32** is held parallel to and spaced from the planar array **36** by a separation distance F. As will be explained further below, the separation distance F can be varied to adjust for signal gain. To do this, the planar array **36** is coupled to a positioning apparatus **42**, e.g., a conventional motorized linear positioner having precise movement capability, that adjusts the position of planar array **36** relative to the plate **32** for changing the separation distance F as indicated by arrow **43**. With respect to the array of holes **34**, each of the holes **34** are of equal size and shape with a circle being typical owing to its ease of manufacture. As herein described by way of

example, a square array geometry is used for the array of holes **34**, although other array geometries will be used without departing from the teachings of the present invention.

As illustrated with reference to FIG. **4**, when the wavefront **24** impinges on the plate **32**, a portion of the wavefront **24**, indicated by arrow **25**, passes through the hole **34** to illuminate planar array **36**. To a first order, the resulting image formed by each such wavefront portion **25** is a positive shadow of the respective hole **34**. However, diffraction occurs as determined by the diameter D of each hole **34**, the wavelength A of the light source (e.g. the wavefront **24**) and the separation distance F between the plate **32** and the planar array **36**. The value of F is varied by the positioning apparatus **42** to adjust the gain based on the particular patient as will be explained further below.

Note that performance of the plate **32** with holes **34** may also be accomplished using a solid plate or film made from a light-sensitive material such as a photolithographic film. In such a case, the array of holes **34** would be replaced by an array of shaped light transmissive apertures through which light passes when impinging thereon. The remainder of such a plate or film would be impervious to light. Such an embodiment permits the light transmissive apertures to be easily made to conform to any desired shape.

Regardless of how each wavefront portion **25** is generated, the present invention measures the amount of angular deflection of each wavefront portion **25** relative to a wavefront portion **112** that results from a calibration wavefront such as the planar wavefront earlier described. The calibration or planar wavefront of light results in the wavefront portion **112** impinging at a normal or perpendicular to plate **32** and illuminates a geometric spot **114** on the planar array **36**. In contrast, continuing with the wavefront **24** representing a distorted wavefront as described above, the wavefront portion **25** will exhibit an amount of angular deflection relative to the calibration wavefront portion **112**. The angular deflection causes the wavefront portion **25** to illuminate a geometric spot **27** on the planar array **36** that is offset from the spot **114**. In terms of the present invention, the amount of offset is measured relative to centroids **116** and **29** of spots **114** and **27**, respectively. In the two dimensions of the planar array **36**, the centroid **29** is typically deflected in both the x and y directions of the array **36**. Thus, the angular deflection in each of the x and y directions is given by $\Delta x/F$ and $\Delta y/F$, respectively.

With reference again to FIG. **2**, the lenses **220** and **224** in one embodiment are identical as mentioned above. However, in certain applications it may be desirable to magnify or minify the wavefront at the wavefront sensor. This can be accomplished by using lenses **220** and **224** of different focal lengths and adjusting dimensions of the apparatus **10** accordingly. For ophthalmic evaluation, the object plane of the apparatus should ideally be tangent to the corneal surface which can be achieved by a variety of means. Thus, each point at the object plane of the optical train **22** very nearly corresponds to the same point on the cornea **126**. However, since the cornea **126** is curved, there will be a slight lateral displacement. The plate **32** described earlier with reference to FIG. **4** of the wavefront analyzer **26**, or an imaging plane of any wavefront sensor portion, is positioned at the focal plane of lens **220**. In this way, the object plane is always imaged on the plate **32** in direct correspondence with the wavefront image emerging from cornea **126**. This will be true regardless of the optical path length between the lenses **220** and **224**. There are several advantages to this structure, one of which is that there are very good planar arrays of light-sensitive cells that are commercially available to image an area corresponding to the 6 millimeter central circular region of the cornea.

The plate **32** (or the imaging plane of any wavefront sensor portion of a wavefront analyzer) breaks the wavefront **24** into wavefront pieces that can each be measured independently in terms of propagation direction at the planar array **36**. Since in an embodiment herein described by way of example, the optical train **22** does not magnify or reduce the image in the object plane, a point at the object plane corresponds to the same point at the image plane of the optical train. With the Porro mirror **222** set at its zero position, the direction each portion of the wavefront **24** is traveling toward the object plane is reproduced exactly at the image plane of wavefront analyzer **26**. By way of example, if one wavefront portion at a location in the object plane was traveling away from the optical axis at an angle of 20° with respect to the optical axis that is perpendicular to the object plane, the wavefront portion at the same location in the image plane will also be traveling away from the optical axis at an angle of 20°.

Note that a person who is myopic will produce a wavefront such that the wavefront portions/pieces isolated by the plate **32** will converge toward the center of planar array **36**. A hyperopic person will produce a wavefront such that the wavefront pieces isolated by the plate **32** diverge. Thus, a person with a significant vision error becomes difficult to evaluate because wavefront portions can either overlap (myopia) at the planar array **36** or spill off (hyperopia) the planar array.

In the present invention, five ways of compensating for such severe aberrations are herein described by way of example. The first way is to utilize a wavefront sensor with sufficiently small light sensitive cells **38** and sufficiently large holes **34** (or any other transmissive aperture). In this way, measurement of each wavefront piece can be performed to an acceptable accuracy using a small value for F. A second way is to move planar array **36** along the optical axis to change the separation distance F to the plate **32**. For a person with a severe aberration, the planar array **36** is positioned close to the plate **32** to keep the projected wavefront portions well separated and on the planar array. For a mild aberration, the planar array **36** is moved to increase the separation distance F to the plate **32** to make a more accurate measurement. The advantage of moving the planar array **36** to change the separation distance F to the plate **32** is that the wavefront analysis is easily achieved for any position. Yet another way of compensating for severe aberrations using the present invention is to change the optical path length between lenses **220** and **224**. Moving the Porro mirror **222** will not affect where the wavefront hits the plate **32**, but will change the angular deflections at which the projected wavefront portions pass through the plate **32**, i.e., $\Delta x/F$ and $\Delta y/F$. Decreasing the optical path length between lenses **220** and **224** will tend to pull the wavefront portions toward the center of planar array **36** thereby compensating for hyperopia. Increasing the optical path length between lenses **220** and **224** will tend to spread the wavefront portions toward the edges of the planar array **36** thereby compensating for myopia. The degree to which the angular deflection associated with each wavefront piece is altered is a linear function of its distance off the optical axis and the movement of the Porro mirror **222** from its zero position. A fourth way of compensating for severe aberrations is to insert one or more trial lenses of specified sphero-cylindrical power at the location of the intermediate focal plane, as will be discussed in detail later in this section. This serves to

reduce or remove low order aberrations from the wavefront so that displacement of spots at the CCD cells **38** is minimized and accurate evaluation can proceed. The effect of the specified lens addition is then included in the final wavefront reconstruction. A fifth way is to increase the magnification of the wavefront at the wavefront sensor relative to that at the eye.

This is accomplished by an appropriate choice of lenses in the relay optic design. Magnification will reduce the slope of the wavefront uniformly, thereby reducing the displacement of each spot at the CCD.

By way of example, to accurately determine the centroid **29** of the spot **27** of light impinging on the planar array **36**, a fine structure of cells **38** relative to a spot size is provided. Each spot covers a plurality of cells **38**. One method used to determine the centroid **29** of each spot **27** unambiguously with respect to a spot caused by another one of the holes **34**, assigns a unique number of cells **38** to each hole **34**. The "assigned areas" are designated, as illustrated with reference to FIG. **5**, by way of example, with the heavy grid lines **39**. It is to be understood that the grid lines **39** are not actual physical boundaries between cells **38** but are shown simply to illustrate the unique designated areas containing a plurality of the cells **38**. It is anticipated that other centroid strategies will be utilized that do not necessitate such partitioning of the array **36** given the teachings of the present invention. An alternative method for identifying and correlating centroids is later described in this section.

By way of example, the present invention could also be practiced with a wavefront analyzer that replaces plate **32** described with reference to FIG. **3**, with a two dimensional array of identical spherical lenslets **33**, as illustrated with reference to FIG. **6**. In such an embodiment, the lenslet array **33** may be operable by the positioning apparatus **42** such that separation distance F is independent of the focal length f that defines the focal plane of the lenslet array **33** which is represented by dashed line **35**. Each wavefront portion **37** passed through a sub-aperture of the lenslet array **33** is reduced in size (e.g., diameter) but is not necessarily brought to a minimum focus at the planar array **36** as it would be if separation distance F were equal to focal length f. In the operation of this embodiment configuration, the lenslet array **33** is positioned to concentrate the light in each wavefront portion of an area for providing sufficient intensity onto the planar array **36**, yet still illuminating a substantial plurality of cells **38** for greatest accuracy in determining the deflection of the centroids **29**.

Regardless of the structure of the wavefront sensor, the processor **40** computes each two-dimensional centroid **29** of each spot **27** generated by the wavefront **24**. The amount of two dimensional centroid shift relative to the centroid of the calibrating spot for each designated area associated with a corresponding hole **34** (or sub-aperture of lenslet array **33**) is divided by the separation distance F to generate a matrix of local slopes of the wavefront, i.e., $\partial W(x,y)/\partial x$ and $\partial W(x,y)/\partial y$ at the (x,y) coordinates of the centers of holes **34**. For simplicity of discussion, these will be indicated by $P(x,y)=\partial W(x,y)/\partial x$ and $Q(x,y)=\partial W(x,y)/\partial y$, respectively.

Numerous methods exist for using the partial derivative data to calculate the distorted wavefront **130** and **24** as described above with reference to FIGS. **1**B and **2**. One acceptable approach is that described by Liang et al. in the aforementioned Journal of the Optical Society of America paper, where the wavefront is approximated using Zernike polynomials. This is a standard analytic technique described in numerous optics texts such as "Principles of Optics, 11 by M. Born and E. Wolf, Pergamon Press, Oxford, England, 1964. By way of example, the Zernike polynomial approach will be discussed herein. However, it is to be understood that other mathematical approaches can be used in approximating the distorted wavefront. By way of example, such approaches may include the use of Fourier series and Taylor series.

$$W(x,y)=\sum_{i=0}^{n} C_i Z_i(x,y) \tag{4}$$

Briefly, the wavefront W(x,y) is expressed as a weighted sum of the individual polynomials where Ci are the weighting coefficients, and $Z_i(x,y)$ are the Zernike polynomials up to some order. The upper limit n of the summation is a function of the number of Zernike polynomials, i.e., the highest order, used to approximate the true wavefront. If m is the highest order used, then

$$n=(m+1)(m+2)/2 \tag{5}$$

Derivation of the Zernike polynomials up to an arbitrary order n is described in numerous optical texts such as the aforementioned book by Born and Wolf. One possible method of determining the centroid **29**, **116** of a spot **27**, **114**, respectively, as earlier described with reference to FIGS. **4** and **5**, and calculation of the Zernike weighting coefficients will now be explained. The directions of the unit normals at the center of each hole **34** are based on the centroids of the spots on cells **38**.

Since each spot will illuminate a plurality of cells varying intensity, a standard amplitude-weighted centroid calculation can be used to find the center of each spot. In order to clearly delineate each centroid from background noise, by way of example, resulting from spurious light reaching the CCD surface between valid spots, standard mathematical techniques such as a matched spatial filter can be applied to the CCD data prior to centroid identification.

An alternative method is herein described for identifying individual spots and correlating their geometry. The apparatus is configured such that the optical axis is aligned to the center of a particular aperture at the entrance face of the wavefront sensor. This aperture is located at or near the center of the entrance face. If the probe beam entering the eye is also aligned to the system optical axis, then due to the reversible nature of light rays, a light spot will always be seen directly behind the aligned aperture. That is, a spot will always be seen on the CCD sensor at this location, regardless of the wavefront aberrations, and will always correspond to the overlying aperture. Immediately adjacent spots will be minimally displaced from their "zero slope" locations. As one moves further from the central reference spot, generally greater spot displacements will occur. Using this knowledge, it is a relatively straight forward process to identify all the spots in the CCD pattern and establish their geometric relationships.

The displacement of the centroid from that of a perfectly collimated light beam, corresponding to ideal and emmetropic vision, is then calculated and used to determine the wavefront slope at each sample location. The location of the centroids for a collimated light beam may either be directly measured in a calibration step prior to the patient exam, or taken from a calculated reference pattern based on the wavefront sensor construction.

Multiple exposures may be used to check for improper eye alignment or eye movement during individual exposures. If eye movement during exposures cannot be analyzed successfully by acquiring multiple exposures, then the appa-

ratus **10** can be augmented by the addition of an eye tracker **25**, illustrated with reference again to FIG. **2**. One possible placement of the eye tracker **25** is herein illustrated. However, it is to be understood that the eye tracker **25** could be placed elsewhere within the apparatus **10**. In this way, wavefront analysis is performed even during a limited amount of eye motion.

A one-time calibration exposure can also be used to determine the relative sensitivities of the individual cells. This is made in uniform collimated light with plate **32** removed. The responses of individual cells are then recorded. For each light transmissive aperture (e.g., hole **34**), the centroid in the collimated case serves as a dedicated origin for the particular hole. The shift from the "origin" for each hole to the centroid caused by the wavefront **24** (as observed in this coordinate system) is determined by the direction of the wave surface corresponding to that hole. If Δx(m,n) is the x-component of the (m,n)th centroid and F is the plate separation, then the P-value for the (m,n)th centroid is:

$$P(m,n)=\partial x(m,n)/\partial z=\Delta x(m,n)/F \tag{6}$$

The corresponding expression for Q is:

$$Q(m,n)=\partial y(m,n)/\partial z=\Delta y(m,n)/F \tag{7}$$

Thus, each P(m,n) and Q(m,n) represents the partial derivatives of W(x,y) with respect to x and y for the (x,y) coordinates of each hole **34**. For an m-order Zernike approximation of the original wavefront, the experimentally determined P's and Q's are then used in the following equations to calculate the appropriate C_i weighting coefficients as follows:

$$P(m,n)=\frac{\partial W(x,y)}{\partial x}=\sum_{i=0}^{n} C_i \frac{\partial Z_i(x,y)}{\partial x} \tag{8}$$

$$Q(m,n)=\frac{\partial W(x,y)}{\partial x}=\sum_{i=0}^{n} C_i \frac{\partial Z_i(x,y)}{\partial x} \tag{9}$$

By using a least-squares approx(m,n)/∂zach to minimize the error between the actual wavefront slopes on the left hand side in the above equations and the Zernike approximations on the right hand side, optimal values for the weighting coefficients can be obtained.

In one possible approach to calculating a centroid $(x_{c'}y_{c'})$, each hole **34** is assigned its dedicated area of the array **36** or $(i_{m,n}\pm\Delta i,j_{m,n}\pm\Delta j)$. This square of many light-sensitive cells is large enough that neighboring hole images never encroach, and all illumination from this hole is contained. The square contains 4Δi*Δj cells.

If array **36** is designated $C_{k,1}=(x_c(i,j), y_{c'}(i,j))$, k, 1=0 . . . 2Δ1, 2Δj, and the spacing on centers is Δx=Δy=d, the measured cell responses are V(k, 1) and the relative responsivities are R(k,I), then the x-component $x_{c'}$ a function of i, j is represented by

$$x_c(i,j)=[\Sigma_{k,1}V(k,1)*R(k,1)*d*k]/[\Sigma_{k,1}V(k,1)*R(k,1)] \tag{10}$$

and the y-component $y_{c'}$ as a function of i,j is represented by

$$y_c(i,j)=[\Sigma_{k,1}V(k,1)*R(k,1)*d*I]/[\Sigma_{k,1}V(k,1)*R(k,1)] \tag{11}$$

Then, if $(x_{c0}(i,j), y_{c0}(i,j))$ is the "origin centroid" for the (i, j) hole, i.e., made in perpendicular collimated light, and $(x_{cw}(i,j), y_{cw}(i,j))$ is the corresponding centroid found for the wavefront to be measured, then the relative centroid shift $(x_{cr}(i,,j)), Y_{cr}(i,j))$ is found as

$$x_{cr}(i,j)=x_{cw}(i,j)-x_{c0}(i,j) \tag{12}$$

$$y_{cr}(i,j)=y_{cw}(i,j)-y_{c0}(i,j) \tag{13}$$

The values P(i,j) and Q(i,j) are determined from

$$P(i,j)=x_{cr}(i,j)/F \tag{14}$$

and

$$Q(i,j)=y_{cr}(i,j)/F \tag{15}$$

The surface partial derivatives P(i,j) and Q(i,j) for the array of hole centers of plate **32** are next used to calculate the appropriate Zernike polynomial weighting coefficients to describe the original wavefront W(x,y). This will now be explained by way of illustration for a 7×7 square array of holes **34**. However, it is to be understood that other sizes and shapes of hole arrays could be used.

First, a 1×98 matrix (i.e., column vector) PQ(k) is formed as

$$PQ(k)=P(7i+j),\ j=0\ldots 6,\ i=0\ldots 6,\ k=0\ldots 48 \tag{16}$$

$$PQ(k)=Q(7i+j),\ j=0\ldots 6,\ i=0\ldots 6,\ k=49\ldots 98 \tag{17}$$

with j cycling for each i, i.e., PQ(18)=P(2,5).

The matrix PQ is multiplied from the left with a transition matrix TM to get the matrix C as follows

$$C=TM*PQ \tag{18}$$

where TM is a 98 wide by 14 high matrix and C is a 1 wide by 14 high matrix or column vector. C is the matrix C_k k=1, . . . , 14 such that, to a least square error,

$$W(x,y)=\Sigma_k C_k*Z_k(x,y) \tag{19}$$

and TM is calculated for a given aperture, e.g., a 6 millimeter pupil aperture. The functions $Z_k(x,y)$ in equation (19) are the Zernike polynomials. There is no standard convention as to their sequence. Thus, for consistency, it is important that the same sequence is used to produce the set C_k that was chosen for deriving the matrix TM. They occur in groups of the same order, which is the highest exponent in the group, with the total number of members in an order increasing with the order. For example, in a fourth order analysis, orders up to and including 4 are used (less Z_0—the single member of order 0 that is the constant 1 which describes the reference position of the group in the z direction). Since wavefront **24** is moving along z (at the velocity of light), this "piston term" describes only an arbitrary offset in Z, and this term may be ignored. The first 5 orders (0, 1, . . . ,4) contain 15 functions including the piston term.

Thus, in the illustrated example, 14 values of C_k are calculated as coefficients of 14 Zernike polynomials. By way of example, one such order used to calculate TM is herein illustrated, and includes both the Zernike functions and their partial derivatives.

ZERNIKE (X,Y) POLYNOMIAL EXPANSION THROUGH ORDER 4	
Polynomial Order 0	
Z(0)	+1
dZ(0)/dx	0.0
DZ(0)/dy	0.0
Polynomial Order 1	
Z(1)	+y
dZ(1)/dx	0.0
dZ(1)/dy	+1
Z(2)	+x
dZ(2)/dx	+1
dZ(2)/dy	0.0
Polynomial Order 2	
Z(3)	$-1 + 2y^2 + 2x^2$
dZ(3)/dx	+4x
dZ(3)/dy	+4y
Z(4)	+2xy
dZ(4)/dx	+2y
dZ(4)/dy	+2x
Z(5)	$-y^2 + x^2$
dZ(5)/dx	+2x
dZ(5)/dy	−2y
1 Polynomial Order 3	
Z(6)	$-2y + 3y^3 + 3x^2y$
dZ(6)/dx	+6xy
dZ(6)/dy	$-2 + 9y^2 + 3x^2$
Z(7)	$-2x + 3xy^2 + 3x^3$
dZ(7)/dx	$-2 + 3y^2 + 9x^2$
dZ(7)/dy	+6xy
Z(8)	$-y^3 + 3x^2y$
dZ(8)/dx	+6xy
dZ(8)/dy	$-3y^2 + 3x^2$
Z(9)	$-3xy^2 + x^3$
dZ(9)/dx	$-3y^2 + 3x^2$
dZ(9)/dy	−6xy
Polynomial Order 4	
Z(10)	$+1 - 6y^2 + 6y^4 - 6x^2 + 12x^2y^2 + 6x^4$
dZ(10)/dx	$-12x + 24xy^2 + 24x^3$
dZ(10)/dy	$-12y + 24y^3 + 24x^2y$
Z(11)	$-6xy + 8xy^3 + 8x^3y$
dZ(11)/dx	$-6y + 8y^3 + 24x^2y$
dZ(11)/dy	$-6x + 24xy^2 + 8x^3$
Z(12)	$+3y^2 - 4y^4 - 3x^2 + 4x^4$
dZ(12)/dx	$-6x + 16x^3$
dZ(12)/dy	$+6y - 16y^3$
Z(13)	$-4xy^3 + 4x^3y$
dZ(13)/dx	$-4y^3 + 12x^2y$
dZ(13)/dy	$-12xy^2 + 4x^3$
Z(14)	$+y^4 - 6x^2y^2 + x^4$
dZ(14)/dx	$-12xy^2 + 4x^3$
dZ(14)/dy	$+4y^3 - 12x^2y$

The choice of sequencing the Zernike polynomials dictates the interpretations of the C_k in equation (19) and therefore the order of terms in the TM matrix. Hence, the TM matrix is calculated after the choice is made. The development of the TM matrix for the illustrated example will be explained below.

Note that the fourth order analysis is only an example and is not the only possibility. A Zernike analysis can be done to any order. In general, the higher the order, the more accurate the result over the tested points. However, an exact polynomial fit over the tested points is not necessarily desirable. Such fits have the typical disturbing property that, unless the surface itself happens to be an exact polynomial of order no higher than that used for the surface fit, forcing an exact fit at separated points often causes wild swings between fitted points. That is, in polynomial surface fitting, an exact fit at a finite number of points can yield a poor average fit for a general function.

Calculation of the $\Delta z(x,y)$ optical path difference information from the Zernike reconstruction of the wavefront is accomplished simply by subtracting a constant from the Zernike approximation. The value of the constant will depend on the desired characteristics of $\Delta z(x,y)$. Depending on the method chosen to compensate for the aberrations (e.g., lens addition, etc.) it may, for example, be desirable to set either the maximum, mean or minimum value in $\Delta z(x,y)$ equal to zero.

The development of the transition matrix TM will now be explained for the illustrated example of a 7×7 array of holes in plate **32**. At each point (x_i,y_j), the tangents of the components of the normal are $P(x_i,y_j)$ and $Q(x_i,y_j)$ where

$$P(x_i,y_j)=\partial W(x_i,y_j)/\partial x \tag{20}$$

and

$$Q(x_i,y_j)=\partial W(x_i,y_j)/\partial y \tag{21}$$

Combining these with equation (11),

$$P(x_i,y_j)=\Sigma_k C_k \partial W(x_i,y_j)/\partial x \tag{22}$$

and

$$Q(x_i,y_j)=\Sigma_k C_k \partial W(x_i,y_j)/\partial y \tag{23}$$

each applicable to 49(i,j) combinations. These are combined into a single column vector PQ that is 98 elements high, i.e., a 98×1 matrix. Defining two matrices C_k (14 high×1 wide) and $M_{k,(i,j)}$ (14 wide×98 high)

$$(M_{k,(i,j)})=\partial Z_k(x_i,y_j)/\partial x;\ \partial Z_k(x_i,y_j)/\partial y \tag{24}$$

where the x-derivatives are the first 49 rows and the y-derivatives are the last 49 rows. Then, equation (19) can be rewritten as the matrix equation

$$(PQ)=(M)(C) \tag{25}$$

where the top 49 rows of M are the $\partial W(x_i, y_j)/\partial y$.

The expression in equation (25) gives the normal components in terms of the Zernike coefficients for a surface described by the array of 14 C's. These are exact, but it is not guaranteed that the actual total surface can be described by such an array of coefficients. Accordingly, if it is assumed that the description is within an acceptable tolerance, i.e., tolerating the errors that remain after least square error determination, then equation (26) can be considered to define the column vector C implicitly in terms of the mathematical matrix M and the measured vector PQ, both of which are known. The method of effecting the solution under the minimization condition is as follows. First, equation (25) is multiplied on the left by M^T, the transpose of M such that

$$(M^T)(PQ)=(M^T)(M)(C)=(S)(C) \tag{26}$$

where

$$S \equiv M^T M \tag{27}$$

is a square and symmetric matrix, e.g., of dimensions 14×14 (with each element the sum of 98 products). Such a matrix has an inverse unless the determinant of its coefficients is zero. Since this is based on the Zernike polynomials alone, and they are all independent of each other, the determinant is non-zero, so that an inverse S^{-1} is defined. Next, equation (25) is multiplied on the left by S^{-1} to yield

$$(S^{-1})(M^T)(PQ)=(S^{-1})(S)(C)=(I)(C)=C \tag{28}$$

Then, the mathematical transition matrix (independent of measurement) is

$$(TM)=(S^{-1})(M^{T}) \tag{29}$$

and the "best fit" array of C's from the measured PQ's can be produced by the simple matrix multiplication

$$(C)=(TM)(PQ) \tag{30}$$

To evaluate the eye unambiguously, all spots illuminating the planar array **36** due to a wavefront **24** are incident on the planar array simultaneously. If it is desired to reduce effects of eye movement, a pulsing or shuttering laser source may be used, or an eye tracker.

With reference again to FIGS. **7** and **8**, a beam of linearly polarized light (S-component) is emitted from a diode laser (670 nm, 3 mW by way of example), which beam of light passes through an electro-mechanical shutter, which controls the duration of light exposure on the eye **14** of the patient, and in particular, the exposure of the retina **18** of the eye **14** illustrated with reference again to FIGS. **7** and **8**. It is expected that alternate sources of light, for example, non-coherent and non-polarized, as well as alternate light transmitting techniques will come to the mind of those skilled in the art. When the shutter is open, the projected beam, collimated light from the diode laser, is directed by a long focal length lens for focusing on the anterior surface **22** of the cornea **24** of the eye **14**, as illustrated with reference to FIG. **7**, passing through the pupil **72** and lens **28** of the eye **14**, and onto the retina **18** as the small measurable spot **16**. In an alternate embodiment, the lens comprises a zoom lens for varying the focus and moving the focus location as desired. By focusing on the cornea **24**, the measurement is minimally dependent on the curvature of the cornea. However, other locations proximate the corneal surface are acceptable.

It is typical in the art of eye measurements to form a collimated beam and attempt to focus the collimated beam onto the retina, using lenses and lens combinations with the optics of the eye to produce the smallest possible spot **36**, as earlier described with reference to FIG. **8**. Lenses and focusing techniques typically take valuable time and include multiple attempts to focus a spot on the retina using various lenses and lens combinations to accommodate each unique vision of each patient being measured. With this technique, and the understanding that most of the blurring results from the curvature of the cornea, the technique eliminates the need to find lenses or lens combinations to minimize the size of the spot on the retina that is used as the secondary source of radiation.

With reference now to FIGS. **9–11**, an exemplary embodiment of the apparatus **10** will be herein described beginning with series **300**, which improved apparatus **300** is constructed as a patient examination station which allows the patient **302** to be comfortably positioned for the measurement of the eye **120**, as earlier described. For convenience to the technician operating the apparatus **300**, a computer monitor, mouse, and keyboard are located on a separate cart for this embodiment of the present invention, herein described. The apparatus **300** includes a housing **304** having a platform **306** which is carried by a rigid frame **308**. The frame **308** includes wheels **310** to facilitate shipping and installation at the clinical site, as well as locking and leveling feet **312** for securing the apparatus to the supporting floor **314**. Once the apparatus is positioned, the integrated leveling feet **312** are deployed to provide a stable stationary frame **308**, and thus platform **306**.

As illustrated, by way of example with reference again to FIGS. **9–11**, the patient **302** sits at a patient end **316** of the apparatus **300**, with his or her head resting in a headrest **318**, which headrest is adjustable in directions left/right (X-direction), up/down (Y-direction), or toward/away (Z-direction) relative to the platform **306**, using adjustment assembly **320**. The headrest **318** is attached to the lower surface of the platform **306** which forms an optical table for mounting optical components thereon, as illustrated with reference to FIG. **12**, and as will herein be described in further detail. The housing **304** includes a removable optical table cover **322** which protects the optical components carried within the housing. The optical table cover **322** is secured to the platform **306** with keyed locks to prevent unauthorized access to the optical components. The platform **306** is bolted to the rigid frame at four locations **307**, as illustrated with reference again to FIGS. **9** and **10**. The frame **308** also carries electronics **324** and a computer **326** which includes the processor **40** earlier described with reference to FIG. **6**, as well as a connector plate for a computer keyboard, monitor and mouse. The frame **308** also includes an upper bay **328** housing electronics controlling optical components carried by the platform **306**, and a lower bay **330** housing an uninterruptible power supply (UPS) and an isolation transformer.

As illustrated with reference again to FIGS. **9–12**, three ports are positioned within the cover **322**, and include an examination port **332** to allow the wavefront measurement of the eye **120** to take place, and two eye illumination ports **334** which allow lamps **336** carried within the housing **304** to illuminate the eye for visualization by an internal video camera **338**. In addition, the adjustment assembly **320** includes a position sensor **321** which senses an x-direction displacement for detecting a position of the headrest **318** to the left or to the right of a reference center line location **3191**. A signal indicative of the sensed displacement is provided to the computer **326** for automatically recording the appropriate eye **120** (e.g. left or right) being measured.

As illustrated with reference again to FIG. **12**, the platform **306** provides an optical table with the patient positioning the eye **120** for measurement by the apparatus **300**. The platform surface measures approximately two feet by four feet, with the optical components fixed to the surface using a combination of commercial and customized precision hardware mounts. All transmissive optical elements have surface anti-reflection coating optimized for the selected probe beam wavelength. The optical layout includes five distinct optical pathways which share the optical elements as will herein be described, by way of example. With reference again to FIG. **12**, a first optical path **340**, a fixation target image optical path illustrated in isolation in FIG. **12A** for convenience to the reader, displays a fixation target image to the patient seated at the apparatus **300**. The patient aligns his/her visual axis to the optical axis **342** by looking at the center of a target reticle **344** having a grid pattern. With reference again to FIG. **12**, a second optical path **346**, a video image optical path illustrated in isolation in FIG. **12B** for convenience to the reader, captures a video image of the corneal plane. This allows the technician to assist in aligning the eye **120** for examination, and to record the exact location of the eye during each measurement using software reticles superimposed on a video image. With reference again to FIG. **12**, a third optical path **348**, a probe laser optical path illustrated in isolation in FIG. **12C** for convenience to the reader, sends a probe laser beam **360** into the eye **120** along the optical axis **342**. As earlier described with reference to FIGS. **2** and **7**, the probe laser beam **14**, herein referred to

with numeral **350** is attenuated to an eye-safe intensity and linearly polarized before being focused onto the corneal surface. With reference again to FIG. **12**, a fourth optical path **352**, a re-emitted wavefront optical path illustrated in isolation in FIG. **12**D for convenience to the reader, conveys the reflected wavefront **24** of FIG. **2**, and herein described with numeral **364** re-emitted from the eye **120** and directed towards a wavefront sensor **356**. To accomplish this, first and second afocal relay stages **358**, **360** transfer the reflected wavefront **354** from the corneal plane of the eye **120** to the entrance face of the wavefront sensor **356**. Finally, with reference again to FIG. **12**, a fifth optical path **362**, a calibration wavefront optical path illustrated in isolation in FIG. **12**E for convenience to the reader, injects collimated laser light into the wavefront transfer path leading to the sensor **356**. Software operable within the computer **326**, described earlier with reference to FIG. **9**, uses collimated light wavefront sensor output data to calibrate the apparatus **300** prior to patient measurement.

With continued reference to FIGS. **12**, and **12**A, the first optical path **340** is herein described as a fixation path which provides a reference image to the patient, such that the eye **120** is property aligned when the patient is fixating on the reticle **344** of a reference target **366**. A target illumination lamp **368** back-lights the fixation target **366**, which fixation target image reaches the patient eye **120** by transmission through a 50/50 beam splitter **370**, lenses **372**, reflection in 50/50 beam splitters **374**, **376**, and transmission through lens combinations of afocal relay stage **358**, as well as through polarizing beam splitter **378**. In addition, a spectral filter is placed over the target illumination lamp **368** to remove radiation over the 620–790 nm wavelength range that might otherwise interfere with a wavefront measurement at 670 nm. The lens combinations in the first relay stage **358** contain identical lens elements mounted in reverse order. Each consists of two meniscus lens elements, with an interposed achromatic doublet. The lens combinations work in tandem as a unity magnification afocal relay stage.

The optical elements including the polarizing beam splitter **378**, the lenses of the first afocal stage **358**, the beam splitters **374**, **376**, and one lens **380** of the lenses **372** are mechanically fixed in place on the surface of the platform **306**. The optical elements including a lens pair **382** of the lenses **372**, the beam splitter **370**, the fixation target **366**, and the illumination lamp **368** are all mounted on one precision linear translation stage, capable of movement along the optical axis **342** of this pathway. Translation of these optical elements focuses the fixation target **366** for the patient's view, compensating for any myopia/hyperopia present in the eye **120**. During patient examination the focus translation stage is adjusted to place the target optically just beyond the eye's infinity focal plane. This allows the patient to see a relatively distinct reticle pattern without stimulating accommodation by the eye **120**. The beam splitters **378**, **376**, **374** serve as interfaces between other optical pathways within the optical axis **342**, as will herein be described in further detail. By way of example, the beam splitter **370** is included for alignment purposes. A photo-detector **384** attached to the center of the left edge of beam splitter **370** senses light transmitted toward the fixation target along the optical axis.

With reference again to FIGS. **12** and **12**B, the second optical path **346** captures video images of the eye **120** at an examination plane. This allows the clinical operator/technician to assist in patient alignment, and to measure actual eye displacement during the wavefront measurement. As earlier described, the illumination lamps **336** illuminate the eye **120**. The image of the eye is conveyed to the video camera **338** by transmission through the polarizing beam splitter **378** and the lens combinations **358**, reflection in the 50/50 beam splitter **376**, transmission through the 50/50 beam splitter **374**, reflection off mirror **386**, and transmission through lens **388**. All these optical elements are fixed in place on the surface of the platform **306**. By way of example, this second path **346** provides a video field of view approximately 22 mm in diameter at the eye plane, with a limiting resolution of ~64 mm. As earlier described, a number of filters are placed in front of each eye illumination lamp **336** to reduce the spectral bandwidth of the radiation reaching the eye **120**. By way of example, these will includes a blue filter to remove light at wavelengths below ~455 nm (for eye safety), an infrared filter to remove light at wavelengths above ~920 nm (for eye safety), and a rejection filter to remove light over the wavelength range 620 nm–790 nm (to prevent interference with the wavefront measurement at 670 nm).

With continued reference to FIGS. **12** and **12**C, the third optical path **348** irradiates a small spot on the patient's retina with eye safe laser radiation, as earlier described with reference to FIGS. **1**A–**1**D. The irradiated retinal spot on the fovea centralis **123** of the retina **122** is, as herein described, the origin of the re-emitted wavefront **130** measured by the sensor **356**. The output beam, probe laser beam **350** from diode laser **390** reaches the patient eye **120** by transmission through a linear polarizer and attenuator **392**, lens **394**, shutter **396**, and reflection off mirror **398** and in the polarizing beam splitter **378**. All these elements are fixed in position.

In one embodiment of the present invention, output of the diode laser **390** is essentially collimated and is focused onto a corneal surface of the eye **120** by lens **394**. The projected probe laser beam **350**, collimated light from the diode laser **390**, is directed by a long focal length lens **394** for focusing on the anterior surface of the cornea **126** of the eye **120**, as illustrated by way of example with reference again to FIG. **1**B, passing through the pupil and lens **124** of the eye **120**, and onto the retina **122** as a small measurable spot on the fovea centralis **123**. As earlier described with reference to FIG. **7**, in one embodiment, the lens **394** illustrated with reference again to FIG. **12**, comprises a zoom lens for varying the focus and moving the focus location as desired. By focusing on the cornea **126**, the measurement is minimally dependent on the curvature of the cornea. However, other locations proximate the corneal surface are acceptable.

While diffraction and various aberrations are present, the present invention avoids the aberration effects from the cornea which typically dominate. The lens of the eye **120** contributes a relatively small aberration effect when compared to that of the cornea **126**. Further, and with regard to the selection of the lens **394**, selecting a lens with a short focal length would provide a relatively large incident angle of the beam **350**, a well focused point on the surface of the cornea **126**, and less aberration effects from the cornea . A small incident angle provides a larger focus point on the cornea **126**, but a more desirable smaller spot on the retina **122**, which spot size will depend on the wavelength and starting point size and focal length of the lens **394** selected. Embodiments of the present invention including lenses of approximate one half meter and 100 mm, by way of example, haves been effectively used.

The polarizer **392** linearly polarizes the probe beam **350** into an s-state (by way of example, out of the plane of the drawing of FIG. **12**). The angled interior interface of the polarizing beam splitter **378** reflects s-polarized light, so that light entering the eye **120** is s-polarized. A linear polarizer

400 is angled with respect to the polarizer 392 and works in conjunction with the attenuator to attenuate probe beam power delivered to the eye 120 to less than 10 μW, by way of example. The diode laser 390 is triggered by an external electrical trigger signal 402. A nominal illumination duration for eye measurement is 700 ms. The shutter 396 is included as an additional safeguard against overexposure of the eye 120 to the probe laser beam 350. The shutter 396 is normally closed and is opened by an independent electrical trigger signal 404 synchronized to the laser trigger signal 402.

By way of example, one retinal exposure for each illumination by the probe beam is 10 μW×0.7 s=7 μJ. Up to 10 repeat measurements may be obtained during a single patient examination session. Such exposures are well within the safety limits defined in the American National Standard for Safe Use of Lasers (ANSI Z136.1-1993, American National Standards Institute, New York, N.Y.). In that reference, the maximum permissible exposure (MPE) for "intrabeam" viewing a laser beam in the 400–700 nm wavelength range and the 18×10^{-6} to 10 second pulse duration range is $1.8*t^{3/4}$ mJ/cm^2. (t is the pulse duration in seconds). A limiting aperture for the eye is identified as approximately 7 mm in diameter. As a result, an allowable single-pulse energy is $0.6927*t^{3/4}$ mJ. For a single 0.7 second pulse the MPE is 530 μJ, almost two orders of magnitude larger than a delivered energy per pulse, for the apparatus herein described. An additional calculation is performed to assess the safety of the repetitive exposures. The relevant calculation in the Standard multiplies the single pulse MPE by $n^{-¼}$, where n is the total number of pulses in the exposure duration T_{max}. For the apparatus of the present invention, the 10-pulse safety limit is $530\ \mu J/pulse\times10^{-0.25}$= 298 μJ/pulse, still a factor of 40 larger than the actual pulse energy focused into the eye.

As illustrated with reference again to FIGS. 12 and 12D, the fourth optical path 352 conveys the wavefront 354, earlier identified by numeral 130 with reference to FIG. 1B, emerging from the eye 120 to the wavefront sensor 356, herein described using a Hartman-Shack sensor by way of example for the wavefront analysis. The wavefront 354 re-emitted by the eye 120 in response to the probe beam 350 irradiation is conveyed to a CCD camera 406 by transmission through the polarizing beam splitter 378, the first afocal relay stage 358 lens combination, the 50/50 beam splitter 376, a trial lens holder 408, the second afocal relay stage 360 lens combination, reflection off mirror 410, and transmission through microlens array 412, as earlier described with numeral 33 with reference to FIG. 6. With the exception of the changeable trial lens holder 408, illustrated with reference to FIGS. 12F and 12G, all these optical elements are fixed in place on the surface of the platform 306.

The polarizing beam splitter 378 transmits only linearly polarized light in a p-state. The radiation of the probe beam 350 reflected from the corneal surface of the eye 120 will retain the incident s-state polarization and will not be appreciably transmitted by the beam splitter 378. In contrast, light that has been scattered off the retina of eye 120, light forming the wavefront 354 of interest, will be largely depolarized. The p-polarized fraction of this light will be transmitted by the beam splitter 378. Thus the beam splitter 378 selectively suppresses the corneal surface reflection that could otherwise complicate the wavefront measurement. A wavefront originating at the corneal plane of eye 120 is transferred to a plane of the trial lens holder 408 with unity magnification. This plane of the trial lens holder 408 provides an intermediate pupil plane and is included for placing an ideal N-diopter lens 409, see FIGS. 12F and 12G, at the trial lens plane to change the spherical curvature of the wavefront 354 by N-diopters, without altering other aberration content. The capability to reduce/remove the general wavefront curvature in a preselected manner significantly extends the dynamic range in wavefront measurement, without degrading the measurement accuracy. Trial lenses 409*a*–409*m*, by way of example and herein described of varying spherical powers, ranging from −16 diopters to +8 diopters in two-diopter increments, are mounted on a rotating wheel 407 of the holder 408. The wheel's axis of rotation is parallel to but offset from the optical axis 342. Turning the wheel places one of a plurality of preselected trial lenses at the trial lens plane. The wheel has precision mechanical detents that register the selected lens properly in the optical path.

A narrow band-pass optical filter is also placed at trial lens holder 408 location just anterior to the lens position. This filter has maximum transmission for 670 nm wavelength radiation (the probe beam wavelength), and a bandwidth of approximately 10 nm (full-width-half-maximum). This filter is used to reject spurious light (from the fixation target illumination, the eye illumination, and the like) from the wavefront path.

In one embodiment, as herein described by way of example, each of the lenses of the second afocal relay stage 360 consists of three lens elements, two meniscus lenses and an interposed achromatic doublet. However, they are not identical, and their combined action serves to magnify the passing wavefront 130. The wavefront 354 at the trial lens holder 408 location is imaged onto the surface of the microlens array 412 with a magnification of 1.22. Magnification of the wavefront image by this defined factor of 1.22 reduces the wavefront slope at each point in the image plane by the same 1.22 factor. This extends the measurement dynamic range of the device, again without decreasing accuracy. In addition, this magnification distributes the wavefront 130 over more elements, CCD cells 38 as earlier described with reference to FIG. 6, in the microlens array 412, thus increasing the number of slope measurements provided by the wavefront sensor 356. The mirror 410 is included to fit elements of the apparatus 300 within the dimensions of the platform 306. In addition, the mirror 410 also allows optical alignment adjustment for the microlens array 412 and the CCD camera 406 combination. As earlier described, by way of example, with reference to FIGS. 3–6, the microlens array contains a square array of microlenses which divide the incident wavefront into a transverse array of secondary "wavelets." These wavelets are focused onto a detector surface of the CCD camera, which is positioned parallel to the microlens array and one focal length posterior thereto. The pattern of focused wavelets in the CCD image is used to calculate the shape of the incident wavefront.

As illustrated with reference again to FIGS. 12 and 12E, the calibration beam path 362 provides the collimated beam 364 to the Hartman Shack wavefront sensor 356. Wavefront data for the collimated beam 364 is used as a reference in reconstructing the aberrated wavefront 354 from the real eye measurement. The source for the collimated reference beam 364 consists of a diode laser 414 coupled to a beam expander 416. In one embodiment of the invention herein described, the diode laser 414 used for reference is identical to the diode laser 390 used for the probe beam path 348. The collimated reference beam 364 is conveyed to the CCD camera 406 by transmission through polarizer/attenuator 418, negative lens and aperture 420, aperture and positive lens 422, reflection off mirror 424, transmission through aperture 426, reflection in the polarizing beam splitter 378,

transmission through the first afocal relay stage **358**, the 50/50 beam splitter **376**, the trial lens holder **408**, the second afocal relay stage **360**, reflection off the mirror **410**, and finally transmission through the microlens array **412**. Except for trial lens holder **408**, all these optical elements may be fixed in position on the surface of the platform **306**.

The optical element of the polarizer and attenuator **418** contains two linear polarizers and a neutral density filter. The linear polarizer furthest from the diode laser **414** polarizes the laser radiation in the s-state for maximum reflection in the polarizing beam splitter **378**. The linear polarizer closest to the diode laser **414** is partially "crossed" with respect to the polarizer **378** to attenuate the laser power. The neutral density filter further attenuates the beam, such that the laser power reaching the CCD Camera **406** is optimal for calibration of the sensor **356**. The negative lens and positive lens of elements **418**, **420** expand the diode laser output and form the collimated reference beam **364**. Intervening apertures of elements **418**, **420** transmit only the central portion of the expanding beam with the most uniform intensity. The mirror **424** is included to reduce the overall dimensions of the apparatus **300**. The aperture **426** is conjugate to the corneal plane, and is included so that the collimated reference beam **364** illuminates approximately the same area on the microlens array **412** as would the wavefront **354** re-emitted by a maximally dilated eye.

By way of illustration, optical components suitable for use with embodiments of the present invention herein described by way of example, are provided with reference to Table 1. An electrical component layout of the apparatus **300** is illustrated with reference to FIG. **13**, wherein a dashed box **428** indicates the platform **306** with the heretofore described element carried thereon. Except for the computer monitor, keyboard, and mouse all other electrical components are located within the frame under the optical table. Switches in the diagram are all located on a front panel **430** of the electronics **324** for ease in operator/technician access, as described earlier with reference to FIG. **9**. Electrical power from the clinical facility is drawn by an isolation transformer, which in turn supplies power to an uninterruptible power supply (UPS). The UPS delivers power to three power strips carried in the frame **308**. The host computer **326** has a self contained On/Off switch, as do the three power strips. One power strip **432** supplies power to the shutter controller **434**, which commands the probe laser shutter **396** through the signal **404**, two dual power supplies **436**, each capable of providing both 5 VDC and 9–15 VDC output, the host computer **326**, a computer monitor **438**, and a third power strip **440**. One dual power supply supplies 5 VDC power to the two patient illumination lamps **336**, and 9 VDC power to the target illumination lamp **368**. A second dual power supply supplies 5 VDC power to both diode lasers **390**, **414**. A user-accessible 3-position switch **442** allows the system operator/technician to provide power to either the probe laser **390** or the calibration laser **414**, with a center switch position being the "off" state.

A third power strip **444** supplies power to the CCD electronics controller **446**. The power strip **440** also supplies power to cooling fans **448** located on the platform and within the frame.

By way of example and for illustration purposes, operation of the apparatus **300** may generally proceed with the operator/technician first activating each of the electrical elements, with the CCD electronics controller **434** being last to be enabled. The operator then activates the calibration laser **414** via the 3-position switch **442**. The operator then instructs the computer **326** to acquire a calibration wavefront measurement. The computer **326** relays this command to the CCD controller electronics **446**, which activates the CCD camera **406** to take a predefined exposure. The CCD controller electronics **446** also sends trigger signals **402**, **404** described earlier with reference to FIG. **12**, to the probe laser **390** and the probe laser shutter **396**. However, since the probe laser **390** is not powered at this point, no probe beam **350** is delivered. Calibration CCD data are transferred to the CPU of the computer **326**, and stored for later analysis. The calibration laser **414** is switched off at the end of the calibration procedure.

The technician/operator then proceeds to patient measurements. The output switch **442** at the dual voltage power supply **436** is positioned to a probe laser setting. The probe laser **390** is now in a "ready" state awaiting an additional trigger signal to operate. The operator then positions the patient appropriately in the apparatus **300** as earlier described with reference to FIGS. **9–11**, with the assistance of an image from the video camera **338** displayed on the computer monitor, by way of example. With the patient situated, the operator instructs the computer **326** to obtain wavefront data, as earlier described with reference to FIGS. **2–7**. The computer **326** relays appropriate commands to the CCD electronics controller **446**, which triggers the probe laser **396** to fire, triggers the shutter controller **434** to open the probe laser shutter **396**, and exposes the CCD camera **406**. CCD camera image data is transferred back to the computer **326**. The computer **326** includes software that analyzes the patient and calibration data to calculate the patient wavefront profile for use. At the end of the data collection, the operator shuts down the electronics, starting with the CCD electronics controller **446**. The software integrated into the apparatus **300** may be described, by way of example, as including: A graphical user interface (GUI) to allow the technician to perform all desired operations to enter and save patient information and perform the desired measurements; database and file system interfaces to allow for the saving and tracking of patient information, measurement, and hardware details; control of the electro-optical and electro-mechanical components as necessary in order to be able to accurately and safely perform the desired measurements; and processing of the measurement data to generate mathematical descriptions of the aberrations (the optical path difference) measured in the subject eye.

By way of further example, patient measurement and apparatus configuration information is stored in multiple tables in a Microsoft Access™ 7.0 database. The interface to this within the code is based upon the Microsoft Foundation Classes (MFC) wrapper to the Microsoft Jet Engine. The framework generates a Structured Query Language (SQL) to create, retrieve and update records in the database. Use of the Microsoft Access application to access the data is not needed. In one embodiment of the present invention, the following data may be stored in the database: patient information—name, address, medical record number, and the like; measurement Information—geometry, time of measurement, and the like; and system Information—hardware serial numbers and key hardware parameters.

Additionally, the software may be developed with two operating levels—password-protected and not-password-protected. From within the password-protected-mode, the technician/operator has access to system configuration information and features necessary for system setup and maintenance that are not accessible from the not-password-protected mode. All patient entry and measurement capabilities are available from the not-password-protected mode. All patient information desired in order to be able to

uniquely identify and track the patient is entered via the graphical user interface (GUI) and stored in the Microsoft Access database. Selecting the "Patient Data" menu item brings up a patient information data information screen, from which the technician can enter new patient data as well as being able to review and edit existing information. The patient data that can be stored and retrieved, typically includes: name, address, medical record number, data of birth, phone number, sex, manifest and cycloplegic refractions and vertex distance as well as centration information.

Centration information that is measured via a centration process and stored as part of the patient record describes the position of the center of the constricted pupil with respect to the center of the limbus. This information is used in aligning the patient for the measurement where the goal is to align the visual axis of the eve with the optical axis **342** of the apparatus **300**. When the centration procedure is invoked a list is displayed of all patients that have been entered into a database operable with the apparatus **300** but have not yet had the centration steps performed. The monitor displays all patient information including a review of centration information, or alternatively, for just those patients entered for a given time period. In order to perform centration for a given patient and eye, that patient is selected from this list by clicking on the desired patient/eye with the mouse. An example of the centration process is illustrated with reference to FIG. **14**. Once a patient has been selected, the patient is instructed to look into the apparatus **300** and at the fixation target **366**, as earlier described with reference to FIG. **12**.

By way of further disclosure, the fixation target **366** is, as earlier described, included so that the patient **302** can stare along the optical axis **342** of the apparatus **300**. For best fixation, the target should be clearly visible to the patient. However, care should be taken to see that the patient does not attempt to accommodate when fixating on the target. This would occur if the target were optically closer than the patient's infinity focal plane. If the patient did accommodate, i.e., if the lens in the eye changed shape to provide increased focusing, then the eye would appear excessively myopic during the wavefront measurement. To avoid this, the fixation target optics are adjusted so that the target appears to lie optically just beyond the patient's far-field focus. Thus for each patient the target will appear relatively clear, but not in sharp focus. The patient may initially try to accommodate to improve the sharpness of the image, but will eventually find that the clearest image is seen for the most relaxed (non-accommodative) state. This technique is known as "fogging," and is routinely performed by optometrists when doing clinical evaluations. The eye drops used to dilate the eye for the measurement also reduce the lens' ability to accommodate, thereby further ensuring valid wavefront measurement.

With reference again to FIG. **14**, an image of the patients eye **120** is frozen. Two reticles **450**, **452** are then used to locate the centers **454**, **456** of the constricted pupil and limbus, respectively. Each reticle **450**, **452** can be moved and sized—one reticle **450** is positioned over the perimeter of the constricted pupil **458** and the other reticle **452** over the limbus **460**. Once they have been located, the information is saved to the database. This can be performed for as many patients as is desired and the centration procedure is then exited.

For illustration, a sequence of events followed in measuring the refractive errors in an eye and computing the corresponding optical path difference (OPD) is illustrated with reference to FIG. **15**. By way of example, steps include performing a reference measurement **462**. To provide a reference with which to compare the measurement of the eye **120** and also to check the alignment of the apparatus **300**, a reference measurement is made using the collimated laser light **364**, as earlier described with reference to FIG. **12**. The software forces the operator to make at least one such measurement at the start of each day and an additional one at the end of each day. More reference measurements can be performed as desired by the operator. When patient measurements are performed, the measurement records in the database identify which reference measurements correspond to each measurement, i.e., which reference image was the latest one done prior to the measurement. A "Perform Reference Measurement" screen may be provided for viewing a sample reference image.

A next step includes selecting a patient and eye to measure **464**. The patient and eye to be measured may be selected from a "Patient Select" dialog screen. It is desired that all patients are displayed along with a check mark to show whether or not centration has been performed for that patient. If a patient is selected that has not yet had centration performed then the operator is informed of this and no measurement can be performed. Once a valid patient/eye has been selected to be measured then the perform measurement dialog is displayed which includes GUI buttons necessary in order for the operator to perform and check the measurement.

A next step includes aligning the eye using the video camera and reticles **466**. The apparatus **300** is operated with the visual axis of the eye aligned, as close as is practically possible, to the optical axis **342** before performing a measurement. The center of the constricted pupil **454** is used as the approximate anatomical landmark for the visual axis. Given that the eye **120** is dilated when the measurement is performed, it is not possible to directly determine this center. However, the centration procedure performed on each patient defines the center of the constricted pupil **454** with respect to the limbus **460** and thus it is possible to use the position of the limbus to place the eye **120** in a desired location.

As illustrated with reference to FIG. **16**, a reticle **468** is displayed on screen that is offset from the optical axis by the appropriate amount such that when the limbus **460** of the eye **120** is aligned to this reticle **468**, the eye **120** is positioned as desired. Prior to taking the measurement, it is the operator's responsibility to ensure that the patient is positioned appropriately such that the limbus **460** is aligned with the reticle **468** while the patient is looking at the fixation target **366**.

A measurement is then performed **470**. Once the eye **120** is aligned, the operator presses an "acquire" button to perform the wavefront measurement of the patients eye. The system response to the acquire command is as follows:

1. Video image is frozen
2. Probe beam laser is activated
3. External shutter is opened so that the probe beam can reach the eye
4. CCD shutter opens and the CCD is exposed to the re-emitted wavefront (1–4 generally performed simultaneously)
5. CCD shutter closes and the exposure is completed
6. CCD data is transmitted to the computer
7. External shutter closes and the probe beam turns off.

The software continually checks the status of the CCD electronics and the temperature of the camera and only allows measurements to be taken when everything is working nominally.

A review of eye and apparatus geometry is accepted or rejected **472**. Although it is not necessary for the eye **120** to be perfectly aligned with respect to the optical axis **342** (the software compensates for minor misalignments), it is desirable for it to be close. The eye **120** will have been aligned prior to the measurement but uncontrollable eye motion (e.g. saccades and loss-of-fixation) may make the alignment sub-optimal at the time of the exposure. To check that the alignment is acceptable, the video image of the eye is frozen at the time the measurement is taken. The operator then aligns a reticle to the limbus ring and presses a "check geometry" button on the GUI. If the software determines that the alignment is not acceptable, the operator is informed of this and a new exposure is made as desired. By way of example, and with reference to FIG. **17**, optimal measurement as herein described, would have the limbus **460** aligned to circle B. In actuality, the eye **120** was offset during the exposure and the limbus **460** was aligned to circle A. The difference between these two states is shown by the line A'B'. The software determines whether or not the image is acceptable based on the length of A'B'.

It is also at this point that the operator records the rotational state of the eye. Prior to the wavefront measurement, a pattern of four line segments **474** arranged in an "X" pattern **476**, as illustrated with reference to FIG. **18**, around the periphery of the cornea are applied to the eye using a mechanical instrument The pattern **476** consists of two pairs of collinear line segments **474** angled at 45° with respect to each other. Each line segment **474** is 4 mm long, and collinear segments are separated by 7 mm. At the same time the limbus ring reticle is aligned with the actual limbus in the frozen video image, an X reticle that matches this pattern is aligned to the applied eye marks in the frozen image. The orientation information is then saved by the software along with the limbus position data.

As a next step in the process, the CCD image is processed, accepted and saved, or rejected **478**, as illustrated with reference again to FIG. **15**. If the geometry of the measurement is acceptable, it is then probable that the quality of the CCD image will be high. It is desirable, however, to check that this is so. The software processes the image and then presents an auto-scaled image to the operator to review. If the software determines that the image is unacceptable then the operator will be informed of this and a new exposure made. If the user decides that the image is unacceptable for whatever reason then the image can be manually rejected at this stage. An example of an unacceptable image is illustrated with reference to FIG. **19**. In this example, a significant portion **479** of the image is obscured in some manner, resulting in wavefront data for only part of the pupil. By unacceptable, it is meant that such an image is not believed to result in the accuracy and precision of measurement that is desired for surgical procedures which are obtained by the present invention. It does not mean that such as illustrated may not be usable in any sense.

Once a valid measurement has been made the next step **480** is to measure the local slopes of the wavefront **130**, as earlier described with reference to equations herein presented. As described with reference to FIGS. **4–6**, it is necessary for the software to compute the centroids **116** of the clusters of light on the CCD array **38** and then determine the distances of each of these centroids **116** from the corresponding reference centroids **29**. The centroids are determined by first computing which pixels should be processed and grouping them together into clusters. The intensity-weighted centroid of each cluster is then computed. As illustrated with reference to FIG. **20**, an example of an image from a myopic eye with the computed centroids **482** of cluster **484** marked by "X"s is shown. FIG. **21** illustrates a close-up of one of the clusters **484** and displays not only the centroid **482** but also the pixels **486** used in the centroiding calculation for the cluster **484**. CCD pixels **488** processed in the centroiding algorithm are marked by dots. This algorithm, by way of example, isolates centroids by use of a spacial filter which removes stray light signals that create noise for the CCD image. Such filtering may be desirable before calculation of light cluster positions.

Without filtering, computation of the cluster centroids may be made difficult as a result of noise on the Image such that individual pixels with no actual data content may be brighter than pixels containing relevant data, speckle in the image may result in valid data clusters having irregular profiles with significant variation in intensity of adjacent pixels, haze or background noise may be high relative to the actual data or may be non-uniform across the image, intensity of valid data may be non-uniform across the image, scatter from different parts of the eye may result in spurious signals on the image, and high aberrations in the eye may significantly distort the clusters of valid data, by way of examples. The spatial filter permits a re-computation of the brightness of each pixel in a bitmap using a weighted averaging technique that considers surrounding pixels. In a particular application herein described for illustration and by way of example, the spatial filter is designed to yield a maximum value when centered on valid data, reduce an effect of individual bright pixels or small groups thereof, normalize background levels, smooth valid data profiles, and simplify the task of extracting the valid data from background noise or haze. One filter employed in one embodiment of the present invention is square (n×n) and includes real values (positive and negative) assigned to each pixel. The filter is designed to be optimally matched to images obtained from eyes with high, yet measurable, levels of aberration. By wave example, a cross-section through the filter is illustrated with reference to FIG. **23**A. An effect of applying such a filter improves an image such as illustrated with reference to FIG. **23**B to the image illustrated with reference again to FIG. **20**, by way of example, a cleaner image and one that is easily processed for identification and computation of cluster centroids. By applying the filter, images that would otherwise be deemed to noisy or of insufficient quality to process, can now be processed and desired wavefront information computed.

The center of each centroid is calculated using a standard center of mass algorithm based on light intensity. The clusters and centroids illustrated with reference to FIG. **22** are illustrated with the locations of the corresponding reference centroids **490** also visible. The open circles in this figure indicate the locations of the reference centroids. Lines connect these with the associated sample centroids **482**. From the distances between the reference and measurement centroids **490**, **482** respectively, and the distance between the lens array **33** and the CCD plane **36**, described with reference to FIG. **6**, the local slopes are calculated. Given these local slopes and information about the apparatus setup, including any and all magnification factors, it is then possible to determine the local slopes at the pupil plane and, from these, and compute the optical path difference of the eye being measured.

A description of the wavefront is then made **492**. As earlier described, the reconstructed wavefront is described via a set of Zernike polynomials. The number of locations on the eye **120** at which the local slopes are determined (i.e. the number of sample points) greatly exceeds the number of

terms in the polynomials that will describe the wavefront. A least-squares-fit calculation is done to find the coefficients that best describe the surface. The order of the polynomial used is sufficient to describe not only the spherical and cylindrical refractive powers (2^{nd} order) but also the levels of coma (3^{rd} order) and spherical aberration (4^{th} order) present.

An example of the computed Zernike coefficients for an eye and the corresponding wavefront reconstruction **493** is illustrated with reference to FIG. **24**A. By way of example, for the wavefront illustrated with reference to FIG. **24**A, the spherical and cylindrical powers computed from the wavefront are −1.60/−1.13×150.4. The corresponding values obtained by an optometrist performing a phoropter examination (converted to the corneal plane) were −1.47/−1.19×150. The standard measurements of spherical and cylindrical powers agree well with the computation of spherical and cylindrical powers, but there are also higher order aberrations present. By way of further example, FIG. **24**B illustrates just these higher order aberrations **495** on the same scale as the plot of FIG. **24**A.

With regard to the optical path difference (OPD), scaling an optical path difference profile, OPD(x,y), by a refractive index difference (cornea to air) is not the only step. This wavefront measurement is made at a plane tangent to the cornea, as illustrated with reference to FIG. **25**, which is exaggerated to illustrate the effect. The image plane of the wavefront path is the lenslet array plate. The object plane of the wavefront path is the reference plane **494**. In this highly-exaggerated myopic case, herein described by way of example, one light ray **496** emerging from the eye **120** at transverse location a is detected at a transverse location b. The wavefront reconstructed from sensor data will have the slope of this ray at location b. Although this is true of the wavefront at the reference plane **494**, simple scaling of this wavefront would suggest a measurement at corneal location b that may not be entirely accurate. In actuality this effect is small. The radius of curvature of the cornea is typically on the order of 7.5 mm. (a range of 7–8 mm encompasses most eyes.) At a transverse location 3 mm from the corneal apex, the distance from the corneal surface to the reference plane is only ~0.63 μm. For a 10 diopter myope, a light ray exiting the cornea at a=3.0 mm will cross the reference plane at b=2.98 mm. The difference between a and b in this example is only 20 μm. Although small this geometric effect is systematic, having progressively greater impact on the measurement with increasing radial distance from the corneal apex. To increase accuracy, compensating for the curved geometry may be performed in the following manner:

1. Wavefront slopes are calculated at each measurement point in the reference plane.
2. The cornea is assumed to have a nominal radius of curvature (~7.5 mm).
3. The wavefront slopes measured at the reference plane is projected back onto the nominally curved cornea. The wavefront is measured to have a certain slope at b in the reference plane, described above. It is a straightforward mathematical process to calculate the point a where this ray exited the cornea.
4. The wavefront is reconstructed based on the measured slopes at the calculated corneal locations.

As above described, it is desirable to obtain the best information with a wavefront measurement having patient positioned at the apparatus **300**. The eye **120** being measured is at the desired location and looking in the appropriate direction. Based on analysis of the allowable eye-positioning tolerances, the apparatus **300** of this embodiment of the present invention provides the following patient position information:

The capability for ensuring that the subject eye is at the right location along the longitudinal (z) axis of the apparatus with an accuracy of +/−1 mm.

The capability for ensuring that the subject eye is properly positioned laterally with respect to the apparatus (i.e., in x-y) with an accuracy of +/−1 mm.

The capability for ensuring that the subject eye is desirably positioned in angle with respect to the apparatus (i.e., the difference between the visual axis and the optical axis of the system) with an accuracy of +/−0.5 degrees.

The capability for aligning an on-screen reticule to a set of marks applied to the eye outside the limbus to record the rotational orientation of the eye (i.e., about z) with respect to the apparatus with an accuracy of +/−one degree.

Once in position, the patient's eye can be successfully examined by the wavefront sensing technique. This embodiment of the apparatus includes a sufficient dynamic range to measure eyes over the expected scope of refractive errors.

The following list provides range and accuracy parameters, by way of example, for clinical wavefront measurements that can be obtained by this embodiment of the apparatus. This list is provided by way of illustration and does not limit the scope of the present invention.

1. capable of measuring wavefronts with spherical refractive powers in the range +6 to −15 diopters and cylindrical powers in the range 0 to −6 diopters.
2. capable of measuring coma and spherical aberration.
3. capable of measuring refractive errors over a pupil zone of up to 8 mm in diameter.
4. able to measure the refractive errors within the specified ranges to an accuracy of 0.042 μm RMS in air.

With reference again to FIG. **6**, and by way of further example, the output from wavefront analyzer **26**, e.g., the Zernike expansion of equation (19), can be used in a variety of ways. For example, the output may be used to continually or periodically monitor the progress or effects of an ophthalmic procedure, with such stored on disc or transmitted via e-mail, and the like. The output of the wavefront analyzer **26** is input to a processor **90** which converts the Zernike expansion of equation (19) into a form suitable for subsequent use as desired. Alternatively, the processor **90** may also be implemented at the processor **40** of the wavefront analyzer **26**, described earlier with reference to FIG. **6**.

By way of further example, the processor **90** can be used with preselected Zernike coefficients from the expansion of equation (19) to generate a standard sphero-cylindrical specification for a lens grinder **92** to produce a convectional optical lens, e.g., a lens for glasses, a contact lens, and the like.

As described earlier with reference to FIG. **12**, the apparatus **300** of the present venture includes first and second afocal relays stages **358**, **360**. To retain the benefit of wavefront magnification, as a means of increasing the dynamic range of the wavefront sensor **356** to accommodate patients with large refractive errors, while at the same time allowing for incorporation of a small format, inexpensive camera to record the wavefront slope data, a modification **500** to the apparatus **300** as illustrated with reference to FIG. **26**A is provided.

By way of example, a lens array may also be positioned and configured as illustrated with reference to FIG. **26**B, wherein a portion of the apparatus **300** of FIG. **12** includes the first and second afocal stages **358**, **360** within the optical axis **342**, and the wavefront sensor **356** consist of the microlens array and CCD camera separated by a fixed

distant, as earlier described with reference to FIG. **6**. This optical path through the afocal relay stages results in an image of the corneal plane **502** at the lenslet array, i.e. at the entrance face of the actual wave front sensor **356**. This can be accomplished by a single afocal stage. As earlier described with reference to FIG. **12**, the apparatus **300** includes an intermediate image plane as insertion point, the holder **408**, for a trial lens. Placing a spherical lens into the optical axis **342** at the first image plane, in theory, could be used to remove the defocus wavefront error. This would potentially expand the dynamic range of the apparatus **300**. However, the trial lens approach s a moving mechanism that can position lenses at the first image plane with tremendous accuracy in repeatability. It is highly desirable that alternative means be developed to address dynamic range.

One way to accomplish this is to magnify the corneal plane image at the lenslet array with the afocal stage **360**, earlier described. Magnification of the wavefront reduces the wavefront slope, so that the displacement of the focused lights spots on the CCD is decreased. The chosen magnification factor used with the apparatus **300** second afocal stage **360** is approximately 1.2 which is sufficient to cover the desired range in refractive errors. A magnification factor in excess of 1.5 is desirable for expanding the use of the apparatus **300**. However, simply magnifying the corneal plane has a drawback in that it necessitate a large aperture wavefront sensor. That is, both the lens array and the CCD camera preferably have large cross-sectional areas to encompass the magnified image of the point of plane. This is not a significant issue for the lens array. However, a large format CCD camera is quite expensive and such cameras are only available from a limited number of vendors.

To resolve such concerns, the modification **500** illustrated with reference again to FIG. **26**A is provided. The corneal plane **502** is imaged at a reference plane **504** by an afocal relay stage **506**, which magnifies the corneal plane by a preselected amount. The lenslet array **412** is placed at the reference plane **504**. Focused spots of light from the eye **120** are produced at the lenslet array focal plane **504**. Rather than place the CCD detector face at the reference plane **504**, an optical train **508** is inserted to image the array focal plane **413** at yet another plane, a final image plane **510**, at which plane the CCD detector face is positioned. The afocal relay stages **358**, **360** described earlier with reference to FIGS. **12** and **26**B, may or may not be included, as desired. However, the magnification of the array focal plane at the final image plane **510** is provided. This allows a small, relatively inexpensive, active area camera to be used as the light recording element in the wavefront sensor. Details of optical design including magnification specifics can be adjusted to maximize performance for a given camera and lens array plate specification.

The advantages of the present invention are numerous. A totally objective approach is presented for measuring ocular aberrations. The approach is effective for a wide range of vision defects. Accordingly, the present invention will be of great utility in a wide variety of clinical applications. For example, the calculated Zernike coefficients can be used to develop a completely objective lens prescription. In addition, each of the wavefront sensor embodiments provides for a greater degree of accuracy over the prior art with respect to measuring wavefront deflections. Further, the present wavefront sensor can be adjusted in terms of gain simply by adjusting the separation distance between the imaging plane of the sensor and the planar array of light-sensitive cells.

The objective measurement of the present invention will also find great utility for a large variety of applications where the "patient" is unable to provide feedback as d by conventional eye diagnosis. For example, the present invention could be used to evaluate the eyes of any patient not possessed of demonstrative communicative skills, e.g., babies, animals, dead specimens, as well as any constructed optical system, since the present invention is an objective analysis not requiring any assessment from the "subject". All that is necessary is for the subject's eye to be properly positioned so that proper optical access to the eye can be obtained.

The present invention will also be used in the area of identification should it be determined that each eye's Zernike coefficients are unique. Then, the present invention would find great utility in the fields of law enforcement, credit card/bank security, or any other field where positive identification would be beneficial.

Although the invention has been described relative to a specific embodiment thereof, there are numerous variations and modifications that will be readily apparent to those skilled in the art in light of the above teachings. It is therefore to be understood that, within the scope of the appended claims, the invention may be practiced other than as specifically described.

That which is claimed is:

1. A method for determining higher order aberrations of an eye requiring a correction of greater than +3 or −3 diopters, the method comprising:

directing an optical beam onto a retina of an eye;

reflecting the optical beam from the retina of the eye;

determining characteristics of a wavefront in the reflected optical beam; and

generating data based on the characteristics of the wavefront, which data quantifies at least one higher order aberration of the eye.

2. A method according to claim **1**, wherein the correction is made for an eye having myopia of greater than −3 diopters.

3. A method according to claim **1**, wherein the correction is made for an eye having hyperopia of greater than +3 diopters.

4. A method for determining higher order aberrations of an eye requiring a correction of greater than +3 or −3 diopters, the method comprising:

directing an optical beam onto a retina of an eye;

reflecting the optical beam from the retina of the eye;

determining characteristics of a wavefront in the reflected optical beam; and

generating data based on the characteristics of the wavefront and refractive indices of media through which the optical beam passes, which data quantifies at least one higher order aberration of the eye.

5. A method for determining higher order aberrations of an eye requiring a correction of greater than +3 or −3 diopters, the method comprising:

directing an optical beam onto a retina of an eye;

reflecting the optical beam from the retina of the eye;

determining characteristics of a wavefront in the reflected optical beam for a discrete section of the eye; and

generating data based on the characteristics of the wavefront, which data quantifies at least one higher order aberration of the eye for the discrete section.

6. A method for determining aberrations of an eye comprising:

directing a probe beam along a probe beam path toward an eye;

directing a fixation image along a fixation image path toward the eye;

directing a light source along a video image path toward the eye;

generating a video image of the eye;

directing a wavefront originating from the eye along a wavefront path, wherein the probe beam path, the fixation image path, the video image path, and the wavefront path being coincident at least along a portion of their respective paths, the probe beam path terminating at a retina of the eye and the probe beam reflecting from the retina of the eye as a wavefront;

aligning the eye with the probe beam path based at least in part on the video image of the eye generated by the light source directed along the video image path;

measuring the wavefront; and

generating data representative of aberrations of the eye based on the measurement of the wavefront.

7. A method for determining aberrations of an eye comprising:

directing a probe beam along a probe beam path toward an eye;

directing a fixation image along a fixation image path toward the eye;

directing a light source along a video image path toward the eye;

generating a video image of the eye;

directing a wavefront originating from the eye along a wavefront path, the probe beam path, the fixation image path, the video image path, and the wavefront path being coincident at least along a portion of their respective paths, the probe beam path terminating at a retina of the eye and the probe beam reflecting from the retina of the eye as a wavefront;

aligning the eye with the probe beam path based at least in part on the video image of the eye generated by the light source directed along the video image path, the wavefront passing through a single microlens array;

measuring the wavefront; and

generating data representative of aberrations of the eye based on the measurement of the wavefront.

* * * * *

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(12) **United States Patent**
Dinger

(10) **Patent No.: US 6,495,839 B1**
(45) **Date of Patent: Dec. 17, 2002**

(54) **MICROLITHOGRAPHY PROJECTION OBJECTIVE AND PROJECTION EXPOSURE APPARATUS**

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(73) Assignee: **Carl-Zeiss Stiftung**, Heidenheim (DE)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

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(52) **U.S. Cl.** **250/492.2**; 378/34; 359/359; 359/366; 359/856; 359/857; 359/858; 359/861

(58) **Field of Search** 250/492.2; 378/34; 359/359, 366, 856, 857, 858, 861

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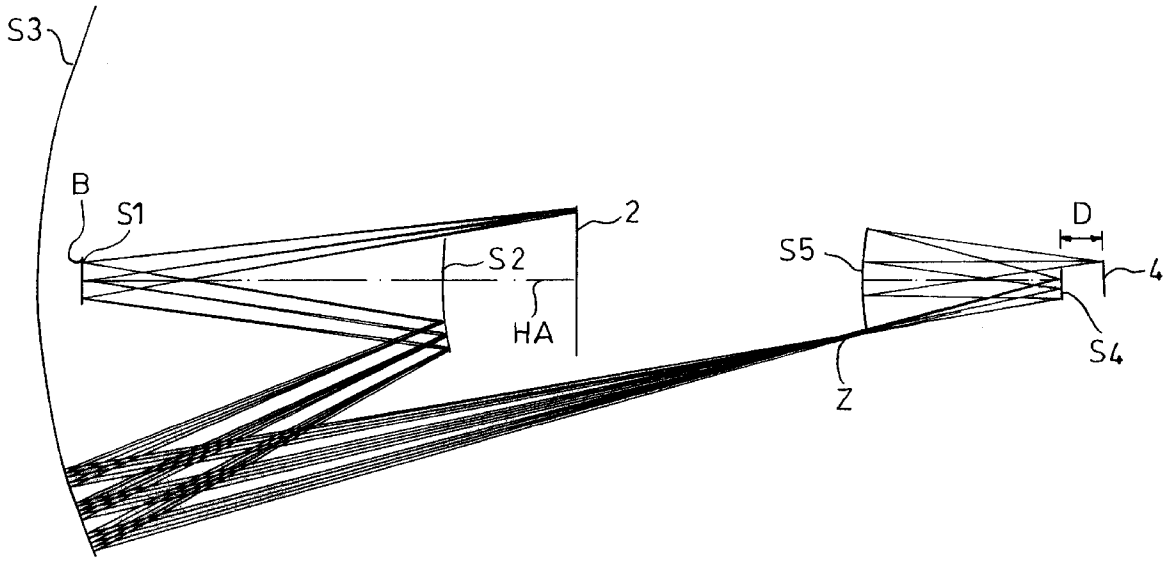
(74) *Attorney, Agent, or Firm*—Marshall, Gerstein & Borun

(57) **ABSTRACT**

The invention is concerned with a microlithography projection objective device for short wavelength microlithography, preferably <100 nm, with a first mirror (**S1**), a second mirror (**S2**), a third mirror (**S3**), a fourth mirror (**S4**) and a fifth mirror (**S5**). The invention is characterized by the fact that the image-side numerical aperture (NA) is greater than or equal to 0.10 and that the mirror closest to the object to be illuminated, preferably the wafer, is arranged in such a way that the image-side optical free working distance corresponds at least to the used diameter (D) of the mirror closest to the wafer; the image-side optical free working distance is at least the sum of one-third of the used diameter (D) of the mirror closest to the wafer and a length which lies between 20 mm and 30 mm; and/or the image-side optical free working distance is at least 50 mm, preferably 60 mm.

17 Claims, 3 Drawing Sheets



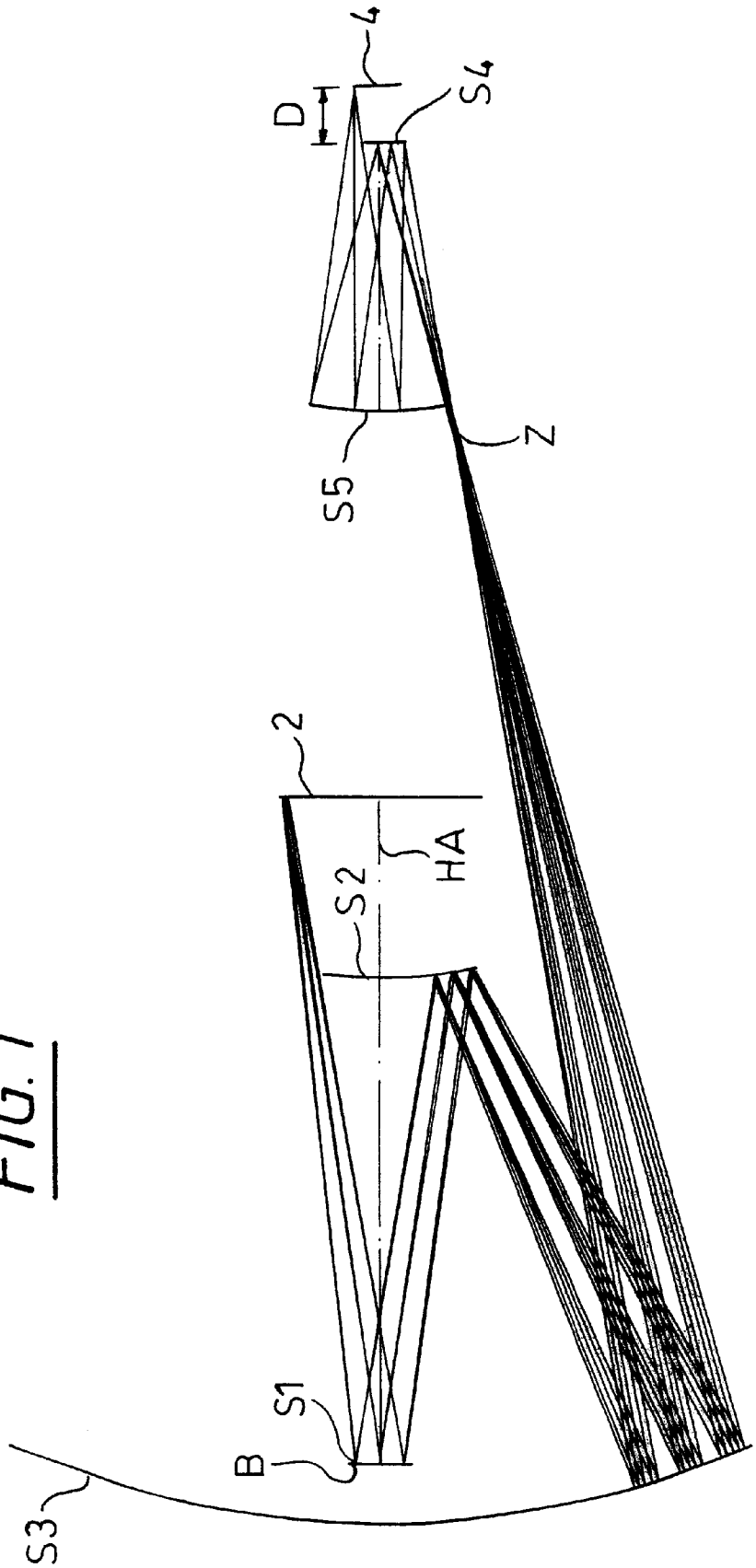
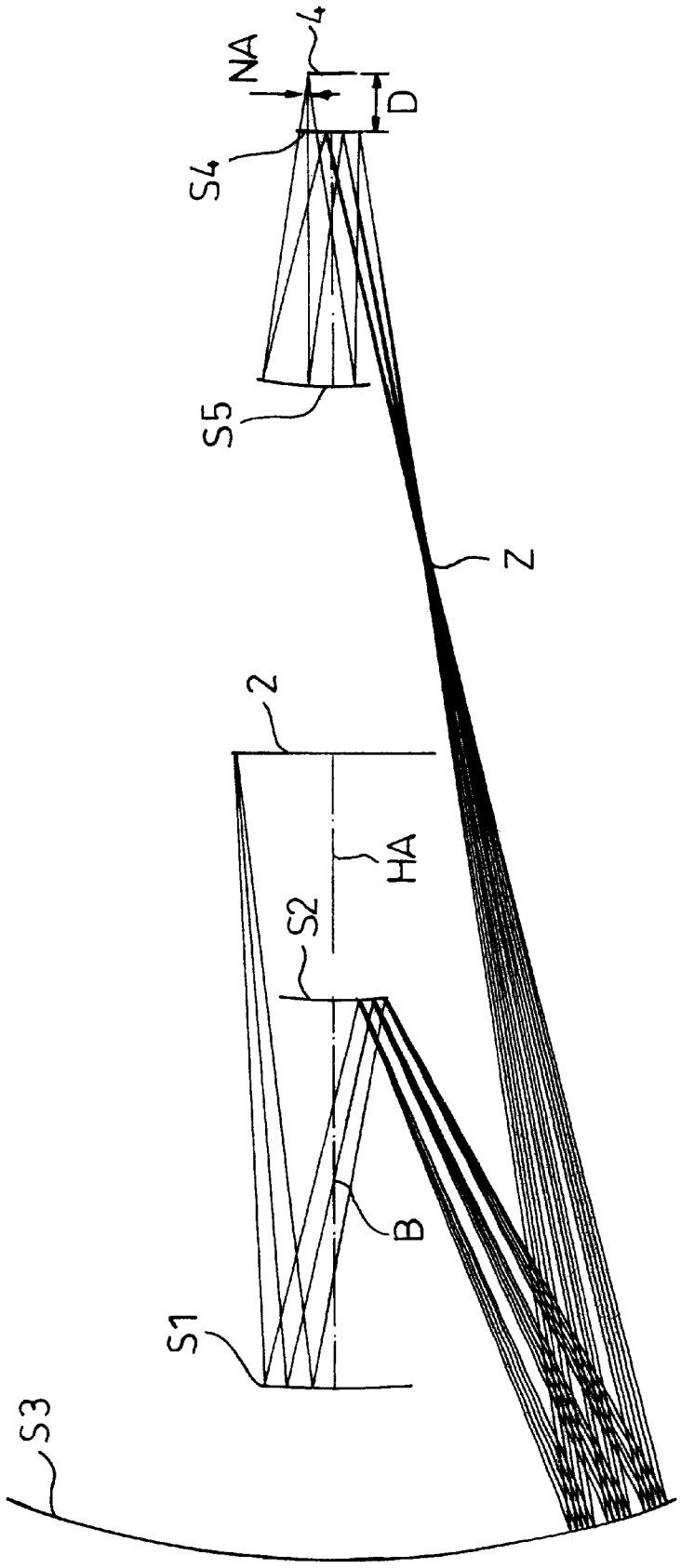


FIG. 1

FIG. 2



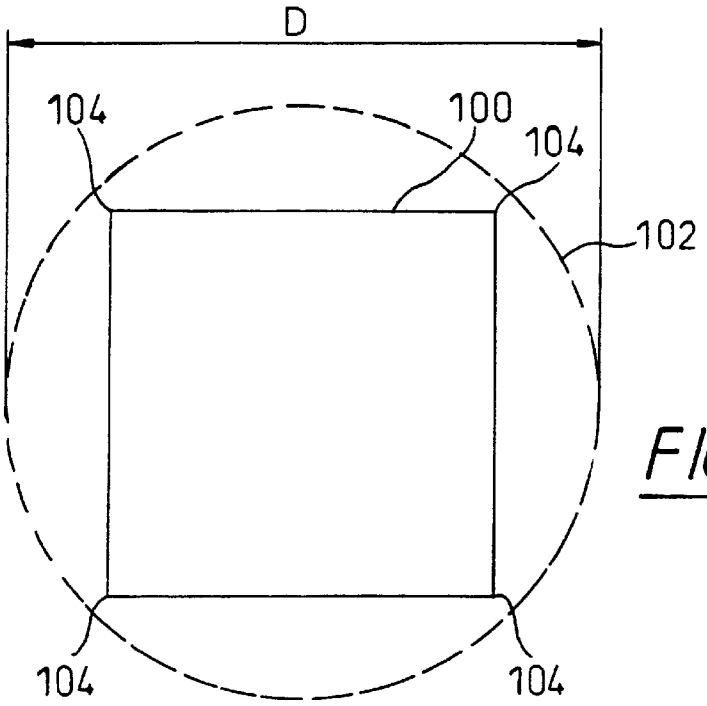


FIG. 3A

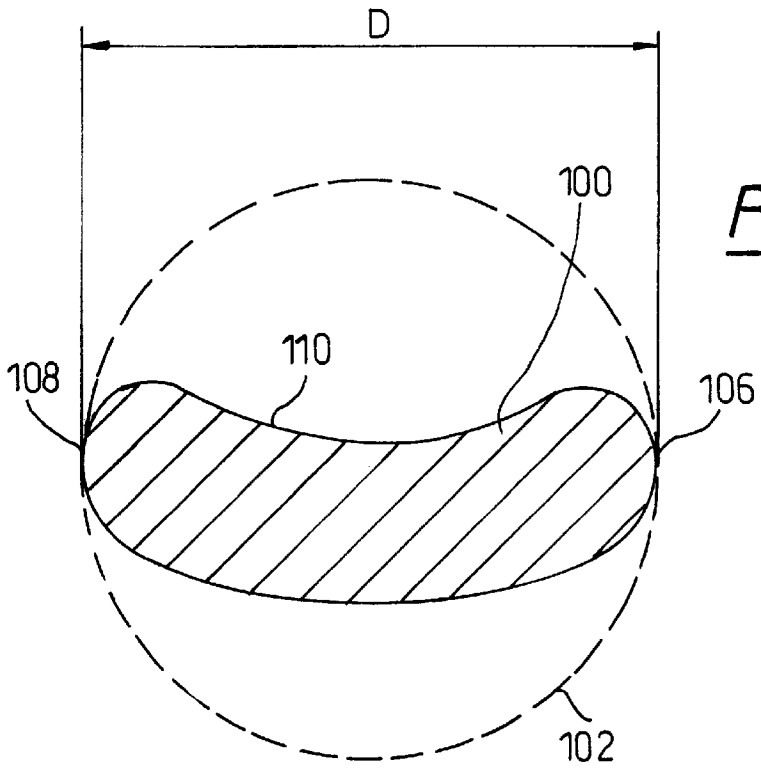


FIG. 3B

MICROLITHOGRAPHY PROJECTION OBJECTIVE AND PROJECTION EXPOSURE APPARATUS

FIELD OF THE INVENTION

The invention relates to a microlithography objective, a projection exposure apparatus containing the objective, and a method of manufacturing an integrated circuit using the same.

BACKGROUND OF THE INVENTION

Using a lithography system operating with wavelengths below 193 nm for imaging structures of below 130 nm resolution has been proposed. In fact, such lithography systems have been suggested for the extreme ultraviolet (EUV) range with wavelengths of λ=11 nm or λ=13 nm producing structures of below 100 nm. The resolution of a lithographic system is described by the following equation:

$$RES=k_1\cdot\lambda/NA,$$

where k_1 is a specific parameter of the lithographic process, λ is the wavelength of the incident light, and NA is the image-side numerical aperture of the system. For example, if one assumes a numerical aperture of 0.2, then the imaging of 50 nm structures with 13 nm radiation requires a process with k_1=0.77. With k_1=0.64, the imaging of 35 nm structures is possible with 11 nm radiation.

For imaging systems in the EUV region, substantially reflective systems with multilayer coatings are available as optical components. Preferably multiple layers of Mo/Be are used as multilayer coating systems for systems operating at λ=11 nm, whereas Mo/Si systems are used for λ=13 mm. With the reflectivity of the multilayer coatings approximating 70%, it is desirable to use as few optical components as possible in applications such as EUV projection objective microlithography to achieve sufficient light intensity. Specifically, to achieve high light intensity and to allow for the correction of imaging errors, systems with six mirrors and a numerical aperture (NA)=0.20 have been used.

The six-mirror systems for microlithography have become known from the publications U.S. Pat. No. 5,686,728, EP 779,528 and U.S. Pat. No. 5,815,310. The projection lithography system according to U.S. Pat. No. 5,686,728 has a projection objective with six mirrors, where each of the reflective mirror surfaces has an aspherical form. The mirrors are arranged along a common optical axis in such a way that an obscuration-free light path is achieved. Since the projection objective known from U.S. Pat. No. 5,686,728 is used only for UV light with a wavelength of 100–300 nm, the mirrors of this projection objective have a very high asphericity of approximately ±50 μm as well as very large angles of incidence of approximately 38°. Even after reducing the numerical aperture to NA=0.2, an asphericity of 25 μm from peak to valley remains, with little reduction in the the angle of incidence. Such asphericities and angles of incidence are not practicable in the EUV region according to the present state of the art because of the higher requirements on surface quality and reflectivity of the mirrors in these latter systems.

Another disadvantage of the objectives disclosed in U.S. Pat. No. 5,686,728, which precludes their use with wavelengths below 100 nm such as the 11 nm and 13 nm wavelengths desirable for EUV microlithography, is the short distance between the wafer and the mirror lying closest to the wafer. This short distance allows only very thin

mirrors to be used in the U.S. Pat. No. 5,686,728 apparatus. Because of the extreme stresses on the coatings of the multilayer systems suitable for the 11 nm and 13 nm wavelengths in question, such thin mirrors are very unstable.

A projection objective with six mirrors for use in EUV lithography, even at wavelengths of 13 nm and 11 nm, has become known from EP 779,528. This projection objective also has the disadvantage, however, that at least two of the six mirrors have very high asphericities of 26 and 18.5 μm. Furthermore, in the EP 779,528 arrangement, the optical free working distance between the mirror next to the wafer and the wafer is so small that either instabilities occur or a negative mechanical free working distance is obtained.

Four-mirror projection objectives have become known from the following publications:

U.S. Pat. No. 5,315,629

EP 480,617

U.S. Pat. No. 5,063,586

EP 422,853

In U.S. Pat. No. 5,315,629, a four-mirror projection objective with NA=0.1, 4×, 31.25×0.5 mm^2 is claimed. From EP 480,617, two NA=0.1, 5×, 25×2 mm^2 systems have become known. The system according to U.S. Pat. No. 5,063,586 and EP 422,853 have a rectangular image field of at least 5×5 mm^2. These generally decentered systems exhibit very high distortion values. Therefore, the objectives can only be used in steppers with distortion correction on the reticle. However, the high level of distortion makes such objectives impractical at wavelengths below 100 nm.

From U.S. Pat. No. 5,153,898, overall arbitrary three to five-multilayer mirror systems have become known. The disclosed embodiments, however, all describe three-mirror systems with a rectangular field and small numerical aperture (NA<0.04). Therefore, the systems described therein can only image structures above 0.25 μm in length. The distortion of most examples lies in the μm range.

Furthermore, reference is made to T. Jewell: "Optical system design issues in development of projection camera for EUV lithography", Proc. SPIE 2437 (1995) and the citations given there, the entire disclosure of which is incorporated by reference.

Thus, it is desirable to provide a projection objective suitable for lithography with short wavelengths, preferably smaller than 100 nm, which does not have the disadvantages of the state of the art mentioned above, and which has as few optical elements as possible and a sufficiently large numerical aperture.

SUMMARY OF THE INVENTION

According to the invention, the short comings of the prior art are overcome by using a projection objective device which has five mirrors. By omitting a mirror from the known six-mirror systems—according to the five-mirror system of the invention—one can achieve a transmission which is at least 30% higher at wavelengths in the EUV region, if a reflectivity of the multilayer coating system of 70% is assumed for this radiation. In addition, numerical apertures of NA>0.10 can be realized. The five-mirror objective according to the invention is thus characterized by high resolution, low manufacturing costs and high throughput.

In a first embodiment of the invention, the mirror closest to the wafer is arranged in such a way that the image-side numerical aperture NA is greater than or equal to 0.10. Furthermore, the mirror closest to the wafer is arranged such that (1) the image-side free optical working distance corresponds at least to the used diameter of the mirror closest to

the wafer, (2) the image-side optical free working distance is at least the sum of one-third of the used diameter of the mirror closest the wafer and a length which lies between 20 and 30 mm, and/or (3) the image-side optical free working distance is at least 50 mm. Preferably, the optical free working distance is 60 mm.

In a second embodiment of the invention, the image-side numerical aperture NA is greater than or equal to 0.10, the annular field width W at the wafer lies in the region 1.0 mm≦W, and the peak-to-valley deviation, A, of the aspheres is limited with respect to the best-fitting sphere in the useful region on all mirrors, by:

$$A \leqq 24\ \mu m - 129\ \mu m(0.20 - NA) - 2.1\ \mu m/mm(2\ mm - W).$$

In a preferred embodiment, the peak-to-valley deviation A of the aspheres on all mirrors is limited by:

$$A \leqq 9\ \mu m - 50\ \mu m(0.20 - NA) - 0.4\ \mu m/mm(2\ mm - W).$$

In a third embodiment of the invention, with a numerical aperture in the range NA≧0.10 and an image-side width of the annular field in the range W≧1 mm, the angles of incidence, AOI, on all mirrors, relative to the normal of the surface of a given mirror, is limited by:

$$AOI \leqq 22° - 2°(0.20 - NA) - 0.3°/mm(2\ mm - W).$$

Combinations of the above may also be used according to the invention. For example, in a preferred embodiment, all three conditions are fulfilled, i.e., the free optical working distance is more than 50 mm at NA greater than 0.10 and the peak-to-valley deviation of the aspheres as well as the angles of incidence in the region defined above.

The asphericities herein refer to the peak-to-valley (PV) deviation, A, of the aspherical surfaces with respect to the best fitting sphere in the used area. The aspherical surfaces are approximated in the examples by using a sphere with center on the figure axis vertex of the mirror and which intersects the asphere in the upper and lower endpoint of the used area in the meridian section. The data regarding the angles of incidence always refer to the angle between the incident rays and the normal to the surface at the points of incidence. The largest angle of any incident light ray occurring on any of the mirrors is always given, i.e., the angle of a bundle-limiting ray. The used diameter will be defined here and below as the envelope circle diameter of the used area, which is generally not circular.

Preferably, the wafer-side optical free working distance is 60 mm.

The objective can be used not only in the EUV, but also at other wavelengths, without deviating from the scope of the invention. In any respect, however, to avoid degradation of image quality, especially degradation due to central shading, the mirrors of the projection objectives should be arranged so that the light path is obscuration-free. Furthermore, to provide easy mounting and adjusting of the system, the mirror surfaces should be designed on a surface which shows rotational symmetry to a principal axis (PA). Moreover, to have a compact design with an accessible aperture stop and to establish an obscuration-free path, the projection objective devices are designed to produce an intermediate image. It is preferred that the system include of a first and second subsystem, where a real intermediate image is formed by the first subsystem (with an imaging ratio in the range of $\beta<0$), and that the second subsystem images the intermediate image to a real system image in the wafer plane. In such structures, it is possible to have the plane for the object to be imaged located within the structural space of the entire mirror system, including the first, second, third, fourth and fifth mirrors.

In an embodiment of the invention, the aperture stop B lies on the first mirror. Alternatively, the freely accessible aperture stop can lie, both optically and physically, between the second and third mirrors.

In order to be able to make the necessary corrections of the imaging errors in the five-mirror systems, in a preferred embodiment, all five mirrors are aspherical. However, an alternative embodiment whereby at most four mirrors are aspherical, thus simplifying the manufacturing process, can be achieved. Then it is possible to make at least one mirror spherical, preferably the largest mirror.

In order to reach a resolution of at least 50 nm, the design part of the rms wave front part of the system should be at most 0.07 λ and preferably 0.03 λ.

Advantageously, in the examples of the invention, the objectives are always designed to be telecentric on the image-side. In projection systems which are operated with a reflection mask, a telecentric beam path on the object-side is not possible without illumination through a beam splitter which reduces transmission strongly such as known, for example, from JP-A-95 28 31 16. Therefore, the chief ray angles on the reticle are chosen so that vignetting-free illumination is possible. Alternatively, in systems with transmission masks, the projection objective can be telecentric on the object-side. Overall, the telecentricity error on the wafer should not exceed 10 mrad and typically is between 5 mrad and 2 mrad, with 2 mrad being preferred. This ensures that changes of the imaging ratio remain within tolerable limits over the focus.

In the embodiments of the invention, the projection objective is divided into two subsystems. The first subsystem is a reducing three-mirror system, preferably with imaging ratio (β) in range of $-0.5>\beta>-1.0$, and the second subsystem is a two-mirror subsystem.

In addition to the projection objective, the invention also provides a projection exposure apparatus, including at least one projection objective. In a first embodiment, the projection exposure apparatus has a reflection mask, while in an alternative embodiment, it has a transmission mask.

Furthermore, in a preferred embodiment, the projection exposure apparatus is an arc-shaped field scanner, and includes an illumination device for illuminating an off-axis arc-shaped field. Advantageously, the secant length of the scan slit is at least 26 mm and that the arc width is greater than 0.5 mm, so that homogenous illumination becomes possible.

The invention will be described below with the aid of drawings as examples.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a first embodiment of the invention with a real intermediate image between the first and second subsystem.

FIG. **2** is a second embodiment of the invention in which the aperture stop lies between the first and second mirror;

FIGS. **3**A and **3**B show the used diameter for differently illuminated light fields.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

In FIGS. **1** and **2**, preferred arrangements of the five-mirror projection objectives according to the invention are shown. Each has an optical free working distance that corresponds at least to the used diameter of the mirror

closest to the wafer or object to be illuminated. In all embodiments below, the same reference numbers are used for the same components with the following nomenclature employed:

first mirror (S1), second mirror (S2), third mirror (S3), fourth mirror (S4), and fifth mirror (S5).

In particular, FIG. 1 shows a five-mirror projection objective with a beam path from the reticle plane 2 to the wafer plane 4. The embodiment can be considered as a series circuit with (1) a three-mirror system consisting of S1, S2 and S3, that produces a real, reduced image of the object, as the intermediate-image Z and (2) a two-mirror system S4, S5, which images the intermediate image Z in the wafer plane 4 while maintaining the telecentricity requirements. The aberrations of the subsystems are balanced against one another in such a way that the total system has sufficient quality for the application.

A physical aperture stop B is arranged on the first mirror S1. To block light from passing above the aperture stop B, a narrow ring is used to block the light reflected toward S2 from S1. In the embodiment shown in FIG. 1, the aperture is realized as an opening at the S1 mirror. The aperture stop can also be positioned between the mirror S1 and the mirror S2.

In the system according to FIG. 1, the optical free working distance D between the mirror next to the wafer plane 4, the fourth mirror S4 in the present embodiment, and the wafer plane 4 is greater than the used diameter of mirror S4, that is, the following condition is fulfilled:

optical distance from S4 to the wafer plane 4> used diameter S4. Other distance conditions are possible, for example, that the optical free working distance is greater than the sum of one-third of the used diameter of the mirror S4 nearest to the wafer plane 4 plus 20 mm or that the optical free working distance can be greater than 50 mm. In the embodiment of FIG. 1, the free optical working distance is 60 mm. Such an optical working distance guarantees sufficient free mechanical working distance, which is greater than 0, as well as the use of optical components with sufficient strength properties to be used at wavelengths <100 nm and preferably of 11 or 13 nm.

The optical components for a wavelength of λ=13 nm and λ=11 nm include, for example, Mo/Si and Mo/Be multilayer coating systems, respectively, where the typical multilayer coating systems for λ=13 nm are 40 Mo/Si layer pairs, while the Mo/Be systems that are suitable for λ11 nm have approximately 70 layer pairs. Reflectivities of such systems lie in the range of approximately 70%. In the multilayer coating systems, layer stresses of above 350 MPa and more may occur. Stresses of such values may induce surface deformation, especially in the edge regions of the mirror.

The systems according to the invention, as shown as an example in FIG. 1, have:

$$RES=k_1\lambda/NA.$$

This results in a nominal resolution of at least 50 nm and 35 nm at a minimum numerical aperture of NA=0.15 for k_1=0.57 and λ=13 nm, and k_1=0.47 and λ=11 nm, respectively, where k_1 is a parameter specific for the lithographic process.

Furthermore, the beam path of the objective shown in FIG. 1 is obscuration-free. For example, in order to produce image formats of 26×34 mm^2 or 26×52 mm^2, the projection objectives according to the invention are preferably used in an arc-shaped field scan projection exposure apparatus, where the secant length of the scan slit is at least 26 mm.

Numerous types of mask can be used in the projection exposure apparatus, including transmission masks, stencil masks, and reflection masks, and the system, which is telecentric on the image-side can be telecentric or not telecentric on the object-side. For example, to form a telecentric beam path on the object-side, when using a reflection mask, a transmission-reducing beam splitter must be employed. With a beam path not telecentric on the object-side, unevenness of the mask will not lead to scaling errors in the image. The main beam angles at the reticle plane 2 are therefore preferably less than 10°, so that the requirements for reticle evenness lie in technologically realizable range. Moreover, the system according to FIG. 1 has an image-side telecentering error on the wafer plane 4 of 3±0.1 mrad at a numerical aperture of 0.15.

In the embodiment shown, all mirrors S1–S5 are aspherical, and the maximum asphericity in the used area lies at 14 μm. The maximum asphericity occurs on mirror S3. The low asphericity of the arrangement is advantageous from a manufacturing point of view, since the technological difficulties in producing of the surfaces of the multilayer mirror increase with the aspherical deviation and increasing gradient of the asphere.

The highest angle of incidence in the arrangement according to FIG. 1 occurs at S2 and is 18.9°. The wavefront error of the arrangement is better than 0.023 λ in the 2 mm wide arc-shaped field at λ=13 nm.

With the embodiments shown in FIGS. 1 and 2, the disadvantage of a mirror system with an odd number of mirrors, namely that a stretched structure reticle-projection optics-wafer can no longer be realized, is overcome. This disadvantage results from the fact that the reticle plane and the wafer plane were illuminated from the same direction especially in the case of systems with near normal incidence. This condition led to the reticle plane and the wafer plane lying on the same side of the objective.

According to FIG. 1 or 2, the reticle plane 2 is placed within the projection system. The mirror arrangement is chosen so that, in the direction of the optical axis, the structural space provided for the reticle stage, within the projection system, is as large as possible, preferably 400 mm. In addition, the plane of the object, i.e., the reticle, has a sufficiently large distance to the light bundles traveling in the objective. This ensures that a sufficiently large object, i.e., reticle, can be scanned in an annular field scanning operation. In a preferred example, approximately 200 mm can be scanned on the reticle, corresponding to 50 mm on the wafer.

In the embodiment shown in FIG. 1, the two mirrors of the two-mirror subsystem (S4, S5) have approximately the same radii R, within a few percent, and the distance between the two of the two oblate ellipsoidal mirrors is approximately R/$\sqrt{2}$. The three-mirror subsystem near the reticle plane 2 consists of three almost concentric mirrors (S1, S2, S3) of which the primary (S1) and the tertiary mirror (S3) have similar radii. The subsystem near the reticle plane 2 differs from a disturbed Offner system mainly by the position of the aperture stop B on the primary mirror and the non-telecentric beam path on the reticle.

A real intermediate image Z is produced between the two subsystems. The chief-ray angle inclination on the reticle plane 2 permits a vignetting-free illumination of a reflection mask. Furthermore, in the embodiments according to FIGS. 1 and 2, the distances between the mirrors are chosen to have a value such that the mirrors can be sufficiently thick so that the required strength properties are still obtained at the high layer stresses that occur.

The parameters of the systems shown in FIG. 1 are given in Table 1 in Code V (™) nomenclature. The objective is a 4× system with a 26×2 mm^2 arc-shaped field and a numerical aperture NA of 0.15. The mean image-side radius of the system is approximately 26 mm.

TABLE 1

element number	radius	thickness	diameter	type
object	INF	−693.4069		
			52.0652	
		354.7680		
			135.9392	
		−92.4573		
			114.0805	
		−262.3106		
		aperture	52.0652	
		0.0000		
1	A(1)	354.7680		
			52.1468	REFL
			150.4663	
		148.5214		
			191.7567	
		0.0000		
2	A(2)	−148.5214	194.3744	REFL
			375.2582	
		−415.6887		
3	A(3)	564.2101	763.1343	REFL
			488.5602	
		590.1176		
			161.9611	
		276.5162		
4	A(4)	−276.5162	56.7269	REFL
5	A(5)	276.5162	150.9852	REFL
			71.4698	
image	image width	59.0000		
			54.0239	

Asphericity constants:

$$Z = \frac{(CURV)Y^2}{1 + (1 - (1 + K)(CURV)^2Y^2)^{1/2}} + (A)Y^4 + (B)Y^6 + (C)Y^8 + (D)Y^{10}$$

asphere	CURV	K	A	B	C	D
A(1)	0.00101481	5.839224	0.00000E+00	3.87962E−14	4.75060E−18	−3.72457E−22
A(2)	0.00199897	−1.309152	0.00000E+00	2.41371E−15	1.33811E−19	−4.72546E−24
A(3)	0.00101913	−0.062382	0.00000E+00	−4.60126E−18	2.36912E−23	−4.12881E−29
A(4)	0.00276967	9.874573	0.00000E+00	−3.75169E−13	2.32666E−17	−7.34689E−21
A(5)	0.00276492	0.076718	0.00000E+00	2.43566E−17	−1.36024E−20	1.02666E-25

Reference wavelength = 13 nm

FIG. **2** shows an alternative embodiment of the invention of a five-mirror system in which the aperture stop B is between the first mirror and the second mirror. The same components as in FIG. **1** are assigned the same reference numbers.

The optical free working distance at the wafer plane **4** is approximately 60 mm in this embodiment, and thus it is larger than the used diameter of the mirror **S4**, which is closest to the wafer plane **4**. In contrast to the embodiment according to FIG. **1**, in FIG. **2** the aperture stop B is placed physically between the first and second mirrors so that it is freely accessible. The wavefront error is 0.024 λ, within the 1.7 mm wide arc-shaped field at λ=13 nm.

Table 2 shows the constructional data of the 4× objective according to FIG. **2** in Code V (™) nomenclature. The mean radius of the 26×1.7 mm^2 is again 26 mm and the aperture NA=0.15.

TABLE 2

element number	radius	thickness	diameter	type
object	INF	−693.4069		
			154.7165	
		354.7645		
			186.0707	
		−92.4523		
			177.8997	
		−262.3122		
			154.7165	
		−0.0000		

TABLE 2-continued

1	A(1)	236.0296	155.0648	REFL
			37.8314	
		0.0000		
		aperture	37.8314	
		184.2473		
2	A(2)	−168.2690	108.2091	REFL
			290.4780	
		−435.4421		
3	A(3)	603.7111	685.3018	REFL
			431.6713	
		673.5394		
			148.3568	
		275.3310		
4	A(4)	−275.3310	61.3839	REFL
5	A(5)	275.3310	153.1871	REFL
			72.9358	
		63.1295		
image	image width		54.0638	

Asphericity constants:

$$Z = \frac{(CURV)Y^2}{1 + (1 - (1 + K)(CURV)^2Y^2)^{1/2}} + (A)Y^4 + (B)Y^6 + (C)Y^8 + (D)Y^{10}$$

asphere	CURV	K	A	B	C	D
A(1)	0.00130732	0.130035	0.00000E+00	1.69206E−15	−1.65350E−19	8.14629E−24
A(2)	0.00277574	0.091769	0.00000E+00	−7.44262E−14	2.28766E−17	−2.87177E−21
A(3)	0.00102490	−0.014023	0.00000E+00	−2.96927E−17	1.64882E−22	−3.87456E−28
A(4)	0.00210508	12.753039	0.00000E+00	−8.13887E−14	−1.07272E−16	3.55319E−20
A(5)	0.00262203	0.142491	0.00000E+00	3.75109E−17	−3.86791E−20	−3.22849E−24

Reference wavelength = 13 nm

FIGS. **3**A and **3**B illustrate the meaning of the used diameter D in the present application. As an example, let the illuminated field **100** on a mirror in FIG. **3**A be a rectangular field. The used diameter D is then the diameter of the envelope circle **102**, which encompasses the rectangle **100**, where the corners **104** of the rectangle **100** lie on the envelope circle **102**.

FIG. **3**B shows a second example. The illuminated field **100** has a kidney shape, as expected for the useful range when using the objective according to the invention in a microlithography projection exposure apparatus. The envelope circle **102** encompasses the kidney shape fully and coincides with the edge **110** of the kidney shape at two points **106**, **108**. The used diameter D is then the diameter of the envelope circle **102**.

Thus, with the invention, a five-mirror projection objective is given for the first time, with an imaging scale of preferably 4×, 5× as well as 6× for preferred use in an EUV arc-shaped projection system. The projection objection has the necessary resolution for the required image field and provides conditions that make functional structural design possible, since the aspheres are sufficiently mild, the angles are sufficiently small for the layers and the structural spaces for the mirror carriers are sufficiently large.

What I claim is:

1. A projection objective for use in short wavelength microlithography to image an object onto a wafer plane, comprising:

a first mirror (**S1**), a second mirror (**S2**), a third mirror (**S3**), a fourth mirror (**S4**), and a fifth mirror (**S5**) such that the projection objective comprises a first subsystem and a second subsystem and wherein the object is imaged by a first subsystem, formed of the first mirror, the second mirror, and the third mirror (**S1**, **S2**, **S3**) with an imaging ratio (β) less than 0, into a real intermediate image (Z), and wherein a second subsystem, formed of the fourth mirror and the fifth mirror (**S4**, **S5**), images the intermediate image as a real system image in the wafer plane.

2. The projection objective of claim **1**, wherein

the first mirror (**S1**), the second mirror (**S2**), the third mirror (**S3**), the fourth mirror (**S4**), and the fifth mirror (**S5**) are arranged such that the image-side numerical aperture (NA) is

$$NA \geqq 0.10,$$

the arc-shaped field width (W) at the wafer plane lies in the range of

$$W \geqq 1.0 \text{ mm},$$

and the peak-to-valley deviation (A) of the aspheres in comparison to the best-fitting sphere in the used area is limited on all mirrors by

$$A \leqq 24\ \mu m - 129\ \mu m(0.20 - NA) - 2.1\ [\mu m/mm](2\ mm - W).$$

3. The projection objective of claim **1**, wherein

the first mirror (**S1**), the second mirror (**S2**), the third mirror (**S3**), the fourth mirror (**S4**), and the fifth mirror (**S5**) are arranged such that the image-side numerical aperture (NA) is at least 0.10, the image-side width of the arc-shaped field (W) at the wafer plane is at least 1.0 mm, and the angle of incidence (AOI) on all mirrors are in the range:

$$AOI \leqq 22° - 2°(0.20 - NA) - [0.3°/mm](2\ mm - W),$$

where the angle of incidence is measured for any given mirror relative to the surface normal of that mirror.

4. The projection objective of claim 1, wherein

the first mirror (S1), the second mirror (S2), the third mirror (S3), the fourth mirror (S4), and the fifth mirror (S5) are arranged such that the image-side numerical aperture (NA) is at least 0.10, and an object plane, where the object is located, is within the structural space of a mirror system consisting of the first mirror, second mirror, third mirror, fourth mirror and fifth mirror.

5. The projection objective according to claim 1, wherein the first subsystem is disposed near the object and that the second subsystem is disposed near the wafer plane.

6. The projection objective according to claim 4, wherein the mirrors are arranged in such a way that there is sufficient lateral structural space provided for a scan of the object plane so that an obscuration-free beam path is achieved.

7. The projection objective according to claim 4, wherein the mirrors are arranged in such a way that there is sufficient axial structural space for a scan of the object plane so that an obscuration-free beam path is achieved.

8. The projection objective according to claim 1, wherein the fourth mirror and the fifth mirror have substantially the same radii (R).

9. The projection objective according to claim 8, wherein the distance between the fourth mirror and the fifth mirror is approximately $\frac{R}{\sqrt{2}}$.

10. The projection objective according to claim 1, wherein the mirror surfaces are arranged on surfaces which exhibit rotational symmetry with respect to a principal axis (PA).

11. The projection objective according to claim 1, further comprising an aperture stop (B) arranged on the body of the first mirror (S1).

12. The projection objective according to claim 1, wherein the aperture stop lies between the first mirror and second mirror so that it is freely accessible.

13. The projection objective according to claim 1, wherein at least four mirrors are aspherical.

14. The projection objective according to claim 13, wherein all mirrors are aspherical.

15. The projection objective according to claim 1, wherein the imaging ratio (β) of the first subsystem is between −0.5 and −1.0.

16. The projection objective according to claim 1, wherein the rms wavefront error of the objective is at most 0.07 λ over an entire image field.

17. The projection exposure apparatus with a microlithography projection objective according to claim 1, further comprising an illumination device for illuminating an arc-shaped field.

* * * * *

US006460997B1

(12) **United States Patent**
Frey et al.

(10) **Patent No.: US 6,460,997 B1**
(45) **Date of Patent: Oct. 8, 2002**

(54) **APPARATUS AND METHOD FOR OBJECTIVE MEASUREMENTS OF OPTICAL SYSTEMS USING WAVEFRONT ANALYSIS**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

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(52) **U.S. Cl.** **351/211**

(58) **Field of Search** 351/205, 206, 351/211, 212, 215, 219, 221, 246, 247; 356/124; 606/4, 5

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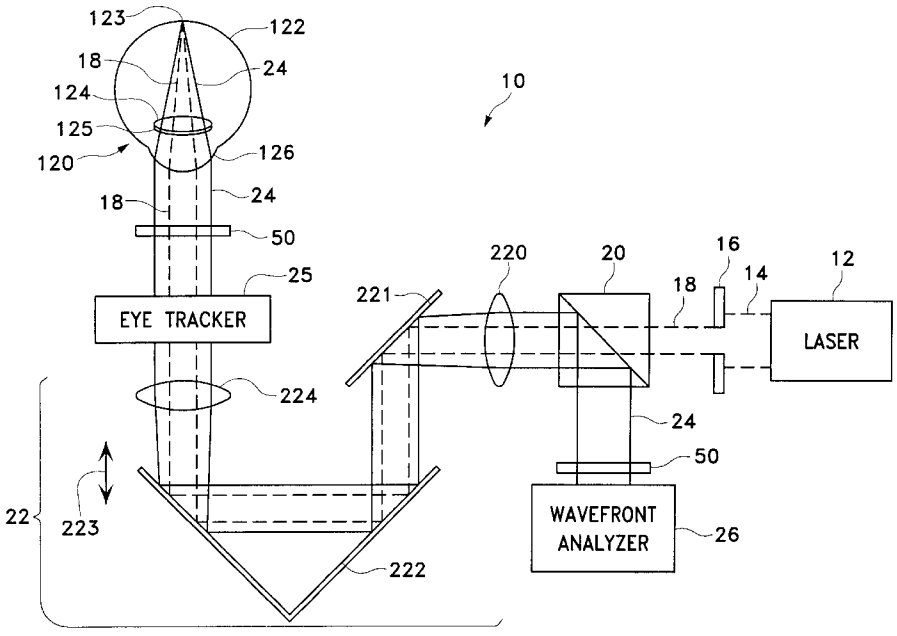
(57) **ABSTRACT**

An apparatus for determining aberrations of an eye includes a patient head rest allowing for positioning adjustment. The patient head rest is operable with an optical table having a base. The base includes a probe beam generating apparatus, probe beam directing optics which itself comprises a beam splitter; a mirror; and a lens. The probe beam directing optics is capable of directing a probe beam toward an eye of a patient positioned on the patient head rest. Video image components are provided and comprise a light source, a mirror; and a video camera. The video image components are capable of generating an image of an eye of a patient positioned on the patient head rest. Eye fixation components generate a target that the eye of a patient positioned on the patient head rest can view. The eye fixation components comprise a fixation target, a light source, a lens, and a mirror. Wavefront directing and analyzing components measure a wavefront emanating from the eye of a patient positioned on the patient head rest and determine aberrations of the eye that range from at least about + or − 1 diopters to at least about + or − 6 diopters. The wavefront directing and analyzing components include a lens; a mirror, a microlens array, a camera, and a data processor.

6 Claims, 28 Drawing Sheets



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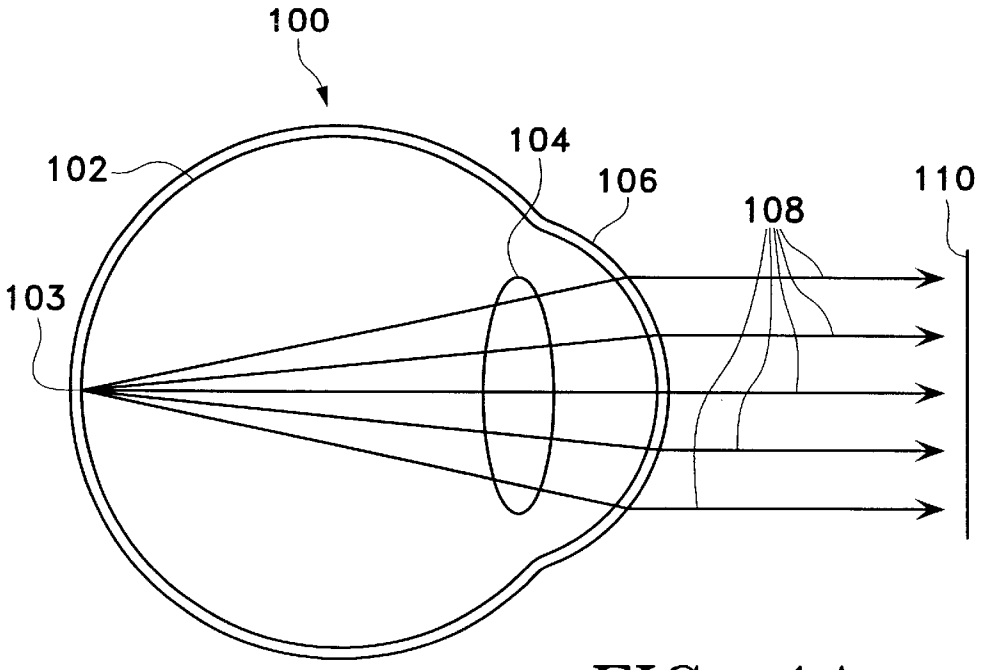


FIG. 1A

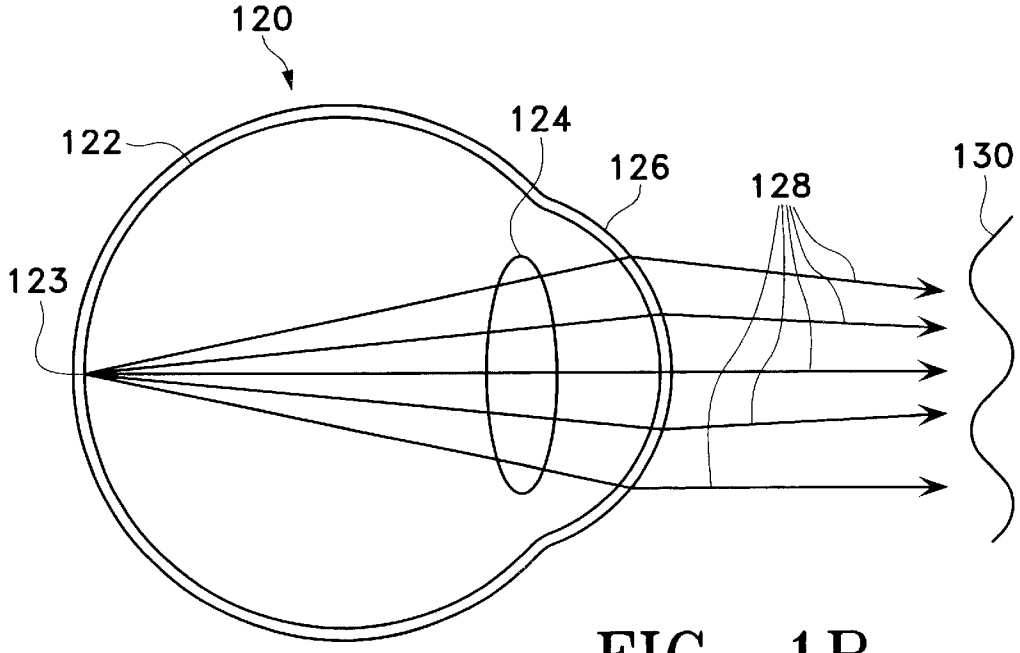


FIG. 1B

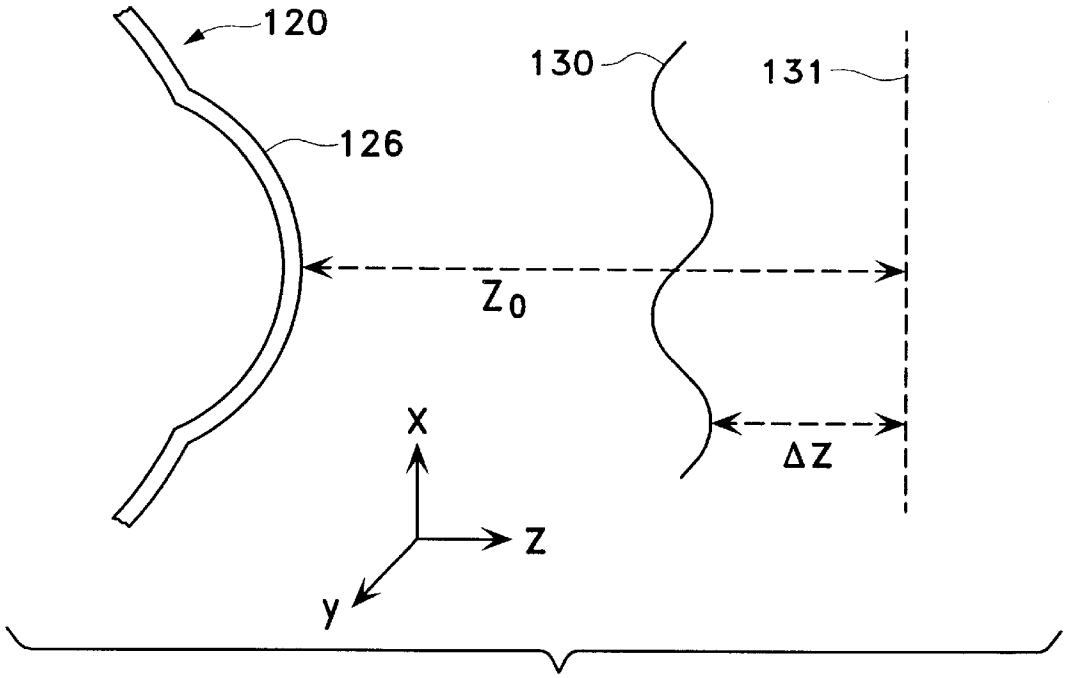

120
130
131
126
Z_0
X
Z
y
ΔZ

FIG. 1C

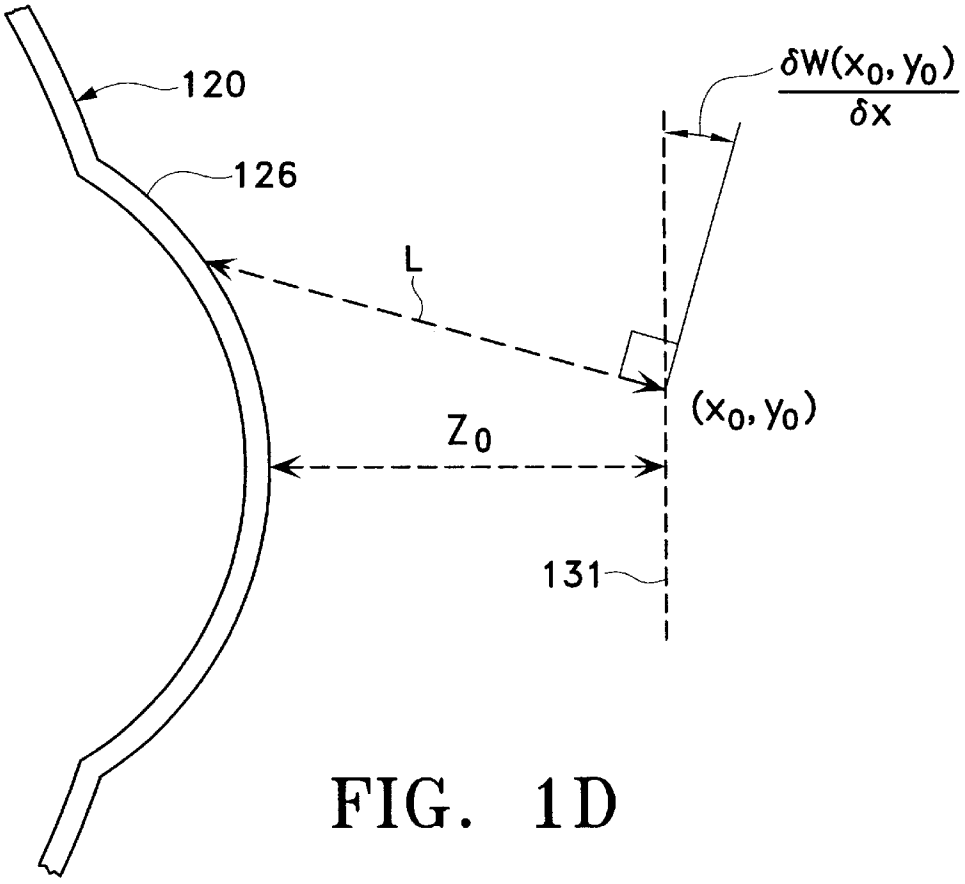
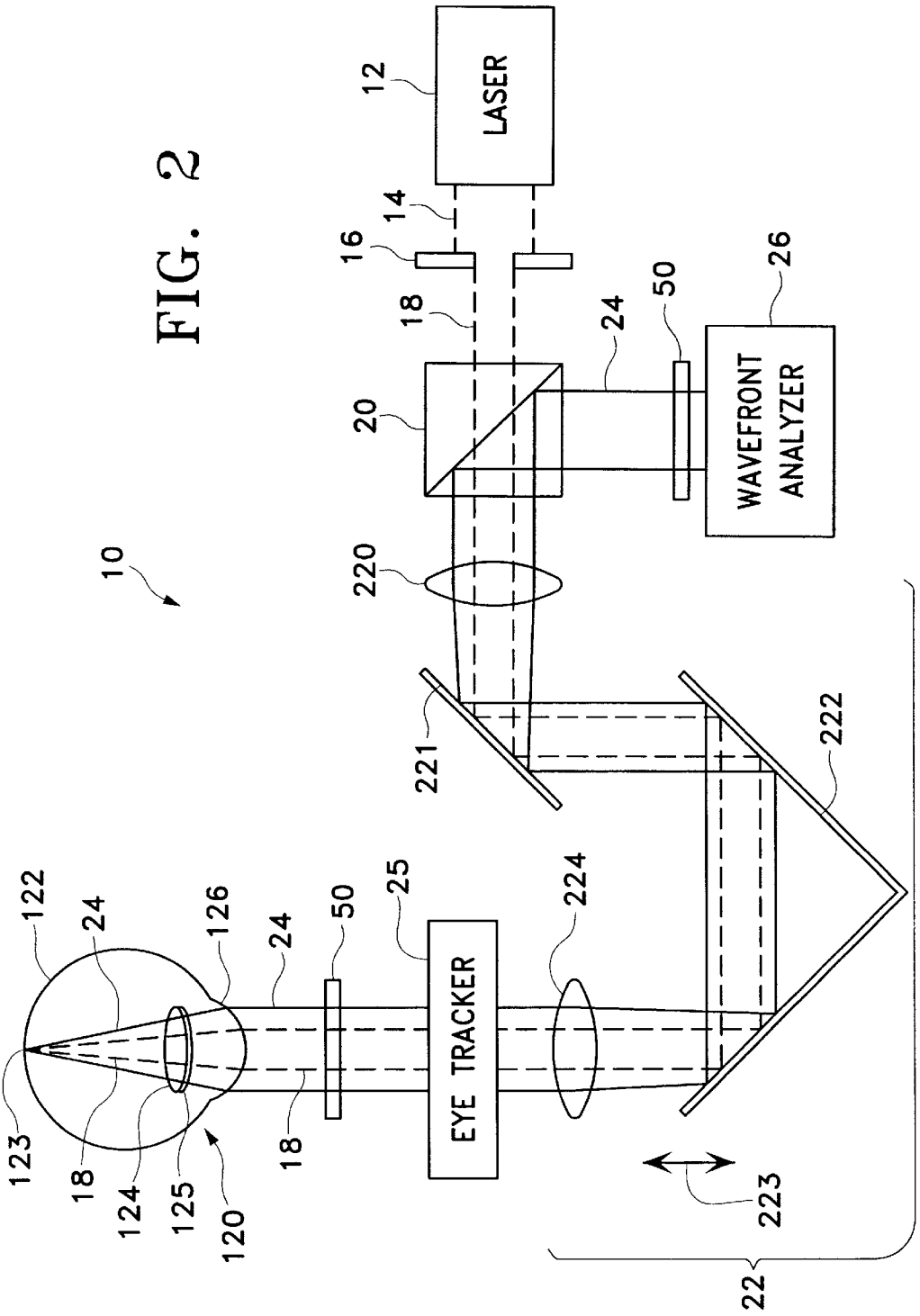

120
126
$\frac{\delta W(x_0, y_0)}{\delta x}$
L
(x_0, y_0)
Z_0
131

FIG. 1D

FIG. 2


10
12
LASER
14
16
18
20
24
50
26
WAVEFRONT ANALYZER
220
221
222
224
25
EYE TRACKER
223
22
122
126
123
18
124
125
120

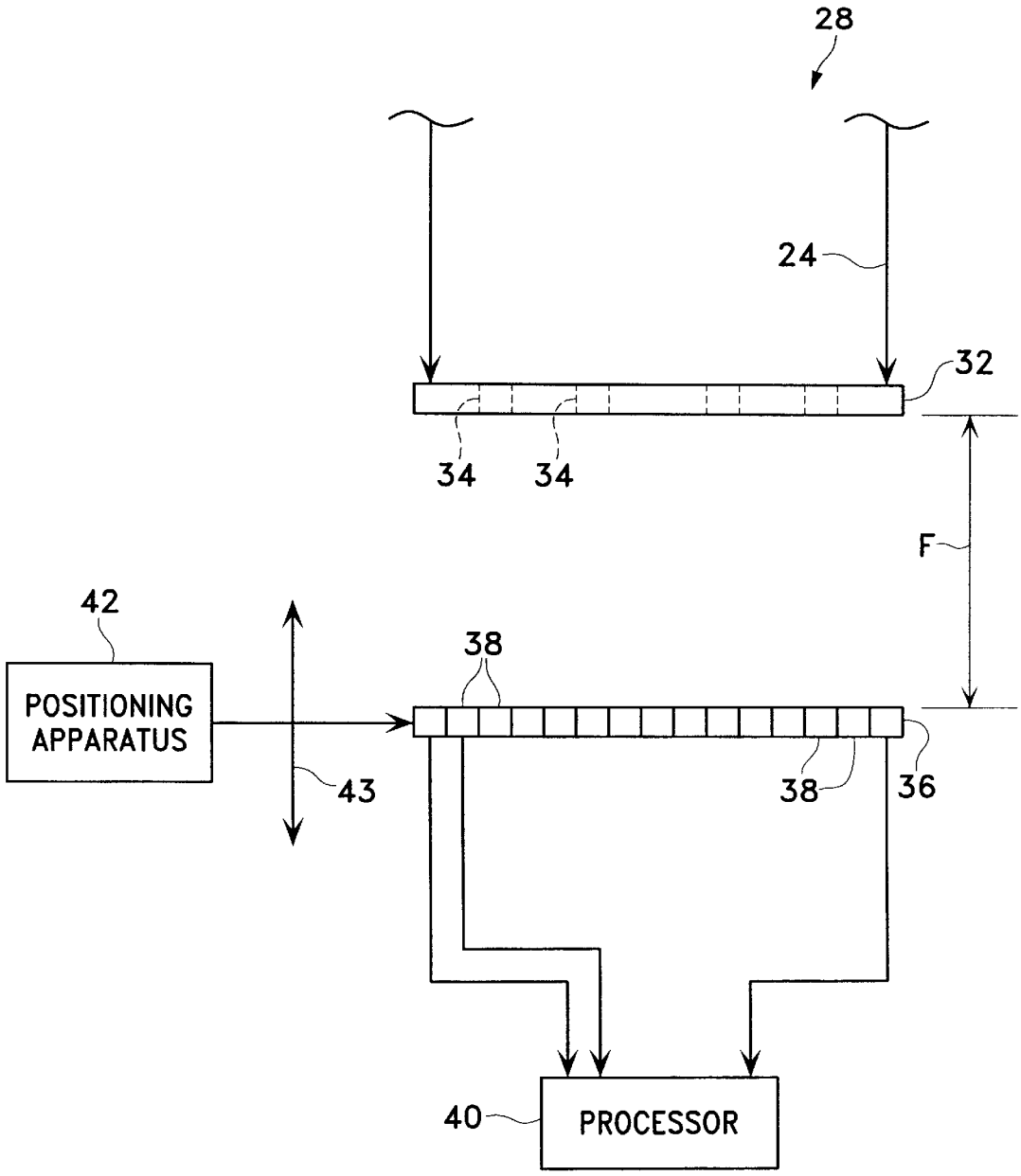

28
24
32
34
34
F
42
POSITIONING APPARATUS
38
43
38
36
40
PROCESSOR

FIG. 3

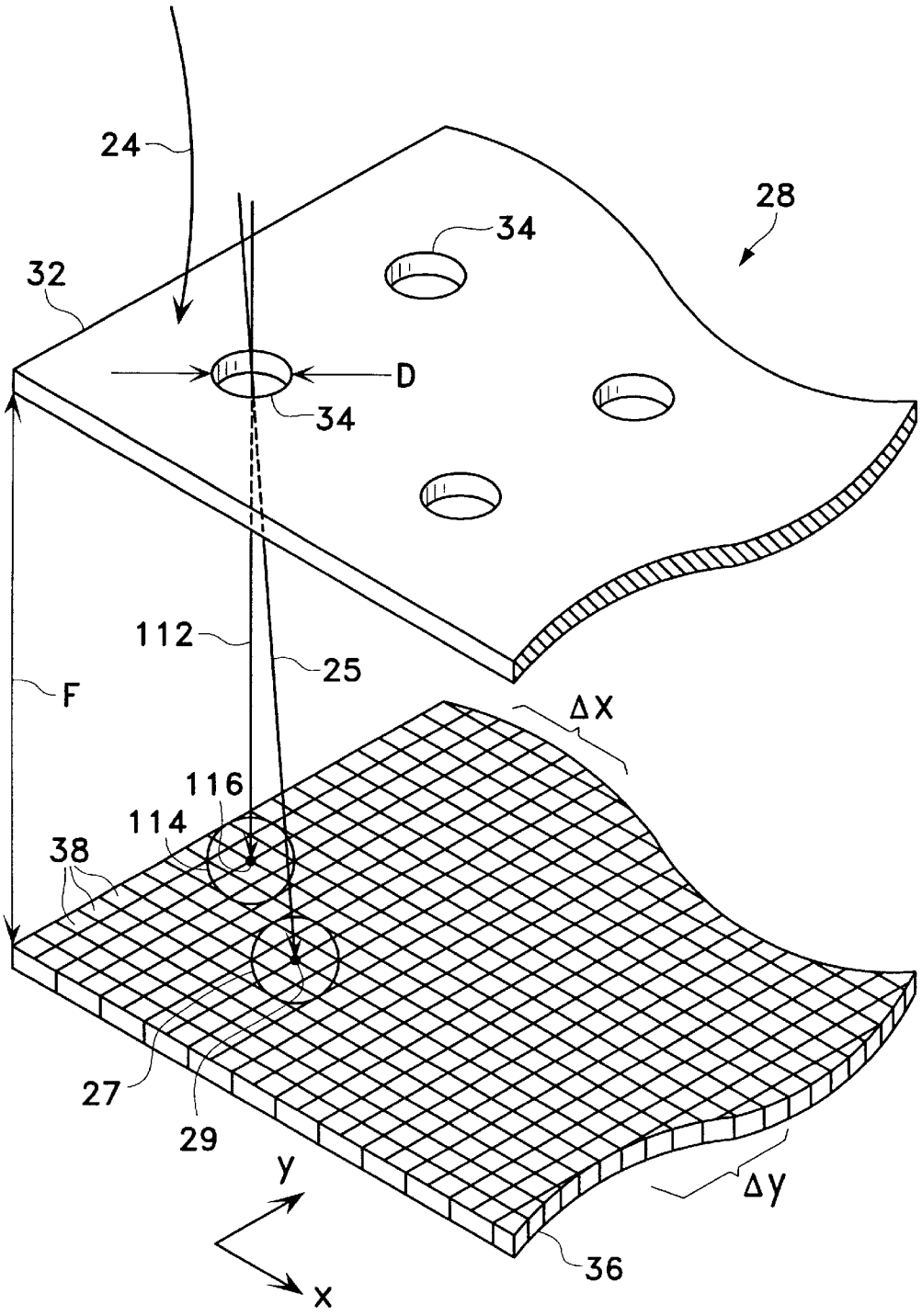


FIG. 4

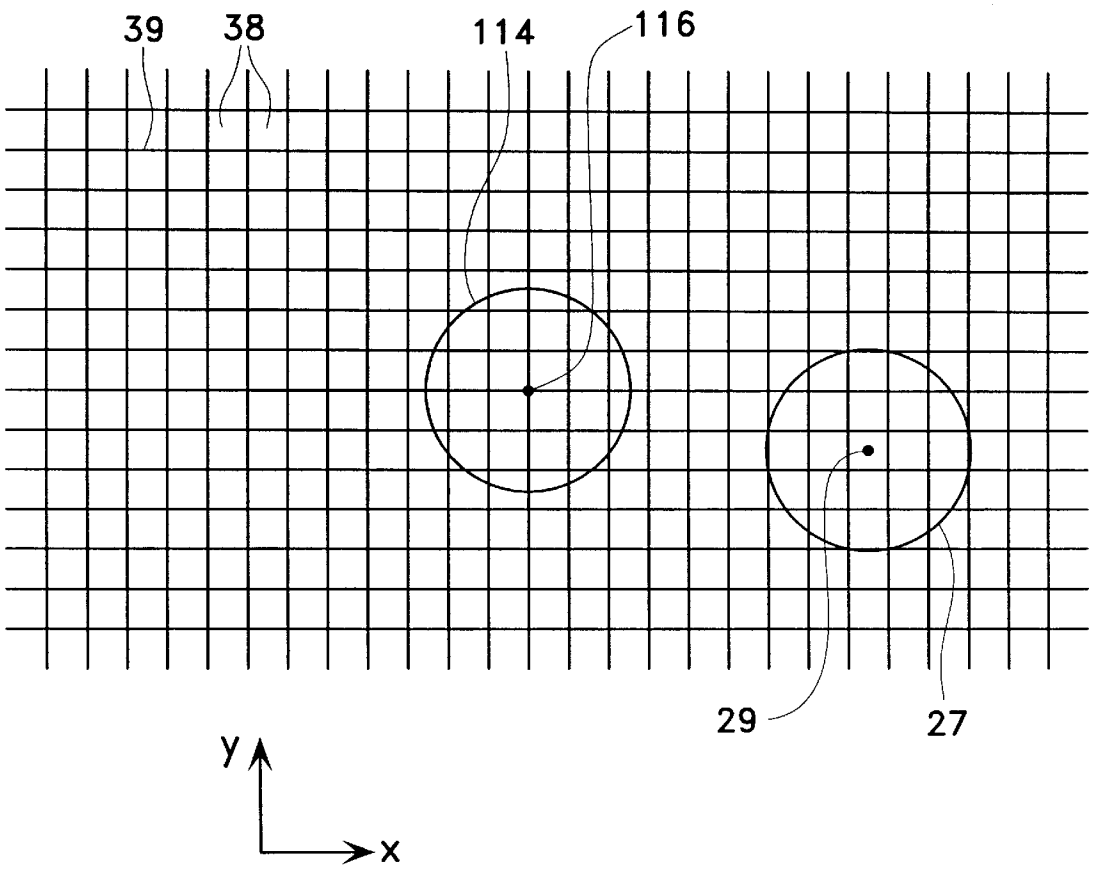


FIG. 5

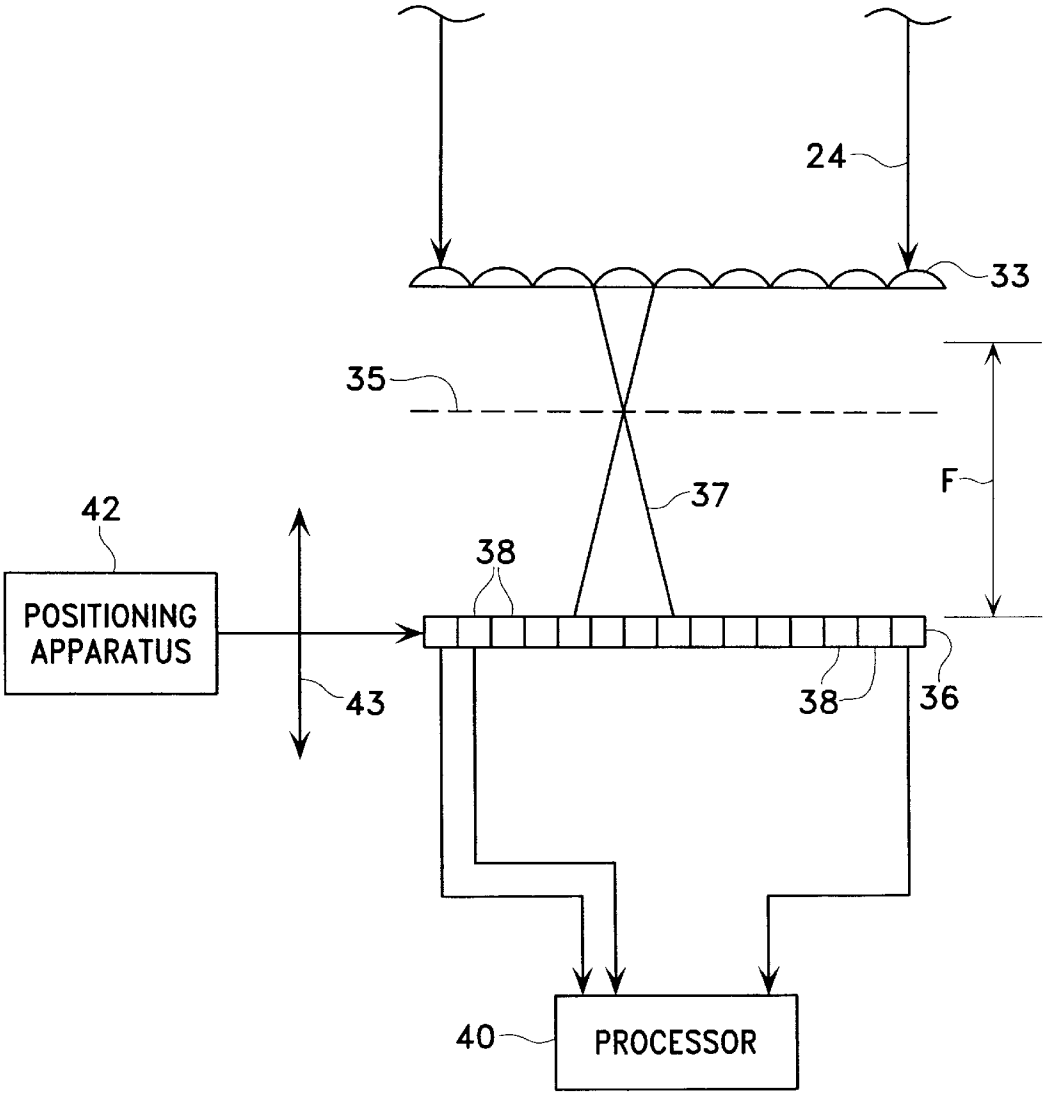

24
33
35
F
37
42
38
POSITIONING APPARATUS
43
38
36
40
PROCESSOR

FIG. 6

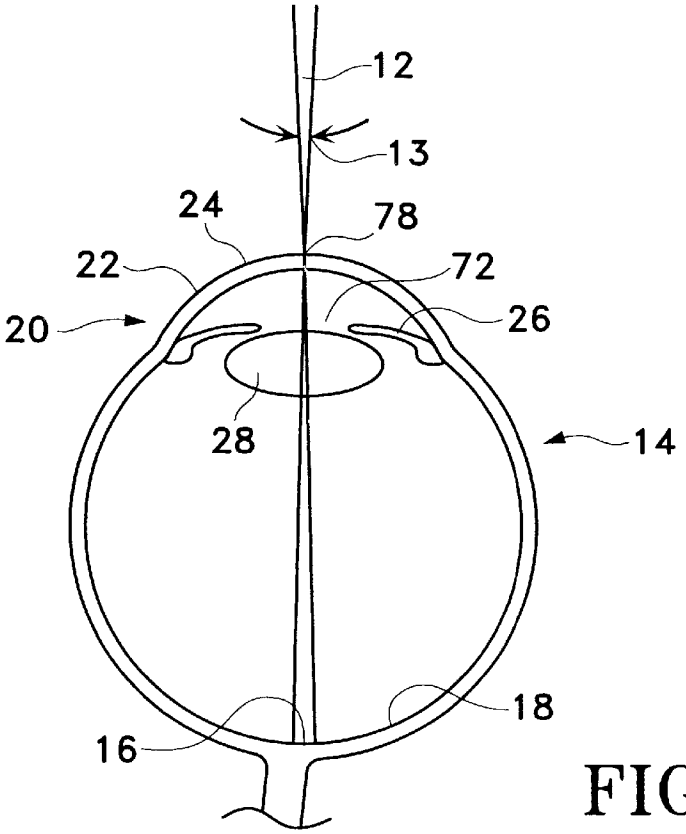


FIG. 7

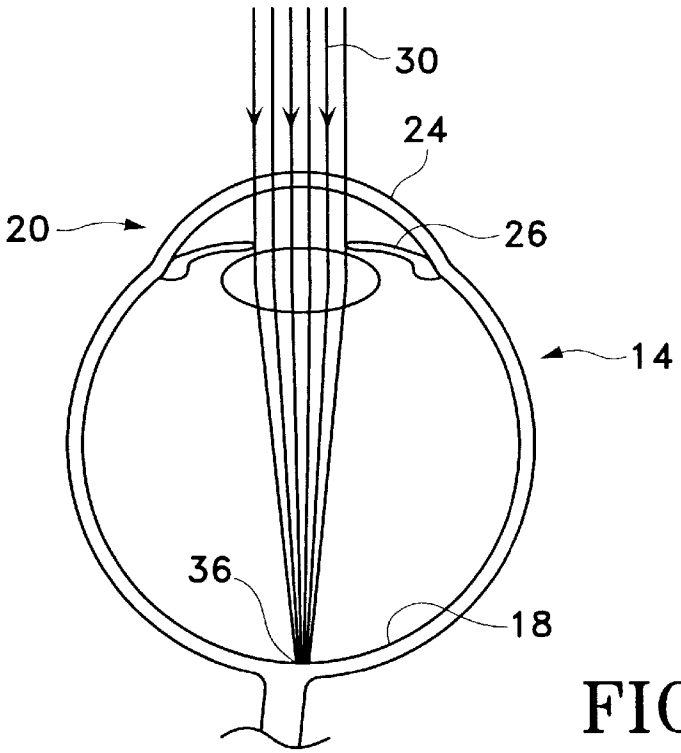


FIG. 8

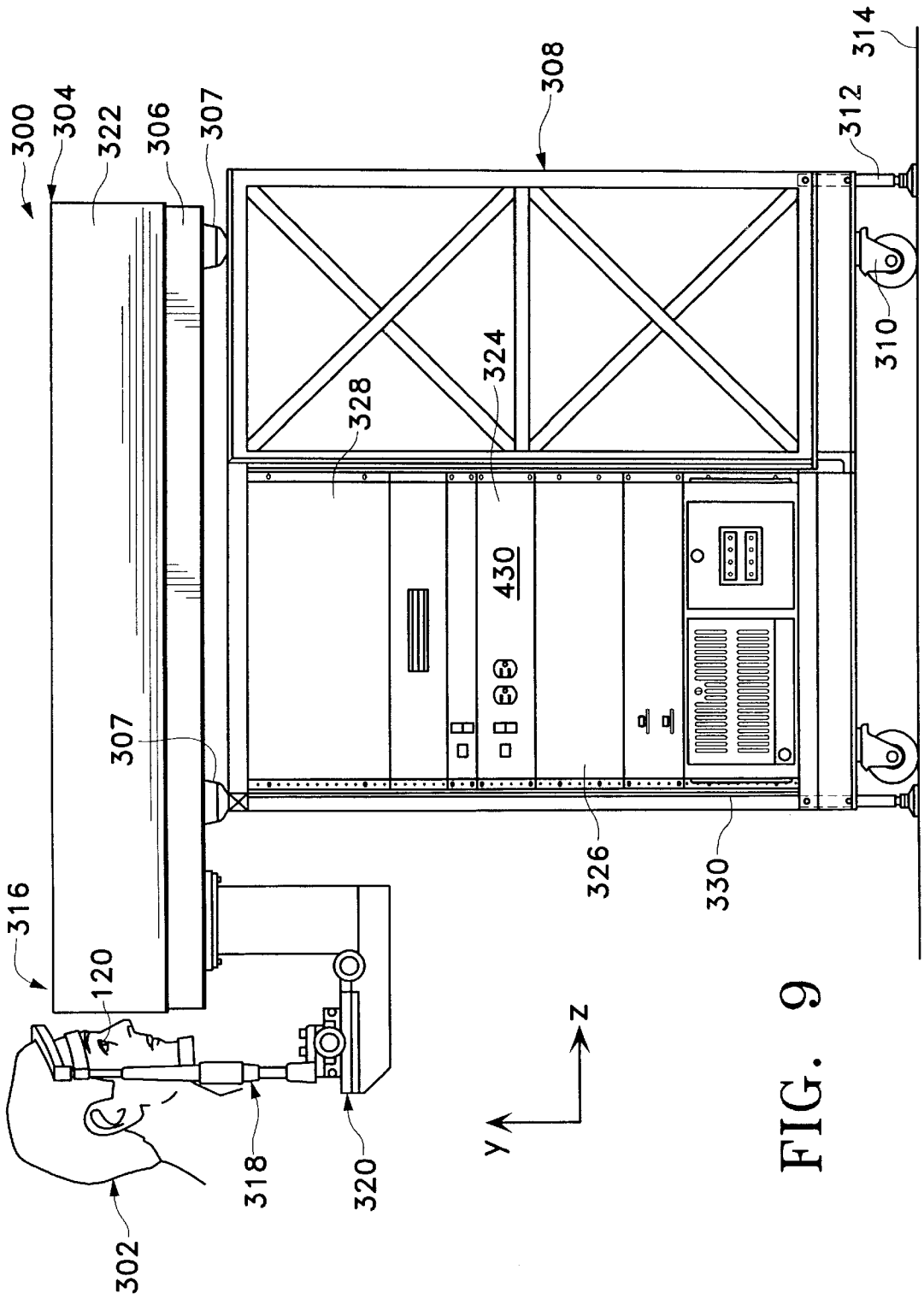
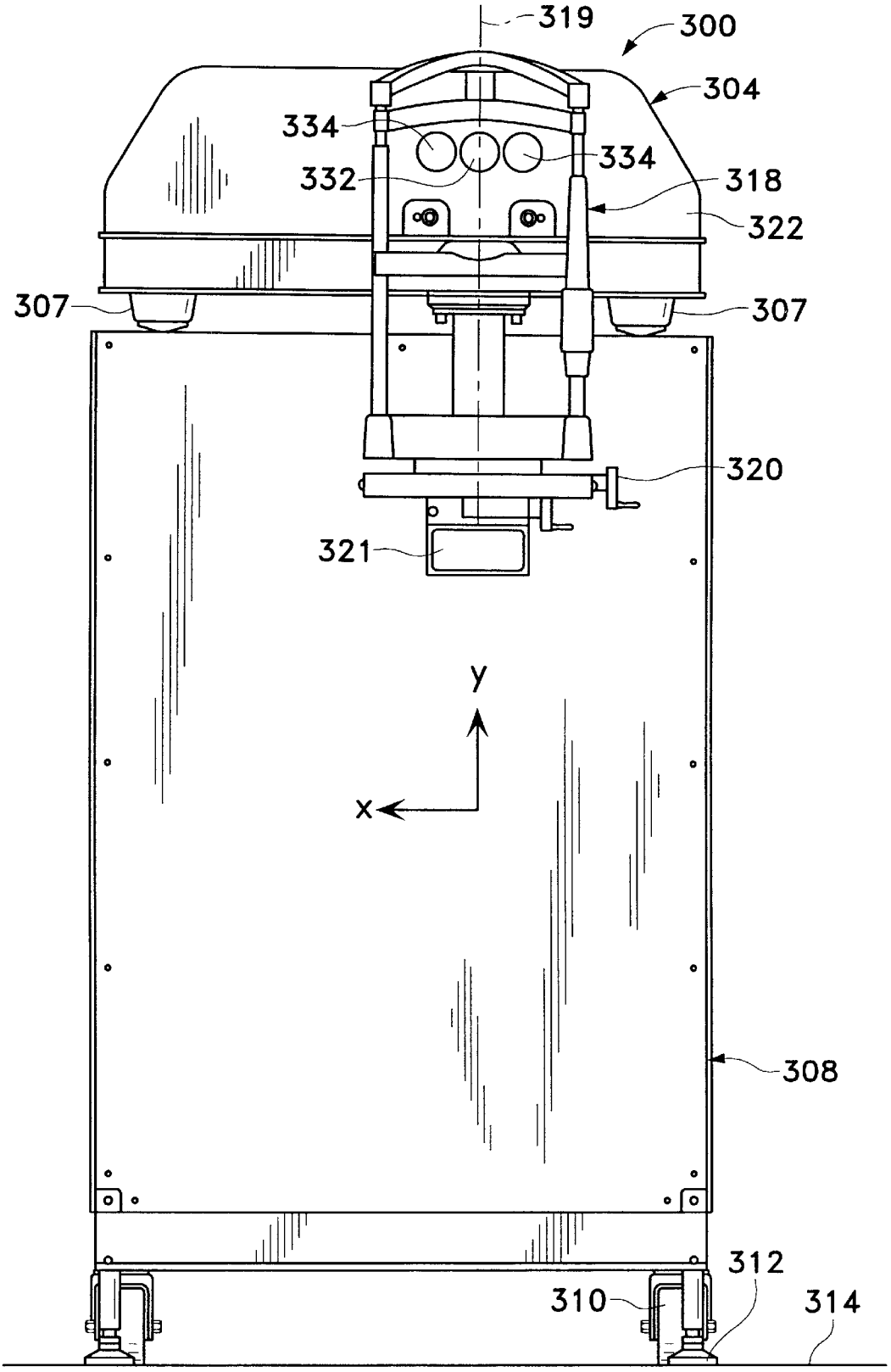

300
304
322
306
307
308
314
312
310
328
324
430
307
316
120
326
330
318
320
302
Y
Z

FIG. 9


319
300
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334
334
332
318
322
307
307
320
321
y
x
308
312
310
314

FIG. 10

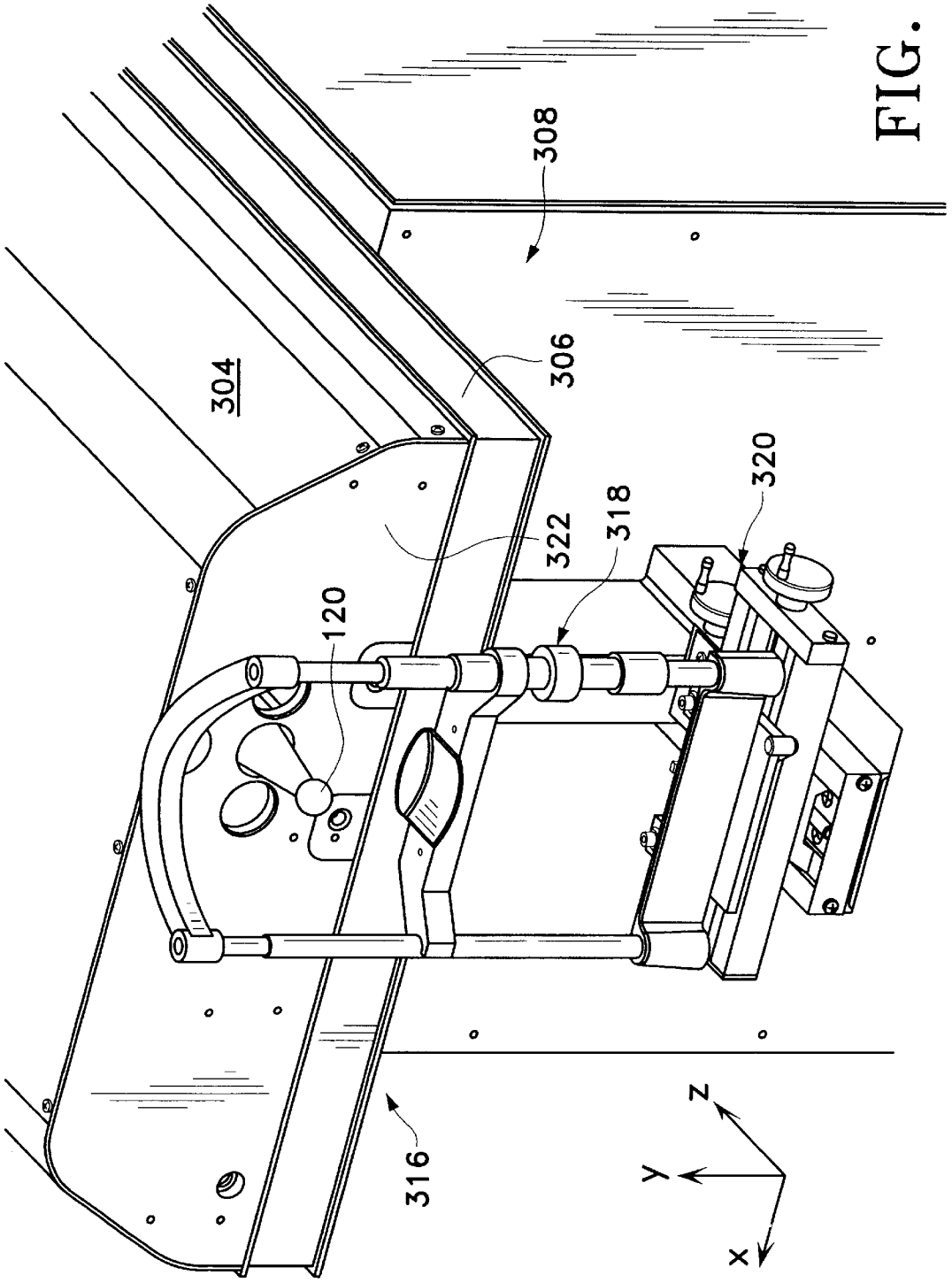


FIG. 11

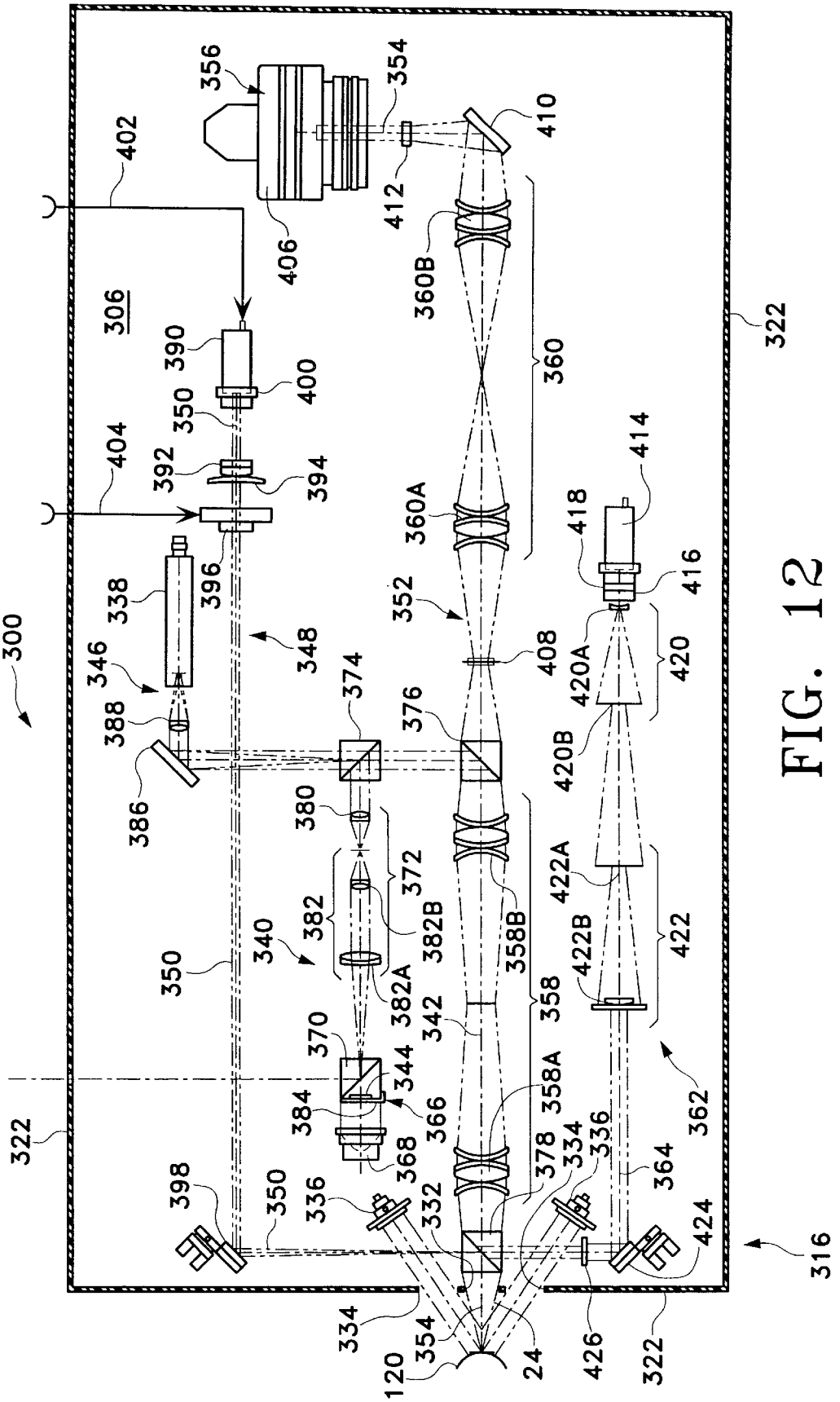
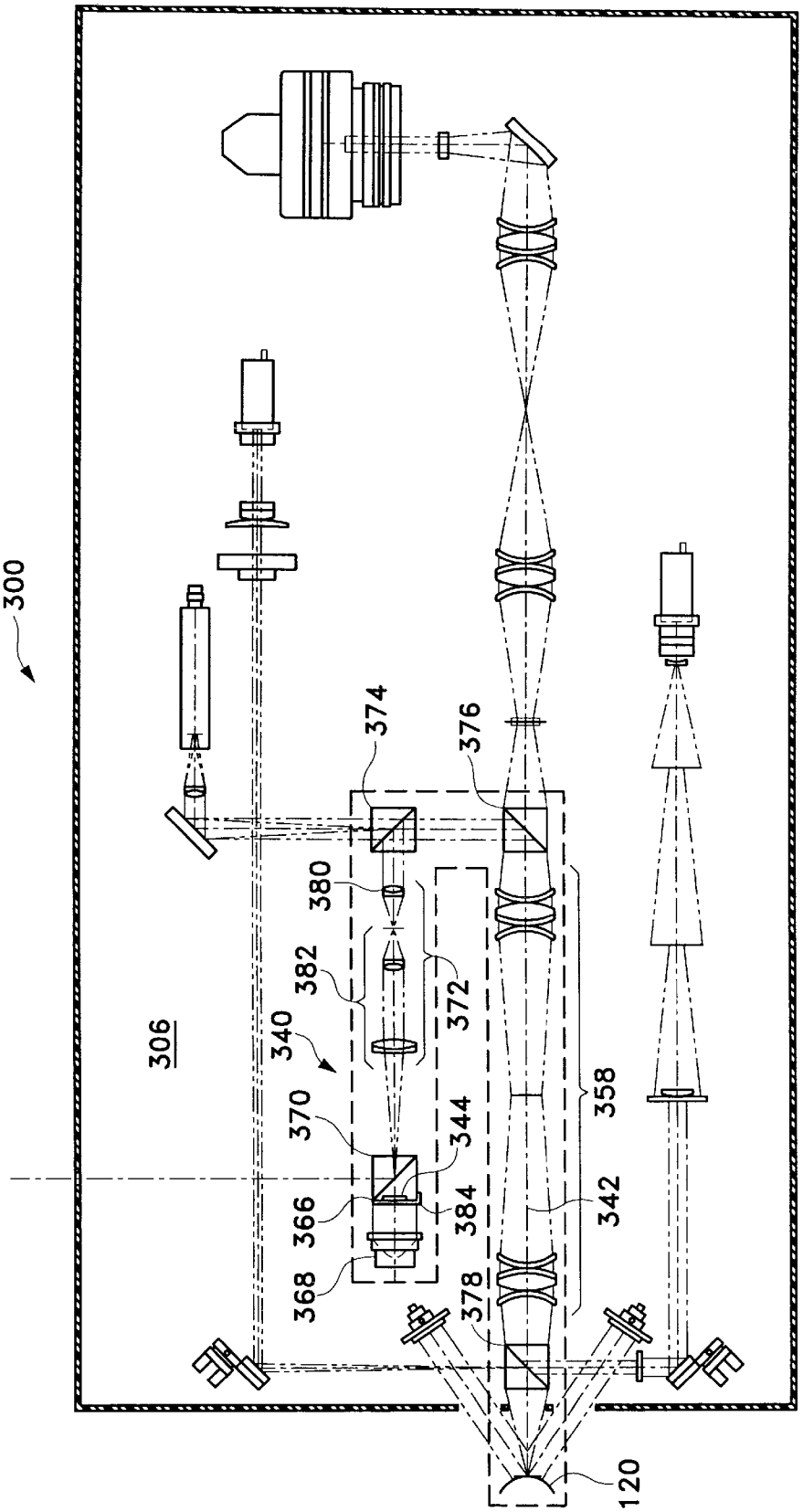

300
306
316
322
322
322
334
354
120
24
426
322
346
348
352
338
396
374
376
380
372
382
382B
382A
340
350
342
358B
358
358A
370
344
366
384
368
378
334
336
362
364
424
422
422A
422B
420
420A
420B
418
414
416
408
360
360A
360B
410
412
354
356
406
402
404
392
394
350
390
400
398
386
388
332
336

FIG. 12


300
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340
342
344
358
366
368
370
372
374
376
378
380
382
384
120

FIG. 12A

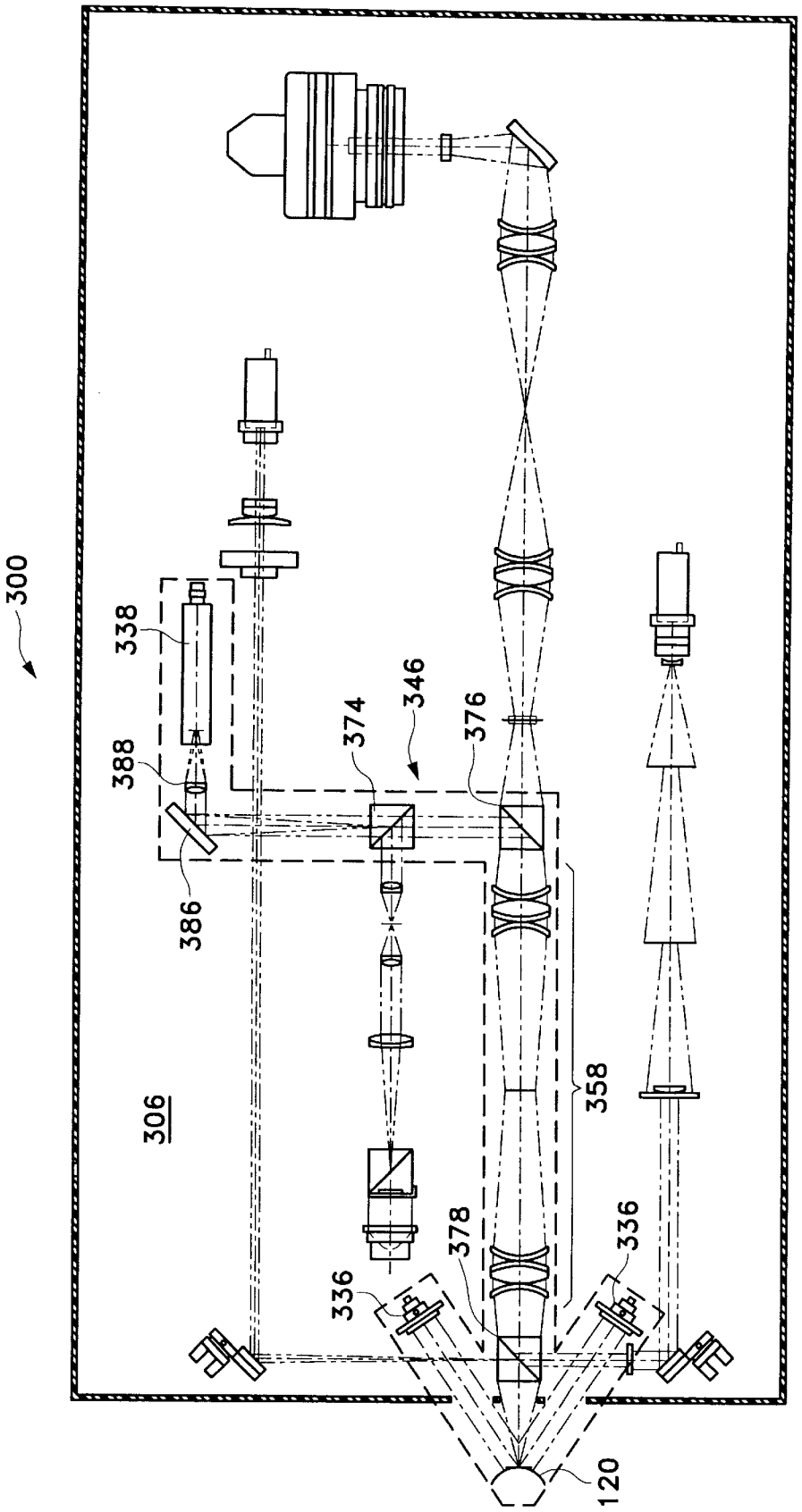

FIG. 12B

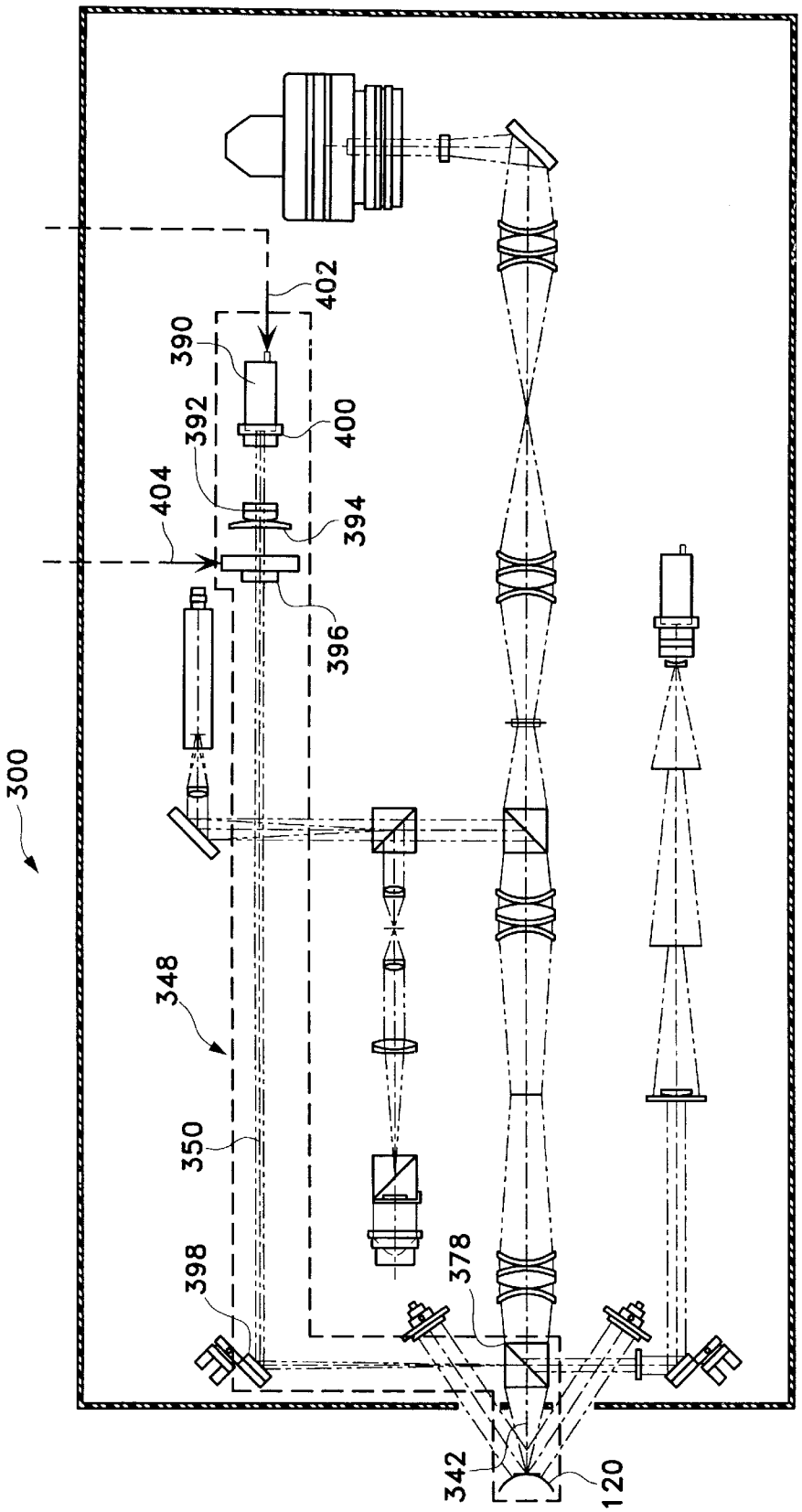

FIG. 12C

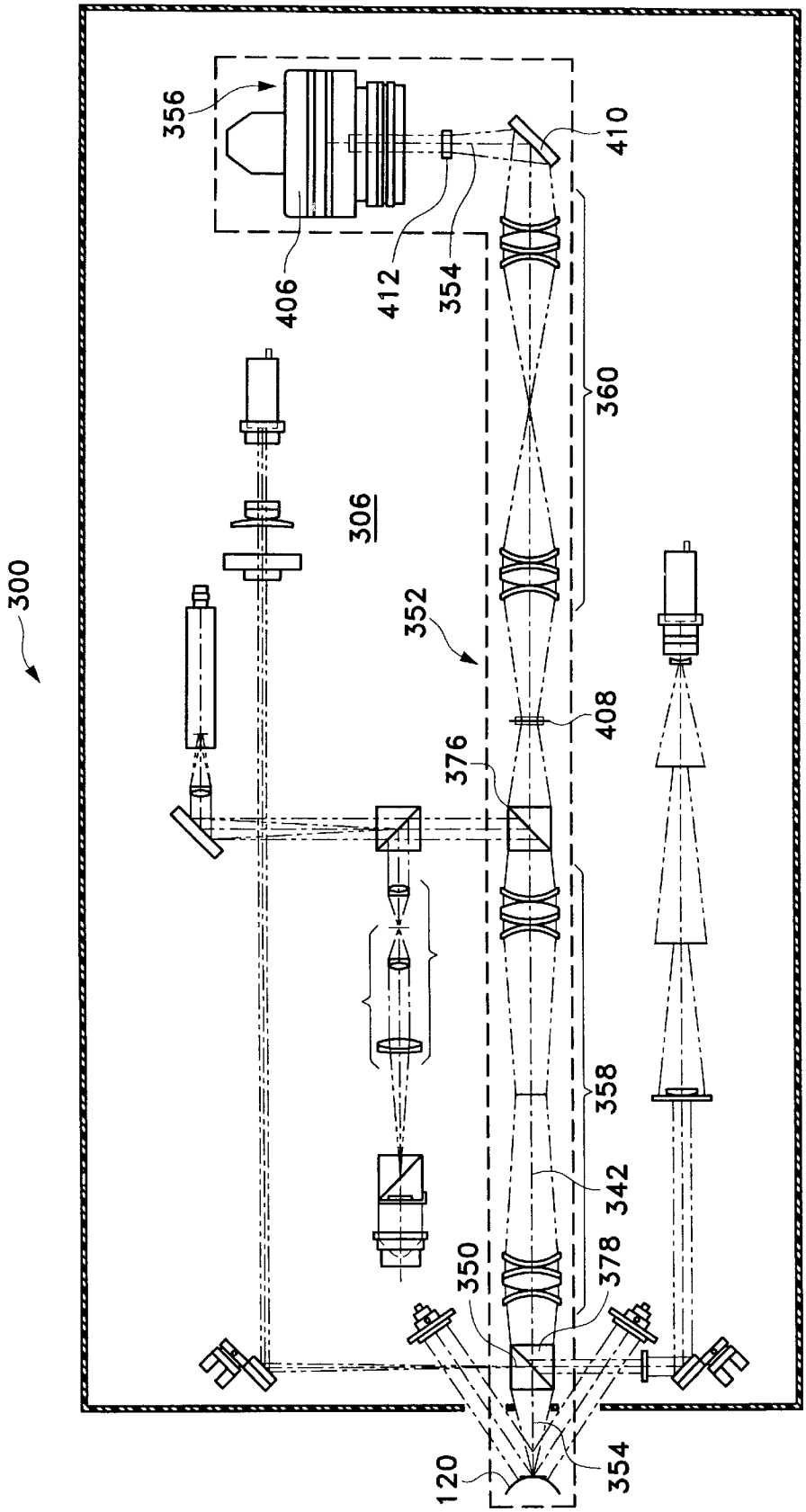
300
306
352
356
406
412
354
410
360
408
376
358
342
378
350
120
354

FIG. 12D

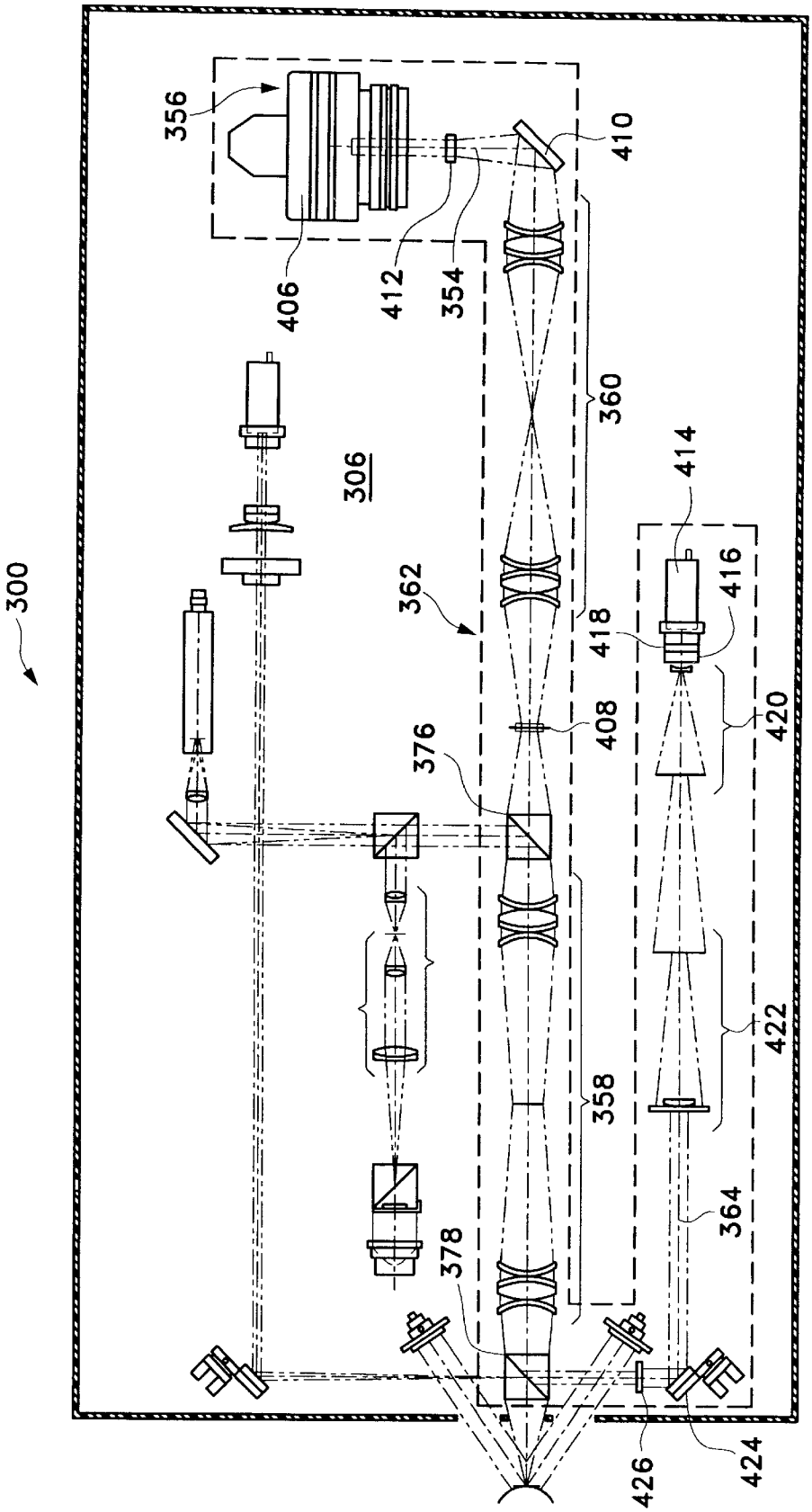
300
306
356
406
412
354
410
360
414
416
362
418
408
420
376
422
358
364
378
426
424

FIG. 12E

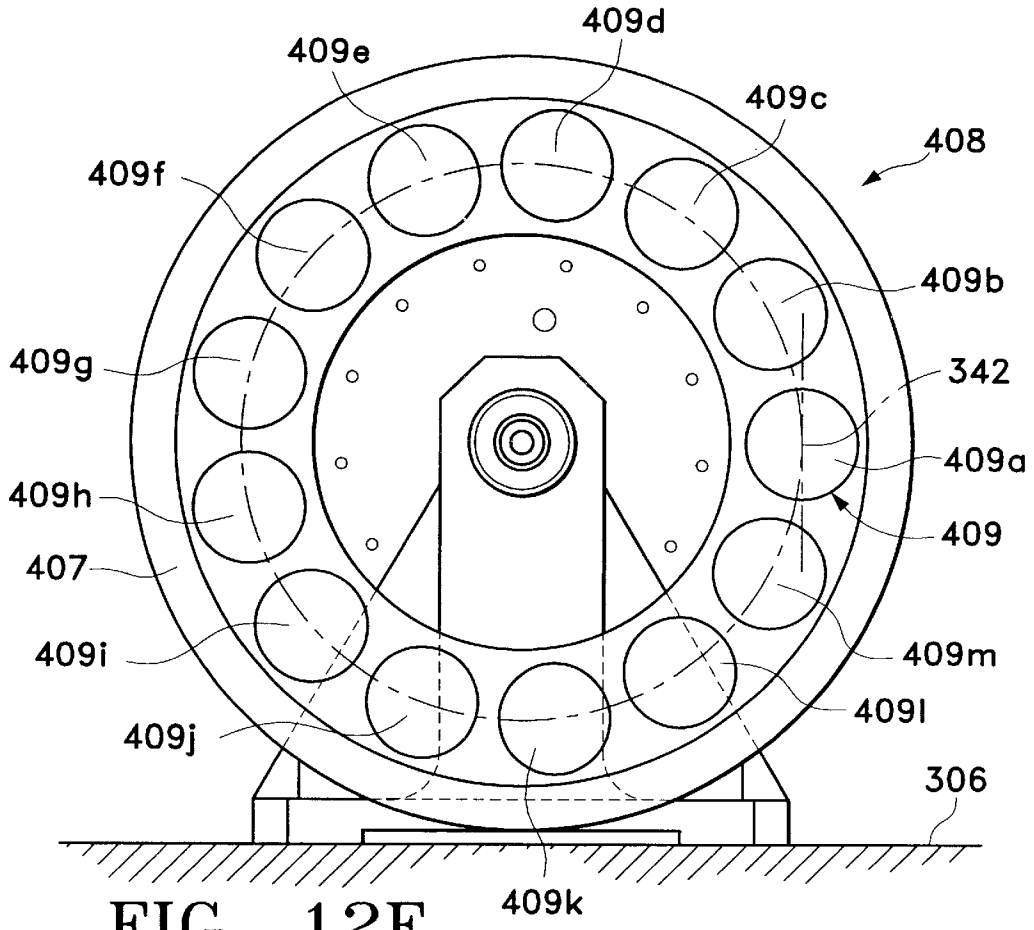

FIG. 12F

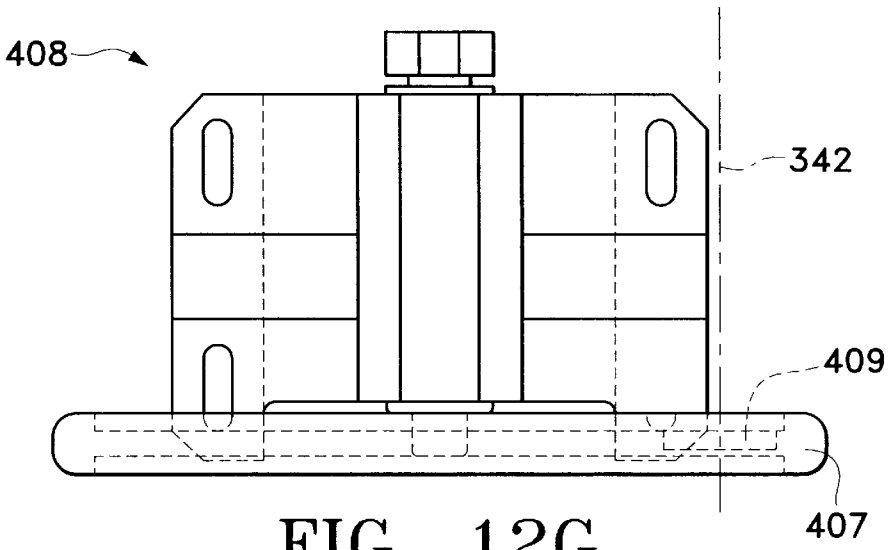

FIG. 12G

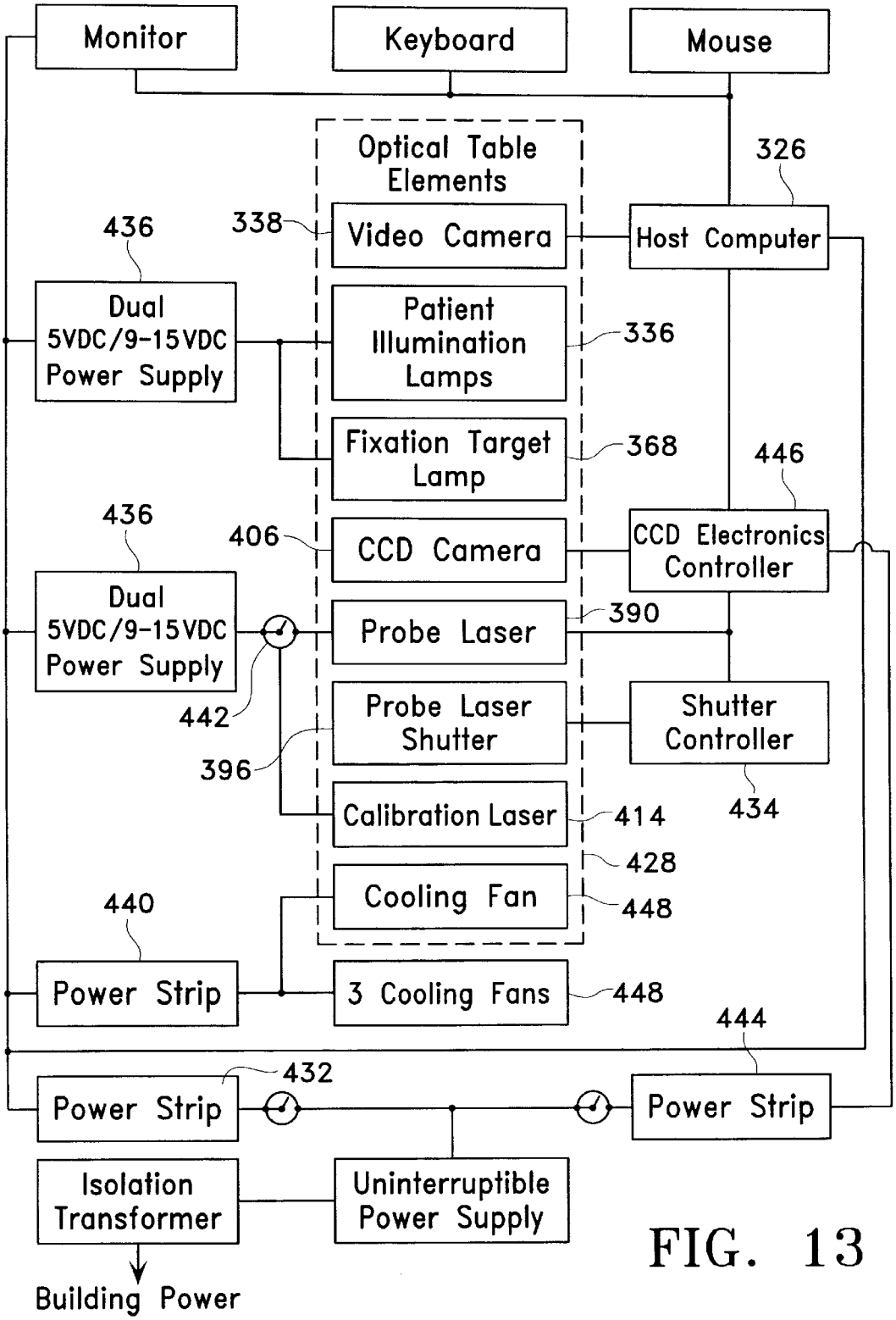
Monitor
Keyboard
Mouse
Optical Table Elements
326
436
338
Video Camera
Host Computer
Dual 5VDC/9-15VDC Power Supply
Patient Illumination Lamps
336
Fixation Target Lamp
368
446
436
406
CCD Camera
CCD Electronics Controller
Dual 5VDC/9-15VDC Power Supply
390
Probe Laser
442
Probe Laser Shutter
Shutter Controller
396
434
Calibration Laser
414
428
Cooling Fan
448
440
Power Strip
3 Cooling Fans
448
444
432
Power Strip
Power Strip
Isolation Transformer
Uninterruptible Power Supply
Building Power

FIG. 13

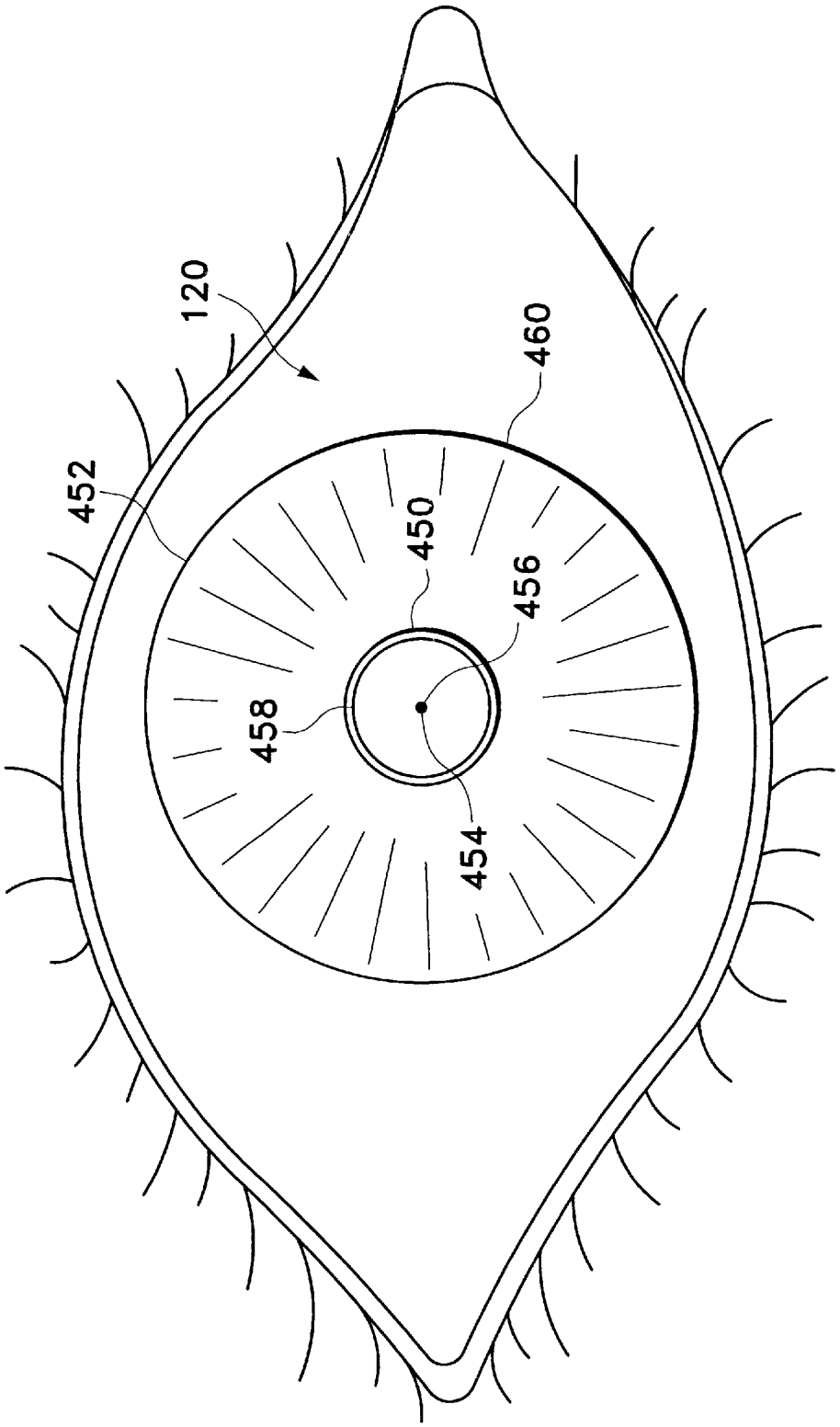

FIG. 14

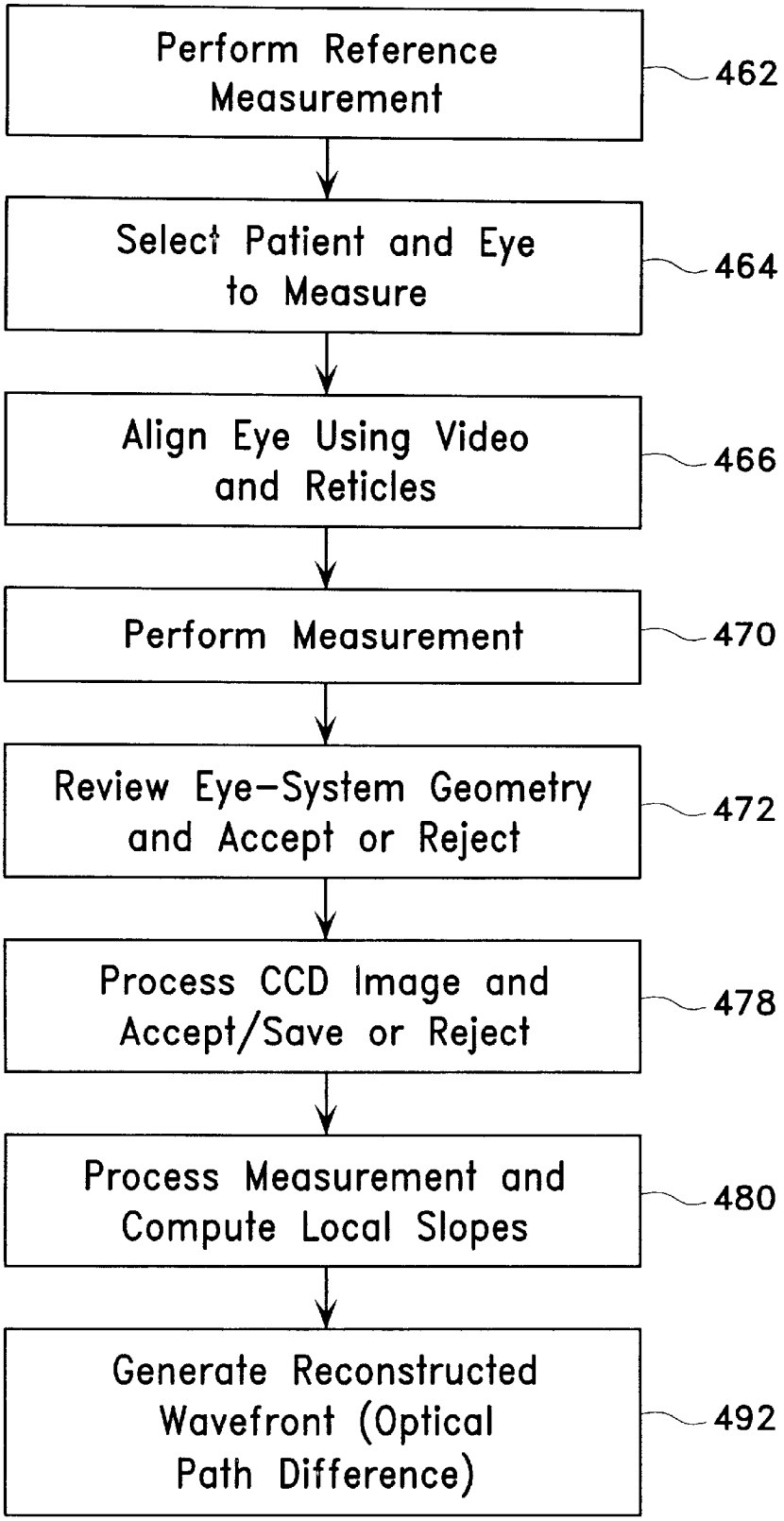
Perform Reference Measurement
462
Select Patient and Eye to Measure
464
Align Eye Using Video and Reticles
466
Perform Measurement
470
Review Eye-System Geometry and Accept or Reject
472
Process CCD Image and Accept/Save or Reject
478
Process Measurement and Compute Local Slopes
480
Generate Reconstructed Wavefront (Optical Path Difference)
492

FIG. 15

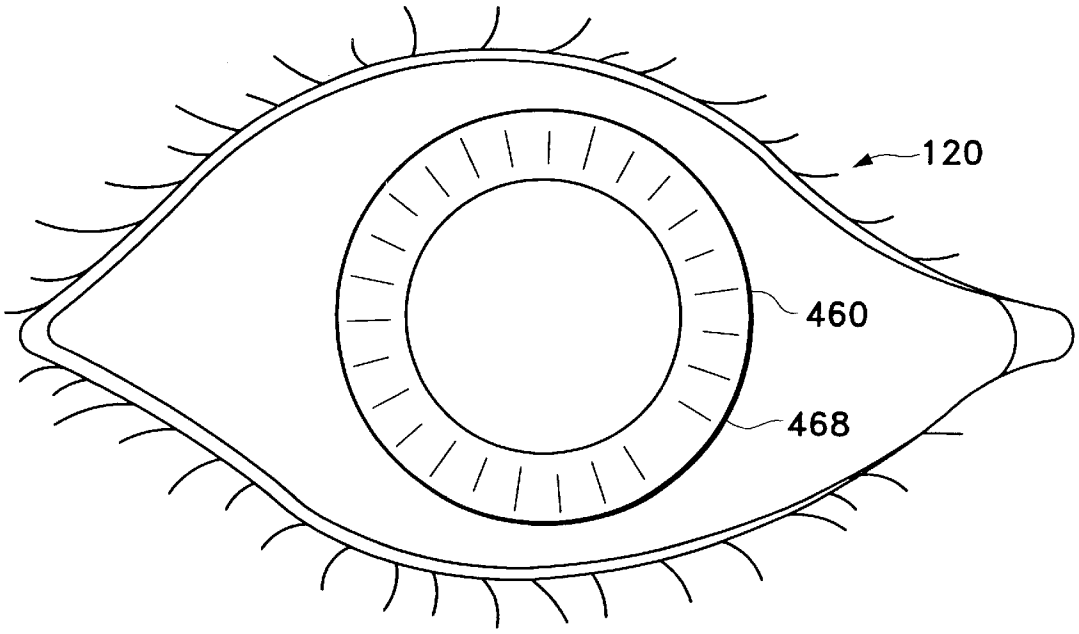

FIG. 16

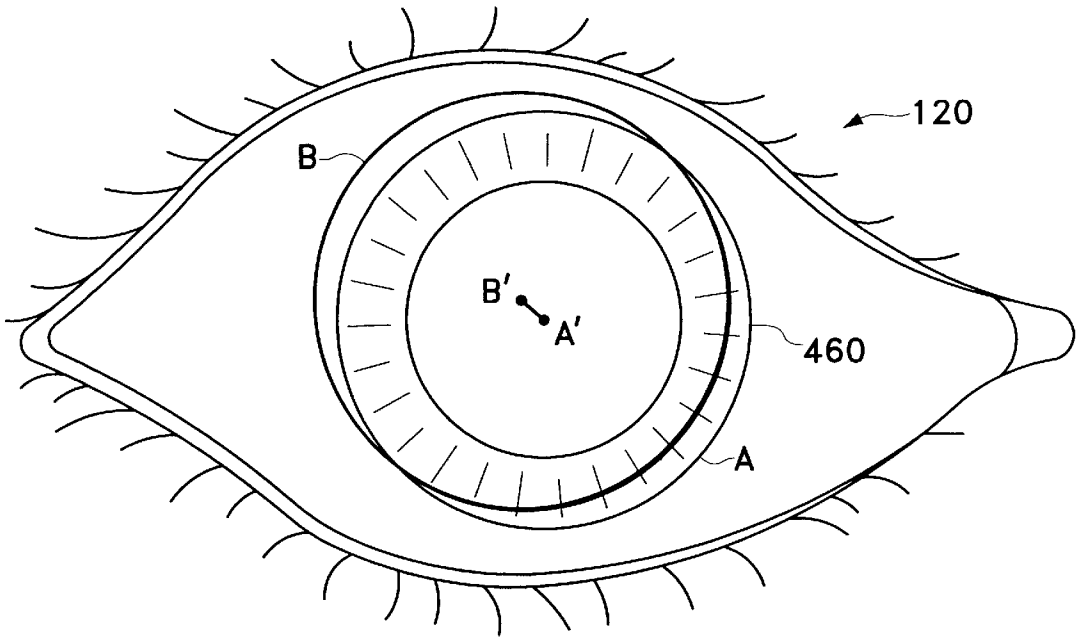

FIG. 17

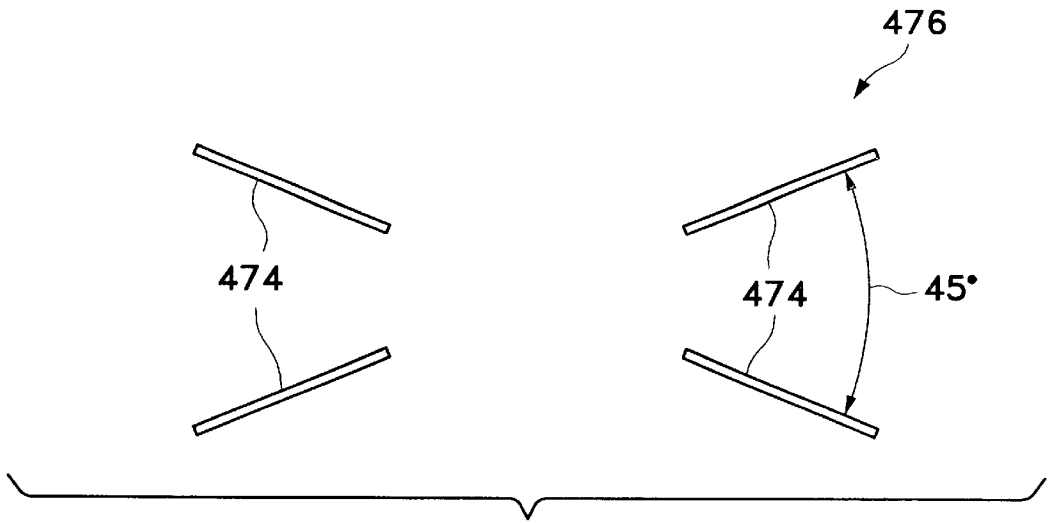

FIG. 18

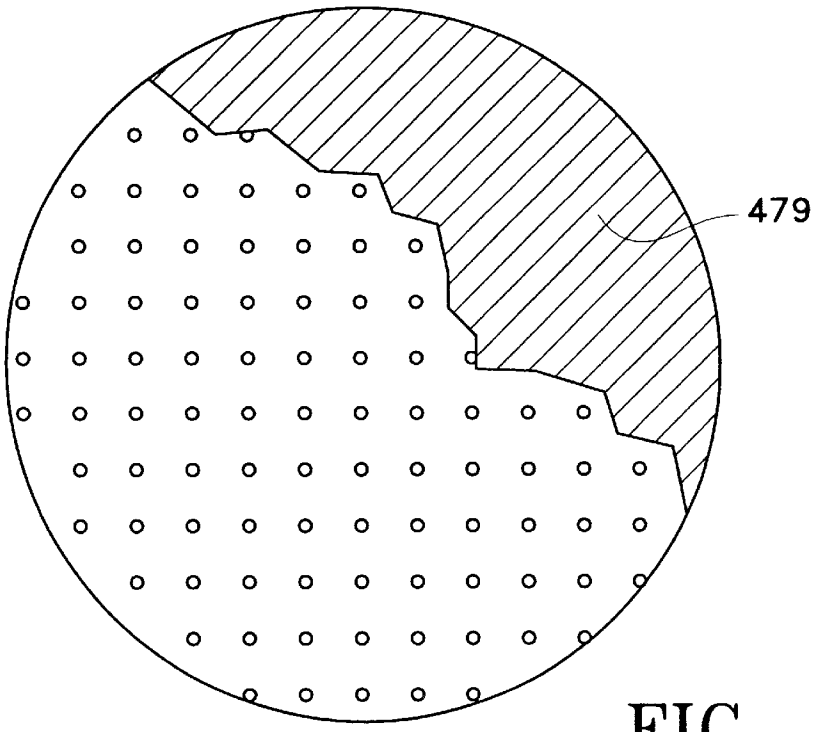

FIG. 19

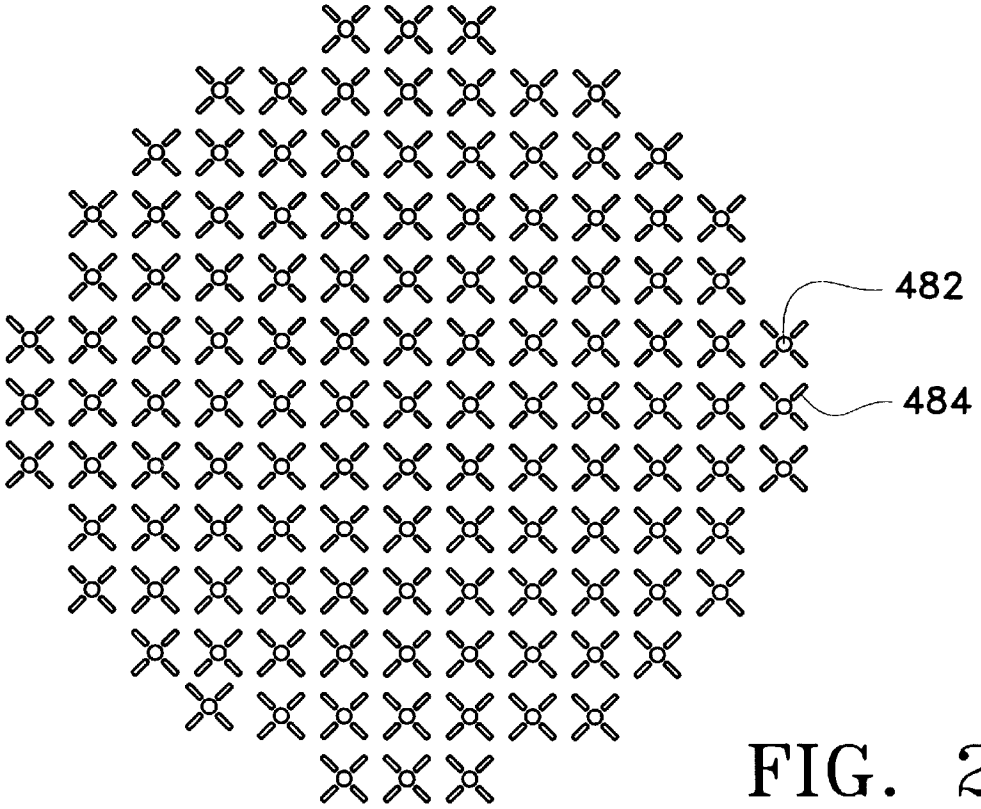

FIG. 20

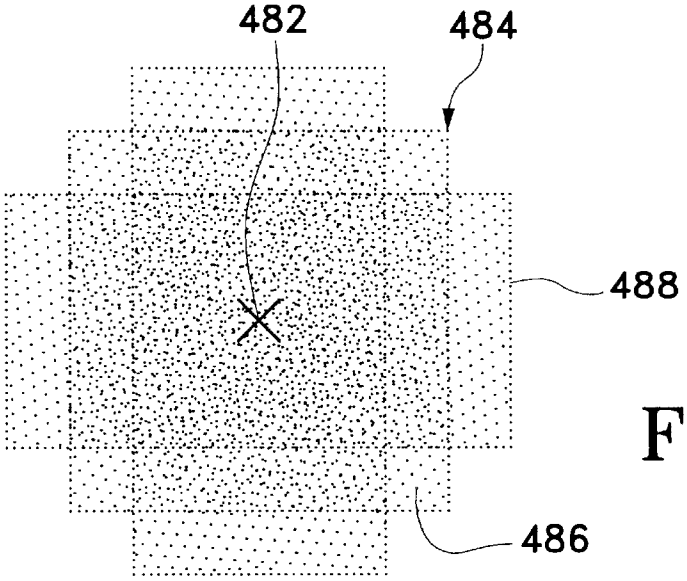

FIG. 21

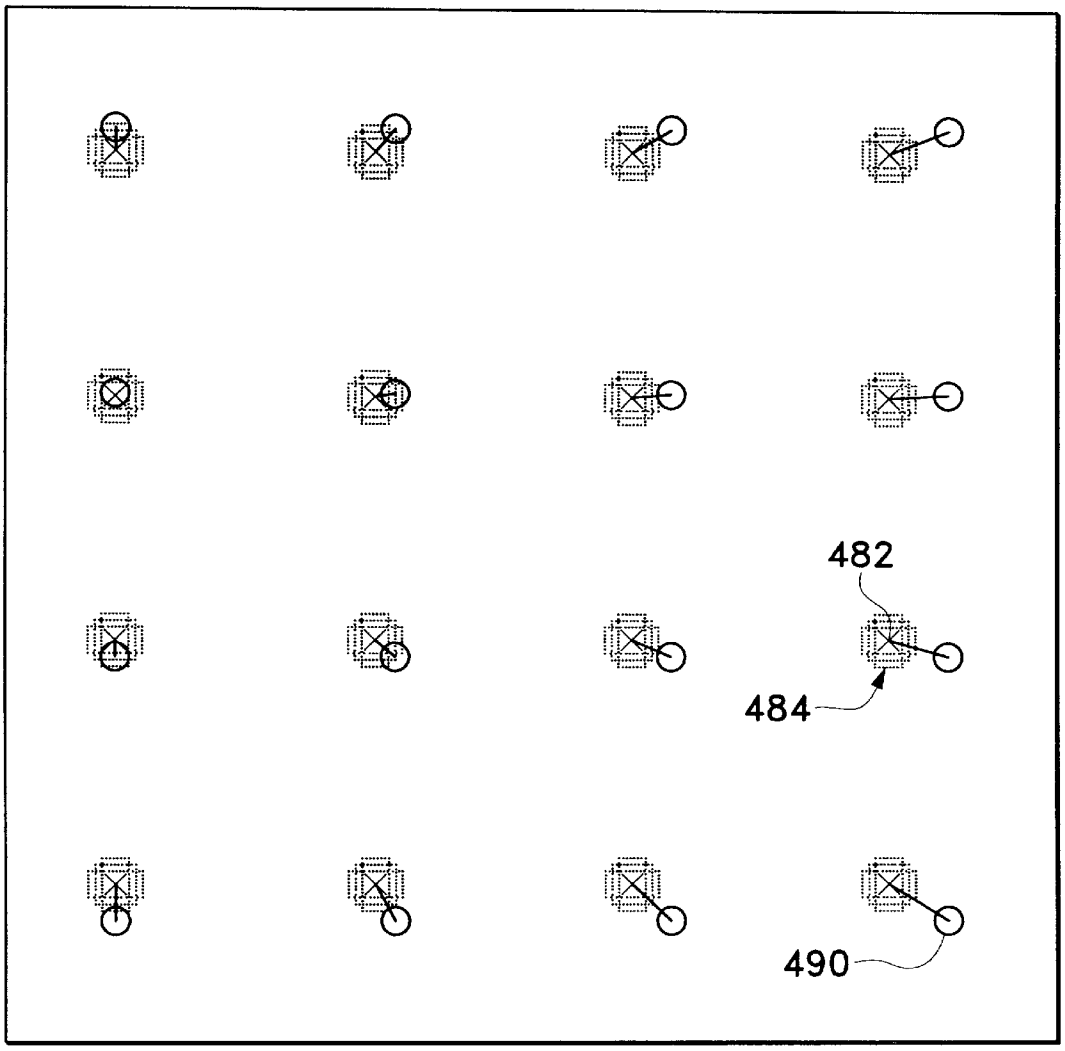

FIG. 22

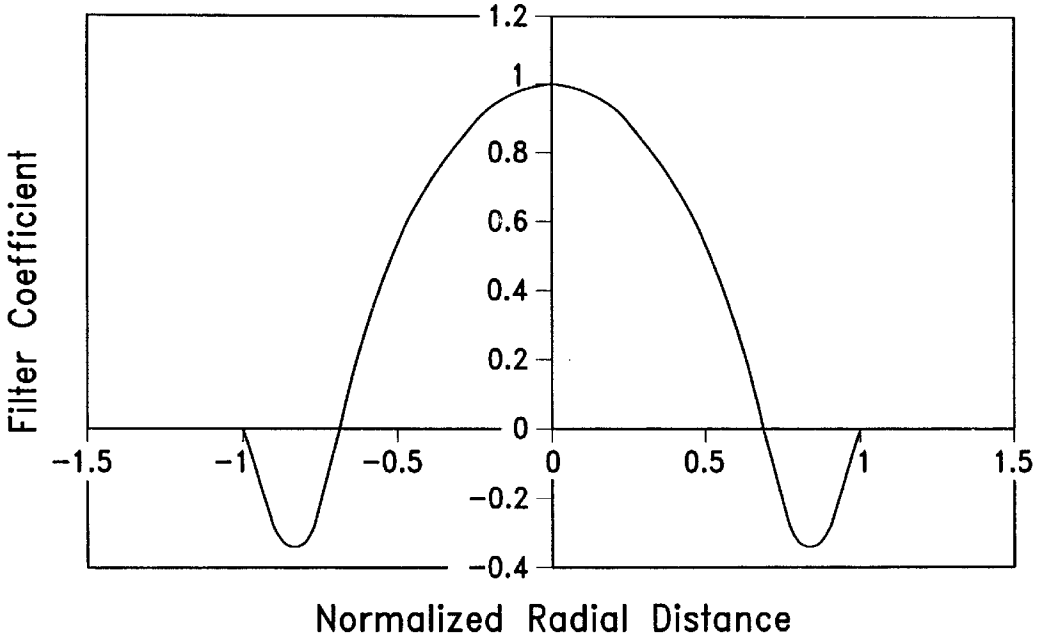

FIG. 23A

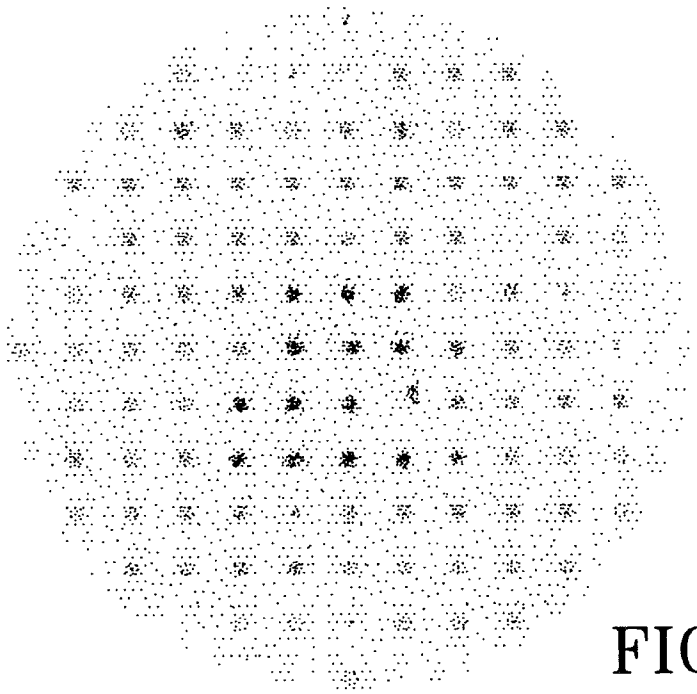

FIG. 23B

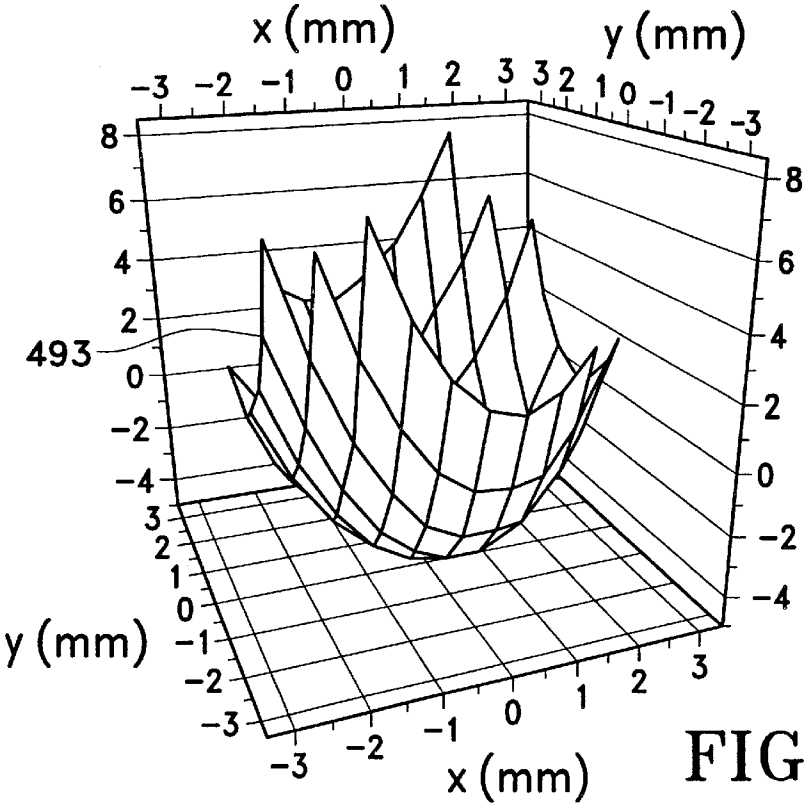

FIG. 24A

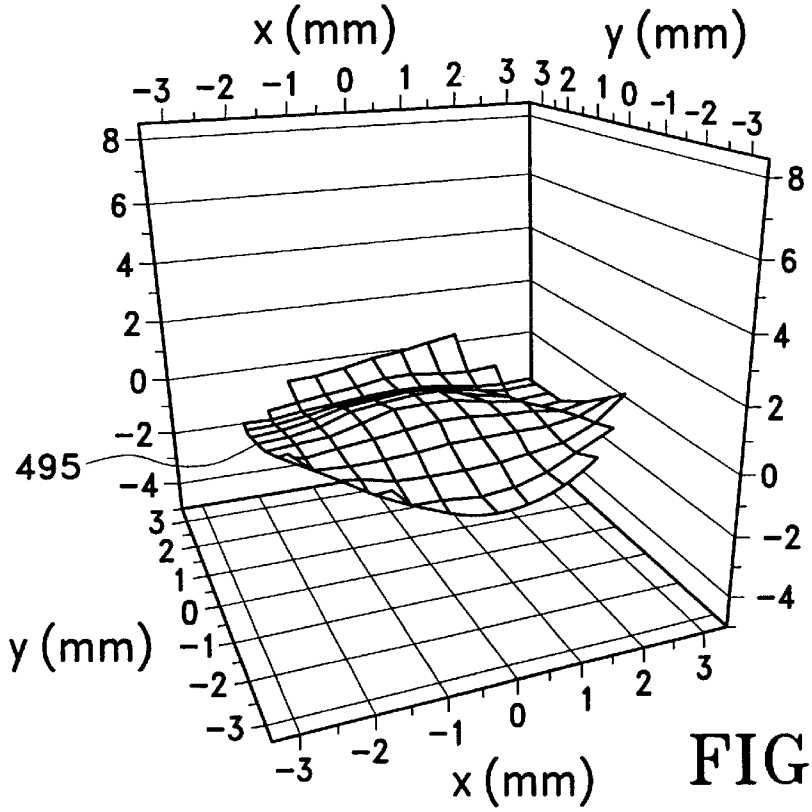

FIG. 24B

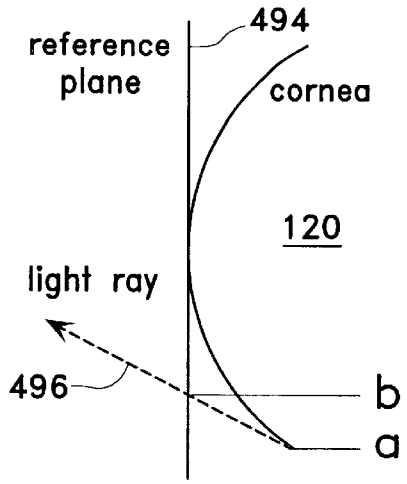

FIG. 25

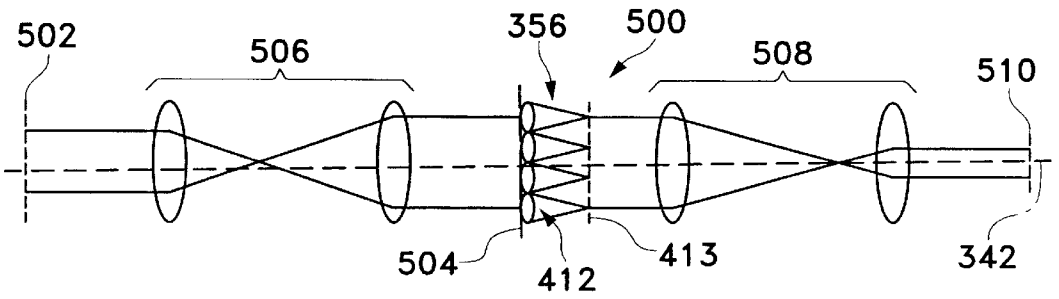

FIG. 26A

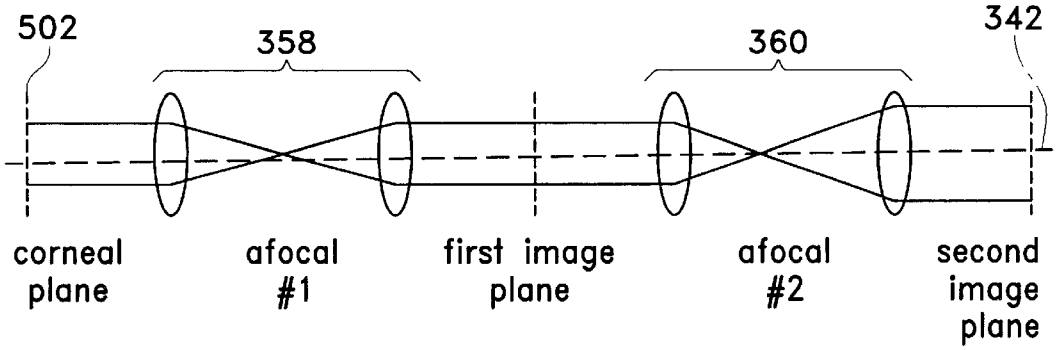

FIG. 26B

APPARATUS AND METHOD FOR OBJECTIVE MEASUREMENTS OF OPTICAL SYSTEMS USING WAVEFRONT ANALYSIS

FIELD OF THE INVENTION

The invention relates generally to optical aberration measurement and analysis, and more particularly to an objective measurement of optical systems, such as systems of a human eye.

BACKGROUND OF THE INVENTION

Optical systems having a real image focus can receive collimated light and focus it at a point. Such optical systems can be found in nature, e.g., human and animal eyes, or can be man-made, e.g., laboratory systems, guidance systems, and the like. In either case, aberrations in the optical system can affect the system's performance. By way of example, the human eye will be used to explain this problem.

A perfect or ideal eye diffusely reflects an impinging light beam from its retina through optics of the eye which includes a lens and a cornea. For such an ideal eye in a relaxed state, i.e., not accommodating to provide near-field focus, reflected light exits the eye as a sequence of plane waves. However, an eye typically has aberrations that cause deformation or distortion of reflected light waves exiting the eye. An aberrated eye diffusely reflects an impinging light beam from its retina through its lens and cornea as a sequence of distorted wavefronts.

There are a number of technologies that attempt to provide the patient with improved visual acuity. Typically, treatment is determined by placing spherical and/or cylindrical lenses of known refractive power at the spectacle plane (approximately 1.0–1.5 centimeters anterior to cornea) and literally asking the patient which lens or lens combination provides the clearest vision. This is an imprecise measurement of true distortions in the reflected wavefront because 1) a single spherocylindrical compensation is applied across the entire wavefront, 2) vision is tested at discrete intervals (i.e., diopter units) of refractive values, and 3) subjective determination by the patient is employed. Thus, conventional methodology for determining refractive errors in the eye is substantially less accurate than the techniques now available for measuring the ocular aberrations.

One method of measuring ocular refractive errors is disclosed in U.S. Pat. No. 5,258,791 to Penney et al. for "Spatially Resolved Objective Autorefractometer," which teaches the use of an autorefractometer to measure the refraction of the eye at numerous discrete locations across the corneal surface. The autorefractometer is designed to deliver a narrow beam of optical radiation to the surface of the eye, and to determine where that beam strikes the retina using a retinal imaging system. Both the angle of the beam's propagation direction with respect to the optical axis of the system and the approximate location at which the beam strikes the corneal surface of the eye are independently adjustable. However, a small uncertainty or error in the location of the beam's point of incidence on the cornea exists due to the curved corneal surface. For each point of incidence across the corneal surface, the refraction of the eye corresponding to that surface point can be determined by adjusting the angle at which the beam strikes the cornea until the beam refracted on to the iris strikes the fovea centralis. Adjustment of the beam angle of propagation can be accomplished either manually by the patient or automatically by the autorefractometer, if a feedback loop involving a retinal imaging component is incorporated.

Penney '791 further teaches the use of the autorefractometer measurements in determining the appropriate corneal surface reshaping to provide emmetropia, a condition of a normal eye when parallel beams or rays of light are focused exactly on the retina and vision is perfect. This is accomplished by first obtaining an accurate measurement of corneal surface topography using a separate commercially available device. A mathematical analysis is then performed using an initial corneal topography at each surface reference point, the measured refraction at each surface point, and Snell's law of refraction, to determine a desired change in surface contour at each reference point.

A major limitation to the approach described by Penney '791 is that a separate measurement of corneal topography is desired to perform the Snell's Law analysis of needed refraction change. This adds significantly to the time and cost of a complete and desirable diagnostic evaluation. Further, the accuracy of the refraction change analysis will be dependent upon the accuracy of the topographic measurement and the accuracy of the autorefractometer measurement. In addition, any error in the spatial orientation of a topography map with respect to a refraction map will degrade the accuracy of the measured profile. Yet another limitation to known approaches such as described in Penney '791, by way of example, is that test points on the corneal surface are examined sequentially. Eye motion during the examination, either voluntary or involuntary, could introduce substantial errors in the refraction measurement. Penney '791 teaches detection of such eye movement by deliberately including measurement points outside the pupil, i.e., in the corneal region overlying the iris, where the return from the retina will obviously be zero at specific intervals in the examination sequence. However, this approach may still allow substantial undetected eye movement error between such iris reference points.

By way of example, one method and system known in the art, are disclosed by Junzhong Liang et al. in "Objective Measurement Of Wave Aberrations Of The Human Eye With The Use Of A Hartmann-Shack Wave-Front Sensor," published in the Journal of the Optical Society of America, Volume 11, No. 7, July 1994, pages 1949–1957. Liang et al. teach the use of a Hartmann-Shack wavefront sensor to measure ocular aberrations by measuring the wavefront emerging from the eye by the retinal reflection of a focused laser light spot on the retina's fovea. The actual wavefront is reconstructed using wavefront-estimation with Zernike polynomials.

The imprecise measurement technique of placing lenses of known refractive power anterior to the cornea and asking a patient which lens or lens combination provides the clearest vision has been improved with the use of autorefractometers, as described in Penny '79, or with the use of wavefront sensors as described by Liang et al. Spatially resolved refraction data, in combination with measured existing surface contour of the anterior surface of the eye, enable a calculation of a detailed spatially resolved new contour. However, it would be an improvement in this art if such vision measurements could be made without the need for this contour data, and further without the need for feedback from the patient regarding an appropriate lens. Liang et al. discloses the use of a Hartmann-Shack wavefront sensor to measure ocular aberrations by measuring the wavefront emerging from the eye by retinal reflection of a focused laser light spot on the retina's fovea. A parallel beam of laser light passes through beam splitters and a lens pair which brings the beam to a focus point on the retina by the optics of the eye. Possible myopia or hyperopia of the tested

eye is determined by movement of a lens within the lens pair. The focused light on the fovea is then assumed to be diffusely reflected and acts as a point source located on the retina. The reflected light passes through the eye and forms a distorted wavefront in front of the eye that results from the ocular aberrations. The aberrated wavefront is then directed to the wavefront sensor.

A point source of radiation on the retina would be ideal for such measurements. However, when the perfect eye receives a collimated beam of light, the best possible image on the retina is a diffraction limited spot. As illustrated by way of example, with Penny et al. and Liang et al., discussed above, and typical for those of skill in the art, parallel or collimated beams are used with the optics of the eye being measured to achieve this diffraction limited spot for such objective measurements. To do so, a setup for each patient includes a lens or lens combination and adjustments thereto for accommodating that patient's specific visual acuity. Providing a lens combination, as well as setting up for their use becomes cumbersome, time consuming, and at an additional expense. Eliminating the need for such optics is desirable and eliminates a variable within optical measurement systems that typically include many variables. Further, there is a need for providing optical characteristics of an eye without requiring feedback from the patient. By way of example, the patient may be a wild or domestic animal, living or dead.

The Hartmann-Shack wavefront sensor disclosed by Liang et al. includes two identical layers of cylindrical lenses with the layers arranged so that lenses in each layer are perpendicular to one another, as further disclosed in U.S. Pat. No. 5,062,702 to Bille. In this way, the two layers operate as a two-dimensional array of spherical lenslets that divide the incoming light wave into sub-apertures. The light through each sub-aperture is brought to focus in the focal plane of the lens array where a charge coupled device (CCD) image module resides.

The system of Liang et al. is calibrated by impinging an ideal plane wave of light on the lenslet array so that a reference or calibrating pattern of focus spots is imaged on the CCD. Since the ideal wavefront is planar, each spot related to the ideal wavefront is located on the optical axis of the corresponding lenslet. When a distorted wavefront passes through the lenslet array, the image spots on the CCD are shifted with respect to a reference pattern generated by the ideal wavefront. Each shift is proportional a local slope, i.e., partial derivatives of the distorted wavefront, which partial derivatives are used to reconstruct the distorted wavefront, by means of modal wavefront estimation using Zernike polynomials.

However, the system disclosed by Liang et al. is effective only for eyes having fairly good vision. Eyes that exhibit considerable myopia (nearsightedness) would cause the focus spots to overlap on the CCD, thereby making local slope determination practically impossible for eyes having this condition. Similarly, eyes that exhibit considerable hyperopia (farsightedness) deflect the focus spots such that they do not impinge on the CCD thereby again making local slope determination practically impossible for eyes having this condition.

SUMMARY OF THE INVENTION

In general, an embodiment of the present invention provides a method and system for objectively measuring aberrations of optical systems by wavefront analysis. Another embodiment further provides for the objective measurement of ocular aberrations having a dynamic range that can cope with large amounts of such aberrations so as to be useful in practical applications. Still another embodiment of the present invention provides a method and system for objectively measuring ocular aberrations using a wavefront analyzer of simple and inexpensive design.

One embodiment of the present invention provides an apparatus and method for making objective and detailed measurements of aberrations present in human eyes.

Aberrations measured by the apparatus include "higher order" phenomena, such as spherical aberration and coma, in addition to the traditional myopia/hyperopia and astigmatism.

In accordance with an embodiment of the present invention, an energy source generates a beam of radiation. Optics, disposed in the path of the beam, direct the beam through a focusing optical system that has a rear portion which provides a diffuse reflector. The beam is diffusely reflected back from the rear portion as a wavefront of radiation that passes through the focusing optical system to impinge on the optics. The optics project the wavefront to a wavefront analyzer in direct correspondence with the wavefront as it emerges from the focusing optical system. A wavefront analyzer is disposed in the path of the wavefront projected from the optics and calculates distortions of the wavefront as an estimate of ocular aberrations of the focusing optical system. The wavefront analyzer includes a wavefront sensor coupled to a processor that analyzes the sensor data to reconstruct the wavefront to include the distortions thereof.

One embodiment of the present invention, herein described by way of example, utilizes wavefront sensing to measure the aberrations of the eye. When one considers the perfect or ideal eye as earlier described, a perfectly collimated light beam (i.e., a bundle of parallel light rays) incident on the perfect, ideal emmetropic eye, focuses to a diffraction-limited small spot on the retina. This perfect focusing is true for all light rays passing through the entrance pupil, regardless of position. From the wavefront perspective, the collimated light represents a series of perfect plane waves striking the eye. Due to the reversible nature of light ray propagation, the light emanates from an illuminated spot created on the retina as wavefronts exiting the ideal eye as a series of perfect plane waves. The apparatus of the present invention achieves this ray reversal effect using a probe beam optical path for projecting a small diameter, eye-safe laser beam into the eye and onto the fovea. The light scattered from the irradiated retina serves as a secondary source for a re-emitted wavefront. The probe laser beam strikes the retina at an appropriate foveal location to illuminate a sufficiently small spot. A fixation optical path is provided which includes a reference target aligned to an optical axis. This allows a patient to fixate on a target. A video path provides a video image of the eye plane, centered on the optical axis. A video image of the eye allows a clinical operator to assist in orienting the eye for the wavefront measurement.

Embodiments of the present invention, herein described, provide a refraction measurement system that easily accommodates the measurement of vision characteristics of the eye, even in the presence of finite refractive errors. The time for a patient to be in a fixed position during examination is reduced, while at the same time providing a useful source of light on the retina of the eye to be measured regardless of the characteristics of the eye of that patient or other patients to be examined. Desirably, measurements are made without requiring patient or operator feedback. One method aspect of

the invention for measuring optical characteristics of an optical system, such as the eye, includes focusing an optical beam onto an anterior surface of the eye for providing a finite source of secondary radiation on the retina of the eye, which secondary radiation is emitted from the retina as a reflected wavefront of radiation that passes through the eye. The reflected wavefront is directed onto a wavefront analyzer for measuring distortions associated with the reflected wavefront.

In one embodiment, the radiation is optical radiation and the wavefront sensor is implemented using a plate and a planar array of light-sensitive cells. The plate is generally opaque but that has an array of light transmissive apertures that selectively let impinging light therethrough. The plate is disposed in the path of the wavefront so that portions of the wavefront pass through the light transmissive apertures. The planar array of cells is arranged parallel to and spaced apart from the plate by a selected distance. Each portion of the wavefront passing through one of the light transmissive apertures illuminates a geometric shape covering a unique plurality of cells.

As herein described, by way of example, the wavefront optical path of the present invention relays the re-emitted wavefront from the corneal plane to an entrance face of a Hartman-Shack wavefront sensor. The wavefront incident on the sensor is received by a sensitive charged-coupled device (CCD) camera and an optical plate containing an array of lenslets. The lenslet array is parallel to the CCD detector face with a distance therebetween approximately equal to the focal length of each lens in the lenslet array. The lenslet array divides the incoming wavefront into a matching array of "wavelets," each of which focuses to a small spot on the CCD detector plane. The constellation of wavelet spots in the CCD is used to reconstruct the shape of the incident wavefront. Collimated light striking the lenslet at normal (perpendicular) incidence would focus to the spot on the CCD face where this optical axis intersects. The optics of the apparatus provides such collimated light to the wavefront sensor using a calibration optical path. Collimated light CCD images are routinely obtained as part of a daily calibration process and used for reference in analyzing experimental data.

However, in the case of a reflected aberrated wave front, light focuses to a spot displaced from the collimated reference point by a distance Dx. The distance from the lenslet face to the CCD surface, Dz, is precisely known. Therefore, dividing the measured displacement, Dx, by the known propagation distance, Dz, the slope of the wavefront at the location of this lens element is determined. The same calculation is applied in the y direction within the plane, and the entire process applied to every lenslet element irradiated by the wavefront. A mathematical algorithm is then applied to reconstruct the wavefront shape consistent with the calculated Dx/Dz and Dy/Dz slope data. Regardless of which wavefront sensor is used, the distance between the planar array of cells and the opaque plate, or the array of lenslets, can be varied to adjust the slope measurement gain of the wavefront sensor and thereby improve the dynamic range of the system.

Another measure of dynamic range enhancement is provided by the focusing optics. The focusing optics includes first and second lenses maintained in fixed positions in the path of the beam and wavefront. An arrangement of optical elements is disposed between the lenses in the path of the beam and the wavefront. The optical elements are adjustable to change the optical path length between the lenses.

A method aspect of the present invention, as herein described, determines aberrations of an eye requiring greater than a + or −3 diopter change, and includes directing an optical beam onto a retina of an eye, reflecting the optical beam from the retina of the eye, determining characteristics of a wavefront in a reflected optical beam, and generating data based on the characteristics of the wavefront, which data quantifies the aberrations of the eye. The data may further be generated based on refractive indices of media through which the optical beam passes. Yet further, data based on the characteristics of the wavefront, which data quantifies the aberrations of the eye for a discrete section of the eye may also be generated.

One method for determining aberrations of an eye, herein described by way of example, includes directing a probe beam along a probe beam path toward an eye, directing a fixation image along a fixation image path toward the eye, directing a light source along a video image path toward the eye, generating a video image of the eye, directing a wavefront originating from the eye along a wavefront path, wherein the probe beam path, the fixation image path, the video image path, and the wavefront path are coincident at least along a portion of their respective paths, the probe beam path terminating at the retina of the eye and the probe beam reflecting from the retina of the eye as a wavefront, aligning the eye with the probe beam path based at least in part on the video image of the eye generated by the light source directed along the video image path, measuring the wavefront, and generating data representative of the aberrations of the eye based on the measurement of the wavefront. Further, the aligning of the eye with the probe beam path based at least in part on the video image of the eye generated by the light source directed along the video image path, may have the wavefront pass through a single microlens array.

One apparatus for determining the aberrations of an eye comprises a patient head rest comprising vertical adjustment, the patient head rest associated with an optical table having a base. The base carries a probe beam generating apparatus, probe beam directing optics, the probe beam directing optics comprising a beam splitter; a mirror; and a lens, the probe beam directing optics being capable of directing a probe beam toward an eye of a patient positioned on the patient head rest, video image components, the video image components comprising a light source, a mirror, and a video camera, the video image components being capable of generating an image of an eye of a patient positioned on the patient head rest, eye fixation components, the eye fixation component comprising a fixation target; a light source; a lens; and a mirror, the fixation components being capable of generating a target that the eye of a patient positioned on the patient head rest can view, and wavefront directing and analyzing components, the wavefront directing and analyzing components comprising a lens, a mirror, a microlens array, a camera, and a data processor. The wavefront directing and analyzing components are capable of measuring the wavefront emanating from the eye of a patient positioned on the patient head rest and determining aberrations of said eye that range from at least about + or −1 diopters to at least about + or −6 diopters.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the invention are described by way of example with reference to the accompanying drawings in which:

FIG. **1A** is a schematic view of the ideal eye reflecting light from its retina as a planar wavefront;

FIG. **1B** is a schematic view of an aberrated eye reflecting light from its retina as a deformed wavefront;

FIG. **1**C is a schematic view of the distorted wavefront relative to a reference plane to show the wavefront error or optical path difference as a function of transverse distance in the propagation direction;

FIG. **1**D is a schematic view illustrating use of a reference plane;

FIG. **2** is a simplified schematic of the system for determining ocular aberrations in accordance with the essential features of the present invention;

FIG. **3** is a schematic of one embodiment of a Hartmann-Shack wavefront analyzer used in the present invention;

FIG. **4** is a perspective view of a portion of the pinhole imaging plate and planar array of light-sensitive cells comprising the wavefront sensor from the embodiment of FIG. **3** where the deflection of a wavefront piece associated with an aberrated eye is shown in comparison with a wavefront piece associated with a calibration or planar wavefront;

FIG. **5** is a plan view of a designated area on the planar array of light-sensitive cells associated with a corresponding hole;

FIG. **6** is a schematic of another embodiment of a wavefront analyzer used in the present invention;

FIG. **7** is a schematic view of an eye to be measured by the present invention;

FIG. **8** is a schematic view of an eye to be measured by the present invention;

FIG. **9** is a side elevation view of one embodiment of the present invention illustrating a patient positioning for measurement;

FIG. **10** is an end elevation view of the embodiment of FIG. **9**;

FIG. **11** is an enlarged perspective view of an patient positioning portion of the embodiment of FIG. **9**;

FIG. **12** is a top plan view of optical elements of the embodiment of FIG. **9**;

FIG. **12**A illustrates a fixation target optical path of FIG. **12**;

FIG. **12**B illustrates a video image optical path of FIG. **12**;

FIG. **12**C illustrates a probe laser optical path of FIG. **12**;

FIG. **12**D illustrates a re-emitted wavefront optical path of FIG. **12**;

FIG. **12**E illustrates a calibration wavefront optical path of FIG. **12**;

FIGS. **12**F and **12**G are front elevation and top plan views of a trial lens holder useful with embodiments of the present invention herein described;

FIG. **13** is a block diagram illustrating electrical components of the embodiment of FIG. **9**;

FIG. **14** is an enlarged image of an eye illustrating a centration image;

FIG. **15** is a block diagram illustrating an operable flow of steps used in one embodiment of the present invention;

FIG. **16** is an enlarged image of an eye illustrating a pre-measurement eye alignment;

FIG. **17** is an enlarged image of an eye illustrating a pre-measurement eye alignment checking thereof;

FIG. **18** is a line diagram illustrating an eye registration pattern;

FIG. **19** illustrates a rejected CCD image;

FIG. **20** illustrates a CCD image including centroids;

FIG. **21** is an enlarged image of a centroid;

FIG. **22** illustrates an image available to an operator of a measured and reference centroid;

FIG. **23**A illustrates a spacial filter operable in one embodiment of the present invention;

FIG. **23**B illustrates a noisy CCD image before filtering to provide an image as illustrated with reference to FIG. **20**;

FIG. **24**A is a three dimensional plot of a wavefront reconstruction in accordance with the present invention;

FIG. **24**B illustrates a higher order aberration for the wavefront of FIG. **23**;

FIG. **25** illustrates a geometric effect of a curved corneal surface on a wavefront measurement;

FIG. **26**A is a pictorial line drawing illustrating magnification modification to the embodiment of FIG. **12**; and

FIG. **26**B is a pictorial line drawing illustrating optical elements of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

The present invention will now be described more fully hereinafter with reference to the accompanying drawings, in which embodiments of the present invention are shown by way of illustration and example. This invention may, however, be embodied in many forms and should not be construed as limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. Like numbers refer to like elements throughout.

By way of illustrative example, the present invention will be described with respect to diagnosing a human eye. However, it is to be understood that the teachings of the present invention are applicable to any optical system having a real image focus that can be, or can be adapted to diffusely reflect a focused spot of radiation from a rear portion of the optical system back through the optical system as a wavefront of radiation. Thus, the present invention can be used with human or animal eyes of patients that may be alive or dead, or any man-made optical system.

The method of using wavefront analysis will be introduced with reference to the eye example and the aid of the schematic drawings of FIGS. **1**A, **1**B, and **1**C. As earlier described with reference to an ideal eye, and with reference now to FIG. **1**A, the ideal emmetropic or perfect eye **100** diffusely reflects an impinging light beam (not shown for sake of clarity) from the back of its retina **102** (i.e., the fovea centralis **103**) through the eye's optics which includes lens **104** and cornea **106**. For such an ideal eye **100** in a relaxed state, i.e., not accommodating to provide near-field focus, the reflected light (represented by arrows **108**) exits the eye **100** as a sequence of plane waves, one of which is represented by straight line **110**. However, as illustrated with reference to FIG. **1**B, a typical eye **120** normally has aberrations that cause deformation or distortion of a reflected wave exiting the eye, where the aberrated eye **120** diffusely reflects an impinging light beam (again not shown for sake of clarity) from the back of its retina **122** of the fovea centralis **123** through lens **124** and cornea **126**. For the aberrated eye **120**, the reflected light **128** exits the eye **120** as a sequence of distorted wavefronts, one of which is represented by wavy line **130**.

With reference now to FIG. **1**C, a coordinate system is defined for convenience, where positive x is upward in the plane of the figure, positive y is outward from the plane of the figure, and positive z is to the right along a propagation direction. The distorted wavefront **130** is herein described mathematically as W(x,y). One method of measuring dis-

tortions in the wavefront **130** is by determining a spatial separation Δz between a reference plane 131 (by way of example, a plane analogous to the ideal wavefront **110**) at a known distance Z_0 from the eye **120** at each (x,y) point of the distorted wavefront **130** as the leading edge of the wavefront **130** traverses the distance z_0. This is described mathematically as:

$$\Delta z(x,y)=z_0-W(w,y) \quad (1)$$

These Δz measurements define optical path differences due to aberrations in the eye **120** being tested, by way of example.

Depending on the desired therapy (for example, synthetic lens addition), the material thickness at each (x,y) coordinate can be calculated directly if the refractive index of the material in question is known. For many procedures, such as intra-ocular lens implantation, a wavefront analysis may be performed repetitively during a procedure to provide feedback information as to the appropriate endpoint of the procedure.

In terms of the illustrative example, the differences Δz(x, y) between the distorted wavefront **130** and the ideal wavefront **110** are the consequence of the aberrations in the eye. Measuring these aberrations consists of introducing an optical path difference at the reference plane **131** of negative Δz(x,y). If the treatment approach, by way of example, consists of adding material to the cornea **126**, then one choice for the location of reference plane **131** is tangential to the surface of cornea **126** (i.e. at z=O). This is illustrated schematically with reference to FIG. **1**D, where the curvature of the cornea **126** is greatly exaggerated for clarity of illustration.

The appropriate corneal addition at any (x,y) transverse coordinate is, to within a small error, given by:

$$\Delta z(x,y)/(n_c-1) \quad (2)$$

where n_c is the refractive index of corneal tissue or 1.3775. The method described in detail below calculates Δz(x,y) by first measuring the local slopes in wavefront **130**, i.e. ∂W(x, y)l∂x and ∂W(x,y)/∂y, at a number of points in the transverse x and y directions in reference plane **131** and then generating a mathematical description of W(x,y) having slopes in best possible agreement with the experimentally determined values. One such slope ∂W(x,y)/∂x is illustrated with reference again to FIG. **1**D. In doing this, a small error is introduced due to the fact that distorted wavefront **130** is measured at the reference plane **131** while wavefront **130** emerged from a curved corneal surface just posterior to reference plane **131**. By way of example, an error $E_x(x,y)$ is the lateral displacement in the x-direction at each (x,y) location at the measurement plane (i.e., reference plane **131**) to the curved corneal surface. A similar error will be manifest for any measurements involving curved optical surfaces. The error will generally increase with both (x,y) displacement from the point of tangency and local wavefront error.

The magnitude of error $E_x(x,y)$ can be found for each measurement location (x,y) measured at an arbitrary coordinate, e.g., (x_0,y_0) by projecting that location back to the point of origin on the cornea **126**. This is explained mathematically with reference again to FIG. **1**D, where by way of example, it is assumed that the error is in the plane of the figure, i.e., the plane defined by $y=y_0$, although it is quite straightforward mathematically to extend the analysis to include errors in the y-dimension. The quantification of a line L tracing the propagation of the wavefront **131** measured at (x_0,y_0) in the z_0 reference plane from the corneal surface to the reference plane is:

$$L(x) = z_0 - \frac{(x - x_0)}{\partial W(x_0, y_0)/\partial x} \quad (3)$$

If the corneal surface in the plane of the figure is described by the expression $S(x_0,y_0)$, then the point of origin for the wavefront **131** in question can be found by finding the point of intersection between L(x) and S (x,y_0). Mathematically, one finds the value x^1, that satisfies $L(x^1)=S(x_0,y_0)$. The error $E_x(x_0,y_0)$ is then given as $Ex(x_0,y_0)=x^1-x_0$. Extending the analysis to consider errors in the y-direction would yield a similar expression for E_y where $E_y(x_0, y_0)=y^1-y_0$. If significant, these transverse errors can be compensated for by laterally displacing the aberration calculated at each (x,y) coordinate by the amounts $E_x(x,y)$ and $E_y(x,y)$.

In the case of human corneas, the transverse error under most circumstances will be negligible. The error will be zero at the origin where the corneal tissue and reference plane **131** are tangent. For human corneas, the tissue is approximately spherical with a radius of curvature of approximately 7.5–8.0 mm. The treatment radius is typically no more than 3 mm, and local wavefront radius of curvature will almost never exceed 50 mm (a 20 diopter refractive error). The transverse error E at a 3 mm treatment radius for a local wavefront radius of curvature of 50 mm is less than 40 μm.

For certain ophthalmic procedures, wavefront analysis can also be used repetitively during the procedure to provide useful feedback information. One example of such use would be following placement of an intra-ocular lens implant (IOL). The analysis helps to identify whether the appropriate refractive power IOL has been inserted, or whether a different refractive power IOL should be used.

In order to perform wavefront analysis in a manner compatible with procedures such as those described above, the amount of spatial separation of component portions of wavefront **130** relative to the corresponding component portions of the planar or ideal wavefront **110** is measured. It is the system and method of the present invention that allows such separation to be objectively and accurately measured for even substantially aberrated eyes **120** including those exhibiting severe defects such as severe myopia or hyperopia.

For the evaluation or measurement portion of the present invention, the patient's pupil should ideally be dilated to approximately 6 mm or more, i.e., the typical size of a human pupil in low light. Smaller amounts of dilation or no dilation at all may also evaluated or measured. In this way, the eye is evaluated while it is using the greatest area of the cornea so that any measurement takes into account the largest usable corneal area of the patient's eye. A lesser amount of the cornea is used in daylight where the pupil is considerable smaller, e.g., on the order of 3 millimeters. Dilation can be brought about naturally by implementing the measurement portion of the present invention in a low light environment such as a dimly lit room. Dilation can also be induced through the use of pharmacologic agents.

Referring now to FIG. **2**, a simplified schematic of one exemplary embodiment of the apparatus **10** of the present invention is illustrated. The apparatus **10** includes a laser **12** for generating optical radiation used to produce a small-diameter laser beam **14**. The laser **12** generates a collimated laser light beam (represented by dashed lines for the beam **14**) of a wavelength and power that is eye-safe. For ophthalmic applications, appropriate wavelengths would include the entire visible spectrum and the near infrared

spectrum. By way of example, appropriate wavelengths may be in a range of from approximately 400 to 1000 nanometers, including 550, 650, 850 useful wavelengths. While operation in the visible spectrum is generally desired, since these are the conditions in which the eye operates, the near infrared spectrum may offer advantages in certain applications. For example, the patient's eye may be more relaxed if the patient does not know measurement is taking place. Regardless of the wavelength of the optical radiation, power should be restricted in ophthalmic applications to eye safe levels. For laser radiation, appropriate eye-safe exposure levels can be found in the U.S. Federal Performance Standard for Laser Products. If the analysis is to be performed on an optical system other than the eye, the examination wavelength range logically should incorporate the intended performance range of the system.

To select a small-diameter collimated core of laser light beam **14**, an iris diaphragm **16** is used to block all of laser light beam **14** except for the laser beam **18** of a size desired for use. In terms of the present invention, the laser beam **18** will have a diameter in the range of approximately 0.5–4.5 millimeters with 1–3 millimeters being typical, by way of example. A badly aberrated eye uses a smaller diameter beam while an eye with only slight aberrations can be evaluated with a larger diameter beam. Depending on the output divergence of the laser **12**, a lens, as will be later described, can be positioned in the beam path to optimize collimating of the beam.

Laser beam **18**, as herein described by way of example, is a polarized beam that is passed through a polarization sensitive beam splitter **20** for routing to a focusing optical train **22** which optical train operates to focus the laser beam **18** through the optics of the eye **120** (e.g., the cornea **126**, pupil **125** and the lens **124**) to the retina **122**. It is to be understood that the lens **124** may not be present for a patient that has undergone a cataract procedure. However, this does not affect the present invention.

In the illustrated example of FIG. **2**, the optical train **22** images the laser beam **18** as a small spot of light at or near the eye's fovea centralis **123** where the eye's vision is most acute. Note that the small spot of light could be reflected off another portion of retina **122** in order to determine aberrations related to another aspect of one's vision. For example, if the spot of light were reflected off the area of the retina **122** surrounding the fovea centralis **123**, aberrations specifically related to one's peripheral vision could then be evaluated. In all cases, the spot of light may be sized to form a near-diffraction limited image on the retina **122**. Thus, the spot of light produced by laser beam **18** at fovea centralis **123** does not exceed approximately 100 micrometers in diameter and, typically, is on the order of 10 micrometers.

The diffuse reflection of the laser beam **18** back from the retina **122** is represented in FIG. **2** by solid lines **24** indicative of radiation that passes back through the eye **120**. The wavefront **24**, earlier described with reference to FIG. **1B** as distorted wavefront **130** impinges on and is passed through the optical train **22** and on to the polarization sensitive beam splitter **20**. The wavefront **24** is depolarized relative to the laser beam **18** due to reflection and refraction as the wavefront **24** emanates from the retina **122**. Accordingly, the wavefront **24** is turned at the polarization sensitive beam splitter **20** and directed to a wavefront analyzer **26** such as a Hartmann-Shack (H-S) wavefront analyzer. In general, the wavefront analyzer **26** measures the slopes of wavefront **24**, i.e., the partial derivatives with respect to x and y, at a number of (x,y) transverse coordinates, as earlier described with reference to FIGS. **1C** and **1D**. This partial derivative information is then used to reconstruct or approximate the original wavefront with a mathematical expression such as a weighted series of Zernike polynomials.

The polarization states for the incident laser beam **18** and the beam splitter **20** minimizes the amount of stray laser radiation reaching the sensor portion of the wavefront analyzer **26**. In some situations, stray radiation may be sufficiently small when compared to the radiation returning from the desired target (e.g., the retina **122**) so that the polarization specifications are unnecessary.

The present invention is able to adapt to a wide range of vision defects and as such achieves a new level of dynamic range in terms of measuring ocular aberrations. Dynamic range enhancement is accomplished with the optical train **22** and/or a wavefront sensor portion of the wavefront analyzer **26**. With continued reference to FIG. **2**, the optical train **22** includes a first lens **220**, a flat mirror **221**, a Porro mirror **222** and a second lens **224** all of which lie along the path of laser beam **18** and the wavefront **24**. The first lens **220** and the second lens **224** are identical lenses maintained in fixed positions. The Porro mirror **222** is capable of linear movement as indicated by arrow **223** to change the optical path length between the lenses **220** and **224**. However, it is to be understood that the present invention is not limited to the particular arrangement of the flat mirror **221** and the Porro mirror **222** and that other optical arrangements, as will herein be described by way of example, will be used without departing from the teachings and benefits of the present invention.

A "zero position" of the Porro mirror **222** is identified by replacing the eye **120** illustrated with reference again to FIG. **2**, by a calibration source, as will be described later by way of further example, of collimated light to provide a reference wavefront such as the perfect plane wave **110**, earlier described with reference to FIG. **1A**. Such a source could be realized by a laser beam expanded by a beam telescope to the diameter that will cover the imaging plane of wavefront analyzer **26** and adjustment of the Porro mirror **222** until the wavefront analyzer **26** detects the light as being collimated. Note that the changes in optical path length brought about by the Porro mirror **222** can be calibrated in diopters to provide an approximate spherical dioptric measurement, as will be explained further below.

The dynamic range of the apparatus **10** is further improved by providing an improved wavefront sensor arrangement **28** as illustrated with reference to FIGS. **3** and **4**. The wavefront analyzer **26** includes an opaque imaging plate **32** having an array of holes **34** passing therethrough, a planar array **36** of light-sensitive cells such as charge coupled device (CCD) cells **38**, and a processor **40** operable with the planar array **36** of the CCD cells **38**. The combination of the plate **32** and the planar array **36** provides one embodiment of the present invention. The plate **32** is held parallel to and spaced from the planar array **36** by a separation distance F. As will be explained further below, the separation distance F can be varied to adjust for signal gain. To do this, the planar array **36** is coupled to a positioning apparatus **42**, e.g., a conventional motorized linear positioner having precise movement capability, that adjusts the position of planar array **36** relative to the plate **32** for changing the separation distance F as indicated by arrow **43**. With respect to the array of holes **34**, each of the holes **34** are of equal size and shape with a circle being typical owing to its ease of manufacture. As herein described by way of example, a square array geometry is used for the array of holes **34**, although other array geometries will be used without departing from the teachings of the present invention.

As illustrated with reference to FIG. **4**, when the wavefront **24** impinges on the plate **32**, a portion of the wavefront **24**, indicated by arrow **26**, passes through the hole **34** to illuminate planar array **36**. To a first order, the resulting image formed by each such wavefront portion **25** is a positive shadow of the respective hole **34**. However, diffraction occurs as determined by the diameter D of each hole **34**, the wavelength λ of the light source (e.g. the wavefront **24**) and the separation distance F between the plate **32** and the planar array **36**. The value of F is varied by the positioning apparatus **42** to adjust the gain based on the particular patient as will be explained further below.

Note that performance of the plate **32** with holes **34** may also be accomplished using a solid plate or film made from a light-sensitive material such as a photo-lithographic film. In such a case, the array of holes **34** would be replaced by an array of shaped light transmissive apertures through which light passes when impinging thereon. The remainder of such a plate or film would be impervious to light. Such an embodiment permits the light transmissive apertures to be easily made to conform to any desired shape.

Regardless of how each wavefront portion **25** is generated, the present invention measures the amount of angular deflection of each wavefront portion **25** relative to a wavefront portion **112** that results from a calibration wavefront such as the planar wavefront earlier described. The calibration or planar wavefront of light results in the wavefront portion **112** impinging at a normal or perpendicular to plate **32** and illuminates a geometric spot **114** on the planar array **36**. In contrast, continuing with the wavefront **24** representing a distorted wavefront as described above, the wavefront portion **25** will exhibit an amount of angular deflection relative to the calibration wavefront portion **112**. The angular deflection causes the wavefront portion **25** to illuminate a geometric spot **27** on the planar array **36** that is offset from the spot **114**. In terms of the present invention, the amount of offset is measured relative to centroids **116** and **29** of spots **114** and **27**, respectively. In the two dimensions of the planar array **36**, the centroid **29** is typically deflected in both the x and y directions of the array **36**. Thus, the angular deflection in each of the x and y directions is given by $\Delta x/F$ and $\Delta y/F$, respectively.

With reference again to FIG. **2**, the lenses **220** and **224** in one embodiment are identical as mentioned above. However, in certain applications it may be desirable to magnify or minify the wavefront at the wavefront sensor. This can be accomplished by using lenses **220** and **224** of different focal lengths and adjusting dimensions of the apparatus **10** accordingly. For ophthalmic evaluation, the object plane of the apparatus should ideally be tangent to the corneal surface which can be achieved by a variety of means. Thus, each point at the object plane of the optical train **22** very nearly corresponds to the same point on the cornea **126**. However, since the cornea **126** is curved, there will be a slight lateral displacement. The plate **32** described earlier with reference to FIG. **4** of the wavefront analyzer **26**, or an imaging plane of any wavefront sensor portion, is positioned at the focal plane of lens **220**. In this way, the object plane is always imaged on the plate **32** in direct correspondence with the wavefront image emerging from cornea **126**. This will be true regardless of the optical path length between the lenses **220** and **224**. There are several advantages to this structure, one of which is that there are very good planar arrays of light-sensitive cells that are commercially available to image an area corresponding to the 6 millimeter central circular region of the cornea.

The plate **32** (or the imaging plane of any wavefront sensor portion of a wavefront analyzer) breaks the wavefront **24** into wavefront pieces that can each be measured independently in terms of propagation direction at the planar array **36**. Since in an embodiment herein described by way of example, the optical train **22** does not magnify or reduce the image in the object plane, a point at the object plane corresponds to the same point at the image plane of the optical train. With the Porro mirror **222** set at its zero position, the direction each portion of the wavefront **24** is traveling toward the object plane is reproduced exactly at the image plane of wavefront analyzer **26**. By way of example, if one wavefront portion at a location in the object plane was traveling away from the optical axis at an angle of 20° with respect to the optical axis that is perpendicular to the object plane, the wavefront portion at the same location in the image plane will also be traveling away from the optical axis at an angle of 20°.

Note that a person who is myopic will produce a wavefront such that the wavefront portions/pieces isolated by the plate **32** will converge toward the center of planar array **36**. A hyperopic person will produce a wavefront such that the wavefront pieces isolated by the plate **32** diverge. Thus, a person with a significant vision error becomes difficult to evaluate because wavefront portions can either overlap (myopia) at the planar array **36** or spill off (hyperopia) the planar array.

In the present invention, five ways of compensating for such severe aberrations are herein described by way of example. The first way is to utilize a wavefront sensor with sufficiently small light sensitive cells **38** and sufficiently large holes **34** (or any other transmissive aperture). In this way, measurement of each wavefront piece can be performed to an acceptable accuracy using a small value for F. A second way is to move planar array **36** along the optical axis to change the separation distance F to the plate **32**. For a person with a severe aberration, the planar array **36** is positioned close to the plate **32** to keep the projected wavefront portions well separated and on the planar array. For a mild aberration, the planar array **36** is moved to increase the separation distance F to the plate **32** to make a more accurate measurement. The advantage of moving the planar array **36** to change the separation distance F to the plate **32** is that the wavefront analysis is easily achieved for any position. Yet another way of compensating for severe aberrations using the present invention is to change the optical path length between lenses **220** and **224**. Moving the Porro mirror **222** will not affect where the wavefront hits the plate **32**, but will change the angular deflections at which the projected wavefront portions pass through the plate **32**, i.e., $\Delta x/F$ and $\Delta y/F$. Decreasing the optical path length between lenses **220** and **224** will tend to pull the wavefront portions toward the center of planar array **36** thereby compensating for hyperopia. Increasing the optical path length between lenses **220** and **224** will tend to spread the wavefront portions toward the edges of the planar array **36** thereby compensating for myopia. The degree to which the angular deflection associated with each wavefront piece is altered is a linear function of its distance off the optical axis and the movement of the Porro mirror **222** from its zero position. A fourth way of compensating for severe aberrations is to insert one or more trial lenses of specified sphero-cylindrical power at the location of the intermediate focal plane, as will be discussed in detail later in this section. This serves to reduce or remove low order aberrations from the wavefront so that displacement of spots at the CCD cells **38** is minimized and accurate evaluation can proceed. The effect of the specified lens addition is then included in the final wavefront reconstruction. A fifth way is to increase the

magnification of the wavefront at the wavefront sensor relative to that at the eye. This is accomplished by an appropriate choice of lenses in the relay optic design. Magnification will reduce the slope of the wavefront uniformly, thereby reducing the displacement of each spot at the CCD.

By way of example, to accurately determine the centroid **29** of the spot **27** of light impinging on the planar array **36**, a fine structure of cells **38** relative to a spot size is provided. Each spot covers a plurality of cells **38**. One method used to determine the centroid **29** of each spot **27** unambiguously with respect to a spot caused by another one of the holes **34**, assigns a unique number of cells **38** to each hole **34**. The "assigned areas" are designated, as illustrated with reference to FIG. **5**, by way of example, with the heavy grid lines **39**. It is to be understood that the grid lines **39** are not actual physical boundaries between cells **38** but are shown simply to illustrate the unique designated areas containing a plurality of the cells **38**. It is anticipated that other centroid strategies will be utilized that do not necessitate such partitioning of the array **36** given the teachings of the present invention. An alternative method for identifying and correlating centroids is later described in this section.

By way of example, the present invention could also be practiced with a wavefront analyzer that replaces plate **32** described with reference to FIG. **3**, with a two dimensional array of identical spherical lenslets **33**, as illustrated with reference to FIG. **6**. In such an embodiment, the lenslet array **33** may be operable by the positioning apparatus **42** such that separation distance F is independent of the focal length f that defines the focal plane of the lenslet array **33** which is represented by dashed line **35**. Each wavefront portion **37** passed through a sub-aperture of the lenslet array **33** is reduced in size (e.g., diameter) but is not necessarily brought to a minimum focus at the planar array **36** as it would be if separation distance F were equal to focal length f. In the operation of this embodiment configuration, the lenslet array **33** is positioned to concentrate the light in each wavefront portion of an area for providing sufficient intensity onto the planar array **36**, yet still illuminating a substantial plurality of cells **38** for greatest accuracy in determining the deflection of the centroids **29**.

Regardless of the structure of the wavefront sensor, the processor **40** computes each two-dimensional centroid **29** of each spot **27** generated by the wavefront **24**. The amount of two dimensional centroid shift relative to the centroid of the calibrating spot for each designated area associated with a corresponding hole **34** (or sub-aperture of lenslet array **33**) is divided by the separation distance F to generate a matrix of local slopes of the wavefront, i.e., $\partial W(x,y)/\partial x$ and $\partial W(x,y)/\partial y$ at the (x,y) coordinates of the centers of holes **34**. For simplicity of discussion, these will be indicated by $P(x,y)=\partial W(x,y)/\partial x$ and $Q(x,y)=\partial W(x,y)/\partial y$, respectively.

Numerous methods exist for using the partial derivative data to calculate the distorted wavefront **130** and **24** as described above with reference to FIGS. **1**B and **2**. One acceptable approach is that described by Liang et al. in the aforementioned Journal of the Optical Society of America paper, where the wavefront is approximated using Zernike polynomials. This is a standard analytic technique described in numerous optics texts such as "Principles of Optics, 11 by M. Born and E. Wolf, Pergamon Press, Oxford, England, 1964. By way of example, the Zernike polynomial approach will be discussed herein. However, it is to be understood that other mathematical approaches can be used in approximating the distorted wavefront. By way of example, such approaches may include the use of Fourier series and Taylor series.

$$W(x,y)=\sum_{i=0}^{n} C_i Z_i(x,y) \tag{4}$$

Briefly, the wavefront W(x,y) is expressed as a weighted sum of the individual polynomials where Ci are the weighting coefficients, and $Z_i(x,y)$ are the Zernike polynomials up to some order. The upper limit n of the summation is a function of the number of Zernike polynomials, i.e., the highest order, used to approximate the true wavefront. If m is the highest order used, then

$$n=(m+1)(m+2)/2 \tag{5}$$

Derivation of the Zernike polynomials up to an arbitrary order n is described in numerous optical texts such as the aforementioned book by Born and Wolf. One possible method of determining the centroid **29**, **116** of a spot **27**, **114**, respectively, as earlier described with reference to FIGS. **4** and **5**, and calculation of the Zernike weighting coefficients will now be explained. The directions of the unit normals at the center of each hole **34** are based on the centroids of the spots on cells **38**. Since each spot will illuminate a plurality of cells varying intensity, a standard amplitude-weighted centroid calculation can be used to find the center of each spot. In order to clearly delineate each centroid from background noise, by way of example, resulting from spurious light reaching the CCD surface between valid spots, standard mathematical techniques such as a matched spatial filter can be applied to the CCD data prior to centroid identification.

An alternative method is herein described for identifying individual spots and correlating their geometry. The apparatus is configured such that the optical axis is aligned to the center of a particular aperture at the entrance face of the wavefront sensor. This aperture is located at or near the center of the entrance face. If the probe beam entering the eye is also aligned to the system optical axis, then due to the reversible nature of light rays, a light spot will always be seen directly behind the aligned aperture. That is, a spot will always be seen on the CCD sensor at this location, regardless of the wavefront aberrations, and will always correspond to the overlying aperture. Immediately adjacent spots will be minimally displaced from their zero slope" locations. As one moves further from the central reference spot, generally greater spot displacements will occur. Using this knowledge, it is a relatively straight forward process to identify all the spots in the CCD pattern and establish their geometric relationships.

The displacement of the centroid from that of a perfectly collimated light beam, corresponding to ideal and emmetropic vision, is then calculated and used to determine the wavefront slope at each sample location. The location of the centroids for a collimated light beam may either be directly measured in a calibration step prior to the patient exam, or taken from a calculated reference pattern based on the wavefront sensor construction.

Multiple exposures may be used to check for improper eye alignment or eye movement during individual exposures. If eye movement during exposures cannot be analyzed successfully by acquiring multiple exposures, then the apparatus **10** can be augmented by the addition of an eye tracker **25**, illustrated with reference again to FIG. **2**. One possible placement of the eye tracker **25** is herein illustrated. However, it is to be understood that the eye tracker **25** could

be placed elsewhere within the apparatus **10**. In this way, wavefront analysis is performed even during a limited amount of eye motion.

A one-time calibration exposure can also be used to determine the relative sensitivities of the individual cells. This is made in uniform collimated light with plate **32** removed. The responses of individual cells are then recorded. For each light transmissive aperture (e.g, hole **34**), the centroid in the collimated case serves as a dedicated origin for the particular hole. The shift from the "origin" for each hole to the centroid caused by the wavefront **24** (as observed in this coordinate system) is determined by the direction of the wave surface corresponding to that hole. If $\Delta x(m,n)$ is the x-component of the (m,n)th centroid and F is the plate separation, then the P-value for the (m,n)th centroid is:

$$P(m,n)=\partial x(m,n)/\partial z=\Delta x(m,n)/F \tag{6}$$

The corresponding expression for Q is:

$$Q(m,n)=\partial y(m,n)/\partial z=\Delta y(m,n)/F \tag{7}$$

Thus, each P(m,n) and Q(m,n) represents the partial derivatives of W(x,y) with respect to x and y for the (x,y) coordinates of each hole **34**. For an m-order Zernike approximation of the original wavefront, the experimentally determined P's and Q's are then used in the following equations to calculate the appropriate C_i weighting coefficients as follows:

$$P(m,n)=\frac{\partial W(x,y)}{\partial x}=\sum_{i=0}^{n} C_i \frac{\partial Z_i(x,y)}{\partial x} \tag{8}$$

$$Q(m,n)=\frac{\partial W(x,y)}{\partial x}=\sum_{i=0}^{n} C_i \frac{\partial Z_i(x,y)}{\partial x} \tag{9}$$

By using a least-squares approx(m,n)/∂zach to minimize the error between the actual wavefront slopes on the left hand side in the above equations and the Zernike approximations on the right hand side, optimal values for the weighting coefficients can be obtained.

In one possible approach to calculating a centroid (x_c,y_c) each hole **34** is assigned its dedicated area of the array **36** or $(i_{m,n}\pm\Delta i, j_{m,n}\pm\Delta j)$. This square of many light-sensitive cells is large enough that neighboring hole images never encroach, and all illumination from this hole is contained. The square contains $4\Delta i^*\Delta j$ cells.

If array **36** is designated $C_{k,1}=(x_c(i,j),y_c,(i,j)),k$, 1=0 . . . $2\Delta 1$, $2\Delta j$, and the spacing on centers is $\Delta x=\Delta y=d$, the measured cell responses are V (k,1) and the relative responsivities are R (k, I), then the x-component x_c, a function of i, j is represented by

$$x_c(i,j)=[\Sigma_{k,1}V(k,1)^*R(k,1)^*d^*k]/[\Sigma_{k,1}V(k,1)^*R(k,1)] \tag{10}$$

and the y-component y_c, as a function of i,j is represented by

$$y_c(i,j)=[\Sigma_{k,1}V(k,1)^*R(k,1)^*d^*1]/[\Sigma_{k,1}V(k,1)^*R(k,1)] \tag{11}$$

Then, if $(x_{c0}(i,j),y_{c0}(i,j))$ is the "origin centroid" for the (i,j) hole, i.e., made in perpendicular collimated light, and $(x_{cw}(i,j),y_{cw}(i,j))$ is the corresponding centroid found for the wavefront to be measured, then the relative centroid shift $(x_{cr}(i,j)), Y_{cr}(i,j))$ is found as

$$x_{cr}(i,j)=x_{cw}(i,j)-x_{c0}(i,j) \tag{12}$$

$$y_{cr}(i,j)=y_{cw}(i,j)-y_{c0}(i,j) \tag{13}$$

The values P(i,j) and Q(i,j) are determined from

$$P(i,j)=x_{cr}(i,j)/F \tag{14}$$

and

$$Q(i,j)=y_{cr}(i,j)/F \tag{15}$$

The surface partial derivatives P(i,j) and Q(i,j) for the array of hole centers of plate **32** are next used to calculate the appropriate Zernike polynomial weighting coefficients to describe the original wavefront W(x,y). This will now be explained by way of illustration for a 7×7 square array of holes **34**. However, it is to be understood that other sizes and shapes of hole arrays could be used.

First, a 1×98 matrix (i.e., column vector) PQ(k) is formed as

$$PQ(k)=P(7i+j),j=0 \ldots 6,i=0 \ldots 6,k=0 \ldots 48 \tag{16}$$

$$PQ(k)=Q(7i+j),j=0 \ldots 6,i=0 \ldots 6,k=49 \ldots 98 \tag{17}$$

with j cycling for each i, i.e., PQ (18)=P (2,5).

The matrix PQ is multiplied from the left with a transition matrix TM to get the matrix C as follows

$$C=TM^*PQ \tag{18}$$

where TM is a 98 wide by 14 high matrix and C is a 1 wide by 14 high matrix or column vector. C is the matrix C_k k=1, . . . , 14 such that, to a least square error,

$$W(x,y)=\Sigma_k C_k^* Z_k(x,y) \tag{19}$$

and TM is calculated for a given aperture, e.g., a 6 millimeter pupil aperture. The functions Z_k (x,y) in equation (19) are the Zernike polynomials. There is no standard convention as to their sequence. Thus, for consistency, it is important that the same sequence is used to produce the set C_k that was chosen for deriving the matrix TM. They occur in groups of the same order, which is the highest exponent in the group, with the total number of members in an order increasing with the order. For example, in a fourth order analysis, orders up to and including 4 are used (less Z_0—the single member of order 0 that is the constant 1 which describes the reference position of the group in the z direction). Since wavefront **24** is moving along z (at the velocity of light), this "piston term" describes only an arbitrary offset in Z, and this term may be ignored. The first 5 orders (0, 1, . . . , 4) contain 15 functions including the piston term.

Thus, in the illustrated example, 14 values of C_k are calculated as coefficients of 14 Zemike polynomials. By way of example, one such order used to calculate TM is herein illustrated, and includes both the Zernike functions and their partial derivatives. ZERNIKE (X,Y) POLYNOMIAL EXPANSION THROUGH ORDER 4

Polynomial Order 0	
Z(0)	+1
dZ(0)/dx	0.0
DZ(0)/dy	0.0
Polynomial Order 1	
Z(1)	+y
dZ(1)/dx	0.0
dZ(1)/dy	+1
Z(2)	+x
dZ(2)/dx	+1
dZ(2)/dy	0.0

-continued

Polynomial Order 2	
Z(3)	$-1 + 2y^2 + 2x^2$
dZ(3)/dx	$+4x$
dZ(3)/dy	$+4y$
Z(4)	$+2xy$
dZ(4)/dx	$+2y$
dZ(4)/dy	$+2x$
Z(5)	$-y^2 + x^2$
dZ(5)/dx	$+2x$
dZ(5)/dy	$-2y$
Polynomial Order 3	
Z(6)	$-2y + 3y^3 + 3x^2y$
dZ(6)/dx	$+6xy$
dZ(6)/dy	$-2 + 9y^2 + 3x^2$
Z(7)	$-2x + 3xy^2 + 3x^3$
dZ(7)/dx	$-2 + 3y^2 + 9x^2$
dZ(7)/dy	$+6xy$
Z(8)	$-y^3 + 3x^2y$
dZ(8)/dx	$+6xy$
dZ(8)/dy	$-3y^2 + 3x^2$
Z(9)	$-3xy^2 + x^3$
dZ(9)/dx	$-3y^2 + 3x^2$
dZ(9)/dy	$-6xy$
Polynomial Order 4	
Z(10)	$+1 - 6y^2 + 6y^4 - 6x^2 + 12x^2y^2 + 6x^4$
dZ(10)/dx	$-12x + 24xy^2 + 24x^3$
dZ(10)/dy	$-12y + 24y^3 + 24x^2y$
Z(11)	$-6xy + 8xy^3 + 8x^3y$
dZ(11)/dx	$-6y + 8y^3 + 24x^2y$
dZ(11)/dy	$-6x + 24xy^2 + 8x^3$
Z(12)	$+3y^2 - 4y^4 - 3x^2 + 4x^4$
dZ(12)/dx	$-6x + 16x^3$
dZ(12)/dy	$+6y - 16y^3$
Z(13)	$-4xy^3 + 4x^3y$
dZ(13)/dx	$-4y^3 + 12x^2y$
dZ(13)/dy	$-12xy^2 + 4x^3$
Z(14)	$+y^4 - 6x^2y^2 + x^4$
dZ(14)/dx	$-12xy^2 + 4x^3$
dZ(14)/dy	$+4y^3 - 12x^2y$

The choice of sequencing the Zernike polynomials dictates the interpretations of the C_k in equation (19) and therefore the order of terms in the TM matrix. Hence, the TM matrix is calculated after the choice is made. The development of the TM matrix for the illustrated example will be explained below.

Note that the fourth order analysis is only an example and is not the only possibility. A Zernike analysis can be done to any order. In general, the higher the order, the more accurate the result over the tested points. However, an exact polynomial fit over the tested points is not necessarily desirable. Such fits have the typical disturbing property that, unless the surface itself happens to be an exact polynomial of order no higher than that used for the surface fit, forcing an exact fit at separated points often causes wild swings between fitted points. That is, in polynomial surface fitting, an exact fit at a finite number of points can yield a poor average fit for a general function.

Calculation of the $\Delta z\ (x,y)$ optical path difference information from the Zernike reconstruction of the wavefront is accomplished simply by subtracting a constant from the Zernike approximation. The value of the constant will depend on the desired characteristics of $\Delta z\ (x,y)$. Depending on the method chosen to compensate for the aberrations (e.g., lens addition, etc.) it may, for example, be desirable to set either the maximum, mean or minimum value in $\Delta z\ (x,y)$ equal to zero.

The development of the transition matrix TM will now be explained for the illustrated example of a 7×7 array of holes in plate **32**. At each point (x_i,y_j), the tangents of the components of the normal are P (x_i,y_j) and Q (x_i,y_j) where

$$P(x_i,y_j)=\partial W(x_i,y_j)/\partial x \tag{20}$$

and

$$Q(x_i,y_j)=\partial W(x_i,y_j)/\partial y \tag{21}$$

Combining these with equation (11),

$$P(x_i,y_j)=\Sigma_k C_k \partial W(x_i,y_j)/\partial x \tag{22}$$

and

$$Q(x_i,y_j)=\Sigma_k C_k \partial W(x_i,y_j)/\partial y \tag{23}$$

each applicable to 49 (i,j) combinations. These are combined into a single column vector PQ that is 98 elements high, i.e., a 98×1 matrix. Defining two matrices C_k (14 high×1 wide) and $M_{k,(i,j)}$ (14 wide×98 high)

$$(M_{k,(i,j)})=\partial Z_k(x_i,y_j)/\partial x;\partial Z_k(x_i,y_j)/\partial y \tag{24}$$

where the x-derivatives are the first 49 rows and the y-derivatives are the last 49 rows. Then, equation (19) can be rewritten as the matrix equation

$$(PQ)=(M)(C) \tag{25}$$

where the top 49 rows of M are the $\partial W\ (x_i, y_j)/\partial y$.

The expression in equation (25) gives the normal components in terms of the Zernike coefficients for a surface described by the array of 14 C's. These are exact, but it is not guaranteed that the actual total surface can be described by such an array of coefficients. Accordingly, if it is assumed that the description is within an acceptable tolerance, i.e., tolerating the errors that remain after least square error determination, then equation (26) can be considered to define the column vector C implicitly in terms of the mathematical matrix M and the measured vector PQ, both of which are known. The method of effecting the solution under the minimization condition is as follows. First, equation (25) is multiplied on the left by MT, the transpose of M such that

$$(M^T)(PQ)=(M^T)(M)(C)=(S)(C) \tag{26}$$

where

$$S\equiv M^TM \tag{27}$$

is a square and symmetric matrix, e.g., of dimensions 14×14 (with each element the sum of 98 products). Such a matrix has an inverse unless the determinant of its coefficients is zero. Since this is based on the Zernike polynomials alone, and they are all independent of each other, the determinant is non-zero, so that an inverse S^{-1} is defined. Next, equation (25) is multiplied on the left by S^{-1} to yield

$$(S^{-1})(M^T(PQ)=(S^{-1})(S)(C)=(I)(C)=C \tag{28}$$

Then, the mathematical transition matrix (independent of measurement) is

$$(TM)=(S^{-1})(M^T) \tag{29}$$

and the "best fit" array of C's from the measured PQ's can be produced by the simple matrix multiplication

$$(C)=(TM)(PQ) \tag{30}$$

To evaluate the eye unambiguously, all spots illuminating the planar array **36** due to a wavefront **24** are incident on the planar array simultaneously. If it is desired to reduce effects of eye movement, a pulsing or shuttering laser source may be used, or an eye tracker.

With reference again to FIGS. **7** and **8**, a beam of linearly polarized light (S-component) is emitted from a diode laser (670 nm, 3 mW by way of example), which beam of light passes through an electromechanical shutter, which controls the duration of light exposure on the eye **14** of the patient, and in particular, the exposure of the retina **18** of the eye **14** illustrated with reference again to FIGS. **7** and **8**. It is expected that alternate sources of light, for example, non-coherent and non-polarized, as well as alternate light transmitting techniques will come to the mind of those skilled in the art. When the shutter is open, the projected beam, collimated light from the diode laser, is directed by a long focal length lens for focusing on the anterior surface **22** of the cornea **24** of the eye **14**, as illustrated with reference to FIG. **7**, passing through the pupil **72** and lens **28** of the eye **14**, and onto the retina **18** as the small measurable spot **16**. In an alternate embodiment, the lens comprises a zoom lens for varying the focus and moving the focus location as desired. By focusing on the cornea **24**, the measurement is minimally dependent on the curvature of the cornea. However, other locations proximate the corneal surface are acceptable.

It is typical in the art of eye measurements to form a collimated beam and attempt to focus the collimated beam onto the retina, using lenses and lens combinations with the optics of the eye to produce the smallest possible spot **36**, as earlier described with reference to FIG. **8**. Lenses and focusing techniques typically take valuable time and include multiple attempts to focus a spot on the retina using various lenses and lens combinations to accommodate each unique vision of each patient being measured. With this technique, and the understanding that most of the blurring results from the curvature of the cornea, the technique eliminates the need to find lenses or lens combinations to minimize the size of the spot on the retina that is used as the secondary source of radiation.

With reference now to FIGS. **9–11**, an exemplary embodiment of the apparatus **10** will be herein described beginning with series **300**, which improved apparatus **300** is constructed as a patient examination station which allows the patient **302** to be comfortably positioned for the measurement of the eye **120**, as earlier described. For convenience to the technician operating the apparatus **300**, a computer monitor, mouse, and keyboard are located on a separate cart for this embodiment of the present invention, herein described. The apparatus **300** includes a housing **304** having a platform **306** which is carried by a rigid frame **308**. The frame **308** includes wheels **310** to facilitate shipping and installation at the clinical site, as well as locking and leveling feet **312** for securing the apparatus to the supporting floor **314**. Once the apparatus is positioned, the integrated leveling feet **312** are deployed to provide a stable stationary frame **308**, and thus platform **306**.

As illustrated, by way of example with reference again to FIGS. **9–11**, the patient **302** sits at a patient end **316** of the apparatus **300**, with his or her head resting in a headrest **318**, which headrest is adjustable in directions left/right (X-direction), up/down (Y-direction), or toward/away (Z-direction) relative to the platform **306**, using adjustment assembly **320**. The headrest **318** is attached to the lower surface of the platform **306** which forms an optical table for mounting optical components thereon, as illustrated with reference to FIG. **12**, and as will herein be described in further detail. The housing **304** includes a removable optical table cover **322** which protects the optical components carried within the housing. The optical table cover **322** is secured to the platform **306** with keyed locks to prevent unauthorized access to the optical components. The platform **306** is bolted to the rigid frame at four locations **307**, as illustrated with reference again to FIGS. **9** and **10**. The frame **308** also carries electronics **324** and a computer **326** which includes the processor **40** earlier described with reference to FIG. **6**, as well as a connector plate for a computer keyboard, monitor and mouse. The frame **308** also includes an upper bay **328** housing electronics controlling optical components carried by the platform **306**, and a lower bay **330** housing an uninterruptible power supply (UPS) and an isolation transformer.

As illustrated with reference again to FIGS. **9–12**, three ports are positioned within the cover **322**, and include an examination port **332** to allow the wavefront measurement of the eye **120** to take place, and two eye illumination ports **334** which allow lamps **336** carried within the housing **304** to illuminate the eye for visualization by an internal video camera **338**. In addition, the adjustment assembly **320** includes a position sensor **321** which senses an x-direction displacement for detecting a position of the headrest **318** to the left or to the right of a reference center line location **3191**. A signal indicative of the sensed displacement is provided to the computer **326** for automatically recording the appropriate eye **120** (e.g. left or right) being measured.

As illustrated with reference again to FIG. **12**, the platform **306** provides an optical table with the patient positioning the eye **120** for measurement by the apparatus **300**. The platform surface measures approximately two feet by four feet, with the optical components fixed to the surface using a combination of commercial and customized precision hardware mounts. All transmissive optical elements have surface anti-reflection coating optimized for the selected probe beam wavelength. The optical layout includes five distinct optical pathways which share the optical elements as will herein be described, by way of example. With reference again to FIG. **12**, a first optical path **340**, a fixation target image optical path illustrated in isolation in FIG. **12**A for convenience to the reader, displays a fixation target image to the patient seated at the apparatus **300**. The patient aligns his/her visual axis to the optical axis **342** by looking at the center of a target reticle **344** having a grid pattern. With reference again to FIG. **12**, a second optical path **346**, a video image optical path illustrated in isolation in FIG. **12**B for convenience to the reader, captures a video image of the corneal plane. This allows the technician to assist in aligning the eye **120** for examination, and to record the exact location of the eye during each measurement using software reticles superimposed on a video image. With reference again to FIG. **12**, a third optical path **348**, a probe laser optical path illustrated in isolation in FIG. **12**C for convenience to the reader, sends a probe laser beam **350** into the eye **120** along the optical axis **342**. As earlier described with reference to FIGS. **2** and **7**, the probe laser beam **14**, herein referred to with numeral **350** is attenuated to an eye-safe intensity and linearly polarized before being focused onto the corneal surface. With reference again to FIG. **12**, a fourth optical path **352**, a re-emitted wavefront optical path illustrated in isolation in FIG. **12**D for convenience to the reader, conveys the reflected wavefront **24** of FIG. **2**, and herein described with numeral **354** re-emitted from the eye **120** and directed towards a wavefront sensor **356**. To accomplish this, first

and second afocal relay stages **358**, **360** transfer the reflected wavefront **354** from the corneal plane of the eye **120** to the entrance face of the wavefront sensor **356**. Finally, with reference again to FIG. **12**, a fifth optical path **362**, a calibration wavefront optical path illustrated in isolation in FIG. **12**E for convenience to the reader, injects collimated laser light into the wavefront transfer path leading to the sensor **356**. Software operable within the computer **326**, described earlier with reference to FIG. **9**, uses collimated light wavefront sensor output data to calibrate the apparatus **300** prior to patient measurement.

With continued reference to FIGS. **12**, and **12**A, the first optical path **340** is herein described as a fixation path which provides a reference image to the patient, such that the eye **120** is properly aligned when the patient is fixating on the reticle **344** of a reference target **366**. A target illumination lamp **368** back-lights the fixation target **366**, which fixation target image reaches the patient eye **120** by transmission through a 50/50 beam splitter **370**, lenses **372**, reflection in 50/50 beam splitters **374**, **376**, and transmission through lens combinations of afocal relay stage **358**, as well as through polarizing beam splitter **378**. In addition, a spectral filter is placed over the target illumination lamp **368** to remove radiation over the 620–790 nm wavelength range that might otherwise interfere with a wavefront measurement at **670** nm. The lens combinations in the first relay stage **358** contain identical lens elements mounted in reverse order. Each consists of two meniscus lens elements, with an interposed achromatic doublet. The lens combinations work in tandem as a unity magnification afocal relay stage.

The optical elements including the polarizing beam splitter **378**, the lenses of the first afocal stage **358**, the beam splitters **374**, **376**, and one lens **380** of the lenses **372** are mechanically fixed in place on the surface of the platform **306**. The optical elements including a lens pair **382** of the lenses **372**, the beam splitter **370**, the fixation target **366**, and the illumination lamp **368** are all mounted on one precision linear translation stage, capable of movement along the optical axis **342** of this pathway. Translation of these optical elements focuses the fixation target **366** for the patient's view, compensating for any myopia/hyperopia present in the eye **120**. During patient examination the focus translation stage is adjusted to place the target optically just beyond the eye's infinity focal plane. This allows the patient to see a relatively distinct reticle pattern without stimulating accommodation by the eye **120**. The beam splitters **378**, **376**, **374** serve as interfaces between other optical pathways within the optical axis **342**, as will herein be described in further detail. By way of example, the beam splitter **370** is included for alignment purposes. A photo-detector **384** attached to the center of the left edge of beam splitter **370** senses light transmitted toward the fixation target along the optical axis.

With reference again to FIGS. **12** and **12**B, the second optical path **346** captures video images of the eye **120** at an examination plane. This allows the clinical operator/technician to assist in patient alignment, and to measure actual eye displacement during the wavefront measurement. As earlier described, the illumination lamps **336** illuminate the eye **120**. The image of the eye is conveyed to the video camera **338** by transmission through the polarizing beam splitter **378** and the lens combinations **358**, reflection in the 50/50 beam splitter **376**, transmission through the 50/50 beam splitter **374**, reflection off mirror **386**, and transmission through lens **388**. All these optical elements are fixed in place on the surface of the platform **306**. By way of example, this second path **346** provides a video field of view approximately 22 mm in diameter at the eye plane, with a limiting resolution of ~64 mm. As earlier described, a number of filters are placed in front of each eye illumination lamp **336** to reduce the spectral bandwidth of the radiation reaching the eye **120**. By way of example, these will includes a blue filter to remove light at wavelengths below ~455 nm (for eye safety), an infrared filter to remove light at wavelengths above ~920 nm (for eye safety), and a rejection filter to remove light over the wavelength range 620 nm–790 nm (to prevent interference with the wavefront measurement at 670 nm).

With continued reference to FIGS. **12** and **12**C, the third optical path **348** irradiates a small spot on the patient's retina with eye safe laser radiation, as earlier described with reference to FIGS. **1**A–**1**D. The irradiated retinal spot on the fovea centralis **123** of the retina **122** is, as herein described, the origin of the re-emitted wavefront **130** measured by the sensor **356**. The output beam, probe laser beam **350** from diode laser **390** reaches the patient eye **120** by transmission through a linear polarizer and attenuator **392**, lens **394**, shutter **396**, and reflection off mirror **398** and in the polarizing beam splitter **378**. All these elements are fixed in position.

In one embodiment of the present invention, output of the diode laser **390** is essentially collimated and is focused onto a corneal surface of the eye **120** by lens **394**. The projected probe laser beam **350**, collimated light from the diode laser **390**, is directed by a long focal length lens **394** for focusing on the anterior surface of the cornea **126** of the eye **120**, as illustrated by way of example with reference again to FIG. **1**B, passing through the pupil and lens **124** of the eye **120**, and onto the retina **122** as a small measurable spot on the fovea centralis **123**. As earlier described with reference to FIG. **7**, in one embodiment, the lens **394** illustrated with reference again to FIG. **12**, comprises a zoom lens for varying the focus and moving the focus location as desired. By focusing on the cornea **126**, the measurement is minimally dependent on the curvature of the cornea. However, other locations proximate the corneal surface are acceptable.

While diffraction and various aberrations are present, the present invention **5** avoids the aberration effects from the cornea which typically dominate. The lens of the eye **120** contributes a relatively small aberration effect when compared to that of the cornea **126**. Further, and with regard to the selection of the lens **394**, selecting a lens with a short focal length would provide a relatively large incident angle of the beam **350**, a well focused point on the surface of the cornea **126**, and less aberration effects from the cornea. A small incident angle provides a larger focus point on the cornea **126**, but a more desirable smaller spot on the retina **122**, which spot size will depend on the wavelength and starting point size and focal length of the lens **394** selected. Embodiments of the present invention including lenses of approximate one half meter and 100 mm, by way of example, haves been effectively used.

The polarizer **392** linearly polarizes the probe beam **350** into an s-state (by way of example, out of the plane of the drawing of FIG. **12**). The angled interior interface of the polarizing beam splitter **378** reflects s-polarized light, so that light entering the eye **120** is s-polarized. A linear polarizer **400** is angled with respect to the polarizer **392** and works in conjunction with the attenuator to attenuate probe beam power delivered to the eye **120** to less than 10 μW, by way of example. The diode laser **390** is triggered by an external electrical trigger signal **402**. A nominal illumination duration for eye measurement is 700 ms. The shutter **396** is included as an additional safeguard against overexposure of the eye **120** to the probe laser beam **350**. The shutter **396** is normally

closed and is opened by an independent electrical trigger signal **404** synchronized to the laser trigger signal **402**.

By way of example, one retinal exposure for each illumination by the probe beam is 10 μW×0.7 s=7 μJ. Up to 10 repeat measurements may be obtained during a single patient examination session. Such exposures are well within the safety limits defined in the American National Standard for Safe Use of Lasers (ANSI Z136.1-1993, American National Standards Institute, New York, N.Y.). In that reference, the maximum permissible exposure (MPE) for "intrabeam" viewing a laser beam in the 400–700 nm wavelength range and the 18×10^{-6} to 10 second pulse duration range is $1.8*t^{3/4}$ mJ/cm^2. (t is the pulse duration in seconds). A limiting aperture for the eye is identified as approximately 7 mm in diameter. As a result, an allowable single-pulse energy is $0.6927*t^{3/4}$ mJ. For a single 0.7 second pulse the MPE is 530 μJ, almost two orders of magnitude larger than a delivered energy per pulse, for the apparatus herein described. An additional calculation is performed to assess the safety of the repetitive exposures. The relevant calculation in the Standard multiplies the single pulse MPE by $n^{-1/4}$, where n is the total number of pulses in the exposure duration T_{max}. For the apparatus of the present invention, the 10-pulse safety limit is 530 μJ/pulse$\times10^{-0.25}$= 298 μJ/pulse, still a factor of 40 larger than the actual pulse energy focused into the eye.

As illustrated with reference again to FIGS. **12** and **12**D, the fourth optical path **352** conveys the wavefront **354**, earlier identified by numeral **130** with reference to FIG. **1**B, emerging from the eye **120** to the wavefront sensor **356**, herein described using a Hartman-Shack sensor by way of example for the wavefront analysis. The wavefront **354** re-emitted by the eye **120** in response to the probe beam **350** irradiation is conveyed to a CCD camera **406** by transmission through the polarizing beam splitter **378**, the first afocal relay stage **358** lens combination, the 50/50 beam splitter **376**, a trial lens holder **408**, the second afocal relay stage **360** lens combination, reflection off mirror **410**, and transmission through microlens array **412**, as earlier described with numeral **33** with reference to FIG. **6**. With the exception of the changeable trial lens holder **408**, illustrated with reference to FIGS. **12**F and **12**G, all these optical elements are fixed in place on the surface of the platform **306**.

The polarizing beam splitter **378** transmits only linearly polarized light in a p-state. The radiation of the probe beam **350** reflected from the corneal surface of the eye **120** will retain the incident s-state polarization and will not be appreciably transmitted by the beam splitter **378**. In contrast, light that has been scattered off the retina of eye **120**, light forming the wavefront **354** of interest, will be largely depolarized. The p-polarized fraction of this light will be transmitted by the beam splitter **378**. Thus the beam splitter **378** selectively suppresses the corneal surface reflection that could otherwise complicate the wavefront measurement. A wavefront originating at the corneal plane of eye **120** is transferred to a plane of the trial lens holder **408** with unity magnification. This plane of the trial lens holder **408** provides an intermediate pupil plane and is included for placing an ideal N-diopter lens **409**, see FIGS. **12**F and **12**G, at the trial lens plane to change the spherical curvature of the wavefront **354** by N-diopters, without altering other aberration content. The capability to reduce/remove the general wavefront curvature in a preselected manner significantly extends the dynamic range in wavefront measurement, without degrading the measurement accuracy. Trial lenses **409***a*–**409***m*, by way of example and herein described of varying spherical powers, ranging from −16 diopters to +8 diopters in two-diopter increments, are mounted on a rotating wheel **407** of the holder **408**. The wheel's axis of rotation is parallel to but offset from the optical axis **342**. Turning the wheel places one of a plurality of preselected trial lenses at the trial lens plane. The wheel has precision mechanical detents that register the selected lens properly in the optical path.

A narrow band-pass optical filter is also placed at trial lens holder **408** location just anterior to the lens position. This filter has maximum transmission for 670 nm wavelength radiation (the probe beam wavelength), and a bandwidth of approximately 10 nm (full-width-half-maximum). This filter is used to reject spurious light (from the fixation target illumination, the eye illumination, and the like) from the wavefront path.

In one embodiment, as herein described by way of example, each of the lenses of the second afocal relay stage **360** consists of three lens elements, two meniscus lenses and an interposed achromatic doublet. However, they are not identical, and their combined action serves to magnify the passing wavefront **130**. The wavefront **354** at the trial lens holder **408** location is imaged onto the surface of the microlens array **412** with a magnification of 1.22. Magnification of the wavefront image by this defined factor of 1.22 reduces the wavefront slope at each point in the image plane by the same 1.22 factor. This extends the measurement dynamic range of the device, again without decreasing accuracy. In addition, this magnification distributes the wavefront **130** over more elements, CCD cells **38** as earlier described with reference to FIG. **6**, in the microlens array **412**, thus increasing the number of slope measurements provided by the wavefront sensor **356**. The mirror **410** is included to fit elements of the apparatus **300** within the dimensions of the platform **306**. In addition, the mirror **410** also allows optical alignment adjustment for the microlens array **412** and the CCD camera **406** combination. As earlier described, by way of example, with reference to FIGS. **3**–**6**, the microlens array contains a square array of microlenses which divide the incident wavefront into a transverse array of secondary "wavelets." These wavelets are focused onto a detector surface of the CCD camera, which is positioned parallel to the microlens array and one focal length posterior thereto. The pattern of focused wavelets in the CCD image is used to calculate the shape of the incident wavefront.

As illustrated with reference again to FIGS. **12** and **12**E, the calibration beam path **362** provides the collimated beam **364** to the Hartman Shack wavefront sensor **356**. Wavefront data for the collimated beam **364** is used as a reference in reconstructing the aberrated wavefront **354** from the real eye measurement. The source for the collimated reference beam **364** consists of a diode laser **414** coupled to beam expander **416**. In one embodiment of the invention herein described, the diode laser **414** used for reference is identical to the diode laser **390** used for the probe beam path **348**. The collimated reference beam **364** is conveyed to the CCD camera **406** by transmission through polarizer/attenuator **418**, negative lens and aperture **420**, aperture and positive lens **422**, reflection off mirror **424**, transmission through aperture **426**, reflection in the polarizing beam splitter **378**, transmission through the first afocal relay stage **358**, the 50/50 beam splitter **376**, the trial lens holder **408**, the second afocal relay stage **360**, reflection off the mirror **410**, and finally transmission through the microlens array **412**. Except for trial lens holder **408**, all these optical elements may be fixed in position on the surface of the platform **306**.

The optical element of the polarizer and attenuator **418** contains two linear polarizers and a neutral density filter.

The linear polarizer furthest from the diode laser **414** polarizes the laser radiation in the s-state for maximum reflection in the polarizing beam splitter **378**. The linear polarizer closest to the diode laser **414** is partially "crossed" with respect to the polarizer **378** to attenuate the laser power. The neutral density filter further attenuates the beam, such that the laser power reaching the CCD Camera **406** is optimal for calibration of the sensor **356**. The negative lens and positive lens of elements **418**, **420** expand the diode laser output and form the collimated reference beam **36**. Intervening apertures of elements **418**, **420** transmit only the central portion of the expanding beam with the most uniform intensity. The mirror **424** is included to reduce the overall dimensions of the apparatus **300**. The aperture **426** is conjugate to the corneal plane, and is included so that the collimated reference beam **364** illuminates approximately the same area on the microlens array **412** as would the wavefront **354** re-emitted by a maximally dilated eye.

By way of illustration, optical components suitable for use with embodiments of the present invention herein described by way of example, are provided with reference to Table 1. An electrical component layout of the apparatus **300** is illustrated with reference to FIG. **13**, wherein a dashed box **428** indicates the platform **306** with the heretofore described element carried thereon. Except for the computer monitor, keyboard, and mouse all other electrical components are located within the frame under the optical table. Switches in the diagram are all located on a front panel **430** of the electronics **324** for ease in operator/technician access, as described earlier with reference to FIG. **9**. Electrical power from the clinical facility is drawn by an isolation transformer, which in turn supplies power to an uninterruptible power supply (UPS). The UPS delivers power to three power strips carried in the frame **308**. The host computer **326** has a self contained On/Off switch, as do the three power strips. One power strip **432** supplies power to the shutter controller **434**, which commands the probe laser shutter **396** through the signal **404**, two dual power supplies **436**, each capable of providing both 5 VDC and 9–15 VDC output, the host computer **326**, a computer monitor **438**, and a third power strip **440**. One dual power supply supplies 5 VDC power to the two patient illumination lamps **336**, and 9 VDC power to the target illumination lamp **368**. A second dual power supply supplies 5 VDC power to both diode lasers **390**, **414**. A user-accessible 3-position switch **442** allows the system operator/technician to provide power to either the probe laser **390** or the calibration laser **414**, with a center switch position being the "off" state.

A third power strip **444** supplies power to the CCD electronics controller **446**. The power strip **440** also supplies power to cooling fans **448** located on the platform and within the frame.

By way of example and for illustration purposes, operation of the apparatus **300** may generally proceed with the operator/technician first activating each of the electrical elements, with the CCD electronics controller **434** being last to be enabled. The operator then activates the calibration laser **414** via the 3-position switch **442**. The operator then instructs the computer **326** to acquire a calibration wavefront measurement. The computer **326** relays this command to the CCD controller electronics **446**, which activates the CCD camera **406** to take a predefined exposure. The CCD controller electronics **446** also sends trigger signals **402**, **404** described earlier with reference to FIG. **12**, to the probe laser **390** and the probe laser shutter **396**. However, since the probe laser **390** is not powered at this point, no probe beam **350** is delivered. Calibration CCD data are transferred to the CPU of the computer **326**, and stored for later analysis. The calibration laser **414** is switched off at the end of the calibration procedure.

The technician/operator then proceeds to patient measurements. The output switch **442** at the dual voltage power supply **436** is positioned to a probe laser setting. The probe laser **390** is now in a "ready" state awaiting an additional trigger signal to operate. The operator then positions the patient appropriately in the apparatus **300** as earlier described with reference to FIGS. **9–11**, with the assistance of an image from the video camera **338** displayed on the computer monitor, by way of example. With the patient situated, the operator instructs the computer **326** to obtain wavefront data, as earlier described with reference to FIGS. **2–7**. The computer **326** relays appropriate commands to the CCD electronics controller **446**, which triggers the probe laser **396** to fire, triggers the shutter controller **434** to open the probe laser shutter **396**, and exposes the CCD camera **406**. CCD camera image data is transferred back to the computer **326**. The computer **326** includes software that analyzes the patient and calibration data to calculate the patient wavefront profile for use. At the end of the data collection, the operator shuts down the electronics, starting with the CCD electronics controller **446**.The software integrated into the apparatus **300** may be described, by way of example, as including: A graphical user interface (GUI) to allow the technician to perform all desired operations to enter and save patient information and perform the desired measurements; database and file system interfaces to allow for the saving and tracking of patient information, measurement, and hardware details; control of the electro-optical and electro-mechanical components as necessary in order to be able to accurately and safely perform the desired measurements; and processing of the measurement data to generate mathematical descriptions of the aberrations (the optical path difference) measured in the subject eye.

By way of further example, patient measurement and apparatus configuration information is stored in multiple tables in a Microsoft Access™ 7.0 database. The interface to this within the code is based upon the Microsoft Foundation Classes (MFC) wrapper to the Microsoft Jet Engine. The framework generates a Structured Query Language (SQL) to create, retrieve and update records in the database. Use of the Microsoft Access application to access the data is not needed. In one embodiment of the present invention, the following data may be stored in the database: patient information—name, address, medical record number, and the like; measurement Information—geometry, time of measurement, and the like; and system Information—hardware serial numbers and key hardware parameters.

Additionally, the software may be developed with two operating levels—password-protected and not-password-protected. From within the password-protected-mode, the technician/operator has access to system configuration information and features necessary for system setup and maintenance that are not accessible from the not-password-protected mode. All patient entry and measurement capabilities are available from the not-password-protected mode. All patient information desired in order to be able to uniquely identify and track the patient is entered via the graphical user interface (GUI) and stored in the Microsoft Access database. Selecting the "Patient Data" menu item brings up a patient information data information screen, from which the technician can enter new patient data as well as being able to review and edit existing information. The patient data that can be stored and retrieved, typically includes: name, address, medical record number, data of

birth, phone number, sex, manifest and cycloplegic refractions and vertex distance as well as centration information.

Centration information that is measured via a centration process and stored as part of the patient record describes the position of the center of the constricted pupil with respect to the center of the limbus. This information is used in aligning the patient for the measurement where the goal is to align the visual axis of the eye with the optical axis **342** of the apparatus **300**. When the centration procedure is invoked a list is displayed of all patients that have been entered into a database operable with the apparatus **300** but have not yet had the centration steps performed. The monitor displays all patient information including a review of centration information, or alternatively, for just those patients entered for a given time period. In order to perform centration for a given patient and eye, that patient is selected from this list by clicking on the desired patient/eye with the mouse. An example of the centration process is illustrated with reference to FIG. **14**. Once a patient has been selected, the patient is instructed to look into the apparatus **300** and at the fixation target **366**, as earlier described with reference to FIG. **12**.

By way of further disclosure, the fixation target **366** is, as earlier described, included so that the patient **302** can stare along the optical axis **342** of the apparatus **300**. For best fixation, the target should be clearly visible to the patient. However, care should be taken to see that the patient does not attempt to accommodate when fixating on the target. This would occur if the target were optically closer than the patient's infinity focal plane. If the patient did accommodate, i.e., if the lens in the eye changed shape to provide increased focusing, then the eye would appear excessively myopic during the wavefront measurement. To avoid this, the fixation target optics are adjusted so that the target appears to lie optically just beyond the patient's far-field focus. Thus for each patient the target will appear relatively clear, but not in sharp focus. The patient may initially try to accommodate to improve the sharpness of the image, but will eventually find that the clearest image is seen for the most relaxed (non-accommodative) state. This technique is known as "fogging," and is routinely performed by optometrists when doing clinical evaluations. The eye drops used to dilate the eye for the measurement also reduce the lens' ability to accommodate, thereby further ensuring valid wavefront measurement.

With reference again to FIG. **14**, an image of the patients eye **120** is frozen. Two reticles **450**, **452** are then used to locate the centers **454**, **456** of the constricted pupil and limbus, respectively. Each reticle **450**, **452** can be moved and sized—one reticle **450** is positioned over the perimeter of the constricted pupil **458** and the other reticle **452** over the limbus **460**. Once they have been located, the information is saved to the database. This can be performed for as many patients as is desired and the centration procedure is then exited.

For illustration, a sequence of events followed in measuring the refractive errors in an eye and computing the corresponding optical path difference (OPD) is illustrated with reference to FIG. **15**. By way of example, steps include performing a reference measurement **462**. To provide a reference with which to compare the measurement of the eye **120** and also to check the alignment of the apparatus **300**, a reference measurement is made using the collimated laser light **36**, as earlier described with reference to FIG. **12**. The software forces the operator to make at least one such measurement at the start of each day and an additional one at the end of each day. More reference measurements can be performed as desired by the operator. When patient measurements are performed, the measurement records in the database identify which reference measurements correspond to each measurement, i.e., which reference image was the latest one done prior to the measurement. A "Perform Reference Measurement" screen may be provided for viewing a sample reference image.

A next step includes selecting a patient and eye to measure **464**. The patient and eye to be measured may be selected from a "Patient Select" dialog screen. It is desired that all patients are displayed along with a check mark to show whether or not centration has been performed for that patient. If a patient is selected that has not yet had centration performed then the operator is informed of this and no measurement can be performed. Once a valid patient/eye has been selected to be measured then the perform measurement dialog is displayed which includes GUI buttons necessary in order for the operator to perform and check the measurement.

A next step includes aligning the eye using the video camera and reticles **466**. The apparatus **300** is operated with the visual axis of the eye aligned, as close as is practically possible, to the optical axis **342** before performing a measurement. The center of the constricted pupil **454** is used as the approximate anatomical landmark for the visual axis. Given that the eye **120** is dilated when the measurement is performed, it is not possible to directly determine this center. However, the centration procedure performed on each patient defines the center of the constricted pupil **454** with respect to the limbus **460** and thus it is possible to use the position of the limbus to place the eye **120** in a desired location.

As illustrated with reference to FIG. **16**, a reticle **468** is displayed on screen that is offset from the optical axis by the appropriate amount such that when the limbus **460** of the eye **120** is aligned to this reticle **468**, the eye **120** is positioned as desired. Prior to taking the measurement, it is the operator's responsibility to ensure that the patient is positioned appropriately such that the limbus **460** is aligned with the reticle **468** while the patient is looking at the fixation target **366**.

A measurement is then performed **470**. Once the eye **120** is aligned, the operator presses an "acquire" button to perform the wavefront measurement of the patients eye. The system response to the acquire command is as follows:

1. Video image is frozen
2. Probe beam laser is activated
3. External shutter is opened so that the probe beam can reach the eye
4. CCD shutter opens and the CCD is exposed to the re-emitted wavefront (1–4 generally performed simultaneously)
5. CCD shutter closes and the exposure is completed
6. CCD data is transmitted to the computer
7. External shutter closes and the probe beam turns off.

The software continually checks the status of the CCD electronics and the temperature of the camera and only allows measurements to be taken when everything is working nominally.

A review of eye and apparatus geometry is accepted or rejected **472**. Although it is not necessary for the eye **120** to be perfectly aligned with respect to the optical axis **342** (the software compensates for minor misalignments), it is desirable for it to be close. The eye **120** will have been aligned prior to the measurement but uncontrollable eye motion (e.g. saccades and loss-of-fixation) may make the alignment sub-optimal at the time of the exposure. To check that the

alignment is acceptable, the video image of the eye is frozen at the time the measurement is taken. The operator then aligns a reticle to the limbus ring and presses a "check geometry" button on the GUI. If the software determines that the alignment is not acceptable, the operator is informed of this and a new exposure is made as desired. By way of example, and with reference to FIG. **17**, optimal measurement as herein described, would have the limbus **460** aligned to circle B. In actuality, the eye **120** was offset during the exposure and the limbus **460** was aligned to circle A. The difference between these two states is shown by the line A'B'. The software determines whether or not the image is acceptable based on the length of A'B'.

It is also at this point that the operator records the rotational state of the eye. Prior to the wavefront measurement, a pattern of four line segments **474** arranged in an "X" pattern **476**, as illustrated with reference to FIG. **18**, around the periphery of the cornea are applied to the eye using a mechanical instrument. The pattern **476** consists of two pairs of collinear line segments **474** angled at 45° with respect to each other. Each line segment **474** is 4 mm long, and collinear segments are separated by 7 mm. At the same time the limbus ring reticle is aligned with the actual limbus in the frozen video image, an X reticle that matches this pattern is aligned to the applied eye marks in the frozen image. The orientation information is then saved by the software along with the limbus position data.

As a next step in the process, the CCD image is processed, accepted and saved, or rejected **478**, as illustrated with reference again to FIG. **15**. If the geometry of the measurement is acceptable, it is then probable that the quality of the CCD image will be high. It is desirable, however, to check that this is so. The software processes the image and then presents an auto-scaled image to the operator to review. If the software determines that the image is unacceptable then the operator will be informed of this and a new exposure made. If the user decides that the image is unacceptable for whatever reason then the image can be manually rejected at this stage. An example of an unacceptable image is illustrated with reference to FIG. **19**. In this example, a significant portion **479** of the image is obscured in some manner, resulting in wavefront data for only part of the pupil. By unacceptable, it is meant that such an image is not believed to result in the accuracy and precision of measurement that is desired for surgical procedures which are obtained by the present invention. It does not mean that such as illustrated may not be usable in any sense.

Once a valid measurement has been made the next step **480** is to measure the local slopes of the wavefront **130**, as earlier described with reference to equations herein presented. As described with reference to FIGS. **4–6**, it is necessary for the software to compute the centroids **116** of the clusters of light on the CCD array **38** and then determine the distances of each of these centroids **116** from the corresponding reference centroids **29**. The centroids are determined by first computing which pixels should be processed and grouping them together into clusters. The intensity-weighted centroid of each cluster is then computed. As illustrated with reference to FIG. **20**, an example of an image from a myopic eye with the computed centroids **482** of cluster **484** marked by "X"s is shown. FIG. **21** illustrates a close-up of one of the clusters **484** and displays not only the centroid **482** but also the pixels **486** used in the centroiding calculation for the cluster **484**. CCD pixels **488** processed in the centroiding algorithm are marked by dots. This algorithm, by way of example, isolates centroids by use of a spacial filter which removes stray light signals that create noise for the CCD image. Such filtering may be desirable before calculation of light cluster positions.

Without filtering, computation of the cluster centroids may be made difficult as a result of noise on the image such that individual pixels with no actual data content may be brighter than pixels containing relevant data, speckle in the image may result in valid data clusters having irregular profiles with significant variation in intensity of adjacent pixels, haze or background noise may be high relative to the actual data or may be non-uniform across the image, intensity of valid data may be non-uniform across the image, scatter from different parts of the eye may result in spurious signals on the image, and high aberrations in the eye may significantly distort the clusters of valid data, by way of examples. The spatial filter permits a re-computation of the brightness of each pixel in a bitmap using a weighted averaging technique that considers surrounding pixels. In a particular application herein described for illustration and by way of example, the spatial filter is designed to yield a maximum value when centered on valid data, reduce an effect of individual bright pixels or small groups thereof, normalize background levels, smooth valid data profiles, and simplify the task of extracting the valid data from background noise or haze. One filter employed in one embodiment of the present invention is square (n×n) and includes real values (positive and negative) assigned to each pixel. The filter is designed to be optimally matched to images obtained from eyes with high, yet measurable, levels of aberration. By wave example, a cross-section through the filter is illustrated with reference to FIG. **23**A. An effect of applying such a filter improves an image such as illustrated with reference to FIG. **23**B to the image illustrated with reference again to FIG. **20**, by way of example, a cleaner image and one that is easily processed for identification and computation of cluster centroids. By applying the filter, images that would otherwise be deemed to noisy or of insufficient quality to process, can now be processed and desired wavefront information computed.

The center of each centroid is calculated using a standard center of mass algorithm based on light intensity. The clusters and centroids illustrated with reference to FIG. **22** are illustrated with the locations of the corresponding reference centroids **490** also visible. The open circles in this figure indicate the locations of the reference centroids. Lines connect these with the associated sample centroids **482**. From the distances between the reference and measurement centroids **490**, **482** respectively, and the distance between the lens array **33** and the CCD plane **36**, described with reference to FIG. **6**, the local slopes are calculated. Given these local slopes and information about the apparatus setup, including any and all magnification factors, it is then possible to determine the local slopes at the pupil plane and, from these, and compute the optical path difference of the eye being measured.

A description of the wavefront is then made **492**. As earlier described, the reconstructed wavefront is described via a set of Zernike polynomials. The number of locations on the eye **120** at which the local slopes are determined (i.e. the number of sample points) greatly exceeds the number of terms in the polynomials that will describe the wavefront. A least-squares-fit calculation is done to find the coefficients that best describe the surface. The order of the polynomial used is sufficient to describe not only the spherical and cylindrical refractive powers (2^{nd} order) but also the levels of coma (3^{rd} order) and spherical aberration (4^{th} order) present.

An example of the computed Zernike coefficients for an eye and the corresponding wavefront reconstruction **493** is

illustrated with reference to FIG. **24**A. By way of example, for the wavefront illustrated with reference to FIG. **24**A, the spherical and cylindrical powers computed from the wavefront are −1.60/−1.13×150.4. The corresponding values obtained by an optometrist performing a phoropter examination (converted to the corneal plane) were −1.47/−1.19×150. The standard measurements of spherical and cylindrical powers agree well with the computation of spherical and cylindrical powers, but there are also higher order aberrations present. By way of further example, FIG. **24**B illustrates just these higher order aberrations **495** on the same scale as the plot of FIG. **24**A.

With regard to the optical path difference (OPD), scaling an optical path difference profile, OPD(x,y), by a refractive index difference (cornea to air) is not the only step. This wavefront measurement is made at a plane tangent to the cornea, as illustrated with reference to FIG. **25**, which is exaggerated to illustrate the effect. The image plane of the wavefront path is the lenslet array plate. The object plane of the wavefront path is the reference plane **494**. In this highly-exaggerated myopic case, herein described by way of example, one light ray **496** emerging from the eye **120** at transverse location a is detected at a transverse location b. The wavefront reconstructed from sensor data will have the slope of this ray at location b. Although this is true of the wavefront at the reference plane **494**, simple scaling of this wavefront would suggest a measurement at corneal location b that may not be entirely accurate. In actuality this effect is small. The radius of curvature of the cornea is typically on the order of 7.5 mm. (a range of 7–8 mm encompasses most eyes.) At a transverse location 3 mm from the corneal apex, the distance from the corneal surface to the reference plane is only ~0.63 μm. For a 10 diopter myope, a light ray exiting the cornea at a=3.0 mm will cross the reference plane at b=2.98 mm. The difference between a and b in this example is only 20 μm. Although small this geometric effect is systematic, having progressively greater impact on the measurement with increasing radial distance from the corneal apex. To increase accuracy, compensating for the curved geometry may be performed in the following manner:

1. Wavefront slopes are calculated at each measurement point in the reference plane.
2. The cornea is assumed to have a nominal radius of curvature (~7.5 mm).
3. The wavefront slopes measured at the reference plane is projected back onto the nominally curved cornea. The wavefront is measured to have a certain slope at b in the reference plane, described above. It is a straightforward mathematical process to calculate the point a where this ray exited the cornea.
4. The wavefront is reconstructed based on the measured slopes at the calculated corneal locations.

As above described, it is desirable to obtain the best information with a wavefront measurement having patient positioned at the apparatus **300**. The eye **120** being measured is at the desired location and looking in the appropriate direction. Based on analysis of the allowable eye-positioning tolerances, the apparatus **300** of this embodiment of the present invention provides the following patient position information:

The capability for ensuring that the subject eye is at the right location along the longitudinal (z) axis of the apparatus with an accuracy of +/−1 mm.

The capability for ensuring that the subject eye is properly positioned laterally with respect to the apparatus (i.e., in x-y) with an accuracy of +/−1 mm.

The capability for ensuring that the subject eye is desirably positioned in angle with respect to the apparatus (i.e., the difference between the visual axis and the optical axis of the system) with an accuracy of +/−0.5 degrees.

The capability for aligning an on-screen reticule to a set of marks applied to the eye outside the limbus to record the rotational orientation of the eye (i.e., about z) with respect to the apparatus with an accuracy of +/−one degree.

Once in position, the patient's eye can be successfully examined by the wavefront sensing technique. This embodiment of the apparatus includes a sufficient dynamic range to measure eyes over the expected scope of refractive errors.

The following list provides range and accuracy parameters, by way of example, for clinical wavefront measurements that can be obtained by this embodiment of the apparatus. This list is provided by way of illustration and does not limit the scope of the present invention.

1. capable of measuring wavefronts with spherical refractive powers in the range +6 to −15 diopters and cylindrical powers in the range 0 to −6 diopters.
2. capable of measuring coma and spherical aberration.
3. capable of measuring refractive errors over a pupil zone of up to 8 mm in diameter.
4. able to measure the refractive errors within the specified ranges to an accuracy of 0.042 μm RMS in air.

With reference again to FIG. **6**, and by way of further example, the output from wavefront analyzer **26**, e.g., the Zernike expansion of equation (19), can be used in a variety of ways. For example, the output may be used to continually or periodically monitor the progress or effects of an ophthalmic procedure, with such stored on disc or transmitted via e-mail, and the like. The output of the wavefront analyzer **26** is input to a processor **90** which converts the Zernike expansion of equation (19) into a form suitable for subsequent use as desired. Alternatively, the processor **90** may also be implemented at the processor **40** of the wavefront analyzer **26**, described earlier with reference to FIG. **6**.

By way of further example, the processor **90** can be used with preselected Zernike coefficients from the expansion of equation (19) to generate a standard sphero-cylindrical specification for a lens grinder **92** to produce a convectional optical lens, e.g., a lens for glasses, a contact lens, and the like.

As described earlier with reference to FIG. **12**, the apparatus **300** of the present venture includes first and second afocal relays stages **358**, **360**. To retain the benefit of wavefront magnification, as a means of increasing the dynamic range of the wavefront sensor **356** to accommodate patients with large refractive errors, while at the same time allowing for incorporation of a small format, inexpensive camera to record the wavefront slope data, a modification **500** to the apparatus **300** as illustrated with reference to FIG. **26**A is provided.

By way of example, a lens array may also be positioned and configured as illustrated with reference to FIG. **26**B, wherein a portion of the apparatus **300** of FIG. **12** includes the first and second afocal stages **358**, **360** within the optical axis **342**, and the wavefront sensor **356** consist of the microlens array and CCD camera separated by a fixed distant, as earlier described with reference to FIG. **6**. This optical path through the afocal relay stages results in an image of the corneal plane **502** at the lenslet array, i.e. at the entrance face of the actual wave front sensor **356**. This can be accomplished by a single afocal stage. As earlier described with reference to FIG. **12**, the apparatus **300** includes an intermediate image plane as insertion point, the holder **408**, for a trial lens. Placing a spherical lens into the optical axis **342** at the first image plane, in theory, could be used to remove the defocus wavefront error. This would

potentially expand the dynamic range of the apparatus **300**. However, the trial lens approach s a moving mechanism that can position lenses at the first image plane with tremendous accuracy in repeatability. It is highly desirable that alternative means be developed to address dynamic range.

One way to accomplish this is to magnify the corneal plane image at the lenslet array with the afocal stage **360**, earlier described. Magnification of the wavefront reduces the wavefront slope, so that the displacement of the focused lights spots on the CCD is decreased. The chosen magnification factor used with the apparatus **300** second afocal stage **360** is approximately 1.2 which is sufficient to cover the desired range in refractive errors. A magnification factor in excess of 1.5 is desirable for expanding the use of the apparatus **300**. However, simply magnifying the corneal plane has a drawback in that it necessitate a large aperture wavefront sensor. That is, both the lens array and the CCD camera preferably have large cross-sectional areas to encompass the magnified image of the point of plane. This is not a significant issue for the lens array. However, a large format CCD camera is quite expensive and such cameras are only available from a limited number of vendors.

To resolve such concerns, the modification **500** illustrated with reference again to FIG. **26**A is provided. The corneal plane **502** is imaged at a reference plane **504** by an afocal relay stage **506**, which magnifies the corneal plane by a preselected amount. The lenslet array **412** is placed at the reference plane **504**. Focused spots of light from the eye **120** are produced at the lenslet array focal plane **504**. Rather than place the CCD detector face at the reference plane **504**, an optical train **508** is inserted to image the array focal plane **413** at yet another plane, a final image plane **510**, at which plane the CCD detector face is positioned. The afocal relay stages **358**, **360** described earlier with reference to FIGS. **12** and **26**B, may or may not be included, as desired. However, the magnification of the array focal plane at the final image plane **510** is provided. This allows a small, relatively inexpensive, active area camera to be used as the light recording element in the wavefront sensor. Details of optical design including magnification specifics can be adjusted to maximize performance for a given camera and lens array plate specification.

The advantages of the present invention are numerous. A totally objective approach is presented for measuring ocular aberrations. The approach is effective for a wide range of vision defects. Accordingly, the present invention will be of great utility in a wide variety of clinical applications. For example, the calculated Zernike coefficients can be used to develop a completely objective lens prescription. In addition, each of the wavefront sensor embodiments provides for a greater degree of accuracy over the prior art with respect to measuring wavefront deflections. Further, the present wavefront sensor can be adjusted in terms of gain simply by adjusting the separation distance between the imaging plane of the sensor and the planar array of light-sensitive cells.

The objective measurement of the present invention will also find great utility for a large variety of applications where the "patient" is unable to provide feedback as d by conventional eye diagnosis. For example, the present invention could be used to evaluate the eyes of any patient not possessed of demonstrative communicative skills, e.g., babies, animals, dead specimens, as well as any constructed optical system, since the present invention is an objective analysis not requiring any assessment from the "subject". All that is necessary is for the subject's eye to be properly positioned so that proper optical access to the eye can be obtained.

The present invention will also be used in the area of identification should it be determined that each eye's Zernike coefficients are unique. Then, the present invention would find great utility in the fields of law enforcement, credit card/bank security, or any other field where positive identification would be beneficial.

Although the invention has been described relative to a specific embodiment thereof, there are numerous variations and modifications that will be readily apparent to those skilled in the art in light of the above teachings. It is therefore to be understood that, within the scope of the appended claims, the invention may be practiced other than as specifically described.

TABLE 1

Sample Optical Component
(Refers to FIG. 12)

Ref No.	Component	Parameter	Specification	Supplier
378	Polarizing Beamsplitter	Physical dimensions	38.1 mm (1.5") cube	Tower Optical Corporation
		S-pol. transmittance	<6%	Delray Beach, Florida
		S-pol. reflectance	>94%	
		P-pol. transmittance	>94%	
		P-pol. reflectance	>6%	
358A	Lens Combination	Effective Focal Length	149.5 mm	Tower Optical Corporation
		Clear Aperture	40 mm	Delray Beach, Florida
358B	Lens Combination	Effective Focal Length	149.5 mm	Tower Optical Corporation
		Clear Aperture	40 mm	Delray Beach, Florida
376	50/50 Beamsplitter	Physical dimensions	38.1 mm (1.5") cube	Tower Optical Corporation Delray Beach, Florida
374	50/50 Beamsplitter	Physical dimensions	38.1 mm (1.5") cube	Tower Optical Corporation Delray Beach, Florida
380	Lens	Focal length	40 mm	Melles Griot
		Clear aperture	18 mm	Irvine, California
382A	Lens	Focal length	40 mm	Melles Griot
		Clear aperture	18 mm	Irvine, California
382B	Lens	Focal length	120 mm	Melles Griot
		Clear aperture	40 mm	Irvine, California
370	50/50 Beamsplitter	Physical dimensions	38.1 mm (1.5") cube	Tower Optical Corporation Delray Beach, Florida

TABLE 1-continued

Sample Optical Component
(Refers to FIG. 12)

Ref No.	Component	Parameter	Specification	Supplier
366	Fixation Target	Physical dimensions	38.1 mm	Diversified Graphics
		Material	Vellox	Orlando, Florida
368	Target Illumination Lamp	Type	Halogen/parabolic reflector	Welch Allyn
		Reflector diameter	51 mm (2")	Skaneateles Falls, New York
		Voltage	9 V maximum	
		Current	1 A	
	Short-Pass Filter	Wavelength Rejection Range	620–790 nm (Part #03SWP410)	Melles Griot Irvine, California
336	Eye Illumination Lamps	Type	Gas/parabolic reflector	Welch Allyn
		Reflector diameter	25 mm (1")	Skaneateles Falls, New York
		Voltage	5 V maximum	
		Current	0.97 A	
	Short-λ attenuation filter	1% transmission λ	~455 nm (Schott Glass GG 455)	Melles Griot Irvine, California
	Short-Pass Filter	Wavelength Rejection Range	620–790 nm (Part #03SWP410)	Melles Griot Irvine, California
	IR-λ attenuation filter	Half-max. transmission λ	~920 nm (Schott Glass KG-3)	Florida High Tech Optics Palmetto, Florida
386	Mirror	Clear aperture	50 mm	Melles Griot Irvine, California
388	Lens	Focal length	40 mm	Melles Griot
		Clear aperture	18 mm	Irvine, California
338	Video Camera	CCD array dimensions	6 mm × 8 mm	Industrial Vision Source
		CCD pixel number	494 × 768	Carrollton, Texas
398	Mirror	Clear aperture	25 mm	Melles Griot Irvine, California
396	Shutter	Clear aperture	25.4 mm (1") diameter	Melles Griot Irvine, California
394	Lens	Focal length	1000 mm	Melles Griot
		Clear aperture	50 mm	Irvine, California
392	Polarizer	Clear aperture	16.9 mm diameter	Melles Griot
		Extinction ratio	10^{-4}	Irvine, California
	Attenuator	Clear Aperture	25 mm diameter	Melles Griot
		Transmission	0.5/0.1 (interchangeable)	Irvine, California
400	Polarizer	Clear aperture	16.9 mm diameter	Melles Griot
		Extinction ratio	10^{-4}	Irvine, California
390	Diode Laser	Wavelength	670 nm	Power Technologies, Inc.
		Output port diameter	52 mm	Little Rock Arkansas
		Beam divergence	0.3 mrad	
408	Trial Lenses	Dioptric range	−16 to +8 diopters	Optimax
		Dioptric step size	2 diopters	Rochester, New York
		Clear aperture	12.7 mm (0.5")	
	Band-Pass Filter	Peak Transmission	670 nm	Melles Griot
		Wavelength Bandwidth (FWHM)	10 nm	Irvine, California
360A	Lens Combination	Effective Focal Length	122.2 mm	Tower Optical Corporation
		Clear Aperture	40 mm	Delray Beach, Florida
360B	Lens Combination	Effective Focal Length	149.5 mm	Tower Optical Corporation
		Clear Aperture	40 mm	Delray Beach, Florida
410	Mirror	Clear Aperture	50 mm	Melles Griot Irvine, California
412	Microlens Array	Array clear aperture	25 mm diameter	Adaptive Optics Systems
		Lenslet configuration	Square array	Cambridge, Massachusetts
		lenslet dimensions	768 μm square	
		nominal focal length	86 mm	
406	CCD Camera	CCD array dimensions	12.3 mm square	Roper Scientific
		CCD pixel dimensions	24 mm square	Tucson, Arizona
		CCD pixel number	512 × 512	
414	Diode Laser	Wavelength	670 nm	Power Technologies, Inc.
		Output port diameter	5.2 mm	Little Rock, Arkansas
		Beam divergence	0.3 mrad	
416	Beam Expander	Magnification	10 X	Edmund Scientific Company Barrington, New Jersey (Coherent)
418	Polarizers	Clear aperture	16.9 mm diameter	Melles Griot
		Extinction ratio	10^{-4}	Irvine, California
	Attenuator	Clear Aperture	25 mm diameter	Melles Griot
		Transmission	0.5/0.1 (interchangeable)	Irvine, California
420A	Lens	Nominal focal length	−30 mm	Melles Griot
		Diameter	20 mm	Irvine, California
420B	Aperture	Clear aperture	12.7 mm	TechFab Mount Dora, Florida

TABLE 1-continued

Ref No.	Component	Parameter	Specification	Supplier
		Sample Optical Component (Refers to FIG. 12)		
422A	Aperture	Clear aperture	127 mm	TechFab Mount Dora, Florida
422B	Aperture	Clear aperture	15 mm	TechFab Mount Dora, Florida
	Lens	Nominal focal length	400 mm	Melles Griot
		Diameter	25 mm	Irvine, California
424	Mirror	Clear aperture	25 mm	Melles Griot Irvine, California
426	Aperture	Clear aperture	10 mm	TechFab Mount Dora Florida

That which is claimed is:

1. A method for determining higher order aberrations of an eye requiring a correction of greater than −6 diopters, the method comprising:

directing an optical beam onto a retina of an eye;

reflecting the optical beam from the retina of the eye;

determining characteristics of a wavefront in the reflected optical beam; and

generating data based on the characteristics of the wavefront, which data quantifies at least one higher order aberration of the eye.

2. An apparatus for determining aberrations of an eye comprising:

a patient head rest comprising an adjustment, the patient head rest associated with an optical table having a base, the base comprising:

a) a probe beam generating apparatus for providing a probe beam;

b) probe beam directing optics operable with the probe beam generating apparatus, the probe beam directing optics comprising a beam splitter, a mirror, and a lens operable within a beam path of the probe beam, the probe beam directing optics being capable of directing the probe beam toward an eye of a patient positioned on the patient head rest;

c) video image components, the video image components comprising a light source for illuminating the eye of the patient, and a mirror and a video camera for viewing the eye, the video image components being capable of generating an image of the eye of a patient positioned on the patient head rest;

d) eye fixation components, the eye fixation components comprising a fixation target for viewing by the eye of a patient, a light source for illuminating the target, and a lens and a mirror operable within a path of the target, the fixation components being capable of generating a target that the eye of a patient positioned on the patient head rest can view; and

e) wavefront directing and analyzing components operable with the eye of a patient, the wavefront directing and analyzing components comprising a lens, a mirror, a microlens array, and a camera operable within an optical path of the eye, and a data processor operable with the camera, the wavefront directing and analyzing components being capable of measuring a wavefront emanating from the eye of a patient positioned on the patient head rest and determining aberrations of said eye that range from at least about + or −1 diopters to at least about + or −6 diopters.

3. A method for determining higher order aberrations of an eye requiring a correction of greater than −6 diopters of myopia, the method comprising the steps of:

directing an optical beam onto a retina of an eye;

reflecting the optical beam from the retina of the eye;

determining characteristics of a wavefront in the reflected optical beam; and

generating data based on the characteristics of the wavefront, which data quantifies at least one higher order aberration of the eye.

4. A method for determining higher order aberrations of an eye requiring a correction of greater than +6 diopters of hyperopia, the method comprising the steps of:

directing an optical beam onto a retina of an eye;

reflecting the optical beam from the retina of the eye;

determining characteristics of a wavefront in the reflected optical beam; and

generating data based on the characteristics of the wavefront, which data quantifies at least one higher order aberration of the eye.

5. An apparatus for determining aberrations of an eye, comprising:

a patient head rest associated with an optical table having a base, the base having:

i) a probe beam generating apparatus for providing a probe beam;

ii) probe beam directing optics operable with the probe beam generating apparatus, the probe beam directing optics comprising a beam splitter, a mirror, and a lens operable within a beam path of the probe beam, the probe beam directing optics being capable of directing the probe beam toward an eye of a patient positioned on the patient head rest;

iii) video image components, the video image components comprising a light source for illuminating the eye of the patient, and a mirror and a video camera for viewing the eye, the video image components being capable of generating an image of the eye of the patient positioned on the patient head rest;

iv) eye fixation components, the eye fixation components comprising a fixation target for viewing by the eye of a patient, a light source for illuminating the target, and a lens and a mirror operable within a path of the target, the fixation components being capable of generating a target that the eye of the patient positioned on the patient head rest can view; and

v) wavefront directing and analyzing components operable with the eye of a patient, the wavefront directing and analyzing components comprising a lens, a mirror, a microlens array, and a camera operable within an optical path of the eye, and a data processor operable with the camera, the wavefront directing and analyzing components being capable of measuring a wavefront emanating from the eye of the patient positioned on the patient head rest and determining higher order aberrations of the eye that range from at least about +1 diopter to at least about +6 diopters and from at least about −1 diopter to at least about −6 diopters.

6. A method for determining higher order aberrations of an eye requiring a correction of greater than +6 diopters, the method comprising:

directing an optical beam onto a retina of an eye;

reflecting the optical beam from the retina of the eye;

determining characteristics of a wavefront in the reflected optical beam; and

generating data based on the characteristics of the wavefront, which data quantifies at least one higher order aberration of the eye.

* * * * *

US006450651B1

(12) **United States Patent**
Hoganson

(10) **Patent No.: US 6,450,651 B1**
(45) **Date of Patent: Sep. 17, 2002**

(54) **ANTI-GLARE DEVICE FOR OBJECTIVE LENSES**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 820 days.

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Related U.S. Application Data

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(51) **Int. Cl.**[7] **G02B 27/00**

(52) **U.S. Cl.** **359/601**; 359/399; 359/510; 359/511; 359/512; 359/600

(58) **Field of Search** 359/399, 510, 359/511, 512, 600, 601, 608, 609, 610, 611, 612, 613, 614; 42/70.6, 72, 96, 101, 100; 150/114

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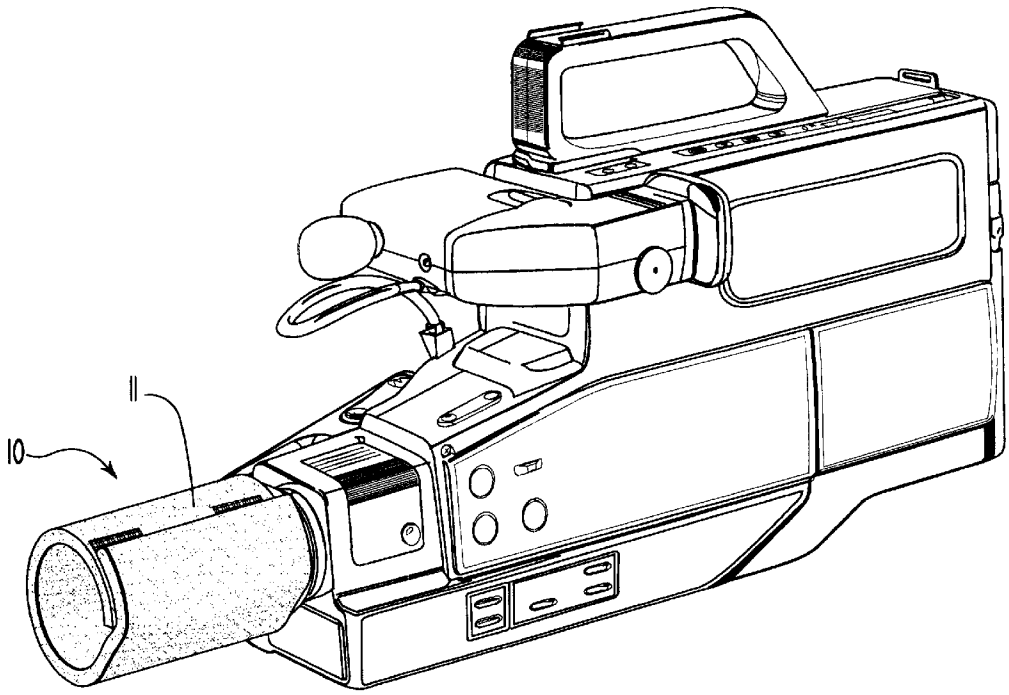
Primary Examiner—Mohammad Sikder

(57) **ABSTRACT**

This invention is an anti-glare device comprising a flexible, soft material that is rolled as a sleeve to be wrapped around, while projecting from an end of an objective lens housing such as is found on telescopic scopes, spotting scopes, binoculars, cameras and video cameras to prevent sun glare on the lens or lenses of such devices regardless of the angle of the sun rays otherwise engaging such lens or lenses.

1 Claim, 3 Drawing Sheets



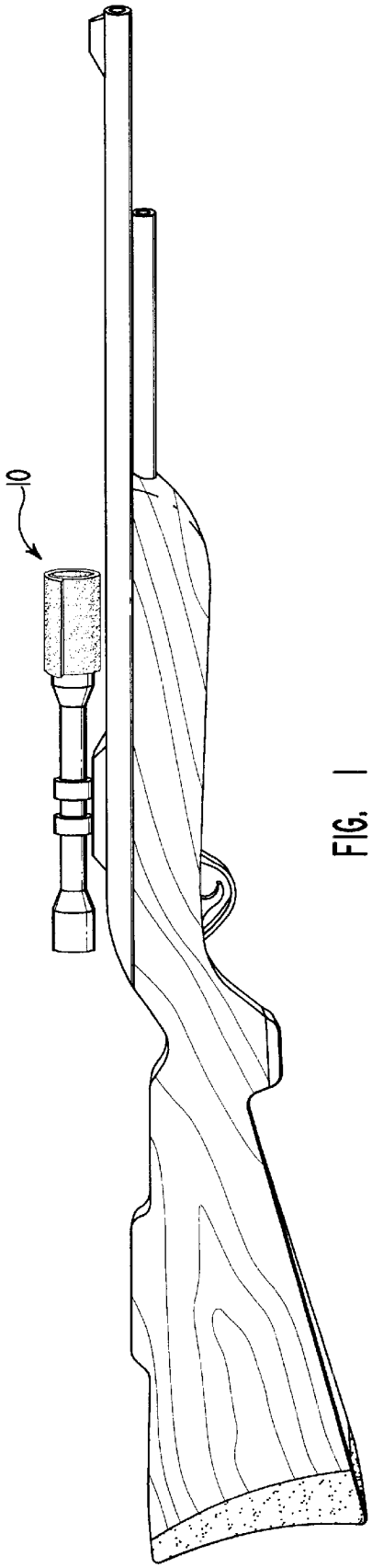


FIG. 1

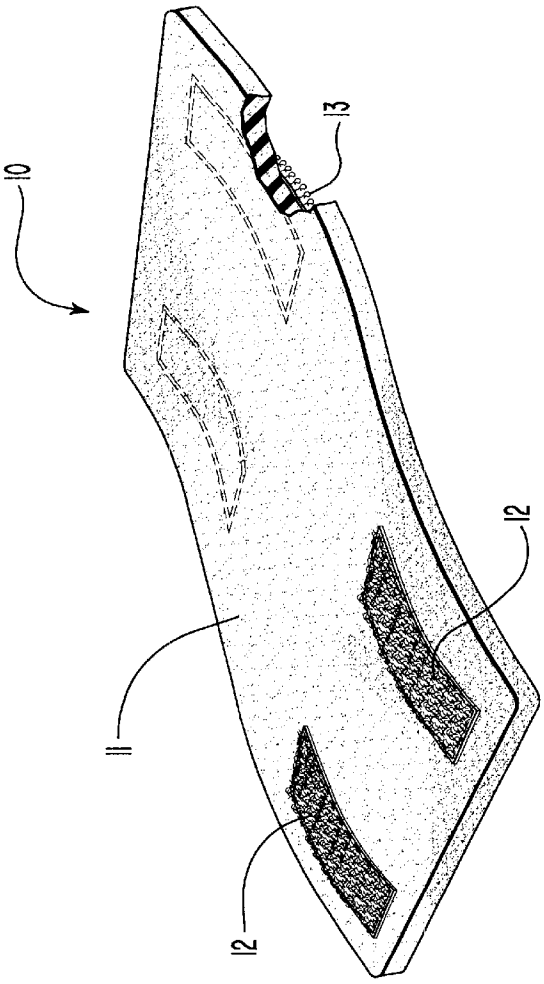


FIG. 2

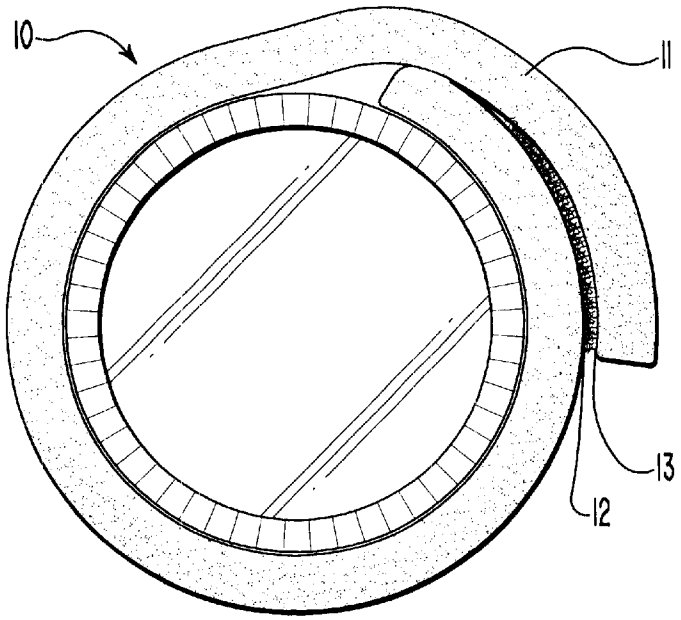


FIG. 3

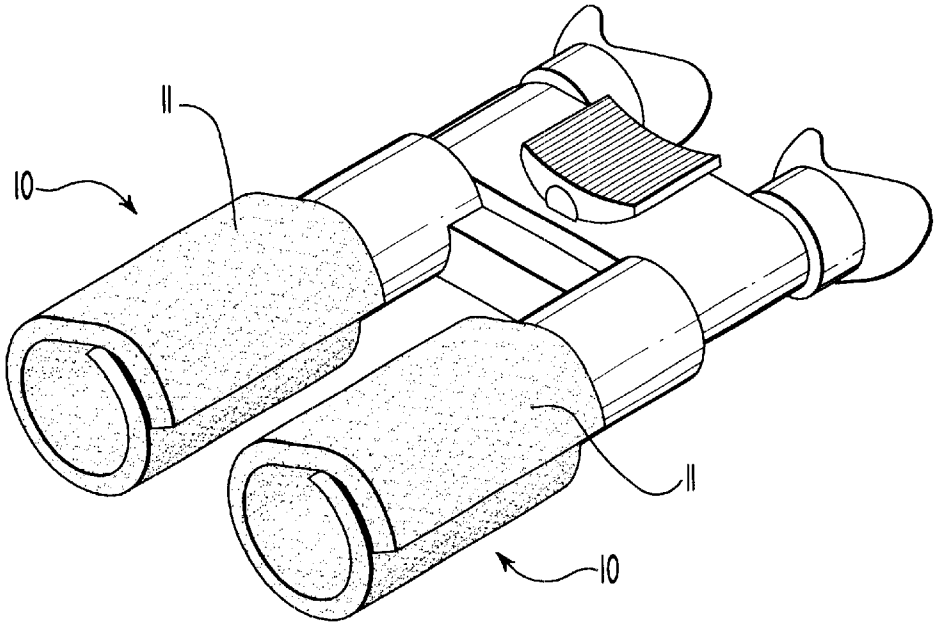


FIG. 4

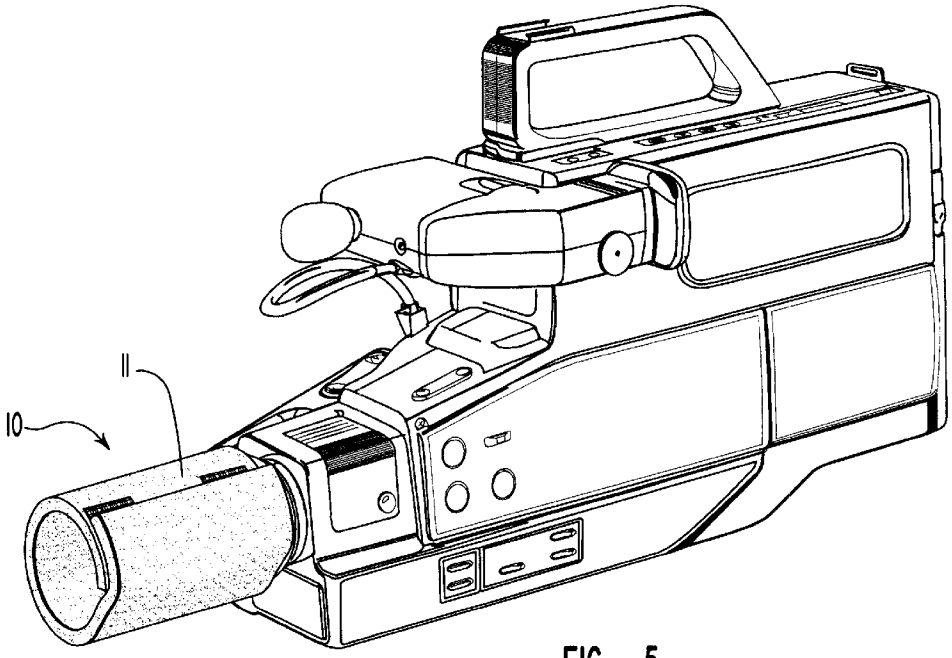


FIG. 5

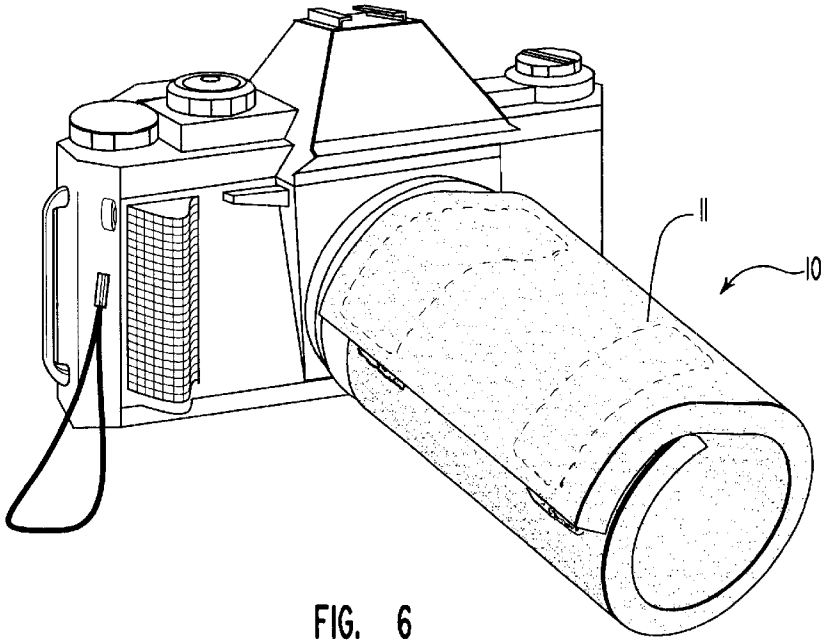


FIG. 6

ANTI-GLARE DEVICE FOR OBJECTIVE LENSES

CLAIM OF PRIORITY

This application is a continuation-in-part of my prior application Ser. Nos. 08/637,270, filed Sep. 8, 1997, now abandoned, which was a continuation in part of my prior application Ser. No. 08/344,995 Nov. 25, 1994, now abandoned

FIELD OF SEARCH

359/601; 359/611; 33/244

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4,610,517	09/1986	Fukino et al	359/611
4,926,560	05/1990	Kilgore et al	33/244
5,181,140	01/1993	Brown et al	33/244

BACKGROUND OF THE INVENTION

The field of the invention relates to geometrical instruments and specifically to an adjustable anti-glare device for use on devices having objective lenses, i.e., a variety of telescopes spotting scopes, binoculars, cameras, and video cameras.

DESCRIPTION OF THE PRIOR ART

Sunshade equipment for use in providing protection from glare on objective lenses is used in the prior art. Examples of such devices may be found in U.S. Pat. No. 5,181,140 to Brown et al, which is for a sun shading device for binoculars, and U.S. Pat. No. 4,089,117, which is for a sunshade for a rifle scope. U.S. Pat. No. 4,384,767 to Kawai is for a hood-like structure that is clamped onto a camera lens. U.S. Pat. No. 4,610,517 to Fukino et al is for a similar type of lens hood that clamps to a lens housing. These devices are designed to reduce glare on the lenses from above, but they do not fully address the problem of glare from either side.

U.S. Pat. No. 5,201,135 to Cowles does address the problem of additional glare sources, but discloses a rigid precise device that requires complicated manufacturing methods.

U.S. Pat. No. 5,101,298 to Lentz discloses a television lens shade including a soft mounting means to surround the lens and to support separate shading structures. It does not disclose the use of the mounting means as a sun shade.

All of the above listed shading devices are specific to only one field of objective lenses, i.e. rifle scopes, binoculars or cameras. The present invention is not specific to only one field as it is so completely adjustable that it fits a variety of types of objective lenses in housings, i.e. telescopic scopes, spotting scopes, binoculars, cameras,, or video cameras.

The present invention is effective, attached easily, and quickly removed. All of the prior inventions required more complicated methods of manufacture than those required by the present invention. There continues to be a need for a new and improved anti-glare device for objective lenses and the present invention substantially fills that need.

SUMMARY OF THE INVENTION

The primary use of this invention is as an attachment to a housing for an objective lens or lenses to reduce glare upon the lens or lenses. This anti-glare device is comprised of a sheet of thin, flexible foam rubber, or the like, having sufficient rigidity to maintain a rolled assigned shape around the housing of the lens or lenses while projecting beyond an end of the housing. Strips of hook and loop type members, sold under the trade name "Velcro", or other devices, are used for holding the sheet in the rolled configuration as a sleeve around the housing and projecting beyond an end of the housing. This construction permits the attachment of the anti-glare device quickly and firmly to the housings of many different types of objective lenses. The anti-glare device of the invention is easily and quickly removed and folds up compactly and is easily stored in pockets, camera cases, etc. This anti-glare device also costs less to manufacture and fits on a larger variety of lens housings than do devices heretofore known.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a side view of the invention attached to a rifle scope.

FIG. **2** is a perspective view of the invention showing proper attachment of "Velcro" fasteners.

FIG. **3** is an end elevation view showing the invention attached to a spotting scope.

FIG. **4** is a perspective view of two units of the invention attached to binoculars.

FIG. **5** is a perspective view of the invention attached to a video camera.

FIG. **6** is a perspective view of the invention attached to a camera.

DETAILED DESCRIPTION OF THE INVENTION

This anti-glare device of the invention comprises an adjustable, elongated, flexible wrap around sleeve **10** that is designed as an adjustable anti-glare device for use on housings containing objective lenses and that is particularly suitable for use on a variety of telescopic scopes, spotting scopes, binoculars,cameras, or video cameras. As illustrated in FIGS. **1**, **3**, **4**, **5**, and **6**, the sleeve **10** is designed to fit snugly around the outer surface of housings of a variety of telescopic scopes, spotting scopes, binoculars, cameras and video cameras and to extend beyond the lens or lenses within the housings to provide shade. As shown in FIGS. **1**, **3**, **4**, **5**, and **6**, sleeve **10** is wrapped fully around a lens housing and then is secured to itself with "Velcro" strips including loops **12** and hook like members **13**, as a fastening system. Sleeve **10** is designed to prevent: light from glaring on the lens or lenses of a wide variety of telescopic scopes, spotting scopes, binoculars, cameras, and video cameras, such as are illustrated in FIGS. **1**, **3**, **4**, **5**, and **6**. Sleeve **10** is constructed of any material **11** having size, flexibility, and shape holding properties to allow it to snugly grip the outer surface or surfaces of said variety of housings of telescopic scopes, spotting scopes, binoculars, cameras, or video cameras and to maintain its assigned shape, without collapsing as it projects beyond the end of the housing. Material such as foam rubber, plastic, nylon, or foam coated, light, flexible metal **11** are suitable, for example. A sufficient amount of "Velcro" loop materials **12** and hook materials **13** is used to enable the sleeve **10** to fit a variety of telescopic scopes, spotting scopes, binoculars, cameras, and video cameras.

The "Velcro" loop material strips **12** and **13** are attached by gluing or sewing to the inner and outer surfaces of the foam rubber, or the like, **11** in such a manner as to cause the foam rubber **11** to form an elongated sleeve **10** when the loop material **12** and hook material **13** surfaces of the "Velcro" material are interlocked. As best illustrated in FIG. **2**, the sleeve **10** is tightly wrapped around a lens housing and is secured by means of interlocking of the "Velcro" loop material **12** and hook material **13** around the housing surface of a variety of telescopic scopes, spotting scopes, binoculars, cameras, and video cameras. For use on binoculars two units of the sleeve are required, as illustrated in FIG. **4**, with one unit wrapped around the housing at the remote end of each lens assembly of the binocular,

It will be apparent that the sizes and shapes of the loop material **12** and hook material **13** can be varied, as desired. However, the fastening system formed by such loop material and hook material must secure the rolled sleeve **10** to the lens housing while allowing a side edge of the sleeve to project beyond the lens housing while allowing a side edge of the sleeve to project beyond the lens housing and with the edge being held in the rolled configuration without collapsing.

Although a preferred embodiment of my invention has been herein disclosed it is to be understood that such disclosure is by way of example and that variations are possible without departing from the subject matter coming within the scope of the following claim, which subject matter I regard as my invention.

I claim:

1. An anti-glare device for use with objective lenses mounted in a housing, said device comprising:

an elongated strip of flexible, soft material having a length between ends to wrap around a housing containing objective lenses and to overlap on itself, a width to project from said housing and sufficient rigidity to maintain an encircling formation projecting from said housing;

connector means fixed to one face of one of said ends of said elongate strip of flexible, soft material; and

co-operating connector means fixed to at least an opposite end of said elongate strip of flexible, soft material, said connector means interlocking when one of said ends overlaps the other of said ends when said elongate strip is wrapped around and projects from an end of said housing.

* * * * *

US006423969B1

(12) **United States Patent**
Amon

(10) **Patent No.: US 6,423,969 B1**
(45) **Date of Patent: Jul. 23, 2002**

(54) **DUAL INFRARED BAND OBJECTIVE LENS**

(75) Inventor: **Max Amon**, Maitland, FL (US)

(73) Assignee: **Lockheed Martin Corporation**, Bethesda, MD (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **08/310,108**

(22) Filed: **Sep. 22, 1994**

(51) **Int. Cl.**[7] **G08B 13/14**
(52) **U.S. Cl.** **250/339.01**; 359/356
(58) **Field of Search** 250/339.01, 347; 359/354, 356

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T.H. Jamieson, "Ultrawide waveband optics," *Optical Engineering*, Mar./Apr. 1984, vol. 23, No. 2, pp. 111–116.
M.O. Lidwell, "Achromatism of lenses for thermal IR," *Proceedings SPIE*, vol. 518, 1984, pp. 73–80.
M. Roberts et al., "Wide waveband infrared optics," *Proceedings SPIE*, vol. 1013, 1988, pp. 84–91.

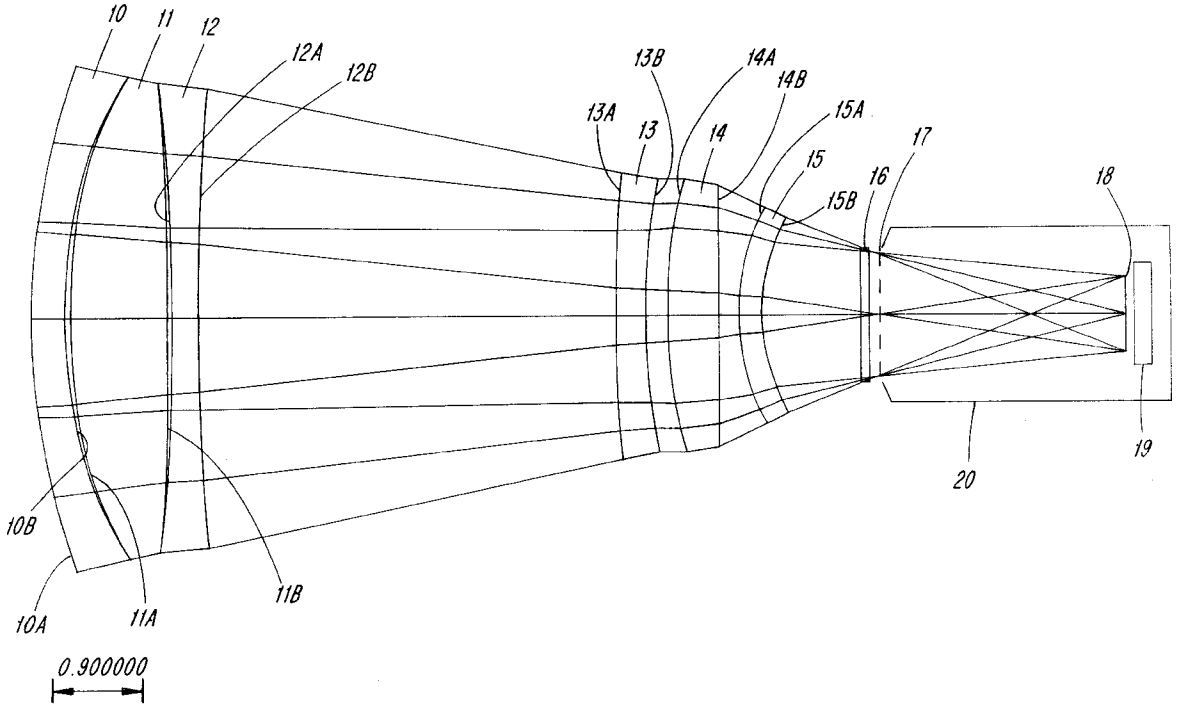
* cited by examiner

Primary Examiner—Mark Hellner
(74) *Attorney, Agent, or Firm*—Burns, Doane, Swecker & Mathis, LLP

(57) **ABSTRACT**

An infrared refractive lens triplet having color correction properties for radiation within the 3 to 12 micrometer spectral band for use with a quantum well detector for simultaneous dual band imagery. In certain embodiments of the invention, two widely spaced triplets form a Petzval-type objective lens. Each lens triplet is made up of a negative zinc sulfide lens, a positive zinc selenide lens, and a negative gallium arsenide lens coaxially positioned along a chief ray of the lens system.

9 Claims, 3 Drawing Sheets



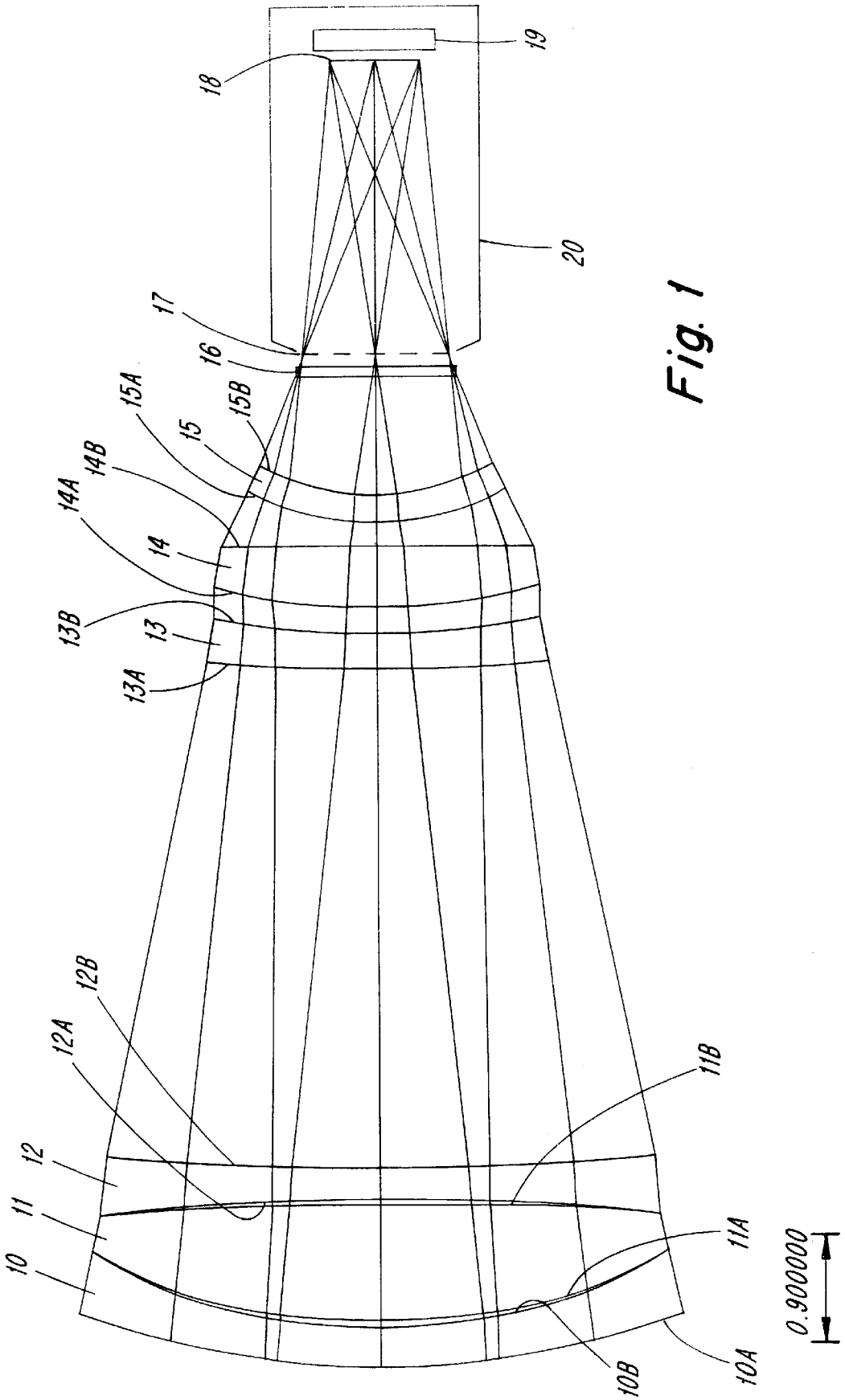

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Fig. 1

Fig. 2a

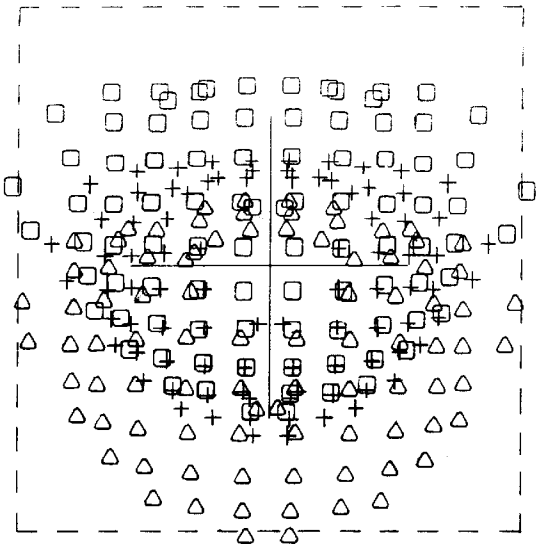


Fig. 2b

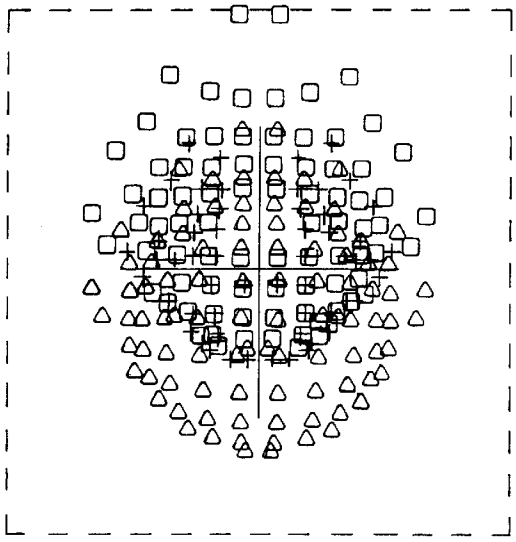


Fig. 2c

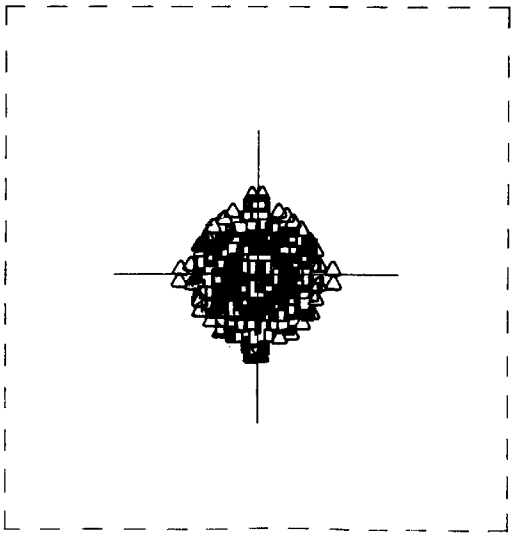


Fig. 3a

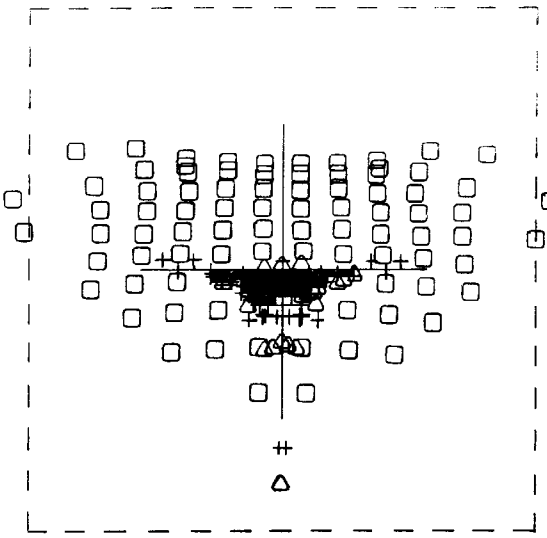


Fig. 3b

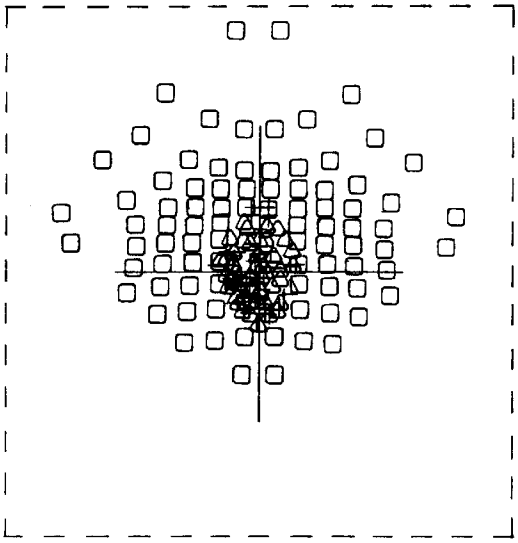
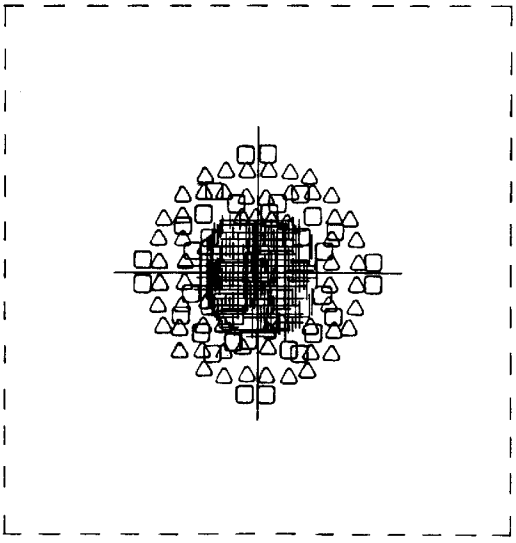


Fig. 3c



DUAL INFRARED BAND OBJECTIVE LENS

BACKGROUND

1) Field of the Invention

The present invention relates to an objective lens system and, in particular, a Petzval objective, capable of simultaneous dual band imagery in both the 3–5 and 8–12 micrometer spectral ranges, for use with a dual spectral band detector, such as a quantum well detector.

2) Discussion of Related Art

Recent advancements in quantum well detector technologies permit the simultaneous processing and display of dual infrared band imagery with a single detector at a single focal plane. There are advantages of imaging each spectral band and the possibility of focusing both bands simultaneously may yield greater information for surveillance and/or target discrimination by imaging devices.

Imaging devices, search and track sensors such as forward looking infrared systems, and other types of optical devices which operate in the 3–12 micrometer spectral region use either reflective or refractive objective lens systems. An advantage of reflective optics is that they operate within a wide spectral band. However, reflective optics systems have several undesirable features, such as, for example, a more limited field of view and a large physical size. In addition, central obstructions in reflective optics limit the modulation transfer function (MTF), or sine wave response.

Additionally, efficient cold shielding is important with any cooled detector array. Reflective optics are not appropriate for wide field of view applications, particularly when efficient cold shielding is necessary.

In the past, refractive lens systems have been designed for limited ranges, e.g., either the 3–5 or the 8–12 micrometer bands. This is because the refractive indices of the component lens materials vary significantly between the two spectral bands. For example, germanium behaves like a crown (a low dispersion material) in the 8–12 micrometer wavelengths and like a flint (a high dispersion material) in the 3–5 micrometer region. Systems designed to operate in one band exhibit intolerable chromatic aberrations in the other band. The design for either long wave (8–12 micrometers) or short wave (3–5 micrometers) lenses are commonplace, but the need for simultaneous dual band operation is a relatively new requirement.

The number of optical materials that can transmit wavelengths in the spectral range of interest for this application is limited, and many infrared lens materials are soft or water soluble, which make them unsuitable for tactical systems.

Several studies have been carried out to isolate optical material combinations that yield refractive lens designs that are color corrected over the entire 3–12 micron spectral region. The following publications describe such studies: Thomas H. Jamieson, "Ultrawide Waveband Optics", *Optical Engineering*, Vol. 23, No. 2, April 1984, pages 111–116; M. O. Lidwell, "Achromatism of Lenses for Thermal IR", *Proceedings SPIE*, Vol. 518, 1984, pages 73–80; and, M. Roberts and P. Rogers, "Wide Waveband Infrared Optics", *Proceedings SPIE*, Vol. 1013, 1988, pages 84–91.

These publications describe optical design studies that employ many different infrared lens material combinations. The solutions described in these studies yield excellent color correction over the spectral range of 3–12 microns, but the material combinations are poor choices from the standpoint of durability, manufacturability and reliability.

SUMMARY

The present invention overcomes the problems of the prior art by providing a combination of lens materials that yield excellent broad band color correction in the 3–12 micron spectral range; that are durable, easily produced and highly reliable; and therefore that are suitable for tactical infrared imaging systems.

Specifically, the present invention is an optical lens system made up of at least one lens triplet of a negative zinc sulfide lens, a positive zinc selenide lens, and a negative gallium arsenide lens, each of the lenses being positioned along a chief ray for simultaneous dual band imagery in both the 3–5 and 8–12 micrometer spectral bands. Alternatively, the lens system can include two widely spaced, net positive triplets, forming a Petzval-type lens. A quantum well detector may be placed at the focal plane for dual band image detection.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention may be best understood by reference to the following detailed description when read in conjunction with the following drawings, wherein:

FIG. **1** illustrates a YZ profile of a wide band Petzval objective lens employing two widely spaced triplets in accordance with the present invention;

FIGS. **2***a*–**2***c* are spot diagrams illustrating the performance achieved in the spectral band of 3–5 micrometers; and

FIGS. **3***a*–**3***c* are spot diagrams illustrating the performance achieved in the spectral band of 8–12 micrometers.

DETAILED DESCRIPTION

The index of refraction of optical materials varies with wavelength. The refractive index is generally higher at shorter wavelengths so that light converges faster (the focal length is shorter) than at longer wavelengths. This spread in the focal position over a spectral range is the primary chromatic aberration called axial color. It is relatively easy to correct the axial color aberration in either the 3–5 or the 8–12 micrometer spectral range by simply combining low and high dispersion elements and dividing the magnification power of the lens system among positive and negative lens elements. Color correction of both bands is much more difficult.

The present inventor has discovered a unique combination of lens powers, including an aspheric surface, and materials that yield color correction for both spectral bands simultaneously. The type of lens and the materials are, in order of their appearance along a chief ray of a focal optical lens system, as follows:

Lens	Material
Negative	Zinc sulfide (ZnS)
Positive	Zinc selenide (ZnSe)
Negative	Gallium arsenide (GaAs)

Recent advances in the quantum well detectors, or any present or future detectors capable of dual spectral band imagery, give rise to a need for dual band optics such as disclosed herein so that such detectors can be utilized to their best efficiency.

An exemplary set of lens characteristics for a conventional quantum well detector is as follows:

Effective Focal Length (EFL)	7.5"
f/#	2.0
Field of View	4.0 × 4.0 degrees
Pixel Size	0.002"
Format Size	0.5 × 0.5
Spectral Range	3 to 5 μm and 8 to 12 μm
Cold Shield Efficiency	100%

To achieve the above characteristics, the simple lens triplet, while acceptable for some applications, does not provide optimum speed and field of view. Speed refers to the light gathering power of the lens. In commercial camera optics, this property of the lens system is indicated by the f/number. The exposure time required for a given photograph is proportional to the square of the f/number and will be shorter when a lens with a low f/number is used; thus, a lens having a higher speed reduces light gathering time.

Two widely spaced triplets in the form of a Petzval-type lens provide an optimum speed and field of view for the above-listed lens characteristics. A classic Petzval lens involves two spaced doublets, but the term is used here by analogy because each triplet is a net positive lens group.

The six element combination with two aspheric surfaces can be optimized on the ACCOSV optical design program. A resulting lens design shown in FIG. **1** and listed in Table 1 below.

TABLE 1

BASIC LENS DATA

Surf.	Radius	Thickness	Medium		Refrac. Index	Label
0	0.00000000	1.50000000E+20	AIR			
1	0.00000000	−18.27594933	AIR			
2	7.28700000	0.33000000	MATL	C_ZnS	2.200833	10A
3	4.64064000	0.06544000	AIR			10B
4	5.14400000	0.98000000	MATL	ZnSe	2.406485	11A
5	−33.65800000	0.05074000	AIR			11B
6	−21.27500000	0.28000000	MATL	GaAs	3.277944	12A
7	33.65800000	4.27000000	AIR			12B
8	21.27500000	0.30000000	MATL	C_ZnS	2.200833	13A
9	7.05700000	0.22000000	AIR			13B
10	5.14400000	0.52500000	MATL	ZnSe	2.406485	14A
11	0.00000000	0.21700000	AIR			14B
12	2.20300000	0.22500000	MATL	GaAs	3.277944	15A
13	1.90900000	1.01703000	AIR			15B
14	0.00000000	0.08000000	MATL	ZnSe	2.406485	16A
15	0.00000000	0.10000000	MATL			16B
16*	0.00000000	2.50000000	AIR			17
17	0.00000000	0.00000000	AIR			

CONIC CONSTANT (CC) AND ASPHERIC DATA

Surf.	CC	AD	AE	AF	AG
3	0.00000E+00	−2.5363E−04	−1.59381E−05	−7.91405E−07	−6.71513E−08
9	0.00000E+00	9.85522E−04	3.35206E−05	7.40680E−06	−2.89437E−06

wherein AD, AE, AF and AG represent 4th, 6th, 8th and 10th order deformation coefficients, respectively and the asterisk * signifies where the aperture stop/cold shield is located.

REFRACTIVE INDICES

Surf.	N1	N2	N3	N4	N5	ABBE
2	2.200833	2.212892	2.186965	1.000000	1.000000	46.316416
4	2.406485	2.412209	2.400068	1.000000	1.000000	115.848590
6	3.277944	3.282937	3.272502	1.000000	1.000000	218.286360
8	2.200833	2.212892	2.186965	1.000000	1.000000	46.316416
10	2.406485	2.412209	2.400068	1.000000	1.000000	115.848590
12	3.277944	3.282937	3.272502	1.000000	1.000000	218.286360
14	2.406485	2.412209	2.400068	1.000000	1.000000	115.848590

These refractive indices correspond to the 8–12 micrometer range and are different for the 3–5 micrometer range when generating the spot diagrams of FIGS. **2***a*–**2***c*.

WAVELENGTH DESIGNS					
Wavelength #	1	2	3	4	5
Wavelength	10.00000	9.00000	11.00000	0.00000	0.00000
Spectral Weight	1.0000	1.0000	1.0000	1.0000	1.0000

OPERATING CONDITIONS				
Reference Object Height	Reference Aperture Ht.	Object Surface	Reference Surface	Image Surface
-0.7336233+19 (2.8000 Deg.)	0.62393	0	16	17

APERTURE STOP AT SURFACE 15 (EN ADJUSTMENT)				
Effective Focal Length (EFL)	Back Focus	f/Number	Length	Gauss Image Height
7.4911	2.5000	2.00	8.6602	0.3662

STANDARD AND BOOLEAN APERTURE (TM) DATA (CA ON)						
Surf.	Type	CAY	CAX	Y-OFFSET	X-OFFSET	LABEL
2	Cir.	2.54959		0.00000	0.00000	10A
3	Cir.	2.42975		0.00000	0.00000	10B
4	Cir.	2.43030		0.00000	0.00000	11A
5	Cir.	2.36548		0.00000	0.00000	11B
6	Cir.	2.36344		0.00000	0.00000	12A
7	Cir.	2.30949		0.00000	0.00000	12B
8	Cir.	1.43501		0.00000	0.00000	13A
9	Cir.	1.38404		0.00000	0.00000	13B
10	Cir.	1.37450		0.00000	0.00000	14A
11	Cir.	1.31524		0.00000	0.00000	14B
12	Cir.	1.08791		0.00000	0.00000	15A
13	Cir.	0.97822		0.00000	0.00000	15B
14	Cir.	0.68097		0.00000	0.00000	16A
15	Cir.	0.66855		0.00000	0.00000	16B
17	Cir.	0.37445		0.00000	0.00000	

Lens units are inches.
Evaluation mode is focal.
Control wavelength is 1.

Naturally, other lens characteristics can be used within the scope of the present invention. The above data is exemplary and reflects an optimum lens data for a particular quantum well detector chip.

In the preferred embodiments of the present invention, in each lens triplet, a first lens **10**, **13** is negative, a second lens **11**, **14** is positive, and a third lens **12**, **15** is negative as taken along the chief ray. Surfaces **10**B and **13**B of the ZNS lens are selected for receiving aspheric surfaces. ZnS is a diamond turnable lens material which greatly eases manufacturing requirements. Also, of the manufacturing methods available for making ZnS lenses, the Cleartran™ method provides a better, more homogenous material (C_ZnS) which is clearer in the 3–5 micrometer range than produced by some other methods.

As illustrated in FIG. **1**, parallel light impinging on the Petzval lens system is focused on an image plane **18**. A quantum well detector **19** can be placed at the image plane **18**. A cryogenic vessel or Dewar houses the quantum well detector **19** to maintain the detector **19** at a temperature of approximately 77° Kelvin in order to increase detector sensitivity. The cold shield **20** of the Dewar is shown.

In these types of systems, optimum performance is achieved by cold shielding the detector array. This is done by introducing a cold diaphragm, or cold shield **20**, with an aperture stop **17** in front of the detector array so that the viewing angle of the detector to the warm background is limited as nearly as possible to only that required for transmission of radiation from the scene. Since the amount of radiation reaching the detector from the cold shield **20** is negligible compared to the amount reaching the detector from the warm background of the field of view, induced noise in the detector is minimized. The cold shield **20** is typically placed within the Dewar. Also included in the optical system may be a Dewar window **16**.

The performance achieved in each spectral band is shown by the spot diagrams in FIGS. **2***a*–**2***c* and **3***a*–**3***c*. Rays representative of three wavelengths in each of the 3 to 5 and 8 to 12 spectral bands from an on-axis and two off-axis field points are distributed through the full aperture and are traced through the system, producing FIGS. **2***c*, **2***a* and **2***b*, respectively. In FIG. **2***a*, the FOB-Y is 1.0000 and the FOB-X is 0.0000; in FIG. **2***b*, the FOB-Y is 0.7000 and the FOB-X is 0.0000; in FIG. **2***c*, the FOB-Y is 0.0000 and the FOB-X is 0.0000; in FIG. **3***a*, the FOB-Y is 1.0000 and the FOB-X is 0.0000; in FIG. **3***b*, the FOB-Y is 0.7071 and the FOB-X is 0.0000; and in FIG. **3***c*, the FOB-Y is 0.0000 and the FOB-X is 0.0000, wherein FOB stands for fractional object height. FOB refers to the object point (or field angle when the object is at infinity) from which rays are traced.

As shown in FIGS. **2***a*–**2***c* and **3***a*–**3***c*, the square in phantom is the pixel size of a typical quantum well detector, e.g., 50.8×50.8 micrometers (0.002 inches). In FIGS. **2***a*–**2***c* and **3***a*–**3***c*, all spot diagram origins are on the chief ray. Since virtually all of the ray intercepts are contained within the pixel, the image resolution will be limited by such a detector.

By the above disclosed imaging system, the optimum capability of a quantum well detector can be utilized. A quantum well detector's capability could go under-utilized without an optical system such as disclosed herein that can simultaneously deliver the image quality required over both the 3 to 5 μm and 8 to 5 μm spectral bands. The lens system in accordance with the present invention yields excellent broadband color correction by a combination of infrared lens material suitable for tactical applications.

Certain preferred embodiments of the invention have been described by way of example. Various other embodiments and components thereof will be apparent, particularly in applying the lens triplets to perform various functions. Various parameters may be optimized for different purposes. For example, a beam splitter may be introduced into the lens system to split an image into the 3–5 μm range and the 8–12 μm range, whereupon the lens powers may vary and color correction requirements loosened because of the using more than one focal plane. The lens system can be useful with detectors capable of imaging either the 3 to 5 μm or 8 to 12 μm spectral bands, and an imaging system can be envisioned wherein high and low spectral band detectors can be selectively placed at the focal plane(s), by use of a beam splitter or employing a detector change-over mechanism. Naturally, optimum performance is achieved when employing a single detector capable of detecting both the 3 to 5 μm and 8 to spectral bands. The foregoing description is offered as illustrative and not limitative. Other variations and equivalents thereof are intended to be encompassed by the invention, which is defined by the claims appended hereto.

I claim:

1. An optical imaging system comprising:

a lens system simultaneously focusing light in both the 3–5 and 8–12 micrometer spectral bands onto a single focal plane, wherein said lens system includes:

a first, negative zinc sulfide lens,

a second, positive zinc selenide lens, and

a third, negative gallium arsenide lens,

each of said first through third lenses being positioned along a chief ray and capable of simultaneous dual band imagery in both the 3–5 and 8–12 micrometer spectral bands; and

a detector, located at said single focal plane, capable of simultaneous dual band imagery in both the 3–5 and 8–12 micrometer spectral bands.

2. An optical imaging system according to claim **1**, wherein said detector is a quantum well detector.

3. An optical imaging system according to claim **1**, wherein said lens system further includes:

a fourth, negative zinc sulfide lens,

a fifth, positive zinc selenide lens,

a sixth, negative gallium arsenide lens,

each of said first through sixth lenses being positioned along a chief ray, said first through third and said fourth through sixth lenses forming two widely spaced triplets.

4. An optical imaging system according to claim **3**, wherein said two widely spaced triplets form a Petzval-type lens.

5. An optical imaging system according to claim **3**, wherein said lens system further includes a field flattener lens, and a cold shield diaphragm.

6. An optical imaging system according to claim **1**, wherein at least one of said lenses has an aspheric surface.

7. An optical imaging system according to claim **6**, wherein said aspheric surface is on said second zinc selenide lens.

8. An optical imaging system according to claim **3**, wherein a surface on said fifth zinc selenide lens is aspheric.

9. An optical imaging system according to claim **3**, wherein said lens system has the following basic lens data:

BASIC LENS DATA

Surf.	Radius	Thickness	Medium		Refrac. Index
0	0.00000000	1.50000000E+20	AIR		
1	0.00000000	−18.27594933	AIR		
2	7.28700000	0.33000000	MATL	C_ZnS	2.200833
3	4.64064000	0.06544000	AIR		
4	5.14400000	0.98000000	MATL	ZnSe	2.406485
5	−33.65800000	0.05074000	AIR		
6	−21.27500000	0.28000000	MATL	GaAs	3.277944
7	33.65800000	4.27000000	AIR		
8	21.27500000	0.30000000	MATL	C_ZnS	2.200833
9	7.05700000	0.22000000	AIR		
10	5.14400000	0.52500000	MATL	ZnSe	2.406485
11	0.00000000	0.21700000	AIR		
12	2.20300000	0.22500000	MATL	GaAs	3.277944
13	1.90900000	1.01703000	AIR		
14	0.00000000	0.08000000	MATL	ZnSe	2.406485
15	0.00000000	0.10000000	MATL		
16	0.00000000	2.50000000	AIR		
17	0.00000000	0.00000000	AIR		

* * * * *

US006392680B2

(12) **United States Patent**
Akada et al.

(10) **Patent No.: US 6,392,680 B2**
(45) **Date of Patent: *May 21, 2002**

(54) **IMAGE FORMATION ON OBJECTIVE BODIES**

(75) Inventors: **Masanori Akada**; **Yoshikazu Ito**; **Jumpei Kanto**, all of Tokyo-To; **Mitsuru Takeda**, Yokohama; **Masaki Kutsukake**, Tokyo-To; **Noritaka Egashira**, Ichikawa; **Shunsuke Mukasa**, Tokyo-To; **Takao Suzuki**, Kawagoe; **Hideo Hosoi**, Tokyo-To; **Yasuo Otatsume**, Chiba, all of (JP)

(73) Assignee: **Dai Nippon Insatsu Kabushiki Kaisha** (JP)

(*) Notice: This patent issued on a continued prosecution application filed under 37 CFR 1.53(d), and is subject to the twenty year patent term provisions of 35 U.S.C. 154(a)(2).

Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/260,017**

(22) Filed: **Mar. 2, 1999**

Related U.S. Application Data

(60) Continuation of application No. 08/797,726, filed on Feb. 11, 1997, which is a division of application No. 08/395,850, filed on Feb. 28, 1995, now Pat. No. 5,629,259, which is a continuation of application No. 08/034,186, filed on Mar. 18, 1993, now Pat. No. 5,451,560, which is a continuation of application No. 07/467,415, filed on Jan. 19, 1990, now abandoned, which is a division of application No. 07/138,384, filed as application No. PCT/JP87/00228 on Apr. 10, 1987, now Pat. No. 4,923,848.

(30) **Foreign Application Priority Data**

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Apr. 11, 1986 (JP) 61-81989
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Sep. 24, 1986 (JP) 61-225473
Oct. 1, 1986 (JP) 61-231224
Jan. 14, 1987 (JP) 62-5066

(51) **Int. Cl.**[7] **B41J 2/325**
(52) **U.S. Cl.** **347/213**; 156/230
(58) **Field of Search** 8/467, 468, 470, 8/471, 472; 347/172, 171, 176, 213; 156/234, 235, 230; 503/227

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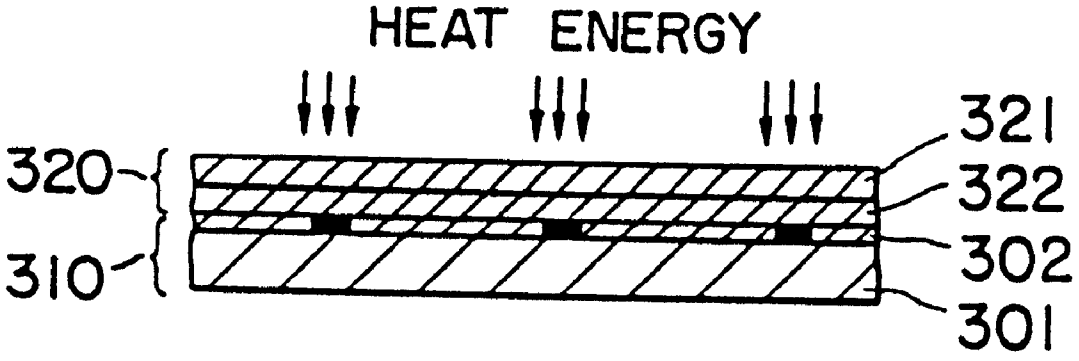
Primary Examiner—Huan Tran
(74) *Attorney, Agent, or Firm*—Parkhurst & Wendel, LLP

(57) **ABSTRACT**

The present invention relates to image-formation on any selected kind of objective body. The characterizing features reside in such that, based upon fed image data, required images are formed on an image-transferable sheet acting for image carry-over service and in reliance on sublimation image transfer technique, and then, by the use of said sheet with said images thus formed thereon, the formed images thereon are transferringly applied on the objective body. By adopting the above measures, the objective body can be formed sharply and clearly with any desired images, irrespective of kind and configuration thereof, with such superior results of highly improved unity and solidability between the formed images and the objective body to be decorated with.

2 Claims, 16 Drawing Sheets



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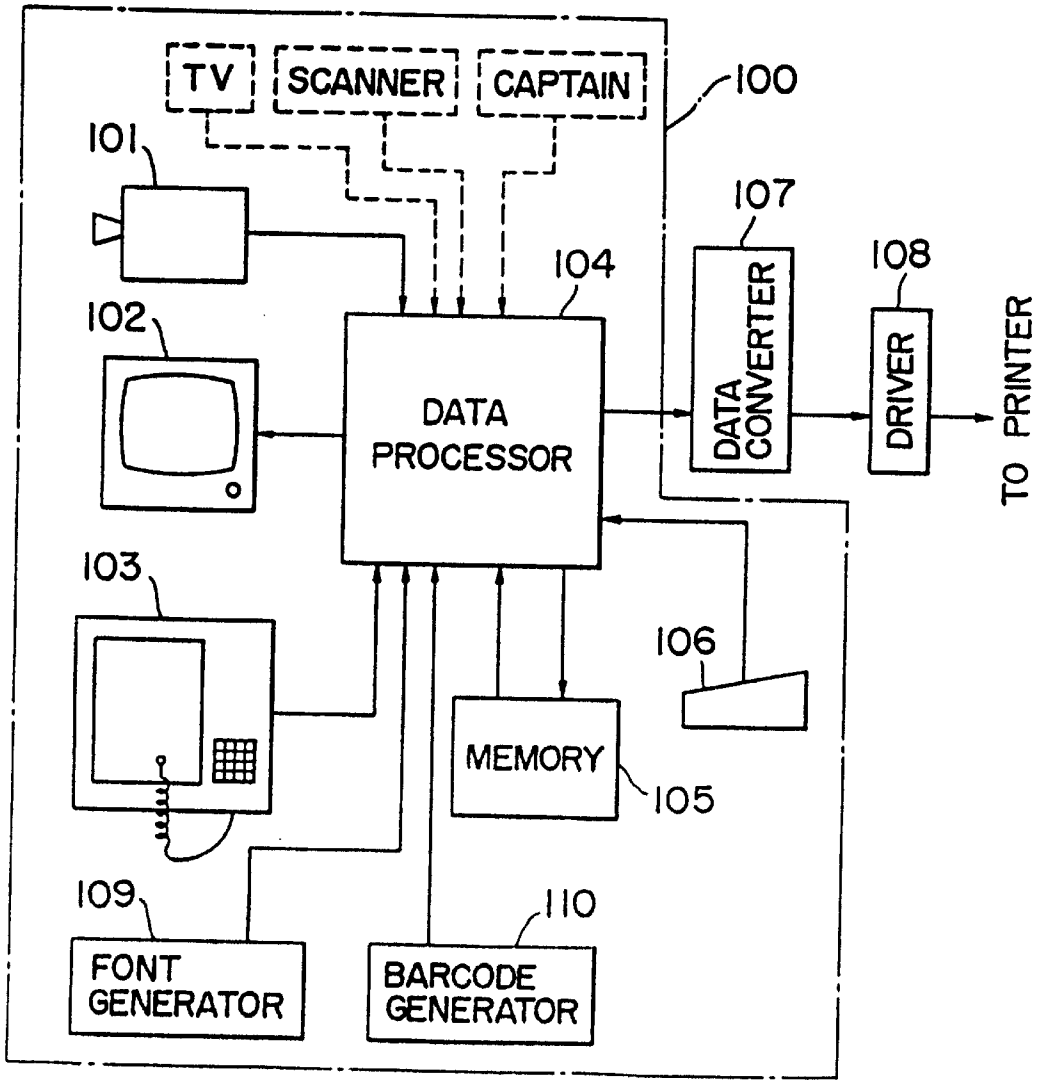

TV
SCANNER
CAPTAIN
100
101
107
104
108
102
DATA PROCESSOR
DATA CONVERTER
DRIVER
TO PRINTER
103
106
MEMORY
105
109
110
FONT GENERATOR
BARCODE GENERATOR

FIG. 1A

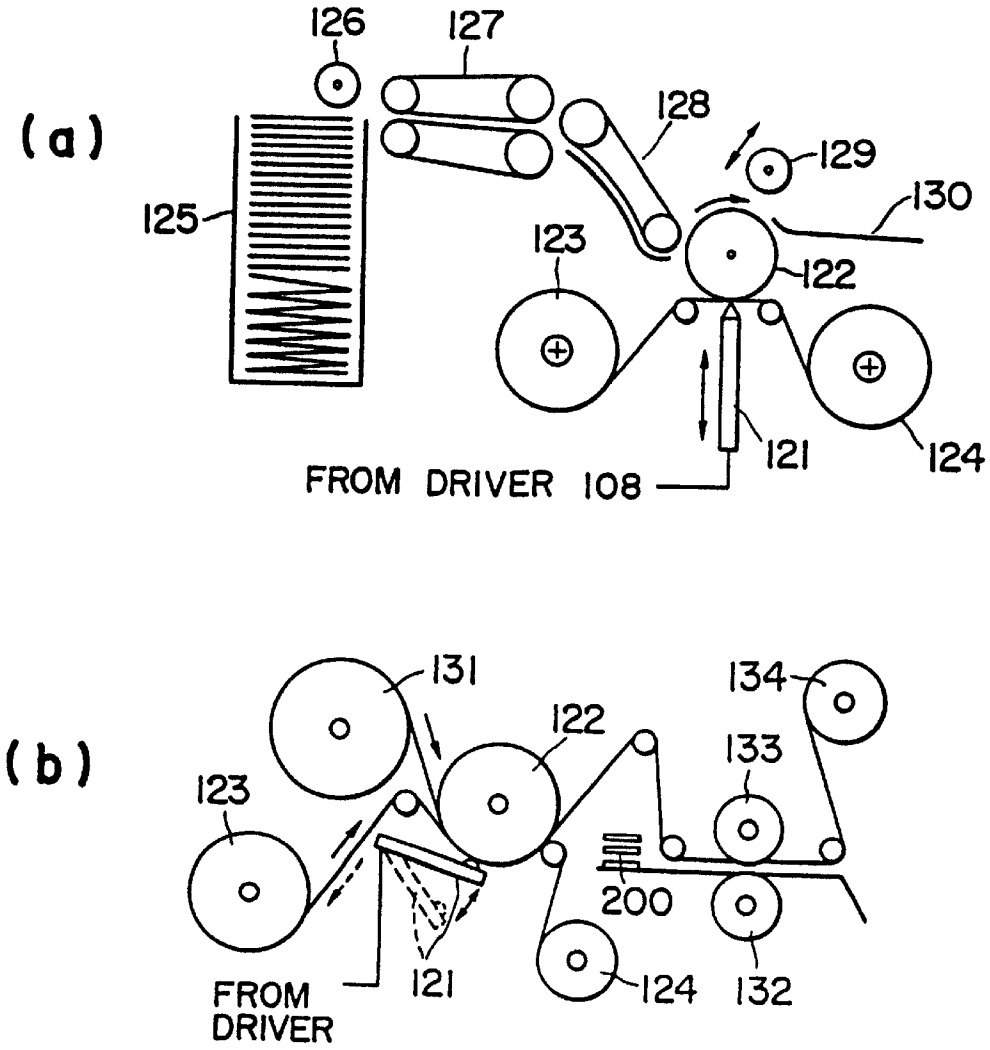

(a)
126
127
128
129
130
125
123
122
121
124
FROM DRIVER 108
(b)
131
134
122
133
123
200
121
124
132
FROM DRIVER
(c)
133'
132'

FIG. 1B

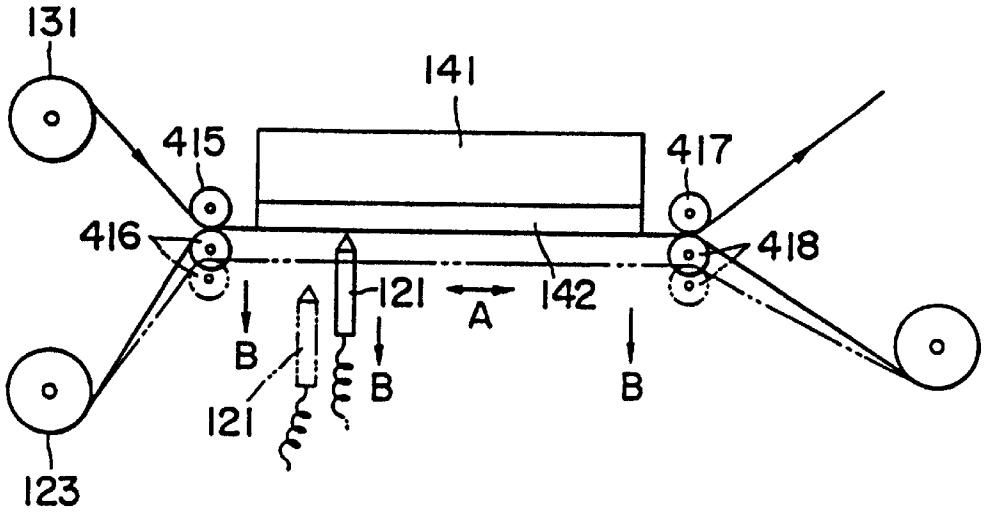


FIG. 1C

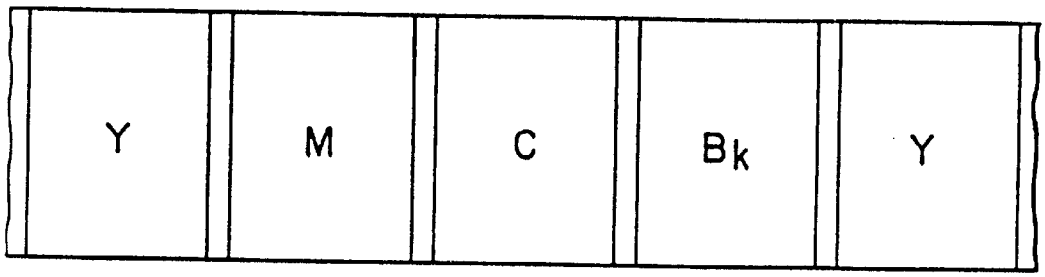


FIG. 1D

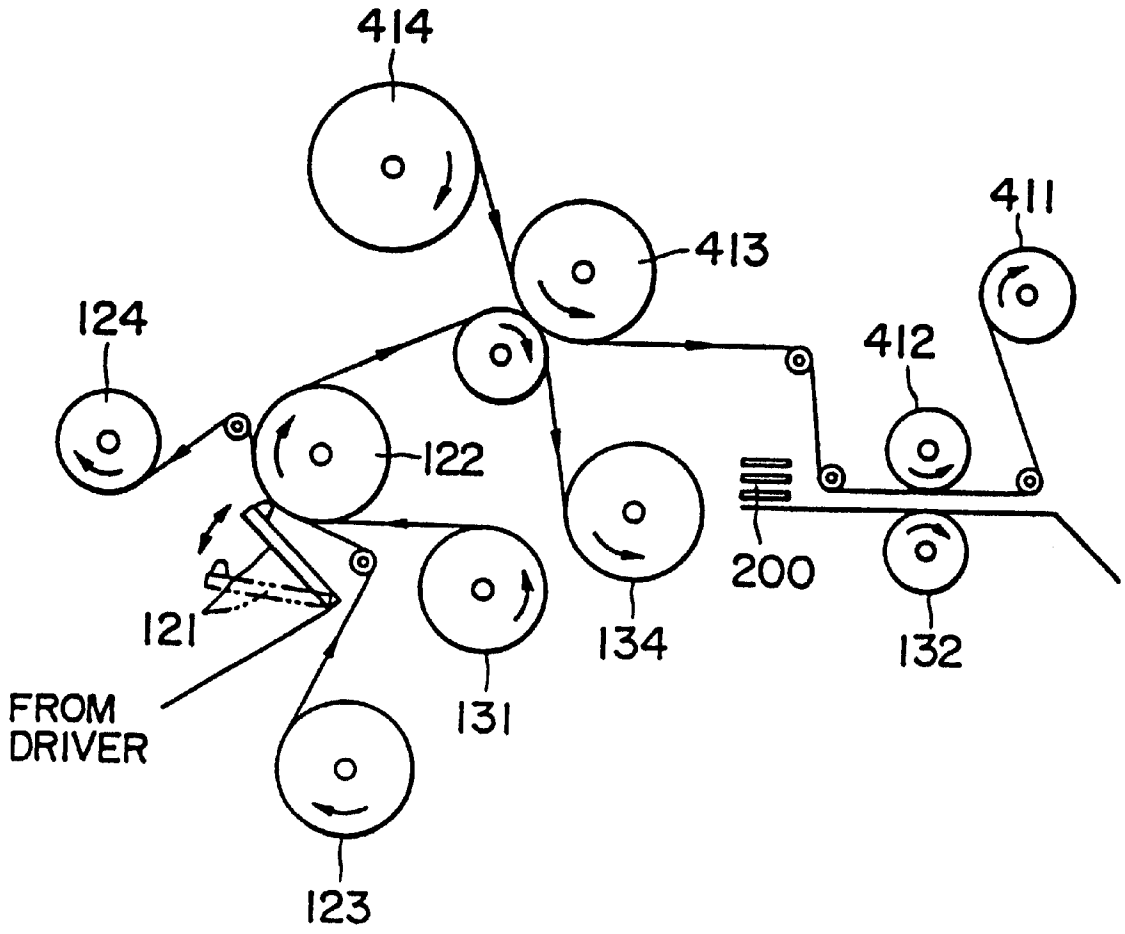


FIG. 1E

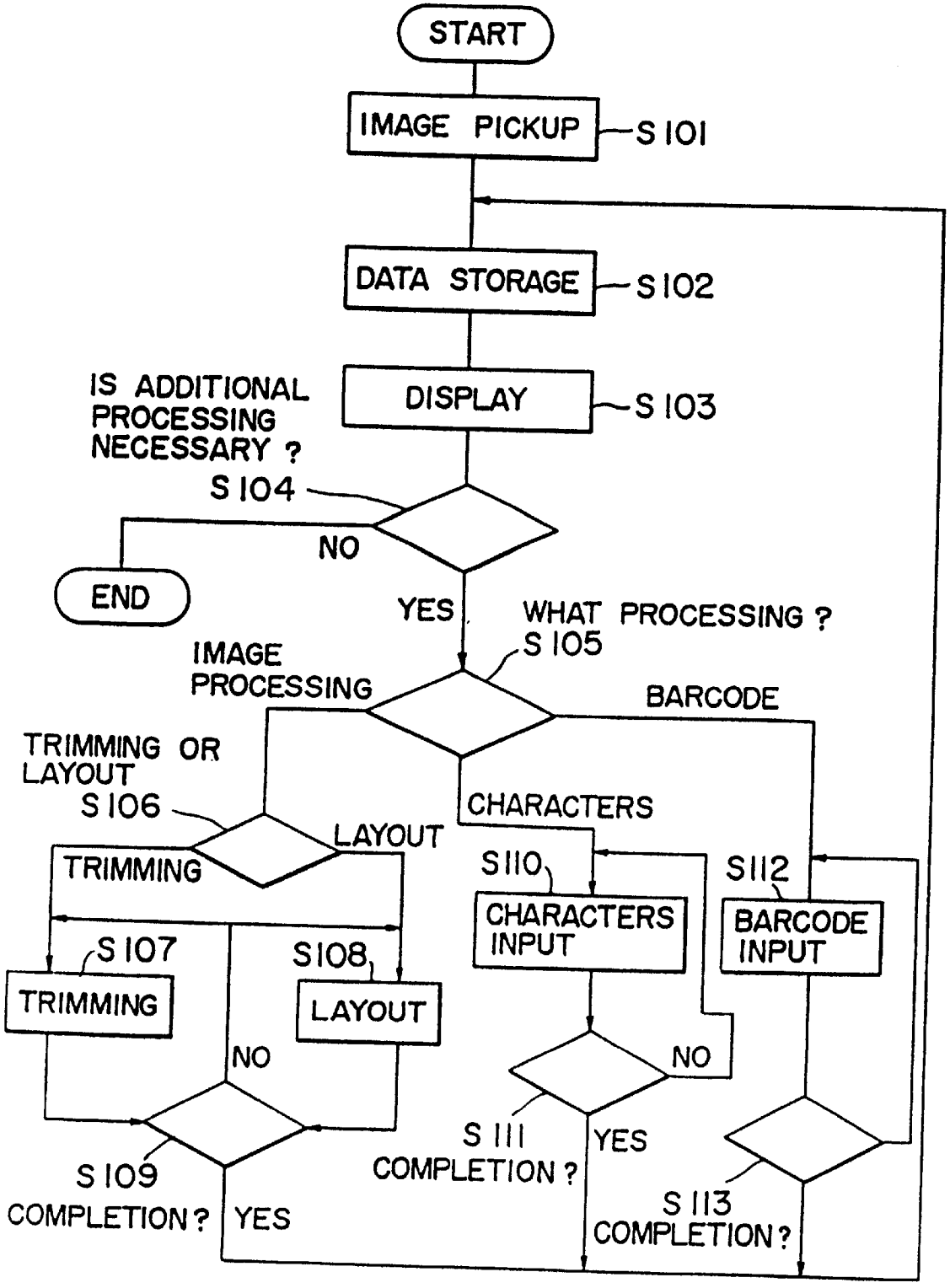

START
IMAGE PICKUP
S101
DATA STORAGE
S102
DISPLAY
S103
IS ADDITIONAL PROCESSING NECESSARY ?
S104
NO
END
YES
WHAT PROCESSING ?
S105
IMAGE PROCESSING
BARCODE
TRIMMING OR LAYOUT
S106
CHARACTERS
LAYOUT
TRIMMING
S110
S112
CHARACTERS INPUT
BARCODE INPUT
S107
S108
TRIMMING
LAYOUT
NO
NO
S111
YES
COMPLETION ?
S109
COMPLETION ?
YES
S113
COMPLETION ?

FIG. 2

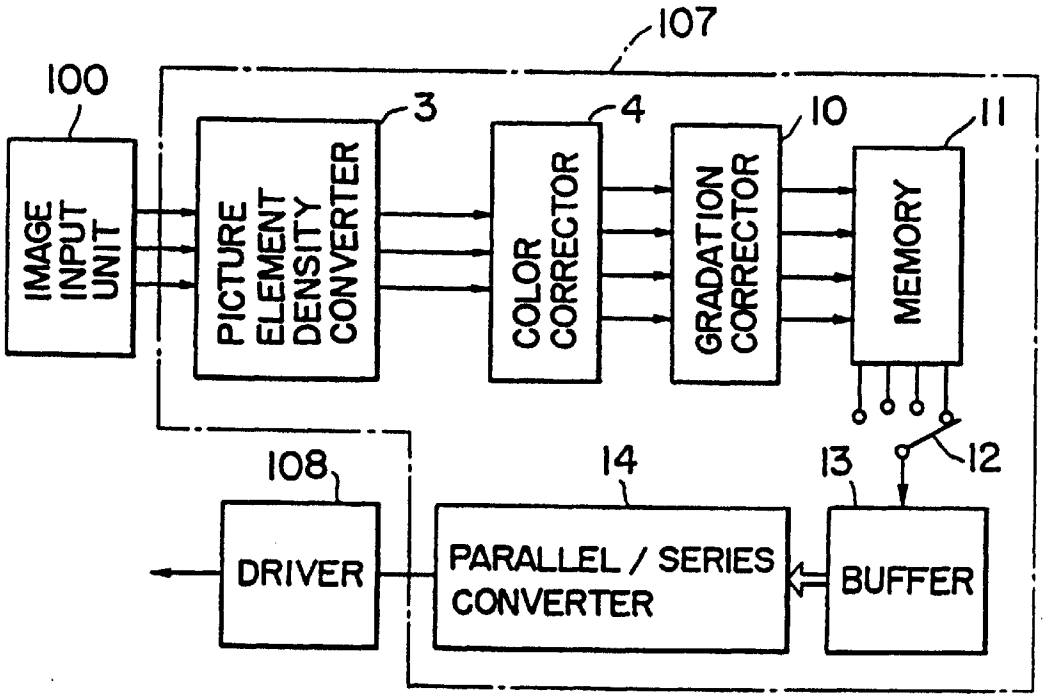

107
100
3
4
10
11
IMAGE INPUT UNIT
PICTURE ELEMENT DENSITY CONVERTER
COLOR CORRECTOR
GRADATION CORRECTOR
MEMORY
108
14
13
12
DRIVER
PARALLEL / SERIES CONVERTER
BUFFER

FIG. 3A

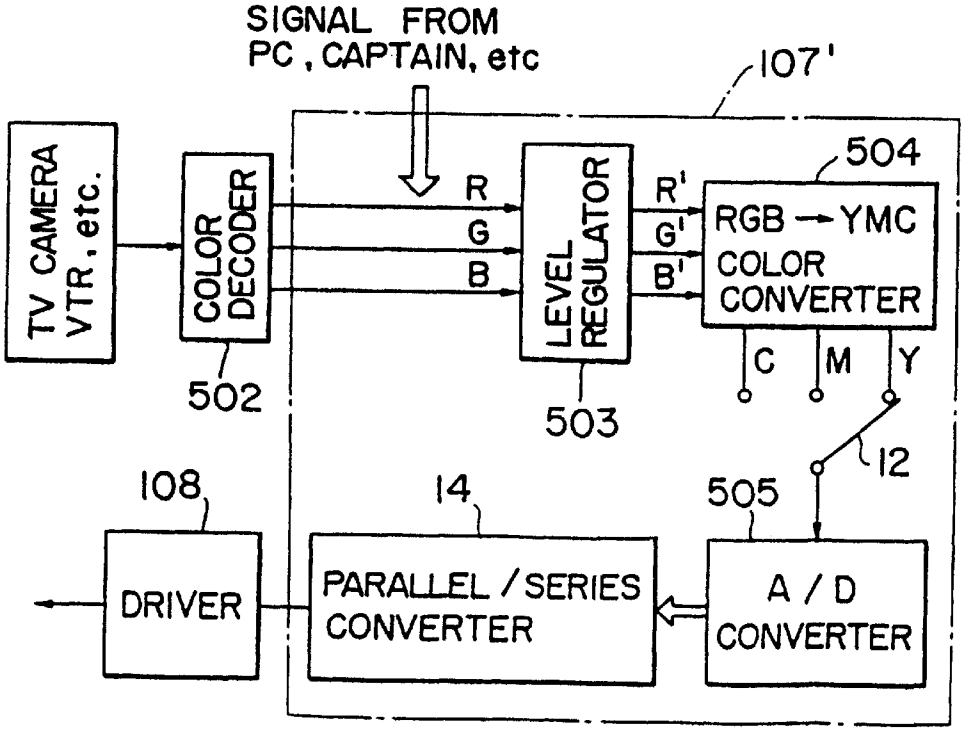

SIGNAL FROM PC, CAPTAIN, etc
107'
TV CAMERA VTR, etc.
COLOR DECODER
502
R
G
B
LEVEL REGULATOR
503
R'
G'
B'
504
RGB → YMC COLOR CONVERTER
C
M
Y
12
108
14
505
DRIVER
PARALLEL / SERIES CONVERTER
A / D CONVERTER

FIG. 3B

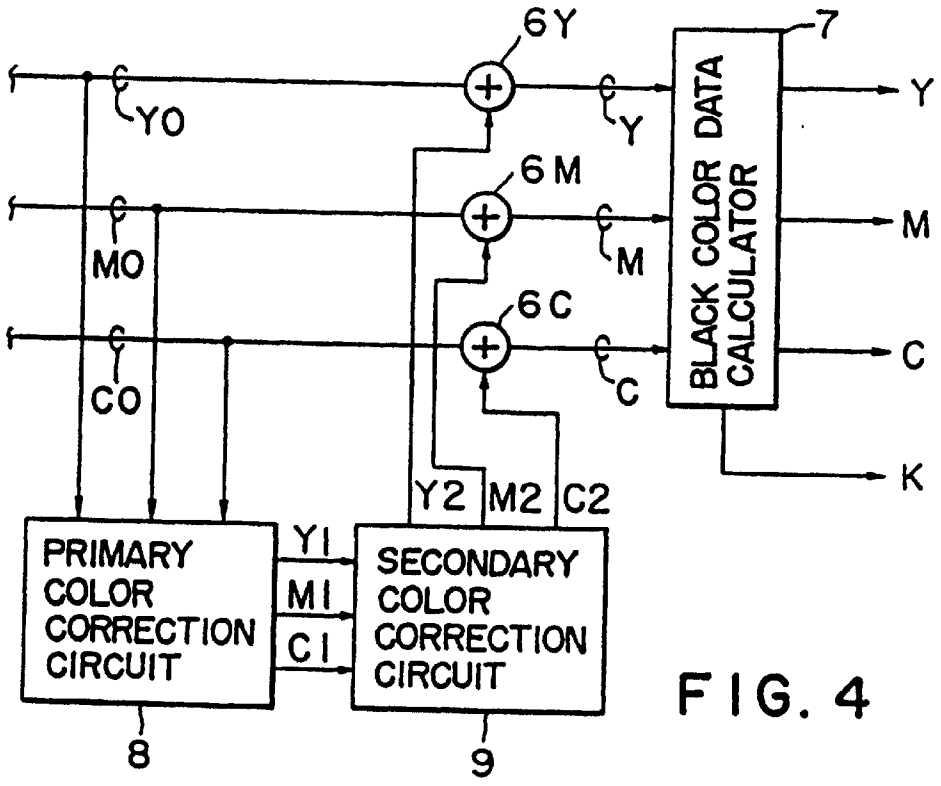

6Y
7
Y0
Y
Y
6M
MO
M
M
6C
CO
C
C
BLACK COLOR DATA CALCULATOR
Y
M
C
K
Y2
M2
C2
PRIMARY COLOR CORRECTION CIRCUIT
Y1
M1
C1
SECONDARY COLOR CORRECTION CIRCUIT
8
9

FIG. 4

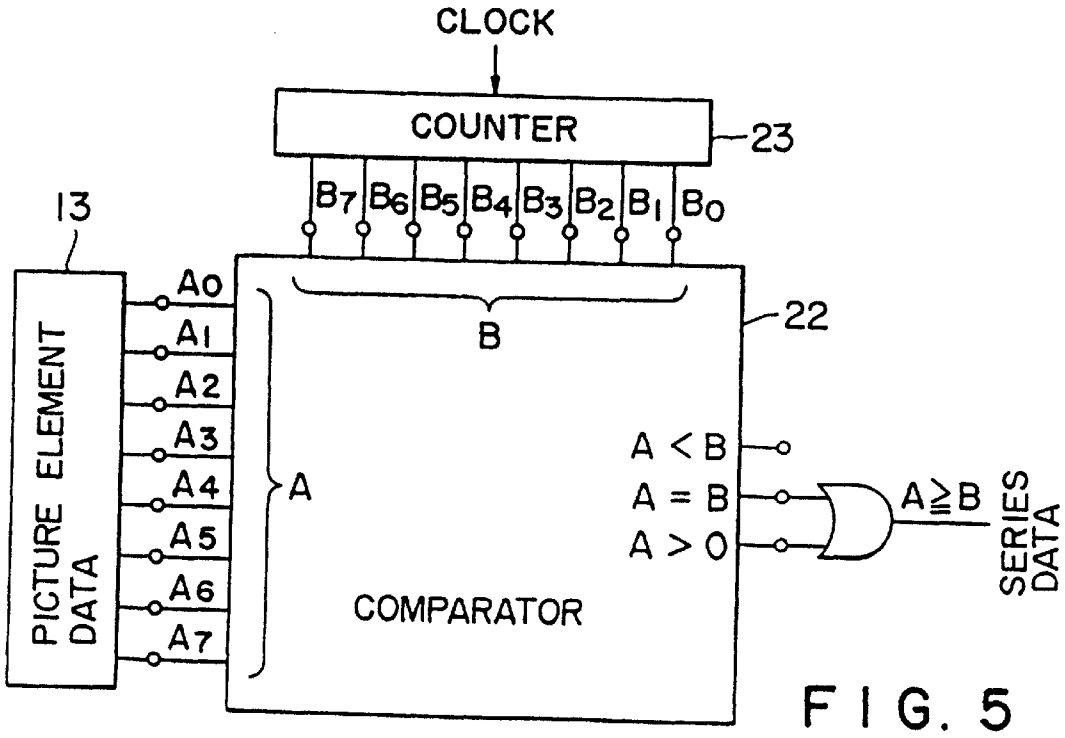

CLOCK
COUNTER
23
B7 B6 B5 B4 B3 B2 B1 B0
13
A0
A1
A2
A3
A4
A5
A6
A7
A
B
22
PICTURE ELEMENT DATA
A < B
A = B
A > 0
A≧B
SERIES DATA
COMPARATOR

FIG. 5

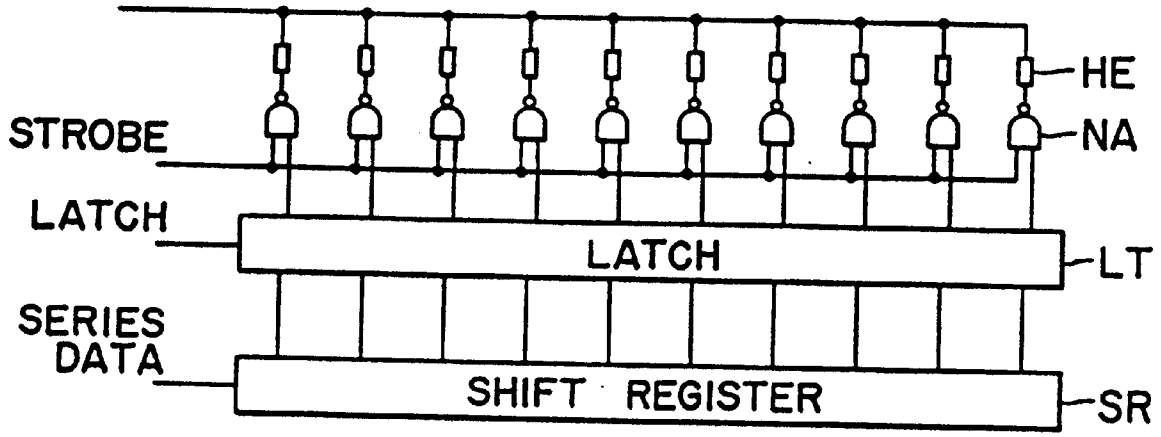

HE
NA
STROBE
LATCH
LATCH
LT
SERIES DATA
SHIFT REGISTER
SR

FIG. 6

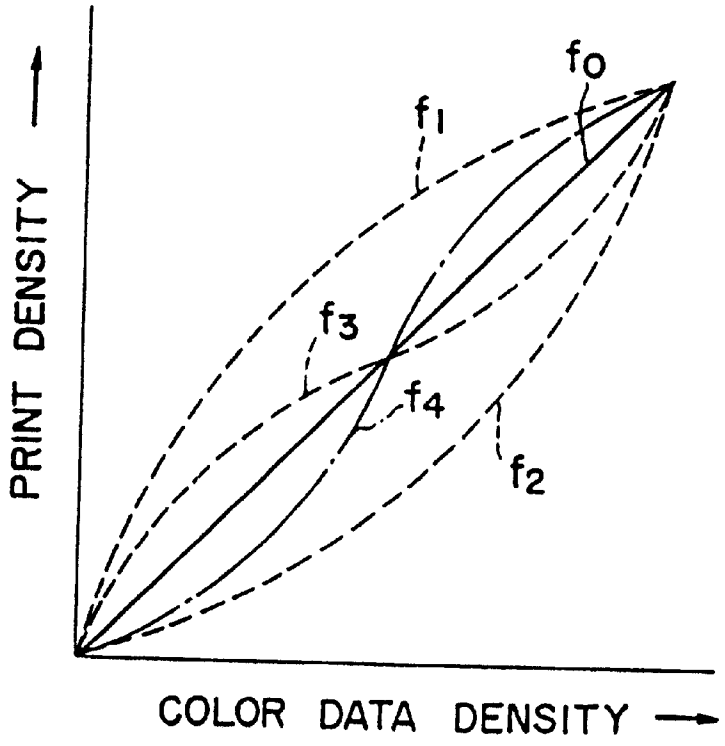

PRINT DENSITY
COLOR DATA DENSITY
f0
f1
f2
f3
f4

FIG. 7

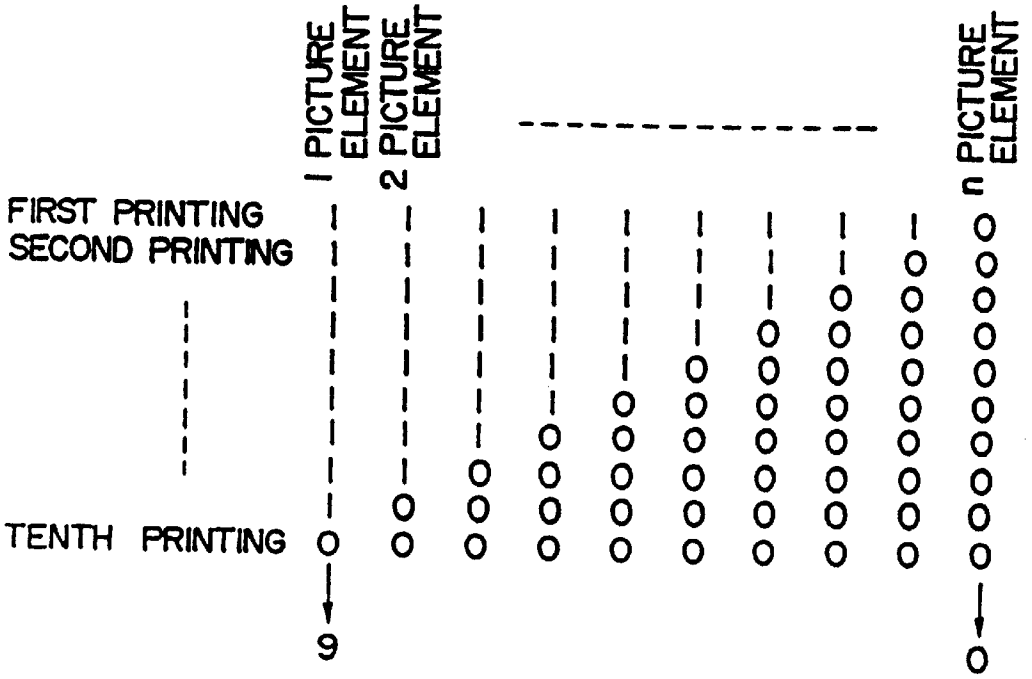

1 PICTURE ELEMENT
2 PICTURE ELEMENT
n PICTURE ELEMENT
FIRST PRINTING
SECOND PRINTING
TENTH PRINTING
9
0

FIG. 8

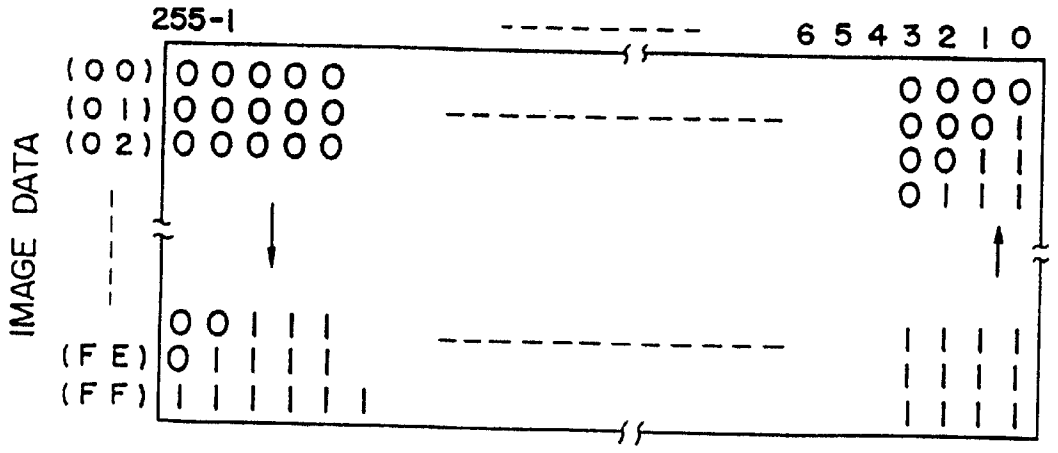

255-1
6 5 4 3 2 1 0
(0 0)
(0 1)
(0 2)
(F E)
(F F)
IMAGE DATA

FIG. 9

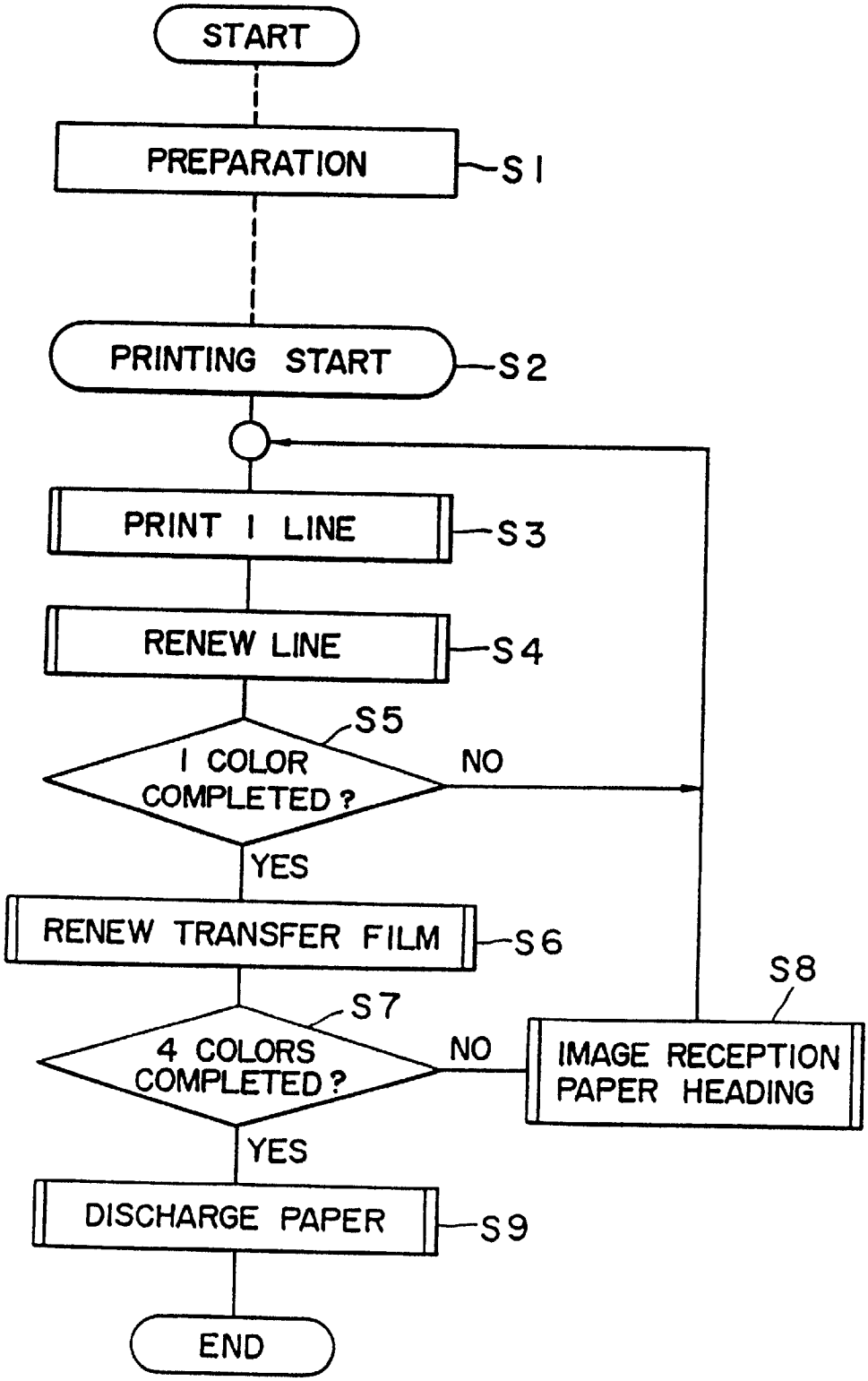

START
PREPARATION
S1
PRINTING START
S2
PRINT 1 LINE
S3
RENEW LINE
S4
S5
1 COLOR COMPLETED?
NO
YES
RENEW TRANSFER FILM
S6
S7
4 COLORS COMPLETED?
NO
S8
IMAGE RECEPTION PAPER HEADING
YES
DISCHARGE PAPER
S9
END

FIG. 10

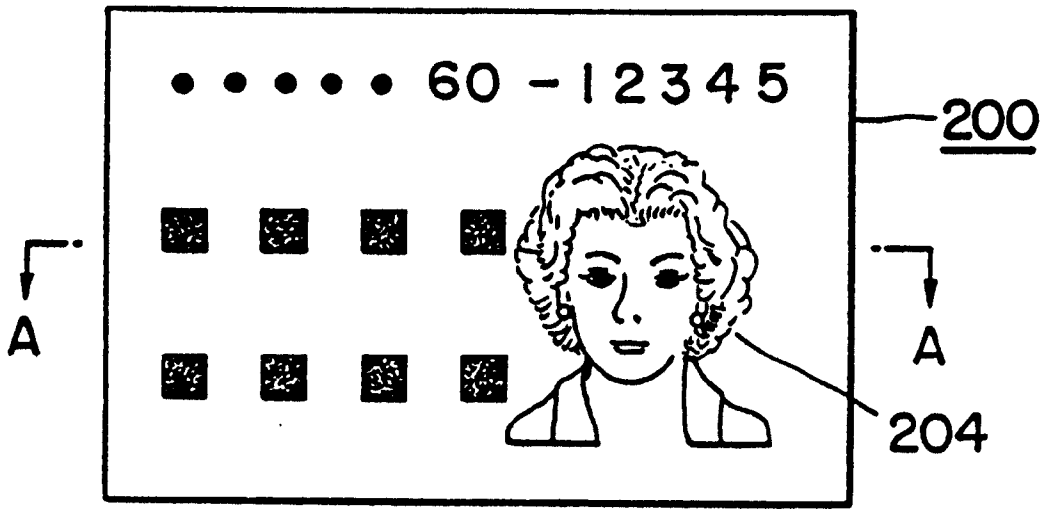


FIG. 11

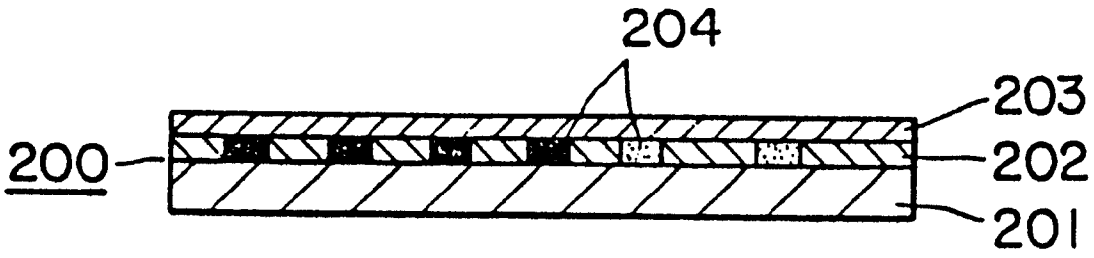


FIG. 12

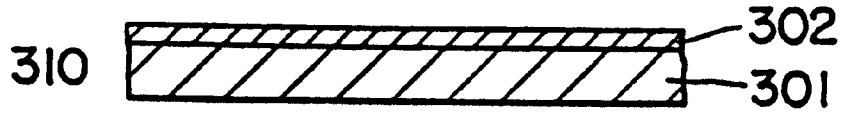


FIG. 13

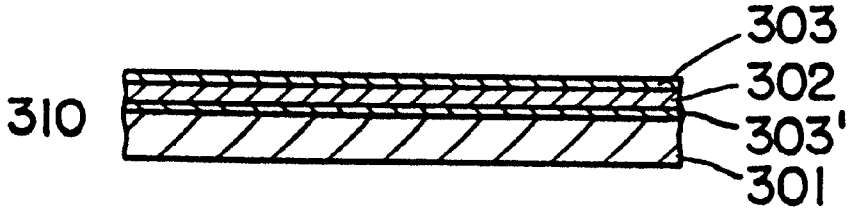


FIG. 14

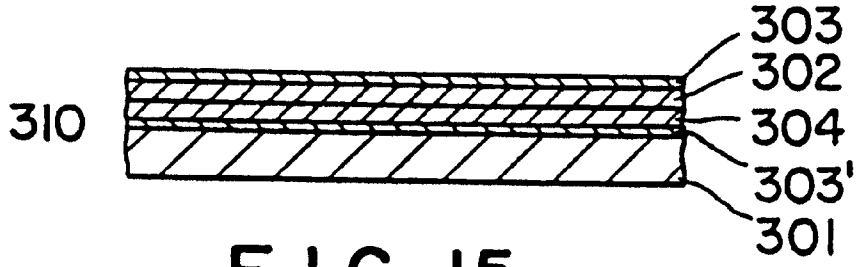


FIG. 15

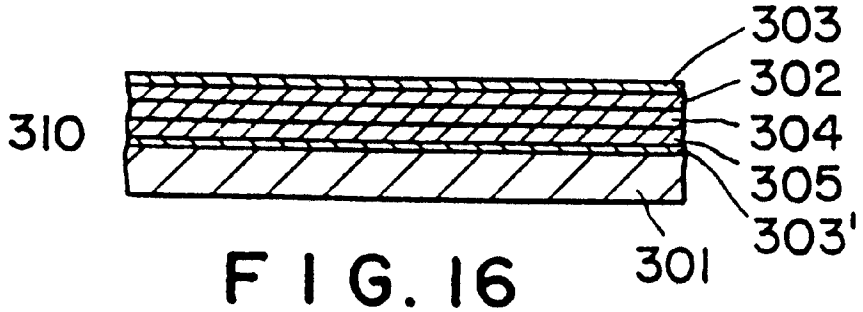


FIG. 16

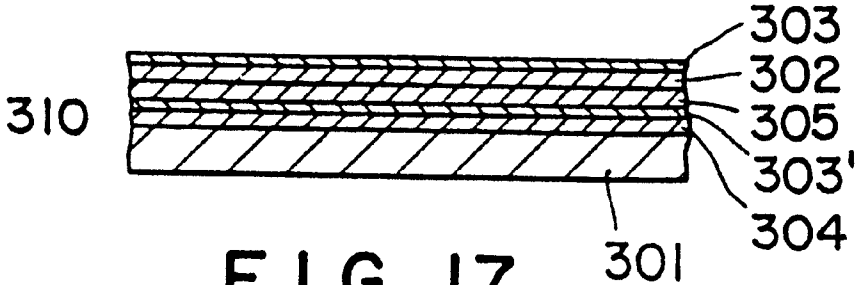


FIG. 17

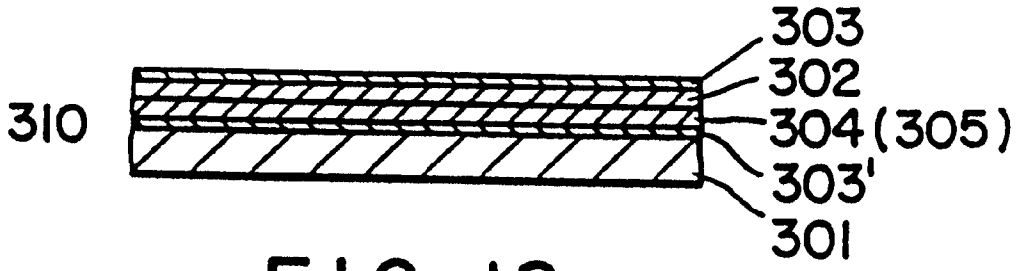


FIG. 18

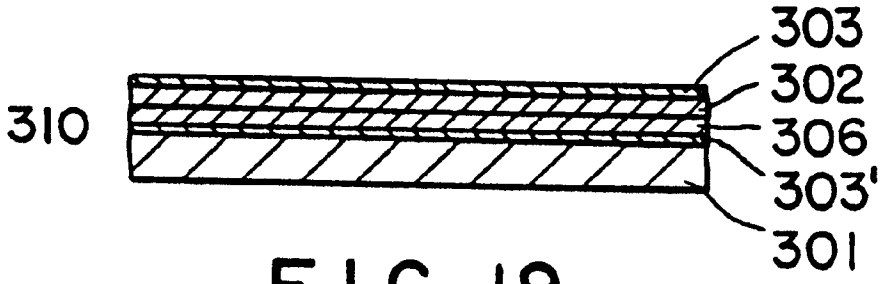


FIG. 19

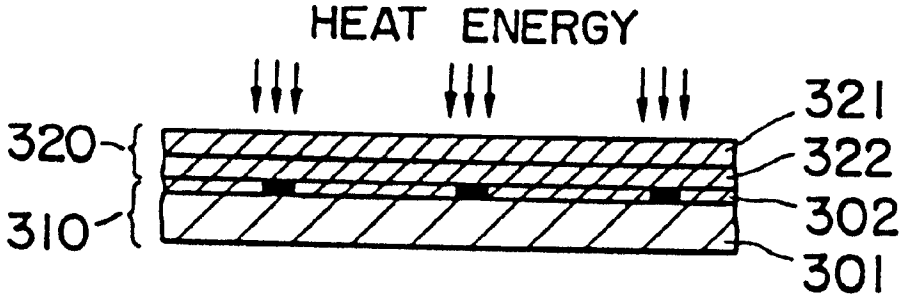


FIG. 20

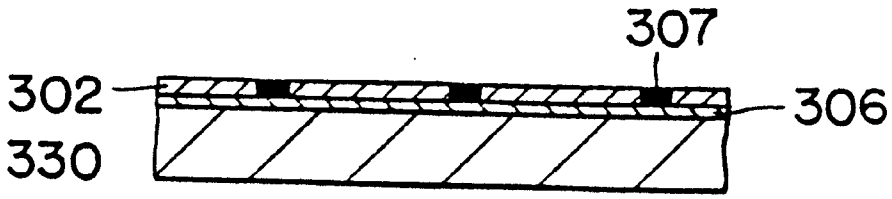


FIG. 21

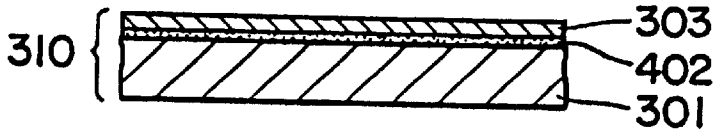


FIG. 22

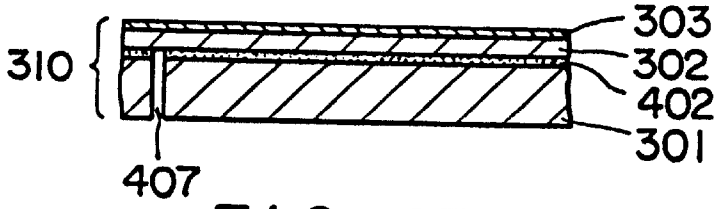


FIG. 23

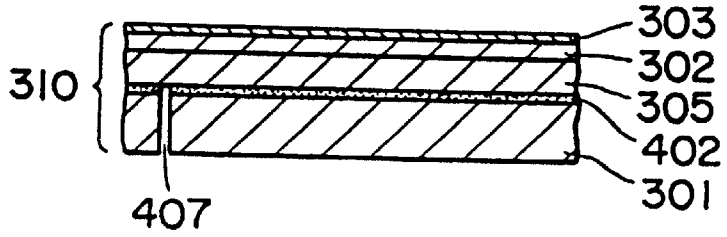


FIG. 24

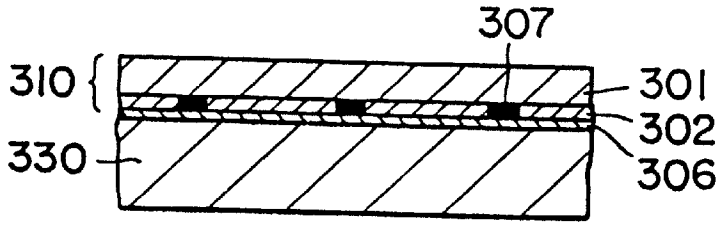


FIG. 25

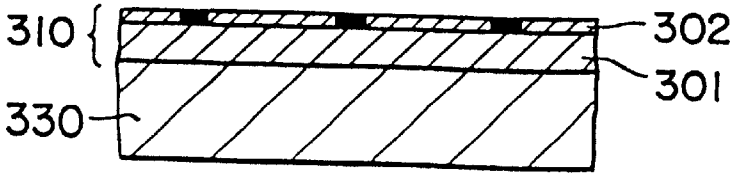


FIG. 26

FIG. 27

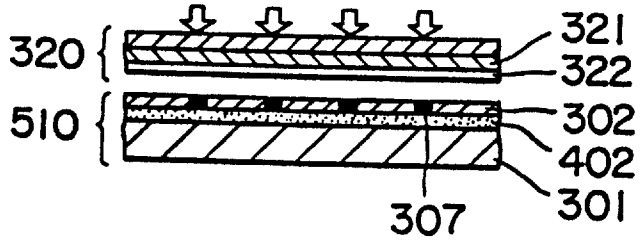


FIG. 28

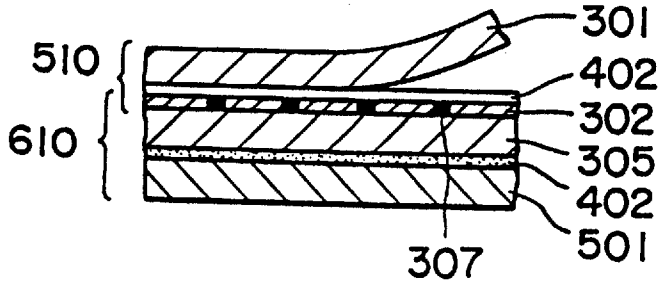


FIG. 29

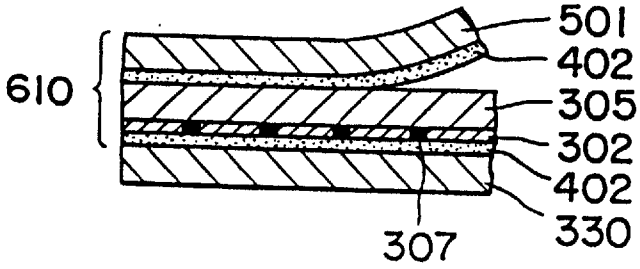


FIG. 30

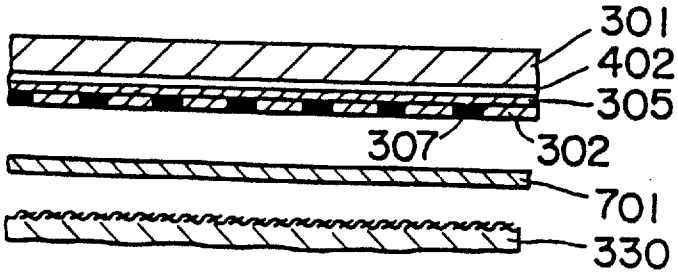
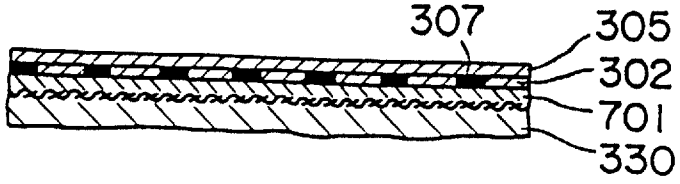


FIG. 31



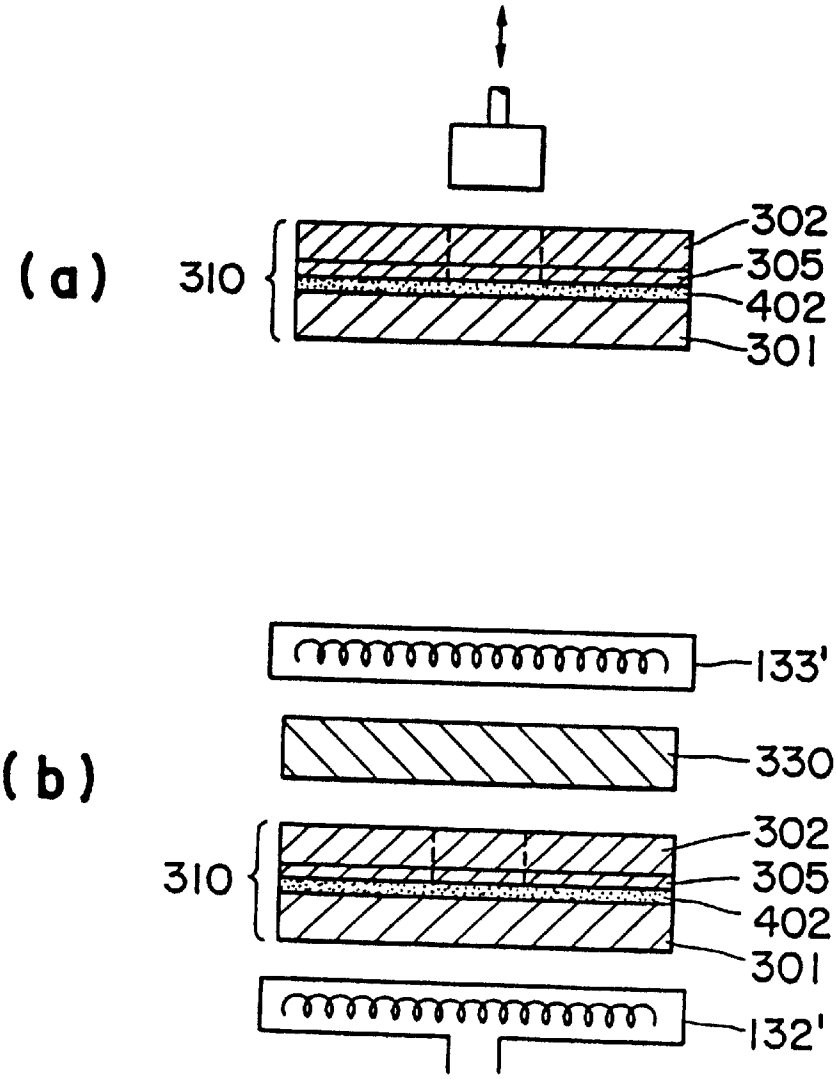

(a)
310
302
305
402
301
(b)
133'
330
310
302
305
402
301
132'
(c)
330
302
305

FIG. 32

IMAGE FORMATION ON OBJECTIVE BODIES

This is a continuation of application Ser. No. 08/797,726 filed Feb. 11, 1997, now allowed, which in turn is a divisional of Ser. No. 08/395,850 filed Feb. 28, 1995 now U.S. Pat. No. 5,629,259 which in turn is a continuation of Ser. No. 08/034,186, filed Mar. 18, 1993, now U.S. Pat. No. 5,451,560 which in turn is a continuation of Ser. No. 07/467,415 filed Jan. 19, 1990, now abandoned, which in turn is a division of Ser. No. 07/138,384 filed Dec. 8, 1987 now U.S. Pat. No. 4,923,848, of which is a National Stage Application of PCT/JP87/00228 filed on Apr. 10, 1987.

TECHNICAL FIELD

This invention relates to methods and apparatus for the formation of images as prints on objective bodies through transfer of images preformed by the sublimation transfer technique, and more specifically it relates to such systems as adapted for the formation of images on any selected objective body, such as cards, clothes, papers, and transparent sheets, although these are not limitative to the present invention.

BACKGROUND ART

Reliance is made generally upon the normal printing technique for formation of images on objective bodies. For the execution of the printing technique, provision and use of printing plates (forms or blocks) are requisite. No matter how simple the image-printing is, the plate-making is a very time-consuming the laborious procedure. This is much more so in the printing of various and complexed image combinations, such as those of graphic or portrait images combined with characters, letters or barcodes, as an example, representing extremely complicated and troublesome work.

Further, in the normal printing operation, various operating conditions, including ink selection and the like, must be carefully considered, depending upon the kind and nature of the printing object, thus the best selection thereof is highly delicate and not as simple as expected.

The present invention is proposed upon careful consideration of the foregoing facts, and an object of the invention is to provide a unique process for the formation of sharp and clear images regardless of the kind and nature of the object to be printed upon, and usable and effective materials and apparatuses for carrying out this unique process.

The method of thermal image transfer (sublimation image transfer) on clothes or fabrics with the use of thermal transfer dyestuffs has been practiced for a long time. In this conventional process, a dyestuff picture layer carrying thermal transfer dyestuff is formed on a substrate sheet which is then subjected to heat in an overlapped state on a cloth or fabric, the dyestuff thereby being transferred thermally onto the latter for forming the desired images thereon. By utilizing this technique, and with recent development of the image forming technology concerning fine thermal printers and the like, various fine image forming processes have been proposed to provide fine images which are comparable to photographic images and are transferred onto plastic films from thermal transfer sheets carrying thermal transfer dyestuffs.

According to these recently proposed processes, various images of cameras, or TVs, graphic images of personal computers and the like can be reproduced-easily in the form of hard copies on the surface of a transferred material

such-as a paper or the like sheet carrying thereon a fixedly attached layer of polyester resin, as an example. These images thus reproduced represent an amply high level comparable to those obtained by photography or fine printing arts.

The thermal transfer process so far set forth has an advantage in that it can form any image in a convenient manner yet entails a problem in that it is limited to image-transferred products preferably of polyester and the like materials which must be dyed with thermal transfer dyes. On the other hand, the image-transferred products must be limited to specifically selected shapes, preferably film, sheet or the like configuration, and thus, such materials as wood, metal, glass or ceramics cannot be formed with images in this way. Further, even if the material is plastics such as polyester or the like, and when the image-forming surface is curved or undulated, or physical body other than sheet, even if it represents a plane surface, it is almost impossible to reproduce images precisely thereon, which naturally constitutes a grave problem in the art.

With recent development and enlargement of utilizing fields of various card-style products, such as cash-cards, telephone-cards, prepayment cards; and ID-cards, there are increasing demands for providing these cards with images, symbols and codes, so as to give various other functional and/or decorative effects. Moot of these cards are of planar form, but they are frequently not pliable and/or have uneven rough portions due to provision of characters and symbols, resulting in great difficulty in the scheduled image formation relying upon the thermal image transfer process.

There is therefore an urgent demand among those skilled in the art for the provision of a unique technique capable of forming sharp and clear images of desired patterns on the surface of an objective body of any preferred kind of material and having any shape and configuration and surface condition of any kind, and indeed, for combining and unifying image- and decoration effects.

DISCLOSURE OF THE INVENTION

The present invention is basically based on such a principle that a first image transfer pattern is formed on an image transfer material, preferably an image-transferable sheet, and in the form of dyestuff images through the sublimation image transfer process executed by first image transfer means, depending upon given image data, preferably including those of letters, characters, symbols, line images, graduated graphic representations, and then the first transfer pattern is transferred to second transfer means for retransferring the images onto an objective body so as to provide a final product.

Based upon the image data fed from various image data input means and at the first image-transfer means, a thermal head is actuated to execute printing operation through a dyestuff film (thermal image-transfer sheet) on an image-transfer material (or more specifically on an image-transferable material which means an image-transferable sheet. This image-printing is carried out according to the sublimation or sublimative image transfer technique. Thus, in this case, the dyestuff on the dyestuff film is transferred or shifted under the influence of heat energy from the thermal head onto the image-transferable material through sublimation, thus providing the first image-transferred means. Since this first image-transferred means has been thus formed with the images by the sublimated dyestuff, they are, then, transferred onto the second image-transferable means which will be brought into tight contact with the

object to be decorated and subjected to heat and pressure for execution of further image-transfer operation to provide the final desired product.

In the present invention, the image-transfer material (image-transferable sheet) is, as above referred to, formed with images by the sublimative image transfer technique for providing first image-transfer means which has highly sharp and clear images as the operation and results of the characterizing feature of the sublimation image-transfer technique. Therefore, because of the transfer of such sharp and clear images onto the object, it becomes possible to form the images thereon, and indeed, practically irrespective of the kind and nature of the object. In this way, thus, fine image-formation is assured onto practically any objective substance.

And further, by execution of control of the thermal energy applied during the sublimative image-transfer step, the resulting color effect is superior and the image quality is good.

The images sublimatingly applied and formed in the foregoing way are subjected to a further transfer, and onto a substrate product, for providing a final decorative product as desired. In this final product, it should be noted that the underlying layer underneath the images during the sublimative image-transfer stage appears now at the top, acting thus as a kind of protecting layer upon up-and-down positional conversion during execution of the second and final image-transfer stage, resulting in realization of various and numerous effects. As an example, attainment of substantial reduction of contamination, improvement of light resistance, weather resistance and chemical resistance; substantial reduction of color fading; provision of glazing effect; easier and simpler introduction of granular and/or undulated image appearance.

The inventive process is carried into effect basically in such a manner that an image-reception layer provided on one surface of an image-transferable sheet is subjected to an image-forming step with the use of dyestuff capable of depositing therein depending upon the fed image data, so as to form the required images, and then, the image-reception layer of the image-transferable sheet, having been image-fixed and thus now image-carrying, is stuck onto the surface of the object to be decorated upon.

As for the image-transferable sheet adapted for use in the image-transfer during execution of the inventive process, it consists basically of a sheet-like substrate and a reception layer attached, however, in a separable manner, onto one surface thereof. As a modification of the inventive process from the basic mode set forth above, the sheet-like substrate is caused to remain, even after completion of the image-transfer step, as may be occasionally required. In this modified case, it is unnecessary to make the image-reception layer of the image-transfer sheet separable.

Under occasion, the inventive process may be brought into effect in such a way that the image-reception layer of the image-transfer sheet is transferred upon execution of the image-forming step, and indeed, once onto an intermediate image-transfer substrate which is then retransferred, together with the once transferred image-reception layer, onto the surface of an object to be decorated on, and thus, in a retransferring manner.

BRIEF DESCRIPTION OF THE DRAWING

In the accompanying drawings:

FIG. **1A** is a block diagram, showing a preferred embodiment of the apparatus according to the present invention;

FIG. **1B** is a schematic view illustrating at B-**1**, B-**2** and B-**3**, several image-transfer steps for the execution of a process according to the invention;.

FIG. **1C** is a schematic view of an image-transfer step, using a platen roll;

FIG. **1D** is a plan view of part of a multi-color dyestuff film adapted for use in an image-forming step;

FIG. **1E** is a schematic view for the illustration of several image-transfer steps;

FIG. **2** is a flow chart of successive operation steps with use of a data-processor, shown in FIG. **1**, functioning as an operating center;

FIG. **3A** is a schematic block diagram, showing a data-processor for the printer;

FIG. **3B** is a block diagram of a sublimative image-transferring printer adopted in the present invention, as a preferred embodiment thereof;

FIG. **4** is a schematic block diagram, showing a color correction unit shown in FIG. **3A**, and several related parts cooperating therewith;

FIG. **5** is a schematic block diagram of a comparator and several related parts cooperating therewith;

FIG. **6** is a circuit block diagram of an image-transfer head shown in FIG. **1B**;

FIG. **7** is a graph showing operational characteristics of a color tone or -gradation corrector unit shown in FIG. **3A**;

FIG. **8** is a table for the illustration, as an example, of picture- or image-elements, as expressed in binary signals;

FIG. **9** is a table showing a conversion operation, as an example, of a parallel/series converter shown in FIG. **3A**;

FIG. **10** is a flow chart, illustrating the operation of the sublimative image transfer printer;

FIG. **11** is a plan view of a final decorative product prepared according to the inventive technique;

FIG. **12** is a sectional view of the product card shown in FIG. **11**, and taken along a section line A—A shown therein;

FIGS. **13** through **31** are a series of sectional views, respectively illustrating several structural examples of image-transferable sheets, suitable for use in the invention; and

FIGS. **32**(*a*), (*b*), and (*c*) are sectional views, indicating final transfer steps.

BEST MODES FOR CARRYING OUT THE INVENTION

Referring now to FIG. **1A** and FIGS. **1B-1**, **1B-2** and **1B-3**, a basic schema of the inventive image data processing and image formation will be illustrated. First, in FIG. **1A**, numeral **101** represents an image input means which is adapted for forming image data based upon optical and the like inputs delivered from a TV-camera, line sensor or the like. Other than those above enlisted only by way of example, video; CD; TV; scanner; personal computer, captain system, capable of providing R.G.B.—and picture image and the like signals may also be utilized in a similar way. The image signal data delivered from the image input means are fed through a data processor **104** to a memory **105** for being stored therein. These stored data can be taken out from the memory and fed through data processor **104** to display means **102** for being displayed thereat.

To the data processer **104**, a mouth/tablet digitizer and/or the like position data processer **103** is electrically connected for introducing position data concerning displayed images

appearing at the display **102**. In addition, key board and the like character data input means **106** and font generator **109** are provided for introducing character data. Still further, a barcode generator **110** is provided for introducing barcode when necessary. By the use of these means and units, various additional processing modes can be executed.

The thus processed data are subjected to conversion at a data converter **107** into proper data adapted for operating a sublimation transfer printer and fed forward through a driver **108** to the thermal head.

In this case, by controlling the current duration period to the thermal element of the thermal head, the transfer quantity from the dyestuff film (thermal transfer sheet) is controlled depending upon the thermal energy of the element for realization of the desired gradation degree of concentration on the transfer sheet. There are two different modes of such control of current duration period as follows:

(a) A method for controlling the pulse length corresponding to the picture element in the impressed data to the thermal element of the thermal head or, more specifically, a series data introduced as input to the shift register shown in FIG. **6** and to be described more specifically hereinafter.

(b) A method for controlling the number of pulses of the pulse series corresponding to the picture elements of the data impressed upon the thermal element in the thermal head (in this case, the pulse length being constant).

The degree of gradation of the transfer image can be controlled in the above mentioned way by the regulation of the current-conducting period depending upon the desired gradation degree. On the other hand, the image concentration can be controlled by adjusting the pulse length or the number of pulses contained in the pulse series in correspondence to the picture elements contained in the data as introduced in the shift register and depending upon the driving mode of the thermal head. Further in this case, if the number of gradation of introduced image data is larger than that which can be expressed by the printer unit, a proper conversion operation can be performed by the known strobe control method. As an example, in such case, the conversion of gradation number 256 to 64 may be executed by a ROM, and the thus reduced gradation number can be used as output.

Next, referring to FIGS. **1**B at **1**B-**1** and **1**B-**2**, reference numeral **121** represents a thermal head which receives signals from the driver **108** shown in FIG. **1**A. This thermal head **121** is arranged in opposition to platen roll **122**, forming the printing position therebetween. The dyestuff film (thermal transfer sheet) is fed from a delivery roll **123** to a winding roll **124** through this printing position, these structural and functional features being commonly employed in both the arrangements shown in FIGS. **1**B at **1**B-**1** and **1**B-**2**.

In the case of FIG. **1**B, **1**B-**1**, the mechanism is so arranged that card or sheet style transfer sheets are printed with dyestuff images.

On the other hand, in the case of FIGS. **1**B, **1**B-**2**, the mechanism is so arranged that cards are continuously produced with the use of a film style transfer sheet and a dyestuff film in combination.

Now turning back to FIGS. **1**B, **1**B-**1**, a number of transfer sheets (cards, sheets or the like) have been stacked and stored within a storage casing **125** and are being thrust upward from below by a spring so that the uppermost sheet is kept in pressure contact with a take-out roll **126**. With the rotation of the roll **126**, the sheets are successively delivered from the casing **125** by conveyer belts **127**, **128** onto a platen roll **122**. Each one of the sheets is fixed on the peripheral surface of the platen roll, now positionally indexed, by means of a gripper or the like mechanical attaching and separating means, static attracting means, or electromagnetic attaching means. Then, the roll **122** is so rotated that the transfer sheet is positioned at the ready-for-printing-position.

Next, the thermal head **121** is brought into pressure contact with the transfer sheet through the intermediary of the dyestuff film, and then the thermal head **121** is energized with electric current while the dyestuff film and platen roll **122** are moved in synchronism for the execution of image transfer (first image transfer).

Upon execution of the image transfer, the platen roll **122** is rotated, the gripper is released and the take-out roll **129** is rotated and brought into pressure contact for taking out the image transfer sheet onto a tray **130**.

The thus taken-out sheet is brought into overlapped state with a new image transfer sheet, not shown, and then, both the sheets are fusingly united together by pressure application of a heated roll, not shown, for execution of a second transfer step job. The whole operation has thus been completed. Before the fusion process, the sheets may be subjected to punching, trimming and/or the like processing, if necessary.

By execution of the foregoing operational steps, a monocolor printing operation has been completed. However, in the case of multicolor printing, use is made of tricolored or quadruple colored dyestuff film and the corresponding printing operations must be repeated. In this case, upon completion of a single monocolor printing procedure, the platen roll is rotated without contact of the take-out roll **129**, until it arrives again at the gag printing-initiation position, and so on.

In the following, a tricolor printing job will be illustrated with reference to FIGS. **1**B, **1**B-**2**, and with use of three different series color zones, of cyan, magenta and yellow.

First, a platen roll **122** is positionally indexed, and an image transfer sheet taken out from the roll **131** and a dyestuff film taken out from the roll **123** are brought into pressure contact in an overlapped state. Then a thermal head **121** is pressed against the platen roll **122** through the intermediary of the overlapped sheets. At this stage, the platen roll **122** is rotated counterclockwise while synchronism is kept between the platen roll **122** and the dyestuff film, and the thermal head **121** is kept electrically energized. In this way, the first color printing is executed.

Further, the dyestuff film is fed to the second color zone position, and then, the platen roll **122**, the dyestuff film and the image transfer sheet are fed forward clockwise around the center roll **122**. Thus a second color printing step is executed.

Further, the print-serviced two color sections of the film is fed back counter clockwise around the center of the platen roll **122** for the execution of a third color printing step. Then, each card sheet is taken out from the stack **200** under the action of take-out rolls or the like, not shown, towards and between a pair of thermal transfer rolls **132**, **133**, brought into overlapping state with the image transfer sheet positionally indexed and already subjected to image transfer steps as was described above, and finally subjected to a picture printing operation by pressurizing application of the thermal image transfer rolls **132**, **133** from both sides of each taken-out card, and so on.

The color-printing step with the use of the thermal head is carried into effect in the following manner, as an example.

(First Color Printing)

Platen roll, image transfer sheet and dyestuff film perform the printing while they are moved in the counterclockwise direction.

(Second Color Printing)

Platen roll and image transfer sheet are moved in the clockwise direction while the dyestuff film is moved at the same speed and in the counterclockwise direction for performing the color printing under consideration.

(Third Color Printing)

Platen roll, image transfer sheet and dyestuff film are moved in the counterclockwise direction for execution of the color printing under consideration.

In the modified arrangement shown in FIG. **1**B, **1**B-**3**, thermal image transfer rolls **132**, **133** have been replaced by a flat press type image transfer head having up-and-down movable flat printer elements **132'**, **133'**.

It should be noted that in the course of the foregoing first and second image transfer steps, image reversal phenomenon is necessarily brought about upon execution of each image transfer step. In other words and more specifically, when two successive image transfer steps in the foregoing sense are executed, reverse images which have once appeared will return to the original normal images. Therefore, when the printed-out products are to be provided upon execution of the first image transfer step, it is necessary to provide reversed image data in the signal porocessing system. For this purpose, it is only necessary to reverse the addressing order at the data introduction or readout stage into or from the memory.

In the modified arrangement shown in FIG. **1**C, the foregoing platen roll means has been replaced by a metal block **141** lined with a rubber plate **142** in an overlapped manner. The image transfer sheet and dyestuff film are fed out from respective rolls **131** and **123**. With the use of this modified arrangement, the dyestuff surface layer of the dyestuff film can be brought into tight contact with the image-receiving surface layer of the image transfer sheet, and thermal energy will be transferred evenly form the thermal head **121** to the dyestuff film.

In this case, the image transfer sheet is delivered from the roll **131**, and the desired zone or region of the sheet is set underneath the rubber plate **142** (step **1**).

At the same time, the dyestuff film shown in FIG. **1**D on an enlarged scale is delivered from the roll **123** and a selected one of the different color regions is set underneath the rubber plate **142** (step **2**).

Next, the thermal head **121** is brought into the rear surface of the dyestuff film which is the opposite surface to the dyestuff-coated front layer, and the head **121** is driven while it is being translated in the direction shown by an arrow A, images thereby being formed at the specifically allocated zone(s) or region(s) of the image transfer sheet (step **3**).

Further, the thermal-head **121** and rolls **416** and **418** are shifted downwards as shown by arrows Br so as to form an idle gap between the image transfer sheet and the dyestuff film for allowing the latter to shift towards the next following color region (step **4**).

Further, the thermal head **121** and rolls **416** and **418** are returned to their original positions, whereupon the third and further succeeding steps are repeatedly executed until a certain predesired number of color printings are completed.

As shown in FIG. **1**D, the dyestuff film is colored to have several different color regions denoted by Y (yellow), M (magenta), C (cyan) and Bk (black). However, the arrangement order is not limited to that shown: Y; M; C and Bk. In addition, as occasionally required, the Bk-region may be dispensed with. Further, as the color elements to be adopted in the Y, M, C-system may not be limited to the three primary colors provided by the subtractive color mixture. On occasion, a characterizing color which means such a color as preadjusted to provide an objective specifically selected one may be used to form the images concerned. As a further modification, the arrangement shown in FIG. **1**C may be so modified that the traveling direction of the image transfer sheet is selected to be perpendicular to that of the dyestuff film.

FIG. **2** is an operation flow chart for showing schematically operational modes taking the data processor **104** adopted in the embodiment shown in FIG. **1** as the centrum of description. The operational contents of several working parts downstream of the data converter **107** will be set forth separately hereinbelow. Now referring to FIG. **2**, in combination with FIG. **1** and at the step of **S101**, image pickup operation is carried out by means of the image pickup means **101**. For execution of this step, it may be better to pick up the face of a person per se which is to be represented on the card, or alternatively, a photograph, portrait or imagery product thereof will do. Depending upon the nature of the object, a TV camera, line sensor or the like instrument may naturally be selectively utilized.

The data taken by the image pickup means **101** are stored through the data processor **104** at a memory **105** (**S102**). By the use of these stored data, image or images is/are displayed at the display **102** (**S103**). Since this display image is not yet subjected to any processing, it is generally unsuitable for representing on the card. However, under certain circumstances, it may be represented thereon as it is.

Then, the operator observed the displayed image or images on the display unit **102** and adjudges whether additional processing is necessary or not (**S104**). If it is not necessary, he will manipulate the key board **106** to make a certain operation, resulting in the termination of processing at the data processing unit **104**, data being fed out therefrom to the succeeding data converter **107**.

On the contrary, when additional processing is necessary, the operator observes carefully the displayed image or images on the unit **102** and adjudges whether the picture image data, or character data or barcode data should be processed. If the picture image data should be processed, such an operation is made for selecting the proper mass of trimming or layout within the menu range of position-data input means **103**. By the execution of this operation, functions and operations at steps **S105** and **S106** can be executed at one stroke. If trimming is taken as an example, the next step is executed in such a way that position data are fed from the position input means **103** to the data-processer **104** with the use of a carsor. When a tablet digitizer is used as the position data input means, the carsor image displayed in an overlapped manner on the displayed picture image appearing at the display unit **102** by carsor manipulation is positionally specified beforehand in registration with the specified position on the card, for determining the trimming range. Then the operation is carried out in such a way that the picture image data outside the specified trimming range are canceled. By completing these operations, data processing operations relating to step **107** are executed, and, then, the mass for completion of the menu range is selected out. By these measures, steps progress through **S109** to **S102**, and data storing is executed, and further, display representation is brought about through step **S103**. If there is no need for additional processing, an operation termination manipulation is carried out as before at key board **106**, and further operations will be made through data converter **107**.

As for the layout, the operation is carried out with the position data input means **103**, similarly as in the foregoing trimming operation. More specifically, layout is selected out in the menu range of position data input means **103**, and the overall configuration of the card and the display position of picture image are shown at display unit **102**. Then, image inclination correcting operation and the like are carried out so as to realize correspondence thereof with the displayed positional information, the processing operations relating to step **S108** thereby being brought about. After completion of these operations, the mass for the ending in the menu range is selected.

In this way, when selection is made from the menu range by reliance on the position data input means **103**, trimming or layout operation can be brought about. At this stage, when manual operation is carried out at the key board **106**, introduction of character data is executed (**S110**). As the character data in this sense, in the case of ID card, as an example, the name and/or birthday, month and year of the owner may be used. The data introduced from the key board **106** in accordance with the output character style from the font generator **109** are shown at the display unit **102** in the specified positions on the displaying surface and respectively arranged in accordance with display items. The operator acknowledges these items and detailed displays of the represented images. When he acknowledges them as being true, he will operate the key board **106** for showing the operation ending (**S111**).

Upon ending the operations as described above, the data are stored in memory **105** (**S102**) and represented at the display **102**. The operator will acknowledge again this fact, and upon the execution of this, the operations are terminated.

As for the barcode introduction, the data are subjected to inputing at steps **S112** and **S113**, as in a manner similar to the character data introduction as set forth above. The barcodes and the like data may be introduced separately through printing or other mechanical method.

In FIG. **3**A, a data processing circuitry usable in the sublimation image transfer printing method is shown only schematically. As shown, the circuitry **107** comprises a picture element density converter **3**; a color corrector **4**; a gradation corrector **10**; a memory **11**; a switch **12**; a buffer **13** and parallel/series converter **14**. The picture element density converter **3** is connected to a picture image input unit **100**.

The unit **100** serves for generation of three primary color data of R.G.B.- or Y.M.C.-mode from original picture images and is connected through the picture element density converter **3** to the color corrector **4**. The converter **3** converts the picture element density of the image data fed from the unit **100** to the desired one, by subtracting or supplementing, as the case may be, image data for each color element. It should be mentioned that for attaining high quality hard copies, conversion of the picture element density to at least 10 lines/ma or so is preferable.

Color corrector **4** consists preferably of a color decoder, level adjuster or color converter, and serves to correct three primary color data converted to those of a predetermined density of picture elements in consideration of characteristics of the image transfer ink in the image transfer sheet and in addition to provide black color data.

The data processing circuitry **107** is connected through a driver **108** to the sublimation image transfer printer.

In FIG. **4**, an example of the color corrector **4** is shown schematically in structure. As shown, it comprises adders **6**Y; **6**M and **6**C, a black color data calculator **7**, and primary and secondary color correction circuits **8** and **9**. Primary color correction circuit **8** serves for making correction of turbidity of the image transfer ink, while secondary color correction circuit **9** provides a capability of arbitrary and selective correction control relative to specifically selected color hue.

The gradation corrector **10** is so arranged as to make correction of the gradation of the data for each color Y, M, C or K (representing black color) fed from the foregoing color corrector **4** when necessary. For this purpose, the corrector **10** includes a gradation circuit (not shown) and the like, whereby a certain mode of highlight stressing or shadow stressing is introduced and realized.

The memory **11** functions to preserve temporarily the data of each color delivered from the gradation corrector **10**, a selection switch **12** being provided at the output side of the memory for selective writing-in of the data of each color to the buffer **13**. The buffer **13** is capable of writing-in the data of one line of the image transfer head **16** and kept in connection with the parallel/series converter **14** adapted for converting parallel data into series data. Additionally, in the simplified machine, black color data series is dispensed with in some instances.

In FIG. **5**, a schematic construction of the parallel/series converter **14** is shown. As shown, parallel data delivered from the buffer **13** are fed to an input side of a comparator **22**, while outputs from a counter **23** are fed to another input side of the comparator **22** which delivers the converted series data to the driver **15** for driving a thermal head **121**.

If necessary, however, the comparator **22** may be replaced by a converter table, not shown, utilizing a parallel/series converting ROM.

In FIG. **6**, a detailed circuit schema of the thermal head **121** is shown. As shown, series data delivered from the comparator **22** are fed into a shift register SR and thence, after being subjected to latching at a latch circuit LT, fed to thermal elements HE through NAND gates NA which are fed at respective one side inlets with strobe signals.

Next, referring to FIG. **3**A, the operation of the data processing circuitry **107** will be described more specifically.

First, when three primary color image data are fed from the picture image inlet circuit **100** to the picture element density converter **3**, the latter converts these three primary color data to those which represent a predetermined picture element density and then are fed to the color correction unit **4**. In this case, it is assumed that the unit **4** is fed with three primary color data expressed in respective concentration signals, which are of yellow: **Y0**; of magenta: **M0** and of cyan: **C0**, respectively, in the present example.

These data: **Y0**; **M0** and **C0** are, as shown in FIG. **4**, fed through respective adders **6**Y; **6**M and **6**C to the black color data calculator **7**, to provide a K-output as expressed mathematically by the following formula:

$$K=\min(Y, M, C)$$

wherein, "min" represents a function which provides a possible minimum value.

These data: **Y0**, **M0** and **C0** are fed from the converter **3** to the primary color correction circuit **8** to provide primarily corrected data **Y1**, **M1** and **C1** which are thence fed to the secondary color correction circuit **9** to provide, through calculation, secondarily corrected data: **Y2**, **M2** and **C2**, respectively. These are then fed to respective adders **6**Y, **6**M and **6**C, which add them to respective data **Y0**, **M0** and **C0**, to provide respectively added output data Y, M, and C to be fed to the gradation correcter circuit **10**, respectively, after being utilized for calculation of the K-output signal value.

The primary color correction circuit **8** serves to calculate primarily corrected data: **Y1**, **M1** and **C1** which are necessarily utilized for correct-out of transfer ink turbit. In this case, the original data: **Y0**, **M0** and **C0** are subjected to matrix calculation to provide the primarily corrected data **Y1**, **M1** and **C1**, as folows:

$$Y1=k_{11}\cdot C0-k_{12}\cdot M0+ti\ k_{13}\cdot Y0$$

$$M1=k_{21}\cdot C0+k_{22}\cdot M0-k_{23}\cdot Y0$$

$$C1=k_{31}\cdot C0+k_{32}\cdot M0-k_{33}\cdot Y0$$

where, k_{ij} represents weight coefficients;

i=1–3;

and

j=1–3.

The secondary color correction circuit **9** serves to calculate secondary color correction data **Y2**, **M2** and **C2** from primary color correction data **Y1**, **M1** and **C1** by modifying the latter to make certain thereto by performing matrix calculations so as to provide a capability for making an arbitral and selective color control at a certain specifically selected-out color hue, in the following manner:

$$Y2=Y1+l_{11}\cdot\Delta B+l_{12}\cdot\Delta C+l_{13}\cdot\ \cdot\Delta G+l_{14}\cdot\Delta Y+l_{15}\cdot\Delta R+l_{16}\cdot\Delta M$$

$$M2=M1+l_{21}\cdot\Delta B+l_{22}\cdot\Delta C+l_{23}\cdot\Delta G+l_{24}\cdot\Delta Y+l_{25}\cdot\Delta R+l_{26}\cdot\Delta M,$$

and

$$C2=C1+l_{31}\cdot\Delta B+l_{32}\cdot\Delta C+l_{33}\cdot$$

$$\Delta G+l_{34}\cdot\Delta Y+l_{35}\cdot\Delta R+l_{36}\cdot\Delta M$$

wherein, l_{ij} represents weight coefficients:

i=1–3;

j=1–6;

ΔB, ΔC, ΔG, ΔY, ΔR, ΔM:
characterizing color data.

Thus, when these-secondary correction data **Y2**, **M2** and **C2** are added to the corresponding original data **Y0**, **M0** and **C0** by means of respective adders **6Y**, **6M** and **6C** and under proper selection of weight coefficients k_{ij} for primary color correction circuit **8**, any color discrepancy of the ideal color of the ink appearing on the printed picture images under the action of the sublimation transfer printer can be arbitrarily ammended. In this case, when the weight coefficients l_{ij} for the secondary correction circuit **9** are selected out properly, the color tone of the printing picture images can be modified to an arbitrary degree.

Further, as for the black color data K, correction data **K2** can be calculated by the following formula. With use of these correction data **K2**, which are added to the original black color data K, the desired correction can be executed in a similar manner.

$$K2=K+m1\cdot\Delta B+m2\cdot\Delta C+m3\cdot\Delta G+m4\cdot$$

$$\Delta Y+m5\cdot\Delta R30\ m6\cdot\Delta M$$

wherein, Mi represents weight coefficients:

i=1–6.

In this way, output data: Y, M, C and K delivered from the color correction circuit **4** are introduced into the gradation corrector **10** as inputs thereof, and each constituent of these data can be subjected to correction as desired.

FIG. **7** shows several characteristic curves illustrating corrections by means of the gradation corrector **10**. More specifically, f**0** represents a standard characteristic curve; f**1** a highlight-stressing operation curve; f**2** a shadow-stressing operation curve; f**3** a highlight-and-shadow stressing operation curve; and f**4** a medium tone stressing operation curve.

As indicated in FIG. **7**, by presetting, as necessary, the tone-reproducing characteristics, which determine the relationship between that concentration of color data and that of the prints printed by means of a sublimation image transferring printer, a color tone similar to that possessed by the original image can be reproduced. More specifically, when no correction is adopted, the curve f**0** is used, while in the case of correction, any selected one of these curves f**1** to f**4** may be utilized depending upon the part of gradation to be stressed. Further, it should be noted that the tone reproducing characteristic curves are not exclusively limited to those which have been specifically shown and described above. As an example, the control of gradation correction by color tone reproducing characteristic mentioned above is executed by a gradation circuit, not shown, and the setting of the color tone reproducing characteristic is brought about by manipulation of any selected one of the control knobs, not shown, which are provided separately for "highlight"; "medium tone" and "shadow".

Y.M.C.K.-data subjected to correction by the gradation corrector **10** are once stored in the memory unit **11**. The thus stored data may be read out from the memory for each color by manipulation of the selection switch **12** and, after provisional storing, per one line of transfer head **16**, at the buffer **13**, introduced into the parallel/series converter **14** for conversion thereby into corresponding series data.

Another example of the data processing circuit for the sublimation transfer printer is shown only schematically in FIG. **3**B. As shown, the processing circuit in **107'** comprises a level regulator **503**; a color converter **504**; an A/D converter **505** and a parallel/series converter **14**.

As the image data introduced into the processing circuit **107'**, those which have been subjected to conversion into R.G.B.-signals in the color decoder **502** from composite video signals delivered from a T.V. camera, VTR or the like are used. On the other hand, R.G.B.-signals delivered from a personal computer, captain system or the like means are introduced as input into the level adjuster **503**.

As the color correction method with the use of the foregoing arrangements, it is possible, more specifically, to adjust the hue saturation and/or brightness in the color decoder **502**, or to adjust the signal level of each color light of R.G.B.-system in the level regulator **503**.

As an example, the color conversion from R.G.B.- to Y.M.C.-system can be executed in the color converter **504**. The simplest possible method in this color conversion is to procure the opposite color to each of the normal colors.

The thus produced color signals of Y.M.C.-system issubjected to A/D conversion and then fed successively through the parallel/series converter **14** and the driver **108** to the thermal head, not shown, to carry out printing in the sublimation transfer principle.

Additionally, in normal cases, with the use of the foregoing system composition, input image data must be of static mode. However, by provision of memory means in front of the color decoder or at an intermediate position between the A/D converter and parallel/series converter, animating images can be processed.

The series data converted in the foregoing manner in the data converter **107** or **107'** are fed to the shift register SR

shown in FIG. **6** by n-image elements and then, upon being subjected to latching in the latch circuit LT are further delivered to NAND gate NA as its inputs. When a strobe signal ST is fed as input to the NAND gate NA, the foregoing n-image element data is fed to the thermal element HE.

FIG. **8** is a schematic diagram, showing signals for respective image elements. The gradation has been so selected that the first image element is at the highest gradation level, while the n-th image element corresponds to the lowest gradation level, and that the second to (n−1)th image elements vary linearly in gradation levels, so as to provide representatively a better understandable example of the invention.

Next, the operation of the parallel/series converter **14** will be described.

First, as shown in FIG. **5**, image elements data A, consisting of parallel data, more specifically, comprising parallel eight bit data A**0**–A**7**, are fed to one-side inputs of comparator **22**, while another side inputs thereof are fed with outputs B, comprising eight bit increment outputs B**0**–B**7**, of counter **23**. The counter **23** counts clock signals in increments, the outputs B**0**–B**7** being successively varied.

The comparator **22** performs comparison between the two inputs A and B, so as to deliver successively outputs of binary "1" until the increment output B is brought into coincidence with image elements data A, or more specifically, under the condition of A>B and A=B, while, thereafter, binary "0"-outputs are delivered therefrom. More specifically, comparator **22** will continue to deliver binary "1" until an increment value which corresponds to the weight of concentration of image element data A is given thereto. As an example, if the image element data A has a concentration of gradation **128** of a total **256**, output "1" will be repeated to deliver 128 times first and then, output "0" will follow after again 128 times, so as to provide in total a specific series data peculiarly in this case.

These series data are taken out from the comparator **22** in the form of A>B- and A≧B-outputs and of A=B- outputs through an attributed OR-gate **24**, and in the present example, the gradation consists of 256 steps or increments. However, in practice, the gradation may represent a smaller number of steps. As an example, if the incrementing bit is B**1** instead of hitherto employed B**0**, the gradation will have 128 steps; and if B**2** is employed, it will have only 64 steps. In this way, the gradation setting may be varied in a simple manner.

When in the foregoing way, the output B from the counter **23** is stepwise incremented, such series data consisting of a first series of "1" will be delivered until the relationship between the image elements data A and the output B from counter **23** becomes A=B, and of a second series of "0" issued thereafter, as shown in FIG. **8**.

In FIG. **9**, a conversion mode at the parallel/series converter **14**, which, however, is different from that shown in FIG. **8**, as an example, is shown again in the form of a matrix. As shown, when the image data are of 8-bit parallel kind, as an example, the gradation data are ranged from 0 to 255, providing, therefore, binary series data from "00 . . . 00" to "11 . . . 11".

In this way, the data, per line in the transfer head **16**, kept preserved in the buffer **13** are fed to the parallel/series converter **14** for providing as outputs therefrom into corresponding series data which are then delivered through the driver **15** to the transfer head **16** and thus recorded on a print paper P supported on the transfer drum **17**.

FIG. **10** represents a flow chart illustrating the operation of the sublimate printer as employed in the present invention.

At the first step **S1**, print papers are set in position and the printing ribbon is also set in position ready for performing the required procedure.

At the second step **S2**, printing operation is initiated, and line printings are executed, line by line, accompanying necessary intermittent line shifts, with relation to any selected one of four colors: C (cyan); M (magenta); Y (yellow) and K (black) being carried out. Refer to **S3** and **S4**. When line printings with the selected-out single color have been completed (**S5**), the image transfer sheet is replaced by another color sheet (**S6**) and so on. In this way, line printings are completed in all four colors. In this case, it is naturally most preferable to use a long extended single transfer sheet on which four color ink regions are repeatedly printed in a certain predetermined pattern. The image reception paper is initiated to make print from a certain prescribed position for each of these colors (**S8**). When all of the printing steps have been completed with the four colors, the paper is discharged from position (**S9**) and the printing operation is terminated to be repeated.

In FIG. **11**, a card style sample of the final products according to this invention is shown in front view at **200**. FIG. **12** is a sectional view thereof. Numeral **201** represents the substrate material of the card; **202** a display layer; **203** a surface protecting layer; and **204** a display image as an example. Depending upon the kind of usage and when necessary, the protecting layer **203** may be dispensed with. It should be noted that the display image **204** on the display layer **202** is represented by a sublimative dyestuff, as a characterizing feature of the present invention.

As the main and substantial material of the image transfer sheet, various plain papers, converted papers, plastic resin sheets or the like may be used per se or in combination. When a plastic resin sheet which can be colored directly with a sublimative dye or dyes is used, these image transfer substrates (articles or objects) as at **201** can be united each with the display layer **202**. Each of these substrate materials, when it is of the card style, may have generally such dimensions; thickness of 0.68 to 0.80 mm and size; 11 to 8×8 to 5 cm.

As the material of the display layer **202**, various known materials which may be colored with sublimative dyestuffs, such as polyethylene, polypropylene, polyester, ABS, AS, polyvinylchloride, polyvinyl/vinyl acetate copolymer, polystyrene, polyacrylate, polyester, polyamide, polyurethane and the like plastic material, may be advantageously utilized. As will be more specifically described hereinafter, this material layer can be united with the substrate material layer **201**. In the case of such unified structure with substrate layer **201**, the thickness and size dimensions may be substantially as the same as before. However, when normal and/or converted papers or metals, which are practically impossible to color with sublimative dyestuffs, are used as the substrate layer **201**, various methods can be utilized for desired coloring. As an example, a solution including at least any selected one of plastic resin materials capable of coloring with sublimative dyestuffs may be coated on the substrate surface, or alternatively used in the form of a film which is laminated thereon. This kind of film preferably has a thickness of about 3 to 50 μm or so. One of main characterizing features represented in and by the final products **200** is that the appearing display image or images as at **204** is/are formed at least partially or wholly with a sublimative dyestuff or dyestuffs. Additionally, the process for formation of such images can be executed in the conventional art.

As an example, the processing method may be executed conventionally as follows.

As an example, a sublimative image transferable sheet, such as a paper sheet, plastic resin film or sheet capable of acting as the carrier is coated on its surface with any suitable binder resin carrier carrying sublimative a dyestuff or dyestuffs under heat, is overlapped on the display layer **202** and then subjected to heat from behind the heat-transferable sheet, preferably in the pattern mode, so as to transfer the dyestuff or dyestuffs into the display layer **202**. It is proper to select the molecular weight of 250 or larger of the dyestuff, for improving the fastness thereof. However, a molecular weight higher than 370 is more favorable. In the case of provision of the surface protecting layer, there is practically no limitation to the selectability of the dyestuff molecular weight.

The sublimative image transfer may be executed directly on the surface of substrate **201** provided with the display layer **202**. Or alternatively, a carrying, image transferable sheet is prepared separately and, after formation of the image **204** thereon, may be stuck onto or laminated on the substrate **201**.

Image-Carrying and Image-Transferable Sheet

In the following, structure, material, usage and application purpose of the image-transferable sheet to be employed in the present invention will be described in detail:

FIG. **13** illustrates only basically and in schematic sectional view the image-transferable sheet adopted in the present invention, while FIGS. **14** through **19** and **22** through **24** illustrate preferable embodiments thereof.

The basic structure of the image transferable sheet **310** is characterized in that, as shown in FIG. **13**, a sheet-like substrate **301** is provided at its one surface with an image-reception layer **302** capable of peel-off from the substrate. By adopting such a structural configuration of the image-transferable sheet, the image-reception layer **302** can be formed with the required image or images with the use of an image transferable sheet having thermally shiftable dyestuff, and then, the image-formed, image-reception layer **302** is peeled off from substrate **301** and attached firmly, preferably as by sticking, on the surface of any selected object or article with use of any suitable means. In this way, various conventional drawbacks inherent in the comparative conventional technique can be basically overcome.

More specifically, as the material of the aforementioned image-reception layer **302**, limitation must be imposed to those which can be colored with thermally shiftable or transferable dyestuff. However, upon formation of necessary images and upon peel-off from the sheet-like substrate **301**, the image-reception layer **302** may be attached fixedly onto the surface of glass-made, metal-made or wooden-made products or plastic-resin made ones which are very difficult to color with thermally shiftable and transferable dyestuffs, indeed, by reliance on conventional sticking techniques as properly adopted in consideration of the specific nature and kind of the material of decorative products to be ornamented. Further, the image-formed and peeled-off, image-reception layer **302** from the sheet substrate **301**, is highly thin and thus sufficiently pliable so that it may be applied even onto any uneven and complicated surface of a product to be decorated or ornamented, having undulations, convexities, concavities, recesses and projections. Therefore, a maximum possible better fitness of the image-reception layer to be ornamented is attained and guaranteed by the present invention. Thus, practically no limitation in the attaching use thereof may be encountered. Further, in sharp contrast to conventional sealing seals and the like, the very thin image-reception layer bearing necessary images can be applied easily to the product per se in a very uniform manner, thus providing no raised and thickened feeling, and giving rise to no foreign feeling upon attachment.

FIG. **14** shows a further example of the image transferable sheet **310**. In this case, there is provided a parting agent layer **303** on the surface of image-reception layer **302**. Between the latter and the sheet substrate **301**, there is provided a parting agent layer **303'**. If necessary, however, any one of the two layers **303**; **303'** may be dispensed with.

The first parting agent layer **303** is provided for prevention of thermal fusion between the image-reception layer **302** and an image transferable sheet, not shown, as may occur during image transfer and formation on the first layer **302** through transfer of thermally transferable dyestuff from the said transferable sheet to the first layer. If there is no risk of such thermal fusion of the above nature, or when the image-transferable sheet has been already provided with such a parting agent layer, the present provision thereof may be unnecessary. As for another parting agent layer **303'**, it is for the purpose of making the latter peel-off operation, to be executed after image-forming step, easier. When the sheet-like substrate **301** is made of polyester or the like material which has, as it is, sufficient separability from image-reception layer **302**, provision of parting agent layer may naturally bedispensed with.

FIG. **15** illustrates a still further example of image transferable sheet **310**. In this case, between the image-reception **302** and the sheet-like substrate **301**, an intermediate layer **304** and/or parting agent layer **303'** is/are provided. The laminating order is optional and thus not binding. The intermediate layer **304** will serve to assist the image formation to be rather firm and beautiful, the image formation being carried out by transferring the thermally shifting and transferring dyestuff from the image transferable sheet to the image-reception layer **302**. For this purpose, the intermediate layer **304** may take, for example, the form of a cushioning layer or heat insulating layer. When a cushioning layer is provided as the intermediate layer **304**, the cohesion between the image transferable sheet and the image reception layer **302** is greatly improved and the thermal shift and transfer of the dyestuff during image formation with the use of a thermal head is evenly executed, the image formation thereby being carried out amply in correspondence with the supplied image signals. Further, when a heat insulating layer consisting of a highly heat-insulative material is used as the intermediate layer **304**, ineffective release of the heat applied during'shift and transfer of the dyestuff from the image transferable sheet to the image-reception layer **302** can be reduced to a minimum possible, the effective thermal efficiency thereby being correspondingly improved and ample image formation being accelerated. If necessary, however, these cushioning layer-and heat-oinsulating layer can be prepared independently and arranged concurrently in any arranging order.

Additionally, when the intermediate layer **304** is arranged at a higher level than the parting agent layer **303'**, the intermediate layer **304** will be conjointedly peeled off in the case of peel-off of the image-reception layer **302**. On the contrary, when the intermediate layer **304** is arranged at a-lower level than the parting agent layer **303'**, the intermediate layer will remain on the sheet-like substrate **301** after execution of the separation of image-reception layer **302**. In this case, therefore, the intermediate layer **304** may be made preferably and at least substantially transparent, when the peeled-off image-reception layer **302** is stuck on a decorative product, while directing the surface of parting agent layer **303** towards the latter.

In the modifications shown in FIGS. **16**, **17**, and **18**, modified from the foregoing embodiment shown in FIG. **15**,

a further protecting layer **305** is provided between the image-reception layer **302** and the sheet-like substrate **301**. This protecting layer **305** serves to prevent deterioration of the formed images in the image-reception layer **302** when the latter is stuck on the decorating product while directing the surface (more specifically the image-formed surface) towards the product. For example, this protecting layer **305** is prepared from a superior material which exhibits at least one of desirous properties such as antiwearing, light-fast, weather proofing and anti-chemical qualities. With the use of the protecting layer **305** having these superior qualities, the images can represent improved fastness in the above various aspects, even after execution of the foregoing sticking procedure.

In the modification shown in FIG. **16**, the protecting layer **305** is arranged between the intermediate layer **304** and the parting agent layer **303'**.

In the further modification shown in FIG. **17**, the protecting layer **305** is arranged between the image-reception layer **302** and the parting agent layer **303'**.

In still another modification shown in FIG. **18**, the intermediate layer **304** takes the role of the protecting layer **305**.

In each of these modifications, the protecting layer **305** is arranged in neighboring relationship with the partition agent layer **303'**, whereby the image-formed and remotely arranged, image-reception layer **302**, kept in its up-and-down reversed state, is capable of adhering securely to the decorative product, so as to be positioned as an uppermost layer, as may be required. In a still further modification shown in FIG. **19**, derived from that shown in FIG. **14**, a sticking layer **306** is further provided between the image-reception layer **302** and the partition agent layer **303**. It should be noted, however, that such a sticking layer as at **306** may beprovided in any one of other foregoing examples and modifications, if necessary, in neighboring relationship with the parting agent layer **303'**.

The provision of such a sticking layer as at **306** is highly valuable when the image-formed and peeled-off, image-reception layer is adhering without position reversal onto the decorative product. With this arrangement mode, the protecting layer **305** shown in FIGS. **16**, **17**, and **18** may be dispensed with. If, however, the protecting layer **305** is composed of a material in the form of a sheet-like substrate, the part to be peeled off is thereby strengthed, the peel-off procedure thus being greatly facilitated.

By previous provision of the sticking layer **306**, the image-formed and peeled-off, image-reception sheet **302** can be caused to adhere as it is onto the decorative product without use of a separate sticking agent. As the sticking layer **306**, an ordinary sticking agent which is active at room temperature can be used. Or alternatively, a heat-sensible or light-sensitive sticking agent may be used, if necessary.

In the foregoing, the main structure of the image transferable sheet employed in the present invention has been described in detail. However, other structural modes than those set forth hereinbefore which occur easily to those skilled in the art may be employable in the invention, and thus they may be included within the scope of the invention without departing from the appended claims.

It should be further noted that, in the present invention, the sheet-like substrate may be provided on its one surface with an image-transferable layer capable of peeling off through the intermediary of only one weakly sticking layer.

FIG. **22** shows only schematically in a sectional view a preferred embodiment of such an image-transferable go sheet, denoted with same reference numeral **310**.

As shown in FIG. **22**, the image-transferable sheet **310** represents a basic structural characteristic such that any suitable sheet-like substrate **301** is provided on one of the surfaces with an image-reception layer **302** through an only weakly sticking intermediate layer **402**, the layer **302** thus being easily peeled-off when desired. By providing the image-transferable sheet with such a structural characteristic as set forth above, desired positive or negative images are formed by transferring thermally shiftable and transferable dyestuff from the image heat transferable sheet to the image-reception layer **302**, and the thus image-formed layer is peeled off from the sheet-like substrate **301** and then attached onto any suitably selected product with the use of proper means or attached per se thereon without the peeling-off operation, the substrate then being peeled off, whereby an image-formed final product can be obtained.

In the foregoing example, it should be noted that the image reception sheet **302** per se has only a thin thickness and thus represents only poor feedability during the sheet-feeding period within the printer at the time of image formation, insufficient cushioning effect and only insufficient thermal efficiency during the printing operation, and further, it is very difficult to treat in advance of as well as after execution of the image formation. Therefore, the coexistence of the image-reception layer **302** and the sheet-like substrate **301** is absolutely necessary. In addition, it is a requisite requirement that the image reception layer **302** be easily peeled off from the sheet-like substrate **301** upon execution of the image-forming operation, and thus, the layer **302** and the sheet **301** should not be stuck too strongly together. In order to satisfy this requirement, provision is made of weakly stuck layer **402** therebetween. Thus, it should be noted that the term "weakly stuck" employed in this specification and appended claims may be defined as "to be separable by finger's end and the like means from each other without entailing destruction or breakage of the parts originally stuck together". It is worthwhile to say, in considering the relative relationship between the image-reception layer **302** and the sheet-like substrate **301**, there is no necessity to provide the weakly-stuck layer **402** if the aforementioned peeling-off is very easy to bring about.

FIG. **23** illustrates still another modification of the image-transferable sheet **310** denoted by the same reference numeral **310** only for simplicity and convenience, wherein a further parting agent layer **303** is provided on the surface of image-reception layer **302**.

This layer **302** is provided for occasional thermal sticking between the thermal image transferable sheet, not shown, and the image reception layer **302** in the progress of thermal shift and transfer of the dyestuff from the sheet to the layer **302**. This provision of the parting agent layer **303** may be dispensed with if there is no risk of occurrence of such disadvantageous sticking attachment or the sheet under consideration has already been fitted with such a parting agent layer.

A modification shown in FIG. **24** from that shown in FIG. **23** has such a modified structure that a protecting layer **305** is provided between the image-reception layer **302** and the weakly stuck layer **305**. This layer **305** serves to prevent otherwise occurring deterioration of the images at the image-reception layer **302** which has been formed with preferably reversed images and subjected to peeling-off, together with protecting layer **305**, preferably a plastic sheet layer, from the sheet-like substrate **301** and finally stuck onto the decorative product, while directing the image-formed surface of the image-reception layer towards the product. The protecting layer **305** is made of a material having various excellent physical properties, such as anti-wearing-, light-fastness and antichemical characteristics. Provision of

such a protecting layer improves various fastness performances of the formed images after sticking attachment of the image-reception layer **302**.

When necessary, a separate parting agent layer, not shown, may be provided between the protecting layer **305** and the weakly stuck layer **402** for providing easy peel-off capability between these two layers **305** and **402**, as being applicable to the example shown in FIG. **24**. If the surface of the protecting layer **305** should have sufficient peel-off capability, it is natural to provide such an intermediate parting agent layer as above.

Further, in the case of the image-transferable sheet **310**, it is naturally easy to separate from each other through a peel-off operation, upon the formation of necessary images thereon and before practical use thereof as the image-transfer sheet, and a cut-out slit as at **407** in the sheet-like substrate **301** may be provided forattaining such an easy separation as stated above at a portion of the sheet **310** in proximity to one end thereof. Upon the provision of such a cut-out slit as at **407**, the thus formed flap-like portion can be easily folded out by the operator's finger-tip, thereby affording convenience in a peel-off operation.

The usable materials and composing methods of the foregoing image transferable sheets will now be described.

As a material usable for the sheet-like substrate may be any one or any combination of the following categories;

(1) synthetic paper (polyolefin-series; polystyrene series and the like);

(2) fine quality paper; art paper; coated paper; cast-coated paper, wall paper, back-up paper; backing paper; resin-, emulsion- or synthetic rubber-imprignated paper; resin-admixed paper; paper board; cellulose fiber paper;

(3) polyolefin-, polyvinyl chloride-, polyethylene terephthalate; polystyrene; polymethacrylate; polycarbonate and the like plastic film or sheet.

Use of the synthetic paper belonging to the foregoing category (1) is highly suitable for the purpose of the present invention since the surface thereof generally represents a microvoid layer which provides a low heat conductivity and thus a high heat-insulating peformance. A laminated material representing any combination of the foregoing categories (1), (2) and (3) can be used in the present invention. A representative and recommendable example of such a laminate is that of cellulose fiber paper and synthetic paper or that of cellulose fiber paper and plastic resin film or sheet. Among others, use of the first mentioned kind of laminate will provide an advantage in that the thermal instability such as thermal elongation or shrinkage possessed by the synthetic paper component is compensated for by the cellulose fiber paper, whereby a high thermal sensibility is demonstrated during the printing step due to low thermal conductivity of the synthetic paper component. Further, in the case of the present paper combination, however, a further modified combination of a three-layer laminate: synthetic paper-cellulose fiber paper-synthetic paper may be more advantageously employed for making the frequently appearing lesser by providing a well-balanced structure between both the surfaces of the final laminate.

As the synthetic paper mentioned above, any suitable one usable as a synthetic paper substrate used as a component of the image-transferable sheet layer may be used. As a recommendable example thereof, having a fine porous fine paper structure layer, the synthetic paper called "YUPO", manufactured and sold by Oji Yuka Goseishi Kabushiki Kaishal Tokyo, may be mentioned. This paper layer having a fine pore structure may be prepared in such a way that a suitable plastic resin material containing a filler of finely divided state is subjected to a mechanical elongation step. When the image-transferable sheet composed of the synthetic paper sheet containing finely divided air as above mentioned is formed with images through a thermal image transfer setp, the concentration of the thus formed images is surprisingly high and no fluctuation of image configuration and concentration is encountered, thanks to the heat insulation effect provided by the very existence of fine air pores, in addition to the improved thermal energy efficiency. Especially, due to the advantageous cushioning effect provided by the air-filled fine pores, the image-receiving layer is supposed to be rather advantageously affected during the image formation step. As an alternative measure, the paper-like layer containing the above-mentioned fine air pores may be, if desired, provided directly with the core material consisting of the cellulose fiber paper or the like.

It is further possible to use plastic film in addition to the cellulose fiber paper in the laminate described above. Still further, a laminate of said cellulose fiber paper and plastic film composed together can be used.

As the method for co-sticking of synthetic paper and cellulose fiber paper, use of a known adhesive agent is naturally adopted, as an example. Or alternatively, the extrusion-laminating, heat-adhesion, or the like process may be relied upon, as the case may be. On the other hand, as the sticking-process between the synthetic paper and the plastic film, the lamination process to be carried out simultaneously with the formation of the film may be adopted. Calendering or the like method may be utilized for the same purpose. Selection of any suitable one of the several foregoing sticking processes depends upon the kind of material or the like condition of the partner member to be stuck together with the synthetic paper. As for the adhesive agent mentioned above, emulsion adhesive such as ethylene-vinyl acetate copolymer, polyvinyl acetate or the like, aqueous solution type adhesive polyester containing carboxyl radicals; or the like may be mentioned. On the other hand, as the laminating use adhesive, organic solvent solution type one such as polyurethane-, acrylic- or the like, may be mentioned.

The material for the image-reception layer must be suitable for reception of heat-transfer dyestuff, such as sublimative disperse dye from the image transfer sheet and holding and maintaining the thus formed images thereon. From the view point of image-holding and blocking prevention, use of such synthetic resin as having glass transition temperature higher than 40° C. may be advantageous. For example, the synthetic resins set forth in the following items (a) through (e) may be used separately or in combination.

(a) Ester bond-bearing resins: Polyester resin; polyacrylic ester resin; polycarbonate resin; polyvinyl acetate resin; styrene acrylate resin; vinyltoluene acrylate resin and the like.

(b) Urethane bond-bearing resins; Polyurethane resin and the like.

(c) Amide-bond carrying resins: Polyamide resins (nylons).

(d) Urea-bond carrying resins: Urea resins and the like.

(e) Other high polar-bond carrying substances:

Polycaprolacton resin; polystyrene resin; polyvinylchloride resin; polyacrylonitrile resin and the like.

The image-reception layer may be prepared from a resin mixture of saturated polyester and vinylchloridevinyl acetate copolymer. As the saturated polyester, such commercialized products: "Vylon 200"; "Vylon 290"; "Vylon 600";

"Vylon 103" and the like, manufactured and sold by Toyoboseki K.K., Osaka, Japan; "KA-1038C" (manufactured and sold by Arakawa Kagaku K.K., Osaka, Japan; "TP 220"; "TP 235", manufactured and sold by Nippon Gosei K.K., Osaka, Japan; may be advantageously used. The vinyl chloride-vinyl acetate copolymer may have preferably 85–97 wt. % of vinyl chloride component, the polymerization degree being between about 200 and 800. The vinyl chloride-vinyl acetate copolymer may further contain a vinyl alcohol component, maleic acid component within the purpose of the invention in addition to the main components. According to our experiments, it has been found that these modified copolymers should have rather superior compatibility with polyester resin. The image-reception layer may be, if necessary, composed of polystyrene resin, for example, in this case, styrene monomer, preferably styrene, α-methyl styrene, and vinyl toluene may be used separately or in the form of copolymer or saying in general sense polystyrene resin. Further, such styrene copolymer resin may be used as specifically recommendable material in the above sense, comprising said styrene monomer(s) with other monomer, preferably for example, acrylic acid ester, methacrylic acid ester, acrylonitrile, methacrylonitrile and the acrylic or methacrylic monomer, or further styrene copolymer resin comprising maleic acid anhydride.

It should be noted, however, that among others, polyester series resin is especially superior for the purpose of the present invention.

In any of the foregoing embodiments, however, white pigment is preferably admixed with the material of the image-reception layer for improving the whiteness thereof and further accentuating the sharpness and fineness of the images when transferred thereto and to provide a manually writing-on performance. As the white pigment for this purpose, the following materials may be used separately or in any combination: titanium oxide; zinc oxide; china clay calcium carbonate; finely divided silica and the like.

For further improving the whiteness fluorescent whiteness-increasing agent or -bleaching agent may be added to. Further, for improving the light fastness of transferred images, ultraviolet absorption agent and/or photostabilizing agent may be added to, preferably in a quantity of 0.05 to 10 and 0.5 to 3 weight parts per 100 weight parts of the material resin composing the image-reception layer.

The image-transferable sheet used in the present invention is preferably constituted for improving the separability from the image-transfer sheet in such a way that the surface of the image-reception layer is formed with a partition agent layer, or instead, such agent is admixed to the image-reception layer. As for the partition agent to be used for this purpose, polyethylene wax; Amido Wax, Teflon Powder or the like solid wax; surface active agents such as fluorine-contained agent or phosphoric acid ester series surfactant; silicone oil or the like may be selectively used. Among others, silicone oil may be advantageously utilized.

The silicone oil may be used in oily state, but a hardenable type thereof may be rather advantageous. As the hardenable silicone oil, reaction-hardening one, photo-hardening one, catalytically hardening or the like one may be used selectively according to necessity. However, use of the reaction-hardenable one is most highly recommendable. Silicone oil of this type may be obtained, as example, by reacting amino-modified silicone oil with epoxy-modified silicone oil to obtain a reaction-hardened product. As for the amino-modified silicone oil, "KF-394", "KP-857", "KF-858"; and "X-22-3680"; "X-22-3801C" (manufactured and sold by Shinetsu Kagaku Kogyo K.K., (Tokyo, Japan)) and equivalents thereof may be used. As for the epoxy-modified silicone oil, "KF-100"; "KF-101"; "KF-60-164"; and "KF-103" (manufactured by Shinetsu, above mentioned) and equivalents thereof may be used. Further, as the catalytically hardenable and photohardenable silicone oils in the above sense, "KS-705F"; "KS-770" of the catalytic hardenable or hardened silicone oils, manufactured by Shinetsu; and "KS-720" and "KS-774" of the photo-hardenable or hardened silicone oils (manufactured equally by Shinetsu) and equivalents thereof may be used. The adding quantity of each of these hardenable or hardened silicone oils may advantageously range from 0.5 to 30 wt. % depending on the material of the resin composing the image-reception layer.

At least a part of the image-reception layer is coated with a solution or dispersion of any of the foregoing partition agents in a suitable solvent and dried and further treated, a suitable parting layer being provided thereon. A particularly suitable partition agent for the formation of this kind of partition layer is the aforementioned reaction type hardenable one obtainable by reacton of an amine-modified silicone oil with an epoxy-modified one. The thickness of the partition layer is 0.01–5 μ, preferably 0.05–2μ.

It should be noted that when silicone oil is admixed during formation of the image-reception layer, the silicone oil will bleed out after coating and the parting agent layer can be formed by the hardening even after such bleeding. In order to improve the parting ability between the image transferable layer and sheet-like substrate, it is possible to provide a parting layer consisting of a heat-hardenable resin, preferably of the melamine series, and having better affinity for the image transferable layer compositions. For the same purpose as above, however, without special provision of the parting layer, a protecting layer consisting of polymethyl methacrylate resin or cellulose acetate propionate can be provided.

For the formation of the image transferable layer, a solution or dispersion of a material composition suitable for the purpose is applied on the sheet-like substrate through conventional coating or printing. As an alternative way, a separate film or sheet for the image transferable layer **302** is formed preparatorily on a provisional carrier sheet or film and then, as a succeeding step, subjected to an image-transfer onto the substrate.

The intermediate layer is made of either a cushioning or a porous material. In some cases, the intermediate layer may additionally function as the adhesive layer.

The cushioning layer is mainly composed of such a resin which has a value of 100%-modulus as defined at JIS-K-6031 (Japanese Industrial Standard) of less than 100 kg/cm^2. If this value should exceed the above prescribed value, the rigidity will become much higher than that recommended for the intermediate layer. When the layer is formed with such disadvantageous material resin, sufficient adhesion between the heat image-transfer sheet and the image-reception layer cannot be maintained during the printing step. The lower limit of the prescribed 100%-modulus is of the order of 0.5 kg/cm^2 in actual practice.

Preferable kinds of resin to be used for the above purpose, may be enlisted as follows:

polyurethane resin; polyester resin; polybutadine resin; polyacrylic acid ester resin; epoxy resin; polyamide resin; rosin-modified phenol resin; terpene phenol resin; ethylene/vinylacetate copolymer resin; and the like.

These resins can be used independently or in combination of two or more kinds. Since these resins are rather viscous and tend to give rise to manufacturing troubles inorganic

additives may be admixed, such as, for example, silica; alumina; clay; calcium carbonate; amide series substance such as amide stearate; and/or the like.

The cushioning layer is preferably formed with the use of one or more of the above specified resins, occasionally with the addition of suitable additive(s); solvent or diluent, prepared into a coating agent or printing ink which is then applied on, according to a known coating or printing process and then subjected to drying to provide a coating. The thickness of the coating should be between 0.5–50 μm, preferably 2–20 μm or so. With a thickness less than 0.5 μm, the coating will not be able to compensate for the surface irregularities on the substrate, thus being ineffective for the desired purpose. On the other hand, when the thickness exceeds the above specified maximum value or more specifically 50 μm, the overall thickness of the image-transferable layer becomes much too large, so that handling troubles may be encountered during wind-up and overlapping procedures, without attaining further effect as desired. In addition, in this case, a loss of production economy will be inevitably introduced.

The thus obtainable improvement of intimate adhesion between the heat-image transfer sheet and the thermally image-transferable sheet by the provision of the above intermediate layer may be conceivably attributed to the lower rigidity of the intermediate layer per se, whereby it is liably to be deformed under the influence of the printing pressure, and further to the generally relatively low glass transition temperature and softening temperature of the aforementioned kinds of resin resulting in further lowering of rigidity and tendency to deform than at room temperatures upon reception of heat energy during the image printing step.

The porous layer may be formed generally in the following four ways: 1) through 4).

1) Emulsion of polyurethane or the like resin, methylmethacrylate-butadiene series synthetic rubber latex is foamed by mechanical agitation, coated, and dried on the sheet substrate into a layer.
2) The synthetic resin emulsion or synthetic rubber latex is admixed with a foaming agent and the liquid mixture is coated and dried on the substrate into a layer.
3) Vinyl chloride-plastisol, polyurethane or the like synthetic resin or styrene-butadiene series or the like synthetic rubber is added with a foaming agent and the liquid mixture is coated on the substrate and subjected to heating to provide a foamed layer formed thereon.
4) A thermoplastic resin or synthetic rubber is dissolved in an organic solvent to provide a solution, and a non-solvent (including that containing aqueous main component), and the latter solution are mixed together to provide a liquid mixture, said nonsolvent being less volatile than the organic solvent and having a considerable mutual solubility with the solvent, and showing, however, non-solubility with the thermoplastic resin or synthetic rubber. The thus prepared liquid mixture is then coated on the sheet-like substrate and dried, to provide a porous membrane upon micro-coagulation of the constituents. The resulting microporous layer can be utilized for the above purpose.

It should be noted that the layers produced by any of the foregoing three processes 1) to 3) have rather large foams contained therein, and thus when the foaming solution for the image-transferable layer is applied thereon and dried, the latter may exhibit excessively coarse surface conditions. Therefore, in order to obtain an optimumly image-transferable smooth surface capable of providing transferred images of high uniformity, provision of the micro-porous layer prepared by the process as set forth in the foregoing item 4) is highly recommendable.

As the thermoplastic resin suitable for the formation of the above porous layer, saturated polyester; polyurethane; vinylchloride-vinylacetate copolymer; cellulose acetopropionate and the like can be used. Further, as the synthetic rubber usable for the same purpose, those of styrene-butadiene series, isoprene series, urethane and the like series may be used. Still further, as the organic solvent and non-solvent liquid used for the formation of the microporous layer, various known substances may be used. Generally speaking, however, methyl ethyl ketone; alcohol and the like are representatively used. On the other hand, as the non-solvent, water is mostly used.

The thickness of the porous layer usable in the present invention is preferably greater than 3 μm, especially preferably in the range of 5 to 20 μm. With the use of a porous layer having a thickness of less than 3 μm, the desired cushioning and heat-insulating effects cannot be attained.

As was referred to hereinbefore in the description stage for the formation of the image-transferable layer, the intermediate layer may act simultaneously as the sticking layer in some cases.

This kind of intermediate layer(s) may be provided on one or both of the surfaces of the thermally image-transferable sheet.

In practice, however, an electrostatic charge may accumulate in the material of the thermally image-transferable sheet during its processing step or during running through the printer. As a countermeasure, a proper antistatic agent may be applied on one surface of the image-transferable layer or on the bottom surface of the thermally image-transferable sheet or it can be included in the material of the image-transferable layer. As the antistatic agent in this sense, a surfactant such as a cation-exchange agent (for example, a quaternary ammonium salt, polyamide derivatives and the like) may be advantageously used. Further, an anion exchange type surfactant, such as alkyl sulfonate may be used. Otherwise, amphoteric ion type surfactants or even, non-ionic surfactants may be used for the same purpose.

On the other hand, the antistatic agents may be coated on the surface of image-reception layer by gravure-coating, bar-coating or the like process or alternatively, these agents may be kneaded with the material resin and then subjected to transfer towards the surface during the coating formation and drying step for preparing and providing the image-transferable layer. As the antistatic agents to be admixed with the image-transferable layer material resin, cation-type acrylic polymers may be employed.

The protecting layer is peeled off together with the image-transferred layer, from the sheet-like substrate, and then stuck, in inverted reversed state, onto any desired decorative object, the protecting layer thereby being positioned at the uppermost position, for improving the anti-wearing-light-proofing and anti-chemical performances of the image-bearing layer. As the material adapted for the formation of the protecting layer, for example, alkyd resin; phenol-modified alkyd resin; aminoalkyd resin; phenol resin; urea resin, melamine resin; silicone resin, thermosetting acryl resin, thermosetting polyurethane resin and the like thermosetting resin or normal temperature setting resin; further, ultraviolet hardenable resin; electron ray hardenable and the like activating energy flux hardenable resins or thermoplastic resins such as polyester-; polyurethane-; polyvinyl acetate resin; vinyl chloride-vinyl acetate copolymer resin; polyolefin resin, acryl resin and the like, can be used.

Preparation and use of a protecting layer comprising one or more of the above-mentioned resins are made in such a way that the material resin is dissolved in a properly selected solvent according to the necessity, so as to provide a coating liquid or ink, as the case may be, which is provided between the parting layer and the image transferable layer. The thickness thereof is generally 0.5 to 20 μm. It is also possible to form the protecting layer with the use of a resin film which consists of polyester-; acryl-; acrylpolyol-; polyvinyl chloride-; olefin resin or the like resin. It is further possible advantageously to admix an ultraviolet ray absorbing agent and/or photostabilizer to the material of the protecting layer.

The protecting layers prepared and formed in the foregoing way are thus not made integral with the sheet-like substrate or parting layer and, therefore, the peel-off operation of the sheet-like substrate upon execution of the image transfer is very simple and easy.

It is further recommendable, if necessary, to provide a slip-promoting layer on the bottom surface of the sheet-like substrate, which surface is naturally the one opposite to the image-transferable layer side, so as to properly adjust the friction between the image-transferable sheet and feed roll paper or carrier belt acting during passage through the printer and to improve the running performance of the thermally image-transferable sheet in the printer.

The slip-promoting layer can be formed by adding an organic powder such as polyethylene wax fluorine resin powder or an inorganic powder such as talc, according to necessity, to a resin such as polymethyl methacrylate resin; vinyl chloride-vinylacetate copolymer; vinyl chloride copolymer; cellulose acetate butylate; cellulose acetate propionate; styrene-acryl series or the like resin and kneading the resulting mixture to prepare a composition, applying this composition as a coating on the sheet substrate either directly or after application of a suitable primer treatment, and drying the coating thus applied. A suitable quantity of the slip-promoting layer is 0.5 to 5 g/m^2 after drying.

In the embodiments shown in FIGS. **22**, **23**, and **24**, as the adhesive agent to be used in the slightly weak or weak adhesive layer, it should be noted that those conventionally used adhesives for adhesive tapes and seals can all be used. Preferred examples are polyisoprene rubber; polyisobutyl rubber; styrene butadiene rubber; butadiene acrylonitrile rubber and the like rubber-series resins; (meth)acrylic acid ester-series resins; polyvinyl ether-series resins; polyvinyl acetate-series resins; vinylchloride-acetate copolymer series resins; polystyrene-series resins; polyester-series resins; polyamide-series resins; polychlorinated olefin-series resins; and polyvinyl butyrol-series resins. To the suitably selected adherent may be added a proper quantity of a stickness improver, such as rosin; dammar; polymerized rosin; partially hydrogenated rosin; ester rosin; polyterpene-series resins, terpene-modified substances; petroleum-originated resins; cycropentadiene-series resins; phenol resins; styrene resins; xylene resins; and coumarone-indene resin. Further, when necessary, to the mixture may be added a softening agent, filler; antiaging substance or the like conventional agent(s). As the material for the formation of slightly or weak-adherent layer said above, emulsion type adhesive, preferably of acryl acid ester series can be used. As for the parting function after a long time of preservation, emulsion type adhesives are highly recommendable. These adhesive agents are easily procurable from market.

When necessary, these adhesives are added with proper organic solvent(s) for the adjustment of the viscosity, and then applied by roll coating, die-coating, knife coating, gravure coating or the like conventional technique on the surface of the sheet-like substrate, image-reception layer or protecting layer, so as to provide an adhesive agent layer. The thus formed adhesive layer is preferably of a thickness of 1–50 μm, although this is not limitative.

Formation of Images

In the following, the decorating process according to this invention will be set forth in detail. Utilization of the image-transferable sheet according to this invention constitutes an important main feature thereof.

In FIGS. **20** and **21**, basic practising processes will be described first.

The embodiment shown in FIG. **20** is a result of the use of the transferable sheet shown in FIG. **13**. First, a known transfer sheet 320 is applied onto the image-transferable sheet **310** in an overlapped manner such that the dye-carrying layer **321** is kept in opposition to the image-reception layer **302** of image-transfer sheet **320**, and heat energy is applied, as schematically shown by a plurality of arrows, in accordance with image signals fed at a thermal head, not shown, from the side of image-transferable sheet **310**, or preferably, from the side of the image-transfer sheet **320**, thereby forming the desired images as at **307** in the image-reception layer **302**. Next, the image-reception layer **302** formed therein with the desired images **307** is peeled off from sheet-like substrate **301** and stuck onto the decorative product **306**. Or alternatively, both the sheets **302**; **301** are stuck onto the product **306** without preparatory peeling-off. In the latter case, the peel-off step may be executed after execution of the stickingly attaching step. In the above former case, and in such a case where an adhesive agent layer **306** has preparatorily provided between image-reception layer **302** and sheet-like substrate **301** as was set forth hereinbefore, the sticking attachment is carried into effect in such a way that the adhesive layer **306** is kept in opposing contact with the product **330**, and then the sticking operation is brought about by application of heat and pressure or light and pressure, depending upon the nature and structure of the layer **306**. In this way, the decoration according to the present invention is completed as a preferred one mode thereof.

On the other hand, if there is no preparatory provision of the adhesive layer, either the surface of product **330** or of the peeled-off image reception layer **302**, may be coated with the adhesive agent, and the latter layer **302** per se or otherwise in the up-and-down reversed state may be stickingly attached onto the product **330** (refer to FIG. **21**).

Since the image-reception layer **302** is composed generally of such thermoplastic resin material as is liable to be colored with thermally transferable dyestuff, it can be thermally and fusingly attached to plastic resin-made formlings, clothes or metals even with provision of an adhesive layer, if necessary.

In this case, the image-bearing layer **302**, the image thereof having been formed in the aforementioned way, is stuck on, through the intermediary of the adhesive agent layer **306** as shown in FIG. **25**, while retaining the sheet-like substrate **301** on the surface of the image-reception layer **302**.

A modification of the last-mentioned mode is shown in FIG. **26**. In this case, sheet-like substrate **301** is formed on the surface of the product **330** and the image-reception layer **302** is formed as the outermost layer. Further, in this case, sheet-like substrate **301** and product **330** may be stuck together, and, through the intermediary of a suitable adhesive layer, sticking layer or heat-sealable sheet or the like.

As for the transparent film usable as the said sheet-like substrate, it must be transparent to such a degree as not to

conceal the images formed in the image-reception layer, and, in addition, it must have superior surface properties such as, for instance, antiwearing characteristics. As an example, polyolefine; polyvinyl chloride; polyethylene terephthalate; polystyrene; polymethacrylate; polycarbonate and the like plastic resin-made films may be used upon variously surface conditioning. If these transparent films should be too thick, the images will be raised, and the unitary feelings may be lost when these are stuck on respective products to be decorated. Therefore, the film thickness is preferably of the order of 0.5 to 50 μm.

In the case of a further embodiment of the present invention, the image reception layer of image transferable sheet which has been, however, formed with necessary images is subjected to image transfer treatment onto an intermediate image transferable substrate, the latter is then subjected to an image-retransfer with the images, and the thus retransferred images are again transferred onto the surface of the product to be decorated. In the following, this image transfer mode will be set forth in detail.

Embodiments shown in FIGS. **27**, **28** and **29** represent such a process for execution of image transfer operation as by the intermediary of intermediate image transfer sheet **510**. First, as shown in FIG. **27**, a thermally image-transfer sheet **320** having a thermal transferable dyestuff layer **321** is overlapped to image-transfer sheet **510** which is, at this stage, not formed with images **307** and thus consists of a thermal image-transferable sheet, in such a way that the dyestuff layer **321** or more specifically the parting layer **322** is in opposition to the image-reception layer **302** of the foregoing sheet **510**. In such a case, however, that heat energy is supplied in accordance with image-forming signals delivered from the thermal head, not shown, and, indeed, preferably from the side of the sheet **320** as hinted by a plurality of double-line arrows for thermal formation of desired images (positive images) as at **307** in the image-reception layer **302**, it is highly recommendable to provide an adhesive layer **402** between the layer **302** and sheet-like substrate **301**.

Then, with the use of the image transfer sheet **510** formed with positive images **307**, the images of layer **302** are transferred, as shown in FIG. **28**, to a separate intermediate substrate **501**, which is, however, fitted with a protecting film layer **305**, thus, the transfer being carried out, in fact, onto the latter, and indeed, with the correspondingly inverted images, attached with same reference numeral only for convenience, from the foregoing layer **302**. In this case, it is preferable to subject the adhesive layer **402** of the image-transfer sheet **510** to the image-transfer operation, together with the image-reception layer **302**. Further, as for the intermediate image-transfer substrate **501**, it is recommendable to provide the protecting film layer **305** through the intermediary of a weak-adhesive layer **402'** as shown. The thus provided intermediate image-transfer sheet **610** represents generally the image-transferable sheet.

FIG. **29** illustrates the step for transfer of theimage-reception layer **302** now carrying positive images **307** onto the object **330** to be decorated and under utilization of the previously described intermediate image-transfer sheet **610**.

More specifically, the intermediate image-transfer sheet **610** is overlapped onto the said object **330** in such a way that the adhesive layer **402** of the former in opposition to the surface of the object **330** and pressurized together. Then, the intermediate transfer substrate **501** together with the weak-adhesive layer **402'** is peeled off from the remainder of the thus-pressurized assembly, the now image-carrying layer **302** formed with positive images **307** covered with protecting the film layer **305** thereby remaining in the transferred state on the product **330**. In the case of no provision of the protecting film layer **305** on the intermediate image-transferable sheet **610**, the layer **302** remains in an exposed state. Therefore, an overcoat layer, if necessary, can be provided on the now image-carrying layer **302**.

The previously set forth process carried out by the use of said intermediate image-transferable sheet can be executed by means of the apparatus which is shown schematically in FIG. **1**E.

In this apparatus, more specifically, there is provided a carrier system comprising a series of rolls **411**, **412**, **413** and **414** for conveying the intermediate transfer substrate (sheet), arranged in addition to the apparatus shown in FIG. **1**B. More specifically, the substrate is drawn out from feed roll **414**, conveyed through successive rolls **413**; **412** and retransferred onto one of the products **200**. Other operations are same as set forth hereinbefore with reference to FIG. **1**B. Further, in the case of FIG. **1**E, the final product may take the form of a roll-like substrate which is subjected to an image transfer operation through the intermediate substrate, by transferring its image-carrying, image-transferable layer, for later being punched out properly. Alternatively, under occasion, it may be subjected to half-cut operations downstream of roll **122**.

As was set forth herein above, the preferable method for the formation of desired images on the image-transferable sheet is carried out by use of a heat image-transfer sheet comprising a sheet-like substrate having a layer including a thermally transferable dye (evaporative dye). The heat image-transfer sheet which can be utilized in this method is known per se. And almost every kind of these known sheets can be useful in the practice of the present invention. It should be noted that by employing the foregoing image-transfer method, mono-color or full-color images can be easily formed as occasion may desire.

It should be further noted that details of such heat image-transferable sheet can be easily understood with reference to our U.S. patent application Ser. No. 833,039. As for the heat image-transferable sheet usable in the present invention, the coating layer of the sheet (coating film) may include a parting agent. By adopting this measure, the image-reception layer of the image-transferable sheet or the surface thereof, to be subjected to sublimative image-transfer, must not have a separate parting agent layer, the adhesive ability between the image-reception and the surface of object to be decorated can be still further improved upon execution of the sublimative image-transfer and image-formation at the image-reception layer and adherent attachment thereof to the object. As the parting agent to be included in the coating layer of the thermally image-transferable sheet (coating film), silicone oil; silicone resin; phosphoric ester or the like surfactant; and/or chelate—and the like agents, may be selectively utilized. These agents, upon mixed, will ooze out from inside to the outer surface of the coating layer, resulting in providing a better parting quality. However, it is preferable to properly select the kind and nature of the parting agent to be used for this purpose, being such that the agent cannot transfer to the image-reception layer of the image transferable sheet during the sublimating image-transfer stage. The adding quantity of the parting agent may preferably be 3-25 wt. parts based upon the total amount of resin and coating composing the coating layer taken as 100 wt. %.

In practice, any kind of conventionally known heat transfer sheets is overlapped on the thermally image-transfer sheet employed in the present invention, and then necessary heat energy of 5–100 mj/mm^2 is applied by use of a

conventionally known heat transfer unit, for instance, "Video-printer: VY-100" manufactured and sold by Hitachi Seisakusho, Tokyo, or its equivalent machine, for the formation of necessary images on the image-reception layer of the image-transfer sheet as set forth hereinbefore.

Peel-off operation for removal of the image-reception layer formed with necessary images in the above manner may be carried into effect in a very easy manner, so as to provide it in a thin film carrying the images thereon. In case where the thus-peeled off film carrying the images is provided beforehand with an adhesive layer, composed of a suitable adhesive agent as was referred to, at the opposite surface to the image-carrying one, the peeled-off film can be, as it is, stuck on the object to be decorated. It is natural that this adhesive attachment procedure can be performed only partially and locally on selected part of the whole surface of the object, or totally thereon, as the case may be. On the contrary, if the peel-off film is provided beforehand with no adhesive layer, the film can be subjected occasionally to a heat fusion onto the surface of the object, if the physical properties or material kind thereof is suitable for such kind of thermal fusion. Or alternatively, a properly selected adhesive agent can be preparatorily applied onto the surface of the film or object, and then, the stick-on job can be executed.

If the image-reception layer is provided preparatorily with a parting layer thereon, as was referred to, the latter layer can be removed off partially or wholly, by grinding or rubbing operation after execution of the sublimating image-transfer job, for avoiding otherwise occurrence of ill effect by the very presence of parting layer in the adhesive attachment of the image-carrying layer film onto the decorative object.

In case of that where the image-transferable sheet is provided with a protecting layer and the latter is composed of a plastic resin film, this film may preferably be cut into pieces or subjected to punch-cuttings.

FIG. **32** illustrates successive die-cutting steps in sectional views, serving for the above purpose. In this case, as shown in FIG. **32** at (a), only image-reception layer **305** of the image-transferable sheet **310**, which has been image-formed through the way of the foregoing image-transfer step, are die-cut by operation of a cutter **801**. Next, as shown in FIG. **32** at (b), a pair of hot stamps **132**'; **133**' are used to execute a pressurizing job under heat from opposite sides, thereby the decorative product **330** being processed into a final product provided tightly with an image-reception layer and a protecting layer, as shown in FIG. **32** at (c).

Further, when occasion desires, the image-carrying film is reversed up-and-down in position after execution of the peel-off job, and, the film is stuck onto the product to be decorated in such a state that the image-carrying surface of the film is kept in direct opposition to the product's decorating surface. In this case, however, it would be rather preferable that in advance of preparatory peel-off of the image-reception layer, the image-carrying transferable sheet is stuck onto the surface of the product to be decorated, and indeed, preferably with use of an adhesive agent, in such a way that the image-carrying layer is kept in direct opposition to the product surface and finally, the sheet-like substrate is peeled off, so as to leave the image-carrying surface on the product's surface.

As in the foregoing, when the images are once reversed and then stuck onto the object to be decorated, the forming images are preferable to reverse in mode (mirror-like relationship) the original to those of reversed mode.

It is further possible that the transfer or sticking-on of the image-carrying layer is carried out through the intermediary of a separate fusing sheet.

In FIG. **30**, use of such fusing sheet **701** for reimage-transfer operation of image-carrying layer **2** already formed with necessary images **307**, however, of reversed mode, and onto the surface of a product.

More specifically, the image-transferable sheet **310** is overlapped onto the product **330** to be decorated in such a way that the image-reception layer **302** carrying the necessary images **307** is kept in opposition to the surface of the product, and indeed, through the intermediary of a fusing seat **701** and then these three components are pressurized together. Further, sheet-like substrate **301**, together with parting layer **303**', is peeled off, thereby the image-reception layer **302**, now having positive images **307** formed thereon, and protecting the latter, being transferred onto the product **330**. Itwill be seen in this case, that there is no need for this transfer job, to provide in advance on adhesive layer on the surface of image-reception layer **302** and/or on the surface of the product **330**, and further that a direct heat fusion onto the surface of the product **330** which may be composed of plastic resin, textile fabric, metal or the like common material, however, through the intermediary of a heat-fusible or heat-sealable sheet.

In case where the protecting layer **305** is of plastic resin, similar composing technique as mentioned above may be employed by substituting a weak-sticking layer **402**' for parting layer **303**'.

As the heat-fusible or heat-sealable sheet as at **701** employable in the present invention, it may be composed of one or other material capable of adhering under heat, pressure or both, especially suitable one of those which become soft to be adhesive upon heating. These heat adhering materials in the form of sheets will be, upon softening, charge the pores, meshes or stitches of the product material composed preferably of textiles, woven or non-woven; knits, rough-surface papers or meshed materials, thereby the surface of the product becoming highly smooth for well receiving the image-reception layer **302** for desired image-retransfer with trouble, which effect is superior in the art.

On the contrary, when such heat-fusible or heat adhesive sheet materials which may be called "heat bond sheets" as at **701** are not utilized, it is highly difficult to realize the image-retransfer operation onto certain kind of objects such as rough-surfaced or rough-meshed fabric or the like. Even if the retransfer job could be executed, the obtained images may be blurred and the adhesive may be insufficient, on account of the very thin thickness of the image-reception layer **302**, thus giving rise to technical and commercial troubles.

As for the heat fusible sheet **701** to be used in the foregoing manner, ethylene/vinyl acetate copolymer, nylon copolymer; epoxy/phenol copolymer; epoxy/vinyl copolymer; acrylic resin; polyester resin; or polyolefin resin and the like thermoplastic resins (heat sensible adhesive agents) which are formed into sheets or films may be used. These materials must be softened at 100-250° C. or so to represent viscous adhesive characteristics. These materials are, when used, capable of being stuck to both the image-transferred product **330** and the image-carrying layer **302**.

These heat bond sheets **701** have generally thickness of 1–200 μm. When the surface of the product **330** to be decorated is relatively smooth, the sheet selected out may be of relatively thin thickness, while, on the contrary, when the surface of the decorative product **330** is relatively rough, as in the case of textile fabrics, unwoven fabrics, meshed fabrics or the like, use of thicker heat bond sheets is rather recommendable.

As set forth above, the use of heat bond sheets is highly recommendable in the decorative image-transfer onto rough

surface products, such as those of rough fabrics, woven or non-woven, knitted clothes, meshed one or the like, thereby a better quality image-transfer being executed, in spite of the meshed or highly undulating surface conditions of the objects to be decorated.

Further in the present invention, during the adhering attachment of the image-reception layer already formed with necessary images onto the object or product, an additional processing step is preferably introduced for prevention of occasional interference in the foregoing adhering attachment step, by rubbing-off or grinding-off part or whole of the parting layer, provided on the surface of the now image-carrying layer, upon completion of the sublimating image-transfer step.

Still further, in such a case that the image-transferable sheet is fitted with a protecting layer which is composed of a plastic resin film, the latter must in advance be subjected to punching or the like cutting step for cutting the film into desirously sized pieces.

FIG. **32** represents such a die-cut (half-cut) process in sectional schema. In this case, at first, as shown at (a) of FIG. **32**, the image-reception layer **302** of an image-transferable sheet **310**, now formed with necessary images through a sublimative image-transfer step, and the protecting layer **305**, are subjected to a die-cutting process by means of a cutter **801** to shape a desired shape. And then, as shown at (b) in FIG. **32**, the cut-out piece is subjected to a pressurizing step under heat by means of a pair of hot stamps **132'**; **133'** to provide a final decorative object, as shown at (c) in FIG. **32**, which is composed of a product **330** to be decorated, however, now attached integrally and jointly with image-carrying layer **302** and protecting layer **305**.

Applied Products

The products applicable with the inventive process for decorating purposes are not limited to occasionally employed kind, shape and nature of the materials. Preferred examples of the usable product may be: cartons; vessels or packages; bags; cassette cases; cassette halves; floppy cases; paper packages and envelopes; stock certificates; personal and bank cheques; bills; bonds; certificates; notifications; car tickets; travel tickets; betting tickets; tax stamps; postage stamps; entrance tickets, money-exchangeable papers and documents; cash-cards, credit cards, orange cards, telephone cards; member's cards; greeting cards; postcards, name cards; driver's certificates; IC-cards; optical cards and the like various cards; accounting cards and documents-envelopes; tags; OHP-sheets; slide films; bookmark slips; calendars; posters; pamphlets; menus; passports; POP-goods and articles; coasters; displays; nameplates; keyboards; cosmetics; personal ornaments (watches; cigarette lighters); stationaries; construction materials; radio-receiving sets; T.V.-sets; speakers; table calculators; automotive gauge boards; emblems; keys; clothes; wearing commodities; footwears; appliances; OA-instruments; sample books; tickets in general, albums; computer graphic and/or medicare graphic image printouts; and the like, where the material kinds, sizes and configurations are regardless for purposes of the invention.

The aforementioned goods and instruments may have printed or the like other images in advance of execution of the process of the invention. Or conversely, the goods and instruments can be formed with necessary images in accordance with the present process, and then, additional images may be formed in conventional printing or the like process.

As an example, when the invention is applied to a card style intermediate product, it is possible to combine image-forming means of the present invention with conventional recording means. As the latter, magnetic recording by use of a magnetic material layer; optical recording by use of an optical recording layer; preferably composed of a membrane having low melting point metal; application of hologram; embossing formation of characters and numerals; application of personal face photograph; engraved formation of personal face or the like; human signatures; recorded information with use of IC-memory; mechanical printing; formation of bar codes; formation of characters and patterns by use of printer, typewriter or pen plotter may be used independently or in any combination.

In the following, the present invention will be more fully described by way of preferred embodiments. In these embodiments, parts or % will be given by weight, not otherwise specifically referred to.

As the image transfer film (dye film) used for sublimating transfer onto the image-transferable sheets, a polyester film, 6 μm thick, subjected to a heat-resisting treatment on one surface thereof only, and bearing color ink composition areas of yellow, magenta and cyan, respectively, was used. The coating rate of the color ink composition was 1.0 g/m^2 when measuring at the dry state.

These color ink compositions were as follows.

Yellow ink composition	
polyvinyl butyral resin ("Eslek-BX-1", manufactured and sold by Sekisui Kagaku K.K., Tokyo)	4.80 parts
dispersion dye ("PTY-52, Disperse Yellow-141", manufactured and sold by Mitsubishi Kasei Kogyo Co., Ltd., Tokyo)	5.50 parts;
methyl ethyl ketone	55.00 parts;
toluene	34.70 parts;
(parting agent	1.03 parts)

Magenta ink composition	
polyvinyl butyral resin (same as above in the case of yellow color, ink)	3.92 parts;
dispersion dye ("MS Red G, disperse red 60", manufactured and sold by Mitsui Toatsu K.K.)	2.60 parts;
dispersion dye ("Macrolex Red Violet R, Disperse Violet 26", manufactured and sold by Beyer A.G., West Germany)	1.40 parts;
methyl ethyl ketone	43.34 parts;
toluene	43.34 parts;
(parting agent	0.40 part)

Cyan color ink composition	
polyvinyl butyral resin (same as in said yellow color ink composition)	3.92 parts;
dispersion dye ("Kayaset Blue-714, solvent blue-63", manufactured and sold by Nippon Kayaku K.K., Tokyo)	5.50 parts;
methyl ethyl ketone	68.18 parts;
(parting agent	0.94 parts)

Each of the foregoing color ink compositions was prepared with and without addition of parting agent.

As the parting agent occasionally used in each of the foregoing color ink compositions, any of the following specific agents may be employed:

(a) silicone alkyd parting agent, "KR-5206", manufactured and sold by Shinetsu Kagaku Kogyo K.K., Tokyo;

(b) graft polymer of silicone and acryl, "GS-30", manufactured and sold by Toa Gosei Kagaku K.K.;

(c) silicone graft polymer, "US 3000", manufactured and sold by the above company;

(d) phosphoric acid ester, natrium salt, "RE-410", manufactured and sold by Toho Kagaku Kogyo K.K.;

(e) natural phosphoric acid ester, "Lecytin" , manufactured and sold by Ajinomoto Co., Ltd., Tokyo;

(f) silicone oil, "KF 412", manufactured and sold by Shinetsu Kagaku Kogyo K.K., Tokyo;

(g) aluminum chelate agent, "ALM", manufactured and sold by Ajinomoto; and

(h) titanium chelate agent, "TTS", manufactured and sold by Nippon Soda K.K., Tokyo.

EXAMPLE A-1

As the substrate, a laminate of a synthetic paper, "Yupo FPG 150 μm thick" manufactured and sold by Oji Yuka Co., Ltd., Tokyo, and a polyester film, 6 μm thick, was prepared and coated on the polyester film side surface by a wire bar with a mixture of pull-separating varnish, "Bakurinisu 45" manufactured and sold by Showa Ink Co., Ltd., Tokyo, with an ultra-violet absorbing agent, or more specifically, 2.5-bis (5'-tert-butylbenzoxazolyl (2))-thiofin, 0.5% based on the resin content of the varnish, and dried up to provide a protecting layer of 1 g/m^2, when weighed upon drying.

Then, on the surface of the foregoing protecting layer, an ink composition adapted for the formation of an image-reception layer was coatingly applied and dried up. The applied quantity amounted to 7 g/m^2 when measured upon drying.

Ink composition for the formation of image-reception layer	
polyester resin (manufactured and sold by Toyobo K.K.)	100 parts;
amino-modified silicone ("KF-393", manufactured and sold by Shinetsu Kagaku Kogyo K.K., Tokyo)	5 parts;
epoxy-modified silicone ("X-22-343", manufactured and sold by Shinetsu Kagaku Kogyo)	5 parts;
solvent (methyl ethyl ketone/toluene/ cyclohexanon 4/2/2)	900 parts.

The ink composition was coated, dried up and cured one day under normal temperature. Then, the layer was kept at 100° C. for 30 minutes under beat, for letting the silicone to bleed up to the surface, to provide an image-transferable layer formed on its surface with a hardened silicone layer.

On the thus-provided image-reception layer, a sublimating image-transfer film was overlapped which is composed of cyan color sublimative dye (molecular weight being higher than 250) carried by a proper binder resin and thermal energy is fed thereon from a thermal head adapted for receiving electric signals representing cyan color components obtained by a color analysis of a portrait photograph, as an example, for providing portrait images corresponding thereto. Then, two successive sublimative image-transfer jobs were executed with use of respective sublimating image-transfer films carrying sublimative magenta and yellow color dyes, each molecular weight being higher than 250, and substantially in the manner set forth above. In this way, after all, an overall combined display image composed of a full color portrait, in combination with several characters and graphics, was provided.

The image-reception layer of the sheet, now carrying these display images, was overlapped on the card substrate composed of a polyester resin sheet, 100 μm thick, which had been primed to white-opaque state, and pressurized together at 160° C. by means of heated pressure rolls. Then, the polyester film was peeled off at the interface with the protecting layer, thereby providing a final product card transferrd with image-reception layer now carrying the desired image display.

It was found that the overall surface of the product card was generally smooth and showing no raised feeling of the thus-formed and displaying images. Even upon an accelerated testing of the product card for three months held in an atmosphere of 40° C., the images showed no blurrings as well as no interlayer separation. Further, according to an accelerated light-proof test carried out as prescribed in JIS-Standard with use of a carbon arc lamp, the results showed to be classified to JIS-4 or -5 corresponding to an acceptable superior performance. Additionally, a surface scratch test and the like showed also superior durability.

EXAMPLE A-2

The foregoing image-transferable sheet, now image-carrying, as processed in Example A-1, is then subjected to a peel-off operation for separating the image-carrying layer from the sheet. Then, an adhesive agent of polyester series was coated on the exposed surface of the peeled-off film, and stuck under pressure on a curved surface part of a telephone set. The images could follow up to the stuck curvature into a unitary solid mass, and indeed, without inviting any stuck-on feeling, contrary to the case when a sticky loose-leaf stamp should have been stuck on. In this way, miracle viewing feelings as obtainable with direct-printing operation only, were created and maintained.

EXAMPLE A-3

A white polyester film, baked on one surface thereof with melamine coating, "E 20", 100 μm thick, manufactured and sold by Toray Co., Ltd. Tokyo, is formed on the opposite surface with a slipping layer, same as in the following Example C-2, through application of polyurethane primer. And an identification mark was provided thereon through the way of regular printing technique. On the melamine resin-baked surface of the white polyester resin film, a layer of peeling varnish (of polymethyl methacrylate-series), manufactured and sold by Showa Inku. Co., Ltd., Tokyo) was applied in dry quantity of 2 g/m^2 and dried up to provide a definite layer.

On the thus-formed protecting layer, the following image-reception layer-forming composition was coated and dried up, so as to form an image-heat transferable sheet. The coated composition was in quantity of 6 g/m^2 by dry weight.

Image-reception layer-forming composition	
polyester resin ("Vylon 600", Tg: 47° C., manufactured and sold by Toyobo, Osaka)	80 parts;
polyester resin	20 parts;

-continued

Image-reception layer-forming composition	
("Vylon 290", Tg: 77° C., manufactured and sold by Toyobo)	
amino-modified silicone ("KF-393", manufactured and sold by Shinetsu Kagaku Kogyo)	7 parts;
epoxy-modified silicone ("X-22-343", manufactured and sold by Shinetsu Kagaku Kogyo)	7 parts;
solvent (methyl ethyl ketone/toluene = 1/1)	800 parts.

On the image-reception layer of the foregoing heat image-transferable sheet, reversed images composed of full color portrait images together with characters and graphics by use of a thermal head, as in the same way with Example A-1, were formed.

Next, the image-reception layer, however, now carrying the reversed images formed in the foregoing manner was brought into contacting and overlapping state with the image displayable surface on a card style substrate made of white color polyester resin, 125 μm thick, preparatorily primer treated as before, and pressurized together under the action of thermal rolls, and the white polyester film, 100 μm, was peeled off between the protecting layer and the melamine-baked layer, thus providing a final card-style product transferred with the image-reception layer now carrying the necessary images.

The surface of the final card style product represented a smooth and slippery, without fear of interlayer separation and with superior light resistant power.

EXAMPLE A-4

A white foam polyester resin film, "Merinex", 125 μm thick, manufactured and sold by ICI, was provided with an identification mark on one surface thereof, with regular printing technique.

Then, on the opposite surface of the white foam polyester resin film to the foregoing surface formed with the identification mark, a coating of a polyurethane-series primer was applied and dried up. Further, the following protecting layer-forming composition was applied in dry quantity of 3 g/m^2 and dried up to form a protecting layer.

Protecting layer-forming composition	
acrylic polyole ("Acrit 6416MA", manufactured and sold by Taisei Kako K.K.)	41 parts;
toluene	36 parts;
methyl ethyl ketone	27 parts;
diisocyanate ("Colonate", manufactured and sold by Nippon Polyurethane K.K.)	6 parts.

On the above protecting layer, the following composition was applied in dry quantity of 3 g/m^2 and dried up, to provide an intermediate layer.

Intermediate layer-forming composition	
polyester resin ("Vylon 290", manufactured and sold by Toyo Boseki (Toyobo) K.K., Osaka)	15 parts;
toluene/methyl ethyl ketone = 1/1	85 parts.

On the thus-formed intermediate layer, an image-reception layer which is substantially same with that in the foregoing Example A-3 was provided, so as to form an image-transferable sheet. Then, as same in the foregoing Example A-3, correspondingly inverted images were formed on the image-reception layer and further then, subjected to transfer onto the card substrate by use of thermal rollers. In this way, a final product card, having an image transferable, yet now image-formed layer, was provided.

This card showed favorable results of light-resisting test. Further, it showed a better scratch test result than the foregoing card obtained in Example A-3.

EXAMPLE A-5

Substrate

A white polyester film, "E-20", 100 μm thick, manufactured and sold by Toray Co., Ltd., Tokyo, was used.

Intermediate layer-forming composition	
Polyester resin ("Vylon 600", manufactured and sold by Toyo Boseki K.K., Osaka)	15 parts;
toluene/methyl ethyl ketone = 1/1 (dry weight: 5 g/m^2)	85 parts.

Protecting layer-forming composition	
"Hakuri-Nisu" (acrylic resin varnish, manufactured and sold by Showa Ink K.K.) (dry weight)	2 g/m^2

Image-reception layer-forming composition	
polyester resin ("Vylon 600", manufactured and sold by Toyo Boseki K.K., Osaka)	10 parts;
polyester resin ("Vylon 200", supplied by Toyo Boseki K.K.)	5 parts;
toluene/methyl ethyl ketone = 1/1	85 parts;
amino-modified silicone ("KF-393", manufactured and sold by Shinetsu Kagaku Kogyo)	1 part;
epoxy-modified silicone ("X-22-343", supplied by Shinetsu Kagaku Kogyo)	1 part.
(coated quantity (dry)	5 g/m^2)

With use of the foregoing composition and processed in similar way as in Example A-3, to provide a final card product, having an image-reception layer transferred with necessary images.

EXAMPLE A-6

Substrate

White polyester resin film, "E-20", 100 μm thick, manufactured and sold by Toray was coated with polyurethane-series primer and dried up.

Parting layer-forming composition	
melamine resin ("Meran 45", manufactured and sold by Hitachi Kasei)	100 parts;
hardener (para-toluenesulfonic acid)	20 parts;
(coating quantity (dry), 2 g/m^2)	

Protecting layer-forming composition	
vinylchloride-vinylacetate ("Vinylite VYHH", manufactured and sold by Union Carbide Corp.)	15 parts;
methyl ethyl ketone = 2/1	85 parts;
(coating quantity (dry): 2 g/m^2)	

Intermediate layer-forming composition	
polyurethane resin ("Takelac T-3350", manufactured and sold by Takeda Pharmaceutical Company, Osaka, of 23%-concentration)	50 parts;
isopropyl alcohol	15 parts;
toluene	25 parts;
methyl ethyl ketone	10 parts.
(coating quantity (dry) 5 g/m^2)	

Image-reception layer composition	
polystyrene resin ("Picolastic D125" (Tg = 53° C.), manufactured and sold by Hercules	15 parts;
toluene/methyl ethyl ketone = 1/1	85 parts;
amino-modified silicone ("KF-393", manufactured and sold by Shinetsu Kagaku)	1 part;
epoxy-modified silicone ("X-22-343", manufactured and sold by Shinetsu Kagaku)	1 part.
(coating quantity (dry): 6 g/m^2)	

The foregoing composition was prepared and used as in the same manner with Example A-3, to provide a card with the image-reception layer subjected to image-transfer as desired.

EXAMPLE B-1

As the substrate, a polyester resin film, 6 μm thick, was used and a polyester resin-series primer was coated on one surface thereof and dried up. Further, the following ink composition was applied and dried up. The coating quantity of the composition was set to about 7 g/m^2.

Image-reception layer-forming composition	
polyester resin ("Vylon 200", manufactured and sold by Toyo Boseki K.K.)	100 parts;
amino-modified silicone ("KF-393", manufactured and sold by Shinetsu Kagaku)	5 parts;
epoxy-modified silicone ("X-22-343", manufactured and sold by Shinetsu Kagaku)	5 parts;
solvent (methyl ethyl ketone/toluene/cyclohexanone = 4/2/2)	900 parts.

The ink composition was coated, dried up and left standing for a full day, and then subjected to heat treatment at 100° C. for 30 minutes, so as to bleed the silicone towards the film surface for providing thereon an acceptable image-reception layer composing the active surface.

Then, a sublimative image-transferable film, composed of a resin binder evenly mixed with a proper amount of sublimative cyanic dye, the molecular weight being higher than 250, was overlapped on the above image-reception layer and applied with heat energy by means of a thermal head supplied with electric signals corresponding to cyanic color components of a portrait full color photograph as determined by regular color analysis, thus providing cyanic color component images.

Next, as for magenta and yellow color components, similar respective processings were executed and finally, full color display portrait images could be formed.

Then, the exposed surface of image-reception layer of the thus-display image-formed film was overlapped on a card substrate composed of a white opaque, hard vinyl chloride resin sheet, 100 μm thick and pretreated with a conventional primer, and then this assembly was subjected to heat and pressure by means of a pair of heated rolls. In this way, a card product stuck with an image-transferable and now carrying layer was provided.

The surface of this card was generally smooth and slippy, the thus-formed images thereon providing no raised feelings. In an accelerated test of these formed images in hot atmosphere of 40° C. for a continuous period of three months, there were no appreciable image blurring and interlayer separation. Upon execution of a light exposure test in accordance with prescribed conditions in JIS with use of an arc lamp, the results were classified to JIS-4 to 5 Classes which means as acceptable and better image quality. Scratch test results were also superior.

EXAMPLE B-3

A sticking layer, 1 μm thick, was formed with a polyamide resin sticking agent on the image-carrying surface of the image-transferable sheet, image-formed in the manner as described in foregoing Example B-1, and the thus provided sheet was stuck on the curved surface of a glass tumbler. These images express practically no stuck-on feelings, rather providing such a touch and viewing feeling as if they had been formed by the regular and direct printing technique.

EXAMPLE C-1

With use of the image-transferable sheet prepared in the foregoing Example A-1, images were formed substantially

in accordance with procedures mentioned therein, however, with exception of the formation ofreversed images, and then, the image-carrying layer was, without execution of the foregoing peel-off operation, stuck on a portion of curved outer surface of a glass tumbler, whereupon the sheet-like substrate was peeled off, together with the weak-sticking layer. The thus-applied images represent almost no sticking-on grip and viewing feeling, as if they should have been applied through regular and direct-printing technique.

EXAMPLE C-2

On the surface of a transparent polyester film, 12 μm thick, employed as a protecting film, the following image-reception layer forming composition was applied to form a coated layer (in quantity of 6 g/m^2 when measuring upon drying), dried up and left as it was for full one day. Then, it was held at 100° C. for 30 minutes, to form an image-reception layer. On the surface thereof, a parting surface layer was found to exist, which was composed of a combined hardened product of amino-modified silicone resin and epoxy-modified silicone resin.

Image-reception layer-forming composition	
polyester resin ("Vylon 600", manufactured and sold by Toyo Boseki)	100 parts;
amino-modified silicone resin ("KF-393", manufactured and sold by Shinetsu)	7 parts;
epoxy-modified silicone resin ("X-22-343", manufactured and sold by Shinetsu)	5 parts;
solvent (methyl ethyl ketone/toluene = 1/1)	800 parts.

As the substrate, on the other hand, white polyester resin film, "E-20", 75 μm, manufactured and sold by Toray, was used and coated on one surface thereof with a polyurethane-series primer and dried up. Then, the following composition (in the dried quantity of 1 g/m^2) and dried up, so as to provide a smooth and stick layer.

Smooth layer-forming composition	
polymethyl methacrylate resin ("Dianal BR-85", manufactured and sold by Mitsubishi Rayon Co., Ltd., Tokyo)	12 parts;
polyethylene wax ("MF8F", manufactured and sold by Dulacon Co.)	0.5 part;
toluene/methyl ethyl ketone = 1/1	85 parts.

On the opposite surface of the-white-polyester resin sheet to the smoothed surface there, a primer coating of polyurethane-series is applied and dried up, and further coated thereon with the following composition, in quantity of 3 g/m^2, so as to provide a weak-sticky layer.

Weak-sticky layer-forming composition	
weak-sticky adhering agent ("Esdyme AE-206", manufactured and sold by Sekisui Kagaku Kogyo K.K., Tokyo)	50 parts;
water	50 parts.

The weak-sticky adhering layer is brought into contact with the protecting film consisting of a polyester film, 12 μm thick, at the opposite surface to the image-reception layer, and then subjected to heat and pressure, to provide an image-transferable sheet. Upon bringing the image-reception layer of the image-transferable sheet and the dyestuff layer of the heat-image transfer sheet into contact with each other, heat energy was applied from a thermal head, as in the similar manner mentioned in the foregoing Example A-1, and thus heat image-transfer job was executed, so as to provide reversed mode images for expressing a full color portrait as well as characters and graphics.

Next, the image-reception layer formed with the reversed images thereon was overlapped onto the image-displayable surface of a card style substrate, 100 μm thick, made of a white color polyester resin material preparatorily applied with a primer layer by coating a composition, consisting of "Vylon 200", 100 μm thick, manufactured and sold by Toyo Boseki K.K., and then subjected together to heat and pressure by means of at least a heated roll at 160° C. Then, the white polyester film, 75 μm thick, and the weak-sticky adhesive layer were peeled off in unison, for providing a final decorative product card having the image-reception layer transferred with images and carrying dislay images.

This card had a highly smooth surface and was not liable to invite any interlayer separation and showed superior light fastness.

In place of white color polyester-made card substrate preparatorily formed with a primer layer, such a modification was prepared and experimented that the white polyester sheet was formed on its rear surface with a magnetic layer, while, on its front surface there is formed with a write-on layer which consists of proper filler and resin as conventionally, so as to provide a telephone card. This processed telephone card had the write-on layer provided with display images formed by image-transfer.

EXAMPLE C-3

On the surface of a transparent polyester film, 9 μm thick, used as the protecting layer, an intermediate layer was provided by coating. The coated amount was 5 g/m^2 as measured upon being dried up.

Intermediate layer-forming composition	
polyurethane resin ("Takelack T-3350", solid content 23%, manufactured and sold by Takeda Pharmaceutical Co., Ltd., Osaka)	50 parts;
isopropyl alcohol	15 parts;
toluene	25 parts;
methyl ethyl ketone	10 parts.

Onto the intermediate layer, the following composition was applied for the formation of an image-reception layer. The coated quantity was 5 g/m^2 as measured upon being dried up.

Image-reception layer-forming composition	
polyester resin ("Vylon 600", manufactured and sold by Toyo Boseki)	10 parts;
polyester resin ("Vylon 200", manufactured and sold by Toyo Boseki)	5 parts;
amino-modified silicone ("KF-393", manufactured and sold by Shinetsu)	1 part;
epoxy-modified silicone ("X-22-343", manufactured and sold by Shinetsu)	1 part;
solvent (methyl ethyl ketone/toluene = 1/1)	85 parts.

On the other hand, a white color polyester film, which was similar to that employed in the foregoing Example C-2 was formed with a slidingly smooth layer, as well as a weak-sticking adhesive layer, the latter being brought into intimate contact with a transparent polyester film, 9 μm thick, at the opposite surface to the image-reception layer and then, subjected to heat and pressure, for providing a heat image-transferable sheet. As further processed in the similar manner in the foregoing Example C-2, full-color photographic images (reversed images) were thus formed on the image-reception surface. In this way, a final product card, having its image-reception layer transferringly formed with display images.

EXAMPLE C-4

Substrate

White color polyester sheet, "E-20", 100 μm thick, manufactured and sold by Toray was formed thereon with a polyurethane-series primer coating. Then, a weak-sticking layer was applied thereon with use of the following composition.

Weak-sticking layer-forming composition	
weak-sticking agent ("Esdyne AE-206", manufactured and sold by Sekisui Kagaku Kogyo K.K., Tokyo)	50 parts;
water	50 parts.

Protecting layer-forming composition	
polyester resin ("Vylon-200", manufactured and sold by Toyo Boseki)	15 parts;
diisocyanate ("Colonate L", manufactured and sold by Nippon Polyurethane Co., Ltd.)	1 part;
toluene/methyl ethyl ketone = 1/1	84 parts.

Image-reception layer-forming composition	
polyester resin ("Vylon 600", manufactured and sold by Toyo Boseki K.K.)	10 parts;
vinyl chloride-vinyl acetate copolymer resin ("Vinylite VAGH" (Tg = 79° C.), manufactured and sold by Union Carbide Corp)	5 parts;
toluene/methyl ethyl ketone = 1/1	85 parts;
amino-modified silicone ("KF-393", manufactured and sold by Shinetsu)	1 part;
epoxy-modified silicone ("X-22-343", manufactured and sold by Shinetsu)	1 part.

With use of the above composition and processed substantially same as in the foregoing Example C-2, a final card product was obtained.

EXAMPLE D-1

An image-transferable sheet was prepared as in the foregoing Example A-1 and thermally image-transferred with reversed mode images of a full color portrait photograph, to provide an intermediate image-transfer medium. The latter is overlapped by its image-reception layer onto the surface of a sheet of rough-textured cotton cloth, however, through the intermediary of an acrylic acid ester-vinyl acetate copolymer sheet, 100 μm thick. Then, the assembly was subjected to heat and pressure. Then, the substrate sheet and weak-sticky adhesive layer, together, were peeled off. The thus transfered images have sufficient surface smoothness, showing superior surface conditions.

Without use of the bond-attaching sheet in the above process and when similar image-transfer job as above was performed, the resulted images followed the surface undulations appearing disadvantageously on the material product of the rough fabrics and thus were highly uneven, and further, on account of insufficient adhering performance acting between the image-receiving layer and the woven fabrics serving as product material, easy and frequent separations took place therebetween.

EXAMPLE D-2

In the similar way as was disclosed in the foregoing Example D-1, an intermediate image-transfer medium carrying reversed images was prepared and overlapped on a polymethacrylate board preparatorily subjected to surface-roughening operation through a conventional sand-blasting step, and through the intermediary of a bond-adhering sheet pressurized together under heat, as was employed in Example D-1. Then, the sheet-like substrate was peeled off, together with the weak adhesive layer. The thus-provided images were highly smooth and even in spite of the highly rough and undulating conditions at the surface to be image-transferred. In addition, the image-carrying surface showed superior results in various resisting tests.

Without use of the foregoing bond-sticking layer, the similarly transferred images showed considerable undulations and distortions. Further, on account of insufficient adhering performance, easy and frequent peel-offs of applied images were feared.

EXAMPLE D-3

On the surface of a polyester resin film, 25 μm thick, the following composition adapted for the formation of bond-

sticking layer was coated and dried up, in dried quantity of 5 g/m^2, to provide a film formed thereon a bond sticking sheet.

Bond-sticking sheet-forming composition	
polyester resin ("Vylon 600", manufactured and sold by Toyo Boseki)	15 parts;
methyl ethyl ketone/toluene = 1/1	84 parts.

The bond-sticking sheet surface, together the polyester resin film proper, was brought into contact with the image-representing surface of a white color polyester made-card substrate, 25 μm thick, and then, subjected to heat and pressure by means of at least a heat roll kept at 200° C., arranged to supply heat energy from the side of the polyester resin surface, thereby heat bonding the bond-sticking sheet onto the card surface, whereupon the polyester resin film being forcedly peeled off.

Further then, as in the similar way as adopted in foregoing Examples C-2; A-3; A-4 and C-3, use is made of the image-reception layers representing reversed images thereon, the respective image-reception layers were whereupon brought into contact with the card's bond-sticking surface of the card and subjected to heat and pressure by use of at least a heat roll kept at 200° C. Then, the white color polyester resin substrate was peeled off, together with the weak-sticky adhering layer. In this way, a final product card displaying the portrait photograph was obtained.

EXAMPLE D-4

Substrate

A white color polyester resin sheet, "E-20", 100 μm thick, manufactured and sold by Toray Co. Ltd., was coated with a polyurethane-series primer. On the surface of the thus precoated sheet, the following composition was coated to form a weak-sticking adhesive layer.

Weak-sticking adhesive component	
weak-sticking adhesive agent, ("Esdyne AE-206", manufactured and sold by Sekisui Kagaku)	50 parts.

Image-reception layer-forming composition	
polyester resin ("Vylon 200", manufactured and sold by Toyo Boseki)	7.5 parts;
polyester resin ("Vylon 290", manufactured and sold by Toyo Boseki)	7.5 parts;
toluene/methyl ketone = 1/1	85 parts;
amino-modified silicone ("KF-393", manufactured and sold by Shinetsu)	1 part;
epoxy-modified silicone ("X-22-343", manufactured and sold by Shinetsu)	1 part.

The foregoing compositions were prepared. On the other hand, a polyester resin film, 25 μm thick, was coated on one surface thereof with a 15%-solution of polyester resin, "Vylon 200", manufactured and sold by Toyo Boseki, in toluene/methyl ethyl ketone=1/1 and dried up. The coating quantity was adjusted to 5 g/m^2 when measuring in dried state. In this way, a bond-sticking sheet was provided.

Then, the coated surface of the thus prepared bond-sticking sheet was brought into contact with the image display surface of a card style substrate of white color-hard vinyl chloride or the like resin material preparatorily subjected to a primer coating treatment in overlapping state and then, the whole assembly was subjected to heat and pressure with use of at least a heated roll to 130° C., thus the bond-sticking layer being stuck on the card surface. Under this condition, the polyester resin film, 25 μm thick, was peeled off.

Then, the image-reception layer, now carrying thereon reversed images, was brought into contact with the bond-sticking sheet and the resulted whole was subjected to heat and pressure by use of at least a heated roll and the white color polyester resin substrate, together with the weak-sticking adhesive layer, was peeled off. In this way, the card, now displaying the portrait images, was provided.

EXAMPLE D-5

Substrate

Same as in the foregoing Example D-4.

Weak-sticking adhesive layer

Same as in the foregoing Example D-4.

Protecting layer-forming composition	
polyester resin ("Vylon 200", manufactured and sold by Toyo Boseki)	15 parts;
diisocyanate ("Colonate L", manufactured and sold by Nippon Polyurethane)	1 part;
toluene/methyl ethyl ketone = 1/1	84 parts.

Image-reception layer-forming composition	
polyester resin ("Vylon 600", manufactured and sold by Toyo Boseki)	10 parts;
toluene/methyl ethyl ketone = 1/1	85 parts;
amino-modified silicone ("KF-393", manufactured and sold by Shinetsu)	1 part;
epoxy-modified silicone ("X-22-343", manufactured and sold by Shinetsu)	1 part.

With use of the foregoing materials and compositions, the processings were carried out as in the foregoing Example D-4, to provide a final product card displaying portrait images as was desired.

EXAMPLE D-6

Substrate

Same as in the foregoing Example D-4.

Weak-sticking adhesive layer

Same as in the foregoing Example D-4.

Image-reception layer-forming composition	
polyester resin ("Vylon 600", manufactured and sold by Toyo Boseki)	10 parts;
vinyl chloride-vinyl acetate copolymer resin ("Vinylite VAGH", manufactured and sold by Union Carbide Corp.)	5 parts;
toluene/methyl ethyl ketone = 1/1	85 parts.

The foregoing materials and compositions were prepared and processed in the similar way as in the foregoing Example D-4, to provide a final product card, displaying the desired portrait images as were desired.

EXAMPLE E-1

On a polyethylene terephthalate film, 9 μm thick, a solution of saturated polyester resin, "Vylon 600", manufactured and sold by Toyo Boseki, in toluene/methyl ethyl ketone=1/1, was coated by reliance of the known reverse roll-coating process, and dried up. The coated quantity was 7 g/m^2 when measuring in dry condition. In this way, a weak-sticking adhesive layer could be formed.

On the weak-sticking adhesive layer, the following composition, 3 g/m^2 (dry), was coated by means of an oblique-lined gravure roll for solid and full printing use and in the reverse roll-coating process, and then dried up, to provide an image-reception layer.

Image-reception layer-forming composition	
polyester resin ("Vylon 200", manufactured and sold by Toyo Boseki)	70 parts;
polyester resin, ("Vylon 290", manufactured and sold by Toyo Boseki)	30 parts;
amino-modified silicone ("KF-393", manufactured and sold by Shinetsu)	5 parts;
epoxy-modified silicone ("X-22-343", manufactured and sold by Shinetsu)	5 parts;
methyl ethyl ketone (wt. ratio 1/1)	700 parts.

On the opposite surface to the image-reception layer of the thus-prepared image-transferable sheet, a synthetic paper substrate, "Yupo FPG 110", 110 μm thick, manufactured and sold by Oji Yuka K.K., coated with "Vylon 600" as the adhesive agent in quantity of 10 g/m^2 (dry) was stuck intimately together.

On the other hand, a polyethylene terephthalate film substrate, 6 μm thick, preparatorily provided on one surface thereof with a heat-resisting layer was used and the following composition was applied on the opposite surface of the substrate with use of a wire bar and dried up, in the quantity of 1 g/m^2 (dry), so as to provide a dyestuff layer. In this way, a heat image-transferable sheet was prepared and provided.

Dyestuff layer-forming composition	
dispersion dye ("Kayaseo Blue-136", manufactured and sold by Nippon Kayaku K.K.)	4 parts;
ethylhydroxyethyl cellulose	6 parts;
methylethylketone/toluene (wt. ratio: 1/1)	90 parts.

The dyestuff layer of the foregoing heat image-transfer sheet was brought into contact with the image-reception layer of the image-transferable sheet in overlapping manner, then, heat energy was applied from a thermal head from the side of heat-resisting layer of the heat image-transfer sheet, thereby dyestuff being transferred to the image-reception layer of image-transferable sheet, and indeed, for the formation of positive images.

Then, the image-transferable sheet, now carrying the required positive images was stuck together under heat and pressure at 140° C. for 5 seconds on the intermediate image-transfer substrate prepared in the following manner, in mutually opposed manner. Then, the synthetic paper "Yupo" was peeled off at the intersurface between the polyester resin film and the "Vylon 600" layer. In thus way, the inventive image-transfer sheet (intermediate image-transfer medium) carrying the corresponding reverse images was provided.

Method for the preparation of intermediate image-transfer substrate

A sheet-of fine quality or stick paper, unit weight: 82 g/m^2 was applied with a coating, about 20 μm thick, of polyethylene resin through conventional extrusion coating process. Thereon, further, a catalyst-added toluene solution of a parting agent silicone, "KS-707", manufactured and sold by Shinetsu was applied and dried up in quantity of about 2 g/m^2 (dry), for the purpose of curing. Thereon, still further, the following coating liquid composition was applied by means of a conventional coating bar and dried up, to provide an intermediate image transfer substrate. The thus coated and dried resin quantity was measured to 7 g/m^2.

Coating liquid composition	
polyester resin ("Vylon 200", manufactured and sold by Toyo Boseki)	100 parts;
methyl ethyl ketone/toluene (mixing ratio by weight: 1/1)	700 parts.

A sheet of coated paper, pretreated for pore-filling, was coated, in the similar manner as above, with the foregoing liquid composition, to provide an image-transferable medium. On and with the presently coated surface, the image carrying surface of the foregoing intermediate image-transfer medium is brought into opposing contact and stuck together under heat and pressure at 140° C. for 7 seconds. Finally, the laminate of fine-quality paper and polyethylene was peeled off, to provide a final decorative product now displaying the positive images as required.

It will thus be seen that by adopting the above processing steps, the positive images formed under the action of the thermal head are transferred, through the intermediary of intermediate image transfer medium, onto the final object to be decorated, and indeed, in the form of positive mode. It will be further seen that, since the dyestuff is well distributed

within the image-reception layer, the transferred positive images are highly sharp and fresh, in addition to much profundities.

Since a resin layer was overlappingly applied on the thus-formed images, weather fastness, frictional durability and light-fastness of the finally formed images could be highly and amazingly improved. When suitable ultraviolet absorbing agent, antioxydant, quenching agent and/or radical scavenger is added to, further improvement of the light-fastness can be attained.

EXAMPLE E-2

The substrate of image-transferable medium adopted in the foregoing Example E-1 was replaced by a hard polyvinyl chloride card, 100 μm thick, and other processing modes were same as in Example E-1. In this way, a high quality, positive-image transferred, decorative final product was successfully provided. When the image include human portrait photograph, the final product was highly useful for ID-card.

EXAMPLE E-3

The substrate of image-transferable medium adopted in the foregoing Example E-1 was replaced by a transparent polyester film, and other processing modes were same as employed therein. In this way, a transparent film formed with the wanted positive images of better quality as before was obtained. This film was highly useful in OHP-services.

EXAMPLE E-4

A sheet of high quality paper, unit weight: 104 g/m^2, was coated with a layer of polypropylene resin, thickness: about 20 μm, through the way of conventional extrusion coating technique, then the coating was further coated with a silicone solution for use in parting service and hardenable under electron rays and dried up. The quantity of the coating silicone was about 1 g/m^2 upon drying. In this way, an electron-hardened, provisional substrate was provided. On this substrate, the following, image-reception layer-forming composition was applied as a layer by use of a coating bar, and then dried up, for providing an image-reception layer. The coated resin quantity in the above last step amounted about 5 g/m^2.

Image-reception layer-forming composition	
polystyrene ("Picolastic D 150" (Tg = 69° C.), manufactured and sold by Rika-Hercules Co., Ltd.	100 parts;
amino-modified silicone ("KF-393", manufactured and sold by Shinetsu)	7 parts;
epoxy-modified silicone ("X-22-343", manufactured and sold by Shinetsu)	7 parts.

Further processing was carried out as was set forth in the foregoing Example E-2, for providing a final product card, carrying thereon the wanted positive images of same superior quality, as was in Example E-2.

EXAMPLE E-5

On the image transferable medium used in the foregoing Example E-4, however, in the present Example, a thermoplastic resin, adhesive, polyolefine-series film, "Adwin 500", manufactured and sold by Showa Denko K.K., Tokyo, was applied as a layer. Other materials were used and processed as set forth therein. In this way, a decorative final product formed with necessary positive was obtained with superior results.

Industrial Availabilities

As will be well understood from the foregoing detailed description of the invention, it is possible according to the present inventive system, to form highly easily and evenly the desired images sharply and attractingly on any product and object to be decorated or graphically ornamented, substantially irrespective of material kind and configuration thereof, and indeed, with a surprising unitary touch and feeling with the substrate. Therefore, the invention can be utilized broadly and conveniently in such various industrial fields, where unitary formation of various images, characters, symbols, numerals and graphics, on and to the articles, objects and substrate products to a sufficiently miracle and attracting degree.

What is claimed is:

1. A method for producing a sublimatingly image-transferred product comprising an article and an image reception layer provided on said article, said image reception layer having a sublimatingly transferred image, said method comprising the steps of:

providing an article to be image-transferred;

providing image data;

forming an image, on the basis of the image data, on an image reception layer by means of a thermal printer having thermal heads; and

transferring the image reception layer onto a surface of the article to produce a sublimatingly image-transferred product.

2. The method according to claim **1**, wherein said image formed on said image-reception layer is formed at a bottom portion thereof and is positioned to face towards the article or on the outer surface of said image-reception layer.

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(12) **United States Patent**
Frey et al.

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(45) **Date of Patent: Aug. 7, 2001**

(54) **OBJECTIVE MEASUREMENT AND CORRECTION OF OPTICAL SYSTEMS USING WAVEFRONT ANALYSIS**

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(51) **Int. Cl.**[7] **G01B 9/00**
(52) **U.S. Cl.** **356/124**
(58) **Field of Search** 356/124; 606/5

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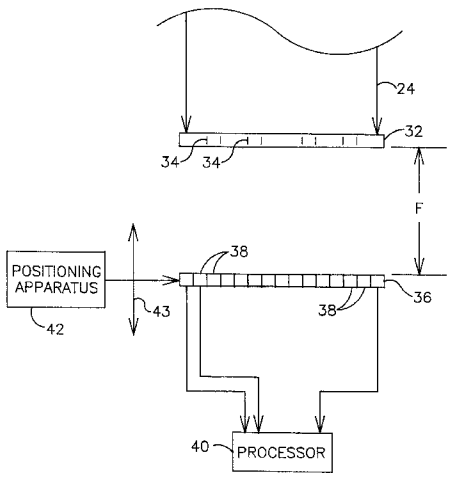
(57) **ABSTRACT**

Vision in an eye is corrected using an energy source for generating a beam of optical radiation and focusing optics disposed in the path of the beam for directing the beam through the eye, where the beam is reflected back from the retina of the eye as a wavefront of radiation to be measured. An optical correction based on an optical path difference between the measured wavefront and a desired plane wave, and refractive indices of the media through which the wavefront passes is provided to a laser delivery system with a laser beam sufficient for ablating corneal material from the cornea of the eye. The laser beam is directed at selected locations on the cornea for ablating the corneal material in response to the optical correction to cause the measured wavefront to approximate the desired plane wave, and thus provide an optical correction.

43 Claims, 9 Drawing Sheets



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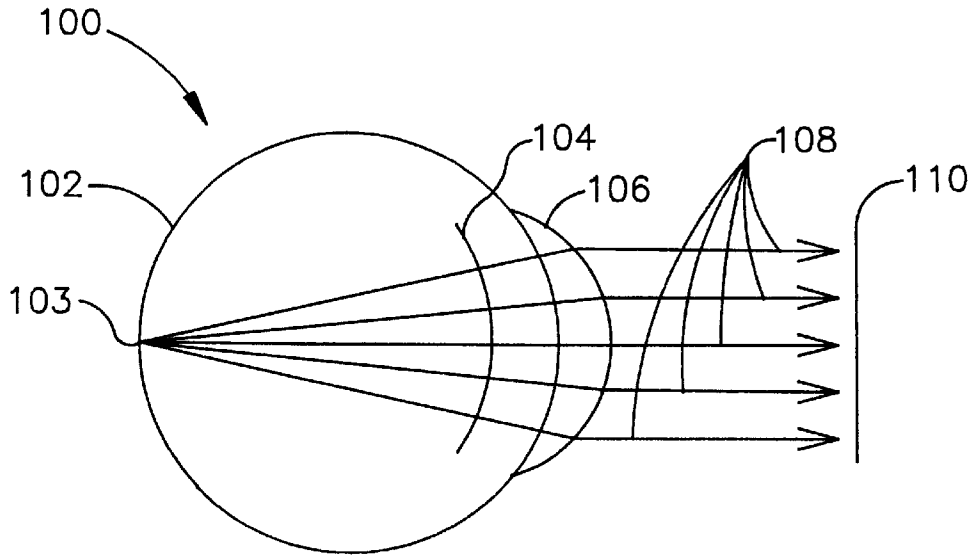

FIG. 1A

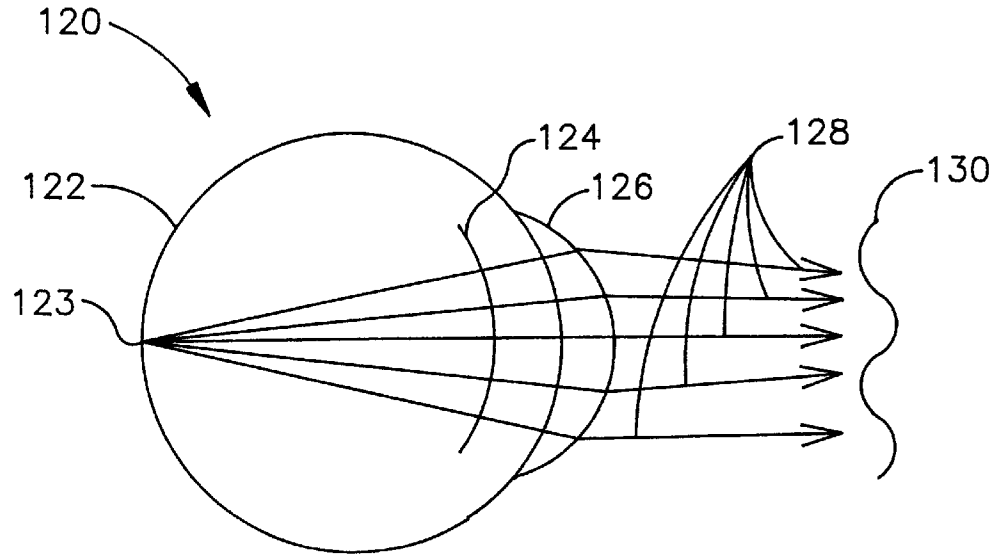

FIG. 1B

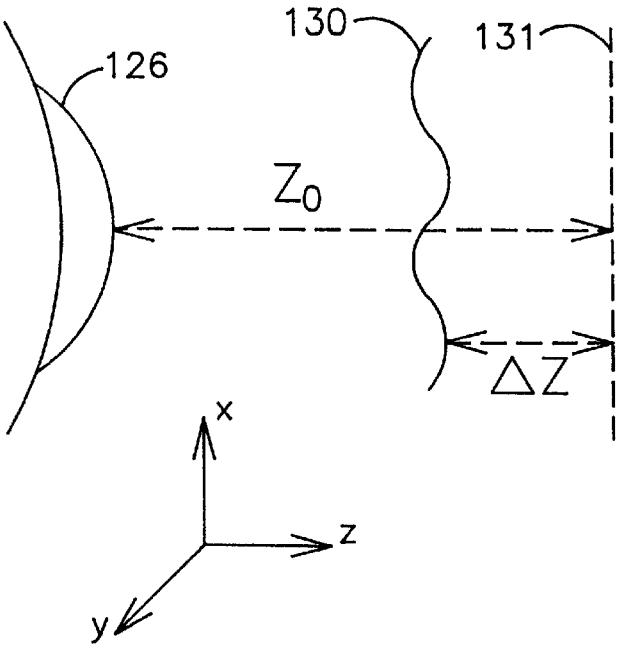
130
131
126
Z_0
ΔZ
x
z
y

FIG. 1C

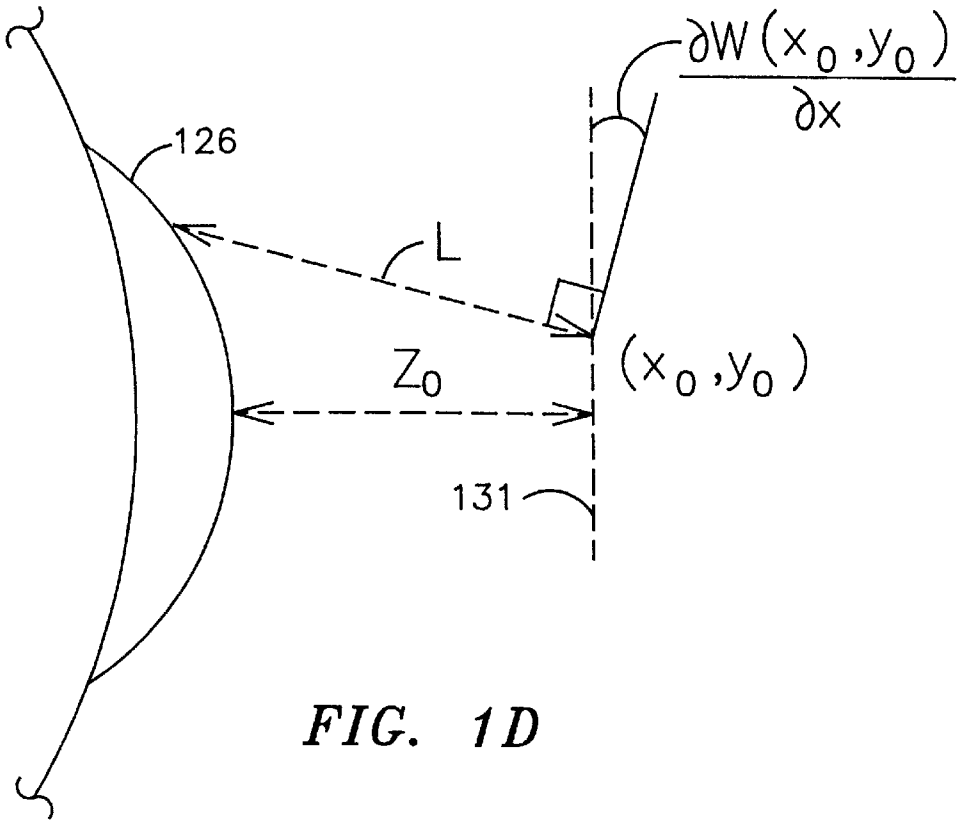
$\frac{\partial W(x_0, y_0)}{\partial x}$
126
L
Z_0
(x_0, y_0)
131

FIG. 1D

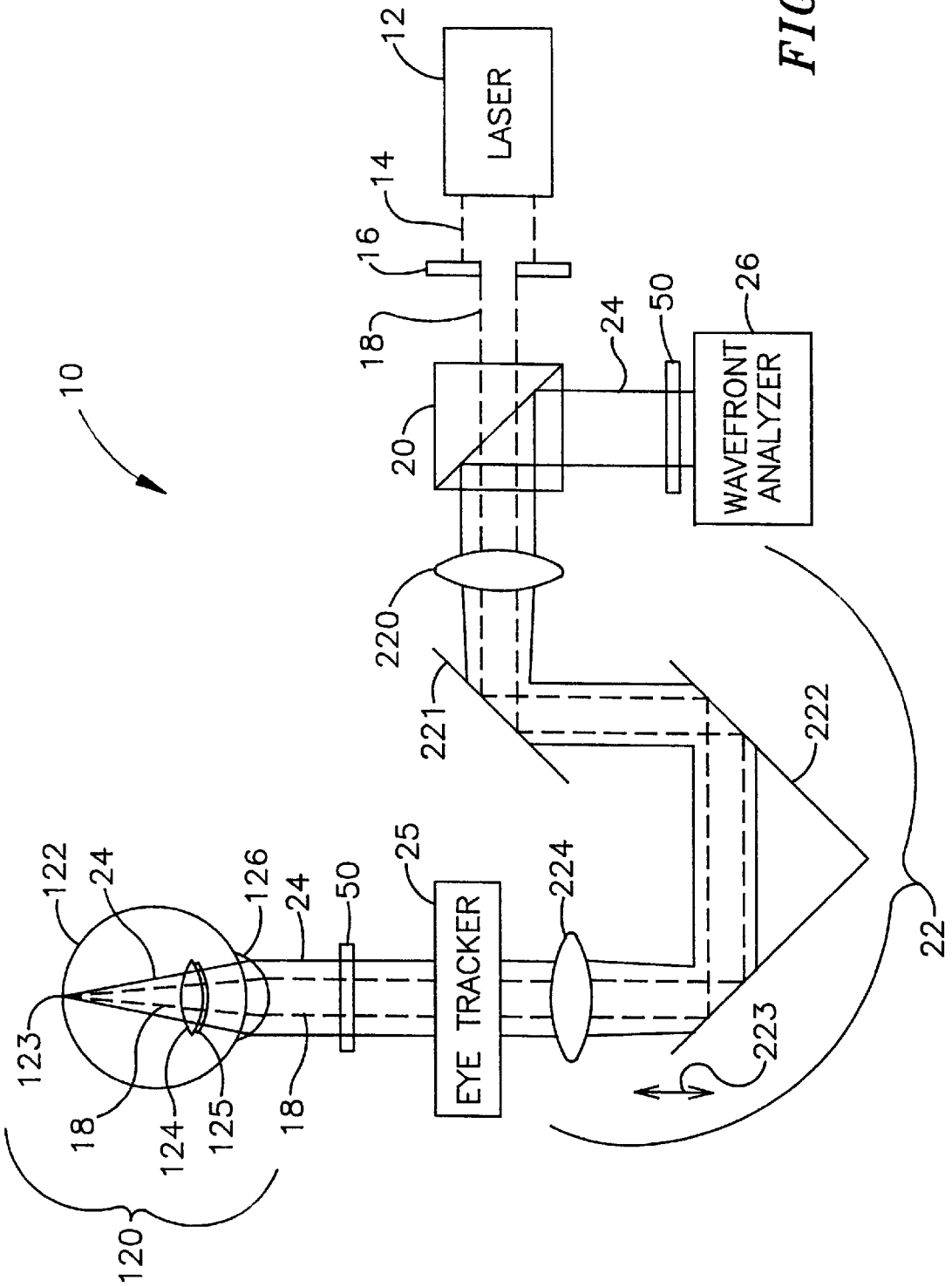
10
LASER
12
14
16
18
20
24
50
26
WAVEFRONT ANALYZER
220
221
222
223
224
22
25
EYE TRACKER
122
126
123
124
125
120

FIG. 2

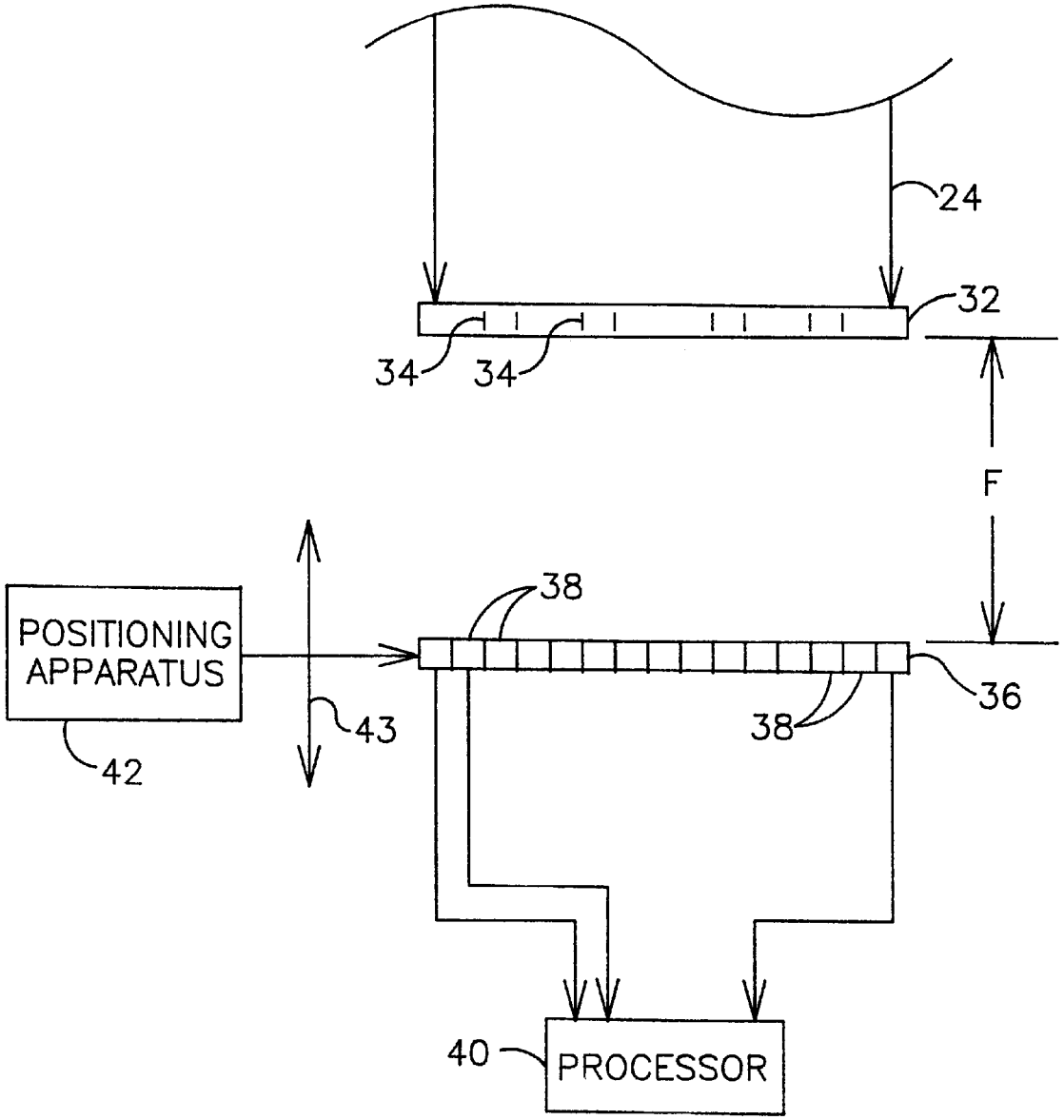
24
32
34
34
F
38
POSITIONING APPARATUS
36
38
43
42
40
PROCESSOR

FIG. 3

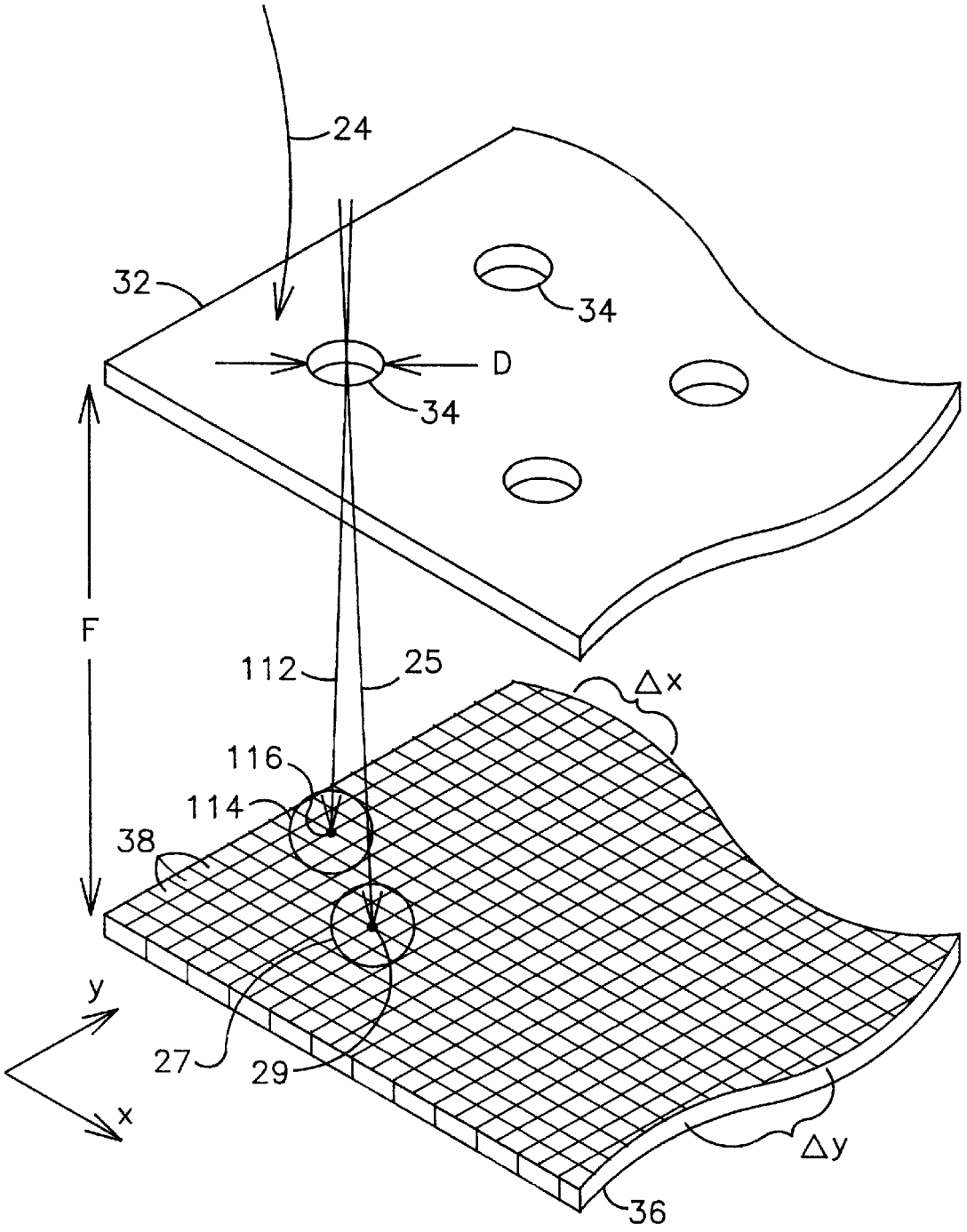

FIG. 4

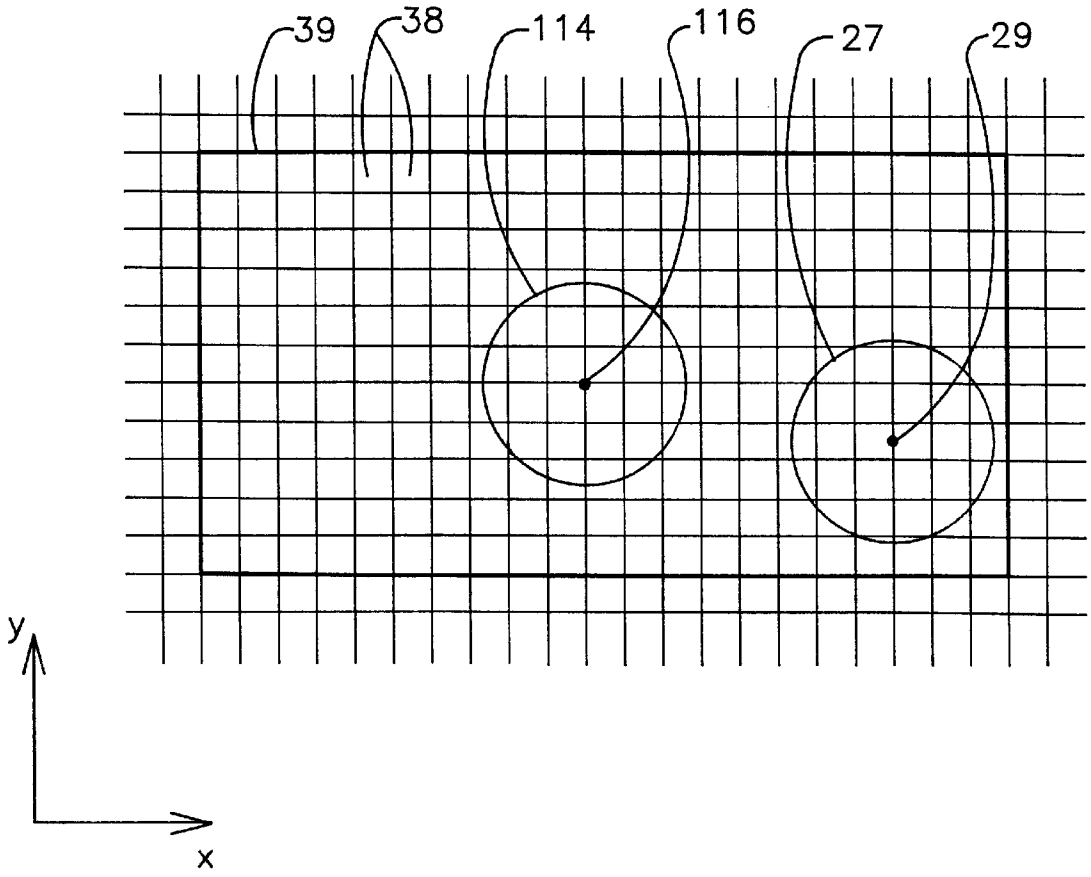

FIG. 5

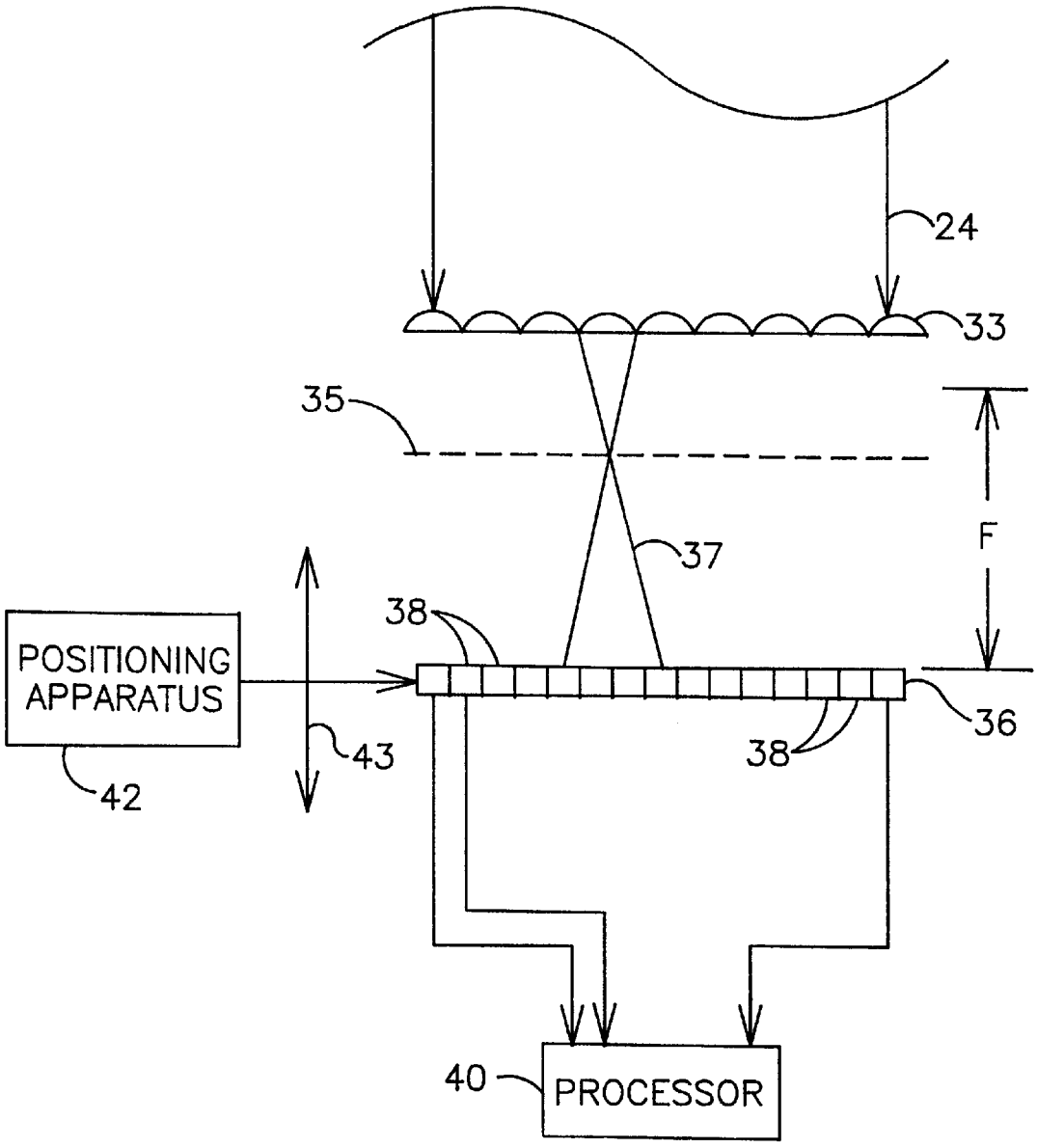
24
33
35
F
37
38
POSITIONING APPARATUS
43
42
38
36
40
PROCESSOR

FIG. 6

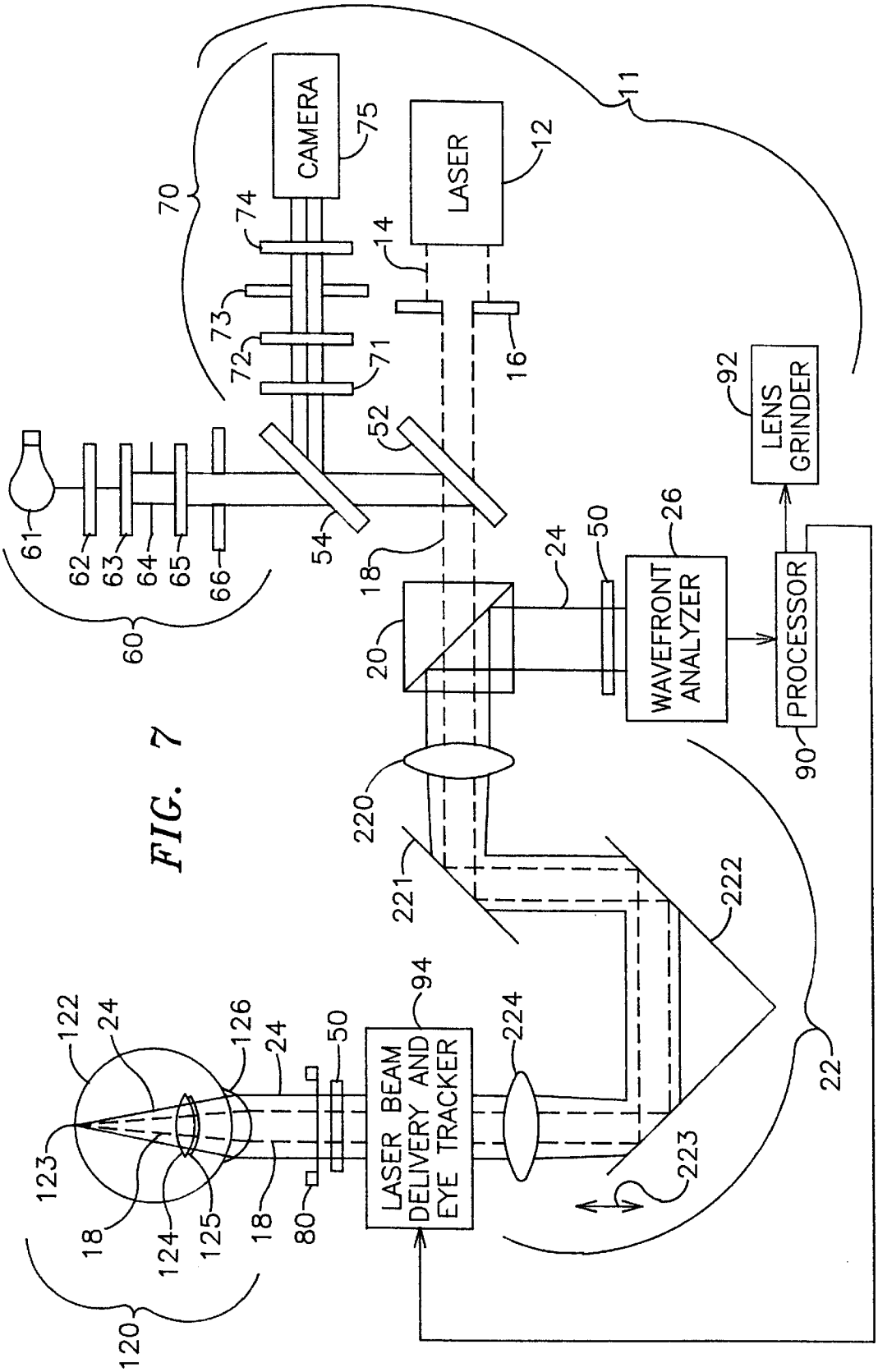
CAMERA
75
LASER
12
11
70
74
14
73
72
71
16
52
54
18
61
62
63
64
65
66
60
20
24
50
26
WAVEFRONT ANALYZER
92
LENS GRINDER
PROCESSOR
90
220
221
222
223
224
22
94
LASER BEAM DELIVERY AND EYE TRACKER
122
24
126
24
50
123
18
124
125
18
80
120

FIG. 7

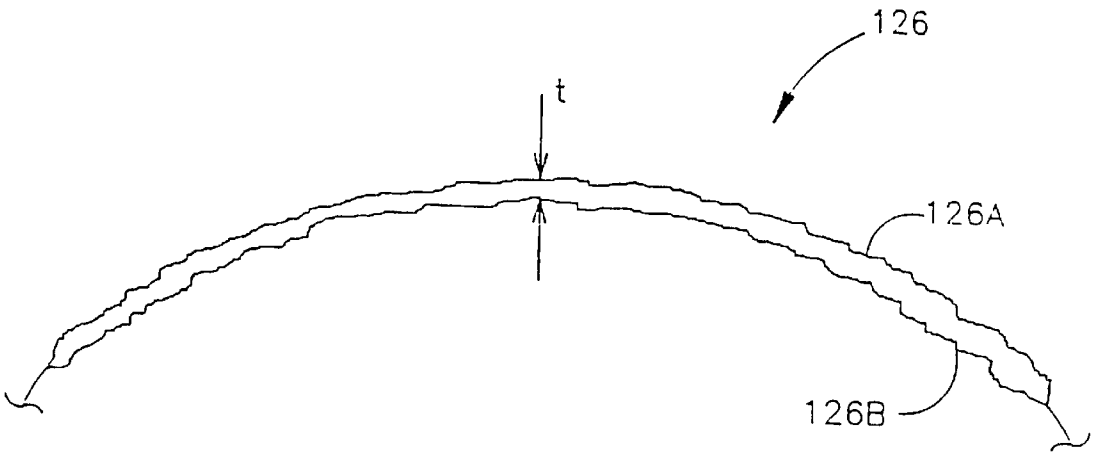

FIG. 8

OBJECTIVE MEASUREMENT AND CORRECTION OF OPTICAL SYSTEMS USING WAVEFRONT ANALYSIS

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation of and incorporates by reference application Ser. No. 09/496,368 now abandoned, filed Feb. 2, 2000, which itself is a continuation of abandoned application Ser. No. 08/756,272, filed Nov. 25,1996, all commonly owned with the present application.

FIELD OF THE INVENTION

The invention relates generally to optical aberration measurement and correction, and more particularly to the objective measurement and correction of optical systems having a real image focus such as human and animal eyes.

BACKGROUND OF THE INVENTION

Optical systems having a real image focus can receive collimated light and focus it at a point. Such optical systems can be found in nature, e.g., human and animal eyes, or can be man-made, e.g., laboratory systems, guidance systems, etc. In either case, aberrations in the optical system can affect the system's performance. By way of example, the human eye will be used to explain this problem.

Referring to FIG. **1**A, a perfect or ideal eye **100** is shown diffusely reflecting an impinging light beam (not shown for sake of clarity) from the back of its retina **102** (i.e., the fovea centralis **103**) through the eye's optics to include lens **104** and cornea **106**. For such an ideal eye in a relaxed state, i.e., not accommodating to provide near-field focus, the reflected light (represented by arrows **108**) exits eye **100** as a sequence as of plane waves, one of which is represented by straight line **110**. However, an eye normally has aberrations that cause deformation or distortion of the wave exiting the eye. This is shown by way of example in FIG. **1**B where aberrated eye **120** diffusely reflects an impinging light beam (again not shown for sake of clarity) from the back of its retina **122** of the fovea centralis **123** through lens **124** and cornea **126**. For aberrated eye **120**, reflected light **128** exits eye **120** as a sequence of distorted wavefronts, one of which is represented by wavy line **130**.

Currently, there are a number of technologies that attempt to provide the patient with improved visual acuity. Examples of such technologies include remodeling of cornea **126** using refractive laser surgery or intra-corneal implants, and adding synthetic lenses to the optical system using intraocular lens implants or precision-ground spectacles. In each case, the amount of corrective treatment is typically determined by placing spherical and/or cylindrical lenses of known refractive power at the spectacle plane (approximately 1.0–1.5 centimeters anterior to cornea **126**) and asking the patient which lens or lens combination provides the clearest vision. This is obviously a very imprecise measurement of the true distortions in wavefront **130** because 1) a single spherocylindrical compensation is applied across the entire wavefront, 2) vision is tested at discrete intervals (i.e., diopter units) of refractive correction, and 3) subjective determination by the patient is required in order to determine the optical correction. Thus, the conventional methodology for determining refractive errors in the eye is substantially less accurate than the techniques now available for correcting the ocular aberrations.

One method of measuring ocular refractive errors is disclosed by Penney et al. in "Spatially Resolved Objective Autorefractometer," U.S. Pat. No. 5,258,791, issued Nov. 2, 1993. Penney et al. teach the use of an autorefractometer to measure the refraction of the eye at numerous discrete locations across the corneal surface. The autorefractometer is designed to deliver a narrow beam of optical radiation to the surface of the eye, and to determine where that beam strikes the retina using a retinal imaging system. Both the angle of the beam's propagation direction with respect to the optical axis of the system and the approximate location at which the beam strikes the corneal surface of the eye are independently adjustable. A small uncertainty or error in the location of the beam's point of incidence on the cornea exists due to the curved corneal surface. For each point of incidence across the corneal surface, the refraction of the eye corresponding to that surface point can be determined by adjusting the angle at which the beam strikes the cornea until the beam refracted on to the iris strikes the fovea centralis. Adjustment of the beam angle of propagation can be accomplished either manually by the patient or automatically by the autorefractometer if a feedback loop involving a retinal imaging component is incorporated.

Penney et al. further teach the use of the autorefractometer measurements in determining the appropriate corneal surface reshaping to provide emmetropia. This is accomplished by first obtaining accurate measurement of corneal surface topography (using a separate commercially available device). A mathematical analysis is then performed using the initial corneal topography at each surface reference point, the measured refraction at each surface point, and Snell's law of refraction, to determine the required change in surface contour at each reference point. The contour changes at the various reference points are then combined to arrive at a single reshaping profile to be applied across the full corneal surface.

The major limitation to the approach described by Penney et al. is that a separate measurement of corneal topography is required to perform the Snell's Law analysis of needed refraction change. This requirement adds significantly to the time and cost of the complete diagnostic evaluation. Furthermore, the accuracy of the refraction change analysis will be dependent on the accuracy of the topographic measurement and the accuracy of the autorefractometer measurement. In addition, any error in the spatial orientation of the topography "map" with respect to the refraction map will degrade the accuracy of the needed correction profile.

A second limitation to the approach described by Penney et al. is that test points on the corneal surface are examined sequentially. Eye motion during the examination, either voluntary or involuntary, could introduce substantial errors in the refraction measurement. Penney et al. attempt to provide detection of such eye movement by deliberately including measurement points outside the pupil, i.e., in the corneal region overlying the iris, where the return from the retina will obviously be zero at specific intervals in the examination sequence. However, this approach may still allow substantial undetected eye movement error between such iris reference points.

At present, no corrective method is based on the concurrent examination of the complete distortions in wavefront **130**. Measurement of wave aberrations of the human eye, i.e., ocular aberrations, has been studied for a number of years. One prior art method and system are disclosed by Liang et al. in "Objective Measurement of Wave Aberrations of the Human Eye With the Use of a Hartmann-Shack Wave-front Sensor," Journal of the Optical Society of America, Volume 11, No. 7, July 1994, p.p. 1949–1957. Liang et al. teach the use of a Hartmann-Shack wavefront

sensor to measure ocular aberrations by measuring the wavefront emerging from the eye by the retinal reflection of a focused laser light spot on the retina's fovea. The actual wavefront is reconstructed using wavefront estimation with Zernike polynomials.

The Hartmann-Shack wavefront sensor disclosed by Liang et al. includes two identical layers of cylindrical lenses with the layers arranged so that the lenses in each layer are perpendicular to one another. In this way, the two layers act like a two-dimensional array of spherical lenslets that divide the incoming light wave into subapertures. The light through each subaperture is brought to focus in the focal plane of the lens array where a charge coupled device (CCD) image module resides.

The system of Liang et al. is calibrated by impinging an ideal plane wave of light on the lenslet array so that a reference or calibrating pattern of focus spots is imaged on the CCD. Since the ideal wavefront is planar, each spot related to the ideal wavefront is located on the optical axis of the corresponding lenslet. When a distorted wavefront passes through the lenslet array, the image spots on the CCD are shifted with respect to the reference pattern generated by the ideal wavefront. Each shift is proportional to the local slopes, i.e., partial derivatives, of the distorted wavefront which can be used to reconstruct the distorted wavefront, by means of modal wavefront estimation with Zernike polynomials.

However, the system disclosed by Liang et al. is effective only for eyes having fairly good vision. Eyes that exhibit considerable myopia (near-sightedness) would cause the focus spots to overlap on the CCD thereby making local slope determination impossible for eyes having this condition. Similarly, eyes that exhibit considerable hyperopia (farsightedness) deflect the focus spots such that they do not impinge on the CCD thereby again making local slope determination impossible for eyes having this condition.

Another limitation of the system of Liang et al. is the configuration of the Hartmann-Shack sensor in that the lenses must be uniform in order to define a uniform lenslet array so that the entire array shares a common focal plane and does not itself induce distortions in the wavefront. However, the manufacturing costs associated with such constraints are considerable.

Thus, owing to all of the above-noted limitations, Liang et al. can only achieve wavefront measurement for a relatively small class of patients. Such patients can have, at most, mildly distorted vision.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a method and system for objectively measuring aberrations of optical systems by wavefront analysis and for using such measurement to generate an optical correction.

Another object of the present invention is to provide for the objective measurement of ocular aberrations having a dynamic range that can cope with large amounts of such aberrations so as to be useful in practical applications.

Still another object of the present invention to provide a method and system for objectively measuring ocular aberrations using a wavefront analyzer of simple and inexpensive design.

It is further an object to correct vision by ablating corneal material using a laser beam directed to locations on the surface of the cornea of the eye in response to the objective measurements, thereby providing a measured wavefront that approximates a desired wavefront such as a plane wave.

Other objects and advantages of the present invention will become more obvious hereinafter in the specification and drawings.

To meet such objects, an optical correction system for correcting visual defects of an eye is provided which includes a wavefront analyzer disposed in the path of a wavefront emanating from the eye for determining an optical path difference between a plane wave and the wavefront, a converter for providing an optical correction based on the path difference and refractive indices of media through which the wavefront passes, and a laser beam having power sufficient for ablating corneal material of the cornea of the eye, wherein the optical correction is achieved by the removal of a selected amount of the corneal material.

A method aspect of the invention includes enhancing vision of an eye by optically correcting the eye based on an optical path difference between a plane wave and a wavefront emanating from the retina of the eye and refractive indices of media through which the wavefront passes, to thereby cause the wavefront to approximate the shape of the plane wave. Further, corneal surface altering is based on a Zernike reconstruction of the wavefront, and the optically correcting includes dividing the optical path difference by a difference between an index of refraction of corneal material and an index of refraction of air. The cornea is then ablated using a laser beam directed at selected locations on the surface of the cornea for altering the corneal surface of the eye without regard to a resulting topography of the surface of the cornea.

In accordance with the present invention, an energy source generates a beam of radiation. Optics, disposed in the path of the beam, direct the beam through a focusing optical system, e.g., an eye, that has a rear portion thereof functioning as a diffuse reflector. The beam is diffusely reflected back from the rear portion as a wavefront of radiation that passes through the focusing optical system to impinge on the optics. The optics project the wavefront to a wavefront analyzer in direct correspondence with the wavefront as it emerges from the focusing optical system. A wavefront analyzer is disposed in the path of the wavefront projected from the optics and calculates distortions of the wavefront as an estimate of ocular aberrations of the focusing optical system. The wavefront analyzer includes a wavefront sensor coupled to a processor that analyzes the sensor data to reconstruct the wavefront to include the distortions thereof.

In one embodiment, the radiation is optical radiation and the wavefront sensor is implemented using a plate and a planar array of light-sensitive cells. The plate is generally opaque but that has an array of light transmissive apertures that selectively let impinging light therethrough. The plate is disposed in the path of the wavefront so that portions of the wavefront pass through the light transmissive apertures. The planar array of cells is arranged parallel to and spaced apart from the plate by a selected distance. Each portion of the wavefront passing through one of the light transmissive apertures illuminates a geometric shape covering a unique plurality of cells. In another embodiment, the wavefront sensor comprises a two-dimensional array of spherical lenslets and a planar array of cells. The array of lenslets defines a focal plane that is a focal length away therefrom. The array of lenslets is disposed in the path of the wavefront where portions of the wavefront pass therethrough. The planar array of cells is arranged parallel to and spaced apart from the array of lenslets by a selected distance independent of the focal length. Similar to the first embodiment wavefront sensor, each portion of the wavefront illuminates a geometric shape covering a unique plurality of cells. Regardless of

which wavefront sensor is used, the distance between the planar array of cells and the opaque plate, or the array of lenslets, can be varied to adjust the slope measurement gain of the wavefront sensor and thereby improve the dynamic range of the system.

Another measure of dynamic range enhancement is provided by the focusing optics. The focusing optics includes first and second lenses maintained in fixed positions in the path of the beam and wavefront. An arrangement of optical elements is disposed between the lenses in the path of the beam and the wavefront. The optical elements are adjustable to change the optical path length between the lenses.

If an optical correction is desired, the distortions are converted to an optical correction which, if placed in the path of the wavefront, causes the wavefront to appear approximately as a plane wave. The optical correction can be in the form of a lens or an amount of corneal material ablated from the eye.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1A** is a schematic view of the ideal eye reflecting light from its retina as a planar wavefront;

FIG. **1B** is a schematic view of an aberrated eye reflecting light from its retina as a deformed wavefront;

FIG. **1C** is a schematic view of the distorted wavefront relative to a reference plane to show the wavefront error or optical path difference as a function of transverse distance in the propagation direction;

FIG. **1D** is a schematic view of the distorted wavefront relative to a reference plane that is tangent to the surface of the cornea;

FIG. **2** is a simplified schematic of the system for determining ocular aberrations in accordance with the essential features of the present invention;

FIG. **3** is a schematic of one embodiment of a Hartmann Shack wavefront analyzer used in the present invention;

FIG. **4** is a perspective view of a portion of the pinhole imaging plate and planar array of light-sensitive cells comprising the wavefront sensor from the embodiment of FIG. **3** where the deflection of a wavefront piece associated with an aberrated eye is shown in comparison with a wavefront piece associated with a calibration or planar wavefront;

FIG. **5** is a plan view of a designated area on the planar array of light-sensitive cells associated with a corresponding hole;

FIG. **6** is a schematic of another embodiment of a wavefront analyzer used in the present invention;

FIG. **7** is a schematic view of an embodiment of the present invention suitable for ophthalmic use; and

FIG. **8** is a side view of a cornea showing a thickness of corneal material to be ablated as an optical correction generated by the present invention.

DETAILED DESCRIPTION OF THE INVENTION

By way of illustrative example, the present invention will be described with respect to diagnosing and correcting a human eye. However, it is to be understood that the teachings of the present invention are applicable to any optical system having a real image focus that can (or can be adapted to) diffusely reflect a focused spot of radiation from a rear portion of the optical system back through the optical system as a wavefront of radiation. Thus, the present invention can be used with human or animal eyes of patients that may be alive or dead, or any man-made optical system satisfying the criteria regarding the real image focus.

The method of using wavefront analysis to determine an appropriate optical correction will be introduced with reference to the eye example and the aid of the schematic shown in FIG. **1C**. For convenience, a coordinate system is defined where positive x is upward in the plane of the figure, positive y is outward from the plane of the figure, and positive z is to the right along the propagation direction. Distorted wavefront **130** can be described mathematically as W(x,y).

One method of measuring the distortions in wavefront **130** is to determine the spatial separation Δz between a reference plane **131** (analogous to ideal wavefront **110**) at a known distance z_O from the eye at each (x,y) point of distorted wavefront **130** as the leading edge of wavefront **130** traverses distance z_O. This is illustrated in FIG. **1C** and is described mathematically as

$$\Delta z(x,y)=z_0-W(w,y) \quad (1)$$

These Δz measurements define the inappropriate optical path differences due to the aberrations in the test eye. The appropriate correction consists of removing these optical path differences. Ideally, such correction is performed at reference plane **131**.

Depending on the corrective therapy (i.e., corneal tissue ablation, synthetic lens addition, etc.), the amount of material removed or added at each (x,y) coordinate can be calculated directly if the refractive index of the material in question is known. For many procedures, such as intraocular lens implantation or radial keratotomy, such wavefront analysis can be performed repetitively during the procedure to provide feedback information as to the appropriate endpoint of the procedure.

In terms of the illustrative example, the differences Δz(x, y) between the distorted and ideal wavefronts are the consequence of the aberrations in the eye. Ideal correction of those aberrations consists of introducing an optical path difference at reference plane **131** of negative Δz(x,y). If the treatment approach consists of removing tissue from the surface of the cornea by laser ablation, then a logical choice for the location of reference plane **131** is tangential to the surface of cornea **126** (i.e., z_O=0). This is shown schematically in FIG. **1D** where the curvature of cornea **126** is greatly exaggerated for clarity of illustration. Ablation could then be carried out discretely at each (x,y) coordinate along the cornea by a laser beam delivery and eye tracking system such as disclosed in U.S. patent application Ser. No. 08/232,615, filed Apr. 25, 1994, owned by the same assignee as the present invention, and which is incorporated herein by reference.

The appropriate corneal ablation depth at any (x,y) transverse coordinate is, to within a small error, given by

$$\Delta z(x,y)/(n_c-1) \quad (2)$$

where n_c is the refractive index of corneal tissue or 1.3775. The method described in detail below calculates Δz(x,y) by first measuring the local slopes in wavefront **130**, i.e., δW(x,y)/δx and δW(x,y)/δy, at a number of points in the transverse x and y directions in reference plane **131** and then generating a mathematical description of W(x,y) having slopes in best possible agreement with the experimentally determined values. One such slope $\delta W(x_O,y_O)/\delta x$ is referenced in FIG. **1D**. In doing this, a small error is introduced due to the fact that distorted wavefront **130** is measured at reference plane **131** while wavefront **130** emerged from a

curved (corneal) surface just posterior to reference plane **131**. This error is similar to that encountered with the prior art method of Penney et al. discussed above. The error $E_x(x,y)$ is the lateral displacement in the x-direction at each (x,y) location at the measurement plane (i.e., reference plane **131**) to the curved corneal surface. A similar error will be manifest for any corrections involving curved optical surfaces. The error will generally increase with both (x,y) displacement from the point of tangency and local wavefront error.

The magnitude of error $E_x(x,y)$ can be found for each measurement location (x,y) measured at an arbitrary coordinate, e.g., (x_O,y_O) by projecting that location back to the point of origin on cornea **126**. This can be explained mathematically using FIG. **1**D. For simplicity, the explanation will assume that the error is only in the plane of the figure, i.e., the plane defined by $y=y_O$, although it is quite straightforward mathematically to extend the analysis to include errors the y-dimension. The quantation of the line L tracing the propagation of the wavefront element measured at (x_O,y_O) in the z_O reference plane from the corneal surface to the reference plane is:

$$L(x) = z_0 - \frac{(x - x_0)}{\delta W(x_0, y_0)/\delta x} \tag{3}$$

If the corneal surface in the plane of the figure is described by the expression $S(x_O,y_O)$, then the point of origin for the wavefront element in question can be found by finding the point of intersection between L(x) and $S(x,y_O)$. Mathematically, this requires finding the value x' that satisfies $L(x')=S(x_O,y_O)$. The error $E_x(x_O,y_O)$ then is given as $E_x(x_O,y_O)=x'-x_O$. Extending the analysis to consider errors in the y-direction would yield a similar expression for E_Y where $E_Y(x_O,y_O)=y'-y_O$. If significant, these transverse errors can be compensated for by laterally displacing the aberration correction calculated at each (x,y) coordinate by the amounts $E_X(x,y)$ and $E_Y(x,y)$

In the case of human corneas, the transverse error under most circumstances will be negligible. The error will be zero at the origin where the corneal tissue and reference plane **131** are tangent. For human corneas, the tissue is approximately spherical with a radius of curvature of approximately 7.5–8.0 mm. The corrective treatment radius is typically no more than 3 mm, and local wavefront radius of curvature will almost always exceed 50 mm (a 20 diopter refractive error). The transverse error E at a 3 mm treatment radius for a local wavefront radius of curvature of 50 mm is less than 40 mm.

For certain ophthalmic procedures, wavefront analysis can also be used repetitively during the corrective procedure to provide useful feedback information. One example of such use would be in cataract surgery where wavefront analysis could be performed on the eye following placement of an intra-ocular lens implant (IOL). The analysis could help identify whether the appropriate refractive power IOL has been inserted, or whether a different refractive power IOL should be used. Another example of repetitive wavefront analysis would be during keratoplastic procedures where the cornea of the eye is deliberately distorted by altering the mechanical tension around the periphery thereof. Here, repetitive wavefront analysis could be used to refine the degree of induced tension change at each point around the cornea thereby providing the tool to obtain, optimum surface curvature for best visual acuity.

In order to perform wavefront analysis in a manner compatible with corrective procedures such as those described above, the amount of spatial separation of component portions of wavefront **130** relative to the corresponding component portions of a planar or ideal wavefront must be measured. It is the system and method of the present invention that allows such separation to be objectively and accurately measured for even substantially aberrated eyes including those exhibiting severe defects such as severe myopia or hyperopia.

For the evaluation or measurement portion of the present invention, the patient's pupil should ideally be dilated to approximately 6 millimeters or more, i.e., the typical size of a human pupil in low light. In this way, the eye is evaluated while it is using the greatest area of the cornea so that any correction developed from such measurement takes into account the largest usable corneal area of the patient's eye. (A lesser amount of the cornea is used in daylight where the pupil is considerable smaller, e.g., on the order of 3 millimeters.) Dilation can be brought about naturally by implementing the measurement portion of the present invention in a low light environment such as a dimly lit room. Dilation can also be induced through the use of pharmacologic agents.

Referring now to FIG. **2**, a simplified schematic of the system of the present invention depicting its essential elements is shown and referenced generally by numeral **10**. System **10** includes laser **12** for generating the optical radiation used to produce a small-diameter laser beam. Laser **12** is typically a laser generating collimated laser light (represented by dashed lines **14**) of a wavelength and power that is eye-safe. For ophthalmic applications, appropriate wavelengths would include the entire visible spectrum from approximately 400–710 nanometers and the near infrared spectrum from approximately 710–1000 nanometers. While operation in the visible spectrum is generally preferable (since these are the conditions in which the eye operates), the near infrared spectrum may offer advantages in certain applications. For example, the patient's eye may be more relaxed if the patient does not know measurement is taking place. Regardless of the wavelength of the optical radiation, power should be restricted in ophthalmic applications to eyesafe levels. For laser radiation, appropriate eye-safe exposure levels can be found in the U.S. Federal Performance Standard for Laser Products. If the analysis is to be performed on an optical system other than the eye, the examination wavelength range logically should incorporate the intended performance range of the system.

To select a small-diameter collimated core of laser light **14**, an iris diaphragm **16** can be used to block all of laser light **14** except for laser beam **18** of a size desired for use by the present invention. In terms of the present invention, laser beam **18** can have a diameter in the range of approximately 0.5–4.5 millimeters with 1–3 millimeters being typical. A badly aberrated eye requires a smaller diameter beam while an eye with only slight aberrations can be evaluated with a larger diameter beam. Depending on the output divergence of laser **12**, a lens (not shown) can be positioned in the beam path to optimize collimation.

Laser beam **18** is a polarized beam that is passed through a polarization sensitive beam splitter **20** enroute to being directed to a focusing optical train **22**. Optical train **22** operates to focus laser beam **18** through the optics of eye **120** (e.g., cornea **126**, pupil **125** and lens **124**) to the back of the eye's retina **122**. (It is to be understood that lens **124** may not be present for a patient that has undergone a cataract procedure, however, this does not affect the present invention.) In the illustrated example, optical train **22** images laser beam **18** as a small spot of light at or near the

eye's fovea centralis **123** where the eye's vision is most acute. Note that the small spot of light could be reflected off another portion of retina **122** in order to determine aberrations related to another aspect of one's vision. For example, if the spot of light were reflected off the area of retina **122** surrounding the fovea centralis **123**, aberrations specifically related to one's peripheral vision could be evaluated. In all cases, the spot of light is sized to form a near-diffraction limited image on retina **122**. Thus, the spot of light produced by laser beam **18** at fovea centralis **123** does not exceed approximately 100 micrometers in diameter and, typically, is on the order of 10 micrometers.

The diffuse reflection of laser beam **18** back from retina **122** is represented in FIG. **2** by solid lines **24** indicative of the wavefront of radiation that passes back through eye **120**. Wavefront **24** impinges on and is passed through optical train **22** enroute to polarization sensitive beam splitter **20**. Wavefront **24** is depolarized relative to laser beam **18** due to reflection and refraction as wavefront **24** comes off retina **122**. Accordingly, wavefront **24** is turned at polarization sensitive beam splitter **20** and directed to a wavefront analyzer **26** such as a Hartmann-Shack (H-S) wavefront analyzer. In general, wavefront analyzer **26** measures the slopes of wavefront **24**, i.e., the partial derivatives with respect to x and y, at a number of (x,y) transverse coordinates. This partial derivative information is then used to reconstruct or approximate the original wavefront with a mathematical expression such as a weighted series of Zernike polynomials.

The purpose of the above-specified polarizations states for incident laser beam **18** and beamsplitter **20** is to minimize the amount of stray laser radiation reaching the sensor portion of wavefront analyzer **26**. In some situations, stray radiation may be sufficiently small when compared to the radiation returning from the desired target (e.g., retina **122**) so that the above polarization specifications are unnecessary.

The present invention is able to adapt to a wide range of vision defects and as such achieves a new level of dynamic range in terms of measuring ocular aberrations. Dynamic range enhancement is accomplished with optical train **22** and/or the wavefront sensor portion of wavefront analyzer **26** as will now be explained.

In the illustrated embodiment, optical train **22** includes a first lens **220**, a flat mirror **221**, a Porro mirror **222** and a second lens **224** all of which lie along the path of laser beam **18** and wavefront **24**. First lens **220** and second lens **224** are identical lenses maintained in fixed positions. Porro mirror **222** is capable of linear movement as indicated by arrow **223** to change the optical path length between lenses **220** and **224**. However, it is to be understood that the present invention is not limited to the particular arrangement of flat mirror **221** and Porro mirror **222** and that other optical arrangements could be used between lenses **220** and **224** to change the optical path length therebetween.

The "zero position" of Porro mirror **222** can be identified by replacing eye **120** in FIG. **2** by a broad beam source (not shown) of collimated light to simulate a perfect plane wave. Such a source could be realized by a laser beam expanded by a beam telescope to the diameter that will cover the imaging plane of wavefront analyzer **26** and adjusting Porro mirror **222** until wavefront analyzer **26** detects the light as being collimated. Note that the changes in optical path length brought about by Porro mirror **222** can be calibrated in diopters to provide an approximate spherical dioptric correction as will be explained further below.

The dynamic range of system **10** can be further improved by utilizing a preferred embodiment wavefront analyzer to include an improved wavefront sensor arrangement. One such wavefront sensor arrangement will now be explained with the aid of FIGS. **3** and **4**. In FIG. **3**, the wavefront analyzer includes an opaque imaging plate **32** having an array of holes **34** passing therethrough, a planar array **36** of light-sensitive cells such as charge coupled device cells **38**, and a processor **40** coupled to planar array **36** of cells **38**. The combination of plate **32** and planar array **36** comprises the unique wavefront sensor of this embodiment. Plate **32** is maintained parallel to and spaced apart a separation distance F from planar array **36**. As will be explained further below, separation distance F can be varied to adjust the gain of the sensor. To do this, planar array **36** is coupled to a positioning apparatus **42**, e.g., a conventional motorized linear positioner having precise movement capability, that can adjust the position of planar array **36** relative to plate **32** to change separation distance F as indicated by arrow **43**. With respect to the array of holes **34**, each of holes **34** is of equal size and shape with a circle being typical owing to its ease of manufacture. In the illustrated example, a square array geometry is used for array of holes **34** although other array geometries can be used.

As shown in FIG. **4**, when wavefront **24** impinges on plate **32**, a piece or portion of wavefront **24**, indicated by arrow **25**, passes through hole **34** to illuminate planar array **36**. To a first order, the resulting image formed by each such wavefront piece **25** is a positive shadow of the respective hole **34**. However, diffraction does occur in a way determined by the diameter D of each hole **34**, the wavelength A of the light source (i.e., wavefront **24**) and the separation distance F between plate **32** and planar array **36**. The value F is varied by positioning apparatus **42** to adjust the gain based on the particular patient as will be explained further below.

Note that the function provided by plate **32** with holes **34** could also be accomplished using a solid plate or film made from a light-sensitive material such as a photolithographic film. In such a case, the array of holes **34** would be replaced by an array of shaped light transmissive apertures through which light passes when impinging thereon. The remainder of such a plate or film would be impervious to light. The advantage achieved by such an embodiment is that the light transmissive apertures could easily be made to conform to any desired shape.

Regardless, of how each wavefront piece **25** is generated, the present invention measures the amount of angular deflection of each wavefront piece **25** relative to a wavefront piece that would result from a planar wavefront. This is best seen in FIG. **4** where the calibration or planar wavefront of light results in a wavefront piece represented by arrow **112** (normal to plate **32**) that illuminates a geometric spot **114** on planar array **36**. In contrast, assuming wavefront **24** represents a distorted wavefront as described above, wavefront piece **25** will exhibit an amount of angular deflection relative to (calibrating) wavefront piece **112**. The angular deflection causes wavefront piece **25** to illuminate a geometric spot **27** on planar array **36** that is offset from (calibrating) spot **114**. In terms of the present invention, the amount of offset is measured relative to the centroids **116** and **29** of spots **114** and **27**, respectively. In the two dimensions of planar array **36**, centroid **29** is (typically) deflected in both the x and y directions of array **36**. Thus, the angular deflection in each of the x and y directions is given by $\Delta x/F$ and $\Delta y/F$, respectively.

In the preferred embodiment, lenses **220** and **224** are identical as mentioned above. However, in certain applications it may be desirable to magnify or minify the wavefront

at the wavefront sensor. This can be accomplished by using lenses **220** and **224** of different focal lengths and adjusting the apparatus dimensions accordingly. For ophthalmic evaluation, the object plane of the apparatus should ideally be tangent to the corneal surface which can be achieved by a variety of means. Thus, each point at the object plane of optical train **22** very nearly corresponds to the same point on the cornea (although since the cornea is curved, there will be a slight lateral displacement). Plate **32** (or the imaging plane of any wavefront sensor portion) of wavefront analyzer **26** is positioned at the focal plane of lens **220**. In this way, the object plane is always imaged on plate **32** in direct correspondence with the wavefront image emerging from cornea **126**. This will be true regardless of the optical path length between lenses **220** and **224**. There are several advantages to this structure, one of which is that there are very good planar arrays of light-sensitive cells that are commercially available to image an area corresponding to the 6 millimeter central circular region of the cornea. Additional advantages will now be explained.

The purpose of plate **32** (or the imaging plane of any wavefront sensor portion of wavefront analyzer **26**) is to break wavefront **24** into wavefront pieces that can each be measured independently (in terms of propagation direction) at planar array **36**. Since in the preferred embodiment optical train **22** does not magnify or reduce the image in the object plane, a point at the object plane corresponds to the same point at the image plane of optical train **22**. With Porro mirror **222** set at its "zero position," the direction each piece of wavefront **24** is traveling at the object plane is reproduced exactly at the image plane of wavefront analyzer **26**. For example, if a wavefront piece at a location in the object plane was traveling away from the optical axis at an angle of 20° with respect to the optical axis that is perpendicular to the object plane, the wavefront piece at the same location in the image plane will also be traveling away from the optical axis at an angle of 20°.

Note that a person who is myopic will produce a wavefront such that the wavefront pieces isolated by plate **32** will converge toward the center of planar array **36**. A hyperopic person will produce a wavefront such that the wavefront pieces isolated by plate **32** diverge. Thus, a person with a significant vision error becomes difficult to evaluate because wavefront pieces can either overlap (myopia) at planar array **36** or spill off (hyperopia) planar array **36**.

In the present invention, there are three ways of compensating for such severe aberrations. The first way is to utilize a wavefront sensor with sufficiently small light-sensitive cells **38** and sufficiently large holes **34** (or any other transmissive aperture). In this way, measurement of each wavefront piece can be performed to an acceptable accuracy using a small value for F. The second way is to move planar array **36** along the optical axis to change the separation distance F to plate **32**. For a person with a severe aberration, planar array **36** is positioned close to plate **32** to keep the projected wavefront pieces well separated and on planar array **36**. For a mild aberration, planar array **36** can be moved to increase the separation distance F to plate **32** to make a more accurate measurement. The advantage of moving planar array **36** to change the separation distance F to plate **32** is that the wavefront analysis is easily achieved for any position. The third way of compensating for severe aberrations in the present invention is to change the optical path length between lenses **220** and **224**. Moving Porro mirror **222** will not affect where the wavefront hits plate **32**, but will change the angular deflections at which the projected wavefront pieces pass through plate **32**, i.e., $\Delta x/F$ and $\Delta y/F$. Decreasing the optical path length between lenses **220** and **224** will tend to pull the wavefront pieces toward the center of planar array **36** thereby compensating for hyperopia. Increasing the optical path length between lenses **220** and **224** will tend to spread the wavefront pieces toward the edges of planar array **36** thereby compensating for myopia. The degree to which the angular deflection associated with each wavefront piece is altered is a linear function of its distance off the optical axis and the movement of Porro mirror **222** from its zero position.

In order to accurately determine the centroids of a spot of light impinging on array **36**, it is necessary to provide a fine structure of cells **38** relative to a spot size. In other words, each spot must cover a plurality of cells **38**. In the preferred embodiment, to determine the centroid of each spot unambiguously with respect to a spot caused by another one of holes **34**, a unique number of cells **38** is assigned to each hole **34**. The "assigned areas" are designated in FIG. **5** by the heavy grid lines **39**. It is to be understood that grid lines **39** are not actual physical boundaries between cells **38** but are shown simply to illustrate the unique designated areas containing a plurality of cells **38**. Other centroid strategies can be utilized that do not necessitate such partitioning of array **36**.

Since the wavefront sensor of the present invention does not focus each wavefront piece to a minimum at the surface of array **36**, a larger plurality of cells **38** are illuminated by each geometric spot so that the centroid of each spot can be determined to a greater precision than was previously possible.

The present invention could also be practiced with a wavefront analyzer that replaced plate **32** (FIG. **3**) with a two-dimensional array of identical spherical lenslets **33** as shown in FIG. **6**. To achieve the advantages of the present invention, array **33** is positioned by positioning apparatus **42** such that separation distance F is independent of the focal length f that defines the focal plane of array **33** which is represented by dashed line **35**. In other words, each wavefront piece (e.g., wavefront piece **37**) passed through a subaperture of array **33** is reduced in size (e.g., diameter) but is not necessarily brought to a minimum focus at array **36** as it would be if separation distance F were equal to focal length f. Thus, in practice, array **33** is positioned to concentrate the light in each wavefront piece over an area for sufficient intensity on planar array **36**, yet still illuminate a substantial plurality of cells **38** (as described above) for greatest accuracy in determining the deflection of the spot's centroid.

Regardless of the structure of the wavefront sensor, processor **40** computes each two-dimensional centroid of each spot generated by a wavefront **24**. The amount of two-dimensional centroid shift (relative to the centroid of the calibrating spot) for each designated area associated with a corresponding hole **34** (or subaperture of array **33**) is divided by the separation distance F to generate a matrix of local slopes of the wavefront, i.e., $\delta W(x,y)/\delta x$ and $\delta W(x,y)/\delta y$ at the (x,y), coordinates of the centers of holes **34**. For simplicity, these will be indicated by $P(x,y)=\delta W(x,y)/\delta x$ and $Q(x,y)=\delta W(x,y)/\delta y$, respectively.

Numerous methods exist for using the partial derivative data to calculate the original (distorted) wavefront. One acceptable approach is that used by Liang et al. in the aforementioned paper where the wavefront is approximated using Zernike polynomials. This is a standard analytic technique described in numerous optics texts such as "Principles of Optics," by M. Born and E. Wolf, Pergamon Press, Oxford, England, 1964. By way of example, the Zernike

polynomial approach will be discussed herein. However, it is to be understood that other mathematical approaches can be used in approximating the distorted wavefront.

Briefly, the wavefront W(x,y) is expressed as a weighted sum of the individual polynomials

$$W(x, y) = \sum_{i=0}^{n} C_i Z_i(x, y) \tag{4}$$

where C_i are the weighting coefficients, and $Z_i(x,y)$ are the Zernike polynomials up to some order. The upper limit n on the summation is a function of the number of Zernike polynomials, i.e., the highest order, used to approximate the true wavefront. If m is the highest order used, then

$$n=(m+1)(m+2)/2 \tag{5}$$

Derivation of the Zernike polynomials up to an arbitrary order n is described in numerous optical texts such as the aforementioned book by Born and Wolf.

One possible method of determining a centroid of a spot and calculation of the Zernike weighting coefficients will now be explained. The directions of the unit normals at the center of each hole **34** are based on the centroids of the spots on cells **38**. Since each spot will illuminate a plurality of cells with varying intensity, a standard amplitude-weighted centroid calculation can be used to find the center of each spot. Each centroid must be measured twice, once for perpendicular collimated light, and again for the wavefront to be analyzed. Of course, all spots are imaged simultaneously during each exposure.

Multiple exposures may be used to check for improper eye alignment or eye movement during individual exposures. If eye movement during exposures cannot be analyzed successfully by acquiring multiple exposures, then system **10** can be augmented by the addition of an eye tracker **25**. One possible placement of eye tracker **25** is shown in FIG. **2**. However, it is to be understood that eye tracker **25** could be placed elsewhere in system **10**. One such eye tracker is disclosed in the aforementioned U.S. patent application Ser. No. 08/232,615. In this way, wavefront analysis could be performed even during a limited amount of eye motion.

A one-time calibration exposure can also be used to determine the relative sensitivities of the individual cells. This is made in uniform collimated light with plate **32** removed. The responses of individual cells are then recorded.

For each light transmissive aperture (e.g., hole **34**), the centroid in the collimated case serves as a dedicated origin for the particular hole. The shift from the "origin" for each hole to the centroid caused by wavefront **24** (as observed in this coordinate system) is determined by the direction of the wave surface corresponding to that hole. If Δx(m,n) is the x-component of the (m,n)th centroid and F is the plate separation, then the P-value for the (m,n)th centroid is

$$P(m,n)=\delta x(m,n)/\delta z=\Delta x(m,n)/F \tag{6}$$

The corresponding expression for Q is:

$$Q(m,n)=\delta y(m,n)/\delta z=\Delta y(m,n)/F \tag{7}$$

Thus, each P(m,n) and Q(m,n) represents the partial derivatives of W(x,y) with respect to x and y for the (x,y) coordinates of each hole **34**. For an m-order Zernike approximation of the original wavefront, the experimentally determined P's and Q's are then used in the following equations to calculate the appropriate C_i weighting coefficients as follows:

$$P(m, n) = \frac{\delta W(x, y)}{\delta x} = \sum_{i=0}^{n} C_i \frac{\delta Z_i(x, y)}{\delta x} \tag{8}$$

$$Q(m, n) = \frac{\delta W(x, y)}{\delta x} = \sum_{i=0}^{n} C_i \frac{\delta Z_i(x, y)}{\delta x} \tag{9}$$

By using a least-squares approx(m,n)/δzach to minimize the error between the actual wavefront slopes on the left hand side in the above equations and the Zernike approximations on the right hand side, optimal values for the weighting coefficients can be obtained.

In one possible approach to calculating a centroid (x_c,y_c,) each hole **34** is assigned its dedicated area of the array **36** or ($i_{m,n}$±Δi, $j_{m,n}$±Δj). This square of many light-sensitive cells is large enough that neighboring hole images never encroach, and all illumination from this hole is contained. The square contains 4Δi*Δj cells.

If array **36** is designated $c_{k,1}$=(x_c(i,j),y_c(i,j)), k, 1=0 . . . 2Δ1, 2Δj, and the spacing on centers is Δx=Δy=d, the measured cell responses are V(k,1) and the relative responsivities are R(k,I), then the x-component x_c, a function of i,j is represented by

$$x_c(i,j)=[\Sigma_{k,1}V(k,1)*R(k,1)*d*k]/[\Sigma_{k,1}V(k,1)*R(k,1)] \tag{10}$$

and the y-component y_c, as a function of i,j is represented by

$$y_c(i,j)=[\Sigma_{k,1}V(k,1)*R(k,1)*d*1]/[\Sigma_{k,1}V(k,1)*R(k,1)] \tag{11}$$

Then, if (x_{c0}(i,j), y_{c0}(i,j)) is the "origin centroid" for the (i,j) hole, i.e., made in perpendicular collimated light, and (x_{cw}(i,j), y_{cw}(i,j)) is the corresponding centroid found for the wavefront to be measured, then the relative centroid shift (x_{cr}(i,j), Y_{cr}(i,j)) is found as

$$x_{cr}(i,j)=x_{cw}(i,j)-x_{c0}(i,j) \tag{12}$$

$$y_{cr}(i,j)=y_{cw}(i,j)-y_{c0}(i,j) \tag{13}$$

The values P(i,j) and Q(i,j) are determined from

$$P(i,j)=x_{cr}(i,j)/F \tag{14}$$

and

$$Q(i,j)=y_{cr}(i,j)/F \tag{15}$$

The surface partial derivatives P(i,j) and Q(i,j) for the array of hole centers of plate **32** are next used to calculate the appropriate Zernike polynomial weighting coefficients to describe the original wavefront W(x,y). This will now be explained by way of illustration for a 7×7 square array of holes **34**. However, it is to be understood that other sizes and shapes of hole arrays could be used.

First, a 1×98 matrix (i.e., column vector) PQ(k) is formed as

$$PQ(k)=P(7i+j),\ j=0 \ldots 6,\ i=0 \ldots 6,\ k=0 \ldots 48 \tag{16}$$

$$PQ(k)=Q(7i+j),\ j=0 \ldots 6,\ i=0 \ldots 6,\ k=49 \ldots 98 \tag{17}$$

with j cycling for each i, i.e., PQ (18)=P(2,5).

The matrix PQ is multiplied from the left with a transition matrix TM to get the matrix C as follows

$$C=TM*PQ \tag{18}$$

where TM is a 98 wide by 14 high matrix and C is a 1 wide by 14 high matrix or column vector. C is the matrix C_k k=1, . . . , 14 such that, to a least square error,

$$W(x,y)=\Sigma_k C_k * Z_k(x,y) \quad (19)$$

and TM is calculated for a given aperture, e.g., a 6 millimeter pupil aperture.

The functions Z_k (x,y) in equation (19) are the Zernike polynomials. There is no standard convention as to their sequence. Thus, for consistency, it is important that the same sequence is used to produce the set C_k that was chosen for deriving the matrix TM. They occur in groups of the same order, which is the highest exponent in the group, with the total number of members in an order increasing with the order. For example, in a fourth order analysis, orders up to and including 4 are used (less Z_0—the single member of order 0 that is the constant 1 which describes the reference position of the group in the z direction). Since wavefront **24** is moving along z (at the velocity of light), this "piston term" describes only an arbitrary offset in Z, and this term may be ignored. The first 5 orders (0, 1, . . . ,4) contain 15 functions including the piston term.

Thus, in the illustrated example, 14 values of C_k are calculated as coefficients of 14 Zernike polynomials. By way of example, one such order used to calculate TM is given in Table 1, which includes both the Zernike functions and their partial derivatives.

TABLE 1

ZERNIKE (X,Y) POLYNOMIAL EXPANSION THROUGH ORDER 4

	Polynomial Order 0
Z(0)	+1
dZ(0)/dx	0.0
DZ(0)/dy	0.0
	Polynomial Order 1
Z(1)	+y
dZ(1)/dx	0.0
dZ(1)/dy	+1
Z(2)	+x
dZ(2)/dx	+1
dZ(2)/dy	0.0
	Polynomial Order 2
Z(3)	$+1 + 2y^2 + 2x^2$
dZ(3)/dx	+4x
dZ(3)/dy	+4y
Z(4)	+2xy
dZ(4)/dx	+2y
dZ(4)/dy	+2x
Z(5)	$-y^2 + x^2$
dZ(5)/dx	+2x
dZ(5)/dy	−2y
	Polynomial Order 3
Z(6)	$-2y + 3y^3 + 3x^2y$
dZ(6)/dx	+6xy
dZ(6)/dy	$-2 + 9y^2 + 3x^2$
Z(7)	$-2x + 3xy^2 + 3x^3$
dZ(7)/dx	$-2 + 3y^2 + 9x^2$
dZ(7)/dy	+6xy
Z(8)	$-y^3 + 3x^2y$
dZ(8)/dx	+6xy
dZ(8)/dy	$-3y^2 + 3x^2$
Z(9)	$-3xy^2 + x^3$
dZ(9)/dx	$-3y^2 + 3x^2$
dZ(9)/dy	−6xy
	Polynomial Order 4
Z(10)	$+1 - 6y^2 + 6y^4 - 6x^2 + 12x^2y^2 + 6x^4$
dZ(10)/dx	$-12x + 24xy^2 + 24x^3$
dZ(10)/dy	$-12y + 24y^3 + 24x^2y$
Z(11)	$-6xy + 8xy^3 + 8x^3y$
dZ(11)/dx	$-6y + 8y^3 + 24x^2y$
dZ(11)/dy	$-6x + 24xy^2 + 8x^3$
Z(12)	$+3y^2 - 4y^4 - 3x^2 + 4x^4$
dZ(12)/dx	$-6x + 16x^3$
dZ(12)/dy	$+6y - 16y^3$
Z(13)	$-4xy^3 + 4x^3y$
dZ(13)/dx	$-4y^3 + 12x^2y$
dZ(13)/dy	$-12xy^2 + 4x^3$
Z(14)	$+y^4\ 6x^2y^2 + x^4$
dZ(14)/dx	$-12xy^2 + 4x^3$
dZ(14)/dy	$+4y^3 - 12x^2y$

The choice of sequencing the Zernike polynomials dictates the interpretations of the C_k in equation (19) and therefore the order of terms in the TM matrix. Hence, the TM matrix must be calculated after the choice is made. The development of the TM matrix for the illustrated example will be explained below.

Note that the fourth order analysis is only an example and is not the only possibility. A Zernike analysis can be done to any order. In general, the higher the order, the more accurate the result over the tested points. However, an exact polynomial fit over the tested points is not necessarily desirable. Such fits have the typical disturbing property that, unless the surface itself happens to be an exact polynomial of order no higher than that used for the surface fit, forcing an exact fit at separated points often causes wild swings between fitted points. That is, in polynomial surface fitting, an exact fit at a finite number of points can yield a poor average fit for a general function. For ophthalmic application of the system as described above, computer simulations suggest that a sixth order Zernike analysis may yield the best results.

Calculation of the $\Delta z(x,y)$ optical path difference information from the Zernike reconstruction of the wavefront is accomplished simply by subtracting a constant from the Zernike approximation. The value of the constant will depend on the desired characteristics of $\Delta z(x,y)$. Depending on the method chosen to correct the aberrations (e.g., laser ablation, lens addition, etc.) it may, for example, be desirable to set either the maximum, mean or minimum value in $\Delta z(x,y)$ equal to zero.

The development of the transition matrix TM will now be explained for the illustrated example of a 7×7 array of holes in plate **32**. At each point (x_i,y_j), the tangents of the components of the normal are $P(x_i,y_j)$ and $Q(x_i,y_j)$ where

$$P(x_i,y_j)=\delta W(x_i, y_j)/\delta x \quad (20)$$

and

$$Q(x_i,y_j)=\delta W(x_i,y_j)/\delta y \quad (21)$$

Combining these with equation (11),

$$P(x_i,y_j)=\Sigma_k C_k \delta W(x_i,y_j)/\delta x \quad (22)$$

and

$$Q(x_i,y_j)=\Sigma_k C_k \delta W(x_i,y_j)/\delta y \quad (23)$$

each applicable to 49 (i,j) combinations. These are combined into a single column vector PQ that is 98 elements high, i.e., a 98×1 matrix. Defining two matrices C_k (14 high×1 wide) and $M_{k(i,j)}$ (14 wide×98 high)

$$(M_{k,(i,j)})=\delta Z_k(x_i,y_j)/\delta x;\ \delta Z_k(x_i,y_j)/\delta y \quad (24)$$

where the x-derivatives are the first 49 rows and the y-derivatives are the last 49 rows. Then, equation (19) can be rewritten as the matrix equation

$$(PQ)=(M)(C) \tag{25}$$

where the top 49 rows of M are the $\delta W(x_i, y_j)/\delta y$.

The expression in equation (25) gives the normal components in terms of the Zernike coefficients for a surface described by the array of 14 C's. These are exact, but it is not guaranteed that the actual total surface can be described by such an array of coefficients. Accordingly, if it is assumed that the description is within an acceptable tolerance, i.e., tolerating the errors that remain after least square error determination, then equation (26) can be considered to define the column vector C implicitly in terms of the mathematical matrix M and the measured vector PQ, both of which are known. The method of effecting the solution under the minimization condition is as follows.

First, equation (25) is multiplied on the left by M^T, the transpose of M such that

$$(M^T)(PQ)=(M^T)(M)(C)=(S)(C) \tag{26}$$

where

$$S\equiv M^T M \tag{27}$$

is a square and symmetric matrix, e.g., of dimensions 14×14 (with each element the sum of 98 products). Such a matrix has an inverse unless the determinant of its coefficients is zero. Since this is based on the Zernike polynomials alone, and they are all independent of each other, the determinant is non-zero, so that an inverse S^{-1} is defined. Next, equation (25) is multiplied on the left by S^{-1} to yield

$$(S^{-1})(M^T)(PQ)=(S^{-1})(S)(C)=(I)(C)=C \tag{28}$$

Then, the mathematical transition matrix (independent of measurement) is

$$(TM)=(S^{-1})(M^T) \tag{29}$$

and the "best fit" array of C's from the measured PQ's can be produced by the simple matrix multiplication

$$(C)=(TM)(PQ) \tag{30}$$

To evaluate the eye unambiguously, all spots illuminating planar array **36** due to a wavefront **24** must be incident on planar array **36** simultaneously. This is achieved by pulsing or shuttering the laser source (i.e., laser **12**) such that pulse duration is less than the saccadic motion interval of the eye, i.e., a few milliseconds. Alternatively, the laser source could be left on continuously and wavefront **24** could be shuttered to appear as a wavefront pulse of a duration that is less than saccadic motion of the eye. Accordingly, as shown in FIG. **2**, shutter **50** could be positioned in the path of laser beam **18** before eye **120** or in the path of wavefront **24** before wavefront analyzer **26**.

An implementation of the present invention suitable for clinical use is shown schematically in FIG. **7** and is referenced generally by numeral **11**. Like reference numerals are used to describe elements that are the same as those described above with respect to system **10**. Accordingly, the like elements and their functions will not be described further.

A dichroic beam splitter **52** is interposed between beam splitter **20** and optical train **22** to introduce fixation target optics **60** and observation optics **70** into system **11** which are optically separated from one another by 50/50 beam splitter **54**. Functionally, fixation target optics provide eye **120** with visible light in the shape of a target. The visible light generated by fixation target optics **60** is reflected by dichroic beam splitter **50** and directed through optical train **22**.

It is to be understood that fixation target optics **60** can be implemented in a variety of fashions. By way of example, one such embodiment is shown and includes visible light source **61**, light diffuser **62**, target **63**, field stop **64**, lens **65** and iris **66**. Light source **61** and light diffuser **62** are used to provide uniform illumination of fixation target **63**. Field stop **64**, lens **65**, and iris **66** are used in conjunction with optical train **22** to present a clear image of the fixation target to (patient) eye **120**.

Functionally, observation optics **70** allows a technician to view and document the eye evaluation procedure. While a variety of implementations of observation optics **70** are possible, one such implementation is shown by way of example. In FIG. **7**, observation optics **70** includes field lens **71**, lens **72**, iris **73**, lens **74**, and camera **75**. A ring illuminator **80** is placed in front of eye **120** to illuminate same for observation and/or filming purposes.

The output from wavefront analyzer **26**, e.g., the Zernike expansion of equation (19), can be used in a variety of ways. For example, the output could be used to continually or periodically monitor the progress or effects of an ophthalmic procedure. The output could also be used to develop an optical correction for eye **120**. The optical correction will make wavefront **24** appear approximately as a plane wave. As described above, the optical correction can be implemented in a variety of ways. In each case, the output of wavefront analyzer **26** is input to a processor **90** which converts the Zernike expansion of equation (19) into a form suitable for being implemented as one of the possible optical corrections. (The functions of processor **90** could also be implemented at processor **40** of wavefront analyzer **26**.)

Processor **90** could use some of the Zernike coefficients from the expansion of equation (19) to generate a standard sphero-cylindrical correction for lens grinder **92** to produce a conventional optical lens, e.g., a lens for glasses, a contact lens, etc. Processor **90** could also divide the Zernike reconstruction of the aberrated wavefront by the index of refraction of cornea **126** minus 1, to calculate the amount of corneal material to be ablated at each corresponding (x,y) location on the cornea. The amount of corneal material at each location is input to a laser beam delivery system that typically has eye tracking capability **94** such as described in the afore-mentioned U.S. patent application Ser. No. 08/232,615. Laser beam delivery and eye tracker **94** is placed in line with the optical axis of system **11**. The eye tracker portion of this element allows system **11** to respond unwanted eye motion. Laser beam delivery and eye tracker **94** would typically focus short pulses or "shots" of ablating laser light at cornea **126** or eye **120** to remove the specified thickness t of material at each location. This is shown diagrammatically in FIG. **8** where the uncorrected surface of cornea **126** is referenced by numeral **126**A and the corrected surface of cornea **126** after ablation is referenced by numeral **126**B.

In accordance with the present invention, ablation thickness t is specified across the aperture of the cornea measured, e.g., the 6 millimeter circle to which the eye's pupil was dilated during the measurement of the eye. Outside the prescribed treatment circle, a tapering blend zone of partial ablation may be added to minimize severe changes in corneal curvature and hence lessen regression. Laser beam delivery system **94** removes thickness t to achieve the optical correction, i.e., corrected cornea surface **126**B. Note that the optical correction is not concerned with the ultimate corneal topography, but instead removes corneal material to achieve an optical correction that takes into account all ocular aberrations of the eye. This is important because the shape of the corneal surface can be independent of the

correction required because the eye's vision depends on numerous factors besides corneal curvature. Hence, the best corneal surface topography for optimal vision may be far from regular in that it must compensate for the errors in the eye's other surfaces. Thus, it is apparent that the present invention can be used to provide corneal surface corrections other than the conventional spherical and/or cylindrical corrections.

The advantages of the present invention are numerous. A totally objective approach is presented for measuring ocular aberrations. The approach is effective for a wide range of vision defects. Accordingly, the present invention will be of great utility in a wide variety of clinical applications. For example, the calculated Zernike coefficients can be used to develop a completely objective lens prescription or a corneal correction that could be accomplished with laser ablation. In addition, each of the wavefront sensor embodiments provides for a greater degree of accuracy over the prior art with respect to measuring wavefront deflections. Further, the present wavefront sensor can be adjusted in terms of gain simply by adjusting the separation distance between the imaging plane of the sensor and the planar array of light-sensitive cells.

The objective measurement of the present invention will also find great utility for a large variety of applications in which the "patient" is unable to provide feedback as required by conventional eye diagnosis. For example, the present invention could be used to evaluate the eyes of any patient not possessed of demonstrative communicative skills, e.g., babies, animals, dead specimens, as well as any constructed optical system, since the present invention is an objective analysis not requiring any assessment from the "subject." All that is necessary is for the subject's eye to be properly positioned so that proper optical access to the eye can be obtained.

The present invention could also be used in the area of identification should it be determined that each eye's Zernike coefficients are unique. Then, the present invention would find great utility in the fields of law enforcement, credit card/bank security, or any other field where positive identification would be beneficial.

Although the invention has been described relative to a specific embodiment thereof, there are numerous variations and modifications that will be readily apparent to those skilled in the art in light of the above teachings. It is therefore to be understood that, within the scope of the appended claims, the invention may be practiced other than as specifically described.

That which is claimed is:

1. A system comprising:

an energy source for generating a beam of optical radiation;

focusing optics disposed in the path of said beam for directing said beam through a focusing optical system having a rear portion thereof functioning as a diffuse reflector, wherein said beam is diffusely reflected back from said rear portion as a wavefront of radiation that passes through said focusing optical system to impinge on said optics, said optics projecting said wavefront in direct correspondence with said wavefront impinging on said optics, said focusing optics comprising

a first lens maintained in a first fixed position in the path of said beam and said wavefront;

a second lens maintained in a second fixed position in the path of said beam and said wavefront; and

an arrangement of optical elements disposed between said first lens and said second lens in the path of said beam and said wavefront, said arrangement of optical elements being adjustable for changing the optical path length between said first lens and said second lens; and

a wavefront analyzer disposed in the path of said wavefront projecting from said optics for calculating distortions of the wavefront as an estimate of aberrations of said focusing optical system.

2. A system as in claim **1** wherein said energy source comprises:

a collimated laser for generating collimated laser light; and

an iris diaphragm disposed in the path of said collimated laser light to project a collimated core of said collimated laser light, wherein said collimated core is said beam of radiation having a diameter in the range of approximately 0.5 millimeters to approximately 4.5 millimeters.

3. A system as in claim **1** wherein said wavefront analyzer includes a wavefront sensor for dividing said wavefront into a plurality of optical radiation beams, wherein a focal plane of said first lens is at said wavefront sensor, and wherein a focal plane of said second lens is at an object plane of said focusing optical system.

4. A system as in claim **1** wherein said focusing optical system is an eye and wherein said wavefront analyzer includes a wavefront sensor for dividing said wavefront into a plurality of optical radiation beams, wherein a focal plane of said first lens is at said wavefront sensor, and wherein a focal plane of said second lens is at the pupil of said eye.

5. A system as in claim **1** wherein said wavefront analyzer is a Hartmann-shack wavefront analyzer.

6. A system as in claim **1** wherein said focusing optical system is any eye and further comprising means for causing said beam to occur as a pulse of duration that is less than the saccadic motion interval of said eye.

7. A system as in claim **1** wherein said focusing optical system is any eye and further comprising means for causing said wavefront to appear to said wavefront analyzer as a pulse of duration that is less than the saccadic motion interval of said eye.

8. A system as in claim **1** wherein said focusing optical system is any eye and further comprising a fixation target generator for generating visible light in the shape of a target, said fixation target generator arranged so that said visible light is directed through said optics wherein said visible light can be viewed by said eye.

9. A system as in claim **1** further comprising a converter for converting said distortions to an optical correction which, if placed in the path of said wavefront, causes said wavefront to appear approximately as a plane wave.

10. A system as in claim **9** wherein said converter converts said distortions to a lens prescription, and wherein said optical correction is achieved by a lens based on said lens prescription.

11. A system as in claim **9** wherein said optical system is an eye and wherein said converter converts said distortions to an amount of corneal material of complex geometric shape to be ablated from said eye, said system further comprising a laser beam delivery system for bombarding said eye with a plurality of small-diameter laser beam pulses of a wavelength and power that ablates said corneal material, wherein said optical correction is achieved by the removal of said amount of corneal material.

12. A system as in claim **11** wherein said laser beam delivery system further includes an eye tracker for monitoring motion of said eye and for adjusting the positions of said

plurality of small-diameter laser beam pulses in correspondence with said motion.

13. A system as in claim **9** wherein said optical system is an eye and wherein said converter converts said distortions to a prescribed alteration of corneal surface curvature of said eye, and wherein said optical correction is achieved by the reshaping of said corneal surface curvature of said eye based on said prescribed alteration.

14. A system as in claim **1** wherein said optical system is an eye and further comprising an eye tracker for monitoring motion of said eye.

15. A system comprising:

an energy source for generating a beam of radiation;

optics disposed in the path of said beam for directing said beam through a focusing optical system having a rear portion thereof functioning as a diffuse reflector, wherein said beam is diffusely reflected back from said rear portion as a wavefront of radiation that passes through said focusing optical system to impinge on said optics, said optics projecting said wavefront in direct correspondence with said wavefront impinging on said optics; and

a wavefront analyzer disposed in the path of said wavefront projecting from said optics for calculating distortions of the wavefront as an estimate of aberrations of said focusing optical system, said wavefront analyzer comprising

a plate that is light impervious except for an array of light transmissive apertures that allow impinging light to pass therethrough, said plate disposed in the path of said wavefront wherein portions of said wavefront pass through said array of light transmissive apertures;

a planar array of light-sensitive cells arranged parallel to and spaced apart from said plate by a selected distance, wherein each of said portions of said wavefront passing through one of said array of light transmissive apertures illuminates a geometric shape covering a unique plurality of cells from said planar array of cells;

a processor coupled to said planar array of cells for calculating said distortions based on a centroid of each said geometric shape; and

means for adjusting said selected distance between said plate and said planar array of cells.

16. A system as in claim **15** wherein each light transmissive aperture in said array of light transmissive apertures is of equal size.

17. A system as in claim **15** wherein each light transmissive aperture insaid array of light transmissive apertures is circular.

18. A system as in claim **15** wherein said array of light transmissive apertures is a square array.

19. A system as in claim **15** wherein said radiation is optical radiation and wherein said focusing optics comprises:

a first lens maintained in a first fixed position in the path of said beam and said wavefront;

a second lens maintained in a second fixed position in the path of said beam and said wavefront; and

an arrangement of optical elements disposed between said first lens and said second lens in the path of said beam and said wavefront, said arrangement of optical elements being adjustable for changing the optical path length between said first lens and said second lens.

20. A system comprising:

an energy source for generating a beam of optical radiation;

focusing optics disposed in the path of said beam for directing said beam through a focusing optical system having a rear portion thereof functioning as a diffuse reflector, wherein said beam is diffusely reflected back from said rear portion as a wavefront of radiation that passes through said focusing optical system to impinge on said optics, said optics projecting said wavefront in direct correspondence with said wavefront impinging on said optics, said focusing optics comprising

a first lens maintained in a first fixed position in the path of said beam and said wavefront;

a second lens maintained in a second fixed position in the path of said beam and said wavefront; and

an arrangement of optical elements disposed between said first lens and said second lens in the path of said beam and said wavefront, said arrangement of optical elements being adjustable for changing the optical path length between said first lens and said second lens; and

a wavefront analyzer disposed in the path of said wavefront projecting from said optics for calculating distortions of the wavefront as an estimate of aberrations of said focusing optical system, said wavefront analyzer comprising

a two-dimensional array of spherical lenslets that defines a focal plane that is a focal length away from said two-dimensional array of spherical lenslets, said two-dimensional array of spherical lenslets disposed in the path of said wavefront wherein portions of said wavefront pass through said two-dimensional array of spherical lenslets;

a planar array of light-sensitive cells arranged parallel to and spaced apart from said two-dimensional array of spherical lenslets by a selected distance independent of said focal length, wherein each of said portions of said wavefront passing through said two-dimensional array of spherical lenslets illuminates a geometric shape covering a unique plurality of cells from said planar array of cells;

a processor coupled to said planar array of CCD cells for calculating said distortions based on a centroid of each said geometric shape; and

means for adjusting said selected distance between said two dimensional array of spherical lenslets and said planar array of cells.

21. A system as in claim **20** wherein said optics comprises:

a first lens maintained in a first fixed position in the path of said beam and said wavefront;

a second lens maintained in a second fixed position in the path of said beam and said wavefront; and

an arrangement of optical elements disposed between said first lens and said second lens in the path of said beam and said wavefront, said arrangement of optical elements being adjustable for changing the optical path length between said first lens and said second lens.

22. An optical wavefront sensor, comprising:

a plate that is light impervious except for an array of light transmissive apertures that allow impinging light to pass therethrough, said plate disposed in the path of an optical wavefront wherein portions of said optical wavefront pass through said array of light transmissive apertures;

a planar array of lightsensitive cells arranged parallel to and spaced apart from said plate by a selected distance,

wherein each of said portions of said optical wavefront passing through one of said array of light transmissive apertures illuminates a geometric shape covering a unique plurality of cells from said planar array of cells; and

means for adjusting said selected distance between said plate and said planar array of cells.

23. An optical wavefront sensor as in claim **22** wherein each light transmissive aperture in said array of light transmissive apertures is of equal size.

24. An optical wavefront sensor as in claim **22** wherein each light transmissive aperture in said array of light transmissive apertures is circular.

25. An optical wavefront sensor as in claim **22** wherein said array of light transmissive apertures is a square array.

26. An optical wavefront sensor as in claim **22** further comprising a processor coupled to said planar array of cells for determining a centroid of each said geometric shape.

27. A method comprising the steps of:

generating a beam of optical radiation;

focusing said beam with focusing optics into an eye to image said beam as a focused spot forming a near-diffraction limited image at a back portion of the retina of said eye, wherein said beam is diffusely reflected back from the retina as a wavefront of radiation that passes through said eye;

allowing said wavefront to impinge on said focusing optics;

projecting, with said focusing optics, said wavefront in direct correspondence with said wavefront impinging on said focusing optics;

calculating distortions associated with said wavefront projecting from said focusing optics using a wavefront analyzer disposed in the path of said wavefront projecting from said focusing optics, wherein said wavefront analyzer includes a plate that is light impervious except for an array of light transmissive apertures that allow impinging light to pass therethrough, said plate disposed in the path of said wavefront wherein portions of said wavefront pass through said array of light transmissive apertures, and a planar array of light-sensitive cells arranged parallel to and spaced apart from said plate by a selected distance, wherein each of said portions of said wavefront passing through one of said array of light transmissive apertures illuminates a geometric shape covering a unique plurality of cells from said planar array of cells; and

adjusting said selected distance to adjust the gain of said wavefront analyzer.

28. A method according to claim **27** wherein said step of generating comprises the steps of: producing collimated laser light; and selecting a collimated core of said collimated laser light as said beam of optical radiation having a diameter in the range of approximately 0.5 millimeters to approximately 4.5 millimeters.

29. A method according to claim **27** wherein said step of focusing comprises the steps of:

fixing a first lens in a first position in the path of said beam and said wavefront;

fixing a second lens in a second position in the path of said beam and said wavefront; and

positioning an arrangement of optical elements between said first lens and said second lens in the path of said beam and said wavefront; and

adjusting positions of said arrangement of optical elements to change the optical path length between said first lens and said second lens.

30. A method according to claim **29** wherein said wavefront analyzer includes a wavefront sensor for dividing said wavefront into a plurality of optical radiation beamed wherein said step of fixing said first lens includes the Step of locating a focal plane of said first lens at said wavefront sensor, and wherein said step of fixing said second lens includes the step of locating a focal plane of said second lens at the pupil of said eye.

31. A method according to claim **27** wherein said step of focusing comprises the steps of:

fixing a first lens in a first position in the path of said beam and said wavefront;

fixing a second lens in a second position in the path of said beam and said wavefront; and

positioning an arrangement of optical elements between said first lens and said second lens in the path of said laser beam and said wavefront; and

adjusting positions of said arrangement of optical elements to change the optical path length between said first lens and said second lens.

32. A method according to claim **27** further comprising the step of Shattering said beam such that a pulse is directed through said focusing optics said pulse having a duration that is less than the saccadic motion interval of said eye.

33. A method according to claim **27** further comprising the step of puttering said wavefront such that said wavefront appears to said wavefront analyzer as a pulse of duration that is less than the saccadic motion interval of said eye.

34. A method according to claim **27** further comprising the steps of: generating visible light in the shape of a target; and directing said visible light through said focusing optics wherein said visible light can be viewed by said eye.

35. A method according to claim **27** further comprising the step of converting said distortions to an optical correction which, if placed in the path of said wavefront, causes said wavefront to appear approximately as a plane wave.

36. A method according to claim **35** wherein said optical correction is in the form of a lens.

37. A method according to claim **35** wherein said optical correction is in the form of an amount of corneal material to be ablated from said eye.

38. A method according to claim **35** wherein said optical correction is in the form of prescribed alteration of corneal surface curvature of said eye.

39. A method according to claim **27** further comprising the step of dilating the pupil of said eye to a size achieved in a low-light environment, said step of dilating being accomplished prior to said steps of focusing, allowing and projecting.

40. A method according to claim **27** further comprising the Steps of: performing an ophthalmic procedure on said eye; and performing said steps of generating, focusing, allowing, projecting and calculating at least once after said ophthalmic procedure has commenced to monitor the effects of said ophthalmic procedure on said eye.

41. A method according to claim **27** wherein said step of calculating comprises the step of calculating Zernike coefficients associated with said distortions.

42. A method comprising the steps of:

generating a beam of optical radiation;

focusing said beam with focusing optics into an eye to image said beam as a focused spot forming a near-diffraction limited image at a back portion of the retina of said eye, wherein said beam is diffusely reflected back from the retina as a wavefront of radiation that passes through said eye;

allowing said wavefront to impinge on said focusing optics;

projecting, with said focusing optics, said wavefront in direct correspondence with said wavefront impinging on said focusing optics;

calculating distortions associated with said wavefront projecting from said focusing optics using a wavefront analyzer disposed in the path of said wavefront projecting from said focusing optics, wherein said wavefront analyzer includes a two-dimensional array of spherical lenslets that defines a focal plane that is a focal length away from said two-dimensional array of spherical lenslets, said two-dimensional array of spherical lenslets disposed in the path of said wavefront wherein portions of said wavefront pass through said two-dimensional array of spherical lenslets, and a planar array of lightsensitive cells arranged parallel to and spaced apart from said two-dimensional array of spherical lenslets by a selected distance not equal to said focal length, wherein each of said portions of said wavefront passing through said two-dimensional array of spherical lenslets illuminates a geometric shape covering a unique plurality of cells from said planar array of cells having an array of holes passing therethrough; and

adjusting said selected distance to adjust the gain of said wavefront analyzer.

43. A method according to claim **42** wherein said step of focusing comprises the steps of: fixing a first lens in a first position in the path of said beam and said wavefront; fixing a second lens in a second position in the path of said beam and said wavefront; and positioning an arrangement of optical elements between said first lens and said second lens in the path of said beam and said wavefront; and adjusting positions of said arrangement of optical elements to change the optical path length between said first lens and said second lens.

* * * * *

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(12) **United States Patent**
Frey et al.

(10) **Patent No.: US 6,271,914 B1**
(45) **Date of Patent: Aug. 7, 2001**

(54) **OBJECTIVE MEASUREMENT AND CORRECTION OF OPTICAL SYSTEMS USING WAVEFRONT ANALYSIS**

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(73) Assignee: **Autonomous Technologies Corporation**, Orlando, FL (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/662,083**

(22) Filed: **Sep. 14, 2000**

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(63) Continuation of application No. 09/324,179, filed on May 20, 1998, now abandoned, which is a continuation of application No. 08/756,272, filed on Nov. 25, 1996, now abandoned.

(51) **Int. Cl.**[7] **G01B 9/00**
(52) **U.S. Cl.** **356/124**
(58) **Field of Search** 356/124; 606/5

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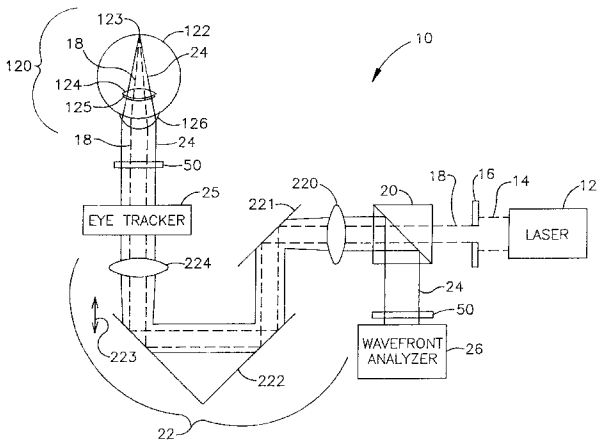
(57) **ABSTRACT**

Vision in an eye is corrected using an energy source for generating a beam of optical radiation and focusing optics disposed in the path of the beam for directing the beam through the eye, where the beam is reflected back from the retina of the eye as a wavefront of radiation to be measured. An optical correction based on an optical path difference between the measured wavefront and a desired plane wave, and refractive indices of the media through which the wavefront passes is provided to a laser delivery system with a laser beam sufficient for ablating corneal material from the cornea of the eye. The laser beam is directed at selected locations on the cornea for ablating the corneal material in response to the optical correction to cause the measured wavefront to approximate the desired plane wave, and thus provide an optical correction.

40 Claims, 9 Drawing Sheets



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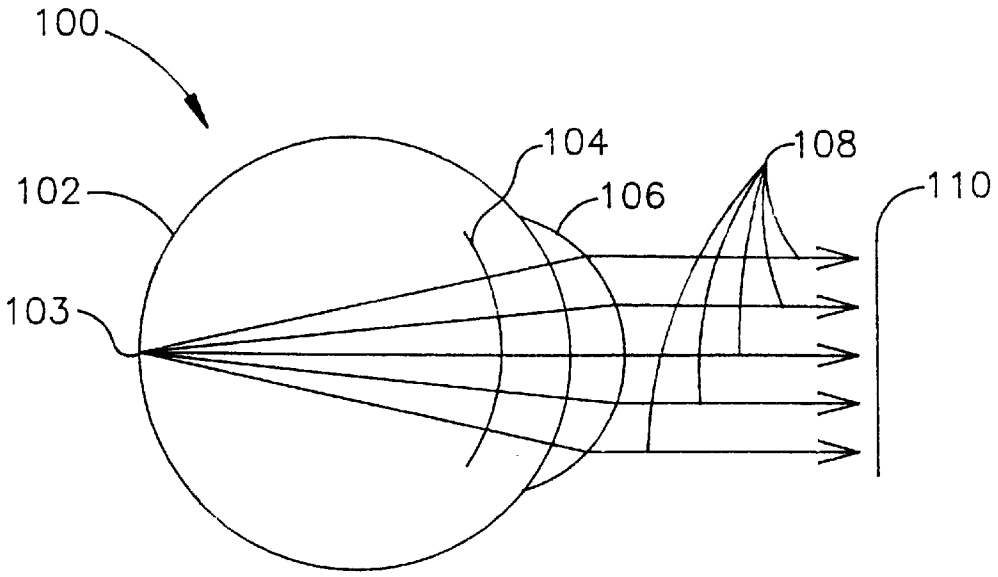

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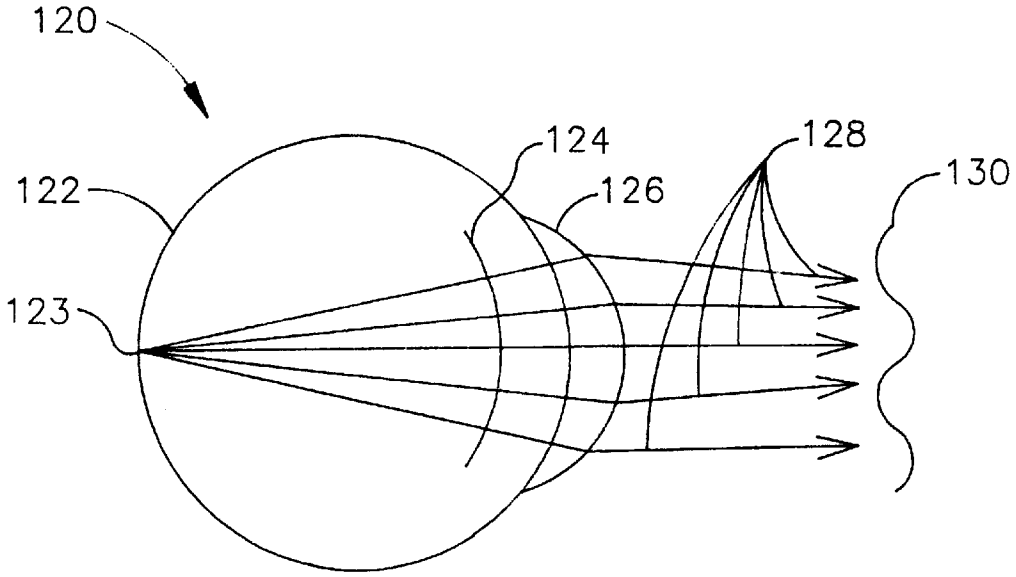

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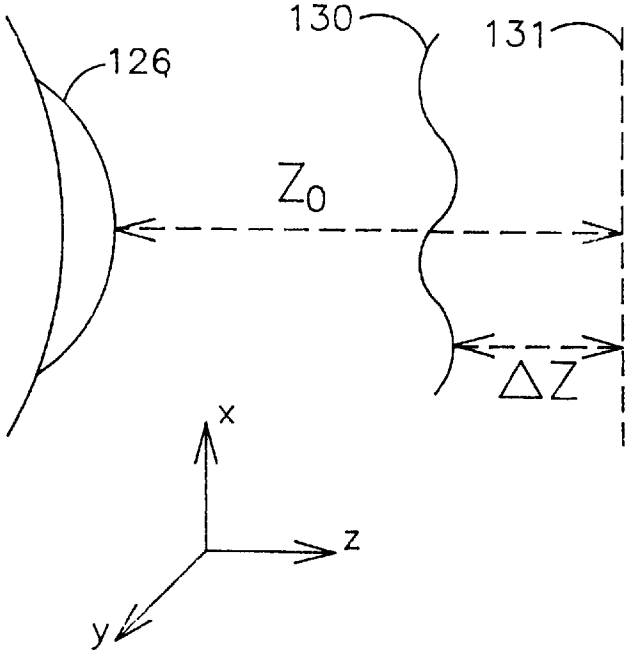

130
131
126
Z_0
ΔZ
x
z
y

FIG. 1C

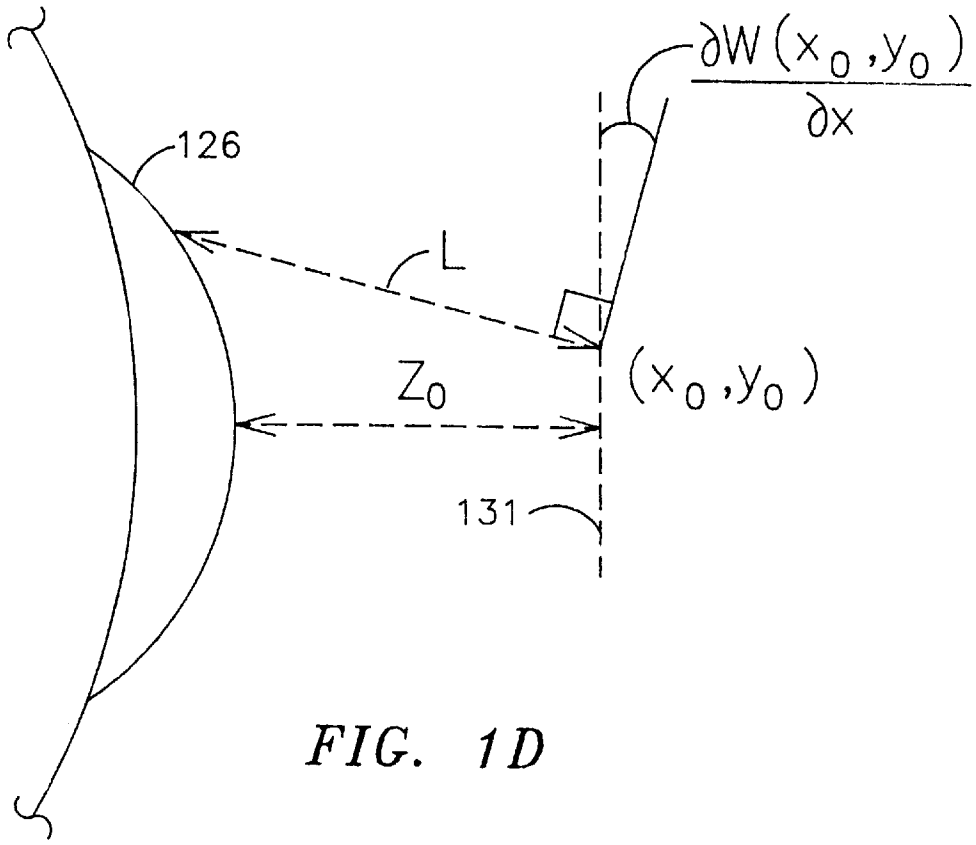
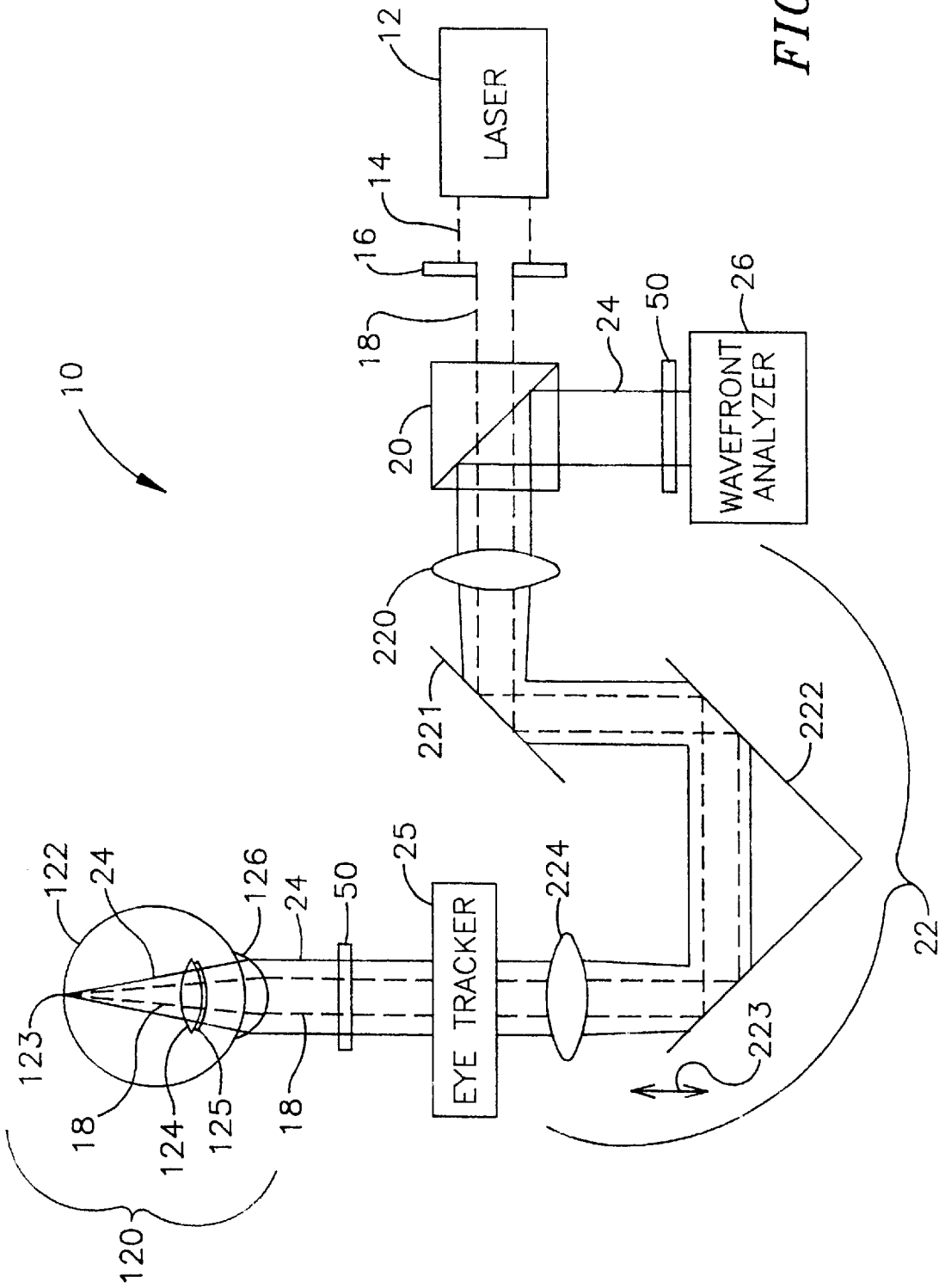

$\frac{\partial W(x_0, y_0)}{\partial x}$
126
L
Z_0
(x_0, y_0)
131

FIG. 1D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12
LASER
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16
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24
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WAVEFRONT ANALYZER
220
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25
EYE TRACKER
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18
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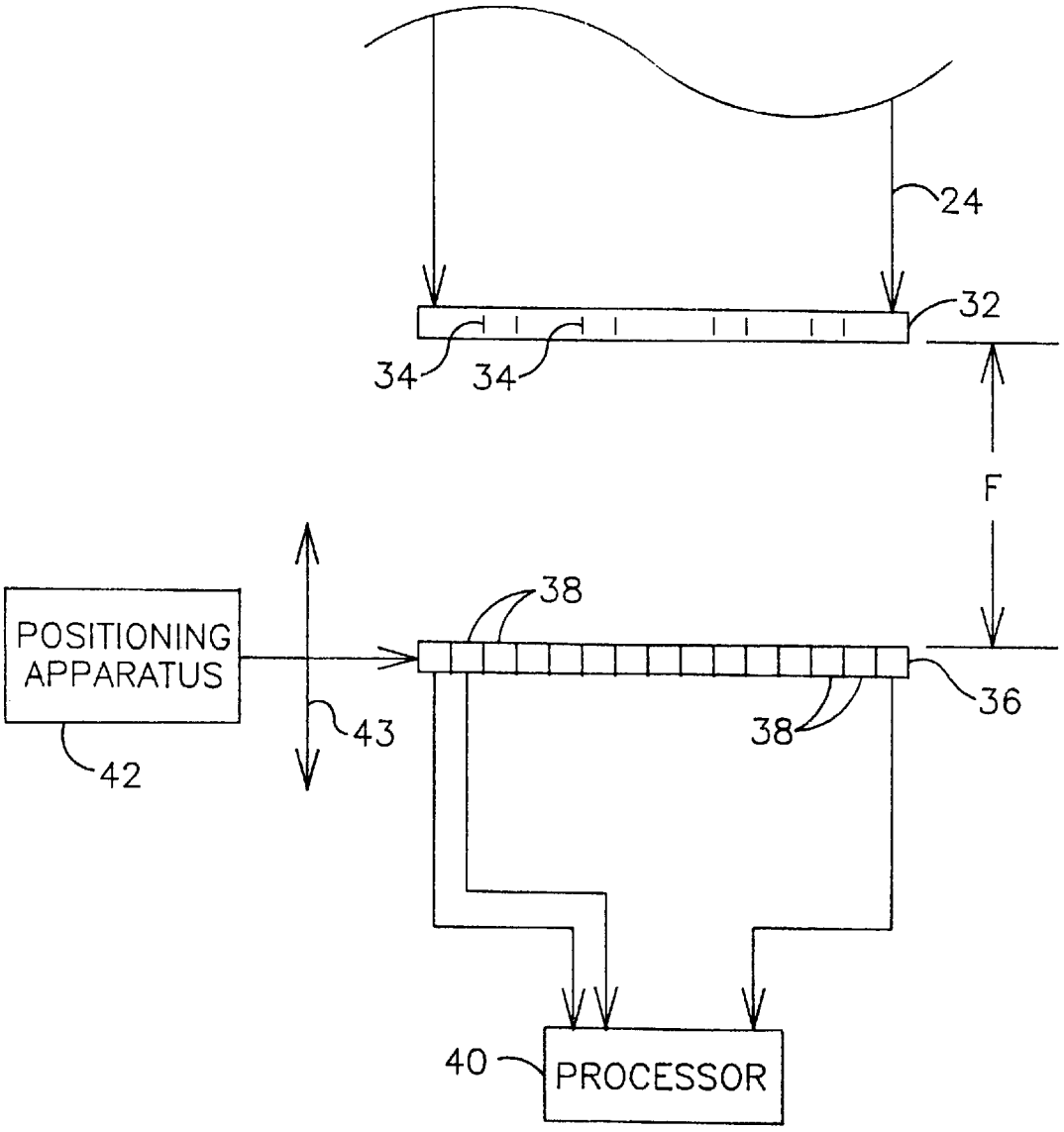
FIG. 2


24
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F
38
POSITIONING APPARATUS
43
38
36
42
40
PROCESSOR

FIG. 3

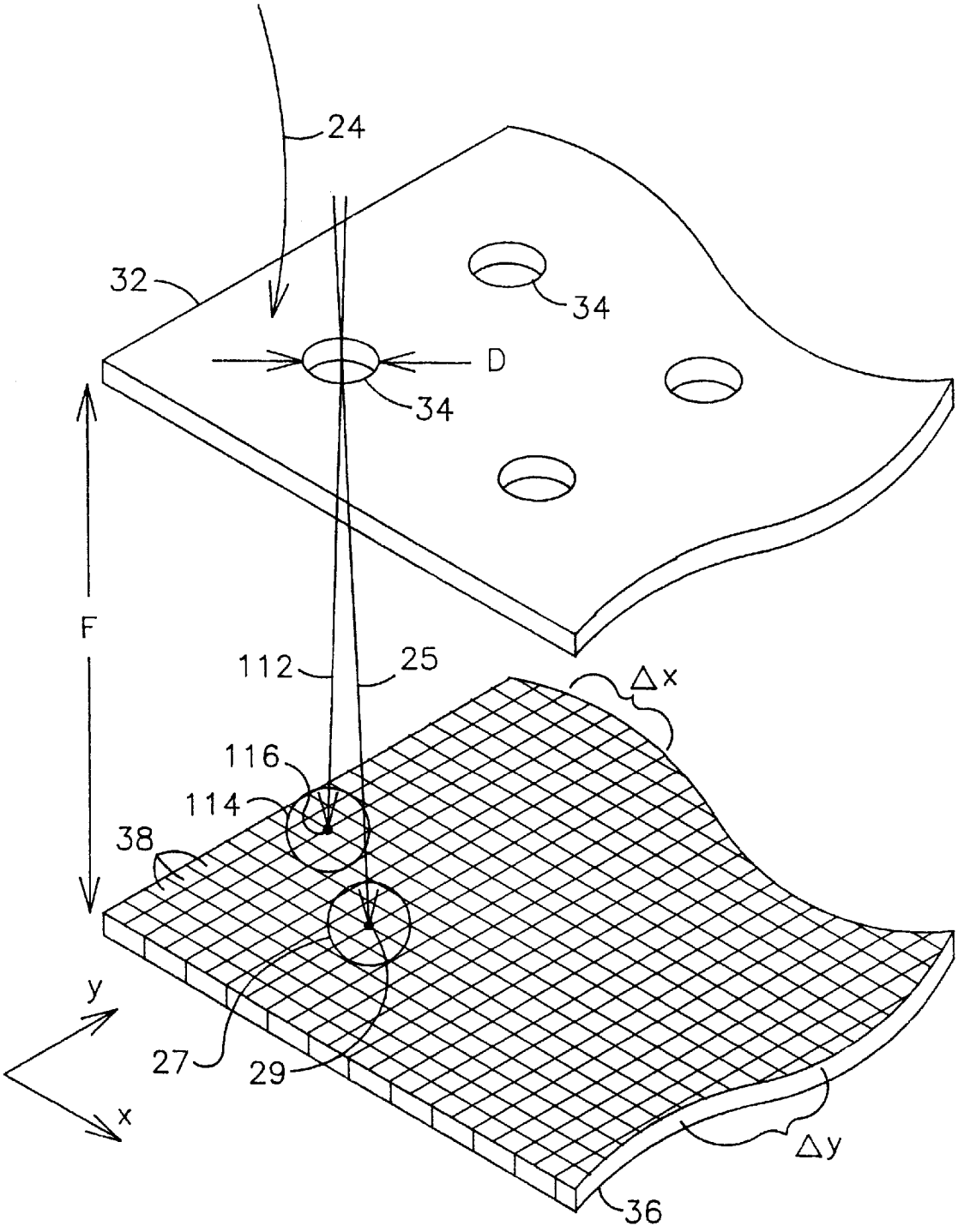


FIG. 4

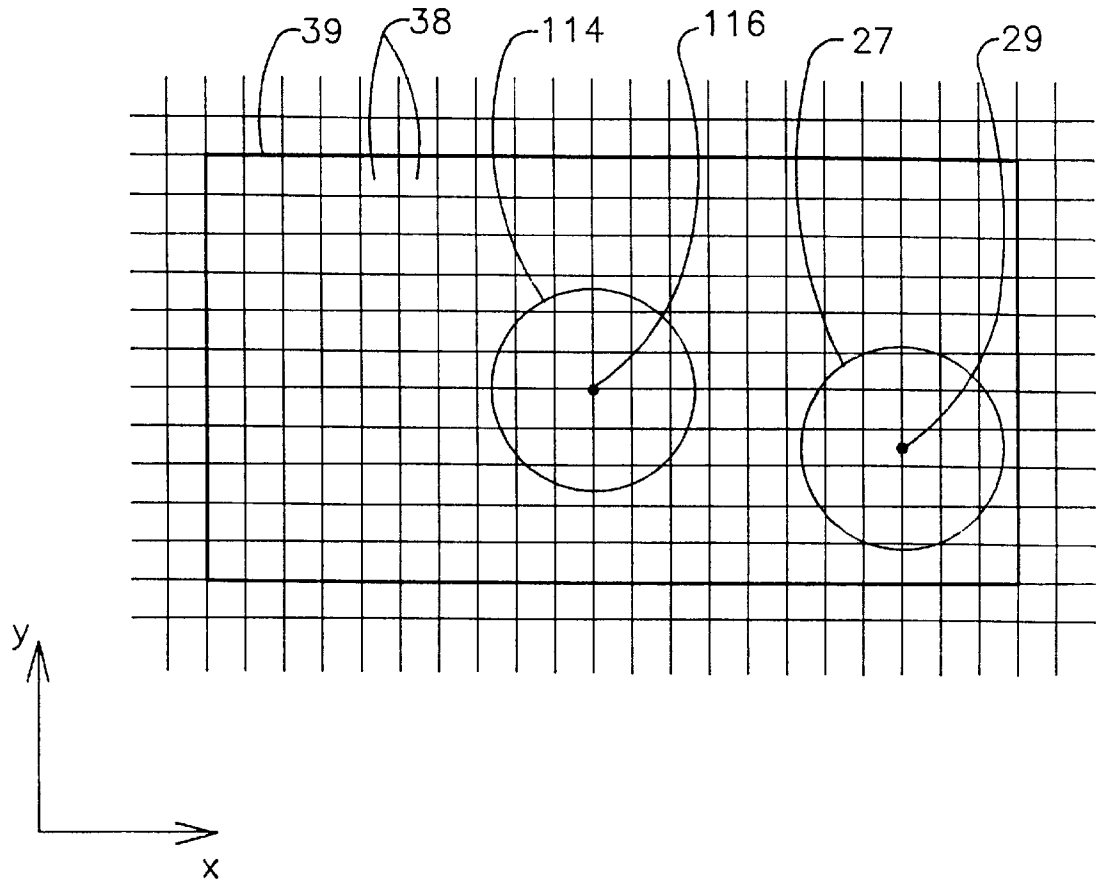
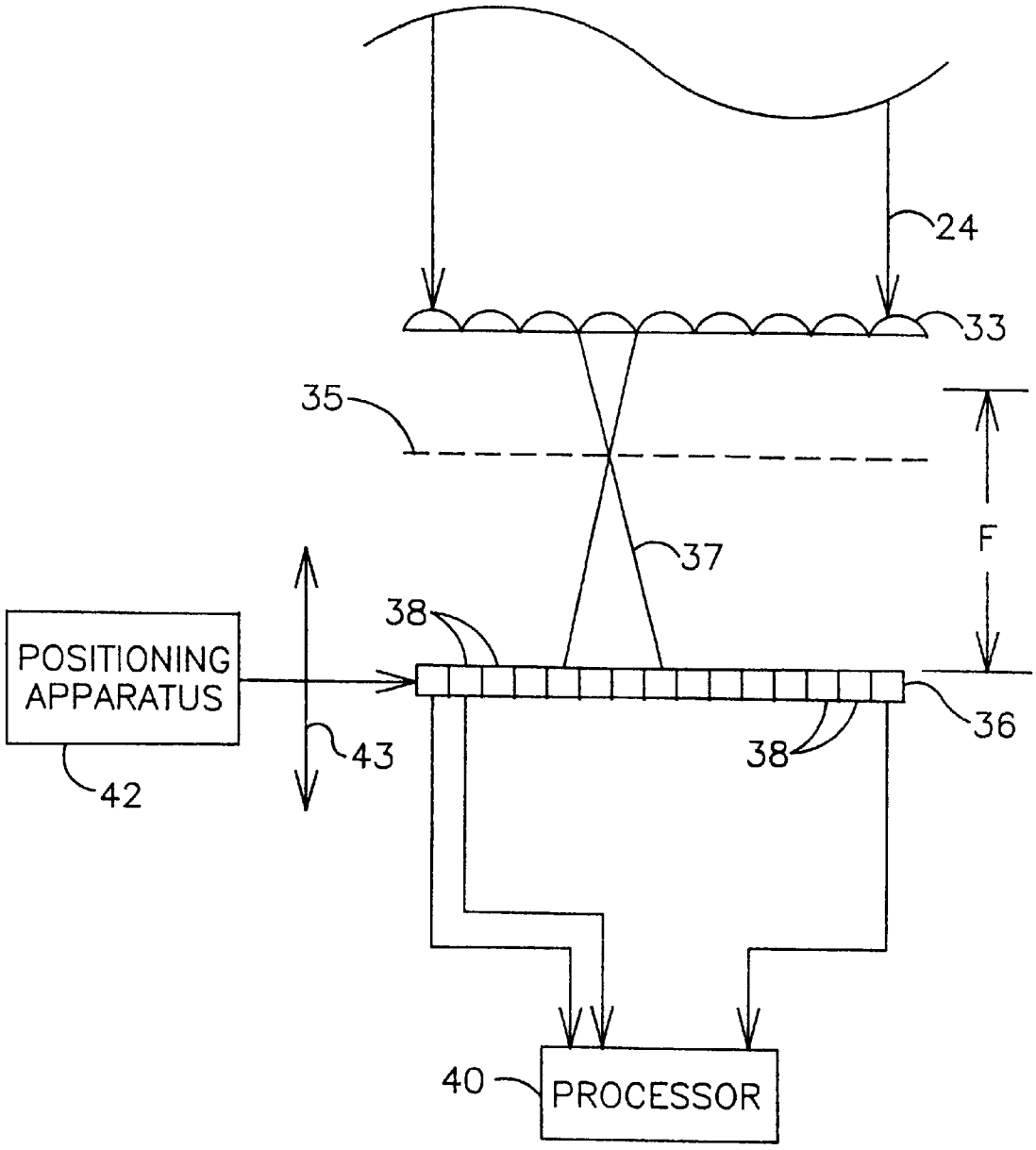


FIG. 5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POSITIONING APPARATUS
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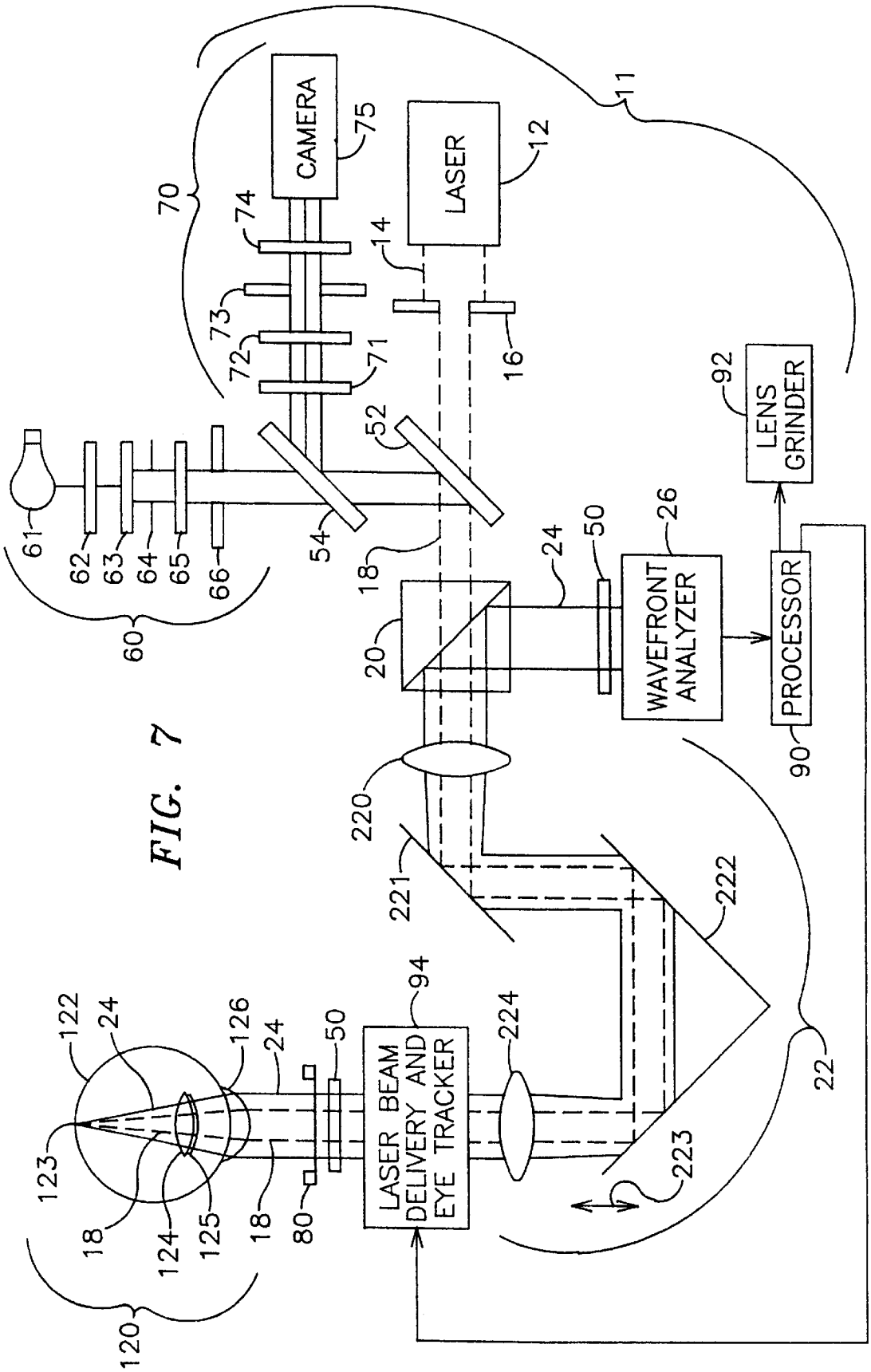
PROCESSOR

FIG. 6


CAMERA
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LASER
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16
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92
LENS GRINDER
61
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63
64
65
66
54
18
24
50
26
WAVEFRONT ANALYZER
PROCESSOR
60
20
90
220
221
222
122
24
126
24
50
94
LASER BEAM DELIVERY AND EYE TRACKER
224
123
18
124
125
18
80
223
22
120

FIG. 7

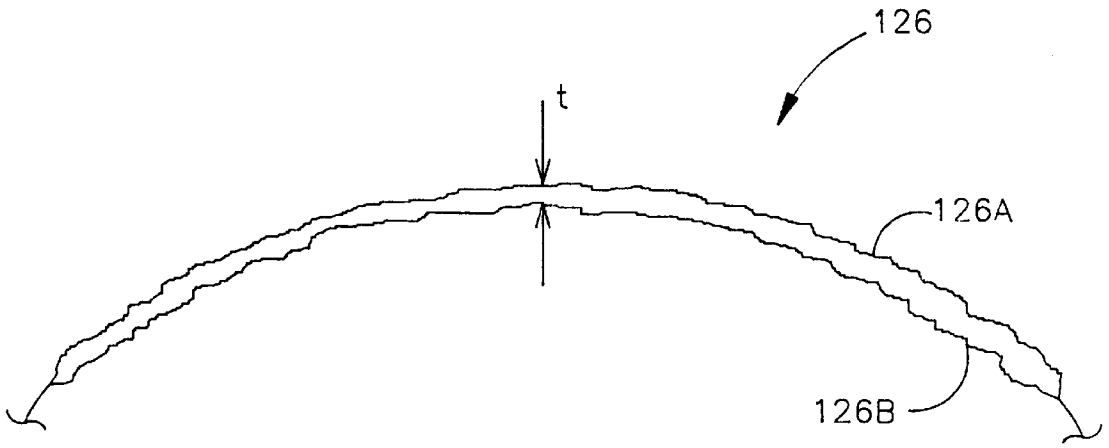

FIG. 8

OBJECTIVE MEASUREMENT AND CORRECTION OF OPTICAL SYSTEMS USING WAVEFRONT ANALYSIS

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation of and incorporates by reference application Ser. No. 09/324,179, filed May 20, 1998, now abandoned, which itself is a continuation of abandoned application Ser. No. 08/756,272, filed Nov. 25, 1996, all commonly owned with the present application.

FIELD OF THE INVENTION

The invention relates generally to optical aberration measurement and correction, and more particularly to the objective measurement and correction of optical systems having a real image focus such as human and animal eyes.

BACKGROUND OF THE INVENTION

Optical systems having a real image focus can receive collimated light and focus it at a point. Such optical systems can be found in nature, e.g., human and animal eyes, or can be man-made, e.g., laboratory systems, guidance systems, etc. In either case, aberrations in the optical system can affect the system's performance. By way of example, the human eye will be used to explain this problem.

Referring to FIG. **1A**, a perfect or ideal eye **100** is shown diffusely reflecting an impinging light beam (not shown for sake of clarity) from the back of its retina **102** (i.e., the fovea centralis **103**) through the eye's optics to include lens **104** and cornea **106**. For such an ideal eye in a relaxed state, i.e., not accommodating to provide near-field focus, the reflected light (represented by arrows **108**) exits eye **100** as a sequence as of plane waves, one of which is represented by straight line **110**. However, an eye normally has aberrations that cause deformation or distortion of the wave exiting the eye. This is shown by way of example in FIG. **1B** where aberrated eye **120** diffusely reflects an impinging light beam (again not shown for sake of clarity) from the back of its retina **122** of the fovea centralis **123** through lens **124** and cornea **126**. For

Currently, there are a number of technologies that attempt to provide the patient with improved visual acuity. Examples of such technologies include remodeling of cornea **126** using refractive laser surgery or intra-corneal implants, and adding synthetic lenses to the optical system using intraocular lens implants or precision-ground spectacles. In each case, the amount of corrective treatment is typically determined by placing spherical and/or cylindrical lenses of known refractive power at the spectacle plane (approximately 1.0–1.5 centimeters anterior to cornea **126**) and asking the patient which lens or lens combination provides the clearest vision. This is obviously a very imprecise measurement of the true distortions in wavefront **130** because 1) a single spherocylindrical compensation is applied across the entire wavefront, 2) vision is tested at discrete intervals (i.e., diopter units) of refractive correction, and 3) subjective determination by the patient is required in order to determine the optical correction. Thus, the conventional methodology for determining refractive errors in the eye is substantially less accurate than the techniques now available for correcting the ocular aberrations.

One method of measuring ocular refractive errors is disclosed by Penney et al. in "Spatially Resolved Objective Autorefractometer," U.S. Pat. No. 5,258,791, issued Nov. 2,

1993. Penney et al. teach the use of an autorefractometer to measure the refraction of the eye at numerous discrete locations across the corneal surface. The autorefractometer is designed to deliver a narrow beam of optical radiation to the surface of the eye, and to determine where that beam strikes the retina using a retinal imaging system. Both the angle of the beam's propagation direction with respect to the optical axis of the system and the approximate location at which the beam strikes the corneal surface of the eye are independently adjustable. A small uncertainty or error in the location of the beam's point of incidence on the cornea exists due to the curved corneal surface. For each point of incidence across the corneal surface, the refraction of the eye corresponding to that surface point can be determined by adjusting the angle at which the beam strikes the cornea until the beam refracted on to the iris strikes the fovea centralis. Adjustment of the beam angle of propagation can be accomplished either manually by the patient or automatically by the autorefractometer if a feedback loop involving a retinal imaging component is incorporated.

Penney et al. further teach the use of the autorefractometer measurements in determining the appropriate corneal surface reshaping to provide emmetropia. This is accomplished by first obtaining accurate measurement of corneal surface topography (using a separate commercially available device). A mathematical analysis is then performed using the initial corneal topography at each surface reference point, the measured refraction at each surface point, and Snell's law of refraction, to determine the required change in surface contour at each reference point. The contour changes at the various reference points are then combined to arrive at a single reshaping profile to be applied across the full corneal surface.

The major limitation to the approach described by Penney et al. is that a separate measurement of corneal topography is required to perform the Snell's Law analysis of needed refraction change. This requirement adds significantly to the time and cost of the complete diagnostic evaluation. Furthermore, the accuracy of the refraction change analysis will be dependent on the accuracy of the topographic measurement and the accuracy of the autorefractometer measurement. In addition, any error in the spatial orientation of the topography "map" with respect to the refraction map will degrade the accuracy of the needed correction profile.

A second limitation to the approach described by Penney et al. is that test points on the corneal surface are examined sequentially. Eye motion during the examination, either voluntary or involuntary, could introduce substantial errors in the refraction measurement. Penney et al. attempt to provide detection of such eye movement by deliberately including measurement points outside the pupil, i.e., in the corneal region overlying the iris, where the return from the retina will obviously be zero at specific intervals in the examination sequence. However, this approach may still allow substantial undetected eye movement error between such iris reference points.

At present, no corrective method is based on the concurrent examination of the complete distortions in wavefront **130**. Measurement of wave aberrations of the human eye, i.e., ocular aberrations, has been studied for a number of years. One prior art method and system are disclosed by Liang et al. in "Objective Measurement of Wave Aberrations of the Human Eye With the Use of a Hartmann-Shack Wave-front Sensor," Journal of the Optical Society of America, Volume 11, No. 7, July 1994, p.p. 1949–1957. Liang et al. teach the use of a Hartmann-Shack wavefront sensor to measure ocular aberrations by measuring the

wavefront emerging from the eye by the retinal reflection of a focused laser light spot on the retina's fovea. The actual wavefront is reconstructed using wavefront estimation with Zernike polynomials.

The Hartmann-Shack wavefront sensor disclosed by Liang et al. includes two identical layers of cylindrical lenses with the layers arranged so that the lenses in each layer are perpendicular to one another. In this way, the two layers act like a two-dimensional array of spherical lenslets that divide the incoming light wave into subapertures. The light through each subaperture is brought to focus in the focal plane of the lens array where a charge coupled device (CCD) image module resides.

The system of Liang et al. is calibrated by impinging an ideal plane wave of light on the lenslet array so that a reference or calibrating pattern of focus spots is imaged on the CCD. Since the ideal wavefront is planar, each spot related to the ideal wavefront is located on the optical axis of the corresponding lenslet. When a distorted wavefront passes through the lenslet array, the image spots on the CCD are shifted with respect to the reference pattern generated by the ideal wavefront. Each shift is proportional to the local slopes, i.e., partial derivatives, of the distorted wavefront which can be used to reconstruct the distorted wavefront, by means of modal wavefront estimation with Zernike polynomials.

However, the system disclosed by Liang et al. is effective only for eyes having fairly good vision. Eyes that exhibit considerable myopia (nearsightedness) would cause the focus spots to overlap on the CCD thereby making local slope determination impossible for eyes having this condition. Similarly, eyes that exhibit considerable hyperopia (farsightedness) deflect the focus spots such that they do not impinge on the CCD thereby again making local slope determination impossible for eyes having this condition.

Another limitation of the system of Liang et al. is the configuration of the Hartmann-Shack sensor in that the lenses must be uniform in order to define a uniform lenslet array so that the entire array shares a common focal plane and does not itself induce distortions in the wavefront. However, the manufacturing costs associated with such constraints are considerable.

Thus, owing to all of the above-noted limitations, Liang et al. can only achieve wavefront measurement for a relatively small class of patients. Such patients can have, at most, mildly distorted vision.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a method and system for objectively measuring aberrations of optical systems by wavefront analysis and for using such measurement to generate an optical correction.

Another object of the present invention is to provide for the objective measurement of ocular aberrations having a dynamic range that can cope with large amounts of such aberrations so as to be useful in practical applications.

Still another object of the present invention to provide a method and system for objectively measuring ocular aberrations using a wavefront analyzer of simple and inexpensive design.

It is further an object to correct vision by ablating corneal material using a laser beam directed to locations on the surface of the cornea of the eye in response to the objective measurements, thereby providing a measured wavefront that approximates a desired wavefront such as a plane wave.

Other objects and advantages of the present invention will become more obvious hereinafter in the specification and drawings.

To meet such objects, an optical correction system for correcting visual defects of an eye is provided which includes a wavefront analyzer disposed in the path of a wavefront emanating from the eye for determining an optical path difference between a plane wave and the wavefront, a converter for providing an optical correction based on the path difference and refractive indices of media through which the wavefront passes, and a laser beam having power sufficient for ablating corneal material of the cornea of the eye, wherein the optical correction is achieved by the removal of a selected amount of the corneal material.

A method aspect of the invention includes enhancing vision of an eye by optically correcting the eye based on an optical path difference between a plane wave and a wavefront emanating from the retina of the eye and refractive indices of media through which the wavefront passes, to thereby cause the wavefront to approximate the shape of the plane wave. Further, corneal surface altering is based on a Zernike reconstruction of the wavefront, and the optically correcting includes dividing the optical path difference by a difference between an index of refraction of corneal material and an index of refraction of air. The cornea is then ablated using a laser beam directed at selected locations on the surface of the cornea for altering the corneal surface of the eye without regard to a resulting topography of the surface of the cornea.

In accordance with the present invention, an energy source generates a beam of radiation. Optics, disposed in the path of the beam, direct the beam through a focusing optical system, e.g., an eye, that has a rear portion thereof functioning as a diffuse reflector. The beam is diffusely reflected back from the rear portion as a wavefront of radiation that passes through the focusing optical system to impinge on the optics. The optics project the wavefront to a wavefront analyzer in direct correspondence with the wavefront as it emerges from the focusing optical system. A wavefront analyzer is disposed in the path of the wavefront projected from the optics and calculates distortions of the wavefront as an estimate of ocular aberrations of the focusing optical system. The wavefront analyzer includes a wavefront sensor coupled to a processor that analyzes the sensor data to reconstruct the wavefront to include the distortions thereof.

In one embodiment, the radiation is optical radiation and the wavefront sensor is implemented using a plate and a planar array of light-sensitive cells. The plate is generally opaque but that has an array of light transmissive apertures that selectively let impinging light therethrough. The plate is disposed in the path of the wavefront so that portions of the wavefront pass through the light transmissive apertures. The planar array of cells is arranged parallel to and spaced apart from the plate by a selected distance. Each portion of the wavefront passing through one of the light transmissive apertures illuminates a geometric shape covering a unique plurality of cells. In another embodiment, the wavefront sensor comprises a two-dimensional array of spherical lenslets and a planar array of cells. The array of lenslets defines a focal plane that is a focal length away therefrom. The array of lenslets is disposed in the path of the wavefront where portions of the wavefront pass therethrough. The planar array of cells is arranged parallel to and spaced apart from the array of lenslets by a selected distance independent of the focal length. Similar to the first embodiment wavefront sensor, each portion of the wavefront illuminates a geometric shape covering a unique plurality of cells. Regardless of

which wavefront sensor is used, the distance between the planar array of cells and the opaque plate, or the array of lenslets, can be varied to adjust the slope measurement gain of the wavefront sensor and thereby improve the dynamic range of the system.

Another measure of dynamic range enhancement is provided by the focusing optics. The focusing optics includes first and second lenses maintained in fixed positions in the path of the beam and wavefront. An arrangement of optical elements is disposed between the lenses in the path of the beam and the wavefront. The optical elements are adjustable to change the optical path length between the lenses.

If an optical correction is desired, the distortions are converted to an optical correction which, if placed in the path of the wavefront, causes the wavefront to appear approximately as a plane wave. The optical correction can be in the form of a lens or an amount of corneal material ablated from the eye.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1A** is a schematic view of the ideal eye reflecting light from its retina as a planar wavefront;

FIG. **1B** is a schematic view of an aberrated eye reflecting light from its retina as a deformed wavefront;

FIG. **1C** is a schematic view of the distorted wavefront relative to a reference plane to show the wavefront error or optical path difference as a function of transverse distance in the propagation direction;

FIG. **1D** is a schematic view of the distorted wavefront relative to a reference plane that is tangent to the surface of the cornea;

FIG. **2** is a simplified schematic of the system for determining ocular aberrations in accordance with the essential features of the present invention;

FIG. **3** is a schematic of one embodiment of a Hartmann Shack wavefront analyzer used in the present invention;

FIG. **4** is a perspective view of a portion of the pinhole imaging plate and planar array of light-sensitive cells comprising the wavefront sensor from the embodiment of FIG. **3** where the deflection of a wavefront piece associated with an aberrated eye is shown in comparison with a wavefront piece associated with a calibration or planar wavefront;

FIG. **5** is a plan view of a designated area on the planar array of light-sensitive cells associated with a corresponding hole;

FIG. **6** is a schematic of another embodiment of a wavefront analyzer used in the present invention;

FIG. **7** is a schematic view of an embodiment of the present invention suitable for ophthalmic use; and

FIG. **8** is a side view of a cornea showing a thickness of corneal material to be ablated as an optical correction generated by the present invention.

DETAILED DESCRIPTION OF THE INVENTION

By way of illustrative example, the present invention will be described with respect to diagnosing and correcting a human eye. However, it is to be understood that the teachings of the present invention are applicable to any optical system having a real image focus that can (or can be adapted to) diffusely reflect a focused spot of radiation from a rear portion of the optical system back through the optical system as a wavefront of radiation. Thus, the present invention can be used with human or animal eyes of patients that may be alive or dead, or any man-made optical system satisfying the criteria regarding the real image focus.

The method of using wavefront analysis to determine an appropriate optical correction will be introduced with reference to the eye example and the aid of the schematic shown in FIG. **1C**. For convenience, a coordinate system is defined where positive x is upward in the plane of the figure, positive y is outward from the plane of the figure, and positive z is to the right along the propagation direction. Distorted wavefront **130** can be described mathematically as W(x,y).

One method of measuring the distortions in wavefront **130** is to determine the spatial separation Δz between a reference plane **131** (analogous to ideal wavefront **110**) at a known distance z_O from the eye at each (x,y) point of distorted wavefront **130** as the leading edge of wavefront **130** traverses distance z_O This is illustrated in FIG. **1C** and is described mathematically as

$$\Delta z(x,y)=z_0-W(w,y) \quad (1)$$

These Δz measurements define the inappropriate optical path differences due to the aberrations in the test eye. The appropriate correction consists of removing these optical path differences. Ideally, such correction is performed at reference plane **131**.

Depending on the corrective therapy (i.e., corneal tissue ablation, synthetic lens addition, etc.), the amount of material removed or added at each (x,y) coordinate can be calculated directly if the refractive index of the material in question is known. For many procedures, such as intraocular lens implantation or radial keratotomy, such wavefront analysis can be performed repetitively during the procedure to provide feedback information as to the appropriate endpoint of the procedure.

In terms of the illustrative example, the differences Δz(x, y) between the distorted and ideal wavefronts are the consequence of the aberrations in the eye. Ideal correction of those aberrations consists of introducing an optical path difference at reference plane **131** of negative Δz(x,y). If the treatment approach consists of removing tissue from the surface of the cornea by laser ablation, then a logical choice for the location of reference plane **131** is tangential to the surface of cornea **126** (i.e., z_O=0). This is shown schematically in FIG. **1D** where the curvature of cornea **126** is greatly exaggerated for clarity of illustration. Ablation could then be carried out discretely at each (x,y) coordinate along the cornea by a laser beam delivery and eye tracking system such as disclosed in U.S. patent application Ser. No. 08/232,615, filed Apr. 25, 1994, owned by the same assignee as the present invention, and which is incorporated herein by reference.

The appropriate corneal ablation depth at any (x,y) transverse coordinate is, to within a small error, given by

$$\Delta z(x,y)/(n_c-1) \quad (2)$$

where n_c is the refractive index of corneal tissue or 1.3775. The method described in detail below calculates Δz(x,y) by first measuring the local slopes in wavefront **130**, i.e., δW(x,y)/δx and δW(x,y)/δy, at a number of points in the transverse x and y directions in reference plane **131** and then generating a mathematical description of W(x,y) having slopes in best possible agreement with the experimentally determined values. One such slope $\delta W(x_O,y_O)/\delta x$ is referenced in FIG. **1D**. In doing this, a small error is introduced due to the fact that distorted wavefront **130** is measured at reference plane **131** while wavefront **130** emerged from a

curved (corneal) surface just posterior to reference plane **131**. This error is similar to that encountered with the prior art method of Penney et al. discussed above. The error $E_X(x,y)$ is the lateral displacement in the x-direction at each (x,y) location at the measurement plane (i.e., reference plane **131**) to the curved corneal surface. A similar error will be manifest for any corrections involving curved optical surfaces. The error will generally increase with both (x,y) displacement from the point of tangency and local wavefront error.

The magnitude of error $E_X(x,y)$ can be found for each measurement location (x,y) measured at an arbitrary coordinate, e.g., (x_O,y_O) by projecting that location back to the point of origin on cornea **126**. This can be explained mathematically using FIG. **1**D. For simplicity, the explanation will assume that the error is only in the plane of the figure, i.e., the plane defined by $y=y_O$, although it is quite straightforward mathematically to extend the analysis to include errors the y-dimension. The quantation of the line L tracing the propagation of the wavefront element measured at (x_O,y_O) in the z_O reference from the corneal surface to the reference plane is:

$$L(x) = z_0 - \frac{(x - x_0)}{\delta W(x_0, y_0)/\delta x} \tag{3}$$

If the corneal surface in the plane of the figure is described by the expression $S(x_O,y_O)$, then the point of origin for the wavefront element in question can be found by finding the point of intersection between L(x) and $S(x,y_O)$. Mathematically, this requires finding the value x' that satisfies $L(x')=S(x_O,y_O)$. The error $E_X(x_O,y_O)$ then is given as $E_X(x_O,y_O)=x'-x_O$. Extending the analysis to consider errors in the y-direction would yield a similar expression for E_Y where $E_Y(x_O,y_O)=y'-y_O$. If significant, these transverse errors can be compensated for by laterally displacing the aberration correction calculated at each (x,y) coordinate by the amounts $E_X(x,y)$ and $E_Y(x,y)$

In the case of human corneas, the transverse error under most circumstances will be negligible. The error will be zero at the origin where the corneal tissue and reference plane **131** are tangent. For human corneas, the tissue is approximately spherical with a radius of curvature of approximately 7.5–8.0 mm. The corrective treatment radius is typically no more than 3 mm, and local wavefront radius of curvature will almost always exceed 50 mm (a 20 diopter refractive error). The transverse error E at a 3 mm treatment radius for a local wavefront radius of curvature of 50 mm is less than 40 mm.

For certain ophthalmic procedures, wavefront analysis can also be used repetitively during the corrective procedure to provide useful feedback information. One example of such use would be in cataract surgery where wavefront analysis could be performed on the eye following placement of an intra-ocular lens implant (IOL). The analysis could help identify whether the appropriate refractive power IOL has been inserted, or whether a different refractive power IOL should be used. Another example of repetitive wavefront analysis would be during keratoplastic procedures where the cornea of the eye is deliberately distorted by altering the mechanical tension around the periphery thereof. Here, repetitive wavefront analysis could be used to refine the degree of induced tension change at each point around the cornea thereby providing the tool to obtain, optimum surface curvature for best visual acuity.

In order to perform wavefront analysis in a manner compatible with corrective procedures such as those described above, the amount of spatial separation of component portions of wavefront **130** relative to the corresponding component portions of a planar or ideal wavefront must be measured. It is the system and method of the present invention that allows such separation to be objectively and accurately measured for even substantially aberrated eyes including those exhibiting severe defects such as severe myopia or hyperopia.

For the evaluation or measurement portion of the present invention, the patient's pupil should ideally be dilated to approximately 6 millimeters or more, i.e., the typical size of a human pupil in low light. In this way, the eye is evaluated while it is using the greatest area of the cornea so that any correction developed from such measurement takes into account the largest usable corneal area of the patient's eye. (A lesser amount of the cornea is used in daylight where the pupil is considerable smaller, e.g., on the order of 3 millimeters.) Dilation can be brought about naturally by implementing the measurement portion of the present invention in a low light environment such as a dimly lit room. Dilation can also be induced through the use of pharmacologic agents.

Referring now to FIG. **2**, a simplified schematic of the system of the present invention depicting its essential elements is shown and referenced generally by numeral **10**. System **10** includes laser **12** for generating the optical radiation used to produce a small-diameter laser beam. Laser **12** is typically a laser generating collimated laser light (represented by dashed lines **14**) of a wavelength and power that is eye-safe. For ophthalmic applications, appropriate wavelengths would include the entire visible spectrum from approximately 400–710 nanometers and the near infrared spectrum from approximately 710–1000 nanometers. While operation in the visible spectrum is generally preferable (since these are the conditions in which the eye operates), the near infrared spectrum may offer advantages in certain applications. For example, the patient's eye may be more relaxed if the patient does not know measurement is taking place. Regardless of the wavelength of the optical radiation, power should be restricted in ophthalmic applications to eyesafe levels. For laser radiation, appropriate eye-safe exposure levels can be found in the U.S. Federal Performance Standard for Laser Products. If the analysis is to be performed on an optical system other than the eye, the examination wavelength range logically should incorporate the intended performance range of the system.

To select a small-diameter collimated core of laser light **14**, an iris diaphragm **16** can be used to block all of laser light **14** except for laser beam **18** of a size desired for use by the present invention. In terms of the present invention, laser beam **18** can have a diameter in the range of approximately 0.5–4.5 millimeters with 1–3 millimeters being typical. A badly aberrated eye requires a smaller diameter beam while an eye with only slight aberrations can be evaluated with a larger diameter beam. Depending on the output divergence of laser **12**, a lens (not shown) can be positioned in the beam path to optimize collimation.

Laser beam **18** is a polarized beam that is passed through a polarization sensitive beam splitter **20** enroute to being directed to a focusing optical train **22**. Optical train **22** operates to focus laser beam **18** through the optics of eye **120** (e.g., cornea **126**, pupil **125** and lens **124**) to the back of the eye's retina **122**. (It is to be understood that lens **124** may not be present for a patient that has undergone a cataract procedure, however, this does not affect the present invention.) In the illustrated example, optical train **22** images laser beam **18** as a small spot of light at or near the

eye's fovea centralis **123** where the eye's vision is most acute. Note that the small spot of light could be reflected off another portion of retina **122** in order to determine aberrations related to another aspect of one's vision. For example, if the spot of light were reflected off the area of retina **122** surrounding the fovea centralis **123**, aberrations specifically related to one's peripheral vision could be evaluated. In all cases, the spot of light is sized to form a near-diffraction limited image on retina **122**. Thus, the spot of light produced by laser beam **18** at fovea centralis **123** does not exceed approximately 100 micrometers in diameter and, typically, is on the order of 10 micrometers.

The diffuse reflection of laser beam **18** back from retina **122** is represented in FIG. **2** by solid lines **24** indicative of the wavefront of radiation that passes back through eye **120**. Wavefront **24** impinges on and is passed through optical train **22** enroute to polarization sensitive beam splitter **20**. Wavefront **24** is depolarized relative to laser beam **18** due to reflection and refraction as wavefront **24** comes off retina **122**. Accordingly, wavefront **24** is turned at polarization sensitive beam splitter **20** and directed to a wavefront analyzer **26** such as a Hartmann-Shack (H-S) wavefront analyzer. In general, wavefront analyzer **26** measures the slopes of wavefront **24**, i.e., the partial derivatives with respect to x and y, at a number of (x,y) transverse coordinates. This partial derivative information is then used to reconstruct or approximate the original wavefront with a mathematical expression such as a weighted series of Zernike polynomials.

The purpose of the above-specified polarizations states for incident laser beam **18** and beamsplitter **20** is to minimize the amount of stray laser radiation reaching the sensor portion of wavefront analyzer **26**. In some situations, stray radiation may be sufficiently small when compared to the radiation returning from the desired target (e.g., retina **122**) so that the above polarization specifications are unnecessary.

The present invention is able to adapt to a wide range of vision defects and as such achieves a new level of dynamic range in terms of measuring ocular aberrations. Dynamic range enhancement is accomplished with optical train **22** and/or the wavefront sensor portion of wavefront analyzer **26** as will now be explained.

In the illustrated embodiment, optical train **22** includes a first lens **220**, a flat mirror **221**, a Porro mirror **222** and a second lens **224** all of which lie along the path of laser beam **18** and wavefront **24**. First lens **220** and second lens **224** are identical lenses maintained in fixed positions. Porro mirror **222** is capable of linear movement as indicated by arrow **223** to change the optical path length between lenses **220** and **224**. However, it is to be understood that the present invention is not limited to the particular arrangement of flat mirror **221** and Porro mirror **222** and that other optical arrangements could be used between lenses **220** and **224** to change the optical path length therebetween.

The "zero position" of Porro mirror **222** can be identified by replacing eye **120** in FIG. **2** by a broad beam source (not shown) of collimated light to simulate a perfect plane wave. Such a source could be realized by a laser beam expanded by a beam telescope to the diameter that will cover the imaging plane of wavefront analyzer **26** and adjusting Porro mirror **222** until wavefront analyzer **26** detects the light as being collimated. Note that the changes in optical path length brought about by Porro mirror **222** can be calibrated in diopters to provide an approximate spherical dioptric correction as will be explained further below.

The dynamic range of system **10** can be further improved by utilizing a preferred embodiment wavefront analyzer to include an improved wavefront sensor arrangement. One such wavefront sensor arrangement will now be explained with the aid of FIGS. **3** and **4**. In FIG. **3**, the wavefront analyzer includes an opaque imaging plate **32** having an array of holes **34** passing therethrough, a planar array **36** of light-sensitive cells such as charge coupled device cells **38**, and a processor **40** coupled to planar array **36** of cells **38**. The combination of plate **32** and planar array **36** comprises the unique wavefront sensor of this embodiment. Plate **32** is maintained parallel to and spaced apart a separation distance F from planar array **36**. As will be explained further below, separation distance F can be varied to adjust the gain of the sensor. To do this, planar array **36** is coupled to a positioning apparatus **42**, e.g., a conventional motorized linear positioner having precise movement capability, that can adjust the position of planar array **36** relative to plate **32** to change separation distance F as indicated by arrow **43**. With respect to the array of holes **34**, each of holes **34** is of equal size and shape with a circle being typical owing to its ease of manufacture. In the illustrated example, a square array geometry is used for array of holes **34** although other array geometries can be used.

As shown in FIG. **4**, when wavefront **24** impinges on plate **32**, a piece or portion of wavefront **24**, indicated by arrow **25**, passes through hole **34** to illuminate planar array **36**. To a first order, the resulting image formed by each such wavefront piece **25** is a positive shadow of the respective hole **34**. However, diffraction does occur in a way determined by the diameter D of each hole **34**, the wavelength λ of the light source (i.e., wavefront **24**) and the separation distance F between plate **32** and planar array **36**. The value F is varied by positioning apparatus **42** to adjust the gain based on the particular patient as will be explained further below.

Note that the function provided by plate **32** with holes **34** could also be accomplished using a solid plate or film made from a light-sensitive material such as a photolithographic film. In such a case, the array of holes **34** would be replaced by an array of shaped light transmissive apertures through which light passes when impinging thereon. The remainder of such a plate or film would be impervious to light. The advantage achieved by such an embodiment is that the light transmissive apertures could easily be made to conform to any desired shape.

Regardless, of how each wavefront piece **25** is generated, the present invention measures the amount of angular deflection of each wavefront piece **25** relative to a wavefront piece that would result from a planar wavefront. This is best seen in FIG. **4** where the calibration or planar wavefront of light results in a wavefront piece represented by arrow **112** (normal to plate **32**) that illuminates a geometric spot **114** on planar array **36**. In contrast, assuming wavefront **24** represents a distorted wavefront as described above, wavefront piece **25** will exhibit an amount of angular deflection relative to (calibrating) wavefront piece **112**. The angular deflection causes wavefront piece **25** to illuminate a geometric spot **27** on planar array **36** that is offset from (calibrating) spot **114**. In terms of the present invention, the amount of offset is measured relative to the centroids **116** and **29** of spots **114** and **27**, respectively. In the two dimensions of planar array **36**, centroid **29** is (typically) deflected in both the x and y directions of array **36**. Thus, the angular deflection in each of the x and y directions is given by $\Delta x/F$ and $\Delta y/F$, respectively.

In the preferred embodiment, lenses **220** and **224** are identical as mentioned above. However, in certain applications it may be desirable to magnify or minify the wavefront

at the wavefront sensor. This can be accomplished by using lenses **220** and **224** of different focal lengths and adjusting the apparatus dimensions accordingly. For ophthalmic evaluation, the object plane of the apparatus should ideally be tangent to the corneal surface which can be achieved by a variety of means. Thus, each point at the object plane of optical train **22** very nearly corresponds to the same point on the cornea (although since the cornea is curved, there will be a slight lateral displacement). Plate **32** (or the imaging plane of any wavefront sensor portion) of wavefront analyzer **26** is positioned at the focal plane of lens **220**. In this way, the object plane is always imaged on plate **32** in direct correspondence with the wavefront image emerging from cornea **126**. This will be true regardless of the optical path length between lenses **220** and **224**. There are several advantages to this structure, one of which is that there are very good planar arrays of light-sensitive cells that are commercially available to image an area corresponding to the 6 millimeter central circular region of the cornea. Additional advantages will now be explained.

The purpose of plate **32** (or the imaging plane of any wavefront sensor portion of wavefront analyzer **26**) is to break wavefront **24** into wavefront pieces that can each be measured independently (in terms of propagation direction) at planar array **36**. Since in the preferred embodiment optical train **22** does not magnify or reduce the image in the object plane, a point at the object plane corresponds to the same point at the image plane of optical train **22**. With Porro mirror **222** set at its "zero position," the direction each piece of wavefront **24** is traveling at the object plane is reproduced exactly at the image plane of wavefront analyzer **26**. For example, if a wavefront piece at a location in the object plane was traveling away from the optical axis at an angle of 20° with respect to the optical axis that is perpendicular to the object plane, the wavefront piece at the same location in the image plane will also be traveling away from the optical axis at an angle of 20°.

Note that a person who is myopic will produce a wavefront such that the wavefront pieces isolated by plate **32** will converge toward the center of planar array **36**. A hyperopic person will produce a wavefront such that the wavefront pieces isolated by plate **32** diverge. Thus, a person with a significant vision error becomes difficult to evaluate because wavefront pieces can either overlap (myopia) at planar array **36** or spill off (hyperopia) planar array **36**.

In the present invention, there are three ways of compensating for such severe aberrations. The first way is to utilize a wavefront sensor with sufficiently small light-sensitive cells **38** and sufficiently large holes **34** (or any other transmissive aperture). In this way, measurement of each wavefront piece can be performed to an acceptable accuracy using a small value for F. The second way is to move planar array **36** along the optical axis to change the separation distance F to plate **32**. For a person with a severe aberration, planar array **36** is positioned close to plate **32** to keep the projected wavefront pieces well separated and on planar array **36**. For a mild aberration, planar array **36** can be moved to increase the separation distance F to plate **32** to make a more accurate measurement. The advantage of moving planar array **36** to change the separation distance F to plate **32** is that the wavefront analysis is easily achieved for any position. The third way of compensating for severe aberrations in the present invention is to change the optical path length between lenses **220** and **224**. Moving Porro mirror **222** will not affect where the wavefront hits plate **32**, but will change the angular deflections at which the projected wavefront pieces pass through plate **32**, i.e., $\Delta x/F$ and $\Delta y/F$. Decreasing the optical path length between lenses **220** and **224** will tend to pull the wavefront pieces toward the center of planar array **36** thereby compensating for hyperopia. Increasing the optical path length between lenses **220** and **224** will tend to spread the wavefront pieces toward the edges of planar array **36** thereby compensating for myopia. The degree to which the angular deflection associated with each wavefront piece is altered is a linear function of its distance off the optical axis and the movement of Porro mirror **222** from its zero position.

In order to accurately determine the centroids of a spot of light impinging on array **36**, it is necessary to provide a fine structure of cells **38** relative to a spot size. In other words, each spot must cover a plurality of cells **38**. In the preferred embodiment, to determine the centroid of each spot unambiguously with respect to a spot caused by another one of holes **34**, a unique number of cells **38** is assigned to each hole **34**. The "assigned areas" are designated in FIG. **5** by the heavy grid lines **39**. It is to be understood that grid lines **39** are not actual physical boundaries between cells **38** but are shown simply to illustrate the unique designated areas containing a plurality of cells **38**. Other centroid strategies can be utilized that do not necessitate such partitioning of array **36**.

Since the wavefront sensor of the present invention does not focus each wavefront piece to a minimum at the surface of array **36**, a larger plurality of cells **38** are illuminated by each geometric spot so that the centroid of each spot can be determined to a greater precision than was previously possible.

The present invention could also be practiced with a wavefront analyzer that replaced plate **32** (FIG. **3**) with a two-dimensional array of identical spherical lenslets **33** as shown in FIG. **6**. To achieve the advantages of the present invention, array **33** is positioned by positioning apparatus **42** such that separation distance F is independent of the focal length f that defines the focal plane of array **33** which is represented by dashed line **35**. In other words, each wavefront piece (e.g., wavefront piece **37**) passed through a subaperture of array **33** is reduced in size (e.g., diameter) but is not necessarily brought to a minimum focus at array **36** as it would be if separation distance F were equal to focal length f. Thus, in practice, array **33** is positioned to concentrate the light in each wavefront piece over an area for sufficient intensity on planar array **36**, yet still illuminate a substantial plurality of cells **38** (as described above) for greatest accuracy in determining the deflection of the spot's centroid.

Regardless of the structure of the wavefront sensor, processor **40** computes each two-dimensional centroid of each spot generated by a wavefront **24**. The amount of two-dimensional centroid shift (relative to the centroid of the calibrating spot) for each designated area associated with a corresponding hole **34** (or subaperture of array **33**) is divided by the separation distance F to generate a matrix of local slopes of the wavefront, i.e., $\delta W(x,y)/\delta x$ and $\delta W(x,y)/\delta y$ at the (x,y), coordinates of the centers of holes **34**. For simplicity, these will be indicated by $P(x,y)=\delta W(x,y)/\delta x$ and $Q(x,y)=\delta W(x,y)/\delta y$, respectively.

Numerous methods exist for using the partial derivative data to calculate the original (distorted) wavefront. One acceptable approach is that used by Liang et al. in the aforementioned paper where the wavefront is approximated using Zernike polynomials. This is a standard analytic technique described in numerous optics texts such as "Principles of Optics," by M. Born and E. Wolf, Pergamon Press, Oxford, England, 1964. By way of example, the Zernike

polynomial approach will be discussed herein. However, it is to be understood that other mathematical approaches can be used in approximating the distorted wavefront.

Briefly, the wavefront W(x,y) is expressed as a weighted sum of the individual polynomials

$$W(x, y) = \sum_{i=0}^{n} C_i Z_i(x, y) \tag{4}$$

where C_i are the weighting coefficients, and $Z_i(x,y)$ are the Zernike polynomials up to some order. The upper limit n on the summation is a function of the number of Zernike polynomials, i.e., the highest order, used to approximate the true wavefront. If m is the highest order used, then

$$n=(m+1)(m+2)/2 \tag{5}$$

Derivation of the Zernike polynomials up to an arbitrary order n is described in numerous optical texts such as the aforementioned book by Born and Wolf.

One possible method of determining a centroid of a spot and calculation of the Zernike weighting coefficients will now be explained. The directions of the unit normals at the center of each hole **34** are based on the centroids of the spots on cells **38**. Since each spot will illuminate a plurality of cells with varying intensity, a standard amplitude-weighted centroid calculation can be used to find the center of each spot. Each centroid must be measured twice, once for perpendicular collimated light, and again for the wavefront to be analyzed. Of course, all spots are imaged simultaneously during each exposure.

Multiple exposures may be used to check for improper eye alignment or eye movement during individual exposures. If eye movement during exposures cannot be analyzed successfully by acquiring multiple exposures, then system **10** can be augmented by the addition of an eye tracker **25**. One possible placement of eye tracker **25** is shown in FIG. **2**. However, it is to be understood that eye tracker **25** could be placed elsewhere in system **10**. One such eye tracker is disclosed in the aforementioned U.S. patent application Ser. No. 08/232,615. In this way, wavefront analysis could be performed even during a limited amount of eye motion.

A one-time calibration exposure can also be used to determine the relative sensitivities of the individual cells. This is made in uniform collimated light with plate **32** removed. The responses of individual cells are then recorded.

For each light transmissive aperture (e.g., hole **34**), the centroid in the collimated case serves as a dedicated origin for the particular hole. The shift from the "origin" for each hole to the centroid caused by wavefront **24** (as observed in this coordinate system) is determined by the direction of the wave surface corresponding to that hole. If $\Delta x(m,n)$ is the x-component of the (m,n)th centroid and F is the plate separation, then the P-value for the (m,n)th centroid is

$$P(m,n)=\delta x(m,n)/\delta z=\Delta x(m,n)/F \tag{6}$$

The corresponding expression for Q is:

$$Q(m,n)=\delta y(m,n)/\delta z=\Delta y(m,n)/F \tag{7}$$

Thus, each P(m,n) and Q(m,n) represents the partial derivatives of W(x,y) with respect to x and y for the (x,y) coordinates of each hole **34**. For an m-order Zernike approximation of the original wavefront, the experimentally determined P's and Q's are then used in the following equations to calculate the appropriate C_i weighting coefficients as follows:

$$P(m, n) = \frac{\delta W(x, y)}{\delta x} = \sum_{i=0}^{n} C_i \frac{\delta Z_i(x, y)}{\delta x} \tag{8}$$

$$Q(m, n) = \frac{\delta W(x, y)}{\delta x} = \sum_{i=0}^{n} C_i \frac{\delta Z_i(x, y)}{\delta x} \tag{9}$$

By using a least-squares approx(m,n)/δzach to minimize the error between the actual wavefront slopes on the left hand side in the above equations and the Zernike approximations on the right hand side, optimal values for the weighting coefficients can be obtained.

In one possible approach to calculating a centroid $(x_c,y_c,)$ each hole **34** is assigned its dedicated area of the array **36** or $(i_{m,n}\pm\Delta i, j_{m,n}\pm\Delta j)$. This square of many light-sensitive cells is large enough that neighboring hole images never encroach, and all illumination from this hole is contained. The square contains $4\Delta i*\Delta j$ cells.

If array **36** is designated $C_{k,1}=(x_c(i,j),y_c(i,j))$, k, 1=0 . . . $2\Delta 1$, $2\Delta j$, and the spacing on centers is $\Delta x=\Delta y=d$, the measured cell responses are V(k, 1) and the relative responsivities are R(k,l), then the x-component x_c, a function of i,j is represented by

$$x_c(i,j)=[\Sigma_{k,l}V(k,l)*R(k,l)*d*k]/[\Sigma_{k,l}V(k,l)*R(k,l)] \tag{10}$$

and the y-component y_c, as a function of i,j is represented by

$$y_c(i,j)=[\Sigma_{k,l}V(k,l)*R(k,l)*d*l]/[\Sigma_{k,l}V(k,l)*R(k,l)] \tag{11}$$

Then, if $(x_{c0}(i,j), y_{c0}(i,j))$ is the "origin centroid" for the (i,j) hole, i.e., made in perpendicular collimated light, and $(x_{cw}(i,j), y_{cw}(i,j))$ is the corresponding centroid found for the wavefront to be measured, then the relative centroid shift $(x_{cr}(i,j), Y_{cr}(i,j))$ is found as

$$X_{cr}(i,j)=x_{cw}(i,j)-x_{c0}(i,j) \tag{12}$$

$$y_{cr}(i,j)=y_{cw}(i,j)-y_{c0}(i,j) \tag{13}$$

The values P(i,j) and Q(i,j) are determined from

$$P(i,j)=x_{cr}(i,j)/F \tag{14}$$

and

$$Q(i,j)=y_{cr}(i,j)/F \tag{15}$$

The surface partial derivatives P(i,j) and Q(i,j) for the array of hole centers of plate **32** are next used to calculate the appropriate Zernike polynomial weighting coefficients to describe the original wavefront W(x,y). This will now be explained by way of illustration for a 7×7 square array of holes **34**. However, it is to be understood that other sizes and shapes of hole arrays could be used.

First, a 1×98 matrix (i.e., column vector) PQ(k) is formed as

$$PQ(k)=P(7i+j),\ j=0 \ldots 6,\ i=0 \ldots 6,\ k=0 \ldots 48 \tag{16}$$

$$PQ(k)=Q(7i+j),\ j=0 \ldots 6,\ i=0 \ldots 6,\ k=49 \ldots 98 \tag{17}$$

with j cycling for each i, i.e., PQ (18)=P(2,5).

The matrix PQ is multiplied from the left with a transition matrix TM to get the matrix C as follows

$$C=TM*PQ \tag{18}$$

where TM is a 98 wide by 14 high matrix and C is a 1 wide by 14 high matrix or column vector. C is the matrix C_k k=1, . . . , 14 such that, to a least square error,

$$W(x,y)=\Sigma_k C_k * Z_k(x,y) \quad (19)$$

and TM is calculated for a given aperture, e.g., a 6 millimeter pupil aperture.

The functions Z_k (X,y) in equation (19) are the Zernike polynomials. There is no standard convention as to their sequence. Thus, for consistency, it is important that the same sequence is used to produce the set C_k that was chosen for deriving the matrix TM. They occur in groups of the same order, which is the highest exponent in the group, with the total number of members in an order increasing with the order. For example, in a fourth order analysis, orders up to and including 4 are used (less Z_0—the single member of order 0 that is the constant 1 which describes the reference position of the group in the z direction). Since wavefront **24** is moving along z (at the velocity of light), this "piston term" describes only an arbitrary offset in Z, and this term may be ignored. The first 5 orders (0, 1, . . . , 4) contain 15 functions including the piston term.

Thus, in the illustrated example, 14 values of C_k are calculated as coefficients of 14 Zernike polynomials. By way of example, one such order used to calculate TM is given in Table 1, which includes both the Zernike functions and their partial derivatives.

TABLE 1

ZERNIKE (X,Y) POLYNOMIAL EXPANSION THROUGH ORDER 4

	Polynomial Order 0
Z(0)	+1
dZ(0)/dx	0.0
DZ(0)/dy	0.0
	Polynomial Order 1
Z(1)	+y
dZ(1)/dx	0.0
dZ(1)/dy	+1
Z(2)	+x
dZ(2)/dx	+1
dZ(2)/dy	0.0
	Polynomial Order 2
Z(3)	$-1 + 2y^2 + 2x^2$
dZ(3)/dx	+4x
dZ(3)/dy	+4y
Z(4)	+2xy
dZ(4)/dx	+2y
dZ(4)/dy	+2x
Z(5)	$-y^2 + x^2$
dZ(5)/dx	+2x
dZ(5)/dy	−2y
	Polynomial Order 3
Z(6)	$-2y + 3y^3 + 3x^2y$
dZ(6)/dx	+6xy
dZ(6)/dy	$-2 + 9y^2$ 30 $3x^2$
Z(7)	$-2x + 3xy^2 + 3x^3$
dZ(7)/dx	$-2 + 3y^2 + 9x^2$
dZ(7)/dy	+6xy
Z(8)	$-y^3 + 3x^2y$
dZ(8)/dx	+6xy
dZ(8)/dy	$-3y^2 + 3x^2$
Z(9)	$-3xy^2 + x^3$
dZ(9)/dx	$-3y^2 + 3x^2$
dZ(9)/dy	−6xy
	Polynomial Order 4
Z(10)	$+1 - 6y^2 + 6y^4 - 6x^2 + 12x^2y^2 + 6x^4$
dZ(10)/dx	$-12x + 24xy^2 + 24x^3$
dZ(10)/dy	$-12y + 24y^3 + 24x^2y$
Z(11)	$-6xy + 8xy^3 + 8x^3y$
dZ(11)/dx	$-6y + 8y^3 + 24x^2y$
dZ(11)/dy	$-6x + 24xy^2 + 8x^3$

TABLE 1-continued

ZERNIKE (X,Y) POLYNOMIAL EXPANSION THROUGH ORDER 4

Z(12)	$+3y^2 - 4y^4 - 3x^2 + 4x^4$
dZ(12)/dx	$-6x + 16x^3$
dZ(12)/dy	$+6y - 16y^3$
Z(13)	$-4xy^3 + 4x^3y$
dZ(13)/dx	$-4y^3 + 12x^2y$
dZ(13)/dy	$-12xy^2 + 4x^3$
Z(14)	$+y^4 - 6x^2y^2 + x^4$
dZ(14)/dx	$-12xy^2 + 4x^3$
dZ(14)/dy	$+4y^3 - 12x^2y$

The choice of sequencing the Zernike polynomials dictates the interpretations of the C_k in equation (19) and therefore the order of terms in the TM matrix. Hence, the TM matrix must be calculated after the choice is made. The development of the TM matrix for the illustrated example will be explained below.

Note that the fourth order analysis is only an example and is not the only possibility. A Zernike analysis can be done to any order. In general, the higher the order, the more accurate the result over the tested points. However, an exact polynomial fit over the tested points is not necessarily desirable. Such fits have the typical disturbing property that, unless the surface itself happens to be an exact polynomial of order no higher than that used for the surface fit, forcing an exact fit at separated points often causes wild swings between fitted points. That is, in polynomial surface fitting, an exact fit at a finite number of points can yield a poor average fit for a general function. For ophthalmic application of the system as described above, computer simulations suggest that a sixth order Zernike analysis may yield the best results.

Calculation of the $\Delta z(x,y)$ optical path difference information from the Zernike reconstruction of the wavefront is accomplished simply by subtracting a constant from the Zernike approximation. The value of the constant will depend on the desired characteristics of $\Delta z(x,y)$. Depending on the method chosen to correct the aberrations (e.g., laser ablation, lens addition, etc.) it may, for example, be desirable to set either the maximum, mean or minimum value in $\Delta z(x,y)$ equal to zero.

The development of the transition matrix TM will now be explained for the illustrated example of a 7×7 array of holes in plate **32**. At each point (x_i,y_j), the tangents of the components of the normal are $P(x_i,y_j)$ and $Q(x_i,y_j)$ where

$$P(x_i,y_j)=\delta W(x_i,y_j)/\delta x \quad (20)$$

and

$$Q(x_i,y_j)=\delta W(x_i,y_j)/\delta y \quad (21)$$

Combining these with equation (11),

$$P(x_i,y_j)=\Sigma_k C_k \delta W(x_i,y_j)/\delta x \quad (22)$$

and

$$Q(x_i,y_j)=\Sigma_k C_k \delta W(x_i,y_j)/\delta y \quad (23)$$

each applicable to 49 (i,j) combinations. These are combined into a single column vector PQ that is 98 elements high, i.e., a 98×1 matrix. Defining two matrices C_k (14 high×1 wide) and $M_{k,(i,j)}$ (14 wide×98 high)

$$(M_{k,(i,j)})=\delta Z_k(x_i,y_j)/\delta x;\ \delta Z_k(x_i,y_j)/\delta y \quad (24)$$

where the x-derivatives are the first 49 rows and the y-derivatives are the last 49 rows. Then, equation (19) can be rewritten as the matrix equation

$$(PQ)=(M)(C) \tag{25}$$

where the top 49 rows of M are the $\delta W(x_i, y_j)/\delta y$.

The expression in equation (25) gives the normal components in terms of the Zernike coefficients for a surface described by the array of 14 C's. These are exact, but it is not guaranteed that the actual total surface can be described by such an array of coefficients. Accordingly, if it is assumed that the description is within an acceptable tolerance, i.e., tolerating the errors that remain after least square error determination, then equation (26) can be considered to define the column vector C implicitly in terms of the mathematical matrix M and the measured vector PQ, both of which are known. The method of effecting the solution under the minimization condition is as follows.

First, equation (25) is multiplied on the left by M^T, the transpose of M such that

$$(M^T)(PQ)=(M^T)(M)(C)=(S)(C) \tag{26}$$

where

$$S=M^TM \tag{27}$$

is a square and symmetric matrix, e.g., of dimensions 14×14 (with each element the sum of 98 products). Such a matrix has an inverse unless the determinant of its coefficients is zero. Since this is based on the Zernike polynomials alone, and they are all independent of each other, the determinant is non-zero, so that an inverse S^{-1} is defined. Next, equation (25) is multiplied on the left by S^{-1} to yield

$$(S^{-1})(M^T)(PQ)=(S^{-1})(S)(C)=(I)(C)=C \tag{28}$$

Then, the mathematical transition matrix (independent of measurement) is

$$(TM)=(S^{-1})(M^T) \tag{29}$$

and the "best fit" array of C's from the measured PQ's can be produced by the simple matrix multiplication

$$(C)=(TM)(PQ) \tag{30}$$

To evaluate the eye unambiguously, all spots illuminating planar array **36** due to a wavefront **24** must be incident on planar array **36** simultaneously. This is achieved by pulsing or shuttering the laser source (i.e., laser **12**) such that pulse duration is less than the saccadic motion interval of the eye, i.e., a few milliseconds. Alternatively, the laser source could be left on continuously and wavefront **24** could be shuttered to appear as a wavefront pulse of a duration that is less than saccadic motion of the eye. Accordingly, as shown in FIG. **2**, shutter **50** could be positioned in the path of laser beam **18** before eye **120** or in the path of wavefront **24** before wavefront analyzer **26**.

An implementation of the present invention suitable for clinical use is shown schematically in FIG. **7** and is referenced generally by numeral **11**. Like reference numerals are used to describe elements that are the same as those described above with respect to system **10**. Accordingly, the like elements and their functions will not be described further.

A dichroic beam splitter **52** is interposed between beam splitter **20** and optical train **22** to introduce fixation target optics **60** and observation optics **70** into system **11** which are optically separated from one another by 50/50 beam splitter **54**. Functionally, fixation target optics provide eye **120** with visible light in the shape of a target. The visible light generated by fixation target optics **60** is reflected by dichroic beam splitter **50** and directed through optical train **22**.

It is to be understood that fixation target optics **60** can be implemented in a variety of fashions. By way of example, one such embodiment is shown and includes visible light source **61**, light diffuser **62**, target **63**, field stop **64**, lens **65** and iris **66**. Light source **61** and light diffuser **62** are used to provide uniform illumination of fixation target **63**. Field stop **64**, lens **65**, and iris **66** are used in conjunction with optical train **22** to present a clear image of the fixation target to (patient) eye **120**.

Functionally, observation optics **70** allows a technician to view and document the eye evaluation procedure. While a variety of implementations of observation optics **70** are possible, one such implementation is shown by way of example. In FIG. **7**, observation optics **70** includes field lens **71**, lens **72**, iris **73**, lens **74**, and camera **75**. A ring illuminator **80** is placed in front of eye **120** to illuminate same for observation and/or filming purposes.

The output from wavefront analyzer **26**, e.g., the Zernike expansion of equation (19), can be used in a variety of ways. For example, the output could be used to continually or periodically monitor the progress or effects of an ophthalmic procedure. The output could also be used to develop an optical correction for eye **120**. The optical correction will make wavefront **24** appear approximately as a plane wave. As described above, the optical correction can be implemented in a variety of ways. In each case, the output of wavefront analyzer **26** is input to a processor **90** which converts the Zernike expansion of equation (19) into a form suitable for being implemented as one of the possible optical corrections. (The functions of processor **90** could also be implemented at processor **40** of wavefront analyzer **26**.) Processor **90** could use some of the Zernike coefficients from the expansion of equation (19) to generate a standard sphero-cylindrical correction for lens grinder **92** to produce a conventional optical lens, e.g., a lens for glasses, a contact lens, etc.

Processor **90** could also divide the Zernike reconstruction of the aberrated wavefront by the index of refraction of cornea **126** minus 1, to calculate the amount of corneal material to be ablated at each corresponding (x,y) location on the cornea. The amount of corneal material at each location is input to a laser beam delivery system that typically has eye tracking capability **94** such as described in the afore-mentioned U.S. patent application Ser. No. 08/232,615. Laser beam delivery and eye tracker **94** is placed in line with the optical axis of system **11**. The eye tracker portion of this element allows system **11** to respond unwanted eye motion. Laser beam delivery and eye tracker **94** would typically focus short pulses or "shots" of ablating laser light at cornea **126** or eye **120** to remove the specified thickness t of material at each location. This is shown diagrammatically in FIG. **8** where the uncorrected surface of cornea **126** is referenced by numeral **126**A and the corrected surface of cornea **126** after ablation is referenced by numeral **126**B.

In accordance with the present invention, ablation thickness t is specified across the aperture of the cornea measured, e.g., the 6 millimeter circle to which the eye's pupil was dilated during the measurement of the eye. Outside the prescribed treatment circle, a tapering blend zone of partial ablation may be added to minimize severe changes in corneal curvature and hence lessen regression. Laser beam delivery system **94** removes thickness t to achieve the optical correction, i.e., corrected cornea surface **126**B. Note that the optical correction is not concerned with the ultimate corneal topography, but instead removes corneal material to achieve an optical correction that takes into account all ocular aberrations of the eye. This is important because the

shape of the corneal surface can be independent of the correction required because the eye's vision depends on numerous factors besides corneal curvature. Hence, the best corneal surface topography for optimal vision may be far from regular in that it must compensate for the errors in the eye's other surfaces. Thus, it is apparent that the present invention can be used to provide corneal surface corrections other than the conventional spherical and/or cylindrical corrections.

The advantages of the present invention are numerous. A totally objective approach is presented for measuring ocular aberrations. The approach is effective for a wide range of vision defects. Accordingly, the present invention will be of great utility in a wide variety of clinical applications. For example, the calculated Zernike coefficients can be used to develop a completely objective lens prescription or a corneal correction that could be accomplished with laser ablation. In addition, each of the wavefront sensor embodiments provides for a greater degree of accuracy over the prior art with respect to measuring wavefront deflections. Further, the present wavefront sensor can be adjusted in terms of gain simply by adjusting the separation distance between the imaging plane of the sensor and the planar array of light-sensitive cells.

The objective measurement of the present invention will also find great utility for a large variety of applications in which the "patient" is unable to provide feedback as required by conventional eye diagnosis. For example, the present invention could be used to evaluate the eyes of any patient not possessed of demonstrative communicative skills, e.g., babies, animals, dead specimens, as well as any constructed optical system, since the present invention is an objective analysis not requiring any assessment from the "subject." All that is necessary is for the subject's eye to be properly positioned so that proper optical access to the eye can be obtained.

The present invention could also be used in the area of identification should it be determined that each eye's Zernike coefficients are unique. Then, the present invention would find great utility in the fields of law enforcement, credit card/bank security, or any other field where positive identification would be beneficial.

Although the invention has been described relative to a specific embodiment thereof, there are numerous variations and modifications that will be readily apparent to those skilled in the art in light of the above teachings. It is therefore to be understood that, within the scope of the appended claims, the invention may be practiced other than as specifically described.

That which is claimed is:

1. A method for enhancing vision in an eye, the method comprising:

determining an optical path difference between a plane wave and a wavefront emanating from a region of the retina of the eye; and

optically correcting for visual defects of the eye based on the optical path difference and refractive indices of media through which the wavefront passes, to thereby cause the wavefront to approximate the shape of the plane wave.

2. A method according to claim **1**, wherein the correcting includes forming a lens.

3. A method according to claim **1**, wherein the correcting includes ablating corneal material from the cornea of the eye.

4. A method according to claim **1**, wherein the correcting includes ablating corneal material from the cornea of the eye at selected discrete locations on the surface of the cornea using a laser beam delivery system for ablating the corneal material and thus altering the corneal surface.

5. A method according to claim **1**, wherein the optical path difference results from a Zernike reconstruction of the wavefront, and wherein the optically correcting includes dividing the optical path difference by a difference between an index of refraction of corneal material and an index of refraction of air.

6. A method for enhancing vision of an eye, the method comprising optically correcting the eye based on an optical path difference between a plane wave and a wavefront emanating from the retina of the eye and refractive indices of media through which the wavefront passes, to thereby cause the wavefront to approximate the shape of the plane wave.

7. A method according to claim **6**, wherein the correcting includes forming a lens.

8. A method according to claim **6**, wherein the correcting includes ablating corneal material from the eye.

9. A method according to claim **6**, wherein the correcting includes selectively altering the corneal surface of the eye.

10. A method according to claim **9**, wherein the corneal surface altering is based on a Zernike reconstruction of the wavefront, and wherein the optically correcting includes dividing the optical path difference by a difference between an index of refraction of corneal material and an index of refraction of air.

11. A method for enhancing vision of an eye, the method comprising:

providing a laser delivery system having a laser beam sufficient for ablating corneal material from the cornea of the eye;

measuring an optical path difference for a location at the surface of the cornea of the eye between a plane wave and a wavefront emanating from the retina of the eye;

directing the laser beam to the location on the surface of the cornea;

communicating an optical correction to the laser delivery system for the location based on the optical path difference and refractive indices of media through which the wavefront passes;

ablating corneal material at the location using the laser beam in response to the optical correction, to thereby cause the wavefront to approximate the shape of the plane wave at the location;

repeat the measuring, communicating and ablating for alternate locations at the surface of the cornea of the eye to thereby cause the wavefront to approximate the plane wave, thereby optically correcting visual defects for enhancing vision of the eye.

12. A method according to claim **11**, wherein the ablating results in selectively altering the corneal surface of the eye without regard to a resulting topography of the surface of the cornea.

13. A method according to claim **11**, wherein the optical path difference measuring results from a Zernike reconstruction of the wavefront, and wherein the optically correcting includes dividing the optical path difference by a difference between an index of refraction of corneal material and an index of refraction of air.

14. A method for correcting visual defects of an eye, the method comprising:

measuring a wavefront emanating from a region of the retina of the eye;

calculating distortions associated with the wavefront; and

converting the distortions to an optical correction based on a deviation of the wavefront from a plane wave and refractive indices of media through which the wavefront passes, to thereby cause the wavefront to approximate the shape of the plane wave.

15. A method according to claim **14**, wherein the converting comprises forming a lens, thereby providing the optical correction.

16. A method according to claim **14**, wherein the converting comprises providing a laser beam and the laser beam ablating corneal material from the eye, thereby providing the optical correction.

17. A method according to claim **16**, wherein the converting further comprises directing the laser beam to discrete locations on the surface of the cornea and selectively altering the surface at the discrete location without regard to a resulting topography of the surface, thereby providing the optical correction.

18. A method for correcting human eye vision by removing a preselected shape of material from the cornea of the eye using a laser beam, the preselected shape of material based on a difference between a measured wavefront emanating from the retina of the eye and a desired wavefront and refractive indices of media through which the wavefront passes.

19. A method according to claim **18**, wherein the desired wavefront is a planar wavefront.

20. A method of optically correcting for visual defects of a human eye by approximating the shape of a plane wave responsive to an optical path difference between the plane wave and a wavefront emanating from the retina of the eye and further modifying the shape based on refractive indices of media through which the wavefront passes.

21. A method according to claim **20**, wherein the optical path difference results from a Zernike reconstruction of the wavefront, and wherein the shape modifying includes dividing the optical path difference by a difference between an index of refraction of corneal material and an index of refraction of air.

22. A method according to claim **20**, wherein the approximating the shape includes forming a lens.

23. A method according to claim **20**, further comprising:

providing a laser delivery system having a laser beam sufficient for ablating corneal material from the cornea of the eye;

communicating an optical correction based on the optical path difference and refractive indices to the laser delivery system for providing a laser beam sufficient for ablating corneal material from the cornea of the eye;

ablating corneal material using the laser beam in response to the optical correction, to thereby cause the wavefront to approximate the shape of the plane wave.

24. An optical correction system for correcting visual defects of an eye, the optical correction system comprising:

an energy source for generating a beam of optical radiation;

focusing optics disposed in the path of the beam for directing the beam through the eye, wherein the beam is reflected back from the retina of the eye as a wavefront of radiation emanating from the eye;

a wavefront analyzer disposed in the path of the wavefront for determining an optical path difference between a plane wave and the wavefront; and

a converter for providing an optical correction based on the path difference and refractive indices of media through which the wavefront passes.

25. A system according to claim **24**, wherein the optical correction is a lens prescription.

26. A system according to claim **24**, wherein the optical correction provides an amount of corneal material to be ablated from the eye.

27. A system according to claim **26**, further comprising a laser beam delivery system for bombarding the eye with a plurality of small-diameter laser beam pulses of a wavelength and having power sufficient for ablating the corneal material, wherein the optical correction is achieved by the removal of the amount of corneal material.

28. The system as in claim **27**, wherein the laser beam delivery system includes an eye tracker for monitoring motion of the eye and for adjusting the positions of the plurality of small-diameter laser beam pulses in correspondence with the motion.

29. The system as in claim **24**, wherein the optical correction is a prescribed alteration of corneal surface curvature of the eye, and wherein the optical correction achieved by the reshaping of the corneal surface curvature of the eye is based on the prescribed alteration without regard to a resulting topography of the surface of the cornea.

30. An optical correction system for correcting visual defects of an eye, the optical correction system comprising:

a wavefront analyzer disposed in the path of a wavefront emanating from the eye for determining an optical path difference between a plane wave and the wavefront; and

a converter for providing an optical correction based on the path difference and refractive indices of media through which the wavefront passes.

31. A system according to claim **30**, further comprising:

an energy source for generating a beam of optical radiation; and

focusing optics disposed in the path of the beam for directing the beam through the eye, wherein the beam is reflected back from the retina of the eye as the wavefront of radiation emanating from the eye.

32. A system according to claim **30**, wherein the optical correction is a lens prescription.

33. A system according to claim **30**, further comprising a laser beam delivery system for bombarding the eye with a laser beam having power sufficient for ablating corneal material of the cornea of the eye, and wherein the optical correction is achieved by the removal of an amount of corneal material.

34. A system as in claim **33**, wherein the laser beam delivery system includes an eye tracker for monitoring motion of the eye and for adjusting the positions of the laser beam responsive to the motion.

35. A system as in claim **33**, wherein the optical correction is a prescribed alteration of corneal surface curvature of the eye, and wherein the optical correction achieved by the reshaping of the corneal surface curvature of the eye is based on the prescribed alteration without regard to a resulting topography of the overall surface of the cornea.

36. An optical correction system for correcting visual defects of an eye, the optical correction system comprising:

a wavefront analyzer disposed in the path of a wavefront emanating from the eye for determining an optical path difference between a plane wave and the wavefront;

a converter for providing an optical correction based on the path difference and refractive indices of media through which the wavefront passes; and

a laser beam having power sufficient for ablating corneal material of the cornea of the eye, wherein the optical

correction is achieved by the removal of a selected amount of the corneal material.

37. A system according to claim **36**, further comprising:

an energy source for generating a beam of optical radiation; and

focusing optics disposed in the path of the beam for directing the beam through the eye, wherein the beam is reflected back from the retina of the eye as the wavefront of radiation emanating from the eye.

38. A system as in claim **36**, further comprising an eye tracker for monitoring motion of the eye and for adjusting the positions of the laser beam responsive to the motion.

39. A system as in claim **36**, wherein the optical correction is a prescribed alteration of corneal surface curvature of the eye, and wherein the optical correction achieved by the reshaping of the corneal surface curvature of the eye is based on the prescribed alteration without regard to a resulting topography of the overall surface of the cornea.

40. A system according to claim **36**, wherein the converter provides the path difference from a Zernike reconstruction of the wavefront, and wherein the path difference is divided by a difference between an index of refraction of corneal material and an index of refraction of air.

* * * * *

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(12) **United States Patent**
Nagaoka

(10) **Patent No.: US 6,256,155 B1**
(45) **Date of Patent: Jul. 3, 2001**

(54) **OBJECTIVE OPTICAL SYSTEM**

(75) Inventor: **Toshiyuki Nagaoka**, Akishima (JP)

(73) Assignee: **Olympus Optical Co., Ltd.**, Tokyo (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/391,183**

(22) Filed: **Sep. 7, 1999**

(30) **Foreign Application Priority Data**

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(51) **Int. Cl.**[7] **G02B 13/04**; G02B 9/60; G02B 9/34; G02B 17/00

(52) **U.S. Cl.** **359/753**; 359/770; 359/781; 359/737; 359/726

(58) **Field of Search** 359/726, 737, 359/739, 753, 770, 781, 656, 659, 661

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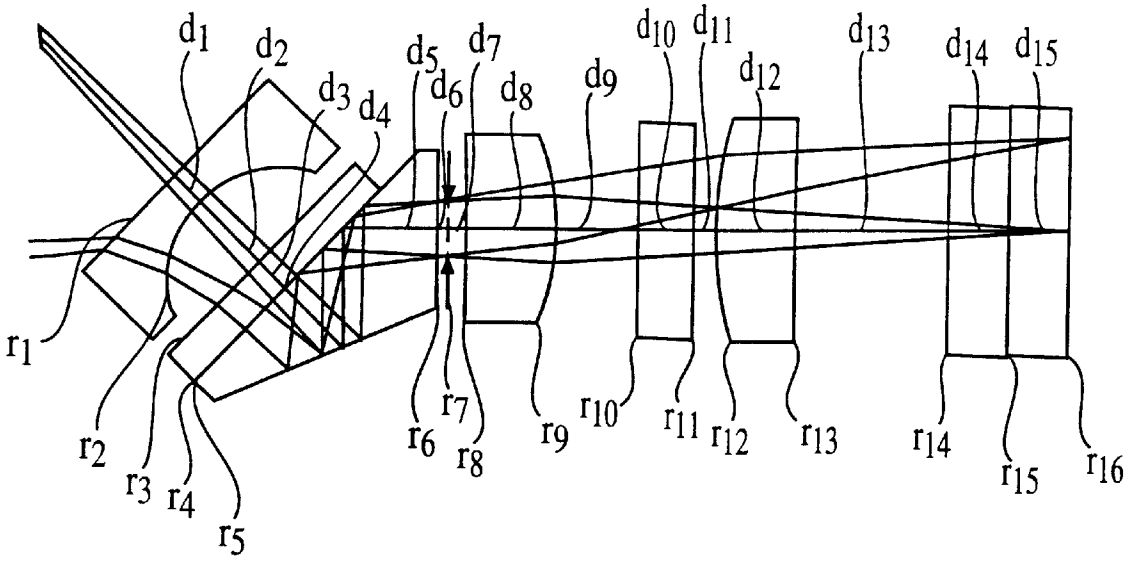
Primary Examiner—Georgia Epps
Assistant Examiner—David N. Spector
(74) *Attorney, Agent, or Firm*—Arnold International; Bruce Y. Arnold

(57) **ABSTRACT**

An objective optical system is disclosed having, in a first construction, in relative order from the object side, a first lens element of negative refractive power, a visual field conversion optical element which folds light rays incident thereon, a stop, and either one or two additional lens elements of positive refractive power which form an objective optical system. Certain prescribed conditions are satisfied in order that the objective optical system be compact and have acceptably small aberrations to thereby enable a high quality image to be formed. In a second alternative construction, the stop is positioned after the second lens element and the third lens element includes a convex surface on the image side and satisfies a prescribed condition. In a third alternative construction, an objective optical system is disclosed having, in relative order from the object side, a visual field conversion optical element which folds light rays incident thereon, a first lens element of positive or negative refractive power, a stop, and a second lens element of positive refractive power with a convex surface on the image side, wherein the second lens element satisfies a certain prescribed condition. In the second and third constructions, the system may be formed in two parts, an adaptor unit and a master unit, which are detachable from one another. The invention is particularly well-suited for forming images for an image pick-up element having pixels as small as 5 micrometers or less.

21 Claims, 24 Drawing Sheets



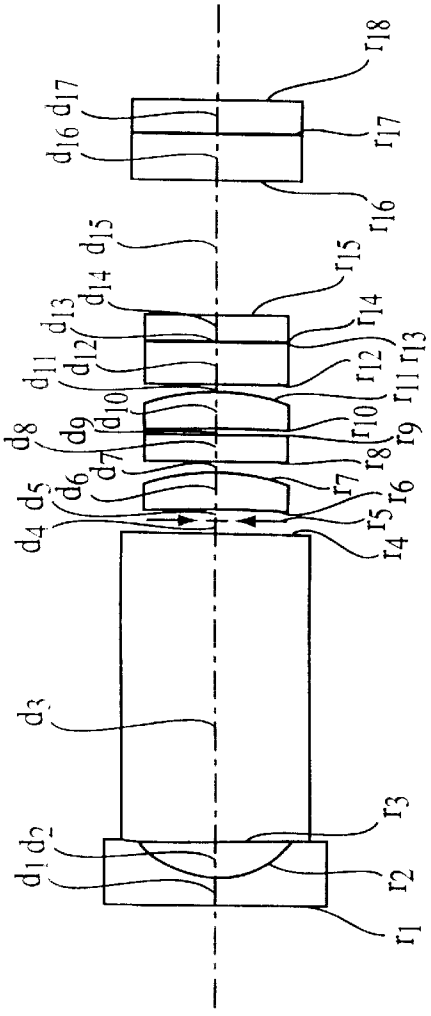

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FIG. 1

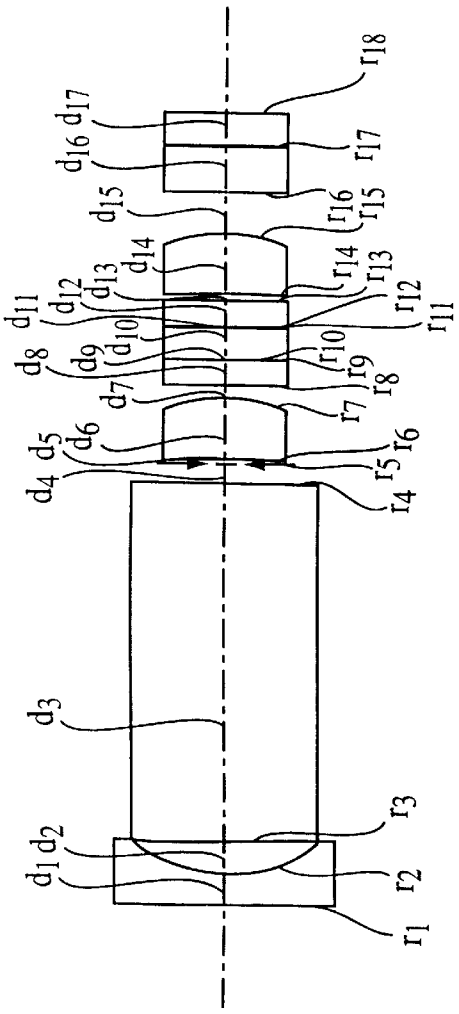
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FIG. 2

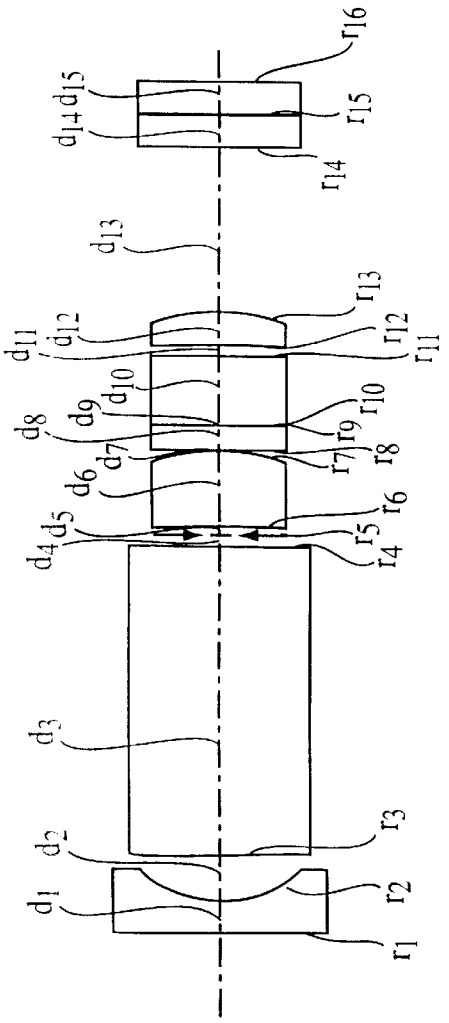
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FIG. 3

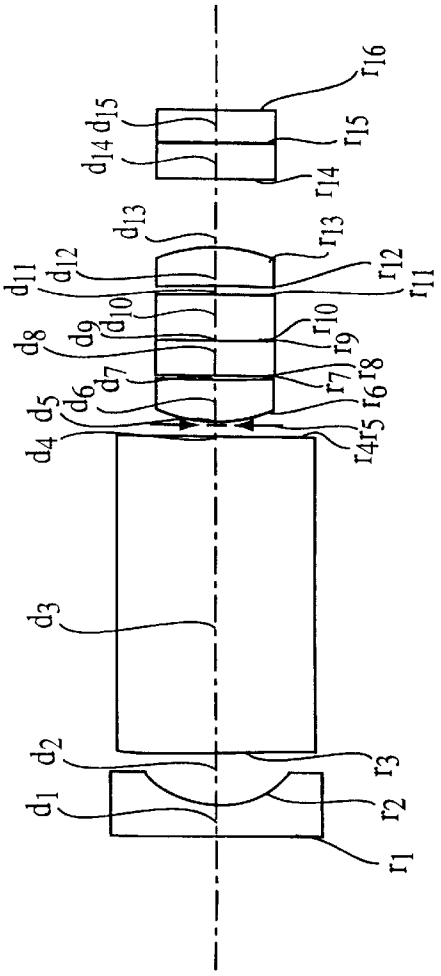
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FIG. 4

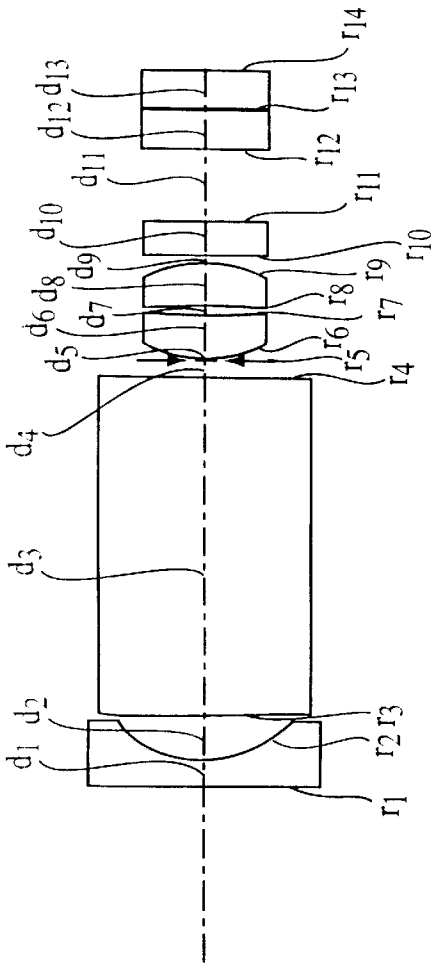
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FIG. 5

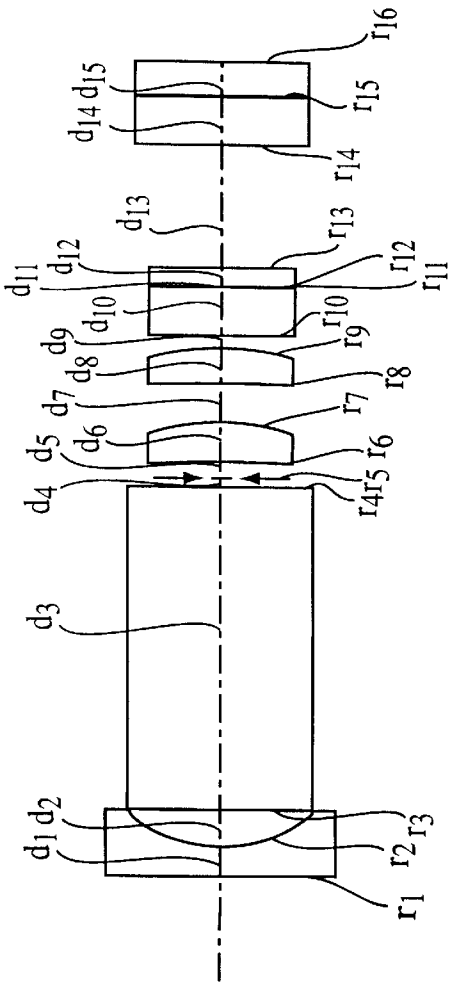
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FIG. 6

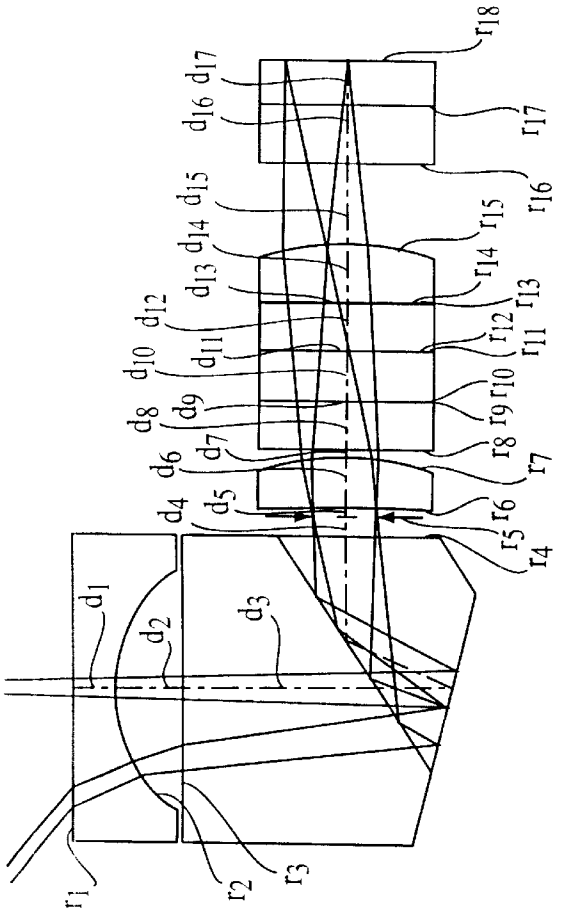
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FIG. 7

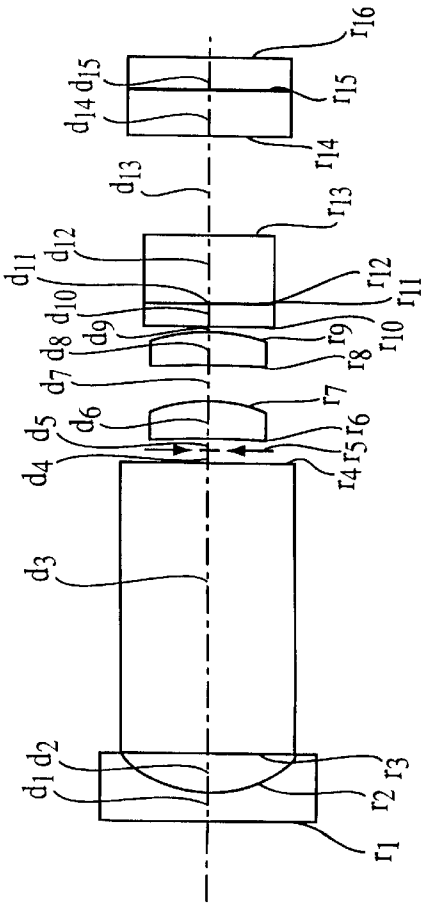
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FIG. 8

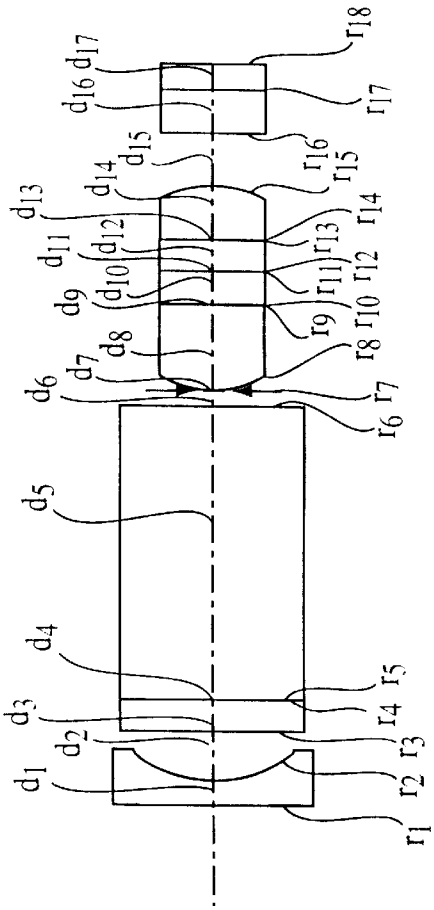
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FIG. 9

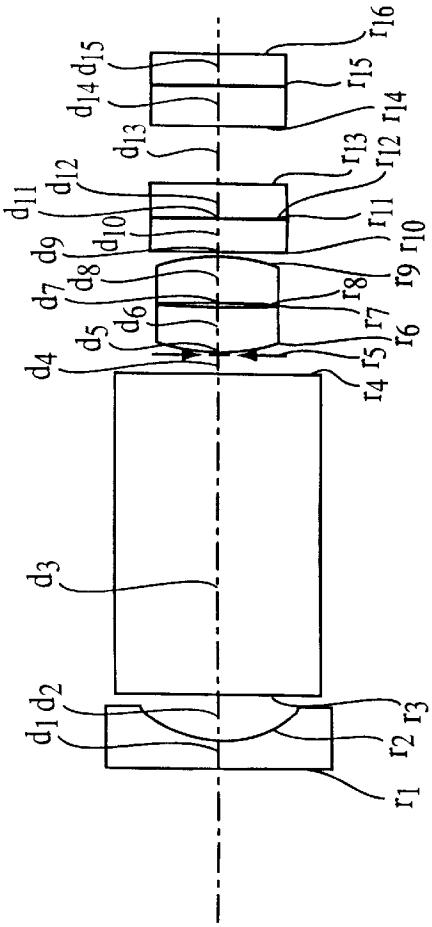
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FIG. 10

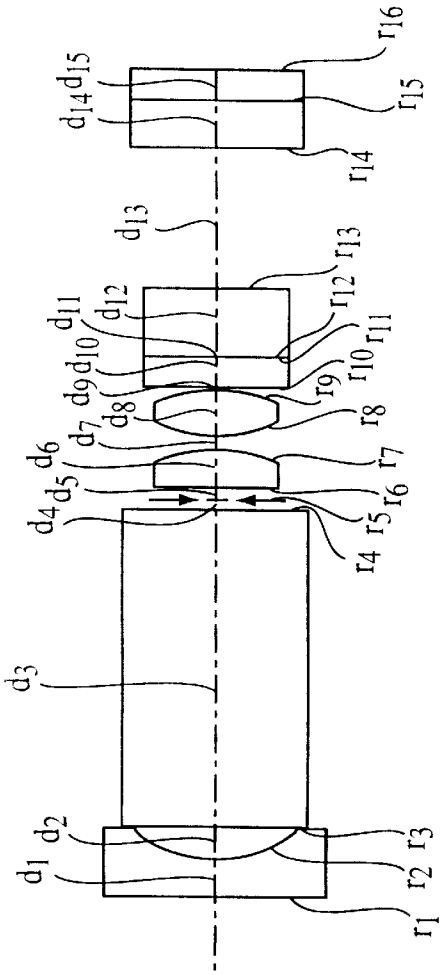
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FIG. 11

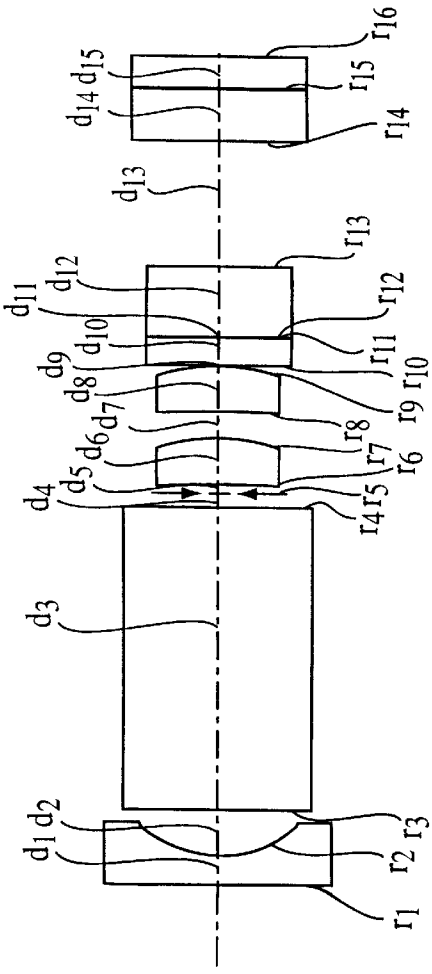
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FIG. 12

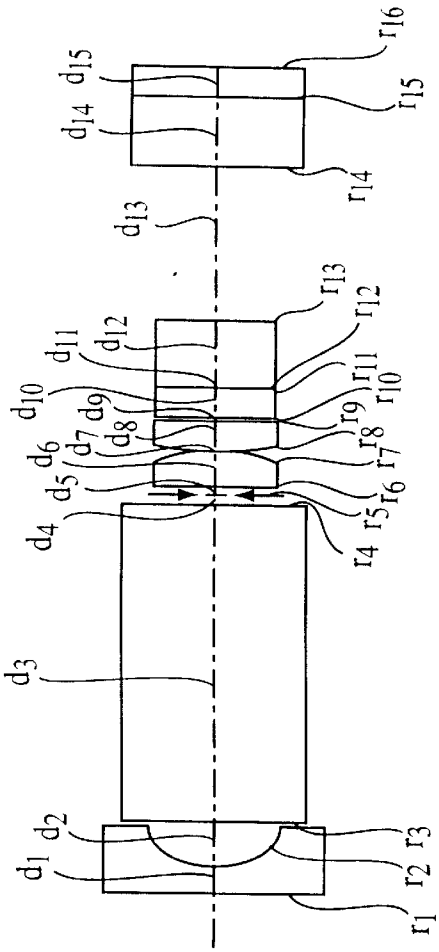
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FIG. 13

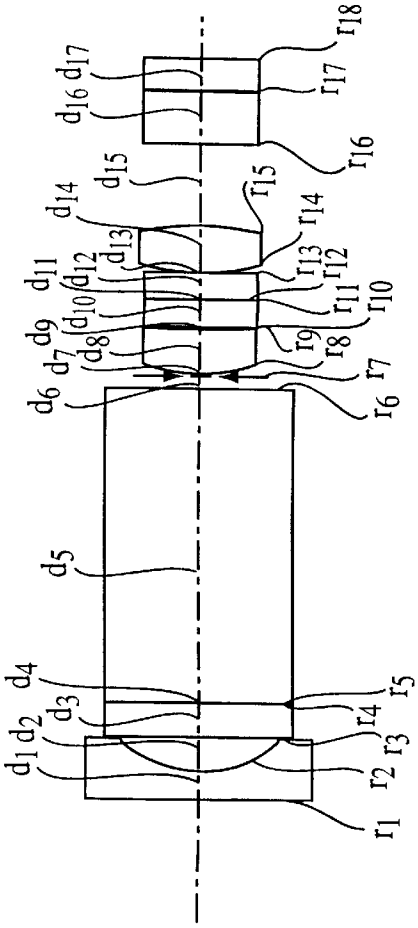
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FIG. 14

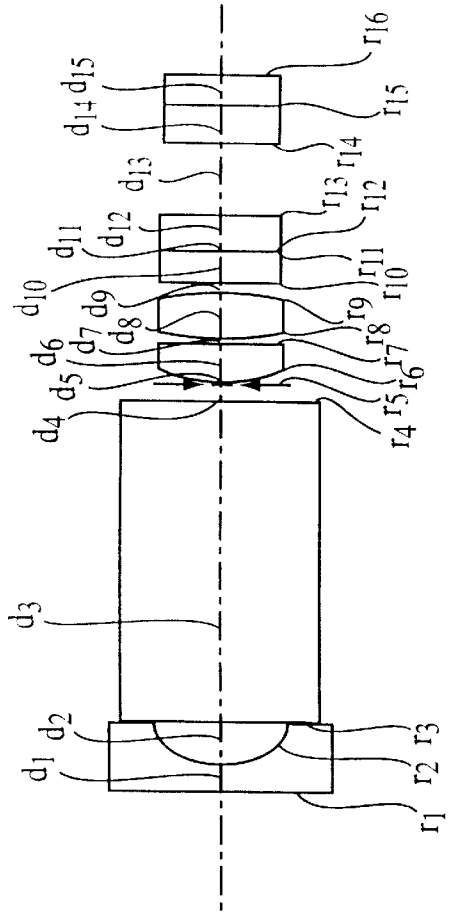
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FIG. 15

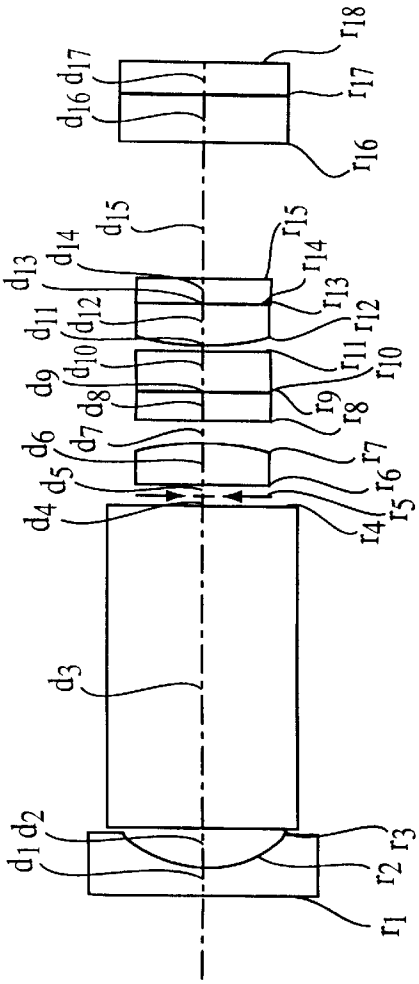
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FIG. 16

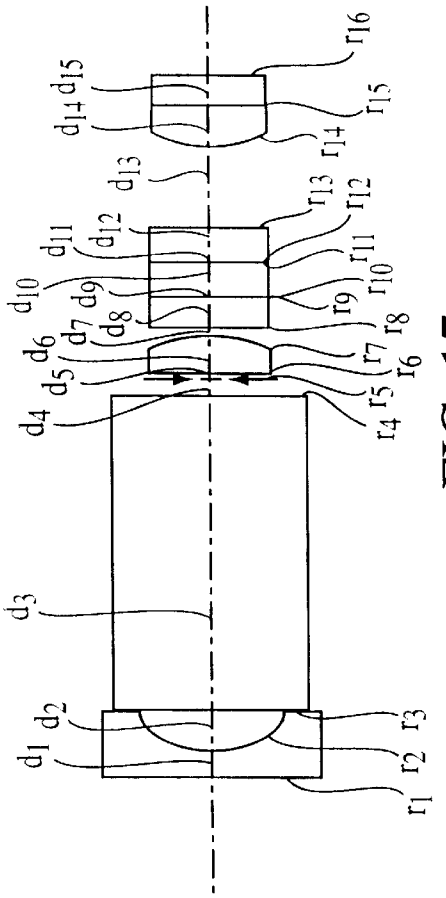
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FIG. 17

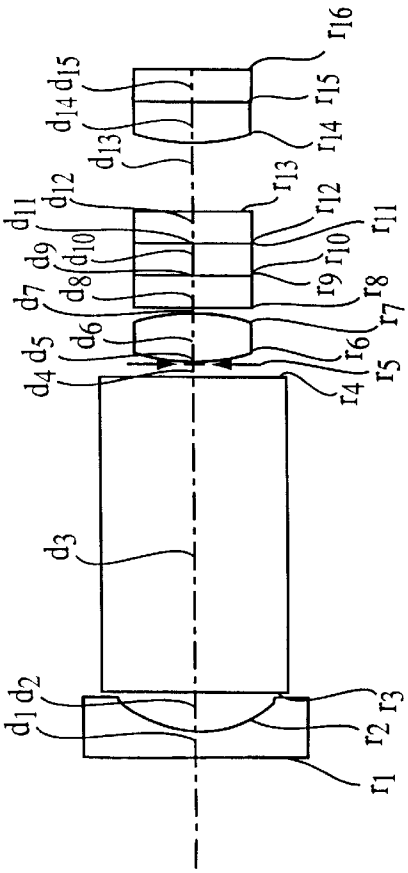
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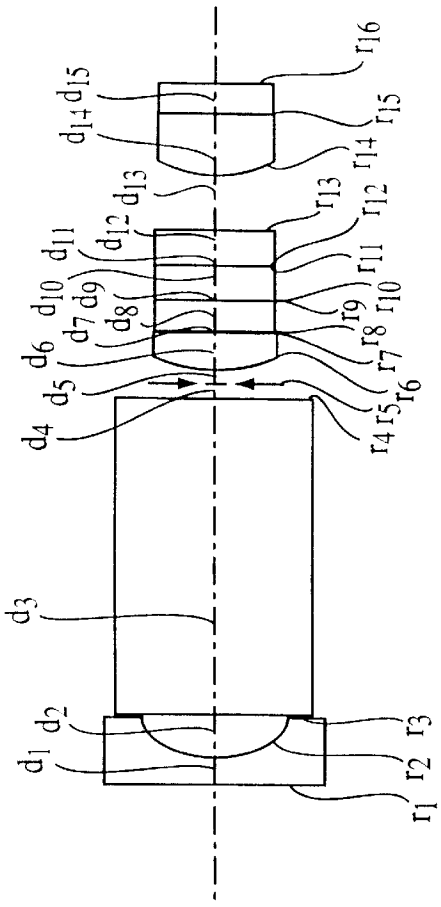
FIG. 18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r1 r2 r3 r4 r5 r6 r7 r8 r9 r10 r11 r12 r13 r14 r15 r16

FIG. 19

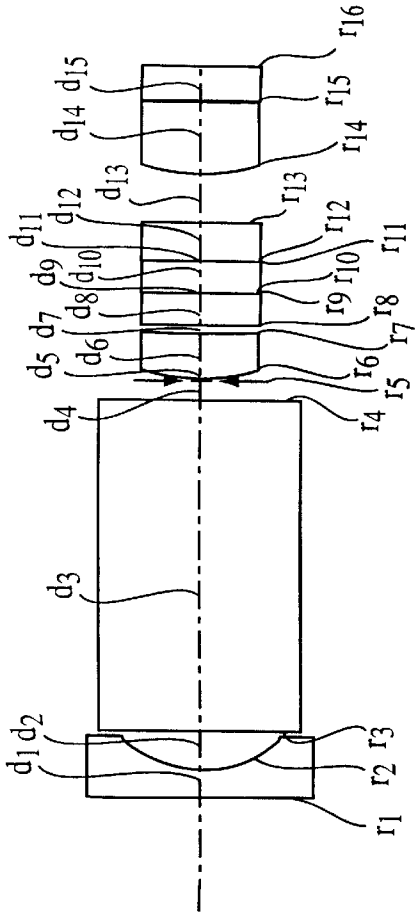

d1 d2 d3 d4 d5 d6 d7 d8 d9 d10 d11 d12 d13 d14 d15
r1 r2 r3 r4 r5 r6 r7 r8 r9 r10 r11 r12 r13 r14 r15 r16

FIG. 20

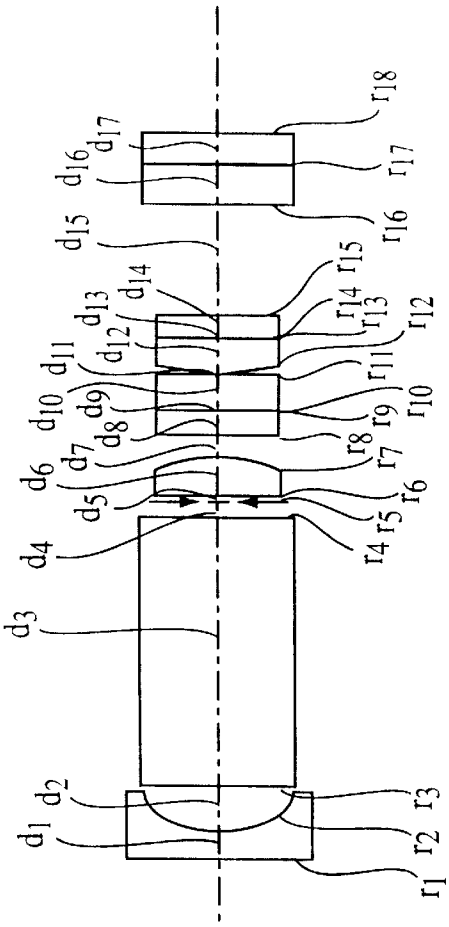
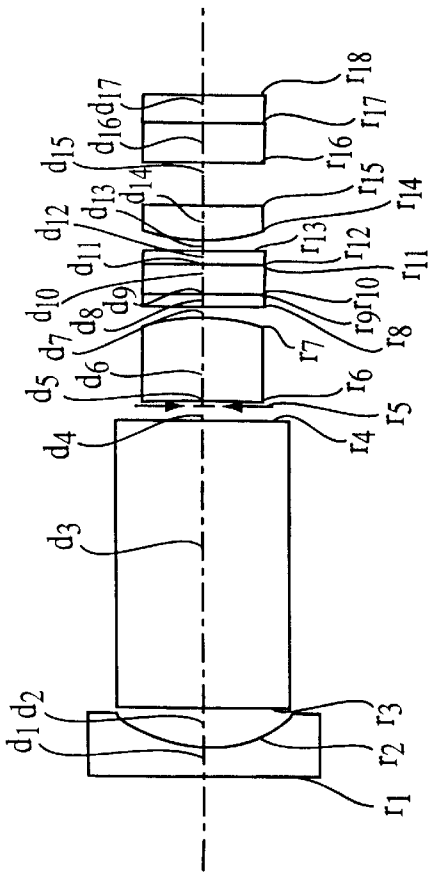

r18
d16 d17
r17
d15
r16
r15
d14
d13
r14
r13
d12
r12
d11
d10
d9
r11
d8
r10
r9
d7
r8
d6
r7
d5
r6
r5
d4
r4
d3
d1 d2
r3
r2
r1

FIG. 21


r18
d16 d17
r17
d15
r16
d14
d13
r15
d12
r14
d11
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r11
d8
r10
r9
d7
r8
d6
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d5
r6
r5
d4
r4
d3
d1 d2
r3
r2
r1

FIG. 22

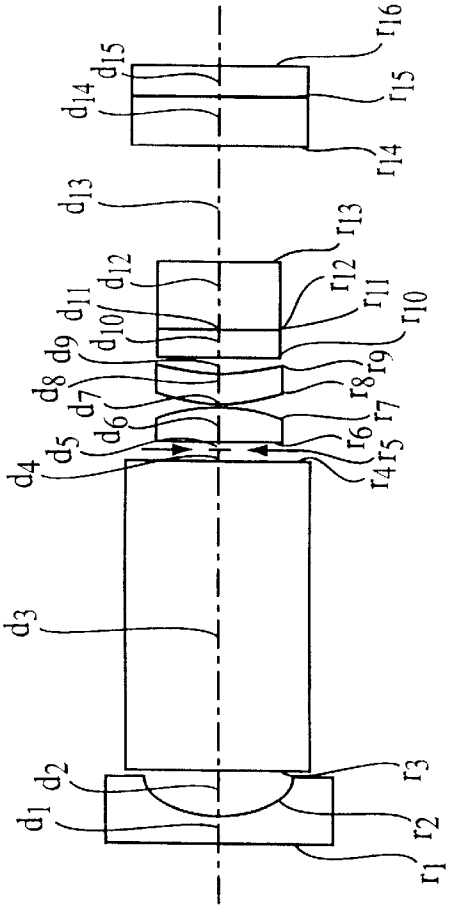

d1 d2 r1 r2 r3
d3
d4 d5 d6 d7 d8 d9 d10 d11 d12 d13 d14 d15
r4 r5 r6 r7 r8 r9 r10 r11 r12 r13 r14 r15 r16

FIG. 23

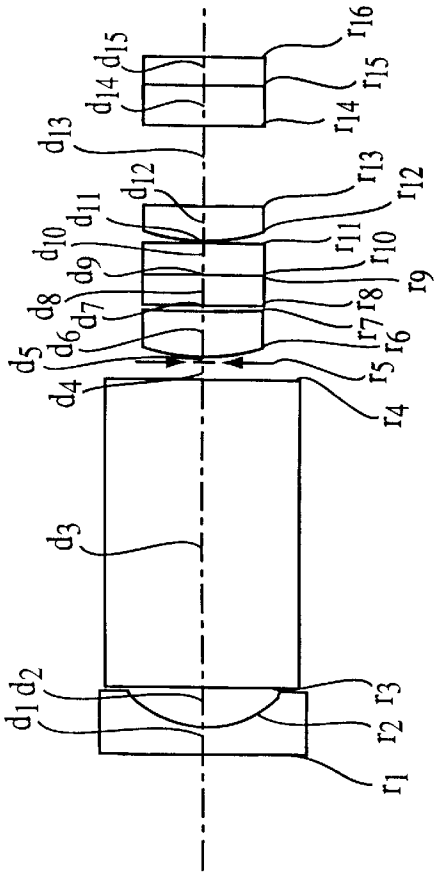
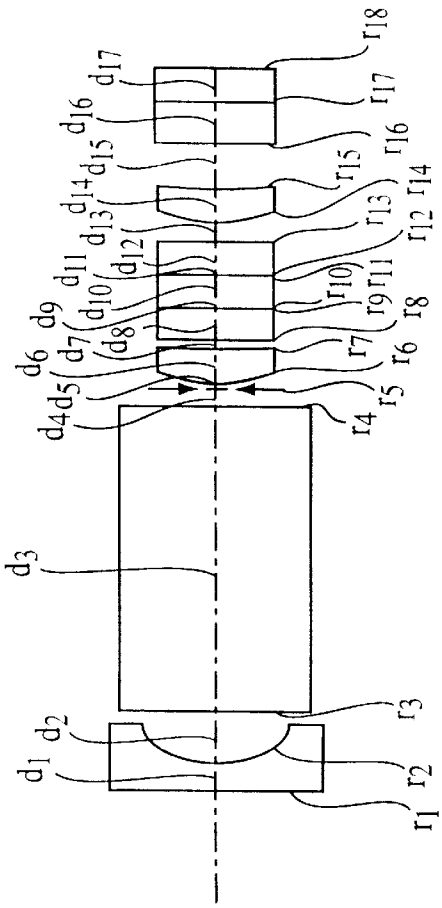

d1 d2 r1 r2 r3
d3
d4 d5 d6 d7 d8 d9 d10 d11 d12 d13 d14 d15
r4 r5 r6 r7 r8 r9 r10 r11 r12 r13 r14 r15 r16

FIG. 24


r18
d17
r17
d16
r16
d15
r15
d14
r14
d13
r13
d12
r12
d11
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d10
r10
d9
r9
d8
r8
d7
r7
d6
r6
d5
r5
d4
r4
d3
r3
d2
r2
d1
r1

FIG. 25

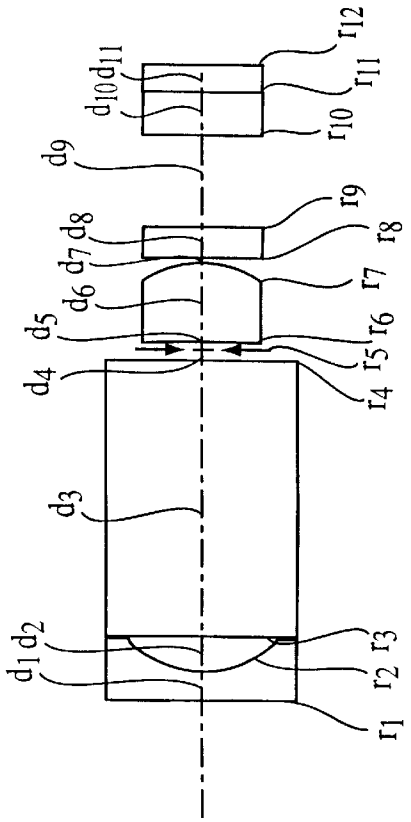

r12
d11
r11
d10
r10
d9
r9
d8
r8
d7
r7
d6
r6
d5
r5
d4
r4
d3
r3
d2
r2
d1
r1

FIG. 26

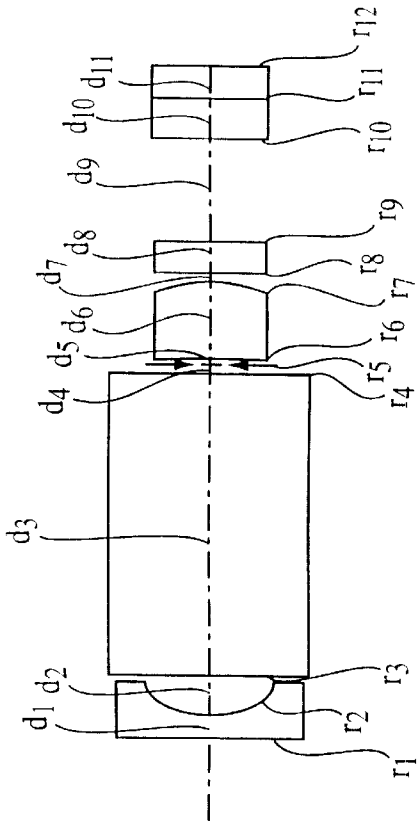

r12
r11
r10
d11
d10
d9
r9
r8
r7
r6
r5
r4
d8
d7
d6
d5
d4
d3
d2
d1
r3
r2
r1

FIG. 27

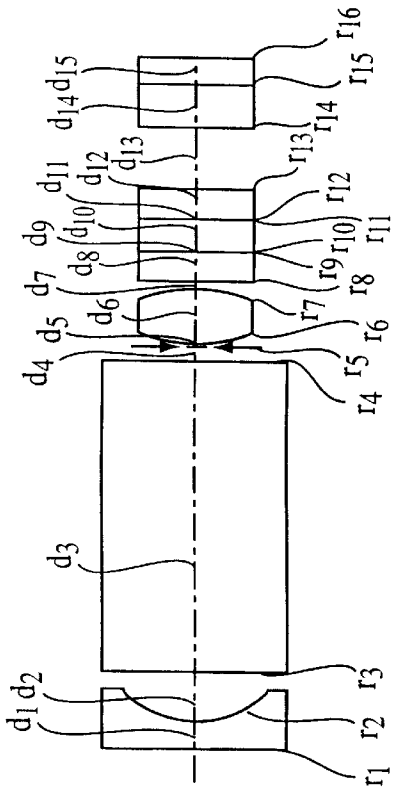

r16
r15
r14
r13
r12
r11
r10
r9
r8
r7
r6
r5
r4
r3
r2
r1
d15
d14
d13
d12
d11
d10
d9
d8
d7
d6
d5
d4
d3
d2
d1

FIG. 28

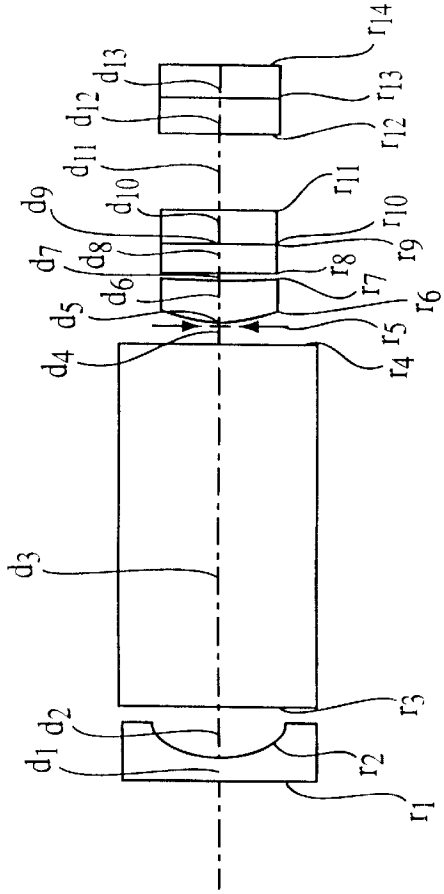

r14
d13
r13
d12
d11
r12
d10
r11
d9
r10
d7
d8
r9
d6
r8
r7
d5
r6
d4
r5
r4
d3
r3
d2
d1
r2
r1

FIG. 29

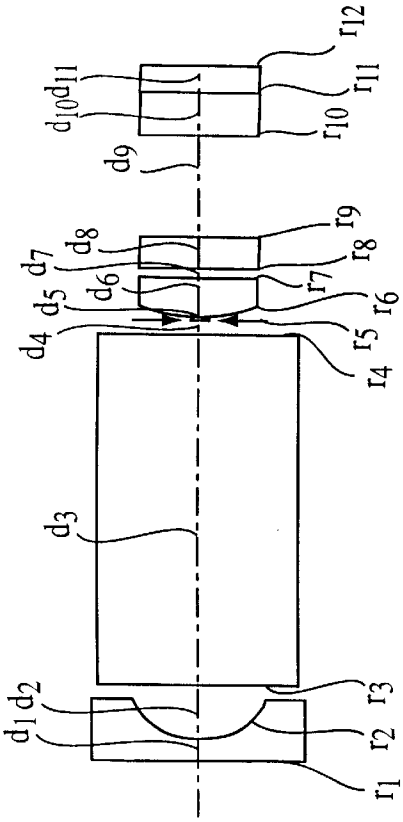
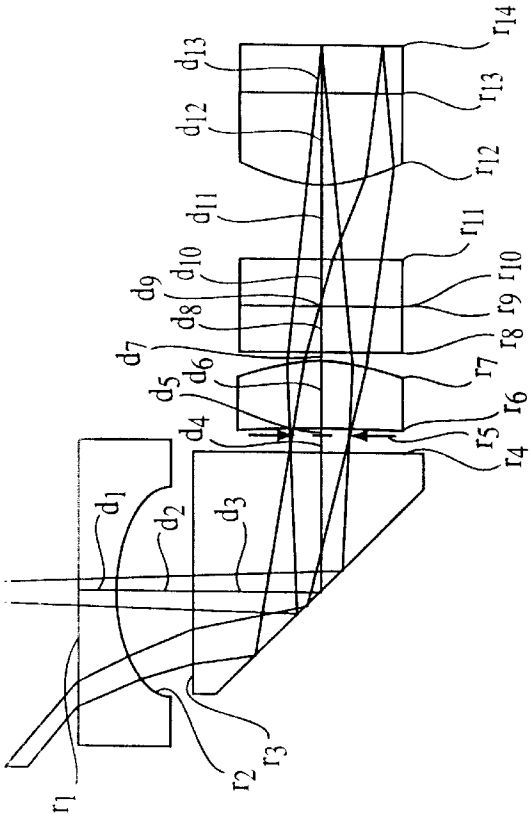

r12
d10
d11
r11
r10
d9
d7
d8
r9
d6
r8
r7
d5
r6
d4
r5
r4
d3
d2
r3
d1
r2
r1

FIG. 30


r1
r2
r3
r4
r5
r6
r7
r8
r9
r10
r11
r12
r13
r14
d1
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d3
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d6
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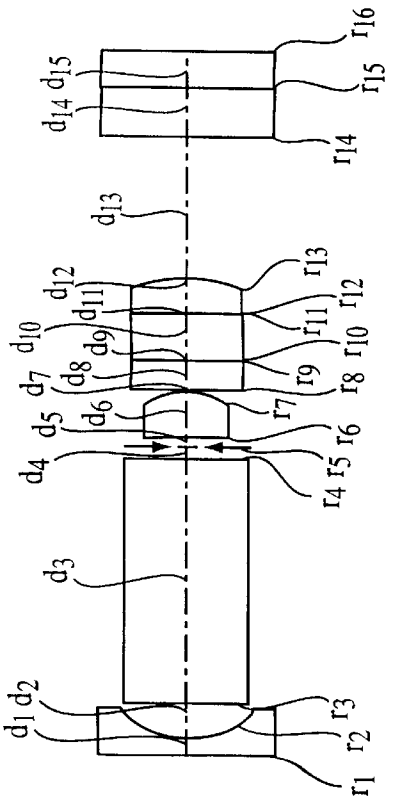
d9
d10
d11
d12
d13

FIG. 31


r1
r2
r3
r4
r5
r6
r7
r8
r9
r10
r11
r12
r13
r14
r15
r16
d1
d2
d3
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d5
d6
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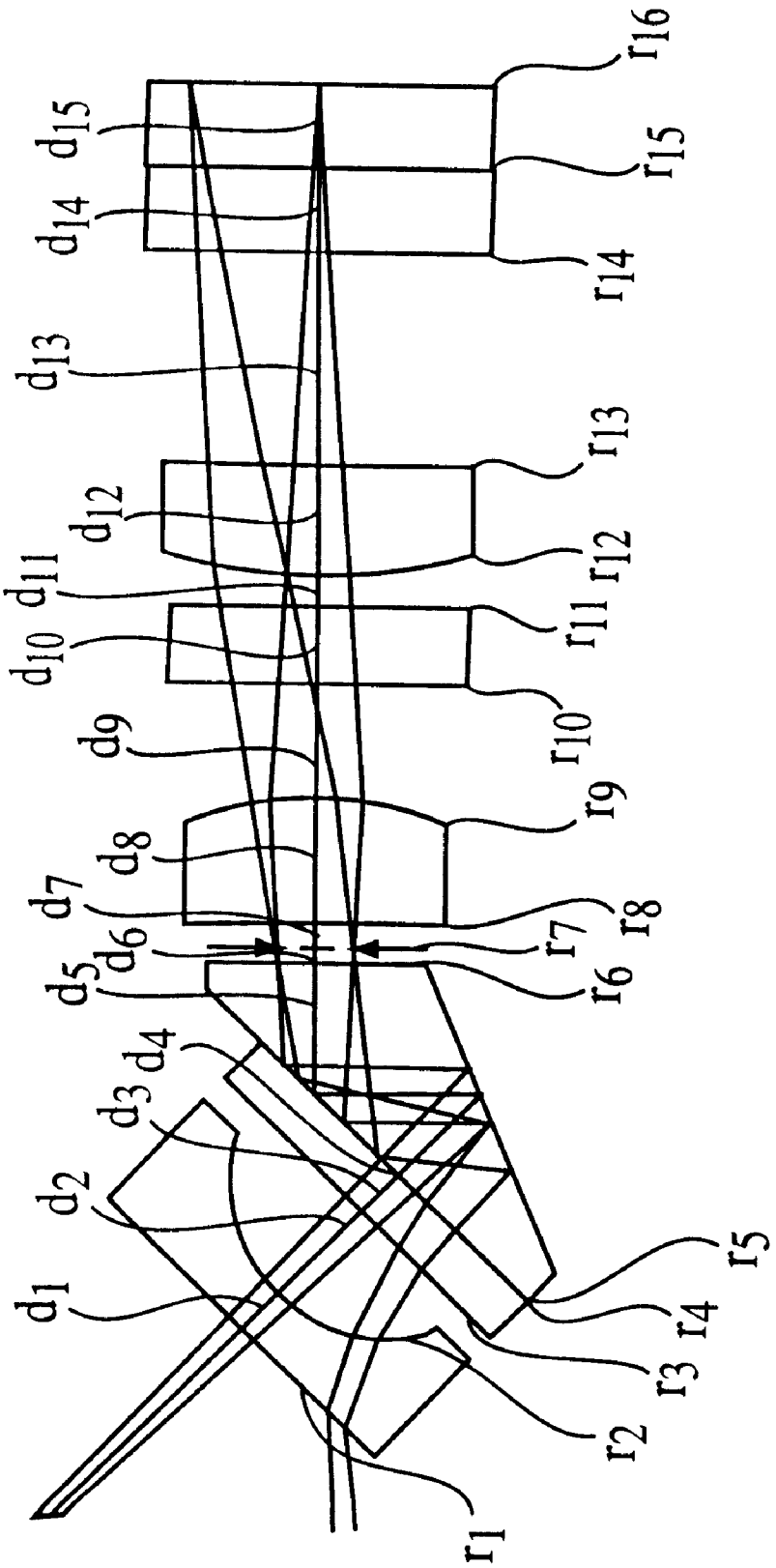
d8
d9
d10
d11
d12
d13
d14
d15

FIG. 32


r16
d15
r15
d14
r14
d13
r13
d12
r12
d11
r11
d10
r10
d9
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d8
r8
d7
r7
d6
r6
d5
d4
d3
d2
r5
d1
r4
r3
r2
r1

FIG. 33

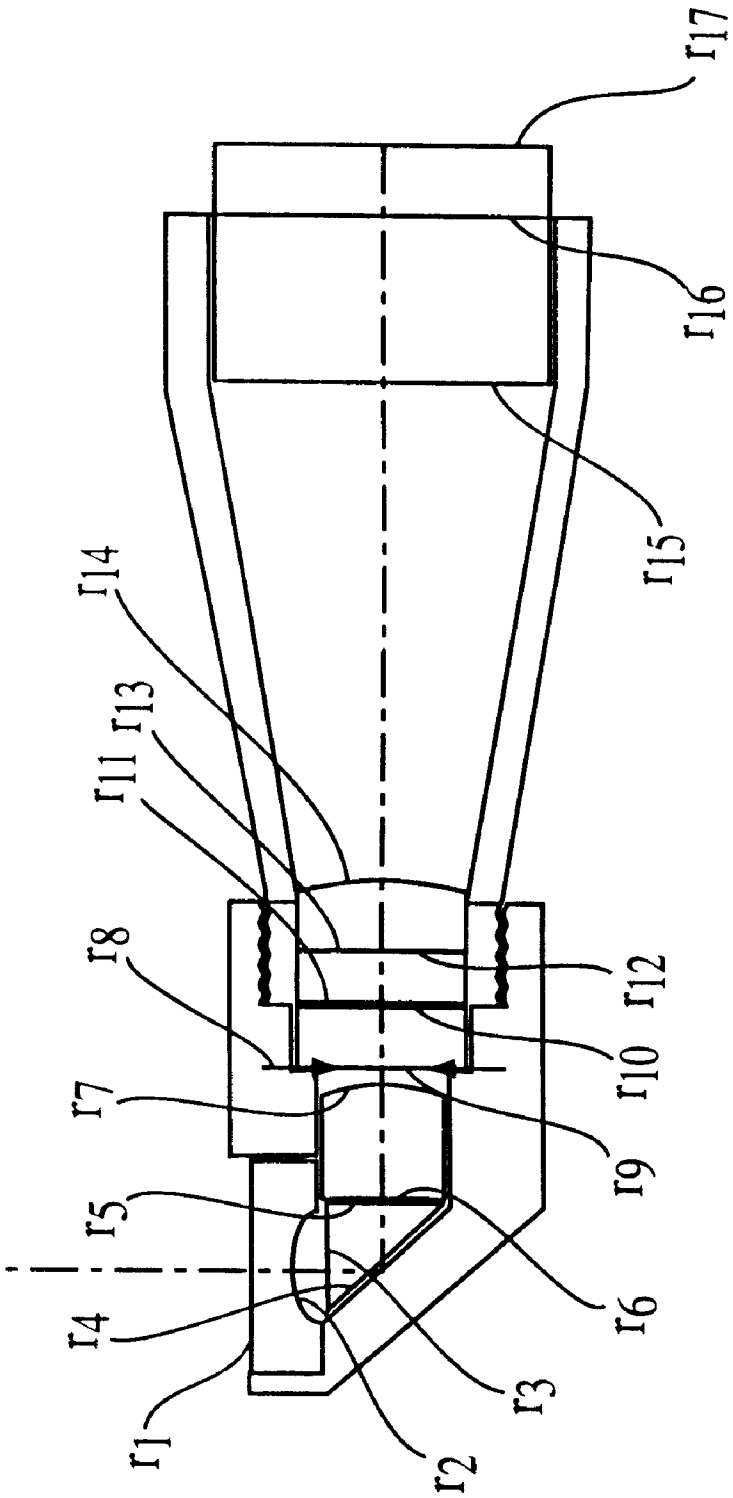

FIG. 34

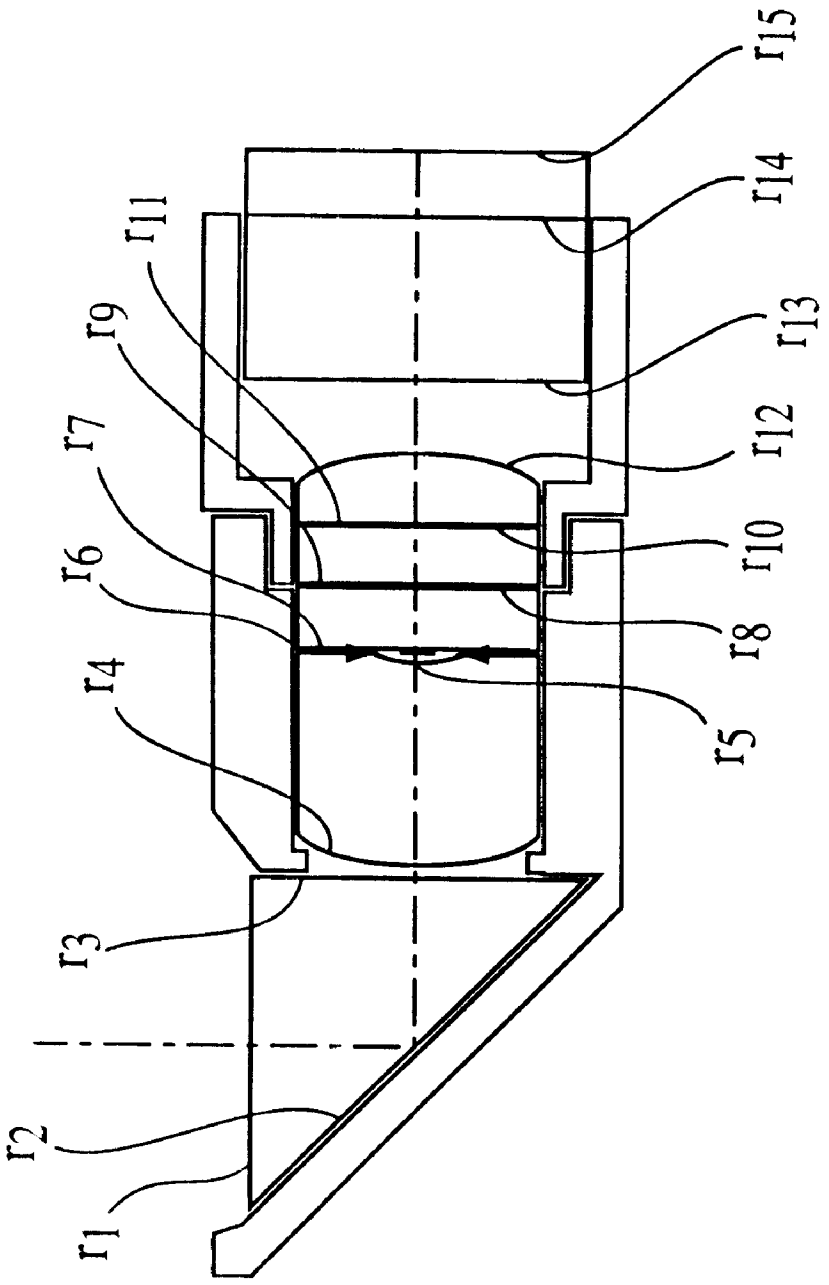

FIG. 35

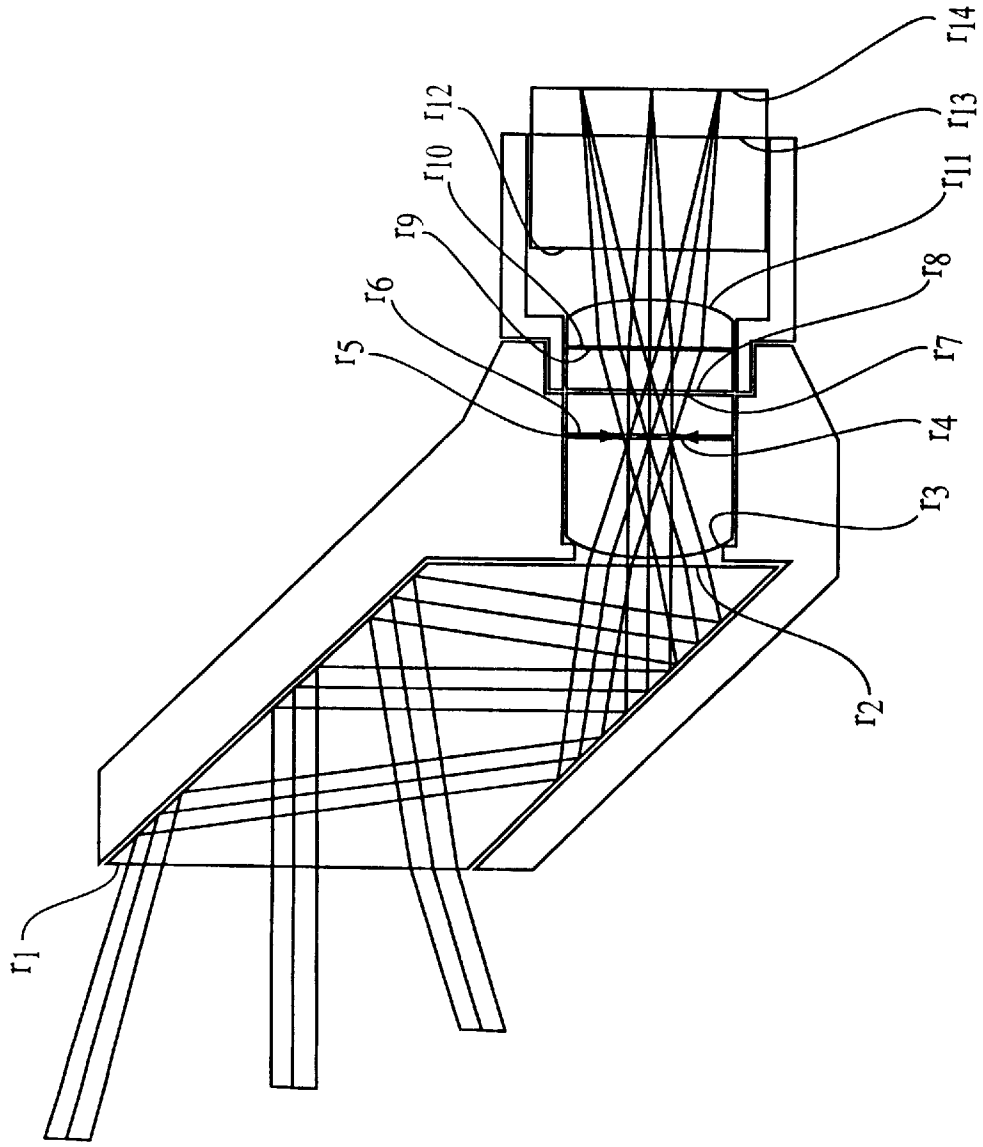

FIG. 36

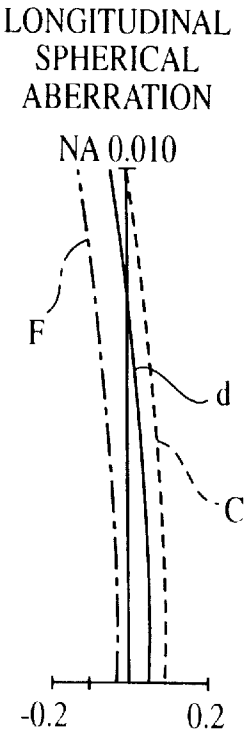

FIG. 37A

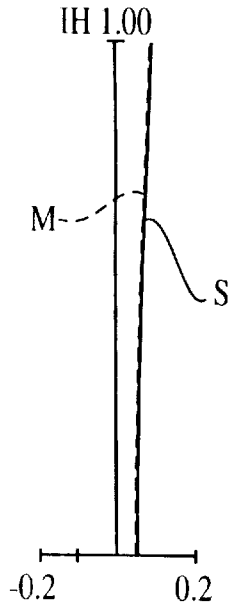

FIG. 37B

FIG. 37C

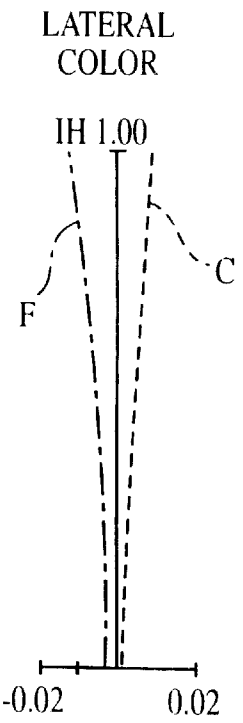

FIG. 37D

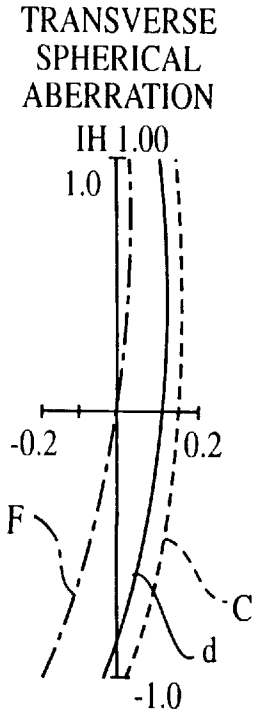

FIG. 37E

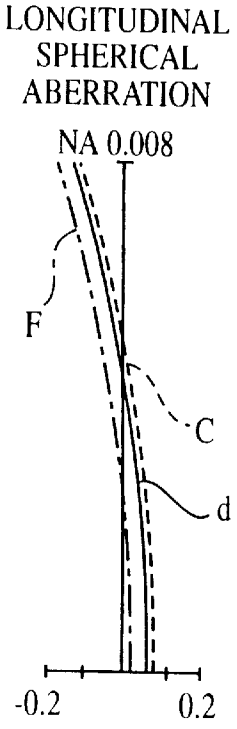

FIG. 38A

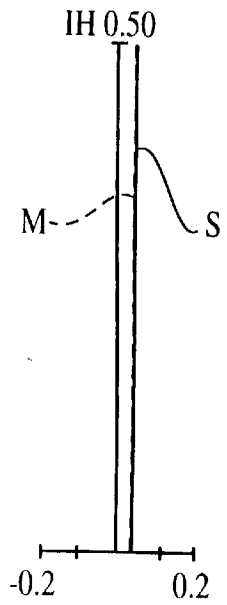

FIG. 38B

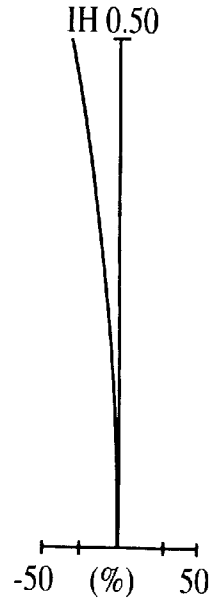

FIG. 38C

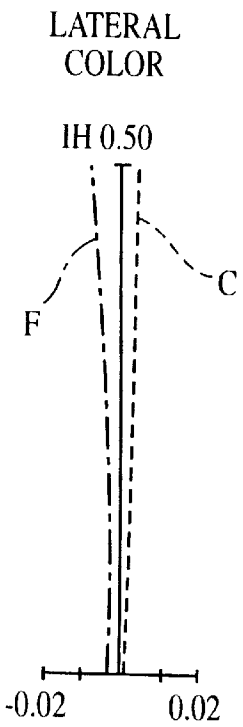

FIG. 38D

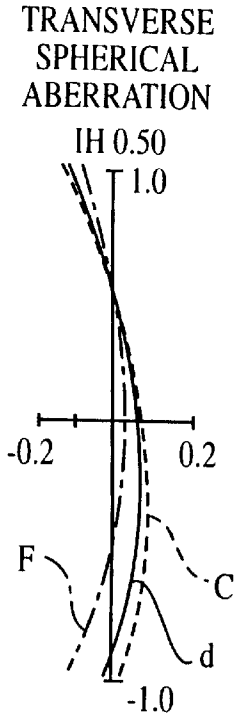

FIG. 38E

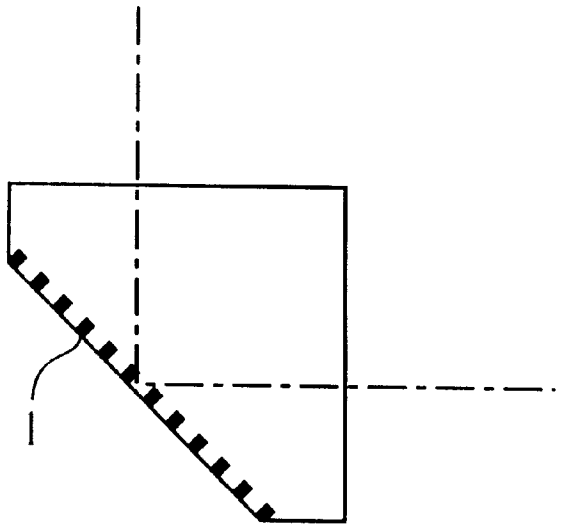

FIG. 39

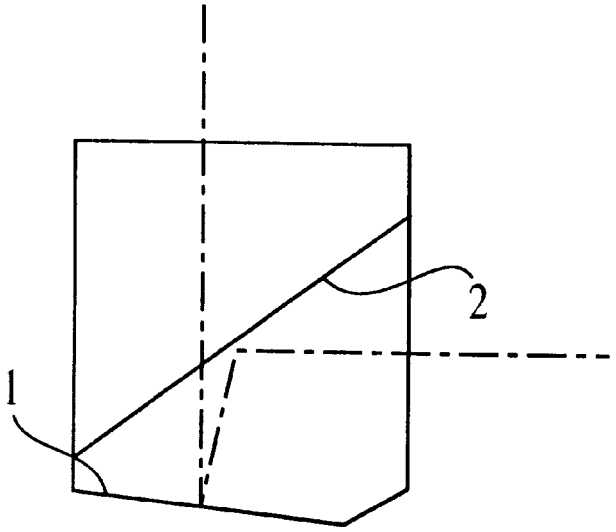

FIG. 40

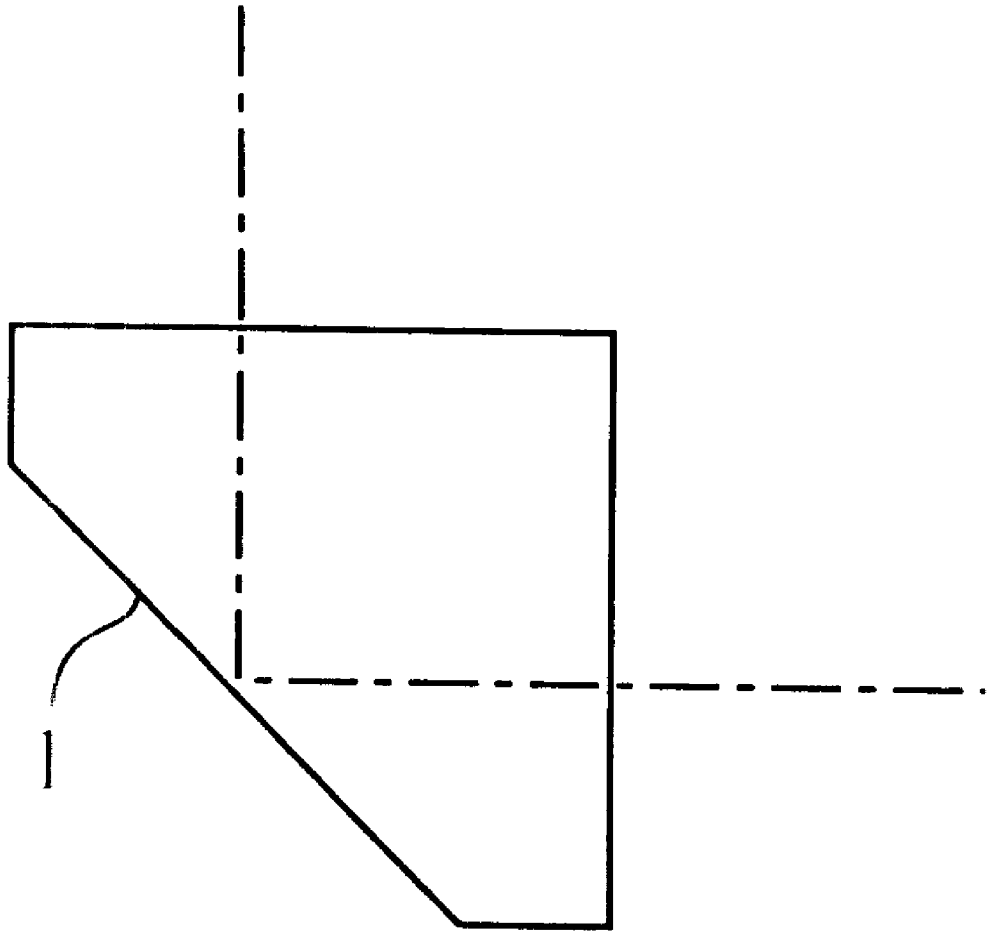

FIG. 41

OBJECTIVE OPTICAL SYSTEM

BACKGROUND OF THE INVENTION

In recent years, image pick-up elements such as CCD devices have achieved high resolution and become compact as a result of advances in fine pattern technology which have enabled the pick-up element pixel size to be reduced. As a result of these advances, highly efficient and much smaller-sized objective optical systems have been in demand in optical systems which employ such image pick-up elements as, for example, endoscope systems. Especially in the case where an optical system employs, for example, a beam-folding prism or mirror which serves as a visual beam conversion element to provide a side or perspective view, there is the tendency for the entire optical system to become large as compared with an optical system that provides only a direct view. Thus, a size-reduction in such an optical system is desired. Moreover, while small size and high performance of an optical system are desired, nevertheless, an inexpensive objective optical system with three or fewer lens elements is also desired.

As a prior art example of an objective optical system that uses a visual field conversion optical element, the optical system described in Japanese Laid Open Patent Application No. H2-69710 is known. This prior art optical system combines a negative lens element, a visual field conversion optical element, a positive lens element and a positive lens element. However, since the refractive power of the negative lens element is weak, the correction of field curvature is insufficient. Moreover, since the Abbe number of a positive lens element is small, the amount of chromatic aberration is large.

Another prior art example of an objective optical system that uses a visual field conversion optical element is disclosed in Japanese Laid Open Patent Application No. H5-307139. This optical system consists of a negative lens element, a visual field conversion optical element, a positive lens element, and a positive lens element. However, the refractive index of the negative lens element is small and the generation of lateral color is large.

Another prior art example of a visual field conversion optical element is disclosed in Japanese Laid Open Patent Application No. 37-9530.

BRIEF SUMMARY OF THE INVENTION

This invention is an objective optical system for use with, for example, an endoscope. A first object of the invention is to provide an objective optical system that includes a visual field conversion optical element which folds the rays at least once. Such an optical element enables a side or perspective view in an optical system which is reduced in size as compared with prior art systems employing a visual field conversion optical element. A second object of the invention is to provide a visual field conversion optical element within an objective optical system that yields a high-quality image at low cost by employing in the objective optical system, at most, three lens elements that can be made of inexpensive materials.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will become more fully understood from the detailed description given below and the accompanying drawings, which are given by way of illustration only and thus are not limitative of the present invention, wherein:

FIG. **1** shows the lens element construction of Embodiment 1,

FIG. **2** shows the lens element construction of Embodiment 2,

FIG. **3** shows the lens element construction of Embodiment 3,

FIG. **4** shows the lens element construction of Embodiment 4,

FIG. **5** shows the lens element construction of Embodiment 5,

FIG. **6** shows the lens element construction of Embodiment 6,

FIG. **7** shows the lens element construction of Embodiment 7,

FIG. **8** shows the lens element construction of Embodiment 8,

FIG. **9** shows the lens element construction of Embodiment 9,

FIG. **10** shows the lens element construction of Embodiment 10,

FIG. **11** shows the lens element construction of Embodiment 11,

FIG. **12** shows the lens element construction of Embodiment 12,

FIG. **13** shows the lens element construction of Embodiment 13,

FIG. **14** shows the lens element construction of Embodiment 14,

FIG. **15** shows the lens element construction of Embodiment 15,

FIG. **16** shows the lens element construction of Embodiment 16,

FIG. **17** shows the lens element construction of Embodiment 17,

FIG. **18** shows the lens element construction of Embodiment 18,

FIG. **19** shows the lens element construction of Embodiment 19,

FIG. **20** shows the lens element construction of Embodiment 20,

FIG. **21** shows the lens element construction of Embodiment 21,

FIG. **22** shows the lens element construction of Embodiment 22,

FIG. **23** shows the lens element construction of Embodiment 23,

FIG. **24** shows the lens element construction of Embodiment 24,

FIG. **25** shows the lens element construction of Embodiment 25,

FIG. **26** shows the lens element construction of Embodiment 26,

FIG. **27** shows the lens element construction of Embodiment 27,

FIG. **28** shows the lens element construction of Embodiment 28,

FIG. **29** shows the lens element construction of Embodiment 29,

FIG. **30** shows the lens element construction of Embodiment 30,

FIG. **31** shows the lens element construction of Embodiment 31,

FIG. **32** shows the lens element construction of Embodiment 32,

FIG. **33** shows the lens element construction of Embodiment 33,

FIG. **34** shows the lens element construction of Embodiment 34,

FIG. **35** shows the lens element construction of Embodiment 35,

FIG. **36** shows the lens element construction of Embodiment 36,

FIGS. **37**A–**37**E show various aberrations of the lens of Embodiment 1,

FIGS. **38**A–**38**E show various aberrations of the lens of Embodiment 26,

FIG. **39** shows a first example of a first visual field conversion optical element that may be used with the present invention,

FIG. **40** shows a second example of a second visual field conversion optical element that may be used with the present invention, and

FIG. **41** shows a third example of a third visual field conversion optical element that may be used with the present invention.

DETAILED DESCRIPTION

This invention is an objective optical system which includes a visual field-of-view conversion optical element (hereinafter termed a visual field conversion optical element) which may be formed, for example, by a beam-folding prism or mirror and which serves to provide a side or perspective view. Such an optical system can be used for various image pick-up systems, such as an endoscope, a video camera, a digital camera, and a conventional camera using silver-salt film. A visual field conversion optical element folds the light one or more times prior to the light being incident onto an image pick-up system, thereby enabling side or perspective viewing. Of course, the system of the present invention can be combined with a direct-view optical element, as well as with one or more additional visual field conversion optical elements in order to provide a view field that is nearly unlimited in extent. The present invention provides an objective optical system which includes a small-sized, highly efficient visual field conversion optical element, an aperture which serves as a stop, and additionally, either two or three lens elements (i.e., individual masses of optical material having optical power).

In the case where there are three lens elements, the relative arrangement of these components is, in order from the object side: a first lens element of negative refractive power, a visual field conversion optical element, a stop, a second lens element of positive refractive power, and a third lens element of positive refractive power. The surface at the image-side of the third lens element is convex, and the following Condition (1) is satisfied.

$$0.1<|R_{(3R)}/f|<20 \qquad \text{Condition (1)}$$

where

$R_{(3R)}$ is the radius of curvature of the image-side surface of the third lens element, and

f is the focal distance of the objective optical system.

For example, an objective optical system for an endoscope that provides a view field that includes a side or a perspective view requires that the image angle (i.e., picture angle) should be about 80 degrees or more. Thus, when an objective optical system having a visual field conversion optical element and a stop is composed of three lens elements, it is desirable that the relative order of the lens elements be as stated above, so that the optical system is of the retro-focus type.

In the case where there are only two lens elements, it is also desirable that the optical system be of the retro-focus type. This is accomplished by having the relative arrangement of the above components be, in order from the object side: a negative lens element, a visual field conversion optical element, a stop, and a positive lens element. However, this arrangement provides an asymmetrical refractive power relative to the stop. For this reason, the generation of aberrations such as astigmatism, coma, and lateral color tends to be large. In order to make the objective optical system more compact, the refractive power of each lens element needs to be strengthened. Therefore, the aberrations generated by each lens element become larger, and it becomes difficult to maintain high image-formation quality. In order to better correct aberrations, the surface at the image-side of the third lens element is made convex in a manner which satisfies the above-mentioned Condition (1).

When Condition (1) is satisfied, aberrations will be well-corrected, and this is especially the case with coma. If the absolute value of the ratio $R_{(3R)}/f$ is 0.1 or less, the refractive power of image-side surface of the third lens element will be too strong, resulting in the generation of excessive aberrations. Moreover, if the absolute value of the ratio $R_{(3R)}/f$ is 20 or more, the refractive power of the image-side surface of the third lens element will be too weak, and it will be difficult to make the objective optical system compact.

In addition, it is preferred that the following Conditions (2) and (3) be satisfied.

$$\nu(p)>42 \qquad \text{Condition (2)}$$

$$N_1>1.6 \qquad \text{Condition (3)}$$

where

$\nu(p)$ is the Abbe number of a lens element of positive refractive power, and

N_1 is the refractive index of the first lens element, in order from the object side.

In the optical system using an image pick-up element such as a CCD device, vignetting (i.e., limb-darkening) and color effects resulting from light rays which are incident at oblique angles to the surface of an image pick-up element need to be prevented. Therefore, it is desirable that the incident light rays strike the image pick-up surface perpendicularly. Where there are three lens elements, it is desirable that the image-side surface of the third lens element be convex. This assists in making the incident light rays strike the image pick-up surface perpendicularly. However, when the surface at the image-side of the third lens element is made convex, correction of aberrations, especially lateral color, generated by this surface becomes difficult.

In order to correct these aberrations, at least one of the positive lens elements must satisfy Condition (2). If Condition (2) is not satisfied, i.e., if the Abbe number $\nu(p)$ of a lens element with positive refractive power does not exceed 42, correction of lateral color will be difficult.

Condition (3) controls the generation of aberrations. By satisfying Condition (3), the refractive index of the first lens element, in order from the object side, is made sufficient to ensure that the aberrations generated by this lens element are small. In other words, if the refractive index of the first lens element exceeds 1.6, the aberrations generated by the first lens element can be sufficiently corrected. The stop is

desirable positioned between the visual field conversion optical element and the second lens element.

It is also desirable if the following Condition (4) is satisfied.

$$0.1<R_{(1R)}/f<3 \quad \text{Condition (4)}$$

where

$R_{(1R)}$ is the radius of curvature of the image-side surface of the first lens element, and

f is as defined above.

Condition (4) limits the aberrations generated by the image-side surface of the first lens element, in order from the object side. If the value of $R_{(1R)}/f$ is 0.1 or less, the aberrations generated by the first lens element will be too large. If the value of $R_{(1R)}/f$ is 3 or more, the refractive power of the first lens element will be too weak, resulting in it being difficult to make the objective lens system compact.

It is also desirable if the following Condition (5) is satisfied.

$$0.05<|f/f_1|<5 \quad \text{Condition (5)}$$

where

f is as defined above, and

f_1 is the focal distance of the first lens element.

Condition (5) also controls aberrations that are generated by the objective optical system of the invention. If the absolute value of the ratio f/f_1 is 0.05 or less, the refractive power of the first lens element will be too large and it will be difficult to satisfactorily correct the aberration outside an axis in the whole system. Moreover, if the absolute value of the ratio f/f_1 is 5 or more, it will be difficult to make the objective optical system compact.

An infrared cut-off filter may be used between the stop and the image surface. When the objective optical system of this invention is used with an image pick-up element which has a sensitivity to some extent to infrared wavelengths, such as CCD, an infrared cut-off filter is needed. However, when an infrared cut-off filter is used, the resulting difference of optical path length in the infrared cut-off filter between the light rays on-axis and off-axis will be large. This results in a disadvantage in that the coloring will be different at the center if the screen verses the peripheral areas of the screen. In the objective optical system of this invention, it is desirable to use an infrared cut-off filter between the image surface and a stop at an axial position where the difference in angle between on-axis and off-axis light rays is small.

It is also desirable if the following Condition (6) is satisfied.

$$1<Dp/f<10 \quad \text{Condition (6)}$$

where

Dp is the air conversion length from the image-side surface of the first lens element to the stop, and

f is as defined previously.

If the lower-limit value of Condition (6) is not satisfied, the construction configuration of a visual field conversion optical element will be difficult. Moreover, if the upper limit of Condition (6) is not satisfied, it will be difficult to make the whole system compact.

In order to correct the aberrations satisfactorily, when the image-side surface of the lens element nearest the image side is made into a convex shape, it is especially important that Condition (1) be satisfied when the pixel size of the image pick-up element of a CCD device is 5 micrometers or less. Moreover, it is desirable if the outer diameter of the lens element nearest the image side is 3 mm or less. Moreover, in order to make a much more favorable image-formation capability, it is desirable to satisfy the following Condition (1-1) instead of Condition (1).

$$0.5<|R_{(3R)}/f|<15 \quad \text{Condition (1-1)}$$

In order to satisfactorily correct the lateral chromatic aberration, at least one lens element surface among the lens elements on the image-side of the stop should desirable satisfy Condition (2). It is important that Condition (2) be satisfied when the pixel size of the image pick-up element of a CCD device is 5 micrometers or less. Moreover, satisfaction of Condition (2) is especially important when the outer diameter of the lens element nearest the image side is 3 mm or less. However, in order to obtain an objective optical system with a much more favorable image-formation capability, it is desirable to satisfy the following Condition (2-1) in lieu of merely satisfying Condition (2).

$$\nu(p)>45 \quad \text{Condition (2-1)}$$

In order to correct aberrations satisfactorily, it is desirable that the image-side surface of the first lens element (i.e., the negative lens element) satisfies Condition (3). Satisfaction of Condition (3) is important when the pixel size of the image pick-up element (such as a CCD device) is 5 micrometers or less. Moreover, satisfaction of Condition (3) is especially important when the outer diameter of the lens element nearest the image is 3 mm or less. However, in order to obtain an objective optical system with a more favorable image-formation capability, it is desirable to satisfy the following Condition (3-1) in lieu of merely satisfying Condition (3).

$$N_1>1.7 \quad \text{Condition (3-1)}$$

In order to satisfactorily correct aberrations, it is desirable that the negative lens element satisfies Condition (4). The satisfaction of Condition (4) is important when the pixel size of the image pick-up element (such as a CCD device) is 5 micrometers or less. Moreover, satisfaction of this condition is especially important when the outer diameter of the lens element nearest the image is 3 mm or less. However, in order to obtain an objective optical system which has a much more favorable image-formation capability, it is desirable to satisfy the following Condition (4-1) in lieu of merely satisfying Condition (4).

$$0.5<R_{(1R)}/f<3 \quad \text{Condition (4-1)}$$

It is desirable that the first lens element (i.e., the negative lens element) satisfies Condition (5). Satisfaction of Condition (5) is important when the pixel size of the image pick-up element is 5 micrometers or less. Moreover, satisfaction of Condition (5) is especially important when the outer diameter of the lens element nearest the image is 3 mm or less. However, in order to obtain an optical system which has a more favorable image-formation capability, it is desirable to satisfy the following Condition (5-1) in lieu of merely satisfying Condition (5).

$$0.1<|f/f_1|<3 \quad \text{Condition (5-1)}$$

In order to make the objective optical system of this invention compact, it is desirable to satisfy above-mentioned Condition (6). Satisfaction of Condition (6) is important when the pixel size of the image pick-up element is 5

micrometers or less. Moreover, satisfaction of Condition (6) is especially important when the outer diameter of the lens element nearest the image is 3 mm or less. However, in order to make the objective optical system even more compact, it is desirable that the following Condition (6-1) be satisfied in lieu of merely satisfying Condition (6).

$$1.5<Dp/f<7 \qquad \text{Condition (6-1)}$$

When using the objective optical system of this invention with an endoscope system, it may be desirable that the object-side surface of the first lens element be a planar surface. A planar surface is advantageous from the point of view of making the object-side surface of the endoscope easy to clean. However, if priority is given to optical performance, the curvature on the object-side surface of the first lens element should be maintained. Further, in the optical system of this invention, in order to reduce cost, it is desirable to make the surface of one side of at least one positive lens element into a flat surface.

In order to make the objective optical system compact while satisfactorily correcting aberrations generated by the first lens element (i.e., the negative lens element), it is desirable to satisfy the following Condition (7).

$$0.4 \text{ mm}<R_{(1R)}<3 \text{ mm} \qquad \text{Condition (7)}$$

where

$R_{(1R)}$ is as defined above.

If the lower-limit value of Condition (7) is not satisfied, the refractive power of the first lens element will be too strong and it will be difficult to satisfactorily correct aberrations of the objective optical system. Moreover if the upper limit of Condition (7) is not satisfied, the refractive power of the first lens element will be too weak and it will be difficult to make the objective optical system compact. However, it is more desirable to satisfy the following Condition (7-1) in lieu of merely satisfying Condition (7).

$$0.6 \text{ mm}<R_{(1R)}<2 \text{ mm} \qquad \text{Condition (7-1)}$$

Further, when at least one positive lens element includes a flat surface, it is desirable that the following Condition (8) be satisfied:

$$0.5 \text{ mm}<|R(p)|<5 \text{ mm} \qquad \text{Condition (8)}$$

where

R(p) is the radius of curvature of the convex side of the positive lens element having its opposite side planar.

Condition (8) allows for the objective optical system to be compact, while ensuring that the aberrations generated by said positive lens element are small. If the lower-limit value of Condition (8) is not satisfied, the refractive power of the positive lens element will be too strong, and the correction of coma aberration will be difficult. Moreover, if the upper limit of Condition (8) is not satisfied, the refractive power of said positive lens element will be too weak and it will be difficult to make the objective optical system compact. However, it is more desirable if the following Condition (8-1) is satisfied in lieu of merely satisfying Condition (8).

$$0.8 \text{ mm}<|R(p)|<3 \text{ mm} \qquad \text{Condition (8-1)}$$

The objective optical system of this invention is effective when pixel size of the image pick-up element (such as a CCD device) is 5 micrometers or less. However, it becomes more effective as the pixel size is reduced to 4 micrometers or less. Moreover, when the outer diameter of the lens element nearest the image side is 3 mm or less, the optical system of this invention is effective, and it is even more effective when the outer diameter of the lens element is 2.5 mm or less. Also, the objective optical system of this invention is effective when the length, width or height of a visual field conversion optical element is smaller than 5 mm. However, it is even more effective when the length, width, or height of a visual field conversion optical element is smaller than 3 mm.

Next, specific examples of the objective optical system of this invention will be described in the following embodiments of the invention, which are given for purposes of illustration only.

In Tables 1–36 which follow, # is the surface number in order from the object side, R is the radius of curvature (in mm) of the surface, D is the on-axis spacing (in mm) between surfaces, N_d is refractive index and ν_d is the Abbe constant (at the sodium d-line) of each lens element. Moreover, f is the focal length of the objective optical system, 2ω is the image angle, $F_{NO.}$ is the F-number, IH is image height, OB is distance of the object, and the other values listed are as defined above. Various color filters may be used in the objective optical system, depending on the application. Further, various filters for blocking specific laser wavelength ranges may be provided, such as light output by a YAG laser or a semiconductor laser. Such filters may be of the absorbing-type, such as an infrared cut-off filter, or may be of the interference-type. The function of these filters can be provided in, or on, various plane-parallel plates or, alternatively, may be instead be provided in, or on, the materials that form the lens elements.

Embodiment 1

FIG. **1** shows a retro-focus type objective optical system of Embodiment 1 which includes, in relative order from the object side: a first lens element (r_1–r_2) of negative refractive power, a visual field conversion optical element (r_3–r_4), a stop (r_5), a second lens element (r_6–r_7) of positive refractive power, and a third lens element (r_{10}–r_{11}) of positive refractive power. In order from the object side, the first lens element is of a planar-concave shape, the second lens element is of a concave-convex shape, and the third lens element is of a concave-convex shape. Also, various filters which block specific wavelength ranges may be provided. In this embodiment, the plane-parallel plate (r_8–r_9) on the image-side of the second lens element is an interference-type filter, the plane-parallel plate (r_{12}–r_{13}) is an absorbing-type, infrared cut-off filter, and the plane-parallel plate (r_{14}–r_{15}) is an interference-type filter. Further, the two plane-parallel plates nearest the image are a cover glass (r_{16}–r_{17}) of a dust guard, and a cover glass (r_{17}–r_{18}) of an image pick-up element. The outer diameter of the positive lens elements in this embodiment is 2 mm.

TABLE 1

#	R	D	N_d	υ_d
1	∞	0.4000	1.88300	40.76
2	1.3595	0.5430		
3	∞	4.6880	1.88300	40.76
4	∞	0.1500		
5	∞ (stop)	0.2000		
6	−12.1267	0.4947	1.88300	40.76
7	−2.6180	0.1735		
8	∞	0.4000	1.52287	59.89
9	∞	0.1000		
10	−12.2163	0.5211	1.88300	40.76
11	−3.3203	0.1500		
12	∞	0.6200	1.51400	75.00

TABLE 1-continued

#	R	D	N_d	υ_d
13	∞	0.0300		
14	∞	0.4000	1.52287	59.89
15	∞	2.0182		
16	∞	0.7000	1.51633	64.14
17	∞	0.5000	1.51633	64.14
18	∞			
f = 1.103	2ω = 119.7°	$F_{NO.}$ = 4.95	IH = 1 mm	OB =
$\lvert R_{(3R)}/f\rvert$ = 3.010	υ(p) = 40.76		N_1 = 1.883	10 mm
$\lvert R_{(1R)}/f\rvert$ = 1.233	$\lvert f/f_1\rvert$ = 0.716		Dp/f = 2.885	
$R_{(1R)}$ = 1.360				

Embodiment 2

FIG. **2** shows Embodiment 2 which includes, in relative order from the object side, a first lens element (r_1–r_2) of negative refractive power, a visual field conversion optical element (r_3–r_4), a stop (r_5), a second lens element (r_6–r_7) of positive refractive power, and a third lens element (r_{14}–r_{15}) of positive refractive power. In order from the object side, the first lens element is of a planar-concave shape, the second lens element is of a planar-convex shape, and the third lens element is of a concave-convex shape. Various filters for blocking specific wavelength ranges may be arranged within the objective optical system. For example, the plane-parallel plate (r_8–r_9) is an interference-type filter, the plane-parallel plate (r_{10}–r_{11}) is an absorbing-type, infrared cut-off filter, and the plane-parallel plate (r_{12}–r_{13}) is an interference-type filter. The two plane-parallel plates nearest the image are the cover glass (r_{16}–r_{17}) of a dust guard and the cover glass (r_{17}–r_{18}) of an image pick-up element, such as a CCD device. The outer diameter of the positive lens elements of this embodiment is 1.4 mm.

TABLE 2

#	R	D	N_d	υ_d
1	∞	0.3500	1.88300	40.76
2	1.5663	0.4951		
3	∞	4.0390	1.88300	40.76
4	∞	0.2000		
5	∞ (stop)	0.0500		
6	∞	0.8529	1.51633	64.14
7	−1.0730	0.1000		
8	∞	0.3000	1.52287	59.89
9	∞	0.0300		
10	∞	0.4000	1.51400	75.00
11	∞	0.0300		
12	∞	0.3000	1.52287	59.89
13	∞	0.1000		
14	−8.4371	0.7068	1.88300	40.76
15	−1.8070	0.6078		
16	∞	0.5000	1.51633	64.14
17	∞	0.4000	1.51633	64.14
18	∞			
f = 0.637	2ω = 100.4°	F_{NO} = 4.16	IH = 0.5 mm	OB =
$\lvert R_{(3R)}/f\rvert$ = 2.837	υ(p) = 64.14		N_1 = 1.883	10 mm
$\lvert R_{(1R)}/f\rvert$ = 2.459	$\lvert f/f_1\rvert$ = 0.359		Dp/f = 4.459	
$R_{(1R)}$ = 1.566 mm	R(p) = 1.073 mm (second lens element)			

Embodiment 3

FIG. **3** shows Embodiment 3 which includes, in relative order from the object side, a first lens element (r_1–r_2) of negative refractive power, a visual field conversion optical element (r_3–r_4), a stop (r_5), a second lens element (r_6–r_7) of positive refractive power, and a third lens element (r_{12}–r_{13}) of positive refractive power. In order from the object side, the first lens element is of a planar-concave shape, the second lens element is of a double-convex shape, and the third lens element is of a concave-convex shape. Two plane-parallel plates are positioned between the second lens element and the third lens elements. The first plane-parallel plate (r_8–r_9) is an interference-type filter. The second plane-parallel plate (r_{10}–r_{11}) is an absorbing-type, infrared cut-off filter. The two plane-parallel plates nearest the image are the cover glass (r_{14}–r_{15}) of a dust guard and the cover glass (r_{15}–r_{16}) of an image pick-up element, such as a CCD device. The outer diameter of the positive lens elements of this embodiment is 2 mm

TABLE 3

#	R	D	N_d	υ_d
1	∞	0.4000	1.88300	40.76
2	1.5373	0.7663		
3	∞	4.8880	1.88300	40.76
4	∞	0.1500		
5	∞ (stop)	0.1000		
6	9.0386	1.1776	1.88300	40.76
7	−3.7585	0.0500		
8	∞	0.4000	1.52287	59.89
9	∞	0.0300		
10	∞	1.0000	1.51400	75.00
11	∞	0.2000		
12	−14.2710	0.4844	1.83481	42.72
13	−4.6110	2.6442		
14	∞	0.5000	1.51633	64.14
15	∞	0.5000	1.51633	64.14
16	∞			
f = 1.252	2ω = 99.8°	F_{NO} = 4.85	IH = 1 mm	OB =
$\lvert R_{(3R)}/f\rvert$ = 3.683	υ(p) = 42.72		N_1 = 1.883	10 mm
$\lvert R_{(1R)}/f\rvert$ = 1.228	$\lvert f/f_1\rvert$ = 0.719		Dp/f = 2.805	
$R_{(1R)}$ = 1.537 mm				

Embodiment 4

FIG. **4** shows the objective optical system of Embodiment 4 which includes, in relative order from the object side, a first lens element (r_1–r_2) of negative refractive power, a visual field conversion optical element (r_3–r_4), a stop (r_5), a second lens element (r_6–r_7) of positive refractive power, and a third lens element (r_{12}–r_{13}) of positive refractive power. In order from the object side, the first lens element is of a planar-concave shape, the second lens element is of a convex-planar shape, and the third lens element is of a concave-convex shape. Two plane-parallel plates (r_8–r_9, r_{10}–r_{11}) are positioned between the second lens element and the third lens element. The plane-parallel plate (r_8–r_9) is an interference-type filter. The plane-parallel plate (r_{10}–r_{11}) is an absorbing-type, infrared cut-off filter. The two plane-parallel plates nearest the image are the cover glass (r_{14}–r_{15}) of a dust guard and the cover glass (r_{15}–r_{16}) of an image pick-up element, such as a CCD device, respectively. The outer diameter of the positive lens elements of this embodiment is 1.4 mm.

TABLE 4

#	R	D	N_d	υ_d
1	∞	0.3000	1.88300	40.76
2	1.1258	0.7185		
3	∞	4.0390	1.88300	40.76
4	∞	0.2000		
5	∞ (stop)	0.0500		
6	1.8193	0.4992	1.88300	40.76
7	∞	0.0491		
8	∞	0.4000	1.52287	59.89
9	∞	0.0300		
10	∞	0.6200	1.51400	75.00
11	∞	0.1000		
12	−10.5214	0.4390	1.83481	42.72
13	−2.1984	0.8591		

TABLE 4-continued

#	R	D	N_d	υ_d
14	∞	0.5000	1.51633	64.14
15	∞	0.4000	1.51633	64.14
16	∞			
f = 0.641	2ω = 100°	F_{NO} = 3.68	IH = 0.5 mm	OB =
$\lvert R_{(3R)}/f \rvert$ = 3.430		υ(p) = 42.72	N_1 = 1.883	10 mm
$\lvert R_{(1R)}/f \rvert$ = 1.756		$\lvert f/f_1 \rvert$ = 0.503	Dp/f = 4.779	
$R_{(1R)}$ = 1.126 mm		R(p) = 1.819 mm (second lens element)		

Embodiment 5

FIG. **5** shows the objective optical system of Embodiment 5 which includes, in relative order from the object side, a first lens element (r_1–r_2) of negative refractive power, a visual field conversion optical element (r_3–r_4), a stop (r_5), a second lens element (r_6–r_7) of positive refractive power, and a third lens element (r_8–r_9) of positive refractive power. In order from the object side, the first lens element is of a planar-concave shape, the second lens element is of a convex-concave shape, and the third lens element is of a concave-convex shape. The two plane-parallel plates (r_{10}–r_{11}, r_{13}–r_{14}) are interference-type filters that are arranged at each side of plane-parallel plate (r_{12}–r_{13}) which is an absorbing type, infrared cut-off filter. The outer diameter of the positive lens elements of this embodiment is 1.4 mm.

TABLE 5

#	R	D	N_d	υ_d
1	∞	0.3000	1.88300	40.76
2	1.2534	0.5830		
3	∞	4.0390	1.88300	40.76
4	∞	0.2000		
5	∞ (stop)	0.0500		
6	1.9756	0.4705	1.83481	42.72
7	10.1433	0.1500		
8	−10.5277	0.4863	1.88300	40.76
9	−1.7330	0.1000		
10	∞	0.4000	1.51400	75.00
11	∞	0.8362		
12	∞	0.5000	1.51633	64.14
13	∞	0.4000	1.51633	64.14
14	∞			
f = 0.634	2ω = 100.3°	F_{NO} = 3.29	IH = 0.5 mm	OB =
$\lvert R_{(3R)}/f \rvert$ = 2.733		υ(p) = 42.72	N_1 = 1.883	10 mm
$\lvert R_{(1R)}/f \rvert$ = 1.977		$\lvert f/f_1 \rvert$ = 0.447	Dp/f = 4.618	
$R_{(1R)}$ = 1.253 mm				

Embodiment 6

FIG. **6** shows the objective optical system of Embodiment 6 which includes, in relative order from the object side, a first lens element (r_1–r_2) of negative refractive power, a visual field conversion optical element (r_3–r_4), a stop (r_5), a second lens element (r_6–r_7) of positive refractive power, and a third lens element (r_8–r_9) of positive refractive power. In order from the object side, the first lens element is of a planar-concave shape, the second lens element is of a concave-convex shape, and the third lens element is of a planar-convex shape. Two plane-parallel plates (r_{10}–r_{11}, r_{12}–r_{13}) are arranged on the image-side of the third lens element. The plane-parallel plate (r_{10}–r_{11}) is an absorbing-type, infrared cut-off filter. The plane-parallel plate (r_{12}–r_{13}) is an interference-type filter. The two plane-parallel plates nearest the image are the cover glass (r_{14}–r_{15}) of a dust guard and the cover glass (r_{15}–r_{16}) of an image pick-up element, such as a CCD device. The outer diameter of the positive lens elements of this embodiment is 2 mm.

TABLE 6

#	R	D	N_d	υ_d
1	∞	0.4000	1.88300	40.76
2	1.7835	0.6086		
3	∞	4.6880	1.88300	40.76
4	∞	0.1500		
5	∞ (stop)	0.2000		
6	−11.5157	0.5519	1.88300	40.76
7	−2.6693	0.5912		
8	∞	0.5469	1.72916	54.68
9	−3.5887	0.1500		
10	∞	0.6200	1.51400	75.00
11	∞	0.0300		
12	∞	0.4000	1.52287	59.89
13	∞	1.7545		
14	∞	0.7000	1.51633	64.14
15	∞	0.5000	1.51633	64.14
16	∞			
f = 1.243	2ω = 99.8°	F_{NO} = 4.76	IH = 1 mm	OB =
$\lvert R_{(3R)}/f \rvert$ = 2.887		υ(p) = 54.68	N_1 = 1.883	10 mm
$\lvert R_{(1R)}/f \rvert$ = 1.435		$\lvert f/f_1 \rvert$ = 0.615	Dp/f = 2.613	
$R_{(1R)}$ = 1.784 mm		R(p) = 3.589 mm (second lens element)		

Embodiment 7

FIG. **7** shows the retro-focus objective optical system of Embodiment 7 which includes, in relative order from the object side, a first lens element (r_1–r_2) of negative refractive power, a visual field conversion optical element (r_3–r_4), a stop (r_5), a second lens element (r_6–r_7) of positive refractive power, and a third lens element (r_{14}–r_{15}) of positive refractive power. In order from the object side, the first lens element is of a planar-concave shape, the second lens element is of a planar-convex shape, and the third lens element is of a planar-convex shape. Three plane-parallel plates are positioned between the second lens element and the third lens element. The plane-parallel plate (r_8–r_9) is an interference-type filter, plane-parallel plate (r_{10}–r_{11}) is an absorbing-type, infrared cut-off filter, and plane-parallel plate (r_{12}–r_{13}) is an interference-type filter. The two plane-parallel plates nearest the image are the cover glass (r_{16}–r_{17}) of a dust guard and the cover glass (r_{17}–r_{18}) of an image pick-up element, such as a CCD device. The visual field conversion optical element is a twice-reflecting prism, similar to the prism shown in FIG. **40**. In this embodiment, each positive lens element includes a side that is planar so as to form an inexpensive objective optical system, and the outer diameter of these positive lens elements is 1.4 mm.

TABLE 7

#	R	D	N_d	υ_d
1	∞	0.3500	1.88300	40.76
2	1.2147	0.5743		
3	∞	4.0390	1.88300	40.76
4	∞	0.2000		
5	∞ (stop)	0.0500		
6	∞	0.4733	1.88300	40.76
7	−1.6382	0.0497		
8	∞	0.4000	1.52287	59.89
9	∞	0.0300		
10	∞	0.4000	1.51400	75.00
11	∞	0.0300		
12	∞	0.4000	1.52287	59.89
13	∞	0.0300		
14	∞	0.4714	1.51633	64.14
15	−2.1154	0.6767		
16	∞	0.5000	1.51633	64.14
17	∞	0.4000	1.51633	64.14
18	∞			
f = 0.639	2ω = 99.8°	F_{NO} = 4.04	IH = 0.5 mm	OB =

TABLE 7-continued

#	R	D	N_d	υ_d
$\lvert R_{(3R)}/f\rvert$ = 3.310	$\upsilon(p)$ = 64.14	N_1 = 1.883	10 mm	
$\lvert R_{(1R)}/f\rvert$ = 1.901	$\lvert f/f_1\rvert$ = 0.465	Dp/f = 4.569		
$R_{(1R)}$ = 1.215 mm	R(p) = 1.638 mm (second lens element)			
	R(p) = 2.115 mm (third lens element)			

Embodiment 8

FIG. **8** illustrates the retro-focus type optical system of Embodiment 8 which includes, in relative order from the object side, a first lens element (r_1–r_2) of negative refractive power, a visual field conversion optical element (r_3–r_4), a stop (r_5), a second lens element (r_6–r_7) of positive refractive power, and a third lens element (r_8–r_9) of positive refractive power. In order from the object side, the first lens element is of a planar-concave shape, the second lens element is of a double-convex shape, and the third lens element is of a planar-convex shape. Two plane-parallel plates are positioned at the image-side of the third lens element. The plane-parallel plate (r_{10}–r_{11}) is an interference-type filter. The plane-parallel plate (r_{12}–r_{13}) is an absorbing-type, infrared cut-off filter. Further, the two plane-parallel plates nearest the image are a cover glass (r_{14}–r_{15}) of a dust guard, and a cover glass (r_{15}–r_{16}) of an image pick-up element. The outer diameter of the positive lens elements of this embodiment is 1.8 mm.

TABLE 8

#	R	D	N_d	υ_d
1	∞	0.4000	1.88300	40.76
2	1.5848	0.7408		
3	∞	4.4880	1.88300	40.76
4	∞	0.1500		
5	∞ (stop)	0.1000		
6	16.6681	0.4742	1.77250	49.60
7	−3.2794	0.6946		
8	∞	0.4742	1.77250	49.60
9	−4.3947	0.1000		
10	∞	0.4000	1.52287	59.89
11	∞	0.0300		
12	∞	1.0000	1.49400	75.00
13	∞	1.5505		
14	∞	0.7000	1.51633	64.14
15	∞	0.5000	1.51633	64.14
16	∞			
f = 1.248	2ω = 99.9°	F_{NO} = 4.04	IH = 1 mm	OB =
$\lvert R_{(3R)}/f\rvert$ = 3.521	$\upsilon(p)$ = 46.62	N_1 = 1.883	10 mm	
$\lvert R_{(1R)}/f\rvert$ = 1.270	$\lvert f/f_1\rvert$ = 0.695	Dp/f = 2.624		
$R_{(1R)}$ = 1.585 mm	R(p) = 4.395 mm (third lens element)			

Embodiment 9

FIG. **9** shows the retro-focus type objective optical system of Embodiment 9 which includes, in relative order from the object side, a first lens element (r_1–r_2) of negative refractive power, a visual field conversion optical element (r_5–r_6), a stop (r_7), a second lens element (r_8–r_9) of positive refractive power, and a third lens element (r_{14}–r_{15}) of positive refractive power. In order from the object side, the first lens element is of a planar-concave shape, the second lens element is of a convex-planar shape, and the third lens element is of a planar-convex shape. A plane-parallel plate (r_3–r_4) is positioned between the first lens element and visual field conversion optical element, and two plane-parallel plates are positioned between the second and third lens elements. The plane-parallel plate (r_3–r_4) is an interference-type filter, the plane-parallel plate (r_{10}–r_{11}) is an absorbing-type, infrared cut-off filter, and the plane-parallel plate (r_{12}–r_{13}) is an interference-type filter. Further, the two plane-parallel plates nearest the image are a cover glass (r_{16}**14** r_{17}) of a dust guard, and a cover glass (r_{17}–r_{18}) of an image pick-up element. The outer diameter of the positive lens elements of this embodiment is 1.4 mm.

TABLE 9

#	R	D	N_d	υ_d
1	∞	0.3000	1.88300	40.76
2	1.3303	0.6927		
3	∞	0.4000	1.52287	59.89
4	∞	0.0300		
5	∞	4.0390	1.88300	40.76
6	∞	0.2000		
7	∞ (stop)	0.0500		
8	2.1515	1.1537	1.88300	40.76
9	∞	0.0300		
10	∞	0.4000	1.52287	59.89
11	∞	0.0300		
12	∞	0.4000	1.51400	75.00
13	∞	0.0300		
14	∞	0.6911	1.88300	40.76
15	−2.1528	0.7187		
16	∞	0.6000	1.51633	64.14
17	∞	0.4000	1.51633	64.14
18	∞			
f = 0.641	2ω = 100°	F_{NO} = 5.18	IH = 0.5 mm	OB = 10 mm
$\lvert R_{(3R)}/f\rvert$ = 3.359	$\upsilon(p)$ = 40.76		N_1 = 1.883	
$\lvert R_{(1R)}/f\rvert$ = 2.075	$\lvert f/f_1\rvert$ = 0.425		Dp/f = 5.196	
$R_{(1R)}$ = 1.330 mm	R(p) = 2.152 mm (second lens element)			
	R(p) = 2.153 mm (third lens element)			

Embodiment 10

FIG. **10** shows the retro-focus type objective optical system of Embodiment 10, which includes, in relative order from the object side, a first lens element (r_1–r_2) of negative refractive power, a visual field conversion optical element (r_3–r_4), a stop (r_5), a second lens element (r_6–r_7) of positive refractive power, and a third lens element (r_8–r_9) of positive refractive power. In order from the object side, the first lens element is of a planar-concave shape, the second lens element is of a convex-concave shape, and the third lens element is of a planar-convex shape. Two plane-parallel plates are positioned at the image side of the third lens element. The plane-parallel plate (r_{10}–r_{11}) is an interference-type filter, and the plane-parallel plate (r_{13}–r_{14}) is an absorbing-type, infrared cut-off filter. Further, the two plane-parallel plates nearest the image are a cover glass (r_{14}–r_{15}) of a dust guard, and a cover glass (r_{15}–r_{16}) of an image pick-up element. The outer diameter of the positive lens elements of this embodiment is 1.4 mm.

TABLE 10

#	R	D	N_d	υ_d
1	∞	0.3000	1.88300	40.76
2	1.2075	0.5716		
3	∞	4.0390	1.88300	40.76
4	∞	0.2000		
5	∞ (stop)	0.0500		
6	2.4057	0.4903	1.83481	42.72
7	9.0763	0.1000		
8	∞	0.5800	1.88300	40.76
9	−1.8097	0.0500		
10	∞	0.4000	1.51400	75.00
11	∞	0.0300		
12	∞	0.4000	1.52287	59.89
13	∞	0.7190		
14	∞	0.5000	1.51633	64.14
15	∞	0.4000	1.51633	64.14
16	∞			
f = 0.638	2ω = 100°	F_{NO} = 3.39	IH = 0.5 mm	OB =10 mm
$\lvert R_{(3R)}/f\rvert$ = 2.837	$\upsilon(p)$ = 42.72		N_1 = 1.883	

TABLE 10-continued

#	R	D	N_d	υ_d
$\|R_{(1R)}/f\|$ = 1.893	$\|f/f_1\|$ = 0.467	Dp/f = 4.571		
$R_{(1R)}$ = 1.208 mm	R(p) = 1.810 mm (third lens element)			

Embodiment 11

FIG. **11** shows the retro-focus type objective optical system of Embodiment 11 which includes, in relative order from the object side, a first lens element (r_1–r_2) of negative refractive power, a visual field conversion optical element (r3–r_4), a stop (r_5), a second lens element (r_6–r_7) of positive refractive power, and a third lens element (r_8–r_9) of positive refractive power. In order from the object side, the first lens element is of a planar-concave shape, the second lens element is of a concave-convex shape, and the third lens element is of a double convex shape. Two plane-parallel plates are positioned at the image side of the third lens element. The plane-parallel plate (r_{10}–r_{11}) is an interference-type filter. The plane-parallel plate (r_{12}–r_{13}) is an absorbing-type, infrared cut-off filter. Further, the two plane-parallel plates nearest the image are a cover glass (r_{14}–r_{15}) of a dust guard, and a cover glass (r_{15}–r_6) of an image pick-up element. The outer diameter of the positive lens elements of this embodiment is 1.8 mm.

TABLE 11

#	R	D	N_d	υ_d
1	∞	0.4000	1.88300	40.76
2	1.3106	0.6564		
3	∞	4.6880	1.88300	40.76
4	∞	0.1500		
5	∞ (stop)	0.2000		
6	−10.7273	0.5473	1.51633	64.14
7	−2.1047	0.2680		
8	3.9808	0.5960	1.51633	64.14
9	−4.8617	0.1000		
10	∞	0.4000	1.52287	59.89
11	∞	0.0300		
12	∞	1.0000	1.49400	75.00
13	∞	2.0324		
14	∞	0.7000	1.51633	64.14
15	∞	0.5000	1.51633	64.14
16	∞			
f = 1.113	2ω = 119.8°	F_{NO} = 5.25	IH = 1 mm	OB = 10 mm
$\|R_{(3R)}/f\|$ = 4.368	υ(p) = 64.14		N_1 = 1.883	
$\|R_{(1R)}/f\|$ = 1.178	$\|f/f_1\|$ = 0.750		Dp/f = 2.961	
$R_{(1R)}$ = 1.311 mm				

Embodiment 12

FIG. **12** shows the retro-focus type objective optical system of Embodiment 12 which includes, in relative order from the object side, a first lens element (r_1–r_2) of negative refractive power, a visual field conversion optical element (r_3–r_4), a stop (r_5), a second lens element (r_6–r_7) of positive refractive power, and a third lens element (r_8–r_9) of positive refractive power. In order from the object side, the first lens element is of a planar-concave shape, the second lens element is of a planar-convex shape, and the third lens element is of a double-convex shape. Two plane-parallel plates are positioned at the image side of the third lens element. The plane-parallel plate (r_{10}–r_{11}) is an interference-type filter. The plane-parallel plate (r_{12}–r_{13}) is an absorbing-type, infrared cut-off filter. Further, the two plane-parallel plates nearest the image are a cover glass (r_{14}–r_{15}) of a dust guard, and a cover glass (r_{15}–r_{16}) of an image pick-up element. The outer diameter of the positive lens elements of this embodiment is 1.8 mm.

TABLE 12

#	R	D	N_d	υ_d
1	∞	0.4000	1.88300	40.76
2	1.5501	0.6505		
3	∞	4.4880	1.88300	40.76
4	∞	0.1500		
5	∞ (stop)	0.1000		
6	∞	0.6311	1.51633	64.14
7	−1.9922	0.5026		
8	14.5808	0.5623	1.51633	64.14
9	−3.2050	0.1000		
10	∞	0.4000	1.52287	59.89
11	∞	0.0300		
12	∞	1.0000	1.49400	75.00
13	∞	1.7914		
14	∞	0.7000	1.51633	64.14
15	∞	0.5000	1.51633	64.14
16	∞			
f = 1.246	2ω = 99.9°	F_{NO} = 5.15	IH = 1 mm	OB = 10 mm
$\|R_{(3R)}/f\|$ = 2.572	υ(p) = 64.14		N_1 = 1.883	
$\|R_{(1R)}/f\|$ = 1.244	$\|f/f_1\|$ = 0.710		Dp/f = 2.555	
$R_{(1R)}$ = 1.550 mm	R(p) = 1.992 mm (second lens element)			

Embodiment 13

FIG. **13** shows the retro-focus type objective optical system of Embodiment 13, which includes, in relative order from the object side, a first lens element (r_1–r_2) of negative refractive power, a visual field conversion optical element (r_3–r_4), a stop (r_5), a second lens element (r_6–r_7) of positive refractive power, and a third lens element (r_8–r_9) of positive refractive power. In order from the object side, the first lens element is of a planar-concave shape, the second lens element is of a double-convex shape, and the third lens element is of a double-convex shape. Two plane-parallel plates are positioned at the image side of the third lens element. Plane-parallel plate (r_{10}–r_{11}) is an interference-type filter, and plane-parallel plate (r_{12}–r_{13}) is an absorbing-type, infrared cut-off filter. Further, the two plane-parallel plates nearest the image are a cover glass (r_{14}–r_{15}) of a dust guard, and a cover glass (r_{15}–r_{16}) of an image pick-up element. The outer diameter of the positive lens elements of this embodiment is 1.8 mm.

TABLE 13

#	R	D	N_d	υ_d
1	∞	0.4000	1.88300	40.76
2	1.2388	0.6010		
3	∞	4.8880	1.88300	40.76
4	∞	0.1500		
5	∞ (stop)	0.1000		
6	13.7617	0.5107	1.88300	40.76
7	−4.2664	0.0500		
8	9.0191	0.4747	1.83481	42.72
9	−13.1527	0.1000		
10	∞	0.4000	1.52287	59.89
11	∞	0.0300		
12	∞	1.0000	1.49400	75.00
13	∞	2.3207		
14	∞	1.0000	1.51633	64.14
15	∞	0.5000	1.51633	64.14
16	∞			
f = 1.249	2ω = 100.2°	F_{NO} = 4.0	IH = 1 mm	OB = 10 mm
$\|R_{(3R)}/f\|$ = 10.531	υ(p) = 42.72		N_1 = 1.883	
$\|R_{(1R)}/f\|$ = 0.992	$\|f/f_1\|$ = 0.890		Dp/f = 2.680	
$R_{(1R)}$ = 1.239 mm				

Embodiment 14

FIG. **14** shows the retro-focus type objective optical system of Embodiment 14, which includes, in relative order from the object side, a first lens element (r_1–r_2) of negative refractive power, a visual field conversion optical element

(r_5–r_6), a stop (r_7), a second lens element (r_8–r_9) of positive refractive power, and a third lens element (r_{14}–r_{15}) of positive refractive power. In order from the object side, the first lens element is of a planar-concave shape, the second lens element is of a convex-planar shape, and the third lens element is of a double-convex shape. A plane-parallel plate (r_3–r_4) is positioned between the first lens element and the visual field conversion optical element, and two plane parallel plates are positioned between the second lens element and the third lens element. The plane-parallel plate (r_3–r_4) is an interference-type filter, the plane-parallel plate (r_{10}–r_{11}) is an absorbing-type, infrared cut-off filter, and the plane-parallel plate (r_{12}–r_{13}) is an interference-type filter. Further, the two plane-parallel plates nearest the image are a cover glass (r_{16}–r_{17}) of a dust guard, and a cover glass (r_{17}–r_{18}) of an image pick-up element. The outer diameter of the positive lens elements of this embodiment is 1.4 mm.

TABLE 14

#	R	D	N_d	υ_d
1	∞	0.3000	1.88300	40.76
2	1.1154	0.5044		
3	∞	0.4000	1.52287	59.89
4	∞	0.0300		
5	∞	4.0390	1.88300	40.76
6	∞	0.2000		
7	∞ (stop)	0.0500		
8	2.5074	0.4719	1.88300	40.76
9	∞	0.0300		
10	∞	0.4000	1.52287	59.89
11	∞	0.0300		
12	∞	0.4000	1.51400	75.00
13	∞	0.0300		
14	3.6479	0.4770	1.88300	40.76
15	−6.9940	1.1741		
16	∞	0.6000	1.51633	64.14
17	∞	0.4000	1.51633	64.14
18	∞			
f = 0.638	2ω = 100.3°	F_{NO} = 3.23	IH = 0.5 mm	OB =
$\lvert R_{(3R)}/f \rvert$ = 10.962		$\upsilon(p)$ = 40.76	N_1 = 1.883	10 mm
$\lvert R_{(1R)}/f \rvert$ = 1.748		$\lvert f/f_1 \rvert$ = 0.505	Dp/f = 4.925	
$R_{(1R)}$ = 1.115 mm		R(p) = 2.507 mm (second lens element)		

Embodiment 15

FIG. **15** shows the retro-focus type objective optical system of Embodiment 15, which includes, in relative order from the object side, a first lens element (r_1–r_2) of negative refractive power, a visual field conversion optical element (r_3–r_4), a stop (r_5), a second lens element (r_6–r_7) of positive refractive power, and a third lens element (r_8–r_9) of positive refractive power. In order from the object side, the first lens element is of a planar-concave shape, the second lens element is of a convex-concave shape, and the third lens element is of a double-convex shape. Two plane-parallel plates (r_{10}–r_{11}, r_{12}–r_{13}) are positioned on the image side of the third lens element. The plane-parallel plate (r_{10}–r_{11}) is an interference-type filter, and the plane-parallel plate (r_{12}–r_{13}) is an absorbing-type, infrared cut-off filter. Further, the two plane-parallel plates nearest the image are a cover glass (r_{14}–r_{15}) of a dust guard, and a cover glass (r_{15}–r_{16}) of an image pick-up element. The outer diameter of the positive lens elements of this embodiment is 1.4 mm.

TABLE 15

#	R	D	N_d	υ_d
1	∞	0.3000	1.88300	40.76
2	1.0348	0.6120		
3	∞	4.0390	1.88300	40.76
4	∞	0.2000		
5	∞ (stop)	0.0500		
6	3.3166	0.4451	1.90135	31.55
7	7.6870	0.1000		
8	3.4558	0.5628	1.81600	46.62
9	−2.7646	0.0968		
10	∞	0.4000	1.51400	75.00
11	∞	0.0300		
12	∞	0.4000	1.52287	59.89
13	∞	0.9328		
14	∞	0.5000	1.51633	64.14
15	∞	0.4000	1.51633	64.14
16	∞			
f = 0.646	2ω = 100°	F_{NO} = 2.9	IH = 0.5 mm	OB = 10 mm
$\lvert R_{(3R)}/f \rvert$ = 4.280		$\upsilon(p)$ = 46.62	N_1 = 1.883	
$\lvert R_{(1R)}/f \rvert$ = 1.602		$\lvert f/f_1 \rvert$ = 0.551	Dp/f = 4.577	
$R_{(1R)}$ = 1.035 mm				

Embodiment 16

FIG. **16** shows the retro-focus type objective optical system of Embodiment 16, which includes, in relative order from the object side, a first lens element (r_1–r_2) of negative refractive power, a visual field conversion optical element (r_3–r_4), a stop (r_5), a second lens element (r_6–r_7) of positive refractive power, and a third lens element (r_{12}–r_{13}) of positive refractive power. In order from the object side, the first lens element is of a planar-concave shape, the second lens element is of a concave-convex shape, and the third lens element is of a convex-planar shape. The plane-parallel plate (r_8–r_9) adjacent the second lens element is an interference-type filter, the next plane-parallel plate (r_{10}–r_{11}) is an absorbing-type, infrared cut-off filter, and the next plane-parallel plate (r_{14}–r_{15}) is an interference-type filter. Further, the two plane-parallel plates nearest the image are a cover glass (r_{16}–r_{17}) of a dust guard, and a cover glass (r_{17}–r_{18}) of an image pick-up element. The outer diameter of the positive lens elements of this embodiment is 1.2 mm.

TABLE 16

#	R	D	N_d	υ_d
1	∞	0.4000	1.88300	40.76
2	1.6597	0.7110		
3	∞	4.6880	1.88300	40.76
4	∞	0.1500		
5	∞ (stop)	0.2000		
6	−13.1964	0.5930	1.88300	40.76
7	−2.3885	0.3400		
8	∞	0.4000	1.52287	59.89
9	∞	0.0300		
10	∞	0.6200	1.51400	75.00
11	∞	0.1000		
12	5.4290	0.5015	1.77250	49.60
13	∞	0.0300		
14	∞	0.4000	1.52287	59.89
15	∞	2.0082		
16	∞	0.7000	1.51633	64.14
17	∞	0.5000	1.51633	64.14
18	∞			
f = 1.248	2ω = 100.1°	F_{NO} = 5.1	IH = 1 mm	OB = 10 mm
		$\upsilon(p)$ = 49.60	N_1 = 1.883	
$\lvert R_{(1R)}/f \rvert$ = 1.330		$\lvert f/f_1 \rvert$ = 0.664	Dp/f = 2.685	
$R_{(1R)}$ = 1.660 mm				

Embodiment 17

FIG. **17** shows the retro-focus type objective optical system of Embodiment 17 which includes, in relative order from the object side, a first lens element (r_1–r_2) of negative refractive power, a visual field conversion optical element

(r_3–r_4), a stop (r_5), a second lens element (r_6–r_7) of positive refractive power, and a third lens element (r_{14}–r_{15}) of positive refractive power. In order from the object side, the first lens element is of a planar-concave shape, the second lens element is of a planar-convex shape, and the third lens element is of a convex-planar shape. The plane-parallel plate (r_8–r_9) adjacent the second lens element is an interference-type filter, the next plane-parallel plate (r_{10}–r_{11}) is an absorbing-type, infrared cut-off filter, and the next plane-parallel plate (r_{12}–r_{13}) is an interference-type filter. Further, the third lens element is connected to the cover glass (r_{15}–r_{16}) of an image pick-up element, such as a CCD. The outer diameter of the positive lens elements of this embodiment is 1.2 mm.

TABLE 17

#	R	D	N_d	υ_d
1	∞	0.3500	1.88300	40.76
2	1.2100	0.5829		
3	∞	4.0390	1.88300	40.76
4	∞	0.2000		
5	∞ (stop)	0.0500		
6	∞	0.5267	1.88300	40.76
7	−1.5173	0.0626		
8	∞	0.4000	1.52287	59.89
9	∞	0.0300		
10	∞	0.4000	1.51400	75.00
11	∞	0.0300		
12	∞	0.4000	1.52287	59.89
13	∞	1.0059		
14	1.5190	0.5443	1.51633	64.14
15	∞	0.4000	1.51633	64.14
16	∞			
f = 0.634	2ω = 99.8°	F_{NO} = 4.0	IH = 0.5 mm	OB = 10 mm
		υ(p) = 64.14	N_1 = 1.883	
$\lvert R_{(1R)}/f \rvert$ = 1.909		$\lvert f/f_1 \rvert$ = 0.463	Dp/f = 4.618	
$R_{(1R)}$ = 1.210 mm		R(p) = 1.517 mm (second lens element)		
		R(p) = 1.519 mm (third lens element)		

Embodiment 18

FIG. **18** shows the retro-focus type objective optical system of Embodiment 18 which includes, in relative order from the object side, a first lens element (r_1–r_2) of negative refractive power, a visual field conversion optical element (r_3–r_4), a stop (r_5), a second lens element (r_6–r_7) of positive refractive power, and a third lens element (r_{14}–r_{15}) of positive refractive power. In order from the object side, the first lens element is of a planar-concave shape, the second lens element is of a double-convex shape, and the third lens element is of a convex-planar shape. The plane-parallel plate (r_8–r_9) adjacent the second lens element is an interference-type filter, the next plane-parallel plate (r_{10}–r_{11}) is an absorbing-type, infrared cut-off filter, and the next plane-parallel plate (r_{12}–r_{13}) is an interference-type filter. Further, the third lens element is joined to the cover glass (r_{15}–r_{16}) of an image pick-up element, such as a CCD. The outer diameter of the positive lens elements of this embodiment is 1.4 mm.

TABLE 18

#	R	D	N_d	υ_d
1	∞	0.3000	1.88300	40.76
2	0.9656	0.5198		
3	∞	4.0390	1.88300	40.76
4	∞	0.2000		
5	∞ (stop)	0.0500		
6	2.3698	0.5850	1.88300	40.76
7	−3.3261	0.0736		
8	∞	0.4000	1.52287	59.89
9	∞	0.0300		
10	∞	0.4000	1.51400	75.00
11	∞	0.0300		
12	∞	0.4000	1.52287	59.89
13	∞	0.8997		
14	1.9322	0.5354	1.77250	49.60
15	∞	0.4000	1.51633	64.14
16	∞			
f = 0.56	2ω = 120.4°	F_{NO} = 3.64	IH = 0.5 mm	OB =
		υ(p) = 49.60	N_1 = 1.883	10 mm
$\lvert R_{(1R)}/f \rvert$ = 1.724		$\lvert f/f_1 \rvert$ = 0.512	Dp/f = 5.116	
$R_{(1R)}$ = 0.966 mm		R(p) = 1.932 mm (third lens element)		

Embodiment 19

FIG. **19** shows the retro-focus type objective optical system of Embodiment 19 which includes, in relative order from the object side, a first lens element (r_1–r_2) of negative refractive power, a visual field conversion optical element (r_3–r_4), a stop (r_5), a second lens element (r_6–r_7) of positive refractive power, and a third lens element (r_{14}–r_{15}) of positive refractive power. In order from the object side, the first lens element is of a planar-concave shape, and both the second lens element and the third lens element are of a convex-planar shape. The plane-parallel plate (r_8–r_9) adjacent the second lens element is an interference-type filter, the next plane-parallel plate (r_{10}–r_{11}) is an absorbing-type, infrared cut-off filter, and the next plane-parallel plate (r_{12}–r_{13}) is an interference-type filter. Further, the third lens element is joined to the cover glass (r_{15}–r_{16}) of an image pick-up element, such as a CCD. The outer diameter of the positive lens elements of this embodiment is 1.4 mm.

TABLE 19

#	R	D	N_d	υ_d
1	∞	0.3000	1.88300	40.76
2	1.2315	0.5909		
3	∞	4.0390	1.88300	40.76
4	∞	0.2000		
5	∞ (stop)	0.0500		
6	1.6105	0.5617	1.88300	40.76
7	∞	0.0500		
8	∞	0.4000	1.52287	59.89
9	∞	0.0300		
10	∞	0.4000	1.51400	75.00
11	∞	0.0300		
12	∞	0.4000	1.52287	59.89
13	∞	0.6810		
14	1.1837	0.8094	1.51633	64.14
15	∞	0.4000	1.51633	64.14
16	∞			
f = 0.645	2ω = 100.4°	F_{NO} = 4.03	IH = 0.5 mm	OB =
		υ(p) = 64.14	N_1 = 1.883	10 mm
$\lvert R_{(1R)}/f \rvert$ = 1.909		$\lvert f/f_1 \rvert$ = 0.462	Dp/f = 4.552	
$R_{(1R)}$ = 1.232 mm		R(p) = 1.611 mm (second lens element)		
		R(p) = 1.184 mm (third lens element)		

Embodiment 20

FIG. **20** shows the retro-focus type objective optical system of Embodiment 20 which includes, in relative order from the object side, a first lens element (r_1–r_2) of negative refractive power, a visual field conversion optical element (r_3–r_4), a stop (r_5), a second lens element (r_6–r_7) of positive refractive power, and a third lens element (r_{14}–r_{15}) of positive refractive power. In order from the object side, the first lens element is of a planar-concave shape, the second lens element is of a convex-concave shape, and the third lens element is of a convex-planar shape. The plane-parallel plate

(r_8–r_9) adjacent the second lens element is an interference-type filter, the next plane-parallel plate (r_{10}–r_{11}) is an absorbing-type, infrared cut-off filter, and the next plane-parallel plate (r_{12}–r_{13}) is an interference-type filter. Further, the third lens element is joined to the cover glass (r_{15}–r_{16}) of an image pick-up element, such as a CCD. The outer diameter of the positive lens elements of this embodiment is 1.4 mm.

TABLE 20

#	R	D	N_d	υ_d
1	∞	0.3000	1.88300	40.76
2	1.2344	0.5872		
3	∞	4.0390	1.88300	40.76
4	∞	0.2000		
5	∞ (stop)	0.0500		
6	1.3963	0.5499	1.88300	40.76
7	7.6320	0.1000		
8	∞	0.4000	1.52287	59.89
9	∞	0.0300		
10	∞	0.4000	1.51400	75.00
11	∞	0.0300		
12	∞	0.4000	1.52287	59.89
13	∞	0.5706		
14	1.1560	0.8894	1.51633	64.14
15	∞	0.4000	1.51633	64.14
16	∞			
f = 0.650	2ω = 100.4°	F_{NO} = 4.05	IH = 0.5 mm	OB =
	υ(p) = 64.14		N_1 = 1.883	10 mm
$\lvert R_{(1R)}/f \rvert$ = 1.899	$\lvert f/f_1 \rvert$ = 0.465		Dp/f = 4.511	
$R_{(1R)}$ = 1.234 mm	R(p) = 1.156 mm (third lens element)			

Embodiment 21

FIG. **21** shows the retro-focus type objective optical system of Embodiment 21 which includes, in relative order from the object side, a first lens element (r_1–r_2) of negative refractive power, a visual field conversion optical element (r_3–r_4), a stop (r_5), a second lens element (r_6–r_7) of positive refractive power, and a third lens element (r_{12}–r_{13}) of positive refractive power. In order from the object side, the first lens element is of a planar-concave shape, the second lens element is of a concave-convex shape, and the third lens element is of a convex-concave shape. The plane-parallel plate (r_8–r_9) on the image-side of the second lens element is an interference-type filter, the next plane-parallel plate (r_{10}–r_{11}) is an absorbing-type, infrared cut-off filter, and the next plane-parallel plate (r_{14}–r_{15}) is an interference-type filter. Further, the two plane-parallel plates nearest the image are a cover glass (r_{16}–r_{17}) of a dust guard, and a cover glass (r_{17}–r_{18}) of an image pick-up element. The outer diameter of the positive lens elements of this embodiment is 2 mm

TABLE 21

#	R	D	N_d	υ_d
1	∞	0.4000	1.88300	40.76
2	1.6531	0.7157		
3	∞	4.6880	1.88300	40.76
4	∞	0.1500		
5	∞ (stop)	0.2000		
6	−13.2955	0.6361	1.88300	40.76
7	−2.3467	0.3879		
8	∞	0.4000	1.52287	59.89
9	∞	0.0300		
10	∞	0.6200	1.51400	75.00
11	∞	0.0500		
12	4.7058	0.4811	1.88300	40.76
13	14.2899	0.1000		
14	∞	0.4000	1.52287	59.89
15	∞	1.9094		
16	∞	0.7000	1.51633	64.14
17	∞	0.5000	1.51633	64.14
18	∞			
f = 1.247	2ω = 100.2°	F_{NO} = 5.12	IH = 1 mm	OB =
$\lvert R_{(3R)}/f \rvert$ = 11.459	υ(p) = 40.76		N_1 = 1.883	10 mm
$\lvert R_{(1R)}/f \rvert$ = 1.326	$\lvert f/f_1 \rvert$ = 0.666		Dp/f = 2.691	
$R_{(1R)}$ = 1.653 mm				

Embodiment 22

FIG. **22** shows the retro-focus type objective optical system of Embodiment 22 which includes, in relative order from the object side, a first lens element (r_1–r_2) of negative refractive power, a visual field conversion optical element (r_3–r_4), a stop (r_5), a second lens element (r_6–r_7) of positive refractive power, and a third lens element (r_{14}–r_{15}) of positive refractive power. In order from the object side, the first lens element is of a planar-concave shape, the second lens element is of a planar-convex shape, and the third lens element is of a convex-concave shape. The plane-parallel plate (r_8–r_9) on the image-side of the second lens element is an interference-type filter, the next plane-parallel plate (r_{10}–r_{11}) is an absorbing-type, infrared cut-off filter, and the next plane-parallel plate (r_{12}–r_{13}) is an interference-type filter. Further, the two plane-parallel plates nearest the image are a cover glass (r_{16}–r_{17}) of a dust guard, and a cover glass (r_{17}–r_{18}) of an image pick-up element. The outer diameter of the positive lens elements of this embodiment is 1.6 mm.

TABLE 22

#	R	D	N_d	υ_d
1	∞	0.3500	1.88300	40.76
2	1.9016	0.6099		
3	∞	4.0390	1.88300	40.76
4	∞	0.2000		
5	∞ (stop)	0.0300		
6	∞	1.2309	1.51633	64.14
7	−1.4141	0.1000		
8	∞	0.2000	1.52287	59.89
9	∞	0.0300		
10	∞	0.4000	1.51400	75.00
11	∞	0.0300		
12	∞	0.2000	1.52287	59.89
13	∞	0.1000		
14	1.7054	0.4974	1.88300	40.76
15	7.1193	0.6214		
16	∞	0.5000	1.51633	64.14
17	∞	0.4000	1.51633	64.14
18	∞			
f = 0.657	2ω = 100°	F_{NO} = 3.92	IH = 0.5 mm	OB = 10 mm
$\lvert R_{(3R)}/f \rvert$ = 10.836	υ(p) = 64.14		N_1 = 1.883	
$\lvert R_{(1R)}/f \rvert$ = 2.894	$\lvert f/f_1 \rvert$ = 0.305		Dp/f = 4.498	
$R_{(1R)}$ = 1.902 mm	R(p) = 1.414 mm (second lens element)			

Embodiment 23

FIG. **23** shows the retro-focus type objective optical system of Embodiment 23 which includes, in relative order from the object side, a first lens element (r_1–r_2) of negative refractive power, a visual field conversion optical element (r_3–r_4), a stop (r_5), a second lens element (r_6–r_7) positive refractive power, and a third lens element (r_8–r_9) of positive refractive power. In order from the object side, the first lens element is of a planar-concave shape, the second lens element is of a double-convex shape, and the third lens element is of a convex-concave shape. The plane-parallel plate (r_{10}–r_{11}) on the image-side of the third lens element is an interference-type filter, and the next plane-parallel plate (r_{12}–r_{13}) is an absorbing-type, infrared cut-off filter. Further,

the two plane-parallel plates nearest the image are a cover glass (r_{14}–r_{15}) of a dust guard, and a cover glass (r_{15}–r_{16}) of an image pick-up element. The outer diameter of the positive lens elements of this embodiment is 1.7 mm.

TABLE 23

#	R	D	N_d	υ_d
1	∞	0.4000	1.72916	54.68
2	1.1726	0.7320		
3	∞	4.4880	1.88300	40.76
4	∞	0.1500		
5	∞ (stop)	0.1000		
6	14.6431	0.5042	1.88300	40.76
7	−2.9454	0.0500		
8	2.6726	0.4488	1.83481	42.72
9	3.2697	0.2000		
10	∞	0.4000	1.52287	59.89
11	∞	0.0300		
12	∞	1.0000	1.49400	75.00
13	∞	1.6254		
14	∞	0.7000	1.51633	64.14
15	∞	0.5000	1.51633	64.14
16	∞			
f = 1.245	2ω = 100.1°	F_{NO} = 4.37	IH = 1 mm	OB =
$\lvert R_{(3R)}/f \rvert$ = 2.626		υ(p) = 42.72	N_1 = 1.729	10 mm
$\lvert R_{(1R)}/f \rvert$ = 0.942		$\lvert f/f_1 \rvert$ = 0.774	Dp/f = 2.623	
$R_{(1R)}$ = 1.173 mm				

Embodiment 24

FIG. **24** shows the retro-focus type objective optical system of Embodiment 24 which includes, in relative order from the object side, a first lens element (r_1–r_2) of negative refractive power, a visual field conversion optical element (r_3–r_4), a stop (r_5), a second lens element (r_6–r_7) of positive refractive power, and a third lens element (r_{12}–r_{13}) of positive refractive power. In order from the object side, the first lens element is of a planar-concave shape, the second lens element is of a convex-planar shape, and the third lens element is of a convex-concave shape. The plane-parallel plate (r_8–r_9) on the image-side of the third lens element is an interference-type filter, and the next plane-parallel plate (r_{10}–r_{11}) is an absorbing-type, infrared cut-off filter. Further, the two plane-parallel plates nearest the image are a cover glass (r_{14}–r_{15}) of a dust guard, and a cover glass (r_{15}–r_{16}) of an image pick-up element. The outer diameter of the positive lens elements of this embodiment is 1.4 mm.

TABLE 24

#	R	D	N_d	υ_d
1	∞	0.3000	1.88300	40.76
2	1.0731	0.5796		
3	∞	4.0390	1.88300	40.76
4	∞	0.2000		
5	∞ (stop)	0.0500		
6	2.0317	0.6447	1.81600	46.62
7	∞	0.0687		
8	∞	0.4000	1.52287	59.89
9	∞	0.0300		
10	∞	0.4000	1.51400	75.00
11	∞	0.0300		
12	2.0312	0.5094	1.88300	40.76
13	7.5718	0.9475		
14	∞	0.5000	1.51633	64.14
15	∞	0.4000	1.51633	64.14
16	∞			
f = 0.651	2ω = 100°	F_{NO} = 3.23	IH = 0.5 mm	OB = 10 mm
$\lvert R_{(3R)}/f \rvert$ = 11.631		υ(p) = 46.62	N_1 = 1.883	
$\lvert R_{(1R)}/f \rvert$ = 1.648		$\lvert f/f_1 \rvert$ = 0.536	Dp/f = 4.492	
$R_{(1R)}$ = 1.073 mm		R(p) = 2.032 mm (second lens element)		

Embodiment 25

FIG. **25** shows the retro-focus type objective optical system of Embodiment 25 which includes, in relative order from the object side, a first lens element (r_1–r_2) of negative refractive power, a visual field conversion optical element (r_3–r_4), a stop (r_5), a second lens element (r_6–r_7) of positive refractive power, and a third lens element (r_{14}–r_{15}) of positive refractive power. In order from the object side, the first lens element is of a planar-concave shape, the second lens element is of a convex-concave shape, and the third lens element is of a convex-concave shape. The plane-parallel plate (r_8–r_9) on the image-side of the second lens element is an interference-type filter, the next plane-parallel plate (r_{10}–r_{11}) is an absorbing-type, infrared cut-off filter, and the next plane-parallel plate (r_{12}–r_{13}) is an interference-type filter. Further, the two plane-parallel plates nearest the image are a cover glass (r_{16}–r_{17}) of a dust guard, and a cover glass (r_{17}–r_{18}) of an image pick-up element. The outer diameter of the positive lens elements of this embodiment is 1.4 mm.

TABLE 25

#	R	D	N_d	υ_d
1	∞	0.3000	1.88300	40.76
2	1.2489	0.5958		
3	∞	4.0390	1.88300	40.76
4	∞	0.2000		
5	∞ (stop)	0.0500		
6	1.7203	0.4897	1.88300	40.76
7	7.4565	0.1000		
8	∞	0.4000	1.52287	59.89
9	∞	0.0300		
10	∞	0.4000	1.51400	75.00
11	∞	0.0300		
12	∞	0.4000	1.52287	59.89
13	∞	0.2520		
14	1.6711	0.4317	1.88300	40.76
15	7.6612	0.5947		
16	∞	0.5000	1.51633	64.14
17	∞	0.4000	1.51633	64.14
18	∞			
f = 0.661	2ω = 100°	F_{NO} = 4.11	IH = 0.5 mm	OB = 10 mm
$\lvert R_{(3R)}/f \rvert$ = 11.590		υ(p) = 40.76	N_1 = 1.883	
$\lvert R_{(1R)}/f \rvert$ = 1.889		$\lvert f/f_1 \rvert$ = 0.467	DP/f = 4.449	
$R_{(1R)}$ = 1.249 mm				

Embodiment 26

FIG. **26** shows the retro-focus type objective optical system of Embodiment 26 which includes, in relative order from the object side, a first lens element (r_1–r_2) of negative refractive power, a visual field conversion optical element (r_3–r_4), a stop (r_5), and a second lens element (r_6–r_7) of positive refractive power. In order from the object side, the first lens element is of a planar-concave shape, and the second lens element is of a concave-convex shape. The plane-parallel plate (r_8–r_9) on the image-side of the second lens element is an absorbing-type, infrared cut-off filter that has applied to both sides thereof an interference-type filter. Further, the two plane-parallel plates nearest the image are a cover glass (r_{10}–r_{11}) of a dust guard, and a cover glass (r_{11}–r_{12}) of an image pick-up element. The outer diameter of the positive lens element of this embodiment is 1.4 mm.

TABLE 26

#	R	D	N_d	υ_d
1	∞	0.2500	1.88300	40.76
2	1.2811	0.5287		
3	∞	3.5630	1.88300	40.76
4	∞	0.1000		
5	∞ (stop)	0.1000		
6	−9.4131	1.0028	1.83481	42.72
7	−1.1013	0.1000		

TABLE 26-continued

#	R	D	N_d	υ_d
8	∞	0.4000	1.52287	59.89
9	∞	1.1204		
10	∞	0.5000	1.51633	64.14
11	∞	0.4000	1.51633	64.14
12	∞			
f = 0.634	2ω = 99.9°	F_{NO} = 3.82	IH = 0.5 mm	OB =
	υ(p) = 42.72		N_1 = 1.883	10 mm
$\lvert R_{(1R)}/f \rvert$ = 2.021	$\lvert f/f_1 \rvert$ = 0.437		Dp/f = 3.976	
$R_{(1R)}$ = 1.281 mm				

Embodiment 27

FIG. **27** shows the retro-focus type objective optical system of Embodiment 27 which includes, in relative order from the object side, a first lens element (r_1–r_2) of negative refractive power, a visual field conversion optical element (r_3–r_4), a stop (r_5), and a second lens element (r_6–r_7) of a positive refractive power. In order from the object side, the first lens element is of a planar-concave shape. and the second lens element is of a planar-convex shape. The plane-parallel plate (r_8–r_9) on the image side of the second lens element is an absorbing-type, infrared cut-off filter that has applied both sides thereof an interference-type filter. Further, the two plane-parallel plates nearest the image are a cover glass (r_{10}–r_{11}) of a dust guard, and a cover glass (r_{11}–r_{12}) of an image pick-up element. The outer diameter of the positive lens element of this embodiment is 1.4 mm.

TABLE 27

#	R	D	N_d	υ_d
1	∞	0.3000	1.88300	40.76
2	1.1153	0.4299		
3	∞	3.7630	1.88300	40.76
4	∞	0.1000		
5	∞ (stop)	0.0500		
6	∞	1.0284	1.88300	40.76
7	−1.2974	0.1000		
8	∞	0.4000	1.52287	59.89
9	∞	1.2320		
10	∞	0.5000	1.51633	64.14
11	∞	0.4000	1.51633	64.14
12	∞			
f = 0.636	2ω = 100°	F_{NO} = 4.21	IH = 0.5 mm	OB = 10 mm
	υ(p) = 40.76		N_1 = 1.883	
$\lvert R_{(1R)}/f \rvert$ = 1.754	$\lvert f/f_1 \rvert$ = 0.504		Dp/f = 3.975	
$R_{(1R)}$ = 1.115 mm	R(p) = 1.297 mm (sccond lens element)			

Embodiment 28

FIG. **28** shows the retro-focus type objective optical system of Embodiment 28 which includes, in relative order from the object side, a first lens element (r_1–r_2) of negative refractive power, a visual field conversion optical element (r_3–r_4), a stop (r_5), and a second lens element (r_6–r_7) of positive refractive power. In order from the object side, the first lens element is of a planar-concave shape, and the second lens element is of a double-convex shape. The plane-parallel plate (r_{10}–r_{11}) is an absorbing-type, infrared cut-off filter that has applied to both sides thereof an interference-type filter. Further, the two plane-parallel plates nearest the image are a cover glass (r_{14}–r_{15}) of a dust guard, and a cover glass (r_{15}–r_{16}) of an image pick-up element. The outer diameter of the positive lens element of this embodiment is 1.4 mm.

TABLE 28

#	R	D	N_d	υ_d
1	∞	0.3000	1.88300	40.76
2	0.9748	0.6682		
3	∞	4.0390	1.88300	40.76
4	∞	0.2000		
5	∞ (stop)	0.0500		
6	2.4323	0.6869	1.88300	40.76
7	−2.9398	0.1000		
8	∞	0.4000	1.52287	59.89
9	∞	0.0300		
10	∞	0.4000	1.51400	75.00
11	∞	0.0300		
12	∞	0.4000	1.52287	59.89
13	∞	0.7739		
14	∞	0.5000	1.51633	64.14
15	∞	0.4000	1.51633	64.14
16	∞			
f = 0.646	2ω = 100.2°	F_{NO} = 4.09	IH = 0.5 mm	OB =
	υ(p) = 40.76		N_1 = 1.883	10 mm
$\lvert R_{(1R)}/f \rvert$ = 1.509	$\lvert f/f_1 \rvert$ = 0.585		Dp/f = 4.664	
$R_{(1R)}$ = 0.975 mm				

Embodiment 29

FIG. **29** shows the retro-focus type objective optical system of Embodiment 29 which includes, in relative order from the object side, a first lens element (r_1–r_2) of negative refractive power, a visual field conversion optical element (r_3–r_4), a stop (r_5), and a second lens element (r_6–r_7) of positive refractive power. In order from the object side, the first lens element is of a planar-concave shape, and the second lens element is of a convex-planar shape. The plane-parallel plate (r_8–r_9) on the image-side of the second lens element is an interference-type filter, and the plane-parallel plate (r_{10}–r_{11}) is an absorbing-type, infrared cut-off filter. Further, the two plane-parallel plates nearest the image are a cover glass (r_{12}–r_{13}) of a dust guard, and a cover glass (r_{13}–r_{14}) of an image pick-up element. The outer diameter of the positive lens element of this embodiment is 1.4 mm.

TABLE 29

#	R	D	N_d	υ_d
1	∞	0.3000	1.88300	40.76
2	0.9188	0.7000		
3	∞	4.8410	1.88300	40.76
4	∞	0.2000		
5	∞ (stop)	0.0500		
6	1.4439	0.5733	1.88300	40.76
7	∞	0.1000		
8	∞	0.4000	1.52287	59.89
9	∞	0.0300		
10	∞	0.4000	1.51400	75.00
11	∞	0.9752		
12	∞	0.5000	1.51633	64.14
13	∞	0.4000	1.51633	64.14
14	∞			
f = 0.581	2ω = 120.4°	F_{NO} = 4.27	IH = 0.5 mm	OB =
	υ(p) = 40.76		N_1 = 1.883	10 mm
$\lvert R_{(1R)}/f \rvert$ = 1.581	$\lvert f/f_1 \rvert$ = 0.558		Dp/f = 5.974	
$R_{(1R)}$ = 0.919 mm	R(p) = 1.444 mm (second lens element)			

Embodiment 30

FIG. **30** shows the retro-focus type objective optical system of Embodiment 30 which includes, in relative order from the object side, a first lens element (r_1–r_2) of negative refractive power, a visual field conversion optical element (r_3–r_4), a stop (r_5), and a second lens element (r_6–r_7) of positive refractive power. In order from the object side, the first lens element is of a planar-concave shape, and the second lens element is of a convex-concave shape. The

plane-parallel plate (r_8–r_9) on the image-side of the second lens element is an absorbing-type, infrared cut-off filter having an interference-type filter (not separately illustrated) deposited on each surface thereof Further, the two plane-parallel plates nearest the image are a cover glass (r_{10}–r_{11}) of a dust guard, and a cover glass (r_{11}–r_{12}) of an image pick-up element. The outer diameter of the positive lens element of this embodiment is 1.4 mm.

TABLE 30

#	R	D	N_d	υ_d
1	∞	0.3000	1.88300	40.76
2	0.8285	0.7000		
3	∞	4.3390	1.88300	40.76
4	∞	0.2000		
5	∞ (stop)	0.0500		
6	1.2429	0.5523	1.88300	40.76
7	8.8763	0.1000		
8	∞	0.4000	1.52287	59.89
9	∞	1.2684		
10	∞	0.5000	1.51633	64.14
11	∞	0.4000	1.51633	64.14
12	∞			
f = 0.58	2ω = 120.3°	F_{NO} = 5.2	IH = 0.5 mm	OB = 10 mm
	υ(p) = 40.76		N_1 = 1.883	
$\lvert R_{(1R)}/f \rvert$ = 1.428	$\lvert f/f_1 \rvert$ = 0.618		Dp/f = 5.525	
$R_{(1R)}$ = 0.829 mm				

Embodiment 31

FIG. **31** shows the retro-focus type objective optical system of Embodiment 31 which includes, in relative order from the object side, a first lens element (r_1–r_2) of negative refractive power, a visual field conversion optical element (r_3–r_4), a stop (r_5), a second lens element (r_6–r_7) of positive refractive power, and a third lens element (r_{12}–r_{13}) of positive refractive power. In order from the object side, the first lens element is of a planar-concave shape, the second lens element is of a planar-convex shape, and the third lens element is of a convex-planar shape. The plane-parallel plate (r_8–r_9) on the image-side of the second lens element is an absorbing-type, infrared cut-off filter, and the next plane-parallel plate (r_{10}–r_{11}) is also an absorbing-type, infrared cut-off filter. Further, the third lens element is joined to the cover glass (r_{13}–r_{14}) of an image pick-up element, such as a CCD device. The outer diameter of the positive lens elements of this embodiment is 1.4 mm. In this example, as shown in FIG. **41**, the visual field conversion optical element uses a one-time reflecting prism. However, although the image detected is a mirror image (in which there is an inversion from left to right), the detected image is then inverted by electronic means, as mentioned above.

TABLE 31

#	R	D	N_d	υ_d
1	∞	0.3500	1.88300	40.76
2	1.3725	0.5886		
3	∞	2.3000	1.88300	40.76
4	∞	0.1500		
5	∞ (stop)	0.0500		
6	∞	0.6108	1.88300	40.76
7	−1.3173	0.0497		
8	∞	0.4000	1.52287	59.89
9	∞	0.0300		
10	∞	0.4000	1.52287	59.89
11	∞	0.6357		
12	1.2048	0.7804	1.51633	64.14
13	∞	0.4000	1.51633	64.14
14	∞			

TABLE 31-continued

#	R	D	N_d	υ_d
f = 0.643	2ω = 99.8°	F_{NO} = 2.93	IH = 0.5 mm	OB =
	υ(p) = 64.14		N_1 = 1.883	10 mm
$\lvert R_{(1R)}/f \rvert$ = 2.135	$\lvert f/f_1 \rvert$ = 0.414		Dp/f = 3.048	
$R_{(1R)}$ = 1.373 mm	R(p) = 1.317 mm (second lens element)			
	R(p) = 1.205 mm (third lens element)			

Embodiment 32

FIG. **32** shows the retro-focus type objective optical system of Embodiment 32 which includes, in relative order from the object side, a first lens element (r_1–r_2) of negative refractive power, a visual field conversion optical element (r_3–r_4), a stop (r_5), a second lens element (r_6–r_7) of positive refractive power, and a third lens element (r_{12}–r_{13}) of positive refractive power. In order from the object side, the first lens element is of a planar-concave shape, the second lens element is of a planar-convex shape, and the third lens element is of a planar-convex shape. The plane-parallel plate (r_8–r_9) on the image-side of the second lens element is an interference-type filter, and the next plane parallel plate (r_{10}–r_{11}) is an absorbing-type, infrared cut-off filter. Further, the two plane-parallel plates nearest the image are a cover glass (r_{14}–r_{15}) of a dust guard, and a cover glass (r_{15}–r_{16}) of an image pick-up element. The outer diameter of the second and third lens elements, both of positive refractive power, is 1.2 mm and 1.6 mm, respectively.

TABLE 32

#	R	D	N_d	υ_d
1	∞	0.2800	1.88300	40.76
2	1.4218	0.4493		
3	∞	3.6100	1.88300	40.76
4	∞	0.1500		
5	∞ (stop)	0.1000		
6	∞	0.6769	1.58913	61.14
7	−1.4741	0.0498		
8	∞	0.4000	1.52287	59.89
9	∞	0.0300		
10	∞	0.6200	1.51400	75.00
11	∞	0.0500		
12	∞	0.4838	1.51633	64.14
13	−4.2495	2.1010		
14	∞	0.7000	1.51633	64.14
15	∞	0.5000	1.51633	64.14
16	∞			
f = 1.231	2ω = 100.4°	F_{NO} = 6.5	IH = 1 mm	OB = 10 mm
$\lvert R_{(3R)}/f \rvert$ = 3.452	υ(p) = 64.14		N_1 = 1.883	
$\lvert R_{(1R)}/f \rvert$ = 1.155	$\lvert f/f_1 \rvert$ = 0.765		Dp/f = 2.044	
$R_{(1R)}$ = 1.422 mm	R(p) = 1.474 mm (second lens element)			
	R(p) = 4.250 mm (third lens element)			

Embodiment 33

FIG. **33** shows the retro-focus type objective optical system of Embodiment 33 which includes, in relative order from the object side, a first lens element (r_1–r_2) of negative refractive power, a visual field conversion optical element (r_5–r_6), a stop (r_7), a second lens element (r_8–r_9) of positive refractive power, and a third lens element (r_{12}–r_{13}) of positive refractive power. In order from the object side, the first lens element is of a planar-concave shape, the second lens element is of a planar-convex shape, and the third lens element is of a convex-planar shape. The plane-parallel plate (r_3–r_4) on the image-side of the first lens element is an interference-type filter, and the next plane-parallel plate (r_{10}–r_1) is an absorbing-type, infrared cut-off filter. Further, the two plane-parallel plates nearest the image are a cover glass (r_{14}–r_{15}) of a dust guard, and a cover glass (r_{15}–r_{16}) of

an image pick-up element. The second and third lens elements are both of positive refractive power. The outer diameter of the second lens element is 2 mm, and the outer diameter of the third lens element is 2.4 mm. In this embodiment the visual field conversion optical element uses a twice-reflecting prism which forms an uninverted image of an object field that is centered at about a 45 degree angle to the optical axis of the image. Depending on the design of the twice-reflecting prism, the optical axis of the object field can be any direction from 0 degrees to nearly 180 degrees to the optical axis of the image (i.e., the in-line direction) by choosing a desired design for the visual field conversion optical element.

TABLE 33

#	R	D	N_d	υ_d
1	∞	0.4000	1.88300	40.76
2	1.4055	0.9106		
3	∞	0.4000	1.51633	64.14
4	∞	0.0400		
5	∞	3.3313	1.88300	40.76
6	∞	0.1000		
7	∞ (stop)	0.2000		
8	∞	1.0527	1.88300	40.76
9	−2.5247	0.9208		
10	∞	0.6200	1.51400	75.00
11	∞	0.3000		
12	5.5668	0.9115	1.51633	64.14
13	∞	1.6870		
14	∞	0.7000	1.51633	64.14
15	∞	0.7000	1.53172	48.91
16	∞			
f = 1.255	2ω = 100.4°	F_{NO} = 6.29	IH = 1 mm	OB =
	υ(p) = 64.14		N_1 = 1.883	10 mm
$\lvert R_{(1R)}/f \rvert$ = 1.120	$\lvert f/f_1 \rvert$ = 0.788		Dp/f = 2.457	
$R_{(1R)}$ = 1.406 mm	R(p) = 2.525 mm (second lens element)			
	R(p) = 5.567 mm (third lens element)			

Embodiment 34

FIG. **34** shows the objective optical system of Embodiment 34 which includes, in relative order from the object side, a first lens element (r_1–r_2) of negative refractive power and plano-concave shape, a visual field conversion optical element (r_3–r_5), a second lens element (r_6–r_7) of positive refractive power and biconvex shape, a stop (r_8), two cover glasses (r_9–r_{10}), (r_{11}–r_{12}), a third lens element (r_{13}–r_{14}) of positive refractive power and plano-convex shape, and an absorbing-type infrared cut-off filter (r_{15}–r_{16}) that is joined to a CCD cover glass (r_{16}–r_{17}). The objective optical system is constructed in two parts, a front part and a back part, and these two parts can be separated between the cover glasses (r_9–r_{10}) and the cover glass (r_{11}–r_{12}), each being formed as plane-parallel plates. The front part (r_1 through r_{10}) is made to be an adaptor unit, the back part (r_{11}–r_{17}) is made to be a master unit, with the adaptor unit being selected according to the particular intended use. Although this embodiment has a watertight construction by arranging a cover glass at the dividing part of each unit, the cover glasses may not be needed depending on the purpose for which it is used. The outer diameter of the lens element of positive refractive power in the master unit in this embodiment is 1 mm.

TABLE 34

#	R	D	N_d	υ_d
Object	∞	10.0000		
1	∞	0.2500	1.88300	40.76
2	0.6511	0.1500		
3	∞	0.3500	1.88300	40.76
4	∞	0.3500	1.88300	40.76
5	∞	0.0500		
6	2.7174	0.7000	1.51633	64.14
7	−1.1199	0.1000		
8 (stop)	∞	0.0300		
9	∞	0.3000	1.51633	64.14
10	∞	0.0500		
11	∞	0.3000	1.51633	64.14
12	∞	0.0300		
13	∞	0.3814	1.51633	64.14
14	−2.0653	3.0069		
15	∞	1.0000	1.49400	75.00
16	∞	0.4000	1.51633	64.14
17	∞	0.0000		
Image	∞	0.0000		
	F_{NO} = 8		IH = 0.9	

Embodiment 35

FIG. **35** shows the objective optical system of Embodiment 35 which includes, in relative order from the object side, a visual field conversion optical element (r_1–r_3), a first lens element (r_4–r_5) of negative refractive power and convex-concave shape, a stop (r_6), two cover glasses (r_7–r_8), (r_9–r_{10}), a second lens element (r_{11}–r_{12}) of positive refractive power and plano-convex shape, an absorbing-type infrared cut-off filter (r_{13}–$_{14}$), and a CCD cover glass (r_{14}–r_{15}). The infrared cut-off (r_{13}–r_{14}) is formed of a plane-parallel plate that is joined to the CCD cover glass (r_{14}–r_{15}), which is also a plane-parallel plate. The objective optical system is constructed in two parts, a front part and a back part, and these two parts can be separated between the cover glass (r_7–r_8) and the cover glass (r_9–r_{10}), each of these cover glasses being formed as a plane-parallel plate. The front part (r_1 through r_8) is made to be an adaptor unit, the back part (r_9–r_{15}) is made to be a master unit, with the adaptor unit being selected according to the particular intended use. Although this embodiment has a watertight construction by arranging a cover glass at the dividing part of each unit, the cover glass may not be needed depending on the purpose for which it is used. The outer diameter of the lens element of positive refractive power in the master unit in this embodiment is 1.4 mm.

TABLE 35

#	R	D	N_d	υ_d
Object	∞	10.0000		
1	∞	1.0000	1.88300	40.76
2	∞	1.0000	1.88300	40.76
3	∞	0.0500		
4	1.5896	1.2382	1.88300	40.76
5	1.0000	0.0492		
6 (stop)	∞	0.0300		
7	∞	0.3500	1.51633	64.14
8	∞	0.0500		
9	∞	0.3500	1.51633	64.14
10	∞	0.0300		
11	∞	0.3974	1.88300	40.76
12	−1.2362	0.9000		
13	∞	1.0000	1.49400	75.00
14	∞	0.4000	1.51633	64.14
15	∞	0.0000		
Image	∞	0.0000		
	F_{NO} = 4.7		IH = 0.9	

Embodiment 36

Embodiment 36 is nearly identical to that of Embodiment 35 except that the visual field conversion optical element has

a different design and, in this case, the first lens element (r_3–r_4) has a positive refractive power (thick lens conditions apply). As evident from Embodiments 35 and 36, the power of the first lens element may be either positive or negative.

TABLE 36

#	R	D	N_d	υ_d
Object	∞	10.0000		
1	∞	5.9000	1.88300	40.76
2	∞	0.0500		
3	1.5896	1.2382	1.88300	40.76
4	1.3113	0.0492		
5 (stop)	∞	0.0300		
6	∞	0.3500	1.51633	64.14
7	∞	0.0500		
8	∞	0.3500	1.51633	64.14
9	∞	0.0300		
10	∞	0.3974	1.88300	40.76
11	−1.2362	0.4069		
12	∞	1.0000	1.49400	75.00
13	∞	0.4000	1.51633	64.14
14	∞	0.0000		
Image	∞	0.0000		
	F_{NO} = 4.7		IH = 0.9	

The construction of Embodiment 34 is characterized by there being, sequentially from the object side, a first lens element of negative refractive power, a visual field conversion optical element, a second lens element of positive refractive power, a stop, and a third lens element of positive refractive power, with a convex-shaped surface on the image side, wherein the following condition is satisfied:

$$1.5<f_3/IH<5 \qquad \text{Condition (9)}$$

where

f_3 is the focal distance of the third lens element, and

IH is the maximum image height.

In Embodiment 34, the value of f_3/IH equals 4.44, thus satisfying Condition (9).

The construction of Embodiments 35 and 36 is characterized by there being, sequentially from the object side, a visual field conversion optical element, a first lens element of positive or negative refractive power, a stop, and a second lens element of positive refractive power having a convex-shaped surface on the image side, wherein the following condition is satisfied:

$$1.5<f_2/IH<5 \qquad \text{Condition(10)}$$

where

f_2 is the focal distance of the second lens element, and

IH is the maximum image height.

In Embodiments 35 and 36, the value of f_2 /IH equals 1.56, thus satisfying Condition (10).

In Embodiments 34–36, because the master unit includes one positive lens element, the size of the master unit can be made very small Also, because the stop of the adaptor unit is arranged on the master unit side of the lens element more to the master unit side of the lens within the adaptor unit, the outer diameter of the positive lens element inside the master unit can be made small Furthermore, although dust can easily fall on a cover glass between the adaptor unit and the master unit when the two units are detached from each other, thereby influencing the image, by arranging the stop of the adaptor unit on the master unit side of the lens element more to the master unit side of the lens element within the adaptor unit, the light flux diameter in the dividing part can be made large, thereby reducing the influence of dust on the image. Because the adaptor unit also includes one or two lens elements, the adaptor unit size can be made compact.

FIGS. **37**A–**37**E show various aberrations of Embodiment 1. FIG. **37**A shows the longitudinal spherical aberration, for the F, d and C lines. FIG. **37**B shows the astigmatism in the Meridional M (i.e. tangential) and Sagittal S planes. FIG. **37**C illustrates the distortion. FIG. **37**D illustrates the lateral color for the C and F lines, and FIG. **37**E illustrates the transverse spherical aberration for the F, d and C lines.

FIGS. **38**A–**38**E show the same aberrations as discussed in the paragraph above, but the curves are for the aberrations of Embodiment 26.

FIG. **39** shows a visual field conversion optical element having a single reflecting surface 1. Such an arrangement inverts the image once by reflection from the roof surface of the prism However, if the roof prism is manufactured with poor accuracy, there is a disadvantage in that the accuracy of image formation will deteriorate remarkably. This can be a problem, especially when any of the length, width, or height of the visual field conversion optical element is 5 mm or less. In order to avoid such a disadvantage, a twice-reflecting prism as shown in FIG. **40** may be used. When a visual field conversion optical element as shown in FIG. **40** is used, any of the length, width, or height of the visual field conversion element may be smaller than 5 mm without a problem. In addition, such a visual field conversion element does not invert the image from left to right and vice-versa, as is the case in the visual field conversion element of FIG. **39**. Of course, where the incident rays do not undergo total internal reflection, it is necessary to make the prism surface reflective by having, for example, a reflecting coating applied thereto.

Another visual field conversion optical element is illustrated in FIG. **41**. Although a once-reflecting prism is used, the visual field conversion optical element has a favorable image-formation capability by virtue of there being electronic means or software provided to reverse the order of the data read with the image-pickup element.

In the objective optical system of the invention, the visual field conversion optical element allows direct views, side views, and oblique views to be directed to an image pick-up element, as illustrated in, for example, FIGS. **30**, **31**, and **33**, respectively. Further, these views can be readily combined into a single image, as illustrated by the optical system in Japanese Laid Open Patent Application No. 37-9530.

The invention being thus described, it will be obvious that the same may be varied in many ways. Such variations are not to be regarded as a departure from the spirit and scope of the invention. Rather the scope of the invention shall be defined as set forth in the following claims and their legal equivalents. All such modifications as would be obvious to one skilled in the art are intended to be included within the scope of the following claims.

What is claimed is:

1. An objective optical system comprising no more than three lens elements having refractive power, as follows, in relative order from the object side:

a first lens element of negative refractive power;

a visual field conversion optical element which folds light rays incident thereon;

a stop;

a second lens element of positive refractive power; and a third lens element of positive refractive power;

wherein the image side of the third lens element is of a convex shape and satisfies the following condition

$$0.1 <|R_{(3R)}/f<20$$

where

$R_{(3R)}$ is the radius of curvature of the image-side surface of the third lens element, and

f is the focal distance of the objective optical system.

2. An objective optical system comprising, in relative order from the object side:

a first lens element of negative refractive power;

a visual field conversion optical element which folds light rays incident thereon;

a second lens element of positive refractive power; and

a third lens element of positive refractive power;

wherein the object side of the third lens element is of a convex shape, and the objective optical system satisfies the following conditions

$$\nu(p)>42$$

$$N_1>1.6$$

where

ν(p) is the Abbe number at the d-line of one of said second lens element or said third lens element, and

N_1 is the index of refraction of the first lens element.

3. An objective optical system comprising, in relative order from the object side:

a first lens element of negative refractive power;

a visual field conversion optical element which folds light rays incident thereon;

a stop;

a second lens element of positive refractive power; and

a third lens element of positive refractive power;

wherein said first lens element satisfies the following conditions

$$N_1>1.6$$

$$0.1<R_{(1R)}/f<3$$

where

N_1 is the index of refraction of the first lens element.

$R_{(1R)}$ is the radius of curvature of the image-side surface of the first lens element, and

f is the focal distance of the objective optical system.

4. An objective optical system comprising no more than two lens elements having refractive power, as follows, in relative order from the object side:

a first lens element of negative refractive power;

a visual field conversion optical element which folds light rays incident thereon;

a stop; and

a second lens element of positive refractive power;

wherein the first lens element satisfies the following condition

$$0.05<|f/f_1|<5$$

where

f is the focal distance of the objective optical system, and

f_1 is the focal distance of the first lens element.

5. The objective optical system of claim **1**, wherein at least one of the lens elements of positive refractive power includes one surface that is planar and an opposite surface that is convex, with the convex surface thereof satisfying the following condition

$$0.5 \text{ mm}<|R(p)|<5 \text{ mm}$$

where

R(p) is the radius of curvature of said opposite surface that is convex.

6. The objective optical system of claim **2**, wherein at least one of the lens elements of positive refractive power includes one surface that is planar and an opposite surface that is convex, with the convex surface thereof satisfying the following condition

$$0.5 \text{ mm}<|R(p)|<5 \text{ mm}$$

where

R(p) is the radius of curvature of said opposite surface that is convex.

7. The objective optical system of claim **3**, wherein at least one of the lens elements of positive refractive power includes one surface that is planar and an opposite surface that is convex, with the convex surface thereof satisfying the following condition

$$0.5 \text{ mm}<|R(p)|<5 \text{ mm}$$

where

R(p) is the radius of curvature of said opposite surface that is convex.

8. The objective optical system of claim **4**, wherein at least one of the lens elements of positive refractive power includes one surface that is planar and an opposite surface that is convex, with the convex surface thereof satisfying the following condition

$$0.5 \text{ mm}<|R(p)|<5 \text{ mm}$$

where

R(p) is the radius of curvature of said opposite surface that is convex.

9. The objective optical system of claim **1**, in combination with an image pick-up element having a pixel size of 5 micrometers or less.

10. The objective optical system of claim **2**, in combination with an image pick-up element having a pixel size of 5 micrometers or less.

11. The objective optical system of claim **3**, in combination with an image pick-up element having a pixel size of 5 micrometers or less.

12. The objective optical system of claim **4**, in combination with an image pick-up element having a pixel size of 5 micrometers or less.

13. The objective optical system of claim **1**, wherein one of the lens elements of positive refractive power has an outer diameter of 3 mm or less.

14. The objective optical system of claim **2**, wherein one of the lens elements of positive refractive power has an outer diameter of 3 mm or less.

15. The objective optical system of claim **3**, wherein one of the lens elements of positive refractive power has an outer diameter of 3 mm or less.

16. The objective optical system of claim **4**, wherein one of the lens elements of positive refractive power has an outer diameter of 3 mm or less.

17. The objective optical system of claim **4**, wherein the index of refraction of the first lens element is greater than 1.6.

18. An objective optical system, comprising, in relative order from the object side:

a first lens element of negative refractive power;

a visual field conversion optical element which folds light rays incident thereon;

a second lens element of positive refractive power;

a stop;

a third lens element of positive refractive power and having a convex-shaped surface on the image side, wherein the following condition is satisfied

$$1.5<f_3/IH<5$$

where

f_3 is the focal distance of the third lens element, and

IH is the maximum image height.

19. The objective optical system of claim **18**, wherein said objective optical system is formed of two parts comprising, in relative order from the object side:

an adaptor unit formed of

said first lens element,

said visual field conversion optical element,

said second lens element, and

said stop; and

a master unit, detachable from said adaptor unit, formed of

said third lens element.

20. An objective optical system comprising, in relative order from the object side:

a visual field conversion optical element which folds light rays incident thereon;

a first lens element of positive or negative refractive power;

a stop;

a second lens element of positive refractive power and having a convex surface on the image side, wherein the following condition is satisfied

$$1.5<f_2/IH<5$$

where

f_2 is the focal distance of the second lens element, and

IH is the maximum image height.

21. The objective optical system of claim **20**, wherein said objective optical system is formed of two parts comprising, in relative order from the object side:

an adaptor unit formed of

said visual field conversion optical element

said first lens element, and

said stop; and

a master unit, detachable from said adaptor unit, formed of

said second lens element.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 6,256,155 B1
DATED : July 3, 2001
INVENTOR(S) : Nagaoka

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 5,
Line 1, change "desirable" to -- desirably --;
Line 39, insert -- a -- before "CCD";

Column 14,
Line 1, change "$r_{16}14r_{17}$" to -- r_{16}-r_{17} --;

Column 15,
Lne 24, change "(r_{15} - r_6)" to -- (r_{15}-r_{16}) --;

Column 21,
Line 49, after "2 mm" insert a period;

Column 25,
Line 26, after "applied" insert -- to --;

Column 28,
Line 65, change "(r_{10}-r_1)" to -- (r_{10}-r_{11});

Column 30,
Line 28, change "(r_{13}-$_{14}$)" to -- (r_{13} - r_{14}) --;

Column 32,
Line 66, change "$0.1 < |R_{(3R)}/f < 20$" to -- $0.1 < |R_{(3R)}/f| < 20$ --;

Column 33,
Line 42, change the period after "element" to a comma; and

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 6,256,155 B1
DATED : July 3, 2001
INVENTOR(S) : Nagaoka

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 36,
Line 20, add a comma after "element".

Signed and Sealed this

Twenty-third Day of April, 2002

Attest:

Attesting Officer

JAMES E. ROGAN
Director of the United States Patent and Trademark Office

US006244717B1

(12) **United States Patent**
Dinger

(10) **Patent No.: US 6,244,717 B1**
(45) **Date of Patent: Jun. 12, 2001**

(54) **REDUCTION OBJECTIVE FOR EXTREME ULTRAVIOLET LITHOGRAPHY**

(75) Inventor: **Udo Dinger**, Oberkochen (DE)

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

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(52) **U.S. Cl.** **359/859**; 359/861; 359/900; 359/731; 359/366; 359/359; 378/35; 378/34

(58) **Field of Search** 359/355, 359, 359/365, 366, 730, 731, 859, 861, 900; 378/34, 35

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5,353,322	*	10/1994	Bruning et al.	378/34
5,361,292	*	11/1994	Sweatt	378/34
5,379,157	*	1/1995	Wang	359/861
5,410,434	*	4/1995	Shafer	359/859
5,459,771	*	10/1995	Richardson et al. .	
5,737,137	*	4/1998	Cohen et al.	359/861
5,805,365	*	9/1998	Sweatt	378/34
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0480617 A2	*	4/1992	(EP) .
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Jewell "Reflective systems design study for soft x–ray projection lithography." Journal of Vaccum Science & Technology B vol. 8, No. 6, pp. 1519–1523 (Nov./Dec. 1990).
Jewell "Optical system design issues in development of projection camera for EUV lithography." SPIE vol. 2437, pp. 340–346 (Feb. 1995).
Sweeney, et al. "EUV Optical Design for a 100 nm CD Imaging System." SPIE vol. 3331, pp. 2–10 (Feb. 1998).
European Patent Office Search Report, Application No. 99 110 265, dated Aug. 30, 1999.

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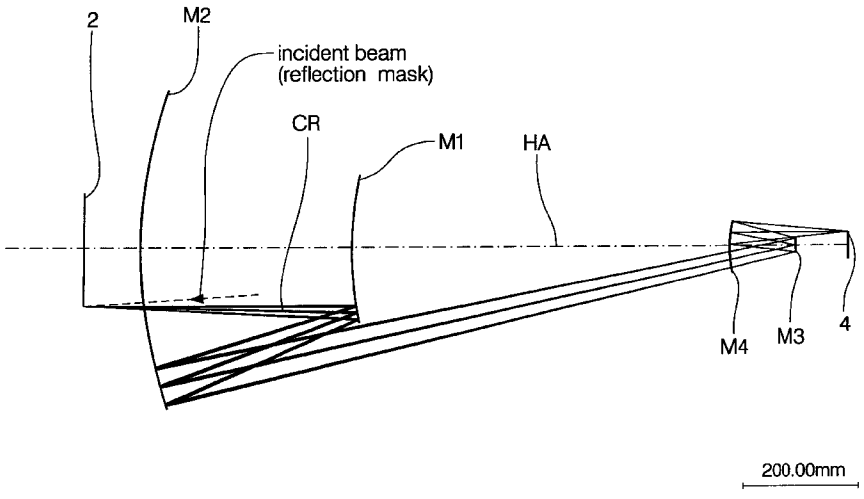
Primary Examiner—Ricky D. Shafer
(74) *Attorney, Agent, or Firm*—Marshall, O'Toole, Gerstein, Murray & Borun

(57) **ABSTRACT**

A reduction objective, a projection exposure apparatus with a reduction objective, and a method of use thereof are disclosed. The reduction objective comprises four (primary, secondary, tertiary, and quaternary) mirrors in centered arrangement with respect to an optical axis. The primary mirror is a convex mirror and the second mirror has a positive angular magnification. The reduction objective has an obscuration-free light path and is suitable for annular field scanning operation, such as is used in soft X-ray, i.e. and EUV and UV, lithography.

19 Claims, 7 Drawing Sheets



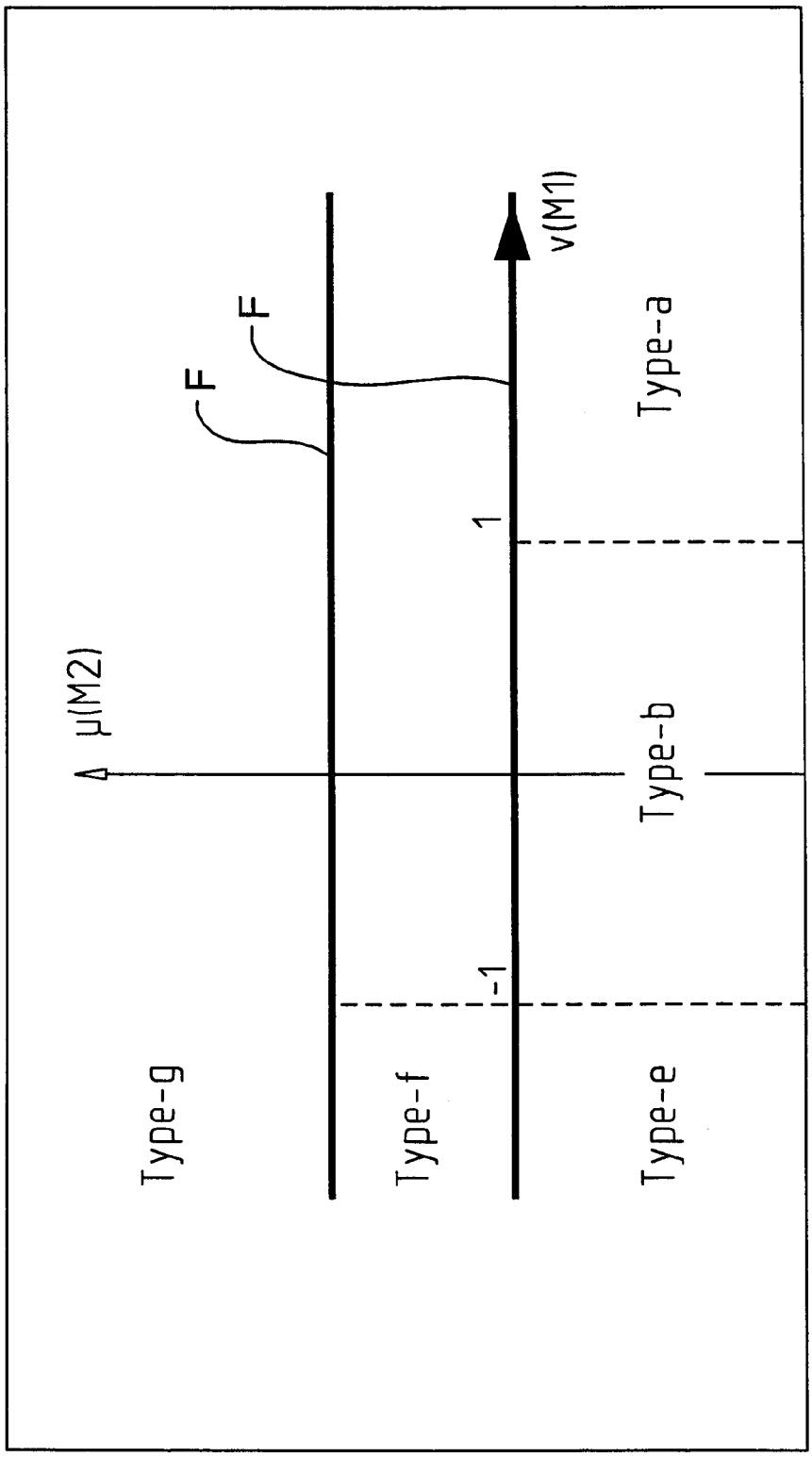


Fig.1

Fig.2

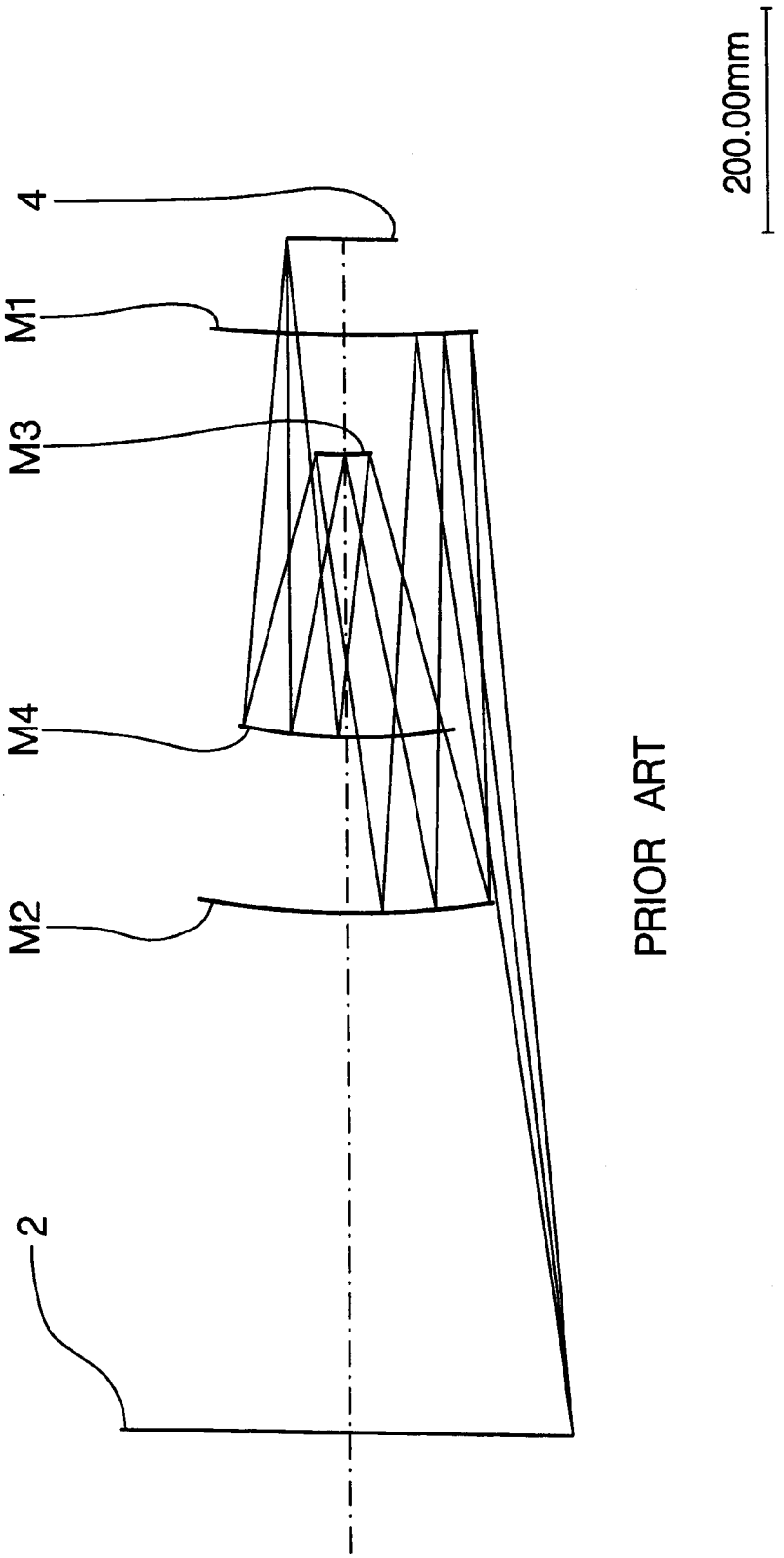


Fig.3

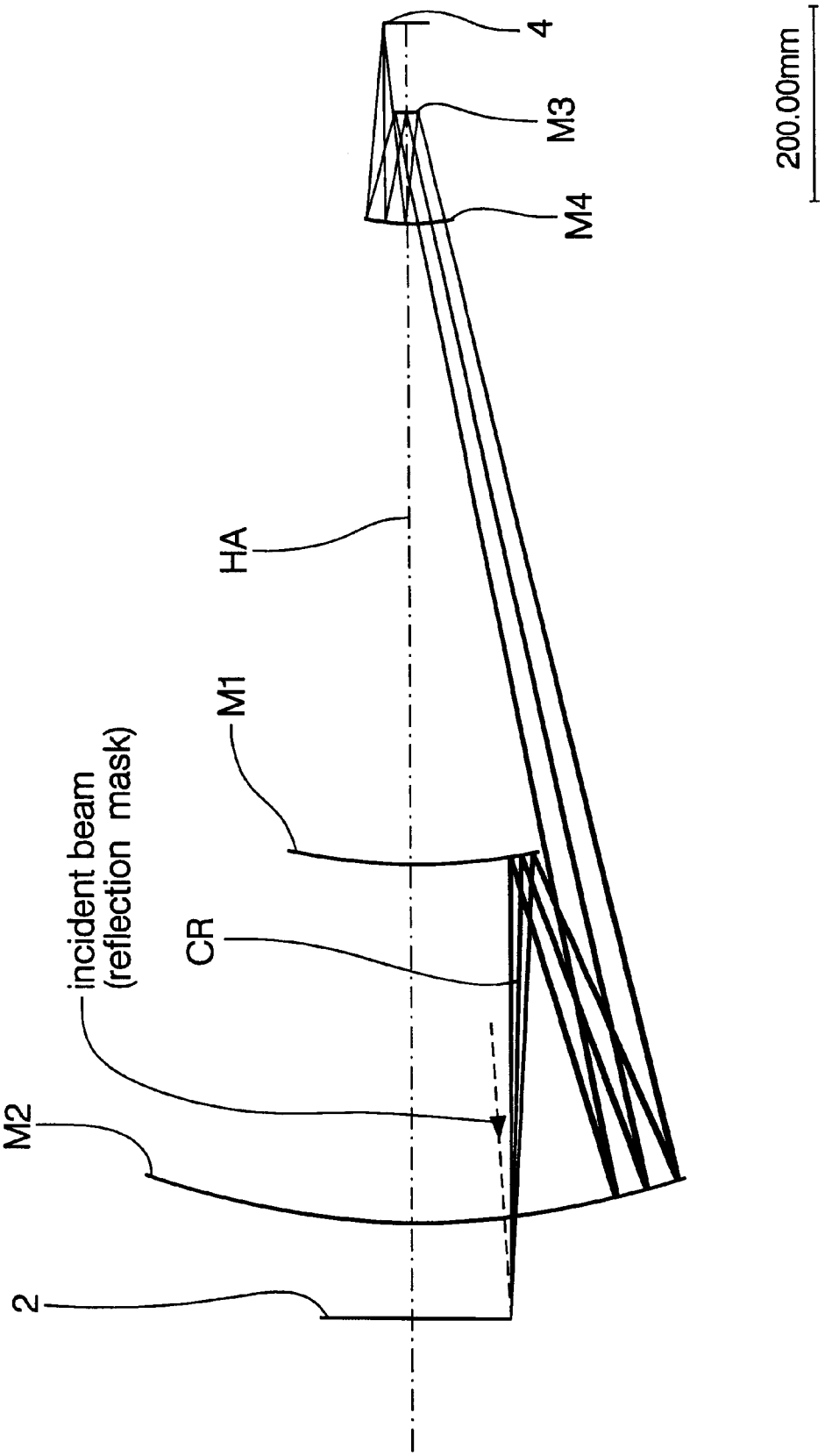
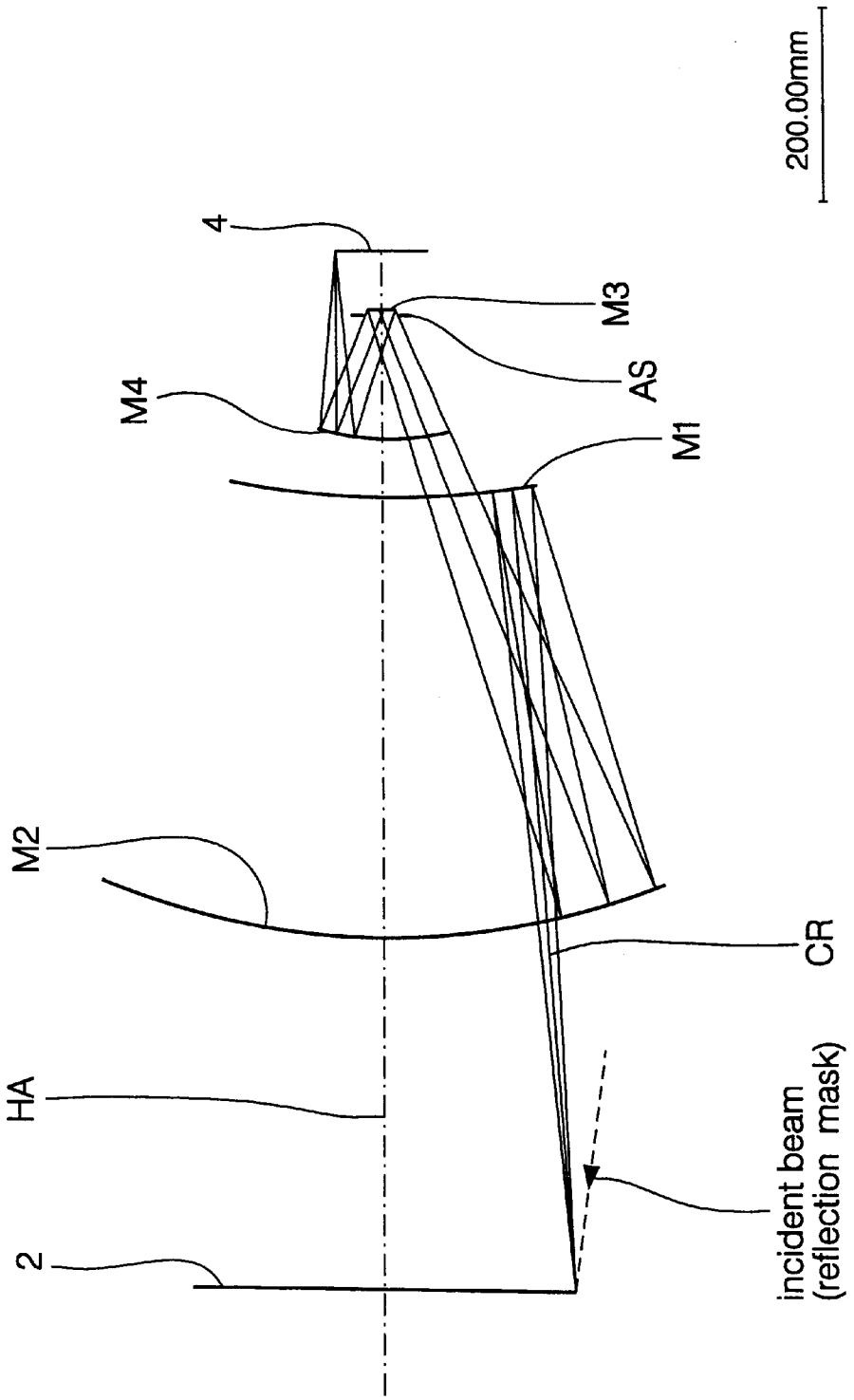


Fig.4



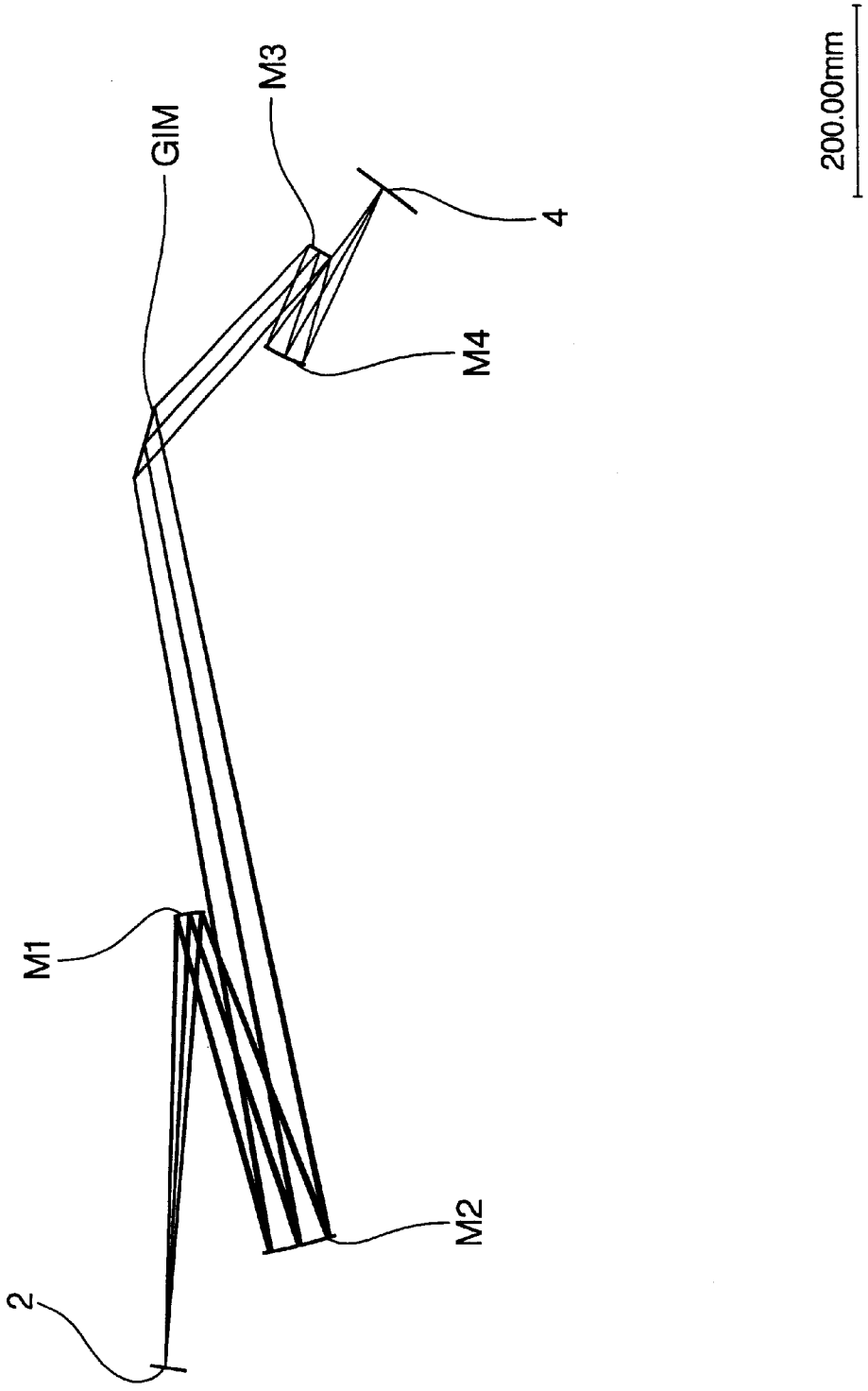


Fig.5

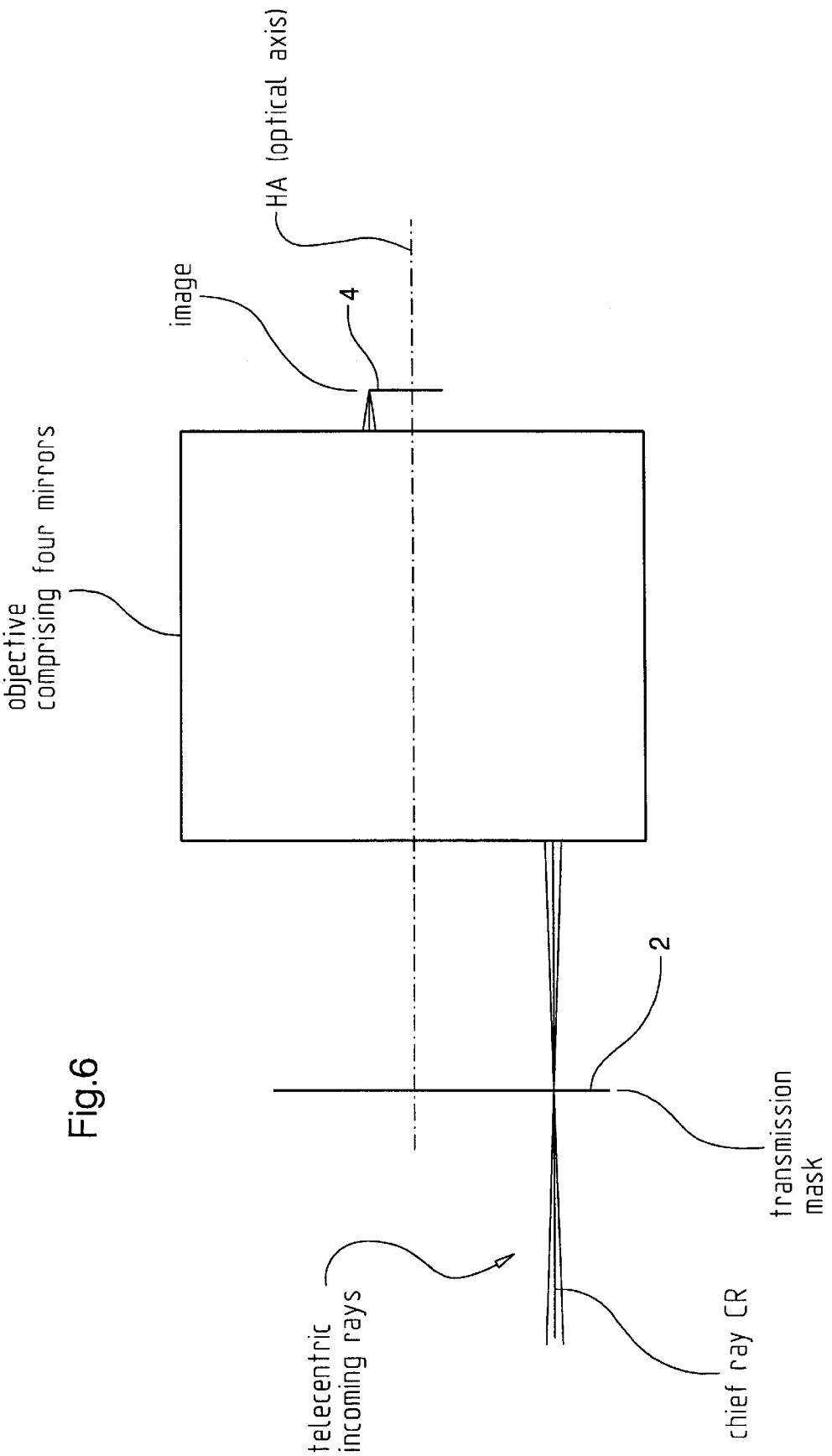

HA (optical axis)
image
4
objective comprising four mirrors
2
transmission mask
telecentric incoming rays
chief ray CR

Fig.6

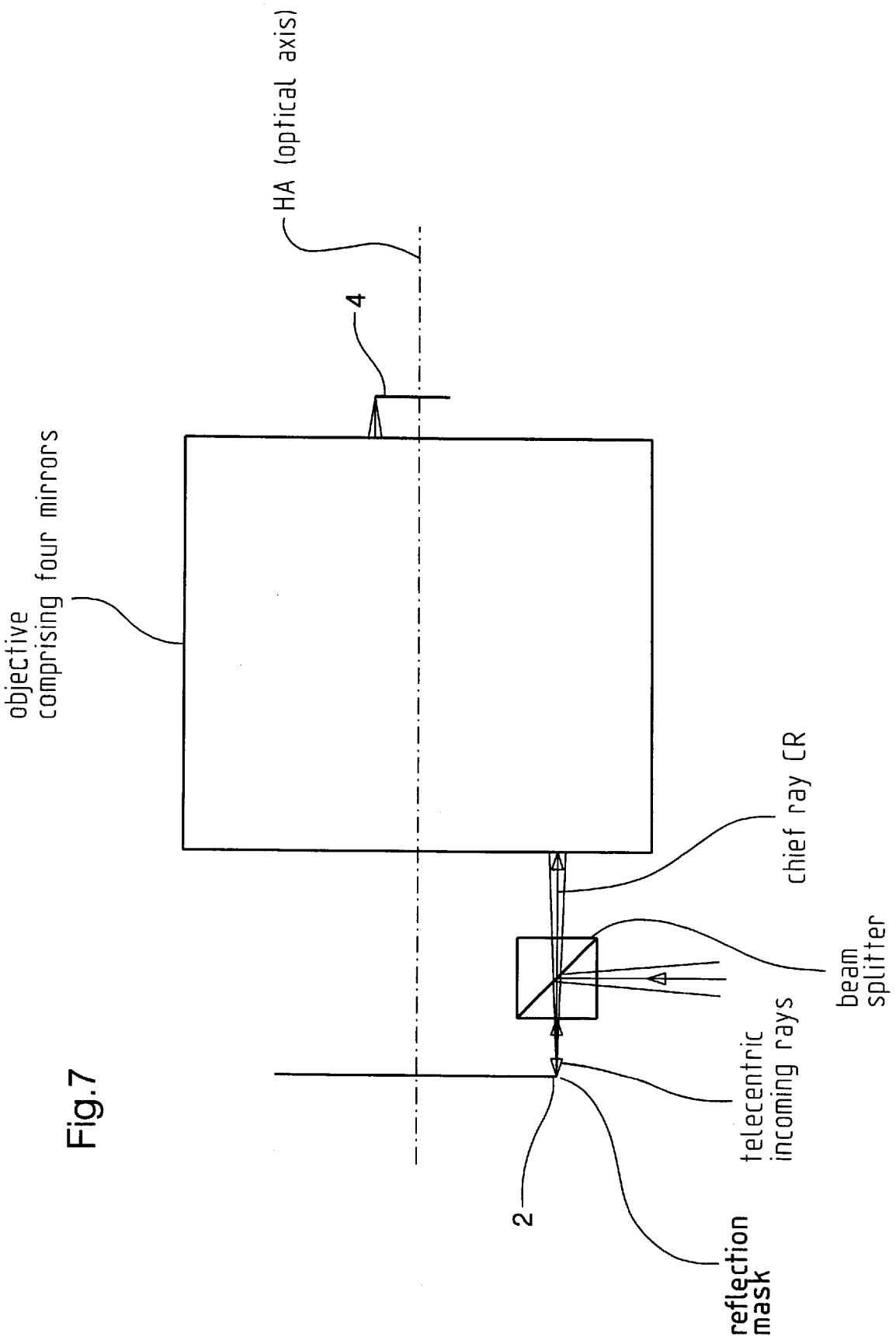

HA (optical axis)
4
objective comprising four mirrors
chief ray CR
beam splitter
telecentric incoming rays
2
reflection mask

Fig.7

REDUCTION OBJECTIVE FOR EXTREME ULTRAVIOLET LITHOGRAPHY

FIELD OF THE INVENTION

The invention relates to a reduction objective, a projection exposure apparatus, and method of use thereof for exposing patterned information onto a reduced image plane for use in lithography applications, such as integrated circuit fabrication.

BACKGROUND OF THE INVENTION

The desirability of creating lithography systems which operate with incident light wavelengths below 193 nm to achieve imaging structures or patterns with resolution below 130 nm has been established. In fact, there has been a need for lithography systems using soft X-ray, or so called extreme ultraviolet (EUV), wavelength incident light, such as λ=11 nm or λ=13 nm light, to obtain image resolution in the below 100 nm range. The resolution of a lithography system is described by the following equation:

$$RES=k_1\lambda/NA$$

where k_1 is a specific parameter of the lithography process, λ is the wavelength of the incident light and NA is the numerical aperture of the system on the image side. This equation can be used to establish design criteria for soft X-ray lithography systems. Thus, for a numerical aperture of 0.10, the imaging of 100 nm structures with 13 nm radiation requires a process with k_1=0.77. Alternatively, with k_1=0.64, which occurs with 11 nm radiation, imaging of 70 nm structures is possible with a numerical aperture of 0.10.

For lithography imaging systems in the soft X-ray region, multilayer coated reflective systems, such as Distributed Bragg Reflectors (DBRs) and mirrors, are used as optical components. These multilayer systems employ alternating layers of different indices of refraction. The particular multilayer reflective system depends on the wavelength of incident light used. For example, with incident light of λ=11 nm alternating layers of Mo/Be are preferred and with incident light of λ=13 nm Mo/Si layers are used. In the case of projection objectives used in soft X-ray or EUV microlithography, the reflectivity of these multilayer systems is approximately 70%. It is, therefore, desirable to use as few optical components in the projection objective as possible to ensure sufficient light intensity at the image. With high intensity light, four-mirror projection objective systems were found to be useful in correcting imaging errors at NA=0.10.

Other requirements for soft X-ray projection objectives, in addition to using a limited number of multilayer reflectors, relate to obscuration, image field curvature, distortion, telecentricity on both the image and the object side, free working distance, and aperture stop positioning and accessibility. Obscurations, for example the central obscuration apparent in Schwarzschild systems, create intolerable degradation in image quality. If an obscuration-free light path is required, then, in the case of centered systems, an off-axis image field must be used. In order to provide image formats of 26×34 mm^2 or 26×52 mm^2, it is advantageous to design the projection objective system as an annular field scanner. In such systems, the useful secant length of the scanning slit should be at least 26 mm, and the annular width should lie in the range of 0.5 mm to 2 mm in order to make uniform illumination and illumination-control and dose-control possible.

Regarding distortion, a distinction between static and dynamic or scan distortion is made. Scan distortion is the

effective distortion which is obtained by integration of the static distortion over the scanning path. The limits for magnification-corrected, static distortion follow essentially from the specifications for contrast and CD variation.

Image-side telecentricity is also desired in soft X-ray lithography systems. Whether telecentricity is possible on the object side depends on the type of projection application used. If the projection system uses a reflection mask, then a telecentric optical path on the object side is not possible. If transmission masks, for example stencil masks, are used then a telecentric optical path on the object side can be realized.

In order to enable clean limitations of the beam, the aperture stop should be physically accessible. The image-side telecentricity requirement, referred to above, means that the entrance pupil of the last mirror would lie in or near its focal point. In order to obtain a compact design and maintain an accessible aperture stop, it is recommended that a beam-limiting element be placed before the last mirror. This, preferably, results in the place of the beam-limiting element at the third mirror.

Four-mirror projection or reduction objectives have become known from the following publications:

U.S. Pat. No. 5,315,629

EP 480,617

U.S. Pat. No. 5,063,586

EP 422,853

Donald W. Sweeney, Russ Hudyma, Henry N. Chapman, David Shafer, EUV optical Design for a 100 mm CD Imaging System, 23rd International Symposium of microlithography, SPIE, Santa Clara, Calif., Feb. 22–27, 1998, SPIE Vol. 3331, p. 2ff.

In U.S. Pat. No. 5,315,629, a four-mirror projection objective with NA=0.1, 4×, 31.25×0.5 mm^2 is claimed. The mirror sequence is concave, convex, concave, concave. From EP 480,617, two NA=0.1, 5×, 25×2 mm^2 systems have become known. The mirror sequence is concave, convex, arbitrary/convex, concave.

The systems according to U.S. Pat. No. 5,063,586 and EP 422,853 have a rectangular image field, for example, at least 5×5 mm^2, and use a mirror sequence of convex, concave, convex, concave. These generally decentered systems exhibit very high distortion values. Therefore, the objectives can only be used in steppers with distortion correction on the reticle. However, the high level of distortion makes such objectives impractical in the structural resolution regions discussed here (≦130 nm).

From U.S. Pat. No. 5,153,898, overall arbitrary three to five-multilayer mirror systems have become known. However, the disclosed embodiments all describe three-mirror systems with a rectangular field and small numerical aperture (NA<0.04). Therefore, the systems described therein can only image structures above 0.25 μm in length.

Furthermore, reference is made to T. Jewell: "Optical system design issues in development of projection camera for EUV lithography", Proc. SPIE 2437 (1995) and the citations given there, the entire disclosure of which is incorporated by reference.

In the known systems according to EP 480,617 as well as U.S. Pat. No. 5,315,629 and according to Sweeney, cited above, it was found to be disadvantageous that the outside-axially used part of the primary mirror conflicts with the wafer-side sensor structures of a projection exposure installation when not very large free mechanical working distances greater than 100 mm are realized. By using mirror segments which are placed "near the image field", these conflicts occur only at significantly lower distances (≈10 mm).

Thus, it is desired from the prior art to provide a projection objective arrangement which is suitable for lithography with short wavelengths (at least below 193 nm and preferably below 100 nm) which does not have the disadvantages of the prior art mentioned above, uses as few optical elements as possible and, yet, has a sufficiently large aperture and fulfills the telecentricity requirements as well as all other requirements for a projection system operating with incident light of wavelengths below 193 nm.

SUMMARY OF THE INVENTION

According to an aspect of the invention, the shortcomings of the prior art are overcome by using a reduction objective that includes four mirrors (primary, secondary, tertiary, and quaternary) and is characterized by a convex primary mirror as well as by a positive chief ray angular magnification of the secondary mirror. Using this four-mirror system, high transmission efficiency is achieved at wavelengths in the soft X-ray and EUV region with a multilayer mirror system of 70% reflectivity and an aperture in the range of NA≈0.10. The four-mirror objective according to the invention is thus characterized by high resolution, low manufacturing costs and high throughput.

In a preferred embodiment of the invention, it is provided that an aperture stop lies on or near a mirror, especially on the tertiary mirror. In this embodiment, the aperture stop is physically accessible and the reduction objective is compact and free from vignetting. In a further embodiment, one or two additional mirrors with aspherical surfaces, as derived from a plane, are disposed between selected mirrors of the four-mirror system at grazing angle of incidence. In a further embodiment, at least one of the additional mirrors is an active mirror.

In another embodiment of the reduction objective of the invention, the secondary mirror and the quaternary mirror are concave. In still a further embodiment, the four-mirrors are arranged in the convex-concave-convex-concave sequence.

The asphericities discussed herein refer to the peak-to-peak or peak-to-valley (PV) deviation A of the aspherical surfaces in comparison to the best fitting sphere in the used region of the mirrors. In the embodiments of the invention discussed herein, these are approximated by a sphere, the center of which lies on the figure-axis of the mirror and the meridional plane of the aspherical element intersects in the upper and lower end point of the useful region. The data on the angles of incidence, as provided below in Table II, refer to the angle between the particular incident radiation and the normal to the surface at the point of incidence. The largest angle of incidence of a ray is established by a rim-ray at one of the mirrors.

Preferably, the optically free working distance on the wafer side is 60 mm and the free working distance on the reticle side is at least 100 mm.

As will be appreciated from this disclosure by persons of ordinary skill in the art, the objectives described above can be used not only for soft X-ray lithography, but for other wavelengths, both in the EUV range and outside of this range, without deviation from the invention. Nonetheless, the invention is preferably used at soft X-ray and EUV wavelengths in the region of 193 nm and below. Wavelengths within this range can be generated using excimer lasers.

In order to achieve a diffraction-limited system, it is preferred that the design part of the rms wave front section of the system is at most 0.07λ, and preferably 0.03λ. It is further preferred that the reduction objective is designed so that it is telecentric on the image side. In systems with a transmission mask, the projection objective is also designed to be telecentric on the object side. In projection systems which are operated with a reflection mask, a telecentric beam path without illumination over a beam splitter which reduces transmission greatly, such as is shown in JP-A-95/28 31 16, is not possible on the object side. Therefore, the chief ray angle in the reticle is chosen so that shading-free illumination, that is no obscuration, is possible. Overall, the telecentricity error on the wafer should not exceed 10 mrad, and preferably is in the 5 mrad to below 2 mrad range. This ensures that the change in the image scale or distortion lies within tolerable limits in the depth of field.

According to another aspect of the invention, the reduction objective is used with a mask and a soft X-ray or EUV exposure source, for example, in a projection exposure apparatus, such as those used in lithography for integrated circuit fabrication. In the embodiment, the projection exposure apparatus has a reflection mask and, in an alternative embodiment, it has a transmission mask.

The projection exposure apparatus is preferably designed as an annular-field scanner illuminating an off-axis annular field. Advantageously, it is provided that the secant length of the scanning slit is at least 26 mm and that the annular width is greater than 0.5 mm, so that uniform illumination is made possible.

Another advantage of the objective of the invention, is that the asphericity of the aspherical optical elements is small enough so that the system requirements of being "diffraction-limited" and having high reflectivity multilayer mirrors can be achieved, such that the resulting accuracy requirements on these surfaces in all spatial frequency regions from the free diameter of the mirror to atomic dimensions can be obeyed.

According to another aspect of the invention, a method of integrated circuit fabrication using a projection exposure apparatus including a reduction objective is provided. The method comprises the steps of providing a mask, providing a soft X-ray or EUV, illumination source, and providing four mirrors (primary, secondary, tertiary, and quaternary) in centered arrangement with respect to an optical axis, wherein the primary mirror is a convex mirror and the secondary mirror has a positive angular magnification.

Traditionally, approximately 40 pairs of alternating Mo/Si DBR layers are used to create mirrors with high reflectivity of 13 nm wavelength incident light. Similarly, high reflectivity of 11 nm wavelength radiation, requires approximately 70 pairs of Mo/Be alternating layers. By using large numbers of DBR layers, the acceptance angle of mirrors and thus their objective systems is only a few degrees and decreases with increasing angle of incidence. Furthermore, with this increasing angle of incidence, detrimental phase effects can occur. If the test-point-related mean angle of incidence varies greatly over a system surface, then layer packets with changing thickness must be applied. These disadvantages of existing multilayer mirror objective systems are reduced in the present invention in which the objectives have a low mean angle of incidence and a low surface-specific variation around the mean angle of incidence.

The invention will be explained below with the aid of drawings depicting the preferred embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic representation of the system classification used in the invention.

FIG. **2** is a lens cross-section of a first four-mirror system (type-e system) according to the prior art.

FIG. **3** is a lens cross-section of a four-mirror system (type-f system) according to the invention.

FIG. **4** is a lens cross-section of another four-mirror system (type-g system) according to the invention.

FIG. **5** is a four-mirror system of type-f with an introduced grazing-incidence mirror according to the invention.

FIG. **6** is a depiction of a four-mirror reduction objective that is telecentric on the object side and used with a transmission mask.

FIG. **7** is a depiction of a four-mirror reduction objective that is telecentric on the object side and used with a reflection mask.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The practical examples identified in FIGS. **2–5** are centered reduction systems, telecentric on the image side, with an aperture stop (indicated by AS in FIG. **4**, for example) at the third mirror **M3**. In all systems, the same reference numbers are used for the same components and the following nomenclature is employed:

first (primary) mirror (**M1**), second (secondary) mirror (**M2**),

third (tertiary) mirror (**M3**), fourth (quaternary) mirror (**M4**).

Reduction objectives used in lithography are classified by their primary mirror magnification m(**M1**), or convergence ratio ν(**M1**)=−1/m(**M1**), and their secondary-mirror chief ray angular magnification μ(**M2**). This nomenclature is taken from Dietrich Korsch, Reflective optics, Academic Press, 1991, p. 41ff, which is incorporated herein by reference. For the different types of primary mirrors Table I, below, summarizes the different convergence ratio and angular magnification values obtainable.

TABLE I

	M1	ν(M1)	μ(M2)
type-a	concave	$\epsilon]1,\infty[$	$<-\epsilon_4$
type-b	plane, concave	$\epsilon[-1,1]$	$<-\epsilon_4$
type-e	convex	$\epsilon]-\infty,-1[$	$<-\epsilon_4$
type-f	convex	$\epsilon]-\infty,-1[$	$\epsilon]\epsilon_4,1-\epsilon_2[$
type-g	convex	$\epsilon]-\infty,-1[$	$\epsilon]1+\epsilon_3,\infty[$

The following is true for these systems: $\epsilon_i > 0$ increases with the numerical aperture NA of the system, that is, $\epsilon_i = 0 \rightarrow NA = 0$. A schematic representation of the system classification as used below is shown in FIG. 1.

The concept of the chief ray angular magnification or angular magnification refers to the tangents of the chief ray (see Korsch, Reflective Optics, incorporated by reference above). A positive angular magnification means that the slopes of the straight lines identifiable with the incident and reflected chief rays to the optical axis have the same sign, that is, that the entrance and exit pupils of the respective mirror lie on the same physical side of the mirror.

As shown in FIG. **1**, type-a, type-b and type-e are topologically connected components of the two-dimensional parameter space. Therefore, type-a, type-b, and type-e objectives can be transformed continuously into each other. In contrast, this is not possible between each of the two other classes of the three systems shown in FIG. **1**. The class including types-a, -b, and -e, can not be continuously transformed into the type-f class (system) or the type-g class (system). FIG. **1** indicates the forbidden regions F in which, in the case of a finite NA, obscuration of the light beam by the mirror will occur and therefore the objectives will fail to image properly.

The particular topologically-connected component region is determined by μ(**M2**). The annular field systems disclosed in U.S. Pat. No. 5,315,629 and EP 480,617 are type-a systems. Type-b systems provide continuous transition to the type-e system which also include the system known from Donald W. Sweeney et al., 23rd International Symposium of Microlithography. Type-a, type-b, and type-e systems are known in the prior art.

Systems of type-f and type-g are not known from any of the publications referred to above. The systems according to type-f and type-g differ from the systems of U.S. Pat. No. 5,315,629 and EP 480,617 by having a convex primary mirror. The system disclosed in Donald W. Sweeney et al., 23rd International Symposium of Microlithography, loc. cit., has a convex primary mirror but it also has a different angular magnification μ at **M2** and thus a different optical path in the system, which does not overcome the prior art problems described above.

Systems of type-f with ν(**M1**) above approximately −1.5 lead to large chief ray angles on the reticle and to large system diameters. As a result, sensible system design with a concave **M1**, i.e. $\nu(M1) \geqq 1$, is difficult.

In the following Table II, typical functional data are given for some of the embodiments of the various system categories. The distortion values follow from the magnification correction through the annular field. Objective systems belonging to the individual system classes are shown in FIGS. **2–5**.

TABLE II

	type-f (94)	type-g (68)
M1	convex	convex
ν(M1)	−2.4	−2.9
μ(M2)	0.6	1.6
NA	0.1	0.1
Red	4x	4x
annular field [mm^2]	26.0 × 1.0	26.0 × 1.25
mean annular field radius [mm]	25	51
OO[1] [mm]	1368	1112
FWD [mm]	92	62
CRAO [mm]	$\epsilon[-2.1, -2.0]$	$\epsilon[4.1, 4.2]$
CRA [mrad]	$\epsilon[-0.35, -0.50]$	$\epsilon[-0.2, 0.2]$
max. asph. [μm]	19.6	8.3
AOI max. [deg]	14.1	22.0
ΔAOI max. [deg]	±2.5	±2.8
WFE max. [λrms]	0.029	0.025
distortion [nmPV]	7	30

Explanation of the abbreviations used in Table II are listed in Table III, below.

TABLE III

	Meaning
M1	form of the primary mirror
ν(M1)	"conversion ratio" according to Korsch
μ(M2)	"angular magnification" according to Korsch
NA	image-side numerical aperture
Red	reduction factor = −1/imaging scale
annular field [mm^2]	secant length × annular width in the image field

TABLE III-continued

	Meaning
mean annular field radius [mm]	image field radius in the middle of the annular field
OO[1] [mm]	object-image distance
FWD [mm]	optically free working distance on the image side
CRAO [deg]	chief ray angle in the object space
CRA [mrad]	chief ray angle in the image space
max. asph. [μm]	maximum deviation of the asphere from the best fitting sphere with respect to the used region of the mirror
AOI max. [deg]	maximum angle of incidence
ΔAOI max. [deg]	variation of the angle of incidence over the mirror
WFE max. [λrms]	maximum rms wavefront error in units of λ
distortion [nmPV]	peak-to-peak value over the annular field scale-corrected chief ray distortion

Systems with a convex M1, i.e. primary mirror, show a significantly higher asphericity than the type-a designs with a concave M1.

FIG. **2** shows a cross-section of a type-e system from a reticle plane **2**, or mask, to a wafer plane **4**. The mirror nearest to the wafer is the first mirror **M1**. Type-e systems have the lowest AOI and ΔAOI on mirrors **M1**, **M2**, **M3**, **M4**, which favors the polarization-optical properties of the system. However, the high chief ray angles on the reticle plane **2** requires plane reticles. Conversely, type-g systems, as shown in cross-section in FIG. **4**, have relatively large AOI and ΔAOI on mirrors **M1**, **M2**, **M3**, **M4** with tolerable chief ray angles on the reticle.

As shown in FIG. **3**, type-f systems require the largest aspherical elements, but have favorable angular distributions on mirrors **M1**, **M2**, **M3**, **M4** and on the reticle **2**. The low distortion results in a relatively small image field. Although the constructional length, i.e. the physical length, of the system is larger than in the other systems, the long drift sections within the objective permit the optional use of additional components, such as an alignment system, deflecting mirror, etc. A chief ray CR and an optical axis HA are also shown in FIG. **3**.

The type-f and type-g systems, as shown in FIGS. **3** and **4**, respectively, can be realized with positive and negative chief ray angles on reticle **2**. Thus, an optimal geometry can be selected, especially a comparatively low free working distance to reticle **2**, for imaging the light when using a reflection mask. Furthermore, when using a transmission mask, a telecentric beam path can be realized.

The systems of type-a and type-f have relatively long "drift sections" before or within the actual image system. Therefore, it is possible to introduce grazing-incidence mirrors of high reflectivity as correction elements. These correction elements can include Schmidt corrector-type elements or an active optical correction system. Based on known values for molybdenum-coated mirrors, it is theoretically possible to achieve approximately 85% reflectivity of non-polarized incident light of wavelength 13.3 nm incident at an angle of 75°. Due to the grazing incidence of the beam, the illuminated part of the mirror can be made very large in one direction, in comparison to that on the neighboring mirror, which facilitates the design of the correcting elements. Preferably, the individual mirrors are designed in a pair-wise manner with the normals to the surface being almost perpendicular to one another, in order to be able to manipulate the beams in all spatial directions with the same resolution. FIG. **5** shows such a design of type-f with an introduced grazing-incidence mirror GIM.

The parameters of the system according to FIG. **3** in the code V format are given in Table 1 below.

TABLE 1

Type-f (94) 4 ×/0.10 1.0 mm annular field

ELEMENT NUMBER	RADIUS	THICKNESS	DIAMETER	TYPE
OBJECT	INF	0.000		
			204.000	
		100.228		
			217.084	
		380.421		
M1	A(1)	−380.421	264.271	REFL.
M2	A(2)	380.421	563.054	REFL.
			390.422	
		796.185		
		APERTURE-STOP	23.764	
M3	A(3)	−117.968	23.764	REFL.
M4	A(4)	117.968	92.608	REFL.
			71.790	
		284.465		
			89.622	
IMAGE	IMAGE WIDTH = INF.	−192.945		
			50.989	

Aspherical Constants:

$$Z = \frac{(CURV)Y^2}{1+(1-(1+K)(CURV)^2Y^2)^{1/2}} + (A)Y^4 + (B)Y^6 + (C)Y^8 + (D)Y^{10}$$

Asphere	CURV	K	A	B	C	D
A(1)	0.0014137	−4.643893	0.00000E − 00	−6.97355E-15	7.87388E-20	0.00000E + 00
A(2)	0.0011339	−0.232793	0.00000E + 00	−5.35926E-17	3.35875E-23	0.00000E + 00

TABLE 1-continued

A(3)	0.0040246	6.006678	0.00000E − 00	3.76117E-13	−1.43488E-15	0.00000E + 00
A(4)	0.0042162	0.289323	0.00000E + 00	8.76473E-15	−5.59142E-19	0.00000E + 00
Reference wavelength = 13 nm						

Similar to Table 1 above, the constructional data of the type-g system shown in FIG. **4** can be seen in the following Table 2:

TABLE 2

ELEMENT	RADIUS	THICKNESS	DIAMETER	TYPE
NUMBER				
OBJECT	INF	0.000		
			413.000	
		378.925		
			373.642	
		474.629		
M1	A(1)	−474.629	327.612	REFL.
M2	A(2)	474.629	600.624	REFL.
			206.075	
		196.627		
		APERTURE-STOP	28.266	
M3	A(3)	−136.037	28.266	REFL.
M4	A(4)	136.037	141.438	REFL.
			115.807	
		−196.627		
			155.535	
		160.000		
	IMAGE WIDTH =	98.781		
IMAGE	INF.		103.302	

Aspherical Constants	CURV	K	A	B	C	D
A(1)	0.0010894	−0.738027	0.00000E+00	3.65218E−16	−1.37411E−20	0.00000E+00
A(2)	0.0012023	0.031851	0.00000E−00	1.38321E−17	−6.58953E−23	0.00000E+00
A(3)	0.0036931	1.579939	0.00000E+00	−1.26703E−13	3.53973E−16	0.00000E+00
A(4)	0.0035917	0.316575	0.00000E+00	3.15592E−15	1.74158E−19	0.00000E+00
Reference Wavelength	13.0 nm					

If a grazing incidence, deflecting mirror GIM is introduced between mirrors **M1**, **M2** and **M3**, **M4**, then one obtains the structure of type-f shown in FIG. **5**. The data for this embodiment can be seen in Table 3.

TABLE 3

Type -f(xx) 4x/0.10 1.0 mm annular field

ELEMENT	RADIUS	THICKNESS	DIAMETER	TYPE
NUMBER				
OBJECT	INF	0.000		
			204.000	
		100.000		
			217.065	
		380.407		
M1	A(1)	−380.407	264.287	REFL.
M2	A(2)	380.407	563.152	REFL.
			390.481	
		296.123		
	DECENTER (1)			
GIM	INF	−499.995	536.341	REFL.
		APERTURE STOP	23.757	
M3	A(3)	117.968	23.757	REFL.

TABLE 3-continued

		Type -f(xx) 4x/0.10 1.0 mm annular field			
M4	A(4)		−117.968	92.614	REFL.
				69.580	
			−284.465		
	IMAGE WIDTH =		192.994		
IMAGE	INF.			51.000	

Aspherical Constants	CURV	K	A	B	C	D
N						
A(1)	0.0014140	−4.643296	0.00000E+00	−96.99186−15	7.89877E−20	0.00000E−0
A(2)	0.0012023	0.031851	0.00000E−00	1.38321E−17	−6.58953E−23	0.00000E+0
A(3)	0.0012023	1.579939	0.00000E+00	−1.26703E−13	3.5973E−16	0.00000E+0
A(4)	−0.0042169	0.289286	0.00000E+00	−8.76770E−15	5.47269E−19	0.00000E+00
DECENTER CONSTANTS						
DECENTER		Deflection Angle ALPHA AM GIM				
D(1)						75.00000 Degree
Wavelength 13 nm						

FIG. **6** shows the four-mirror reduction objective of FIG. **3** or **4** with the reticle plane **2** as a transmission mask. Thus, it can be seen from FIG. **6** that the reduction objective is telecentric on the object side in such a configuration. Similarly, FIG. **7** shows the four-mirror reduction objective of FIG. **3** or **4** with the reticle plane **2** as a reflection mask. In such a configuration, a beam splitter may be used, for example, to ensure the reduction objective is also telecentric on the object side.

Thus, the invention provides for a four-mirror reduction objective with an imaging reduction scale of approximately 4× for use in soft X-ray, i.e. EUV and UV, annular field projection applications, such as lithography. The reduction objection achieves the necessary resolution at the required image field and provides a structural design with optical elements of sufficiently mild asphericity, sufficiently small incident angles for the multilayered optics, and sufficiently large constructional space for the image carriers.

What is claimed is:

1. A reduction objective, with an image side and an object side, comprising:

a primary multilayer mirror, a secondary multilayer mirror, a tertiary multilayer mirror and a quaternary multilayer mirror in centered arrangement with respect to an optical axis situated between the image side and the object side, wherein the primary mirror is convex and the secondary mirror has positive chief ray angular magnification.

2. A reduction objective according to claim **1**, comprising an aperture stop disposed on or near the primary mirror, the secondary mirror, the tertiary mirror, or the quaternary mirror.

3. A reduction objective according to claim **1**, comprising an aperture stop disposed on or near said tertiary mirror.

4. A reduction objective according to claim **1**, comprising a fifth mirror or a sixth mirror disposed at a grazing incidence.

5. A reduction objective according to claim **4**, wherein said fifth mirror or said sixth mirror has an aspherical surface derived from a planar surface.

6. A reduction objective according to claim **4**, wherein at least said fifth mirror or said sixth mirror is an active mirror.

7. A reduction objective according to claim **1**, wherein the secondary mirror and the quaternary mirror are concave.

8. A reduction objective according claim **1**, wherein the primary mirror, the secondary mirror, the tertiary mirror and the quaternary mirror are shaped in a convex-concave-convex-concave sequence.

9. A reduction objective according to claim **1**, wherein the reduction objective is telecentric on the object side.

10. A reduction objective according to claim **1**, wherein a chief ray at the object side is directed away from the optical axis.

11. A reduction objective according to claim **1**, wherein the reduction objective is telecentric on the image side.

12. A reduction objective according to claim **1**, wherein the secondary mirror in centered arrangement with the optical axis has a used area in which rays traveling through the objective are impinging the secondary mirror, and wherein a bundle of rays from the object side to the primary mirror is traveling between the used area of the secondary mirror and the optical axis.

13. A reduction objective according to claim **1**, wherein the primary mirror in centered arrangement with the optical axis has a used area in which rays traveling through the objective are impinging the primary mirror, and wherein a bundle of rays reflected from the secondary mirror and impinging the tertiary mirror is traveling between the used area of the primary mirror and the optical axis.

14. A reduction objective according to claim **1**, wherein the primary mirror in centered arrangement with the optical axis has a used area in which rays traveling through the objective are impinging the primary mirror, and wherein a bundle of rays reflected from the secondary mirror and impinging the tertiary mirror is traveling along a light channel such that the used area of the primary mirror is situated between the light channel and the optical axis.

15. A reduction objective according to claim **1**, wherein the chief ray angular magnification on the second mirror is greater than or equal to 0.6.

16. A projection exposure apparatus including a reduction objective, with an image side and an object side, for annular field scanning operation, comprising:

a mask; and

a primary multilayer mirror, a secondary multilayer mirror, a tertiary multilayer mirror and a quaternary multilayer mirror in centered arrangement with respect to an optical axis situated between the image side and the object side, wherein the primary mirror is convex and the secondary mirror has a positive chief ray angular magnification.

17. A projection exposure apparatus according to claim 16, wherein the mask is a reflection mask.

18. A projection exposure apparatus according to claim 16, wherein the mask is a transmission mask.

19. A method for integrated circuit fabrication using a projection exposure apparatus including a reduction objective, with an image side and an object side, including the steps of:

providing a mask; and

providing a primary multilayer mirror, a secondary multilayer mirror, a tertiary multilayer mirror and a quaternary multilayer mirror in centered arrangement with respect to an optical axis situated between the image side and the object side, wherein the primary mirror is convex and the secondary mirror has a positive chief ray angular magnification.

* * * * *

US006243217B1

(12) **United States Patent**
Nagaoka

(10) **Patent No.: US 6,243,217 B1**
(45) **Date of Patent: Jun. 5, 2001**

(54) **OBJECTIVE LENS SYSTEM**

(75) Inventor: **Toshiyuki Nagaoka**, Akishima (JP)

(73) Assignee: **Olympus Optical Co., Ltd.**, Tokyo (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/455,362**

(22) Filed: **Dec. 6, 1999**

Related U.S. Application Data

(62) Division of application No. 08/713,069, filed on Sep. 12, 1996, now Pat. No. 5,999,327.

(30) **Foreign Application Priority Data**

Sep. 12, 1995 (JP) 7-258220

(51) **Int. Cl.**[7] **G02B 9/04**; G02B 13/18

(52) **U.S. Cl.** **359/793**; 359/717

(58) **Field of Search** 359/793, 784, 359/661, 708, 713–717; 348/552; 345/168–169

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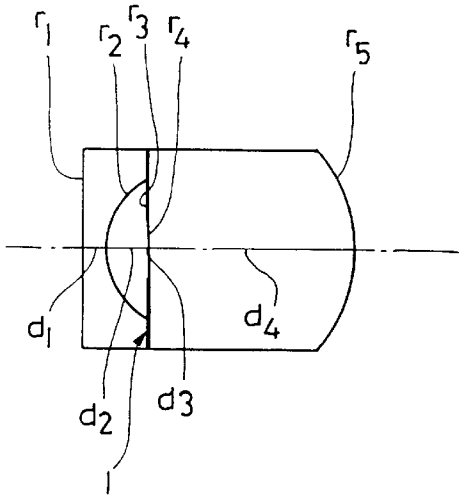
Primary Examiner—Georgia Epps
Assistant Examiner—Jordan M. Schwartz
(74) *Attorney, Agent, or Firm*—Pillsbury Winthrop LLP

(57) **ABSTRACT**

A portable TV telephone includes an objective lens system. The objective lens system is configured to form an image of an object. An antenna is configured to transmit and receive at least one of said image of the object, a dial number and a voice carried by radio waves. A display is configured to display at least one of the image of the object and the dial number. The objective lens system includes a first negative lens unit and a second positive lens unit in order from an object side. An aperture stop is disposed between the first lens unit and said second lens unit. In one embodiment, the first lens and the second lens each have a lens barrel configured to position the respective lens units such that circumferences of the lens units contact interior walls of the portable TV telephone. In another embodiment, the first lens unit and the second lens unit are cemented at outer circumferential portions outside an effective diameter through which rays transmit.

15 Claims, 16 Drawing Sheets



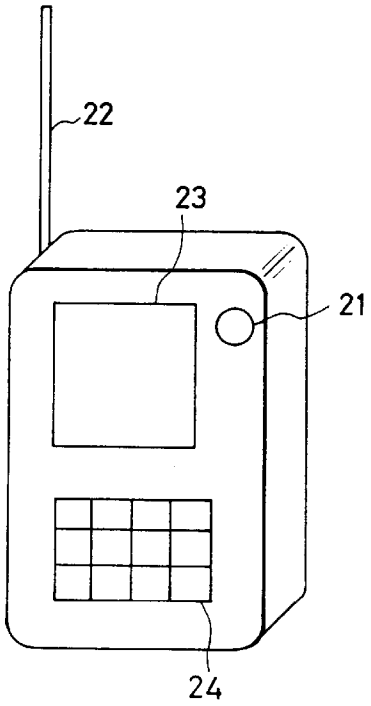


FIG. 1
PRIOR ART

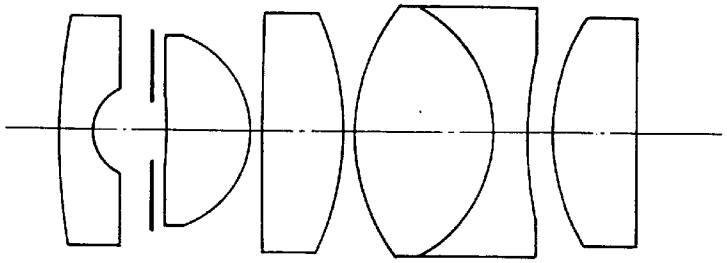


FIG. 2

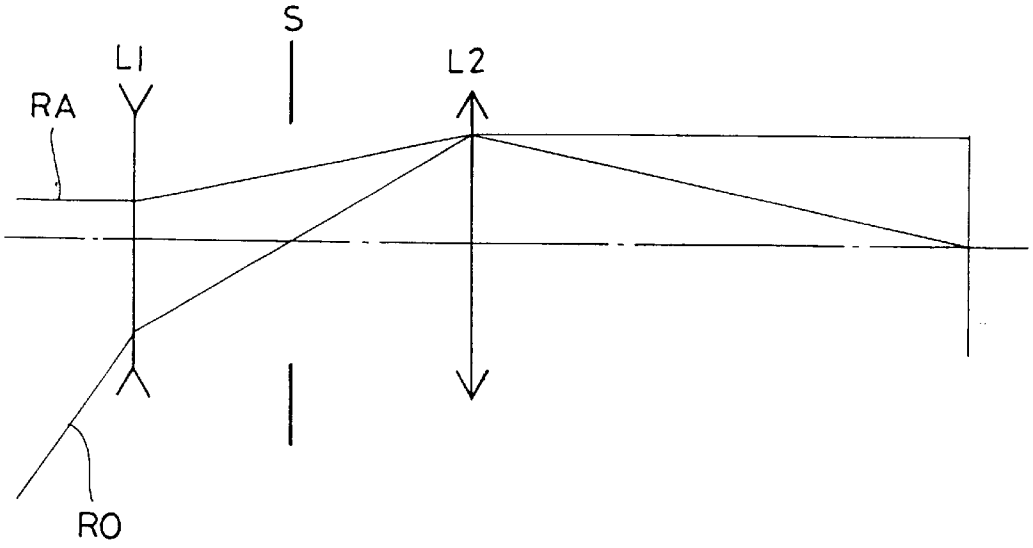


FIG. 3

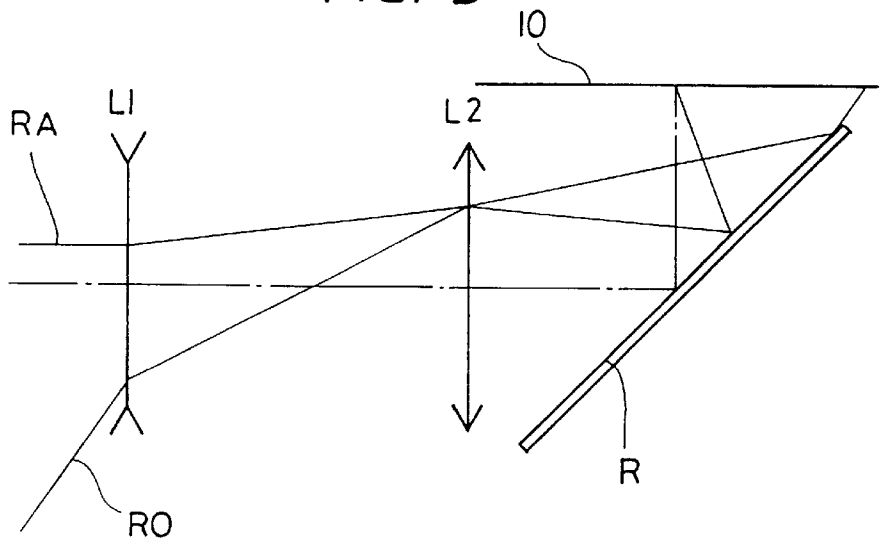


FIG. 4

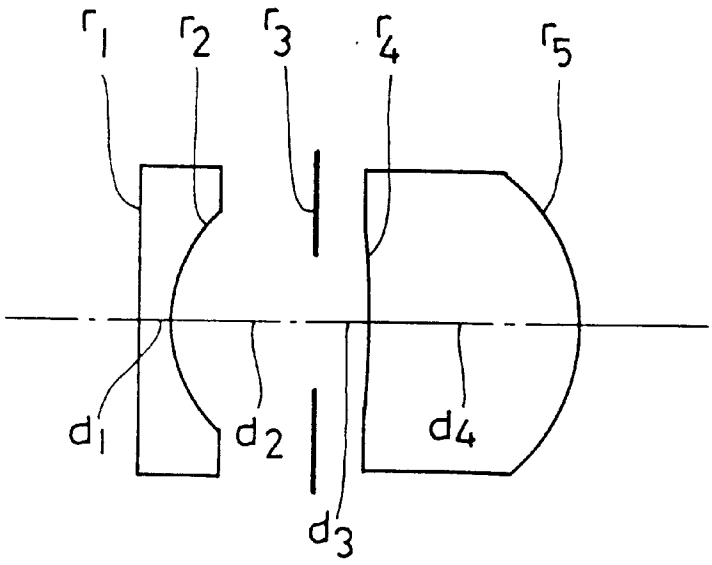


FIG. 5

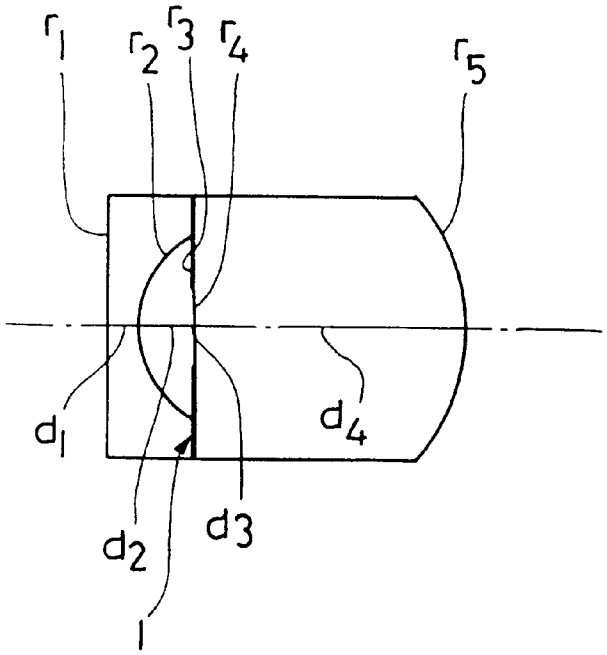


FIG. 6

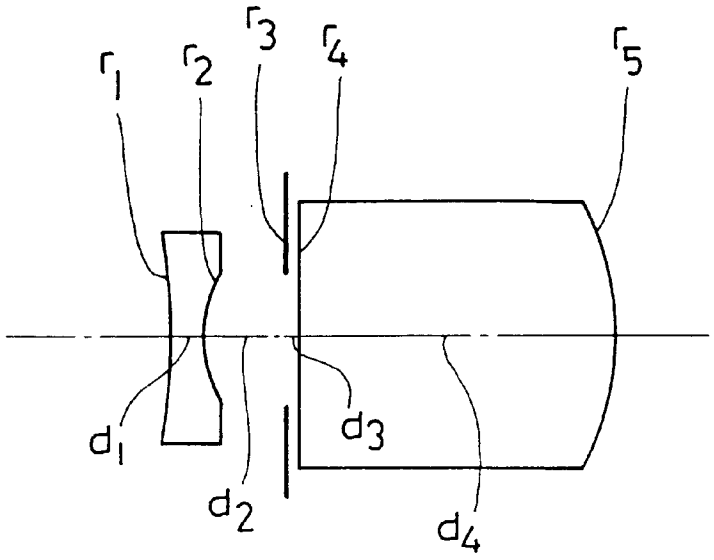


FIG. 7

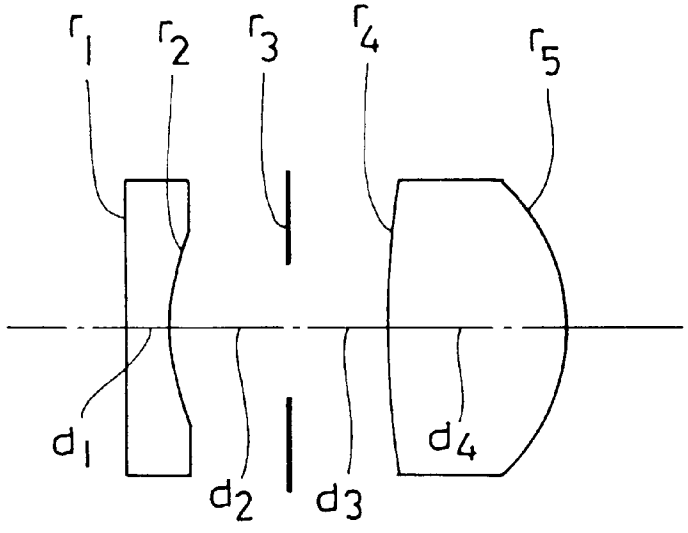


FIG. 8

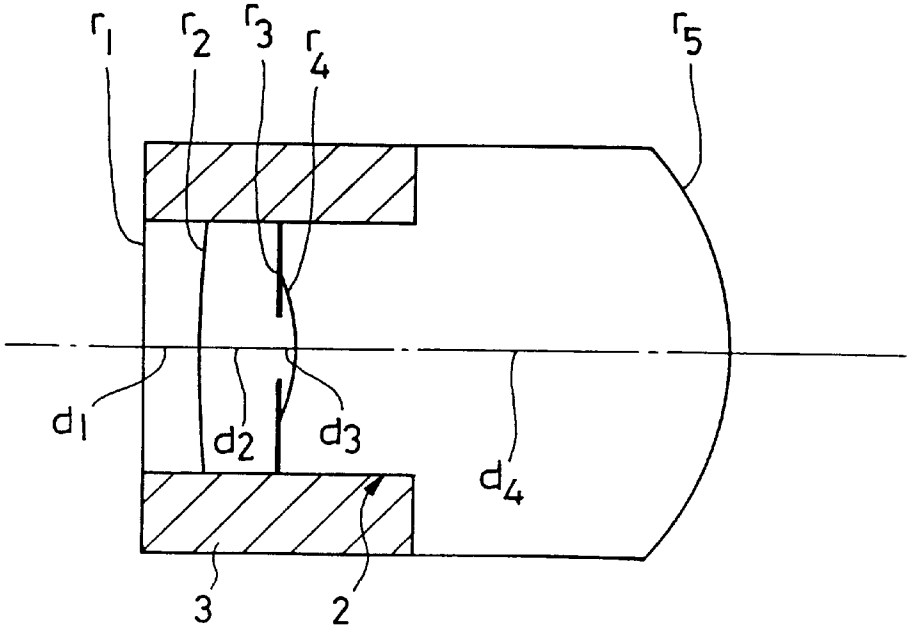


FIG. 9

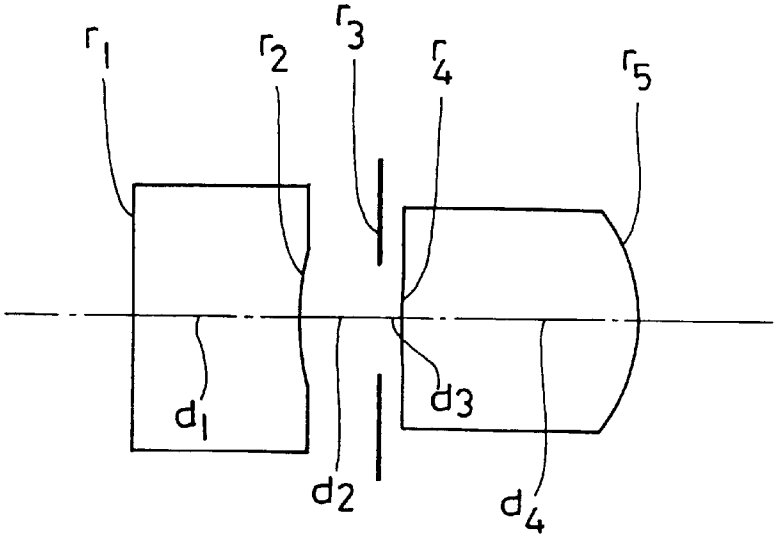


FIG. 10

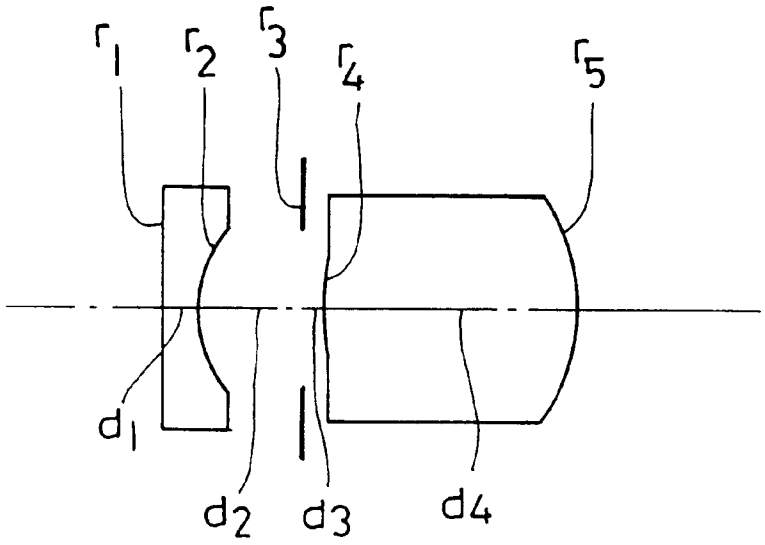


FIG. 11

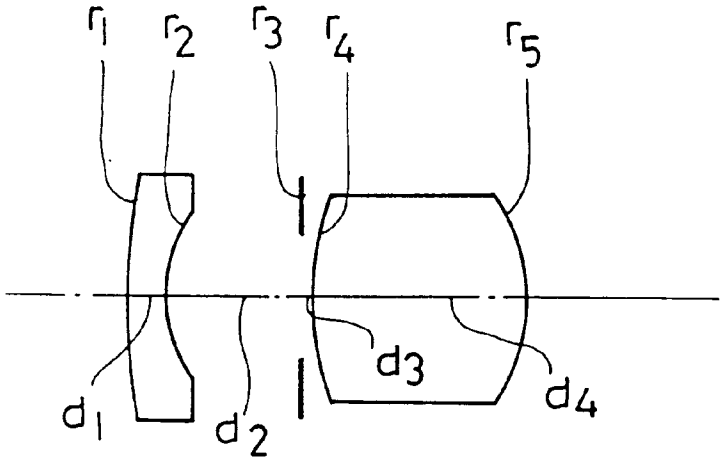


FIG. 12

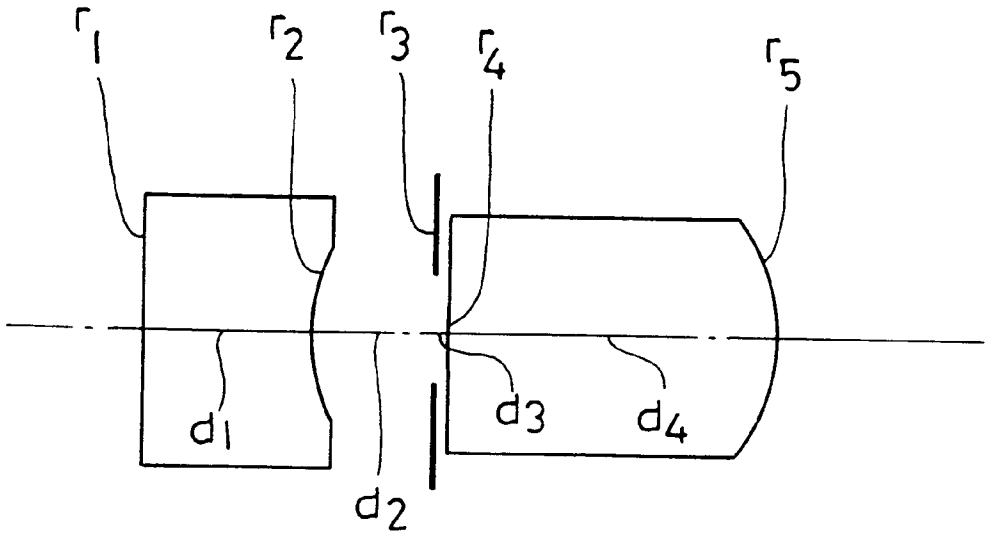


FIG. 13

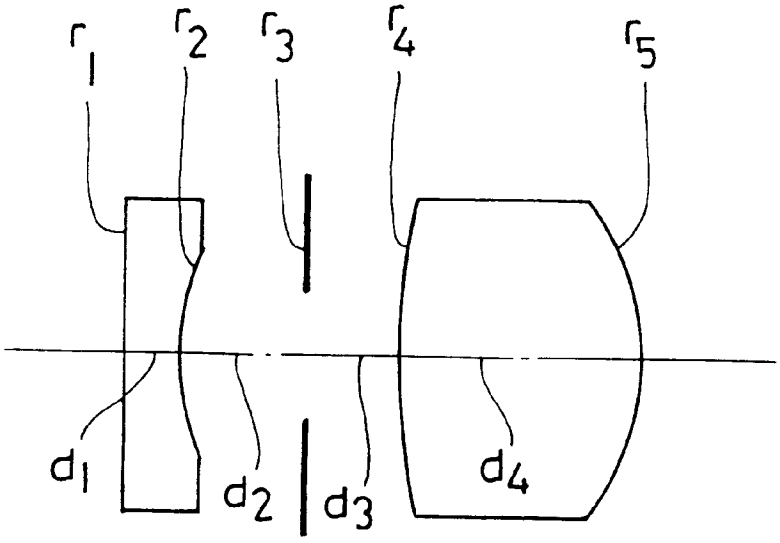


FIG. 14

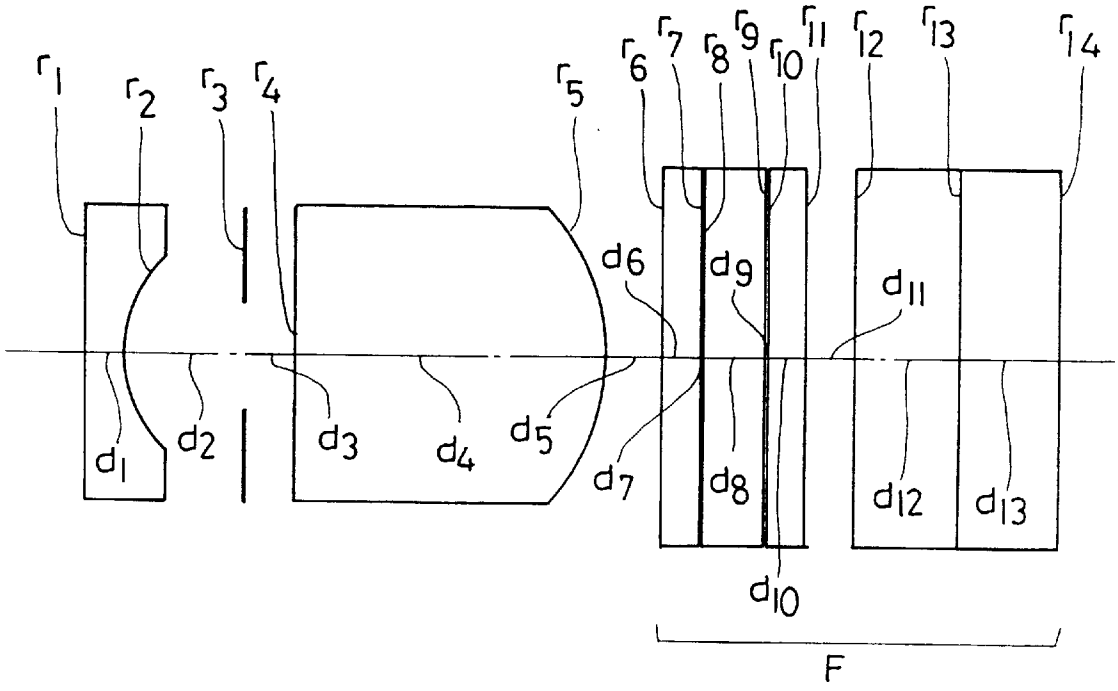

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FIG. 15

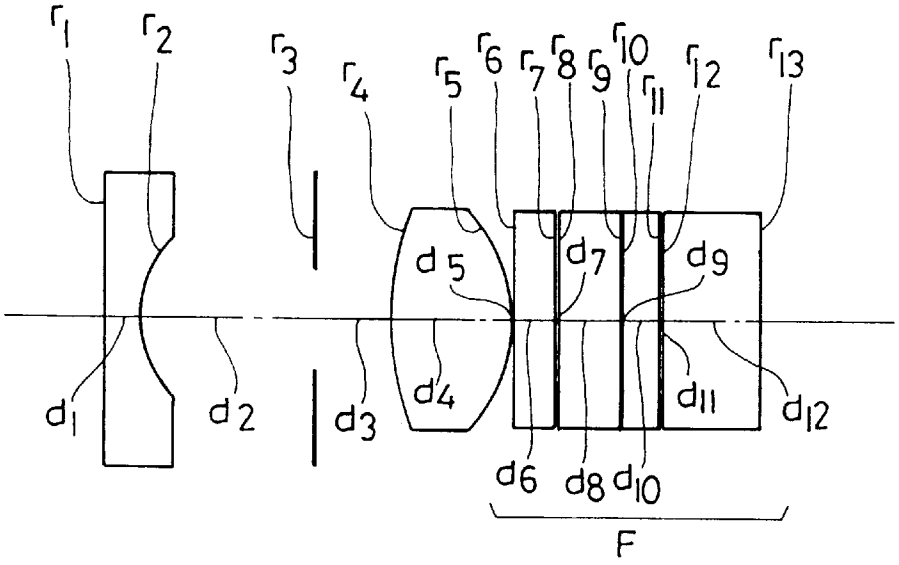
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FIG. 16A

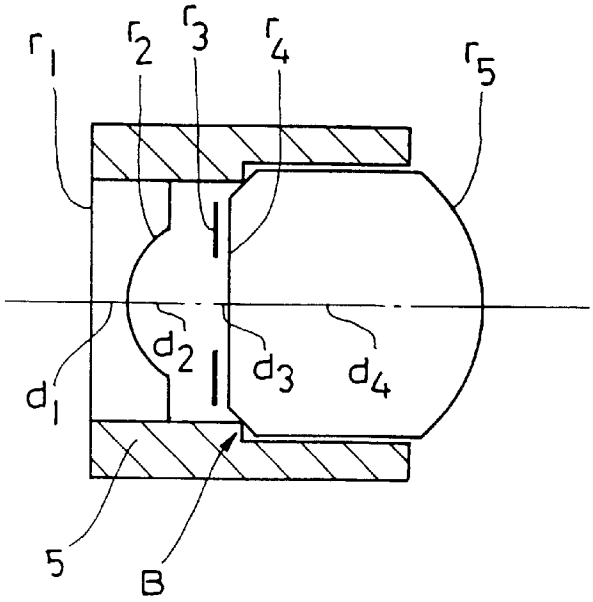

FIG. 16B

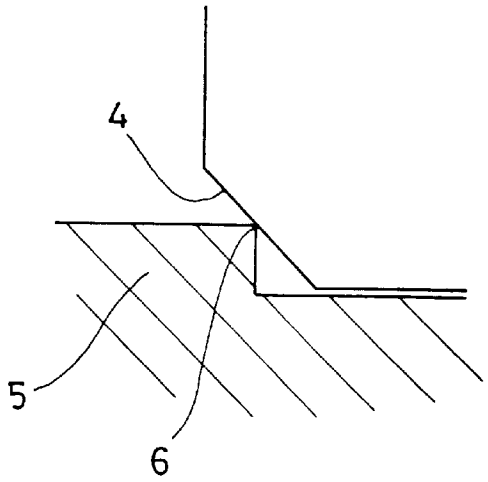

FIG. 17

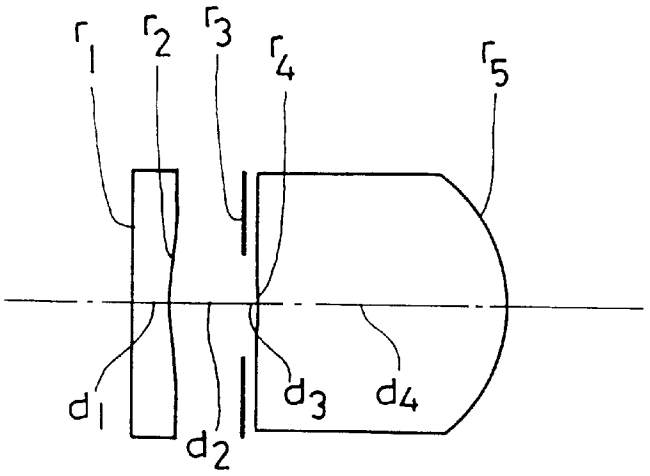

FIG. 18

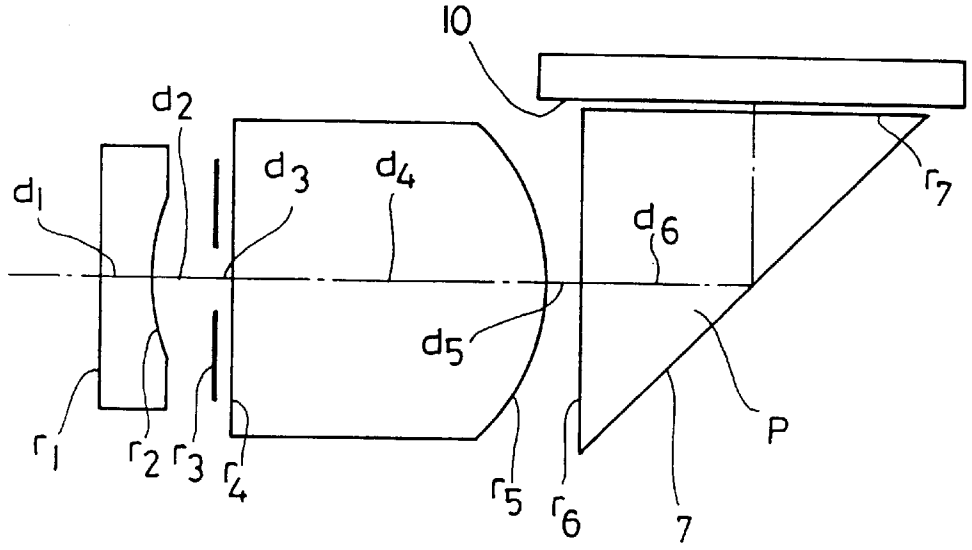

FIG. 19

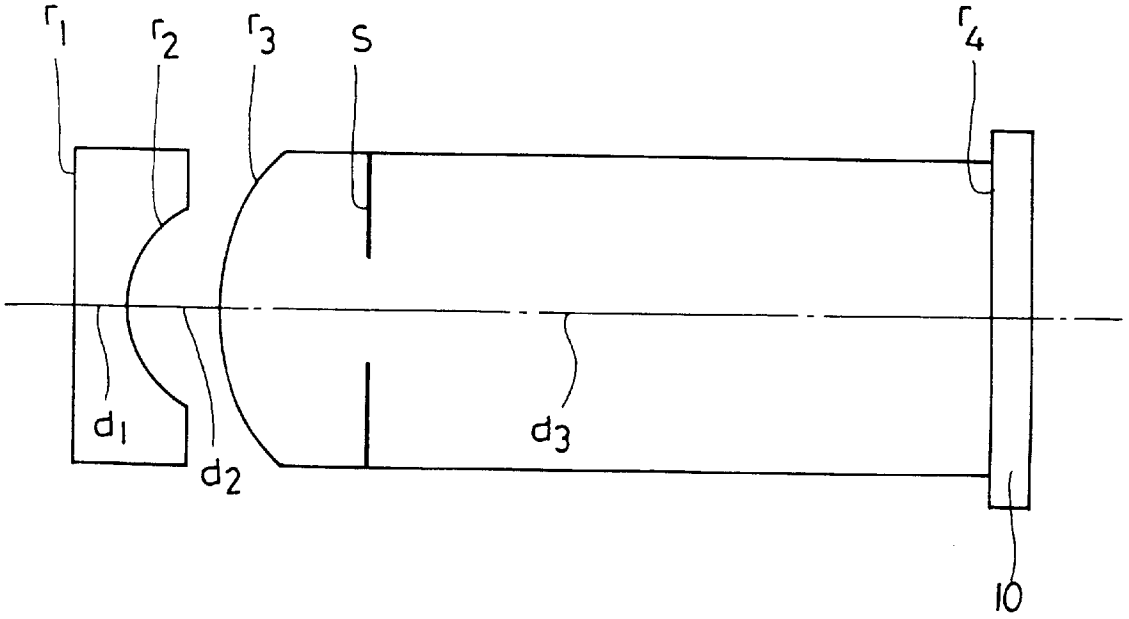

FIG. 20

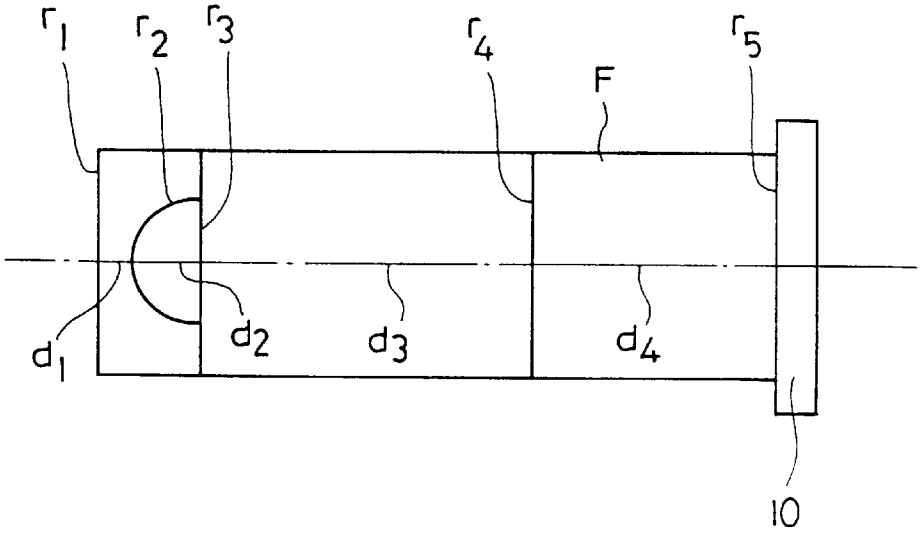

FIG. 21

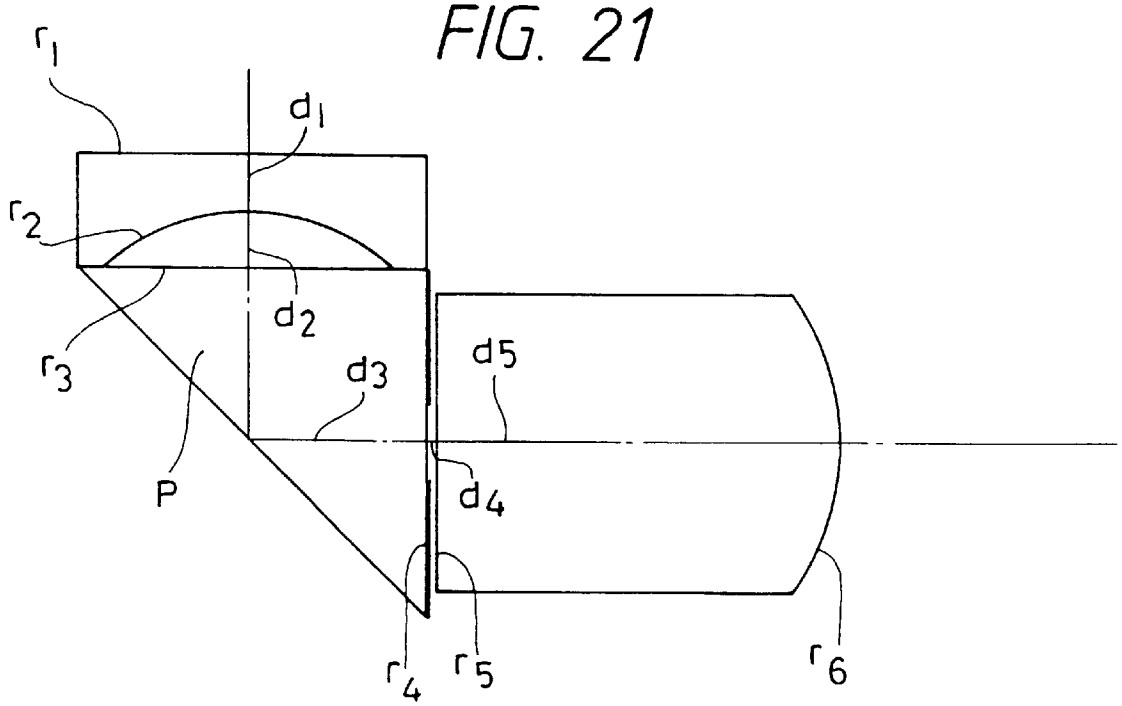

FIG. 22A

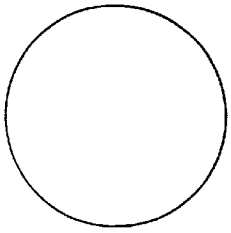

FIG. 22B

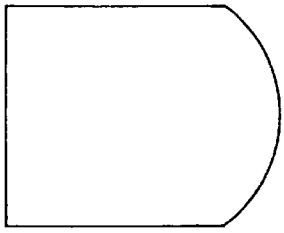

FIG. 22C

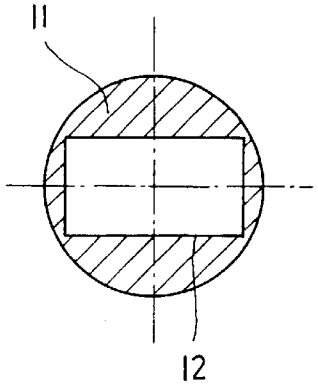

FIG. 23A

FIG. 23B

FIG. 23C

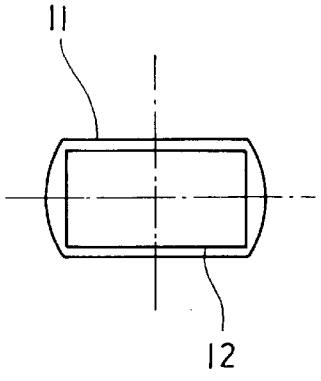

FIG. 24

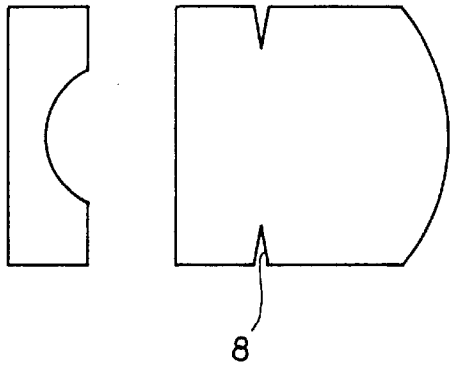

FIG. 25

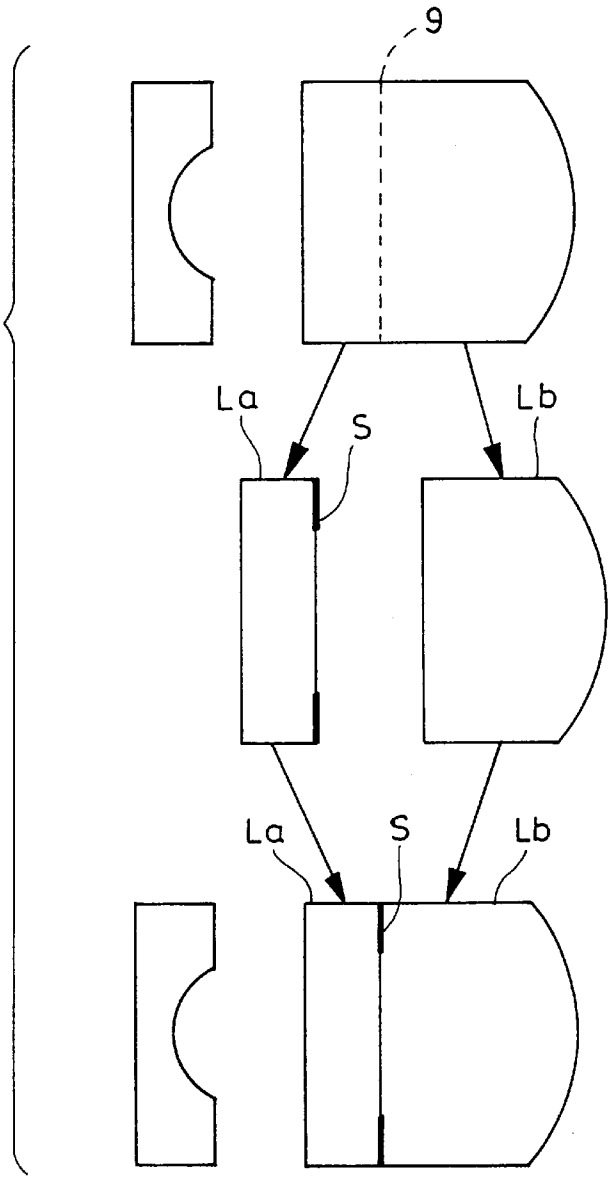

FIG. 26

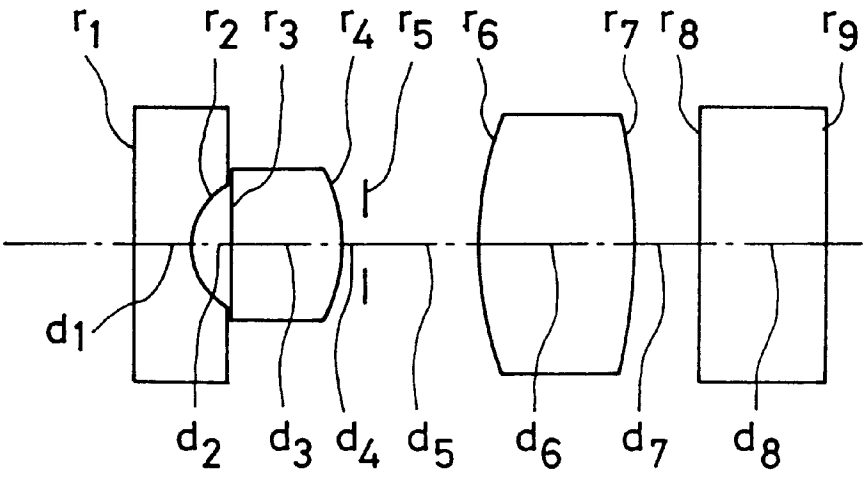
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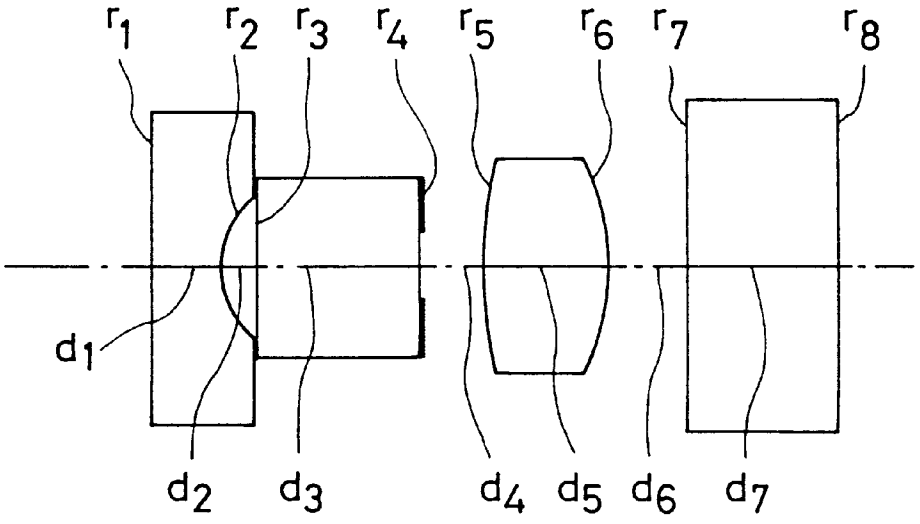
FIG. 27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d7

FIG. 28

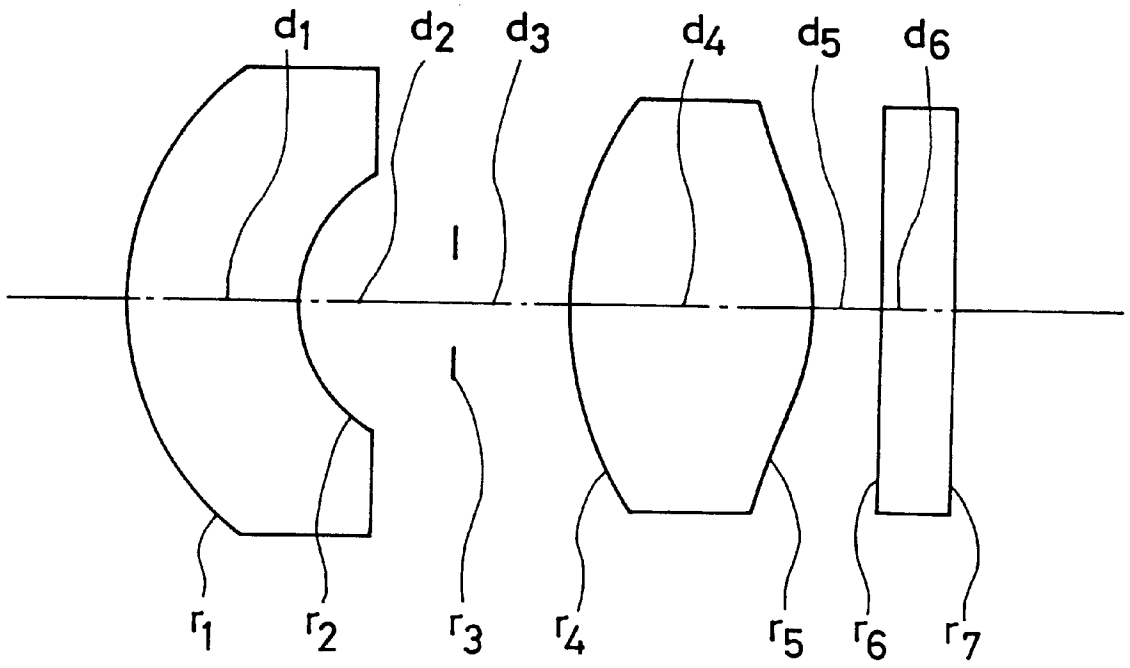


FIG. 29

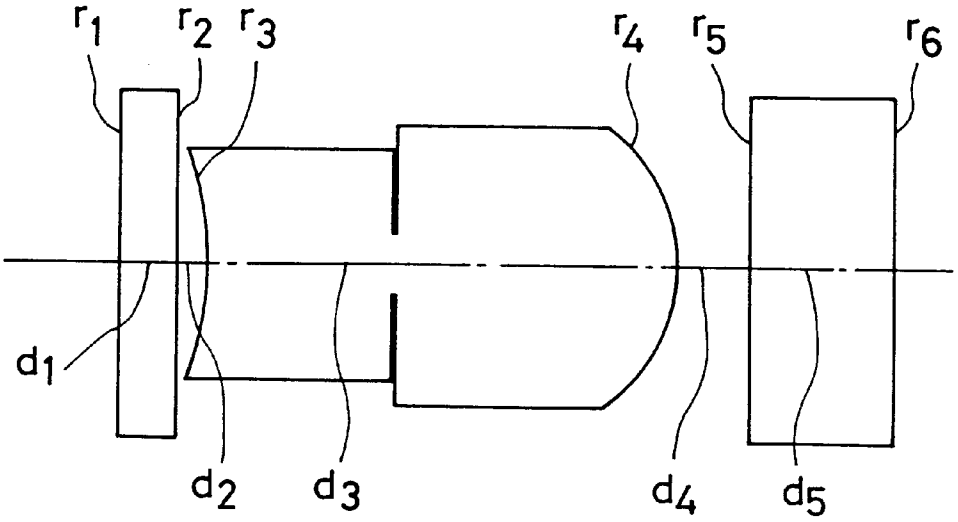


FIG. 30

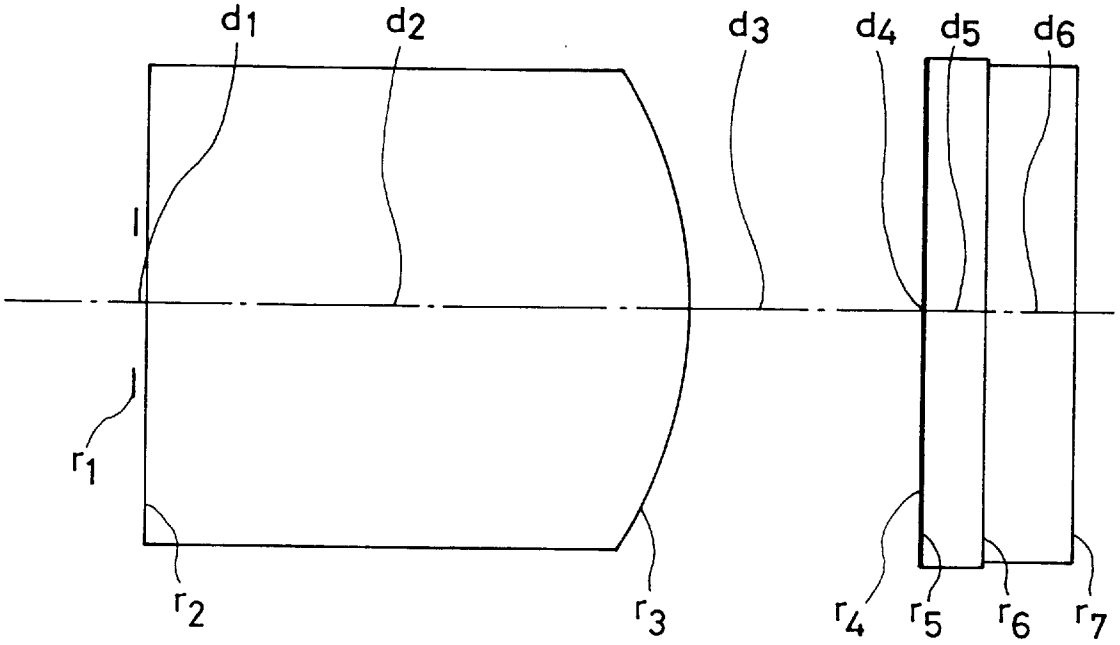

d1
d2
d3
d4
d5
d6
I
r1
r2
r3
r4
r5
r6
r7

FIG. 31

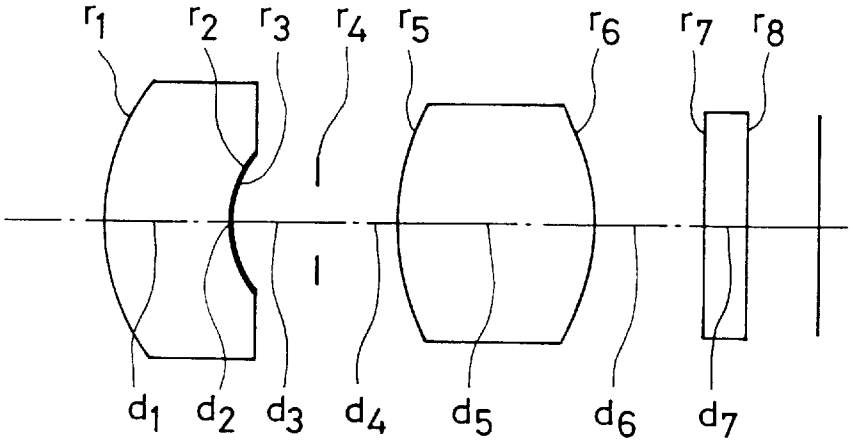

r1
r2
r3
r4
r5
r6
r7
r8
I
d1
d2
d3
d4
d5
d6
d7

FIG. 32

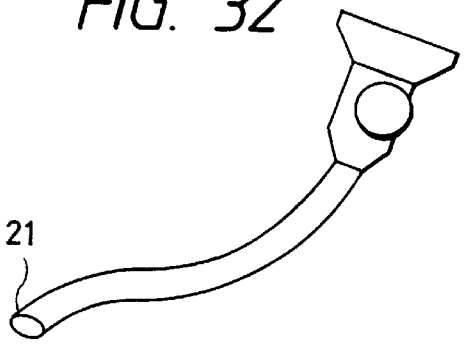


FIG. 33

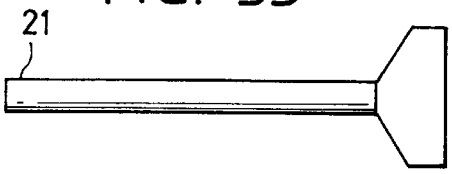


FIG. 34

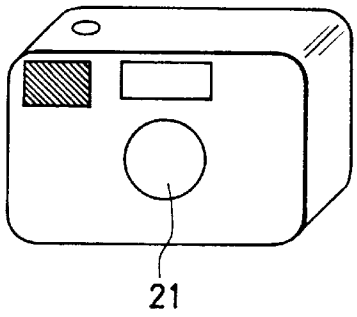


FIG. 35

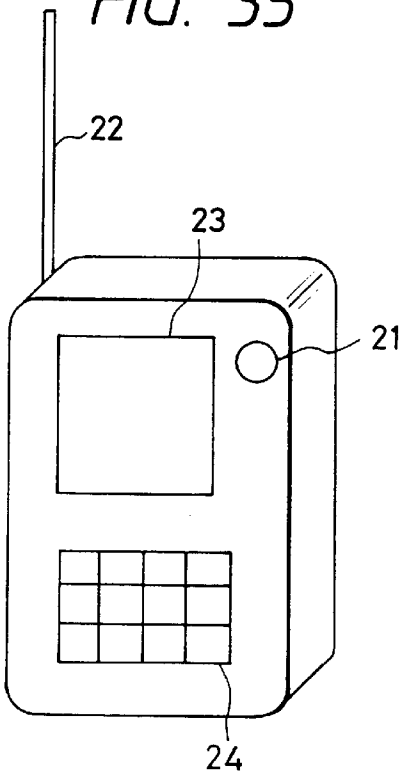
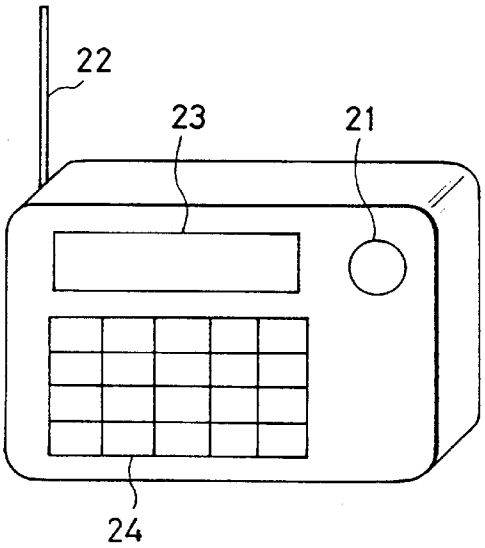


FIG. 36



OBJECTIVE LENS SYSTEM

This is a division of application Ser. No. 08/713,069, filed Sep. 12, 1996 now U.S. Pat. No. 5,999,327.

BACKGROUND OF THE INVENTION

a) Field of the Invention

The present invention relates to an objective lens system which uses a radial type gradient index lens element.

b) Description of the Prior Art

As conventional examples of lens systems having relatively wide field angles and high optical performance which are used, for example, as objective lens systems for endoscopes, there are known many lens systems such as a lens system disclosed by Japanese Patent Kokoku Publication No. Sho 60-46410 shown in FIG. **1**. A conventional example shown in FIG. **1** is a lens system of the so-called retrofocus type which is composed, in order from the object side, of a front lens unit having negative refractive power, a stop and a rear lens unit having a positive refractive power. In this lens system, the front lens unit has a function to widen a field angle and another function to correct curvature of field by reducing a Petzval's sum of the lens system as a whole, the rear lens unit serves for suppressing production of spherical aberration and coma by distributing refractive powers among three positive lens elements and a cemented lens component, and the cemented lens component corrects lateral chromatic aberration which poses a problem, in particular, in a lens system which has a wide field angle. Though this conventional example favorably corrects aberrations, it is composed of lens elements in a number as large as six, thereby posing a problem of low producibility or a high manufacturing cost. Accordingly, it is expected to develop a retrofocus type objective lens system for endoscopes which is composed of an extremely small number of lens elements and has a high producibility. However, a lens system which favorably corrects aberrations and has high optical performance can hardly be composed of two homogenous spherical lens elements.

Further, an endoscope is generally equipped with a system for illuminating a location to be observed since it is used frequently for observing and photographing dark locations such as interiors of human bodies, aircraft engines, pipings and so on. In addition, an objective lens system for endoscopes has an NA which is not so large for obtaining a large depth of field. Accordingly, axial aberrations do not pose a serious problem, but a wide field angle and a negative-positive asymmetrical composition as shown in FIG. **1** make it difficult to correct offaxial aberrations. When an objective lens system is to be composed of two negative and positive lens elements, it is impossible to use a cemented lens component as in the objective lens system disclosed by Japanese Patent Kokoku Publication No. Sho 60-46410 mentioned above as the conventional example, whereby lateral chromatic aberration can hardly be corrected and offaxial imaging performance is remarkably degraded. It is therefore difficult to favorably correct offaxial aberrations with two homogenous lens elements so as to obtain favorable offaxial imaging performance.

It is therefore conceivable to use a radial type gradient index lens element which is characterized in that it corrects chromatic aberration in particular more favor- ably than a homogenous lens element. As a conventional example of an objective lens system for endoscopes which uses a radial type gradient index lens element and is composed of two lens elements, there is known a lens system disclosed by

Japanese Patent Kokai Publication No. Sho 52-29238. However, this conventional example has a field angle as narrow as 72° which is insufficient for use as an objective lens system for endoscopes.

Further, a lens system disclosed by Japanese Patent Kokai Publication No. Hei 5-107471,for example, is known as a conventional example of an objective lens system having a wide field angle obtained with two lens elements. Though this example uses a radial type gradient index lens element, it does not effectively make use of the chromatic aberration correcting capability of the radial type gradient index lens element and does not sufficiently correct lateral chromatic aberration which poses a problem in a lens system having a wide field angle in particular.

SUMMARY OF THE INVENTION

A primary object of the present invention is to provide an objective lens system which is composed of lens elements in a number on the order of 2, that favorably corrects aberrations and has a wide field angle.

The objective lens system according to the present invention is characterized in that it comprises, in order from the object side, a first lens unit having a negative refractive power and a second lens unit having a positive refractive power; that at least the first lens unit comprises a radial gradient index lens element which has a refractive index distribution in a radial direction of the lens element; and that the first lens unit satisfies the following condition (1):

$$1/V_{10}<1/V_{00} \tag{1}$$

wherein the reference symbols V_{00} and V_{10} represent parameters expressing a dispersing power of the radial type gradient index lens element which are given by the following formulae (b) and (c) respectively:

$$V_{00}=(N_{00d}-1)/(N_{00F}-N_{00C}) \tag{b}$$

$$V_{10}=N_{10d}/(N_{10F}-N_{10C})$$

wherein the reference symbols N_{00d}, N_{00F} and N_{00C} represent refractive indices of the radial type gradient index lens element for the d-line, F-line and C-line respectively, and the reference symbols N_{10d}, N_{10F} and N_{10C} designate values of a coefficient of a term r^2 for the d-line, F-line and C-line respectively when a refractive indices of the radial type gradient index lens element is expressed in a form of a poly-nominal. In embodiments of the present invention which are to be described later, refractive indices of radial type gradient index lens elements are given by the following formula (a):

$$n(r)=N_{00}+N_{10}r^2+N_{20}r^4+ \tag{a}$$

wherein the reference symbol r represents a distance as measured from an optical axis in a radial direction of the radial type gradient index element and the reference symbol n(r) designates a refractive index of a portion of the radial type gradient index lens element located at the distance r.

Further, the objective lens system according to the present invention is characterized in: that it is composed, in order from the object side, of a first lens unit having a negative refractive power, and a second lens unit having a positive refractive power, that at least the second lens unit comprises a radial type gradient index lens element having a refractive index distribution in a radial direction of the lens element,

and that the second lens unit satisfies the following conditions (1) and (3):

$$1/V_{10}<1/V_{00} \quad (1)$$

$$0.05<\phi_{2m}/\phi<1.0 \quad (3)$$

wherein the reference symbol ϕ_{2m} represents a refractive index of a medium of the radial type gradient lens element used in the second lens unit.

Further, it is desirable that the objective lens system according to the present invention described above satisfies the following condition (2):

$$-0.5<\phi_{1m}/\phi<-0.02$$

wherein the reference symbol ϕ_{1m} represents a refractive power of a medium of the radial type gradient index lens element used in the first lens unit and the reference symbol ϕ designates a refractive power of the objective lens system as a whole.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** shows a sectional view illustrating a composition of a conventional objective lens system;

FIG. **2** shows a diagram schematically showing a fundamental composition of the objective lens system according to the present invention;

FIG. **3** shows a diagram schematically showing the fundamental composition of the objective lens system according to the present invention wherein an image surface is positioned in parallel with an optical axis;

FIGS. **4** through **15** show sectional views illustrating compositions of first through twelfth embodiments of the objective lens system according to the present invention;

FIGS. **16**A and **16**B show views illustrating a composition of a thirteenth embodiment of the objective lens system according to the present invention;

FIGS. **17** through **21** show sectional views illustrating composition of fourteenth through eighteenth embodiments of the objective lens system according to the present invention;

FIGS. **22**A, **22**B and **22**C show diagrams exemplifying a shape, before working, of a lens element which is to be used in the objective lens system according to the present invention;

FIGS. **23**A, **23**B and **23**C show diagrams exemplifying a shape, after working, of the lens system which is to be used in the objective lens system according to the present invention;

FIG. **24** is a diagram showing an example of a stop which is to be disposed in the objective lens system according to the present invention;

FIG. **25** is a diagram showing another example of a stop which is to be disposed in the objective lens system according to the present invention;

FIGS. **26** through **31** show sectional views illustrating compositions of nineteenth through twenty-fourth embodiments of the objective lens system according to the present invention;

FIG. **32** shows a perspective view illustrating an endoscope which uses the objective lens system according to the present invention;

FIG. **33** shows a side view of a non-flexible endoscope which uses the objective lens system according to the present invention;

FIG. **34** shows a perspective view illustrating a video camera which uses the objective lens system according to the present invention;

FIG. **35** shows a perspective view illustrating a portable TV telephone which uses the objective lens system according to the present invention; and FIG. **36** shows a perspective view illustrating a portable data input unit which uses the objective lens system according to the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

It is desirable that an objective lens system which has a relatively wide field angle for use in endoscopes, for example, is configured as the so-called retrofocus type composed, in order from the object side, of a first lens unit having a negative refractive power and a second lens unit having a positive refractive power.

Further, it is desirable that endoscopes, for example, which are inserted into human bodies and pipings for observing interiors thereof use objective lens systems having small diameters. When the lens system according to the present invention is to be used as an objective lens system for endoscopes, it is desirable for reducing a diameter of the lens system to compose it by disposing a stop between a negative lens unit and a positive lens unit. By selecting such a composition, it is possible to lower heights of rays passing through a first lens unit or a second lens unit, thereby reducing the diameter of the lens system. When the lens system has an asymmetrical composition, or is composed of a positive lens unit and a negative lens unit disposed on both sides of a stop, however, offaxial aberrations are apt to be produced in large amounts in the lens system as a whole, or it is difficult to favorably correct lateral chromatic aberration in particular. For favorably correcting lateral chromatic aberration, it is desirable to use a radial type gradient index lens element which has a more excellent characteristic for correcting chromatic aberration than a homogenous lens element.

It is known that lateral chromatic aberration LTC produced by a thin radial type gradient index lens element is expressed by the following formula (d):

$$LTC=K(\phi_s/V_{00}+\phi_m/v_{10}) \quad (d)$$

wherein the reference symbol K represents a constant determined dependently on a height of an offaxial ray and an angle of a final axial ray, the reference symbol ϕ_s designates a refractive power of a surface of the radial type gradient index lens element and the reference symbol ϕ_m denotes a refractive power of a medium of the radial type gradient index lens element which is known to be approximated by the following formula (e):

$$\phi_m \approx 2N_{10}d_G \quad (e)$$

wherein the reference symbol d_G represents thickness of the radial type gradient index lens element.

As is apparent from the formula (d), it is possible to control an amount of chromatic aberration to a desired value by varying V_{10} in the second term of the formula.

Since the objective lens system according to the present invention has an asymmetrical composition, like the model of thin lens elements shown in FIG. **2**, wherein a first negative lens unit L_1 and a second positive lens unit L_2 are disposed in that order from the object side and on both side of a stop S, each of the lens units refracts a ray RO coming

from an offaxial object point, unlike a ray RA coming from an axial object point, in a direction which is the same as a refracted direction (downward in FIG. **2**) of an incident light bundle. Accordingly, lateral chromatic aberration is produced in a very large amount in the objective lens system according to the present invention, thereby making it difficult to compose the objective lens system, in order from the object side, of a negative lens unit and a positive lens unit which consist of two homogenous lens elements.

For solving this problem or favorably correcting lateral chromatic aberration by adopting a radial type gradient index lens element, it is conceivable to select either of two cases: one where the radial index lens element is used in the first negative lens unit and the other where the radial gradient lens element is used in the second positive lens unit.

Description will be made of a first composition of the objective lens system according to the present invention where a radial gradient index element is used in the first negative lens unit.

For allowing a radial type gradient index lens element to produce chromatic aberration in an amount smaller than that of chromatic aberration produced by a homogenous lens element which has the same refractive power as that of the radial type gradient index lens element, it is necessary from the formula (d) to satisfy the following relationship:

$$\phi_s/V_{00}+\phi_m/V_{10}<\phi_t/V_{00}$$

wherein the reference symbol ϕ_t represents a refractive power of the homogenous lens element on an assumption that it has an Abbe's number which is equal to that on the optical axis of the radial type gradient index lens element.

Since the radial type gradient index lens element and the homogenous lens element which are compared with each other have the same refractive power, we obtain:

$$\phi_t=\phi_s+\phi_m$$

From the two formulae mentioned above, there establishes the following relationship:

$$\phi_s/V_{00}+\phi_m/V10<\phi_s/V_{00}+\phi_m/V_{00}$$

The above-mentioned condition (1) is obtained from this formula.

For favorably correcting lateral chromatic aberration in the objective lens system according to the present invention, it is desirable to use a radial type gradient index lens element satisfying the condition (1) as the first lens unit which has the negative refractive power as described above. The condition (1) is required for allowing a radial type gradient index lens element to produce chromatic aberration in an amount smaller than that of chromatic aberration produced by a homogenous lens element which has the same refractive power as that of the radial type gradient index lens element. If the condition (1) is not satisfied, a radial type gradient index lens element cannot correct lateral chromatic aberration more favorably than a homogenous lens element which has the same refractive power as that of the radial type gradient index lens element.

When a radial type gradient index lens element is to be used for correcting lateral chromatic aberration, it is necessary, as apparent from the formula (d), to take into sufficient consideration not only a value of V_{10} but also refractive powers of a surface and a medium. For reducing an amount of lateral chromatic aberration to be produced by the first lens unit in the objective lens system according to the present invention, it is desirable from the formula (d) to meet the following equation:

$$\phi_s/V_{00}+\phi_m/V_{10}\approx 0$$

By using a total refractive power of a surface and a medium $\phi_G(=\phi_s+\phi_m)$ in this formula and developing it, we obtain:

$$\phi_m\approx\phi_G\times V_{10}/(V_{10}-V_{00})$$

Since the Abbe's number V_{00} of a radial type gradient index lens element ordinarily has a value on the order of 30 to 80 on an optical axis and the first lens unit has the negative refractive power, the condition (1) required for correcting chromatic aberration can be transformed as follows:

$$\phi_G\times V_{10}/(V_{10}-V_{00})<0$$

It is desirable as understood from this formula that a medium has a negative refractive power. Taking into consideration this fact and the requirement to correct lateral chromatic aberration favorably in the objective lens system as a whole, it is desirable that a radial type gradient index lens element which is to be used in the objective optical system according to the present invention is made of a medium having a refractive power ϕ_{1m} satisfying the above-mentioned condition (2).

When a ratio of a refractive power of a medium of the first lens unit relative to a refractive power of the objective lens system satisfies the condition (2), it is possible to correct lateral chromatic aberration favorably in the objective lens system as a whole. If the upper limit of −0.02 of the condition (2) is exceeded, a medium of the radial type gradient index lens element will have a weak refractive power, thereby undesirably making it difficult to correct lateral chromatic aberration favorably in the objective lens system as a whole. If the lower limit of −0.5 of the condition (2) is not satisfied, in contrast, a medium will have too strong a refractive power, thereby overcorrecting lateral chromatic aberration.

The objective lens system according to the present invention which has a second composition is composed of a first lens unit having a negative refractive power and a second lens unit having a positive refractive power; a radial type gradient index lens element being used in the second lens unit having the positive refractive power; and the radial type gradient index lens element used in the second lens unit having a refractive index expressed by the above-mentioned formula (a) and satisfying the following conditions (1) and (3):

$$1/V_{10}<1/V_{00} \quad (1)$$

$$0.05<\phi_{2m}/\phi<1.0 \quad (3)$$

wherein the reference symbol ϕ_{2m} represents a refractive power of the gradient index lens element which is used in the second lens unit and the reference symbol ϕ designates a refractive power of the objective lens system as a whole.

Since lateral chromatic aberration is produced in a very large amount in the objective lens system as a whole as described above, it is difficult to compose the lens system, in order from the object side, of two negative and positive homogenous lens elements. When a radial type gradient index lens element is to be used in the second lens lens unit for solving this problem or favorably correcting lateral chromatic aberration, it is desirable to configure this lens element so as to satisfy the condition (1) mentioned above.

The condition (1) is required for allowing the radial type gradient index lens element to produce chromatic aberration in an amount smaller than that of chromatic aberration produced by a homogenous lens element which has the same refractive power as that of the radial type gradient index lens element.

If the condition (1) is not satisfied, the radial type gradient index lens element cannot correct chromatic aberration more favorably than the homogenous lens element having the same refractive power as that of the radial type gradient index lens element.

When a radial type gradient index lens element is to be used for correcting lateral chromatic aberration, it is necessary to take into consideration not only a value of V_1o but also refractive powers of a surface and a medium as described above. When lateral chromatic aberration produced by the second lens unit is to be reduced in the objective lens system according to the present invention, the formula (d) is transformed, as in the case where a radial type gradient index lens element is used in the first lens unit, into the following formula:

$$\phi_m \approx \phi_G \times V_{10}/(V_{10}-V_{00})$$

Since the second lens unit has a positive refractive power, it is desirable that ϕ_m has a positive value. When a radial type gradient index lens element is to be used in the second lens unit for correcting lateral chromatic aberration favorably in the objective lens system as a whole, it is desirable that the refractive power ϕ_m of a medium satisfies the above-mentioned condition (3).

When a ratio of a refractive power of medium relative to a refractive power of the objective lens system as a whole satisfies the condition (3), it is possible to correct lateral chromatic aberration favorably in the objective lens system as a whole.

If the lower limit of 0.05 of the condition (3) is not satisfied, a medium of the radial type gradient index lens element will have a weak refractive power, thereby undesirably making it difficult to correct lateral chromatic aberration favorably in the objective lens system as a whole. If the upper limit of 1.0 of the condition (3) is exceeded, in contrast, a refractive power of medium will be too strong, thereby undesirably overcorrecting lateral chromatic aberration.

The condition (3) is required also for favorably correcting not only chromatic aberration but also the other aberrations.

The objective optical system according to the present invention which has a wide field angle produces a positive Petzval's sum in the lens system as a whole, thereby tending to tilt an image surface toward the object side. For favorably correcting this Petzval's sum, it is desirable to use a radial type gradient index lens element in the second lens unit which has a large positive Petzval's sum.

A Petzval's sum PTZ of a radial type gradient index lens element is expressed by the following formula (f):

$$PTZ=\phi_s/N_{00}+\phi_m/N_{00}^2$$

As is apparent from the formula (f) in which the denominator of the second term on the right side is squared, it is possible to configure a radial type gradient index lens element so as to have a Petzval's sum which is smaller than that of a homogenous lens element having the same refractive power as that of the radial type gradient index lens element.

For reducing a Petzval's sum of the objective lens system with a radial type gradient index lens element, it is desirable from the formula (f) that the radial type gradient index lens element satisfies the following formula:

$$\phi_s/N_{00}+\phi_m/N_{00}^2 \approx 0$$

The formula shown below can be derived by using a total refractive power of surface and medium $\phi_G(=\phi_2+\phi_m)$ in the above formula and developing it.

$$\phi_m \approx \phi_G \times N_{00}/(N_{00}-1)$$

Since refractive indices N_{00} on an optical axis of radial gradient index lens elements ordinarily have values larger than 1, or on the order of 1.45 to 1.85, it is desirable for favorably correcting a Petzval's sum to use a radial type gradient index lens element which has a positive refractive power of medium when it is to be used in the second lens unit having the positive refractive power. If a radial type gradient index lens element which has a negative refractive power of medium is used in the second lens unit, the positive Petzval's sum will be further enlarged, hereby undesirably tilting an image surface toward the object side.

For correcting the Petzval's sum in the objective lens system according to the present invention, it is desirable from the formula (f) that a refractive power of medium is strong to a certain degree or refractive power of medium fm satisfies the condition (3). When a ratio of the refractive power of medium relative to a refractive power of the objective lens system as a whole satisfies the condition (3), it is possible to favorably correct the Petzval's sum in the objective lens system as a whole. If the lower limit of 0.05 of the condition (3) is not satisfied, a refractive power of medium will be weak, thereby making it difficult to correct the Petzval's sum favorably in the objective lens system as a whole. If the upper limit of 1.0 of the condition (3) is exceeded, in contrast, a refractive power of medium will be too strong and the Petzval's sum will be overcorrected, thereby undesirably tilting an image surface in a direction away from the object side.

As understood from the foregoing description, the condition (3) is required for favorably correcting lateral chromatic aberration and Petzval's sum at the same time in the objective lens system according to the present invention (which has the second composition).

Further, an objective lens system for endoscopes is generally used in combination with a solid-state image pickup device such as CCD or an end surface of the so-called image guide composed of an optical fiber bundle which is disposed on an image surface. When an objective lens system is to be combined not with a silver salt photographic film but with a solid-state image pickup device or an image guide, it is desirable for enhancing a light condensing efficiency to configure the objective lens system so as to be telecentric on the image side so that incident rays are as perpendicular as possible to an image surface. For configuring the objective lens system according to the present invention so as to meet this requirement, the second lens unit having the positive refractive power must have an image side surface which has a positive refractive power stronger than that of an object side surface thereof. When the image side surface of the second lens unit on which offaxial rays are relatively high has a strengthened refractive power in the objective lens system according to the present invention having a wide field angle, however, this surface will produce coma in a large amount and it will be difficult to correct this coma favorably with a homogenous lens element.

Accordingly, it was conceived to correct coma favoraly in the objective lens system according to the present invention

with a radial type gradient index lens element used in the second lens unit. For correcting this aberration, it is desirable that the radial type gradient index lens element has such a refractive index distribution as to progressively lower refractive indices from the optical axis toward a marginal portion. An amount of coma to be produced by the image side surface of the second lens unit can be reduced by configuring the radial type gradient index lens element to be used in the second lens unit so as to have such a refractive index distribution. Therefore, the condition (3) serves for favorable correction of coma in addition to favorable correction of lateral chromatic aberration. When the condition (3) is satisfied, the radial type gradient index lens element has a refractive index distribution wherein refractive indices are progressively lowered from the optical axis toward the marginal portion, thereby being capable of favorably correcting coma. If the lower limit of 0.05 of the condition (3) is not satisfied, it will be difficult to favorably correct coma with the radial type gradient index lens element. If the upper limit of 1.0 of the condition (3) is exceeded, in contrast, coma will undesirably be overcorrected.

Since the objective lens system according to the present invention has a wide field angle and the asymmetrical composition which is negative-positive in order from the object side, it tends to produce remarkable barrel form distortion which can hardly be corrected favorably with two homogenous lens elements. For correcting the barrel form distortion favorably in the objective lens system according to the present invention, it is desirable to use, in the second lens unit having the positive refractive power, a radial type gradient index lens element which has a refractive index distribution wherein refractive indices are progressively lowered from the optical axis toward the marginal portion. Distortion to be produced by the second lens unit can be reduced by using a radial type gradient index lens element having such a refractive index distribution. Accordingly, the condition (3) serves for favorable correction of distortion in addition to favorable correction of lateral chromatic aberration. When the contition (3) is satisfied, refractive indices are progressively lowered from the optical axis toward the marginal portion, thereby enabling to favorably correct distortion. If the lower limit of 0.05 of the condition (3) is not satisfied, it will be difficult to favorably correct distortion with a radial type gradient index lens element. If the upper limit of 1.0 of the condition (3) is not satisfied, in contrast, aberrations other than distortion will undesirably be overcorrected.

The objective lens system according to the present invention which has a third composition is characterized in: that it is composed, in order from the object side, of a first lens unit having a negative refractive power and a second lens unit having a positive refractive power; that it uses at least one radial type gradient index lens element having a refractive index distribution in a radial direction from an optical axis which is expressed by the formula (a); and that at least one of the surfaces of lens elements including the radial type gradient index lens element composing the lens system is configured as an aspherical surface which has such a shape as to weaken a refractive power of the lens element having the aspherical surface from the optical axis toward the marginal portion.

Since the objective lens system according to the present invention has a wide field angle and an asymmetrical composition which is negative-positive in order from the object side, it tends to produce remarkable distortion in addition to lateral chromatic aberration. Though distortion can be corrected to a certain degree by using a radial type gradient index lens element in the second lens unit as described above, it is desirable for correcting distortion more favorably to configure the objective optical system according to the present invention so as to comprise at least one surface of at least one lens element which is configured as an aspherical surface having such a shape as to weaken a refractive power of the lens element having the aspherical surface from the optical axis toward the marginal portion. In the objective lens system according to the present invention, barrel form distortion is produced by both the first lens unit having the negative refractive power and the second lens unit having the positive refractive power. When an aspherical surface is to be used in either of the lens units in the objective lens system, it is therefore desirable to configure the aspherical surface so as to have such a shape as to weaken a refractive power from the optical axis toward the marginal portion of the lens element using the aspherical surface. When the second lens unit uses a radial type gradient index lens element, for example, it is desirable to use an aspherical surface in the first lens unit having the negative refractive power and configure the aspherical surface so as to have such a shape as to weaken the negative refractive power from the optical axis toward the marginal portion. Though distortion produced by the second lens unit can be corrected to a certain degree by using a radial type gradient index lens element in the second lens unit as described above, distortion can be corrected more favorably by using an aspherical surface in the first lens unit.

When a radial type gradient index lens element is used in the first lens unit, it is desirable to use, in the second lens unit having a positive refractive power, an aspherical surface which has such a shape as to weaken the positive refractive power toward the optical axis to a marginal portion.

If an aspherical surface has such a shape as to strengthen the refractive power of a lens unit which comprises this aspherical surface, it will undesirably make barrel form distortion more remarkable in the objective lens system as a whole.

It is needless to say that an effect similar to that described above can be obtained by configuring a surface of a radial type gradient index lens element as an aspherical surface.

For correcting lateral chromatic aberration in the objective lens system according to the present invention which has the third composition, it is desirable to configure the radial type gradient index lens element so as to satisfy the condition (1). If the condition (1) is not satisfied, lateral chromatic aberration will undesirably be more remarkable in the objective lens system according to the present invention.

It is needless to say that lateral chromatic aberration can be corrected more favorably by using two radial type gradient index lens elements when the objective lens system according to the present invention is to be composed of two negative and positive lens elements.

It is also needless to say that distortion can be corrected more favorably by using an aspherical surface on each of the lens elements when the objective lens system is to be composed of two negative and positive lens elements.

The objective lens system according to the present invention which has a fourth composition is characterized in that it is composed, in order from the object side, of a first lens unit having a negative refractive power and a second lens unit having a positive refractive power. The second lens unit comprises at least one radial type gradient index lens element which has a refractive index distribution in a radial direction expressed by the formula (a), or wherein refractive indices are progressively lowered from an optical axis toward a marginal portion. The radial type gradient index

lens element has a shape of a positive lens element. The radial type gradient index lens element satisfies the condition (1).

When a radial type gradient index lens element is to be used in the second lens unit, it is desirable for correcting lateral chromatic aberration to configure it so as to satisfy the condition (1) as described above, and it is desirable for correcting a Petzval's sum, coma or distortion that this lens element has a refractive index distribution wherein refractive indices are lowered from the optical axis toward the marginal portion. When not only correction of aberrations but also manufacturing facility are taken into consideration, it is desirable that the radial type gradient index lens element has a shape of a positive lens element.

Since the objective lens system according to the present invention has a wide field angle, it is necessary that the second lens unit has a strong positive refractive power. When a radial type gradient index lens element is to be used in the second lens unit, it is therefore desirable that the radial type gradient index lens element also has a strongly positive refractive power. However, it is undesirable that the radial type gradient index lens element has an extremely strong positive refractive power of medium for a reason described below. As apparent from the formula (e), it is sufficient for strengthening a refractive power of medium of a radial type gradient index lens element to enlarge an absolute value of the refractive index distribution coefficient of the second order N_{10} or thickness d_G of the radial type gradient index lens element. However, an absolute value of the refractive index distribution coefficient of the second order can be enlarged only within a range limited by preparation of materials and enlargement of thickness d_G makes it difficult to configure the objective lens system compactly, thereby making it unusable as an objective lens system for endoscopes, for example, which are desired to be compact. Accordingly, it is desirable not to impart an extremely strong positive refractive power to a medium but to impart refractive powers to both the medium and surfaces, or configure the radial type gradient index lens element so as to have a shape of a positive lens element.

The objective lens system according to the present invention which has a fifth composition is characterized in that it is composed, in order from the object side, of a first lens unit having a negative refractive power and a second lens unit having a positive refractive power; that it uses at least one lens element which is configured as a radial type gradient index lens element having a refractive index distribution in the radial direction from an optical axis expressed by the formula (a); and that a lens unit comprising the radial type gradient index lens element or at least one optical element disposed in the objective lens system has a function to shield components having specific wavelengths.

By using a radial type gradient index lens element, it is possible to obtain an objective lens system which favorably corrects chromatic aberration in particular and has high imaging performance. An objective lens system for endoscopes which comprises a solid-state image pickup device such as a CCD, for example, may use an infrared cut filter for cutting off rays in the infrared region since the image pickup device has high sensitivity at wavelengths in the infrared region. Further, such an optical system may use a low pass filter made, for example, of quartz for eliminating noise components produced due to moiré. Furthermore, such an objective lens system may use a band cut filter for cutting off components having specific wavelengths since endoscopes may be used not only for observing interiors of human bodies but also for cutting off diseased portions of patients with laser knives. It is therefore desirable that the objective lens system according to the present invention uses not only a radial type gradient index lens element but also filters of the kinds mentioned above so that it can exhibit high imaging performance when it is used in optical systems for endoscopes which use, for example, solid-state image pickup devices such as CCD's.

It is desirable that these filters are disposed at locations between a lens element disposed on the image side and an image surface at which offaxial rays, in particular, are nearly in parallel with the optical axis. By disposing the filters as described above, it is possible to prepare approximately equal optical path lengths for axial and offaxial rays, thereby allowing the filters to exhibit their effects uniformly over the entire image pickup surface.

Endoscopes which are to be inserted into human bodies must be compact and require compacter optical systems. When importance is laid on compactness rather than optical performance, it is effective to dispose filters between the first lens unit and the second lens unit. Further, for obtaining an objective lens system which is compact and can be manufactured at a low cost, it is effective to impart filter functions to at least one of the lens elements including a radial type gradient index lens element.

The objective lens system according to the present invention which has a sixth embodiment is characterized in that it is composed, in order from the object side, of a first lens unit having a negative refractive power and a second lens unit having a positive refractive power; that it uses at least one radial type gradient index lens element which has a refractive index distribution in a radial direction expressed by the formula (a); and that it uses a reflecting surface for at least a single reflection disposed on the image side of the second lens unit.

Resolution of an optical system for endoscopes which uses a solid-state image pickup device such as a CCD, for example, can be enhanced by reducing the size of picture elements and arranging these picture elements in a larger number at a higher density on the image pickup device. However, the size of a picture element can be reduced only within a certain manufacturing limit and it is therefore conceivable to enhance resolution by enlarging an image pickup surface. However, it is desirable that endoscopes which may be inserted into human bodies have smaller diameters, or it is undesirable to enlarge image pickup surfaces, thereby enlarging diameters of endoscopes.

For allowing solid-state image pickup devices having larger image pickup surfaces to be used without enlarging diameters of endoscopes, the objective lens system according to the present invention uses a reflecting surface for at least one reflection on the image side of the second lens unit which makes it possible to dispose a solid-state image pickup device, not in parallel with a radial direction of the endoscope, but in a position inclined with regard thereto. FIG. **3** shows a conceptional diagram of the objective lens system according to the present invention which has the sixth composition. In FIG. **3**, the reference symbol L_1 represents the first negative lens unit, the reference symbol L_2 designates the second positive lens unit, the reference symbol RA denotes an axial ray, the reference symbol RO represents an offaxial ray, the reference symbol R designates the reflecting surface and the reference numeral **10** denotes the image pickup device disposed on an image pickup plane. The reflecting surface R disposed on the image side of the second lens unit makes it possible to arrange the solid-state image pickup device which has a large image pickup surface nearly parallel to the optical axis. Though a system for a

single reflection is illustrated in FIG. **3**, it is possible, needless to say, to obtain a similar effect by using a larger number of reflecting surfaces for a plurality of reflections.

When a solid-state image pickup device having a large image pickup surface is used, an image height can be enhanced in a lens system for obtaining a lens system having a wide field angle. However, it is desired for an objective lens system to correct aberrations more favorably over a range from a center to a marginal portion of an image plane. For an objective lens system having a wide field angle in particular, it is desired to favorably correct lateral chromatic aberration.

An objective lens system which has high imaging performance for axial and offaxial rays can therefore be obtained by using a radial gradient index lens element which has high capability to correct chromatic aberration in particular. It is possible to obtain an objective lens system having higher performance by combining an objective lens system which uses a radial type gradient index lens element with a reflection system shown in FIG. **3** which permits enlarging an image pickup surface.

When a radial type gradient index lens element is used in the second lens unit in each of the compositions (first through sixth compositions) of the objective lens system according to the present invention, it is desirable for more favorable correction of lateral chromatic aberration, coma and distortion to satisfy the following condition (4):

$$-0.5<N_{10p}\cdot f^2<-0.01 \tag{4}$$

wherein the reference symbol N_{10p} represents a refractive index distribution coefficient of the second order when a radial type gradient index lens element is used in the second lens unit and the reference symbol f designates a focal length of the objective lens system as a whole.

When the condition (4) is satisfied, a refractive power of medium of the radial type gradient index lens element has a sufficiently large value, thereby making it possible to correct lateral chromatic aberration favorably. Further, refractive indices are progressively lowered from the optical axis toward a marginal portion and a difference in refractive index (An) is large between the optical axis and the marginal portion, thereby making it possible to favorably correct coma produced by an image side surface of the second lens unit and barrel form distortion which poses a problem in the objective lens system as a whole.

If the upper limit of −0.01 of the condition (4) is exceeded, the radial type gradient index lens element will have a weak refractive power of medium, thereby making it difficult to correct lateral chromatic aberration favorably in the objective lens system as a whole, and the difference in refractive indices will be small between the optical axis and the marginal portion, thereby making it difficult to correct coma and distortion. If the lower limit of −0.5 of the condition (4) is not satisfied, in contrast, the radial type gradient index lens element will have a large refractive index difference An, thereby undesirably making it difficult to prepare a material for the radial type gradient index lens element.

When a radial type gradient index lens element is used in the first lens unit in the objective lens system according to the present invention which has one of the compositions described above, it is desirable for correcting lateral chromatic aberration more favorably to satisfy the following condition (5):

$$0.01<N_{10n}\cdot f^2<0.6 \tag{5}$$

wherein the reference symbol N_{10n} represents the refractive index distribution coefficient of the second order of a gradient index lens element when the radial type gradient index lens element is used in the first lens unit and the reference symbol f designates a focal length of the objective lens system as a whole.

When the condition (5) is satisfied, a refractive power of medium of the radial type gradient index lens element has a sufficiently large value, thereby making it possible to correct lateral chromatic aberration favorably.

If the lower limit of 0.01 of the condition (5) is not satisfied, the radial type gradient index lens element will have a weak refractive power of medium, thereby making it difficult to correct lateral chromatic aberration favorably in the objective lens system as a whole. If the upper limit of 0.6 of the condition (5) is exceeded, the radial type gradient index lens element will have a large refractive index difference Δn, thereby making it difficult to prepare a material for the radial type gradient index lens element.

When the radial type gradient index lens element is used in the first lens unit or the second lens unit of the objective lens system according to the present invention, it is desirable for correcting lateral chromatic aberration more favorably in the lens system to satisfy the following condition (6):

$$1/V_{10}<0.01 \tag{6}$$

The objective lens system which satisfies the condition (6) can favorably correct lateral chromatic aberration. Since radial type gradient index lens elements have Abbe's numbers on the order of 30 to 80 as described above, it is desirable from the formula (d), for allowing a radial type gradient index lens element to exhibit a sufficient function for correcting chromatic aberration to satisfy the condition (6). If the condition (6) is not satisfied, it will undesirably be impossible to sufficiently correct lateral chromatic aberration.

When a radial type gradient index lens element is used in the first lens unit of the objective lens system according to the present invention which has any one of the first through sixth compositions, it is desirable for correcting lateral chromatic aberration more favorably to satisfy the following condition (7):

$$0.05<d_{Gn}/f_{Gn}<1.2 \tag{7}$$

wherein the reference symbol d_{Gn} represents thickness of the radial type gradient index lens element used in the first lens unit and the reference symbol f_{Gn} designates a focal length of the radial type gradient index lens element used in the first lens unit.

A radial type gradient index lens element can exhibit its effect to correct chromatic aberration when it has refractive power of medium ϕ_m having a value which is large to a certain degree as described above. When a radial type gradient index lens element has extremely small thickness, for example, the refractive power of medium ϕ_m is weak as judged from the formula (e), thereby making it difficult to favorably correct chromatic aberration. It is therefore desirable that the objective lens system according to the present invention satisfies the condition (7) when a radial type gradient index lens element is used in the first lens unit.

If the lower limit of 0.05 of the condition (7) is not satisfied, the refractive power of medium will be weak, thereby undesirably making it difficult to favorably correct lateral chromatic aberration. If the upper limit of 1.2 of the condition (7) is exceeded, in contrast, the radial type gradient index lens element will have a large thickness, thereby undesirably prolonging a total length of the objective lens system.

When a radial type gradient index lens element is used in the second lens unit of the objective lens system according to the present invention which has any one of the composition described above, it is desirable for correcting lateral chromatic aberration more favorably to satisfy the following condition (8):

$$0.3<d_{Gp}/f_{Gp}<4.0 \quad (8)$$

wherein the reference symbol d_{Gp} represents the thickness of the radial type gradient index lens element used in the second lens unit and the reference symbol f_{Gp} designates a focal length of the radial type gradient index lens element used in the second lens unit.

When a radial type gradient index lens element has extremely small thickness as described above, for example, the refractive power of medium fm is weak, thereby making it difficult to correct chromatic aberration favorably. When a radial type gradient index lens element is to be used in the second lens unit of the objective lens system according to the present invention, the lens system is therefore configured so as to satisfy the condition (8).

If the lower limit of 0.3 of the condition (8) is exceeded, a refractive power of medium will be weak, thereby undesirably making it difficult to favorably correct lateral chromatic aberration. If the upper limit of 4.0 of the condition (8) is exceeded, a radial type gradient index lens element will have large thickness, thereby undesirably enlarging the objective lens system.

When the first lens unit is to be composed of a single negative lens element in the objective lens system according to the present invention which has any one of the compositions described above, it is desirable for favorably correcting aberrations to satisfy the following condition (9):

$$0.1<1H/r_2<1.7 \quad (9)$$

wherein the reference symbol 1H represents an image height and the reference symbol r_2 designates a radius of curvature on an image side surface of the first lens unit having the negative refractive power.

If the lower limit of 0.1 of the condition (9) is not satisfied, the image side surface of the first lens unit will have a weak refractive power and it will be necessary to strengthen a negative refractive power of an object side surface of the first lens unit on which offaxial rays are relatively high, whereby the object side surface will undesirably produce distortion, astigmatism, etc. in larger amounts. If the upper limit of 1.7 of the condition (9) is exceeded, in contrast, the image side surface of the first lens unit will have a strong negative refractive power, thereby undesirably overcorrecting spherical aberration in the objective lens system as a whole.

When the second lens unit is to be composed of a single positive lens element in the objective lens system according to the present invention which has any one of the compositions described above, it is desirable for favorably correcting aberrations to satisfy the following condition (10):

$$-1.5<IH/r_3<0.8 \quad (10)$$

wherein the reference symbol 1H represents an image height and the reference symbol r_3 designates a radius of curvature on an object side surface of the second lens unit having the positive refractive power.

If the lower limit of −1.5 of the condition (10) is not satisfied, the object side surface of the second lens unit will have a strong negative refractive power, thereby undesirably overcorrecting spherical aberration in the objective lens system as a whole. If the upper limit of 0.8 of the condition (10) is exceeded, in contrast, the object side surface will undesirably produce spherical aberration, etc. in larger amounts.

When the second lens unit is to be composed of a single positive lens element in the objective lens system according to the present invention which has any one of the compositions described above, it is desirable for favorably correcting aberrations to satisfy the following condition

$$-1.0<IH/r_4<-0.1 \quad (11)$$

wherein the reference symbol IH represents an image height and the reference symbol r_4 designates a radius of curvature on an image side surface of the second lens unit having the positive refractive power.

If the lower limit of −1.0 of the condition (11) is not satisfied, the image side surface of the second lens unit will have a strong positive refractive power, thereby undesirably aggravating astigmatism and distortion in the objective lens system as a whole. If the upper limit of −0.1 of the condition (11) is exceeded, in contrast, it will be necessary to strengthen a positive refractive power of the object side surface of the second lens unit, whereby the object side surface will undesirably produce astigmatism and distortion in large amounts.

When a radial type gradient index element is to be used in the first lens unit in the objective lens system according to the present invention which has any one of the compositions described above, it is desirable for correcting lateral chromatic aberration more favorably to satisfy the following condition (12):

$$0.05<N_{10n}\cdot f_{Gn}{}^2<1.2 \quad (12)$$

wherein the reference symbol f_{Gn} represents a focal length of the radial type gradient index lens element to be used in the first lens unit.

When the condition (12) is satisfied, the refractive power of medium of the radial type gradient index lens element will have a value which is sufficiently large relative to its total refractive power and can favorably correct lateral chromatic aberration. If the lower limit of 0.05 of the condition (12) is not satisfied, the refractive power of medium will be weak, thereby undesirably making it difficult to correct lateral chromatic aberration favorably with the radial type gradient index lens element. If the upper limit of 1.2 of the condition (12) is exceeded, refractive index difference Δn will be large, thereby undesirably making it difficult to prepare a material for the radial type gradient index lens element.

When a radial type gradient index lens element is to be used in the second lens element in the objective lens system according to the present invention which has any one of the compositions described above, it is desirable for correcting lateral chromatic aberration, a Petzval's sum, coma or distortion more favorably to satisfy the following condition (13):

$$-0.8<N_{10p}\cdot f_{Gp}{}^2<-0.05 \quad (13)$$

wherein the reference symbol f_{Gp} represents a focal length of the radial type gradient index lens element to be used in the second lens unit.

When the condition (13) is satisfied, the refractive power of medium of the radial type gradient index lens will have a value which is sufficiently large relative to its total refractive power and can favorably correct lateral chromatic

aberration. If the upper limit of −0.05 of the condition (13) is not satisfied, the refractive power of medium will be weak, thereby undesirably making it difficult to correct lateral chromatic aberration favorably with the radial type gradient index lens element. If the lower limit of −0.8 of the condition (13) is not satisfied, in contrast, refractive index difference Δn will be large, thereby undesirably making it difficult to prepare a material for the radial type gradient index lens element.

When a radial type gradient index lens element is to be used in the second lens unit in the objective lens system according to the present invention which has any one of the compositions described above, it is desirable, for facilitating preparation of a material in addition to correction of lateral chromatic aberration, to satisfy the following condition (14):

$$0.1<\phi_{2m}/\phi<0.8 \quad (14)$$

When the condition (14) is satisfied, the radial type gradient index lens element will have a strong refractive power of medium and can correct lateral chromatic aberration favorably. If the lower limit of 0.1 of the condition (14) is not reached, the radial type gradient index lens element will have a weak refractive power of medium and can hardly correct lateral chromatic aberration favorably in the objective lens system as a whole, and a difference in refractive indices will be small between a portion of the radial type gradient index lens element located on the optical axis and a marginal portion thereof, thereby making it difficult to correct coma and distortion. If the upper limit of 0.8 of the condition (14) is exceeded, in contrast, the radial type gradient index lens element will have a large refractive index difference An or large thickness, thereby undesirably making it difficult to prepare a material for the radial type gradient index lens element in the former case or undesirably enhancing a manufacturing cost and prolonging a total length of the objective lens system in the latter case.

When a radial type index lens element is to be used in the first lens unit in the objective lens system according to the present invention which has any one of the compositions described above, it is desirable, for facilitating manufacturing of the radial type gradient index lens element in addition to correction of lateral chromatic aberration, to satisfy the following condition (15):

$$-0.25<\phi_{1m}/\phi<-0.05 \quad (15)$$

When the condition (15) is satisfied, the radial type gradient index lens element will have a strong refractive power of medium and can favorably correct lateral chromatic aberration. If the upper limit of −0.05 of the condition (15) is exceeded, the radial type gradient index lens element will undesirably have a weak refractive power of medium and can hardly correct lateral chromatic aberration favorably. If the lower limit of −0.25 of the condition (15) is not reached, the radial type gradient index lens element will undesirably have a large refractive index difference Δn, whereby it can hardly be manufactured or it will be thicker and more expensive to manufacture.

When a radial type gradient index lens element is to be used in the first lens unit in the objective lens system according to the present invention which has any one of the compositions described above, it is desirable, for facilitating manufacturing of the radial type gradient index lens element in addition to correction of lateral chromatic aberration, to satisfy the following condition (16):

$$0.02<N_{10n}\cdot f^2<0.4 \quad (16)$$

When the condition (16) is satisfied, a marginal portion of the radial type gradient index lens element used in the first lens unit may have a refractive index higher than that of a portion thereof on the optical axis, whereby the radial type gradient index lens element has a sufficiently strong refractive power of medium and can correct lateral chromatic aberration favorably.

If the lower limit of 0.02 of the condition (16) is not satisfied, the radial type gradient index lens element will have a weak refractive power of medium, thereby making it difficult to correct lateral chromatic aberration favorably in the objective lens system as a whole. If the upper limit of 0.4 of the condition (16) is exceeded, the radial type gradient index lens element will have a large refractive index difference Δn, thereby undesirable making it difficult to prepare a material therefor.

When a radial type gradient index lens element is to be used in the second lens unit of the objective lens system according to the present invention which has any one of the compositions described above, it is desirable, for facilitating manufacturing of the radial type gradient index lens element in addition to correction of lateral chromatic aberration, to satisfy the following condition (17):

$$-0.25<N_{10p}\cdot f^2<-0.04 \quad (17)$$

When the condition (17) is satisfied, the radial type gradient index lens element has a sufficiently strong refractive power of medium and can favorably correct lateral chromatic aberration.

If the upper limit of −0.04 of the condition (17) is exceeded, the radial type gradient index lens element will have a weak refractive power of medium, thereby making it difficult to correct lateral chromatic aberration favorably in the objective lens system as a whole. If the lower limit of −0.25 of the condition (17) is not satisfied, in contrast, the radial type gradient index lens element will have a large refractive index difference Δn, thereby making it difficult to prepare a material therefor.

For correcting lateral chromatic aberration more favorably in the objective lens system according to the present invention which has any one of the compositions described above, it is desirable to configure a radial type gradient index lens element so as to satisfy the following condition (18):

$$1/V_{10}<0 \quad (18)$$

When the condition (18) is satisfied, the radial type gradient index lens element produces chromatic aberration in a direction opposite to that of chromatic aberration produced by a homogenous lens element having a refractive power which is the same as that of the radial type gradient index lens element. That is to say, when a radial type gradient index lens element which is used in the first lens unit or the second lens unit of the objective lens system according to the present invention satisfies the condition (18), lateral chromatic aberration is overcorrected independently by the radial type gradient index lens element, but this overcorrected chromatic aberration cancels lateral chromatic aberration produced by the other lens element, thereby correcting chromatic aberration favorably in the objective lens system as a whole.

When a radial type gradient index lens element is to be used in the first lens unit of the objective lens system according to the present invention which has any one of the compositions described above, it is desirable, for facilitating manufacturing of the radial type gradient index lens element in addition to correction of lateral chromatic aberration, to satisfy the following condition (19):

$$0.1<d_{Gn}/f_{Gn}<0.9 \quad (19)$$

If the lower limit of 0.1 of the condition (19) is exceeded, the radial type gradient index lens element will undesirably have a weak refractive power of medium, thereby undesirably making it difficult to correct lateral chromatic aberration favorably. If the upper limit of 0.9 of the condition (19) is exceeded, in contrast, the radial type gradient index lens element will be thick, thereby undesirably increasing the manufacturing cost of the objective lens system.

When a radial type gradient index lens element is to be used in the first lens unit of the objective lens system according to the present invention which has any one of the composition described above, it is desirable, for facilitating manufacturing of the radial type gradient index lens element in addition to correction of lateral chromatic aberration, to satisfy the following condition (20):

$$0.7<d_{GP}/f_{GP}<2.8 \tag{20}$$

When a radial type gradient index lens element has extremely small thickness, for example, it has a weak refractive power of medium Am and can hardly correct chromatic aberration favorably. When a radial type gradient index lens element is to be used in the second lens unit of the objective lens system according to the present invention, it is therefore desirable to configure the radial type gradient index lens element so as to satisfy the condition (20).

If the lower limit of 0.7 of the condition (20) is exceeded, the radial type gradient index lens element will undesirably have a weak refractive power of medium, thereby undesirably making it difficult to correct lateral chromatic aberration favorably. If the upper limit of 2.8 of the condition (20) is exceeded, in contrast, the radial type gradient index lens element will have large thickness, thereby undesirably increasing the manufacturing cost of the objective lens system.

When the first lens unit is to be composed of a single negative lens element in the objective lens system according to the present invention which has any one of the compositions described above, it is desirable for more favorable correction of aberrations to configure it so as to satisfy the following condition (21):

$$0.25<IH/r_2<1.4 \tag{21}$$

If the lower limit of 0.25 of the condition (21) is not satisfied, an image side surface of the first lens unit will have a weak negative refractive power and it will be necessary to strengthen a negative refractive power of an object side surface of the first lens unit on which offaxial rays are relatively high, whereby the object side surface will undesirably produce distortion, astigmatism, etc. in large amounts. If the upper limit of 1.4 of the condition (21) is exceeded, in contrast, the image side surface of the first lens unit will have a strong negative refractive power, thereby undesirably overcorrecting spherical aberration in the objective lens system as a whole.

When the second lens unit is to be composed of a single positive lens element in the objective lens system according to the present invention which has any one of the compositions described above, it is desirable for favorably correcting aberrations to satisfy the following condition (22):

$$-0.9<IH/r_3<0.6 \tag{22}$$

If the lower limit of −0.9 of the condition (22) is not reached, an object side surface of the second lens unit will have a strong negative refractive power, thereby undesirably overcorrecting spherical aberration in the objective lens system as a whole. If the upper limit of 0.6 of the condition (22) is exceeded, in contrast, the object side surface will undesirably produce astigmatism, distortion, etc. in large amounts.

When the second lens unit is to be composed of a single positive lens element in the objective lens system according to the present invention which has any one of the compositions described above, it is desirable for favorable correction of aberrations to satisfy the following condition (23):

$$-0.8<IH/r_4<-0.2 \tag{23}$$

If the lower limit of −0.8 of the condition (23) is not reached, the image side surface of the second lens unit will have a strong negative refractive power, thereby undesirably aggravating astigmatism and distortion in the objective lens system as a whole. If the upper limit of −0.2 of the condition (23) is exceeded, in contrast, it will be necessary to strengthen the positive refractive power of the object side surface of the second lens unit, whereby the object side surface will undesirably produce spherical aberrations, etc. in large amounts.

When a radial type gradient index lens element is to be used as the first lens unit of the objective lens system according to the present invention which has any one of the compositions described above, it is desirable, for facilitating manufacturing of the radial type gradient index lens element in addition to correction of lateral chromatic aberration, to satisfy the following condition (24):

$$0.1<N_{10n}f_{Gn}{}^2<0.85 \tag{24}$$

When the condition (24) is satisfied, a refractive power of medium of the radial type gradient index lens element has a value sufficiently large relative to a total refractive power thereof, thereby making it possible to correct lateral chromatic aberration favorably. If the lower limit of 0.1 of the condition (24) is not satisfied, the radial type gradient index lens element will undesirably have a weak refractive power of medium and can hardly correct lateral chromatic aberration favorably. If the upper limit of 0.85 of the condition (24) is exceeded, in contrast, a refractive index difference Δn will undesirably be large, thereby making it difficult to prepare a material for the radial type gradient index lens element.

When a radial type gradient index lens element is to be used as the second lens element of the objective lens system according to the present invention which has any one of the compositions described above, it is desirable, for facilitating manufacturing of the radial type gradient index lens element in addition to correction of lateral chromatic aberration, to satisfy the following condition (25):

$$-0.3<N_{10p}f_{GP}{}^2<-0.1 \tag{25}$$

When the condition (25) is satisfied, a refractive power of medium of the radial type gradient index lens element has a value sufficiently large relative to a total refractive power thereof, whereby the radial type gradient index lens element can correct lateral chromatic aberration favorably. If the upper limit of −0.1 of the condition (25) is exceeded, the refractive power of medium will undesirably be weakened, thereby undesirably making it difficult to correct lateral chromatic aberration with the radial type gradient index lens element. If the lower limit of −0.3 of the condition (25) is not reached, in contrast, the refractive index difference Δn will undesirably be large, thereby making it difficult to prepare a material for the radial type gradient index lens element.

Though it is desirable to satisfy the condition (18) for correcting lateral chromatic aberration more favorably in the objective lens system according to the present invention

which has any one of the compositions described above, lateral chromatic aberration is overcorrected when $1/V_{10}$ has a negative value which is too large. Therefore, it is further desirable to satisfy the following condition (26):

$$-0.5<1/V_{10}<0 \quad (26)$$

When the condition (26) is satisfied, it is possible to correct lateral chromatic aberration favorably. If the upper limit of 0 of the condition (26) is exceeded, lateral chromatic aberration will undesirably be undercorrected. If the lower limit of −0.5 of the condition (26) is not reached, lateral chromatic aberration will undesirably be over-corrected.

From a viewpoint of reducing a manufacturing cost of the objective lens system according to the present invention, it is desirable that a radial type gradient index lens element has a planar surface on one side or planar surfaces on both sides.

The objective lens system according to the present invention which has a seventh composition uses a diffraction type optical element as an optical element which is disposed in the lens system.

The objective lens system according to the present invention which has the seventh composition is composed, for example, of a first lens unit having a negative refractive power, a stop and a second lens unit having a positive refractive power: the first lens unit being composed of a diffractive optical element and the second lens unit being composed of a refractive optical element (lens).

Further, an objective lens system which can accomplish the object of the present invention can be obtained by composing a lens system of a positive lens unit and a positive lens unit: the positive lens unit disposed on the object side being composed of a radial type gradient index lens element and the lens unit disposed on the image side being composed of a diffractive optical element.

The objective lens system which has each of the compositions described above is composed of a small number of optical elements, has a compact size and exhibits favorable optical performance. It is therefore suited for use as an objective lens system for endoscopes, non-flexible endoscopes and video cameras.

Accordingly, endoscopes, non-flexible endoscopes, video cameras, portable TV telephones, portable data input units, etc. which use the objective lens system according to the present invention having the compositions described above are included within the scope of the present invention.

Now, embodiments of the objective lens system according to the present invention will be described below:

Embodiment 1

focal length=1.07 mm, object distance=11.8 mm, image height=0.97 mm, NA=0.0115, 2ω=113.1°

$r_1 = -\infty$
$d_1 = 0.3000$ $n_1 = 1.48749$ $\nu_1 = 70.21$
$r_2 = 1.2764$
$d_2 = 1.2646$
$r_3 = -\infty$ (stop)
$d_3 = 0.5196$
$r_4 = -11.2580$
$d_4 = 1.8811$ n_2 (radial type gradient index lens)
$r_5 = -1.6678$

radial type gradient index lens

	N_{00}	N_{10}	N_{20}	N_{30}
d line	1.72000,	-0.87464×10^{-1},	0.44719×10^{-2},	0.37403×10^{-2}
C line	1.71540,	-0.88776×10^{-1},	0.45390×10^{-2},	0.37964×10^{-2}
F line	1.73072,	-0.84403×10^{-1},	0.43154×10^{-2},	0.36094×10^{-2}

$1/V_{10}=-0.050$, $1/V_{00}=0.021$, $\phi_{2m}/\phi=0.353$, $N_{10p}\cdot f^2=-0.100$, $IH/r_2=0.799$, $IH/r_3=-0.091$ $IH/r_4=-0.612$, $N_{10p}\cdot fG^2=-0.213$, $d_{Gp}/f_G=1.207$

Embodiment 2

focal length=1.1 mm, object distance=14 mm, image height=0.85 mm, NA=0.01, 2ω=96.4°

$r_1 = -\infty$
$d_1 = 0.3000$ $n_1 = 1.51633$ $\nu_1 = 64.18$
$r_2 = 0.9785$
$d_2 = 0.3992$
$r_3 = -\infty$ (stop)
$d_3 = 0.1000$
$r_4 = -2.6225$
$d_4 = 2.4188$ n_2 (radial type gradient index lens)
$r_5 = -1.8297$

radial type gradient index lens

	N_{00}	N_{10}	N_{20}
d line	1.88300,	−0.11306,	0.10113×10^{-2}
C line	1.87656,	−0.11340,	0.10143×10^{-2}
F line	1.89821,	−0.11227,	0.10042×10^{-2}

$1/V_{10}=-0.010$, $1/V_{00}=0.025$, $\phi_{2m}/\phi=0.603$, $N_{10p}\cdot f^2=-0.137$, $IH/r_2=0.869$, $IH/r_3=-0.324$, $IH/r_4=-0.465$, $N_{10p}\cdot f_G{}^2=-0.192$, $d_{Gp}/f_G=1.858$

Embodiment 3

focal length=1.1 mm, object distance=11 mm, image height=0.85 mm, NA=0.01, 2ω=103.5°

$r_1 = -5.5224$
$d_1 = 0.3000$ $n_1 = 1.51633$ $\nu_1 = 64.15$
$r_2 = 1.2132$
$d_2 = 0.7397$
$r_3 = -\infty$ (stop)
$d_3 = 0.1000$
$r_4 = -4.0638$
$d_4 = 2.8548$ n_2 (radial type gradient index lens)
$r_5 = -2.5042$

radial type gradient index lens

	N_{00}	N_{10}	N_{20}
d line	1.88300,	−0.10007,	0.17880×10^{-3}
C line	1.87656,	-0.99971×10^{-1},	0.17863×10^{-3}
F line	1.89821,	−0.10030,	0.17922×10^{-3}

$1/V_{10}=0.003$, $1/V_{00}=0.025$, $\phi_{2m}/\phi=0.627$, $N_{10p}\cdot f^2=-0.120$, $IH/r_2=0.701$, $IH/r_3=-0.209$, $IH/r_4=-0.339$, $N_{10p}\cdot f_G=-0.221$, $d_{Gp}/f_G=1.922$

Embodiment 4

focal length=1.02 mm, object distance=13 mm, image height=1.0 mm, NA=0.012, 2ω=99.1°

$r_1 = \infty$		
$d_1 = 0.3842$	$n_1 = 1.74100$	$\nu_1 = 52.65$
$r_2 = 1.4937$	(aspherical surface)	
$d_2 = 1.0970$		
$r_3 = \infty$ (stop)		
$d_3 = 0.8723$		
$r_4 = 11.2798$		
$d_4 = 1.6154$	n_2 (radial type gradient index lens)	
$r_5 = -1.7612$		

aspherical surface coefficients

P=1, A_4=−0.30311, A_6=0.20982

radial type gradient index lens

	N_{00}	N_{10}	N_{20}	N_{30}
d line	1.70000,	-0.79349×10^{-1},	0.34621×10^{-1},	-0.10102×10^{-1}
C line	1.69580,	-0.81730×10^{-1},	0.35660×10^{-1},	-0.10405×10^{-1}
F line	1.70980,	-0.73795×10^{-1},	0.32198×10^{-1},	-0.93948×10^{-2}

$1/V_{10}$=−0.100, $1/V_{00}$=0.020, ϕ_{2m}/ϕ=0.260, $N_{10p}\cdot f^2$=−0.082, IH/r_2=0.670, IH/r_3=0.089, IH/r_4=−0.568, $N_{10p}\cdot f_G^2$=−0.201, d_{Gp}/f_G=1.015

Embodiment 5

focal length=1.1 mm, object distance=14 mm, image height=0.85 mm, NA=0.01, 2ω=83.4°

$r_1 = \infty$		
$d_1 = 0.3000$	$n_1 = 1.51633$	$\nu_1 = 64.15$
$r_2 = 2.9790$	(aspherical surface)	
$d_2 = 0.4409$		
$r_3 = \infty$ (stop)		
$d_3 = 0.1000$		
$r_4 = -1.1911$		
$d_4 = 2.4102$	n_2 (radial type gradient index lens)	
$r_5 = -1.6277$		

aspherical surface coefficients

P=1, A_4=−0.55346, A_6=0.76608

radial type gradient index lens

	N_{00}	N_{10}	N_{20}
d line	1.88300,	−0.12090,	0.11838×10^{-1}
C line	1.87656,	−0.12126,	0.11874×10^{-1}
F line	1.89821,	−0.12005,	0.11755×10^{-1}

$1/V_{10}$=−0.010, $1/V_{00}$=0.025, ϕ_{2m}/ϕ=0.641, $N_{10p}\cdot f^2$=−0.146, IH/r_2=0.336, IH/r_3=−0.840, IH/r_4=−0.614, $N_{10p}\cdot f_G^2$=−0.173, d_{Gp}/f_G=2.017

Embodiment 6

focal length=1.37 mm, object distance=14 mm, image height=0.85 mm, NA=0.01, 2ω=93.3°

$r_1 = \infty$		
$d_1 = 1.5026$	n_2 (radial type gradient index lens)	
$r_2 = 2.5886$		
$d_2 = 0.8187$		
$r_3 = \infty$ (stop)		
$d_3 = 0.1000$		
$r_4 = 3.7062$		
$d_4 = 2.1446$	$n_2 = 1.88300$	$\nu_2 = 40.78$
$r_5 = -1.5967$		

radial type gradient index lens

	N_{00}	N_{10}	N_{20}	N_{30}
d line	1.65000,	0.21000×10^{-1},	0.20240×10^{-1},	0.14372×10^{-1}
C line	1.64443,	0.21630×10^{-1},	0.20847×10^{-1},	0.14803×10^{-1}
F line	1.66300,	0.19530×10^{-1},	0.18823×10^{-1},	0.13366×10^{-1}

$1/V_{10}$=−0.100, $1/V_{00}$=0.029, ϕ_{1m}/ϕ=−0.086, $N_{10n}\cdot f^2$=0.041, IH/r_2=0.328, IH/r_3=0.229, IH/r_4=−0.532, $N_{10n}\cdot f_G^2$=0.203, d_{Gn}/f_G=0.484

Embodiment 7

focal length=1.11 mm, object distance=14 mm, image height=0.85 mm, NA=0.01, 2ω=104.8°

$r_1 = \infty$		
$d_1 = 0.2945$	n_1 (radial type gradient index lens)	
$r_2 = 1.0451$		
$d_2 = 0.8845$		
$r_3 = \infty$ (stop)		
$d_3 = 0.1000$		
$r_4 = 2.6882$		
$d_4 = 2.0134$	$n_2 = 1.88300$	$\nu_2 = 40.78$
$r_5 = -1.5483$		

radial type gradient index lens

	N_{00}	N_{10}	N_{20}
d line	1.51633,	0.26303,	−0.10874
C line	1.51385,	0.26382,	−0.10907
F line	1.52190,	0.26119,	−0.10798

$1/V_{10}$=−0.010, $1/V_{00}$=0.016, ϕ_{1m}/ϕ=−0.171, $N_{10n}\cdot f^2$=0.322, IH/r_2=0.708, IH/r_3=0.244, IH/r_4=−0.586, $N_{10n}\cdot fG^2$=0.609, d_{Gn}/f_G=0.194

Embodiment 8

focal length=1.13 mm, object distance=20 mm, image height=0.8 mm, NA=0.007, 2ω=102.0°

$r_1 = 5.5159$		
$d_1 = 0.3200$	n_1 (radial type gradient index lens)	
$r_2 = 1.1306$		
$d_2 = 1.0270$		
$r_3 = \infty$ (stop)		

-continued

d_3 = 0.1000		
r_4 = 3.2778		
d_4 = 1.6805	n_2 = 1.81600	ν_2 = 46.62
r_5 = −1.3650		

radial type gradient index lens

	N_{00}	N_{10}	N_{20}
d line	1.55000,	0.21140,	0.20293
C line	1.54633,	0.21119,	0.20273
F line	1.55856,	0.21190,	0.20340

$1/V_{10}$=0.003, $1/V_{00}$=0.022, ϕ_{1m}/ϕ=−0.153,
$N_{10n}\cdot f^2$=0.269, IH/r_2=0.708, IH/r_3=0.244
IH/r_4=−0.586, $N_{10n}\cdot f_G^{\,2}$=0.787, d_{Gn}/f_G=0.166

Embodiment 9

focal length=1.11 mm, object distance=14 mm, image height=0.9 mm, NA=0.01, 2ω=98.3°

r_1 = ∞		
d_1 = 1.3941	n_1 (radial type gradient index lens)	
r_2 = 1.7035		
d_2 = 1.0045		
r_3 = ∞ (stop)		
d_3 = 0.1000		
r_4 = 2.3343	(aspherical surface)	
d_4 = 2.7508	n_2 = 1.72916	ν_2 = 54.68
r_5 = −1.3745	(aspherical surface)	

aspherical surface coefficients

(4th surface) P=1, A_4=0.60639×10^{-1}, A_6=−0.86398 A_8=−0.85186

(5th surface) P=1, A_4=0.33872×10^{-1}, A_6=0.71755×10^{-1}, A_8=−0.27664×10^{-1}

radial type gradient index lens

	N_{00}	N_{10}	N_{20}	N_{30}
d line	1.70000,	0.53850 × 10^{-1},	−0.25175 × 10^{-4},	−0.19807 × 10^{-2}
C line	1.69300,	0.55466 × 10^{-1},	−0.25931 × 10^{-4},	−0.20401 × 10^{-2}
F line	1.71633,	0.50081 × 10^{-1},	−0.23413 × 10^{-4},	−0.18420 × 10^{-2}

$1/V_{10}$=−0.100, $1/V_{00}$=0.033, ϕ_{1m}/ϕ=−0.167,
$N_{10n}\cdot f^2$=0.066, IH/r_2=0.528, IH/r_3=0.386,
IH/r_4=−0.655, $N_{10n}\cdot f_G^{\,2}$=0.155, d_{Gn}/f_G=0.822

Embodiment 10

focal length=1.01 mm, object distance=11.8 mm, image height=0.97 mm, NA=0.0115, 2ω=115.2°

r_1 = ∞		
d_1 = 0.4395	n_1 (radial type gradient index lens 1)	
r_2 = 1.9633		
d_2 = 1.1006		
r_3 = ∞ (stop)		
d_3 = 0.7310		
r_4 = 7.6592		
d_4 = 2.0532	n_2 (radial type gradient index lens 2)	
r_5 = −1.8838		

radial type gradient index lens 1

	N_{00}	N_{10}	N_{20}	N_{30}
d line	1.65000,	0.19087,	−0.20292,	0.10047
C line	1.64443,	0.19468,	−0.20698,	0.10248
F line	1.66300,	0.18196,	−0.19345,	0.95778 × 10^{-1}

radial type gradient index lens 2

	N_{00}	N_{10}	N_{20}	N_{30}
d line	1.72000,	−0.64751 × 10^{-1},	0.21345 × 10^{-1},	−0.39150 × 10^{-2}
C line	1.71568,	−0.66046 × 10^{-1},	0.21772 × 10^{-1},	−0.39933 × 10^{-2}
F line	1.73008,	−0.61729 × 10^{-1},	0.20349 × 10^{-1},	−0.37323 × 10^{-2}

1st lens

$1/V_{10}$=−0.067, $1/V_{00}$=0.029, ϕ_{2m}/ϕ=0.433,
$N_{10p}\cdot f^2$=−0.066, IH/r_2=0.494, IH/r_3=0.127,
IH/r_4=−0.515, $N_{10p}\cdot f_G^{\,2}$=−0.172, d_{Gp}/f_G=1.260

2st lens

$1/V_{10}$=−0.067, $1/V_{00}$=0.020, ϕ_{1m}/ϕ=−0.170,
$N_{10n}\cdot f^2$=0.195, IH/r_2=0.494, IH/r_3=0.127,
IH/r_4=−0.515, $N_{10n}\cdot f_G^{\,2}$=0.741, d_{Gn}/f_G=0.233

Embodiment 11

focal length=1.48 mm, object distance=11.6 mm, image height=1.54 mm, NA=0.0082, 2ω=140.3°

r_1 = ∞		
d_1 = 0.3999	n_1 = 1.65160	ν_1 = 58.52
r_2 = 1.3620		
d_2 = 1.2404		
r_3 = ∞ (stop)		
d_3 = 0.4587		
r_4 = 27.7558		
d_4 = 3.0744	n_2 (radial type gradient index lens)	
r_5 = −2.1899		
d_5 = 0.5724		
r_6 = ∞		
d_6 = 0.4000	n_3 = 1.51633	ν_3 = 64.15
r_7 = ∞		
d_7 = 0.0300		
r_8 = ∞		
d_8 = 0.6200	n_4 = 1.52000	ν_4 = 74.00
r_9 = ∞		
d_9 = 0.0300		
r_{10} = ∞		
d_{10} = 0.4000	n_5 = 1.51633	ν_5 = 64.15
r_{11} = ∞		
d_{11} = 0.4800		
r_{12} = ∞		
d_{12} = 1.1000	n_6 = 1.51633	ν_6 64.15
r_{13} = ∞		
d_{13} = 1.0000	n_7 = 1.51633	ν_7 = 64.15
r_{14} = ∞		

radial type gradient index lens

	N_{00}	N_{10}	N_{20}	N_{30}
d line	1.63300,	-0.37202×10^{-1},	0.26687×10^{-2},	0.94109×10^{-3}
C line	1.62841,	-0.37680×10^{-1},	0.21318×10^{-2},	0.11022×10^{-2}
F line	1.64370,	-0.36087×10^{-1},	0.39213×10^{-2},	0.56515×10^{-3}

$1/V_{10}=-0.043$, $1/V_{00}=0.024$, $\phi_{2m}/\phi=0.339$,
$N_{10p}\cdot f^2=-0.082$, $IH/r_2=1.130$, $IH/r_3=0.055$,
$IH/r_4=-0.703$, $N_{10p}-f_G^2=-0.185$, $d_{Gp}/f_G=1.378$

Embodiment 12

focal length=0.83 mm, object distance=9.3 mm, image height=0.8 mm, NA=0.0115, 2ω=128.9°

$r_1 = \infty$
$d_1 = 0.3700$ $n_1 = 1.51633$ $\nu_1 = 64.15$
$r_2 = 1.1462$
$d_2 = 1.7257$
$r_3 = \infty$ (stop)
$d_3 = 0.7547$
$r_4 = 3.0329$
$d_4 = 1.2159$ n_2 (radial type gradient index lens)
$r_5 = -1.5583$
$d_5 = 0.0300$
$r_6 = \infty$
$d_6 = 0.4000$ $n_3 = 1.52287$ $\nu = 59.89$
$r_7 = \infty$
$d_7 = 0.0300$
$r_8 = \infty$
$d_8 = 0.6200$ $n_4 = 1.52000$ $\nu_4 = 74.00$
$r_9 = \infty$
$d_9 = 0.0300$
$r_{10} = \infty$
$d_{10} = 0.4000$ $n_5 = 1.51633$ $\nu_5 = 64.15$
$r_{11} = \infty$
$d_{11} = 0.0300$
$r_{12} = \infty$
$d_{12} = 1.0000$ $n_6 = 1.51633$ $\nu_6 = 64.15$
$r_{13} = \infty$

radial type gradient index lens

	N_{00}	N_{10}	N_{20}	N_{30}
d line	1.63300,	-0.82149×10^{-1},	0.25774×10^{-1},	0.17638×10^{-1}
C line	1.62848,	-0.82067×10^{-1},	0.25748×10^{-1},	0.17621×10^{-1}
F line	1.64377,	-0.82341×10^{-1},	0.25834×10^{-1},	0.17679×10^{-1}
g line	1.65257,	-0.82452×10^{-1},	0.25869×10^{-1},	0.17703×10^{-1}

$1/V_{10}=0.003$, $1/V_{00}=0.024$, $\phi_{2m}/\phi=0.166$,
$N_{10p}\cdot f^2=-0.057$, $IH/r_2=0.698$, $IH/r_3=0.264$,
$IH/r_4=-0.513$, $N_{10p}\cdot f_G^2=-0.166$, $d_{Gp}/f_G=0.855$

Embodiment 13

focal length=1.04 mm, object distance=13 mm, image height=1.1 mm, NA=0.01, 2ω=140.5°

$r_1 = \infty$
$d_1 = 0.3500$ $n_1 = 1.51633$ $\nu_1 = 64.15$
$r_2 = 0.8824$
$d_2 = 0.8722$
$r_3 = \infty$ (stop)
$d_3 = 0.1000$
$r_4 = \infty$
$d_4 = 2.4666$ n_2 (radial type gradient index lens)
$r_5 = -1.6539$

radial type gradient index lens

	N_{00}	N_{10}	N_{20}
d line	1.70000,	-0.82964×10^{-1},	0.16995×10^{-1}
C line	1.69475,	-0.84814×10^{-1},	0.17477×10^{-1}
F line	1.71225,	-0.78645×10^{-1},	0.15871×10^{-1}

$1/V_{10}=-0.074$, $1/V_{00}=0.025$, $\phi_{2m}/\phi=0.426$,
$N_{10p}\cdot f^2=-0.090$, $IH/r_2=1.245$, $IH/r_3=0.000$
$IH/r_4=-0.665$, $N_{10p}\cdot f_G^2=-0.183$, $d_{Gp}/f_G=1.661$

Embodiment 14

focal length=0.99 mm, object distance=13 mm, image height=1.1 mm, NA=0.01, 2ω=108.9°

$r_1 = \infty$
$d_1 = 0.3500$ $n_1 = 1.53996$ $\nu_1 = 59.57$
$r_2 = 2.3039$ (aspherical surface)
$d_2 = 0.7372$
$r_3 = \infty$ (stop)
$d_3 = 0.1000$
$r_4 = -1.9109$
$d_4 = 2.4559$ n_2 (radial type gradient index lens)
$r_5 = -1.5046$

aspherical surface coefficients
$P=1$, $A_4=-0.28151$, $A_6=0.21002$, $A_8=-0.73150\times10^{-1}$
radial type gradient index lens

	N_{00}	N_{10}	N_{20}	N_{30}
d line	1.70000,	−0.14024,	0.31859×10^{-1},	-0.54102×10^{-2}
C line	1.69475,	−0.14257,	0.32390×10^{-1},	-0.55004×10^{-2}
F line	1.71225,	−0.13478,	0.30620×10^{-1},	-0.51998×10^{-2}

$1/V_{10}=-0.056$, $1/V_{00}=0.025$, $\phi_{2m}/\phi=0.681$,
$N_{10p}\cdot f^2=-0.137$, $IH/r_2=0.478$, $IH/r_3=-0.576$,
$IH/r_4=-0.731$, $N_{10p}\cdot f_G^2=-0.198$, $d_{Gp}/f_G=2.066$

Embodiment 15

focal length=1.06 mm, object distance=14 mm, image height=0.85 mm, NA=0.01, 2ω=98.5°

$r_1 = \infty$
$d_1 = 0.3000$ $n_1 = 1.51633$ $\nu_1 = 64.15$
$r_2 = 1.2020$
$d_2 = 0.4079$
$r_3 = \infty$ (stop)
$d_3 = 0.0500$
$r_4 = \infty$

-continued

	d_4 = 1.8037	n_2 (radial type gradient index lens)	
r_5 = −1.1988			
	d_5 = 0.2000		
r_6 = ∞			
	d_6 = 2.0000	n_3 = 1.51633	ν_3 = 64.15
r_7 = ∞			

radial type gradient index lens

	N_{00}	N_{10}	N_{20}
d line	1.75000,	−0.10566,	0.60988×10^{-1}
C line	1.74500,	−0.10598,	0.61170×10^{-1}
F line	1.76167,	−0.10492,	0.60561×10^{-1}

$1/V_{10}$=−0.01, $1/V_{00}$=0.022, ϕ_{2m}/ϕ=0.404,

$N_{10p}\cdot f^2$=−0.119, IH/r_2=0.707, IH/r_3=0

IH/r_4=−0.709, $N_{10p}\cdot f_G^2$=−0.142, d_{Gp}/f_G=1.558

Embodiment 16

focal length=0.87 mm, object distance=11 mm,

image height=0.8 mm, NA=0.011, 2ω=131.3°

r_1 = ∞			
	d_1 = 0.3600	n_1 = 1.88300	ν_1 = 40.78
r_2 = 0.7400			
	d_2 = 0.6000		
r_3 = 1.6000			
	d_3 = 5.1250	n_2 (radial type gradient index lens)	
r_4 = ∞			

radial type gradient index lens

	N_{00}	N_{10}	N_{20}	N_{30}
d line	1.70000,	−0.12580,	0.78000×10^{-2},	-0.47000×10^{-3}
C line	1.69475,	−0.12567,	0.77985×10^{-2},	-0.47001×10^{-3}
F line	1.71225,	−0.12609,	0.79935×10^{-2},	-0.48176×10^{-3}

$1/V_{10}$=0.003, $1/V_{00}$=0.025, ϕ_{2m}/ϕ=0.499,

$N_{10p}\cdot f^2$=−0.087, IH/r_2=1.081, IH/r_3=0.5,

IH/r_4=0, $N_{10p}\cdot f_G^2$=−0.676, d_{Gp}/f_G=2.211

Embodiment 17

focal length=0.84 mm, object distance=11 mm,

image height=0.8 mm, NA=0.011, 2ω=129.2°

r_1 = ∞			
	d_1 = 0.3600	n_1 = 1.88300	ν_1 = 40.78
r_2 = 0.6800			
	d_2 = 0.8000		
r_3 = ∞			
	d_3 = 3.8000	n_2 (radial type gradient index lens)	
r_4 = ∞			
	d_4 = 2.8000	n_3 = 1.51633	ν_3 = 64.15
r_5 = ∞			

radial type gradient index lens

	N_{00}	N_{10}	N_{20}	N_{30}
d line	1.70000,	−0.12580,	0.78000×10^{-2},	-0.47000×10^{-3}
C line	1.69475,	−0.12567,	0.77985×10^{-2},	-0.47001×10^{-3}
F line	1.71225,	−0.12609,	0.79935×10^{-2},	-0.48176×10^{-3}

$1/V_{10}$=0.003, $1/V_{00}$=0.025, ϕ_{2m}/ϕ=0.549,

$N_{10p}\cdot f^2$=−0.090, IH/r_2=1.177, IH/r_3=0,

IH/r_4=0, $N_{10p}\cdot f_G^2$=−0.298, d_{Gp}/f_G=2.471

Embodiment 18

focal length=0.96 mm, object distance=10 mm,

image height=0.85 mm, NA=0.01, 2ω=108.5°

r_1 = ∞			
	d_1 = 0.3500	n_1 = 1.77250	ν_1 = 49.60
r_2 = 1.3385			
	d_2 = 0.3000		
r_3 = ∞			
	d_3 = 2.0000	n_2 = 1.51633	ν_2 = 64.15
r_4 = ∞ (stop)			
	d_4 = 0.0500		
r_5 ∞			
d_5 = 2.3091		n_3 (radical type gradient index lens)	
r_6 =−1.4778			

radial type gradient index lens

	N_{00}	N_{10}	N_{20}
d line	1.75000,	-0.33160×10^{-1},	0.27722×10^{-1}
C line	1.74500,	-0.33359×10^{-1},	0.27888×10^{-1}
F line	1.76167,	-0.32696×10^{-1},	0.27334×10^{-1}

$1/V_{10}$=−0.02, $1/V_{00}$=0.022, ϕ_{2m}/ϕ=0.147,

$N_{10p}\cdot f^2$=−0.031, IH/r_2=0.717, IH/r_3=0,

IH/r_4=−0.650, N_{10p}−f_G^2=−0.091, d_{Gp}/f_G=1.397

Embodiment 19

f=0.77, F/4.7, 2ω=113.3°

r_1 = ∞			
	d_1 = 0.3200	n_1 = 1.51633	ν_1 = 64.15
r_2 = 0.4025			
	d_2 = 0.2229		
r_3 = ∞			
	d_3 = 0.6556	n_2 = 1.84666	ν_2 = 23.78
r_4 = −0.9538			
	d_4 = 0.1230		
r_5 ∞ (stop)			
	d_5 = 0.6316		
r_6 = 2.1852			
	d_6 = 0.8955	n_3 (radial type gradient index lens)	
r_7 = −3.2816			
	d_7 = 0.3800		

-continued

$r_8 = \infty$			
	$d_8 = 0.7500$	$n_4 = 1.53172$	$\nu_4 = 48.91$
$r_9 = \infty$			

radial type gradient index lens

	N_{00}	N_{10}	N_{20}	N_{30}
d line	1.65000,	-1.5405×10^{-1},	1.5784×10^{-1},	2.9179×10^{-2}
C line	1.64512,	-1.5400×10^{-1},	1.5784×10^{-1},	2.9179×10^{-2}
F line	1.66138,	-1.5418×10^{-1},	1.5784×10^{-1},	2.9179×10^{-2}
g line	1.67088,	-1.5430×10^{-1},	1.5784×10^{-1},	2.9179×10^{-2}

Embodiment 20

f=0.65, F/4.25, 2ω=113°

$r_1 = \infty$			
	$d_1 = 0.3200$	$n_1 = 1.51633$	$\nu_1 = 64.15$
$r_2 = 0.4397$			
	$d_2 = 0.1672$		
$r_3 = \infty$			
	$d_3 = 0.7894$	n_3 (radial type gradient index lens)	
r_4 =(stop)			
	$d_4 = 0.2910$		
r_5 2.1800			
	$d_5 = 0.5912$	$n_3 = 1.88300$	$\nu_3 = 40.78$
r_6 =−1.2158			
	$d_6 = 0.3800$		
$r_7 = \infty$			
	$d_7 = 0.7500$	n_4= 1.53172	$\nu_4 = 48.91$
$r_8 = \infty$			

radial type gradient index lens

	N_{00}	N_{10}	N_{20}	N_{30}
d line	1.65200,	-5.4253×10^{-1},	6.6408×10^{-1},	1.0097
C line	1.64616,	-5.3145×10^{-1},	6.5052×10^{-1},	9.8907×10^{-1}
F line	1.66562,	-5.6836×10^{-1},	6.9570×10^{-1},	1.0578
g line	1.67733,	-5.9247×10^{-1},	7.2632×10^{-1},	1.1002

Embodiment 21

f=2.47, F/2.8, 2ω=68.1°

$r_1 = 3.0226$			
	$d_1 = 1.7507$	n_1 (radial type gradient index lens)	
$r_2 = 1.4700$			
	$d_2 = 1.6154$		
$r_3 = \infty$ (stop)			
	$d_3 = 1.1572$		
$r_4 = 3.7806$			
	$d_4 = 2.4588$	$n_2 = 1.69680$	$\nu_2 = 55.53$
$r_5 = -2.2830$		(aspherical surface)	
	$d_5 = 0.7143$		
$r_6 = \infty$			

-continued

	$d_6 = 0.7500$	$n_3 = 1.48749$	$\nu_3 = 70.21$
$r_7 = \infty$			

aspherical surface coefficients

P=1, A_4=3.1652×10^{-2}, A_6=5.4023×10^{-5}, A_8=5.2354×10^{-4}

radial type gradient index lens

	N_{00}	N_{10}	N_{20}
d line	1.60000,	-8.0063×10^{-3},	-2.4555×10^{-3}
C line	1.59400,	-7.7381×10^{-3},	-2.3621×10^{-3}
F line	1.61400,	-8.5860×10^{-3},	-2.6962×10^{-3}
g line	1.62646,	-8.8951×10^{-3},	-2.9391×10^{-3}

Embodiment 22

f=0.96, F/4.25, 2ω=112.9°

$r_1 = \infty$			
	$d_1 = 0.3000$	$n_1 = 1.51633$	$\nu_1 = 64.15$
$r_2 = \infty$			
	$d_2 = 0.1500$		
$r_3 = -1.7433$			
	$d_3 = 2.3691$	n_2 (radial type gradient index lens)	
$r_4 = -0.9326$			
	$d_4 = 0.3800$		
$r_5 = \infty$			
	$d_5 = 0.7500$	$n_3 = 1.53172$	$\nu_3 = 48.91$
$r_6 = \infty$			

racial type gradient index lens

	N_{00}	N_{10}	N_{20}	N_{30}
d line	1.57000,	-1.8143×10^{-1},	9.8792×10^{-2},	-1.8066×10^{-1}
C line	1.56715,	-1.7983×10^{-1},	9.7920×10^{-2},	-1.7907×10^{-1}
F line	1.57665,	-1.8517×10^{-1},	1.0083×10^{-1},	-1.8338×10^{-1}
g line	1.58176,	-1.8795×10^{-1},	1.0115×10^{-1},	-1.8621×10^{-1}

Embodiment 23

f=3.1, F/2.8, 2ω=65.4°

$r_1 = \infty$ (stop)			
	$d_1 = 0.1000$		
$r_2 = \infty$			
	$d_2 = 4.6740$	n_1 (radial type gradient index lens)	
$r_3 = -3.7203$			
	$d_3 = 1.9817$		
$r_4 = 7000.0000$			
	$d_4 = 0.0010$	$n_2 = 1000$	$\nu_2 = -3.45$ (DOE)
$r_5 = \infty$			
	$d_5 = 0.5000$	$n_3 = 1.45851$	$\nu_3 = 66.75$
$r_6 = \infty$			
	$d_6 = 0.7500$	n_4= 1.53172	$\nu_4 = 48.91$
$r_7 = \infty$			

aspherical surface coefficients

(diffraction type optical element)

P = 1,	$A_4 = -2.1097 \times 10^{-5}$,	$A_6 = 5.0147 \times 10^{-6}$,
	$A_8 = -3.0443 \times 10^{-7}$,	$A_{10} = -1.3365 \times 10^{-8}$

radial type gradient index lens

	N_{00}	N_{10}	N_{20}	N_{30}
d line	1.70000,	-1.4314×10^{-2},	-7.4587×10^{-4},	3.4977×10^{-4}
C line	1.69580,	-1.4176×10^{-2},	-7.4587×10^{-4},	3.4977×10^{-4}
F line	1.70980,	-1.4636×10^{-2},	-7.4587×10^{-4},	3.4977×10^{-4}
g line	1.71757,	-1.4899×10^{-2},	-7.4587×10^{-4},	3.4977×10^{-4}

Embodiment 24
f=3.4, F/2.8, 2ω=60.4°

$r_1 = 3.9329$			
	$d_1 = 2.1359$	$n_1 = 1.58423$	$\nu_1 = 30.49$
$r_2 = 1.9115$			
	$d_2 = 0$	$n_2 = 1000$	$\nu_2 = -3.45$ (DOE)
$r_3 = 1.9114$			
	$d_3 = 1.5050$		
$r_4 = \infty$ (stop)			
	$d_4 = 1.3716$		
$r_5 = 4.6967$			
	$d_5 = 3.3378$	$n_3 = 1.69680$	$\nu_3 = 55.53$
$r_6 = -2.9928$ (aspherical surface)			
	$d_6 = 1.8296$		
$r_7 = \infty$			
	$d_7 = 0.7500$	$n_4 = 1.48749$	$\nu_4 = 70.21$
$r_8 = \infty$			
	$d_8 = 1.2084$		
$r_9 = \infty$ (image)			

aspherical surface coefficients
(diffraction type optical element)
P=1, $A_4=9.1010\times10^{-6}$, $A_6=-6.4422\times10^{-6}$,
(6th surface)

P = 1,	$A_4 = 1.1402 \times 10^{-2}$,	$A_6 = -9.8667 \times 10^{-5}$,
	$A_8 = 1.5019 \times 10^{-4}$	

wherein the reference symbols r_1, r_2, . . . represent radii of curvature on surfaces of respective lens elements, the reference symbols d_1, d_2, . . . designate thicknesses of the respective lens elements and air-spaces reserved therebetween, the reference symbols n_1, n_2. . . denote refractive indices of the respective lens elements, and the reference symbols υ_1, υ_2, . . . represent Abbe's numbers of the respective lens elements.

The first embodiment of the objective lens system according to the present invention has a composition illustrated in FIG. **4**. Speaking concretely, it is composed of two lens units, i.e., in order from the object side, a first lens unit consisting of a negative lens element, a stop and a second lens unit consisting of a positive lens element. The second lens unit having the positive refractive power is configured as a radial type gradient index lens element. The first lens unit is composed of a homogenous lens element which has a planar surface on the object side and a concave surface on the image side, whereas the second lens unit is composed of a radial type gradient index lens element having a meniscus shape which has a concave surface on the object side.

Though it is ordinarily difficult to favorably correct lateral chromatic aberration in particular with two lens elements, the lens system preferred as the first embodiment is capable of favorably correcting lateral chromatic aberration by using the radial type gradient index lens element as the second lens unit.

Further, distortion and coma produced by the second lens unit are favorably corrected by the radial type gradient index lens element used as the second lens unit which has a refractive index distribution wherein refractive indices are progressively lowered from an optical axis toward a marginal portion.

In the first embodiment, lateral chromatic aberration in particular is corrected favorably by configuring the radial type gradient index lens element used as the second lens unit so as to satisfy the condition (18).

Furthermore, the object side planar surface of the first lens unit is effective for lowering a cost required for polishing the lens element.

Though the first embodiment is composed only of the two lens elements, it favorably corrects aberrations and has high optical performance.

The second embodiment of the present invention is an objective lens system which has a composition illustrated in FIG. **5**. Speaking concretely, it is composed of two lens elements, i.e., in order from the object side, a first lens unit composed of a negative lens element, a stop and a second lens unit composed of a positive lens element. The second lens unit having the positive refractive power is configured as a radial type gradient index lens element.

The second embodiment is an example in which the objective lens system is configured so as to have a total length that is shorter than that of the first embodiment. In the second embodiment also, lateral chromatic aberration in particular is favorably corrected by using the radial type gradient index lens element as the second lens unit.

The radial type gradient index lens element has a meniscus shape which has a concave surface on the object side. When a radial type gradient index lens element has such a meniscus shape, its refractive power of surface and refractive power of medium which are weaker and stronger respectively than a refractive power of surface and a refractive power of medium of a radial type gradient index lens element having a biconvex shape and a refractive power which is the same as that of the radial type gradient index lens element. When a radial type gradient index lens element has a strong refractive power of medium, its effect for correcting chromatic aberration can be effectively utilized as seen from the formula (d). For effectively utilizing the effect of a radial type gradient index lens element, the second embodiment adopts the radial type gradient index lens element which has the meniscus shape. The meniscus shape which has the concave surface on the object side is effective in particular for preventing offaxial aberrations from being aggravated.

In the second embodiment, the outer circumferential portion located outside an effective diameter of the first lens unit and the second lens unit is configured as a nearly planar surfaces on which both the lens units are cemented or kept in contact with each other. By cementing these two lens units into an integrated part, it is possible to simplify a structure of a lens barrel and facilitate assembly of the objective lens system.

The second embodiment also has high optical performance though it is composed only of the two lens elements.

The third embodiment of the present invention is an objective lens system which has a composition illustrated in FIG. **6**. That is to say, the objective lens system is composed of two lens units, in order from the object side, of a first lens unit composed of a negative lens element, a stop, and a second lens unit composed of a positive lens element. The second lens unit having the positive refractive power is configured as a radial type gradient index lens element. The first lens unit is composed of a homogenous lens element having a biconcave shape, whereas the second lens unit is composed of a radial type gradient index lens element having a meniscus shape which has a concave surface on the object side.

Though it is ordinarily difficult to favorably correct lateral chromatic aberration with two lens elements, the objective lens system according to the present invention is capable of favorably correcting lateral chromatic aberration by using the radial type gradient index lens element as the second lens unit.

The third embodiment is an example wherein amounts of aberrations to be produced by the first lens unit are reduced by selecting the biconcave surface for the first lens unit so that a power of this lens unit is shared between the surfaces.

Though $1/V_{10}$ of the radial type gradient index lens element has a positive value, lateral chromatic aberration is favorably corrected by satisfying the condition (1).

The objective lens system preferred as the third embodiment also has high optical performance though it is composed only of the two lens elements.

The fourth embodiment of the present invention is an objective lens system which has a composition shown in FIG. **7**. Concretely, it is composed of two lens units, in order from the object side, a first lens unit composed of a negative lens element, a stop and a second lens unit composed of a positive lens element. The second lens unit having the positive refractive power is configured as a radial type gradient index lens element. The first lens unit has a planar surface on the object side and a concave surface on the image side configured as an aspherical surface which weakens a negative refractive power as portions of the aspherical surface are farther from an optical axis toward a marginal portion. The second lens unit is composed of a radial type gradient index lens element which has a biconvex shape.

The aspherical surface used in this embodiment has a shape expressed by the following formula:

$$x = \frac{y^2/r}{1+\sqrt{1-p(y/r)^2}} + \Sigma A_{2i} y^{2i}$$

wherein a direction along the optical axis is taken as the x axis, a direction perpendicular to the optical axis is taken as the y axis, the reference symbol r represents a radius of curvature on the optical axis, the reference symbol p designates a conical constant and the reference symbol A_{2i} denotes an aspherical surface coefficient.

In the fourth embodiment, the aspherical surface used in the first lens unit is capable of favorably correcting mainly barrel form distortion produced in the lens system as a whole.

Though the first lens unit has the planar surface on the object side in the fourth embodiment, a similar effect can be obtained by using an aspherical surface as the object side surface of the first lens unit.

The fourth embodiment is an example wherein the second lens unit is configured as the biconvex radial type gradient index lens element which has a weakened refractive power of medium and a strengthened refractive power of surface. Accordingly, the radial type gradient index lens element can have a small refractive index difference An contributing to a refractive power of medium, thereby enhancing productibility or shortening a time required for imparting a refractive index distribution at a stage to prepare a material for the radial type gradient index lens element.

In spite of the fact that the fourth embodiment is composed only of the two lens elements, it has high optical performance.

It is possible to obtain a similar effect by using, in place of the aspherical surface disposed in the first lens unit, an axial type gradient index lens element having a refractive index continuously varying in the direction along the optical axis.

The fifth embodiment of the present invention is an objective lens system which has a composition illustrated in FIG. **8**. That is to say, it is composed of two lens elements, in order from the object side, a first lens unit composed of a negative lens element, a stop and a second lens unit composed of a positive lens element configured as a radial type gradient index lens element. The first lens unit has a planar surface on the object side and a concave surface on the image side which is configured as an aspherical surface which has such a shape as to weaken a negative refractive power as portions of the aspherical surface are farther from the optical axis toward a marginal portion, whereas the second lens unit is configured as a radial type gradient index lens element having a biconvex shape. The aspherical surface used in the first lens unit is capable of favorably correcting barrel form distortion which is produced in the objective lens system as a whole as in the fourth embodiment.

For configuring compactly a tip of an endoscope which is to comprise the objective lens system according to the present invention, an outer circumferential portion of the radial type gradient index lens element used as the second lens unit is cut off as shown in FIG. **8**. A tip of the objective lens system can be made thinner since a lens barrel or the like can be disposed, for example, as the slashed location **3** on the cut portion **2**.

The fifth embodiment is an example wherein the objective lens system has a total length that is shorter than that of the fourth embodiment. Though the fifth embodiment is composed only of the two lens elements, it has high optical performance.

The sixth embodiment of the present invention has a composition shown in FIG. **9**. Speaking concretely, it is composed of two lens units, in order from the object side, a first lens unit composed of a negative lens element, a stop and a second lens unit composed of a positive lens element. The first lens unit having the negative refractive power is configured as a radial type gradient index lens element. The first lens unit is a radial type gradient index lens element which has a planar surface on the object side and a concave surface on the image side, whereas the second lens unit is a biconvex homogenous lens element.

Unlike the first through fifth embodiments, the six- th embodiment uses the radial type gradient index lens element as the first lens unit for favorably correcting lateral chromatic aberration which poses a problem in particular in the objective lens system according to the present invention.

The planar surface adopted as the object side surface of the first lens unit makes it possible to reduce the cost for polishing the lens element.

Further, aberrations are reduced by selecting the biconvex shape for the second lens unit so that its power is shared between the two surfaces.

Furthermore, the image side surface of the second lens unit has a refractive power of surface which is stronger than that of the object side surface thereof so that offaxial rays are incident on an image surface nearly at telecentric angles.

The sixth embodiment also has high optical performance though it is composed only of the two lens elements.

The seventh embodiment of the present invention has a composition illustrated in FIG. **10**. That is to say, an objective lens system preferred as the seventh embodiment is composed of two lens units, in order from the object side, a first lens unit composed of a negative lens element, stop and a second lens unit composed of a positive lens element. The first lens unit having the positive refractive power is configured as a radial type gradient index lens element. The first lens unit is a radial type gradient index lens element which has a planar surface on the object side and a concave surface on the image side, whereas the second lens unit is a homogenous lens element which has a biconvex shape.

This embodiment also has high optical performance though it is composed only of the two lens elements.

The eighth embodiment of the present invention is an objective lens system which has a composition shown in FIG. **11**. This lens system is composed of two lens units, in order from the object side, a first lens unit composed of a negative lens element, a stop and a second lens unit composed of a positive lens element. The first lens unit having the positive refractive power is configured as a radial type gradient index lens element. The first lens unit is a radial type gradient index lens element having a meniscus shape which has a concave surface on the image side, whereas the second lens unit is a homogenous lens element which has a biconvex shape.

The composition of the eighth embodiment, in which the radial type gradient index lens element has the meniscus shape which has a concave surface on the image side is advantageous for correcting offaxial aberrations in particular.

The eighth embodiment also has high optical performance in spite of the fact that it is composed only of the two lens elements.

The ninth embodiment of the present invention is an objective lens system which has a composition illustrated in FIG. **12**. Speaking concretely, this lens system is composed of two lens elements, in order from the object side, a first lens unit composed of a negative lens units, a stop and a second lens unit composed of a positive lens element. The first lens unit having the negative refractive power is configured as a radial type gradient index lens element. The first lens unit is a radial type gradient index lens element having a meniscus shape which has a planar surface on the object side and a concave surface on the image side, whereas the second lens unit has aspherical surfaces on both sides.

Owing to a fact that an image side surface of the second lens unit on which offaxial rays are relatively high is configured as an aspherical surface having such a shape as to weaken a positive refractive power as portions of the aspherical surface are farther from an optical axis toward a marginal portion, the ninth embodiment is capable of favorably correcting barrel form distortion produced in the lens system as a whole.

Though the ninth embodiment uses the aspherical surfaces on both sides of the second lens unit, a similar effect can be obtained by using an aspherical surface only on one side.

The ninth embodiment also exhibits high optical performance though it consists only of the two lens elements.

Further, a similar effect can be obtained by adopting, in place of the aspherical surfaces used in the second lens unit, an axial type gradient index lens element which continuously varies a refractive index in a direction along the optical axis.

The tenth embodiment of the present invention is an objective lens system which has a composition shown in FIG. **13**. This lens system consists of two lens units, in order from the object side, a first lens unit composed of a negative lens element, a stop and a second lens unit composed of a positive lens element. The first lens unit having the negative refractive power and the second lens unit having the positive refractive power are configured as radial type gradient index lens elements. The first lens unit is a radial type gradient index lens element which has a planar surface on the object side and a concave surface on the image side, whereas the second lens unit is a radial type gradient index lens element which has a bi-convex shape.

The tenth embodiment is an example wherein lateral chromatic aberration produced in the lens system as a whole is favorably corrected by using radial type gradient index lens elements in both the lens units. In other words, lateral chromatic aberration is favorably corrected by con- figuring the radial type gradient index lens element used in the first lens unit to satisfy the condition (1) and the condition (2), and designing the radial type gradient index lens element used in the second embodiment to satisfy the condition (1) and the condition (3).

Though the tenth embodiment consists only of the two lens elements, it has high optical performance.

Preferred as an eleventh embodiment of the present invention is an objective lens system which has a composition illustrated in FIG. **14**. This lens system comprises two lens units, or is composed, in order from the object side, a first lens unit composed of a negative lens element, a stop, a second lens unit composed of a positive lens element and filters F disposed on the image side of the second positive lens unit. The first lens unit is configured as a homogenous lens element which has a planar surface on the object side and a concave surface on the image side, whereas the second lens unit is configured as a biconcave radial type gradient index lens element which has an object side surface having a weak positive refractive power.

When the objective lens system according to the present invention is used in a video scope or the like which uses a solid-state image pickup device such as a CCD, a low pass filter and an infrared cut filter composed, for example, of quartz or diffraction gratings may be disposed on the object side of an image surface as exemplified in FIG. **14**. The eleventh embodiment is an example comprising such filters. In the objective lens system according to the present invention, the above-mentioned filters can be disposed between the negative lens element and the positive lens element.

Preferred as the twelfth embodiment of the present invention is an objective lens system which has a composition shown in FIG. **15**. Like the eleventh embodiment, the

twelfth embodiment comprises two lens units, or is composed, in order from the object side, of a first lens unit composed of a negative lens element, a stop, a second lens unit composed of a positive lens element, and filters which are disposed between the two lens elements and on the image side of the positive lens element. The first lens unit is configured as a homogenous lens element which has a planar surface on the object side and a concave surface on the image side, whereas the second lens unit is configured as a radial type gradient index lens element which has a biconvex shape.

The thirteenth embodiment of the present invention has a composition illustrated in FIGS. **16**A and 16B: FIG. **16**A being a sectional view showing the thirteenth embodiment as a whole and FIG. **16**B being a diagram illustrating only a portion B on an enlarged scale. The thirteenth embodiment is composed, in order from the object side, of a first lens unit composed of a negative lens element, a stop and a second lens unit composed of a positive lens element. A radial type gradient index lens element is used as the second lens unit. The first lens unit has a planar surface on the object side and a concave surface on the image side, whereas the second lens unit has a planar surface on the object side and a convex surface on the image side.

The thirteen embodiment is an example wherein aberrations are favorably corrected by using a radial type gradient index lens element and a large number of planar surfaces are adopted for reducing a cost required for polishing lens elements, or the object side surface of the first lens unit and the object side surface of the second lens unit are configured to be planar.

Further, for preventing eccentricities of lens elements, in directions along an optical axis and perpendicular thereto in particular, which pose a problem at a stage of assembly, an outer circumferential portion **4** is obliquely chamfered as shown in FIG. **16**B so that a chamfered portion **4** is limited at a location **6** of a lens barrel **5**. Since a radial type gradient index lens element which has a refractive power of medium requires a manufacturing precis-on stricter than that for a homogenous lens element, the thirteenth embodiment provides an effective assembling convenience. A similar effect can, needless to say, be obtained by assembling the first lens unit having the negative refractive power in a similar manner.

Though the thirteenth embodiment uses a large number of planar surfaces, it has high optical performance.

The fourteenth embodiment of the present invention is an objective lens system which has a composition illustrated in FIG. **17**. That is to say, the fourteenth embodiment is composed, in order from the object side, of a first lens unit consisting of a negative lens element, a stop and a second lens unit consisting of a positive lens element which is configured as a radial type gradient index lens element. The first lens unit has a planar surface on the object side and a concave surface on the image side, whereas the second lens unit has a meniscus shape which has a concave surface on the object side.

When a radial type gradient index lens element is used as the second lens unit, it is desirable for correcting aberrations such as spherical aberration that the term of the fourth order N_{20} of a refractive index distribution has a positive value.

The fifteenth embodiment o- the present invention has a composition shown in FIG. **18**. Speaking concretely, the fifteenth embodiment is composed, in order from the object side, of a first lens unit consisting of a negative lens element, a second lens unit consisting of a positive lens element and a reflecting optical element. A radial type gradient index lens element is used as the second lens unit. In this embodiment, a light bundle emerging from the second lens unit is reflected by a reflecting surface **7** of a reflecting optical element P made, for example, of a mirror or a prism so that it is imaged onto a solid-state image pickup device **10** which is disposed nearly parallel to the optical axis. This reflecting surface makes it possible to dispose a solid-state image pickup device such as a CCD that is not parallel to a radial direction of the lens elements but oblique. Though a solid-state image pickup device **10** is disposed nearly parallel to the optical axis in the fifteenth embodiment, the image pickup device can be disposed more obliquely by selecting an adequate inclination angle for the reflecting surface **7** relative to the optical axis. Though the fifteenth embodiment is configured to reflect the light bundle only once, it is possible to reflect the light bundle twice, three times or more times by adopting a larger number of reflecting surfaces.

The sixteenth embodiment of the present invention is an objective lens system which has a composition shown in FIG. **19**. That is to say, the sixteenth embodiment is composed, in order from the object side, of a first lens unit composed of a negative lens element, a second lens unit composed of a positive lens element and a solid-state image pickup device. A radial type gradient index lens element is used as the second lens unit. In this embodiment, the radial type gradient index lens element has a nearly planar image side surface which is cemented or kept in close contact to or with a solid-state image pickup device **10** such as a CCD. Further, disposed in the second lens unit, is a member which extends from an outer circumference toward an optical axis for shielding a light bundle passing through the lens unit or functioning as an aperture stop of the objective lens system. Such a shielding member can be constituted, for example, by forming a cut **8** from the outer circumference toward the optical axis. For preventing the cut from producing flare, it is desirable to color the cut **8**. Further, it is possible to cut the second lens unit along a dashed line **9** shown in FIG. **25** into a front portion La and a rear portion Lb, attach a stop S to a cut surface of the front portion La and cementing the two portions to each other or bringing them into close contact with each other. A similar effect can be obtained by attaching the stop S to the rear portion Lb in place of the front portion La. As means for attaching the stop, it is conceivable to utilize deposition, printing or bonding a stop plate. This means can be utilized for manufacturing not only an aperture stop but also a flare stop.

In the sixteenth embodiment, the aperture stop is disposed at a location 1 mm apart from an object side sur- face of the second lens unit toward an image surface.

It is needless to say that an aperture stop, a flare stop or the like can be manufactured by the means described above in each of the embodiments.

The seventeenth embodiment of the present invention has a composition illustrated in FIG. **20**. That is to say, the seventeenth embodiment is composed, in order from the object side, of a first lens unit composed of a negative lens element, a second lens unit composed of a positive lens element, an optical filter F and a solid-state image pickup device **10**. A radial type gradient index lens element is used as the second lens unit. In the seventeenth embodiment, the second lens unit has planar surfaces on both sides for reducing the cost for polishing the lens unit. The seventeenth embodiment is an example wherein the second lens unit is cemented to the optical filter F for simplifying a structure of a lens barrel and assembly of the objective lens system. Further, the optical filter F is cemented or kept in close contact to or with the solid- state image pickup device **10**.

Furthermore, the first lens unit and the second lens unit are cemented or kept in close contact to or with each other on outer circumferences thereof outside an effective diameter thereof.

In the seventeenth embodiment, an aperture stop is disposed at a location 1 mm apart from an object side surface of the second lens unit toward an image surface.

The eighteenth embodiment of the present invention has a composition shown in FIG. **21**. That is to say, the eighteenth embodiment is composed, in order from the object side, of a first lens unit composed of a negative lens element, a regularly reflecting optical element and a second lens unit composed of a positive lens element. The second lens unit which is disposed on the image side is configured as a radial type gradient index lens element.

Certain endoscopes are specified for oblique observation in directions inclined relative to the optical axis. When the objective lens system according to the present invention is used in an endoscope for oblique observation, a reflecting optical element P composed of a mirror or a prism is disposed between the first lens unit and the second lens unit as shown in FIG. **21** so that a light bundle emerging from the first lens unit is reflected by a reflecting surface **7** of the reflecting optical element and led to the second lens unit.

Though a lens element ordinarily has a circular sectional shape, it may have a different sectional shape. FIGS. **22**A, **22**B, **22**C, **23**A, **23**B and **23**C exemplify lens elements which have external shapes cut or worked in accordance with shapes of image pickup devices for configuring objective lens systems compactly. FIGS. **22**A, **22**B and **22**C schematically show the second lens unit which is used in the first through eighteenth embodiments before being shaped. FIG. **22**A slows a sectional view taken in a direction from an object, FIG. **22**B is a sectional view taken in a direction in parallel with the optical axis, and FIG. **22**C illustrates an image circle **11** of the objective lens system and an image pickup surface **12** of an image pickup device. FIGS. **23**A, **23**B and **23**C schematically show the lens element illustrated in FIGS. **22**A, **22**B and **22**C in another condition after it is shaped. Since a solid-state image pickup device such as a CCD may have a rectangular shape and a lens element ordinarily has a circular shape as shown in FIG. **22**A, there is produced, as slashed in FIG. **22**C, a region which serves for image formation but is not used for image pickup. Since it is desired to configure an objective lens system for endoscopes compacter, it is conceivable to cut off the region of the lens element which is not used for image pickup. The eithteenth embodiment is an example wherein lens portions through which rays to be condensed outside an image pickup surface of an image pickup device are cut off as exemplified by FIGS. **23**A and **23**B so that an image formation range of the lens element is nearly coincident with the image pickup surface of the image pickup device. It is possible to obtain a compacter objective lens system or endoscopes by configuring a lens element so as to occupy a narrower space.

Though the second lens unit is worked for narrowing a lens space in the example described above, it is needless to say that a similar effect can be obtained by working other lens element or optical element, for example, the first lens unit or the reflecting optical element.

The nineteenth embodiment has a composition illustrated in FIG. **26**. Speaking concretely the nineteenth embodiment is a retrofocus type objective lens system which is composed, in order from the object side, of a first negative lens unit, a second positive lens unit and a third positive lens unit. A stop is disposed between the second lens unit and the third lens unit. The nineteenth embodiment is an objective lens system which has a wide field angle and is usable for endoscopes, video cameras, etc. Though the nineteenth embodiment has a wide field angle which makes it rather hard to correct lateral chromatic aberration, it corrects lateral chromatic aberration with a radial type gradient index lens element. In the nineteenth embodiment, the first lens unit has a plano- concave shape and a function to widen a field angle, the second lens unit has a plano-convex shape and a function to correct mainly lateral chromatic aberration produced by the first lens unit, and the third lens unit has a biconvex shape and a main imaging function, and is configured as a radial type gradient index lens element.

Though it is rather hard in the nineteenth embodiment to correct coma which is produced by the third lens unit disposed on the image side of a stop, coma is corrected by configuring the third lens unit as a radial type gradient index lens element which has such a characteristic as to progressively lower a refractive index in a radial direction from an optical axis. In other words, coma is corrected by imparting a positive refractive power to a medium of the radial type gradient index lens element. The composition described above is capable of correcting not only coma but also distortion.

For correcting coma with a medium of a radial type gradient index lens element, it is desirable that terms of high orders of a refractive index distribution satisfy the following condition (27):

$$-0.05 < \sum_{i=2}^{n} N_{iod} e^{2i} < 0.2 \tag{27}$$

wherein the reference symbol e represents an effective diameter of the lens element.

If the lower limit of −0.05 of the condition (27) is not reached, coma will be undercorrected. If the upper limit of 0.2 of the condition (27) is exceeded, in contrast, coma will be overcorrected.

It is desirable for more favorable correction of coma to satisfy the following condition (28):

$$0 < \sum_{i=2}^{n} N_{iod} e^{2i} < 0.1 \tag{28}$$

If the lower limit of 0 of the condition (28) is not reached, coma will be undercorrected. If the upper limit of 0.1 of the condition (28) is exceeded, in contrast, coma will be overcorrected. Either of these cases is undesirable for more favorable correction of coma.

Further, a planar surface used as an object side surface of the lens element disposed on the image side in the nineteenth embodiment has an effect for preventing adhesion of foreign matter such as dust.

In this embodiment, at least one lens element can have a function to cut off components having specific wavelengths, or a radial type gradient index lens element can have such a function.

When an image pickup device such as a CCD which has high sensitivity in the infrared wavelength region is to be disposed on an image pickup surface, for example, it is desirable to provide a function to cut off components having wavelengths in the infrared region. Accordingly, it is desirable that at least one lens element has a function to cut off components having specific wavelengths such as those in the infrared region.

The function to cut off components having specific wavelengths can be obtained by forming, on a flat portion of a

lens element or a flat plate, an interference film which cuts off the components having specific wavelengths.

A stop can be manufactured from a thin plate.

Further, amounts of aberrations produced can be reduced by configuring a radial type gradient index lens element so as to have a biconvex shape, thereby sharing a refractive power between the two surfaces.

Use of a radial type gradient index lens element makes it possible to obtain an optical system which is compact and composed of a small number of lens elements, and has a wide field angle and favorably corrected aberrations such as chromatic aberration and coma. Accordingly, it is effective to use an optical system such as an optical system for image input units for portable TV telephones and portable data input units such as those shown in FIGS. **35** and **36**.

The twentieth embodiment is an optical system which has a composition illustrated in FIG. **27**. It is a retro-focus type optical system which is composed, in order from the object side, of a first lens unit having a negative refractive power, a second lens unit having a positive refractive power and a third lens unit having a positive refractive power. A stop is disposed between the second lens unit and the third lens unit.

The twentieth embodiment is an optical system which has a wide field angle and is usable as an objective lens system for endoscopes or a lens system for video cameras, etc. Though the twentieth embodiment also has a wide field angle and hardly allows correction of Lateral chromatic aberration in particular, aberrations Ere favorably corrected in this embodiment by using a radial type gradient index lens element.

In the twentieth embodiment, the first lens unit is a plano-concave lens element having a function to widen a field angle, the second lens unit is a radial type gradient index lens element having plarar surfaces on both sides and a function to correct lateral chromatic aberration produced by the first lens unit, end the third lens unit has a biconvex shape and a main imaging function. The twentieth embodiment favorably corrects lateral chromatic aberration in particular by using, as the second lens unit disposed on the object side of the stop, a radial type gradient index lens element made of a medium which has a positive refractive power and a relatively strong dispersing power. The medium having the positive refractive power favorably corrects a Petzval's sum.

For correcting lateral chromatic aberration by disposing a radial type gradient index lens element on a stop, it is desirable to satisfy the following condition (29)

$$0.01<1/V_{10}<0.5 \tag{29}$$

If the lower limit of 0.01 of the condition (29) is not reached, lateral chromatic aberration will be undercorrected. If the upper limit of 0.5 of the condition (29) is not satisfied, in contrast, lateral chromatic aberration will be overcorrected.

For correcting lateral chromatic aberration more favorably by disposing a radial type gradient index lens element on the object side of the stop, it is desirable to satisfy the following condition (30):

$$0.015<1/V_{10}<0.1 \tag{30}$$

If the lower limit of 0.015 of the condition (30) is not reached, lateral chromatic aberration will be undercorrected. If the upper limit of 0.1 of the condition (30) is exceeded, lateral chromatic aberration will be overcorrected. Either of these cases is undesirable for correcting lateral chromatic aberration extremely favorably.

When preparation of a material for a radial type gradient index lens element is taken into consideration, it is desirable that $1/V_{10}$ has a value not exceeding 0.05. From viewpoints of manufacturing convenience and cost, it is desirable to configure a radial type gradient index lens element so as to have planar surfaces on both sides. When durability of a radial type gradient index lens element is taken into consideration, it is desirable to make it entirely of a glass material.

The twenty-first embodiment has a composition illustrated in FIG. **28**, or is a retrofocus type optical system which is composed, in order from the object side, of a first lens unit having a negative refractive power and a second lens unit having a positive refractive power. A stop is disposed between the first lens unit and the second lens unit. The twenty-first embodiment which is an optical system having a wide field angle is usable as an objective lens system for endoscopes or video cameras and so on. Though this optical system also has a wide field angle and hardly allows correction of lateral chromatic aberration in particular, lateral chromatic aberration is favorably corrected by using a radial type gradient index lens element.

In the optical system preferred as the twenty-first embodiment, the first lens unit has a negative meniscus shape which has a concave surface on the image side, and the second lens unit has a biconvex shape and a main imaging function. A radial type gradient index lens element is used as the first lens unit.

Offaxial aberrations can be corrected favorably by configuring the radial type gradient index lens element used as the first lens unit so as to have the meniscus shape which has the concave surface on the side of the stop. Lateral chromatic aberration is favorably corrected in particular owing to a fact that the radial type gradient index lens element has a positive refractive power of medium and is configured so as to satisfy the condition (29).

Further, coma is corrected favorably by using an aspherical surface on the lens element disposed on the object side of the stop. This aspherical surface has such a shape as to weaken a positive refractive power as portions of the aspherical surface are farther from an optical axis toward a marginal portion. Owing to this aspherical surface, the twenty-first embodiment is configured as an optical system which is compact and composed of a small number of lens elements, has a wide field angle and favorably corrects aberrations such as coma. It is therefore effective to apply the twenty-first embodiment as an optical system for image intake devices for portable TV telephones and portable date input units.

The twenty-second embodiment has a composition shown in FIG. **29**, or is an optical system composed of a single radial type gradient index lens element. The radial type gradient index lens element has a meniscus shape which has a concave surface on the object side and a positive power of medium. A stop is disposed at a location 0.9471 mm apart from an object side surface of the lens element toward the image side.

The twenty-second embodiment has a wide field angle, and is usable as an objective lens system for endoscopes or a lens system for video cameras and so on. Though the twenty-second embodiment which has the wide field angle hardly allows correction of chromatic aberration, it is corrected with the radial type gradient index lens element. A flat glass plate is disposed on the object side as a cover glass plate. A stop is disposed in the radial type gradient index lens element for obtaining highly symmetrical refractive power of medium, thereby favorably correcting offaxial aberra-

tions. The radial type gradient index lens element satisfies the condition (29) for correcting lateral chromatic aberration produced by an object side concave or convex surface with a medium located on the object side of the stop.

For reducing chromatic aberration to be produced by surfaces of the radial type gradient index lens element, it is desirable that V_{00} has a value of at least 30, or more desirably, at least 40. For reducing aberrations to be produced by the surfaces of the radial type gradient index lens element, it is desirable that N_{00} has a value of at least 1.55, or more desirably, at least 1.6.

The twenty-third embodiment has a composition shown in FIG. **30**, or is composed of two lens units, in order from the object side, a first positive lens unit and a second positive lens unit. The twenty-third embodiment is an example wherein aberrations are corrected favorably by composing an optical system of a radial type gradient index lens element and a diffraction type optical element(DOE). Speaking more concretely, the twenty-third embodiment is composed, in order from the object side, of a first lens unit composed of a radial type gradient index lens element and a second lens unit composed of a diffraction type optical element.

A diffraction type optical element is equivalent to a lens element which has a very high imaginary refractive index as described in literature SPIE, Vol. 126, P46 (1997). For this reason, the diffractive optical element is assumed to be a lens element which is optically equivalent to the optical element including aberrations to be produced thereby, and radii of curvature, thickness, a refractive index, an Abbe's number and aspherical surface coefficients of the lens element are described in the numerical data of the twenty-third embodiment. In the twenty-third embodiment, a stop is disposed on the object side of the optical system (the first lens unit).

In the twenty-third embodiment, the first lens unit composed of the radial type gradient index lens element has a main imaging function and the second lens unit composed of the diffraction type optical element favorably corrects lateral chromatic aberration. The twenty-third embodiment is an example of an optical system which is composed of a small number of optical elements and has a wide field angle, and favorably corrects lateral chromatic aberration with a diffractive optical element disposed on the image side of a stop. The diffraction type optical element has a positive refractive power, is disposed on the image side of the radial type gradient index lens element and has a function to favorably correct lateral chromatic aberration produced by a convex surface of the radial type gradient index lens element. Further, the radial type gradient index lens element has another function to favorably correct a Petzval's sum.

The twenty-third embodiment is usable, as described above, as an objective lens system for endoscopes or an optical system for video cameras and so on. Since the twenty-third embodiment is an optical system which is compact and is composed of a small number of lens elements, and favorably corrects aberrations such as chromatic aberration owing to the fact that it uses the diffraction type optical element, it is effective to apply it as an optical system for image intake devices for portable TV telephones and portable data input units.

The twenty-fourth embodiment has a composition illustrated in FIG. **31**, or is composed, in order from the object side, of a first lens unit having a negative refractive power and a second lens unit having a positive refractive power. A stop is disposed between the first lens unit and the second lens unit. In the twenty-fourth embodiment, the first lens unit having the negative refractive power serves mainly for widening a field angle and the second lens unit having the positive refractive power functions mainly for imaging.

The twenty-fourth embodiment favorably corrects aberrations by using the diffraction type optical element in place of the radial type gradient index lens element adopted for the twenty-first embodiment.

The twenty-fourth embodiment hardly allows correction of offaxial aberrations since it has an asymmetrical refractive power distribution wherein a negative refractive power is disposed on the object side of the stop and a positive refractive power is disposed on the image side of the stop. For this reason, lateral chromatic aberration is corrected favorably by disposing the diffraction type optical element on the object side of the stop and imparting a negative refractive power to this optical element. Coma and distortion in particular can be corrected favorably by using an aspherical surface on a positive lens unit disposed on the image side of the stop and configuring this aspherical surface so as to have such a shape as to weaken a positive refractive power in a radial direction from an optical axis. The negative lens unit has a meniscus shape which has a concave surface on the side of the stop for reducing amounts of offaxial aberrations in particular. Further, the positive lens unit has a biconvex shape so that amounts of aberrations are reduced by sharing a refractive power between two surfaces. Furthermore, the diffraction type optical element is disposed on a surface which is concave toward the stop so that differences between angles of incidence of paraxial rays and offaxial rays are reduced, thereby enhancing a diffraction efficiency.

FIG. **32** is a perspective view illustrating an endoscope according to the present invention which uses an objective lens system such as the embodiment described above. The reference numeral **21** represents the objective lens system.

FIG. **33** is a side view of a non-flexible endoscope according to the present invention which uses an objective lens system such as the embodiment described above. The reference numeral **21** represents the objective lens system.

FIG. **34** shows a video camera according to the present invention which uses an objective lens system such as the embodiment described above. The reference numeral **21** represents the objective lens system.

FIG. **35** shows a perspective view illustrating a portable TV telephone according to the present invention which uses an objective lens system such as the embodiment described above. The reference numeral **21** represents the objective lens system, the reference numeral **22** designates an antenna for transmission and reception, the reference numeral **23** denotes a display, and the reference numeral **24** represents switches.

Further, FIG. **36** shows a perspective view illustrating a portable data input unit according to the present invention which uses an objective lens system such as the embodiment described above. The reference numeral **21** represents the objective lens system, the reference numeral **22** designates an antenna for transmission and reception, the reference numeral **23** denotes a display, and the reference numeral **24** represents switches.

As understood from the foregoing description, the objective lens system for endoscopes according to the present invention is composed of lens elements in a number on the order of 2, and is nevertheless an optical system which favorably corrects aberrations, lateral chromatic aberration in particular, and has high optical performance.

What is claimed is:

1. A portable TV telephone, comprising:

an objective lens system configured to form an image of an object;

an antenna configured to transmit and receive at least one of said image of the object, a dial number and a voice carried by radio waves; and

a display configured to display at least one of said image of the object and the dial number,

wherein said objective lens system comprises a first negative lens unit and a second positive lens unit in order from an object side,

wherein said objective lens system further comprises an aperture stop disposed between said first lens unit and said second lens unit, and

wherein said first lens unit and said second lens unit each have a lens barrel configured to position the respective lens units such that circumferences of the lens units contact interior walls of the portable TV telephone.

2. The portable TV telephone according to claim **1**, further comprising a switch configured to operate at least the dial number.

3. The portable TV telephone according to claim **2**, wherein said first lens unit consists only of a negative lens element and said second lens unit consists only of a positive lens element.

4. The portable TV telephone according to claim **2**, wherein said second lens unit has an outer circumferential portion that has a cutout portion outside an effective diameter through which rays transmit and said lens barrel partially contacts said outer circumferential portion.

5. The portable TV telephone according to claim **2**, wherein said first lens unit consists only of a negative lens element and said second lens unit consists only of a positive lens element, and

wherein said second lens unit has an outer circumferential portion that has a cutout portion outside an effective diameter through which rays transmit and said lens barrel partially contacts said outer circumferential portion.

6. The portable TV telephone according to claim **3** or **5**, wherein said first lens unit is configured to have an aspherical surface.

7. The portable TV telephone according to claim **6**, wherein said aspherical surface is configured to weaken refractive power for rays as portions of the aspherical surface are distanced from an optical axis toward a marginal portion, said optical axis being positioned at a center of the lens unit.

8. A portable TV telephone, comprising:

an objective lens system configured to form an image of an object;

an antenna configured to transmit and receive at least one of said image of the object, a dial number and a voice carried by radio waves; and

a display configured to display at least one of said image of the object and the dial number,

wherein said objective lens system comprises a first negative lens unit and a second positive lens unit in order from an object side,

wherein said objective lens system further comprises an aperture stop disposed between said first lens unit and said second lens unit, and

wherein said first lens unit and said second lens unit are cemented at outer circumferential portions outside an effective diameter through which rays transmit.

9. The portable TV telephone according to claim **8**, further comprising a switch configured to operate at least the dial number.

10. The portable TV telephone according to claim **3**, **5** or **9**, wherein said first lens unit has a planar surface on the object side.

11. The portable TV telephone according to claim **3**, **5** or **9**, wherein said aperture stop and said second lens unit are cemented at outer circumferential portions outside the effective diameter.

12. The portable TV telephone according to any one of claims **2** through **5** and **9**, wherein said objective lens system is disposed on a surface located on the same side as a surface on which said image display is disposed.

13. The portable TV telephone according to any one of claims **2** through **5** and **9**, wherein said objective lens system is disposed on a surface located on the same side as a surface on which said switch is disposed.

14. A portable TV telephone comprising:

an optical system comprising

a first lens unit; and

a second lens unit,

one of the said first and second lens units comprising a lens having at least one aspherical surface, and

wherein said first lens unit and said second lens unit are cemented to each other outside an effective diameter thereof.

15. A portable data input unit comprising:

an optical system comprising

a first lens unit; and

a second lens unit,

one of the said first and second lens units comprising a lens having at least one aspherical surface, and

wherein said first lens unit and said second lens unit are cemented to each other outside an effective diameter thereof.

* * * * *

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(54) **OBJECTIVE LENS**

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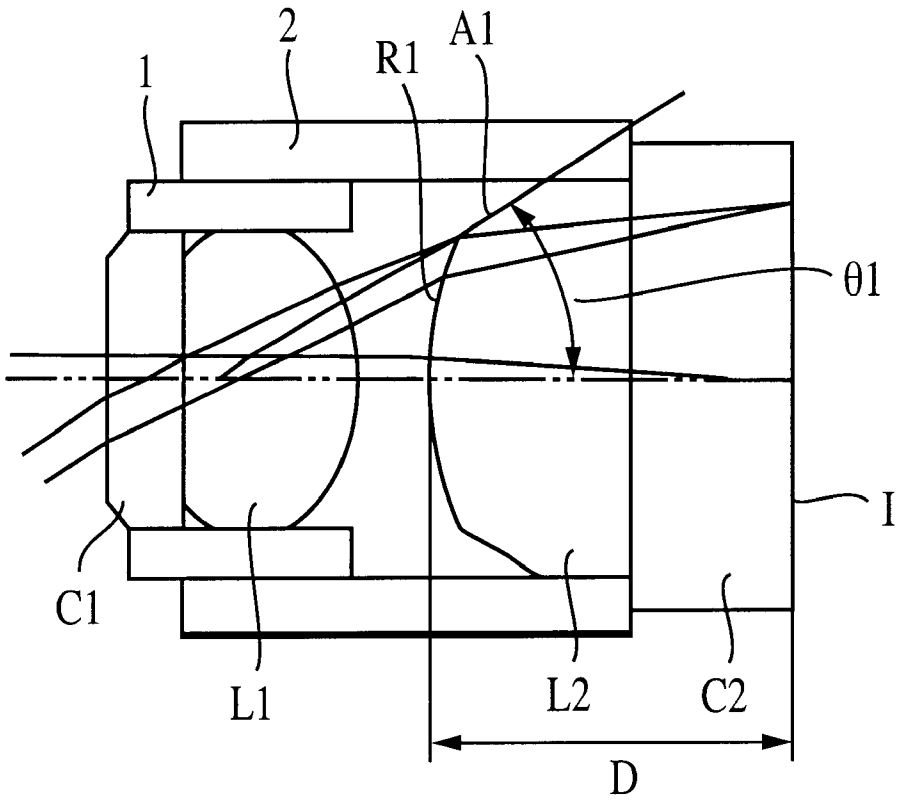
(57) **ABSTRACT**

In an image-forming lens, an inclined slope or section is provided at a marginal annular region on a surface of an optical member and a light shield is provided on this inclined slope or section. The optical member is mounted longitudinally so that the inclined slope or section is located near where off-field fight (i.e, fight from outside the designed field of view of the lens) reflects off an inner surface of a holding member or at the periphery of an optical member. Thus, the inclined slope or section with light shield acts to shield the reflected off-field light from passing to the image. The invention finds particular advantage in very small lenses that include optical members less than 3 mm in diameter.

22 Claims, 7 Drawing Sheets



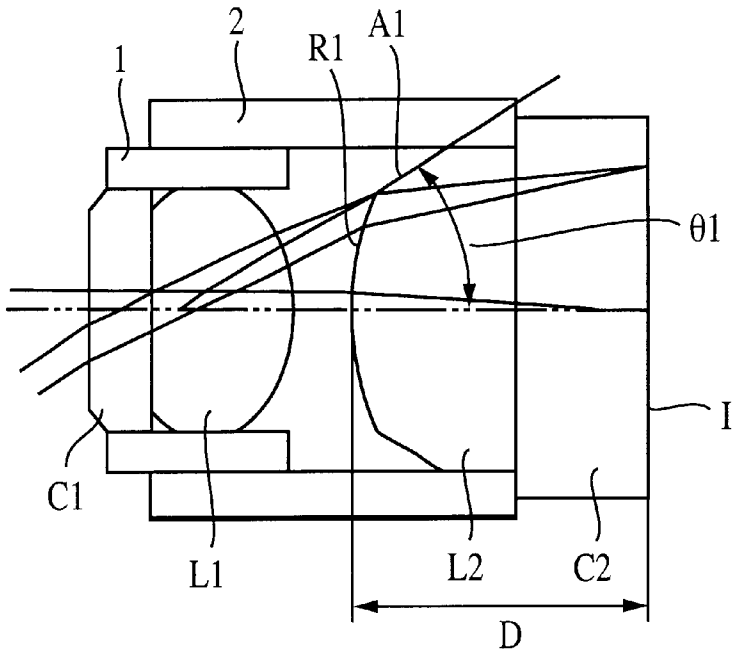


FIG. 1(a)

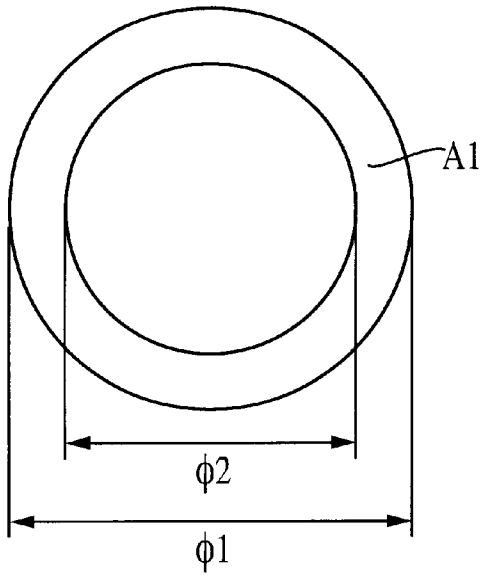


FIG. 1(b)

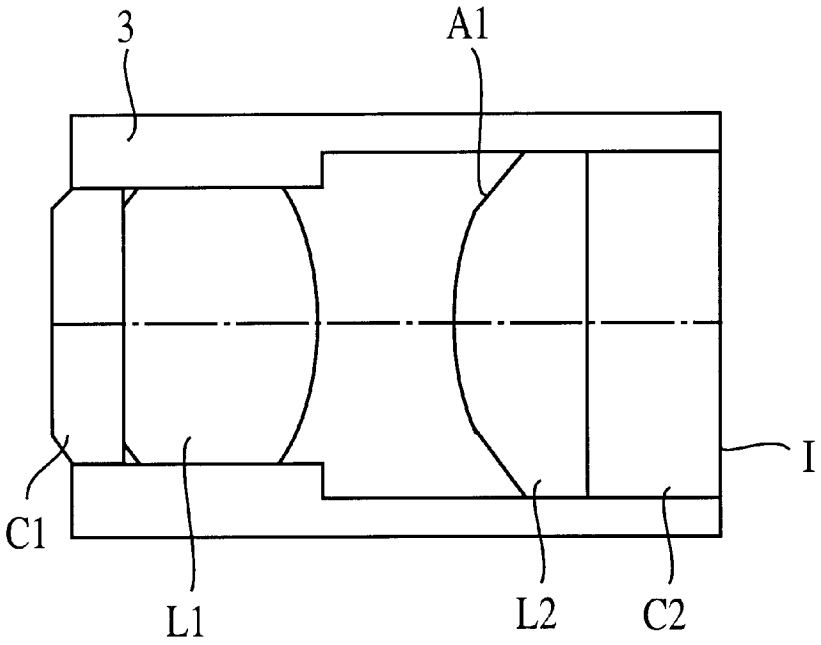
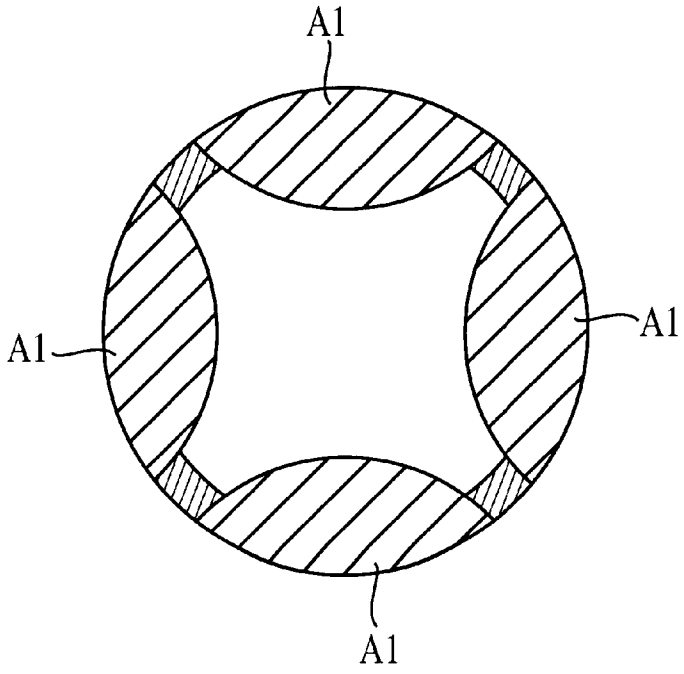


FIG. 2(a)



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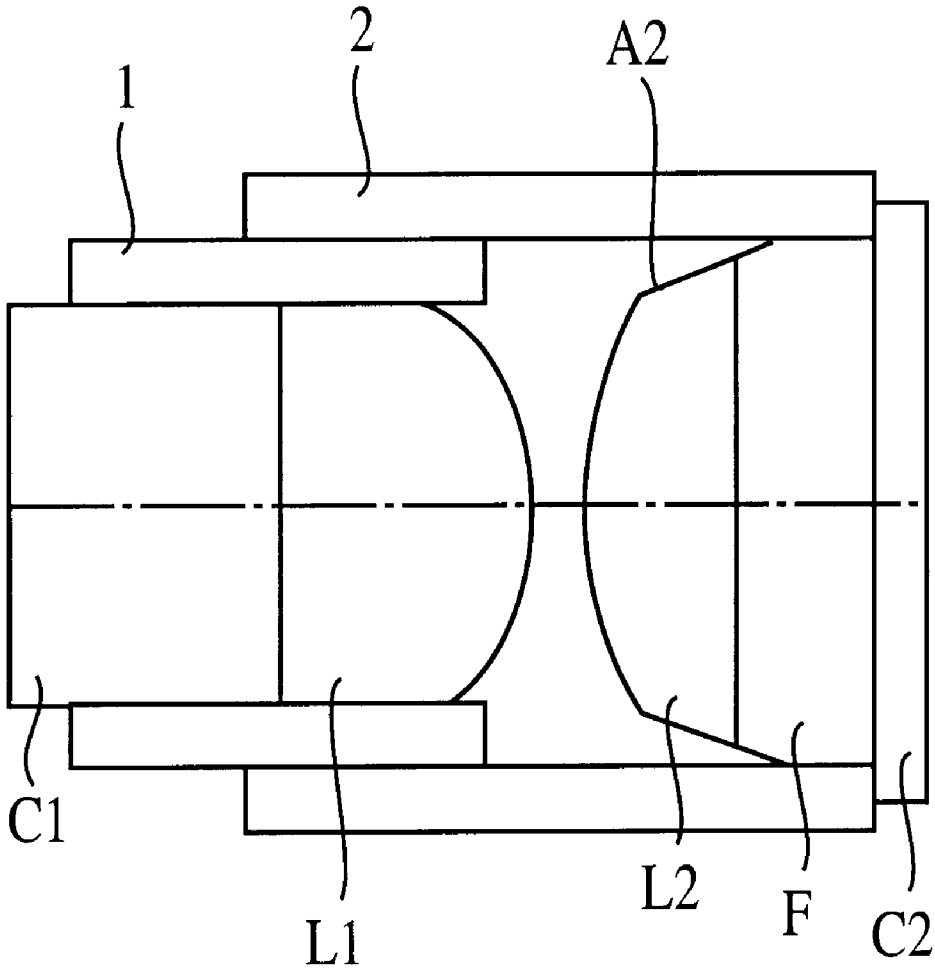


FIG. 3

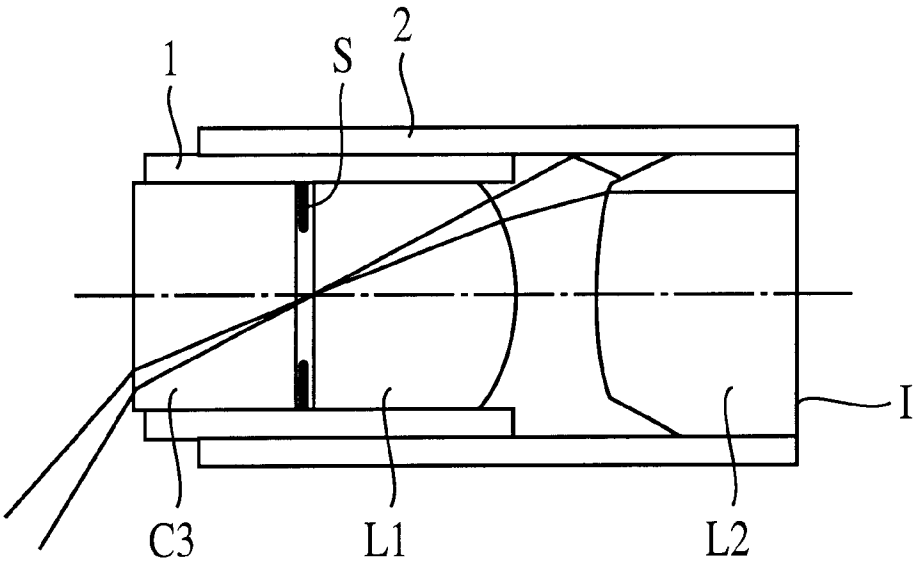


FIG. 4

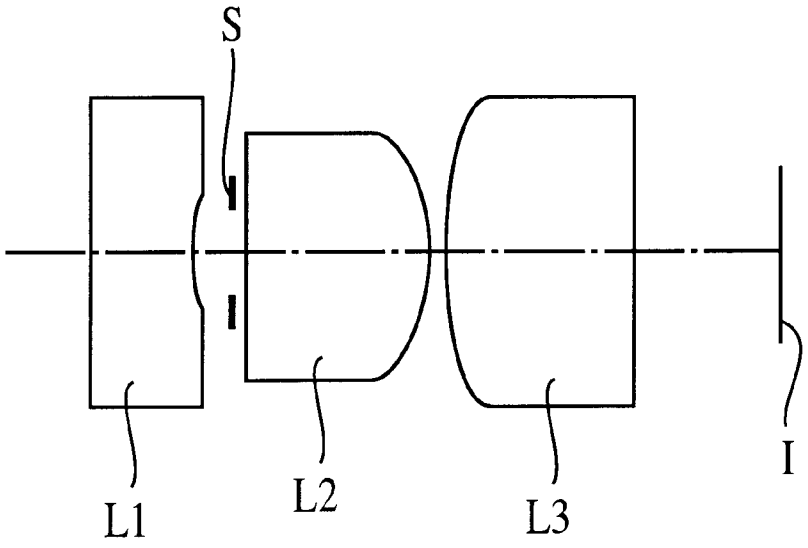
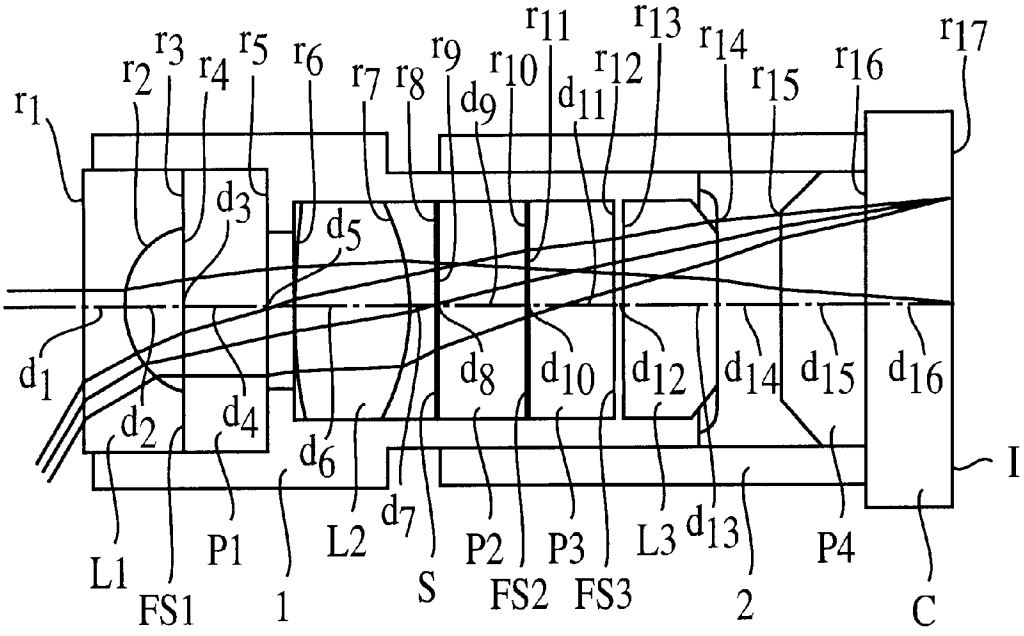


FIG. 5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r2
r3
r4
r5
r6
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r9
r10
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r17
d1
d2
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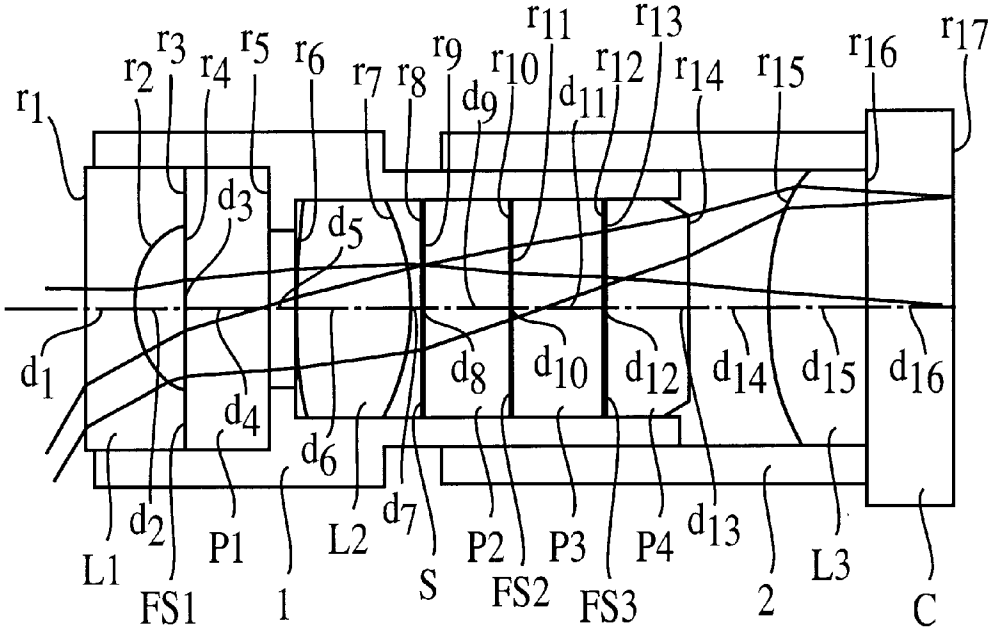
d6
d7
d8
d9
d10
d11
d12
d13
d14
d15
d16
I
L1
FS1
P1
1
L2
S
P2
FS2
P3
FS3
L3
2
P4
C

FIG. 6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d13
d14
d15
d16
L1
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P1
1
L2
S
P2
FS2
P3
FS3
P4
2
L3
C

FIG. 7

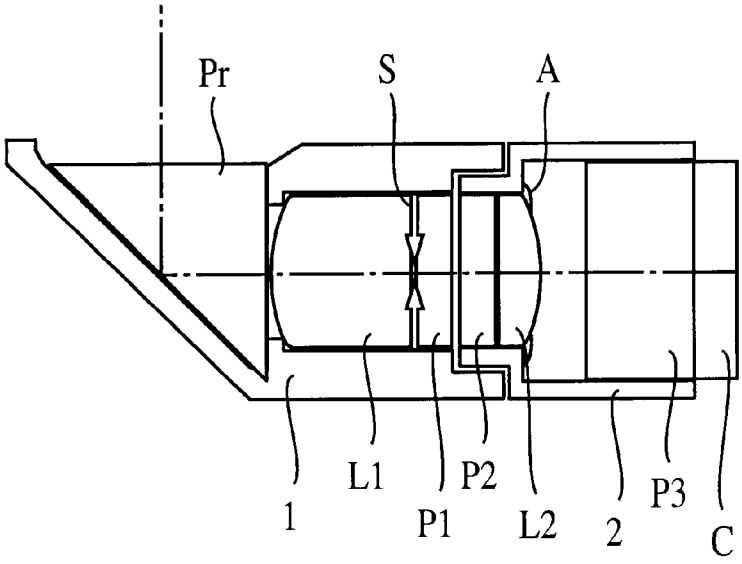

FIG. 8(a)

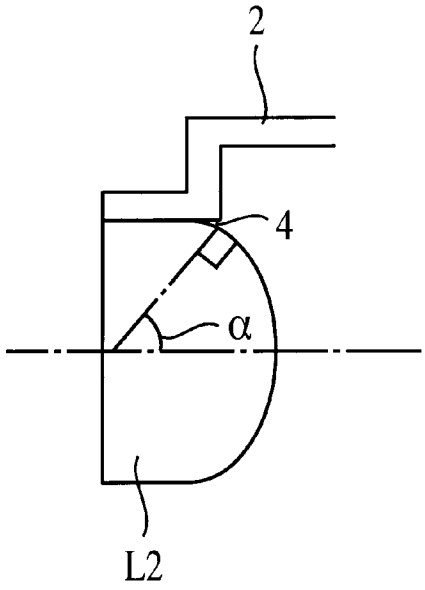

FIG. 8(b)

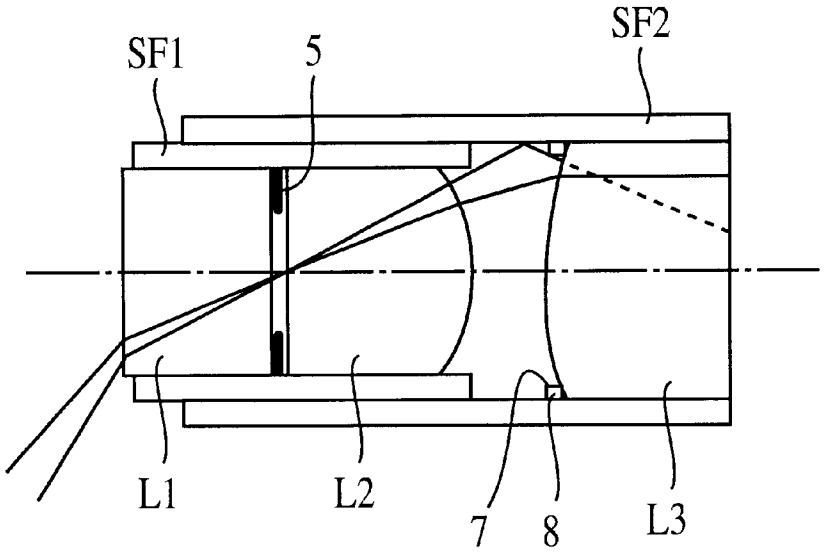

FIG. 9
(PRIOR ART)

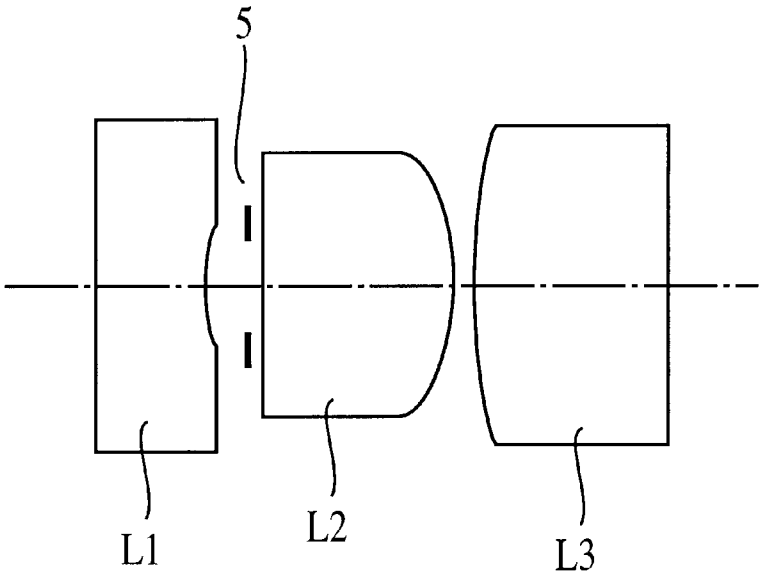

FIG. 10
(PRIOR ART)

OBJECTIVE LENS

BACKGROUND OF THE INVENTION

An endoscope is inserted into narrow spaces such as human internal body parts or the interior of an engine. Therefore it is desirable that the outer diameter of an endoscope be as small as possible, and this requires that the diameter of the lens that is arranged at the tip of an endoscope be as small as possible. An example of a lens of an endoscope that has a comparatively small diameter and wherein the lens is made using only a few lens elements is described in Japanese Laid-Open Patent Applications H9-68647 and H7-84179.

FIG. **9** illustrates the same objective lens element structure as that of Example 1 of Japanese Laid-Open Patent Application H9-68647, but includes different labels and, in addition to showing the objective lens elements themselves, FIG. **9** also illustrates conjectured support structure and flare-reducing structure for these lens elements. The lens comprises, in order from the object side, a first lens element lens **L1**, an aperture stop **5** (ie., a brightness diaphragm), a second lens element **L2** of positive refractive power and a third lens element **L3** of positive refractive power. In one embodiment of Japanese Laid-Open Patent Application H9-68647, lens element **L1**, which in all other embodiments is piano-concave, is replaced by a plane-parallel cover plate. Although no support structure whatsoever for these lens elements is actually shown in Japanese Laid-Open Patent Application H9-68647, FIG. **9** illustrates the assumed support structure for these components based on standard practices in the art, as will now be discussed. Because the first lens element **L1** (or cover plate, as the case may be) and the second lens element **L2** have the same outer diameter, they have been illustrated in FIG. **9** as being fixed to a first support frame **SF1**. An aperture stop **5** lies between the first lens element **L1** and the second lens element **L2**. Thus, the first support frame **SF1**, is shown supporting these three elements. Further, it is likely that the outer diameter of the first support frame **SF1** would be sized to equal the outer diameter of the third lens element **L3**, which in Japanese Laid-Open Patent Application H9-68647 is shown as having an outer diameter that is slightly larger than the outer diameter of the other two lens elements. Having their outer diameters equal would enable the first support frame **SF1** and the second lens element **L2** to each be inserted into a second support frame **SF2**, as illustrated in FIG. **9**. Adjacent lens element **L3** in FIG. **9** is illustrated a conjectured flare diaphragm **7** and a diaphragm receiving member **8**, as would commonly be used in the prior art to form a flare stop.

FIG. **10** illustrates the lens element structure of Example 6 of Japanese Laid Open Patent Application H7-84179. The lens of this example includes, in order from the object side, a plano-concave lens **L1**, an aperture stop **5**, a positive meniscus lens element **L2**, and a positive lens element **L3**.

In image formation lenses generally, in order to remove the light which does not contribute to image formation, a flare stop is often provided. There is no known description in the above-mentioned two patents which relates to a flare stop. However, as shown in prior art FIG. **9** for optical diaphragms generally, a flare diaphragm **7** and a diaphragm receiving member **8** are often provided on the object side of lens element **L3**. In many cases, such a flare stop is provided at this position in order to prevent stray light that has been reflected off the inner surface of the frame from passing through to the observer. The flare stop is positioned before lens element **L3** because stray light rays (i.e., those from a larger angle of view than for which the lens was designed to image) in many cases are incident on the frame between positive lens elements **L2** and **L3**.

However, if the outer diameter of a lens element is made smaller to achieve size reduction, the associated diaphragm receiving member and flare stop member must also be made smaller. Because these members are each shaped as an annular ring which circumscribes an aperture having a diameter that is nearly the same diameter as the lens element itself, as the lens element becomes smaller, the width of the annular ring becomes so small that manufacture and assembly of the ring become difficult.

Although it is known to bevel the edge of a lens element so as to form a sloped surface near the circumference of the lens element and to use this surface to self-center a lens element in lieu of using a spacer ring (as taught, for example, in U.S. Pat. No. 5,589,989) there is no teaching in this reference or any other reference known to applicant which suggests beveling an edge of a lens element and applying a light shielding material (i.e., one which absorbs or attenuates light) to a sloped surface created by the beveling process in order to reduce flare. Nor is there any suggestion that such an approach to reducing flare will result in fewer components and result in an overall cost reduction for assembling a lens system having small diameter components.

BRIEF SUMMARY OF THE INVENTION

The present invention forms an inclined or sloped surface on an optical member (such as a lens element, plane-parallel plate of a filter or cover glass, etc.), near the outer diameter of the optical member and applies a light shielding substance to the sloped surface in order to achieve flare reduction. The sloped or inclined surface, which may be the lens element surface itself, is immediately adjacent a circumferential edge of the optical element, and the circumferential edge is supported by a holding member. Alternatively, the present invention omits forming a separate, planar, sloped surface for the light shield, and instead designs the optical member so a light shielding substance may be easily applied to a sloped surface of a convex lens element near its periphery in order to shield flare from reaching the image. Flare, as used herein, refers to unwanted light which enters an optical system outside the intended field of view and is reflected toward the image plane by one or more surfaces of the optical system. A first object of the invention is to avoid using an annular ring for flare reduction in the case where the diameter of the optical member is small A second object of the invention is to enable the overall manufacturing and assembly cost of an optical system to be reduced by achieving the first object of the invention, while still maintaining adequate flare reduction. Thus, the present invention relates particularly to very small optical members, such as lens elements, filters or cover plates as may be found in endoscopes, or in other applications (e.g., in small electronic cameras, small cameras for monitoring, etc.) where size reduction causes the prior art structures and methods for flare reduction (discussed above) to become unsatisfactory.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will become more fully understood from the detailed description given below and the accompanying drawings, which are given by way of illustration only and thus are not limitative ofthe present invention, wherein:

FIG. **1**(*a*) is a side, sectional view of a first embodiment of the invention,

FIG. **1**(*b*) is an end view of the lens element **L2** shown in FIG. **1** (*a*),

FIG. **2**(*a*) is a side, sectional view of a second embodiment of the invention,

FIG. **2**(*b*) is a different sectional view of the second embodiment of the invention, in the case where a square detector is used that eats into the optical surface of lens **L2** from four sides.

FIG. **3** is a side, sectional view of a third embodiment of the invention,

FIG. **4** is a sectional view of a fourth embodiment of the invention,

FIG. **5** is a sectional view of a fifth embodiment of the invention, less the support structure for the optical elements,

FIG. **6** is a sectional view of a sixth embodiment of the invention,

FIG. **7** is a sectional view of a seventh embodiment of the invention,

FIG. **8**(*a*) is a sectional view of an eighth embodiment of the invention,

FIG. **8**(*b*) is an expanded view of the lens element **L2** shown in FIG. **8**(*a*),

FIG. **9** is a sectional view of a conventional lens, and

FIG. **10** is a sectional drawing of another conventional lens, less the support structure for the optical elements.

DETAILED DESCRIPTION

As used herein, the term "optical member" refers to either a single lens element, two lens elements that are cemented together, a plane-parallel plate such as a filter or cover glass, or any combinations of these elements. The present invention relates particularly to optical systems having small diameter optical members. However, the invention may also find utility in other optical systems as well. In optical systems having small diameter optical members, the invention enables such systems to be made and assembled less expensively than previously possible while retaining the same capability of preventing unwanted light from outside the design field of view of the lens from reaching the image plane. Such light is termed flare and, if not shielded, may reach the image surface as a result of undesired reflections of off-axis rays within the lens and cause artifacts in the image.

In the present invention, it is preferable if the following Conditions (1) and (2), below, are satisfied.

$$\Phi 1 < 3 \text{ mm} \qquad \text{Condition (1)}$$

$$0.6 < \Phi 2/\Phi 1 < 0.95 \qquad \text{Condition (2)}$$

where

$\Phi 1$ is the outer diameter of an optical member

$\Phi 2$ is the maximum clear aperture diameter of the optical member (excluding a peripheral region, to which is applied a light shielding substance).

If the upper limit value of 0.95 of Condition (2) is exceeded, there will be too little width to adequately shield the rays that cause flare at the image plane. In other words, the slope becomes smaller, and the effect of flare reduction decreases. Moreover, if the lower limit value (0.6) of Condition (2) is not satisfied, the outer diameter for the portion of the optical member other than the slope will become large. Thus, although flare reduction will be obtained, light throughput of the optical member will become small and the image brightness will decrease.

Moreover, it is better if either of the stricter conditions (3) or (4) is satisfied by at least one of the optical members in the lens of the invention.

$$\Phi 1 < 2 \text{ mm} \qquad \text{Condition (3)}$$

$$0.6 < \Phi 2/\Phi 1 < 0.85 \qquad \text{Condition (4)}$$

In other words, instead of merely satisfying Conditions (1) and (2), it is better if one of the stronger Conditions (3) and (4) is also satisfied by at least one of the optical members in the lens of the invention. Further, it is best if both of the stronger Conditions (3) and (4) are satisfied by at least one of the optical members in the lens of the invention.

A lens according to the invention includes, in order from the object side, an aperture stop, a positive lens element having a convex surface on the image side, and a positive lens element having a convex surface on the object side. Further, the positive lens element with the convex surface on the object side is held by a holding member, a region of the convex surface near the edge of this positive lens has a slope, the slope has a light attenuating or light absorbing material thereon which reduces flare by the slope being near the region (and thus in the path) where a light ray from outside the visual field reflects at the interior of the holding member and is incident on the convex surface side of a positive lens element.

The lens of this invention includes a lens element, plane-parallel plate (such as a filter or cover glass) or other optical member. A slope is provided on the circumference edge of at least one optical member. A fight shield is provided on the slope, and the following condition is satisfied.

$$0.5 < D/f < 2 \qquad \text{Condition (5)}$$

where

D is the air path equivalent length (i.e., the sum of the values d/n) from the on-axis position of the surface of the optical member having the slope formed thereon to an image surface, and

f is the focal length of the lens.

Condition (5) defines the distance from the on-axis position of the surface which includes the slope to the image surface. In other words Condition (5) defines an effective axial position for the slope which removes flare, which also corresponds to the axial position at which flare tends to be generated by light being reflected off a framework surface.

In the objective optical system of the above-mentioned type with two convex surfaces, the principal ray has a tendency to become farther removed from the optical axis as it progresses past the aperture stop. For this reason, since the image surface tends to be close to the aperture stop at the position where the upper limit of Condition (5) is exceeded, the light ray height is low. Removal of flare light, on the other hand, is best achieved where the ray height is high, i.e., where it is so high that it reflects from the frame. For this reason, axial positions near an aperture stop are not suitable as a position for providing a flare stop.

On the other hand, if the lower limit of Condition (5) is exceeded, the flare stop must be too near the image surface, making it impossible to remove flare that is generated before the slope. Moreover, there is a possibility that the image-formation beam for which the height of the light-rays becomes high may be scattered.

The lens of this invention relates particularly to optical members which are inserted and held inside a holding member. A slope is formed on an annular surface of an optical member in a section adjacent to the edge of the

optical surface that is held by the holding member. Usually, the optical member selected for having the flare-reducing slope is the one nearest the image side of the holding member. In the case where a lens has several optical members and holding members, and the optical members are held by different holding members, at least one of the optical members held by the holding member which is nearest the image side should have a flare-reducing slope (either a planar or convex slope) provided.

An important characteristic of the present invention is that a flare stop that is an integral part of the optical member is provided. A conventional flare stop is in many cases inserted and held between optical members. Many optical members, such as a lens element provided at the end of a support frame of a lens, do not have another optical member attached in the same support frame (on one side). Thus, using a conventional flare stop becomes difficult, since there are not the necessary optical components within which the flare stop may be inserted. For this reason, when flare removal is necessary at such a position, it is preferable to employ the slope structure of the present invention for flare reduction.

Furthermore, in forming a light shielding means using adhesives while fixing a lens element to a frame, a specially formed (i.e., planar) slope for supporting the light absorbing or light attenuating adhesive material to shield against flare is not required, provided the following Condition (6) is satisfied:

$$\Phi 1/(2\times|R|)>0.34 \qquad \text{Condition (6)}$$

where Φ1 and R are as defined above.

Condition (6) provides that the angle between a normal to the lens element surface at the periphery of the lens and the optical axis is greater than 20°, thereby ensuring that a groove **4**, as illustrated in FIG. **8**(*b*), is formed at the periphery of the lens element in which a light shielding adhesive may be applied to the sloped, convex surface of a positive lens at the lens periphery for flare reduction.

Several embodiments of the invention will now be described in detail, with reference to the drawings.

Embodiment 1

FIG. **1**(*a*) is a side, sectional view of a first embodiment of the invention. The lens of this embodiment includes two lens elements, and is formed of the following components, in order from the object side: a cover glass C**1**, a film (not visible in this side view), a first lens element L**1** of positive power, a second lens element L**2** of positive power, and a second cover glass C**2**. The cover glass C**1** has film (not visible in this view) deposited on a portion of its image-side surface, and the film thus serves as an aperture stop. A first lens element L**1** is cemented to the film and the remaining portion of the image-side surface of the cover glass C**1**, and all of these elements are inserted within and held by a first frame **1**. The first frame **1** is partially inserted into one end of a second frame **2**, and all of these components are fixed by bonding. A second lens element L**2** having an outer diameter the same as, or nearly the same as, that of the outer diameter of the first frame **1** is inserted within the other end of the second frame **2** and is fixed by being bonded. Second frame **2** maintains a cover glass C**2** of an image pick-up element against its image-side end. Moreover, the image side of the cover glass C**2** is at the position of the image plane I, which coincides with the pick-up face of a detector, such as a CCD array.

For the lens of this first embodiment, the circumference edge of the convex surface on the object side of the second positive lens element L**2** is made to have a planar slope A**1**, as illustrated. The slope A**1** extends to the side of the lens element and provides an annular cone-like surface. The slope A**1** itself provides some assistance in reducing flare by reason of its ability to reflect some of the flare fight reflected off the second frame **2** in a direction away from the image. However, in those embodiments of the present invention which use a separately-formed, planar slope to reduce flare, a light shielding material (not visible in this view) is applied to this slope to prevent the passage of light reflected from second frame **2** from progressing to the image plane at I.

FIG. **1**(*b*) is an end view of the lens element L**2** shown in FIG. **1**(*a*). The outer diameter of this lens element is Φ1 and the maximum clear aperture diameter is Φ2, as illustrated. In this embodiment Φ1 is 1 mm and Φ2 is 0.75 mm; thus, the ratio Φ2/Φ1 is 0.75. This embodiment prevents the sloping surface from eclipsing part of the image-forming beam, and thus enables a maximum image height to pass to the image plane unhindered.

Also, the air path equivalent length D from the on-axis position of the object side surface of the second positive lens element L**2** to the image plane at I is 0.6 mm. The focal distance of the lens is 0.626 mm. Therefore, the ratio of D/f is 0.96, which satisfies Condition (5).

The slope angle θ1 (illustrated in FIG. **1**(*a*)) of the second positive lens element L**2** is 45 degrees. Moreover, this amount is less than 70 degrees, which is advantageous.

In this embodiment, the second positive lens element L**2** is attached to the second frame **2** with a black adhesive. The black adhesive is coated on the periphery surface of the lens (ie., the part supported by the frame) as well as on the slope A**1**. Thus, the adhesive serves to block light from passing through the lens portion having slope A**1**. Alternatively, the bonding of the lens elements to the lens frame can use a more common adhesive that is transparent or translucent, and instead of using adhesive on the slope A**1**, this portion can be coated with black paint to thereby enable the slope A**1** to block off-field light that has been reflected by the frame **2** or the periphery surface of a lens element from passing through to the image plane at I.

The lens of this embodiment can be used for an endoscope, an electronic camera, a surveillance camera, etc.

Table 1 lists the surface # in order from the object side, the radius of curvature R (in mm) of each surface, the on-axis surface spacing d (in mm) of each surface, as well as the index of refraction N_d and the Abbe constant V_d (for the d-line) of each optical member of Embodiment 1. In the bottom portion of the table are listed some of the performance values of the lens of this embodiment.

TABLE 1

#	R	d	N_d	V_d
1	∞	0.2000	1.51633	64.15
2	∞	0.4500	1.51633	64.15
3	0.4420	0.1600		
4	0.9770	0.5000	1.51633	64.15
5	∞	0.4000	1.51633	64.15
6	∞			
F_{NO} = 5.2 D/f = 0.95	Image height = 0.45		f = 0.626	D = 0.594

Embodiment 2

FIG. **2**(*a*) illustrates a second embodiment of the invention. The lens of this embodiment includes a first cover glass C**1**, a first lens element L**1** of positive power, a second lens

element L2 of positive power, and a charge-coupled device (hereinafter CCD) cover glass C2. These optical members are inserted in a single frame **3** having one end bored to a larger diameter than the other end. In this embodiment, a square image pick-up surface of an image pick-up element (not shown) is used. As shown in FIG. **2**(*b*), four sloped surfaces A1 (which correspond to segments ofthe annular ring A1 illustrated in FIG. **1**(*b*)) are visible and a light shield is provided on each of these sloped surfaces.

The outer diameter Φ1 of the second lens element L2 of this embodiment is 1.2 mm, and the diameter Φ2 the part except for the slope (i.e., the maximum clear aperture) is 0.84 mm. Further, Φ2/Φ1 equals 0.7. Moreover, the air equivalent path length D from the on-axis position of the second lens element L2 to the image plane I is 0.466 mm. The focal distance of the lens is 0.66 mm Therefore, D/f is 0.71.

Table 2 lists the surface # in order from the object side, the radius of curvature R (in mm) of each surface, the on-axis surface spacing d (in mm) of each surface, as well as the index of refraction N_d and the Abbe constant V_d (for the d-line) of each optical member of Embodiment 2. In the bottom portion of the table are listed some of the performance values of the lens of this embodiment.

TABLE 2

#	R	d	N_d	V_d
1	∞	0.2000	1.51633	64.15
2	∞	0.6100	1.88300	40.76
3	−0.8170	0.4100		
4	1.1310	0.3800	1.88300	40.76
5	∞	0.4000	1.51633	64.15
6	∞			
F_{NO} = 5.5 D/f = 0.71	Image height = 0.45		f = 0.66	D = 0.466

Embodiment 3

FIG. **3** illustrates a third embodiment of the lens of the present invention. In this embodiment the lens includes a cover glass C1, a first lens element L1 of positive power, a second lens element L2 of positive power, an infrared cut-off filter F, and a CCD cover glass C2. The cover glass C1 and the first lens L1 of positive power are held by the first frame **1**. The second positive lens element L2 and the infrared cut-off-filter F are joined and held by the second frame **2**, and C2 is the CCD cover glass.

In this third embodiment, the second positive lens element L2 and the infrared cut-off filter F are joined to form an integrated part. A slope A2 is provided on the object side of this optical member, and a light shading means, which may be formed of a light absorbing substance or film, is provided on the slope A2. Therefore, the second lens element L2 does not provide a side for attaching to a support frame **2**. However, if the integrated optical member provides the side, installation is not affected.

In this third embodiment, the outer diameter Φ1 of the optical member is 2.85 mm, and the maximum clear aperture diameter Φ2 is 2.28 mm. Therefore, the ratio of Φ2/Φ1 is 0.8. Moreover, the air path equivalent length from the on-axis convex surface with the slope to the image surface is 1.173 mm. The focal-distance ofthe lens is 1.239 mm. Therefore, the ratio D/f is 0.95.

Table 3 fists the surface # in order from the object side, the radius of curvature R (in mm) of each surface, the on-axis surface spacing d (in mm) of each surface, as well as the index of refraction N_d and the Abbe constant V_d (for the d-line) of each optical member of Embodiment 3. In the bottom portion of the table are listed some of the performance values of the lens of this embodiment.

TABLE 3

#	R	d	N_d	V_d
1	∞	1.5000	1.88300	40.76
2	∞	1.3875	1.88300	40.76
3	−1.5367	0.3750		
4	2.5485	0.8325	1.75500	52.32
5	∞	0.7500	1.49400	75.00
6	∞	0.3000	1.52287	59.89
F_{NO} = 6.9 D/f = 0.95	Image height = 1.23		f = 1.239	D = 1.173

Embodiment 4

FIG. **4** illustrates a fourth embodiment of the lens of the present invention. This embodiment of the invention is an improvement over the conventional optical system shown in FIG. **9**. The lens of FIG. **4** includes a cover glass C3, an aperture stop S, a first lens element L1 of positive power, and a second lens element L2 of positive power. The cover glass C3, the aperture stop S, and the first lens element L1 of positive power are held by the first frame **1**. The second lens element L2 of positive power as well as the first frame **1** are held by the second frame **2**.

In this embodiment, a slope is formed on the circumference part of the surface on the object side of the second lens element L2 of positive power, without employing a flare stop as in the prior art. Black paint or black ink is applied at this slope so as to form a light blocking region or shade.

The outer diameter Φ1 of the second lens element L2 of this embodiment is 0.5 mm, and the maximum clear aperture diameter Φ2 is 0.4 mm. Therefore, Φ2/Φ1=0.8. The air path equivalent length D from the object side of the positive lens element L2 to the image surface at I is 0.214 mm. The focal distance ofthe lens is 0.32 mm. Therefore, the ratio D/f is 0.67.

Table 4 lists the surface # in order from the object side, the radius of curvature R (in mm) of each surface, the on-axis surface spacing d (in mm) of each surface, as well as the index of refraction N_d and the Abbe constant V_d (for the d-line) of each optical member of Embodiment 4. In the bottom portion of the table are listed some of the performance values of the lens of this embodiment.

TABLE 4

#	R	d	N_d	V_d
1	∞	0.30	1.88300	40.8
2	∞	0.03		
3	∞	0.37	1.88300	40.8
4	−0.346	0.15		
5	0.725	0.37	1.72916	54.7
6	∞			
F_{NO} = 1.75 D/f = 0.67	Image height = 0.24		f = 0.32	D = 0.214

Embodiment 5

FIG. **5** illustrates a fifth embodiment of the lens of the present invention, which applies the invention to the prior art example shown in FIG. **10**. That is, the lens is formed of, in order from the object side: a negative lens element L1, a

diaphragm S, a first lens element L2 of positive power and a second lens element L3 of positive power. A slope is provided on the object-side surface of the second lens element L3, and a light shield is again provided in this slope.

For this embodiment, the outer diameter Φ1 of the second positive lens element L3 is 1 mm The maximum clear aperture diameter Φ2 of this lens element is 0.85 mm. Therefore, Φ2/Φ1=0.85. The air path equivalent length D from the optical member with the flare stop to the image surface I is 0.798 mm. Further, the focal distance f of the lens is 0.52 mm Therefore, D/f=1.53.

Table 5 lists the surface # in order from the object side, the radius of curvature R (in mm) of each surface, the on-axis surface spacing d (in mm) of each surface, as well as the index of refraction N_d and the Abbe constant V_d (for the d-line) of each optical member of Embodiment 5. In the bottom portion of the table are listed some of the performance values of the lens of this embodiment.

TABLE 5

#	R	d	N_d	V_d
1	∞	0.32	1.51633	64.1
2	0.817	0.13		
3	∞ (aperture stop)	0.03	1.88300	40.8
4	−1.454	0.58	1.88300	40.8
5	−0.538	0.06		
6	1.653	0.58	1.88300	40.8
7	∞			
F_{No} = 2.2 D/f = 1.53	Image height = 0.45		f = 0.52	D = 0.798

Embodiment 6

FIG. 6 shows the lens element structure of the sixth embodiment of the present invention. In this embodiment, the lens is formed of a first lens element L1 that is a plano-concave lens, a plane-parallel plate P1, a second lens element L2 that is a biconvex lens, two plane-parallel plates P2 and P3, a third lens element L3 that is a piano-convex lens, a plane-parallel plate P4, and CCD cover glass C. The image-side surface of plane-parallel plate P4 is attached to the CCD cover glass C and bonded within the frame 2 to form the CCD sub-assembly. A frame I supports lens element L1 and plane parallel plate P1, which are inserted into the object-side end of the frame 1, which has a larger bore at the object side end The frame 1 also supports the second lens element L2, the plane parallel plates P2, P3 as well as the third lens element L3 at the image side of the frame 1, within the smaller bore. The optical members illustrated in FIG. 6 that are held by the frame 1 are bonded thereto after being inserted in the appropriate end of frame 1 so as to form another sub-assembly. These two sub-assemblies can be attached to one another as illustrated and bonded to form the lens.

The light-rays near the CCD sub-assembly are located far from the optical axis. Therefore, flare is easily generated in this vicinity, and accordingly it is necessary to remove flare near the CCD subassembly. Thus, the present invention can be applied in this vicinity to reduce flare. Moreover, if the plane-parallel plate P4 is provided with a slope (as illustrated) near its circumferential edge, any flare resulting from off-field rays being reflected by the inside surface of the frame 2 can be removed. If a slope is provided on an attached cover glass or on a lens element flare generated by off-field rays being reflected by the circumferential edge of these elements or the inside surface of the frame 1 can be removed

As illustrated, a flare stop FS1 is arranged on the object side of a plane-parallel plate P1. Aperture stop S is arranged on the object side of plane-parallel plate P2. A flare stop FS2 is arranged between the two plane-parallel plates P2 and P3, and a flare stop FS3 is arranged between plane-parallel plate P3 and the third lens element L3.

For this sixth embodiment, a slope is provided at the image-side surface of the third lens element L3, i.e., on the surface supported by frame 1 nearest the image-side. A shading means, such as a light absorbing substance, is provided on this slope. In addition, a slope is also provided on the object-side surface of plate P4, and a shading means, such as a light absorbing substance, is also provided on this slope. Thus, the present invention is advantageous if a flare stop is to be provided at a location where, using a conventional flare stop formed of an annular diaphragm, it would be difficult to locate the support for the annular diaphragm. Thus the present invention is especially suitable at locations, such as the image-side end of frame 1, where it would be especially difficult to hold a conventional flare stop.

The outer diameter Φ1 of the third lens element L3, which is the optical member with the slope in this embodiment, is 1 mm. The maximum clear aperture diameter Φ2 (except for the slope) of this optical member is 0.9 mm. Therefore, Φ2/Φ1=0.9. Moreover, the air path equivalent length D from the image side of the third lens element L3 to the image plane I (i.e., measured on-axis from surface #14 to surface #17) is 0.819. The focal distance f of the lens is 0.573 mm; thus, the ratio D/f is 1.43. Moreover, the angle θ1 of the slope provided at the image side of the third lens element L3 is 40 degrees.

When the third lens element L3 is inserted into the frame 1, the third lens element L3 is fixed by applying an adhesive to which India ink has been added and mixed-in. The adhesive is applied not only to the circumference edge of the third lens element L3, but is also applied to the slope. In this way the adhesive serves as the shading means on the slope. The other optical member having a slope provided for flare reduction is plane parallel plate P4. The outer diameter Φ1 of plane-parallel plate P4 in this embodiment is 1.3 mm, and the maximum clear aperture diameter Φ2 is 1 mm Therefore, the ratio Φ2/Φ1 is 0.77. Moreover, the air path equivalent length D from object side surface of plane-parallel plate P4 to the image surface I (measured from surface #15 to surface #17) is 0.529 mm. Thus, D/f is 0.92. The angle of the slope θ1 on this optical member is 60 degrees.

Table 6 lists the surface # in order from the object side, the radius of curvature R (in mm) of each surface, the on-axis surface spacing d (in mm) of each surface, as well as the index of refraction N_d and the Abbe constant V_d (for the d-fine) of each optical member of Embodiment 6. In the bottom portion of the table are listed some of the performance values of the lens of this embodiment.

TABLE 6

#	R	d	N_d	V_d
1	∞	0.2000	1.88300	40.76
2	0.4270	0.2400		
3	∞ (flare stop)	0.0300		
4	∞	0.4000	1.52287	59.89
5	∞	0.1000		
6	2.4060	0.57	1.90135	31.55
7	−0.9770	0.1100		
8	∞ (aperture stop)	0.0300		
9	∞	0.4000	1.51400	75.00

TABLE 6-continued

#	R	d	N_d	V_d
10	∞ (flare stop)	0.0300		
11	∞	0.4000	1.52287	59.89
12	∞ (flare stop)	0.0300		
13	∞	0.4500	1.88300	40.76
14	−2.6340	0.2900		
15	∞	0.4000	1.51633	64.15
16	∞	0.4000	1.51100	64.14
17	∞			
F_{NO} = 3.6	Image height = 0.5		f = 0.573	
For L3:	D = 0.819		D/f = 1.43	
For P4:	D = 0.529		D/f = 0.92	

Embodiment 7

FIG. **7** illustrates the seventh embodiment of the invention. The lens of this embodiment includes a first lens element **L1** formed of a piano-concave lens with its concave surface on the image side, a plane-parallel plate **P1**, a second lens element **L2** that is biconvex, three plane-parallel plates **P2**–**P4**, a third lens element **L3** formed of a piano-convex lens with its convex surface on the object side, and a CCD cover plate C. The third lens element **L3** and the CCD cover glass C are attached to one another. And, the third lens element **L3**, the CCD cover glass C and the CCD array are integrated to form a CCD sub-assembly. An aperture stop S is arranged at the object-side surface of plane-parallel plate **P2**, a flare stop FSI is arranges at the object-side of plane-parallel plate **P1**, and flare stops **FS2** and **FS3** are arranged and pressed between plane-parallel plates **P2**–**P3** and between plates **P3**–**P4**, respectively.

In this embodiment, the flare-reducing slope is formed on the image-side surface of the plane-parallel plate **P4** , which is the optical member at the image-side of frame **1**. The outer diameter Φ1 of plane-parallel plate **P4** is 1 mm The maximum clear aperture diameter Φ2 is 0.9 mm. Therefore, Φ2/Φ1 is 0.9. The air path equivalent length D from the optical element to the image plane (measured on-axis from surface #14 to #17) is 0.879 mm. The focal-distance of the lens is 0.564 mm. Therefore, D/f=1.56. In addition, flare reduction can be maximized if a slope is also provided on the object side of the third lens element **L3**. Moreover, the inclination angle of the slope at the image side of plane-parallel plate **P4** in this embodiment is 50 degrees.

Table 7 lists the surface # in order from the object side, the radius of curvature R (in mm) of each surface, the on-axis surface spacing d (in mm) of each surface, as well as the index of refraction N_d and the Abbe constant V_d (for the d-line) of each optical member of Embodiment 7. In the bottom portion of the table are listed some of the performance values of the lens of this embodiment.

TABLE 7

#	R	d	N_d	V_d
1	∞	0.2000	1.88300	40.76
2	0.4620	0.2100		
3	∞ (flare stop)	0.0300		
4	∞	0.4000	1.51633	64.14
5	∞	0.0900		
6	2.0490	0.5700	1.90135	31.55
7	−1.0090	0.0200		
8	∞ (aperture stop.)	0.0300		
9	∞	0.4000	1.52287	59.89
10	∞ (flare stop)	0.0300		

TABLE 7-continued

#	R	d	N_d	V_d
11	∞	0.4000	1.52287	59.89
12	∞ (flare stop)	0.0300		
13	∞	0.4000	1.51400	75.00
14	∞	0.3700		
15	1.3920	0.4600	1.88300	40.76
16	∞	0.4000	1.51100	64.10
17	∞			
F_{NO} = 3.5	Image height = 0.5		f = 0.564	D = 0.879
D/f = 1.56				

Embodiment 8

FIG. **8**(*a*) illustrates an eighth embodiment of the lens of the present invention. Embodiment 8 includes, in order from the object side, a field transforming optical element Pr, a first lens element **L1** of positive power, aperture stop S, a plane-parallel cover glass **P1** held in a frame **1**, a plane-parallel cover glass **P2**, a second lens element **L2** of positive power, a plane-parallel absorption-type infrared blocking filter **P3** and a CCD cover glass C held in a frame **2**.

This embodiment has a structure wherein the front and back of an optical system can be separated between the two plane-parallel cover glasses **P1** and **P2**. An adapter unit is placed before the plane-parallel cover glass **P1** and a master unit is placed after the plane-parallel cover glass **P2**. The adapter unit may be selected in accordance with the intended purposes.

The marginal section of a surface of the positive lens element **L2** on the image side is fixed to the frame **2** with adhesives A. The adhesives contain a black, light-absorbing material such as carbon so as to form a light shield. In this embodiment, in lieu of there being an inclined section at the marginal periphery of the positive lens element **L2**, the inclination angle of the lens surface itself at the periphery is made large, so that a groove **4** (FIG. **8**(*b*)) is formed between the optical surface and the frame. The light blocking adhesive is then applied to this slot.

The positive lens element **L2** of this embodiment is arranged nearest the image side among those lens elements of the lens having curvature. It is preferable to provide light shielding at the lens element arranged closest to the image side. This is because, as the position of the lens element approaches the image side of the lens, the ray height of a principal ray gets larger (i.e, the ray is farther from the optical axis) and thus it is more likely that flare is generated.

In this embodiment, the outer diameter Φ1 of the second positive lens element **L2** is 1.4 mm and the radius of curvature R ofthe optical surface on the image side is −1.2362. Thus the right side of Condition (6) is 0.57. The air path equivalent length (D) from the on-axis position of the image side of positive lens element **L2** to the image plane I is 1.34 mm and the focal length ofthe lens is 1.98 mm. Therefore, the ratio D/f equals 0.68.

FIG. **8**(*b*) is an expanded view of the lens element **L2** shown in FIG. **8**(*a*). When the angle a between the normal line at the marginal section of an optical surface and the optical axis is larger than 20°, the groove **4** is formed between the optical surface and a frame, so that it will be easy to apply an adhesive to the marginal section without need for forming a separate annular inclined surface near the circumferential edge of the lens, as done for the previous embodiments. Condition (4) is specifies that the angle α exceeds 20°, and the constant 0.34 on the right side of this

condition represents the value of sin 20°. In this embodiment, the adhesive is mixed with a black light absorbing material, such as carbon.

Moreover, in forming a light shield using adhesive mixtures while fixing a lens element to a frame, it is preferable to form the light shield on the lens element, among those lens elements having curvature, that is arranged in the objective portion of the lens nearest the image side. This is because the ray height (i.e., distance from the optical axis) becomes higher as the lens element position approaches the image side, and thus flare is more likely to occur. Furthermore, in forming a light shield using an adhesive mixture while fixing a lens to a frame, it is preferable to satisfy Condition (3) even when Condition (6) is satisfied and an inclined section is not separately formed at the marginal section of an optical surface.

Table 8 lists the surface # in order from the object side, the radius of curvature R (in mm) of each surface, the on-axis surface spacing d (in mm) of each surface, as well as the index of refraction N_d and the Abbe constant V_d (for the d-line) of each optical member of Embodiment 8. In the bottom portion ofthe table are listed some of the performance values of the lens of this embodiment.

TABLE 8

#	R	d	N_d	V_d
1	∞	1.0000	1.88300	40.76
2	∞	1.0000	1.88300	40.76
3	∞	0.0500		
4	1.5896	1.2382	1.88300	40.76
5	1.3113	0.0492		
6	∞ (aperture stop)	0.0300		
7	∞	0.3500	1.51633	40.76
8	∞	0.0500		
9	∞	0.3500	1.51633	64.14
10	∞	0.0300		
11	∞	0.3974	1.88300	64.14
12	−1.2362	0.4069		
13	∞	1.0000	1.49400	75.00
14	∞	0.4000	1.51633	64.14
15	∞	0.0000		
F_{No} = 4.7 D/f = 0.68	Image height = 0.9		f = 1.98	D = 1.34

The invention being thus described, it will be obvious that the same may be varied in many ways. For example, the light shield could be modified to be reflective, since the flare rays would in most instances be reflected to an absorbing surface and thereby be greatly attenuated. Such variations are not to be regarded as a departure from the spirit and scope of the invention. Rather the scope of the invention shall defined as set forth in the following claims and their legal equivalents. All such modifications as would be obvious to one skilled in the art are intended to be included within the scope of the following claims.

What is claimed is:

1. In a lens in which an optical member having an optical axis is inserted inside and held by a holding member, the improvement of:

the optical member having a sloped surface that is non-parallel to the optical axis and a circumferential edge, said sloped surface being immediately adjacent the circumferential edge, the circumferential edge being supported by said holding member; and

a light absorbing or light attenuating substance on said sloped surface, so that off-axis light rays from outside the designed angle of view of said lens which strike an inside surface of the holding member or the circumferential edge of the optical member are intercepted by the sloped surface and absorbed or attenuated, thereby reducing flare in an image plane of said lens.

2. The lens of claim **1**, wherein said sloped surface is either planar or convex.

3. The lens of claim **1**, wherein the diameter of the lens is 3 mm or less.

4. In a lens in which an optical member is inserted inside and held by a holding member, the improvement of:

the optical member having a sloped surface outside the circumference of a maximum clear aperture portion of said optical member; and

a light absorbing or light attenuating substance on said sloped surface, so that off-axis light rays from outside the designed angle of view of said lens which strike an inside surface of the holding member or the circumferential edge of an optical member held by the holding member may be intercepted by the sloped surface and absorbed or attenuated, thereby reducing flare in an image plane of said lens, said lens further satisfying the following conditions:

$$\Phi 1<3 \text{ mm}$$

$$0.6<\Phi 2/\Phi 1<0.95$$

where

Φ1 is the outer diameter of an optical member, and

Φ2 is the diameter of the maximum clear aperture portion of said optical member.

5. A lens having an optical axis and comprising, in order from the object side:

an aperture stop;

a first lens element of positive power with a convex surface on the image side;

a second lens element of positive power with a convex surface on the object side; and

a holding member;

wherein

the second lens element is inserted into and is held by the holding member;

the second lens element has a sloped surface that is non-parallel to the optical axis and a circumferential edge, said sloped surface being immediately adjacent the circumferential edge, the circumferential edge being supported by said holding member; and

the sloped surface has a light absorbing or light attenuating substance applied thereto,

whereby

off-axis light rays from outside the designed angle of view of said lens and which strike an inside surface of the holding member or the circumferential edge of an optical member held by the holding member are intercepted by the sloped surface and absorbed or attenuated, thereby reducing flare in an image plane of said lens.

6. The lens of claim **5**, wherein the diameter of the lens is 3 mm or less.

7. In a lens wherein an optical member is inserted within and held by a holding member, the improvement of:

the optical member having a sloped surface at the circumference edge of an optical face, and

a light absorbing or light attenuating substance provided on the slope surface;

wherein

the on-axis position of the optical face which includes the sloped surface satisfies the following condition

$$0.5<D/f<2$$

where

D is the air path equivalent length from the on-axis position of the optical face which includes the sloped surface to the image plane of said lens, and

f is the focal length of said lens.

8. The lens of claim **7**, said lens further satisfying the following condition:

$$0.6<\Phi2/\Phi1<0.95$$

where

Φ1 is the outer diameter of the optical member, and

Φ2 is the diameter of the optical member excluding the sloped surface.

9. The lens of claim **7**, said lens further comprising, in order from the object side:

an aperture stop;

a first lens element of positive power with a convex surface on the image side;

a second lens element of positive power with a convex surface on the object side; and

a holding member;

wherein

the second lens element is inserted into and is held by the holding member;

the second lens element has a sloped surface outside the circumference of a clear aperture portion of the second lens element; and

the sloped surface has a light absorbing or light attenuating substance applied thereto,

whereby

off-axis light rays from outside the designed angle of view of said lens and which strike an inside surface of the holding member or the circumferential edge of an optical member held by the holding member may be intercepted by the sloped surface and absorbed or attenuated, thereby reducing flare in an image plane of said lens.

10. In a lens in which an optical member is inserted inside and held by a holding member, the improvement of:

the optical member having a sloped surface outside the circumference of a maximum clear aperture portion of said optical member said sloped surface being either planar or convex; and

a light absorbing or light attenuating substance on said sloped surface, so that off-axis light rays from outside the designed angle of view of said lens which strike an inside surface of the holding member or the circumferential edge of an optical member held by the holding member may be intercepted by the sloped surface and absorbed or attenuated, thereby reducing flare in an image plane of said lens, said lens further satisfying the following conditions:

$$\Phi1<3 \text{ mm}$$

$$0.6<\Phi2/\Phi1<0.95$$

where

Φ1 is the outer diameter of the optical member, and

Φ2 is the diameter of the optical member excluding the sloped surface.

11. In a lens in which a sub-assembly is inserted within and held by a first holding member and the sub-assembly is formed of a plurality of optical members that are combined and held by a second holding member, the improvement of:

among the optical members that are held by at least one holding member, the optical member nearest the image side having a circumferential edge and an inclined surface, the inclined surface being immediately adjacent the circumferential edge of the optical member, the circumferential edge being supported by said holding member; and

the inclined surface including a light attenuating or light absorbing substance,

whereby

off-field light, which passes through an optical surface and is reflected at an inner surface of a holding member or at a circumferential edge of an optical member, is incident on the inclined surface.

12. The lens of claim **11**, said inclined surface being either planar or convex.

13. The lens of claim **11**, said lens further comprising, in order from the object side:

an aperture stop;

a first lens element of positive power with a convex surface on the image side;

a second lens element of positive power with a convex surface on the object side; and

a holding member;

wherein

the second lens element is inserted within and held by the holding member, said second lens element including an inclined surface at a marginal section of its object-side surface, said inclined surface including a light absorbing or light attenuating substance.

14. The lens of claim **11**, wherein the diameter of the lens is 3 mm or less.

15. In a lens in which a sub-assembly is inserted within and held by a first holding member and the sub-assembly is formed of a plurality of optical members that are combined and held by a second holding member, the improvement of:

among the optical members that are held by at least one holding member, the optical member nearest the image side having an inclined surface outside a clear aperture of an optical surface; and

the inclined surface including a light attenuating or light absorbing substance,

whereby

off-field light which passes through an optical surface and is reflected at an inner surface of a holding member or at a periphery edge of an optical member, is incident on the inclined surface;

said lens further satisfying the following conditions:

$$\Phi1<3 \text{ mm}$$

$$0.6<\Phi2/\Phi1<0.95$$

where

Φ1 is the outer diameter of the optical member, and

Φ2 is the diameter of the optical member excluding the sloped surface.

16. In a lens in which a sub-assembly is inserted within and held by a first holding member and the sub-assembly is formed of a plurality of optical members that are combined and held by a second holding member, the improvement of:

among the optical members that are held by at least one holding member, the optical member nearest the image side having an inclined surface outside a clear aperture of an optical surface; and

the inclined surface being either planar or convex and including a light attenuating or light absorbing substance,

whereby

off-field light which passes through an optical surface and is reflected at an inner surface of a holding member or at a periphery edge of an optical member, is incident on the inclined surface;

said lens further satisfying the following conditions:

$$\Phi 1<3 \text{ mm}$$

$$0.6<\Phi 2/\Phi 1<0.95$$

where

Φ1 is the outer diameter ofthe optical member, and

Φ2 is the diameter of the optical member excluding the sloped surface.

17. In a lens having an optical axis in which a sub-assembly is inserted within and held by a holding member and the sub-assembly includes optical members that are held by a first frame, the improvement of:

at least one of said optical members having an inclined surface that is non-parallel to the optical axis and a circumferential edge, said inclined surface begin a immediately adjacent the circumferential edge, the circumferential edge being supported by said holding member, said inclined surface having an adhesive applied thereto which includes a light absorbing or light attenuating substance.

18. The lens of claim **17**, wherein the diameter of the lens is 3 mm or less.

19. In a lens in which a sub-assembly is inserted within and held by a holding member and the sub-assembly includes optical members that are held by a first frame, the improvement of:

at least one of said optical members having an inclined surface at a marginal section, said inclined surface having an adhesive applied thereto which includes a light absorbing or light attenuating substance;

wherein the optical member having an inclined surface is one of:

a CCD cover glass,

an optical member that is positioned directly in front of a CCD cover glass, or

an optical member directly in front of a CCD unit.

20. In a lens in which a sub-assembly is inserted within and held by a first holding member, said sub-assembly including one or more optical members being held by a second holding member, the improvements comprising:

an optical member having a light absorbing or light attenuating substance on an optical surface that is outside a clear aperture of said optical member;

the light absorbing or light attenuating substance being mixed with an adhesive to form an adhesive mixture, said optical member being fixed by said adhesive mixture to a holding member and applied in a groove near the outer circumference of the optical member, said groove being formed by the optical member satisfying the following condition

$$\Phi 1/(2\times|R|)>0.34$$

where

Φ1 is the outer diameter of the optical member to which the adhesive mixture is applied, and

R is the radius of curvature of the optical surface on which the adhesive mixture is applied.

21. The lens of claim **20**, wherein the optical member on which the adhesive mixture is applied is the lens element arranged closest to the image side of said lens.

22. The lens of claim **20**, wherein the optical surface on which an adhesive mixture is applied is positioned axially so as to satisfy the following condition

$$0.5<D/f<2$$

where

D is the air path equivalent length between the on-axis position of the optical surface having the adhesive mixture applied and the image surface of said lens, and

f is a focal length of the lens.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

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DATED : May 29, 2001
INVENTOR(S) : Nakamura

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 7,
Line 63, change "ofthe" to -- of the --;

Column 8,
Line 40, change "ofthe" to -- of the --;

Column 10,
Line 53, change "d-fine" to -- d-line --;

Column 12,
Line 56, change "ofthe" to -- of the --;

Column 15, claim 10,
Line 49, insert a comma after "optical member";

Column 17, claim 16,
Line 20, change "ofthe" to -- of the --; and

Column 17, claim 17,
Line 30, change "begin" to -- being --.

Signed and Sealed this

Fifteenth Day of January, 2002

Attest:

Attesting Officer

JAMES E. ROGAN
Director of the United States Patent and Trademark Office

US006236521B1

(12) **United States Patent**
Nanba

(10) **Patent No.: US 6,236,521 B1**
(45) **Date of Patent: May 22, 2001**

(54) **OBJECTIVE LENS AND IMAGE PICKUP DEVICE USING THE SAME**

(75) Inventor: **Norihiro Nanba**, Kawasaki (JP)

(73) Assignee: **Canon Kabushiki Kaisha**, Tokyo (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/245,309**

(22) Filed: **Feb. 5, 1999**

(30) **Foreign Application Priority Data**

Feb. 9, 1998 (JP) 10-042874
Feb. 25, 1998 (JP) 10-060640

(51) **Int. Cl.**[7] **G02B 3/02**
(52) **U.S. Cl.** **359/715**; 359/660; 359/661; 359/781; 359/782
(58) **Field of Search** 359/660, 661, 359/781, 782, 715

(56) **References Cited**

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* cited by examiner

Primary Examiner—Georgia Epps
Assistant Examiner—Tim Thompson
(74) *Attorney, Agent, or Firm*—Fitzpatrick, Cella, Harper & Scinto

(57) **ABSTRACT**

An objective lens including first, second, third, and fourth lens units in order from the object side. The first lens unit consists of a first lens of negative refractive power in the shape of a meniscus with a concave surface toward the image field side. The second lens unit consists of a second lens of positive refractive power. The third lens unit consists of a composite lens having joined together a third lens of negative refractive power with a concave surface toward the object side and a fourth lens of positive refractive power with a convex surface toward the image field side, the third lens unit having as a whole negative refractive power. The fourth lens unit consists of a fifth lens of positive refractive power. The objective lens has a predetermined condition for focal length.

22 Claims, 20 Drawing Sheets

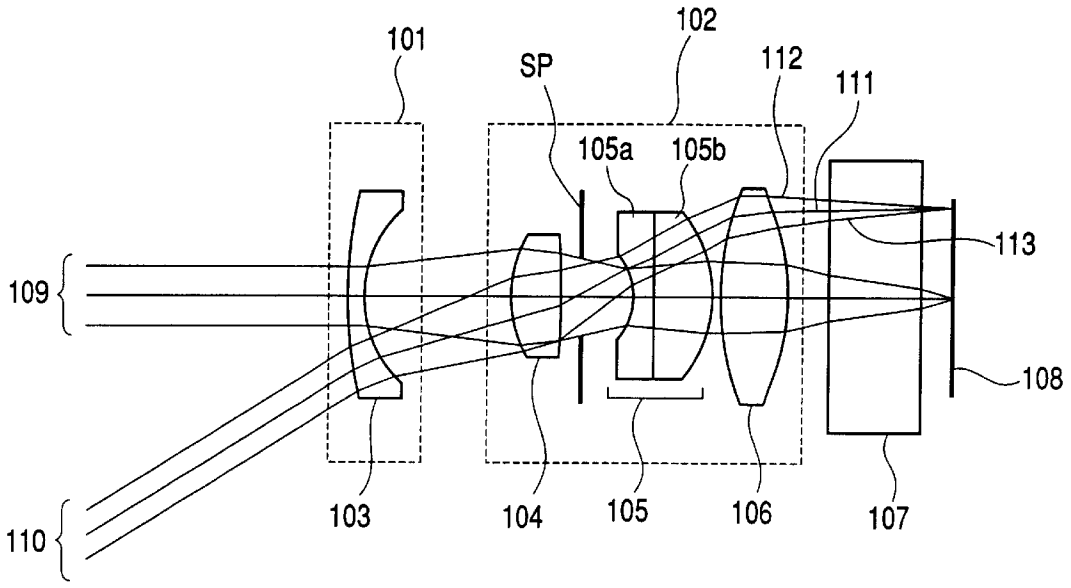


FIG. 1

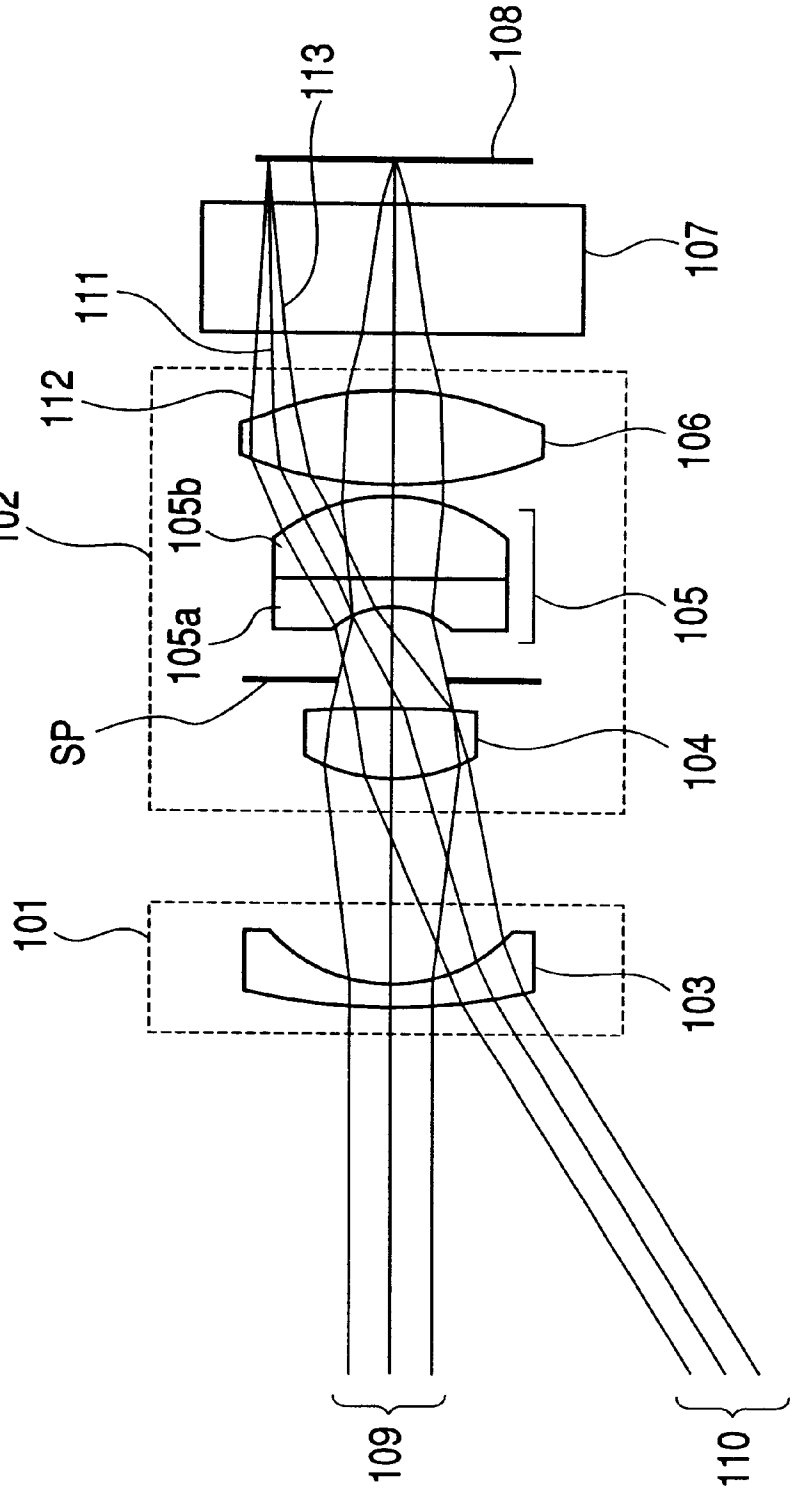


FIG. 2

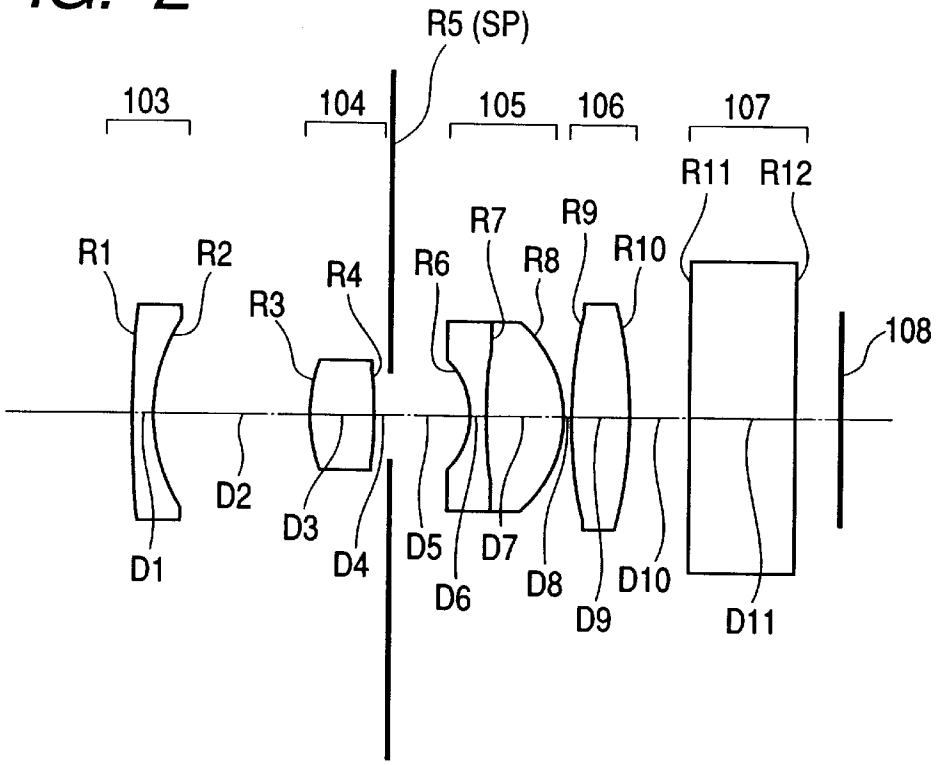

R5 (SP)
103
104
105
106
107
R11
R12
R7
R9
R1
R2
R6
R8
R10
R4
R3
108
D2
D3
D5
D7
D8
D10
D1
D4
D6
D9
D11

FIG. 3

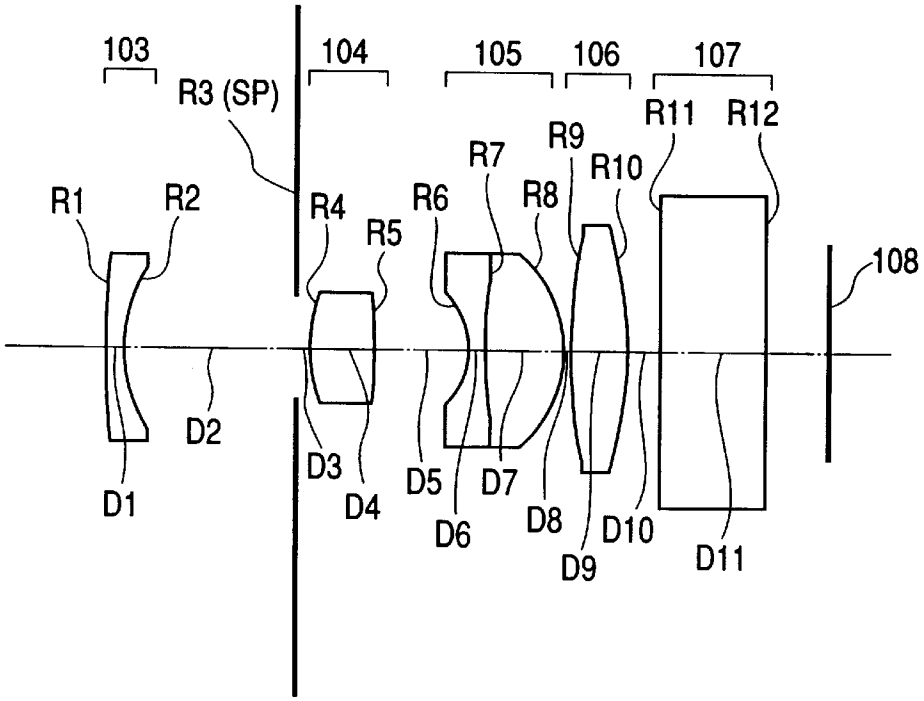

103
104
105
106
107
R3 (SP)
R11
R12
R9
R7
R10
R1
R2
R4
R6
R8
R5
108
D2
D3
D5
D7
D8
D10
D1
D4
D6
D9
D11

FIG. 4

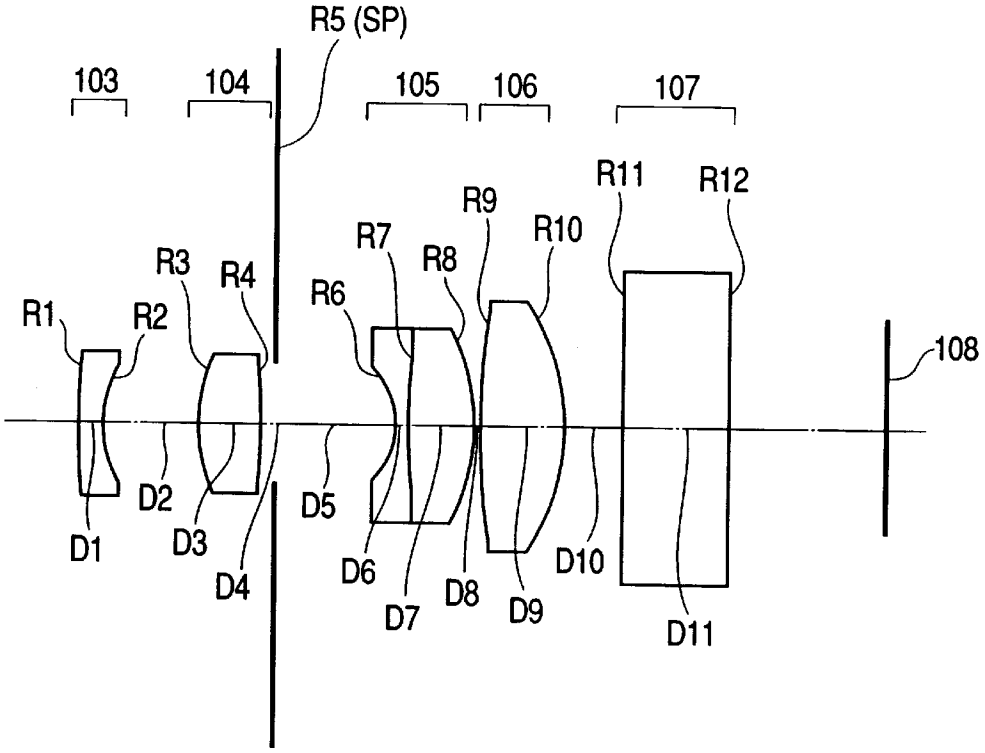

R5 (SP)
103
104
105
106
107
R11
R12
R9
R10
R7
R8
R3
R4
R6
R1
R2
108
D2
D5
D1
D3
D6
D10
D4
D8
D7
D9
D11

FIG. 5

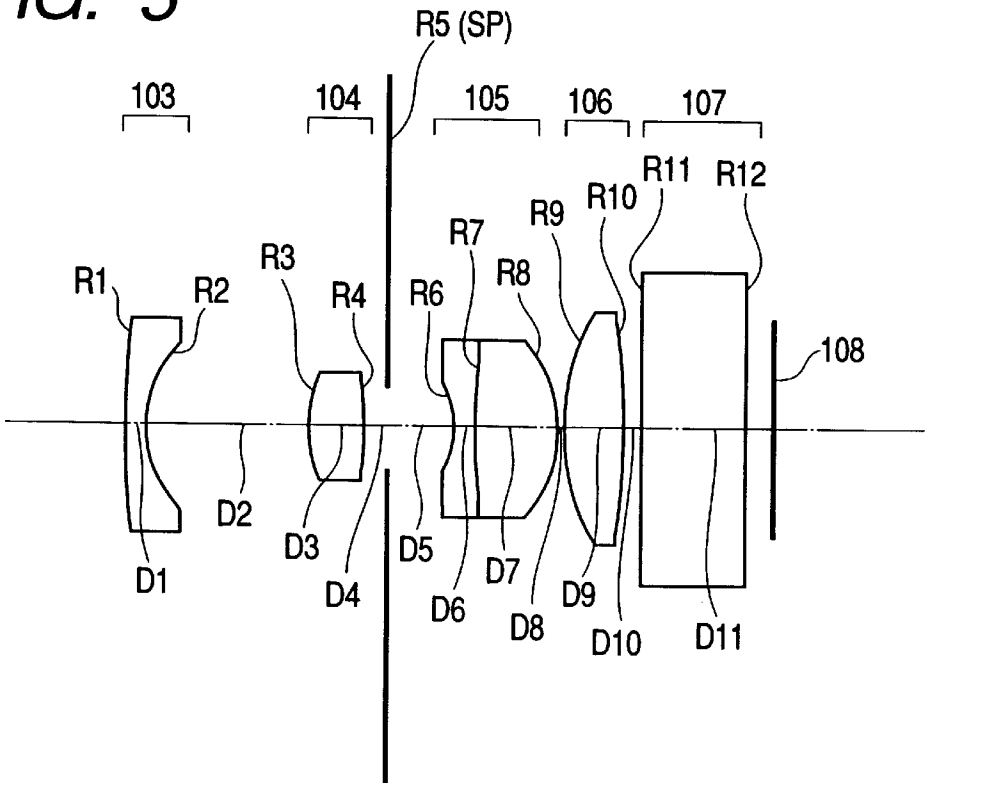

R5 (SP)
103
104
105
106
107
R11
R12
R10
R9
R7
R3
R8
R1
R2
R4
R6
108
D2
D3
D5
D1
D4
D7
D6
D9
D8
D10
D11

FIG. 6

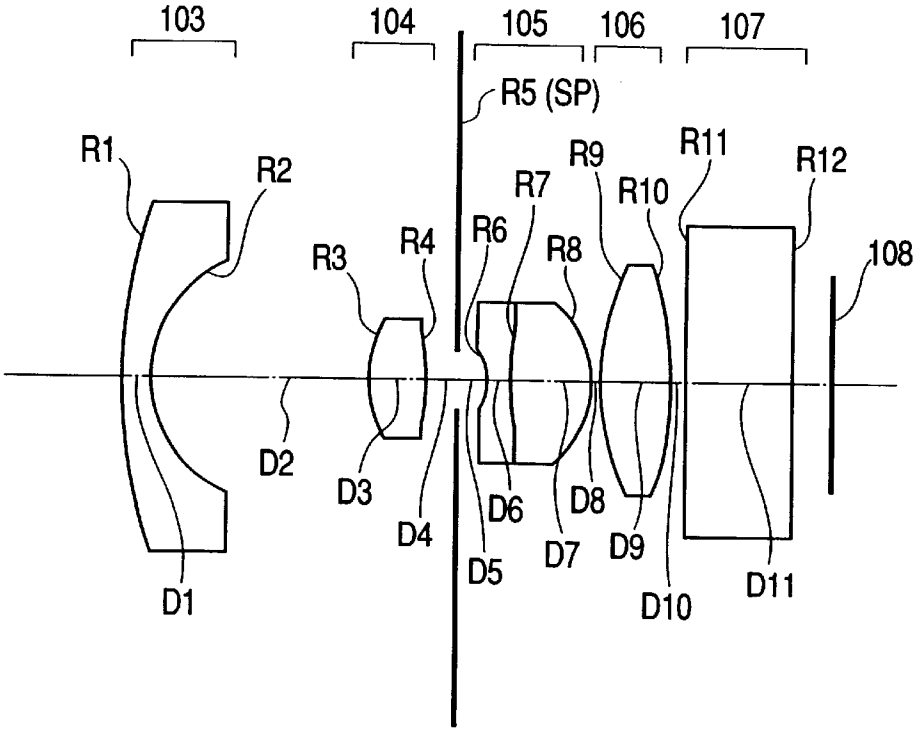
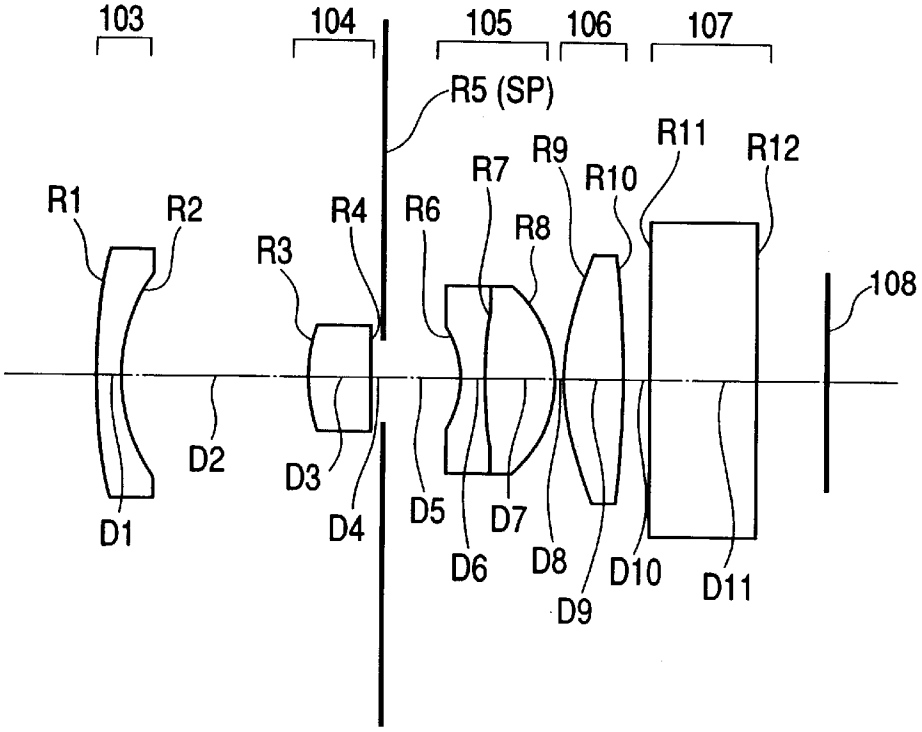

103
104
105
106
107
R5 (SP)
R1
R2
R3
R4
R6
R7
R8
R9
R10
R11
R12
108
D1
D2
D3
D4
D5
D6
D7
D8
D9
D10
D11

FIG. 7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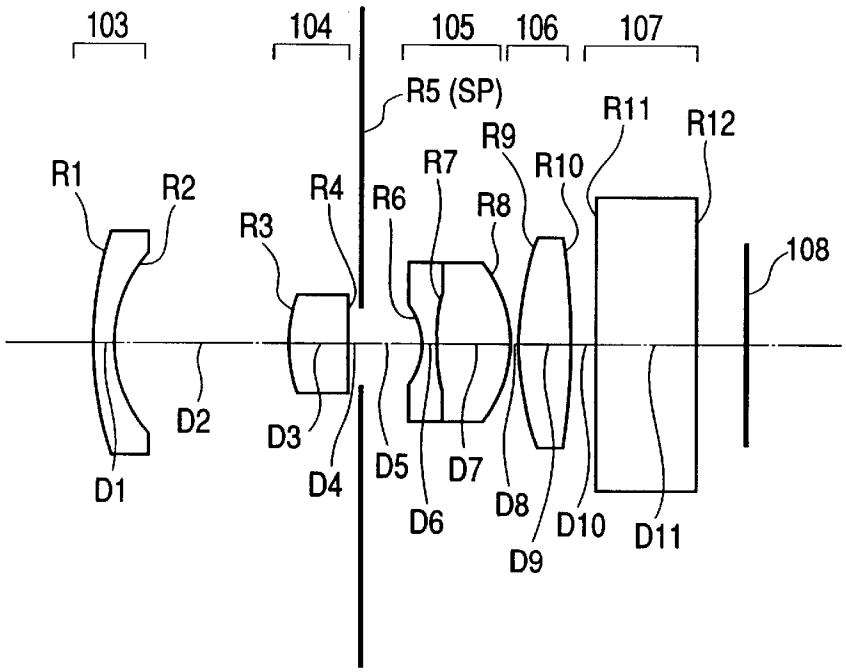
104
105
106
107
R5 (SP)
R1
R2
R3
R4
R6
R7
R8
R9
R10
R11
R12
108
D1
D2
D3
D4
D5
D6
D7
D8
D9
D10
D11

FIG. 8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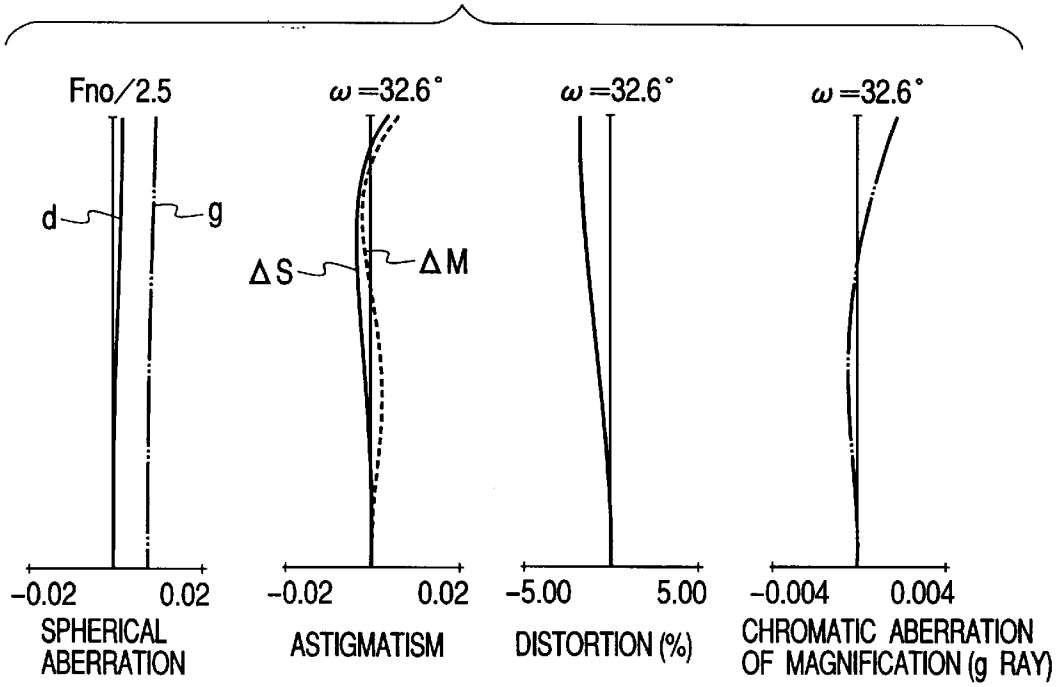
104
105
106
107
R5 (SP)
R11
R12
R9
R7
R10
R1
R2
R4
R6
R8
R3
108
D2
D3
D5
D7
D8
D10
D1
D4
D6
D9
D11

FIG. 9


Fno/2.5
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g
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0.02
SPHERICAL ABERRATION
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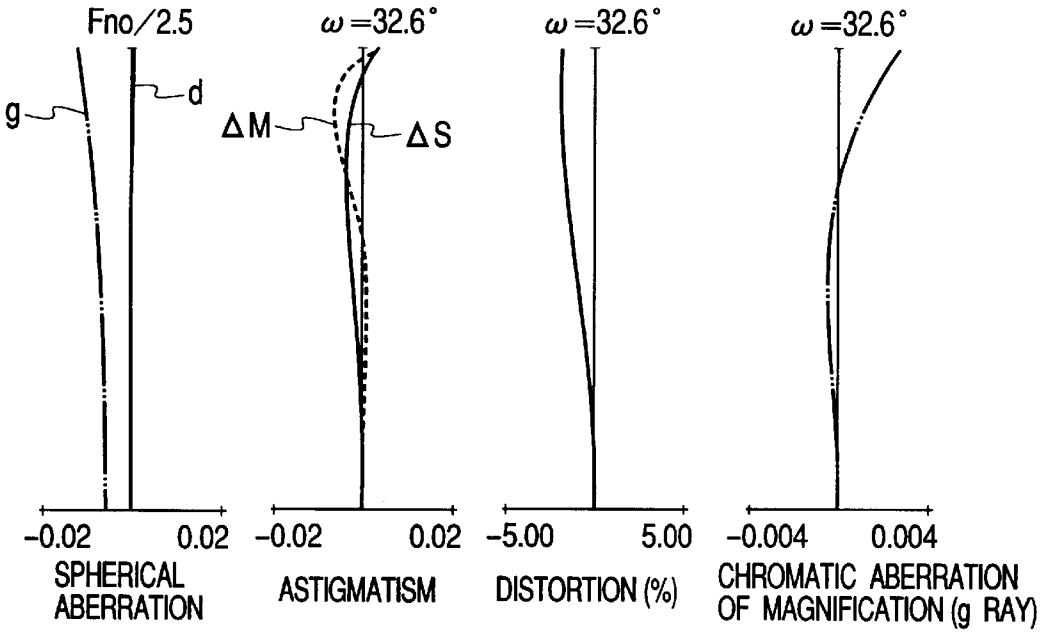
ΔS
ΔM
-0.02
0.02
ASTIGMATISM
ω=32.6°
-5.00
5.00
DISTORTION (%)
ω=32.6°
-0.004
0.004
CHROMATIC ABERRATION OF MAGNIFICATION (g RAY)

FIG. 10


Fno/2.5
ω =32.6°
ω =32.6°
ω =32.6°
g
d
ΔM
ΔS
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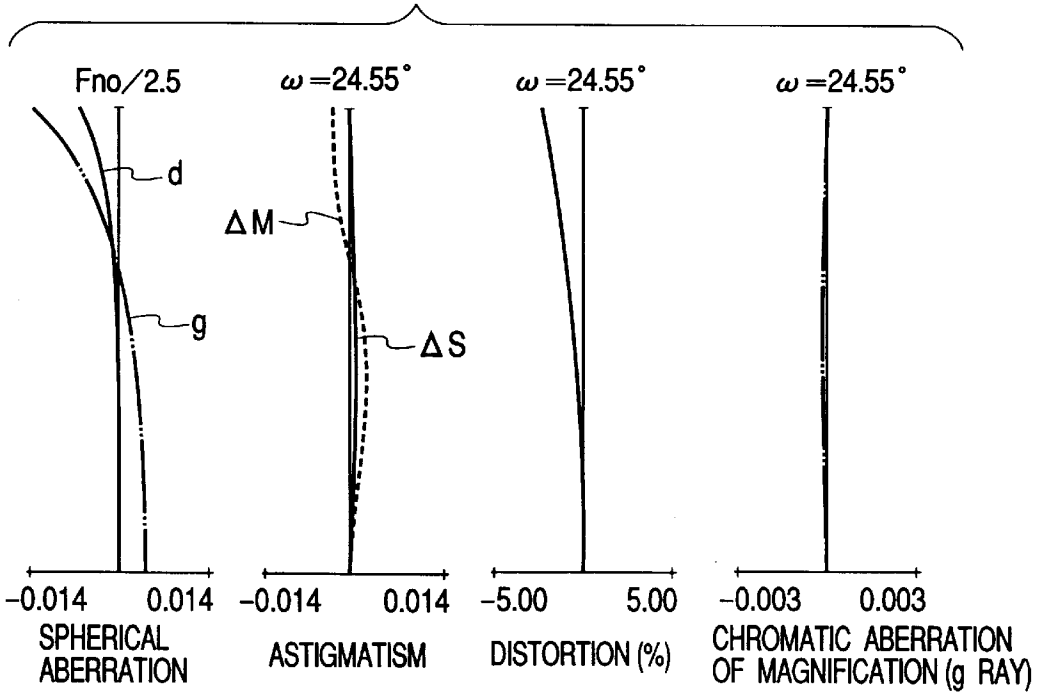
0.02
-0.02
0.02
-5.00
5.00
-0.004
0.004
SPHERICAL ABERRATION
ASTIGMATISM
DISTORTION (%)
CHROMATIC ABERRATION OF MAGNIFICATION (g RAY)

FIG. 11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ω =24.55°
ω =24.55°
d
g
ΔM
ΔS
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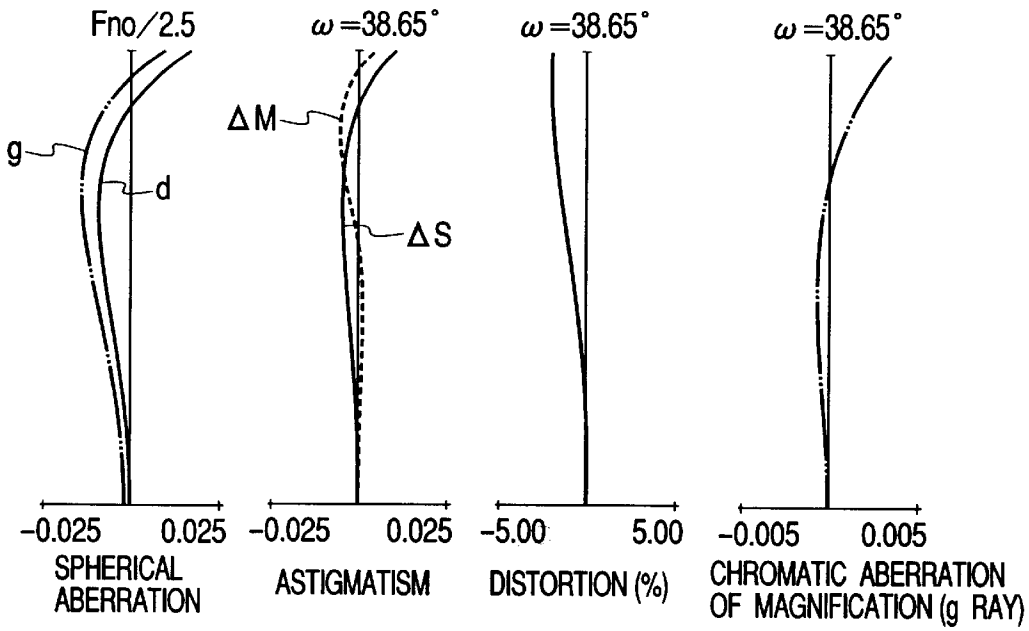
0.014
-0.014
0.014
-5.00
5.00
-0.003
0.003
SPHERICAL ABERRATION
ASTIGMATISM
DISTORTION (%)
CHROMATIC ABERRATION OF MAGNIFICATION (g RAY)

FIG. 12


Fno/2.5
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ω=38.65°
ω=38.65°
g
d
ΔM
ΔS
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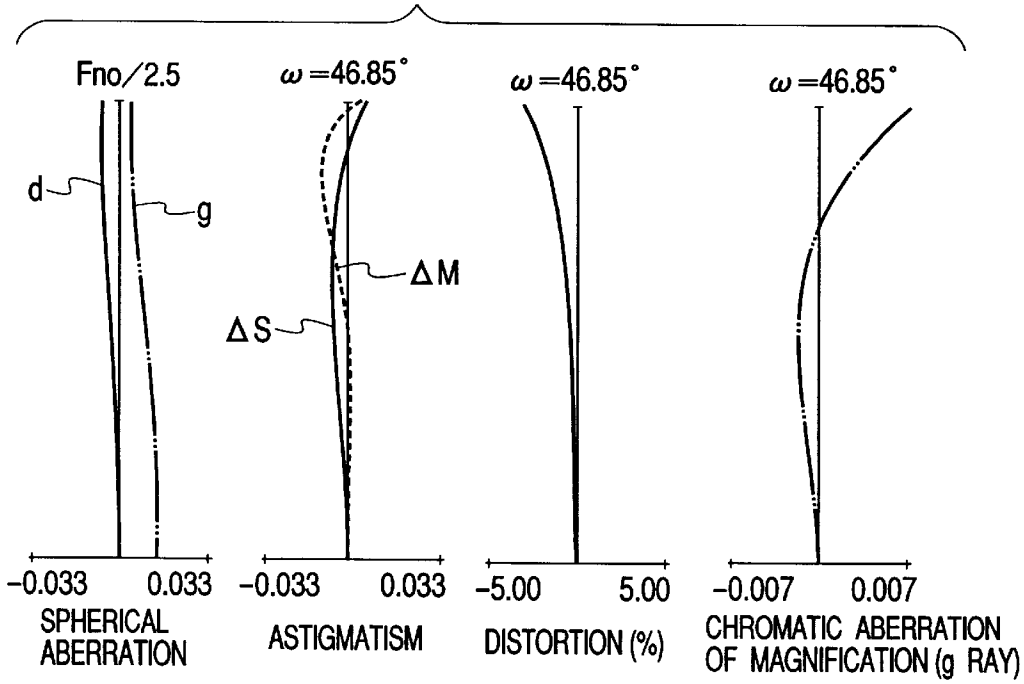
0.025
-0.025
0.025
-5.00
5.00
-0.005
0.005
SPHERICAL ABERRATION
ASTIGMATISM
DISTORTION (%)
CHROMATIC ABERRATION OF MAGNIFICATION (g RAY)

FIG. 13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ω=46.85°
ω=46.85°
d
g
ΔM
ΔS
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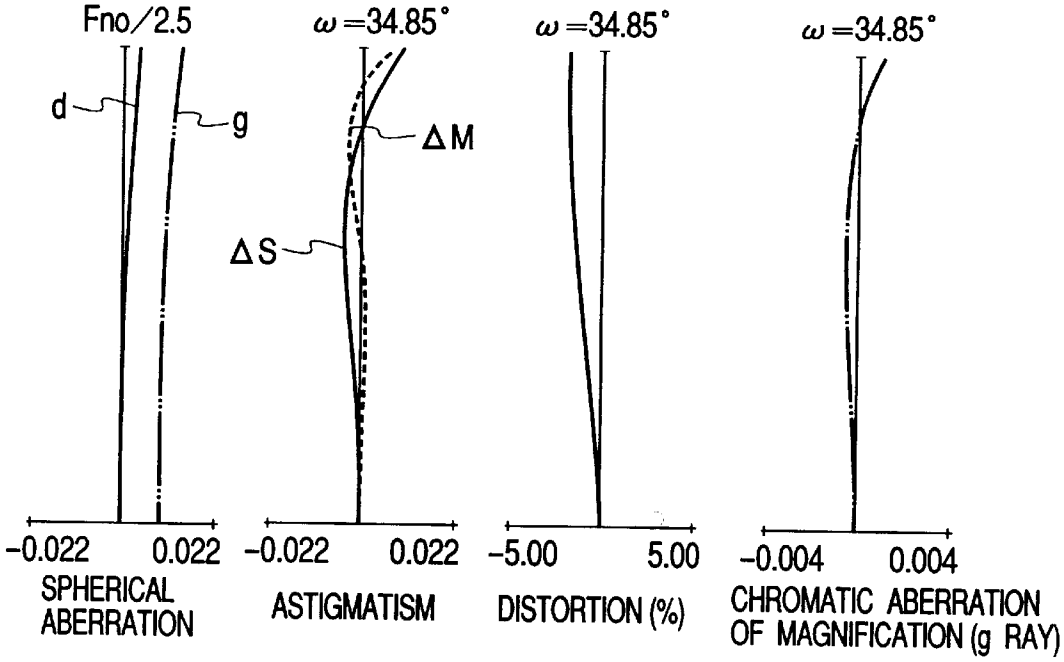
0.033
-0.033
0.033
-5.00
5.00
-0.007
0.007
SPHERICAL ABERRATION
ASTIGMATISM
DISTORTION (%)
CHROMATIC ABERRATION OF MAGNIFICATION (g RAY)

FIG. 14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ω=34.85°
ω=34.85°
d
g
ΔM
ΔS
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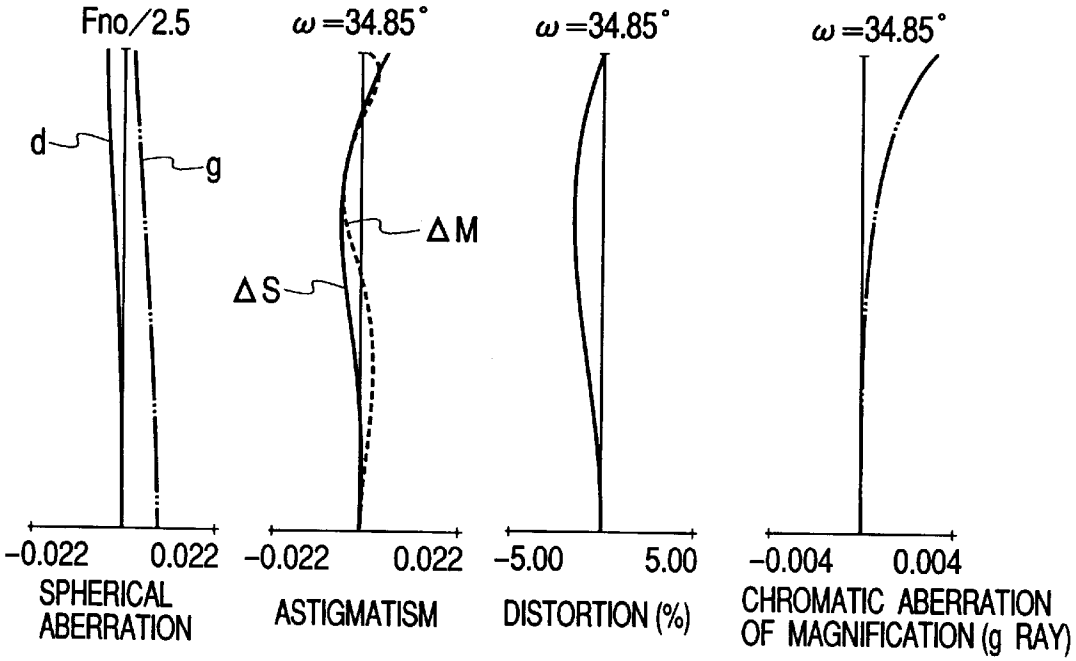
0.022
-0.022
0.022
-5.00
5.00
-0.004
0.004
SPHERICAL ABERRATION
ASTIGMATISM
DISTORTION (%)
CHROMATIC ABERRATION OF MAGNIFICATION (g RAY)

FIG. 15


Fno/2.5
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ω=34.85°
ω=34.85°
d
g
ΔM
ΔS
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0.022
-0.022
0.022
-5.00
5.00
-0.004
0.004
SPHERICAL ABERRATION
ASTIGMATISM
DISTORTION (%)
CHROMATIC ABERRATION OF MAGNIFICATION (g RAY)

FIG. 16A

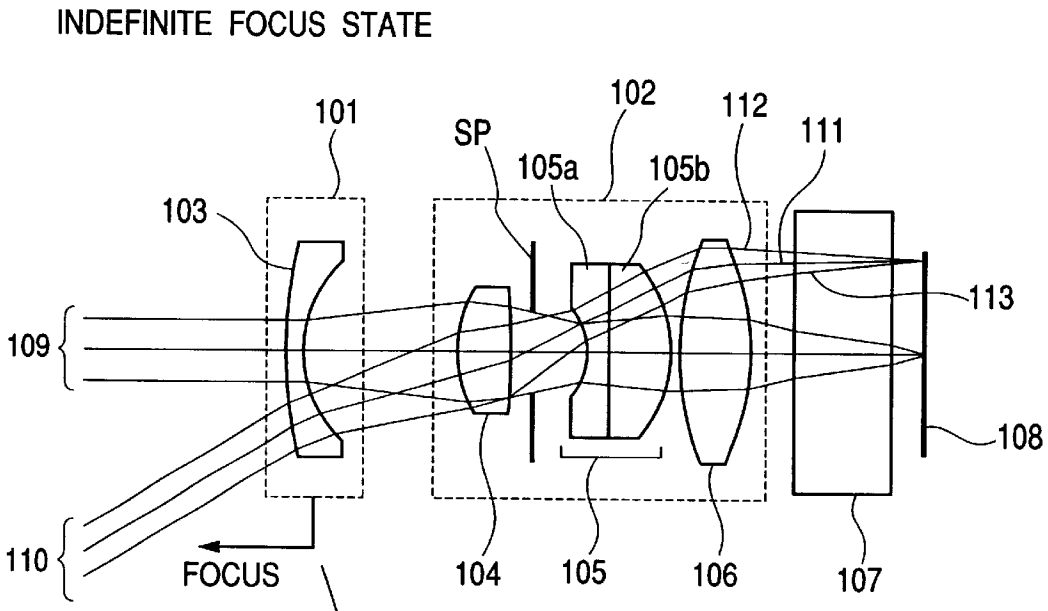


FIG. 16B

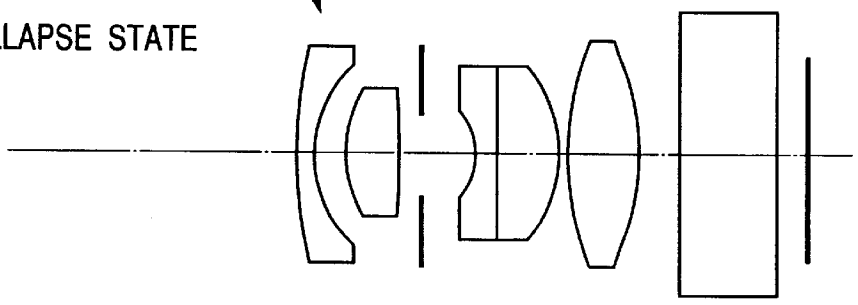


FIG. 17A

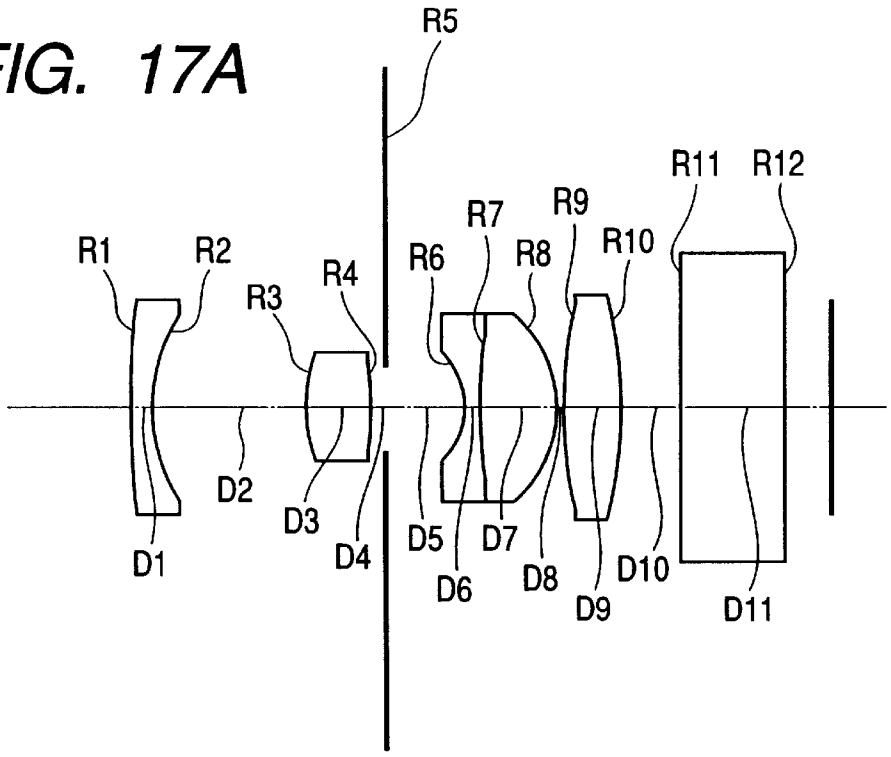


FIG. 17B

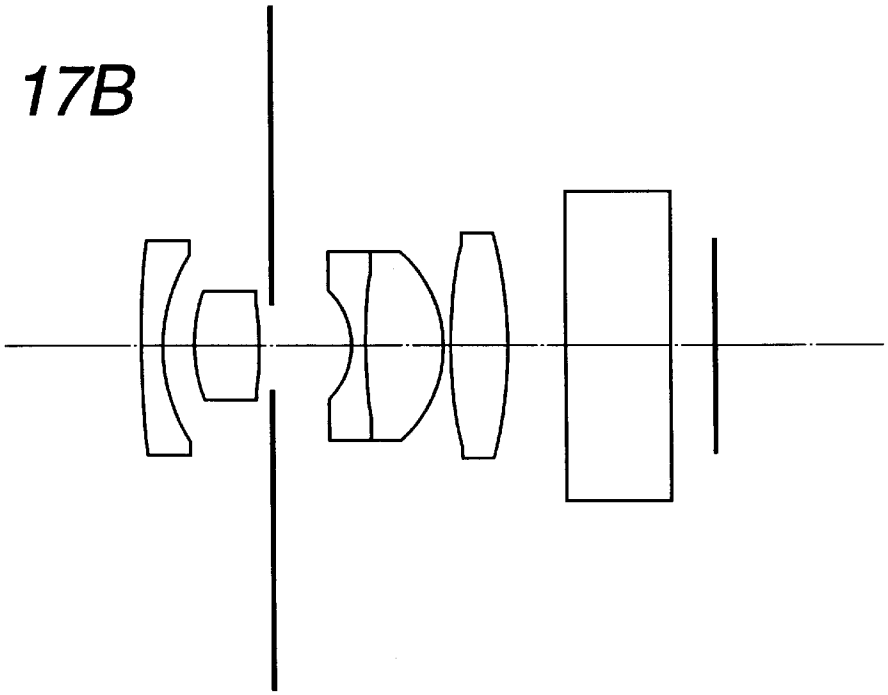


FIG. 18A

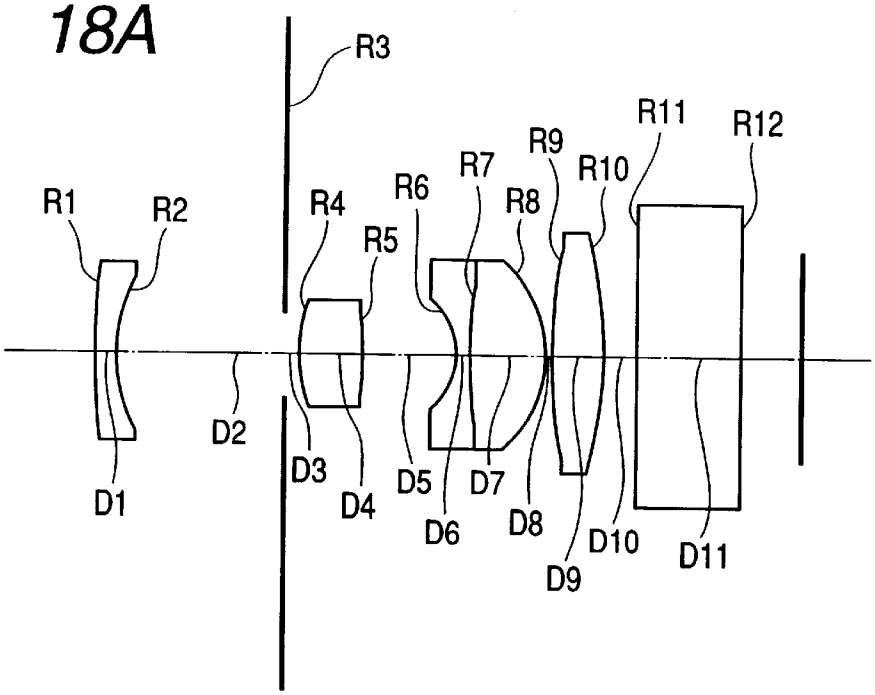


FIG. 18B

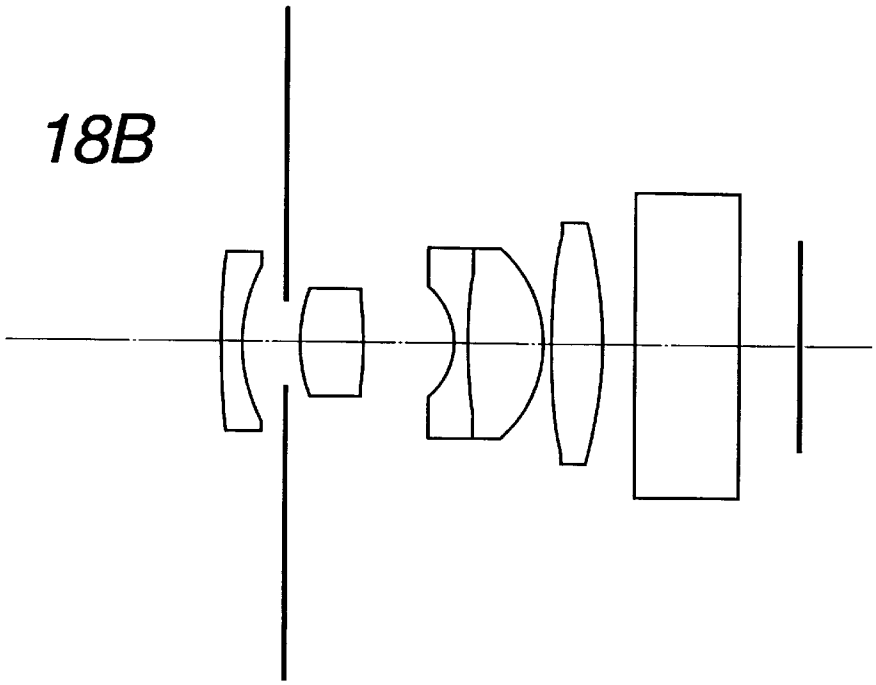


FIG. 19A

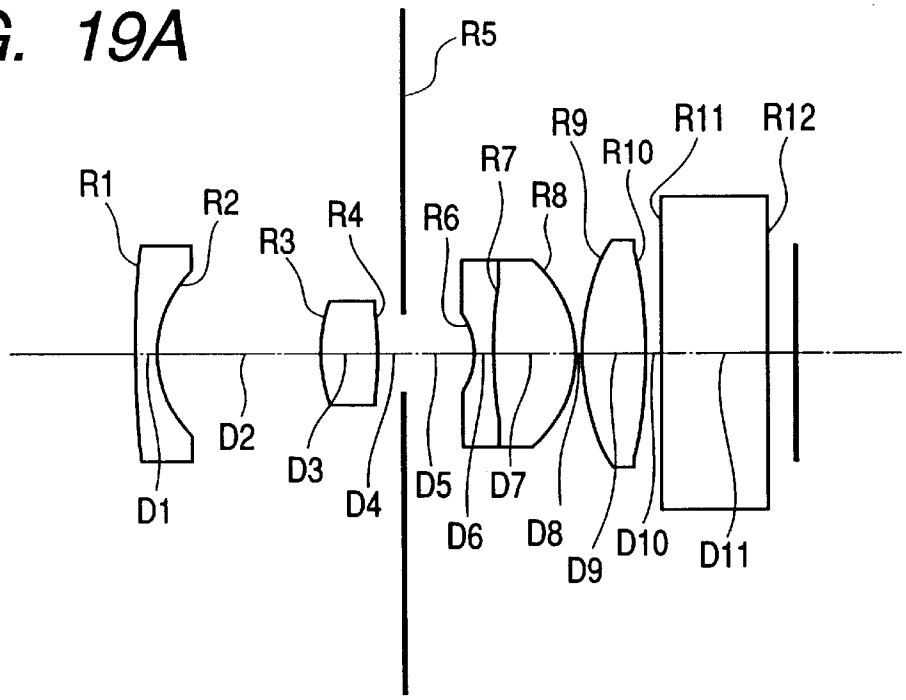


FIG. 19B

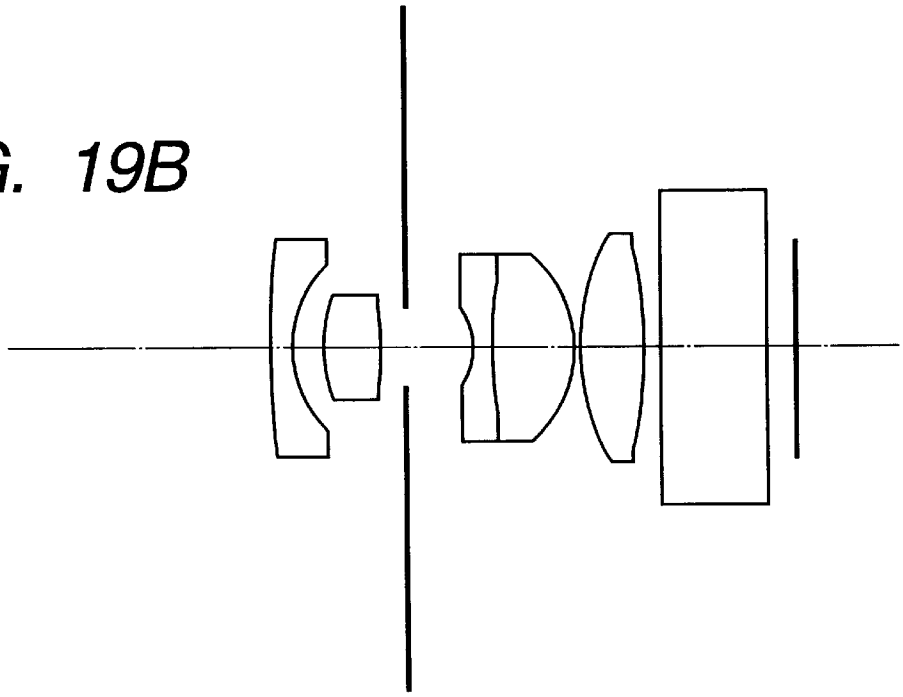


FIG. 20A

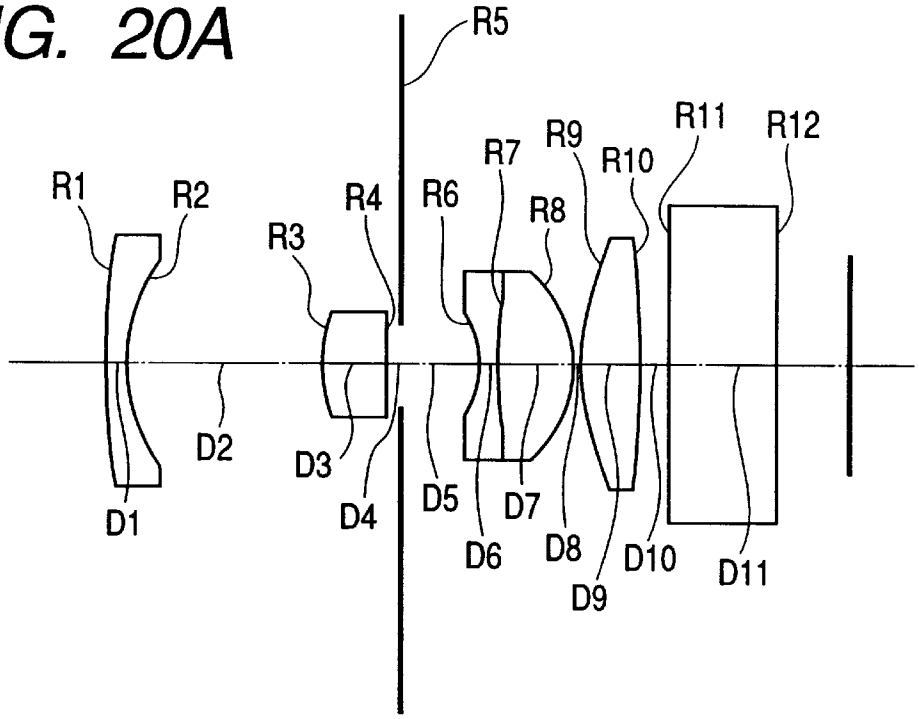


FIG. 20B

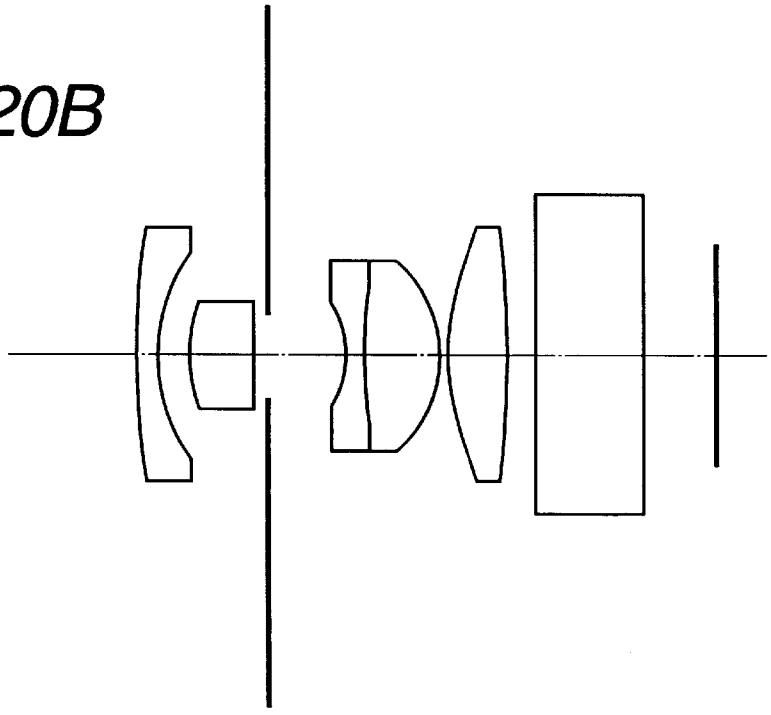


FIG. 21A

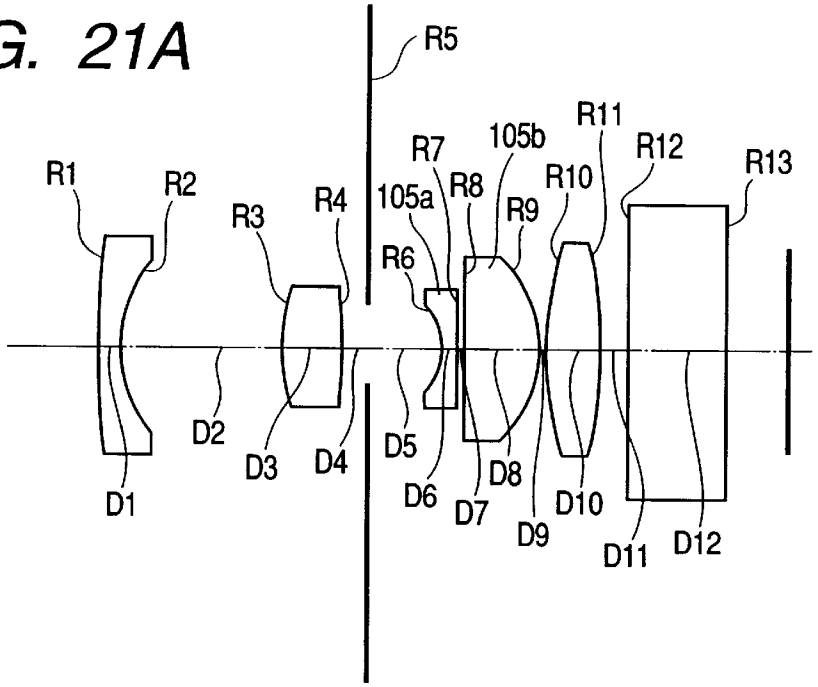


FIG. 21B

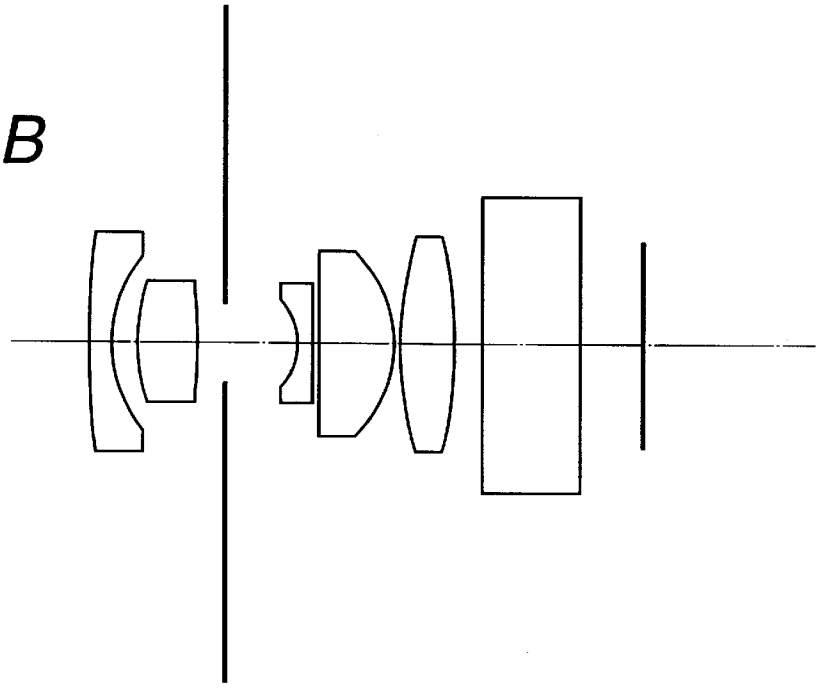


FIG. 22A

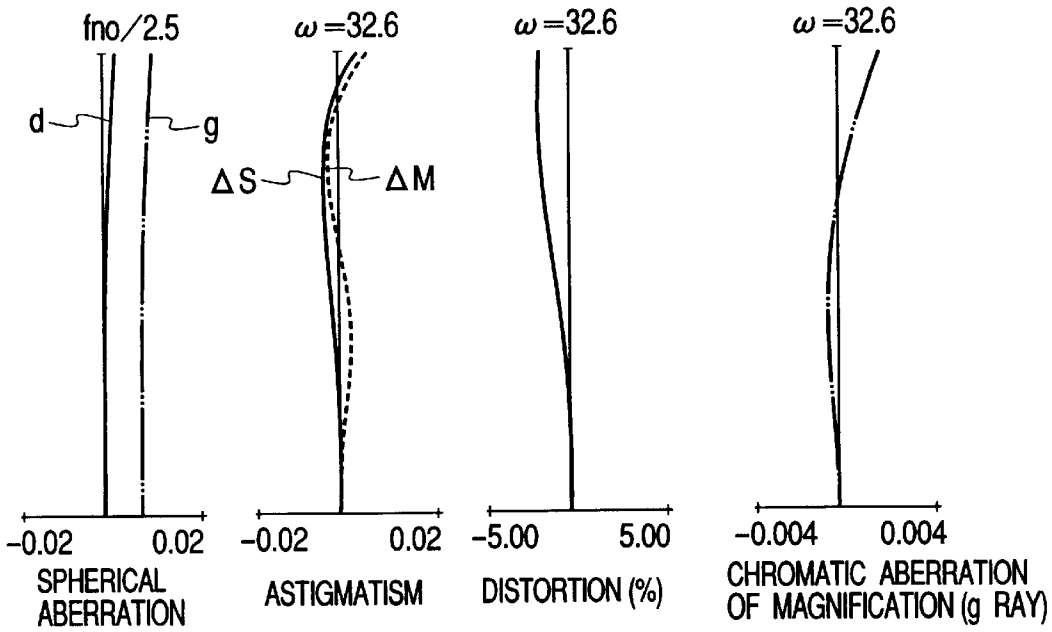


FIG. 22B

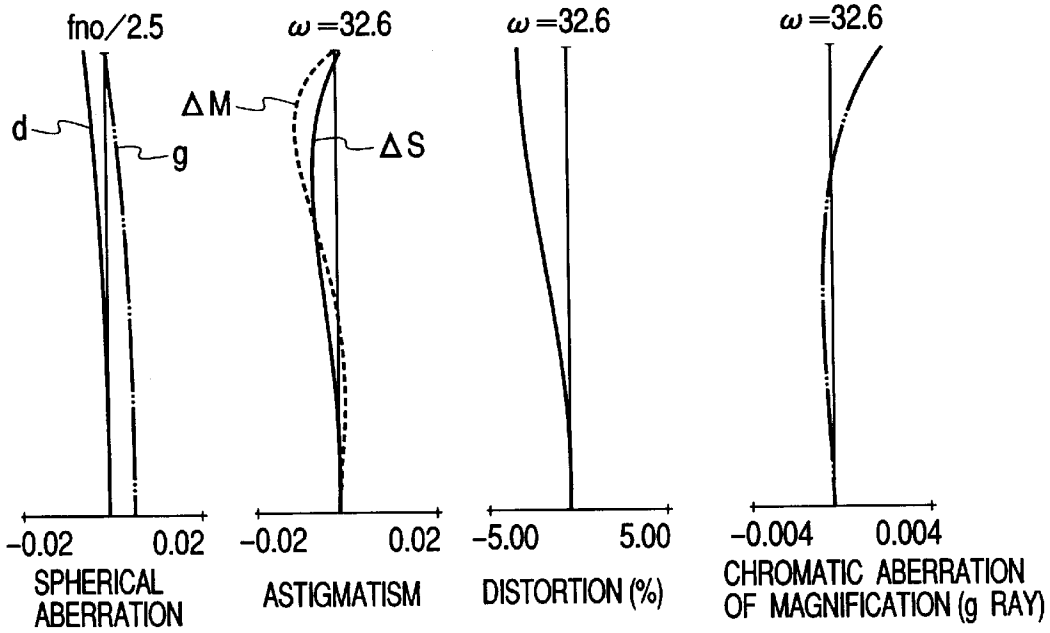


FIG. 23A

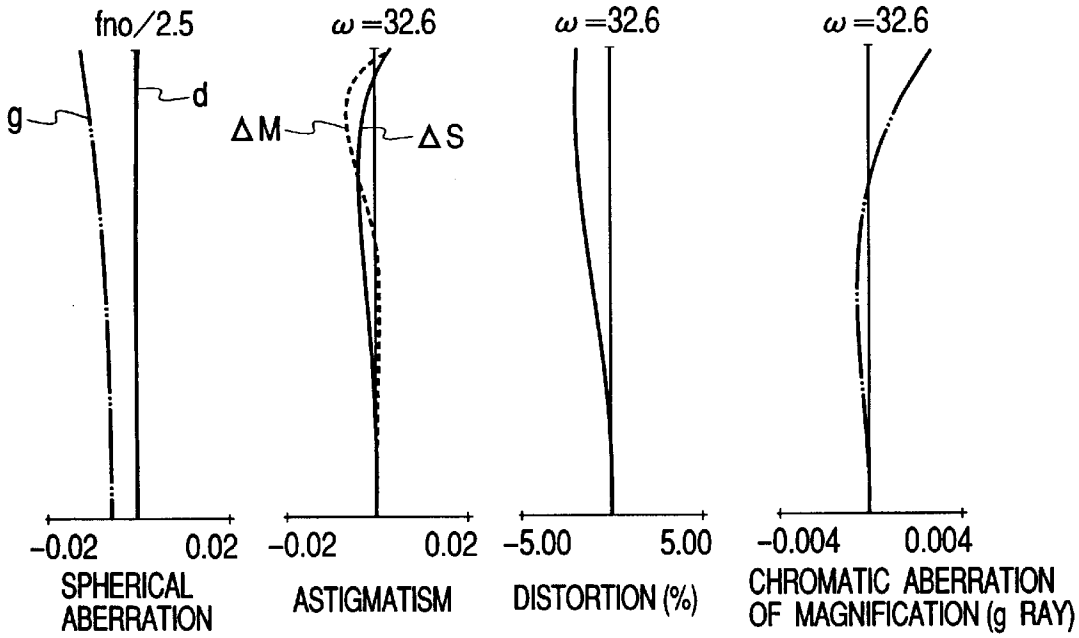


FIG. 23B

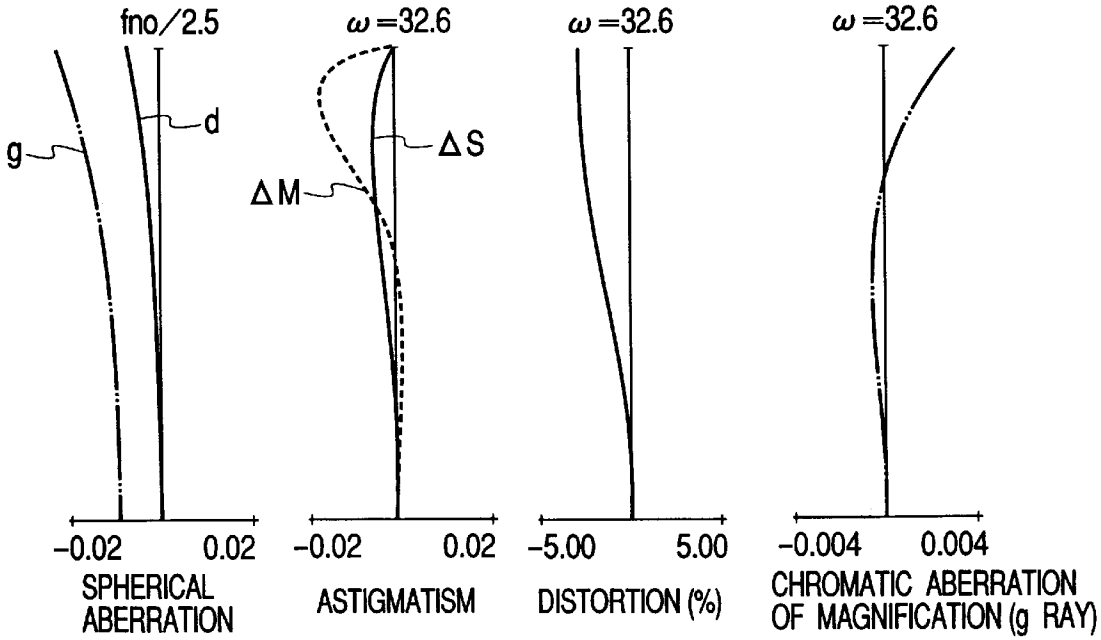


FIG. 24A

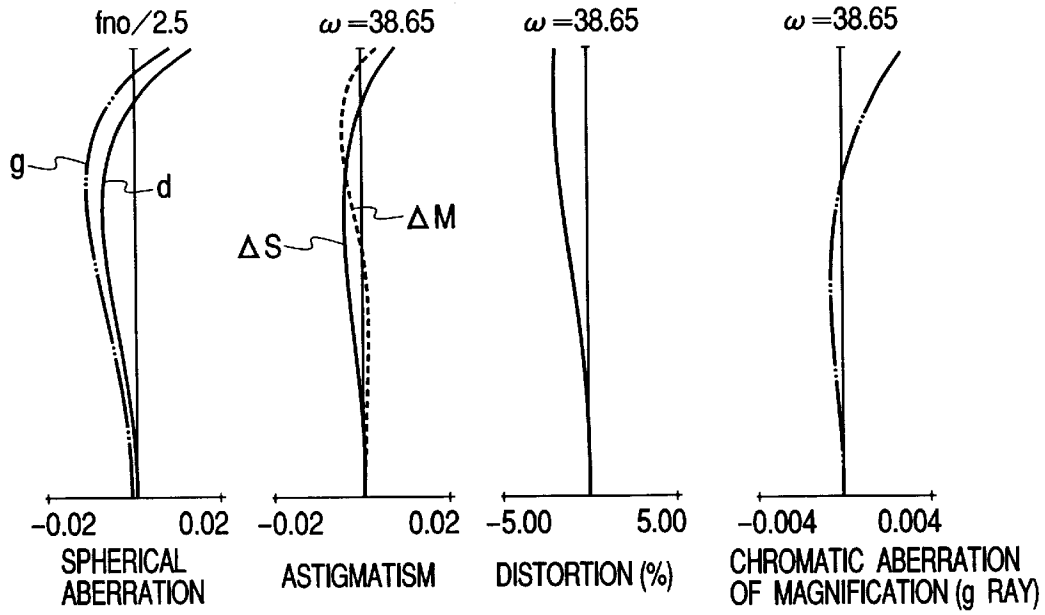


FIG. 24B

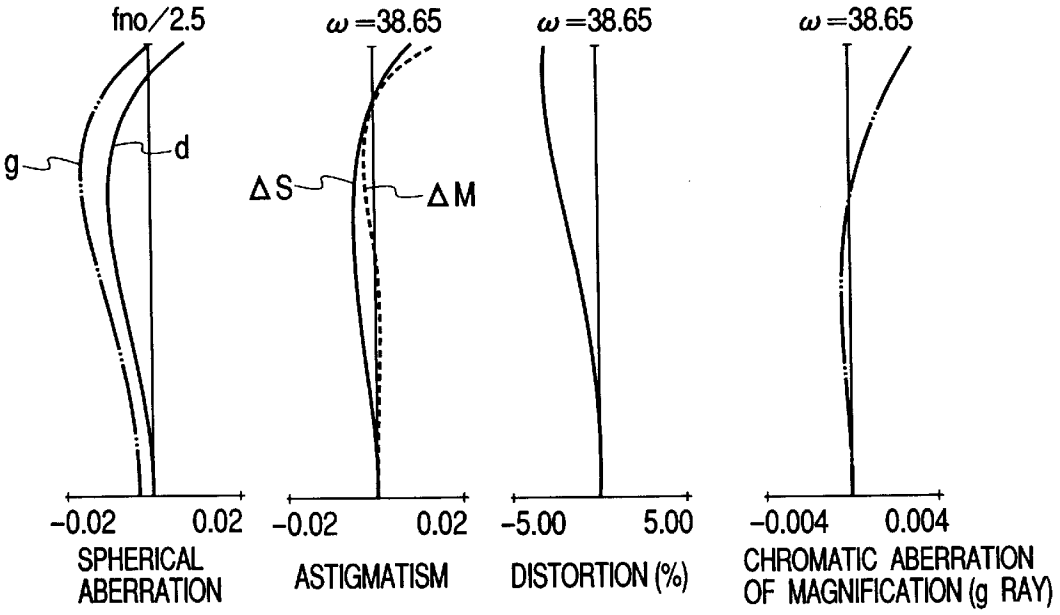


FIG. 25A

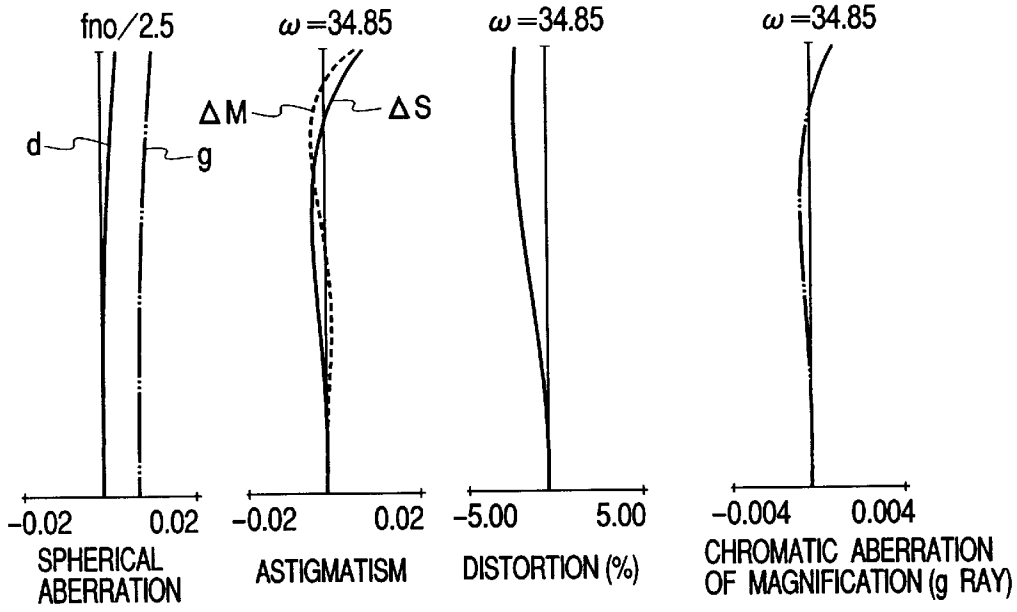


FIG. 25B

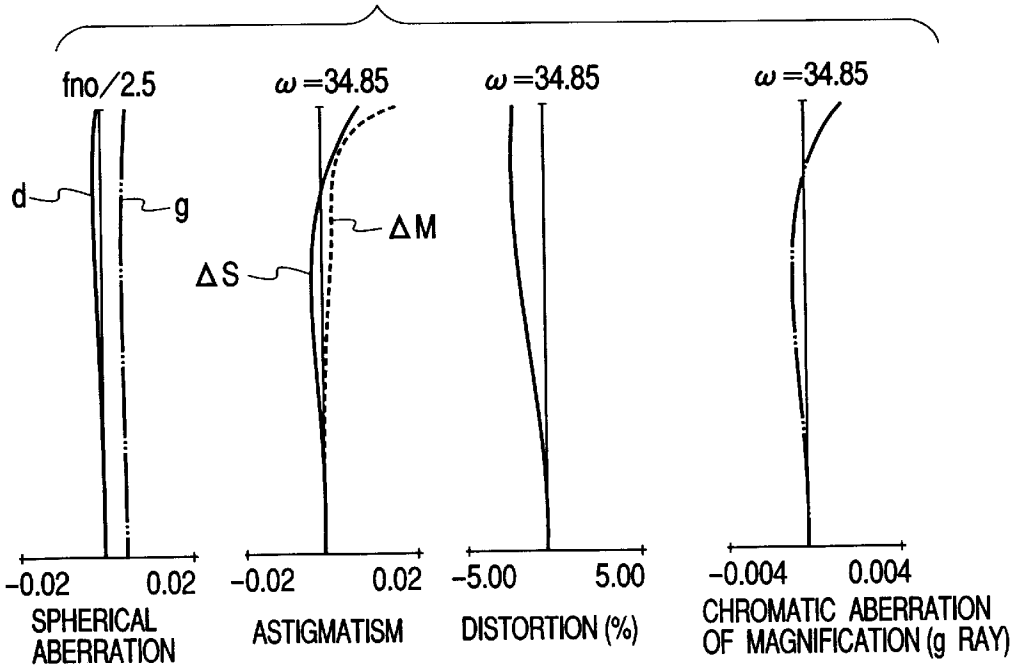


FIG. 26A

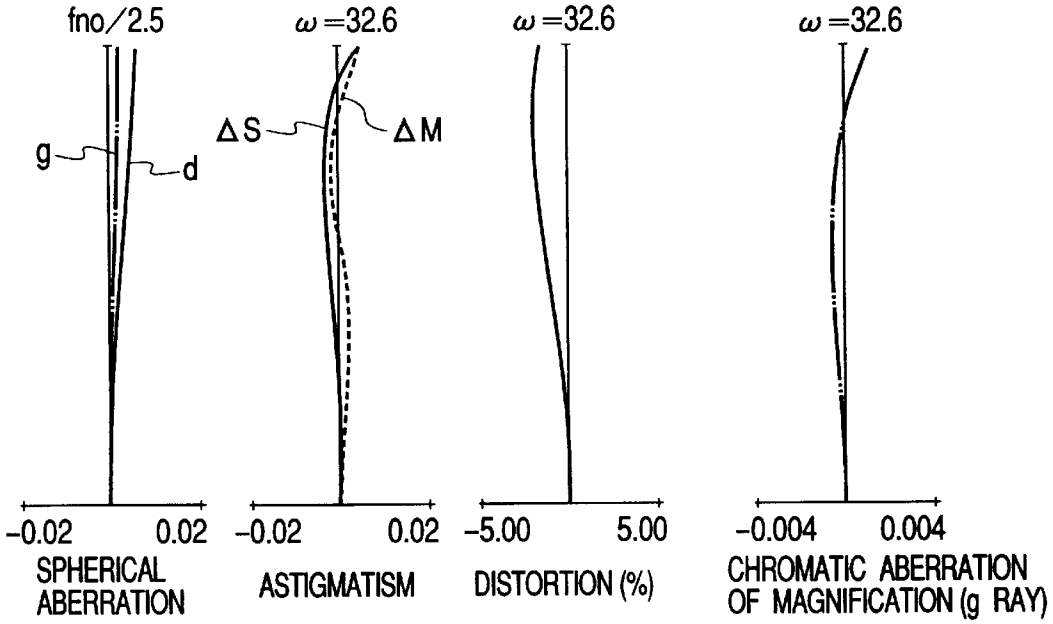


FIG. 26B

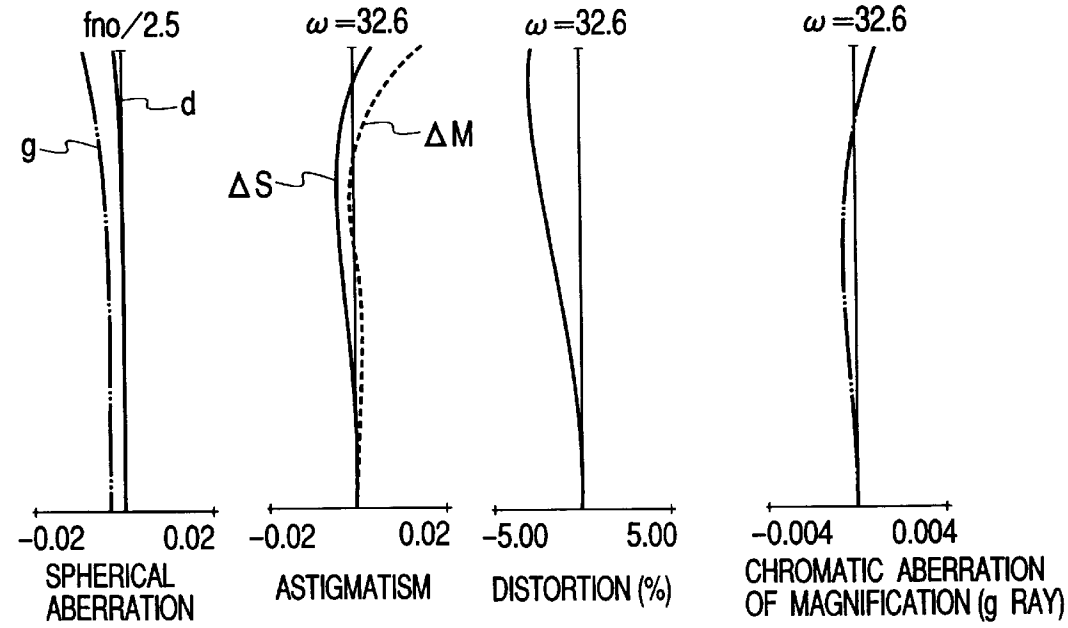


FIG. 27

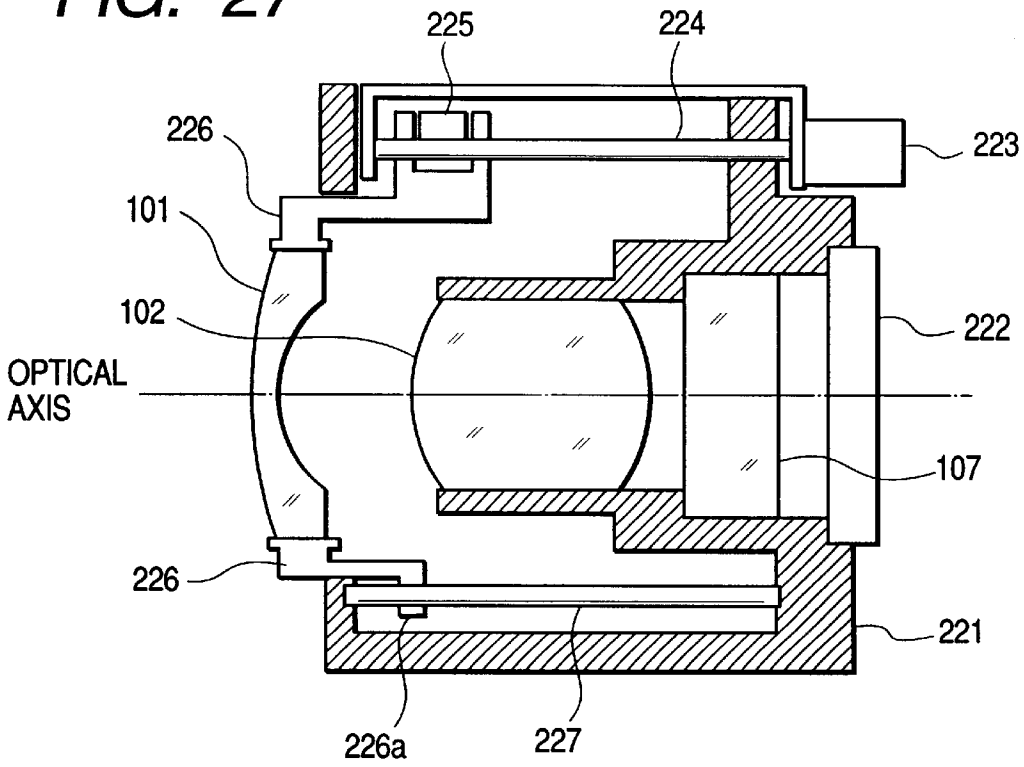
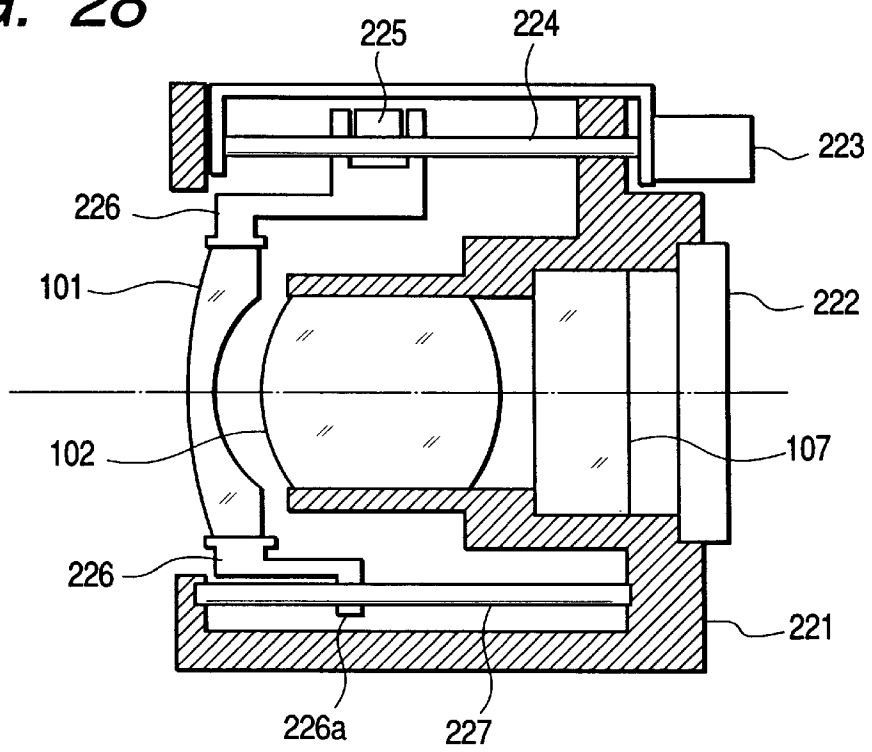

225
224
226
223
101
102
222
OPTICAL AXIS
107
226
221
226a
227

FIG. 28


225
224
223
226
101
222
102
107
226
221
226a
227

OBJECTIVE LENS AND IMAGE PICKUP DEVICE USING THE SAME

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to an objective lens and an image pickup device using the same and is appropriate in particular to a camera system in a device using an image pickup element such as digital still camera, a video camera, a broadcasting camera or a photograph camera with an exit pupil kept far apart from the image field while widening an angle of field devised by employing the retro-focus type.

2. Related Background Art

Recent years, a digital still camera has been spreading out as the image input device. In this digital still camera there is generally carried out a process comprising AD-converting an output signal from a solid image pickup element such as CCD into image data, subjecting them to an image compression such as JPEG and storing the compressed data in a storage medium such as flash memory. After being developed on a computer, the compressed data thus stored are displayed on a monitor or the like.

In such a digital still camera, a higher precision of photographed images and a smaller size of image pickup devices has recently become a task and the compatibility of a high resolution and a smaller size is required therewith. Especially, to attain a thin model camera with stress laid on the portability, shortening the total lens length is required in a photographing lens (objective lens). For shortening the total lens length, it is advantageous to use an objective lens having as small a number of constituent lenses as possible.

Besides, as objective lenses for implementing a wide angle of field, many retro-focus type ones composed of a front lens unit having a negative refractive power and a rear lens unit having a positive refractive power are known. Especially as retro-focus type objective lenses having a small number of constituent lenses, those of the above front lens unit comprising one negative lens are proposed.

As such retro-focus type objective lenses with a front lens unit comprising one negative lens, for example, a 3 group 3 piece configuration comprising a negative lens, a positive lens and a positive lens in sequence from the object side is disclosed in U.S. Pat. No. 5,418,649 and a 3 group 4 piece configuration comprising a negative lens, a positive lens and a positive composite lens in sequence from the object side is disclosed in another embodiment of the same U.S. Pat. No. 5,418,649. As other examples, Japanese Patent Publication No. 7-122692 (corresponding to U.S. Pat. No. 4,984,878), Japanese Patent Publication No. 5-37288, Japanese Patent Publication No. 5-20724, Japanese Patent Publication No. 61-46807, Japanese Patent Publication No. 58-7 and Japanese Patent Application Laid-Open No. 9-189856 (corresponding to U.S. Pat. No. 5,706,141), U.S. Pat. No. 4,146,304, U.S. Pat. No. 4,674,844 and Japanese Patent Publication No. 60-32165 (corresponding to U.S. Pat. No. 4,130,349) disclose a 4 group 4 piece configuration comprising: a negative lens, a positive lens, a positive lens and a positive lens in sequence from the object side; a 4 group 4 piece configuration comprising:

a negative lens, a positive lens, a negative lens and a positive lens in sequence from the object side;

a 4 group 4 piece configuration comprising:

a negative lens, a positive lens, a positive lens and a negative lens in sequence from the object side;

a 4 group 5 piece configuration comprising: a negative lens, a positive lens, a positive lens and a positive composite lens in sequence from the object side;

a 4 group 5 piece configuration comprising:

a negative lens, a positive lens, a negative composite lens and a positive lens in sequence from the object side;

a 4 group 5 piece configuration comprising:

a negative lens, a positive lens, a positive composite lens and a negative lens in sequence from the object side; and

a 5 group 5 piece configuration comprising:

a negative lens, a positive lens, a negative lens, a positive lens, and a positive lens in sequence from the object side, respectively. All of them are of retro-focus model and consist of a negative front lens unit and a positive rear lens unit.

Besides, the focusing approach is divided into the pan focus approach with the pint fixed at an ultrafocal length and a method for focusing by driving the focusing lens for each release. Generally, in a digital still camera of much consumed power, it is desired to lengthen the service life of a battery and the pan focus is effective for saving the power consumption. To obtain an image of high resolution, however, focusing is preferably made so as to make the pint best according to the object distance. Especially, in the case of a macro photographing with an objective lens small in shortest object distance, those of focusing mechanism is better than those of pan focus.

As regards a retro-focus type objective lens, the total thrust method by moving the whole lens system is well known. Besides, as a method of making a partial thrust while making a total thrust and a rear focus method by thrusting a lens on the image side, Japanese Patent Publication No. 45-39875 and Japanese Patent Application Laid-Open No. 55-143517 are referred to.

Besides, as a method for the thinnest possible image pickup device in optical axis, a collapsible mount method comprising moving the objective lens toward the imaging surface side and collapsing it into the front cover of a camera when not using is well known. To minimize the drive mechanism including the actuator of lenses in the collapsible mount method, it is effective to make the focus mechanism and the collapsible mount mechanism into common use by collapsing the focusing lens in a single focus lens.

In the photographing system using a solid image pickup element, the incident angle to the receiving surface of an off-axis ray increases with a smaller distance from the image field to the exit pupil, so that a problem of shading or the like takes place. Thus, the objective lens of a image pickup system using such an image pickup element must be chosen to a telecentric optical system with an exit pupil kept sufficiently apart from the image field. To be specific, the objective lens is so arranged preferably that the off-axis chief ray incident to the optical axis at an angle corresponding to the photographing face angle reaches the image pickup element forming an imaging surface nearly in parallel with the optical axis. The wider the photographing face angle is, the stronger the refractive power required for such a refraction of an off-axis chief ray as to become in parallel with the optical axis is.

Generally, affording a negative refractive power to a group of lenses on the object side from the stop and a positive refractive power to a group of lenses on the image field side from the stop is advantageous to the reduction of an angle of an off-axis chief ray with the optical axis, i.e., to make it nearly parallel to the optical axis. Namely, in a retro-focus type objective lens, the front group of a negative refractive power is generally disposed on the object side with respect to the stop and accordingly the angle of an

off-axis chief ray with the optical axis can be reduced in presence of this front group. In the positive rear group, the angle of an off-axis chief ray with the optical axis can be reduced under action of positive lenses on the image field side with respect to the stop. Since both the front lens unit and the rear lens unit have an effect of making the exit pupil apart from the image field side, the retro-focus type optical system is very effective in the case of a wide photographing face angle.

Furthermore, for making the exit pupil sufficiently apart from the image field by shortening the total lens length, it is preferable to set at least the final lens of the rear group to a positive lens. More preferably, the surface on the image field side of the lens directly in front of the final lens is set to a convex surface. In such a manner, since the action of refracting an off-axis chief ray can be shared between the surfaces of three lenses including the final lens, the refractive power of the final lens cannot be made extremely strong. Too strong a refractive power of the final lens is inadequate because of causing the barrel-shaped aberration and the astigmatism.

From these, it is concluded that to employ the retro-focus type as the whole system and to set only the first lens of the negative front group and the final lens of the positive rear group to positive lenses is effective for making the objective lens telecentric at a wider photographing face angle and in a shortened total lens length and that the surface on the image field side of the lens directly in front of the final lens is preferably convex.

Furthermore, it is necessary for a better planarity of an image field to reduce the Petzval sum to some extent. If there is no negative refractive power in the above rear group, it is necessary for the reduction of the Petzval sum to intensify the refractive power of the first lens in the front group to considerable extent. On intensifying the refractive power of the first lens like this, a very large barrel-shaped aberration occurs as a result. In general cameras including a digital still camera, a large aberration is problematic. If there is a negative refractive power in the rear lens unit, the Petzval term in the rear lens unit can be control to some extent. Since the Petzval term in the front lens unit comprising a single lens is not corrected within the lens unit, it is only necessary to set the Petzval term in the rear lens unit in such a manner as to correct the front lens unit. Thus, for better image field characteristics, it is required that the rear lens unit has at least one concave lens or a group of composite lenses having a negative refractive power.

The configurations of Japanese Patent Publication No. 5-20724 and U.S. Pat. No. 4,674,844 have a problem that the exit pupil cannot be made sufficiently apart from the image field in the case of a shortened back focus because the final lens is not a positive lens.

The 3 group 3 piece configuration of U.S. Pat. No. 5,418,649 and the configuration of Japanese Patent Publication No. 7-122692 have a problem that the exit pupil cannot be made sufficiently apart from the image field while reducing the Petzval sum because there is no concave lens in the rear group.

In the 3 group 4 piece configuration of U.S. Pat. No. 5,418,649 and the configurations of Japanese Patent Publication No. 61-46807 and U.S. Pat. No. 4,146,304, the rear lens unit has a negative lens, which constitutes a positive composite lens. This negative lens is effective in the chromatic aberration, but these configurations have a problem that the exit pupil cannot be made sufficiently apart from the image field while reducing the Petzval sum.

In Japanese Patent Publication No. 5-37288, the rear lens unit has an independent negative lens. However, this negative lens is the lens directly in front of the final lens. Since the surface on the image field is concave, the exit pupil cannot be made sufficiently apart from the image field unless the refractive power of the final lens is made considerably greater. In the configuration of Japanese Patent Publication No. 5-37288, the refractive power of the final lens is not so strong as to make the pupil sufficiently apart from the image field. Besides, on excessively intensifying the refractive power of the final lens for making the pupil sufficiently apart from the image field, a barrel-shaped aberration and a astigmatism occur and therefore this intensification is inappropriate. Also in the configuration of Japanese Patent Publication No. 58-7, the negative composite lens directly in front of the final lens is of meniscus shape having a strongly concave surface on the image field side.

Besides, in Japanese Patent Application Laid-Open No. 9-189856, the composite lens is so constructed as to have a convex surface toward the image field side but to be 48° in the angle of field and does not correspond to an objective lens of a wide angle of field. Furthermore, since the refractive power of the composite system comprising the first lens unit and the second lens unit is weak, the lens back is so long that a compact camera cannot be constructed in the direction of the optical axis.

Besides, on employing the total thrust as a focusing method, the weight of the moving lens unit becomes heavy. In a camera having an autofocus mechanism, a good response of the focusing lens is desired. And, in a camera of much consumed power, a small power needed for the focusing is desired. For this purpose, the focusing lens is preferably as small in size and light in weight as possible and the total thrust is disadvantageous in this respect. Japanese Patent Publication No. 45-39875 has also a similar problem.

The rear focus scheme of Japanese Patent Application Laid-Open No. 55-143517 requires a space for thrust on the side of the focusing lens. Besides, a space for adjusting the shift of a pint due to manufacturing errors or assembling errors is further required in front of or behind the focusing lens, which is disadvantageous to constructing a compact camera in the optical axis direction. And, in an attempt to the compaction at the time of not photographing, it is required to move lenses on the object side rather than the focusing lens and a plurality of drive systems are required.

Besides, on employing the first lens unit as a focusing lens in the configuration of Japanese Patent Publication No. 60-32165, variations in short-distance spherical aberration and curvature of field are marked. Since in a short distance, the spherical aberration varies greatly on the under side and the curvature of field varies greatly on the over side, no focusible construction is formed in the first lens unit.

SUMMARY OF THE INVENTION

It is a first object of the present invention to provide a telecentric objective lens good in optical performance over all the object distance from an infinite object to a near object with an exit pupil kept far apart from the image field while a wider photographing face angle and a shorter total lens length intended by appropriately setting the lens configuration.

Besides, it is a second object to provide an image pickup device excellent in focusing response and small in power consumption.

Furthermore, it is a third object to provide an image pickup device further compact in the direction of optical axis at the time of not photographing.

To attain these objects, an objective lens according to the present invention is featured by the provision of:

a first lens unit consisting of a first lens of negative refractive power in the shape of a meniscus with a concave surface toward the image field side;

a second lens unit consisting of a second lens of positive refractive power;

a third lens unit consisting of a composite lens joined of a third lens of negative refractive power with a concave surface toward the object side and a fourth lens of positive refractive power with a convex surface toward the image field side and totally having negative refractive power; and

a fourth lens unit consisting of a fifth lens of positive refractive power;

in sequence from the object side, wherein on letting fi, f12 and f be the focal length of an i-th lens unit, the composite focal length of the first lens unit and a second lens unit and the focal length of the whole objective lens system, respectively, the conditions of

$$0.7<|f1|/f<3.0,$$

$$0.7<f4/f<3.0, \text{ and}$$

$$0.8<f12/f<2.5$$

are satisfied.

Besides, another objective lens according to the present invention is featured by the provision of:

a front lens unit of negative refractive power consisting of a first lens of negative refractive power in the shape of a meniscus with a convex surface toward the image field side;

and

a rear lens unit comprising a second lens of positive refractive power nearest to the object with a convex surface directed toward the object side; in sequence from the object side, wherein

focusing is carried out by moving the above front lens unit in the direction of the optical axis.

Besides, an image pickup device according to the present invention is featured by the provision of an objective lens comprising the following units in sequence from the object side:

a front lens unit of negative refractive power consisting of a first lens of negative refractive power in the shape of a meniscus with a concave surface directed toward the image field side;

and

a rear lens unit comprising a second lens of positive refractive power nearest to the object with a convex surface directed toward the object side; wherein

focusing is carried out by moving the above front lens unit in the direction of the optical axis;

driving means for moving the above front lens unit in focusing;

and

selecting means for selecting a specific mode from a plurality of modes in possession of the above image pickup device, wherein when a predetermined mode is selected, the above front lens unit is moved by the driving means to a still nearer position of than the focused position for an infinite object.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is an illustration of the basic configuration of an objective lens according to the Embodiment;

FIG. **2** is a sectional lens view of an objective lens according to Numerical Example 1;

FIG. **3** is a sectional lens view of an objective lens according to Numerical Example 2;

FIG. **4** is a sectional lens view of an objective lens according to Numerical Example 3;

FIG. **5** is a sectional lens view of an objective lens according to Numerical Example 4;

FIG. **6** is a sectional lens view of an objective lens according to Numerical Example 5;

FIG. **7** is a sectional lens view of an objective lens according to Numerical Example 6;

FIG. **8** is a sectional lens view of an objective lens according to Numerical Example 7;

FIG. **9** is a representation of various aberrations of an objective lens according to Numerical Example 1;

FIG. **10** is a representation of various aberrations of an objective lens according to Numerical Example 2;

FIG. **11** is a representation of various aberrations of an objective lens according to Numerical Example 3;

FIG. **12** is a representation of various aberrations of an objective lens according to Numerical Example 4;

FIG. **13** is a representation of various aberrations of an objective lens according to Numerical Example 5;

FIG. **14** is a representation of various aberrations of an objective lens according to Numerical Example 6;

FIG. **15** is a representation of various aberrations of an objective lens according to Numerical Example 7;

FIGS. **16**A and **16**B are illustration of the infinite focus state and the collapse state of the objective lens of FIG. **1**, respectively;

FIGS. **17**A and **17**B are sectional lens views of an objective lens according to Numerical Example 8;

FIGS. **18**A and **18**B are sectional lens views of an objective lens according to Numerical Example 10;

FIGS. **19**A and **19**B are sectional lens views of an objective lens according to Numerical Example 10;

FIGS. **20**A and **20**B are sectional lens views of an objective lens according to Numerical Example 11;

FIGS. **21**A and **21**B are sectional lens views of an objective lens according to Numerical Example 12;

FIGS. **22**A and **22**B are representations of various aberrations of an objective lens according to Numerical Example 8;

FIGS. **23**A and **23**B are representations of various aberrations of an objective lens in Numerical Example 9;

FIGS. **24**A and **24**B are representations of various aberrations of an objective lens in Numerical Example 10;

FIGS. **25**A and **25**B are representations of various aberrations of an objective lens in Numerical Example 11;

FIGS. **26**A and **26**B are representations of various aberrations of an objective lens in Numerical Example 12;

FIG. **27** is an illustration of the basic configuration of an image pickup device (during the photographing state); and

FIG. **28** is an illustration of the basic configuration of an image pickup device (during the collapse state).

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. **1** is an illustration of the basic configuration of one embodiment of objective lens according to the present invention. FIGS. **2** to **8** are sectional views of lenses accord-

ing to the Numerical Examples 1 to 7 mentioned later. FIGS. **9** to **15** are representations of various aberrations in the Numerical Examples 1 to 7. Moreover, FIG. **16**A is a drawing showing the infinite focus state of the objective lens shown in FIG. **1** and FIG. **16**B (not shown) is the collapse state of the objective lens collapsed into the camera body. And, FIGS. **17**A, **18**A, **19**A, **20**A and **21**A are sectional lens views of the objective lens according to Numerical Examples 8 to 12 during the infinite focus state. FIGS. **17**B, **18**B, **19**B, **20**B and **21**B are sectional lens views of the objective lens according to Numerical Examples 8 to 12 during the collapse state. FIGS. **22**A, **23**A, **24**A, **25**A and **26**A are representations of various aberrations of the objective lens according to Numerical Examples 8 to 12 during the infinite focus state. FIGS. **22**B, **23**B, **24**B, **25**B and **26**B are representations of various aberrations of the objective lens according to Numerical Examples 8 to 12 during the state of focused to a short-distance object at a magnification of β=−0.058. Incidentally, the numerical data indicated in pairs of Numerical Examples of 1 and 8, 2 and 9, 4 and 10, 6 and 11 are in common.

In individual drawings, Numerals **101** and **102** denote the front group of negative refractive power and the rear group of positive refractive power. The front lens unit **101** has a first lens unit **103** of negative refractive power, the rear lens unit **102** has a second lens unit **104** of positive refractive power, a third lens unit **105** of negative refractive power and a fourth lens unit **106** of positive refractive power. Numeral **107** denotes a filter unit (glass block) composed of a crystal low-pass filter, an infrared cut filter and like filters. SP denotes a aperture stop, provided between the first lens unit **103** and the second lens unit **104** or between the second lens unit **104** and the third lens unit **105**. Numerals **108**, **109**, **110** and **111** denote an imaging surface on which an image pickup element such as CCD is disposed, an on-axis light flux, an off-axis light flux and the principal ray of an off-axis flux **110**, respectively. Numerals **112** and **113** denote marginal rays of an off-axis light flux **110**, corresponding to the upper and lower rays, respectively.

An objective lens according to this embodiment is a retro-focus type lens configuration comprising a front lens unit **101** of negative refractive power and a rear lens unit **102** of positive refractive power. The first lens unit **103** of negative refractive power consists only of a first negative lens in the shape of a meniscus with the concave surface toward the image field side. The second lens unit **104** of positive refractive power consists only of a second positive lens with the convex surface toward the object side. The third group **105** of negative refractive power consists of a composite lens joined of a third negative lens **105***a* and a fourth positive lens **105***b* in the shape of a meniscus with the concave surface as a whole toward the object side or two independent flat lenses. The fourth lens unit **106** of positive refractive power consists of a single positive fifth lens with both lens surfaces being convex. The total system of an objective lens comprises 4 groups and 5 pieces.

As mentioned above, for widening the photographing field angle and making the exit pupil sufficiently apart from the image field, it is preferable to set the total system to a retro-focus type. Besides, for shortening the total lens length, it is preferable to minimize the number of lenses. The present invention comprises a front lens unit **101** consisting of a single negative lens and a rear lens unit **102** having a positive fifth lens as the final lens. Besides, to keep the exit pupil apart from the image field without intensifying the refractive power of the final lens excessively, a fourth lens **105***b* or a negative composite lens as the lens directly in front of the final lens has the surface on the image field side set to a convex surface.

Besides, to improve the image field characteristics, with the objective lenses shown in Numerical Examples 1 to 11, a negative composite lens is disposed in the rear lens unit **102**. Because of comprising a single lens, the front lens unit **101** has the Petzval sum uncorrected within itself. Consequently, by setting a negative refractive power in the rear lens unit **102**, the front lens unit **101** and the rear lens unit **102** are canceled out to reduce the Petzval sum in the total system. Especially, by pasting the third and fourth lenses from the object side together to make a composite lens among five lenses of a negative, a positive, a negative, a positive and a positive lenses in sequence from the object side, a configuration without a highly eccentrically sensitive air clearance part are implemented. Thereby, the deteriorations of imaging performances due to manufacturing errors, assembling errors or the like is prevented throughout the total system.

Besides, an objective lens according to this embodiment has a stop SP provided between the first lens unit **103** and the second lens unit **104** or between the second lens unit **104** and the third lens unit **105**. For keeping the exit pupil apart from the image field, it is preferable that the front lens unit of retro-focus type is disposed on the object side to the stop SP and an objective lens according to this embodiment has the stop SP disposed on the image field side from the first lens unit. Besides, when the stop is disposed between the third lens unit and the fourth lens unit, an excessively strong refractive power of the fourth lens unit is required for keeping the exit pupil apart from the image field while shortening the total lens length. As a result, the Petzval sum cannot be reduced. Thus, for shortening the total lens length and for keeping the exit pupil apart from the image field, the stop SP is disposed between the first lens unit and the second lens unit or between the second lens unit and the third lens unit.

Besides, the first lens is set to a meniscus lens with a concave surface on the image field side. For keeping the exit pupil far of f from the image field, action of refracting an off-axis chief ray must be afforded to the first lens to some extent. Thus, a certain degree of negative refractive power is necessary for the first lens, but as a result, a barrel-shaped aberration is likely to occur in the first lens. In minimizing the occurrence of this aberration, minimizing the angle of the principal ray of an off-axis light flux incident to a lens surface is effective. For example, if the first lens has a concentric curvature radius, the incident angle of an off-axis ray can be set to 0, but a certain negative refractive power cannot be afforded in this case unlike the above. Thus, in an object lens according to this embodiment, the curvature radius of the surface on the object side is made greater and that of the surface on the image field side is made smaller to intensify the negative refractive power in contrast to a concentric shape, but the occurrence of aberration is minimized by keeping a meniscus shape with a strongly concave surface on the image field side. And correction of aberrations is made so as to cancel this in the rear lens unit **102**.

Besides, in an objective lens according to this embodiment, the total lens length is further shortened by applying an aspherical surface to at least one lens of the fourth lens unit **106** as the final lens and a better imaging performance is obtained. With the above 4 group 5 piece configuration, employing a spherical surface alone has a limit in making the exit pupil sufficiently apart from the image field and shortening the total lens length. In shortening the total lens length with the exit pupil kept apart from

the image field, especially the refractive power of the final lens must be intensified and thereby a barrel-shaped aberration and a under aberration of the image field occur. In an objective lens according to the present invention, shortening the total lens length with the exit pupil kept sufficiently apart from the image is further made easier by applying an aspherical surface to the final lens than in the configuration of a spherical lens alone.

In the case of setting an aspherical surface for the final lens, employing such a shape that the convergent action is weakened from the optical axis toward the marginal portion is effective in correcting a barrel-shaped aberration. This is a shape as slackening the curvature radius in a convex surface. With such an arrangement, both the curvature radius on the surface of lens and the incident angle of a ray act so as to weaken the refraction for an off-axis ray, so that the barrel-shaped aberration is corrected. Besides, since the imaging action is weakened for an off-axis light flux, there is a tendency of correcting the under curvature of field. Thus, in an objective lens according to the present invention, both the aberration and the curvature of field are corrected with the total lens length shortened by applying such an aspherical surface to the final lens. Incidentally, the marginal refractive power is relatively weakened as compared with the neighborhood of the optical axis on account of the above aspherical shape, but the refractive power of the fourth lens unit **106** itself is intensified by introduction of an aspherical surface, so that aberrations can be corrected with the exit pupil kept sufficient apart from the image field.

Besides, in an objective lens according to the present invention, occurrence of comatic aberration is suppressed while the angle of field widened by appropriately setting up the lens shape of the second lens unit **104**. After an off-axis light flux is refracted through the first lens unit **103**, the principal ray is incident to the second lens unit **104** at a certain angle with the optical axis. At this time, a comatic aberration occurs unless the lens surface of the second lens unit **104** has no concentric curvature radius. Thus, in this embodiment, occurrence of a comatic aberration is reduced by making a relatively small curvature radius while the lens surface on the object side of the second group **104** remaining convex.

Furthermore, in an objective lens according to this embodiment, a far better imaging performance is implemented even when the total lens length is shortened while the angle of field widened, by applying at least one aspherical surface to the second lens unit **104**. After an off-axis light flux is refracted through the first lens unit **103**, the principal ray is incident on the second lens unit **104** at a certain angle with the optical axis. At this time, a comatic aberration occurs unless the lens surface of the second lens unit **104** has no concentric curvature radius. Thus, in objective lens of this embodiment, occurrence of a comatic aberration is reduced though the angle of field remains wide by setting the lens surface on the object side of the second lens unit **104** to a relatively small curvature radius. Besides, in an on-axis light flux, a spherical over aberration occurs through the concave surface on the image side of the first lens unit **103**. If the lens surface on the object side of the second lens unit **104** is set to a convex surface, a spherical under aberration occurs and the spherical aberration occurring in the first lens unit **103** can be corrected. If the curvature of the lens surface on the object side of the second lens unit **104**, however, is sharpened for the correction of a comatic aberration with the angle of field kept wide, then a spherical under aberration may occur to greater extent in the second lens unit **104** than required. Though occurring in the concave surface of the third lens unit **105**, the spherical over aberration cannot be corrected too great a degree of spherical under aberration in the second lens unit **104** and accordingly the correction becomes incomplete in the total system. Thus, in this embodiment, the spherical under aberration is corrected by establishing such an aspherical surface that the convergence action is weakened from the optical axis toward the margin in the second lens unit **104**. Since an on-axis land ray is refracted at a position apart from the optical axis on any one surface of the second lens unit **104**, an aspherical surface to be provided for the correction of a spherical aberration is effective even on any lens surface of the second lens unit **104**.

Besides, for a wider photographing field angle, it is effective to apply at least one aspherical surface also to the first lens unit **103** in addition to the fourth lens unit **106**. At a fixed value of total lens length, the refractive power of the first lens unit **103** must be intensified with a wider photographing field angle. In the first lens unit **103**, a barrel-type aberration occurs, but an excessive strength of refractive power results in lack of correction even if an aspherical surface is applied to the fourth lens unit **106**. In such cases, applying an aspherical surface to the first lens unit **103** enables a aberration to be well corrected while the angle of field in the objective lens remaining wider. As mentioned above, the first lens unit **103** consists of a meniscus lens with the negative refractive power intensified in contrast to the concentric shape. Thus, in the lens surface of the first lens unit **103**, the principle ray is refracted at a greater incident angle with more eccentric off-axis light flux. For the correction of a barrel-shaped aberration, it is preferable to employ such an aspherical surface that the divergent action is gradually weakened from the optical axis toward the marginal portion. Namely, it is preferable to make the lens surface on the object side of the first lens unit **103** into an aspherical surface shape with its curvature radius sharpened from the optical axis toward the marginal portion and the one on the image field side into an aspherical surface shape with its curvature radius slackened from the optical axis toward the marginal portion.

Incidentally, even if the composite lens of the third lens unit **105** is separated to make the whole into a 5 piece configuration of simple lenses as shown in FIGS. **21**A and **21**B, shortening the total lens length and improving the optical performance are compatible with the exit pupil remaining sufficiently apart from the image field. In general, however, the air lens formed by separating the third lens unit is highly sensitive and characterized in that curvature of field is likely to occur in the presence of manufacturing errors, assembling errors or the like. Thus, only if manufacturing errors, assembling errors and the like are controllable, the configuration shown in FIGS. **21**A and **21**B is effective as an objective lens.

Besides, in an objective lens according to this embodiment, only a single lens of the first lens unit **103** is used for focusing lens. Thereby, the focusing lens can be constructed at an extremely light weight, so that the focusing performance excellent in response is obtained. In a digital still camera or the like using a solid image pickup element, there is employed a focusing method by positioning a focusing lens at the position of maximum in AF signal after reading an AF signal for each drive distance at definite intervals while driving the focusing lens over the whole focal range extending from an infinite object to a short distance object. In such a focusing method, excellency in the response of a focusing lens is preferable for raising the focusing speed and is important especially where a reversal

motion of driving direction is included. Besides, since the consumed power needed for the drive is small enough, this method leads to a longer life of service in a camera operated with a battery.

Besides, an image pickup device using an objective lens according to this embodiment enables the compaction in the direction of optical axis by collapsing a part of the above objective lens. In the above objective lens, though the total optical length is shortened to the utmost, further shortening the total optical length is implementable by moving the focusing lens toward the image field side as shown in FIG. **16**B during not photographing operation in an image pickup device.

FIG. **27** is a sectional view of the basic configuration of an image pickup device. In FIG. **27**, the image pickup element comprises a lens barrel **221** designated with hatching for retaining the rear lens unit **102**, the filter **107** and the like, a solid image pickup device **222** disposed on the imaging surface of the objective lens comprising the front lens unit **101**, the rear lens unit **102** and the filter **107**, a stepping motor (driving means) **223**, an output axis **224** of the stepping motor **223**, a rack member **225** engaged with the output axis **224**, a moving ring **226** for retaining the front group **101** and a guide bar **227** positioned opposite the output axis **224** across the optical axis. Besides, the solid image pickup element also comprises an unshown guide bar on a section different from that of FIG. **27**.

The moving ring **226**, retained by the guide bar **227** and the unshown guide bar, is so arranged as movable in the direction of optical axis. At this time, the moving ring **226** has an unshown sleeve part for mating with the unshown guide bar and a U-shaped groove (U-shaped, viewed in the direction of optical axis) **226***a* for suppressing the rotation around the optical axis to the guide bar **227**. Besides, by converting the rotation of the output axis **224** into the torque toward the optical axis via the rack member **225**, the moving ring **226** is driven along the optical axis. At this time, the moving ring **226** is driven by the distance corresponding to the number of input steps of the stepping motor **223**. FIG. **27** shows the thrust state of the focusing lens for photographing, whereas FIG. **28** shows the collapse state of the focusing lens **101** by moving the moving ring **226** to the image field side at the not photographing time. Focusing is carried out by moving the focusing lens **101** in the direction of optical axis through the drive of the stepping motor **223** in FIG. **27**. On the other hand, at the not photographing time, the focusing lens **101** is driven toward the image field side from the infinite focus position to reach the collapse state by using the same mechanism. Like this, an image pickup device according to the present invention jointly employs the focusing mechanism for the collapse mechanism and accordingly has no special mechanism for the collapse, the compaction in the direction of optical axis is implemented without making the apparatus greater in size.

Meanwhile, the focusing lens in an image pickup device according to this embodiment is driven to the photographing position shown in FIG. **27** and to the collapse position shown in FIG. **28** corresponding to the mode of a camera. In a digital still camera having display means such as liquid crystal device, for example, the following modes are considered.

<1> Autophotographing mode;

<2> Manual photographing mode;

<3> Power source off;

<4> Playback mode;

<5> Setting mode;

<6> Communicating mode.

MODE <1> is a photographing mode of automatically setting the ON/OFF of focus, exposure or stroboscope for a camera. MODE <2> is a photographing mode of setting the ON/OFF of focus, exposure or stroboscope for a photographer. MODE <3> is a mode of turning OFF the power supply of the total camera. MODE <4> is a mode of playbacking the photographed image by display means. MODE <5> is a mode of setting the level, date or the like of a file compression. MODE <6> is a mode of performing a data communication with a computer. Among these, Modes <1> and <2> are photographing modes and MODES <3> to <6> are not-photographing modes. With Power Supply OFF MODE <3> among MODES <3> to <6>, the focusing lens never fails to become the collapse state. Besides, also when other modes of MODES <3> to <6> are selected, the focusing lens may be collapsed. Especially, from the viewpoint of protecting the focusing lens, it is preferable to keep the collapse state as far as possible at the time of not photographing. Any of these modes can be selected optionally for a photographer by selecting means such as dial provided in the main camera body.

Besides, an objective lens according to the present invention is so arranged as to satisfy the following conditional expressions (1) to (3):

$$0.7<|f1|/f<3.0 \quad (1)$$

$$0.7<f4/f<3.0 \quad (2)$$

$$0.8<f12/f<2.5 \quad (3)$$

Here, fi: focal length of the i-th lens unit,

f12: composite focal length of the first and second lens units

f: focal length of the total objective lens system.

The technical meaning of conditional expressions (1) to (3) will be described.

The conditional expression (1) is an expression for defining the focal length or refractive power of the first lens unit **103**.

When the refractive power weakens beyond the upper limit of the conditional expression (1), the action of holding the exit pupil far off from the image field in the first lens unit **103** weakens. If an attempt is made to hold the exit pupil far off from the image field in such a manner as to compensate this by means of the refractive power in the rear lens unit, the refractive power of a convex surface in the rear lens unit must be intensified, thereby disabling the Petzval sum to be reduced and leading to a frequent occurrence of curvature of field, so that this attempt is not advisable. Besides, if an attempt is made to hold the exit pupil far off from the image field without intensifying the refractive power of the rear lens unit, the total lens length becomes longer, thereby disabling a compact objective lens to be constructed. On the other hand, when the refractive power is intensified beyond the lower limit, an excess of aberration and astigmatism occurs in the first lens unit **103** and the correction becomes impossible even by using an aspherical surface, so that this case is not advisable. Besides, the back focus lengthens and shortening the total optical length becomes difficult.

The conditional expression (2) is an expression for defining the focal length or refractive power of the fourth lens unit **106**.

When the refractive power weakens beyond the upper limit of the conditional expression (2), it becomes impossible to hold the exit pupil sufficiently apart from the image field and accordingly this case is not advisable. On the other hand, when the refractive power is intensified beyond the lower limit, an excess of aberration, curvature of field and astigmatism occur in the fourth lens unit **106** and the correction becomes impossible even by using an aspherical surface.

The conditional expression (3) is an expression for defining the focal length or refractive power of the composite system composed of the first lens unit **103** and the second lens unit **104**.

When the refractive power weakens beyond the upper limit of the conditional expression (3), the back focus lengthens and it becomes difficult to shorten the total optical length. On the other hand, when the refractive power is intensified beyond the lower limit, it becomes difficult to obtain a good optical performance by suppressing the occurrence of various aberrations. Especially an excess of spherical aberration occurs and consequently the correction becomes difficult even by applying an aspherical surface.

Furthermore, in the correction of aberrations, those of satisfying the following conditions is preferable.

Letting r1, r2 and r3 be curvatures of radius in lens surfaces of the first lens of the first lens unit **103** on the object side and on the image field side and that of the second lens of the second lens unit **104** on the object side, it is preferable to satisfy the following relations:

$$0.7<r3/r2<1.5 \quad (4)$$

$$-2.3<(r2+r1)/(r2-r1)<-1.0 \quad (5)$$

The conditional expression (4) is an expression for defining the ratio of curvature radius between the lens surface on the image side of the first lens of the first lens unit and the lens surface on the object side of the second lens of the second lens unit.

When this ratio exceeds the upper limit of the conditional expression (4), the curvature radius in the lens surface on the object side of the second lens unit **104** goes apart from the concentric curvature radius for an off-axis ray and consequently the occurrence of comatic aberration becomes especially excessive often, thus leading to difficulty in the correction even by using an aspherical surface. When this ratio exceeds the lower limit of the conditional expression (4), the correction to the lens surface on the image side of the second lens unit **104** becomes excessive for a spherical over aberration occurring in the lens surface on the image side of the first lens unit **103**, thus leading to difficulty in the correction even by using an aspherical surface.

The conditional expression (5) is an expression for defining the lens shape of the first lens of the first lens unit **103**.

When the relevant ratio exceeds the upper limit of the conditional expression (5), the incident angle of an off-axis light flux on the lens surface on the object side in the first lens unit **103** increase, thus leading to difficulty in a good correction of curvature of field and astigmatism even by using an aspherical surface. When the ratio exceeds the lower limit of the expression (5), the curvature of the lens surface on the image side of the first lens unit **103** is excessively sharpened, thus leading to occurrence of spherical excessively over aberration.

Next, Numerical Examples 1 to 12 of numerical data according to the present invention will be shown. In individual numerical examples, Numerals Ri, Di and Ni and vi denote the curvature radius of the i-th optical part from the object side, the size or air clearance of the i-th optical part from the object side, and the refractive index and Abbe's number of the i-th optical part.

Numerical Expression 1

$$X = \frac{h^2/R}{1+\{1-(h/R)^2\}^{1/2}} + Bh^4 + Ch^6 + Dh^8 + Eh^{10}$$

wherein

X: Coordinate determined from the object toward the image side along the optical axis by setting the vertex of an aspherical surface to the origin;

h: Coordinate vertical to the optical axis by setting the vertex of an aspherical surface to the origin;

R: Paraxial radius of curvature of an aspherical surface; and

B, C, D and E: Aspherical coefficients.

Besides, Table 1 shows the values of individual conditional expressions in individual numerical embodiments.

NUMERICAL EXAMPLE 1

f = 1.00	Fno = 2.50	2ω = 65.2°	
R1 = 6.561	D1 = 0.14	N1 = 1.772499	ν1 = 49.6
R2 = 1.100	D2 = 1.00		
R3 = 1.186	D3 = 0.40	N2 = 1.772499	ν2 = 49.6
R4 = −3.441	D4 = 0.10		
R5 = Stop	D5 = 0.51		
R6 = −0.539	D6 = 0.10	N3 = 1.846660	ν3 = 23.8
R7 = 4.804	D7 = 0.50	N4 = 1.677900	ν4 = 55.3
R8 = −0.763	D8 = 0.04		
R9 = 2.452	D9 = 0.36	N5 = 1.772499	ν5 = 49.6
R10 = −3.035	D10 = 0.40		
R11 =ω	D11 = 0.68	N6 = 1.516330	ν6 = 64.2
R12 =ω			

Aspherical coefficients:

R9 B=−1.07887e−01; C=3.37571e−02;

D=−8.37316e−02; and E=0.00000e+00

Position of the exit pupil from the paraxial image field: −13.609

Total optical length: 4.511

NUMERICAL EXAMPLE 2

f = 1.00	Fno = 2.50	2ω = 65.2°	
R1 = 4.006	D1 = 0.14	N1 = 1.772499	ν1 = 49.6
R2 = 1.018	D2 = 1.08		
R3 = Stop	D3 = 0.10		
R4 = 1.027	D4 = 0.40	N2 = 1.743997	ν2 = 44.8
R5 = −4.383	D5 = 0.62		
R6 = −0.499	D6 = 0.10	N3 = 1.846660	ν3 = 23.8
R7 = 8.829	D7 = 0.50	N4 = 1.677900	ν4 = 55.3
R8 = −0.799	D8 = 0.04		
R9 = 2.287	D9 = 0.36	N5 = 1.772499	ν5 = 49.6
R10 = −2.601	D10 = 0.20		
R11 =ω	D11 = 0.68	N6 = 1.516330	ν6 = 64.2
R12 =ω			

Aspherical coefficients:

R9 B=−1.05540e−01; C=1.62936e−02;

D=−2.41597e−02; and E=−1.56026e−02

Position of the exit pupil from the paraxial image field: −9.081

Total optical length: 4.622

NUMERICAL EXAMPLE 3

f = 1.00	Fno = 2.50	2ω = 49.1°	
R1 = 7.143	D1 = 0.10	N1 = 1.772499	ν1 = 49.6
R2 = 0.686	D2 = 0.43		
R3 = 0.862	D3 = 0.29	N2 = 1.743997	ν2 = 44.8
R4 = −2.521	D4 = 0.07		
R5 = Stop	D5 = 0.54		
R6 = −0.436	D6 = 0.07	N3 = 1.846660	ν3 = 23.8
R7 = 9.048	D7 = 0.31	N4 = 1.696797	ν4 = 55.5
R8 = −0.949	D8 = 0.03		
R9 = 3.504	D9 = 0.37	N5 = 1.772499	ν5 = 49.6
R10 = −0.944	D10 = 0.29		
R11 =ω	D11 = 0.49	N6 = 1.516330	ν6 = 64.2
R12 =ω			

Aspherical coefficients:

R10 B=2.54127e−01; C=4.98937e−02;

D=3.61130e−01; and E=−4.06567e−01

Position of the exit pupil from the paraxial image field: −24.255

Total optical length: 3.711

NUMERICAL EXAMPLE 4

f = 1.00	Fno = 2.50	2ω = 77.3°	
R1 = 5.506	D1 = 0.18	N1 = 1.772499	ν1 = 49.6
R2 = 0.975	D2 = 1.30		
R3 = 1.059	D3 = 0.45	N2 = 1.677900	ν2 = 54.9
R4 = −2.511	D4 = 0.20		
R5 = Stop	D5 = 0.55		
R6 = −0.574	D6 = 0.18	N3 = 1.846660	ν3 = 23.8
R7 = 6.627	D7 = 0.65	N4 = 1.696797	ν4 = 55.5
R8 = −1.025	D8 = 0.05		
R9 = 1.928	D9 = 0.50	N5 = 1.677900	ν5 = 54.9
R10 = −2.424	D10 = 0.13		
R11 =ω	D11 = 0.85	N6 = 1.516330	ν6 = 64.2
R12 =ω			

Aspherical coefficients:

R3 B=−3.74809e−02; C=−2.99963e−01;

D=0.00000e+00; and E=0.00000e+00

R10 B=1.40788e−01; C=−3.66529e−02;

D=1.89036e−02; and E=0.00000e+00

Position of the exit pupil from the paraxial image field: −16.540

Total optical length: 5.257

NUMERICAL EXAMPLE 5

f = 1.00	Fno = 2.50	2ω = 93.7°	
R1 = 6.740	D1 = 0.33	N1 = 1.772499	ν1 = 49.6
R2 = 1.338	D2 = 2.33		
R3 = 1.161	D3 = 0.60	N2 = 1.567322	ν2 = 42.8
R4 = −4.006	D4 = 0.33		
R5 = Stop	D5 = 0.33		
R6 = −0.747	D6 = 0.23	N3 = 1.846660	ν3 = 23.8
R7 = 2.537	D7 = 0.83	N4 = 1.696797	ν4 = 55.5
R8 = −1.207	D8 = 0.07		
R9 = 1.832	D9 = 0.80	N5 = 1.563839	ν5 = 60.7
R10 = −3.531	D10 = 0.17		
R11 =ω	D11 = 1.13	N6 = 1.516330	ν6 = 64.2
R12 =ω			

Aspherical coefficients:

R1 B=1.89860e−02; C=−2.97310e−03;

D=2.60021e−04; and E=0.00000e+00

R3 B=5.12444e−03; C=−1.59078e−02;

D=−9.71925e−02; and E=0.00000e+00

R9 B=−7.18366e−02; C=1.84468e−02;

D=−5.98903e−03; and E=0.00000e+00

Position of the exit pupil from the paraxial image field: −14.695

Total optical length: 7.570

NUMERICAL EXAMPLE 6

f = 1.00	Fno = 2.50	2ω = 69.7°	
R1 = 3.492	D1 = 0.15	N1 = 1.772499	ν1 = 49.6
R2 = 1.069	D2 = 1.30		
R3 = 1.027	D3 = 0.43	N2 = 1.743997	ν2 = 44.8
R4 = 24.503	D4 = 0.09		
R5 = Stop	D5 = 0.54		
R6 = −0.582	D6 = 0.11	N3 = 1.846660	ν3 = 23.8
R7 = 2.694	D7 = 0.54	N4 = 1.677900	ν4 = 55.3
R8 = −0.850	D8 = 0.04		
R9 = 1.494	D9 = 0.39	N5 = 1.772499	ν5 = 49.6
R10 = −8.547	D10 = 0.22		
R11 =ω	D11 = 0.74	N6 = 1.516330	ν6 = 64.2
R12 =ω			

Aspherical coefficients:

R2 B=−3.29786e−02; C=−9.81517e−02;

D=4.58637e−02; and E=0.00000e+00

R9 B=−7.58203e−02; C=−1.94961e−02;

D=3.80518e−02; and E=−2.74684e−02

Position of the exit pupil from the paraxial image field: −22.865

Total optical length: 5.059

NUMERICAL EXAMPLE 7

f = 1.00	Fno = 2.50	2ω = 69.7°	
R1 = 2.174	D1 = 0.15	N1 = 1.772499	ν1 = 49.6
R2 = 0.870	D2 = 1.30		
R3 = 0.932	D3 = 0.43	N2 = 1.743997	ν2 = 44.8
R4 = −19.264	D4 = 0.09		
R5 = Stop	D5 = 0.43		
R6 = −0.576	D6 = 0.11	N3 = 1.846660	ν3 = 23.8
R7 = 1.679	D7 = 0.54	N4 = 1.677900	ν4 = 55.3
R8 = 31 0.870	D8 = 0.04		
R9 = 1.551	D9 = 0.39	N5 = 1.772499	ν5 = 49.6
R10 = −7.189	D10 = 0.22		
R11 =ω	D11 = 0.74	N6 = 1.516330	ν6 = 64.2
R12 =ω			

Aspherical coefficients:

R2 B=−1.46698e−02; C=−1.58150e−01;

D=−5.05301e02; and E=0.00000e+00

R9 B=−6.95675e−02; C=−3.59198e−02;

D=3.48474e−02; and E=−1.07646e−02

Position of the exit pupil from the paraxial image field: −8.071

Total optical length: 4.796

NUMERICAL EXAMPLE 8

f = 1.00	Fno = 2.50	2ω = 65.2°	
R1 = 6.561	D1 = 0.14	N1 = 1.772499	ν1 = 49.6
R2 = 1.100	D2 = 1.00		
R3 = 1.186	D3 = 0.40	N2 = 1.772499	ν2 = 49.6
R4 = −3.441	D4 = 0.10		
R5 = Stop	DS = 0.51		
R6 = −0.539	D6 = 0.10	N3 = 1.846660	ν3 = 23.8
R7 = 4.804	D7 = 0.50	N4 = 1.677900	ν4 = 55.3
R8 = −0.763	D8 = 0.04		
R9 = 2.452	D9 = 0.36	NS = 1.772499	ν5 = 49.6
R10 = −3.035	D10 = 0.40		
R11 =ω	D11 = 0.68	N6 = 1.516330	ν6 = 64.2
R12 =ω			
Infinite focus	Short distance (β = −0.058)	Collapse state	
D2 1.00	1.17	0.20	

Aspherical coefficients:

R9 B=−1.07887e−01; C=3.37571e−02;

D=−8.37316e−02; and E=0.00000e+00

Position of the exit pupil from the paraxial image field: −13.609

Total optical length (infinite object state): 4.511

Total optical length (collapse state): 3.711

NUMERICAL EXAMPLE 9

f = 1.00	Fno = 2.50	2ω 32 65.2°	
R1 = 4.006	D1 = 0.14	N1 = 1.772499	ν1 = 49.6
R2 = 1.018	D2 = 1.08		
R3 = Stop	D3 = 0.10		
R4 = 1.027	D4 = 0.40	N2 = 1.743997	ν2 = 44.8
R5 = −4.383	D5 = 0.62		
R6 = −0.499	D6 = 0.10	N3 = 1.846660	ν3 = 23.8
R7 = 8.829	D7 = 0.50	N4 = 1.677900	ν4 = 55.3
R8 = −0.799	D8 = 0.04		
R9 = 2.287	D9 = 0.36	N5 = 1.772499	ν5 = 49.6
R10 = −2.601	D10 = 0.20		
R11 =ω	D11 = 0.68	N6 = 1.516330	ν6 = 64.2
R12 =ω			
Infinite focus	Short distance (β = −0.058)	Collapse state	
D2 1.08	1.27	0.28	

Aspherical coefficients:

R9 B=−1.05540e−01; C=1.62936e−02;

D=−2.41597e−02; and E=−1.56026e−02

Position of the exit pupil from the paraxial image field: −9.081

Total optical length (infinite object state): 4.622

Total optical length (collapse state): 3.822

NUMERICAL EXAMPLE 10

f = 1.00	Fno = 2.50	2ω = 77.3°	
R1 = 5.506	D1 = 0.18	N1 = 1.772499	ν1 = 49.6
R2 = 0.975	D2 = 1.30		
R3 = 1.059	D3 = 0.45	N2 = 1.677900	ν2 = 54.9
R4 = −2.511	D4 = 0.20		
R5 = Stop	D5 = 0.55		
R6 = −0.574	D6 = 0.18	N3 = 1.846660	ν3 = 23.8
R7 = 6.627	D7 = 0.65	N4 = 1.696797	ν4 = 55.5
R8 = −1.025	D8 = 0.05		
R9 = 1.928	D9 = 0.50	N5 = 1.677900	ν5 = 54.9

-continued

R10 = −2.424	D10 = 0.13		
R11 =ω	D11 = 0.85	N6 = 1.516330	ν6 = 64.2
R12 =ω			
Infinite focus	Short distance (β = −0.047)	Collapse state	
D2 1.30	1.41	0.25	

Aspherical coefficients:

R3 B=−3.74809e−02; C=−2.99963e−01;

D=0.00000e;00; and E=0.00000e+00

R10 B=1.40788e−01; C=−3.66529e−02;

D=1.89036e−02; and E=0.00000e+00

Position of the exit pupil from the paraxial image field: −16.540

Total optical length (infinite object state): 5.257

Total optical length (collapse state): 4.207

NUMERICAL EXAMPLE 11

f = 1.00	Fno = 2.50	2ω = 69.7°	
R1 = 3.492	D1 = 0.15	N1 = 1.772499	ν1 = 49.6
R2 = 1.069	D2 = 1.30		
R3 = 1.027	D3 = 0.43	N2 = 1.743997	ν2 = 44.8
R4 = 24.503	D4 = 0.09		
R5 = Stop	D5 = 0.54		
R6 = −0.582	D6 = 0.11	N3 = 1.846660	ν3 = 23.8
R7 = 2.694	D7 = 0.54	N4 = 1.677900	ν4 = 55.3
R8 = −0.850	D8 = 0.04		
R9 = 1.494	D9 = 0.39	N5 = 1.772499	ν5 =49.6
R10 = −8.547	D10 = 0.22		
R11 =ω	D11 = 0.74	N6 = 1.516330	ν6 = 64.2
R12 =ω			
Infinite focus	Short distance (β = −0.054)	Collapse state	
D2 1.30	1.53	0.22	

Aspherical coefficients:

R2 B=−3.29786e−02; C=−9.81517e−02;

D=4.58637e−02; and E=0.00000e+00

R9 B=−7.58203e−02; C=−1.94961e−02;

D=3.80518e−02; and E=−2.74684e−02

Position of the exit pupil from the paraxial image field: −22.865

Total optical length (infinite object state): 5.059

Total optical length (collapse state): 3.979

NUMERICAL EXAMPLE 12

f = 1.00	Fno = 2.50	2ω = 65.2°	
R1 = 6.750	D1 = 0.14	N1 = 1.696797	ν1 = 55.5
R2 = 1.003	D2 = 1.10		
R3 = 1.197	D3 = 0.40	N2 = 1.772499	ν2 = 49.6
R4 = −3.396	D4 = 0.20		
R5 = Stop	D5 = 0.46		
R6 = −0.539	D6 = 0.10	N3 = 1.846660	ν3 = 23.8
R7 = −30.127	D7 = 0.06		
R8 = 65.281	D8 = 0.50	N4 = 1.696797	ν4 = 55.5
R9 = −0.834	D9 = 0.04		
R10 = 1.723	D10 = 0.36	N5 = 1.583126	ν5 = 59.4
R11 = -3.113	D11 = 0.20		
R12 =ω	D12 = 0.68	N6 = 1.516330	ν6 = 64.2
R13 =ω			

-continued

	Infinite focus	Short distance (β = −0.059)	Collapse state
D2	1.10	1.27	0.20

Aspherical coefficients:

R10 B=−1.57488e−01; C=4.03051e−02;

D=−1.37226e−01; and E=0.00000e+00

Position of the exit pupil from the paraxial image field: −14.174

Total optical length (infinite object state): 4.672

Total optical length (collapse state): 3.772

TABLE 1

Example	1, 8	2, 9	3	4, 10	5	6, 11	7	12
(1)	1.73	1.80	0.99	1.56	2.22	2.05	1.97	1.71
(2)	1.81	1.63	1.00	1.66	2.26	1.68	1.68	1.96
(3)	1.29	1.13	1.58	1.02	1.25	1.56	1.18	1.22
(4)	1.08	1.03	1.26	1.09	0.87	0.96	1.07	1.19
(5)	−1.40	−1.68	−1.21	−1.43	−1.50	−1.88	−2.33	−1.35

By appropriately setting the lens configuration like this, according to this embodiment, telecentric objective lenses can be attained which has a good optical performance over all the object distance from an infinite object to a near object with the exit pupil kept apart from the image field while widening the photographing field angle and shortening the total lens length is intended and moreover a high optical performance of well corrected various aberrations on the whole image at a photographing field angle of about 65–77 and an F number of about 2.5.

Besides, it is possible to provide an image pickup device excellent in focusing response and small in power consumption.

Besides, it is possible to provide an image pickup device still more compact in the direction of optical axis at the time of not photographing.

What is claimed is:

1. An objective lens consisting of the following four lens units in sequence from the object side:

a first lens unit consisting of a first lens of negative refractive power in the shape of a meniscus with a concave surface toward the image field side;

a second lens unit consisting of a second lens of positive refractive power;

a third lens unit consisting of a composite lens having joined together a third lens of negative refractive power with a concave surface toward the object side and a fourth lens of positive refractive power with a convex surface toward the image field side, said third lens unit having, as a whole, negative refractive power; and

a fourth lens unit consisting of a fifth lens of positive refractive power,

wherein on letting fi, f12, and f be the focal length of an i-th lens unit, the composite focal length of the first lens unit and a second lens unit, and the focal length of the whole objective lens system, respectively, the conditions of

$0.7<|f1|/f<3.0$,

$0.7<f4/f<3.0$, and

$0.8<f12/f<2.5$ are satisfied.

2. An objective lens according to claim **1**, wherein said fourth lens unit has at least one aspherical surface.

3. An objective lens according to claim **2**, wherein the aspherical surface of said fourth lens unit is so shaped that the convergent action weakens gradually in a direction from the optical axis to the marginal portion.

4. An objective lens according to claim **2**, wherein said first lens unit has at least one aspherical surface.

5. An objective lens according to claim **4**, wherein the aspherical surface of said first lens unit is so shaped that the divergent action weakens gradually in a direction from the optical axis to the marginal portion.

6. An objective lens comprising the following lens units in sequence from the object side:

a first lens unit consisting of a first lens of negative refractive power in the shape of a meniscus with a concave surface toward the image field side;

a second lens unit consisting of a second lens of positive refractive power;

a third lens unit consisting of a composite lens having joined together a third lens of negative refractive power with a concave surface toward the object side and a fourth lens of positive refractive power with a convex surface toward the image field side, said third lens unit having, as a whole, negative refractive power; and

a fourth lens unit consisting of a fifth lens of positive refractive power,

wherein on letting fi, f12, and f be the focal length of an i-th lens unit, the composite focal length of the first lens unit and a second lens unit, and the focal length of the whole objective lens system, respectively, the conditions of

$0.7<|f1|/f<3.0$,

$0.7<f4/f<3.0$, and

$0.8<f12/f<2.5$ are satisfied,

wherein said second lens unit has at least one aspherical surface.

7. An objective lens according to claim **6**, wherein the aspherical surface of said second lens unit is so shaped that the convergent action weakens gradually in a direction from the optical axis to the marginal portion.

8. An objective lens according to claim **6**, wherein said first lens unit has at least one aspherical surface.

9. An objective lens according to claim **8**, wherein the aspherical surface of said first lens unit is so shaped that the divergent action weakens gradually in a direction from the optical axis to the marginal portion.

10. An objective lens according to claim **1**, wherein said fifth lens is a biconvex lens.

11. An objective lens according to claim **1**, further comprising a stop, wherein said stop is disposed either between said first lens unit and said second lens unit or between said second lens unit and said third lens unit.

12. An objective lens comprising the following lens units in sequence from the object side:

a front lens unit of negative refractive power, said front lens unit consisting of a first lens of negative refractive power in the shape of a meniscus with a concave surface toward the image field side; and

a rear lens unit of positive refractive power, said rear lens unit comprising a second lens of positive refractive power nearest to the object with a convex surface toward the object side,

wherein, a lens free region is provided between said front lens unit and said rear lens unit, and focusing is carried out by moving only said front lens unit in the direction of the optical axis.

13. An objective lens comprising the following lens units in sequence from the object side:

a front lens unit of negative refractive power, said front lens unit consisting of a first lens of negative refractive power in the share of a meniscus with a concave surface toward the image field side; and

a rear lens unit of positive refractive power, said rear lens unit comprising a second lens of positive refractive power nearest to the object with a convex surface toward the object side,

wherein focusing is carried out by moving only said front lens unit in the direction of the optical axis, and

wherein on letting r1 and r2 be radii of curvature of lens surfaces on the object side and the image field side of said first lens and r3 be a radius of lens surface on the object side of said second lens, the conditions of

$$0.7<r3/r2<1.5 \text{ and}$$

$$-2.3<(r2+r1)/(r2-r1)<-1.0 \text{ are satisfied.}$$

14. An objective lens comprising the following lens units in sequence from the object side:

a front lens unit of negative refractive power, said front lens unit consisting of a first lens of negative refractive power in the shape of a meniscus with a concave surface toward the image field side; and

a rear lens unit of positive refractive power, said rear lens unit comprising a second lens of positive refractive power nearest to the object with a convex surface toward the object side,

wherein focusing is carried out by moving only said front lens unit in the direction of the optical axis, and

wherein said rear lens unit has at least one negative lens and consists of 4 lenses or less.

15. An objective lens comprising the following lens units in sequence from the object side:

a front lens unit of negative refractive power, said front lens unit consisting of a first lens of negative refractive power in the shape of a meniscus with a concave surface toward the image field side; and

a rear lens unit of positive refractive power, said rear lens unit comprising a second lens of positive refractive power nearest to the object with a convex surface toward the object side,

wherein focusing is carried out by moving said front lens unit in the direction of the optical axis,

wherein said rear lens unit has at least one negative lens and consists of four lenses or less, and

wherein said rear lens unit consists of the following lenses in order from the object side:

said second lens;

a composite lens of negative refractive power in the shape of a meniscus with a convex surface directed toward the image field side, said composite lens having joined together a negative lens with a concave surface directed toward the object side and a positive lens with a convex surface directed toward the image field side; and

a biconvex positive lens.

16. An objective lens comprising the following lens units in sequence from the object side:

a front lens unit of negative refractive power, said front lens unit consisting of a first lens of negative refractive power in the shape of a meniscus with a concave surface toward the image field side; and

a rear lens unit of positive refractive power, said rear lens unit comprising a second lens of positive refractive power nearest to the object with a convex surface toward the object side,

wherein focusing is carried out by moving said front lens unit in the direction of the optical axis,

wherein said rear lens unit has at least one negative lens and consists of four lenses or less,

wherein said rear lens unit consists of the following lenses in order from the object side:

said second lens;

a negative lens with a concave surface directed toward the object side;

a positive lens with a convex surface directed toward the image field side; and

a biconvex positive lens.

17. An objective lens according to claim **12**, wherein said objective lens has at least one aspherical surface.

18. An image pickup device comprising:

an objective lens as set forth in any of claims **1** to **17** and an image pickup element for receiving an image formed by said objective lens.

19. An image pickup device comprising: an objective lens which comprises the following lens units in sequence from the object side, (a) a front lens of negative refractive power, said front lens unit consisting of a first lens of negative refractive power in the shape of a meniscus with a concave surface toward the image field side, and (b) a rear lens unit of positive refractive power, said rear lens unit comprising a second lens of positive refractive power nearest to the object with a convex surface directed toward the object side, wherein, a lens free region is provided between said front lens unit and said rear lens unit, and focusing is carried out by moving only said front lens unit in the direction of the optical axis;

driving means for moving said front lens unit in focusing; and selecting means for selecting a specific mode from a plurality of modes of said image pickup device, wherein when a predetermined mode is selected, said front lens unit is moved by said driving means to a still nearer position of the image side than the focused position for an infinite object.

20. An image pickup device according to claim **19**, wherein

said predetermined mode is a mode of not photographing for said image pickup device.

21. An objective lens according to claim **12**, wherein light emerging from said front lens unit is directly incident on said rear lens unit.

22. An image pickup device according to claim **19**, wherein light emerging from said front lens unit is directly incident on said rear lens unit.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 6,236,521 B1
DATED : May 22, 2001
INVENTOR(S) : Norihiro Nanba

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 3,
Line 39, "control" should read -- controlled --.

Column 6,
Line 31, "illustration" should read -- illustrations --.

Column 7,
Line 30, "a" should read -- an --.

Column 8,
Line 40, "of f" should read -- off --.

Column 9,
Line 28, "sufficient" should read -- sufficiently --.

Column 16,
Line 51, "R8=31 0.870" should read -- R8= -0.870 --.

Column 17,
Line 8, "DS" should read -- D5 --.
Line 12, "NS" should read -- N5 --.
Line 32, "32", should read -- = --.

Column 18,
Line 13, "e;00;" should read -- e+00 --.

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

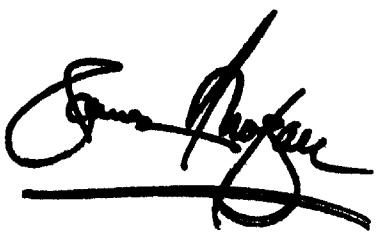
PATENT NO. : 6,236,521 B1
DATED : May 22, 2001
INVENTOR(S) : Norihiro Nanba

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 22,
Line 29, "1 to 17" should read -- 1 to 17 and 21 --.

Signed and Sealed this

Fifteenth Day of October, 2002



Attest:

Attesting Officer

JAMES E. ROGAN
Director of the United States Patent and Trademark Office

US006219182B1

(12) **United States Patent**
McKinley

(10) **Patent No.: US 6,219,182 B1**
(45) **Date of Patent: Apr. 17, 2001**

(54) **MULTIPLE MAGNIFICATION STEREO VIDEO TELESCOPE OBJECTIVE LENS SYSTEM**

(75) Inventor: **Harry R. McKinley**, Southampton, MA (US)

(73) Assignee: **McKinley Optics, Inc.**, Southampton, MA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/322,838**

(22) Filed: **May 28, 1999**

Related U.S. Application Data

(60) Provisional application No. 60/087,000, filed on May 28, 1998.

(51) **Int. Cl.**[7] **G02B 23/00**; G02B 23/12; G02B 7/16

(52) **U.S. Cl.** **359/407**; 359/421; 359/821; 359/400

(58) **Field of Search** 359/376, 377, 359/375, 374, 373, 372, 407, 421, 744, 821, 369, 400, 381, 656–660; 396/17, 432

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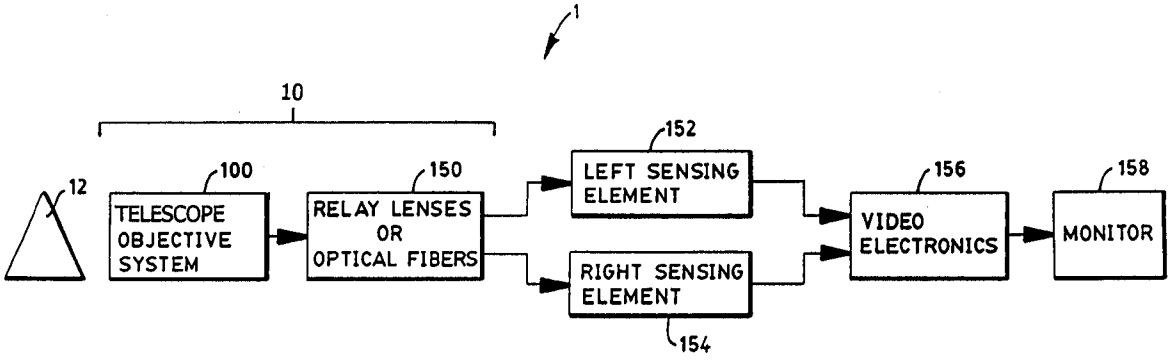
* cited by examiner

Primary Examiner—Jon Henry
(74) *Attorney, Agent, or Firm*—McDermott, Will & Emery

(57) **ABSTRACT**

A stereoscopic objective lens system for video endoscopes and borescopes includes two full-diameter doublets and two lens pairs forming a stereo lens set. A rotatable dual telescope is disposed between the two doublets and the stereo lens pairs, establishing a Galilean telescope associated with each stereo channel. The Galilean telescopes are each rotatable, preferably in convert, to be in or out of alignment with the system optical axis. When out of alignment, the Galilean telescopes have no effect along the optical path. When in alignment, the Galilean telescopes provide an increase or decrease in magnification, depending on orientation of the telescopes. The full-diameter doublets present equal-angle pairs from symmetrically disposed object points to the lenses of the stereo lens pair. This equal-angle property enables accurate object/image mapping onto the final stereo image pair, such that all parts of each left/right image can be mapped to within a fraction of a video pixel to each other.

23 Claims, 16 Drawing Sheets



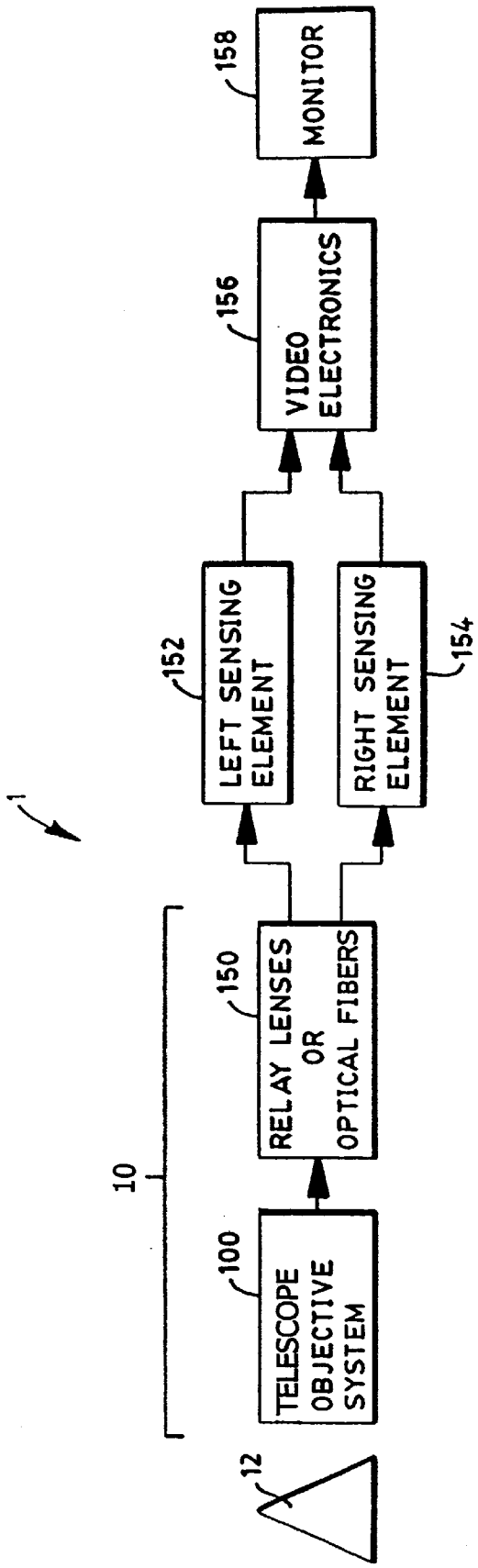
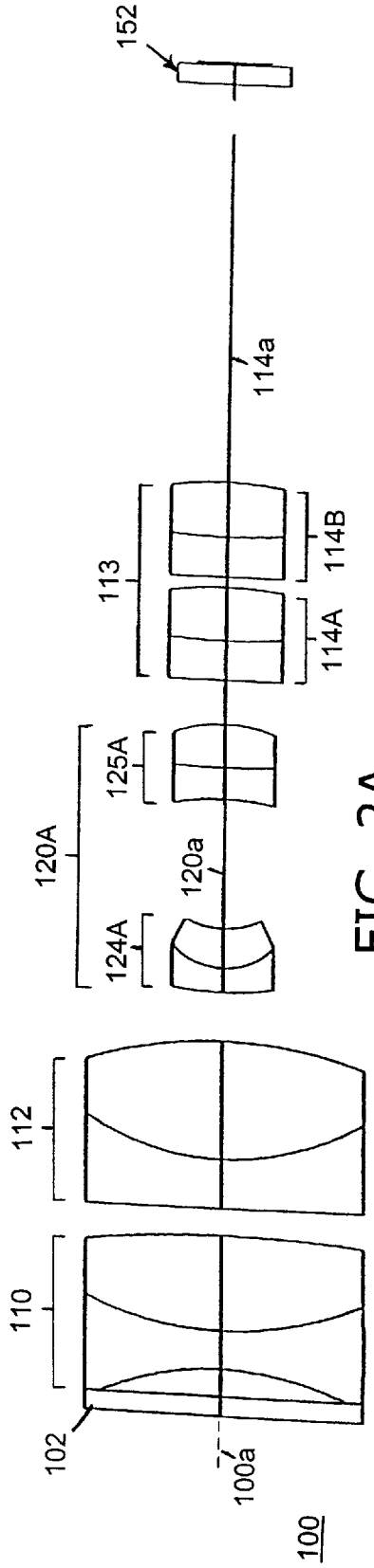

158
MONITOR
156
VIDEO ELECTRONICS
152
LEFT SENSING ELEMENT
154
RIGHT SENSING ELEMENT
1
10
150
RELAY LENSES OR OPTICAL FIBERS
100
TELESCOPE OBJECTIVE SYSTEM
12

FIG. 1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114B
114A
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120a
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112
110
102
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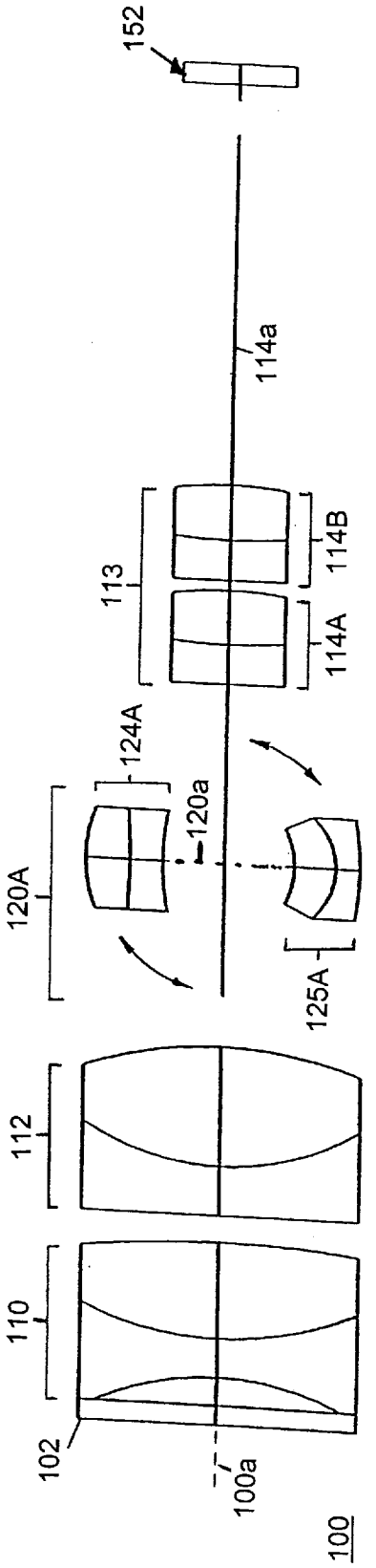
100

FIG. 2A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114B
114A
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120a
125A
112
110
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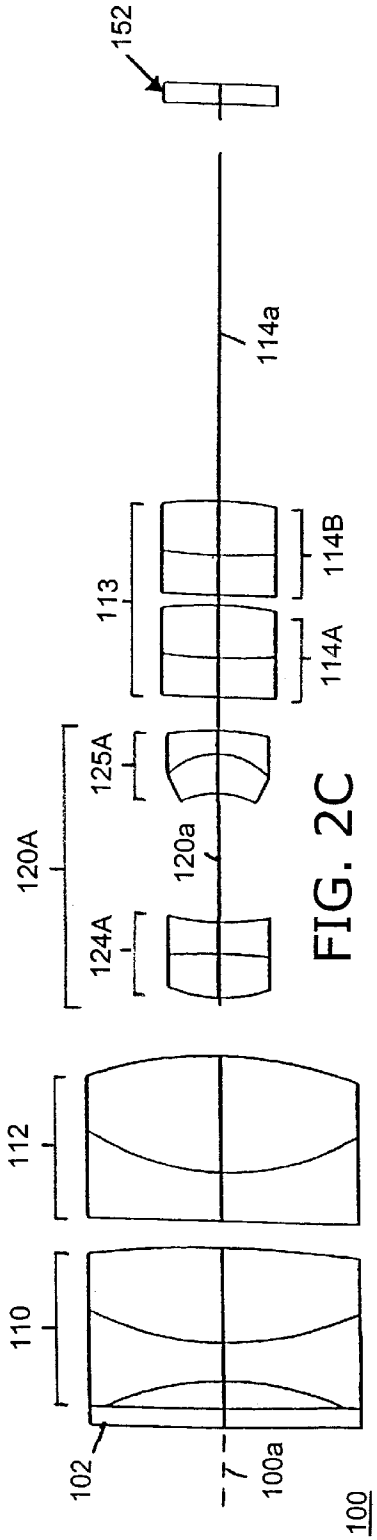
100

FIG. 2B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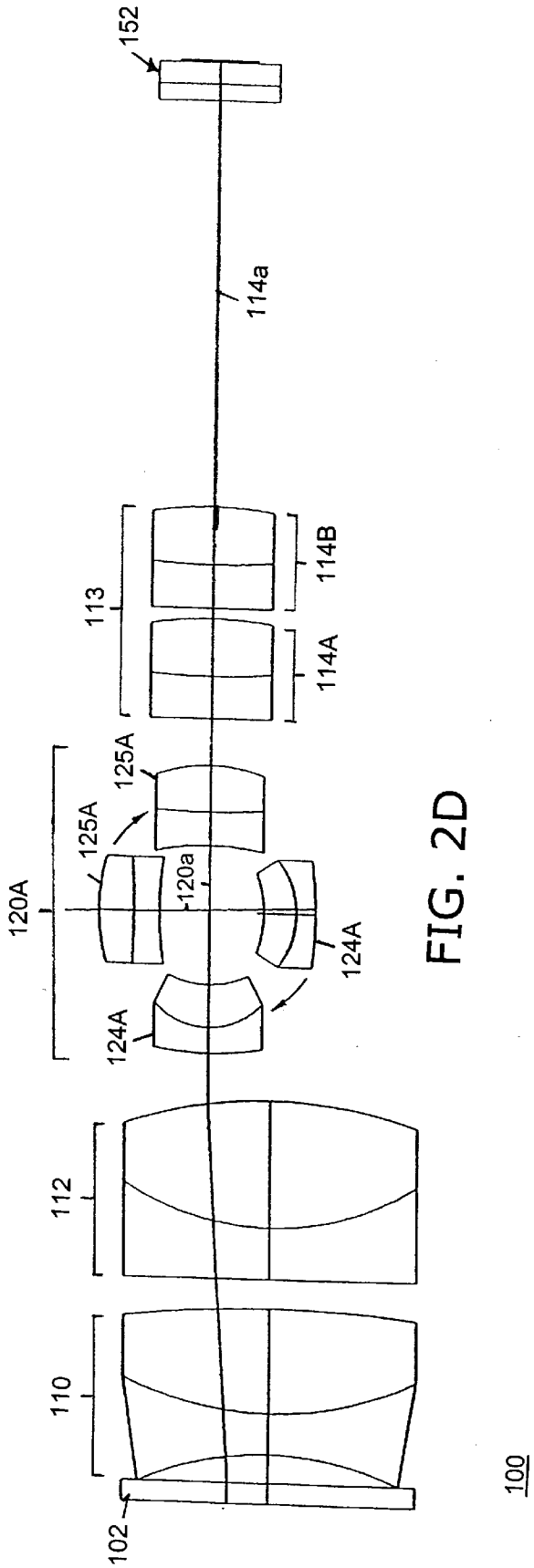
114A
125A
120A
120a
124A
112
110
102
100a
100

FIG. 2C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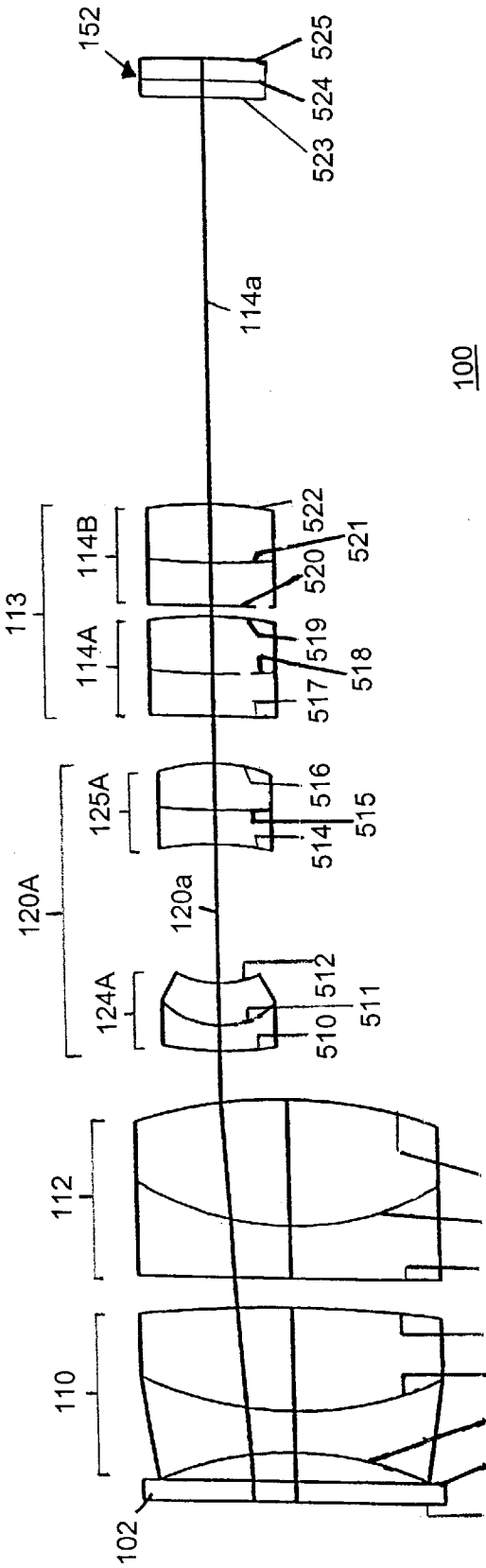
100

FIG. 2D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525
524
523
114a
100
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114B
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521
520
114A
519
518
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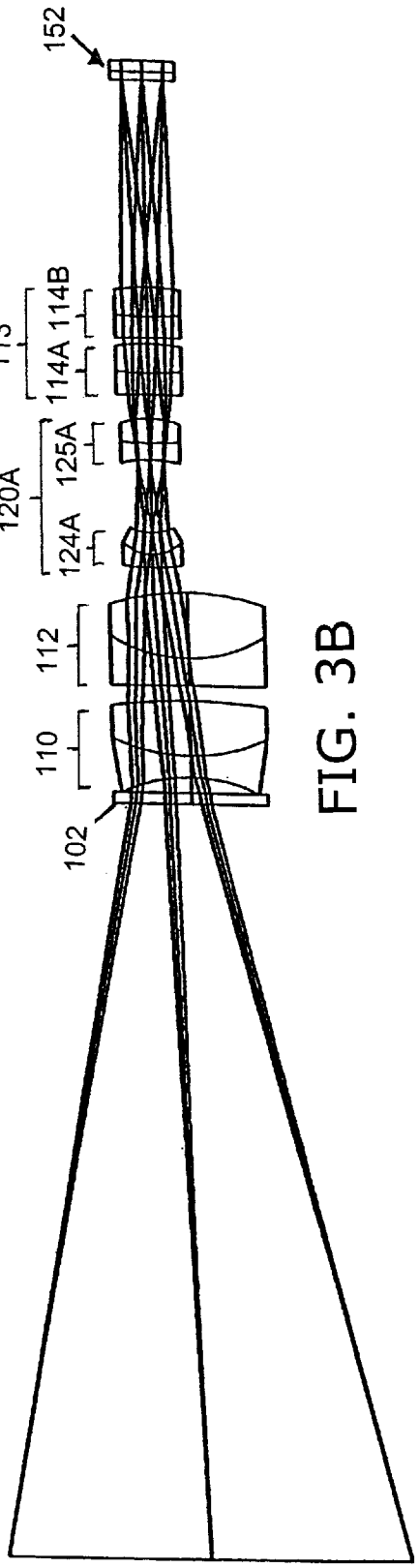
125A
516
515
514
120A
120a
124A
512
511
510
112
58
57
56
110
55
54
53
52
51
102

FIG. 3A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102
110
112
113
114A
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120A
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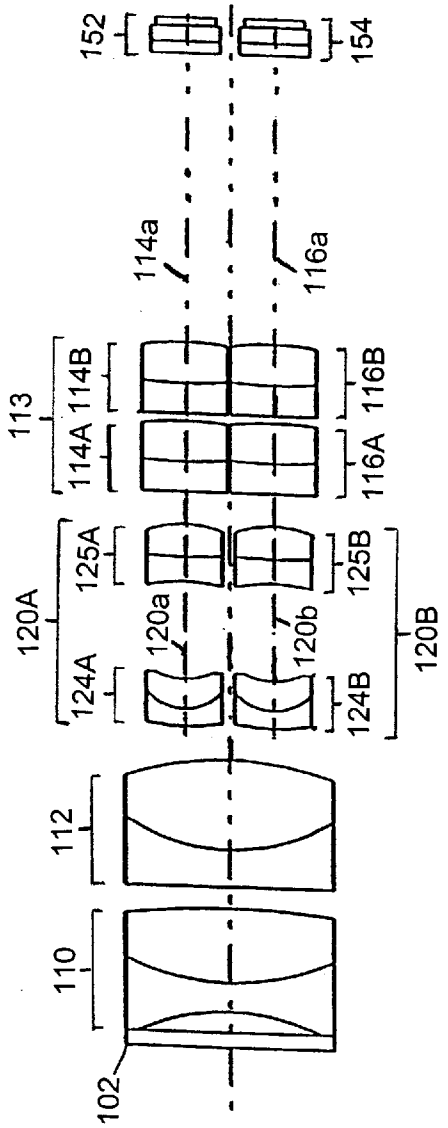
125A
152

FIG. 3B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114B
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120b
120B
124A
124B
125A
125B
152
154

FIG. 3C

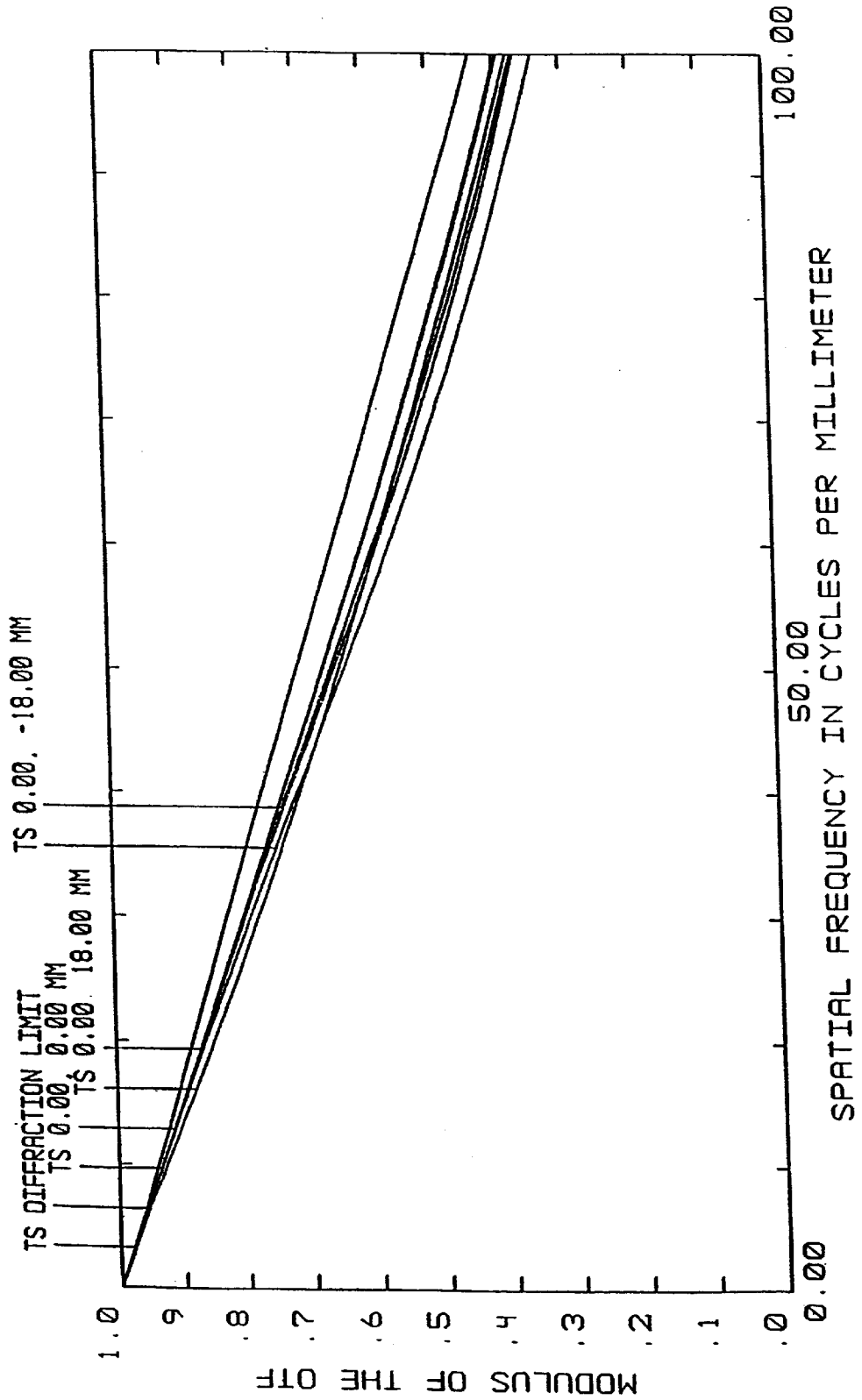

MODULUS OF THE OTF
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
.0
0.00
50.00
100.00
SPATIAL FREQUENCY IN CYCLES PER MILLIMETER
TS DIFFRACTION LIMIT
TS 0.00, 0.00 MM
TS 0.00, 18.00 MM
TS 0.00, -18.00 MM

FIG. 3D

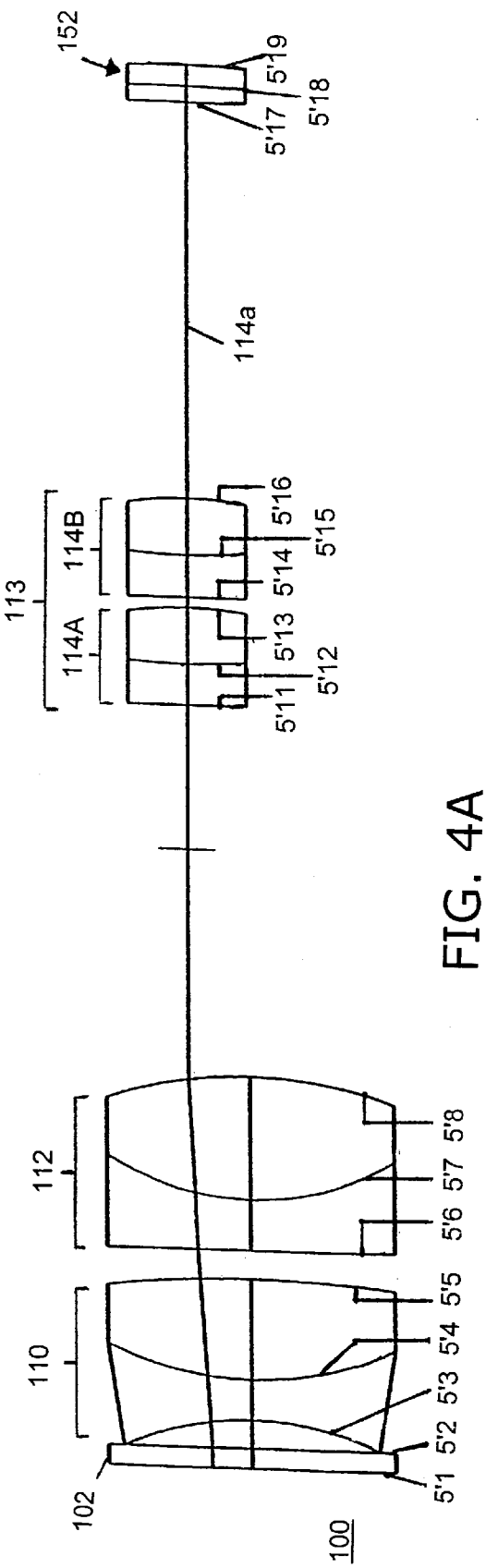
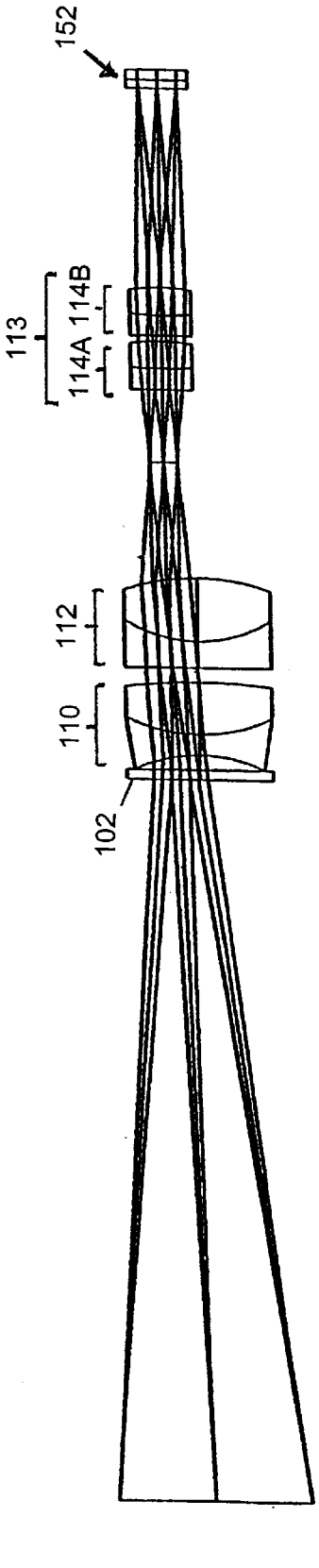

152
5'19
5'18
5'17
114a
113
114B
114A
5'16
5'15
5'14
5'13
5'12
5'11
112
5'8
5'7
5'6
110
5'5
5'4
5'3
5'2
5'1
102
100

FIG. 4A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113
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110
102
100

FIG. 4B

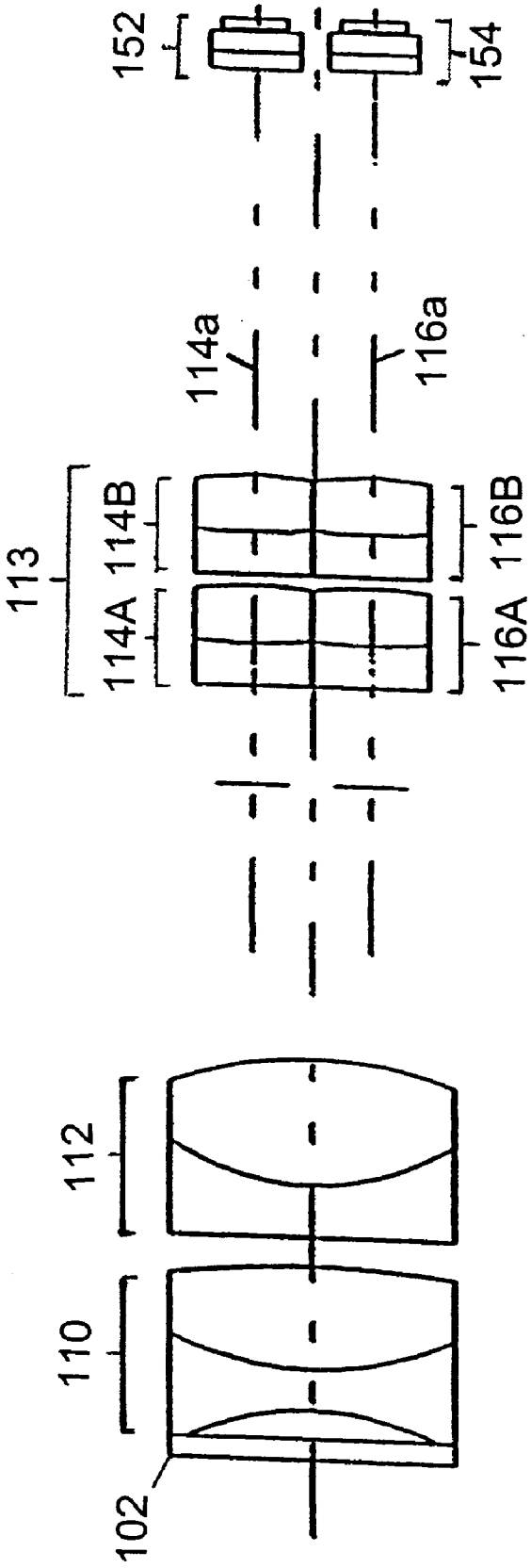

FIG. 4C

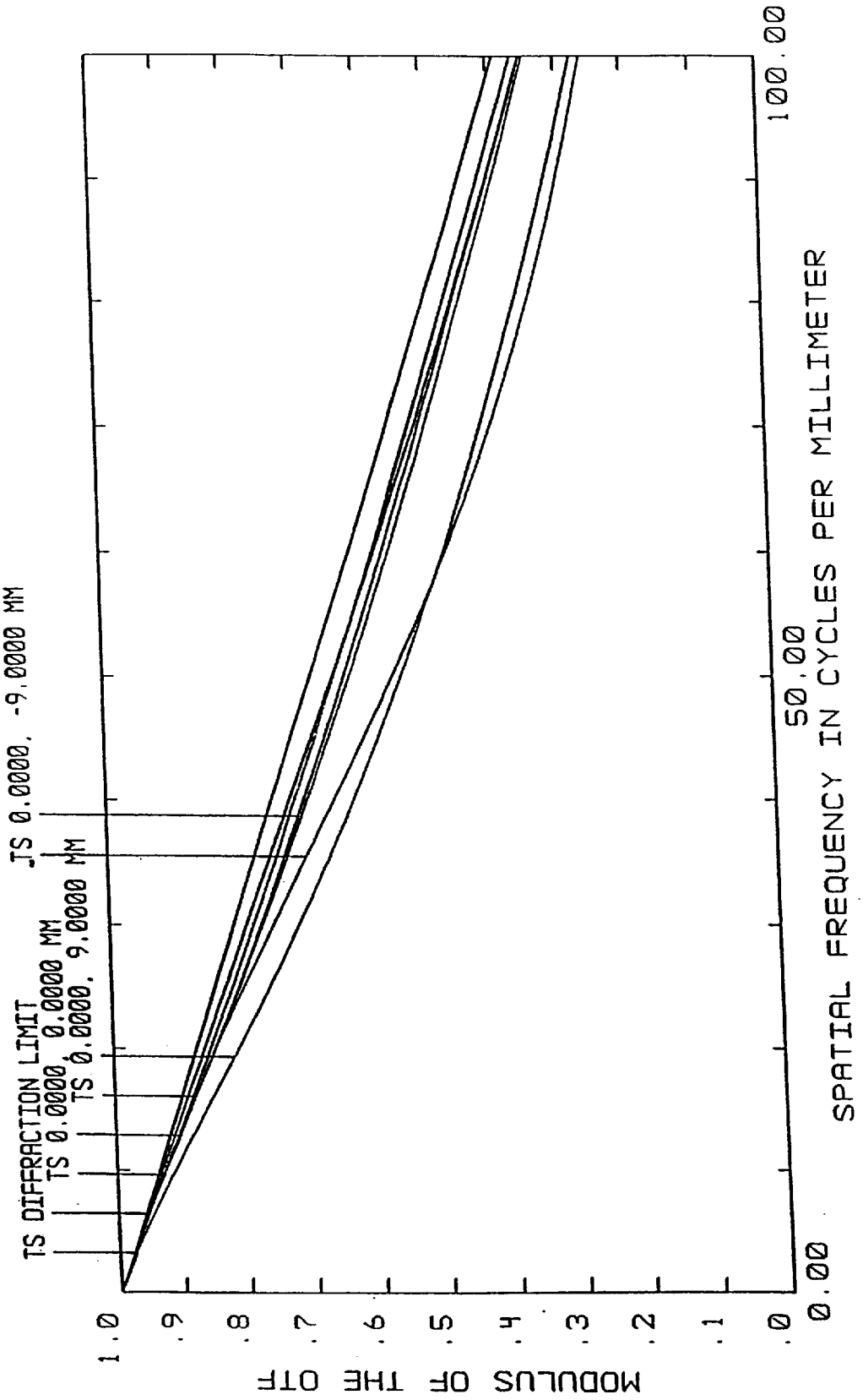
MODULUS OF THE OTF
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
.0
0.00
50.00
100.00
SPATIAL FREQUENCY IN CYCLES PER MILLIMETER
TS DIFFRACTION LIMIT
TS 0.0000, 0.0000 MM
TS 0.0000, 9.0000 MM
TS 0.0000, -9.0000 MM

FIG. 4D

GENERAL LENS DATA:

Surfaces	:	26
Stop	:	13
System Aperture	:	Float By Stop Size
Ray aiming	:	On
X Pupil shift	:	0
Y Pupil shift	:	0
Z Pupil shift	:	0
Apodization	:	Uniform, factor = 0.000000
Eff. Focal Len.	:	8.74912 (in air)
Eff. Focal Len.	:	8.74912 (in image space)
Total Track	:	69.9339
Image Space F/#	:	8.10197
Para. Wrkng F/#	:	8.29095
Working F/#	:	8.29511
Obj. Space N.A.	:	0.00636022
Stop Radius	:	1.1
Parax. Ima. Hgt.	:	1.8961
Parax. Mag.	:	-0.105339
Entr. Pup. Dia	:	1.07988
Entr. Pup. Pos.	:	14.8912
Exit Pupil Dia.	:	5.15074
Exit Pupil Pos.	:	-42.5646
Field Type	:	Object height in Millimeters
Maximum Field	:	18
Primary Wave	:	0.587600
Lens Units	:	Millimeters
Angular Mag.	:	0.209655

Fields : 3

Field Type: Object height in Millimeters

#	X-Value	Y-Value	Weight
1	0.000000	0.000000	1.000000
2	0.000000	18.000000	1.000000
3	0.000000	-18.000000	1.000000

Vignetting Factors

#	VDX	VDY	VCX	VCY
1	0.000000	0.000000	0.000000	0.000000
2	0.000000	0.000000	0.000000	0.000000
3	0.000000	0.000000	0.000000	0.000000

Wavelengths : 3

Units: Microns

#	Value	Weight
1	0.587600	1.000000
2	0.486100	1.000000
3	0.656300	1.000000

FIG. 5A

SURFACE DATA SUMMARY:

Surf(s)	Type	Radius	Thickness	Glass	Diameter	Conic
OBJ	STANDARD	Infinity	70		36	0
1	STANDARD	Infinity	1	SAPPHIRE	13.5	0
2	STANDARD	Infinity	1.39394		13.5	0
3	STANDARD	-14	2	BALF4	12	0
4	STANDARD	16	5	F2	13.5	0
5	STANDARD	-63.3	1.4		13.5	0
6	STANDARD	Infinity	2.5	F2	13.5	0
7	STANDARD	12.7	6	BALF4	13.5	0
8	STANDARD	-20.1	2.2		13.5	0
9	COORDBRK	---------	0		0	--------
10	STANDARD	14.1	1.2	SSKN5	5	0
11	STANDARD	3.6	2	SF5	5	0
12	STANDARD	4	6.53		3.7	0
STO	STANDARD	Infinity	0		2.2	0
14	STANDARD	-12.2	1.6	SF5	5	0
15	STANDARD	33	2.2	SSKN5	5	0
16	STANDARD	-7.14	2.2		5	0
17	STANDARD	Infinity	2	BASF2	5.6	0
18	STANDARD	26.65	2.7	BK7	5.6	0
19	STANDARD	-18.11	0.5		5.6	0
20	STANDARD	Infinity	2	BASEF2	5.6	0
21	STANDARD	26.65	2.7	BK7	5.6	0
22	STANDARD	-18.11	20.9		5.6	0
23	STANDARD	Infinity	0.81	BALF5	5.6	0
24	STANDARD	Infinity	1	K50	5.6	0
25	STANDARD	Infinity	0.1		5.6	0

FIG. 5B

GENERAL LENS DATA:

Surfaces	:	20
Stop	:	10
System Aperture	:	Float By Stop Size
Ray aiming	:	On
X Pupil shift	:	0
Y Pupil shift	:	0
Z Pupil shift	:	0
Apodization	:	Uniform, factor = 0.000000
Eff. Focal Len.	:	16.3991 (in air)
Eff. Focal Len.	:	16.3991 (in image space)
Total Track	:	68.9339
Image Space F/#	:	8.20185
Para. Wrkng F/#	:	8.8074
Working F/#	:	8.75226
Obj. Space N.A.	:	0.011609
Stop Radius	:	1.28
Parax. Ima. Hgt.	:	1.83856
Parax. Mag.	:	-0.204284
Entr. Pup. Dia	:	1.99944
Entr. Pup. Pos.	:	16.1104
Exit Pupil Dia.	:	5.62011
Exit Pupil Pos.	:	-49.3129
Field Type	:	Object height in Millimeters
Maximum Field	:	9
Primary Wave	:	0.587600
Lens Units	:	Millimeters
Angular Mag.	:	0.355766

Fields : 3
Field Type: Object height in Millimeters

#	X-Value	Y-Value	Weight
1	0.000000	0.000000	1.000000
2	0.000000	9.000000	1.000000
3	0.000000	-9.000000	1.000000

Vignetting Factors

#	VDX	VDY	VCX	VCY
1	0.000000	0.000000	0.000000	0.000000
2	0.000000	0.000000	0.000000	0.000000
3	0.000000	0.000000	0.000000	0.000000

Wavelengths : 3
Units: Microns

#	Value	Weight
1	0.587600	1.000000
2	0.486100	1.000000
3	0.656300	1.000000

FIG. 6A

Table B2

SURFACE DATA SUMMARY:

Surf(s)	Type	Radius	Thickness	Glass	Diameter	Conic
OBJ	STANDARD	Infinity	70		18	0
1	STANDARD	Infinity	1	SAPPHIRE	13.5	0
2	STANDARD	Infinity	1.39394		13.5	0
3	STANDARD	-14	2	BALF4	12	0
4	STANDARD	16	5	F2	13.5	0
5	STANDARD	-63.3	1.4		13.5	0
6	STANDARD	Infinity	2.5	F2	13.5	0
7	STANDARD	12.7	6	BALF4	13.5	0
8	STANDARD	-20.1	2.2		13.5	0
9	COORDBRK	---------	8.73		0	--------
STO	STANDARD	Infinity	7		2.56	0
11	STANDARD	Infinity	2	BASF2	5.6	0
12	STANDARD	26.65	2.7	BK7	5.6	0
13	STANDARD	-18.11	0.5		5.6	0
14	STANDARD	Infinity	2	BASF2	5.6	0
15	STANDARD	26.65	2.7	BK7	5.6	0
16	STANDARD	-18.11	19.9		5.6	0
17	STANDARD	Infinity	0.81	BALF5	5.6	0
18	STANDARD	Infinity	1	K50	5.6	0
19	STANDARD	Infinity	0.1		5.6	0
IMA	STANDARD	Infinity	0		3.723724	0

FIG. 6B

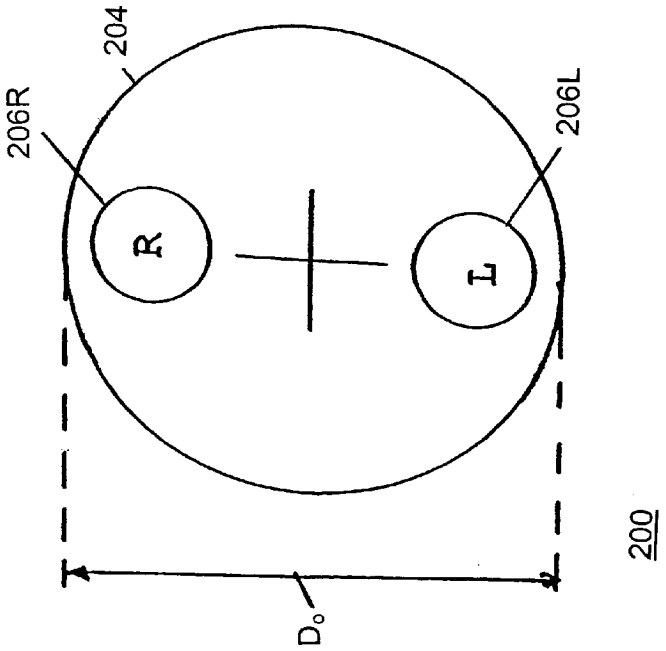

FIG. 7B

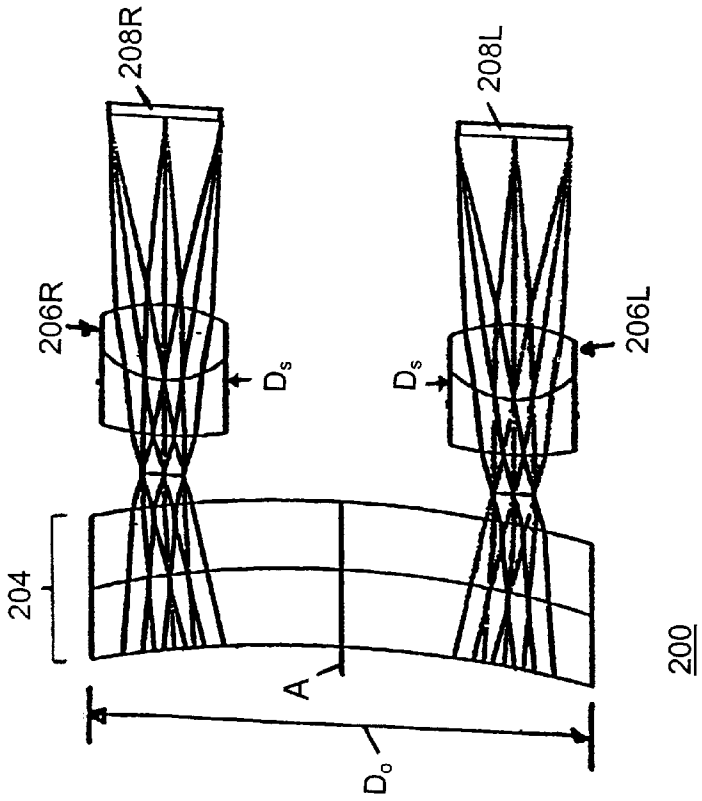

FIG. 7A

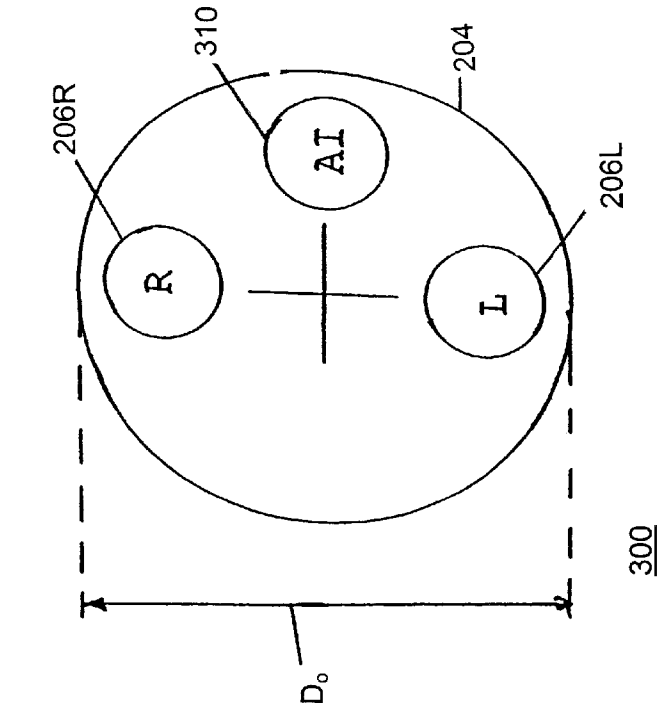

FIG. 8B

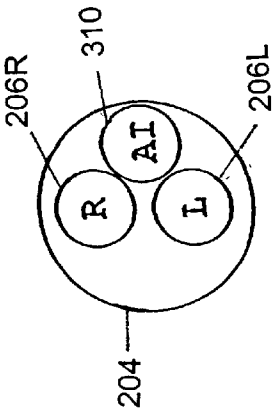

FIG. 9

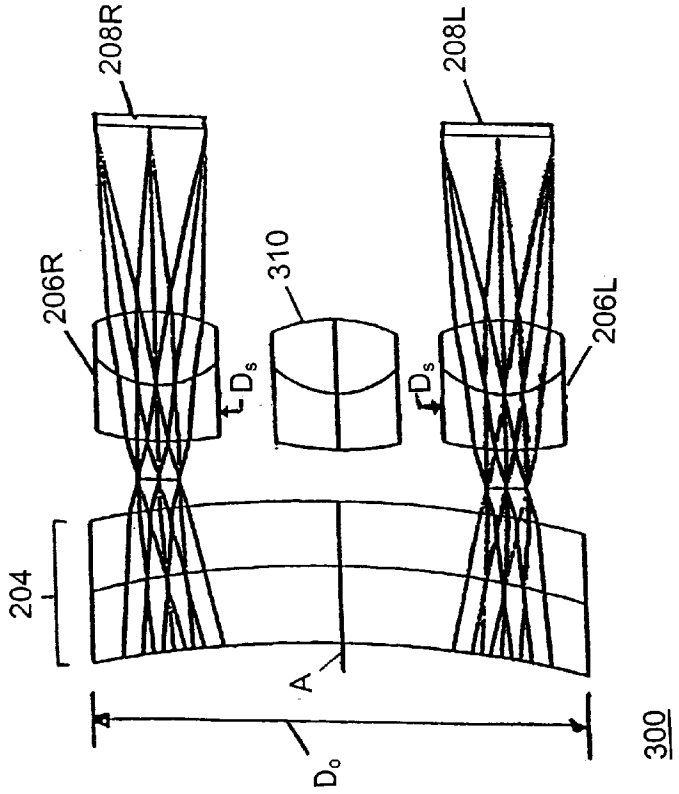

FIG. 8A

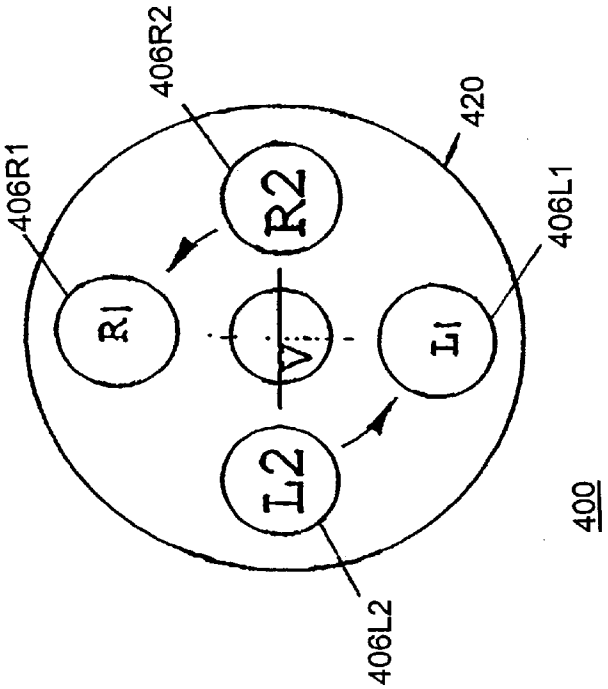

FIG. 10B

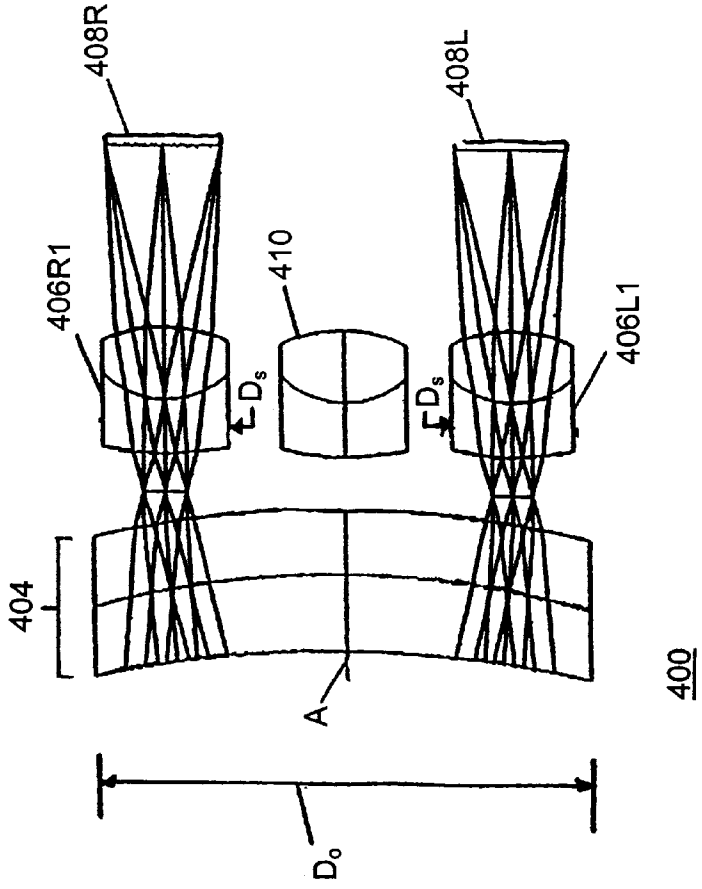

FIG. 10A

MULTIPLE MAGNIFICATION STEREO VIDEO TELESCOPE OBJECTIVE LENS SYSTEM

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is related to and takes priority from U.S. Patent and Trademark Office Provisional Application Ser. No. 60/087,000 filed May 28, 1998, which is incorporated herein by reference.

BACKGROUND OF THE INVENTION

This invention relates generally to optical lens systems, and, more particularly, relates to stereoscopic objective lens designs adapted for use in stereo video telescopes.

Medical endoscopes are a form of telescope which is widely utilized to view internal regions of the human body during diagnostic, surgical, and other medical procedures. Endoscopes typically include a long, thin, rigid or semi-rigid optical cylinder affixed to a viewing mechanism. The cylinder is sufficiently narrow to be inserted through a small opening in the body, which may be natural or surgical. When the endoscope is inserted and positioned for use, an image of the object being viewed is formed at an inserted end of the endoscope by an objective lens. The image passes through a series of relay lenses down the cylinder to an eye lens or video camera at a viewing end of the endoscope.

In recent years, researchers have attempted to improve the imaging available through endoscopic devices by developing stereoscopic video endoscopes. These endoscopes present an apparently three-dimensional image on a video monitor. The stereoscopic effect is created by producing two optical images—a left image and a right image—through the endoscope. The left and right optical images are presented by the endoscope to left and right image sensors, which may be charge-coupled device (CCD) cameras or other image sensing devices. The sensing devices convert the left and right optical images into left and right video images which are then presented as alternating left/right images on a monitor, at a switching rate higher than the flicker-sensing limit of the human eye, so that observed images appear flicker-free.

The images are alternately switched from a left-hand polarization mode to a right-hand polarization mode, such that, for example, the left image has a left-hand polarization and the right image has a right-hand polarization. In accord with this example, the observer wears polarized glasses in which the left lens has the left-hand polarization and the right lens has the right-hand polarization. Thus, the left eye sees only images from the left channel of the endoscope system and the right eye sees only images from the right channel, resulting in stereoscopic viewing.

The following United States and foreign patents disclose examples of stereo endoscopes, some of which utilize video imaging and display elements:

U.S. Pat. No. 4,061,135
U.S. Pat. No. 4,615,332
U.S. Pat. No. 4,651,201
U.S. Pat. No. 4,862,873
U.S. Pat. No. 4,873,572
U.S. Pat. No. 4,895,431
U.S. Pat. No. 5,122,650
U.S. Pat. No. 5,191,203
U.S. Pat. No. 5,673,147
EP Patent No. 211,783

In particular, U.S. Pat. No. 4,061,135 discloses a binocular endoscope in which images are transmitted from the viewed object to the viewing station through an optical system utilizing a dove prism and mechanical linkage to compensate for rotation effects.

U.S. Pat. No. 4,615,332 discloses a binocular endoscope having flexible light guides and binocular eyepieces.

U.S. Pat. No. 4,651,201 discloses a stereoscopic video endoscope including two image guides and an illumination light guide. The image guides are optically coupled to a stereoscopic viewer for three dimensional viewing. The viewer includes couplings for attaching miniature video camera that can be connected to a head mounted stereoscopic video display.

U.S. Pat. No. 4,862,873 discloses a stereo endoscope having two light guides for carrying images of an object an electro-optical imaging assembly. A lens system directs light from the object to the objective end of the light guides. Illuminating light is transmitted to the object from the opposite end of one light guide, thereby illuminating the object. Simultaneously, the image transmitted through the other optical guide is conducted to the imaging assembly.

U.S. Pat. No. 4,873,572 discloses a stereo endoscope having a CCD camera module and two image-forming lens systems that form two object images. The object images are integrated and directed to the CCD camera to provide a stereoscopic output. The lens systems include red, green, and blue color filters disposed at the camera imaging surface.

U.S. Pat. No. 4,895,431 discloses an endoscope apparatus that generates a three-dimensional image of an object from overlapping images recorded by a camera. The endoscope includes an insertion module and a movable end section capable of being deflected through an angle. A first image is recorded with the end section positioned at a first angle. A second image, partially overlapping the first image, is recorded after moving the end section to a second angle. The relative position of the movable end section is detected by an encoder that generates position signals for input to a microprocessor, which utilizes the position signals to generate a three-dimensional image of the object.

U.S. Pat. No. 5,122,650 discloses a stereo video endoscope objective lens system using six doublet lenses to generate pixel mapped left-right images for stereo viewing.

U.S. Pat. No. 5,191,203 discloses a stereo video endoscope objective lens system using lenses having a graded index of refraction to generate pixel mapped left-right images for stereo viewing.

U.S. Pat. No. 5,673,147 discloses a stereo video endoscope objective lens system which uses ball lenses for the left and right stereo lens pair.

European Patent No. 211,783 discloses a stereo video endoscope in which two light pipes deliver two images of the same object. These images are presented by a binocular device to the user's eyes to show a three dimensional image of the target. The apparatus includes two television cameras and video recorders for recording the images. The recorded images can be displayed on separate screens and viewed by a binocular viewing system.

Most conventional stereo endoscopes, however, share a number of deficiencies associated with their objective lens systems. These problems include a bulky and unwieldy configuration; high cost and complexity of fabricating the objective lens system; and the less than optimal optical performance afforded by conventional objective lens systems.

An additional problem associated with conventional stereo video endoscope objectives involves the requirement

that all portions of each left/right image be mapped to within a fraction of a video pixel to each other. This pixel mapping condition is a significant optical design constraint, because the object-to-image ray paths through the lens system are quite different for the left and right image points associated with a common object point.

A further problem is the general characteristic of conventional endoscopes that the magnification is fixed for each such instrument. The present invention is directed to the latter problem.

Accordingly, it is a general object of the present invention to provide improved stereo telescope objective lens systems that selectively provides multiple magnifications.

A more specific object is to provide an improved stereo telescope objective lens system having optical elements that may be selectively placed in the optical train to provide different magnifications.

The above and other objects and advantages of this invention will become more readily apparent when the following description is read in conjunction with the accompanying drawings.

SUMMARY OF THE INVENTION

The foregoing objects are attained by the invention, which provides an improved stereo objective lens system for video imaging for various applications.

One aspect of the invention includes two full-diameter (D) doublets disposed along an optical axis, and a left/right stereo lens pair. A rotatable dual telescope, including two Galilean telescopes, is disposed between the full diameter doublets and the left/right stereo lens pair. The stereo lens pair includes a set of two pairs of doublet lenses.

The full-diameter doublets substantially collimate object points, i.e., image them substantially to infinity. The Galilean telescopes preferably each include a pair of doublets positioned along an optical axis, in a rotatable assembly which permits selectively positioning of the Galilean telescopes of their axes (in a magnifying orientation or a reducing orientation or neither). The stereo lens pair is disposed to collect light from the second doublet, if the Galilean telescope is out of the optical train, or from the Galilean telescope if it is in the optical train, with the optical axis of each lens being substantially parallel, and offset from the optical axis of the doublets.

The doublets and the stereo lens pair cooperate so that the doublets present equal angle light ray pairs from symmetrically disposed object points to the lenses of the stereo lens pair. The left and right stereo lenses generate left and right images respectively, at an image plane, where corresponding portions of those images are mapped to within a selected distance of each other.

In another aspect of the invention, the large collimator doublets provide accurate object/image mapping onto the final stereo image pair. In this design, the larger, and hence easier to fabricate doublets carry the corrective burden, so that the smaller, more difficult to manufacture lenses can be made a simple as possible.

The invention will next be described in connection with certain illustrated embodiments; however, it should be clear to those skilled in the art that various modifications, additions and subtractions can be made without departing from the spirit or scope of the claims.

BRIEF DESCRIPTION OF THE DRAWING

For a fuller understanding of the nature and objects of the invention, reference should be made to the following detailed description and the accompanying drawings, in which:

FIG. **1** is a schematic diagram depicting a stereo video endoscope utilizing an objective lens system constructed in accordance with the invention;

FIGS. **2**A–**2**C is an optical schematic diagram of a stereo objective lens system in accordance with the invention, in "wide angle" mode, "normal" mode and "telephoto" mode, respectively;

FIG. **2**D is an optical schematic diagram of an alternative embodiment of the invention;

FIG. **3**A is an optical schematic layout of the embodiment of FIG. **2**D in wide angle mode;

FIG. **3**B is an optical schematic diagram depicting the objective lens system of FIG. **2**D in wide angle mode, showing light rays transmitted through the system;

FIG. **3**C is an optical schematic diagram depicting the objective lens system of FIG. **2**D in wide angle mode, identifying optical surfaces;

FIG. **3**D shows the polychromatic diffraction modulation transfer function for the objective lens system of FIG. **2**D in wide angle mode;

FIG. **4**A is an optical schematic layout of the embodiment of FIG. **2**D in normal angle mode;

FIG. **4**B is an optical schematic diagram depicting the objective lens system of FIG. **2**D in normal mode, showing light rays transmitted through the system;

FIG. **4**C an optical schematic diagram depicting the objective lens system of FIG. **2**D, in normal mode, identifying optical surfaces;

FIG. **4**D shows the polychromatic diffraction modulation transfer function for the objective lens system of FIG. **2**D in normal mode;

FIGS. **5**A and **5**B set forth Tables A**1** and B**1** respectively, which define exemplary lenses for the embodiment of FIG. **2**D in wide angle mode;

FIGS. **6**A and **6**B set forth Tables A**2** and B**2** respectfully, which define exemplary lenses for the embodiment of FIG. **2**D in narrow mode;

FIG. **7**A is an optical schematic diagram of a stereo objective lens system in accordance with another embodiment of the invention, suitable for relatively long object distances;

FIG. **7**B is an end view of the system of FIG. **7**A;

FIG. **8**A is an optical schematic diagram of a stereo objective lens system in accordance with another embodiment of the invention, showing a third information channel;

FIG. **8**B is an end view of the system of FIG. **8**A; and

FIG. **9** is an end view of a stereo objective lens system similar to that of FIGS. **8**A and **8**B, but being a small, closely packed configuration.

FIGS. **10**A and **10**B show views of a stereo objective system similar to the stereo objective system as illustrated in FIGS. **7**A and **7**B respectively.

In the various figures, corresponding elements are identified with the same reference designations.

DESCRIPTION OF ILLUSTRATED EMBODIMENTS

FIG. **1** depicts the invention, a telescope objective system **100**, utilized in a stereo video optical system **1** for generating stereoscopic images of an object **12**. The system **1** principally includes a stereoscopic telescope **10** containing objective system **100**; sensing modules **152**, **154**; switching module **156**; and a monitor **158**. In addition to objective lens

system **100**, the telescope **10** includes conventional relay lenses or optical fibers **150** for transmitting light collected by the endoscope objective system **100** to light sensing modules **152, 154**.

The telescope objective system **100** generates left and right optical images of the object **12** that are processed by sensing elements **152, 154** and video switching module **156** in a known manner to display an apparently three-dimensional image of the object **12** on video monitor **158**.

The stereoscopic effect is created by producing two optical images—a left image and a right image—through the telescope objective system **100**. The left and right optical images generated by the objective system **100** are presented by the relay lens or optical fiber system **150** to left and right image sensors **152, 154**, which can be conventional charge-coupled device (CCD) cameras or other image sensing devices. The CCD elements operate in a known manner to convert the light collected by the objective system **100**, and transmitted by the relay lenses or optical fibers **150**, into electrical signals representative of the left and right optical images of the object **12**.

Conventional video switching circuitry **156** transmits the electronic signals representative of left and right video images as alternating left-right images on the monitor **158**. In accord with known video practice, these alternating images are presented at a switching rate higher than the flicker-sensing limit of the human eye, so that observed images appear flicker-free.

Moreover, the images can be alternately switched from a left-hand polarization mode to a right-hand polarization mode, such that, for example, the left image has a left-hand polarization and the right image has a right-hand polarization. The observer wears polarized glasses in which the left lens has the left-hand polarization and the right lens has the right-hand polarization. Thus, when the observer views the monitor **158**, the left eye sees only images from the left channel of the endoscope system and the right eye sees only images from the right channel, resulting in stereoscopic viewing. Video switching and display equipment of this type is commercially available from Stereographics, Inc. of San Rafael, Calif.; and from Tektronix Corp., of Beaverton, Oreg.

The accuracy and quality of the image displayed on monitor **158** is controlled by the performance of the telescope objective system **100**, which is the subject of the present invention.

FIGS. **2**A–**2**C and **2**D respectively depict alternate forms of an objective lens system **100** constructed in accordance with the invention.

The objective systems **100** of FIGS. **2**A–**2**C and **2**D include a window **102** followed by a first doublet **110** and a second doublet **112** positioned in sequence along and centered about a common system axis **100***a*, followed by a stereo lens set **113**. Both of the first doublets have circular cross sections with a diameter D**1**. The stereo lens set **113** includes two pairs doublets **114**A/**114**B, **116**A/**116**B, each having a circular cross-section with diameter D**2**, extending along an associated one of lens axes **114***a* and **116***a* which are parallel to, and spaced apart by D**2** from, the system axis **100***a*. The two doublets **110**, **112** cooperate to collimate object points, i.e., image them to infinity. A CCD detector element **152, 154** follows each of the doublet pairs **114, 116**.

A rotatable telescope is positioned between the doublet **112** and stereo lens set **113**. The dual telescope includes a first Galilean telescope **120**A (including doublets **124**A and **125**A extending along an optical axis **120***a*) associated with the axis **114***a* and second Galilean telescope **120**B (including doublets **124**B and **125**B extending along an optical axis **120***b*) associated with the axis **116***a*. Galilean telescope **120**A is selectively rotatable about an axis perpendicular to the axis **114***a* so that (1) its optical axis **120***a* is aligned with axis **114***a* (FIGS. **2**A, **2**C, **2**D, **3**A, **3**B, **3**C), with its components doublets **124**A, **125**A along the system optical axes **100***a*/**114***a*, or (2) its optical axis **120***a* is out of line with axis **114***a* (FIGS. **2**B, **2**D, **4**A, **4**B, **4**C) with its component doublets **124**A, **125**A removed completely from the system optical axes **100***a*, **114***a*.

Similarly, Galilean telescope **120**A is selectively rotatable about an axis perpendicular to the axis **116***a* so that (1) its optical axis **120***b* is aligned with axis **114***a* (FIG. **3**C), with its components doublets **124**B, **125**B along the system optical axes **100***a*/**116***a*, or (2) its optical axis **120***b* is out of line with axis **114***b* (FIGS. **2**B, **2**D, **4**A, **4**B, **4**C) with its component doublets **124**B, **125**B removed completely from the system optical axes **100***a*, **116***a*. Preferably both Galilean telescopes **120**A and **120**B of the dual telescope are mounted in a single carriage so that they may be rotated by a user in a single motion. When in the dual telescope is oriented as shown in FIGS. **2**B, **4**A–**4**C, the telescope has no effect on the magnification and is termed the "normal" mode. When the telescope is oriented as shown in FIGS. **2**A, **3**A–**3**C, the field is increased (with decreased magnification compared with normal mode), and is termed "wide angle" mode. When the telescope is oriented as shown in FIG. **2**C, the field is reduced (with increased magnification compared to the normal mode), and is termed the "narrow angle" mode.

FIGS. **3**D and **4**D show the polychromatic diffraction modulation transfer function for the embodiment of FIG. **2**D, for wide angle mode and normal mode respectively.

Those skilled in the art will appreciate that the lenses of the objective system **100** depicted in FIG. **2**D, define a sequence of optical surfaces. Tables A**1** (FIG. **5**A), A**2** (FIG. **5**B), B**1** (FIG. **5**A) and B**2** (FIG. **6**B) define the exemplary lenses for the embodiment of FIG. **2**D. Reference numerals preceded by S (in FIG. **3**A) and S' (in FIG. **4**A) correspond to the numerals respectively in the "SURFACE" column of Tables A**1** and B**1**. As those skilled in the art will appreciate, surfaces **9** and STO do not correspond to physical surfaces and are indicated in Tables A**2** and B**2** for convenience of analysis.

In Tables A**2** and B**2**, the numerical values in the "RADIUS", "THICKNESS" and "DIAMETER" columns are set forth in millimeters. The "GLASS" descriptions are standard optical glass characterizations as found in the product catalog of the Schott Glass Company of Germany. The "THICKNESS" column refers to the distance to the next optical surface. The "RADIUS" column refers to the radii of curvature of the respective curved surfaces.

The system **100** is designed so that all parts of each left/right image are mapped to within a selected distance of each other such that stereoscopic image quality is maintained. For video applications, this selected distance is typically a fraction of a video pixel. This is a difficult condition to satisfy, because the objectto-image ray paths through the lens system are quite different for the left and right image points of a common object point. The ray paths shown in FIGS. **3**B and **4**B demonstrate how differently an object point is imaged through the lens elements for one of the left and right images.

The objective systems **100** depicted in the above figures are able to map all parts of each left/right image to within a fraction of a video pixel to each other, because the large

collimator doublets present equal-angle pairs from symmetrically disposed object points to the lenses of the stereo lens set **113**. This exact equal-angle solution results in an accurate object/image mapping onto the final stereo image pair.

In the illustrated embodiments, the front full-diameter lenses are essentially a collimator, rendering an object into a virtual image at infinity. This is not essential but rather is a characteristic of the illustrated embodiments.

The collimator provides equal-angle chief rays from symmetrical edges of the field. This equal angle concept, coupled with the symmetry of the system in the left/right channels, insures that the smaller stereo lenses image those field edges at exactly the same positions on the CCD. That is, the right image of the left edge will be at the same position on the left CCD as is the left image of the left edge on the right CCD, and so on. This is an important factor in stress-free 3D viewing.

To obtain such equal-angle chief rays the front lenses have widely separated left-right pupils, so the chief rays of all field bundles are widely separated. As a result, these bundles have non-trivial included angles in object space—i.e. the front lenses are working at some tangible optical speed. In close-up medical use or inspection systems, this optical speed in stereo object space can be considerable, so any aberration of the front lens group will cause a disparity in the chief ray angles in the left-right bundles presented to the stereo lens sets, resulting in left-right image position errors. This stereo mapping error can lead to eyestrain, headaches, and the like, that make stereo visualization difficult.

Objective system **100**, as described in Tables A**1**, A**2**, B**1**, and B**2**, shown in FIG. **2**D, achieves accurate object/image mapping with user selectable field magnification depending on the rotational state of the dual Galilean telescope. Tables A**1** and A**2** in FIGS. **5**A and **5**B respectively, set forth a detailed description of the embodiment of FIG. **2**D in the wide angle mode (FIGS. **3**A–**3**C), and Tables B**1** and B**2** in FIGS. **6**A and **6**B, respectively, set forth a detailed description of the embodiment of FIG. **2**D in the normal mode (FIGS. **4**A–**4**C).

As indicated in FIG. **1**, a telescope constructed using relay lenses **150** or optical fibers or alternatively can employ a conventional CCD array mounted within the same housing as the objective system. The CCD array can include left and right sensing elements **152**, **154**, disposed to receive the optical images generated at the output of the lenses of stereo lens set **113**. The design and construction of CCD elements having more than one photosensitive region in a monolithic package is well known in the art. The electrical signals generated by the CCD array can be conducted from the housing by a conventional conduit. This configuration eliminates the requirement for a relay lens system or optical fibers.

The above described stereo optical systems are particularly well suited for relatively small geometry endoscope systems. However, similar configurations may be used for larger sized systems, such as may be useful for 3-D video teleconferencing or industrial use. By way of example, a system **200** is shown in FIGS. **7**A and **7**B, which includes a full diameter collimating doublet lens assembly **204**, having a relatively large diameter followed by a pair of stereo doublet lenses **206**R, **206**L, each having a relatively small diameter D_S, for the respective right and left channels. The stereo pair is followed by, right and left channel detectors **208**R, **208**L. In the configuration of FIGS. **7**A and **7**B, the front full diameter lens assembly **204** is essentially a collimator, rendering an object into a virtual image at infinity. This is not essential, but is the form of the preferred embodiment.

The collimator lens assembly **204** provides equal-angle chief rays from symmetrical edges of the field. This equal angle concept, coupled with the symmetry of the system in the left/right channels, insures that the small stereo lenses image those field edges at exactly the same positions on the CCD detectors **208**R and **208**L. That is, the left image of the left edge is at the same position on the left CCD **208**L, as is the right image of the left edge on the right CCD **208**R. This aspect enables stress-free viewing for a user.

The front lenses have widely separated left-right pupils, so that the chief rays of all field bundles are widely separated. As a result, these bundles have nontrivial included angles in object space—i.e. the front lenses are working at some tangible optical speed. In close-up medical use or inspection systems, this optical speed in stereo object space is important since any aberration of the front lens group causes a disparity in the chief ray angles in the left-right bundles presented to the stereo lens sets, resulting in left-right image position errors. This stereo mapping error can cause eyestrain, headaches and the like, that are the problematic for stereo visualization.

In prior art configurations for endoscopes, the front lenses have been designated as "full diameter", while the stereo components have been "half-diameter". In many non-medical applications, however, the stereo components **206**R and **206**L are considerably less than half the diameter of the front lens assembly **204**. This sizing of elements is primarily the result of achieving useful stereo parallax angles in object space. Because large, non-medical systems, especially teleconferencing systems, are designed with long object distances, in the order of a meter, stereoscopy requires a relatively wide stereo baseline. The stereo baseline is established by the separation of the stereo lens pairs **206**R, **206**L. Accordingly, these lenses are relatively widely separated with respect to the front components **204**, compared with the short working distance medical designs, such as those in FIGS. **2**A–**2**C and **2**D.

Still another form of the invention is shown in FIGS. **10**A and **10**B. In those figures, a stereo objective system **400** is shown, which is similar the stereo objective system **200** of FIGS. **7**A and **7**B, and includes a collimator doublet lens **404** and a first pair of right/left stereo lenses, **406**R**1**, **406**L**1**, and CCD detectors **408**R, **408**L, and further includes a second right/left stereo lens pair **406**R**2**, **406**L**2** and an optional third "added information", or "AI", channel lens **410**. The lenses **406**R**1**, **406**L**1**, **406**R**2**, **406**L**2** and **410** are all mounted on a base **420** which is selectively rotatable about the axis A of the collimator doublet lens **404**.

In a first state, the base **420** is oriented about axis A (as shown in FIGS. **10**A and **10**B) so that the optical axes of the first stereo lens pair **406**R**1**, **406**L**1** are aligned in the same manner as the corresponding lenses in the system of FIGS. **7**A and **7**B, where those lenses **406**R**1**, **406**L**1** are in the optical path of the overall system, including collimator doublet lens **404** and earlier elements in the optical train; lenses **406**R**2** and **406**L**2** are not in the system optical path in this first state. In a second state (not shown), the base **420** is oriented about axis A so that the optical axes of the second stereo lens pair **406**R**2**, **406**L**2** are aligned in the manner of the system of FIGS. **7**A and **7**B, where those lenses **406**R**2**, **406**L**2** are in the optical path of the overall system, including collimator doublet lens **404**, and earlier elements in the optical train; lenses **406**R**1** and **406**L**1** are not in the system

optical path in this second state. Preferably, lenses **406R1**, **406L1** provide a different magnification train lenses **406R2**, **406L2**, so that switching the orientation of base **420** between the first state and second state provides different magnifications for the optical train of the overall system. This aspect of the invention is useful in a camera, and particularly useful in a digital camera. While shown for two discrete magnifications, in other embodiments, additional stereo lens pairs may be mounted on base **420**, permitting addition magnifications to be selectively used.

In one exemplary configuration, the diameters of lenses **406R1**, **406L1**, **406R2**, **406L2**, and **410** are approximately one fourth the diameter of lens **404**, and the lenses **406R1**, **406L1**, **406R2**, **406L2** and **410** are offset from the axis of lens **404** by approximately one third the diameter of lens **404**. Other dimensions may be used in other embodiments.

The third channel includes a third channel lens **410**. The third channel can be used in many ways—to provide a "viewfinder" for a camera system, to present a "picture-in-picture" display, to provide a 2D image for recording and the like. In addition, with the addition of an external (to the large lens) mirror and/or prism system, the third channel can be steered to view another object. This other object could be another person, in a teleconferencing system "picture-in-picture" (PIP) mode, or an object or a drawing, or just another general scene of interest. The third channel lens **310** need not be the same as the stereo lenses **406R1**, **406L1**, **406R2**, and **406L2**. A different object and image format may be chosen to meet specific system requirements. While shown in FIGS. **10**A and **10**B for large format systems, such as may be useful in cameras, teleconferencing and other large scale industrial applications, the third channel aspect of the invention may be implemented in a closely packed small stereo system, in the same manner as in the system illustrated in FIG. **9**.

The invention may be embodied in other specific forms without departing from the spirit or essential characteristics thereof. The present embodiments are therefore to be considered in all respects as illustrative and not restrictive, the scope of the invention being indicated by the appended claims rather than by the foregoing description, and all changes which come within the meaning and range of equivalency of the claims are therefore intended to be embraced therein.

Having described the invention, what is claimed as new and secured by Letters Patent is:

1. A stereoscopic objective lens system for a stereo video telescope, the objective lens system having elements disposed along an optical path to convert light propagated from an object and received at an objective end of the objective system to pixel-mapped right and left optical images of said object at an image plane end of the objective system, the objective lens system comprising:

A. a first collimator doublet lens disposed along said optical path and proximate to the objective end for collecting light from points on the object, said first collimator doublet lens having a first optical axis, a selected diameter and a selected optical power,

B. a second collimator doublet lens for collecting light from said first collimator doublet lens, said second collimator doublet lens being disposed along said optical path and adjacent to said first collimator doublet lens and having a second optical axis substantially collinear with said first optical axis of the first collimator doublet lens, said second collimator doublet lens having a selected diameter and a selected optical power, whereby said first and second collimator doublet lenses cooperate to image the object points substantially to infinity so that light transmitted by the second collimator doublet lens from the object points is substantially collimated,

C. a multiple field right/left stereo lens pair assembly including on a base:

(i). a first right/left stereo lens pair, said first pair including a first pair right stereo lens and a first pair left stereo lens, said first pair right and first pair left stereo lenses being adjacent to said second collimator doublet lens and disposed for collecting light from said second collimator doublet lens, said first pair right stereo lens and said first pair left stereo lens each having a respective optical axis substantially parallel to said second optical axis of the second collimator doublet lens,

(ii). a second right/left stereo lens pair, said second pair including a second pair right stereo lens and a second pair left stereo lens, said second pair right and second pair left stereo lenses being adjacent to said second collimator doublet lens and disposed for collecting light from said second collimator doublet lens, said second pair right stereo lens and said second pair left stereo lens each having a respective optical axis substantially parallel to said second optical axis of the second collimator doublet lens, wherein the magnifications of said first and second pair right and left stereo lenses are different,

wherein said base and said first and second right/left stereo lens pair are rotatable about a pivot axis parallel to said first optical axis to selectively be in a first state wherein:

said optical axes of said first right/left stereo lens pair are each a parallel sub-component part of said optical path, and said first and second collimator doublet lenses and said first right/left stereo lens pair cooperate so that the first and second collimator doublet lenses present equal-angle chief ray pairs from symmetrically disposed object points to the lenses of said first right/left stereo lens pair, and

whereby said first pair right lens generates a right image at the image plane, and said first pair left lens generates a left image at the image plane, such that corresponding portions of each right/left image are mapped to within a selected distance of each other, or

in a second state wherein

said optical axes of said second right/left stereo lens pair are each a parallel sub-component part of said optical path, and said first and second collimator doublet lenses and said second right/left stereo lens pair cooperate so that the first and second collimator doublet lenses present equal-angle chief ray pairs from symmetrically disposed object points to the lenses of said second right/left stereo lens pair, and whereby said second pair right stereo lens generates a right image at the image plane, and said second pair left stereo lens generates a left image at the image plane, such that corresponding portions of each right/left image are mapped to within a selected distance of each other.

2. A lens system according to claim **1** wherein the diameter of said second collimator doublet lens is approximately equal to the diameter of said first collimator doublet lens.

3. A lens system according to claim **2** wherein said right stereo lens is substantially identical to said left stereo lens.

4. A lens system according to claim **3** wherein said right stereo lens and said left stereo lens each have a circular

cross-section transverse to the respective optical axes of said right stereo lens and said left stereo lens.

5. A lens system according to claim **3** wherein the diameters of said right stereo lens and said left stereo lens are less than or equal to one-half the diameter of said first and second collimator doublet lenses, and said optical axes of said right stereo lens and said left stereo lens are off-set from said first and second optical axes of said first and second collimator doublet lenses by more than one-fourth the diameter of said first and second collimator doublet lenses.

6. A lens system according to claim **5** wherein said right stereo lens and said left stereo lens each have a circular cross-section transverse to the respective optical axes of said right stereo lens and said left stereo lens.

7. A dual telescope including a first Galilean telescope including two doublets extending along a first axis and a second Galilean telescope including two doublets extending along a second axis, said second Galilean telescope being adjacent to a right/left stereo lens pair, said pair including a right stereo lens and a left stereo lens for generating a right image and a left image, respectively of an object, said right stereo lens and said left stereo lens each having a respective optical axis, said optical axes of said right/left stereo lens pair each being a parallel sub-component part of an optical path, wherein said first and second Galilean telescopes are each rotatable about a respective pivot axis perpendicular to said optical axes of said right and left stereo lenses to selectively be in a first state wherein:

said first axis is in alignment with said optical axis of said left stereo lens and said second axis is in alignment with said optical axis of said right stereo lens, whereby said doublets of said first and second Galilean telescopes are in said optical path, or

in a second state wherein:

said first axis is out of alignment with said optical axis of said left stereo lens and said second axis is out of alignment with said optical axis of said right stereo lens, whereby said doublets of said first and second Galilean telescopes are out of said optical path.

8. A stereoscopic objective lens system for a stereo video telescope, the objective lens system having elements disposed along an optical path to convert light propagated from an object and received at an objective end of the objective system to pixel-mapped left and right optical images at an image plane end of the objective system, the objective lens system comprising:

A. a collimator lens system proximate to the objective end for collecting light propagated from points on the object, said collimator lens system being disposed along said optical path and having a defined optical axis, a selected diameter and a selected optical power, whereby said collimator lens system images the object points substantially to infinity so that light transmitted by said collimator lens system from the object points is substantially collimated,

B. a right/left stereo lens pair, said pair including a right stereo lens and a left stereo lens, said right and left stereo lenses being adjacent to said collimator lens system and disposed for collecting light from said collimator lens system, said right stereo lens and said left stereo lens each having a respective optical axis substantially parallel to the optical axis of the collimator lens system, said optical axes of said right/left stereo lens pair each being a parallel sub-component part of said optical path,

wherein said collimator lens system and said right/left stereo lens pair cooperate so that the collimator lens system presents equal-angle chief ray pairs from symmetrically disposed object points to the lenses of said right/left stereo lens pair,

C. a dual telescope including a first Galilean telescope including two doublets extending along a first axis and a second Galilean telescope including two doublets extending along a second axis, wherein said first and second Galilean telescopes are each rotatable about a respective pivot axis perpendicular to said optical axes of said right and left stereo lenses to selectively be in a first state wherein:

said first axis is in alignment with said optical axis of said left stereo lens and said second axis is in alignment with said optical axis of said right stereo lens, whereby said doublets of said first and second Galilean telescopes are in the optical path of said system, or

in a second state wherein

said first axis is out of alignment with said optical axis of said left stereo lens and said second axis is out of alignment with said optical axis of said right stereo lens, whereby said doublets of said first and second Galilean telescopes are out of said optical path of said system,

whereby said right stereo lens generates a right image at the image plane, and

said left stereo lens generates a left image at the image plane, such that corresponding portions of each right/left image are mapped to within a selected distance of each other.

9. A lens system according to claim **8** wherein said collimator lens system comprises:

A. a first collimator doublet lens disposed along said optical path and proximate to the objective end for collecting light from points on the object, said first collimator doublet lens having a first optical axis substantially collinear with said optical axis of said collimator lens system, said first collimator doublet lens having a selected diameter and a selected optical power,

B. a second collimator doublet lens for collecting light from said first collimator doublet lens, said second collimator doublet lens being disposed along said optical path and adjacent to said first collimator doublet lens and having a second optical axis substantially collinear with said first optical axis of said first collimator doublet lens, said second collimator doublet lens having a selected diameter and a selected optical power, whereby said first and second collimator doublet lenses cooperate to image the object points substantially to infinity so that light transmitted by the second collimator doublet lens from the object points is substantially collimated; and

further wherein the diameter of said second collimator doublet lens is approximately equal to the diameter of said first collimator doublet lens.

10. A lens system according to claim **9** wherein said right stereo lens is substantially identical to said left stereo lens.

11. A lens system according to claim **10** wherein said right stereo lens and said left stereo lens each have a circular cross-section transverse to the respective optical axes of said right stereo lens and said left stereo lens.

12. A lens system according to claim **9** wherein the diameters of said right stereo lens and said left stereo lens are less than or equal to one-half the diameter of said first and second collimator doublet lenses, and said optical axes of said right stereo lens and said left stereo lens are off-set from said first and second optical axes of said first and

second collimator doublet lenses by one-fourth the diameter of said first and second collimator doublet lenses.

13. A lens system according to claim **12** wherein said right stereo lens and said left stereo lens each have a circular cross-section transverse to the respective optical axes of said right stereo lens and said left stereo lens.

14. A lens system according to claim **8** wherein first and second Galilean telescopes are mounted in a single carriage whereby said first and second telescopes are rotatable in concert about said pivot axis in response to an applied force.

15. A multiple field stereoscopic objective lens system for a stereo digital camera, the objective lens system having elements disposed along an optical path to convert light propagated from an object and received at an objective end of the objective system to pixel-mapped left and right optical images of said object at an image plane end of the objective system, the objective lens system comprising:

A. a first collimator doublet lens disposed along said optical path and proximate to the objective end for collecting light from points on the object, said first doublet lens having a first optical axis, a selected diameter and a selected optical power,

B. a second collimator doublet lens for collecting light from said first collimator doublet lens, said second collimator doublet lens being disposed along said optical path and adjacent to said first collimator doublet lens and having a second optical axis substantially collinear with said first optical axis of the first collimator doublet lens, said second collimator doublet lens having a selected diameter and a selected optical power, whereby said first and second collimator doublet lenses cooperate to image the object points substantially to infinity so that light transmitted by the second collimator doublet lens from the object points is substantially collimated,

C. a multiple field left/right stereo lens pair assembly including on a base:

i. a first right/left stereo lens pair, said first pair including a first pair right stereo lens and a first pair left stereo lens, said first pair right and first pair left stereo lenses being adapted for positioning adjacent to said second collimator doublet lens and disposed for collecting light from said second collimator doublet lens, said first pair right stereo lens and said first pair left stereo lens each having a respective optical axis substantially parallel to said second optical axis of the second collimator doublet lens,

ii. a second right/left stereo lens pair, said second pair including a second pair right stereo lens and a second pair left stereo lens, said second pair right and second pair left stereo lenses being adapted for positioning adjacent to said second collimator doublet lens and disposed for collecting light from said second collimator doublet lens, said second pair right stereo lens and said second pair left stereo lens each having a respective optical axis substantially parallel to said second optical axis of the second collimator doublet lens, wherein the magnification of said first and second pair right and left stereo lenses are different,

wherein said base and said first and second right/left stereo lens pairs are rotatable about a pivot axis parallel to said first optical axis to selectively be in a first state wherein:

said optical axes of said first right/left stereo lens pair are each a parallel sub-component part of said optical path, and said first and second collimator doublet lenses and said first right/left stereo lens pair cooperate so that the first and second collimator doublet lenses present equal-angle chief ray pairs from symmetrically disposed object points to the lenses of first said right/left stereo lens pair, and whereby said first pair right stereo lens generates a right image at the image plane, and said first pair left stereo lens generates a left image at the image plane, such that corresponding portions of each right/left image are mapped to within a selected distance of each other, and

in a second state wherein

said optical axes of said second right/left stereo lens pair are each a parallel sub-component part of said optical path, and

said first and second collimator doublet lenses and said second right/left stereo lens pair cooperate so that the first and second collimator doublet lenses present equal-angle chief ray pairs from symmetrically disposed object points to the lenses of said second right/left stereo lens pair, and whereby said second pair right stereo lens generates a right image at the image plane, and

said second pair left stereo lens generates a left image at the image plane, such that corresponding portions of each right/left image are mapped to within a selected distance of each other.

16. A lens system according to claim **15** wherein the diameter of said second collimator doublet lens is approximately equal to the diameter of said first collimator doublet lens.

17. A lens system according to claim **16** wherein said first pair right stereo lens is substantially identical to said first pair left stereo lens, and said second pair right stereo lens is substantially identical to said second pair left stereo lens.

18. A lens system according to claim **17** wherein said first and second pair right stereo lens and said first and second left stereo lens each have a circular cross-section transverse to the respective optical axes of said first and second pair right stereo lens and said first and second pair left stereo lens.

19. A lens system according to claim **18** wherein the diameters of said first and second pair right stereo lens and said first and second pair left stereo lens are less than or equal to one-half the diameter of said first and second collimator doublet lenses, and said optical axes of said first and second pair right stereo lens and said first and second pair left stereo lens are off-set from said first and second optical axes of said first and second collimator doublet lenses by more than one-fourth the diameter of said first and second collimator doublet lenses.

20. A lens system according to claim **15** further comprises a third channel lens adjacent to said second collimator doublet lens and disposed for collecting light from said second collimator doublet lens, said third channel lens having an optical axis substantially parallel to the optical axis of said second collimator doublet lens.

21. A lens system according to claim **20** wherein the optical axis of said third channel lens is coaxial with the optical axis of said second collimator doublet lens.

22. A lens system according to claim **19** further comprises a third channel lens adjacent to said second collimator doublet lens and disposed for collecting light from said second collimator doublet lens, said third channel lens having an optical axis substantially parallel to the optical axis of said second collimator doublet lens.

23. A lens system according to claim **22** wherein the optical axis of said third channel lens is coaxial with the optical axis of said second collimator doublet lens.

* * * * *

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United States Patent [19]

Bauer

[11] **Patent Number: 6,148,151**

[45] **Date of Patent: Nov. 14, 2000**

[54] **CONTROL SYSTEM FOR AN OBJECTIVE OF A CAMERA**

[76] Inventor: **Fritz Bauer**, Pummergasse 20, 3002 Purkersdorf, Austria

[21] Appl. No.: **09/206,483**

[22] Filed: **Dec. 7, 1998**

[30] **Foreign Application Priority Data**

Mar. 9, 1998 [AT] Austria 407/98

[51] **Int. Cl.**[7] **G03B 3/12**; G03B 7/00; G03B 13/30; G03B 17/00

[52] **U.S. Cl.** **396/56**; 396/87; 396/88; 396/131; 396/147; 396/259; 396/508

[58] **Field of Search** 396/85, 86, 87, 396/88, 131, 133, 56, 57, 259, 508, 505, 147; 348/211–214

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Primary Examiner—W. B. Perkey
Attorney, Agent, or Firm—Henry M. Feiereisen

[57] **ABSTRACT**

A control system for an objective of the camera, in particular a film camera, includes one or several drive units for automatically positioning at least one lens ring, e.g., for adjusting the focus position, the opening of the iris diaphragm and/or the focal length. The drive units can be used to adjust the lens ring(s) to a predefined set position. A device coupled to each of the lens rings determines the actual position of the lens rings relative to the objective and converts this position into a measuring output signal.

32 Claims, 2 Drawing Sheets

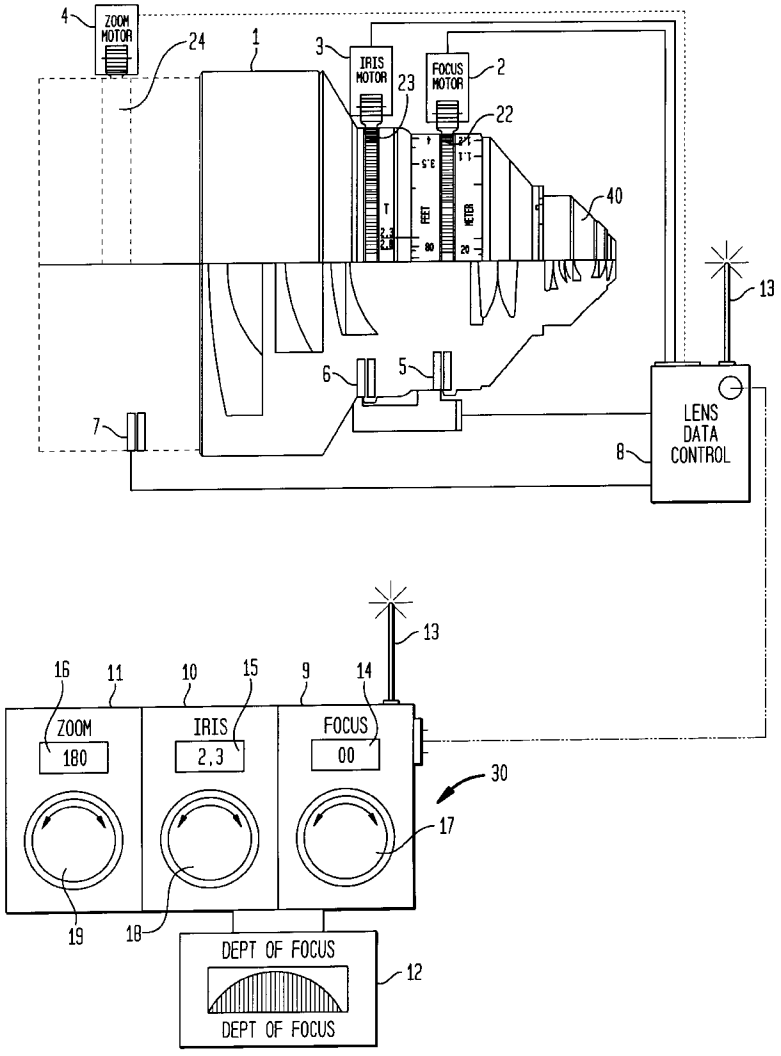
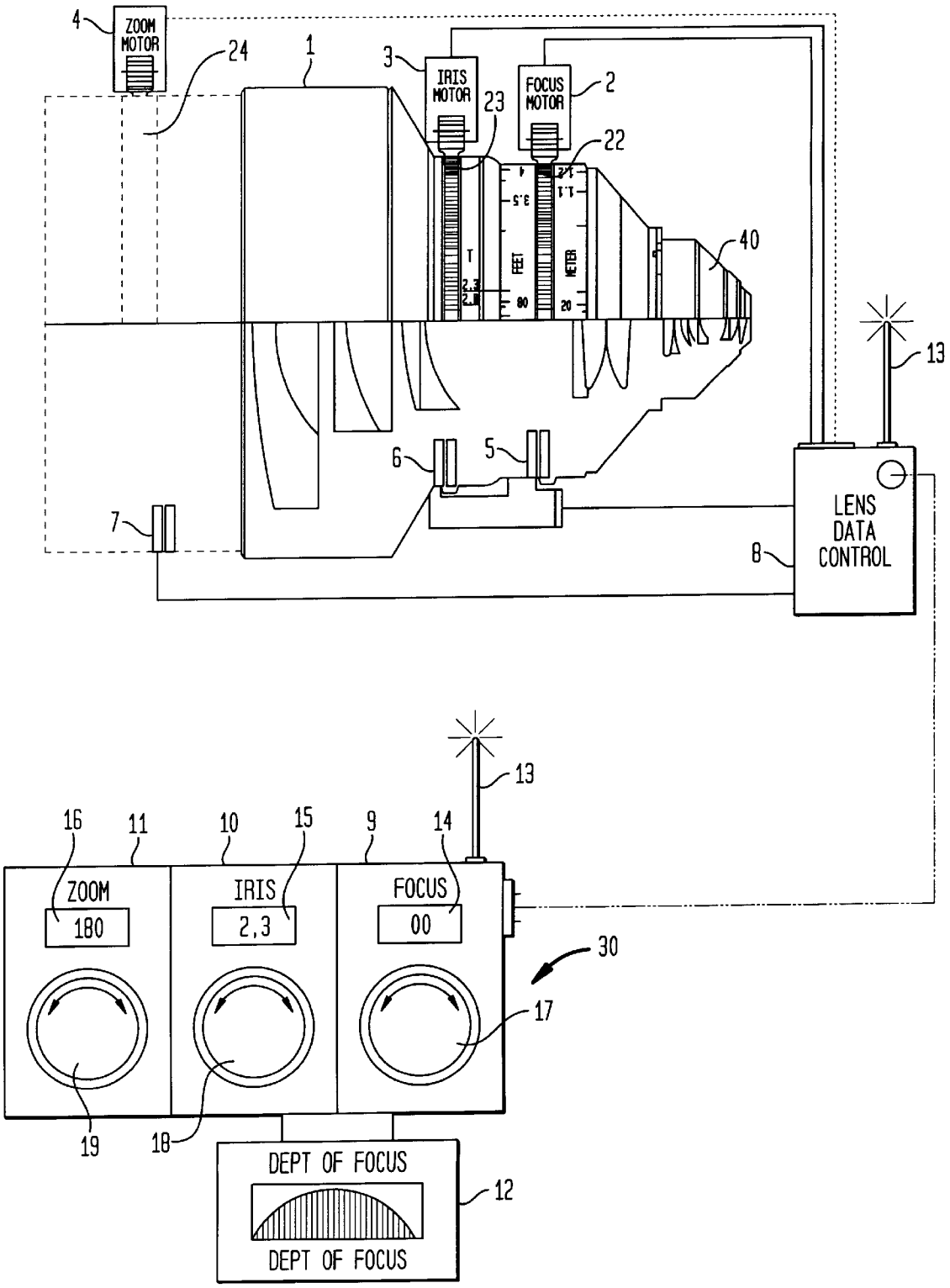


FIG. 1


ZOOM MOTOR
IRIS MOTOR
FOCUS MOTOR
LENS DATA CONTROL
ZOOM
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IRIS
2,3
FOCUS
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DEPT OF FOCUS
DEPT OF FOCUS
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FIG. 2

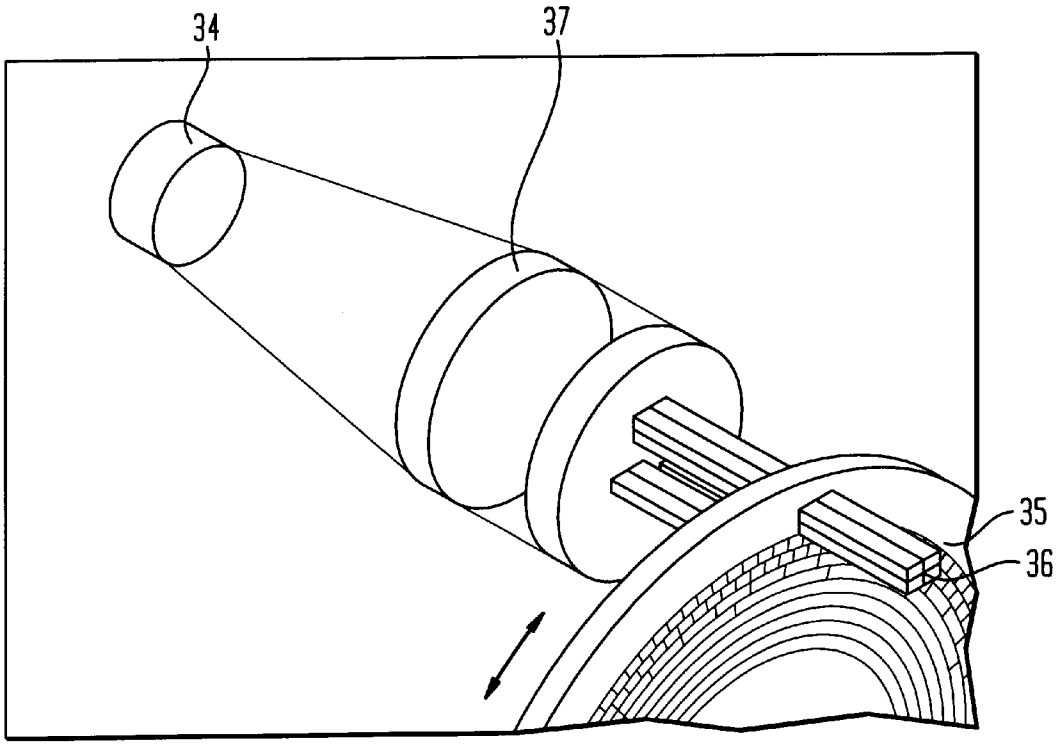
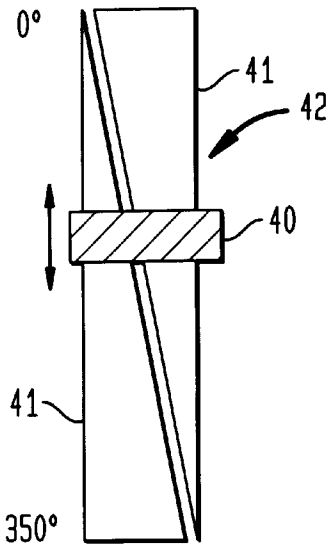


FIG. 3



CONTROL SYSTEM FOR AN OBJECTIVE OF A CAMERA

CROSS-REFERENCES TO RELATED APPLICATIONS

This application claims the priority of Austrian Patent Application, Serial No. A 407/98, filed Mar. 9, 1998, the subject matter of which is incorporated herein by reference.

BACKGROUND OF THE INVENTION

The present invention relates in general to a control system for an objective of a camera, in particular a film camera, and in particular to a control system of a type including one or several drive units for automatically adjusting the positions of at least one lens ring, e.g., for focus position, iris diaphragm and focal length. The drive units can adjust the lens rings or rings to a predetermined set position.

Conventional control systems of this type allow remote adjustment of various lens rings of a camera objective. The angular position of the respective lens ring which is preset in an adjusting device, is adjusted by a motor drive that always moves the lens ring from a current position to the next desired position in incremental steps. With this method, however, after several adjustment steps a cumulative error is introduced which can cause a noticeable misalignment. This misalignment interferes with the camera operation and may require a manual fine adjustment in regular intervals.

A larger number of tiltable film cameras that operate completely automatically and are able to attain specific camera positions, are already in use. These cameras are frequently located in areas that cannot be reached by a camera assistant. Movie scenes must then frequently be re-taken because the automatic adjustment of the lens rings is not accurate enough. The film takes then become unusable because the exposure is wrong or the scenes are not in focus.

SUMMARY OF THE INVENTION

It is thus an object of the present invention to provide an improved control system for an objective of a camera, obviating the afore-stated drawbacks.

In particular, it is an object of the present invention to provide an improved control system of the aforedescribed type with allows a precise angular positioning of the lens ring or rings on the camera objective.

These objects, and others which will become apparent hereinafter, are attained in accordance with the present invention by providing a device which is coupled to the lens ring(s) and determines the actual position of the lens ring(s), with the device determining the actual position of the lens ring(s) relative to the camera objective and converts the actual position into a measuring output signal.

By determining the actual position, the deviation from the set position of the respective lens ring can be exactly determined and subsequently corrected. Consequently, the actual values of the lens ring positions are always available, so that an assistant or the cameraman may not have to read the lens ring positions manually which may be difficult. If the camera is located at a remote location, the actual lens ring position may be read remotely and the lens ring position may be corrected by remote control.

According to another feature of the present invention, the device for determining the actual position of the lens ring(s) may include an optical angular encoder in the form of an encoding element that is non-rotatably connected to the lens ring. The encoding element may include encoding tracks that can be read optically through reflection or transmission of light. The encoding element may also include a light transmitter and receiver system, wherein the light receiver produces the measuring output signal.

By applying appropriate encoding methods, the position of the lens ring(s) can be determined with great precision and high-resolution since mechanical friction forces do not interfere with the adjustment of the lens ring(s).

According to still another feature of the present invention, the device for determining the actual position of the lens ring(s) may include a magnetic distance sensor in the form of a tape that is preferably placed on the lens ring and filled with magnetic particles. The tape may be polarized periodically along several parallel tracks. The device may also include a magnetic sensor for sensing the tape without making physical contact with the tape, and for producing the measuring output signal.

This makes it possible to determine the position of the respective lens ring with great precision, without requiring a direct mechanical connection with the lens ring.

Advantageously, the magnetic sensor may be a magneto-resistive magnetic sensor.

According to still another feature of the present invention, the device for determining the actual position of the lens ring(s) may include a waveguide extending around the circumference of the objective in the region of the lens ring and a magnet that is connected to the lens ring at a predetermined location. The magnet may be at least partially movable inside the waveguide. An electromagnetic transmitter element and an acoustic receiver element may be arranged in the waveguide. The measured time difference between the signal transmitted by the transmitter element and the signal received by the receiver element represents the measuring output signal.

This feature also allows a precise and unambiguous measurement of the position of the lens ring.

According to yet another feature of the invention, the device for determining the actual position of the lens ring(s) may include an electrode located on the lens ring. The electrode can be rotated about a two-piece electrode that is located on the objective and increases or decreases in size depending on the position of the lens ring(s), without making physical contact with the electrode. The measuring output signal is produced by the capacitance ratio measured between the two-piece regions of the electrode and the rotatable electrode.

The position can therefore be determined through a capacitance measurement without making physical contact.

According to still another feature of the invention, the two-piece electrode may be represented by a rectangle that is parted along a diagonal. If lens rings are designed to rotate by more than 180°, an electrode that follows the helical path of the rotation, may be placed on the objective.

According to another embodiment of the invention, the measured values of the actual position may be transmitted to a different location for evaluation. Each of the measuring outputs of the device for determining the actual positions may be connected to a respective input of a measuring signal transmitter unit, with the output of the measuring signal transmitter unit connected to a measuring signal receiver unit capable of displaying the actual state of the lens ring(s) via one or several displays arranged in the measuring signal receiver unit.

In order to be able to reliably transmit the measured actual position values even for extreme camera positions, the

measuring signal transmitter unit may include a wireless transmitter section. The measuring signal receiver unit may include a corresponding wireless receiver section. Both sections are capable of exchanging the measuring signal data.

The measuring signal transmitter unit may be attached to the camera that is associated with the objective, Alternatively, the measuring signal transmitter unit may be incorporated in the camera and form a part of the camera. The measuring signal transmitter unit may also be placed at other locations.

According to still another feature of the present invention, the measuring signal transmitter unit may also include a control receiver unit that is electrically connected to the drive(s) for positioning the lens ring(s) and a control transmitter unit that is located in the measuring signal receiver unit and has control actuator elements capable of adjusting the set position of the lens ring(s).

In this way, the control devices and the units which indicate the actual positions, can be functionally combined into a single unit rather than forming separate units.

According to yet another feature of the invention, the measuring signal receiver unit may be connected to a device for determining and displaying the depth of field. With this device, the actual positions of the lens ring(s) can be measured to determine the depth of field that is actually usable with the objective. The actual depth of field range can then be determined for each actual setting of the objective. This may eliminate the need to re-shoot a movie scene because the actors or the backdrop were outside the focal range due to a camera movement. Since is the actual data relating to the position of the lens ring(s) are automatically available, the actual useful depth of field can be automatically determined without to tedium of inspecting tables.

BRIEF DESCRIPTION OF THE DRAWING

The above and other objects, features and advantages of the present invention will now be described in more detail with reference to the accompanying drawing, in which:

FIG. **1** is a schematic overall view of one embodiment of a control system according to the present invention for an objective of a camera;

FIGS. **2** and **3** are schematic illustrations of a device for determining the actual position of the lens ring position.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Throughout all the Figures, same or corresponding elements are generally indicated by same reference numerals.

Turning now to the drawing, and in particular to FIG. **1**, there is shown a schematic overall view of one embodiment of a control system according to the present invention for an objective **1** of a film camera which includes three lens rings **22, 23, 24** for adjusting the focus position, the aperture of the iris diaphragm and the focal length of the objective. The objective **1** includes a system of optical lenses which are shown as a split elevation view of the objective. The objective is secured to the lens mount of the film camera through a bayonet mount. The system of the invention can also be used with other types of cameras and objectives.

The objective **1** includes several drive units **2, 3, 4** for automatically adjusting the position of the lens rings to predetermined set positions. When a control signal is sent to one of the drives, the drive initiates a rotation of the lens ring through a geared wheel that is driven by a motor, and stops the lens ring at the desired position. The rotation of the lens rings automatically causes a displacement of the optical lenses inside the objective **1** and/or an increase or decrease in the size of the iris diaphragm. The number and the functionality of the lens rings is in no way limited and can be varied in a number of different ways.

The lens ring can still be adjusted manually if a motor-controlled actuation is not desired.

It has been demonstrated in practice that an automatic adjustment of the lens rings, even if performed with great precision, is still inferior to a precise manual adjustment. The reason is that the drive units are not capable of providing the required precision along the entire circumference of the objective and during several adjustments.

In accordance with the invention, this situation can be corrected by providing a device that is coupled to each of the lens rings **22, 23, 24** for determining the actual positions **5, 6, 7** of the lens rings. The device determines the actual position of the lens rings **22, 23, 24** relative to the objective **1** and converts the position into a measuring output signal.

In this way, the adjustment movements that are actually performed by the drive units **2, 3, 4**, can be controlled and, if necessary, corrected.

Various possible methods for coupling the lens rings with the devices that determine the actual positions **5, 6, 7**, are described hereinafter with reference to several exemplified embodiments. In principle, these embodiments are independent of the specific device used to determine the positions.

In accordance with the nonlimiting example of FIG. **2**, the device for determining the actual position includes an optical angular encoder with an encoder element **35** that is non-rotatably connected with the lens ring. The lens ring includes encoding tracks that can be read out optically using transmitted light. The device further includes a light transmitter and receiver system **34, 36**. The measuring output signal is generated by the light receiver **36**. A reflecting encoding disk can also be used, in which case the light receiver would be located on the same side as the light transmitter **34**. To improve illumination of the tracks and to prevent crosstalk between the encoded tracks, a capacitor **37** is connected between the light transmitter **34** and the light receiver **36**. To provide a sufficiently high resolution of the respective angular position, several encoded tracks are arranged on the encoding disk. Accordingly, the light receiver is subdivided into several active elements.

Although not shown in detail in the drawing, a device for determining the actual position of the lens ring may also include a magnetic distance sensor system. The magnetic distance sensor system is formed of a tape that is filled with magnetic particles and preferably attached to the lens ring. The tape is preferably periodically polarized along several parallel tracks. A magnetic sensor which scans the tape without making physical contact with the tape, produces the measuring output signal. The parallel tracks can be polarized periodically in a sinusoidal or rectangular pattern. The magnetic sensor which is preferably a magneto-resistive sensor, is guided across the tape in close proximity thereto according to the angular position of the lens ring and scans the magnetic signatures.

The resistance of the magneto-resistive sensor elements varies as a function of the magnetic fields strength so that under constant current conditions, the elements produce a voltage that is modulated according to the changing magnetic field of the tape. The sensor elements are manufactured using semiconductor technology and can therefore be miniaturized. The output signal of the magnetic sensor is pro-

cessed by signal processing electronics capable of processing digital as well as analog signals, depending on the modulation type of the tape, to determine the position.

In order to provide higher resolution, phase-shifted magnetic tracks with a predetermined pattern are written on the tape. When this pattern is scanned, phase shifted signals are produced which are capable of resolving even those positions on the tape that are located between the magnetization periods. The measuring process operates incrementally and therefore requires that a reference signal be defined. An absolute position can be determined by scanning several parallel tracks.

It is also possible to provide the device for determining the actual position of the lens ring in the form of a waveguide that extends around the circumference of the objective in the region of the lens ring, and a magnet that is connected to the lens ring at a predetermined location.

The magnet is at least partially movable inside the waveguide. An electromagnetic transmitter element and an acoustic receiver element are arranged in the waveguide.

The transmitter element produces an electromagnetic pulse striking the permanent magnetic field of the magnet. The position of the magnet follows the position of the lens ring. This produces an angular momentum or a torsional pulse at the respective location of the waveguide. The latter pulse propagates with a constant sound velocity from the measuring location to the acoustic receiver element which converts the pulse into an electric pulse which is then sensed.

The measured time difference between the signal transmitted by the transmitter element and the signal received by the acoustic receiver element represents the measuring output signal. The measurement of the propagation time corresponds to a distance information between the magnet and the acoustic receiver element and subsequently has to be converted to corresponding angular data.

As shown in FIG. **3**, the device for determining an actual position includes an electrode **40** which is attached to the lens ring **22**, **23**, **24**. The electrode **40** can be pivoted across a split electrode **42** attached to the objective and increasing or decreasing in size depending on the position of the lens ring **22**, **23**, **24**.

The measuring output signal is generated based on the capacitance ratio measured between the two-piece regions **41** of the electrode **42** and the rotatable electrode **40**. The absolute position of the lens ring can be determined from the output signal.

According to the embodiment of FIG. **3**, the split electrode **42**, when in a flat state, represents a rectangle that is divided along a diagonal and composed of the rectangular triangles **41**. However, the electrode **42** can also be selected to have another two-piece shape.

To attain a very high resolution, stray capacitances have to be eliminated by providing adequate shielding. In order to obtain the largest possible capacitance, an intermediate layer with a relatively high dielectric constant, e.g., a Teflon layer, on which the rotatable electrode **40** glides, is preferably placed between the rotatable electrode **40** and the two-piece electrode **42** in situations where these two electrode are separated by a small gap. If the two electrodes are be prevented from contacting each other at all, then the measured signal may have to be amplified.

As also seen in FIG. **1**, each of the measuring outputs of the device for measuring the actual positions **5**, **6**, **7** is connected to a respective input of a measuring signal transmitter unit **8**. This unit receives the measuring signals from the devices determining the actual positions **5**, **6**, **7** and transmits the signals to a measuring signal receiver unit **30** connected thereto.

This connection can be provided in different ways, e.g., via infrared, ultrasound, electrical wires and the like. Illustrated is a wireless connection exemplified by antennas **13**. For this purpose, the measuring signal transmitter unit **8** includes a wireless transmitter section and the measuring signal receiver unit **30** includes a corresponding wireless receiver section which are adapted to transmit the measuring signal data. These data may have already been processed or can alternatively be processed after having been transmitted.

The measuring signal transmitter unit **8** can either be attached to the camera that is associated with the objective or can be a part of the camera. The transmitter unit **8** can also be carried by an assistant accompanying the camera man.

The wireless connection is advantageously implemented at camera locations that have automatic camera control and where the objective cannot be adjusted manually.

Several displays **14**, **15**, **16** capable of displaying the processed measuring signals indicating the actual position of the various lens rings **22**, **23**, **24** are arranged in the measuring signal receiver unit **30**. In the example of FIG. **1**, the focus setting is set to infinity, the iris diaphragm is set to the value 2.3 and the focal length to 180 mm. These values correspond to the values actually indicated on the objective which may be different from the set values inputted earlier.

As can be seen from FIG. **1**, the measuring signal transmitter unit **8** also includes a control receiver unit that is electrically connected to the drives **2**, **3**, **4** for positioning the lens rings **22**, **23**, **24**. The measuring signal receiver unit **30** also includes a control transmitter unit having control actuator elements **17**, **18**, **19**. These control transmitter and receiver units can also be separate from the measuring signal units. In a simpler arrangement, the control units can be combined with the measuring signal units and can be used to adjust the desired state of the lens rings **22**, **23**, **24**. The desired value of the lens ring positions can then be set via the control actuating elements **17**, **18**, **19** which are implemented as rotary control knobs. The desired value is transmitted as a control command via wireless transmission to the drive units **2**, **3**, **4** which drive the respective lens rings **22**, **23**, **24**.

When the set value is changed from one position to the next, the displays **14**, **15**, **16** indicate the actual position of the lens rings **22**, **23**, **24**. The position of the focusing rings **22**, **23**, **24** can be corrected with the control knobs **17**, **18** or **19**, which can be rotated until the desired values on the objective **1** are attained.

Since the actually set position values of the lens rings are accessible, the depth of field can also be precisely determined and displayed. In this way, the cameraman is always kept current of the limiting values for the depth of field of the exposed film. The use of tables can be eliminated by connecting the measuring signal receiver unit **30** to a device for determining and displaying the depth of field **12**. The device can be used in conjunction with the actual position of the lens ring **22**, **23**, **24** to measure and display the useful depth of field that the objective **1** can provide. The depth of field range can then be readily viewed.

While the invention has been illustrated and described as embodied in a control system for an objective of a camera, it is not intended to be limited to the details shown since various modifications and structural changes may be made without departing in any way from the spirit of the present invention.

What is claimed as new and desired to be protected by Letters Patent is set forth in the appended claims:

1. A control system for an objective of a camera, comprising:

at least one lens ring disposed on the objective;

at least one drive unit or automatically adjusting a position of the lens ring to a predetermined desired state; and

at least one position determining means coupled to the lens ring for determining an actual position of the lens ring relative to the objective, said position determining means converting the actual position into a measuring output signal,

wherein the position determining means includes a waveguide extending about the circumference of the objective in the region of the lens ring, a magnet connected to the lens ring at a predetermined location and at least partially movable inside the waveguide, an electromagnetic transmitter element, and an acoustic receiver element arranged in the waveguide, wherein the electromagnetic transmitter element transmits a signal that is received by the acoustic receiver element and wherein a time difference measured between transmission of the signal by the electromagnetic transmitter element and reception of the signal by the acoustic receiver element represents the measuring output signal.

2. A control system for an objective of a camera, comprising:

at least one lens ring disposed on the objective; at least one drive unit for automatically adjusting a position of the lens ring to a predetermined desired state; and

at least one position determining means coupled to the lens ring for determining an actual position of the lens ring relative to the objective, said position determining means converting the actual position into a measuring output signal,

wherein the position determining means includes a first electrode located on the objective and comprised of two sections having areas that increase or decrease in size depending on the position of the lens ring, and a second electrode arranged on the lens ring and capable of rotating without physically contacting the first electrode, the first and second electrode forming a capacitor, wherein the measuring output signal is produced based on a capacitance ratio measured between the two sections of the first electrode and the second electrode.

3. The control system of claim **2** wherein the sections of the first electrode, when arrange on a plane, form a rectangle which is separated along a diagonal of the rectangle.

4. A control system for an objective of a camera, comprising:

at least one lens ring disposed on the objective;

at least one drive unit for automatically adjusting a position of the lens ring to a predetermined desired state;

at least one position determining means coupled to the lens ring for determining an actual position of the lens ring relative to the objective, said position determining means converting the actual position into a measuring output signal; and

a measuring signal transmitter unit receiving as an input signal the measuring output signal of the position determining means and producing an output signal; a measuring signal receiver unit receiving the output signal from the measuring signal transmitter unit; and at least one display device arranged in the measuring signal receiver unit for displaying the actual position of the lens ring.

5. The control system of claim **4** wherein the position determining means is provided in the form of an optical angular encoder which includes an optical encoding element connected to the lens ring, an encoding tracks capable of at least one of reflecting or transmitting optical radiation, a light transmitter for generating the optical radiation, and a light receiver for generating the measuring output signal.

6. The control system of claim **4** wherein the position determining means is provided in the form of a magnetic distance sensor which includes a tape connected to the lens ring and periodically magnetically polarized along at least one track, and a magnetic sensor for sensing the tape without making physical contact with the tape and for generating the measuring output signal.

7. The control system of claim **6** wherein the magnetic sensor is a magneto-resistive magnetic sensor.

8. The control system of claim **4** wherein the measuring signal transmitter unit includes a wireless transmitter section, and the measuring signal receiver unit includes a wireless receiver section, said wireless transmitter section and said wireless receiver section being adapted to transmit the measuring signal data.

9. The control system of claim **4** wherein the measuring signal transmitter unit is attached to the camera.

10. The control system of claim **4** wherein the measuring signal transmitter unit forms a part of the camera.

11. The control system of claim **4** wherein the measuring signal transmitter unit further includes a control receiver unit which is electrically connected to the drive positioning the lens ring, said measuring signal receiver unit further including a control transmitter unit having control actuator elements capable of adjusting the set position of the lens ring.

12. The control system of claim **4** wherein the position of the lens ring defines a focus position of the objective.

13. The control system of claim **4** wherein the position of the lens ring defines a size of an iris diaphragm of the objective.

14. The control system of claim **4** wherein the position of the lens ring defines a focal length of the objective.

15. The control system of claim **6** wherein the tape is filled with magnetic particles.

16. The control system of claim **6** wherein the at least one track is a plurality of tracks that are parallel with respect to each other.

17. The control system of claim **5** wherein the optical encoding element is secured against rotation with respect to the lens ring.

18. A control system for an objective of a camera, comprising:

at least one lens ring disposed on the objective;

at least one drive unit for automatically adjusting a position of the lens ring to a predetermined desired state;

at least one position determining means coupled to the lens ring for determining actual position of the lens ring relative to the objective, said position determining means converting the actual position into a measuring output signal;

a measuring signal receiver unit responsive to the measuring output signal of the position determining means; and

a means connected to the measuring signal receiver unit for determining and optically displaying the depth of

field from the actual positions of the lens ring attainable with the objective.

19. A control system for an objective of a camera, comprising at least one drive unit for automatically adjusting a position of at least one lens ring to thereby impact at least one of a focus position, an iris diaphragm and a focal length, with the drive unit adjusting a predetermined desired state of the lens ring; and at least one device coupled to the lens ring for determining the actual position of the lens ring, wherein the device determines the actual position of the lens ring relative to the objective and converts the actual position into a measuring output signal, wherein the device for determining the actual position of the lens ring includes a waveguide extending around the circumference of the objective in the region of the lens ring and a magnet that is connected to the lens ring at a predetermined location, wherein the magnet is at least partially movable inside the waveguide, wherein an electromagnetic transmitter element and an acoustic receiver element are arranged in the waveguide and wherein the measured time difference between the signal transmitted by the transmitter element and the signal received by the receiver element represents the measuring output signal.

20. A control system for an objective of a camera, comprising at least one drive unit for automatically adjusting a position of at least one lens ring to thereby impact at least one of a focus position, an iris diaphragm and a focal length, with the drive unit adjusting a predetermined desired state of the lens ring; and at least one device coupled to the lens ring for determining the actual position of the lens ring, wherein the device determines the actual position of the lens ring relative to the objective and converts the actual position into a measuring output signal, wherein the device for determining the actual position of the lens ring includes an electrode located on the lens ring, wherein the electrode is rotatable, in a contact-free manner, about a split electrode which is located on the objective and increases or decreases in size depending on the position of the lens ring, wherein the measuring output signal is produced based on the capacitance ratio of the two-piece regions of the electrode with respect to the rotatable electrode.

21. The control system of claim **20** wherein the split electrode in a planar state is represented by a rectangle that is separated along a diagonal.

22. A control system for an objective of a camera, comprising at least one drive unit for automatically adjusting a position of at least one lens ring to thereby impact at least one of a focus position, an iris diaphragm and a focal length, with the drive unit adjusting a predetermined desired state of the lens ring; and at least one device coupled to the lens ring for determining the actual position of the lens ring, wherein the device determines the actual position of the lens ring relative to the objective and converts the actual position into a measuring output signal, wherein the measuring outputs of the device for determining the actual position is connected to a respective input of a measuring signal transmitter unit, and wherein the output of the measuring signal transmitter unit is connected to a measuring signal receiver unit capable of displaying the actual state of the lens ring via one or several displays arranged in the measuring signal receiver unit.

23. The control system of claim **22** wherein the device for determining the actual position of the lens ring includes an optical angular encoder which is formed from an encoding element that is non-rotatably connected to the lens ring and provided with encoding tracks that can be read optically through reflection or transmission of light and a light transmitter and receiver system, wherein the light receiver generates the measuring output signal.

24. The control system of claim **22** wherein the device for determining the actual position of the lens ring includes a magnetic distance sensor in the form of a tape that is preferably placed on the lens ring and filled with magnetic particles, wherein the tape is preferably periodically polarized along several parallel tracks, and a magnetic sensor for sensing the tape without making contact with the tape and generating the measuring output signal.

25. The control system of claim **24** wherein the magnetic sensor is a magneto-resistive magnetic sensor.

26. The control system of claim **22** wherein the measuring signal transmitter unit includes a wireless transmitter section and the measuring signal receiver unit includes a corresponding wireless receiver section which are adapted to transmit the measuring signal data.

27. The control system of claim **22** wherein the measuring signal transmitter unit is attachable to the camera that is associated with the objective, or forms part of the camera.

28. The control system of claim **27** wherein the measuring signal transmitter unit further includes a control receiver unit that is electrically connected with the drive for positioning the lens ring, and wherein the measuring signal receiver unit further includes a control transmitter unit having control actuator elements capable of adjusting the set position of the lens ring.

29. A control system for an objective of a camera, comprising at least one drive unit for automatically adjusting a position of at least one lens ring to thereby impact at least one of a focus position, an iris diaphragm and a focal length, with the drive unit adjusting a predetermined desired state of the lens ring; at least one device coupled to the lens ring for determining the actual position of the lens ring, wherein the device determines the actual position of the lens ring relative to the objective and converts the actual position into a measuring output signal, a measuring signal receiver unit capable of displaying the actual state of the lens ring via one or several displays arranged in the measuring signal receiver unit, wherein the measuring signal receiver unit is connected to a device for determining and optically displaying the depth of field, wherein the device is used to determine from the actual positions of the lens ring the depth of field that can actually be used with the objective.

30. The control system of claim **29** wherein the device for determining the actual position of the lens ring includes an optical angular encoder which is formed from an encoding element that is non-rotatably connected to the lens ring and provided with encoding tracks that can be read optically through reflection or transmission of light and a light transmitter and receiver system, wherein the light receiver generates the measuring output signal.

31. The control system of claim **29** wherein the device for determining the actual position of the lens ring includes a magnetic distance sensor in the form of a tape that is preferably placed on the lens ring and filled with magnetic particles, wherein the tape is preferably periodically polarized along several parallel tracks, and a magnetic sensor for sensing the tape without making contact with the tape and generating the measuring output signal.

32. The control system of claim **31** wherein the magnetic sensor is a magneto-resistive magnetic sensor.

* * * * *

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United States Patent [19]

Lagerway et al.

[11] Patent Number: 6,142,934

[45] Date of Patent: Nov. 7, 2000

[54] **OBJECTIVE LENS SYSTEM FOR IMAGING INSTRUMENT**

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[73] Assignee: **Welch Allyn, Inc.**, Skaneateles Falls, N.Y.

[21] Appl. No.: **09/221,922**

[22] Filed: **Dec. 28, 1998**

Related U.S. Application Data

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[60] Provisional application No. 60/043,374, Apr. 4, 1997, and provisional application No. 60/075,406, Feb. 20, 1998.

[51] **Int. Cl.**[7] **A61B 1/227**

[52] **U.S. Cl.** **600/200**; 600/156; 600/167

[58] **Field of Search** 600/172, 176, 600/109, 200, 167; 385/119

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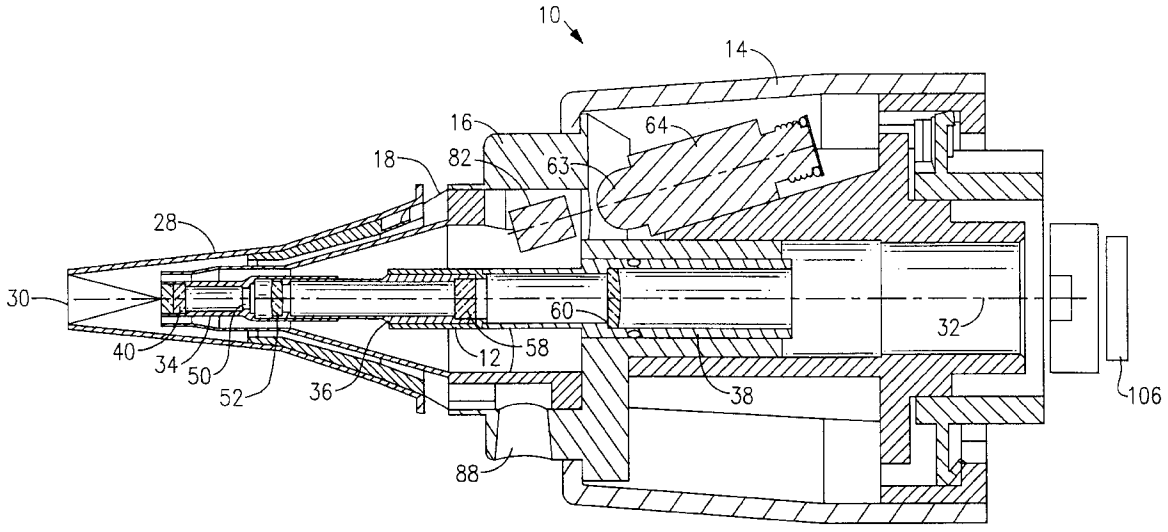
Primary Examiner—John P. Leubecker

Attorney, Agent, or Firm—Wall Marjama & Bilinski

[57] **ABSTRACT**

A retrofocus objective lens system which is conducive for an otoscope includes a first group of optical elements positioned at a distal portion and a second group of optical elements proximally spaced from the first group of optical elements. The first group of optical elements includes at least one negative small diameter lens while the second group of optical elements include a plurality of small diameter lenses having an aggregate optical power which is positive, allowing an image of interest to be transmitted through the system without any intermediate imaging planes, and without the need for rod lenses. The first and second lens groups are retained in a plurality of linearly interconnected lens tubes such that one lens tubes is linearly adjustable in relation to the remaining lens tubes in order to vary the focal length of the lens system.

20 Claims, 6 Drawing Sheets



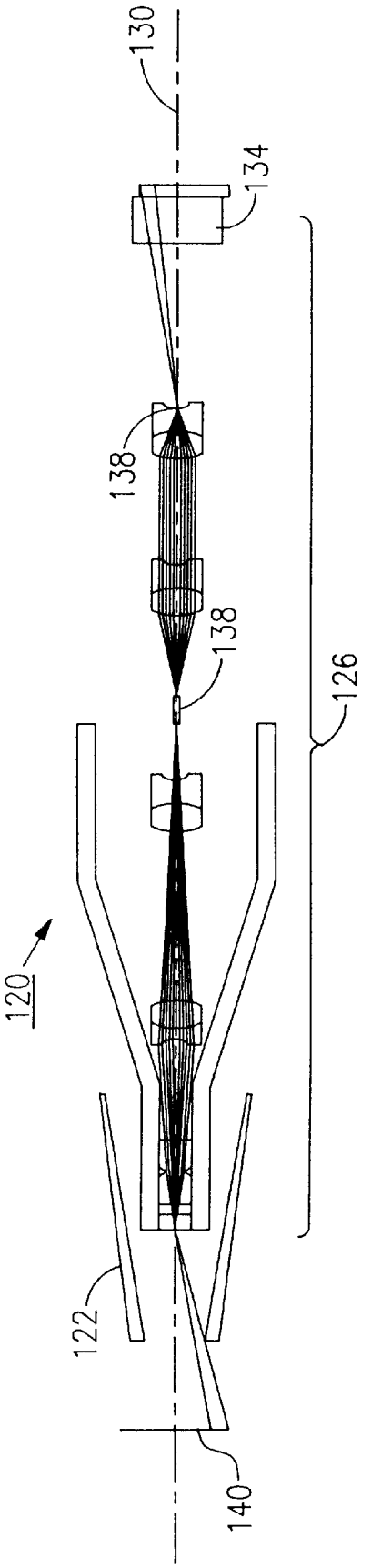


FIG.1
Prior Art

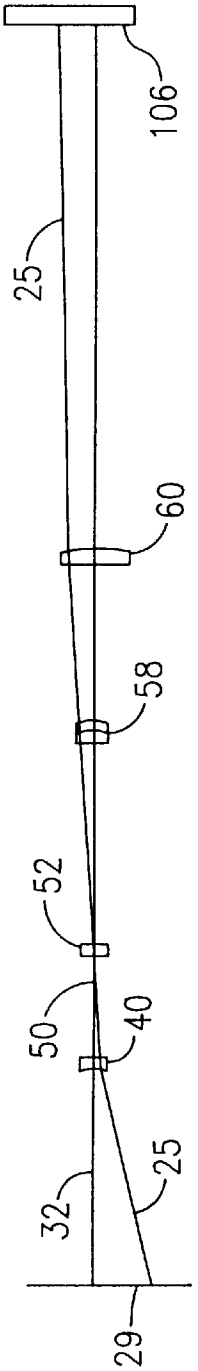


FIG.2

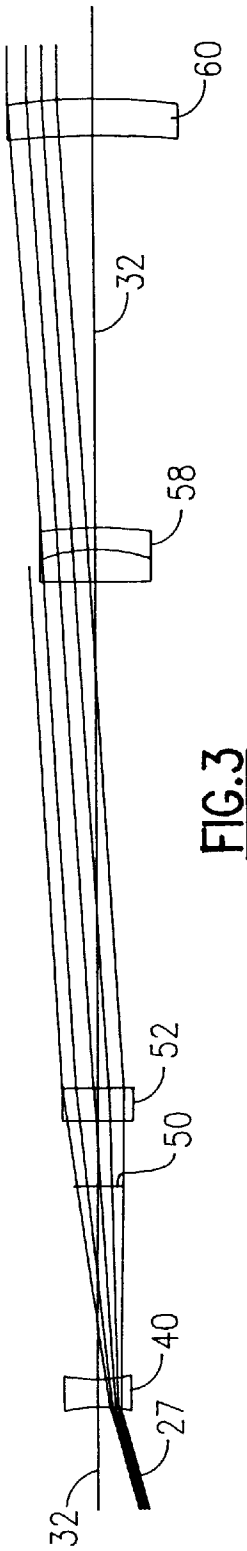

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FIG.3

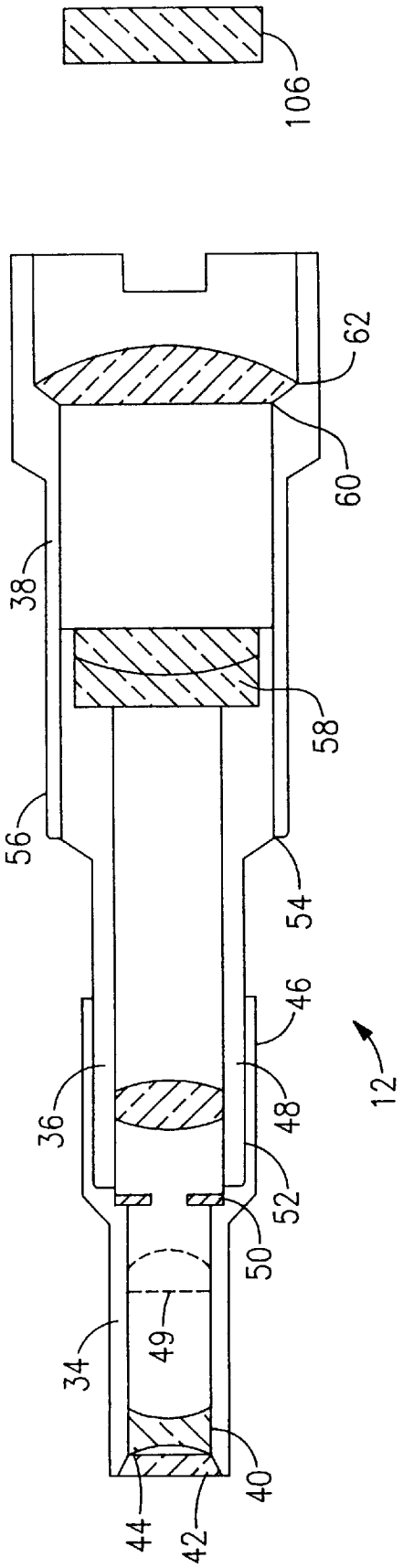
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FIG.4

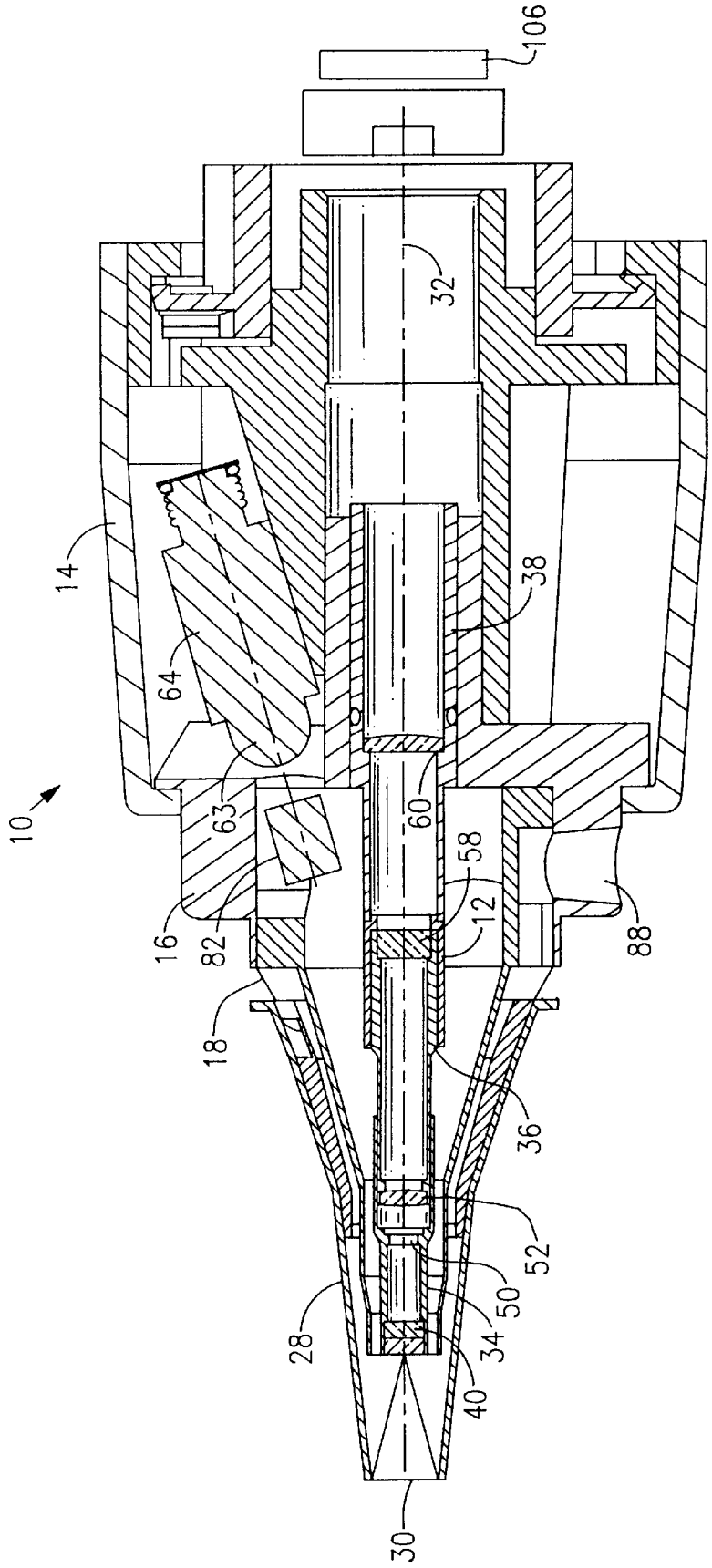

FIG.5

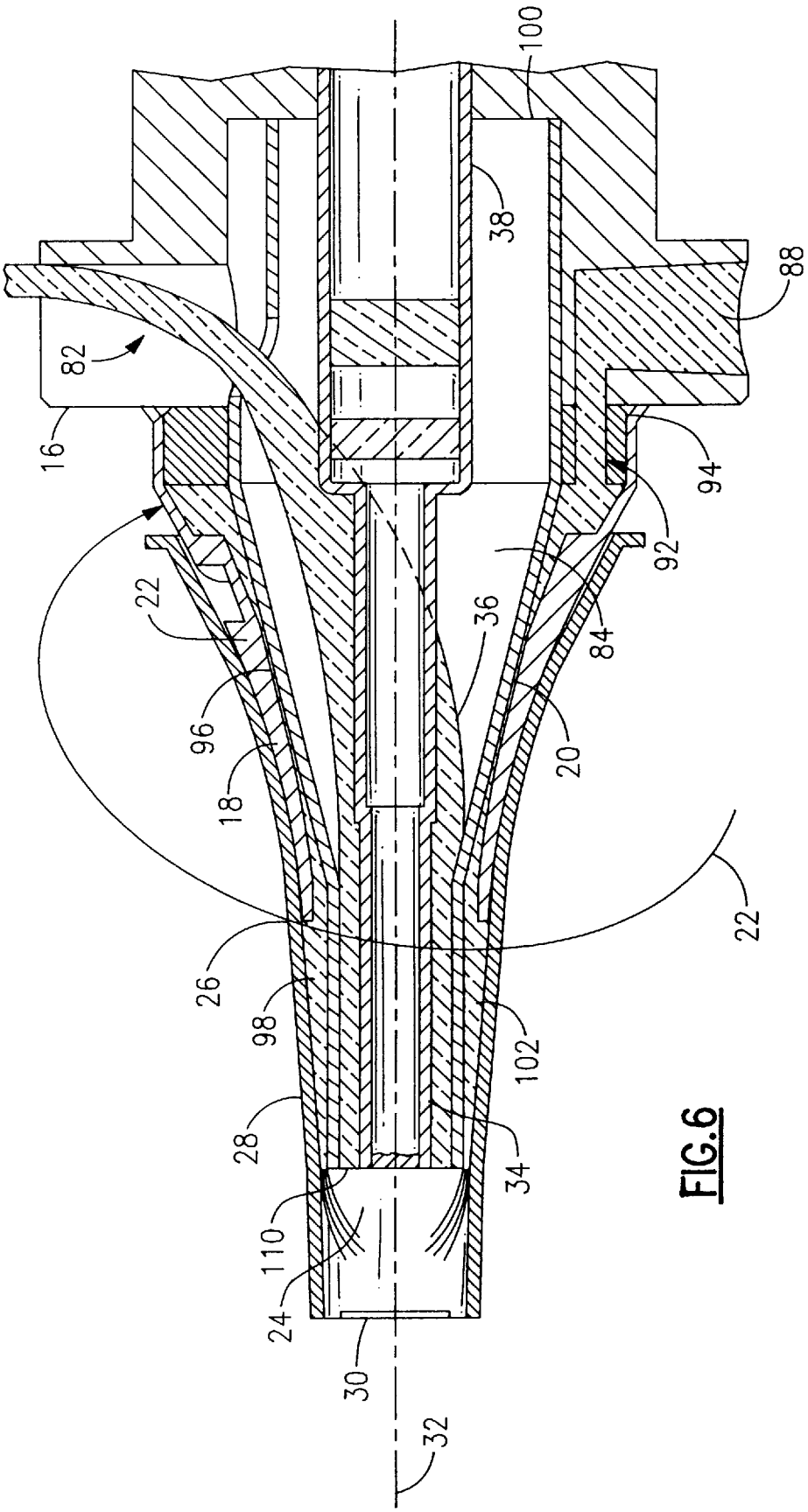

FIG.6

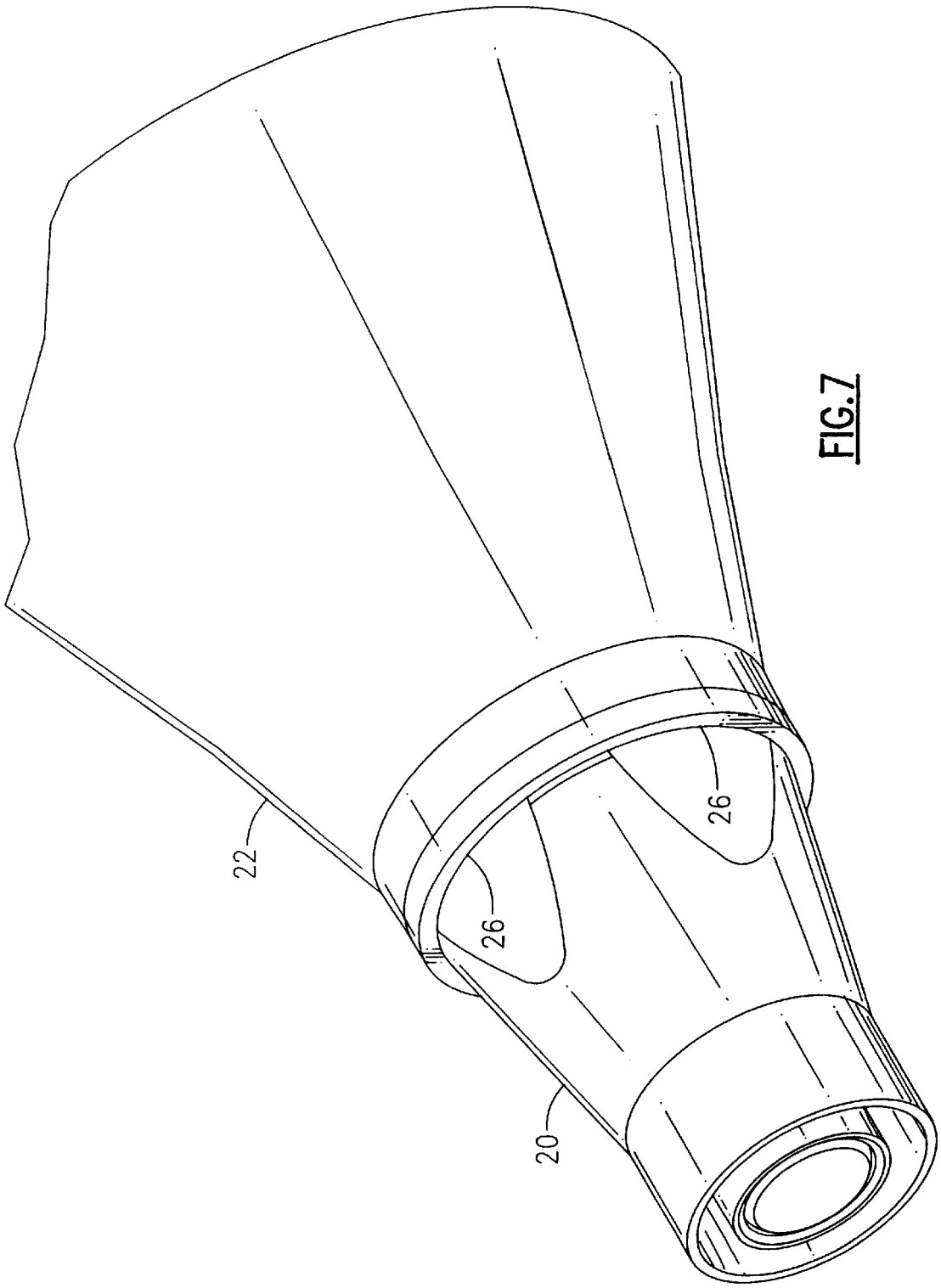

FIG.7

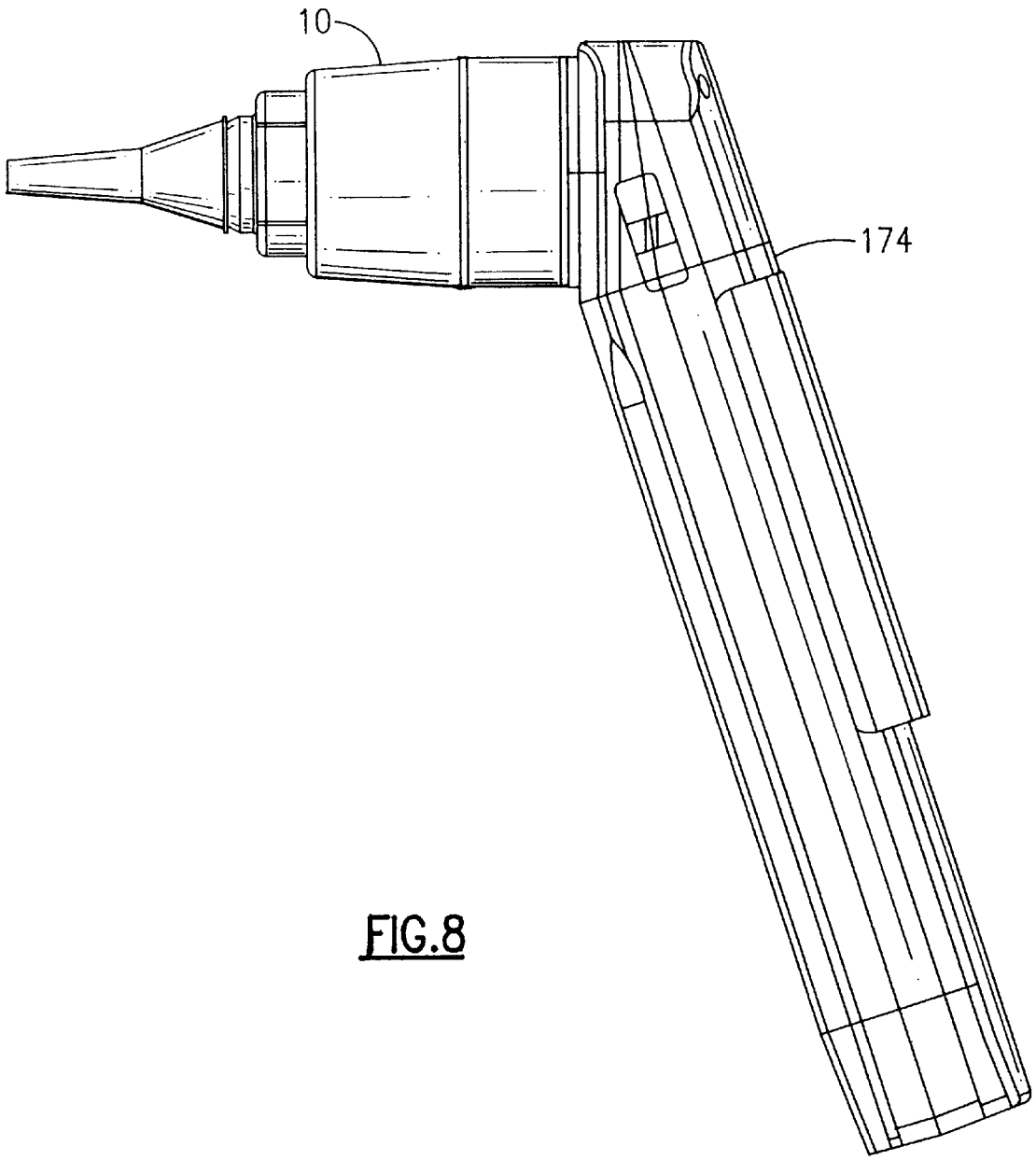

FIG.8

OBJECTIVE LENS SYSTEM FOR IMAGING INSTRUMENT

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a continuation-in-part of U.S. Ser. No. 09/052,570, filed Mar. 31, 1998, which is based upon provisional applications U.S. Ser. No. 60/043,374, filed Apr. 4, 1997, and U.S. Ser. No. 60/075,406, filed Feb. 20, 1998.

FIELD OF THE INVENTION

This invention relates to the field of imaging instruments, and particularly to a retrofocus objective lens system for use in an imaging instrument such as an otoscope.

BACKGROUND OF THE INVENTION

An otoscope is a portable, direct viewing examination instrument that aids in the observance and study of the inner ear canal, including the tympanic membrane. Many otoscopes are presently known, each typically having a housing including a frusto-conical head portion and specula capable of being placed a predetermined distance within the ear canal of a patient. The interior of the housing includes an optical viewing system, as well as an illumination system for providing light in a coaxial manner with the viewing system. In use, the optics permit viewing using an eyepiece attached to a proximal end of the housing.

With the advent of "telemedicine", videoized versions of medical examination instruments, including otoscopes, have been developed, such as those described in U.S. Pat. No. 5,363,829 issued to Lankford; U.S. Pat. No. 5,239,984, issued to Cane, et al; and U.S. Pat. No. 4,947,245, issued to Ogawa, et al. In each of the above, a miniature video camera, such as a CCD or other electronic sensor, is positioned either within the interior of the instrument or adjacently coupled thereto. The electronic sensor includes a light receiving surface or substrate which receives a focused optical image of a target of interest through the optical viewing system. The sensor then converts the optical signal into an electrical signal and subsequently through processing electronics into a monitor-ready video signal.

In order to provide a complete ear examination of a patient, it is desirable that the otoscope include the capability of producing a stream of air for stimulating the tympanic membrane. This feature is known as insufflation.

To provide insufflation capability, the inner tip housing of the otoscope must be sufficiently large enough to accommodate the illumination system, the optical viewing system, and an air path permitting insufflation.

In addition, and though the ear canal is a relatively small chamber, it is also desirable to provide a sufficient field of view to allow the entirety of the tympanic membrane (approximately 8 mm) to be viewed at one time during an examination. In the past, videoized versions of otoscopes have utilized relay lens systems to achieve this goal.

Several attempts to attach a video camera to a standard otoscope have proved less than successful due to compromises in field size, vignetting (clipping) and lack of video lens interchangeability. In addition, the lens elements must be under three millimeters in diameter in order to fit inside the specula tip of the otoscope.

In order to achieve the relatively long total conjugate length (approximately 99 mm) of a video otoscope, While maintaining the small element diameters (under 3 mm) required, the resulting optical system tends to be complex.

Most of these lens systems **126** are composed of some form of objective means in the distal portion **122** of the otoscope, followed by one or more relay configurations. This type of system has many disadvantages based upon to its overall complexity, therefore producing greater likelihood of manufacturing errors, and requiring a plurality of intermediate imaging planes **138**, as shown in FIG. **1**. The intermediate image planes **138** are necessitated by the relay configurations and are subject to cosmetic issues.

As shown in FIG. **1**, these known lens systems include a number of axially disposed optical elements which transmit the optical signal through a series of intermediate image planes located between the target plane **140** and the image substrate **134** of a miniature video camera along an axis **130**.

For a normally constructed objective lens system, the object and image plane conjugates are essentially in proportion to the system magnification, or more specifically to the ratio of M and 1/M, in which M is the system magnification. By knowing the desired magnification, (1:1), (1:2), etc., it is straight forward to calculate the total conjugate length (the distance from the object to image) for any focal length. Similarly, the focal length required to achieve a desired total conjugate length is also easily calculated.

It is readily known that an objective lens system operating at unit magnification (1:1) is normally located equidistant from the object and image planes. For an objective lens system to operate at a reduction of 0.5 (1:2), the object conjugate must normally be twice that of the image conjugate.

Most often undesirable or unattainable objective positions are produced with the lens systems typically employed in many videoized instruments, including otoscopes. It is desirable to produce a system that allows for the placement of the objective lens at a more favorable location.

SUMMARY OF THE INVENTION

Therefore, it is an object of the present invention to provide a viewing system for an imaging instrument which overcomes the disadvantages of the prior art.

It is another primary object of the present invention to provide an imaging instrument having an optical viewing system that does not include any intermediate imaging planes.

Another object of the invention is to provide an optical system for a diagnostic instrument such as an otoscope which provides adequate spacing to allow viewing while still allowing permitting incorporation of insufflation or other features.

It is yet another object of the invention to provide an improved objective lens system for an imaging instrument, particularly an instrument requiring small diameter lenses.

Therefore, and according to a preferred aspect of the present invention, there is provided a retrofocus objective lens system for an imaging instrument, comprising;

a first group of optical elements positioned at a distal portion of said system;

a second group of optical elements proximally spaced from said first optical element and aligned along an optical axis; and

a single imaging plane disposed along said optical axis proximal to said first optical element and said plurality of intermediate optical elements, wherein said first group of optical elements includes at least one lens component, said at least one lens component having negative optical power, and said second group of

optical elements including a plurality of elements having an aggregate optical power which is positive and wherein an image of a target viewed by said system is focused only at the imaging plane.

Preferably, the first group of optical elements is defined by a single small diameter negative lens, the diameter in fact being smaller than its corresponding focal length. The second group of optical elements includes a combination of positive and negative lens having an overall or aggregate positive optical power which allows an image transferred through the system to be focused only at the single image plane, preferably onto the imaging substrate of a suitably positioned electronic sensor.

According to a preferred embodiment, the second group of optical elements includes a plurality of lenses including respective second, third, and fourth lens components. Preferably, the second lens and fourth lenses are positive, and the third lens is a doublet containing a negative lens contiguous with a positive lens and having an overall or aggregate optical power which is negative. An aperture stop of convenient size is suitably positioned between the first and second lenses according to this design.

In an alternative embodiment, the second optical group includes a second positive lens, a third lens proximally spaced relative to the second lens, a fourth lens proximally spaced relative to the third lens, and a fifth lens proximally spaced relative to the fourth lens. In this system design, the second and fifth lenses are positive, and the fourth lens element is a doublet containing a negative lens contiguous with a positive lens such that the aggregate optical power of the doublet is negative. The aperture stop, according to this system design, is positioned between the second and third lenses.

According to another preferred aspect of the present invention, there is provided an otoscope having a retrofocus objective lens system for reducing an object onto a single image plane, said lens system comprising:

- a first group of optical elements positioned at a distal portion of said system;
- a second group of optical elements proximally spaced from said first group of optical elements and aligned along an optical axis;
- a single imaging plane disposed proximally from said second group wherein an image of a target of interest is transmitted through said system without intermediate imaging planes.

In a preferred embodiment, each group of optical elements is disposed in a lens tube or cell retained within an instrument housing. More preferably, the elements used in the objective lens system are sized such that coaxial illumination and insufflation features can be included in an otoscope without interfering with the viewing of an object through the objective lens system.

According to yet another embodiment there is described an otoscope comprising a housing including a distal tip opening, an imaging element disposed in relation to a proximal end of said housing; and an optical system disposed within said housing and aligned between said distal tip opening and said imaging element, wherein said optical system contains focussing means for focussing an optical image of a target of interest at said imaging element without any intermediate imaging planes between said target and said imaging element. Preferably, the otoscope includes illumination means for illuminating the target of interest through the distal tip opening and insufflation means for stimulating the tympanic membrane, each being disposed in the housing without interfering with the functions of the optical system.

An advantageous feature of the present invention is that a retrofocus lens system, as described, produces desirable objective positions and includes a long overall length using small diameter lens elements, yet produces minimal distortion and minimal vignetting, making this system ideal for an imaging instrument such as an otoscope.

A further advantage is that the above optical system can be suitably arranged in an instrument housing of compact size without compromising the ability to provide other needed instrument features, such as insufflation in the case of an otoscope.

These and other objects, advantages, and features will be described in the following Detailed Description of the Invention which should be read in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a partial sectional view of an otoscope having an optical viewing system according to the prior art, including a partial ray trace of a target object as transmitted through the system;

FIG. **2** is a diagrammatic view of an optical viewing system in accordance with a preferred embodiment of the present invention illustrating the transmission of a chief ray relative to the optical axis of the system;

FIG. **3** is the ray trace diagram of FIG. **2**, illustrating a bundle of rays through the optical viewing system relative to the optical axis;

FIG. **4** is a sectional view of the optical viewing system of FIGS. **2** and **3** as contained within a lens cell in accordance with a preferred embodiment of the invention;

FIG. **5** is an enlarged partial sectional view of an otoscope having the contained optical viewing system of FIG. **4**;

FIG. **6** is a sectional view of FIG. **5**, further indicating the combination of insufflation and illumination with the optical viewing system of FIGS. **2–5**;

FIG. **7** is a partial front perspective view of an otoscopic head including a modified insufflation feature; and

FIG. **8** is a side partial view of a compact otoscopic head having the optical system of FIGS. **2–6** as used in combination with a hand-held multimedia instrument.

DETAILED DESCRIPTION OF THE INVENTION

The following discussion describes an optical viewing system according to a specific embodiment for use with a specific medical examination instrument, i.e.: an otoscope. As will be apparent from the following discussion, however, there are other suitable applications for an optical viewing system embodying the concepts described herein. That is, the described objective lens system can be used in other medical (endoscopic) and/or non-medical (such as borescopic) applications involving the examination of cavities having narrow or shaped openings.

Reference is now made to FIGS. **2–6** which relates to an optical viewing system **12** in accordance with the present invention. Referring first to FIGS. **2** and **3**, the viewing system **12** is shown diagrammatically. A first lens **40** is disposed at the distal end of the system **12**. A key feature of the present invention is that the first lens **40** is a negative lens of suitable power which is aligned along a system viewing axis **32**. An aperture stop **50** is disposed proximally from the first lens **40** and is aligned therewith along the viewing axis **104**. A second lens **52** is disposed somewhat adjacently and proximally from the aperture stop **50**. According to the

present embodiment, the second lens **52** is a positive lens. A third lens **58** in the form of a doublet is disposed proximally from the previously described elements **40**, **52** at a predetermined distance followed by a fourth positive lens **60**, each also aligned with the viewing axis **32**.

As shown in FIGS. **2** and **3**, a chief ray **25**, FIG. **2** or bundle of rays **27**, FIG. **3**, entering the system from a target plane **29** are first directed through the negative lens **40** which diverges the light and fills the aperture stop **50**. Light emerging the aperture stop **50** passes through the second lens **52** having sufficient power to partially converge the light which then passes to the doublet **58** having an aggregate negative power which further diverges the light transmitted to the fourth positive lens **60** which essentially collimates the light until the light is focused at the imager **106**. There are no intermediate imaging planes. In use, an optical signal is channeled through each of the above disposed optical elements and is ultimately focused at the imaging substrate of the imager **106**.

Referring to FIGS. **4–6**, the objective system **12** of the invention is shown in use within an otoscopic instrument head **10**. Referring to FIG. **5**, the illustrated otoscopic instrument head **10** includes a substantially cylindrically shaped proximal housing portion **14**, an intermediate housing portion **16**, and a frusto-conical distal insertion portion **18**. The distal insertion portion **18** has a defined interior which includes overlapping and conically shaped inner and outer tip housings **20**, **22**, each tip housing having a respective distal tip opening **24**, **26** coaxially arranged along a defined optical axis **32**. The inner tip housing **20** extends distally from the tip opening **26** of the outer tip housing **22**. A hollow safety speculum **28**, preferably made from a plastic material and having a distal tip opening **30**, is mounted onto the conical periphery of the distal insertion portion **18**, also in overlapping relation. Each of the distal tip openings **24**, **26**, **30** are coaxial with one another along the optical axis **32**, the tip openings of the mounted speculum **28** and the distal insertion portion **18** being slightly displaced from the tip opening **24** of the inner tip housing **20**.

An illumination assembly **63** includes a miniature halogen lamp **64** which is disposed within the proximal housing portion **14**. Light from the halogen lamp **64** is directed to one end of a bundle of optical fibers **82** (partially shown), the fibers being fanned out into a first annular space **84** formed between the exterior portion of a series of interconnected lens tubes **34**, **36**, **38** supporting the viewing system **12** and the interior wall of the inner tip housing **20** so as not to interfere with the transmission of optical data through the lens tubes. The bundle of fibers **82** terminate at the distal tip opening **24** of the inner tip housing **20**, preferably as a polished light emitting end **110** which is coterminous with a first lens tube **34**, as described below.

As noted, the safety speculum **28** is releasably attached to the exterior of the front insertion portion **18**. A preferred attaching arrangement is described in commonly owned U.S. Pat. No. 4,380,998 issued to Kieffer, et al, the entire contents of which are herein incorporated by reference. The instrument head **10** is locked into engagement with the front interface **170** of the instrument, as shown in FIG. **8**.

As noted above, the above lens system **12** is disposed within the series of interconnected lens tubes **34**, **36**, **38**, each coaxially arranged within the interior of the instrument head **10** along an optical axis **32**. The first lens **40** is disposed in a first lens tube **34** adjacent the distal opening **24** of the inner tip housing **20** along with a plano glass section **42**, preferably disposed directly in front of the first lens **40**.

Preferably, the interior wall of the first lens tube **34** defines a shoulder **44** for supporting and positioning the adjacent elements **40**, **42**. The proximal end **46** of the first lens tube **34** is wider than that of the remainder of the tube and is sized for receiving the distal end **48** of an attached second lens tube **36**. The aperture stop **50** and the second lens **52** are each retained within the widened proximal end **46** of the first lens tube **34** prior to the distal end **48** of the second lens tube **36**. The aperture stop **50** provides the proper direction of the image through the objective, limits the distortion of the image, and limits vignetting at the full field position. The second lens **52** is a positive lens of sufficient power. A proximal end of the second lens tube **36** is retained within a cavity **54** of the distal end **56** of a third lens tube **38**, wherein a third lens **58** is attached at the proximal end of the second lens tube **36**. According to this embodiment, the third lens **58** is a doublet containing respective concave and convex lenses of an appropriate size. The third lens **58**, preferably having an overall or aggregate negative optical power provides a large dispersion and is used to provide color correction to the image.

Finally, and according to this particular system design, the fourth lens **60** is provided and disposed in a cavity **62** at approximately the midpoint of the length of the third lens tube **38**. As noted above, the fourth lens **60** is preferably of positive optical power and functionally takes collimated parallel light arriving from the third lens **58** and focuses the light down to the imager **106**, providing for correction of the direction of the image.

It should be readily evident that the fourth lens **60** could alternately be disposed within a pilot section (not shown) of the instrument **174**.

As should be apparent from the design of the above system, there are no intermedia image planes thereby defining a retrofocus objective lens system. The lens system has an overall fixed length, a fixed focal length, and a fixed magnification.

The defining characteristics of the lens system, such as the focal length, are adjustable by changing the position of the first lens tube **34** in relation to the second lens tube **36**.

Specifics for the design of the above system **12** are provided in Table I and the parameters of the lens elements are provided in Table II.

TABLE I

Overall length of lens system (TCL)	82.78 mm
Focal Length of lens system (EFL)	10.076 mm
Back focal length of lens system (BFL)	36.432 mm
Lens diameters (distal end)	less than 3 mm
Total conjugate distance (distance from target plane to image plane)	98.78 mm
Distortion	less than 5%
Vignetting (at full field position)	less than 20%
Magnification	0.5
Field of view	8.3 mm
Target distance	16 mm

TABLE II

Optical Element	Radius	Material	Thickness
Plano Glass	Plano	BK7	1.0000
First Lens Element	−3.101	BK7	0.7500
	3.101		
	Concave		

TABLE II-continued

Optical Element	Radius	Material	Thickness
Second Lens Element	19.7350 −7.226 Convex	BK7	1.0000
Third Lens Element Doublet	−8.7590 Concave	BK7	1.0000
	−2.9700 −7.4700 Convex	F2	0.7500
Fourth Lens Element	−13.332 Concave −8.3670 Convex	BK7	1.0000

The aperture stop **50** limits the distortion to under 5% and vignetting to under 20% at the full field position. The lens system achieves a magnification of 0.5 reduction for an object having a diameter (field of view) of 8.3 mm and positioned at an object or target distance of 16 mm from the piano glass section **42**.

It should be readily apparent to one of sufficient skill in the field that it is possible to vary the position of at least some of the lens elements or alternately add lens elements to the above retrofocus objective lens system design and achieve the desired results.

For example, and as shown in phantom in FIG. **4**, a fifth lens **49** can be added to the above system and positioned between the first lens **40** and the aperture stop **50** in the first lens tube **34**. Moreover, it is also possible to selectively vary the position of certain elements in the described system depending on the optical distance. For example, by adjusting the separation between lenses **40** and **52**, by up to approximately 0.35 mm, the optical working distance can be varied from 16 mm to infinity.

Referring to FIG. **6**, an insufflation port **88** is provided in the intermediate housing portion **16**, the port being adequately sized to receive a fitting (not shown). The insufflation port **88** defines one end of a passageway extending into the interior of the distal insertion portion **18**. The fitting allows a known depressible pneumatic bulb (not shown) to be connected thereto for directing air (or creating a vacuum) through the path **92** which is defined through an opening of an interior wall **94** into a second annular space **96** between the inner and outer tip housings **20**, **22**. The air passes through the annular space and exits the distal tip opening **26** of the outer tip housing **22** into a third annular space **98** defined between the inner tip housing **20** and the interior of the safety speculum **28**. The directed air exits through the distal tip opening **30** of the safety speculum **28**. A rear wall **100** according to this embodiment acts to seal the assembly, to prevent air from passing through the rear portion of the instrument head, while the mounted safety speculum **28** assists in preventing air leakage other than through the distal tip opening **30**.

In use, the target of interest (e.g., the interior of the ear canal) is viewed by the instrument by placing the front insertion portion **18** into an ear canal (not shown) of interest, placing the tympanic membrane (not shown) approximately 16 mm away from the negative lens **40**. The retrofocus objective lens assembly **12** through the aligned tip opening **30**, **24** projects an optical image of the target (approximately 8 mm in size) along the optical viewing axis **32**, FIG. **2**, ultimately focusing the image onto the imager **106**, FIG. **2**.

Insufflation can be further achieved in the manner shown in FIG. **8**, wherein the outer tip housing **22** includes a predetermined number of flattened areas **80** provided on the outer periphery thereof. Other variations can easily be imagined.

PARTS LIST FOR FIGS. **1–8**

10 instrument head
12 objective lens system
14 housing portion
18 insertion portion
20 inner tip housing
22 outer tip housing
24 tip opening
25 chief ray
26 tip opening
27 bundle of rays
28 speculum
29 target plane
30 distal tip opening
32 optical axis
34 first lens tube
36 second lens tube
38 third lens tube
40 first lens
42 plano glass section
44 shoulder
46 proximal end
48 distal end
50 aperture stop
52 second lens
54 cavity
56 distal end
58 third lens
60 fourth lens
62 cavity
63 illumination assembly
64 halogen lamp
80 flattened areas
82 optical fiber bundle
84 first annular space
88 insufflation port
92 path
94 interior wall
96 annular space
98 third annular space
100 rear wall
106 imager
110 polished end
122 distal portion
126 viewing system
130 axis
134 image substrate
138 intermediate imaging planes
140 target plane
170 front interface

While the foregoing description and drawings represent the preferred embodiments of the present invention, it will be understood that various changes and modifications may be made without departing from the spirit and scope of the present invention.

We claim:

1. An otological imaging instrument for viewing an ear interior, said instrument comprising:

an instrument housing including a frusto-conical insertion portion at a distal end thereof;

an electronic imager disposed in a proximal end of said instrument housing opposite said distal end;

illumination means disposed within said insertion portion for illuminating the interior of the ear for viewing; and

a retrofocusing lens system for reducing an object onto said proximally disposed imager at a single imaging plane located at said proximally disposed imager without the need of intermediate imaging planes and rod lenses, said retrofocusing lens system including a plurality of optical elements housed within a plurality of linearly interconnected lens tubes retained within said instrument housing, at least one of said lens tubes being linearly adjustable in relation to the remaining lens tubes in order to vary the focal length of the lens system, said plurality of optical elements including a first group of optical elements positioned within the frusto-conical insertion portion of said instrument housing opposite from said proximal end and a second group of optical elements disposed proximally from said first group, said first and second groups being aligned along an optical axis and in which said first group includes at least one first negative lens and said second group includes a plurality of lenses having an aggregate positive optical power.

2. The instrument as recited in claim **1**, wherein said illumination means includes a plurality of optical fibers having distal light-emitting ends which are substantially coterminous with said first group of optical elements.

3. The instrument as recited in claim **2**, wherein at least one lens tube and an interior wall of said insertion portion define a first annular space.

4. The instrument as recited in claim **3**, wherein said plurality of optical fibers extends through said first annular space.

5. The instrument as recited in claim **1**, wherein said second group of optical elements includes a second lens, a third lens spaced proximally relative to said second lens, and a fourth lens spaced proximally relative to said third lens, each of said second and said fourth lenses being positive lenses.

6. The instrument as recited in claim **5**, wherein said third lens is a doublet containing a negative lens contiguous with a positive lens, said doublet having a negative aggregate optical power.

7. The instrument as recited in claim **1**, wherein said first group of optical elements is retained within a first lens tube of said interconnected lens tubes.

8. The instrument as recited in claim **7**, wherein said first lens tube is linearly adjustable relative to an adjacent second lens tube so as to adjust the relative focal length of said retrofocusing lens system.

9. The instrument as recited in claim **8**, wherein said first lens tube includes a widened proximal end which is sized to receive a distal end of said second lens tube in overlapping engagement therewith and allowing relative linear adjustment of each of said first and second lens tubes so as to adjust the relative focal length of said retrofocusing lens system.

10. An instrument as recited in claim **9**, wherein said plurality of interconnected lens tubes includes a third lens tube, said third lens tube having a cavity for receiving a proximal end of said second lens tube in overlapping engagement therewith.

11. An instrument as recited in claim **8**, wherein said plurality of interconnected lens tubes includes a third lens tube, said third lens tube having a cavity for receiving a proximal end of said second lens tube in overlapping engagement therewith.

12. The instrument as recited in claim **1**, including an aperture stop disposed between said first and second groups of optical elements.

13. The instrument as recited in claim **1**, wherein said second group of optical elements includes a second lens, a third lens spaced proximally relative to said second lens, a fourth lens spaced proximally relative to said third lens, and a fifth lens spaced proximally relative to said fourth lens said fifth lens being a positive lens.

14. The instrument as recited in claim **13**, wherein said fourth lens is a doublet containing a negative lens contiguous with a positive lens such that the aggregate sum of optical power of said fourth lens is negative.

15. The instrument as recited in claim **13**, including an aperture stop disposed between said second and said third lenses.

16. The instrument as recited in claim **1**, wherein said distal insertion portion includes an inner tip housing and an outer tip housing, each of said inner tip housing and said outer tip housing being coaxial with said optical axis wherein the interior of said outer tip housing and the exterior of said inner tip housing define a second annular space.

17. The instrument as recited in claim **16**, including insufflation means for stimulating the tympanic membrane, said insufflation means including an insufflation path provided by said second annular space.

18. The instrument as recited in claim **1**, including means for varying the linear distance between the first and second groups of optical elements along said optical axis.

19. The instrument as recited in claim **1**, including insufflation means for stimulating the tympanic membrane through said insertion portion, said retrofocusing lens system being retained within said insertion portion so as not to interfere with the operation of said illumination means and said insufflation means.

20. An otological imaging instrument for viewing an ear interior, said instrument comprising:

an instrument housing including a frusto-conical insertion portion at a distal end thereof;

an electronic imager disposed in a proximal end of said instrument housing opposite said distal end;

illumination means disposed within said insertion portion for illuminating the interior of the ear for viewing; and

a retrofocusing lens system for reducing an object onto said proximally disposed imager;

wherein said retrofocusing lens system includes a first group of optical elements positioned within the frusto-conical insertion portion of said instrument housing opposite from said proximal end and a second group of optical elements disposed proximally from said first group of elements and aligned therewith along an optical axis, said first group of optical elements including at least one negative lens and said second group of optical elements including a plurality of lenses having an aggregate positive optical power,

whereby an optical image is imaged at a single imaging plane located at said proximally disposed imager using said retrofocusing lens system without the need of intermediate imaging planes wherein said distal insertion portion includes an inner tip housing and an outer tip housing, each of said inner tip housing and said outer tip housing being coaxial with said optical axis wherein the interior of said outer tip housing and the exterior of said inner tip housing define a second annular space, said instrument further including insufflation means for stimulating the tympanic membrane, said insufflation means including an insufflation path provided by said second annular space wherein said inner tip housing includes a plurality of circumferentially disposed flattened sections to provide vents for said insufflation means.

* * * * *

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United States Patent [19]

Ohmori

[11] Patent Number: 6,126,334

[45] Date of Patent: Oct. 3, 2000

[54] **CAMERA HAVING INTERCHANGEABLE OBJECTIVE LENS**

[75] Inventor: **Kazuyuki Ohmori**, Kawasaki, Japan

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[21] Appl. No.: **09/102,239**

[22] Filed: **Jun. 22, 1998**

[30] **Foreign Application Priority Data**

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[51] **Int. Cl.**[7] **G03B 19/12**

[52] **U.S. Cl.** **396/354**; 348/342; 348/374

[58] **Field of Search** 348/342, 373, 348/374, 340, 341; 396/355, 429, 354

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Primary Examiner—David M. Gray

Attorney, Agent, or Firm—Robin, Blecker & Daley

[57] **ABSTRACT**

An optical filter, such as a low-pass filter, which is disposed between a photo-taking lens mounted on a mount part of the camera body having an image sensor disposed on an image forming plane and a main mirror disposed within the camera body, is held in position jointly by a holding member fixed to the lower end of a front aperture part of the camera body and an elastic member fixed to the rear side of the holding member with a resilient force applied to the optical filter. In mounting the photo-taking lens on the camera body, when an end part of the photo-taking lens comes to touch the optical filter, the optical filter is allowed to temporarily move to escape from the photo-taking lens and to come back to its original position upon completion of the lens mounting operation.

11 Claims, 7 Drawing Sheets

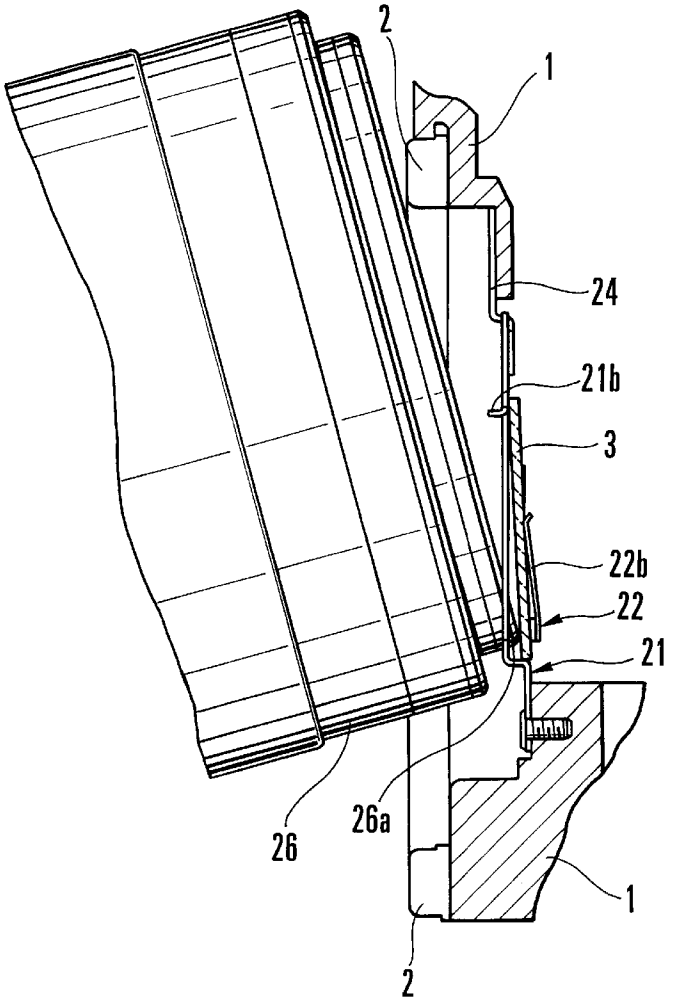


FIG. 1

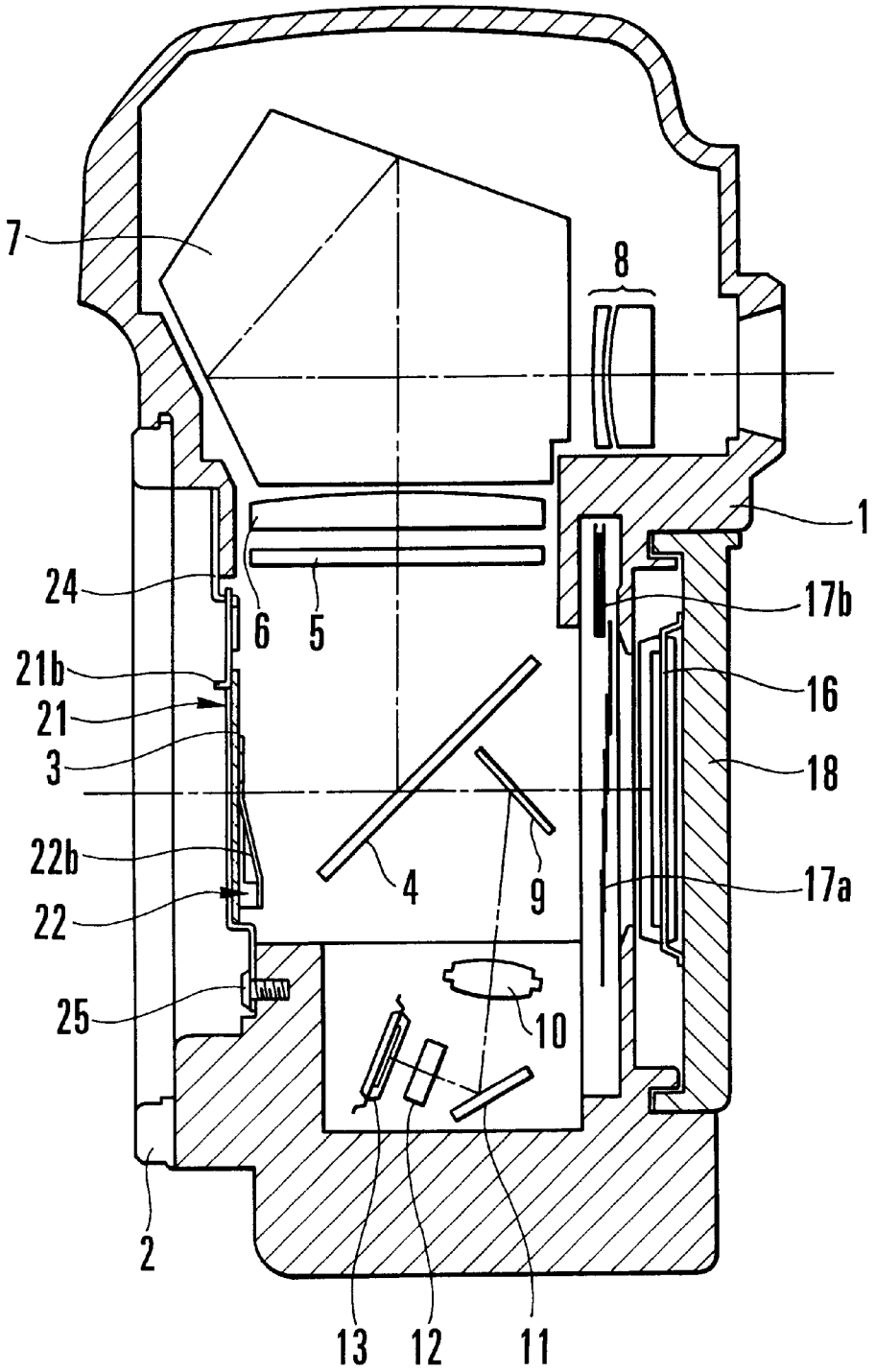


FIG. 2

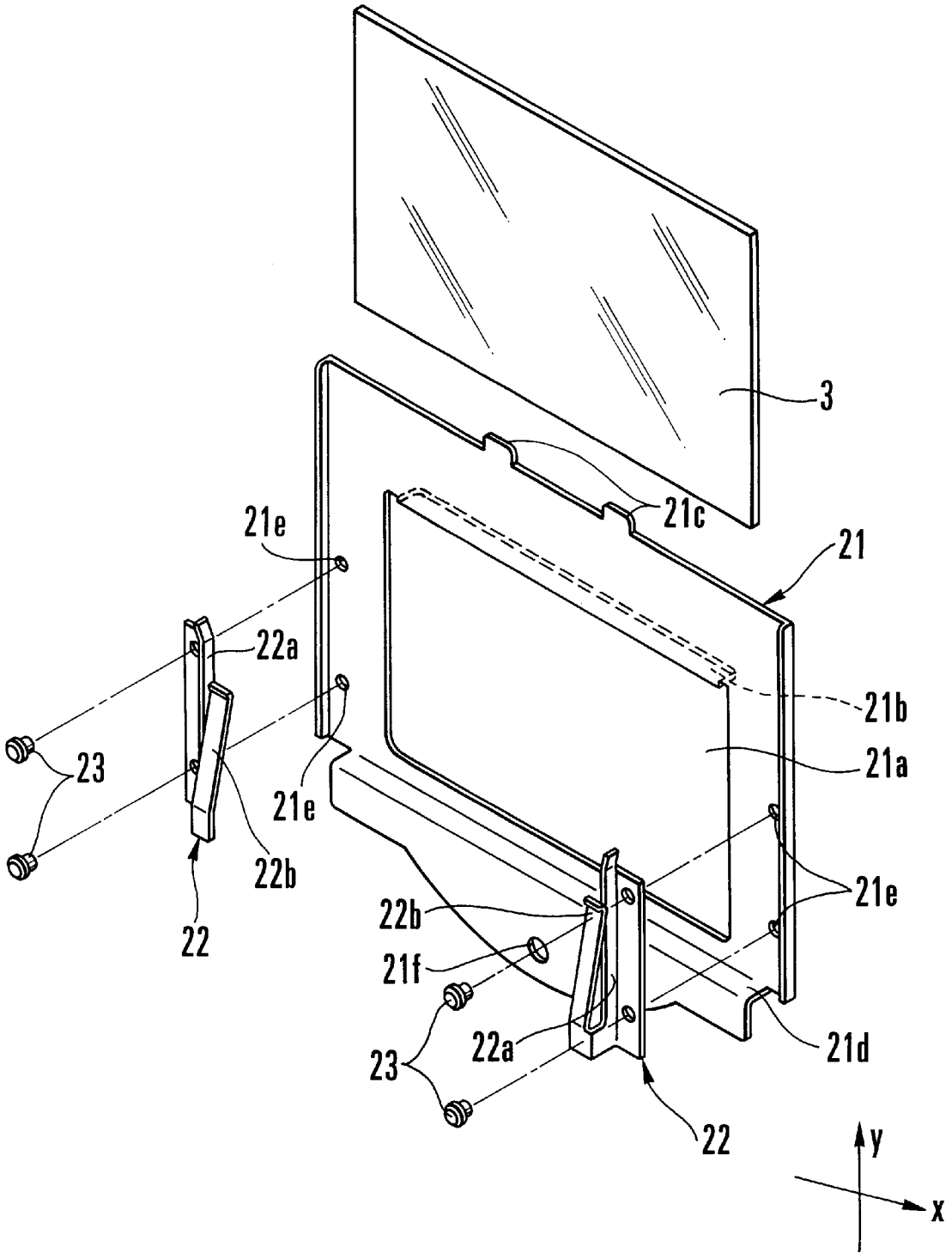
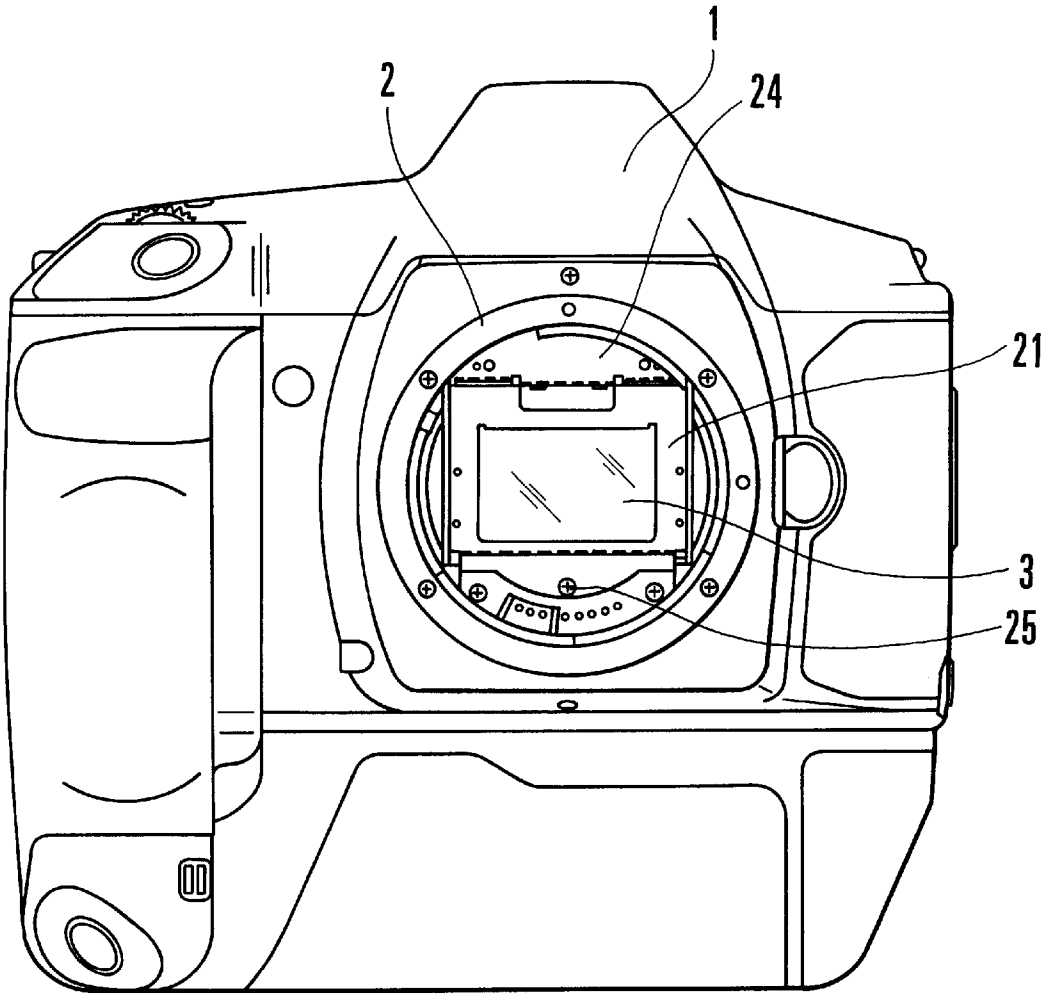


FIG. 3



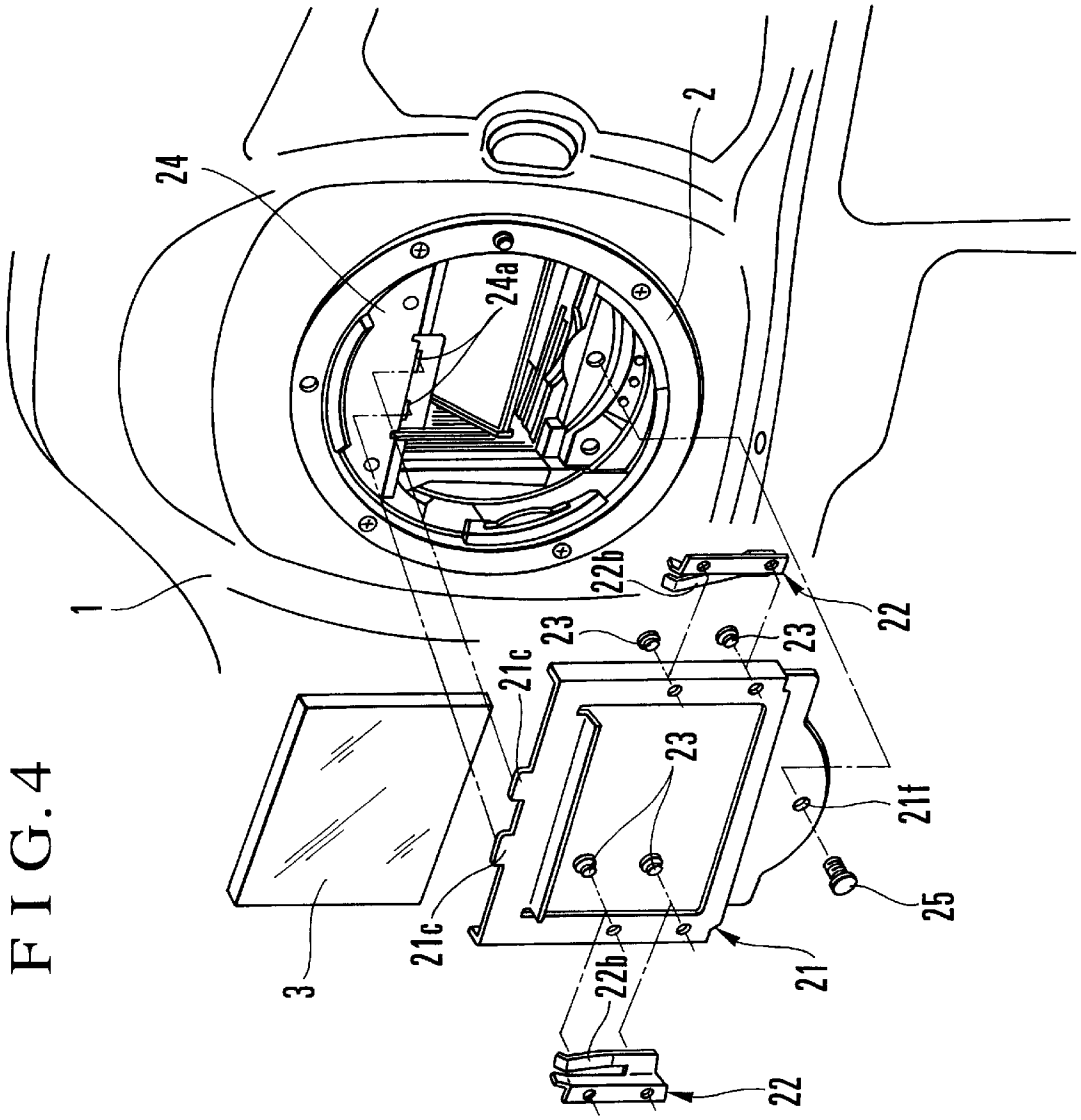


FIG. 4

FIG. 5

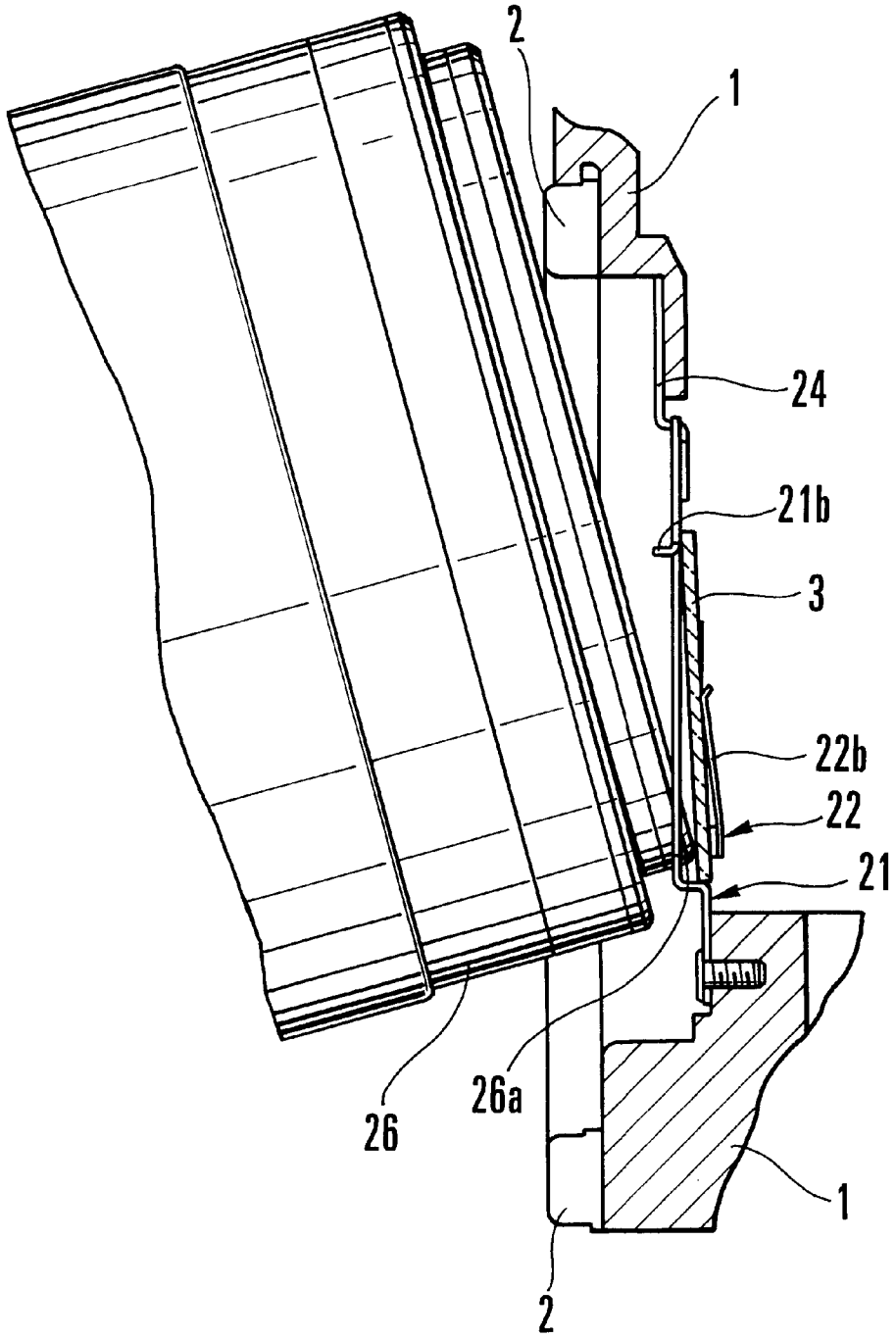


FIG. 6

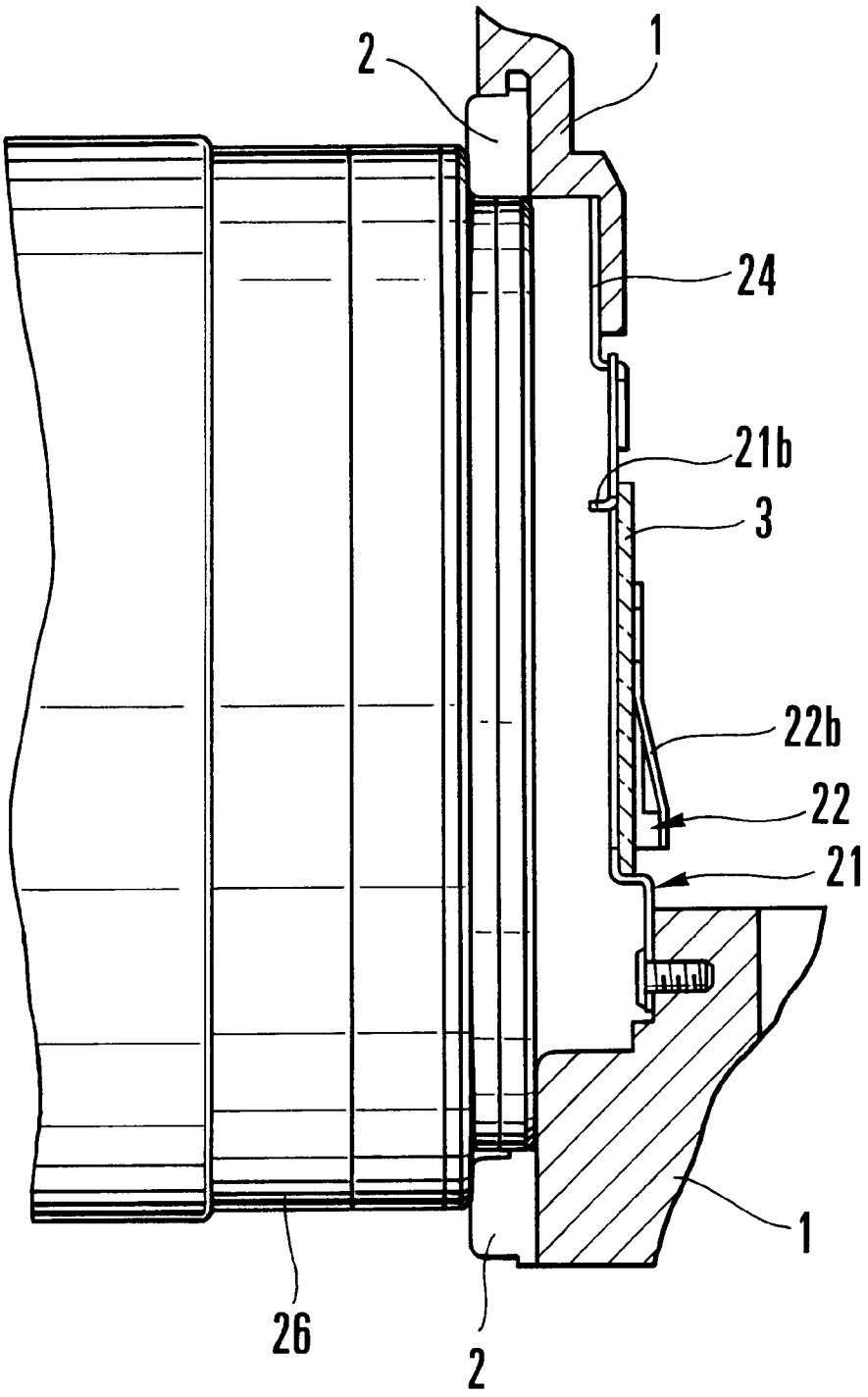
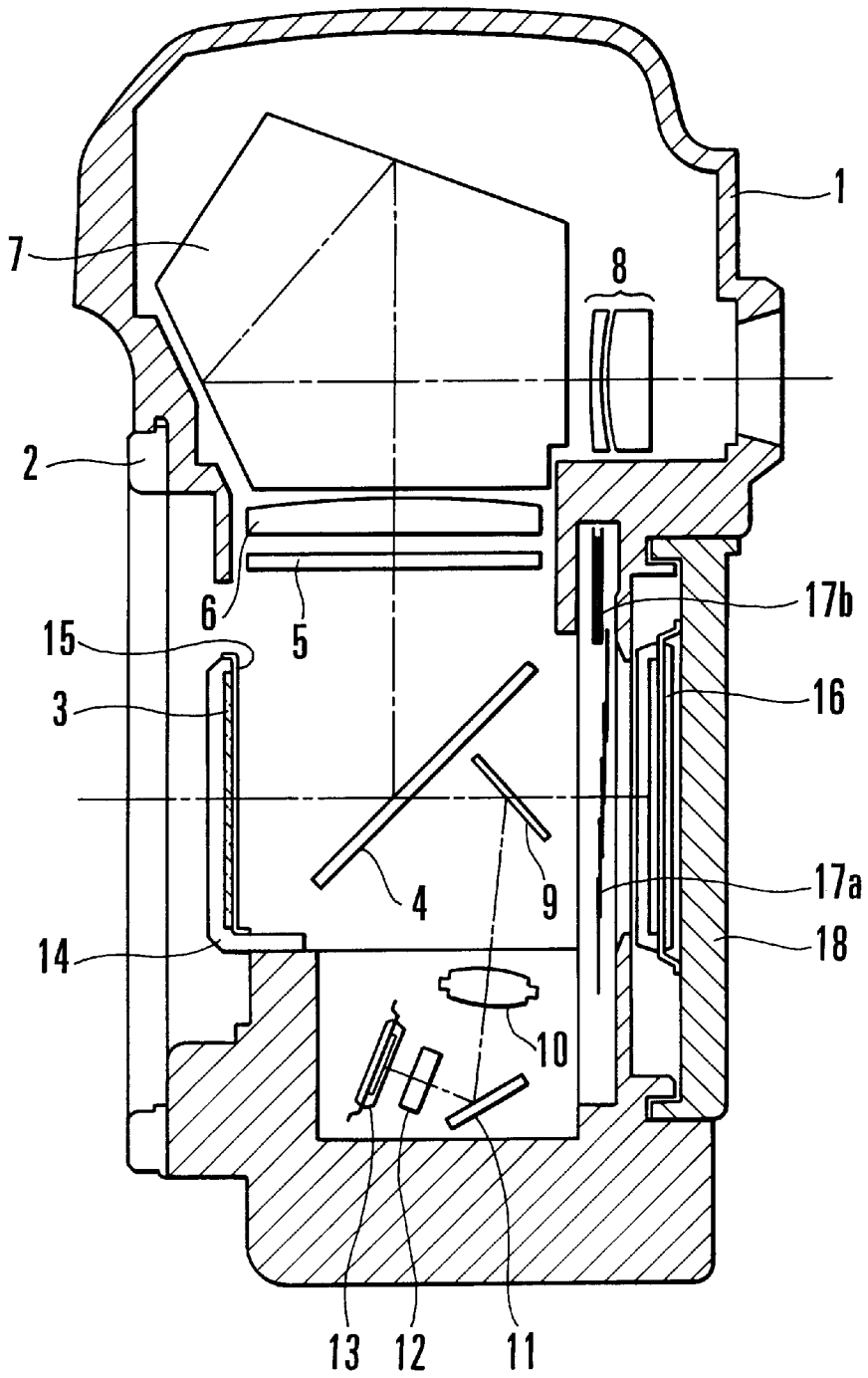


FIG. 7



CAMERA HAVING INTERCHANGEABLE OBJECTIVE LENS

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a single-lens reflex type camera having a solid-state image sensor and arranged to be capable of recording information by using the solid-state image sensor and to permit use of an interchangeable photo-taking lens.

2. Description of Related Art

A number of cameras of the single-lens reflex type having a light flux obtained through a photo-taking lens used both by a viewfinder optical system for observing a photo-taking object and by an image forming system for taking a picture of the object have been developed to use a solid-state image sensor in place of a silver-halide film at an image recording part. However, if accessories used for the conventional single-lens reflex cameras, such as interchangeable lenses, external electronic flash devices, etc., are not usable for the cameras having the solid-state image sensors, it is greatly disadvantageous not only to the users of conventional single-lens reflex cameras but also to the providers of the cameras.

Accordingly, a number of cameras have been variously proposed in which, to provide a camera having a solid-state image sensor without varying the system interchangeability of single-lens reflex cameras, the solid-state image sensor is placed at a focal image forming portion corresponding to the position of the silver-halide film on the base of the conventional silver-halide-film-using single-lens reflex camera.

In the case of such a camera having a solid-state image sensor, a CCD image sensor or the like is used in general. However, such an image sensor has a spectral sensitivity characteristic which requires some correction. To meet this requirement, some optical filters are used in general. These filters include a low-pass filter which is used for avoiding a moire pattern resulting from a relation between the number of pixels of the image sensor and the high spatial frequency of the photo-taking object and for avoiding a spurious color obtained in the case of a color image sensor, and an infrared cut filter for cutting off an infrared component. As disclosed in Japanese Patent Publication No. HEI 4-435, the optical filter can be disposed in a space immediately before a shutter.

However, such a disposition of the optical filter in that space brings about the following two problems.

Firstly, unlike the conventional single-lens reflex camera, the camera of the kind having a solid-state image sensor requires no film replacing action and thus requires no back lid (back cover) arranged to be opened and closed for replacing a film. Therefore, if it is taken into consideration that the work of removing dust attached to the optical filter or replacing the optical filter with another optical filter is performed through a lens-mount opening part of the camera, the existence of a main mirror makes it very difficult to perform that working.

Secondly, since a light flux coming from a photo-taking object is split by the main mirror into light fluxes which are directed respectively toward a viewfinder system and a photo-taking system and, then, only the light flux directed to the photo-taking system passes through the optical filter, a change in optical path length caused by the optical filter takes place only in the photo-taking system. Hence, the optical path length of the viewfinder system must be made

to be equal to that of the photo-taking system either by providing the viewfinder system also with an optical filter or by modifying the design of optical path length of the viewfinder or that of the total optical path length of the photo-taking system. However, such a modification not only necessitates redesign work but also results in an increase in size of the camera.

To solve the above-stated two problems, it has been considered to change the installing position of the optical filter to a position immediately before the main mirror, i.e., immediately behind the photo-taking lens.

Such a change in the installing position of the optical filter solves the above first problem to facilitate the above-stated optical filter cleaning and replacing work, because the optical filter is located immediately behind the lens-mount opening part.

As for the above second problem, since the object light flux is split by the main mirror to the viewfinder system and the photo-taking system after passing through the optical filter, the change in optical path length is equally caused by the optical filter both in the viewfinder system and the photo-taking system. Therefore, a change in the focal image forming position resulting from an increase of the optical path length due to the optical filter can be corrected by just changing the thickness of the mount.

FIG. **7** shows by way of example the arrangement of the conventional single-lens reflex type camera having a solid-state image sensor in which an optical filter is installed immediately before a main mirror. Referring to FIG. **7**, a bayonet mount part **2** is provided at the front surface of a camera body **1**. A photo-taking lens (not shown) is detachably mounted on the mount part **2**. An optical filter **3** which is a low-pass filter or an infrared cut filter is disposed between the mount part **2** and the main mirror **4**. When the user of the camera observes an object image, an object light flux coming through the photo-taking lens passes through the optical filter, so that a spectral sensitivity characteristic of the object light flux is corrected there. After the correction, a part of the object light flux is reflected upward almost at a right angle by the main mirror **4**, which is a half-mirror. The reflected object light flux passes through a focusing screen **5** and a condenser lens **6** to be converted into an erecting image by a vertical and lateral inverting action of an erecting image forming element **7**. The light flux of the erecting image thus obtained is led to the user through an eyepiece lens group **8**. In addition, another part of the object light flux passes through the main mirror **4** and is then totally reflected by a total-reflection submirror **9**. The light flux reflected by the submirror **9** is led to an automatic focusing sensor **13** through an automatic focusing optical system (**10**, **11** and **12**) so as to detect a focusing state of the photo-taking lens.

The optical filter **3** is interposed in between a support member **14** and a fixing plate **15** to be fixed in position perpendicularly to an optical axis and not to become aslant. The support member **14** is mounted, integrally with the optical filter **3**, on the camera body **1** with a screw (not shown).

In taking a shot at an object, the main mirror **4** and the submirror **9** required for the above-stated observation and focus detection are beforehand retracted from the path of the object light flux between an objective lens group of the photo-taking lens and a CCD image sensor **16** serving as a focal plane.

Next, a photo-taking light flux having passed through the objective lens group of the photo-taking lens passes through

the optical filter **3** to have a spectral sensitivity characteristic thereof corrected there. When a fully-open state of shutter leading blades (front curtain) **17***a* is obtained, an image of the photo-taking object is formed on the CCD image sensor **16**, which is mounted from the side of a back lid **18** in a focal image forming position that is about the same as the position of a silver-halide film in a single-lens reflex camera. After the CCD image sensor is exposed to the light of the object image to accumulate it for a predetermined period of time, the light flux of the photo-taking object image is cut off by a closing action of shutter trailing blades (rear curtain) **17***b*. After that, information on the image thus picked up is transferred to be recorded as an image signal on a storage device disposed either within the camera body or outside of the camera body.

The single-lens reflex type camera arranged to have the optical filter mounted immediately before the main mirror as described above, however, has the following problem. Since the main mirror **4** is arranged to be retracted upward at the time of an exposure, the size of a flange back part must be increased for the purpose of preventing the main mirror **4** from interfering with the optical filter **3**. This increase causes an increase in size of the camera.

This problem may be solved by arranging the main mirror **4** in a smaller size to prevent the main mirror **4** from interfering with the optical filter **3**.

However, in mounting a photo-taking lens on the above-stated camera having a solid-state image sensor, the base of which is the conventional single-lens reflex camera using a silver-halide film, an end part of the photo-taking lens tends to damage, or might break, the surface of the optical filter if the end part of the photo-taking lens comes to touch the optical filter. This problem still remains to be solved.

BRIEF SUMMARY OF THE INVENTION

The invention is directed to the solution of the above-stated problem. It is, therefore, an object of the invention to provide a camera having a solid-state image sensor, in which an optical filter is prevented from being damaged by a mounting or demounting operation on a photo-taking lens and is easy for maintenance work.

To attain the above object, in accordance with an aspect of the invention, there is provided a camera having a solid-state image sensor, in which an optical filter is disposed between a photo-taking lens and a main mirror and the optical filter is held by a support member which supports the optical filter and an elastic member which pushes the optical filter against the support member.

The above and other objects and features of the invention will become apparent from the following detailed description of a preferred embodiment thereof taken in connection with the accompanying drawings.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING

FIG. **1** is a vertical section view of a camera having a solid-state image sensor according to an embodiment of the invention.

FIG. **2** is an exploded perspective view showing an optical filter unit of the camera.

FIG. **3** is a front view of the camera with a photo-taking lens demounted.

FIG. **4** is a perspective view showing the manner of fixing the optical filter unit to the camera body.

FIG. **5** is a sectional view showing essential parts of the camera during the process of mounting the photo-taking lens on the camera body.

FIG. **6** is a sectional view showing essential parts of the camera at the time of completion of mounting the photo-taking lens on the camera body.

FIG. **7** is a vertical section view of the conventional camera having a solid-state image sensor.

DETAILED DESCRIPTION OF THE INVENTION

Hereinafter, a preferred embodiment of the invention will be described in detail with reference to the drawings.

FIG. **1** is a vertical section view of a camera having a solid-state image sensor according to the embodiment of the invention. FIG. **2** is an exploded perspective view of an optical filter unit of the camera. FIG. **3** is a front view of the camera with a photo-taking lens demounted. FIG. **4** is an exploded perspective view showing the manner of fixing the optical filter unit to the camera body.

The structural arrangement of the camera having a solid-state image sensor shown in FIG. **1** is the same as that of the conventional camera shown in FIG. **7**, except for the support structure for the optical filter unit. Therefore, the parts of the camera shown in FIG. **1** which are the same as those shown in FIG. **7** are denoted by the same reference numerals as in FIG. **7**, and the details of them are omitted from the following description.

Referring to FIGS. **1** and **2**, a support member **21** is arranged to support an optical filter **3**. The support member **21** is provided with an aperture part **21***a* for restricting the amount of an object light flux coming through the photo-taking lens, and a picking part **21***b* which is formed along the upper edge of the aperture part **21***a* to serve as a knob in mounting and removing the optical filter unit on and from the camera body **1**. Further, the support member **21** is provided with a pair of projections **21***c* and an L-shaped bent part **21***d*, which are formed respectively on the upper and lower edges of the support member **21**. Furthermore, a pair of pin holes **21***e* for receiving caulking pins **23** are formed in the edge part of each of two sides of the support member **21**, and the L-shaped bent part **21***d* is provided with a hole **21***f* for a stop screw **25** which will be described later herein.

Referring to FIGS. **2** and **4**, a pair of elastic members **22** are arranged to push the optical filter **3** against the support member **21** so as to ensure that the optical filter **3** never moves nor comes off when the camera is moved. Each of the elastic members **22** is composed of a restricting part **22***a* and an elastic part **22***b*. The restricting part **22***a* has two faces. One face of the restricting part **22***a* defines the position of the optical filter **3** in the direction of "x" on a plane orthogonally intersecting the direction of an optical axis, while the other face thereof slants outward at the upper end of the restricting part **22***a*. The restricting part **22***a* is thus arranged to guide the optical filter **3** when the optical filter **3** is inserted. The elastic part **22***b* exerts a resilient force to push the optical filter **3** against the support member **21**. The caulking pins **23** are inserted into the pin holes **21***e* of the support member **21** to have the elastic member **22** secured there by caulking.

Referring to FIGS. **3** and **4**, a shield member **24** is fixedly secured to the upper edge side of a front aperture part of the camera body **1**. The shield member **24** has a pair of open parts **24***a* formed in its lower edge part to insert therein the projections **21***c* of the support member **21**. The stop screw **25** is arranged to secure the support member **21** to the lower edge side of the front aperture part of the camera body **1** through the hole part **21***f* provided in the support member **21**.

The optical filter unit having the above structure is assembled and fixed to the camera body **1**, as described below with reference to FIGS. **2** and **4**.

With the elastic member **22** in a state of having been fixed to the support member **21** with the caulking pins **23**, the optical filter **3** is first slid from above in between the support member **21** and the elastic parts **22***b* of the elastic member **22**. The optical filter **3** is thus inserted until the lower end face of the optical filter **3** abuts on the bent part **21***d* of the support member **21**. Thus, the optical filter unit is assembled in the above manner.

Next, the projections **21***c* provided at the upper part of the support member **21** are inserted into the pair of open parts **24***a* of the shield member **24** fixed to the front aperture side of the camera body **1**. Then, the optical filter unit is fixedly secured to the camera body **1** with the stop screw **25** inserted into the lower hole part **21***f* of the support member **21**.

With the optical filter unit thus fixed to the camera body **1**, in mounting a photo-taking lens **26** on the camera body **1** at the bayonet mount part **2**, the optical filter unit acts as follows, as shown in FIGS. **5** and **6**.

As shown in FIG. **5**, in mounting the photo-taking lens **26** on the bayonet mount part **2**, an end part **26***a* of the photo-taking lens **26** comes to touch the surface of the optical filter **3**. Therefore, there arises some force of pushing the optical filter **3** with the photo-taking lens **26**. When this pushing force comes to exceed a certain amount of force, the resilient force of the elastic part **22***b* of the elastic member **22**, which keeps the optical filter **3** in contact with the support member **21**, yields to the pushing force, so that the optical filter **3** slants as shown in FIG. **5**. Accordingly, since the optical filter **3** moves in the direction of escaping from the photo-taking lens **26**, the optical filter **3** is effectively saved from receiving any force that exceeds a predetermined value.

The optical filter **3** thus can be prevented from being damaged or broken by the photo-taking lens **26**.

In this instance, the picking part **21***b* of the support member **21** is located closer to the photo-taking lens **26** than the aperture part **21***a* in the direction of the optical axis and serves to prevent the end part **26***a* of the photo-taking lens **26** from touching the upper half of the surface of the optical filter **3** which extends perpendicular to the optical axis.

Next, the end part **26***a* of the photo-taking lens **26** no longer touches the optical filter **3** after completion of mounting the photo-taking lens on the bayonet mount part **2**. As a result, the optical filter **3** is pushed only by the resilient force of the elastic part **22***b* of the elastic member **22** and is thus allowed to resume its state of abutting on the support member **21**, as shown in FIG. **6**.

As described above, in accordance with the invention, in a camera of the kind having a solid-state image sensor and an interchangeable photo-taking lens with an optical filter disposed between the photo-taking lens and the main mirror, a fixing member for the optical filter is composed of a support member which supports the optical filter and an elastic member which causes the optical filter to abut on the support member with its elastic part. This arrangement allows the optical filter to move in the direction of escaping from the photo-taking lens when the photo-taking lens comes to touch the optical filter in mounting the photo-taking lens on the camera body. Therefore, the photo-taking lens can be mounted on the camera body without damaging or breaking the optical filter. Besides, the arrangement facilitates maintenance work on the optical filter.

Further, according to the arrangement of the embodiment disclosed, the elastic member causes the optical filter to abut on the support member by exerting its resilient force on the side of the second surface of the optical filter located opposite to its first surface which faces the end part of the photo-taking lens in mounting the photo-taking lens. That arrangement ensures that the photo-taking lens can be mounted and demounted without damaging the optical filter, and the optical filter can be promptly set in its predetermined position after the photo-taking lens is mounted.

Further, according to the invention, the optical filter is composed of a low-pass filter or an infrared cut filter. Therefore, the use of the optical filter enables the camera having a solid-state image sensor to take pictures with an excellent picture quality.

What is claimed is:

1. A camera body on which an interchangeable objective lens is mountable, comprising:

a solid-state image sensor disposed in a position where said objective lens forms an image; and

an optical filter disposed within said camera body in facing relation with said objective lens,

wherein said optical filter is mounted so as to be displaceable, as a result of contact with said objective lens during mounting of said objective lens, away from a position where said objective lens is mountable, and so as to move toward said position where said objective lens is mountable during the releasing of said contact.

2. A camera body according to claim **1**, further comprising a mirror arranged between said optical filter and said solid-state image sensor to reflect a light flux coming through said objective lens toward a viewfinder unit.

3. A camera body according to claim **1**, wherein said optical filter is an optical low-pass filter.

4. A camera body according to claim **1**, wherein said optical filter is an infrared cut filter.

5. A camera body according to claim **1**, further comprising a holding member which holds said optical filter, said holding member being fixed to said camera body and being provided with an elastic member for urging said optical filter toward said holding member.

6. A camera body on which an interchangeable objective lens is mountable, comprising:

a solid-state image sensor disposed in a position where said objective lens forms an image; and

an optical filter mounted within said camera body so as to be displaceable, as a result of contact with said objective lens in the course of mounting of said objective lens, away from a position where said objective lens is mountable, and so as to move toward said position where said objective lens is mountable during releasing of said contact.

7. A camera body according to claim **6**, further comprising a holding member which holds said optical filter, said holding member being fixed to said camera body and supporting said holding member for said displacement by said objective lens.

8. A camera body according to claim **7**, wherein said holding member includes an elastic member for returning said optical filter to undisplaced disposition following displacement of said optical filter by said objective lens.

9. A camera body according to claim **6**, wherein said displacement of said optical filter is a slanting movement along an optical axis.

10. A camera body comprising:

a mount for an interchangeable objective lens; and

an optical filter disposed within said camera body in facing relation with said objective lens mount,

wherein said optical filter is mounted so as to be displaceable, as a result of contact with said objective lens during mounting of said objective lens on said objective lens mount, away from said objective lens mount, and so as to move toward said objective lens mount during the releasing of said contact.

11. A camera body comprising:

a mount for an interchangeable objective lens; and

an optical filter mounted within said camera body so as to be displaceable, as a result of contact with said objective lens in the course of mounting of said objective lens on said objective lens mount, and so as to move toward said objective lens mount during release of said contact.

* * * * *

US006101046A

United States Patent [19]

De Winter

[11] Patent Number: 6,101,046

[45] Date of Patent: Aug. 8, 2000

[54] **CYLINDRICAL MOUNT FOR OPTICAL COMPONENTS OF A VARIABLE-POWER OBJECTIVE**

[75] Inventor: **Andrè De Winter**, Penetang, Canada

[73] Assignee: **Leica Camera AG**, Solms, Germany

[21] Appl. No.: **09/384,028**

[22] Filed: **Aug. 26, 1999**

[30] **Foreign Application Priority Data**

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[51] **Int. Cl.**[7] **G02B 15/14**

[52] **U.S. Cl.** **359/699**; 359/695

[58] **Field of Search** 359/694, 699, 359/700, 819, 823, 695

[56] **References Cited**

U.S. PATENT DOCUMENTS

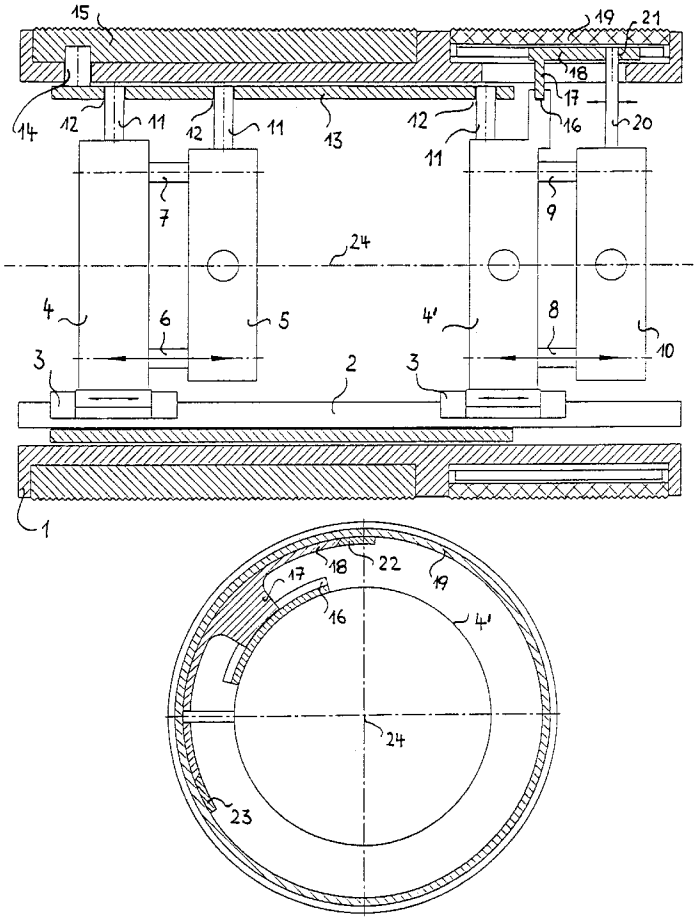
4,993,815	2/1991	Yamazaki et al.	359/699
5,675,444	10/1997	Ueyama et al.	359/824
5,748,390	5/1998	Koiwai et al.	359/811

Primary Examiner—Georgia Epps
Assistant Examiner—Ricky Mack
Attorney, Agent, or Firm—Foley & Lardner

[57] **ABSTRACT**

A cylindrical mount (**1**) for optical components of a variable-power objective, includes an inner straight-line guide (**2**, **3**), with a cam control (**13**) which is capable of being actuated via a rotary ring (**15**) arranged on the outside of the mount and which is intended for the adjustment of carriers, (**4**, **4'**, **5**) for lenses or lens groups relative to one another in order to change the focal length. A further rotary ring (**19**) is provided for adjusting a holder (**10**) for lenses or lens groups for setting the focus of the objective. The holder (**10**) is arranged on a linear guide (**8**, **9**) which is adjustable in the direction of the optical axis (**24**) and which is fastened to a carrier (**4'**) displaceable with the change in focal length. The further rotary ring (**19**) has, on its inner cylindrical surface, a cam carrier (**18**) which is held displaceably in the direction of the optical axis (**24**) on the cylindrical surface. The holder (**10**) has a transmission element (**20**) which is in engagement with the cam carrier (**18**), and the cam carrier (**18**) possesses a guide element (**17**) which points inward in the radial direction and which is in engagement with a guide slot (**16**) arranged perpendicularly to the optical axis (**24**) of the objective on the outer cylindrical surface of the carrier (**4'**).

8 Claims, 1 Drawing Sheet



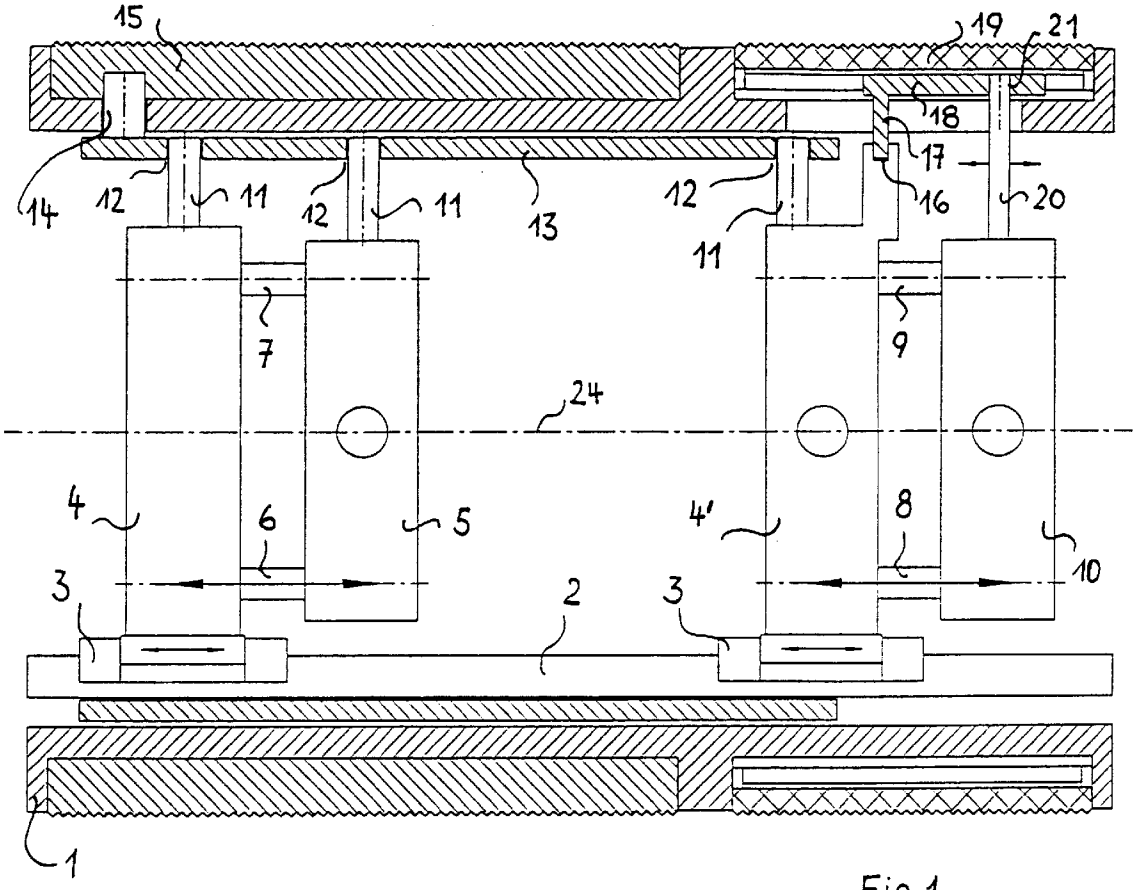

15
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Fig. 1

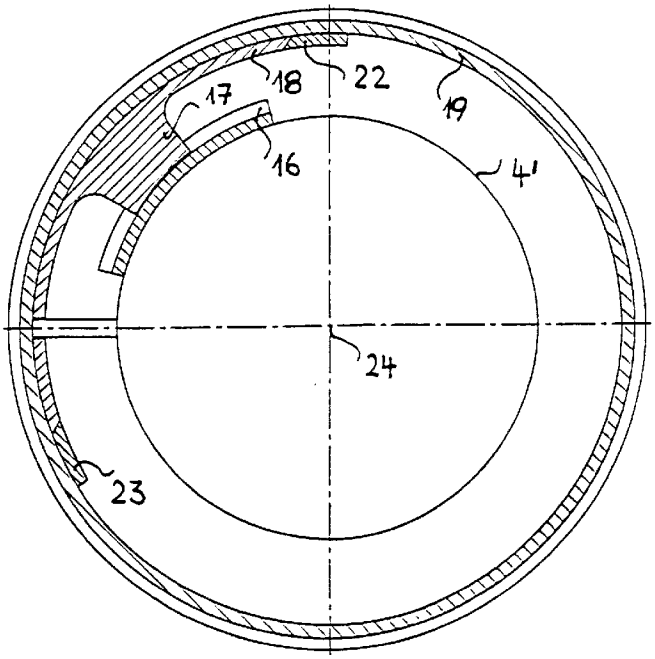
18
22
19
17
16
4'
24
23

Fig. 2

CYLINDRICAL MOUNT FOR OPTICAL COMPONENTS OF A VARIABLE-POWER OBJECTIVE

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention relates to a cylindrical mount for optical components of a variable-power objective.

2. Related Art

Many versions of mounts for variable-power objectives, such as zoom lenses, are known. In them, a plurality of lenses or lens groups are held in different carriers and are displaced relative to one another along the optical axis of the objective in order to change the focal length. Thus, in variable-power (or zoom) objectives, a change in focal length of the objective results in variable magnification of the object in the image plane.

In addition, it is often necessary to displace individual lenses or lens groups in order to set the focus of the objective, which is independent of changing the focal length. A zoom objective in a position of a selected focal length setting should be adjusted or focussed to the correct distance of the object for sharp imaging in the image plane.

As may be gathered, for example, from U.S. Pat. No. 5,675,444, the displacement of the lenses or lens groups relative to one another normally takes place via a cam control which is driven by an outer rotary ring. In this case, the carrier of the lenses or lens groups engages via a pin into the cam track of a rotatably mounted cam carrier and is simultaneously guided in the axial direction in a straight-line guide. U.S. Pat. No. 5,748,390 discloses rod systems for guidance in a straight line, on which the lens carriers run and which are fastened to the mount. Further rod systems may also be fastened to one of the adjustable lens carriers. This ensures that, in the event of displacement, the lenses are not rotated, so as to avoid optical imaging errors due to decentering. It is also known to separate the cam control and the straight-line guide from one another, in which case separate straight-line guide elements for the carriers of the lenses are provided in the mount cylinder.

In the known mounts, the focus setting movement is transmitted via a helical gearing, in which the mount of the lenses or lens components to be displaced is rotated. Depending on the pitch of the driving worm, the angle of rotation is generally not too great, so that any possible imaging errors due to the rotation of the optical surfaces relative to the fixed lens surfaces are often acceptable. However, for example, some sluggishness in the movement of the worm is unavoidable.

Front lens groups, onto which filters and diaphragms are also attached, are frequently used for focussing. In order to use polarizing filters and noncircular diaphragms, it is then necessary to choose a different type of fastening, so that their orientation can be maintained when the focus is being set.

SUMMARY OF THE INVENTION

An object on which the invention is based is, therefore, to provide a device for focus setting, which allows axial adjustment of the lens components without rotation. The focus setting is not to change in the event of a subsequent focal length setting and nevertheless is to be very smooth.

In a cylindrical mount, this object can be achieved, according to one aspect of the present invention, by an inner straight-line guide, with a cam control which is capable of being actuated via a rotary ring arranged on the outside of the mount and which is intended for the adjustment of carriers, for lenses or lens groups relative to one another in order to change the focal length. A further rotary ring is provided for adjusting a holder for lenses or lens groups for setting the focus of the objective. The holder is arranged on a linear guide which is adjustable in the direction of the optical axis and which is fastened to a carrier displaceable with the change in focal length. The further rotary ring has, on its inner cylindrical surface, a cam carrier which is held displaceably in the direction of the optical axis on the cylindrical surface. The holder has a transmission element which is in engagement with the cam carrier, and the cam carrier possesses a guide element which points inward in the radial direction and which is in engagement with a guide slot arranged perpendicularly to the optical axis of the objective on the outer cylindrical surface of the carrier.

Further features of the invention form the subject matter of the claims and will be explained in more detail, in conjunction with further advantages of the invention, with reference to an exemplary embodiment.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the invention, serving as an examples, are illustrated schematically in the drawings, in which:

FIG. **1** shows a longitudinal section through the mount, and

FIG. **2** shows a cross section through the mount.

DETAILED DESCRIPTION OF THE EXEMPLARY EMBODIMENTS

FIG. **1** illustrates a cylindrical mount **1**, for example, for a camera, which has an inner straight-line guide. The straight-line guide comprises a rail **2**, on which ball-mounted slides **3** slide. Fastened to the slides **3** are carriers **4**,**4'**, into which lenses or lens groups, not illustrated, are inserted. A further carrier **5** is displaceably mounted, via ball bearings not illustrated, on the carrier **4** on two rod guides **6**, **7**. For setting the focus, a holder **10** for lenses or lens groups, likewise not illustrated, is displaceably mounted on the carrier **4'** via further rod guides **8**, **9** and ball bearings. The rod guides, located diametrically opposite one another, bring about play-free and extremely smooth straight-line guidance to the carrier **5** and the holder **10**.

The carriers **4**, **4'**, **5** engage, with the pins **11** fastened to them, into cam guides **12** which are milled into a cylinder **13**. The cylinder **13** is connected via a pin **14** to a rotary ring **15** which is rotatably mounted on the mount **1**. When the rotary ring **15** is actuated, the cylinder **13** is co-rotated and, by virtue of the gradient of the milled-in cam guides **12**, transmits said gradient to the carriers **4**, **4'**, **5** as an axial displacement along the rail **2** or the rod guides **6**, **7**, **8**, **9**. Each of the carriers **4**, **4'**, **5** may be provided with its own form of the cam guide **12**, so that each executes its own displacement movement.

Fastened to the outer cylindrical part of the carrier **4'** is a guide slot **16**. Into this engages a guide element which is designed as a flat web **17** and which is fastened to a cam carrier **18**. The cam carrier **18** is held displaceably in the axial direction on the inner cylindrical surface of a further rotary ring **19**. The holder **10** has a pin **20** which is in engagement with a cam track **21** in the cam carrier **18**.

During axial adjustment of the carrier **4'**, via the cam guide **12** assigned to it, in order to change the focal length, carrier **4'** also displaces the holder **10** in the same way by virtue of the axially rigid coupling of the guide slot **16** to the

web **17**, cam carrier **18** and pin **20**. When the rotary ring **19** is actuated only the cam carrier **18** is co-rotated and via the gradient of the cam guide **21** and the pin **20** exerts an axial adjusting force on the holder **10**. In this case, the axial position of the cam carrier **18** is maintained via the web **17** and the guide slot **16**. Rotation of the holder **10** about the optical axis **24** is ruled out by the rod guides **8**, **9**. On account of the smooth movement of the axially adjustable focussing component, a motor drive (not shown) may also be used, instead of the manually actuable rotary ring **19**, so that the solution according to the invention can also be used, in particular, for auto-focus objectives.

FIG. **2** illustrates how the cam carrier **18** is held on the inner cylindrical surface of the rotary ring **19** in two dovetail guides **22**, **23** which extend in the axial direction. Flat web **17**, which slides in the guide slot **16**, is integrally formed on the cam carrier **18**. The guide slot **16** is fastened to the carrier **4'**.

Although the invention has been described above by reference to certain embodiments of the invention, the invention is not limited to the embodiments described above. Modifications and variations of the embodiments described above will occur to those skilled in the art, in light of the above teachings.

German Patent Application No. 198 40 775.0, filed Sep. 7, 1998, including the specification, the drawings, the claims, and the abstract, upon which this application is based, is incorporated herein by reference in its entirety.

What is claimed is:

1. A cylindrical mount for optical components of a variable-power objective, comprising:

an inner straight-line guide having a cam control actuatable using a first rotary ring arranged on an outside of the mount;

a first adjustable carrier for carrying a first optical element; and

a second rotary ring for adjusting a holder of a second optical element for setting a focus of the variable-power objective, wherein said holder is coupled to a linear guide that is adjustable in the direction of an optical axis and which is coupled to a second adjustable carrier for carrying an additional optical element that is displaceable with a change in focal length, wherein said second rotary ring further includes, on its inner cylindrical surface, a cam carrier that is held displaceably in the direction of said optical axis on a cylindrical surface, wherein said holder includes a transmission element in engagement with said cam carrier, and wherein said cam carrier includes a guide element that points inward in a radial direction and which is in engagement with a guide slot arranged perpendicularly to said optical axis on an outer cylindrical surface of said second adjustable carrier.

2. The cylindrical mount according to claim **1**, wherein said first adjustable carrier comprises a plurality of carriers of lenses or lens groups adjustable relative to one another in order to change said focal length.

3. The cylindrical mount according to claim **1**, wherein said guide element is a flat web.

4. The cylindrical mount according to claim **1**, wherein said cam carrier is held in a dovetail guide.

5. The cylindrical mount according to claim **1**, wherein an axial adjustment of said carriers is accomplished without a rotation of said optical elements.

6. A cylindrical mount for optical components of a variable-power objective, comprising:

an inner straight-line guide;

a cam control which is actuatable via a first rotary ring arranged on the outside of the mount and which is intended for the adjustment of first, second and third carriers for lenses or lens groups relative to one another in order to change the focal length; and

a second rotary ring for adjusting a holder for lenses or lens groups for setting the focus of the objective, wherein the holder is arranged on a linear guide which is adjustable in the direction of the optical axis and which is fastened to the second carrier displaceable with the change in focal length, the second rotary ring has, on its inner cylindrical surface, a cam carrier which is held displaceably in the direction of the optical axis on the cylindrical surface, the holder has a transmission element which is in engagement with the cam carrier, and the cam carrier possesses a guide element which points inward in the radial direction and which is in engagement with a guide slot arranged perpendicularly to the optical axis of the objective on the outer cylindrical surface of the second carrier.

7. The cylindrical mount as claimed in claim **6**, wherein the guide element arranged on the cam carrier is a flat web.

8. The cylindrical mount as claimed in claim **6**, wherein the cam carrier displaceable in the direction of the optical axis is held in a dovetail guide.

* * * * *

US006072634A

United States Patent [19]

Broome et al.

[11] **Patent Number: 6,072,634**

[45] **Date of Patent: Jun. 6, 2000**

[54] **COMPACT DIGITAL CAMERA OBJECTIVE WITH INTERDIGITATED ELEMENT ALIGNMENT, STRAY LIGHT SUPPRESSION, AND ANTI-ALIASING FEATURES**

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[73] Assignee: **Intel Corporation**, Santa Clara, Calif.

[21] Appl. No.: **08/980,658**

[22] Filed: **Dec. 1, 1997**

[51] **Int. Cl.**[7] **G02B 27/14**; G02B 27/10

[52] **U.S. Cl.** **359/637**; 359/627; 359/635

[58] **Field of Search** 359/637, 627, 359/635

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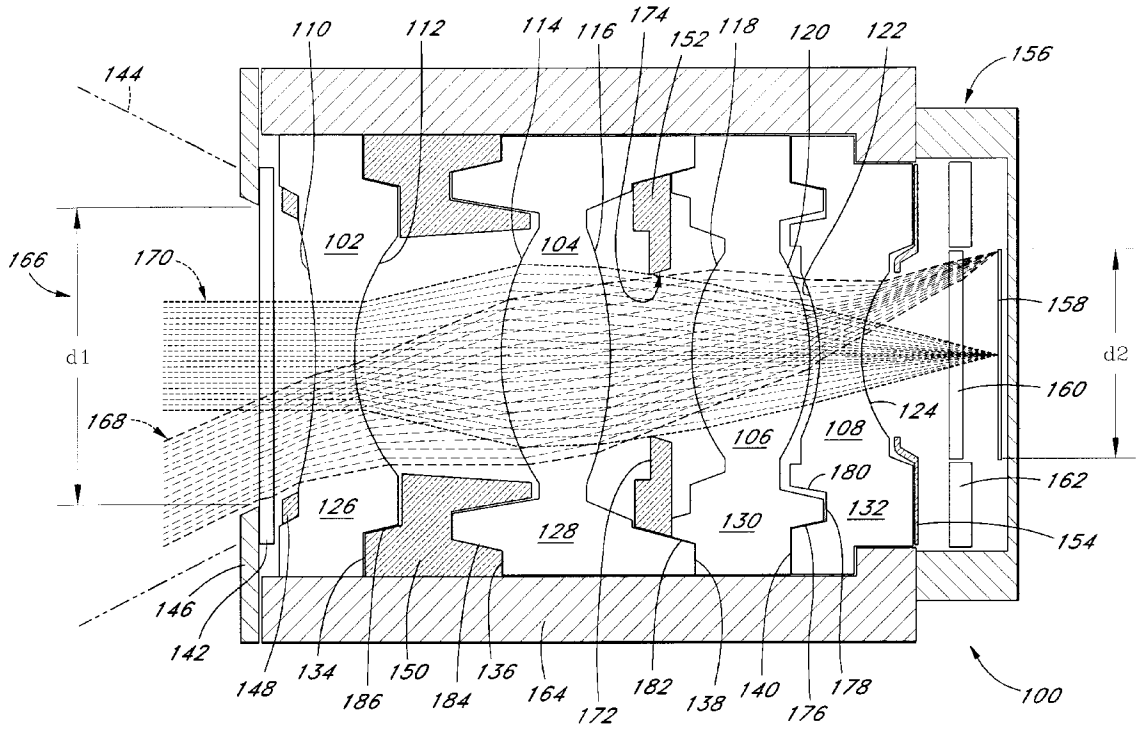
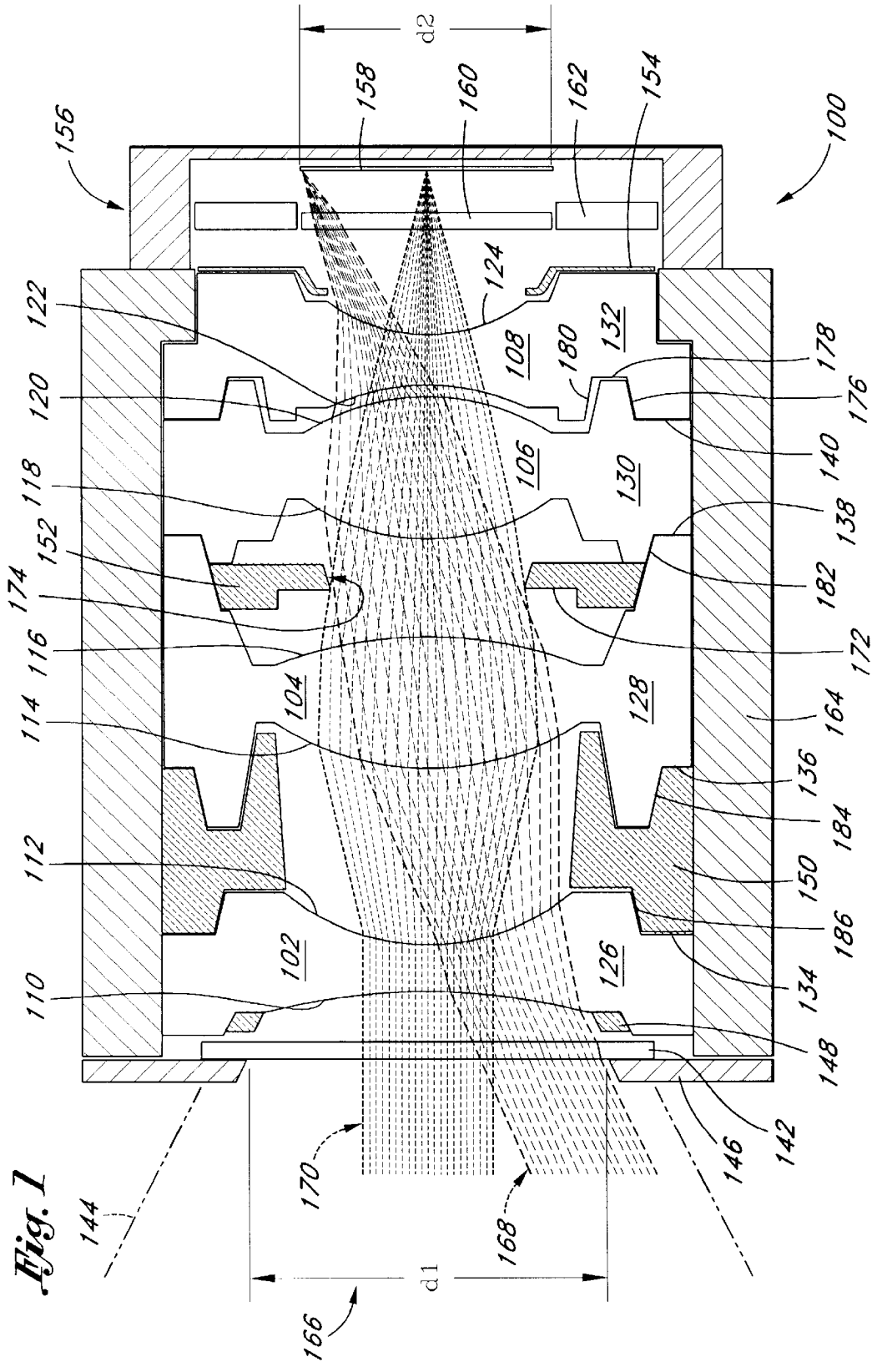
Assistant Examiner—Michael A Lucas
Attorney, Agent, or Firm—Blakely, Sokoloff, Taylor & Zafman LLP

[57] **ABSTRACT**

There is disclosed a compact lens system having four injection-molded singlet lens elements with one of the singlet lens elements having a diffractive optical surface to control axial chromatic aberrations and another of the singlet lens elements having a flint-like plastic material to control lateral chromatic aberration. The lens system includes interdigitated flange features which provides interdigitated alignment between the lens elements. A plurality of light suppression elements are used to suppress stray light paths from reaching a detector array of the lens system. Moreover, the lens system includes an anti-aliasing surface on one of the lens elements for controlling aliasing effects.

43 Claims, 2 Drawing Sheets




d2
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d1
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Fig. 1

Fig. 2A

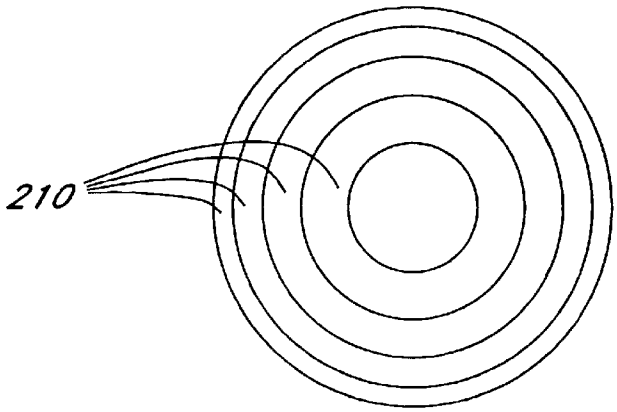


Fig. 2B

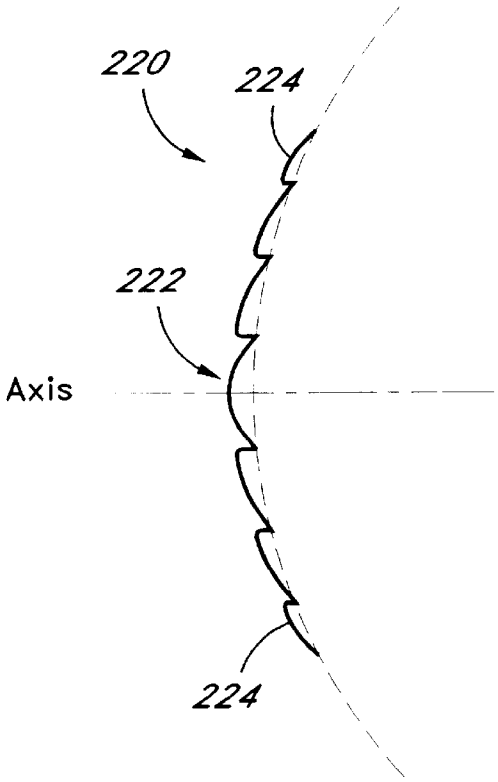
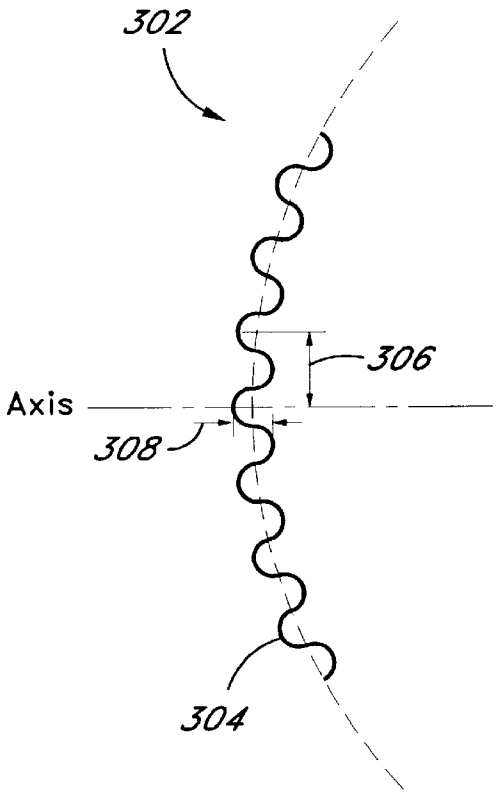


Fig. 3



COMPACT DIGITAL CAMERA OBJECTIVE WITH INTERDIGITATED ELEMENT ALIGNMENT, STRAY LIGHT SUPPRESSION, AND ANTI-ALIASING FEATURES

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates generally to the field of lens systems, and specifically, to a compact digital camera objective having interdigitated element alignment, stray light suppression, and anti-aliasing features.

2. Background Information

Prior art complex lens systems with a f/2.0 relative aperture and a 50 degrees field of view that cover color applications (e.g., white light applications, visual applications, film applications, etc.) typically require six lens elements in high index optical glasses with doublet construction in at least two groups of lens elements to provide control of (axial and lateral) chromatic aberrations. Chromatic aberrations are typically severe for plastic lenses and there are only a limited number of materials to choose from. The doublet construction typically includes a positive lens element that has a low dispersion material (e.g., crown) and a negative lens element that has a high dispersion material (e.g., flint) coupled together. However, the disadvantage with prior art lens systems is that the doublet construction in the two groups of lens elements requires two extra lens elements which is very expensive to produce. Moreover, a lens system with six lens elements cannot be made as compact as a lens system with four lens elements.

Accordingly, there is a need in the art for a method and apparatus to provide a complex lens system that is compact and inexpensive while correcting chromatic and all other optical aberrations.

In addition, complex lens systems that operate in the f/2.0 relative aperture, 50 degree full field diagonal and have a small imaging device format (e.g., less than an 8.0 mm diagonal) require very sensitive fabrication and assembly tolerances for acceptable "as-built", image quality. The prior art lens systems typically align lens elements by using spacers. The disadvantage with using spacers is that they add to the cost of the lens system and require a high degree of accuracy in assembly of the lens system.

Therefore, there is a further need in the technology to provide interdigitated alignment between lens elements without the need for extra parts while facilitating construction of the lens system. There is also a need to suppress stray light from reaching a detector array in a lens system that includes interdigitated single piece lens elements having an optical portion and a non-optical mechanical flange portion.

A further problem with optical systems that form images on detector arrays (e.g., a charge-coupled detector, "CCD") and discretely sample images is that they produce aliasing effects in the displayed image. An example of aliasing effects is Moiré effects which occur when objects move, change patterns, and/or change color relative to the detector array and have dimensions commensurate with the pixel dimensions of the detector array. One solution for eliminating or minimizing aliasing effects is to add a quartz plate in front of the detector array. The quartz plate blurs and reduces the sharpness of the image just the right amount to minimize such aliasing effects. However, quartz plates are very expensive, virtually costing as much as the lens system.

It is therefore desirable to provide an optical lens system that eliminates aliasing effects while maintaining a low cost.

SUMMARY OF THE INVENTION

In one embodiment, the present invention is a lens system. The lens system includes a first lens element having a diffractive surface disposed on one surface to correct axial chromatic aberrations of light passing therethrough. The lens system further includes a second lens element having a flint-like material to correct lateral chromatic aberrations of light passing therethrough.

BRIEF DESCRIPTION OF THE DRAWINGS

The features and advantages of the present invention will become apparent from the following detailed description of the present invention in which:

FIG. **1** illustrates a cross section of a lens system of the present invention.

FIG. **2**A illustrates a front view of the diffractive surface of the present invention.

FIG. **2**B illustrates a side view of the diffractive surface of the present invention.

FIG. **3** illustrates an expanded side view of a lens element anti-alias surface of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

In the preferred embodiment, the present invention is a method and apparatus for providing a compact digital camera objective having, at most, four lens elements with one lens element having a diffractive surface and another lens element made out of flint-like material to correct axial and lateral chromatic aberrations. The present invention further provides interdigitated lens element alignment, stray light suppression, and anti-aliasing features. The compact digital camera objective may be used with any imaging system (e.g., cameras, camcorders, video conferencing imagers, etc.) that have isolated pixelated detectors such as, but not limited or restricted to, a charge coupled device ("CCD"), a charge injection device ("CID"), or a complementary metal oxide semiconductor ("CMOS") device.

In the following description, for purposes of explanation, numerous details are set forth in order to provide a thorough understanding of the present invention. However, it will be apparent to one skilled in the art that these specific details are not required in order to practice the present invention.

FIG. **1** illustrates a cross section of a lens system **100** of the present invention. Referring to FIG. **1**, the lens system **100** includes a first lens element **102** (also referred to as an objective lens element) having first and second surfaces **110** and **112**, a second lens element **104** having first and second surfaces **114** and **116**, a third lens element **106** having first and second surfaces **118** and **120**, and a fourth lens element **108** having first and second surfaces **122** and **124**. The lens elements are enclosed in a housing **164** (or lens cell). The first lens element **102** is closest to the object side while the fourth lens element **108** is closest to an imaging device. The first lens element **102** is a negative lens element and is used to increase (or modify) the field of view of the lens system **100**. The second lens element **104** is a positive lens element having an aspheric first surface **114** (e.g., an eighth order asphere). The third lens element **106** is a positive lens element and adds focusing power to the lens system **100**. The fourth lens element **108** is a negative lens element and has an aspheric first surface **122** (e.g., a sixth order asphere). All of the lens elements **102**, **104**, **106**, and **108** are injection molded plastic singlet lens elements.

To correct axial chromatic aberrations, one of the lens elements of the lens system **100** has a diffractive surface. In

a preferred embodiment, the diffractive surface is on the second surface **116** of the second lens element **104**. However, it is contemplated that the diffractive surface may be placed on another surface such as, but not limited or restricted to, the first surface **118** of the third lens element **106**.

FIG. **2**A illustrates a front view of the diffractive surface of the present invention. Referring to FIG. **2**A, the diffractive surface includes a plurality of rings **210** that are concentric from the center of an aperture. The rings **210** at the center of the surface are widely spaced apart and as the surface is traversed from the center, the rings are more and more closely spaced together.

FIG. **2**B illustrates a side view of the diffractive surface **220**. As shown in FIG. **2**B, the diffractive surface **220** includes a center zone **222** and successive annular zones **224**. In the embodiment shown, the diffractive surface **220** adds strong negative axial chromatic aberration which offsets the positive axial chromatic aberration of the remainder of the optical surfaces. That is, with the diffractive surface, flint elements used in a doublet construction of the prior art lens systems are no longer required.

Referring back to FIG. **1**, since the diffractive surface **116** is close to an aperture stop **152**, it only operates on the axial chromatic aberrations. In order to correct lateral chromatic aberrations, the lens system **100** uses a flint-like lens element. Typically, the flint-like lens element is placed close to the image or close to the object.

In the preferred embodiment, the fourth lens element **108** is made out of flint-like material (e.g., SAN, NAS, polycarbonate, styrene, etc.) and the first, second, and third lens elements **102**, **104**, and **106** are made out of crown-like material (e.g., acrylic, cyclic olefin co-polymer "COC", etc.). The specific configuration of the lens system **100** of FIG. **1**, i.e., the combination of the diffractive optical surface **116** and the flint-like fourth lens element **108**, corrects chromatic (axial and lateral) aberrations. In another embodiment, the first lens element **102** is made out of flint-like material and the second, third, and fourth lens elements **104**, **106**, and **108** are made out of crown-like material. The compact form of the lens system **100** is a direct result of the reduction of the six lens element (or more) configuration of the prior art lens systems to a four lens element configuration of the present invention.

On the object side of the first lens element **102** is an opening **166** that provides the optical pathway to the lens system **100**. The diameter of the opening **166** is shown by distance d**1**, and in one embodiment, is 14.5 millimeters ("mm"). Moreover, in one embodiment, the lens system **100** has a relative aperture of f/2.0 with a 50 degrees full field diagonal. However, it is to be appreciated that the lens system of the present invention may be designed to have a different relative aperture (e.g., f/1.6) and a different size field of view (e.g., 35 degrees). A glass window **142** is incorporated within the lens cell **164** on the object side of the first lens element **102** to protect the lens system **100** from the environment.

On the second side **124** of the fourth lens element **108** is an imaging device **156** having an image plane **158** (hereinafter referred to as a detector array). The diameter of the detector array **158** is shown by distance d**2** and, in one embodiment, is 8 mm. The imaging device **156** may be a CCD, CID, or CMOS detector array, to name a few. In front of the detector array **158** is a glass plate **160**. The detector array **158** and the glass plate **160** are incorporated in a case **162**. Light rays, such as light ray bundles **168** and **170** enter the lens system **100** through the opening **166**, propagate through the four lens elements, and onto the detector array **158**. The detector array **158** generates signals that represent an image formed by the light rays.

The four lens elements **102**, **104**, **106**, and **108** have minimal airspace between them in order to force a compact design and also to permit alignment between the lens elements. Because the imaging device **156** is small, the focal length of the lens system **100** is short, and all four lens elements are small. Small lens elements require very small fabrication and assembly tolerances to maintain the "as-built" image quality. By way of example, if two lens elements are each four inches in diameter, a centration error of approximately 0.005 inches represents a small tolerance error and the impact on the image quality is negligible. On the other hand, if two lens elements are each approximately 0.20 inches in diameter (typical values for this invention), a centration error of approximately 0.005 inches is a substantial tolerance error, yielding a totally unacceptable image quality. The latter example has at least twenty times the affect on image quality that would be present using four inch diameter lens elements. In one embodiment, the tolerances for the lens system **100** of the present invention are approximately on the order of 0.0005 to 0.0008 inches. Accordingly, it is critical to force alignment between the lens elements.

Continuing to refer to FIG. **1**, each of the lens elements is injection molded into a single part. During fabrication of the mold, the entire surface of each lens element is diamond turned in one setup. Each lens element has an optical portion designated by numerals **102**, **104**, **106**, and **108** and a mechanical flange portion (also referred to as an alignment finger) designated as numerals **126**, **128**, **130**, and **132**, respectively, which serves as the mechanical alignment function of the lens element. The mechanical flanges of adjacent lens elements interdigitate, i.e., form a substantially perfect fit or alignment, in order to capture each lens element and its neighbor with one or more alignment surfaces. That is, each pair of adjacent lens elements are pushed together until they come into intimate contact and there is no clearance in-between.

In the embodiment of FIG. **1**, the mechanical flange **132** of the fourth lens element **108** interdigitates with the mechanical flange **130** of the third lens element **106** at only two surfaces, as shown by numerals **140** and **176**. The first surface **140** sets the separation between the third and fourth lens elements **106** and **108**. The second surface **176** sets the centration of the two lens elements. The other two surfaces, designated by numerals **178** and **180**, are clear and do not touch. If any of these surfaces touch, it can cause an over-constrained condition which stresses the lens elements, causing the optical surfaces to distort images.

Similarly, the mechanical flange **130** of the third lens element **106** interdigitates with the mechanical flange **128** of the second lens element **104** at surfaces **138** and **182**. The mechanical flanges **128** and **130** of the second and third lens elements interdigitate with an aperture stop **152**. As will be apparent by the description below, the first and second lens elements **102** and **104** are not directly interdigitated together. Rather, the mechanical flanges **128** of the second lens element **104** interdigitates with an opaque spacer **150** at surfaces **136** and **184**. Similarly, the mechanical flange **126** of the first lens element **102** interdigitates with the opaque separator **150** at surfaces **134** and **186**. Surfaces **134** and **136** set the separation between the first and second lens elements **102** and **104** and the opaque separator **150**. Moreover, the surfaces **184** and **186** set the centration of the first and second lens elements **102** and **104**. The opaque spacer **150**

serves as a stray light suppression element. As discussed above, each pair of adjacent lens elements or a lens element and the adjacent opaque spacer **150** interdigitate at only two surfaces, as designated.

The mechanical flange **126** of the first lens element **102** has the property of allowing light that enters it to propagate in an uncontrolled manner through the mechanical flanges of the other lens elements and eventually become dispersed across the detector array **158**. This uncontrolled stray light on the detector array **158** causes unwanted bright artifacts localized at various points in the detector array which in turn causes a general loss of contrast across the entire detector array. This effect is dramatic and makes the lens system useless if the stray light is not effectively suppressed.

Accordingly, the lens system **100** of the present invention comprises a plurality of light suppression elements for suppressing stray light that may propagate through the mechanical flanges of the lens elements and onto the detector array **158**. The first light suppression element is a lens shroud **144** which is coupled to and projects forward from the front of the lens cell **164** and limits the field of view. In the preferred embodiment, the lens shroud **144** limits the full field of view to 50 degrees diagonal. Moreover, in one embodiment, the lens shroud **144** is a conical baffle which serves the function of preventing sun light, when it is outside the used field of view, from illuminating the glass window **142** or the first lens element **102**. If these optical surfaces are illuminated and have micro-scratches or dust, they will scatter sun light onto the detector array **158**. The lens shroud **144** may be made as long as the cosmetic requirements of the objective lens permits. The internal surface of the lens shroud **144** (not shown) is typically a cone with slightly greater included angle than the full field diagonal of the lens field of view.

The second light suppression element is a light baffle surface **146** located on the front of the lens system **100** and projects over most of the mechanical flange **126** (i.e., the non-optical portion) of the first lens element **102**. The third light suppression element is a compressible foam seal **148** which projects over the remaining exposed portion of the mechanical flange **126** of the first lens element **102**. The compressible foam seal **148** also serves to seal the lens system from the environment while forcing the four lens elements (**102**, **104**, **106**, **108** including opaque spacer **150**) into intimate contact.

The fourth light suppression element is the opaque black spacer **150** which is interdigitated between the mechanical flanges **126** and **128** of the first and second lens elements **102** and **104**, respectively. The opaque black spacer **150** absorbs stray light which may enter the lens system **100** through the mechanical flange **126** of the first lens element **102** and subsequently propagate through the mechanical flange **128** of the second lens element **104**. In one embodiment, the internal surface of the opaque black spacer **150** is either diffused or has micro grooves to prevent specular reflection of light into the rest of the lens system **100**.

The fifth light suppression element is an aperture stop **152**. The aperture stop **152** is placed near the second surface **116** of the second lens element **104** and defines the optical pathway of the bundle of light rays. It is made of opaque black material to suppress much of the stray light. The aperture stop **152** structure prevents light that enters from the front of the lens system from reaching the mechanical flanges (i.e., the non-optical portions) **130** and **132** of the third and fourth lens elements **106** and **108**. In the preferred embodiment, the front surface **172** of the aperture stop **152** is in a rough diffused condition. The aperture stop **152** includes an inner surface **174** which is also left in a diffused condition. In the preferred embodiment, the inner surface **174** is a V-blade cross-section to eliminate flat specular surfaces that could reflect light toward the detector array **158**. The sixth light suppression element is an opaque black baffle **154** which is placed adjacent to the mechanical flange **132** of the fourth lens element **108**. The baffle **154** prevents stray light, which has been diffusely or multiply scattered by other structures, from reaching the detector array **158**.

The lens system **100** of the present invention further includes an antialiasing feature for eliminating aliasing effects that occur when an object moves relative to the detector array **158** and has dimensions commensurate with the pixel dimensions of the detector array **158**. FIG. **3** illustrates an expanded side view of a lens element anti-alias surface **302** of the present invention. Referring to FIG. **3**, the lens element surface **302** includes a radially-symmetric periodic "cosine-like" surface **304** molded on the lens element surface **302**. The periodic surface **302** (or microscopic ripple) causes the image of a point to be spread in a controlled manner.

In the preferred embodiment, the lens element surface **302** is the first surface **118** of the third lens element **106** of FIG. **1**. The period **306** and depth **308** of the rippled surface are carefully selected and optimized to control the size of the blur and the rate at which energy is distributed. In one embodiment, the radially-symmetric cosine ripple has a constant amplitude and at least two periods across the semi-diameter of the aperture stop **152** of FIG. **1**. In a second embodiment, the cosine ripple has a monotonically decreasing amplitude across the aperture. In a third embodiment, the cosine ripple has a monotonically changing period across the aperture. In yet a fourth embodiment, the cosine ripple has both a monotonically decreasing amplitude and changing period across the aperture. The cosine ripple is created on a tool, typically made out of stainless steel. The lens element is then injection molded with hot plastic which forms the ripple on the surface. In another embodiment, the lens element surface **302** includes a "puckered" structure that has a two-dimensional array of elevated "bumps" which cause the image to become blurred in a controlled manner. These type of anti-aliasing features are insensitive to the relative aperture and the object distance.

In the preferred embodiment, the lens system of the present invention achieves a fast relative aperture (f/2.0) and a moderately large field of view of 50 degrees using four lens elements in a very compact form. Prior art lens systems with the same relative aperture and field of view require six lens elements using high index optical glasses which are very expensive to produce. The lens elements are each injection molded into single pieces and are interdigitated to provide optical alignment of the lens system. A plurality of light suppression features are provided to suppress and prevent stray light from entering the mechanical flange portions of the lens elements and dispersing onto the detector array. In addition, a cosine-like structure or a "puckered" structure is molded on a lens element surface to minimize aliasing effects (e.g., Moiré effects).

While certain exemplary embodiments have been described and shown in the accompanying drawings, it is to be understood that such embodiments are merely illustrative of and not restrictive on the broad invention, and that this invention not be limited to the specific constructions and arrangements shown and described, since various other modifications may occur to those ordinarily skilled in the art.

What is claimed is:

1. A lens system comprising:

a detector array;

a first lens element made of crown-like material and located in front of the detector array, the first lens element including a diffractive surface;

a second lens element made of a flint-like material and located in front of the detector array; and

third and fourth lens elements made of crown-like material and located in front of the detector array,

said first through fourth lens elements to correct axial and lateral chromatic aberration of light passing through the lens elements and falling on the detector array.

2. The lens system of claim 1 wherein the second lens element is located between the first lens element and the detector array.

3. The lens system of claim 1 wherein the first lens element is located between the second lens element and the detector array.

4. The lens system of claim 3 wherein each of the first, second, third, and fourth lens elements includes a mechanical flange, wherein the mechanical flanges of the first and fourth lens elements interdigitate and the mechanical flanges of the second and fourth lens elements interdigitate.

5. The lens system of claim 4 further comprising an opaque spacer that interdigitates with the mechanical flanges of the first and third lens element.

6. The lens system of claim 1 wherein the flint-like material comprises one of the following: SAN, NAS, polycarbonate, and styrene; and wherein the crown-like material comprises one of the following: acrylic and cyclic olefin copolymer.

7. The lens system of claim 1 further comprising an aperture stop proximate to the diffractive surface of the first lens element.

8. The lens system of claim 7 wherein the lens system has a relative aperture ranging between approximately f/1.6 approximately to f/2.0.

9. The lens system of claim 1 wherein the detector array and the first, second, third, and fourth lens elements are incorporated into a housing having an opening.

10. The lens system of claim 9 further comprising a light baffle surface placed in front of the housing to prevent stray light from entering the mechanical flange of the third lens element.

11. The lens system of claim 9 further comprising a lens shroud placed proximate to the opening of the housing to limit the field of view of the lens system.

12. The lens system of claim 1 wherein the detector array is a complementary metal oxide semiconductor device.

13. The lens system of claim 1 further comprising a baffle placed behind the second lens element, said baffle to prevent stray light from falling on the detector array.

14. The lens system of claim 1 wherein each of the first and second lens elements has an aspheric surface on one of the surfaces.

15. The lens system of claim 1 wherein the fourth lens element includes a periodic surface molded thereon to reduce aliasing effects.

16. The lens system of claim 15 wherein an amount of aliasing is controlled by varying a period and depth of the periodic surface.

17. The lens system of claim 1 wherein each of the first, second, third, and fourth lens elements is injection molded into a single piece having an optical portion and a mechanical alignment portion.

18. The lens system of claim 1 wherein the fourth lens element includes an array of elevated bumps on one surface for controlling aliasing effects.

19. A lens system comprising:

a housing having an opening, the housing including,

(a) a first lens element including a first mechanical flange;

(b) a second lens element including a second mechanical flange;

(c) an opaque spacer that interdigitates with the first and second mechanical flanges of the first and second lens elements;

(d) a third lens element including a third mechanical flange that interdigitates with the second mechanical flange of the second lens element; and

(e) a fourth lens element including a fourth mechanical flange that interdigitates with the third mechanical flange of the third lens element.

20. The lens system of claim 19 wherein each of the first, second, third, and fourth lens elements is injection molded into a single piece having an optical portion and a mechanical alignment portion.

21. The lens system of claim 19 wherein said second lens element includes a diffractive surface disposed on one surface, said first through third lens elements are made from crown-like material, and said fourth lens element is made from flint-like material to correct axial and lateral chromatic aberrations of light passing therethrough.

22. The lens system of claim 19 wherein said third lens element includes a diffractive surface disposed on one surface, said first through third lens elements are made from crown-like material, and said fourth lens element is made from flint-like material to correct axial and lateral chromatic aberrations of light passing therethrough.

23. The lens system of claim 19 wherein the housing further includes an aperture stop between the second and third lens elements.

24. The lens system of claim 19 wherein the housing further includes a glass window and a compressible foam seal placed between the first lens element and the glass window, said compressible foam seal to reduce an amount of stray light from entering the first mechanical flange of the first lens element and alternatively to force alignment between the lens elements.

25. The lens system of claim 19 wherein each of the second and fourth lens elements has an aspheric surface on one of the surfaces.

26. The lens system of claim 19 wherein the housing further includes a detector array placed behind the first, second, third, and fourth lens elements.

27. The lens system of claim 26 wherein the detector array comprises one of the following devices; a complementary metal oxide semiconductor device, a charge coupled device, and a charge injection device.

28. The lens system of claim 26 wherein the third lens element includes a periodic surface molded thereon to reduce aliasing effects.

29. The lens system of claim 28 wherein an amount of aliasing is controlled by varying a period and depth of the periodic surface.

30. The lens system of claim 26 wherein the third lens element includes an array of elevated bumps on one surface for controlling aliasing effects.

31. A camera system having an optical axis, comprising:

a lens system including,

a first lens element on the optical axis, the first lens element including a diffractive surface disposed on one surface and made of crown-like material,

an aperture stop,

a second lens element on the optical axis, the second lens element made of a flint-like material,

a third lens element on the optical axis, and made of crown-like material, and

a fourth lens element on the optical axis, and made of crown-like material; and

a detector array on the optical axis behind the first through fourth lens elements.

32. The camera system of claim **31** wherein said the first through fourth lens elements to correct axial and lateral chromatic aberrations of light passing therethrough.

33. The camera system of claim **31** wherein the first lens element is in front of the second lens element.

34. The camera system of claim **33** wherein the third lens element is in front of the first lens element and the fourth lens element is between the first and second lens elements.

35. The camera system of claim **33** wherein each of the first, second, third, and fourth lens elements include a mechanical flange, wherein the mechanical flanges of the first and fourth lens elements interdigitate and the mechanical flanges of the second and fourth lens elements interdigitate.

36. The camera system of claim **31** wherein the second lens element is in front of the first lens element.

37. The camera system of claim **36** wherein the first lens element is in front of the third and fourth lens elements.

38. The camera system of claim **31** wherein the diffractive surface includes a plurality of concentric rings.

39. The camera system of claim **35** further comprising an opaque spacer that interdigitates with the mechanical flanges of the first and third lens elements.

40. The camera system of claim **31** wherein the lens system has a relative aperture ranging between approximately f/1.6 to approximately f/2.0.

41. The camera system of claim **31** wherein the detector array comprises one of the following devices: a complementary metal oxide semiconductor device, a charge coupled device, and a charge injection device.

42. The camera system of claim **31** wherein the fourth lens element includes a periodic surface molded thereon to reduce aliasing effects.

43. The camera system of claim **31** wherein the fourth lens element includes an array of elevated bumps on one surface for reducing aliasing effects.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 6,072,634
DATED : June 6, 2000
INVENTOR(S) : Broome et al.

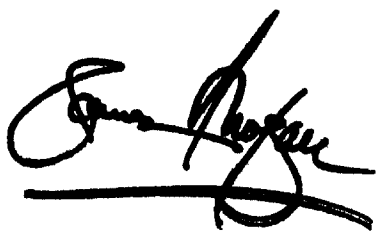
It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 7,
Line 39, delete "approximately to", insert -- to approximately --.

Column 9,
Line 11, after "said", delete "the".

Signed and Sealed this

Twenty-first Day of January, 2003



JAMES E. ROGAN
Director of the United States Patent and Trademark Office

US006040943A

United States Patent [19]

Schaub

[11] Patent Number: 6,040,943

[45] Date of Patent: Mar. 21, 2000

[54] **DIGITAL CAMERA OBJECTIVE WITH DIFFRACTIVE OPTICAL SURFACE**

[75] Inventor: **Michael P. Schaub**, Tucson, Ariz.

[73] Assignee: **Donnelly Optics**, Tucson, Ariz.

[21] Appl. No.: **09/046,168**

[22] Filed: **Mar. 23, 1998**

[51] **Int. Cl.**[7] **G02B 27/44**; G02B 3/02; G02B 9/00

[52] **U.S. Cl.** **359/565**; 359/571; 359/716; 359/740; 359/784

[58] **Field of Search** 359/16, 19, 565, 359/571, 645, 661, 740, 784, 716

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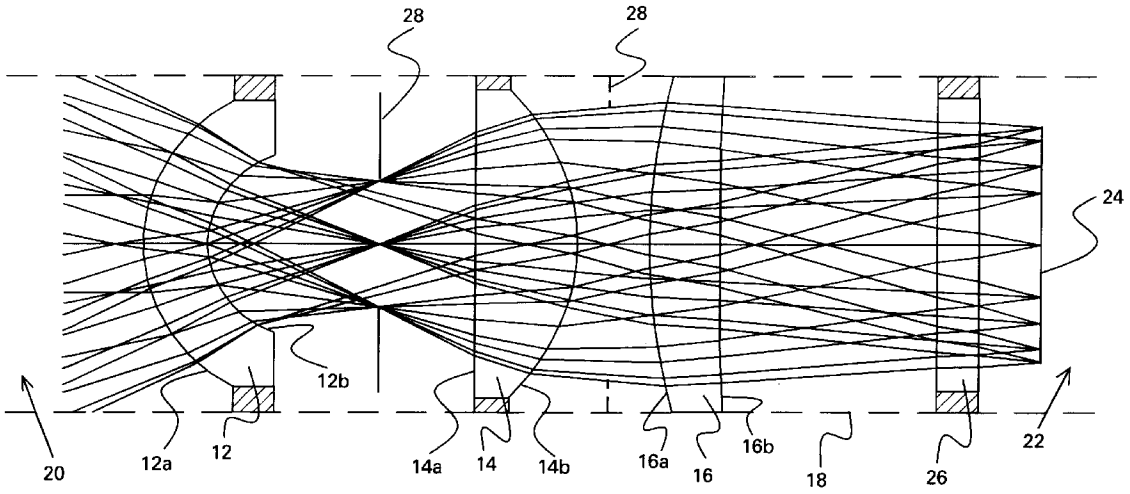
Primary Examiner—Cassandra Spyrou
Assistant Examiner—John Juba, Jr.
Attorney, Agent, or Firm—Benman & Collins

[57] **ABSTRACT**

A lens system having a reduced number of injection-molded singlet lens elements with at least one diffractive surface to control axial and lateral chromatic aberrations is disclosed. In one embodiment, the diffractive surface is placed on the first surface of the third lens, which is closest to the image plane. An opaque spacer provides suppression of stray light from reaching the image plane.

40 Claims, 2 Drawing Sheets



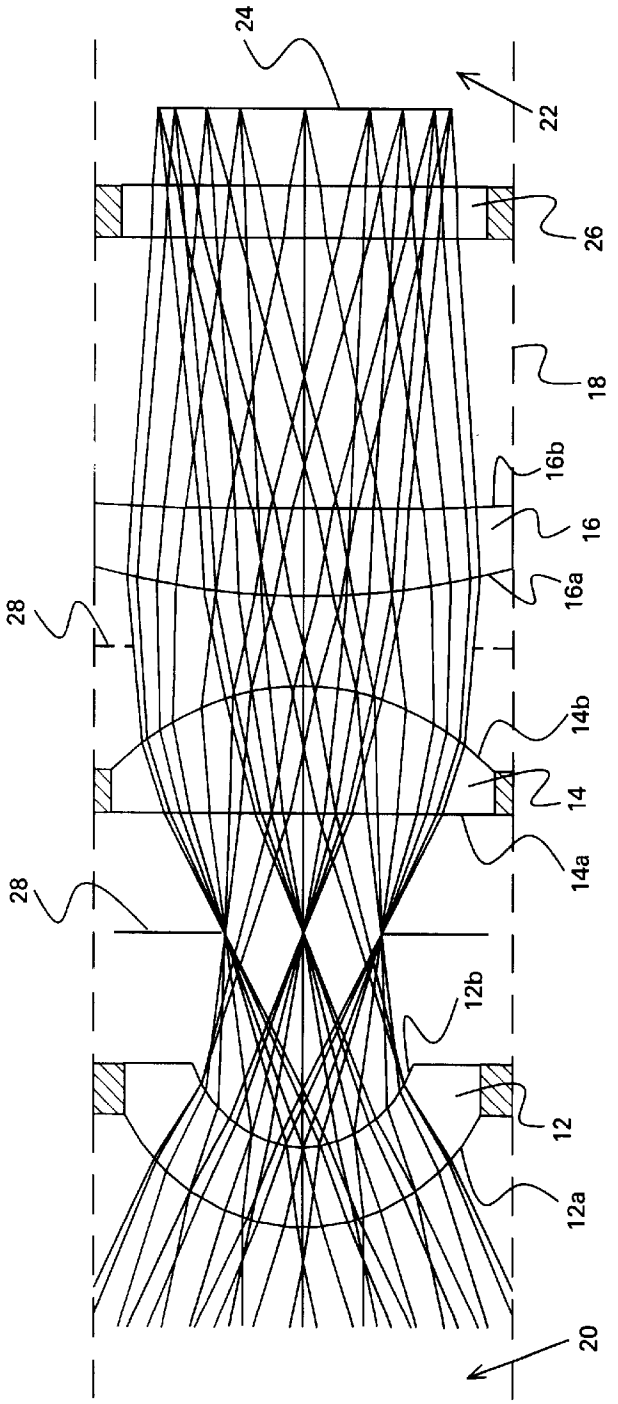


FIG. 1

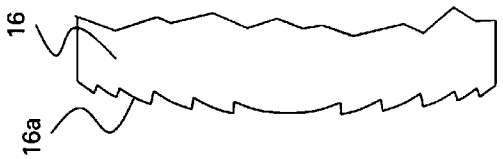


FIG. 2

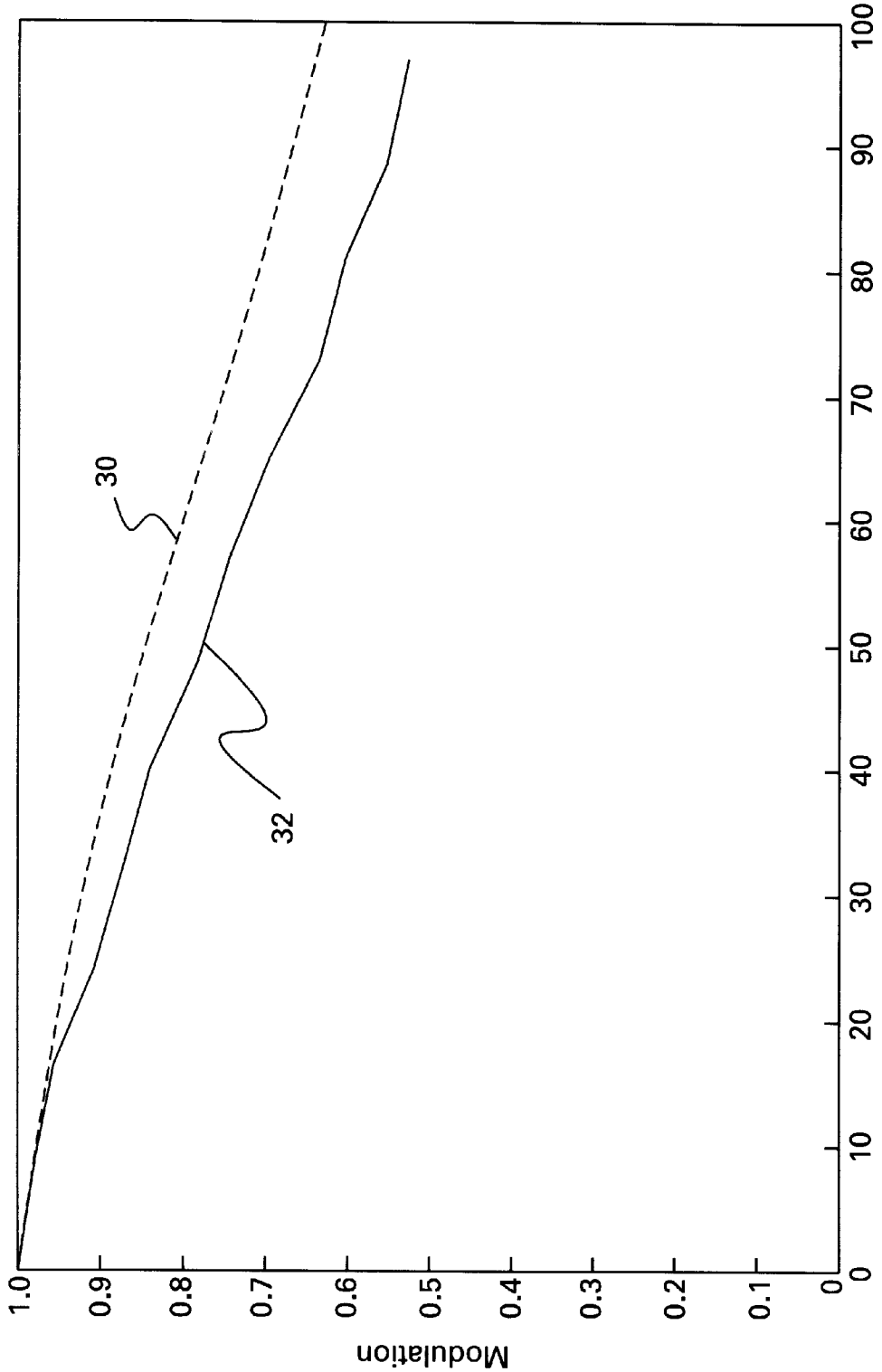

Modulation
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
10
20
30
40
50
60
70
80
90
100
Frequency (cy/mm)
30
32

FIG. 3

DIGITAL CAMERA OBJECTIVE WITH DIFFRACTIVE OPTICAL SURFACE

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates generally to the field of lens systems, and, more particularly, to a digital camera objective having stray light suppression features.

2. Description of Related Art

Prior art complex lens systems with a relative aperture of F/2 and 50 degree field of view for color applications typically require numerous lens elements such as five or six lens elements in high index optical glass. These utilize doublet construction in at least two groups of lens elements to provide control of lateral and axial chromatic aberrations. The doublet construction typically consists of a positive lens of a low dispersion material and a negative lens of a high dispersion material. The disadvantage of the doublet construction is that it requires an extra element, which increases the cost of the lens system. Also, the overall length, weight, and cost of the lens system that utilizes numerous lens elements is increased.

There is a need to provide a lens system with a reduced number of elements, while still maintaining correction of chromatic aberrations.

SUMMARY OF THE INVENTION

In accordance with the present invention, a lens system for forming an image of an object is provided which comprises a reduced number of elements, while still maintaining correction of chromatic aberrations. This is achieved by using an appropriately defined and positioned diffractive surface. If the diffractive surface is positioned at (or near) the aperture stop, it will affect the axial aberration. The remaining lateral color may be corrected by using a high dispersion material for one of the lenses. However, if the diffractive surface is appropriately defined and positioned away from the aperture stop, it will affect both the axial and lateral color, and will eliminate the need for the high dispersion material. In any event, the number of lenses is reduced from the prior art five or six and the need for multiple materials.

Other objects, features, and advantages of the present invention will become apparent upon consideration of the following detailed description and accompanying drawings, in which like reference designations represent like features throughout the FIGURES.

BRIEF DESCRIPTION OF THE DRAWINGS

The drawings referred to in this description should be understood as not being drawn to scale except if specifically noted.

FIG. **1**, in cross-section, illustrates a lens system of the present invention;

FIG. **2**, also in cross-section, is a view of the diffractive surface employed in the practice of the present invention; and

FIG. **3**, on coordinates of relative modulation and frequency (in cycles per millimeter), is a plot depicting the modulation transfer function of a specific lens system of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Reference is now made in detail to a specific embodiment of the present invention, which illustrates the best mode presently contemplated by the inventor for practicing the invention. Alternative embodiments are also briefly described as applicable.

In the preferred embodiment, the present invention is a digital camera objective having no more than five lens elements, preferably no more than four lens elements, and most preferably no more than three lens elements. Alternatively, the digital camera objective may have no more than two lens elements. In any event, each of the lens elements has a first surface and a second surface and at least one of the surfaces of the lens elements comprises a diffractive surface to correct axial and lateral chromatic aberrations. The digital camera objective may be used with any imaging system (e.g., cameras, camcorders, video conferencing imagers, scanners, etc.), employing detectors such as, but not limited or restricted to, charge coupled devices ("CCD"), charge injection devices ("CID"), or complementary metal oxide semiconductor ("CMOS") devices.

In the following description, details are given to provide an understanding of the present invention. It will be apparent to one skilled in the art that these specific details are not required in order to practice the present invention.

The lens system of the present invention forms an image of an object on an image plane. The object is located on the object side of the lens system, which comprises no more than five lens elements. Each of the lens elements has a first surface and a second surface, with at least one of the surfaces comprising a diffractive surface, which provides correction of axial and lateral chromatic aberrations of light passing through the lens system. In appropriate situations, the object and the image plane of the lens system may be interchanged.

FIG. **1** is a cross-sectional view of a three element lens system **10** of the invention. The lens system **10** comprises a first lens **12**, with a first surface **12***a* and a second surface **12***b*, a second lens **14** having a first surface **14***a* and a second surface **14***b*, and a third lens **16** having a first surface **16***a* and a second surface **16***b*. The lenses **12**, **14**, **16** are enclosed in a housing **18**. The first lens **12** is closest to the object side, generally denoted at **20**, while the third lens **16** is closest to the image side, generally denoted at **22**. In a specific application, such as a camera, there may be a detector **24** located on the image side **22**, with a window **26** between the third lens **16** and the detector **24**.

Preferably, all of the lenses **12**, **14**, **16** may be injection-molded plastic singlet lenses, most preferably of a conventional crown-like material. Examples of suitable crown-like materials that may be employed in the practice of the present invention include acrylates and methacrylates.

To correct axial and lateral chromatic aberrations, one of the lens elements has a diffractive surface. It is preferred that this diffractive surface be on the first surface **16***a* of the third element **16**, although it may be placed on another surface such as, but not restricted to, the second surface **14***b* of the second element **14**.

The first element **12** is a negative lens, which serves to increase the field of view. The second element **14** is a power lens. The surfaces of the first lens **12**, the second lens **14**, and the third lens **16** may be provided with aspheric surfaces.

An aperture stop **28** is placed between the first lens **12** and the second lens **14**. Alternatively, but less preferred, the aperture stop **28** may be placed between the second lens **14** and the third lens **16**, as shown in phantom. In any event, the aperture stop is an opaque spacer and serves to limit a bundle of rays passing through the first element **12**. To further reduce stray light, the aperture stop **28** may be placed at both locations.

FIG. **2** shows a cross-sectional view of the diffractive surface, here, **16***a*. With this diffractive surface, the doublet construction of the prior art lens systems is no longer required. Since the diffractive surface **16***a* (or **14***b*) is away from the aperture stop **28** in the preferred case, it operates on both axial and lateral chromatic aberrations.

Turning now to the nature of the diffractive surface **16***a* (or **14***b*), it is well-known that a major difference between a refractive optical surface and a diffractive optical surface in ray tracing analysis is that a refractive surface is governed by Snell's law:

$$n_1 \sin\Theta_1 = n_2 \sin\Theta_2$$

where n is the refractive index of the material.

On the other hand, a diffractive optical surface is, in scalar terms, subject to the grating equation:

$$m\lambda = d \sin\Theta,$$

where

m=diffractive order;

λ=the wavelength of the incident light beam;

d=grating periodicity; and

Θ=diffractive angle.

The grating height h is determined according to the formula

$$h = \frac{\lambda}{(n-1)}.$$

Depending upon the particular effect desired, the feature size will be some multiple of h, where the multiple will determine the phase shift in units of wave-length. In practice, this multiple will generally be between 1/20 and 200 times the wavelength of light. Typical values include ¼, ½, ¾, 1, 2, 3, etc. In general, for plastic materials with visible light, this translates into feature heights on the order of micrometers.

The lateral dimensions of spacing of the features, as well as the periodicity, is determined differently for different diffractive patterns, as will be discussed in more detail below. Typically, the lateral dimensions will range from a fraction to about a thousand times the wavelength of light. For plastic materials with visible light, the range is generally between about one-half to about one hundred micrometers. It should be noted that the present invention applies equally as well to light outside the visible spectrum, i.e., infrared and ultraviolet light.

In refractive analysis, when a collimated beam of light impinges on a curved surface of a lens, the plane wavefront is transformed according to Snell's law into a spherical wavefront. Using a diffractive structure, the wavefront is transformed as determined by the grating equation.

The design of the diffraction grating itself depends upon its desired effect. For example, the diffractive surface may be designed to cooperate with the remaining refractive power to achieve the desired correction of chromatic aberration. Other uses include, but are not limited to, athermalization, replacement of refractive power, aspheric correction, or color filtration.

The design of the diffractive optical surface can be achieved through mathematical modeling, using any of several techniques depending upon the level of sophistication required. These techniques include scalar analysis, rigorous coupled wave theory, parabasal ray tracing, vector analysis, and the beam propagation method. Commercially available codes can be employed to carry out the diffractive design analysis. Some of these codes include "Code V" or "Light Tools", both from Optical Research Associates (Pasadena, Calif.), "ASAP" from Breault Research Organization (Tucson, Ariz.), "Diffract" from MM Research (Tucson, Ariz.), or "Grating Solver" from Grating Solver Development Corporation (Allen, Tex.). Examples of this mathematical analysis are discussed in more depth in U.S. Pat. No. 5,218,471 to Swanson et al., which is incorporated herein by reference. U.S. Pat. No. 5,538,674 to Nisper et al, which is incorporated herein by reference, discloses techniques for fabricating diffractive optical elements.

One example of such a lens system as depicted in FIG. **1** comprises:

- a first lens **12** having a first surface **12***a* with a radius of 3 mm, and a second surface **12***b* having a radius of 1.6 mm,
- a second lens **14**, having a first surface **14***a* with a radius of 166 mm, and a second surface **14***b* having a radius of −3.5 mm, and
- a third lens **16**, having a first surface **16***a* with a diffractive optical element defined by the phase coefficient -6×10^{-3}, and a second surface **16***b* having a radius of 800 mm.

Another example of such a lens system as depicted in FIG. **1** comprises:

- a first lens **12** having a first surface **12***a* with a radius of 6.9 mm, and a second surface **12***b* having a radius of 1.9 mm,
- a second lens **14**, having a first surface **14***a* with a radius of 12.4 mm, and second surface **14***b* having a radius of −6.7 mm, and
- a third lens **16**, having a first surface **16***a* with radius 7.8 mm and with a diffractive optical element defined by the phase coefficient -7.2×10^{-3}, and a second surface **16***b* having a radius of 8.3 mm.

The modulation transfer function of one such lens system is depicted in FIG. **3**, in which Curve **30** is the predicted result and Curve **32** is the measured result, indicating the high degree of correction of the system.

INDUSTRIAL APPLICABILITY

The digital camera objective of the present invention is expected to find use in still and video camera applications.

Thus, there has been disclosed a digital camera objective, which includes a lens having a diffractive surface. It will be readily apparent to those skilled in this art that various changes and modifications of an obvious nature may be made, and all such changes and modifications are considered to fall within the scope of the present invention, as defined by the appended claims.

What is claimed is:

1. A lens system for forming an image of an object on an image plane, said lens system comprising a first negative lens closest to an object side, a third lens closest to an image side, and a second power lens disposed between said first lens and said third lens, with each lens having first and second surfaces, at least one of said surfaces of said lenses comprising a diffractive surface, said lens system further comprising an opaque spacer between said second lens and said third lens, to prevent stray light from reaching said image side, said lens system comprising no more than three lens elements and being corrected for axial and lateral chromatic aberrations of light passing therethrough.

2. The lens system of claim **1** having an opaque spacer between said first lens and said second lens, creating an aperture stop to limit a bundle of rays passing through said first lens.

3. The lens system of claim 1 wherein at least one of said first surface and said second surface of said third lens comprises a diffractive surface.

4. The lens system of claim 3 wherein said first surface comprises said diffractive surface, said first surface being closer to said object side.

5. The lens system of claim 1 wherein at least one of said first surface and said second surface of the second lens comprises a diffractive surface.

6. The lens system of claim 5 wherein said second surface of said second lens comprises said diffractive surface, said second surface being closer to said image side.

7. The lens system of claim 1 wherein a detector is located on said image side at said image plane.

8. The lens system of claim 1 wherein each of said lens elements comprises a crown-like material.

9. The lens system of claim 1 in which at least one of said lens elements comprises a plastic material.

10. The lens system of claim 9 in which at least one of said lens elements comprises an injection-molded plastic material.

11. The lens system of claim 1 wherein at least one of said surfaces of said lens elements comprises a spheric surface.

12. The lens system of claim 1 wherein at least one of said surfaces of said lens elements comprises an aspheric surface.

13. A lens system for forming an image of an object on an image plane, comprising no more than three lens elements, each of said lens elements having a first surface and a second surface, said lens system comprising a first lens closest to an object side, a third lens closest to an image side, and a second lens disposed between said first lens and said third lens, wherein said third lens has a diffractive surface, wherein each of said lens elements comprises a crown-like material, and wherein at least one of said surfaces of said lens elements comprises an aspheric surface, said lens system being corrected for axial and lateral chromatic aberrations of light passing therethrough.

14. The lens system of claim 13 in which at least one of said lens elements comprises a plastic material.

15. The lens system of claim 14 in which at least one of said lens elements comprises an injection-molded plastic material.

16. The lens system of claim 13 wherein at least one of said surfaces of said lens elements comprises a spheric surface.

17. The lens system of claim 13 having an opaque spacer between said first lens and said second lens, creating an aperture stop to limit a bundle of rays passing through said first lens.

18. The lens system of claim 13 having an opaque spacer between said second lens and said third lens, to prevent stray light from reaching said image surface.

19. The lens system of claim 13 wherein said first surface of said third lens comprises said diffractive surface, said first surface being closer to said object side.

20. The lens system of claim 13 wherein a detector is located on said image side at said image plane.

21. A lens system for forming an image of an object on an image plane, said lens system comprising no more than three elements, each of said lens elements having a first surface and a second surface and comprising a crown-like material, said lens system being corrected for axial and lateral chromatic aberrations of light passing therethrough, said lens system comprising:

(a) a first negative lens closest to an object side,

(b) a second power lens,

(c) a third lens closest to said image plane, wherein said third lens has a diffractive surface on a surface away from said image plane; and

(d) an opaque spacer between said first lens and said second lens, creating an aperture stop to limit a bundle of rays passing through said first lens.

22. The lens system of claim 21 wherein each of said first and second lenses has an aspheric surface.

23. The lens system of claim 21 wherein a detector is located at said image plane.

24. A lens system for forming an image of an object on an image plane, said lens system comprising a first negative lens closest to an object side, a third lens closest to an image side, and a second power lens disposed between said first lens and said third lens, with each lens having first and second surfaces, said first surface of said third lens comprising a diffractive surface, said first surface being closer to said object side, said lens system comprising no more than three lens elements and being corrected for axial and lateral chromatic aberrations of light passing therethrough.

25. The lens system of claim 24 having an opaque spacer between said first lens and said second lens, creating an aperture stop to limit a bundle of rays passing through said first lens.

26. The lens system of claim 24 having an opaque spacer between said second lens and said third lens, to prevent stray light from reaching said image side.

27. The lens system of claim 24 wherein a detector is located on said image side at said image plane.

28. The lens system of claim 24 wherein each of said three elements comprises a crown-like material.

29. The lens system of claim 24 wherein at least one of said lens elements comprises a plastic material.

30. The lens system of claim 29 wherein at least one of said lens elements comprises an injection-molded plastic material.

31. The lens system of claim 24 wherein at least one of said surfaces of said lens elements comprises a spheric surface.

32. The lens system of claim 24 wherein at least one of said surfaces of said lens elements comprises an aspheric surface.

33. A lens system for forming an image of an object on an image plane, said lens system comprising a first negative lens closest to an object side, a third lens closest to an image side, and a second power lens disposed between said first lens and said third lens, with each lens having first and second surfaces, said second surface of said second lens comprising a diffractive surface, said second surface being closer to said image side, said lens system comprising no more than three lens elements and being corrected for axial and lateral chromatic aberrations of light passing therethrough, wherein said lens elements each comprise a crown-like material.

34. The lens system of claim 33 having an opaque spacer between said first lens and said second lens, creating an aperture stop to limit a bundle of rays passing through said first lens.

35. The lens system of claim 33 having an opaque spacer between said second lens and said third lens, to prevent stray light from reaching said image side.

36. The lens system of claim 33 wherein a detector is located on said image side at said image plane.

37. The lens system of claim 33 wherein at least one of said lens elements comprises a plastic material.

38. The lens system of claim 37 wherein at least one of said lens elements comprises an injection-molded plastic material.

39. The lens system of claim 33 wherein at least one of said surfaces of said lens elements comprises a spheric surface.

40. The lens system of claim 33 wherein at least one of said surfaces of said lens elements comprises an aspheric surface.

* * * * *

US006038079A

United States Patent [19]

Michaels

[11] Patent Number: 6,038,079

[45] Date of Patent: Mar. 14, 2000

[54] **SAPPHIRE OBJECTIVE SYSTEM**

[75] Inventor: **Richard J. Michaels**, Irvine, Calif.

[73] Assignee: **Imagyn Medical Technologies, Inc.**, Irvine, Calif.

[21] Appl. No.: **08/947,740**

[22] Filed: **Oct. 9, 1997**

[51] **Int. Cl.**[7] **G02B 21/02**

[52] **U.S. Cl.** **359/661**; 359/656; 359/657; 359/658; 359/659; 359/660

[58] **Field of Search** 359/656–661

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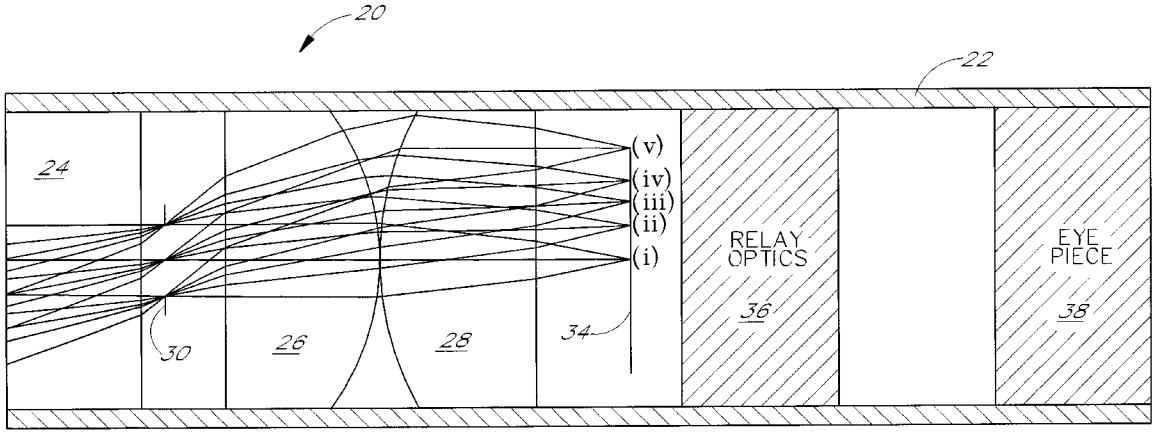
Primary Examiner—Georgia Epps
Assistant Examiner—Michael A Lucas
Attorney, Agent, or Firm—Knobbe, Martens, Olson & Bear, LLP

[57] **ABSTRACT**

Objective lenses for endoscopes are made substantially of sapphire. The high refractive index of sapphire results in optical components with shallower curvatures, leading to smaller geometric aberrations, and consequently, fewer components are required to correct for these aberrations. Chromatic aberrations are less severe because of sapphire's low dispersion. The objectives may be either of the landscape or retrofocus type, and are compact with moderate field of view, low f-number, and less distortion than most conventional designs.

60 Claims, 14 Drawing Sheets



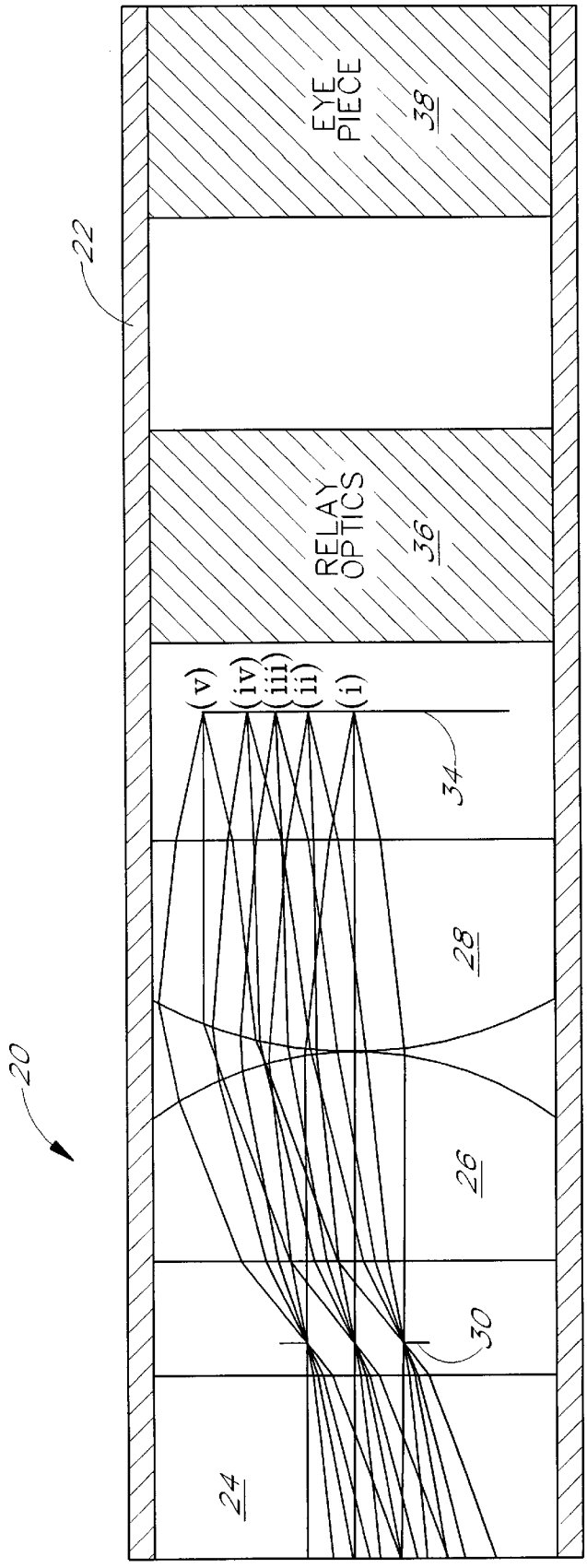


FIG. 1a

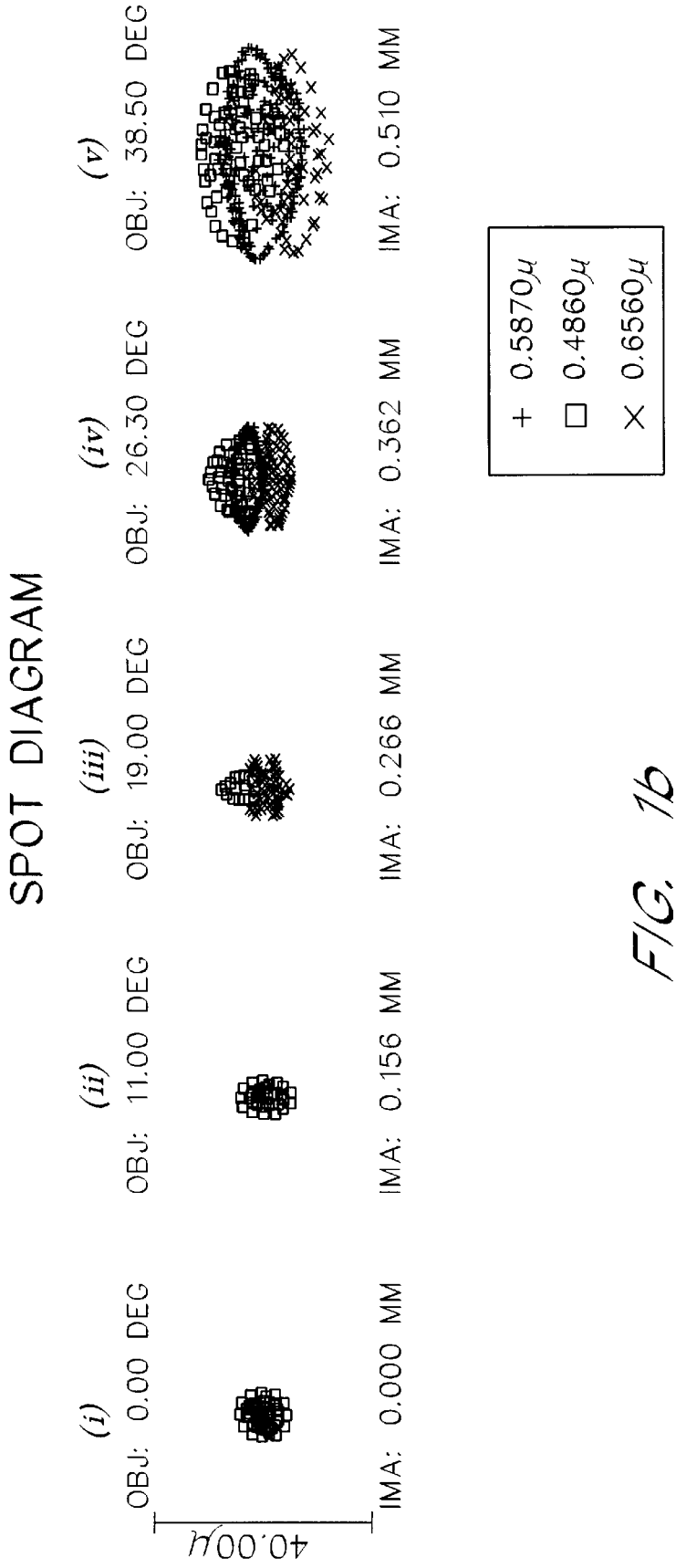
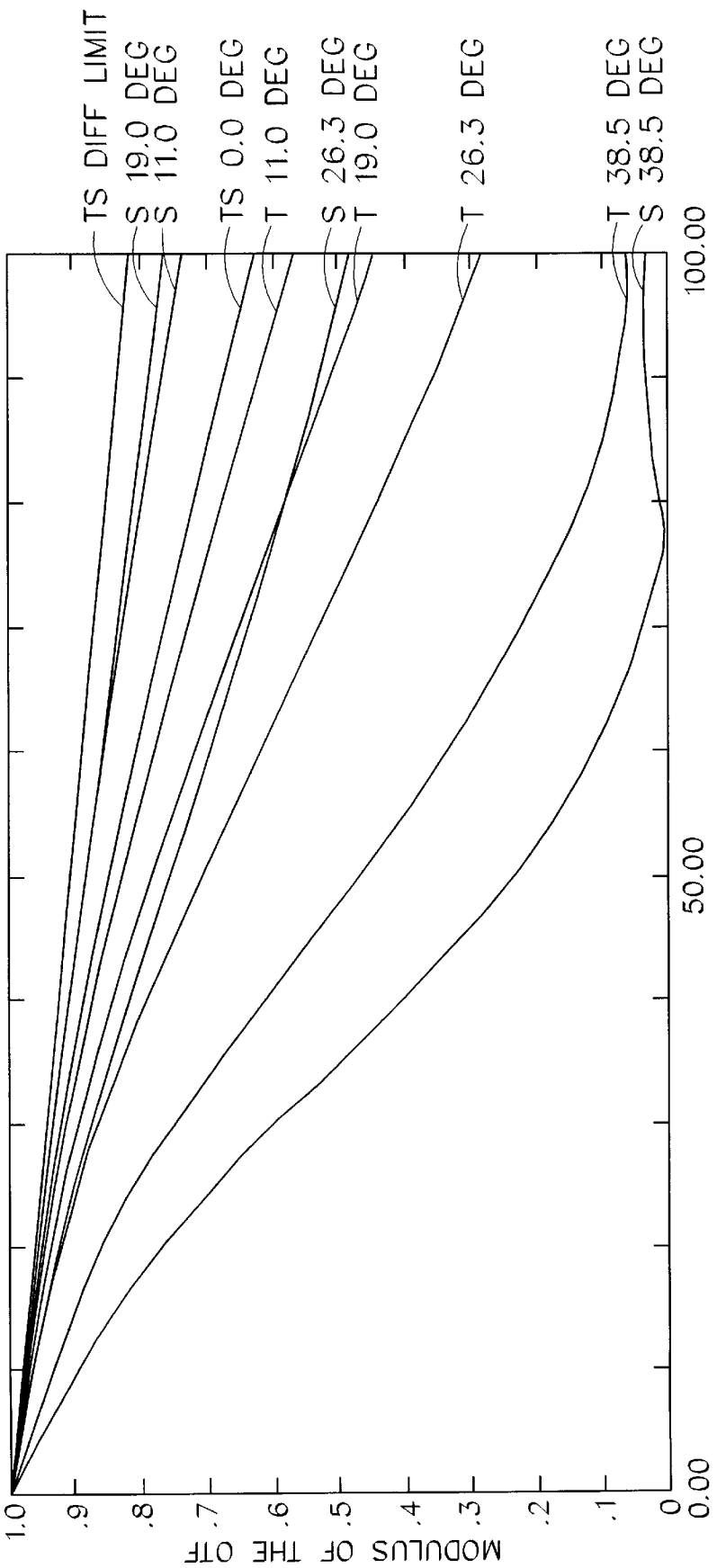

SPOT DIAGRAM
(i)
OBJ: 0.00 DEG
IMA: 0.000 MM
(ii)
OBJ: 11.00 DEG
IMA: 0.156 MM
(iii)
OBJ: 19.00 DEG
IMA: 0.266 MM
(iv)
OBJ: 26.30 DEG
IMA: 0.362 MM
(v)
OBJ: 38.50 DEG
IMA: 0.510 MM
40.00μ
+ 0.5870μ
□ 0.4860μ
× 0.6560μ

FIG. 1b

FIG. 1c



POLYCHROMATIC DIFFRACTION MODULATION TRANSFER FUNCTION

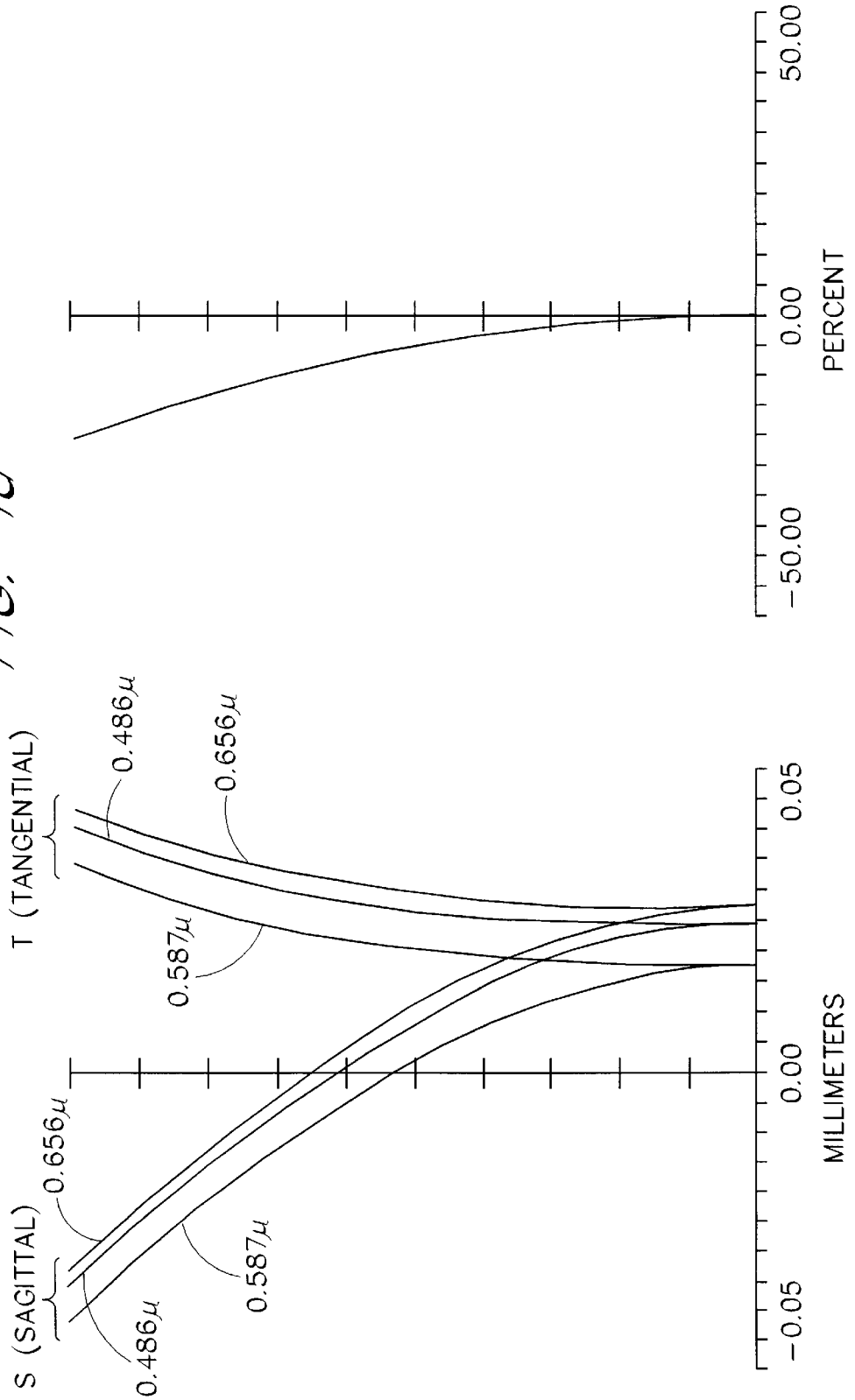


FIG. 1d
FIELD CURVATURE/DISTORTION
S (SAGITTAL)
T (TANGENTIAL)
0.656μ
0.486μ
0.587μ
0.656μ
0.486μ
0.587μ
−0.05
0.00
0.05
MILLIMETERS
−50.00
0.00
50.00
PERCENT

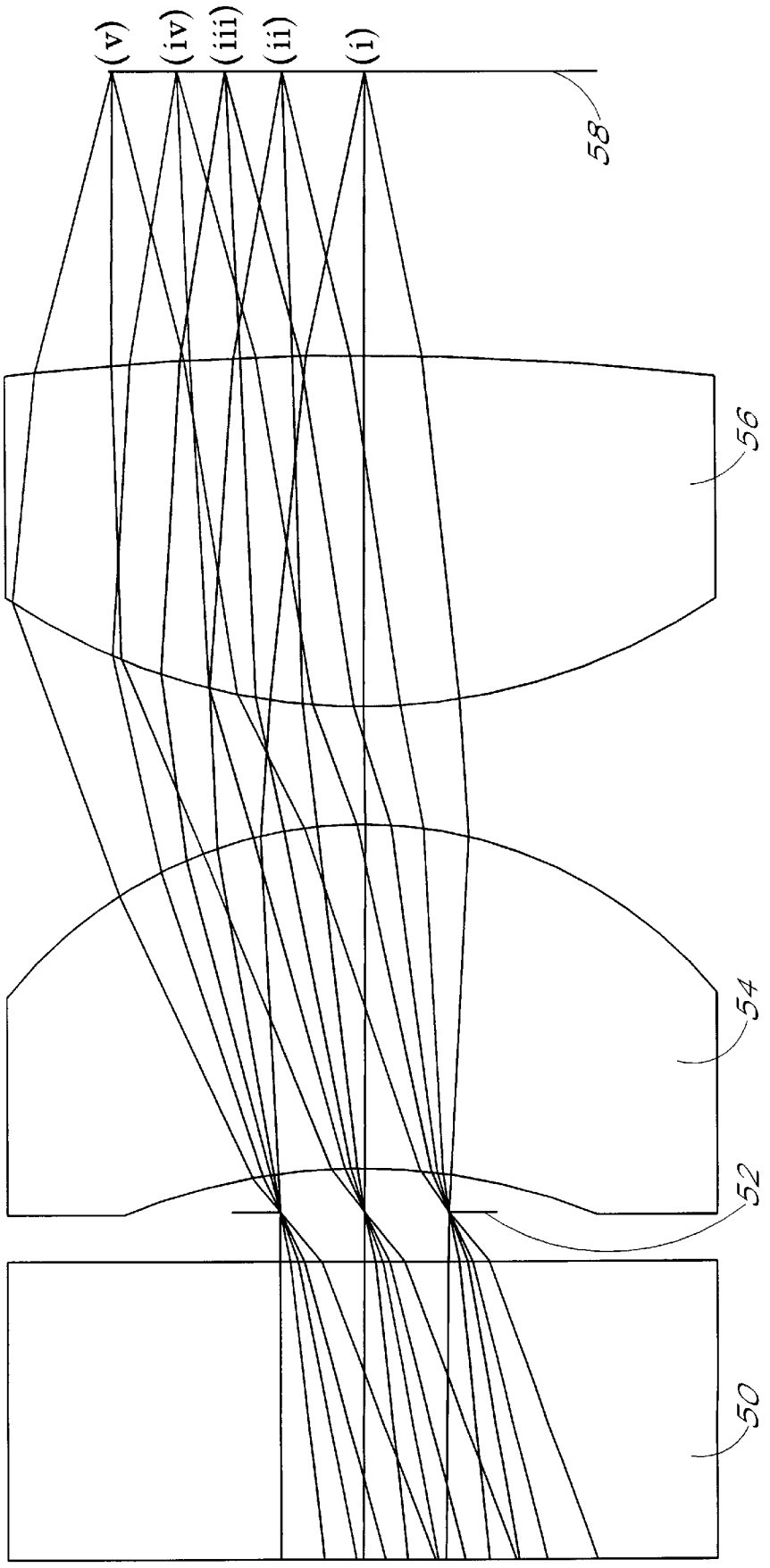


FIG. 2

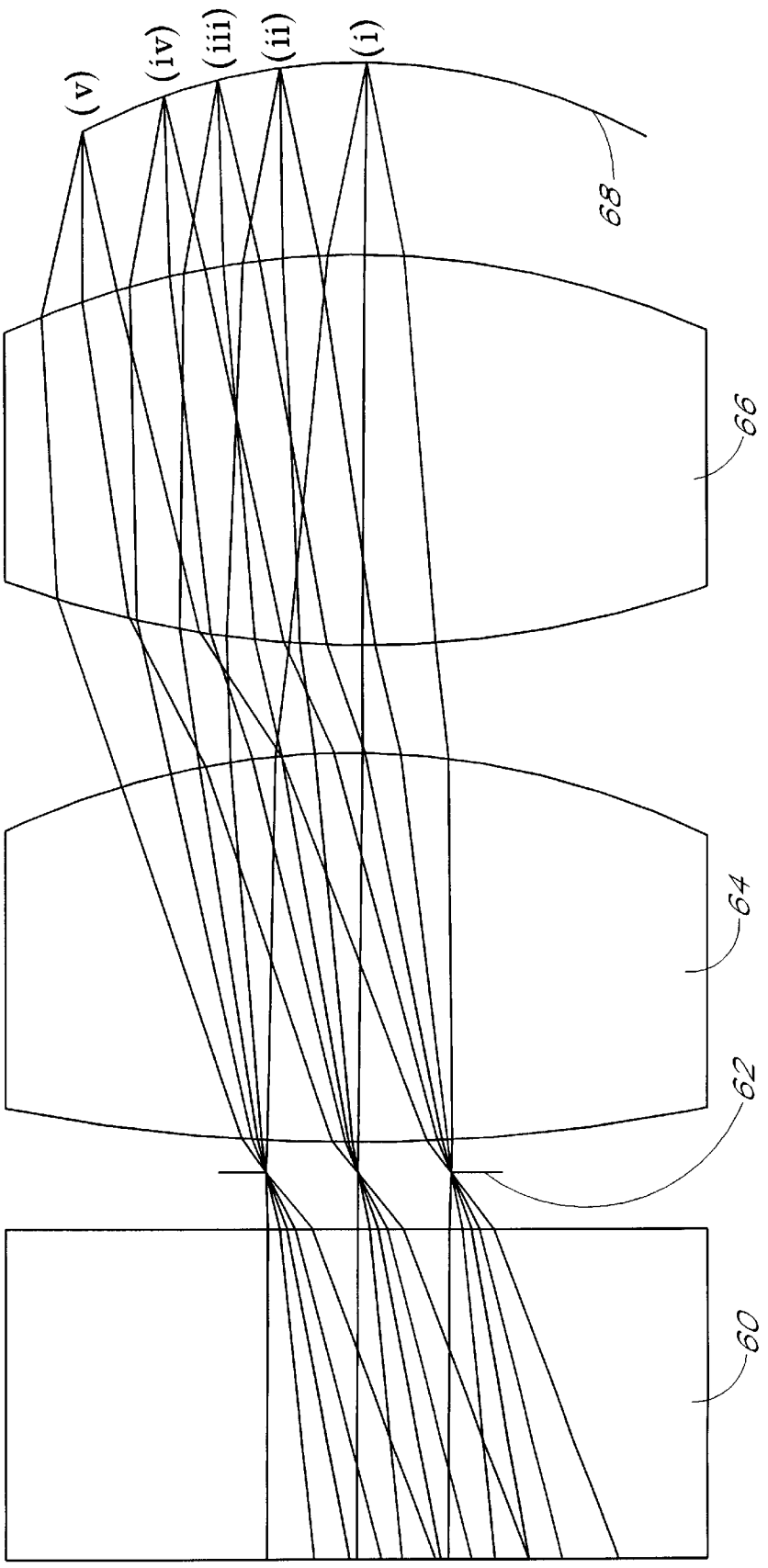


FIG. 3

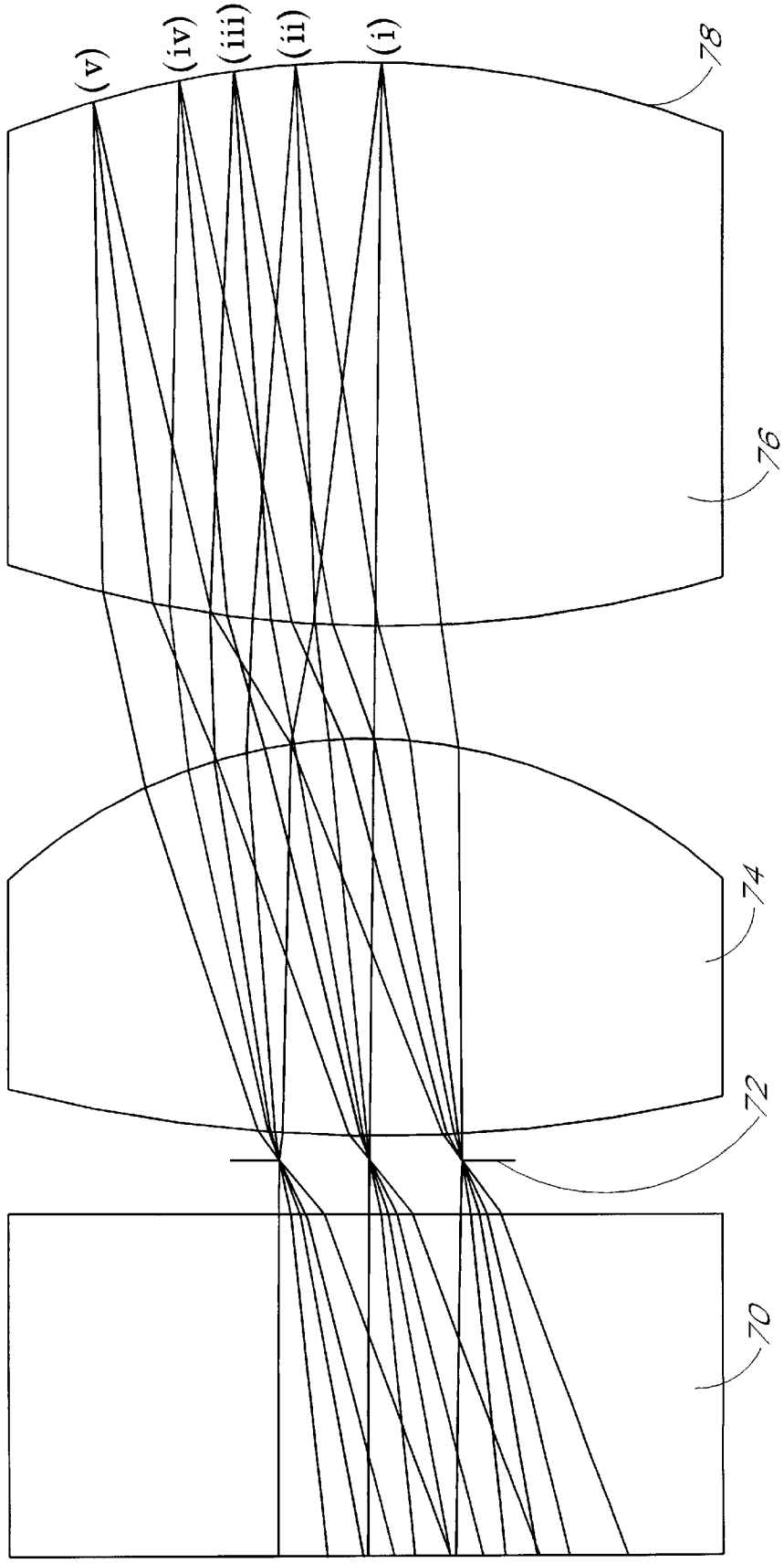


FIG. 4

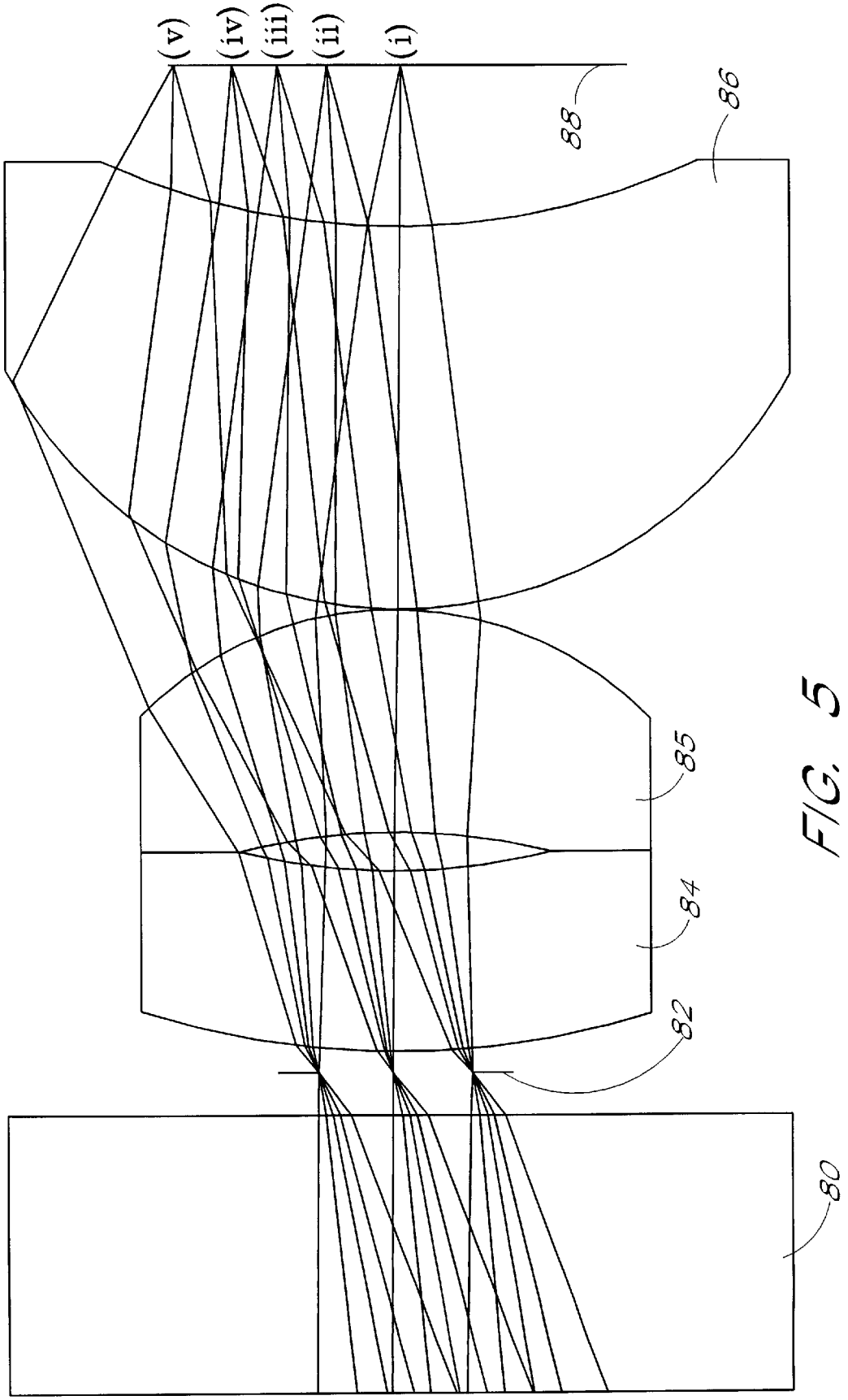


FIG. 5

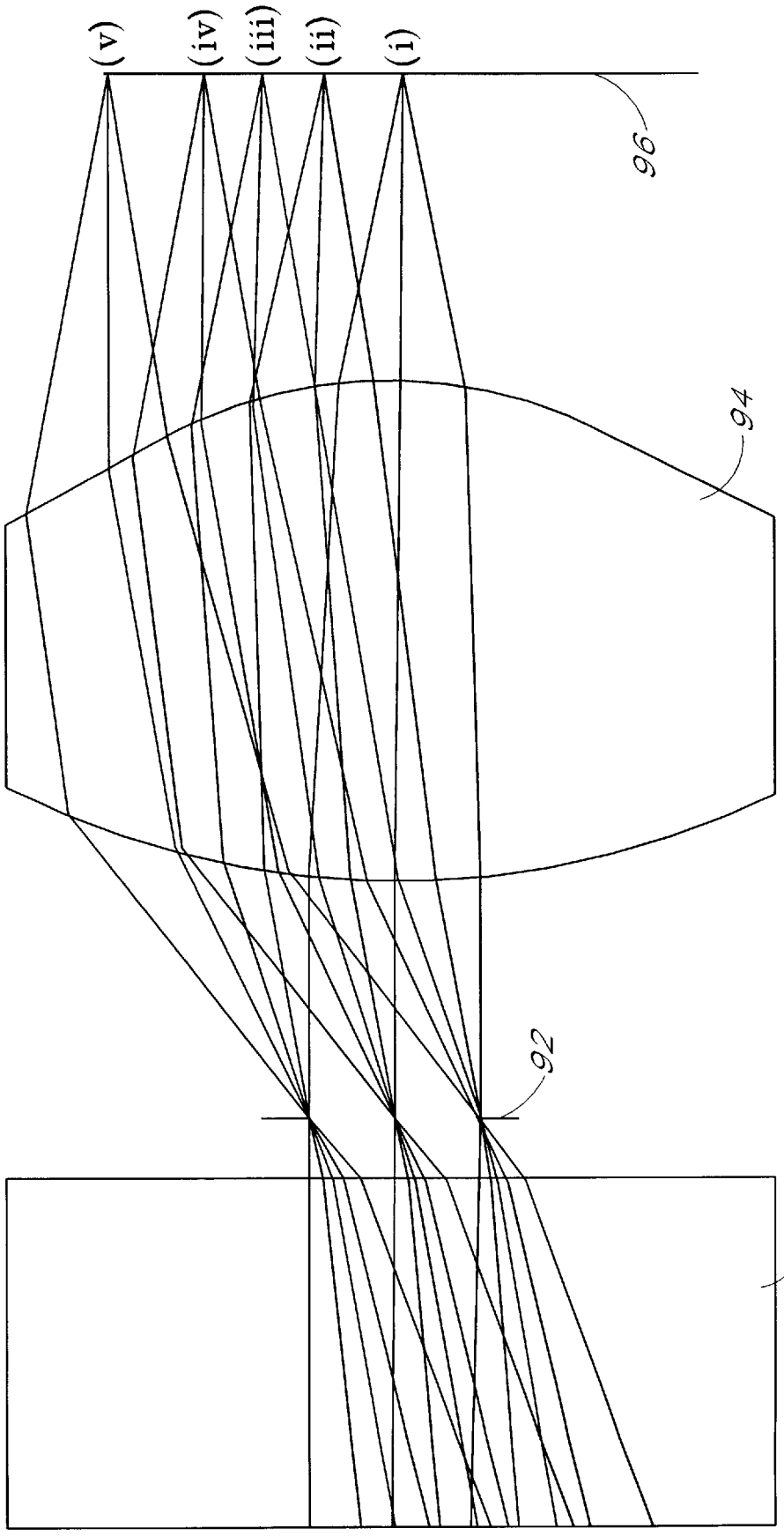


FIG. 6

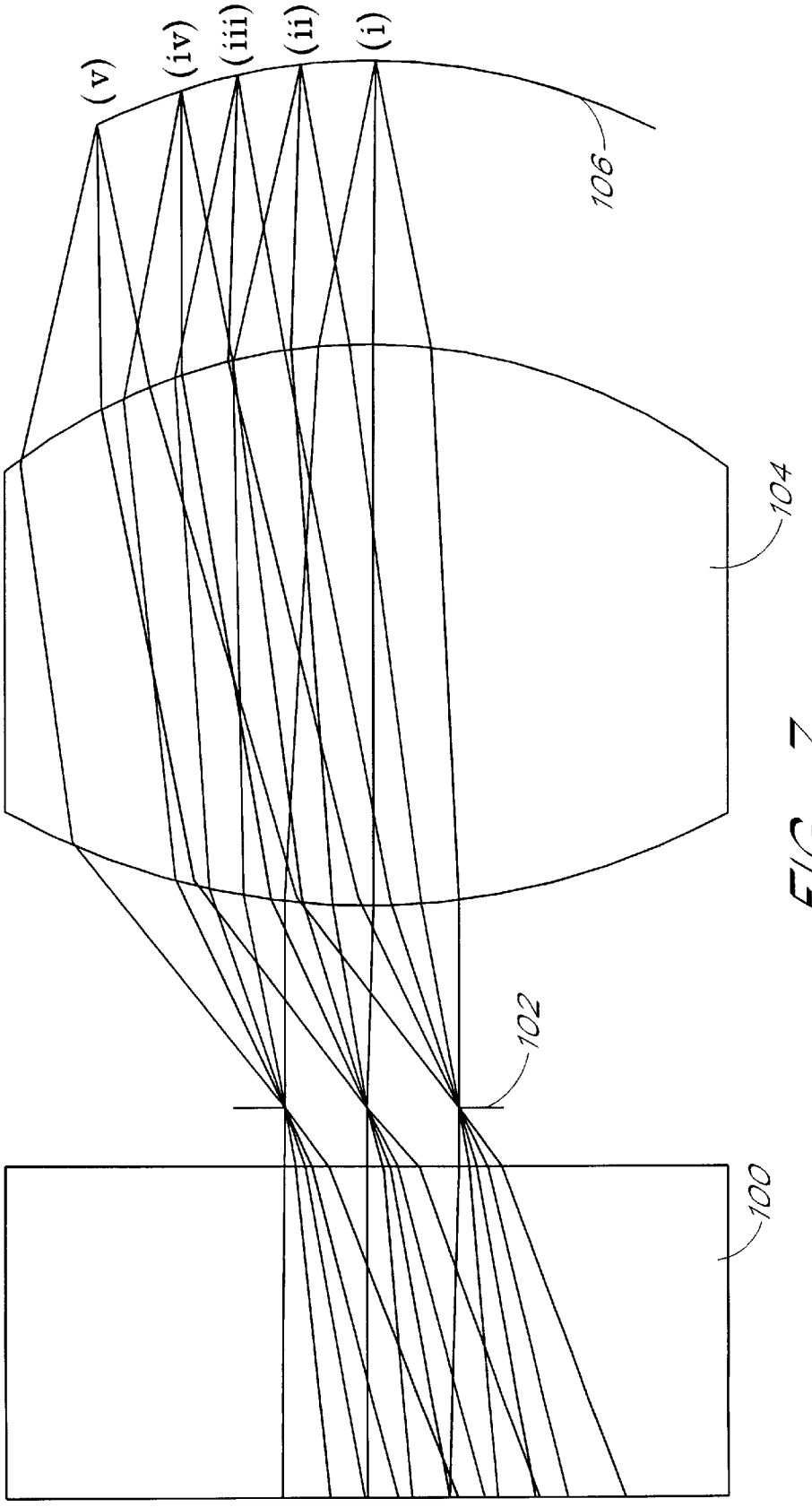


FIG. 7

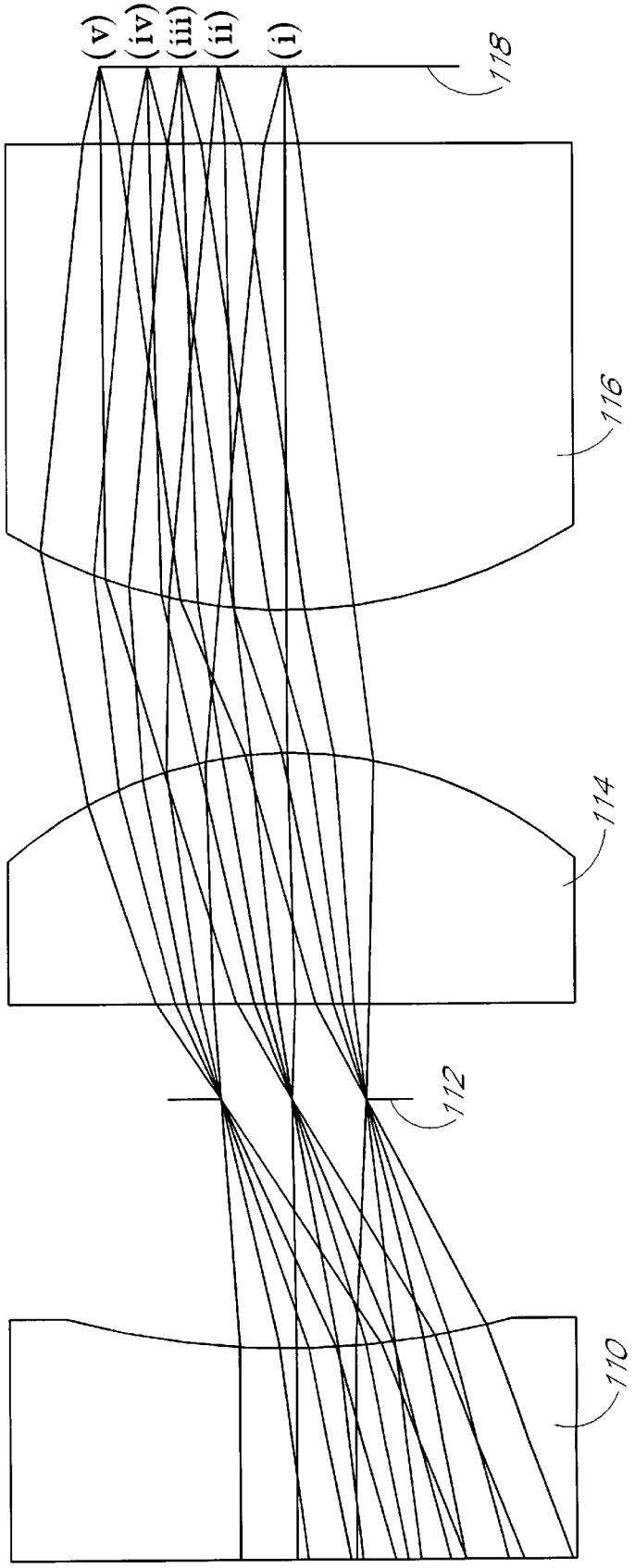


FIG. 8

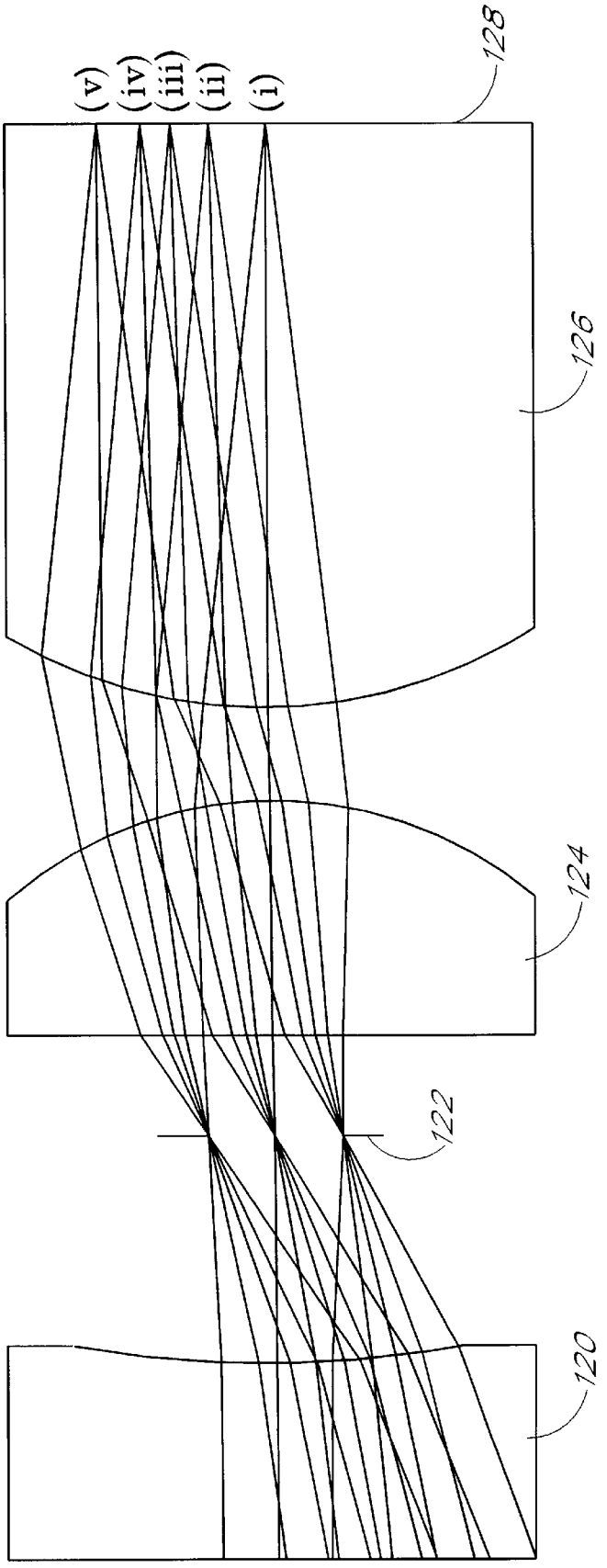


FIG. 9

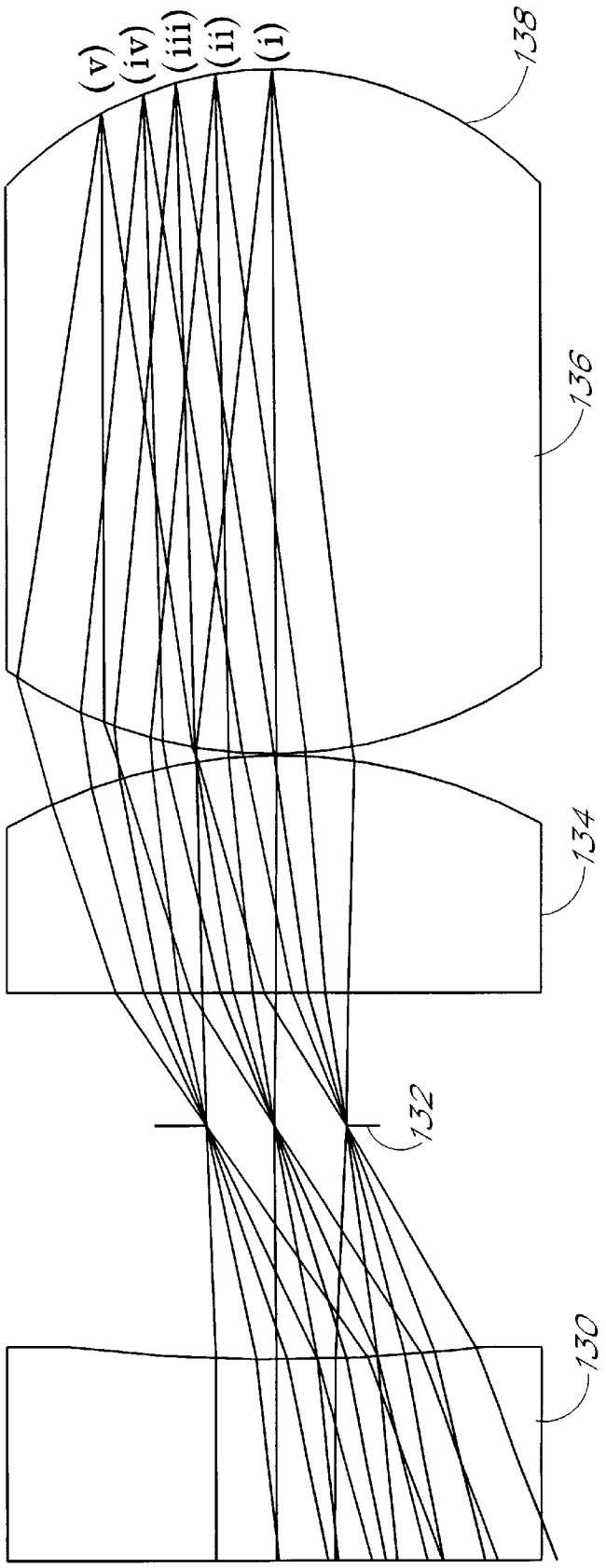


FIG. 10

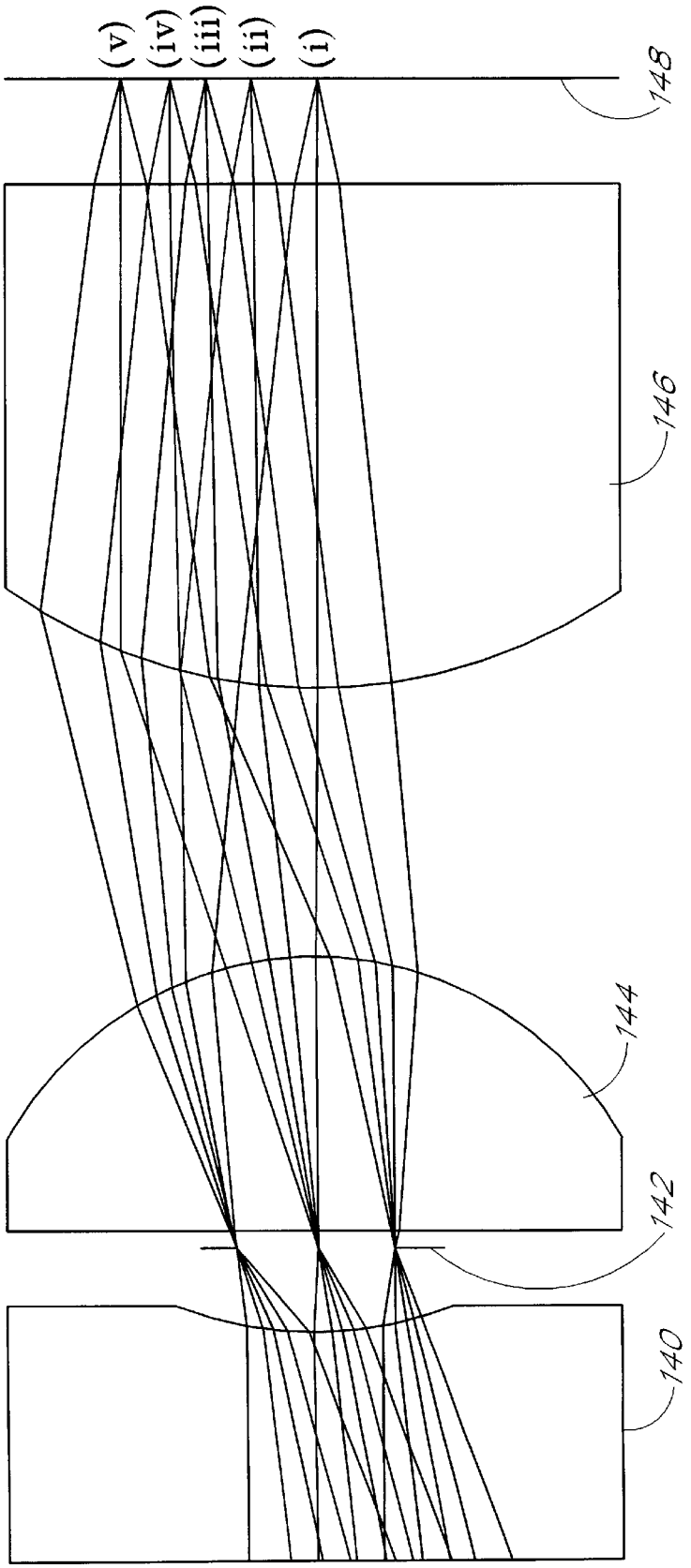


FIG. 11

SAPPHIRE OBJECTIVE SYSTEM

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention relates generally to an objective lens system ("objective") for use in endoscopes and the like, and more specifically to landscape and retrofocus type objectives for endoscopes.

2. Description of the Prior Art

Endoscopy is a technique that allows the examination of an area of a body by means of an endoscope, which is a tube like instrument with lenses and a light source attached. The endoscope provides a visual examination of the interior of a body through a natural body opening such as the throat, or through a small incision into the body. Because an endoscope can be inserted through a very small opening, it is a less invasive method than other surgical techniques, causing less scaring and quicker recovery time. A camera or video recorder is often used during an endoscopic procedure to provide long term records of internal organs which can be used for later reference. The increasing use of endoscopes for both diagnostic and therapeutic uses has substantially reduced the need for invasive surgical procedures such as gynecological and reproductive disorders, biopsies, gastrointestinal track inspection, knee and other joint surgery and the like.

In basic structure, the endoscope typically includes an ocular at its proximal end and an objective assembly at its distal end. Between the ocular and the objective assembly, a typical endoscope will include elongated relay optics of relatively small cross-section. The relay optics can be rigid and include rod lenses spaced along a sheath. Alternatively, the relay optics can be flexible and include optical fibers.

The smaller the cross-section of the distal end of the endoscope, the less invasive the procedure. For medical applications, these optics have to be relatively good and without visible distortion. There is a tension between reducing the cross-section of the endoscope distal end and improving its optical quality. The resulting conventional optical systems used in endoscopes are generally complex and employ various combinations of lenses within the elongated tube or sheath, typically including the objective lens, the relay lens system, and the ocular or eyepiece. The objective lens forms an image at the inner distal end of the tube which is then picked up and transmitted by the relay lens system to the proximal end of the tube where it is viewed with the ocular.

The objective lens is generally a wide angle lens having a short focal length and is physically separated from its environment by a rugged, transparent optical material. In order to correct for the various chromatic as well as geometric aberrations inherent in lenses, it is generally necessary to employ several different lenses, each of which corrects or partially corrects for aberrations in the optical train. Geometric aberrations are typically reduced by increasing the number of lenses or aspherizing one or more surfaces, whereas chromatic aberration can be corrected for by the proper choice of low and high dispersion glasses. Typical prior art endoscope designs include retrofocus lens systems made of glass having one or more aspheric surfaces. (See, for example, U.S. Pat. Nos. 4,403,837 to Nakahasi and 4,867,546 to Nishioka et al.) Unfortunately, these systems are relatively complicated, employing aspheric lenses, and typically have relatively long total tracks and higher than desirable distortion.

The use of sapphire as a material in endoscopic systems has been largely limited to that of a protective covering or window at the distal end of the endoscope. A sapphire barrier at the distal end of an endoscope is said to have enhanced resistance to the higher temperatures and pressures associated with sterilization procedures, such as found in an autoclave. U.S. Pat. No. 5,377,669 to Schulz discloses a sapphire protective covering whose proximal end is so constructed that the sapphire also functions as a negative lens. Although this sapphire negative lens increases the field of view of the objective, following nonsapphire optics are used to correct for geometric and chromatic aberrations. U.S. Pat. No. 5,555,131 to Horton describes an objective that employs a sapphire positive lens/plastic negative lens combination immediately following a virtual image of the stop. The other elements in the optical train are plastic with low indices of refraction and moderate dispersion. Since the refractive index of plastic is relatively low, an endoscope in accordance with the Horton patent has a relatively small field of view and a high f-number. To compensate for plastic's low index of refraction, aspheric surfaces are required, but they do not have enough bending power to limit the lenses to a small diameter, which results in the endoscopic procedure being more invasive in a surgical procedure. U.S. Pat. No. 5,424,877 to Tsuyuki et al. discloses an observation optical system for endoscopes in which the objective lens system may include a sapphire negative lens element for obtaining a wide angle visual field. Sapphire is also used in rod form in fiber optic probe systems (U.S. Pat. No. 5,166,756 to McGee et al. and U.S. Pat. No. 5,351,322 to VonBargen) and as a contact member in a surgical laser probe (U.S. Pat. No. 4,592,353 to Daikuzono).

There is still a need, however, for endoscopic systems, and in particular objective lens systems for endoscopes and the like, that are compact, small in diameter, simple, and offer the user high optical performance.

SUMMARY OF THE INVENTION

The invention relates to landscape and retrofocus type objectives for endoscopes whose objectives are made substantially or entirely from sapphire optical components. The resulting objectives have good fields of view, are rugged enough to withstand high temperatures such as found in an autoclave, of a same diameter, provide fast (i.e., low) f-numbers, and good optical quality with low distortion.

In one embodiment of the invention, there is provided an objective lens system for forming an image at the distal end of an endoscope that is to be transmitted to the proximal end of the endoscope. The objective lens system has a first optical group of a net positive optical power that includes a plurality of optical components, more than one of which comprise sapphire, or alternatively, an all sapphire, first optical group of positive optical power having at least one optical component. The objective lens system also includes an aperture stop on the object side of said first optical group. In one embodiment, the objective lens system further comprises a second optical group on the object side of the first optical group. The second optical group may comprise an optical window such that the objective lens system is of the landscape type, or alternatively, the second optical group may be of negative optical power with the objective lens system being of the retrofocus type.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1***a* shows an embodiment of an endoscopic landscape-type objective lens system along with ray paths through the system.

FIG. **1***b* shows ray trace information in the form of spot diagrams for the embodiment of FIG. **1***a*.

FIG. **1***c* shows polychromatic diffraction modulation transfer functions for the embodiment of FIG. **1***a*.

FIG. **1***d* shows field curvature and distortion plots for the embodiment of FIG. **1***a*.

FIGS. **2–7** show additional embodiments of endoscopic landscape-type objective lens systems along with respective ray paths through the systems.

FIG. **8** shows an embodiment of an endoscopic retrofocus-type objective lens system along with ray paths through the system.

FIGS. **9–11** show additional embodiments of endoscopic retrofocus-type objective lens systems.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

The numerical information and descriptions given below are surface specifications for preferred embodiments of the endoscope objectives according to the present invention, in which Embodiments 1–7 are landscape-type objectives and Embodiments 8–11 are retrofocus-type objectives. Herein "retrofocus" refers to a lens or lens system consisting of an ordinary objective and a negative component near its front focal point. Thus, the back focus is large, relative to its focal length, and the field angle is relatively large. Retrofocus lenses are sometimes referred to as reversed telephoto lens systems. A (rear) landscape-type objective is composed of a stop followed by a positive lens group. In its simplest form, it is a single positive meniscus lens with a stop that is positioned between the lens and the object to minimize coma and tangential field curvature. Other geometric aberrations are either tolerated or minimized by reducing the aperture diameter. It is possible to have a front landscape lens (i.e., a lens with the positive group before the stop), although its aberration residuals are generally much worse than the rear landscape lens. In the embodiments disclosed herein, generally the stop is shifted to the front focal point of the lens group to make the lens telecentric in image space, although this position may be somewhat shifted depending on the numerical aperture of the relay optics to favorably correct aberrations. Spherical aberration is well corrected by the second lens and high refractive index of the sapphire, and therefore faster (i.e., lower) f-numbers are possible. Lateral color is held to negligible levels because of sapphire's low dispersion.

In accordance with the present invention, the objective lens system includes optical elements made of sapphire. Sapphire has a high index of refraction (i.e., n_d=1.768), as well as low dispersion, and these optical properties are utilized to produce favorable designs for objective lens systems. In particular, less curvature is required in the optical elements that constitute the objective, so that geometric aberrations are reduced, and the low dispersion leads to less severe chromatic aberration.

The following abbreviations and notation are used throughout: "FOV" is the field of view in degrees, "ROC" is the radius of curvature of the optical element (indicated as infinity in the case of a plano surface), "Thickness" is the center thickness of the optical element (or the distance between elements in the case of a space between elements), and "Diameter" is the diameter at the given surface. All lengths are in millimeters (corresponding to the preferred embodiments). The conic constant defines the curvature of the conic section, in which a conic constant of 0 corresponds to a spherical surface, a conic constant less than −1 to a hyperboloid, a conic constant=−1 to a paraboloid, a conic constant between −1 and 0 to a prolate ellipsoid, and a conic constant greater than 0 to an oblate ellipsoid.

The invention relates to landscape and retrofocus type objectives for endoscopes and the like, in which the objectives are comprised substantially or entirely of sapphire optical components or another material having a high index of refraction (on the order of 1.7 or greater) and a high Abbe number (on the order of 65 or greater). Because sapphire has a high index of refraction (n_d=1.768), there is effectively more bending power per surface, and therefore less curvature is required to bring an image to a focus, so that geometric aberrations are reduced. Furthermore, sapphire has low dispersion (i.e., an Abbe number of 72.2), so that chromatic aberrations are intrinsically less severe. Because of these favorable optical properties, the lens objectives of the present invention are compact and have excellent optical properties, such as moderately wide field of view (up to about 80° or less) and relatively fast f-numbers (e.g., down to about 1.7), which makes them advantageous for endoscopic use. Additionally, sapphire is a highly durable material that may be fabricated more precisely and to higher optical quality than conventional glasses or plastics. Further, because of sapphire's high index of refraction, an antireflection coating may consist of only a single layer of magnesium fluoride, instead of the multiple layers generally required for glass optics.

FIG. **1***a* shows a first preferred embodiment of the present invention. The surface specifications of Embodiment 1 appear in Table 1. This embodiment is advantageous due to the low number of lenses and the simplicity of their design, but edge performance is better in other embodiments. At the object side of an objective **20** within an endoscopic sheath **22**, there is preferably a window **24** followed by two plano-convex sapphire elements **26** and **28**. The window **24** in this and the other embodiments physically separates the objective **20** from the surrounding environment. The window is preferably made of sapphire but alternatively can be polycarbonate, fused silica or another transparent optical material.

TABLE 1

EMBODIMENT 1
Image space F/# = 2.5
Effective focal length = 8.150E − 001
Maximum FOV = 7.700E + 001

SURFACE	ELEMENT	ROC	THICKNESS	MATERIAL	DIAMETER	CONIC CONSTANT
Object		Infinity	2.000E + 001		3.254E + 001	0
1	24	Infinity	6.100E − 001	Sapphire	1.330E + 000	0
2	24	Infinity	0		1.330E + 000	0
3 (Dummy)		Infinity	1.100E − 001		4.997E − 001	0
Stop	30	Infinity	2.747E − 001		3.260E + 000	0
5	26	Infinity	7.000E − 001	Sapphire	1.350E + 000	0
6	26	−1.120E + 000	0		1.350E + 000	0

TABLE 1-continued

EMBODIMENT 1
Image space F/# = 2.5
Effective focal length = 8.150E − 001
Maximum FOV = 7.700E + 001

SURFACE	ELEMENT	ROC	THICKNESS	MATERIAL	DIAMETER	CONIC CONSTANT
7	28	1.420E + 000	6.999E − 001	Sapphire	1.350E + 000	0
8	28	Infinity	4.273E − 001		1.350E + 000	0
IMAGE	34	Infinity			1.029E + 000	0

The window **24** and sapphire element **26** are preferably separated by an aperture stop **30**, although in all the embodiments discussed herein, the aperture stop can alternatively be located on the object side of the most distal optical component or within the objective. In this and the other embodiments, if a window is not used, then the aperture stop is preferably placed in direct contact with the outside of the most distal of the sapphire elements so as to avoid clogging the aperture. Elements **26** and **28** are preferably in contact with each other so that ancillary spacers are not required. The objective **20** images an object onto a focal plane **34** on the image side of the objective at the distal end of the endoscope, with the image being transmitted to the proximal end of the endoscope, generally through relay optics **36** (shown schematically) that may include a fiber optic followed by an eyepiece **38**.

The spot diagram information of FIG. **1***b* corresponds to Embodiment 1 and illustrates the extent of chromatic aberrations in the focal plane **34** at the wavelengths 0.486, 0.587, and 0.656 microns, as determined for five different angles of inclination designated (i)–(v): 0 degrees (the on-axis case), 11, 19, 26.3, and 38.5 degrees (the marginal ray case, representing the maximum possible inclination). These angles correspond to the field points (i)–(v) shown in FIG. **1***a* as well as in FIGS. **2–11** below (except that in FIGS. **8–11** the maximum possible inclination is 37.5 degrees, corresponding to a maximum field of view of 75 degrees). Even for the marginal rays, the extent of chromatic aberration is quite limited, as can be seen in FIG. **1***b*. FIG. **1***c* illustrates the polychromatic diffraction modulation transfer functions for the same 5 field points and indicates that performance is quite good. The field curvature and distortion plots for the objective **20** shown in FIG. **1***d* likewise illustrate that the optical performance is good. The weighting factors used for these calculations are 1.0, 0.3, and 0.3 for 0.587, 0.486, and 0.656 microns, respectively. The apparent resolution as perceived by an observer may actually be higher than what is shown in FIG. **1***c*, since barrel distortion (cf. FIG. **1***d*) causes compression of the image at the edge of the field, an effect that may be partially deconvolved by the observer.

FIG. **2** shows a more optically optimized configuration corresponding to Embodiment 2, in which performance at the edge of the field is improved at the expense of design simplicity and distortion. The lens data for the second embodiment appear in Table 2, below. In this embodiment, a window **50** is followed by an aperture stop **52** and two sapphire elements **54** and **56** that are preferably noncontacting. The sapphire elements **54** and **56** have curvature on both of their respective sides, leading to improved performance of the objective. The image is focused onto a focal plane **58**.

TABLE 2

EMBODIMENT 2
Image space F/# = 2.5
Effective focal length = 8.533E − 001
Maximum FOV = 7.700E + 001

SURFACE	ELEMENT	ROC	THICKNESS	MATERIAL	DIAMETER	CONIC CONSTANT
Object		Infinity	2.000E + 001		3.252E + 001	0
1	50	Infinity	6.100E − 001	Sapphire	1.440E + 000	0
2	50	Infinity	0		1.440E + 000	0
3 (Dummy)		Infinity	1.000E − 001		4.991E − 001	0
Stop	52	Infinity	8.098E − 002		3.413E − 001	0
5	54	−1.428E + 000	7.000E − 001	Sapphire	9.600E − 001	0
6	54	−9.330E − 001	2.404E − 001		1.440E + 000	0
7	56	1.334E + 000	6.999E − 001	Sapphire	1.440E + 000	0
8	56	−6.719E + 000	5.759E − 001		1.440E + 000	0
IMAGE	58	Infinity			1.021E + 000	0

FIG. **3** shows a third embodiment, in which the image "plane" is curved to better compensate for field curvature, which is especially important at the edge of the field. The lens data for the third embodiment appear in Table 3, below. This embodiment comprises a window **60**, an aperture stop **62**, and sapphire elements **64** and **66**, which focus the image to a curved image surface **68**. The objective shown here results in acceptable distortion with excellent resolution over the full extent of the field and is pixel-limited (i.e., the resolution of the optical system is better than pixel resolution) across the entire field, given state of the art pixel technology.

TABLE 3

EMBODIMENT 3
Image space F/# = 2.5
Effective focal length = 8.351E − 001
Maximum FOV = 7.700E + 001

SURFACE	ELEMENT	ROC	THICKNESS	MATERIAL	DIAMETER	CONIC CONSTANT
Object		Infinity	2.000E + 001		3.236E + 001	0
1	60	Infinity	6.100E − 001	Sapphire	1.260E + 000	0
2	60	Infinity	0		1.260E + 000	0
3 (Dummy)		Infinity	1.000E − 001		3.340E − 001	0
Stop	62	Infinity	0		3.340E − 001	0
5	64	5.799E + 000	7.000E − 001	Sapphire	1.260E + 000	0
6	64	−1.309E + 000	2.410E − 001		1.260E + 000	0
7	66	2.012E + 000	6.999E − 001	Sapphire	1.260E + 000	0
8	66	−1.425E + 000	3.494E − 001		1.260E + 000	0
IMAGE	68	−1.033E + 000			1.022E + 000	0

Alternative landscape-type objectives (Embodiments 4–7) are shown in FIGS. **4–7**, respectively. FIG. **4** shows an objective comprising a window **70**, aperture stop **72**, and sapphire elements **74** and **76**. The lens data for the fourth embodiment appear in Table 4, below. The image surface **78** is embedded in sapphire element **76** and is preferably aligned with the sapphire element's proximal surface, thereby facilitating direct coupling of the image into a fiber optic cable, for example. Embodiment 4 has resolution similar to Embodiment 2 with distortion performance similar to Embodiment 1.

FIG. **5** illustrates an objective composed of, in addition to a window **80** and aperture stop **82**, three sapphire elements **84**, **85**, and **86**. The lens data for the fifth embodiment appear in Table 5, below. Embodiment 5 has an increased complexity to yield optical performance similar to Embodiment 3, but in a flat focal plane **88**.

TABLE 4

EMBODIMENT 4
Image space F/# = 2.5
Effective focal length = 8.075E − 001
Maximum FOV = 7.700E + 001

SURFACE	ELEMENT	ROC	THICKNESS	MATERIAL	DIAMETER	CONIC CONSTANT
Object		Infinity	2.000E + 001		3.236E + 001	0
1	70	Infinity	6.100E − 001	Sapphire	1.260E + 000	0
2	70	Infinity	0		1.260E + 000	0
3 (Dummy)		Infinity	0.1		3.230E − 001	0
Stop	72	Infinity	4.782E − 002		3.230E − 001	0
5	74	2.869E + 000	7.000E − 001	Sapphire	1.260E + 000	0
6	74	−9.341E − 001	1.992E − 001		1.260E + 000	0
7	76	2.242E + 000	9.972E − 001	Sapphire	1.260E + 000	0
8	76	−1.735E + 000	0		1.260E + 000	0
IMAGE	78	−1.735E + 000			1.022E + 000	0

TABLE 5

EMBODIMENT 5
Image space F/# = 2.5
Effective focal length = 8.548E − 001
Maximum FOV = 7.700E + 001

SURFACE	ELEMENT	ROC	THICKNESS	MATERIAL	DIAMETER	CONIC CONSTANT
Object		Infinity	2.000E + 001		3.236E + 001	0
1	80	Infinity	6.100E − 001	Sapphire	1.440E + 000	0
2	80	Infinity	0		1.700E + 000	0
3 (Dummy)		Infinity	0.1		3.419E − 001	0

TABLE 5-continued

EMBODIMENT 5
Image space F/# = 2.5
Effective focal length = 8.548E − 001
Maximum FOV = 7.700E + 001

SURFACE	ELEMENT	ROC	THICKNESS	MATERIAL	DIAMETER	CONIC CONSTANT
Stop	82	Infinity	0.1		3.419E − 001	0
5	84	1.552E + 000	3.997E − 001	Sapphire	1.140E + 000	0
6	84	1.378E + 000	6.676E − 002		6.218E − 001	0
7	85	−1.562E + 000	5.659E − 001	Sapphire	6.218E − 001	0
8	85	−8.066E − 001	0		1.140E + 000	0
9	86	9.992E − 001	8.409E − 001	Sapphire	1.700E + 000	0
10	86	1.859E + 000	3.496E − 001		1.259E + 000	0
IMAGE	88	Infinity			1.033E + 000	0

FIG. **6** shows an objective comprising a window **90**, an aperture stop **92**, and a single sapphire element **94** with two aspheric surfaces leading to a flat image plane **96**. The lens data for the sixth embodiment appear in Table 6, below. This embodiment is easy to assemble and has a higher per lens fabrication cost due to the aspheric surfaces. It yields an objective having resolution about the same as Embodiment 1, but with improved distortion.

FIG. **7** shows another single sapphire lens embodiment comprising a window **100**, an aperture stop **102**, and a sapphire element **104** having two aspheric surfaces leading to a curved image surface **106**. The lens data for the seventh embodiment appear in Table 7, below. Embodiment 7 has excellent resolution over the entire field with low distortion. Like Embodiment 3, it is pixel-limited across the entire field, in view of state of the art pixel technology.

TABLE 6

EMBODIMENT 6
Image space F/# = 2.5
Effective focal length = 7.343E − 001
Maximum FOV = 7.700E + 001

SURFACE	ELEMENT	ROC	THICKNESS	MATERIAL	DIAMETER	CONIC CONSTANT
Object		Infinity	2.000E + 001		3.254E + 001	0
1	90	Infinity	6.100E − 001	Sapphire	1.340E + 000	0
2	90	Infinity	0		4.676E − 001	0
3 (Dummy)		Infinity	1.100E − 001		4.676E − 001	0
Stop	92	Infinity	4.129E − 001		2.937E − 001	0
5	94	1.294E + 000	8.617E − 001	Sapphire	1.340E + 000	−2.865E + 000
6	94	−7.107E − 001	5.334E − 001		1.340E + 000	−2.924E + 000
IMAGE	96	Infinity			1.038E + 000	0

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TABLE 7

EMBODIMENT 7
Image space F/# = 2.5
Effective focal length = 7.969E − 001
Maximum FOV = 7.700E + 001

SURFACE	ELEMENT	ROC	THICKNESS	MATERIAL	DIAMETER	CONIC CONSTANT
Object		Infinity	2.000E + 001		3.254E + 001	0
1	100	Infinity	6.100E − 001	Sapphire	1.320E + 000	0
2	100	Infinity	0		4.925E − 001	0
3 (Dummy)		Infinity	1.100E − 001		4.925E − 001	0
Stop	102	Infinity	3.723E − 001		3.187E − 001	0
5	104	1.162E + 000	1.018E + 000	Sapphire	1.320E + 000	−3.011E + 000
6	104	−8.008E − 001	5.185E − 001		1.320E + 000	−2.395E + 000
IMAGE	106	−1.181E + 000			1.037E + 000	0

FIGS. **8–11** show retrofocus-type objectives corresponding to Embodiments 8–11. In FIG. **8**, a plano-convex element **110** that is preferably made of sapphire acts simultaneously as a window and as a negative lens, due to the curvature of its proximal surface. The objective further comprises an aperture stop **112** proximal to the element **110** and two sapphire elements **114** and **116**, leading to a focal plane **118**. The performance is about the same as in Embodiment 2.

Respective pairs of optical elements **124** and **126**, **134** and **136**, and **144** and **146** focus light on respective image planes **128**, **138**, and **148**. The optical elements of Embodiments 9–11 are all preferably sapphire. The focal plane **128** of Embodiment 9 is embedded in optical element **126**. Embodiment 9 has about the same performance as Embodiment 8 but with improved distortion. The image plane **138** of Embodiment 10 is likewise embedded in optical element **136**. As in Embodiment 3, the field curvature in Embodiment 10 is corrected, providing resolution that is pixel-limited given state of the art fiber image bundles. Embodiment 11 employs an aspheric surface as the proximal surface of the plano-convex element **140** to provide performance similar to that of Embodiment 10,

TABLE 8

EMBODIMENT 8
Image space F/# = 2.5
Effective focal length = 8.717E – 001
Maximum FOV = 7.500E + 001

SURFACE	ELEMENT	ROC	THICKNESS	MATERIAL	DIAMETER	CONIC CONSTANT
Object		Infinity	2.000E + 001		3.212E + 001	0
1	110	Infinity	6.000E – 001	Sapphire	1.600E + 000	0
2	110	2.990 + 000	7.000E – 001		1.092E + 000	0
Stop	112	Infinity	2.710E – 001		4.130E – 001	0
4	114	Infinity	7.000E – 001	Sapphire	7.678E – 001	0
5	114	–1.215 + 000	4.029E – 001		1.600E + 000	0
6	116	1.551 + 000	1.3000 + 0000	Sapphire	1.600E + 000	0
7	116	Infinity	2.340E – 001		1.128E + 000	0
IMAGE	118	Infinity			1.031E + 000	0

The embodiments shown in FIGS. **9–11** also comprise elements that simultaneously act as a window and negative lens, namely, plano-convex elements **120**, **130**, and **140**. These embodiments include respective aperture stops **122**, **132**, and **142** on the proximal of the plano-convex elements **120**, **130**, and **140**. The lens data for the ninth through eleventh embodiments appear in Tables 9–11, below.

TABLE 9

EMBODIMENT 9
Image space F/# = 2.5
Effective focal length = 8.748E – 001
Maximum FOV = 7.500E + 001

SURFACE	ELEMENT	ROC	THICKNESS	MATERIAL	DIAMETER	CONIC CONSTANT
Object		Infinity	20		32.14	0
1	120	Infinity	0.6	Sapphire	1.6	0
2	120	3.418	0.7000		1.24	0
Stop	122	Infinity	0.3119		0.4066	0
4	124	Infinity	0.7	Sapphire	0.8207	0
5	124	–1.267	0.2908		1.6	0
6	126	1.549	1.790	Sapphire	1.6	0
EMBEDDED IMAGE	126, 128	Infinity	0		1.6	0

TABLE 10

EMBODIMENT 10
Image space F/# = 2.5
Effective focal length = 9.309E – 001
Maximum FOV = 7.500E + 001

SURFACE	ELEMENT	ROC	THICKNESS	MATERIAL	DIAMETER	CONIC CONSTANT
Object		Infinity	20		32.18	0
1	130	Infinity	0.6	Sapphire	1.6	0
2	130	5.070	0.7000		1.24	0
Stop	132	Infinity	0.3915		0.4135	0

TABLE 10-continued

EMBODIMENT 10
Image space F/# = 2.5
Effective focal length = 9.309E − 001
Maximum FOV = 7.500E + 001

SURFACE	ELEMENT	ROC	THICKNESS	MATERIAL	DIAMETER	CONIC CONSTANT
4	134	Infinity	0.7	Sapphire	0.9852	0
5	134	−1.656	0		1.6	0
6	136	1.381	2.029	Sapphire	1.6	0
EMBEDDED IMAGE	136, 138	−1.124	0		1.6	0

TABLE 11

EMBODIMENT 11
Image space F/# = 2.5
Effective focal length = 8.945E − 001
Maximum FOV = 7.500E + 001

SURFACE	ELEMENT	ROC	THICKNESS	MATERIAL	DIAMETER	CONIC CONSTANT
Object		Infinity	2.000E + 001		3.151E + 001	0
1	140	Infinity	6.000E − 001	Sapphire	1.600E + 000	0
2	140	1.125E + 000	2.232E − 001		7.000E − 001	6.300E + 000
Stop	142	Infinity	4.492E − 002		4.139E − 001	0
4	144	Infinity	7.000E − 001	Sapphire	4.875E − 001	0
5	144	−9.271E − 001	7.000E − 001		1.600E + 000	0
6	146	1.401E + 000	1.300E + 000	Sapphire	1.600E + 000	0
7	146	Infinity	2.720E − 001		1.600E + 000	0
IMAGE	148	Infinity			1.600E + 000	0

Although the present invention is described herein with respect to endoscopic objective lens systems, it will be understood by those in the art that the principles disclosed herein can be used to design other optical systems, e.g., microscope objectives, optical systems for photocopier machines and the like, which use a wide field of view with low dispersion in perhaps a rugged environment with a broad temperature range. While sapphire has been emphasized, it should be noted that other, future materials having the same optical characteristics as sapphire would be within the spirit and scope of the present invention.

What is claimed is:

1. An objective lens system for forming an image at the distal end of an endoscope to be transmitted to the proximal end of the endoscope, comprising:

a first optical group, said first optical group having positive optical power and including a plurality of optical components, more than one of which comprises sapphire to reduce optical aberrations;

an aperture stop on the object side of said first optical group; and

a second optical group, in which said second optical group is on the object side of said first optical group

in which said second optical group comprises an optical window and said objective lens system is of the landscape type.

2. The objective lens system of claim **1**, said first optical group comprising two sapphire elements that contact each other.

3. The objective lens system of claim **1**, said first optical group comprising two noncontacting sapphire elements.

4. The objective lens system of claim **1**, in which the image at the distal end of the endoscope is nonplanar at its focus.

5. The objective lens system of claim **4**, in which the image at the distal end of the endoscope is at a focus near the proximal surface of an optical element.

6. The objective lens system of claim **1**, said first optical group comprising three sapphire elements.

7. The objective lens system of claim **1**, further comprising relay optics and an eyepiece to form an endoscope.

8. An objective lens system for forming an image at the distal end of an endoscope to be transmitted to the proximal end of the endoscope, comprising:

a first optical group, said first optical group having positive optical power and including a plurality of optical components, more than one of which comprises sapphire to reduce optical aberrations,

an aperture stop on the object side of said first optical group; and

a second optical group, in which said second optical group is on the object side of said first optical group, and

in which said aperture stop is located between said first and said second optical groups.

9. The objective lens system of claim **8**, further comprising relay optics and an eyepiece to form an endoscope.

10. An objective lens system for forming an image at the distal end of an endoscope to be transmitted to the proximal end of the endoscope, comprising:

a first optical group, said first optical group having positive optical power and including a plurality of optical components, more than one of which comprises sapphire to reduce optical aberrations;

an aperture stop on the object side of said first optical group; and

a second optical group, in which said second optical group is on the object side of said first optical group,

in which said second optical group is of negative optical power and said objective lens system is of the retrofocus type.

11. The objective lens system of claim **10**, in which said first optical group comprises two noncontacting sapphire elements and the image at the distal end of the endoscope is at a planar focus.

12. The objective lens system of claim **11**, in which the planar focus is near the proximal surface of an optical element.

13. The objective lens system of claim **10**, in which said first optical group comprises two contacting sapphire elements and the image at the distal end of the endoscope is at a nonplanar focus.

14. The objective lens system of claim **10**, further comprising relay optics and an eyepiece to form an endoscope.

15. An objective lens system for forming an image at the distal end of an endoscope to be transmitted to the proximal end of the endoscope, comprising:

an all sapphire, first optical group, said first optical group having positive optical power and including at least one optical component, said first optical group comprising sapphire to reduce optical aberrations;

an aperture stop on the object side of said first optical group; and

a second optical group, in which said second optical group is on the object side of said first optical group, and

in which said first optical group is a single sapphire element and the image at the distal end of the endoscope is non-planar at its focus.

16. The objective lens system of claim **15**, further comprising relay optics and an eyepiece to form an endoscope.

17. An objective lens system for forming an image at the distal end of an endoscope to be transmitted to the proximal end of the endoscope, comprising:

an all sapphire, first optical group, said first optical group having positive optical power and including at least one optical component, said first optical group comprising sapphire to reduce optical aberrations;

an aperture stop on the object side of said first optical group; and

a second optical group, in which said second optical group is on the object side of said first optical group, and

in which said second optical group comprises an optical window and said objective lens system is of the landscape type.

18. The objective lens system of claim **17**, in which said first optical group is a single sapphire element that focuses the image at the distal end of the endoscope to an image plane.

19. The objective lens system of claim **17**, further comprising relay optics and an eyepiece to form an endoscope.

20. An objective lens system having an object side and an image side, comprising:

a first optical group, said first optical group having positive optical power and including a plurality of optical components, more than one of which has an index of refraction greater than 1.7 and an Abbe number of at least 65 to reduce optical aberrations; and

an aperture stop on the object side of said first optical group.

21. The objective lens system of claim **20**, comprising:

a second optical group, in which said second optical group is on the object side of said first optical group and includes an optical window, and

in which said objective lens system is of the landscape type.

22. The objective lens system of claim **21**, said first optical group comprising two sapphire elements that contact each other.

23. The objective lens system of claim **21**, said first optical group comprising two non-contacting sapphire elements.

24. The objective lens system of claim **21**, in which the image at the distal end of the endoscope is non-planar at its focus.

25. The objective lens system of claim **24**, in which the image at the distal end of the endoscope is at a focus near the proximal surface of an optical element.

26. The objective lens system of claim **21**, said first optical group comprising three sapphire elements.

27. The objective lens system of claim **21**, further comprising relay optics and an eyepiece to form an endoscope.

28. The objective lens system of claim **20**, further comprising a second optical group, in which said second optical group is on the object side of said first optical group, and in which said aperture stop is located between said first and said second optical groups.

29. The objective lens system of claim **28**, further comprising relay optics and an eyepiece to form an endoscope.

30. The objective lens system of claim **20**, further comprising a second optical group, in which said second optical group is on the object side of said first optical group, and in which said second optical group is of negative optical power and said objective lens system is of the retrofocus type.

31. The objective lens system of claim **30**, in which said first optical group comprises two non-contacting sapphire elements and the image at the distal end of the endoscope is at a planar focus.

32. The objective lens system of claim **31**, in which the planar focus is near the proximal surface of an optical element.

33. The objective lens system of claim **30**, in which said first optical group comprises two contacting sapphire elements and the image at the distal end of the endoscope is at a non-planar focus.

34. The objective lens system of claim **30**, further comprising relay optics and an eyepiece to form an endoscope.

35. An objective lens system having an object side and an image side, comprising:

a first optical group having positive optical power and including at least one optical component, said first optical group consisting essentially of optical material having an index of refraction greater than 1.7 and an Abbe number of at least 65 to reduce optical aberrations; and

an aperture stop on the object side of said first optical group.

36. The objective lens system of claim **35**, further comprising:

a second optical group, in which said second optical group is on the object side of said first optical group, and

in which said first optical group is a single sapphire element and the image at the distal end of the endoscope is non-planar at its focus.

37. The objective lens system of claim **36**, further comprising relay optics and an eyepiece to form an endoscope.

38. The objective lens system of claim 35, further comprising:

a second optical group, in which said second optical group is on the object side of said first optical group and comprises an optical window, and

in which said objective lens system is of the landscape type.

39. The objective lens system of claim 38, further comprising relay optics and an eyepiece to form an endoscope.

40. The objective lens system of claim 38, in which said first optical group is a single sapphire element that focuses the image at the distal end of the endoscope to an image plane.

41. A method of forming an image of an object, comprising:

imaging light through an objective, the objective including a first optical group having positive optical power and further including an aperture stop on the object side of the first optical group, the first optical group including a plurality of optical components of which more than one includes sapphire to reduce optical aberrations of the light imaged through the objective;

forming an image at the distal end of the objective; and

transmitting the image to the proximal end of an endoscope.

42. A method of forming an image of an object, comprising:

imaging light through an objective, the objective including a first optical group having positive optical power and further including an aperture stop on the object side of the first optical group, the first optical group consisting essentially of sapphire to reduce optical aberrations of the light imaged through the objective;

forming an image at the distal end of the objective; and

transmitting the image to the proximal end of an endoscope.

43. An objective lens system for forming an image at the distal end of an endoscope to be transmitted to the proximal end of the endoscope, comprising:

a first optical group, said first optical group having positive optical power and including a plurality of optical components, more than one of which comprises sapphire; and

an aperture stop on the object side of said first optical group, said aperture stop being conjugate with both an entrance pupil and an exit pupil of said lens system.

44. An objective lens system for forming an image at the distal end of an endoscope to be transmitted to the proximal end of the endoscope, comprising:

an all sapphire, first optical group, said first optical group having positive optical power and including at least one optical component; and

an aperture stop on the object side of said first optical group, said aperture stop being conjugate with both an entrance pupil and an exit pupil of said lens system.

45. An objective lens system for forming an image at the distal end of an endoscope to be transmitted to the proximal end of the endoscope, comprising:

a first optical group, said first optical group having positive optical power and including a plurality of optical components, more than one of which comprises sapphire;

an aperture stop on the object side of said first optical group; and

a second optical group of non-negative optical power, in which said second optical group is on the object side of said first optical group, said first optical group, said aperture stop, and said second optical group forming an objective lens system.

46. An objective lens system for forming an image at the distal end of an endoscope to be transmitted to the proximal end of the endoscope, comprising:

a first optical group, said first optical group having positive optical power and including a plurality of optical components, more than one of which comprises sapphire;

an aperture stop on the object side of said first optical group; and

a second optical group, in which said second optical group is on the object side of said aperture stop, wherein said first optical group, said aperture stop, and said second optical group form an objective lens system.

47. An objective lens system for forming an image at the distal end of an endoscope to be transmitted to the proximal end of the endoscope, comprising:

an all sapphire, first optical group, said first optical group having positive optical power and including at least one optical component;

an aperture stop on the object side of said first optical group; and

a second optical group, in which said second optical group is on the object side of said aperture stop, wherein said first optical group, said aperture stop, and said second optical group form an objective lens system.

48. An objective lens system for forming an image at the distal end of an endoscope to be transmitted to the proximal end of the endoscope, comprising:

a first optical group, said first optical group having positive optical power and including a plurality of optical components, more than one of which comprises sapphire;

an aperture stop on the object side of said first optical group; and

a second optical group, in which said second optical group is on the object side of said first optical group, said first optical group, said aperture stop, and said second optical group forming an objective lens system capable of imaging a field of view of up to 80 degrees.

49. The objective lens system of claim 48, in which said second optical group comprises an optical window and said objective lens system is of the landscape type.

50. The objective lens system of claim 49, said first optical group comprising two sapphire elements that contact each other.

51. The objective lens system of claim 49, said first optical group comprising two non-contacting sapphire elements.

52. The objective lens system of claim 49, in which the image at the distal end of the endoscope is non-planar at its focus.

53. The objective lens system of claim 52, in which the image at the distal end of the endoscope is at a focus near the proximal surface of an optical element.

54. The objective lens system of claim 49, said first optical group comprising three sapphire elements.

55. The objective lens system of claim 48, in which said aperture stop is located between said first and said second optical groups.

56. The objective lens system of claim 48, in which said second optical group is of negative optical power and said objective lens system is of the retrofocus type.

57. The objective lens system of claim 56, in which said first optical group comprises two non-contacting sapphire elements and the image at the distal end of the endoscope is at a planar focus.

58. The objective lens system of claim 57, in which the planar focus is near the proximal surface of an optical element.

59. The objective lens system of claim 56, in which said first optical group comprises two contacting sapphire elements and the image at the distal end of the endoscope is at a non-planar focus.

60. The objective lens system of claim 48, further comprising relay optics and an eyepiece to form an endoscope.

* * * * *

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United States Patent [19]

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[54] **METHOD AND APPARATUS FOR ALIGNING AN OBJECTIVE LENS**

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[58] **Field of Search** 359/822, 819, 359/823, 811, 813, 818

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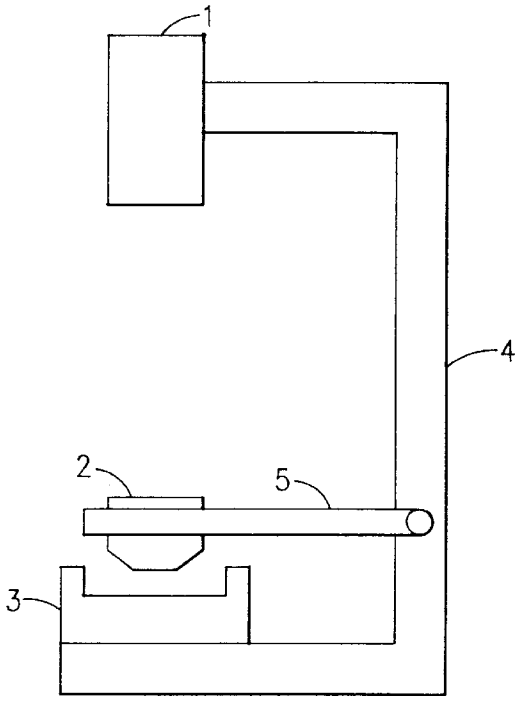
Primary Examiner—Georgia Epps
Assistant Examiner—Michael A Lucas
Attorney, Agent, or Firm—Keiji Masaki; Donald Bollella; Donald L. Wenskay

[57] **ABSTRACT**

An apparatus for aligning an actuator lens within a baseplate using a beam of radiant energy. The actuator lens has an actuator optical axis and an actuator optical center and the apparatus includes a frame, a cradle, a tower assembly, a lever assembly, and a gripper assembly. The cradle assembly is employed to hold the baseplate and is mounted to the frame with at least one degree of freedom of motion. The tower assembly defines a tower axis and is also mounted to the frame. The cradle and tower assemblies are positioned to receive the beam of radiant energy along the tower axis and analyze a spot profile of the beam. The lever assembly is rotatably mounted to the frame and the gripper assembly is mounted to the lever assembly.

1 Claim, 8 Drawing Sheets



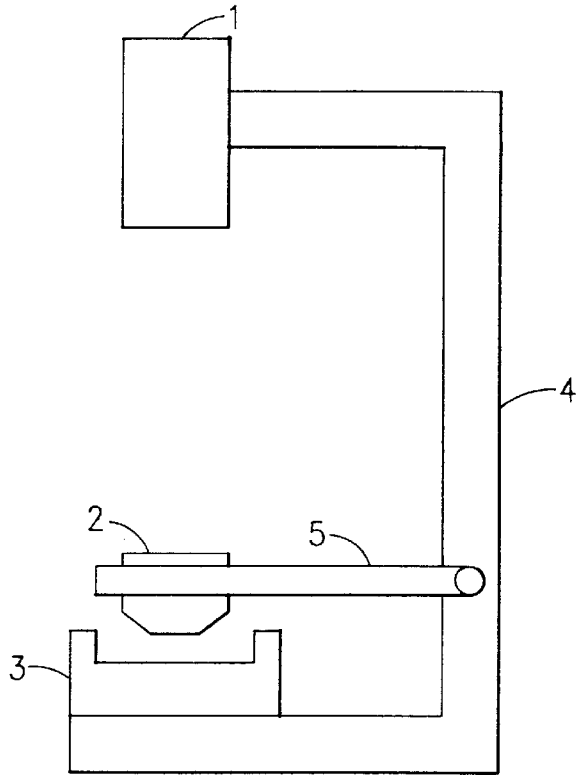


FIG.1

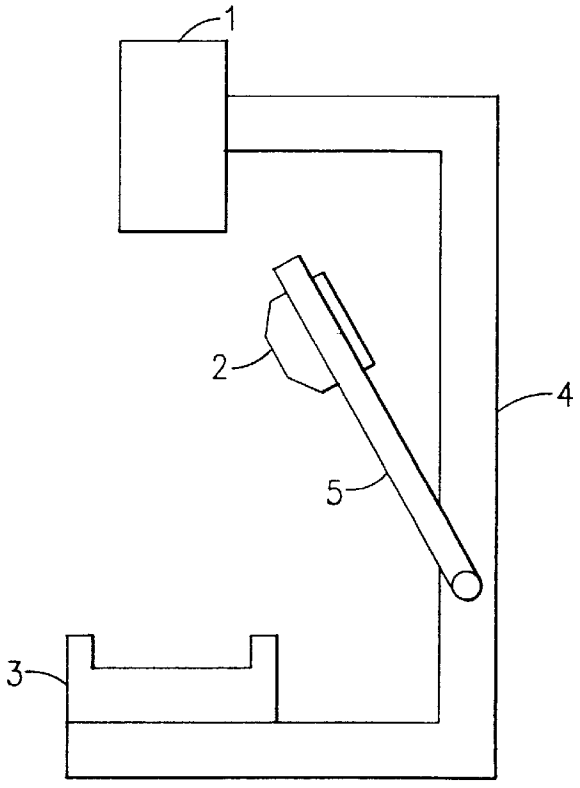


FIG.2

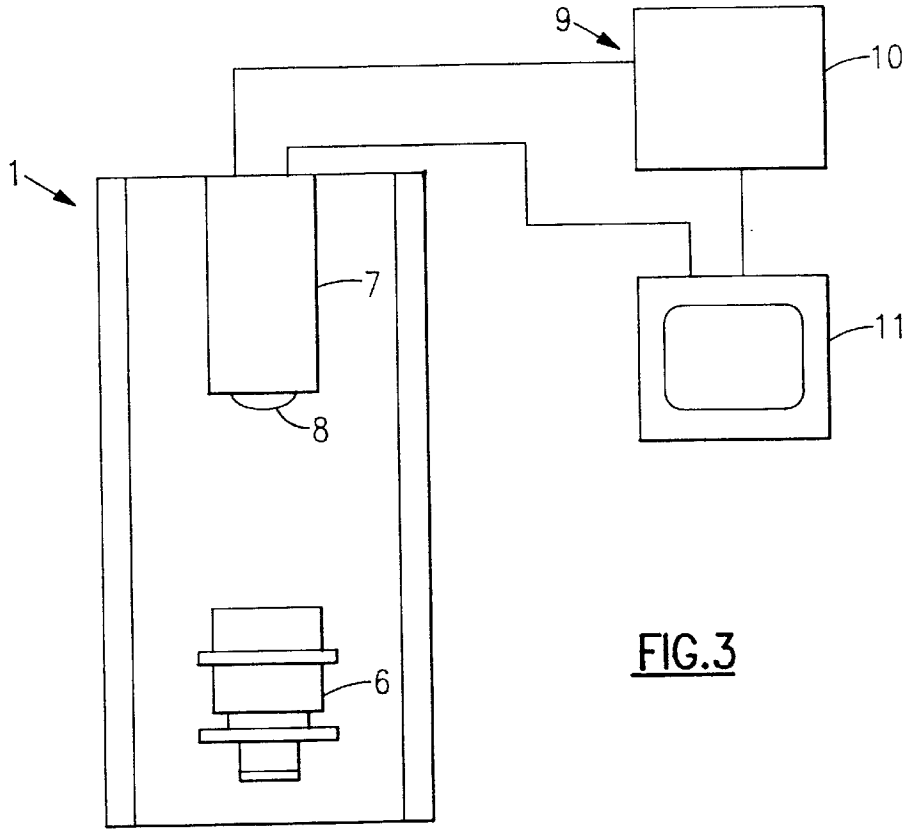


FIG.3

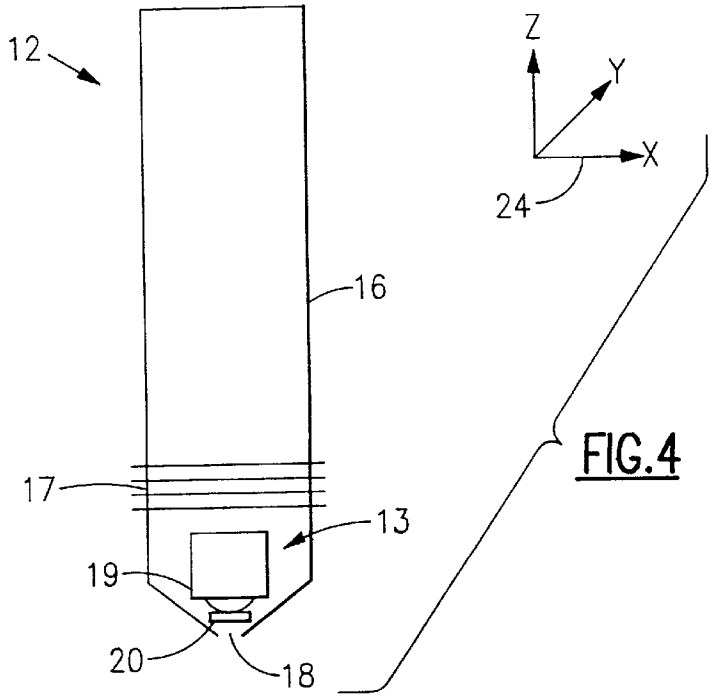


FIG.4

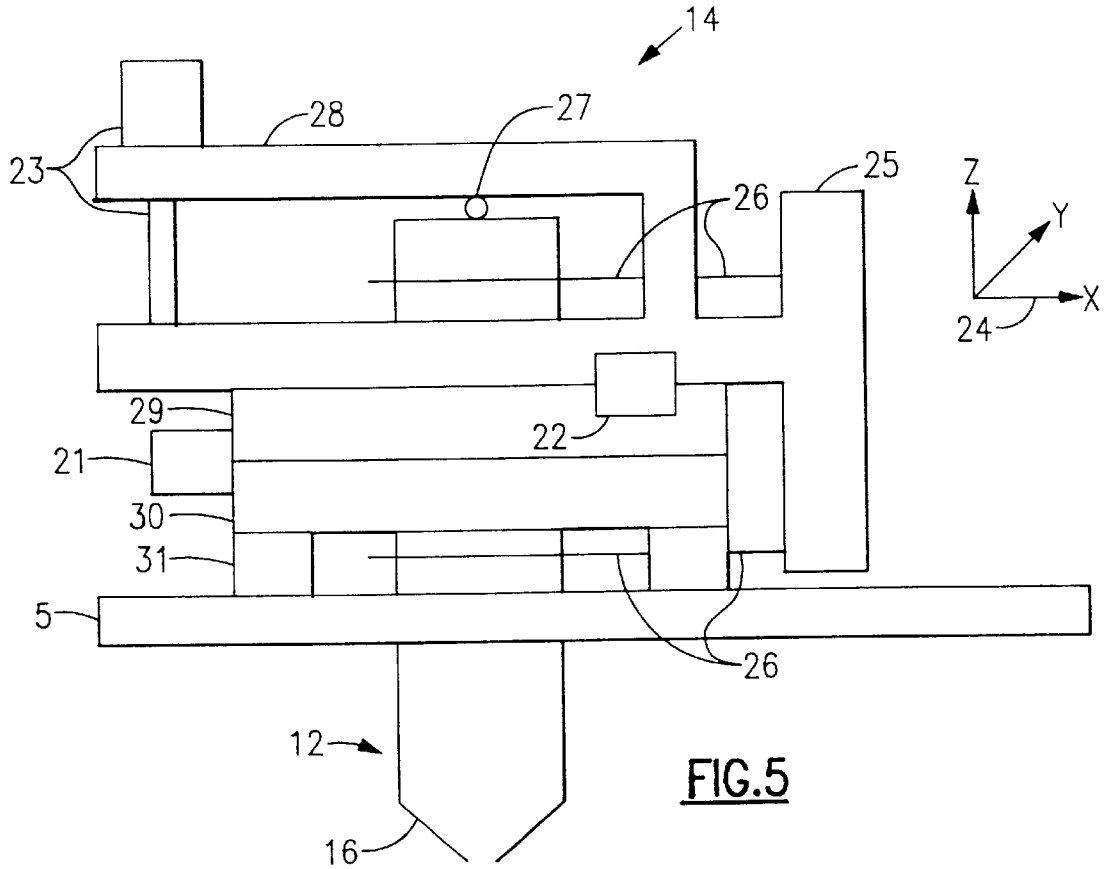

14
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FIG.5

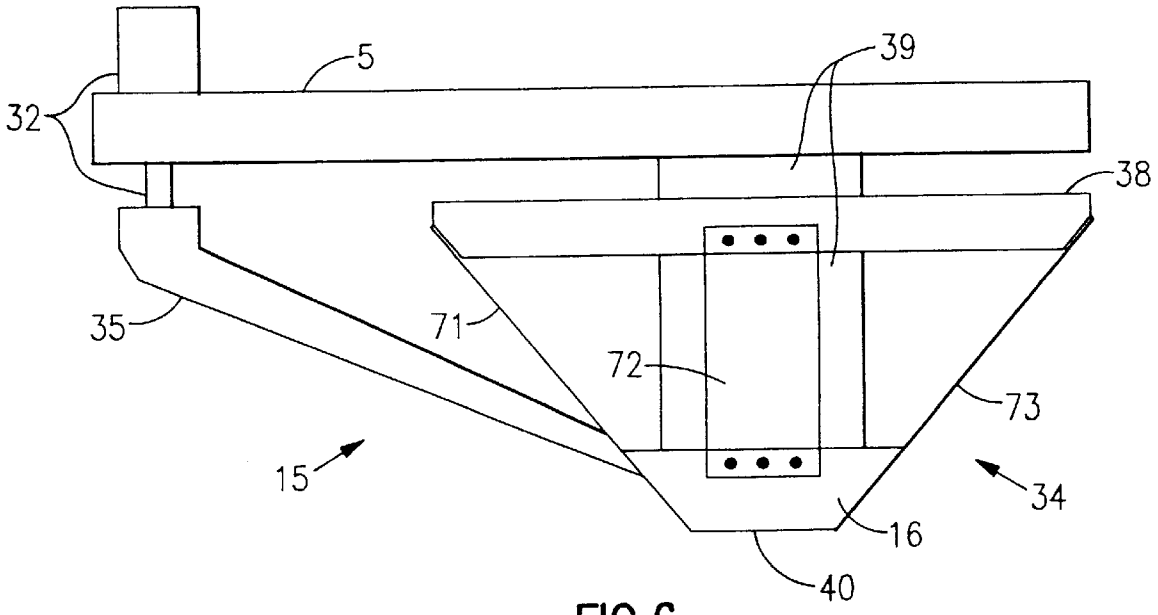
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FIG.6

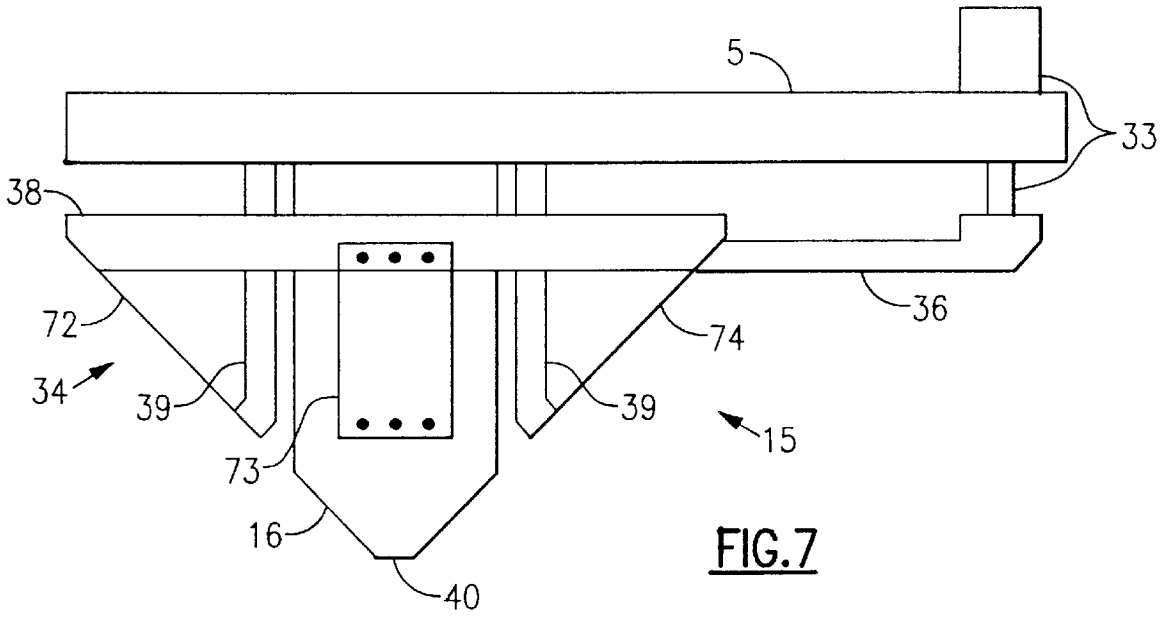

FIG.7

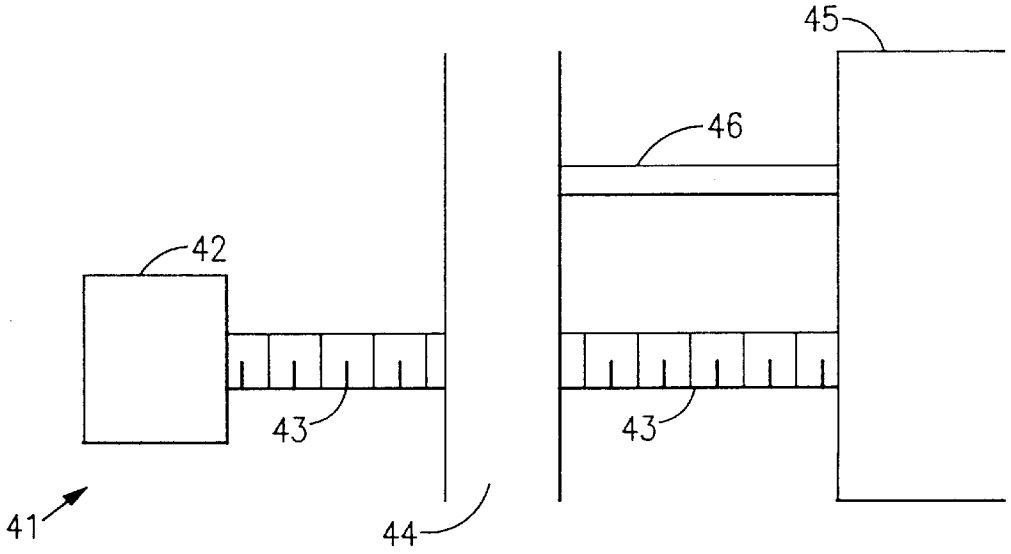

FIG.8

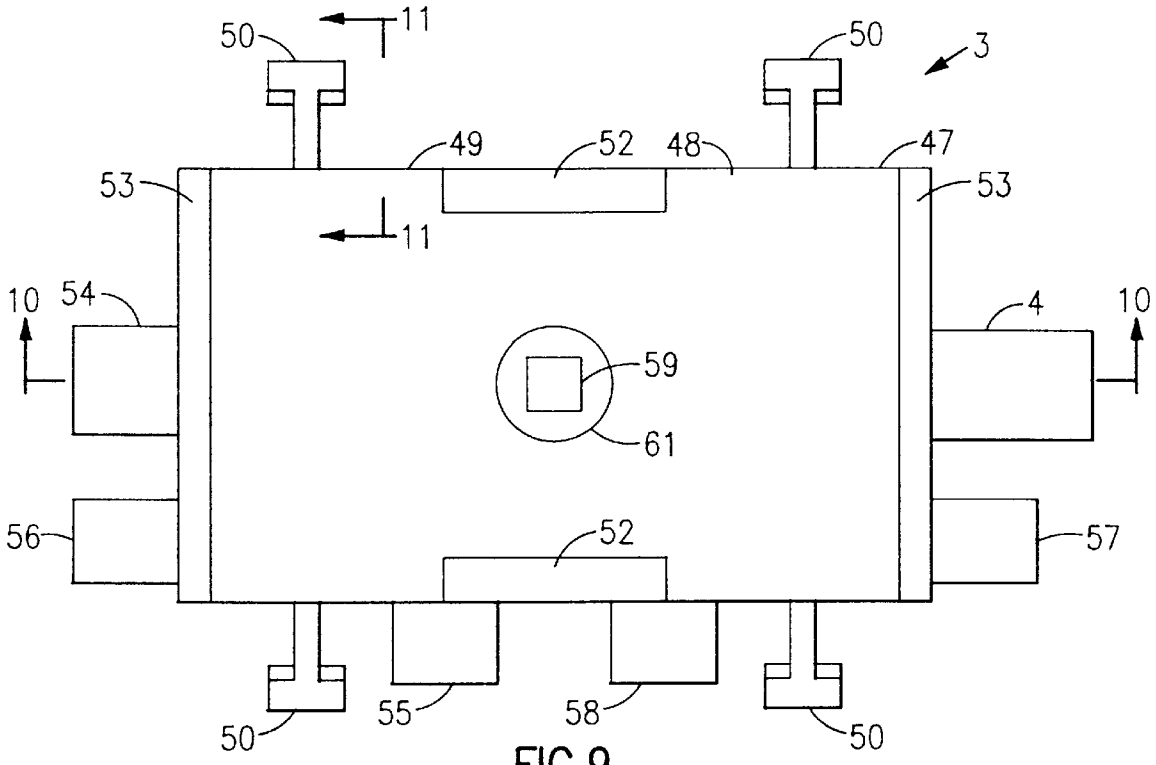
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FIG.9

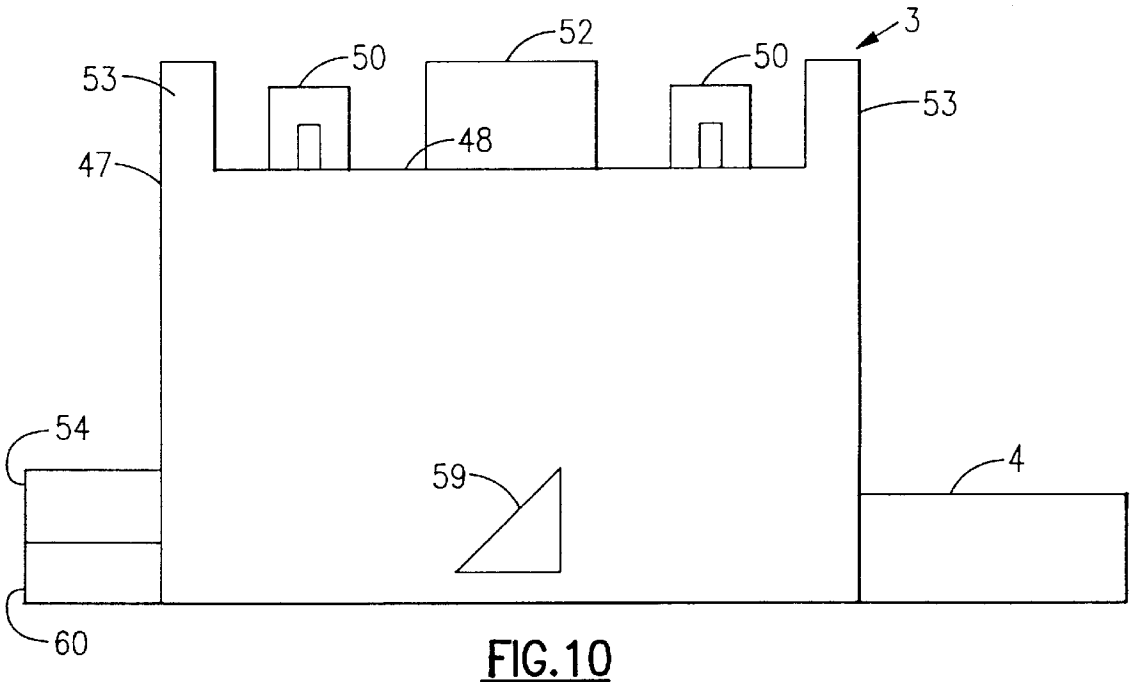
3
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FIG.10

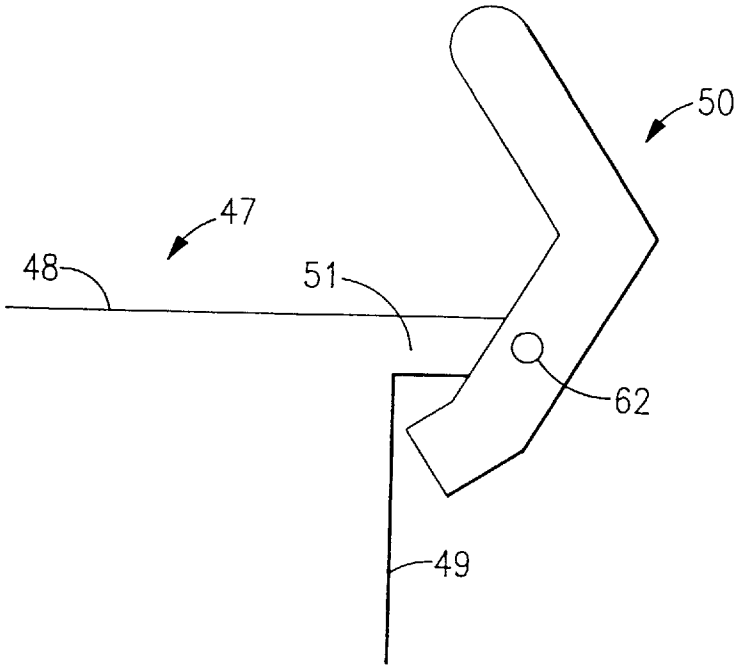

FIG.11

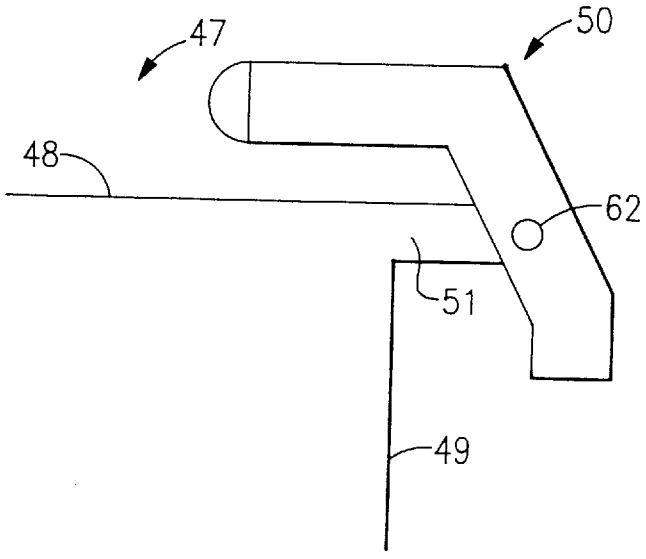

FIG.12

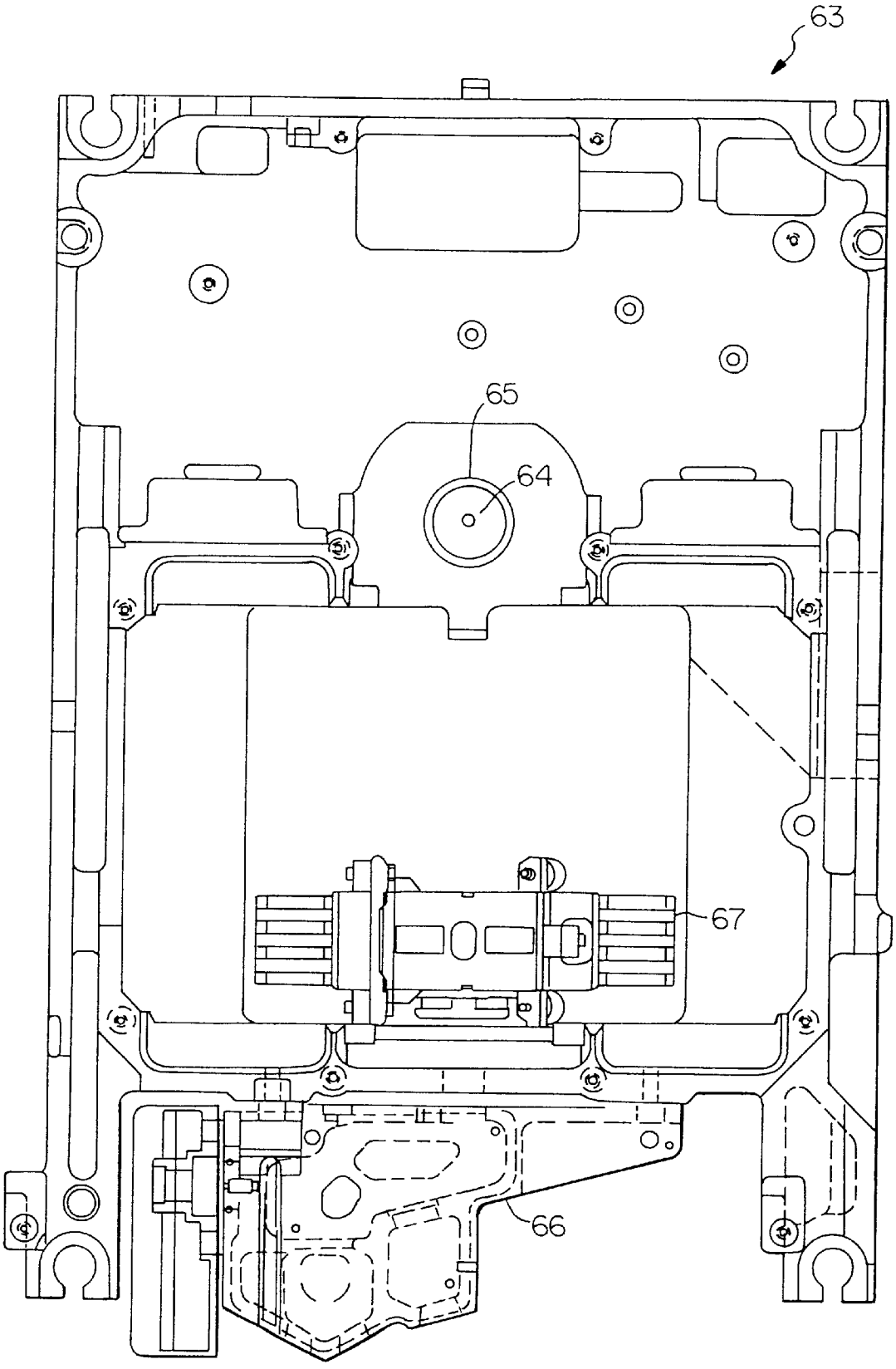

FIG.13

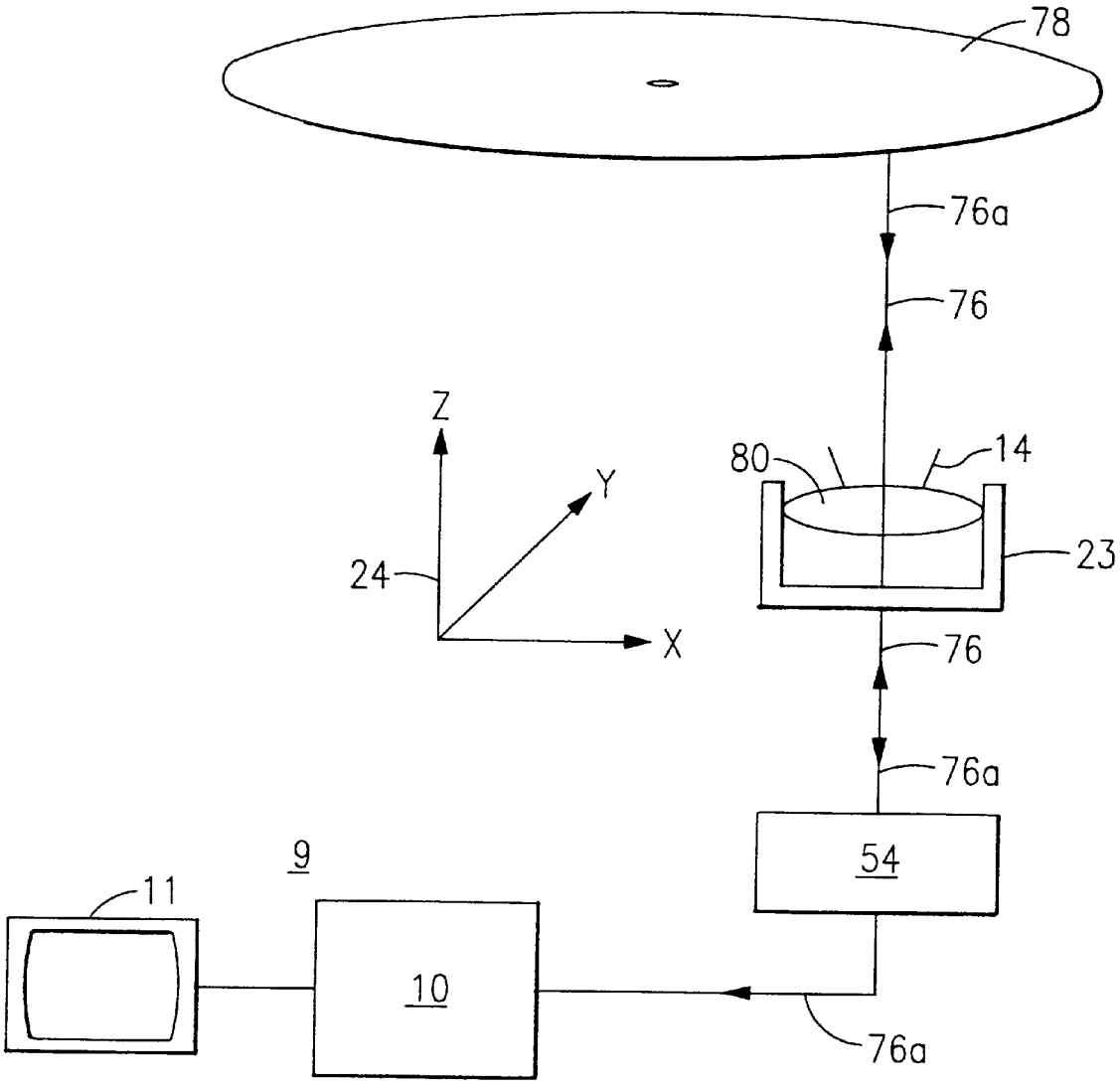

FIG.14

METHOD AND APPARATUS FOR ALIGNING AN OBJECTIVE LENS

CROSS REFERENCE TO RELATED APLICATIONS

This application is a divisional application of U.S. application Ser. No. 08/474,831, filed Jun. 7, 1995, now U.S. Pat. No. 5,790,325, which is a divisional application of U.S. application Ser. No. 08/418,698, filed Apr. 7, 1995, now U.S. Pat. No. 5,742,441.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to manufacturing of optical systems, and, in particular, to the manipulation and alignment of an objective lens during manufacture of an optical system.

2. Description of the Related Art

In the manufacture of prior optical systems, specific alignment of the objective lens with respect to a storage medium was not critical. In those systems, a spindle which holds the storage medium is aligned with respect to guide rails. A carriage rides along the guide rails, and the objective lens is placed within the carriage. Because the information storage densities used in such optical systems were sufficiently low, and because manufacturing tolerances of the spindle, rails, and objective lens were sufficiently high, specific alignment of the objective lens was not necessary. The objective lens was placed, then tested for alignment within tolerable limits.

Another example of a prior art optical system does perform active alignment of the objective lens. However, the objective lens is fixedly mounted to an actuator, and the objective lens/actuator combination is aligned with respect to a carriage assembly. Once aligned with respect to the carriage assembly, the actuator is mounted to the carriage assembly, which is aligned with respect to the storage medium. This prior art optical system requires that the actuator be alignable with respect to the carriage assembly. Additionally, the actuator/carriage assembly combination is quite large relative to such assemblies in other optical systems.

SUMMARY OF THE INVENTION

As information storage densities increase, the alignment between the objective lens and the storage medium becomes more critical. As a result, either stricter manufacturing tolerances or improved alignment of the objective lens is necessary. Because stricter manufacturing tolerances increase manufacturing cost significantly, improved alignment of the objective lens allows higher information storage densities at an economically feasible cost.

An apparatus is described which aligns such an objective lens. The apparatus comprises a frame, a cradle assembly mounted to the frame with at least one degree of freedom of motion, a tower assembly mounted to the frame, a lever assembly rotatably mounted to the frame, and a gripper assembly mounted to the lever assembly. The cradle assembly includes a baseplate alignment assembly comprising a source of radiant energy for projecting a beam of radiant energy, means for determining the tilt alignment of the beam with respect to the tower assembly, and a plurality of tilt actuators for aligning the tilt of the beam with respect to the tower assembly. The baseplate alignment assembly may further comprise means for determining the lateral alignment of the beam with respect to the tower assembly and a plurality of lateral actuators for aligning the beam laterally with respect to the tower assembly. The tower assembly comprises a video camera having a camera lens, a tower magnifying lens, and a monitor for displaying a representation of a beam of radiant energy passing through the tower magnifying lens and into the video camera.

The gripper assembly comprises an objective lens assembly, a gripper objective lens mounted to the objective lens assembly, an objective lens alignment assembly for aligning the gripper objective lens with respect to the tower assembly and the cradle assembly, and an actuator lens tilt assembly for aligning the objective lens with respect to the tower assembly and the cradle assembly. The objective lens assembly further comprises a housing having an opening at one end for receiving an objective lens and a bellows structure on its surface to allow bending of the housing, a gripper objective lens, a non-opaque substrate mounted within the housing, and a pneumatic tube attached to the housing for creating a pressure differential between the interior and the exterior of the housing sufficient to hold the actuator lens against the opening. The objective lens alignment assembly further comprises an assembly support, a first lateral alignment support slidably mounted to the assembly support, a first lateral actuator for positioning the first lateral alignment support, a second lateral alignment support slidably mounted to the first lateral alignment support, a second lateral actuator for positioning the second lateral alignment support, a support frame having a frame base and a frame extension, mounted to the second lateral actuator, a support leaf spring mounted to the support frame and biasing the housing against the frame extension, and a focus actuator for positioning the frame extension with respect to the frame base. The actuator lens tilt assembly further comprises a flexure support ring; two flexure support plates; four flexure plates mounted at equal intervals around the flexure support ring, two of which are mounted to the housing and two of which are mounted to the flexure support plates; a first lever disposed against a flexure plate; a first tilt actuator mounted against the first lever for imparting motion on the first lever which is translated into rotational motion by the flexure support ring, the flexure support plates, and the flexure plates; a second lever disposed against a flexure plate; and a second tilt actuator mounted against the second lever for imparting motion on the second lever which is translated into rotational motion by the flexure support ring, the flexure support plates, and the flexure plates.

A method for aligning an actuator lens is described comprising the steps of moving a baseplate assembly with respect to the tower assembly, moving the objective lens assembly with respect to the tower assembly, and moving the actuator lens with respect to the tower assembly. The step of moving the baseplate assembly further comprises moving the baseplate assembly laterally with respect to the tower assembly and rotating the baseplate assembly with respect to the tower assembly. The step of moving the actuator lens further comprises moving the actuator lens laterally with respect to the tower assembly and rotating the actuator lens with respect to the tower assembly. Such a method may be used with the above-described apparatus.

For a better understanding of these and other objects of the present invention, reference is made to the detailed description of the invention which is to be read in conjunction with the following drawings, wnerein:

BRIEF DESCRIPTION OF THE DRAWING

FIG. **1** is a generalized side view of one embodiment of the invention, showing the gripper assembly in a closed position.

FIG. **2** is a generalized side view of one embodiment of the invention, showing the gripper assembly in an open position.

FIG. **3** is a cross-sectional view of the tower assembly, including an embodiment of the analysis assembly.

FIG. **4** is a cross-section view of the vacuum chuck and the microscope objective lens assembly.

FIG. **5** is a view of the microscope objective lens alignment assembly.

FIG. **6** is a side view of the actuator lens tilt assembly.

FIG. **7** is a front view of the actuator lens tilt assembly.

FIG. **8** is a view of an alignment actuator.

FIG. **9** is a top view of one embodiment of the cradle assembly.

FIG. **10** is a cross-sectional view of one embodiment of the cradle assembly, taken along line **10**—**10** of FIG. **9**.

FIG. **11** is a cross-sectional view of one embodiment of a vacuum clamp in the open position, taken along line **11**—**11** of FIG. **9**.

FIG. **12** is a cross-sectional view of one embodiment of a vacuum clamp in the closed position, taken along line **11**—**11** of FIG. **9**.

FIG. **13** is a top view of a baseplate assembly.

FIG. **14** is a pictorial representation illustrating the focusing of an objective lens according to the methods of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to exemplary FIGS. **1** and **2**, according to one aspect of the invention, the apparatus comprises a tower assembly **1**, a gripper assembly **2**, and a cradle assembly **3**. The tower assembly **1** is fixedly mounted to a frame **4**. The tower assembly **1** defines a tower axis. The gripper assembly **2** is fixedly mounted to a lever assembly **5**, which is rotatably mounted to the frame **4**. The cradle assembly **3** is mounted to the frame **4** with at least one degree of freedom of motion. A line (not shown) between the tower assembly **1** and the cradle assembly **3** is referred to as an assembly axis. In the closed position, as shown in FIG. **1**, the gripper assembly **2** is between the tower assembly **1** and the cradle assembly **3** along the assembly axis. In the open position, as shown in FIG. **2**, the gripper assembly **2** is not along the assembly axis.

Referring to exemplary FIG. **3**, a cross-section of the tower assembly **1** is shown in more detail. The tower assembly **1** comprises a tower magnifying lens **6** and a video camera **7** having a camera lens **8**. The optical axes of the camera lens **8** of the video camera **7** and the tower magnifying lens **6** are the same, and are referred to collectively as the tower optical axis. The output from the video camera **7** is connected to an analysis assembly **9**. The analysis assembly **9** may be any assembly suitable for analyzing the characteristics of a radiant beam of energy. In the embodiment shown in exemplary FIG. **3**, the analysis assembly **9** comprises a processor **10** and a monitor **11**.

Referring to exemplary FIGS. **4**, **5**, **6** and **7**, the gripper assembly **2** comprises a vacuum chuck **12**, a microscope objective lens assembly **13**, a microscope objective lens alignment assembly **14**, and an actuator lens tilt assembly **15**. FIG. **4** shows a cross-sectional view of one embodiment of the vacuum chuck **12** and the microscope objective lens assembly **13**. FIG. **5** shows a view of one embodiment of the microscope objective lens alignment assembly **14**. FIGS. **6** and **7** show two views of the actuator lens tilt assembly **15**.

Referring to exemplary FIG. **4**, the vacuum chuck **12** comprises a housing **16**, a bellows structure **17**, and an actuator lens receiving opening **18**. A pneumatic tube **37** is connected to the housing **16**. In operation, an actuator lens (not shown) is placed within the actuator lens receiving opening **18** such that the actuator lens receiving opening **18** is completely covered. The actuator lens may be an objective lens. Air is then evacuated from the housing **16** through the pneumatic tube **37** to create a pressure differential between the interior and the exterior of the housing **16**. This pressure differential operates to hold the actuator lens against the actuator lens receiving opening **18** when the gripper assembly **2** moves. The housing **16** contains the bellows structure **17** to allow the housing **16** to bend while maintaining a pressure differential.

The microscope objective lens assembly **13** comprises a microscope objective lens **19** and a substrate **20**. In operation, a beam of radiant energy will enter the housing **16** through the actuator lens receiving opening **18** and, if present, through the actuator lens. The beam will pass through the substrate **20** and through the microscope objective lens **19**. The beam then passes through the housing **16** and into the tower assembly **1**, where it passes through the tower magnifying lens **6** and is received by the video camera **7**. Together, the microscope objective lens **19** and the tower magnifying lens **6** magnify the beam and focus the beam in the video camera **7**. The tower magnifying lens **6** may be a tube lens. The substrate **20** simulates the optical properties of an information-bearing disk, and the effects of those properties on the beam. The substrate **20** is mounted such that, when the gripper assembly **2** is in the closed position, the substrate **20** is orthogonal to the tower optical axis.

Referring to exemplary FIG. **5**, the microscope objective lens alignment assembly **14** comprises an X-axis lateral alignment actuator **21**, a Y-axis lateral alignment actuator **22**, and a focus actuator **23**. Referring to exemplary FIG. **5**, there is shown a reference coordinate system **24**. This reference coordinate system **24** is chosen for purposes of explanation only, and it will be obvious to one skilled in the art that any convenient coordinate system could be chosen without departing from the spirit and scope of the present invention.

In the embodiment particularly shown in FIG. **5**, a microscope support frame **25** having a frame extension **28** supports the housing **16** by a support leaf spring **26**. The support leaf spring **26** biases the housing **16** against a cylindrical bearing **27** located between the housing **16** and the frame extension **28**. The focus actuator **23** is mounted to the frame extension **28**, and maintains a distance between the frame extension **28** and the microscope support frame **25** along the Z-axis, as indicated by the reference coordinate system **24**. Motion of the housing **16** along the Z-axis adjusts the focus of the microscope objective lens **19** in combination with the tower magnifying lens **6**.

The microscope support frame **25** is mounted on a Y-axis lateral alignment support **29** such that the microscope support frame **25** may slide relative to the Y-axis lateral alignment support **29** along the Y-axis, as indicated by the reference coordinate system **24**. The Y-axis lateral alignment actuator **22** is mounted to the microscope support frame **25**, and will actuate the relative sliding motion along the Y-axis.

The Y-axis lateral alignment support **29** is mounted on an X-axis lateral alignment support **30** such that the Y-axis lateral alignment support **29** may slide relative to the X-axis lateral alignment support **30** along the X-axis, as indicated by the reference coordinate system **24**. The X-axis lateral alignment actuator **21** is mounted to the Y-axis lateral

alignment support **29**, and will actuate the relative sliding motion along the X-axis.

The X-axis lateral alignment support **30** is mounted to a lateral alignment assembly support **31**. The lateral alignment assembly support **31** is mounted to the lever assembly **5**. It will be apparent to one skilled in the art that the mountings between the microscope support frame **25**, the Y-axis lateral alignment support **29**, the X-axis lateral alignment support **30**, and the lateral alignment assembly support **31** may be rearranged from the above description without departing from the spirit and scope of the present invention.

Referring to exemplary FIGS. **6** and **7**, there are shown two views of the actuator lens tilt assembly **15**. FIG. **6** represents a left side view of the actuator lens tilt assembly **15** according to one aspect of the invention. FIG. **7** represents a front view of the same actuator lens tilt assembly **15**. The actuator lens tilt assembly **15** comprises an X-axis tilt actuator **32**, a Y-axis tilt actuator **33**, and a flexure assembly **34**. The X-axis tilt actuator **32** is mounted to the lever assembly **5** and against an X-axis lever **35**. The X-axis lever **35**, at the end nearest the X-axis tilt actuator **32**, is biased against the lever assembly **5**, and at the other end is mounted to the flexure assembly **34**. The Y-axis tilt actuator **33** is mounted to the lever assembly **5** and against a Y-axis lever **36**. The Y-axis lever **36**, at the end nearest the Y-axis tilt actuator **33**, is biased against the lever assembly **5**, and at the other end is mounted to the flexure assembly **34**.

The flexure assembly **34** comprises a plurality of flexure plates **71**, **72**, **73**, **74**, a flexure support ring **38**, and a plurality of flexure support plates **39**. Flexure plate **71** is mounted at one end to the flexure support ring **38**, and mounted at its other end to the X-axis lever **35** and the housing **16**. Flexure plate **73** is mounted opposite flexure plate **71** to the flexure support ring **38** and to the housing **16**. Flexure plate **74** is mounted at one end to the Y-axis lever **36** and the flexure support ring **38**, and mounted at its other end to a flexure support plate **39**. Flexure plate **74** is mounted at a 90 degree interval from both flexure plate **71** and flexure plate **73**. Flexure plate **72** is mounted opposite flexure plate **74** to the flexure support ring **38** and to a flexure support plate **39**. The flexure support plates **39** are mounted to the lever assembly **5**.

Flexure plates **71**, **72**, **73**, **74** each lie in a separate plane. The planes in which flexure plates **71** and **73** lie intersect along a line through an intersection point **40**. The planes in which flexure plates **71** and **73** lie intersection along a line through the intersection point **40**. The lines may be orthogonal to each other.

The operation of the actuator lens tilt assembly **15** will be described with respect to a downward motion imparted on each of the tilt actuators, the X-axis tilt actuator **32** and the Y-axis tilt actuator **33**.

A downward motion of the X-axis tilt actuator **32** imparts a downward motion on the X-axis lever **35**. This downward force produces a counterclockwise rotational force on flexure plate **71** about the point where flexure plate **71** is mounted to the flexure support ring **38**. The downward force also translates into a counterclockwise rotational force on flexure plate **73** about the point where flexure plate **73** is mounted to the flexure support ring **38**. These two rotational forces cause rotation about the intersection of the two planes in which the flexure plates **71**, **73** lie. This intersection occurs at intersection point **40**.

A downward motion of the Y-axis tilt actuator **33** imparts a downward force on the Y-axis lever **36**. This downward force produces a clockwise rotational force on flexure plate **74** about the point where flexure plate **74** is mounted to the flexure support plate **39**. Because of the rigidity of the flexure support ring **38**, this rotational force translates into a clockwise rotational force on flexure plate **72** about the point where flexure plate **72** is mounted to the flexure support plate **39**. These two rotational forces cause rotation about the intersection of the two planes in which the flexure plates **72** and **74** lie. This intersection occurs at intersection point **40**.

Referring to exemplary FIG. **8**, there is shown one embodiment of an alignment actuator **41**. The alignment actuator **41** may be a tilt actuator or a lateral alignment actuator, as described above. The alignment actuator **41** contains a handle **42** and a threaded body **43**. The threaded body **43** is threadably mounted through a fixed surface **44** and against a movable surface **45**. The movable surface **45** is biased toward the fixed surface **44** by a spring **46** or other suitable biasing means. The mounting of the movable surface **45** determines whether the force by the alignment actuator **41** or the biasing by the spring **46** produces a lateral or rotational force. The alignment actuator **41** may include what is commonly referred to as a micrometer stage.

Referring to exemplary FIG. **9**, there is shown a top view of the cradle assembly **3**. Referring to exemplary FIG. **10**, there is shown a cross-sectional view of the cradle assembly **3**, taken along line **10**—**10** of FIG. **9**. The cradle assembly **3** comprises a cradle **47** having a surface **48** and a side **49**, a plurality of vacuum clamps **50**, and a baseplate alignment assembly (not shown). The cradle includes side walls **52** and end wails **53** for securing a baseplate assembly (not shown) in the cradle **47**. In the embodiment particularly shown in exemplary FIGS. **9** and **10**, the baseplate alignment assembly (not shown) comprises a source of radiant energy **54**, a Y-axis source lateral actuator **55**, a Z-axis source lateral actuator **56**, an X-axis cradle assembly tilt actuator **57**, a Y-axis cradle assembly tilt actuator **58**, a mirror **59**, and an alignment analyzer **60**. In another embodiment, the baseplate alignment assembly (not shown) comprises a source of radiant energy **54**, an X-axis cradle assembly tilt actuator **57**, a Y-axis cradle assembly tilt actuator **58**, a mirror **59**, and an alignment analyzer **60**. In both embodiments, the mirror **59** is aligned below a hole **61** in the surface **48** of the cradle **47**. Additionally, the source of radiant energy **54** and the alignment analyzer **60** may be combined in an auto-collimator or an auto-collimator/telescope.

Referring to exemplary FIG. **11**, a cross-sectional view of a vacuum clamp **50** is shown in the open position. Exemplary FIG. **12** shows a cross-sectional view of a vacuum clamp **50** in the closed position. The surface **48** of the cradle **47** extends laterally beyond the side **49** of the cradle **47**. The vacuum clamp **50**, having with a U-shaped cross-section, is placed over the extension **51** of the cradle **47**, with one leg of the "U" on each side of the extension **51**. A pivot pin **62** is placed through each leg of the U-shape and through the extension of the cradle **47**. In the open position, a baseplate assembly can be placed on the cradle **47**. Once in place, a pneumatic tube **81** biases the vacuum clamp **50** to the closed position, securing the baseplate against movement.

In operation, as shown in exemplary FIG. **13**, a baseplate assembly **63** is provided. The baseplate assembly **63** contains a spindle **64** and a spindle motor **65** for rotating an information-bearing disk, and a spindle servo (not shown) for controlling the speed of the spindle motor **65**. The baseplate assembly **63** further contains an optics module assembly **66**. The baseplate assembly. **63** also contains a carriage motor (not shown) and a carriage assembly **67** for directing a beam of radiant energy from the optics module assembly **66** toward a position on the information-bearing

disk, and a carriage control servo (not shown) for controlling the position of the carriage assembly. At this point, the carriage assembly **67** does not contain an actuator lens for focussing the beam of radiant energy on the information-bearing disk. The carriage assembly **67** may be held in place relative to the spindle **64** by a carriage stop (not shown).

The baseplate assembly **63** is placed on the surface **48** of the cradle **47** and secured with the vacuum clamps **50**. A test disk of glass or other suitable material (not shown) is placed on the spindle of the baseplate assembly **63**. The gripper assembly **2** is then lowered into the closed position.

The source of radiant energy **54** radiates two cradle alignment beams of radiant energy toward the mirror **59**. The first cradle alignment beam is reflected from the mirror **59**, then passes through the hole **61** in the cradle **47** and through the baseplate assembly **63**. The first cradle alignment beam reflects off the test disk and is received by the alignment analyzer **60**. The second cradle alignment beam is reflected from the mirror **59**, then passes through the hole **61** in the cradle **47** and through the baseplate assembly **63**. The second cradle alignment beam reflects off the substrate **20** and is received by the alignment analyzer **60**. By analyzing the relative positions of the first and second cradle alignment beams, the alignment analyzer **60** determines the tilt of the test disk with respect to the substrate **20**. It will be obvious that the mirror **59** may comprise two parallel mirrors, each reflecting one of the cradle alignment beams.

Tilt between the test disk and the substrate **20** is corrected in the following manner. The X-axis cradle assembly tilt actuator **57** tilts the cradle assembly **3** about the X-axis. The Y-axis cradle assembly tilt actuator **58** tilts the cradle assembly **3** about the Y-axis. Acting together, the cradle assembly tilt actuators **57**, **58** tilt the cradle assembly **3**, including the test disk, with respect to the substrate **20**. Because the substrate **20** is orthogonal to the tower optical axis, this action tilts the cradle assembly **3** with respect to the tower optical axis. Each of the actuators **57**, **58** may be an alignment actuator **41** as shown in exemplary FIG. **8**.

In one embodiment, lateral alignment of the cradle assembly **3** with respect to the tower optical axis is done mechanically, and is not tested or measured. In another embodiment, if the cradle alignment beam is not received by the alignment analyzer **60**, or is off-center when received by the alignment analyzer **60**, the position of the source of radiant energy **54** can be moved using the Y-axis source lateral actuator **55** and the Z-axis source lateral actuator **56**. As shown best in FIG. **9**, the mirror **59** is situated such that a change in the position of the source of radiant energy **54** along the Y-axis is translated into a change in the position of the cradle alignment beam along the Y-axis as it is received by the alignment analyzer **60**. The Y-axis source lateral actuator **55** effects this change in position. Similarly, a change in the position of the source of radiant energy **54** along the Z-axis is translated into a change in the position of the cradle alignment beam along the X-axis as it is received by the alignment analyzer **60**. The Z-axis source lateral actuator **56** effects this change in position. Each of the actuators **55**, **56** may be an alignment actuator **41** as shown in exemplary FIG. **8**.

In the embodiment particularly described below, all references to a coordinate system are made in accordance with reference coordinate system **24** shown in exemplary FIG. **5**. This reference coordinate system **24** is chosen for purposes of explanation only, and it will be obvious to one skilled in the art that any convenient coordinate system could be chosen without departing from the spirit and scope of the present invention.

Once aligned, the source of radiant energy **54** is turned off and the test disk is removed. If not previously aligned, the carriage assembly of the baseplate assembly **63** is moved in approximate alignment with the assembly axis, and an actuator lens (not shown) is placed within the carriage assembly of the baseplate assembly **63** and is allowed to assume a natural rest position. The lever assembly **5** is lowered to the closed position.

A pressure differential is then created between the vacuum chuck **12** and the atmosphere. This pressure differential operates to hold the actuator lens against the vacuum chuck **12**, while maintaining the orientation of the actuator lens. Additionally, the optical center of the actuator lens is maintained at the intersection point **40**. This optical center may also be substantially at the center of mass of the actuator lens.

An adjustable power supply is attached to the radiant energy source within the optics module assembly **66**. The radiant energy source projects a lens alignment beam of radiant energy into the carriage assembly. Within the carriage assembly, the lens alignment beam passes through pentaprism (not shown) and through the actuator lens. The lens alignment beam then passes through the substrate **20**, through the microscope objective lens **19**, and into the tower assembly **1**, where the lens alignment beam passes through the tower magnifying lens **6** and is received by the video camera **7**. The analysis assembly **9** then displays and analyzes the spot profile of the lens alignment beam.

If the lens alignment beam is not received by the video camera **7** and passed to the analysis assembly **9**, the X-axis lateral alignment actuator **21** and the Y-axis lateral alignment actuator **22** are used to move the microscope objective lens **19** laterally with respect to the tower assembly **1**. The X-axis lateral alignment actuator **21** and the Y-axis lateral alignment actuator **22** may be alignment actuators **41** as shown in exemplary FIG. **8**.

If the lens alignment beam is not focussed properly in the video camera **7** and analysis assembly **9**, the focus actuator **23** is used to move the microscope objective lens **19** toward or away from the tower assembly **1** until the lens alignment beam is in proper focus within the video camera **7** and analysis assembly **9**. The focus actuator **23** may be an alignment actuator **41** as shown in exemplary FIG. **8**.

Once focussed properly, the analysis assembly **9** analyzes the profile of the beam for coma and astigmatism, as the cradle alignment beam was previously analyzed. If these optical aberrations occur, the actuator lens tilt assembly **15** operates to minimize these aberrations by aligning the actuator lens. As described above, the X-axis tilt actuator **32** rotates the actuator lens about the X-axis. Likewise, the Y-axis tilt actuator **33** rotates the actuator lens about the Y-axis. Together, the actuator lens tilt assembly **15** can rotate the actuator lens in any direction with respect to the lens alignment beam, while maintaining the optical center or the center of mass of the actuator lens at the intersection point **40**.

Once the misalignment is corrected to within an acceptable tolerance, the gripper assembly **2**, including the vacuum chuck **12** and the actuator lens, is raised to the open position. A fastening agent is placed on the pedestals of the carriage assembly, and the gripper assembly **2** is again lowered to the closed position. The actuator lens is secured by the fastening agent to the carriage assembly, without changing the orientation of the actuator lens established by the actuator lens tilt assembly **15**. The fastening agent may be a selectably curable adhesive, such as ultraviolet radiation curable adhesive.

Once the fastening agent has cured, the actuator lens is tested for alignment. As above, a lens alignment beam is radiated through the actuator lens, the substrate **20**, the microscope objective lens **19**, the tower magnifying lens **6**, and into the video camera **7**. The analysis assembly **9** then analyzes the spot profile of the lens alignment beam. Each of the alignments described above may need to be adjusted for this testing process. Depending on its configuration, the vacuum chuck **12** may need to be retracted or removed to avoid contacting and damaging the carriage assembly.

In another embodiment of the invention, the cradle assembly **3** may comprise a plurality of cradles **47**, a plurality of vacuum clamps **50**, and a baseplate alignment assembly (not shown). The cradles **47** may be movable with respect to the tower assembly **1**, and there may be either one baseplate alignment assembly (not shown) for each cradle **47**, or a single baseplate alignment assembly (not shown) which aligns only the cradle **47** presently in position with respect to the tower assembly **1**. Further, there may be a single source of radiant energy **54** and set of actuators **55**, **56**, **57**, **58** regardless of the number of cradles **47**, with one mirror **59** associated with each cradle **47**.

According to this embodiment, there may be a second tower assembly **1** identical to the first tower assembly **1** described above. In addition, there may be a second gripper assembly **2** associated with the second tower assembly **1** as described above. The second gripper assembly **2** will not contain a vacuum chuck **12**.

In operation, the first tower assembly **1** and first gripper assembly **2** operate as described in the previous embodiment. After fastening the actuator lens to the carriage assembly with the fastening agent, the cradle **47** containing the baseplate assembly **63** is moved beneath the second tower assembly **1** and second gripper assembly **2**. Again, a lens alignment beam of radiant energy is projected by the optics module assembly **66** through the same path in the second tower assembly **1** and second gripper assembly **2** as described with respect to the first tower assembly **1** and first gripper assembly **2**. The analysis assembly **9** associated with the second tower assembly **1** analyzes the spot profile of the lens alignment beam after the actuator lens is fastened to the baseplate assembly **63**. It will be obvious to one skilled in the art that, by allowing the vacuum chuck **12** to be removable or retractable, the first tower assembly **1** and first gripper assembly **2** may function as the second tower assembly **1** and second gripper assembly **2**, respectively.

With reference now to FIG. **14**, there is shown a method of focusing a beam of radiant energy **76** onto an optical disc **78**. The beam of radiant energy **76** may be provided by the source of radiant energy **54** shown in FIG. **9**. The method of focusing the beam of radiant energy **76** onto the optical disc **78** includes the step of directing the beam of radiant energy **76** through an objective lens **80** onto the optical disc **78**. The objective lens **80** may be held in position by the actuator lens receiving opening **18** of the microscope objective lens assembly shown in FIG. **4**. As indicated above, the actuator lens may be an objective lens. The present method further includes the step of aligning the beam of radiant energy **76** with respect to the optical disc **78** with the alignment assembly **14**, FIG. **5**, while maintaining the optical center of the objective lens **80** at a predetermined intersection point relative to the reference coordinate system **24**. The alignment assembly **14** may advantageously include the alignment actuator **41** shown in FIG. **8**. The present method also includes receiving a return beam of radiant energy **76***a* reflected from the optical disc **78**, and analyzing the spot profile of the return beam **76***a* with the analyzer assembly **9** which includes the processor **10** and monitor **11**. While viewing the monitor **11**, the objective lens **23** may be moved toward and away from the optical disc **78** using the focus actuator **23**, FIG. **5**, until the analyzer assembly **9** indicates that the beam **76** is in proper focus. This method may be alternatively performed after placing the objective lens **80** in the carriage assembly **67** shown in FIG. **13**.

While this invention has been described in detail with reference to certain preferred embodiments, it should be appreciated that the present invention is not limited to those precise embodiments. Rather, in view of the present disclosure which describes the current best mode for practicing the invention, many modifications and variations would present themselves to those of skill in the art without departing from the scope and spirit of this invention. The scope of the invention is, therefore, indicated by the following claims rather than by the foregoing description. All changes, modifications, and variations coming within the meaning and range of equivalency of the claims are to be considered within their scope.

What is claimed is:

1. An apparatus for aligning an actuator lens within a baseplate using a beam of radiant energy, the actuator lens having an actuator optical axis and an actuator optical center, said apparatus comprising:

a frame;

a cradle assembly for holding the baseplate, said cradle assembly mounted to said frame with at least one degree of freedom of motion;

a tower assembly defining a tower axis and mounted to said frame, said cradle assembly and said tower assembly defining an assembly axis, for receiving the beam of radiant energy along said tower axis and analyzing a spot profile of said beam of radiant energy;

a lever assembly rotatably mounted to said frame; and

a gripper assembly mounted to said lever assembly.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 6,023,379
DATED : February 8, 2000
INVENTOR(S) : Leonardus J. Grassens et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Drawing,
Fig. 4,
Insert the pneumatic tube and reference numeral -- 37 --.

Figs. 11 and 12,
Insert the pneumatic tube and reference numeral -- 81 --.

Signed and Sealed this

Fourth Day of December, 2001

Attest:

Nicholas P. Godici

Attesting Officer

NICHOLAS P. GODICI
Acting Director of the United States Patent and Trademark Office

US005999327A

United States Patent [19]

Nagaoka

[11] Patent Number: 5,999,327

[45] Date of Patent: Dec. 7, 1999

[54] **OBJECTIVE LENS SYSTEM**

[75] Inventor: **Toshiyuki Nagaoka**, Akishima, Japan

[73] Assignee: **Olympus Optical Co., Ltd.**, Tokyo, Japan

[21] Appl. No.: **08/713,069**

[22] Filed: **Sep. 12, 1996**

[30] **Foreign Application Priority Data**

Sep. 12, 1995 [JP] Japan 7-258220

[51] **Int. Cl.**[6] **G02B 3/00**

[52] **U.S. Cl.** **359/654**; 359/661; 359/793

[58] **Field of Search** 359/654, 652, 359/793, 656–661

[56] **References Cited**

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5,729,389	3/1998	Nagaoka	359/654

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Primary Examiner—Georgia Epps
Assistant Examiner—Jordan M. Schwartz
Attorney, Agent, or Firm—Pillsbury Madison & Sutro LLP

[57] **ABSTRACT**

An objective lens system consisting of a first lens unit having a negative refractive power and a second lens unit having a positive refractive power wherein the first lens unit or the second lens unit comprises at least one radial type gradient index lens element which has a refractive index distribution in a radial direction from an optical axis. This objective lens system favorably corrects chromatic aberration and other aberrations by adequately selecting a value expressing an Abbe's number and a refractive power of medium for the radial type gradient index lens element.

7 Claims, 16 Drawing Sheets

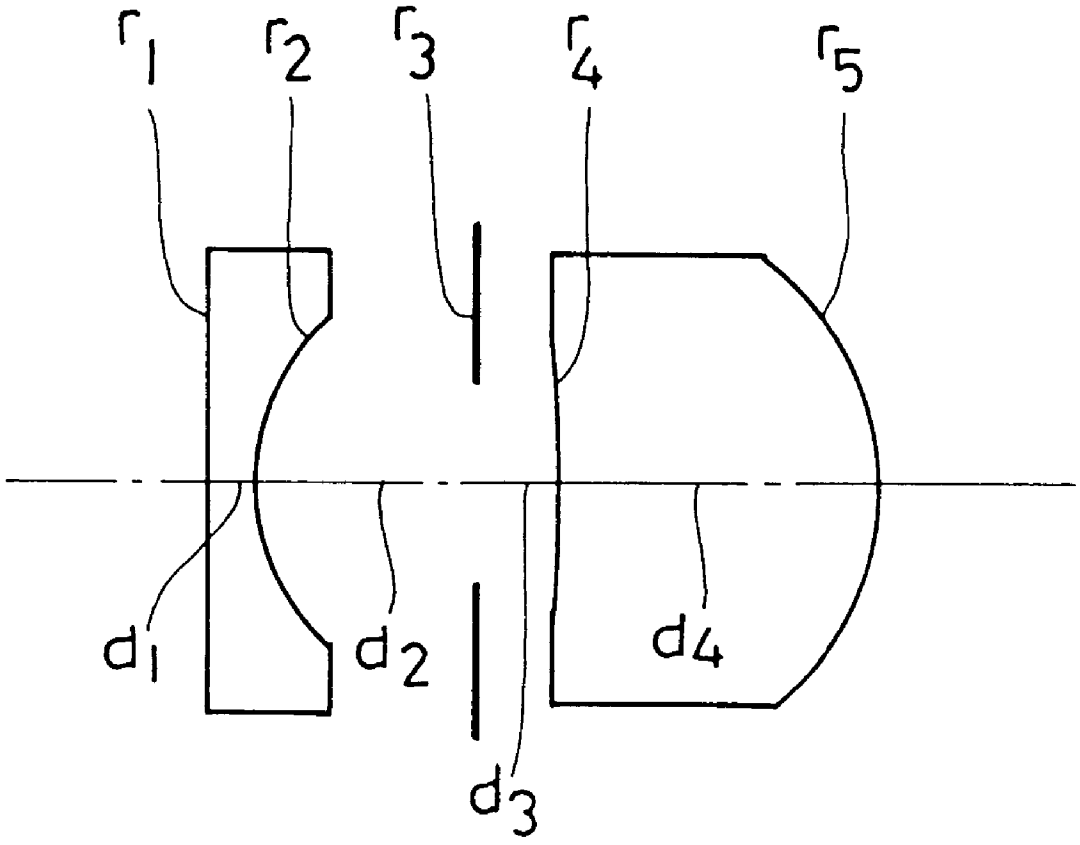

FIG. 1
PRIOR ART

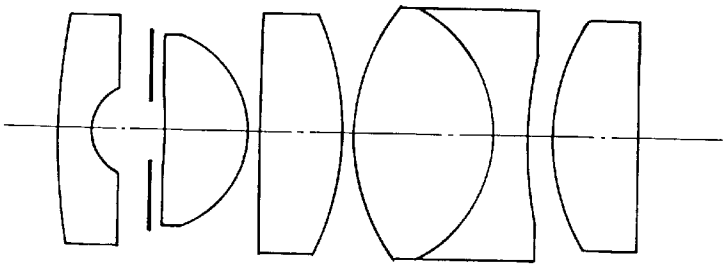

FIG. 2

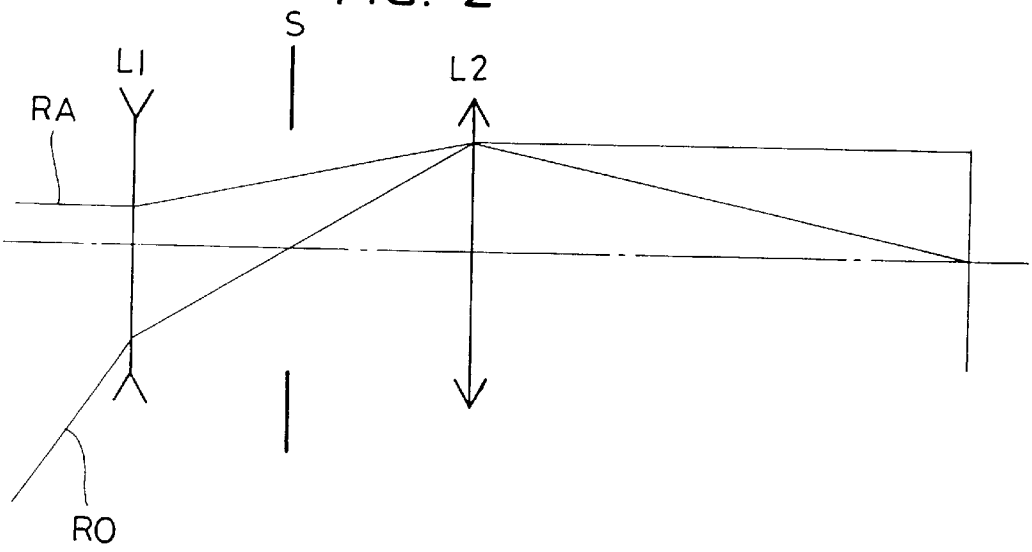

FIG. 3

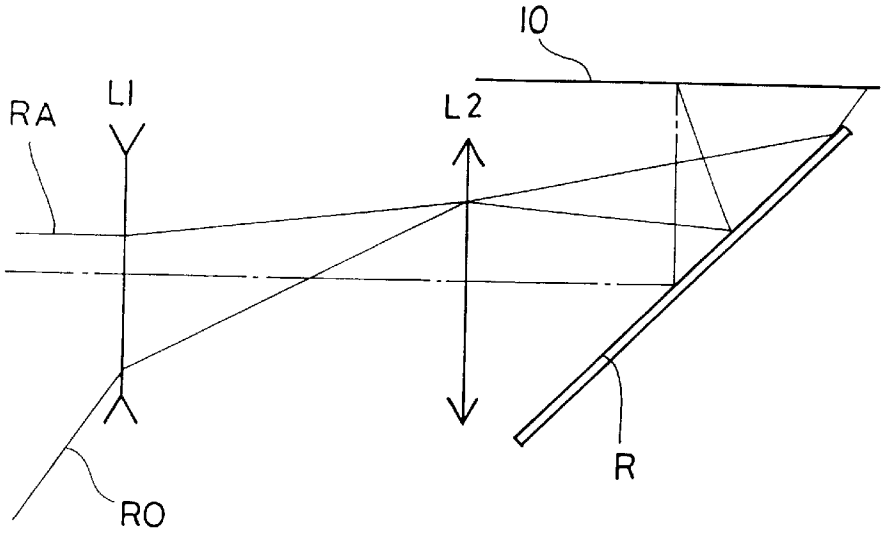

FIG. 4

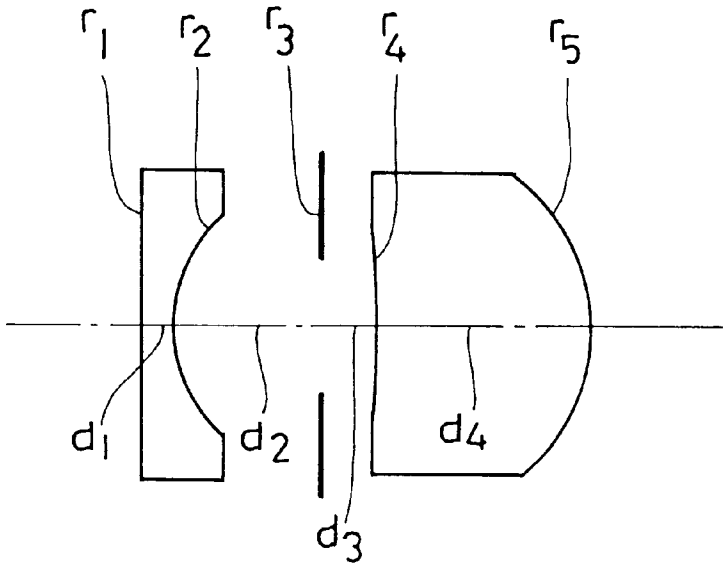

FIG. 5

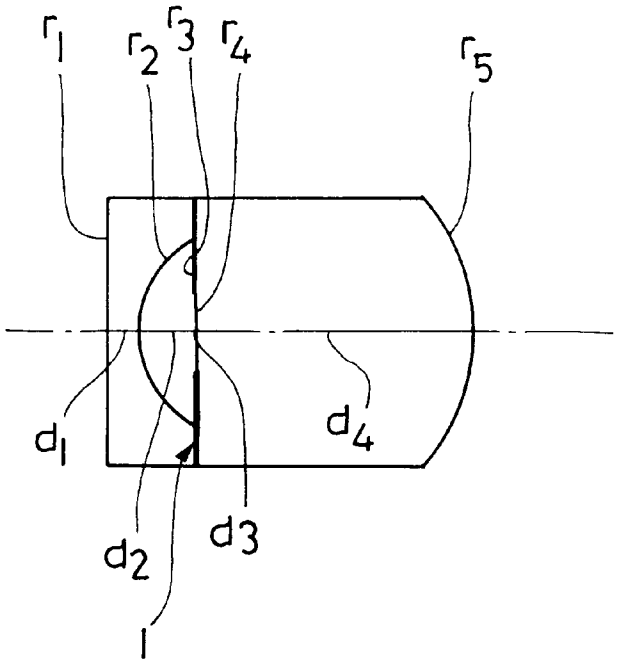

FIG. 6

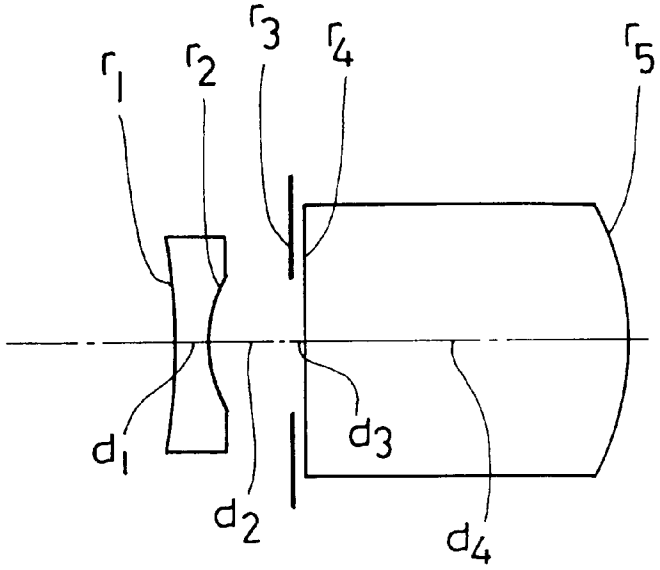

FIG. 7

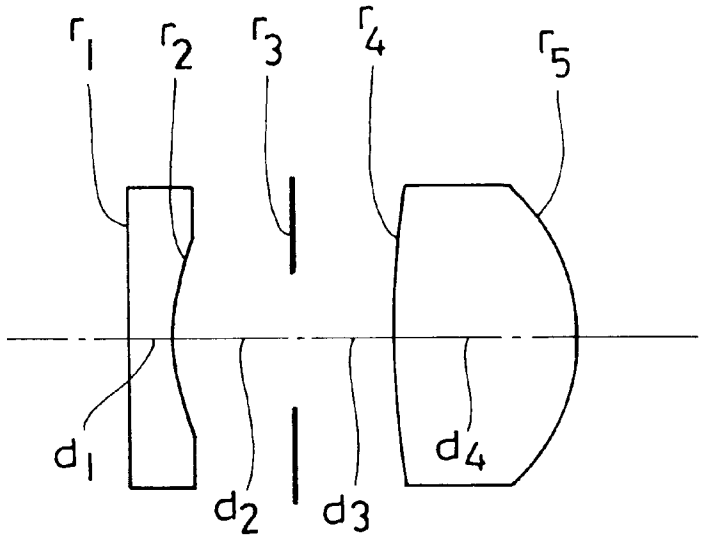

FIG. 8

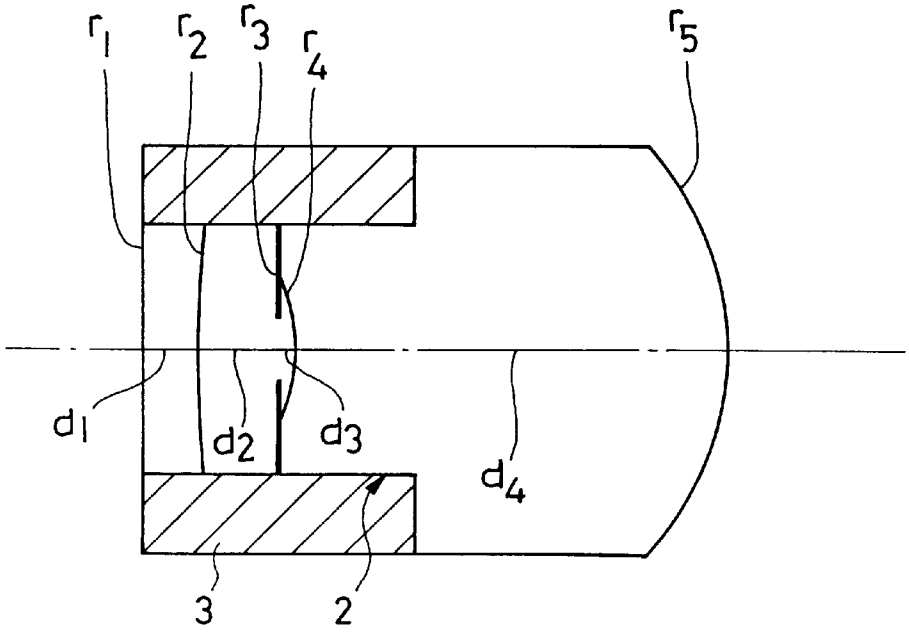

FIG. 9

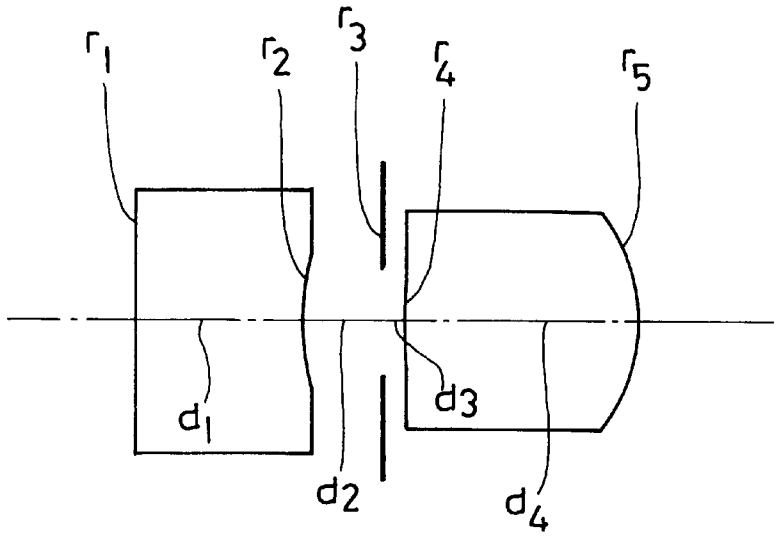

FIG. 10

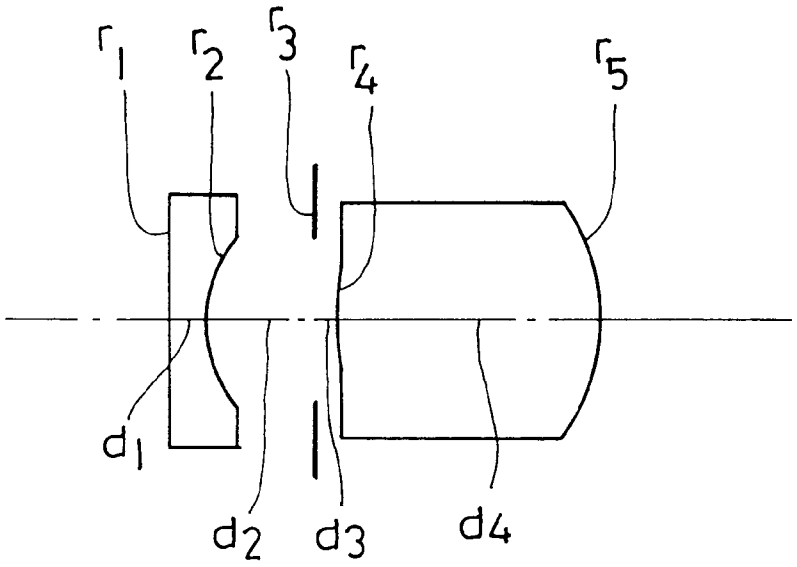

FIG. 11

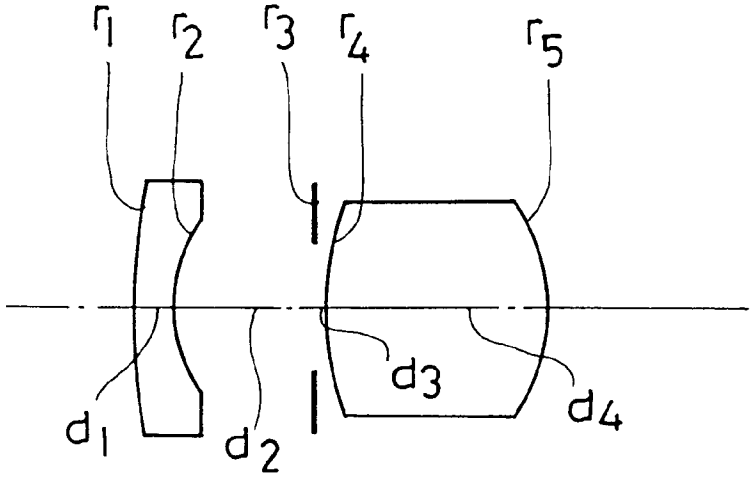

FIG. 12

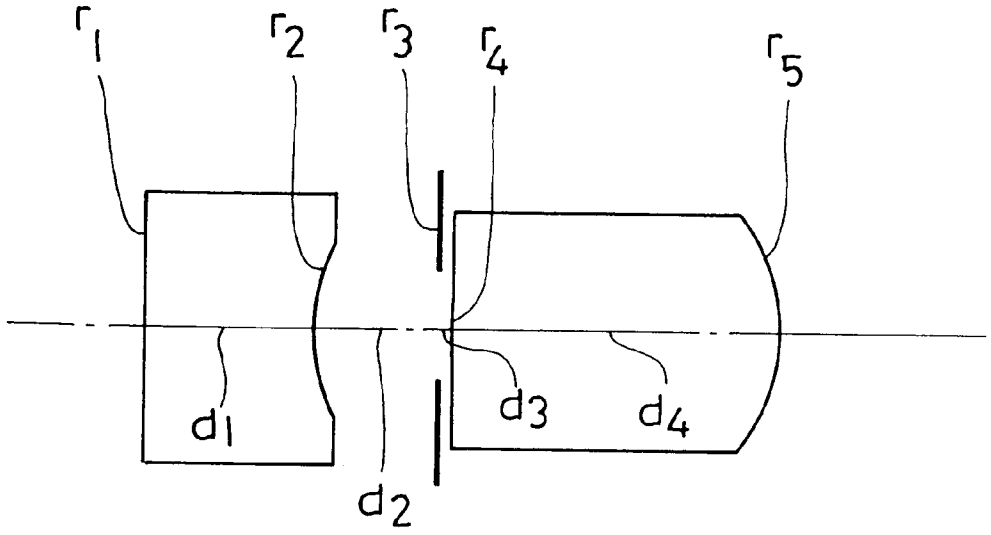

FIG. 13

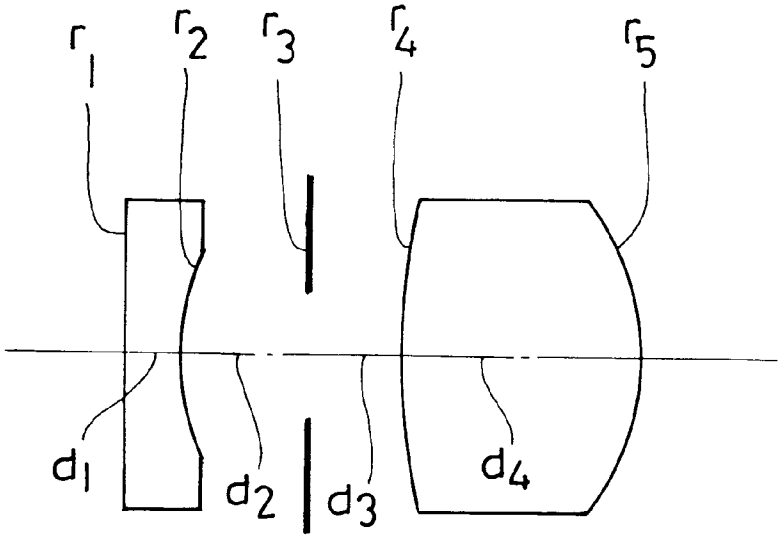

FIG. 14

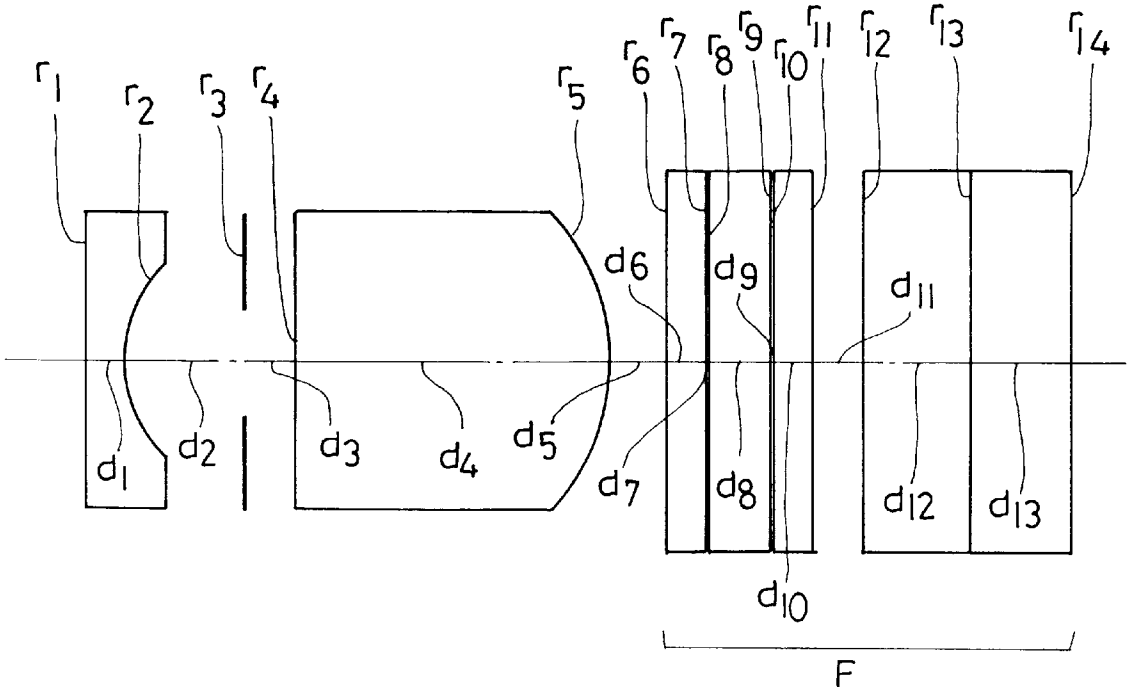
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FIG. 15

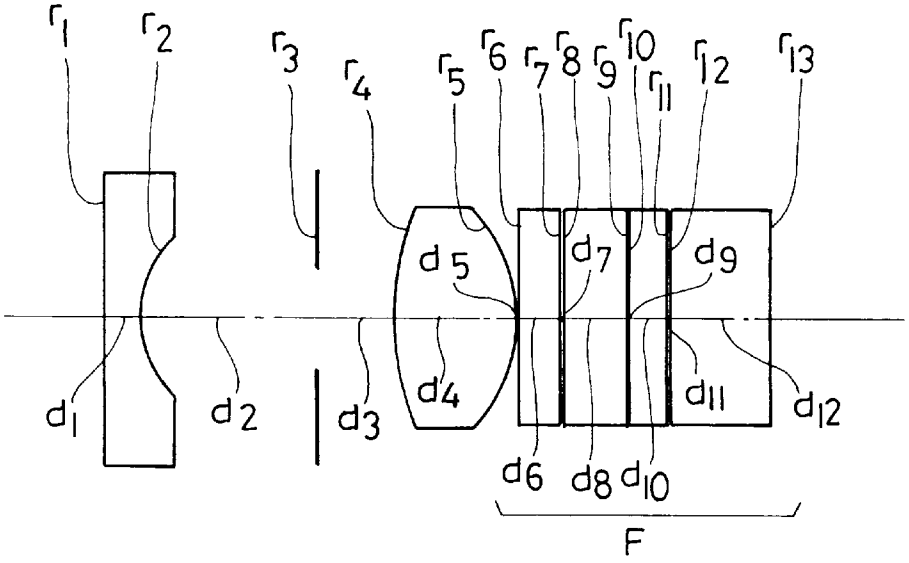
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FIG. 16A

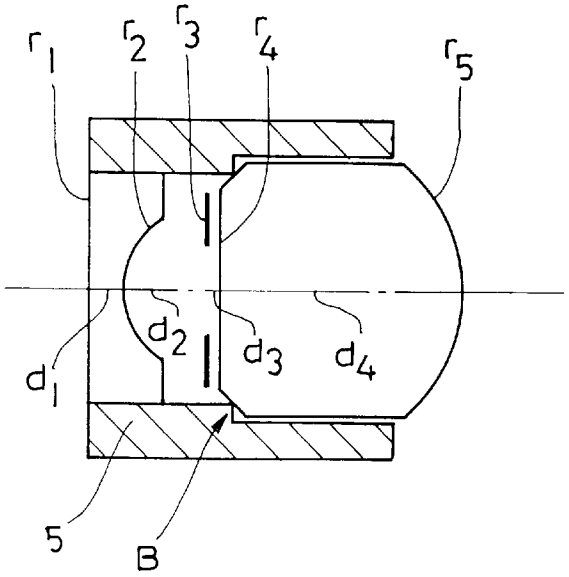


FIG. 16B

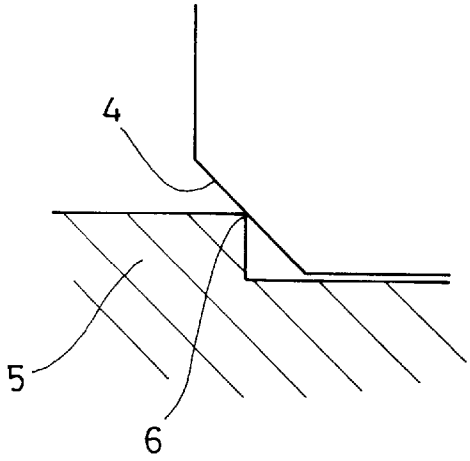


FIG. 17

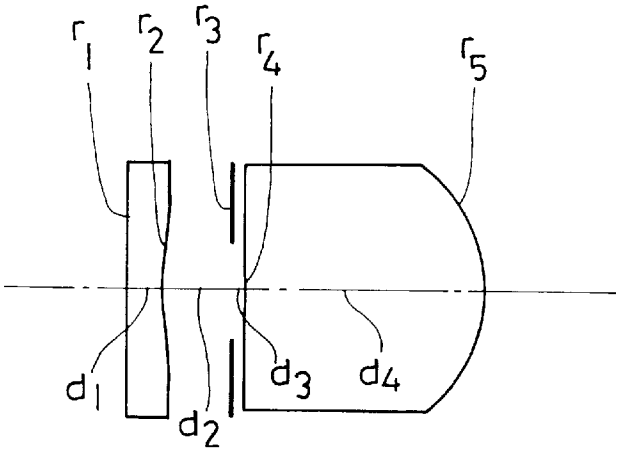


FIG. 18

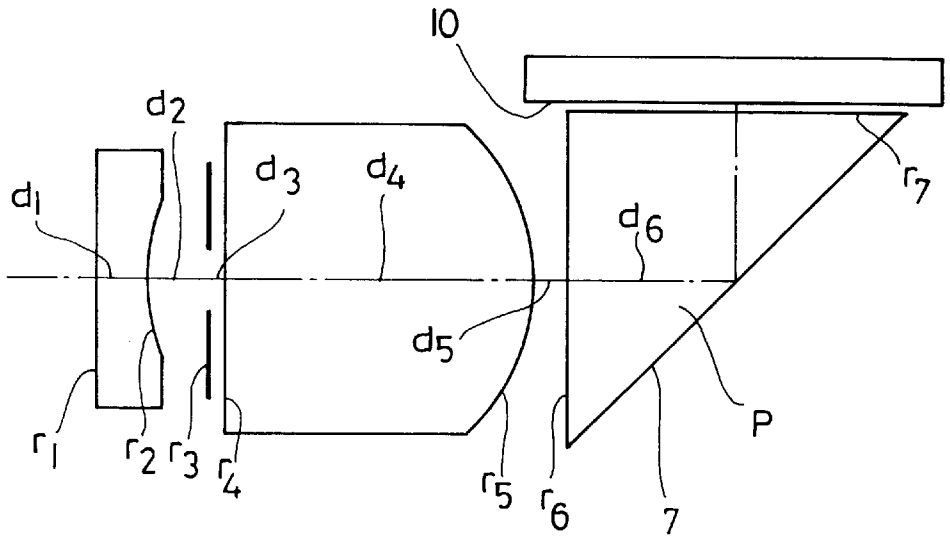


FIG. 19

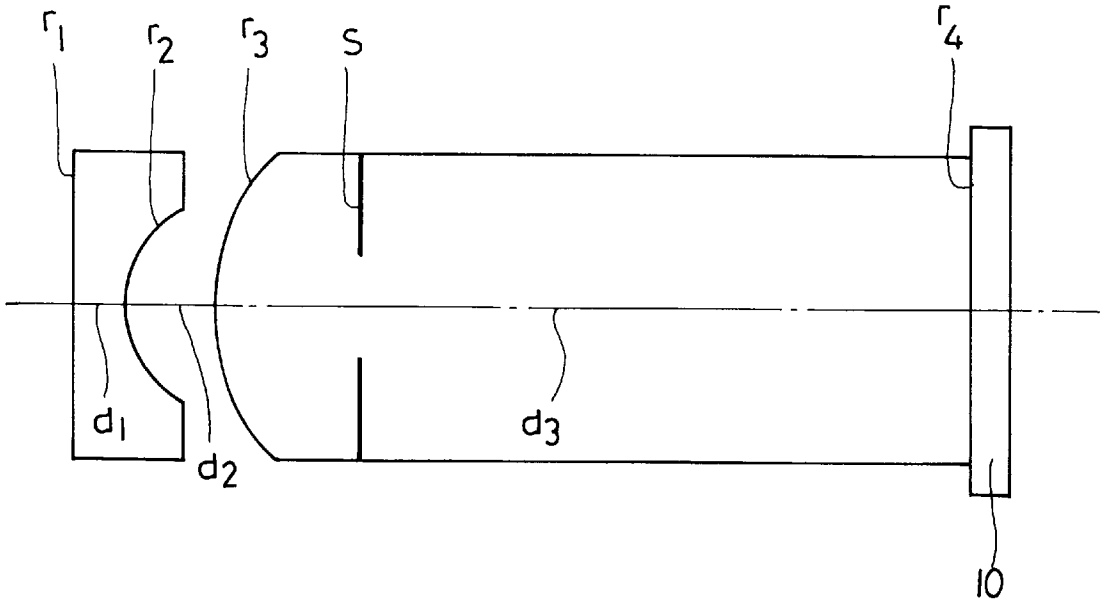


FIG. 20

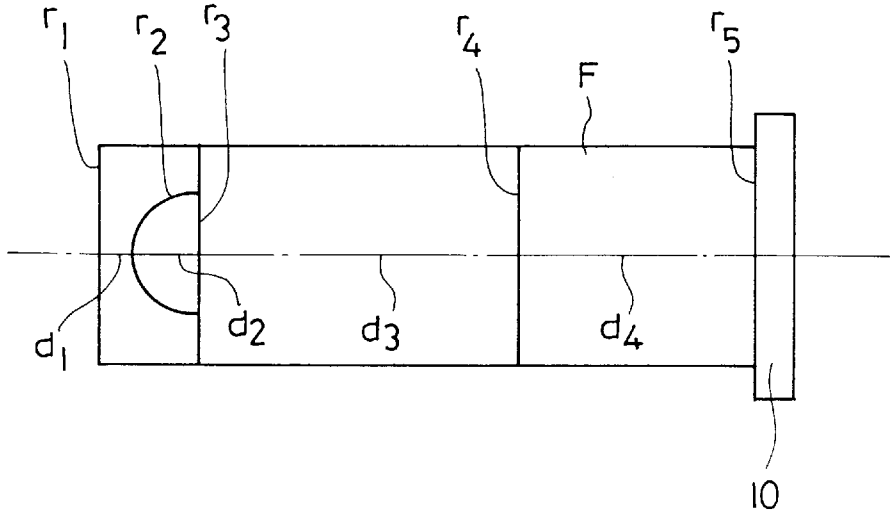


FIG. 21

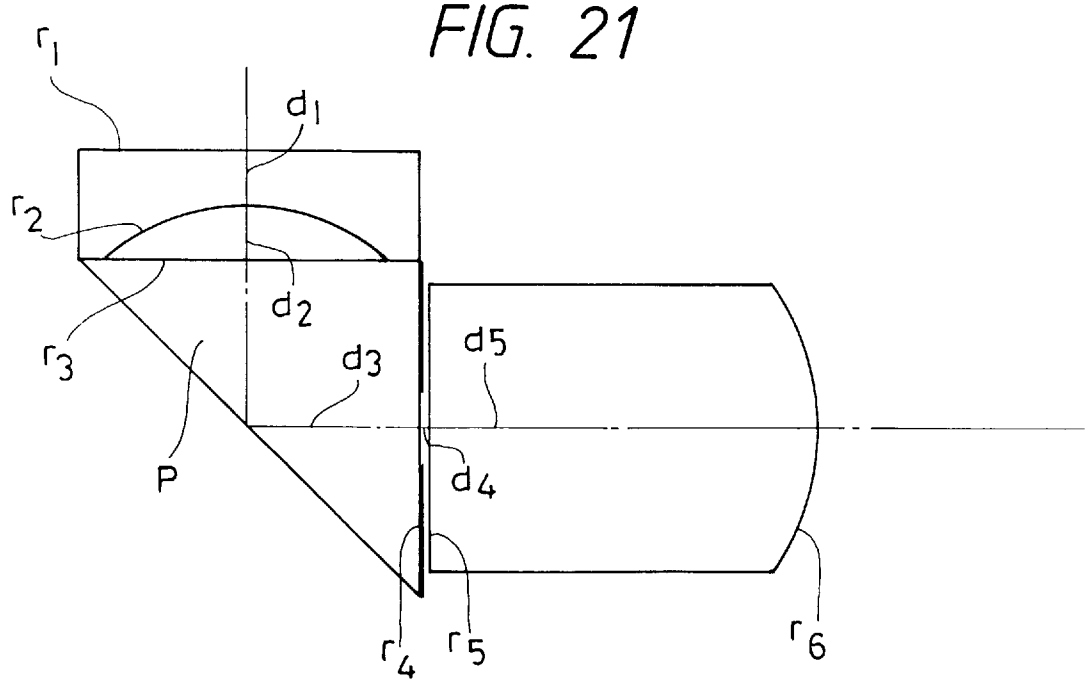


FIG. 22A

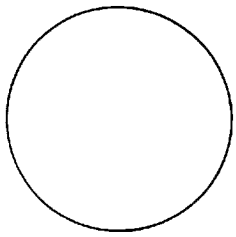


FIG. 22B

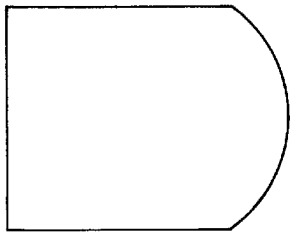


FIG. 22C

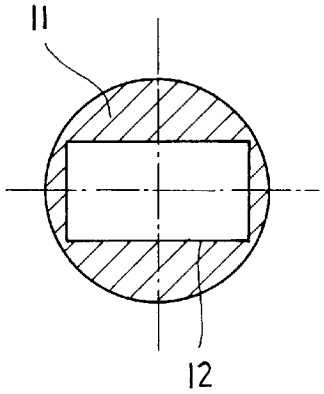


FIG. 23A

FIG. 23B

FIG. 23C

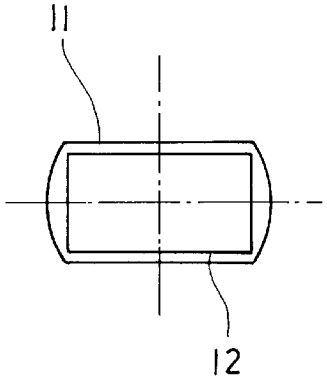


FIG. 24

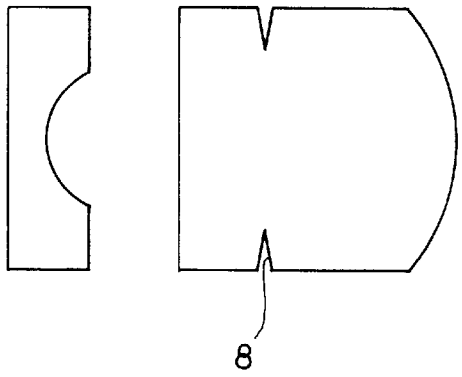


FIG. 25

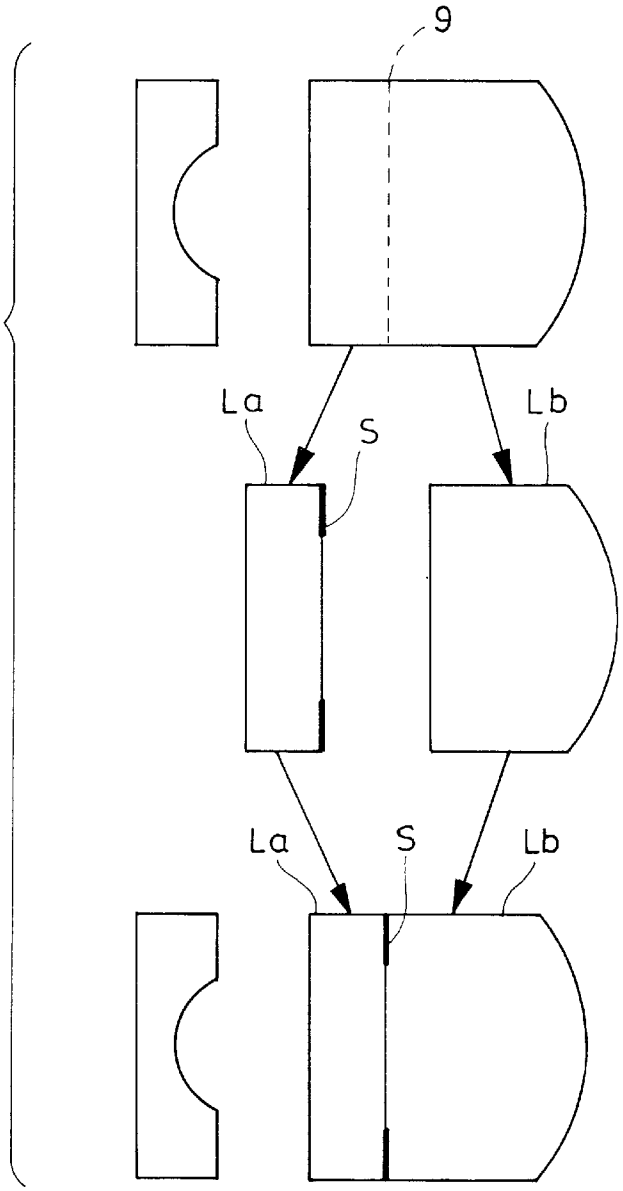


FIG. 26

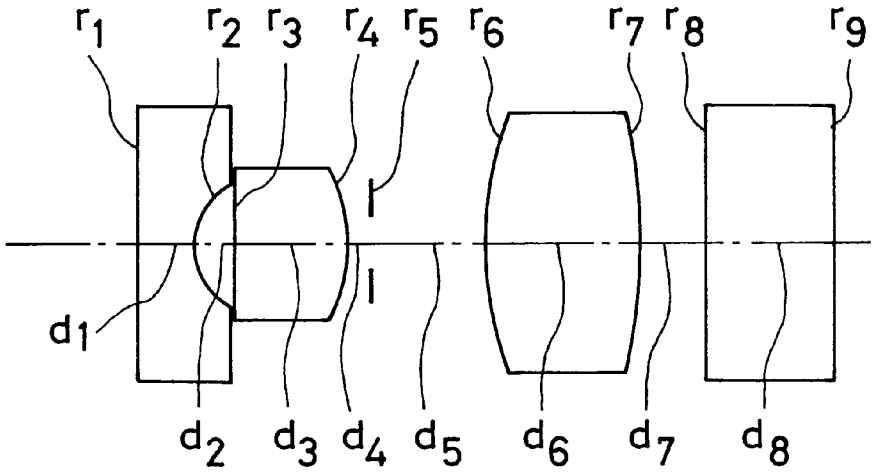

r1
r2
r3
r4
r5
r6
r7
r8
r9
d1
d2
d3
d4
d5
d6
d7
d8

FIG. 27

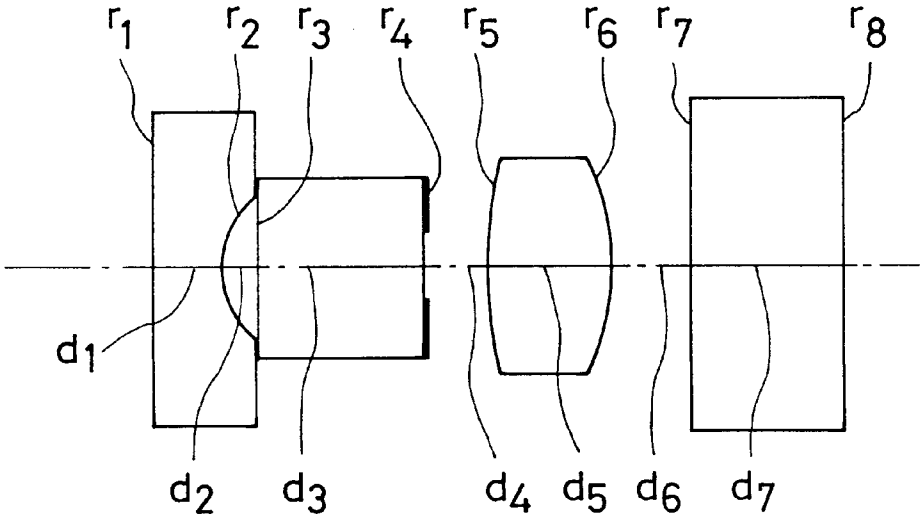

r1
r2
r3
r4
r5
r6
r7
r8
d1
d2
d3
d4
d5
d6
d7

FIG. 28

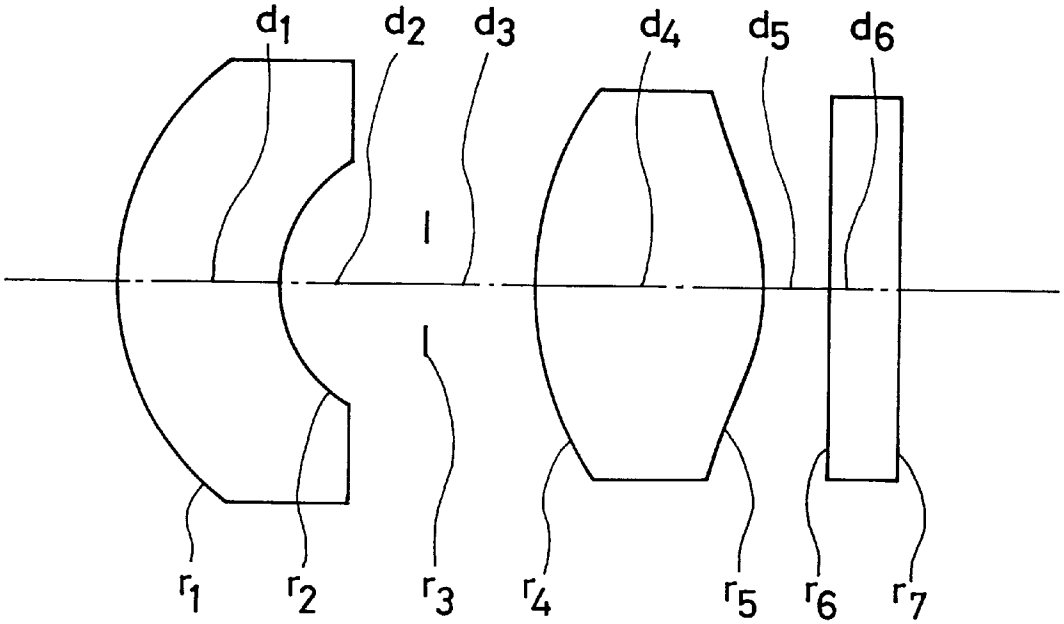


FIG. 29

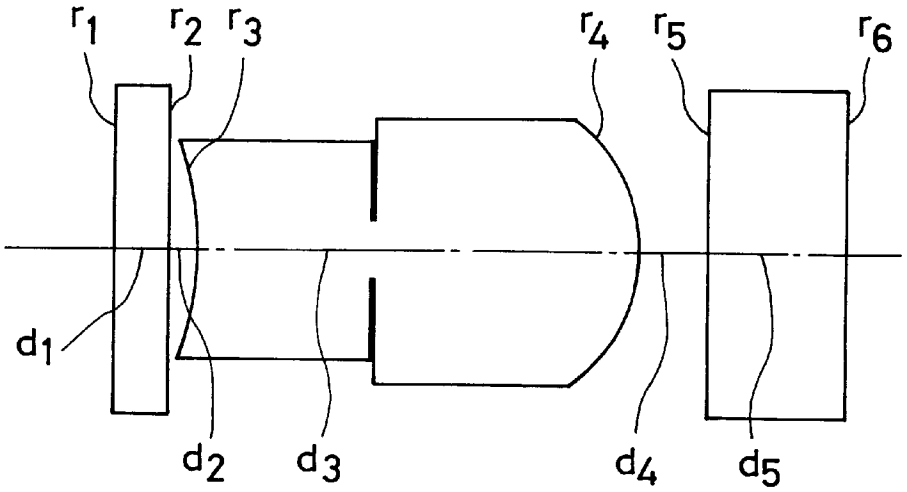


FIG. 30

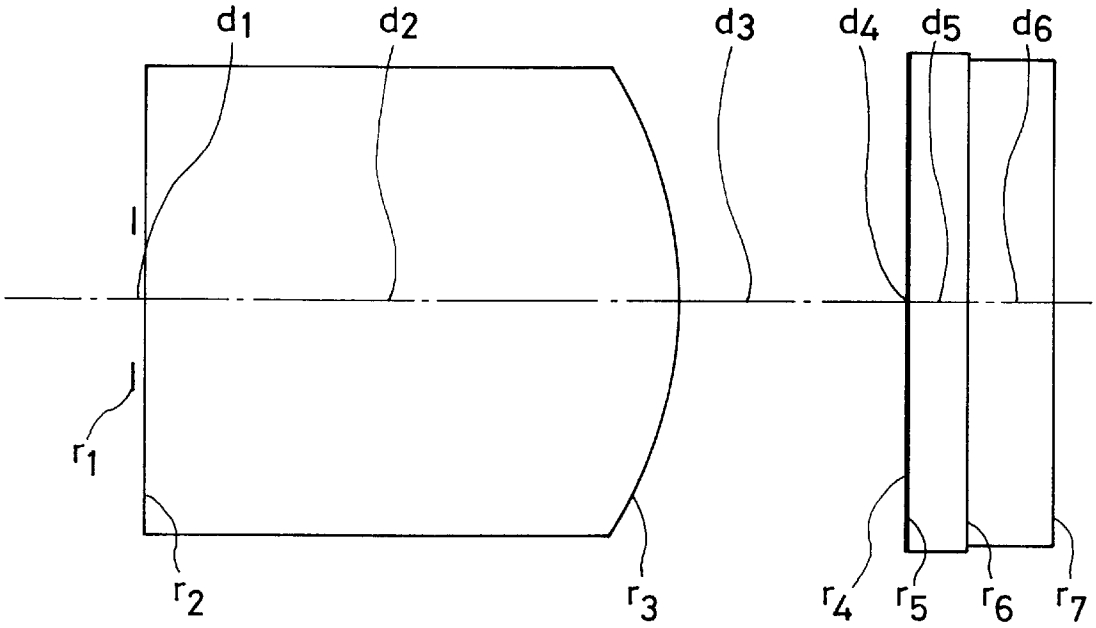

d1
d2
d3
d4
d5
d6
I
r1
r2
r3
r4
r5
r6
r7

FIG. 31

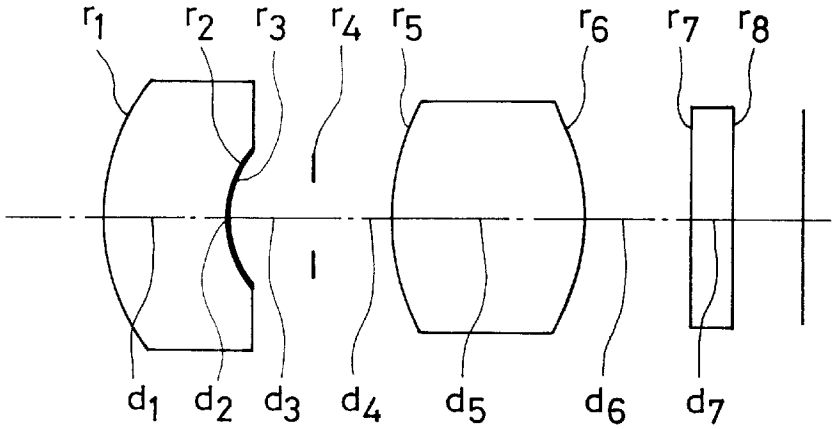

r1
r2
r3
r4
r5
r6
r7
r8
I
d1
d2
d3
d4
d5
d6
d7

FIG. 32

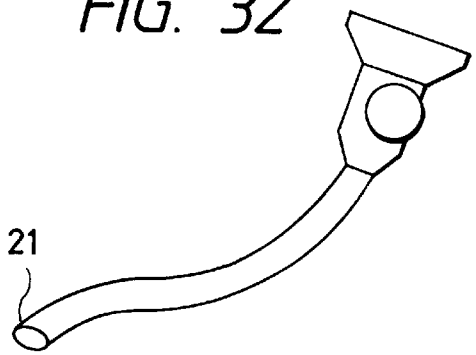


FIG. 33

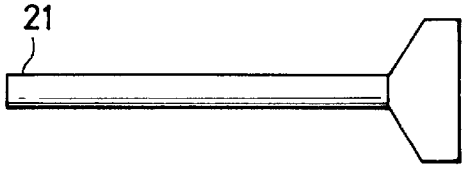


FIG. 34

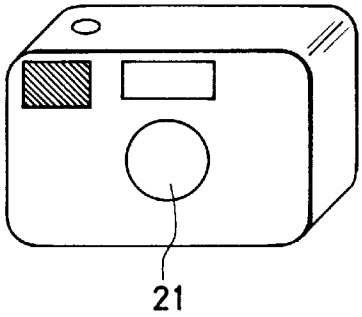


FIG. 35

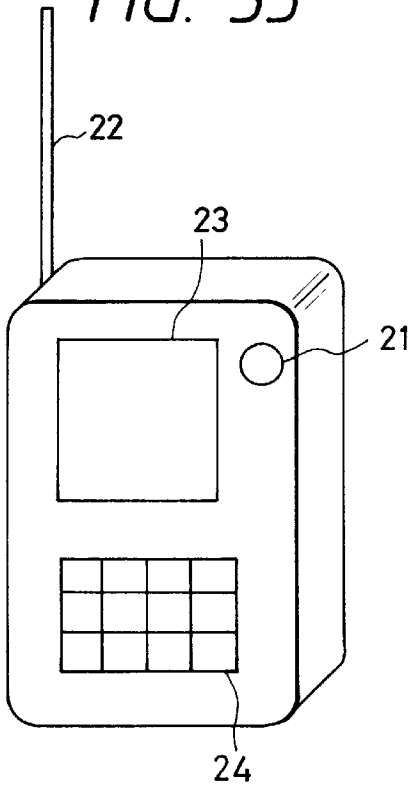
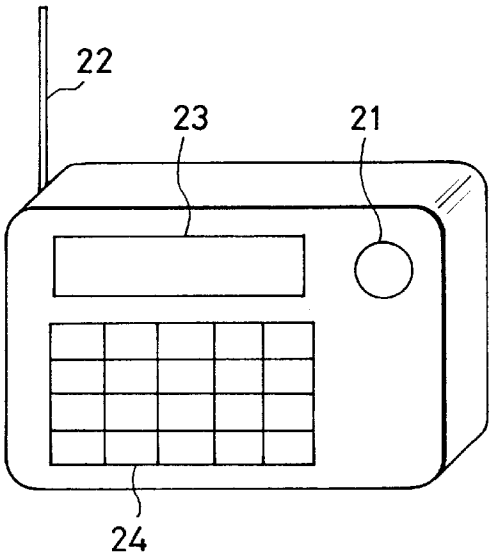


FIG. 36



OBJECTIVE LENS SYSTEM

BACKGROUND OF THE INVENTION

a) Field of the Invention

The present invention relates to an objective lens system which uses a radial type gradient index lens element.

b) Description of the Prior Art

As conventional examples of lens systems having relatively wide field angles and high optical performance which are used, for example, as objective lens systems for endoscopes, there are known many lens systems such as a lens system disclosed by Japanese Patent Kokoku Publication No. Sho 60-46410 shown in FIG. **1**. A conventional example shown in FIG. **1** is a lens system of the so-called retrofocus type which is composed, in order from the object side, of a front lens unit having negative refractive power, a stop and a rear lens unit having a positive refractive power. In this lens system, the front lens unit has a function to widen a field angle and another function to correct curvature of field by reducing a Petzval's sum of the lens system as a whole, the rear lens unit serves for suppressing production of spherical aberration and coma by distributing refractive powers among three positive lens elements and a cemented lens component, and the cemented lens component corrects lateral chromatic aberration which poses a problem, in particular, in a lens system which has a wide field angle. Though this conventional example favorably corrects aberrations, it is composed of lens elements in a number as large as six, thereby posing a problem of low producibility or a high manufacturing cost. Accordingly, it is expected to develop a retrofocus type objective lens system for endoscopes which is composed of an extremely small number of lens elements and has a high producibility. However, a lens system which favorably corrects aberrations and has high optical performance can hardly be composed of two homogenous spherical lens elements.

Further, an endoscope is generally equipped with a system for illuminating a location to be observed since it is used frequently for observing and photographing dark locations such as interiors of human bodies, aircraft engines, pipings and so on. In addition, an objective lens system for endoscopes has an NA which is not so large for obtaining a large depth of field. Accordingly, axial aberrations do not pose a serious problem, but a wide field angle and a negative-positive asymmetrical composition as shown in FIG. **1** make it difficult to correct offaxial aberrations. When an objective lens system is to be composed of two negative and positive lens elements, it is impossible to use a cemented lens component as in the objective lens system disclosed by Japanese Patent Kokoku Publication No. Sho 60-46410 mentioned above as the conventional example, whereby lateral chromatic aberration can hardly be corrected and offaxial imaging performance is remarkably degraded. It is therefore difficult to favorably correct offaxial aberrations with two homogenous lens elements so as to obtain favorable offaxial imaging performance.

It is therefore conceivable to use a radial type gradient index lens element which is characterized in that it corrects chromatic aberration in particular more favorably than a homogenous lens element. As a conventional example of an objective lens system for endoscopes which uses a radial type gradient index lens element and is composed of two lens elements, there is known a lens system disclosed by Japanese Patent Kokai Publication No. Sho 52-29238. However, this conventional example has a field angle as narrow as 72° which is insufficient for use as an objective lens system for endoscopes.

Further, a lens system disclosed by Japanese Patent Kokai Publication No. Hei 5-107471,for example, is known as a conventional example of an objective lens system having a wide field angle obtained with two lens elements. Though this example uses a radial type gradient index lens element, it does not effectively make use of the chromatic aberration correcting capability of the radial type gradient index lens element and does not sufficiently correct lateral chromatic aberration which poses a problem in a lens system having a wide field angle in particular.

SUMMARY OF THE INVENTION

A primary object of the present invention is to provide an objective lens system which is composed of lens elements in a number on the order of 2, that favorably corrects aberrations and has a wide field angle.

The objective lens system according to the present invention is characterized in that it comprises, in order from the object side, a first lens unit having a negative refractive power and a second lens unit having a positive refractive power; that at least the first lens unit comprises a radial gradient index lens element which has a refractive index distribution in a radial direction of the lens element; and that the first lens unit satisfies the following condition (1):

$$1/V_{10}<1/V_{00} \tag{1}$$

wherein the reference symbols V_{00} and V_{10} represent parameters expressing a dispersing power of the radial type gradient index lens element which are given by the following formulae (b) and (c) respectively:

$$V_{10}=(N_{00d}-1)/(N_{00F}-N_{00C}) \tag{b}$$

$$V_{10}=N_{10d}/(N_{10F}-N_{10C}) \tag{c}$$

wherein the reference symbols N_{00d}, N_{00F} and N_{00C} represent refractive indices of the radial type gradient index lens element for the d-line, F-line and C-line respectively, and the reference symbols N_{10d}, N_{10F} and N_{10C} designate values of a coefficient of a term r^2 for the d-line, F-line and C-line respectively when a refractive indices of the radial type gradient index lens element is expressed in a form of a polynominal. In embodiments of the present invention which are to be described later, refractive indices of radial type gradient index lens elements are given by the following formula (a):

$$n(r)=N_{00}+N_{10}r^2+N_{20}r^4+ \tag{a}$$

wherein the reference symbol r represents a distance as measured from an optical axis in a radial direction of the radial type gradient index element and the reference symbol n(r) designates a refractive index of a portion of the radial type gradient index lens element located at the distance r. Further, the objective lens system according to the present invention is characterized in: that it is composed, in order from the object side, of a first lens unit having a negative refractive power, and a second lens unit having a positive refractive power, that at least the second lens unit comprises a radial type gradient index lens element having a refractive index distribution in a radial direction of the lens element, and that the second lens unit satisfies the following conditions (1) and (3):

$$1/V_{10}<1/V_{00} \tag{1}$$

$$0.05<\phi_{2m}/\phi<1.0 \tag{3}$$

wherein the reference symbol ϕ_{2m} represents a refractive index of a medium of the radial type gradient lens element used in the second lens unit.

Further, it is desirable that the objective lens system according to the present invention described above satisfies the following condition (2):

$$-0.5<\phi_{1m}/\phi<-0.02 \quad (2)$$

wherein the reference symbol ϕ_{1m} represents a refractive power of a medium of the radial type gradient index lens element used in the first lens unit and the reference symbol ϕ designates a refractive power of the objective lens system as a whole.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** shows a sectional view illustrating a composition of a conventional objective lens system;

FIG. **2** shows a diagram schematically showing a fundamental composition of the objective lens system according to the present invention;

FIG. **3** shows a diagram schematically showing the fundamental composition of the objective lens system according to the present invention wherein an image surface is positioned in parallel with an optical axis;

FIGS. **4** through **15** show sectional views illustrating compositions of first through twelfth embodiments of the objective lens system according to the present invention;

FIGS. **16**A and **16**B show views illustrating a composition of a thirteenth embodiment of the objective lens system according to the present invention;

FIGS. **17** through **21** show sectional views illustrating composition of fourteenth through eighteenth embodiments of the objective lens system according to the present invention;

FIGS. **22**A, **22**B and **22**C show diagrams exemplifying a shape, before working, of a lens element which is to be used in the objective lens system according to the present invention;

FIGS. **23**A, **23**B and **23**C show diagrams exemplifying a shape, after working, of the lens system which is to be used in the objective lens system according to the present invention;

FIG. **24** is a diagram showing an example of a stop which is to be disposed in the objective lens system according to the present invention;

FIG. **25** is a diagram showing another example of a stop which is to be disposed in the objective lens system according to the present invention;

FIGS. **26** through **31** show sectional views illustrating compositions of nineteenth through twenty-fourth embodiments of the objective lens system according to the present invention;

FIG. **32** shows a perspective view illustrating an endoscope which uses the objective lens system according to the present invention;

FIG. **33** shows a side view of a non-flexible endoscope which uses the objective lens system according to the present invention;

FIG. **34** shows a perspective view illustrating a video camera which uses the objective lens system according to the present invention;

FIG. **35** shows a perspective view illustrating a portable TV telephone which uses the objective lens system according to the present invention; and FIG. **36** shows a perspective view illustrating a portable data input unit which uses the objective lens system according to the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

It is desirable that an objective lens system which has a relatively wide field angle for use in endoscopes, for example, is configured as the so-called retrofocus type composed, in order from the object side, of a first lens unit having a negative refractive power and a second lens unit having a positive refractive power.

Further, it is desirable that endoscopes, for example, which are inserted into human bodies and pipings for observing interiors thereof use objective lens systems having small diameters. When the lens system according to the present invention is to be used as an objective lens system for endoscopes, it is desirable for reducing a diameter of the lens system to compose it by disposing a stop between a negative lens unit and a positive lens unit. By selecting such a composition, it is possible to lower heights of rays passing through a first lens unit or a second lens unit, thereby reducing the diameter of the lens system. When the lens system has an asymmetrical composition, or is composed of a positive lens unit and a negative lens unit disposed on both sides of a stop, however, off-axial aberrations are apt to be produced in large amounts in the lens system as a whole, or it is difficult to favorably correct lateral chromatic aberration in particular. For favorably correcting lateral chromatic aberration, it is desirable to use a radial type gradient index lens element which has a more excellent characteristic for correcting chromatic aberration than a homogenous lens element.

It is known that lateral chromatic aberration LTC produced by a thin radial type gradient index lens element is expressed by the following formula (d):

$$LTC=K(\phi_s/V_{00}+\phi_m/V_{10}) \quad (d)$$

wherein the reference symbol K represents a constant determined dependently on a height of an offaxial ray and an angle of a final axial ray, the reference symbol ϕ_s designates a refractive power of a surface of the radial type gradient index lens element and the reference symbol ϕ_m denotes a refractive power of a medium of the radial type gradient index lens element which is known to be approximated by the following formula (e):

$$\phi_m \approx -2N_{10}d_G \quad (e)$$

wherein the reference symbol d_G represents thickness of the radial type gradient index lens element.

As is apparent from the formula (d), it is possible to control an amount of chromatic aberration to a desired value by varying V_{10} in the second term of the formula.

Since the objective lens system according to the present invention has an asymmetrical composition, like the model of thin lens elements shown in FIG. **2**, wherein a first negative lens unit L_1 and a second positive lens unit L_2 are disposed in that order from the object side and on both side of a stop S, each of the lens units refracts a ray RO coming from an offaxial object point, unlike a ray RA coming from an axial object point, in a direction which is the same as a refracted direction (downward in FIG. **2**) of an incident light bundle. Accordingly, lateral chromatic aberration is produced in a very large amount in the objective lens system according to the present invention, thereby making it difficult to compose the objective lens system, in order from the object side, of a negative lens unit and a positive lens unit which consist of two homogenous lens elements.

For solving this problem or favorably correcting lateral chromatic aberration by adopting a radial type gradient index lens element, it is conceivable to select either of two cases: one where the radial index lens element is used in the first negative lens unit and the other where the radial gradient lens element is used in the second positive lens unit.

Description will be made of a first composition of the objective lens system according to the present invention where a radial gradient index element is used in the first negative lens unit.

For allowing a radial type gradient index lens element to produce chromatic aberration in an amount smaller than that of chromatic aberration produced by a homogenous lens element which has the same refractive power as that of the radial type gradient index lens element, it is necessary from the formula (d) to satisfy the following relationship:

$$\phi_s/V_{00}+\phi_m/V_{10}<\phi_t/V_{00}$$

wherein the reference symbol ϕ_t represents a refractive power of the homogenous lens element on an assumption that it has an Abbe's number which is equal to that on the optical axis of the radial type gradient index lens element.

Since the radial type gradient index lens element and the homogenous lens element which are compared with each other have the same refractive power, we obtain:

$$\phi_t=\phi_s+\phi_m$$

From the two formulae mentioned above, there establishes the following relationship:

$$\phi_s/V_{00}+\phi_m/V_{10}<\phi_s/V_{00}+\phi_m/V_{00}$$

The above-mentioned condition (1) is obtained from this formula.

For favorably correcting lateral chromatic aberration in the objective lens system according to the present invention, it is desirable to use a radial type gradient index lens element satisfying the condition (1) as the first lens unit which has the negative refractive power as described above. The condition (1) is required for allowing a radial type gradient index lens element to produce chromatic aberration in an amount smaller than that of chromatic aberration produced by a homogenous lens element which has the same refractive power as that of the radial type gradient index lens element. If the condition (1) is not satisfied, a radial type gradient index lens element cannot correct lateral chromatic aberration more favorably than a homogenous lens element which has the same refractive power as that of the radial type gradient index lens element.

When a radial type gradient index lens element is to be used for correcting lateral chromatic aberration, it is necessary, as apparent from the formula (d), to take into sufficient consideration not only a value of V_{10} but also refractive powers of a surface and a medium. For reducing an amount of lateral chromatic aberration to be produced by the first lens unit in the objective lens system according to the present invention, it is desirable from the formula (d) to meet the following equation:

$$\phi_s/V_{00}+\phi_m/V_{10}\approx 0$$

By using a total refractive power of a surface and a medium $\phi_G(=\phi_s+\phi_m)$ in this formula and developing it, we obtain:

$$\phi_m\approx\phi_G\times V_{10}/(V_{10}-V_{00})$$

Since the Abbe's number V_{00} of a radial type gradient index lens element ordinarily has a value on the order of 30 to 80 on an optical axis and the first lens unit has the negative refractive power, the condition (1) required for correcting chromatic aberration can be transformed as follows:

$$\phi_G\times V_{10}/(V_{10}-V_{00})<0$$

It is desirable as understood from this formula that a medium has a negative refractive power. Taking into consideration this fact and the requirement to correct lateral chromatic aberration favorably in the objective lens system as a whole, it is desirable that a radial type gradient index lens element which is to be used in the objective optical system according to the present invention is made of a medium having a refractive power ϕ_{1m} satisfying the above-mentioned condition (2).

When a ratio of a refractive power of a medium of the first lens unit relative to a refractive power of the objective lens system satisfies the condition (2), it is possible to correct lateral chromatic aberration favorably in the objective lens system as a whole. If the upper limit of −0.02 of the condition (2) is exceeded, a medium of the radial type gradient index lens element will have a weak refractive power, thereby undesirably making it difficult to correct lateral chromatic aberration favorably in the objective lens system as a whole. If the lower limit of −0.5 of the condition (2) is not satisfied, in contrast, a medium will have too strong a refractive power, thereby overcorrecting lateral chromatic aberration.

The objective lens system according to the present invention which has a second composition is composed of a first lens unit having a negative refractive power and a second lens unit having a positive refractive power; a radial type gradient index lens element being used in the second lens unit having the positive refractive power; and the radial type gradient index lens element used in the second lens unit having a refractive index expressed by the above-mentioned formula (a) and satisfying the following conditions (1) and (3):

$$1/V_{10}<1/V_{00} \quad (1)$$

$$0.05<\phi_{2m}/\phi<1.0 \quad (3)$$

wherein the reference symbol ϕ_{2m} represents a refractive power of the gradient index lens element which is used in the second lens unit and the reference symbol ϕ designates a refractive power of the objective lens system as a whole.

Since lateral chromatic aberration is produced in a very large amount in the objective lens system as a whole as described above, it is difficult to compose the lens system, in order from the object side, of two negative and positive homogenous lens elements. When a radial type gradient index lens element is to be used in the second lens lens unit for solving this problem or favorably correcting lateral chromatic aberration, it is desirable to configure this lens element so as to satisfy the condition (1) mentioned above.

The condition (1) is required for allowing the radial type gradient index lens element to produce chromatic aberration in an amount smaller than that of chromatic aberration produced by a homogenous lens element which has the same refractive power as that of the radial type gradient index lens element.

If the condition (1) is not satisfied, the radial type gradient index lens element cannot correct chromatic aberration more favorably than the homogenous lens element having the same refractive power as that of the radial type gradient index lens element.

When a radial type gradient index lens element is to be used for correcting lateral chromatic aberration, it is necessary to take into consideration not only a value of V_{10} but also refractive powers of a surface and a medium as described above. When lateral chromatic aberration produced by the second lens unit is to be reduced in the objective lens system according to the present invention, the

formula (d) is transformed, as in the case where a radial type gradient index lens element is used in the first lens unit, into the following formula:

$$\phi_m \approx \phi_G \times V_{10}/(V_{10}-V_{00})$$

Since the second lens unit has a positive refractive power, it is desirable that ϕ_m has a positive value. When a radial type gradient index lens element is to be used in the second lens unit for correcting lateral chromatic aberration favorably in the objective lens system as a whole, it is desirable that the refractive power ϕ_m of a medium satisfies the above-mentioned condition (3).

When a ratio of a refractive power of medium relative to a refractive power of the objective lens system as a whole satisfies the condition (3), it is possible to correct lateral chromatic aberration favorably in the objective lens system as a whole.

If the lower limit of 0.05 of the condition (3) is not satisfied, a medium of the radial type gradient index lens element will have a weak refractive power, thereby undesirably making it difficult to correct lateral chromatic aberration favorably in the objective lens system as a whole. If the upper limit of 1.0 of the condition (3) is not satisfied, in contrast, a refractive power of medium will be too strong, thereby undesirably overcorrecting lateral chromatic aberration.

The condition (3) is required also for favorably correcting not only chromatic aberration but also the other aberrations.

The objective optical system according to the present invention which has a wide field angle produces a positive Petzval's sum in the lens system as a whole, thereby tending to tilt an image surface toward the object side. For favorably correcting this Petzval's sum, it is desirable to use a radial type gradient index lens element in the second lens unit which has a large positive Petzval's sum.

A Petzval's sum PTZ of a radial type gradient index lens element is expressed by the following formula (f):

$$PTZ=\phi_s/N_{00}+\phi_m/N_{00}^2 \quad (f)$$

As is apparent from the formula (f) in which the denominator of the second term on the right side is squared, it is possible to configure a radial type gradient index lens element so as to have a Petzval's sum which is smaller than that of a homogenous lens element having the same refractive power as that of the radial type gradient index lens element.

For reducing a Petzval's sum of the objective lens system with a radial type gradient index lens element, it is desirable from the formula (f) that the radial type gradient index lens element satisfies the following formula:

$$\phi_s/N_{00}+\phi_m/N_{00}^2 \approx 0$$

The formula shown below can be derived by using a total refractive power of surface and medium. $\phi_G(=\phi_2+\phi_m)$ in the above formula and developing it.

$$\phi_m \approx \phi_G \times N_{00}/(N_{00}-1)$$

Since refractive indices N_{00} on an optical axis of radial gradient index lens elements ordinarily have values larger than 1, or on the order of 1.45 to 1.85, it is desirable for favorably correcting a Petzval's sum to use a radial type gradient index lens element which has a positive refractive power of medium when it is to be used in the second lens unit having the positive refractive power. If a radial type gradient index lens element which has a negative refractive power of medium is used in the second lens unit, the positive Petzval's sum will be further enlarged, hereby undesirably tilting an image surface toward the object side.

For correcting the Petzval's sum in the objective lens system according to the present invention, it is desirable from the formula (f) that a refractive power of medium is strong to a certain degree or refractive power of medium ϕ_m satisfies the condition (3). When a ratio of the refractive power of medium relative to a refractive power of the objective lens system as a whole satisfies the condition (3), it is possible to favorably correct the Petzval's sum in the objective lens system as a whole. If the lower limit of 0.05 of the condition (3) is not satisfied, a refractive power of medium will be weak, thereby making it difficult to correct the Petzval's sum favorably in the objective lens system as a whole. If the upper limit of 1.0 of the condition (3) is exceeded, in contrast, a refractive power of medium will be too strong and the Petzval's sum will be overcorrected, thereby undesirably tilting an image surface in a direction away from the object side.

As understood from the foregoing description, the condition (3) is required for favorably correcting lateral chromatic aberration and Petzval's sum at the same time in the objective lens system according to the present invention (which has the second composition).

Further, an objective lens system for endoscopes is generally used in combination with a solid-state image pickup device such as CCD or an end surface of the so-called image guide composed of an optical fiber bundle which is disposed on an image surface. When an objective lens system is to be combined not with a silver salt photographic film but with a solid-state image pickup device or an image guide, it is desirable for enhancing a light condensing efficiency to configure the objective lens system so as to be telecentric on the image side so that incident rays are as perpendicular as possible to an image surface. For configuring the objective lens system according to the present invention so as to meet this requirement, the second lens unit having the positive refractive power must have an image side surface which has a positive refractive power stronger than that of an object side surface thereof. When the image side surface of the second lens unit on which offaxial rays are relatively high has a strengthened refractive power in the objective lens system according to the present invention having a wide field angle, however, this surface will produce coma in a large amount and it will be difficult to correct this coma favorably with a homogenous lens element.

Accordingly, it was conceived to correct coma favoraly in the objective lens system according to the present invention with a radial type gradient index lens element used in the second lens unit. For correcting this aberration, it is desirable that the radial type gradient index lens element has such a refractive index distribution as to progressively lower refractive indices from the optical axis toward a marginal portion. An amount of coma to be produced by the image side surface of the second lens unit can be reduced by configuring the radial type gradient index lens element to be used in the second lens unit so as to have such a refractive index distribution. Therefore, the condition (3) serves for favorable correction of coma in addition to favorable correction of lateral chromatic aberration. When the condition (3) is satisfied, the radial type gradient index lens element has a refractive index distribution wherein refractive indices are progressively lowered from the optical axis toward the marginal portion, thereby being capable of favorably correcting coma. If the lower limit of 0.05 of the condition (3) is not satisfied, it will be difficult to favorably correct coma

with the radial type gradient index lens element. If the upper limit of 1.0 of the condition (3) is exceeded, in contrast, coma will undesirably be overcorrected.

Since the objective lens system according to the present invention has a wide field angle and the asymmetrical composition which is negative-positive in order from the object side, it tends to produce remarkable barrel form distortion which can hardly be corrected favorably with two homogenous lens elements. For correcting the barrel form distortion favorably in the objective lens system according to the present invention, it is desirable to use, in the second lens unit having the positive refractive power, a radial type gradient index lens element which has a refractive index distribution wherein refractive indices are progressively lowered from the optical axis toward the marginal portion. Distortion to be produced by the second lens unit can be reduced by using a radial type gradient index lens element having such a refractive index distribution. Accordingly, the condition (3) serves for favorable correction of distortion in addition to favorable correction of lateral chromatic aberration. When the contition (3) is satisfied, refractive indices are progressively lowered from the optical axis toward the marginal portion, thereby enabling to favorably correct distortion. If the lower limit of 0.05 of the condition (3) is not satisfied, it will be difficult to favorably correct distortion with a radial type gradient index lens element. If the upper limit of 1.0 of the condition (3) is exceeded, in contrast, aberrations other than distortion will undesirably be overcorrected.

The objective lens system according to the present invention which has a third composition is characterized in: that it is composed, in order from the object side, of a first lens unit having a negative refractive power and a second lens unit having a positive refractive power; that it uses at least one radial type gradient index lens element having a refractive index distribution in a radial direction from an optical axis which is expressed by the formula (a); and that at least one of the surfaces of lens elements including the radial type gradient index lens element composing the lens system is configured as an aspherical surface which has such a shape as to weaken a refractive power of the lens element having the aspherical surface from the optical axis toward the marginal portion.

Since the objective lens system according to the present invention has a wide field angle and an asymmetrical composition which is negative-positive in order from the object side, it tends to produce remarkable distortion in addition to lateral chromatic aberration. Though distortion can be corrected to a certain degree by using a radial type gradient index lens element in the second lens unit as described above, it is desirable for correcting distortion more favorably to configure the objective optical system according to the present invention so as to comprise at least one surface of at least one lens element which is configured as an aspherical surface having such a shape as to weaken a refractive power of the lens element having the aspherical surface from the optical axis toward the marginal portion. In the objective lens system according to the present invention, barrel form distortion is produced by both the first lens unit having the negative refractive power and the second lens unit having the positive refractive power. When an aspherical surface is to be used in either of the lens units in the objective lens system, it is therefore desirable to configure the aspherical surface so as to have such a shape as to weaken a refractive power from the optical axis toward the marginal portion of the lens element using the aspherical surface. When the second lens unit uses a radial type gradient index lens element, for example, it is desirable to use an aspherical surface in the first lens unit having the negative refractive power and configure the aspherical surface so as to have such a shape as to weaken the negative refractive power from the optical axis toward the marginal portion. Though distortion produced by the second lens unit can be corrected to a certain degree by using a radial type gradient index lens element in the second lens unit as described above, distortion can be corrected more favorably by using an aspherical surface in the first lens unit.

When a radial type gradient index lens element is used in the first lens unit, it is desirable to use, in the second lens unit having a positive refractive power, an aspherical surface which has such a shape as to weaken the positive refractive power toward the optical axis to a marginal portion.

If an aspherical surface has such a shape as to strengthen the refractive power of a lens unit which comprises this aspherical surface, it will undesirably make barrel form distortion more remarkable in the objective lens system as a whole.

It is needless to say that an effect similar to that described above can be obtained by configuring a surface of a radial type gradient index lens element as an aspherical surface.

For correcting lateral chromatic aberration in the objective lens system according to the present invention which has the third composition, it is desirable to configure the radial type gradient index lens element so as to satisfy the condition (1). If the condition (1) is not satisfied, lateral chromatic aberration will undesirably be more remarkable in the objective lens system according to the present invention.

It is needless to say that lateral chromatic aberration can be corrected more favorably by using two radial type gradient index lens elements when the objective lens system according to the present invention is to be composed of two negative and positive lens elements.

It is also needless to say that distortion can be corrected more favorably by using an aspherical surface on each of the lens elements when the objective lens system is to be composed of two negative and positive lens elements.

The objective lens system according to the present invention which has a fourth composition is characterized in that it is composed, in order from the object side, of a first lens unit having a negative refractive power and a second lens unit having a positive refractive power. The second lens unit comprises at least one radial type gradient index lens element which has a refractive index distribution in a radial direction expressed by the formula (a), or wherein refractive indices are progressively lowered from an optical axis toward a marginal portion. The radial type gradient index lens element has a shape of a positive lens element. The radial type gradient index lens element satisfies the condition (1).

When a radial type gradient index lens element is to be used in the second lens unit, it is desirable for correcting lateral chromatic aberration to configure it so as to satisfy the condition (1) as described above, and it is desirable for correcting a Petzval's sum, coma or distortion that this lens element has a refractive index distribution wherein refractive indices are lowered from the optical axis toward the marginal portion. When not only correction of aberrations but also manufacturing facility are taken into consideration, it is desirable that the radial type gradient index lens element has a shape of a positive lens element.

Since the objective lens system according to the present invention has a wide field angle, it is necessary that the second lens unit has a strong positive refractive power. When a radial type gradient index lens element is to be used

in the second lens unit, it is therefore desirable that the radial type gradient index lens element also has a strongly positive refractive power. However, it is undesirable that the radial type gradient index lens element has an extremely strong positive refractive power of medium for a reason described below. As apparent from the formula (e), it is sufficient for strengthening a refractive power of medium of a radial type gradient index lens element to enlarge an absolute value of the refractive index distribution coefficient of the second order N_{10} or thickness d_G of the radial type gradient index lens element. However, an absolute value of the refractive index distribution coefficient of the second order can be enlarged only within a range limited by preparation of materials and enlargement of thickness d_G makes it difficult to configure the objective lens system compactly, thereby making it unusable as an objective lens system for endoscopes, for example, which are desired to be compact. Accordingly, it is desirable not to impart an extremely strong positive refractive power to a medium but to impart refractive powers to both the medium and surfaces, or configure the radial type gradient index lens element so as to have a shape of a positive lens element.

The objective lens system according to the present invention, which has a fifth composition, is characterized in that it is composed, in order from the object side, of a first lens unit having a negative refractive power and a second lens unit having a positive refractive power; that it uses at least one lens element which is configured as a radial type gradient index lens element having a refractive index distribution in the radial direction from an optical axis expressed by the formula (a); and that a lens unit comprising the radial type gradient index lens element or at least one optical element disposed in the objective lens system has a function to shield components having specific wavelengths.

By using a radial type gradient index lens element, it is possible to obtain an objective lens system which favorably corrects chromatic aberration in particular and has high imaging performance. An objective lens system for endoscopes which comprises a solid-state image pickup device such as a CCD, for example, may use an infrared cut filter for cutting off rays in the infrared region since the image pickup device has high sensitivity at wavelengths in the infrared region. Further, such an optical system may use a low pass filter made, for example, of quartz for eliminating noise components produced due to moiré. Furthermore, such an objective lens system may use a band cut filter for cutting off components having specific wavelengths since endoscopes may be used not only for observing interiors of human bodies but also for cutting off diseased portions of patients with laser knives. It is therefore desirable that the objective lens system according to the present invention uses not only a radial type gradient index lens element but also filters of the kinds mentioned above so that it can exhibit high imaging performance when it is used in optical systems for endoscopes which use, for example, solid-state image pickup devices such as CCD's.

It is desirable that these filters are disposed at locations between a lens element disposed on the image side and an image surface at which offaxial rays, in particular, are nearly in parallel with the optical axis. By disposing the filters as described above, it is possible to prepare approximately equal optical path lengths for axial and offaxial rays, thereby allowing the filters to exhibit their effects uniformly over the entire image pickup surface.

Endoscopes which are to be inserted into human bodies must be compact and require compacter optical systems. When importance is laid on compactness rather than optical performance, it is effective to dispose filters between the first lens unit and the second lens unit. Further, for obtaining an objective lens system which is compact and can be manufactured at a low cost, it is effective to impart filter functions to at least one of the lens elements including a radial type gradient index lens element.

The objective lens system according to the present invention which has a sixth embodiment is characterized in that it is composed, in order from the object side, of a first lens unit having a negative refractive power and a second lens unit having a positive refractive power; that it uses at least one radial type gradient index lens element which has a refractive index distribution in a radial direction expressed by the formula (a); and that it uses a reflecting surface for at least a single reflection disposed on the image side of the second lens unit.

Resolution of an optical system for endoscopes which uses a solid-state image pickup device such as CCD, for example, can be enhanced by reducing the size of picture elements and arranging these picture elements in a larger number at a higher density on the image pickup device. However, the size of a picture element can be reduced only within a certain manufacturing limit and it is therefore conceivable to enhance resolution by enlarging an image pickup surface. However, it is desirable that endoscopes which may be inserted into human bodies have smaller diameters, or it is undesirable to enlarge image pickup surfaces, thereby enlarging diameters of endoscopes.

For allowing solid-state image pickup devices having larger image pickup surfaces to be used without enlarging diameters of endoscopes, the objective lens system according to the present invention uses a reflecting surface for at least one reflection on the image side of the second lens unit which makes it possible to dispose a solid-state image pickup device, not in parallel with a radial direction of the endoscope, but in a position inclined with regard thereto. FIG. **3** shows a conceptional diagram of the objective lens system according to the present invention which has the sixth composition. In FIG. **3**, the reference symbol L_1 represents the first negative lens unit, the reference symbol L_2 designates the second positive lens unit, the reference symbol RA denotes an axial ray, the reference symbol RO represents an offaxial ray, the reference symbol R designates the reflecting surface and the reference numeral **10** denotes the image pickup device disposed on an image pickup plane. The reflecting surface R disposed on the image side of the second lens unit makes it possible to arrange the solid-state image pickup device which has a large image pickup surface nearly parallel to the optical axis. Though a system for a single reflection is illustrated in FIG. **3**, it is possible, needless to say, to obtain a similar effect by using a larger number of reflecting surfaces for a plurality of reflections.

When a solid-state image pickup device having a large image pickup surface is used, an image height can be enhanced in a lens system for obtaining a lens system having a wide field angle. However, it is desired for an objective lens system to correct aberrations more favorably over a range from a center to a marginal portion of an image plane. For an objective lens system having a wide field angle in particular, it is desired to favorably correct lateral chromatic aberration.

An objective lens system which has high imaging performance for axial and offaxial rays can therefore be obtained by using a radial gradient index lens element which has high capability to correct chromatic aberration in particular. It is possible to obtain an objective lens system having higher performance by combining an objective lens system which

uses a radial type gradient index lens element with a reflection system shown in FIG. **3** which permits enlarging an image pickup surface.

When a radial type gradient index lens element is used in the second lens unit in each of the compositions (first through sixth compositions) of the objective lens system according to the present invention, it is desirable for more favorable correction of lateral chromatic aberration, coma and distortion to satisfy the following condition (4):

$$-0.5<N_{10p}\cdot f^2<-0.01 \quad (4)$$

wherein the reference symbol N_{10p} represents a refractive index distribution coefficient of the second order when a radial type gradient index lens element is used in the second lens unit and the reference symbol f designates a focal length of the objective lens system as a whole.

When the condition (4) is satisfied, a refractive power of medium of the radial type gradient index lens element has a sufficiently large value, thereby making it possible to correct lateral chromatic aberration favorably. Further, refractive indices are progressively lowered from the optical axis toward a marginal portion and a difference in refractive index (Δn) is large between the optical axis and the marginal portion, thereby making it possible to favorably correct coma produced by an image side surface of the second lens unit and barrel form distortion which poses a problem in the objective lens system as a whole.

If the upper limit of −0.01 of the condition (4) is exceeded, the radial type gradient index lens element will have a weak refractive power of medium, thereby making it difficult to correct lateral chromatic aberration favorably in the objective lens system as a whole, and the difference in refractive indices will be small between the optical axis and the marginal portion, thereby making it difficult to correct coma and distortion. If the lower limit of −0.5 of the condition (4) is not satisfied, in contrast, the radial type gradient index lens element will have a large refractive index difference Δn, thereby undesirably making it difficult to prepare a material for the radial type gradient index lens element.

When a radial type gradient index lens element is used in the first lens unit in the objective lens system according to the present invention which has one of the compositions described above, it is desirable for correcting lateral chromatic aberration more favorably to satisfy the following condition (5):

$$0.01<N_{10n}\cdot f^2<0.6$$

wherein the reference symbol N_{10n} represents the refractive index distribution coefficient of the second order of a gradient index lens element when the radial type gradient index lens element is used in the first lens unit and the reference symbol f designates a focal length of the objective lens system as a whole.

When the condition (5) is satisfied, a refractive power of medium of the radial type gradient index lens element has a sufficiently large value, thereby making it possible to correct lateral chromatic aberration favorably.

If the lower limit of 0.01 of the condition (5) is not satisfied, the radial type gradient index lens element will have a weak refractive power of medium, thereby making it difficult to correct lateral chromatic aberration favorably in the objective lens system as a whole. If the upper limit of 0.6 of the condition (5) is exceeded, the radial type gradient index lens element will have a large refractive index difference Δn, thereby making it difficult to prepare a material for the radial type gradient index lens element.

When the radial type gradient index lens element is used in the first lens unit or the second lens unit of the objective lens system according to the present invention, it is desirable for correcting lateral chromatic aberration more favorably in the lens system to satisfy the following condition (6):

$$1/V_{10}<0.01 \quad (6)$$

The objective lens system which satisfies the condition (6) can favorably correct lateral chromatic aberration. Since radial type gradient index lens elements have Abbe's numbers on the order of 30 to 80 as described above, it is desirable from the formula (d), for allowing a radial type gradient index lens element to exhibit a sufficient function for correcting chromatic aberration to satisfy the condition (6). If the condition (6) is not satisfied, it will undesirably be impossible to sufficiently correct lateral chromatic aberration.

When a radial type gradient index lens element is used in the first lens unit of the objective lens system according to the present invention which has any one of the first through sixth compositions, it is desirable for correcting lateral chromatic aberration more favorably to satisfy the following condition (7):

$$0.05<d_{Gn}/f_{Gn}<1.2 \quad (7)$$

wherein the reference symbol d_{Gn} represents thickness of the radial type gradient index lens element used in the first lens unit and the reference symbol f_{Gn} designates a focal length of the radial type gradient index lens element used in the first lens unit.

A radial type gradient index lens element can exhibit its effect to correct chromatic aberration when it has refractive power of medium ϕ_m having a value which is large to a certain degree as described above. When a radial type gradient index lens element has extremely small thickness, for example, the refractive power of medium ϕ_m is weak as judged from the formula (e), thereby making it difficult to favorably correct chromatic aberration. It is therefore desirable that the objective lens system according to the present invention satisfies the condition (7) when a radial type gradient index lens element is used in the first lens unit.

If the lower limit of 0.05 of the condition (7) is not satisfied, the refractive power of medium will be weak, thereby undesirably making it difficult to favorably correct lateral chromatic aberration. If the upper limit of 1.2 of the condition (7) is exceeded, in contrast, the radial type gradient index lens element will have a large thickness, thereby undesirably prolonging a total length of the objective lens system.

When a radial type gradient index lens element is used in the second lens unit of the objective lens system according to the present invention which has any one of the composition described above, it is desirable for correcting lateral chromatic aberration more favorably to satisfy the following condition (8):

$$0.3<d_{Gp}/f_{Gp}<4.0 \quad (8)$$

wherein the reference symbol d_{Gp} represents the thickness of the radial type gradient index lens element used in the second lens unit and the reference symbol f_{Gp} designates a focal length of the radial type gradient index lens element used in the second lens unit.

When a radial type gradient index lens element has extremely small thickness as described above, for example, the refractive power of medium ϕ_m is weak, thereby making it difficult to correct chromatic aberration favorably. When a

radial type gradient index lens element is to be used in the second lens unit of the objective lens system according to the present invention, the lens system is therefore configured so as to satisfy the condition (8).

If the lower limit of 0.3 of the condition (8) is exceeded, a refractive power of medium will be weak, thereby undesirably making it difficult to favorably correct lateral chromatic aberration. If the upper limit of 4.0 of the condition (8) is exceeded, a radial type gradient index lens element will have large thickness, thereby undesirably enlarging the objective lens system.

When the first lens unit is to be composed of a single negative lens element in the objective lens system according to the present invention which has any one of the compositions described above, it is desirable for favorably correcting aberrations to satisfy the following condition (9):

$$0.1<1H/r_2<1.7 \tag{9}$$

wherein the reference symbol 1H represents an image height and the reference symbol r_2 designates a radius of curvature on an image side surface of the first lens unit having the negative refractive power.

If the lower limit of 0.1 of the condition (9) is not satisfied, the image side surface of the first lens unit will have a weak refractive power and it will be necessary to strengthen a negative refractive power of an object side surface of the first lens unit on which offaxial rays are relatively high, whereby the object side surface will undesirably produce distortion, astigmatism, etc. in larger amounts. If the upper limit of 1.7 of the condition (9) is exceeded, in contrast, the image side surface of the first lens unit will have a strong negative refractive power, thereby undesirably overcorrecting spherical aberration in the objective lens system as a whole.

When the second lens unit is to be composed of a single positive lens element in the objective lens system according to the present invention which has any one of the compositions described above, it is desirable for favorably correcting aberrations to satisfy the following condition (10):

$$-1.5<IH/r_3<0.8 \tag{10}$$

wherein the reference symbol IH represents an image height and the reference symbol r_3 designates a radius of curvature on an object side surface of the second lens unit having the positive refractive power.

If the lower limit of −1.5 of the condition (10) is not satisfied, the object side surface of the second lens unit will have a strong negative refractive power, thereby undesirably overcorrecting spherical aberration in the objective lens system as a whole. If the upper limit of 0.8 of the condition (10) is exceeded, in contrast, the object side surface will undesirably produce spherical aberration, etc. in larger amounts.

When the second lens unit is to be composed of a single positive lens element in the objective lens system according to the present invention which has any one of the compositions described above, it is desirable for favorably correcting aberrations to satisfy the following condition (11):

$$-1.0<IH/r_4<-0.1 \tag{11}$$

wherein the reference symbol IH represents an image height and the reference symbol r_4 designates a radius of curvature on an image side surface of the second lens unit having the positive refractive power.

If the lower limit of −1.0 of the condition (11) is not satisfied, the image side surface of the second lens unit will have a strong positive refractive power, thereby undesirably aggravating astigmatism and distortion in the objective lens system as a whole. If the upper limit of −0.1 of the condition (11) is exceeded, in contrast, it will be necessary to strengthen a positive refractive power of the object side surface of the second lens unit, whereby the object side surface will undesirably produce astigmatism and distortion in large amounts.

When a radial type gradient index element is to be used in the first lens unit in the objective lens system according to the present invention which has any one of the compositions described above, it is desirable for correcting lateral chromatic aberration more favorably to satisfy the following condition (12):

$$0.05<N_{10n}\cdot f_{Gn}{}^2<1.2 \tag{12}$$

wherein the reference symbol f_{Gn} represents a focal length of the radial type gradient index lens element to be used in the first lens unit.

When the condition (12) is satisfied, the refractive power of medium of the radial type gradient index lens element will have a value which is sufficiently large relative to its total refractive power and can favorably correct lateral chromatic aberration. If the lower limit of 0.05 of the condition (12) is not satisfied, the refractive power of medium will be weak, thereby undesirably making it difficult to correct lateral chromatic aberration favorably with the radial type gradient index lens element. If the upper limit of 1.2 of the condition (12) is exceeded, refractive index difference Δn will be large, thereby undesirably making it difficult to prepare a material for the radial type gradient index lens element.

When a radial type gradient index lens element is to be used in the second lens element in the objective lens system according to the present invention which has any one of the compositions described above, it is desirable for correcting lateral chromatic aberration, a Petzval's sum, coma or distortion more favorably to satisfy the following condition (13):

$$-0.8<N_{10p}\cdot f_{Gp}{}^2<-0.05 \tag{13}$$

wherein the reference symbol f_{Gp} represents a focal length of the radial type gradient index lens element to be used in the second lens unit.

When the condition (13) is satisfied, the refractive power of medium of the radial type gradient index lens will have a value which is sufficiently large relative to its total refractive power and can favorably correct lateral chromatic aberration. If the upper limit of −0.05 of the condition (13) is exceeded, the refractive power of medium will be weak, thereby undesirably making it difficult to correct lateral chromatic aberration favorably with the radial type gradient index lens element. If the lower limit of −0.8 of the condition (13) is not satisfied, in contrast, refractive index difference Δn will be large, thereby undesirably making it difficult to prepare a material for the radial type gradient index lens element.

When a radial type gradient index lens element is to be used in the second lens unit in the objective lens system according to the present invention which has any one of the compositions described above, it is desirable, for facilitating preparation of a material in addition to correction of lateral chromatic aberration, to satisfy the following condition (14):

$$0.1<\phi_{2m}/\phi<0.8 \tag{14} (14)$$

When the condition (14) is satisfied, the radial type gradient index lens element will have a strong refractive

power of medium and can correct lateral chromatic aberration favorably. If the lower limit of 0.1 of the condition (14) is not satisfied, the radial type gradient index lens element will have a weak refractive power of medium and can hardly correct lateral chromatic aberration favorably in the objective lens system as a whole, and a difference in refractive indices will be small between a portion of the radial type gradient index lens element located on the optical axis and a marginal portion thereof, thereby making it difficult to correct coma and distortion. If the upper limit of 0.8 of the condition (14) is exceeded, in contrast, the radial type gradient index lens element will have a large refractive index difference Δn or large thickness, thereby undesirably making it difficult to prepare a material for the radial type gradient index lens element in the former case or undesirably enhancing a manufacturing cost and prolonging a total length of the objective lens system in the latter case.

When a radial type index lens element is to be used in the first lens unit in the objective lens system according to the present invention which has any one of the compositions described above, it is desirable, for facilitating manufacturing of the radial type gradient index lens element in addition to correction of lateral chromatic aberration, to satisfy the following condition (15):

$$-0.25<\phi_{1m}/\phi<-0.05 \tag{15}$$

When the condition (15) is satisfied, the radial type gradient index lens element will have a strong refractive power of medium and can favorably correct lateral chromatic aberration. If the upper limit of −0.05 of the condition (15) is exceeded, the radial type gradient index lens element will undesirably have a weak refractive power of medium and can hardly correct lateral chromatic aberration favorably. If the lower limit of −0.25 of the condition (15) is not reached, the radial type gradient index lens element will undesirably have a large refractive index difference Δn, whereby it can hardly be manufactured or it will be thicker and more expensive to manufacture.

When a radial type gradient index lens element is to be used in the first lens unit in the objective lens system according to the present invention which has any one of the compositions described above, it is desirable, for facilitating manufacturing of the radial type gradient index lens element in addition to correction of lateral chromatic aberration, to satisfy the following condition (16):

$$0.02<N_{10n}\cdot f^2<0.4 \tag{16}$$

When the condition (16) is satisfied, a marginal portion of the radial type gradient index lens element used in the first lens unit may have a refractive index higher than that of a portion thereof on the optical axis, whereby the radial type gradient index lens element has a sufficiently strong refractive power of medium and can correct lateral chromatic aberration favorably.

If the lower limit of 0.02 of the condition (16) is not satisfied, the radial type gradient index lens element will have a weak refractive power of medium, thereby making it difficult to correct lateral chromatic aberration favorably in the objective lens system as a whole. If the upper limit of 0.4 of the condition (16) is exceeded, the radial type gradient index lens element will have a large refractive index difference Δn, thereby undesirable making it difficult to prepare a material therefor.

When a radial type gradient index lens element is to be used in the second lens unit of the objective lens system according to the present invention which has any one of the compositions described above, it is desirable, for facilitating manufacturing of the radial type gradient index lens element in addition to correction of lateral chromatic aberration, to satisfy the following condition (17):

$$-0.25<N_{10p}\cdot f^2<-0.04 \tag{17}$$

When the condition (17) is satisfied, the radial type gradient index lens element has a sufficiently strong refractive power of medium and can favorably correct lateral chromatic aberration.

If the upper limit of −0.04 of the condition (17) is exceeded, the radial type gradient index lens element will have a weak refractive power of medium, thereby making it difficult to correct lateral chromatic aberration favorably in the objective lens system as a whole. If the lower limit of −0.25 of the condition (17) is not satisfied, in contrast, the radial type gradient index lens element will have a large refractive index difference Δn, thereby making it difficult to prepare a material therefor.

For correcting lateral chromatic aberration more favorably in the objective lens system according to the present invention which has any one of the compositions described above, it is desirable to configure a radial type gradient index lens element so as to satisfy the following condition (18):

$$1/V_{10}<0 \tag{18}$$

When the condition (18) is satisfied, the radial type gradient index lens element produces chromatic aberration in a direction opposite to that of chromatic aberration produced by a homogenous lens element having a refractive power which is the same as that of the radial type gradient index lens element. That is to say, when a radial type gradient index lens element which is used in the first lens unit or the second lens unit of the objective lens system according to the present invention satisfies the condition (18), lateral chromatic aberration is overcorrected independently by the radial type gradient index lens element, but this overcorrected chromatic aberration cancels lateral chromatic aberration produced by the other lens element, thereby correcting chromatic aberration favorably in the objective lens system as a whole.

When a radial type gradient index lens element is to be used in the first lens unit of the objective lens system according to the present invention which has any one of the compositions described above, it is desirable, for facilitating manufacturing of the radial type gradient index lens element in addition to correction of lateral chromatic aberration, to satisfy the following condition (19):

$$0.1<d_{Gn}/f_{Gn}<0.9 \tag{19}$$

If the lower limit of 0.1 of the condition (19) is exceeded, the radial type gradient index lens element will undesirably have a weak refractive power of medium, thereby undesirably making it difficult to correct lateral chromatic aberration favorably. If the upper limit of 0.9 of the condition (19) is exceeded, in contrast, the radial type gradient index lens element will be thick, thereby undesirably increasing the manufacturing cost of the objective lens system.

When a radial type gradient index lens element is to be used in the first lens unit of the objective lens system according to the present invention which has any one of the composition described above, it is desirable, for facilitating manufacturing of the radial type gradient index lens element in addition to correction of lateral chromatic aberration, to satisfy the following condition (20):

$$0.7<d_{Gp}/f_{Gp}<2.8 \tag{20}$$

When a radial type gradient index lens element has extremely small thickness, for example, it has a weak refractive power of medium ϕ_m and can hardly correct chromatic aberration favorably. When a radial type gradient index lens element is to be used in the second lens unit of the objective lens system according to the present invention, it is therefore desirable to configure the radial type gradient index lens element so as to satisfy the condition (20).

If the lower limit of 0.7 of the condition (20) is exceeded, the radial type gradient index lens element will undesirably have a weak refractive power of medium, thereby undesirably making it difficult to correct lateral chromatic aberration favorably. If the upper limit of 2.8 of the condition (20) is exceeded, in contrast, the radial type gradient index lens element will have large thickness, thereby undesirably increasing the manufacturing cost of the objective lens system.

When the first lens unit is to be composed of a single negative lens element in the objective lens system according to the present invention which has any one of the compositions described above, it is desirable for more favorable correction of aberrations to configure it so as to satisfy the following condition (21):

$$0.25<IH/r_2<1.4 \tag{21}$$

If the lower limit of 0.25 of the condition (21) is not satisfied, an image side surface of the first lens unit will have a weak negative refractive power and it will be necessary to strengthen a negative refractive power of an object side surface of the first lens unit on which offaxial rays are relatively high, whereby the object side surface will undesirably produce distortion, astigmatism, etc. in large amounts. If the upper limit of 1.4 of the condition (21) is exceeded, in contrast, the image side surface of the first lens unit will have a strong negative refractive power, thereby undesirably overcorrecting spherical aberration in the objective lens system as a whole.

When the second lens unit is to be composed of a single positive lens element in the objective lens system according to the present invention which has any one of the compositions described above, it is desirable for favorably correcting aberrations to satisfy the following condition (22):

$$-0.9<IH/r_3<0.6 \tag{22}$$

If the lower limit of −0.9 of the condition (22) is not reached, an object side surface of the second lens unit will have a strong negative refractive power, thereby undesirably overcorrecting spherical aberration in the objective lens system as a whole. If the upper limit of 0.6 of the condition (22) is exceeded, in contrast, the object side surface will undesirably produce astigmatism, distortion, etc. in large amounts.

When the second lens unit is to be composed of a single positive lens element in the objective lens system according to the present invention which has any one of the compositions described above, it is desirable for favorable correction of aberrations to satisfy the following condition (23):

$$-0.8<IH/r_4<-0.2 \tag{23}$$

If the lower limit of −0.8 of the condition (23) is not reached, the image side surface of the second lens unit will have a strong negative refractive power, thereby undesirably aggravating astigmatism and distortion in the objective lens system as a whole. If the upper limit of −0.2 of the condition (23) is exceeded, in contrast, it will be necessary to strengthen the positive refractive power of the object side surface of the second lens unit, whereby the object side surface will undesirably produce spherical aberrations, etc. in large amounts.

When a radial type gradient index lens element is to be used as the first lens unit of the objective lens system according to the present invention which has any one of the compositions described above, it is desirable, for facilitating manufacturing of the radial type gradient index lens element in addition to correction of lateral chromatic aberration, to satisfy the following condition (24):

$$0.1N_{10n}{f_{Gn}}^2<0.85 \tag{24}$$

When the condition (24) is satisfied, a refractive power of medium of the radial type gradient index lens element has a value sufficiently large relative to a total refractive power thereof, thereby making it possible to correct lateral chromatic aberration favorably. If the lower limit of 0.1 of the condition (24) is not satisfied, the radial type gradient index lens element will undesirably have a weak refractive power of medium and can hardly correct lateral chromatic aberration favorably. If the upper limit of 0.85 of the condition (24) is exceeded, in contrast, a refractive index difference Δn will undesirably be large, thereby making it difficult to prepare a material for the radial type gradient index lens element.

When a radial type gradient index lens element is to be used as the second lens element of the objective lens system according to the present invention which has any one of the compositions described above, it is desirable, for facilitating manufacturing of the radial type gradient index lens element in addition to correction of lateral chromatic aberration, to satisfy the following condition (25):

$$-0.3<N_{10p}{f_{Gp}}^2<-0.1 \tag{25}$$

When the condition (25) is satisfied, a refractive power of medium of the radial type gradient index lens element has a value sufficiently large relative to a total refractive power thereof, whereby the radial type gradient index lens element can correct lateral chromatic aberration favorably. If the upper limit of −0.1 of the condition (25) is exceeded, the refractive power of medium will undesirably be weakened, thereby undesirably making it difficult to correct lateral chromatic aberration with the radial type gradient index lens element. If the lower limit of −0.3 of the condition (25) is not reached, in contrast, the refractive index difference Δn will undesirably be large, thereby making it difficult to prepare a material for the radial type gradient index lens element.

Though it is desirable to satisfy the condition (18) for correcting lateral chromatic aberration more favorably in the objective lens system according to the present invention which has any one of the compositions described above, lateral chromatic aberration is overcorrected when $1/V_{10}$ has a negative value which is too large. Therefore, it is further desirable to satisfy the following condition (26):

$$-0.5<1/V_{10}<0 \tag{26}$$

When the condition (26) is satisfied, it is possible to correct lateral chromatic aberration favorably. If the upper limit of 0 of the condition (26) is exceeded, lateral chromatic aberration will undesirably be undercorrected. If the lower limit of −0.5 of the condition (26) is not satisfied, lateral chromatic aberration will undesirably be overcorrected.

From a viewpoint of reducing a manufacturing cost of the objective lens system according to the present invention, it is desirable that a radial type gradient index lens element has a planar surface on one side or planar surfaces on both sides.

The objective lens system according to the present invention which has a seventh composition uses a diffraction type

optical element as an optical element which is disposed in the lens system.

The objective lens system according to the present invention which has the seventh composition is composed, for example, of a first lens unit having a negative refractive power, a stop and a second lens unit having a positive refractive power: the first lens unit being composed of a diffractive optical element and the second lens unit being composed of a refractive optical element (lens).

Further, an objective lens system which can accomplish the object of the present invention can be obtained by composing a lens system of a positive lens unit and a positive lens unit: the positive lens unit disposed on the object side being composed of a radial type gradient index lens element and the lens unit disposed on the image side being composed of a diffractive optical element.

The objective lens system which has each of the compositions described above is composed of a small number of optical elements, has a compact size and exhibits favorable optical performance. It is therefore suited for use as an objective lens system for endoscopes, non-flexible endoscopes and video cameras.

Accordingly, endoscopes, non-flexible endoscopes, video cameras, portable TV telephones, portable data input units, etc. which use the objective lens system according to the present invention having the compositions described above are included within the scope of the present invention.

Now, embodiments of the objective lens system according to the present invention will be described below:

Embodiment 1

focal length = 1.07 mm, object distance = 11.8 mm,
image height = 0.97 mm, NA = 0.0115, 2ω = 113.1°

$r_1 = \infty$

$d_1 = 0.3000$ $n_1 = 1.48749$ $\nu_1 = 70.21$

$r_2 = 1.2764$

$d_2 = 1.2646$

$r_3 = \infty$ (stop)

$d_3 = 0.5196$

$r_4 = -11.2580$

$d_4 = 1.8811$ n_2 (radial type gradient index lens)

$r_5 = -1.6678$

radial type gradient index lens

	N_{00}	N_{10}	N_{20}	N_{30}
d line	1.72000,	-0.87464×10^{-1},	0.44719×10^{-2},	0.37403×10^{-2}
C line	1.71540,	-0.88776×10^{-1},	0.45390×10^{-2},	0.37964×10^{-2}
F line	1.73072,	-0.84403×10^{-1},	0.43154×10^{-2},	0.36094×10^{-2}

$1/V_{10} = -0.050$, $1/V_{00} = 0.021$, $\phi_{2m}/\phi = 0.353$,
$N_{10p} \cdot f^2 = -0.100$, $IH/r_2 = 0.799$, $IH/r_3 = -0.091$
$IH/r_4 = -0.612$, $N_{10p} \cdot f_G^2 = -0.213$, $d_{Gp}/f_G = 1.207$

Embodiment 2

focal length = 1.1 mm, object distance = 14 mm,
image height = 0.85 mm, NA = 0.01, 2ω = 96.4°

$r_1 = \infty$

$d_1 = 0.3000$ $n_1 = 1.51633$ $\nu_1 = 64.15$

$r_2 = 0.9785$

$d_2 = 0.3992$

$r_3 = \infty$ (stop)

$d_3 = 0.1000$

$r_4 = -2.6225$

$d_4 = 2.4188$ n_2 (radial type gradient index lens)

$r_5 = -1.8297$

radial type gradient index lens

	N_{00}	N_{10}	N_{20}
d line	1.88300,	−0.11306,	0.10113×10^{-2}
C line	1.87656,	−0.11340,	0.10143×10^{-2}
F line	1.89821,	−0.11227,	0.10042×10^{-2}

$1/V_{10} = -0.010$, $1/V_{00} = 0.025$, $\phi_{2m}/\phi = 0.603$,
$N_{10p} \cdot f^2 = -0.137$, $IH/r_2 = 0.899$, $IH/r_3 = -0.324$
$IH/r_4 = -0.465$, $N_{10p} \cdot f_G^2 = -0.192$, $d_{Gp}/f_G = 1.858$

Embodiment 3

focal length = 1.1 mm, object distance = 11 mm,
image height = 0.85 mm, NA = 0.01, 2ω = 103.5°

$r_1 = -5.5224$

$d_1 = 0.3000$ $n_1 = 1.51633$ $\nu_1 = 64.15$

$r_2 = 1.2132$

$d_2 = 0.7397$

$r_3 = \infty$ (stop)

$d_3 = 0.1000$

$r_4 = -4.0638$

$d_4 = 2.8548$ n_2 (radial type gradient index lens)

$r_5 = -2.5042$

radial type gradient index lens

	N_{00}	N_{10}	N_{20}
d line	1.88300,	−0.10007,	0.17880×10^{-3}
C line	1.87656,	-0.99971×10^{-1},	0.17863×10^{-3}
F line	1.89821,	−0.10030,	0.17922×10^{-3}

$1/V_{10} = 0.003$, $1/V_{00} = 0.025$, $\phi_{2m}/\phi = -0.627$,
$N_{10p} \cdot f^2 = -0.120$, $IH/r_2 = 0.701$, $IH/r_3 = -0.209$,
$IH/r_4 = -0.339$, $N_{10p} \cdot f_G^2 = -0.221$, $d_{Gp}/f_G = 1.922$

Embodiment 4

focal length = 1.02 mm, object distance = 13 mm,
image height = 1.0 mm, NA = 0.012, 2ω = 99.1°

$r_1 = \infty$

$d_1 = 0.3842$ $n_1 = 1.74100$ $\nu_1 = 52.65$

$r_2 = 1.4937$ (aspherical surface)

$d_2 = 1.0970$

$r_3 = \infty$ (stop)

$d_3 = 0.8723$

$r_4 = 11.2798$

$d_4 = 1.6154$ n_2 (radial type gradient index lens)

$r_5 = -1.7612$

aspherical surface coefficients

$P = 1$, $A_4 = -0.30311$, $A_6 = 0.20982$

radial type gradient index lens

	N_{00}	N_{10}	N_{20}	N_{30}
d line	1.70000,	-0.79349×10^{-1},	0.34621×10^{-1},	-0.10102×10^{-1}
C line	1.69580,	-0.81730×10^{-1},	0.35660×10^{-1},	-0.10405×10^{-1}
F line	1.70980,	-0.73795×10^{-1},	0.32198×10^{-1},	-0.93948×10^{-2}

-continued

Embodiment 4

$1/V_{10} = -0.100$, $1/V_{00} = 0.020$, $\phi_{2m}/\phi = 0.260$,
$N_{10p} \cdot f^2 = -0.082$, $IH/r_2 = 0.670$, $IH/r_3 = -0.089$,
$IH/r_4 = -0.568$, $N_{10p} \cdot f_G^2 = -0.201$, $d_{Gp}/f_G = 1.015$

Embodiment 5

focal length = 1.1 mm, object distance = 14 mm,
image height = 0.85 mm, NA = 0.01, 2ω = 83.4°

$r_1 = \infty$
$d_1 = 0.3000$ $n_1 = 1.51633$ $\nu_1 = 64.15$
$r_2 = 2.9790$ (aspherical surface)
$d_2 = 0.4409$
$r_3 = \infty$ (stop)
$d_3 = 0.1000$
$r_4 = -1.1911$
$d_4 = 2.4102$ n_2 (radial type gradient index lens)
$r_5 = -1.6277$

aspherical surface coefficients

$P = 1$, $A_4 = -0.55346$, $A_6 = 0.76608$

radial type gradient index lens

	N_{00}	N_{10}	N_{20}
d line	1.88300,	−0.12090,	0.11838×10^{-1}
C line	1.87656,	−0.12126,	0.11874×10^{-1}
F line	1.89821,	−0.12005,	0.11755×10^{-1}

$1/V_{10} = -0.010$, $1/V_{00} = 0.025$, $\phi_{2m}/\phi = 0.641$,
$N_{10p} \cdot f^2 = -0.146$, $IH/r_2 = 0.336$, $IH/r_3 = -0.840$,
$IH/r_4 = -0.614$, $N_{10p} \cdot f_G^2 = -0.173$, $d_{Gp}/f_G = 2.017$

Embodiment 6

focal length = 1.37 mm, object distance = 14 mm,
image height = 0.85 mm, NA = 0.01, 2ω = 93.3°

$r_1 = \infty$
$d_1 = 1.5026$ n_1 (radial type gradient index lens)
$r_2 = 2.5886$
$d_2 = 0.8187$
$r_3 = \infty$ (stop)
$d_3 = 0.1000$
$r_4 = 3.7062$
$d_4 = 2.1446$ $n_2 = 1.88300$ ν_2 40.78
$r_5 = -1.5967$

radial type gradient index lens

	N_{00}	N_{10}	N_{20}	N_{30}
d line	1.65000,	0.21000×10^{-1},	0.20240×10^{-1},	0.14372×10^{-1}
C line	1.64443,	0.21630×10^{-1},	0.20847×10^{-1},	0.14803×10^{-1}
F line	1.66300,	0.19530×10^{-1},	0.18823×10^{-1},	0.13366×10^{-1}

$1/V_{10} = -0.100$, $1/V_{00} = 0.029$, $\phi_{1m}/\phi = -0.086$,
$N_{10n} \cdot f^2 = -0.041$, $IH/r_2 = 0.328$, $IH/r_3 = -0.229$,
$IH/r_4 = -0.532$, $N_{10n} \cdot f_G^2 = 0.203$, $d_{Gp}/f_G = 0.484$

Embodiment 7

focal length = 1.11 mm, object distance = 14 mm,
image height = 0.85 mm, NA = 0.01, 2ω = 104.8°

$r_1 = \infty$
$d_1 = 0.2945$ n_1 (radial type gradient index lens)
$r_2 = 1.0451$
$d_2 = 0.8845$
$r_3 = \infty$ (stop)
$d_3 = 0.1000$
$r_4 = 2.6882$
$d_4 = 2.0134$ $n_2 = 1.88300$ $\nu_2 = 40.78$
$r_5 = -1.5483$

radial type gradient index lens

	N_{00}	N_{10}	N_{20}
d line	1.51633,	0.26303,	−0.10874
C line	1.51385,	0.26382,	−0.10907
F line	1.52190,	0.26119,	−0.10798

$1/V_{10} = -0.010$, $1/V_{00} = 0.016$, $\phi_{1m}/\phi = -0.171$,
$N_{10n} \cdot f^2 = -0.322$, $IH/r_2 = 0.708$, $IH/r_3 = 0.244$,
$IH/r_4 = -0.586$, $N_{10n} \cdot f_G^2 = 0.609$, $d_{Gp}/f_G = 0.194$

Embodiment 8

focal length = 1.13 mm, object distance = 20 mm,
image height = 0.8 mm, NA = 0.007, 2ω = 102.0°

$r_1 = 5.5159$
$d_1 = 0.3200$ n_1 (radial type gradient index lens)
$r_2 = 1.1306$
$d_2 = 1.0270$
$r_3 = \infty$ (stop)
$d_3 = 0.1000$
$r_4 = 3.2778$
$d_4 = 1.6805$ $n_2 = 1.81600$ $\nu_2 = 46.62$
$r_5 = -1.3650$

radial type gradient index lens

	N_{00}	N_{10}	N_{20}
d line	1.55000,	0.21140,	0.20293
C line	1.54633,	0.21119,	0.20273
F line	1.55856,	0.21190,	0.20340

$1/V_{10} = 0.003$, $1/V_{00} = 0.022$, $\phi_{1m}/\phi = -0.153$,
$N_{10n} \cdot f^2 = 0.269$, $IH/r_2 = 0.708$, $IH/r_3 = 0.244$,
$IH/r_4 = -0.586$, $N_{10n} \cdot f_G^2 = 0.787$, $d_{Gp}/f_G = 0.166$

Embodiment 9

focal length = 1.11 mm, object distance = 14 mm,
image height = 0.9 mm, NA = 0.01, 2ω = 98.3°

$r_1 = \infty$
$d_1 = 1.3941$ n_1 (radial type gradient index lens)
$r_2 = 1.7035$
$d_2 = 1.0045$
$r_3 = \infty$ (stop)
$d_3 = 0.1000$
$r_4 = 2.3343$ (aspherical surface)
$d_4 = 2.7508$ $n_2 = 1.72916$ $\nu_2 = 54.68$
$r_5 = -1.3745$ (aspherical surface)

aspherical surface coefficients

(4th surface) $P = 1$, $A_4 = 0.60639 \times 10^{-1}$, $A_6 = -0.86398$
$A_8 = -0.85186$

-continued

Embodiment 9

(5th surface) $P = 1$, $A_4 = 0.33872 \times 10^{-1}$, $A_6 = 0.71755 \times 10^{-1}$, $A_8 = -0.27664 \times -10^{-1}$

radial type gradient index lens

	N_{00}	N_{10}	N_{20}	N_{30}
d line	1.70000,	0.53850×10^{-1},	-0.25175×10^{-4},	-0.19807×10^{-2}
C line	1.69300,	0.55466×10^{-1},	-0.25931×10^{-4},	-0.20401×10^{-2}
F line	1.71633,	0.50081×10^{-1},	-0.23413×10^{-4},	-0.18420×10^{-2}

$1/V_{10} = -0.100$, $1/V_{00} = 0.033$, $\phi_{1m}/\phi = -0.167$, $N_{10n} \cdot f^2 = -0.066$, $IH/r_2 = 0.528$, $IH/r_3 = 0.386$, $IH/r_4 = -0.655$, $N_{10n} \cdot f_G^2 = 0.155$, $d_{Gp}/f_G = 0.822$

Embodiment 10

focal length = 1.01 mm, object distance = 11.8 mm, image height = 0.97 mm, NA = 0.0115, $2\omega = 115.2°$

$r_1 = \infty$

$d_1 = 0.4395$ n_1 (radial type gradient index lens 1)

$r_2 = 1.9633$

$d_2 = 1.1006$

$r_3 = \infty$ (stop)

$d_3 = 0.7310$

$r_4 = 7.6592$

$d_4 = 2.0532$ n_2 (radial type gradient index lens 2)

$r_5 = -1.8838$

radial type gradient index lens 1

	N_{00}	N_{10}	N_{20}	N_{30}
d line	1.65000,	0.19087,	−0.20292,	0.10047
C line	1.64443,	0.19468,	−0.20698,	0.10248
F line	1.66300,	0.18196,	−0.19345,	0.95778×10^{-1}

radial type gradient index lens 2

	N_{00}	N_{10}	N_{20}	N_{30}
d line	1.72000,	-0.64751×10^{-1},	0.21345×10^{-1},	-0.39150×10^{-2}
C line	1.71568,	-0.66046×10^{-1},	0.21772×10^{-1},	-0.39933×10^{-2}
F line	1.73008,	-0.61729×10^{-1},	0.20349×10^{-1},	-0.37323×10^{-2}

1st lens

$1/V_{10} = -0.067$, $1/V_{00} = 0.029$, $\phi_{2m}/\phi = 0.433$, $N_{10p} \cdot f^2 = -0.066$, $IH/r_2 = 0.494$, $IH/r_3 = 0.127$, $IH/r_4 = -0.515$, $N_{10p} \cdot f_G^2 = -0.172$, $d_{Gp}/f_G = 1.260$

2st lens

$1/V_{10} = -0.067$, $1/V_{00} = 0.020$, $\phi_{1m}/\phi = -0.170$, $N_{10n} \cdot f^2 = 0.195$, $IH/r_2 = 0.494$, $IH/r_3 = 0.127$, $IH/r_4 = -0.515$, $N_{10n} \cdot f_G^2 = 0.741$, $d_{Gp}/f_G = 0.233$

Embodiment 11

focal length = 1.48 mm, object distance = 11.6 mm, image height = 1.54 mm, NA = 0.0082, $2\omega = 140.3°$

$r_1 = \infty$

$d_1 = 0.3999$ $n_1 = 1.65160$ $\nu_1 = 58.52$

$r_2 = 1.3620$

$d_2 = 1.2404$

$r_3 = \infty$ (stop)

$d_3 = 0.4587$

$r_4 = 27.7558$

-continued

Embodiment 11

$d_4 = 3.0744$ n_2 (radial type gradient index lens)

$r_5 = -2.1899$

$d_5 = 0.5724$

$r_6 = \infty$

$d_6 = 0.4000$ $n_3 = 1.51633$ $\nu_3 = 64.15$

$r_7 = \infty$

$d_7 = 0.0300$

$r_8 = \infty$

$d_8 = 0.6200$ $n_4 = 1.52000$ $\nu_4 = 74.00$

$r_9 = \infty$

$d_9 = 0.0300$

$r_{10} = \infty$

$d_{10} = 0.4000$ $n_5 = 1.51633$ $\nu_5 = 64.15$

$r_{11} = \infty$

$d_{11} = 0.4800$

$r_{12} = \infty$

$d_{12} = 1.1000$ $n_6 = 1.51633$ $\nu_6 = 64.15$

$r_{13} = \infty$

$d_{13} = 1.0000$ $n_7 = 1.51633$ $\nu_7 = 64.15$

$r_{14} = \infty$

radial type gradient index lens

	N_{00}	N_{10}	N_{20}	N_{30}
d line	1.63300,	-0.37202×10^{-1},	0.26687×10^{-2},	0.94109×10^{-3}
C line	1.62841,	-0.37680×10^{-1},	0.21318×10^{-2},	0.11022×10^{-2}
F line	1.64370,	-0.36087×10^{-1},	0.39213×10^{-2},	0.56515×10^{-3}

$1/V_{10} = -0.043$, $1/V_{00} = 0.024$, $\phi_{2m}/\phi = 0.339$, $N_{10p} \cdot f^2 = -0.082$, $IH/r_2 = 1.130$, $IH/r_3 = 0.055$, $IH/r_4 = -0.703$, $N_{10p} \cdot f_G^2 = -0.185$, $d_{Gp}/f_G = 1.378$

Embodiment 12

focal length = 0.83 mm, object distance = 9.3 mm, image height = 0.8 mm, NA = 0.0115, $2\omega = 128.9°$

$r_1 = \infty$

$d_1 = 0.3700$ $n_1 = 1.51633$ $\nu_1 = 64.15$

$r_2 = 1.1462$

$d_2 = 1.7257$

$r_3 = \infty$ (stop)

$d_3 = 0.7547$

$r_4 = 3.0329$

$d_4 = 1.2159$ n_2 (radial type gradient index lens)

$r_5 = -1.5583$

$d_5 = 0.0300$

$r_6 = \infty$

$d_6 = 0.4000$ $n_3 = 1.52287$ $\nu_3 = 59.89$

$r_7 = \infty$

$d_7 = 0.0300$

$r_8 = \infty$

$d_8 = 0.6200$ $n_4 = 1.52000$ $\nu_4 = 74.00$

$r_9 = \infty$

$d_9 = 0.0300$

$r_{10} = \infty$

$d_{10} = 0.4000$ $n_5 = 1.51633$ $\nu_5 = 64.15$

$r_{11} = \infty$

$d_{11} = 0.0300$

$r_{12} = \infty$

$d_{12} = 1.0000$ $n_6 = 1.51633$ $\nu_6 = 64.15$

$r_{13} = \infty$

radial type gradient index lens

	N_{00}	N_{10}	N_{20}	N_{30}
d line	1.63300,	-0.82149×10^{-1},	0.25774×10^{-1},	0.17638×10^{-1}
C line	1.62848,	-0.82067×10^{-1},	0.25748×10^{-1},	0.17621×10^{-1}

-continued

Embodiment 12

F line	1.64377,	-0.82341×10^{-1},	0.25834×10^{-1},	0.17679×10^{-1}
g line	1.65257,	-0.82452×10^{-1},	0.25869×10^{-1},	0.17703×10^{-1}

$1/V_{10} = 0.003$, $1/V_{00} = 0.024$, $\phi_{2m}/\phi = 0.166$,
$N_{10p} \cdot f^2 = -0.057$, $IH/r_2 = 0.698$, $IH/r_3 = 0.264$,
$IH/r_4 = -0.513$, $N_{10p} \cdot f_G^2 = -0.166$, $d_{Gp}/f_G = 0.855$

Embodiment 13

focal length = 1.04 mm, object distance = 13 mm,
image height = 1.1 mm, NA = 0.01, 2ω = 140.5°

$r_1 = \infty$
$d_1 = 0.3500$ $n_1 = 1.51633$ $\nu_1 = 64..15$
$r_2 = 0.8824$
$d_2 = 0.8722$
$r_3 = \infty$ (stop)
$d_3 = 0.1000$
$r_4 = \infty$
$d_4 = 2.4666$ n_2 (radial type gradient index lens)
$r_5 = -1.6539$

radial type gradientindex lens

	N_{00}	N_{10}	N_{20}
d line	1.70000,	-0.82964×10^{-1},	0.16995×10^{-1}
C line	1.69475,	-0.84814×10^{-1},	0.17477×10^{-1}
F line	1.71225,	-0.78645×10^{-1},	0.15871×10^{-1}

$1/V_{10} = -0.074$, $1/V_{00} = 0.025$, $\phi_{2m}/\phi = 0.426$,
$N_{10p} \cdot f^2 = -0.090$, $IH/r_2 = 1.245$, $IH/r_3 = 0.000$
$IH/r_4 = -0.665$, $N_{10p} \cdot f_G^2 = -0.183$, $d_{Gp}/f_G = 1.661$

Embodiment 14

focal length = 0.99 mm, object distance = 13 mm,
image height = 1.1 mm, NA = 0.01, 2ω = 108.9°

$r_1 = \infty$
$d_1 = 0.3500$ $n_1 = 1.53996$ $\nu_1 = 59.57$
$r_2 = 2.3039$ (aspherical surface)
$d_2 = 0.7372$
$r_3 = \infty$ (stop)
$d_3 = 0.1000$
$r_4 = -1.9109$
$d_4 = 2.4559$ n_2 (radial type gradient index lens)
$r_5 = -1.5046$

aspherical surface coefficients

$P = 1$, $A_4 = -0.28151$, $A_6 = 0.21002$, $A_8 = -0.73150 \times 10^{-1}$

radial type gradient index lens

	N_{00}	N_{10}	N_{20}	N_{30}
d line	1.70000,	−0.14024,	0.31859×10^{-1},	-0.54102×10^{-2}
C line	1.69475,	−0.14257,	0.32390×10^{-1},	-0.55004×10^{-2}
F line	1.71225,	−0.13478,	0.30620×10^{-1},	-0.51998×10^{-2}

$1/V_{10} = -0.056$, $1/V_{00} = 0.025$, $\phi_{2m}/\phi = 0.681$,
$N_{10p} \cdot f^2 = -0.137$, $IH/r_2 = 0.478$, $IH/r_3 = -0.576$,
$IH/r_4 = -0.731$, $N_{10p} \cdot f_G^2 = -0.198$, $d_{Gp}/f_G = 2.066$

Embodiment 15

focal length = 1.06 mm, object distance = 14 mm,
image height = 0.85 mm, NA = 0.01, 2ω = 98.5°

$r_1 = \infty$
$d_1 = 0.3000$ $n_1 = 1.51633$ $\nu_1 = 64.15$
$r_2 = 1.2020$
$d_2 = 0.4079$
$r_3 = \infty$ (stop)
$d_3 = 0.0500$
$r_4 = \infty$
$d_4 = 1.8037$ n_2 (radial type gradient index lens)
$r_5 = -1.1988$
$d_5 = 0.2000$
$r_6 = \infty$
$d_6 = 2.0000$ $n_3 = 1.51633$ $\nu_3 = 64.15$
$r_7 = \infty$

radial type gradient index lens

	N_{00}	N_{10}	N_{20}
d line	1.75000,	−0.10566,	0.60988×10^{-1}
C line	1.74500,	−0.10598,	0.61170×10^{-1}
F line	1.76167,	−0.10492,	0.60561×10^{-1}

$1/V_{10} = -0.01$, $1/V_{00} = 0.022$, $\phi_{2m}/\phi = 0.404$,
$N_{10p} \cdot f^2 = -0.119$, $IH/r_2 = 0.707$, $IH/r_3 = 0$
$IH/r_4 = -0.709$, $N_{10p} \cdot f_G^2 = -0.142$, $d_{Gp}/f_G = 1.558$

Embodiment 16

focal length = 0.87 mm, object distance = 11 mm,
image height = 0.8 mm, NA = 0.011, 2ω = 131.3°

$r_1 = \infty$
$d_1 = 0.3600$ $n_1 = 1.88300$ $\nu_1 = 40.78$
$r_2 = 0.7400$
$d_2 = 0.6000$
$r_3 = 1.6000$
$d_3 = 5.1250$ n_2 (radial type gradient index lens)
$r_4 = \infty$

radial type gradient index lens

	N_{00}	N_{10}	N_{20}	N_{30}
d line	1.70000,	−0.12580,	0.78000×10^{-2},	-0.47000×10^{-3}
C line	1.69475,	−0.12567,	0.77985×10^{-2},	-0.47001×10^{-3}
F line	1.71225,	−0.12609,	0.79935×10^{-2},	-0.48176×10^{-3}

$1/V_{10} = 0.003$, $1/V_{00} = 0.025$, $\phi_{2m}/\phi = 0.499$,
$N_{10p} \cdot f^2 = -0.087$, $IH/r_2 = 1.081$, $IH/r_3 = 0.5$,
$IH/r_4 = -0$, $N_{10p} \cdot f_G^2 = -0.676$, $d_{Gp}/f_G = 2.211$

Embodiment 17

focal length = 0.84 mm, object distance = 11 mm,
image height = 0.8 mm, NA = 0.011, 2ω = 129.2°

$r_1 = \infty$
$d_1 = 0.3600$ $n_1 = 1.88300$ $\nu_1 = 40.78$
$r_2 = 0.6800$
$d_2 = 0.8000$
$r_3 = \infty$
$d_3 = 3.8000$ n_2 (radial type gradient index lens)
$r_4 = \infty$
$d_4 = 2.8000$ $n_3 = 1.51633$ $\nu_3 = 64.15$
$r_5 = \infty$

-continued

Embodiment 17

radial type gradient index lens

	N_{00}	N_{10}	N_{20}	N_{30}
d line	1.70000,	−0.12580,	0.78000×10^{-2},	-0.47000×10^{-3}
C line	1.69475,	−0.12567,	0.77985×10^{-2},	-0.47001×10^{-3}
F line	1.71225,	−0.12609,	0.79935×10^{-2},	-0.48176×10^{-3}

$1/V_{10} = 0.003$, $1/V_{00} = 0.025$, $\phi_{2m}/\phi = 0.549$,
$N_{10p} \cdot f^2 = -0.090$, $IH/r_2 = 1.177$, $IH/r_3 = 0$,
$IH/r_4 = -0$, $N_{10p} \cdot f_G^2 = -0.298$, $d_{Gp}/f_G = 2.471$

Embodiment 18

focal length = 0.96 mm, object distance = 10 mm,
image height = 0.85 mm, NA = 0.01, 2ω = 108.5°

$r_1 = \infty$
$d_1 = 0.3500$ $n_1 = 1.77250$ $\nu_1 = 49.60$
$r_2 = 1.3385$
$d_2 = 0.3000$
$r_3 = \infty$
$d_3 = 2.0000$ $n_2 = 1.51633$ $\nu_2 = 64.15$
$r_4 = \infty$ (stop)
$d_4 = 0.0500$
$r_5 = \infty$
$d_5 = 2.3091$ n_3 (radial type gradient index lens)
$r_6 = -1.4778$

radial type gradient index lens

	N_{00}	N_{10}	N_{20}
d line	1.75000,	-0.33160×10^{-1},	0.27722×10^{-1}
C line	1.74500,	-0.33359×10^{-1},	0.27888×10^{-1}
F line	1.76167,	-0.32696×10^{-1},	0.27334×10^{-1}

$1/V_{10} = -0.02$, $1/V_{00} = 0.022$, $\phi_{2m}/\phi = 0.147$,
$N_{10p} \cdot f^2 = -0.031$, $IH/r_2 = 0.717$, $IH/r_3 = 0$,
$IH/r_4 = -0.650$, $N_{10p} \cdot f_G^2 = -0.091$, $d_{Gp}/f_G = 1.397$

Embodiment 19

f = 0.77, F/4.7, 2ω = 113.3°

$r_1 = \infty$
$d_1 = 0.3200$ $n_1 = 1.51633$ $\nu_1 = 64.15$
$r_2 = 0.4025$
$d_2 = 0.2229$
$r_3 = \infty$
$d_3 = 0.6556$ $n_2 = 1.84666$ $\nu_2 = 23.78$
$r_4 = -0.9538$
$d_4 = 0.1230$
$r_5 = \infty$ (stop)
$d_5 = 0.6316$
$r_6 = 2.1852$
$d_6 = 0.8955$ n_3 (radial type gradient index lens)
$r_7 = -3.2816$
$d_7 = 0.3800$
$r_8 = \infty$
$d_8 = 0.7500$ $n_4 = 1.53172$ $\nu_4 = 48.91$
$r_9 = \infty$

radial type gradient index lens

	N_{00}	N_{10}	N_{20}	N_{30}
d line	1.65000,	-1.5405×10^{-1},	1.5784×10^{-1},	2.9179×10^{-2}
C line	1.64512,	-1.5400×10^{-1},	1.5784×10^{-1},	2.9179×10^{-2}

-continued

Embodiment 19

F line	1.66138,	-1.5418×10^{-1},	1.5784×10^{-1},	2.9179×10^{-2}
g line	1.67088,	-1.5430×10^{-1},	1.5784×10^{-1},	2.9179×10^{-2}

Embodiment 20

f = 0.65, F/4.25, 2ω = 113°

$r_1 = \infty$
$d_1 = 0.3200$ $n_1 = 1.51633$ $\nu_1 = 64.15$
$r_2 = 0.4397$
$d_2 = 0.1672$
$r_3 = \infty$
$d_3 = 0.7894$ n_2 (radial type gradient index lens)
$r_4 = \infty$ (stop)
$d_4 = 0.2910$
$r_5 = 2.1800$
$d_5 = 0.5912$ $n_3 = 1.88300$ $\nu_3 = 40.78$
$r_6 = -1.2158$
$d_6 = 0.3800$
r_7
$d_7 = 0.7500$ $n_4 = 1.53172$ $\nu_4 = 48.91$
$r_8 = \infty$

radial type gradient index lens

	N_{00}	N_{10}	N_{20}	N_{30}
d line	1.65200,	-5.4253×10^{-1},	6.6408×10^{-1},	1.0097
C line	1.64616,	-5.3145×10^{-1},	6.5052×10^{-1},	9.8907×10^{-1}
F line	1.66562,	-5.6836×10^{-1},	6.9570×10^{-1},	1.0578
g line	1.67733,	-5.9247×10^{-1},	7.2632×10^{-1},	1.1002

Embodiment 21

f = 2.74, F/2.8, 2ω = 68.1°

$r_1 = 3.0226$
$d_1 = 1.7507$ n_1 (radial type gradient index lens)
$r_2 = 1.4700$
$d_2 = 1.6154$
$r_3 = \infty$ (stop)
$d_3 = 1.1572$
$r_4 = 3.7806$
$d_4 = 2.4588$ $n_2 = 1.69680$ $\nu_2 = 55.53$
$r_5 = -2.2830$ (aspherical surface)
$d_5 = 0.7143$
$r_6 = \infty$
$d_6 = 0.7500$ $N_3 = 1.48749$ $\nu_3 = 70.21$
$r_7 = \infty$

aspherical surface coefficients

$P = 1$, $A_4 = 3.1652 \times 10^{-2}$, $A_6 = 5.4023 \times 10^{-5}$,
$A_8 = 5.2354 \times 10^{-4}$

radial type gradient index lens

	N_{00}	N_{10}	N_{20}
d line	1.60000,	-8.0063×10^{-3},	-2.4555×10^{-3}
C line	1.59400,	-7.7381×10^{-3},	-2.3621×10^{-3}
F line	1.61400,	-8.5860×10^{-3},	-2.6962×10^{-3}
g line	1.62646,	-8.8951×10^{-3},	-2.9391×10^{-3}

Embodiment 22

f = 0.96, F/4.25, 2ω = 112.9°

$r_1 = \infty$			
	$d_1 = 0.3000$	$n_1 = 1.51633$	ν_1 1 = 64.15
$r_2 = \infty$			
	$d_2 = 0.1500$		
$r_3 = -1.7433$			
	$d_3 = 2.3691$	n_2 (radial type gradient index lens)	
$r_4 = -0.9326$			
	$d_4 = 0.3800$		
$r_5 = \infty$			
	$d_5 = 0.7500$	$n_3 = 1.53172$	$\nu_3 = 48.91$
$r_6 = \infty$			

radial type gradient index lens

	N_{00}	N_{10}	N_{20}	N_{30}
d line	1.57000,	-1.8143×10^{-1},	9.8792×10^{-2},	-1.8066×10^{-1}
C line	1.56715,	-1.7983×10^{-1},	9.7920×10^{-2},	-1.7907×10^{-1}
F line	1.57665,	-1.8517×10^{-1},	1.0083×10^{-1},	-1.8438×10^{-1}
g line	1.58176,	-1.8795×10^{-1},	1.0115×10^{-1},	-1.8621×10^{-1}

Embodiment 23

f = 3.1, F/2.8, 2ω = 65.4°

$r_1 = \infty$ (stop)			
	$d_1 = 0.1000$		
$r_2 = \infty$			
	$d_2 = 4.6740$	n_1 (radial type gradient index lens)	
$r_3 = -3.7203$			
	$d_3 = 1.9817$		
$r_4 = 7000.0000$			
	$d_4 = 0.0010$	$n_2 = 1000$	$\nu_2 = -3.45$ (DOE)
$r_5 = \infty$			
	$d_5 = 0.5000$	$n_3 = 1.45851$	$\nu_3 = 66.75$
$r_6 = \infty$			
	$d_6 = 0.7500$	$n_4 = 1.53172$	$\nu_4 = 48.91$
$r_7 = \infty$			

aspherical surface coefficients
(diffraction type optical element)

P = 1, $A_4 = -2.1097 \times 10^{-5}$, $A_6 = 5.0147 \times 10^{-6}$,
$A_8 = -3.0443 \times 10^{-7}$, $A_{10} = -1.3365 \times 10^{-8}$

radial type gradient index lens

	N_{00}	N_{10}	N_{20}	N_{30}
d line	1.70000,	-1.4314×10^{-2},	-7.4587×10^{-4},	3.4977×10^{-4}
C line	1.69580,	-1.4176×10^{-2},	-7.4587×10^{-4},	3.4977×10^{-4}
F line	1.70980,	-1.4636×10^{-2},	-7.4587×10^{-4},	3.4977×10^{-4}
g line	1.71757,	-1.4899×10^{-2},	-7.4587×10^{-4},	3.4977×10^{-4}

Embodiment 24

f = 3.4, F/2.8, 2ω = 60.4°

$r_1 = 3.9329$			
	$d_1 = 2.1359$	$n_1 = 1.58423$	$\nu_1 = 30.49$
$r_2 = 1.9115$			
	$d_2 = 0$	$n_2 = 1000$	ν_2 2 = 3.45 (DOE)
$r_3 = 1.9114$			

-continued

Embodiment 24

	$d_3 = 1.5050$		
$r_4 = \infty$ (stop)			
	$d_4 = 1.3716$		
$r_5 = 4.6967$			
	$d_5 = 3.3378$	$n_3 = 1.69680$	$\nu_3 = 55.53$
$r_6 = -2.9928$ (aspherical surface)			
	$d_6 = 1.8296$		
$r_7 = \infty$			
	$d_7 = 0.7500$	$n_4 = 1.48749$	$\nu_4 = 70.21$
$r_8 = \infty$			
	$d_8 = 1.2084$		
$r_9 = \infty$ (image)			

aspherical surface coefficients
(diffraction type optical element)

P = 1, $A_4 = 9.1010 \times 10^{-6}$, $A_6 = -6.4422 \times 10^{-6}$,
(6th surface)
P = 1, $A_4 = 1.1402 \times 10^{-2}$, $A_6 = -9.8667 \times 10^{-5}$,
$A_8 = 1.5019 \times 10^{-4}$

wherein the reference symbols r_1, r_2, . . . represent radii of curvature on surfaces of respective lens elements, the reference symbols d_1, d_2, . . . designate thicknesses of the respective lens elements and air-spaces reserved therebetween, the reference symbols n_1, n_2, . . . denote refractive indices of the respective lens elements, and the reference symbols ν_1, ν_2, . . . represent Abbe's numbers of the respective lens elements.

The first embodiment of the objective lens system according to the present invention has a composition illustrated in FIG. **4**. Speaking concretely, it is composed of two lens units, i.e., in order from the object side, a first lens unit consisting of a negative lens element, a stop and a second lens unit consisting of a positive lens element. The second lens unit having the positive refractive power is configured as a radial type gradient index lens element. The first lens unit is composed of a homogenous lens element which has a planar surface on the object side and a concave surface on the image side, whereas the second lens unit is composed of a radial type gradient index lens element having a meniscus shape which has a concave surface on the object side.

Though it is ordinarily difficult to favorably correct lateral chromatic aberration in particular with two lens elements, the lens system preferred as the first embodiment is capable of favorably correcting lateral chromatic aberration by using the radial type gradient index lens element as the second lens unit.

Further, distortion and coma produced by the second lens unit are favorably corrected by the radial type gradient index lens element used as the second lens unit which has a refractive index distribution wherein refractive indices are progressively lowered from an optical axis toward a marginal portion.

In the first embodiment, lateral chromatic aberration in particular is corrected favorably by configuring the radial type gradient index lens element used as the second lens unit so as to satisfy the condition (18).

Furthermore, the object side planar surface of the first lens unit is effective for lowering a cost required for polishing the lens element.

Though the first embodiment is composed only of the two lens elements, it favorably corrects aberrations and has high optical performance.

The second embodiment of the present invention is an objective lens system which has a composition illustrated in FIG. **5**. Speaking concretely, it is composed of two lens elements, i.e., in order from the object side, a first lens unit

composed of a negative lens element, a stop and a second lens unit composed of a positive lens element. The second lens unit having the positive refractive power is configured as a radial type gradient index lens element.

The second embodiment is an example in which the objective lens system is configured so as to have a total length that is shorter than that of the first embodiment. In the second embodiment also, lateral chromatic aberration in particular is favorably corrected by using the radial type gradient index lens element as the second lens unit.

The radial type gradient index lens element has a meniscus shape which has a concave surface on the object side. When a radial type gradient index lens element has such a meniscus shape, its refractive power of surface and refractive power of medium which are weaker and stronger respectively than a refractive power of surface and a refractive power of medium of a radial type gradient index lens element having a biconvex shape and a refractive power which is the same as that of the radial type gradient index lens element. When a radial type gradient index lens element has a strong refractive power of medium, its effect for correcting chromatic aberration can be effectively utilized as seen from the formula (d). For effectively utilizing the effect of a radial type gradient index lens element, the second embodiment adopts the radial type gradient index lens element which has the meniscus shape. The meniscus shape which has the concave surface on the object side is effective in particular for preventing offaxial aberrations from being aggravated.

In the second embodiment, the outer circumferential portion located outside an effective diameter of the first lens unit and the second lens unit is configured as a nearly planar surfaces on which both the lens units are cemented or kept in contact with each other. By cementing these two lens units into an integrated part, it is possible to simplify a structure of a lens barrel and facilitate assembly of the objective lens system.

The second embodiment also has high optical performance though it is composed only of the two lens elements.

The third embodiment of the present invention is an objective lens system which has a composition illustrated in FIG. **6**. That is to say, the objective lens system is composed of two lens units, in order from the object side, of a first lens unit composed of a negative lens element, a stop, and a second lens unit composed of a positive lens element. The second lens unit having the positive refractive power is configured as a radial type gradient index lens element. The first lens unit is composed of a homogenous lens element having a biconcave shape, whereas the second lens unit is composed of a radial type gradient index lens element having a meniscus shape which has a concave surface on the object side.

Though it is ordinarily difficult to favorably correct lateral chromatic aberration with two lens elements, the objective lens system according to the present invention is capable of favorably correcting lateral chromatic aberration by using the radial type gradient index lens element as the second lens unit.

The third embodiment is an example wherein amounts of aberrations to be produced by the first lens unit are reduced by selecting the biconcave surface for the first lens unit so that a power of this lens unit is shared between the surfaces.

Though $1/V_{10}$ of the radial type gradient index lens element has a positive value, lateral chromatic aberration is favorably corrected by satisfying the condition (1).

The objective lens system preferred as the third embodiment also has high optical performance though it is composed only of the two lens elements.

The fourth embodiment of the present invention is an objective lens system which has a composition shown in FIG. **7**. Concretely, it is composed of two lens units, in order from the object side, a first lens unit composed of a negative lens element, a stop and a second lens unit composed of a positive lens element. The second lens unit having the positive refractive power is configured as a radial type gradient index lens element. The first lens unit has a planar surface on the object side and a concave surface on the image side configured as an aspherical surface which weakens a negative refractive power as portions of the aspherical surface are farther from an optical axis toward a marginal portion. The second lens unit is composed of a radial type gradient index lens element which has a biconvex shape.

The aspherical surface used in this embodiment has a shape expressed by the following formula:

$$x = \frac{y^2/r}{1+\sqrt{1-p(y/r)^2}} + \sum A_{2i}y^{2i}$$

wherein a direction along the optical axis is taken as the x axis, a direction perpendicular to the optical axis is taken as the y axis, the reference symbol r represents a radius of curvature on the optical axis, the reference symbol p designates a conical constant and the reference symbol A_{2i} denotes an aspherical surface coefficient.

In the fourth embodiment, the aspherical surface used in the first lens unit is capable of favorably correcting mainly barrel form distortion produced in the lens system as a whole.

Though the first lens unit has the planar surface on the object side in the fourth embodiment, a similar effect can be obtained by using an aspherical surface as the object side surface of the first lens unit.

The fourth embodiment is an example wherein the second lens unit is configured as the biconvex radial type gradient index lens element which has a weakened refractive power of medium and a strengthened refractive power of surface. Accordingly, the radial type gradient index lens element can have a small refractive index difference Δn contributing to a refractive power of medium, thereby enhancing productibility or shortening a time required for imparting a refractive index distribution at a stage to prepare a material for the radial type gradient index lens element.

In spite of the fact that the fourth embodiment is composed only of the two lens elements, it has high optical performance.

It is possible to obtain a similar effect by using, in place of the aspherical surface disposed in the first lens unit, an axial type gradient index lens element having a refractive index continuously varying in the direction along the optical axis.

The fifth embodiment of the present invention is an objective lens system which has a composition illustrated in FIG. **8**. That is to say, it is composed of two lens elements, in order from the object side, a first lens unit composed of a negative lens element, a stop and a second lens unit composed of a positive lens element configured as a radial type gradient index lens element. The first lens unit has a planar surface on the object side and a concave surface on the image side which is configured as an aspherical surface which has such a shape as tc weaken a negative refractive power as portions of the aspherical surface are farther from the optical axis toward a marginal portion, whereas the second lens unit is configured as a radial type gradient index lens element having a biconvex shape. The aspherical sur-

face used in the first lens unit is capable of favorably correcting barrel form distortion which is produced in the objective lens system as a whole as in the fourth embodiment.

For configuring compactly a tip of an endoscope which is to comprise the objective lens system according to the present invention, an outer circumferential portion of the radial type gradient index lens element used as the second lens unit is cut off as shown in FIG. **8**. A tip of the objective lens system can be made thinner since a lens barrel or the like can be disposed, for example, as the slashed location **3** on the cut portion **2**.

The fifth embodiment is an example wherein the objective lens system has a total length that is shorter than that of the fourth embodiment. Though the fifth embodiment is composed only of the two lens elements, it has high optical performance.

The sixth embodiment of the present invention has a composition shown in FIG. **9**. Speaking concretely, it is composed of two lens units, in order from the object side, a first lens unit composed of a negative lens element, a stop and a second lens unit composed of a positive lens element. The first lens unit having the negative refractive power is configured as a radial type gradient index lens element. The first lens unit is a radial type gradient index lens element which has a planar surface on the object side and a concave surface on the image side, whereas the second lens unit is a biconvex homogenous lens element.

Unlike the first through fifth embodiments, the sixth embodiment uses the radial type gradient index lens element as the first lens unit for favorably correcting lateral chromatic aberration which poses a problem in particular in the objective lens system according to the present invention.

The planar surface adopted as the object side surface of the first lens unit makes it possible to reduce the cost for polishing the lens element.

Further, aberrations are reduced by selecting the biconvex shape for the second lens unit so that its power is shared between the two surfaces.

Furthermore, the image side surface of the second lens unit has a refractive power of surface which is stronger than that of the object side surface thereof so that offaxial rays are incident on an image surface nearly at telecentric angles.

The sixth embodiment also has high optical performance though it is composed only of the two lens elements.

The seventh embodiment of the present invention has a composition illustrated in FIG. **10**. That is to say, an objective lens system preferred as the seventh embodiment is composed of two lens units, in order from the object side, a first lens unit composed of a negative lens element, stop and a second lens unit composed of a positive lens element. The first lens unit having the positive refractive power is configured as a radial type gradient index lens element. The first lens unit is a radial type gradient index lens element which has a planar surface on the object side and a concave surface on the image side, whereas the second lens unit is a homogenous lens element which has a biconvex shape

This embodiment also has high optical performance though it is composed only of the two lens elements

The eighth embodiment of the present invention is an objective lens system which has a composition shown in FIG. **11**. This lens system is composed of two lens units, in order from the object side, a first lens unit composed of a negative lens element, a stop and a second lens unit composed of a positive lens element. The first lens unit having the positive refractive power is configured as a radial type gradient index lens element. The first lens unit is a radial type gradient index lens element having a meniscus shape which has a concave surface on the image side, whereas the second lens unit is a homogenous lens element which has a biconvex shape.

The composition of the eighth embodiment, in which the radial type gradient index lens element has the meniscus shape which has a concave surface on the image side is advantageous for correcting offaxial aberrations in particular.

The eighth embodiment also has high optical performance in spite of the fact that it is composed only of the two lens elements.

The ninth embodiment of the present invention is an objective lens system which has a composition illustrated in FIG. **12**. Speaking concretely, this lens system is composed of two lens elements, in order from the object side, a first lens unit composed of a negative lens units, a stop and a second lens unit composed of a positive lens element. The first lens unit having the negative refractive power is configured as a radial type gradient index lens element. The first lens unit is a radial type gradient index lens element having a meniscus shape which has a planar surface on the object side and a concave surface on the image side, whereas the second lens unit has aspherical surfaces on both sides.

Owing to a fact that an image side surface of the second lens unit on which offaxial rays are relatively high is configured as an aspherical surface having such a shape as to weaken a positive refractive power as portions of the aspherical surface are farther from an optical axis toward a marginal portion, the ninth embodiment is capable of favorably correcting barrel form distortion produced in the lens system as a whole.

Though the ninth embodiment uses the aspherical surfaces on both sides of the second lens unit, a similar effect can be obtained by using an aspherical surface only on one side.

The ninth embodiment also exhibits high optical performance though it consists only of the two lens elements.

Further, a similar effect can be obtained by adopting, in place of the aspherical surfaces used in the second lens unit, an axial type gradient index lens element which continuously varies a refractive index in a direction along the optical axis.

The tenth embodiment of the present invention is an objective lens system which has a composition shown in FIG. **13**. This lens system consists of two lens units, in order from the object side, a first lens unit composed of a negative lens element, a stop and a second lens unit composed of a positive lens element. The first lens unit having the negative refractive power and the second lens unit having the positive refractive power are configured as radial type gradient index lens elements. The first lens unit is a radial type gradient index lens element which has a planar surface on the object side and a concave surface on the image side, whereas the second lens unit is a radial type gradient index lens element which has a biconvex shape.

The tenth embodiment is an example wherein lateral chromatic aberration produced in the lens system as a whole is favorably corrected by using radial type gradient index lens elements in both the lens units. In other words, lateral chromatic aberration is favorably corrected by configuring the radial type gradient index lens element used in the first lens unit to satisfy the condition (1) and the condition (2), and designing the radial type gradient index lens element used in the second embodiment to satisfy the condition (1) and the condition (3).

Though the tenth embodiment consists only of the two lens elements, it has high optical performance.

Preferred as an eleventh embodiment of the present invention is an objective lens system which has a composition illustrated in FIG. **14**. This lens system comprises two lens units, or is composed, in order from the object side, a first lens unit composed of a negative lens element, a stop, a second lens unit composed of a positive lens element and filters F disposed on the image side of the second positive lens unit. The first lens unit is configured as a homogenous lens element which has a planar surface on the object side and a concave surface on the image side, whereas the second lens unit is configured as a biconcave radial type gradient index lens element which has an object side surface having a weak positive refractive power.

When the objective lens system according to the present invention is used in a video scope or the like which uses a solid-state image pickup device such as a CCD, a low pass filter and an infrared cut filter composed, for example, of quartz or diffraction gratings may be disposed on the object side of an image surface as exemplified in FIG. **14**. The eleventh embodiment is an example comprising such filters. In the objective lens system according to the present invention, the above-mentioned filters can be disposed between the negative lens element and the positive lens element.

Preferred as the twelfth embodiment of the present invention is an objective lens system which has a composition shown in FIG. **15**. Like the eleventh embodiment, the twelfth embodiment comprises two lens units, or is composed, in order from the object side, of a first lens unit composed of a negative lens element, a stop, a second lens unit composed of a positive lens element, and filters which are disposed between the two lens elements and on the image side of the positive lens element. The first lens unit is configured as a homogenous lens element which has a planar surface on the object side and a concave surface on the image side, whereas the second lens unit is configured as a radial type gradient index lens element which has a biconvex shape.

The thirteenth embodiment of the present invention has a composition illustrated in FIGS. **16**A and **16**E: FIG. **16**A being a sectional view showing the thirteenth embodiment as a whole and FIG. **16**B being a diagram illustrating only a portion B on an enlarged scale. The thirteenth embodiment is composed, in order from the object side, of a first lens unit composed of a negative lens element, a stop and a second lens unit composed of a positive lens element. A radial type gradient index lens element is used as the second lens unit. The first lens unit has a planar surface on the object side and a concave surface on the image side, whereas the second lens unit has a planar surface on the object side and a convex surface on the image side.

The thirteen embodiment is an example wherein aberrations are favorably corrected by using a racial type gradient index lens element and a large number of planar surfaces are adopted for reducing a cost required for polishing lens elements, or the object side surface of the first lens unit and the object side surface of the second lens unit are configured the planar.

Further, for preventing eccentricities of lens elements, in directions along an optical axis and perpendicular thereto in particular, which pose a problem at a stage of assembly, an outer circumferential portion **4** is obliquely chamfered as shown in FIG. **16**B so that a chamfered portion **4** is limited at a location **6** of a lens barrel **5**. Since a radial type gradient index lens element which has a refractive power of medium requires a manufacturing precision stricter than that for a homogenous lens element, the thirteenth embodiment provides effective assembling convenience. A similar effect can, needless to say, be obtained by assembling the first lens unit having the negative refractive power in similar manner.

Though the thirteenth embodiment uses a large number of planar surfaces, it has high optical performance.

The fourteenth embodiment of the present invention is an objective lens system which has a composition illustrated in FIG. **17**. That is to say, the fourteenth embodiment is composed, in order from the object side, of a first lens unit consisting of a negative lens element, a stop and a second lens unit consisting of a positive lens element which is configured as a radial type gradient index lens element. The first lens unit has a planar surface on the object side and a concave surface on the image side, whereas the second lens unit has a meniscus shape which has a concave surface on the object side.

When a radial type gradient index lens element is used as the second lens unit, it is desirable for correcting aberrations such as spherical aberration that the term of the fourth order N_{20} of a refractive index distribution has a positive value.

The fifteenth embodiment of the present invention has a composition shown in FIG. **18**. Speaking concretely, the fifteenth embodiment is composed, in order from the object side, of a first lens unit consisting of a negative lens element, a second lens unit consisting of a positive lens element and a reflecting optical element. A radial type gradient index lens element is used as the second lens unit. In this embodiment, a light bundle emerging from the second lens unit is reflected by a reflecting surface **7** of a reflecting optical element P made, for example, of a mirror or a prism so that it is imaged onto a solid-state image pickup device **10** which is disposed nearly parallel to the optical axis. This reflecting surface makes it possible to dispose a solid-state image pickup device such as a CCD that is not parallel to a radial direction of the lens elements, but oblique. Though a solid-state image pickup device **10** is disposed nearly parallel to the optical axis in the fifteenth embodiment, the image pickup device can be disposed more obliquely by selecting an adequate inclination angle for the reflecting surface **7** relative to the optical axis. Though the fifteenth embodiment is configured to reflect the light bundle only once, it is possible to reflect the light bundle twice, three times or more times by adopting a larger number of reflecting surfaces.

The sixteenth embodiment of the present invention is an objective lens system which has a composition shown in FIG. **19**. That is to say, the sixteenth embodiment is composed, in order from the object side, of a first lens unit composed of a negative lens element, a second lens unit composed of a positive lens element and a solid-state image pickup device. A radial type gradient index lens element is used as the second lens unit. In this embodiment, the radial type gradient index lens element has a nearly planar image side surface which is cemented or kept in close contact to or with a solid-state image pickup device **10** such as a CCD. Further, disposed in the second lens unit, is a member which extends from an outer circumference toward an optical axis for shielding a light bundle passing through the lens unit or functioning as an aperture stop of the objective lens system. Such a shielding member can be constituted, for example, by forming a cut **8** from the outer circumference toward the optical axis. For preventing the cut from producing flare, it is desirable to color the cut **8**. Further, it is possible to cut the second lens unit along a dashed line **9** shown in FIG. **25** into a front portion La and a rear portion Lb, attach a stop S to a cut surface of the front portion La and cementing the two portions to each other or bringing them into close contact with each other. A similar effect can be obtained by attaching

the stop S to the rear portion Lb in place of the front portion La. As means for attaching the stop, it is conceivable to utilize deposition, printing or bonding a stop plate. This means can be utilized for manufacturing not only an aperture stop but also a flare stop.

In the sixteenth embodiment, the aperture stop is disposed at a location 1 mm apart from an object side surface of the second lens unit toward an image surface.

It is needless to say that an aperture stop, a flare stop or the like can be manufactured by the means described above in each of the embodiments.

The seventeenth embodiment of the present invention has a composition illustrated in FIG. **20**. That is to say, the seventeenth embodiment is composed, in order from the object side, of a first lens unit composed of a negative lens element, a second lens unit composed of a positive lens element, an optical filter F and a solid-state image pickup device **10**. A radial type gradient index lens element is used as the second lens unit. In the seventeenth embodiment, the second lens unit has planar surfaces on both sides for reducing the cost for polishing the lens unit. The seventeenth embodiment is an example wherein the second lens unit is cemented to the optical filter F for simplifying a structure of a lens barrel and assembly of the objective lens system. Further, the optical filter F is cemented or kept in close contact to or with the solid-state image pickup device **10**. Furthermore, the first lens unit and the second lens unit are cemented or kept in close contact to or with each other on outer circumferences thereof outside an effective diameter thereof.

In the seventeenth embodiment, an aperture stop is disposed at a location 1 mm apart from an object side surface of the second lens unit toward an image surface.

The eighteenth embodiment of the present invention has a composition shown in FIG. **21**. That is to say, the eighteenth embodiment is composed, in order from the object side, of a first lens unit composed of a negative lens element, a regularly reflecting optical element and a second lens unit composed of a positive lens element. The second lens unit which is disposed on the image side is configured as a radial type gradient index lens element.

Certain endoscopes are specified for oblique observation in directions inclined relative to the optical axis. When the objective lens system according to the present invention is used in an endoscope for oblique observation, a reflecting optical element P composed of a mirror or a prism is disposed between the first lens unit and the second lens unit as shown in FIG. **21** SO that a light bundle emerging from the first lens unit is reflected by a reflecting surface **7** of the reflecting optical element and led to the second lens unit.

Though a lens element ordinarily has a circular sectional shape, it may have a different sectional shape. FIGS. **22**A, **22**B, **22**C, **23**A, **23**B and **23**C exemplify lens elements which have external shapes cut or worked in accordance with shapes of image pickup devices for configuring objective lens systems compactly. FIGS. **22**A, **22**B and **22**C schematically show the second lens unit which is used in the first through eighteenth embodiments before being shaped. FIG. **22**A shows a sectional view taken in a direction from an object, FIG. **22**B is a sectional view taken in a direction in parallel with the optical axis, and FIG. **22**C illustrates an image circle **11** of the objective lens system and an image pickup surface **12** of an image pickup device. FIGS. **23**A, **23**B and **23**C schematically show the lens element illustrated in FIGS. **22**A, **22**B and **22**C in another condition after it is shaped. Since a solid-state image pickup device such as a CCD may have a rectangular shape and a lens element ordinarily has a circular shape as shown in FIG. **22**A, there is produced, as slashed in FIG. **22**C, a region which serves for image formation but is not used for image pickup. Since it is desired to configure an objective lens system for endoscopes compacter, it is conceivable to cut off the region of the lens element which is not used for image pickup. The eithteenth embodiment is an example wherein lens portions through which rays to be condensed outside an image pickup surface of an image pickup device are cut off as exemplified by FIGS. **23**A and **23**B so that an image formation range of the lens element is nearly coincident with the image pickup surface of the image pickup device. It is possible to obtain a compacter objective lens system or endoscopes by configuring a lens element so as to occupy a narrower space.

Though the second lens unit is worked for narrowing a lens space in the example described above, it is needless to say that a similar effect can be obtained by working other lens element or optical element, for example, the first lens unit or the reflecting optical element.

The nineteenth embodiment has a composition illustrated in FIG. **26**. Speaking concretely, the nineteenth embodiment is a retrofocus type objective lens system which is composed, in order from the object side, of a first negative lens unit, a second positive lens unit and a third positive lens unit. A stop is disposed between the second lens unit and the third lens unit. The nineteenth embodiment is an objective lens system which has a wide field angle and is usable for endoscopes, video cameras, etc. Though the nineteenth embodiment has a wide field angle which makes it rather hard to correct lateral chromatic aberration, it corrects lateral chromatic aberration with a radial type gradient index lens element. In the nineteenth embodiment, the first lens unit has a plano-concave shape and a function to widen a field angle, the second lens unit has a plano-convex shape and a function to correct mainly lateral chromatic aberration produced by the first lens unit, and the third lens unit has a biconvex shape and a main imaging function, and is configured as a radial type gradient index lens element.

Though it is rather hard in the nineteenth embodiment to correct coma which is produced by the third lens unit disposed on the image side of a stop, coma is corrected by configuring the third lens unit as a radial type gradient index lens element which has such a characteristic as to progressively lower a refractive index in a radial direction from an optical axis. In other words, coma is corrected by imparting a positive refractive power to a medium of the radial type gradient index lens element. The composition described above is capable of correcting not only coma but also distortion.

For correcting coma with a medium of a radial type gradient index lens element, it is desirable that terms of high orders of a refractive index distribution satisfy the following condition (27):

$$-0.05 < \sum_{i=2}^{n} N_{iod} e^{2i} < 0.2 \tag{27}$$

wherein the reference symbol e represents an effective diameter of the lens element.

If the lower limit of −0.05 of the condition (27) is not satisfied, coma will be undercorrected. If the upper limit of 0.2 of the condition (27) is exceeded, in contrast, coma will be overcorrected.

It is desirable for more favorable correction of coma to satisfy the following condition (28):

$$0 < \sum_{i=2}^{n} N_{iod} e^{2i} < 0.1 \quad (28)$$

If the lower limit of 0 of the condition (28) is not satisfied, coma will be undercorrected. If the upper limit of 0.1 of the condition (28) is exceeded, in contrast, coma will be overcorrected. Either of these cases is undesirable for more favorable correction of coma.

Further, a planar surface used as an object side surface of the lens element disposed on the image side in the nineteenth embodiment has an effect for preventing adhesion of foreign matter such as dust.

In this embodiment, at least one lens element can have a function to cut off components having specific wavelengths, or a radial type gradient index lens element can have such a function.

When an image pickup device such as a CCD which has high sensitivity in the infrared wavelength region is to be disposed on an image pickup surface, for example, it is desirable to provide a function to cut off components having wavelengths in the infrared region. Accordingly, it is desirable that at least one lens element has a function to cut off components having specific wavelengths such as those in the infrared region.

The function to cut off components having specific wavelengths can be obtained by forming, on a flat portion of a lens element or a flat plate, an interference film which cuts off the components having specific wavelengths.

A stop can be manufactured from a thin plate.

Further, amounts of aberrations produced can be reduced by configuring a radial type gradient index lens element so as to have a biconvex shape, thereby sharing a refractive power between the two surfaces.

Use of a radial type gradient index lens element makes it possible to obtain an optical system which is compact and composed of a small number of lens elements, and has a wide field angle and favorably corrected aberrations such as chromatic aberration and coma. Accordingly, it is effective to use an optical system such as an optical system for image input units for portable TV telephones and portable data input units such as those shown in FIGS. **35** and **36**.

The twentieth embodiment is an optical system which has a composition illustrated in FIG. **27**. It is a retrofocus type optical system which is composed, in order from the object side, of a first lens unit having a negative refractive power, a second lens unit having a positive refractive power and a third lens unit having a positive refractive power. A stop is disposed between the second lens unit and the third lens unit.

The twentieth embodiment is an optical system which has a wide field angle and is usable as an objective lens system for endoscopes or a lens system for video cameras, etc. Though the twentieth embodiment also has a wide field angle and hardly allows correction of lateral chromatic aberration in particular, aberrations are favorably corrected in this embodiment by using a radial type gradient index lens element.

In the twentieth embodiment, the first lens unit is a plano-concave lens element having a function to widen a field angle, the second lens unit is a radial type gradient index lens element having planar surfaces on both sides and a function to correct lateral chromatic aberration produced by the first lens unit, and the third lens unit has a biconvex shape and a main imaging function. The twentieth embodiment favorably corrects lateral chromatic aberration in particular by using, as the second lens unit disposed on the object side of the stop, a radial type gradient index lens element made of a medium which has a positive refractive power and a relatively strong dispersing power. The medium having the positive refractive power favorably corrects a Petzval's sum.

For correcting lateral chromatic aberration by disposing a radial type gradient index lens element on a stop, it is desirable to satisfy the following condition (29):

$$0.01 < 1/V_{10} < 0.5 \quad (29)$$

If the lower limit of 0.01 of the condition (29) is not satisfied, lateral chromatic aberration will be undercorrected. If the upper limit of 0.5 of the condition (29) is exceeded, in contrast, lateral chromatic aberration will be overcorrected.

For correcting lateral chromatic aberration more favorably by disposing a radial type gradient index lens element on the object side of the stop, it is desirable to satisfy the following condition (30):

$$0.015 < 1/V_{10} < 0.1 \quad (30)$$

If the lower limit of 0.015 of the condition (30) is not satisfied, lateral chromatic aberration will be undercorrected. If the upper limit of 0.1 of the condition (30) is exceeded, lateral chromatic aberration will be overcorrected. Either of these cases is undesirable for correcting lateral chromatic aberration extremely favorably.

When preparation of a material for a radial type gradient index lens element is taken into consideration, it is desirable that $1/V_{10}$ has a value not exceeding 0.05. From viewpoints of manufacturing convenience and cost, it is desirable to configure a radial type gradient index lens element so as to have planar surfaces on both sides. When durability of a radial type gradient index lens element is taken into consideration, it is desirable to make it entirely of a glass material.

The twenty-first embodiment has a composition illustrated in FIG. **28**, or is a retrofocus type optical system which is composed, in order from the object side, of a first lens unit having a negative refractive power and a second lens unit having a positive refractive power. A stop is disposed between the first lens unit and the second lens unit. The twenty-first embodiment which is an optical system having a wide field angle is usable as an objective lens system for endoscopes or video cameras and so on. Though this optical system also has a wide field angle and hardly allows correction of lateral chromatic aberration in particular, lateral chromatic aberration is favorably corrected by using a radial type gradient index lens element.

In the optical system preferred as the twenty-first embodiment, the first lens unit has a negative meniscus shape which has a concave surface on the image side, and the second lens unit has a biconvex shape and a main imaging function. A radial type gradient index lens element is used as the first lens unit.

Offaxial aberrations can be corrected favorably by configuring the radial type gradient index lens element used as the first lens unit so as to have the meniscus shape which has the concave surface on the side of the stop. Lateral chromatic aberration is favorably corrected in particular owing to a fact that the radial type gradient index lens element has a positive refractive power of medium and is configured so as to satisfy the condition (29).

Further, coma is corrected favorably by using an aspherical surface on the lens element disposed on the object side of the stop. This aspherical surface has such a shape as to

weaken a positive refractive power as portions of the aspherical surface are farther from an optical axis toward a marginal portion. Owing to this aspherical surface, the twenty-first embodiment is configured as an optical system which is compact and composed of a small number of lens elements, has a wide field angle and favorably corrects aberrations such as coma. It is therefore effective to apply the twenty-first embodiment as an optical system for image intake devices for portable TV telephones and portable date input units.

The twenty-second embodiment has a composition shown in FIG. **29**, or is an optical system composed of a single radial type gradient index lens element. The radial type gradient index lens element has a meniscus shape which has a concave surface on the object side and a positive power of medium. A stop is disposed at a location 0.9471 mm apart from an object side surface of the lens element toward the image side.

The twenty-second embodiment has a wide field angle, and is usable as an objective lens system for endoscopes or a lens system for video cameras and so on. Though the twenty-second embodiment which has the wide field angle hardly allows correction of chromatic aberration, it is corrected with the radial type gradient index lens element. A flat glass plate is disposed on the object side as a cover glass plate. A stop is disposed in the radial type gradient index lens element for obtaining highly symmetrical refractive power of medium, thereby favorably correcting offaxial aberrations. The radial type gradient index lens element satisfies the condition (29) for correcting lateral chromatic aberration produced by an object side concave or convex surface with a medium located on the object side of the stop.

For reducing chromatic aberration to be produced by surfaces of the radial type gradient index lens element, it is desirable that V_{00} has a value of at least 30, or more desirably, at least 40. For reducing aberrations to be produced by the surfaces of the radial type gradient index lens element, it is desirable that N_{00} has a value of at least 1.55, or more desirably, at least 1.6.

The twenty-third embodiment has a composition shown in FIG. **30**, or is composed of two lens units, in order from the object side, a first positive lens unit and a second positive lens unit. The twenty-third embodiment is an example wherein aberrations are corrected favorably by composing an optical system of a radial type gradient index lens element and a diffraction type optical element(DOE) Speaking more concretely, the twenty-third embodiment is composed, in order from the object side, of a first lens unit composed of a radial type gradient index lens element and a second lens unit composed of a diffraction type optical element.

A diffraction type optical element is equivalent to a lens element which has a very high imaginary refractive index as described in literature SPIE, Vol. 126, P46 (1997). For this reason, the diffractive optical element is assumed to be a lens element which is optically equivalent to the optical element including aberrations to be produced thereby, and radii of curvature, thickness, a refractive index, an Abbe's number and aspherical surface coefficients of the lens element are described in the numerical data of the twenty-third embodiment. In the twenty-third embodiment, a stop is disposed on the object side of the optical system (the first lens unit).

In the twenty-third embodiment, the first lens unit composed of the radial type gradient index lens element has a main imaging function and the second lens unit composed of the diffraction type optical element favorably corrects lateral chromatic aberration. The twenty-third embodiment is an example of an optical system which is composed of a small number of optical elements and has a wide field angle, and favorably corrects lateral chromatic aberration with a diffractive optical element disposed on the image since of a stop. The diffraction type optical element has a positive refractive power, is disposed on the image side of the radial type gradient index lens element and has a function to favorably correct lateral chromatic aberration produced by a convex surface of the radial type gradient index lens element. Further, the radial type gradient index lens element has another function to favorably correct a Petzval's sum.

The twenty-third embodiment is usable, as described above, as an objective lens system for endoscopes or an optical system for video cameras and so on. Since the twenty-third embodiment is an optical system which is compact and is composed of a small number of lens elements, and favorably corrects aberrations such as chromatic aberration owing to the fact that it uses the diffraction type optical element, it is effective to apply it as an optical system for image intake devices for portable TV telephones and portable data input units.

The twenty-fourth embodiment has a composition illustrated in FIG. **31**, or is composed, in order from the object side, of a first lens unit having a negative refractive power and a second lens unit having a positive refractive power. A stop is disposed between the first lens unit and the second lens unit. In the twenty-fourth embodiment, the first lens unit having the negative refractive power serves mainly for widening a field angle and the second lens unit having the positive refractive power functions mainly for imaging.

The twenty-fourth embodiment favorably corrects aberrations by using the diffraction type optical element in place of the radial type gradient index lens element adopted for the twenty-first embodiment.

The twenty-fourth embodiment hardly allows correction of offaxial aberrations since it has an asymmetrical refractive power distribution wherein a negative refractive power is disposed on the object side of the stop and a positive refractive power is disposed on the image side of the stop. For this reason, lateral chromatic aberration is corrected favorably by disposing the diffraction type optical element on the object side of the stop and imparting a negative refractive power to this optical element. Coma and distortion in particular can be corrected favorably by using an aspherical surface on a positive lens unit disposed on the image side of the stop and configuring this aspherical surface so as to have such a shape as to weaken a positive refractive power in a radial direction from an optical axis. The negative lens unit has a meniscus shape which has a concave surface on the side of the stop for reducing amounts of offaxial aberrations in particular. Further, the positive lens unit has a biconvex shape so that amounts of aberrations are reduced by sharing a refractive power between two surfaces. Furthermore, the diffraction type optical element is disposed on a surface which is concave toward the stop so that differences between angles of incidence of paraxial rays and offaxial rays are reduced, thereby enhancing a diffraction efficiency.

FIG. **32** is a perspective view illustrating an endoscope according to the present invention which uses an objective lens system such as the embodiment described above. The reference numeral **21** represents the objective lens system.

FIG. **33** is a side view of a non-flexible endoscope according to the present invention which uses an objective lens system such as the embodiment described above. The reference numeral **21** represents the objective lens system.

FIG. **34** shows a video camera according to the present invention which uses an objective lens system such as the

embodiment describes above. The reference numeral **21** represents the objective lens system.

FIG. **35** shows a perspective view illustrating a portable TV telephone according to the present invention which uses an objective lens system such as the embodiment described above. The reference numeral **21** represents the objective lens system, the reference numeral **22** designates an antenna for transmission and reception, the reference numeral **23** denotes a display, and the reference numeral **24** represents switches.

Further, FIG. **36** shows a perspective view illustrating a portable data input unit according to the present invention which uses an objective lens system such as the embodiment described above. The reference numeral **21** represents the objective lens system, the reference numeral **22** designates an antenna for transmission and reception, the reference numeral **23** denotes a display, and the reference numeral **24** represents switches.

As understood from the foregoing description, the objective lens system for endoscopes according to the present invention is composed of lens elements in a number on the order of 2, and is nevertheless an optical system which favorably corrects aberrations, lateral chromatic aberration in particular, and has high optical performance.

I claim:

1. An objective lens system comprising, in order from the object side:

a first lens unit consisting of a lens element having a homogeneous lens medium and having a negative refracting power, said first lens unit being the most object-side lens unit of said objective system; and

a second lens unit consisting of a lens element having a radial type gradient refractive index and having a positive refractive power, said second lens unit being the second most object-side lens unit of said objective system,

wherein only one radial type gradient index lens element, which has a refractive index distribution in a radial direction from an optical axis, is disposed in said second lens unit and in the lens system as a whole,

wherein said radial type gradient index lens element has a planar surface on at least one side, and

wherein said radial type gradient index lens element satisfies the following condition (6):

$$1/V_{10}<0.01 \quad (6)$$

wherein the reference symbol V_{10} represents a dispersing power of said radial type gradient index lens element which is given by the formula (c) shown below:

$$V_{10}=N_{10d}/(N_{10F}-N_{10C})$$

wherein the reference symbols N_{10d}, N_{10F} and N_{10C} designate values of a coefficient of a term r^2 for the d-line, F-line and C-line, respectively, when a refractive index of said radial type gradient index lens element is expressed as a polynomial of r.

2. An objective lens system according to claim **1** wherein said radial type gradient index lens element has planar surfaces on both sides.

3. An objective lens system according to claim **1**, wherein said first lens unit and said second lens unit are cemented to each other outside an effective diameter thereof, thereby forming a cemented lens unit.

4. An objective lens system according to claim **1** wherein a term of the fourth order N_{20} of a refractive index distribution coefficient of said radial type gradient index lens element has a positive value.

5. An objective lens system according to claim **1** satisfying the following condition (3):

$$0.05<\phi_{2m}/\phi<1.0 \quad (3)$$

wherein the reference symbol ϕ_{2m} represents a refractive power of said radial type gradient index lens element used in the second lens unit and the reference symbol ϕ designates a refractive power of said objective lens system as a whole.

6. An objective lens system according to claim **1** satisfying the following condition (4):

$$-0.5<N_{10P}\cdot f^2<-0.01 \quad (4)$$

wherein the reference symbol N_{10P} represents a refractive index distribution coefficient of the second order when the radial type gradient index lens element is used in said second lens unit and the reference symbol f designates a focal length of said objective lens system as a whole.

7. An image pickup apparatus comprising an objective lens system according to claim **1**.

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[54] **HYBRID PHOTOGRAPHIC OBJECTIVE**

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[73] Assignee: **Olympus Optical Co., Ltd.**, Tokyo, Japan

[21] Appl. No.: **08/982,415**

[22] Filed: **Dec. 2, 1997**

[30] **Foreign Application Priority Data**

Dec. 2, 1996 [JP] Japan 8-321307

[51] **Int. Cl.**[6] **G02B 9/04**; G02B 5/18

[52] **U.S. Cl.** **359/793**; 359/570; 359/576

[58] **Field of Search** 359/563, 564, 359/566, 570, 571, 576, 708, 724, 736, 737; 396/6

[56] **References Cited**

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Primary Examiner—Georgia Epps
Assistant Examiner—David N. Spector
Attorney, Agent, or Firm—Pillsbury Madison & Sutro, LLP

[57] **ABSTRACT**

The invention provides a high-performance yet low-cost phototaking optical system using a diffractive optical element. The optical system comprises, in order from an object side thereof, a first positive lens in a meniscus form convex toward the object side, an aperture stop, and a second positive lens in a double-convex form, with a diffractive surface formed on the object side of the first lens. The system comprising an aperture stop, at least two lenses and at least one diffractive surface satisfies the condition $0<d_{DOE}/f<0.24$ where f is a focal length of the overall system and d_{DOE} is a distance on an optical axis thereof from the aperture stop to the diffractive surface. This condition is provided to locate the diffractive surface in the vicinity of the aperture stop to lower ray height, thereby placing chromatic aberration in a well-balanced state.

25 Claims, 19 Drawing Sheets

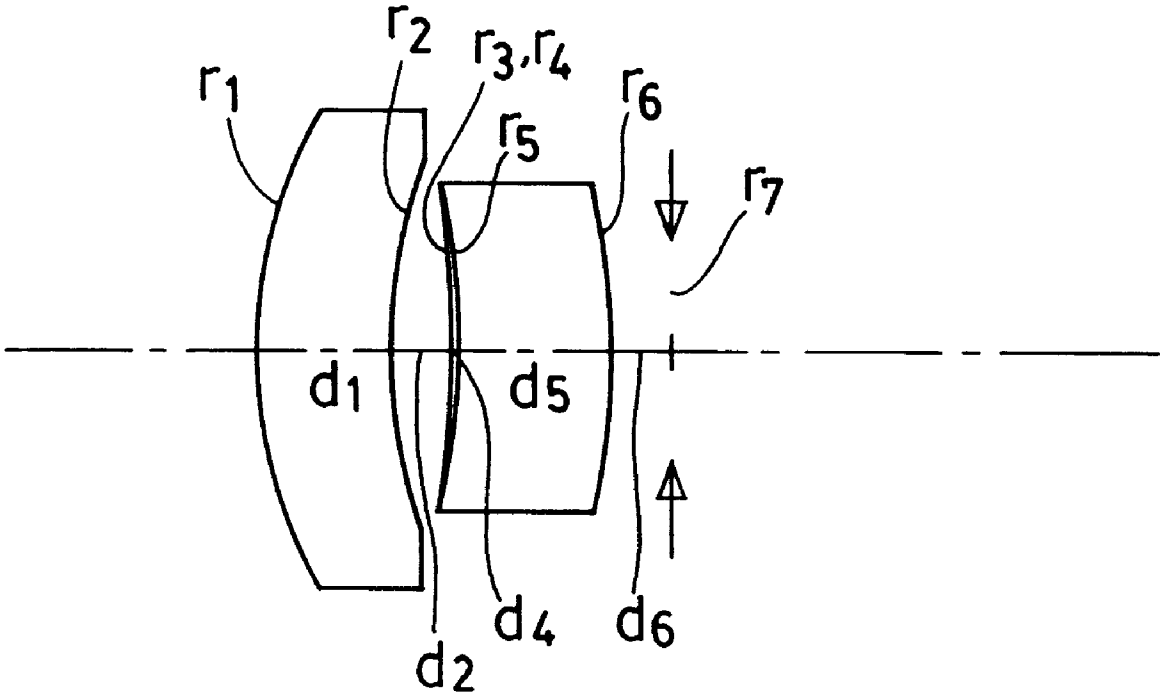


FIG. 1

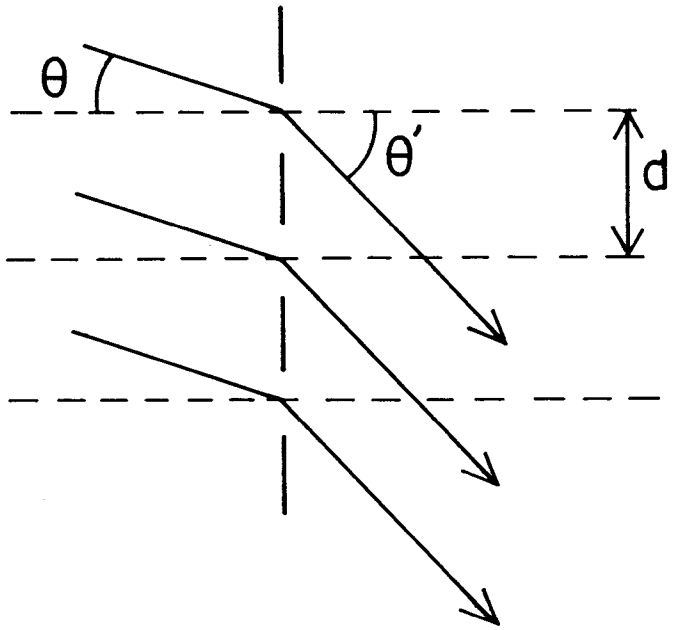


FIG. 2

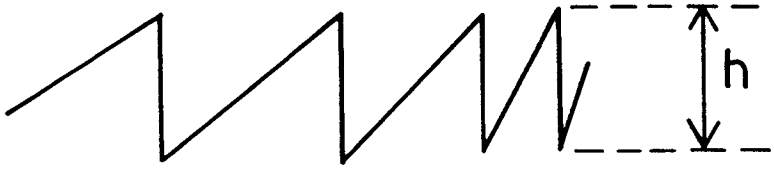


FIG. 3

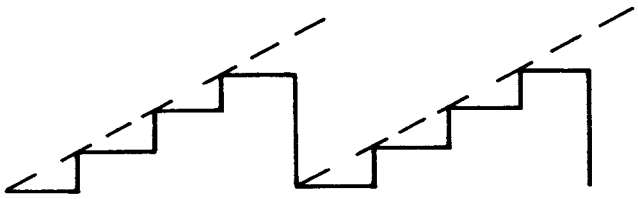


FIG. 4

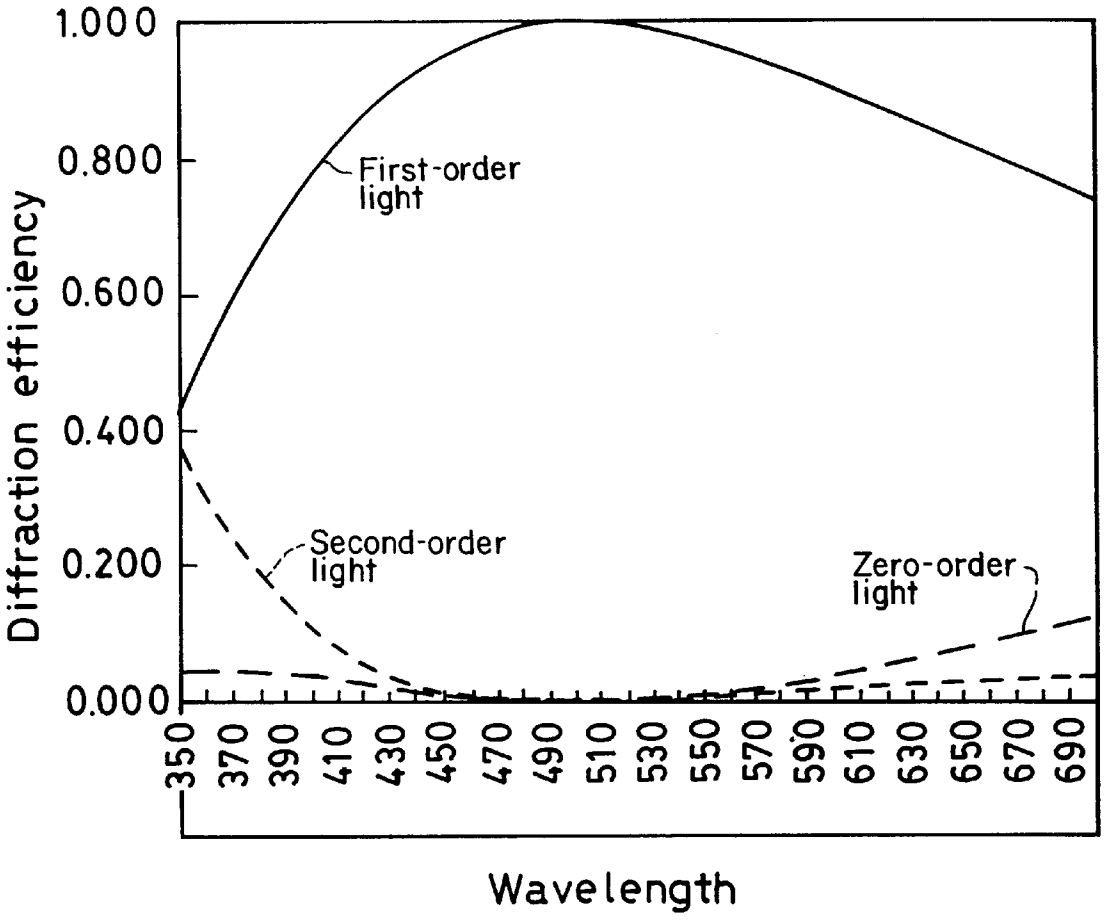

1.000
0.800
0.600
0.400
0.200
0.000
Diffraction efficiency
First-order light
Second-order light
Zero-order light
350
370
390
410
430
450
470
490
510
530
550
570
590
610
630
650
670
690
Wavelength

FIG. 5

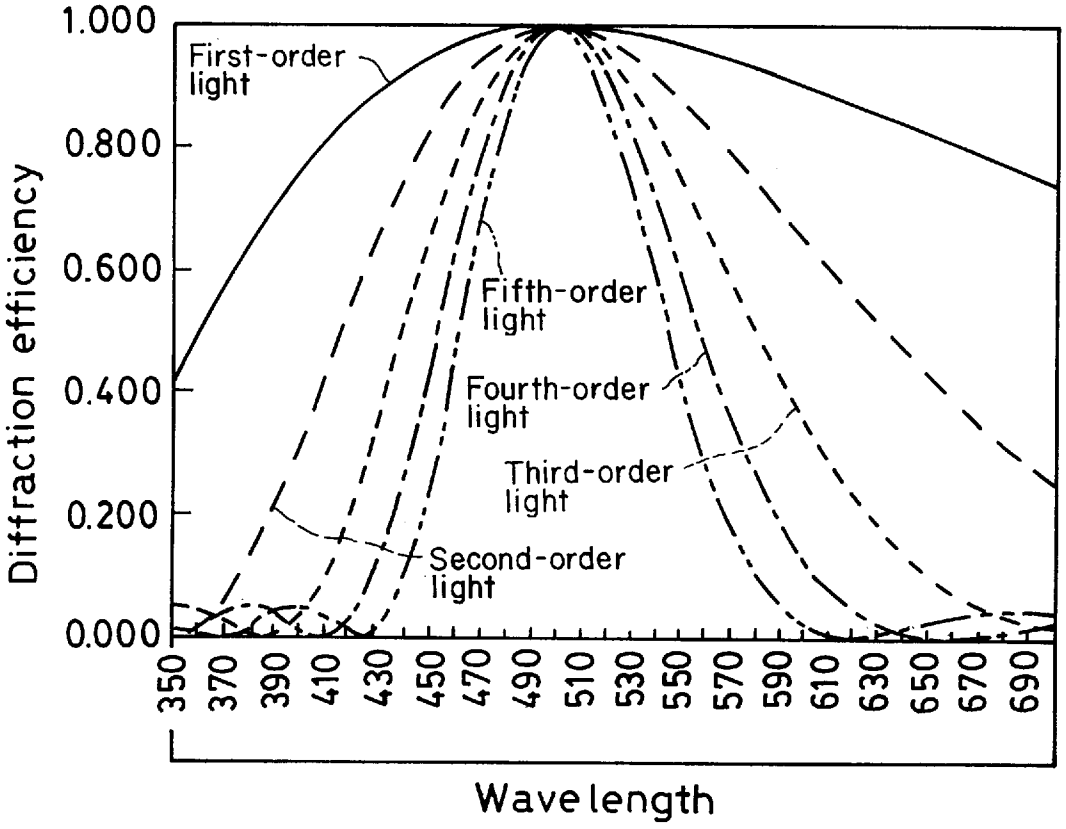

1.000
0.800
0.600
0.400
0.200
0.000
Diffraction efficiency
First-order light
Fifth-order light
Fourth-order light
Third-order light
Second-order light
350
370
390
410
430
450
470
490
510
530
550
570
590
610
630
650
670
690
Wavelength

FIG. 6

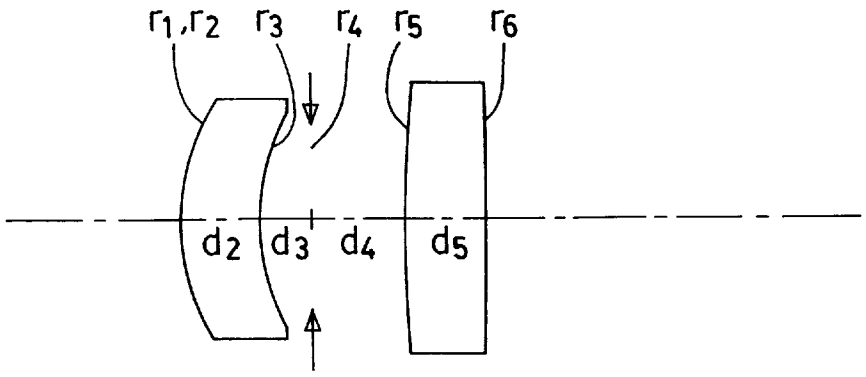


FIG. 7

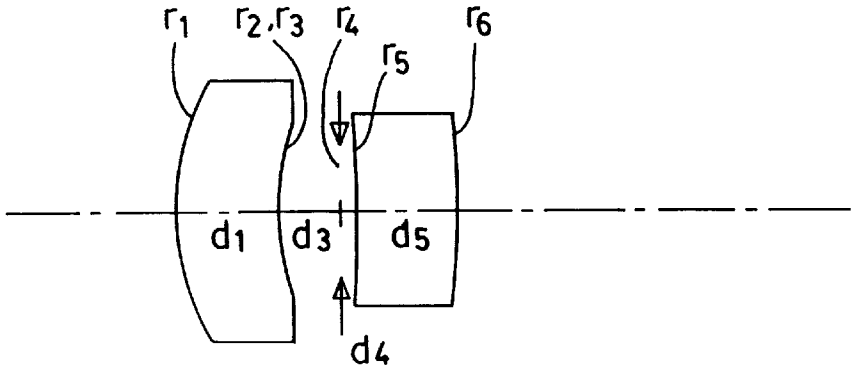


FIG. 8

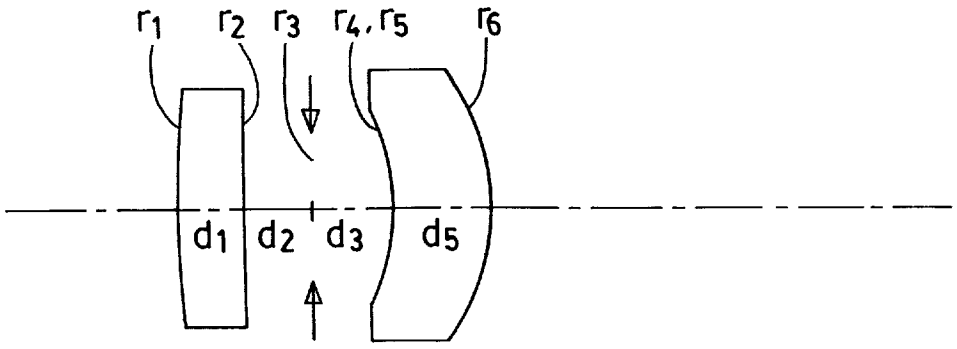


FIG. 9

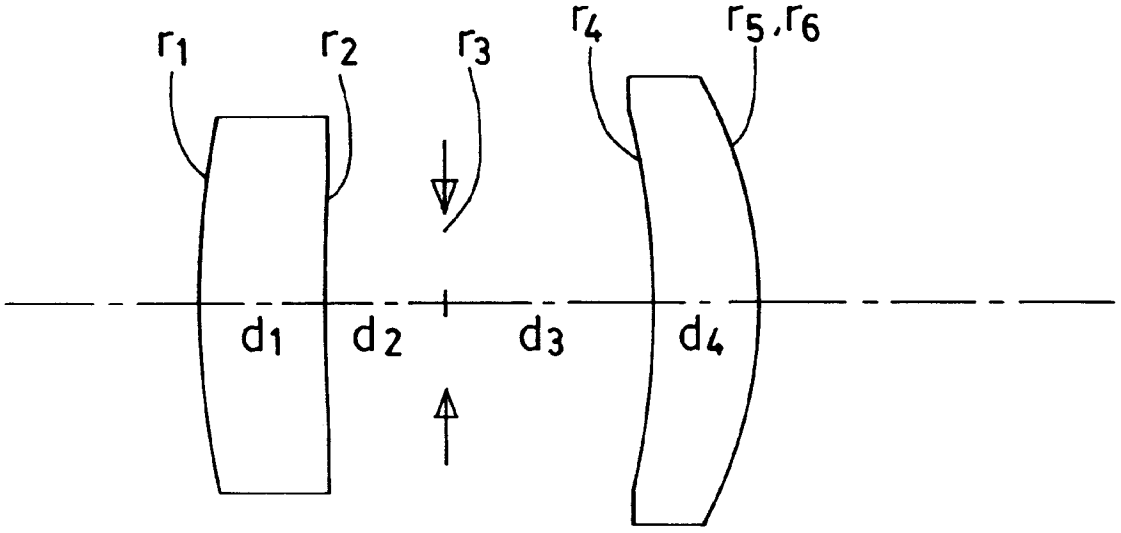


FIG. 10

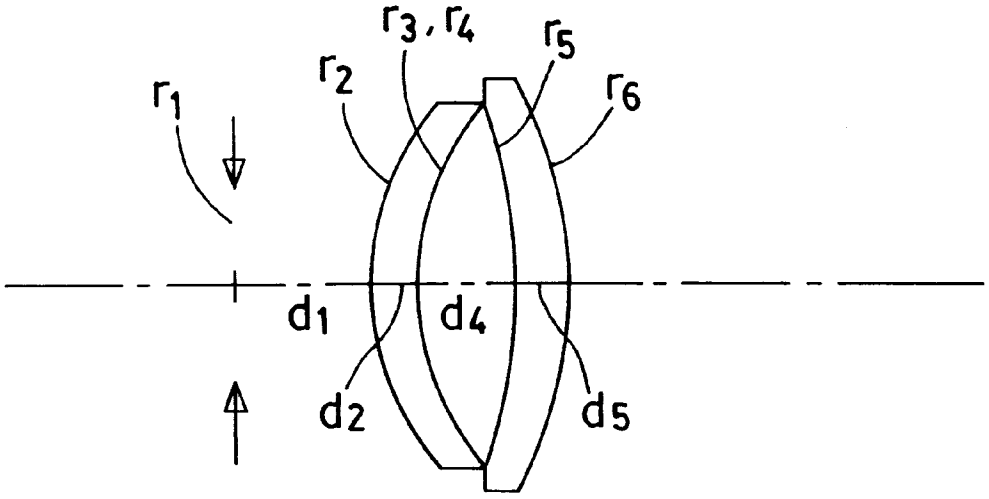


FIG. 11

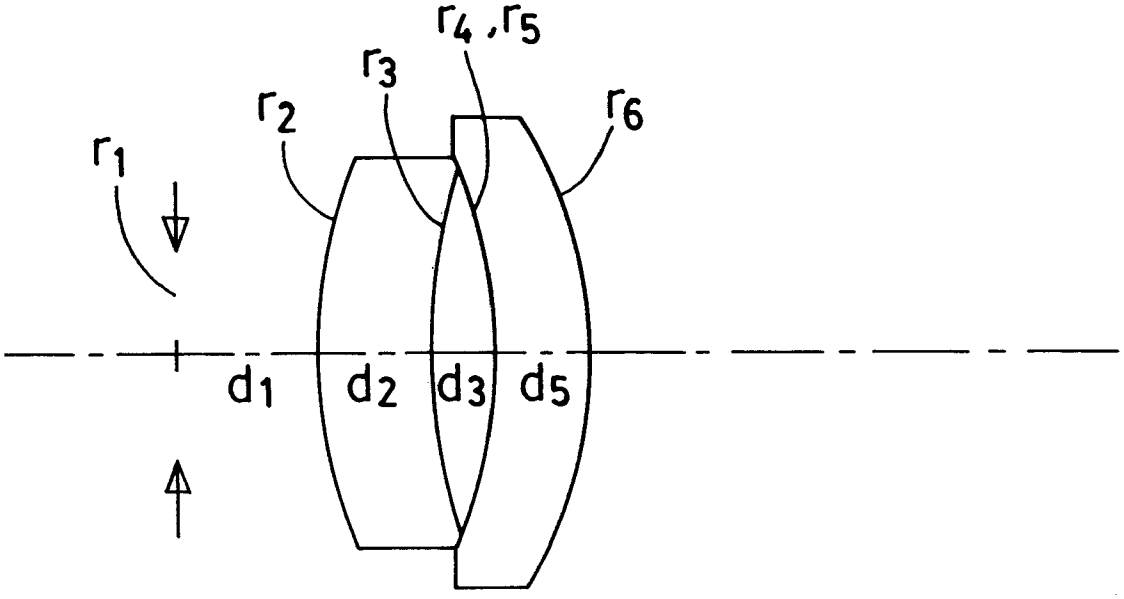


FIG. 12

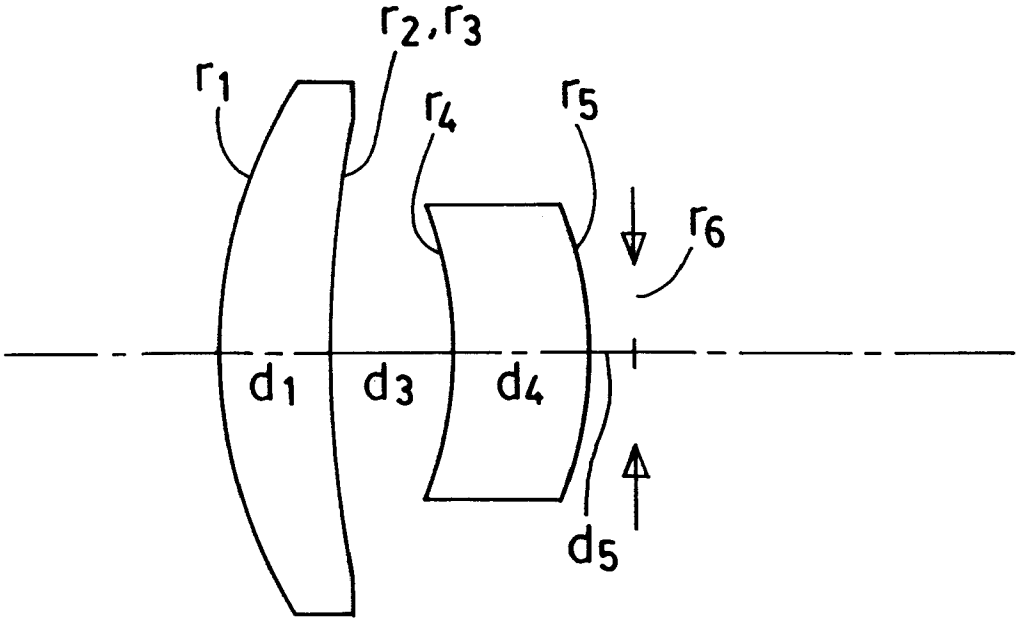


FIG. 13

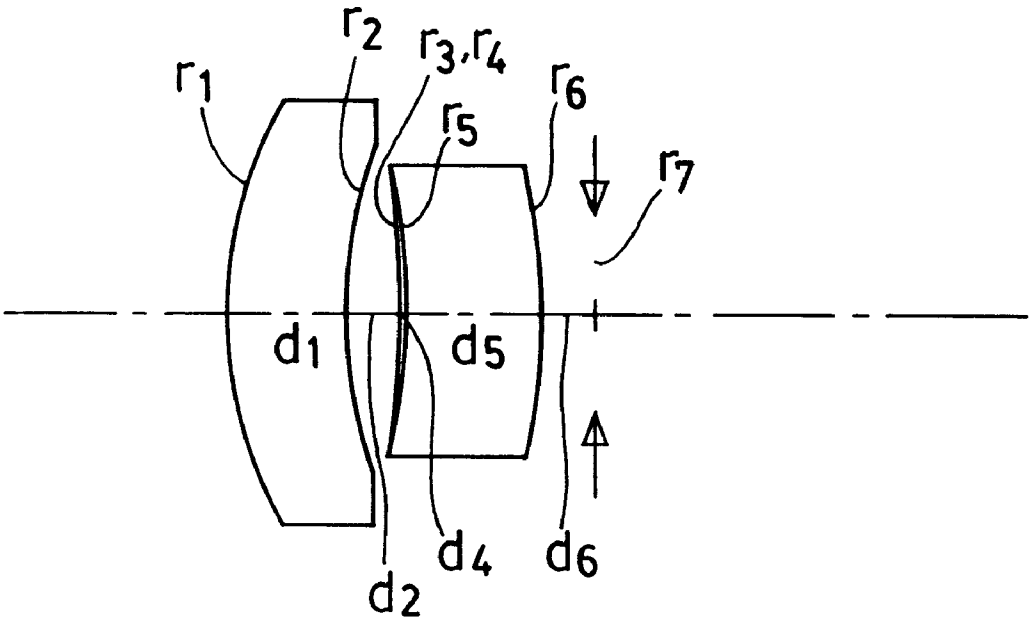


FIG. 14

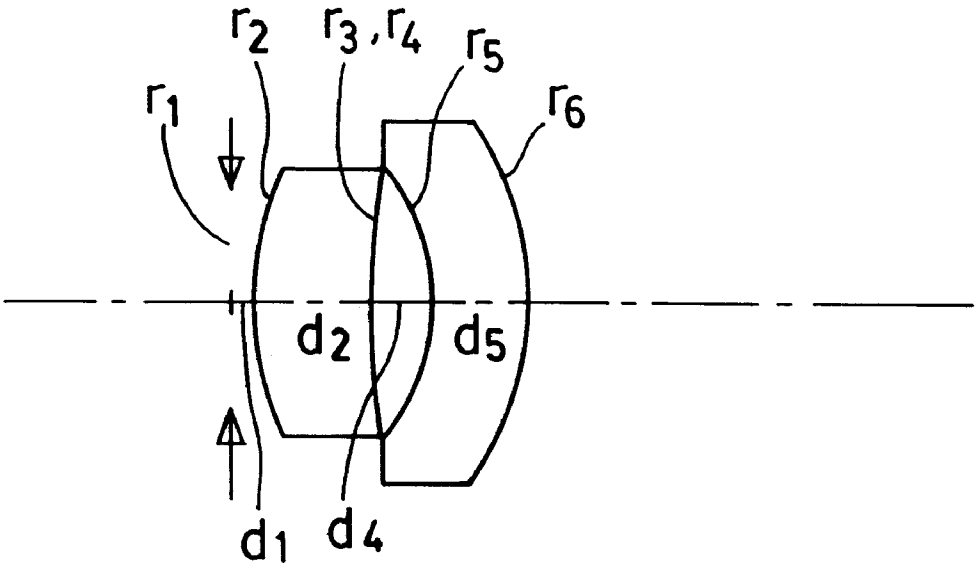
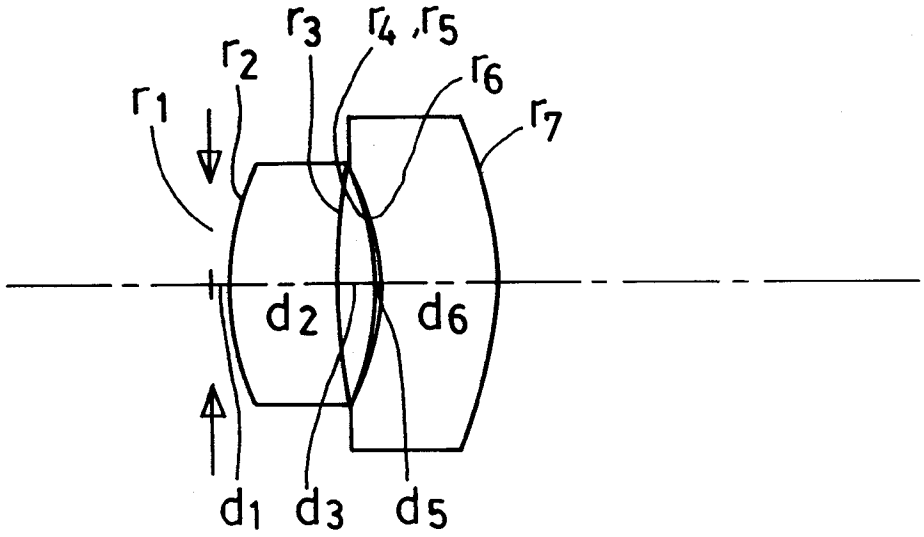


FIG. 15



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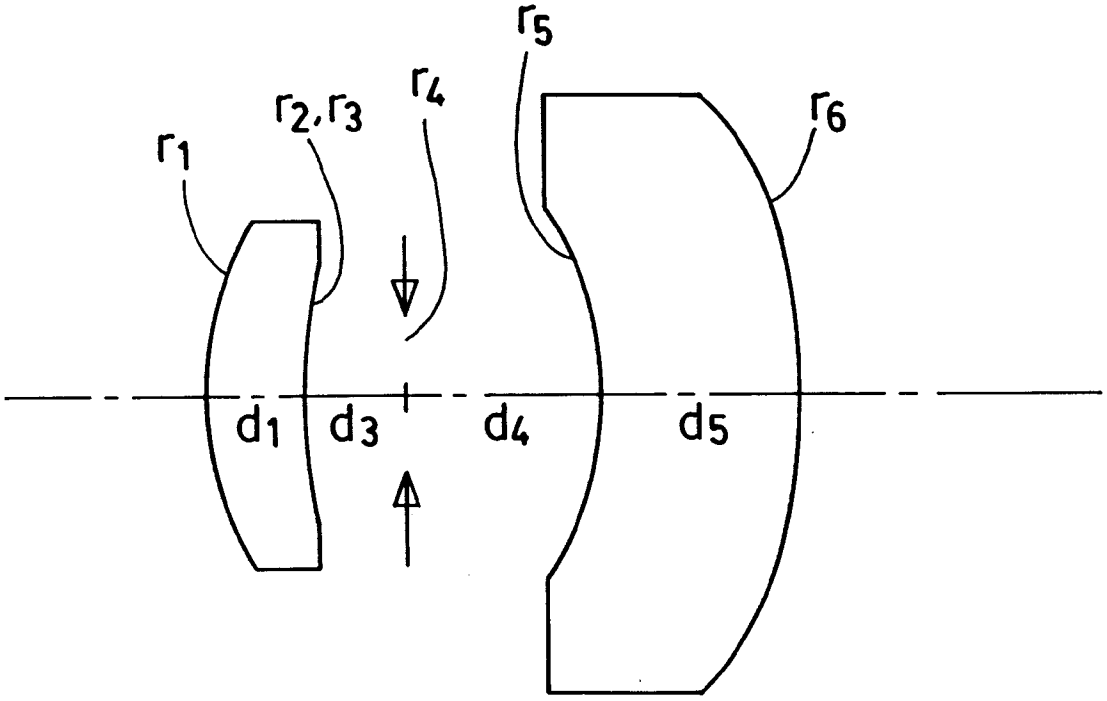


FIG. 17

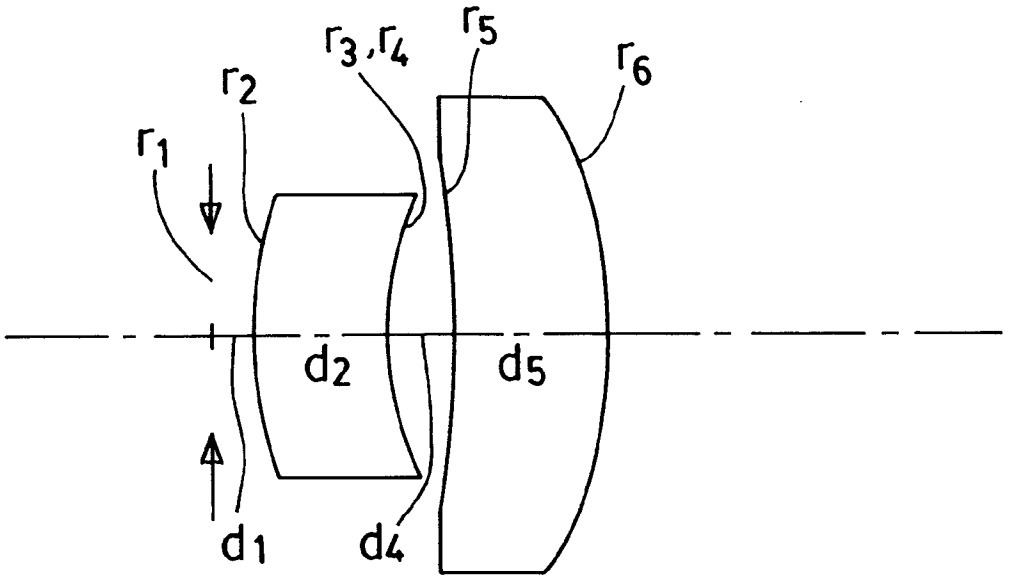
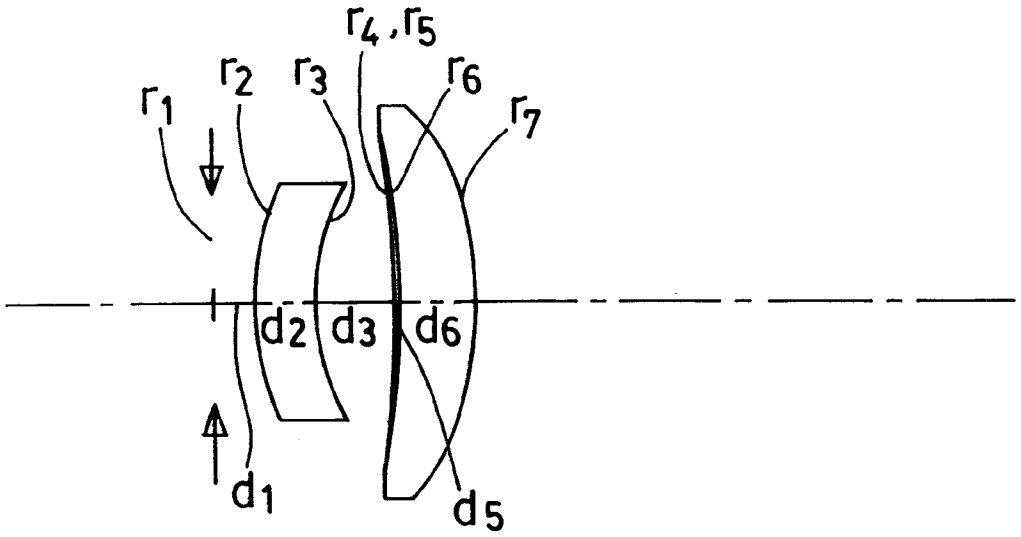


FIG. 18



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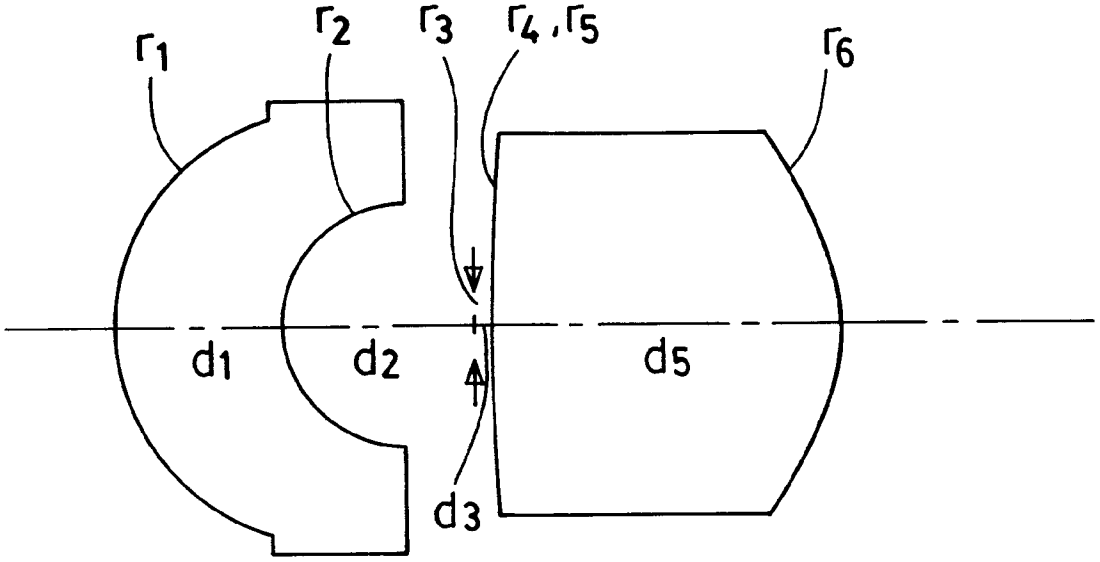


FIG. 20

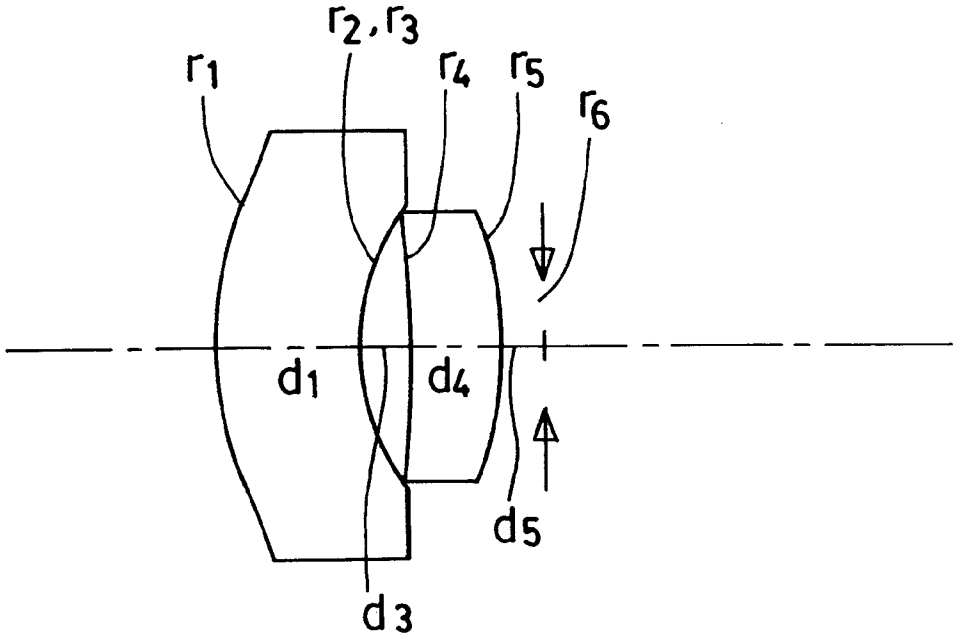


FIG. 21

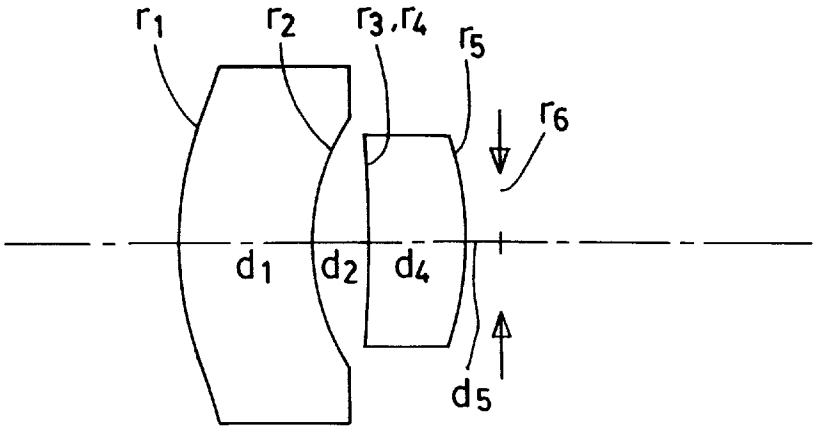

r1
r2
r3,r4
r5
r6
d1
d2
d4
d5

FIG. 22

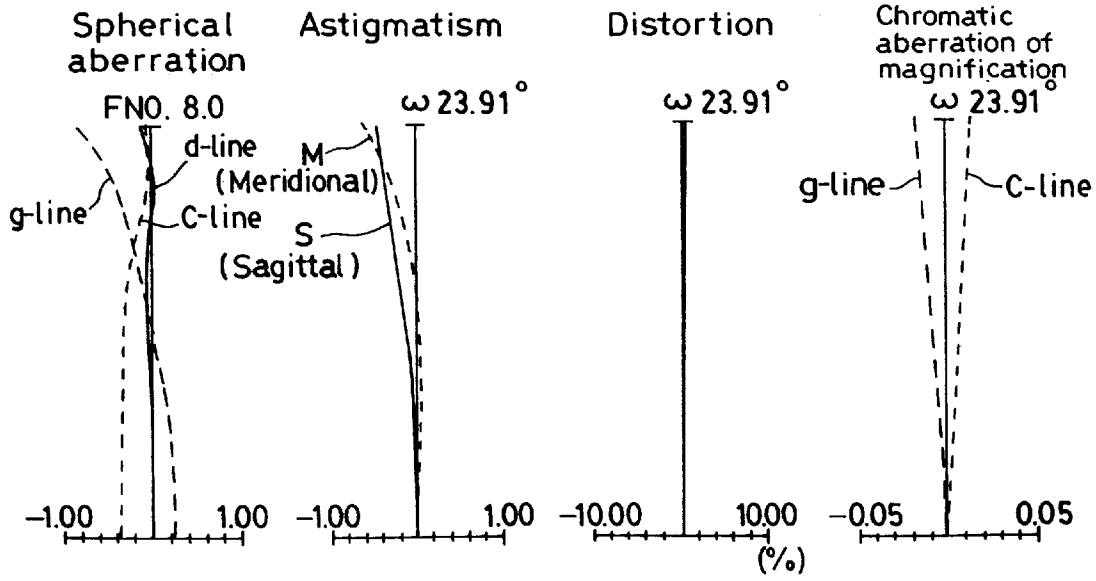

Spherical aberration
FNO. 8.0
d-line
g-line
C-line
-1.00
1.00
Astigmatism
ω 23.91°
M
(Meridional)
S
(Sagittal)
-1.00
1.00
Distortion
ω 23.91°
-10.00
10.00
(%)
Chromatic aberration of magnification
ω 23.91°
g-line
C-line
-0.05
0.05

FIG. 23

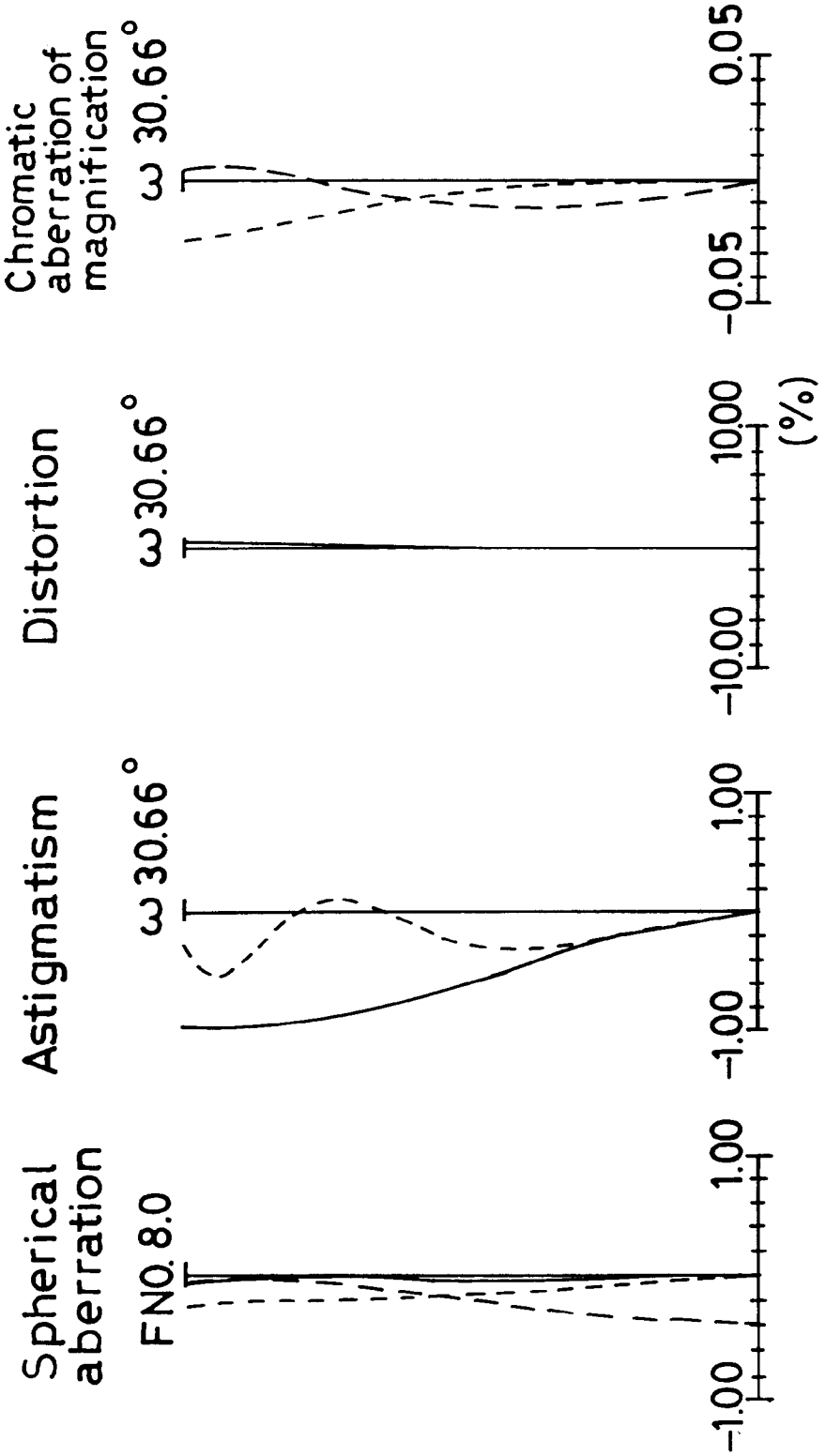

Spherical aberration
FNO. 8.0
1.00
-1.00
Astigmatism
ω 30.66°
1.00
-1.00
Distortion
ω 30.66°
10.00
-10.00
(%)
Chromatic aberration of magnification
ω 30.66°
0.05
-0.05

FIG. 24

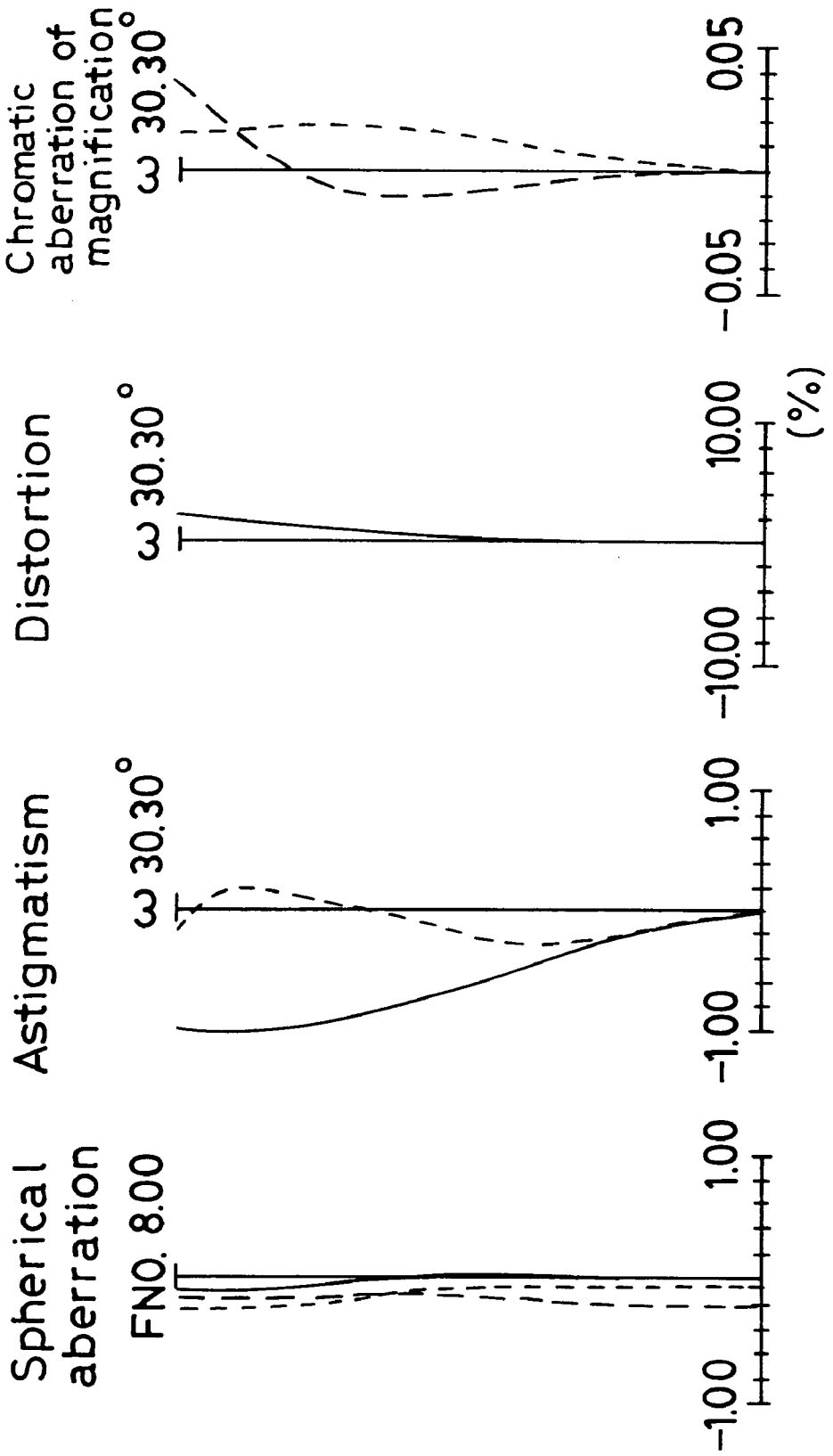

Spherical aberration
FNO. 8.00
1.00
-1.00
Astigmatism
ω 30.30°
1.00
-1.00
Distortion
ω 30.30°
10.00
-10.00
(%)
Chromatic aberration of magnification
ω 30.30°
0.05
-0.05

FIG. 25

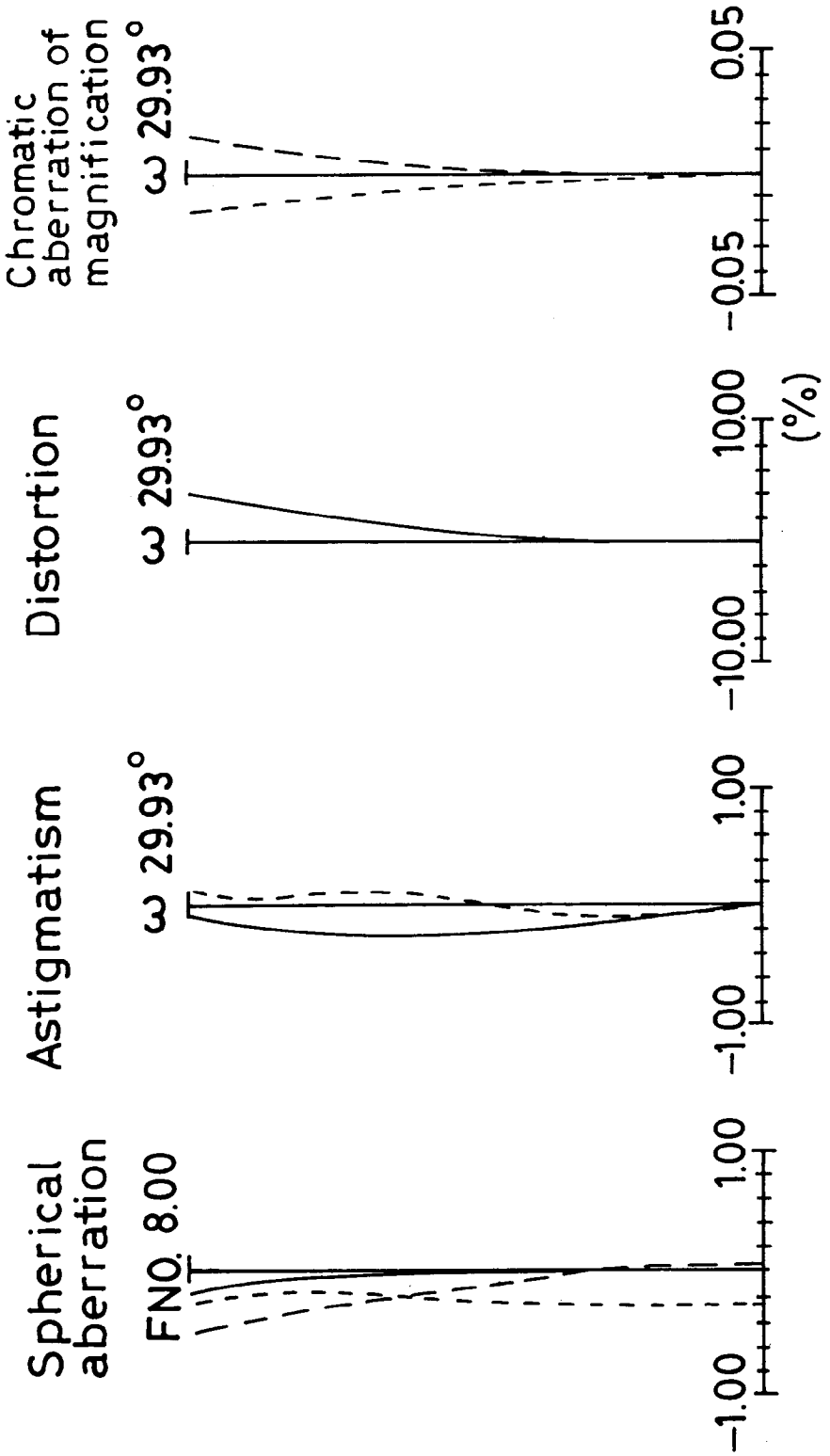

Spherical aberration
FNO. 8.00
1.00
-1.00
Astigmatism
ω 29.93°
1.00
-1.00
Distortion
ω 29.93°
10.00
-10.00
(%)
Chromatic aberration of magnification
ω 29.93°
0.05
-0.05

FIG. 26

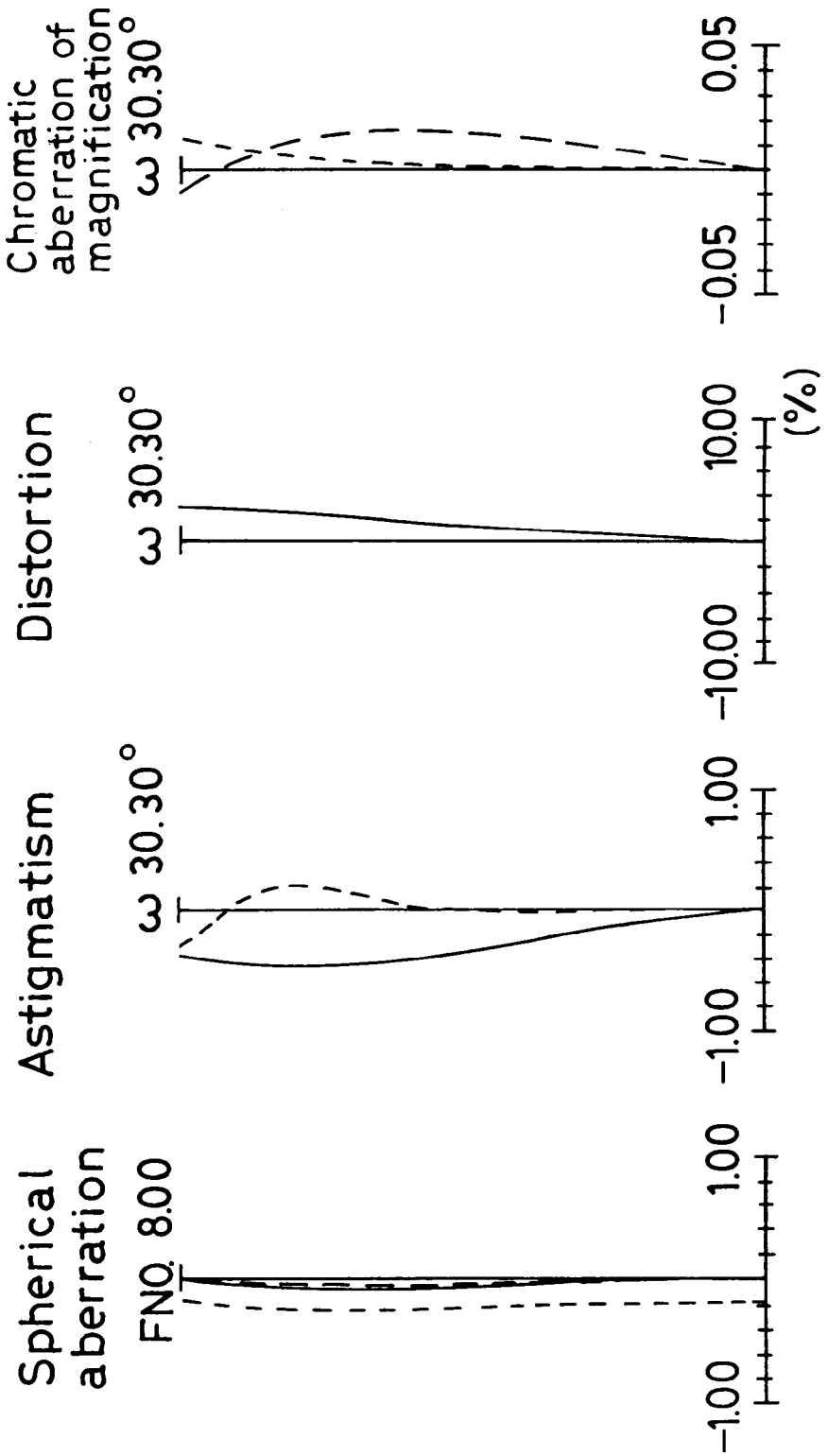

Spherical aberration
FNO. 8.00
1.00
-1.00
Astigmatism
ω 30.30°
1.00
-1.00
Distortion
ω 30.30°
10.00
-10.00
(%)
Chromatic aberration of magnification
ω 30.30°
0.05
-0.05

FIG. 27

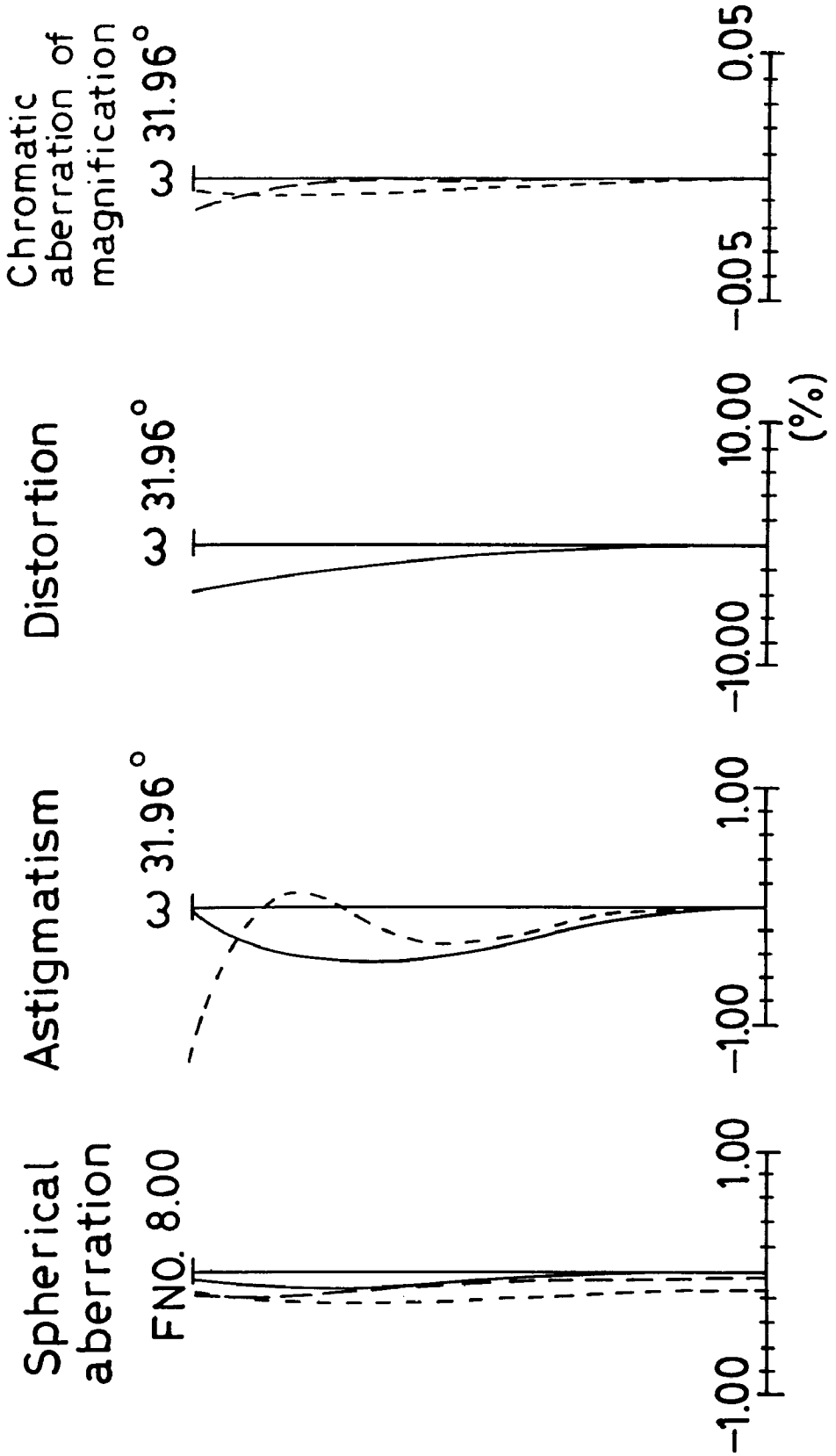

Spherical aberration
FNO. 8.00
1.00
-1.00
Astigmatism
ω 31.96°
1.00
-1.00
Distortion
ω 31.96°
10.00
(%)
-10.00
Chromatic aberration of magnification
ω 31.96°
0.05
-0.05

FIG. 28

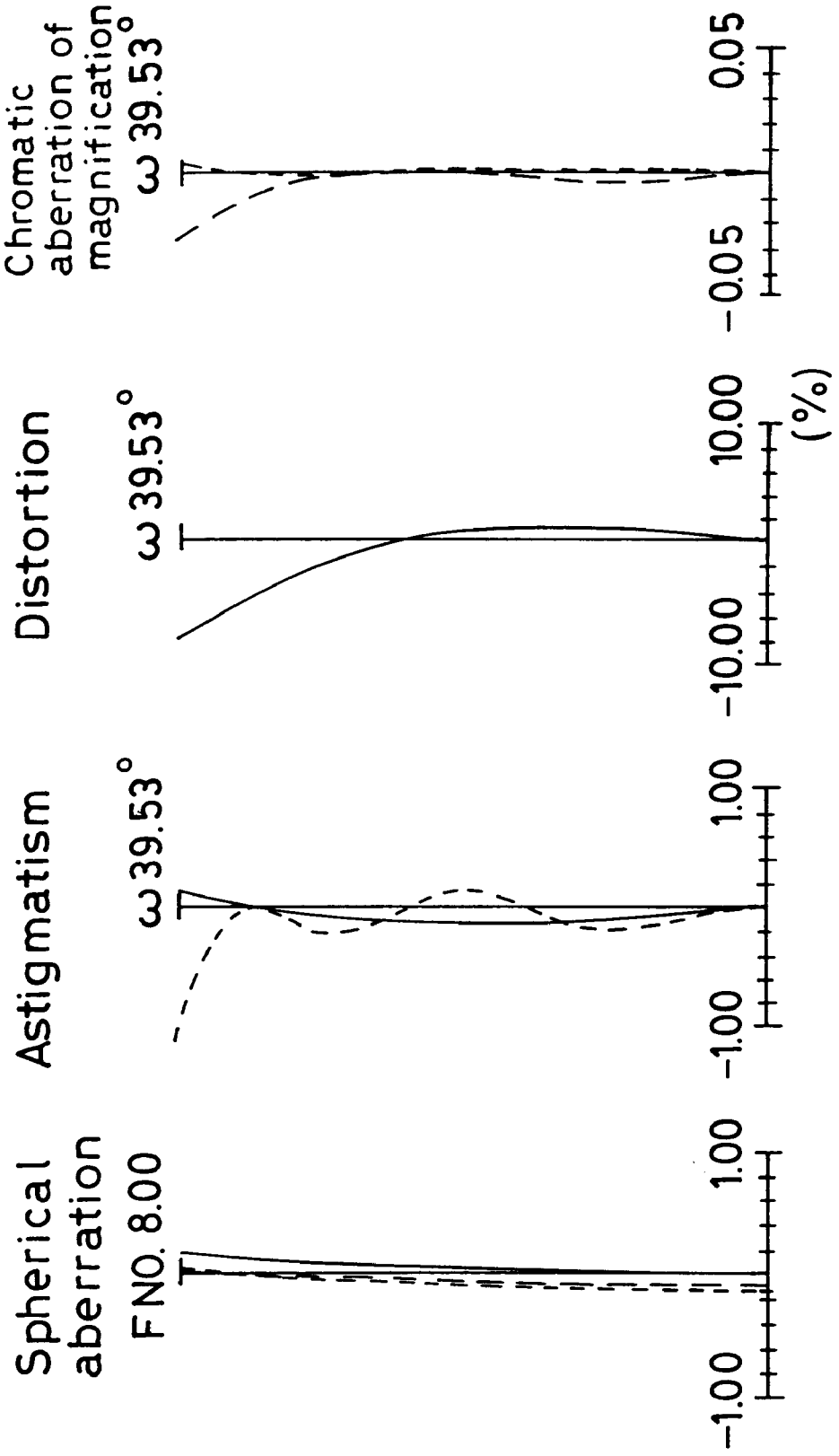

Spherical aberration
FNO. 8.00
1.00
-1.00
Astigmatism
ω 39.53°
1.00
-1.00
Distortion
ω 39.53°
10.00
-10.00
(%)
Chromatic aberration of magnification
ω 39.53°
0.05
-0.05

FIG. 29

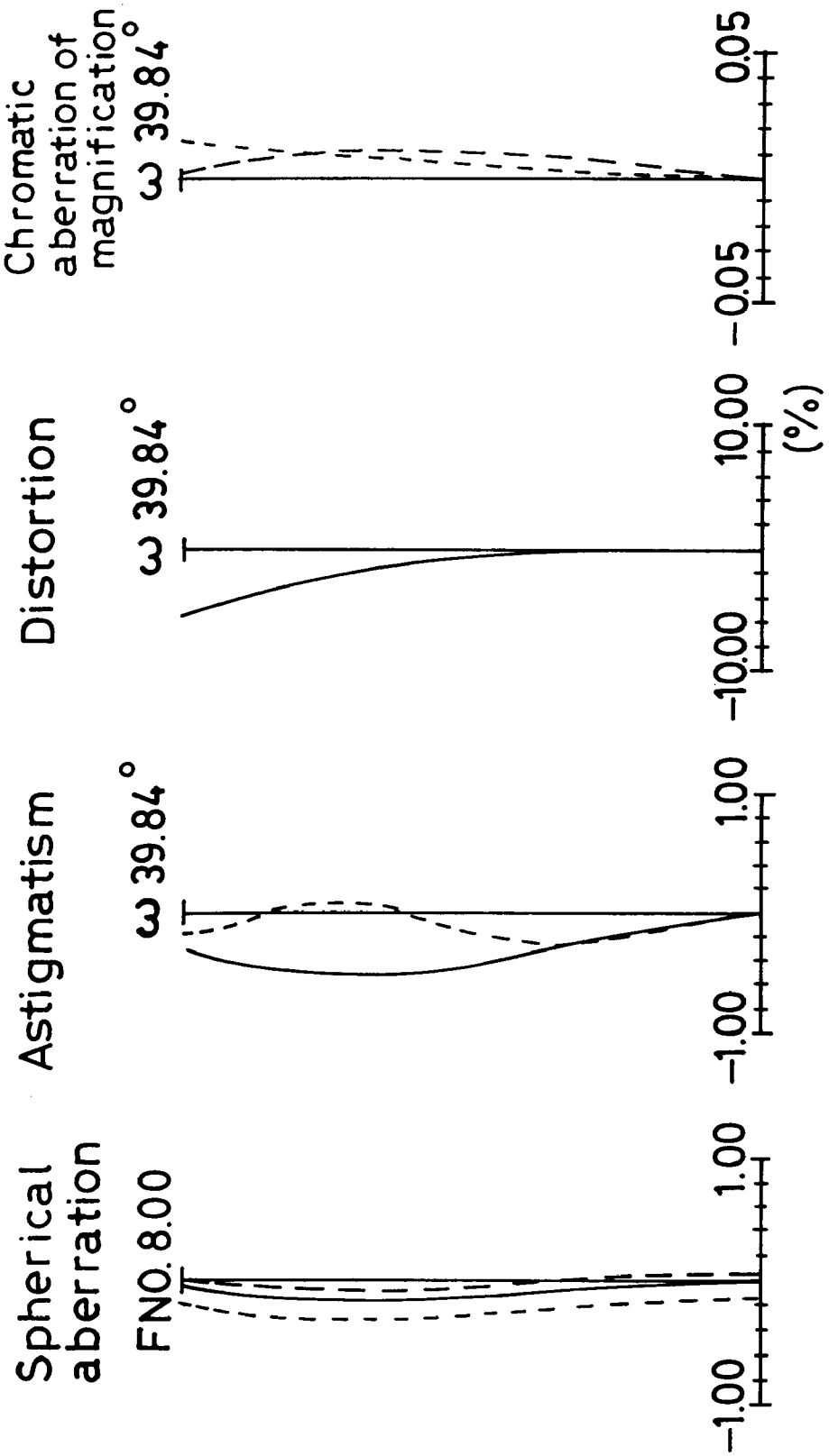

Spherical aberration
FNO. 8.00
1.00
-1.00
Astigmatism
ω 39.84°
1.00
-1.00
Distortion
ω 39.84°
10.00
-10.00
(%)
Chromatic aberration of magnification
ω 39.84°
0.05
-0.05

FIG. 30 (a)

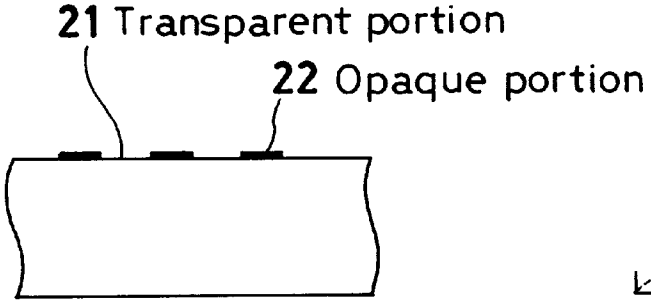


FIG. 30 (b)

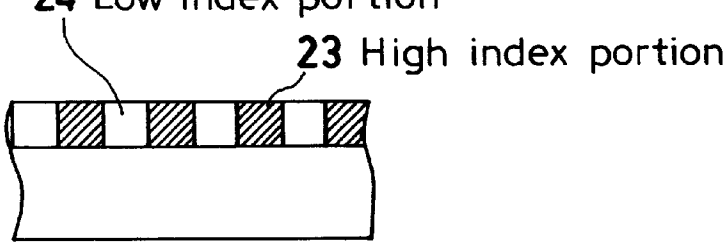


FIG. 30 (c)

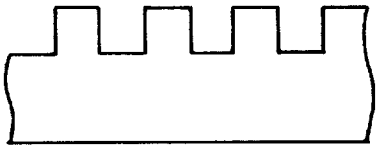


FIG. 30 (d)

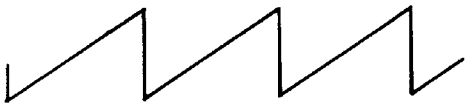


FIG. 30 (e)

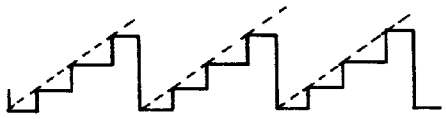
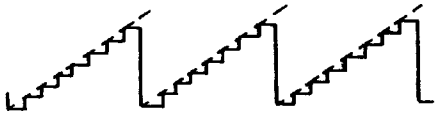


FIG. 30 (f)



HYBRID PHOTOGRAPHIC OBJECTIVE

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a phototaking optical system using a diffractive optical element (DOE for short). More particularly, this invention is directed to a phototaking optical system designed for use on cameras such as silver halide or electronic cameras.

2. Discussion of Related Art

For phototaking optical systems designed for use on silver halide or electronic cameras, it has so far been proposed to improve their performance and cut down their cost. In regard to a general phototaking optical system, it is difficult to achieve cost reductions because many lenses are needed for achieving high performance by correcting aberrations. In recent years, therefore, cost reductions have been accomplished by reducing the number of lenses while keeping performance acceptable by the use of aspheric surfaces. However, aspheric surfaces have a grave disadvantage of being incapable of correcting for chromatic aberrations although they may correct monochromatic aberrations such as spherical aberrations, and coma. Therefore, an extreme reduction in the number of lenses for the purpose of achieving cost reductions often results in performance loss because chromatic aberrations become worse. To correct chromatic aberrations, there is thus no choice but to use suitable combinations of lenses of varying powers, but this inevitably incurs an increase in the number of lenses. That is, it is difficult to arrive at a sensible tradeoff between high performance and low cost.

Attention is now directed to a diffractive optical element (or DOE) having diffractive action to bend light rays. Unlike a general vitreous material, the DOE is characterized by having reciprocal dispersion, i.e., an Abbe number of −3.45, so that achromatization is achievable by a combination of positive power and positive power, unlike a conventional refractive system. Such a characteristic feature is believed to enable the DOE to be used with a phototaking optical system.

An account is here given of a DOE in general. The DOE is interpreted at great length in "Optics", Vol. 22, pp. 635–642, and pp. 730–737, for instance.

A conventional lens is based on refracting action at an interface of the medium, whereas the DOE is based on the diffraction of light. Now assume that light is incident on such a diffraction grating as depicted in FIG. **1**. In general, the light leaving the grating upon diffraction then satisfies the following relation:

$$\sin\theta-\sin\theta'=m\lambda/d \tag{a}$$

where θ is the angle of incidence, θ' is the exit angle, λ is the wavelength of light, d is the pitch of the diffraction grating, and m is the order of diffraction.

Therefore, if a ring form of diffraction grating is designed to have a proper pitch according to equation (a), it is then possible to focus light upon one point. In other words, the diffraction grating is allowed to have lens action. Here, let r_j and f represent the radius of a j-th grating ring and the focal length of a diffractive surface, respectively. If an optical path difference between a light ray diffracted by the j-th grating and a light ray passing through the center of the diffraction grating is designed to be integral multiples of wavelength, both light rays interact with each other to increase their intensity. That is, the following relation holds:

$$\sqrt{(r_j^2+f^2)}-f=j\lambda \tag{b-1}$$

Also, if r_j is not very large with respect to the focal length, the radius r_j of the grating ring is then given by

$$r_j=\sqrt{(2j\lambda f)} \tag{b-2}$$

For the diffraction grating, several types are proposed, for instance, an amplitude modulation type made up of a bright-and-dark ring, and a phase modulation type with a variable refractive index or optical path length. In the amplitude type DOE, the ratio between the quantity of incident light and the quantity of light subject to first-order diffraction (hereinafter called diffraction efficiency), for instance, is at most about 6% because light of plural orders of diffraction is generated. The amplitude modulation type DOE, even when bleached or otherwise treated for diffraction efficiency improvements, has a diffraction efficiency of at most about 34%. However, the same phase modulation type DOE, if it is of a sawtoothed shape in section as depicted in FIG. **2**, can have a diffraction efficiency increased to 100%. Such a DOE is called a kinoform. Here the height of each sawtooth is given by

$$h=m\lambda/(n-1) \tag{c}$$

where h is the height of the sawtooth, m is the order of diffraction (hereinafter called the design order of diffraction), and n is the index of refraction of an optical member forming the diffractive surface.

As can be expected from equation (c) depending on wavelength, however, the diffraction efficiency of 100% is achievable for only one wavelength. Thus, the diffraction efficiency $D_M(\lambda)$ depends on wavelength, and so is given by:

$$D_M(\lambda)=\mathrm{sinc}^2[\pi\{M-m\{(1-n)/(1-n_{DOE})\}(\lambda_{DOE}/\lambda)] \tag{d}$$

where M is the order of diffraction at which the DOE is used, m is the design order of diffraction, λ is the wavelength at which the DOE is used, λ_{DOE} is the design wavelength, and n and n_{DOE} are the indices of refraction of an optical member forming the diffractive surface at the wavelengths λ and λ_{DOE}.

A kinoform element, if it is to step approximation as depicted in FIG. **3**, is often called a binary optical element, and can be relatively easily fabricated by lithographic techniques. The binary optical element is known to have a diffraction efficiency of 81%, 95%, and 99% according to 4-, 8-, and 16-step approximation, respectively.

Examples of such a DOE applied to phototaking optical systems are disclosed in the following publications.

WO95/18393 shows a phototaking optical system comprising a single lens and a diffractive surface for making correction for aberrations. JP-A 4-181908 discloses an easy-to-manufacture radial type inhomogeneous lens wherein the chromatic aberrations produced are set off and corrected by a diffractive lens. This inhomogeneous lens is made up of one to three lens elements. JP-A's 6-324262 and 6-331887 teach that a diffractive surface is formed on front lenses of telescopic systems to make correction for chromatic aberrations. The former system is made up of six lens elements, and the latter system is made up of 10 or 11 lens elements.

However, all these phototaking optical systems using DOEs are found to be still less than satisfactory in terms of performance and cost. The system disclosed in WO95/18393 is somewhat more inexpensive because of being a single lens, but its performance is insufficient because coma, and other aberrations remain under-corrected.

The system set forth in JP-A 4-181908 achieves high performance albeit being composed of a reduced number of

lens elements. However, this system actually costs much because it uses an inhomogeneous lens. Inhomogeneous lenses are still unsuitable for mass production of cameras, etc., and so are unfavorable.

The systems set forth in JP-A's 6-324262 and 6-331887 achieve high performance by using DOEs for lenses in telescopic systems. However, these systems fail to take full advantage of DOEs because the DOEs are used only for the purpose of making fine correction for chromatic aberrations.

Thus, all these prior art arrangements fail to make a reasonable compromise between low cost and high performance.

SUMMARY OF THE INVENTION

In view of such problems associated with the prior art, it is an object of the present invention to provide a high-performance yet inexpensive phototaking optical system making use of a diffractive optical element.

According to the first aspect of the invention, there is provided a phototaking optical system making use of a diffractive optical element, which comprises an aperture stop, at least two lenses, and at least one diffractive surface, and satisfies the following condition (1):

$$0<d_{DOE}/f<0.24 \quad (1)$$

Here f is a focal length of the overall phototaking optical system, and d_{DOE} is a distance on an optical axis of the phototaking optical system from the aperture stop to the diffractive surface.

According to the second aspect of the invention, there is provided a phototaking optical system making use of a diffractive optical element, which comprises an aperture stop, two lenses, and one diffractive surface.

According to the third aspect of the invention, there is provided a phototaking optical system making use of a diffractive optical element, which comprises an aperture stop, two lenses, positive and positive, in order from an object side of the phototaking optical system, and at least one diffractive surface, all being formed of a homogeneous medium.

According to the fourth aspect of the invention, there is provided a phototaking optical system making use of a diffractive optical element, which comprises an aperture stop, two lenses, positive and positive, in order from an object side of the phototaking optical system, and at least one diffractive surface, and satisfies the following condition (3):

$$-1<SF_1<0.15 \quad (3)$$

Here $SF_1=(r_A-r_B)/(r_A+r_B)$ where r_A is a radius of curvature of a surface of the first lens that faces the object side, and r_B is a radius of curvature of a surface of the first lens that faces an image side of the phototaking optical system.

According to the fifth aspect of the invention, there is provided a phototaking optical system making use of a diffractive optical element, which comprises an aperture stop, two lenses, positive and negative, in order from an object side of the phototaking optical system, and at least one diffractive surface.

According to the sixth aspect of the invention, there is provided a phototaking optical system making use of a diffractive optical element, which comprises an aperture stop, two lenses, negative and positive, in order from an object side of the phototaking optical system, and at least one diffractive surface.

The first to sixth aspects of the phototaking optical system according to the present invention are now explained with the features and advantages thereof.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** illustrates the diffractive action of a diffraction grating.

FIG. **2** illustrates a sectional shape of the kinoform.

FIG. **3** illustrates a sectional shape of the binary optical element.

FIG. **4** is a schematic representation showing the relation between wavelength and diffraction efficiency at a design order of 1 and a design wavelength of 500 nm.

FIG. **5** is a schematic representation illustrative of a diffraction efficiency change at design orders of 1 to 5.

FIG. **6** is a sectional schematic of Example 1 inclusive of an optical axis thereof.

FIG. **7** is a sectional schematic of Example 2 inclusive of an optical axis thereof.

FIG. **8** is a sectional schematic of Example 3 inclusive of an optical axis thereof.

FIG. **9** is a sectional schematic of Example 4 inclusive of an optical axis thereof.

FIG. **10** is a sectional schematic of Example 5 inclusive of an optical axis thereof.

FIG. **11** is a sectional schematic of Example 6 inclusive of an optical axis thereof.

FIG. **12** is a sectional schematic of Example 7 inclusive of an optical axis thereof.

FIG. **13** is a sectional schematic of Example 8 inclusive of an optical axis thereof.

FIG. **14** is a sectional schematic of Example 9 inclusive of an optical axis thereof.

FIG. **15** is a sectional schematic of Example 10 inclusive of an optical axis thereof.

FIG. **16** is a sectional schematic of Example 11 inclusive of an optical axis thereof.

FIG. **17** is a sectional schematic of Example 12 inclusive of an optical axis thereof.

FIG. **18** is a sectional schematic of Example 13 inclusive of an optical axis thereof.

FIG. **19** is a sectional schematic of Example 14 inclusive of an optical axis thereof.

FIG. **20** is a sectional schematic of Example 15 inclusive of an optical axis thereof.

FIG. **21** is a sectional schematic of Example 16 inclusive of an optical axis thereof.

FIG. **22** is an aberration diagram for Example 1, wherein (a), (b), (c), and (d) show spherical aberration, astigmatism, distortion, and chromatic aberration of magnification, respectively.

FIG. **23** is a similar aberration diagram for Example 5.

FIG. **24** is a similar aberration diagram for Example 7.

FIG. **25** is a similar aberration diagram for Example 9.

FIG. **26** is a similar aberration diagram for Example 11.

FIG. **27** is a similar aberration diagram for Example 12.

FIG. **28** is a similar aberration diagram for Example 14.

FIG. **29** is a similar aberration diagram for Example 15.

FIG. **30** is a sectional schematic illustrative of specific shapes of the diffractive surface used in the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

First of all, the conditions required for the accomplishment of the object of the invention are explained in con-

junction with all the first to sixth aspects of the invention. So far, it has been proposed to use a one-lens system as a low-cost lens system. As the number of lenses comes down to one, however, the degree of freedom of design becomes very low because the power is determined by the lens specification alone and so there is no choice but to make a selection from bending shapes for the purpose of making correction of aberrations. With the one-lens system, therefore, it is structurally impossible to make correction for chromatic aberration of magnification and Petzval's sum. Even when such a one-lens system is used in combination with an aspheric surface, aberrations such as distortion and coma remain under-corrected. Thus, the one-lens system is inexpensive but has difficulty in achieving high performance.

If the system is made up of at least two lenses, it is then possible to make the degree of freedom of design so high that a sensible selection can be made from lens power profiles, aperture stop positions, and so on. It is thus possible to make good correction for the aforesaid aberrations that cannot be corrected by the one-lens system. To achieve a low-cost yet high-performance lens system, therefore, it is required to construct the system of at least two lenses.

It has been found, however, that the system, even when made up of two lenses, is still insufficient insofar as the correction of chromatic aberrations is concerned. The diffractive surface of a diffractive optical element, or DOE, on the other hand, has a reciprocal dispersion or Abbe number of −3.45. Therefore, if this diffractive surface is used for a refractive surface of a lens, it is then possible to make correction for chromatic aberrations without recourse to an additional lens. According to the invention, it is thus possible to achieve low cost and high performance by proper use of the DOE, as described below.

The first aspect of the invention as well as the features and advantages thereof are explained. With reference here to the effect of the DOE on the correction of aberrations, the DOE has very high dispersion; chromatic aberrations produced at the DOE increase with an increase in its power, resulting in performance loss. To make correction for chromatic aberrations in a well-balanced state, it is required to relatively decrease the power of the DOE.

Even when the DOE is used in this manner, however, there is often a deterioration of chromatic aberration of magnification. The effect of the DOE on the correction of chromatic aberration of magnification varies with not only power but also ray height. When the DOE having very large dispersion is placed at a position of considerable ray height, therefore, the chromatic aberration of magnification is over-corrected. This is a leading cause of the deterioration of chromatic aberration of magnification. In the practice of the invention, therefore, the diffractive surface is located in the vicinity of the aperture stop to lower ray height, thereby placing the chromatic aberration of magnification in a well-balanced state.

It is thus preferred that the position of the diffractive surface satisfies the following condition (1):

$$0<d_{DOE}/f<0.24 \quad (1)$$

Here f is a focal length of the overall phototaking optical system and d_{DOE} is a distance on an optical axis of the system from the aperture stop to the diffractive surface.

When the upper limit of 0.24 in condition (1) is exceeded, chromatic aberration of magnification produced at the diffractive surface becomes too large to be balanced against longitudinal chromatic aberration. At the lower limit of 0 the DOE interferes physically with the aperture stop.

To meet high-performance and low-cost requirements at the same time, it is desired for the position of the DOE to satisfy the following condition (2):

$$0.02<d_{DOE}/f<0.21 \quad (2)$$

The second aspect of the phototaking optical system according to the invention is then explained together with the features and advantages thereof.

First, a problem concerning unnecessary orders of light produced at a DOE is explained. The DOE is characterized by having a diffraction efficiency of 100% with respect to a specific wavelength alone, as can be seen from equation (c) regarding the prior art. Upon incidence on the DOE of a light ray whose wavelength is different from that wavelength, therefore, the design or m-th order diffraction efficiency drops. This in turn causes other orders of (e.g., m+1-th, and m−1-th) diffraction efficiencies to increase, resulting in the occurrence of unnecessary light. In this connection, diffraction efficiency changes at 350 nm to 700 nm wavelengths are illustrated in FIG. **4** on condition that the design order is 1 and the design wavelength is 500 nm. FIG. **4** shows that when the DOE is used in conjunction with white light, unnecessary light such as zero-order light and second-order light is produced and image quality is often adversely affected by such unnecessary light. Thus, even when aberration performance is improved by use of many DOEs, there is an image quality drop due to large influences of the unnecessary orders of light.

The placement of one diffractive surface is sufficient for the correction of chromatic aberrations. In other words, when a plurality of diffractive surfaces are used, the chromatic aberrations are over-corrected; chromatic aberrations produced at one diffractive surface must be corrected by another diffractive surface. In addition, an eccentricity of such diffractive surfaces, which may be caused by assembling, etc., leads possibly to performance loss.

To achieve the object of the present invention, therefore, it is desired that at least one diffractive surface be used in conjunction witn a lens arrangement consisting of two lenses.

The third aspect of the phototaking optical system according to the present invention is explained together with the features and advantages thereof.

The optimum arrangement of two lenses of positive power and positive power in the third, and fourth aspects of the photo-taking optical system according to the present invention is described just below.

In a conventional system comprising two lenses each having positive power, the curvature of each lens is not very strong because the positive power is divided into halves with respect to the focal length of the overall system. For this reason, the amount of higher-order aberrations produced is so small that monochromatic aberrations such as spherical aberration and coma are in a generally good state. For this lens system comprising positive lenses alone, however, there is no choice but to reduce the amount of aberrations produced at the individual lenses so as to reduce longitudinal chromatic aberration, but it is in principle impossible to reduce them to zero. Thus, this system is less than satisfactory in terms of performance.

By using at least one diffractive surface in conjunction with a lens arrangement consisting of two lenses and having a positive-positive power profile according to the present invention, it is possible to make effective correction for chromatic aberrations and, hence, improve performance.

Incidentally, it is expected that, in view of performance improvements, inhomogeneous medium lenses are prefer-

able to homogeneous medium lenses because not only chromatic aberrations but also monochromatic aberrations such as coma can be corrected. However, inhomogeneous lenses are much higher in cost than homogeneous lenses, and so are not suitable for use on cameras, etc. because cost reductions are hardly achievable even though the number of inhomogeneous lenses used is reduced. In addition, the quality control, and manufacture of inhomogeneous lenses are more difficult than those of homogeneous lenses, and so the inhomogeneous lenses are not suitable for application to mass-produced cameras, etc. Thus, the inhomogeneous medium lenses may be favorable for performance improvements, but are generally more unfavorable than the homogeneous medium because grave problems arise in connection with cost, and productivity.

To accomplish the object of the present invention, therefore, it is desired that the diffractive surface be used in conjunction with two lenses each having positive power.

The fourth aspect of the phototaking optical system according to the present invention is described together with the features and advantages thereof.

When the lens system is constructed of only two lenses, it is often difficult to correct large aberrations produced at one lens with another lens. It is thus required that the amount of aberrations produced at the individual lenses be reduced as much as possible. Especially with a lens system having a positive-positive power profile, it is difficult to correct the second lens for spherical aberration and coma because a light beam passing through the second lens is more slender than that passing through the first lens. It is thus required that the amount of aberrations produced at the first lens be reduced as much as possible. This is achieved by allowing the first lens to have a shape convex toward the object side of the system, so that the aforesaid aberrations can be well corrected with considerable distortion and astigmatism reductions.

Accordingly, it is preferable for the first lens to satisfy the following condition (3):

$$-1<SF_1<0.15 \quad (3)$$

Here $SF_1=(r_A-r_B)/(r_A+r_B)$ where r_A is a radius of curvature of the first lens that faces the object side of the system, and r_B is a radius of curvature of the first lens that faces the image side of the system.

Condition (3) defines the shape factor of the first lens. When the upper limit of 0.15 is exceeded, the effect of the first lens on the correction of aberrations becomes slender due to its positive power decrease. When the lower limit of −1 is not reached, aberrations such as coma become worse with performance loss because the convexity of the first lens toward the object side of the system vanishes.

To achieve ever-higher performance, it is preferable for the first lens to satisfy the following condition (4):

$$-0.5<SF_1<0.08 \quad (4)$$

For the second to fourth phototaking optical system embodiments, it is noted that their Petzval's sum cannot be reduced to a sufficient level because they are composed only of positive lenses, and so their peripheral performance becomes worse due to field of curvature. However, this is avoided by allowing the image plane to have a cylindrical shape whose major or minor side has a given curvature, thereby making the influence of field of curvature less.

The fifth aspect of the phototaking optical system according to the present invention is explained together with the features and advantages thereof.

The system constructed of two positive lenses each having positive power has a demerit of being incapable of reducing the Petzval's sum to a sufficient level because it is composed only of positive lenses. For this reason, the field of curvature increases, offering a certain problem in connection with the peripheral performance. In addition, some limitation is in principle placed on an overall length reduction because the principal point is positioned in the vicinity of the center of the system.

If the system is constructed of two lenses, positive and negative, in order from the object side thereof, it is then possible to make correction for the Petzval's sum, and reduce the overall length of the system because the principal point is shifted toward the object side of the system. With an arrangement consisting of two lenses and having a positive-negative power profile, it is impossible to achieve a power profile best suited for the correction of chromatic aberrations and so make sufficient correction therefor. This is because if the power of the arrangement is too strong, spherical aberration and coma then become worse.

By using at least one diffractive surface in conjunction with the arrangement having a positive-negative power profile according to the present invention, it is possible to make effective correction for chromatic aberrations and so improve performance.

Such a system is better in performance than a conventional lens system, and enables a camera to be made more compact because its overall length can be reduced.

To achieve the object of the present invention, therefore, it is preferable that at least one diffractive surface is used in conjunction with the arrangement consisting of a lens of positive power and a lens of negative power in order from the object side of the system.

The sixth aspect of the phototaking optical system according to the present invention is explained together with the features and advantages thereof.

An arrangement consisting of two lenses and having a negative-positive power profile is described with reference to the sixth aspect of the phototaking optical system according to the present invention. With the arrangement having a positive-positive power profile, the field of curvature increases under the influence of the Petzval's sum, offering a certain problem in connection with the peripheral performance, as previously stated. In addition, since the principal point is positioned in the vicinity of the center of the arrangement, it is often impossible to ensure a sufficient back focus when the focal length of the system is short.

If the arrangement is constructed of two lenses, negative and positive, in order from the object side of the system, it is then possible to make correction for the Petzval's sum. In addition, the principal point is shifted toward the image side of the system in such a manner as to make sure of the back focus. With a conventional arrangement consisting of two lenses of negative power and positive power, however, it is impossible to achieve a power profile best suited for the correction of chromatic aberrations and hence make sufficient correction therefor. This is because when the power of the arrangement is too strong, spherical aberration and coma become worse.

By using at least one diffractive surface in conjunction with an arrangement consisting of two lenses and having a negative-positive power profile according to the present invention, it is possible to make effective correction for chromatic aberrations and so improve performance.

Such a system is better in performance than a conventional lens system, and can physically make sure of a back focus when applied to an optical system having a reduced

focal length, for instance, a wide-angle lens system or an optical system having a small image size, e.g., a lens for monitor cameras.

To achieve the object of the present invention, therefore, it is preferable that at least one diffractive surface is used in conjunction with an arrangement consisting of two lenses of negative power and positive power in order from the object side of the system.

For the fifth, and sixth phototaking optical system embodiments where one of the two lenses is a negative lens, it is required that the power of the positive lens is increased so as to make sure of the power of the overall system. It is noted, however, that the correction of chromatic aberrations and Petzval's sum, the overall length reduction of the system, etc. cause the power of the system to become strong, resulting in performance loss due to increases in the amount of aberrations produced at the individual lens surfaces. It is thus desired that, in addition to at least one diffractive surface, at least one aspheric surface be used in conjunction with the lens arrangement so that the aberrations can be well corrected.

For the fifth, and sixth phototaking optical system embodiments, it is desired that the negative lens satisfy the following condition (5):

$$-1.2<f/f_{NEG}<-0.05 \quad (5)$$

Here f is a focal length of the overall phototaking optical system and f_{NEG} is a focal length of the negative lens.

Condition (5) gives a definition of the power of the negative lens. When the upper limit of −0.05 is exceeded, the power of the negative lens becomes too weak to have an effect on the correction of chromatic aberrations and Petzval's sum, and below the lower limit of −1.2, the power of the negative lens becomes too strong to make correction for coma and astigmatism even when used in combination with the aspheric surface.

To achieve ever-higher performance, it is desirable for the negative lens to satisfy the following condition (6):

$$-0.9<f/f_{NEG}<-0.15 \quad (6)$$

With reference here to the second, third, fourth, fifth, and sixth phototaking optical system embodiments, where to locate the aperture stop is explained. In a conventional arrangement consisting of two lenses, some severe limitation is placed on where to locate an aperture stop for the purpose of making sure of performance, because it is impossible to make sufficient correction for chromatic aberration of magnification. By use of a DOE, however, it is possible to make the degree of freedom regarding where to locate the aperture stop higher than would be possible in the art because it is possible to make good correction for chromatic aberration of magnification.

Especially if the aperture stop is positioned on the object or image side of the system, a lens member can be positioned irrespective of a space allowed for lenses, and so can be mounted within a camera with a high degree of design.

The placement of the aperture stop between two lenses is favorable for the correction of coma because upper and lower portions of marginal rays can be cut off by the barrel of lenses, etc.

In the first, and second phototaking optical system embodiments, two lenses each of positive power may be used. By doing so, spherical aberration and coma are kept in good condition and monochromatic aberrations are maintained in generally good condition as well, as previously explained with reference to the third, and fourth phototaking optical system embodiment.

In the first, and second phototaking optical system embodiment, two lenses of negative power, and positive power may be used. By doing so, it is possible to eliminate the problem regarding the Petzval's sum, as previously explained in connection with the sixth phototaking optical system embodiment. This also enables even a lens system having a short focal length to readily make sure of the back focus.

In the first, third, fourth, fifth, and sixth phototaking optical system embodiments, only one diffractive surface may be used. By doing so, the problem regarding the unnecessary order of light may be solved to some extent and so any image quality drop may be avoided, as previously explained with reference to the second phototaking optical system embodiment.

In the first, second, fourth, fifth, and sixth phototaking optical system embodiments, all the lenses may be formed of a homogeneous medium. By doing so, the problems regarding cost and productivity may be settled to some extent, as previously explained with reference to the third phototaking optical system embodiment.

With reference to the problem regarding the unnecessary order of light, the preferable design order is 1 in the first to sixth phototaking optical system embodiments. FIG. **5** shows diffraction efficiency changes when the design order is 1 to 5 in equation (c) explained with reference to the prior art. From FIG. **5** it is found that as the design order increases, the diffraction efficiency drops sharply with wavelength changes in a wide wavelength range in which phototaking optical systems are used. To reduce the occurrence of flare due to the unnecessary order of light, therefore, it is preferable that the design order is 1 at which the minimum diffraction efficiency is obtained.

In reference to the same problem, it is preferable in the first to sixth phototaking optical system embodiments to use a design wavelength λ_{DOE} at which the maximum diffraction efficiency is achieved, as defined below.

$$470 \text{ nm}<\lambda_{DOE}<550 \text{ nm} \quad (9)$$

Condition (9) gives a definition of design wavelength λ_{DOE} in such a manner that flare due to DOE does not noticeably show up, while taking into account the transmittance of lenses, the spectral properties of film, CCD, etc., and the spectral properties of a light source. Above the upper limit of 550 nm or below the lower limit of 470 nm flare becomes relatively noticeable.

In addition, the first to sixth phototaking optical system embodiments may be modified as follows.

In some cases, the diffractive surface of a DOE is formed in a plane shape. If this is done, it is then easy to fabricate the diffractive surface. However, such a plane form of diffractive surface is unfavorable because coma is likely to occur with an increase in the angle of incidence of light thereon. For this reason and in view of the correction of aberrations, it is preferable to impart a certain curvature to the surface of the DOE providing the diffractive surface.

For a conventional lens system, achromatization is achieved by using a negative lens relative to a positive lens. In the case of a DOE having reciprocal dispersion, however, achromatization is achieved by using a DOE of positive power relative to a positive lens. In the lens system according to the present invention, too, it is preferable that the diffractive surface has positive power.

At this time, it is preferable that the power of the diffractive surface satisfies the following condition (7):

$$0.02<f/f_{DOE}<0.5 \quad (7)$$

Here f is a focal length of the overall phototaking optical system and f_{DOE} is a power of the diffractive surface.

When the upper limit of 0.5 in condition (7) is exceeded, the power of the diffractive surface becomes too strong to cause over-correction of chromatic aberrations, resulting in performance loss, and when the lower limit of 0.02 is not reached, the power of the diffractive surface becomes too small to cause under-correction of chromatic aberrations, resulting in no performance improvement.

To achieve ever-higher performance, it is desired that the power of the diffractive surface satisfies the following condition (8):

$$0.05<f/f_{DOE}<0.25 \quad (8)$$

The diffractive surface is preferably in a kinoform configuration because unnecessary light is reduced with good image quality by increasing the efficiency of utilization of light of the phototaking optical system. It is also preferable to use a so-called binary optical element that is a stepwise approximation of the kinoform configuration.

Plastic DOEs are best suited for use on cameras, etc., because they can be mass-produced by monolithic molding. Low-hygroscopicity plastic DOEs are less susceptible to shape changes due to humidity, and so deterioration of performance due to environmental changes. When DOEs are constructed of glass, etc., it is not easy to provide fine diffraction gratings on the surfaces of lenses. For ease of manufacture, it is then preferable to provide a diffraction grating on the surface of a thin resin layer formed on the surface of glass. In view of productivity, it is then preferable to use a resin curable by ultraviolet rays, heat, etc.

When a phototaking element is a CCD, etc., it is required to make an optical system telecentric because the quantity of light must be obtained by making the angle of incidence of light substantially vertical to the CCD. However, such an arrangement is not preferable because of an increased overall length. It is therefore preferable to set the exit pupil of the optical system at a finite position.

Still other objects and advantages of the invention will in part be obvious and will in part be apparent from the specification.

The invention accordingly comprises the features of construction, combinations of elements, and arrangement of parts which will be exemplified in the construction hereinafter set forth, and the scope of the invention will be indicated in the claims.

Examples 1 to 16 of the phototaking optical system of the invention using a diffractive optical element are now explained below.

The diffractive surface used in the lens system of the present invention has been designed using the ultra-high index technique, and is more specifically expressed in the form of a refractive lens having a refractive index of 1001 as measured at a thickness of 0 and a d-line wavelength. In numerical data given later, too, the diffractive surface is given by an ordinary aspherical formula as described below. That is, the aspherical shape is given by

$$Z=CY^2/[1+\sqrt{\{1-(1+K)C^2Y^2\}}]+A_4Y^4+A_6Y^6+A_8Y^8+A_{10}Y^{10} \quad (e)$$

where Z is an axis representing an optical axis direction, Y is an axis representing a direction perpendicular to the optical axis, C is a curvature of a surface apex (=1/r where r is a radius of curvature), K is a conical coefficient, and A_4, A_6, A_8, and A_{10} are fourth, sixth, eighth, and tenth aspherical coefficients, respectively.

A surface that is in contact with the diffractive surface at a thickness of 0 is a surface of DOE substrate material. In actual production, a phase change is first found from a difference between the aspherical shape of the diffractive surface and the surface shape of the substrate material, and the index of refraction. Then, this phase change is converted into the pitch of a diffraction grating, which is in turn formed on the surface of the substrate material. For this reason, the aspheric surface defined by the ultra-high index refractive lens does not actually exist, although referred to as a diffractive surface. It is noted, however, that the surface Number ("NO.") referred to as the diffractive surface in the numerical data is denoted as a substrate surface in the sectional schematic corresponding to each example.

Some specific shapes of the diffractive surface, for instance, are shown in section in FIG. **30**. A diffractive surface depicted in FIG. **30**(*a*) comprises an alternation of transparent portions **21**, and opaque portions **22** whose thickness is substantially zero, and is called an amplitude modulation type. A diffractive surface depicted in FIG. **30**(*b*) comprises an alternation of portions having different indices of refraction, i.e., a high-refractive-index portions **23** and low-refractive-index portions **24**, and produces diffraction action through a phase difference due to a refractive index difference. A diffractive surface depicted in FIG. **30**(*c*) comprises an alternation of convex and concave portions, each in a rectangular form, and produces diffractive action through a phase difference due to a thickness difference. This may be called a two-level binary element. A diffractive surface depicted in FIG. **30**(*d*), called a kinoform, is in a saw-toothed form, and produces diffractive action through a phase difference due to a continuous thickness difference (see FIG. **2**). Diffractive surfaces depicted in FIG. **30**(*e*) and **30**(*f*) are binary elements with the kinoform approximated at four, and eight levels, respectively (see FIG. **3**). In the present invention, it is desired to use the kinoform of FIG. **30**(*d*), and the binary element of FIG. **30**(*e*) or **30**(*f*), with the kinoform approximated at four or more levels, because the quantity of light can effectively be used at an increased diffraction efficiency.

Sectional schematics of Examples 1 through 16 including their optical axes are shown in FIGS. **6** through **21**. Set out below are Examples 1 through 16.

EXAMPLES 1 TO 4

In Examples 1, 2, 3 and 4 an aperture stop is located between two positive lenses, as can be seen from FIGS. **6**, **7**, **8**, and **9**, respectively. In Example 1 a first positive lens in a meniscus form that is convex toward an object side of the system, an aperture stop, and a second positive lens in a double convex form are located in order from the object side, and a diffractive surface (DOE) is formed on the object side of the first lens. In Examples 2, 3, and 4, a first positive lens in a meniscus form that is convex toward an object side of the system, an aperture stop, and a second positive lens in a meniscus form that is convex toward an image side of the system, are located in order from the object side. A diffractive surface is formed on the image side of the first lens in Example 2, on the object side of the second lens in Example 3, and on the image side of the second lens in Example 4. In Examples 2, 3, and 4 the diffractive surface is formed on an acrylic resin substrate. Throughout Examples 1 to 4, all the diffractive surfaces are in an aspheric form.

EXAMPLES 5 & 6

In Examples 5, and 6 an aperture stop is located between an object side of the system and an arrangement consisting of two positive lenses, as can be seen from FIGS. **10**, and **11**,

respectively. More specifically, the aperture stop, a first positive lens in a meniscus form that is convex toward the object side, and a second positive lens in a meniscus form that is convex toward an image side of the system are located in order from the object side, and two aspheric surfaces are used, one on the object side of the first positive lens and another on the image side of the second positive lens. A diffractive surface is formed on the image side of the first positive lens in Example 5, and on the object side of the second positive lens in Example 6. In Example 6, both the positive lenses are formed of acrylic resin and a diffractive surface is formed on the substrate of the second positive lens. In Examples 5, and 6 the diffractive surface is in an aspheric form.

EXAMPLES 7 & 8

In Examples 7, and 8 an aperture stop is located between an image side of the system and an arrangement consisting of two positive lenses, as can be seen from FIGS. **12**, and **13**, respectively. More specifically, a first positive lens in a meniscus form that is convex toward an object side of the system, a second positive lens in a meniscus form that is convex toward the image side, and the aperture stop are located in order from the object side. In Example 7 aspheric surfaces are formed, one on the object side of the first positive lens and another on the image side of the second positive lens, and in Example 8 an aspheric surface is formed on the object side of the first positive lens. A diffractive surface is formed on the image side of the first positive lens in Example 7, and on the object side of the second positive lens in Example 8. In Example 7 both the positive lenses are formed of polyolefinic resin of low hygroscopicity and the diffractive surface is formed on a substrate of the first positive lens. In Example 8 the diffractive surface is formed on the surface of a thin resin layer on a glass substrate. In both Examples 7 and 8 the diffractive surfaces are in an aspheric form.

EXAMPLES 9 & 10

In Examples 9, and 10 an aperture stop is located between an object side of the system and an arrangement consisting of two lenses, positive and negative, as can be seen from FIGS. **14**, and **15**, respectively. More specifically, a first positive lens in a meniscus form toward the object side, a second negative lens in a meniscus form convex toward an image side of the system, and the aperture stop are located in order from the object side, and aspheric surfaces are formed, one on the object side of the first positive lens and another on the image side of the second negative lens. A diffractive surface is formed on the image side of the first positive lens in Example 9, and on the object side of the second negative lens in Example 10. In Example 9 both the lenses are formed of polyolefinic resin of low hygroscopicity and the diffractive surface is formed on a substrate of the first positive lens. In Example 10 the diffractive surface is formed on the surface of a thin resin layer on a glass substrate. In both Examples 9 and 10 the diffractive surfaces are in an aspheric form.

EXAMPLE 11

In Example 11 an aperture stop is located between two lenses, positive and negative, in order from an object side of the system, as can been from FIG. **16**. More specifically, a first positive lens in a meniscus form that is convex toward the object side, the aperture stop, and a second negative lens that is in a meniscus form that is convex toward an image side of the system are located in order from the object side. Aspheric surfaces are formed, one on the object side of the first positive lens and two on both sides of the second negative lens, and a diffractive surface is formed on the image side of the first positive lens. The first positive lens is formed of acrylic resin while the second negative lens is formed of polycarbonate resin, and the diffractive surface is formed on a substrate of the first positive lens. This diffractive surface is in an aspheric form.

EXAMPLES 12 & 13

In Examples 12, and 13 an aperture stop is located between an object side of the system and an arrangement consisting of two lenses, negative and positive, in order from the object side, as can be seen from FIGS. **17**, and **18**, respectively. More specifically, the aperture stop, a first negative lens in a meniscus form convex toward the object side, and a second positive lens in a meniscus form convex toward an image side of the system are located in order from the object side. Two aspheric surfaces are used in Example 12, one on the object side of the first negative lens and another on the image side of the second positive lens, and three aspheric surfaces are used in Example 13, two on both surfaces of the first negative lens and one on the image side of the second positive lens. A diffractive surface is formed on the image side of the first negative lens in Example 12, and on the object side of the second positive lens in Example 13. In Example 12 the diffractive surface is formed on a low-hygroscopicity polyolefinic resin substrate of the first negative lens. In Example 13 the diffractive surface is formed on the surface of a thin resin layer provided on a glass substrate. The diffractive surface is in an aspheric form in Example 12, and in a spherical form in Example 13.

EXAMPLE 14

In Example 14 an aperture stop is located between two lenses, negative and positive, in order from an object side of the system, as can be seen from FIG. **19**. More specifically, a first negative lens in a meniscus form that is convex toward the object side, the aperture stop, and a second positive lens in a double-convex form are located in order from the object side. Aspheric surfaces are formed, one on the object side of the first negative lens and another on the image side of the second positive lens, and a diffractive surface is formed on the object side of the second positive lens. The first negative lens is formed of polycarbonate resin, and the second positive lens is formed of polyolefinic resin having low hygroscopicity. The diffractive surface is formed on the substrate of the second positive lens. The diffractive surface is in a spherical form.

EXAMPLES 15 & 16

In Examples 15, and 16 an aperture stop is located between an image side of the system and an arrangement consisting of two lenses, negative and positive, in order from an object side of the system, as can be seen from FIGS. **20**, and **21**, respectively. More specifically, a first negative lens in a meniscus form that is convex toward the object side, a second positive lens that is in a meniscus lens convex toward the image side, and the aperture stop are located in order from the object side. Aspheric surfaces are formed in Example 15, one on the object side of the first negative lens and another on the image side of the second positive lens, and three aspheric surfaces are formed in Example 16, two on both surfaces of the first negative lens and on the image side of the second negative lens. A diffractive surface is

formed on the image side of the first negative lens in Example 15, and on the object side of the second positive lens in Example 16. In Example 15 the first negative lens is formed of polycarbonate resin on which the diffractive surface is provided. The diffractive surface is in an aspheric form in Example 15, and in a spherical form in Example 16.

Enumerated below are numerical data about Examples 1 to 16, wherein f=focal length, F_{NO}=F-number, F_B=back focus, ω=half field angle, r_1, r_2, etc.=radii of curvature of lens surfaces, d_1, d_2, etc.=spacing between lens surfaces, n_{d1}, n_{d2}, etc.=d-line refractive indices of lenses, and ν_{d1}, ν_{d2}, etc.=d-line Abbe number. The aspheric shape is represented by the aforesaid equation (e). Note that the abbreviation "DIFER. SF" indicates a diffractive surface.

EXAMPLE 1

f=48.58 mm, F_{NO}=8.0, f_B=39.04 mm, ω=23.91°

r_1 = 6.91373 (DIFFR. SF)	d_1 = 0	n_{d1} = 1001	ν_{d1} = −3.45
r_2 = 6.91384	d_2 = 2.29102	n_{d2} = 1.69680	ν_{d2} = 55.53
r_3 = 6.21043	d_3 = 1.57116		
r_4 = ∞ (Stop)	d_4 = 2.74000		
r_5 = 38.30240	d_5 = 2.50000	n_{d3} = 1.51633	ν_{d3} = 64.14
r_6 = −145.27686			

Aspherical Coefficients

1 st surface

K=−0.0175

A_4=6.5806×10^{-6}

A_6=1.3958×10^{-7}

A_8=1.9281×10^{-9}

A_{10}=1.0779×10^{-10}

EXAMPLE 2

f=36.06 mm, F_{NO}=8.0, f_B=29.48 mm, ω=30.43°

r_1 = 7.42410	d_1 = 3.09803	n_{d1} = 1.49241	ν_{d1} = 57.66
r_2 = 7.78222	d_2 = 0	n_{d2} = 1001	ν_{d2} = −3.45
r_3 = 7.78246 (DIFFR. SF)	d_3 = 1.83377		
r_4 = ∞ (Stop)	d_4 = 0.50406		
r_5 = −62.16903	d_5 = 3	n_{d3} = 1.74400	ν_{d3} = 44.78
r_6 = −27.10094			

Aspherical Coefficients

3 rd surface

K=−0.0917

A_4=2.4369×10^{-5}

A_6=4.0193×10^{-7}

A_8=3.2435×10^{-9}

A_{10}=2.2080×10^{-10}

EXAMPLE 3

f=35.94 mm, F_{NO}=8.0, f_B=35.73 mm, ω=31.22°

r_1 = 33.62695	d_1 = 2.00000	n_{d1} = 1.51633	ν_{d1} = 64.15
r_2 = 3203.77273	d_2 = 2.00000		
r_3 = ∞ (Stop)	d_3 = 2.35882		
r_4 = −7.63487 (DIFFR. SF)	d_4 = 0.00000	n_{d2} = 1001	ν_{d2} = −3.45
r_5 = −7.63464	d_5 = 3.00000	n_{d3} = 1.49241	ν_{d3} = 57.66
r_6 = −7.20525			

Aspherical Coefficients

4 th surface

K=−0.0002

A_4=−1.1363×10^{-7}

A_6=−3.4337×10^{-8}

A_8=4.3313×10−9

A_{10}=−2.0047×10^{-10}

EXAMPLE 4

f=36.02 mm, F_{NO}=8.0, f_B=31.87 mm, ω=30.93°

r_1 = 19.71078	d_1 = 3.00000	n_{d1} = 1.51633	ν_{d1} = 64.15
r_2 = 30.64933	d_2 = 3.00000		
r_3 = ∞ (Stop)	d_3 = 5.00000		
r_4 = −20.19943	d_4 = 2.50000	n_{d2} = 1.49241	ν_{d2} = 57.66
r_5 = −11.84776	d_5 = 0.00000	n_{d3} = 1001	ν_{d3} = −3.45
r_6 = −11.84746 (DIFFR. SF)			

Aspherical Coefficients

6 th surface

K=0.0000

A_4=7.0440×10^{-8}

A_6=−6.2362×10^{-9}

A_8=2.9135×10^{-10}

A_{10}=−4.7735×10^{-12}

EXAMPLE 5

f=36.23 mm, F_{NO}=8.0, f_B=33.79 mm, ω=30.66°

r_1 = ∞ (Stop)	d_1 = 3.40340		
r_2 = 6.58384 (Aspheric)	d_2 = 1.20000	n_{d1} = 1.57099	ν_{d1} = 50.80
r_3 = 6.87553	d_3 = 0.00000	n_{d2} = 1001	ν_{d2} = −3.45
r_4 = 6.87561 (DIFFR. SF)	d_4 = 2.30073		
r_5 = −13.48876	d_5 = 1.20000	n_{d3} = 1.63854	ν_{d3} = 55.38
r_6 = −9.94660 (Aspheric)			

Aspherical Coefficients

2 nd surface

K=−0.6318

A_4=−1.1042×10^{-4}

A_6=4.0200×10^{-5}

A_8=−2.8152×10^{-6}

A_{10}=1.2034×10^{-7}

4 th surface

K=−0.0765

A_4=2.9184×10^{-5}

A_6=6.4199×10^{-7}

A_8=6.4026×10^{-9}

A_{10}=5.2385×10^{-10}

6 th surface

K=−0.2013

A_4=5.1608×10^{-5}

A_6=−1.1148×10^{-6}

A_8=6.8045×10^{-8}

A_{10}=−8.1066×10^{-10}

EXAMPLE 6

f=36.07 mm, F_{NO}=8.0, f_B=33.72 mm, ω=30.77°

r_1 = ∞ (Stop)	d_1 = 3.05845			
r_2 = 9.97541 (Aspheric)	d_2 = 2.47667	n_{d1} = 1.49241	ν_{d1} = 57.66	
r_3 = 12.19426	d_3 = 1.45021			
r_4 = −11.88229 (DIFFR. SF)	d_4 = 0.00000	n_{d2} = 1001	ν_{d2} = −3.45	
r_5 = −11.88196	d_5 = 2.24201	n_{d3} = 1.49241	ν_{d3} = 57.66	
r_6 = −9.08945 (Aspheric)				

Aspherical Coefficients

2 nd surface

K=0

A_4=−1.3961×10^{-4}

A_6=4.0138×10^{-6}

A_8=0

A_{10}=0

4 th surface

K=−0.0186

A_4=−1.3469×10^{-6}

A_6=−1.6823×10^{-8}

A_8=4.8156×10^{-10}

A_{10}=−1.3513×10^{-11}

6 th surface

K=−0.1908

A_4=7.7812×10^{-5}

A_6=−3.3883×10^{-6}

A_8=2.0185×10^{-7}

A_{10}=2.3491×10^{-10}

EXAMPLE 7

f=36.10 mm, F_{NO}=8.0, f_B=31.44 mm, ω=30.30°

r_1 = 11.59844 (Aspheric)	d_1 = 2.50000	n_{d1} = 1.52542	ν_{d1} = 55.78	
r_2 = 25.87488	d_2 = 0.00000	n_{d2} = 1001	ν_{d2} = −3.45	
r_3 = 25.87622 (DIFFR. SF)	d_3 = 2.70248			
r_4 = −8.32192	d_4 = 3.00000	n_{d3} = 1.52542	ν_{d3} = 55.78	
r_5 = −8.91705 (Aspheric)	d_5 = 1.00000			
r_6 = ∞ (Stop)				

Aspherical Coefficients

1 st surface

K=1.4496

A_4=−8.6872×10^{-5}

A_6=1.0217×10^{-6}

A_8=8.2837×10^{-8}

A_{10}=−1.0350×10^{-9}

3 rd surface

K=−0.0204

A_4=7.7872×10^{-8}

A_6=5.9898×10^{-9}

A_8=−1.0838×10^{-10}

A_{10}=−1.5893×10^{-12}

5 th surface

K=0.2234

A_4=3.2547×10^{-4}

A_6=−3.3400×10^{-5}

A_8=4.6694×10^{-6}

A_{10}=−2.3879×10^{-7}

EXAMPLE 8

f=36.09 mm, F_{NO}=8.0, f_B=32.06 mm, ω=30.97°

r_1 = 9.51696 (Aspheric)	d_1 = 2.50000	n_{d1} = 1.74400	ν_{d1} = 44.78	
r_2 = 10.52707	d_2 = 1.04033			
r_3 = −15.46041 (DIFFR. SF)	d_3 = 0.00000	n_{d2} = 1001	ν_{d2} = −3.45	
r_4 = −15.45937	d_4 = 0.10000	n_{d3} = 1.52288	ν_{d3} = 52.50	
r_5 = −15.45937	d_5 = 3.00000	n_{d4} = 1.80440	ν_{d4} = 39.59	
r_6 = −13.67783	d_6 = 1.00000			
r_7 = ∞ (Stop)				

Aspherical Coefficients

1 st surface

K=0.1880

A_4=−7.5555×10^{-5}

A_6=4.2084×10^{-6}

A_8=−2.6452×10^{-7}

A_{10}=4.4126×10^{-9}

3 rd surface

K=0.4814

A_4=1.6249×10^{-5}

A_6=7.4952×10^{-8}

A_8=1.4691×10^{-9}

A_{10}=−3.6227×10^{-11}

EXAMPLE 9

f=36.06 mm, F_{NO}=8.0, f_B=32.81 mm, ω=29.83°

r_1 = ∞ (Stop)	d_1 = 0.50000			
r_2 = 7.57760 (Aspheric)	d_2 = 2.46929	n_{d1} = 1.52542	ν_{d1} = 55.78	
r_3 = 15.05913	d_3 = 0.00000	n_{d2} = 1001	ν_{d2} = −3.45	
r_4 = 15.06001 (DIFFR. SF)	d_4 = 1.35207			
r_5 = −4.28197	d_5 = 1.99511	n_{d3} = 1.52542	ν_{d3} = 55.78	
r_6 = −5.43794 (Aspheric)				

Aspherical Coefficients

2 nd surface

K=0

A_4=6.2449×10^{-4}

A_6=2.7831×10^{-5}

A_8=−2.3513×10^{-7}

A_{10}=3.0083×10^{-7}

4 th surface

K=0

A_4=1.3125×10^{-7}

A_6=−8.8085×10^{-9}

A_8=−1.3059×10^{-9}

A_{10}=1.5398×10^{-10}

6 th surface

K=0

A_4=4.0201×10^{-4}

A_6=4.0097×10^{-5}

A_8=−9.8937×10^{-7}

A_{10}=1.7083×10^{-7}

EXAMPLE 10

f=36.14 mm, F_{NO}=8.0, f_B=33.18 mm, ω=29.98°

r_1 = ∞ (Stop)	d_1 = 0.50000		
r_2 = 7.87896 (Aspheric)	d_2 = 2.38715	n_{d1} = 1.63854	ν_{d1} = 55.38
r_3 = 20.16269	d_3 = 0.93137		
r_4 = −5.56618 (DIFFR. SF)	d_4 = 0.00000	n_{d2} = 1001	ν_{d2} = −3.45
r_5 = −5.56608	d_5 = 0.10000	n_{d3} = 1.52288	ν_{d3} = 52.50
r_6 = −5.56608	d_6 = 2.60967	n_{d4} = 1.74950	ν_{d4} = 35.27
r_7 = −8.18851 (Aspheric)			

Aspherical Coefficients

2 nd surface

K=0

A_4=5.8651×10^{-4}

A_6=2.3985×10^{-5}

A_8=2.0588×10^{-6}

A_{10}=6.2312×10^{-10}

4 th surface

K=0

A_4=−7.5180×10^{-8}

A_6=6.3634×10^{-10}

A_8=6.5392×10^{-10}

A_{10}=−2.2491×10^{-10}

7 th surface

K=0

A_4=3.4101×10^{-4}

A_6=2.2906×10^{-5}

A_8=−2.7705×10^{-7}

A_{10}=3.6877×10^{-8}

EXAMPLE 11

f=35.91 mm, F_{NO}=8.0, f_B=21.52 mm, ω=30.30°

r_1 = 7.05746 (Aspheric)	d_1 = 2.30000	n_{d1} = 1.49241	ν_{d1} = 57.66
r_2 = 14.08423	d_2 = 0.00000	n_{d2} = 1001	ν_{d2} = −3.45
r_3 = 14.08473 (DIFFR. SF)	d_3 = 2.29582		
r_4 = ∞ (Stop)	d_4 = 4.48559		
r_5 = −10.25229 (Aspheric)	d_5 = 4.50403	n_{d3} = 1.58423	ν_{d3} = 30.49
r_6 = −15.83454 (Aspheric)			

Aspherical Coefficients

1 st surface

K=0

A_4=−2.3262×10^{-5}

A_6=8.1332×10^{-7}

A_8=−6.2628×10^{-8}

A_{10}=1.5511×10^{-9}

5 th surface

K=0.2201

A_4=−5.2563×10^{-4}

A_6=−7.8289×10^{-5}

A_8=5.5639×10^{-6}

A_{10}=−2.4568×10^{-7}

6 th surface

K=0

A_4=−1.3974×10^{-4}

A_6=−8.0349×10^{-6}

A_8=1.9598×10^{-7}

A_{10}=−2.8489×10^{-9}

EXAMPLE 12

f=36.06 mm, F_{NO}=8.0, f_B=34.03 mm, ω=31.96°

r_1 = ∞ (Stop)	d_1 = 1.00000		
r_2 = 10.03481 (Aspheric)	d_2 = 3.20127	n_{d1} = 1.58423	ν_{d1} = 30.49
r_3 = 7.76426	d_3 = 0.00000	n_{d2} = 1001	ν_{d2} = −3.45
r_4 = 7.76443 (DIFFR. SF)	d_4 = 1.47535		
r_5 = −33.63417	d_5 = 3.65580	n_{d3} = 1.72916	ν_{d3} = 54.68
r_6 = −13.04871 (Aspheric)			

Aspherical Coefficients

2 nd surface

K=0

A_4=−1.4407×10^{-4}

A_6=4.1761×10^{-6}

A_8=1.7471×10^{-7}

A_{10}=−9.7508×10^{-8}

4 th surface

K=0

A_4=−3.4278×10^{-8}

A_6=2.0277×10^{-8}

A_8=−1.9875×10^{-9}

A_{10}=5.6037×10^{-11}

6 th surface

K=0

A_4=−9.9931×10^{-5}

A_6=−4.8519×10^{-6}

A_8=1.0625×10^{-7}

A_{10}=−6.0450×10^{-9}

EXAMPLE 13

f=36.10 mm, F_{NO}=8.0, f_B=35.68 mm, ω=32.33°

r_1 = ∞ (Stop)	d_1 = 1.00000		
r_2 = 6.35269 (Aspheric)	d_2 = 1.39370	n_{d1} = 1.67270	ν_{d1} = 32.10
r_3 = 4.91600 (Aspheric)	d_3 = 1.80000		
r_4 = −30.98742 (DIFFR. SF)	d_4 = 0.00000	n_{d2} = 1001	ν_{d2} = −3.45
r_5 = −30.98563	d_5 = 0.10000	n_{d3} = 1.52288	ν_{d3} = 52.50
r_6 = −30.98563	d_6 = 1.83346	n_{d4} = 1.60311	ν_{d4} = 60.64
r_7 = −9.42965 (Aspheric)			

Aspherical Coefficients

2 nd surface

K=0

A_4=−8.9798×10^{-4}

A_6=−4.1523×10^{-5}

A_8=4.5065×10^{-6}

A_{10}=−5.8311×10^{-7}

3 rd surface

K=0

A_4=−1.1345×10^{-3}

A_6=−8.8333×10^{-6}

A_8=−4.1509×10^{-6}

A_{10}=−8.4669×10^{-8}

7 th surface

K=0

A_4=−2.8189×10^{-4}
A_6=−2.7086×10^{-5}
A_8=1.4981×10^{-6}
A_{10}=−9.5050×10^{-8}

EXAMPLE 14

f=28.40 mm, F_{NO}=8.0, f_B=27.99 mm, ω=39.53°

r_1 = 10.25543 (Aspheric)	d_1 = 7.83781	n_{d1} = 1.58423	ν_{d1} = 30.49
r_2 = 5.62830	d_2 = 8.99453		
r_3 = ∞ (Stop)	d_3 = 0.74914		
r_4 = 94.91775 (DIFFR. SF)	d_4 = 0.00000	n_{d2} = 1001	ν_{d2} = −3.45
r_5 = 94.95548	d_5 = 16.43054	n_{d3} = 1.52542	ν_{d3} = 55.78
r_6 = −11.73144 (Aspheric)			

Aspherical Coefficients

1 st surface

K=0

A_4 1.3631×10^{-5}
A_6 1.4664×10^{-8}
A_8=−1.5347×10^{-9}
A_{10}=1.3247×10^{-11}

6 th surface

K=0

A_4=9.1625×10^{-5}
A_6=−1.5954×10^{-7}
A_8=5.2916×10^{-9}
A_{10}=4.1098×10^{-12}

EXAMPLE 15

f=28.49 mm, F_{NO}=8.0, f_B=24.33 mm, ω=38.84°

r_1 = 7.63416 (Aspheric)	d_1 = 3.33983	n_{d1} = 1.58423	ν_{d1} = 30.49
r_2 = 5.17443	d_2 = 0.00000	n_{d2} = 1001	ν_{d2} = −3.45
r_3 = 5.17454 (DIFFR. SF)	d_3 = 1.13367		
r_4 = −52.74007	d_4 = 2.20000	n_{d3} = 1.67790	ν_{d3} = 55.34
r_5 = −9.91155 (Aspheric)	d_5 = 1.00000		
r_6 = ∞ (Stop)			

Aspherical Coefficients

1 st surface

K=0

A_4=−3.2760×10^{-4}
A_6=−4.8325×10^{-6}
A_8=−5.6482×10^{-7}
A_{10}=−3.3557×10^{-9}

3 rd surface

K=0

A_4=−1.3215×10^{-7}
A_6=7.6302×10^{-8}
A_8=−1.1646×10^{-8}
A_{10}=6.3223×10^{-10}

5 th surface

K=0

A_4=−5.1452×10^{-4}
A_6=−1.0559×10^{-5}
A_8=−1.5190×10^{-6}
A_{10}=−6.5933×10^{-10}

EXAMPLE 16

f=36.10 mm, F_{NO}=8.0, f_B=32.90 mm, ω=32.38°

r_1 = 10.03645 (Aspheric)	d_1 = 3.91802	n_{d1} = 1.60342	ν_{d1} = 38.01
r_2 = 6.33133 (Aspheric)	d_2 = 1.60282		
r_3 = −53.44303 (DIFFR. SF)	d_3 = 0.00000	n_{d2} = 1001	ν_{d2} = −3.45
r_4 = −53.43722	d_4 = 2.84551	n_{d3} = 1.63854	ν_{d3} = 55.38
r_5 = −10.39640 (Aspheric)	d_5 = 1.00000		
r_6 = ∞ (Stop)			

Aspherical Coefficients

1 st surface

K=0

A_4=−1.6933×10^{-4}
A_6=−5.5657×10^{-6}
A_8=−3.6642×10^{-9}
A_{10}=−1.8218×10^{-9}

2 nd surface

K=0

$A_4$6.5371×10^{-5}
A_6=3.4012×10^{-6}
A_8=−4.5904×10^{-7}
A_{10}=6.2789×10^{-8}

5 th surface

K=0

A_4=−2.8991×10^{-4}
A_6=−1.6823×10^{-5}
A_8=9.4645×10^{-7}
A_{10}=−6.2250×10^{-8}

FIGS. **22** to **29** are aberration diagrams showing (a) spherical aberration, (b) astigmatism, (c) distortion, and (d) chromatic aberration of magnification for Examples 1, 5, 7, 9, 11, 12, 14, and 15 with respect to an object point at infinity.

Tabulated below are values of conditions (1) to (8) in the aforesaid examples.

	(1), (2)	(3), (4)	(5), (6)	(7), (8)
Example 1	0.080	0.054	—	0.112
2	0.051	−0.024	—	0.143
3	0.066	−0.979	—	0.142
4	0.208	−0.217	—	0.077
5	0.127	−0.022	—	0.061
6	0.194	−0.100	—	0.084
7	0.186	−0.381	—	0.072
8	0.144	−0.050	—	0.157
9	0.082	—	−0.381	0.140
10	0.106	—	−0.781	0.117
11	0.064	—	−0.507	0.091
12	0.117	—	−0.205	0.102
13	0.116	—	−0.681	0.067
14	0.026	—	−0.499	0.086
15	0.152	—	−0.419	0.117
16	0.107	—	−0.765	0.073

As can be seen from the foregoing explanation, a high-performance optical system which, albeit being composed of a reduced number of lenses, is well corrected for chromatic aberrations can be achieved by proper use of diffractive surfaces, whereby a high-performance phototaking optical system used on cameras, etc. can be provided at low cost.

What we claim is:

1. A phototaking optical system making use of a diffractive optical element, which comprises an aperture stop, at

least two lenses having at least one diffractive surface, and satisfies the following condition (1):

$$0<d_{DOE}/f<0.24 \quad (1)$$

where f is a focal length of the overall phototaking optical system, and d_{DOE} is a distance on an optical axis of the phototaking optical system from the aperture stop to the diffractive surface.

2. A phototaking optical system according to claim **1**, wherein said at least two lenses are the only lenses in said phototaking optical system.

3. A phototaking optical system making use of a diffractive optical element, which comprises an aperture stop, one positive lens and another positive lens in order from an object side of the phototaking optical system, at least one of said lenses having at least one diffractive surface, and both said lenses being formed of a homogeneous medium.

4. A phototaking optical system making use of a diffractive optical element, which comprises an aperture stop, one positive lens and another positive lens in order from an object side of the phototaking optical system and at least one diffractive surface, and satisfies the following condition (3):

$$-1<SF_1<0.15 \quad (3)$$

where $SF_1=(r_A-r_B)/(r_A+r_B)$ wherein r_A is a radius of curvature of a surface of the first lens that faces the object side, and r_B is a radius of curvature of a surface of the first lens that faces an image side of the phototaking optical system.

5. A phototaking optical system making use of a diffractive optical element, which comprises an aperture stop, one negative lens and one positive lens in order from an object side of the phototaking optical system, at least one of said lenses having at least one diffractive surface.

6. A phototaking optical system according to claim **5**, which satisfies the following condition (5):

$$-1.2<f/f_{NEG}<-0.05 \quad (5)$$

where f is a focal length of the overall phototaking optical system and f_{NEG} is a focal length of the negative lens.

7. A phototaking optical system according to claim **5**, wherein at least one of said lenses has an aspheric surface in addition to the at least one diffractive surface.

8. A phototaking optical system according to claim **2** or **3**, wherein the aperture stop is located on a side of an arrangement consisting of the two lenses that faces the object side of the phototaking optical system.

9. A phototaking optical system according to claim **2** or **3**, wherein the aperture stop is located between the two lenses.

10. A phototaking optical system according to claim **2** or **3**, wherein the aperture stop is located on a side of an arrangement consisting of the two lenses that faces the image side of the phototaking optical system.

11. A phototaking optical system according to claim **1** or **4**, which includes only one diffractive surface.

12. A phototaking optical system according to claim **1** or **3**, wherein the diffractive surface is formed on a curved lens surface.

13. A phototaking optical system according to claim **1** or **3**, wherein both the lenses are formed of a homogeneous medium.

14. A phototaking optical system according to claim **1** or **3**, wherein the diffractive surface has a positive power.

15. A phototaking optical system according to claim **14**, wherein the diffractive surface satisfies the following condition (7):

$$0.02<f/f_{DOE}<0.5 \quad (7)$$

where f is a focal length of the overall phototaking optical system and f_{DOE} is a power of the diffractive surface.

16. A phototaking optical system according to claim **1** or **3**, which satisfies the following condition (9):

$$470 \text{ nm}<\lambda_{DOE}<550 \text{ nm} \quad (9)$$

where λ_{DOE} is a design wavelength at which a maximum diffraction efficiency is obtained.

17. A phototaking optical system making use of a diffractive optical element, which comprises an aperture stop, one positive lens and one negative lens in order from an object side of the phototaking optical system, at least one of said lenses having at least one diffractive surface, wherein said phototaking optical system satisfies the following condition (5):

$$-1.2<f/f_{NEG}<-0.05 \quad (5)$$

where f is a focal length of the overall phototaking optical system and f_{NEG} is a focal length of the negative lens.

18. A phototaking optical system making use of a diffractive optical element, which comprises an aperture stop, one positive lens and one negative lens in order from an object side of the phototaking optical system, at least one of said lenses having a diffractive surface, and at least one of said lenses having an aspheric surface.

19. A phototaking optical system making use of a diffractive optical element, which comprises an aperture stop and two lenses, at least one of said lenses having a diffractive surface, wherein the aperture stop is located between the two lenses.

20. A phototaking optical system making use of a diffractive optical element, which comprises an aperture stop and two lenses, at least one of said lenses having a diffractive surface, wherein the aperture stop is located on a side of an arrangement consisting of the two lenses that faces the image side of the phototaking optical system.

21. A phototaking optical system making use of a diffractive optical element, which comprises an aperture stop and two lenses, at least one of said lenses having a diffractive surface, wherein the diffractive surface is formed on a curved lens surface.

22. A phototaking optical system making use of a diffractive optical element, which comprises an aperture stop and two lenses, at least one of said lenses having a diffractive surface, wherein the diffractive surface has positive power.

23. A phototaking optical system making use of a diffractive optical element, which comprises an aperture stop and two lenses, at least one of said lenses having a diffractive surface, which satisfies the following condition (9):

$$470 \text{ nm}<\lambda_{DOE}<550 \text{ nm} \quad (9)$$

where λ_{DOE} is a design wavelength at which a maximum diffraction efficiency is obtained.

24. A phototaking optical system making use of a diffractive optical element according to claim **19** or **20**, wherein said two lenses are the only lenses in said phototaking optical system.

25. A phototaking optical system according to claim **22**, wherin the diffractive surface satisfies the following condition (7):

$$0.02<f/f_{DOE}<0.5 \quad (7)$$

where f is a focal length of the overall phototaking optical system and f_{DOE} is a power of the diffractive surface.

* * * * *

US005978155A

United States Patent [19]

Suenaga

[11] Patent Number: 5,978,155

[45] Date of Patent: Nov. 2, 1999

[54] **ADAPTERS FOR CORRECTING SPHERICAL ABERRATIONS OF OBJECTIVE LENS**

[75] Inventor: **Yutaka Suenaga**, Yokohama, Japan

[73] Assignee: **Nikon Corporation**, Tokyo, Japan

[21] Appl. No.: **09/023,397**

[22] Filed: **Feb. 13, 1998**

[30] **Foreign Application Priority Data**

Feb. 14, 1997 [JP] Japan 9-044878

[51] **Int. Cl.**[6] **G02B 15/14**

[52] **U.S. Cl.** **359/691**; 359/676

[58] **Field of Search** 359/676, 691, 359/684, 692, 754, 771, 781, 782, 783, 793

[56] **References Cited**

U.S. PATENT DOCUMENTS

5,796,530 8/1998 Oshita 359/692

Primary Examiner—Hung Xuan Dang

Attorney, Agent, or Firm—Klarquist Sparkman Campbell Leigh & Whinston, LLP

[57] **ABSTRACT**

Objective lenses (e.g., for microscopy), and adapters for such lenses, are disclosed providing adjustability of the amount of spherical aberration imparted to an image by an objective lens due to variations in cover glass thickness. The adapter can be axially inserted imagewise of the objective lens, or between a first objective lens and a second objective lens of an objective lens system. The adapter comprises an axially movable lens group comprising a cemented lens including a negative lens and a positive lens and a cemented surface having negative refractive power. Spherical aberration of the objective lens is adjusted by axially moving the movable lens group. Where r_1 is the curvature radius of the cemented surface, n_P is the refractive index of the positive lens, n_N is the refractive index of the negative lens, the lens satisfies the condition $|(n_N-n_P)/r_1|<0.3$.

14 Claims, 8 Drawing Sheets

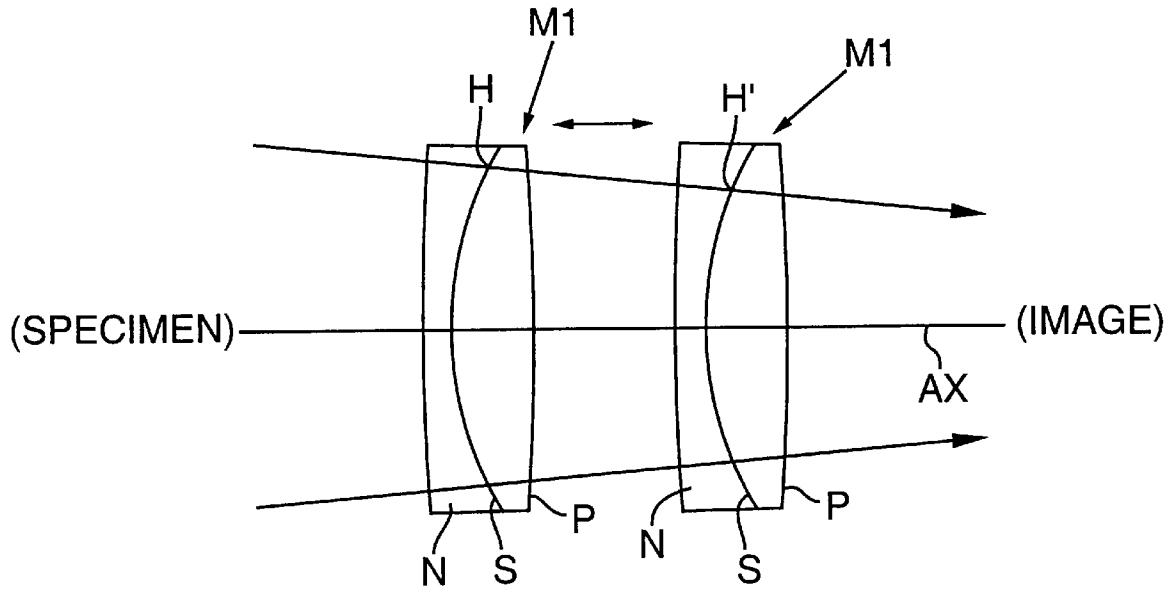


FIG. 1

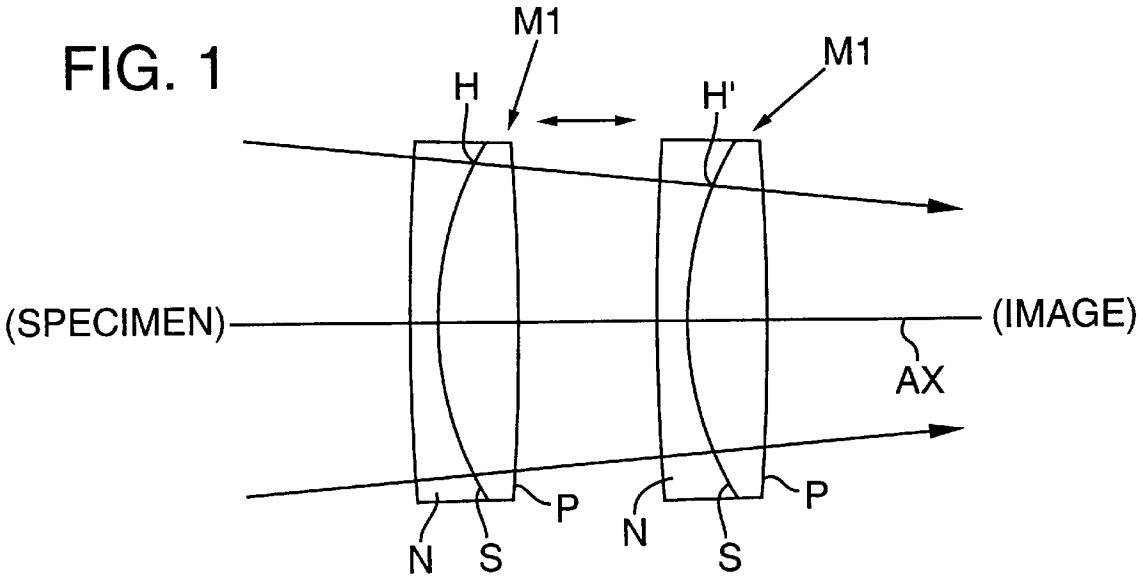

M1
M1
H
H'
(SPECIMEN)
(IMAGE)
AX
P
P
N
S
N
S

FIG. 2

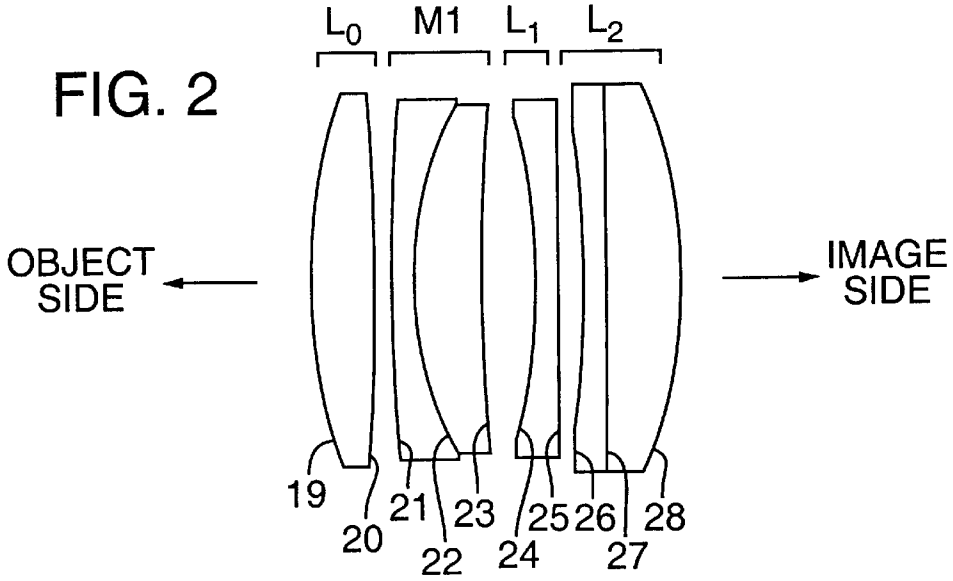

L_0
M1
L_1
L_2
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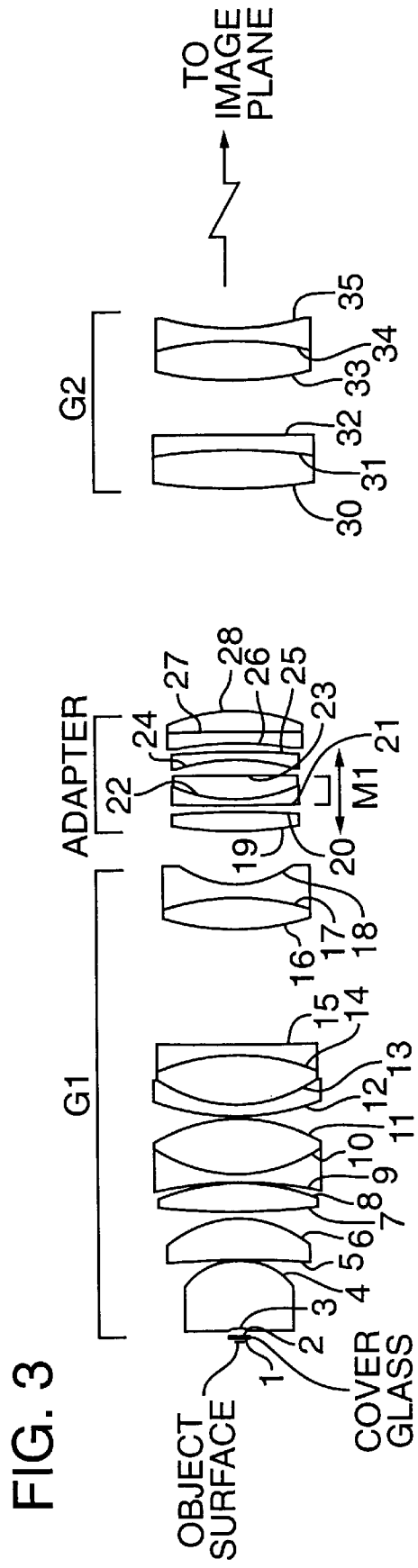
IMAGE SIDE
19
20
21
22
23
24
25
26
27
28


TO IMAGE PLANE
G2
35
34
33
32
31
30
ADAPTER
27
28
26
25
24
23
22
21
M1
19
20
G1
16
17
18
15
14
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10
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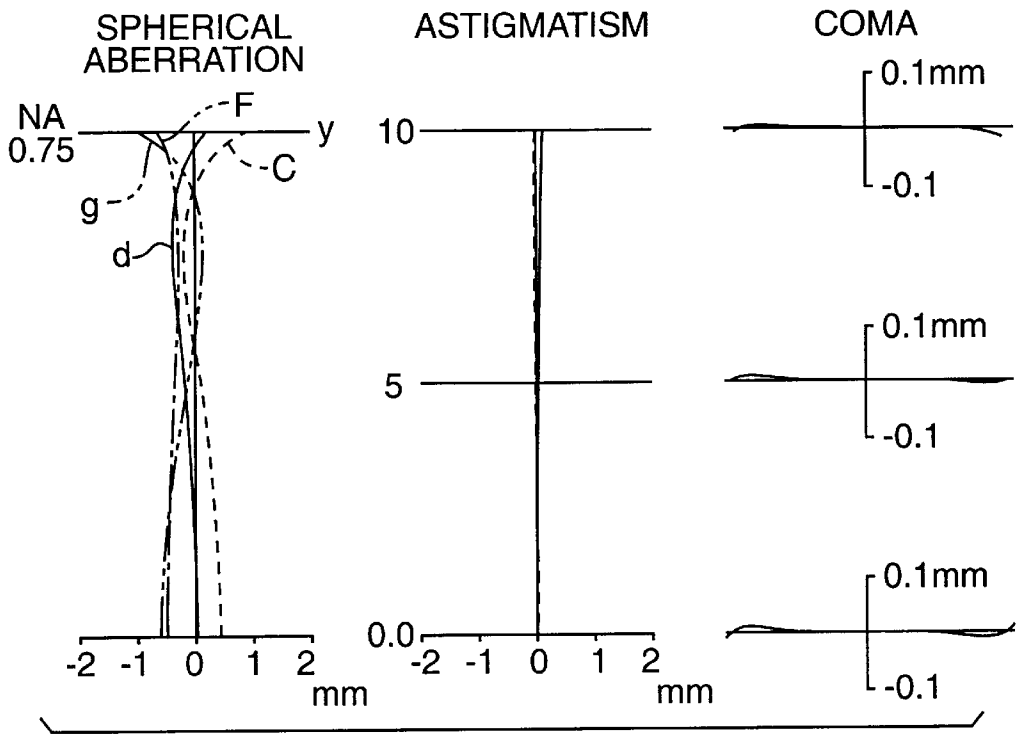
8
7
6
5
4
3
2
1
OBJECT SURFACE
COVER GLASS

FIG. 3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ASTIGMATISM
COMA
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F
y
C
g
d
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mm
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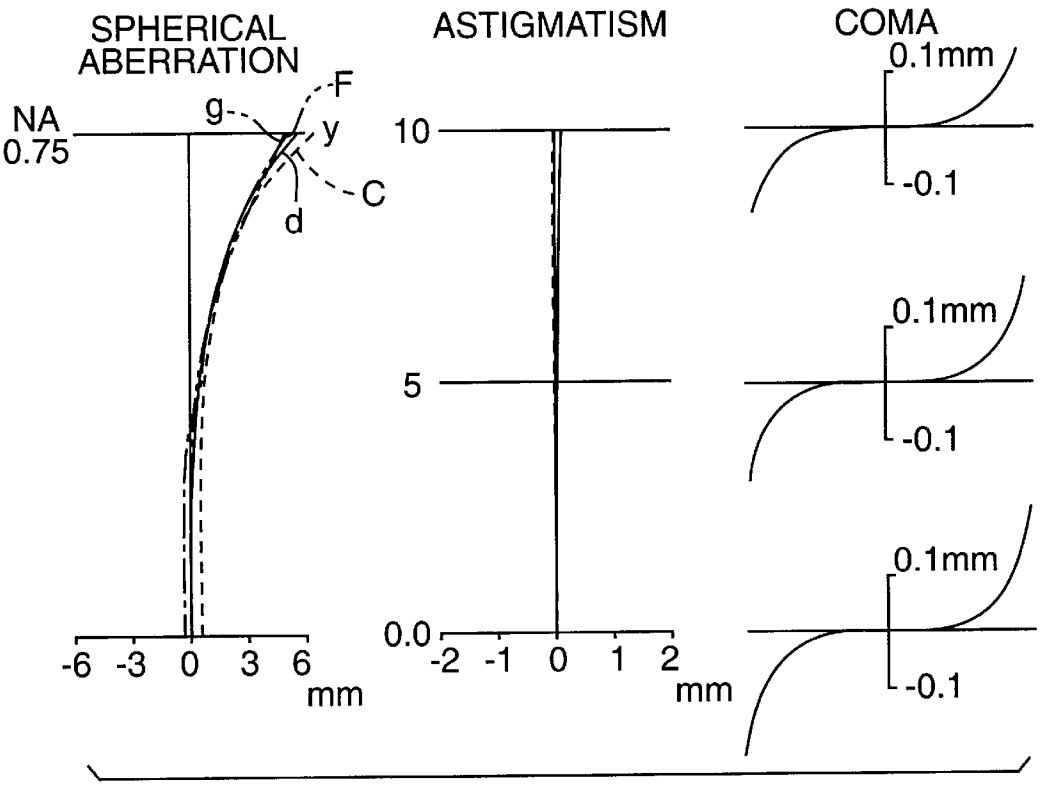
-0.1

FIG. 4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ASTIGMATISM
COMA
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FIG. 5

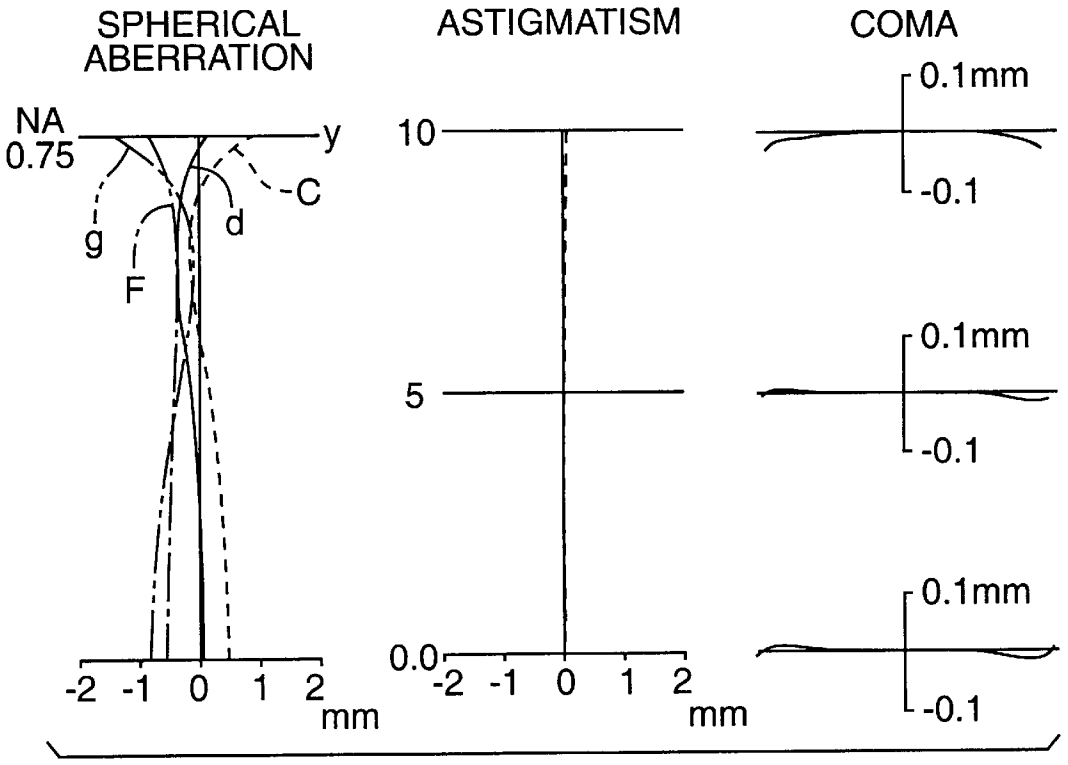
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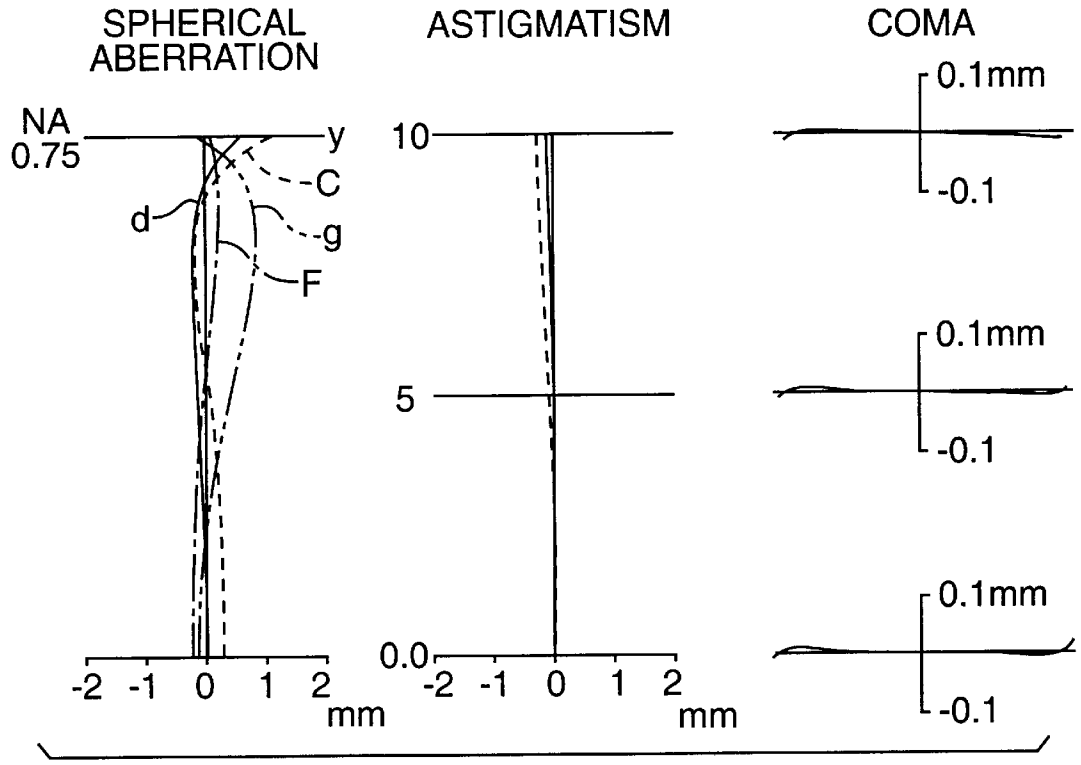
FIG. 6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COMA
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-2 -1 0 1 2
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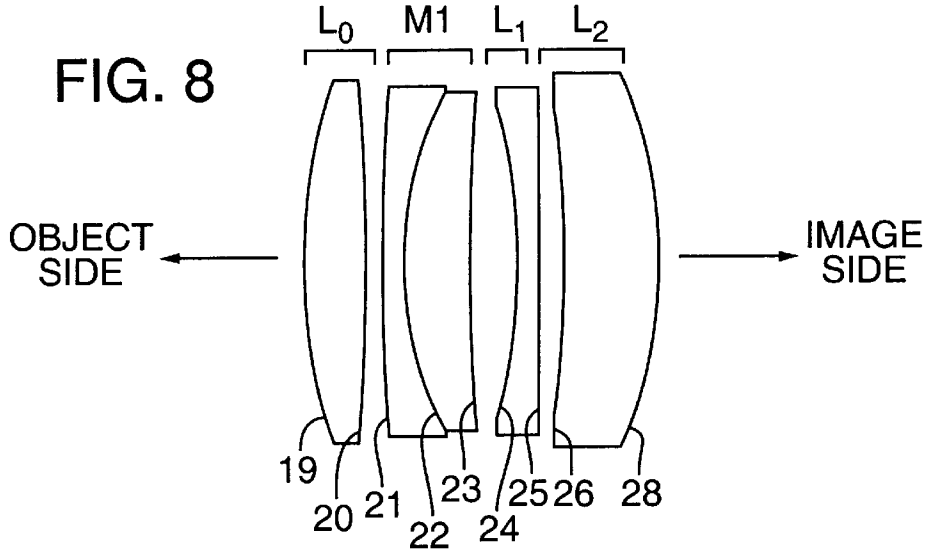
0.1mm
-0.1

FIG. 7

FIG. 8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L_1
L_2
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IMAGE SIDE
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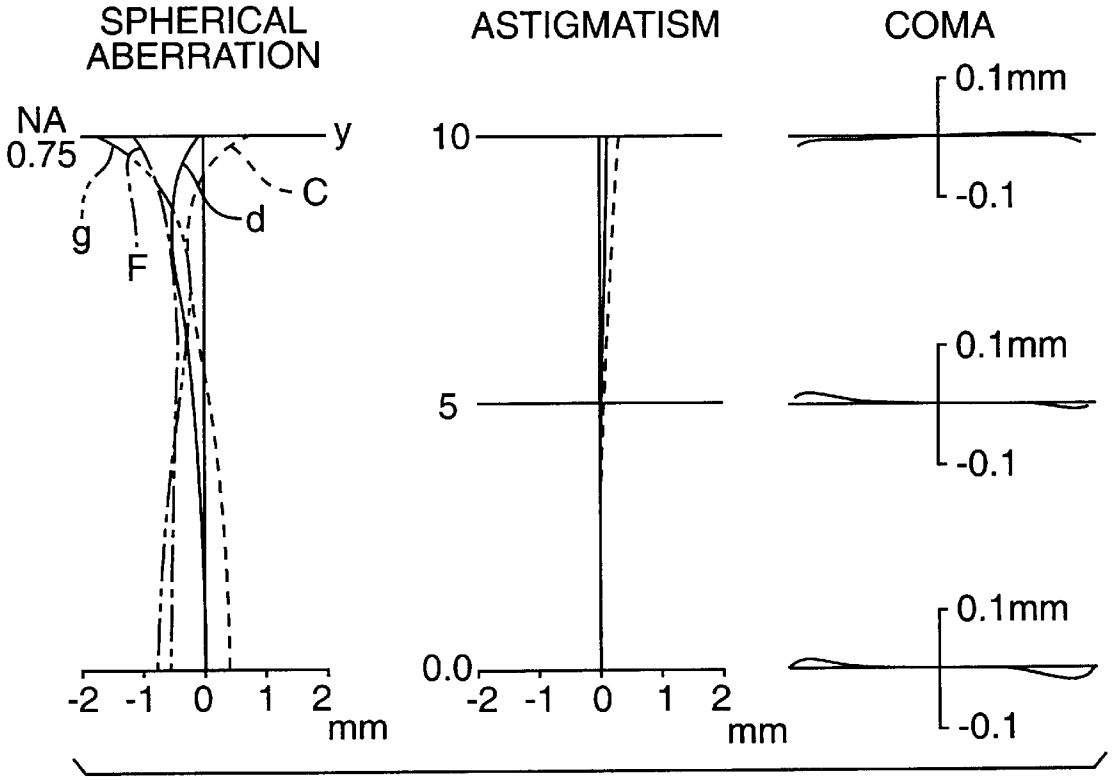
SPHERICAL ABERRATION
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FIG. 9

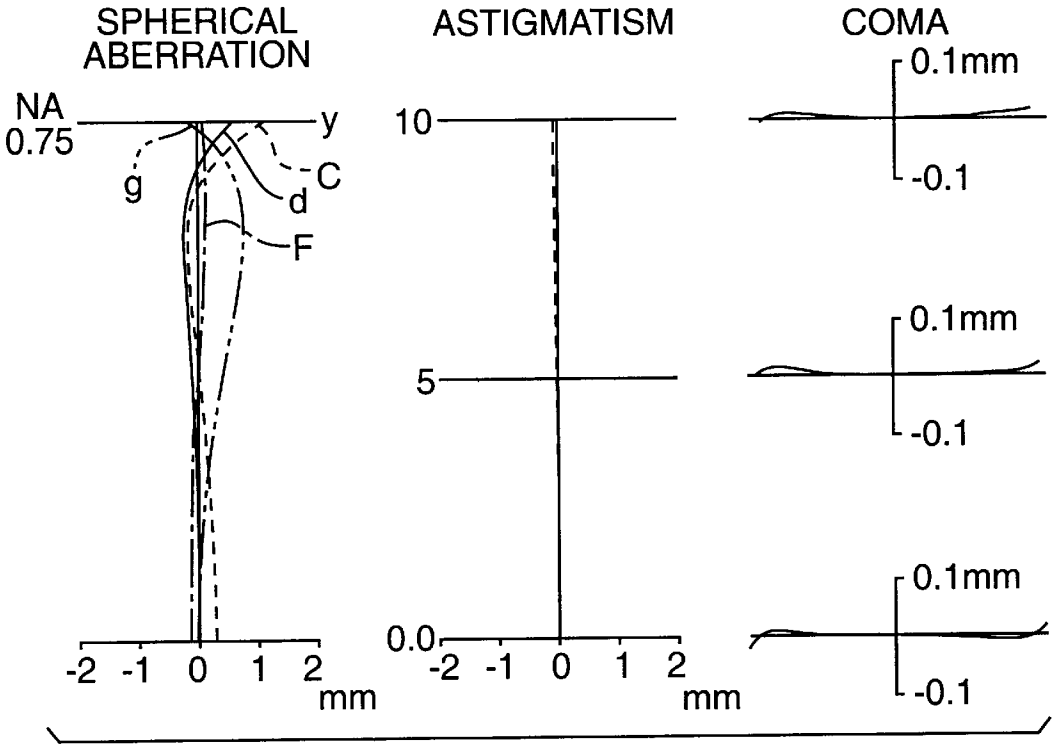


FIG. 10

FIG. 11(a)

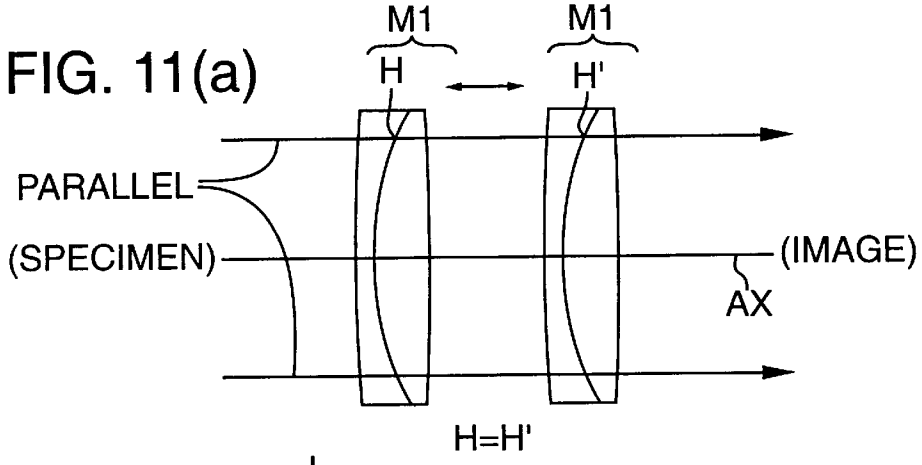


FIG. 11(b)

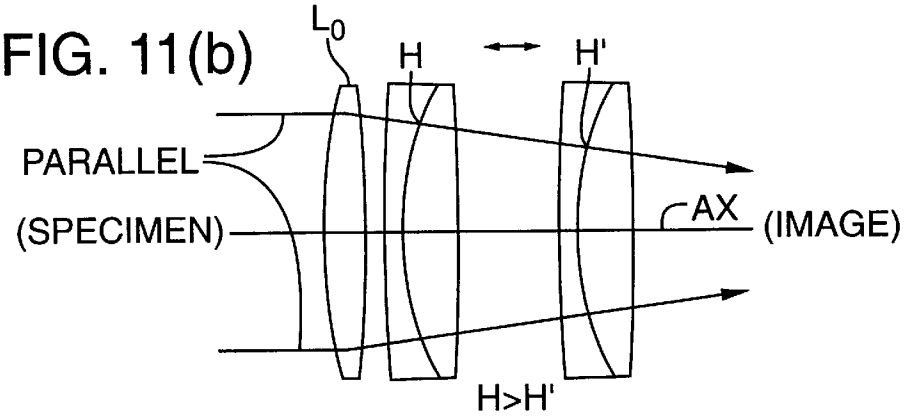


FIG. 12(a)

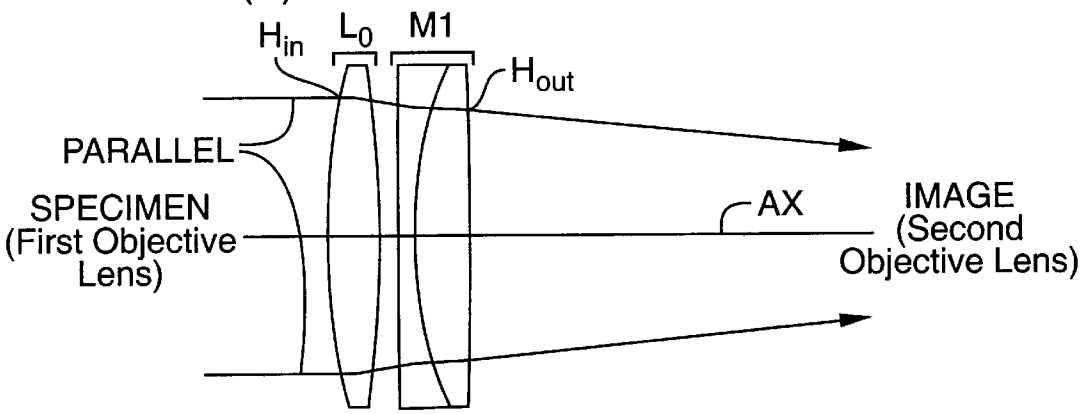
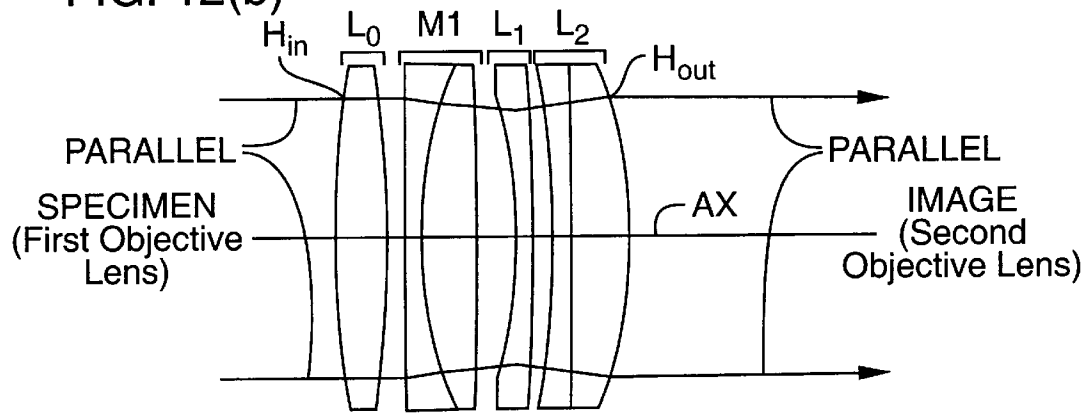


FIG. 12(b)



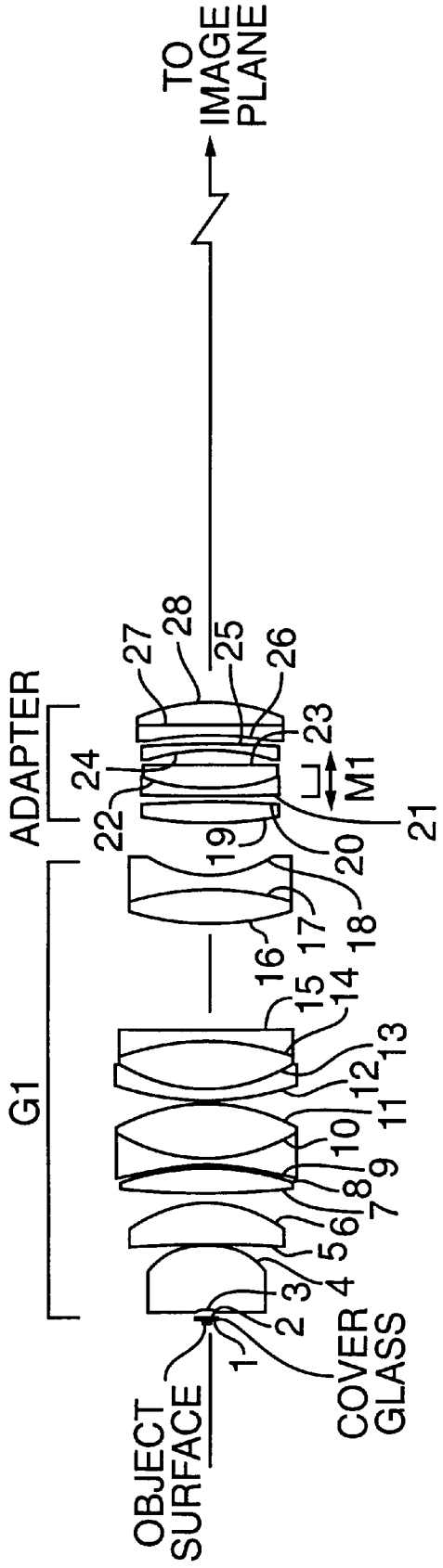

TO IMAGE PLANE
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FIG. 13

ADAPTERS FOR CORRECTING SPHERICAL ABERRATIONS OF OBJECTIVE LENS

FIELD OF THE INVENTION

This invention pertains to light microscopy. More specifically, the invention pertains to adapter lenses that are used in connection with a microscope objective lens system (or other objective lens system) to correct spherical aberrations arising from variations in the refractive index and thickness of a refractive body (e.g., cover glass, laboratory dish, parallel plate) located between a specimen and the objective lens system.

BACKGROUND OF THE INVENTION

In light microscopy, cover glasses or laboratory dishes and the like are frequently used to cover, enclose, or protect the specimen. Microscope objective lenses intended to be used with cover glasses and the like normally specify a specific refractive index and thickness of the cover glass. Consequently, whenever the thickness or refractive index of the cover glass or laboratory dish is not as specified for the objective lens, spherical aberrations can arise that degrade imaging performance of the objective lens and reduce contrast of the image.

Metallurgical microscopes and the like used to observe metal and semiconductor surfaces typically utilize objective lenses that are not designed to be used with a cover glass or other refractive body between the specimen and the objective lens. Thus, such objective lenses are designed without consideration of the thickness of a refractive body through which the lens would otherwise view the object. In actual practice, however, there are times when a glass plate or the like must be used to protect the surface of a semiconductor wafer or integrated circuit during microscopic examination. In such instances, the generation of spherical aberrations by the plate can make high-quality observations of the specimen impossible.

Immersion objective lenses adapted to be used with an immersion fluid such as water or oil are also adapted to be used with such fluids having a particular refractive index. If the refractive index of the immersion fluid changes, then unwanted spherical aberrations can arise that make high-quality observations impossible.

In certain conventional objective lenses intended for use with a refractive body situated between the objective lens and the specimen (e.g., cover glass or wall of a laboratory dish), an adjustable correcting lens (adjusted by turning a so-called "correcting ring") is conventionally employed to vary the internal spacing between lenses or lens groups within the objective lens. The amount by which the lens spacing is adjusted is a function of the amount of spherical aberration generated by the refractive body. The adjustment serves to offset changes in such spherical aberration as viewed by the observer. Microscope objective lenses of this sort are disclosed in Japanese laid-open patent document nos. Sho 60-205521 and Sho 60-247613.

Conventional adjustable objective lenses require that a considerable amount of air space be provided in front of (i.e., objectwise) and behind (i.e., imagewise) certain lens groups in the objective lens to provide a sufficient range of adjustment. Such space requirements significantly limit the degrees of freedom that can be exploited in the design of the objective lens, thus increasing the difficulty with which the performance of the lens can be optimized.

Another problem with conventional adjustable objective lenses is that the mechanical device used to move the movable lens(es) lenses had to be located in the objective lens. This undesirably increased the size and complexity of the objective lens.

With conventional objective lenses that are not designed to be used with an intervening cover glass or the like between the lens and the specimen, if a specimen were observed with a cover glass in place, spherical and other aberrations caused by the thickness of the cover glass reduce the contrast of the observed image, thus making high-quality observations impossible.

SUMMARY OF THE INVENTION

In view of the shortcomings of the prior art, as summarized above, the present invention provides, inter alia, adapters intended to be used with an objective lens system (e.g., microscope objective lens systemA) for adjusting the spherical aberration of the objective lens system.

A preferred embodiment of an adapter comprises, from the object side to the image side, a movable lens group comprising a negative lens cemented to a positive lens to define a cemented surface having negative refractive power. The movable lens group is axially movable on the optical axis. The adapter satisfies at least the following condition:

$$|(n_N-n_P)/r_1|<0.3$$

wherein n_P is the refractive index of the positive lens, n_N is the refractive index of the negative lens, and r_1 is the curvature radius of the cemented surface. The adapter is axially mountable to an objective lens system. If the objective lens system comprises only one objective lens, then the adapter is axially placed on the image side of the objective lens. If the objective lens system comprises first and second objective lenses (the second objective lens being, e.g., a so-called "tube lens" or "imaging lens"), then the adapter is axially placed between the first objective lens and the second objective lens. Movement of the movable lens group along the optical axis relative to the objective lens system allows correction of spherical aberration of an image formed by the objective lens system.

The adapter preferably also satisfies the conditions:

$$-0.6<(f_P+f_N)/(f_P-f_N)<0.6$$

$$-0.4<(\nu_P-\nu_N)/\nu_P<0.4$$

wherein f_P is the focal length of the positive lens, f_N is the focal length of the negative lens, ν_P is the Abbe number (relative to d-line light) of the positive lens, and ν_N is the Abbe number (relative to d-line light) of the negative lens.

The adapter can further comprise a first lens group situated imagewise of the movable lens group and a second lens group situated imagewise of the first lens group. The first lens group has a negative refractive power and a focal length f_1, and the second lens group has a positive refractive power and a focal length f_2. Such an adapter further satisfies the condition:

$$-0.6<(f_2+f_1)/(f_2-f_1)<0.6$$

The adapter can also comprise a positive lens situated objectwise of the movable lens group.

According to another aspect of the invention, objective lens systems are provided. A first representative embodiment of such a system comprises, objectwise to imagewise on an optical axis, an objective lens and an adapter removably attached to the image side of the objective lens. The adapter is coaxial with the objective lens when attached to the

objective lens, and comprises a movable lens group comprising a negative lens cemented to a positive lens. The resulting cemented surface has a negative refractive power and a curvature radius r_1. The movable lens group satisfies at least the condition:

$$|(n_N-n_P)/r_1|<0.3$$

in which the variables are as defined above. The movable lens group is movable on the optical axis relative to the first objective lens to adjust an amount of spherical aberration produced by the objective lens.

In the foregoing lens system, the adapter can further satisfy the conditions:

$$-0.6<(f_P+f_N)/(f_P-f_N)<0.6$$

$$-0.4<(\nu_P-\nu_N)/\nu_P<0.4$$

in which the variables are as defined above. The adapter can further comprise a first lens group situated imagewise of the movable lens group and a second lens group situated imagewise of the first lens group. The first lens group has a negative refractive power and a focal length f_1, and the second lens group has a positive refractive power and a focal length f_2. Such an adapter can further satisfies the condition:

$$-0.6<(f_2+f_1)/(f_2-f_1)<0.6$$

Another representative embodiment of an objective lens system further comprises a first objective lens and a second objective lens situated axially imagewise of the first objective lens. The adapter is situated between the first objective lens and the second objective lens.

According to another aspect of the invention, objective lens systems are provided that exhibit variable spherical aberration correction. One representative embodiment of such a lens system comprises, objectwise to imagewise on an optical axis, an objective lens and a spherical-aberration-correcting lens group (adapter) situated on the image side of the objective lens. Another representative embodiment comprises a first objective lens and a second objective lens, with the spherical-aberration-correcting lens group situated between the first objective lens and the second objective lens. In either instance, the spherical-aberration-correcting lens group comprises an axially movable cemented lens including a negative lens cemented to a positive lens for adjusting the spherical aberration of the objective lens(es). The spherical-aberration-correcting lens group preferably is removable from the objective lens(es).

The cemented lens preferably has a cemented surface having a negative refractive power. The lens system preferably satisfies the condition:

$$|(n_N-n_P)/r_1|<0.3$$

in which the variables are as defined above.

The lens system can further satisfy the conditions:

$$-0.6<(f_P+f_N)/(f_P-f_N)<0.6$$

$$-0.4<(\nu_P-\nu_N)/\nu_P<0.4$$

in which the variables are as defined above.

The spherical-aberration-correcting lens group can further comprise a first lens group situated imagewise of the movable lens group, and a second lens group situated imagewise of the first lens group. The first lens group has a negative refractive power and a focal length f_1, and the second lens group has a positive refractive power and a focal length f_2. The system preferably further satisfies the condition:

$$-0.6<(f_2+f_1)/(f_2-f_1)<0.6$$

The foregoing and additional features and advantages of the present invention will be more readily apparent from the following detailed description which proceeds with reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** depicts general aspects of the placement and movement of an adapter lens according to the invention, in a converging light flux; this figure accompanies a discussion herein of the effect of the adapter lens on spherical aberrations.

FIG. **2** is an optical diagram of an adapter lens according to Example Embodiment 1 of the invention.

FIG. **3** is an optical diagram of the adapter lens of Example Embodiment 1 in axial alignment with a microscope objective lens.

FIG. **4** includes plots of spherical aberration, astigmatism, and coma exhibited by the microscope objective lens of FIG. **3** as used with a cover glass thickness of 0.17 mm but without an adapter lens according to the invention.

FIG. **5** includes plots of spherical aberration, astigmatism, and coma exhibited by the microscope objective lens of FIG. **3** as used with a cover glass thickness of 0.23 mm but without an adapter lens according to the invention.

FIG. **6** includes plots of spherical aberration, astigmatism, and coma exhibited by the microscope objective lens of FIG. **3** as used with the adapter lens of Example Embodiment 1 and with a cover glass thickness of 0.17 mm.

FIG. **7** includes plots of spherical aberration, astigmatism, and coma exhibited by the microscope objective lens of FIG. **3** as used with the adapter lens of Example Embodiment 1 and with a cover glass thickness of 0.23 mm.

FIG. **8** is an optical diagram of an adapter lens according to Example Embodiment 2 of the invention.

FIG. **9** includes plots of spherical aberration, astigmatism, and coma exhibited by microscope objective lens of FIG. **3** as used with the adapter lens of Example Embodiment 2 and with a cover glass thickness of 0.17 mm.

FIG. **10** includes plots of spherical aberration, astigmatism, and coma exhibited by microscope objective lens of FIG. **3** as used with the adapter lens of Example Embodiment 2 and with a cover glass thickness of 0.23 mm.

FIG. **11**(*a*) depicts axial movement of the movable lens group relative to rays of an "infinite correction" objective lens.

FIG. **11**(*b*) depicts axial movement of the movable lens group in a system as depicted in FIG. **11**(*a*) but including the lens group L_0.

FIG. **12**(*a*) is an optical diagram of an adapter according to the invention comprising the cemented movable lens group **M1** and the positive lens L_0, producing a convergent downstream light flux.

FIG. **12**(*b*) is an optical diagram of an adapter according to the invention comprising the cemented movable lens group **M1**, the positive lens L_0, and the lenses L_1, and L_2, producing a parallel downstream light flux.

FIG. **13** is an optical diagram of an objective lens system according to the invention, comprising an objective lens and an adapter located on the image side of the objective lens.

DETAILED DESCRIPTION

The present invention is directed to spherical-aberration-correcting adapter lens assemblies ("adapters") used in

conjunction with a microscope objective lens system or analogous lens system. An adapter according to the invention can serve to effectively cancel (or at least significantly reduce) spherical aberrations that otherwise would exist in the image formed by the objective lens system due to variations in the thickness or other refractive property of a "cover glass" placed between a specimen and the objective lens system.

As used herein, a "cover glass" is understood to encompass any of various conventional cover glasses, coverslips, laboratory dishes, plates, immersion fluids, and the like that can be placed between the objective lens system and the specimen, typically to protect or contain the specimen. Cover glasses according to this definition can be made of any suitable transparent material, such as glass or plastic, and thus exhibit a refractive property with respect to light passing through the cover glass.

The adapters according to the invention are preferably detachable from the objective lens. Thus, an adapter can be attached to the objective lens (e.g., inserted between an objective lens and an image plane of the objective lens, or inserted between a "first" objective lens and a "second" objective lens), inserted between an objective lens system and the objective-lens turret, or between the turret and the image formed by the objective lens system. By axially moving the movable lens group in the adapter, spherical aberrations generated by variations in the thickness or other refractive characteristic of the cover glass can be cancelled or otherwise controlled to the desired degree.

An adapter according to the invention generally comprises an axially movable lens group comprising a cemented lens **M1** (FIG. **1**) including (objectwise to imagewise) a negative lens N and a positive lens P. The axially movable lens group can also comprise, as required, additional single and/or cemented lenses. The cemented lens can further comprise additional lens(es) as required; e.g., the cemented lens can be a cemented triplet (positive-positive-negative, or negative-positive-negative). The cemented surface S of the cemented lens **M1** has a negative refractive power. Spherical aberration is corrected by axially moving the movable lens group. The adapter preferably satisfies the following condition:

$$|(n_N-n_P)/r_1|<0.3 \quad (1)$$

wherein r_1 is the curvature radius of the cemented surface, n_P is the refractive index of the positive lens P, and n_N is the refractive index of the negative lens N of the cemented lens **M1**.

Condition (1) stipulates the appropriate degree of spherical-aberration correction imparted by the cemented surface S of the cemented lens **M1** in the movable lens group. Exceeding the upper limit of condition (1) reduces the effect on correcting spherical aberration. I.e., the change in spherical aberration imparted by the movable lens group is prohibitively small per unit movement of the movable lens group along the optical axis AX, thereby providing insufficient correction of spherical aberration. Falling below the lower limit causes a higher order spherical aberration, which makes it difficult to effectively correct aberrations.

An adapter according to the invention also preferably satisfies conditions (2) and (3):

$$-0.6<(f_P+f_N)/(f_P-f_N)<0.6 \quad (2)$$

$$-0.4<(\nu_P-\nu_N)/\nu_P<0.4 \quad (3)$$

wherein f_P and f_N are the focal lengths of the positive lens P and the negative lens N, respectively, of the cemented lens **M1**, and ν_P and ν_N are the Abbe numbers (relative to d-line light; λ=587.6 nm) of the positive and negative lenses P, N, respectively.

Condition (2) establishes an appropriate range of focal lengths of lenses in the movable lens group. Exceeding the upper limit or falling below the lower limit of condition (2) causes the refractive index of the entire movable lens group to be so high that axially moving the movable lens group in an effort to correct spherical aberration causes excessive movement of the image. Such a situation makes it prohibitively difficult to ascertain whether image contrast has degraded due to defocusing or to spherical aberration. This, in turn, makes it prohibitively difficult to find a setting at which spherical aberration is optimally corrected, and to focus the image.

Exceeding the upper limit of condition (3) causes an excessive change in the correction of chromatic aberrations by the movable lens group whenever the movable lens group is axially moved, thus changing the "balance" achieved by correction of chromatic aberration. This also causes a reduction in contrast. Falling below the lower limit of condition (3) renders the movable lens group incapable of providing sufficient correction of chromatic aberrations as the movable lens group is axially moved. This results in degraded contrast with a change in the "balance" of chromatic aberration correction, making high-quality observations impossible.

The adapter of the present invention is preferably co-axially mounted with respect to the objective lens system. In the case of a so-called "infinite correction" objective lens system, the objective lens system with which the adapter is used typically comprises a "first" objective lens and a "second" objective lens (the second objective lens being, e.g., a so-called "tube lens" or "imaging lens"). With such a system, the adapter is preferably inserted coaxially ("intercalated") between the first objective lens and the second objective lens. (FIG. **3**, for example, shows the adapter intercalated between first and second objective lenses of an infinite-correction objective lens system.) A so-called "finite" correction" system typically lacks a second objective lens because imaging is performed by one objective lens. With a finite correction system the adapter is inserted between the actual objective lens and the image plane of the objective lens. (FIG. **13** shows the adapter inserted on the image side of an objective lens of a finite-correction objective lens system.)

Especially whenever the adapter is inserted into a parallel optical flux (such as between a first objective lens G1 and a second objective lens G2 of an objective lens system having infinite correction), the following condition (4) is preferably satisfied, especially whenever the adapter comprises (in addition to the movable group) a negative lens L_1 and a positive lens L_2:

$$-0.6<(f_2+f_1)/(f_2-f_1)<0.6 \quad (4)$$

wherein f_1 is the focal length of the negative lens L_2, and f_2 is the focal length of the positive lens L_2. Such an adapter is shown in FIG. **2**. It will be understood that the adapter shown in FIG. **2** can be inserted into either a parallel light flux or a non-parallel light flux.

A function of the movable lens group (comprising the cemented lens **M1**) is illustrated in FIG. **1**, which shows, by way of example, the cemented lens **M1** in two different positions along the optical axis AX. In FIG. **1**, a light flux from a point on an object (e.g., on the specimen) propagates along an optical axis AX and is converged by lenses in the objective lens situated toward the specimen. Moving the cemented lens **M1** along the optical axis AX changes

spherical aberration. I.e., in FIG. **1**, when the movable lens group is placed in a convergent light flux, the entrance height H of the light flux on the cemented surface S of the cemented lens **M1** changes. The greater the height H of the light flux incident on the cemented surface, the greater the spherical aberration imparted by the cemented surface. Thus, changing the height H correspondingly changes the spherical aberration.

If the light flux between the first objective lens and the second objective lens of the objective lens system is parallel, the objective lens system is characteristically an "infinite correction" objective lens system. If an axially movable lens group as described above were to be inserted between the first objective lens and the second objective lens of such a system, the height H (and thus spherical aberration) would not change with axial movement of the movable lens group, no matter how far along the optical axis the movable lens group were moved (FIG. **11**(*a*)). To make the adapter functional in such a situation, a lens group L_0 (see, e.g., FIG. **2**), preferably having a positive refractive power, can be inserted between the movable lens group and the first objective lens G1 of the objective lens system; the lens L_0 causes the light flux to be not parallel (preferably convergent) to the optical axis, and enables the movable lens group to provide variable control of the amount of spherical-aberration correction (FIG. **11**(*b*)). I.e., with such a configuration, moving the movable lens group along the optical axis would cause a corresponding change in the height H and thus a corresponding change in spherical aberration. The adapter in such a configuration comprises the movable lens group and the lens group L_0.

With an objective lens system that includes a first objective lens and a second objective lens, the movable lens group, and the lens L_0, the light flux leaving the movable lens group may not be parallel to the optical axis (FIG. **12**(*a*)). Thus, the image plane of the objective lens system changes with movement of the movable lens group along the optical axis. This can complicate use of the objective lens system for microscopy. To correct such a situation, a negative lens group L_1 can be used in combination with a positive lens group L_2 on the image side of the movable lens group (FIG. **12**(*b*)) to restore the image plane to the same position on the optical axis at which the image plane was located before the adapter was inserted. In such a configuration, the adapter comprises the lens group L_0, the movable lens group **M1**, the negative lens L_1, and the positive lens L_2.

Exceeding the upper limit or falling below the lower limit of condition (4) disrupts the desired balance of power between the positive lens L_2 and the negative lens L_1, which increases the absolute value of the Petzval's sum of the adapter. This, in turn, degrades the flatness of the image plane of the objective lens system.

An adapter according to the invention is axially inserted at least on the image side of an objective lens. Thus, in a "finite correction" objective lens system as representatively depicted in FIG. **13**, the resulting corrected objective lens system comprises the objective lens G1 and the adapter. The adapter shown in FIG. **13** comprises an axially movable lens group comprising a cemented lens M_1 including a positive lens P and a negative lens N.

In an "infinite correction" objective lens system as representatively depicted in FIG. **3** and corrected by including an adapter, the resulting corrected objective lens system comprises the adapter intercalated between the first objective lens G1 and the second objective lens G2.

Adapters (and objective lens systems) according to the invention now make it possible to correct spherical aberrations that would otherwise arise in an existing objective lens system used with, e.g., cover glasses having any thickness within a range of thicknesses rather than only a single specified thickness. This is accomplished by inserting an adapter according to the invention on the image side of an objective lens or between a first objective lens and a second objective lens of an objective lens system. This eliminates the need to use a "correcting ring" objective lens with its inherent limitations. Also, with a single adapter according to the invention, a much greater flexibility of microscopic observations can be realized without having to have on hand a large assortment of expensive objective lenses for correcting spherical aberrations arising from any of various cover glass thicknesses.

Several example embodiments of the invention are described below, which represent the current best mode of the invention. It will be understood that the invention is not intended to be limited to these example embodiments.

Example Embodiment 1

An adapter according to this example embodiment is shown in FIG. **2**. FIG. **3** shows the adapter of FIG. **2** intercalated between a first objective lens G1 and a second objective lens G2 of a microscope objective lens system exhibiting "infinite correction." In FIG. **3**, the first objective lens G1 has a focal length f_{G1}=10 mm, and the second objective lens has a focal length f_{G2}=200 mm. The magnification of the entire objective lens system shown in FIG. **3** is 20×, and the numerical aperture is 0.75.

Specifications for the objective lens system shown in FIG. **3** are listed in Tables 1 and 2. Data are listed in order from the object side. Table 1 lists optical data concerning the first and second objective lenses G1, G2 without the adapter being inserted; and Table 2 lists optical data with the adapter inserted. In each of Tables 1 and 2, the first column lists lenses, the second column lists surface numbers, the third column lists curvature radii (r), the fourth column lists axial distances (D) between adjacent surfaces, the fifth column lists refractive indices n(d) relative to d-line light (λ=587.6 nm), and the sixth column lists Abbe numbers ν(d) relative to d-line light of the respective optical components.

Tables 1 and 2 also list a lens mirror and tube prism that are not shown in FIG. **1**.

TABLE 1

Lens	Surface No.	r (mm)	D (mm)	n (d)	ν (d)
C. Glass	1	0.00000	t	1.522160	58.802
"	2	0.00000	d_0		
G1	3	−4.80110	9.25000	1.693500	53.718
"	4	−8.57140	0.10000		
"	5	−61.98900	5.55000	1.497820	82.516
"	6	−13.88870	1.00000		
"	7	83.46600	3.70000	1.497820	82.516
"	8	−27.20600	0.20000		
"	9	−42.20000	1.20000	1.671629	38.798
"	10	20.27050	7.40000	1.433880	95.568
"	11	−20.27050	0.20000		
"	12	27.84500	1.70000	1.671629	44.405
"	13	18.00040	6.70000	1.433880	95.568
"	14	−26.42594	1.30000	1.612658	44.405
"	15	216.06200	15.30000		
"	16	29.04000	4.60000	1.723421	37.903
"	17	−29.04000	1.80000	1.518230	58.903
"	18	13.46050			
"	29		d_2		
G2	30	75.04300	5.10000	1.622801	57.033
"	31	−75.04300	2.00000	1.749501	35.191
"	32	1600.58000	7.50000		
"	33	50.25600	5.10000	1.667551	41.963

TABLE 1-continued

Lens	Surface No.	r (mm)	D (mm)	n (d)	ν (d)
"	34	−84.54100	1.80000	1.612658	44.405
"	35	36.91100	5.50000		
Mirror	36	0.00000	30.00000	1.568829	56.048
Tube	37	0.00000	143.8		
Prism					
		d2 = 100 mm			

Plots of spherical aberration, astigmatism, and coma for the first and second objective lenses as used with a cover glass thickness of t=0.17 mm are shown in FIG. **4**. (For the spherical aberration plot in FIG. **4** as well as in FIGS. **5**–**7** and **9**–**10**, the line denoted "C" pertains to C-line light (λ=656.28 nm), the line denoted "d" pertains to d-line light (λ=587.56 nm), the line denoted "F" pertains to F-line light (λ=486.13 nm), and the line denoted "g" pertains to g-line light (λ=435.84 nm)). All determinations are based on the axial space (d_2) between the first objective lens G1 and the second objective lens G2 being 100 mm.

In FIG. **5** are plots of spherical aberration, astigmatism, and coma for the first and second objective lenses as used with a cover-glass thickness of t=0.23 mm. Comparing FIGS. **4** and **5**, it can be seen that FIG. **5** exhibits more pronounced aberrations than FIG. **4**.

Table 2 lists specifications of the first and second objective lenses used together with an adapter according to the present invention.

TABLE 2

Lens	Surface No.	r (mm)	D (mm)	n (d)	ν (d)
C. Glass	1	0.00000	t	1.522160	58.802
"	2	0.00000	d_0		
G1	3	−4.80110	9.25000	1.693500	53.718
"	4	−8.57140	0.10000		
"	5	−61.98900	5.55000	1.497820	82.516
"	6	−13.88870	1.00000		
"	7	83.46600	3.70000	1.497820	82.516
"	8	−27.20600	0.20000		
"	9	−42.20000	1.20000	1.671629	38.798
"	10	20.27050	7.40000	1.433880	95.568
"	11	−20.27050	0.20000		
"	12	27.84500	1.70000	1.671629	44.405
"	13	18.00040	6.70000	1.433880	95.568
"	14	−26.42594	1.30000	1.612658	44.405
"	15	216.06200	15.30000		
"	16	29.04000	4.60000	1.723421	37.903
"	17	−29.04000	1.80000	1.518230	58.903
"	18	13.46050	d_1		
"	19	32.36640	2.80000	1.501370	56.410
Adapter	20	−75.62441	0.35821		
"	21	343.65573	1.00000	1.766840	46.804
"	22	19.58420	3.10000	1.548139	45.869
"	23	264.09882	2.85775		
"	24	−26.08098	1.00000	1.802180	44.695
"	25	−158.68382	1.20000		
"	26	−43.80436	0.93796	1.589130	61.088
"	27	−488.98032	3.0000	1.531721	48.966
"	28	−22.49337			
"	29		d_2		
G2	30	75.04300	5.10000	1.622801	57.033
"	31	−75.04300	2.00000	1.749501	35.191
"	32	1600.58000	7.50000		
"	33	50.25600	5.10000	1.667551	41.963
"	34	−84.54100	1.80000	1.612658	44.405
"	35	36.91100	5.50000		
Mirror	36	0.00000	30.00000	1.568829	56.048
Tube	37	0.00000	143.8		
Prism					

TABLE 2-continued

Lens	Surface No.	r (mm)	D (mm)	n (d)	ν (d)
		d_1 = 5 mm	t = 0.17~0.23 mm		
		d_2 = 78.55 mm	d_0 = 1.398~1.392 mm		

FIGS. **6** and **7** are plots of spherical aberration, astigmatism, and coma exhibited by the objective lens system of FIG. **3** (with adapter according to this example embodiment inserted between the first objective lens G1 and the second objective lens G2) as used with a cover glass thickness (t) of 0.17 mm and 0.23 mm, respectively. As can be seen by comparing FIGS. **5** and **7**, when the cover glass thickness (t) is changed from 0.17 mm to 0.23 mm, spherical aberration and other aberrations increase. However, by inserting an adapter according to this example embodiment between the first objective lens G1 and the second objective lens G2, spherical aberrations are corrected to a remarkable degree.

Example Embodiment 2

FIG. **8** shows the lens configuration of an adapter according to this example embodiment. The microscope objective lens system with which the adapter is used is, by way of example, the same as used with the adapter of Example Embodiment 1. Lens specifications are listed in Table 3 below.

TABLE 3

Lens	Surface No.	r (mm)	D (mm)	n (d)	ν (d)
C. Glass	1	0.00000	t	1.522160	58.802
"	2	0.00000	d_0		
G1	3	−4.80110	9.25000	1.693500	53.718
"	4	−8.57140	0.10000		
"	5	−61.98900	5.55000	1.497820	82.516
"	6	−13.88870	1.00000		
"	7	83.46600	3.70000	1.497820	82.516
"	8	−27.20600	0.20000		
"	9	−42.20000	1.20000	1.671629	38.798
"	10	20.27050	7.40000	1.433880	95.568
"	11	−20.27050	0.20000		
"	12	27.84500	1.70000	1.671629	44.405
"	13	18.00040	6.70000	1.433880	95.568
"	14	−26.42594	1.30000	1.612658	44.405
"	15	216.06200	15.30000		
"	16	29.04000	4.60000	1.723421	37.903
"	17	−29.04000	1.80000	1.518230	58.903
"	18	13.46050	d_1		
Adapter	19	32.65380	2.80000	1.501370	56.410
"	20	−78.79597	1.31400		
"	21	283.04932	1.00000	1.766840	46.804
"	22	19.43468	3.10000	1.548139	45.869
"	23	315.45581	1.72500		
"	24	−25.89658	1.00000	1.787971	47.465
"	25	−165.70078	1.20000		
"	26	−38.28343	4.31014	1.575010	41.421
"	28	−22.46741			
"	29		d_2		
G2	30	75.04300	5.10000	1.622801	57.033
"	31	−75.04300	2.00000	1.749501	35.191
"	32	1600.58000	7.50000		
"	33	50.25600	5.10000	1.667551	41.963
"	34	−84.54100	1.80000	1.612658	44.405
"	35	36.91100	5.50000		
Mirror	36	0.00000	30.00000	1.568829	56.048
Tube	37	0.00000	143.8		
Prism					
		d_1 = 5 mm	t = 0.17~0.23 mm		
		d_2 = 78.55 mm	d_0 = 1.398~1.390 mm		

FIGS. **9** and **10** are plots of spherical aberration, astigmatism, and coma exhibited by a microscope objective

lens system as shown in FIG. **3** used with an adapter according to this example embodiment and with a cover-glass thickness of t=0.17 mm and 0.23 mm, respectively. As can be seen by comparing FIG. **5** with FIG. **10**, when the cover glass thickness (t) is changed from 0.17 mm to 0.23 mm (and without an adapter present), spherical aberrations and other aberrations increase. However, by inserting the adapter of this example embodiment and axially moving the movable lens group to an appropriate position, spherical aberrations are corrected to a remarkable degree.

In Example Embodiments 1 and 2, the light flux on the object side and the image side of the subject adapter is parallel to the optical axis. Thus, the same beneficial function of reducing spherical aberrations can be realized by reversing the lens configuration of the adapter.

Values of variables and of conditions (1)–(4) as exhibited by Example Embodiments 1 and 2 are listed in Table 4 below.

Variable	Example Embodiment 1	Example Embodiment 2
n_P	1.766840	1.766840
n_N	1.548139	1.531721
r_1	19.5842	19.43468
Condition (1)	0.0112	0.121
f_P	38.418	38.809
f_N	−27.119	−27.257
Condition (2)	0.1724	0.17486
ν_P	45.869	48.966
ν_N	46.804	46.804
Condition (3)	−0.02038	0.02137
f_2	89.487	86.02
f_1	−39.038	−39.076
Condition (4)	0.392523	0.3752

Therefore, with an adapter according to this invention, spherical aberrations and other aberrations imparted to a objective lens system by variations in the thickness of a "cover glass" can be corrected to a high degree. By attaching such an adapter to an existing objective lens system, spherical aberrations can be controlled to the desired degree. It will be understood that, in addition to microscope objective lens systems, an adapter according to the invention can also be used with other optical systems such as a camera optical system.

Whereas the invention has been described in connection with several example embodiments, it will be understood that the invention is not limited to those embodiments. On the contrary, the invention is intended to encompass all alternatives, modifications, and equivalents as may be included within the spirit and scope of the invention as defined by the appended claims.

What is claimed is:

1. An adapter for correcting spherical aberration of an objective lens, the adapter comprising, from an object side to an image side on an optical axis:

(a) a movable lens group comprising a negative lens cemented to a positive lens to define a cemented surface having negative refractive power and a curvature radius r_1, the movable lens group being axially movable on the optical axis;

(b) the adapter satisfying the condition:

$$|(n_N-n_P)/r_1|<0.3$$

wherein n_P is the refractive index of the positive lens and n_N is the refractive index of the negative lens; and

(c) the adapter being axially mountable to an image side of an objective lens to allow correction, by axially moving the movable lens group relative to the objective lens system, of spherical aberration of an image formed by the objective lens.

2. The adapter of claim **1**, further satisfying the conditions:

$$-0.6<(f_P+f_N)/(f_P-f_N)<0.6$$

$$-0.4<(\nu_P-\nu_N)/\nu_P<0.4$$

wherein f_P is the focal length of the positive lens, f_N is the focal length of the negative lens, ν_P is the Abbe number (relative to d-line light) of the positive lens, and ν_N is the Abbe number (relative to d-line light) of the negative lens.

3. The adapter of claim **2**, further comprising:

a first lens group situated imagewise of the movable lens group, the first lens group having negative refractive power and a focal length f_1; and

a second lens group situated imagewise of the first lens group, the second lens group having positive refractive power and a focal length f_2, the adapter further satisfying the condition:

$$-0.6<(f_2+f_1)/(f_2-f_1)<0.6.$$

4. The adapter of claim **3**, further comprising a positive lens situated objectwise of the movable lens group.

5. The adapter of claim **1**, further comprising:

a first lens group situated imagewise of the movable lens group, the first lens group having negative refractive power and a focal length f_1; and

a second lens group situated imagewise of the first lens group, the second lens group having positive refractive power and a focal length f_2, the adapter further satisfying the condition:

$$-0.6<(f_2+f_1)/(f_2-f_1)<0.6.$$

6. The adapter of claim **5**, further comprising a positive lens situated objectwise of the movable lens group.

7. An objective lens system, comprising, objectwise to imagewise on an optical axis:

(a) an objective lens; and

(b) an adapter removably attached to the image side of the objective lens and coaxial with the objective lens when attached to the objective lens, the adapter comprising a movable lens group comprising a negative lens cemented to a positive lens to define a cemented surface having negative refractive power and a curvature radius r_1, the movable lens group satisfying the condition:

$$|(n_N-n_P)/r_1|<0.3$$

wherein n_P is th e refractive index of th e positive lens and n_N is the refractive index of the negative lens, the movable lens group being movable on the optical axis relative to the objective lens to adjust an amount of spherical aberration produced by the objective lens.

8. The lens system of claim **7**, wherein the adapter further satisfies the conditions:

$$-0.6<(f_P+f_N)/(f_P-f_N)<0.6$$

$$-0.4<(\nu_P-\nu_N)/\nu_P<0.4$$

wherein f_P is the focal length of the positive lens, f_N is the focal length of the negative lens, ν_P is the Abbe number (relative to d-line light) of the positive lens, and ν_N is the Abbe number (relative to d-line light) of the negative lens.

9. The lens system of claim 8, wherein the adapter further comprises:

a first lens group situated imagewise of the movable lens group, the first lens group having negative refractive power and a focal length f_1; and

a second lens group situated imagewise of the first lens group, the second lens group having positive refractive power and a focal length f_2, the adapter further satisfying the condition:

$$-0.6<(f_2+f_1)/(f_2-f_1)<0.6.$$

10. The lens system of claim 7, wherein the adapter further comprises:

a first lens group situated imagewise of the movable lens group, the first lens group having negative refractive power and a focal length f_1; and

a second lens group situated imagewise of the first lens group, the second lens group having positive refractive power and a focal length f_2, the adapter further satisfying the condition:

$$-0.6<(f_2+f_1)/(f_2-f_1)<0.6.$$

11. The lens system of claim 10, wherein the spherical-aberration-correcting lens group further comprises:

a first lens group situated imagewise of the movable lens group, the first lens group having negative refractive power and a focal length f_1; and

a second lens group situated imagewise of the first lens group, the second lens group having positive refractive power and a focal length f_2, the spherical-aberration-correcting lens group further satisfying the condition:

$$-0.6<(f_2+f_1)/(f_2f_1)<0.6.$$

12. An objective lens system exhibiting variable spherical aberration correction, the lens comprising objectwise to imagewise on an optical axis:

(a) a first objective lens;

(b) a second objective lens; and

(c) a spherical-aberration-correcting lens group situated between the first objective lens and the second objective lens, the spherical-aberration-correcting lens group comprising an axially movable cemented lens including a negative lens cemented to a positive lens for adjusting the spherical aberration of the first objective lens and the second objective lens, the spherical-aberration-correcting lens group being removable from between the first objective lens and the second objective lens.

13. The lens system of claim 12, wherein the cemented lens has a cemented surface having a negative refractive power, the lens system satisfying the condition:

$$|(n_N-n_P)/r_1|<0.3$$

wherein r_1 is the curvature radius of the cemented surface, n_P is the refractive index of the positive lens and n_N is the refractive index of the negative lens of the cemented lens.

14. The lens system of claim 13, further satisfying the conditions:

$$-0.6<(f_P+f_N)/(f_P-f_N)<0.6$$

$$-0.4<(\nu_P-\nu_N)/\nu_P<0.4$$

wherein f_P is the focal length of the positive lens, f_N is the focal length of the negative lens, ν_P is the Abbe number (relative to d-line light) of the positive lens and ν_N is the Abbe number (relative to d-line light) of the negative lens.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 5,978,155
DATED : November 2, 1999
INVENTOR(S) : Yutaka Suenaga

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 6,
Line 55, "lens L_2" should be -- lens L_1 --.

Column 9,
Line 10, "d2" should be -- d_2 --.

Signed and Sealed this

Eighteenth Day of September, 2001

Attest:

Nicholas P. Godici

Attesting Officer

NICHOLAS P. GODICI
Acting Director of the United States Patent and Trademark Office

US005978086A

United States Patent [19]

Aziz et al.

[11] Patent Number: 5,978,086

[45] Date of Patent: Nov. 2, 1999

[54] **METHOD AND APPARATUS FOR CORRECTING SHIFTS BETWEEN A REFERENCE FOCAL POINT AND A REFERENCE SURFACE AS A RESULT OF THERMAL EFFECTS IN AN INTERFEROMETRIC OPTICAL OBJECTIVE**

[75] Inventors: **David J. Aziz**; **Robert E. Knowlden**, both of Tucson, Ariz.

[73] Assignee: **Wyko Corporation**, Tucson, Ariz.

[21] Appl. No.: **08/814,351**

[22] Filed: **Mar. 11, 1997**

[51] **Int. Cl.**[6] **G01B 9/02**

[52] **U.S. Cl.** **356/357**

[58] **Field of Search** 356/357, 358; 359/392, 382, 383; 352/140

[56] **References Cited**

U.S. PATENT DOCUMENTS

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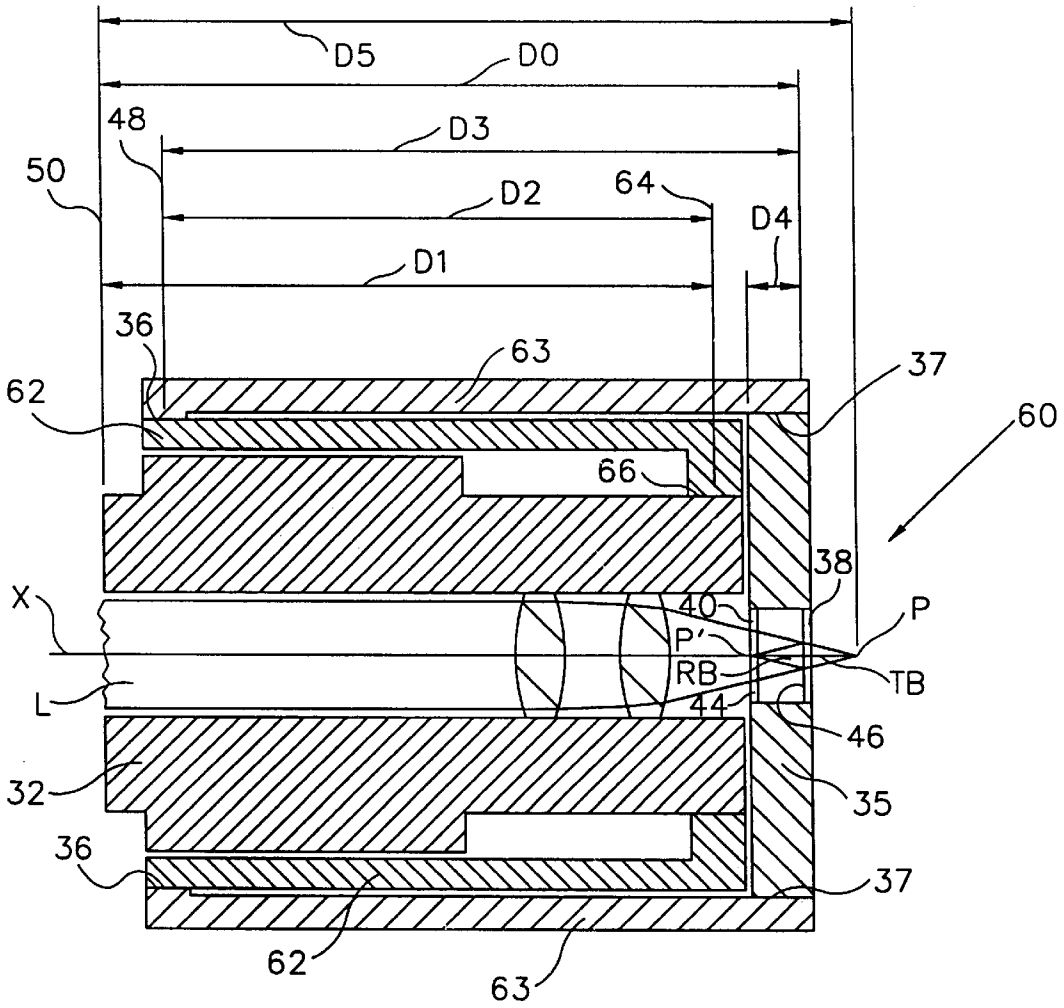
Primary Examiner—Samuel A. Turner

Attorney, Agent, or Firm—Antonio R. Durando

[57] **ABSTRACT**

Structural components are added to an interferometric objective to offset the effects of temperature variations. The components are mounted between the sleeve housing the optics of the objective and the collar housing the optics of the interferometer. Each component is coupled sequentially, such that the thermal response of the assembly is substantially the linear combination of the response of each component and is designed to cause a shift in the opposite direction to the shift produced by a temperature change in the unmodified device. The thermal characteristics and dimensions of the components are chosen empirically to provide a minimum shift between the reference mirror and focal point in the interferometric objective as a function of temperature.

22 Claims, 12 Drawing Sheets



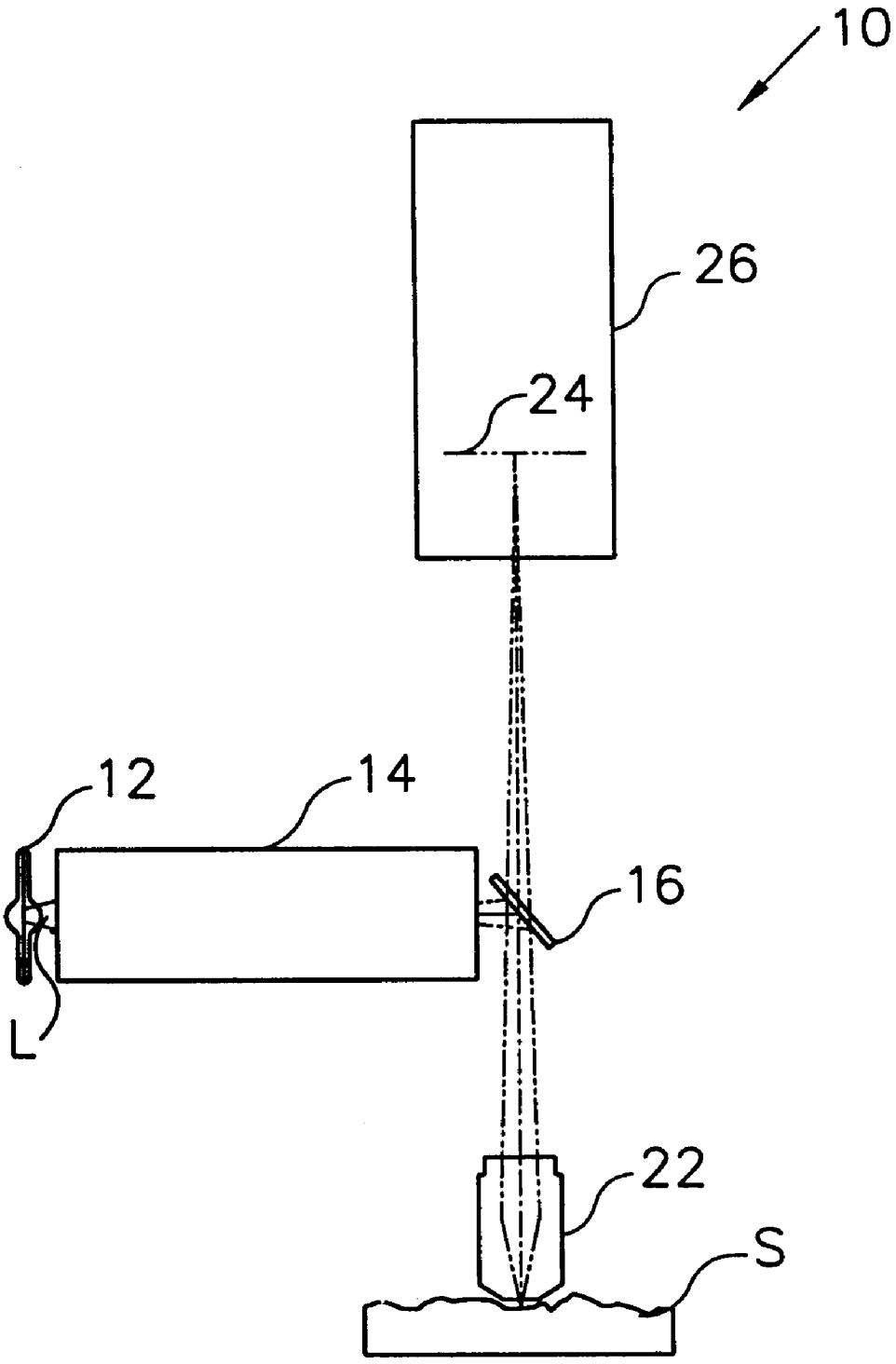


FIG.1 (PRIOR ART)

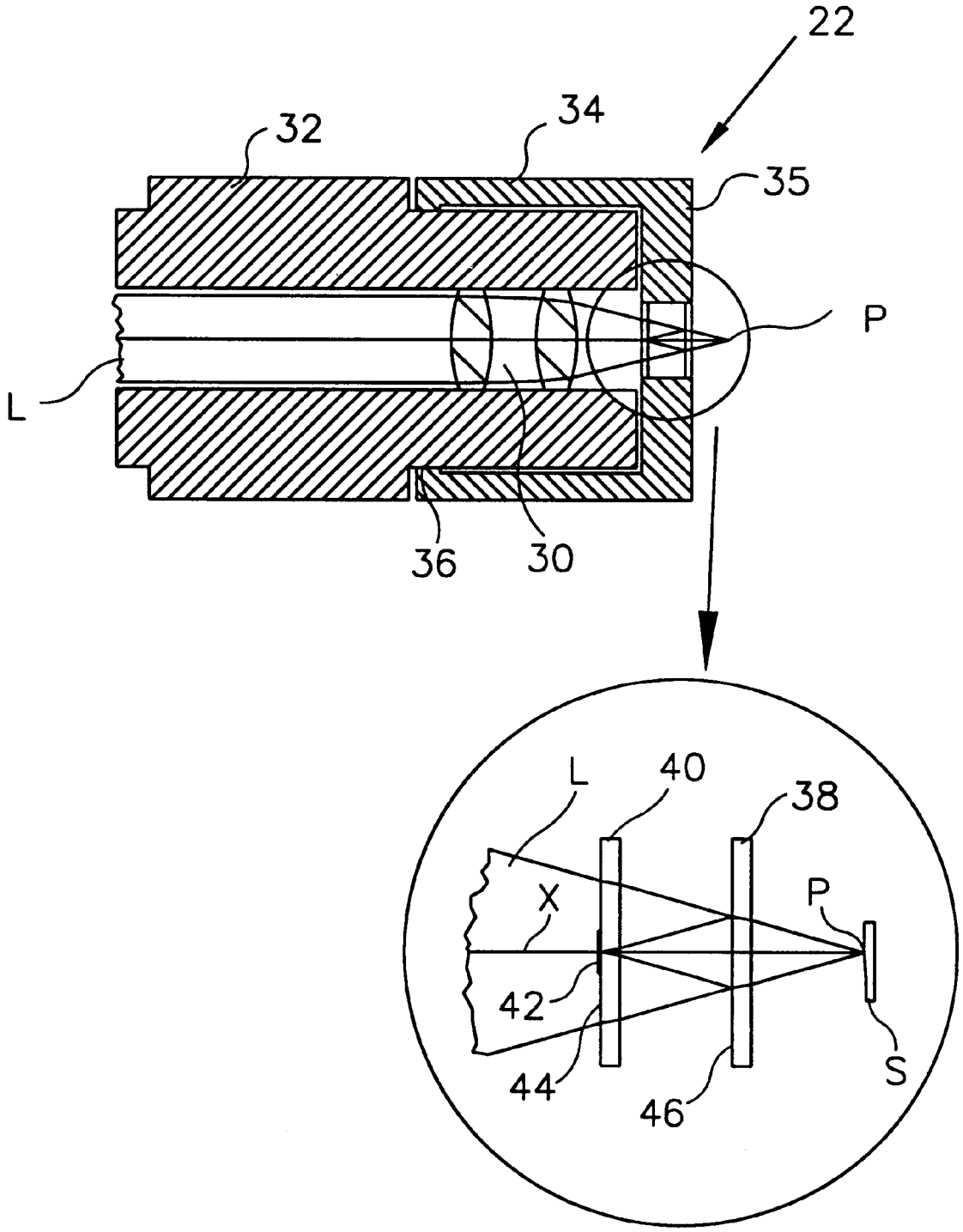


FIG. 2 (PRIOR ART)

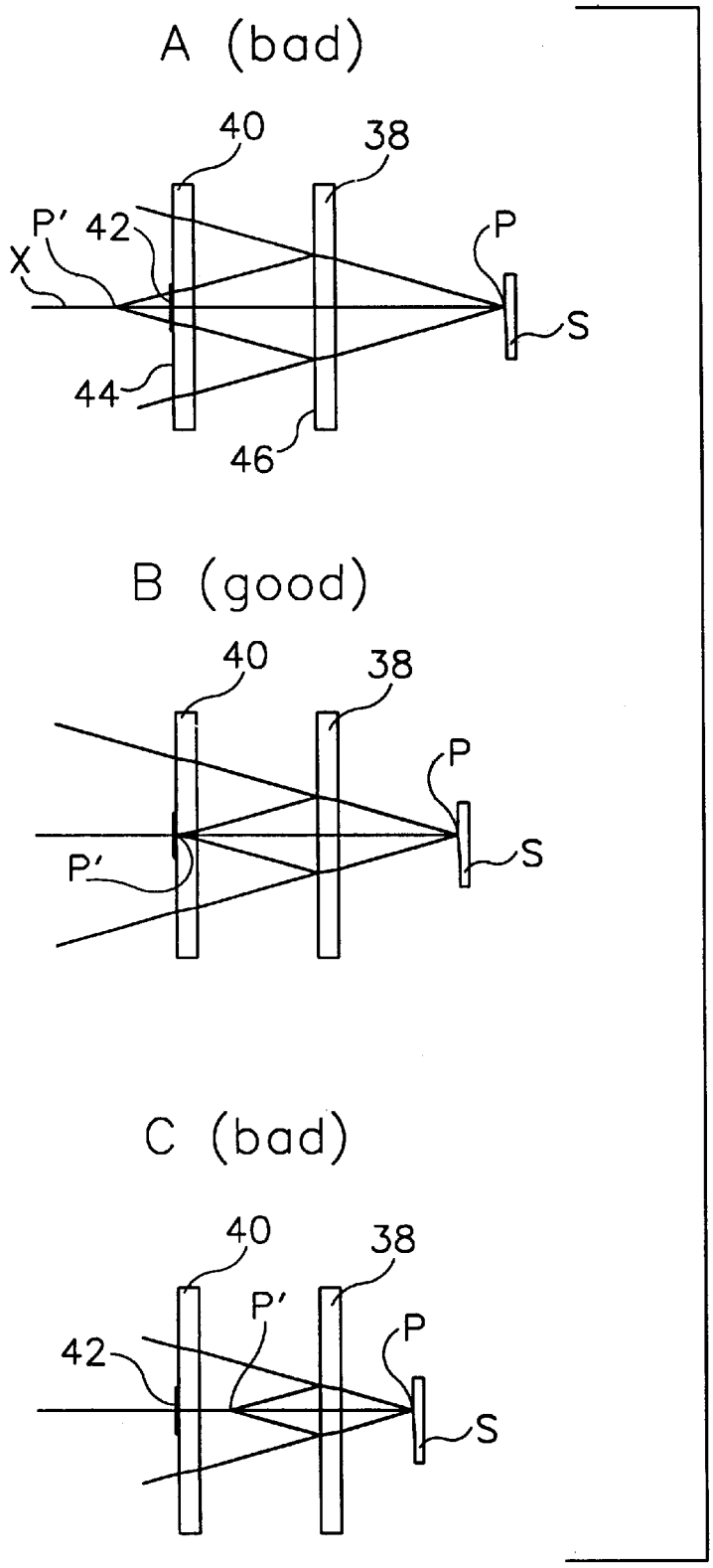


FIG. 3

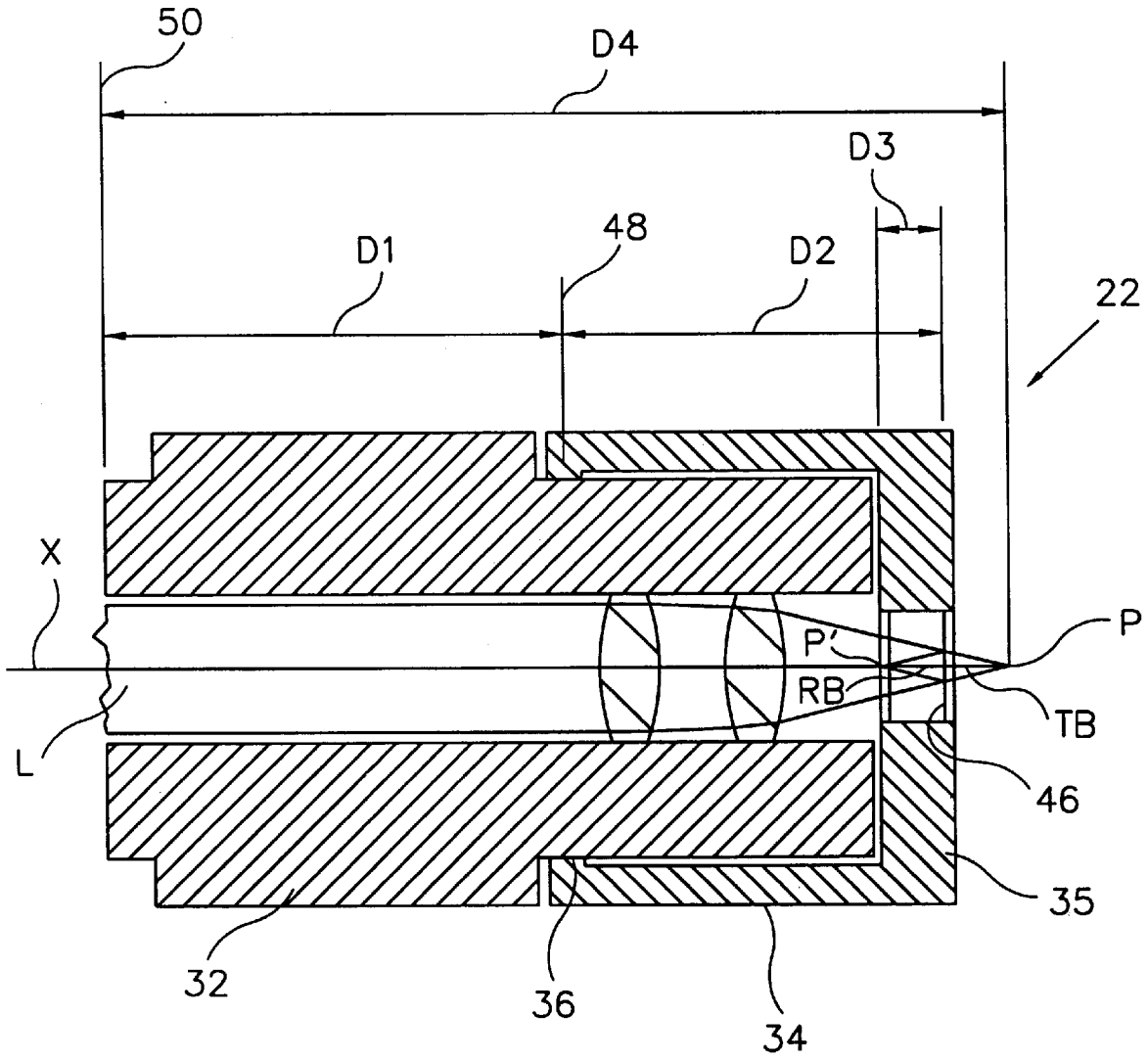


FIG. 4 (PRIOR ART)

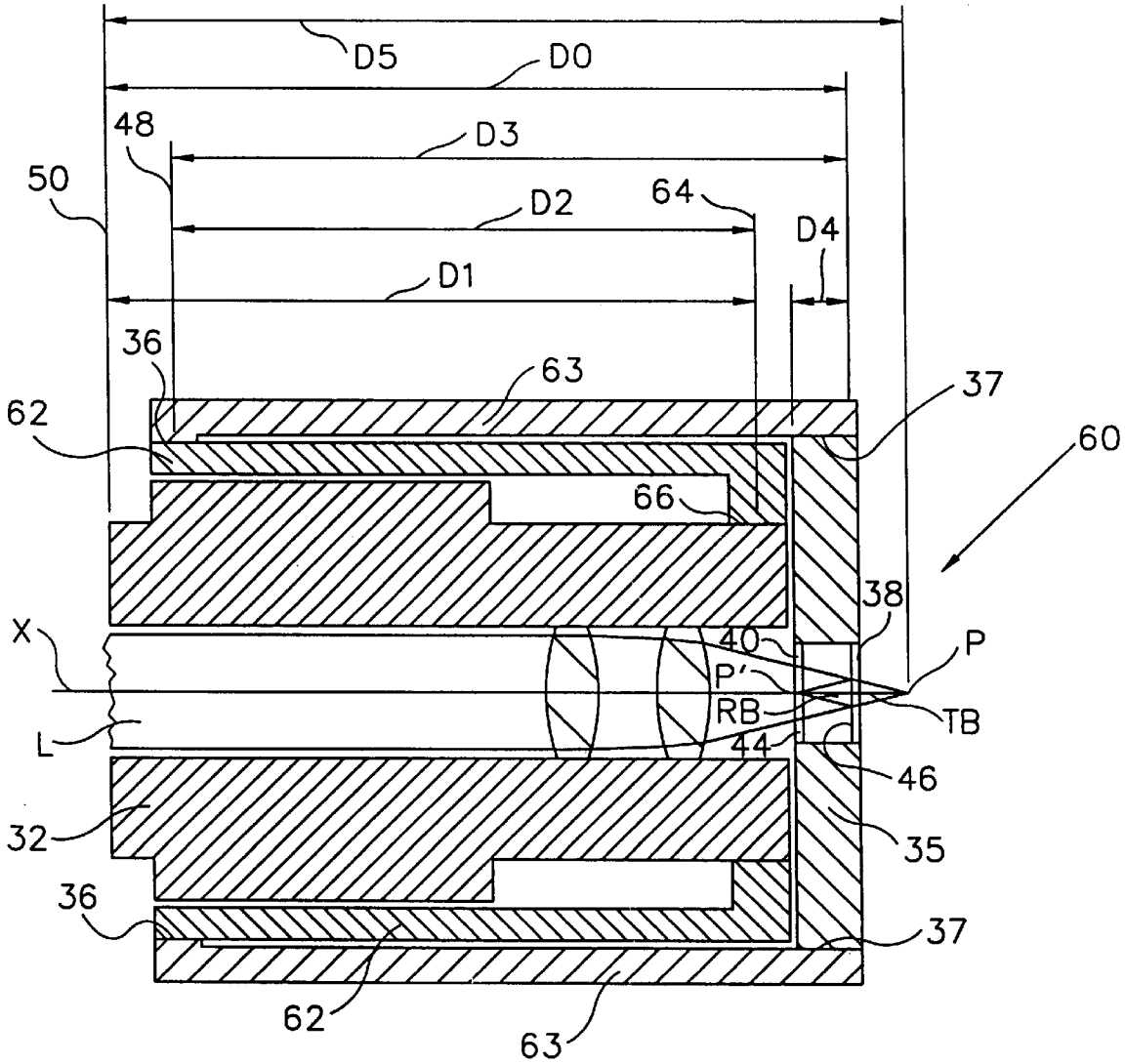

D5
D0
48
D3
50
64
D2
D4
D1
36
63
37
62
60
66
38
X
40
P
P'
RB
TB
L
44
46
32
35
36
37
62
63

FIG. 5

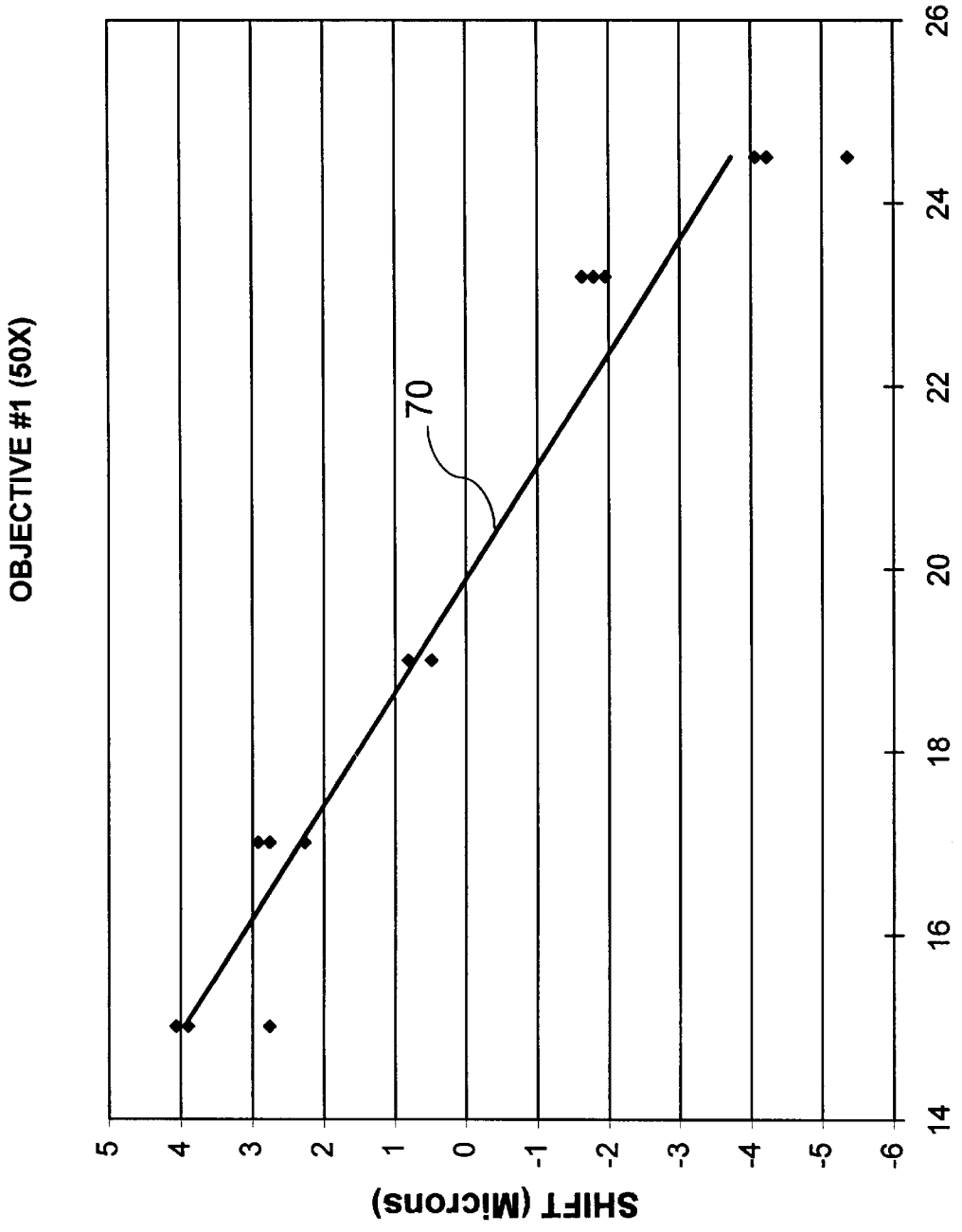

OBJECTIVE #1 (50X)
70
SHIFT (Microns)
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
14
16
18
20
22
24
26
TEMPERATURE (°C)

FIG. 6

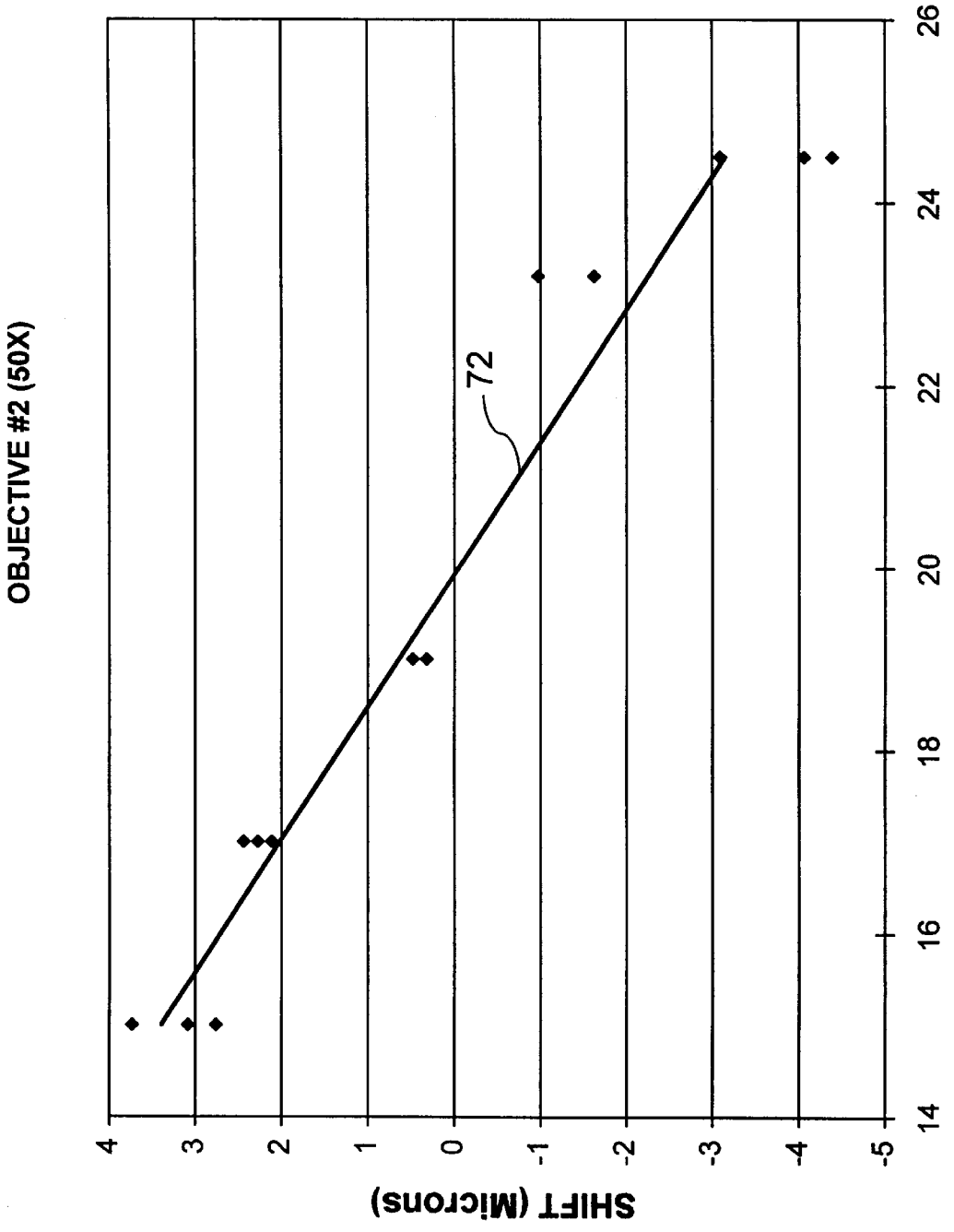

OBJECTIVE #2 (50X)
SHIFT (Microns)
4
3
2
1
0
-1
-2
-3
-4
-5
14
16
18
20
22
24
26
TEMPERATURE (°C)
72

FIG. 7

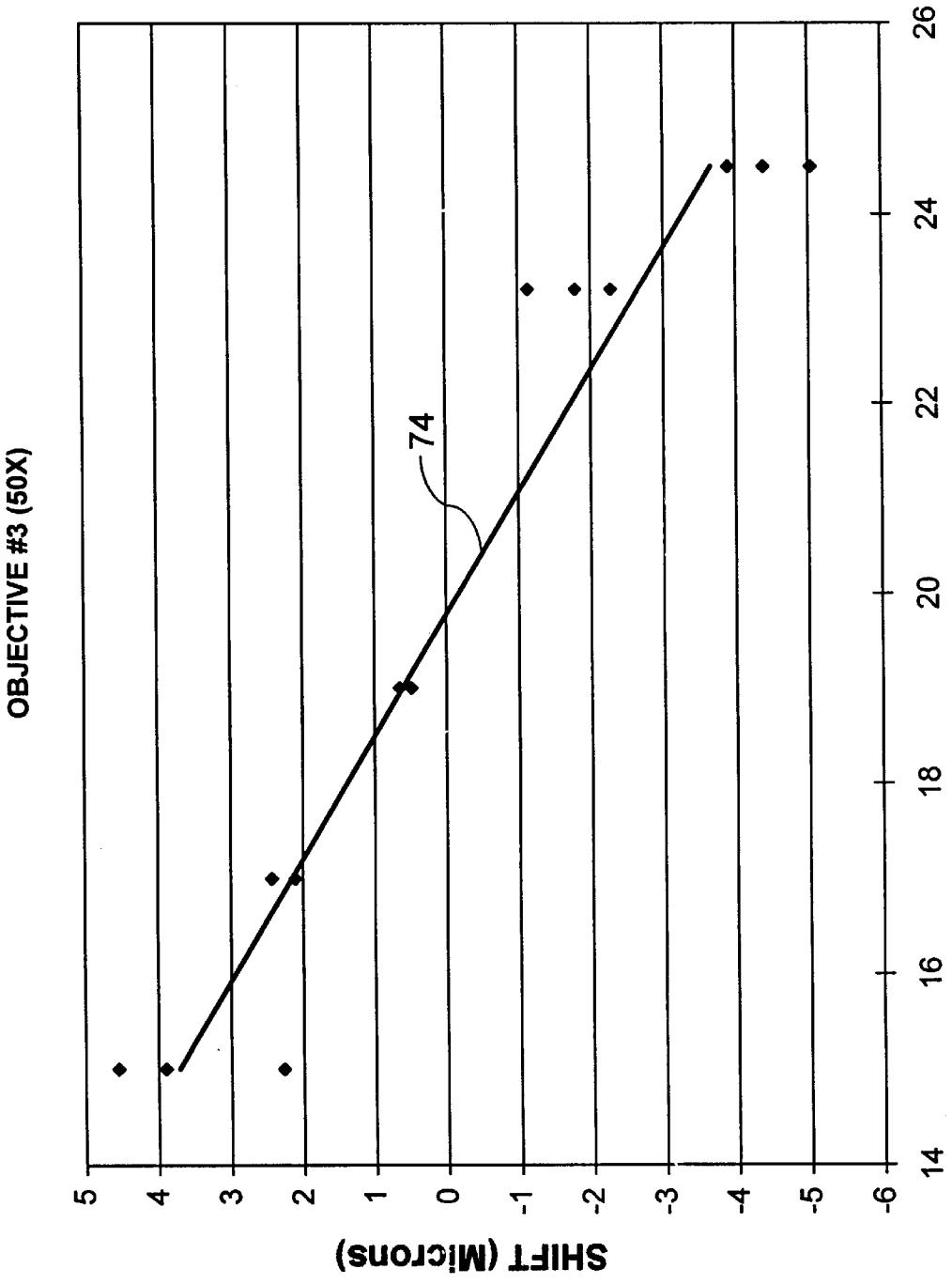

OBJECTIVE #3 (50X)
74
SHIFT (Microns)
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
14
16
18
20
22
24
26
TEMPERATURE (°C)

FIG. 8

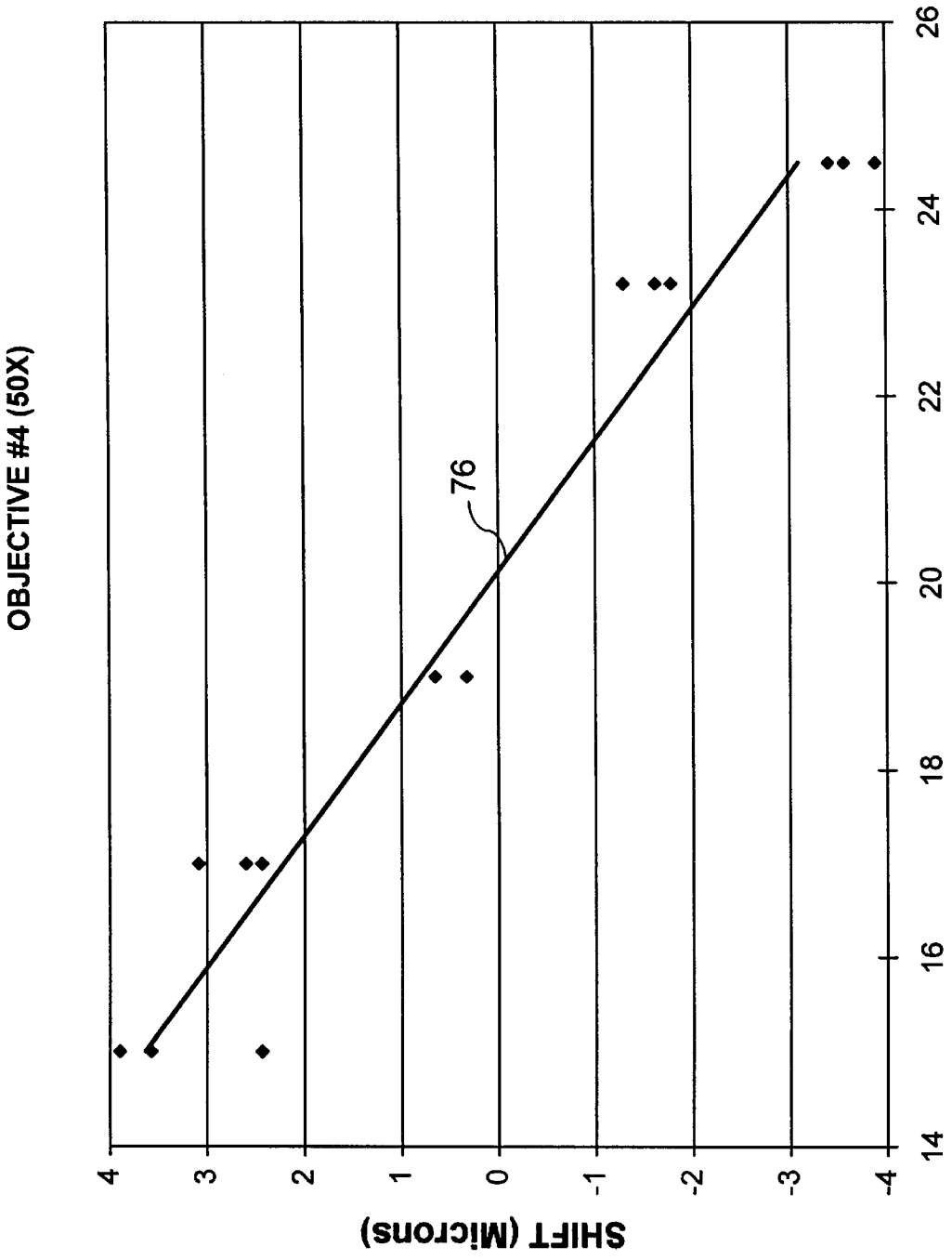

OBJECTIVE #4 (50X)
SHIFT (Microns)
4
3
2
1
0
-1
-2
-3
-4
14
16
18
20
22
24
26
TEMPERATURE (°C)
76

FIG. 9

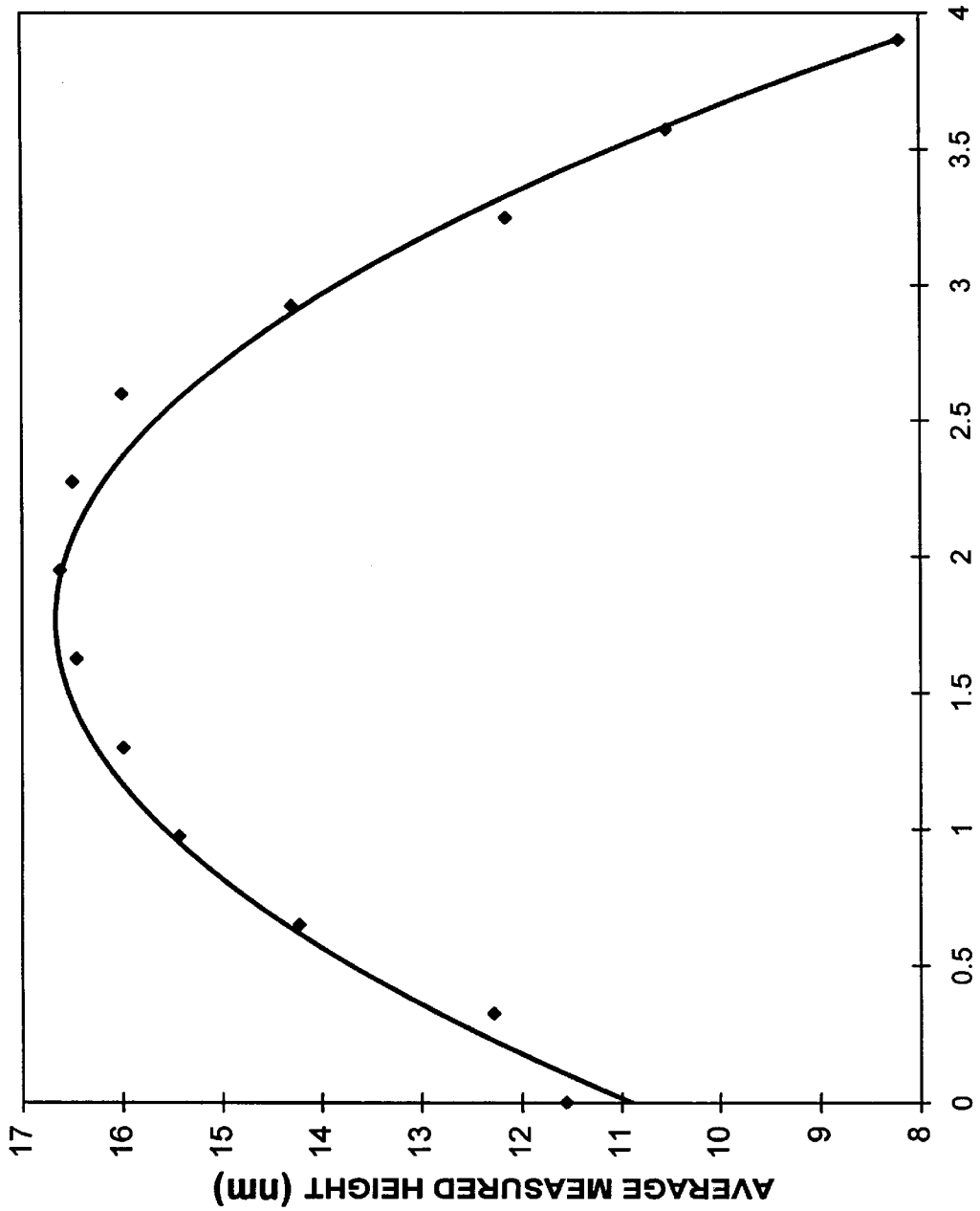

AVERAGE MEASURED HEIGHT (nm)
17
16
15
14
13
12
11
10
9
8
0
0.5
1
1.5
2
2.5
3
3.5
4
FOCAL POINT SHIFT (microns)

FIG. 10

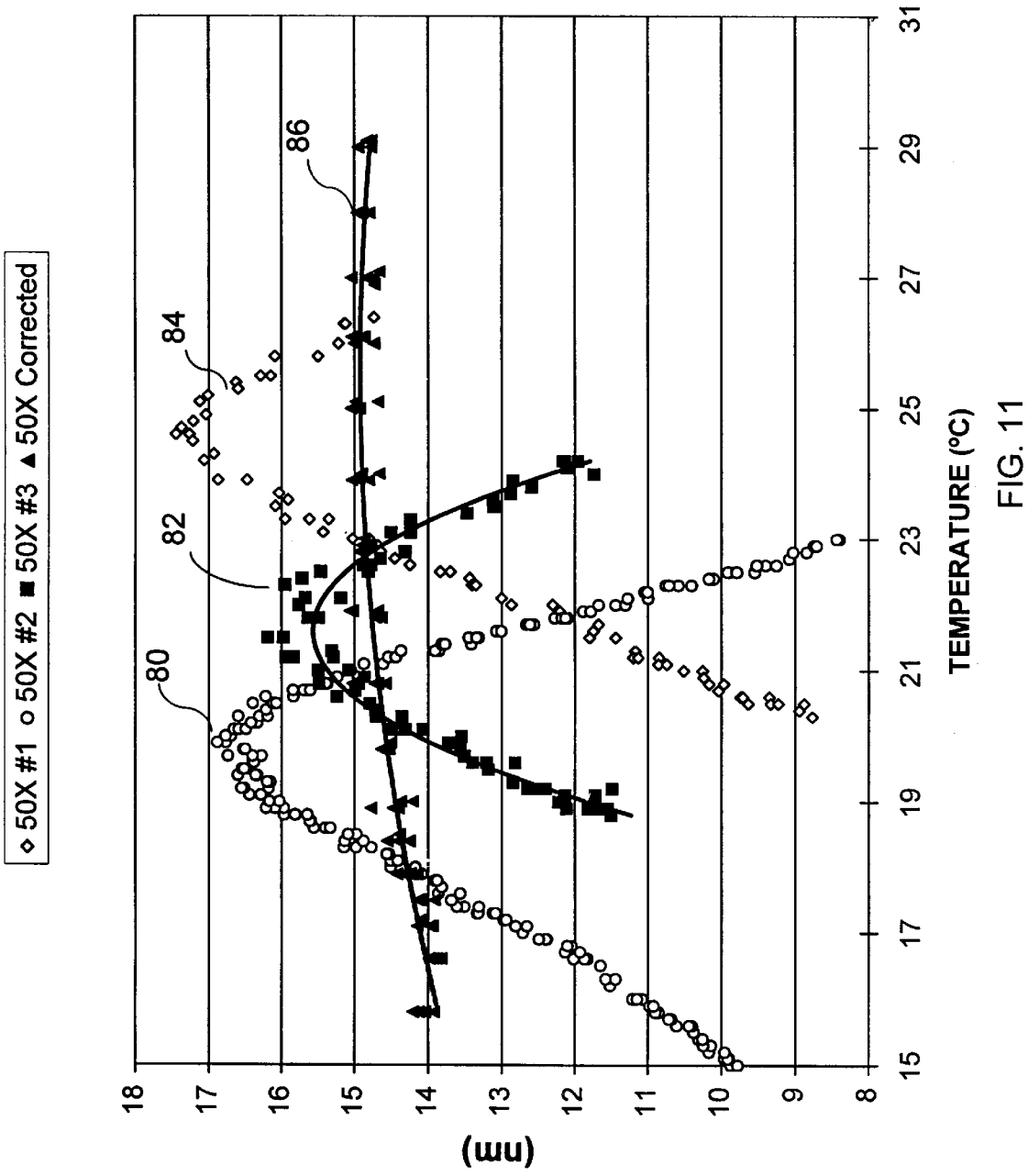

◇ 50X #1 ○ 50X #2 ■ 50X #3 ▲ 50X Corrected
80
82
84
86
(nm)
18
17
16
15
14
13
12
11
10
9
8
15
17
19
21
23
25
27
29
31
TEMPERATURE (°C)

FIG. 11

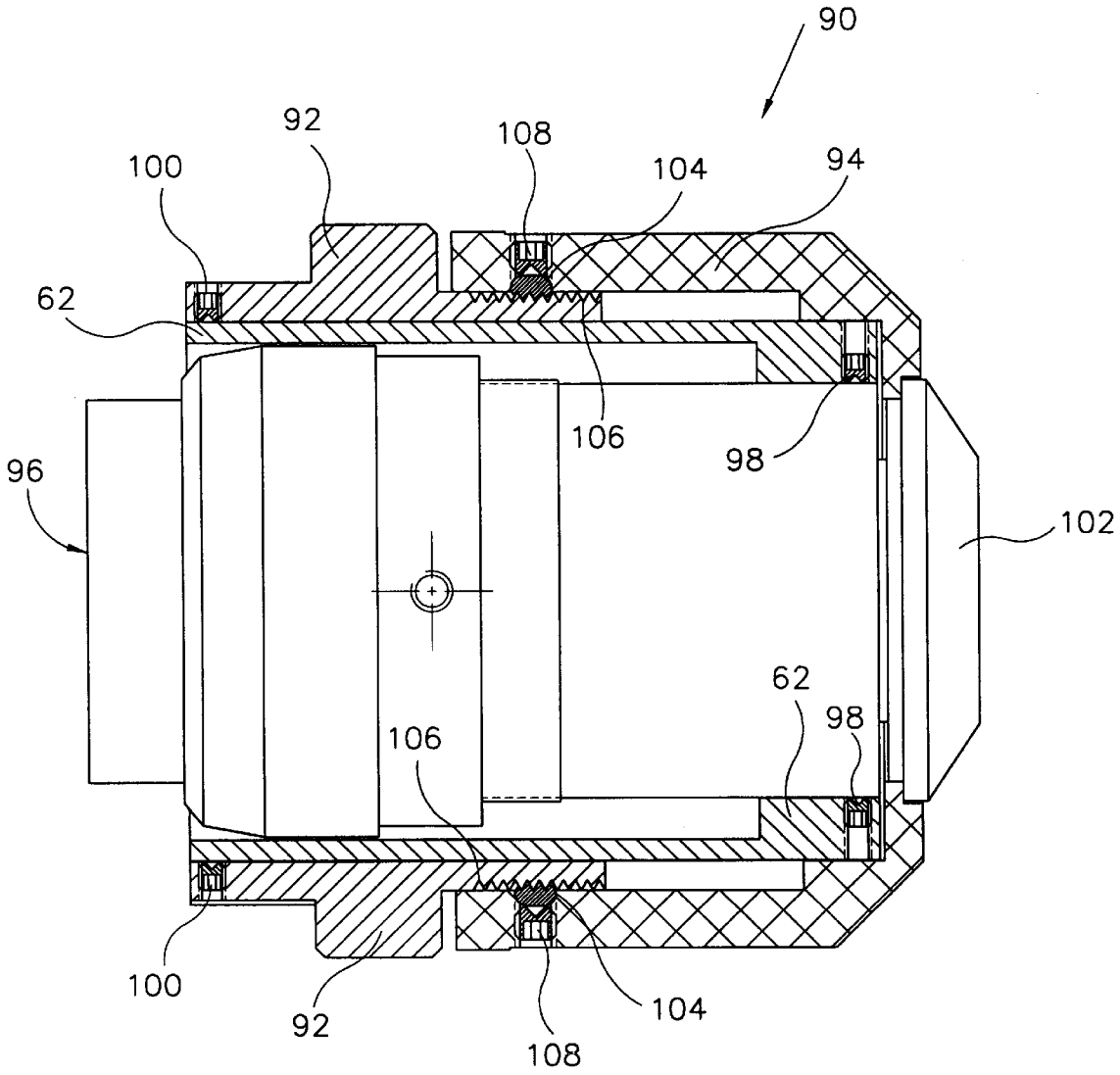


FIG. 12

METHOD AND APPARATUS FOR CORRECTING SHIFTS BETWEEN A REFERENCE FOCAL POINT AND A REFERENCE SURFACE AS A RESULT OF THERMAL EFFECTS IN AN INTERFEROMETRIC OPTICAL OBJECTIVE

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention is related in general to the field of interferometry and, in particular, to a method and apparatus for minimizing shifts between the focal point and the reference mirror caused by thermal effects in the optical microscope objective of an interferometer.

2. Description of the Related Art

Many interferometric devices utilize microscope objectives for focusing beams of light on a sample surface and a reference surface to produce interference fringes representative of the optical path difference (OPD) between the two. As illustrated in simple schematic form in FIG. **1**, typical interferometric apparatus **10** consists of a light source **12** directing a beam L of light through an illuminator **14** toward a beam splitter **16**, which reflects the light in the direction of a test surface S. The light reflected by the beam splitter **16** passes through a microscope objective **22** focused on the test surface S and incorporating an interferometer (not seen in the figure). The interferometer, such as a Mirau device, for example, comprises a beam splitter and a reference mirror, such that the light beam directed to the sample surface S is split and also directed to the reference mirror. As is well understood by those skilled in the art, the light beams reflected from the reference mirror and the test surface S (the reference and test beams, respectively) are combined to produce interference fringes as a result of the optical path difference between the reference mirror and the test surface S. The light is typically passed back through the interferometric microscope objective **22** and through the beam splitter **16** toward an imaging array **24** positioned in a camera **26** in coaxial alignment with the objective **22**. The imaging array **24** typically consists of individual charge-coupled-device (CCD) cells or other sensing apparatus adapted to record a two-dimensional array of signals corresponding to interference effects produced by the interferometer as a result of light reflected at individual x-y coordinates or pixels in the surface S and received at corresponding individual cells in the array. Appropriate electronic hardware (not shown) is also provided to process the signals generated by each cell and transmit them to a computer for further processing. Thus, an interference-fringe map is generated by detecting the intensity of the light signal received in each cell of the array **24**. Additional information about the test surface S can be gained by varying the OPD between the reference and test surfaces with a scanning device (not shown) translating either the reference surface or the test surface.

The present invention is directed at an unsolved problem caused by thermal effects in the typical interferometric objective **22** of the interferometer. As illustrated schematically in FIG. **2**, a conventional interferometric objective **22** consists of microscope-objective optics **30** adapted to focus the light beam L at a test focal point P on the test surface S of the object being measured. For the purpose of this disclosure, the light beam L is assumed to come from an object location an infinite distance behind the microscope objective, thereby locating the test focal point P defined here at the focal point of the objective. As one skilled in the art would readily understand, though, the disclosure applies equally to the case where the source of beam L is located a finite distance behind the objective and the test focal point P does not coincide with the focal point of the objective. Thus, while the "infinite conjugates" imaging condition, as understood in the art, is used here to simplify the description of the invention, the description can be generalized with no loss of accuracy to the "finite conjugates" imaging condition.

The optics in the objective **30** are rigidly housed in a coaxial support sleeve **32** substantially along the entire length of the objective. A focusing sleeve **34** is mounted on the support sleeve **32** so that it can move along the optical axis X of the assembly for focusing the light beam L at the test focal point P. To produce the fine adjustments required for interferometric applications, the focusing sleeve **34** is typically coupled to the support sleeve **32** by means of a threaded engagement (seen in FIG. **12**) along the interior of the sleeve **34**, such as on the inside surface of the end collar **36**.

As also shown in the enlarged partial view contained in FIG. **2**, the focussing sleeve **34** includes a beam splitter **38** and a reference flat **40** with a reference mirror **42** attached to the reference surface **44**. By rotating the focusing sleeve **34** with respect to the support sleeve **32**, their relative axial position is shifted as needed to focus the light beam L on the reference surface **44**. Obviously, the threaded engagement between the two structures is provided with the pitch necessary to produce the focusing adjustments required by the application. By design, once the beam L is focused on the object to be measured, the light reflected from the reference mirror **42** and from the test surface S is combined at the surface **46** of the beam splitter **38** and reflected back through the objective **30** for the necessary interferometric measurements. Therefore, it is critical for good interferometric measurements that the distance between the surface **46** on the beam splitter and the reference mirror **42** remain the same as the distance between the surface **46** and the test focal point P (that is, the reference focal point P' must remain on the mirror **42**). For the purposes of this disclosure, the distance between the splitter's surface **46** and the reference mirror **42** is defined as the "reference length" and the distance between the surface **46** and the test focal point P is defined as the "test length." Thus, the reference length is selected by design such that the position of the reference mirror **42** is conjugate to the location of the test focal point P after the focusing of the objective on the test sample.

In practice, thermal effects cause component shifts that result in material changes in the focal length of the objective. When that happens, the test length changes and a mismatch occurs between the focal position of the test surface and the position of the reference mirror. As shown in FIG. **3**, the nominal design configuration when the interferometric objective **22** is focused on the test surface S is illustrated by condition B, which is optimal, while mismatched configurations caused by thermal effects are shown as conditions A and C. Specifically, condition A is caused by a temperature change that results in an increase of the focal length of the objective, while condition C is produced by a temperature change that results in a decrease of the focal length. Under condition A, assuming, for purposes of illustration, that the distance between the splitter's surface **46** and the reference surface **44** (the reference length) remains unaffected by the change in ambient temperature, when the test beam is focused on the test surface S, the reference focal point P' is shifted beyond the reference mirror **42** and the image reflected by the mirror is out of focus. Similarly, under

condition C the reference focal point P'is shifted ahead of the mirror **42** with the same result. Obviously, the interplay between the coefficients of thermal expansion of the various components in the objective **22** determines exactly what happens as a result of any departure from the design temperature for the device. Moreover, the reference length does not in fact remain constant through temperature variations, but also contributes to the mismatch illustrated above. As discussed above with respect to the test focal point P, the "infinite conjugates" imaging condition is used for simplicity of disclosure, but the description can be generalized with no loss of accuracy to the "finite conjugates" imaging condition with respect to the reference focal point P' as well.

Thus, the temperature dependence of the characteristics of conventional interferometric objectives affects the performance of the instruments under varied temperature conditions. Therefore, it would be very desirable to provide a solution to this problem.

BRIEF SUMMARY OF THE INVENTION

One primary object of this invention is an interferometric objective that has performance characteristics substantially independent of ambient temperature variations.

Specifically, an important goal of the invention is an objective wherein the distance between the reflective surface of the beam splitter in the interferometer and the reference mirror remains substantially the same as the distance between that surface and the focal point of the objective during ambient-temperature variations.

Another object of the invention is a method and apparatus that can be implemented with conventional interferometric objectives.

Still another goal is a method and apparatus that are suitable for incorporation within existing instruments.

A final object is a procedure that can be implemented easily and economically according to the above stated criteria.

Therefore, according to these and other objects, the present invention consists of the addition of structural components in an interferometric objective to offset the effects of temperature variations. The components are mounted between the sleeve housing the optics of the objective and the collar housing the optics of the interferometer. Each component is coupled sequentially, such that the thermal response of the assembly is substantially the linear combination of the response of each component and is designed to cause a shift in the opposite direction to the shift produced by a temperature change in the unmodified device. The thermal characteristics and dimensions of the components are chosen empirically to provide a minimum separation between the reference mirror and focal point in the interferometric objective as a function of temperature.

Various other purposes and advantages of the invention will become clear from its description in the specification that follows and from the novel features particularly pointed out in the appended claims. Therefore, to the accomplishment of the objectives described above, this invention consists of the features hereinafter illustrated in the drawings, fully described in the detailed description of the preferred embodiment and particularly pointed out in the claims. However, such drawings and description disclose but one of the various ways in which the invention may be practiced.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a simplified schematic representation of prior-art apparatus used in phase shifting and vertical scanning interferometry.

FIG. **2** is a schematic representation of a conventional microscope objective incorporating interferometric optics in Mirau configuration.

FIG. **3** illustrates the mismatch between the test and the reference focal lengths of a conventional interferometer caused by ambient temperature variations.

FIG. **4** illustrates the reference length and the test length in the microscope objective of FIG. **2** under nominal temperature conditions.

FIG. **5** is a schematic representation of a conventional interferometric microscope objective modified according to the invention.

FIGS. **6–9** illustrate the typical, substantially linear relationship between the shift in the position of the reference focal point with respect to the reference mirror with temperature changes in four commercial interferometric objectives.

FIG. **10** is a plot of average measured height of a fixed structure versus focal point shift to illustrate the parabolic nature of the correlation.

FIG. **11** shows four plots of average height measurements of fixed structures as a function of temperature variations for the same objectives of FIGS. **6–9** with one objective modified according to the invention.

FIG. **12** is a schematic representation of a conventional interferometric microscope objective modified according to an alternative embodiment of the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS OF THE INVENTION

The present invention is based on the discovery that the shift in position of the reference focal point with respect to the reference mirror in an interferometric objective as a function of temperature variations is roughly linear within the temperature range of interest. Accordingly, since the thermal expansion of most materials within a relatively narrow temperature range is also substantially linear, the invention consists of adding structural components to the objective with the appropriate thermal characteristics required to offset the objective's thermal response and empirically produce an assembly with an effective coefficient of thermal expansion substantially equal to zero within the temperature range of interest.

Referring to the drawings, wherein like parts are designated throughout with like numerals and symbols, FIG. **4** illustrates the optimal condition for operation of a conventional interferometric objective **22**. The distances traveled by the reference beam RB and the test beam TB are defined in terms of structural segments in the objective **22**. Note that a longitudinal position **48** is chosen to represent an average circumferential line of rigid connection within the attachment collar **36** coupling the support and focusing sleeves **32,34**. In fact, the two sleeves are coupled through a surface (the threaded interior surface of the attachment collar **36** mating with the threaded exterior surface of the support sleeve **32**), but the approximation is necessary to provide a longitudinal position corresponding to an effective point of attachment between the two sleeves. Thus, after entering the objective **22**, the reference beam RB (at that point coextensive with the beam L) travels a distance D**1** from the entry point **50** to the point of attachment **48**, then a distance D**2** to the splitter's surface **46**, and finally a distance D**3** to the reference focal point P'. Similarly, the test beam TB travels a distance D**4** from the entry point **50** to the focal point P. The goal of the invention is to manipulate the thermal

characteristics of the objective's components so that the paths to the reference mirror and to the test focal point (and therefore also to the reference focal point) retain substantially equal lengths in spite of temperature fluctuations. Expressed mathematically, it is desired that

$$D1(T)+D2(T)+D3(T)=D4(T), \quad (1)$$

where T is the temperature of the objective.

For various specific objectives, we discovered that the difference between the two paths as a function of temperature is substantially linear; that is,

$$\Delta D(T)=D1(T)+D2(T)+D3(T)-D4(T)=a+bT, \quad (2)$$

where a and b are the intercept and slope of a straight line equation. Note that $a=-bT_n$, T_n being the nominal temperature of the instrument at which $\Delta D(T_n)=0$ by design. Therefore, the goal is to modify the effective coefficient of expansion of the objective so that

$$\Delta D(T)=a+bT\approx 0 \quad (3)$$

for all T in the range of interest. This condition is achieved, of course, when $b\approx 0$.

This understanding of the structure and physical characteristics of the various components in an interferometric objective make it possible to judicially select appropriate materials and components to offset thermal effects. Referring to FIG. **5**, the structure of an interferometric objective **60** modified according to the invention is illustrated. The collar portion **35** (FIGS. **2** and **4**) housing the splitter **38** and reference flat **40** in the original focusing sleeve **34** is separated from the cylindrical portion of the sleeve and coupled to the support sleeve **32** by two new, substantially cylindrical components **62** and **63**. These components are coupled sequentially to increase the length of the material responsive to thermal effects and provide an opportunity to control the assembly's behavior by selecting materials with the appropriate thermal characteristics. Thus, a first component **62** is attached to and directed backward from the forward portion of the support sleeve **32**; then, a second component **63** is attached to and directed forward from the backward portion of component **62**, and is finally coupled to the original collar portion **35**. Thus, a thermal effect will result substantially in the linear combination of the effect on each individual segment of the assembly.

In this new configuration, the distances traveled by the reference beam RB and the test beam TB are defined in terms of the new structural segments in the objective **60**. As in the case of FIG. **4**, longitudinal positions **48** and **64** are chosen to represent average points of rigid connection within respective attachment collars **36** and **66**. The position **64** is intended to represent the position of an effective circumferential line of attachment between the support sleeve **32** and the first component **62**; and the position **48** represents the position of an effective circumferential line of attachment between the first component **62** and the second component **63**. The second component **63** is then connected to the collar portion **35** so as to form an integral member (such as by a solid connection along the annular surface **37**). As in the case illustrated in FIG. **4**, in fact the various members constituting the structure of the objective **60** are coupled through surface attachment (one of which is threaded for focusing purposes), but the line-contact approximations are necessary to provide longitudinal positions corresponding to effective points of attachment between the various components.

Based on the configuration of FIG. **5**, after entering the objective **60**, the reference beam RB (coextensive with the beam L at the point of entry) travels a distance D**0** forward from the entry point **50** to the splitter's surface **46**, and then a distance D**4** backward to the reference focal point P'. Similarly, the test beam TB travels a distance D**5** from the entry point **50** to the focal point P. Analyzing the thermal effects on the structure of the objective **60**, the distance D**0** varies as a result of the composite lengthening or shortening of the support sleeve **32**, the first component **62**, the second component **63**, and the collar portion **35**. So long as the contact surfaces in the attachment collars **36** and **66** are relatively small in comparison to the lengths of the various members (so that the effective-point-of-attachment approximation discussed above is valid), the distance D**0** can be expressed in terms of the distance D**1** from the entry point **50** to the point of attachment **66** between the support sleeve **32** and the first component **62**, the distance D**2** to the point of attachment **48** of the first component **62** to the second component **63**, and the distance D**3** to the splitter's surface **46**, as follows

$$D0(T)=D1(T)-D2(T)+D3(T). \quad (4)$$

Since the goal of the invention remains to manipulate the thermal characteristics of the objective's components so that the reference and test lengths remain substantially equal in spite of temperature fluctuations, the following new identity becomes the desirable goal of the invention

$$D1(T)-D2(T)+D3(T)+D4(T)=D5(T), \quad (5)$$

where T is the temperature of the objective.

That is, the length and material of the components **62** and **63** can be selected so that the shift caused by a temperature differential ΔT between the reference and test lengths is substantially zero within the temperature range of operation. Since the total path length variation ΔD with temperature is the result of the cumulative effect of the length change in each structural segment, the change along the reference beam caused by a temperature differential ΔT is given by

$$\Delta D=\Delta D1-\Delta D2+\Delta D3+\Delta D4 \quad (6)$$

Assuming that the support sleeve **32** and the collar portion **35** are made of the same material **1** with a coefficient of thermal expansion k_1 and that the components **62** and **63** are made of materials **2** and **3** with coefficient of thermal expansion k_2 and k_3, respectively, Equation 6 can be expressed in terms of the length and thermal-expansion coefficient of each segment, as follows

$$\Delta D=k_1D1(\Delta T)-k_2D2(\Delta T)+k_3D3(\Delta T)+k_1D4\ (\Delta T). \quad (7)$$

Furthermore, based on the experimental observation that over the temperature of interest the length of the test beam D**5** varies approximately linearly with temperature, the following can be written:

$$\Delta D5=KD5(\Delta T) \quad (8)$$

where K is an approximate linear expansion coefficient including both mechanical and optical temperature effects on the length of the test beam.

Setting Equation 7 equal to ΔD**5** yields the relation necessary to produce zero relative shift between the reference and test lengths as a function of temperature, thereby producing the approximate a thermal behavior that is desired

for the interferometric objective of the invention. This relation can be written as:

$$KD5=k_1(D1+D4)-k_2D2+k_3D3. \quad (9)$$

Based on Equation 9, it is possible to judiciously select materials for components **62** and **63** that will approximate the desired zero-shift behavior. Once k_2 and k_3 are selected, lengths for D2 and D3 can also be selected to fit the equation, and then optimized by empirical testing to account for the analytical approximations of the procedure. We found that this theoretical approach, further refined with empirical data, produces great improvements in the performance of conventional interferometric objectives.

For example, a Nikon objective model CF Plan 50x/0.55 DI, Part No. 405001, originally constructed with a support sleeve **32** (about 3.6 cm long) and a focusing sleeve **34** made of brass, was modified according to the invention by providing intermediate components **62** and **63** substantially as shown in FIG. **5**. Invar **36** (an iron alloy with 36% nickel and small quantities of manganese, silicon, and carbon) was selected for component **62**. Invar **36** is used in optical instruments because of its very low coefficient of thermal expansion (~1.26 ppm/° C.) over the limited temperature range of interest for most commercial applications (typically between 4 and 38° C.). An aluminum alloy (alloy 6061, made with 0.6 silicon, 0.25 copper, 1.0 magnesium, and 0.2 chromium, having a coefficient of thermal expansion of ~23.6 ppm/° C.) was selected for component **63**. The combination showed excellent thermal behavior for the purposes of the invention, where D2 and D3 were approximately 3.6 cm and 3.8 cm long, respectively.

FIGS. **6–9** illustrate the typical, substantially linear relationship between the shift in the position of the reference focal point P' with respect to the reference mirror **42** with temperature changes in four commercial interferometric objectives. Note that each figure represents data from three sets of measurements fitted with a straight line for a given objective. Each line 70,72,74,76 represents the particular thermal characteristics of its corresponding objective.

Based on the discovery illustrated in FIGS. **6–9**, the corrective approach disclosed above was followed with the object of designing intermediate components **62** and **63** that would reduce the slope of the lines **72–76** to zero. In order to provide flexibility of design for the components **62** and **63** of the invention, we found that the materials selected should preferably combine a relatively low with a relatively high coefficient of thermal expansion. By incorporating the Invar **36** and aluminum components described above in the tested Nikon objectives in a structural configuration of the type shown in FIG. **5**, we were able to change the objective's thermal characteristics and produce a substantially a thermal response. In fact, the thermal response of the modified objectives was so small that it was not possible to directly measure the shift in the position of the reference focal point P' with respect to the reference mirror **42** as a function of temperature changes because it was found to be within the measurement error.

In order to overcome this difficulty, we exploited a correlation, which is well known in the art, between measured heights and focal point shifts resulting from temperature variations. It is known that height measurements of a specific structure on a test surface decrease for temperatures both below and above the nominal temperature of the instrument (that is, the temperature at which the reference mirror **42** is in focus by design or calibration), producing parabolic plots of height versus focal-point-shift of the type shown in FIG. **10** (wherein the data are curve fitted to illustrate their parabolic nature). A corresponding parabolic plot is also produced by height-versus-temperature measurements. Therefore, the effectiveness of the invention was confirmed by plotting the measured average height of a fixed structure in a sample surface as the position of the focal point with respect to the reference mirror (or viceversa) was changed by induced temperature variations. In practice, a flattening of the height-versus-temperature curve produced by the structural modifications of the invention is a measure of a corresponding flattening of the shift-versus-temperature curve of FIGS. **6–9**, which is the goal of the invention.

Accordingly, the invention was tested by plotting average height measurements of a fixed structure as a function of temperature within the range of interest. The structure used consisted of laser texture bumps in a computer drive disk. FIG. **11** shows such plots for the same objectives of FIGS. **6–9** with one objective (#4) modified according to the invention. The parabolic data **80**, **82** and **84** correspond to unmodified objectives with nominal temperatures of about 20, 22 and 25° C., while the substantially linear data **86** correspond to the objective modified according to the invention. Note that data **82** and **86** were fitted by least squares techniques to illustrate the parabolic and substantially linear nature of these data. It is clear from the figure that the addition of components **62** and **63** produced a substantially a thermal objective for which no nominal temperature is identifiable.

It is understood that the concept of the invention is applicable to minimize thermal effects in optical devices with different structural configurations from the objective of FIG. **4**. Components may be added with different lengths and shapes as determined necessary to neutralize focal-point thermal shifts within the temperature range of interest. FIG. **12** is an assembly drawing of another embodiment **90** of the invention where the second component **63** is divided into a fixed portion **92** and a rotatably-movable focusing portion **94**. A commercial interferometric objective **96**, such as the Nikon objective described above, is mounted to the components constituting the invention. One end of a cylindrical first component **62** made of Invar alloy is fixedly connected to the support sleeve of the objective (not seen in the drawing) by means of radial set screws **98**. The fixed portion **92**, made of aluminum alloy, is fixedly connected to the other end of the first component **62** by means of similar set screws **100** (note that no other fixed contact exists between the two structures, so that they are free to move with respect to one another as a result of thermal effects). Finally, the focusing portion **94** is fixedly connected to the collar **102** containing the interferometric optics in the objective **96** and is screwably connected to the fixed portion **92**. The screwable connection is provided by means of radially-distributed threaded inserts **104** meshed with conforming threads **106** (shown enlarged for convenience) in the outer surface of the fixed portion **92**, so that the focusing portion **94** can be rotated and shifted axially to focus the test beam on a sample surface (not shown). Set screws **108** are also used to cause and adjust the engagement of the inserts **104** with the threads **106**.

The invention has been described for convenience illustrating an interferometric objective in horizontal position. In practice, these objectives are usually mounted in vertical position and translated to perform vertical scanning downward from an initial reference position. Similarly, the invention has been described in terms of the effective addition of two new components having a length approximately equal to that of the objective, but different lengths and more or less components could obviously be used if necessary to achieve

the goals of the invention. For example, the first and second components **62**,**63** in FIG. **5** could be extended beyond the length of the objective to provide additional overall thermal expansion. Equivalently, multiple layers of Invar and aluminum components could be connected sequentially and stacked to produce the same effect. Finally, materials with different thermal-expansion characteristics could be used to match the requirements of the particular application.

It is also understood that the concept of the invention is applicable in equivalent fashion not only to interferometric microscope objectives but to any optical device exhibiting a substantially linear focal point misalignment in response to thermal effects and where a second surface must be held in focus throughout some temperature range of interest. In devices exhibiting a nonlinear, but known, thermal response, the invention could still be practiced by assuming a linear behavior over a limited range around the nominal temperature of the instrument. For example, the device's thermal response could be approximated by a linear model over the range of interest and the model could then be used as described to minimize thermal shifts.

Therefore, various changes in the details, steps and components that have been described may be made by those skilled in the art within the principles and scope of the invention herein illustrated and defined in the appended claims. While the present invention has been shown and described herein in what is believed to be the most practical and preferred embodiments, it is recognized that departures can be made therefrom within the scope of the invention, which is not to be limited to the details disclosed herein but is to be accorded the full scope of the claims so as to embrace any and all equivalent processes and products.

We claim:

1. In an optical device including a reference surface fixed in a first support structure and lens means housed in a second support structure for focusing a beam of light onto said surface along an optical axis, said first and second support structures being mechanically connected by rigid coupling means having a length responsive to thermal effects, and the optical device having an optimal operating condition at a predetermined nominal temperature wherein a focal point position of said lens means coincides with a location of said reference surface along said optical axis, a method for maintaining substantial coincidence of said focal point position with said location of the reference surface with temperature variations, the method comprising the following steps:

establishing a first functional relationship between a range of temperature variations and shifts produced thereby in said focal point position with respect to an entry point in the optical device;

establishing a second functional relationship between said range of temperature variations and shifts produced thereby in said location of the reference surface with respect to the entry point in the optical device;

altering said length responsive to thermal effects by introducing at least one additional component in the rigid coupling means connecting the first and second support structures; and

selecting a length and a coefficient of thermal expansion of said at least one additional component adapted to maintain a substantial identity between said first and second functional relationships such that said shifts in the focal point position and in the location of the reference surface with respect to the entry point in the optical device are approximately equal, thereby causing said optimal operating condition to be substantially maintained within the range of temperature variations.

2. The method of claim **1**, wherein said optical device consists of an interferometric microscope objective, said first structure consists of a collar fixedly housing said surface, and said second structure consists of a sleeve fixedly housing said lens means.

3. The method of claim **2**, wherein said first and second functional relationships are substantially linear.

4. The method of claim **2**, wherein said at least one additional component comprises a first component coupled to said sleeve and a second component coupled to said collar.

5. The method of claim **4**, wherein said first and second components are coupled to one another so as to produce an increase in said length responsive to thermal effects.

6. The method of claim **3**, wherein said at least one additional component comprises a first component coupled to said sleeve and a second component coupled to said collar.

7. The method of claim **6**, wherein said first and second components are coupled to one another so as to produce an increase in said length responsive to thermal effects.

8. The method of claim **5**, wherein said first component comprises a portion made with an iron-nickel alloy and said second component comprises a portion made with an aluminum alloy.

9. The method of claim **7**, wherein said first component comprises a portion made with an iron-nickel alloy and said second component comprises a portion made with an aluminum alloy.

10. In an optical device including a reference surface fixed in a first support structure and lens means housed in a second support structure for focusing a beam of light onto said surface along an optical axis, said first and second support structures being mechanically connected by rigid coupling means having a length responsive to thermal effects, and the optical device having an optimal operating condition at a predetermined nominal temperature wherein a focal point position of said lens means coincides with a location of said reference surface along said optical axis, apparatus for maintaining substantial coincidence of said focal point position with said location of the reference surface with temperature variations, the apparatus comprising:

at least one additional component incorporated in the rigid coupling means connecting the first and second support structures;

wherein said at least one additional component is selected according to the following procedure:

establishing a first functional relationship between a range of temperature variations and shifts produced thereby in said focal point position with respect to an entry point in the optical device;

establishing a second functional relationship between said range of temperature variations and shifts produced thereby in said location of the reference surface with respect to the entry point in the optical device; and

establishing a length and a coefficient of thermal expansion for said at least one additional component adapted to maintain a substantial identity between said first and second functional relationships such that said shifts in the focal point position and in the location of the reference surface with respect to the entry point in the optical device are approximately equal, thereby causing said optimal operating condition to be substantially maintained within the range of temperature variations.

11. The apparatus of claim **10**, wherein said optical device consists of an interferometric microscope objective, said

first structure consists of a collar fixedly housing said surface, and said second structure consists of a sleeve fixedly housing said lens means.

12. The apparatus of claim **11**, wherein said first and second relationships are substantially linear.

13. The apparatus of claim **11**, wherein said at least one additional component comprises a first component coupled to said sleeve and a second component coupled to said collar.

14. The apparatus of claim **13**, wherein said first and second components are coupled to one another so as to produce an increase in said length responsive to thermal effects.

15. The apparatus of claim **12**, wherein said at least one additional component comprises a first component coupled to said sleeve and a second component coupled to said collar.

16. The apparatus of claim **15**, wherein said first and second components are coupled to one another so as to produce an increase in said length responsive to thermal effects.

17. The apparatus of claim **14**, wherein said first component comprises a portion made with an iron-nickel alloy and said second component comprises a portion made with an aluminum alloy.

18. The apparatus of claim **16**, wherein said first component comprises a portion made with an iron-nickel alloy and said second component comprises a portion made with an aluminum alloy.

19. The apparatus of claim **10**, wherein said first functional relationship is based on length and coefficient-of-thermal-expansion parameters for the optical device and said second functional relationship is based on length and coefficient-of-thermal-expansion parameters for said coupling means.

20. The apparatus of claim **13**, wherein a length and a coefficient of thermal expansion for each of said first and second components are selected using the following identity between said first and second functional relationships:

$$KD5=k_1(D1+D4)-k_2D2+k_3D3,$$

wherein D**1** is an effective optical length along the optical axis for said sleeve from said entry point; D**2** and D**3** are effective optical lengths along the optical axis for the first component coupled to the sleeve and the second component coupled to the collar, respectively; D**4** is an effective optical length along the optical axis for the collar; D**5** is an optical distance of the focal point from the entry point; k_1 is a coefficient of thermal expansion for the sleeve and the collar; k_2 and k_3 are coefficients of thermal expansion for the first component coupled to the sleeve and the second component coupled to the collar, respectively; and K is an approximate linear expansion coefficient including both mechanical and optical temperature effects for the optical device.

21. The method of claim **1**, wherein said first functional relationship is based on length and coefficient-of-thermal-expansion parameters for the optical device and said second functional relationship is based on length and coefficient-of-thermal-expansion parameters for said coupling means.

22. The method of claim **4**, wherein a length and a coefficient of thermal expansion for each of said first and second components are selected using the following identity between said first and second functional relationships:

$$KD5=k_1(D1+D4)-k_2D2+k_3D3$$

wherein D**1** is an effective optical length along the optical axis for said sleeve from said entry point; D**2** and D**3** are effective optical lengths along the optical axis for the first component coupled to the sleeve and the second component coupled to the collar, respectively; D**4** is an effective optical length along the optical axis for the collar; D**5** is an optical distance of the focal point from the entry point; k_1 is a coefficient of thermal expansion for the sleeve and the collar; k_2 and k_3 are coefficients of thermal expansion for the first component coupled to the sleeve and the second component coupled to the collar, respectively; and K is an approximate linear expansion coefficient including both mechanical and optical temperature effects for the optical device.

* * * * *

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United States Patent [19]

Dan

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[45] Date of Patent: Sep. 21, 1999

[54] **AUTOMATED THRESHOLD-RELATED OBJECTIVE PERIMETRY**

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[51] **Int. Cl.**[6] **A61B 3/10**

[52] **U.S. Cl.** **351/221**; 351/205; 351/210

[58] **Field of Search** 351/221, 211, 351/205, 200, 246, 247, 212, 204, 222, 223, 224, 210, 209

[56] **References Cited**

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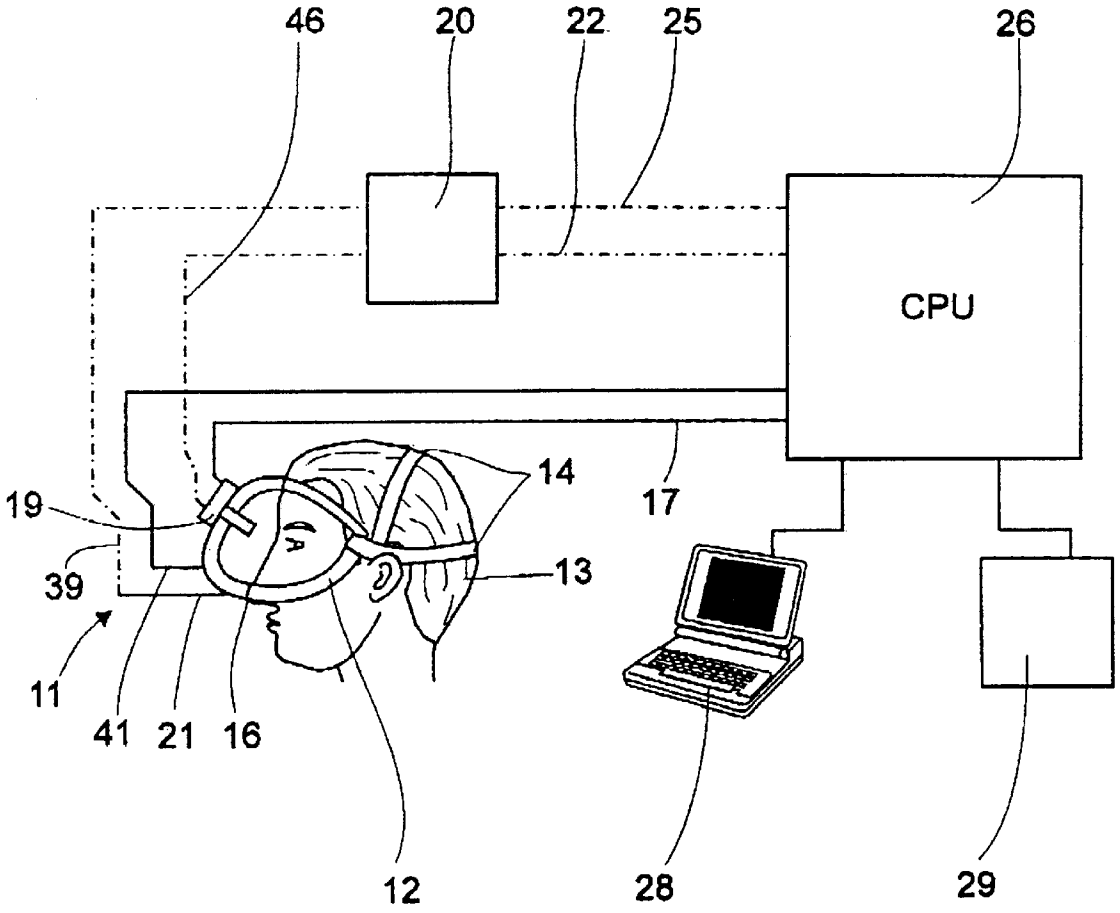
Primary Examiner—Hung Xuan Dang
Attorney, Agent, or Firm—Mark M. Friedman

[57] **ABSTRACT**

A system for an examination of an eye of a patient, the system including: (a) a head set attached to the head of the patient; (b) a screen attached to the head set, such that the eye of the patient is covered by the screen; (c) a plurality of light sources attached to the screen, such that light is projected from at least one of the light sources directly to a preselected area of the retina of the eye of the patient to form reflected light; (d) a light receiving device attached to the head set to receive the reflected light and to transmit a signal according to the received reflected light; (e) an eye tracking device to determine the position of the eye relative to the light receiving device; and (f) a microprocessor for receiving the signal and for analyzing the signal to determine a size of a pupil of the eye and an amount of light reflected from the retina of the eye, such that a pupillary light response is measured to perform the examination. Also provided is a method for using the system of the present invention to perform an examination of the visual field of an eye of the patient. Preferably, the light receiving device is also able to continuously track, or follow, the position of the eye relative to the light receiving device. The method of examination preferably includes the steps of tracking the position of the eye, stimulating a preselected area of the retina with light at a retinal threshold intensity and then measuring both pupillary size and the amount of reflected light in order to determine the field of vision of the patient.

9 Claims, 2 Drawing Sheets



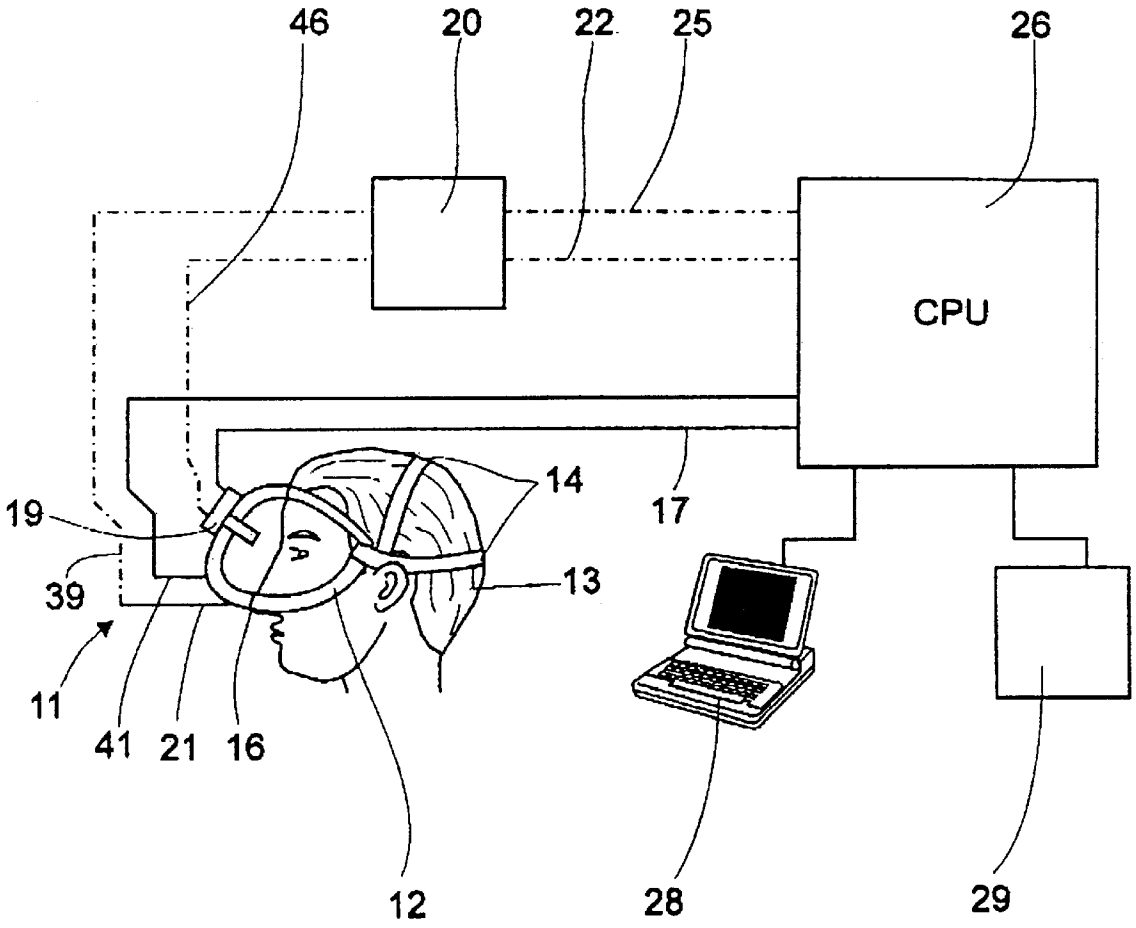


Fig. 1

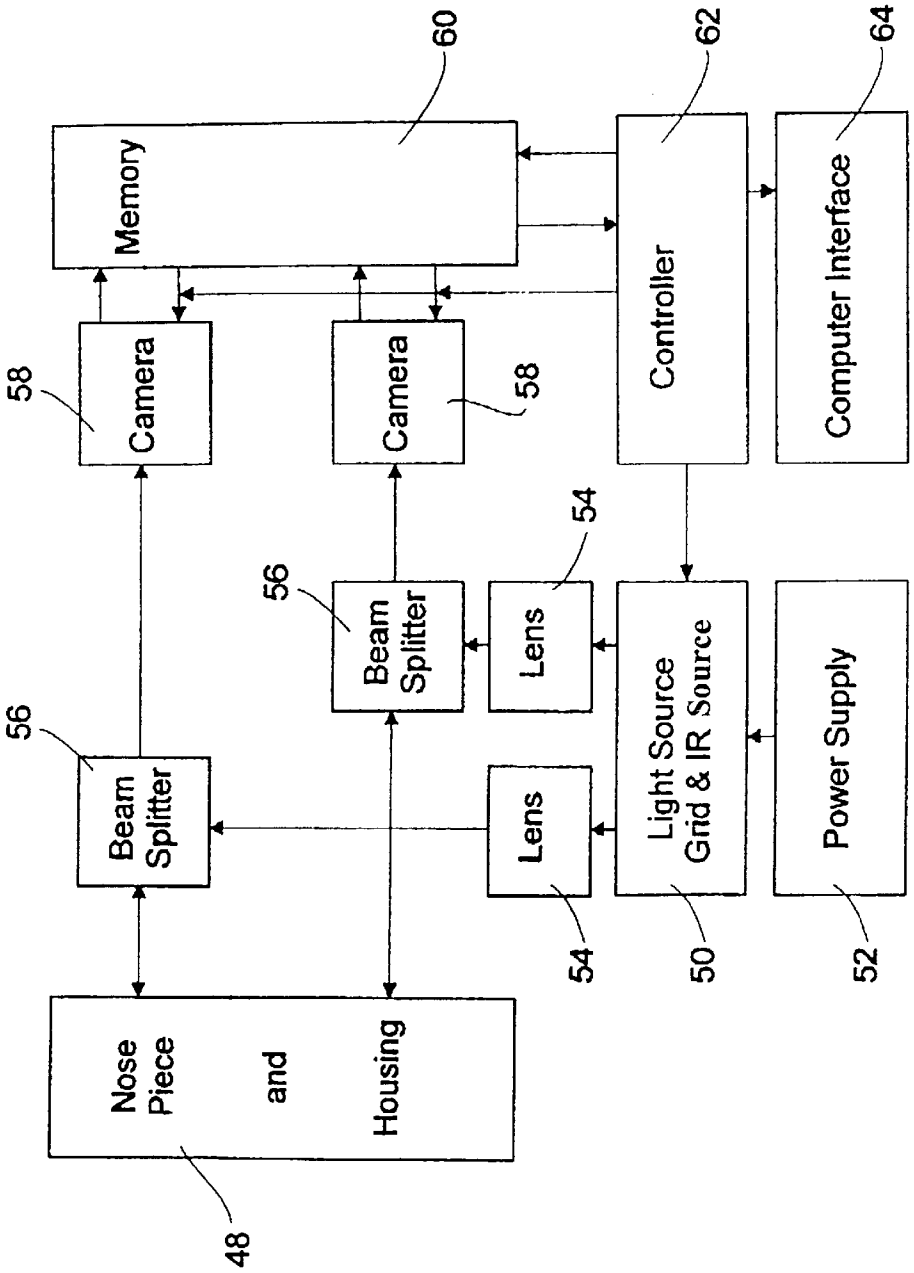


Fig. 2 Sensor Block Diagram

AUTOMATED THRESHOLD-RELATED OBJECTIVE PERIMETRY

FIELD AND BACKGROUND OF THE INVENTION

The present invention is concerned with methods and equipment for diagnostic tests of the eyes, and more particularly, with an automatic system for examination of the field of vision of a patient. The system is mounted on a head set and is equipped to continuously track eye movement so as to focally project a spot of retinal threshold-related light stimuli on preselected retinal areas, regardless of the direction of the gaze of the patient or of the orientation of the head of the patient. The system can concomitantly measure the pupil size and intensity of light reflected through the pupil as a result of the light projected.

The examination of the field of vision of a patient is an extremely important diagnostic tool used to identify and analyze diseases and defects of the retina and as visual pathways, such as glaucoma, optic neuropathy, multiple sclerosis and compression of the visual pathways. In the past, such an examination was performed with manually operated field of vision test instruments known as perimeters. Manually operated perimeters require the services of a physician or a skilled technician in order to examine the patient. In the most widely used system, known as the Goldmann system, the patient must sit still, head clamped in place, and constantly watch a fixation target at the center of a hemispherical screen to eliminate any uncertainties caused by head and eyes movements. A small point of light of varied intensity, size and color is projected onto the screen and its position is varied by the operator. The limits of the visual field are determined on the basis of the manual or verbal indications of the patient as to when the point of light comes into or goes out of view as the light is moved radially between the periphery and the center of his view. The examiner must continuously watch the patient to ascertain that the eye of the patient is fixated on the center of the screens since the examination results are artefactual if the eyes of the patient are not immobile. These factors render the examination of the extent of the field of vision using the commonly available Goldmann system is basically subjective, dependent to a large extent on the skill of the examiner, the fatigue level of the patient and the ability of the examiner to communicate with the patient. Thus, the Goldmann system is not operable for small children and patients who must remain in a supine position.

More recently, automatic perimeters have been marketed and used. However, even these instruments rely upon the Goldmann system and incorporate the control of a microprocessor in order to more efficiently measure the effect of light stimuli from external sources. Other prior art instruments have added a head set or helmet to eliminate any effect of head movements on the final results, as disclosed in United Kingdom Application No. 2096791 and two reports from the IOVS [J. Whiteside-Michel et al., "Virtual Reality Visual Field Test.", IOVS/97, 38:4, S569; and L. Brigatti et al., "Virtual Perimetry: A Novel Perinmetric Technique", IOVS/97, 38:4, S572]. Alternatively, various systems have been disclosed which use more objective means for perimetry such as pupillary size determination during Humfrey perimetry, as disclosed in U.S. Pat. No. 5,490,098. U.S. Pat. No. 5,114,222 discloses a method which includes a light stimulus moved in a continuous circular path according to decreased pupillary response. U.S. Pat. No. 5,459,536 discloses an instrument which includes a device to track eye movement, so that such movements can be incorporated into the final analysis of the results. However, all of these instruments and methods perform indirect measurements in which the light stimulus is projected in front of the eyes of the patient, rather than directly stimulating the retinal nerve fibers with fight.

There is thus an unmet medical need for a method and a system which objectively examines the visual field of a patient in which the retinal nerve fibers are directly stimulated by a retinal threshold-related light stimulus, such that the change in pupillary size in response to this light is automatically measured, and such that this measurement is cross-checked by determination of the change in the amount of light reflected from the retina, such that the patient does not need to remain substantially immobile during the examination and such that the method and system can be used to examine patients which must remain supine or who cannot otherwise comply with the requirements of prior art manual perimetry methods.

SUMMARY OF THE INVENTION

According to the present invention, there is provided a system for an examination of an eye of a patient, the system including: (a) a head set attached to the head of the patient; (b) a screen attached to the head set, such that the eye of the patient is covered by the screen; (c) a plurality of light sources attached to the screen, such that light is projected from at least one of the light sources directly to a retina of the eye of the patient to form reflected light; (d) a light receiving device attached to the head set to receive the reflected light and to transmit a signal according to the received reflected light; and (e) a microprocessor for receiving the signal and for analyzing the signal to determine a size of a pupil of the eye and an amount of light reflected from the retina of the eye, such that a pupillary light response is measured to perform the examination.

Preferably, the light receiving device also collects a visual image of the pupil, the visual image indicating an apparent shape of the pupil, such that a location of the pupil and a position of the eye relative to the light receiving device is determinable from the apparent shape. More preferably, the light sources are in a form of a dense grid, such that a particular light source is able to illuminate a specific area of the retina. Most preferably, the microprocessor transmits a return signal to the light sources, such that the particular light source is selected according to the location of the pupil in order to illuminate the specific area of the retina. Also most preferably, an characteristic of light projected by the at least one light source is determined according to the return signal, the characteristic being selected from the group consisting of an intensity and a wavelength of the light.

According to other preferred embodiments of the present invention, the light source is of a type selected from the group consisting of halogen lamp, mercury arc lamp and LED. Preferably, the halogen lamp and the mercury arc lamp feature a plurality of optic fibers for focusing the emitted light on the retina of the eye.

According to another embodiment of the present invention, there is provided a method for determining a visual field of an eye of a patient, the method comprising the steps of: (a) providing an instrument for determining the visual field, the instrument featuring: (i) a head set attached to the head of the patient; (ii) a screen attached to the head set, such that the eye of the patient is covered; (iii) a plurality of light sources attached to the screen; (iv) an eye tracking device; (v) a light receiving device attached to the head set;

and (vi) a microprocessor; (b) continuously following a position of the eye relative to the light receiving device; (c) projecting light from at least one of the light sources directly onto a preselected area of a retina of the eye; (d) measuring an amount of reflected light from the retina and capturing a visual image of a pupil of the eye with the light receiving device; (e) calculating a pupillary light response from the amount of reflected light and from the visual image of the pupil with the microprocessor; and (f) determining the visual field of the eye from the pupillary light response.

Hereinafter, the term "patient" refers to any subject, particularly a human or higher mammal, capable of being examined with the system of the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention is herein described, by way of example only, with reference to the accompanying drawings, wherein:

FIG. **1** is an illustration of the system of the present invention.

FIG. **2** is a sensor block diagram of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention is of an automatic perimetry system, including an instrument for automated perimetry measurements and a method for operating the instrument. The system includes a headset to be placed on the head of a patient. The headset supports a screen for background illumination; an eye tracking device; a plurality of light sources for focal retinal stimulation; and two light receiving devices, one for each eye. The light sources are preferably capable of emitting light of an adjustable intensity, such that the intensity of the light matches the threshold of the retina to light stimuli. Preferably, each light receiving device is able to follow the position of the eye, to measure the amount of light reflected from the retina, and to visually capture an image of the pupil itself. Thus, the eye tracking device is preferably incorporated within the light receiving device.

The output of the light receiving devices, in terms of both the amount of light reflected from the retina and the image of the pupil, is sent to a microprocessor. From this output, the microprocessor continuously calculates both the resulting pupillary area and the correct amount of reflected light to determine the pupillary light response. Preferably, the microprocessor incorporates information about the position of the eye relative both to the particular active light source and to the light receiving device, such that even if the eye moves, the pupillary light response can be accurately determined. The position of the pupil relative to the light receiving device and the light sources can be determined from the visual image of the pupil. When the pupil is viewed straight on, the pupil appears to be round. If the eye moves so that the pupil is now viewed at an angle, the shape of the pupil appears to change to an oval. Thus, the microprocessor, or more accurately the software instructions performed by the microprocessor, is able to determine the position of the pupil from the visual image.

The microprocessor also directs the light emission from the different light sources to preselected loci on the retina of the eye of the subject, according to the above analysis of the output of the light receiving devices. For example, in order to stimulate one particular area of the retina, the microprocessor must select one particular light source which is focused on that area. In order to determine which light source should be selected, the microprocessor preferably first determines the position of the eye, and hence of the retina, relative to the plurality of light sources. Next, the particular light source which can stimulate the desired retinal area at that moment is selected. The output of the light receiving device is then analyzed as described previously.

Since both the light emission source and the light receiving devices are attached to the headset; the pupil size, amount of reflected light and eye movement can be continuously monitored. Such continuous monitoring permits consensual pupillary monitoring whereby movement of the head and eyes of the patient during perimetry testing does not affect the test results, thus objectively measuring the visual field by automatic determination of the pupillary light response.

The principles and operation of a system according to the present invention may be better understood with reference to the drawing and the accompanying description.

Referring now to the drawing, FIG. **1** illustrates the automatic perimetry system of the present invention. A system **11** includes a head set **12**, in a view partially cut away to show the interior. Head set **12** is attached to the head **13** of a patient, preferably by straps **14**. Head set **12** preferably has an oval shape with a hemispherical construction covering the eyes and the upper part of the face of the patient. Such a construction enables a hemispherical screen **16** to be placed within head set **12**. A plurality of light sources **19** are attached to hemispherical screen **16**. Preferably, hemispherical screen **16** is very close to the eyes of the patient, even as close as about 2 cm. Also preferably, light sources **19** substantially cover the surface of hemispherical screen **16** in the form of a dense grid, for example. Such a grid enables a particular light source **19** to be selected for emitting light in a highly focused manner. Also, such a grid eliminates the need for any mechanical movement of light sources **19** in order to focus on a particular portion of the retina, since simply illuminating one particular tight source **19** would stimulate only one specific area of the retina, automatically giving focus to the emitted light.

Light sources **19** are preferably in the form of a LED, in which the light is generated by a power supply device **20** also attached to head set **12**, more preferably mounted on the outer periphery of head set **12**. Alternatively and preferably, light could be generated by a halogen lamp or a mercury arc lamp connected to power supply device **20** and then directed to the retina by a bundle of fiber optics, the end of each fiber forming a point on the dense grid. In any case, light is focused on a specific area of the retina regardless of any movements of the head or eyes of the patient for a number of reasons. First, light sources **19** are directly attached to head set **12** so that light sources **19** move with the movements of the patient. Second, in the preferred embodiment of a dense grid of light sources **19**, a specific area of the retina is illuminated by the emission of light from one particular light source **19**. These features enable the emitted light to be correctly reflected from the retina of the patient.

Once light is reflected from the retina of the eye of the patient, the reflected light is detected by a light receiving device **21** mounted in the inner periphery of head set **12**. Light receiving device **21** is preferably supplied with energy by power supply device **20**. Light receiving device **21** preferably is a CCD camera, although alternatively light receiving device **21** could be at least one photomultiplier tube. A CCD camera is more preferable because such a camera is capable of continuous video monitoring of the

pupil, including both the capture of a visual image of the pupil and the measurement of the amount of light reflected from the retina. Such information can be used to determine the position of the eye relative to the horizontal and vertical axes, as well as to cross-check the eye position by using the Hirshberg corneal reflex. Thus, light receiving device **21** preferably collects a visual image of the pupil and the amount of light reflected from the retina, and then transmits this information in the form of signals.

These signals obtained by light receiving device **21** are then transmitted through a communication link such as a cable **41** to a microprocessor **26**. Microprocessor **26** operates software (not shown), which permits the analysis of the received data to determine the measured pupillary light response. In particular, the software preferably first analyzes the visual image of the pupil in order to determine the location of the pupil relative to both the particular light source **19** which was illuminated and to light receiving device **21**. As noted previously, such an analysis could include the determination of the apparent shape of the pupil from the visual image which gives information about the position of the pupil relative to light receiving device **21**, and hence to light source **19**. Next, the software determines the size of the pupil both directly from the visual image and also from the amount of light reflected from the retina, which is determined by the size of the pupil. Finally, all of this information is analyzed to determine if the response to stimulation of a particular area of the retina was normal or abnormal.

The software also uses the analysis to enable microprocessor **26** to send return signals to light sources **21**, causing the right intensity of light to be generated by the desired light source **21**, such that light is projected to an area of the retina selected by the software in order to more accurately assess the field of vision. Each area of the retina can thus be examined separately, regardless of the movement of the eye or the position of the pupil, without any voluntary activity on the part of the patient.

Preferably, microprocessor **26** is able to connect and download the data into a computer or alternatively directly to a printer. According to other preferred embodiments, microprocessor **26** also controls the wavelength of light emitted by light sources **19**. Such control could permit additional types of ocular examinations to be performed with system **11**.

While the invention has been described with respect to a limited number of embodiments, it will be appreciated that many variations, modifications and other applications of the invention may be made.

What is claimed is:

1. A system for an examination of an eye of a patient, the system comprising:

(a) a head set attached to the head of the patient;

(b) a screen attached to said head set, such that the eye of the patient is covered by said screen;

(c) a plurality of light sources attached to said screen, such that light is projected from at least one of said light sources directly to a retina of the eye of the patient to form reflected light;

(d) a light receiving device attached to said head set to receive said reflected light and to transmit a signal according to said received reflected light; and

(e) a microprocessor for receiving said signal and for analyzing said signal to determine a size of a pupil of the eye and an amount of light reflected from said retina of the eye, such that a pupillary light response is measured to perform the examination.

2. The system of claim **1**, wherein said light receiving device also collects a visual image of said pupil, said visual image indicating an apparent shape of said pupil, such that a location of said pupil and a position of the eye relative to said light receiving device is determinable from said apparent shape.

3. The system of claim **2**, wherein said light sources are in a form of a dense grid, such that a particular light source is able to illuminate a specific area of said retina.

4. The system of claim **3**, wherein said microprocessor transmits a return signal to said light sources, such that said particular light source is selected according to said location of said pupil in order to illuminate said specific area of said retina.

5. The system of claim **4**, wherein an characteristic of light projected by said at least one light source is determined according to said return signal, said characteristic being selected from the group consisting of an intensity and a wavelength of said light.

6. The system of claim **1**, wherein said light source is of a type selected from the group consisting of halogen lamp, mercury arc lamp and LED.

7. The system of claim **6**, wherein said mercury arc lamp features a plurality of optic fibers for focusing said emitted light on said retina of the eye.

8. The system of claim **6**, wherein said halogen lamp features a plurality of optic fibers for focusing said emitted light on said retina of the eye.

9. A method for determining a visual field of an eye of a patient, the method comprising the steps of:

(a) providing an instrument for determining the visual field, the instrument featuring:

(i) a head set attached to the head of the patient;

(ii) a screen attached to said head set, such that the eye of the patient is covered;

(iii) a plurality of light sources attached to said screen;

(iv) an eye tracking device attached to said head set;

(v) a light receiving device attached to said head set; and

(vi) a microprocessor;

(b) continuously following a position of the eye with said eye tracking device;

(c) projecting light from at least one of said light sources directly onto a preselected area of a retina of the eye, said light being at a retinal threshold intensity;

(d) measuring an amount of reflected light from said retina and capturing a visual image of a pupil of the eye with said light receiving device;

(e) calculating a pupillary light response from said amount of reflected light according to said position of the eye and from said visual image of said pupil with said microprocessor; and

(f) determining the visual field of the eye from said pupillary light response.

* * * * *

US005940111A

United States Patent [19]

Akada et al.

[11] Patent Number: 5,940,111

[45] Date of Patent: Aug. 17, 1999

[54] **IMAGE FORMATION ON OBJECTIVE BODIES**

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[73] Assignee: **Dai Nippon Insatsu Kabushiki Kaisha**, Japan

[21] Appl. No.: **08/797,726**

[22] Filed: **Feb. 11, 1997**

Related U.S. Application Data

[62] Division of application No. 08/395,850, Feb. 28, 1995, which is a continuation of application No. 08/034,186, Mar. 18, 1993, Pat. No. 5,451,560, which is a continuation of application No. 07/467,415, Jan. 19, 1990, abandoned, which is a division of application No. 07/138,384, Dec. 8, 1997, Pat. No. 4,923,848.

[30] **Foreign Application Priority Data**

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Apr. 11, 1986	[JP]	Japan	61-81989
Sep. 24, 1986	[JP]	Japan	61-223896
Sep. 24, 1986	[JP]	Japan	61-225473
Oct. 1, 1986	[JP]	Japan	61-231224
Jan. 14, 1987	[JP]	Japan	62-5066
Apr. 10, 1987	[WO]	WIPO	PCT/JP87/00228

[51] **Int. Cl.**[6] **B41J 2/325**

[52] **U.S. Cl.** **347/213**

[58] **Field of Search** 347/171, 213; 400/120.01, 120.02, 120.04; 503/227

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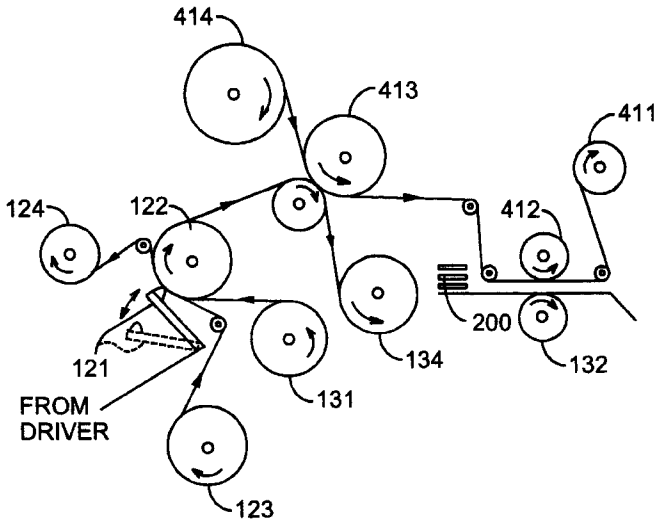
Primary Examiner—Huan Tran

Attorney, Agent, or Firm—Parkhurst & Wendel, L.L.P

[57] **ABSTRACT**

The present invention relates to image-formation on any selected kind of objective body. The characterizing features reside in such that, based upon fed image data, required images are formed on an image-transferable sheet acting for image carry-over service and in reliance on sublimation image transfer technique, and then, by the use of said sheet with said images thus formed thereon, the formed images thereon are transferringly applied on the objective body. By adopting the above measures, the objective body can be formed sharply and clearly with any desired images, irrespective of kind and configuration thereof, with such superior results of highly improved unity and solidability between the formed images and the objective body to be decorated with.

2 Claims, 16 Drawing Sheets



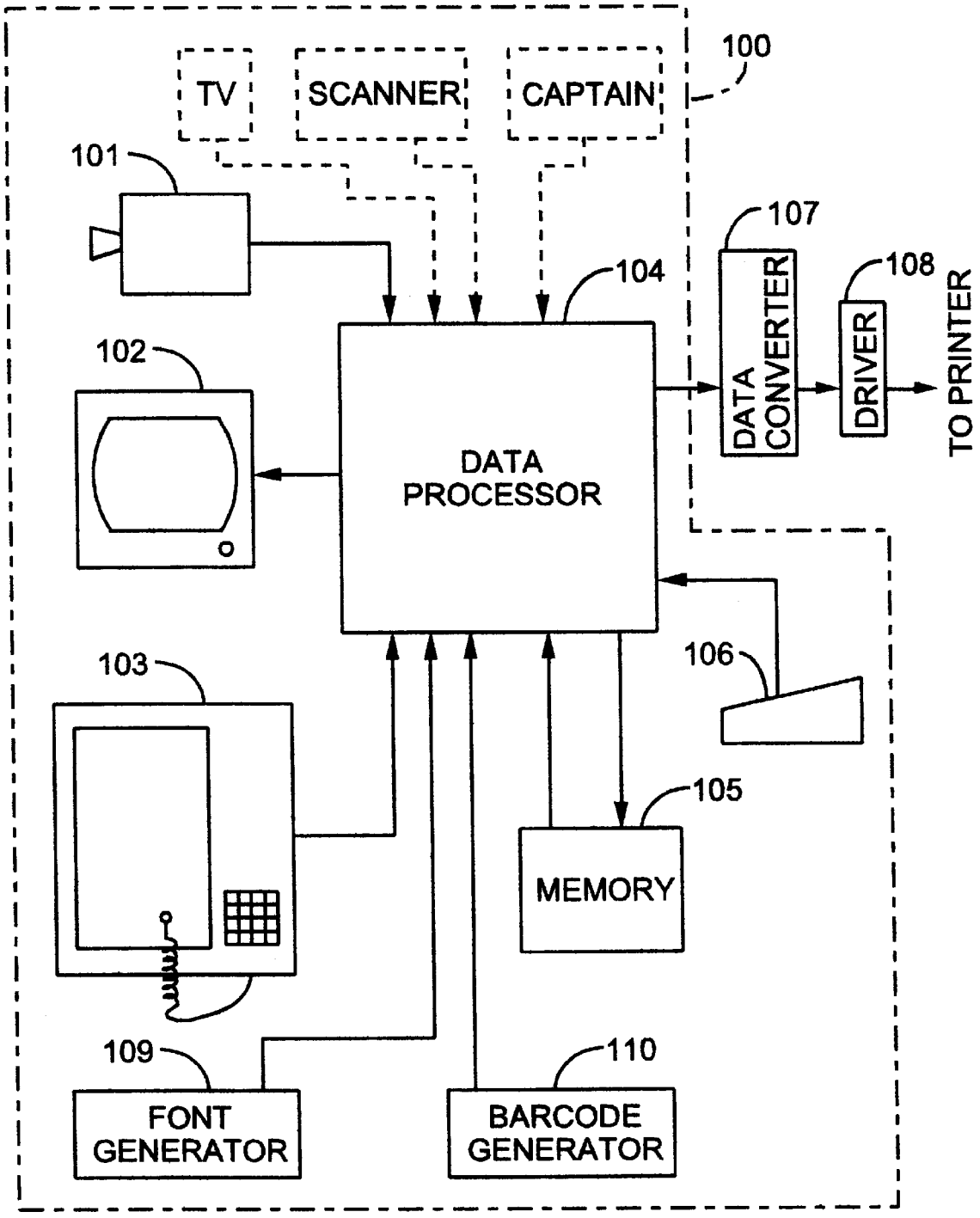

100
TV
SCANNER
CAPTAIN
101
107
104
108
102
DATA CONVERTER
DRIVER
TO PRINTER
DATA PROCESSOR
103
106
105
MEMORY
109
110
FONT GENERATOR
BARCODE GENERATOR

FIG. 1A

FIG. 1 B-1

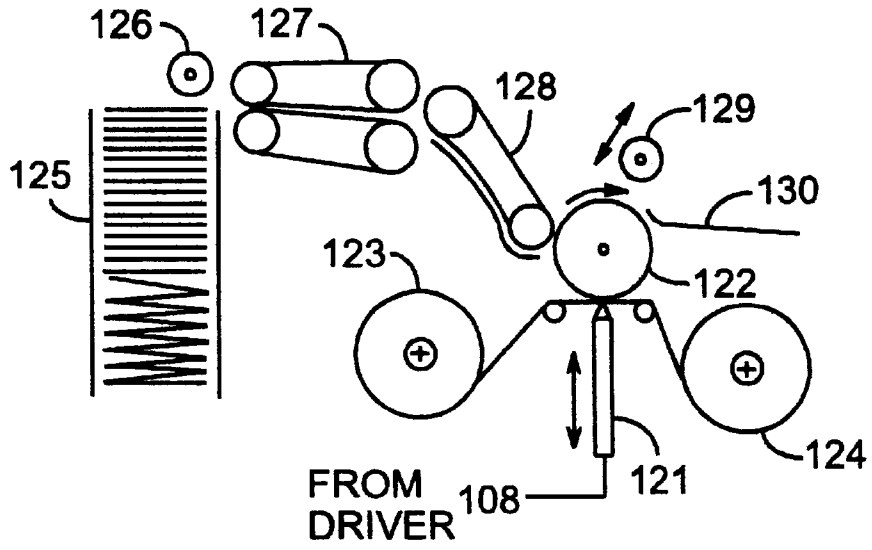


FIG. 1 B-2

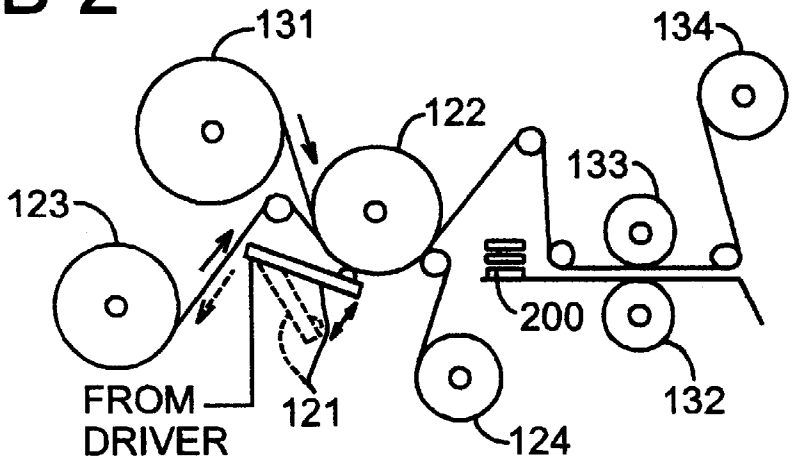
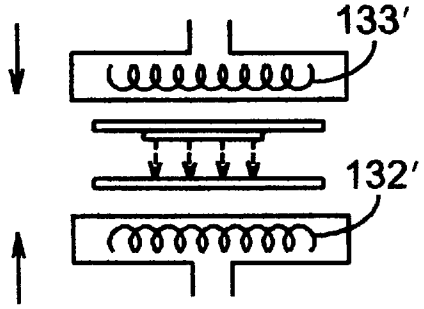


FIG. 1 B-3



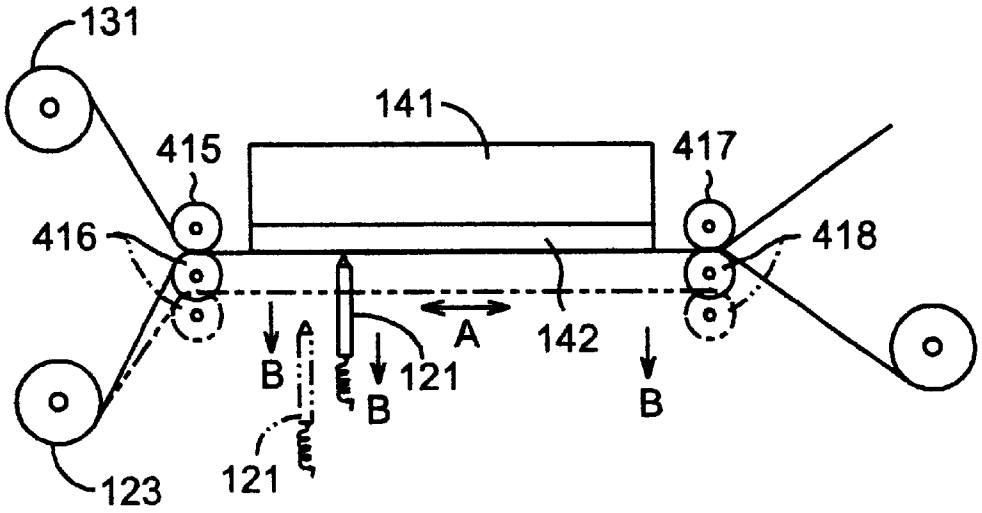


FIG. 1C

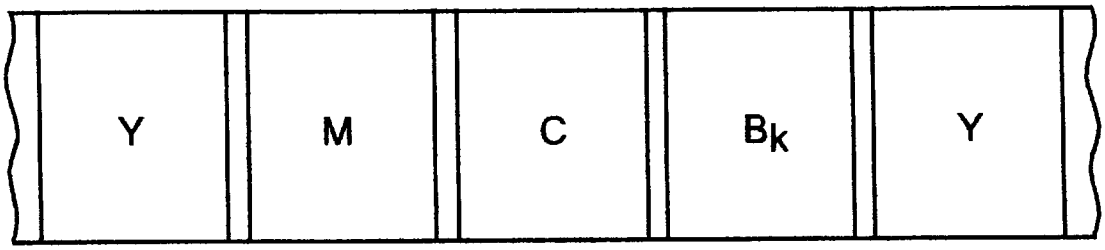


FIG. 1D

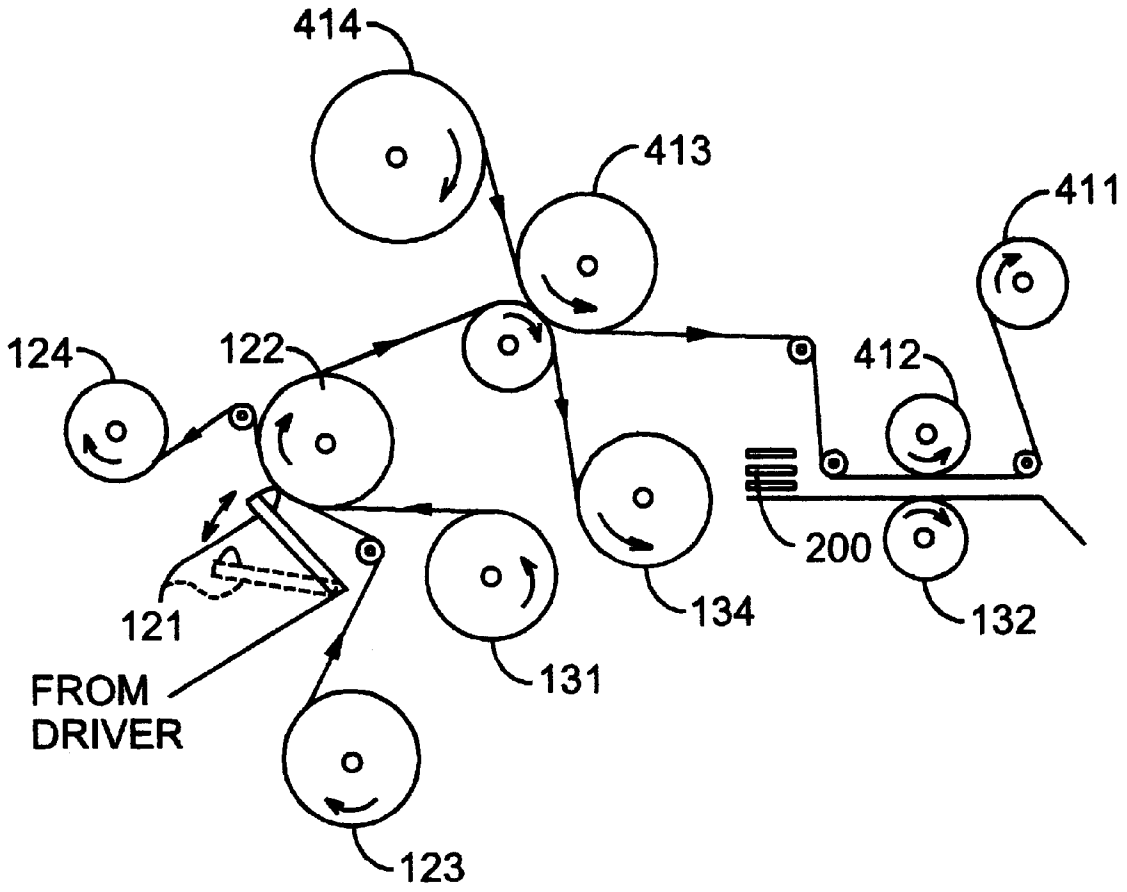


FIG. 1E

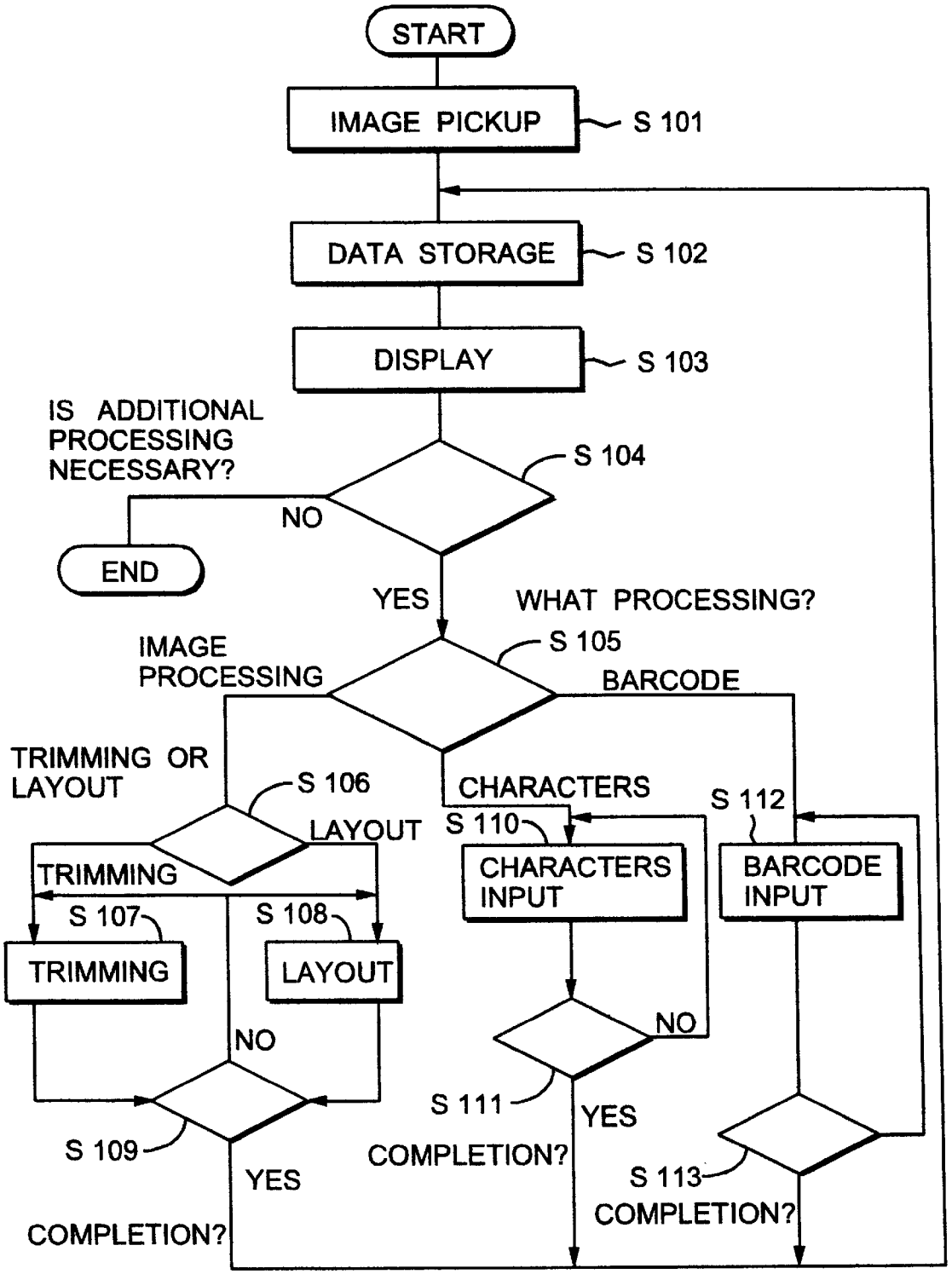

START
IMAGE PICKUP
S 101
DATA STORAGE
S 102
DISPLAY
S 103
IS ADDITIONAL PROCESSING NECESSARY?
S 104
NO
END
YES
WHAT PROCESSING?
IMAGE PROCESSING
S 105
BARCODE
TRIMMING OR LAYOUT
S 106
CHARACTERS
S 112
LAYOUT
S 110
TRIMMING
CHARACTERS INPUT
BARCODE INPUT
S 107
S 108
TRIMMING
LAYOUT
NO
NO
S 111
YES
S 109
COMPLETION?
YES
S 113
COMPLETION?
COMPLETION?

FIG. 2

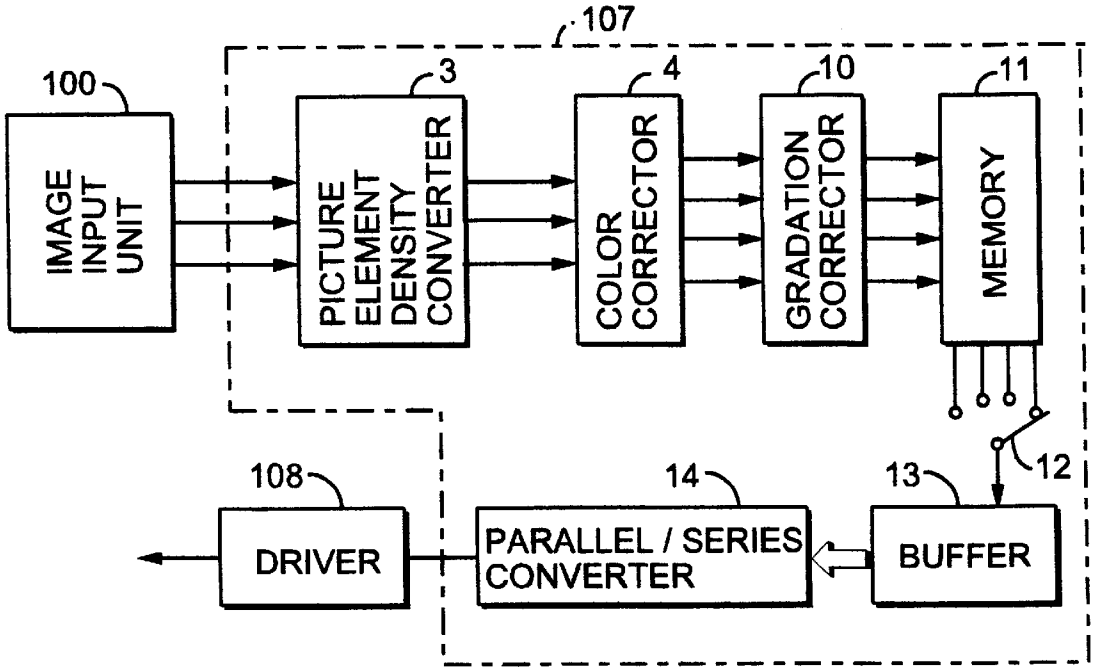

107
100
IMAGE INPUT UNIT
3
PICTURE ELEMENT DENSITY CONVERTER
4
COLOR CORRECTOR
10
GRADATION CORRECTOR
11
MEMORY
12
108
DRIVER
14
PARALLEL / SERIES CONVERTER
13
BUFFER

FIG. 3A

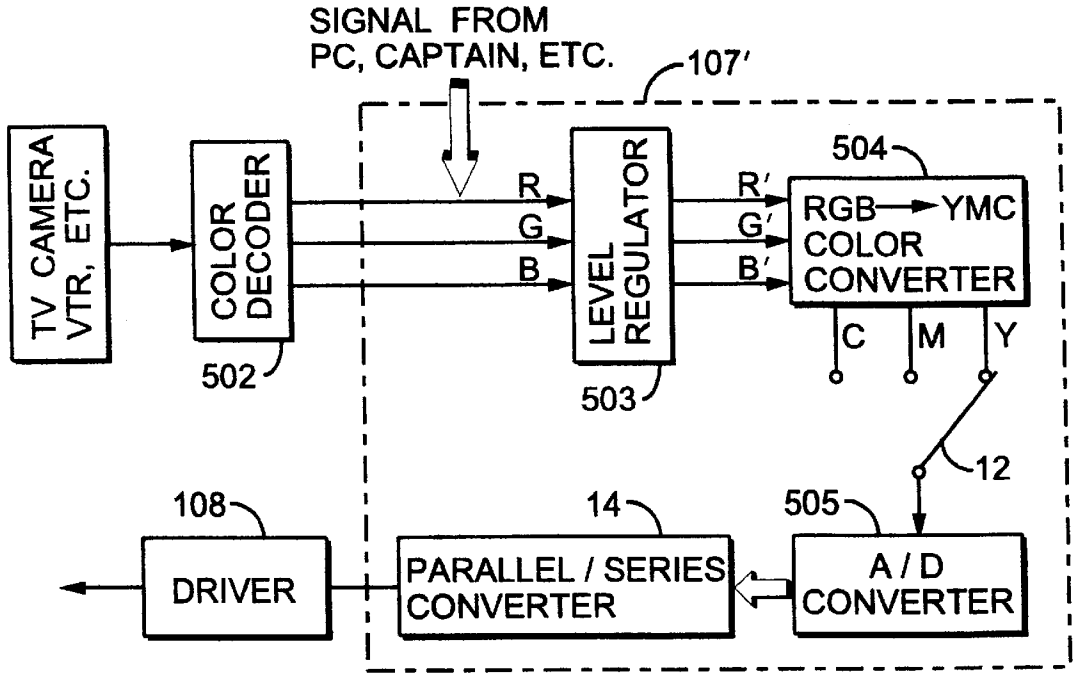

SIGNAL FROM PC, CAPTAIN, ETC.
107'
TV CAMERA VTR, ETC.
COLOR DECODER
502
R
G
B
LEVEL REGULATOR
503
R'
G'
B'
504
RGB → YMC COLOR CONVERTER
C
M
Y
12
108
DRIVER
14
PARALLEL / SERIES CONVERTER
505
A / D CONVERTER

FIG. 3B

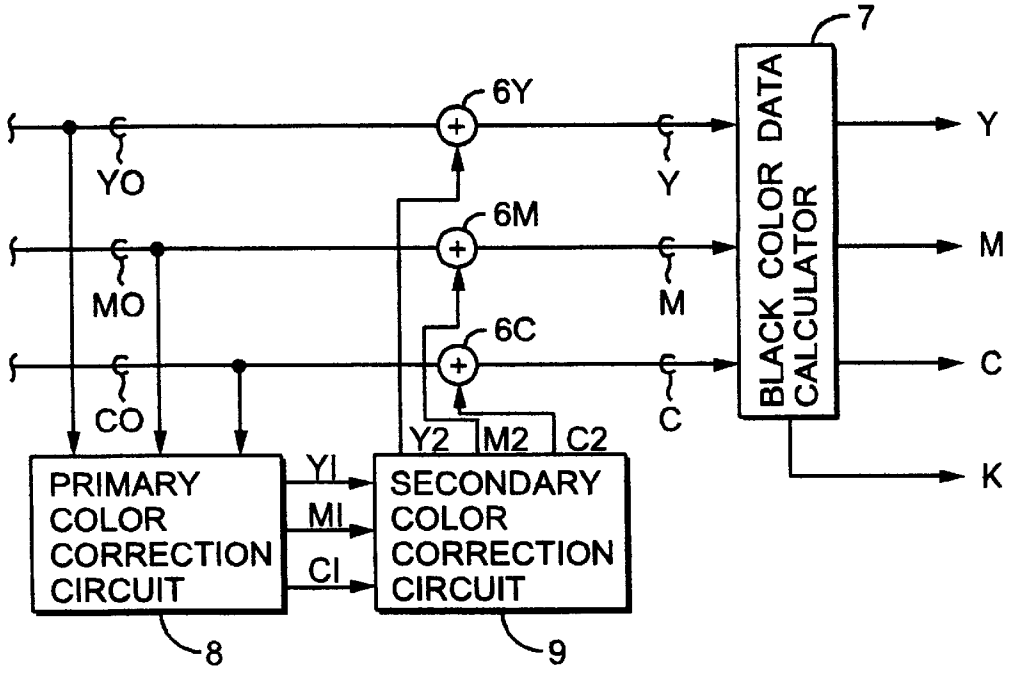

7
6Y
6M
6C
YO
MO
CO
Y
M
C
BLACK COLOR DATA CALCULATOR
Y
M
C
K
Y2
M2
C2
PRIMARY COLOR CORRECTION CIRCUIT
YI
MI
CI
SECONDARY COLOR CORRECTION CIRCUIT
8
9

FIG. 4

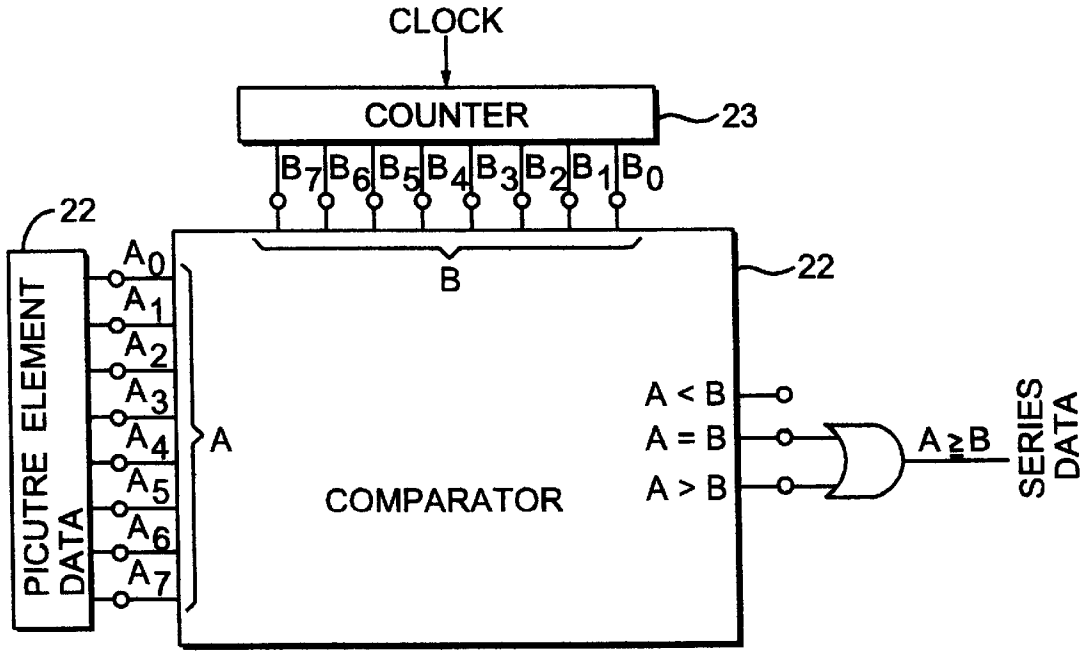

CLOCK
COUNTER
23
B7 B6 B5 B4 B3 B2 B1 B0
B
22
22
PICUTRE ELEMENT DATA
A0 A1 A2 A3 A4 A5 A6 A7
A
COMPARATOR
A < B
A = B
A > B
A≥B
SERIES DATA

FIG. 5

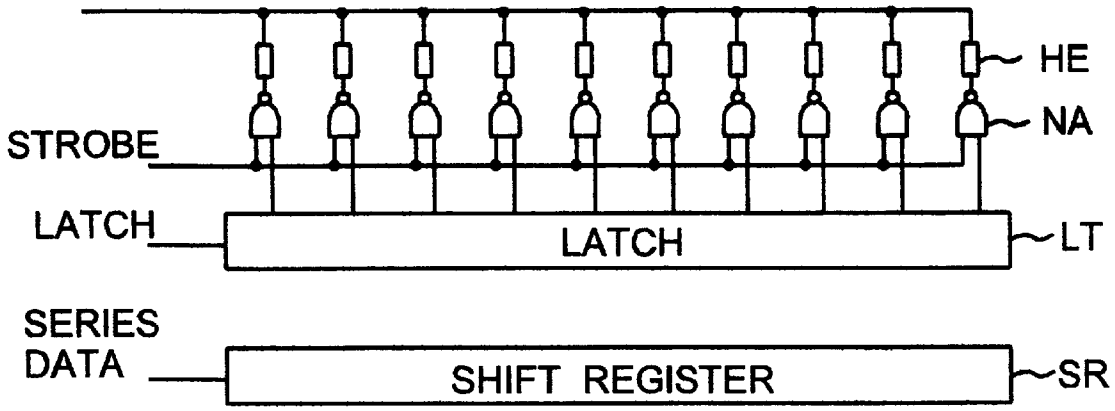

HE
NA
STROBE
LATCH
LATCH
LT
SERIES
DATA
SHIFT REGISTER
SR

FIG. 6

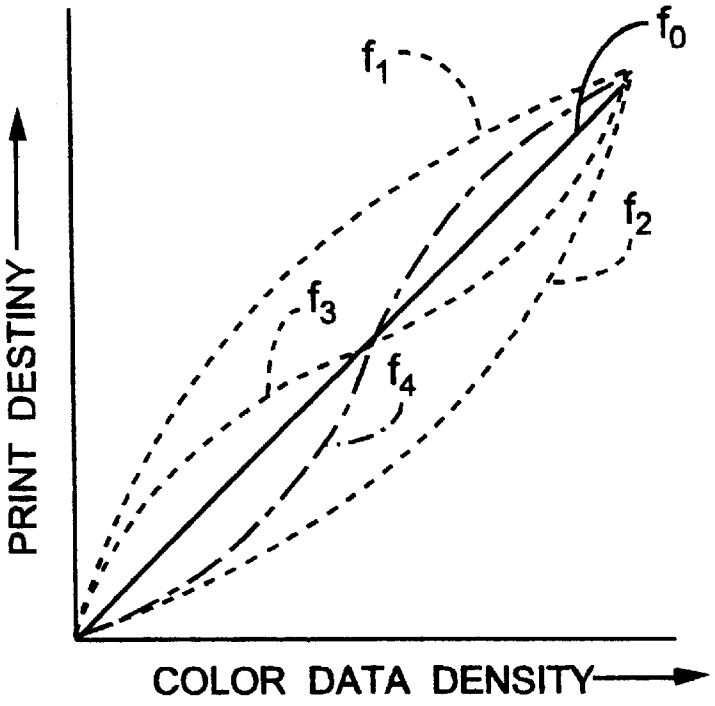

f_0
f_1
f_2
f_3
f_4
PRINT DESTINY
COLOR DATA DENSITY

FIG. 7

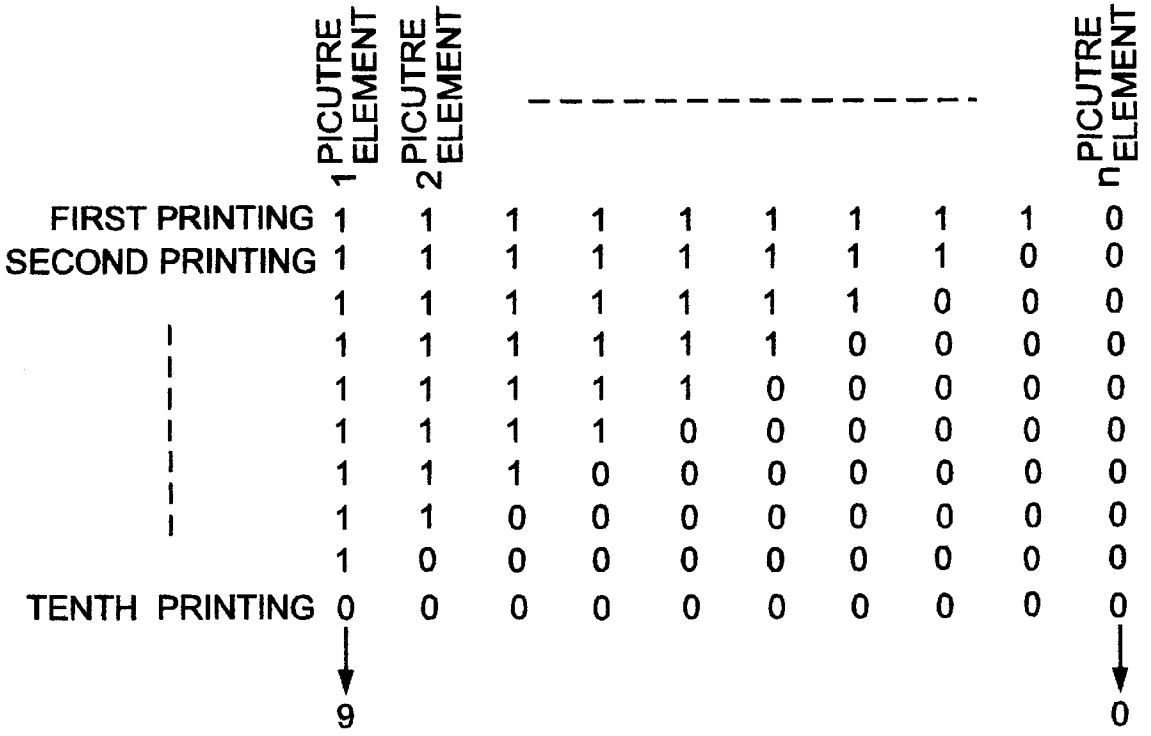

PICUTRE ELEMENT 1
PICUTRE ELEMENT 2
PICUTRE ELEMENT n
FIRST PRINTING 1 1 1 1 1 1 1 1 1 0
SECOND PRINTING 1 1 1 1 1 1 1 1 0 0
1 1 1 1 1 1 1 0 0 0
1 1 1 1 1 1 0 0 0 0
1 1 1 1 1 0 0 0 0 0
1 1 1 1 0 0 0 0 0 0
1 1 1 0 0 0 0 0 0 0
1 1 0 0 0 0 0 0 0 0
1 0 0 0 0 0 0 0 0 0
TENTH PRINTING 0 0 0 0 0 0 0 0 0 0
9
0

FIG. 8

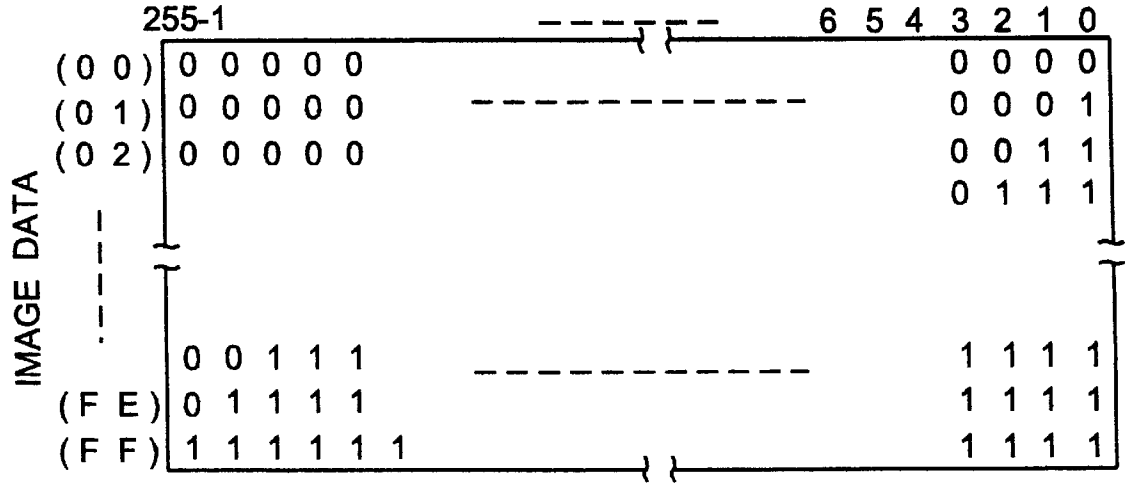

255-1
6 5 4 3 2 1 0
IMAGE DATA
(0 0) 0 0 0 0 0 0 0 0 0 0
(0 1) 0 0 0 0 0 0 0 0 0 1
(0 2) 0 0 0 0 0 0 0 1 1
0 1 1 1
0 0 1 1 1 1 1 1 1
(F E) 0 1 1 1 1 1 1 1 1
(F F) 1 1 1 1 1 1 1 1 1 1

FIG. 9

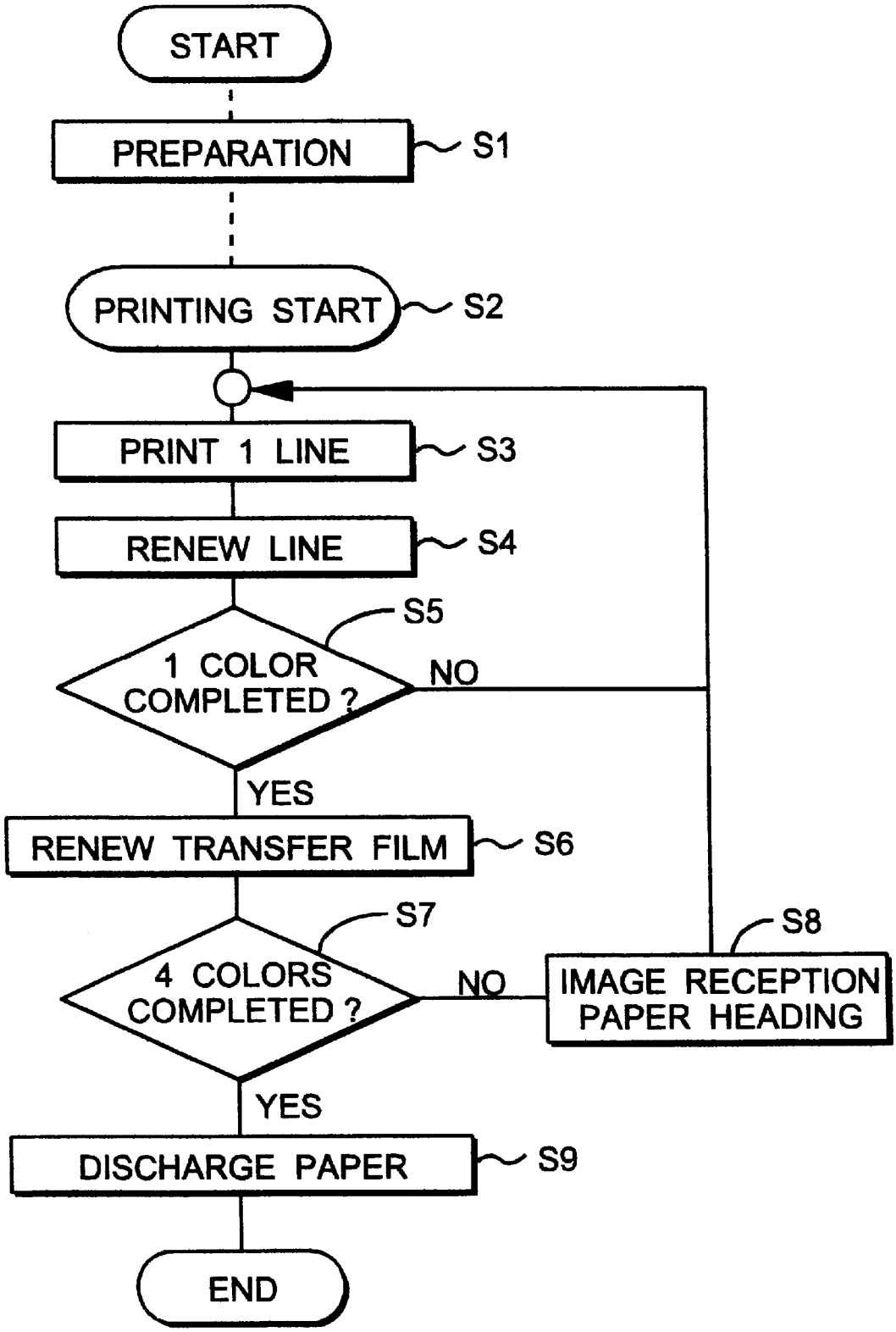

START
PREPARATION
S1
PRINTING START
S2
PRINT 1 LINE
S3
RENEW LINE
S4
S5
1 COLOR COMPLETED ?
NO
YES
RENEW TRANSFER FILM
S6
S7
4 COLORS COMPLETED ?
NO
S8
IMAGE RECEPTION PAPER HEADING
YES
DISCHARGE PAPER
S9
END

FIG. 10

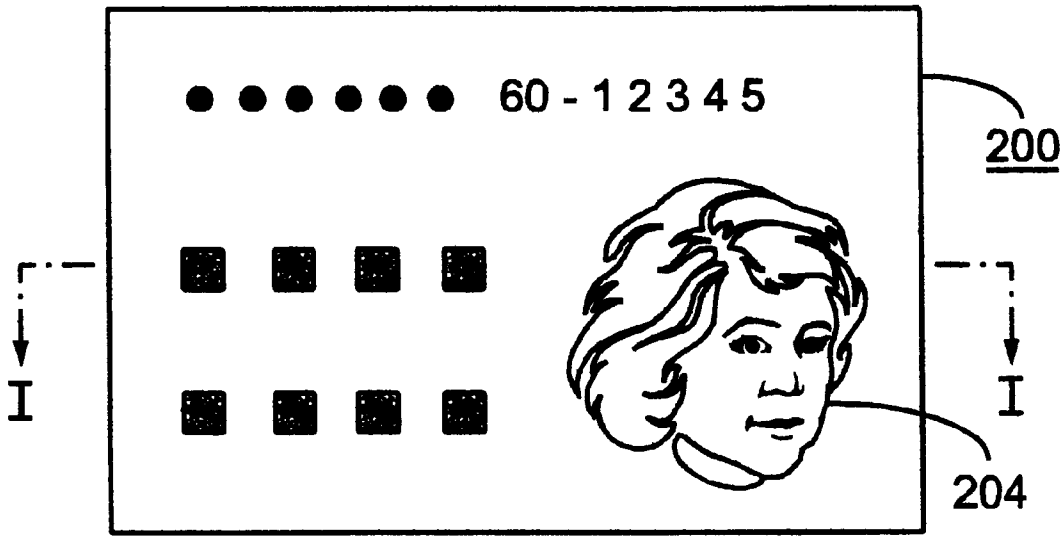


FIG. 11

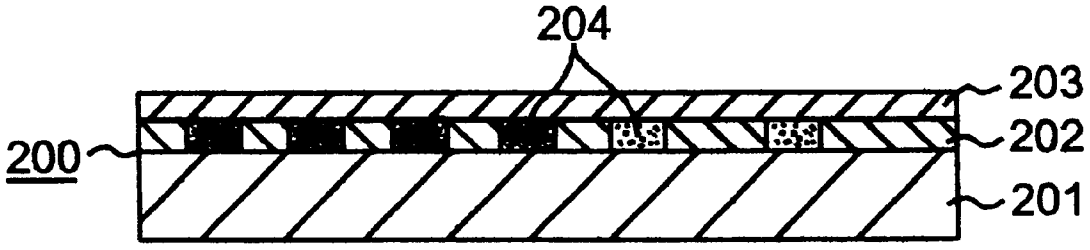


FIG. 12

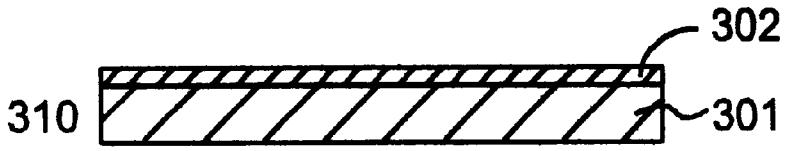


FIG. 13

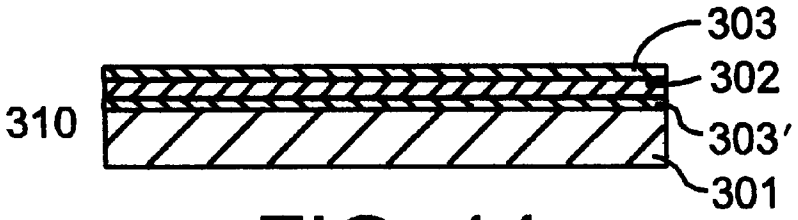


FIG. 14

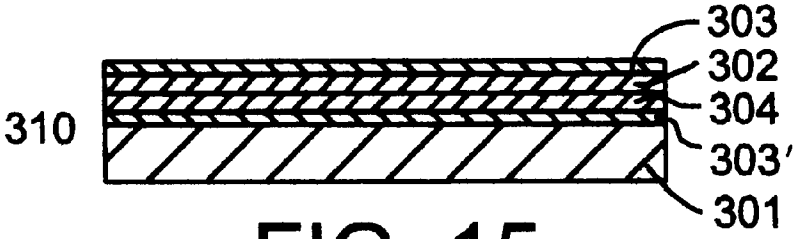


FIG. 15

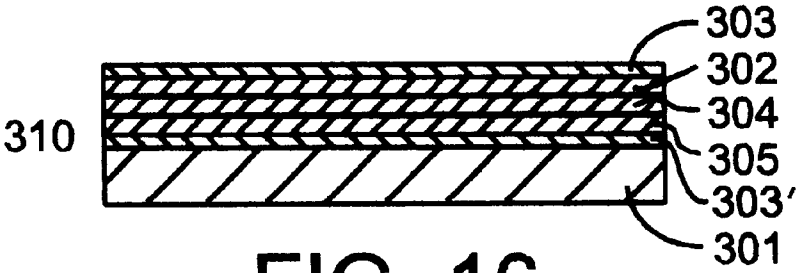


FIG. 16

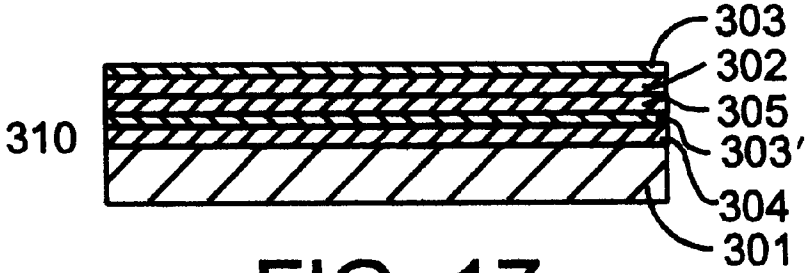


FIG. 17

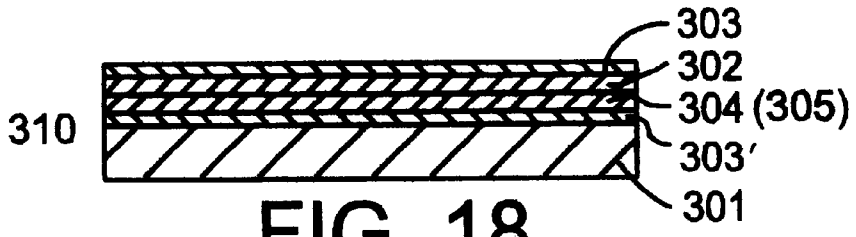


FIG. 18

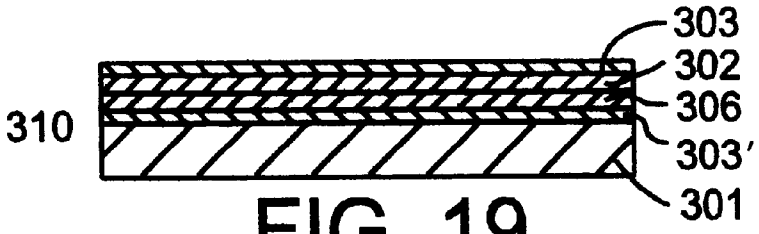


FIG. 19

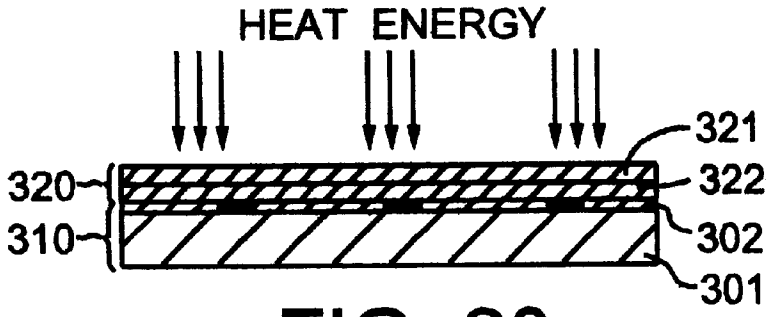


FIG. 20

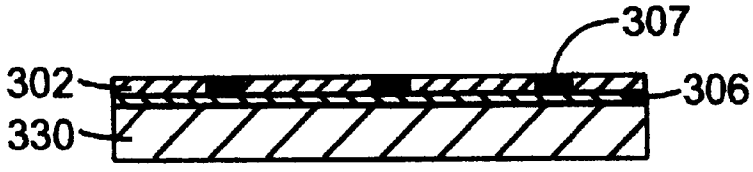


FIG. 21

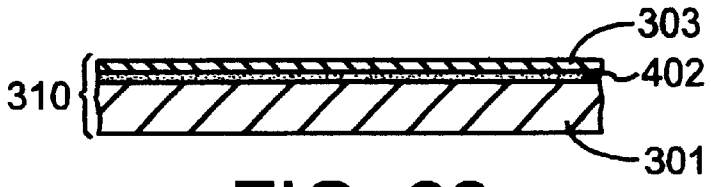


FIG. 22

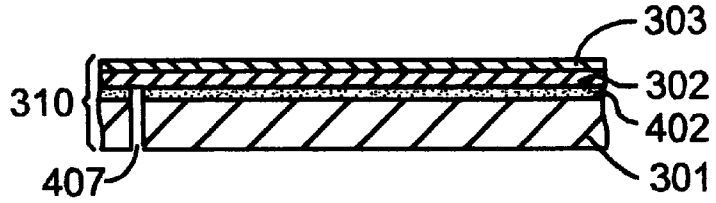


FIG. 23

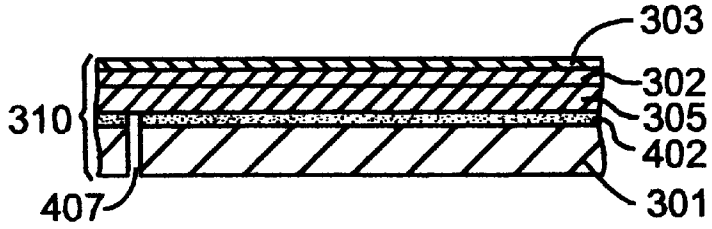


FIG. 24

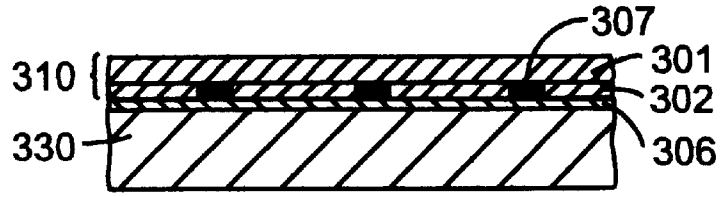


FIG. 25

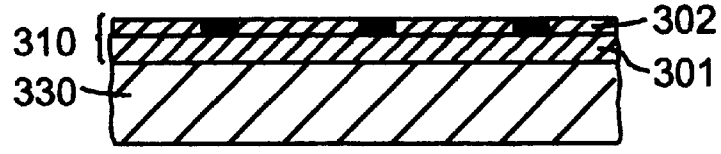


FIG. 26

FIG. 27

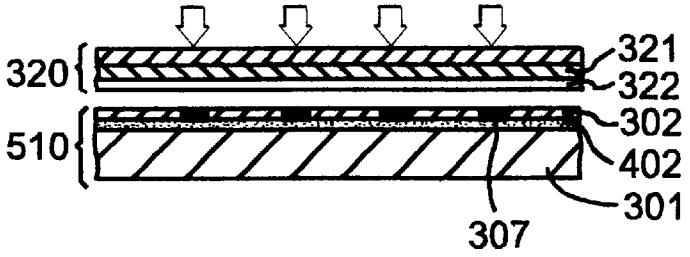


FIG. 28

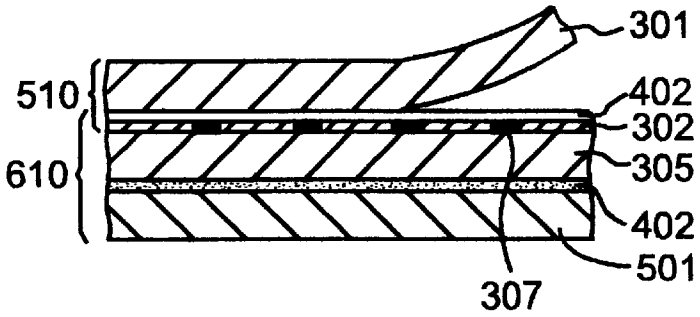


FIG. 29

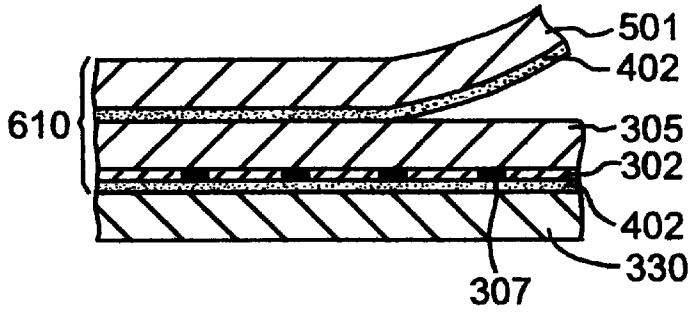


FIG. 30

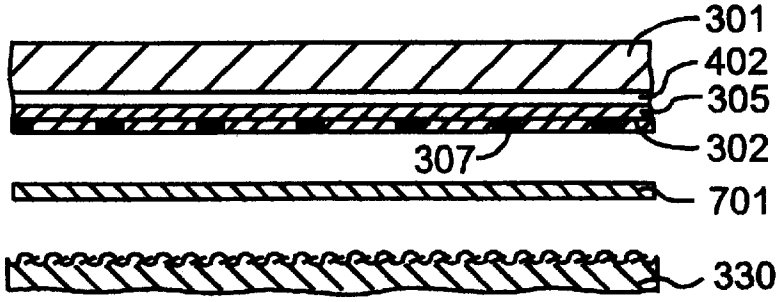


FIG. 31

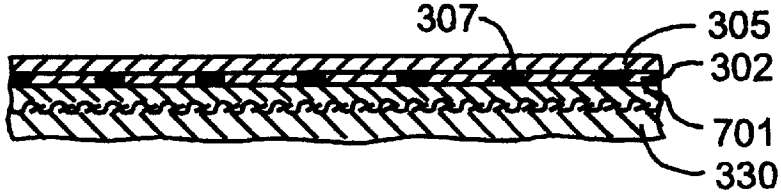


FIG. 32(a)

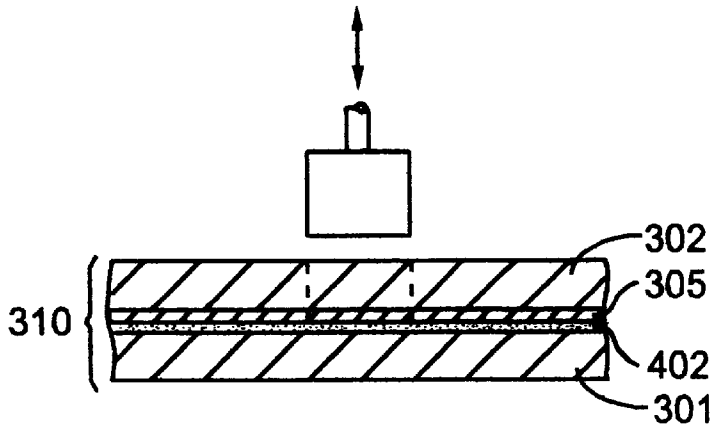


FIG. 32(b)

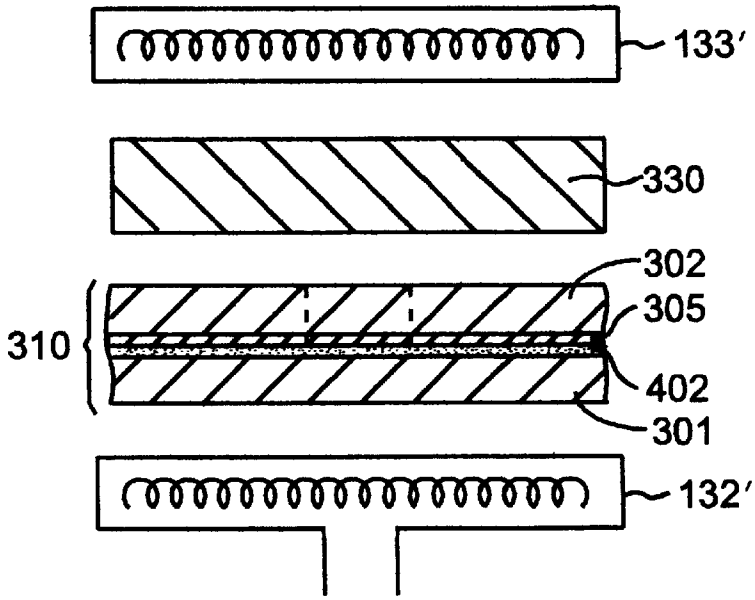


FIG. 32(c)

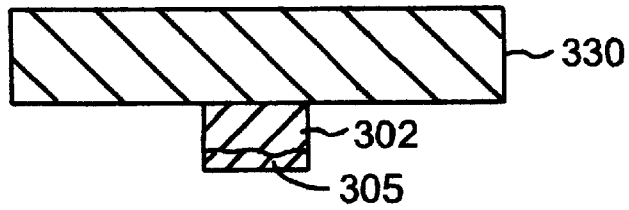


IMAGE FORMATION ON OBJECTIVE BODIES

This is a Division of application Ser. No. 08/395,850 filed Feb. 28, 1995 which in turn is a continuation of 08/034,186, filed Mar. 18, 1993, now U.S. Pat. No. 5,451, 560 which in turn is a continuation of 07/467,415, filed Jan. 19, 1990, now abandoned, which in turn is a division of application Ser. No. 07/138,384 filed Dec. 8, 1987, now U.S. Pat. No. 4,923,848.

TECHNICAL FIELD

This invention relates to methods and apparatus for the formation of images as prints on objective bodies through transfer of images preformed by the sublimation transfer technique, and more specifically it relates to such systems as adapted for the formation of images on any selected objective body, such as cards, clothes, papers, and transparent sheets, although these are not limitative to the present invention.

BACKGROUND ART

Reliance is made generally upon the normal printing technique for formation of images on objective bodies. For the execution of the printing technique, provision and use of printing plates (forms or blocks) are requisite. No matter how simple the image-printing is, the plate-making is a very time-consuming the laborious procedure. This is much more so in the printing of various and complexed image combinations, such as those of graphic or portrait images combined with characters, letters or barcodes, as an example, representing extremely complicated and troublesome work.

Further, in the normal printing operation, various operating conditions including ink selection and the like, must be carefully considered, depending upon the kind and nature of the printing object, thus the best selection thereof is highly delicate and not as simple as expected.

The present invention is proposed upon careful consideration of the foregoing facts, and an object of the invention is to provide a unique process for the formation of sharp and clear images regardless of the kind and nature of the object to be printed upon, and usable and effective materials and apparatuses for carrying out this unique process.

The method of thermal image transfer (sublimation image transfer) on clothes or fabrics with the use of thermal transfer dyestuffs has been practiced for a long time. In this conventional process, a dyestuff picture layer carrying thermal transfer dyestuff is formed on a substrate sheet which is then subjected to heat in an overlapped state on a cloth or fabric, the dyestuff thereby being transferred thermally onto the latter for forming the desired images thereon. By utilizing this technique, and with recent development of the image forming technology concerning fine thermal printers and the like, various fine image forming processes have been proposed to provide fine images which are comparable to photographic images and are transferred onto plastic films from thermal transfer sheets carrying thermal transfer dyestuffs.

According to these recently proposed processes, various images of cameras, or TVs, graphic images of personal computers and the like can be reproduced easily in the form of hard copies on the surface of a transferred material such as a paper or the like sheet carrying thereon a fixedly attached layer of polyester resin, as an example. These images thus reproduced represent an amply high level comparable to those obtained by photography or fine printing arts.

The thermal transfer process so far set forth has an advantage in that it can form any image in a convenient manner yet entails a problem in that it is limited to image-transferred products preferably of polyester and the like materials which must be dyed with thermal transfer dyes. On the other hand, the image-transferred products must be limited to specifically selected shapes, preferably film, sheet or the like configuration, and thus, such materials as wood, metal, glass or ceramics cannot be formed with images in this way. Further, even if the material is plastics such as polyester or the like, and when the image-forming surface is curved or undulated, or physical body other than sheet, even if it represents a plane surface, it is almost impossible to reproduce images precisely thereon, which naturally constitutes a grave problem in the art.

With recent development and enlargement of utilizing fields of various card-style products, such as cash-cards, telephone-cards, prepayment cards; and ID-cards, there are increasing demands for providing these cards with images, symbols and codes, so as to give various other functional and/or decorative effects. Most of these cards are of planar form, but they are frequently not pliable and/or have uneven rough portions due to provision of characters and symbols, resulting in great difficulty in the scheduled image formation relying upon the thermal image transfer process.

There is therefore an urgent demand among those skilled in the art for the provision of a unique technique capable of forming sharp and clear images of desired patterns on the surface of an objective body of any preferred kind of material and having any shape and configuration and surface condition of any kind, and indeed, for combining and unifying image- and decoration effects.

DISCLOSURE OF THE INVENTION

The present invention is basically based on such a principle that a first image transfer pattern is formed on an image transfer material, preferably an image image-transferable sheet, and in the form of dyestuff through the sublimation image transfer process executed by first image transfer means, depending upon given image data, preferably including those of letters, characters, symbols, line images, graduated graphic representations, and then the first transfer pattern is transferred to second transfer means for retransferring the images onto an objective body so as to provide a final product.

Based upon the image data fed from various image data input means and at the first image-transfer means, a thermal head is actuated to execute printing operation through a dyestuff film (thermal image-transfer sheet) on an image-transfer material (or more specifically on an image-transferable material which means an image-transferable sheet. This image-printing is carried out according to the sublimation or sublimative image transfer technique. Thus, in this case, the dyestuff on the dyestuff film is transferred or shifted under the influence of heat energy from the thermal head onto the image-transferable material through sublimation, thus providing the first image-transferred means. Since this first image-transferred means has been thus formed with the images by the sublimated dyestuff, they are, then, transferred onto the second image-transferable means which will be brought into tight contact with the object to be decorated and subjected to heat and pressure for execution of further image-transfer operation to provide the final desired product.

In the present invention, the image-transfer material (image-transferable sheet) is, as above referred to, formed

with images by the sublimative image transfer technique for providing first image-transfer means which has highly sharp and clear images as the operation and results of the characterizing feature of the sublimation image-transfer technique. Therefore, because of the transfer of such sharp and clear images onto the object, it becomes possible to form the images thereon, and indeed, practically irrespective of the kind and nature of the object. In this way, thus, fine image-formation is assured onto practically any objective substance.

And further, by execution of control of the thermal energy applied during the sublimative image-transfer step, the resulting color effect is superior and the image quality is good.

The images sublimatingly applied and formed in the foregoing way are subjected to a further transfer, and onto a substrate product, for providing a final decorative product as desired. In this final product, it should be noted that the underlying layer underneath the images during the sublimative image-transfer stage appears now at the top, acting thus as a kind of protecting layer upon up-and-down positional conversion during execution of the second and final image-transfer stage, resulting in realization of various and numerous effects. As an example, attainment of substantial reduction of contamination, improvement of light resistance, weather resistance and chemical resistance; substantial reduction of color fading; provision of glazing effect; easier and simpler introduction of granular and/or undulated image appearance.

The inventive process is carried into effect basically in such a manner that an image-reception layer provided on one surface of an image-transferable sheet is subjected to an image-forming step with the use of dyestuff capable of depositing therein depending upon the fed image data, so as to form the required images, and then, the image-reception layer of the image-transferable sheet, having been image-fixed and thus now image-carrying, is stuck onto the surface of the object to be decorated upon.

As for the image-transferable sheet adapted for use in the image-transfer during execution of the inventive process, it consists basically of a sheet-like substrate and a reception layer attached, however, in a separable manner, onto one surface thereof. As a modification of the inventive process from the basic mode set forth above, the sheet-like substrate is caused to remain, even after completion of the image-transfer step, as may be occasionally required. In this modified case, it is unnecessary to make the image-reception layer of the image-transfer sheet separable.

Under occasion, the inventive process may be brought into effect in such a way that the image-reception layer of the image-transfer sheet is transferred upon execution of the image-forming step, and indeed, once onto an intermediate image-transfer substrate which is then retransferred, together with the once transferred image-reception layer, onto the surface of an object to be decorated on; and thus, in a retransferring manner.

BRIEF DESCRIPTION OF THE DRAWINGS

In the accompanying drawings:

FIG. **1A** is a block diagram, showing a preferred embodiment of the apparatus according to the present invention;

FIG. **1B** is a schematic view illustrating at (a), (b) and (c), several image-transfer steps for the execution of a process according to the invention;

FIG. **1C** is a schematic view of an image-transfer step, using a platen roll;

FIG. **1D** is a plan view of part of a multi-color dyestuff film adapted for use in an image-forming step;

FIG. **1E** is a schematic view for the illustration of several image-transfer steps;

FIG. **2** is a flow chart of successive operation steps with use of a data-processor, shown in FIG. **1**, functioning as an operating center;

FIG. **3A** is a schematic block diagram, showing a data-processor for the printer;

FIG. **3B** is a block diagram of a sublimative image-transferring printer adopted in the present invention, as a preferred embodiment thereof;

FIG. **4** is a schematic block diagram, showing a color correction unit shown in FIG. **3A**, and several related parts cooperating therewith;

FIG. **5** is a schematic block diagram of a comparator and several related parts cooperating therewith;

FIG. **6** is a circuit block diagram of an image-transfer head shown in FIG. **1B**;

FIG. **7** is a graph showing operational characteristics of a color tone or -gradation corrector unit shown in FIG. **3A**;

FIG. **8** is a table for the illustration, as an example, of picture- or image-elements, as expressed in binary signals;

FIG. **9** is a table showing a conversion operation, as an exampler of a parallel/series converter shown in FIG. **3A**;

FIG. **10** is a flow chart, illustrating the operation of the sublimative image transfer printer;

FIG. **11** is a plan view of a final decorative product prepared according to the inventive technique;

FIG. **12** is a sectional view of the product card shown in FIG. **11**, and taken along a section line A—A shown therein;

FIGS. **13** through **31** are a series of sectional views, respectively illustrating several structural examples of image-transferable sheets, suitable for use in the invention; and

FIGS. **32** (*a*), (*b*), and (*c*) are sectional views, indicating final transfer steps.

BEST MODES FOR CARRYING OUT THE INVENTION

Referring now to FIG. **1A** and FIG. **1B**, (a), (b) and (c), a basic schema of the inventive image data processing and image formation will be illustrated. First, in FIG. **1A**, numeral **101** represents an image input means which is adapted for forming image data based upon optical and the like inputs delivered from a TV-camera, line sensor or the like. Other than those above enlisted only by way of example, video; CD; TV; scanner; personal computer, captain system, capable of providing R.G.B.- and picture image and the like signals may also be utilized in a similar way. The image signal data delivered from the image input means are fed through a data processor **104** to a memory **105** for being stored therein. These stored data can be taken out from the memory and fed through data processor **104** to display means **102** for being displayed thereat.

To the data processer **104**, a mouth/tablet digitizer and/or the like position data processer **103** is electrically connected for introducing position data concerning displayed images appearing at the display **102**. In addition, key board and the like character data input means **106** and font generator **109** are provided for introducing character data. Still further, a barcode generator **110** is provided for introducing barcode when necessary. By the use of these means and units, various additional processing modes can be executed.

The thus processed data are subjected to conversion at a data converter **107** into proper data adapted for operating a sublimation transfer printer and fed forward through a driver **108** to the thermal head.

In this case, by controlling the current duration period to the thermal element of the thermal head, the transfer quantity from the dyestuff film (thermal transfer sheet) is controlled depending upon the thermal energy of the element for realization of the desired gradation degree of concentration on the transfer sheet. There are two different modes of such control of current duration period as follows:

(a) A method for controlling the pulse length corresponding to the picture element in the impressed data to the thermal element of the thermal head or, more specifically, a series data introduced as input to the shift register shown in FIG. **6** and to be described more specifically hereinafter.

(b) A method for controlling the number of pulses of the pulse series corresponding to the picture elements of the data impressed upon the thermal element in the thermal head (in this case, the pulse length being constant).

The degree of gradation of the transfer image can be controlled in the above mentioned way by the regulation of the current-conducting period depending upon the desired gradation degree. On the other hand, the image concentration can be controlled by adjusting the pulse length or the number of pulses contained in the pulse series in correspondence to the picture elements contained in the data as introduced in the shift register and depending upon the driving mode of the thermal head. Further in this case, if the number of gradation of introduced image data is larger than that which can be expressed by the printer unit, a proper conversion operation can be performed by the known strobe control method. As an example, in such case, the conversion of gradation number **256** to **64** may be executed by a ROM, and the thus reduced gradation number can be used as output.

Next, referring to FIG. **1**B at (a) and (b), reference numeral **121** represents a thermal head which receives signals from the driver **108** shown in FIG. **1**A. This thermal head **121** is arranged in opposition to platen roll **122**, forming the printing position therebetween. The dyestuff film (thermal transfer sheet) is fed from a delivery roll **123** to a winding roll **124** through this printing position, these structural and functional features being commonly employed in both the arrangements shown in FIG. **1**B at (a) and (b).

In the case of FIG. **1**B, (a), the mechanism is so arranged that card or sheet style transfer sheets are printed with dyestuff images.

On the other hand, in the case of FIG. **1**B, (b), the mechanism is so arranged that cards are continuously produced with the use of a film style transfer sheet and a dyestuff film in combination.

Now turning back to FIG. **1**B, (a), a number of transfer sheets (cards, sheets or the like) have been stacked and stored within a storage casing **125** and are being thrust upward from below by a spring so that the uppermost sheet is kept in pressure contact with a take-out roll **126**. With the rotation of the roll **126**, the sheets are successively delivered from the casing **125** by conveyer belts **127**, **128** onto a platen roll **122**. Each one of the sheets is fixed on the peripheral surface of the platen roll, now positionally indexed, by means of a gripper or the like mechanical attaching and separating means, static attracting means, or electromagnetic attaching means. Then, the roll **122** is so rotated that the transfer sheet is positioned at the ready-for-printing-position.

Next, the thermal head **121** is brought into pressure contact with the transfer sheet through the intermediary of the dyestuff film, and then the thermal head **121** is energized with electric current while the dyestuff film and platen roll **122** are moved in synchronism for the execution of image transfer (first image transfer).

Upon execution of the image transfer, the platen roll **122** is rotated, the gripper is released and the take-out roll **129** is rotated and brought into pressure contact for taking out the image transfer sheet onto a tray **130**.

The thus taken-out sheet is brought into overlapped state with a new image transfer sheet, not shown, and then, both the sheets are fusingly united together by pressure application of a heated roll, not shown, for execution of a second transfer step job. The whole operation has thus been completed. Before the fusion process, the sheets may be subjected to punching, trimming and/or the like processing, if necessary.

By execution of the foregoing operational steps, a monocolor printing operation has been completed. However, in the case of multicolor printing, use is made of tricolored or quadruple colored dyestuff film and the corresponding printing operations must be repeated. In this case, upon completion of a single monocolor printing procedure, the platen roll is rotated without contact of the take-out roll **129**, until it arrives again at the printing-initiation position, and so on.

In the following, a tricolor printing job will be illustrated with reference to FIG. **1**B, (b), and with use of three different series color zones, of cyan, magenta and yellow.

First, a platen roll **122** is positionally indexed, and an image transfer sheet taken out from the roll **131** and a dyestuff film taken out from the roll **123** are brought into pressure contact in an overlapped state. Then a thermal head **121** is pressed against the platen roll **122** through the intermediary of the overlapped sheets. At this stage, the platen roll **122** is rotated counterclockwise while synchronism is kept between the platen roll **122** and the dyestuff film, and the thermal head **121** is kept electrically energized. In this way, the first color printing is executed.

Further, the dyestuff film is fed to the second color zone position, and then, the. platen roll **122**, the dyestuff film and the image transfer sheet are fed forward clockwise around the center roll **122**. Thus a second color printing step is executed.

Further, the print-serviced two color sections of the film is fed back counter clockwise around the center of the platen roll **122** for the execution of a third color printing step. Then, each card sheet is taken out from the stack **200** under the action of take-out rolls or the like, not shown, towards and between a pair of thermal transfer rolls **132**, **133**, brought into overlapping state with the image transfer sheet positionally indexed and already subjected to image transfer steps as was described above, and finally subjected to a picture printing operation by pressurizing application of the thermal image transfer rolls **132**, **133** from both sides of each taken-out card, and so on.

The color-printing step with the use of the thermal head is carried into effect in the following manner, as an example.

(First color printing)

Platen roll, image transfer sheet and dyestuff film perform the printing while they are moved in the counterclockwise direction.

(Second color printing)

Platen roll and image transfer sheet are moved in the clockwise direction while the dyestuff film is moved at the same speed and in the counterclockwise direction for performing the color printing under consideration.

(Third color printing)

Platen roll, image transfer sheet and dyestuff film are moved in the counterclockwise direction for execution of the color printing under consideration.

In the modified arrangement shown in FIG. **1**B, (c), thermal image transfer rolls **132**, **133** have been replaced by a flat press type image transfer head having up-and-down movable flat printer elements **132'**, **133'**.

It should be noted that in the course of the foregoing first and second image transfer steps, image reversal phenomenon is necessarily brought about upon execution of each image transfer step. In other words and more specifically, when two successive image transfer steps in the foregoing sense are executed, reverse images which have once appeared will return to the original normal images. Therefore, when the printed-out products are to be provided upon execution of the first image transfer step, it is necessary to provide reversed image data in the signal processing system. For this purpose, it is only necessary to reverse the addressing order at the data introduction or readout stage into or from the memory.

In the modified arrangement shown in FIG. **1**C, the foregoing platen roll means has been replaced by a metal block **141** lined with a rubber plate **142** in an overlapped manner. The image transfer sheet and dyestuff film are fed out from respective rolls **131** and **123**. With the use of this modified arrangement, the dyestuff surface layer of the dyestuff film can be brought into tight contact with the image-receiving surface layer of the image transfer sheet, and thermal energy will be transferred evenly form the thermal head **121** to the dyestuff film.

In this case, the image transfer sheet is delivered from the roll **131**, and the desired zone or region of the sheet is set underneath the rubber plate **142** (step **1**).

At the same time, the dyestuff film shown in FIG. **1**D on an enlarged scale is delivered from the roll **123** and a selected one of the different color regions is set underneath the rubber plate **142** (step **2**).

Next, the thermal head **121** is brought into the rear surface of the dyestuff film which is the opposite surface to the dyestuff-coated front layer, and the head **121** is driven while it is being translated in the direction shown by an arrow A, images thereby being formed at the specifically allocated zone(s) or region(s) of the image transfer sheet (step **3**).

Further, the thermal head **121** and rolls **416** and **418** are shifted downwards as shown by arrows B, so as to form an idle gap between the image transfer sheet and the dyestuff film for allowing the latter to shift towards the next following color region (step **4**).

Further, the thermal head **121** and rolls **416** and **418** are returned to their original positions, whereupon the third and further succeeding steps are repeatedly executed until a certain predesired number of color printings are completed.

As shown in FIG. **1**D, the dyestuff film is colored to have several different color regions denoted by Y (yellow), M (magenta), C (cyan) and Bk (black). However, the arrangement order is not limited to that shown: Y; M; C and Bk. In addition, as occasionally required, the Bk-region may be dispensed with. Further, as the color elements to be adopted in the Y, M, C-system may not be limited to the three primary colors provided by the subtractive color mixture. On occasion, a characterizing color which means such a color as preadjusted to provide an objective specifically selected one may be used to form the images concerned. As a further modification, the arrangement shown in FIG. **1**C may be so modified that the traveling direction of the image transfer sheet is selected to be perpendicular to that of the dyestuff film.

FIG. **2** is an operation flow chart for showing schematically operational modes taking the data processor **104** adopted in the embodiment shown in FIG. **1** as the centrum of description. The operational contents of several working parts downstream of the data converter **107** will be set forth separately hereinbelow. Now referring to FIG. **2**, in combination with FIG. **1** and at the step of **S101**, image pickup operation is carried out by means of the image pickup means **101**. For execution of this step, it may be better to pick up the face of a person per se which is to be represented on the card, or alternatively, a photograph, portrait or imagery product thereof will do. Depending upon the nature of the object, a TV camera, line sensor or the like instrument may naturally be selectively utilized.

The data taken by the image pickup means **101** are stored through the data processor **104** at a memory **105** (**S102**). By the use of these stored data, image or images is/are displayed at the display **102** (**S103**). Since this display image is not yet subjected to any processing, it is generally unsuitable for representing on the card. However, under certain circumstances, it may be represented thereon as it is.

Then, the operator observed the displayed image or images on the display unit **102** and adjudges whether additional processing is necessary or not (**S104**). If it is not necessary, he will manipulate the key board **106** to make a certain operation, resulting in the termination of processing at the data processing unit **104**, data being fed out therefrom to the succeeding data converter **107**.

On the contrary, when additional processing is necessary, the operator observes carefully the displayed image or images on the unit **102** and adjudges whether the picture image data, or character data or barcode data should be processed. If the picture image data should be processed, such an operation is made for selecting the proper mass of trimming or layout within the menu range of position-data input means **103**. By the execution of this operation, functions and operations at steps **S105** and **S106** can be executed at one stroke. If trimming is taken as an example, the next step is executed in such a way that position data are fed from the position input means **103** to the data-processer **104** with the use of a carsor. When a tablet digitizer is used as the position data input means, the carsor image displayed in an overlapped manner on the displayed picture image appearing at the display unit **102** by carsor manipulation is positionally specified beforehand in registration with the specified position on the card, for determining the trimming range. Then the operation is carried out in such a way that the picture image data outside the specified trimming range are canceled. By completing these operations, data processing operations relating to step **107** are executed, and, then, the mass for completion of the menu range is selected out. By these measures, steps progress through **S109** to **S102**, and data storing is executed, and further, display representation is brought about through step **S103**. If there is no need for additional processing, an operation termination manipulation is carried out as before at key board **106**, and further operations will be made through data converter **107**.

As for the layout, the operation is carried out with the position data input means **103**, similarly as in the foregoing trimming operation. More specifically, layout is selected out in the menu range of position data input means **103**, and the overall configuration of the card and the display position of picture image are shown at display unit **102**. Then, image inclination correcting operation and the like are carried out so as to realize correspondence thereof with the displayed positional information, the processing operations relating to step **S108** thereby being brought about. After completion of these operations, the mass for the ending in the menu range is selected.

In this way, when selection is made from the menu range by reliance on the position data input means **103**, trimming or layout operation can be brought about. At this stage, when manual operation is carried out at the key board **106**, introduction of character data is executed (**S110**). As the character data in this sense, in the case of ID card, as an example, the name and/or birthday, month and year of the owner may be used. The data introduced from the key board **106** in accordance with the output character style from the font generator **109** are shown at the display unit **102** in the specified positions on the displaying surface and respectively arranged in accordance with display items. The operator acknowledges these items and detailed displays of the represented images. When he acknowledges them as being true, he will operate the key board **106** for showing the operation ending (**S111**).

Upon ending the operations as described above, the data are stored in memory **105** (**S102**) and represented at the display **102**. The operator will acknowledge again this fact, and upon the execution of this, the operations are terminated.

As for the barcode introduction, the data are subjected to inputing at steps **S112** and **S113**, as in a manner similar to the character data introduction as set forth above. The barcodes and the like data may be introduced separately through printing or other mechanical method.

In FIG. **3**A, a data processing circuitry usable in the sublimation image transfer printing method is shown only schematically. As shown, the circuitry **107** comprises a picture element density converter **3**; a color corrector **4**; a gradation corrector **10**; a memory **11**; a switch **12**; a buffer **13** and parallel/series converter **14**. The picture element density converter **3** is connected to a picture image input unit **100**.

The unit **100** serves for generation of three primary color data of R.G.B.- or Y.M.C.-mode from original picture images and is connected through the picture element density converter **3** to the color corrector **4**. The converter **3** converts the picture element density of the image data fed from the unit **100** to the desired one, by subtracting or supplementing, as the case may be, image data for each color element. It should be mentioned that for attaining high quality hard copies, conversion of the picture element density to at least 10 lines/mm or so is preferable.

Color corrector **4** consists preferably of a color decoder, level adjuster or color converter, and serves to correct three primary color data converted to those of a predetermined density of picture elements in consideration of characteristics of the image transfer ink in the image transfer sheet and in addition to provide black color data.

The data processing circuitry **107** is connected through a driver **108** to the sublimation image transfer printer.

In FIG. **4**, an example of the color corrector **4** is shown schematically in structure. As shown, it comprises adders **6**Y; **6**M and **6**C, a black color data calculator **7**, and primary and secondary color correction circuits **8** and **9**. Primary color correction circuit **8** serves for making correction of turbidity of the image transfer ink, while secondary color correction circuit **9** provides a capability of arbitrary and selective correction control relative to specifically selected color hue.

The gradation corrector **10** is so arranged as to make correction of the gradation of the data for each color Y, M, C or K (representing black color) fed from the foregoing color corrector **4** when necessary. For this purpose, the corrector **10** includes a gradation circuit (not shown) and the like, whereby a certain mode of highlight stressing or shadow stressing is introduced and realized.

The memory **11** functions to preserve temporarily the data of each color delivered from the gradation corrector **10**, a selection switch **12** being provided at the output side of the memory for selective writing-in of the data of each color to the buffer **13**. The buffer **13** is capable of writing-in the data of one line of the image transfer head **16** and kept in connection with the parallel/series converter **14** adapted for converting parallel data into series data. Additionally, in the simplified machine, black color data series is dispensed with in some instances.

In FIG. **5**, a schematic construction of the parallel/series converter **14** is shown. As shown, parallel data delivered from the buffer **13** are fed to an input side of a comparator **22**, while outputs from a counter **23** are fed to another input side of the comparator **22** which delivers the converted series data to the driver **15** for driving a thermal head **121**.

If necessary, however, the comparator **22** may be replaced by a converter table, not shown, utilizing a parallel/series converting ROM.

In FIG. **6**, a detailed circuit schema of the thermal head **121** is shown. As shown, series data delivered from the comparator **22** are fed into a shift register SR and thence, after being subjected to latching at a latch circuit LT, fed to thermal elements HE through NAND gates NA which are fed at respective one side inlets with strobe signals.

Next, referring to FIG. **3**A, the operation of the data processing circuitry **107** will be described more specifically.

First, when three primary color image data are fed from the picture image inlet circuit **100** to the picture element density converter **3**, the latter converts these three primary color data to those which represent a predetermined picture element density and then are fed to the color correction unit **4**. In this case, it is assumed that the unit **4** is fed with three primary color data expressed in respective concentration signals, which are of yellow: **Y0**; of magenta: **M0** and of cyan: **C0**, respectively, in the present example.

These data: **Y0**; **M0** and **C0** are, as shown in FIG. **4**, fed through respective adders **6**Y; **6**M and **6**C to the black color data calculator **7**, to provide a K-output as expressed mathematically by the following formula:

$$K=\min(Y, M, C)$$

wherein, "min" represents a function which provides a possible minimum value.

These data: **Y0**, **M0** and **C0** are fed from the converter **3** to the primary color correction circuit **8** to provide primarily corrected data **Y1**, **M1** and **C1** which are thence fed to the secondary color correction circuit **9** to provide, through calculation, secondarily corrected data: **Y2**, **M2** and **C2**, respectively. These are then fed to respective adders **6**Y, **6**M and **6**C, which add them to respective data **Y0**, **M0** and **C0**, to provide respectively added output data Y, M, and C to be fed to the gradation correcter circuit **10**, respectively, after being utilized for calculation of the K-output signal value.

The primary color correction circuit **8** serves to calculate primarily corrected data: **Y1**, **M1** and **C1** which are necessarily utilized for correct-out of transfer ink turbit. In this case, the original data: **Y0**, **M0** and **C0** are subjected to matrix calculation to provide the primarily corrected data **Y1**, **M1** and **C1**, as follows:

$$Y1=k_{11}\cdot C0-k_{12}\cdot M0+k_{13}\cdot Y0$$

$$M1=k_{21}\cdot C0+k_{22}\cdot M0-k_{23}\cdot Y0$$

$$C1=k_{31}\cdot C0+k_{32}\cdot M0-k_{33}\cdot Y0$$

where, k_{ij} represents weight coefficients:

i=1–3; and

j=1–3.

The secondary color correction circuit **9** serves to calculate secondary color correction data **Y2**, **M2** and **C2** from primary color correction data **Y1**, **M1** and **C1** by modifying the latter to make certain thereto by performing matrix calculations so as to provide a capability for making an arbitral and selective color control at a certain specifically selected-out color hue, in the following manner:

$$Y2 = Y1 + l_{11} \cdot \Delta B + l_{12} \cdot \Delta C + l_{13} \cdot \Delta G + l_{14} \cdot \Delta Y + l_{15} \cdot \Delta R + l_{16} \cdot \Delta M$$

$$M2 = M1 + l_{21} \cdot \Delta B + l_{22} \cdot \Delta C + l_{23} \cdot \Delta G + l_{24} \cdot \Delta Y + l_{25} \cdot \Delta R + l_{26} \cdot \Delta M,$$

and

$$C2 = C1 + l_{31} \cdot \Delta B + l_{32} \cdot \Delta C + l_{33} \cdot \Delta G + l_{34} \cdot \Delta Y + l_{35} \cdot \Delta R + l_{36} \cdot \Delta M$$

wherein, l_{ij} represents weight coefficients:

i=1–3;

j=1–6;

ΔB, ΔC, ΔG, ΔY, ΔR, ΔM:

characterizing color data.

Thus, when these secondary correction data **Y2**, **M2** and **C2** are added to the corresponding original data **Y0**, **M0** and **C0** by means of respective adders **6Y**, **6M** and **6C** and under proper selection of weight coefficients k_{ij} for primary color correction circuit **8**, any color discrepancy of the ideal color of the ink appearing on the printed picture images under the action of the sublimation transfer printer can be arbitrarily ammended. In this case, when the weight coefficients l_{ij} for the secondary correction circuit **9** are selected out properly, the color tone of the printing picture images can be modified to an arbitrary degree.

Further, as for the black color data K, correction data **K2** can be calculated by the following formula. With use of these correction data **K2**, which are added to the original black color data K, the desired correction can be executed in a similar manner.

$$K2 = K + m1 \cdot \Delta B + m2 \cdot \Delta C + m3 \cdot \Delta G + m4 \cdot \Delta Y + m5 \cdot \Delta R + m6 \cdot \Delta M$$

wherein, Mi represents weight coefficients:

i=1–6.

In this way, output data: Y, M, C and K delivered from the color correction circuit **4** are introduced into the gradation corrector **10** as inputs thereof, and each constituent of these data can be subjected to correction as desired.

FIG. **7** shows several characteristic curves illustrating corrections by means of the gradation corrector **10**. More specifically, **f0** represents a standard characteristic curve; **f1** a highlight-stressing operation curve; **f2** a shadow-stressing operation curve; **f3** a highlight-and-shadow stressing operation curve; and **f4** a medium tone stressing operation curve.

As indicated in FIG. **7**, by presetting, as necessary, the tone-reproducing characteristics, which determine the relationship between that concentration of color data and that of the prints printed by means of a sublimation image transferring printer, a color tone similar to that possessed by the original image can be reproduced. More specifically, when no correction is adopted, the curve **f0** is used, while in the case of correction, any selected one of these curves **f1** to **f4** may be utilized depending upon the part of gradation to be stressed. Further, it should be noted that the tone reproducing characteristic curves are not exclusively limited to those which have been specifically shown and described above. As an example, the control of gradation correction by color tone reproducing characteristic mentioned above is executed by a gradation circuit, not shown, and the setting of the color tone reproducing characteristic is brought about by manipulation of any selected one of the control knobs, not shown, which are provided separately for "highlight"; "medium tone" and "shadow".

Y.M.C.K.-data subjected to correction by the gradation corrector **10** are once stored in the memory unit **11**. The thus stored data may be read out from the memory for each color by manipulation of the selection switch **12** and, after provisional storing, per one line of transfer head **16**, at the buffer **13**, introduced into the parallel/series converter **14** for conversion thereby into corresponding series data.

Another example of the data processing circuit for the sublimation transfer printer is shown only schematically in FIG. **3**B. As shown, the processing circuit in **107'** comprises a level regulator **503**; a color converter **504**; an A/D converter **505** and a parallel/series converter **14**.

As the image data introduced into the processing circuit **107'**, those which have been subjected to conversion into R.G.B.-signals in the color decoder **502** from composite video signals delivered from a T.V. camera, VTR or the like are used. On the other hand, R.G.B.-signals delivered from a personal computer, captain system or the like means are introduced as input into the level adjuster **503**.

As the color correction method with the use of the foregoing arrangements, it is possible, more specifically, to adjust the hue saturation and/or brightness in the color decoder **502**, or to adjust the signal level of each color light of R.G.B.-system in the level regulator **503**.

As an example, the color conversion from R.G.B.- to Y.M.C.-system can be executed in the color converter **504**. The simplest possible method in this color conversion is to procure the opposite color to each of the normal colors.

The thus produced color signals of Y.M.C.-system is subjected to A/D conversion and then fed successively through the parallel/series converter **14** and the driver **108** to the thermal head, not shown, to carry out printing in the sublimation transfer principle.

Additionally, in normal cases, with the use of the foregoing system composition, input image data must be of static mode. However, by provision of memory means in front of the color decoder or at an intermediate position between the A/D converter and parallel/series converter, animating images can be processed.

The series data converted in the foregoing manner in the data converter **107** or **107'** are fed to the shift register SR shown in FIG. **6** by n-image elements and then, upon being subjected to latching in the latch circuit LT are further delivered to NAND gate NA as its inputs. When a strobe signal ST is fed as input to the NAND gate NA, the foregoing n-image element data is fed to the thermal element HE.

FIG. **8** is a schematic diagram, showing signals for respective image elements. The gradation has been so selected that the first image element is at the highest gradation level, while the n-th image element corresponds to the lowest gradation level, and that the second to (n-1)th image elements vary linearly in gradation levels so as to provide representatively a better understandable example of the invention.

Next, the operation of the parallel/series converter **14** will be described.

First, as shown in FIG. **5**, image elements data A, consisting of parallel data, more specifically, comprising parallel eight bit data A**0**–A**7**, are fed to one-side inputs of comparator **22**, while another side inputs thereof are fed with outputs B, comprising eight bit increment outputs B**0**–B**7**, of counter **23**. The counter **23** counts clock signals in increments, the outputs B**0**–B**7** being successively varied.

The comparator **22** performs comparison between the two inputs A and B, so as to deliver successively outputs of binary "1" until the increment output B is brought into coincidence with image elements data A, or more specifically, under the condition of A>B and A=B, while, thereafter, binary "0"-outputs are delivered therefrom. More specifically, comparator **22** will continue to deliver binary "1" until an increment value which corresponds to the weight of concentration of image element data A is given thereto. As an example, if the image element data A has a concentration of gradation **128** of a total 256, output "1" will be repeated to deliver 128 times first and then, output "0" will follow after again 128 times, so as to provide in total a specific series data peculiarly in this case.

These series data are taken out from the comparator **22** in the form of A>B- and A≧B-outputs and of A=B-outputs through an attributed OR-gate **24**, and in the present example, the gradation consists of 256 steps or increments. However, in practice, the gradation may represent a smaller number of steps. As an example, if the incrementing bit is B**1** instead of hitherto employed B**0**, the gradation will have 128 steps; and if B**2** is employed, it will have only 64 steps. In this way, the gradation setting may be varied in a simple manner.

When in the foregoing way, the output B from the counter **23** is stepwise incremented, such series data consisting of a first series of "1" will be delivered until the relationship between the image elements data A and the output B from counter **23** becomes A B, and of a second series of "0" issued thereafter, as shown in FIG. **8**.

In FIG. **9**, a conversion mode at the parallel/series converter **14**, which, however, is different from that shown in FIG. **8**, as an example, is shown again in the form of a matrix. As shown, when the image data are of 8-bit parallel kind, as an example, the gradation data are ranged from 0 to 255, providing, therefore, binary series data from "00 . . . 00" to "11 . . . 11".

In this way, the data, per line in the transfer head **16**, kept preserved in the buffer **13** are fed to the parallel/series converter **14** for providing as outputs therefrom into corresponding series data which are then delivered through the driver **15** to the transfer head **16** and thus recorded on a print paper P supported on the transfer drum **17**.

FIG. **10** represents a flow chart illustrating the operation of the sublimate printer as employed in the present invention.

At the first step S**1**, print papers are set in position and the printing ribbon is also set in position ready for performing the required procedure.

At the second step S**2**, printing operation is initiated, and line printings are executed, line by line, accompanying necessary intermittent line shifts, with relation to any selected one of four colors; C (cyan); M (magenta); Y (yellow) and K (black) being carried out. Refer to S**3** and S**4**. When line printings with the selected-out single color have been completed (S**5**), the image transfer sheet is replaced by another color sheet (S**6**) and so on. In this way, line printings are completed in all four colors. In this case, it is naturally most preferable to use a long extended single transfer sheet on which four color ink regions are repeatedly printed in a certain predetermined pattern. The image reception paper is initiated to make print from a certain prescribed position for each of these colors (S**8**). When all of the printing steps have been completed with the four colors, the paper is discharged from position (S**9**) and the printing operation is terminated to be repeated.

In FIG. **11**, a card style sample of the final products according to this invention is shown in front view at **200**. FIG. **12** is a sectional view thereof. Numeral **201** represents the substrate material of the card; **202** a display layer; **203** a surface protecting layer; and **204** a display image as an example. Depending upon the kind of usage and when necessary, the protecting layer **203** may be dispensed with. It should be noted that the display image **204** on the display layer **202** is represented by a sublimative dyestuff, as a characterizing feature of the present invention.

As the main and substantial material of the image transfer sheet, various plain papers, converted papers, plastic resin sheets or the like may be used per se or in combination. When a plastic resin sheet which can be colored directly with a sublimative dye or dyes is used, these image transfer substrates (articles or objects) as at **201** can be united each with the display layer **202**. Each of these substrate materials, when it is of the card style, may have generally such dimensions: thickness of 0.68 to 0.80 mm and size: 11 to 8×8 to 5 cm.

As the material of the display layer **202**, various known materials which may be colored with sublimative dyestuffs, such as polyethylene, polypropylene, polyester, ABS, AS, polyvinylchloride, polyvinyl/vinyl acetate copolymer, polystyrene, polyacrylate, polyester, polyamide, polyurethane and the like plastic material, may be advantageously utilized. As will be more specifically described hereinafter, this material layer can be united with the substrate material layer **201**. In the case of such unified structure with substrate layer **201**, the thickness and size dimensions may be substantially as the same as before. However, when normal and/or converted papers or metals, which are practically impossible to color with sublimative dyestuffs, are used as the substrate layer **201**, various methods can be utilized for desired coloring. As an example, a solution including at least any selected one of plastic resin materials capable of coloring with sublimative dyestuffs may be coated on the substrate surface, or alternatively used in the form of a film which is laminated thereon. This kind of film preferably has a thickness of about 3 to 50 μm or so. One of main characterizing features represented in and by the final products **200** is that the appearing display image or images as at **204** is/are formed at least partially or wholly with a sublimative dyestuff or dyestuffs. Additionally, the process for formation of such images can be executed in the conventional art.

As an example, the processing method may be executed conventionally as follows.

As an example, a sublimative image transferable sheet, such as a paper sheet, plastic resin film or sheet capable of acting as the carrier is coated on its surface with any suitable binder resin carrier carrying sublimative a dyestuff or dyestuffs under heat, is overlapped on the display layer **202** and then subjected to heat from behind the heat-transferable sheet, preferably in the pattern mode, so as to transfer the dyestuff or dyestuffs into the display layer **202**. It is proper to select the molecular weight of 250 or larger of the dyestuff, for improving the fastness thereof. However, a molecular weight higher than 370 is more favorable. In the

case of provision of the surface protecting layer, there is practically no limitation to the selectability of the dyestuff molecular weight.

The sublimative image transfer may be executed directly on the surface of substrate **201** provided with the display layer **202**. Or alternatively, a carrying, image transferable sheet is prepared separately and, after formation of the image **204** thereon, may be stuck onto or laminated on the substrate **201**.

Image-carrying and Image-transferable Sheet

In the following, structure, material, usage and application purpose of the image-transferable sheet to be employed in the present invention will be described in detail:

FIG. **13** illustrates only basically and in schematic sectional view the image-transferable sheet adopted in the present invention, while FIGS. **14** through **19** and **22** through **24** illustrate preferable embodiments thereof.

The basic structure of the image transferable sheet **310** is characterized in that, as shown in FIG. **13**, a sheet-like substrate **301** is provided at its one surface with an image-reception layer **302** capable of peel-off from the substrate. By adopting such a structural configuration of the image-transferable sheet, the image-reception layer **302** can be formed with the required image or images with the use of an image transferable sheet having thermally shiftable dyestuff, and then, the image-formed, image-reception layer **302** is peeled off from substrate **301** and attached firmly preferably as by sticking, on the surface of any selected object or article with use of any suitable means. In this way, various conventional drawbacks inherent in the comparative. Conventional technique can be basically overcome.

More specifically, as the material of the aforementioned image-reception layer **302**, limitation must be imposed to those which can be colored with thermally shiftable or transferable dyestuff. However, upon formation of necessary images and upon peel-off from the sheet-like substrate **301**, the image-reception layer **302** may be attached fixedly onto the surface of glass-made, metal-made or wooden-made products or plastic-resin made ones which are very difficult to color with thermally shiftable and transferable dyestuffs, indeed, by reliance on conventional sticking techniques as properly adopted in consideration of the specific nature and kind of the material of decorative products to be ornamented. Further, the image-formed and peeled-off, image-reception layer **302** from the sheet substrate **301**, is highly thin and thus sufficiently pliable so that it may be applied even onto any uneven and complicated surface of a product to be decorated or ornamented, having undulations, convexities, concavities, recesses and projections. Therefore, a maximum possible better fitness of the image-reception layer to be ornamented is attained and guaranteed by the present invention. Thus, practically no limitation in the attaching use thereof may be encountered. Further, in sharp contrast to conventional sealing seals and the like, the very thin image-reception layer bearing necessary images can be applied easily to the product per se in a very uniform manner, thus providing no raised and thickened feeling, and giving rise to no foreign feeling upon attachment.

FIG. **14** shows a further example of the image transferable sheet **310**, In this case, there is provided a parting agent layer **303** on the surface of image-reception layer **302**. Between the latter and the sheet substrate **301**, there is provided a parting agent layer **303'**. If necessary, however, any one of the two layers **303**; **303'** may be dispensed with.

The first parting agent layer **303** is provided for prevention of thermal fusion between the image-reception layer **302** and an image transferable sheet, not shown, as may occur during image transfer and formation on the first layer **302** through transfer of thermally transferable dyestuff from the said transferable sheet to the first layer. If there is no risk of such thermal fusion of the above nature, or when the image-transferable sheet has been already provided with such a parting agent layer, the present provision thereof may be unnecessary. As for another parting agent layer **303'**, it is for the purpose of making the latter peel-off operation, to be executed after image-forming step, easier. When the sheet-like substrate **301** is made of polyester or the like material which has, as it is, sufficient separability from image-reception layer **302**, provision of parting agent layer may naturally be dispensed with.

FIG. **15** illustrates a still further example of image transferable sheet **310**. In this case, between the image-reception **302** and the sheet-like substrate **301**, an intermediate layer **304** and/or parting agent layer **303'** is/are provided. The laminating order is optional and thus not binding. The intermediate layer **304** will serve to assist the image formation to be rather firm and beautiful, the image formation being carried out by transferring the thermally shifting and transferring dyestuff from the image transferable sheet to the image-reception layer **302**. For this purpose, the intermediate layer **304** may take, for example, the form of a cushioning layer or heat insulating layer. When a cushioning layer is provided as the intermediate layer **304**, the cohesion between the image transferable sheet and the image reception layer **302** is greatly improved and the thermal shift and transfer of the dyestuff during image formation with the use of a thermal head is evenly executed, the image formation thereby being carried out amply in correspondence with the supplied image signals. Further, when a heat insulating layer consisting of a highly heat-insulative material is used as the intermediate layer **304**, ineffective release of the heat applied during shift and transfer of the dyestuff from the image transferable sheet to the image-reception layer **302** can be reduced to a minimum possible, the effective thermal efficiency thereby being correspondingly improved and ample image formation being accelerated. If necessary, however, these cushioning layer and heat-insulating layer can be prepared independently and arranged concurrently in any arranging order.

Additionally, when the intermediate layer **304** is arranged at a higher level than the parting agent layer **303'**, the intermediate layer **304** will be conjointedly peeled off in the case of peel-off of the image-reception layer **302**. On the contrary, when the intermediate layer **304** is arranged at a lower level than the parting agent layer **303'**, the intermediate layer will remain on the sheet-like substrate **301** after execution of the separation of image-reception layer **302**. In this case, therefore, the intermediate layer **304** may be made preferably and at least substantially transparent, when the peeled-off image-reception layer **302** is stuck on a decorative product, while directing the surface of parting agent layer **303** towards the latter.

In the modifications shown in FIGS. **16**, **17**, and **18**, modified from the foregoing embodiment shown in FIG. **15**, a further protecting layer **305** is provided between the image-reception layer **302** and the sheet-like substrate **301**. This protecting layer **305** serves to prevent deterioration of the formed images in the image-reception layer **302** when the latter is stuck on the decorating product while directing the surface (more specifically the image-formed surface) towards the product. For example, this protecting layer **305** is prepared from a superior material which exhibits at least one of desirous properties such as antiwearing, light-fast,

weather proofing and anti-chemical qualities. With the use of the protecting layer **305** having these superior qualities, the images can represent improved fastness in the above various aspects, even after execution of the foregoing sticking procedure.

In the modification shown in FIG. **16**, the protecting layer **305** is arranged between the intermediate layer **304** and the parting agent layer **303'**.

In the further modification shown in FIG. **17**, the protecting layer **305** is arranged between the image-reception layer **302** and the parting agent layer **303'**.

In still another modification shown in FIG. **18**, the intermediate layer **304** takes the role of the protecting layer **305**.

In each of these modifications, the protecting layer **305** is arranged in neighboring relationship with the partition agent layer **303'**, whereby the image-formed and remotely arranged, image-reception layer **302**, kept in its up-and-down reversed state, is capable of adhering securely to the decorative product, so as to be positioned as an uppermost layer, as may be required. In a still further modification shown in FIG. **19**, derived from that shown in FIG. **14**, a sticking layer **306** is further provided between the image-reception layer **302** and the partition agent layer **303**. It should be noted, however, that such a sticking layer as at **306** may be provided in any one of other foregoing examples and modifications, if necessary, in neighboring relationship with the parting agent layer **303'**.

The provision of such a sticking layer as at **306** is highly valuable when the image-formed and peeled-off, image-reception layer is adhering without position reversal onto the decorative product. With this arrangement mode, the protecting layer **305** shown in FIGS. **16**, **17**, and **18** may be dispensed with. If, however, the protecting layer **305** is composed of a material in the form of a sheet-like substrate, the part to be peeled off is thereby strengthed, the peel-off procedure thus being greatly facilitated.

By previous provision of the sticking layer **306**, the image-formed and peeled-off, image-reception sheet **302** can be caused to adhere as it is onto the decorative product without use of a separate sticking agent. As the sticking layer **306**, an ordinary sticking agent which is active at room temperature can be used. Or alternatively, a heat-sensible or light-sensitive sticking agent may be used, if necessary.

In the foregoing, the main structure of the image transferable sheet employed in the present invention has been described in detail. However, other structural modes than those set forth hereinbefore which occur easily to those skilled in the art may be employable in the invention, and thus they may be included within the scope of the invention without departing from the appended claims.

It should be further noted that, in the present invention, the sheet-like substrate may be provided on its one surface with an image-transferable layer capable of peeling off through the intermediary of only one weakly sticking layer.

FIG. **22** shows only schematically in a sectional view a preferred embodiment of such an image-transferable sheet, denoted with same reference numeral **310**.

As shown in FIG. **22**, the image-transferable sheet **310** represents a basic structural characteristic such that any suitable sheet-like substrate **301** is provided on one of the surfaces with an image-reception layer **302** through an only weakly sticking intermediate layer **402**, the layer **302** thus being easily peeled-off when desired. By providing the image-transferable sheet with such a structural characteristic as set forth above, desired positive or negative images are formed by transferring thermally shiftable and transferable dyestuff from the image heat transferable sheet to the image-reception layer **302**, and the thus image-formed layer is peeled off from the sheet-like substrate **301** and then attached onto any suitably selected product with the use of proper means or attached per se thereon without the peeling-off operation, the substrate then being peeled off, whereby an image-formed final product can be obtained.

In the foregoing example, it should be noted that the image reception sheet **302** per se has only a thin thickness and thus represents only poor feedability during the sheet-feeding period within the printer at the time of image formation, insufficient cushioning effect and only insufficient thermal efficiency during the printing operation, and further, it is very difficult to treat in advance of as well as after execution of the image formation. Therefore, the coexistence of the image-reception layer **302** and the sheet-like substrate **301** is absolutely necessary. In addition, it is a requisite requirement that the image reception layer **302** be easily peeled off from the sheet-like substrate **301** upon execution of the image-forming operation, and thus, the layer **302** and the sheet **301** should not be stuck too strongly together. In order to satisfy this requirement, provision is made of weakly stuck layer **402** therebetween. Thus, it should be noted that the term "weakly stuck" employed in this specification and appended claims may be defined as "to be separable by finger's end and the like means from each other without entailing destruction or breakage of the parts originally stuck together". It is worthwhile to say, in considering the relative relationship between the image-reception layer **302** and the sheet-like substrate **301**, there is no necessity to provide the weakly-stuck layer **402** if the aforementioned peeling-off is very easy to bring about.

FIG. **23** illustrates still another modification of the image-transferable sheet **310** denoted by the same reference numeral **310** only for simplicity and convenience, wherein a further parting agent layer **303** is provided on the surface of image-reception layer **302**.

This layer **302** is provided for occasional thermal sticking between the thermal image transferable sheet, not shown, and the image reception layer **302** in the progress of thermal shift and transfer of the dyestuff from the sheet to the layer **302**. This provision of the parting agent layer **303** may be dispensed with if there is no risk of occurrence of such disadvantageous sticking attachment or the sheet under consideration has already been fitted with such a parting agent layer.

A modification shown in FIG. **24** from that shown in FIG. **23** has such a modified structure that a protecting layer **305** is provided between the image-reception layer **302** and the weakly stuck layer **305**. This layer **305** serves to prevent otherwise occurring deterioration of the images at the image-reception layer **302** which has been formed with preferably reversed images and subjected to peeling-off, together with protecting layer **305**, preferably a plastic sheet layer, from the sheet-like substrate **301** and finally stuck onto the decorative product, while directing the image-formed surface of the image-reception layer towards the product. The protecting layer **305** is made of a material having various excellent physical properties, such as anti-wearing-, light-fastness and antichemical characteristics. Provision of such a protecting layer improves various fastness performances of the formed images after sticking attachment of the image-reception layer **302**.

When necessary, a separate parting agent layer, not shown, may be provided between the protecting layer **305**

and the weakly stuck layer **402** for providing easy peel-off capability between these two layers **305** and **402**, as being applicable to the example shown in FIG. **24**. If the surface of the protecting layer **305** should have sufficient peel-off capability, it is natural to provide such an intermediate parting agent layer as above.

Further, in the case of the image-transferable sheet **310**, it is naturally easy to separate from each other through a peel-off operation, upon the formation of necessary images thereon and before practical use thereof as the image-transfer sheet, and a cut-out slit as at **407** in the sheet-like substrate **301** may be provided for attaining such an easy separation as stated above at a portion of the sheet **310** in proximity to one end thereof. Upon the provision of such a cut-out slit as at **407**, the thus formed flap-like portion can be easily folded out by the operator's finger-tip, thereby affording convenience in a peel-off operation.

The usable materials and composing methods of the foregoing image transferable sheets will now be described.

As a material usable for the sheet-like substrate may be any one or any combination of the following categories:

(1) synthetic paper (polyolefin-series; polystyrene series and the like);

(2) fine quality paper; art paper; coated paper; cast-coated paper, wall paper; back-up paper; backing paper; resin-, emulsion- or synthetic rubber-imprignated paper; resin-admixed paper; paper board; cellulose fiber paper;

(3) polyolefin-, polyvinyl chloride-, polyethylene terephthalate; polystyrene; polymethacrylate; polycarbonate and the like plastic film or sheet. Use of the synthetic paper belonging to the foregoing category (1) is highly suitable for the purpose of the present invention since the surface thereof generally represents a microvoid layer which provides a low heat conductivity and thus a high heat-insulating peformance. A laminated material representing any combination of the foregoing categories (1), (2) and (3) can be used in the present invention. A representative and recommendable example of such a laminate is that of cellulose fiber paper and synthetic paper or that of cellulose fiber paper and plastic resin film or sheet. Among others, use of the first mentioned kind of laminate will provide an advantage in that the thermal instability such as thermal elongation or shrinkage possessed by the synthetic paper component is compensated for by the cellulose fiber paper, whereby a high thermal sensibility is demonstrated during the printing step due to low thermal conductivity of the synthetic paper component. Further, in the case of the present paper combination, however, a further modified combination of a three-layer laminate: synthetic paper-cellulose fiber paper-synthetic paper may be more advantageously employed for making the frequently appearing lesser by providing a well-balanced structure between both the surfaces of the final laminate.

As the synthetic paper mentioned above, any suitable one usable as a synthetic paper substrate used as a component of the image-transferable sheet layer may be used. As a recommendable example thereof, having a fine porous fine paper structure layer, the synthetic paper called "YUPO", manufactured and sold by Oji Yuka Goseishi Kabushiki Kaishar Tokyo, may be mentioned. This paper layer having a fine pore structure may be prepared in such a way that a suitable plastic resin material containing a filler of finely divided state is subjected to a mechanical elongation step. When the image-transferable sheet composed of the synthetic paper sheet containing finely divided air as above mentioned is formed with images through a thermal image transfer setp, the concentration of. the thus formed images is surprisingly high and no fluctuation of image configuration and concentration is encountered, thanks to the heat insulation effect provided by the very existence of fine air pores, in addition to the improved thermal energy efficiency. Especially, due to the advantageous cushioning effect provided by the air-filled fine pores, the image-receiving layer is supposed to be rather advantageously affected during the image formation step. As an alternative measure, the paper-like layer containing the above-mentioned fine air pores may be, if desired, provided directly with the core material consisting of the cellulose fiber paper or the like.

It is further possible to use plastic film in addition to the cellulose fiber paper in the laminate described above. Still further, a laminate of said cellulose fiber paper and plastic film composed together can be used.

As the method for co-sticking of synthetic paper and cellulose fiber paper, use of a known adhesive agent is naturally adopted, as an example. Or alternatively, the extrusion-laminating, heat-adhesion, or the like process may be relied upon, as the case may be. On the other hand, as the sticking-process between the synthetic paper and the plastic film, the lamination process to be carried out simultaneously with the formation of the film may be adopted. Calendering or the like method may be utilized for the same purpose. Selection of any suitable one of the several foregoing sticking processes depends upon the kind of material or the like condition of the partner member to be stuck together with the synthetic paper. As for the adhesive agent mentioned above, emulsion adhesive such as ethylene-vinyl acetate copolymer, polyvinyl acetate or the like, aqueous solution type adhesive polyester containing carboxyl radicals; or the like may be mentioned. On the other hand, as the laminating use adhesive, organic solvent solution type one such as polyurethane-, acrylic- or the like, may be mentioned.

The material for the image-reception layer must be suitable for reception of heat-transfer dyestuff, such as sublimative disperse dye from the image transfer sheet and holding and maintaining the thus formed images thereon. From the view point of image-holding and blocking prevention, use of such synthetic resin as having glass transition temperature higher than 40° C. may be advantageous. For example, the synthetic resins set forth in the following items (a) through (e) may be used separately or in combination.

(a) Ester bond-bearing resins: Polyester resin; polyacrylic ester resin; polycarbonate resin; polyvinyl acetate resin; styrene acrylate resin; vinyltoluene acrylate resin and the like.

(b) Urethane bond-bearing resins: Polyurethane resin and the like.

(c) Amide-bond carrying resins: Polyamide resins (nylons).

(d) Urea-bond carrying resins: Urea resins and the like.

(e) Other high polar-bond carrying substances: Polycaprolacton resin; polystyrene resin; polyvinylchloride resin; polyacrylonitrile resin and the like.

The image-reception layer may be prepared from a resin mixture of saturated polyester and vinylchloridevinyl acetate copolymer. As the saturated polyester, such commercialized products: "Vylon 200"; "Vylon 290"; "Vylon 600"; "Vylon 103" and the like, manufactured and sold by Toyoboseki K.K., Osaka, Japan; "KA-1038C" (manufactured and

sold by Arakawa Kagaku K.K., Osaka, Japan; "TP 220"; "TP 235", manufactured and sold by Nippon Gosei K.K., Osaka, Japan; may be advantageously used. The vinyl chloride-vinyl acetate copolymer may have preferably 85–97 wt. % of vinyl chloride component, the polymerization degree being between about 200 and 800. The vinyl chloride-vinyl acetate copolymer may further contain a vinyl alcohol component, maleic acid component within the purpose of the invention in addition to the main components. According to our experiments, it has been found that these modified copolymers should have rather superior compatibility with polyester resin. The image-reception layer may be, if necessary, composed of polystyrene resin, for example, in this case, styrene monomer, preferably styrene, α-methyl styrene, and vinyl toluene may be used separately or in the form of copolymer or saying in general sense polystyrene resin. Further, such styrene copolymer resin may be used as specifically recommendable material in the above sense, comprising said styrene monomer(s) with other monomer, preferably for example, acrylic acid ester, methacrylic acid ester, acrylonitrile, methacrylonitrile and the acrylic or methacrylic monomer, or further styrene copolymer resin comprising maleic acid anhydride.

It should be noted, however, that among others, polyester series resin is especially superior for the purpose of the present invention.

In any of the foregoing embodiments, however, white pigment is preferably admixed with the material of the image-reception layer for improving the whiteness thereof and further accentuating the sharpness and fineness of the images when transferred thereto and to provide a manually writing-on performance. As the white pigment for this purpose, the following materials may be used separately or in any combination: titanium oxide; zinc oxide; china clay calcium carbonate; finely divided silica and the like.

For further improving the whiteness fluorescent whiteness-increasing agent or -bleaching agent may be added to. Further, for improving the light fastness of transferred images, ultraviolet absorption agent and/or photostabilizing agent may be added to, preferably in a quantity of 0.05 to 10 and 0.5 to 3 weight parts per 100 weight parts of the material resin composing the image-reception layer.

The image-transferable sheet used in the present invention is preferably constituted for improving the separability from the image-transfer sheet in such a way that the surface of the image-reception layer is formed with a partition agent layer, or instead, such agent is admixed to the image-reception layer. As for the partition agent to be used for this purpose, polyethylene wax; Amido Wax, Teflon Powder or the like solid wax; surface active agents such as fluorine-contained agent or phosphoric acid ester series surfactant; silicone oil or the like may be selectively used. Among others, silicone oil may be advantageously utilized.

The silicone oil may be used in oily state, but a hardenable type thereof may be rather advantageous. As the hardenable silicone oil, reaction-hardening one, photo-hardening one, catalytically hardening or the like one may be used selectively according to necessity. However, use of the reaction-hardenable one is most highly recommendable. Silicone oil of this type may be obtained, as example, by reacting amino-modified silicone oil with epoxy-modified silicone oil to obtain a reaction-hardened product. As for the amino-modified silicone oil, "KF-394", "KF-857", "KF-858"; and "X-22-3680"; "X-22-3801C" (manufactured and sold by Shinetsu Kagaku Kogyo K.K., (Tokyo, Japan)) and equivalents thereof may be used. As for the epoxy-modified silicone oil, "KF-100T"; "KF-101"; "KF-60-164"; and "KF-103" (manufactured by Shinetsu, above mentioned) and equivalents thereof may be used. Further, as the catalytically hardenable and photohardenable silicone oils in the above sense, "KS-705F"; "KS-770" of the catalytic hardenable or hardened silicone oils, manufactured by Shinetsu; and "KS-720" and "KS-774" of the photo-hardenable or hardened silicone oils (manufactured equally by Shinetsu) and equivalents thereof may be used. The adding quantity of each of these hardenable or hardened silicone oils may advantageously range from 0.5 to 30 wt. % depending on the material of the resin composing the image-reception layer.

At least a part of the image-reception layer is coated with a solution or dispersion of any of the foregoing partition agents in a suitable solvent and dried and further treated, a suitable parting layer being provided thereon. A particularly suitable partition agent for the formation of this kind of partition layer is the aforementioned reaction type hardenable one obtainable by reacton of an amine-modified silicone oil with an epoxy-modified one. The thickness of the partition layer is 0.01–5 μ, preferably 0.05–2 μ.

It should be noted that when silicone oil is admixed during formation of the image-reception layer, the silicone oil will bleed out after coating and the parting agent layer can be formed by the hardening even after such bleeding. In order to improve the parting ability between the image transferable layer and sheet-like substrate, it is possible to provide a parting layer consisting of a heat-hardenable resin, preferably of the melamine series, and having better affinity for the image transferable layer compositions. For the same purpose as above, however, without special provision of the parting layer, a protecting layer consisting of polymethyl methacrylate resin or cellulose acetate propionate can be provided.

For the formation of the image transferable layer, a solution or dispersion of a material composition suitable for the purpose is applied on the sheet-like substrate through conventional coating or printing. As an alternative way, a separate film or sheet for the image transferable layer **302** is formed preparatorily on a provisional carrier sheet or film and then, as a succeeding step, subjected to an image-transfer onto the substrate.

The intermediate layer is made of either a cushioning or a porous material. In some cases, the intermediate layer may additionally function as the adhesive layer.

The cushioning layer is mainly composed of such a resin which has a value of 100%-modulus as defined at JIS-K-6031 (Japanese Industrial Standard) of less than 100 kg/cm^2. If this value should exceed the above prescribed value, the rigidity will become much higher than that recommended for the intermediate layer. When the layer is formed with such disadvantageous material resin, sufficient adhesion between the heat image-transfer sheet and the image-reception layer cannot be maintained during the printing step. The lower limit of the prescribed 100%-modulus is of the order of 0.5 kg/cm^2 in actual practice.

Preferable kinds of resin to be used for the above purpose, may be enlisted as follows:

polyurethane resin; polyester resin; polybutadine resin; polyacrylic acid ester resin; epoxy resin; polyamide resin; rosin-modified phenol resin; terpene phenol resin; ethylene/vinylacetate copolymer resin; and the like.

These resins can be used independently or in combination of two or more kinds. Since these resins are rather viscous and tend to give rise to manufacturing troubles inorganic additives may be admixed, such as, for example, silica; alumina; clay; calcium carbonate; amide series substance such as amide stearate; and/or the like.

The cushioning layer is preferably formed with the use of one or more of the above specified resins, occasionally with the addition of suitable additive(s); solvent or diluent, prepared into a coating agent or printing ink which is then applied on, according to a known coating or printing process and then subjected to drying to provide a coating. The thickness of the coating should be between 0.5–50 μm, preferably 2–20 μm or so. With a thickness less than 0.5 μm, the coating will not be able to compensate for the surface irregularities on the substrate, thus being ineffective for the desired purpose. On the other hand, when the thickness exceeds the above specified maximum value or more specifically 50 μm, the overall thickness of the image-transferable layer becomes much too large, so that handling troubles may be encountered during wind-up and overlapping procedures, without attaining further effect as desired. In addition, in this case, a loss of production economy will be inevitably introduced.

The thus obtainable improvement of intimate adhesion between the heat-image transfer sheet and the thermally image-transferable sheet by the provision of the above intermediate layer may be conceivably attributed to the lower rigidity of the intermediate layer per se, whereby it is liably to be deformed under the influence of the printing pressure, and further to the generally relatively low glass transition temperature and softening temperature of the aforementioned kinds of resin resulting in further lowering of rigidity and tendency to deform than at room temperatures upon reception of heat energy during the image printing step.

The porous layer may be formed generally in the following four ways: 1) through 4).

1) Emulsion of polyurethane or the like resin, methylmethacrylate-butadiene series synthetic rubber latex is foamed by mechanical agitation, coated, and dried on the sheet substrate into a layer.
2) The synthetic resin emulsion or synthetic rubber latex is admixed with a foaming agent and the liquid mixture is coated and dried on the substrate into a layer.
3) Vinyl chloride-plastisol, polyurethane or the like synthetic resin or styrene-butadiene series or the like synthetic rubber is added with a foaming agent and the liquid mixture is coated on the substrate and subjected to heating to provide a foamed layer formed thereon.
4) A thermoplastic resin or synthetic rubber is dissolved in an organic solvent to provide a solution, and a non-solvent (including that containing aqueous main component), and the latter solution are mixed together to provide a liquid mixture, said nonsolvent being less volatile than the organic solvent and having a considerable mutual solubility with the solvent, and showing, however, non-solubility with the thermoplastic resin or synthetic rubber. The thus prepared liquid mixture is then coated on the sheet-like substrate and dried, to provide a porous membrane upon microcoagulation of the constituents. The resulting microporous layer can be utilized for the above purpose.

It should be noted that the layers produced by any of the foregoing three processes 1) to 3) have rather large foams contained therein, and thus when the foaming solution for the image-transferable layer is applied thereon and dried, the latter may exhibit excessively coarse surface conditions. Therefore, in order to obtain an optimumly image-transferable smooth surface capable of providing transferred images of high uniformity, provision of the micro-porous layer prepared by the process as set forth in the foregoing item 4) is highly recommendable.

As the thermoplastic resin suitable for the formation of the above porous layer, saturated polyester; polyurethane; vinylchloride-vinylacetate copolymer; cellulose acetopropionate and the like can be used. Further, as the synthetic rubber usable for the same purpose, those of styrene-butadiene series, isoprene series, urethane and the like series may be used. Still further, as the organic solvent and non-solvent liquid used for the formation of the microporous layer, various known substances may be used. Generally speaking, however, methyl ethyl ketone; alcohol and the like are representatively used. On the other hand, as the non-solvent, water is mostly used.

The thickness of the porous layer usable in the present invention is preferably greater than 3 μm, especially preferably in the range of 5 to 20 μm. With the use of a porous layer having a thickness of less than 3 μm, the desired cushioning and heat-insulating effects cannot be attained.

As was referred to hereinbefore in the description stage for the formation of the image-transferable layer, the intermediate layer may act simultaneously as the sticking layer in some cases.

This kind of intermediate layer(s) may be provided on one or both of the surfaces of the thermally image-transferable sheet.

In practice, however, an electrostatic charge may accumulate in the material of the thermally image-transferable sheet during its processing step or during running through the printer. As a countermeasure, a proper antistatic agent may be applied on one surface of the image-transferable layer or on the bottom surface of the thermally image-transferable sheet or it can be included in the material of the image-transferable layer. As the antistatic agent in this sense, a surfactant such as a cation-exchange agent (for example, a quaternary ammonium salt, polyamide derivatives and the like) may be advantageously used. Further, an anion exchange type surfactant, such as alkyl sulfonate may be used. Otherwise, amphoteric ion type surfactants or even, non-ionic surfactants may be used for the same purpose.

On the other hand, the antistatic agents may be coated on the surface of image-reception layer by gravure-coating, bar-coating or the like process or alternatively, these agents may be kneaded with the material resin and then subjected to transfer towards the surface during the coating formation and drying step for preparing and providing the image-transferable layer. As the antistatic agents to be admixed with the image-transferable layer material resin, cation-type acrylic polymers may be employed.

The protecting layer is peeled off together with the image-transferred layer, from the sheet-like substrate, and then stuck, in inverted reversed state, onto any desired decorative object, the protecting layer thereby being positioned at the uppermost position, for improving the anti-wearing-light-proofing and anti-chemical performances of the image-bearing layer. As the material adapted for the formation of the protecting layer, for example, alkyd resin; phenol-modified alkyd resin; aminoalkyd resin; phenol resin; urea resin, melamine resin; silicone resin, thermosetting acryl resin, thermosetting polyurethane resin and the like thermosetting resin or normal temperature setting resin; further, ultraviolet hardenable resin; electron ray hardenable and the like activating energy flux hardenable resins or thermoplastic resins such as polyester-; polyurethane-; polyvinyl acetate resin; vinyl chloridevinyl acetate copolymer resin; polyolefin resin, acryl resin and the like, can be used.

Preparation and use of a protecting layer comprising one or more of the above-mentioned resins are made in such a way that the material resin is dissolved in a properly selected

solvent according to the necessity, so as to provide a coating liquid or ink, as the case may be, which is provided between the parting layer and the image transferable layer. The thickness thereof is generally 0.5 to 20 μm. It is also possible to form the protecting layer with the use of a resin film which consists of polyester-; acryl-; acrylpolyol-; polyvinyl chloride-; olefin resin or the like resin. It is further possible advantageously to admix an ultraviolet ray absorbing agent and/or photostabilizer to the material of the protecting layer.

The protecting layers prepared and formed in the foregoing way are thus not made integral with the sheet-like substrate or parting layer and, therefore, the peel-off operation of the sheet-like substrate upon execution of the image transfer is very simple and easy.

It is further recommendable, if necessary, to provide a slip-promoting layer on the bottom surface of the sheet-like substrate, which surface is naturally the one opposite to the image-transferable layer side, so as to properly adjust the friction between the image-transferable sheet and feed roll paper or carrier belt acting during passage through the printer and to improve the running performance of the thermally image-transferable sheet in the printer.

The slip-promoting layer can be formed by adding an organic powder such as polyethylene wax fluorine resin powder or an inorganic powder such as talc, according to necessity, to a resin such as polymethyl methacrylate resin; vinyl chloride-vinylacetate copolymer; vinyl chloride copolymer; cellulose acetate butylate; cellulose acetate propionate; styrene-acryl series or the like resin and kneading the resulting mixture to prepare a composition, applying this composition as a coating on the sheet substrate either directly or after application of a suitable primer treatment, and drying the coating thus applied. A suitable quantity of the slip-promoting layer is 0.5 to 5 g/m^2 after drying.

In the embodiments shown in FIGS. **22**, **23**, and **24**, as the adhesive agent to be used in the slightly weak or weak adhesive layer, it should be noted that those conventionally used adhesives for adhesive tapes and seals can all be used. Preferred examples are polyisoprene rubber; polyisobutyl rubber; styrene butadiene rubber; butadiene acrylonitrile rubber and the like rubber-series resins; (meth)acrylic acid ester-series resins; polyvinyl ether-series resins; polyvinyl acetate-series resins; vinylchloride-acetate copolymer series resins; polystyrene-series resins; polyester-series resins; polyamide-series resins; polychlorinated olefin-series resins; and polyvinyl butyrol-series resins. To the suitably selected adherent may be added a proper quantity of a stickness improver, such as rosin; dammar; polymerized rosin; partially hydrogenated rosin; ester rosin; polyterpene-series resins, terpene-modified substances; petroleum-originated resins; cycropentadiene-series resins; phenol resins; styrene resins; xylene resins; and coumarone-indene resin. Further, when necessary, to the mixture may be added a softening agent, filler; antiaging substance or the like conventional agent(s). As the material for the formation of slightly or weak-adherent layer said above, emulsion type adhesive, preferably of acryl acid ester series can be used. As for the parting function after a long time of preservation, emulsion type adhesives are highly recommendable. These adhesive agents are easily procurable from market.

When necessary, these adhesives are added with proper organic solvent(s) for the adjustment of the viscosity, and then applied by roll coating, die-coating, knife coating, gravure coating or the like conventional technique on the surface of the sheet-like substrate, image-reception layer or protecting layer, so as to provide an adhesive agent layer. The thus formed adhesive layer is preferably of a thickness of 1–50 μm, although this is not limitative.

Formation of Images

In the following, the decorating process according to this invention will be set forth in detail. Utilization of the image-transferable sheet according to this invention constitutes an important main feature thereof.

In FIGS. **20** and **21**, basic practising processes will be described first.

The embodiment shown in FIG. **20** is a result of the use of the transferable sheet shown in FIG. **13**. First, a known transfer sheet **320** is applied onto the image-transferable sheet **310** in an overlapped manner such that the dye-carrying layer **321** is kept in opposition to the image-reception layer **302** of image-transfer sheet **320**, and heat energy is applied, as schematically shown by a plurality of arrows, in accordance with image signals fed at a thermal head, not shown, from the side of image-transferable sheet **310**, or preferably, from the side of the image-transfer sheet **320**, thereby forming the desired images as at **307** in the image-reception layer **302**. Next, the image-reception layer **302** formed therein with the desired images **307** is peeled off from sheet-like substrate **301** and stuck onto the decorative product **306**. Or alternatively, both the sheets **302**; **301** are stuck onto the product **306** without preparatory peeling-off. In the latter case, the peel-off step may be executed after execution of the stickingly attaching step. In the above former case, and in such a case where an adhesive agent layer **306** has preparatorily provided between image-reception layer **302** and sheet-like substrate **301** as was set forth hereinbefore, the sticking attachment is carried into effect in such a way that the adhesive layer **306** is kept in opposing contact with the product **330**, and then the sticking operation is brought about by application of heat and pressure or light and pressure, depending upon the nature and structure of the layer **306**. In this way, the decoration according to the present invention is completed as a preferred one mode thereof.

On the other hand, if there is no preparatory provision of the adhesive layer, either the surface of product **330** or of the peeled-off image reception layer **302**, may be coated with the adhesive agent, and the latter layer **302** per se or otherwise in the up-and-down reversed state may be stickingly attached onto the product **330** (refer to FIG. **21**).

Since the image-reception layer **302** is composed generally of such thermoplastic resin material as is liable to be colored with thermally transferable dyestuff, it can be thermally and fusingly attached to plastic resin-made formings, clothes or metals even with provision of an adhesive layer, if necessary.

In this case, the image-bearing layer **302**, the image thereof having been formed in the aforementioned way, is stuck on, through the intermediary of the adhesive agent layer **306** as shown in FIG. **25**, while retaining the sheet-like substrate **301** on the surface of the image-reception layer **302**.

A modification of the last-mentioned mode is shown in FIG. **26**. In this case, sheet-like substrate **301** is formed on the surface of the product **330** and the image-reception layer **302** is formed as the outermost layer. Further, in this case, sheet-like substrate **301** and product **330** may be stuck together, and, through the intermediary of a suitable adhesive layer, sticking layer or heat-sealable sheet or the like.

As for the transparent film usable as the said sheet-like substrate, it must be transparent to such a degree as not to conceal the images formed in the image-reception layer, and, in addition, it must have superior surface properties such as,

for instance, antiwearing characteristics. As an example, polyolefine; polyvinyl chloride; polyethylene terephthalate; polystyrene; polymethacrylate; polycarbonate and the like plastic resin-made films may be used upon variously surface conditioning. If these transparent films should be too thick, the images will be raised, and the unitary feelings may be lost when these are stuck on respective products to be decorated. Therefore, the film thickness is preferably of the order of 0.5 to 50 μm.

In the case of a further embodiment of the present invention, the image reception layer of image transferable sheet which has been, however, formed with necessary images is subjected to image transfer treatment onto an intermediate image transferable substrate, the latter is then subjected to an image-retransfer with the images, and the thus retransferred images are again transferred onto the surface of the product to be decorated. In the following, this image transfer mode will be set forth in detail.

Embodiments shown in FIGS. **27**, **28** and **29** represent such a process for execution of image transfer operation as by the intermediary of intermediate image transfer sheet **510**. First, as shown in FIG. **27**, a thermally image-transfer sheet **320** having a thermal transferable dyestuff layer **321** is overlapped to image-transfer sheet **510** which is, at this stage, not formed with images **307** and thus consists of a thermal image-transferable sheet, in such a way that the dyestuff layer **321** or more specifically the parting layer **322** is in opposition to the image-reception layer **302** of the foregoing sheet **510**. In such a case, however, that heat energy is supplied in accordance with image-forming signals delivered from the thermal head, not shown, and, indeed, preferably from the side of the sheet **320** as hinted by a plurality of double-line arrows for thermal formation of desired images (positive images) as at **307** in the image-reception layer **302**, it is highly recommendable to provide an adhesive layer **402** between the layer **302** and sheet-like substrate **301**.

Then, with the use of the image transfer sheet **510** formed with positive images **307**, the images of layer **302** are transferred, as shown in FIG. **28**, to a separate intermediate substrate **501**, which is, however, fitted with a protecting film layer **305**, thus, the transfer being carried out, in fact, onto the latter, and indeed, with the correspondingly inverted images, attached with same reference numeral only for convenience, from the foregoing layer **302**. In this case, it is preferable to subject the adhesive layer **402** of the image-transfer sheet **510** to the image-transfer operation, together with the image-reception layer **302**. Further, as for the intermediate image-transfer substrate **501**, it is recommendable to provide the protecting film layer **305** through the intermediary of a weak-adhesive layer **402'** as shown. The thus provided intermediate image-transfer sheet **610** represents generally the image-transferable sheet.

FIG. **29** illustrates the step for transfer of the image-reception layer **302** now carrying positive images **307** onto the object **330** to be decorated and under utilization of the previously described intermediate image-transfer sheet **610**.

More specifically, the intermediate image-transfer sheet **610** is overlapped onto the said object **330** in such a way that the adhesive layer **402** of the former in opposition to the surface of the object **330** and pressurized together. Then, the intermediate transfer substrate **501** together with the weak-adhesive layer **402'** is peeled off from the remainder of the thus-pressurized assembly, the now image-carrying layer **302** formed with positive images **307** covered with protecting the film layer **305** thereby remaining in the transferred state on the product **330**. In the case of no provision of the protecting film layer **305** on the intermediate image-transferable sheet **610**, the layer **302** remains in an exposed state. Therefore, an overcoat layer, if necessary, can be provided on the now image-carrying layer **302**.

The previously set forth process carried out by the use of said intermediate image-transferable sheet can be executed by means of the apparatus which is shown schematically in FIG. **1**E.

In this apparatus, more specifically, there is provided a carrier system comprising a series of rolls **411**, **412**, **413** and **414** for conveying the intermediate transfer substrate (sheet), arranged in addition to the apparatus shown in FIG. **1**B. More specifically, the substrate is drawn out from feed roll **414**, conveyed through successive rolls **413**; **412** and retransferred onto one of the products **200**. Other operations are same as set forth hereinbefore with reference to FIG. **1**B. Further, in the case of FIG. **1**E, the final product may take the form of a roll-like substrate which is subjected to an image transfer operation through the intermediate substrate, by transferring its image-carrying, image-transferable layer, for later being punched out properly. Alternatively, under occasion, it may be subjected to half-cut operations downstream of roll **122**.

As was set forth herein above, the preferable method for the formation of desired images on the image-transferable sheet is carried out by use of a heat image-transfer sheet comprising a sheet-like substrate having a layer including a thermally transferable dye (evaporative dye). The heat image-transfer sheet which can be utilized in this method is known per se. And almost every kind of these known sheets can be useful in the practice of the present invention. It should be noted that by employing the foregoing image-transfer method, mono-color or full-color images can be easily formed as occasion may desire.

It should be further noted that details of such heat image-transferable sheet can be easily understood with reference to our U.S. patent application Ser. No. 833039. As for the heat image-transferable sheet usable in the present invention, the coating layer of the sheet (coating film) may include a parting agent. By adopting this measure, the image-reception layer of the image-transferable sheet or the surface thereof, to be subjected to sublimative image-transfer, must not have a separate parting agent layer, the adhesive ability between the image-reception and the surface of object to be decorated can be still further improved upon execution of the sublimative image-transfer and image-formation at the image-reception layer and adherent attachment thereof to the object. As the parting agent to be included in the coating layer of the thermally image-transferable sheet (coating film), silicone oil; silicone resin; phosphoric ester or the like surfactant; and/or chelate- and the like agents, may be selectively utilized. These agents, upon mixed, will ooze out from inside to the outer surface of the coating layer, resulting in providing a better parting quality. However, it is preferable to properly select the kind and nature of the parting agent to be used for this purpose, being such that the agent cannot transfer to the image-reception layer of the image transferable sheet during the sublimating image-transfer stage. The adding quantity of the parting agent may preferably be 3–25 wt. parts based upon the total amount of resin and coating composing the coating layer taken as 100 wt. %.

In practice, any kind of conventionally known heat transfer sheets is overlapped on the thermally image-transfer sheet employed in the present invention, and then necessary heat energy of 5–100 mJ/mm^2 is applied by use of a

conventionally known heat transfer unit, for instance, "Video-printer: VY-100" manufactured and sold by Hitachi Seisakusho, Tokyo, or its equivalent machine, for the formation of necessary images on the image-reception layer of the image-transfer sheet as set forth hereinbefore.

Peel-off operation for removal of the image-reception layer formed with necessary images in the above manner may be carried into effect in a very easy manner, so as to provide it in a thin film carrying the images thereon. In case where the thus-peeled off film carrying the images is provided beforehand with an adhesive layer, composed of a suitable adhesive agent as was referred to, at the opposite surface to the image-carrying one, the peeled-off film can be, as it is, stuck on the object to be decorated. It is natural that this adhesive attachment procedure can be performed only partially and locally on selected part of the whole surface of the object, or totally thereon, as the case may be. On the contrary, if the peel-off film is provided beforehand with no adhesive layer, the film can be subjected occasionally to a heat fusion onto the surface of the object, if the physical properties or material kind thereof is suitable for such kind of thermal fusion. Or alternatively, a properly selected adhesive agent can be preparatorily applied onto the surface of the film or object, and then, the stick-on job can be executed.

If the image-reception layer is provided preparatorily with a parting layer thereon, as was referred to, the latter layer can be removed off partially or wholly, by grinding or rubbing operation after execution of the sublimating image-transfer job, for avoiding otherwise occurrence of ill effect by the very presence of parting layer in the adhesive attachment of the image-carrying layer film onto the decorative object.

In case of that where the image-transferable sheet is provided with a protecting layer and the latter is composed of a plastic resin film, this film may preferably be cut into pieces or subjected to punch-cuttings.

FIG. **32** illustrates successive die-cutting steps in sectional views, serving for the above purpose. In this case, as shown in FIG. **32** at (a), only image-reception layer **305** of the image-transferable sheet **310**, which has been image-formed through the way of the foregoing image-transfer step, are die-cut by operation of a cutter **801**. Next, as shown in FIG. **32** at (b), a pair of hot stamps **132**'; **133**' are used to execute a pressurizing job under heat from opposite sides, thereby the decorative product **330** being processed into a final product provided tightly with an image-reception layer and a protecting layer, as shown in FIG. **32** at (c).

Further, when occasion desires, the image-carrying film is reversed up-and-down in position after execution of the peel-off job, and, the film is stuck onto the product to be decorated in such a state that the image-carrying surface of the film is kept in direct opposition to the product's decorating surface. In this case, however, it would be rather preferable that in advance of preparatory peel-off of the image-reception layer, the image-carrying transferable sheet is stuck onto the surface of the product to be decorated, and indeed, preferably with use of an adhesive agent, in such a way that the image-carrying layer is kept in direct opposition to the product surface and finally, the sheet-like substrate is peeled off, so as to leave the image-carrying surface on the product's surface.

As in the foregoing, when the images are once reversed and then stuck onto the object to be decorated, the forming images are preferable to reverse in mode (mirror-like relationship) the original to those of reversed mode.

It is further possible that the transfer or sticking-on of the image-carrying layer is carried out through the intermediary of a separate fusing sheet.

In FIG. **30**, use of such fusing sheet **701** for reimage-transfer operation of image-carrying layer **2** already formed with necessary images **307**, however, of reversed mode, and onto the surface of a product.

More specifically, the image-transferable sheet **310** is overlapped onto the product **330** to be decorated in such a way that the image-reception layer **302** carrying the necessary images **307** is kept in opposition to the surface of the product, and indeed, through the intermediary of a fusing seat **701** and then these three components are pressurized together. Further, sheet-like substrate **301**, together with parting layer **303**', is peeled off, thereby the image-reception layer **302**, now having positive images **307** formed thereon, and protecting the latter, being transferred onto the product **330**. It will be seen in this case, that there is no need for this transfer job, to provide in advance on adhesive layer on the surface of image-reception layer **302** and/or on the surface of the product **330**, and further that a direct heat fusion onto the surface of the product **330** which may be composed of plastic resin, textile fabric, metal or the like common material, however, through the intermediary of a heat-fusible or heat-sealable sheet.

In case where the protecting layer **305** is of plastic resin, similar composing technique as mentioned above may be employed by substituting a weak-sticking layer **402**' for parting layer **303**'.

As the heat-fusible or heat-sealable sheet as at **701** employable in the present invention, it may be composed of one or other material capable of adhering under heat, pressure or both, especially suitable one of those which become soft to be adhesive upon heating. These heat adhering materials in the form of sheets will be, upon softening, charge the pores, meshes or stitches of the product material composed preferably of textiles, woven or non-woven; knits, rough-surface papers or meshed materials, thereby the surface of the product becoming highly smooth for well receiving the image-reception layer **302** for desired image-retransfer with trouble, which effect is superior in the art.

On the contrary, when such heat-fusible or heat adhesive sheet materials which may be called "heat bond sheets" as at **701** are not utilized, it is highly difficult to realize the image-retransfer operation onto certain kind of objects such as rough-surfaced or rough-meshed fabric or the like. Even if the retransfer job could be executed, the obtained images may be blurred and the adhesive may be insufficient, on account of the very thin thickness of the image-reception layer **302**, thus giving rise to technical and commercial troubles.

As for the heat fusible sheet **701** to be used in the foregoing manner, ethylene/vinyl acetate copolymer, nylon copolymer; epoxy/phenol copolymer; epoxy/vinyl copolymer; acrylic resin; polyester resin; or polyolefin resin and the like thermoplastic resins (heat sensible adhesive agents) which are formed into sheets or films may be used. These materials must be softened at 100–250° C. or so to represent viscous adhesive characteristics. These materials are, when used, capable of being stuck to both the image-transferred product **330** and the image-carrying layer **302**.

These heat bond sheets **701** have generally thickness of 1–200 μm. When the surface of the product **330** to be decorated is relatively smooth, the sheet selected out may be of relatively thin thickness, while, on the contrary, when the surface of the decorative product **330** is relatively rough, as in the case of textile fabrics, unwoven fabrics, meshed fabrics or the like, use of thicker heat bond sheets is rather recommendable.

As set forth above, the use of heat bond sheets is highly recommendable in the decorative image-transfer onto rough surface products, such as those of rough fabrics, woven or non-woven, knitted clothes, meshed one or the like, thereby a better quality image-transfer being executed, in spite of the meshed or highly undulating surface conditions of the objects to be decorated.

Further in the present invention, during the adhering attachment of the image-reception layer already formed with necessary images onto the object or product, an additional processing step is preferably introduced for prevention of occasional interference in the foregoing adhering attachment step, by rubbing-off or grinding-off part or whole of the parting layer, provided on the surface of the now image-carrying layer, upon completion of the sublimating image-transfer step.

Still further, in such a case that the image-transferable sheet is fitted with a protecting layer which is composed of a plastic resin film, the latter must in advance be subjected to punching or the like cutting step for cutting the film into desirously sized pieces.

FIG. **32** represents such a die-cut (half-cut) process in sectional schema. In this case, at first, as shown at (a) of FIG. **32**, the image-reception layer **302** of an image-transferable sheet **310**, now formed with necessary images through a sublimative image-transfer step, and the protecting layer **305**, are subjected to a die-cutting process by means of a cutter **801** to shape a desired shape. And then, as shown at (b) in FIG. **32**, the cut-out piece is subjected to a pressurizing step under heat by means of a pair of hot stamps **132**'; **133**' to provide a final decorative object., as shown at (c) in FIG. **32**, which is composed of a product **330** to be decorated, however, now attached integrally and jointly with image-carrying layer **302** and protecting layer **305**.

Applied Products

The products applicable with the inventive process for decorating purposes are not limited to occasionally employed kind, shape and nature of the materials. Preferred examples of the usable product may be: cartons; vessels or packages; bags; cassette cases; cassette halves; floppy cases; paper packages and envelopes; stock certificates; personal and bank cheques; bills; bonds; certificates; notifications; car tickets; travel tickets; betting tickets; tax stamps; postage stamps; entrance tickets, money-exchangeable papers and documents; cash-cards, credit cards, orange cards, telephone cards; member's cards; greeting cards; postcards, name cards; driver's certificates; IC-cards; optical cards and the like various cards; accounting cards and documents-envelopes; tags; ORP-sheets; slide films; bookmark slips; calendars; posters; pamphlets; menus; passports; POP-goods and articles; coasters; displays; nameplates; keyboards; cosmetics; personal ornaments (watches; cigarette lighters); stationaries; construction materials; radio-receiving sets; T.V.-sets; speakers; table calculators; automotive gauge boards; emblems; keys; clothes; wearing commodities; footwears; appliances; OA-instruments; sample books; tickets in general; albums; computer graphic and/or medicare graphic image printouts; and the like, where the material kinds, sizes and configurations are regardless for purposes of the invention.

The aforementioned goods and instruments may have printed or the like other images in advance of execution of the process of the invention. Or conversely, the goods and instruments can be formed with necessary images in accordance with the present process, and then, additional images may be formed in conventional printing or the like process.

As an example, when the invention is applied to a card style intermediate product, it is possible to combine image-forming means of the present invention with conventional recording means. As the latter, magnetic recording by use of a magnetic material layer; optical recording by use of an optical recording layer; preferably composed of a membrane having low melting point metal; application of hologram; embossing formation of characters and numerals; application of personal face photograph; engraved formation of personal face or the like; human signatures; recorded information with use of IC-memory; mechanical printing; formation of bar codes; formation of characters and patterns by use of printer, typewriter or pen plotter may be used independently or in any combination.

In the following, the present invention will be more fully described by way of preferred embodiments. In these embodiments, parts or % will be given by weight, not otherwise specifically referred to.

As the image transfer film (dye film) used for sublimating transfer onto the image-transferable sheets, a polyester film, 6 μm thick, subjected to a heat-resisting treatment on one surface thereof only, and bearing color ink composition areas of yellow, magenta and cyan, respectively, was used. The coating rate of the color ink composition was 1.0 g/m^2 when measuring at the dry state,

These color ink compositions were as follows.

Yellow ink composition	
polyvinyl butyral resin ("Eslek-BX-1", manufactured and sold by Sekisui Kagaku K. K., Tokyo)	4.80 parts
dispersion dye ("PTY-52, Disperse Yellow-141", manufactured and sold by Mitsubishi Kasei Kogyo Co., Ltd., Tokyo)	5.50 parts;
methyl ethyl ketone	55.00 parts;
toluene	34.70 parts;
(parting agent	1.03 parts)
Magenta ink composition	
polyvinyl butyral resin (same as above in the case of yellow color ink)	3.92 parts;
dispersion dye ("MS Red G, disperse red 60", manufactured and sold by Mitsui Toatsu K. K.)	2.60 parts;
dispersion dye ("Macrolex Red Violet R, Disperse Violet 26", manufactured and sold by Beyer A. G., West Germany)	1.40 parts;
methyl ethyl ketone	43.34 parts;
toluene	43.34 parts;
(parting agent	0.40 part)
Cyan color ink composition	
polyvinyl butyral resin (same as in said yellow color ink composition)	3.92 parts;
dispersion dye ("Kayaset Blue-714, solvent blue-63", manufactured and sold by Nippon Kayaku K. K., Tokyo)	5.50 parts;
methyl ethyl ketone	68.18 parts;
(parting agent	0.94 parts)

Each of the foregoing color ink compositions was prepared wish and without addition of parting agent.

As the parting agent occasionally used in each of the foregoing color ink compositions, any of the following specific agents may be employed:

(a) silicone alkyd parting agent, "KR-5206", manufactured and sold by Shinetsu Kagaku Kogyo K.K., Tokyo;

(b) graft polymer of silicone and acryl, "GS-30", manufactured and sold by Toa Gosei Kagaku K.K.;

(c) silicone graft polymer, "US-3000", manufactured and sold by the above company;

(d) phosphoric acid ester, natrium salt, "RE-410", manufactured and sold by Toho Kagaku Kogyo K.K.;

(e) natural phosphoric acid ester, "Lecytin", manufactured and sold by Ajinomoto Co., Ltd., Tokyo;

(f) silicone oil, "KF 412", manufactured and sold by Shinetsu Kagaku Kogyo K.K., Tokyo;

(g) aluminum chelate agent, "ALM", manufactured and sold by Ajinomoto; and

(h) titanium chelate agent, "TTS", manufactured and sold by Nippon Soda K.K., Tokyo.

EXAMPLE A-1

As the substrate, a laminate of a synthetic paper, "Yupo FPG 150 μm thick" manufactured and sold by Oji Yuka Co., Ltd., Tokyo, and a polyester film, 6 μm thick, was prepared and coated on the polyester film side surface by a wire bar with a mixture of pull-separating varnish, "Hakurinisu 45" manufactured and sold by Showa Ink Co., Ltd., Tokyo, with an ultra-violet absorbing agent, or more specifically, 2.5-bis (5'-tert-butylbenzoxazolyl (2))-thiofin, 0.5% based on the resin content of the varnish, and dried up to provide a protecting layer of 1 g/m^2, when weighed upon drying.

Then, on the surface of the foregoing protecting layer, an ink composition adapted for the formation of an image-reception layer was coatingly applied and dried up. The applied quantity amounted to 7 g/m^2 when measured upon drying.

Ink composition for the formation of image-reception layer	
polyester resin (manufactured and sold by Toyobo K.K.)	100 parts;
amino-modified silicon ("KF-393", manufactured and sold by Shinetsu Kagaku Kogyo K.K., Tokyo)	5 parts;
epoxy-modified silicone ("X-22-343", manufactured and sold by Shinetsu Kagaku Kogyo)	5 parts;
solvent (methyl ethyl ketone/toluene/ cyclohexanon 4/2/2)	900 parts.

The ink composition was coated, dried up and cured one day under normal temperature. Then, the layer was kept at 100° C. for 30 minutes under heat, for letting the silicone to bleed up to the surface, to provide an image-transferable layer formed on its surface with a hardened silicone layer.

On the thus-provided image-reception layer, a sublimating image-transfer film was overlapped which is composed of cyan color sublimative dye (molecular weight being higher than 250) carried by a proper binder resin and thermal energy is fed thereon from a thermal head adapted for receiving electric signals representing cyan color components obtained by a color analysis of a portrait photograph, as an example, for providing portrait images corresponding thereto. Then, two successive sublimative image-transfer jobs were executed with use of respective sublimating image-transfer films carrying sublimative magenta and yellow color dyes, each molecular weight being higher than 250, and substantially in the manner set forth above. In this way, after all, an overall combined display image composed of a full color portrait, in combination with several characters and graphics, was provided.

The image-reception layer of the sheet, now carrying these display images, was overlapped on the card substrate composed of a polyester resin sheet, 100 μm thick, which had been primed to white-opaque state, and pressurized together at 160° C. by means of heated pressure rolls. Then, the polyester film was peeled off at the interface with the protecting layer, thereby providing a final product card transferrd with image-reception layer now carrying the desired image display.

It was found that the overall surface of the product card was generally smooth and showing no raised feeling of the thus-formed and displaying images. Even upon an accelerated testing of the product card for three months held in an atmosphere of 40° C., the images showed no blurrings as well as no interlayer separation. Further, according to an accelerated light-proof test carried out as prescribed in JIS-Standard with use of a carbon arc lamp, the results showed to be classified to JIS-4 or -5 corresponding to an acceptable superior performance. Additionally, a surface scratch test and the like showed also superior durability.

EXAMPLE A-2

The foregoing image-transferable sheet, now image-carrying, as processed in Example A-1, is then subjected to a peel-off operation for separating the image-carrying layer from the sheet. Then, an adhesive agent of polyester series was coated on the exposed surface of the peeled-off film, and stuck under pressure on a curved surface part of a telephone set. The images could follow up to the stuck curvature into a unitary solid mass, and indeed, without inviting any stuck-on feeling, contrary to the case when a sticky loose-leaf stamp should have been stuck on. In this way, miracle viewing feelings as obtainable with direct-printing operation only, were created and maintained.

EXAMPLE A-3

A white polyester film, baked on one surface thereof with melamine coating, "E 20", 100 μm thick, manufactured and sold by Toray Co., Ltd. Tokyo, is formed on the opposite surface with a slipping layer, same as in the following Example C-2, through application of polyurethane primer. And an identification mark was provided thereon through the way of regular printing technique. On the melamine resin-baked surface of the white polyester resin film, a layer of peeling varnish (of polymethyl methacrylate-series), manufactured and sold by Showa Inku. Co., Ltd., Tokyo) was applied in dry quantity of 2 g/m^2 and.dried up to provide a definite layer.

On the thus-formed protecting layer, the following image-reception layer-forming composition was coated and dried up, so as to form an image-heat transferable sheet. The coated composition was in quantity of 6 g/m^2 by dry weight.

Image-reception layer-forming composition	
polyester resin ("Vylon 600", Tg: 47° C., manufactured and sold by	80 parts;

-continued

Image-reception layer-forming composition	
Toyobo, Osaka)	
polyester resin	20 parts;
("Vylon 290", Tg: 77° C., manufactured and sold by Toyobo)	
amino-modified silicone	7 parts;
("KF-393", manufactured and sold by Shinetsu Kagaku Kogyo)	
epoxy-modified silicone	7 parts;
("X-22-343", manufactured and sold by Shinetsu Kagaku Kogyo)	
solvent	800 parts.
(methyl ethyl ketone/toluene = 1/1)	

On the image-reception layer of the foregoing heat image-transferable sheet, reversed images composed of full color portrait images together with characters and graphics by use of a thermal head, as in the same way with Example A-1, were formed.

Next, the image-reception layer, however, now carrying the reversed images formed in the foregoing manner was brought into contacting and overlapping state with the image displayable surface on a card style substrate made of white color polyester resin, 125 μm thick, preparatorily primer treated as before, and pressurized together under the action of thermal rolls, and the white polyester film, 100 μm, was peeled off between the protecting layer and the melamine-baked layer, thus providing a final card-style product transferred with the image-reception layer now carrying the necessary images.

The surface of the final card style product represented a smooth and slippery, without fear of interlayer separation and with superior light resistant power.

EXAMPLE A-4

A white foam polyester resin film, "Merinex", 125 μm thick, manufactured and sold by ICI, was provided with an identification mark on one surface thereof, with regular printing technique.

Then, on the opposite surface of the white foam polyester resin film to the foregoing surface formed with the identification mark, a coating of a polyurethane-series primer was applied and dried up. Further, the following protecting layer-forming composition was applied in dry quantity of 3 g/m^2 and dried up to form a protecting layer.

Protecting layer-forming composition	
acrylic polyole	41 parts;
("Acrit 6416MA", manufactured and sold by Taisei Kako K. K.)	
toluene	36 parts;
methyl ethyl ketone	27 parts;
diisocyanate	6 parts.
("Colonate", manufactured and sold by Nippon Polyurethane K. K.)	

On the above protecting layer, the following composition was applied in dry quantity of 3 g/m^2 and dried up, to provide an intermediate layer.

Intermediate layer-forming composition	
polyester resin	15 parts;
("Vylon 290", manufactured and sold by Toyo Boseki (Toyobo) K. K., Osaka)	
toluene/methyl ethyl ketone = 1/1	85 parts.

On the thus-formed intermediate layer, an image-reception layer which is substantially same with that in the foregoing Example A-3 was provided, so as to form an image-transferable sheet. Then, as same in the foregoing Example A-3, correspondingly inverted images were formed on the image-reception layer and further then, subjected to transfer onto the card substrate by use of thermal rollers. In this way, a final product card, having an image transferable, yet now image-formed layer, was provided.

This card showed favorable results of light-resisting test. Further, it showed a better scratch test result than the foregoing card obtained in Example A-3.

EXAMPLE A-5

Substrate

A white polyester film, "20", 100 μm thick, manufactured and sold by Toray Co., Ltd., Tokyo, was used.

Intermediate layer-forming composition	
Polyester resin	15 parts;
("Vylon 600", manufactured and sold by Toyo Boseki K. K., Osaka)	
toluene/methyl ethyl ketone = 1/1	85 parts.
(dry weight: 5 g/m^2)	
Protecting layer-forming composition	
"Hakuri-Nisu"	2 g/m^2
(acrylic resin varnish, manufactured and sold by Showa Ink K. K.)	
(dry weight)	
Image-reception layer-forming composition	
polyester resin	10 parts;
("Vylon 600", manufactured and sold by Toyo Boseki K. K., Osaka)	
polyester resin	5 parts;
("Vylon 200", supplied by Toyo Boseki K. K.)	
toluene/methyl ethyl ketone = 1/1	85 parts;
amino-modified silicone	1 part;
("KF-393", manufactured and sold by Shinetsu Kagaku Kogyo)	
epoxy-modified silicone	1 part.
("X-22-343", supplied by Shinetsu Kagaku Kogyo)	
(coated quantity (dry) 5 g/m^2)	

With use of the foregoing composition and processed in similar way as in Example A-3, to provide a final card product, having an image-reception layer transferred with necessary images.

EXAMPLE A-6

Substrate

White polyester resin film, "E-20", 100 μm thick, manufactured and sold by Toray was coated with polyurethane-series primer and dried up.

Parting layer-forming composition	
melamine resin ("Meran 45", manufactured and sold by Hitachi Kasei)	100 parts;
hardener (para-toluenesulfonic acid)	20 parts;
(coating quantity (dry), 2 g/m^2)	
Protecting layer-forming composition	
vinylchloride-vinylacetate ("Vinylite VYHH", manufactured and sold by Union Carbide Corp.)	15 parts;
methyl ethyl ketone = 2/1	85 parts;
(coating quantity (dry): 2 g/m^2)	
Intermediate layer-forming composition	
polyurethane resin ("Takelac T-3350", manufactured and sold by Takeda Pharmaceutical Company, Osaka, of 23%-concentration)	50 parts;
isopropyl alcohol	15 parts;
toluene	25 parts;
methyl ethyl ketone	10 parts.
(coating quantity (dry) 5 g/m^2)	
Image-reception layer composition	
polystyrene resin ("Picolastic D125" (Tg = 53° C.), manufactured and sold by Hercules	15 parts;
toluene/methyl ethyl ketone = 1/1	85 parts;
amino-modified silicone ("KF-393", manufactured and sold by Shinetsu Kagaku)	1 part;
epoxy-modified silicone ("X-22-343", manufactured and sold by Shinetsu Kagaku)	1 part.
(coating quantity (dry): 6 g/m^2)	

The foregoing composition was prepared and used as in the same manner with Example A-3, to provide a card with the image-reception layer subjected to image-transfer as desired.

EXAMPLE B-1

As the substrate, a polyester resin film, 6 μm thick, was used and a polyester resin-series primer was coated on one surface thereof and dried up. Further, the following ink composition was applied and dried up. The coating quantity of the composition was set to about 7 g/m^2.

Image-reception layer-forming composition	
polyester resin ("Vylon 200", manufactured and sold by Toyo Boseki K.K.)	100 parts;
amino-modified silicone ("KF-393", manufactured and sold by Shinetsu Kagaku)	5 parts;
epoxy-modified silicone ("X-22-343", manufactured and sold by Shinetsu Kagaku)	5 parts;
solvent (methyl ethyl ketone/toluene/ cyclohexanone = 4/2/2)	900 parts.

The ink composition was coated, dried up and left standing for a full day, and then subjected to heat treatment at 100° C. for 30 minutes, so as to bleed the silicone towards the film surface for providing thereon an acceptable image-reception layer composing the active surface.

Then, a sublimative image-transferable film, composed of a resin binder evenly mixed with a proper amount of sublimative cyanic dye, the molecular weight being higher than 250, was overlapped on the above image-reception layer and applied with heat energy -by means of a thermal head supplied with electric signals corresponding to cyanic color components of a portrait full color photograph as determined by regular color analysis, thus providing cyanic color component images.

Next, as for magenta and yellow color components, similar respective processings were executed and finally, full color display portrait images could be formed.

Then, the exposed surface of image-reception layer of the thus-display image-formed film was overlapped on a card substrate composed of a white opaque, hard vinyl chloride resin sheet, 100 μm thick and pretreated with a conventional primer, and then this assembly was subjected to heat and pressure by means of a pair of heated rolls. In this way, a card product stuck with an image-transferable and now carrying layer was provided.

The surface of this card was generally smooth and slippy, the thus-formed images thereon providing no raised feelings. In an accelerated test of these formed images in hot atmosphere of 40° C. for a continuous period of three months, there were no appreciable image blurring and interlayer separation. Upon execution of a light exposure test in accordance with prescribed conditions in JIS with use of an arc lamp, the results were classified to JIS-4 to 5 Classes which means as acceptable and better image quality. Scratch test results were also superior.

EXAMPLE A-3

A sticking layer, 1 μm thick, was formed with a polyamide resin sticking agent on the image-carrying surface of the image-transferable sheet, image-formed in the manner as described in foregoing Example B-1, and the thus provided sheet was stuck on the curved surface of a glass tumbler. These images express practically no stuck-on feelings, rather providing such a touch and viewing feeling as if they had been formed by the regular and direct printing technique.

EXAMPLE C-1

With use of the image-transferable sheet prepared in the foregoing Example A-1, images were formed substantially in accordance with procedures mentioned therein, however, with exception of the formation of reversed images, and then, the image-carrying layer was, without execution of the foregoing peel-off operation, stuck on a portion of curved outer surface of a glass tumbler, whereupon the sheet-like substrate was peeled off, together with the weak-sticking layer. The thus-applied images represent almost no sticking-on grip and viewing feeling, as if they should have been applied through regular and direct-printing technique.

EXAMPLE C-2

On the surface of a transparent polyester film, 12 μm thick, employed as a protecting film, the following image-reception layer forming composition was applied to form a coated layer (in quantity of 6 g/m^2 when measuring upon drying), dried up and left as it was for full one day. Then, it was held at 100° C. for 30 minutes, to form an image-reception layer. On the surface thereof, a parting surface layer was found to exist, which was composed of a combined hardened product of amino-modified silicone resin and epoxy-modified silicone resin.

Image-reception layer-forming composition	
polyester resin ("Vylon 600", manufactured and sold by Toyo Boseki)	100 parts;
amino-modified silicone resin ("KF-393", manufactured and sold by Shinetsu)	7 parts;
epoxy-modified silicone resin ("X-22-343", manufactured and sold by Shinetsu)	5 parts;
solvent (methyl ethyl ketone/toluene = 1/1)	800 parts.

As the substrate, on the other hand, white polyester resin film, "E-20", 75 μm, manufactured and sold by Toray, was used and coated on one surface thereof with a polyurethane-series primer and dried up. Then, the following composition (in the dried quantity of 1 g/m^2) and dried up, so as to provide a smooth and stick layer.

Smooth layer-forming composition	
polymethyl methacrylate resin ("Dianal BR-85", manufactured and sold by Mitsubishi Rayon Co., Ltd., Tokyo)	12 parts;
polyethylene wax ("MF8F", manufactured and sold by Dulacon Co.)	0.5 part;
toluene/methyl ethyl ketone = 1/1	85 parts.

On the opposite surface of the white-polyester resin sheet to the smoothed surface there, a primer coating of polyurethane-series is applied and dried up, and further coated thereon with the following composition, in quantity of 3 g/m^2, so as to provide a weak-sticky layer.

Weak-sticky layer-forming composition	
weak-sticky adhering agent ("Esdyme AE-206", manufactured and sold by Sekisui Kagaku Kogyo K. K., Tokyo)	50 parts;
water	50 parts.

The weak-sticky adhering layer is brought into contact with the protecting film consisting of a polyester film, 12 μm thick, at the opposite surface to the image-reception layer, and then subjected to heat and pressure, to provide an image-transferable sheet. Upon bringing the image-reception layer of the image-transferable sheet and the dyestuff layer of the heat-image transfer sheet into contact with each other, heat energy was applied from a thermal head, as in the similar manner mentioned in the foregoing Example A-1, and thus heat image-transfer job was executed, so as to provide reversed mode images for expressing a full color portrait as well as characters and graphics.

Next, the image-reception layer formed with the reversed images thereon was overlapped onto the image-displayable surface of a card style substrate, 100 μm thick, made of a white color polyester resin material preparatorily applied with a primer layer by coating a composition, consisting of "Vylon 200", 100 μm thick, manufactured and sold by Toyo Boseki K.K., and then subjected together to heat and pressure by means of at least a heated roll at 160° C. Then, the white polyester film, 75 μm thick, and the weak-sticky adhesive layer were peeled off in unison, for providing a final decorative product card having the image-reception layer transferred with images and carrying dislay images.

This card had a highly smooth surface and was not liable to invite any interlayer separation and showed superior light fastness.

In place of white color polyester-made card substrate preparatorily formed with a primer layer, such a modification was prepared and experimented that the white polyester sheet was formed on its rear surface with a magnetic layer, while, on its front surface there is formed with a write-on layer which consists of proper filler and resin as conventionally, so as to provide a telephone card. This processed telephone card had the write-on layer provided with display images formed by image-transfer.

EXAMPLE C-3

On the surface of a transparent polyester film, 9 μm thick, used as the protecting layer, an intermediate layer was provided by coating. The coated amount was 5 g/m^2 as measured upon being dried up.

Intermediate layer-forming composition	
polyurethane resin ("Takelack T-3350", solid content 23%, manufactured and sold by Takeda Pharmaceutical Co., Ltd., Osaka)	50 parts;
isopropyl alcohol	15 parts;
toluene	25 parts;
methyl ethyl ketone	10 parts.

Onto the intermediate layer, the following composition was applied for the formation of an image-reception layer. The coated quantity was 5 g/m^2 as measured upon being dried up.

Image-reception layer-forming composition	
polyester resin ("Vylon 600", manufactured and sold by Toyo Boseki)	10 parts;
polyester resin ("Vylon 200", manufactured and sold by Toyo Boseki)	5 parts;
amino-modified silicone ("KF-393", manufactured and sold by Shinetsu)	1 part;
epoxy-modified silicone ("X-22-343", manufactured and sold by Shinetsu)	1 part;
solvent (methyl ethyl ketone/toluene = 1/1)	85 parts.

On the other hand, a white color polyester film, which was similar to that employed in the foregoing Example C-2 was formed with a slidingly smooth layer, as well as a weak-sticking adhesive layer, the latter being brought into intimate contact with a transparent polyester film, 9 μm thick, at the opposite surface to the image-reception layer and then, subjected to heat and pressure, for providing a heat image-transferable sheet. As further processed in the similar manner in the foregoing Example C-2, full-color photographic images (reversed images) were thus formed on the image-reception surface. In this way, a final product card, having its image-reception layer transferringly formed with display images.

EXAMPLE C-4

Substrate

White color polyester sheet, "E-20", 100 μm thick, manufactured and sold by Toray was formed thereon with a

polyurethane-series primer coating. Then, a weak-sticking layer was applied thereon with use of the following composition.

Weak-sticking layer-forming composition	
weak-sticking agent ("Esdyne AE-206", manufactured and sold by Sekisui Kagaku Kogyo K. K., Tokyo)	50 parts;
water	50 parts.
Protecting layer-forming composition	
polyester resin ("Vylon-200", manufactured and sold by Toyo Boseki)	15 parts;
diisocyanate ("Colonate L", manufactured and sold by Nippon Polyurethane Co., Ltd.)	1 part;
toluene/methyl ethyl ketone = 1/1	84 parts.
Image-reception layer-forming composition	
polyester resin ("Vylon 600", manufactured and sold by Toyo Boseki K. K.)	10 parts;
vinyl chloride-vinyl acetate copolymer resin ("Vinylite VAGH" (Tg = 79° C.), manufactured and sold by Union Carbide Corp)	5 parts;
toluene/methyl ethyl ketone = 1/1	85 parts;
amino-modified silicone ("KF-393", manufactured and sold by Shinetsu)	1 part;
epoxy-modified silicone ("X-22-343", manufactured and sold by Shinetsu)	1 part.

With use of the above composition and processed substantially same as in the foregoing Example C-2, a final card product was obtained.

EXAMPLE D-1

An image-transferable sheet was prepared as in the foregoing Example A-1 and thermally image-transferred with reversed mode images of a full color portrait photograph, to provide an intermediate image-transfer medium. The latter is overlapped by its image-reception layer onto the surface of a sheet of rough-textured cotton cloth, however, through the intermediary of an acrylic acid ester-vinyl acetate copolymer sheet, 100 μm thick. Then, the assembly was subjected to heat and pressure. Then, the substrate sheet and weak-sticky adhesive layer, together, were peeled off. The thus transfered images have sufficient surface smoothness, showing superior surface conditions.

Without use of the bond-attaching sheet in the above process and when similar image-transfer job as above was performed, the resulted images followed the surface undulations appearing disadvantageously on the material product of the rough fabrics and thus were highly uneven, and further, on account of insufficient adhering performance acting between the image-receiving layer and the woven fabrics serving as product material, easy and frequent separations took place therebetween.

EXAMPLE D-2

In the similar way as was disclosed in the foregoing Example D-1, an intermediate image-transfer medium carrying reversed images was prepared and overlapped on a polymethacrylate board preparatorily subjected to surface-roughening operation through a conventional sand-blasting step, and through the intermediary of a bond-adhering sheet pressurized together under heat, as was employed in Example D-1. Then, the sheet-like substrate was peeled off, together with the weak adhesive layer. The thus-provided images were highly smooth and even in spite of the highly rough and undulating conditions at the surface to be image-transferred. In addition, the image-carrying surface showed superior results in various resisting tests.

Without use of the foregoing bond-sticking layer, the similarly transferred images showed considerable undulations and distortions. Further, on account of insufficient adhering performance, easy and frequent peel-offs of applied images were feared.

EXAMPLE D-3

On the surface of a polyester resin film, 25 μm thick, the following composition adapted for the formation of bond-sticking layer was coated and dried up, in dried quantity of 5 g/m^2, to provide a film formed thereon a bond sticking sheet.

Bond-sticking sheet-forming composition	
polyester resin ("Vylon 600", manufactured and sold by Toyo Boseki)	15 parts;
methyl ethyl ketone/toluene = 1/1	84 parts.

The bond-sticking sheet surface, together the polyester resin film proper, was brought into contact with the image-representing surface of a white color polyester made-card substrate, 25 μm thick, and then, subjected to heat and pressure by means of at least a heat roll kept at 200° C., arranged to supply heat energy from the side of the polyester resin surface, thereby heat bonding the bond-sticking sheet onto the card surface, whereupon the polyester resin film being forcedly peeled off.

Further then, as in the similar way as adopted in foregoing Examples C-2; A-3; A-4 and C-3, use is made of the image-reception layers representing reversed images thereon, the respective image-reception layers were whereupon brought into contact with the card's bond-sticking surface of the card and subjected to heat and pressure by use of at least a heat roll kept at 200° C. Then, the white color polyester resin substrate was peeled off, together with the weak-sticky adhering layer. In this way, a final product card displaying the portrait photograph was obtained.

EXAMPLE D-4

Substrate

A white color polyester resin sheet, "E-20", 100 μm thick, manufactured and sold by Toray Co. Ltd., was coated with a polyurethane-series primer. On the surface of the thus precoated sheet, the following composition was coated to form a weak-sticking adhesive layer.

Weak-sticking adhesive component	
weak-sticking adhesive agent, ("Esdyne AE-206", manufactured and sold by Sekisui Kagaku)	50 parts.
Image-reception layer-forming composition	
polyester resin	7.5 parts;

-continued

("Vylon 200", manufactured and sold by Toyo Boseki) polyester resin	7.5 parts;
("Vylon 290", manufactured and sold by Toyo Boseki) toluene/methyl ketone = 1/1	85 parts;
amino-modified silicone ("KF-393", manufactured and sold by Shinetsu)	1 part;
epoxy-modified silicone ("X-22-343", manufactured and sold by Shinetsu)	1 part.

The foregoing compositions were prepared. On the other hand, a polyester resin film, 25 μm thick, was coated on one surface thereof with a 15%-solution of polyester resin, "Vylon 200", manufactured and sold by Toyo Boseki, in toluene/methyl ethyl ketone=1/1 and dried up. The coating quantity was adjusted to 5 g/m^2 when measuring in dried state. In this way, a bond-sticking sheet was provided.

Then, the coated surface of the thus prepared bond-sticking sheet was brought into contact with the image display surface of a card style substrate of white color hard vinyl chloride or the like resin material preparatorily subjected to a primer coating treatment in overlapping state and then, the whole assembly was subjected to heat and pressure with use of at least a heated roll to 130° C., thus the bond-sticking layer being stuck on the card surface. Under this condition, the polyester resin film, 25 μm thick, was peeled off.

Then, the image-reception layer, now carrying thereon reversed images, was brought into contact with the bond-sticking sheet and the resulted whole was subjected to heat and pressure by use of at least a heated roll and the white color polyester resin substrate, together with the weak-sticking adhesive layer, was peeled off. In this way, the card, now displaying the portrait images, was provided.

EXAMPLE D-5

Substrate

Same as in the foregoing Example D-4.

Weak-sticking adhesive layer

Same as in the foregoing Example D-4.

Protecting layer-forming composition

polyester resin ("Vylon 200", manufactured and sold by Toyo Boseki)	15 parts;
diisocyanate ("Colonate L", manufactured and sold by Nippon Polyurethane)	1 part;
toluene/methyl ethyl ketone = 1/1	84 parts.

Image-reception layer-forming composition

polyester resin ("Vylon 600", manufactured and sold by Toyo Boseki)	10 parts;
toluene/methyl ethyl ketone = 1/1	85 parts;
amino-modified silicone ("KF-393", manufactured and sold by Shinetsu)	1 part;
epoxy-modified silicone ("X-22-343", manufactured and sold by Shinetsu)	1 part.

EXAMPLE D-6

Substrate

Same as in the foregoing Example D-4.

Weak-sticking adhesive layer

Same as in the foregoing Example D-4.

Image-reception layer-forming composition

polyester resin ("Vylon 600", manufactured and sold by Toyo Boseki)	10 parts;
vinyl chloride-vinyl acetate copolymer resin ("Vinylite VAGH", manufactured and sold by Union Carbide Corp.)	5 parts;
toluene/methyl ethyl ketone = 1/1	85 parts.

The foregoing materials and compositions were prepared and processed in the similar way as in the foregoing Example D-4, to provide a final product card, displaying the desired portrait images as were desired.

EXAMPLE E-1

On a polyethylene terephthalate film, 9 μm thick, a solution of saturated polyester resin, "Vylon 600", manufactured and sold by Toyo Boseki, in toluene/methyl ethyl ketone=1/1, was coated by reliance of the known reverse roll-coating process, and dried up. The coated quantity was 7 g/m^2 when measuring in dry condition. In this way, a weak-sticking adhesive layer could be formed.

On the weak-sticking adhesive layer, the following composition, 3 g/m^2 (dry), was coated by means of an oblique-lined gravure roll for solid and full printing use and in the reverse roll-coating process, and then dried up, to provide an image-reception layer.

Image-reception layer-forming composition

polyester resin ("Vylon 200", manufactured and sold by Toyo Boseki)	70 parts;
polyester resin, ("Vylon 290", manufactured and sold by Toyo Boseki)	30 parts;
amino-modified silicone ("KF-393", manufactured and sold by Shinetsu)	5 parts;
epoxy-modified silicone ("X-22-343", manufactured and sold by Shinetsu)	5 parts;
methyl ethyl ketone (wt. ratio 1/1)	700 parts.

On the opposite surface to the image-reception layer of the thus-prepared image-transferable sheet, a synthetic paper substrate, "Yupo FPG 110", 110 μm thick, manufactured and sold by oji Yuka K.K., coated with "Vylon 600" as the adhesive agent in quantity of 10 g/m^2 (dry) was stuck intimately together.

On the other hand, a polyethylene terephthalate film substrate, 6 μm thick, preparatorily provided on one surface thereof with a heat-resisting layer was used and the following composition was applied on the opposite surface of the substrate with use of a wire bar and dried up, in the quantity of 1 g/m^2 (dry), so as to provide a dyestuff layer. In this way, a heat image-transferable sheet was prepared and provided.

Dyestuff layer-forming composition	
dispersion dye ("Kayaseo Blue-136", manufactured and sold by Nippon Kayaku K. K.)	4 parts;
ethylhydroxyethyl cellulose	6 parts;
methylethylketone/toluene (wt. ratio: 1/1)	90 parts.

The dyestuff layer of the foregoing heat image-transfer sheet was brought into contact with the image-reception layer of the image-transferable sheet in overlapping manner, then, heat energy was applied from a thermal head from the side of heat-resisting layer of the heat image-transfer sheet, thereby dyestuff being transferred to the image-reception layer of image-transferable sheet, and indeed, for the formation of positive images.

Then, the image-transferable sheet, now carrying the required positive images was stuck together under heat and pressure at 140° C. for 5 seconds on the intermediate image-transfer substrate prepared in the following manner, in mutually opposed manner. Then, the synthetic paper "Yupo" was peeled off at the intersurface between the polyester resin film and the "Vylon 600" layer. In thus way, the inventive image-transfer sheet (intermediate image-transfer medium) carrying the corresponding reverse images was provided.

Method for the Preparation of Intermediate Image-transfer Substrate

A sheet of fine quality or stick paper, unit weight: 82 g/m^2 was applied with a coating, about 20 μm thick, of polyethylene resin through conventional extrusion coating process. Thereon, further, a catalyst-added toluene solution of a parting agent silicone, "KS-707", manufactured and sold by Shinetsu was applied and dried up in quantity of about 2 g/m^2 (dry), for the purpose of curing. Thereon, still further, the following coating liquid composition was applied by means of a conventional coating bar and dried up, to provide an intermediate image transfer substrate. The thus coated and dried resin quantity was measured to 7 g/m^2.

Coating liquid composition	
polyester resin ("Vylon 200", manufactured and sold by Toyo Boseki)	100 parts;
methyl ethyl ketone/toluene (mixing ratio by weight : 1/1)	700 parts.

A sheet of coated paper, pretreated for pore filling, was coated, in the similar manner as above, with the foregoing liquid composition, to provide an image-transferable medium. On and with the presently coated surface, the image carrying surface of the foregoing intermediate image-transfer medium is brought into opposing contact and stuck together under heat and pressure at 140° C. for 7 seconds. Finally, the laminate of fine-quality paper and polyethylene was peeled off, to provide a final decorative product now displaying the positive images as required.

It will thus be seen that by adopting the above processing steps, the positive images formed under the action of the thermal head are transferred, through the intermediary of intermediate image transfer medium, onto the final object to be decorated, and indeed, in the form of positive mode. It will be further seen that, since the dyestuff is well distributed within the image-reception layer, the transferred positive images are highly sharp and fresh, in addition to much profundities.

Since a resin layer was overlappingly applied on the thus-formed images, weather fastness, frictional durability and light-fastness of the finally formed images could be highly and amazingly improved. When suitable ultraviolet absorbing agent, antioxydant, quenching agent and/or radical scavenger is added to, further improvement of the light-fastness can be attained.

EXAMPLE E-2

The substrate of image-transferable medium adopted in the foregoing Example E-1 was replaced by a hard polyvinyl chloride card, 100 μm thick, and other processing modes were same as in Example E-1. In this way, a high quality, positive-image transferred, decorative final product was successfully provided. When the image include human portrait photograph, the final product was highly useful for ID-card.

EXAMPLE E-3

The substrate of image-transferable medium adopted in the foregoing Example E-1 was replaced by a transparent polyester film, and other processing modes were same as employed therein. In this way, a transparent film formed with the wanted positive images of better quality as before was obtained. This film was highly useful in OHP-services.

EXAMPLE E-4

A sheet of high quality paper, unit weight: 104 g/m^2, was coated with a layer of polypropylene resin, thickness: about 20 μm, through the way of conventional extrusion coating technique, then the coating was further coated with a silicone solution for use in parting service and hardenable under electron rays and dried up. The quantity of the coating silicone was about 1 g/m^2 upon drying. In this way, an electron-hardened, provisional substrate was provided. On this substrate, the following, image-reception layer-forming composition was applied as a layer by use of a coating bar, and then dried up, for providing an image-reception layer. The coated resin quantity in the above last step amounted about 5 g/m^2.

Image-reception layer-forming composition	
polystyrene ("Picolastic D 150" (Tg = 69° C.), manufactured and sold by Rika-Hercules Co., Ltd.	100 parts;
amino-modified silicone ("KF-393", manufactured and sold by Shinetsu)	7 parts;
epoxy-modified silicone ("X-22-343", manufactured and sold by Shinetsu)	7 parts.

Further processing was carried out as was set forth in the foregoing Example E-2, for providing a final product card, carrying thereon the wanted positive images of same superior quality, as was in Example E-2.

EXAMPLE E-5

On the image transferable medium used in the foregoing Example E-4, however, in the present Example, a thermoplastic resin, adhesive, polyolefine-series film, "Adwin

500", manufactured and sold by Showa Denko K.K., Tokyo, was applied as a layer. Other materials were used and processed as set forth therein. In this way, a decorative final product formed with necessary positive was obtained with superior results.

Industrial Availabilities

As will be well understood from the foregoing detailed description of the invention, it is possible according to the present inventive system, to form highly easily and evenly the desired images sharply and attractingly on any product and object to be decorated or graphically ornamented, substantially irrespective of material kind and configuration thereof, and indeed, with a surprising unitary touch and feeling with the substrate. Therefore, the invention can be utilized broadly and conveniently in such various industrial fields, where unitary formation of various images, characters, symbols, numerals and graphics, on and to the articles, objects and substrate products to a sufficiently miracle and attracting degree.

We claim:

1. An apparatus for forming required images on an objective body, comprising in combination:

means for processing image data fed thereto;

means for forming images, on the basis of image data, on an image-reception layer of a first intermediate transfer substrate for image-transfer by reliance on a sublimation image transfer system;

means for transferring the image-reception layer of the first intermediate transfer substrate which has been subjected to image forming operation once onto a second intermediate transfer substrate; and

means for retransfer of the image-reception layer stuck on the second intermediate transfer substrate onto said objective body.

2. The apparatus of claim **1**, wherein said image data processing means is provided with image reversing means.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 5,940,111

DATED : August 17, 1999

INVENTOR(S) : Masanori AKADA et al.

It is certified that error appears in the above-indentified patent and that said Letters Patent is hereby corrected as shown below:

On the title page, item [62] **Related U.S. Application Data**, line 6, change "1997," to --1987,--.

Signed and Sealed this

Twenty-second Day of February, 2000

Attest:

Q. TODD DICKINSON

Attesting Officer

Commissioner of Patents and Trademarks

US005916148A

United States Patent [19]

Tsuyuki

[11] Patent Number: 5,916,148

[45] Date of Patent: *Jun. 29, 1999

[54] **OBJECTIVE OPTICAL SYSTEM FOR ENDOSCOPES**

[75] Inventor: **Hiroshi Tsuyuki**, Hachioji, Japan

[73] Assignee: **Olympus Optical Co., Ltd.**, Tokyo, Japan

[*] Notice: This patent issued on a continued prosecution application filed under 37 CFR 1.53(d), and is subject to the twenty year patent term provisions of 35 U.S.C. 154(a)(2).

[21] Appl. No.: **08/671,537**

[22] Filed: **Jun. 27, 1996**

[30] **Foreign Application Priority Data**

Jun. 29, 1995 [JP] Japan 7-184981

[51] **Int. Cl.**[6] **A61B 1/002**

[52] **U.S. Cl.** **600/176**; 600/160; 600/175

[58] **Field of Search** 600/129, 160, 600/167, 172–173, 175, 182, 176; 359/656, 663

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Primary Examiner—John P. Leubecker

Attorney, Agent, or Firm—Pillsbury Madison & Sutro LLP

[57] **ABSTRACT**

An objective optical system for endoscopes to be disposed in a tip of an endoscope in an axial direction thereof and in parallel with a bundle of illumination system, and comprising an optical system which is to be disposed in the tip of the endoscope and has a diameter smaller than that of another optical system to be disposed on the image side thereof.

9 Claims, 12 Drawing Sheets

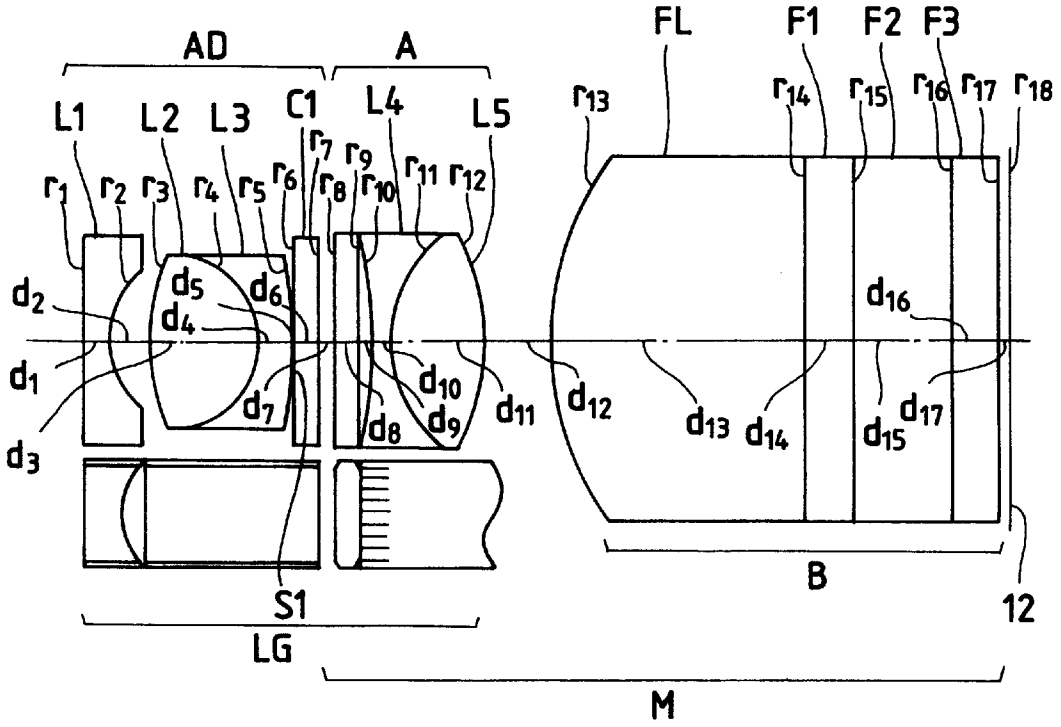


FIG. 1 PRIOR ART

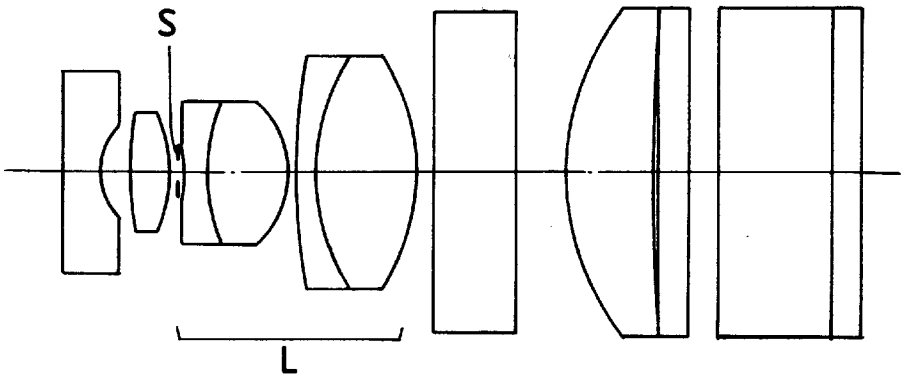


FIG. 2 PRIOR ART

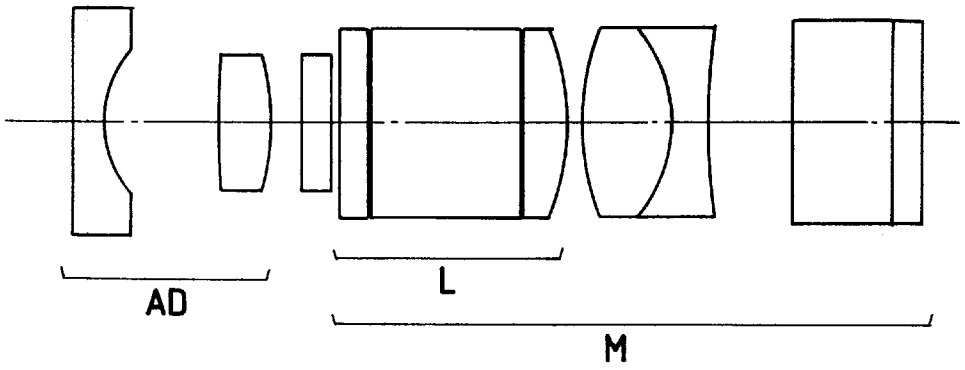


FIG. 3 PRIOR ART

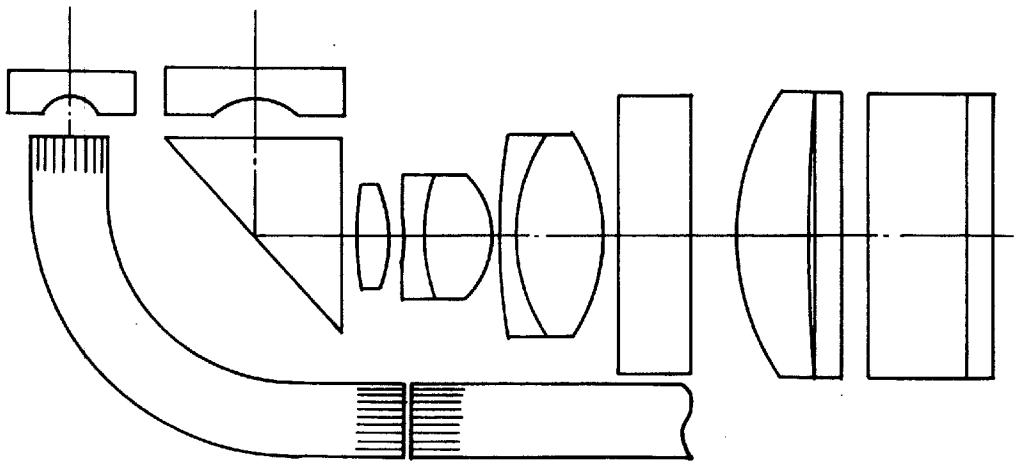
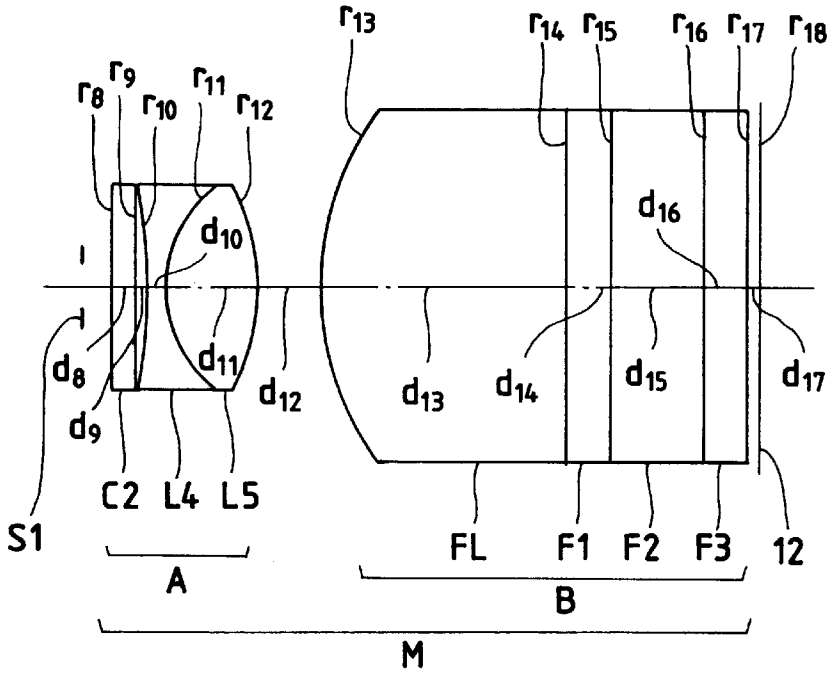


FIG. 4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r8 r9 r10 r11 r12
d16
d10
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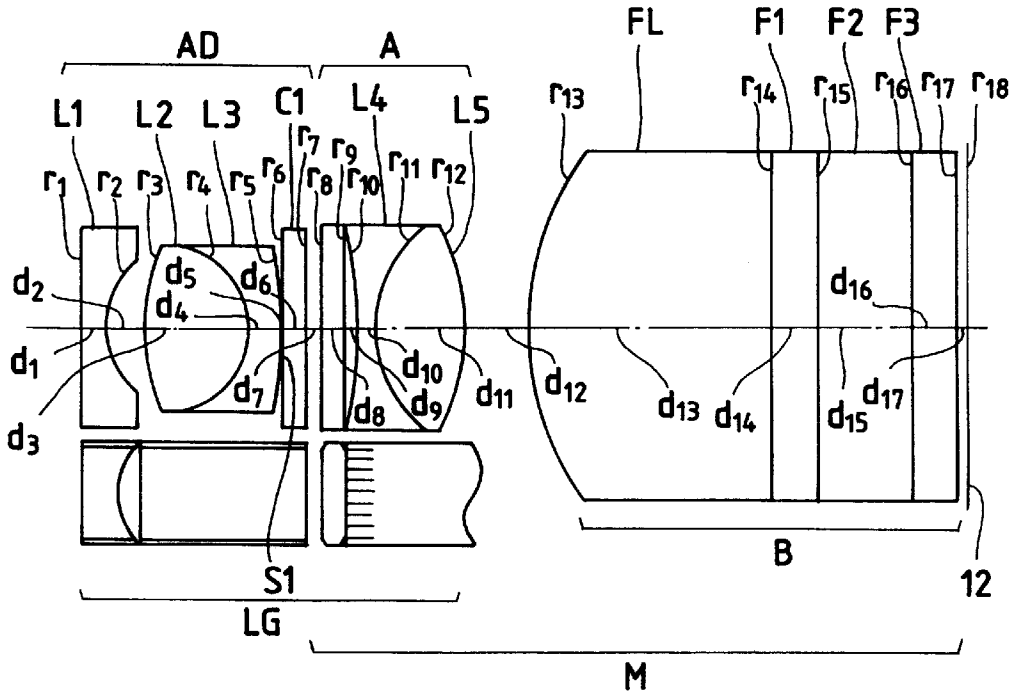
d9
C2 L4 L5
S1
FL F1 F2 F3 12
A
B
M

FIG. 5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A
FL F1 F2 F3
L1 L2 L3 C1 L4 L5
r13
r14 r15 r16 r17 r18
r1 r2 r3 r4 r5 r6 r7 r8 r9 r10 r11 r12
d16
d2 d5 d6
d4
d1 d10 d11 d12 d13 d14 d15 d17
d7 d8 d9
d3
S1
B
12
LG
M

FIG. 6

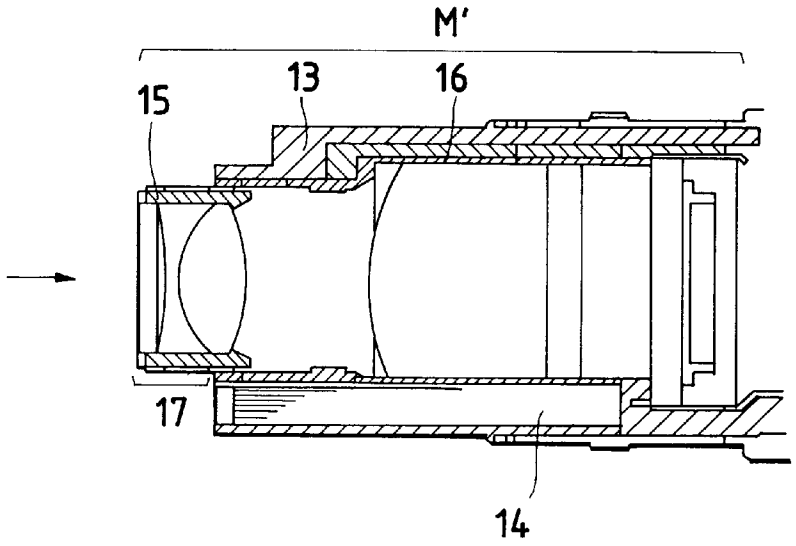


FIG. 7

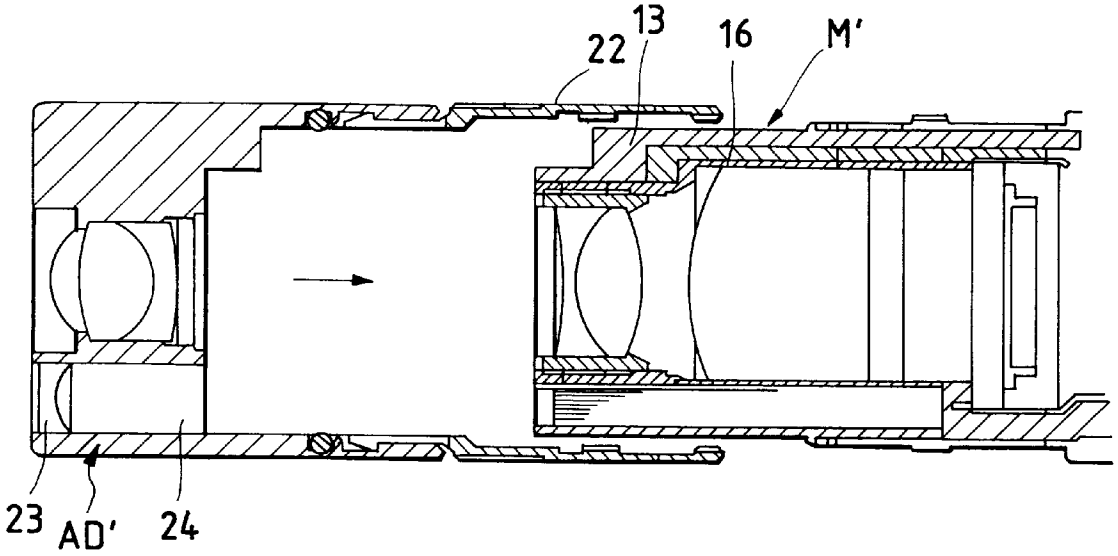


FIG. 8A

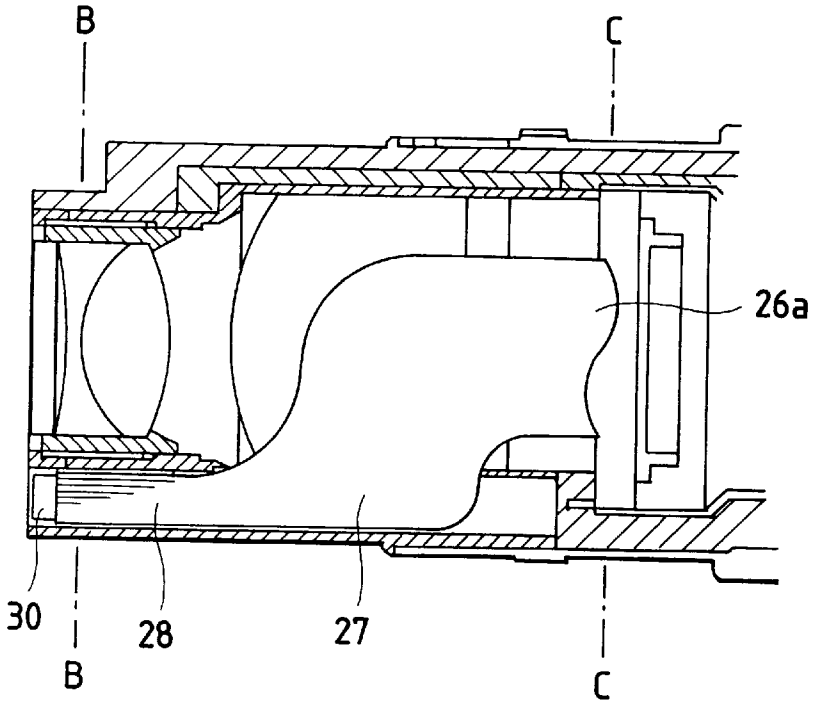


FIG. 8B

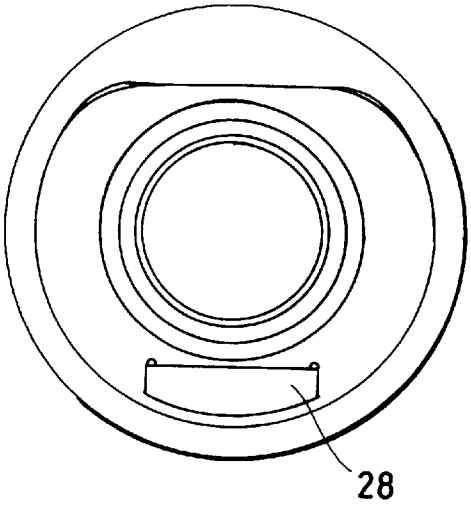


FIG. 8C

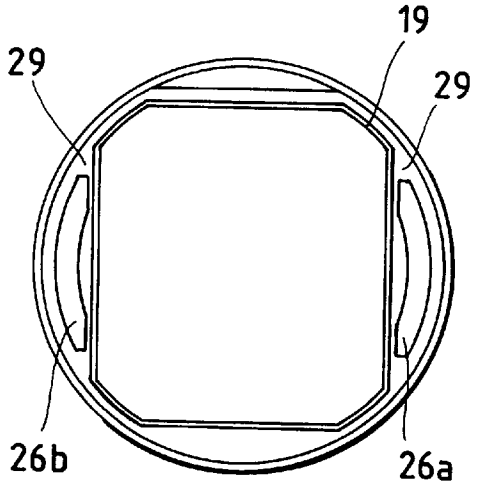


FIG. 9A

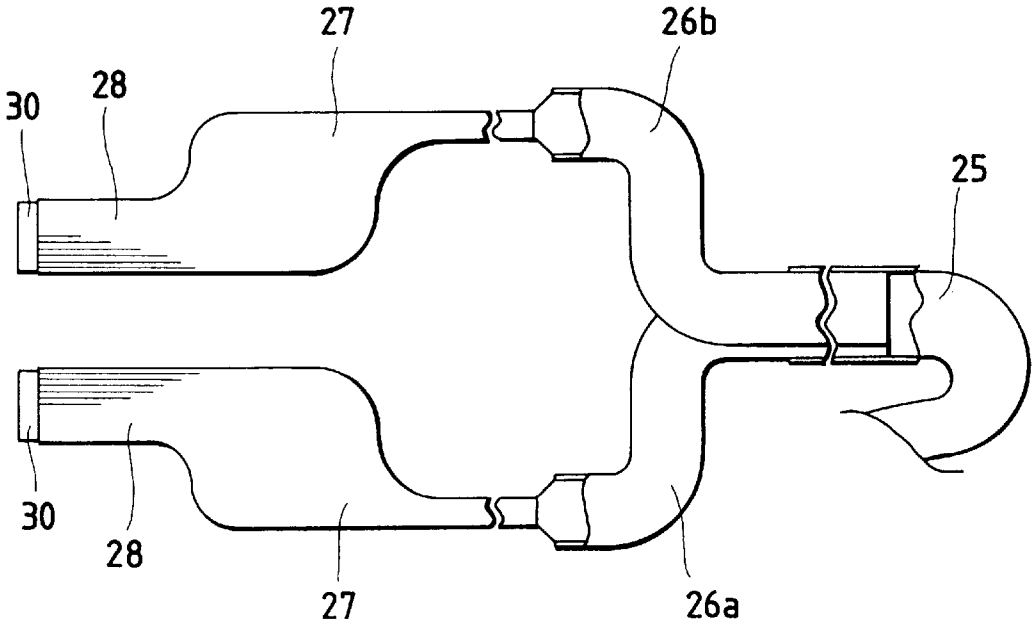


FIG. 9B

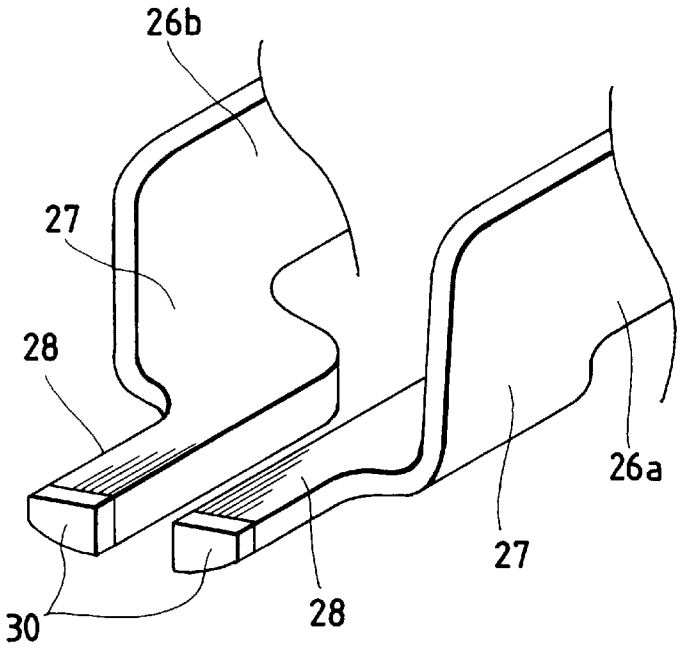


FIG. 10

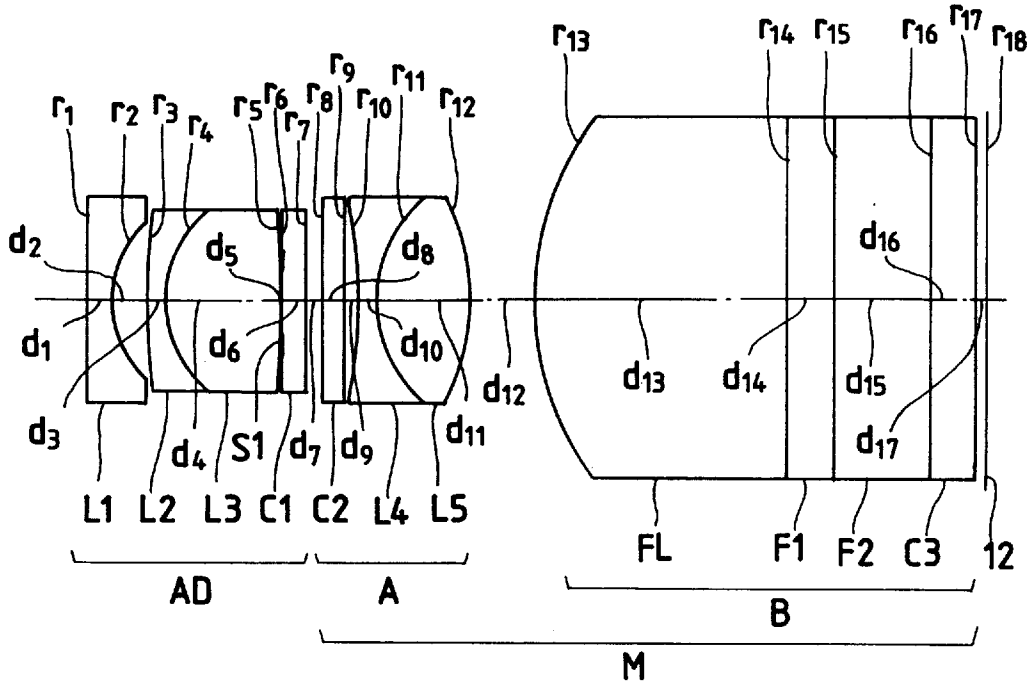

r1 r2 r3 r4 r5 r6 r7 r8 r9 r10 r11 r12 r13 r14 r15 r16 r17 r18
d1 d2 d3 d4 d5 d6 d7 d8 d9 d10 d11 d12 d13 d14 d15 d16 d17
S1
L1 L2 L3 C1 C2 L4 L5
FL F1 F2 C3 12
AD A B M

FIG. 11

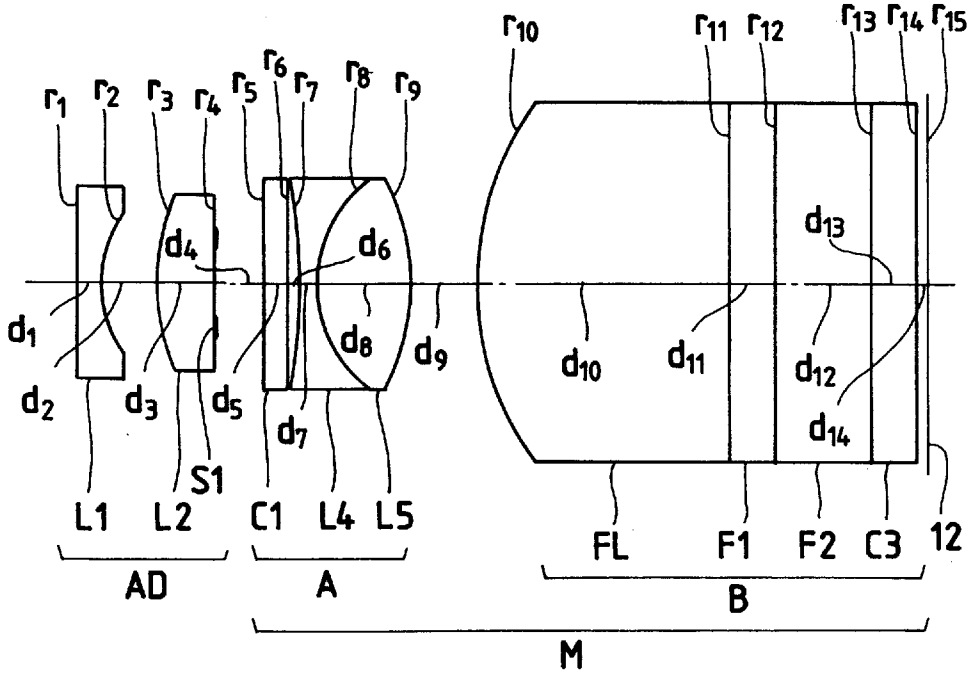

r1 r2 r3 r4 r5 r6 r7 r8 r9 r10 r11 r12 r13 r14 r15
d1 d2 d3 d4 d5 d6 d7 d8 d9 d10 d11 d12 d13 d14
S1
L1 L2 C1 L4 L5
FL F1 F2 C3 12
AD A B M

FIG. 12

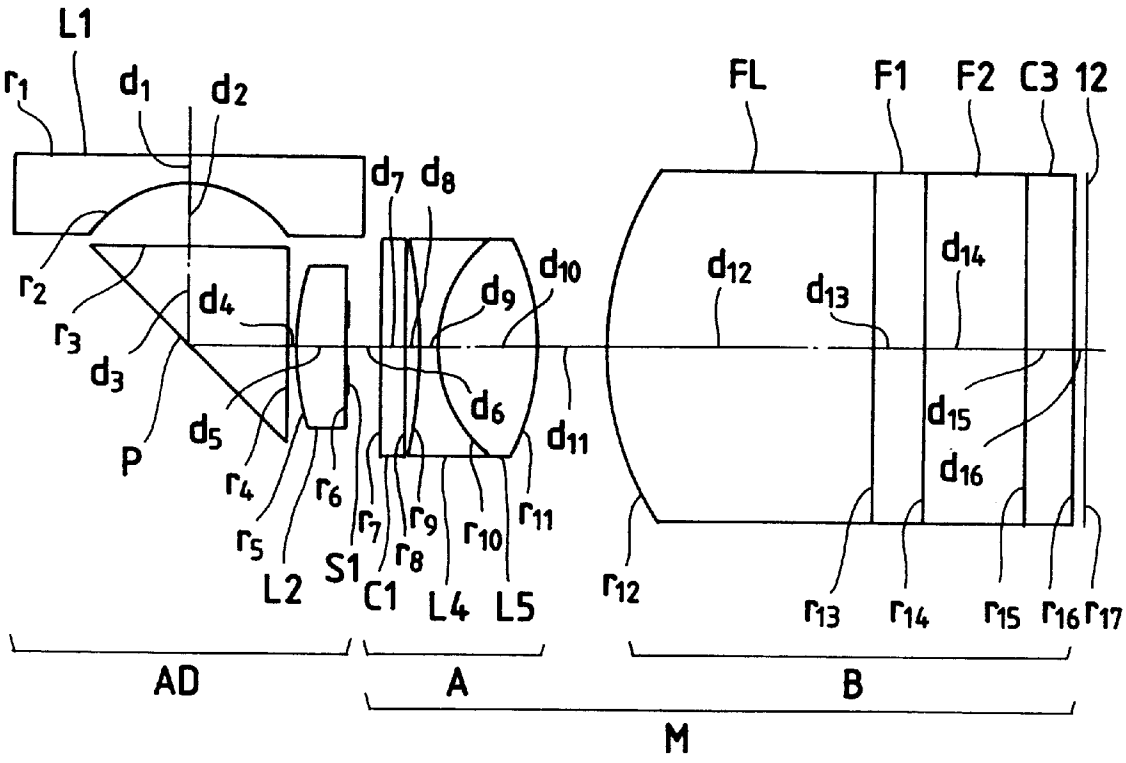

L1
r1
d1
d2
d7
d8
d10
d12
d13
d14
FL
F1
F2
C3
12
r2
d4
d9
r3
d3
d6
d15
d5
d11
d16
P
r4
r6
r7
r9
r10
r11
r5
S1
r8
L2
C1
L4
L5
r12
r13
r14
r15
r16
r17
AD
A
B
M

FIG. 13A

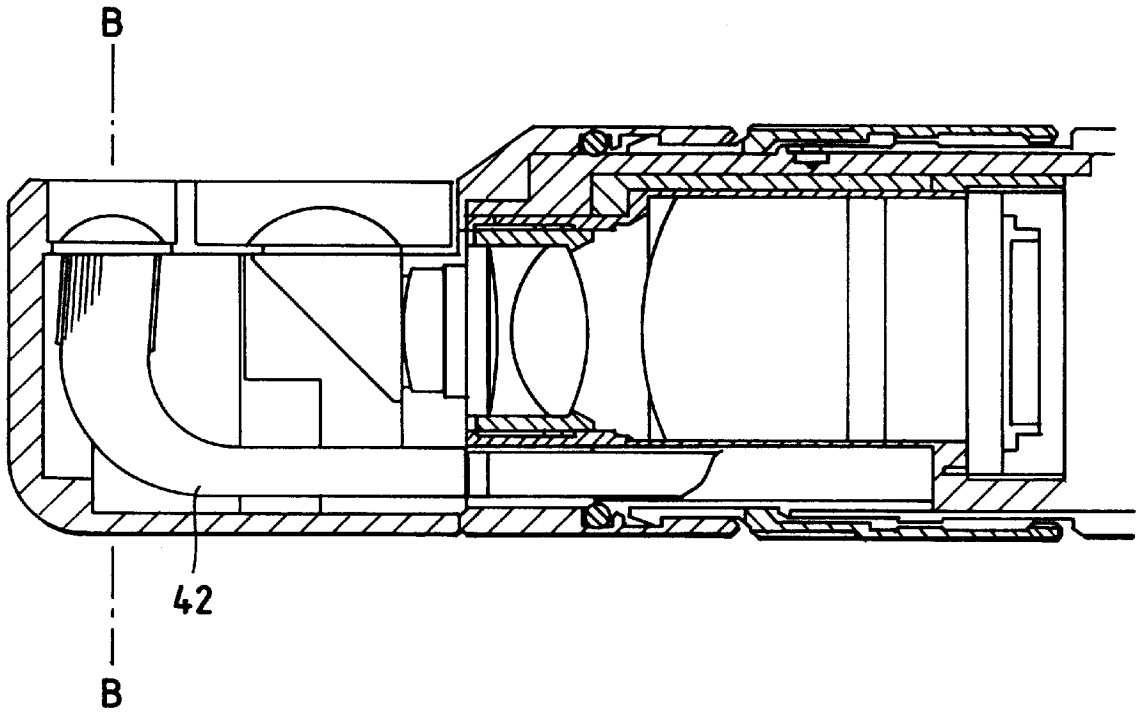


FIG. 13B

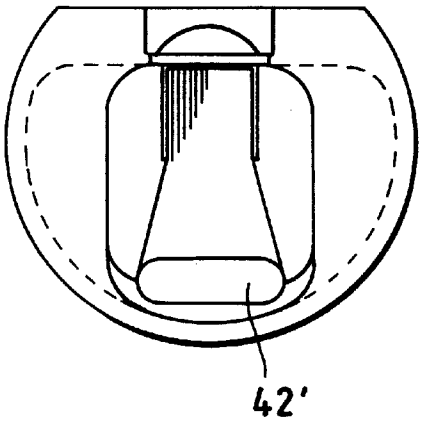


FIG. 14

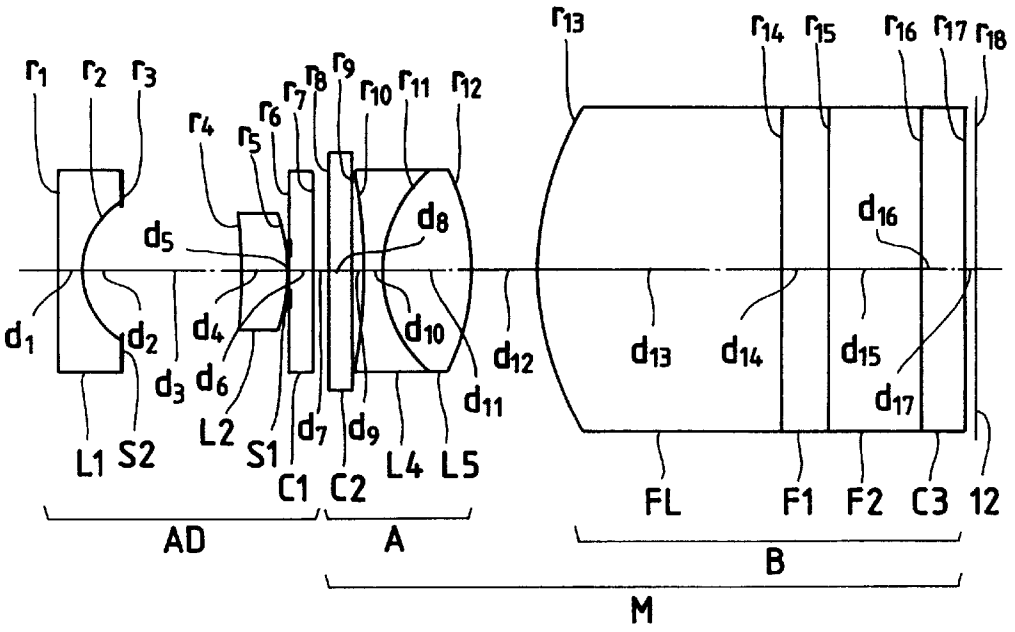

r1 r2 r3 r4 r5 r6 r7 r8 r9 r10 r11 r12 r13 r14 r15 r16 r17 r18
d1 d2 d3 d4 d5 d6 d7 d8 d9 d10 d11 d12 d13 d14 d15 d16 d17
L1 S2 L2 S1 C1 C2 L4 L5 FL F1 F2 C3 12
AD A B M

FIG. 15

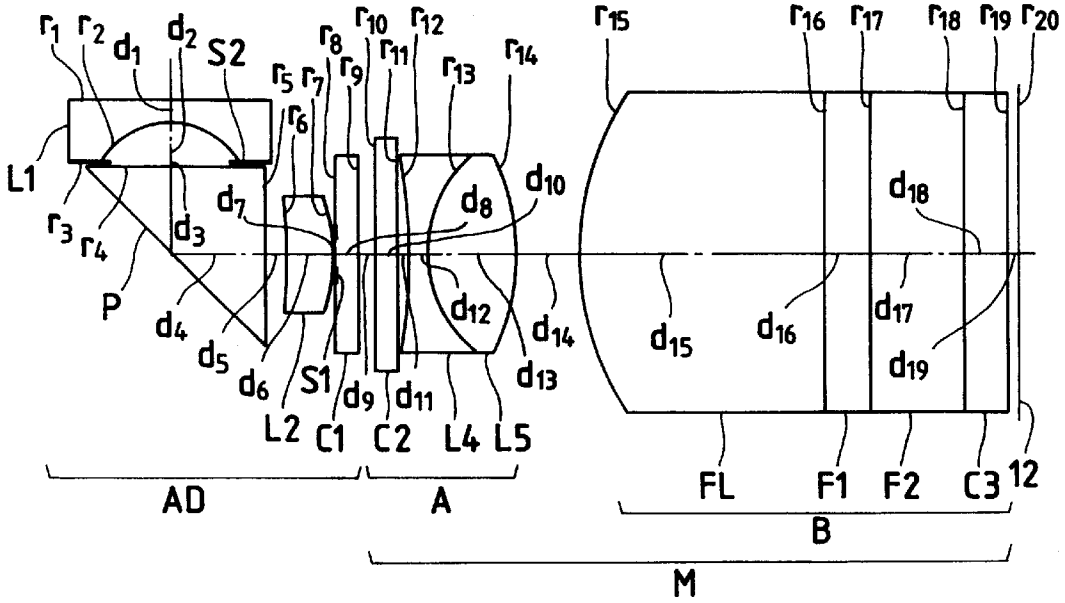

r1 r2 d1 d2 S2 r5 r6 r7 r8 r9 r10 r11 r12 r13 r14 r15 r16 r17 r18 r19 r20
L1 r3 r4 P d3 d4 d5 d6 d7 d8 d9 d10 d11 d12 d13 d14 d15 d16 d17 d18 d19
S1 L2 C1 C2 L4 L5 FL F1 F2 C3 12
AD A B M

FIG. 16

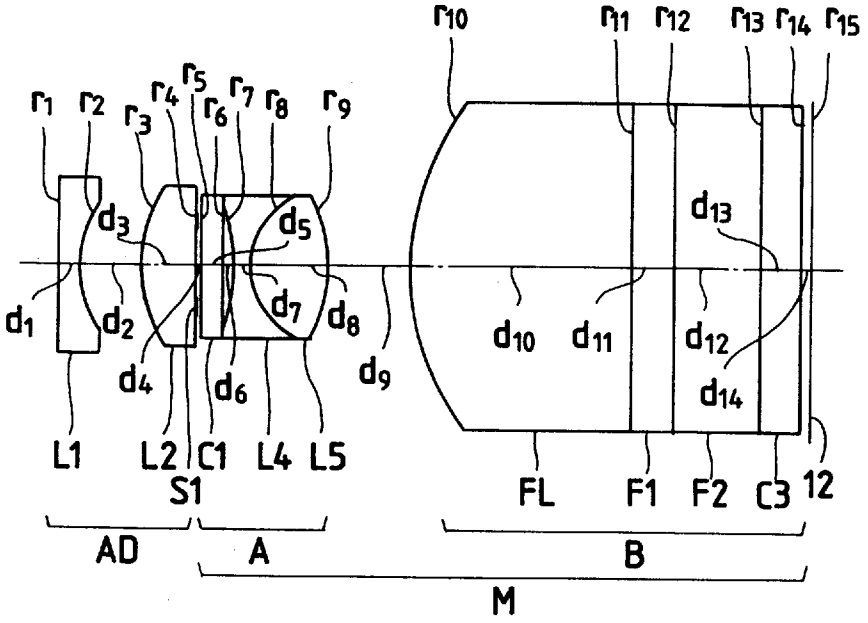

r1 r2 r3 r4 r5 r6 r7 r8 r9
r10 r11 r12 r13 r14 r15
d1 d2 d3 d4 d5 d6 d7 d8 d9
d10 d11 d12 d13 d14
L1 L2 S1 C1 L4 L5
FL F1 F2 C3 12
AD A B M

FIG. 17

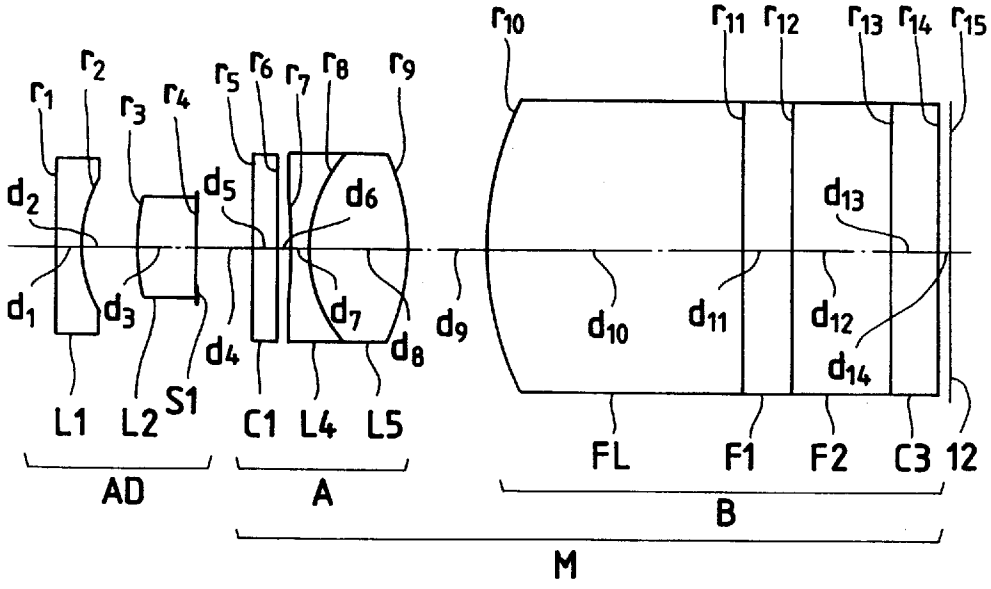

r1 r2 r3 r4 r5 r6 r7 r8 r9
r10 r11 r12 r13 r14 r15
d1 d2 d3 d4 d5 d6 d7 d8 d9
d10 d11 d12 d13 d14
L1 L2 S1 C1 L4 L5
FL F1 F2 C3 12
AD A B M

FIG. 18

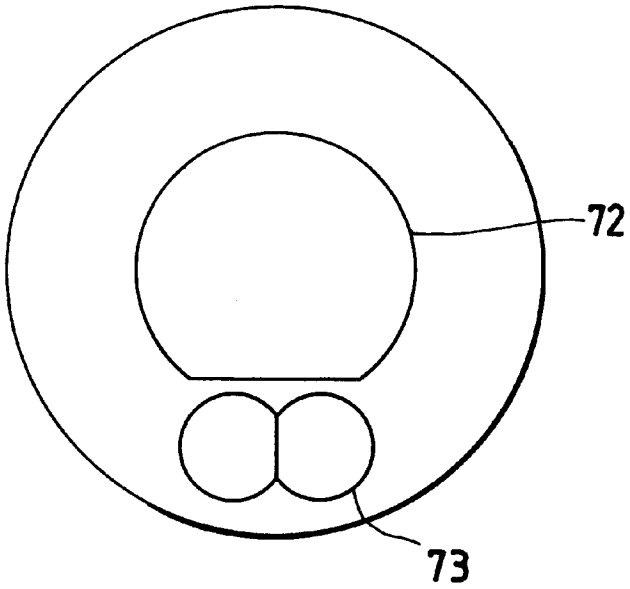


FIG. 19

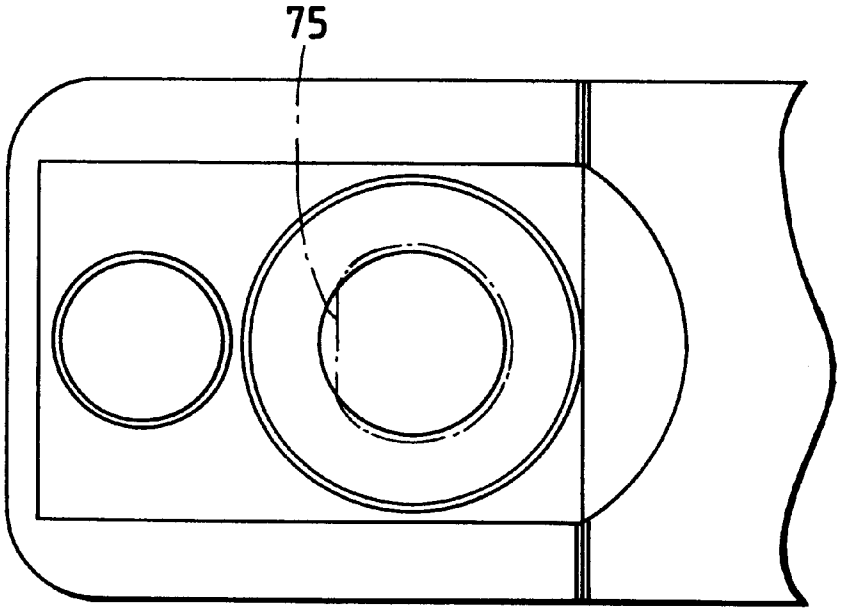
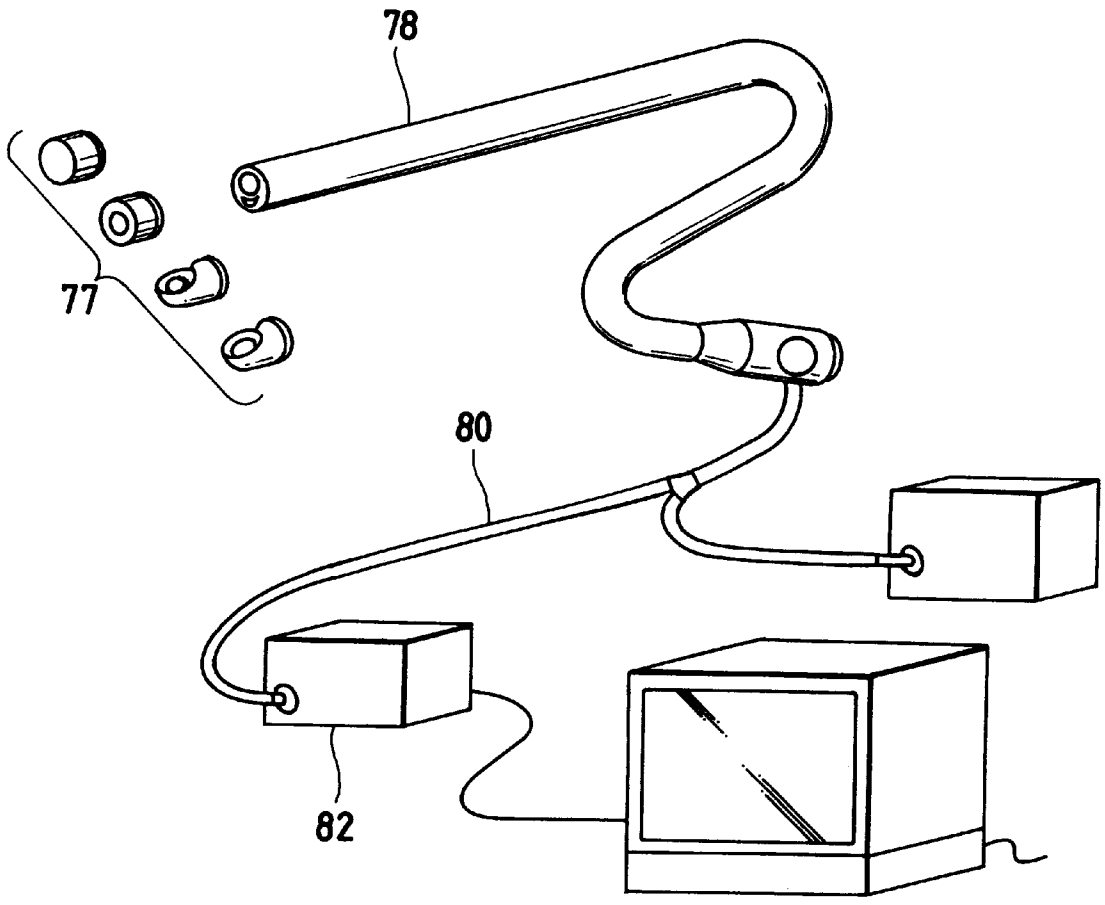


FIG. 20



OBJECTIVE OPTICAL SYSTEM FOR ENDOSCOPES

BACKGROUND OF THE INVENTION

a) Field of the invention

The present invention relates to an objective optical system for endoscopes, and more specifically to an objective optical system for endoscopes which is configured to allow a plurality of adapter optical systems to be attached and detached thereto and therefrom for changing a direction toward a visual field, a field angle and an observation distance.

b) Description of the prior art

Conventionally, medical endoscopes which permit inserting elongated insert sections into living bodies for observing organs in the living bodies and passing forceps through forceps channels for sampling tissues of living bodies for detailedly diagnosing, diseased parts in detail are widely used. Industrial endoscopes which permit observation and inspections of interiors of boilers, turbines, chemical plants and so on are widely known in industrial fields.

Attached to an industrial endoscope, in particular, is a direct view type adapter for observing a diseased part which is located in the longitudinal direction before the insert section or a side-view type adapter for observing an inside wall which is located sideways in a direction perpendicular to the inserting direction. In practice, one simultaneously selects an adapter which has a field angle that is optimum for a location to be observed and another adapter which has an optimum observation distance (or a depth of field) and so on.

It is effective from an economical viewpoint to configure such an expensive endoscope as a tip adapter type endoscope which can be equipped with adapters having a direction of a visual field, a field angle and an observation distance matched with a location to be observed.

Also widely used in the industrial fields are electronic endoscopes which provide images of qualities remarkably improved owing to progress made in solid-state image pickup devices (CCD's).

A conventionally known example of such electronic endoscopes is an electronic endoscope disclosed by Japanese Patent Kokai Publication No. Hei 2-74,912 which has a composition shown in FIG. **1**. This conventional electronic endoscope has no mechanism of the tip adapter type described above and is not versatile in the industrial fields. When an attempt is made to configure this electronic endoscope as the tip adapter type by dividing a lens system thereof into a subsystem which is located before an aperture stop S and replaceable with an adapter, and another subsystem located after the aperture stop S, for example, it is necessary to dispose a light guide to be used in an illumination system at a location of a lens unit L. A reason to select this disposition is that it is optimum to dispose a light guide G so that it turns below a side-viewing prism P as shown in FIG. **2** for attaching a side-viewing adapter.

When the light guide is disposed at the location of the lens unit L in the electronic endoscope disclosed by Japanese Patent Kokai Publication No. Hei 2-74,912, an objective optical system of this electronic endoscope has a large outside diameter at its tip. For disposing the light guide without enlarging its outside diameter, it is necessary to reduce an outside diameter of the lens unit L or a number of optical fibers which are to be used for composing a light guide. As a result, rays are eclipsed by the lens unit L or illuminating rays are reduced, thereby making brightness insufficient.

On the other hand, there is known an objective optical system for tip adapter type electronic endoscopes which has a composition shown in FIG. **3**. This objective optical system for tip adapter type endoscopes is configured to concentrate all light guides at the location of the lens unit L for correcting the defect of the electronic endoscope disclosed by Japanese Patent Kokai publication No. Hei 2-74,912.

In the recent years where images of having higher qualities and full-screen sizes are strongly demanded, it is expected that electronic endoscopes which can provide images suited for display on high definition televisions (HDTV's) will be adopted in the near future.

For obtaining images of such high qualities, however, it is necessary to configure picture elements so as to have a smaller size, or lower illuminance per picture element on an image surface, thereby making it difficult to maintain the conventional image brightness. Further, it is known that depths of field are reduced by reducing sizes of picture elements.

For correcting the defects described above, it is necessary to reserve a required depth of field by enlarging an F number of an objective lens system and compensate for brightness by increasing a number of optical fibers that are used for making the light guide.

In the field of the endoscopes which should desirably have smaller diameters, however, it is undesirable to increase the number of optical fibers that are used for making the light guide since such increase results in enlarging the diameters of the endoscopes. In the case of the objective optical system for the tip adapter type of electronic endoscopes illustrated in FIG. **3**, the objective optical system has an outside diameter which is enlarged by increasing the number of optical fibers. When the objective optical system for tip adapter type endoscopes is configured to provide a full-size screen, it may not accept an increase in the heights of rays caused by enlarging an image side and allow a visual field to be eclipsed. In FIG. **3**, the reference symbol AD represents an adapter lens system and the reference symbol M designates a master lens system.

SUMMARY OF THE INVENTION

A primary object of the present invention is to provide an objective optical system for endoscopes which permits using lens elements having relatively small outside diameters and reducing outside diameters of tips of endoscopes without reducing numbers of optical fibers to be used for composing light guides, and more specifically an objective optical system for tip adapter type endoscopes.

The objective optical system according to the present invention is characterized in that it is disposed, in an object side tip of an endoscope, in parallel with an illumination optical system which is inserted in a longitudinal direction and tied up in a bundle, and that it comprises lens elements which are disposed in the object side tip of the endoscope and have an outside diameter smaller than that of lens elements located in the vicinity of an image pickup device disposed on the object side in the endoscope.

The objective optical system for endoscopes according to the present invention which has the object side tip having a small outside diameter permits reducing outside diameters of tips of endoscopes without reducing numbers of optical fibers which are to be used for composing light guides.

Further, the objective optical system for endoscopes according to the present invention is characterized in that it is configured as an adapter type objective optical system for

endoscopes having a tip to and from which an adaptor comprising an aperture stop for the objective optical system can freely be attached and detached.

The objective optical system for endoscopes according to the present invention consists, as exemplified in FIG. **4**, of a lens unit A which is disposed as a tip on the object side and a lens unit B which is disposed on a side of an image pickup device; the lens unit A having an outside diameter smaller than that of the lens unit B.

A tip adapter lens system AD having a small outside diameter is freely attachable and detachable, as shown in FIG. **5**, to and from the object side of an objective optical system (master lens system) M which is composed of the lens unit A and the lens unit B shown in FIG. **4**.

An image of an object to be observed is allowed by the adapter lens system AD to pass through an aperture stop **S1** and fall nearly perpendicularly onto an image receiving surface of an image pickup device disposed in the objective optical system (master lens system) M. In other words, a nearly telecentric optical system is composed of the adapter lens system AD and the master lens system M.

Furthermore, the optical objective system for endoscopes according to the present invention is characterized in that it is configured so as to satisfy the following conditions (1) and (2):

(1) $1.4 \leqq f_A/F_B \leqq 7.2$

(2) $2.3 \leqq f_A/f_M \leqq 10$

wherein the reference symbol f_A represents a focal length of the lens unit A, the reference symbol f_B designates a focal length of the lens unit B and the reference symbol f_M denotes a focal length of the objective optical system (master lens system) M.

Moreover, the objective optical system for endoscopes according to the present invention is characterized in that the lens unit A having a small diameter comprises a cemented lens component which consists of a negative lens element and a positive lens element, and is configured so as to satisfy the following conditions (3) and (4):

(3) $n_1 > n_2$

(4) $\upsilon_{d1} < \upsilon_{d2}$

wherein the reference symbols n_1 and n_2 represent refractive indices of the negative lens element and the positive lens element respectively of the cemented lens component, and the reference symbols υ_{d1} and υ_{d2} designate Abbe's numbers of the negative lens element and the positive lens element respectively of the cemented lens component.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** shows a sectional view illustrating a composition of a conventional objective optical system for endoscopes;

FIG. **2** shows a sectional view illustrating a composition of another conventional objective optical system for endoscopes;

FIG. **3** shows a sectional view illustrating a composition of still another objective optical system for endoscopes;

FIG. **4** shows a sectional view illustrating a composition of a first embodiment of the objective optical system for endoscopes according to the present invention;

FIG. **5** shows a sectional view illustrating the first embodiment of the objective optical system according to the present invention in a condition where an adapter lens system is attached to the objective optical system;

FIG. **6** shows a sectional view illustrating a composition of a master unit which comprises the objective optical system for endoscopes according to the present invention;

FIG. **7** shows a sectional view illustrating a condition where an adapter unit which comprises the adapter lens system according to the present invention is attached to the master lens unit shown in FIG. **6**;

FIGS. **8**A, **8**B and **8**C show views illustrating a condition of a light guide disposed in the master unit shown shown in FIG. **6**;

FIGS. **9**A and **9**B show sectional views illustrating a composition of a light guide to be used in an endoscope which uses the objective optical system according to the present invention;

FIGS. **10** through **12** show sectional views illustrating compositions of second through fourth embodiments of the objective optical system for endoscopes according to the present invention;

FIGS. **13**A and **13**B show sectional views illustrating a composition of a tip of an endoscope which comprises the fourth embodiment of the present invention and a light guide;

FIGS. **14** through **19** show sectional views illustrating compositions of fifth through tenth embodiments respectively of the objective optical system for endoscopes according to the present invention; and

FIG. **20** shows a perspective view descriptive of a tip adapter type endoscope system according to the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The objective optical system for endoscopes according to the present invention consists, as exemplified in FIG. **4**, of a lens unit A which is disposed as an object side tip and a lens unit B which is disposed on a side of an image pickup device; the lens unit A having an outside diameter smaller than that of the lens unit B.

A tip adapter lens system AD is freely attachable and detachable, as shown in FIG. **5**, to and from the object side of an objective optical system (master lens system) M which is composed of the lens unit A and the lens unit B shown in FIG. **4**. Such a lens system is also referred to as an adapter type objective system.

The objective optical system (master lens system) M and the adapter lens system compose a nearly telecentric system wherein an image of an object to be observed is allowed by the adapter lens system AD to pass through an aperture stop **S1** and fall nearly perpendicularly onto an image receiving surface **12** of an image pickup device **13**.

Further, the optical system according to the present invention is characterized in that it is configured so as to satisfy the following conditions (1) and (2):

(1) $1.4 \leqq f_A/f_B \leqq 7.2$

(2) $2.3 \leqq f_A/f_M \leqq 10$

wherein the reference symbol f_A represents a focal length of the lens unit A, the reference symbol f_B designates a focal length of the lens unit B and the reference symbol f_M denotes a focal length of the objective optical system (master lens system) M.

The condition (1) defines a ratio between the focal length of the lens unit A and that of the lens unit B. Images formed by a simultaneous type electronic endoscope which uses a color mosaic filter may be affected by color shading or luminance shading. Since such a defect is dependent on angles of incidence of rays on image pickup surfaces, it is desirable that an objective optical system -for electronic endoscopes is a telecentric system.

If the upper limit of 7.2 of the condition (1) is exceeded, the lens unit B must have a short focal length for configuring the objective optical system so as to satisfy the telecentric condition and an offaxial principal ray will have a large inclination angle. Accordingly, the lens unit A will have a function of a lens which refracts rays having very low heights and must use a lens element having a very short radius of curvature or a high refractive power. As a result, the lens unit A will have a small outside diameter and can hardly be manufactured in practice. Further, a strong refractive power of the lens unit A is undesirable for correction of aberrations since such a strong power degrades balance of coma. For correcting coma, it is necessary to weaken the refractive power of the lens unit A by reserving a wide airspace therein. However, such an airspace is undesirable since the airspace makes it difficult to configure the objective optical system so as to satisfy the telecentric condition and prolongs a total length thereof.

If the lower limit of 1.4 of the condition (1) is exceeded, the lens unit B will have a long focal length and the offaxial principal ray will be high on the lens unit A, whereby it must have a large outside diameter contrary to the object of the present invention. Further, when an adapter lens system is to be attached to the tip of the objective optical system for composing an adapter type electronic endoscope as described above, a sectional area of a light guide LG which is to be disposed in an objective optical system frame of the endoscope is inevitably restricted by the lens unit since it is desirable to dispose the light guide in the vicinity of the lens unit A. Accordingly, a large outside diameter of the lens unit A is undesirable since it results in insufficiency of brightness by narrowing an area allowed for a light guide or enlarges an outside diameter of the tip of the endoscope.

The condition (2) defines a ratio between the focal length of the lens unit A and that of the objective optical system (master lens system). If the upper limit of 10 of the condition (2) is exceeded, the master lens system M will have a focal length too short for obtaining the objective optical system according to the present invention. In case of a telecentric optical system, an aperture stop is disposed at a location of a front focal point of a lens unit disposed after the aperture stop, or the master lens system M. Accordingly, the master lens system has a short total length but the adapter lens system undesirably has a large outside diameter when the upper limit of the condition (2) is exceeded. When an attempt is made to lower rays by strengthening a refractive power, for example, of a cemented lens component consisting of lens elements **L2** and **L3** disposed in the adapter lens system shown in FIG. **5**, it is necessary to impart a very strong refractive power to this cemented lens component since rays are high on this lens component which is disposed close to the aperture stop. As a result, it will be difficult to manufacture this cemented lens component in practice and spherical aberration will undesirably be aggravated. When the cemented lens component is disposed apart from the aperture stop and has a weakened refractive power, in contrast, the adapter lens system will undesirably have a large outside diameter and a long total length.

If the lower limit of 2.3 of the condition (2) is exceeded, the master lens system M will have a long focal length for configuring the objective optical system so as to satisfy the telecentric condition. As a result, the master lens system will have a large total length. Accordingly, an endoscope which has a tip bending mechanism will have a remarkably prolonged non-flexible distal end which is a fatal defect for an endoscope. Further, the offaxial principal ray will have too small an inclination angle and the lens unit A will undesirably tend to have a large outside diameter.

It is desirable that the lens unit A which comprises at least one cemented lens component and has a positive refractive power as described above is configured so as to have a composition described below. Speaking concretely, it is desirable to compose the lens unit A, in order from a side of the aperture stop, of a negative lens element **L4** and a positive lens element **L5** which has at least one surface convex toward an image surface.

In FIG. **5**, asymmetry of strong coma produced by the negative lens element **L1** disposed in the adapter lens system is corrected favorably by the surface of the lens element which is convex toward the image surface (r_{12} in FIG. **5**). Further, spherical aberration and curvature of field which are produced by the positive lens element disposed in the adapter lens system AD and the master lens system M are corrected to practically allowable levels by a negative function of the cemented surface (r_{11} in FIG. **5**) formed between the lens elements **L4** and **L5** of the cemented lens component disposed in the lens unit A.

Further, it is desirable, for the cemented lens component **L4**, **L5** or the lens unit A comprising at least one cemented lens component and having a positive refractive power, to compose the cemented lens component, in order from the side of the aperture stop **S1**, of the negative lens element **L4** and the positive lens element **L5** having at least one surface convex toward the image surface so as to satisfy the following conditions (3) and (4):

(3) $n_1 > n_2$

(4) $\upsilon_{d1} > \upsilon_{d2}$

wherein the reference symbols n_1 and n_2 represent refractive indices of the negative lens element and the positive lens element respectively of the cemented lens component, and the reference symbols υ_{d1} and υ_{d2} designate Abbe's numbers of the negative lens element and the positive lens element respectively of the cemented lens component.

The conditions (3) and (4) are required for correcting chromatic aberration produced by a front lens unit disposed before the aperture stop, longitudinal chromatic aberration in particular practically favorably, with the cemented lens component described above. Though this chromatic aberration can be corrected to a certain degree with the cemented lens component disposed in the front lens unit, it is difficult to correct the chromatic aberration sufficiently favorably since the cemented lens component is disposed in the vicinity of the aperture stop. For this reason, correction of the chromatic aberration is aided by the cemented lens component used in a rear lens unit disposed in the image side of the aperture stop.

When the conditions (3) and (4) are satisfied by the cemented lens component, it is possible to configure the master lens system M so as to have a small outside diameter, and correct practically favorably aberrations which are produced by the objective optical system as a whole consisting of the adapter lens system AD and the master lens system M.

Now, description will be made of the tip adapter type endoscope according to the present invention. Shown in FIGS. **6** and **7** are sectional views illustrating a composition of the tip adapter type endoscope according to the present invention: FIG. **6** showing only the master unit M, whereas FIG. **7** showing a combination of the master unit M' and a tip adapter unit AD' comprising an adapter lens system AD.

The master unit M' shown in FIG. **6** consists of the above-mentioned master lens system M which is disposed in a master unit frame **13** and a light guide **14** which passes therethrough. The master unit M' is further equipped with a focus adjusting frame **15** which is adjustably fitted, for example by screwing, in a master lens system receiving

frame **16**. Further, integrally fitted in the focus adjusting frame **15** is a focus adjusting lens unit (the lens unit A in FIG. **1**) which is movable back and forth in a direction along an optical axis together with the focus adjusting frame **15** which is moved relatively to the master lens receiving frame **16** by a moving means, for example, of a screw type. By this focus adjusting mechanism, the master unit M' is adjusted to optimum focused conditions. For this adjustment, it is generally desirable to focus the master lens system on infinite distance so as to minimize a variation in focused condition between the master lens system M and the adapter lens system AD. For this reason, it is effective to select a finite distance for adjusting a focused condition of the master unit M' by using a jig lens or the like (not shown). When variations of focused conditions are too large among adapter lens systems AD which are to be used in combination with the master lens system M, the focused conditions can be adjusted as described below. A means for moving adapter lens systems in the direction along the optical axis is disposed in an adapter unit AD' and the variations of the focused conditions are adjusted by this moving means. For example, the focused conditions can be adjusted by reserving an adjustable airspace between the negative lens element L**1** and the cemented lens component consisting of the lens elements L**2** and L**3** shown in FIG. **5** and moving the lens elements in the axial direction of the endoscope. Since the airspace reserved between the lens element L**1** and the cemented lens component consisting of the lens elements L**2** and L**3** has a very large correction coefficient for the positions of focus, these positions can be moved by slightly moving this airspace in the axial direction.

An adapter unit for observing an object located at a short distance or a long distance can be prepared by adjusting the airspace for intentional change of a position of focus. A more adequate observation range can be obtained by selecting different apertures of the aperture stop for the short distance and the long distance. Therefore, the aperture stop according to this embodiment has a variable diameter.

A desired direction toward a visual field, a desired field angle and a desired observation distance can be obtained by integrating the master unit M' having an adjusted position of focus with the adapter unit AD' as shown in FIG. **7**. Disposed in the adapter unit AD' are the adapter lens system and an adapter side illumination system **23**, **24**. The adapter unit AD' having such a composition is freely attachable and detachable to and from the master unit M' with an adapter fitting frame **22** or the like. The adapter fitting frame **22** is attached to the master unit M' by a means such as a knurling tool and the adapter unit AD' is equipped with a means for preventing it from coming off.

It is desirable that an illumination system for leading illumination light from a light source to the tip adapter type endoscope is configured as shown in FIGS. **8**A, **8**B, **8**C, **9**A and **9**B. Speaking concretely, the illumination system for the tip of the endoscope according to the present invention is characterized in that a light guide is divided, in a tip frame of an endoscope, into at least two branches each passing in the axial direction of the endoscope and having at least one bending in the tip frame of the endoscope, and that the two branches are formed again into a single light guide. Speaking concretely with reference to FIG. **8**A and FIG. **9**A, a light guide for leading illumination light from a light source (not shown) is branched into two light guides **26***a* and **26***b* in the tip of the endoscope as shown in FIG. **8**A and FIG. **9**A. As shown in FIG. **8**C (sectional view taken along the C—C line in FIG. **8**A), the branched light guides **26***a* and **26***b* pass through spaces which are not occupied by an image pickup device having a relatively large diameter (spaces between the image pickup device and the outer frame of the endoscope), are bent to have bendings **27** as shown in FIG. **8**A and FIG. **9**B, and are integrated with each other so as to form a light guide **28** as shown in FIG. **8**B (sectional view taken along the B—B line in FIG. **8**A).

By configuring a light guide as described above, it is possible to pass a large number of light guides through the tip of the endoscope and use an image pickup device which has a large image size corresponding to the full screen size. Further, by attaching cover glass plates **30** to end surfaces of the branched light guides **26***a* and **26***b* as shown in FIG. **9**B, it is possible to assure a watertight condition for the lens system, absorb variations of the light guides **16***a* and **16***b* in the longitudinal direction and facilitate assembly of the light guides.

Now, the preferred embodiment of the objective optical system for endoscopes according to the present invention will be described below with reference to the accompanying drawings.

The objective optical system for endoscopes according to the present invention uses lens elements having a small diameter as lens elements to be disposed in a tip out of lens elements adopted for composing the optical system, thereby making it possible to pass a large number of optical fibers through light guides composing an illumination optical system, or obtaining a bright illumination optical system. Further, the objective optical system according to the present invention is characterized in that it is configured as the adapter type permitting attaching and detaching adapter units comprising adapter lens system having different field angles, directions toward visual fields, and so on.

Therefore, each of the embodiments described below is an adapter type objective optical system for endoscopes in which an adapter is attached to the optical system according to the present invention (master lens system).

FIGS. **4** through **9** show a first embodiment of the present invention: FIG. **4** showing a composition of a master unit M' (FIG. **6**) comprising an objective optical system (master-lens system) M, whereas FIG. **5** showing an adapter unit AD' (FIG. **7**) comprising an adapter lens system AD, and freely attachable and detachable to and from the master unit M'.

The first embodiment is an example wherein a direct viewing adapter lens system AD having a field angle of 120° is attached to the master lens system M.

In the first embodiment illustrated in FIG. **4**, the objective optical system (master lens system) M consists of a lens unit A which is composed of a cover glass plate C**2**, and a cemented lens component consisting of a negative lens element L**4** and a positive lens element L**5**, and a lens unit B which is composed of a field lens FL. Further, disposed in the objective optical system (master lens system) M are a low pass filter F**1**, an infrared cut filter F**2**, a CCD cover glass plate C**3** and a CCD image pickup surface **12**. The cover glass plate C**2** is used for maintaining the objective optical system in a watertight condition, whereas the cover glass plate C**3** is adopted for preventing the CCD image pickup surface from being deteriorated. It may be considered, as represented by the reference symbol B in FIGS. **4** and **5**, that the lens unit B comprises the field lens FL, the low pass filter F**1**, the infrared cut filter F**2** and the cover glass plate C**3**. These optical elements have a diameter which is substantially equal to that of the image pickup surface, whereas the lens unit A has a diameter smaller than that of the lens unit B.

The adapter lens system AD which is freely attachable and detachable to and from the objective optical system

(master lens system) M in FIG. **5** is composed of a negative lens element **L1**, a cemented lens component which consists of a positive lens element **L2** and a negative lens element **L3**, and a cover glass plate **C1**. This adapter lens system AD uses, in addition to the negative lens element **L1**, the cemented lens component consisting of the lens elements **L2** and **L3** for correcting chromatic aberration, curvature of field and astigmatism to levels at which these aberrations pose no problem in practical use of the objective optical system. Further, the cover glass plate **C1** is disposed for maintaining the adapter lens system in a watertight condition, thereby preventing a visual field from being dimmed by water vapor, etc. The adapter lens system has a small diameter like the lens unit A.

In the first embodiment, the adapter lens system AD is attached to the objective optical system (master lens system) M for obtaining a wide field angle of 120° so that the objective optical system is efficiently usable for a far visual field or an object located at a relatively long distance. For this embodiment, an illumination system is to be composed as already described above with reference to FIGS. **8A**, **8B**, **8C**, **9A** and **9B**.

The first embodiment has numerical data listed below:

first embodiment

$f = 0.582$, image height = 0.5055,

object distance = −8.0860

$r_1 = \infty$

$d_1 = 0.0886 \quad n_1 = 1.88300 \quad \nu_1 = 40.78$

$r_2 = 0.3372$

$d_2 = 0.1440$

$r_3 = 0.7794$

$d_3 = 0.3988 \quad n_2 = 1.76182 \quad \nu_2 = 26.55$

$r_4 = -0.3285$

$d_4 = 0.1130 \quad n_3 = 1.60342 \quad \nu_3 = 38.01$

$r_5 = -1.9389$

$d_5 = 0.0066$

$r_6 = \infty$ (stop)

$d_6 = 0.0886 \quad n_4 = 1.88300 \quad \nu_4 = 40.78$

$r_7 = \infty$

$d_7 = 0.0576$

$r_8 = \infty$

$d_8 = 0.0886 \quad n_5 = 1.51633 \quad \nu_5 = 64.15$

$r_9 = \infty$

$d_9 = 0.0443$

$r_{10} = -2.1850$

$d_{10} = 0.0665 \quad n_6 = 1.78472 \quad \nu_6 = 25.71$

$r_{11} = 0.5047$

$d_{11} = 0.3434 \quad n_7 = 1.69680 \quad \nu_7 = 55.53$

$r_{12} = -0.8824$

$d_{12} = 0.2437$

-continued

$r_{13} = 1.1630$

$d_{13} = 0.9260 \quad n_8 = 1.72916 \quad \nu_8 = 54.68$

$r_{14} = \infty$

$d_{14} = 0.1772 \quad n_9 = 1.54814 \quad \nu_9 = 45.78$

$r_{15} = \infty$

$d_{15} = 0.3545 \quad n_{10} = 1.51400 \quad \nu_{10} = 75.00$

$r_{16} = \infty$

$d_{16} = 0.1661 \quad n_{11} = 1.49700 \quad \nu_{11} = 81.61$

$r_{17} = \infty$

$d_{17} = 0.0410$

$r_{18} = \infty$ (image)

$f_M = 1$, $f_A = 2.856$, $f_B = 1.594$, $f_A / f_B = 1.792$

$f_A / f_M = 2.856$

A second embodiment of the objective optical system according to the present invention has a composition illustrated in FIG. **10**, wherein an adapter lens system is attached to a master lens system as in FIG. **5**. An objective optical system (master lens system) M used in the second embodiment is the same as that adopted in the first embodiment. The second embodiment adopts an adapter lens system AD which is composed of a negative lens element **L1**, a cemented lens component which consists of lens elements **L2** and **L3**, and an aperture stop. The adapter lens system used in the second embodiment is different from that adopted for the first embodiment in that the former is composed of a negative lens element **L2** and a positive lens element **L3** which are disposed in order from the object side. The reference symbol **C1** used in FIG. **10** represents a cover glass plate. The adapter lens system has a field angle of 80° and is configured for direct viewing.

The second embodiment has the following numerical data;

second embodiment

$f = 0.794$, image height = 0.5055,

object distance = −21.0456

$r_1 = \infty$

$d_1 = 0.0886 \quad n_1 = 1.51633 \quad \nu_1 = 64.15$

$r_2 = 0.3932$

$d_2 = 0.1329$

$r_3 = 3.4298$

$d_3 = 0.0665 \quad n_2 = 1.51633 \quad \nu_2 = 64.15$

$r_4 = 0.4338$

$d_4 = 0.4209 \quad n_3 = 1.88300 \quad \nu_3 = 40.78$

$r_5 = -7.9322$

$d_5 = 0.0066$

$r_6 = \infty$ (stop)

$d_6 = 0.0886 \quad n_4 = 1.88300 \quad \nu_4 = 40.78$

$r_7 = \infty$

-continued

$d_7 = 0.0576$

$r_8 = \infty$

$d_8 = 0.0886$ $n_5 = 1.51633$ $\nu_5 = 64.15$

$r_9 = \infty$

$d_9 = 0.0443$

$r_{10} = -2.1850$

$d_{10} = 0.0665$ $n_6 = 1.78472$ $\nu_6 = 25.71$

$r_{11} = 0.5047$

$d_{11} = 0.3434$ $n_7 = 1.69680$ $\nu_7 = 55.53$

$r_{12} = -0.8824$

$d_{12} = 0.2437$

$r_{13} = 1.1630$

$d_{13} = 0.9260$ $n_8 = 1.72916$ $\nu_8 = 54.68$

$r_{14} = \infty$

$d_{14} = 0.1772$ $n_9 = 1.54814$ $\nu_9 = 45.78$

$r_{15} = \infty$

$d_{15} = 0.3545$ $n_{10} = 1.51400$ $\nu_{10} = 75.00$

$r_{16} = \infty$

$d_{16} = 0.1661$ $n_{11} = 1.49700$ $\nu_{11} = 81.61$

$r_{17} = \infty$

$d_{17} = 0.0410$

$r_{18} = \infty$ (image)

$f_M = 1$, $f_A = 2.886$, $f_B = 1.594$, $f_A / f_B = 1.792$, $f_A / f_M = 2.856$

A third embodiment of the objective optical system according to the present invention has a composition shown in FIG. **11**, wherein an adapter lens system AD is attached to an objective lens system M. This master lens system selected for the third embodiment is also the same as that used in the first or second embodiment.

Further, the adapter lens system AD is composed, in order from the object side, of a negative lens element **L1**, a positive lens element **L2** and an aperture stop, and is configured as a direct-viewing adapter lens system having a field angle of 80°. This adapter lens system corrects aberrations to practically allowable levels and uses a single lens element in place of the cemented lens component used in the second embodiment. Further, an image side surface of the positive lens element **L2** is configured as a planar surface for enhancing adherability to the aperture stop and eliminating the necessity of a cover glass plate which would otherwise be used for maintaining the adapter lens system in a watertight condition. The third embodiment requires a smaller number of parts and uses no cemented lens component, thereby eliminating a cementing step and remarkably lowering a manufacturing cost of the objective optical system.

This adapter lens system may be configured so as to intentionally tilt an image surface on the positive side so that the objective optical system is used exclusively for observing pipes. Further, the adapter lens system may be adjusted so that the third embodiment is to be used exclusively for observing objects located at short distances or long distances as described above. In other words, it is possible to change a location of focus and an observation range by adjusting an airspace reserved in the adapter lens system (airspace d_2 between the lens elements **L1** and **L2**) and varying a diameter of the aperture stop at the same time.

Listed below is numeical data of the third embodiment:

third embodiment

$f = 0.817$, image height = 0.5055,

object distance = −21.045

$r_1 = \infty$

$d_1 = 0.0886$ $n_1 = 1.51633$ $\nu_1 = 64.15$

$r_2 = 0.4836$

$d_2 = 0.2039$

$r_3 = 0.8595$

$d_3 = 0.2127$ $n_2 = 1.78472$ $\nu_2 = 25.71$

$r_4 = \infty$ (stop)

$d_4 = 0.1817$

$r_5 = \infty$

$d_5 = 0.0886$ $n_3 = 1.51633$ $\nu_3 = 64.15$

$r_6 = \infty$

$d_6 = 0.0443$

$r_7 = -2.1850$

$d_7 = 0.0665$ $n_4 = 1.78472$ $\nu_4 = 25.71$

$r_8 = 0.5047$

$d_8 = 0.3434$ $n_5 = 1.69680$ $\nu_5 = 55.53$

$r_9 = -0.8824$

$d_9 = 0.2437$

$r_{10} = 1.1630$

$d_{10} = 0.9260$ $n_6 = 1.72916$ $\nu_6 = 54.68$

$r_{11} = \infty$

$d_{11} = 0.1772$ $n_7 = 1.54814$ $\nu_7 = 45.78$

$r_{12} = \infty$

$d_{12} = 0.3545$ $n_8 = 1.51400$ $\nu_8 = 75.00$

$r_{13} = \infty$

$d_{13} = 0.1661$ $n_9 = 1.49700$ $\nu_9 = 81.61$

$r_{14} = \infty$

$d_{14} = 0.0410$

$r_{15} = \infty$ (image)

$f_M = 1$, $f_A = 2.856$, $f_B = 1.594$, $f_A / f_B = 1.792$, $f_A / f_M = 2.856$

An objective optical system preferred as a fourth embodiment of the present invention has a composition shown in FIG. **12**, wherein an adapter lens system configured for side-viewing is attached to an objective optical system (master lens system) M. The adapter lens system is composed, in order from the object side, of a negative lens element **L1**, a visual field changing prism P, a positive lens element **L2** and an aperture stop **S1**. The objective optical system (master lens system) M is the same as that used in the first, second or third embodiment.

The fourth embodiment is an optical system in which a side-viewing adapter lens system having a field angle of 120° is attached to the objective optical system (master lens

system) M. The fourth embodiment which comprises the visual field changing prism P and permits side viewing is suited in particular for observing inside surfaces of pipes, outside surfaces of heat exchange pipes of nuclear reactors and so on.

FIGS. **13**A and **13**B show an example wherein the tip illumination system described above is applied to the optical system preferred as the fourth embodiment. A light guide **42** used in an adapter lens system shown in FIG. **13**A may be formed by molding. Further, it is desirable that the light guide **42** has an end surface **42'**, on a side of a light source, which has a shape substantially matched with that of a light guide disposed in a master lens system M as shown in FIG. **13**B (sectional view taken along the B—B line in FIG. **13**A) for minimizing loss of illumination light coming from a master unit when the adapter lens unit is attached. This shape of the light guide is applicable also to an optical system to which a direct-viewing adapter lens system is attached. Further, it is desirable that the light guide has a nearly circular end surface on the object side. Since a circular end surface is capable of minimizing loss of the illumination light and ununiformity of illumination, the end surface should desirably have a nearly circular shape.

Selected for the fourth embodiment is the following numerical data:

fourth embodiment

$f = 0.563$, image height = 0.5055,

object distance = −5.0953

$r_1 = \infty$

$d_1 = 0.0997$ $n_1 = 1.51633$ $\nu_1 = 64.15$

$r_2 = 0.4218$

$d_2 = 0.2193$

$r_3 = \infty$

$d_3 = 0.6868$ $n_2 = 1.84666$ $\nu_2 = 23.78$

$r_4 = \infty$

$d_4 = 0.0222$

$r_5 = 1.0326$

$d_5 = 0.1772$ $n_3 = 1.78472$ $\nu_3 = 25.71$

$r_6 = \infty$ (stop)

$d_6 = 0.1108$

$r_7 = \infty$

$d_7 = 0.0886$ $n_4 = 1.51633$ $\nu_4 = 64.15$

$r_8 = \infty$

$d_8 = 0.0443$

$r_9 = -2.1850$

$d_9 = 0.0665$ $n_5 = 1.78472$ $\nu_5 = 25.71$

$r_{10} = 0.5047$

$d_{10} = 0.3434$ $n_6 = 1.69680$ $\nu_6 = 55.53$

$r_{11} = -0.8824$

$d_{11} = 0.2437$

$r_{12} = 1.1630$

$d_{12} = 0.9260$ $n_7 = 1.72916$ $\nu_7 = 54.68$

-continued

$r_{13} = \infty$

$d_{13} = 0.1772$ $n_8 = 1.54814$ $\nu_8 = 45.78$

$r_{14} = \infty$

$d_{14} = 0.3545$ $n_9 = 1.51400$ $\nu_9 = 75.00$

$r_{15} = \infty$

$d_{15} = 0.1661$ $n_{10} = 1.49700$ $\nu_{10} = 81.61$

$r_{16} = \infty$

$d_{16} = 0.0410$

$r_{17} = \infty$ (image)

$f_M = 1$, $f_A = 2.856$, $f_B = 1.594$, $f_A / f_B = 1.792$, $f_A / f_M = 2.856$

A fifth embodiment of the present invention has a composition illustrated in FIG. **14** wherein an adapter lens system is composed of a negative lens element **L1**, a field stop **S2**, a positive lens element **L2**, an aperture stop **S1** and a cover glass plate **C1**. The fifth embodiment is an example wherein a direct-viewing adapter lens system having a field angle of 120° is attached to a master lens system M. In this embodiment, a focal length of an objective optical system is shortened by restricting only a portion of an entire image area. The fifth embodiment therefore makes it possible to obtain a range of observation depth which is broader than that obtainable with any one of the first through fourth embodiments. The first or fourth embodiment provides a field angle of 120° in a diagonal direction of an image area but has a field angle as narrow as approximately 70° in a direction along a shorter side.

The fifth embodiment which restricts the image area in a direction nearly matched with the shorter side of a monitor screen provides a merit that it permits observing a tubular object such as a pipe in all directions nearly at the same time within a circular visual field having a field angle of 120°.

Listed below is numerical data selected for configuring the fifth embodiment:

fifth embodiment

$f = 0.323$, image height = 0.2880,

object distance = −1.7058

$r_1 = \infty$

$d_1 = 0.0886$ $n_1 = 1.88300$ $\nu_1 = 40.78$

$r_2 = 0.3152$

$d_2 = 0.1196$

$r_3 = \infty$ (field stop)

$d_3 = 0.4896$

$r_4 = -2.9903$

$d_4 = 0.1772$ $n_1 = 1.84666$ $\nu_2 = 23.78$

$r_5 = -0.6927$

$d_5 = 0.0066$

$r_6 = \infty$ (stop)

$d_6 = 0.0886$ $n_3 = 1.88300$ $\nu_3 = 40.78$

-continued

$r_7 = \infty$

$d_7 = 0.0576$

$r_8 = \infty$

$d_8 = 0.0886$ $n_4 = 1.51633$ $\nu_4 = 64.15$

$r_9 = \infty$

$d_9 = 0.0443$

$r_{10} = -2.1850$

$d_{10} = 0.0665$ $n_5 = 1.78472$ $\nu_5 = 25.71$

$r_{11} = 0.5047$

$d_{11} = 0.3434$ $n_6 = 1.69680$ $\nu_6 = 55.53$

$r_{12} = -0.8824$

$d_{12} = 0.2437$

$r_{13} = 1.1630$

$d_{13} = 0.9260$ $n_7 = 1.72916$ $\nu_7 = 54.68$

$r_{14} = \infty$

$d_{14} = 0.1772$ $n_8 = 1.54814$ $\nu_8 = 45.78$

$r_{15} = \infty$

$d_{15} = 0.3545$ $n_9 = 1.51400$ $\nu_9 = 75.00$

$r_{16} = \infty$

$d_{16} = 0.1661$ $n_{10} = 1.49700$ $\nu_{10} = 81.61$

$r_{17} = \infty$

$d_{17} = 0.0410$

$r_{18} = \infty$ (image)

$f_M = 1$, $f_A = 2.856$, $f_B = 1.594$, $f_A / f_B = 1.792$, $f_A / f_M = 2.856$

A sixth embodiment of the present invention has a composition illustrated in FIG. **15**. In this embodiment, an adapter lens system is composed, in order from the object side, of a negative lens element **L1**, a field stop **S2**, a visual field changing prism P, a positive lens element **L2**, an aperture stop **S1** and a cover glass plate **C1**.

The sixth embodiment is configured as a side-Viewing objective optical system by adding the visual field changing prism P to the adapter lens system which is used in the fifth embodiment. Since the adapter lens system selected for the sixth embodiment has an observation range broader than that of the side-viewing adapter lens system used in the fourth embodiment, it provides a merit that the sixth embodiment can be placed closer to an object for observation.

The sixth embodiment has numerical data listed below:

sixth embodiment

$f = 0.321$, image $= 0.2880$,

object distance $= -1.7058$

$r_1 = \infty$

$d_1 = 0.0886$ $n_1 = 1.88300$ $\nu_1 = 40.78$

$r_2 = 0.3152$

$d_2 = 0.1196$

$r_3 = \infty$ (field stop)

$d_3 = 0.0443$

$r_4 = \infty$

$d_4 = 0.6868$ $n_2 = 1.84666$ $\nu_2 = 23.78$

$r_5 = \infty$

$d_5 = 0.0775$

$r_6 = -2.9903$

$d_6 = 0.1772$ $n_3 = 1.84666$ $\nu_3 = 23.78$

$r_7 = -0.6927$

$d_7 = 0.0066$

$r_8 = \infty$ (stop)

$d_8 = 0.0886$ $n_4 = 1.88300$ $\nu_4 = 40.78$

$r_9 = \infty$

$d_9 = 0.0576$

$r_{10} = \infty$

$d_{10} = 0.0886$ $n_5 = 1.51633$ $\nu_5 = 64.15$

$r_{11} = \infty$

$d_{11} = 0.0443$

$r_{12} = -2.1850$

$d_{12} = 0.0665$ $n_6 = 1.78472$ $\nu_6 = 25.71$

$r_{13} = 0.5047$

$d_{13} = 0.3434$ $n_7 = 1.69680$ $\nu_7 = 55.53$

$r_{14} = -0.8824$

$d_{14} = 0.2437$

$r_{15} = 1.1630$

$d_{15} = 0.9260$ $n_8 = 1.72916$ $\nu_8 = 54.68$

$r_{16} = \infty$

$d_{16} = 0.1772$ $n_9 = 1.54814$ $\nu_9 = 45.78$

$r_{17} = \infty$

$d_{17} = 0.3545$ $n_{10} = 1.51400$ $\nu_{10} = 75.00$

$r_{18} = \infty$

$d_{18} = 0.1661$ $n_{11} = 1.49700$ $\nu_{11} = 81.61$

$r_{19} = \infty$

$d_{19} = 0.0410$

$r_{20} = \infty$ (image)

$f_M = 1$, $f_A = 2.856$, $f_B = 1.594$, $f_A / f_B = 1.792$, $f_A / f_M = 2.856$

The objective optical system (master lens system) M is common to all the first through sixth embodiments described above.

A seventh embodiment of the present invention has a composition illustrated in FIG. **16**, wherein an objective optical system (master lens system) M is composed, in order from the object side, of a lens unit A which is composed of a cemented lens component consisting of a negative lens element **L4** and a positive lens element **L5** and a lens unit B which is composed of a field lens FL. Further, the seventh embodiment additionally comprises a cover glass plate **C1**,

a low pass filter F1, an infrared cut filter F2, a CCD cover glass plate C3 and a CCD image pickup surface.

An adapter lens system adopted for the seventh embodiment is composed, in order from the object side, of a negative lens element L1, a positive lens element L2 and an aperture stop S1.

In the seventh embodiment, the objective optical system (master lens system) M is configured so as to have an outside diameter as small as possible while satisfying the conditions (1) and (2) so that an increased number of light guides can pass therethrough. It is undesirable to configure the lens unit A so as to have a smaller outside diameter since such an outside diameter will allow eclipse of a visual field, production of flare, etc. and aggravation of aberrations to unallowable levels. Attached to the objective optical system (master lens system) M is an adapter lens system having a field angle of 80°.

The seventh embodiment has the following numerical data:

seventh embodiment

$f = 0.727$, image height = 0.4567,

object distance = −19.0114

$r_1 = \infty$

$d_1 = 0.0800$ $n_1 = 1.51633$ $\nu_1 = 64.15$

$r_2 = 0.4400$

$d_2 = 0.2239$

$r_3 = 0.5969$

$d_3 = 0.1990$ $n_2 = 1.78472$ $\nu_2 = 25.71$

$r_4 = \infty$ (stop)

$d_4 = 0.0155$

$r_5 = \infty$

$d_5 = 0.0800$ $n_3 = 1.51633$ $\nu_3 = 64.15$

$r_6 = \infty$

$d_6 = 0.0400$

$r_7 = -0.7168$

$d_7 = 0.0600$ $n_4 = 1.78472$ $\nu_4 = 25.71$

$r_8 = 0.2927$

$d_8 = 0.2882$ $n_5 = 1.69680$ $\nu_5 = 55.53$

$r_9 = -0.5898$

$d_9 = 0.3002$

$r_{10} = 1.0095$

$d_{10} = 0.8185$ $n_6 = 1.72916$ $\nu_6 = 54.68$

$r_{11} = \infty$

$d_{11} = 0.1601$ $n_7 = 1.54814$ $\nu_7 = 45.78$

$r_{12} = \infty$

$d_{12} = 0.3202$ $n_8 = 1.51400$ $\nu_8 = 75.00$

$r_{13} = \infty$

$d_{13} = 0.1501$ $n_9 = 1.49700$ $\nu_9 = 81.61$

-continued

$r_{14} = \infty$

$d_{14} = 0.0370$

$r_{15} = \infty$ (image)

f_M=1, f_A=9.484, f_B=1.010, f_A/f_B=9.885

f_A/f_M=9.984, outside diameter of lens unit A=2.4 mm, outside diameter of lens unit B=5.4 mm, (outside diameter of lens unit A)/(outside diameter of lens unit B)=0.44

An eighth embodiment of the present invention has a composition illustrated in FIG. 17. In the eighth embodiment, an adapter lens system AD is composed of a negative lens element L1, a positive lens element L2 and an aperture stop S1, whereas an objective optical system (master lens system) M is composed of a lens unit A which is composed of a cover glass plate C2, a cemented lens component consisting of a negative lens element L4 and a positive lens element L5, and a lens unit B which is composed of a field lens FL, a low pass filter F1, an infrared cut filter F2, a CCD cover glass plate C3 and a CCD image pickup surface.

In the eighth embodiment also, the lens unit A disposed in the master lens system M is configured so as to have an outside diameter as small as possible while satisfying the conditions (1) and (2). In the eighth embodiment, it is undesirable to configure the lens unit A so as to have a smaller outside diameter since such an outside diameter will enhance rays on the lens unit B. As a result, it is necessary to enlarge an outside diameter of the lens unit B, thereby producing inconvenience of a necessity to enlarge an outside diameter of a tip of the endoscope or reduce a number of optical fibers to be disposed in light guides. The eighth embodiment is an example wherein an adapter lens system AD which has a field angle of 80° is attached to the master lens system M.

Selected for the eighth embodiment is numerical data which is listed below:

eighth embodiment

$f = 0.825$, image height = 0.5228,

object distance = −21.7640

$r_1 = \infty$

$d_1 = 0.0916$ $n_1 = 1.51633$ $\nu_1 = 64.15$

$r_2 = 0.4946$

$d_2 = 0.2108$

$r_3 = 0.9964$

$d_3 = 0.2199$ $n_2 = 1.78472$ $\nu_2 = 25.71$

$r_4 = \infty$ (stop)

$d_4 = 0.1983$

$r_5 = \infty$

$d_5 = 0.0916$ $n_3 = 1.51633$ $\nu_3 = 64.15$

$r_6 = \infty$

$d_6 = 0.0458$

$r_7 = -3.2009$

$d_7 = 0.0687$ $n_4 = 1.78472$ $\nu_4 = 25.71$

-continued

$r_8 = 0.5537$

$d_8 = 0.3551$ $n_5 = 1.69680$ $\nu_5 = 55.53$

$r_9 = -0.9075$

$d_9 = 0.2978$

$r_{10} = 1.2448$

$d_{10} = 0.9576$ $n_6 = 1.72916$ $\nu_6 = 54.68$

$r_{11} = \infty$

$d_{11} = 0.1833$ $n_7 = 1.54814$ $\nu_7 = 45.78$

$r_{12} = \infty$

$d_{12} = 0.3666$ $n_8 = 1.51400$ $\nu_8 = 75.00$

$r_{13} = \infty$

$d_{13} = 0.1718$ $n_9 = 1.49700$ $\nu_9 = 81.61$

$r_{14} = \infty$

$d_{14} = 0.0424$

$r_{15} = \infty$ (image)

f_M=1, f_A=2.3, f_B=1.707, f_A/f_B=1.347,

f_A/f_M=2.3, outside diameter of lens unit A=3 mm, outside diameter of lens unit B=4.4 mm, (outside diameter of lens unit A)/(outside diameter of lens unit B)=0.68

In each of the seventh and eighth embodiments, it may be considered that the lens unit B used in the master lens system comprises the field lens FL, the low pass filter F**1**, the infrared cut filter F**2** and the cover glass plate C**3**.

In the numerical data of the first through eighth embodiments described above, the reference symbols r_1, r_2, . . . represent radii of curvature on respective lens surfaces, the reference symbols d_1, d_2 . . . designate thicknesses of respective lens elements and airspaces reserved therebetween, the reference symbols n_1, n_2 . . . denote refractive indices of the respective lens elements, and the reference symbols υ_1, υ_2 . . . represent Abbe's numbers of the respective lens elements. Further, the reference symbol f designates a focal length of the optical system as a whole comprising the adapter lens system and the reference symbol f_M denotes a focal length of the master lens system only. The numerical data is normalized to f_M=1.

Out of the embodiments described above, the seventh embodiment is configured to have a ratio (outside diameter of lens unit A)/(outside diameter of lens unit B) of 0.44 which is the smallest of all the ratios or a largest difference between the outside diameters of all the differences selected for the embodiments and the eighth embodiment is configured to have a ratio of 0.68 between the outside diameters which is the largest of all the ratios or a smallest difference between the outside diameters of all the differences selected for the embodiments. Ratios between the outside diameters selected for the other embodiments are between the values adopted for the seventh and eighth embodiments.

When an adapter lens system type objective optical system such as that according to the present invention uses an adapter lens system having a wider field angle, a lens element which is to be disposed on the object side in the optical system tends to have a large outside diameter. For this reason, it is desirable to select for an endoscope tip such a composition as that adopted for a ninth embodiment of the present invention illustrated in FIG. **18**. Schematically shown in this drawing is an adapter lens system which is seen from a side of its tip and has a partially cut objective optical system. Since an image pickup device generally has a rectangular shape, it is unnecessary to shape lens elements circular. Accordingly, a ray which is incident highest on the image pickup device (in a diagonal direction in a visual field) is not eclipsed when an objective optical system **72** is partially cut as shown in FIG. **18**. Further the lens element may be rectangular.

When lens elements cannot be laid within a tip frame or when it is desired to configure an endoscope tip thinner, an illumination lens **73** may be composed of parts which are integrated after shaping as shown in FIG. **18**. An illumination lens having such a shape may be manufactured by shaping or molding a material such as a resin.

Since the image pickup device is rectangular as described above, circular lens elements are apt to allow flare to be produced by detrimental rays (rays outside a visual field). Accordingly, it is possible to select a composition such as that shown in FIG. **19** illustrating a tenth embodiment of the present invention. Shown in this drawing is a side-viewing adapter lens system as seen from a side of its end surface (from above) which is not circular unlike the ordinary flare stop. Detrimental rays to be incident on an image pickup surface can be eliminated by using a flare stop **75** which has a partially cut circular shape. A plurality of portions of a flare stop may be cut off and a flare stop having such a shape may be used in an objective optical system.

FIG. **20** is a perspective view schematically showing an endoscope system which uses the tip adapter lens system type objective optical system for endoscopes according to the present invention. In this drawing, an adapter that is optimum for an object to be observed is selected from among a group of adapters **77** and attached to an endoscope body **78**. In this condition, an image of the object is imaged on a light receiving surface of an image pickup device disposed in the endoscope through the attached adapter lens system and the objective optical system for endoscopes, transferred as image data through a universal cord **80** to a camera control unit **82** for required conversion of the image data, and output to a monitor for display. An illumination light beam emitted from a light source is led through light guides (not shown) so that an illuminator lens disposed in a tip of the endoscope will irradiate the object at proper distribution and intensities.

I claim:

1. An endoscope tip assembly, comprising:

a light guide bundle;

an objective optical system arranged parallel to said light guide bundle, wherein said objective optical system comprises an image side unit and an object side unit, said object side unit being disposed on an object side of said image side unit;

an image pick up element constructed and arranged to be in communication with said objective optical system; and

an adapter lens system which is detachably disposed on the object side of said object side unit,

wherein said image side unit and said image pickup element are secured with respect to each other in a common frame,

wherein each constituent lens of said image side unit has a larger diameter than each constituent lens of said object side unit,

wherein each optical element of said adapter lens system has a diameter which is smaller than a diameter of any lens in said image side unit, and

wherein said adapter lens system comprises an aperture stop.

2. An endoscope tip assembly, comprising:

a light guide bundle;

an objective optical system arranged parallel to said light guide bundle; and

an image pick up element constructed and arranged to be in communication with said objective optical system;

wherein said objective optical system comprises an image side unit and an object side unit, said object side unit being disposed on an object side of said image side unit,

wherein each constituent lens of said image side unit has a larger diameter than each constituent lens of said object side unit,

wherein said object side unit comprises at least one cemented lens component, and

said image side unit has a positive refractive power and satisfies the following conditions (1) and (2):

(1) $1.4 \leqq F_A/f_B \leqq 7.2$

(2) $2.3 \leqq f_A/f_B \leqq 10$

wherein the reference symbols f_A and f_B represent focal lengths of the object side lens unit and the image side lens unit respectively, and the reference symbol f_M designates a total focal length of the objective optical system as a whole.

3. An endoscope tip assembly, comprising:

a light guide bundle;

an objective optical system arranged parallel to said light guide bundle;

an image pick up element constructed and arranged to be in communication with said objective optical system; and

an adapter lens system which is detachably disposed on the object side of said object side unit,

wherein said objective optical system comprises an image side unit and an object side unit, said object side unit being disposed on an object side of said image side unit,

wherein said image side unit and said image pickup element are secured in a common frame,

wherein each constituent lens of said image side unit has a larger diameter than each constituent lens of said object side unit,

wherein each optical element of said adapter lens system has a diameter which is smaller than a diameter any lens in said image side unit,

wherein said adapter lens system comprises an aperture stop, and

wherein said object side unit comprises at least one cemented lens component, and

said image side unit has a positive refractive power and satisfies the following conditions (1) and (2):

(1) $1.4 \leqq f_A/f_B \leqq 7.2$

(2) $2.3 \leqq f_A/f_M \leqq 10$

wherein the reference symbols f_A and f_B represent focal lengths of the object side lens unit and the image side lens unit respectively, and the reference symbol f_M designates a total focal length of the objective optical system as a whole.

4. An endoscope tip assembly according to claim 2 or 3, wherein said at least one cemented lens component in said object side unit comprises, in order from a side of the aperture stop, a negative lens element and a positive lens element, said positive lens element having at least one surface which is concave toward said image side.

5. An endoscope tip assembly according to claim 4 satisfying the following conditions (3) and (4):

(3) $n_1 > n_2$

(4) $\upsilon_{d1} < \upsilon_{d2}$

wherein the reference symbols n_1 and n_2 represent refractive indices of the negative lens element and the positive lens elements respectively, of said cemented lens component, and the reference symbols υ_{d1} and υ_{d2} designate Abbe's numbers of the negative lens element and the positive lens element, respectively, of said cemented lens component.

6. An endoscope tip assembly, comprising:

a light guide bundle;

an objective optical system arranged parallel to said light guide bundle;

an image pick up element constructed and arranged to be in communication with said objective optical system; and

an adapter lens system which is detachably disposed on the object side of said object side unit,

wherein said objective optical system comprises an image side unit and an object side unit, said object side unit being disposed on an object side of said image side unit,

wherein each constituent lens of said image side unit has a larger diameter than each constituent lens of said object side unit,

wherein each optical element of said adapter lens system has a diameter which is smaller than a diameter any lens in said image side unit,

wherein said adapter lens system comprises an aperture stop,

wherein said object side unit comprises at least one cemented lens component, and said image side unit has a positive refractive power,

wherein said at least one cemented lens component in said object side unit comprises, in an order from a side of said aperture stop, a negative lens element and a positive lens element,

said positive lens element having at least one surface which is concave toward said image side,

said adapter lens system is selectable from a plurality of different types of adapter lens systems each of which are attachable and detachable from the object side of said object side unit,

wherein each optical element of said plurality of different types of adapter lens systems has a diameter which is smaller than that of any lens included in said image side unit;

wherein said adapter lens system comprises an aperture stop,

said adapter lens system can be selected for varying at least one of a field angle, a viewing direction and an observation distance, and said objective optical system satisfies the following conditions:

(1) $1.4 \leqq f_A/f_B \leqq 7.2$

(2) $2.3 \leqq f_A/f_M \leqq 10$

(3) $n_1 > n_2$

(4) $\upsilon_{d1} < \upsilon_{d2}$

wherein the reference symbols f_A and f_B represent focal length of the object side lens unit and the image side lens unit, respectively, the reference symbol f_M designates a total focal length of the objective optical system as a whole, the reference symbols n_1 and n_2 represent refractive indices of the negative lens element and the positive lens element, respectively, of said cemented lens component, and the

reference symbols υ_{d1} And υ_{d2} designate Abbe's numbers of the negative lens element and the positive lens element, respectively, of said cemented lens component.

7. An endoscope tip assembly according to claim **6**, wherein said adapter lens system further comprises a moving means for moving, in a direction along an optical axis, some lens elements included in said adapter lens system and some lens elements included in at least one of said object side unit and said image side unit.

8. An endoscope tip assembly according to claim **7**, wherein said aperture stop has a variable aperture, and

said adapter lens system is configured to change an observation distance by moving some lens elements disposed in said adapter lens system, at least one but not all lenses of said object side unit and said image side unit, and varying a diameter of said aperture stop.

9. An endoscope tip assembly, comprising:

a light guide bundle;

an objective optical system arranged parallel to said light guide bundle;

an image pick-up element constructed and arranged to be in communication with said objective optical system; and

an adapter lens system which is detachably disposed on the object side of said objective optical system,

wherein some lenses of said objective optical system and said image pick-up element are secured with respect to each other in a common frame,

wherein said some lenses secured in said common frame have larger diameters than a diameter of a lens which is arranged on an object side of a lens secured in said common frame,

wherein each optical element of said adapter lens system has a diameter which is smaller than a diameter of any lens in said some lenses, and

wherein said adapter lens system comprises an aperture stop.

* * * * *

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United States Patent [19]

Yoshida et al.

[11] Patent Number: 5,912,774

[45] Date of Patent: *Jun. 15, 1999

[54] **LENS MOVING MECHANISM FOR FINELY MOVING A PORTION OF AN OBJECTIVE LENS BY ROTATING A HOLDING MEMBER**

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[73] Assignee: **Canon Kabushiki Kaisha**, Tokyo, Japan

[*] Notice: This patent issued on a continued prosecution application filed under 37 CFR 1.53(d), and is subject to the twenty year patent term provisions of 35 U.S.C. 154(a)(2).

[21] Appl. No.: **08/684,849**

[22] Filed: **Jul. 25, 1996**

[30] **Foreign Application Priority Data**

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Jul. 31, 1995 [JP] Japan 7-194990
Jul. 31, 1995 [JP] Japan 7-195000

[51] **Int. Cl.**[6] **G02B 7/02**
[52] **U.S. Cl.** **359/823**
[58] **Field of Search** 359/811, 813, 359/815, 819, 820, 821, 822, 823, 824, 825, 826

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Primary Examiner—Robert H. Kim
Assistant Examiner—Michael P. Stafira
Attorney, Agent, or Firm—Fitzpatrick, Cella, Harper & Scinto

[57] **ABSTRACT**

A lens moving mechanism for finely moving at least a lens portion of an objective lens in a direction of an optical axis of the objective lens. The lens moving mechanism includes a holding member holding the lens portion and a disc-like disc cam member provided with a cam surface, which lies in a peripheral portion of the disc-like disc cam member. The disc cam member is rotated to thereby move the holding member on a track conforming to the cam surface.

8 Claims, 14 Drawing Sheets

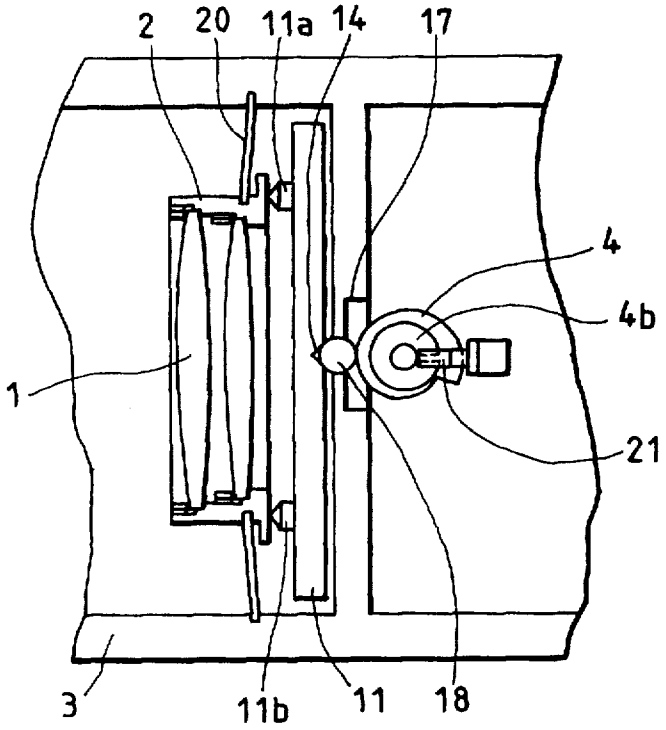


FIG. 1A

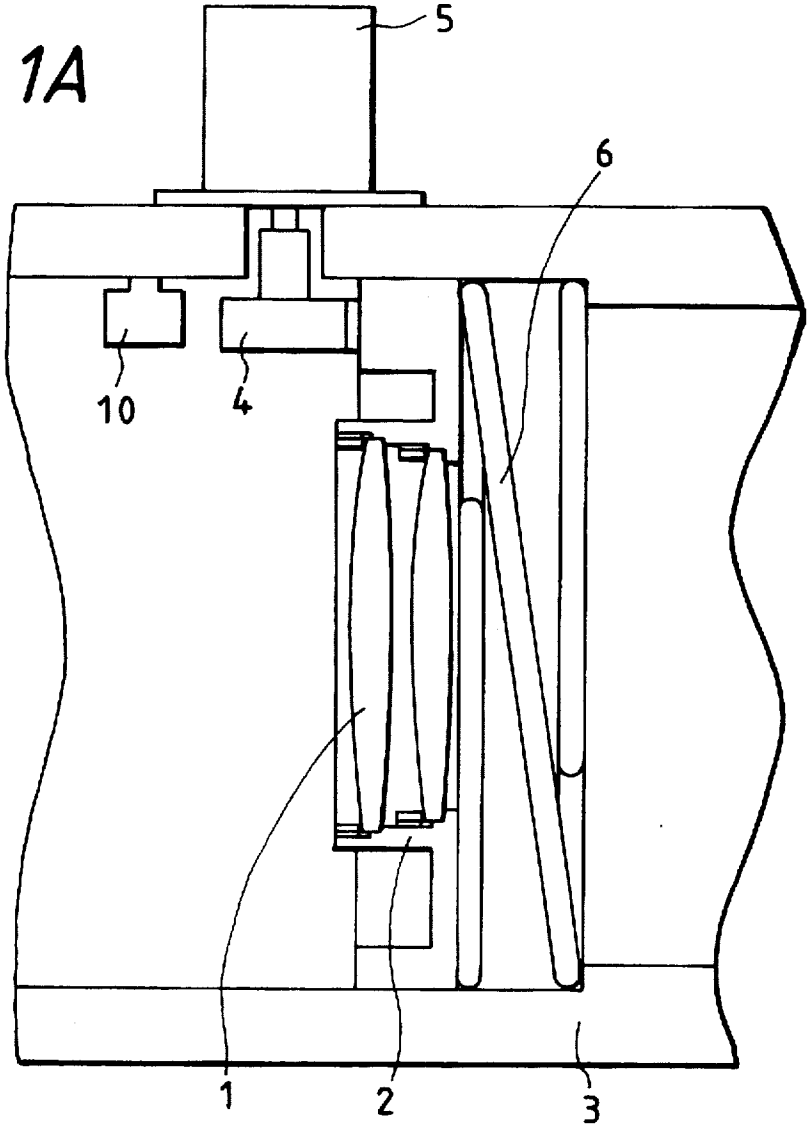


FIG. 1B

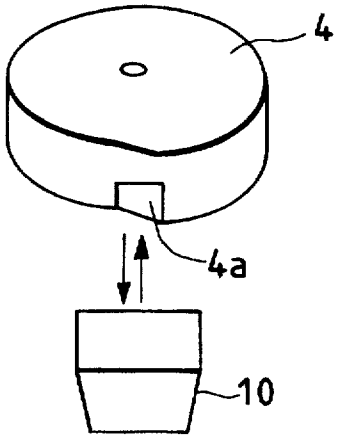


FIG. 2B

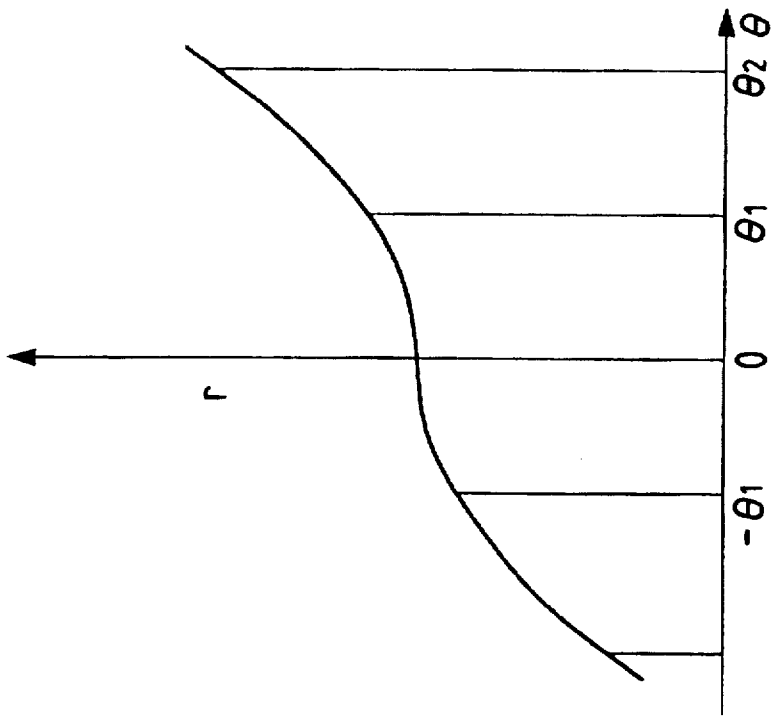


FIG. 2A

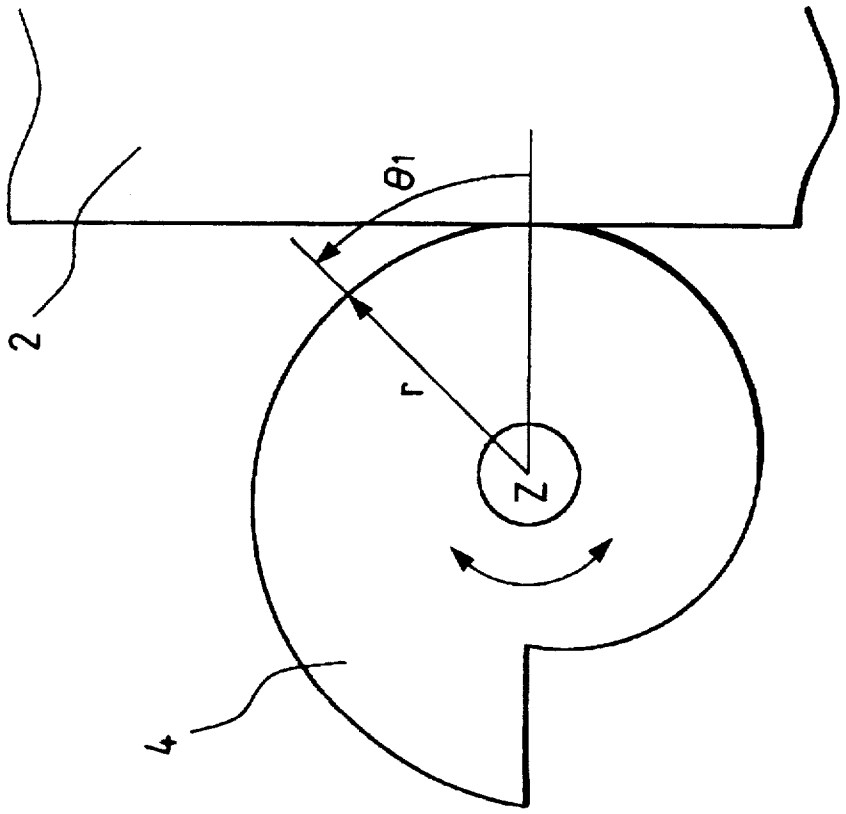


FIG. 3B

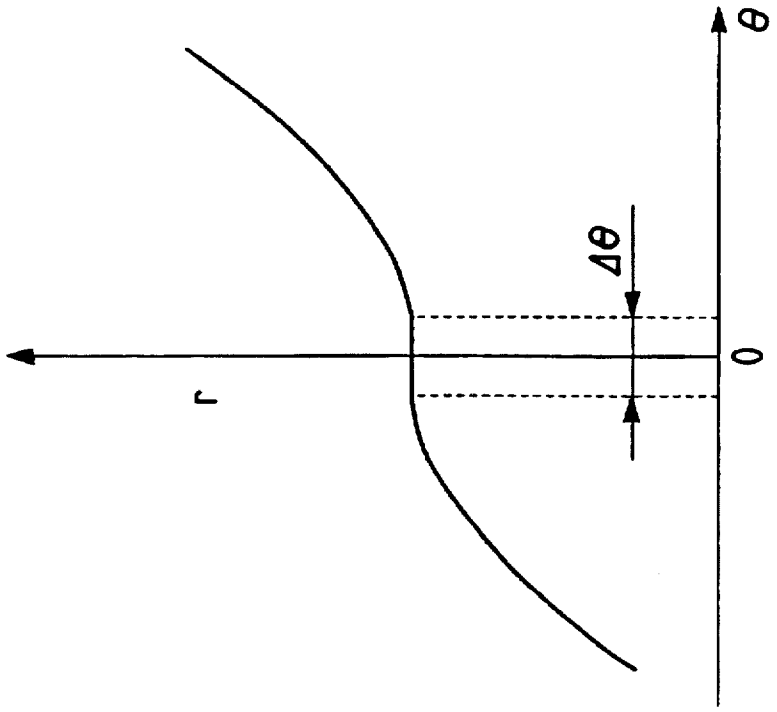


FIG. 3A

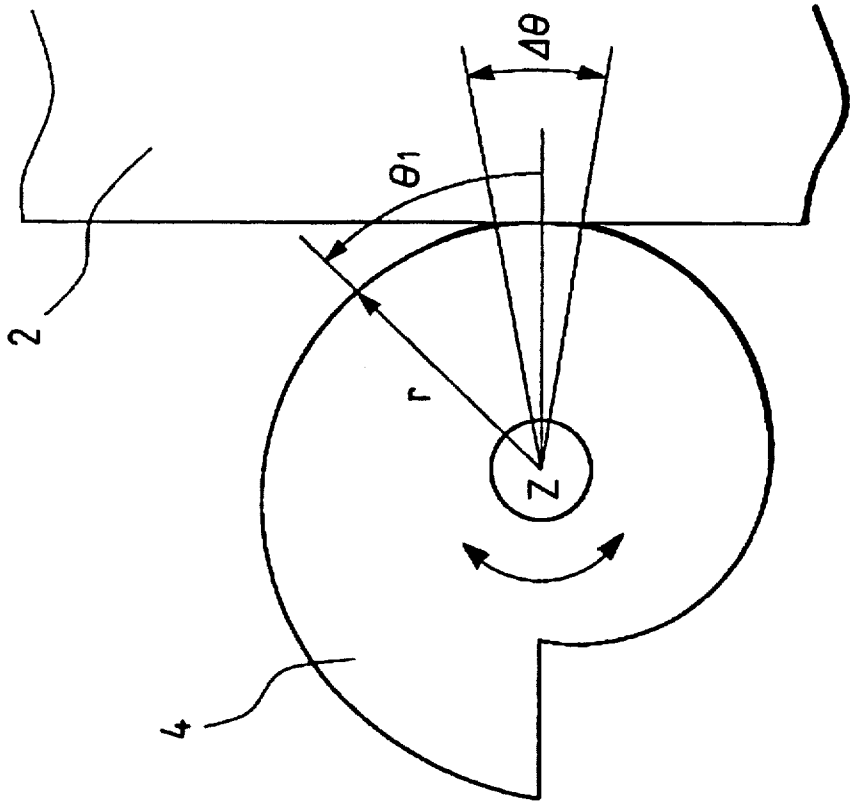


FIG. 4

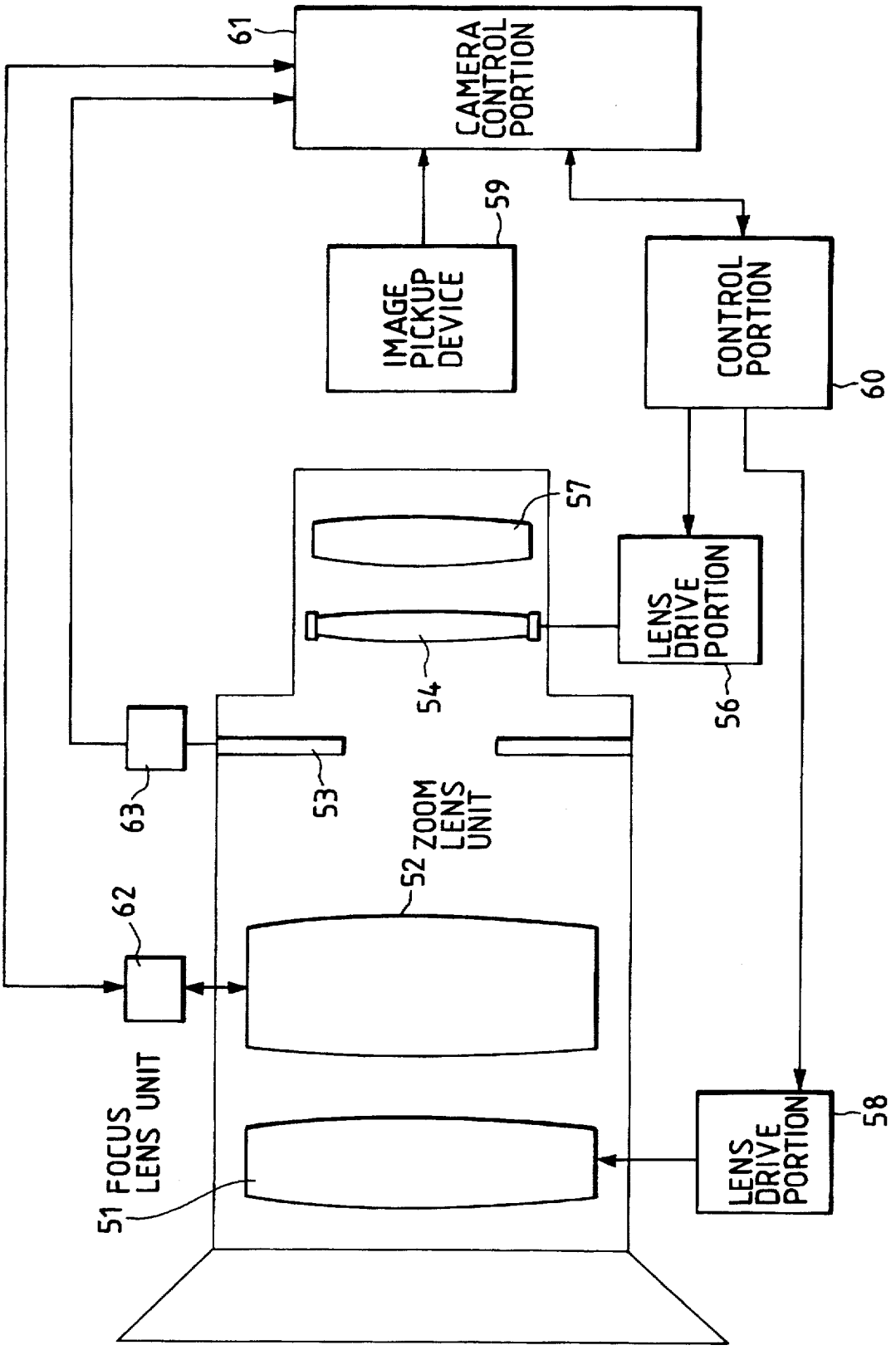

61
CAMERA CONTROL PORTION
59
IMAGE PICKUP DEVICE
CONTROL PORTION
60
57
LENS DRIVE PORTION
56
54
63
53
52 ZOOM LENS UNIT
62
51 FOCUS LENS UNIT
LENS DRIVE PORTION
58

FIG. 5A

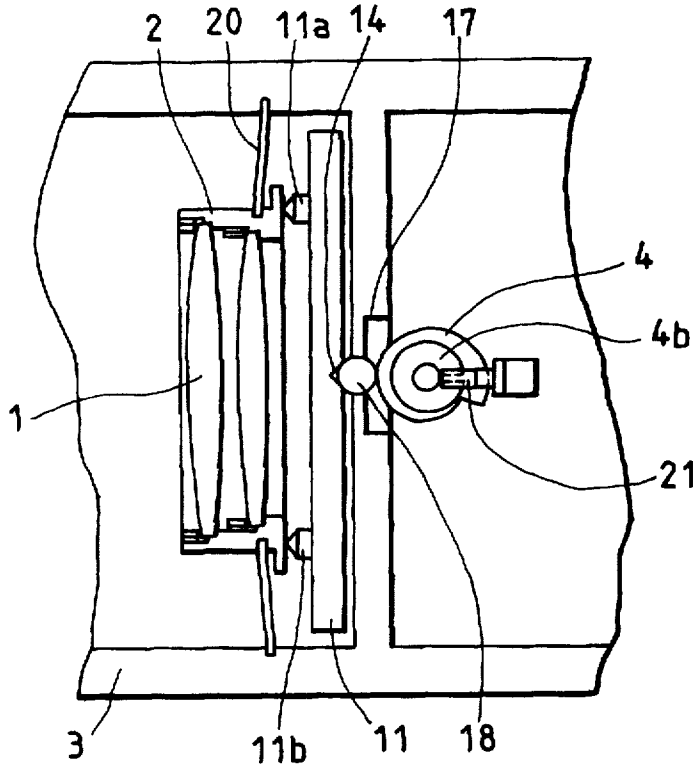

2
20
11a
14
17
4
4b
1
21
3
11b
11
18

FIG. 5B

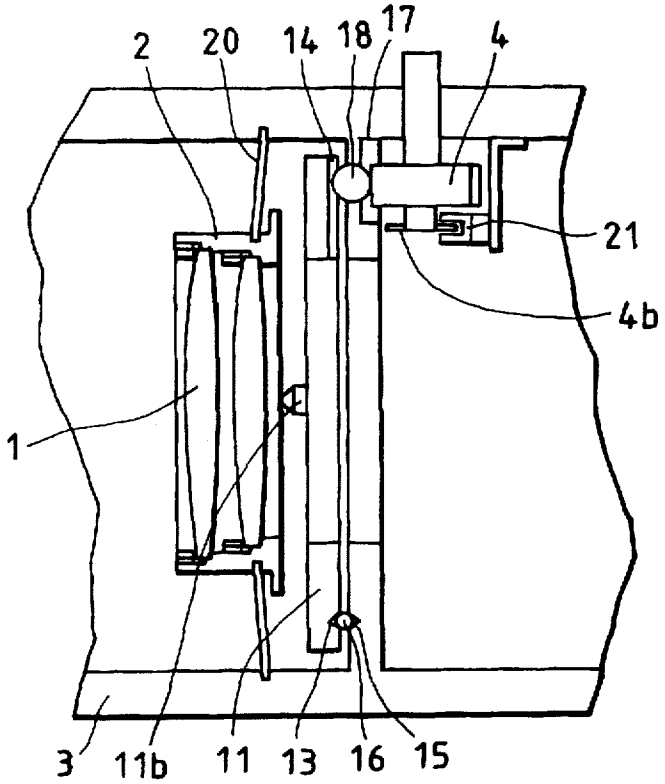

2
20
14
18
17
4
21
4b
1
3
11b
11
13
16
15

FIG. 6
PRIOR ART

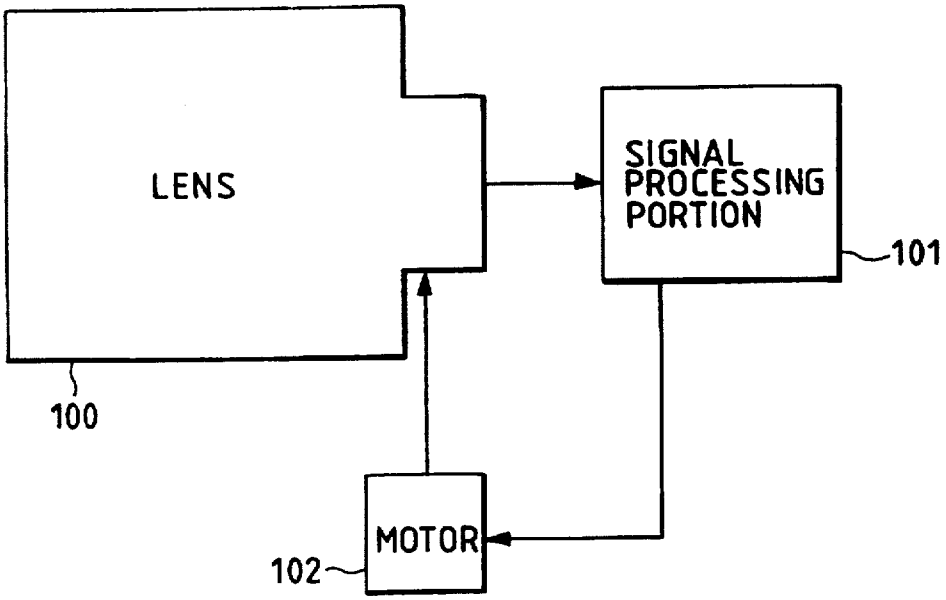


FIG. 7
PRIOR ART

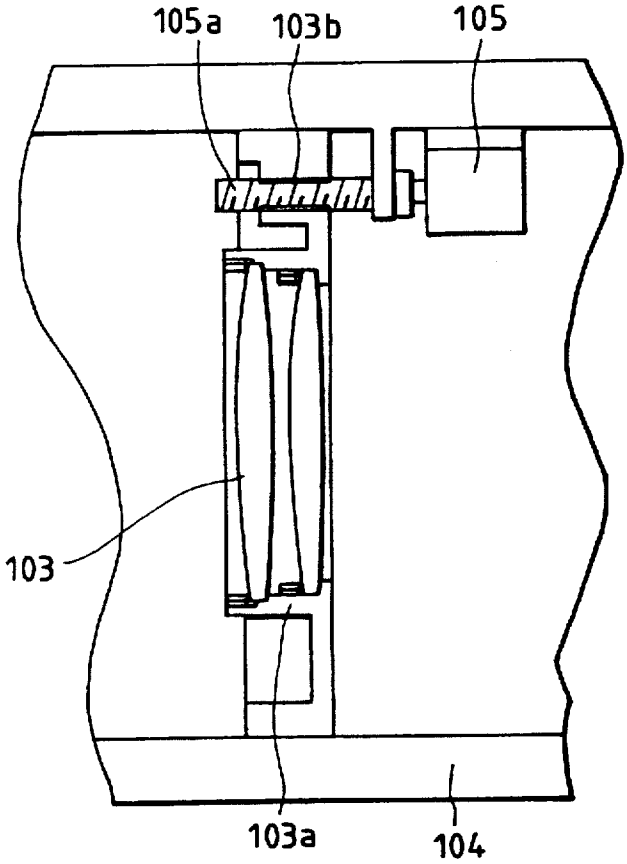


FIG. 8A

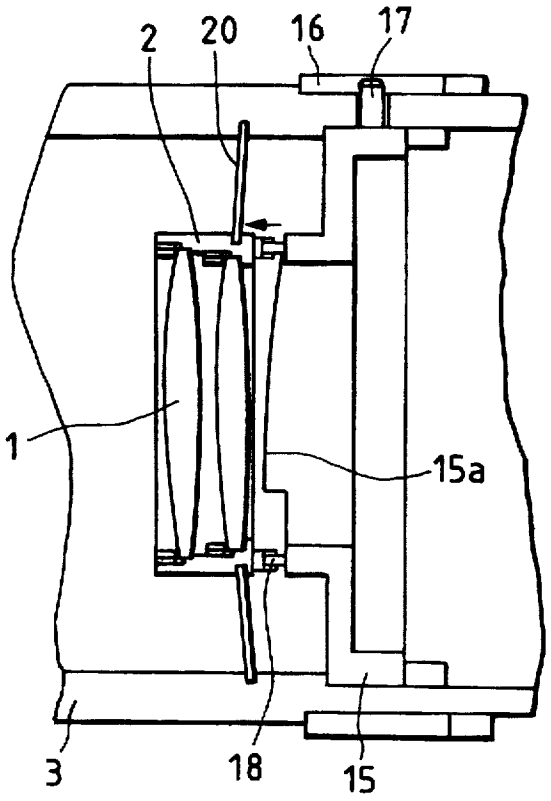


FIG. 8B

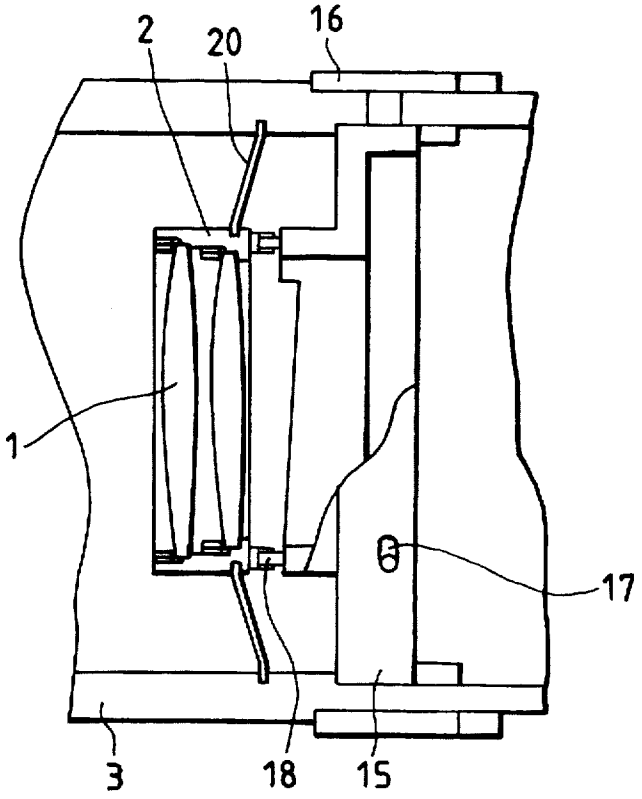


FIG. 9A

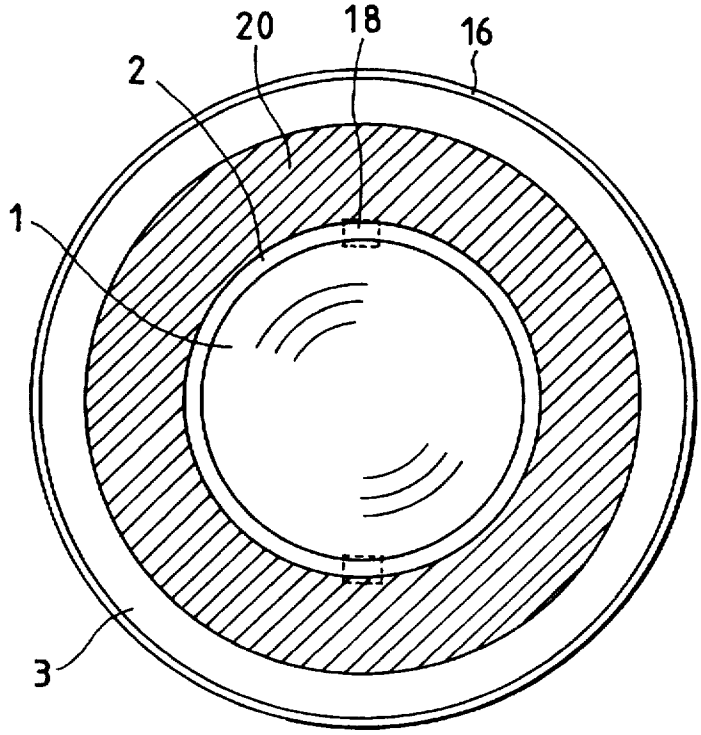


FIG. 9B

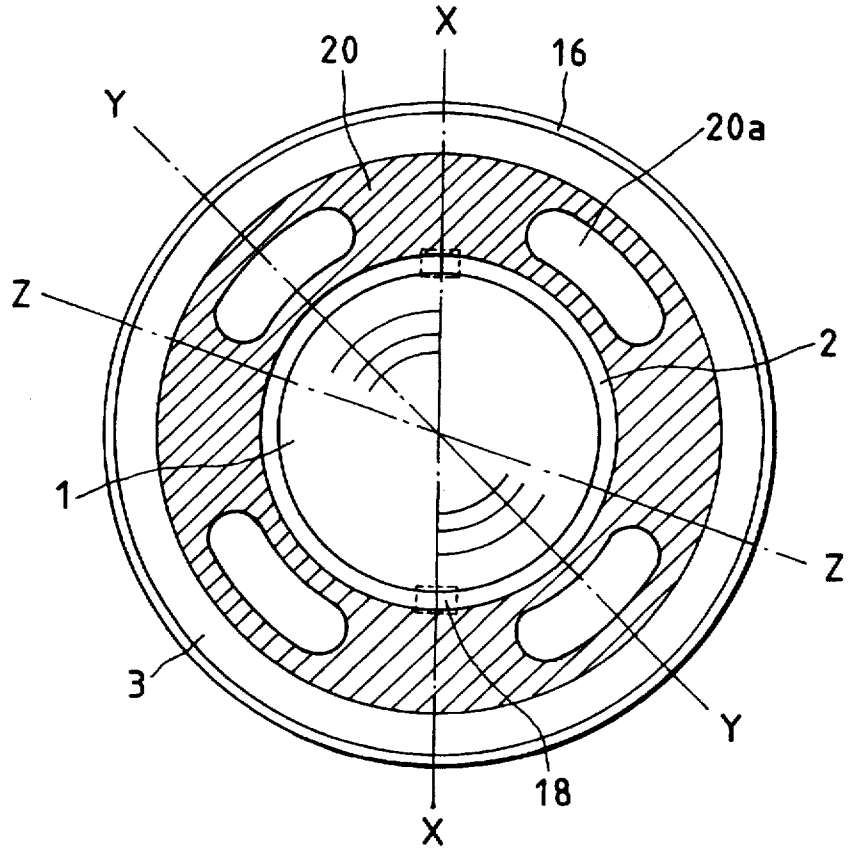


FIG. 10A

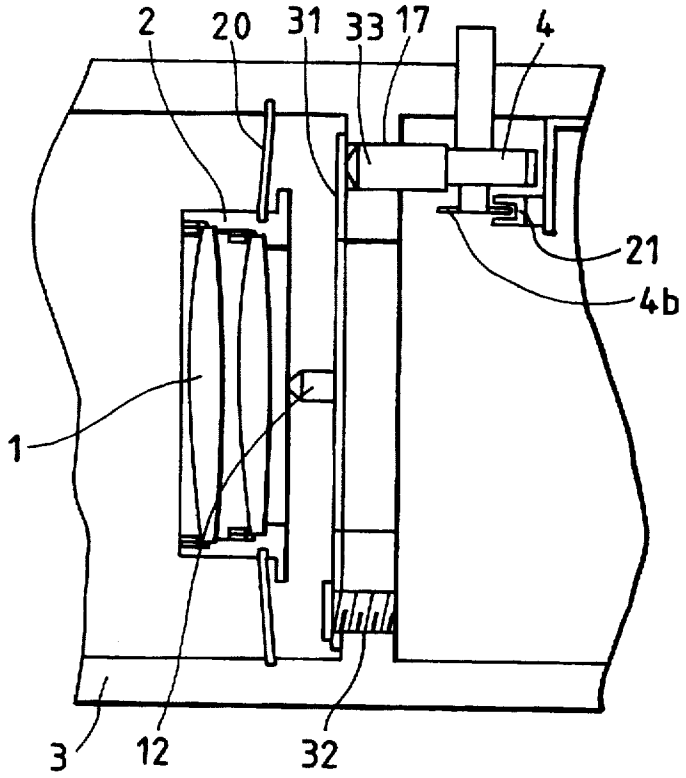


FIG. 10B

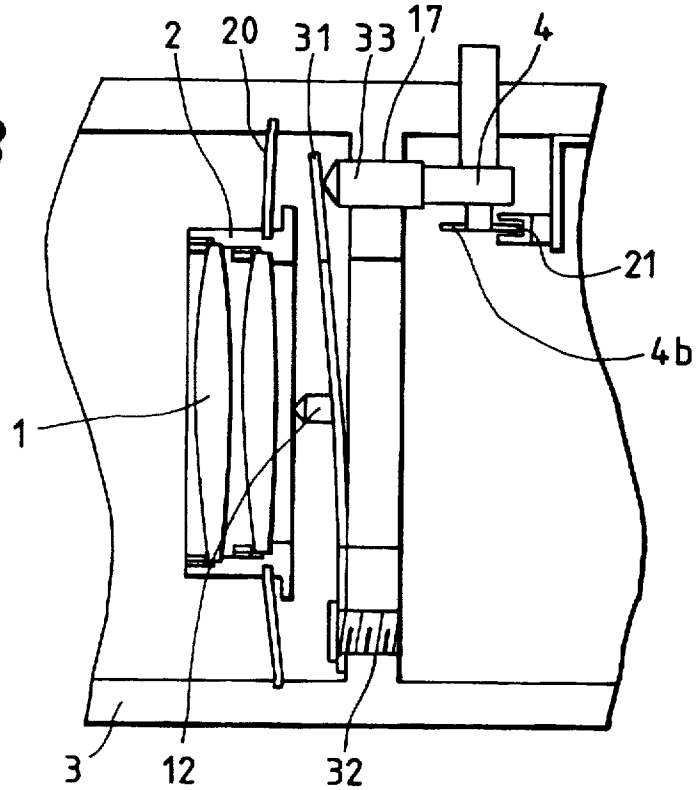


FIG. 11

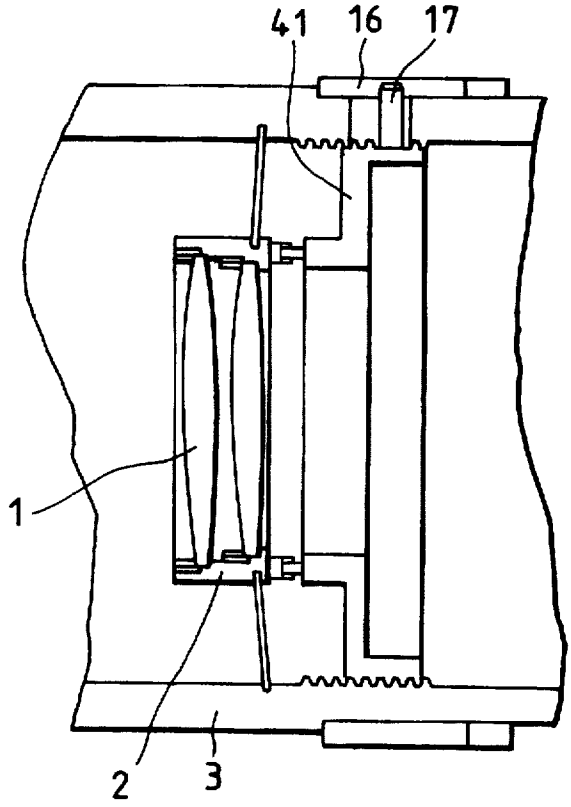


FIG. 12

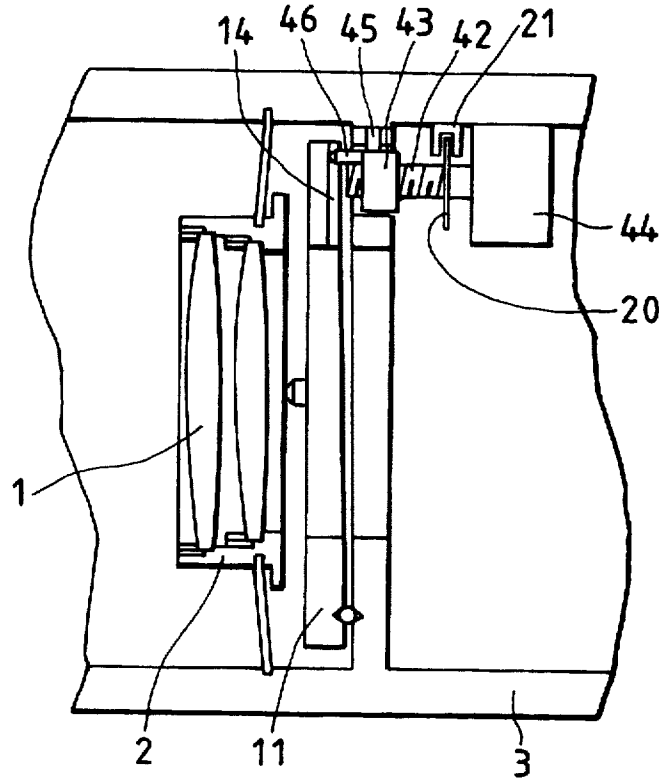


FIG. 13

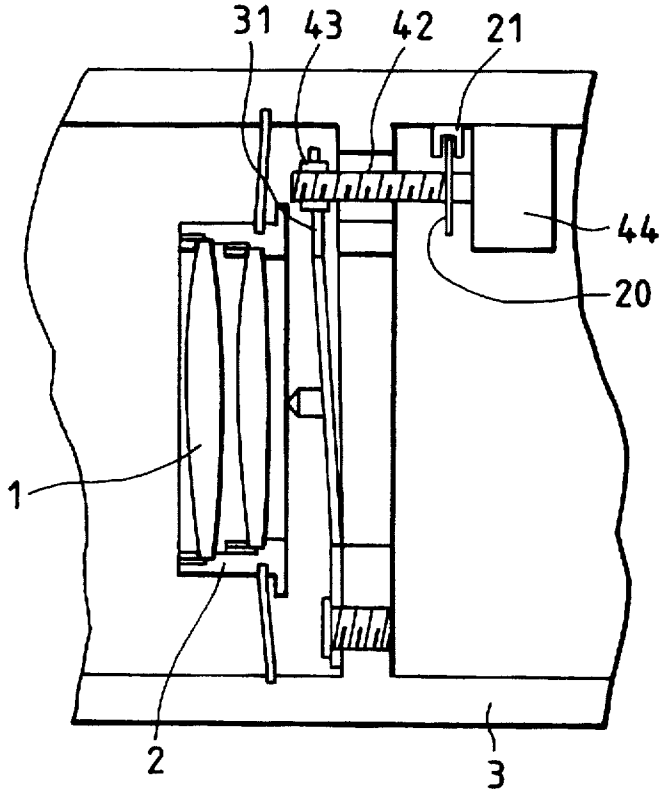


FIG. 14

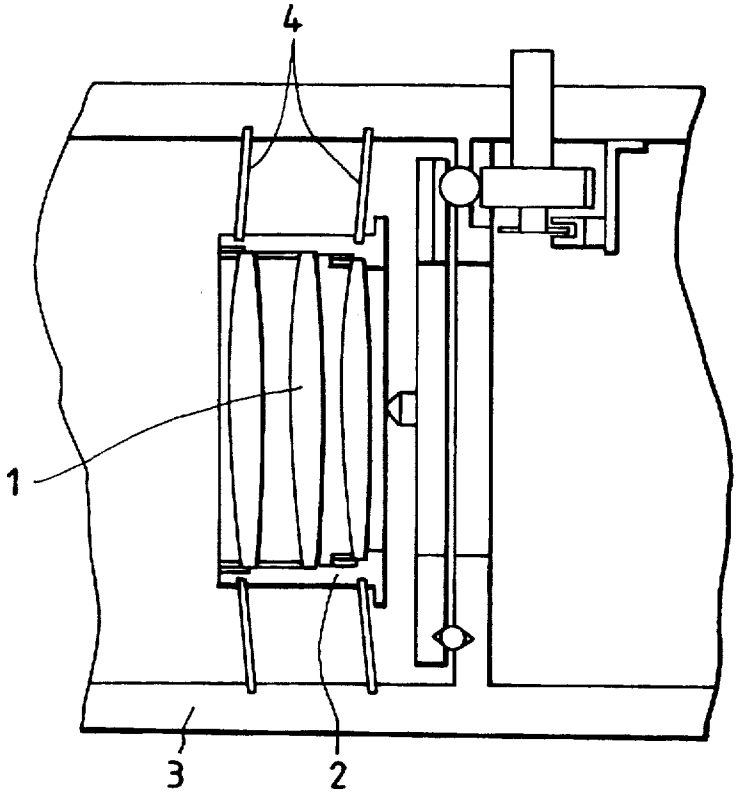


FIG. 15A

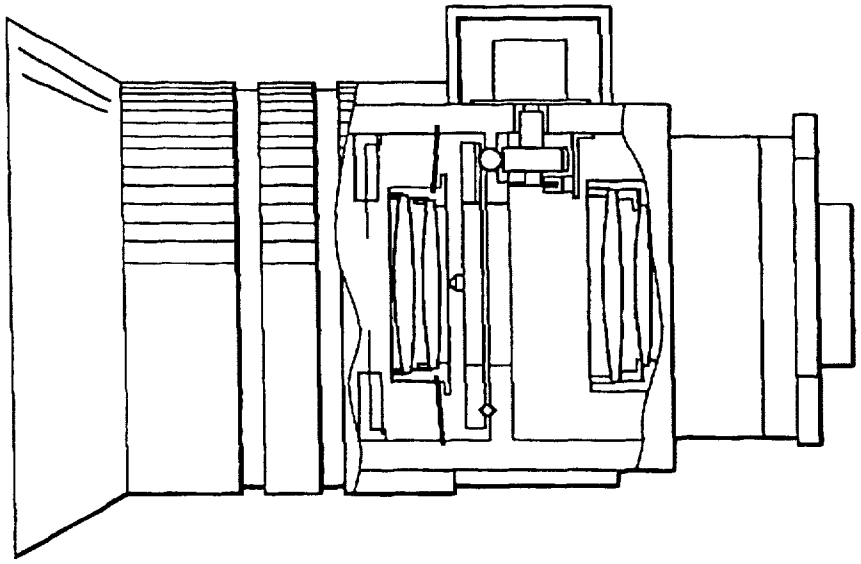


FIG. 15B

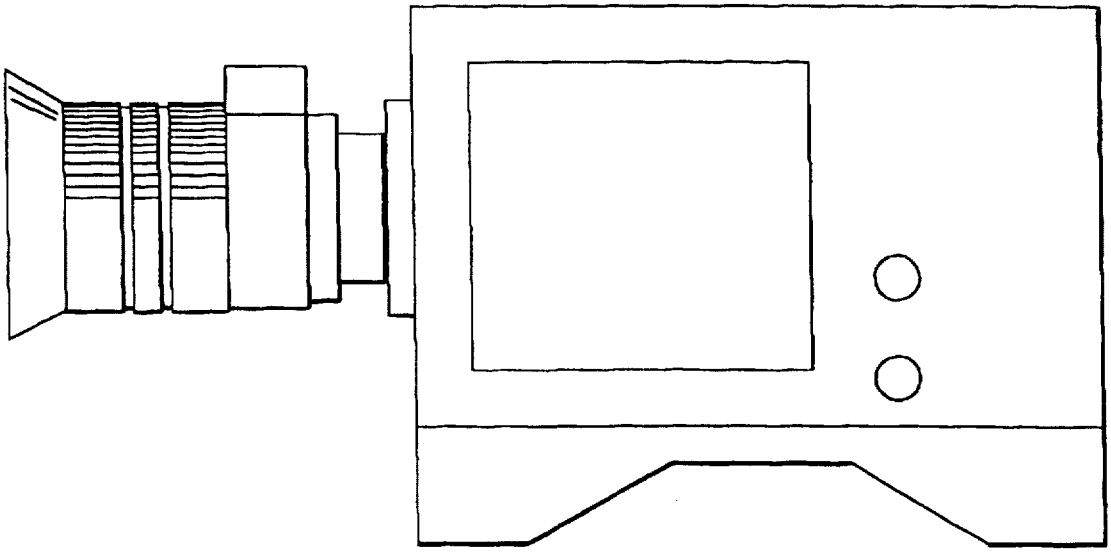


FIG. 16A
PRIOR ART

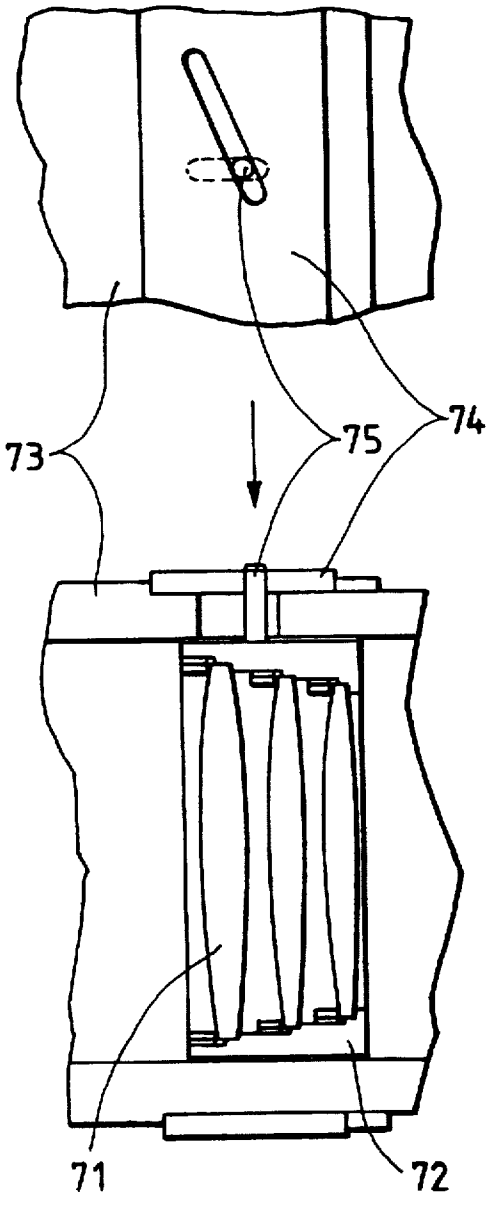


FIG. 16B
PRIOR ART

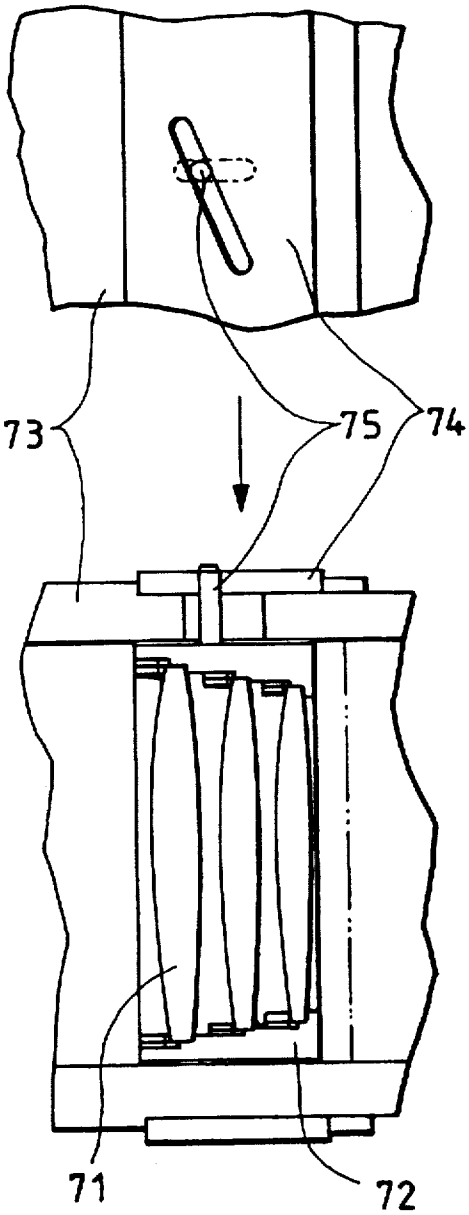


FIG. 17A
PRIOR ART

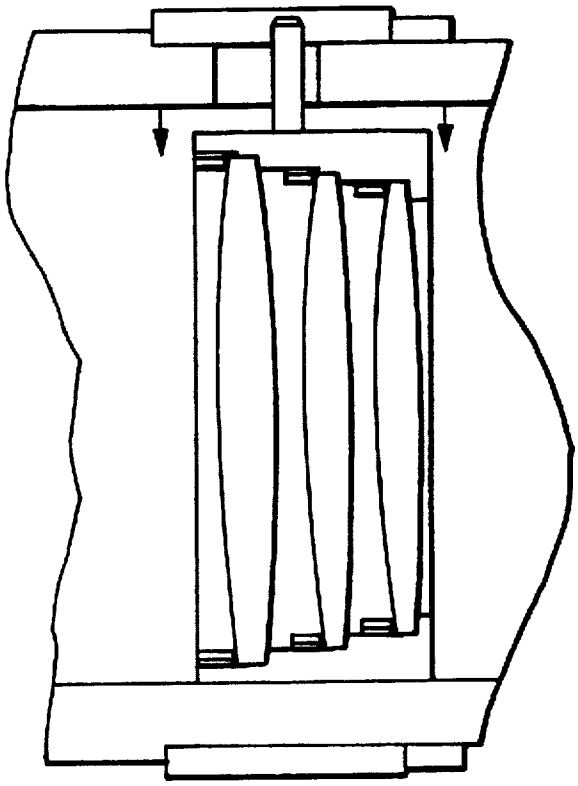
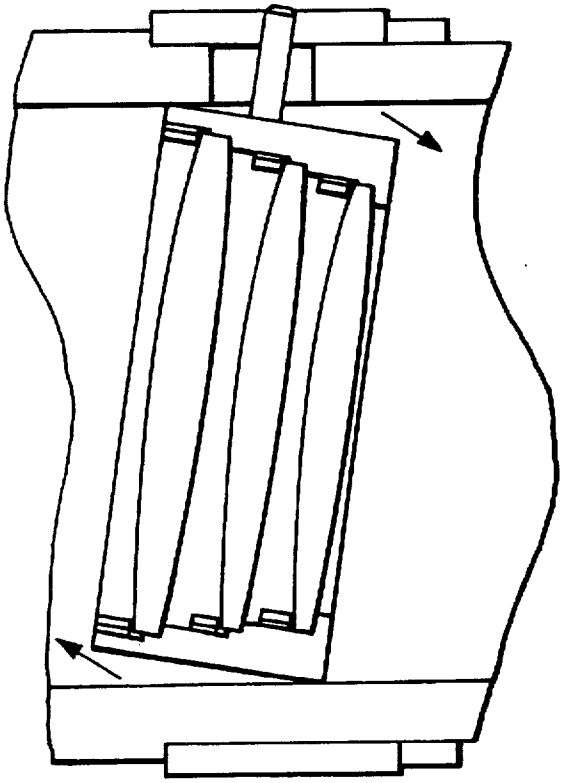


FIG. 17B
PRIOR ART



LENS MOVING MECHANISM FOR FINELY MOVING A PORTION OF AN OBJECTIVE LENS BY ROTATING A HOLDING MEMBER

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to a lens moving mechanism suitable for a photo-taking lens with an auto focus function in which an optical lens unit is finely moved in the direction of the optical axis thereof to thereby effect the detection of an in-focus state.

2. Related Background Art

As the auto focus device of a video camera, there is known a so-to-speak mountain climbing system in which the degree of minuteness of a photographing image field is detected from a high frequency component in an image signal and the position of a lens is controlled so that the degree of minuteness may become maximum. This system is described in detail in Japanese Laid-Open Patent Application No. 56-51164, and this system will hereinafter be described briefly with reference to FIG. **6** of the accompanying drawings. In FIG. **6**, the reference numeral **100** designates a lens, the reference numeral **101** denotes a signal processing portion, and the reference numeral **102** designates a motor.

The light of an object entering the lens **100** is converted into an electrical signal by the signal processing portion **101**. By the utilization of the fact that the high frequency component of this electrical signal is small if the in-focus state of the lens **100** is insufficient, and becomes greater as the lens is more in focus, the signal processing portion **101** causes the converted electrical signal of an image pickup device to pass through a high-pass filter, whereafter it detects and integrates the electrical signal over a period during which an image field is formed, i.e., a field period (in the case of a television system, 1/60 sec.), and detects the state of the focus.

Then, a focus lens is moved by the motor so that a high frequency signal may be obtained, and there is obtained the in-focus state.

Now, when detecting the direction of out-of-focus, it is usually practiced to finely move (wobble) some lens in the photo-taking lens **100** in forward and backward directions along the optical axis thereof.

Heretofore, in such a zoom lens device, as a lens moving mechanism for finely moving a lens unit, use has usually been made of a system as shown in FIG. **7** of the accompanying drawings. In FIG. **7**, the reference numeral **103** denotes a finely moved lens unit, the reference character **103***a* designates a holding member holding the lens **103**, and the reference numeral **104** denotes the fixed portion (fixed barrel) of a lens device body. The lens holding member **103***a* is fitted in an aperture (not shown) formed in the fixed portion and is supported for rectilinear movement in the direction of the optical axis. The reference character **105***a* designates the external thread of a feed screw directly connected to the motor, and disposed parallel to the optical axis and engaged with an internal thread **103***b* provided on the lens holding member **103***a*.

Under such a construction, the lens **103** is finely moved by the rotational operation of a motor **105** and the in-focus direction is detected by the signal processing portion.

Now, in this system, out-of-focus is caused by the fine movement of the lens unit and therefore, in a lens device for photographing, and particularly a TV or video lens device

handling moving images, it is necessary to suppress the out-of-focus within a range in which a variation in an image signal is detectable and moreover to such a degree that it is not conspicuous to the eyes. Also, after the detection by wobbling, a focus lens unit is moved and therefore, to realize auto focus quick in response, it is important to effect the wobbling at high speed.

Here, the amount of variation in the focus by the wobbling is determined by the amount of movement of the lens unit **103**, but the amount of movement of the lens unit **103** which satisfies the above-described condition is related to the depth of focus. That is, when the depth of focus is shallow, the variation in the focus will be conspicuous unless the amount of movement of the lens unit **103** is made small, and when the depth of focus is deep, the variation in the focus cannot be detected unless the amount of movement of the lens unit **103** is made great. On the other hand, the depth of focus greatly varies depending on the focal length of the zoom lens and the F value of the aperture, and the difference between the time when the depth of focus is deepest and the time when the depth of focus is shallowest is on the order of several tens of times. Accordingly, the amount of movement of the lens unit **103** by the wobbling must also be varied as much as several tens of times between the minimum and the maximum.

Heretofore, however, in the lens moving mechanism used for wobbling, use has been made of a feed screw in which the amount of feed relative to the rotation of the motor **105** is constant and therefore, it has been necessary to make the total number of revolutions of the feed screw for moving the lens unit small when the depth of focus is shallow, and very great when the depth of focus is deep. Therefore, to effect the wobbling when the depth of focus is deep, it has been necessary to rotate the motor a lot and thus, much time has been taken until the end of the wobbling and after all, this has led to the problem that the response of auto focus becomes slow. Conversely, if the lead of the feed screw is made great so that the lens unit can be moved quickly when the depth of focus is deep, the number of revolutions of the motor when the depth of focus is shallow becomes very small and therefore, it has become difficult to move the lens unit with good accuracy.

On the other hand, in the lens device for photographing, as a mechanism for moving a lens unit for optical tracking adjustment or the like in the direction of the optical axis thereof, use is made of one as shown in FIGS. **16**A and **16**B of the accompanying drawings. In these figures, the reference numeral **71** designates a movable lens unit, the reference numeral **72** denotes a lens holding member holding the lens **71**, and the reference numeral **73** designates the fixed portion (fixed barrel) of a lens barrel body which corresponds to an outer cylinder, and the lens holding member **72** is fitted in an aperture formed in the fixed portion **73** and is rectilinearly movable in the direction of the optical axis. The reference numeral **74** denotes a ring member having a cam slot, and fitted to the outer periphery of the fixed portion **73** and rotatable about the optical axis. The reference numeral **75** designates a pin member mounted on the lens holding member, and fitted in a straight groove formed in the fixed portion **73** and the cam slot of the ring member **74**.

In the construction as described above, when as shown in FIGS. **16**A and **16**B, the ring member **74** is manually rotated or electrically rotated by the use of a motor or the like, the pin member **75** moves along both of the cam slot of the ring member **74** and the straight groove of the fixed portion **73**, and the lens holding member **72** on which the pin member **75** is mounted rectilinearly moves in the direction of the

optical axis. The movable lens unit **71** is then rectilinearly moved in the direction of the optical axis, whereby the intended optical lens adjustment is achieved.

In the above-described example of the conventional art, however, the lens holding member **72** rectilinearly moves while frictionally sliding by the aperture in the fixed portion **73** and the fitted portion and therefore, for the lens holding member **72** to move smoothly with a small force, it is necessary that there be a suitable gap in the fitted portion between the lens holding member **72** and the fixed portion **73**. This has led to the possibility that as shown in FIG. **17A** of the accompanying drawings, the lens holding member **72** becomes eccentric or as shown in FIG. **17B** of the accompanying drawings, an inclination is caused to the lens holding member **72** by backlash and the optical performance is deteriorated.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a lens moving mechanism which can easily follow any variation in the depth of focus of a photo-taking lens.

It is also an object of the present invention to prevent the occurrence of the eccentricity or inclination of a lens when the lens is moved.

The present invention provides a lens moving mechanism for finely moving a lens portion of a phototaking lens in the direction of the optical axis thereof, characterized by a holding member holding the lens portion, and a disc-like disc cam member provided with a cam surface, the disc cam member being rotated to thereby move the holding member on a track conforming to the cam surface.

Specifically, the disc cam member repeats forward rotation and reverse rotation about a predetermined axis and is rotatively controlled, and the cam surface is of a shape in which the distance from the axis becomes gradually longer or shorter.

It is also an object of the present invention to prevent the occurrence of the inclination or eccentricity of a movable lens caused by the movement in the direction of the optical axis thereof in the conventional art, and in the present invention, a holding member holding the lens is held relative to an outer cylinder by a disc-like resilient member so that the holding member may be pressed in the direction of the optical axis by a pressing member, and particularly, the resilient member is constructed of a metallic thin plate, whereby eccentricity in a direction perpendicular to the optical axis is suppressed even if the lens is moved in the direction of the optical axis.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. **1A** and **1B** show a lens moving mechanism according to the present invention.

FIGS. **2A** and **2B** show the shape of a disc-like cam according to the present invention.

FIGS. **3A** and **3B** show the shape of a disc-like cam according to the present invention.

FIG. **4** is a block diagram of an entire camera carrying thereon the lens moving mechanism according to the present invention.

FIGS. **5A** and **5B** show a second embodiment of the lens moving mechanism according to the present invention.

FIG. **6** is a control block diagram of a zoom lens according to the conventional art.

FIG. **7** shows a lens moving mechanism according to the conventional art.

FIGS. **8A** and **8B** show the moving mechanism according to the present invention.

FIGS. **9A** and **9B** are views of the mechanism shown in FIGS. **8A** and **8B** as it is seen from the front thereof.

FIGS. **10A** and **10B** show another lens moving mechanism according to the present invention.

FIG. **11** shows still another lens moving mechanism according to the present invention.

FIG. **12** shows yet still another lens moving mechanism according to the present invention.

FIG. **13** shows a sixth embodiment of the lens moving mechanism according to the present invention.

FIG. **14** shows the holding structure for a further form of the lens moving mechanism according to the present invention.

FIGS. **15A** and **15B** show the lens moving mechanism according to the present invention as it is carried on a camera.

FIGS. **16A** and **16B** show the mechanism for moving a lens array such as an optical tracking adjusting mechanism.

FIGS. **17A** and **17B** show a lens moving mechanism according to the conventional art.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

First, FIG. **4** shows the lens moving mechanism of the present invention. In FIG. **4**, the reference numeral **51** designates a focus lens unit for focusing, the reference numeral **52** denotes a zoom lens unit for effecting a focal length change, the reference numeral **53** designates an aperture portion for adjusting exposure, the reference numeral **54** denotes a lens unit finely movable in the direction of the optical axis thereof to aid focus detection, the reference numeral **56** designates a lens drive portion for driving the lens, the reference numeral **57** denotes a relay lens unit having the imaging action, and the reference numeral **58** designates a lens drive portion for driving the focus lens unit **51**. Each lens unit is comprised of a plurality of lenses. The reference numeral **59** denotes an image pickup device such as a CCD, the reference numeral **60** designates a control portion for controlling the lens drive portions **56** and **58** and performing the automatic focus function, and the reference numeral **61** denotes a circuit for causing the control of an entire camera to be executed. The reference numeral **62** designates a zoom lens drive portion and a lens position detecting portion. The reference numeral **63** denotes an aperture drive portion and an aperture position detecting portion.

In such a construction, the lens unit **54** for focus detection is designed such that even if it is finely moved in the direction of the optical axis, the image magnification thereof hardly varies and only the focus thereof is out. Accordingly, by the lens unit **54** being finely moved (wobbled) in the direction of the optical axis by the lens drive portion **56**, the focus position on the image pickup surface of the image pickup device **59** is finely varied and this variation can be detected as a variation in an image signal. This signal variation is sent to the circuit **61** on the camera side and is signal-processed thereby, and the amount and direction of the out-of-focus are calculated and are outputted to the control portion **60**. The control portion **60** outputs a drive signal conforming to the amount and direction of the out-of-focus, and the focus lens **51** is driven by the lens drive portion **58**, whereby auto focus can be effected.

FIGS. **1A** and **1B** show the specific lens moving control mechanism **56**, **54** shown in FIG. **4**. In FIGS. **1A** and **1B**, the

reference numeral **1** designates a finely movable lens portion (corresponding to the lens unit **54** in FIG. **4**), and the reference numeral **2** denotes a holding member holding the lens portion **1** and fitted to a fixed portion **3** (fixed barrel) and movable in the direction of the optical axis. The reference numeral **4** designates a disc cam formed with a cam surface on the outer periphery thereof, and connected to the output shaft of a stepping motor **5** mounted on the fixed portion **3** and having its cam surface disposed so as to contact with the end surface of the lens holding member **2**. The motor **5** is controlled so as to repeat forward rotation and reverse rotation.

Also, in FIGS. **1A** and **1B**, the disc cam **4** is directly connected to the output shaft of the motor **5**, but alternatively may be connected to the output shaft through a speed reduction mechanism. The reference numeral **6** denotes a spiral member having a springy property and incorporated between the lens holding member **2** and the fixed portion **3** and biasing the holding member **2** so as to normally contact with the cam surface of the disc cam **4**. The reference numeral **10** designates a photosensor which detects light reflected from a light reflecting portion **40** provided with the cam **4** to thereby detect the rotated position of the cam **4**.

FIGS. **2A** and **2B** are graphs showing the cam shape of the disc cam **4** and the relation between the angle of rotation and the displacement of the cam. In FIGS. **2A** and **2B**, when the center of rotation of the disc cam **4** is defined as the Z-axis and with the position of the cam surface contacted by the lens holding member **2** when wobbling is not being effected, that is, when the lens portion **1** is at a reference position, or the angle when the center of action of the cam surface forwardly and reversely rotated is the reference as $\theta=0$, the cylinder coordinates system $r\theta z$ is taken, the shape of the cam is such a shape that, as is apparent from the characteristic graph thereof, it slightly moves the lens portion **1** back and forth up to a certain range (from $-\theta_1$ to $+\theta_1$) with $\theta=0$ as the center, and greatly moves the lens portion **1** when that range is exceeded. Within the range of use of the cam, the amount of variation in the position (distance) r of the cam surface relative to the angle θ, specifically the shape of this disc-like cam is such a shape that at angles $-\theta a$ to θa within a relatively separate range in the range of use of the cam surface, within the range of $-\theta a$ to **0**,

$$\frac{\partial^2 r}{\partial \theta^2} < 0$$

is satisfied, and within the range of 0 to θa,

$$\frac{\partial^2 r}{\partial \theta^2} > 0$$

is satisfied, and the cam is worked so that the movement distance of the lens portion may become longer away from the center of pivotal movement.

In the construction as described above, when the motor **5** is repetitively rotated in the forward direction and reverse direction, the disc cam **4** connected to the output shaft thereof is likewise rotated. At this time, the lens holding member **2** is urged against the disc cam **4** by the spring **6** and therefore, when the disc cam **4** is rotated and the displacement of the cam surface thereof contacting with the lens holding member **2** varies, the lens holding member **2** moves back and forth in the direction of the optical axis following it, and the lens portion **1** moves back and forth in the direction of the optical axis. In this manner, wobbling is accomplished.

Now, in the present embodiment, by the use of the disc cam of the aforedescribed shape, rotation is controlled up to a maximum angle θ_2 less than one full rotation of the cam when the depth of focus is deep, and it is made possible to effect wobbling at high speed. On the other hand, when the depth of focus is shallow as shown in FIG. **2**, use is made of the cam surface in which the amount of displacement of the cam is small ($-\theta_1$ to θ_1) and therefore, even when the amount of movement of the less unit is small, the number of revolutions of the motor does not become so small and the lens unit can be wobbled with good accuracy.

As described above, by the lens moving mechanism of the present embodiment, wobbling can be done at high speed even when the depth of focus is deep and the amount of movement of the lens is great, and moreover, wobbling becomes possible even when the depth of focus is shallow and the amount of movement of the lens is small. Of course, the control of these angles of rotation is effected on the basis of zoom position information which determines the depth of focus, and the aperture value.

FIGS. **3A** and **3B** show the cam shape of a disc cam in a second embodiment of the present invention. However, it is to be understood that this embodiment is similar to the first embodiment in the portions other

than the disc cam. In FIGS. **3A** and **3B**, when a cylinder coordinates system $r\theta z$ similar to that of FIGS. **2A** and **2B** is taken, the disc cam in the present embodiment is characterized in that within the range of a minute angle $\Delta\theta$ in the vicinity of the position of $\theta=0$ corresponding to that when the wobbling lens unit is at the reference position, the distance r between the z-axis and the cam surface is constant and the shape of the cam is set such that within the range of $\Delta\theta$,

$$\frac{\partial^2 r}{\partial \theta^2} \simeq 0$$

is satisfied, and within the other ranges,

$$\frac{\partial^2 r}{\partial \theta^2} > 0$$

is satisfied.

The present embodiment solves the problem that if the stopped position of the disc cam deviates from the position of $\theta=0$ due to the stop accuracy or the like of the motor when the wobbling operation is not being performed, the wobbling lens unit will move from the reference position and will be out of focus. Again, in the present embodiment, during the wobbling, the motor is rotated so as to rotate the disc cam outside the range of $\Delta\theta$, whereby there is obtained the same effect as that of the first embodiment.

The initial position setting of the cam will now be described.

As previously described, when the motor **5** is driven, the non-linear cam **4** is rotated, and the lens **1** is moved in conformity with the rotation of the cam **4**. On the other hand, a reflecting portion **4***a* for reflecting light is provided on a portion of the cam **4** as shown in FIG. **1B**, and the photosensor **10** is fixed so that light emitted from the light emitting portion of the photosensor may be reflected by the reflecting portion **4***a* and the light may enter the light receiving portion of the photosensor. Design is also made such that when the initial position setting of the lens **1** during the closing of a power source switch is necessary, the motor **5** is driven to thereby rotate the cam **4** and the light of the photosensor **10**

is reflected by the reflecting portion **4***a* and when it arrives at the photosensor **10**, the control circuit senses the signal thereof and stops the motor **5**. Thus, the non-linear cam is used and a sensor for position setting is provided on a portion of the cam, thereby effecting the minute vibration of the wobbling lens and reliable initial position setting necessary for focus adjustment.

In the foregoing, there have been shown embodiments in which the lens holding member is directly moved and controlled by the cam.

FIGS. **5**A and **5**B show another embodiment.

In FIGS. **5**A and **5**B, the reference numeral **1** designates a movable lens unit, the reference numeral **2** denotes a lens holding member holding the movable lens, and the reference numeral **3** designates the fixed portion (fixed barrel) of a lens barrel body. The reference numeral **20** denotes a metallic thin resilient disc with copper as a chief component, and holding the lens holding member **2** in the inner diameter thereof and having its outer diameter fixed to the fixed portion **3**. However, the lens holding member **2** and the resilient disc **20** are not rotatable relative to the fixed portion **3**. The reference numeral **4** designates a cam similar to that previously described, and rotatable relative to the fixed portion **3**. The reference numeral **11** denotes a sling-like plate having pointed-end pin members **11***a* and **11***b* mounted on one surface thereof at two positions symmetrical with respect to the center of the optical axis, and having a conical hole **13** and a V-shaped groove **14** formed on the other surface thereof at positions deviated by 90° with respect to the positions of the pin members **11***a* and **11***b*. However, it is to be understood that the positions of the conical hole **13** and the V-shaped groove **14** deviate by 180° from each other. Also, the tip ends of the pin members **11***a* and **11***b* bear against the end surface of the lens holding member **2**. FIG. **5**A shows the essential portions when the lens is seen from above it, and FIG. **5**B shows the essential portions when the lens is seen from sideways thereof.

A conical hole **15** is formed in that wall surface of the fixed portion **3** which is opposed to the conical hole **13**, and a ball member **16** is interposed between the cylindrical holes **13** and **15**. Further, a through-aperture **17** is formed in that wall surface of the fixed portion **3** which is opposed to the V-shaped groove **14**. A ball member **18** is fitted in the through-aperture **17** so as to protrude to the opposite sides of the through-aperture **17**, and one surface of the ball member **18** fits in the V-shaped groove **14** and the other surface of the ball member **18** bears against the cam surface of the cam member **4**. The cam member **4** is supported for rotation relative to the fixed portion **3** and is electrically rotatable by a motor or the like.

The reference character **4***b* designates a disc having a slit and mounted for rotation in synchronism with the cam member **4**. The reference numeral **21** denotes a photointerrupter disposed so as to embrace the disc **4***b*, and such that the slit of the disc **4***b* passes the photointerrupter **21** when the cam member **4** and the disc **4***b* are rotated.

In such a construction, when the cam member **4** is electrically rotated, the ball member **18** is pushed by the cam surface and is moved toward the ring-like plate **11** through the through-aperture **17** to push the ring-like plate **11**. The plate **11** has its movement in a direction perpendicular to the optical axis regulated by the effects of the ball member **16** interposed between the groove **13** and the conical hole **15** opposed to each other and the ball member **18** fitted in the V-shaped groove **14** and the through-aperture **17** and therefore, it is inclined toward the lens holding member **2** side with the ball member **16** as a fulcrum. Thereupon, the pin member **12** pushes the lens holding member **2**, which is thus moved in the direction of the optical axis.

On the other hand, when the cam member **4** is reversely rotated to thereby decrease the displacement of the cam surface bearing against the ball member **18**, the lens holding member **2** is moved in a direction opposite to that described above by the resilient force of the resilient disc **20**.

Particularly, in this embodiment, the ring-like plate **20** pushing the lens holding member **2** is inclined with the ball member, **16** as a fulcrum and therefore, due to the principle of levers, the ratio between the amount of displacement pushing the holding member **2** at the position of the pin member **12** and the amount of displacement given from the disc cam member **4** to the ring-like plate **11** through the ball member **18** is equal to the ratio between the distance from the ball member **16**, which provides the fulcrum, to the pin member **12** and the distance from the ball member **16** to the ball member **18**. That is, the amount of displacement of the cam becomes greater by the above-described distance ratio times of the amount of movement of the lens. Thus, there is obtained the effect that when it is desired to move the lens unit by a minute amount, the influence of the working error of the cam becomes small as compared with a case wherein the amount of displacement of the cam and the amount of movement of the lens unit are equal to each other, and the working of the cam becomes easier and the accuracy of the lens position becomes better.

As described above, the design is made such that the disc cam worked so that the amount of variation in the displacement of the cam may increase relative to the direction of rotation is disposed at a right angle with respect to the optical axis of the lens system and the disc cam is rotated so as to move the wobbling lens unit in the direction of the optical axis, whereby even when the depth of focus is deep, wobbling can be accomplished at high speed without the number of revolutions of the motor being remarkably increased and moreover, even when the amount of movement of the lens is small, wobbling can be accomplished with high accuracy.

FIGS. **8**A, **8**B, **9**A and **9**B show an embodiment of the present invention. In these figures, the reference numeral **1** designates a movable lens unit, the reference numeral **2** denotes a lens holding member holding the movable lens unit, and the reference numeral **3** designates the fixed portion (fixed barrel) of a lens barrel body. The reference numeral **20** denotes a metallic thin resilient disc with copper as a chief component, held so as to cover the whole of the circumference of the lens holding member **2** and having its outer diameter portion fixed to the fixed portion **3**. The lens holding member **2** and the resilient disc **20** are not rotatable relative to the fixed portion **3**. The reference numeral **15** designates a cam member having surface cams **15***a* on the end surface thereof and rotatable relative to the fixed portion **3**. The reference numeral **16** denotes an operating ring member connected to the cam member **15** through a pin member **17** and rotatable relative to the fixed portion **3**. The reference numeral **18** designates cam follower members provided on the holding member, and two or more such cam follower members are mounted on the lens holding member **2**, at positions symmetrical with respect to the center of the optical axis, and bear against the two surface cams of the cam member **15**. Here, the cam member is formed of a number of surface cams of the same shape corresponding to the number of the cam follower members **18**. Also, the resilient disc **20** is substantially flat in a no-load condition, but is always deformed when it is incorporated into the mechanism of the present embodiment, and is mounted with

its resilient force normally creating an urging force between the cam followers **18** and the surface cams of the cam member **15**.

In such a construction, when the operating ring **16** is manually rotated or electrically rotated by a motor or the like, the cam member **15** connected thereto by the pin member **17** is also rotated. When the cam member **15** is rotated, the cam followers **18** are pushed out by the surface cams of the cam member **15**, as shown in FIG. **8**B, and the lens holding member **2** is moved in the direction of the optical axis and the lens unit **1** is likewise moved. The resilient disc, which is formed of a metallic thin film as previously described, may be deformed in the direction of the optical axis, but hardly becomes eccentric relative to a direction perpendicular to the optical axis.

On the other hand, when the operating ring **16** is reversely rotated from the above-described state, the cam member **15** is also reversely rotated and the amount of displacement of the surface cams at the position whereat the cam followers **18** bear decreases. At this time, the lens barrel (lens holding member) **2** is being pushed toward the cam member side by the resilient force of the resilient disc **20** and therefore, the cam followers **18** are moved in accordance with the surface cams, and the lens holding member **2** also fluctuates in a direction opposite to that described above.

By the operating ring **16** being rotated in this manner, the movable lens unit **1** can be moved back and forth in the direction of the optical axis.

FIGS. **9**A and **9**B are views of the present embodiment as it is seen from the direction of the optical axis in FIGS. **8**A and **8**B. The lens holding member **2** is held by the resilient disc as shown in FIGS. **9**A and **9**B, but the resilient disc is subjected to the force with which the lens holding member is pushed dispersed by the inner diameter thereof, and is deformed into a conical shape. At this time, only a force perpendicular to the surface of the resilient disc is applied and therefore, the center of the disc does not change and it does not happen that the optical axis of the lens unit becomes eccentric. Also, the lens holding member is being pushed by the symmetrically disposed cam followers and therefore is parallel-moved, and no inclination of the optical axis of the lens unit occurs. Further, the present embodiment is simple in structure and therefore, it is possible to make it compact and light in weight and it is also possible to manufacture it inexpensively.

As described above, according to the present embodiment, it becomes possible to realize a compact and light-weight lens moving mechanism, in which the optical axis of the lens unit does not become eccentric and inclined, at low costs.

In the present embodiment, the resilient disc is a doughnut-shaped one as shown in FIG. **9**A, but alternatively a resilient disc **20** having one or more through-apertures **20***a* as shown in FIG. **9**B may be used to obtain a similar effect. In this case, however, the shape and positions of the through-apertures **20***a* in the resilient disc **20** must be in a relation symmetrical with respect to the positions of the cam followers **18** pushing the lens holding member **2** at the center of the optical axis. This is because when the cam followers are at symmetrical position as on line X—X, if the lens holding member **2** is pushed, the resilient disc **20** will be deformed symmetrically as viewed from the cam followers **18** and the lens holding member **2** will move without being inclined, but if the cam followers **18** are at asymmetrical positions as on line Z—Z, the resilient disc **9** will be deformed asymmetrically and therefore, the lens holding member **2** will become inclined.

Also, in the present embodiment, the lens barrel and the resilient disc are constructed as discrete parts, but it can be readily analogized that even if the two are formed integrally with each other, a similar function and effect will be obtained.

FIGS. **10**A and **10**B show another embodiment of the present invention. This embodiment is one in which instead of the ring-like plate **11** in the embodiment shown in FIGS. **5**A and **5**B, a resilient plate **31** is used and the fulcrum is fixed to the fixed portion **3** by a screw **32**. However, for the convenience of illustration, the ball member **18** is replaced by a pointed-end pin member **33**, but they are the same in their roles. The other members designated by the same reference numerals as those in FIGS. **5**A and **5**B are similar in construction.

In FIGS. **10**A and **10**B, when the cam member **4** is rotated, the pin **33** moves along the displacement of the cam and the resilient plate **31** is pushed. When the resilient plate **31** is pushed, the resilient plate **31** is deformed about the fixed portion of the screw **32** and flexure is created, as shown in FIG. **10**B. At this time, the pin member **12** mounted on the resilient plate **31** is also pushed out toward the lens holding member **2** side and therefore, the lens unit **1** is moved back and forth in the same manner as in the embodiment of FIGS. **5**A and **5**B.

The effect of this embodiment is the same as that of the embodiment of FIGS. **5**A and **5**B, but in this embodiment, the resilient plate **31** is deformed and the amount of displacement thereof is a high-order function of the distance from the fixed portion by the screw **32** and therefore, the ratio of the displacement of the position of the pin member **12** to the displacement given at the position of the cam member **19** becomes smaller than in the embodiment of FIGS. **5**A and **5**B wherein the amount of displacement becomes a linear function of the distance from the fulcrum. That is, when an attempt is made to move the lens unit by the same amount, if the dimensional relation is the same, the amount of displacement of the cam becomes greater in this embodiment than in the embodiment of FIGS. **5**A and **5**B. Thus, when the lens unit is finely moved, the working of the cam becomes easy and the effect that the accuracy of the lens position becomes better becomes greater.

FIGS. **11** to **13** show examples in which in each of the previous embodiments, the cam member for moving the lens is replaced by a feed screw.

First, FIG. **11** shows an example in which the cam member **15** of FIGS. **8**A and **8**B is replaced by a ring member **41** formed with a thread on the outer periphery thereof and is brought into engagement with an internal thread formed on the inner diameter of the fixed portion **3** to thereby constitute a feed screw. In this construction, when the operating ring **16** is rotated, the ring member **41** is rotated through the pin member **17** and by the effect of the feed screw, the ring member **41** is moved in the direction of the optical axis to thereby push the lens barrel **2** and thus, the lens unit **1** is moved.

Next, FIG. **12** shows an example in which in the embodiment of FIGS. **5**A and **5**B, the cam member is replaced by a feed screw. In FIG. **12**, the reference numeral **42** designates a male screw which is the feed screw, and the reference numeral **43** denotes a female screw. The male screw **42** is connected to the output shaft of a motor **44**. The reference numeral **45** designates a pin member mounted on the female screw **43** and fitted in a slot formed in the fixed portion **3** and not rotatable from the interval thread **43** but axially rectilinearly movable. The reference numeral **46** denotes a pointed-end pin member mounted on the female screw **43**

and fitted in a V-shaped groove **14** in the ring-like plate **11** to push the ring-like plate **11**. In this construction, when the male screw **42** is rotated, the female screw **43** is rectilinearly moved and the ring-like plate **11** is pushed and thus, the lens unit **1** is moved.

FIG. **13** shows an example in which the cam member of FIGS. **10**A and **10**B is replaced by a feed screw, and in this example, a female screw **43** is constructed integrally with a resilient plate **31**. Thus, when a male screw **42** is rotated, displacement is directly given to the resilient plate **31**, and as in the third embodiment, the lens unit **1** can be moved.

As described above, even if the cam member for moving the lens is replaced by a feed screw, the lens unit can be likewise moved and the same effect can be obtained.

FIG. **14** shows an embodiment in which a plurality of resilient discs **4** for holding the lens barrel **2** are used. This embodiment solves the problem that when the lens barrel **2** is held by a resilient disc **4**, the position of the hold lens barrel **2** is liable to become unstable when the weight of the movable lens unit **1** or the lens barrel **2** is heavy or when the full length of the movable lens unit **1** in the direction of the optical axis is great. This also holds true of the aforedescribed other embodiments.

FIGS. **15**A and **15**B show an example in which the lens moving mechanism according to the present invention is carried on a photographing lens device and is utilized in an apparatus wherein a lens unit is finely moved in the direction of the optical axis thereof to thereby effect focus detection. FIG. **15**B shows an example in which a photographing lens device carrying thereon the lens moving mechanism according to the present invention is mounted on a camera.

As described above, the lens moving mechanism of the present invention is suitable for use in the focus detecting device of a lens device with the automatic focus adjusting function as described above, and thereby, it becomes possible to realize a lens device with a very highly accurate and high-speed automatic focus adjusting function.

What is claimed is:

1. A lens moving mechanism for finely moving at least a lens portion of an objective lens in a direction of an optical axis of the objective lens, said lens moving mechanism comprising:

a holding member holding the lens portion; and

a disc-like disc cam member provided with a cam surface, which lies in a peripheral portion of said disc-like disc cam member, said disc cam member being rotated to thereby move said holding member on a track conforming to said cam surface,

wherein when the angle of rotation is zero, the center of action of the forwardly and reversely rotated cam surface of said disc cam member is the reference, the angle of the cam surface within a certain range of use thereof is θa and the distance from the center of an axis of rotation to the cam surface is r, such that in the range of −θa to **0**,

$$\frac{\partial^2 r}{\partial \theta^2} < 0$$

is satisfied, and in the range of 0 to θa,

$$\frac{\partial^2 r}{\partial \theta^2} > 0$$

is satisfied.

2. The lens moving mechanism of claim **1**, wherein said disc cam member repeats forward rotation and reverse rotation about a predetermined axis of rotation and is rotatively controlled, and said cam surface has a shape in which the distance from the predetermined axis becomes gradually longer or shorter.

3. The lens moving mechanism of claim **1**, wherein said holding member is held relative to an outer cylinder by a disc-like resilient member.

4. The lens moving mechanism of claim **3**, wherein said resilient member is a metallic thin plate.

5. A lens driving apparatus for detecting a focus state, said apparatus comprising:

a lens barrel;

an objective lens comprising a plurality of lens units, said objective lens having an optical axis; and

a rotating member rotating about a predetermined axis of rotation to finely move a lens unit of said plurality of lens units of said objective lens in a direction of the optical axis, said lens unit being connected to said lens barrel by a disk-like resilient member, and said rotating member having a peripheral surface such that a distance from the predetermined axis of rotation to the peripheral surface is gradually changed,

wherein said lens unit is moved forwardly or backwardly in a direction of the optical axis of said objective lens according to rotation of the peripheral surface, and

wherein said rotating member is configured to repeat forward rotation and reverse rotation about the predetermined axis of rotation for detection of a focus condition.

6. An apparatus according to claim **5**, further comprising a motor connected to the predetermined axis of rotation of said rotating member.

7. An apparatus according to claim **6**, further comprising a control circuit for controlling focus detection, to repeat the forward rotation and reverse rotation.

8. An apparatus according to claim **5**, further comprising a ring-shaped member having a plurality of bearing portions bearing against said lens unit, said ring-shaped member being inclined by said rotating member with respect to a fulcrum, so that said lens unit is driven in an optical direction by said bearing portions.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 5,912,774

DATED : June 15, 1999

INVENTOR(S) : Setsuo YOSHIDA, et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

COLUMN 6:

Line 8, "less unit" should read --lens unit--.
Line 23, the right margin should be closed up.
Line 24, the left margin should be closed up, and "In" should begin a new paragraph.

COLUMN 9:

Line 60, "position as on" should read --positions on one--.

Signed and Sealed this

Fourteenth Day of November, 2000

Attest:

Q. TODD DICKINSON

Attesting Officer

Director of Patents and Trademarks

US005907400A

United States Patent [19]

Aziz

[11] Patent Number: 5,907,400

[45] Date of Patent: May 25, 1999

[54] **FOLDED LOW-POWER INTERFERENCE MICROSCOPE OBJECTIVE**

[75] Inventor: **David J. Aziz**, Tucson, Ariz.

[73] Assignee: **Veeco Corporation**, Tucson, Ariz.

[21] Appl. No.: **08/946,303**

[22] Filed: **Oct. 7, 1997**

[51] **Int. Cl.**[6] **G01B 9/02**

[52] **U.S. Cl.** **356/345**; 356/360; 359/370

[58] **Field of Search** 356/345, 357, 356/359, 360; 359/370, 382, 383, 384

[56] **References Cited**

U.S. PATENT DOCUMENTS

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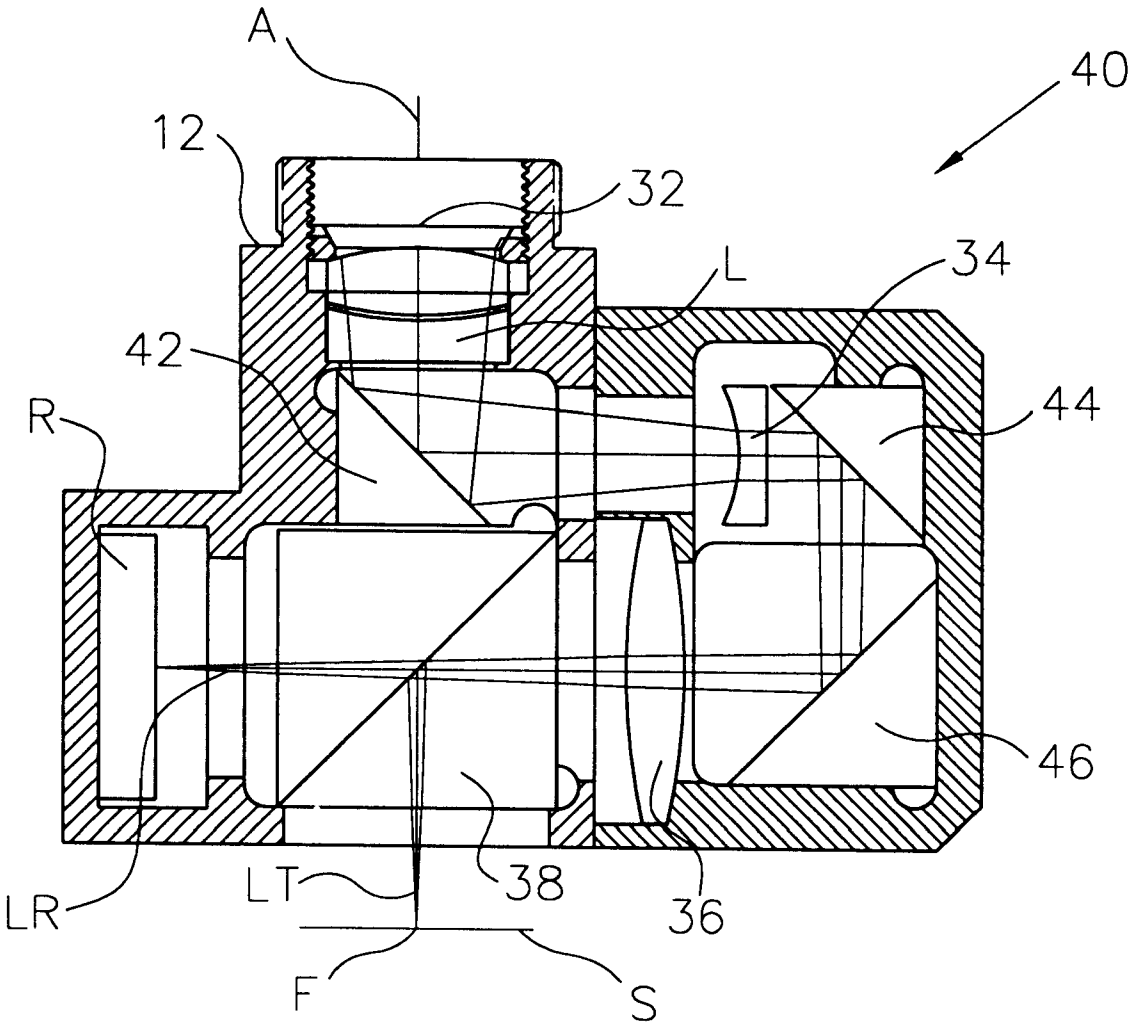
Primary Examiner—Samuel A. Turner

Attorney, Agent, or Firm—Antonio R. Durando

[57] **ABSTRACT**

A low-magnification interference microscope objective is rendered parfocal with a high-magnification objective by folding the light beam to the side of the optical axis of the objective, thereby maintaining the original optical path length while shortening the mechanical length of the objective. The beam is reflected by a mirror, causing it to travel some distance out to the side, and then it is reflected back toward the beamsplitter by an additional pair of mirrors. After a final reflection within the beamsplitter, the resulting beam is coaxial with the original optical axis, while the physical length of the objective has been substantially reduced. This approach makes it possible to obtain a desired distance from the mounting shoulder of the objective to the focal point.

23 Claims, 3 Drawing Sheets



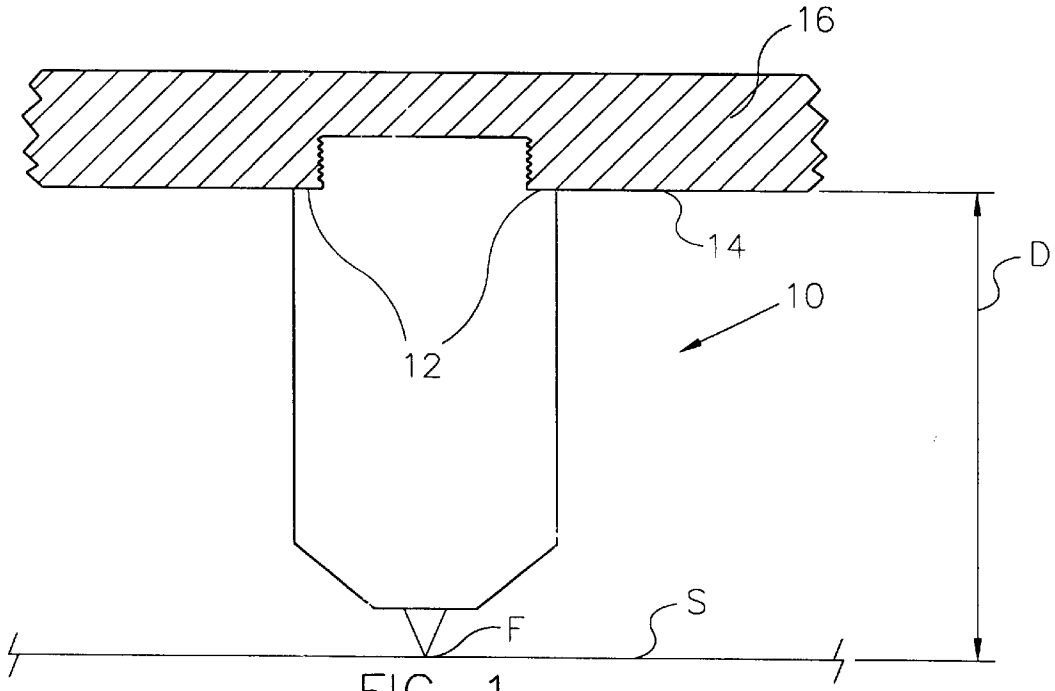


FIG. 1
(PRIOR ART)

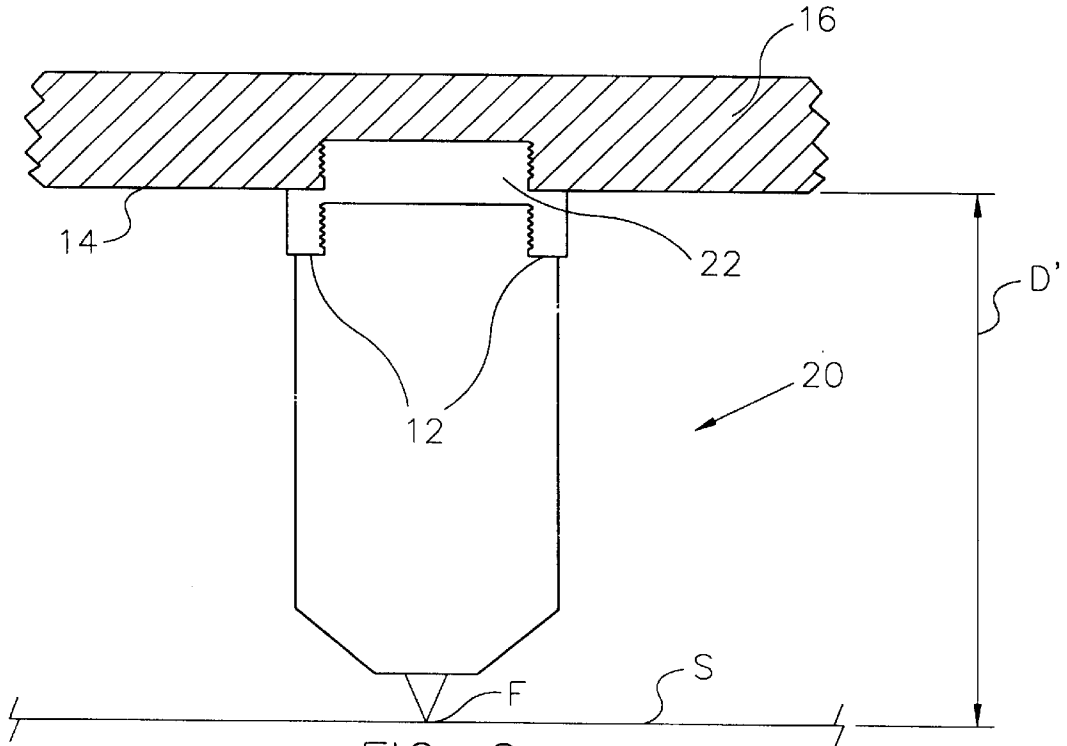


FIG. 2
(PRIOR ART)

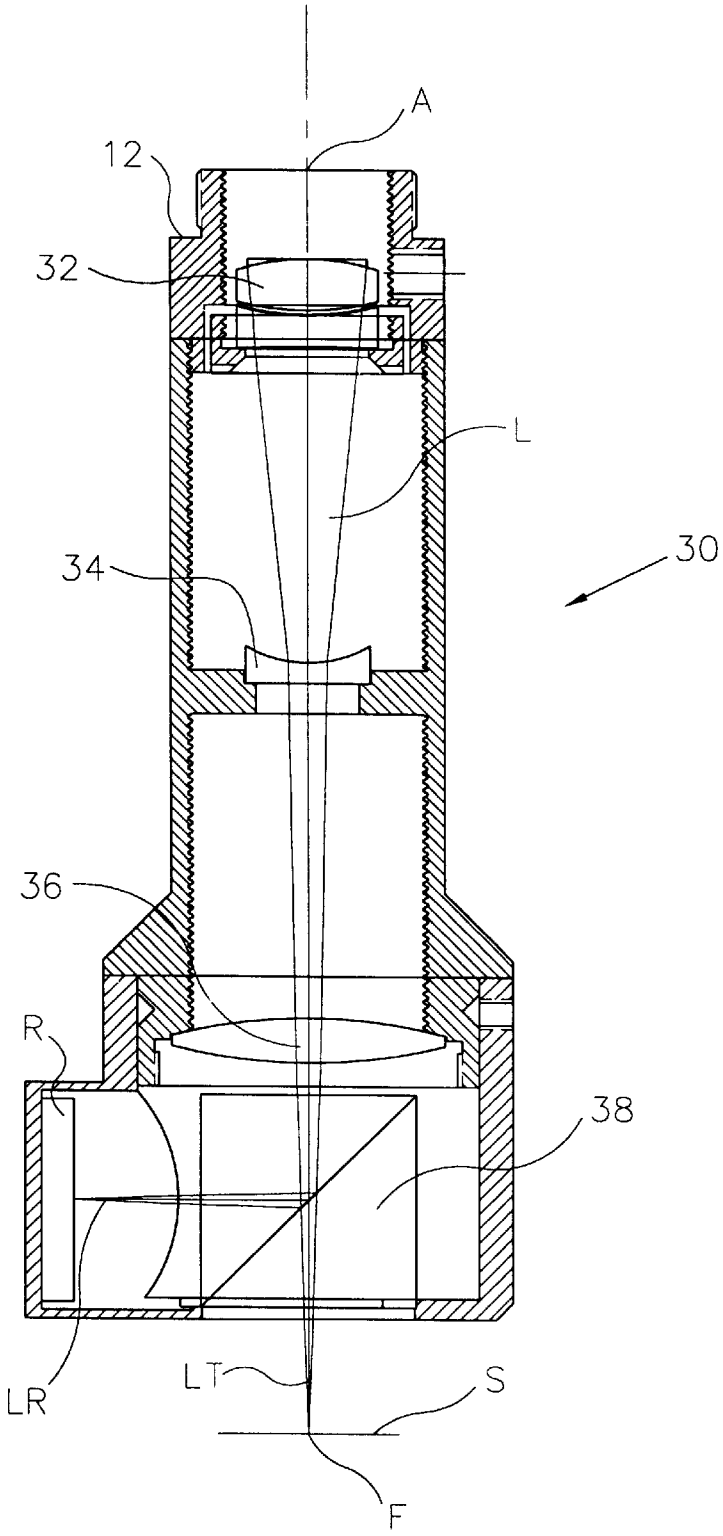


FIG. 3
(PRIOR ART)

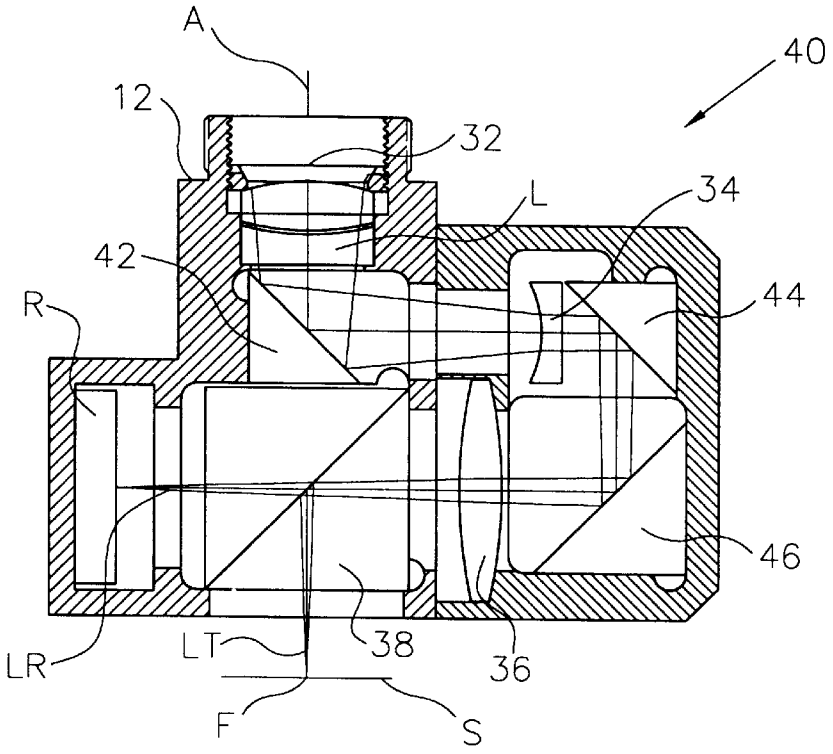


FIG. 4

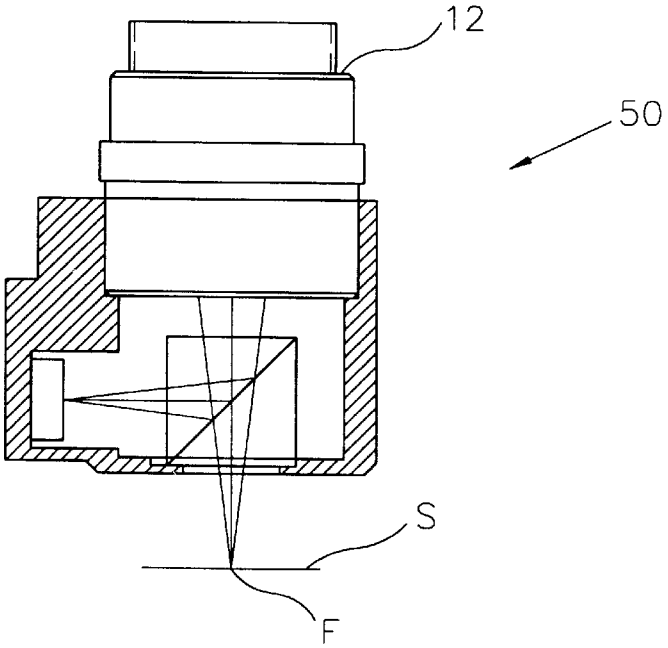


FIG. 5
(PRIOR ART)

FOLDED LOW-POWER INTERFERENCE MICROSCOPE OBJECTIVE

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention is related in general to the field of interferometry and, in particular, to a novel interference microscope objective with a folded optical path to reduce the physical length of the objective.

2. Description of the Related Art

It is desirable to provide interferometric instruments with the flexibility of operating at different magnifications. Accordingly, interferometers used to measure surface roughness are often equipped with a rotatable turret capable of accommodating multiple interference microscope objectives with different optical power. In such a configuration, it is very important that the objectives be substantially parfocal, as defined below, to minimize the need for focussing after switching from one objective to another.

In surface profilometry applications, interference microscope objectives are typically used with magnifications in the 1.5× to 10× range. Based on current commercial availability, microscope objectives commonly used for these applications are used with a tube lens with a specific reference focal length (for example, typically 200 mm for Nikon, 180 mm for Olympus, and 160 mm for Zeiss objectives). Therefore, the focal length of these objectives varies inversely with their power according to the relation $f_{objective}=f_{Reference}/\text{power}$. For example, a 50× Nikon objective has a focal length of 4 mm; a 20× Nikon objective of 10 mm; and so on. Obviously, low power objectives have a relatively long focal length, which makes it difficult to design them with a physical length sufficiently short to fit alongside high power objectives that may be less than half their length. The problem is further exacerbated by the necessity of introducing a beamsplitter between the objective's lens and the test sample for interference purposes.

In practice, objectives in the 2.5× to 50× range are substantially similar in size and can be mounted coplanarly on a turret such that the distance between their mounting shoulder and their focal point is the same. For the purposes of this disclosure, multiple objectives characterized by this condition are defined as "parfocal" objectives. Referring to the Wyko 2.5× microscope objective **10** shown in FIG. **1**, for example, which includes a beamsplitter for interference purposes, the distance D between its mounting shoulder **12**, which in operation abuts the mounting plane **14** of the objective turret **16**, and its focal point F (shown coincident with a sample surface S) is approximately 48 mm. The corresponding distances for comparable Wyko 5×, 10×, 20× and 50× objectives are about 49, 45, 45 and 45 mm, respectively.

Therefore, these reference objectives are readily rendered parfocal by adding collars of different lengths to each one to provide a common nominal parfocal distance D' to the focal point F. This modification is illustrated in the Wyko 10× objective **20** shown in FIG. **2**, also including a beamsplitter for interference purposes, where an extension collar **22** is inserted between the shoulder **12** of the objective and the plane **14** of the turret **16** so as to increase the distance D by about 6.35 mm to a nominal parfocal distance D' of approximately 51.35 mm. Using this approach, all objectives with powers in the range between 2.5× and 50× are modified in a relatively simple manner for parfocal use in a single turret having a mounting plane **14** that produces a substantially focussed condition when the object under test is placed at about the distance D' from the plane **14**. Thus, once an object is in focus for one objective, it remains substantially so when the turret **16** is rotated and other objectives are placed in operation.

For the purpose of this disclosure, the focal point F is assumed to be coincident with the location of the sample surface S. This describes the "infinite conjugates" imaging condition, in which the objective forms an image of the sample an infinite distance above the objective. This image then acts as an object for the tube lens, which forms a (typically) magnified image of the sample at a fixed location in space. As one skilled in the art would readily understand, though, the disclosure applies equally to the case where the focal point is above the sample surface, and an image of the surface is formed a finite distance above the objective without the use of a tube lens. Thus, while the "infinite conjugates" imaging condition is used here to simplify the description of the invention, the description can be generalized with no loss of accuracy to the "finite conjugates" imaging condition. It can also be applied to the case where the focal point is below the sample surface S.

Unfortunately, 1.5× and 2× objectives have a relatively long focal length that in practice is not suitable for the same solution. For example, the distance D for Wyko 1.5× and 2.0× objectives is about 115 mm, about 64 mm too long for fitting within the nominal parfocal distance D' of 51.35 mm used for the more powerful, and shorter, objectives. Thus, it is clear that low-power objectives could not be mounted parfocally on a turret alongside more powerful objectives. If sufficient space were provided to mount both, focussing a "short" objective would cause an adjacent "long" objective on the turret to physically contact the test sample or the microscope stage. The same could happen while rotating the turret to place the long objective in operation. It is noted that for the purpose of this disclosure "low-power" objectives are considered to be those with magnifications of 1.5× and 2×, while "high-power" objectives are those with magnifications of 2.5× to 50×. Although these definitions do not correspond to normal microscopy usage, where high power typically would refer to magnifications somewhat greater than 2.5×, they are appropriate for the description of the invention, which regards the physical length of the objectives in relation to their power of magnification.

Several practical difficulties prevent the design of a turret/microscope assembly with sufficient height D' to accommodate all objectives of interest in a substantially parfocal condition (that is, theoretically, very tall collars **22** could be used with high-power objectives to obtain the same nominal parfocal distance D' for all objectives). One problem with this approach is that degraded illumination would result for the more powerful objectives due to a substantial misalignment along the optical axis of their entrance pupils with respect to the less powerful objectives. This misalignment of the entrance pupils would also cause the light beam to pass through different portions of the collection optics for the high-power versus the low-power objectives. In addition, the telecentricity of microscope objectives, which prevents changes in magnification during focussing, makes it difficult to substantially shorten the length of the low-power objective in a practical and economically feasible manner. Finally, the problem is further complicated by the fact that interference objectives require a beamsplitter in the optical path. Since Michelson interferometers, which employ a cube beamsplitter placed between the last lens and the test object, are most suitable for low-magnification objectives, the additional space occupied by the beamsplitter further decreases the length available for placement of the other optical

components of the objectives while maintaining a given parfocal length.

Accordingly, there is still a need for a low-power interference objective that is substantially commensurate in length with higher-power objectives for concurrent use mounted in parallel on a rotatable turret. This invention is directed at providing a novel approach to that end.

BRIEF SUMMARY OF THE INVENTION

One primary goal of this invention is a design of interference microscope objectives suitable for mounting on a rotatable turret in parfocal condition, such that minimal focussing is required when switching from one objective to another.

Another objective of the invention is the design of 1.5× and 2× interference microscope objectives that have substantially the same mechanical length as higher-power objectives (such as 2.5× to 50× magnification) having a tube lens with a common reference focal length.

Another important goal of the invention is a solution that provides substantially uniform illumination with all objectives mounted on the turret.

Still another objective is a solution that is practically feasible even accounting for the space occupied by the beamsplitter required for the interference portion of the objective.

Another object of the invention is an approach that is particularly suitable for implementation in a Michelson interferometric arrangement.

Finally, a goal of the invention is the development of a method and apparatus that are suitable for implementation with relatively minor modifications to existing interference microscope objectives and interferometric surface profilers.

Therefore, according to these and other objectives, the invention consists of folding the light beam to the side of the optical axis of the objective, thereby maintaining the original optical path length while shortening the mechanical length of the objective. The beam is reflected by a mirror, causing it to travel some distance out to the side, and then it is reflected back toward the beamsplitter by an additional pair of mirrors. After a final reflection within the beamsplitter, the resulting beam is coaxial with the original optical axis, while the physical length of the objective has been substantially reduced. This approach makes it possible to obtain the desired distance from the mounting shoulder of the objective to the focal point.

Various other purposes and advantages of the invention will become clear from its description in the specification that follows and from the novel features particularly pointed out in the appended claims. Therefore, to the accomplishment of the objectives described above, this invention consists of the features hereinafter illustrated in the drawings, fully described in the detailed description of the preferred embodiment and particularly pointed out in the claims. However, such drawings and description disclose but one of the various ways in which the invention may be practiced.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a simplified schematic representation of a conventional interference microscope objective mounted on a turret to illustrate the fixed distance between its mounting shoulder and the objective's focal point.

FIG. **2** is a schematic representation of a microscope objective mounted on a turret by means of an extension collar to obtain parfocal conditions at a predetermined distance between the turret's mounting plane and the objective's focal point.

FIG. **3** is a simplified schematic representation of a conventional, 1.5× magnification, interference microscope objective to illustrate its long physical structure with an optical path that is coaxial with the optical axis of the objective.

FIG. **4** is a simplified schematic representation of a 1.5×-magnification interference microscope objective according to the present invention, wherein its physical structure is substantially shortened and its optical path is folded outside the optical axis of the objective.

FIG. **5** is a simplified schematic representation of a conventional, 5× magnification, interference microscope objective having substantially the same physical length of the 1.5×-magnification objective of the invention, thereby providing a parfocal pair for mounting on an interference microscope turret.

DESCRIPTION OF THE PREFERRED EMBODIMENTS OF THE INVENTION

Although folding beams have been utilized for various purposes in the optical arts, for example in binoculars, the heart of this invention lies in the recognition that the technique of folding a beam can be used advantageously to make a low-power microscope objective parfocal with other objectives. This approach provides a simple solution to a yet unresolved problem and constitutes a useful advance in the art of microscopy in general and interferometric profilometry in particular.

As illustrated in schematic form in FIG. **3**, a typical low-power (1.5× and 2×) interference microscope objective **30** comprises a first optical member **32** downstream of a light source (not shown), followed by second and third optical members **34** and **36**, respectively, through which the light beam L is passed toward a test surface S. A beamsplitter **38** reflects a portion of the light sideways in the direction of a reference surface R. The reference beam LR is focused on the surface of the reference surface R, while the test beam LT is focused on the test or sample surface S. The beams reflected from the reference mirror R and the test surface S pass back up through the optics of the objective and upward to a solid-state detector array (not shown), where interference fringes are produced as a result of the optical path difference between the path from the beamsplitter **38** to reference mirror R and the path from the beamsplitter to the test surface S. The detector array may be replaced by an eyepiece for manual viewing.

An interference microscope objective **40** according to the invention is illustrated in FIG. **4**. Taking the objective **30** of FIG. **3** as an example, the idea is to produce a physically shorter interference microscope objective with the same optical characteristics of the original objective. A reflective surface **42** is positioned between the first optical member **32** and the second optical member **34** to fold the light beam L to the side of the optical axis A in a direction opposite and normal to the plane of the reference mirror R. The second optical member **34** in turn is positioned along the folded beam at the same optical distance from the first optical member **32** as in the original objective. The beam is then folded twice by two reflective surfaces **44** and **46**, each disposed sequentially at a 45° angle to the incident light to direct the beam toward the beamsplitter **38** through the third optical member **36**. The beamsplitter **38** is positioned with respect to the incident beam such that a portion of the light (the reference beam LR) is passed through to reach the

reference surface S and another portion (the test beam LT) is reflected and directed along the optical axis A toward the test surface S.

Obviously, so long as the optical distances between the various optical components are maintained, the optical characteristics of such a physically shortened objective remain unchanged. Thus, the physical length of a low-magnification objective can be shortened to match a desired distance between the objective's mounting shoulder **12** and its focal point P in order to enable a parfocal design of a plurality of objectives with great variation in magnification. A substantially parfocal 5×-magnification objective **50**, with the same tube-lens reference focal length as the shortened 1.5×-magnification objective **40**, is shown in FIG. **5** for comparison.

While the presence of the beamsplitter in low-power interferometric microscope objectives is one of the key motivators for this invention, the technique outlined here is applicable to non-interferometric objectives as well. This can be seen in the design of a 1×, 0.5×, or even lower power objectives with a fixed parfocal length. In general, the difficulty of such a design increases with the ratio of the focal length to the parfocal length. For a sufficiently low power objective, this invention provides a means for simultaneously obtaining the required focal and parfocal lengths.

There is an additional benefit obtained with substantially parfocal and parcentric objectives, independent of the use of a turret. Parcentricity is defined as the property of having a common optical axis among objectives. This results in a sample in the center of the field-of-view in one objective being in the center of the field-of-view in the other objectives, and is independent of the parfocality. This benefit is realized in the case where the tip/tilt adjustment (important in interference microscopy) is obtained by adjusting the orientation of the light source, illumination and collection optics, turret, scanning mechanism, and camera all together rather than the case where these elements are fixed and the sample stage is adjusted. In such case, adjustment of the tip/tilt setting will change only the observed slope of the sample. This is in contrast to the case of non-parfocal objectives, where the tip/tilt can be ideal for only a single parfocal length, and tip/tilt adjustment will be accompanied by an effective translation of the sample when viewed with objectives of different parfocal lengths. This will be the case whether the objectives are mounted together on a turret, or mounted singly onto the system.

As one skilled in the art would readily recognize, the invention has been described in terms of three optical members because such would be the nature of the optics found in a conventional low-magnification telecentric microscope objective, but the concept of the invention is applicable to any combination of optical members so long as the optical distances between them are maintained in the folded beam. Similarly, each optical member may comprise one or more lenses, as necessary to achieve the desired optical behavior. The invention has also been described in terms of three reflective surfaces because they represent one way to fold a light beam to the side and back toward the reference surface. On the other hand, other arrangements, possibly involving fewer or more reflective surfaces, could also be used. It is understood that a reflective surface could be a conventional front-surface mirror disposed at an angle with respect to the beam, a right-angle prism, a total internal reflection prism, or any other optical device used to reflect light. Further, the angle through which the beam is deviated by the reflective surfaces may or may not be 90 degrees, as illustrated in this disclosure. It is also possible for the beam to travel in more than one plane, rather than the single plane employed here; that is, there need not be a common meridional plane among the reflective surfaces. Finally, the invention is particularly directed to interference microscopy, but it is clear that it could be applied advantageously to conventional (non-interferometric) microscope objectives as well.

Various other changes in the details, steps and components that have been described may be made by those skilled in the art within the principles and scope of the invention herein illustrated and defined in the appended claims. Therefore, while the present invention has been shown and described herein in what is believed to be the most practical and preferred embodiments, it is recognized that departures can be made therefrom within the scope of the invention, which is not to be limited to the details disclosed herein but is to be accorded the full scope of the claims so as to embrace any an all equivalent processes and products.

I claim:

1. In an interferometric device comprising a movable objective turret adapted to receive a plurality of interference microscope objectives mounted in parfocal arrangement with respect to a sample stage, wherein a light beam is alternatively passed through any one of the objectives toward the sample stage to perform interferometric measurements on a sample surface, an interference microscope objective that comprises:

(a) an objective housing adapted for mounting on the turret with an optical axis in substantial alignment with the light beam;

(b) a plurality of optical members mounted within said housing at predetermined optical distances along an optical path toward the sample stage;

(c) a reference surface disposed at a predetermined angle with respect to said optical axis;

(d) first means for folding the light beam to a first direction away from said optical axis;

(e) second means for folding the light beam from said first direction to a second direction toward said reference surface; and

(f) means for splitting the light beam traveling in said second direction into a reference beam directed toward the reference surface and a test beam directed toward the sample stage.

2. The microscope objective of claim **1**, wherein said first and second means for folding the light beam are reflective means.

3. The microscope objective of claim **1**, wherein said reference surface is disposed substantially at a right angle with respect to said optical axis.

4. The microscope objective of claim **2**, wherein said first means consists of a right-angle prism.

5. The microscope objective of claim **2**, wherein said second means consists of a pair of right-angle prisms.

6. The microscope objective of claim **3**, wherein said first reflective means consists of a right-angle prism.

7. The microscope objective of claim **6**, wherein said second reflective means consists of a pair of right-angle prisms.

8. The microscope objective of claim **7**, wherein said test beam is aligned with said optical axis.

9. The microscope objective of claim **2**, wherein said plurality of optical members consists of first, second and third optical members; said first reflective means is positioned between the first and second optical members; and said second reflective means is positioned between the second and third optical members.

10. The microscope objective of claim 9, wherein said reference surface is disposed substantially at a right angle with respect to said optical axis.

11. The microscope objective of claim 10, wherein said first reflective means consists of a right-angle prism.

12. The microscope objective of claim 11, wherein said second reflective means consists of a pair of right-angle prisms.

13. An interference microscope objective having an optical axis substantially perpendicular to a plane containing a test surface, comprising:

a beamsplitter producing a reference beam directed to a reference surface and a test beam directed to the test surface;

a plurality of optical members disposed at predetermined optical distances along an optical path to the beamsplitter;

first means for folding a light beam traveling in said optical path to a first direction away from said optical axis; and

second means for folding the light beam to a second direction toward said beamsplitter.

14. The objective of claim 13, wherein said plurality of optical members consists of first, second and third optical members; said first means is positioned between the first and second optical members; and said second means is positioned between the second and third optical members.

15. The objective of claim 14, wherein said first means consists of a reflective surface folding the light beam at a 90-degree angle, and said second means consists of a pair of reflective surfaces each folding the light beam at a 90-degree angle.

16. The objective of claim 14, wherein said test beam is substantially coaxial with said optical axis.

17. An interferometric device comprising;

an objective turret movable between alternative positions;

a plurality of interference microscope objectives, each including an objective housing mounted on the objective turret;

means for alternatively passing a light beam through any one of the interference microscope objectives along an optical axis thereof toward a sample stage to perform interferometric measurements on a sample surface; and

a reference surface disposed at a predetermined angle with respect to said optical axis;

wherein at least one of said interference microscope objectives comprises

(a) a plurality of optical members mounted within the housing at predetermined optical distances along an optical path toward the sample stage;

(b) first means for folding the light beam to a first direction away from said optical axis;

(c) second means for folding the light beam from said first direction to a second direction toward said reference surface; and

(d) means for splitting the light beam traveling in said second direction into a reference beam directed toward the reference surface and a test beam directed toward the sample stage;

such that said plurality of interference microscope objectives is in parfocal arrangement with respect to the sample stage.

18. The interferometric device of claim 17, wherein said first and second means for folding the light beam are reflective means.

19. The interferometric device of claim 17, wherein said reference surface is disposed substantially at a right angle with respect to said optical axis.

20. A method for achieving parfocal conditions between a first interference microscope objective and a second interference microscope objective of substantially greater magnification power in an interferometric device, comprising the following steps:

(a) providing a movable objective turret adapted to receive said objectives in alignment with an optical axis substantially perpendicular to a test surface;

(b) providing a plurality of optical members in said first objective, said members being disposed at predetermined optical distances along an optical path to a beamsplitter adapted to produce a reference beam directed to a reference surface and a test beam directed to the test surface;

(c) folding a light beam traveling in said optical path to a first direction away from said optical axis;

(d) folding the light beam from said first direction to a second direction toward said optical axis; and

(e) folding the light beam from said second direction to a third direction substantially parallel to said optical axis;

wherein said folding steps are carried out along said optical path to the beamsplitter such that the first interference microscope objective achieves a substantially parfocal relation with respect to the second interference microscope.

21. The method of claim 20, wherein said plurality of optical members consists of first, second and third optical members; said step (c) is carried out by folding the light beam between the first and second optical members; said step (d) is carried out by folding the light beam between the second and third optical members; and said step (e) is carried out by folding the light beam in the beamsplitter.

22. The method of claim 21, wherein said step (c) is carried out with a reflective surface folding the light beam at a right angle, and said step (d) is carried out with a pair of reflective surfaces each folding the light beam at a right angle.

23. The method of claim 22, wherein said third direction is substantially coaxial with said optical axis.

* * * * *

US005880879A

United States Patent [19]

Foo

[11] Patent Number: 5,880,879

[45] Date of Patent: Mar. 9, 1999

[54] **OBJECTIVE LENS SYSTEM UTILIZING DIFFRACTIVE OPTICAL ELEMENT**

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[73] Assignee: **Nikon Corporation**, Tokyo, Japan

[21] Appl. No.: **918,412**

[22] Filed: **Aug. 26, 1997**

[51] **Int. Cl.**[6] **G02B 13/14**; G02B 5/18; G02B 27/44

[52] **U.S. Cl.** **359/356**; 359/565; 359/743

[58] **Field of Search** 359/565, 570, 359/574, 575, 742, 743, 356, 357

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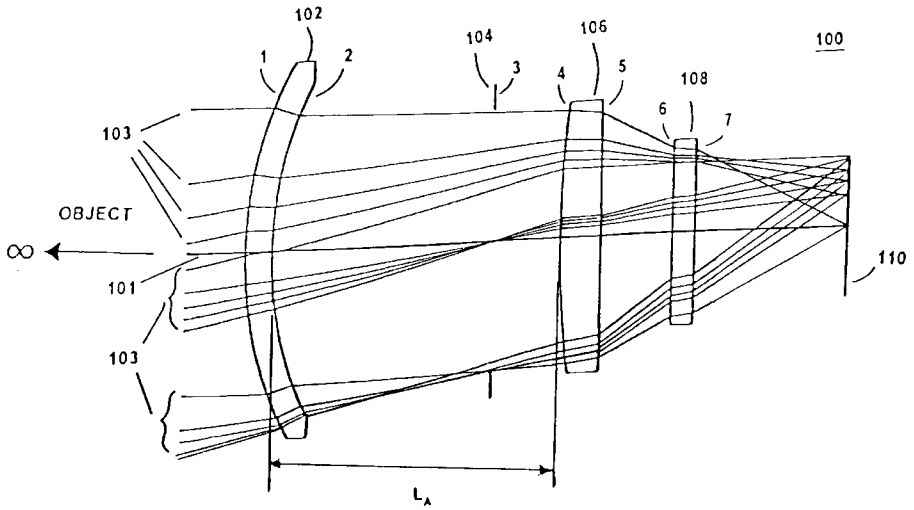
Primary Examiner—Jon Henry

Attorney, Agent, or Firm—H. Donald Nelson

[57] **ABSTRACT**

A low cost objective lens system that provides complete axial color correction with no substantial residual color dependent aberrations such as spherochromatism or chromatic coma. The objective lens system includes a first lens element having an aspherical lens surface and a second lens element having a diffractive optical surface and an aperture disposed between the first and second lens elements. The axial separation of the aspherical lens surface and the diffractive optical surface may be determined by the condition $0.5<L_A/efl<1.25$ where L_A is the axial distance from the lens element with the aspherical surface to the lens element with the diffractive optical surface and efl is the effective focal length of the objective lens system. The diffractive optical surface is optically dispersive and is preferably placed on the refractive lens element in the system having the highest optical power. The objective lens system does not exhibit residual color dependent aberrations such as spherochromatism and chromatic coma. The aspherical lens surface is preferably located on the object side of the aperture stop to provide the most advantageous coma correction and spherical aberration correction. The aspherical lens surface further corrects residual monochromatic aberrations such as astigmatism and distortion.

16 Claims, 5 Drawing Sheets



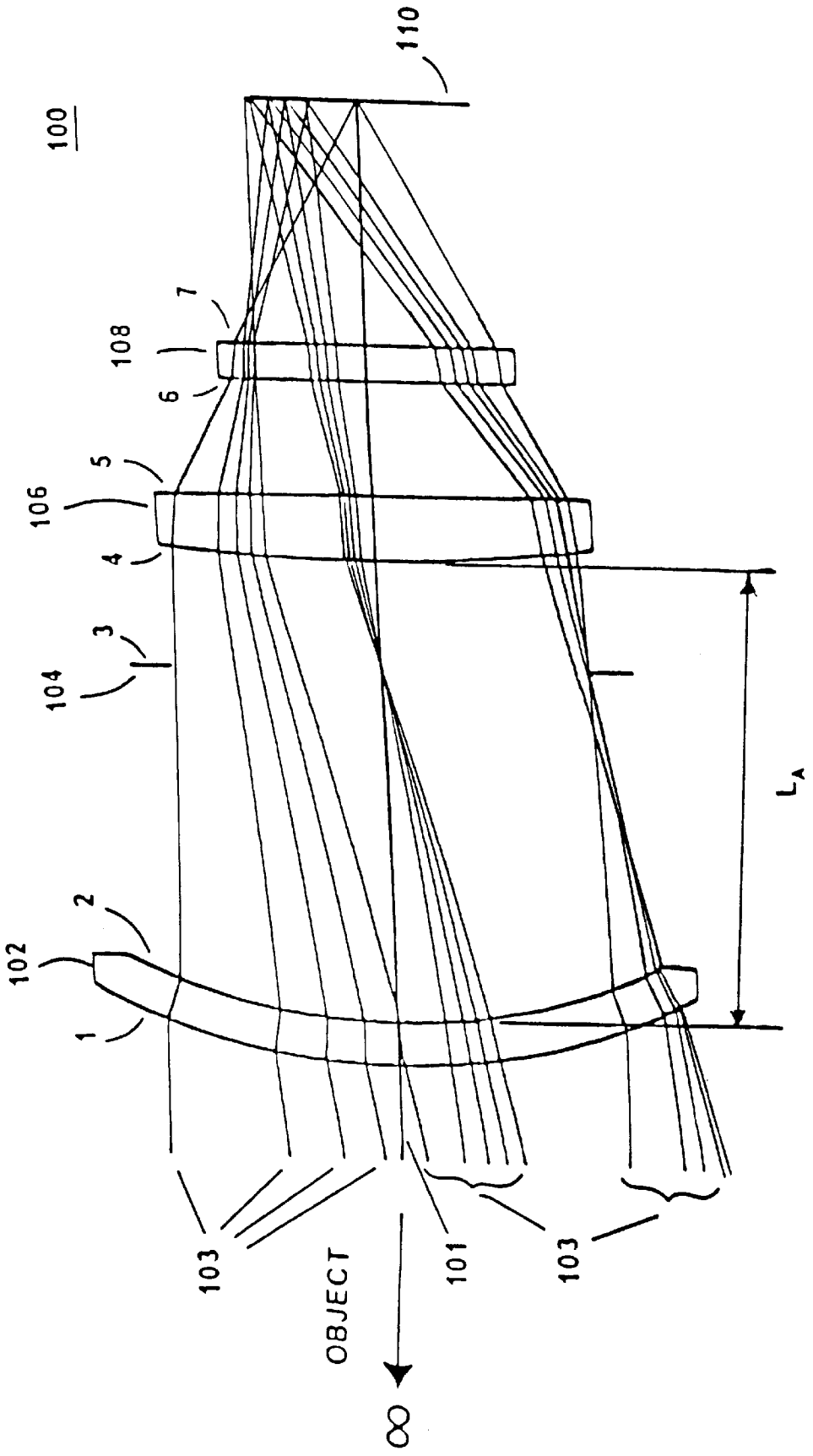


FIGURE 1

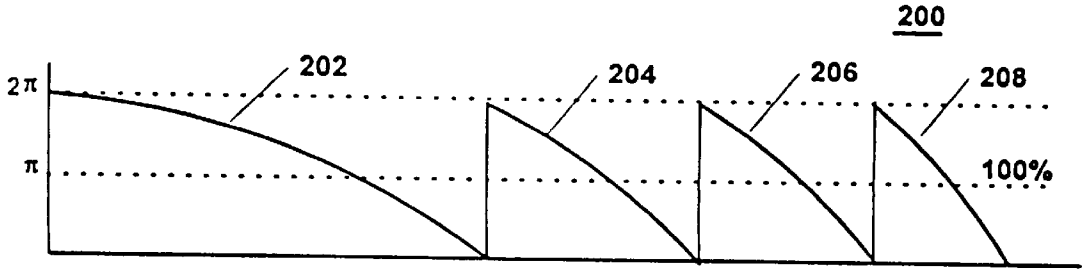


FIGURE 2A

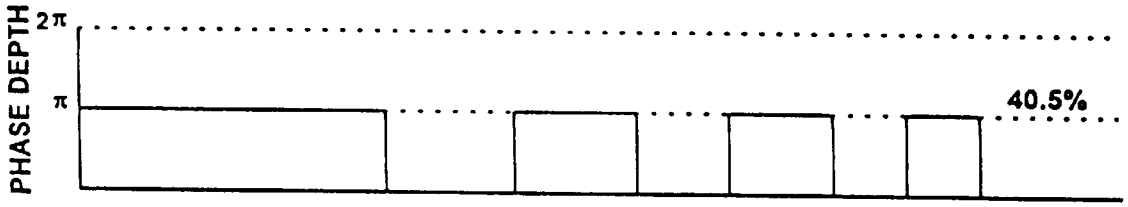


FIGURE 2B

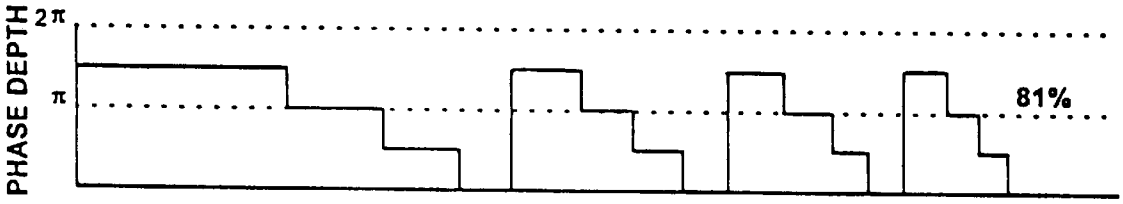


FIGURE 2C

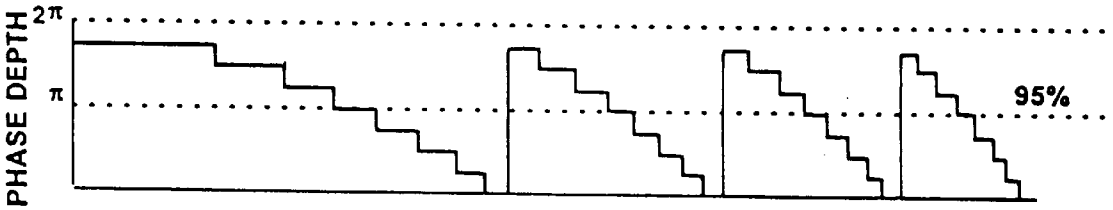


FIGURE 2D

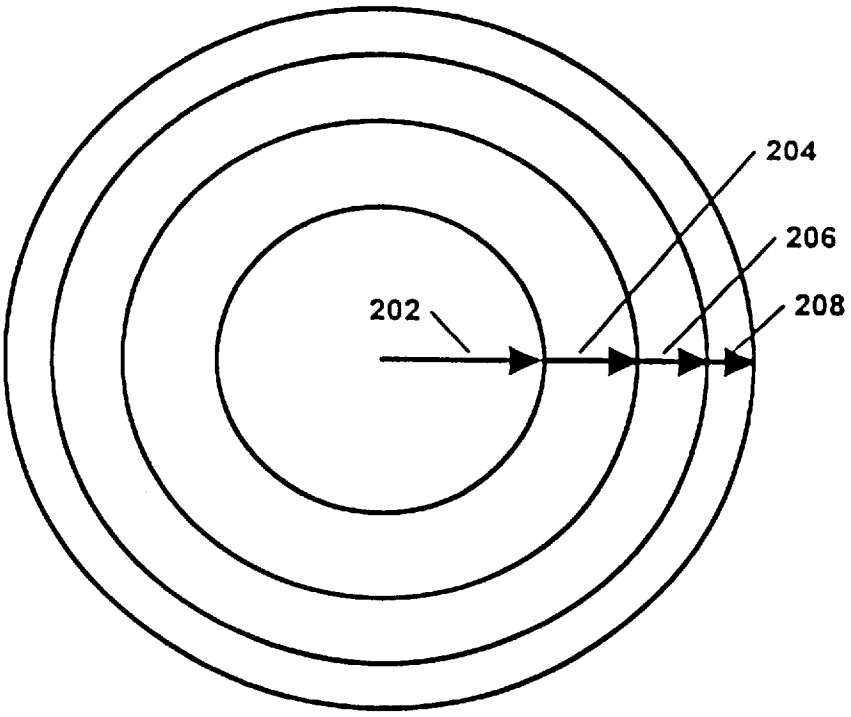


FIGURE 3

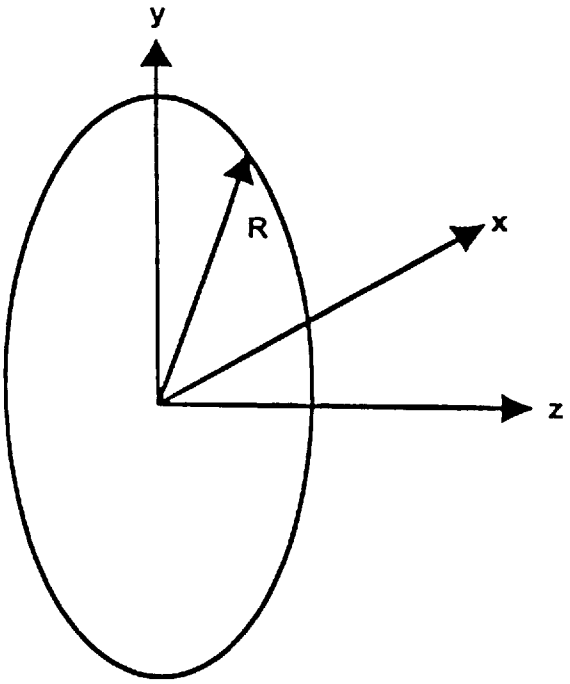


FIGURE 4

FIGURE 5A

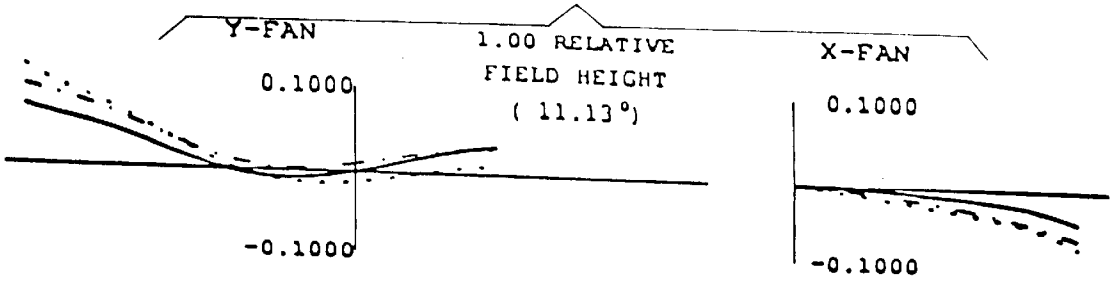


FIGURE 5B

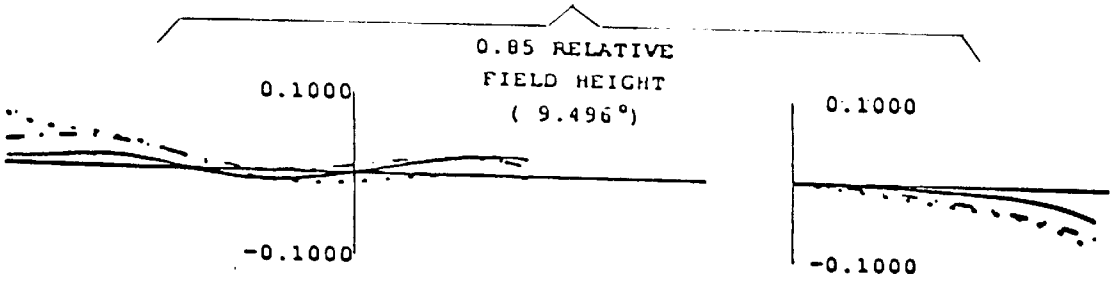


FIGURE 5C

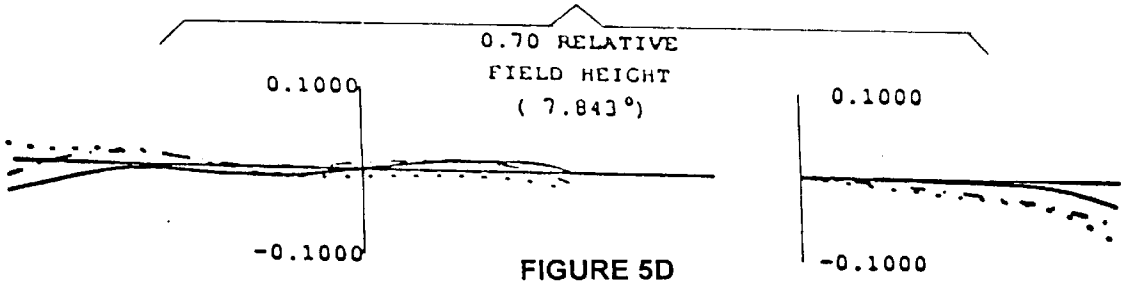


FIGURE 5D

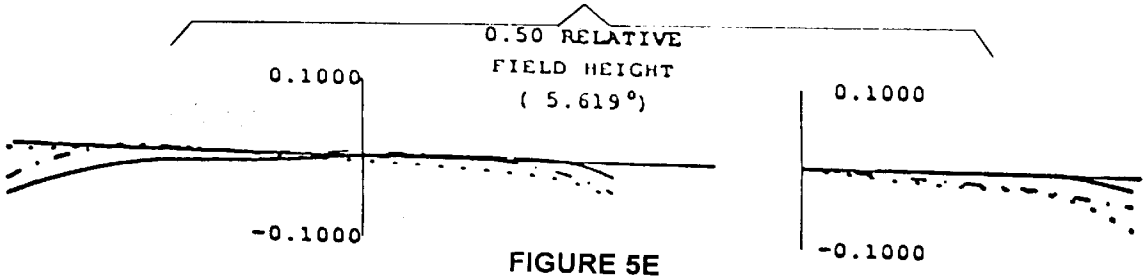
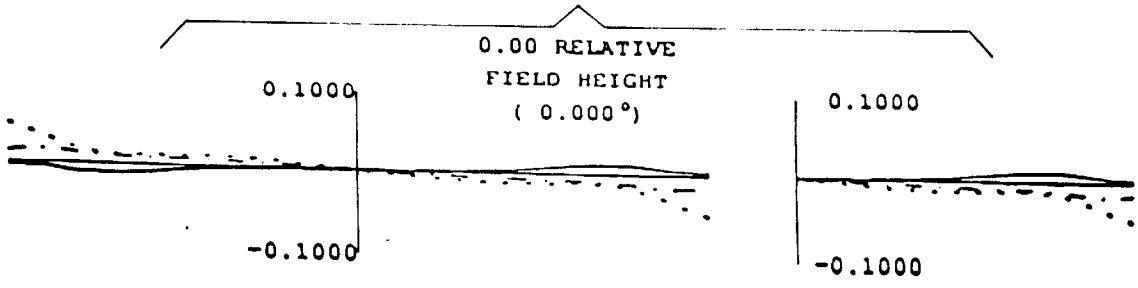


FIGURE 5E



RAY ABERRATIONS (MILLIMETERS)

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4000.0 NM
3000.0 NM

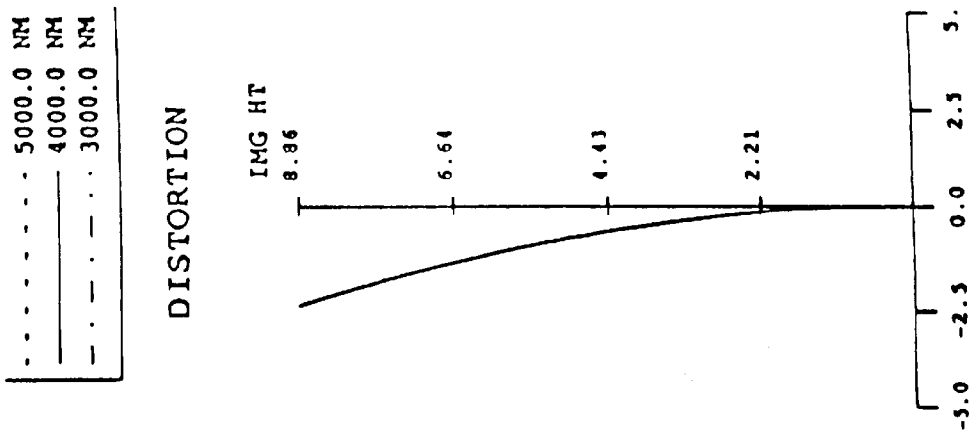

FIGURE 6C

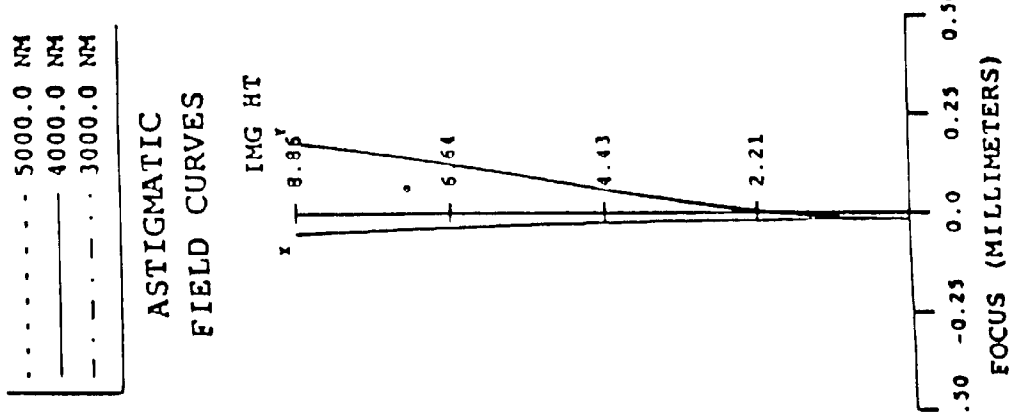

FIGURE 6B

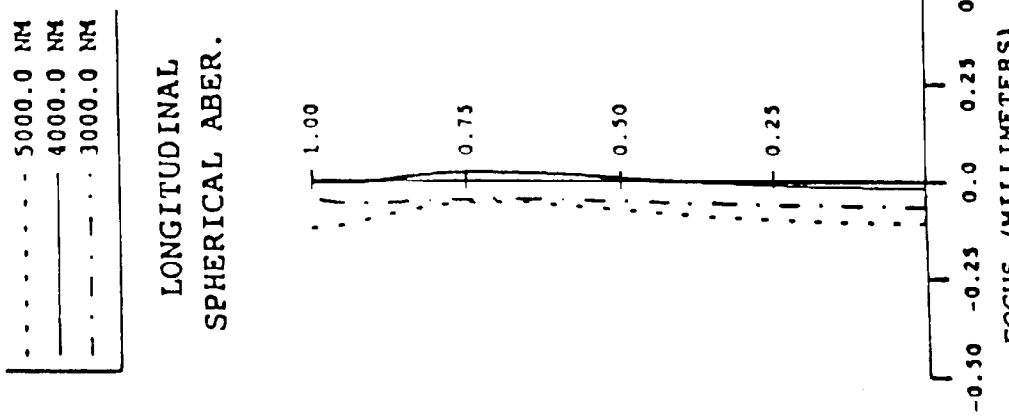

FIGURE 6A

OBJECTIVE LENS SYSTEM UTILIZING DIFFRACTIVE OPTICAL ELEMENT

FIELD OF THE INVENTION

This invention relates generally to optical lens element configurations and, more particularly, to an objective lens system utilizing a lens element having an aspherical surface and/or a lens element having a diffractive surface. Even more particularly, this invention relates to an objective lens system utilizing an aspherical lens surface that is selectively located on the optical axis to correct coma in addition to the basic correction of spherical aberration. The diffractive lens surface may be located on the refractive element with the most optical power to correct the axial color aberration so that chromatic errors are not propagated through the remainder of the optical system.

BACKGROUND OF THE INVENTION

High performance passive and active optical lens systems need very high quality optical elements in order to obtain the required degree of performance. Optical lens systems are composed of multiple individual lens elements designed to achieve the necessary performance over a specified field of view and specified spectral band. The three main considerations in the design of an optical system are cost, weight, and performance.

To control the costs of optical systems, the optical systems are generally designed to contain only spherical surfaces. The use of aspherical surfaces in optical systems can reduce the number of elements needed to achieve the required performance. However, lens elements having aspherical surfaces are significantly more expensive to manufacture than lens elements having only spherical surfaces. Therefore, the decision to use aspherical surfaces in place of spherical surfaces in a particular optical lens system depends upon whether the weight of the optical system is a more critical factor than the cost of the system or whether the cost of the system is a more critical factor than the weight of the optical system.

Examples of optical systems that can require very high quality optical systems are passive and active infrared sensors and infrared camera systems. The number of optical materials that are transmissive at infrared wavelengths is limited. Most infrared lens elements are made from the four materials, germanium, silicon, zinc sulfide, and zinc selenide, all of which are dispersive. The dispersive characteristic of these materials results in an optical system that contains more elements than the optical system would if less dispersive materials were available. The additional elements are necessary to correct chromatic aberration, which is a consequence of dispersion and causes light to have different focal points depending upon wavelength.

The image produced by an optical system has other aberrations that take many forms, such as spherical aberration, spherochromatism, and coma. Spherical aberration results when spherical lens surfaces are used and causes light striking nearer the periphery of the lens to be focused closer to the lens while light striking near the center is focused farther away from the lens. Spherochromatism (or spherochromatic aberration) is a type of spherical aberration in which the focal points of light rays vary with the wavelength of the light. Coma is an aberration that distorts images formed by off-axis light rays that do not strike the lens at its center.

Conventional optical systems therefore require additional lens elements to correct for aberrations, thereby adding cost, weight, size, and complexity to the lens system in order to correct for the aberrations introduced into the lens system. The curvatures of the spherical surfaces of the elements are designed to reduce both the spherical and chromatic aberrations to an acceptable amount. However, without corrective lenses, conventional optical systems would be limited by chromatic aberration to low speeds or low focal ratios.

One alternative to adding lens elements to correct for aberrations is to use diffractive surfaces, such as one of many types of computer-generated Fresnel zone plates manufactured on at least one side of a lens element. A high efficiency binary approximation of a Kinoform-type Fresnel zone plate, called a binary grating surface, has been disclosed for use in infrared systems by Swanson and Veldkamp in "Diffractive optical elements for use in infrared systems," Optical Engineering, Vol.28 (6), pp. 605–608 (June 1989). The use of the diffractive surface can be used with a spherical or conventional lens. When used with a spherical surface, the spherical surface provides focusing and the diffractive surface corrects for as much of the spherical aberration as possible. However, the use of a diffractive surface to correct for spherical aberration results in a significant amount of spherochromatism. In addition, because low speeds or focal ratios are required to limit this chromatic aberration, the usable optical speed is significantly limited.

In an attempt to solve these shortcomings, in U.S. Pat. No. 5,044,706, Chen proposed an optical element having aspherical and binary grating optical surfaces. In embodiment of Chen, the optical element is a positive meniscus optical element made of germanium having a useful spectral bandpass in the infrared wavelength region. A telescope system incorporating two of the optical elements has an aspherical surface and a diffractive surface. In another of Chen's embodiments, an objective element having a convex aspherical surface and a concave binary grating surface is used in the telescope. The necessity of using two of the optical elements each having an aspherical surface and a diffractive surface results in an optical system that uses fewer lens elements than previous optical systems. However, as can be appreciated by one of ordinary skill in the art, the resulting optical systems are very expensive. The fabrication of a lens element having an aspherical surface and a diffractive surface is very difficult and expensive. In addition, the alignment of a system using one or more of the combined lens elements is critical to the performance of the optical system.

Accordingly, there is a need for a low cost objective lens system that has improved aberration correction and that provides axial color and spherochromatism correction so that chromatic aberration is not propagated through the optical system.

SUMMARY OF THE INVENTION

An objective lens system in accordance with the present invention solves the above and other problems associated with conventional objective lens systems by maintaining the same level of performance with less expensive lens elements. The objective lens system in accordance with the present invention provides complete axial color correction with no substantial residual color dependent aberrations such as spherochromatism or chromatic coma.

The above and other objects and advantages of the present invention are attained in one embodiment of the present invention through an objective lens system that includes a first lens element having an aspherical surface and a second lens element having a diffractive optical surface and an

aperture stop disposed between the first and second lens elements. The axial separation of the aspherical surface and the diffractive optical surface is determined by the condition $0.5<L_A/efl<1.25$ where L_A is the axial distance from the lens element with the aspherical surface to the lens element with the diffractive surface and efl is the effective focal length of the objective lens system. The second lens element is a refractive lens element having the most optical power in the objective lens system. The diffractive optical surface is optically dispersive and provides axial color correction and prevents chromatic errors from being propagated to the remainder of the optical system. The diffractive optical surface primarily provides axial color correction and the objective lens system does not exhibit residual color dependent aberrations such as spherochromatism and chromatic coma. The aspherical lens surface is located on the object side of the aperture stop and provides coma correction and spherical aberration correction. The aspherical lens surface further corrects residual monochromatic aberrations such as astigmatism and distortion.

These and other advantages of the present invention will become more apparent upon a reading of the detailed description of the preferred embodiment that follows, when considered in conjunction with the drawings of which the following is a brief description. It should be clear that the drawings are merely illustrative of the currently preferred embodiment of the present invention, and that the invention is in no way limited to the illustrated embodiment. As will be realized, the invention is capable of other embodiments and its several details are capable of modifications in various obvious aspects, all without departing from the scope of the invention. The present invention is best defined by the claims appended to this specification.

BRIEF DESCRIPTION OF THE DRAWINGS

The novel features believed characteristic of the invention are set forth in the appended claims. The invention itself, however, as well as a preferred mode of use, and further objects and advantages thereof, will best be understood by reference to the following detailed description of an illustrative embodiments when read in conjunction with the accompanying drawings, wherein:

FIG. **1** is a schematic diagram of an objective lens system according to the present invention;

FIG. **2**A is an enlarged cross-sectional view of a portion of a Fresnel phase plate having a kinoform diffractive surface and showing the microscopic details thereof;

FIG. **2**B is an enlarged cross-sectional view of a portion of a binary optical element having two surfaces which approximate the kinoform diffractive surface shown in FIG. **2**A and showing the microscopic details thereof;

FIG. **2**C is an enlarged cross-sectional view of a portion of a binary optical element having 4 surfaces which approximate the Kinoform diffractive surface shown in FIG. **2**A and showing the microscopic details thereof;

FIG. **2**D is an enlarged cross-sectional view of a portion of a binary optical element having 8 surfaces which approximate the kinoform diffractive surface shown in FIG. **2**D and showing the microscopic details thereof;

FIG. **3** is a front view of a diffractive Fresnel phase plate showing the concentric relationship of the diffractive rings;

FIG. **4** is a graphical representation showing the relationship of the values used to define and manufacture a diffractive optical element.

FIGS. **5**A–**5**E illustrate in graphical form ray aberrations in millimeters of the objective lens system shown in FIG. **1**; and

FIGS. **6**A–**6**C illustrate in graphical form longitudinal spherical aberration, astigmatic field curves and distortion of the objective lens system shown in FIG. **1**.

DETAILED DESCRIPTION

The following detailed description is of the presently preferred embodiment of the present invention. It is to be understood that while the detailed description is given utilizing the drawings briefly described above, the invention is not limited to the illustrated embodiment. In the detailed description, like reference numbers refer to like elements.

Referring now to the Figures, the preferred embodiment of the present invention will now be described. According to standard practice in the optical art, drawings of optical lens systems, such as those shown in the Figures, have the object space, defined as all the space from the first element of surface of a system towards the object and beyond, on the left in the drawing. Similarly, the image space, defined as all the space from the last element or surface of a system towards the image and beyond, is on the right in the drawings. All surfaces in the drawings of the optical lens systems are sequentially numbered from the object side to the image side. The plane of the aperture stop is considered a surface and is included in the numbering.

FIG. **1** is a schematic diagram of an objective lens system **100** according to the present invention. The objective lens system **100** includes a first lens element **102**, an aperture stop **104**, a second lens element **106**, and a third lens element **108**. The objective lens system **100** forms an image on an image plane **110** of an object (not shown) located at infinity. The objective lens system **100** has an optical axis **101**. The lines **103** are known as ray traces and symbolically represent light or other radiation passing through the optical system and function as a fundamental lens design tool, called analytical ray tracing. One skilled in the art would understand that the rays are sequentially traced through a series of surfaces (refractive and diffractive) and thereby yield a measurement of the performance of the optical lens system.

Surface **2** on the first lens element **102** is an aspherical surface. The aspherical surface is defined by the following equation:

$$z=(curv)Y^2/[1+(1-(1+K)(curv)^2Y^2)^{1/2}]+AY^4+BY^6+CY^8+DY^{10},$$

where "curv" is base radius of curvature, "K" is a conic constant, and the values "A–D" are aspherical constants.

The first lens element **102** and the second lens element **106** are located on the optical axis **101** so that the objective lens system **100** satisfies the condition:

$$0.5<L_A/efl<1.25,$$

wherein L_A is the axial distance from the surface **2** of lens element **102** to the surface **4** of lens element **106** and efl is the effective focal length of the objective lens system **100**. As is known in the optical art, the effective focal length of a combination lens system is the focal length of the combination system if the combination of lenses was replaced by a single thin lens. If L_A/efl is less than 0.5, the off axis aberrations are difficult to correct and the aspheric surface becomes less effective in correcting coma and astigmatism. If L_A/efl is greater than 1.25, spherochromatism becomes more pronounced, the diffractive surface is located too far away from the spherical aberration correction produced by the aspheric surface, and is unable to provide the independent chromatic aberration correction achieved when the condition is satisfied.

The aspherical lens surface **2** is located on the object side of aperture **104** so that the specific aberration correction provided by the aspherical lens surface is the most advantageous aberration correction that can be provided by the aspherical lens. The aspherical lens surface corrects residual monochromatic aberrations such as spherical, coma, astigmatism and distortion. In order to more effectively correct field dependent aberrations such as coma and distortion, the aspherical lens surface must be properly located remotely from the aperture stop. As is known in the optical art, if it is desired to only correct spherical aberration, an aspherical lens surface is most effective when placed at the aperture stop location, as in the Schmidt telescope configuration. In the present invention, the aspherical lens surface is located forward of the aperture stop **106** so that the aspherical lens surface contributes some coma correction as well as basic spherical aberration correction.

Surface **5** is a diffractive optical element surface. The diffractive optical surface is defined by the following equation that describes the phase departure of the diffractive surface: $\phi(R)=C_1R^2+C_2R^4+C_3R^6+C_4R^8+C_5R^{10}$, where the values C_1–C_5 are constants and R is defined by $R^2=X^2+Y^2$. FIG. **4** shows the graphical relationship between R, X and Y. The above equation is a radially symmetric polynomial. The value R is the radial distance from the axis represented by the z coordinate shown in FIG. **4**. The axis represented by the z coordinate coincides with the optical axis in the optical lens system in which the lens element is installed. Preferably, the diffractive optical surface is formed on a planar surface. Forming the diffractive optical surface on a planar surface is preferable because it is easier, and thus less expensive, to manufacture. The formation of a diffractive optical surface on a planar surface also allows more options for manufacturing the diffractive optical surface such as photolithography, replication, and diamond turning.

The diffractive surface **5** on the second lens element **106** is placed on the refractive element with the most optical power. As is known in the optical are, the refractive element with the most optical power is the largest contributor to axial chromatic aberration. With the diffractive surface placed on this element, axial color correction can be most beneficially performed at this location so that chromatic errors are not propagated through the remainder of the optical system. As can be appreciated, if the axial chromatic aberration is not corrected at a specific location, it will be propagated through the optical system and must be corrected by the addition of more optical lens elements before reaching the focal plane. The addition of the lens elements necessary to correct the chromatic aberrations increases the cost and complexity of the resulting optical lens system. The diffractive optical element as used in the present invention provides dispersion in the form of optical power to provide axial color correction to the overall objective lens system. Because the diffractive optical element is utilized to only introduce optical power and not to correct for spherical wavefront type aberrations, the objective lens system does not exhibit residual color dependent aberrations such as spherochromatism or chromatic coma.

In addition, the separation of the aspherical lens surface and the diffractive optical element allows the production tolerances on the individual lens elements and surfaces to be looser than if the aspherical and diffractive surfaces are on the same lens element. The more relaxed tolerances on the individual surface production, alignment and accuracy result in lower production costs. The lower production costs are achieved without a decrease in the optical performance of the objective lens system.

The diffractive optical element may be a binary optical element that is generally produced through photolithographic processes or it may be a true Fresnel phase plate produced by precision diamond machining. Generally, to produce optical power, the binary diffractive optical element is in the form of a Fresnel phase plate with stair step approximations of the true desired periodic phase altering projections. Further details about binary optical surfaces may be found in the publications: G. Swanson and W. Veldkamp, "Diffractive optical elements for use in infrared systems," Optical Engineering, Vol. 28 (6), pp. 605–608 (June 1989); and C. W. Chen and J. S. Anderson, "The Use of Diffractive Optical Element in 3–5 Micrometer Optical System," Proc. IRIS Passive Sensors 1992, Vol. 1.

A prescription table of an objective lens system in accordance with the present invention shown in FIG. **1** is shown below in Table I. In this Table it will be noted that the lens surfaces correspond to the lens surfaces shown in FIG. **1**. The radius refers to the radius of curvature of the particular surface specified in accordance with conventional practice, that is, a positive radius indicates the center of curvature is to the right and a negative radius indicates the center of curvature is to the left. All dimensions are given in millimeters. The aspherical constants are defined above as are the constants needed to manufacture the diffractive lens element. The thickness refers to the distance along the optical axis **101** from the surface for which the thickness is specified to the next highest numbered surface. Thus, the thickness from surface **1** to surface **2** of lens element **102** is 4.0000 mm and the thickness through air between surface **2** of lens element **102** and the plane of the aperture stop **104** is 32.4129 mm.

TABLE I

element	surface	radius	thickness	material
object		Infinity	infinity	
102	1	46.694	4.0000	GERMANIUM
	2*	45.863	32.4129	
104 (ap. stop)	3	Infinity	9.7375	
106	4	130.850	6.0000	GERMANIUM
	5**	DOE	10.9476	
108	6	infinity	3.0000	SILICON
	7	infinity	23.0000	
image		infinity		

*Aspherical constants

K = 0.000000	A = 4.84182E−07	B = 1.65762E−10
curv = 0.02180425	C = 5.06262E−13	D = 0.000000E+0

**DOE constants

C1 = −3.3364E−04	C2 = 2.2959E−07	C3 = 9.4152E−10
C4 = −8.7409E−12	C5 = 1.4345E−14	

Referring to FIGS. **2A–2D** there is shown details of the structure of diffractive optical elements. FIG. **2A** shows a diffractive zone plate type of phase profile **200** having discrete 2π increments **202–208** located along a common plane **210**. This analog type surface relief profile is commonly known as a kinoform and is capable of achieving 100% diffraction efficiency at its functional wavelength. Digitized approximations to the kinoform profile can be formed as shown in FIGS. **2B–2D**. FIG. **2B** shows a 2-level approximation to the kinoform shown in FIG. **2A**. However, the 2-level approximation only has a diffraction efficiency of 40.5%. FIG. **2C** shows a 4-level approximation that has a diffraction efficiency of 81%. FIG. **2D** shows an 8-levely approximation that has a diffraction efficiency of 95%. Diffraction efficiencies of 99% or better are achievable by surface profiles containing 16 or more digitized levels.

As discussed above, a Fresnel zone plate face profile needed to achieve 100% diffraction efficiency requires

curved wedge shaped structures as shown in FIG. **2**A with a height, or phased depth, of 2π. The 2π phase depths correspond to a material etch depth of about 2 microns for mid-infrared radiation. The phase depth is proportional to the wavelength. For wavelengths in the infrared range, diamond-turned optics technology can be used to produce a continuous curved phase profile. Approximations to the kinoform profile discussed above can be produced with a diffraction efficiency of 90% or greater. Diffraction efficiencies in excess of 90% can be achieved by using, for example, integrated circuit fabrication techniques such as high-resolution lithography, mask aligning and reactive ion etching.

FIG. **3** is a front view of a diffractive Fresnel phase plate showing the concentric relationship of the diffractive rings. Each ring is numbered from **202–208** and corresponds to the numbers shown in FIG. **2**A.

FIG. **4** is a graphical representation showing the relationship of the values used to define and manufacture a diffractive optical element. The relationship is discussed above.

FIGS. **5**A–**5**E illustrate in graphical form ray aberrations in millimeters of the objective lens system shown in FIG. **1** and shows the performance of the lens system in accordance with the present invention.

FIGS. **6**A–**6**C illustrate in graphical form longitudinal spherical aberration, astigmatic field curves and distortion of the objective lens system shown in FIG. **1** and further shows the performance of the lens system in accordance with the present invention.

The foregoing description of the embodiment of the invention has been presented for purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise form disclosed. Obvious modifications or variations are possible in light of the above teachings. All such modifications and variations are within the scope of the invention as determined by the appended claims when interpreted in accordance with the breadth to which they are fairly, legally, and equitably entitled.

What is claimed is:

1. An objective lens system that provides complete axial color correction with no substantial residual color dependent aberrations such as spherochromatism or chromatic coma, the objective lens system comprising, in order from an object side to an image plane:

a first lens element having an aspherical surface;

an aperture stop; and

a second lens element having a diffractive optical surface, wherein the first lens element and the second lens element are located on an optical axis such that the objective lens system satisfies the following condition:

$$0.5<L_A/efl<1.25,$$

where L_A is the axial distance from a surface on the image side of the first lens element to a surface on the object side of the second lens element and efl is the effective focal length of the objective lens system.

2. The objective lens system of claim **1**, wherein the second lens element is a refractive lens element having the most optical power in the objective lens system.

3. The objective lens system of claim **2**, wherein the diffractive optical surface is optically dispersive and provides axial color correction to the objective lens system, whereby chromatic errors are not propagated to the image plane.

4. The objective lens system of claim **3**, wherein the diffractive optical surface is optically dispersive and provides axial color correction, whereby the objective lens system does not exhibit residual color dependent aberrations such as spherochromatism and chromatic coma.

5. The objective lens system of claim **4**, wherein the aspherical surface is located on the object side of the aperture stop and provides coma correction and spherical aberration correction.

6. The objective lens system of claim **5**, wherein the aspherical surface further corrects residual monochromatic aberrations such as astigmatism and distortion.

7. The objective lens system of claim **6**, wherein the diffractive surface is located on the image plane side of the aperture stop.

8. The objective lens system of claim **7**, wherein the objective lens system is designed for a wavelength in the range of 3000 to 5000 nanometers.

9. A method of providing complete axial color correction with no substantial residual color dependent aberrations such as spherochromatism or chromatic coma in an objective lens system, the method comprising:

transmission of radiation through a first lens element having an aspherical surface;

transmission of the radiation through an aperture stop; and

transmission of the radiation through a second lens element having a diffractive surface, wherein the first lens element is located on an optical axis of the objective lens system an axial distance from the second lens element by a distance that is determined by the following condition:

$$0.5<L_A/efl<1.25,$$

where L_A is the axial distance from a surface on the image side of the first lens element to a surface on the object side of the second lens element and efl is the effective focal length of the objective lens system.

10. The method of claim **9**, wherein transmission of the radiation through a second lens element having a diffractive surface further comprises transmission of the radiation through a second lens element that is a refractive lens element having the most optical power in the objective lens system.

11. The method of claim **10**, wherein transmission of the radiation through a second lens element having a diffractive surface further comprises transmission of the radiation through a second lens element that is optically dispersive and provides axial color correction whereby chromatic errors are not propagated to the image plane.

12. The method of claim **11**, wherein transmission of the radiation through a second lens element having a diffractive surface further comprises transmission of the radiation through a second lens element that is optically dispersive and provides axial color correction whereby the objective lens system does not exhibit residual color dependent aberrations such as spherochromatism and chromatic coma.

13. The method of claim **12**, wherein transmission of the radiation through an aspherical surface further comprises transmission of the radiation through an aspherical surface that is located on the object side of the aperture stop and provides coma correction and spherical aberration correction.

14. The method of claim **13**, wherein transmission of the radiation through an aspherical surface further comprises transmission of the radiation through an aspherical surface that provides correction to residual monochromatic aberrations such as astigmatism and distortion.

15. The method of claim **14**, wherein transmission of the radiation through a diffractive surface further comprises

transmission of the radiation through a diffractive surface located on the image side of the aperture stop.

16. The method of claim **15**, wherein transmission of the radiation through a first lens element, an aperture stop, and a second lens element further comprises transmission of the radiation having a wavelength in the range of 3000 nm to 5000 nm.

* * * * *

US005878017A

United States Patent [19]

Ikegame

[11] **Patent Number: 5,878,017**

[45] **Date of Patent: Mar. 2, 1999**

[54] **OPTICAL RECORDING AND/OR REPRODUCING APPARATUS HAVING OBJECTIVE LENS ADJUSTING MECHANISM**

[75] Inventor: **Tetsuo Ikegame**, Hachioji, Japan

[73] Assignee: **Olympus Optical Company, Ltd.**, Tokyo, Japan

[21] Appl. No.: **967,258**

[22] Filed: **Nov. 7, 1997**

Related U.S. Application Data

[63] Continuation of Ser. No. 584,463, Jan. 11, 1996, abandoned.

[30] **Foreign Application Priority Data**

Jan. 23, 1995 [JP] Japan 7-008300

[51] **Int. Cl.**[6] **G11B 7/08**; G11B 7/09; G02B 7/02

[52] **U.S. Cl.** **369/219**; 369/244; 359/822

[58] **Field of Search** 369/219, 223, 369/215, 244, 249, 253, 44.14, 44.15, 44.16, 44.22; 359/811, 813, 814, 819, 822, 823, 824

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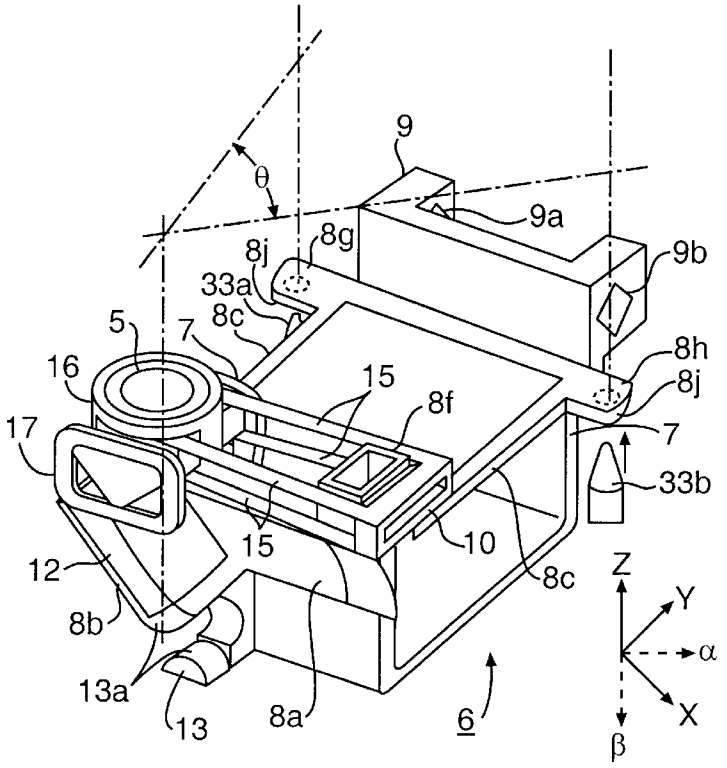
Primary Examiner—David L. Ometz
Attorney, Agent, or Firm—Dougherty & Troxell

[57] **ABSTRACT**

An optical recording and/or reproducing apparatus having an objective lens adjusting mechanism suitable for a compact optical pickup device. The apparatus has a carriage for holding an objective lens, and a guide. The carriage is movable along the guide. The apparatus has an objective lens adjusting device for adjusting an inclination of the optical axis of the objective lens in rotational directions about two axes perpendicular to the optical axis of the objective lens and to each other.

13 Claims, 11 Drawing Sheets



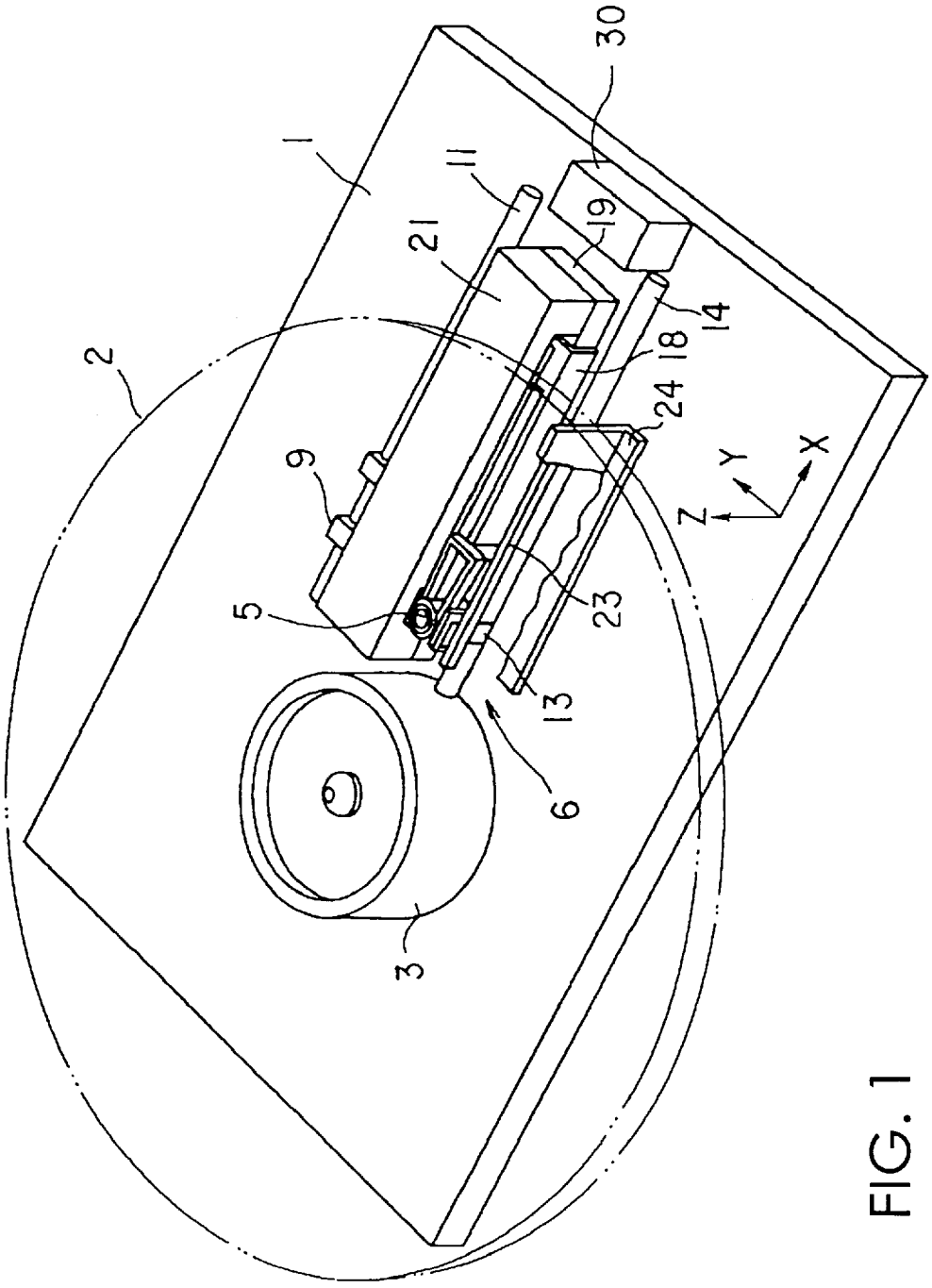
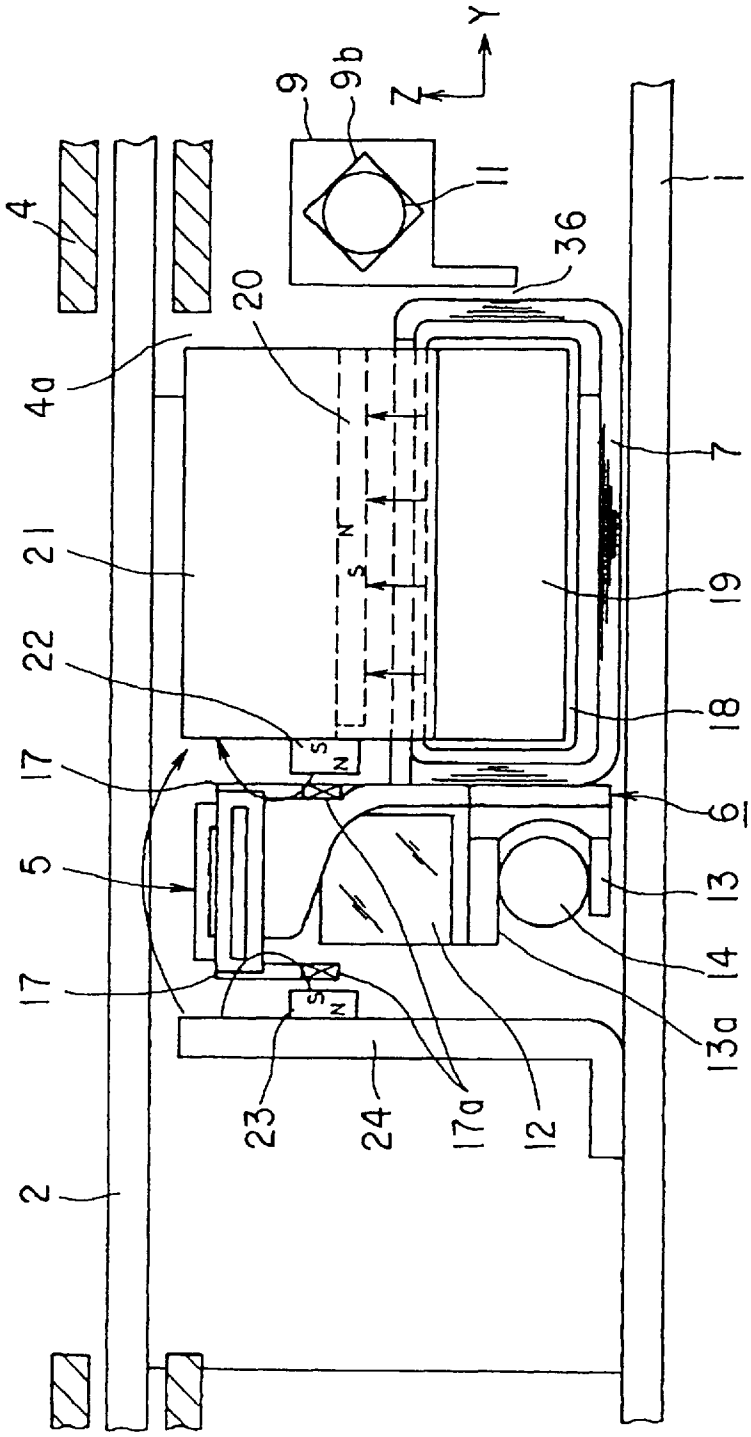


FIG. 1

FIG. 2



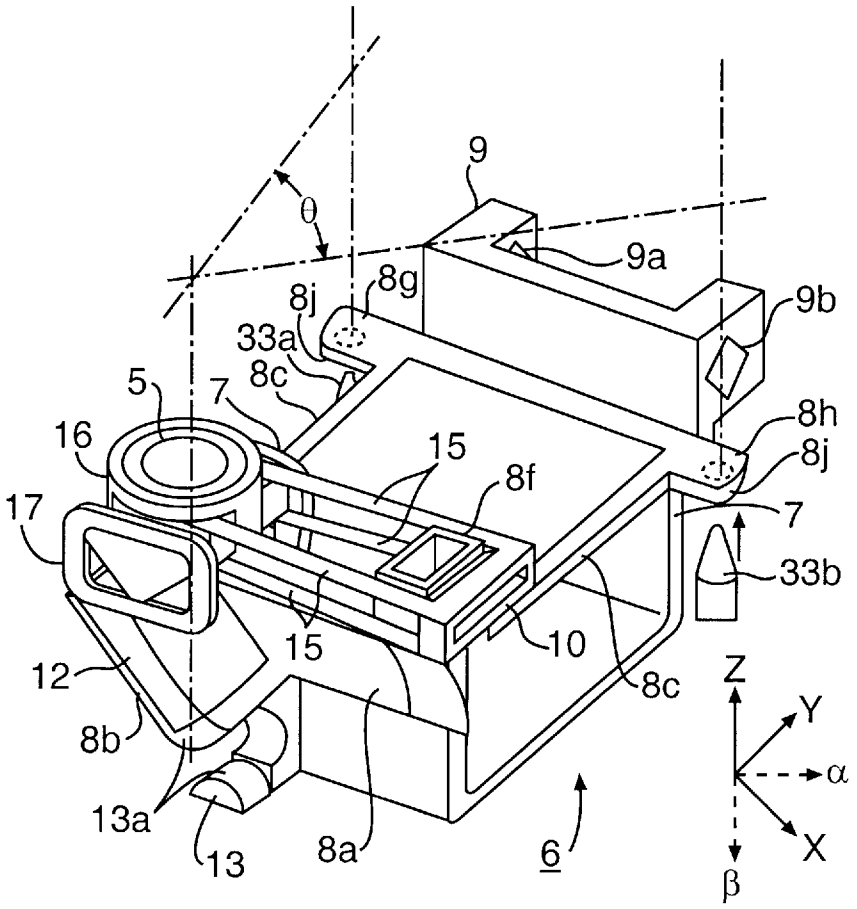

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FIG. 3

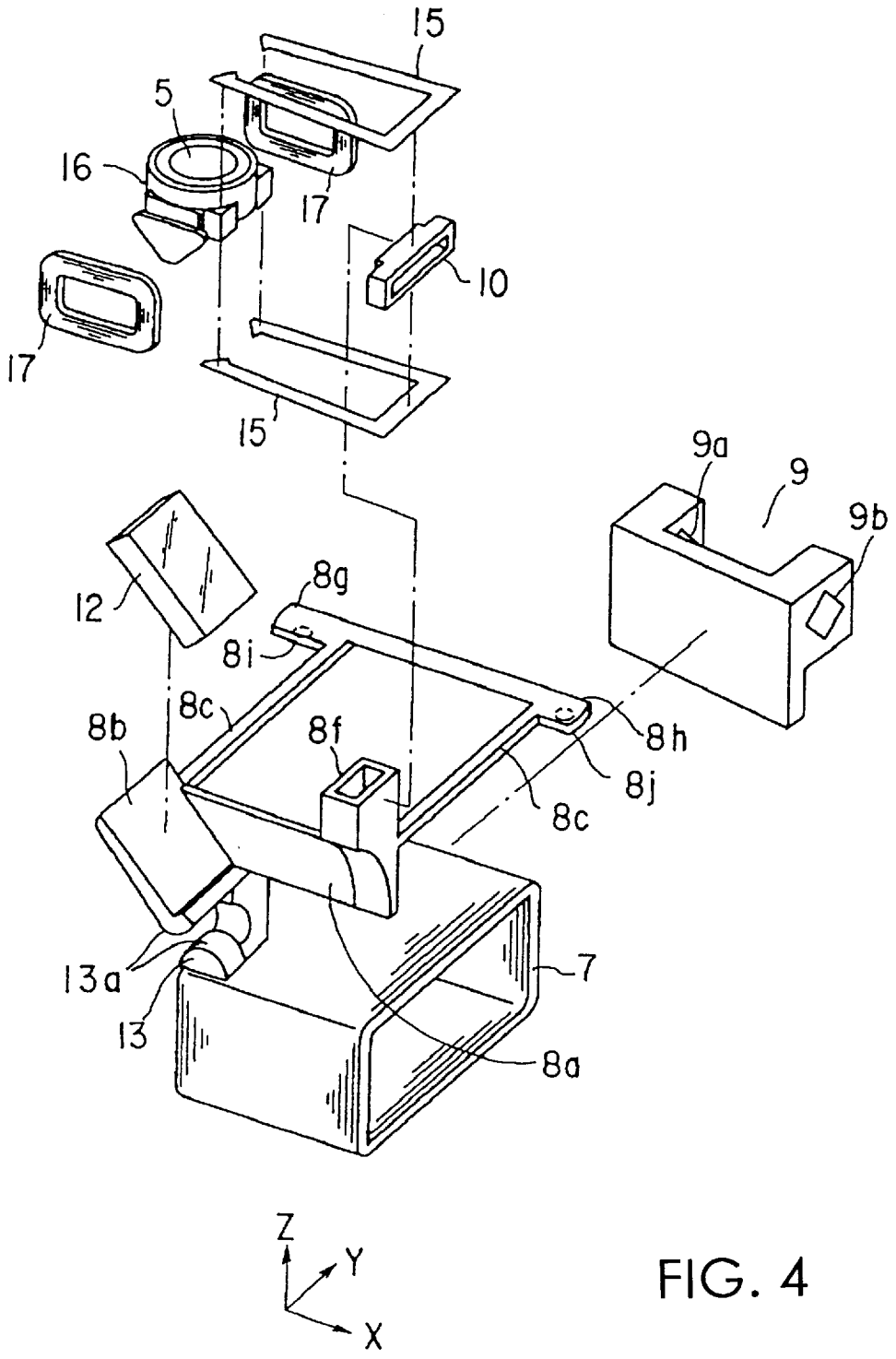
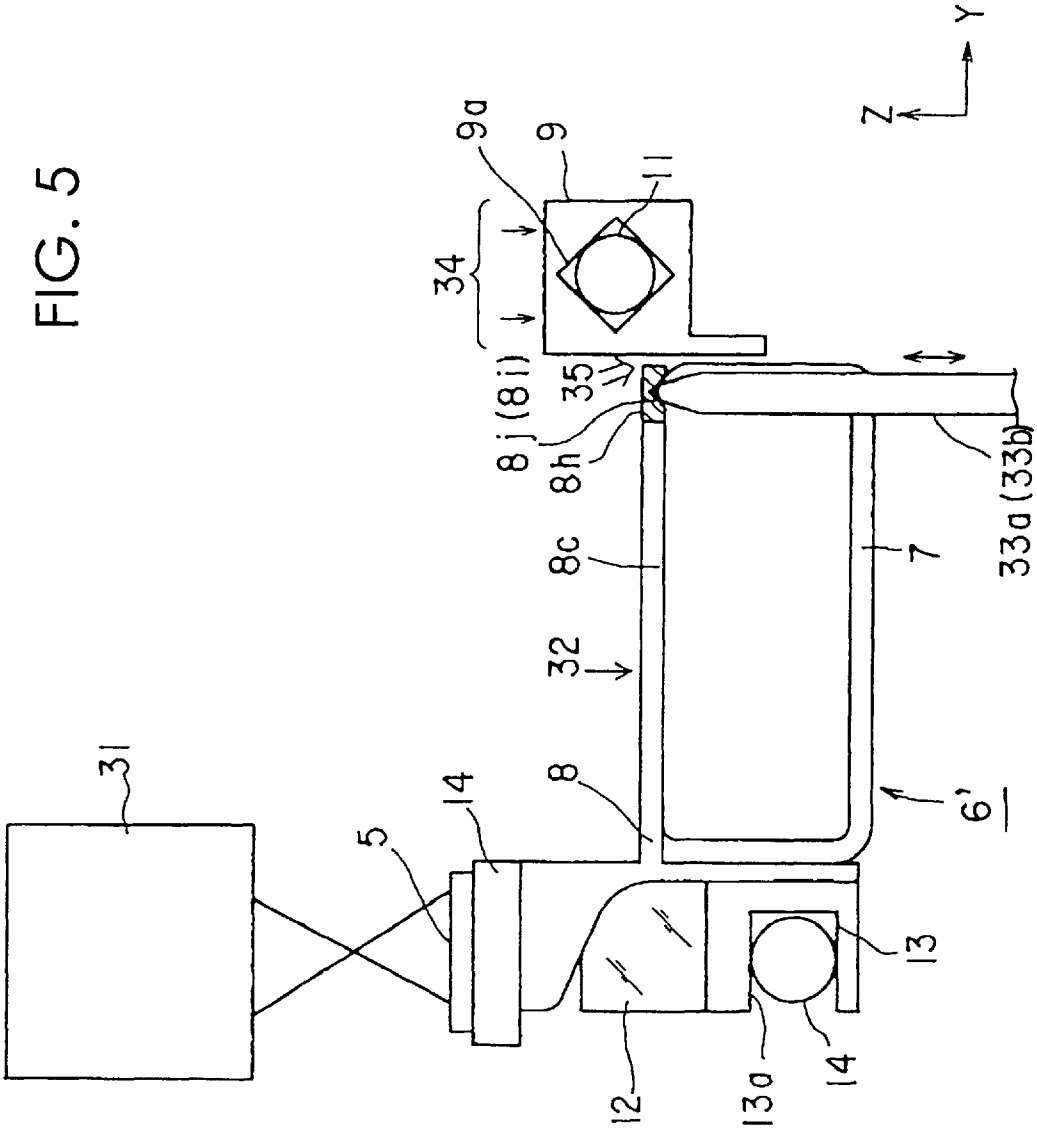


FIG. 4

FIG. 5



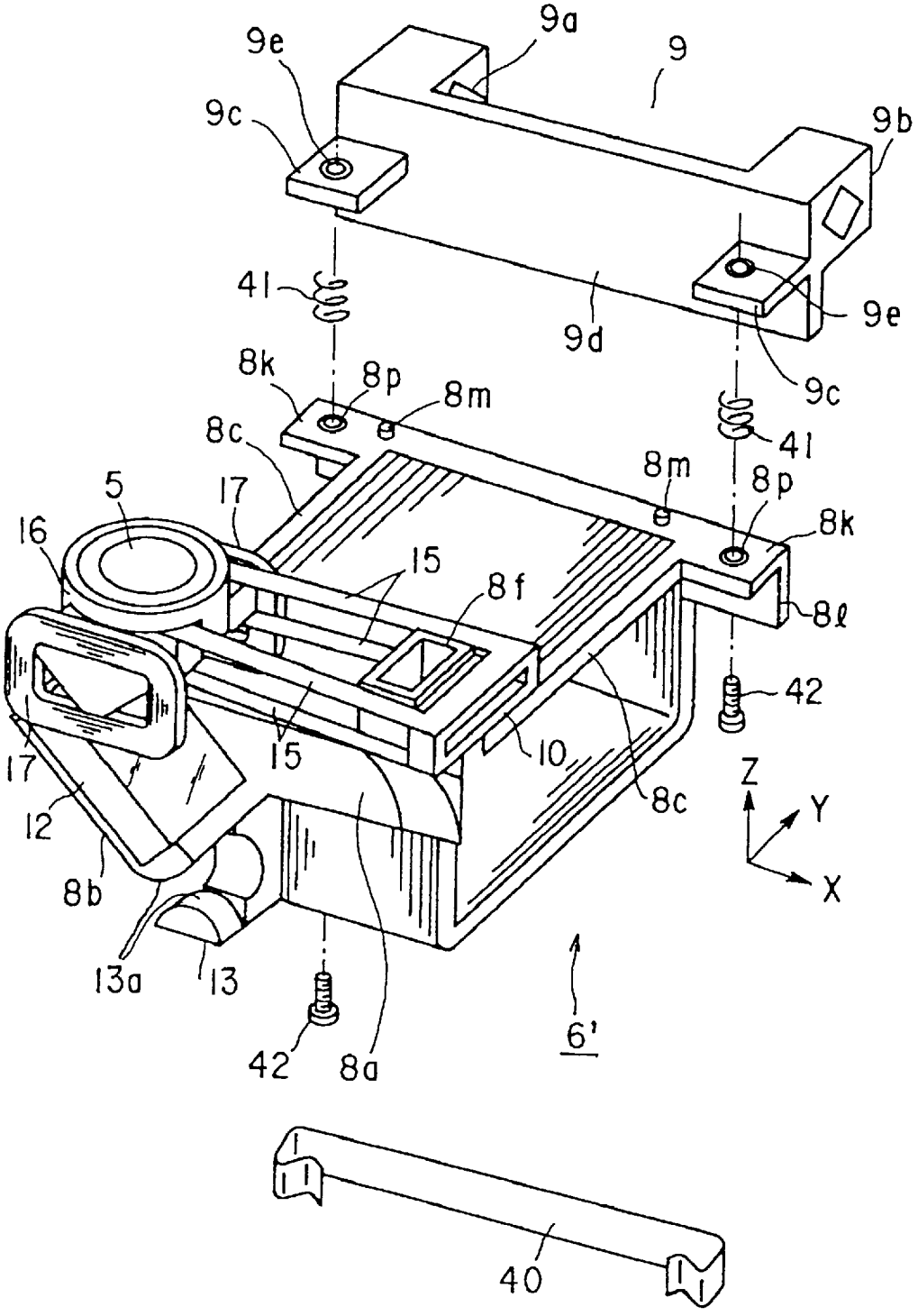

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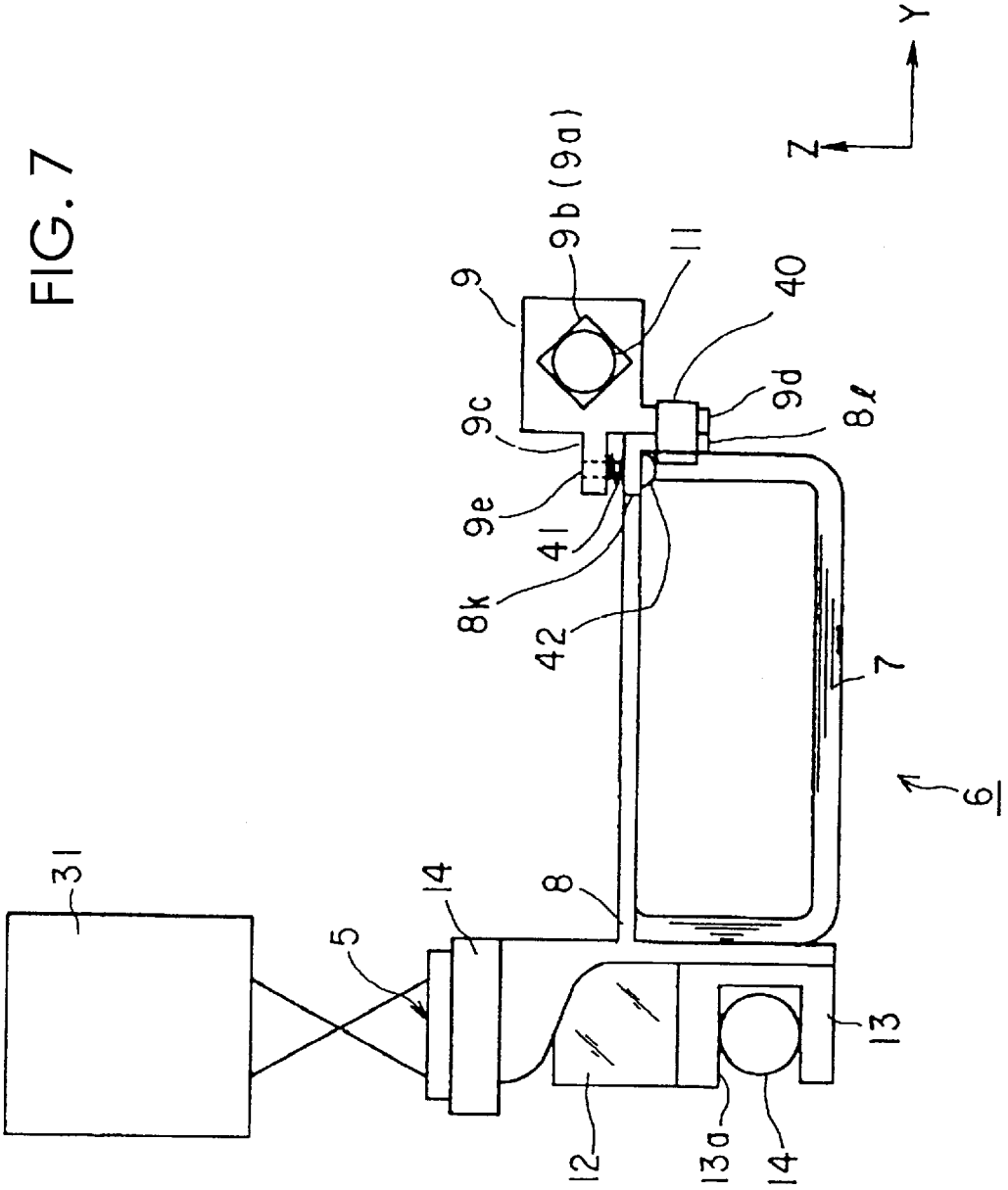
FIG. 6

FIG. 7



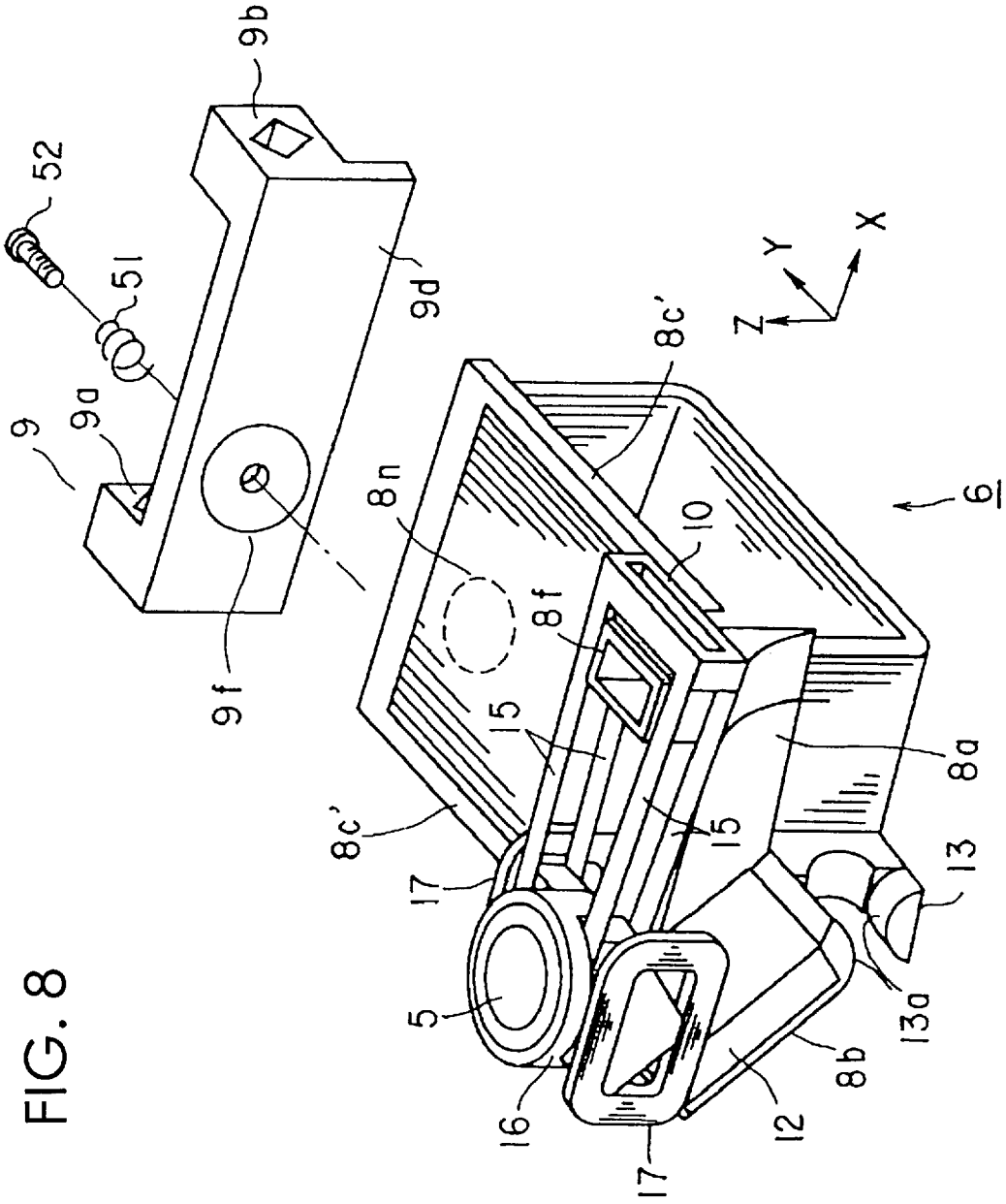


FIG. 8

FIG. 9

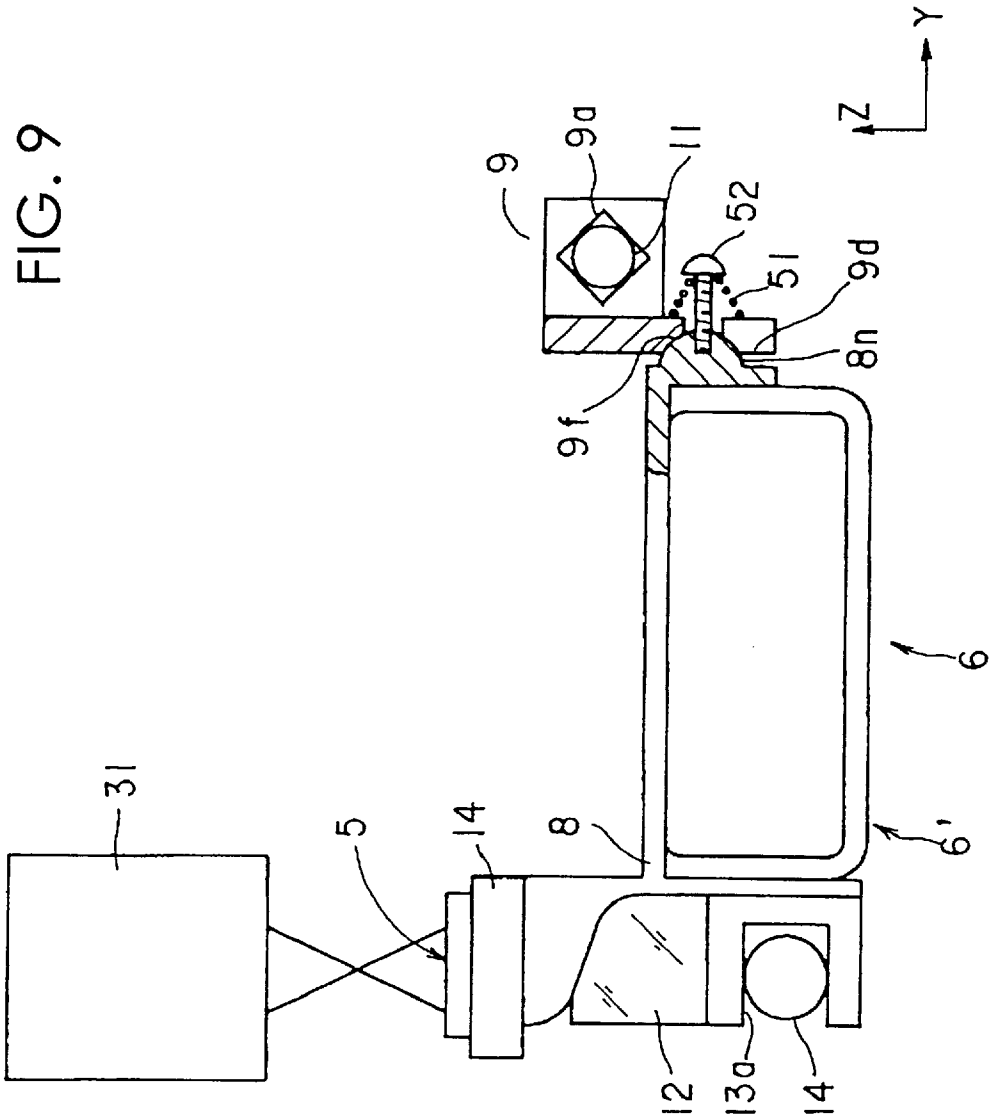
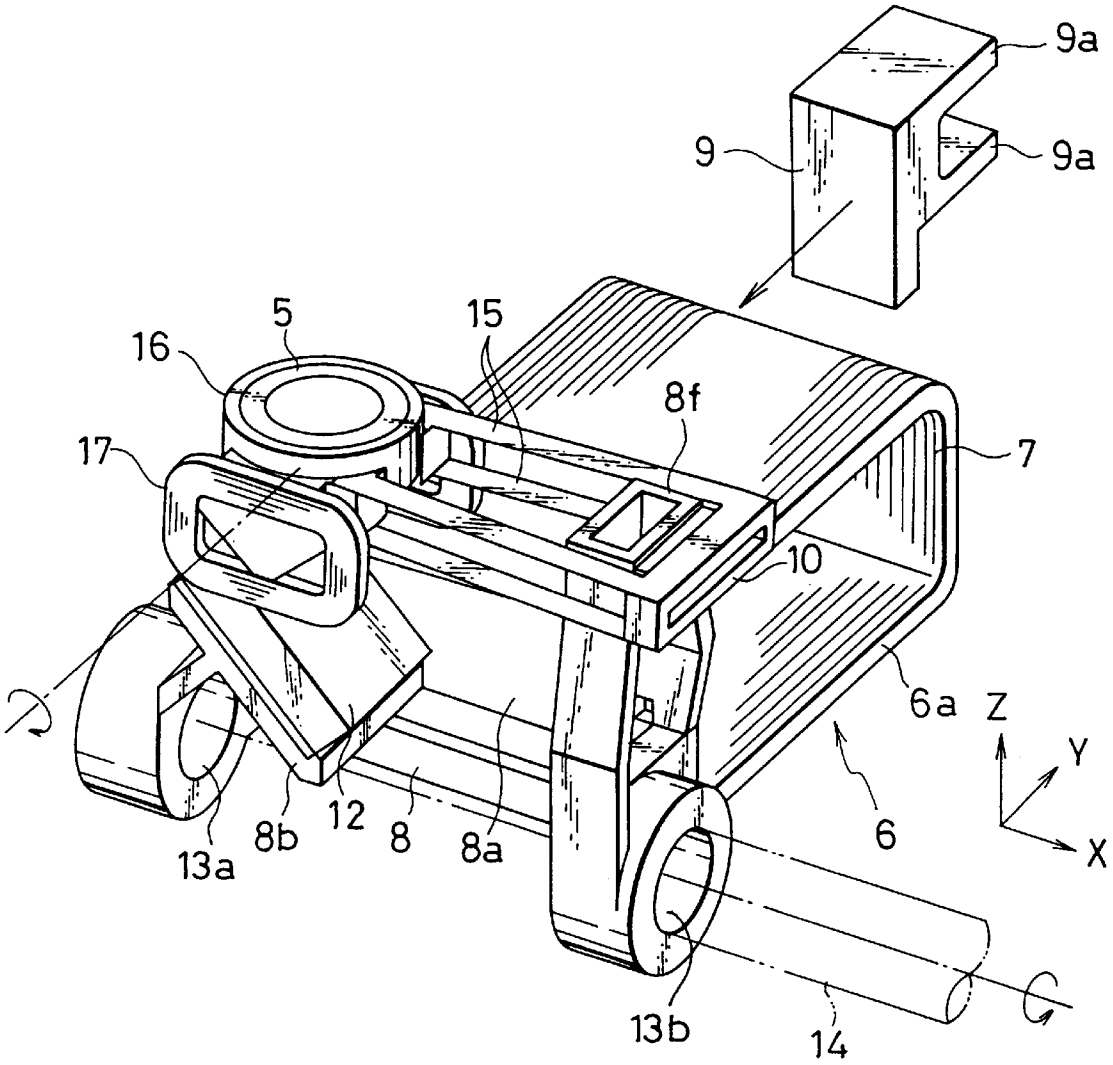


FIG.10



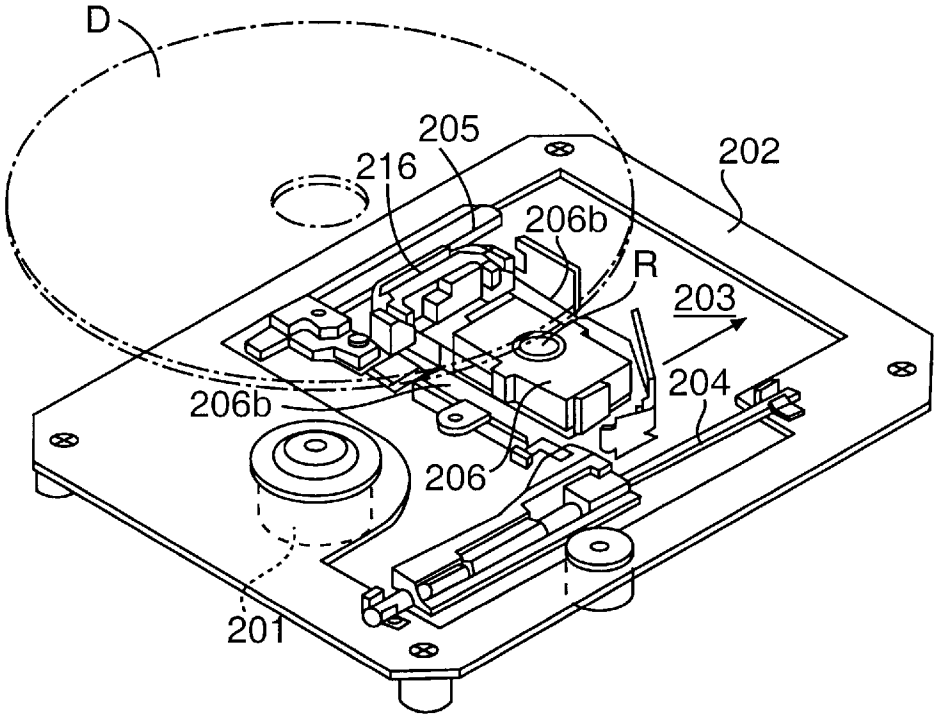


FIG. 11
(PRIOR ART)

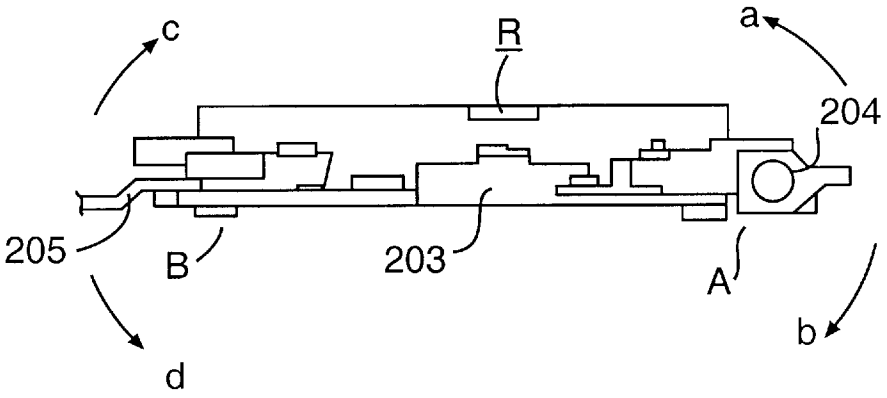


FIG. 12
(PRIOR ART)

OPTICAL RECORDING AND/OR REPRODUCING APPARATUS HAVING OBJECTIVE LENS ADJUSTING MECHANISM

This is a continuation of application Ser. No. 08/584,463, filed Jan. 11, 1996, now abandoned.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to an optical recording and/or reproducing apparatus for recording information on an optical recording medium such as a magneto-optical disk or a compact disk and/or reproducing information recorded on such a medium, and more particularly to an optical recording and/or reproducing apparatus having an objective lens adjusting mechanism.

2. Description of the Related Art

In an optical recording and/or reproducing apparatus, light emitted from a laser beam source is focused on a signal recording surface of an optical recording medium by an objective lens to record and/or reproduce an information signal. If the optical axis of the objective lens is inclined with respect to the signal recording surface, coma is caused so that the signal cannot be recorded and/or reproduced well. Therefore, there have been used various mechanisms for adjusting the two-directional inclination of the optical axis of the objective lens with respect to the signal recording surface.

FIGS. **11** and **12** show an example of a conventional optical pickup device having an adjusting mechanism disclosed in Japanese Laid-Open Patent Application Publication Hei 5-303749.

As shown in FIG. **11**, this optical pickup device has a supporting substrate **203** movable in a radial direction of an optical disk D rotated by a motor **201**. The supporting substrate **203** has a bobbin supporting member **216**, to which a lens bobbin **206** having an objective lens R is secured via a flexible member **206***b* such as a wire.

As shown in FIG. **12**, the supporting substrate **203** is movably supported on one side A thereof by a slide guide shaft **204** arranged on a subchassis **202** and on the other side B thereof by an inner edge **205** of the subchassis **202**. Each of the one side A and the other side B of the supporting substrate **203** is provided with a height adjusting mechanism. These two sets of height adjusting mechanisms cause the one side A to move in the direction of arrow a or arrow b about the slide guide shaft **204** and the other side B to move in the direction of arrow c or arrow d about the inner edge **205**, thereby adjusting the inclination of the objective lens R in a direction parallel to the paper without changing the height of the objective lens R.

SUMMARY OF THE INVENTION

The objective lens adjusting mechanism shown in FIGS. **11** and **12** can adjust the inclination in only one direction and cannot adjust the inclination in a direction perpendicular thereto. In order to do so, it is necessary to add another adjusting mechanism. Further, the two sets of adjusting mechanisms are used in order not to change the height of the objective lens at the time of adjusting the inclination. This results in a large optical pickup device. That is, the adjusting mechanism in FIGS. **11** and **12** is not suitable for a compact optical pickup device. Moreover, although the inclination in only one direction can be adjusted, the two sets of adjusting mechanisms are used. Thus, there is also the drawback that its production costs are high.

A primary object of this invention is to provide an optical recording and/or reproducing apparatus having an objective lens adjusting mechanism suitable for a compact optical pickup device.

An optical recording and/or reproducing apparatus according to this invention comprises a carriage for supporting an objective lens, and a guide, in which the carriage is movable along the guide. In order to attain the above object, the optical recording and/or reproducing apparatus further comprises an objective lens adjusting device for adjusting the inclination of the optical axis of the objective lens in the rotational directions about two axes perpendicular to the optical axis of the objective lens and to each other.

In order to attain the above object, another feature of this invention is that a fulcrum for adjusting the inclination of a carriage in a direction perpendicular to the optical axis of an objective lens is formed by bearings below the objective lens. Thus, there is the special advantage that the Z-directional position of the objective lens is scarcely changed at the time of inclination adjustment.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a perspective view of an information recording and/or reproducing apparatus having an objective lens adjusting mechanism according to a first embodiment of this invention.

FIG. **2** is a cross-sectional view of the information recording and/or reproducing apparatus in FIG. **1**.

FIG. **3** is a perspective view of a movable portion of the information recording and/or reproducing apparatus in FIG. **1**.

FIG. **4** is an exploded perspective view of the movable portion shown in FIG. **3**.

FIG. **5** is a side view of the movable portion shown in FIG. **3**.

FIG. **6** is a perspective view of a movable portion of an information recording and/or reproducing apparatus having an objective lens adjusting mechanism according to a second embodiment of this invention.

FIG. **7** is a side view of the movable portion shown in FIG. **6**.

FIG. **8** is a perspective view of a movable portion of an information recording and/or reproducing apparatus having an objective lens adjusting mechanism according to a third embodiment of this invention.

FIG. **9** is a side view of the movable portion shown in FIG. **8**.

FIG. **10** is a perspective view of a movable portion of an information recording and/or reproducing apparatus having an objective lens adjusting mechanism according to a fourth embodiment of this invention.

FIG. **11** is a perspective view of an optical pickup device having a conventional objective lens adjusting mechanism.

FIG. **12** is a side view of the optical pickup device shown in FIG. **11**.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to the drawings, the embodiments of this invention will be described in detail.

[First Embodiment]

Referring to FIGS. **1** to **5**, a first embodiment of this invention is described. This embodiment has an objective lens adjusting device for adjusting the inclination of the optical axis of the objective lens in the rotational directions about two axes perpendicular to the optical axis of the objective lens and to each other.

FIGS. **1** to **5** show a first embodiment of this invention applied to a coarse access driving device of an objective lens of an information recording and/or reproducing apparatus using a magneto-optical disk as a recording medium.

As shown in FIG. **1** (a perspective view of the whole apparatus), a spindle motor **3** for rotating a disk **2** is fixed to a deck base **1**, and the disk **2** is positioned in a cartridge **4** having an opening **4***a* at its center (FIG. **2**). A movable portion **6** having an objective lens **5** is movably supported so as to be driven with respect to the deck base **1** in the X direction, as described below. Further, a fixed optical system **30** having a laser, a light detector and the like is fixed on the deck base **1**.

Furthermore, as shown in FIG. **3** (a perspective view of the movable portion) and FIG. **4** (an exploded perspective view of the movable portion), the movable portion **6** is provided at its center with an access coil **7** wound in the form of a square pole, and the access coil **7** mainly contributes to the rigidity of the entire movable portion **6**. A carriage **8** provided on the access coil **7** is formed of an epoxy resin including spherical silica and has a fixing portion **8***a* bonded to the Y(−) side surface of the access coil **7**, and the fixing portion **8***a* reinforces the Y(−) side surface of the access coil **7**.

A bearing portion **9** on a reference side is bonded and fixed to the Y(+) side surface of the access coil, as described below, and is provided with bearings **9***a* and **9***b*, into which a guide rail **11** (FIG. **1**) is inserted with both ends thereof fixed on the deck base **1**. The fixing portion **8***a* is provided on its Y(−) side with a fixing portion **8***b* for a mirror, to which a mirror **12** is bonded and fixed. The light reflected by the mirror enters the lens **5**.

A bearing portion **13** on a driven side is positioned under the mirror **12** of the fixing portion **8***a*, and a guide rail **14** (FIG. **1**) is inserted into a U-shaped bearing **13***a* of the bearing portion **13**. The guide rails **11** and **14** are made of silicon carbide ceramic, or stainless steel with fluoride coating. The fixing portion **8***a* and a connecting portion **8***c* are integrated into the carriage **8**, and the access coil **7** mainly contributes to the rigidity between the bearing portions **9** and **13**. The carriage **8** may be formed by inserting the access coil **7**.

A fixing portion **8***f* is formed on the Z(+) side of the fixing portion **8***a*. The X(−) side surface of a holding member **10** abuts on the X(+) side of the fixing portion **8***f* to be positioned properly and is bonded and fixed.

A spring **15** hanged between the holding member **10** and a holder **16** is formed by cutting a thin sheet of stainless steel in a substantial U-shape by a press. A pair of springs **15**, the holding member **10**, and the holder **16** are integrated by insert formation using plastic.

The lens **5** is secured at the center of the holder **16**, and a focus coil **17** wound in a rectangular shape is secured on each of both sides of the holder **16** in the Y direction.

The holding member **10**, the springs **15**, the holder **16**, the focus coils **17**, and the objective lens **5** form an objective lens supporting device.

As shown in FIG. **2** (a cross-sectional view showing magnetic circuits), in the space inside the access coil **7**, there is arranged a center yoke **19** with a short ring **18** fixed around it. A magnet **20** is arranged so as to form a magnetic gap with the center yoke **19** and is fixed inside (on the Z(−) side) of a side yoke in a substantial U-shape. Both ends of the side yoke **21** abut on respective ends of the center yoke **19** to form a magnetic circuit for access.

On the Y(−) side surface of the side yoke **21**, a magnet **22** is fixed so as to face a lower side **17***a* of the focus coil **17** on the Y(+) side. A magnet **23** is fixed to a yoke **24** so as to face a lower side **17***a* of the focus coil **17** on the Y(−) side. The yoke **24** is fixed on the deck base **1**.

Next, an operation of the first embodiment so constructed will be described. As shown in FIG. **2**, a magnetic field acts on the upper and lower sides of the focus coil **17** in opposite Y directions. When an electric current flows through the focus coil **17**, a force in the Z direction is produced in these two sides to drive the lens **5** in the Z direction. At this time, the springs **15** bend to drive the lens **5** in the Z direction.

Further, a force in the X direction is produced in the access coil **7** by the magnet **20** to drive the movable portion **6** in the X direction. At this time, the bearings **9***a*, **9***b* and **13***a* and the guide rails **11** and **14** cooperate to slide the movable portion **6** slides in the X direction.

Since the directions of magnetization of the magnets **20**, **22** and **23** are set as shown in FIG. **2**, the leakage flux from the magnets **22** and **23** near the light spot formed by the lens **5** on the optical disk **2** is in the Y(+) direction whereas the leakage flux from the magnet **20** is in the Y(−) direction, thereby cancelling each other. Thus, the leakage flux near the light spot formed by the lens **5** on the optical disk **2** is reduced a little in the Y direction. Therefore, it does not affect so much a magnetic field generating means (not shown) for generating a magnetic field near the light spot on the optical disk **2** at the time of erasing and/or recording information.

Since the side yoke **21** is positioned in the opening **4***a* of the disk cartridge **4**, the side yoke **21** can be brought near the optical disk **2** to reduce the height of the electromagnetic driving device.

As shown in FIG. **4**, since the carriage **8** is composed of the bearing portion **13**, the fixing portion **8***b* for fixing the mirror **12**, the fixing portion **8***a*, the connecting portions **8***c*, and projecting portions **8***g* and **8***h*, its structure is simple. Further, since the access coil **7** mainly contributes to the rigidity between the projecting portions **8***g* and **8***h* and the bearing portion **13**, it is sufficient for the connecting portion **8***c* to have such a dimension that a resin can flow at the time of its formation and thus the mass of this portion may be small.

When the movable portion **6** is driven in the X direction, the warping deformation in the X and Z directions, the twisting deformation about the Y axis or the like of the entire movable portion **6** is a cause of resonance. However, since the rigidity of the entire movable portion **6** is derived from the access coil **7** whose rigidity is high, there is no problem. Further, since the access coil **7** is made of an alloy of copper and aluminum, its elastic modulus is higher than plastic so that the frequency of resonance can be high.

A coil-moved electromagnetic driving device requires a coil in its movable portion. In this invention, since the coil is formed as a main structural member and contributes to the rigidity of the entire device, the carriage as another main structural member may be minimal.

Now, the main features of this invention will be explained.

As can be seen from FIGS. **2** and **3**, the bearing **13***a* of the bearing **13** on the driven side has cylindrical surfaces to

contact the guide rail **14**. Thus, the guide rail **14** point-contacts the bearing **13***a*. The guide rail **14** is at the same position as the objective lens **5** in the Y direction. The position of the bearing **13***a* in the X direction is near that of the objective lens **5**.

The connecting portions **8***c* are provided on its Y(+) side with the projections **8***g* and **8***h* protruding outward in the X direction. The projections **8***g* and **8***h* are provided in their Z(−) side surfaces with conical recesses **8***i* and **8***j* having an apex angle of about 90° to 120°.

The angle θ formed by the recess **8***i*, the bearing **13***a* and the recess **8***j* is about 90°. The angle θ may be about 60**20** to 120°. However, the more the angle θ is away from 90°, the larger the below-mentioned crosstalk at the time of inclination adjustment becomes. Thus, in order to make adjusting operation easily, it is preferable that the angle θ is near 90°.

The bearing portion **9** on the reference side is formed independently of the carriage **8** and provided with two bearings **9***a* and **9***b* spaced apart in the X direction and whose cross-section is a square tilted by 45°.

Next, the assembly and inclination adjustment of the movable portion will be described.

The bearing portion **9** and an assembly **6'** of the movable portion **6** excluding the bearing portion **9** are mounted on the deck base **1** together with the guide rails **11** and **14**.

As shown in FIG. **5**, the assembly **6'** is supported on the Y(−) side by the guide rail **14** contacting the bearing **13***a* at a point on the Z(+) side and is supported on the Y(+) side by two adjusting pins **33***a* and **33***b* having spherical tips fitted into the recesses **8***i* and **8***j*, respectively, from the Z(−) side. At this time, in order that the assembly **6'** is stable with respect to the guide rail **14** and the adjusting pins **33***a* and **33***b*, the center of the assembly **6'** is pressed from the Z(+) side by a spring or the like, as indicated by arrow **32**.

The deck base **1** is fixed to a jig (or adjusting means) base (not shown), and the adjusting pins **33***a* and **33***b* are stable in the X and Y directions and movable only in the Z direction on the jig base.

The position with respect to and rotation about the X, Y and Z axes of the assembly **6'** are determined by the two adjusting pins **33***a* and **33***b* and the guide rail **14**.

The bearing portion **9** is positioned with a small gap **35** from the access coil **7** in the Y direction and pressed to the guide rail **11** by a spring or the like from the direction indicated by arrows **34**, and its position with respect to and rotation about the X, Y and Z axes are determined.

Light is emitted from the laser of the fixed optical system **30** to enter the objective lens **5** via the mirror **12**, and the light from the objective lens **5** is made incident on a detecting optical system **31**, such as a television camera. Then, in order to correct the comatic aberration of the light from the objective lens which is detected by the detecting optical system **31**, the adjusting pin **33***a* or **33***b* is moved up and down to adjust the relative vertical position of the assembly **6'** with respect to the bearing portion **9** thereby adjusting the inclination of the objective lens **5** in two directions perpendicular to the optical axis of the objective lens **5** parallel to the Z direction and perpendicular to each other, that is, the inclination of the objective lens **5** with respect to the disk **2**. Specifically, the α and β axes in FIG. **3** are in the XY plane and displaced by 45° from the X and Y axes which are perpendicular to each other. When the adjusting pin **33***a* is moved up and down, the assembly **6'** rotates about the α axis, and when the adjusting pin **33***b* is moved up and down, the assembly **6'** rotates about the β axis.

After the comatic aberration is corrected, an adhesive **35** is injected into the gap **36** between the access coil **7** and the bearing portion **9** to fix the bearing portion **9** to the assembly **6'**.

As described above, since there is provided the objective lens adjusting mechanism in which the fixed side of the objective lens supporting member can be fixed to the bearing on the reference side (defining at least two points in the guide direction) after its inclination is adjusted in two directions perpendicular to the optical axis of the objective lens and substantially perpendicular to each other, the following advantages can be obtained:

1. The objective lens supporting device and the movable part of the optical pickup need not be provided with any spherical surface, vis, spring and the like for inclination adjustment. Therefore, the objective lens supporting device and the movable portion can be compact, thin and light, and their production costs can be low.
2. Since the center of inclination (bearing **13***a*) of the objective lens is positioned almost under the objective lens, the objective lens is scarcely moved in the Z direction even though the inclination is adjusted by one set of adjusting mechanism. Although the objective lens is moved in the X and Y directions at the time of inclination adjustment, the amount of movement in the X and Y directions can be small, that is, 0.1 mm or less with respect to an inclination adjustment of 0.5° , since the bearing **13***a* can be arranged under the objective lens at a distance of, for example, about 5 to 10 mm. Further, since the bearing **13***a* is positioned almost under the objective lens, the distance between the bearing **13***a* and the bearings **9***a* and **9***b* can be small, and the movable portion of the optical pickup can be compact especially in the Y direction and also can be light.
3. The inclination of the objective lens can be adjusted by one adjusting mechanism in two directions perpendicular to its optical axis and to each other. Thus, no other adjusting mechanisms are necessary, the movable portion of the optical pickup can be compact and light, and its production costs can be low.
4. Since the bearing **13***a* on the driven side as the center of inclination adjustment (fulcrum) is formed as cylindrical surfaces and point-contacts the guide rail **14**, even if the inclination of the assembly is adjusted in two directions, the contacting state of the bearing **13***a* and the guide rail **14** does not change although their contacting point is shifted a little. Thus, their sliding performance does not change.

If the bearing **13***a* were formed as, for example, planes parallel to the XY plane, the state of contact, such as the place and length, would change.

Since the position with respect to and rotation about the X, Y and Z axes of the assembly **6'** are determined by the two recess **8***i* and **8***j*, the assembly **6'** can be precisely positioned with respect to the guide rail even if it does not have the bearing portion **9** on the reference side.

This invention is not limited to the above embodiment, and various modifications may be made without departing from the spirit and scope thereof. For example, the following modifications are naturally covered by this invention:

Although the embodiment employs a sliding bearing, other bearings such as a radial bearing may be used.

In the embodiment, the movable portion is electromagnetically driven. However, a rack and pinion, a lead screw or the like may be employed. The guide rail may be formed integrally with the yoke or the deck base.

Although in the embodiment the laser and the like are separated from the movable portion, all the optical system such as a laser may be arranged in the movable portion **6**.

In the embodiment, the mirror **12** is arranged in the assembly **6'** whose inclination is adjusted with respect to the guide rails **11** and **14**. However, the bearing **9** remaining fixed at the time of inclination adjustment may be provided with a mounting portion, to which the mirror may be fixed.

In the embodiment, the inclination of the assembly **6'** is adjusted about two axes perpendicular to the optical axis of the objective lens and to each other. However, it may be adjusted about the X and Y axes by interlocking the two adjusting pins **33***a* and **33***b* with each other, the bearing **13***a* being the center of rotation.

Although the embodiment uses a supporting spring for supporting the objective lens in the focus direction (Z direction) only, the supporting spring and the like may be formed as movable in the focus and tracking directions.

In the embodiment, the adjusting pins **33***a* and **33***b* contact the recesses **8***i* and **8***j* of the projecting portions **8***g* and **8***h*, respectively. However, the pins may abut on the Z(−) side of the access coil **7** at two points which are on the Y(+) side and near the opposite ends in the X direction (in FIG. **3**, the points on the access coil **7** near the adjusting pins **33***a* and **33***b*) to adjust the inclination. In this case, the connecting portions **8***c* and the projecting portions **8***g* and **8***h* of the carriage **8** are not necessary and thus the carriage **8** can be further minimized.

Moreover, in the embodiment, the magnetic circuit for driving the objective lens in the focus direction is arranged on the deck base which is a fixed portion with respect to the movable portion. However, it may be arranged on the movable portion.

In this embodiment, the height can be adjusted at two points spaced apart in the direction of movement of the bearing, and the bearing on the driven side serves as the fulcrum of inclination adjustment. Thus, this embodiment can provide an adjusting mechanism in which no special fulcrum of inclination adjustment is necessary and is effective in making an optical pickup compact and light.

[Second Embodiment]

Referring to FIGS. **6** and **7**, a second embodiment of this invention will now be described. In the drawings, the same members as those already explained in the first embodiment are indicated by the same reference numerals and letters. Mainly, the features particular to this embodiment will be described below.

A carriage **8** is provided on its Y(+) side with fitting portions **8***l* and **8***k* having a cross-sectional shape of L.

A bearing portion **9** is provided with a fitting portion **9***c* protruding in the Y(−) direction and a fitting portion **9***d* protruding in the Z(−) direction.

The bearing portion **9** and the carriage **8** are pinched by a spring **40** so as to move relative to each other with the fitting portions **8***l* and **9***d* contacting to each other.

Two screws **42** are screwed through holes **8***p* into threaded holes **9***e* with compression springs **41** interposed between the fitting portions **8***k* and **9***c*. The space between the fitting portions **8***k* and **9***c* can be adjusted by rotating the two screws **42**.

The X-directional position of the bearing portion **9** with respect to the carriage **8** is defined by two bosses **8***m* contacting the insides of the fitting portions **9***c*.

The angle formed by the hole **8***p*, a bearing **13***a* and the hole **8***p* is set to be about 90°, thereby facilitating the adjustment of inclination of the optical axis of the objective lens. The angle θ may be about 60° to 120°. However, the more the angle θ is away from 90°, the larger becomes the crosstalk at the time of inclination adjustment, that is, the amount of inclination in the other adjusting direction at the time of the adjustment in one direction. Thus, in order to make adjusting operation easily, it is preferable that the angle θ is near 90°.

By rotating the two screws **52** of a movable portion **6** mounted on a deck base together with guide rails **11** and **14**, the relative vertical position of an assembly **6'** with respect to the bearing portion **9** can be adjusted to adjust the inclination of an objective lens **5** in two direction perpendicular to the optical axis of the objective lens and to each other.

In order that bearings **9***a*, **9***b* and **13***a* and the guide rails **11** and **14** remain stable at the time of assembly, the bearing portion **9** and the assembly **6'** may be press lightly in the Z(−) direction.

As described above, the fixed portion of the objective lens supporting member is coupled to the bearing on the reference side at two points whose height can be adjusted, and the two points and the bearing on the driven side form an approximately right angle.

This embodiment has the following advantages:

1. Compared with the first embodiment, while the movable portion includes the screws etc. and is heavier, the structure of the inclination adjusting jig is simpler.
2. Since the inclination adjusting mechanism is arranged in a place around the bearing and having enough space, it can be arranged in the movable portion of an optical pickup even if the objective lens supporting device is small.

b **3**.Except for advantage 1 of the first embodiment, this embodiment has the same advantages as those of the first embodiment. Also, the same modifications can be made as the first embodiment.

[Third Embodiment]

Next, referring to FIGS. **8** and **9**, a third embodiment of this invention will be described.

A carriage **8** is provided on its Y(+) side with a semi-spherical convex portion **8***n*. The convex portion **8***n* is at the same position in the X direction as a bearing **13***a*.

A bearing portion **9** is provided on its Y(−) side with a semi-spherical concave portion **9***f* in surface-engagement with the convex portion **8***n*.

The convex portion **8***n* is contacted to the concave portion **9***f*, and a screw **52** is screwed into a threaded hole of the convex portion **8***n*. A compression spring **51** is interposed between the screw **52** and the bearing portion **9**.

Thus, the carriage **8** and the bearing portion **9** are temporarily held by the spring **51** and the screw **52** with the convex portion **8***n* and the concave portion **9***f* being slidable.

In this state, a movable portion **6** is mounted on a deck base together with guide rails **11** and **14**. At this time, the X(−) side of a connecting portion **8***c'* on the X(−) side of an assembly **6'** abuts on a jig (or adjusting means) to prevent the assembly **6'** from being rotated about the Z axis.

The inclination of an objective lens **5** about the X axis is adjusted by sliding the convex portion **8***n* and the concave portion **9***f* in the Z direction to incline the assembly **6'** about the X axis, with a bearing **13***a* being the center of inclination.

The inclination of the objective lens **5** about the Y axis is adjusted by sliding the convex portion **8***n* and the concave portion **9***f* about the screw **52** to rotate the assembly **6'** about the Y axis, with the bearing **13***a* being the center of rotation.

As described above, the bearing portion **9** and the assembly **6'** with the objective lens supporting member fixed are assembled by contacting the semi-spherical portions **8***n* and

9*f* to each other, whereby the inclination of the assembly with respect to the bearing portion on the reference side can be adjusted about two axes perpendicular to the optical axis of the objective lens and to each other.

It is preferable that the X directional position of the centers of the convex portion **8***n* and the concave portion **9***f* is coincident with the bearing **13***a* and the optical axis of the objective lens **5**. In this case, there is the advantage that the Z-directional position of the objective lens **5** is scarcely changed at the time of the inclination adjustment around the Y axis.

Further, it is preferable that the Z directional position of the centers of the convex portion **8***n* and the concave portion **9***f* is coincident with a nodal point of the objective lens **5**. In this case, there is the advantage that the objective lens **5** is not moved in the Z and X axes at the time of the inclination adjustment around the Y axis.

In the first, second and third embodiments, since the bearing on the driven side serving as the fulcrum for inclination adjustment is substantially aligned with the optical axis of the objective lens, the objective lens is moved scarcely in the direction of its optical axis at the time of inclination adjustment.

According to the embodiments of this invention, the inclination of the optical axis of the objective lens can be adjusted in the rotational directions about two axes perpendicular to the optical axis of the objective lens and to each other. Thus, this invention contributes to the reduction of the size and costs of the objective lens supporting device and the movable portion of the optical pickup device.

[Fourth Embodiment]

FIG. **10** shows a fourth embodiment of this invention. In the fourth embodiment, a fulcrum for adjusting the inclination of a carriage in a direction perpendicular to the optical axis of an objective lens is formed by bearings below the objective lens. Thus, there is the special advantage that the Z-directional position of the objective lens is scarcely changed at the time of inclination adjustment. In the drawing, the same members as those of the first embodiment are assigned the same reference numerals, and the description of the common structural parts is omitted.

A carriage **8** is provided with bearings **13***a* and **13***b* on a reference side below an objective lens **5**. A bearing portion **9** is provided with a bearing **9***a* on a driven side.

An assembly **6***a* is rotated about the X axis with a guide rail **14**, that is, the bearings **13***a* and **13***b* being the center of rotation, to adjust the inclination of the objective lens **5** about the X axis. At this time, since the center of rotation is below the objective lens **5**, the objective lens **5** is not moved in the Z direction. The X(+) side surface of a fixing portion **8***f* and the X(−) side surface of a holding member **10** are formed as cylindrical surfaces whose centers are on an axis passing through a nodal point of the objective lens **5** and parallel to the Y axis. The inclination of the objective lens **5** is adjusted about the Y axis by sliding the holding member **10** with respect to the fixing portion **8***f* in the Z direction.

What is claimed is:

1. An optical recording and/or reproducing apparatus for recording information on an optical recording medium and/or reproducing information recorded on said medium, the apparatus comprising:

an objective lens having an optical axis;

a carriage for supporting the objective lens;

a base;

first and second guide members fixed to the base for supporting the carriage movably in a first direction;

the carriage having first and second bearings to be guided by the first and second guide members, the carriage comprising a first portion having at least the objective lens and the first bearing, and a second portion having at least the second bearing; and

an objective lens adjusting device on said carriage for adjusting an inclination of the optical axis of the objective lens by rotating the first portion of said carriage, including the objective lens and the first bearing, with respect to the second portion of said carriage in rotational directions about two axes perpendicular to the optical axis of the objective lens and to each other, the first portion of the carriage, including the objective lens and the first bearing, being displaceable with respect to the second portion of the carriage.

2. The apparatus of claim **1**, in which the first bearing serves as a fulcrum for the rotation of the first portion, and the first portion is substantially aligned with the optical axis of the objective lens.

3. The apparatus of claim **1** in which the position of said objective lens in a direction along the optical axis is scarcely changed at the time of the inclination adjustment around one of the two axes.

4. The apparatus of claim **1** in which the objective lens is not moved in a direction parallel to the optical axis and about a first of said two axes at the time of the inclination adjustment around a second of the two axes.

5. An optical recording and/or reproducing apparatus for recording information on an optical recording medium and/or reproducing information recorded on said medium, the apparatus comprising:

a guide including first and second guide rails; and

a carriage movable along the guide;

the carriage comprising:

an objective lens having an optical axis; and

an objective lens adjusting device for adjusting an inclination of the optical axis in rotational directions about two axes perpendicular to the optical axes of the objective lens and to each other and said carriage including a fulcrum below the objective lens for inclining the objective lens and wherein said fulcrum contacts the first guide rail, and said adjusting device is disposed at a position spaced apart from the fulcrum.

6. The apparatus of claim **5**, in which the fulcrum has a cylindrical surface perpendicular to and contacting the first guide rail.

7. The apparatus of claim **6**, in which the fulcrum is a bearing arranged in the carriage and contacting the first guide rail.

8. The apparatus of claim **5** further comprising a guide receiving portion having a spherical concave portion for contacting the carriage; a spherical convex portion provided on the carriage for contacting the guide receiving portion; and biasing means for contacting the concave portion to the convex portion.

9. The apparatus of claim **5**, in which the adjusting device has first and second adjusting pins whose height is adjustable and which contact the carriage upward to adjust the inclination of the optical axis of the objective lens in rotational directions about said two.

10. The apparatus of claim **9**, in which the first adjusting pin, the fulcrum, and the second adjusting pin form an angle of about 90°.

11. The apparatus of claim **5** further comprising a bearing on the second guide rail; and first and second height-adjustable screws for coupling the bearing to the carriage.

12. The apparatus of claim **11**, in which the first screw, the fulcrum, and the second screw form an angle of about 90°.

13. An optical recording and/or reproducing apparatus for recording information on an optical recording medium and/or reproducing information recorded on said medium, the apparatus comprising:

an objective lens having an optical axis;

a carriage for supporting the objective lens;

a base;

first and second guide members fixed to the base for supporting the carriage movably in a first direction;

the carriage having first and second bearings to be guided by the first and second guide members, the carriage comprising a first portion having at least the objective lens and the first bearing, and a second portion having at least the second bearing; and

an objective lens adjusting device on said carriage for adjusting an inclination of the optical axis of the objective lens by rotating the first portion of said carriage with respect to the second portion of said carriage in rotational directions about two axes perpendicular to the optical axis of the objective lens and to each other, wherein the first bearing serves as a fulcrum for the rotation of the first portion, and the first portion is substantially aligned with the optical axis of the objective lens.

* * * * *

US005867592A

United States Patent [19]

Sasada et al.

[11] Patent Number: 5,867,592

[45] Date of Patent: Feb. 2, 1999

[54] **METHOD OF UTILIZING EDGE IMAGES OF A CIRCULAR SURFACE FOR DETECTING THE POSITION, POSTURE, AND SHAPE OF A THREE-DIMENSIONAL OBJECTIVE HAVING THE CIRCULAR SURFACE PART**

[75] Inventors: **Katsuhiro Sasada**; **Tomoharu Nakahara**; **Hidekazu Araki**, all of Kadoma, Japan

[73] Assignee: **Matsushita Electric Works, Ltd.**, Osaka, Japan

[21] Appl. No.: **907,161**

[22] Filed: **Aug. 6, 1997**

Related U.S. Application Data

[62] Division of Ser. No. 391,006, Feb. 21, 1995, Pat. No. 5,692,061.

[30] **Foreign Application Priority Data**

Feb. 23, 1994 [JP] Japan 6-025731
Dec. 20, 1994 [JP] Japan 6-317279

[51] **Int. Cl.**[6] **G06K 9/46**

[52] **U.S. Cl.** **382/154**; 382/199; 382/203

[58] **Field of Search** 382/103, 154, 382/197, 199, 202, 203; 356/12, 376, 377

[56] **References Cited**

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4-54409	2/1992	Japan	G01B 11/26
6-29695	4/1994	Japan	G01B 11/00

Primary Examiner—Andrew W. Johns
Attorney, Agent, or Firm—Burns, Doane, Swecker & Mathis, L.L.P.

[57] **ABSTRACT**

A method for recognizing a three-dimensional objective in which a two-dimensional image is obtained from the same viewing point as a distance image obtained by picking up the objective in a three-dimensional space and the two-dimensional image is utilized to previously limit an existence zone of the objective under detection for the distance image and to perform objective detecting operation over the partial distance image in the limited zone, thereby realizing a sufficiently high speed detection of, in particular, the three-dimensional objective.

14 Claims, 58 Drawing Sheets

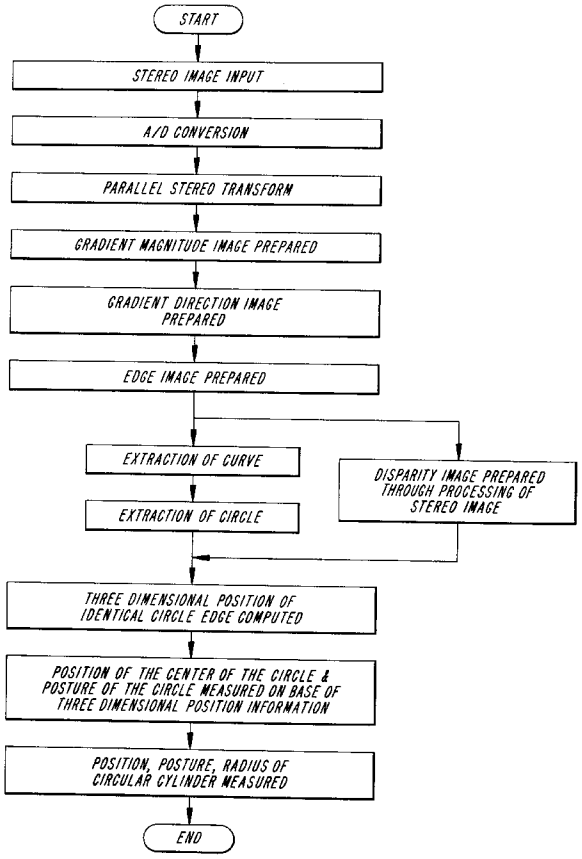


FIG. 1

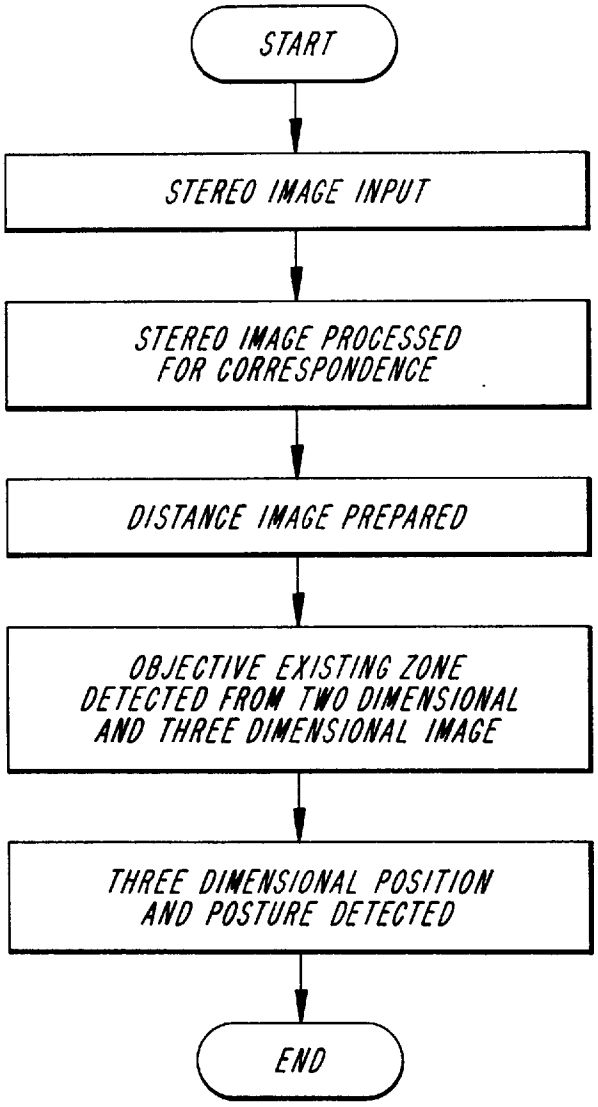

START
STEREO IMAGE INPUT
STEREO IMAGE PROCESSED FOR CORRESPONDENCE
DISTANCE IMAGE PREPARED
OBJECTIVE EXISTING ZONE DETECTED FROM TWO DIMENSIONAL AND THREE DIMENSIONAL IMAGE
THREE DIMENSIONAL POSITION AND POSTURE DETECTED
END

FIG. 2

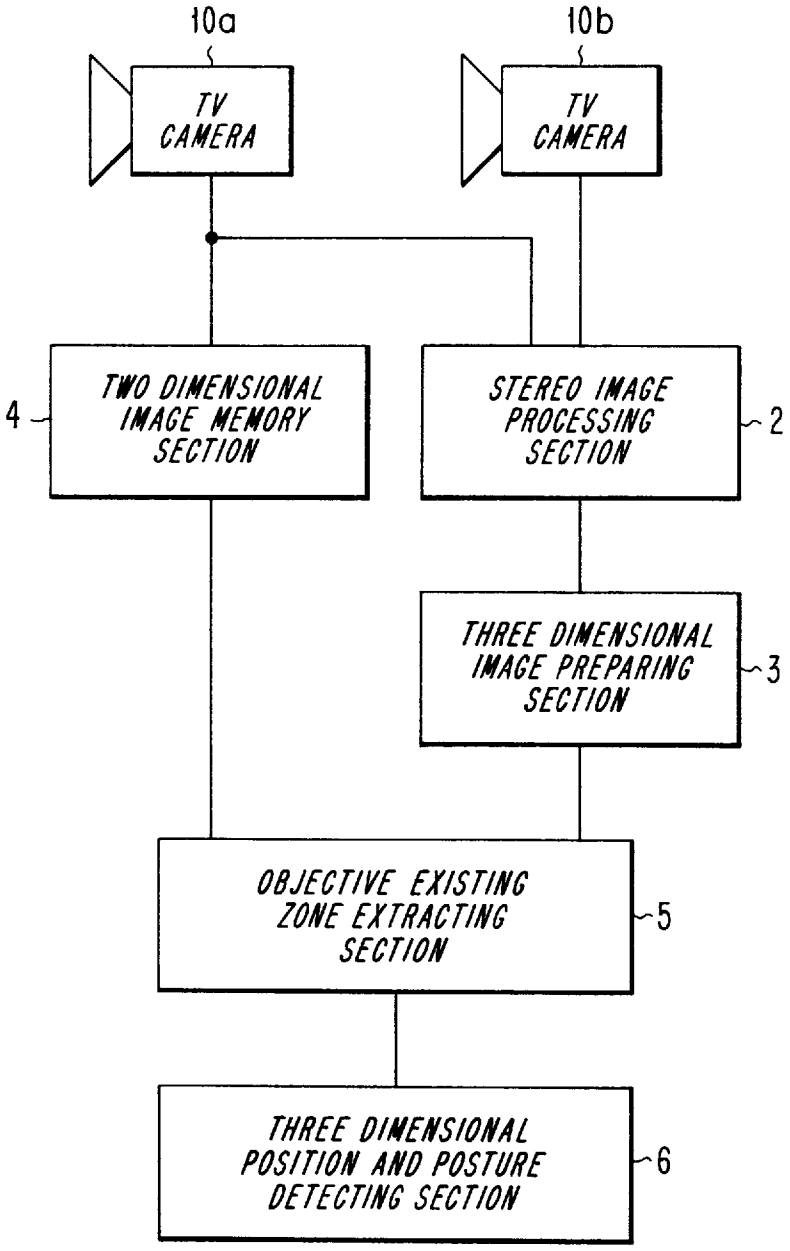

10a
10b
TV CAMERA
TV CAMERA
TWO DIMENSIONAL IMAGE MEMORY SECTION
4
STEREO IMAGE PROCESSING SECTION
2
THREE DIMENSIONAL IMAGE PREPARING SECTION
3
OBJECTIVE EXISTING ZONE EXTRACTING SECTION
5
THREE DIMENSIONAL POSITION AND POSTURE DETECTING SECTION
6

FIG. 3

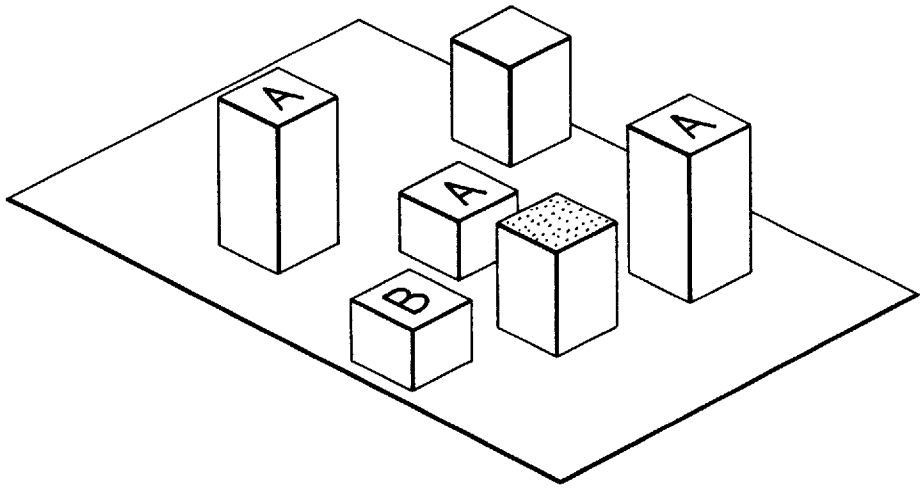


FIG. 4a

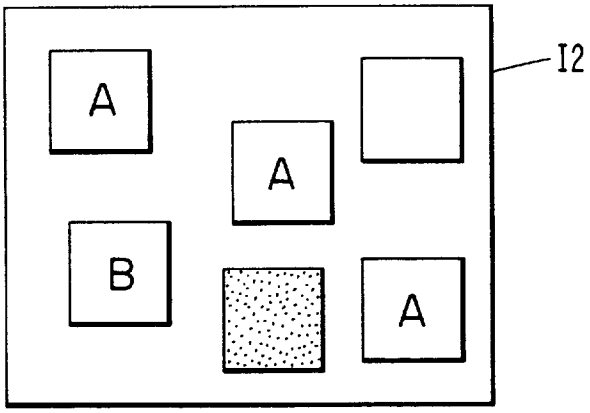


FIG. 4b

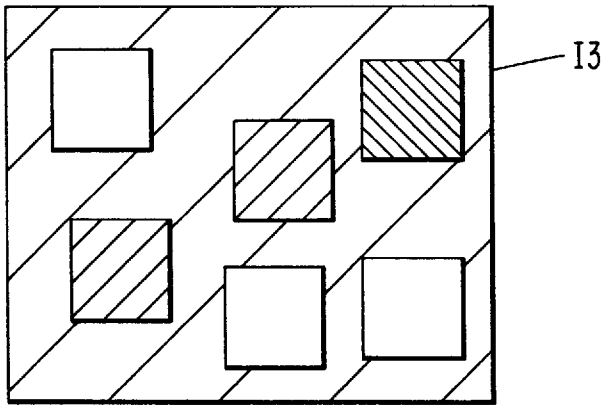


FIG. 5

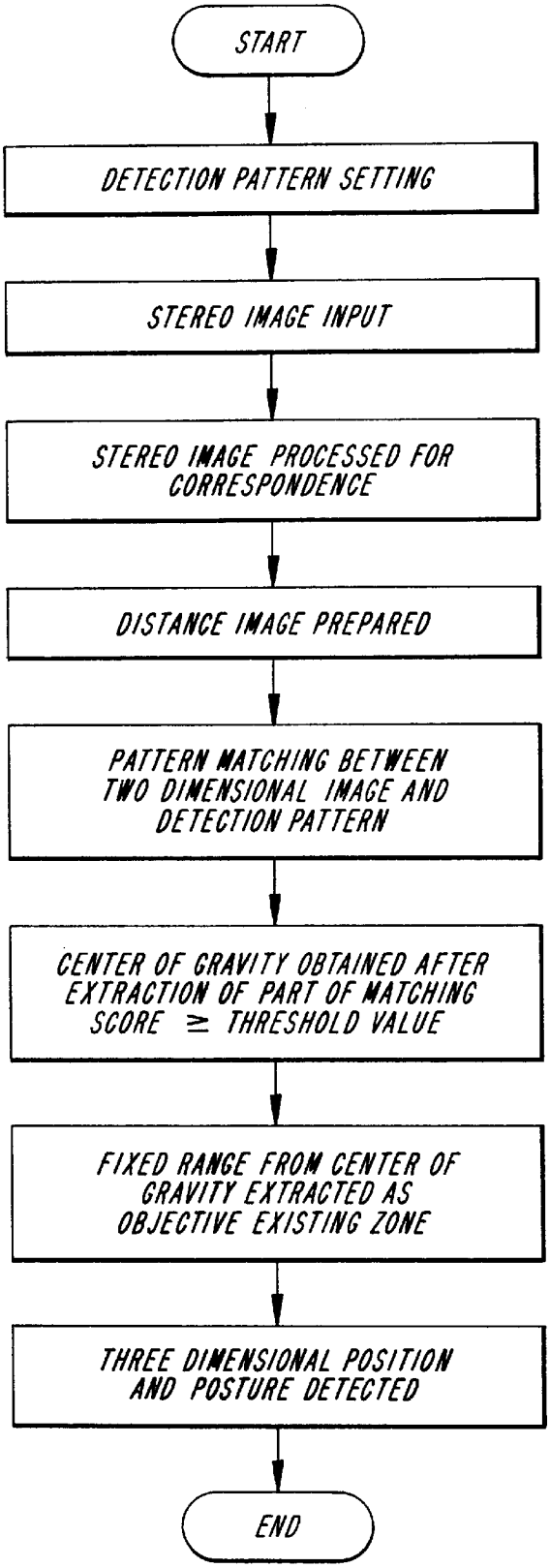

START
DETECTION PATTERN SETTING
STEREO IMAGE INPUT
STEREO IMAGE PROCESSED FOR CORRESPONDENCE
DISTANCE IMAGE PREPARED
PATTERN MATCHING BETWEEN TWO DIMENSIONAL IMAGE AND DETECTION PATTERN
CENTER OF GRAVITY OBTAINED AFTER EXTRACTION OF PART OF MATCHING SCORE ≥ THRESHOLD VALUE
FIXED RANGE FROM CENTER OF GRAVITY EXTRACTED AS OBJECTIVE EXISTING ZONE
THREE DIMENSIONAL POSITION AND POSTURE DETECTED
END

FIG. 6

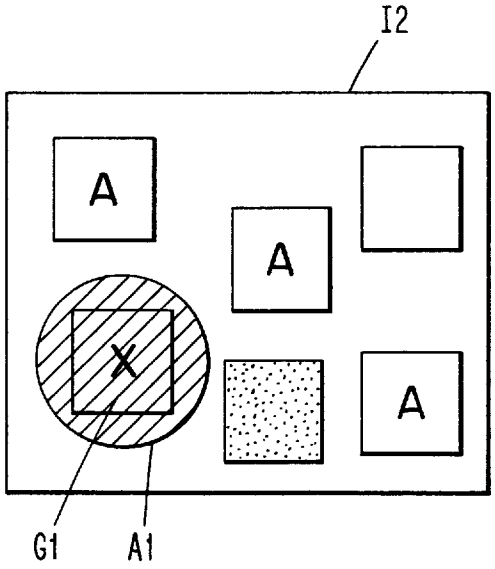


FIG. 8

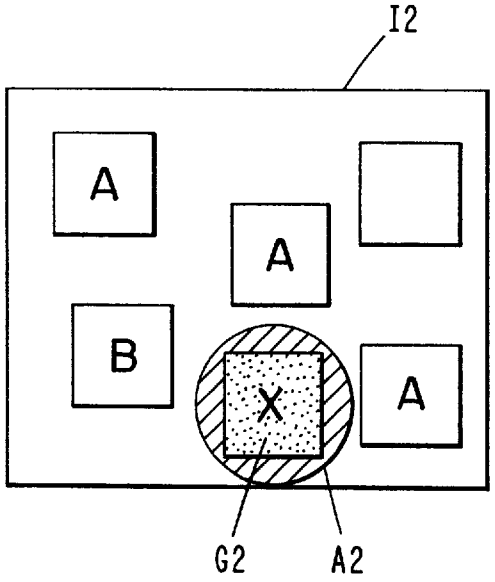


FIG. 7

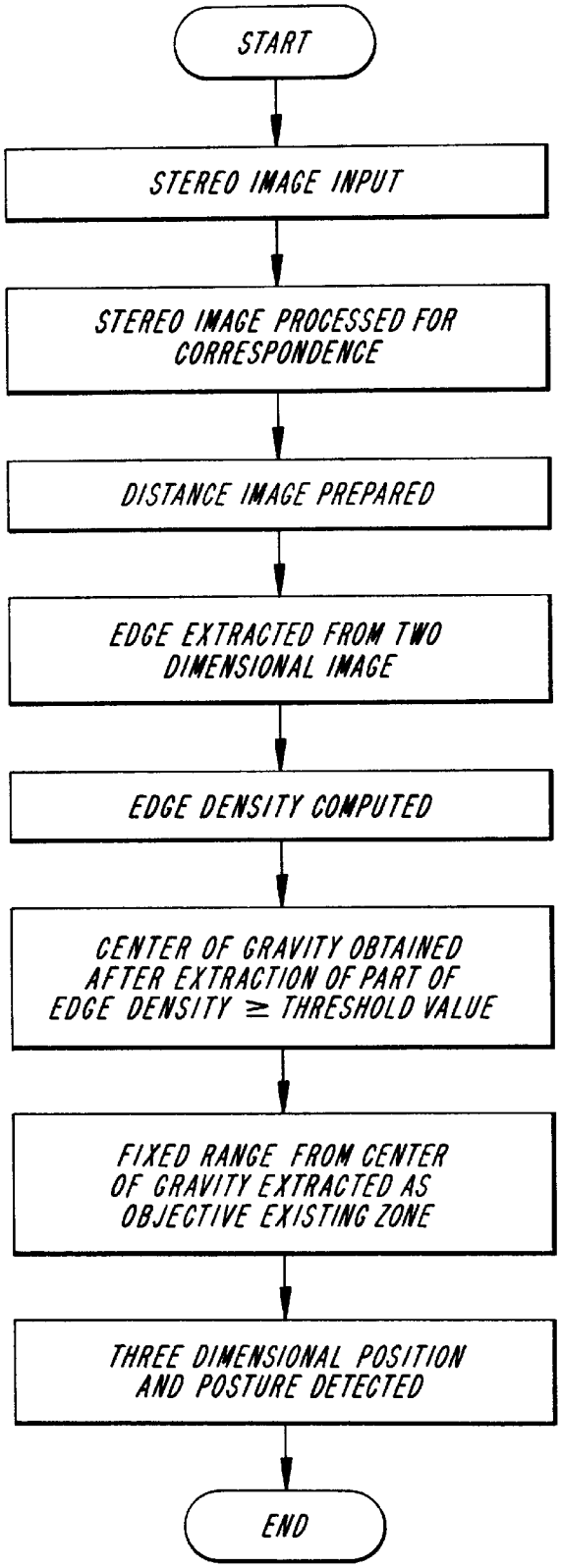

START
STEREO IMAGE INPUT
STEREO IMAGE PROCESSED FOR CORRESPONDENCE
DISTANCE IMAGE PREPARED
EDGE EXTRACTED FROM TWO DIMENSIONAL IMAGE
EDGE DENSITY COMPUTED
CENTER OF GRAVITY OBTAINED AFTER EXTRACTION OF PART OF EDGE DENSITY ≥ THRESHOLD VALUE
FIXED RANGE FROM CENTER OF GRAVITY EXTRACTED AS OBJECTIVE EXISTING ZONE
THREE DIMENSIONAL POSITION AND POSTURE DETECTED
END

FIG. 9

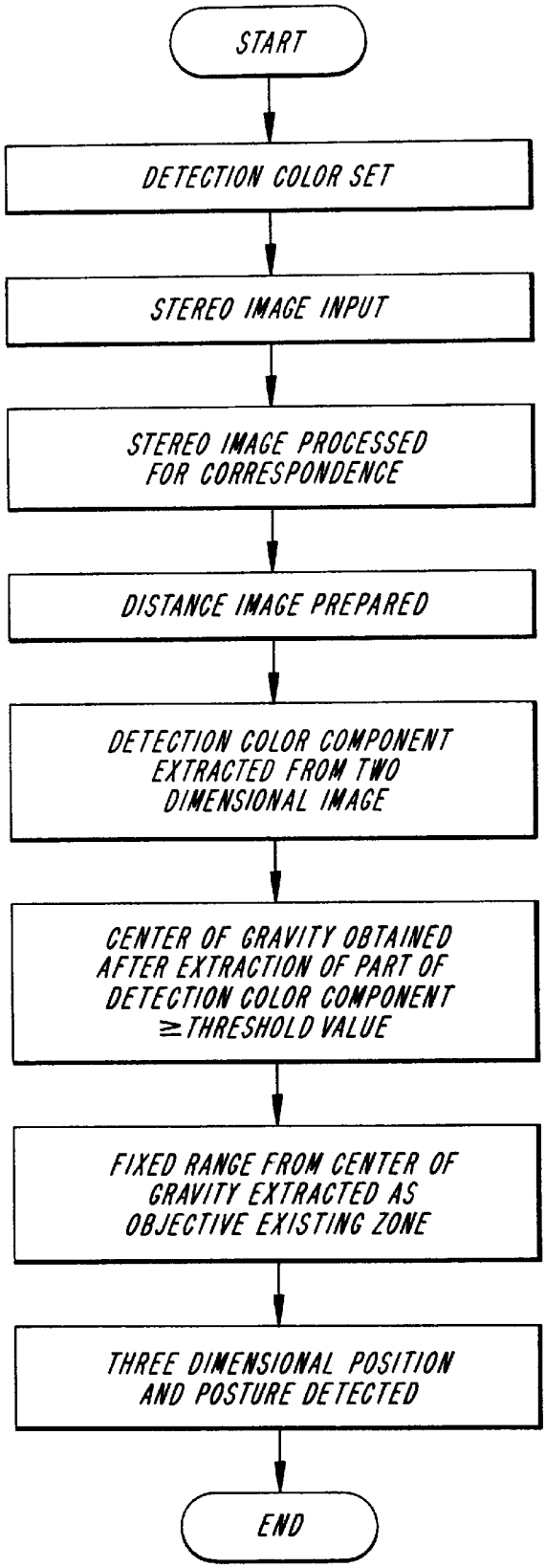

START
DETECTION COLOR SET
STEREO IMAGE INPUT
STEREO IMAGE PROCESSED FOR CORRESPONDENCE
DISTANCE IMAGE PREPARED
DETECTION COLOR COMPONENT EXTRACTED FROM TWO DIMENSIONAL IMAGE
CENTER OF GRAVITY OBTAINED AFTER EXTRACTION OF PART OF DETECTION COLOR COMPONENT ≥THRESHOLD VALUE
FIXED RANGE FROM CENTER OF GRAVITY EXTRACTED AS OBJECTIVE EXISTING ZONE
THREE DIMENSIONAL POSITION AND POSTURE DETECTED
END

FIG. 10

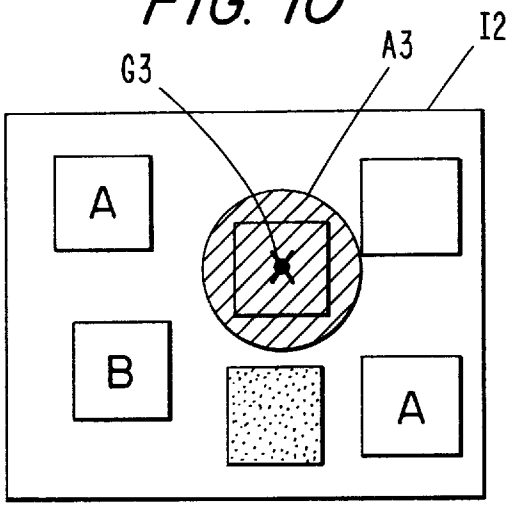
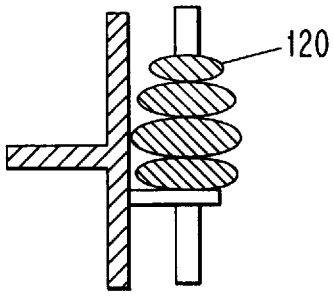


FIG. 12



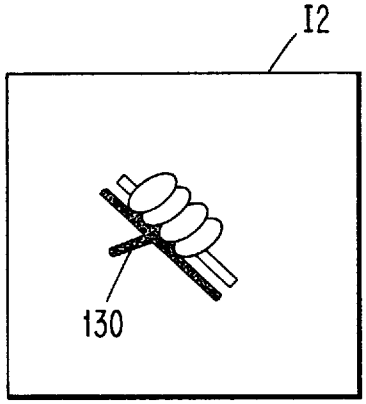


FIG. 13a

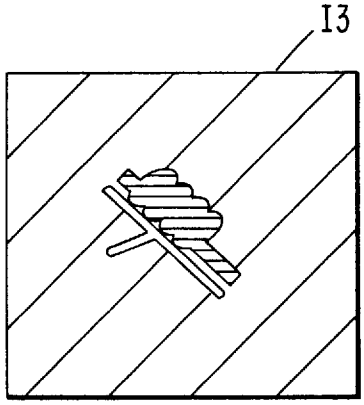


FIG. 13b

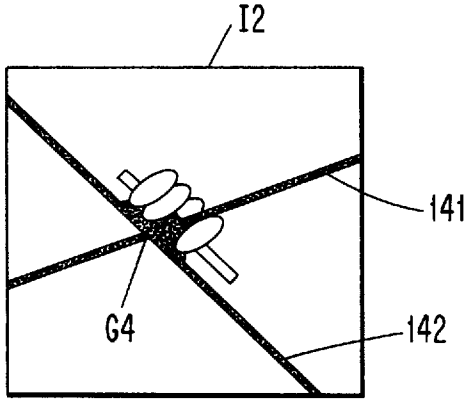


FIG. 14

FIG. 11

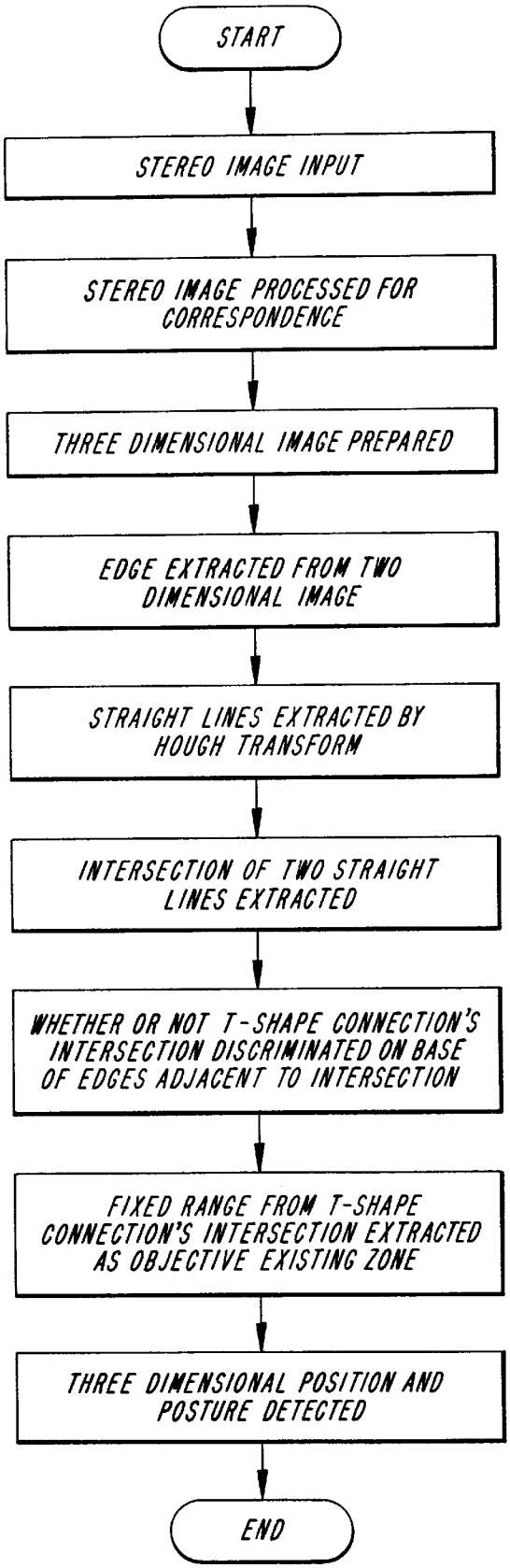

START
STEREO IMAGE INPUT
STEREO IMAGE PROCESSED FOR CORRESPONDENCE
THREE DIMENSIONAL IMAGE PREPARED
EDGE EXTRACTED FROM TWO DIMENSIONAL IMAGE
STRAIGHT LINES EXTRACTED BY HOUGH TRANSFORM
INTERSECTION OF TWO STRAIGHT LINES EXTRACTED
WHETHER OR NOT T-SHAPE CONNECTION'S INTERSECTION DISCRIMINATED ON BASE OF EDGES ADJACENT TO INTERSECTION
FIXED RANGE FROM T-SHAPE CONNECTION'S INTERSECTION EXTRACTED AS OBJECTIVE EXISTING ZONE
THREE DIMENSIONAL POSITION AND POSTURE DETECTED
END

FIG. 15

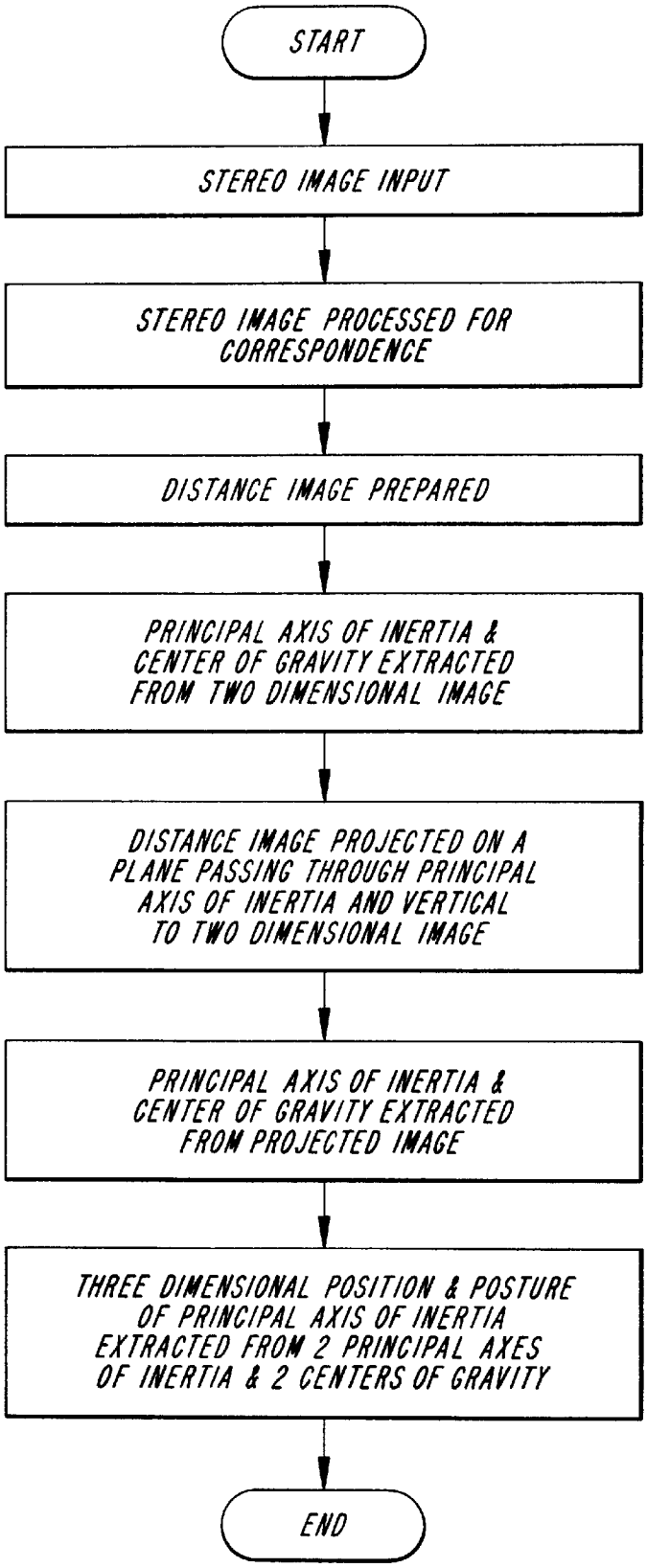

START
STEREO IMAGE INPUT
STEREO IMAGE PROCESSED FOR CORRESPONDENCE
DISTANCE IMAGE PREPARED
PRINCIPAL AXIS OF INERTIA & CENTER OF GRAVITY EXTRACTED FROM TWO DIMENSIONAL IMAGE
DISTANCE IMAGE PROJECTED ON A PLANE PASSING THROUGH PRINCIPAL AXIS OF INERTIA AND VERTICAL TO TWO DIMENSIONAL IMAGE
PRINCIPAL AXIS OF INERTIA & CENTER OF GRAVITY EXTRACTED FROM PROJECTED IMAGE
THREE DIMENSIONAL POSITION & POSTURE OF PRINCIPAL AXIS OF INERTIA EXTRACTED FROM 2 PRINCIPAL AXES OF INERTIA & 2 CENTERS OF GRAVITY
END

FIG. 16

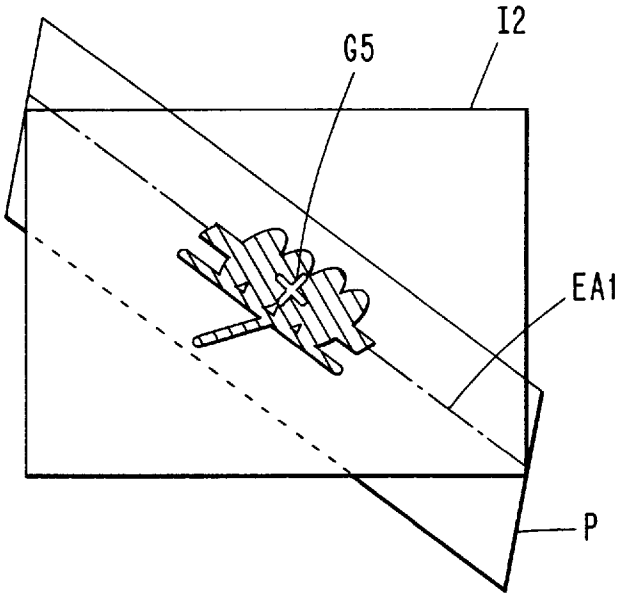


FIG. 17

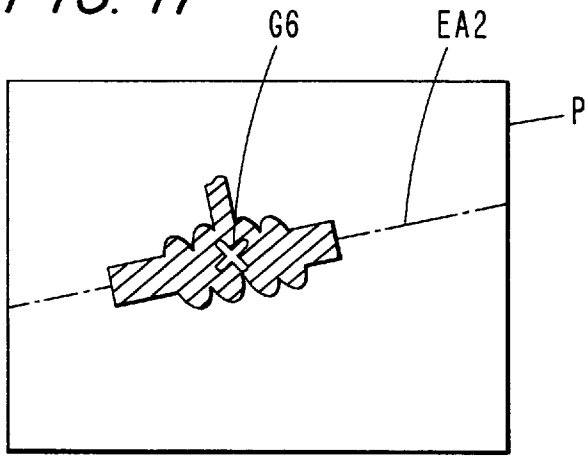


FIG. 18

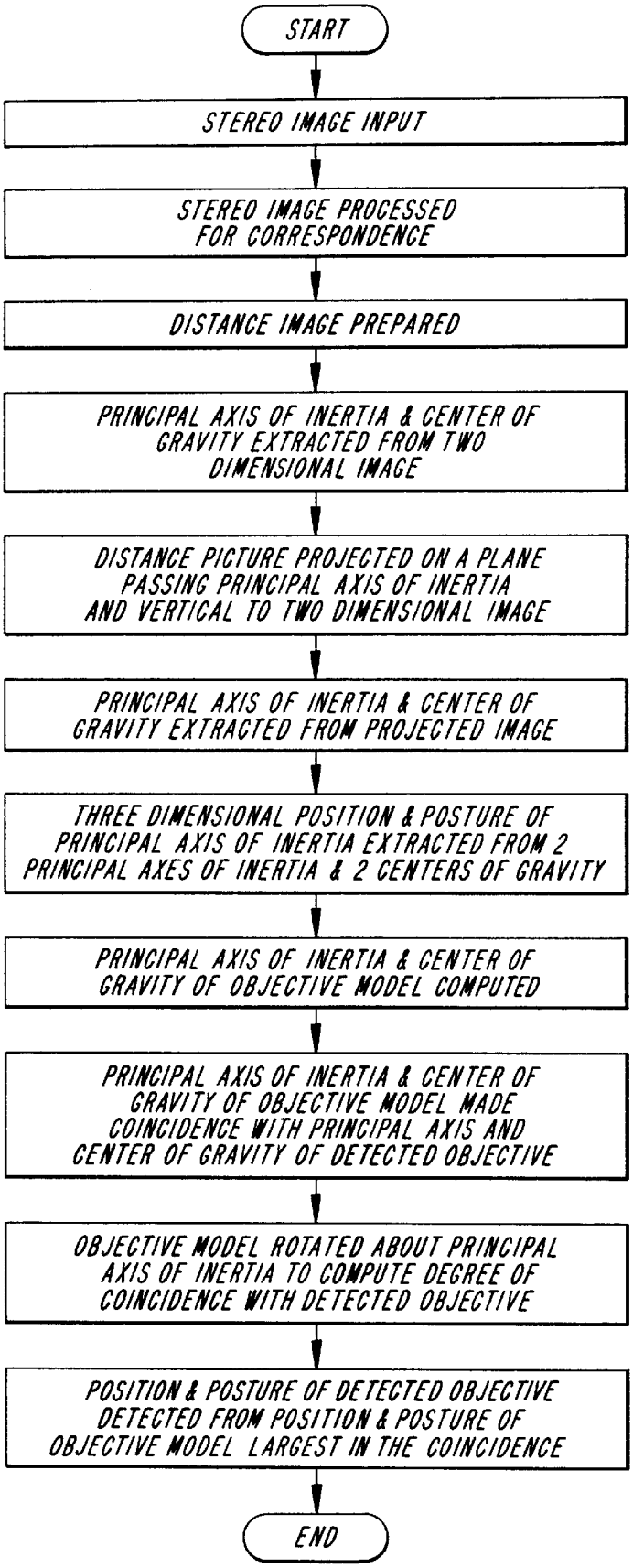
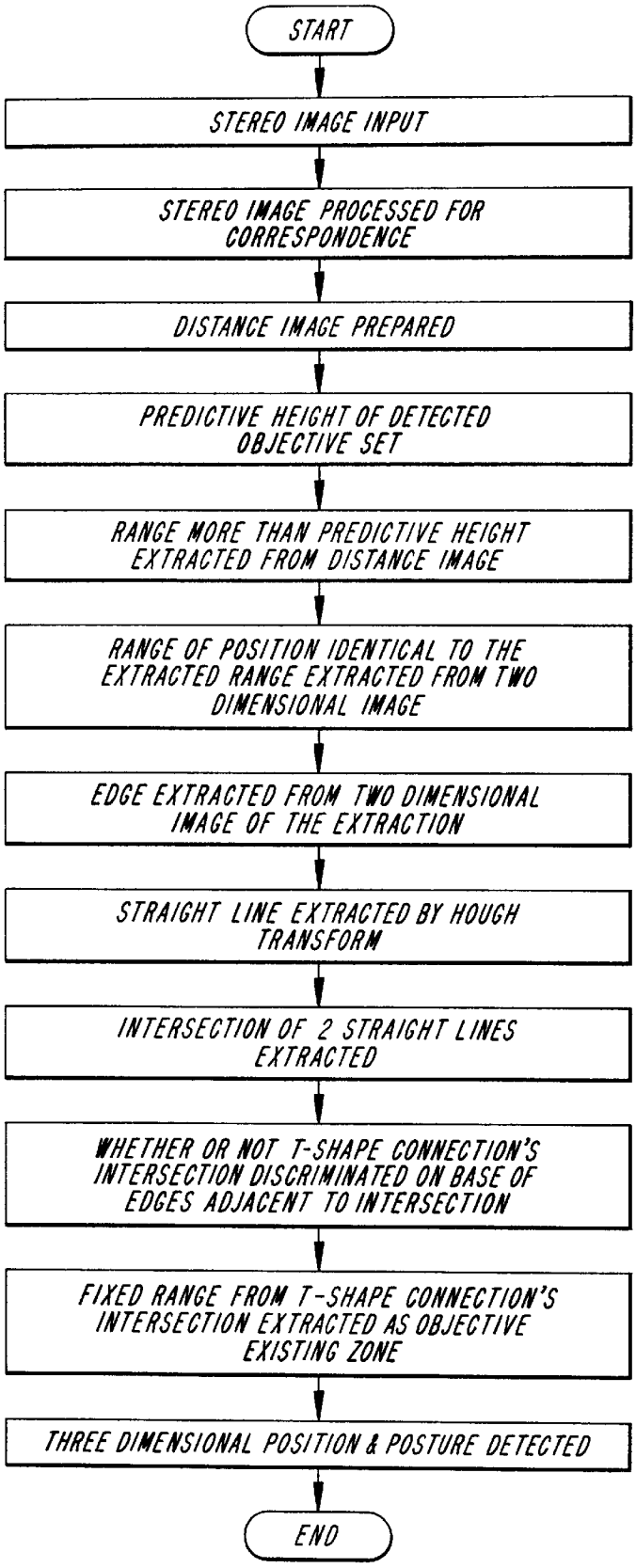

START
STEREO IMAGE INPUT
STEREO IMAGE PROCESSED FOR CORRESPONDENCE
DISTANCE IMAGE PREPARED
PRINCIPAL AXIS OF INERTIA & CENTER OF GRAVITY EXTRACTED FROM TWO DIMENSIONAL IMAGE
DISTANCE PICTURE PROJECTED ON A PLANE PASSING PRINCIPAL AXIS OF INERTIA AND VERTICAL TO TWO DIMENSIONAL IMAGE
PRINCIPAL AXIS OF INERTIA & CENTER OF GRAVITY EXTRACTED FROM PROJECTED IMAGE
THREE DIMENSIONAL POSITION & POSTURE OF PRINCIPAL AXIS OF INERTIA EXTRACTED FROM 2 PRINCIPAL AXES OF INERTIA & 2 CENTERS OF GRAVITY
PRINCIPAL AXIS OF INERTIA & CENTER OF GRAVITY OF OBJECTIVE MODEL COMPUTED
PRINCIPAL AXIS OF INERTIA & CENTER OF GRAVITY OF OBJECTIVE MODEL MADE COINCIDENCE WITH PRINCIPAL AXIS AND CENTER OF GRAVITY OF DETECTED OBJECTIVE
OBJECTIVE MODEL ROTATED ABOUT PRINCIPAL AXIS OF INERTIA TO COMPUTE DEGREE OF COINCIDENCE WITH DETECTED OBJECTIVE
POSITION & POSTURE OF DETECTED OBJECTIVE DETECTED FROM POSITION & POSTURE OF OBJECTIVE MODEL LARGEST IN THE COINCIDENCE
END

FIG. 19


START
STEREO IMAGE INPUT
STEREO IMAGE PROCESSED FOR CORRESPONDENCE
DISTANCE IMAGE PREPARED
PREDICTIVE HEIGHT OF DETECTED OBJECTIVE SET
RANGE MORE THAN PREDICTIVE HEIGHT EXTRACTED FROM DISTANCE IMAGE
RANGE OF POSITION IDENTICAL TO THE EXTRACTED RANGE EXTRACTED FROM TWO DIMENSIONAL IMAGE
EDGE EXTRACTED FROM TWO DIMENSIONAL IMAGE OF THE EXTRACTION
STRAIGHT LINE EXTRACTED BY HOUGH TRANSFORM
INTERSECTION OF 2 STRAIGHT LINES EXTRACTED
WHETHER OR NOT T-SHAPE CONNECTION'S INTERSECTION DISCRIMINATED ON BASE OF EDGES ADJACENT TO INTERSECTION
FIXED RANGE FROM T-SHAPE CONNECTION'S INTERSECTION EXTRACTED AS OBJECTIVE EXISTING ZONE
THREE DIMENSIONAL POSITION & POSTURE DETECTED
END

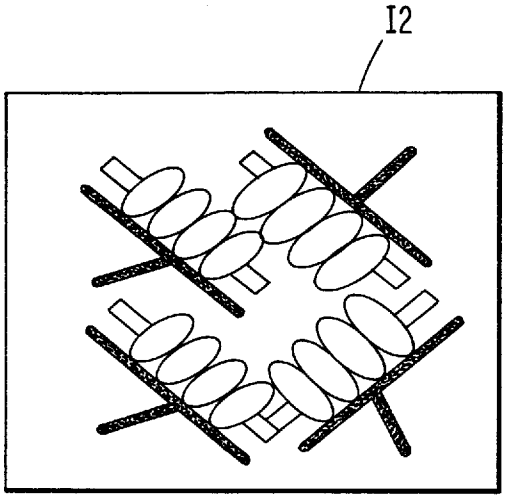


FIG. 20a

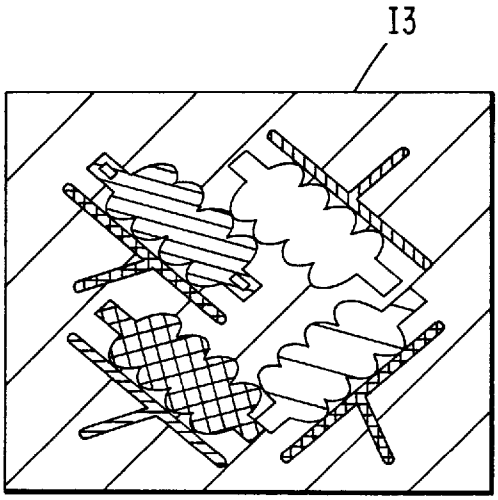


FIG. 20b

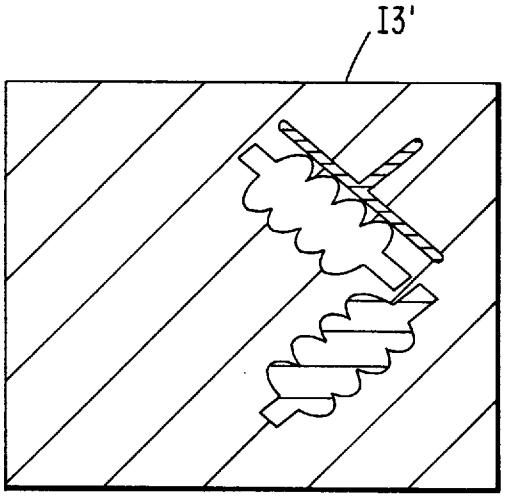


FIG. 21a

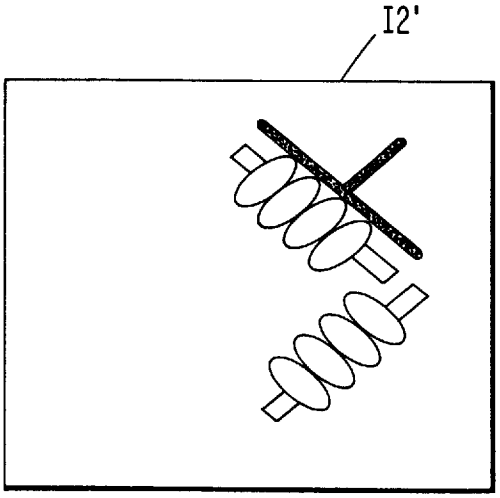


FIG. 21b

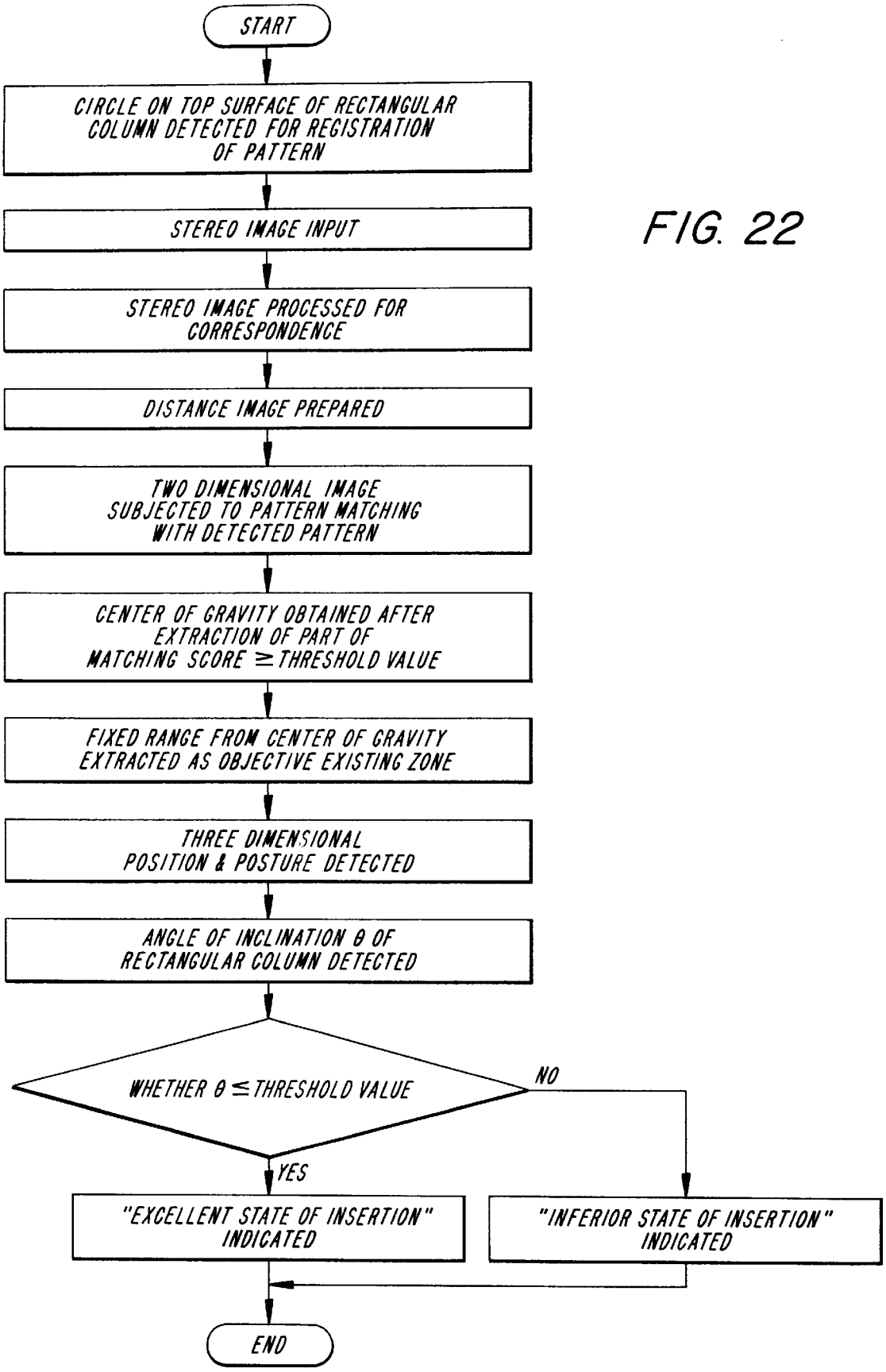
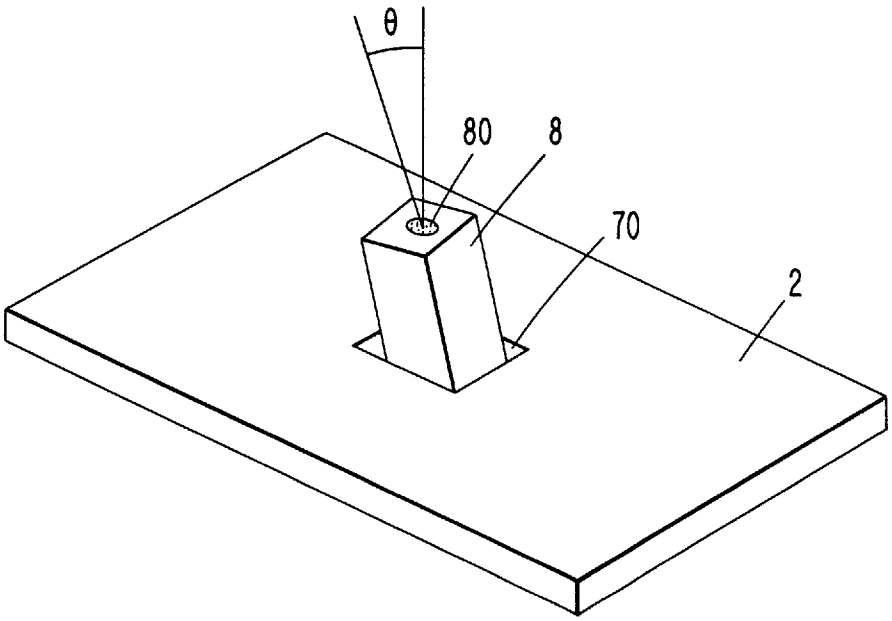

START
CIRCLE ON TOP SURFACE OF RECTANGULAR COLUMN DETECTED FOR REGISTRATION OF PATTERN
STEREO IMAGE INPUT
STEREO IMAGE PROCESSED FOR CORRESPONDENCE
DISTANCE IMAGE PREPARED
TWO DIMENSIONAL IMAGE SUBJECTED TO PATTERN MATCHING WITH DETECTED PATTERN
CENTER OF GRAVITY OBTAINED AFTER EXTRACTION OF PART OF MATCHING SCORE ≥ THRESHOLD VALUE
FIXED RANGE FROM CENTER OF GRAVITY EXTRACTED AS OBJECTIVE EXISTING ZONE
THREE DIMENSIONAL POSITION & POSTURE DETECTED
ANGLE OF INCLINATION θ OF RECTANGULAR COLUMN DETECTED
WHETHER θ ≤ THRESHOLD VALUE
NO
YES
"EXCELLENT STATE OF INSERTION" INDICATED
"INFERIOR STATE OF INSERTION" INDICATED
END

FIG. 22

FIG. 23



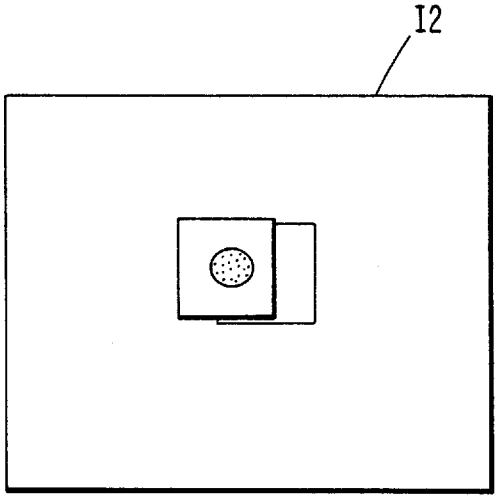


FIG. 24a

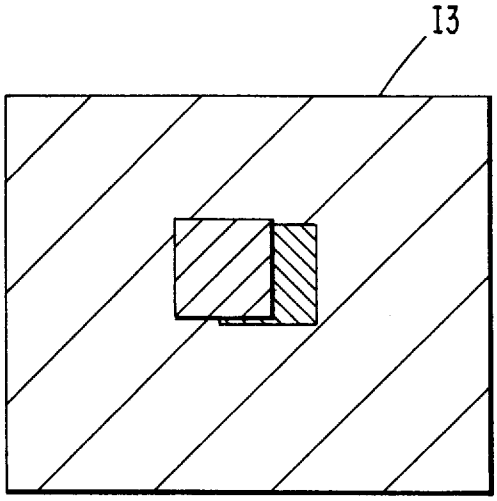


FIG. 24b

FIG. 25

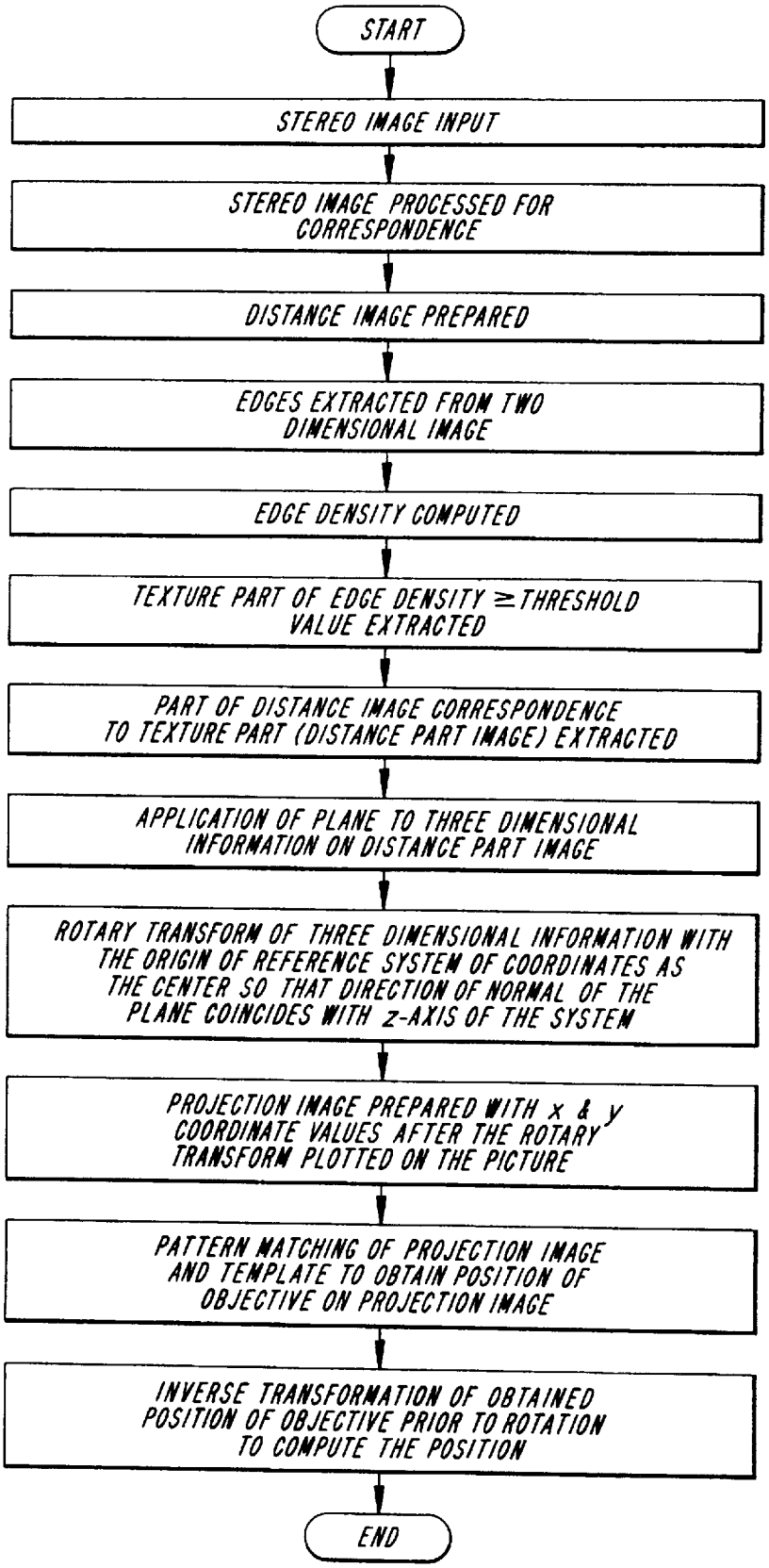

START
STEREO IMAGE INPUT
STEREO IMAGE PROCESSED FOR CORRESPONDENCE
DISTANCE IMAGE PREPARED
EDGES EXTRACTED FROM TWO DIMENSIONAL IMAGE
EDGE DENSITY COMPUTED
TEXTURE PART OF EDGE DENSITY ≥ THRESHOLD VALUE EXTRACTED
PART OF DISTANCE IMAGE CORRESPONDENCE TO TEXTURE PART (DISTANCE PART IMAGE) EXTRACTED
APPLICATION OF PLANE TO THREE DIMENSIONAL INFORMATION ON DISTANCE PART IMAGE
ROTARY TRANSFORM OF THREE DIMENSIONAL INFORMATION WITH THE ORIGIN OF REFERENCE SYSTEM OF COORDINATES AS THE CENTER SO THAT DIRECTION OF NORMAL OF THE PLANE COINCIDES WITH z-AXIS OF THE SYSTEM
PROJECTION IMAGE PREPARED WITH x & y COORDINATE VALUES AFTER THE ROTARY TRANSFORM PLOTTED ON THE PICTURE
PATTERN MATCHING OF PROJECTION IMAGE AND TEMPLATE TO OBTAIN POSITION OF OBJECTIVE ON PROJECTION IMAGE
INVERSE TRANSFORMATION OF OBTAINED POSITION OF OBJECTIVE PRIOR TO ROTATION TO COMPUTE THE POSITION
END

FIG. 26

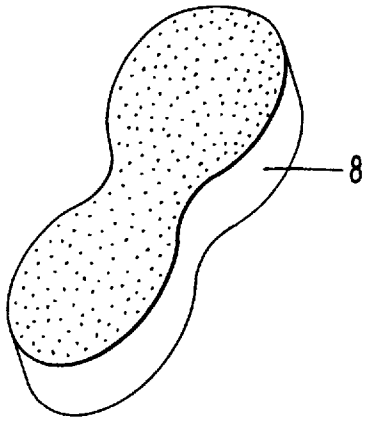


FIG. 27

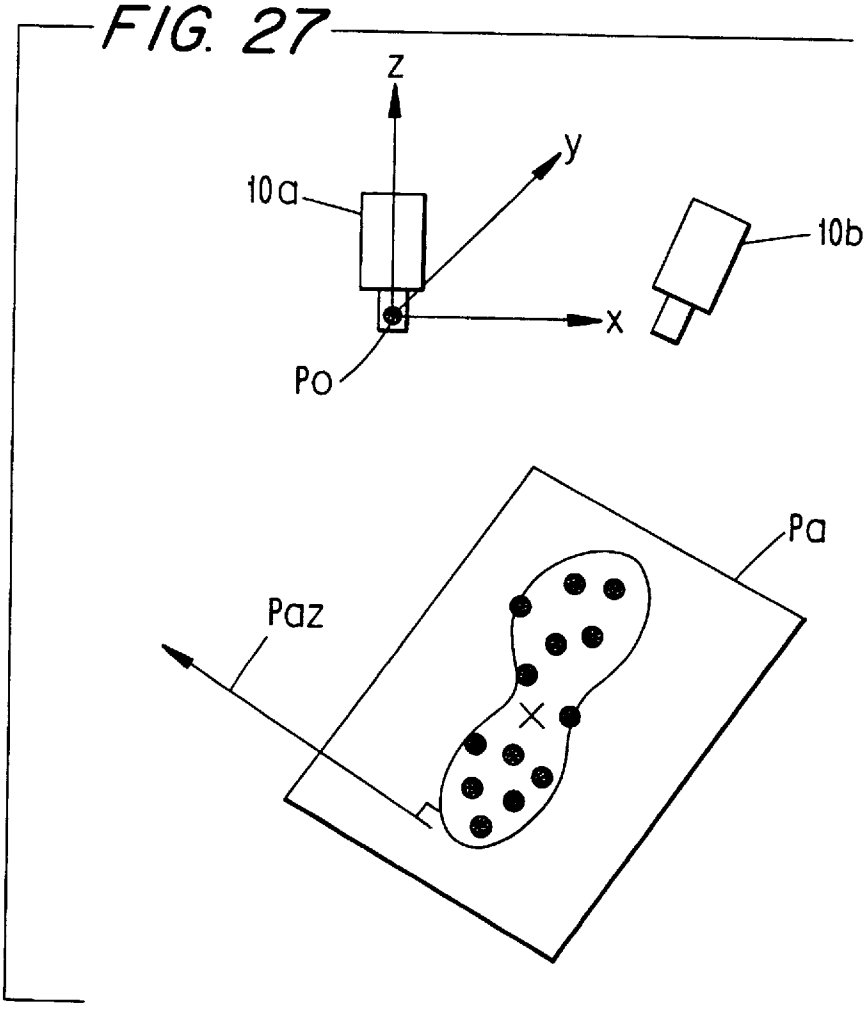
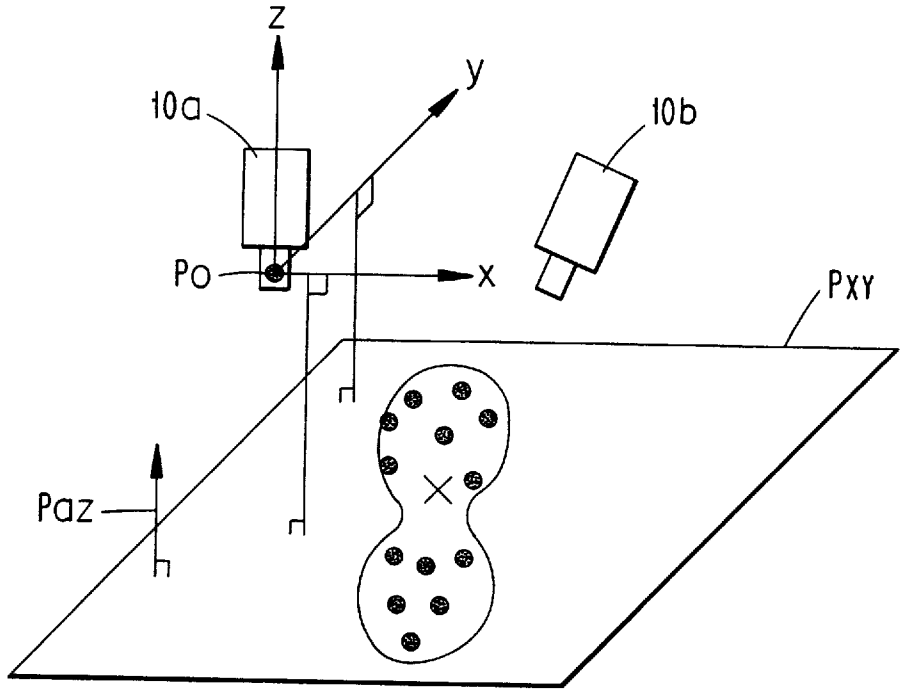


FIG. 28a



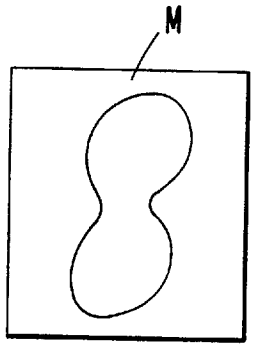
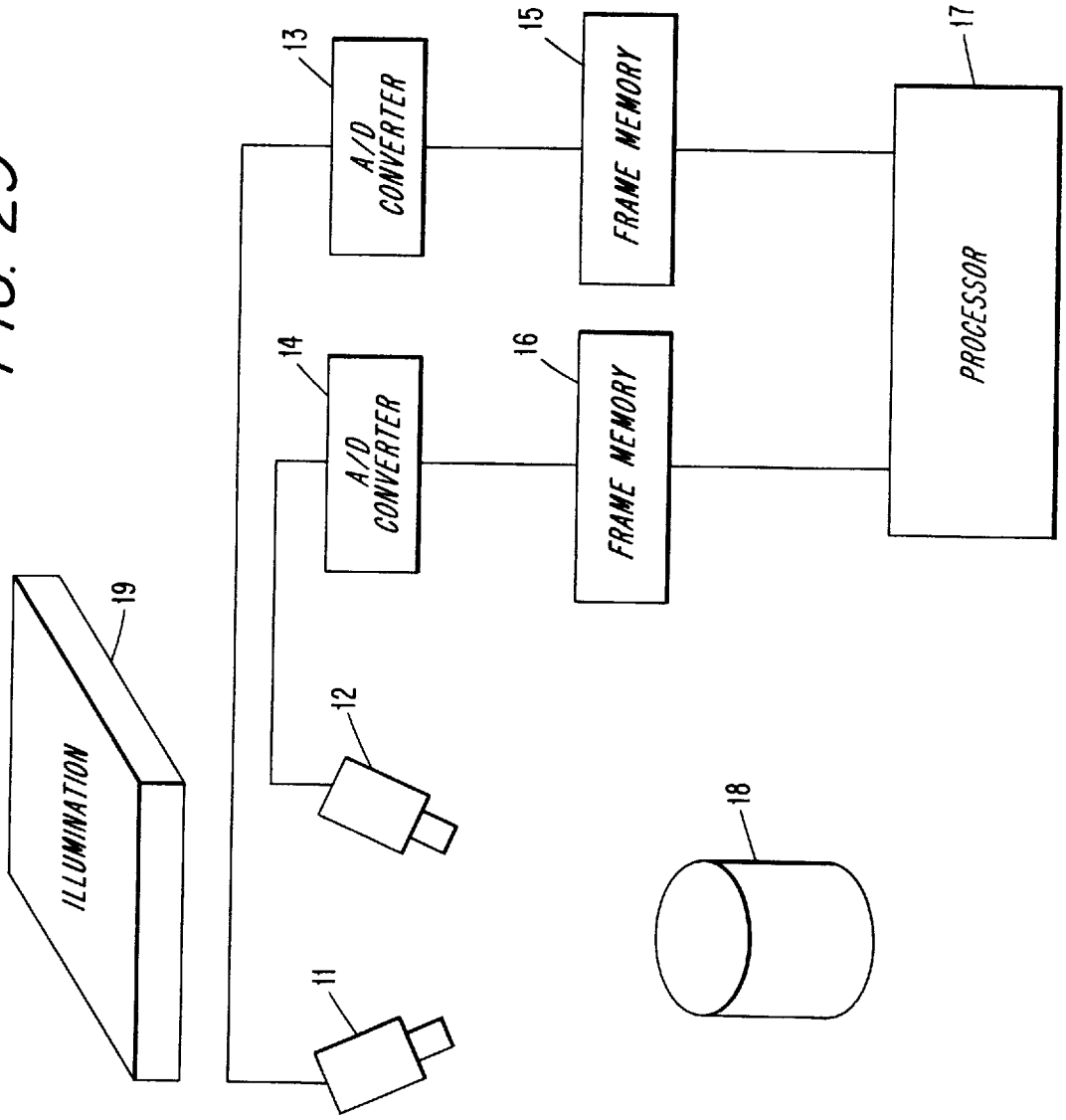


FIG. 28b

FIG. 29


ILLUMINATION
19
A/D CONVERTER
13
A/D CONVERTER
14
FRAME MEMORY
15
FRAME MEMORY
16
PROCESSOR
17
11
12
18

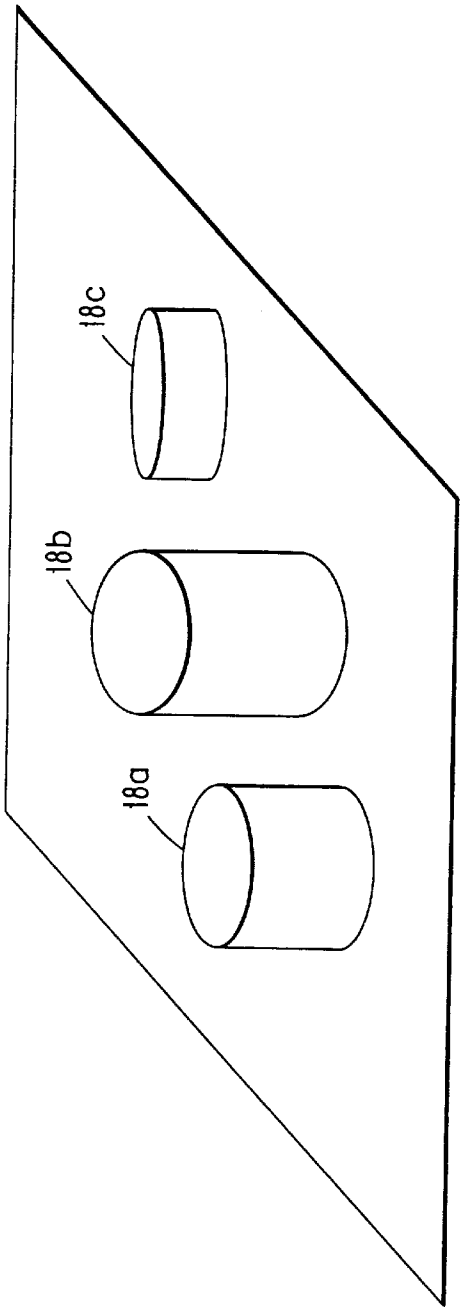


FIG. 30

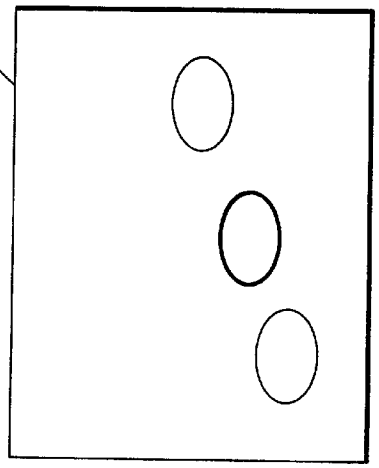


FIG. 31b

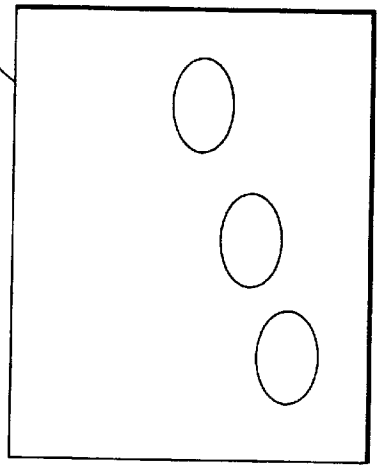


FIG. 31a

FIG. 32c

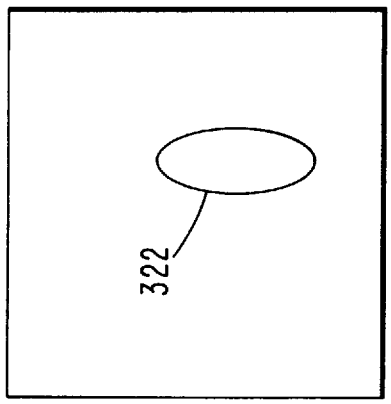


FIG. 32b

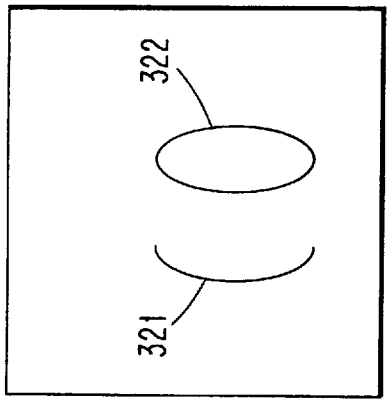


FIG. 32a

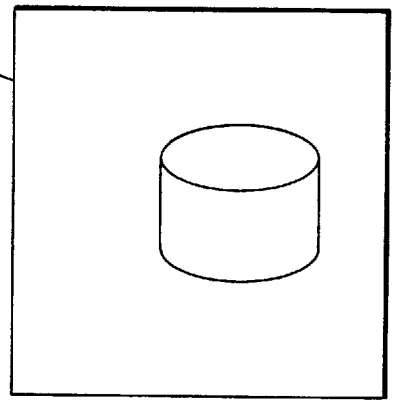
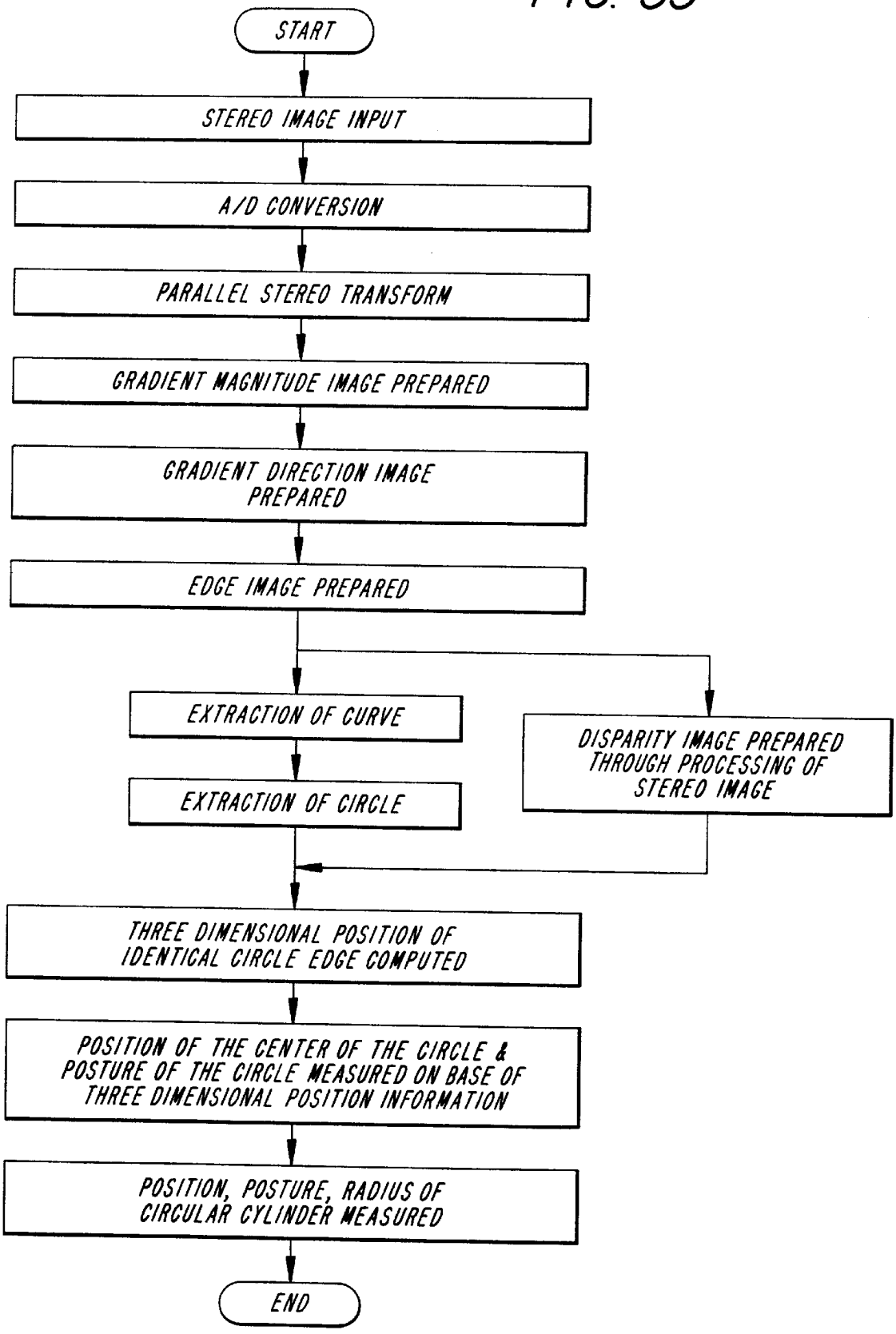


FIG. 33


START
STEREO IMAGE INPUT
A/D CONVERSION
PARALLEL STEREO TRANSFORM
GRADIENT MAGNITUDE IMAGE PREPARED
GRADIENT DIRECTION IMAGE PREPARED
EDGE IMAGE PREPARED
EXTRACTION OF CURVE
EXTRACTION OF CIRCLE
DISPARITY IMAGE PREPARED THROUGH PROCESSING OF STEREO IMAGE
THREE DIMENSIONAL POSITION OF IDENTICAL CIRCLE EDGE COMPUTED
POSITION OF THE CENTER OF THE CIRCLE & POSTURE OF THE CIRCLE MEASURED ON BASE OF THREE DIMENSIONAL POSITION INFORMATION
POSITION, POSTURE, RADIUS OF CIRCULAR CYLINDER MEASURED
END

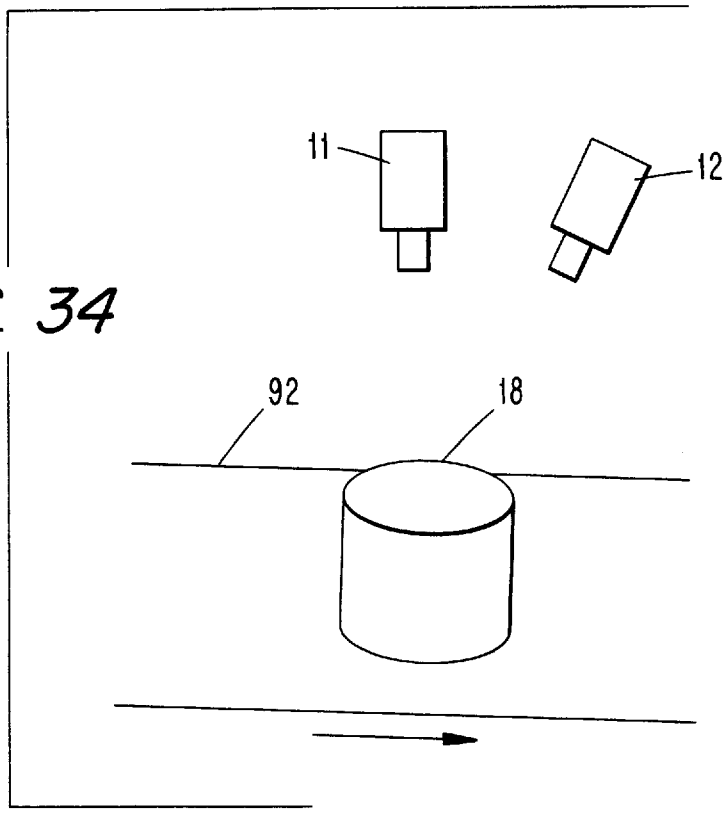


FIG. 34

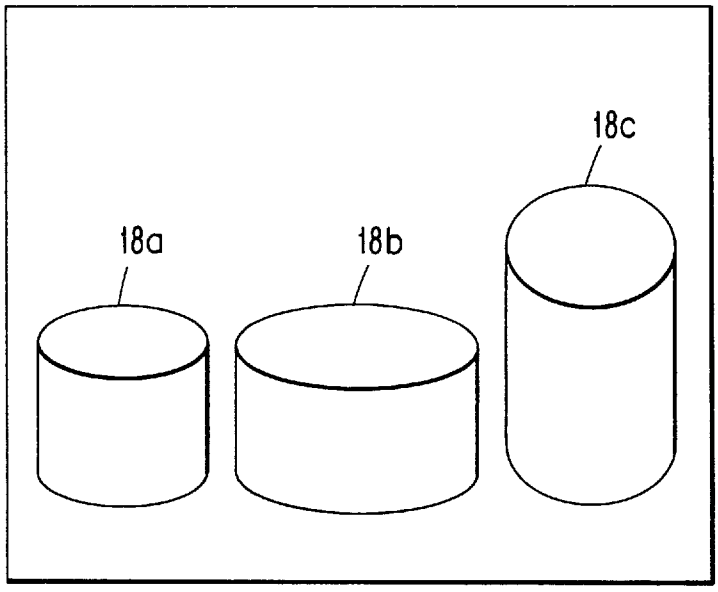


FIG. 35

FIG. 36a

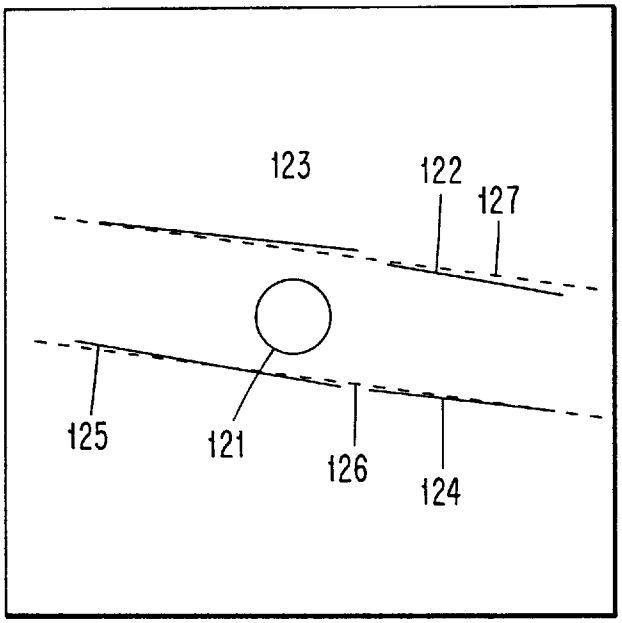


FIG. 36b

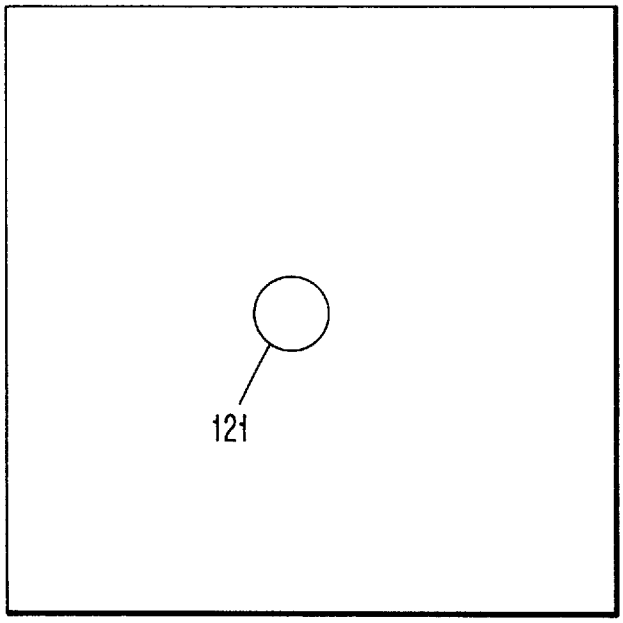


FIG. 37

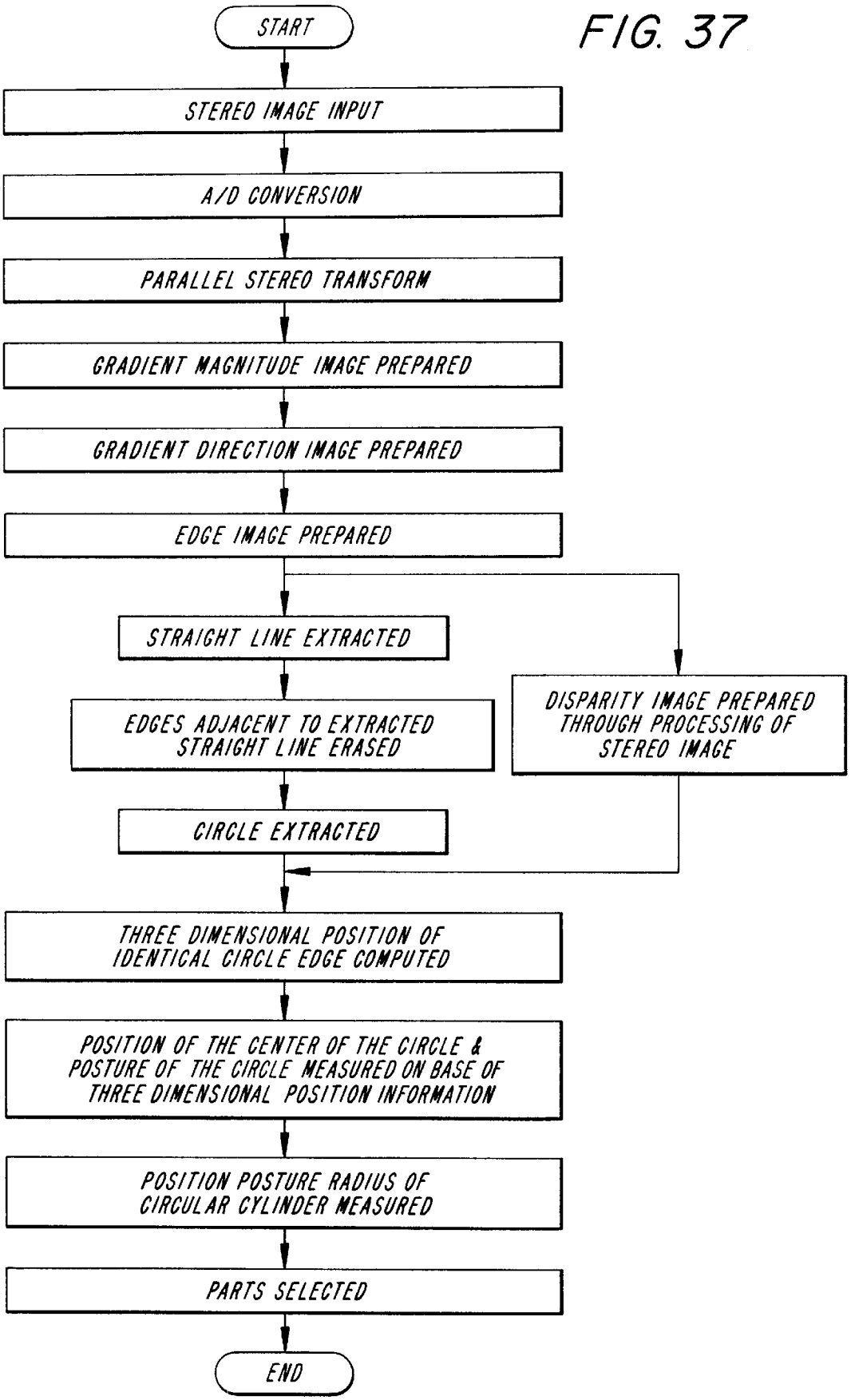

START
STEREO IMAGE INPUT
A/D CONVERSION
PARALLEL STEREO TRANSFORM
GRADIENT MAGNITUDE IMAGE PREPARED
GRADIENT DIRECTION IMAGE PREPARED
EDGE IMAGE PREPARED
STRAIGHT LINE EXTRACTED
EDGES ADJACENT TO EXTRACTED STRAIGHT LINE ERASED
CIRCLE EXTRACTED
DISPARITY IMAGE PREPARED THROUGH PROCESSING OF STEREO IMAGE
THREE DIMENSIONAL POSITION OF IDENTICAL CIRCLE EDGE COMPUTED
POSITION OF THE CENTER OF THE CIRCLE & POSTURE OF THE CIRCLE MEASURED ON BASE OF THREE DIMENSIONAL POSITION INFORMATION
POSITION POSTURE RADIUS OF CIRCULAR CYLINDER MEASURED
PARTS SELECTED
END

FIG. 38

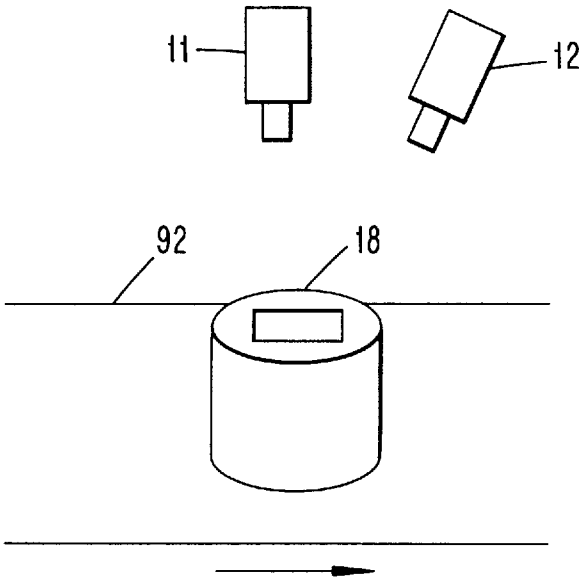


FIG. 39

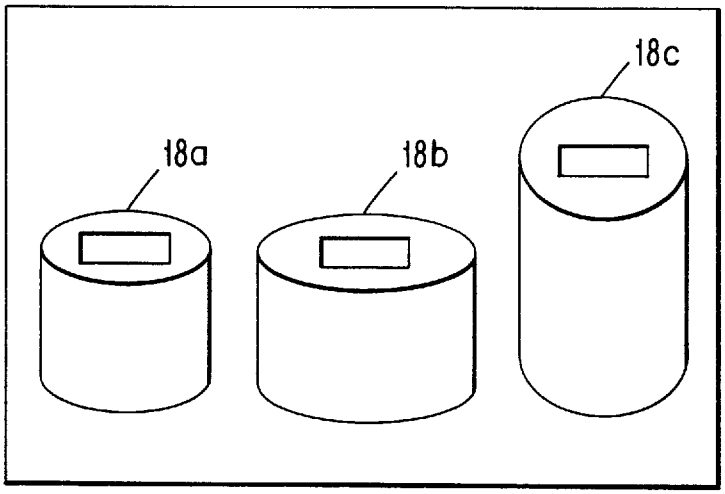


FIG. 40a

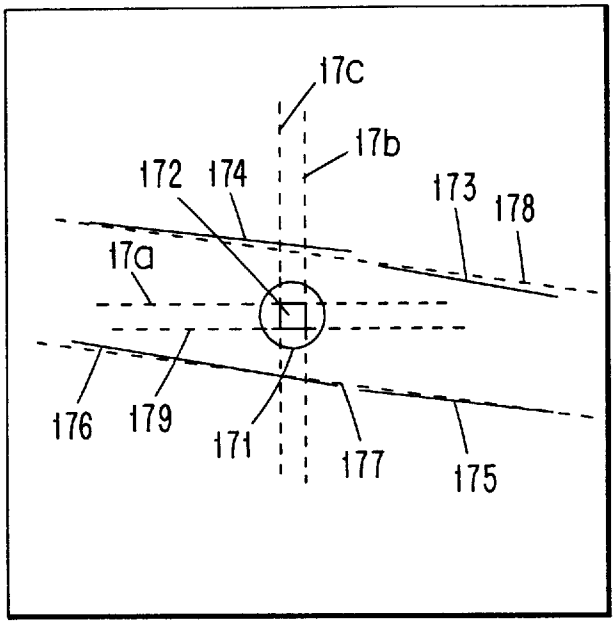


FIG. 40b

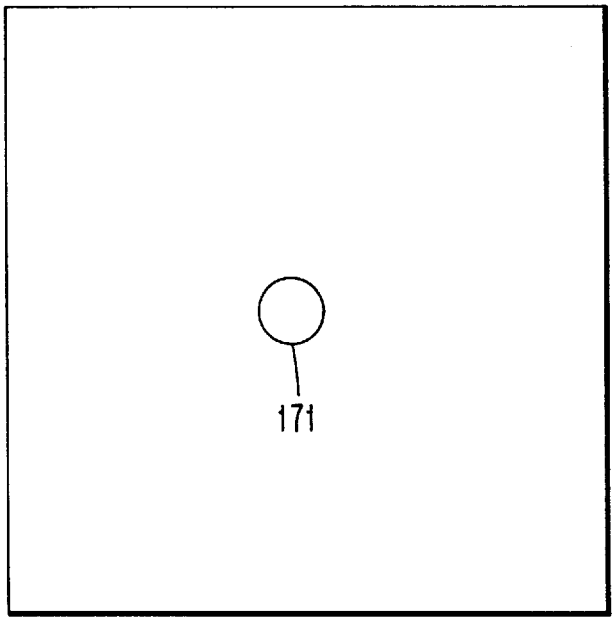


FIG. 41

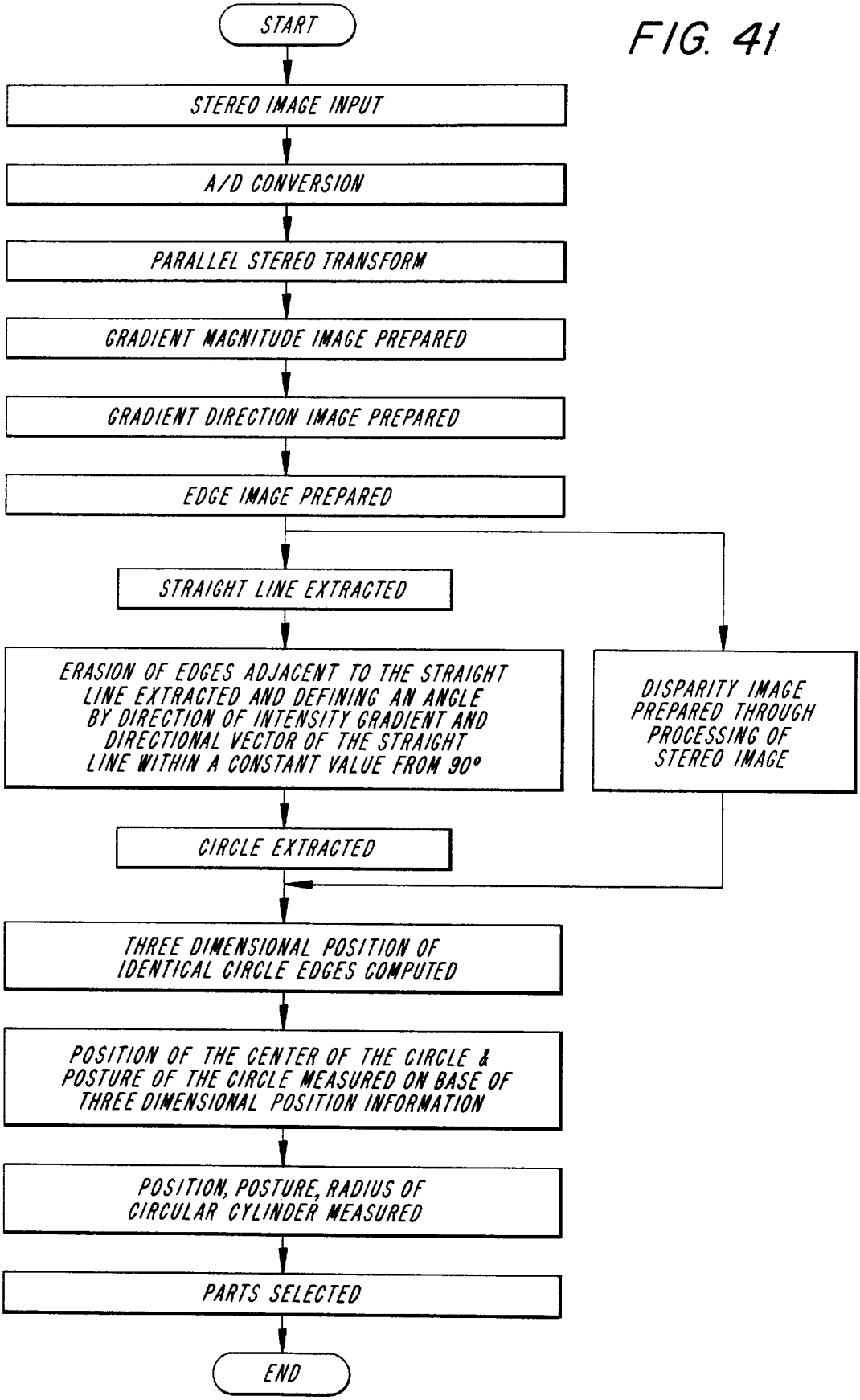

START
STEREO IMAGE INPUT
A/D CONVERSION
PARALLEL STEREO TRANSFORM
GRADIENT MAGNITUDE IMAGE PREPARED
GRADIENT DIRECTION IMAGE PREPARED
EDGE IMAGE PREPARED
STRAIGHT LINE EXTRACTED
ERASION OF EDGES ADJACENT TO THE STRAIGHT LINE EXTRACTED AND DEFINING AN ANGLE BY DIRECTION OF INTENSITY GRADIENT AND DIRECTIONAL VECTOR OF THE STRAIGHT LINE WITHIN A CONSTANT VALUE FROM 90°
DISPARITY IMAGE PREPARED THROUGH PROCESSING OF STEREO IMAGE
CIRCLE EXTRACTED
THREE DIMENSIONAL POSITION OF IDENTICAL CIRCLE EDGES COMPUTED
POSITION OF THE CENTER OF THE CIRCLE & POSTURE OF THE CIRCLE MEASURED ON BASE OF THREE DIMENSIONAL POSITION INFORMATION
POSITION, POSTURE, RADIUS OF CIRCULAR CYLINDER MEASURED
PARTS SELECTED
END

FIG. 42b

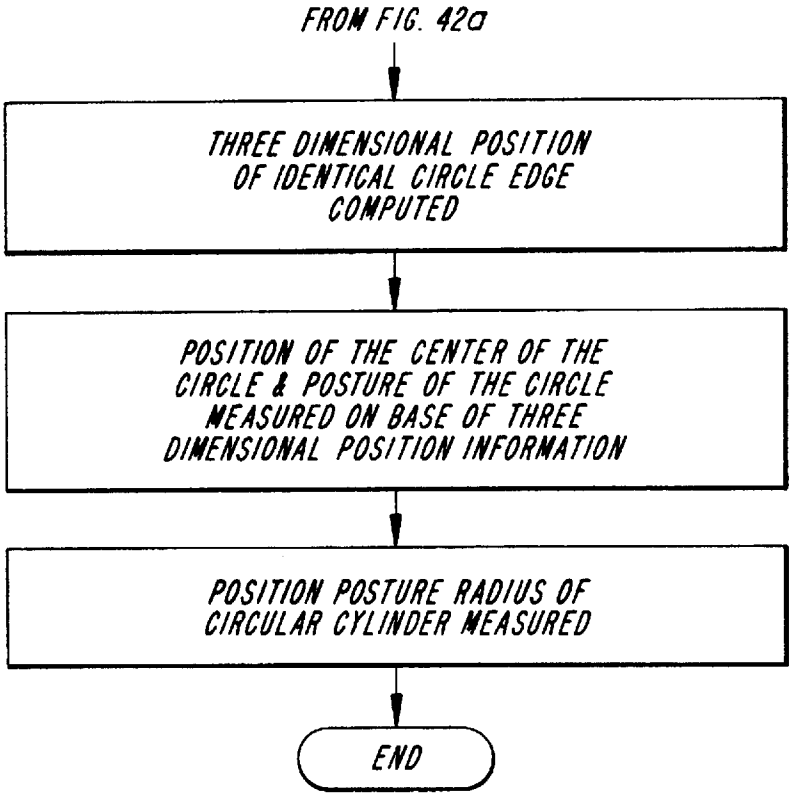
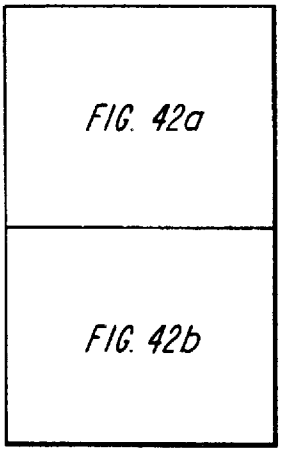


FIG. 42



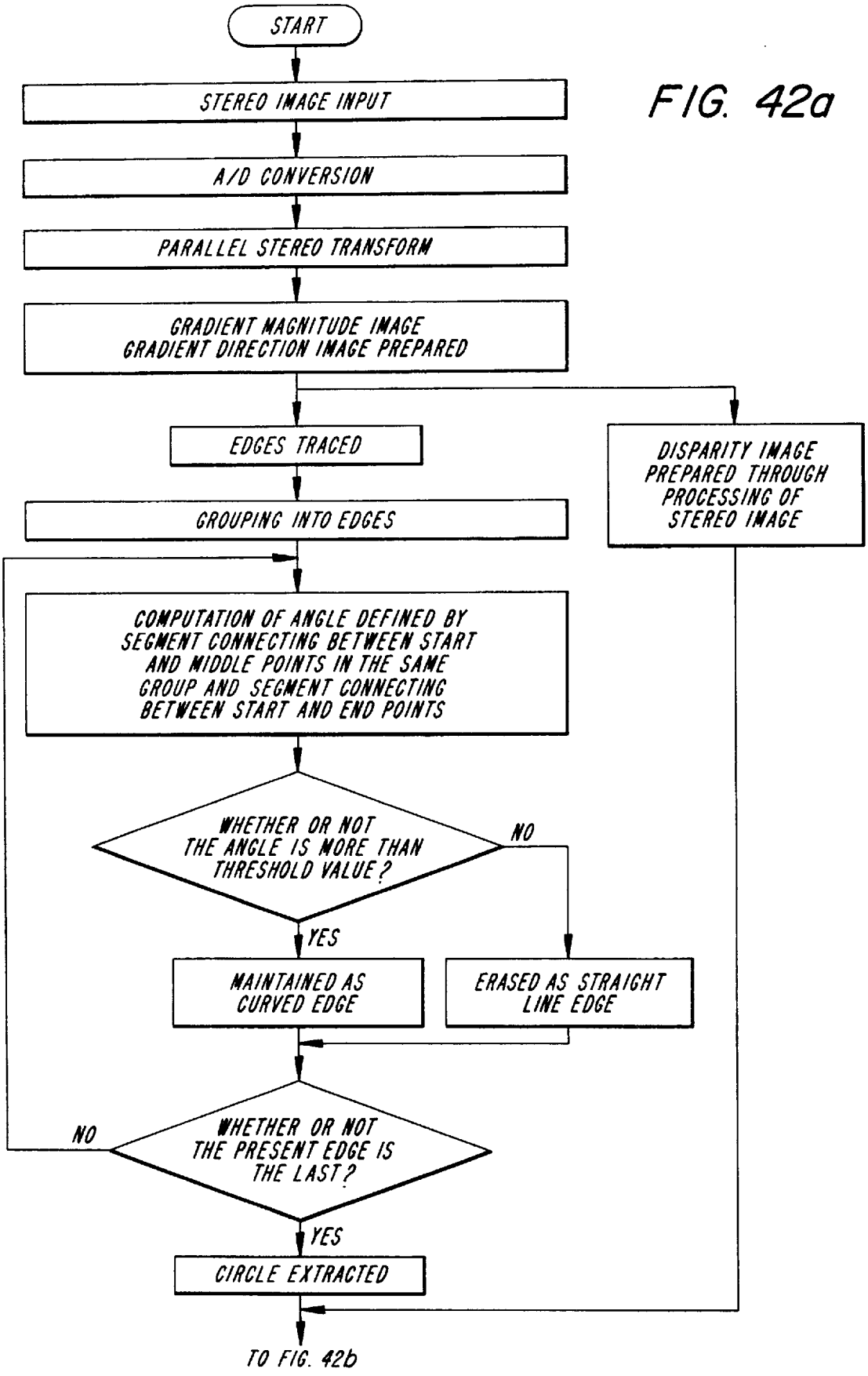

START
STEREO IMAGE INPUT
A/D CONVERSION
PARALLEL STEREO TRANSFORM
GRADIENT MAGNITUDE IMAGE
GRADIENT DIRECTION IMAGE PREPARED
EDGES TRACED
GROUPING INTO EDGES
DISPARITY IMAGE PREPARED THROUGH PROCESSING OF STEREO IMAGE
COMPUTATION OF ANGLE DEFINED BY SEGMENT CONNECTING BETWEEN START AND MIDDLE POINTS IN THE SAME GROUP AND SEGMENT CONNECTING BETWEEN START AND END POINTS
WHETHER OR NOT THE ANGLE IS MORE THAN THRESHOLD VALUE?
NO
YES
MAINTAINED AS CURVED EDGE
ERASED AS STRAIGHT LINE EDGE
WHETHER OR NOT THE PRESENT EDGE IS THE LAST?
NO
YES
CIRCLE EXTRACTED
TO FIG. 42b

FIG. 42a

FIG. 43a

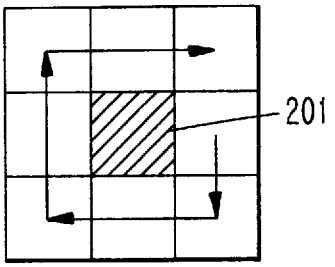


FIG. 43b

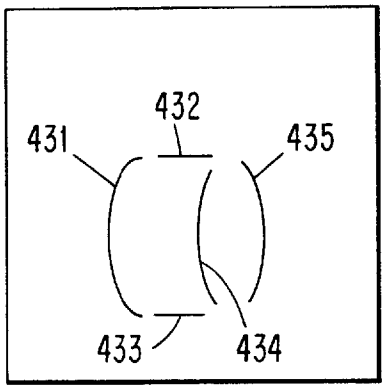
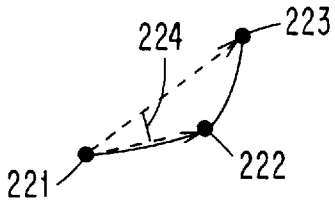


FIG. 44



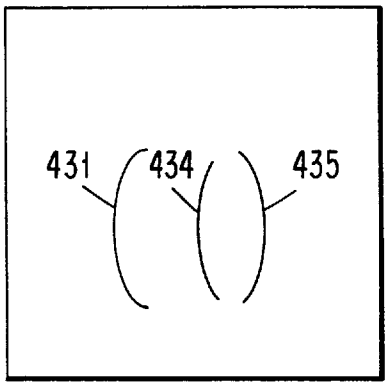


FIG. 45a

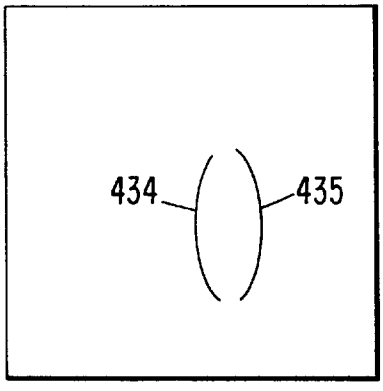


FIG. 45b

FIG. 46

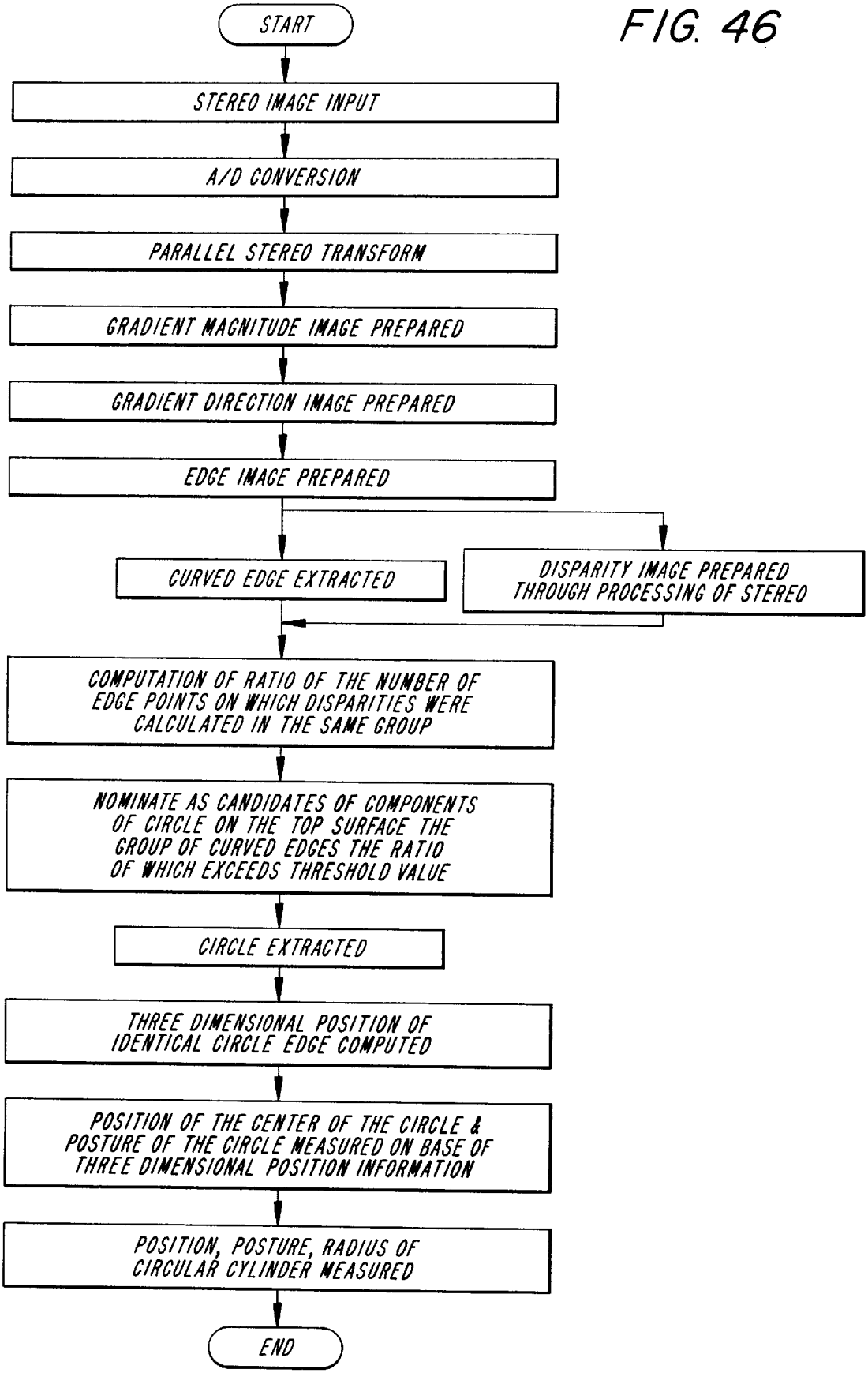

START
STEREO IMAGE INPUT
A/D CONVERSION
PARALLEL STEREO TRANSFORM
GRADIENT MAGNITUDE IMAGE PREPARED
GRADIENT DIRECTION IMAGE PREPARED
EDGE IMAGE PREPARED
CURVED EDGE EXTRACTED
DISPARITY IMAGE PREPARED THROUGH PROCESSING OF STEREO
COMPUTATION OF RATIO OF THE NUMBER OF EDGE POINTS ON WHICH DISPARITIES WERE CALCULATED IN THE SAME GROUP
NOMINATE AS CANDIDATES OF COMPONENTS OF CIRCLE ON THE TOP SURFACE THE GROUP OF CURVED EDGES THE RATIO OF WHICH EXCEEDS THRESHOLD VALUE
CIRCLE EXTRACTED
THREE DIMENSIONAL POSITION OF IDENTICAL CIRCLE EDGE COMPUTED
POSITION OF THE CENTER OF THE CIRCLE & POSTURE OF THE CIRCLE MEASURED ON BASE OF THREE DIMENSIONAL POSITION INFORMATION
POSITION, POSTURE, RADIUS OF CIRCULAR CYLINDER MEASURED
END

FIG. 47a

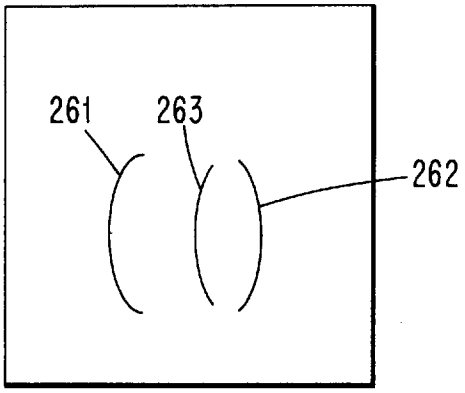


FIG. 47b

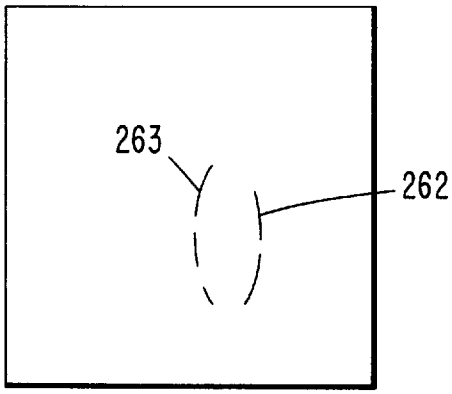


FIG. 47c

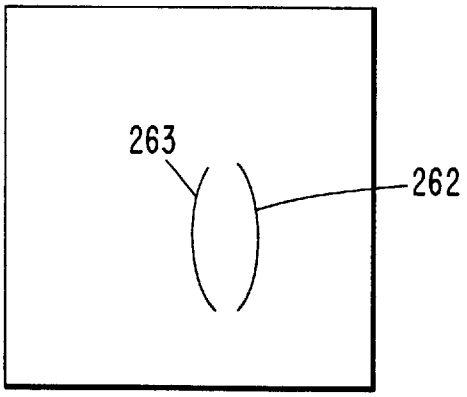


FIG. 48b

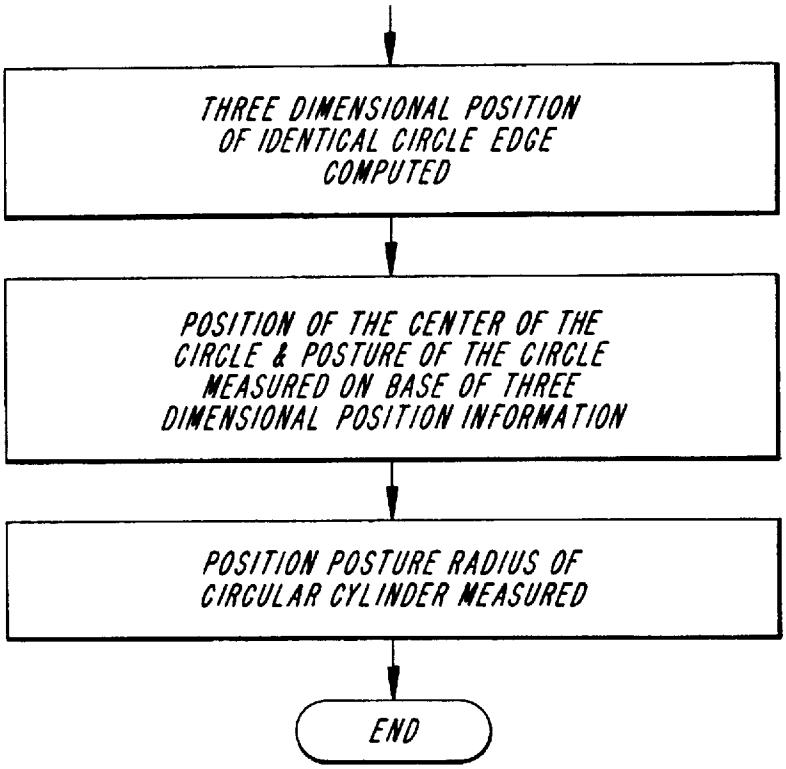


FIG. 48

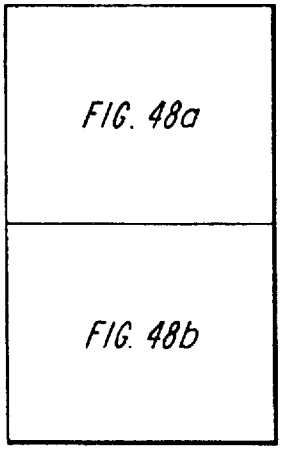


FIG. 48a

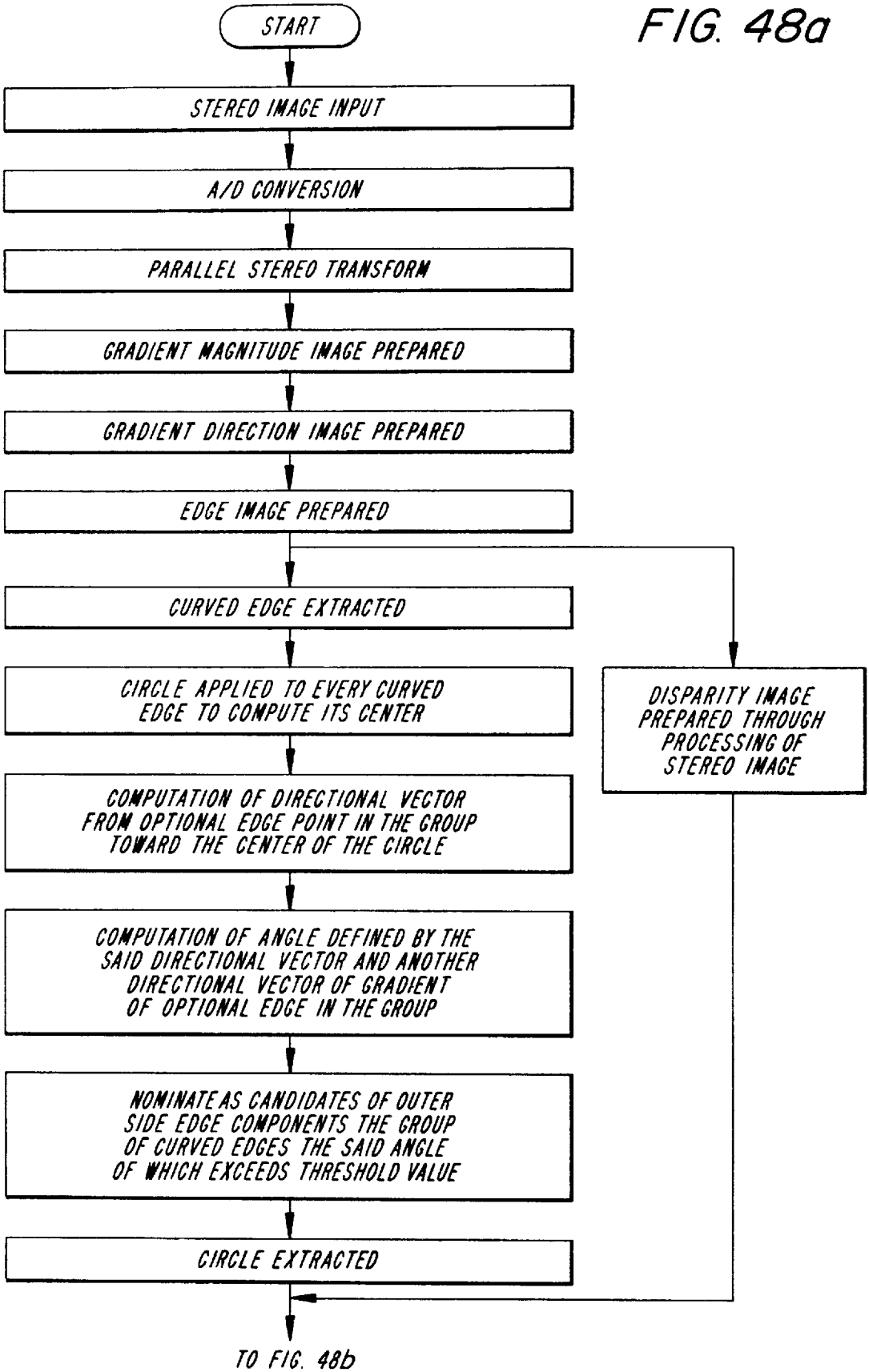

START
STEREO IMAGE INPUT
A/D CONVERSION
PARALLEL STEREO TRANSFORM
GRADIENT MAGNITUDE IMAGE PREPARED
GRADIENT DIRECTION IMAGE PREPARED
EDGE IMAGE PREPARED
CURVED EDGE EXTRACTED
CIRCLE APPLIED TO EVERY CURVED EDGE TO COMPUTE ITS CENTER
COMPUTATION OF DIRECTIONAL VECTOR FROM OPTIONAL EDGE POINT IN THE GROUP TOWARD THE CENTER OF THE CIRCLE
COMPUTATION OF ANGLE DEFINED BY THE SAID DIRECTIONAL VECTOR AND ANOTHER DIRECTIONAL VECTOR OF GRADIENT OF OPTIONAL EDGE IN THE GROUP
NOMINATE AS CANDIDATES OF OUTER SIDE EDGE COMPONENTS THE GROUP OF CURVED EDGES THE SAID ANGLE OF WHICH EXCEEDS THRESHOLD VALUE
CIRCLE EXTRACTED
DISPARITY IMAGE PREPARED THROUGH PROCESSING OF STEREO IMAGE
TO FIG. 48b

FIG. 49

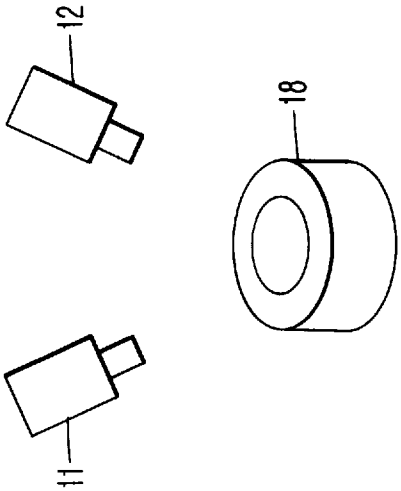


FIG. 50a

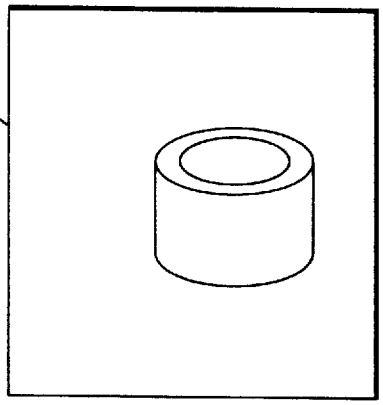


FIG. 50b

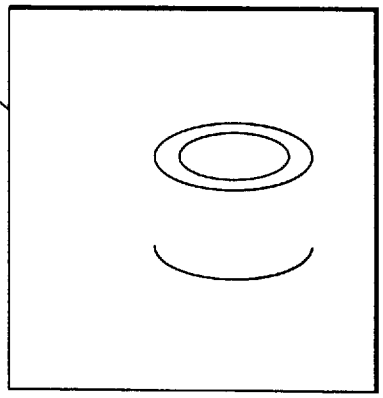


FIG. 50c

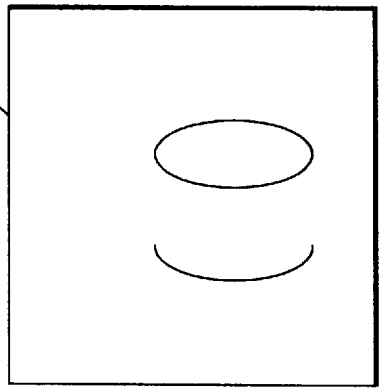


FIG. 51

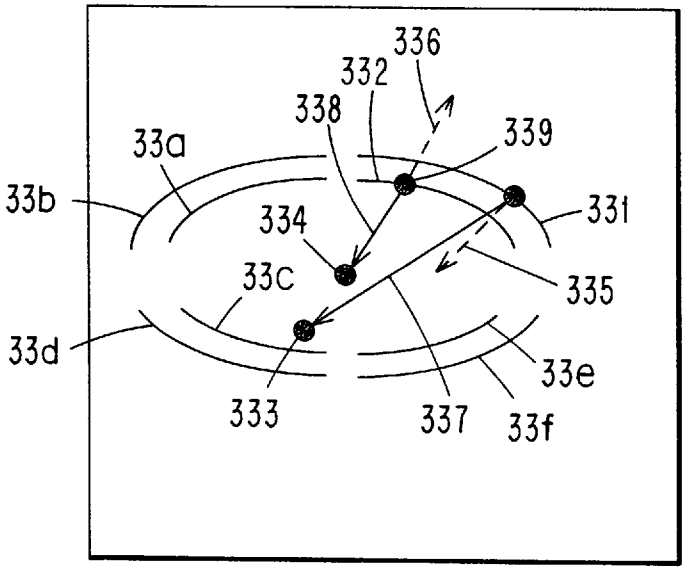
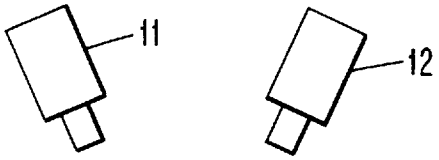

336
332
338
339
33a
33b
331
334
33c
335
33d
33e
333
337
33f

FIG. 53


11
12

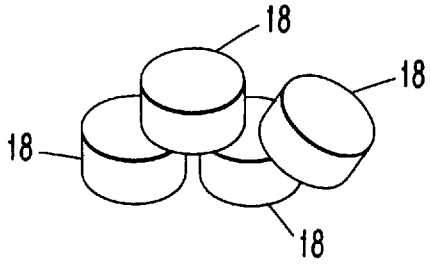
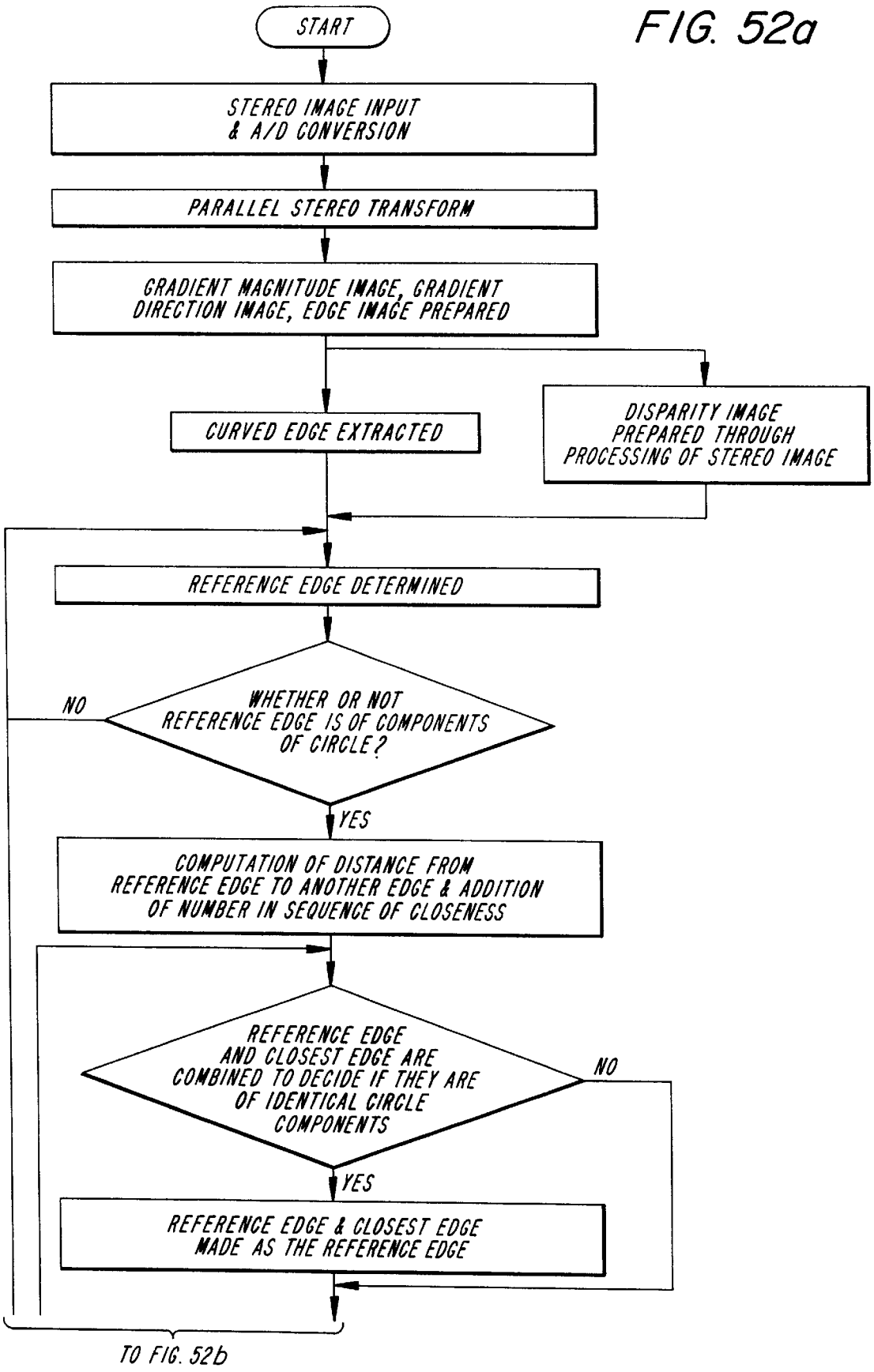

18
18
18
18

FIG. 52a


START
STEREO IMAGE INPUT & A/D CONVERSION
PARALLEL STEREO TRANSFORM
GRADIENT MAGNITUDE IMAGE, GRADIENT DIRECTION IMAGE, EDGE IMAGE PREPARED
CURVED EDGE EXTRACTED
DISPARITY IMAGE PREPARED THROUGH PROCESSING OF STEREO IMAGE
REFERENCE EDGE DETERMINED
WHETHER OR NOT REFERENCE EDGE IS OF COMPONENTS OF CIRCLE?
NO
YES
COMPUTATION OF DISTANCE FROM REFERENCE EDGE TO ANOTHER EDGE & ADDITION OF NUMBER IN SEQUENCE OF CLOSENESS
REFERENCE EDGE AND CLOSEST EDGE ARE COMBINED TO DECIDE IF THEY ARE OF IDENTICAL CIRCLE COMPONENTS
NO
YES
REFERENCE EDGE & CLOSEST EDGE MADE AS THE REFERENCE EDGE
TO FIG. 52b

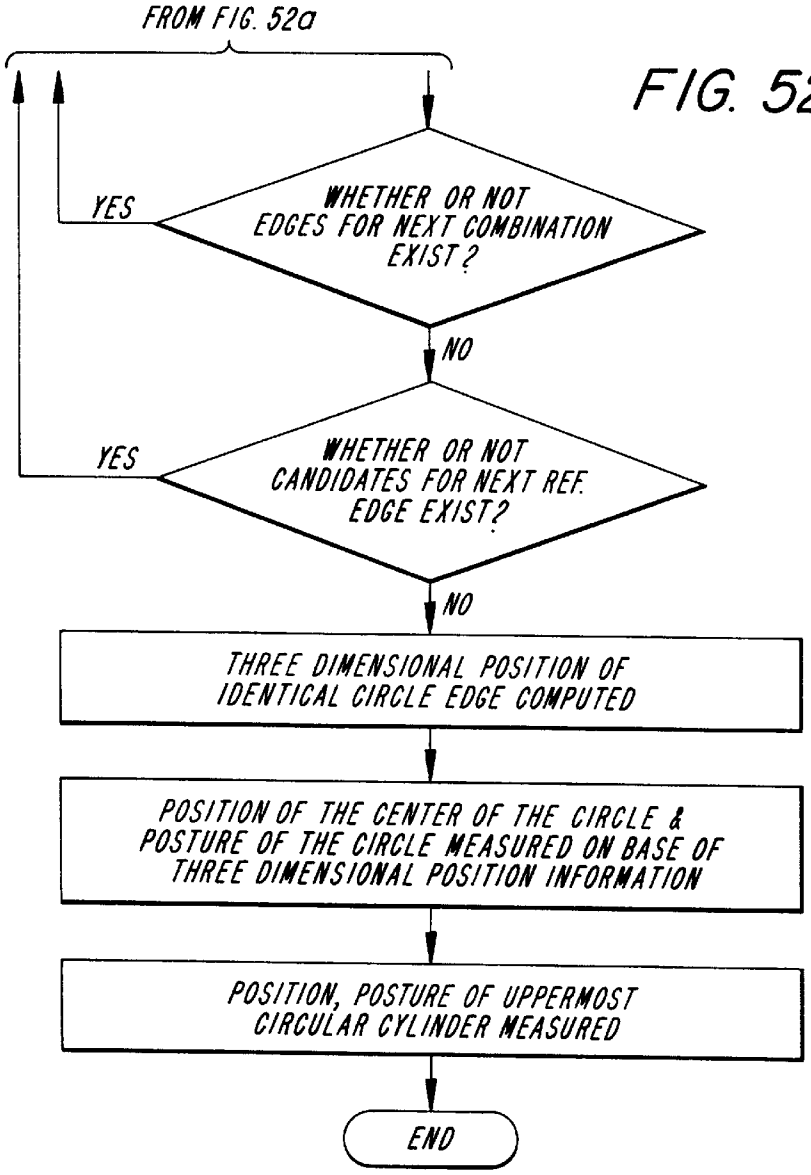


FIG. 52b

FIG. 52

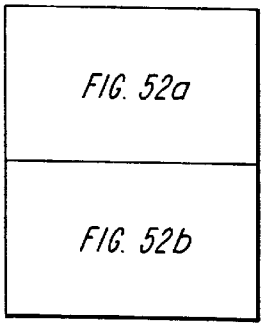
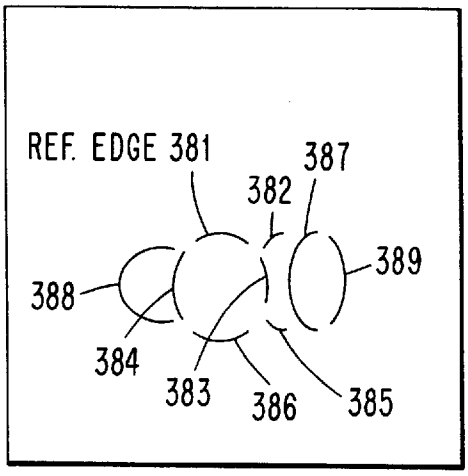


FIG. 54a



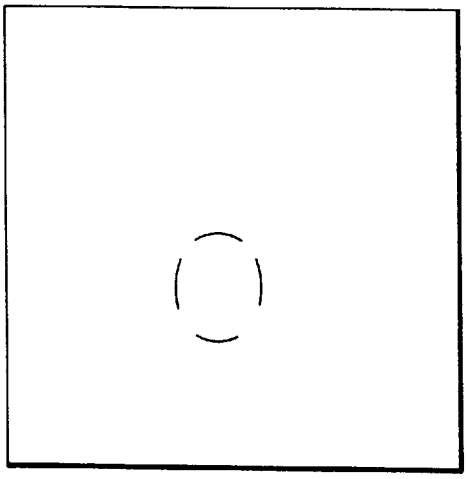


FIG. 54b

FIG. 55a

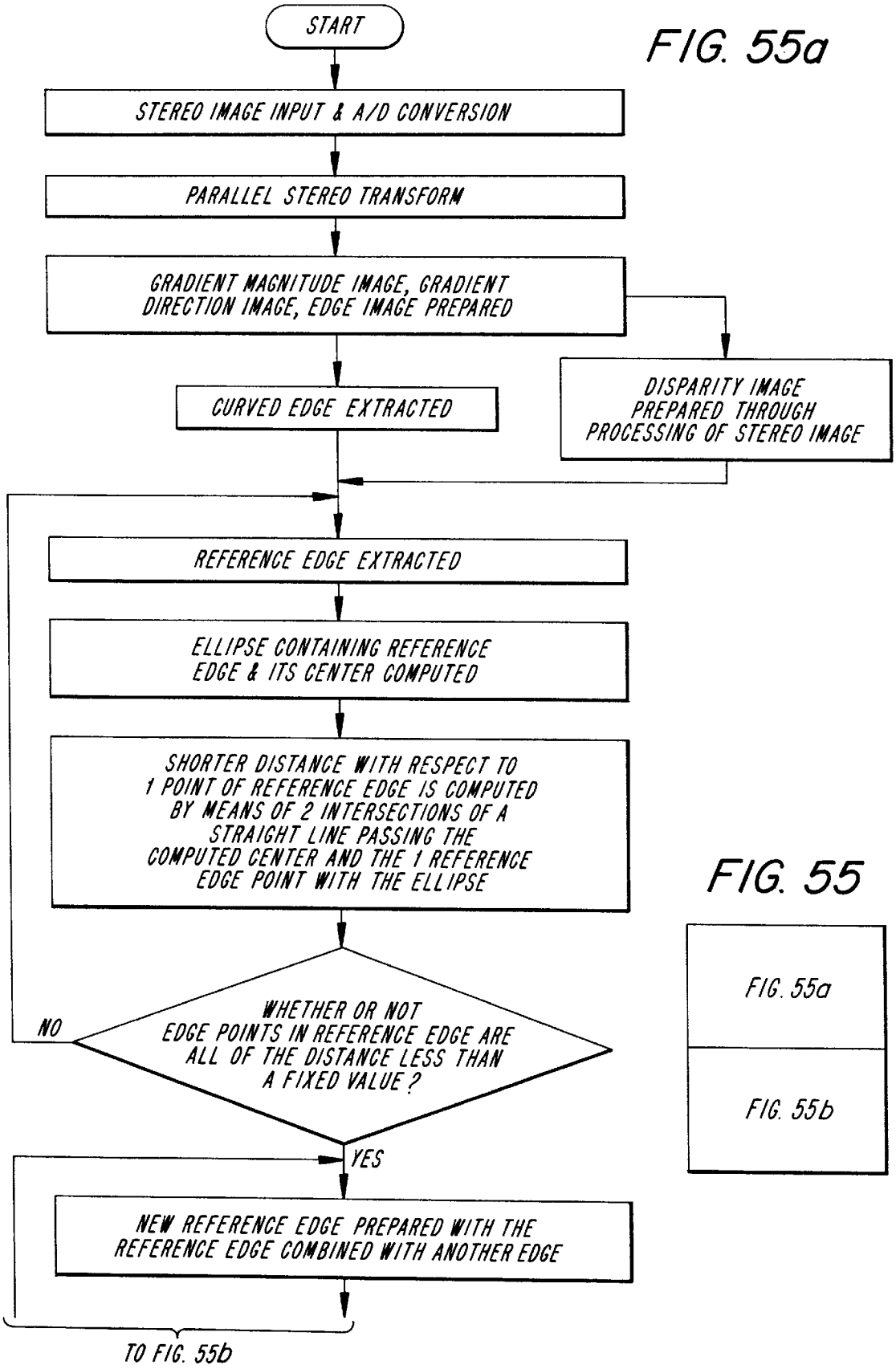


FIG. 55

FIG. 55b

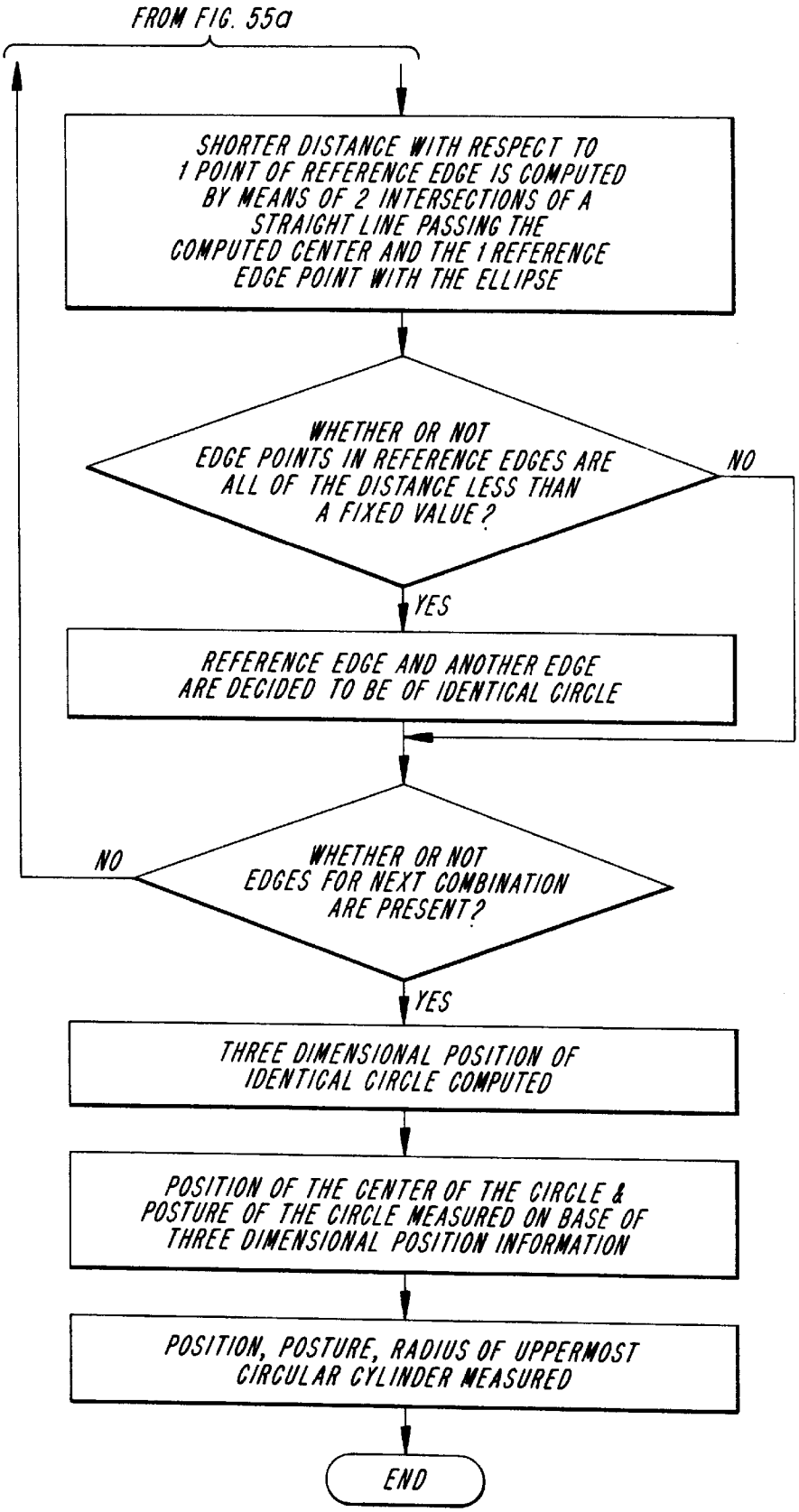

FROM FIG. 55a
SHORTER DISTANCE WITH RESPECT TO 1 POINT OF REFERENCE EDGE IS COMPUTED BY MEANS OF 2 INTERSECTIONS OF A STRAIGHT LINE PASSING THE COMPUTED CENTER AND THE 1 REFERENCE EDGE POINT WITH THE ELLIPSE
WHETHER OR NOT EDGE POINTS IN REFERENCE EDGES ARE ALL OF THE DISTANCE LESS THAN A FIXED VALUE?
NO
YES
REFERENCE EDGE AND ANOTHER EDGE ARE DECIDED TO BE OF IDENTICAL CIRCLE
NO
WHETHER OR NOT EDGES FOR NEXT COMBINATION ARE PRESENT?
YES
THREE DIMENSIONAL POSITION OF IDENTICAL CIRCLE COMPUTED
POSITION OF THE CENTER OF THE CIRCLE & POSTURE OF THE CIRCLE MEASURED ON BASE OF THREE DIMENSIONAL POSITION INFORMATION
POSITION, POSTURE, RADIUS OF UPPERMOST CIRCULAR CYLINDER MEASURED
END

FIG. 56

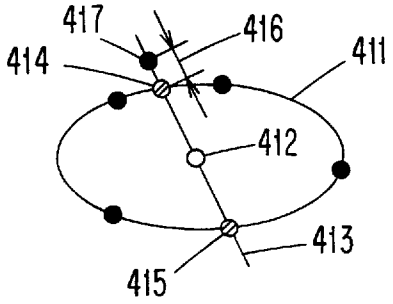


FIG. 58

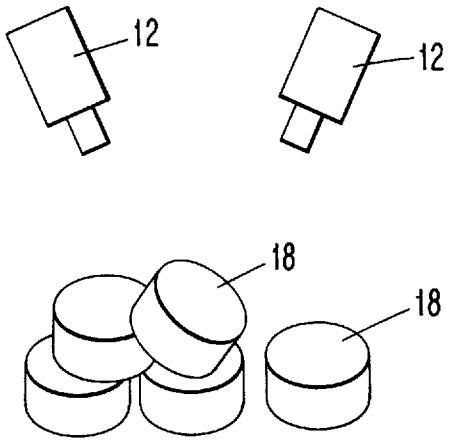


FIG. 57b

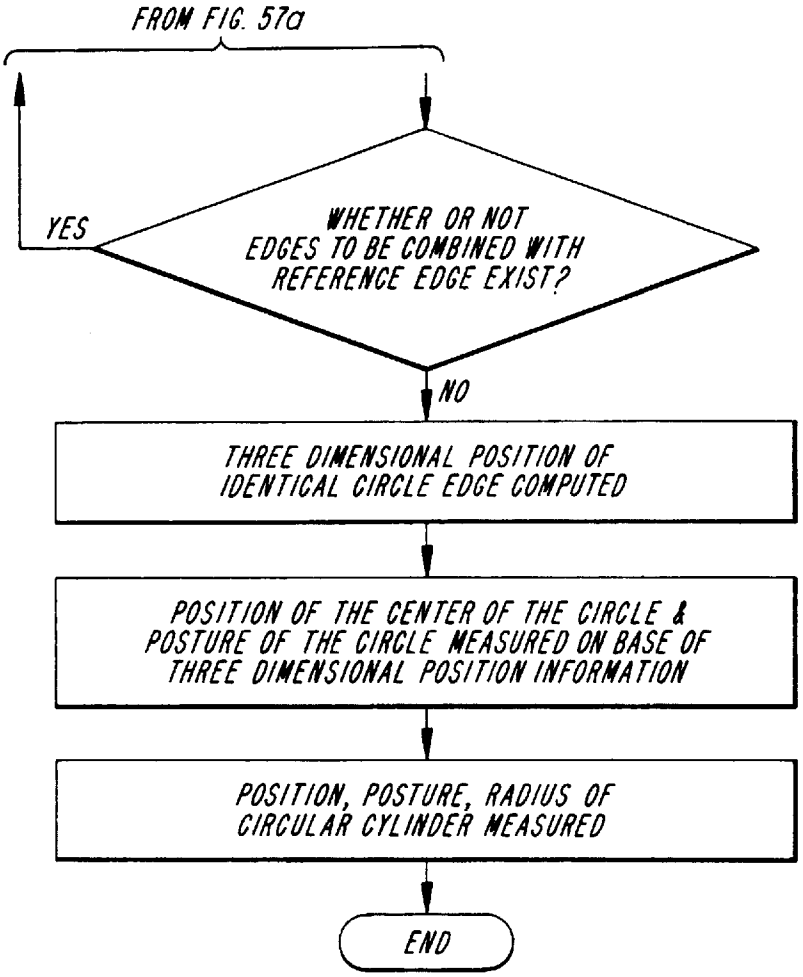


FIG. 57

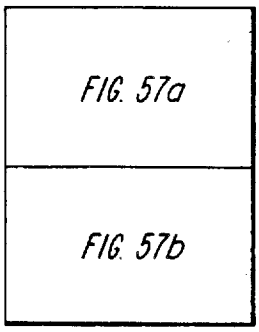


FIG. 57a

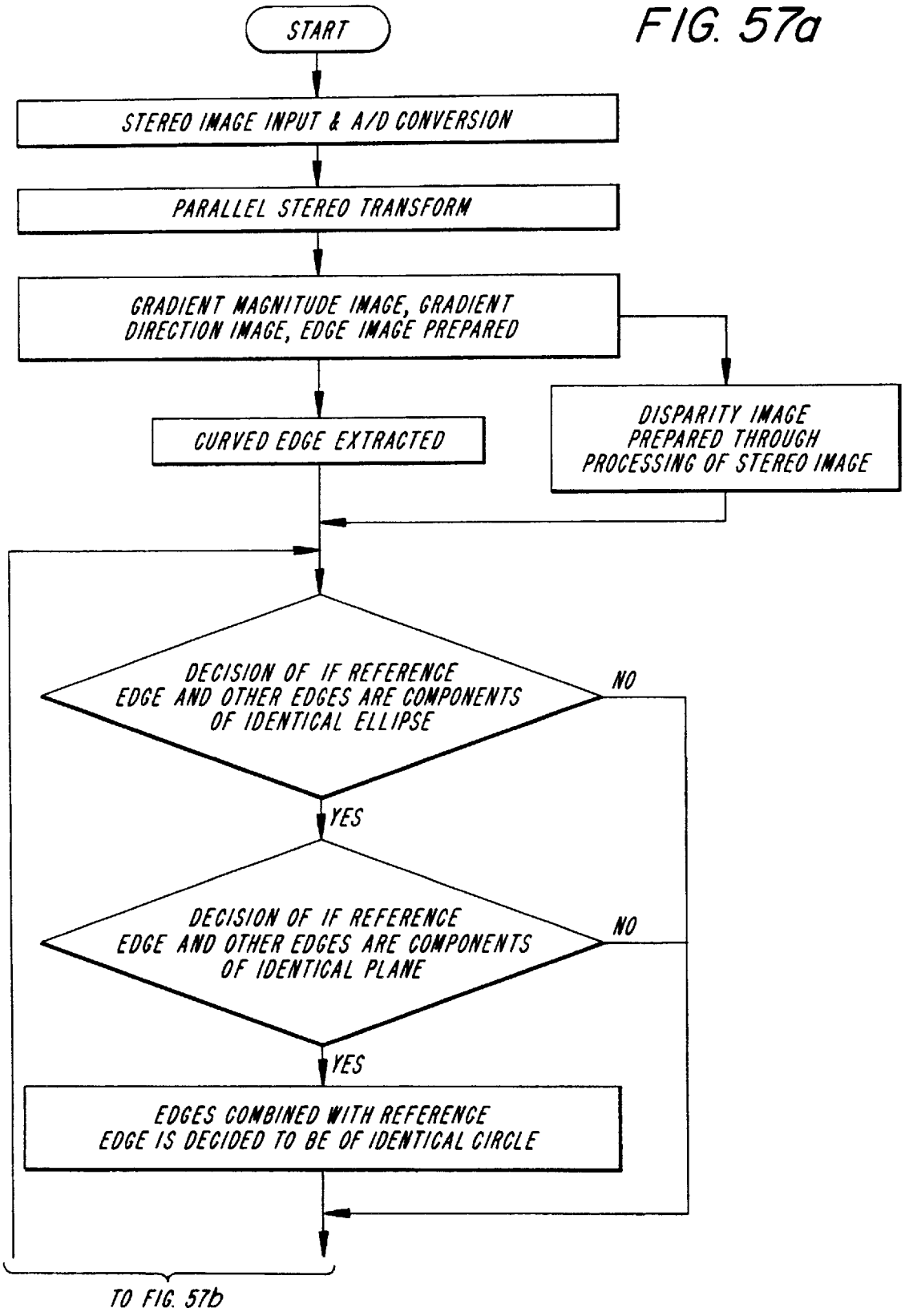

START
STEREO IMAGE INPUT & A/D CONVERSION
PARALLEL STEREO TRANSFORM
GRADIENT MAGNITUDE IMAGE, GRADIENT DIRECTION IMAGE, EDGE IMAGE PREPARED
CURVED EDGE EXTRACTED
DISPARITY IMAGE PREPARED THROUGH PROCESSING OF STEREO IMAGE
DECISION OF IF REFERENCE EDGE AND OTHER EDGES ARE COMPONENTS OF IDENTICAL ELLIPSE
NO
YES
DECISION OF IF REFERENCE EDGE AND OTHER EDGES ARE COMPONENTS OF IDENTICAL PLANE
NO
YES
EDGES COMBINED WITH REFERENCE EDGE IS DECIDED TO BE OF IDENTICAL CIRCLE
TO FIG. 57b

FIG. 59a

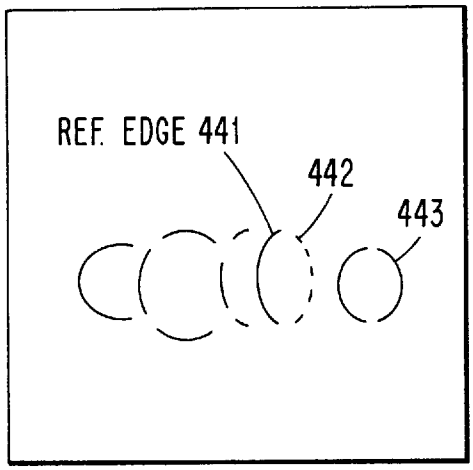


FIG. 59b

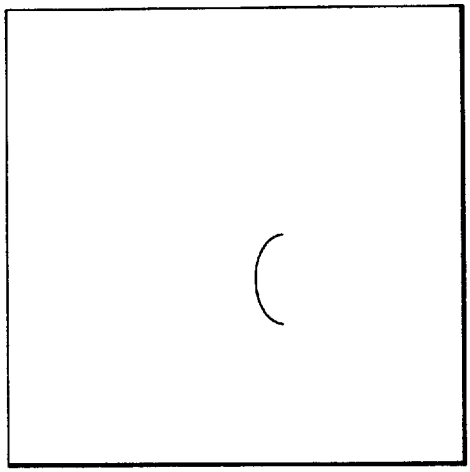


FIG. 60

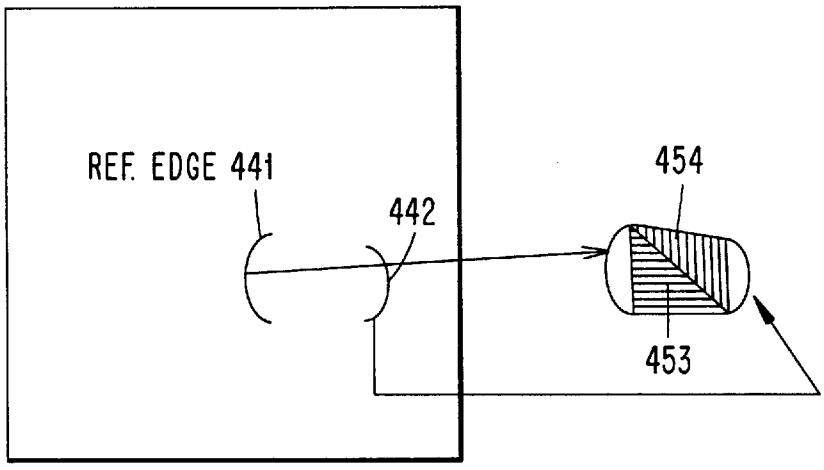


FIG. 61b

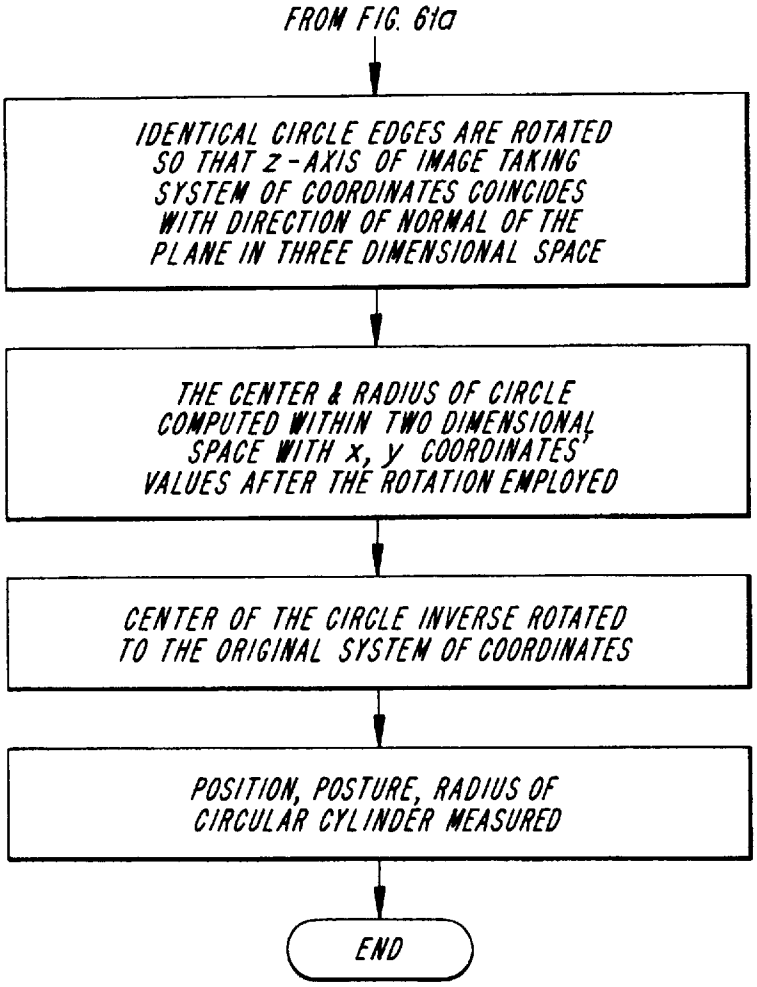


FIG. 61

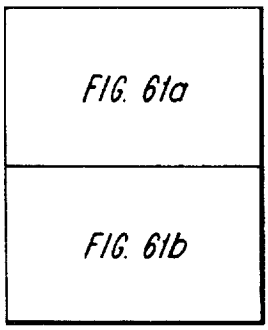
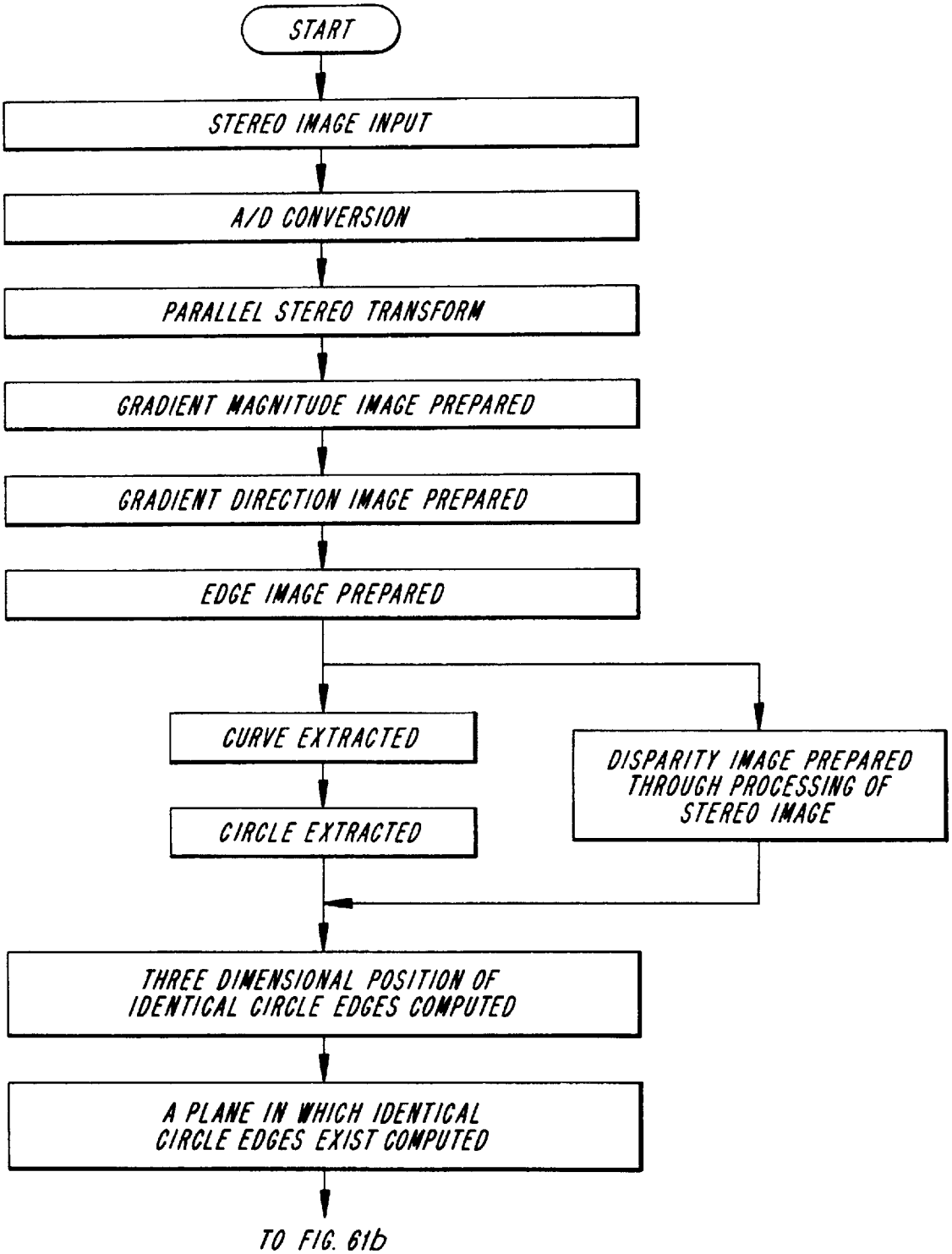


FIG. 61a


START
STEREO IMAGE INPUT
A/D CONVERSION
PARALLEL STEREO TRANSFORM
GRADIENT MAGNITUDE IMAGE PREPARED
GRADIENT DIRECTION IMAGE PREPARED
EDGE IMAGE PREPARED
CURVE EXTRACTED
CIRCLE EXTRACTED
DISPARITY IMAGE PREPARED THROUGH PROCESSING OF STEREO IMAGE
THREE DIMENSIONAL POSITION OF IDENTICAL CIRCLE EDGES COMPUTED
A PLANE IN WHICH IDENTICAL CIRCLE EDGES EXIST COMPUTED
TO FIG. 61b

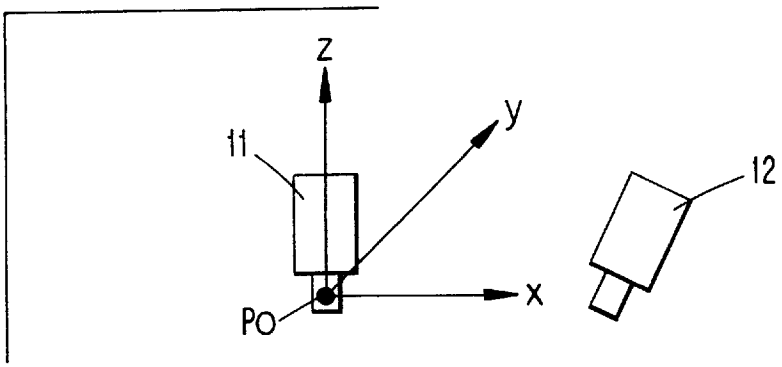
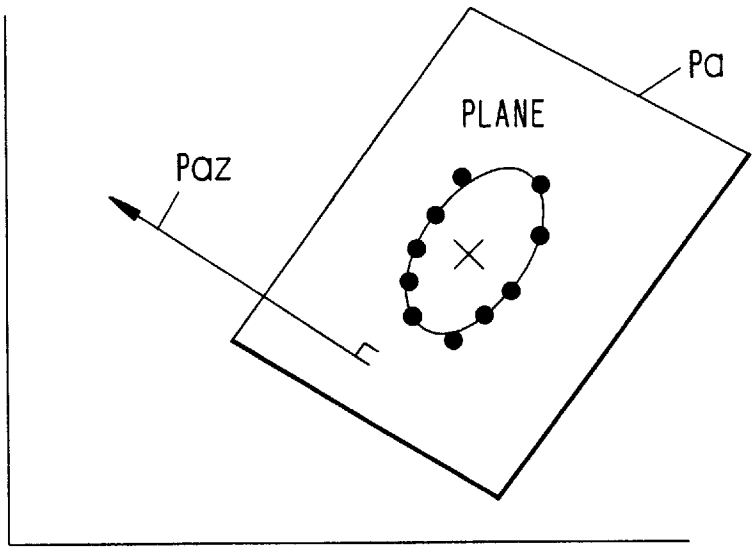


FIG. 62



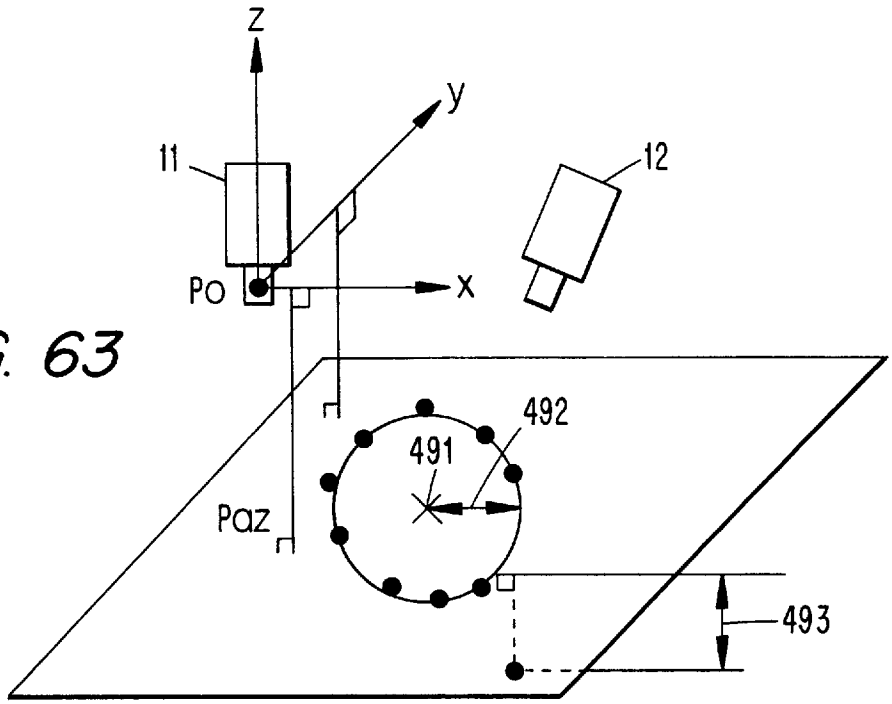


FIG. 63

FIG. 64a

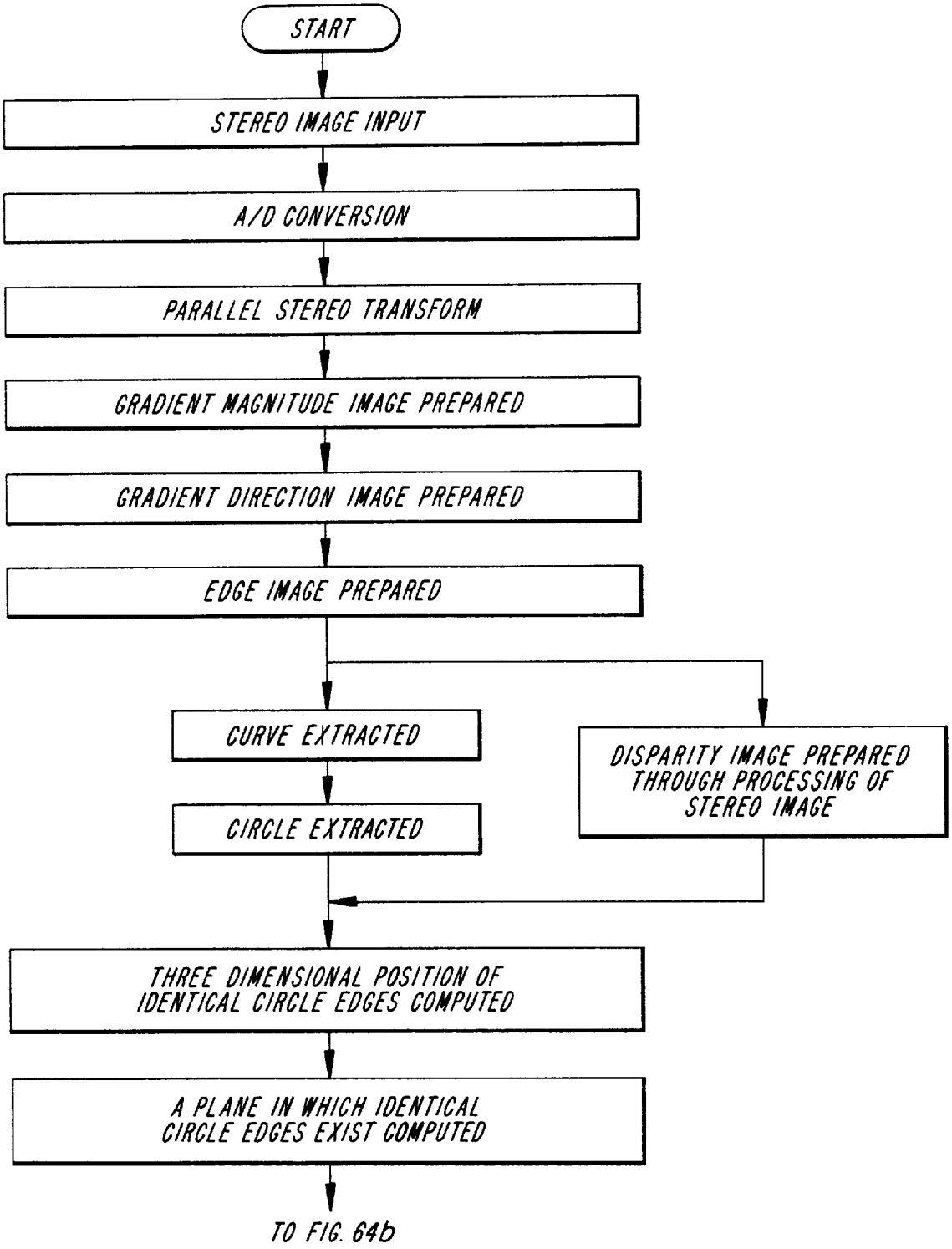

START
STEREO IMAGE INPUT
A/D CONVERSION
PARALLEL STEREO TRANSFORM
GRADIENT MAGNITUDE IMAGE PREPARED
GRADIENT DIRECTION IMAGE PREPARED
EDGE IMAGE PREPARED
CURVE EXTRACTED
CIRCLE EXTRACTED
DISPARITY IMAGE PREPARED THROUGH PROCESSING OF STEREO IMAGE
THREE DIMENSIONAL POSITION OF IDENTICAL CIRCLE EDGES COMPUTED
A PLANE IN WHICH IDENTICAL CIRCLE EDGES EXIST COMPUTED
TO FIG. 64b

FIG. 64b

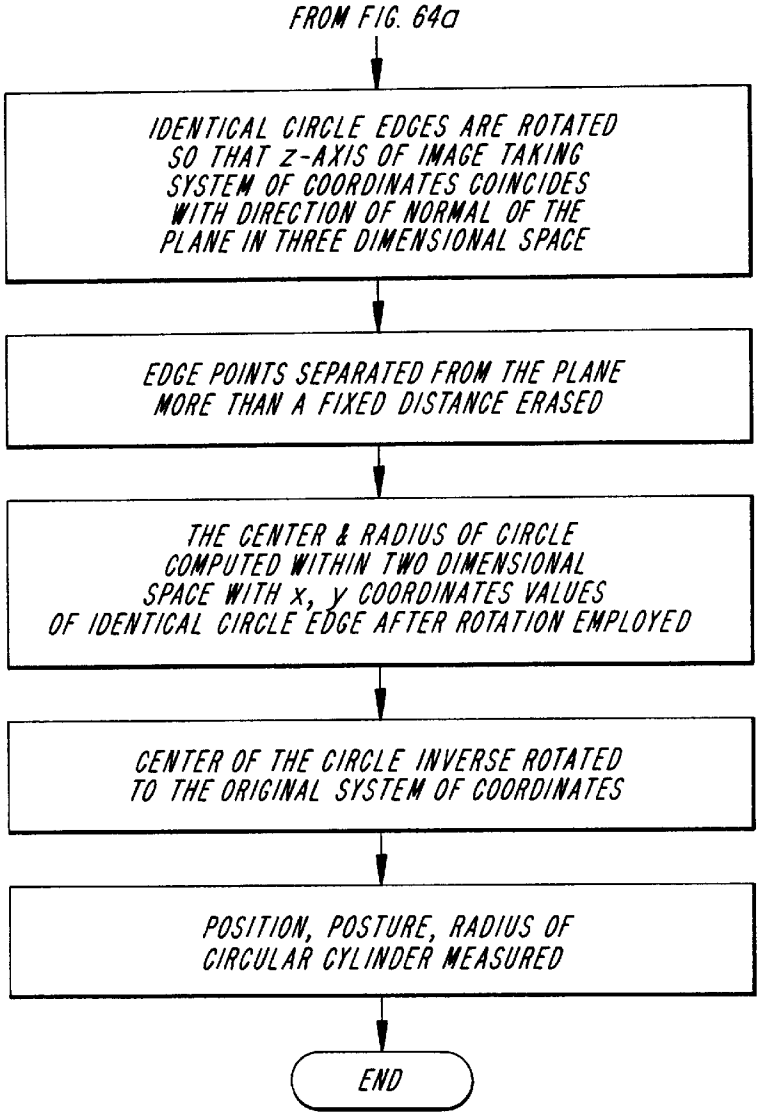


FIG. 64

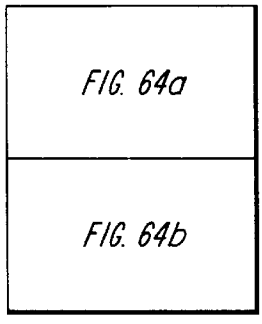


FIG. 65a

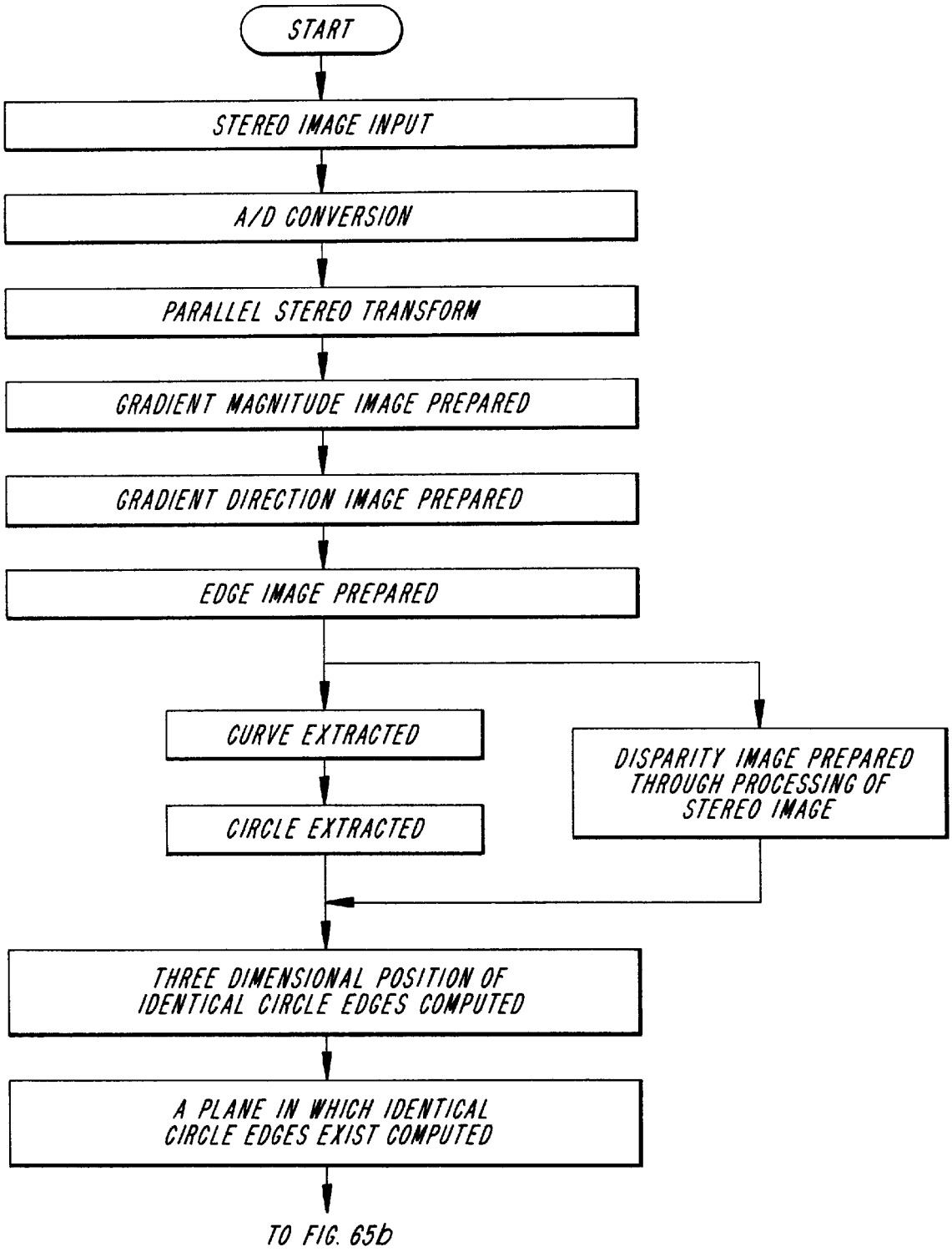

START
STEREO IMAGE INPUT
A/D CONVERSION
PARALLEL STEREO TRANSFORM
GRADIENT MAGNITUDE IMAGE PREPARED
GRADIENT DIRECTION IMAGE PREPARED
EDGE IMAGE PREPARED
CURVE EXTRACTED
CIRCLE EXTRACTED
DISPARITY IMAGE PREPARED THROUGH PROCESSING OF STEREO IMAGE
THREE DIMENSIONAL POSITION OF IDENTICAL CIRCLE EDGES COMPUTED
A PLANE IN WHICH IDENTICAL CIRCLE EDGES EXIST COMPUTED
TO FIG. 65b

FIG. 65b

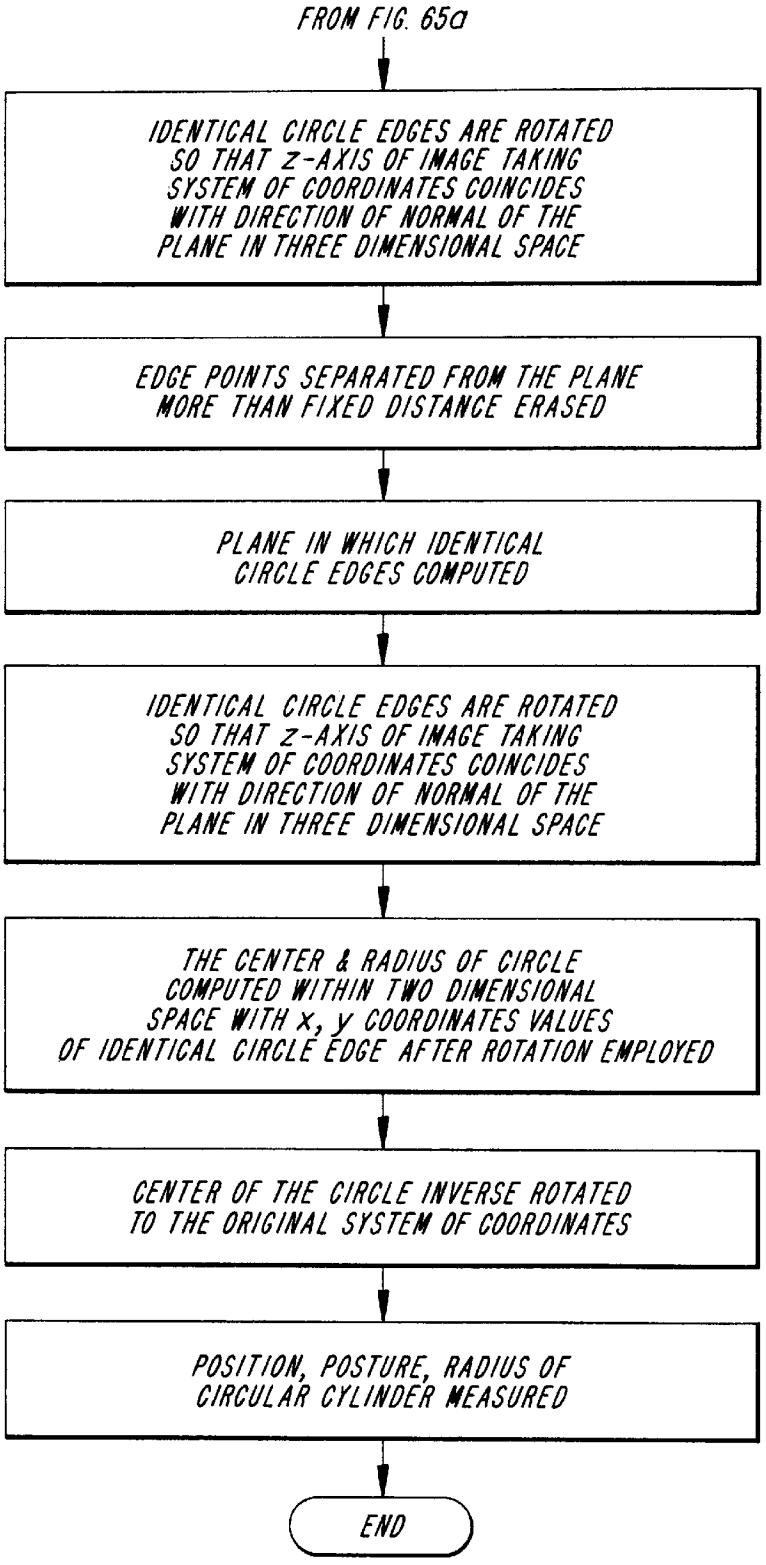
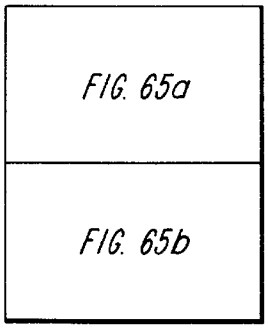


FIG. 65



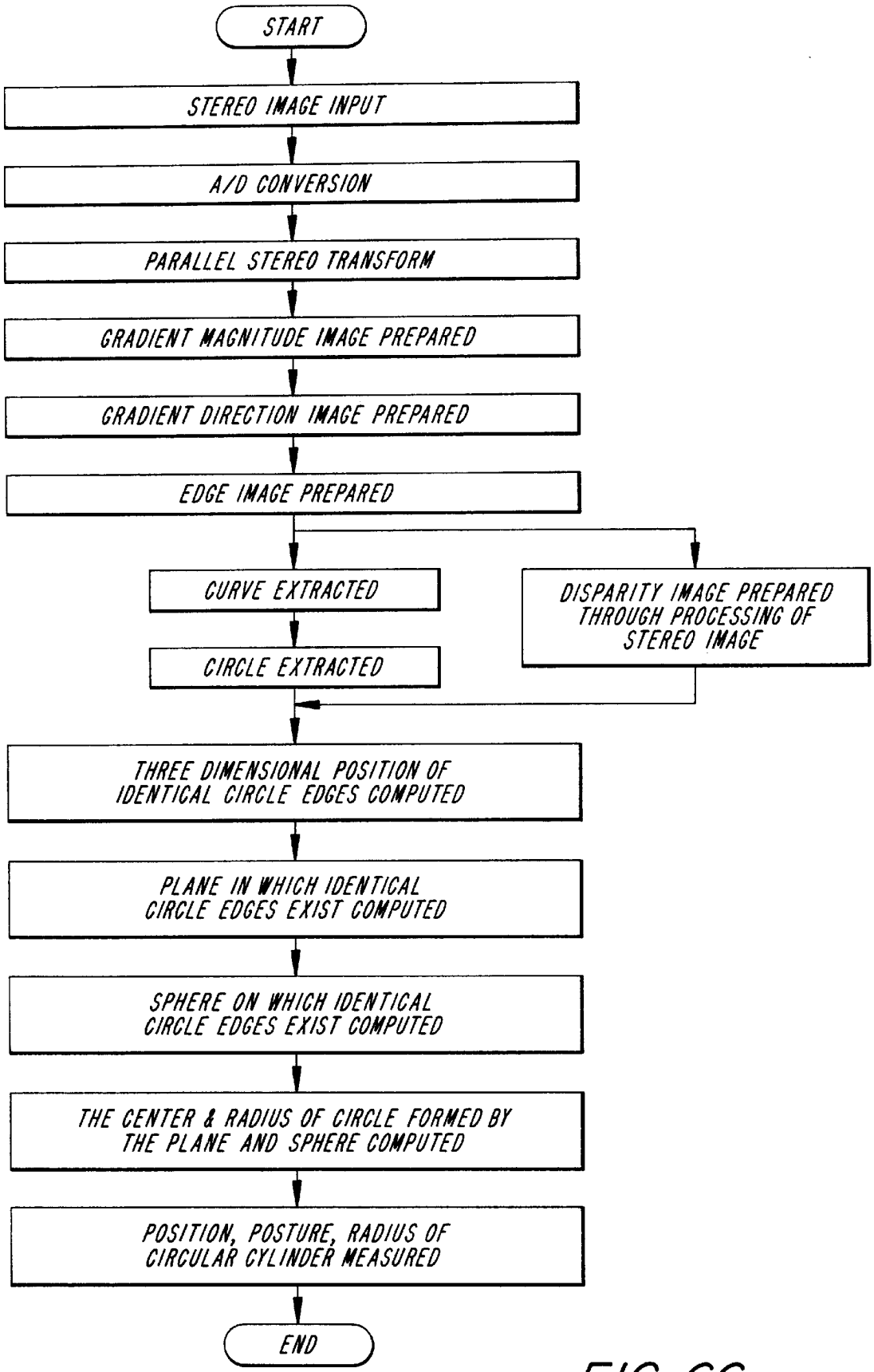

START
STEREO IMAGE INPUT
A/D CONVERSION
PARALLEL STEREO TRANSFORM
GRADIENT MAGNITUDE IMAGE PREPARED
GRADIENT DIRECTION IMAGE PREPARED
EDGE IMAGE PREPARED
CURVE EXTRACTED
CIRCLE EXTRACTED
DISPARITY IMAGE PREPARED THROUGH PROCESSING OF STEREO IMAGE
THREE DIMENSIONAL POSITION OF IDENTICAL CIRCLE EDGES COMPUTED
PLANE IN WHICH IDENTICAL CIRCLE EDGES EXIST COMPUTED
SPHERE ON WHICH IDENTICAL CIRCLE EDGES EXIST COMPUTED
THE CENTER & RADIUS OF CIRCLE FORMED BY THE PLANE AND SPHERE COMPUTED
POSITION, POSTURE, RADIUS OF CIRCULAR CYLINDER MEASURED
END

FIG. 66

FIG. 67

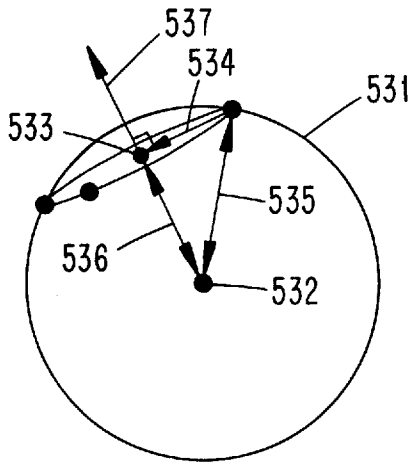
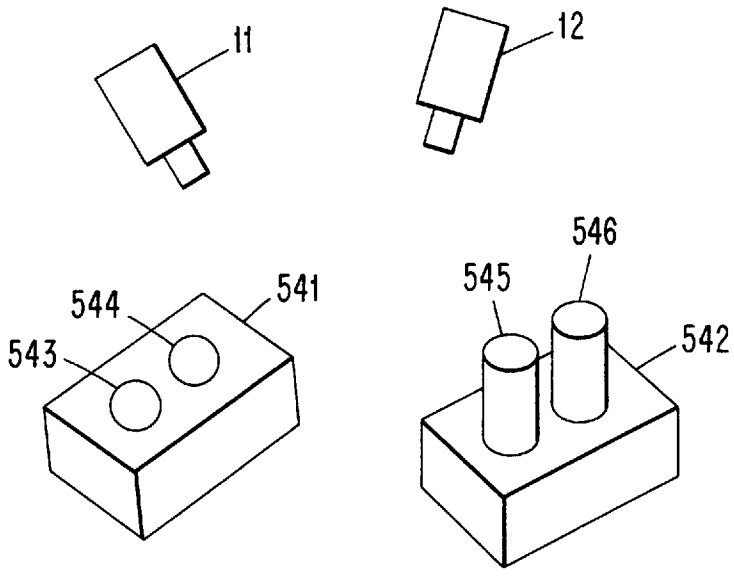


FIG. 69



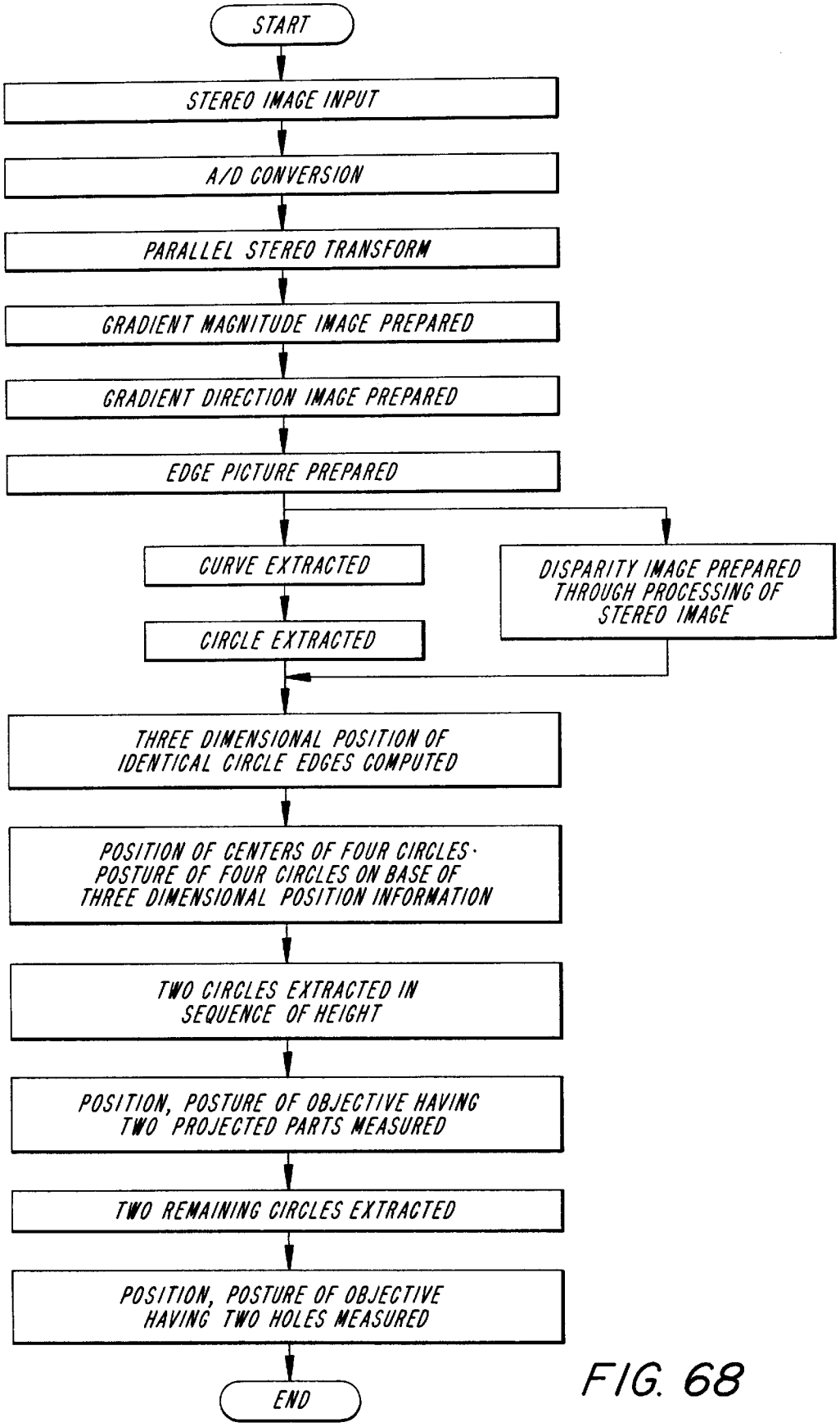

START
STEREO IMAGE INPUT
A/D CONVERSION
PARALLEL STEREO TRANSFORM
GRADIENT MAGNITUDE IMAGE PREPARED
GRADIENT DIRECTION IMAGE PREPARED
EDGE PICTURE PREPARED
CURVE EXTRACTED
CIRCLE EXTRACTED
DISPARITY IMAGE PREPARED THROUGH PROCESSING OF STEREO IMAGE
THREE DIMENSIONAL POSITION OF IDENTICAL CIRCLE EDGES COMPUTED
POSITION OF CENTERS OF FOUR CIRCLES · POSTURE OF FOUR CIRCLES ON BASE OF THREE DIMENSIONAL POSITION INFORMATION
TWO CIRCLES EXTRACTED IN SEQUENCE OF HEIGHT
POSITION, POSTURE OF OBJECTIVE HAVING TWO PROJECTED PARTS MEASURED
TWO REMAINING CIRCLES EXTRACTED
POSITION, POSTURE OF OBJECTIVE HAVING TWO HOLES MEASURED
END

FIG. 68

FIG. 70a

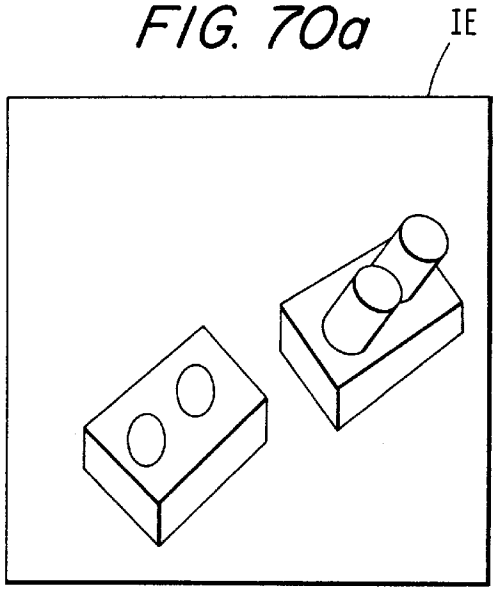


FIG. 70b

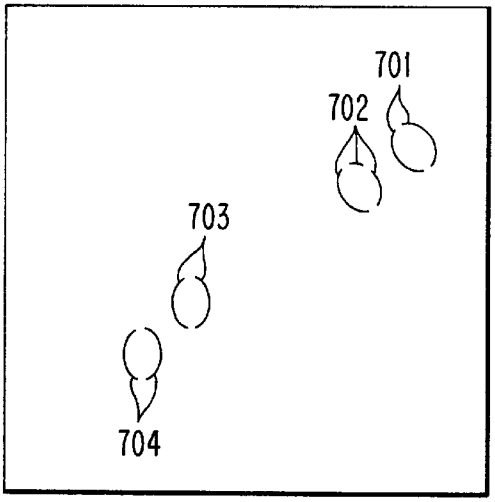
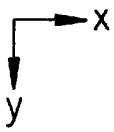


FIG. 71

-1	0	1
-2	0	2
-1	0	1

Gx



1	2	1
0	0	0
-1	-2	-1

Gy

METHOD OF UTILIZING EDGE IMAGES OF A CIRCULAR SURFACE FOR DETECTING THE POSITION, POSTURE, AND SHAPE OF A THREE-DIMENSIONAL OBJECTIVE HAVING THE CIRCULAR SURFACE PART

This application is a divisional of application Ser. No. 08/391,006, filed Feb. 21, 1995, now U.S. Pat. No. 5,692,061.

BACKGROUND OF THE INVENTION

The present invention relates to a method for recognizing an objective in a three-dimensional space and, more particularly, an objective recognition method for detecting the position, attitude or posture and shape of an objective.

DESCRIPTION OF RELATED ART

For recognizing a three-dimensional objective, there have conventionally been suggested a method in which objective position detection is carried out by extracting a cluster in a space of parameters indicative of the positional posture of an objective obtained based on correspondences between all edge segments in an image and all arris or ridge lines of an objective model as disclosed in Japanese Patent Laid-Open Publication No. 2-230478. In another method an objective to be checked is considered to be an objective model comprising a plurality of rigid bodies and joints having degrees of freedom of rotation connected to the bodies. Posture candidates for each of the rigid bodies are found based on correspondences between features (such as designated segments or designated points) in an image and the objective model. An image of the objective image is estimated from the respective posture candidates and collated with the image to thereby determined a suitable posture as disclosed in Japanese Patent Laid-Open Publication No. 4-54409.

In the former method, it is necessary to make correspondences between all the edge segments in the image and all the arris lines of the objective model. Thus, when the target objective has a complicated shape, the number of edge segments in an image and the number of arris lines in an objective model become large, which disadvantageously results in that a lot of time is required for making the correspondences, and a detection accuracy becomes bad. Even in the latter method, when an objective has a flexible structure, the numbers of rigid bodies and joints become large, so final detection of the three-dimensional posture of an objective requires lots of time.

Meanwhile, for the purpose of recognizing an objective having such a shape as a cylindrical shape, there is suggested such a method for realizing high-speed detection of an objective as shown in Japanese Patent Laid-Open Publication No. 6-29695. In this method, an objective to be checked is photographed obliquely by two image pick-up means to obtain two images. Curve edges are extracted from the two images, some of the curve edges when located within a predetermined distance range being regarded as edges in an identical elliptical line. The center of a right circle is regarded as photographed as the center of the ellipse in the images. The centers of the upper and lower ellipses are calculated and made associated with each other from the two images. The centers of right circles corresponding to the upper and lower ellipses are calculated based on the trigonometrical survey. The orientation or direction of a line segment connecting the calculated two centers is calculated to find a central line for the cylinder, thereby determining the position and posture of the cylindrical body.

However, this method has a problem that, when it is desired to recognize a ring-shaped objective or a plurality of cylindrical objectives, combinations of curve edges not in an identical circle are erroneously regarded as in the identical circle, and some edges in the lower cylindrical surface become positioned off the screen, leading to the fact that it becomes impossible to measure the direction of the central line of the cylindrical objective, i.e., its posture. Further, when the center of a circle is projected to an image, the center will be projected as offset from the circle center in the image so long as the plane containing the circle is not perpendicular to the optical axis of the image pick-up means. Furthermore, since nearly half of edges of the lower circle are hidden as unseen, the center accuracy of the circle calculated based on such edges tends to be low. Accordingly, the values of the position and posture thus obtained have been low in accuracy and reliability.

SUMMARY OF THE INVENTION

It is therefore an object of the present invention to provide an objective recognition method for realizing high-speed detection with a high accuracy.

In accordance with an aspect of the present invention, the above objective is attained by providing an objective recognition method which comprises the steps of obtaining a two-dimensional image from the same viewing point as a distance image obtained by photographing an objective in a three-dimensional space, specifying a partial image for the two-dimensional image, applying the specified two-dimensional partial image to the distance image to extract a partial image for the distance image, and subjecting the distance partial image to an objective detecting operation.

In accordance with another aspect of the present invention, there is provided an objective recognition method wherein a two-dimensional image is obtained from the same viewing point as a distance image obtained by photographing an objective in a three-dimensional space, an inertia principal axis and gravity center of a target objective image in the two-dimensional image, the distance image is projected onto a plane passing through the inertia principal axis and perpendicular to the two-dimensional image, an inertia principal axis and gravity center of a target objective image in a projected plane, and a position and posture of an inertia principal axis of the target objective in the three-dimensional space is detected from the 2 obtained inertia principal axes and the 2 obtained gravity centers.

In accordance with yet a further aspect of the present invention, there is provided an objective recognition method wherein an edge image and an intensity gradient direction image are obtained from gray images obtained by photographing an objective having a circular shape in a three-dimensional space from a plurality of directions, an edge image as a reference is created through stereo image processing and a disparity image is created from the reference image and the other edge image, only curved edges are extracted from the reference edge image, a circle is extracted from the curved edges, and a position and posture of the extracted circle are detected with use of three-dimensional information found from the disparity of edge points of the extracted circle.

In the present invention, in the objective detecting operation, the two-dimensional image is utilized to previously restrict the existence zone of the objective under detection in the distance image, and the objective detecting operation is carried out over the distance partial image of the restricted zone. Thus, the present invention can realize the

high-speed detecting operation when compared to the prior art wherein detecting operation is carried out over all zones of the distance image. In this case, the specification of the partial image of the two-dimensional image may be carried out on the basis of the shape pattern of the surface of the target objective, the statistical image feature of texture, the color or brightness classification, or the two-dimensional geometrical feature derived from the three-dimensional geometrical feature of the target objective.

While the present invention is susceptible of various modifications and alternative constructions, certain illustrated embodiments hereof have been shown in the drawings and will be described below in detail. It should be understood, however, that there is no intention to limit the invention to specific forms disclosed, but on the contrary, the intention is to cover all modifications, alternative constructions and equivalents falling within the spirit and scope of the invention.

BRIEF EXPLANATION OF THE DRAWINGS

These and other features of the present invention will become apparent from the following description, with reference to the accompanying drawings, in which:

FIG. **1** is a flowchart for explaining the operation of an embodiment of a system of the present invention:

FIG. **2** is a block diagram of the system of the embodiment of FIG. **1**;

FIG. **3** is a perspective view of an example of objectives under detection in the embodiment of FIG. **1**;

FIG. **4***a* is a diagram for explaining a two-dimensional image of the exemplary objectives in the embodiment of FIG. **1**;

FIG. **4***b* is a diagram for explaining a distance image of the exemplary objectives in the embodiment of FIG. **1**;

FIG. **5** is a flowchart for explaining the operation of a more specific variation of the embodiment of FIG. **1**;

FIG. **6** is a diagram for explaining the operation of the variation of FIG. **5**;

FIG. **7** is a flowchart for explaining the operation of another specific variation of the embodiment of FIG. **1**;

FIG. **8** is a diagram for explaining the operation of the variation of FIG. **7**;

FIG. **9** is a flowchart for explaining the operation of a further specific variation of the embodiment of FIG. **1**;

FIG. **10** is a diagram for explaining the operation of the variation of FIG. **9**;

FIG. **11** is a flowchart for explaining the operation of yet a further specific variation of the embodiment of FIG. **1**;

FIG. **12** is a front view of an example of a detection objective in the variation of FIG. **11**;

FIG. **13***a* is a diagram for explaining a two-dimensional image in the variation of FIG. **11**;

FIG. **13***b* is a diagram for explaining a distance image in the variation of FIG. **11**;

FIG. **14** is a diagram for explaining the operation of the variation of FIG. **11**;

FIG. **15** is a flowchart for explaining the operation of another embodiment of the present invention;

FIG. **16** is a diagram for explaining one operation of the embodiment of FIG. **15**;

FIG. **17** is a diagram for explaining another operation of the embodiment of FIG. **15**;

FIG. **18** is a flowchart for explaining the operation of a further embodiment of the present invention;

FIG. **19** is a flowchart for explaining the operation of yet another embodiment of the present invention;

FIG. **20***a* is a diagram for explaining a two-dimensional image in the embodiment of FIG. **19**;

FIG. **20***b* is a diagram for explaining a distance image in the embodiment of FIG. **19**;

FIG. **21***a* is a diagram for explaining the distance image after subjected to a pre-processing operation in the embodiment of FIG. **19**;

FIG. **21***b* is a diagram for explaining the two-dimensional image after subjected to a pre-processing operation in the embodiment of FIG. **19**;

FIG. **22** is a flowchart for explaining the operation of an embodiment to which the inspection method according to the present invention is applied;

FIG. **23** is a perspective view of an objective to be inspected in the embodiment of FIG. **23**;

FIG. **24***a* is a diagram for explaining a two-dimensional image in the embodiment of FIG. **22**;

FIG. **24***b* is a diagram for explaining a distance image in the embodiment of FIG. **22**;

FIG. **25** is a flowchart for explaining the operation of another embodiment of the present invention to find a position and posture of a target objective;

FIG. **26** is a perspective view of an example of the target objective in FIG. **25**;

FIG. **27** is a diagram for explaining a plane onto which the upper surface of the target objective in the embodiment of FIG. **25** is applied;

FIG. **28***a* is a diagram showing a rotated state of the plane in the embodiment of FIG. **25**;

FIG. **28***b* is a diagram for explaining a template image;

FIG. **29** is a block diagram of a system in which the present invention is employed and an objective to be detected has a cylindrical shape;

FIG. **30** shows perspective views of an example of the detection objective in the system of FIG. **29**;

FIG. **31***a* is a diagram for explaining an edge image in a stereo reference image in the system of FIG. **30**;

FIG. **31***b* is a diagram for explaining a disparity image in the system of FIG. **30**;

FIG. **32***a* is a diagram for explaining an example of an edge image in the system of FIG. **30**;

FIG. **32***b* is a diagram for explaining curve edges in the system of FIG. **30**;

FIG. **32***c* is a diagram for explaining a circular edge extracted in the system of FIG. **30**;

FIG. **33** is a flowchart for explaining the operation of a variation of the present invention;

FIG. **34** is a perspective view of other embodiment of the present invention;

FIG. **35** shows perspective views of an objective in the embodiment of FIG. **34**;

FIG. **36***a* is a diagram for explaining an edge image in the embodiment of FIG. **35**;

FIG. **36***b* is a diagram for explaining a circular edge extracted in the embodiment of FIG. **35**;

FIG. **37** is a flowchart for explaining the operation of another variation of the present invention;

FIG. **38** is a perspective view of an image acquisition state of other embodiment of the present invention;

FIG. **39** shows perspective views of an objective in the embodiment of FIG. **38**;

FIG. **40***a* is a diagram for explaining an edge image in the embodiment of FIG. **38**;

FIG. **40***b* is a diagram for explaining an extracted circular edge in the embodiment of FIG. **38**;

FIG. **41** is a flowchart for explaining the operation of another variation of the present invention;

FIG. **42** is a flowchart for explaining the operation of other embodiment of the present invention;

FIG. **43***a* is a diagram for explaining how to search edge points in the embodiment of FIG. **42**;

FIG. **43***b* is a diagram for explaining extracted edges in the embodiment of FIG. **42**;

FIG. **44** is a diagram for explaining how to extract a curved edge in the embodiment of FIG. **42**;

FIG. **45***a* is a diagram for explaining extracted curved edges in the embodiment of FIG. **42**;

FIG. **45***b* is a diagram explaining extracted curved edges in the embodiment of FIG. **42**;

FIG. **46** is a flowchart for explaining the operation of a variation of other embodiment of the present invention;

FIG. **47***a* is a diagram for explaining extracted curved edges in the embodiment of FIG. **46**;

FIG. **47***b* is a diagram for explaining a binary image of edges with disparities calculated in the embodiment of FIG. **46**;

FIG. **47***c* is a diagram for explaining extracted circular edges in the embodiment of FIG. **46**;

FIG. **48** is a flowchart for explaining the operation of a variation of other embodiment of the present invention;

FIG. **49** is a perspective view of an objective in the embodiment of FIG. **48**;

FIG. **50***a* is a diagram for explaining an edge image in the embodiment of FIG. **48**;

FIG. **50***b* is a diagram for explaining extracted curved edges in the embodiment of FIG. **48**;

FIG. **50***c* is a diagram for explaining extracted curved edges in the embodiment of FIG. **48**;

FIG. **51** is a diagram for explaining how to select curved edges in the embodiment of FIG. **48**;

FIG. **52** is a flowchart for explaining the operation of other embodiment of the present invention;

FIG. **53** shows perspective views of an objective in the embodiment of FIG. **52**;

FIG. **54***a* is a diagram for explaining edge images in the embodiment of FIG. **52**;

FIG. **54***b* is a diagram for explaining extracted circular edges in the embodiment of FIG. **52**;

FIG. **55** is a flowchart for explaining the operation of a variation of other embodiment of the present invention;

FIG. **56** is a flowchart for explaining the extracting operation of the embodiment of FIG. **55**;

FIG. **57** is a flowchart for explaining the operation of a variation of other embodiment of the present invention;

FIG. **58** is a perspective view of objectives in the embodiment of FIG. **57**;

FIG. **59***a* is a diagram for explaining edge images in the embodiment of FIG. **57**;

FIG. **59***b* is a diagram for explaining an extracted circular edge in the embodiment of FIG. **57**;

FIG. **60** is a diagram for explaining how to extract a circular edge in the embodiment of FIG. **57**;

FIG. **61** is a flowchart for explaining the operation of a variation of other embodiment of the present invention;

FIG. **62** is a diagram showing a plane of an objective when viewed from its upper side in the embodiment of FIG. **61**;

FIG. **63** is a diagram for explaining a state of the plane when rotated in the embodiment of FIG. **61**;

FIG. **64** is a flowchart for explaining the operation of a variation of other embodiment of the present invention;

FIG. **65** is a flowchart for explaining the operation of other embodiment;

FIG. **66** is a flowchart for explaining the operation of a variation of other embodiment;

FIG. **67** is a diagram for explaining a form of the operation of the embodiment of FIG. **66**;

FIG. **68** is a flowchart for explaining the operation of an embodiment of the present invention which can be applied to an assembly control system;

FIG. **69** is a perspective view of objectives in the embodiment of FIG. **68**;

FIG. **70***a* is a diagram for explaining edge images in the embodiment of FIG. **68**;

FIG. **70***b* is a diagram for explaining extracted circular edges in the embodiment of FIG. **68**; and

FIG. **71** is a diagram for explaining a Sobel operator used, for example, in the embodiments of FIGS. **29** to **31**.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention will be detailed in connection with illustrated embodiments. First and second features of the present invention involving using a distance image and a two-dimensional image photographed from the same viewing point as the distance image. Though there are various ways of creating the distance image, explanation will be made in connection with a case where the distance image is created from a stereoscopic image, i.e., from two-dimensional images. In FIG. **2**, reference symbols **10***a* and **10***b* denote television cameras for capturing stereo images. An image photographed by one **10***a* of the television cameras **10***a* and **10***b* connected to a two-dimensional image memory **4** is used as a stereo reference image. Images photographed by the television cameras **10***a* and **10***b* are associated with each other in a stereo image processor **2**, and distances calculated based on the associated result are mapped onto the stereo reference image to generate a distance image in a three-dimensional image generator **3**. The two-dimensional image acquired by one television camera **10***a* is stored in the two-dimensional image memory **4**. An objective existence zone extractor **5**, on the basis of the two-dimensional image and distance image, extracts an objective existence zone in which the objective is present, and a three-dimensional position/posture detector **6** detects a three-dimensional position or posture of the objective based on the objective existence zone and the distance image in its vicinity.

FIG. **3** shows an example of objectives to be detected. FIG. **4***a* is a two-dimensional image I**2** of the exemplary objectives, and FIG. **4***b* is a distance image I**3** thereof. Areas which are differently hatched in the distance image I**3** stand for different heights of the objectives. This representation is also applied to cases which will be described later.

Explanation will first be made as to how to extract an objective existence zone using a shape pattern present on a surface of an objective under detection undetectable from the distance image. The extraction of an objective existence zone by the objective existence zone extractor **5** is carried

out by means of pattern matching in the case of FIG. **5**. For example, when a letter "B" is present on a surface of an objective under detection, the letter "B" is used as a detection pattern. Pattern matching is carried out between the two-dimensional image **I2** and the detection pattern to extract a part corresponding to a matching score equal to or larger than a threshold value and to use as an objective existence zone **A1** a zone including the extracted part and covering a circle having a center corresponding to a gravity center **G1** of the extracted part as shown in FIG. **6**. An objective detecting operation is carried out over a partial image of the distance image **I3** corresponding to the objective existence zone **A1**. This objective detecting operation may be realized not only by the two methods already explained in connection with the prior art but also by another method which will be explained later.

For setting the objective existence zone **A2**, as shown in FIGS. **7** and **8**, edges may be extracted from the two-dimensional image **I2**, a part corresponding to an edge intensity equal to or larger than a threshold value may be extracted, an objective existence zone **A2** having a center corresponding to a gravity center **G2** of the extracted part may be set, and an objective detecting operation may be carried out over a partial image of the distance image **I3** corresponding to the objective existence zone **A2**. This objective detecting operation utilizes the fact that differences in the statistical image features of the objective texture appear as different edge densities in the two-dimensional image **I2**.

When only one of a plurality of rectangular parallelepipeds located in their center is red in color and the other rectangular parallelopipeds are blue, as shown in FIG. **9**, color extraction (red extraction in the illustrated example) may be carried out from the two-dimensional image **I2** to extract a part having a red component equal to or larger than a threshold value. And as shown in FIG. **10**, an objective existence zone **A3** having a center corresponding to a gravity center **G3** of the extracted part may be set and objective detecting operation may be performed over a partial image of the distance image **I3** corresponding to the objective existence zone **A3**. It goes without saying that a specific part may be extracted based on its brightness in place of the color. In this case, it will be noted that an objective existence zone is set on the basis of an extracted part of a two-dimensional image having a target component equal to or larger than its threshold value and an image corresponding to the set zone is used as a partial image of the two-dimensional image.

In addition to the above, the existence zone of an objective under detection may be previously limited by utilizing two-dimensional geometrical features derived from three-dimensional geometrical features. FIG. **11** shows a case where a two-dimensional geometrical feature comprised two straight lines connected in the form of a letter T is utilized. More specifically, first, an objective **120** shown in FIG. **12** is photographed to obtain such a two-dimensional image **12** as shown in FIG. **13***a* and such a distance image **I3** as shown in FIG. **13***b*. In this case, a two-dimensional geometrical feature appears as such a T-shape connection of two straight lines as shown by a reference numeral **130**. Next, edges are extracted from the two-dimensional image **I2** and subjected to a Hough transform to detect straight lines, an intersection point of the detected lines is extracted, the presence or absence of a T-shaped connection is judged, whereby an intersection point **G4** in the T-shaped connection is extracted as shown in FIG. **14**. And a zone having a predetermined range and having a center corresponding to the intersection point **G4** of the T-shaped connection is applied to a distance image **I3** to detect a three-dimensional position or posture of the objective from a distance partial image.

As shown in FIGS. **15** and **16**, an inertia principal axis **EA1** and a gravity center **G5** are detected from the two-dimensional image **I2**, and the distance image **I3** is projected onto a plane P passing through the Inertia principal axis **EA1** and perpendicular to the two-dimensional image **I2**. When an inertia principal axis **EA2** and a gravity center **G6** are detected from the projected image as shown in FIG. **17**, the posture of the inertia principal axis can be detected from the two inertia principal axes **EA1** and **EA2** and the position of the inertia principal axis can be detected from the gravity centers **G5** and **G6**.

Further, as shown in FIG. **18**, after the posture and position of the inertia principal axis are detected as mentioned above, an inertia principal axis and gravity center for the objective model are found and made to coincide with the posture and position of the detected inertia principal axis, the objective model is rotated on the inertia principal axis to find a coincidence or matching degree between the objective model and target objective, and a three-dimensional position and posture of the objective can be detected on the basis of the position and posture of the target model when the matching degree becomes maximum. In this case, since the position and posture of the inertia principle axis representative of the position and posture of the objective in the three-dimensional space are used as fixed references, that is, since 5 of 6 degrees of freedom of the objective in the three-dimensional space are restricted, the position and posture of the objective in the three-dimensional space can be accurately detected at a high speed.

As will be seen from a two-dimensional image **I2** shown in FIG. **20***a* and from a distance image **I3** shown in FIG. **20***b*, when a plurality of such objectives as shown in FIG. **12** are piled, a predicted height of an existence position of an objective to be detected is set as a pre-processing, a zone higher than the predicted height is extracted from the distance image **I3** (see FIG. **21***a*), and a zone having the same position as in the image is extracted from the two-dimensional image **I2** (see FIG. **21***b*), as shown in FIG. **19**. Thereafter, the zone restricted by the predicted height references of a two-dimensional image **I2'** and distance image **I3'** is subjected to such processing as mentioned above (in the illustrated example, which is the same as the processing shown in FIG. **11**) to detect a three-dimensional position and posture of the objective.

Such a three-dimensional objective recognition method can be applied to objective inspection situations. For example, FIG. **23** shows a case where a rectangular column **8** is inserted into a square hole **70** of a base **2** and it is desired to examine whether or not the rectangular column **8** was inserted in the square hole perpendicularly (θ=90°) to the base **2**. FIG. **22** shows a flowchart for explaining the operation when the aforementioned pattern matching is employed. That is, such a two-dimensional image **I2** as shown in FIG. **24***a* and such a distance image **I3** as shown in FIG. **24***b* are obtained from stereo images of two television cameras. In more detail, a circle **80** (which may be replaced by an opening or a screw hole) on the top surface of the rectangular column **8** is used as a detection pattern, an objective existence zone is restricted in a similar way to the foregoing embodiment, and then a position and posture of the rectangular column **8** in the three-dimensional space are detected. On the basis of the detection result, a tilt θ of the rectangular column **8** is found to judge whether the inserted state is good or not.

FIGS. **25** to **28** show an example of a detection method in which a position and posture of an objective are detected based on a distance partial image extracted by utilizing the aforementioned texture. More specifically, when such an objective **8** as shown in FIG. **26** is present, a partial image corresponding to the top surface of the objective **8** is extracted from a distance image obtained by photographing the objective **8** and based on the texture, and three-dimensional information obtained from the partial image is applied to find a plane Pa containing the top surface of the objective **8** in the three-dimensional space as shown in FIG. **27**. The plane Pa can be obtained by calculating coefficients a, b and c in the following equation by the least squares method.

$$ax+by+cz+1=0$$

Next, as shown in FIG. **27**, three-dimensional positions of points on the top surface of the objective are rotated on an origin Po of a camera image coordinate system so that a normal Paz of the plane Pa coincides with a Z axis of the image coordinate system as shown in FIG. **28***a*, and the positions are then projected onto a plane (in this case, an X-Y plane Pxy of the above image coordinate system) of a reference coordinate system with use of x and y coordinate values of the points on the top surface of the objective after rotated. A projected image thus obtained and a previously-registered template image M (such as shown in FIG. **28***b*) are subjected to a pattern matching therebetween to find a position and posture of the objective of the projected image. The found objective position is subjected to an inverse transformation to find a position and posture of the top surface of the objective before the above rotation. In order to detect the position and posture of the objective on the two-dimensional image, the pattern matching with the template image has been employed in the illustrated example, but it goes without saying that another method such as a generalized Hough transform can be employed.

In the foregoing embodiment, the two-dimensional image has been obtained from the same viewing point as the distance image obtained by picking up the objective in the three-dimensional space, the zone to be subjected to the detecting operation of the position and posture of the target objective has been extracted and restricted, and the inertia principal axis and gravity center of the target objective have been extracted on the basis of two-dimensional image. However, when the target objective has such a shape as a circular cylinder, a circular part is extracted by utilizing an edge image, and a position, posture and radius of the circle are measured to realize higher speed recognition of the objective.

In this case, such a system as shown in FIG. **29** comprises two cameras **11** and **12** for photographing an objective **18** illuminated by an illuminator **19**, A/D converters **13** and **14** for converting analog image signals from the both cameras **11** and **12** into digital image signals, frame memories **15** and **16** for storing the digital image signals therein, and a processor **17** connected to the frame memories **15** and **16**. With this system, parallel stereo conversion is carried out through the stereo image processing of an edge image, that is, the two cameras **11** and **12** are matched in their orientation and focal distance, the image signals are converted into images so that the corresponding pixels of the two images coincide with each other in the Y coordinate value to thereby realize efficient corresponding point search, and a disparity corresponding to a difference between the X coordinate values of the two calculated images is photographed by the camera **11** and mapped onto an extracted edge image (stereo reference image) to create a disparity image. When a distance image is required, conversion from disparity to distance is added. For example, in the case where circular cylindrical objectives **18***a*, **18***b* and **18***c* having different heights are located as shown in FIG. **30**, when the objectives are photographed from their upper side by the two cameras, such an edge image IE for the stereo reference image as shown in FIG. **31***a* and such a disparity image ID as shown in FIG. **31***b* are obtained. In FIG. **31***b*, a thicker line indicates a higher objective.

The images stored in the frame memories **15** and **16** through the image acquisition are subjected to the parallel stereo conversion to obtain an edge image and a gradient direction image based on the converted image. In order to extract edges from the images, a Sobel operator as shown in FIG. **71** is used. Upon application of this operator, the center of the operator is moved to a target pixel, the intensity values of pixels adjacent to the target pixel are multiplied by the values of the operator, whereby gradient magnitudes Gx and Gy in the X and Y directions, gradient intensity |G| and gradient direction θ are calculated with respect to all the pixels. When I(x,y) denotes the intensity of a pixel at a coordinate point [x,y], the gradient magnitudes Gx and Gy in the X and Y directions are expressed by the following equations.

$$Gx(x,y)=\{I(x+1,y-1)+2I(x+1,y)+I(x+1,y+1)\}-\{I(x-1,y-1)+2I(x-1,y)+I(x-1,y+1)\}$$

$$Gy(x,y)=\{I(x-1,y-1)+2I(x,y-1)+I(x+1,y-1)\}-\{I(x-1,y+1)+2I(x,y+1)+I(x+1,y+1)\}$$

Using Gx and Gy, the gradient intensity |G| and the gradient direction θ at each pixel position are found as follows. Images of pixels having such values are referred to as gradient intensity image and gradient direction image, respectively.

$$|G|=(Gx^2+Gy^2)^{1/2}$$

$$\theta=\tan^{-1}(Gy/Gx)$$

After a threshold value is provided for the value of the gradient intensity |G| and the gradient intensities for pixels having gradient intensities lower than the threshold value are set at 0, points having the highest gradient intensities in the vicinity, i.e., the gradient intensities in the form of a ridge line are extracted as edge points, such an edge image IE as shown in FIG. **32***a* is obtained. And only curved components **321** and **322** are extracted from the edge image of the stereo reference image as shown in FIG. **32***b*, and a circular component **322** is extracted from the extracted curved components as shown in FIG. **32***c*.

A disparity is calculated in the aforementioned manner on the basis of the two stereo edge images through the stereo image processing, the calculated disparity is mapped onto the edge image of the stereo reference image to create a disparities image, three-dimensional positions at points on the circular edge are calculated from the corresponding parts of the circular disparities image extracted in the aforementioned manner, and a central position and posture of a circle of the top surface of the circular cylindrical objective **18** are measured based on the calculated three-dimensional position information to thereby recognize a position and posture of the objective **18**.

The extraction of only the curved components from the edge image of the stereo reference image can be carried out, for example, by extracting straight lines through Hough transform and by erasing edges present within a predeter-

mined distance from the extracted straight lines. Explanation will be made as to the case where three types of such objectives **18***a*. **18***b* and **18***c* as shown in FIG. **35** are conveyed along a conveyor **92** and the target objective **18** is one of three types of such objectives, and as to how to select the target objective from the three types of objectives. As shown in FIG. **37**, an edge image is created through parallel stereo conversion and creation of a gradient magnitude image and a gradient direction image. In this case, a camera **11** for photographing an image to be used as a stereo reference image acquires the image of the objective **18** nearly right from its top, whereupon such an edge image as shown in FIG. **36***a* is obtained. When the edge image is subjected to a Hough transform to extract straight lines therefrom and edges present within a predetermined distance from extracted straight lines **126** and **127** are erased, edges **122** to **125** resulting from the conveyor **92** can be erased. Thus only a circular edge **121** of the top surface of the objective **18** can be extracted. And when three-dimensional positions at points on the circular edge are calculated from the disparity of the extracted circle and when a central position and radius of the circle of the top surface of the objective **18** are measured from the calculated three-dimensional position information, the objective **18** can be specified as one of the three types of objectives shown in FIG. **35** on the basis of the measured central position (height) and radius.

Meanwhile, when the circular cylindrical objectives **18**, **18***a*, **18***b* and **18***c* have straight line components in the edges of their top surface as shown in FIGS. **38** and **39**, mere erasing of edges present within a predetermined distance from the extracted straight lines also causes part of curved lines to be erased. To avoid such disadvantage, as shown in FIGS. **40** and **41**, it is arranged to erase edges which are present within a predetermined distance from extracted straight lines **177**, **178**, **179**, **17***a*, **17***b* and **17***c* and which have values within a predetermined value from 90 degrees in the angle between their gradient direction and straight line direction vector. This enables realization of erasure of straight line edges while preventing partial erasing of a circular edge **171** as shown in FIG. **40***b*.

The erasure of straight line components from the edge image while leaving curve components may be realized by such a method as shown in FIGS. **42** to **45**. That is, edge points are found from an edge image of a stereo reference image for storage, points surrounded by a found target edge point **201** are searched clockwise from its right side to find the presence of another edge point as shown in FIG. **43***a*, storing operation of an edge point which gradient direction is different from the gradient direction of the previously-stored edge point **201** by a predetermined value or less as the next target edge point is continued, in the presence of the edge point, until no edge point is found at the points around the target edge point **201**. When the number of such edge points stored exceeds a predetermined value, such edge points are assembled into edge groups **431** to **435** as shown in FIG. **43***b*. For each edge group, as shown in FIG. **44**, an angle **224** made between a segment connecting an edge start point **221** and a middle point **222** and a segment connecting the edge start point **221** and an end point **223** is examined so that, when only such an edge that has the angle exceeding a predetermined value is left, only curved edges **431**, **434** and **435** can be extracted as shown in FIG. **45***a* and such circular edges **434** and **435** as shown in FIG. **45***b* can be extracted from the edges of FIG. **45***a*.

The extraction of circular edges from curved edges may be carried out in the following manner. First, a method shown in FIG. **46** utilizes the fact that the objective **18** has in its lower side substantially no corresponding parts in its left and right side images and thus its disparity detection ratio becomes considerably low. When the calculated disparities of curved edges **261**, **262** and **263** are examined from such an edge image having only curved edges as shown in FIG. **47***a*, the curved edges **262** and **263** are almost calculated in their disparity as shown by a binary image of edge points with the disparities calculated in FIG. **47***b*. Since the curved edge **261** has no corresponding parts in the left and right side images and its disparity is not calculated yet, when curved edges whose already-calculated disparity ratios are smaller than a predetermined value are deleted, the curved edge **261** is deleted, which results in that only the curved edges **262** and **263** on the top surface of the objective can remain left as shown in FIG. **47***c*, from which the edges **262** and **263** can be extracted to form a circle.

When the objective **18** has such a ring shape as shown in FIG. **49**, since the top surface of the objective has two circular edges, only one (the outer circular edge in FIG. **49**) of the circular edges is extracted. More specifically, an edge image IE for the objective **18** is as shown in FIG. **50***a* and, when straight line components are erased from the edge image, such an edge image IE**2** as shown in FIG. **50***b* is obtained. When the objective **18** is seen bright on the background, and a gradient direction **335** of an edge **331** for the outer ring is directed inwardly of the circle while a gradient direction **336** of an edge **332** for the outer ring is directed outwardly of the circle as shown in FIG. **51**, coefficients a and b and constant r can be found by the least squares method in accordance with a right-circle application equation which follows.

$$X^2+Y^2+ax+by+r=0$$

When the right-circle application equation is applied to the single edge **332** of the top surface to calculate a center (−a/2,−b/2) **334** of the circle, any one **339** of points of the right-circle edge is selected, a direction toward the calculated center **334** of the circle from the selected point **339** is found, and such an edge of the top surface is extracted that a difference between the direction **338** and the gradient direction **336** of the selected point is a predetermined value (90°) or less. Even with respect to edges **331**, **33***a*, **33***b*, **33***c*, **33***d*, **33***e* and **33***f* of the top surface other than the edge **332**, when the aforementioned operation is carried out to calculate a difference between the direction of gradient of a point of each edge and the direction from the point toward the center of the right circle, and when edges of the top surface having such differences of a predetermined value (90°) or less are extracted, such an edge image IE**3** of a stereo reference image with the inner-side circular edges **332**, **33***a*, **33***c* and **33***e* removed as shown in FIG. **50***c* can be obtained. In this connection, when the predetermined value for the difference is selected to be higher than 90°, the outer-side circular edges **331**, **33***b*, **33***d* and **33***f* are erased while the inner-side circular edges **332**, **33***a*, **33***c* and **33***e* are left.

An embodiment of FIG. **52** is designed so that, when such circular cylindrical objectives **18** as shown in FIG. **53** are piled and thus its edge image IE is as shown in FIG. **54***a* a highest-level one of the piled objectives is detected to measure its position and posture. Among a plurality of curved edges present in the edge image, an edge having the maximum disparity because of its highest-level location is selected and the selected edge is set to be a reference edge **381** as shown in FIG. **54***a*, and it is examined whether or not the reference edge **381** forms part of a circle. When the reference edge cannot be regarded as part of the circle, the

edge having a disparity larger next to the edge **381** is selected as a reference edge and it is examined whether or not the edge forms part of the circle. The above operation is repeated until the reference edge capable of forming part of the circle is found. Thereafter, the other edges are denoted by reference numerals **382**, **383**, . . . in an increasing order of the distance from the reference edge **381** and it is examined in the above numeral order whether or not the other edges form part of the same circle. Those of the edges judged to form part of the same circle as the reference edge are contained in the same group as the reference edge. Such processing is also carried out over other edges having distances of a predetermined value or less from the reference edge so that edges **381**, **383**, **384** and **386** having the same circle are assembled as shown in FIG. **54***b*, on the basis of which a position and posture of the highest-level objective **18** can be detected.

In an embodiment of FIG. **55**, an edge having the largest disparity due to the highest-level location of the target objective is selected from the edge image of FIG. **54***a*. The selected edge is used as a reference edge **381**, and the other edges are denoted by reference numerals **382**, **383**, . . . in an increasing order of the distance from the reference edge **381**. Thereafter, coefficients a, b, h, g and f are found by the least squares method in accordance with an equation (to be applied to ellipse) which follows.

$$ax^2+by^2+2hxy+2gx+2fy=1$$

An ellipse is applied to the reference edge **381** to calculate its center coordinate point (xo,yo). As shown in FIG. **56**, a straight line **413** passing through a point **417** of the reference edge and a center **412** of an ellipse **411** intersects the ellipse at two intersection points **414** and **415**, and, when a distance **416** of one **414** of the two intersection points closer to the edge point **417** therefrom exceeds a predetermined value at any points of the reference edge, the reference edge is not regarded as a circle component and a next reference edge is arbitrarily selected. When the distance does not exceed the predetermined value, on the other hand, the reference edge is regarded as a circle component, the reference edge **381** is combined with the edge **382** in the vicinity thereof, and the coefficients a, b, h, g and f are found in the above equation by the least squares method, whereby the ellipse is applied to the reference edge to calculate its center coordinate point (xo,yo). And distances between the points of the reference edge **381** and edge **382** in its vicinity and the found ellipse are found. When the found distances are all less than a predetermined value, the reference edge **381** and the edge **382** in its vicinity are judged to form part of the same circle. When even a single one of the distances is not less than the predetermined value, the edges are judged not to form part of the same circle and the reference edge **381** is combined with the next edge **383** in its vicinity to perform the aforementioned operation. When a series of operations is repeated until edges to be combined become null, edges belonging to the same circle can be combined into one. In this conjunction, the center coordinate point (xo,yo) of the above ellipse is expressed as follows.

$$xo=(hf/bg)/(ab-h^2)$$

$$yo=(hg/af)/(ab-h^2)$$

An embodiment shown in FIG. **57** is also intended to detect a highest-level one of a plurality of circular cylindrical objectives **18** piled as shown in FIG. **58**. FIG. **59***a* shows an edge image IE of such objectives of FIG. **58**. In FIG. **59***a*, a reference edge **441** corresponds to the highest-level edge having the maximum disparity. In this case, according to the method of the above embodiment, when the edge **442** to be detected as part of the same circle as the reference edge **441** cannot be detected due to the tilted objective or the like, it may be erroneously judged that the edge **443** is to be combined with the reference edge **441**. In the illustrated example, in order to avoid such error, when the reference edge **441** and the edge **443** are judged to form part of the same circle according to the method of the above embodiment, final judgement of the same circle is carried out only when a difference is within a predetermined range between the direction of a normal of a plane **453** made with use of three-dimensional information found based on the disparity of any two points of the reference edge **441** and any one point of the other edge **443** and the direction of a normal of a plane **454** made with use of three-dimensional information found based on the disparity of any two points of the edge **443** and any one point of the reference edge **441** except for the selected two points, as shown in FIG. **60**. Through the above operation, the circular edge **441** of the top surface of the highest-level objective can be extracted as shown in FIG. **59***b*.

Explanation will be directed to the operation after the extraction of the circular edges of the top surface of the circular cylindrical objective. In an embodiment of FIGS. **61** to **63**, as in the case of FIG. **25**, three-dimensional positions of points are calculated based on the disparity of the extracted circle edges, and coefficients a, b and c are calculated by the least squares method in accordance with the following equation (to be applied to plane).

$$ax+by+cz+1=0$$

Then, a plane Pa containing the top surface of the objective **18** is found as shown in FIG. **62**, three-dimensional positions of points in the top surface of the objective are rotated on an origin po of a camera coordinate system so that a normal Paz of the plane Pa coincides with the Z axis of the camera coordinate system as shown in FIG. **63**, and coefficients a, b and constant r are found by the least squares method in accordance with the following equation (to be applied to right circle) to calculate a center position **491** and radius **492** of the right circle after the rotation.

$$x^2+y^2+ax+by+r=0$$

In the illustrated example, the camera coordinate system is employed as a reference coordinate system. A center position **486** of the right circle of the top surface of the objective **18** is calculated through inverse transformation (to before the rotation) of the center position **491** of the calculated right circle to obtain a position, posture and radius of the objective **18**. In the calculation of the right circle after the coordinate system rotation, coefficients a, b, h, g and f are found in the above ellipse application equation by the least squares method and conversion to a standard ellipse is carried out to obtain a position and posture of the elliptical cylinder as well as a major and minor radii thereof.

In an embodiment of FIG. **64**, three-dimensional positions of points on the top surface of the objective are rotated on the origin po of the above image coordinate system as mentioned above so that the normal Paz of the plane Pa coincides with the Z axis of the coordinate system, after which certain edge points are removed so that a distance **493** (difference from the Z coordinate value) of the found plane Pa from the edge points of the circle after the rotation in the three-dimensional space exceeds a predetermined value. With use of the x and y coordinate values of edge points of

the top surface of the objective **18** after the rotation except for the above edge points, coefficients a and b and constant r are found by the least squares method in accordance with the right-circle application equation to calculate a center position **491** and radius **492** of the right circle after the rotation. In this connection, the camera coordinate system is used as a reference coordinate system. And a center position **486** of the right circle of the top surface of the objective **18** is calculated through inverse transformation (to before the rotation) of the center position **491** of the calculated right circle to obtain a position, posture and radius of the objective **18** after the coordinate system rotation. In the calculation of the right circle after the coordinate system rotation, further, coefficients a, b, h, g and f are found by the least squares method in accordance with the aforementioned ellipse application equation, and a position and posture of the elliptical cylinder as well as a major and minor radii thereof are obtained through conversion to standard ellipse.

In an embodiment of FIG. **65**, three-dimensional positions of points on the top surface of the objective are rotated on the origin po of the above image coordinate system as mentioned above so that the normal Paz of the plane Pa coincides with the Z axis of the coordinate system, after which certain edge points are so removed that a distance (difference from the Z coordinate value) of the found plane Pa from the edge points of the circle after the rotation in the three-dimensional space exceeds a predetermined value, a plane Pa in the three-dimensional space containing the edge of the top surface of the circular cylindrical objective **18** is again found by the least squares method, and three-dimensional positions of points of the top surface of the objective are rotated on the origin po of the camera coordinate system so that the normal Paz of the found plane Pa coincides with the Z axis of the coordinate system. Thereafter, with use of the x and y coordinate values of edge points of the top surface of the objective **18** after the rotation except for the above edge points, coefficients a and b and constant r are found by the least squares method in accordance with the right-circle application equation to calculate a center position **491** and radius **492** of the right circle after the rotation. And a center position **486** of the right circle of the top surface of the objective **18** is calculated through inverse transformation (to before the rotation) of the center position **491** of the calculated right circle to obtain a position, posture and radius of the objective **18** after the coordinate system rotation. Even in this case, in the calculation of the right circle after the coordinate system rotation, further, coefficients a, b, h, g and f are found by the least squares method in accordance with the aforementioned ellipse application equation, and a position and posture of the elliptical cylinder as well as a major and minor radii thereof are obtained through conversion to standard ellipse.

In an embodiment of FIG. **66**, three-dimensional positions of points are calculated based on the disparity of the extracted circle edges as mentioned above, and coefficients a, b and c are calculated by the least squares method in accordance with the aforementioned plane applying equation to find a plane Pa containing the top surface of the objective **18**. Further, as shown in FIG. **67**, a sphere **531** containing the right circle of the top surface of an objective **18** in a three-dimensional space is found by the least squares method. When a sphere is applied, since the right circle of the top surface is present on the same plane, the sphere is not uniquely determined. However, the center of the sphere is restricted to the extent that the center is present on a straight line perpendicular to the above plane Pa and passing through the center of the right circle present on the plane. Further, since the found sphere may be any sphere so long as its radius is larger than the right circle of the top surface and the sphere contains the right circle of the top surface, when any one value of any one of center coordinate axes of the sphere is fixed, the sphere can be determined. In the present embodiment, the Z coordinate value of the center of the sphere was fixed to a Z coordinate value c_o different by more than the radius of the right circle from the Z coordinate values of the objective existence zone. In other words, an equation for the sphere was expressed as follows to find coefficients a and b and constant R by the least squares method.

$$x^2+y^2+z^2+ax+by-2c_oz+R=0$$

A center **533** of the right circle of the top surface of the circular cylindrical objective **18** is found by calculating an intersection point between the plane Pa and a straight line passing through a center **532** of the sphere and having the same direction vector as a normal vector **537** of the plane Pa. A radius **534** is found by subtracting a square of a distance **536** between the center of the sphere and the center of the right circle from a square of a radius **535** of the sphere to find a subtraction and then by finding a square root of the subtraction. Accordingly, even in this case, a position, posture and radius of the objective **18** can be found.

An embodiment of FIGS. **68** to **70** shows an example where the present invention is applied to automatic assembling work. More in detail, as shown in FIG. **69**, when it is desired to assemble a part **541** having two holes and a part **542** having two projections by means of robot, positions and posture of the holes and projections are detected to detect positions and postures of the parts **541** and **542**.

More specifically, an edge image IE (see FIG. **70***a*) of a stereo reference image, a gradient direction image and a disparity image are created and curved edges are extracted from the edge image. That is, such 4 circular edges **701** to **704** as shown in FIG. **70***b* are extracted. When the direction of a segment connecting the middle point and centers of corresponding 4 circles **543** to **546** in a three-dimensional space as well as the direction of a normal of a plane defined by the 2 circles are calculated from the 4 circle edges, the position and posture of the part **542** having the two projections are determined. When the similar operation is carried out for the remaining 2 circles, the position and posture of the part having the two holes are determined.

In accordance with the present invention, as has been explained in the foregoing, a two-dimensional image is obtained from the same viewing point as a distance image obtained by photographing an objective in a three-dimensional space, a partial image in the two-dimensional image is specified, the specified two-dimensional partial image is applied to the distance image to extract a partial image from the distance image, and an objective detecting operation is carried out over the distance partial image. That is, upon performing the objective detecting operation, an existence zone of the objective under detection in the distance image is previously restricted by utilizing the two-dimensional image, and the objective detecting operation is carried out over a distance partial image of the restricted zone. As a result, it will be appreciated that from the present invention a relatively high detecting operation can be realized when compared with the prior art for performing a detecting operation over all the zones of the distance image.

What is claimed is:

1. A method of utilizing edge images of a circular surface part for detecting the position, posture and shape of a

three-dimensional objective having the circular surface part, wherein at least two gray images are obtained by photographing the three-dimensional object having the circular surface part from at least first and second positions of different angles on the same coordinate with respect to the objective, an edge image and a concentration gradient directional image are obtained from each of the two gray images obtained, a disparity image is prepared through a stereo image processing in which, with the edge image obtained for the first position made as a reference edge image, the correspondence is taken between respective edge points on the reference edge image and respective edge points on the other edge image obtained for the second position and a disparity is obtained with respect to each edge point on the reference edge image, only edges of curves including circles are extracted from the reference edge image, the edges of a circle only are extracted from the edges of curves, and a position and posture of the circular surface part of the objective are detected with use of three-dimensional information obtained from the disparity at parts of the disparity image corresponding to the edge points of the extracted circle.

2. The method as set forth in claim **1**, wherein straight lines are extracted from the reference edge image, and edges in the vicinity of the extracted straight lines are erased to extract only the edges of curves.

3. The method as set forth in claim **1**, wherein straight lines are extracted from the reference edge image, and edges which are located close to the extracted straight lines and which have angles of nearly 90° between their gradient direction and straight line direction vector are erased to extract only the edges of curves.

4. The method as set forth in claim **1**, wherein, upon extraction of only the edges of curves including circles from the reference edge image, an optional one of the edge points forming the edge in the reference edge image is set as a target edge point, other edge points adjacent to and surrounding the target edge point are sequentially searched for determining a next target edge point, the adjacent edge point searched and satisfying conditions that a difference in the direction of concentration gradient of the adjacent edge points searched from the target edge point is below a predetermined value is registered as the next target edge point, such search and registration are continued until failure of determination of the edge point satisfying the conditions in the adjacent edge points to group the edge points into the edges of curves and of straight line, and only the edges of curves are extracted from a distribution of the edge points in an identical group.

5. The method as set forth in claim **1**, wherein, upon extraction of the circle from the extracted edges of curves, one of the extracted edges of curves having a predetermined number or percentage of edge points with disparities calculated are extracted as the circle.

6. The method as set forth in claim **1**, wherein the circle is applied to extracted edges of curves by the least squares method to calculate a center of the circle, ones of the edges of curves having values in a predetermined range in a difference between a direction from an edge point of the respective curve edge toward the center of the circle and a direction of gradient of the edge point are extracted, and the circle is extracted from the extracted edges of curves.

7. The method as set forth in claim **1**, wherein, upon combination of extracted edges of curves to form the circle, the edges of curves are combined in an increasing order of a distance between the edges of curves to form the circle in an image, and ones of the edges of curves having distances of a predetermined value or more therebetween are not used for forming the circle.

8. The method as set forth in claim **7**, wherein, when the circle is found by the least square method from two-dimensional data of the combined edges of curves and only when respective points on the combined edges of curves are within a predetermined distance range from the found circle, the combined edges of curves are judged as present on the same circle and form the circle.

9. The method as set forth in claim **1**, wherein two edges of curves judged as able to form a circle are judged as present in the same circle and form the circle, only when a difference between a normal of a plane defined with use of three-dimensional information found based on disparities between two points of a first curve edge and a point of a second curve edge and a normal of a plane defined with use of three-dimensional information found based on disparities between two points of the second curve edge and a point of the first curve edge except for the selected two points is within a predetermined value range.

10. The method as set forth in claim **1**, wherein a plane to which circle edges are applied is found with use of three-dimensional information of points on the extracted circle edges, the three-dimensional information is rotated on an origin of a camera coordinate system to cause a normal of the found plane to coincide with a Z axis of the camera coordinate system, a center and radius of the circle are calculated by the least squares method with use of X and Y coordinate values of the circle edges after the rotation, the calculated coordinate values are subjected to an inverse transformation to detect a position and posture of the objective before the rotation.

11. The method as set forth in claim **10**, wherein a plane to which circle edges are applied is found, circle edge points corresponding to points spaced by a predetermined distance or more in a three-dimensional space are removed from the found plane, and a center and radius of the circle are calculated.

12. The method as set forth in claim **10**, wherein a plane to which circle edges are applied is found, circle edge points corresponding to points spaced by a predetermined distance or more in a three-dimensional space are removed from the found plane, a plane to which circle edges defined by remaining circle edge points are applied is again found, and the found plane is rotated.

13. The method as set forth in claim **1**, wherein extracted circle edges are applied to a plane and a sphere in a three-dimensional space to calculate a center position and radius of a right circle of a cross section of the sphere defined by an intersection plane between the plane and sphere.

14. The method as set forth in claim **1**, wherein a position and posture of the objective are detected and recognized based on a magnitude of the detected circle and on a positional relationship thereof in a three-dimensional space.

* * * * *

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United States Patent [19]

Tsuchiya

[11] Patent Number: 5,859,727

[45] Date of Patent: Jan. 12, 1999

[54] **OBJECTIVE UNIT**

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[73] Assignee: **Olympus Optical Co., Ltd.**, Tokyo, Japan

[21] Appl. No.: **900,958**

[22] Filed: **Jul. 25, 1997**

[30] **Foreign Application Priority Data**

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Jul. 22, 1997 [JP] Japan 9-195951

[51] **Int. Cl.**[6] **G02B 21/06**; G02B 21/02

[52] **U.S. Cl.** **359/387**; 359/385; 359/661

[58] **Field of Search** 359/368–374, 359/385–390, 642, 656, 808–811, 819

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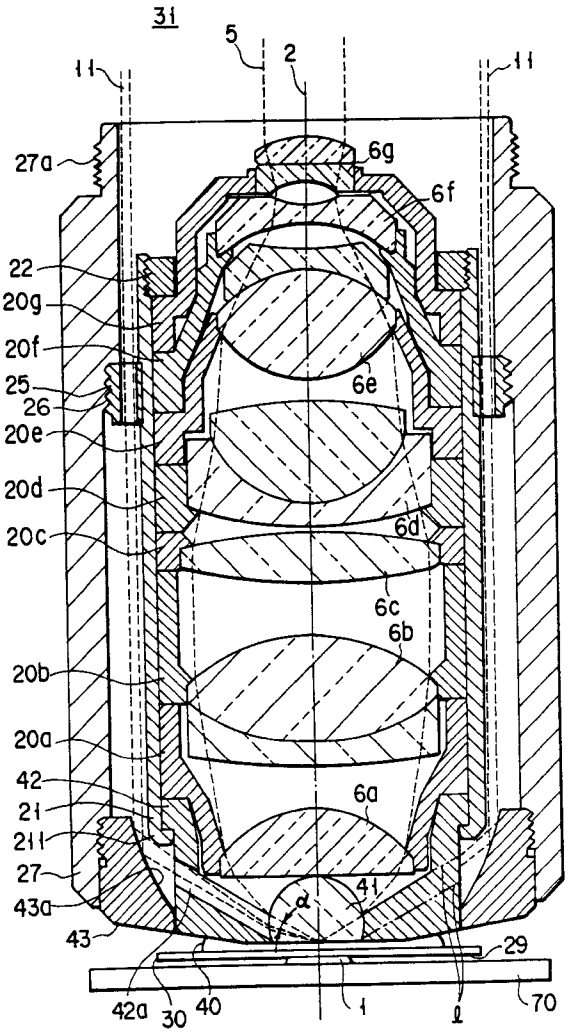
Primary Examiner—Thong Nguyen
Attorney, Agent, or Firm—Frishauf, Holtz, Goodman, Langer & Chick

[57] **ABSTRACT**

An objective unit in which illumination light is applied through an annular illumination light path surrounding lenses for guiding observation light coming from an object of observation, and which includes a shared lens for guiding the illumination light from the illumination light path to the object of observation and for guiding the observation light to the lenses.

12 Claims, 6 Drawing Sheets



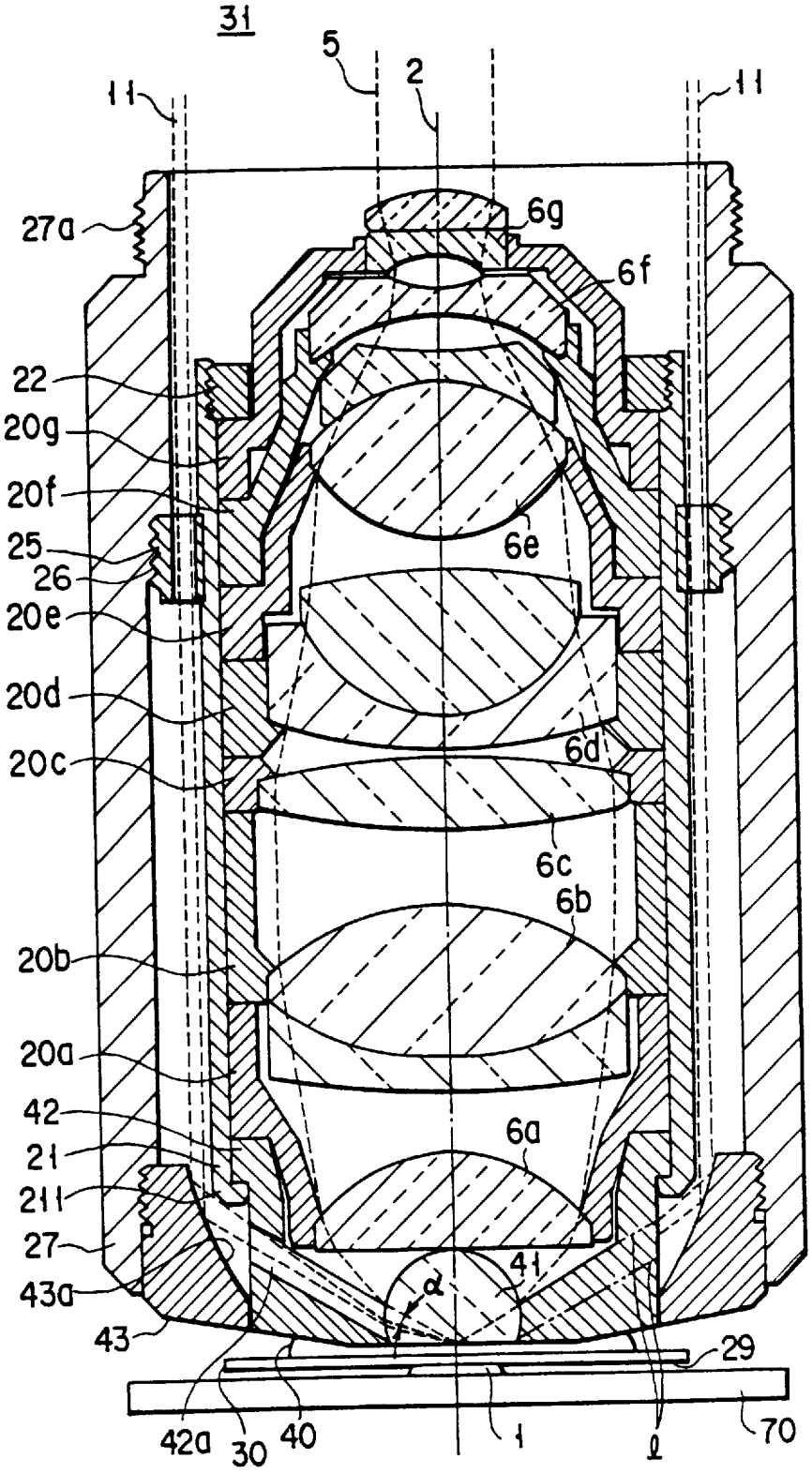

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FIG. 1

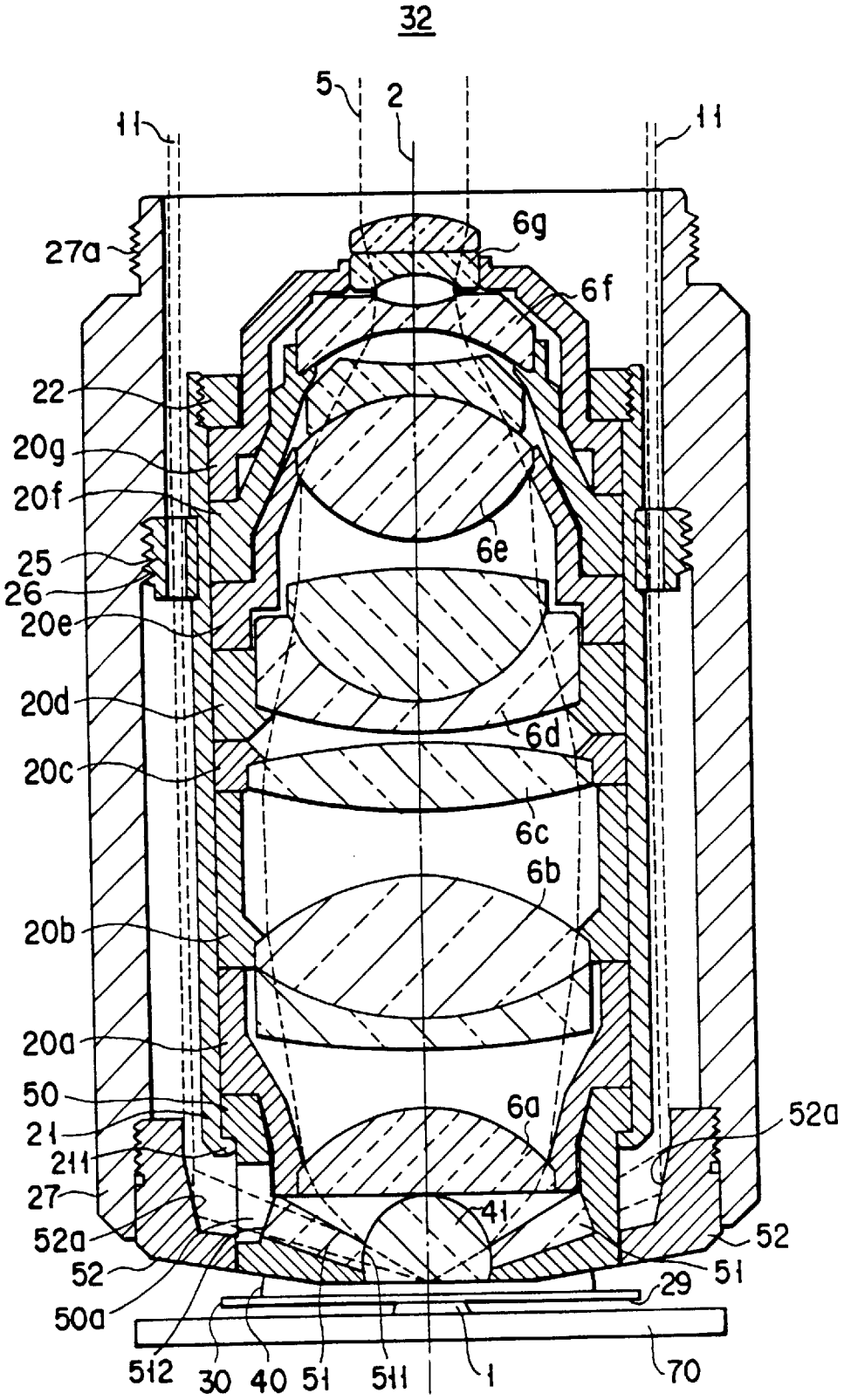
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FIG. 2

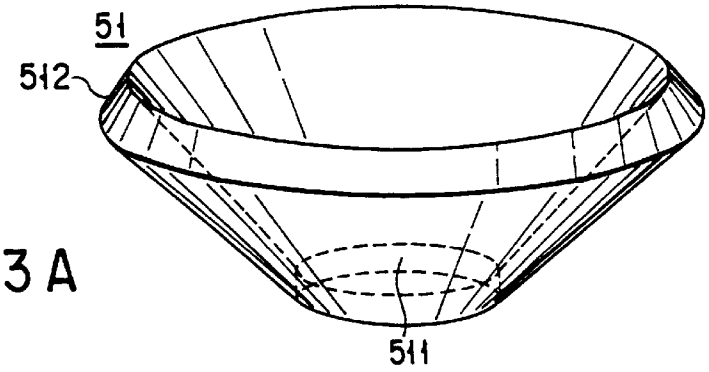

FIG. 3A

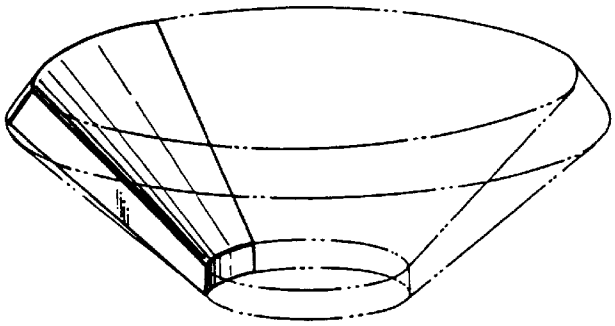

FIG. 3B

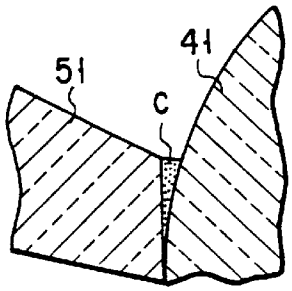

FIG. 4A

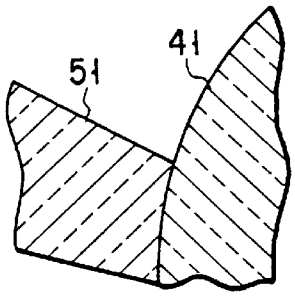

FIG. 4B

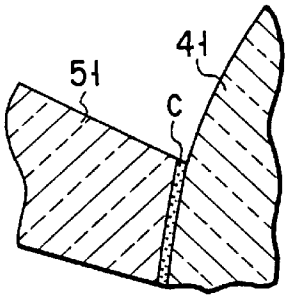

FIG. 4C

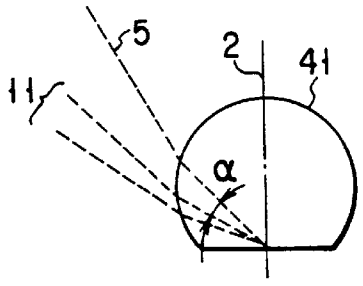

FIG. 5A

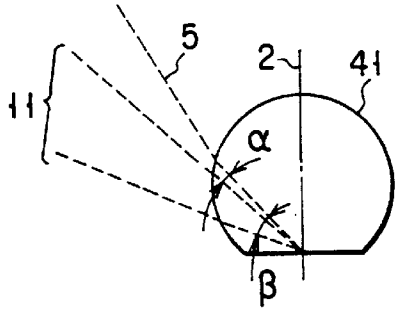

FIG. 5B

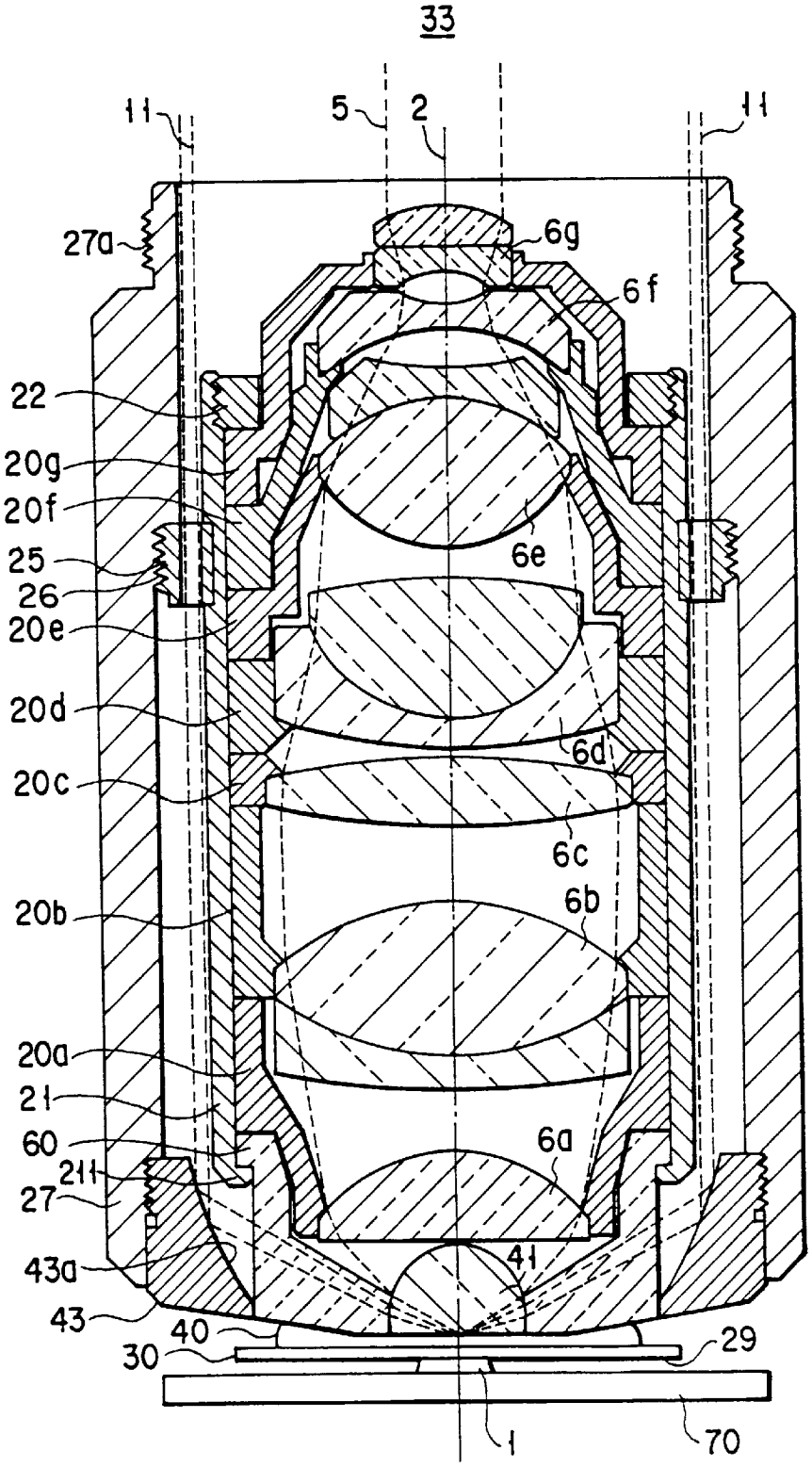
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FIG. 6

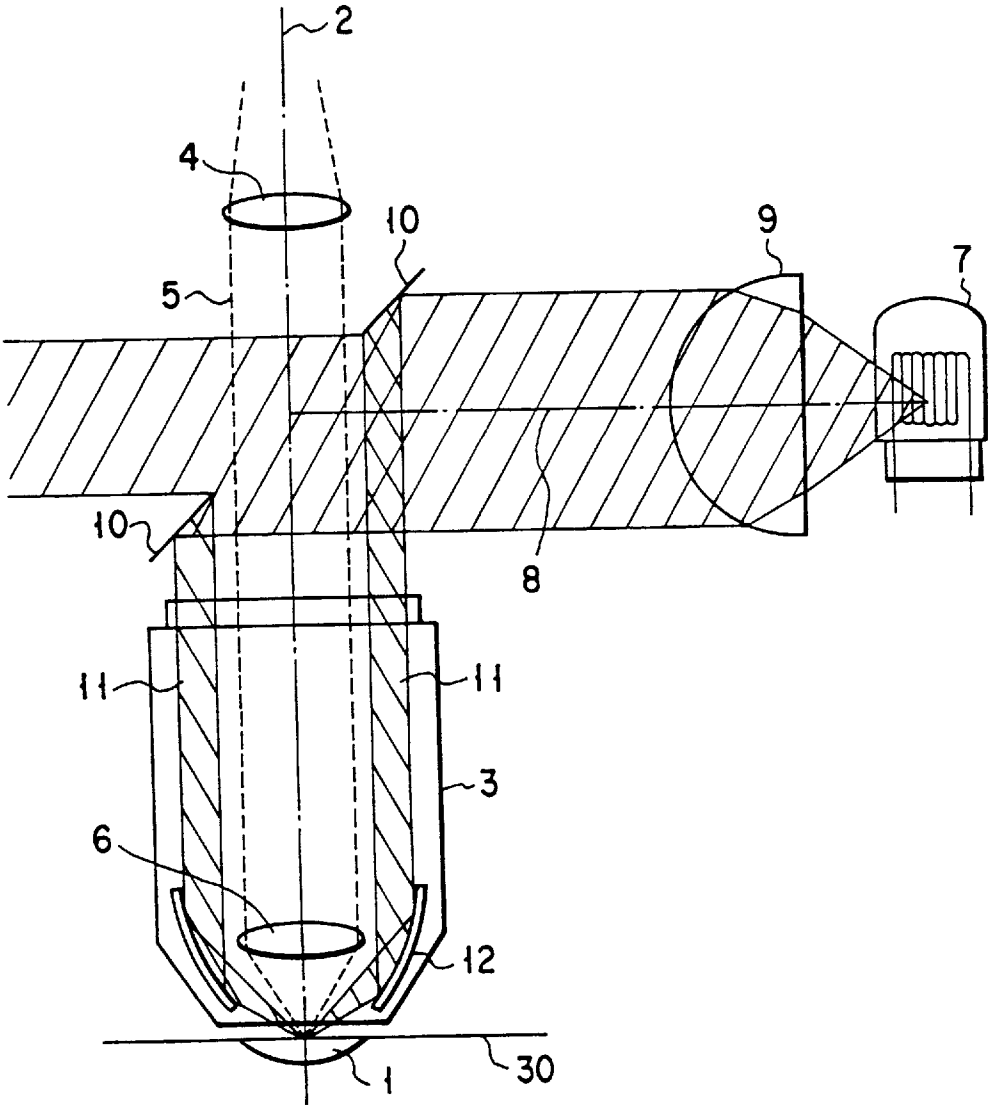

FIG. 7
PRIOR ART

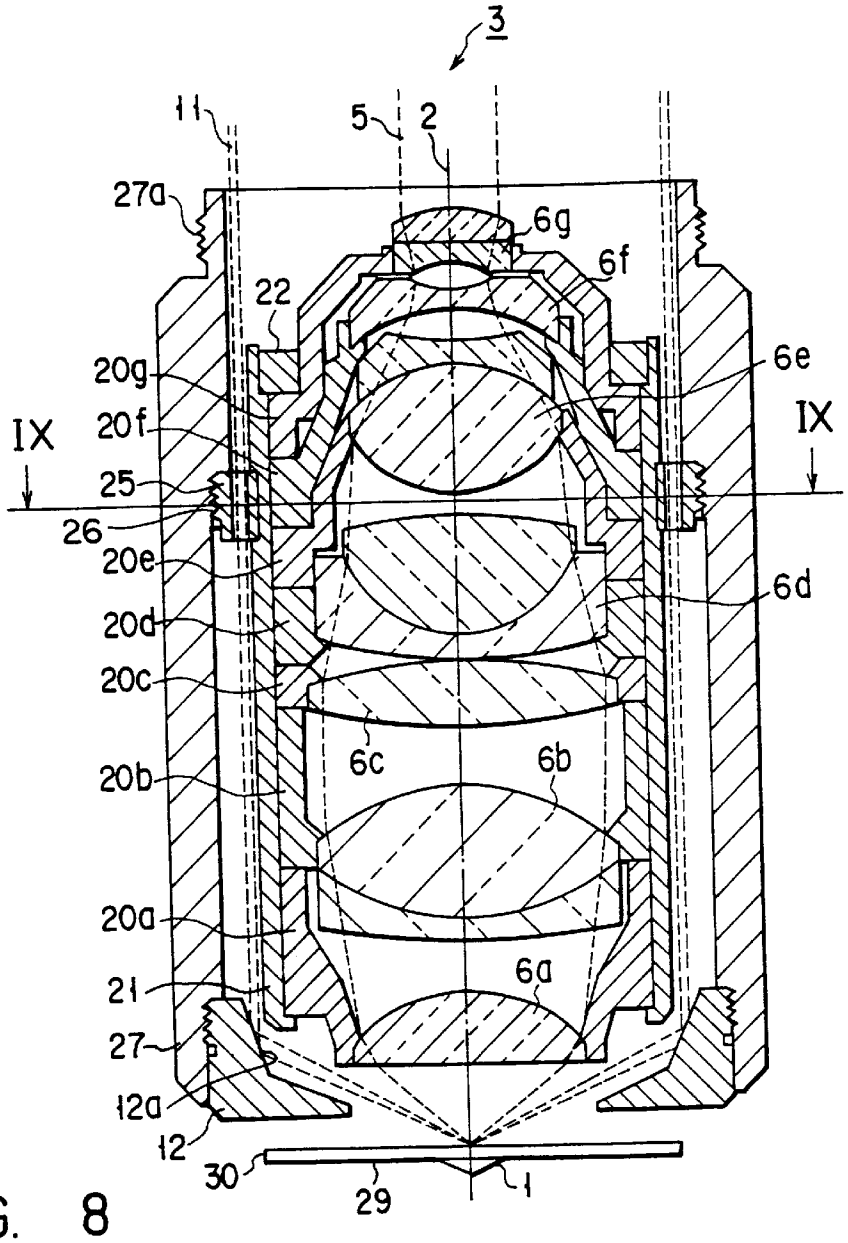

FIG. 8
PRIOR ART

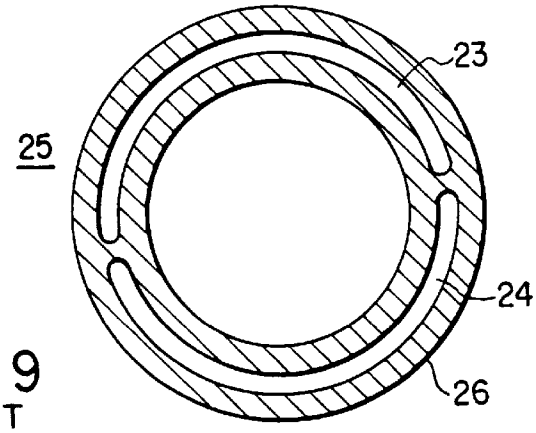

FIG. 9
PRIOR ART

OBJECTIVE UNIT

BACKGROUND OF THE INVENTION

The present invention relates to an objective unit which is for use in an optical microscope and which performs incident lighting, and more particularly to an objective unit which uses a space outside the observation light path to perform lighting for accomplishing dark-field observation or for generating evanescent waves to achieve incident-light fluorescent observation.

FIG. **7** is a sectional view of the illumination system of an optical microscope. The microscope comprises an objective unit **3**, a focusing lens **4**, and eye lens (not shown), a lamp **7**, a collector lens **9**, and mirror **10**. To obtain a magnified image of a sample **1** (i.e., an object of observation), the objective unit **3**, focusing lens **4** and eye lens are arranged in the axis **2** of observation light. The objective unit **3** contains an objective lens system **6**.

The lamp **7** is located at a predetermined distance from the observation-light axis **2**. The lamp **7** emits light for incident lighting, which has an illumination-light axis **8** extending at right angles to the observation-light axis **2**. Arranged in the illumination-light axis **8** are the collector lens **9** and the mirror **10**. The collector lens **9** is semi-spherical, while the mirror **10** is shaped like a ring. The mirror **10** is inclined at 45° to the observation-light axis **2** and the illumination-light axis **8**. The mirror **10** has an annular reflecting surface.

The collector lens **9** collects the light emitted from the lamp **7** for incident lighting, converting the light to a light beam having a circular cross section. The light beam reaches the mirror **10**. Part of the light beam passes through the opening of the mirror **10**. The remaining part of the light beam is reflected downwards from the reflecting surface of the mirror **10**. It is used as an illumination light (incident illumination light) **11** which is suitable for incident lighting. The light beam has an annular cross section and is coaxial with the observation-light axis **2**. The illumination light **11** passes surrounding the observation light path and is guided into objective unit **3**.

The illumination light **11** for incident lighting passes through the objective unit **3**, surrounding the lens system **6**. The illumination light **11** is then reflected by a mirror **12** and converged onto the sample **1**. The observation light beam **5** reflected from the sample **1** passes through the lens system **6** of the unit **3**. The light beam **5** then passes through the focusing lens **4**. Eventually the light beam **5** is guided to the eye lens (not shown), whereby an observer can see a magnified image of the sample **1**.

The objective unit **3** will be described in detail, with reference to FIG. **8** which is a sectional view. The objective unit **3** is a dry objective unit. As seen from FIG. **8**, the unit **3** comprises lens-holding frames **20***a* to **20***g*, a hollow cylinder **21**, and a lens-holding ring **22**, besides the lens system **6**. The lens system **6** consists of seven lenses **6***a* to **6***g* which are arranged in the observation-light axis **2**. The lenses **6***a* to **6***g* are held by the lens-holding frames **20***a* to **20***g*, respectively. The frames **20***a* to **20***g* are provided in the hollow cylinder frame **21** and held in place once the lens-holding ring **22** has been fitted into one end of the hollow cylinder frame **21**.

As shown in FIG. **8**, a ring **25** is mounted on the objective unit **3**. The ring **25** will be described with reference to FIG. **9**, which is a part of a sectional view taken along line IX—IX in FIG. **8**. As FIG. **9** shows, the ring **25** has two arcuate elongated holes **23** and **24**. Thus, the ring has two parts in which no holes are made. The holes **23** and **24** are arranged in the same circle and separated from each other. The ring **25** has a screw thread **26** on its outer circumferential surface.

As seen from FIG. **8**, a hollow cylindrical cover **27** is mounted on the mirror **12** and also on the ring **25**. The cover **27** is set in screw engagement with the ring **25** at the screw **26** thereof, positioned coaxial with the hollow cylinder **21**. Hence, an annular space is provided between the hollow cylinder **21** and the hollow cylindrical cover **27** by holes **23** and **24**. The annular space serves as illumination light path. The mirror **12**, which is fitted in the distal end of the cover **27**, reflects the illumination light **11** at its reflecting surface **12***a*, applying the light **11** onto the sample **1**.

As illustrated in FIG. **8**, a cover glass **30** is located below the objective unit **3**. The cover glass **30** has a sample-mounting surface **29**. The hollow cylindrical cover **27** has a screw **27***a* on its proximal end. At the screw **27***a* the objective unit **3** is removably attached to the body of the microscope.

In the illumination system shown in FIG. **7**, the lamp **7** is the illumination light source, and the illumination light **11** is applied into the objective unit **3** by using the collector lens **9** and the mirror **10**.

The illumination light **11** is applied to the sample **1**, with a numerical aperture (NA) larger than that of the observation light. The 0th-order light totally reflected from the sample **1** does not enter the observation light path provided in the objective unit **3**. The high-order light diffracted and scattered from the sample **1** enters the lens **6***a* set in the observation light path and passes through the lens **6***b* to **6***g* set also in the observation light path. The high-order light is applied to the focusing lens **4**, which focuses the light. The light thus focused is guided to the eye lens (not shown) or a video camera (not shown), etc. Dark-field observation of the sample **1** is thereby accomplished.

The objective lens **3** may be an oil immersion objective. In this case, assume that the cover glass **30**, the oil and the sample **1** have refractive indices of 1.5, 1.5 and 1.3, respectively. Then, the illumination light applied with NA of 1.3 or more is totally reflected at the interface between the cover glass **30** and the sample **1**. In this case, evanescent light is generated on the side of the sample **1**. The evanescent light may be used as excitation light in the oil immersion objective unit. Fluorescent observation can then be achieved by use of the illumination path independent of the observation system even if the objective unit comprises lenses having great NAs. This is utilized when objective lenses designed for mono-molecular fluorescent observation are employed in order to reduce auto-fluorescent light and attain a high S/N ratio.

Being a dry system, not a liquid-immersion system, the objective unit **3** shown in FIG. **8** has a small NA and a long working distance (WD), i.e., the distance between its distal end and the cover glass **30**. Therefore, the unit **3** has a sufficient space for the illumination light path. On the other hand, most liquid immersion objective units, particularly oil immersion ones, comprises lenses having a large NA of about 1 to about 1.45 and have a short working distance of about 0.1 mm. In such a liquid immersion objective unit, the distal end, the lens-holding frames and the hollow cylinder make it difficult to provide a space large enough for an illumination light path.

To enable the objective unit **3** to apply as much illumination light as possible to the sample, it is necessary to increase the NA of the illumination light **11**. If the light **11** has an NA as large as that of the observation light beam, i.e.

it has a large marginal ratio, the peripheral part of the light **11** will be blocked by the lens-holding frames. Hence, the illumination light **11** cannot have a large NA.

To increase the NA of the illumination light **11**, the wall thickness of the lens-holding frames **20***a* to **20***g* may be decreased, making it possible to broaden the annular space for passing the illumination light **11**. If the frames **20***a* to **20***g* have less wall thickness, however, they will become less rigid than is required to hold the lenses **6***a* to **6***g* in a completely coaxial relationship. And, it is difficult to ensure a high degree of precision with respect to the dimensions of the frames. In addition, the size of the objective unit **3** is limited; its overall length should be 45 mm or less. The lenses cannot be made thicker and the lens-holding frames cannot be made longer, in order to increase the working distance so as to provide a space sufficient for an illumination light path.

BRIEF SUMMARY OF THE INVENTION

The object of the present invention is to provide an objective unit which has a large numerical aperture (NA) and a short working distance (WD) as an oil immersion objective unit, and which has an illumination light path outside the observation light path which guides an illumination light such that the light is not blocked by lenses or lens-holding frames.

According to the invention, there is provided an objective unit in which illumination light is applied through an annular illumination light path surrounding lenses for guiding observation light coming from an object of observation, the unit comprising: a shared lens for guiding the illumination light from the illumination light path to the object of observation and for guiding the observation light to the lenses.

Additional objects and advantages of the invention will be set forth in the description which follows, and in part will be obvious from the description, or may be learned by practice of the invention.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING

The accompanying drawings, which are incorporated in and constitute a part of the specification, illustrate presently preferred embodiments of the invention, and together with the general description given above and the detailed description of the preferred embodiments given below, serve to explain the principles of the invention.

FIG. **1** is a longitudinal sectional view of an objective unit according to a first embodiment of the invention, taken along a plane containing the axis of the observation light;

FIG. **2** is a longitudinal sectional view of an objective unit according to a second embodiment of the invention, taken along a plane containing the observation light axis;

FIG. **3**A is a perspective view of the prism incorporated in the second embodiment of the invention;

FIG. **3**B is a perspective view of one of prism pieces which may be used in the second embodiment;

FIG. **4**A is a diagram explaining a method of coupling a shared lens to the prism shown in FIG. **3**A;

FIG. **4**B is a diagram explaining an another of coupling a shared lens to the prism shown in FIG. **3**A;

FIG. **4**C is a diagram explaining still another method of coupling a shared lens to the prism shown in FIG. **3**A;

FIG. **5**A is a diagram representing an angle defined between the illumination light and an observation light;

FIG. **5**B is a diagram representing a different angle defined between the illumination light and an observation light;

FIG. **6** is a longitudinal sectional view of an objective unit according to a third embodiment of the invention, taken along a plane containing the axis of the observation light;

FIG. **7** is a sectional view of the illumination system of an optical microscope;

FIG. **8** which is a sectional view of the dry system objective unit incorporated in the conventional microscope; and

FIG. **9** is a sectional view of the ring mounted on the objective unit shown in FIG. **8**, taken along line IX—IX in FIG. **8**.

DETAILED DESCRIPTION OF THE INVENTION

Embodiments of the present invention will be described, with reference to the accompanying drawing.

FIG. **1** is a longitudinal sectional view of the objective unit **31**, or the first embodiment of the invention, taken along a plane containing the axis of the observation light. The objective unit **31** is located on the position on which there is located on the objective unit **3** incorporated in the illumination system of the conventional optical microscope, which is shown in FIG. **7**. In FIG. **1**, the same components as those of the conventional objective unit shown in FIG. **8** are designated at the same reference numerals.

The objective unit **31** is an oil immersion type wherein oil **40** is filled in the space between a cover glass **30** and the distal end of the unit **31**. The unit **31** has a working distance (WD) of about 0.1 mm. A sample **1** is placed on an object glass **70**. The sample **1** is covered with a cover glass **30**.

Fitted in the distal end of the objective unit **31** are a shared lens **41** and a lens-holding frame **42**. The frame **42** is a hollow cylinder closed at the lower end, in which a circular hole is made. The frame **42** has a path hole **42***a* for guiding an illumination light **11**. The path hole **42***a* is a through hole that extends between the outer and inner circumferential surfaces of the frame **42** and opens in both circumferential surfaces thereof. In other words, the frame **42** has a through hole between the outer and inner circumferential surfaces. The path hole **42***a* opens, but not all around the lens-holding frame **42**. In other words, the frame **42** has one part in which the path hole **42***a* is not formed at all.

The lens-holding frame **42** may have two or more paths, instead of one. In other words, the frame has some through holes between the outer and inner circumferential surfaces. In this case, the paths are spaced apart in the circumferential direction of the frame **42**.

It suffices for the path hole **42***a* to extend from the outer surface of the frame **42** to the inner surface thereof. It may be made in the lower part of the frame **42**, in the form of either a groove or a hole.

The shared lens **41** is fitted in the circular hole made in the lower end of the lens-holding frame **42**. The frame **42** is snap-fitted in the lower end of a hollow cylinder **21**, by virtue of an annular projection **211** of the hollow cylinder **21**. Provided in the hollow cylinder **21** are lenses **6***a* to **6***g* and lens-holding frames **20***a* to **20***g*. The lenses **6***a* to **6***g* are held in the frames **20***a* to **20***b*, respectively. The frames **20***a* to **20***g* are fitted in the cylinder **21** and held in place once a lens-holding ring **22** has been fitted into one end of the hollow cylinder **21**.

A hollow cylindrical mirror **43** is fitted into one end of the hollow cylindrical cover **27**. The mirror **43** has a conical

inner surface, i.e, an inclined reflecting surface **43***a*. The reflecting surface **43***a* reflects the illumination light **11** having an annular cross section, applying the light **11** onto the sample **1** through the path hole **42***a* provided in the lens-holding frame **42**.

The shared lens **41** and the frame **42** will be described in detail. As mentioned above, the objective unit **31** is an oil immersion type and therefore has a large NA. The shared lens **41** is a sphere with a part cut off, having a cross section larger than half the sphere. The lens **41** therefore has a flat circular face whose diameter is shorter than the diameter of the sphere. The circular hole made in the lower end of the lens-holding frame **42** has the same diameter as that of the flat circular face of the shared lens **41**. The lens **41** is fitted in the circular hole of the frame **42**. As indicated above, the frame **42** has a path hole **42***a*. The path hole **42***a* extends between the outer circumferential surface of the frame **42** and the inner circumferential surface thereof (i.e., the lens-holding surface).

How the objective unit **31** works will be explained, with reference to FIG. **7**. As shown in FIG. **7**, the light emitted from the lamp **7** is focused by the collector lens **9**, forming a light beam which has a circular cross section. Part of the light beam passes through the opening of the mirror **10**. The remaining part of the light beam is reflected downwards from the reflecting surface of the mirror **10**. It is used as an illumination light **11** which is suitable for incident lighting. The light has an annular cross section and is coaxial with the observation-light axis **2**. The illumination light **11** is guided through an annular space located outside the observation light path and is applied into the objective unit **31**.

In the objective unit **31**, the illumination light **11** passes through the illumination light path which has an annular cross section. This light path is provided between the cylinder **21** and the hollow cylindrical cover **27** and, hence, surrounds the lens system **6** or the lenses **6***a* to **6***g*. The illumination light **11** reaches the hollow cylindrical mirror **43**. The inclined surface **43***a* of the mirror **43** reflects the illumination light **11**, applying the light **11** to the path hole **42***a* made in the lens-holding frame **42**. The light **11** is applied through the path hole **42***a* to the shared lens **41**. The lens **41** refracts the light **11**. The light **11** thus refracted passes through the oil **40** and the cover glass **30**. The light **11** is therefore applied to the sample **1** mounted on the object glass **70**.

The light reflected from the sample **1**, or the observation light **5**, passes through the cover glass **30**, the oil **40**, the shared lens **41**, the lenses **6***a* to **6***g* and the focusing lens **4**. The observation lights reaches the eye lens (not shown), etc, which provides a magnified image of the sample **1**.

As indicated by the two dash-dotted lines **1** in FIG. **1**, the frame **42** may have a through hole in the part in which the path hole **42***a* is not formed. The hole can guide a part of the light **11** into the illumination light path, said part of the light **11** having been diffracted at the outer surface of the shared lens **41** and then totally reflected from the interface between the sample **1** and cover glass **30**.

Since the objective unit **31** is an oil immersion type, it has a large NA and a short working distance, so that it is difficult for the unit **31** to include in its distal end portion a space for guiding the illumination light **11**. Nonetheless, the lens-holding frame **42** does not block the illumination light **11** because it has the light-guiding path hole **42***a*. The light **11** passes through the path hole **42***a* provided outside the observation light path and reaches, in its entirety, to the sample **1** through the shared lens **41**, oil **40** and cover glass **30**.

Furthermore, the shared lens **41** serves not only to apply the illumination light **11** onto the sample **1** but also to guide the observation light toward the focusing lens **4**. An incident-lighting only lens for guiding the observation need not be used, and a space for accommodating such a lens need not be provided in the objective unit **31**. The unit **31** can be manufactured at lower cost than otherwise. Still further, the shared lens **41** can easily apply the illumination light **11** onto the sample **1** because the lens **41** is designed to guide the light reflected from the sample **1**, along the axis **2** of observation light.

As described above, the path hole **42***a* opens, but not all around the lens-holding frame **42**. Hence, the frame **42** has an inner circumferential surface large enough to hold the shared lens **41** firmly. The path hole **42***a* almost does not reduce that surface of the frame **42** which contacts the shared lens **41**. Since the frame **42** has one part in which the path hole **42***a* is not formed at all, it is rigid enough to maintain its shape even while being machined. In addition, the frame **42** can have dimensions of high precision.

As indicated by the two dash-dotted lines **1**, the frame **42** has a through hole. The hole guide a part of the light **11** into the illumination light path, said part of the light **11** having been totally reflected from the interface between the sample **1** and cover glass **30**. Thus guided through the hole, the part of the light **11** would not be scattered at the frame **42**. It would not enter the observation light path, as noise known as "flare.", etc. Hence, the microscope can provide a high-contrast, high SN ratio image of the sample **1**.

An objective unit **32** according to the second embodiment of the invention will be described, with reference to FIG. **2**. FIG. **2** is a longitudinal sectional view of the objective unit **32** taken along a plane containing the axis of the observation light. The objective unit **32** is located on the position on which there is located on the objective unit **3** incorporated in the illumination system of the conventional optical microsope, which is shown in FIG. **7**. In FIG. **2**, the same components as those of the conventional lens unit shown in FIG. **8** are designated at the same reference numerals. The objective unit **32** is an oil immersion type wherein oil **40** is filled in the space between a cover glass **30** and the distal end of the unit **32**. The unit **32** has a working distance (WD) of about 0.1 mm.

Fitted in the distal end of the objective unit **32** are a shared lens **41** and a lens-holding frame **50**. The frame **50** is a hollow cylinder closed at the lower end, in which a circular hole is made. The frame **50** has a path hole **50***a* for guiding an illumination light. The path hole **50***a* is a through hole that extends between the outer and inner circumferential surfaces of the frame **50** and opens in both circumferential surfaces thereof. In other words, the frame **50** has a through hole between the outer and inner circumferential surfaces. The path hole **50***a* opens, but not all around the lens-holding frame **50**. Namely, the frame **50** has one part in which the path hole **50***a* is not formed at all. Inserted in the path hole **50***a* is a prism **51**, which will be described later in detail. The lens-holding frame **50** may have two or more through holes, instead of one. In this case, the through holes are spaced apart in the circumferential direction of the frame **50**.

It suffices for the path **50***a* to extend from the outer surface of the frame **50** to the inner surface thereof. It may be made in the lower part of the frame **50**, in the form of either a groove or a hole.

The shared lens **41** is fitted in the circular hole made in the lower end of the lens-holding frame **50**. The frame **50** is snap-fitted in the lower end of a hollow cylinder **21**, by

virtue of an annular projection **211** of the hollow cylinder **21**. Provided in the hollow cylinder **21** are lenses **6***a* to **6***g* and lens-holding frames **20***a* to **20***g*. The lenses **6***a* to **6***g* are held in the frames **20***a* to **20***b*, respectively. The frames **20***a* to **20***g* are fitted in the cylinder **21** and held in place once a lens-holding ring **22** has been fitted into one end of the hollow cylinder **21**.

A hollow cylindrical mirror **52** is fitted into one end of the hollow cylindrical cover **27**. The mirror **52** has a closed lower end, in which circular opening is made. It has a conical inner surface, i.e, an inclined reflecting surface **52***a*. The reflecting surface **52***a* reflects the illumination light **11** having an annular cross section, applying the light **11** onto a sample **1** through the path hole **50***a* provided in the lens-holding frame **50**.

The share lens **41**, the frame **50** and the prism **51** will be described in detail.

FIG. **3**A is a perspective view of the prism **51**. As FIG. **3**A shows, the prism **51** is a truncated cone having a circular through hole in its center part. It has a cylindrical inner surface **511** in its lower end and a conical outer surface **512** at its top. The prism **51** is made of material which exhibits a refractive index higher than that of the shared lens **41**. The shared lens **41** has its lower part fitted in the cylindrical inner surface **511** of the prism **51** and the inner surface of the frame **50**. The inner surface of the frame **50** is flush with the cylindrical inner surface **511** of the prism **51**. As indicated above, the path hole **50***a* extends between the outer and inner circumferential surfaces of the lens-holding frame **50**. The inner circumferential surface holds the shared lens **41**.

FIG. **3**B shows one of prism pieces obtained by dividing the prism **51** shown in FIG. **3**A into eight. The prism **51** is not limited to a 8-piece type but may consist of an arbitrary number of pieces. One or more of the pieces of the prism **51** can be buried in the through hole or holes **50***a* formed at the predetermined locations of the lens holding frame **50**. The number of through holes *51*a is determined in accordance with the number of prism pieces used, and the size of each through hole **50** is determined in such a manner that one prism piece can be fitted therein.

The shared lens **41** and the prism **51** can be coupled in various methods, as will be explained with reference to FIGS. **4**A, **4**B and **4**C.

As shown in FIG. **4**A, the lower part of the lens **41** is placed in the cylindrical inner surface **511** of the prism **51** and adhered thereto with adhesive c which has the same refractive index as the prism **51**.

Alternatively, as shown in FIG. **4**B, the lower part of the lens **41** may set in optical contact with the inner surface **511** which is curved in the same way as the surface of the shared lens **41**.

Further, as illustrated in FIG. **4**C, the lower part of the lens **41** may placed in the cylindrical inner surface **511** which is curved in the same way as the surface of the lens **41**. And the gap between the lens **41** and the surface **511** of the prism **51** may be filled with adhesive c which has the same refractive index as the prism **51**.

How the objective unit **32** works will be explained, with reference to FIG. **7**. As shown seen from FIG. **7**, the light emitted from the lamp **7** is focused by the collector lens **9**, forming a light beam which has a circular cross section. Part of the light beam passes through the opening of the mirror **10**. The remaining part of the light beam is reflected downwards from the reflecting surface of the mirror **10** and is used as an illumination light **11**. The illumination light **11** has an annular cross section and is coaxial with the observation-light axis **2**. The light **11** is guided through an annular space located outside the observation path and is applied into the objective unit **32**.

In the objective unit **32**, the illumination light **11** passes through the illumination light path which has an annular cross section. This light path is provided between the cylinder **21** and the hollow cylindrical cover **27** and, hence, surrounds the lenses **6***a* to **6***g*. The illumination light **11** reaches the hollow cylindrical mirror **52**. The inclined surface **52***a* of the mirror **52** reflects the illumination light **11**, applying the light **11** to the path hole **50***a* made in the lens-holding frame **50**. The light **11** is applied through the path hole **50***a* to the shared lens **41**.

Since the prism **51** has a higher refractive index than the shared lens **41**, the illumination light **11** is refracted at the interface between the lens **41** and the prism **51**, away from the observation-light axis **2**. The light **11** is then refracted by the shared lens **41**. Thus refracted, the light **11** passes through the oil **40** and the cover glass **30** and is applied to the sample **1** mounted on the object glass **70**.

The light reflected from the sample **1**, or the observation light **5**, passes through the cover glass **30**, the oil **40**, the shared lens **41**, the lenses **6***a* to **6***g* and the focusing lens **4**. The observation light **5** reaches the eye lens (not shown), etc, which provides a magnified image of the sample **1**.

The second embodiment attain the same advantage as the first embodiment. Moreover, it is advantageous in that the illumination light **11** is refracted at a greater angle to the observation-light axis **2** as will be described below, even if the light **11** has the same NA as the light **11** used in the first embodiment. This is because the prism **51** is held in the lens-holding frame **50** has a higher refractive index than the shared lens **41**.

In the first embodiment, the angle α between the light **11** and the observation light **5** can be reduced but to a certain degree as shown in FIG. **5**A, due to the positions of the hollow cylinder **21** and lens-holding frame **42**. In the second embodiment, the angle α can be reduced as much as is illustrated in FIG. **5**B. The angle α can be reduced so that the diameter of the illumination light beam **11** has a large value, and so that the path for the light **11** is located farther from the hollow cylinder **21** and the lenses **6***a* to **6***g* than in the first embodiment. A larger space is therefore available in the distal end of the second embodiment. Since the illumination light **11** has a larger cross section than the light **11** applied to the sample **1** in the first embodiment, the sample **1** can be illuminated more than in the case the first embodiment is used.

As shown in FIG. **4**A, the shared lens **41** and the prism **51** are connected by adhesive. The adhesive has the same refractive index as the prism **51**. Therefore, the prism **51** can apply the light **11** to the lens **41** at a desired incident angle, even if it has not been processed with high precision at the surface contacting the lens **41**. Optically connected together, the shared lens **41** and the prism **51** prevent the light scattered by the adhesive, from entering the observation light path. This enables the microscope to provide a high SN-ratio (i.e., observation light/scattered light) image of the sample **1**.

The illumination light **11** is scarcely refracted at the conical outer surface **512** of the prism **51**, to which the light **11** is applied. The prism **51** may be re-designed to incline the surface **512** to increase the incidence angle of the beam **11**. The surface **512** may be a part of the surface of a sphere. Further, the prism **51** may have the same refractive index as the shared lens **41** or may be made of the same glass as the

lens **41**, in order to decrease the aberration resulting from the refraction of the light **11** at the interface between the lens **41** and the prism **51**.

An objective unit **33** which is the third embodiment of the invention will be describe, with reference to FIG. **6**. FIG. **6** is a longitudinal sectional view of the objective unit **33**, taken along a plane containing the axis of the observation light. The objective unit **33** is located on the position on which there is located on the objective unit **3** incorporated in the illumination system of the conventional optical microscope, which is shown in FIG. **7**. In FIG. **6**, the same components as those of the conventional lens unit shown in FIG. **8** are designated at the same reference numerals. The objective unit **33** is an oil immersion one. Oil **40** is filled in the space between a cover glass **30** and the distal end of the unit **33**. The unit **33** has a working distance (WD) of about 0.1 mm.

Fitted in the distal end of the objective unit **33** are a shared lens **41** and a lens-holding frame **60**. The frame **60** is a hollow cylinder closed at the lower end, in which a circular hole is made. The frame **60** is made of material which is greatly transparent to light. The frame **60** therefore acts as a prism.

The shared lens **41** is a sphere with a part cut off, having a cross section larger than half the sphere and a flat circular face whose diameter is shorter than the diameter of the sphere. The lower part of the lens **41** is fitted in the circular hole made in the lower end of the lens-holding frame **60**. The frame **60** is snap-fitted in the lower end of a hollow cylinder **21**, by virtue of an annular projection **211** of the hollow cylinder **21**. Provided in the hollow cylinder **21** are lenses **6***a* to **6***g* and lens-holding frames **20***a* to **20***g*. The lenses **6***a* to **6***g* are held in the frames **20***a* to **20***b*, respectively. The frames **20***a* to **20***g* are fitted in the cylinder **21** and held in place once a lens-holding ring **22** has been fitted into one end of the hollow cylinder **21**.

A hollow cylindrical mirror **43** is fitted into one end of the hollow cylindrical cover **27**. The mirror **43** has a conical inner surface, i.e, an inclined reflecting surface **43***a*. The reflecting surface **43***a* reflects the illumination light **11** having an annular cross section, applying the light **11** onto the sample **1** through the the lens-holding frame **60**.

How the objective unit **33** works will be explained, with reference to FIG. **7**. As shown seen from FIG. **7**, the light emitted from the lamp **7** is focused by the collector lens **9**, forming a light beam which has a circular cross section. Part of the light beam passes through the opening of the mirror **10**. The remaining part of the light beam is reflected downwards from the reflecting surface of the mirror **10** and is used as an illumination light **11**. The illumination light **11** has an annular cross section and is coaxial with the observation-light axis **2**. The light **11** is guided through an annular space located outside the observation path and is applied into the objective unit **33**.

In the objective unit **33**, the illumination light **11** passes through the illumination light path which has an annular cross section. This light path is provided between the cylinder **21** and the hollow cylindrical cover **27** and, hence, surrounds the lenses **6***a* to **6***g*. The illumination light **11** reaches the hollow cylindrical mirror **43**. The inclined surface **43***a* of the mirror **43** reflects the illumination light **11**, applying the light **11** to the lens-holding frame **60**. The light **11** passes through the frame **60** which acts as a prism, reaching the shared lens **41**.

The lens **41** refracts the light **11**. The light **11** thus refracted passes through the oil **40** and the cover glass **30**. The light **11** is therefore applied to the sample **1** mounted on the object glass **70**.

The light reflected from the sample **1**, or the observation light **5**, passes through the cover glass **30**, the oil **40**, the shared lens **41**, the lenses **6***a* to **6***g* and the focusing lens **4**. The observation light reaches the eye lens (not shown), etc, which provides a magnified image of the sample **1**.

The third embodiment attain the same advantage as the first embodiment. Further, the lens-holding frame **60** does not block the illumination light **11** at all because it is made of material transparent to light. The light **11** is therefore applied, in its entirety, onto the sample **1**. Moreover, since frame **60** need not have path hole to guide the illumination light **11**, the frame **60** is rigid enough to hold the lens **41** firmly. In addition, since the frame **60** is transparent, the light **11** is applied to the sample **1** at an angle β with respect to the observation light **5**, as shown in FIG. **5**B. The illumination light beam **11** is thus far from the axis **2** of observation light, and this helps to illuminate the sample **1** more brightly.

The lens-holding frame **60** may be replaced by a plurality of segments which forms a hollow cylinder when combined together.

The present invention is not limited to the embodiments described above. Various changes and modifications can be made. For example, the illumination light **11** may be guided by the lens **6***a* and the frame **20***a* holding the lens **6***a*, not by the shared lens **41** and the frame holding the lens **41** as in the first to third embodiments.

Further, the shared lens **41** may be used to guide only the observation light, not both the observation light and the illumination light **11** as in the first to third embodiments. In this case, the illumination light **11** is replaced by dark-field illumination light such as evanescent illumination light. Still further, the present invention is not limited to oil immersion (liquid immersion system) objective units only. It can also be applied to dry system objective units. Specifically, the first to third embodiments can be converted to dry system type objective units merely by draining the oil **40**. Moreover, the components of the first to third embodiments may be used in various combinations, providing various modified objective units.

Furthermore, the embodiments described above can be modified so long as an illumination light is guided parallel to the observation-light axis **2** through the annular space provided between the hollow cylinder **21** and the hollow cylindrical cover **27**. For example, an annular optical fiber may be located above the annular space, and a laser beam may be applied directly from the optical fiber into the space from above.

As has been described, the objective unit according to the invention is simple in structure and makes good use of an internal space, thanks to the shared lens which guides both the illumination light and the observation light. No lens for applying the illumination light only need not be used, and the illumination light can easily focused on the object of observation. Further, the frame holding the shared lens does not block the illumination light at all; rather it guides the illumination light to the object of observation. Since the frame holding the shared lens has a greater refractive index than the shared lens, it can refracts the illumination light at a large angle to the axis of the observation light. Hence, the illumination light path can be located remote from the other lenses used in the unit and from the frames holding these lenses, whereby a larger space is available in the distal end of the objective unit. A thick beam of illumination light can

therefore be applied, achieving effective incident lighting to illuminate the object brightly.

Thus, the present invention achieves an objective unit which has a large numerical aperture (NA) and a short working distance (WD) as an oil immersion objective unit and which has an illumination light path outside the observation light path which guides an illumination light such that the light is not blocked by lenses or lens-holding frames.

Additional advantages and modifications will readily occur to those skilled in the art. Therefore, the invention in its broader aspects is not limited to the specific details and representative embodiments shown and described herein. Accordingly, various modifications may be made without departing from the spirit or scope of the general inventive concept as defined by the appended claims and their equivalents.

I claim:

1. An objective unit comprising:

a plurality of lenses for guiding observation light reflected from a sample;

an inner frame surrounding and holding said plurality of lenses;

an outer frame surrounding said inner frame;

an annular path provided between said inner frame and said outer frame along which illumination light passes; and

a deflecting member for deflecting the illumination light passing along said annular path to thereby guide the illumination light to the sample;

wherein said plurality of lenses includes a shared lens for allowing passage of the observation light and the illumination light, and

wherein said inner frame includes at least one through hole for guiding the illumination light deflected by said deflecting member to the sample through said shared lens, and at least one transparent member inserted in said at least one through hole.

2. The objective unit according to claim **1**, wherein said at least one transparent member has a greater refractive index than said shared lens.

3. The objective unit according to claim **1**, wherein said inner frame includes a plurality of through holes for guiding the illumination light, and a plurality of transparent members provided in a same number as the plurality of through holes, said plurality of transparent members being inserted in respective ones of said plurality of through holes.

4. The objective unit according to claim **1**, wherein said shared lens and said at least one transparent member are coupled by an adhesive which is transparent to light.

5. The objective unit according to claim **1**, wherein said shared lens and said at least one transparent member are optically coupled.

6. An objective unit comprising:

a plurality of lenses for guiding observation light reflected from a sample;

an inner frame surrounding and holding said plurality of lenses;

an outer frame surrounding said inner frame;

an annular path provided between said inner frame and said outer frame along which illumination light passes; and

a deflecting member for deflecting the illumination light passing along said annular path to thereby guide the illumination light to the sample;

wherein said plurality of lenses includes a shared lens for allowing passage of the observation light and the illumination light, and

wherein said inner frame includes at least one transparent portion for guiding the illumination light deflected by said deflecting member to the sample through said shared lens.

7. The objective unit according to claim **6**, wherein said at least one transparent portion of said inner frame has a greater refractive index than said shared lens.

8. The objective unit according to claim **6**, wherein said shared lens and said at least one transparent portion of said inner frame are coupled by an adhesive which is transparent to light.

9. The objective unit according to claim **6**, wherein said shared lens and said at least one transparent portion of said inner frame are optically coupled.

10. The objective unit according to claim **6**, wherein said inner frame includes an additional through hole for guiding reflected beams of the illumination light reflected from the sample to return the reflected beams to said annular path.

11. An objective unit comprising:

a plurality of lenses for guiding observation light reflected from a sample;

an inner frame surrounding and holding said plurality of lenses;

an outer frame surrounding said inner frame;

an annular path provided between said inner frame and said outer frame along which illumination light passes; and

a deflecting member for deflecting the illumination light passing along said annular path to thereby guide the illumination light to the sample;

wherein said plurality of lenses includes a shared lens for allowing passage of the observation light and the illumination light, and

wherein said inner frame includes a through hole for guiding the illumination light deflected by said deflecting member to the sample through said shared lens.

12. The objective unit according to claim **11**, wherein said inner frame includes an additional through hole for guiding reflected beams of the illumination light reflected from the sample to return the reflected beams to said annular path.

* * * * *

US005828498A

United States Patent [19]

Sekiya et al.

[11] Patent Number: 5,828,498

[45] Date of Patent: Oct. 27, 1998

[54] **OBJECTIVE LENS OF ENDOSCOPE**

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[73] Assignee: **Asahi Kogaku Kogyo Kabushiki Kaisha**, Tokyo, Japan

[21] Appl. No.: **967,212**

[22] Filed: **Oct. 29, 1997**

Related U.S. Application Data

[63] Continuation of Ser. No. 547,339, Oct. 24, 1995, abandoned.

[30] **Foreign Application Priority Data**

Oct. 25, 1994 [JP] Japan 6-260702
Nov. 17, 1994 [JP] Japan 6-283811

[51] **Int. Cl.**[6] **G02B 21/02**; G02B 3/02; G02B 9/04

[52] **U.S. Cl.** **359/660**; 359/717; 359/784; 359/793

[58] **Field of Search** 359/717, 793, 359/784, 660, 656–659

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Primary Examiner—David C. Nelms
Assistant Examiner—Evelyn A. Lester
Attorney, Agent, or Firm—Greenblum & Bernstein, P.L.C.

[57] **ABSTRACT**

An objective lens for an endoscope includes a front lens of negative power, an aperture stop, and a rear lens group of positive power in this order from the object side. At least one surface of the front lens group and/or the rear lens group is a compound aspherical lens made of a glass lens and a transparent layer applied to the glass lens surface. A surface of the transparent layer farther from the glass lens is an aspherical surface. The refractive index n of the glass lens to which the transparent layer is applied is more than 1.65 (n>1.65).

22 Claims, 33 Drawing Sheets

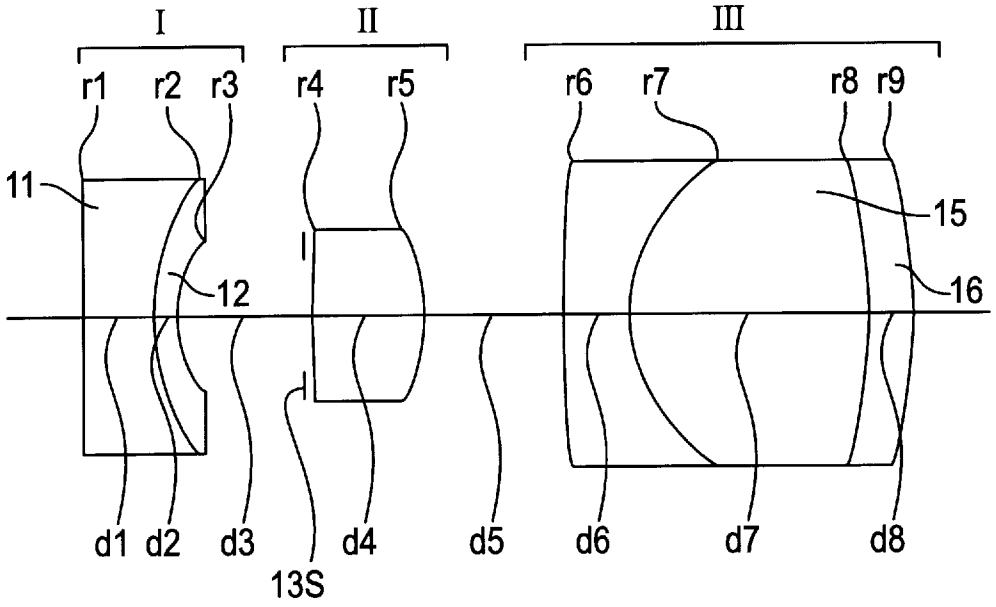
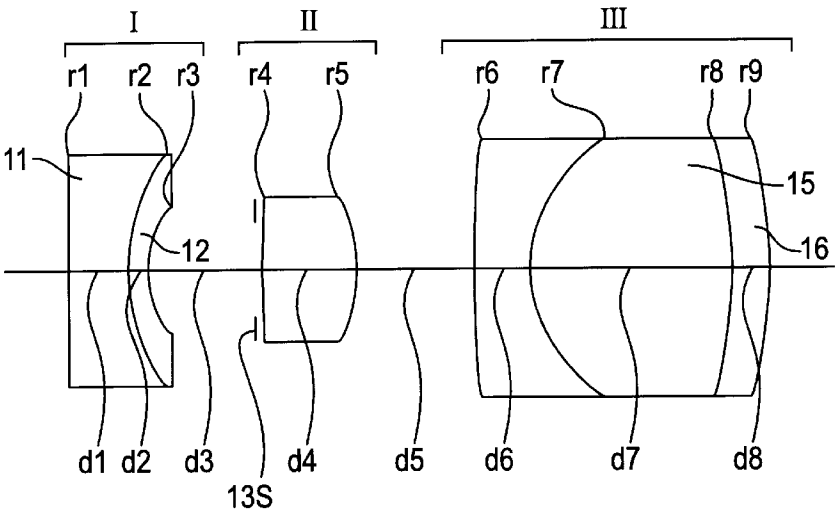


FIG. 1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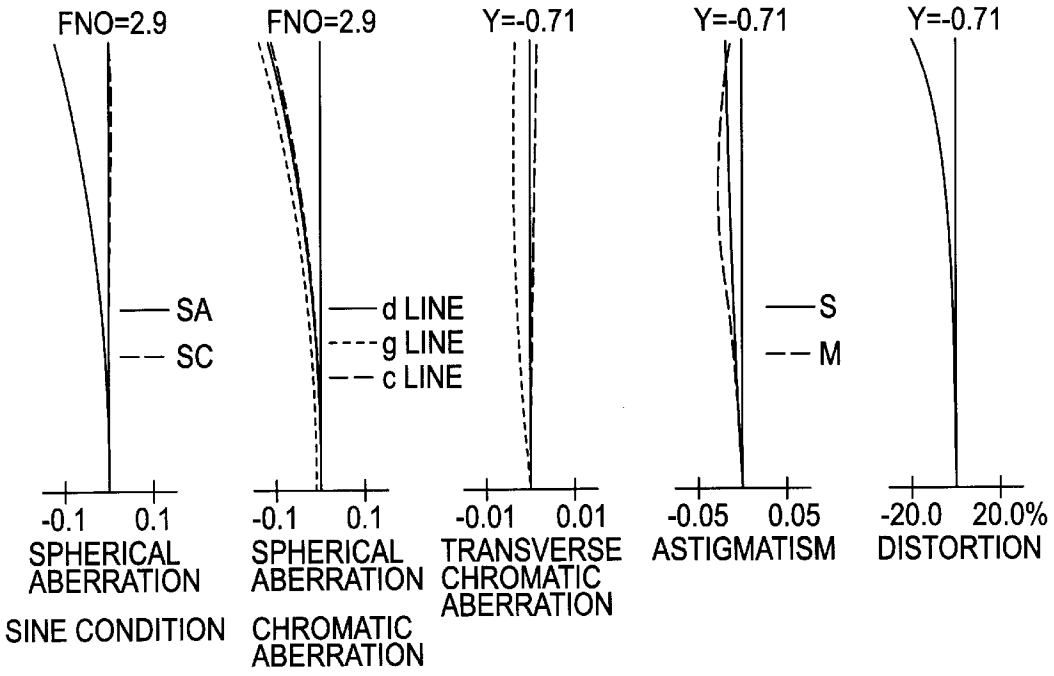
13S

FIG. 2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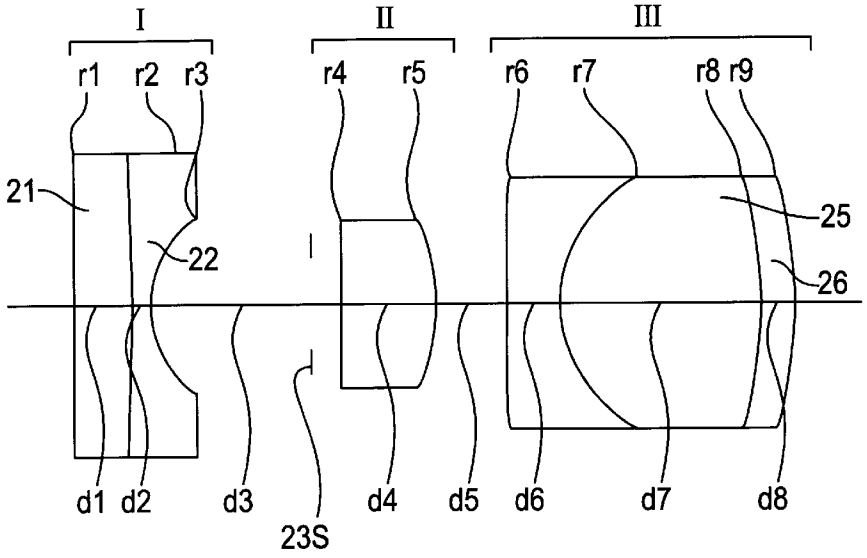
DISTORTION

FIG. 3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d7
d8

FIG. 4

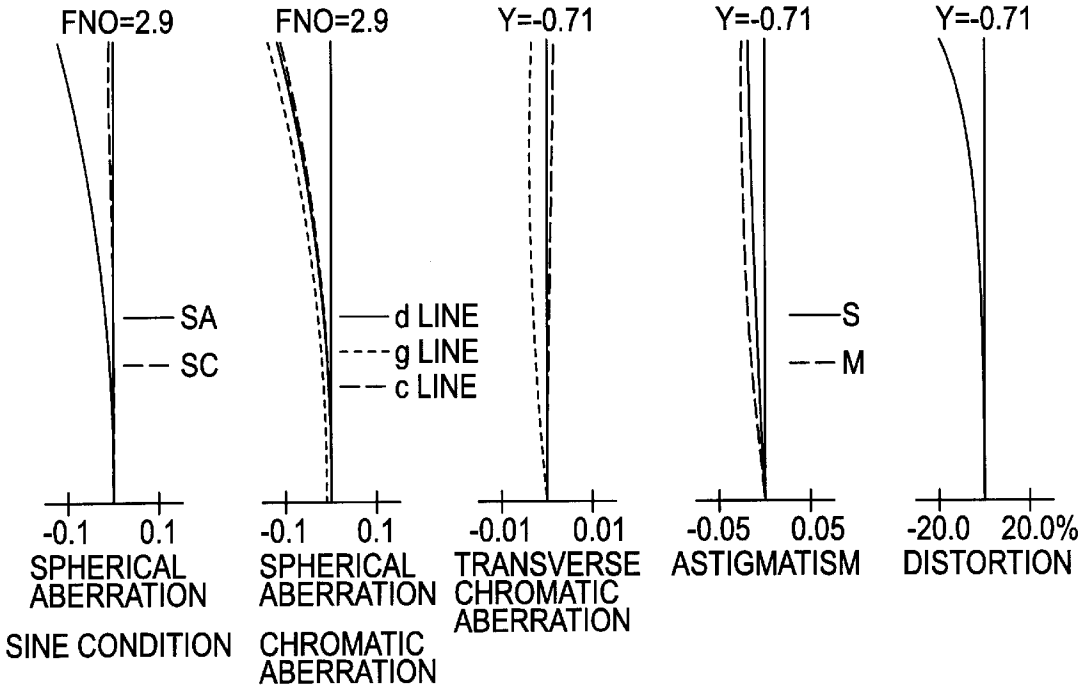
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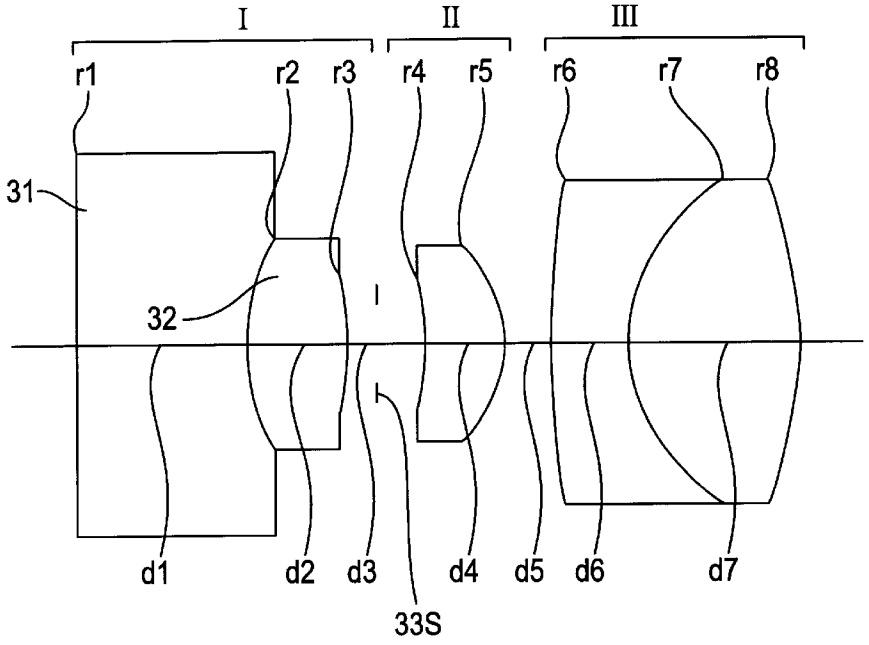
FIG. 5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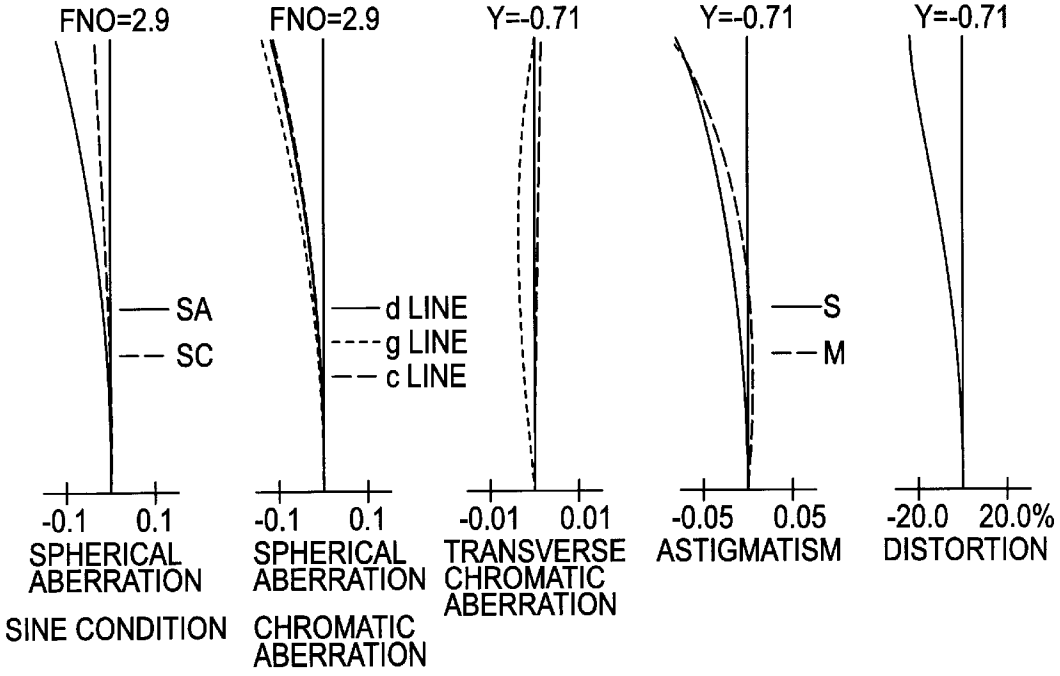
d5
d6
d7
33S

FIG. 6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DISTORTION

FIG. 7

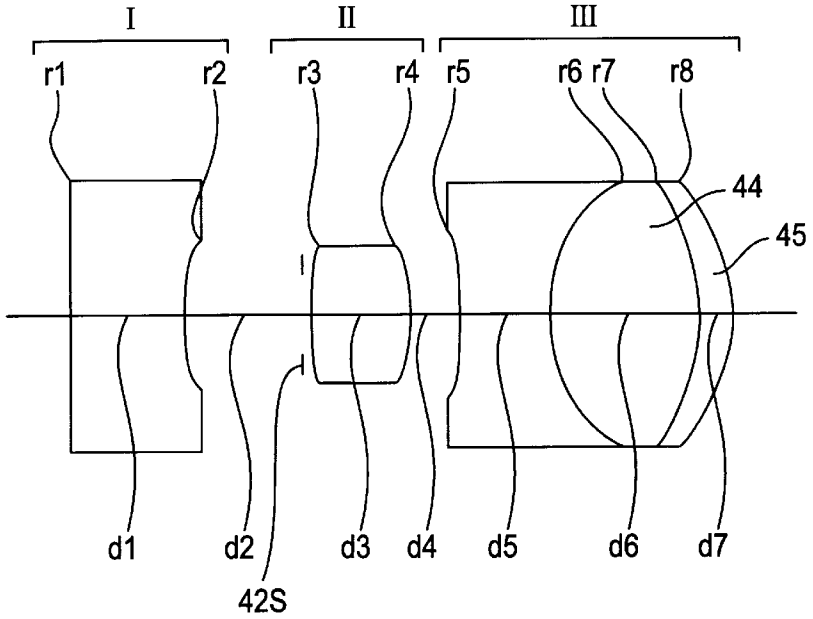
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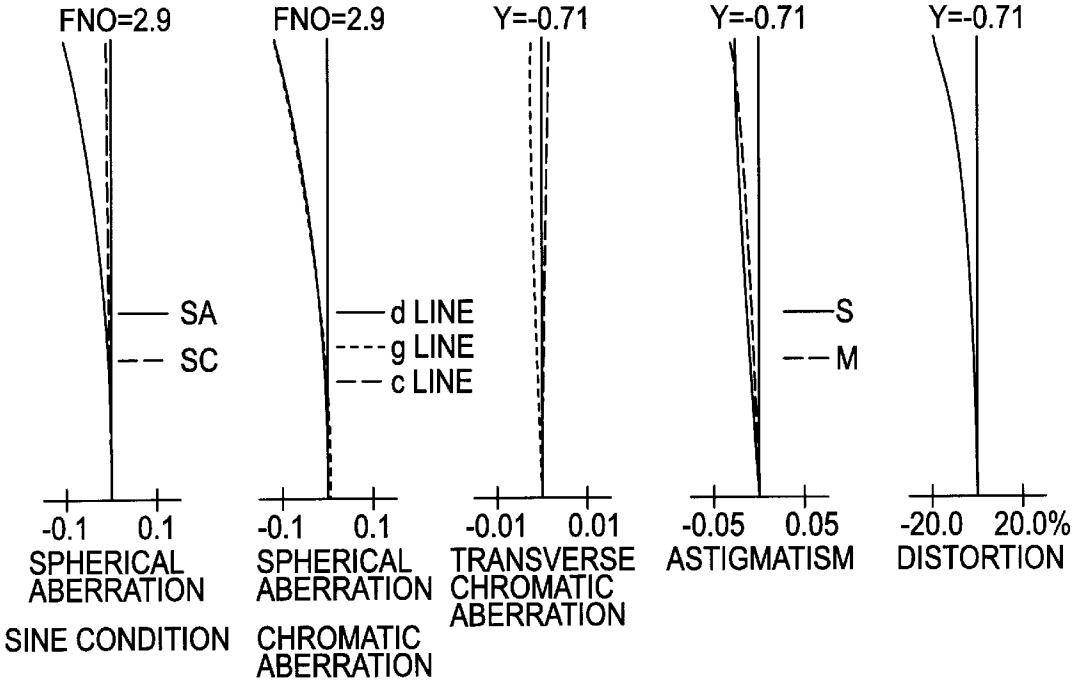
FIG. 8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TRANSVERSE CHROMATIC ABERRATION
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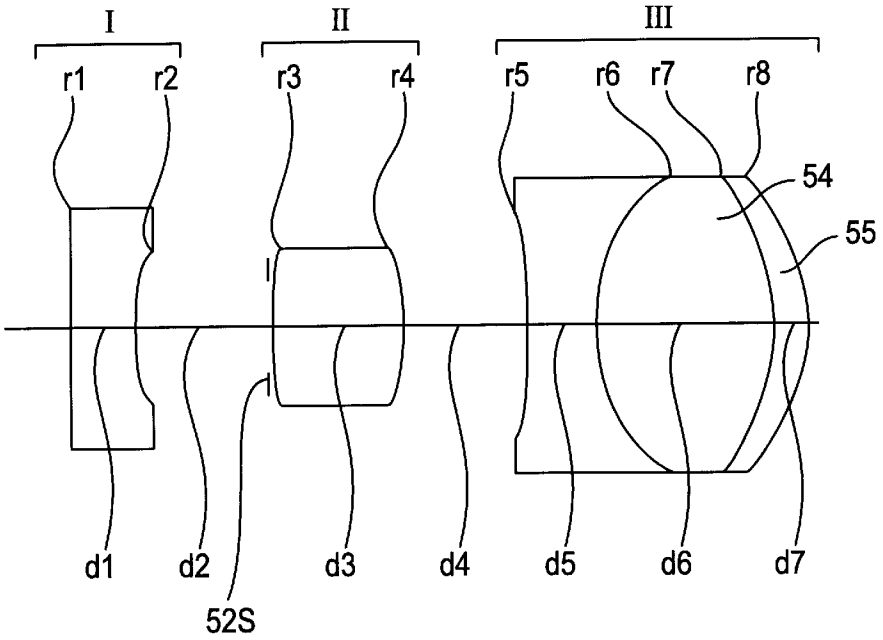
FIG. 9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52S

FIG. 10

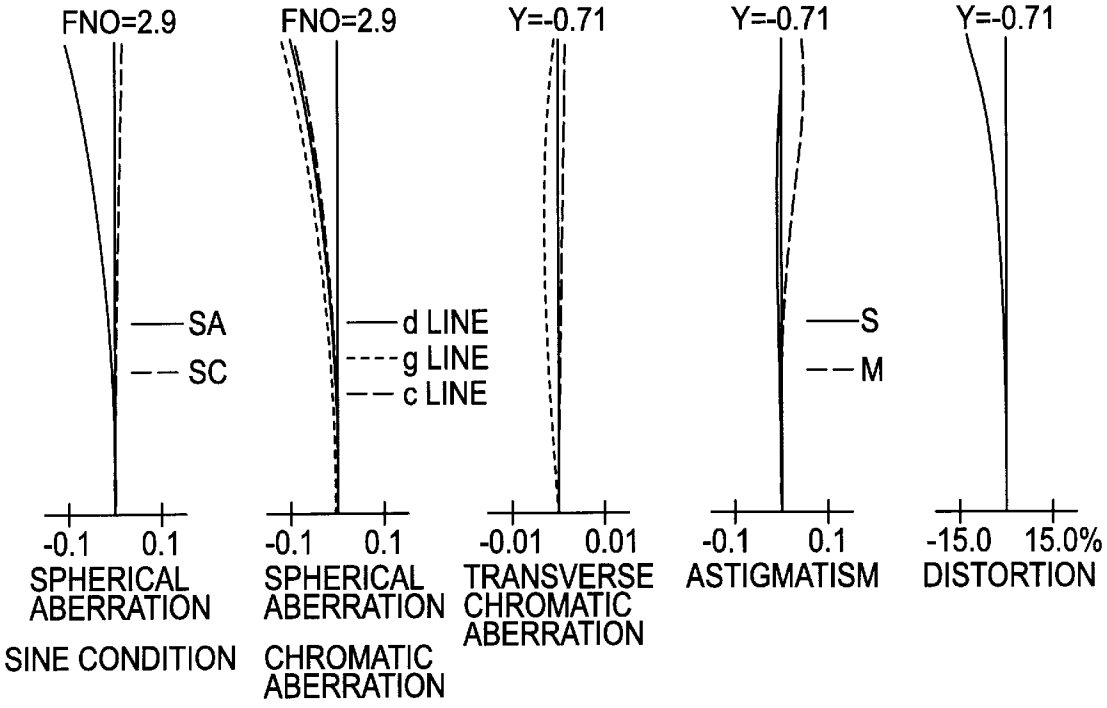
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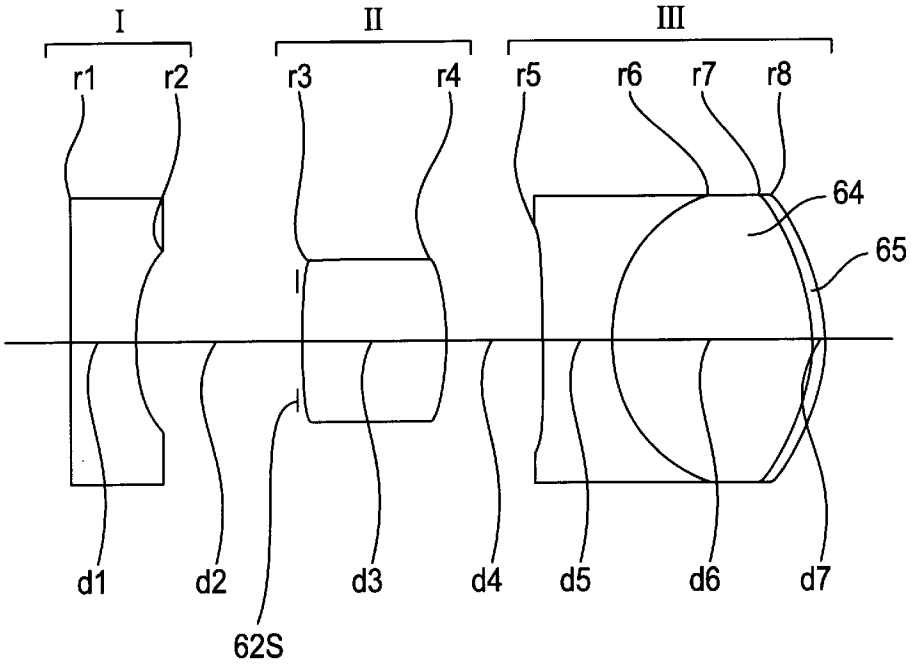
FIG. 11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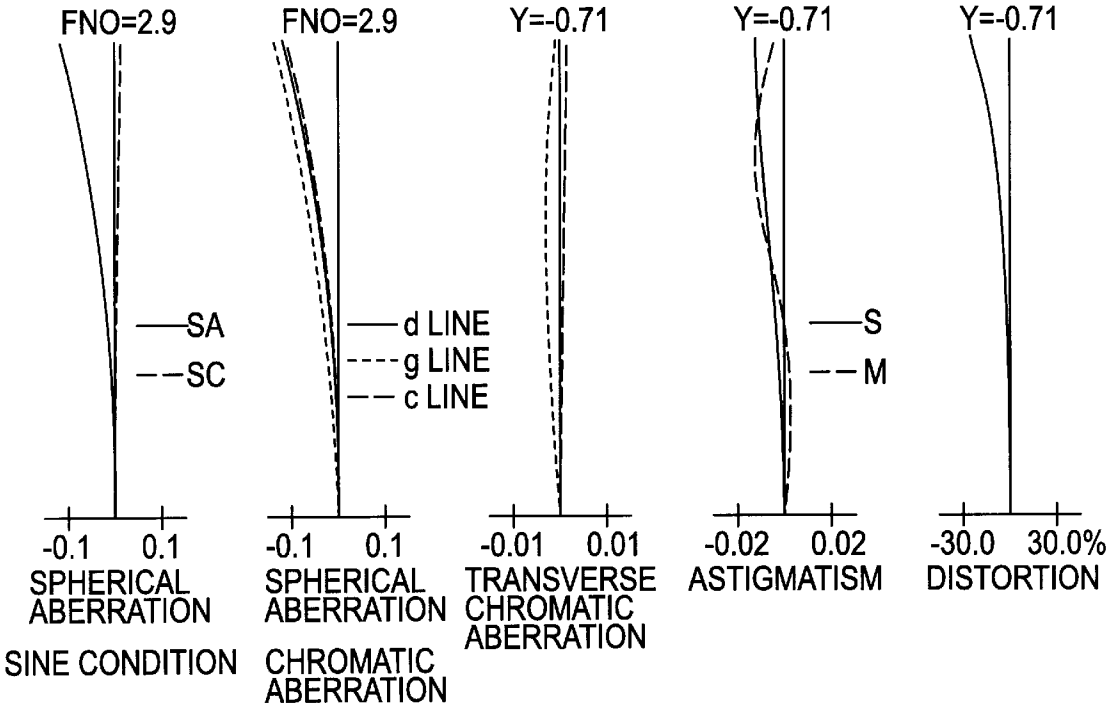
62S

FIG. 12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ASTIGMATISM
DISTORTION

FIG. 13

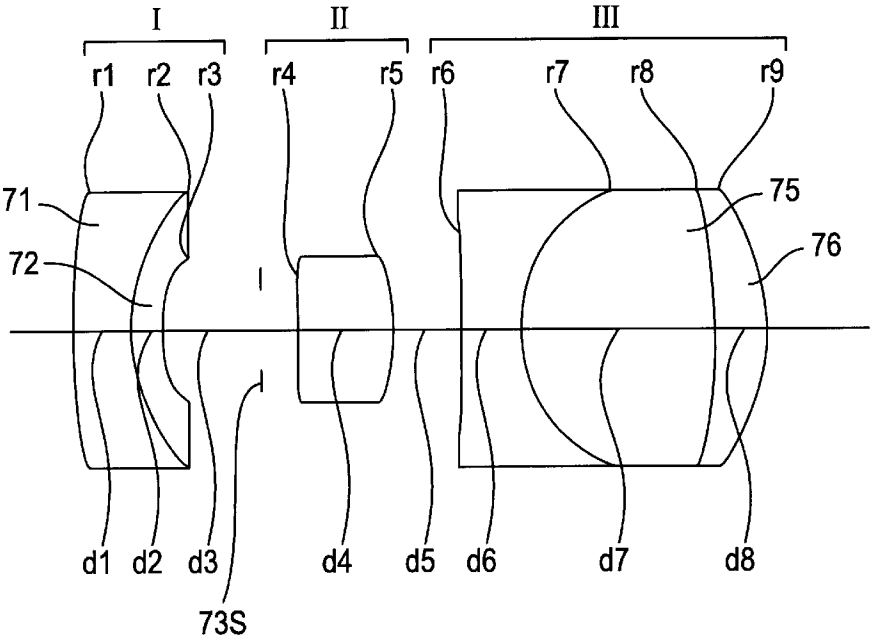
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FIG. 14

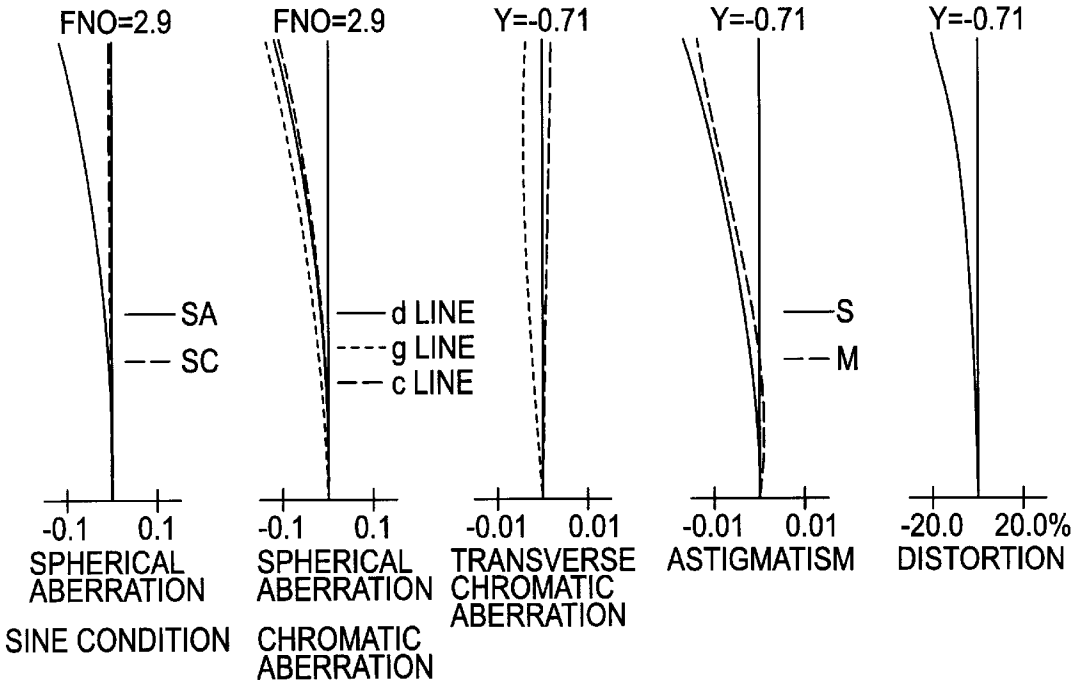
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FIG. 15

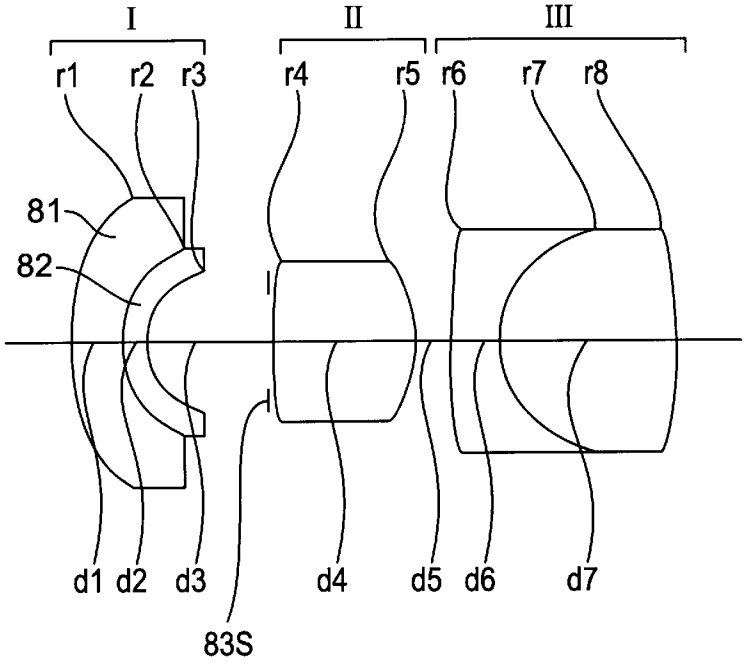
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FIG. 16

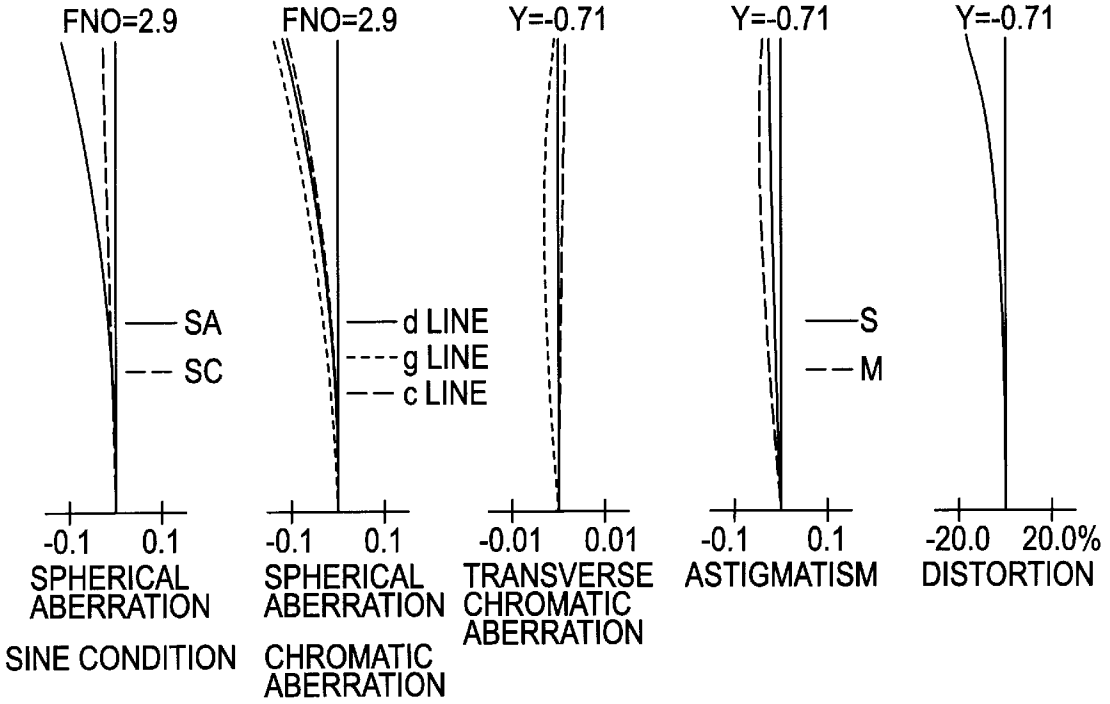
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FIG. 17

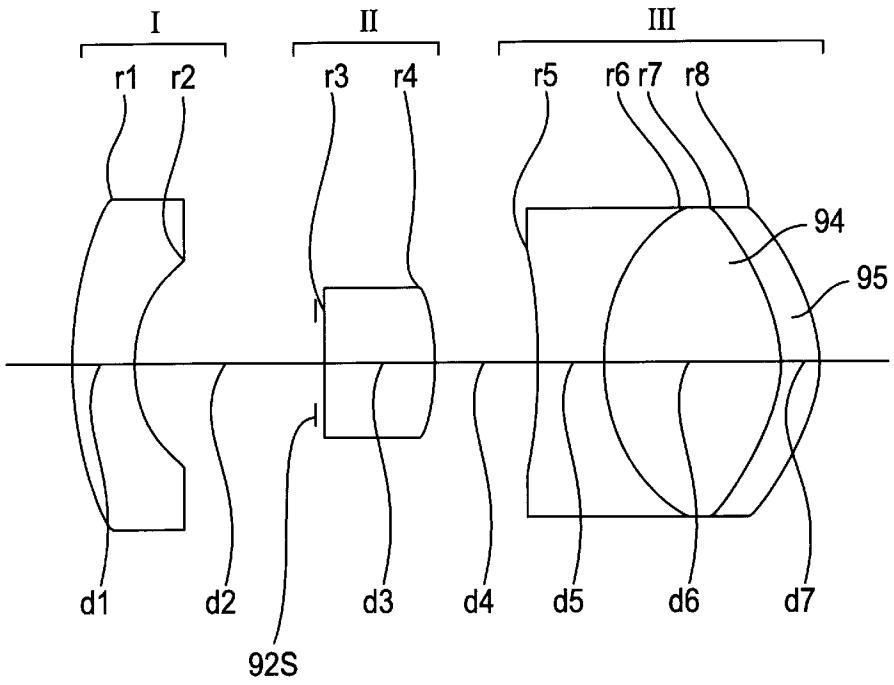
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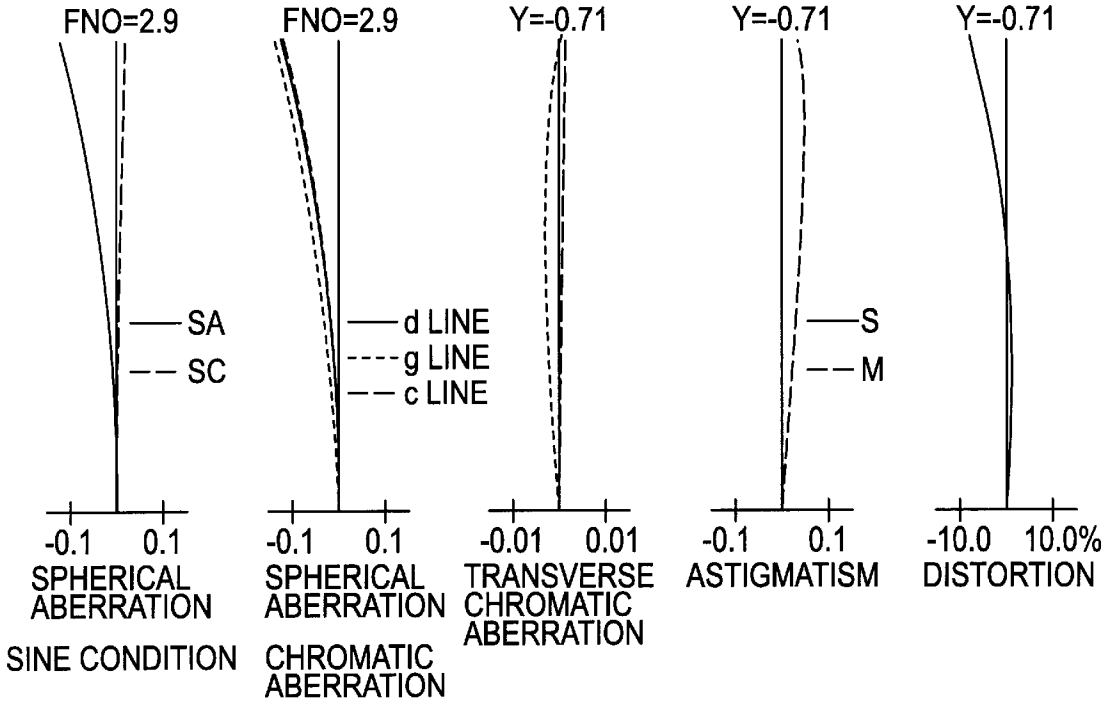
FIG. 18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DISTORTION

FIG. 19

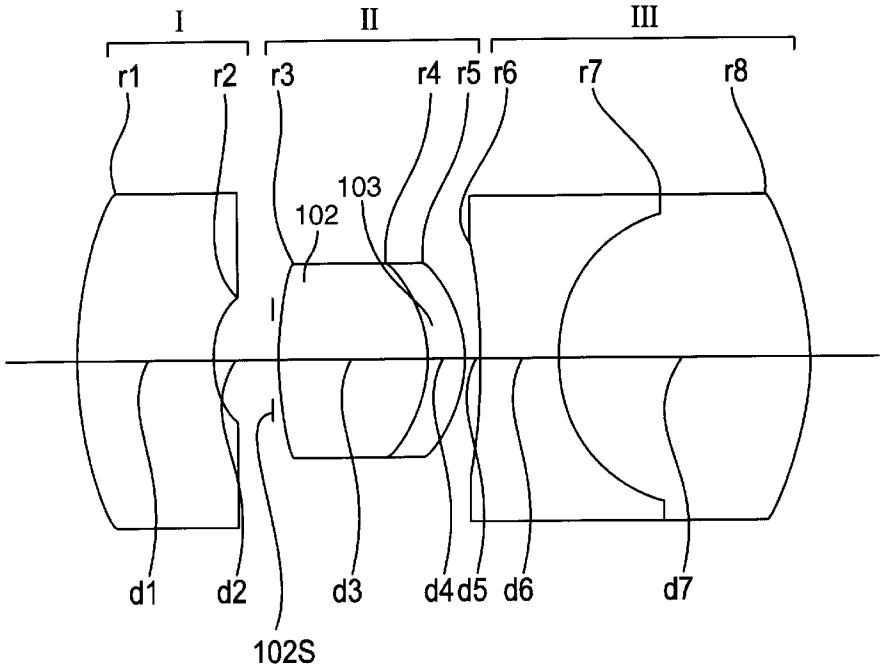

I
II
III
r1
r2
r3
r4
r5
r6
r7
r8
103
102
d1
d2
d3
d4
d5
d6
d7
102S

FIG. 20

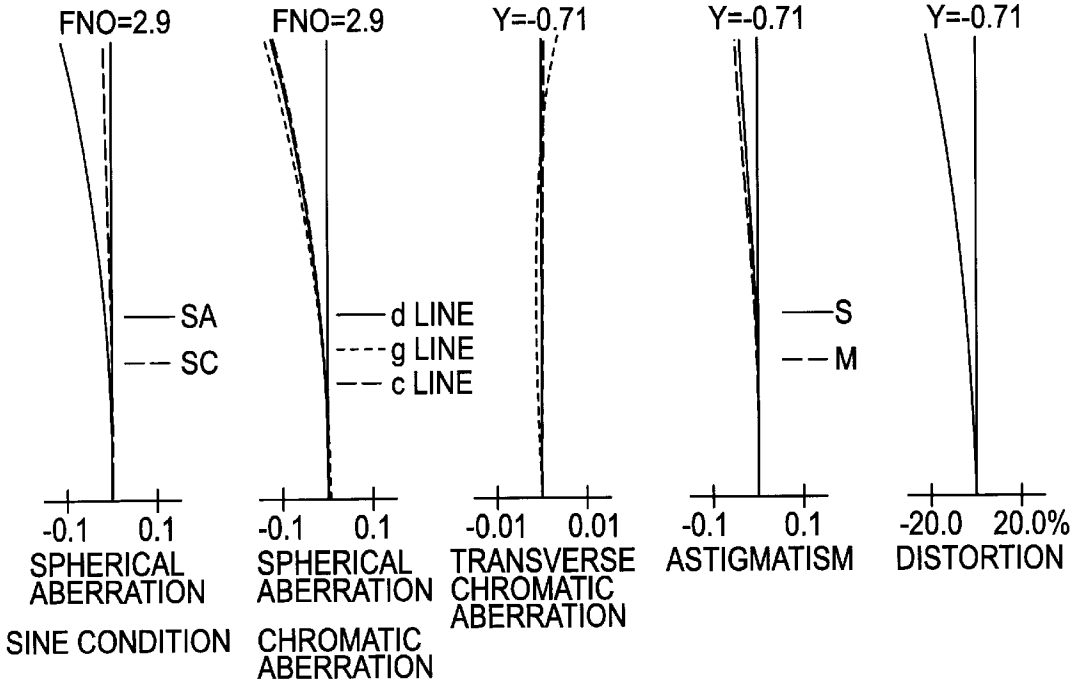

FNO=2.9
SA
SC
-0.1
0.1
SPHERICAL ABERRATION
SINE CONDITION
FNO=2.9
d LINE
g LINE
c LINE
-0.1
0.1
SPHERICAL ABERRATION
CHROMATIC ABERRATION
Y=-0.71
-0.01
0.01
TRANSVERSE CHROMATIC ABERRATION
Y=-0.71
S
M
-0.1
0.1
ASTIGMATISM
Y=-0.71
-20.0
20.0%
DISTORTION

FIG. 21

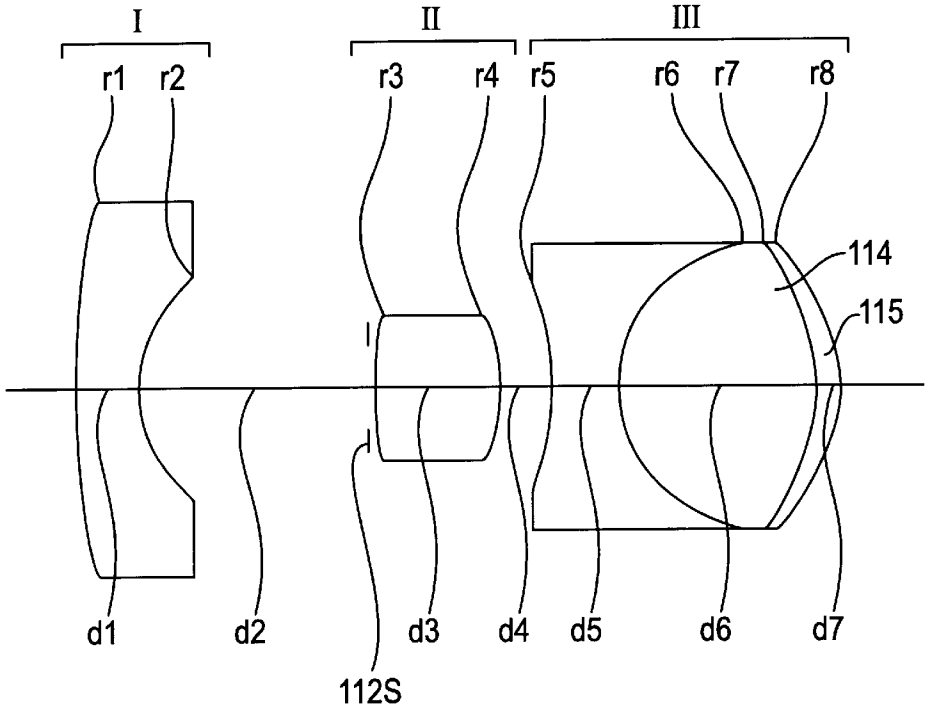

I
II
III
r1
r2
r3
r4
r5
r6
r7
r8
114
115
d1
d2
d3
d4
d5
d6
d7
112S

FIG. 22

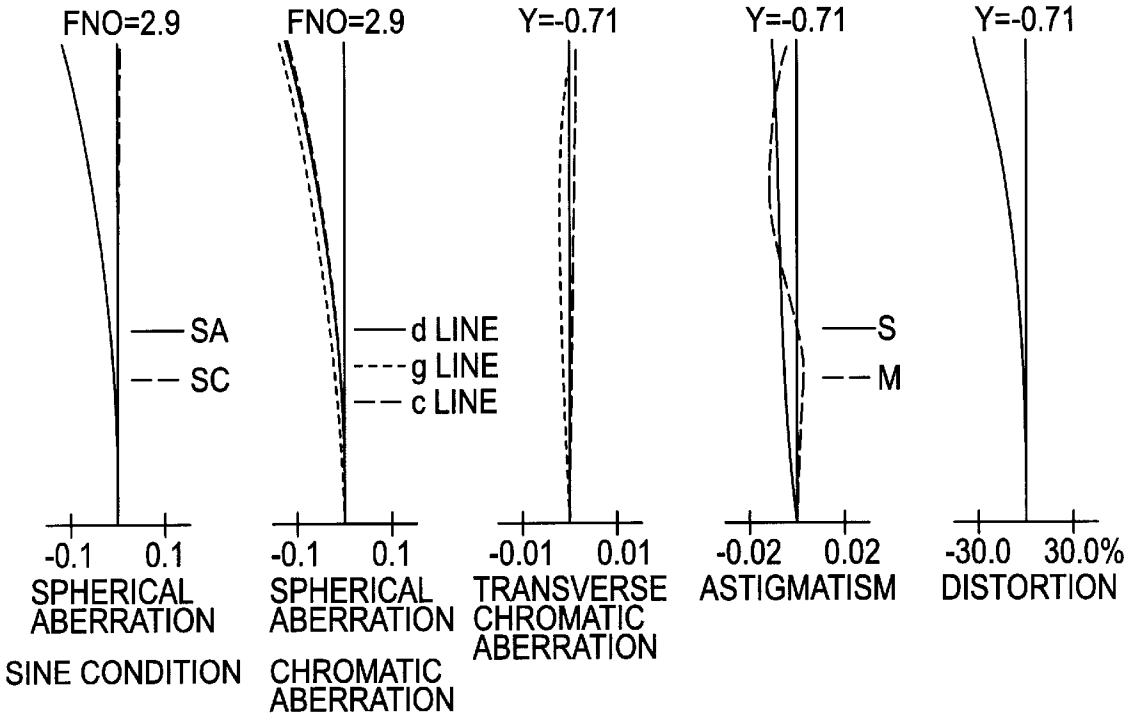

FNO=2.9
SA
SC
-0.1
0.1
SPHERICAL ABERRATION
SINE CONDITION
FNO=2.9
d LINE
g LINE
c LINE
-0.1
0.1
SPHERICAL ABERRATION
CHROMATIC ABERRATION
Y=-0.71
-0.01
0.01
TRANSVERSE CHROMATIC ABERRATION
Y=-0.71
S
M
-0.02
0.02
ASTIGMATISM
Y=-0.71
-30.0
30.0%
DISTORTION

FIG. 23

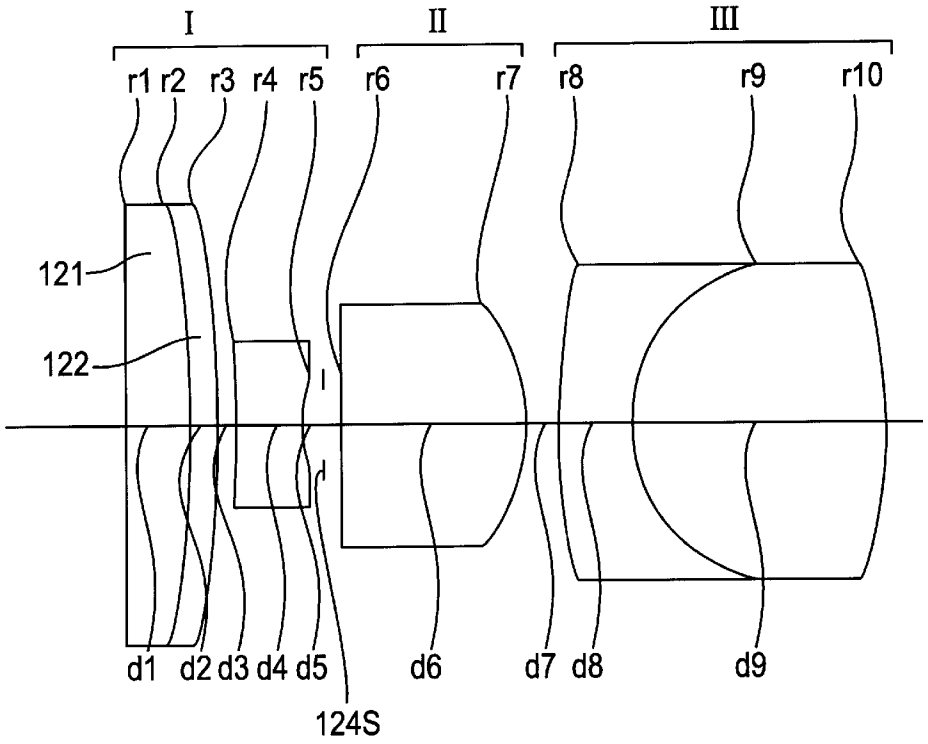

I
II
III
r1 r2 r3 r4 r5 r6 r7 r8 r9 r10
121
122
d1 d2 d3 d4 d5 d6 d7 d8 d9
124S

FIG. 24

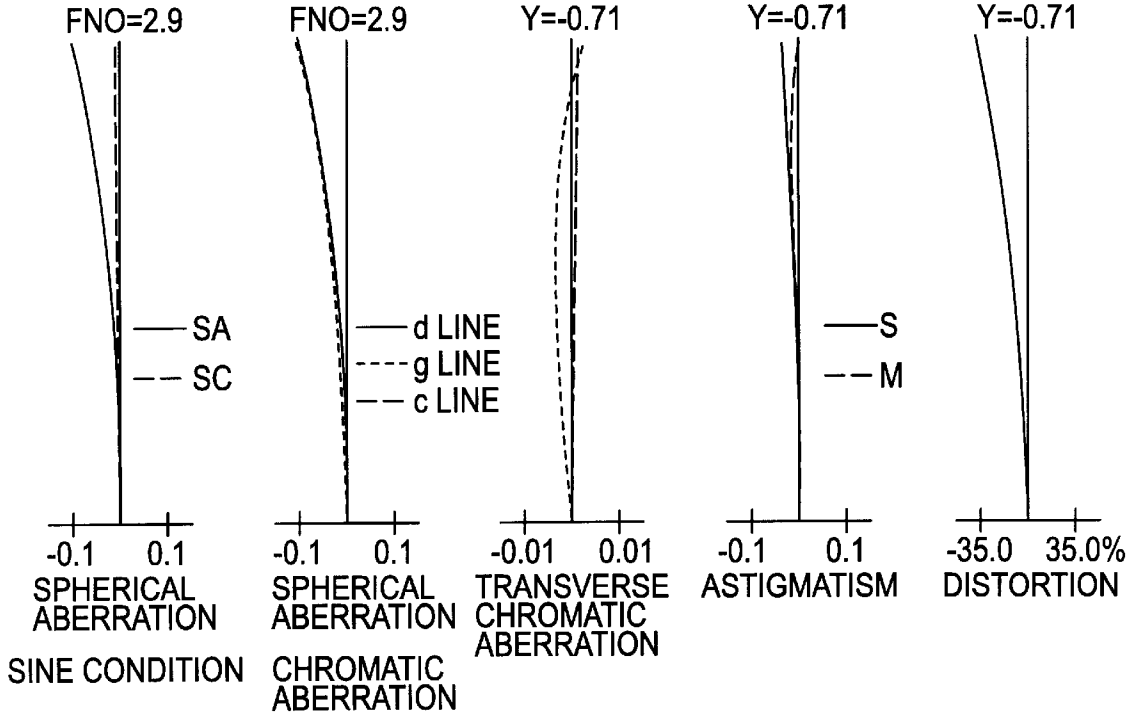

FNO=2.9
SA
SC
-0.1 0.1
SPHERICAL ABERRATION
SINE CONDITION
FNO=2.9
d LINE
g LINE
c LINE
-0.1 0.1
SPHERICAL ABERRATION
CHROMATIC ABERRATION
Y=-0.71
-0.01 0.01
TRANSVERSE CHROMATIC ABERRATION
Y=-0.71
S
M
-0.1 0.1
ASTIGMATISM
Y=-0.71
-35.0 35.0%
DISTORTION

FIG. 25

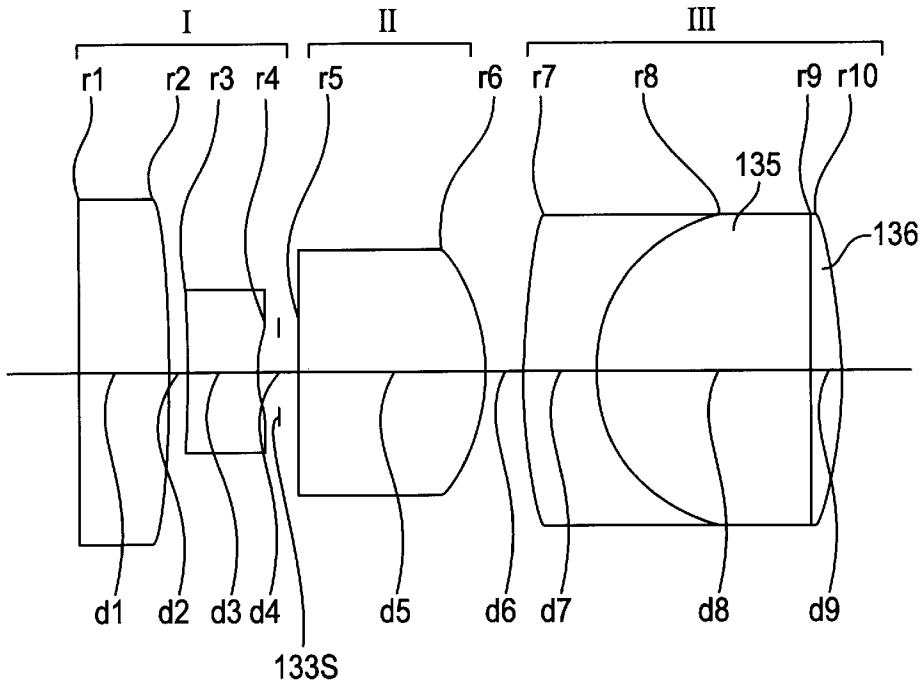

I
II
III
r1
r2
r3
r4
r5
r6
r7
r8
r9
r10
135
136
d1
d2
d3
d4
d5
d6
d7
d8
d9
133S

FIG. 26

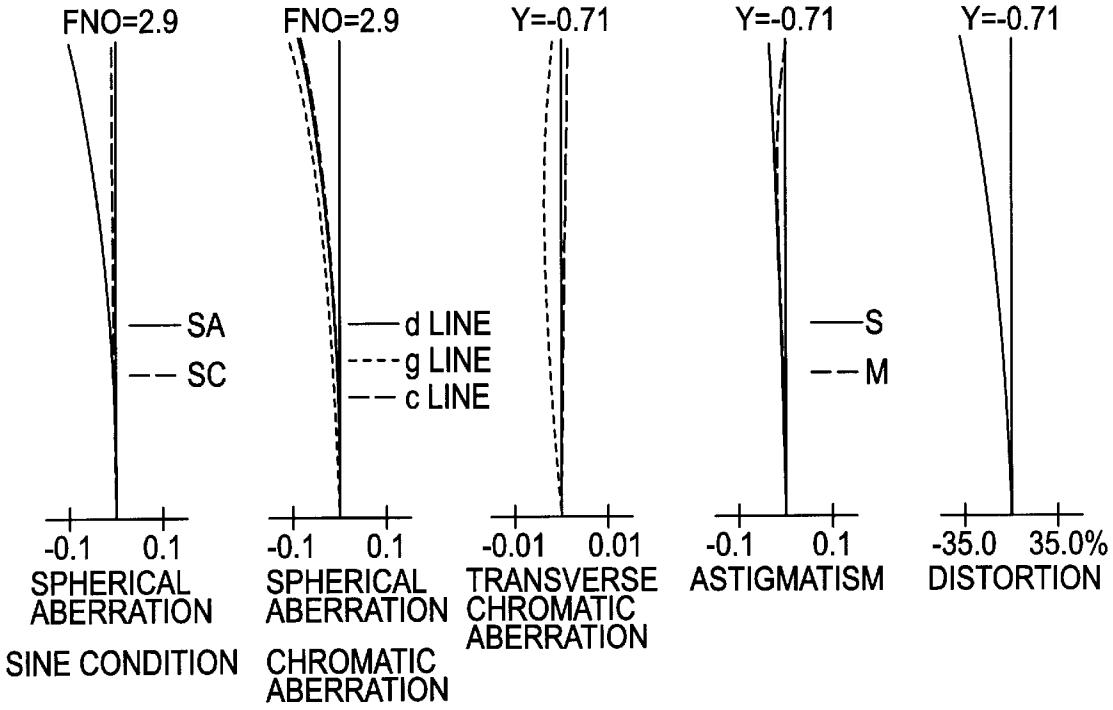

FNO=2.9
SA
SC
-0.1
0.1
SPHERICAL ABERRATION
SINE CONDITION
FNO=2.9
d LINE
g LINE
c LINE
-0.1
0.1
SPHERICAL ABERRATION
CHROMATIC ABERRATION
Y=-0.71
-0.01
0.01
TRANSVERSE CHROMATIC ABERRATION
Y=-0.71
S
M
-0.1
0.1
ASTIGMATISM
Y=-0.71
-35.0
35.0%
DISTORTION

FIG. 27

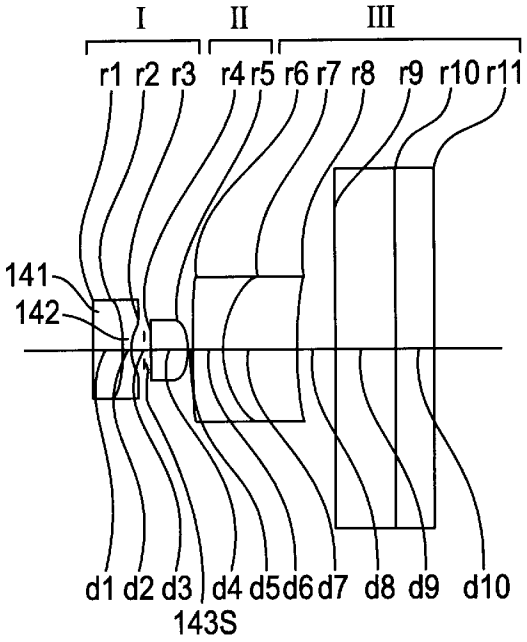

I
II
III
r1 r2 r3 r4 r5 r6 r7 r8 r9 r10 r11
141
142
d1 d2 d3 d4 d5 d6 d7 d8 d9 d10
143S

FIG. 28

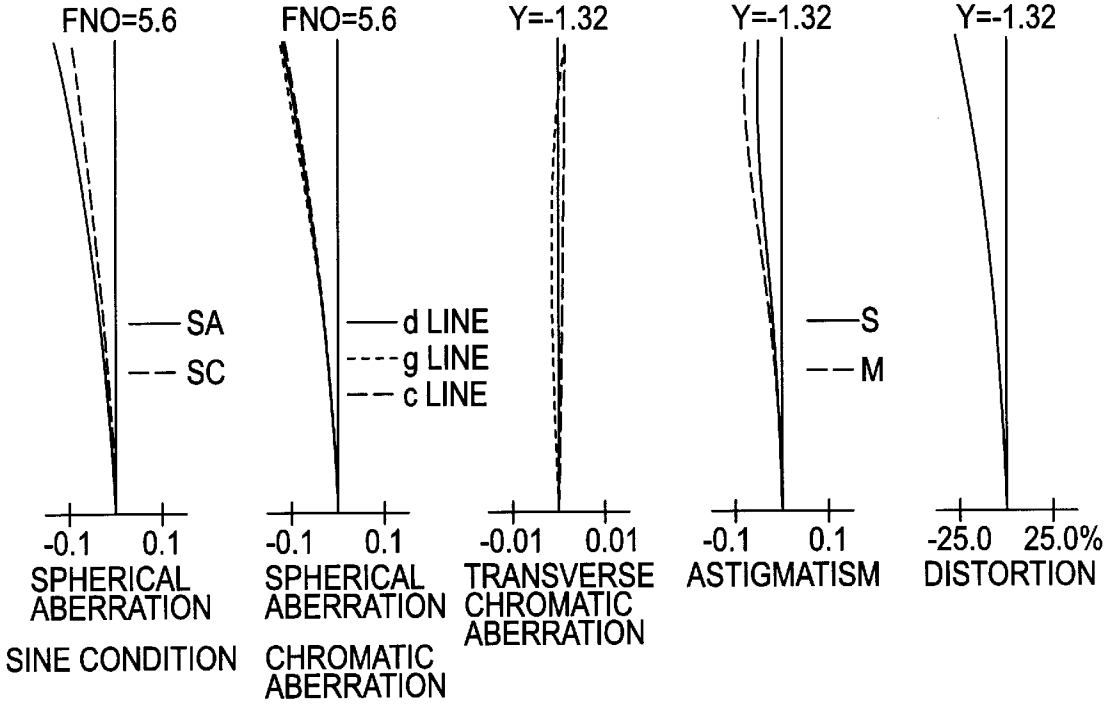

FNO=5.6
SA
SC
-0.1 0.1
SPHERICAL ABERRATION
SINE CONDITION
FNO=5.6
d LINE
g LINE
c LINE
-0.1 0.1
SPHERICAL ABERRATION
CHROMATIC ABERRATION
Y=-1.32
-0.01 0.01
TRANSVERSE CHROMATIC ABERRATION
Y=-1.32
S
M
-0.1 0.1
ASTIGMATISM
Y=-1.32
-25.0 25.0%
DISTORTION

FIG. 29

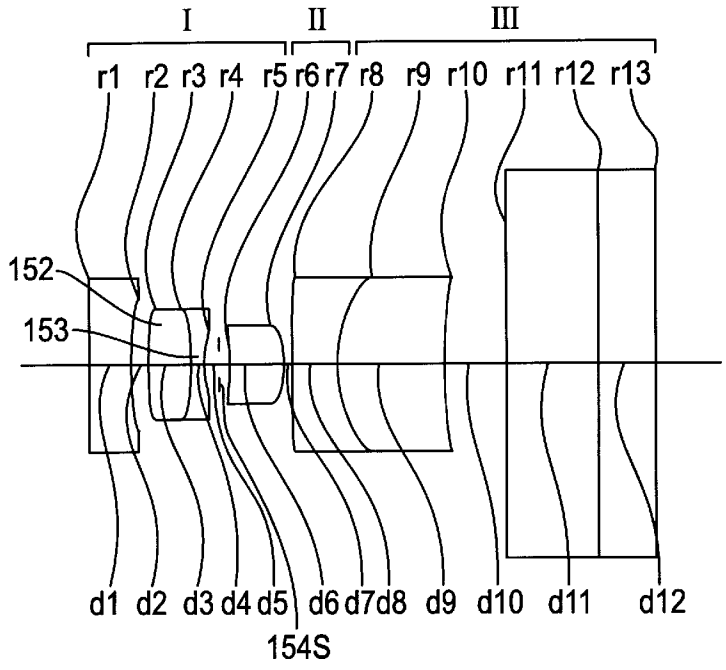

I
II
III
r1 r2 r3 r4 r5 r6 r7 r8 r9 r10 r11 r12 r13
152
153
d1 d2 d3 d4 d5 d6 d7 d8 d9 d10 d11 d12
154S

FIG. 30

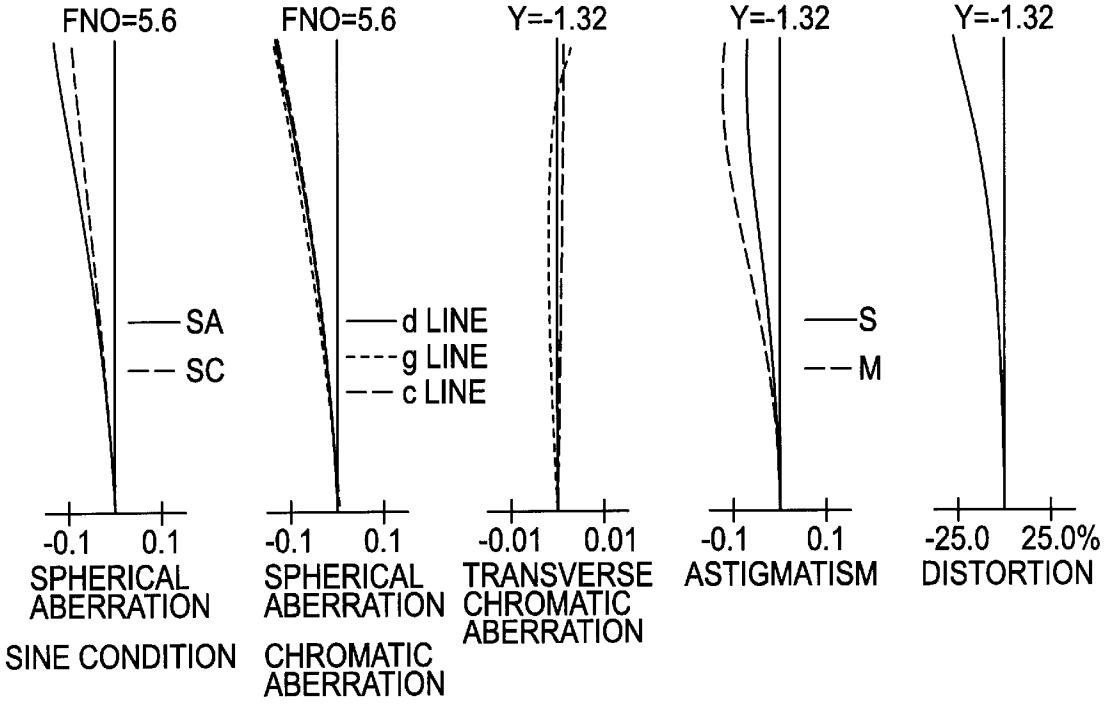

FNO=5.6
SA
SC
-0.1 0.1
SPHERICAL ABERRATION
SINE CONDITION
FNO=5.6
d LINE
g LINE
c LINE
-0.1 0.1
SPHERICAL ABERRATION
CHROMATIC ABERRATION
Y=-1.32
-0.01 0.01
TRANSVERSE CHROMATIC ABERRATION
Y=-1.32
S
M
-0.1 0.1
ASTIGMATISM
Y=-1.32
-25.0 25.0%
DISTORTION

FIG. 31

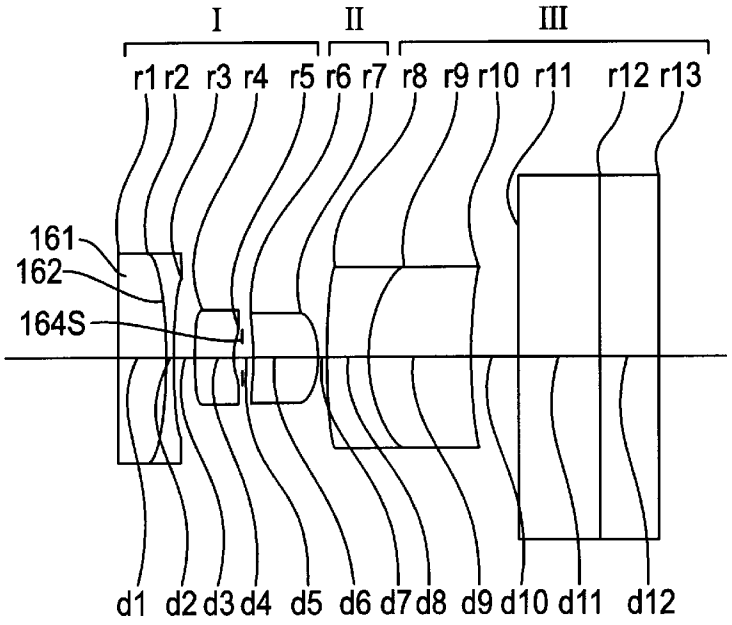

I
II
III
r1 r2 r3 r4 r5 r6 r7 r8 r9 r10 r11 r12 r13
161
162
164S
d1 d2 d3 d4 d5 d6 d7 d8 d9 d10 d11 d12

FIG. 32

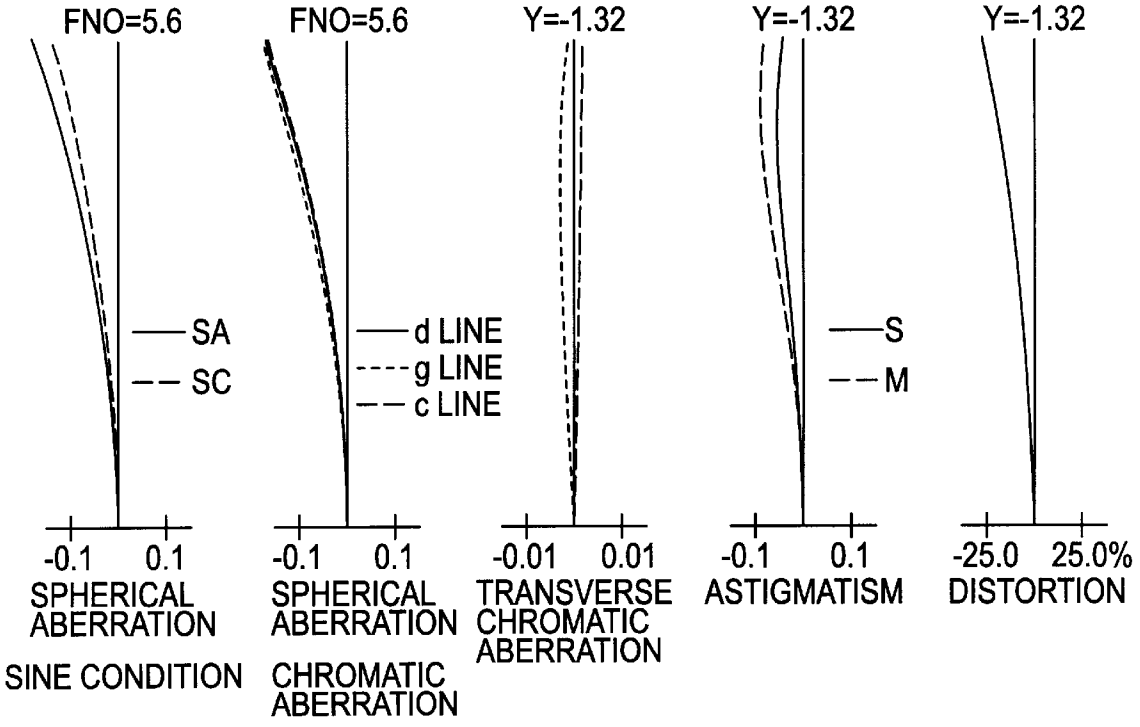

FNO=5.6
SA
SC
-0.1 0.1
SPHERICAL ABERRATION
SINE CONDITION
FNO=5.6
d LINE
g LINE
c LINE
-0.1 0.1
SPHERICAL ABERRATION
CHROMATIC ABERRATION
Y=-1.32
-0.01 0.01
TRANSVERSE CHROMATIC ABERRATION
Y=-1.32
S
M
-0.1 0.1
ASTIGMATISM
Y=-1.32
-25.0 25.0%
DISTORTION

FIG. 33

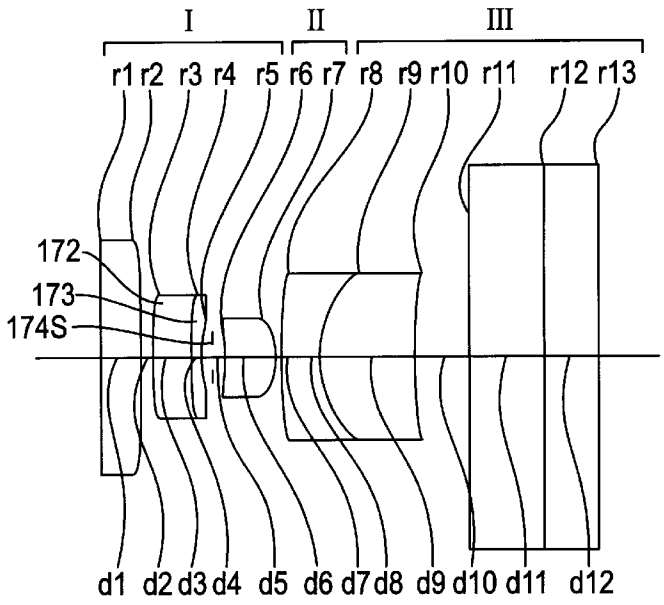

I
II
III
r1 r2 r3 r4 r5 r6 r7 r8 r9 r10 r11 r12 r13
172
173
174S
d1 d2 d3 d4 d5 d6 d7 d8 d9 d10 d11 d12

FIG. 34

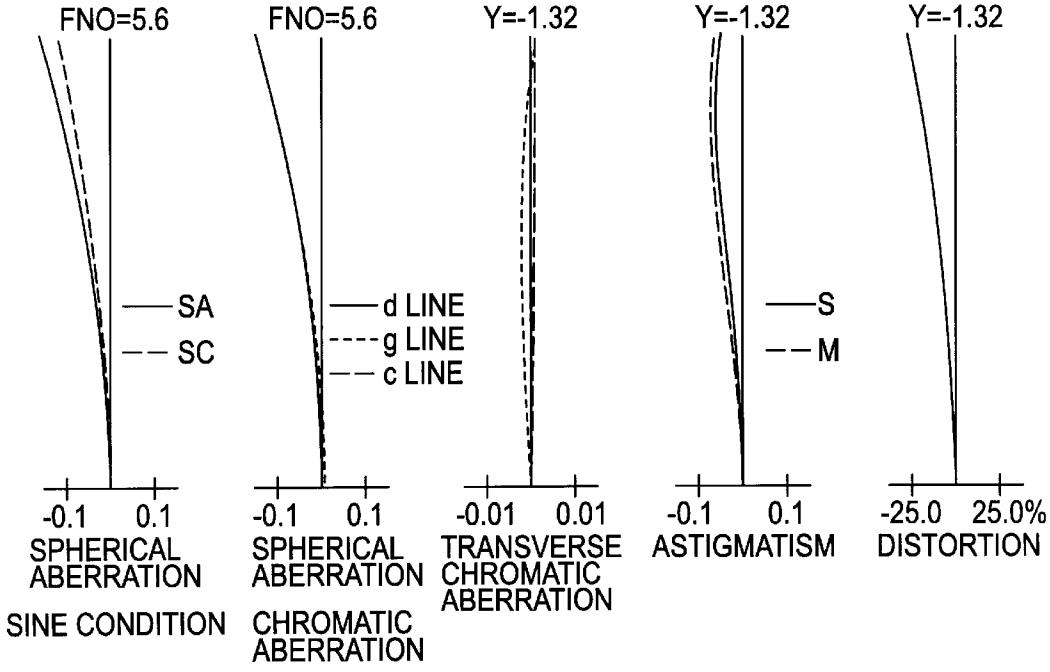

FNO=5.6
SA
SC
-0.1 0.1
SPHERICAL ABERRATION
SINE CONDITION
FNO=5.6
d LINE
g LINE
c LINE
-0.1 0.1
SPHERICAL ABERRATION
CHROMATIC ABERRATION
Y=-1.32
-0.01 0.01
TRANSVERSE CHROMATIC ABERRATION
Y=-1.32
S
M
-0.1 0.1
ASTIGMATISM
Y=-1.32
-25.0 25.0%
DISTORTION

FIG. 35

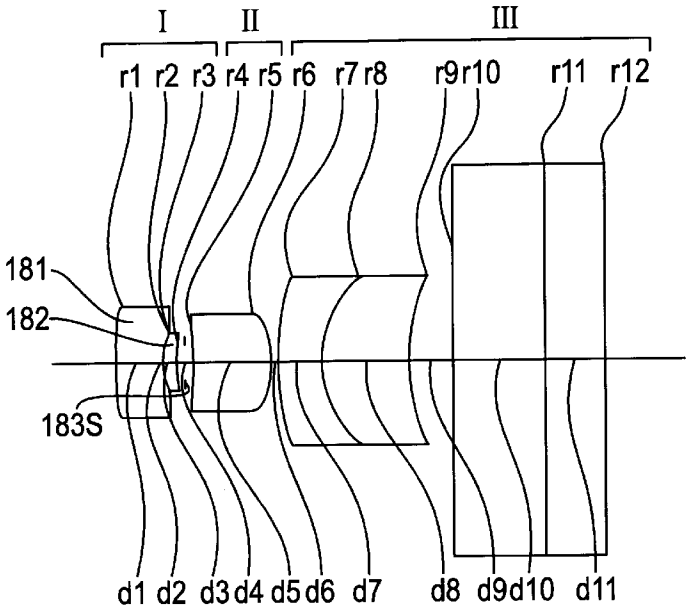

I
II
III
r1 r2 r3 r4 r5 r6 r7 r8 r9 r10 r11 r12
181
182
183S
d1 d2 d3 d4 d5 d6 d7 d8 d9 d10 d11

FIG. 36

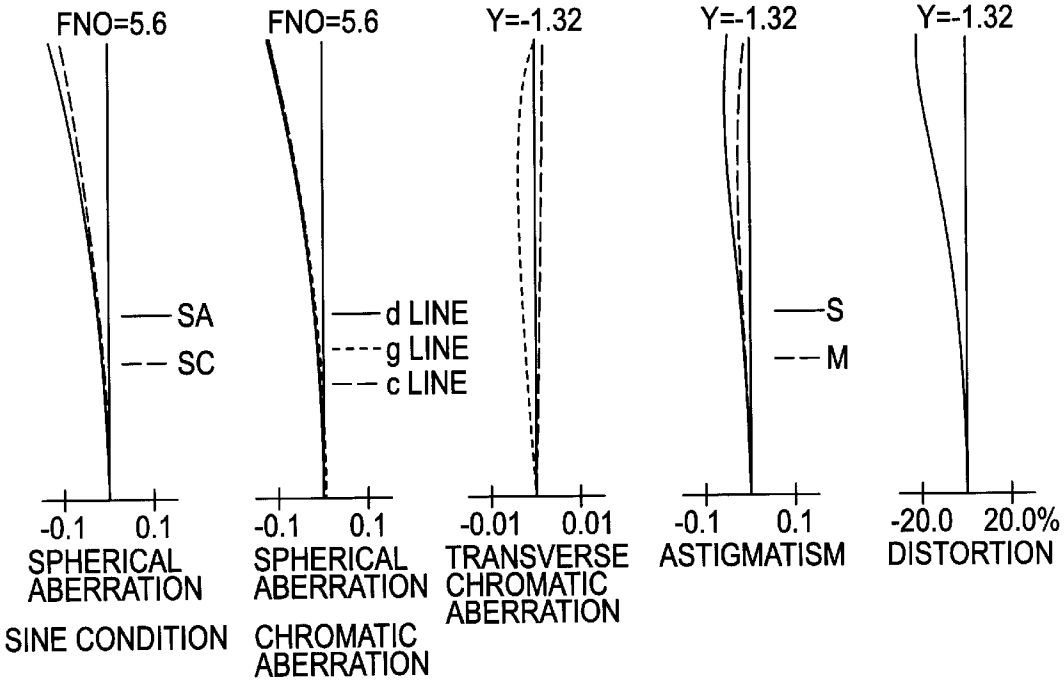

FNO=5.6
SA
SC
-0.1 0.1
SPHERICAL ABERRATION
SINE CONDITION
FNO=5.6
d LINE
g LINE
c LINE
-0.1 0.1
SPHERICAL ABERRATION
CHROMATIC ABERRATION
Y=-1.32
-0.01 0.01
TRANSVERSE CHROMATIC ABERRATION
Y=-1.32
S
M
-0.1 0.1
ASTIGMATISM
Y=-1.32
-20.0 20.0%
DISTORTION

FIG. 37

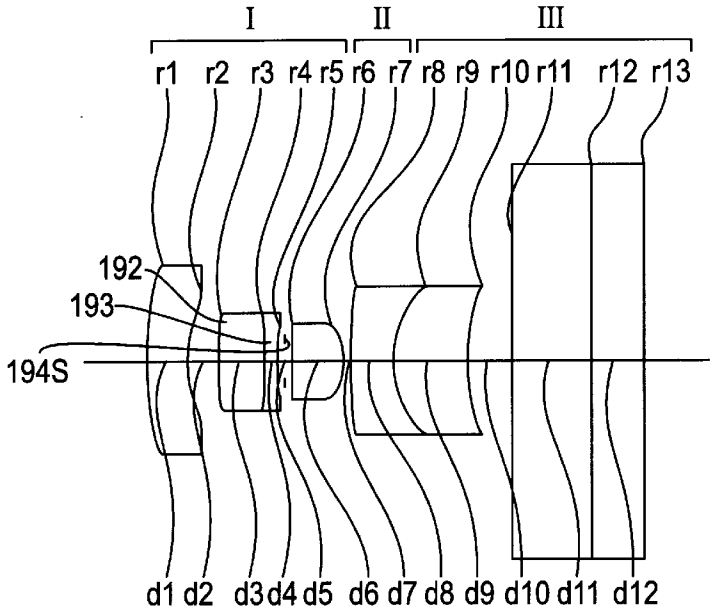

I
II
III
r1 r2 r3 r4 r5 r6 r7 r8 r9 r10 r11 r12 r13
192
193
194S
d1 d2 d3 d4 d5 d6 d7 d8 d9 d10 d11 d12

FIG. 38

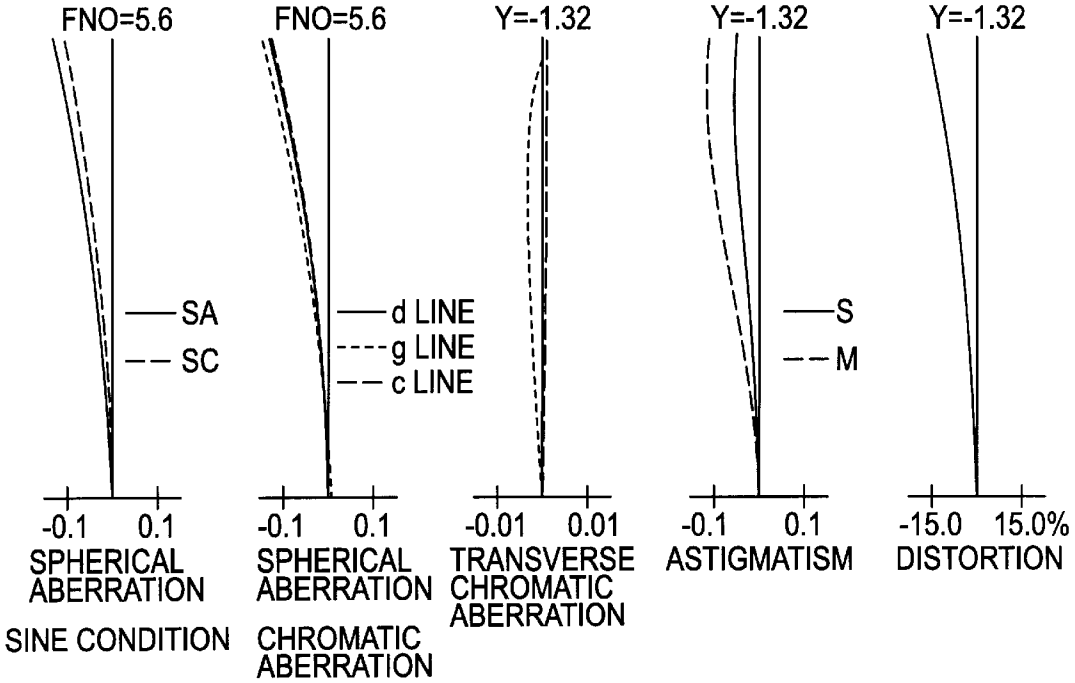

FNO=5.6
SA
SC
-0.1 0.1
SPHERICAL ABERRATION
SINE CONDITION
FNO=5.6
d LINE
g LINE
c LINE
-0.1 0.1
SPHERICAL ABERRATION
CHROMATIC ABERRATION
Y=-1.32
-0.01 0.01
TRANSVERSE CHROMATIC ABERRATION
Y=-1.32
S
M
-0.1 0.1
ASTIGMATISM
Y=-1.32
-15.0 15.0%
DISTORTION

FIG. 39

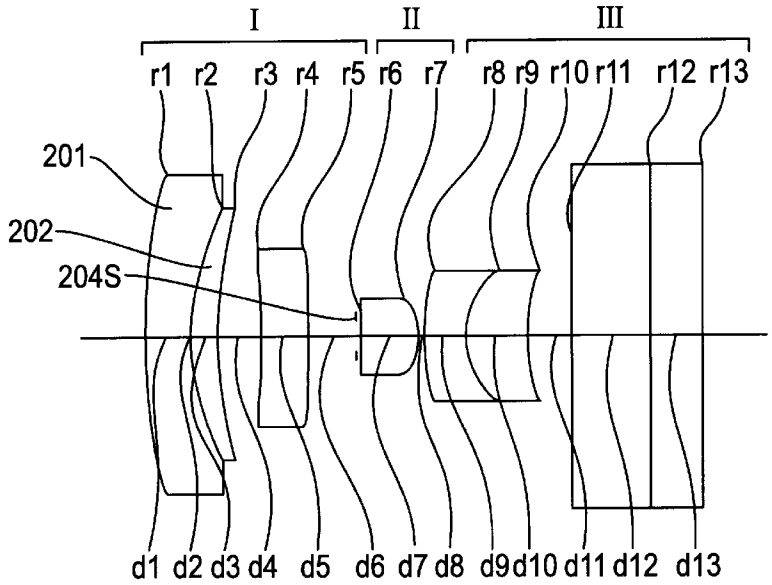

I
II
III
r1 r2 r3 r4 r5 r6 r7 r8 r9 r10 r11 r12 r13
201
202
204S
d1 d2 d3 d4 d5 d6 d7 d8 d9 d10 d11 d12 d13

FIG. 40

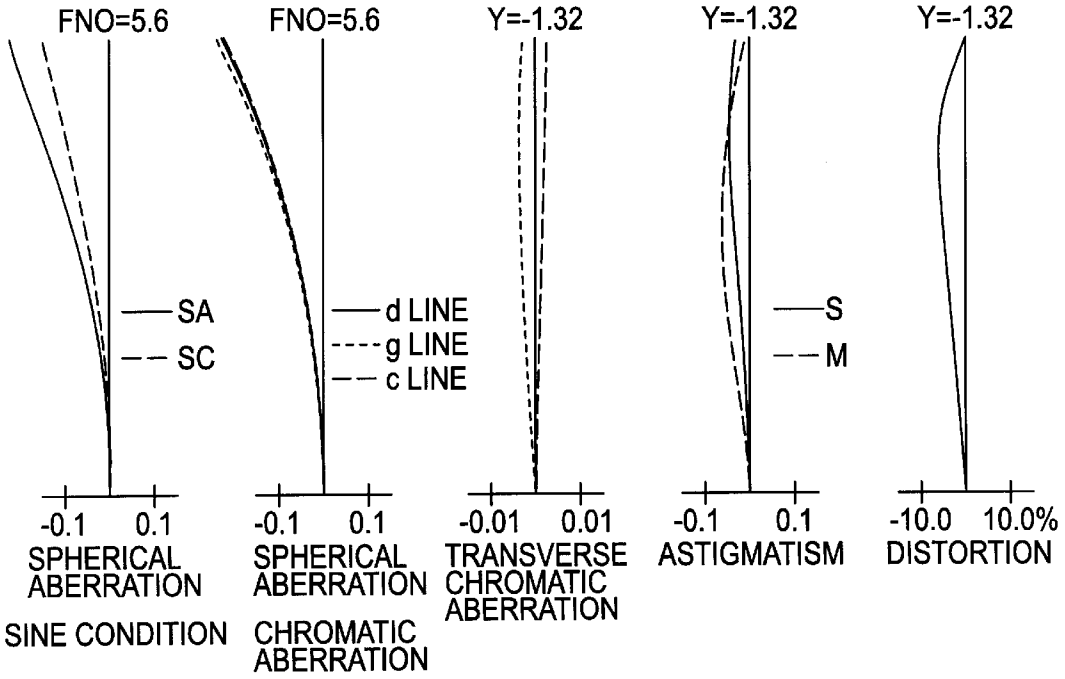

FNO=5.6
SA
SC
-0.1 0.1
SPHERICAL ABERRATION
SINE CONDITION
FNO=5.6
d LINE
g LINE
c LINE
-0.1 0.1
SPHERICAL ABERRATION
CHROMATIC ABERRATION
Y=-1.32
-0.01 0.01
TRANSVERSE CHROMATIC ABERRATION
Y=-1.32
S
M
-0.1 0.1
ASTIGMATISM
Y=-1.32
-10.0 10.0%
DISTORTION

FIG. 41

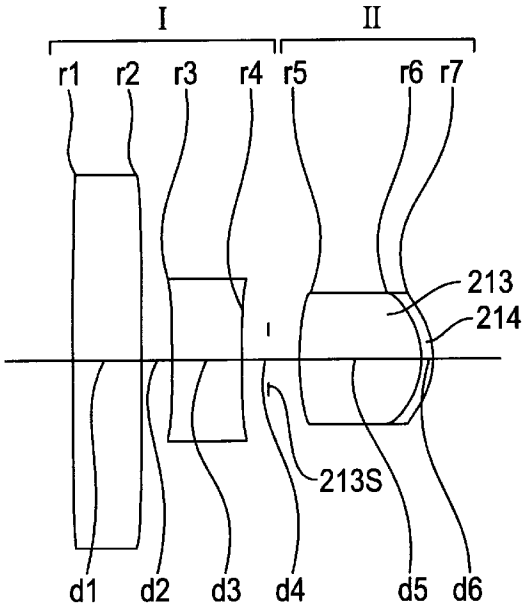

I
II
r1
r2
r3
r4
r5
r6
r7
213
214
213S
d1
d2
d3
d4
d5
d6

FIG. 42

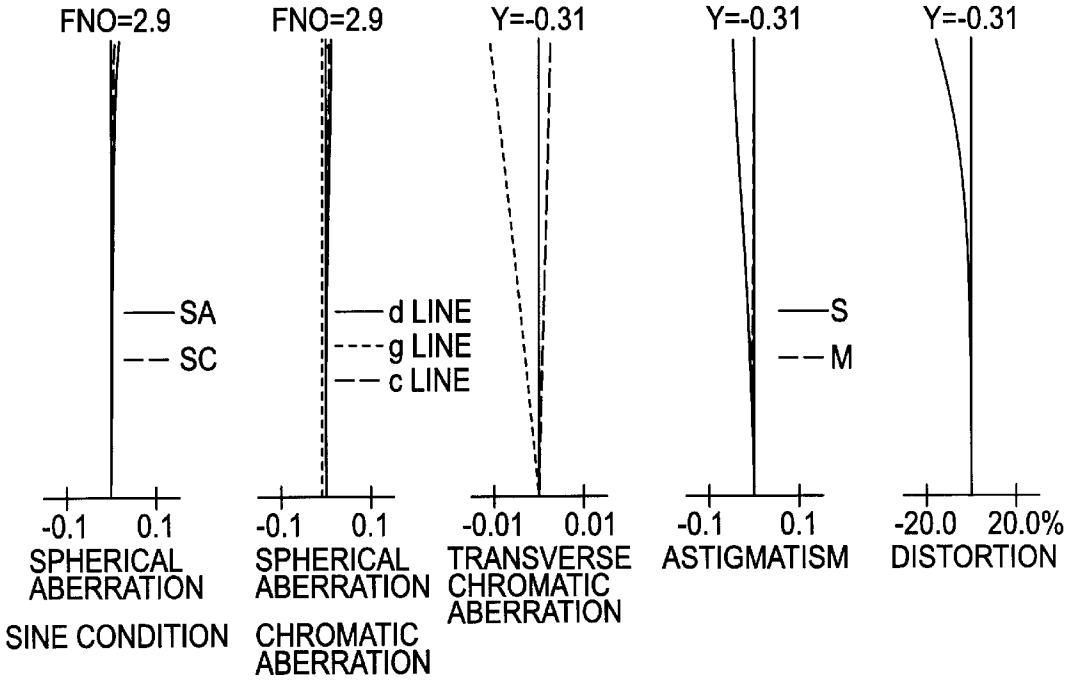

FNO=2.9
SA
SC
-0.1
0.1
SPHERICAL ABERRATION
SINE CONDITION
FNO=2.9
d LINE
g LINE
c LINE
-0.1
0.1
SPHERICAL ABERRATION
CHROMATIC ABERRATION
Y=-0.31
-0.01
0.01
TRANSVERSE CHROMATIC ABERRATION
Y=-0.31
S
M
-0.1
0.1
ASTIGMATISM
Y=-0.31
-20.0
20.0%
DISTORTION

FIG. 43

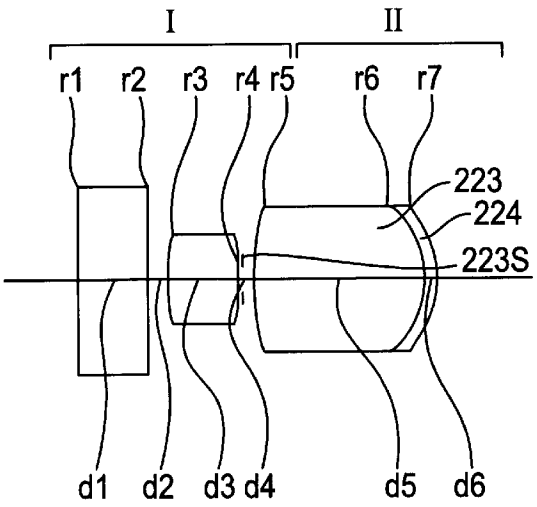

I
II
r1
r2
r3
r4
r5
r6
r7
223
224
223S
d1
d2
d3
d4
d5
d6

FIG. 44

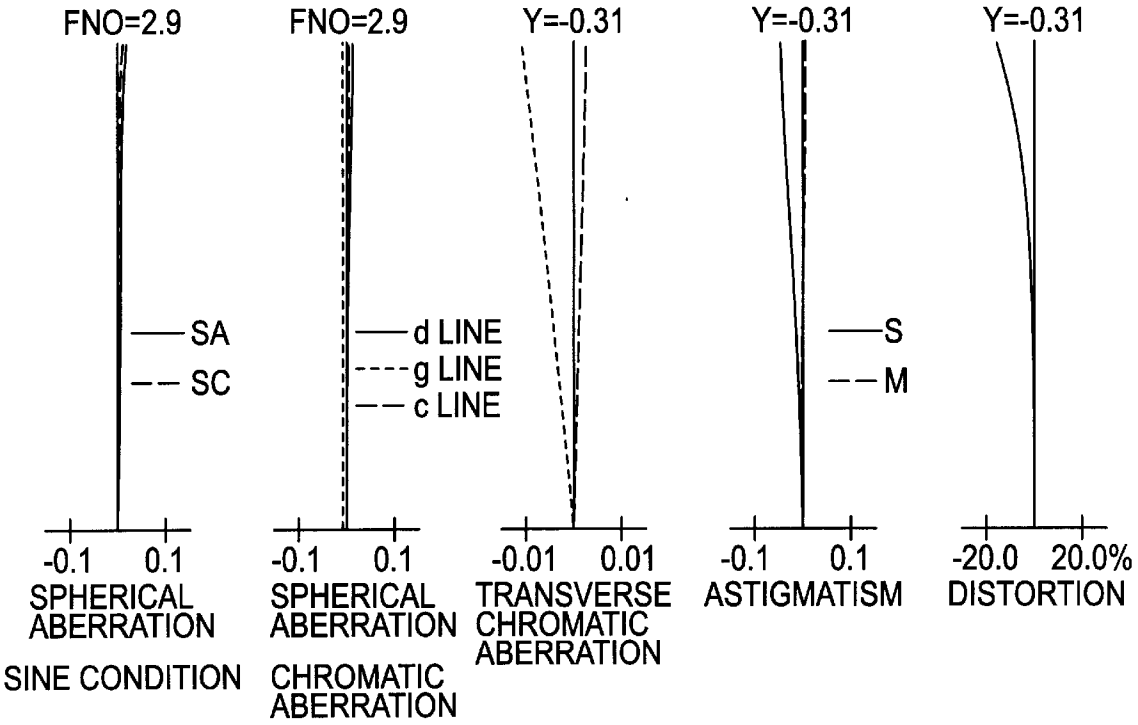

FNO=2.9
SA
SC
-0.1
0.1
SPHERICAL ABERRATION
SINE CONDITION
FNO=2.9
d LINE
g LINE
c LINE
-0.1
0.1
SPHERICAL ABERRATION
CHROMATIC ABERRATION
Y=-0.31
-0.01
0.01
TRANSVERSE CHROMATIC ABERRATION
Y=-0.31
S
M
-0.1
0.1
ASTIGMATISM
Y=-0.31
-20.0
20.0%
DISTORTION

FIG. 45

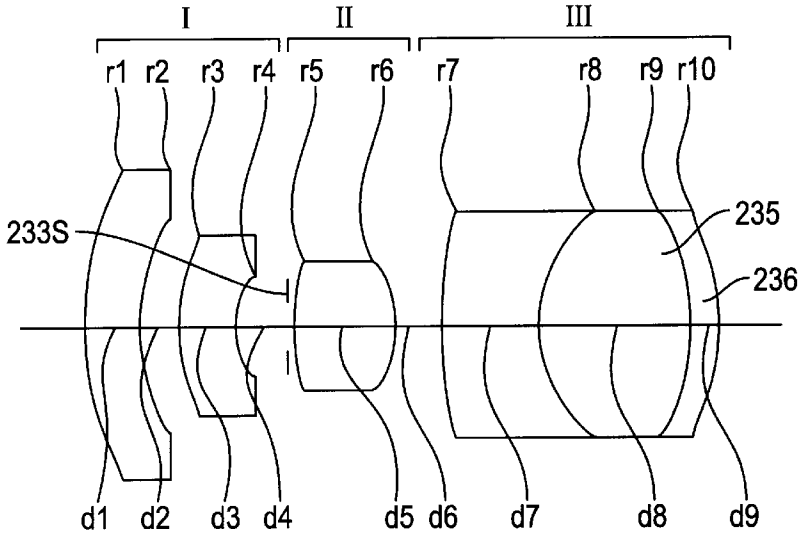

I
II
III
r1 r2 r3 r4 r5 r6 r7 r8 r9 r10
233S
235
236
d1 d2 d3 d4 d5 d6 d7 d8 d9

FIG. 46

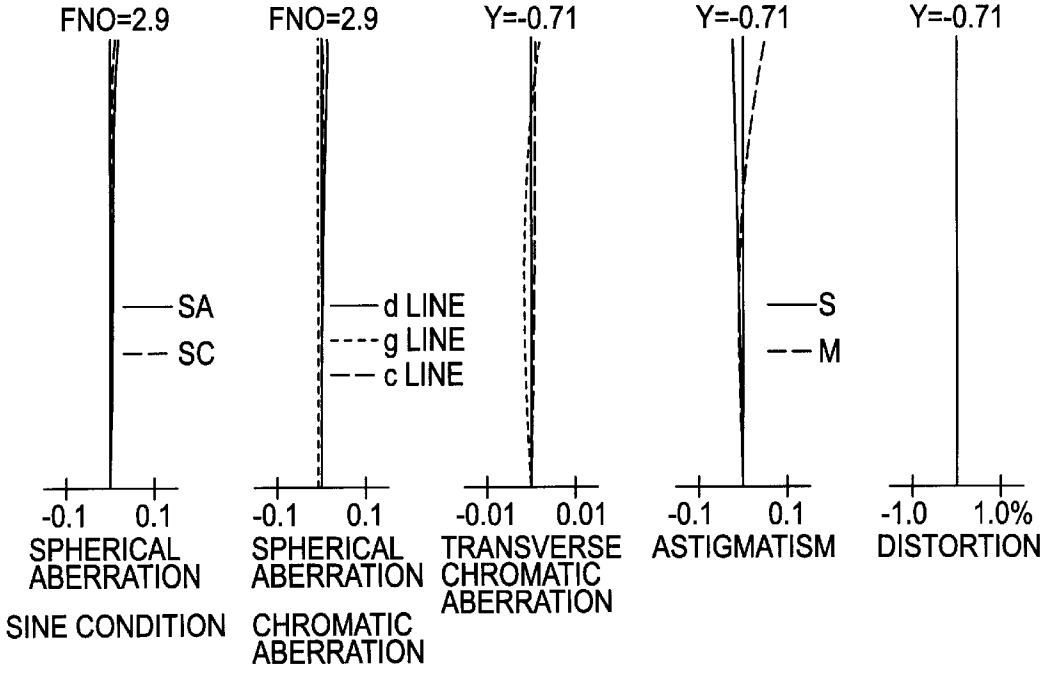

FNO=2.9
SA
SC
-0.1 0.1
SPHERICAL ABERRATION
SINE CONDITION
FNO=2.9
d LINE
g LINE
c LINE
-0.1 0.1
SPHERICAL ABERRATION
CHROMATIC ABERRATION
Y=-0.71
-0.01 0.01
TRANSVERSE CHROMATIC ABERRATION
Y=-0.71
S
M
-0.1 0.1
ASTIGMATISM
Y=-0.71
-1.0 1.0%
DISTORTION

FIG. 47

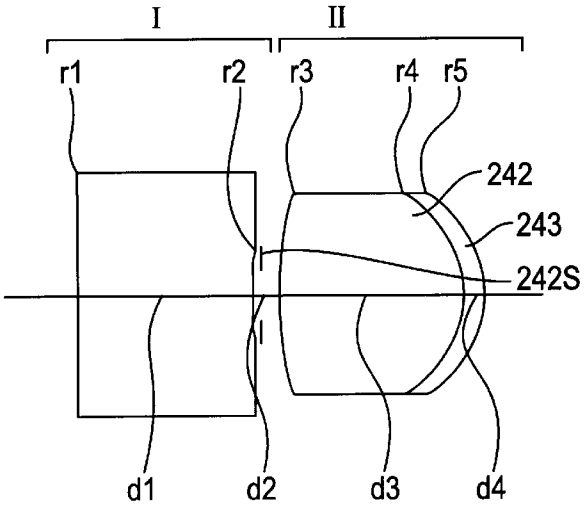

I
II
r1
r2
r3
r4
r5
242
243
242S
d1
d2
d3
d4

FIG. 48

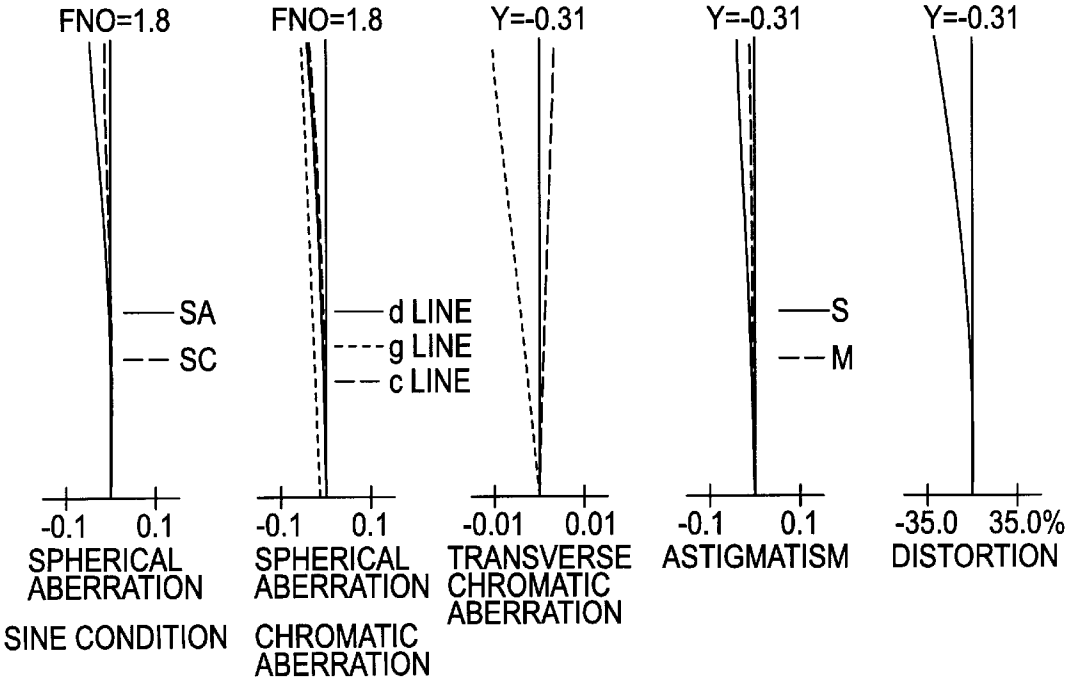

FNO=1.8
SA
SC
-0.1
0.1
SPHERICAL ABERRATION
SINE CONDITION
FNO=1.8
d LINE
g LINE
c LINE
-0.1
0.1
SPHERICAL ABERRATION
CHROMATIC ABERRATION
Y=-0.31
-0.01
0.01
TRANSVERSE CHROMATIC ABERRATION
Y=-0.31
S
M
-0.1
0.1
ASTIGMATISM
Y=-0.31
-35.0
35.0%
DISTORTION

FIG. 49

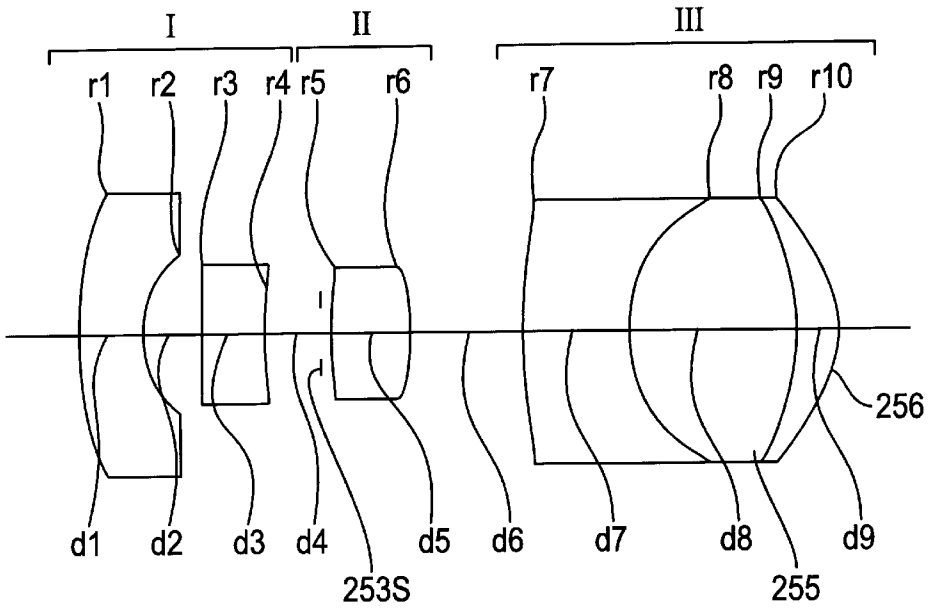
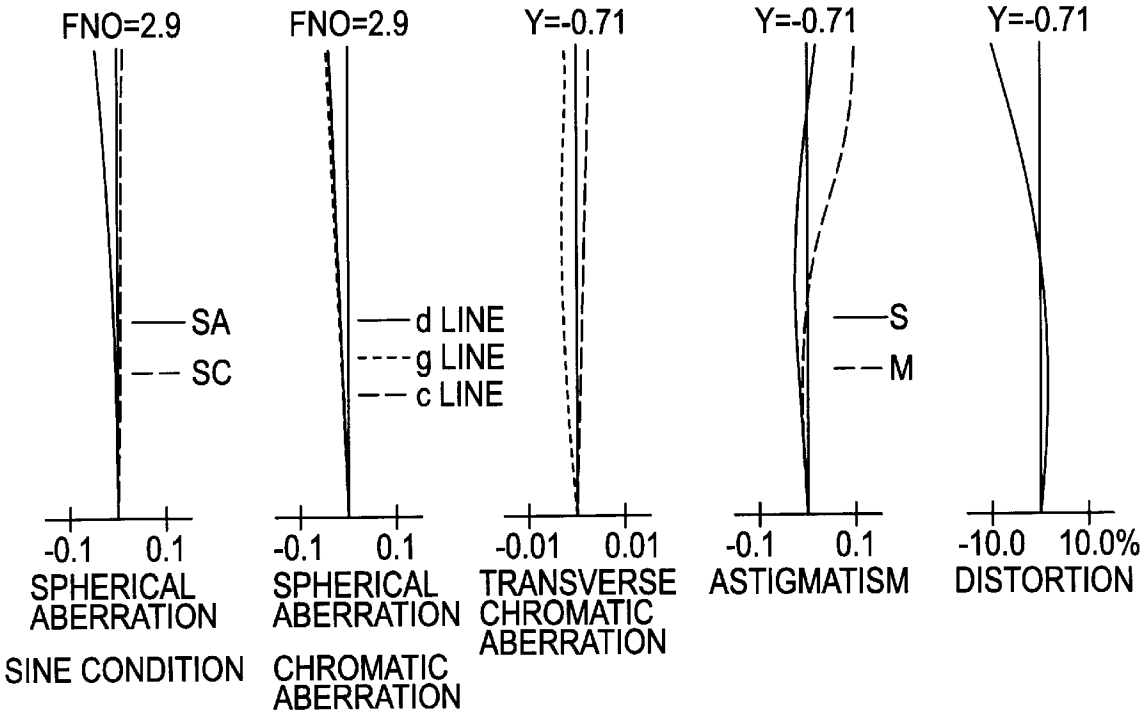

I
II
III
r1
r2
r3
r4
r5
r6
r7
r8
r9
r10
256
d1
d2
d3
d4
d5
d6
d7
d8
d9
253S
255

FIG. 50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SA
SC
-0.1
0.1
SPHERICAL ABERRATION
SINE CONDITION
FNO=2.9
d LINE
g LINE
c LINE
-0.1
0.1
SPHERICAL ABERRATION
CHROMATIC ABERRATION
Y=-0.71
-0.01
0.01
TRANSVERSE CHROMATIC ABERRATION
Y=-0.71
S
M
-0.1
0.1
ASTIGMATISM
Y=-0.71
-10.0
10.0%
DISTORTION

FIG. 51

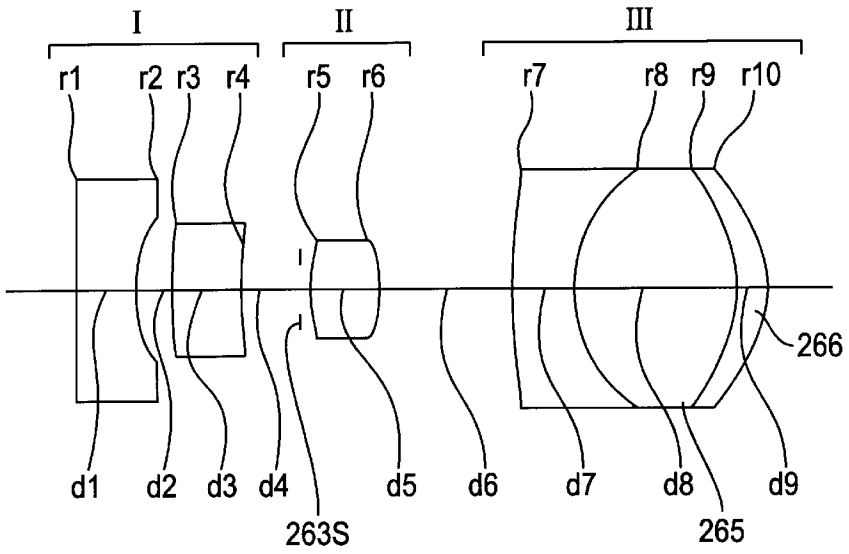

I
II
III
r1
r2
r3
r4
r5
r6
r7
r8
r9
r10
266
d1
d2
d3
d4
d5
d6
d7
d8
d9
263S
265

FIG. 52

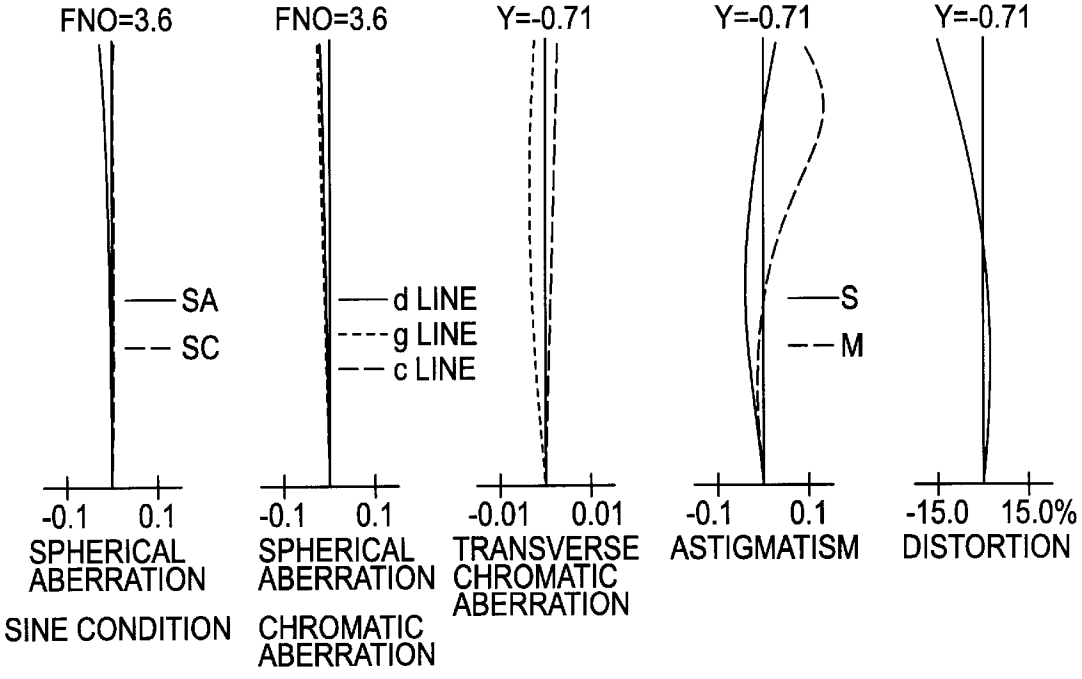

FNO=3.6
SA
SC
-0.1
0.1
SPHERICAL ABERRATION
SINE CONDITION
FNO=3.6
d LINE
g LINE
c LINE
-0.1
0.1
SPHERICAL ABERRATION
CHROMATIC ABERRATION
Y=-0.71
-0.01
0.01
TRANSVERSE CHROMATIC ABERRATION
Y=-0.71
S
M
-0.1
0.1
ASTIGMATISM
Y=-0.71
-15.0
15.0%
DISTORTION

FIG. 53

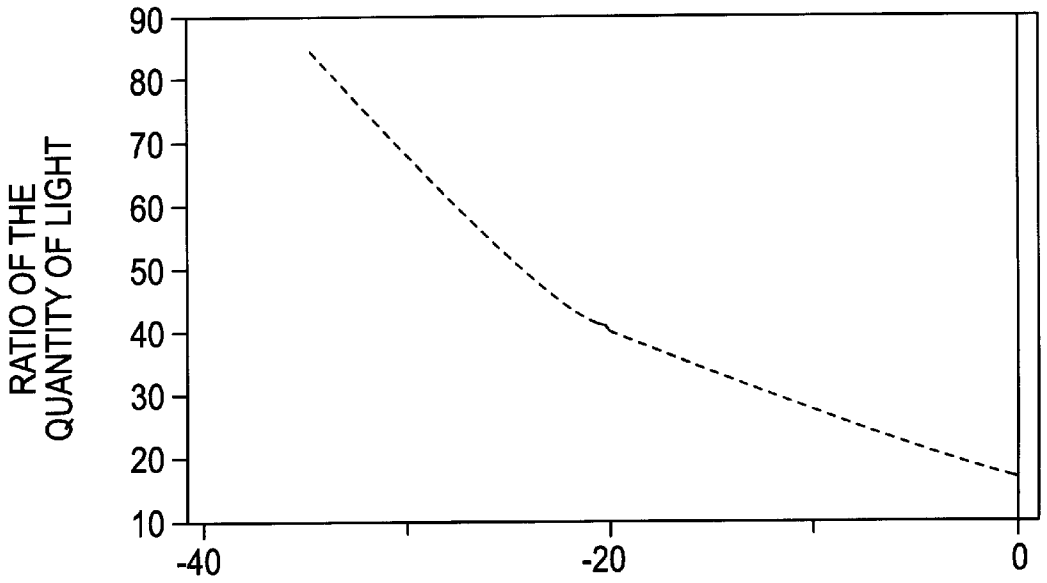


FIG. 54

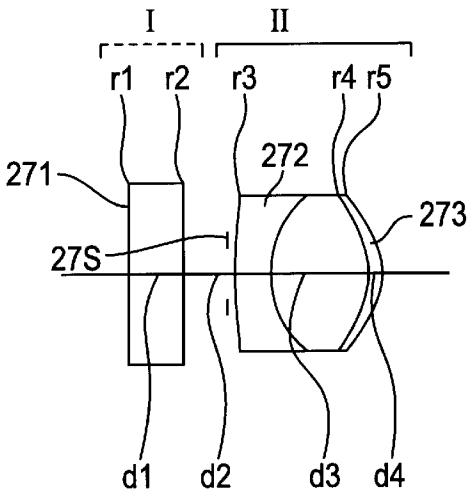

I
II
r1
r2
r3
r4
r5
271
272
273
27S
d1
d2
d3
d4

FIG. 55

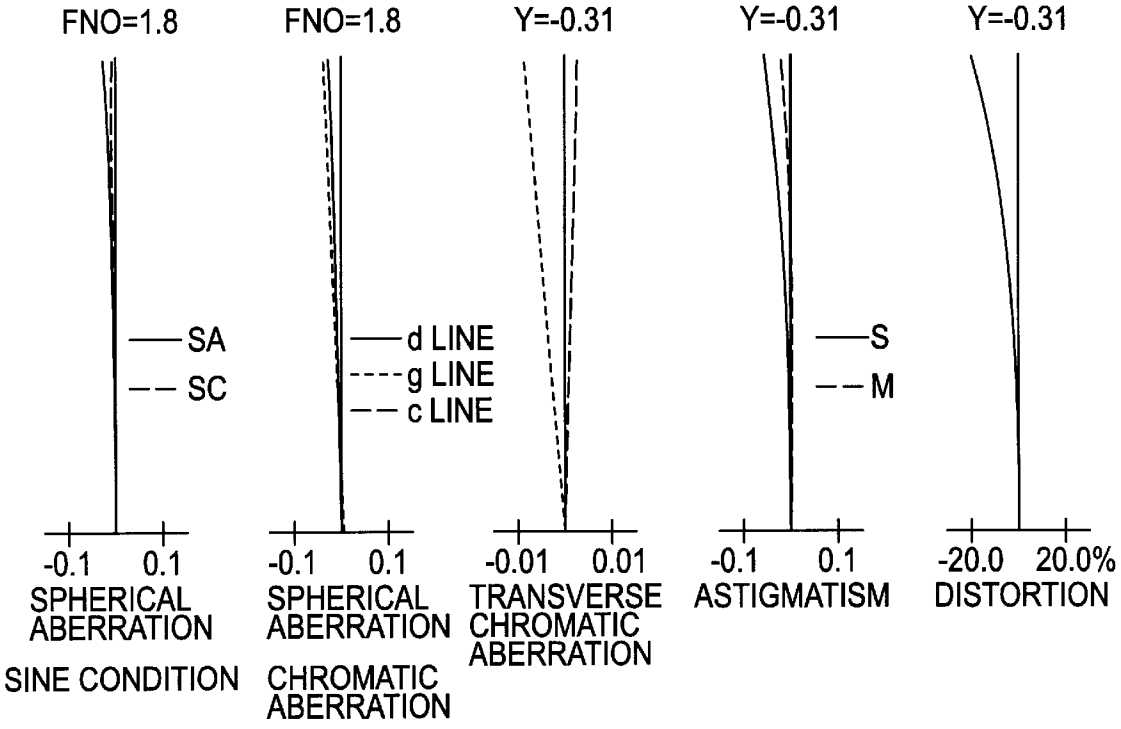

FNO=1.8
FNO=1.8
Y=-0.31
Y=-0.31
Y=-0.31
SA
SC
d LINE
g LINE
c LINE
S
M
-0.1
0.1
-0.01
0.01
-20.0
20.0%
SPHERICAL ABERRATION
SINE CONDITION
SPHERICAL ABERRATION
CHROMATIC ABERRATION
TRANSVERSE CHROMATIC ABERRATION
ASTIGMATISM
DISTORTION

FIG. 56

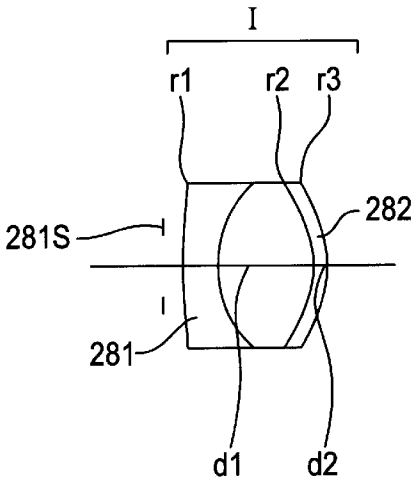

I
r1
r2
r3
281S
282
I
281
d1
d2

FIG. 57

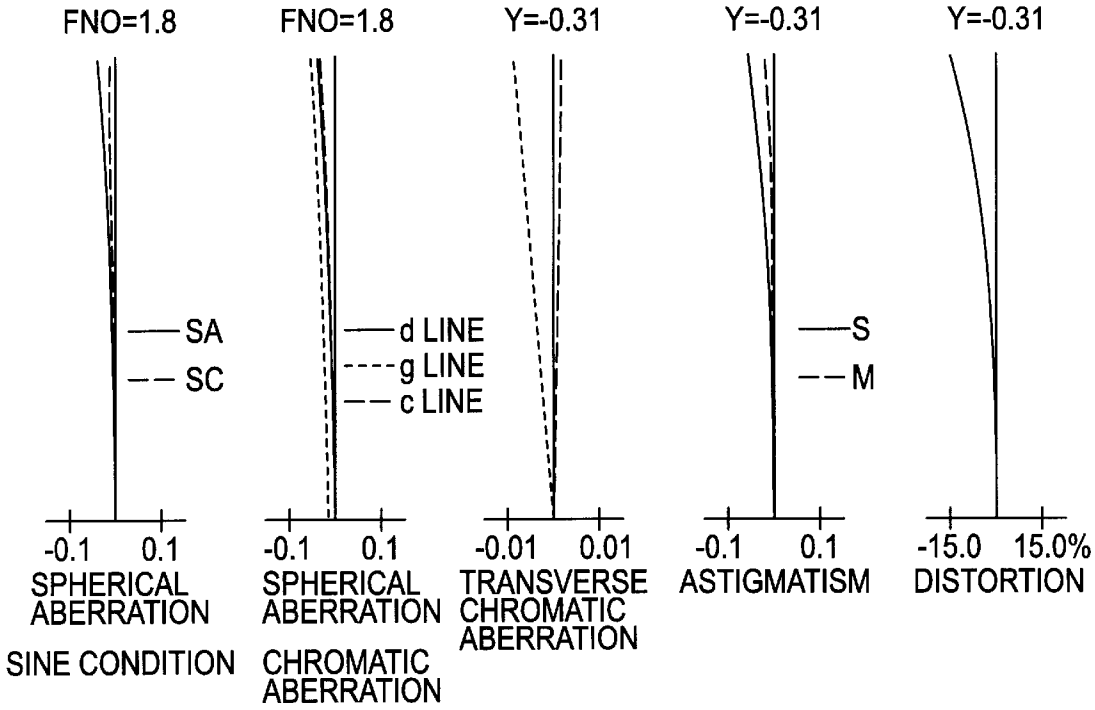

FNO=1.8
FNO=1.8
Y=-0.31
Y=-0.31
Y=-0.31
SA
SC
d LINE
g LINE
c LINE
S
M
-0.1
0.1
-0.1
0.1
-0.01
0.01
-0.1
0.1
-15.0
15.0%
SPHERICAL ABERRATION
SINE CONDITION
SPHERICAL ABERRATION
CHROMATIC ABERRATION
TRANSVERSE CHROMATIC ABERRATION
ASTIGMATISM
DISTORTION

FIG. 58

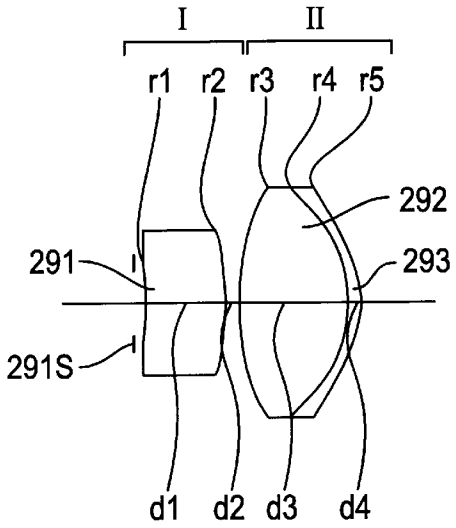

I
II
r1
r2
r3
r4
r5
292
291
293
291S
d1
d2
d3
d4

FIG. 59

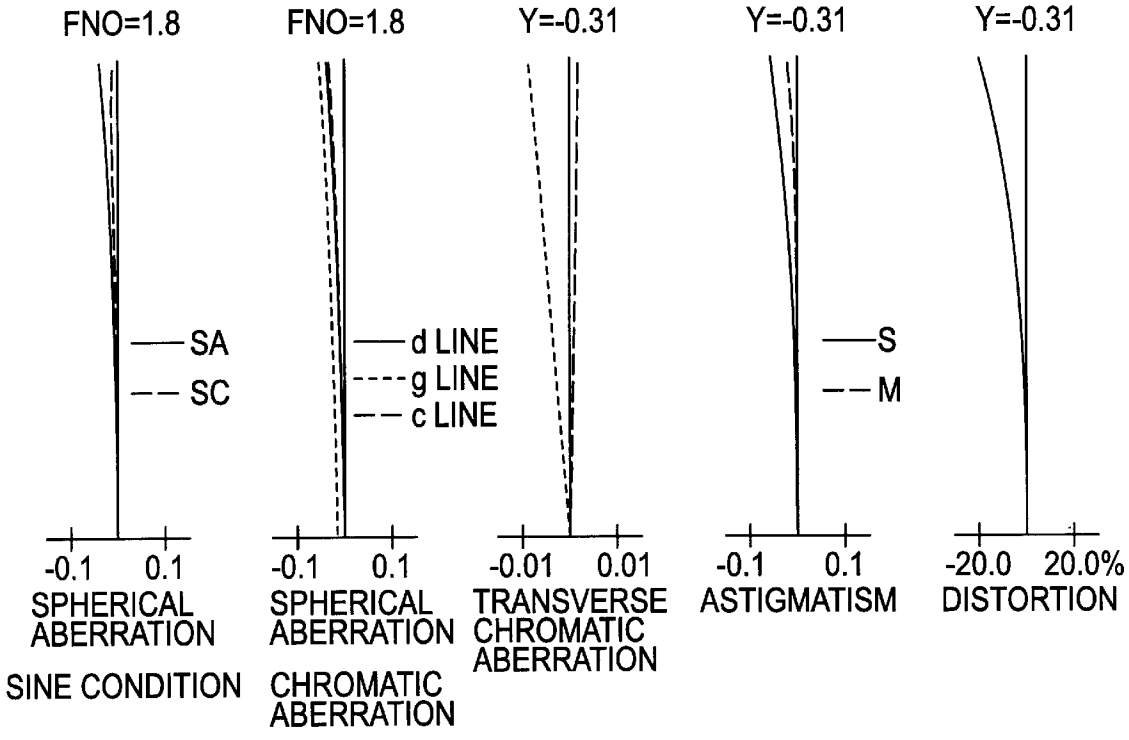

FNO=1.8
SA
SC
-0.1
0.1
SPHERICAL ABERRATION
SINE CONDITION
FNO=1.8
d LINE
g LINE
c LINE
-0.1
0.1
SPHERICAL ABERRATION
CHROMATIC ABERRATION
Y=-0.31
-0.01
0.01
TRANSVERSE CHROMATIC ABERRATION
Y=-0.31
S
M
-0.1
0.1
ASTIGMATISM
Y=-0.31
-20.0
20.0%
DISTORTION

FIG. 60

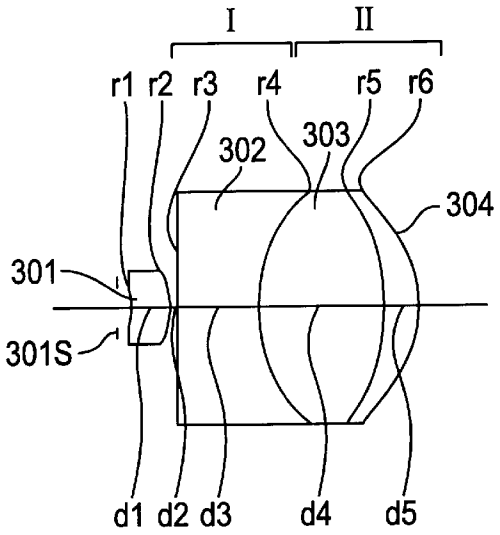
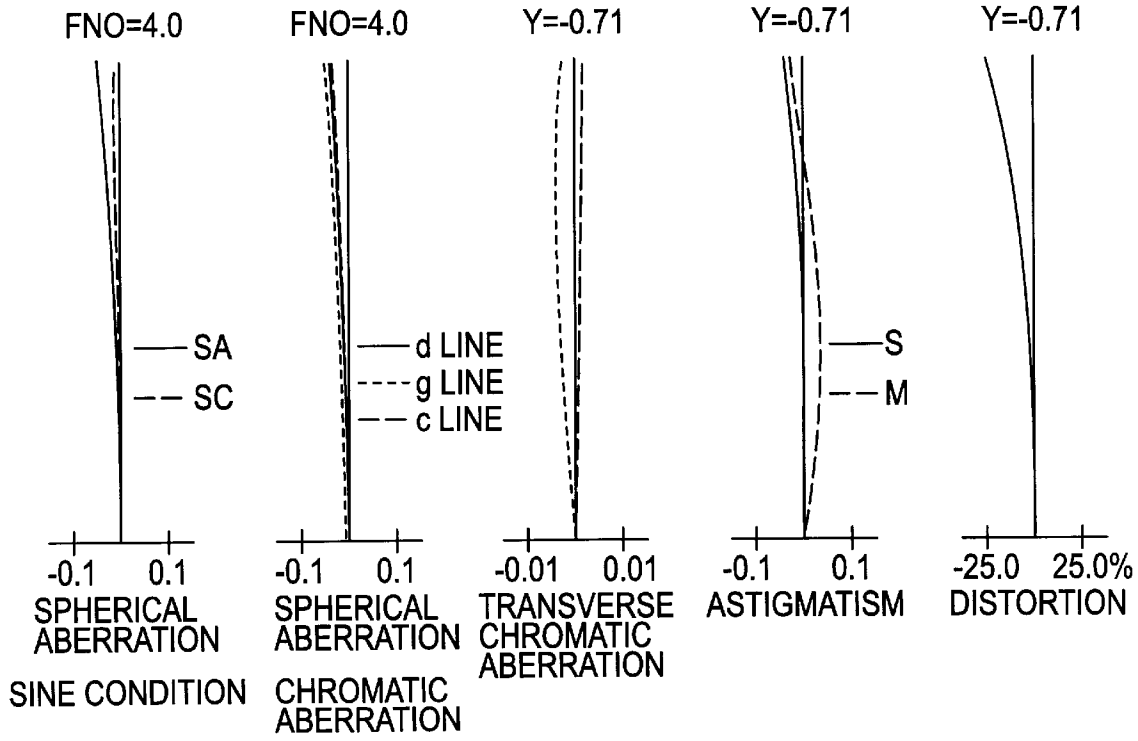

I
II
r1
r2
r3
r4
r5
r6
302
303
304
301
301S
d1
d2
d3
d4
d5

FIG. 61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SA
SC
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0.1
SPHERICAL ABERRATION
SINE CONDITION
FNO=4.0
d LINE
g LINE
c LINE
-0.1
0.1
SPHERICAL ABERRATION
CHROMATIC ABERRATION
Y=-0.71
-0.01
0.01
TRANSVERSE CHROMATIC ABERRATION
Y=-0.71
S
M
-0.1
0.1
ASTIGMATISM
Y=-0.71
-25.0
25.0%
DISTORTION

FIG. 62

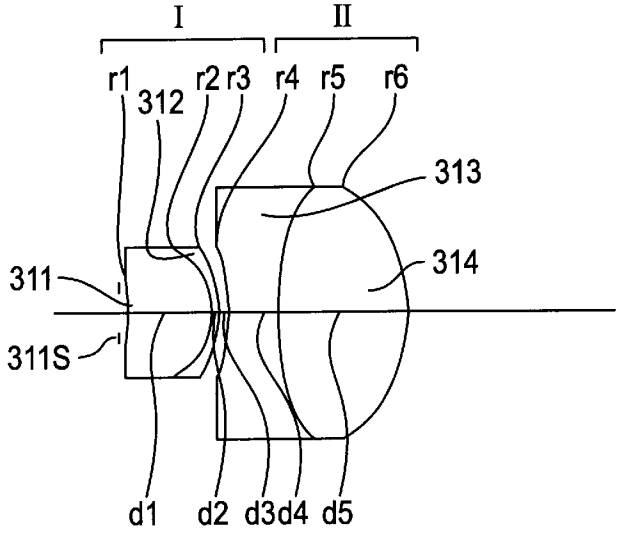
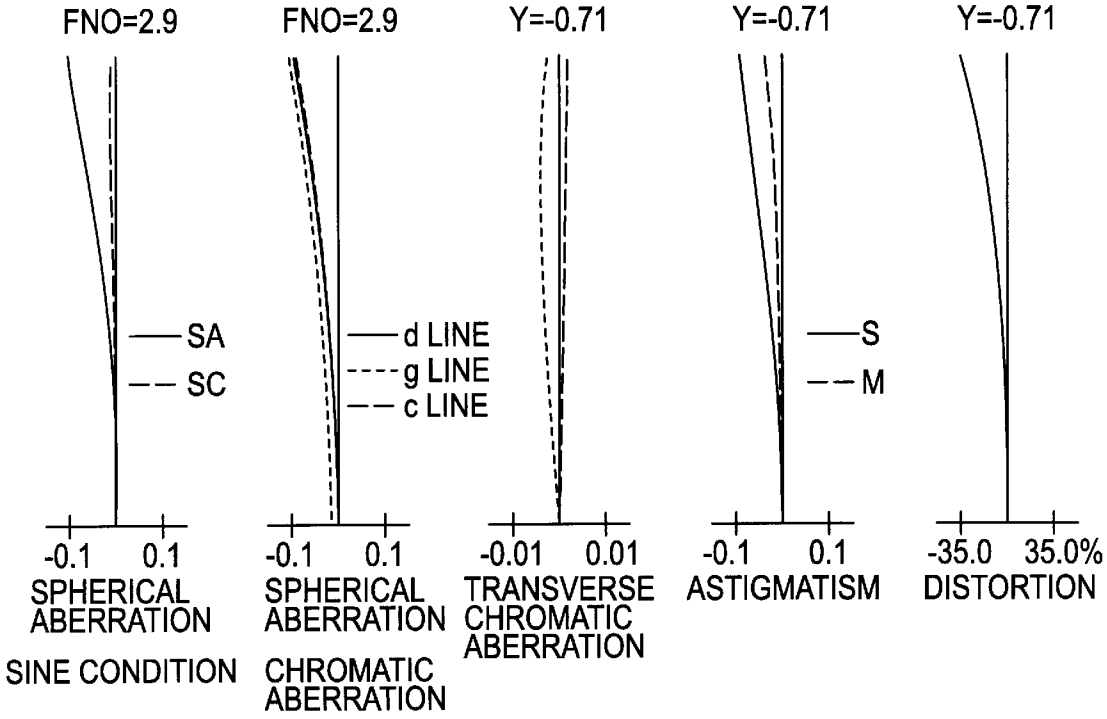

I
II
r1
312
r2
r3
r4
r5
r6
313
314
311
311S
d1
d2
d3
d4
d5

FIG. 63


FNO=2.9
SA
SC
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0.1
SPHERICAL ABERRATION
SINE CONDITION
FNO=2.9
d LINE
g LINE
c LINE
-0.1
0.1
SPHERICAL ABERRATION
CHROMATIC ABERRATION
Y=-0.71
-0.01
0.01
TRANSVERSE CHROMATIC ABERRATION
Y=-0.71
S
M
-0.1
0.1
ASTIGMATISM
Y=-0.71
-35.0
35.0%
DISTORTION

FIG. 64

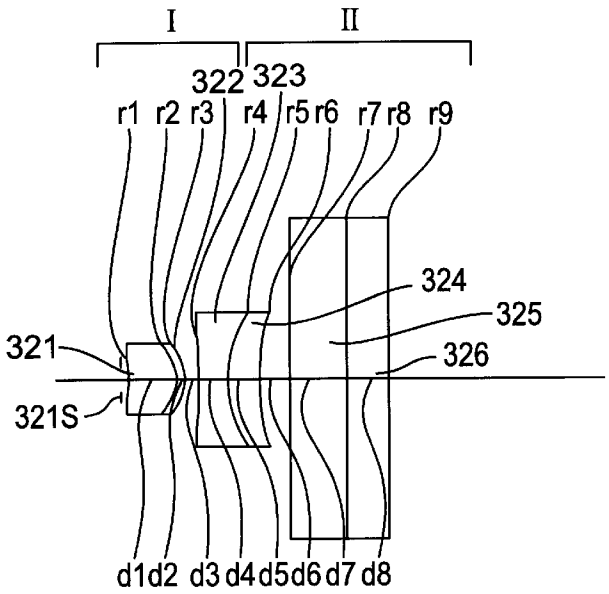
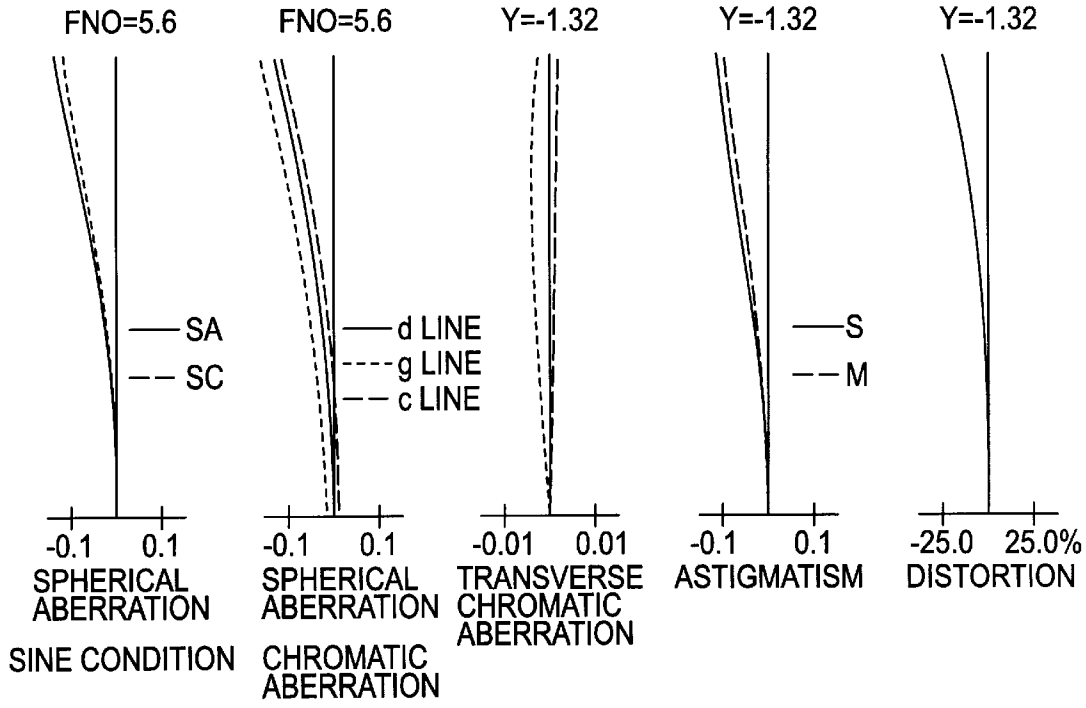

I
II
322
323
r1 r2 r3 r4 r5 r6 r7 r8 r9
324
325
321
326
321S
d1 d2 d3 d4 d5 d6 d7 d8

FIG. 65


FNO=5.6
SA
SC
-0.1 0.1
SPHERICAL ABERRATION
SINE CONDITION
FNO=5.6
d LINE
g LINE
c LINE
-0.1 0.1
SPHERICAL ABERRATION
CHROMATIC ABERRATION
Y=-1.32
-0.01 0.01
TRANSVERSE CHROMATIC ABERRATION
Y=-1.32
S
M
-0.1 0.1
ASTIGMATISM
Y=-1.32
-25.0 25.0%
DISTORTION

OBJECTIVE LENS OF ENDOSCOPE

This application is a continuation of application Ser. No. 08/547,339, filed Oct. 24, 1995, now abandoned.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to an objective lens for an endoscope or a rigid endoscope.

2. Description of Related Art

In general, an endoscope or a rigid endoscope has a wide angle of view from 90° to 120°. Consequently, distortion caused in the objective lens tends to become large. Generally speaking, the distortion is approximately −36% or −50% when the angle of view is 100° or 120°, respectively. To reduce this distortion, it is known to use an aspherical lens, as disclosed for example, in Japanese Unexamined Patent Publication No. 61-162021.

However, since the diameter of an objective lens for an endoscope must be as small as possible, it is more difficult to treat or polish the aspherical surface, than in a lens for a 35 mm camera. Moreover, in general such a small aspherical lens is produced by a glass molding process which is, however, only applicable to a glass material whose transition temperature is relatively low and which can be easily made soft. An endoscope or rigid endoscope needs a fast objective lens, due to the low quantity of illuminating light used in a human body.

However, a fast objective lens tends to be large in diameter and long in length. In view of this, it is possible to make each lens element of a glass material having a high refractive index, to increase the power thereof, to thereby reduce the number of lens elements. Thus, a short and small diameter objective lens having a wide angle of view can be produced. However, many glass materials having a high refractive index have a high transition temperature, and accordingly, the glass molding process is not suitable. Nevertheless, if the glass molding process is applied, the amount of heat necessary to melt the glass is increased, and hence, energy consumption is increased. This results in an increased time for heating and annealing, the service life of molding dies is shortened, and production costs are increased. In addition, the degree of freedom of design of an objective lens made of a glass which can be easily molded is restricted, and it is difficult to obtain a desired optical performance.

Usually in an objective lens for an endoscope, the power mainly relies upon a front lens group located closer to an object to be observed than an aperture-stop. If a front lens group is eliminated, the overall length of the lens can be reduced. However, if there is no front lens group, the power of the rear lens group must be increased accordingly. This leads to a deterioration in optical performance, for example distortions occur. In order to increase the power of the rear lens group, it is necessary to increase the refractive index thereof. An aspherical lens can advantageously be used to effectively compensate aberrations.

However, glass materials having a high refractive index which can be easily molded to form an aspherical surface are limited, as has already been mentioned above. Consequently, it is difficult to produce an aspherical lens by the molding process with a glass having a high refractive index. Therefore, in practice, it is very difficult to produce a short objective lens for an endoscope, in which little or no distortion occurs.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a short and simple objective lens for an endoscope, which can be easily produced, has little or no distortion and includes fewer lens elements than conventional objective lenses for endoscopes.

In the basic concept of the present invention, the main lens power is made mainly of a glass and includes an aspherical surface layer made of transparent resin, or the like, which can be easily machined or processed and applied to the glass to form a compound aspherical lens.

According to one aspect of the present invention, there is provided an objective lens for an endoscope comprising a front lens group of negative power, an aperture stop, and a rear lens group of positive power in this order from the object side, wherein at least one lens of one of the front lens group or rear lens group is a compound aspherical lens made of a glass lens having a transparent layer applied to a surface of the glass lens, a surface of the transparent layer farthest from the glass lens being an aspherical surface, and the refractive index n of the glass lens to which the transparent layer is applied is more than 1.65 (n>1.65).

According to another aspect of the present invention, there is provided an objective lens for an endoscope comprising: a front lens group of negative power; an aperture stop; and, a rear lens group of positive power in this order from the object side; wherein at least one lens of each of the front and rear lens groups is a compound aspherical lens made of a glass lens and a transparent layer applied to a surface of the glass lens, a surface of the transparent layer farthest from the glass lens being an aspherical surface, and the refractive index n of the glass lens to which the transparent layer is applied is more than 1.65 (n>1.65).

In the arrangements mentioned above, the front lens group of negative power is provided on the object side of the diaphragm (stop) and the rear lens group of positive power is provided on the image side of the diaphragm.

Consequently, a wide angle of view can be easily obtained with fewer lenses (lens elements).

Moreover, the degree of freedom to select the number of lens surfaces, to which the aspherical surfaces can be applied to correct distortion, is increased, and hence, distortion can be appropriately compensated, taking into account the balance with other aberrations.

According to a modification of the present invention, there is provided an objective lens for an endoscope comprising: a glass cover; an aperture stop; and, a rear lens group of positive power in this order from the object side; wherein at least one lens of the rear lens group is a compound aspherical lens made of a glass lens and a transparent layer applied to a surface of the glass lens, a surface of the transparent layer farthest from the glass lens being an aspherical surface, and the refractive index n of the glass lens of the compound aspherical lens being more than 1.65 (n>1.65).

According to another aspect of the present invention, there is provided an objective lens for an endoscope comprising: an aperture stop; and, a rear lens group of positive power in this order from the object side; wherein at least one lens of said rear lens group is a compound aspherical lens made of a glass lens and a transparent layer applied to a surface of the glass lens, a surface of the transparent layer farthest from the glass lens being an aspherical surface, and the refractive index n of the glass lens of the compound aspherical lens being more than 1.65 (n>1.65).

According to the present invention, the lens is comprised of an aperture stop and a rear lens group of positive power in this order from the object side, with an absence of a front lens group, wherein at least one lens of the rear lens group is made of a compound aspherical lens comprised of a glass lens and a transparent member applied to the surface of the glass lens; the surface of the transparent member that is not adhered to the glass lens is an aspherical surface; and, the glass lens of the compound aspherical lens is made of a glass material having a refractive index n of more than 1.65 (n>1.65).

Thus, a short and small diameter objective lens for an endoscope can be provided.

In addition, according to the present invention, the aspherical surface effectively reduces various aberrations including spherical aberration, axial chromatic aberration, lateral chromatic aberration, astigmatism, and distortion.

The present disclosure relates to subject matter contained in Japanese patent application Nos. 06-260702 (filed on Oct. 25, 1994) and 06-283811 (filed on Nov. 17, 1994) which are expressly incorporated herein by reference in their entireties.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will be discussed below in detail with reference to the accompanying drawings, in which:

FIG. **1** is a schematic view showing a lens arrangement of an objective lens for an endoscope according to a first embodiment of the present invention;

FIG. **2** shows diagrams of various aberrations of the objective lens shown in FIG. **1**;

FIG. **3** is a schematic view showing a lens arrangement of an objective lens for an endoscope according to a second embodiment of the present invention;

FIG. **4** shows diagrams of various aberrations of the objective lens shown in FIG. **3**;

FIG. **5** is a schematic view showing a lens arrangement of an objective lens for an endoscope according to a third embodiment of the present invention;

FIG. **6** shows diagrams of various aberrations of the objective lens shown in FIG. **5**;

FIG. **7** is a schematic view showing a lens arrangement of an objective lens for an endoscope according to a fourth embodiment of the present invention;

FIG. **8** shows diagrams of various aberrations of the objective lens shown in FIG. **7**;

FIG. **9** is a schematic view showing a lens arrangement of an objective lens for an endoscope according to a fifth embodiment of the present invention;

FIG. **10** shows diagrams of various aberrations of the objective lens shown in FIG. **9**;

FIG. **11** is a schematic view showing a lens arrangement of an objective lens for an endoscope according to a sixth embodiment of the present invention;

FIG. **12** shows diagrams of various aberrations of the objective lens shown in FIG. **11**;

FIG. **13** is a schematic view showing a lens arrangement of an objective lens for an endoscope according to a seventh embodiment of the present invention;

FIG. **14** shows diagrams of various aberrations of the objective lens shown in FIG. **13**;

FIG. **15** is a schematic view showing a lens arrangement of an objective lens for an endoscope according to an eighth embodiment of the present invention;

FIG. **16** shows diagrams of various aberrations of the objective lens shown in FIG. **15**;

FIG. **17** is a schematic view showing a lens arrangement of an objective lens for an endoscope according to a ninth embodiment of the present invention;

FIG. **18** shows diagrams of various aberrations of the objective lens shown in FIG. **17**;

FIG. **19** is a schematic view showing a lens arrangement of an objective lens for an endoscope according to a tenth embodiment of the present invention;

FIG. **20** shows diagrams of various aberrations of the objective lens shown in FIG. **19**;

FIG. **21** is a schematic view showing a lens arrangement of an objective lens for an endoscope according to an eleventh embodiment of the present invention;

FIG. **22** shows diagrams of various aberrations of the objective lens shown in FIG. **21**;

FIG. **23** is a schematic view showing a lens arrangement of an objective lens for an endoscope according to a twelfth embodiment of the present invention;

FIG. **24** shows diagrams of various aberrations of the objective lens shown in FIG. **23**;

FIG. **25** is a schematic view showing a lens arrangement of an objective lens for an endoscope according to a thirteenth embodiment of the present invention;

FIG. **26** shows diagrams of various aberrations of the objective lens shown in FIG. **25**;

FIG. **27** is a schematic view showing a lens arrangement of an objective lens for an endoscope according to a fourteenth embodiment of the present invention;

FIG. **28** shows diagrams of various aberrations of the objective lens shown in FIG. **27**;

FIG. **29** is a schematic view showing a lens arrangement of an objective lens of an endoscope according to a fifteenth embodiment of the present invention;

FIG. **30** shows diagrams of various aberrations of the objective lens shown in FIG. **29**;

FIG. **31** is a schematic view showing a lens arrangement of an objective lens for an endoscope according to a sixteenth embodiment of the present invention;

FIG. **32** shows diagrams of various aberrations of the objective lens shown in FIG. **31**;

FIG. **33** is a schematic view showing a lens arrangement of an objective lens for an endoscope according to a seventeenth embodiment of the present invention;

FIG. **34** shows diagrams of various aberrations of the objective lens shown in FIG. **33**;

FIG. **35** is a schematic view showing a lens arrangement of an objective lens for an endoscope according to an eighteenth embodiment of the present invention;

FIG. **36** shows diagrams of various aberrations of the objective lens shown in FIG. **35**;

FIG. **37** is a schematic view showing a lens arrangement of an objective lens for an endoscope according to a nineteenth embodiment of the present invention;

FIG. **38** shows diagrams of various aberrations of the objective lens shown in FIG. **37**;

FIG. **39** is a schematic view showing a lens arrangement of an objective lens for an endoscope according to a twentieth embodiment of the present invention;

FIG. **40** shows diagrams of various aberrations of the objective lens shown in FIG. **39**;

FIG. **41** is a schematic view showing a lens arrangement of an objective lens for an endoscope according to a twenty first embodiment of the present invention;

FIG. **42** shows diagrams of various aberrations of the objective lens shown in FIG. **41**;

FIG. **43** is a schematic view showing a lens arrangement of an objective lens for an endoscope according to a twenty second embodiment of the present invention;

FIG. **44** shows diagrams of various aberrations of the objective lens shown in FIG. **43**;

FIG. **45** is a schematic view showing a lens arrangement of an objective lens for an endoscope according to a twenty third embodiment of the present invention;

FIG. **46** shows diagrams of various aberrations of the objective lens shown in FIG. **45**;

FIG. **47** is a schematic view showing a lens arrangement of an objective lens for an endoscope according to a twenty fourth embodiment of the present invention;

FIG. **48** shows diagrams of various aberrations of the objective lens shown in FIG. **47**;

FIG. **49** is a schematic view showing a lens arrangement of an objective lens for an endoscope according to a twenty fifth embodiment of the present invention;

FIG. **50** shows diagrams of various aberrations of the objective lens shown in FIG. **49**;

FIG. **51** is a schematic view showing a lens arrangement of an objective lens for an endoscope according to a twenty sixth embodiment of the present invention;

FIG. **52** shows diagrams of various aberrations of the objective lens shown in FIG. **51**;

FIG. **53** is a graph showing a relation between distortions and the quantity of light of an objective lens for an endoscope;

FIG. **54** is a schematic view showing a lens arrangement of an objective lens for an endoscope according to a twenty seventh embodiment of the present invention;

FIG. **55** shows diagrams of various aberrations of the objective lens shown in FIG. **54**;

FIG. **56** is a schematic view showing a lens arrangement of an objective lens for an endoscope according to a twenty eighth embodiment of the present invention;

FIG. **57** shows diagrams of various aberrations of the objective lens shown in FIG. **56**;

FIG. **58** is a schematic view showing a lens arrangement of an objective lens for an endoscope according to a twenty ninth embodiment of the present invention;

FIG. **59** shows diagrams of various aberrations of the objective lens shown in FIG. **58**;

FIG. **60** is a schematic view showing a lens arrangement of an objective lens for an endoscope according to a thirtieth embodiment of the present invention;

FIG. **61** shows diagrams of various aberrations of the objective lens shown in FIG. **60**;

FIG. **62** is a schematic view showing a lens arrangement of an objective lens for an endoscope according to a thirty first embodiment of the present invention;

FIG. **63** shows diagrams of various aberrations of the objective lens shown in FIG. **62**;

FIG. **64** is a schematic view showing a lens arrangement of an objective lens for an endoscope according to a thirty second embodiment of the present invention; and,

FIG. **65** shows diagrams of various aberrations of the objective lens shown in FIG. **64**.

DESCRIPTION OF THE PREFERRED EMBODIMENT

FIGS. **1** and **2** show a first embodiment of the present invention; FIGS. **3** and **4** show a 2nd embodiment; FIGS. **5** and **6** show a 3rd embodiment; FIGS. **7** and **8** show a 4th embodiment; FIGS. **9** and **10** show a 5th embodiment; FIGS. **11** and **12** show a 6th embodiment; FIGS. **13** and **14** show a 7th embodiment; FIGS. **15** and **16** show an 8th embodiment; FIGS. **17** and **18** show a 9th embodiment; FIGS. **19** and **20** show a 10th embodiment; FIGS. **21** and **22** show an 11th embodiment; FIGS. **23** and **24** show a 12th embodiment; FIGS. **25** and **26** show a 13th embodiment; FIGS. **27** and **28** show a 14th embodiment; FIGS. **29** and **30** show a 15th embodiment; FIGS. **31** and **32** show a 16th embodiment; FIGS. **33** and **34** show a 17th embodiment; FIGS. **35** and **36** show an 18th embodiment; FIGS. **37** and **38** show a 19th embodiment; FIGS. **39** and **40** show a 20th embodiment; FIGS. **41** and **42** show a 21st embodiment; FIGS. **43** and **44** show a 22nd embodiment; FIGS. **45** and **46** show a 23rd embodiment; FIGS. **47** and **48** show a 24th embodiment; FIGS. **49** and **50** show a 25th embodiment; FIGS. **51** and **52** show a 26th embodiment; FIGS. **54** and **55** show a 27th embodiment; FIGS. **56** and **57** show a 28th embodiment; FIGS. **58** and **59** show a 29th embodiment; FIGS. **60** and **61** show a 30th embodiment; FIGS. **62** and **63** show a 31st embodiment; and, FIGS. **64** and **65** show a 32nd embodiment, respectively.

In the 1st to 26th embodiments, the front lens group is comprised of a first lens group I; and, the rear lens group is comprised of either only a second lens group II, or a second lens group II and a third lens group III.

In the first (FIG. **1**) and second (FIG. **3**) embodiments, the terminal surfaces of the glass lenses of the first lens group I and the third lens group III are provided with aspheric resin layers. Namely, the glass lens **11** (FIG. **1**) or **21** (FIG. **3**) is located closest to an object to be photographed, and the second surface No. **2** thereof on the image side is provided with a transparent resin layer **12** (or **22**) applied thereto, which is formed by pressing a transparent synthetic resin material. The third surface No. **3**, belonging to the transparent resin layer, on the image side is an aspherical surface. The glass lenses **15** (FIG. **1**) and **25** (FIG. **3**) of the third lens group III, that are located furthest from the object (i.e. on the image side), are provided on the terminal surfaces (eighth surfaces) No. **8**, with transparent resin layers **16** (FIG. **1**) and **26** (FIG. **3**) formed by pressing a transparent synthetic resin material. The ninth surfaces No. **9**, belonging to the transparent resin layers **16** and **26**, on the image side are aspherical surfaces. The aperture stop **13S** (**23S**) is provided between the first lens group I and the second lens group II.

In the third embodiment (FIG. **5**), the terminal surface of the glass lens of the first lens group I is provided with an aspherical resin layer. Namely, the glass lens **31** is located closest to the object and is provided, on the second surface No. **2** thereof on the image side, with a transparent resin layer **32** formed by pressing a synthetic resin material. The surface No. **3**, belonging to the transparent resin layer, on the image side is an aspherical surface. The aperture stop **33S** is provided between the first lens group I and the second lens group II.

In the fourth (FIG. **7**), fifth (FIG. **9**), and sixth (FIG. **11**) embodiments, the terminal surfaces of the glass lenses of the third lens group III furthest from the object are provided with aspherical resin layers. Namely, the glass lenses **44** (FIG. **7**), **54** (FIG. **9**), and **64** (FIG. **11**) are located closest to the image side, and the seventh (terminal) surfaces No. **7** thereof furthest from the object are each provided with a transparent resin layer **45** (**55** or **65**) applied thereto, which is formed by pressing a transparent synthetic resin material. The eighth surfaces No. **8**, belonging to the transparent resin layers, on the image side are aspherical surfaces. The

aperture stop **42S** (**52S** or **62S**) is provided between the first lens group I and the second lens group II.

In the seventh embodiment (FIG. **13**), the terminal surfaces of the glass lenses of the first and third lens groups I and III are provided with aspherical resin layers. Namely, the glass lens **71** is located closest to the object, and the second surface No. **2** thereof on the image side is provided with a transparent resin layer **72** applied thereto, which is formed by pressing a transparent synthetic resin material. The third surface No. **3**, belonging to the transparent resin layer, on the image side is an aspherical surface. The glass lens **75** of the third lens group III that is located furthest from the object (i.e., on the image side) is provided on the terminal surface (eighth surface) No. **8**, with a transparent resin layer **76** formed by pressing a transparent synthetic resin material. The ninth surface No. **9**, belonging to the transparent resin layer **76**, on the image side is an aspherical surface. The aperture stop **73S** is provided between the first lens group I and the second lens group II.

In the eighth embodiment (FIG. **15**), the terminal surface of the glass lens of the first lens group I is provided with an aspherical resin layer. Namely, the glass lens **81** is located closest to the object and is provided, on the second surface No. **2** thereof on the image side, with a transparent resin layer **82** formed by pressing a synthetic resin material. The surface No. **3**, belonging to the transparent resin layer **82**, on the image side is an aspherical surface. The aperture stop **83S** is provided between the first lens group I and the second lens group II.

In the ninth (FIG. **17**) and eleventh (FIG. **21**) embodiments, the terminal surface of the glass lens of the third lens group III furthest from the object is provided with an aspherical resin layer. Namely, the glass lenses **94** and **114** are located closest to the image and are provided, on the seventh surfaces No. **7** thereof on the image side, with transparent resin layers **95** and **115** which are formed by pressing a synthetic resin material. The eighth surfaces No. **8**, belonging to the transparent resin layers, on the image side are aspherical surfaces. The aperture stops **92S** and **112S** are respectively provided between the first lens group I and the second lens group II.

In the tenth embodiment (FIG. **19**), the terminal, surface of the glass lens of the second lens group II is provided with an aspherical resin layer. Namely, the glass lens **102** of the second lens group II is provided, on the fourth surface No. **4** thereof on the image side, with a transparent resin layer **103** formed by pressing a synthetic resin material. The fifth surface No. **5**, belonging to the transparent resin layer, on the image side is an aspherical surface. The aperture stop **102S** is provided between the first lens group I and the second lens group II.

In the twelfth embodiment (FIG. **23**), the lens of the first lens group I on the object side is made of a glass lens **121** which is provided on the surface thereof on the image side with a transparent resin layer **122** formed by pressing a synthetic resin material. The third surface No. **3**, belonging to the transparent resin layer, on the image side is an aspherical surface. The aperture stop **124S** is provided between the first lens group I and the second lens group II.

In the thirteenth embodiment (FIG. **25**), the lens of the third lens group III on the image side is a glass lens **135** which is provided on the surface thereof on the image side with a transparent resin layer **136** formed by pressing a synthetic resin material. The tenth surface No. **10**, belonging to the transparent resin layer **136**, on the image side is an aspherical surface. The aperture stop **133S** is provided between the first lens group I and the second lens group II.

The fourteenth to twentieth embodiments are all applied to an electronic endoscope. In these embodiments, an image sensor, such as a CCD image pickup device (not shown) is used instead of an optical fiber bundle. To this end, a glass cover (flat plate) is provided just in front of the image surface and is closely adhered to the image sensor by an adhesive. In the illustrated embodiments, the rearmost two optical elements are glass covers. Thus, the back focal distance fB is 0 (zero).

In the fourteenth embodiment (FIG. **27**), the first lens group I is comprised of a single glass lens **141** which is provided on the surface thereof on the image side with a transparent resin layer **142** formed by pressing a synthetic resin material. The third surface No. **3**, belonging to the transparent resin layer, on the image side is an aspherical surface. The aperture stop **143S** is provided between the first lens group I and the second lens group II.

In the fifteenth embodiment (FIG. **29**), the lens of the first lens group I on the image side is a glass lens **152** which is provided, on the surface thereof on the image side, with a transparent resin layer **153** formed by pressing a synthetic resin material. The fifth surface No. **5**, belonging to the transparent resin layer, on the image side is an aspherical surface. The aperture stop **154S** is provided between the first lens group I and the second lens group II.

In the sixteenth embodiment (FIG. **31**), the lens of the first lens group I on the object side is made of a glass lens **161** which is provided, on the surface thereof on the image side, with a transparent resin layer **162** formed by pressing a synthetic resin material. The third surface No. **3**, belonging to the transparent resin layer **162**, on the image side is an aspherical surface. The aperture stop **164S** is provided between the first lens group I and the second lens group II.

In the seventeenth embodiment (FIG. **33**), the lens of the first lens group I on the image side is made of a glass lens **172** which is provided, on the surface thereof on the image side, with a transparent resin layer **173** formed by pressing a synthetic resin material. The fifth surface No. **5**, belonging to the transparent resin layer **173**, on the image side is an aspherical surface. The aperture stop **174S** is provided between the first lens group I and the second lens group II.

In the eighteenth embodiment (FIG. **35**), the lens of the first lens group I on the image side is made of a glass lens **181** which is provided, on the surface thereof on the image side, with a transparent resin layer **182** formed by pressing a synthetic resin material. The third surface No. **3**, belonging to the transparent resin layer **182**, on the image side is an aspherical surface. The aperture stop **183S** is provided between the first lens group I and the second lens group II.

In the nineteenth embodiment (FIG. **37**), the lens of the first lens group I on the image side is made of a glass lens **192** which is provided on the surface thereof on the image side with a transparent resin layer **193** formed by pressing a synthetic resin material. The fifth surface No. **5**, belonging to the transparent resin layer **193**, on the image side is an aspherical surface. The aperture stop **194S** is provided between the first lens group I and the second lens group II.

In the twentieth embodiment (FIG. **39**), the lens of the first lens group I on the object side is made of a glass lens **201** which is provided, on the surface thereof on the image side, with a transparent resin layer **202** formed by pressing a synthetic resin material. The third surface No. **3**, belonging to the transparent resin layer **202**, on the image side is an aspherical surface. The aperture stop **204S** is provided between the first lens group I and the second lens group II.

In the twenty first (FIG. **41**) and twenty second (FIG. **43**) embodiments, the lens of the second lens group II on the

object side is made of a glass lens **213** (or **223**) which is provided, on the surfaces thereof on the image side, with a transparent resin layer **214** (or **224**) formed by pressing a synthetic resin material. The surfaces of the transparent resin layers **214** and **224** on the image side are aspherical surfaces. The aperture stops **213**S and **223**S are respectively provided between the first lens group I and the second lens group II.

In the twenty third embodiment (FIG. **45**), the lens of the third lens group III on the image side is made of a glass lens **235** which is provided, on the surface thereof on the image side, with a transparent resin layer **236** formed by pressing a synthetic resin material. The tenth surface No. **10**, belonging to the transparent resin layer **236**, on the image side is an aspherical surface. The aperture stop **233**S is provided between the first lens group I and the second lens group II.

In the twenty fourth embodiment (FIG. **47**), the lens of the second lens group II on the object side is made of a glass lens **242** which is provided, on the surface thereof on the image side, with a transparent resin layer **243** formed by pressing a synthetic resin material. The fifth surface No. **5**, belonging to the transparent resin layer **243**, on the image side is an aspherical surface. The aperture stop **242**S is provided between the first lens group I and the second lens group II. In the twenty fifth (FIG. **49**) and twenty sixth (FIG. **51**) embodiments, the lens of the third lens group III on the image side is made of a glass lens **255** (or **265**) which is provided, on the surfaces thereof on the image side, with a transparent resin layer **256** (or **266**) formed by pressing a synthetic resin material. The tenth surfaces, belonging to the transparent resin layers **256** and **266**, on the image side are aspherical surfaces. The aperture stops **253**S and **263**S are respectively provided between the first lens group I and the second lens group II.

In the above mentioned embodiments, the angle of view **2**w is **2**w=90° (in the 23rd embodiment), **2**w=100° (in the 1st–5th, and 7th–22nd embodiments), **2**w=110° (in the 24th embodiment), **2**w=120° (in the 6th, 11th, 25th, and 26th embodiments), respectively. The F-number is F=2.9 (in the 1st–14th, 21st–23rd, and 25th embodiments), F=5.6 (in the 15th–20th embodiments), F=1.8 (in the 24th embodiment), and F=3.6 (in the 26th embodiment), respectively. The F-number F refers to a value corresponding with an object at infinite, and the angle of view **2**w refers to a value corresponding with a predetermined object distance (design value) which is 10.0 mm (in the 1st–13th, 23rd, 25th and 26th embodiments), 6.0 mm (in the 14th–20th embodiments), or 8.0 mm (in the 21st, 22nd, and 24th embodiments).

The 27th to 31st embodiments are applied to an objective lens for a fiber scope, and the 32nd embodiment is applied to an objective lens for an electronic scope, respectively. The 27th embodiment includes a glass cover (lens group I), but there is no glass cover in the 28th to 32nd embodiments. In the 27th and 28th embodiments, the rear lens group is comprised of a single lens group II, I, respectively. In the 29th through 32nd embodiments, the rear lens group is comprised of two lenses. Namely, the rear lens group is comprised of two positive lens groups I, II (in the 29th–31st embodiments), and a positive lens group and a negative lens group in combination, in this order from the object side in the 32nd embodiment, respectively. Note that although only the optical elements are shown in the drawings, the optical elements are secured to or held by a lens barrel, etc., at the front end of an associated endoscope or rigid endoscope, etc.

In the twenty seventh and twenty eighth embodiments, the rear lens groups **272** and **281** are each made of a glass lens group II, I whose refractive index n is larger than 1.65 (n>1.65). The glass lenses are provided, on the fourth and second surfaces No. **4** and No. **2** thereof on the image side, with transparent resin layers **273** and **282**, respectively formed by pressing a synthetic resin material. The fifth and third surfaces No. **5** and No. **3**, belonging to the transparent resin layers **273** and **282**, on the image side (that are not adhered to the lens surfaces No. **4** and No. **2** of the glass lenses **272** and **281**) are both aspherical surfaces to form compound aspherical lenses comprised of the rear lens group **272** and the transparent layer **273**; and, the rear lens group **281** and the transparent layer **282**, respectively. The aperture stops **272**S and **281**S are respectively provided in the space located closer to the object than the rear lens groups **272** and **281**, respectively.

In the twenty ninth embodiment, at least the second lens **292**, of the two rear lenses (lens elements) **291** and **292**, is made of a glass lens whose refractive index n is more than 1.65 (n>1.65). The glass lens is provided, on the fourth surface No. **4** thereof on the image side, with a transparent resin layer **293** formed by pressing a synthetic resin material. The fifth surface No. **5**, belonging to the transparent resin layer **293**, on the image side (that is not adhered to the lens surface No. **4** of the second lens **292**) is an aspherical surface to form a compound aspherical lens comprised of the second lens **292** and the transparent layer **293**. The aperture stop **291**S is provided in the space located closer to the object than the first lens **291**.

In the thirtieth embodiment, among the first lens **301** of positive power, the second lens **302** of negative power, and the third lens **303** of positive power, of the rear lens group, at least the third lens **303** is made of a glass lens whose refractive index n is more than 1.65 (n>1.65). The glass lens **303** is provided, on the fifth surface No. **5** thereof on the image side, with a transparent resin layer **304** formed by pressing a synthetic resin material. The sixth surface No. **6**, belonging to the transparent resin layer **304**, on the image side (that is not adhered to the lens surface No. **5** of the third lens **303**) is an aspherical surface to form a compound aspherical lens comprised of the third lens **303** and the transparent layer **304**. The aperture stop **301**S is provided in the space located closer to the object than the first lens **301**.

In the thirty first embodiment, among the first lens **311** of positive power, the second lens **313** of negative power, and the third lens **314** of positive power, of the rear lens group, the first lens **311** is made of a glass lens whose refractive index n is more than 1.65 (n>1.65). The glass lens **311** is provided, on the second surface No. **2** thereof on the image side, with a transparent resin layer **312** formed by pressing a synthetic resin material. The third surface No. **3**, belonging to the transparent resin layer **312**, on the image side (that is not adhered to the lens surface No. **2** of the first lens **311**) is an aspherical surface to form a compound aspherical lens comprised of the first lens **311** and the transparent layer **312**. The aperture stop **311**S is provided in the space located closer to the object than the first lens **311**.

In the thirty second embodiment, among the first lens **321** of positive power, the second lens **323** of negative power, and the third lens **324** of positive power, of the rear lens group, at least the first lens **321** is made of a glass lens whose refractive index n is more than 1.65 (n>1.65). The glass lens **321** is provided, on the second surface No. **2** thereof on the image side, with a transparent resin layer **322** formed by pressing a synthetic resin material. The third surface No. **3**, belonging to the transparent resin layer **322**, on the image side (that is not adhered to the lens surface No. **2** of the first lens) is an aspherical surface to form a compound aspherical

lens comprised of the first lens **321** and the transparent layer **322**. The aperture stop **321S** is provided in the space located closer to the object than the first lens **321**. Note that numerals **325** and **326** designate the glass cover and the adhesive layer for a CCD image pickup device used in an electronic endoscope.

In the embodiments mentioned above, a glass product under the trade name "LAH58" marketed by OHARA K. K., can be used as the glass lens, in view of a chemical resistance, a demand for correction of aberrations, polishing efficiency and machinability, etc. The LAH58 has a high transition point (transition temperature) equal to 730° C. and accordingly no molding process can be effectively applied to the LAH58.

Moreover, no glass material having the substantially same refractive index and Abbe number as those of the LAH58 and having a transition point low enough to apply the glass molding process exists. Although the transparent aspherical surface layer is made of thermosetting resin in the above-mentioned embodiments, it is possible to use other resin materials, such as optically setting resin, etc. The refractive index of resin material to be used is not limited to a specific value.

Numerical data of the 1st–32nd embodiments are shown in Tables below and aberrations thereof are shown in FIGS. **2**, **4**, **6**, **8**, **10**, **12**, **14**, **16**, **18**, **20**, **22**, **24**, **26**, **28**, **30**, **32**, **34**, **36**, **38**, **40**, **42**, **44**, **46**, **48**, **50**, **52**, **55**, **57**, **59**, **61**, **63**, and **65**. In the drawings and tables, "SA" designates the spherical aberration; "SC" the sine condition; "d-line", "g-line" and "C-line" the chromatic aberrations represented by the spherical aberrations, and the transverse chromatic aberrations, at the respective wavelengths; and "S" and "M" the sagittal ray and meridional ray, respectively.

Furthermore, "F_{NO}" designates the f-number; "f" the focal length (mm); "M" the lateral magnification, "W" the half angle of view (degree); "f_B" the back focal distance (mm); "r" the radius of curvature of each lens surface (mm); "d" the distance between the surfaces (mm); "n_d" the refractive index of the d-line; and "vd" the Abbe number of the d-line, respectively.

TABLE 1

FIRST EMBODIMENT
F_{NO} = 2.9 f = 0.75 M = −0.072 W = 50 f_B = 0.80

surface NO	r	d	n_d	vd
1	∞	0.30	1.88300	40.8
2	1.000	0.10	1.52010	50.8
3*	0.500	0.55	—	—
STOP	∞	0.03	—	—
4	4.403	0.49	1.71700	47.9
5	−0.849	0.59	—	—
6	5.146	0.29	1.80518	25.4
7	0.740	1.02	1.72916	54.7
8	−2.486	0.20	1.52070	50.8
9*	−1.245	—	—	—

*marked surface is aspherical
NO. 3: K = −1.74470, A4 = 0.63008, A6 = 7.06571
NO. 9: K = −3.15352, A4 = 0.25161, A6 = −0.09732
The shape of the aspherical surface can be generally expressed as follows:
$x = cy^2/[1 + \{1 - (1 + K)c^2y^2\}^{1/2}] + A4y^4 + A6y^6$

TABLE 2

SECOND EMBODIMENT
F_{NO} = 2.9 f = 0.75 M = −0.071 W = 50 f_B = 0.90

surface NO	r	d	n_d	vd
1	∞	0.30	1.88300	40.8
2	−14.000	0.10	1.52010	50.8
3*	0.500	0.84	—	—
STOP	∞	0.15	—	—
4	23.231	0.50	1.88300	40.8
5	−1.061	0.38	—	—
6	23.988	0.29	1.80518	25.4
7	0.740	1.04	1.72916	54.7
8	−2.878	0.20	1.52070	50.8
9*	−1.420	—	—	—

*marked surface is aspherical
NO. 3: K = −0.71376, A4 = 0.16159, A6 = 2.78510
NO. 9: K = −2.39296, A4 = 0.18428, A6 = −0.11540

TABLE 3

THIRD EMBODIMENT
F_{NO} = 2.9 f = 0.80 M = −0.075 W = 50 f_B = 0.51

surface NO	r	d	n_d	vd
1	∞	0.69	1.88300	40.8
2	0.900	0.40	1.52010	50.8
3*	−1.749	0.12	—	—
STOP	∞	0.20	—	—
4	−0.927	0.31	1.80400	46.6
5	−0.554	0.19	—	—
6	3.658	0.30	1.80518	25.4
7	0.740	0.70	1.72916	54.7
8	−1.659	—	—	—

*marked surface is aspherical
NO. 3: K = 16.69143, A4 = −0.15881, A6 = 5.10610

TABLE 4

FOURTH EMBODIMENT
F_{NO} = 2.9 f = 0.76 M = −0.071 W = 50 f_B = 1.15

surface NO	r	d	n_d	vd
1	∞	0.59	1.88300	40.8
2	0.856	0.64	—	—
STOP	∞	0.05	—	—
3*	2.691	0.53	1.88300	40.8
4	−1.047	0.26	—	—
5	−1.432	0.47	1.80518	25.4
6	0.900	0.80	1.72916	54.7
7	−1.189	0.18	1.52010	50.8
8	−0.766	—	—	—

*marked surface is aspherical
NO. 8: K = −0.83579, A4 = 0.18988, A6 = 0.03573

TABLE 5

FIFTH EMBODIMENT
F_{NO} = 2.9 f = 0.70 M = −0.065 W = 50 f_B = 0.80

surface NO	r	d	n_d	vd
1	∞	0.30	1.88300	40.8
2	0.809	0.64	—	—
STOP	∞	0.03	—	—
3	4.372	0.62	1.78800	47.4
4	−0.894	0.60	—	—
5	−2.285	0.30	1.80518	25.4
6	0.900	0.80	1.72916	54.7
7	−1.255	0.20	1.52010	50.8
8*	−0.656	—	—	—

*marked surface is aspherical
NO. 8: K = −1.04130, A4 = 0.39415, A6 = −0.10782

TABLE 6

SIXTH EMBODIMENT
F_{NO} = 2.9 f = 0.64 M = −0.060 W = 60 f_B = 0.75

surface NO	r	d	n_d	vd
1	∞	0.30	1.88300	40.8
2	0.772	0.76	—	—
STOP	∞	0.03	—	—
3	4.078	0.67	1.88300	40.8
4	−0.921	0.46	—	—
5	−1.954	0.30	1.80518	25.4
6	0.720	0.93	1.72916	54.7
7	−1.000	0.05	1.52010	50.8
8*	−0.750	—	—	—

*marked surface is aspherical
NO. 8: K = −2.23469, A4 = 0.11552, A6 = -0.46713×10^{-2}

TABLE 7

SEVENTH EMBODIMENT
F_{NO} = 2.9 f = 0.76 M = −0.071 W = 50 f_B = 0.94

surface NO	r	d	n_d	vd
1	3.234	0.30	1.88300	40.8
2	0.900	0.15	1.52010	50.8
3*	0.500	0.52	—	—
STOP	∞	0.19	—	—
4	−3198.399	0.48	1.88300	40.8
5	−0.878	0.33	—	—
6	−7.376	0.30	1.80518	25.4
7	0.740	0.99	1.72916	54.7
8	−2.818	0.25	1.52070	50.8
9*	−0.950	—	—	—

*marked surface is aspherical
NO. 3: K = −0.03974, A4 = −0.24459, A6 = 2.83022
NO. 9: K = −2.76740, A4 = −0.02280, A6 = -0.57745×10^{-2}

TABLE 8

EIGHTH EMBODIMENT
F_{NO} = 2.9 f = 0.74 M = −0.069 W = 50 f_B = 0.77

surface NO	r	d	n_d	vd
1	1.139	0.30	1.88300	40.8
2	0.621	0.15	1.52010	50.8
3*	0.390	0.74	—	—
STOP	∞	0.03	—	—
4	−4.499	0.82	1.88300	40.8
5	−0.863	0.22	—	—
6	4.428	0.31	1.80518	25.4
7	0.679	1.05	1.72916	54.7
8	−2.461	—	—	—

*marked surface is aspherical
NO. 3: K = −0.31514, A4 = −0.15945, A6 = 2.51091

TABLE 9

NINTH EMBODIMENT
F_{NO} = 2.9 f = 0.66 M = −0.061 W = 50 f_B = 0.77

surface NO	r	d	n_d	vd
1	1.800	0.30	1.88300	40.8
2	0.600	0.86	—	—
STOP	∞	0.03	—	—
3	−8.688	0.53	1.78800	47.4
4	−0.736	0.48	—	—
5	−1.959	0.30	1.80518	25.4
6	0.900	0.80	1.72916	54.7

TABLE 9-continued

NINTH EMBODIMENT
F_{NO} = 2.9 f = 0.66 M = −0.061 W = 50 f_B = 0.77

surface NO	r	d	n_d	vd
7	−0.939	0.20	1.52010	50.8
8*	−0.674	—	—	—

*marked surface is aspherical
NO. 8: K = −1.40396, A4 = 0.27823, A6 = −0.15351

TABLE 10

TENTH EMBODIMENT
F_{NO} = 2.9 f = 0.76 M = −0.072 W = 50 f_B = 0.50

surface NO	r	d	n_d	vd
1	1.400	0.56	1.88300	40.8
2	0.357	0.24	—	—
STOP	∞	0.03	—	—
3	2.177	0.60	1.88300	40.8
4	−0.550	0.15	1.52010	50.8
5*	−0.435	0.06	—	—
6	−1.587	0.30	1.80518	25.4
7	0.620	1.00	1.72916	54.7
8	−1.329	—	—	—

*marked surface is aspherical
NO. 5: K = −1.43936, A4 = −0.45077, A6 = 2.64232

TABLE 11

ELEVENTH EMBODIMENT
F_{NO} = 2.9 f = 0.57 M = −0.053 W = 60 f_B = 0.71

surface NO	r	d	n_d	vd
1	3.412	0.30	1.88300	40.8
2	0.646	1.06	—	—
STOP	∞	0.03	—	—
3	1.806	0.57	1.88300	40.8
4	−0.843	0.24	—	—
5	−0.826	0.30	1.80518	25.4
6	0.641	0.90	1.72916	54.7
7	−1.000	0.10	1.52010	50.8
8*	−0.600	—	—	—

*marked surface is aspherical
NO. 8: K = −1.74863, A4 = 0.12393, A6 = −0.08045

TABLE 12

TWELFTH EMBODIMENT
F_{NO} = 2.9 f = 0.89 M = −0.085 W = 50 f_B = 0.79

surface NO	r	d	N_d	vd
1	∞	0.30	1.88300	40.8
2	−6.247	0.12	1.52010	50.8
3*	−4.825	0.10	—	—
4	−3.440	0.31	1.88300	40.8
5	0.973	0.10	—	—
STOP	∞	0.09	—	—
6	−16.967	0.86	1.80400	46.6
7	−0.801	0.14	—	—
8	3.366	0.33	1.80518	25.4
9	0.750	1.17	1.72916	54.7
10	−2.379	—	—	—

*marked surface is aspherical
NO. 3: K = -0.25257×10^{-2}, A4 = 0.83352×10^{-2}, A6 = −0.01406

TABLE 13

THIRTEENTH EMBODIMENT
F_{NO} = 2.9 f = 0.90 M = −0.086 W = 50 f_B = 0.73

surface NO	r	d	N_d	νd
1	∞	0.44	1.88300	40.8
2	−5.778	0.09	—	—
3	−3.978	0.35	1.88300	40.8
4	0.993	0.08	—	—
STOP	∞	0.09	—	—
5	−19.567	0.89	1.80400	46.6
6	−0.825	0.16	—	—
7	2.840	0.33	1.80518	25.4
8	0.780	1.01	1.72916	54.7
9	−60.912	0.16	1.52010	50.8
10*	−2.067	—	—	—

*marked surface is aspherical

NO. 10: K = −0.01031, A4 = 0.67813 × 10^{-2}, A6 = −0.02074

TABLE 14

FOURTEENTH EMBODIMENT
F_{NO} = 5.6 f = 1.26 M = −0.237 W = 50 f_B = 0.00

surface NO	r	d	N_d	νd
1	∞	0.30	1.88300	40.8
2	−1.663	0.10	1.52010	50.8
3*	0.662	0.10	—	—
STOP	∞	0.06	—	—
4	−4.340	0.38	1.69680	55.5
5	−0.500	0.05	—	—
6	14.165	0.30	1.76182	26.5
7	0.965	0.72	1.65160	58.5
8	2.563	0.40	—	—
9	∞	0.60	1.53000	50.0
10	∞	0.40	1.54000	40.0
11	∞	—	—	—

*marked surface is aspherical

NO. 3: K = 2.0554, A4 = −0.41547, A6 = 0.67062 × 10^{2}

TABLE 15

FIFTEENTH EMBODIMENT
F_{NO} = 5.6 f = 1.28 M = −0.229 W = 50 f_B = 0.00

surface NO	r	d	N_d	νd
1	∞	0.30	1.88300	40.8
2	3.000	0.10	—	—
3	2.974	0.30	1.88300	40.8
4	−1.569	0.10	1.52010	50.8
5*	0.644	0.10	—	—
STOP	∞	0.06	—	—
6	−3.949	0.37	1.69680	55.5
7	−0.500	0.05	—	—
8	16.308	0.30	1.79182	26.5
9	0.914	0.72	1.65160	58.5
10	2.658	0.44	—	—
11	∞	0.60	1.53000	50.0
12	∞	0.40	1.54000	40.0
13	∞	—	—	—

*marked surface is aspherical

NO. 5: K = 1.5589, A4 = −0.48804, A6 = 0.77204 × 10^{2}

TABLE 16

SIXTEENTH EMBODIMENT
F_{NO} = 5.6 f = 1.26 M = −0.222 W = 50 f_B = 0.00

surface NO	r	d	N_d	νd
1	∞	0.35	1.88300	40.8
2	−2.848	0.05	1.52010	50.8
3*	3.139	0.15	—	—
4	1.514	0.30	1.88300	40.8
5	0.710	0.07	—	—
STOP	∞	0.06	—	—
6	−2.683	0.48	1.69680	55.5
7	−0.500	0.05	—	—
8	4.572	0.30	1.76182	26.5
9	1.029	0.72	1.65160	58.5
10	2.286	0.37	—	—
11	∞	0.60	1.53000	50.0
12	∞	0.40	1.54000	40.0
13	∞	—	—	—

*marked surface is aspherical

NO. 3: K = −0.19664, A4 = −0.10294, A6 = 0.50143

TABLE 17

SEVENTEENTH EMBODIMENT
F_{NO} = 5.6 f = 1.27 M = −0.225 W = 50 f_B = 0.00

surface NO	r	d	N_d	νd
1	∞	0.31	1.88300	40.8
2	−14.800	0.10	—	—
3	4.233	0.30	1.88300	40.8
4	4.988	0.08	1.52010	50.8
5*	0.603	0.13	—	—
STOP	∞	0.06	—	—
6	−3.445	0.39	1.69680	55.5
7	−0.500	0.05	—	—
8	6.473	0.30	1.76182	26.5
9	0.883	0.72	1.65160	58.5
10	2.844	0.43	—	—
11	∞	0.60	1.53000	50.0
12	∞	0.40	1.54000	40.0
13	∞	—	—	—

*marked surface is aspherical

NO. 5: K = 1.4580, A4 = −0.54366, A6 = 0.33280 × 10^{2}

TABLE 18

EIGHTEENTH EMBODIMENT
F_{NO} = 5.6 f = 1.15 M = −0.211 W = 50 f_B = 0.00

surface NO	r	d	N_d	νd
1	2.222	0.30	1.88300	40.8
2	0.545	0.10	1.52010	50.8
3*	1.217	0.06	—	—
STOP	∞	0.05	—	—
4	−2.732	0.53	1.69680	55.5
5	−0.500	0.05	—	—
6	2.414	0.30	1.76182	26.5
7	0.736	0.59	1.65160	58.5
8	1.392	0.30	—	—
9	∞	0.60	1.53000	50.0
10	∞	0.40	1.54000	40.0
11	∞	—	—	—

*marked surface is aspherical

NO. 3: K = 3.0282, A4 = 1.3150, A6 = −0.27845 × 10^{2}

TABLE 19

NINETEENTH EMBODIMENT
F_{NO} = 5.6 f = 1.14 M = −0.197 W = 50 f_B = 0.00

surface NO	r	d	N_d	νd
1	2.636	0.30	1.88300	40.8
2	1.038	0.25	—	—
3	3.331	0.36	1.88300	40.8
4	−3.069	0.10	1.52010	50.8
5*	1.150	0.05	—	—
STOP	∞	0.05	—	—
6	−2.680	0.40	1.69680	55.5
7	−0.500	0.05	—	—
8	3.754	0.32	1.76182	26.5
9	0.781	0.56	1.65160	58.5
10	1.550	0.35	—	—
11	∞	0.60	1.53000	50.0
12	∞	0.40	1.54000	40.0
13	∞	—	—	—

*marked surface is aspherical
NO. 5: K = 1.5215, A4 = 0.38064, A6 = 0.52947 × 10^2

TABLE 20

TWENTIETH EMBODIMENT
F_{NO} = 5.6 f = 1.01 M = −0.156 W = 50 f_B = 0.00

surface NO	r	d	N_d	νd
1	4.868	0.35	1.88300	40.8
2	1.862	0.20	1.52010	50.8
3*	1.950	0.34	—	—
4	−35.496	0.36	1.88300	40.8
5	104.922	0.38	—	—
STOP	∞	0.05	—	—
6	−0.803	0.43	1.69680	55.5
7	−0.461	0.05	—	—
8	1.963	0.30	1.76182	26.5
9	0.598	0.50	1.65160	58.5
10	1.346	0.35	—	—
11	∞	0.60	1.53000	50.0
12	∞	0.40	1.54000	40.0
13	∞	—	—	—

*marked surface is aspherical
NO. 3: K = −0.56293 A4 = −0.16915, A6 = 0.03255

TABLE 21

TWENTY FIRST EMBODIMENT
F_{NO} = 2.9 f = 0.31 M = −0.036 W = 50 f_B = 0.26

surface NO	r	d	N_d	νd
1	17.712	0.31	1.88300	40.8
2	−8.302	0.13	—	—
3	−4.534	0.31	1.88789	40.3
4	2.246	0.24	—	—
STOP	∞	0.03	—	—
5	0.772	0.55	1.88300	40.8
6	−0.398	0.05	1.52010	50.8
7*	−0.250	—	—	—

*marked surface is aspherical
NO. 7: K = −2.4732, A4 = −1.5283, A6 = 0.46950 × 10^{-2}

TABLE 22

TWENTY SECOND EMBODIMENT
F_{NO} = 2.9 f = 0.32 M = −0.039 W = 50 f_B = 0.29

surface NO	r	d	N_d	νd
1	33.826	0.25	1.88300	40.8
2	11.562	0.07	—	—
3	72.072	0.25	1.88969	40.3
4	1.341	0.06	—	—

TABLE 22-continued

TWENTY SECOND EMBODIMENT
F_{NO} = 2.9 f = 0.32 M = −0.039 W = 50 f_B = 0.29

surface NO	r	d	N_d	νd
STOP	∞	0.03	—	—
5	0.792	0.60	1.88300	40.8
6	−0.390	0.05	1.52010	50.8
7*	−0.250	—	—	—

*marked surface is aspherical
NO. 7: K = −2.0000, A4 = −1.0000, A6 = 0.25000 × 10^2

TABLE 23

TWENTY THIRD EMBODIMENT
F_{NO} = 2.9 f = 0.72 M = −0.066 W = 45 f_B = 0.54

surface NO	r	d	N_d	νd
1	1.736	0.30	1.88300	40.8
2	1.231	0.20	—	—
3	1.126	0.30	1.72916	54.7
4	0.356	0.30	—	—
STOP	∞	0.03	—	—
5	5.881	0.50	1.75500	52.3
6	−0.683	0.26	—	—
7	2.772	0.50	1.92286	21.3
8	0.700	0.80	1.72916	54.7
9	−1.176	0.15	1.52010	50.8
10*	−0.834	—	—	—

*marked surface is aspherical
NO. 10: K = −0.20020, A4 = 0.78395, A6 = 0.35616

TABLE 24

TWENTY FOURTH EMBODIMENT
F_{NO} = 1.8 f = 0.32 M = −0.039 W = 55 f_B = 0.35

surface NO	r	d	N_d	νd
1	∞	0.50	1.88300	40.8
2	1.000	0.07	—	—
STOP	∞	0.03	—	—
3	1.177	0.51	1.88300	40.8
4	−0.344	0.06	1.52010	50.8
5*	−0.266	—	—	—

*marked surface is aspherical
NO. 5: K = −2.1333, A4 = −4.2127, A6 = 0.33076 × 10^2

TABLE 25

TWENTY FIFTH EMBODIMENT
F_{NO} = 2.9 f = 0.48 M = −0.045 W = 60 f_B = 0.56

surface NO	r	d	N_d	νd
1	2.022	0.30	1.88300	40.8
2	0.528	0.28	—	—
3	51.637	0.30	1.88300	40.8
4	1.784	0.32	—	—
STOP	∞	0.03	—	—
5	3.161	0.37	1.77250	49.6
6	−0.839	0.54	—	—
7	4.721	0.48	1.92286	21.3
8	0.745	0.79	1.72916	54.7
9	−1.471	0.20	1.52010	50.8
10*	−0.499	—	—	—

*marked surface is aspherical
NO. 10: K = −0.85820, A4 = 1.05472, A6 = −0.33103

TABLE 26

TWENTY SIXTH EMBODIMENT
F_{NO} = 3.6 f = 0.50 M = −0.046 W = 60 f_B = 0.54

surface NO	r	d	N_d	vd
1	∞	0.30	1.88300	40.8
2	0.896	0.18	—	—
3	3.000	0.34	1.88300	40.8
4	1.065	0.37	—	—
STOP	∞	0.03	—	—
5	1.718	0.34	1.77250	49.6
6	−1.017	0.66	—	—
7	5.342	0.30	1.92286	21.3
8	0.773	0.81	1.72916	54.7
9	−0.947	0.15	1.52010	50.8
10*	−0.487	—	—	—

*marked surface is aspherical
NO. 10: K = −1.13178, A4 = 0.62990, A6 = −0.13775

TABLE 27

TWENTY SEVENTH EMBODIMENT
F_{NO} = 1.8 f = 0.33 M = −0.040 W = 50 f_B = 0.29

surface NO	r	d	n_d	vd
1	∞	0.20	1.88300	40.8
2	∞	0.16		
STOP	∞	0.03		
3	2.222	0.49	1.88300	40.8
4	−0.389	0.05	1.52010	50.8
5*	−0.244	—	—	—

*marked surface is aspherical
NO. 5: K = −2.38716, A4 = −4.55994, A6 = 0.26567 × 10^2, A8 = 0.00000, A10 = 0.00000, A12 = 0.00000
The shape of the aspherical surface can be generally expressed as follows:
$x = cy^2/[1 + \{1 + (1 + K)c^2y^2\}^{1/2}] + A4y^4 + A6y^6 + A8y^8 + A10y^{10} + A12y^{12}$

TABLE 28

TWENTY EIGHTH EMBODIMENT
F_{NO} = 1.8 f = 0.43 M = −0.054 W = 40 f_B = 0.38

surface NO	r	d	n_d	vd
STOP	∞	0.11		
1	1.848	0.51	1.88300	40.8
2	−0.410	0.05	1.52010	50.8
3*	−0.394	—	—	—

*marked surface is aspherical
NO. 3: K = −1.98384, A4 = −0.03256, A6 = 7.81836, A8 = 0.00000, A10 = 0.00000, A12 = 0.00000

TABLE 29

TWENTY NINTH EMBODIMENT
F_{NO} = 1.8 f = 0.39 M = −0.077 W = 45 f_B = 0.34

surface NO	r	d	n_d	vd
STOP	∞	0.04		
1	−1.121	0.30	1.51633	64.1
2	−0.897	0.05	—	—
3	0.880	0.40	1.65830	57.3
4	−0.510	0.05	1.52010	50.8
5*	−0.309	—	—	—

*marked surface is aspherical
NO. 5: K = −2.87113, A4 = −2.62966, A6 = 0.26542 × 10^2, A8 = −0.32503 × 10^2, A10 = −0.35704 × 10^3, A12 = 0.12321 × 10^4

TABLE 30

THIRTIETH EMBODIMENT
F_{NO} = 4.0 f = 0.91 M = −0.152 W = 46 f_B = 1.01

surface NO	r	d	n_d	vd
STOP	∞	0.04		
1	−0.540	0.23	1.88300	40.8
2	−0.525	0.05	—	—
3	−11.419	0.47	1.80518	25.4
4	0.910	0.73	1.72916	54.7
5	−1.200	0.20	1.52010	50.8
6*	−0.700	—	—	—

*marked surface is aspherical
NO. 6: K = −2.18934, A4 = −0.29640, A6 = −0.23181, A8 = 0.00000, A10 = 0.00000 , A12 = 0.00000

TABLE 31

THIRTY FIRST EMBODIMENT
F_{NO} = 2.9 f = 0.89 M = −0.151 W = 50 f_B = 0.802

surface NO	r	d	n_d	vd
STOP	∞	0.04		
1	−1.449	0.51	1.88300	40.8
2	−0.440	0.05	1.52010	50.8
3*	−0.589	0.05	—	—
4	−1.100	0.30	1.80518	25.4
5	1.596	0.78	1.72916	54.7
6	−0.920	—	—	—

*marked surface is aspherical
NO. 3: K = −0.83413, A4 = 0.42655, A6 = 0.41254, A8 = 0.00000, A10 = 0.00000 , A12 = 0.00000

TABLE 32

THIRTY SECOND EMBODIMENT
F_{NO} = 5.6 f = 1.19 M = −0.235 W = 50 f_B = 0.00

surface NO	r	d	n_d	vd
STOP	∞	0.06		
1	−1.774	0.51	1.88300	40.8
2	−0.472	0.05	1.52010	50.8
3*	−0.732	0.16	—	—
4	−6.062	0.30	1.80518	25.4
5	1.142	0.34	1.72916	54.7
6	2.620	0.30	—	—
7	∞	0.60	1.53000	50.0
8	∞	0.40	1.54000	40.0
9	∞	—	—	—

*marked surface is aspherical
NO. 3: K = −0.74470, A4 = −0.20247, A6 = −0.26087, A8 = 0.00000, A10 = 0.00000 , A12 = 0.00000

The distortion in the 1st–11th, 25th and 26th embodiments is around −25% to −8%, and the distortion in the 12th–19th, 21st, 22nd, and 24th embodiments, is around −34% to −14%. If this distortion is corrected to be almost 0%, the quantity of light at the peripheral portion of the lens is reduced. FIG. **53**, shows a relationship between the distortion and the ratio (%) of the quantity of light (ratio of the quantity of paraxial light to the quantity of light at the peripheral portion) when the angle of view is 100°. It can be seen from FIG. **53** that, even at the same angle of view, if the distortion is reduced, the quantity ratio is reduced so that the peripheral portion becomes dark. Therefore, in the embodiments mentioned above, the distortion remains to prevent the quantity of light at the peripheral portion from decreasing.

However, in the 20th and 23rd embodiments, the distortion is almost 0%, but nevertheless, the quantity of light at

the peripheral portion is about 30%. Namely, there is a sufficient quantity of light at the peripheral portion. This effect is achieved by the fact that, in the 20th embodiment in which the lens has a wide angle of view, the first lens has a large negative power, so that the aperture efficiency at the peripheral portion is improved owing to the aspherical terminal surface; and in the 23rd embodiment, the lens surfaces of the first lens group I are concentric with respect to the aperture stop **233**S, and hence, the aperture efficiency is improved.

It can be also seen that in the 27th and 28th embodiments, astigmatism, curvature of the field, and distortion are effectively compensated, in comparison with a lens having no aspherical surface.

In the 29th embodiment, the rear lens group II is split into the first lens **291** and the second lens **292**, so that the radius of curvature r of each of the first and second lenses can be increased in comparison with the 1st and 2nd embodiments. Thus, not only can the lens be more easily produced, but also spherical aberrations can be reduced. Moreover, a comparison with a corresponding lens having no aspherical surface, distortion can be reduced from −27% to −19%.

In the 30th and 31st embodiments, the lenses **302** and **313** of the rear lens group II on the object side are cemented to the lenses **303** and **314** thereof on the image side, respectively, and hence, chromatic aberrations can be reduced.

Moreover, since the surfaces of the transparent layers **304** and **312** that are not adhered to the glass lenses are aspherical surfaces, distortion can be reduced in the 30th embodiment and astigmatism can be reduced in the 31st embodiment, respectively.

In the 32nd embodiment (FIGS. **64** and **65**) which is applied to an objective lens for an electronic endoscope, an image pickup device such as a CCD (not shown) is closely connected to the adhesive layer **326** located furthest from the object. In the 32nd embodiment in which the image height is greater than, for example, that of the 31st embodiment at the same angle of view, the focal length becomes longer than that in the 31st embodiment, if the lens arrangement is identical. This results in an increase in the overall length of the lens. To prevent this, the lens group furthest from the object has a negative power, and thus, the overall length of the lens can be reduced. The length of the lens is reduced by about 20% in comparison with the 31st embodiment. Furthermore, the distortion can be reduced.

As can be understood from the above discussion, according to the present invention, since the transparent resin layer is formed on the surface of the glass lens and the surface of the transparent resin layer is an aspherical surface, an objective lens for an endoscope having an appropriate distortion can be obtained.

Moreover, since the surfaces of the glass lens can be aspherical surfaces in the present invention, not only can the glass lens be easily produced, but also the glass to be used is not limited to a specific material. Consequently, according to the present invention, even a glass material of which it is difficult to produce an aspherical surface by the molding process can be used, thus increasing the degree of freedom of design and production process.

What is claimed is:

1. An objective lens for an endoscope comprising:

a front lens group of negative power;

an aperture stop; and,

a rear lens group of positive power in this order from the object side;

wherein at least one lens of one of said front lens group or rear lens group is a compound aspherical lens comprising a glass lens and a transparent resin layer applied to a surface of said glass lens, a surface of said transparent resin layer farthest from said glass lens being an aspherical surface, and a refractive index n of said glass lens to which said transparent resin layer is applied being more than 1.65 (n>1.65)

wherein a thickness of said glass lens on which said transparent resin layer is formed is larger on an optical axis of said objective lens than a thickness of said transparent resin layer.

2. An objective lens for an endoscope according to claim **1**, wherein said front lens group is comprised of said compound aspherical lens.

3. An objective lens for an endoscope according to claim **1**, wherein said front lens group is comprised of a first lens group having negative power, and said rear lens group is comprised of a second lens group having positive power and a third lens group having positive power.

4. An objective lens for an endoscope according to claim **1**, wherein said rear lens group is comprised of said compound aspherical lens.

5. An objective lens for an endoscope according to claim **1**, wherein said front lens group is comprised of a first lens group having negative power, and said rear lens group is comprised of a second lens group having positive power and a third lens group having negative power.

6. An objective lens of an endoscope comprising:

a front lens group of negative power;

an aperture stop; and,

a rear lens group of positive power in this order from the object side;

wherein at least one lens of said each of said front and rear lens groups is a compound aspherical lens group is a compound aspherical lens comprising a glass lens and a transparent resin layer applied to a surface of said glass lens, a surface of said transparent resin layer farthest from said glass lens being an aspherical surface, and a refractive index n of said glass lens to which said transparent resin layer is applied being more than 1.65 (n>1.65);

wherein a thickness of said glass lens on which said transparent resin layer is formed is larger on an optical axis of said objective lens than a thickness of said transparent resin layer.

7. An objective lens for an endoscope according to claim **6**, wherein said front lens group is comprised of a first lens group having negative power, and said rear lens group is comprised of a second lens group having positive power and a third lens group having positive power.

8. An objective lens of an endoscope comprising:

a glass cover;

an aperture stop; and,

a rear lens group of positive power in this order from the object side;

wherein at least one lens of said rear lens group is a compound aspherical lens comprising a glass lens and a transparent resin layer applied to a surface of said glass lens, a surface of said transparent resin layer farthest from said glass lens being an aspherical surface, and a refractive index n of said glass lens of said compound aspherical lens being more than 1.65 (n>1.65);

wherein a thickness of said glass lens on which said transparent resin layer is formed is larger on an optical

axis of said objective lens than a thickness of said transparent resin layer.

9. An objective lens for an endoscope according to claim **8**, wherein said rear lens group is made of a single compound aspherical lens.

10. An objective lens of an endoscope comprising:

an aperture stop; and

a rear lens group of positive power in this order from the object side;

wherein at least one lens of said rear lens group is a compound aspherical lens comprising a glass lens and a transparent resin layer applied to a surface of said glass lens, a surface of said transparent resin layer farthest from said glass lens being an aspherical surface, and a refractive index n of said glass lens of said compound aspherical lens being more than 1.65 (n>1.65);

wherein a thickness of said glass lens on which said transparent resin layer is formed is larger on an optical axis of said objective lens than a thickness of said transparent resin layer.

11. An objective lens for an endoscope according to claim **10**, wherein said rear lens group is made of a single compound aspherical lens.

12. An objective lens for an endoscope according to claim **10**, wherein said rear lens group is comprised of a first lens group having positive power and a second lens group having positive power, at least one of said first and second lens groups being provided with said compound aspherical lens.

13. An objective lens for an endoscope according to claim **10**, wherein said rear lens group is comprised of a first lens group having positive power and a second lens group having negative power, at least one of said first and second lens groups being provided with said compound aspherical lens.

14. An objective lens for an endoscope according to claim **12**, wherein said first lens group is constituted by said compound aspherical lens.

15. The objective lens for an endoscope according to claim **1**,

wherein a radius of curvature of said surface of said glass lens on which said transparent resin layer is formed, and a paraxial curvature of an aspherical surface of said transparent resin layer, have the same sign.

16. The objective lens for an endoscope according to claim **1**,

wherein said transparent resin layer is formed by pressing a transparent synthetic resin material.

17. The objective lens for an endoscope according to claim **6**,

wherein a radius of curvature of said surface of said glass lens on which said transparent resin layer is formed, and a paraxial curvature of an aspherical surface of said transparent resin layer, have the same sign.

18. The objective lens for an endoscope according to claim **6**,

wherein said transparent resin layer is formed by pressing a transparent synthetic resin material.

19. The objective lens for an endoscope according to claim **8**,

wherein a radius of curvature of said surface of said glass lens on which said transparent resin layer is formed, and a paraxial curvature of an aspherical surface of said transparent resin layer, have the same sign.

20. The objective lens for an endoscope according to claim **8**,

wherein said transparent resin layer is formed by pressing a transparent synthetic resin material.

21. The objective lens for an endoscope according to claim **10**,

wherein a radius of curvature of said surface of said glass lens on which said transparent resin layer is formed, and a paraxial curvature of an aspherical surface of said transparent resin layer, have the same sign.

22. The objective lens for an endoscope according to claim **10**,

wherein said transparent resin layer is formed by pressing a transparent synthetic resin material.

* * * * *

US005828453A

United States Patent [19]

Yamamoto et al.

[11] Patent Number: 5,828,453

[45] Date of Patent: Oct. 27, 1998

[54] **LENS DESIGNING METHOD AND OBJECTIVE LENS APPARATUS WITH TWO LENSES**

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[73] Assignee: **Sony Corporation**, Tokyo, Japan

[21] Appl. No.: **812,736**

[22] Filed: **Mar. 6, 1997**

[30] **Foreign Application Priority Data**

Mar. 13, 1996 [JP] Japan 8-055676

[51] **Int. Cl.**[6] **G01B 9/02**

[52] **U.S. Cl.** **356/345**; 356/360; 359/654; 359/794

[58] **Field of Search** 356/345, 360; 359/794, 654; 350/432; 369/100, 112

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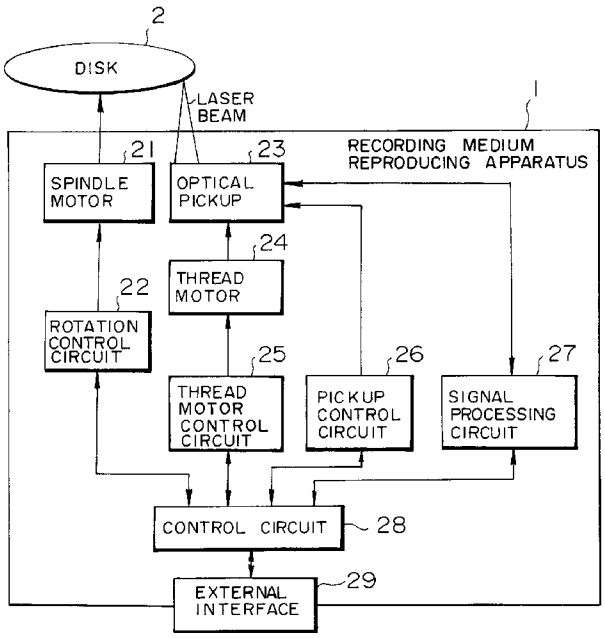
Primary Examiner—Frank G. Font
Assistant Examiner—Tu T. Nguyen
Attorney, Agent, or Firm—Ronald P. Kananen

[57] **ABSTRACT**

A method for designing an objective lens apparatus formed by at least two lenses, a first lens and a second lens, which includes the steps of: measuring aberration which occurs when a light beam is converged by the first lens; setting the first lens is set such that the aberration occurring in the first lens satisfies Maréchal's criterion, in accordance with the measurement results; measuring aberration which occurs when a light beam is converged by the first lens and the second lens; and setting the second lens such that the aberrations occurring in the first lens and the second lens satisfy Maréchal's criterion, in accordance with the measurement results. Accordingly, an objective lens apparatus with a small aberration and a large numerical aperture NA can be designed by this method.

19 Claims, 9 Drawing Sheets



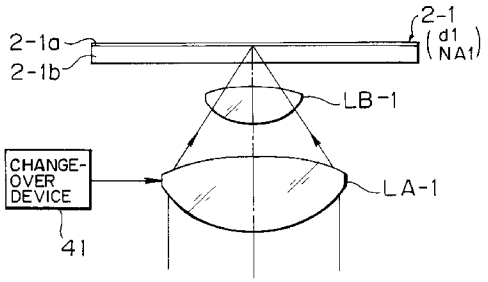


FIG. 1

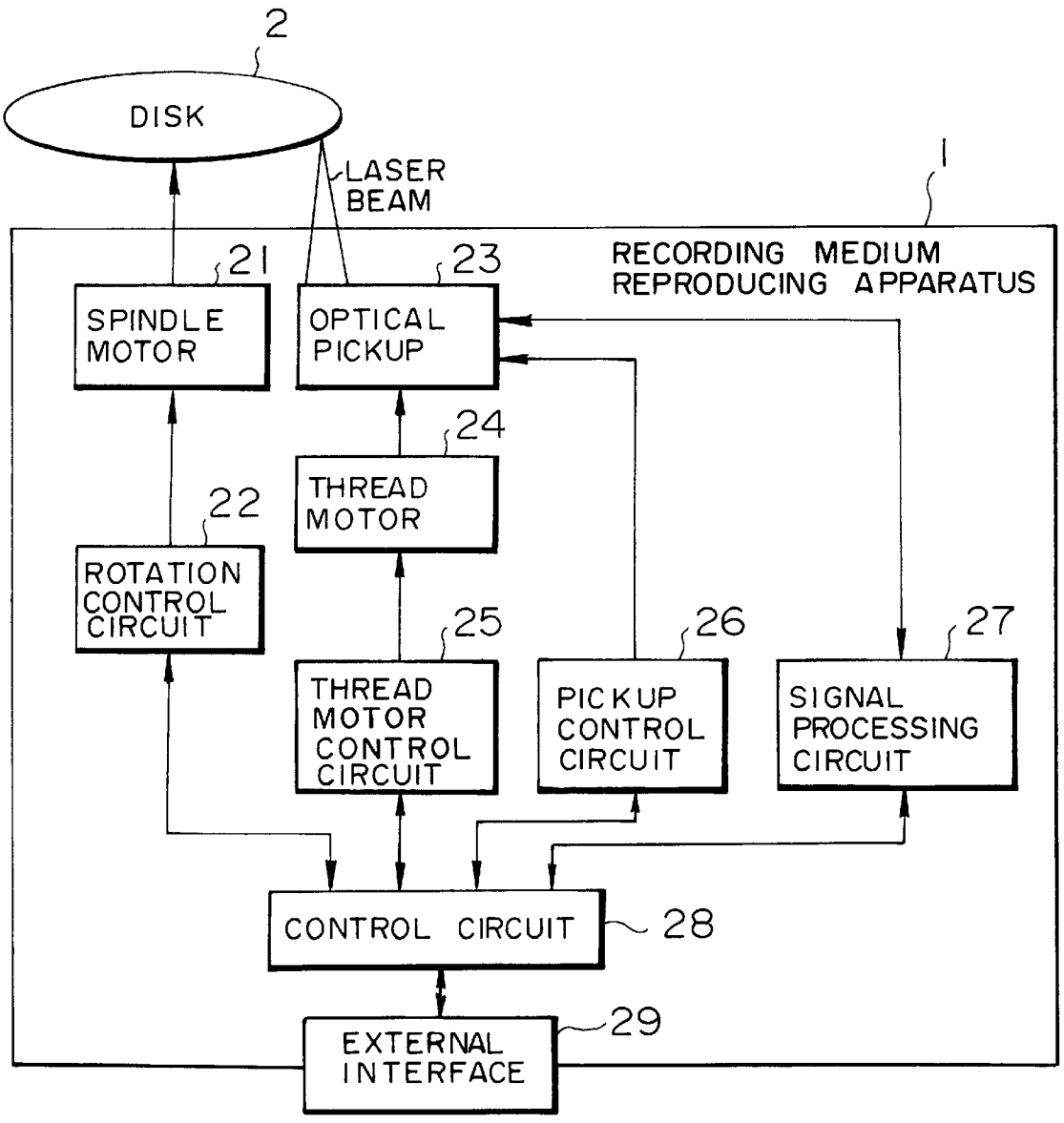

2
DISK
LASER BEAM
1
RECORDING MEDIUM REPRODUCING APPARATUS
21
SPINDLE MOTOR
23
OPTICAL PICKUP
24
THREAD MOTOR
22
ROTATION CONTROL CIRCUIT
25
THREAD MOTOR CONTROL CIRCUIT
26
PICKUP CONTROL CIRCUIT
27
SIGNAL PROCESSING CIRCUIT
CONTROL CIRCUIT
28
29
EXTERNAL INTERFACE

FIG. 2

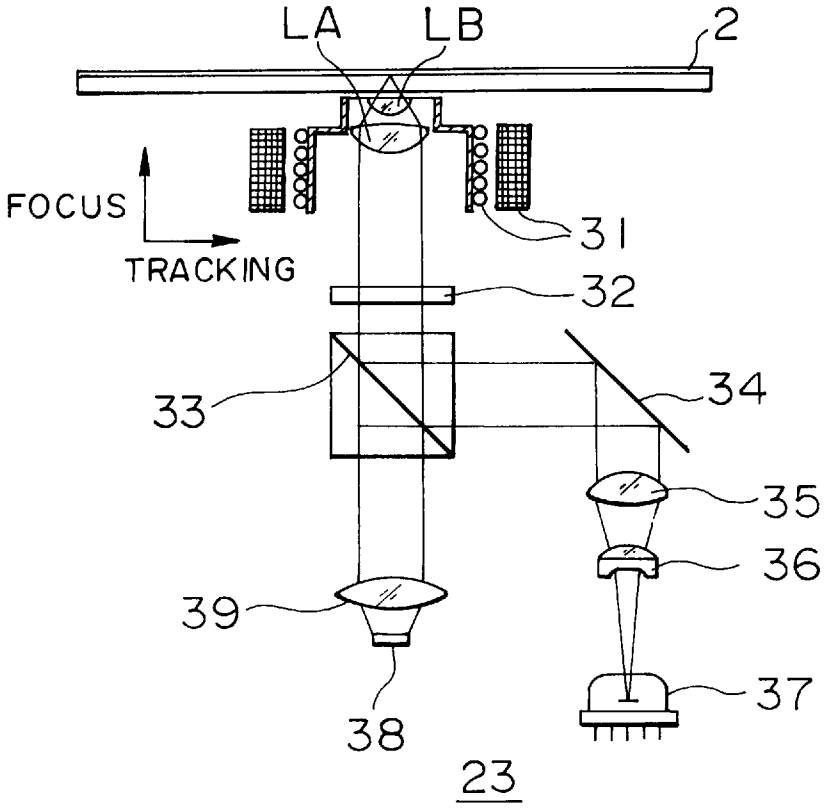

LA
LB
2
FOCUS
TRACKING
31
32
33
34
35
36
39
37
38
23

FIG. 3

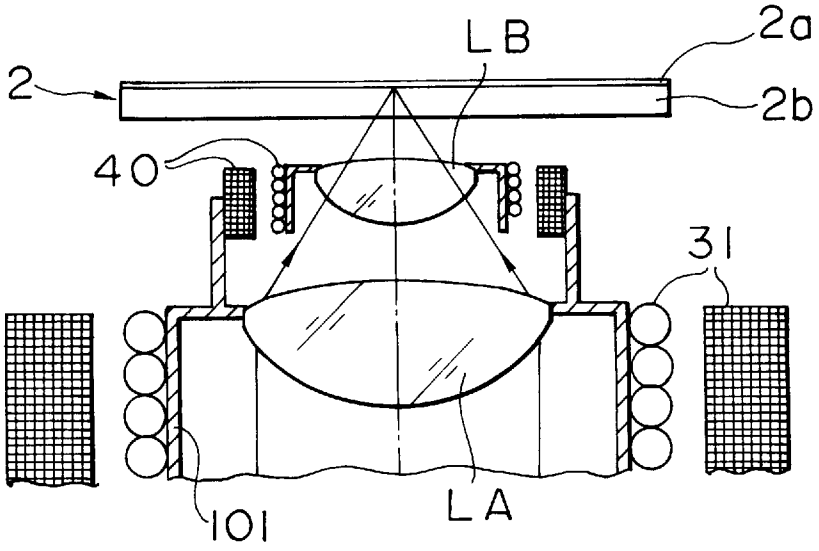

LB
2a
2
2b
40
31
101
LA

FIG. 4

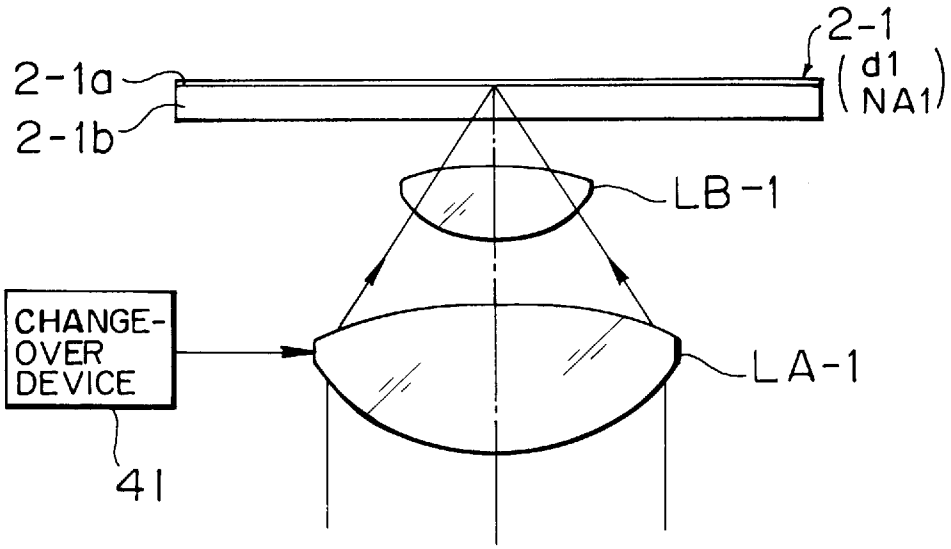

2-1
(d1
NA1)
2-1a
2-1b
LB-1
CHANGE-
OVER
DEVICE
LA-1
41

FIG. 5

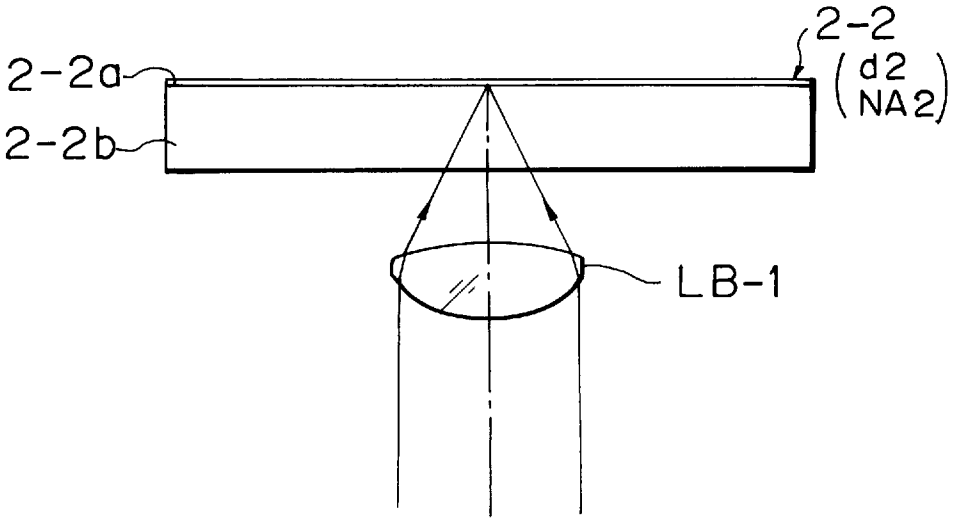

2-2
(d2
NA2)
2-2a
2-2b
LB-1

FIG. 6

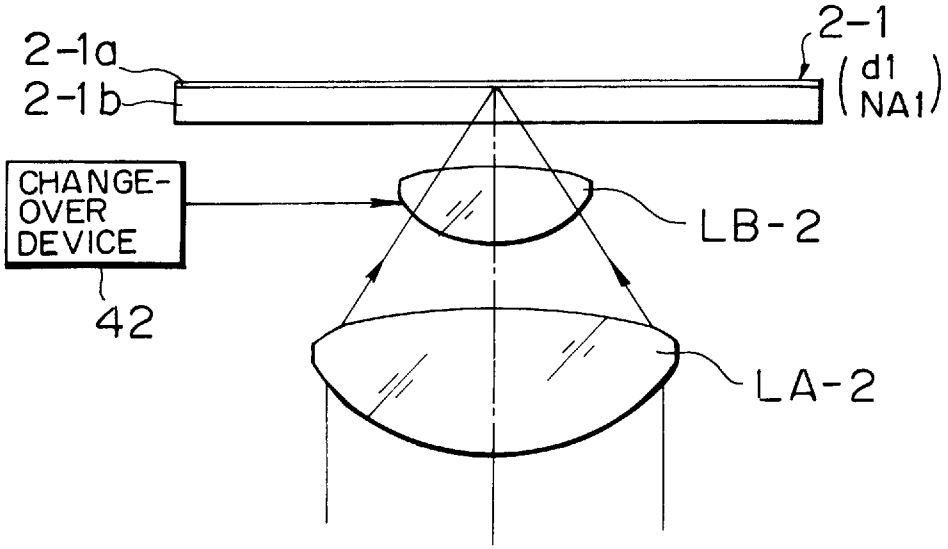

2-1
2-1a
2-1b
(d1
NA1)
CHANGE-
OVER
DEVICE
42
LB-2
LA-2

FIG. 7

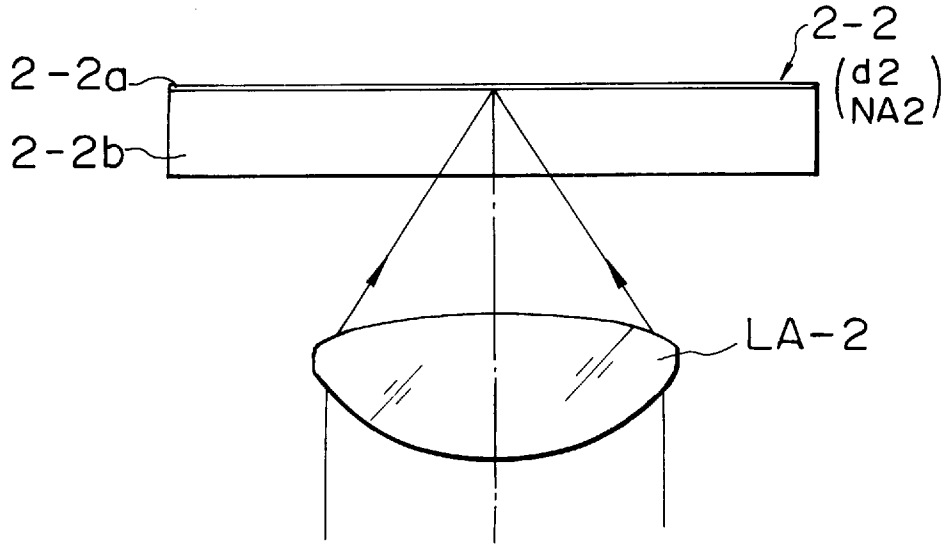

2-2
2-2a
2-2b
(d2
NA2)
LA-2

FIG. 8

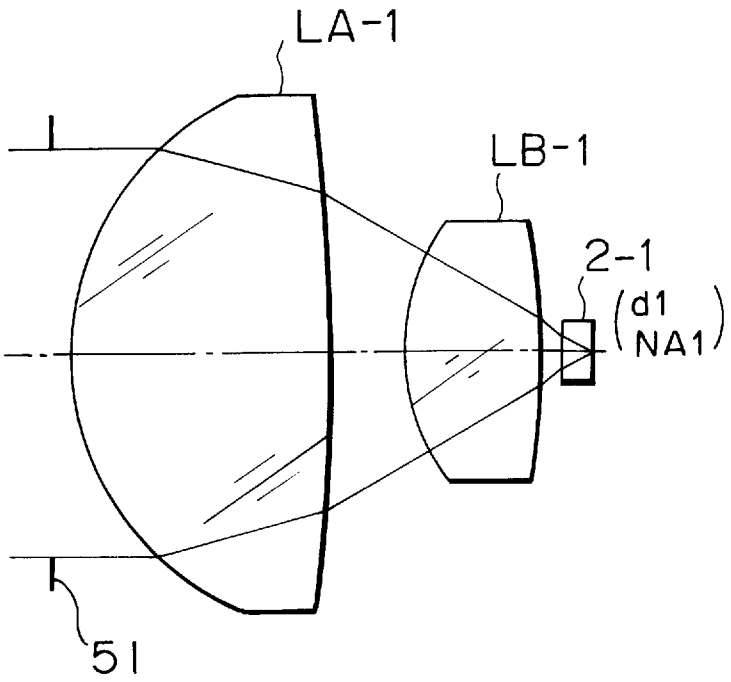


FIG. 9

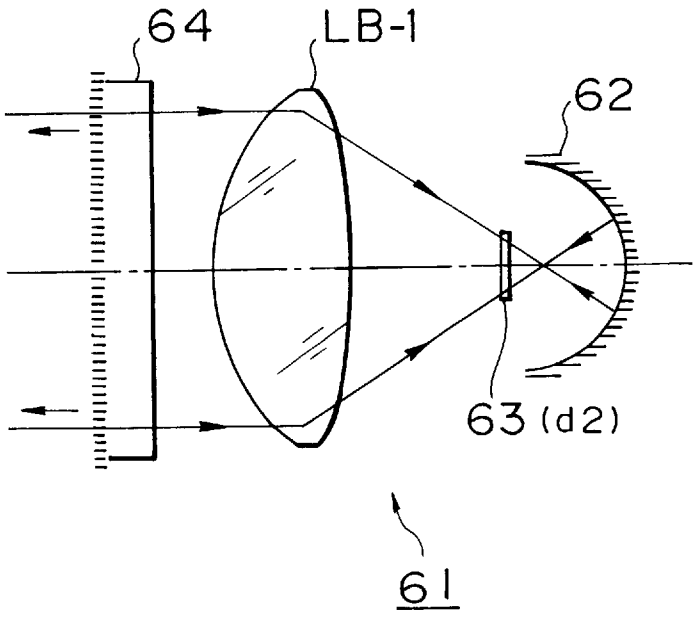


FIG. 10

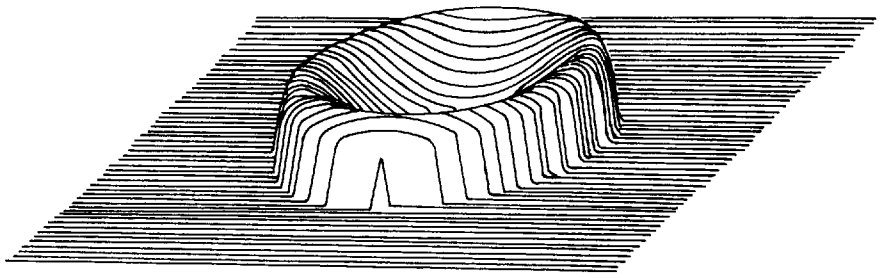


FIG. 11

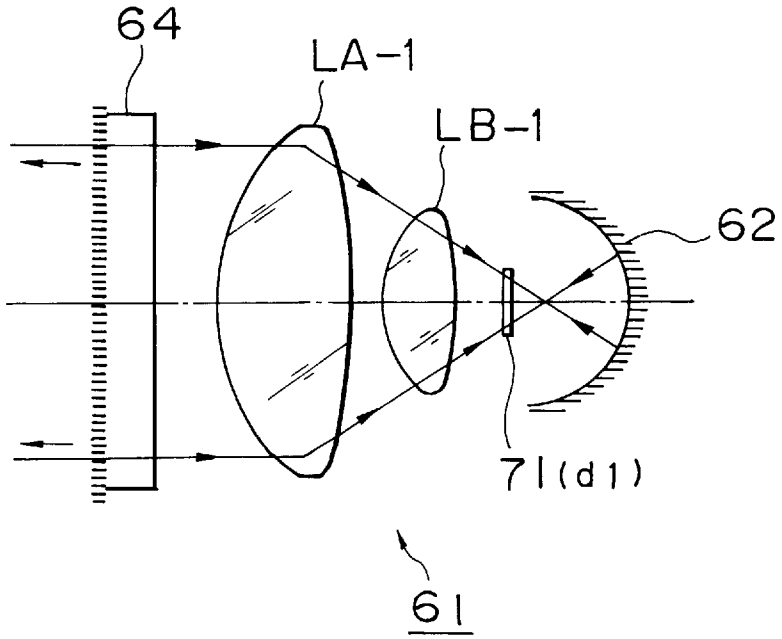


FIG. 12

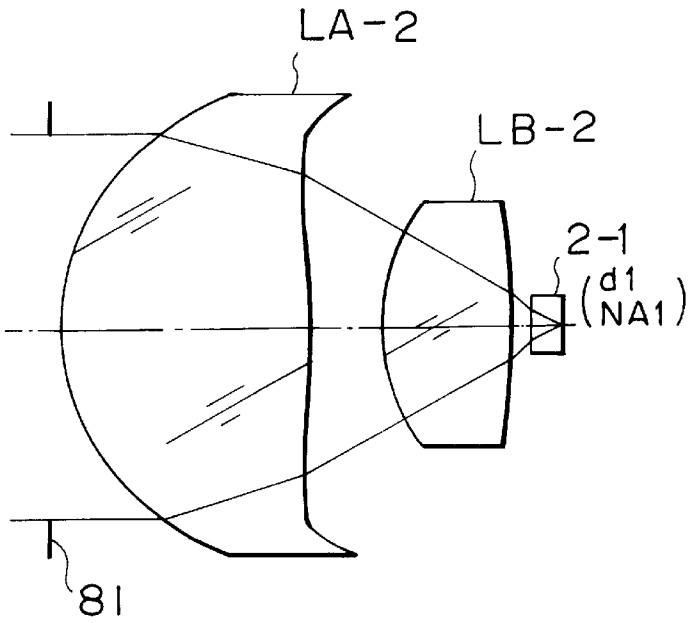


FIG. 13

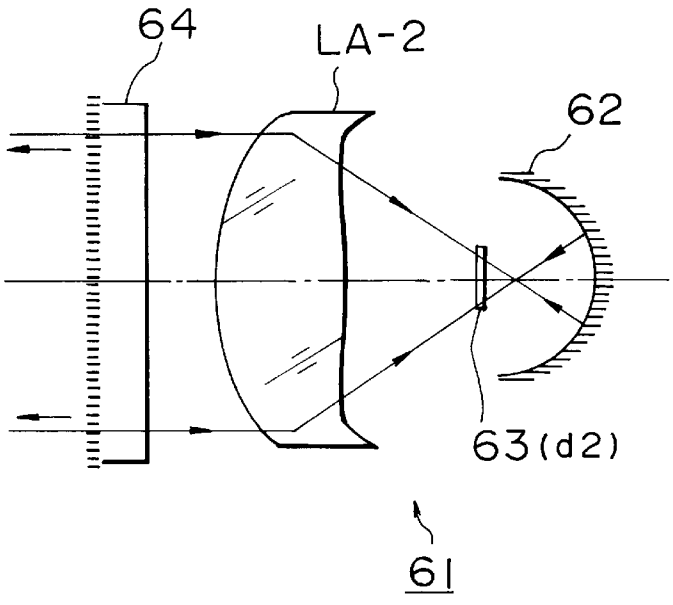


FIG. 14

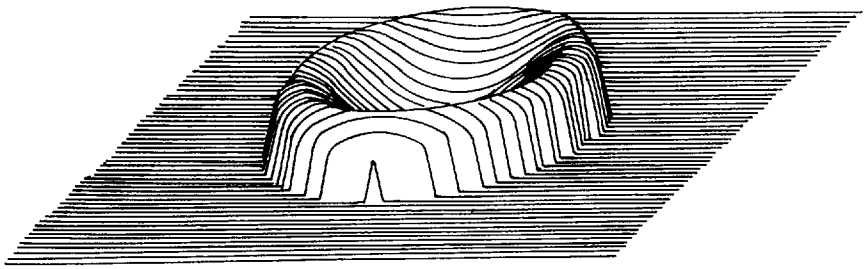


FIG. 15

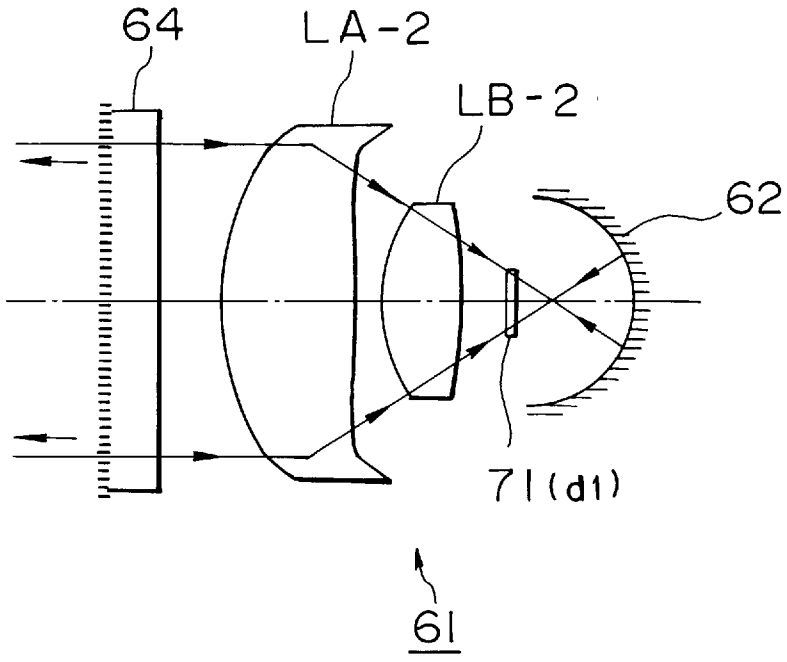


FIG. 16
PRIOR ART

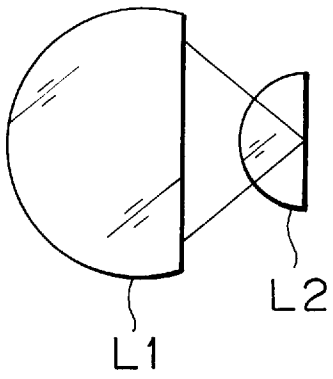
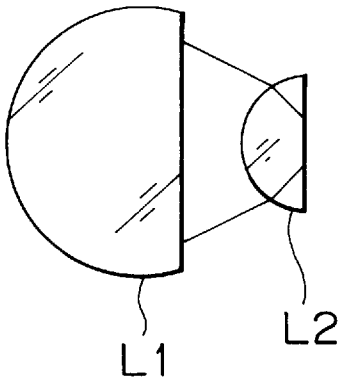


FIG. 17
PRIOR ART



LENS DESIGNING METHOD AND OBJECTIVE LENS APPARATUS WITH TWO LENSES

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention broadly relates to a lens designing method, and, more particularly, to a lens designing method for separately determining the aberrations of a first lens and a second lens forming a two lens assembly which allows the numerical aperture NA to be increased and records or reproduces information of two recording media having different substrate thicknesses.

2. Description of the Related Art

In recent years, the moving picture expert group (MPEG) system has put into practical use a technique for performing recording and reproducing operations on a recording medium by compressing image signals and audio signals to a high density. In the audio visual (AD) field, the digital video disk (DVD) is drawing attention as the next generation optical disk recording medium, while in the computer field, the optical disk for high-capacity recording by opto-magnetic recording method or phase change method is drawing attention as the next generation optical disk recording medium. A DVD for recording thereon image signals and audio signals based on MPEG and an optical disk for recording thereon a large quantity of data than was previously possible have been proposed.

Accordingly, in order to record digital data at a high density onto, for example, a DVD or other recording media allowing high capacity recording, it is necessary to decrease the size of the spot formed by the light beam compared to the sizes of spots formed on conventional recording media such as compact disks (CD).

When the spot size of the light beam has radius R, the objective lens has an exit angle θ, and the light beam has a wavelength λ., the radius R of the spot size of the light beam is roughly:

$$R=0.32\lambda/\mathrm{SIN}\ \theta \quad (1)$$

From Formula (1), the spot size of the light beam is reduced by decreasing the wavelength λ of the light beam and increasing the numerical aperture NA of the objective lens (SIN θ (=n*SIN θ: In air, the index of refraction N is 1).

Although the numerical aperture NA can be made larger by increasing the diameter of the objective lens, this not only results in a larger optical head which records or reproduces information on and from a disk, but also makes it difficult to perform focusing control and tracking control operations due to a larger mass.

To overcome the above-described problems, the use of a solid immersion lens has been proposed, which is disclosed, for example, in U.S. Pat. No. 5,125,750, to irradiate a recording light beam or a reproducing light beam onto a disk.

In the proposal, as illustrated for example in FIG. **16**, a light beam is converged by an objective lens L1 and impinges upon a solid immersion lens having a spherical light-entering surface and a planar light-exiting surface. From the objective lens L1, the light beam impinges perpendicular to the spherical surface of the solid immersion lens L2, so that the light beam converges at the center of the planar light-exiting surface. Accordingly, when the index of refraction of the solid immersion lens L2 is n, the numerical aperture NA of the objective lens L1 can be made substantially n times the original value.

However, since it is actually necessary to converge the light beam from the solid immersion lens L2 onto a disk (not shown), the thickness of the solid immersion lens L2 is set at a value which is smaller by an amount corresponding to the thickness of the substrate of the disk, such that the light beam actually converges on the disk.

In order to obtain a large NA, the light beam from the objective lens L1 is slightly refracted at the spherical surface of the solid immersion lens L2, as shown in FIG. **17**.

In order to produce an objective lens apparatus with, for example, a single lens in order to converge the light beam on the disk, it is necessary to form the spherical surface of the objective lens apparatus into a perfectly spherical surface to correct wave aberration of the objective lens apparatus. Therefore, it is difficult to precisely produce the die used to produce a glass molded objective lens.

Therefore, accurate production of an objective lens is ordinarily achieved by repeating the processes of measuring the aberration occurring in the objective lens formed by a predetermined die using, for example, an interferometer, modifying the die of the objective lens based on the measurement results, and producing an objective lens using the modified die, when necessary.

However, when the lens apparatus for converging the light beam is formed by a two lens assembly as described above, it becomes necessary to produce each lens such that no aberration occurs when these two lenses are combined. The individual lenses obviously have predetermined aberrations, so that it is difficult to use the conventional producing method which consists in using, for example, an interferometer to measure the aberrations occurring in the two combined lenses and modifying the dies used for producing the lenses, based on the measurement results. In addition, since the individual lenses have predetermined aberrations when an aberration occurs in the produced two lens assembly, it becomes difficult to judge which lens needs to be corrected for aberration and the manner in which the lens needs to be corrected. As a result, the aberration of the produced two lens assembly cannot be easily corrected, thus making it difficult to produce the two lens assembly based exactly on the design values.

SUMMARY OF THE INVENTION

Accordingly, in view of the above-described problems, an object of the present invention is to make it possible to separately determine the aberration of each lens of a two lens assembly, and separately produce each lens, thereby facilitating production of a two lens assembly having no aberration.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram showing the construction of an embodiment of a recording medium reproducing apparatus **1** to which a lens designing method in accordance with the present invention is applied;

FIG. **2** is a diagram showing the construction of the optical pickup **23** of an embodiment in accordance with the present invention.

FIG. **3** is an enlarged view of the actuating portion of the two lenses of the optical pickup **23**.

FIG. **4** is a diagram showing the construction of a two lens assembly in Embodiment 1 of the present invention.

FIG. **5** is a diagram showing the first lens LA-1 of the two lens assembly of FIG. **4** moved out of an optical path.

FIG. **6** is a diagram showing the construction of a two lens assembly in Embodiment 2 of the present invention.

FIG. **7** is a diagram showing the second lens LB-2 of the two lens assembly of FIG. **6** moved out of an optical path.

FIG. **8** is a diagram showing the optical path when the two lens assembly of FIG. **4** is used.

FIG. **9** is a diagram showing the aberration of the second lens LB-1 of FIG. **8** with respect to the substrate **63** being measured.

FIG. **10** is a diagram illustrating the aberration of the first lens LA-1 alone.

FIG. **11** is a diagram showing the aberration of the first lens LA-1 of FIG. **8** being measured.

FIG. **12** is a diagram showing the optical path when the two lens assembly of FIG. **6** is used.

FIG. **13** is a diagram showing the aberration of the first lens LA-2 of FIG. **12** with respect to the substrate **63** being measured.

FIG. **14** is a diagram illustrating the aberration of the second lens LB-2 alone.

FIG. **15** is a diagram showing the aberration of the second lens LB-2 of FIG. **12** being measured.

FIG. **16** is a diagram illustrating the principle of a solid immersion lens.

FIG. **17** is a diagram showing the solid immersion lens being in actual use.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. **1** is a block diagram showing the construction of an embodiment of a recording medium reproducing apparatus **1** to which a lens designing method in accordance with the present invention is applied.

The spindle motor **21** is such as to rotate a disk **2** in accordance with a command generated from a rotation control circuit **22** which drives the spindle motor **21** in accordance with a command generated from a control circuit **28**.

The optical pickup **23** causes convergence of a light beam onto an information recording layer of the disk **2** in order to convert the light beam reflected from the information recording layer of the disk **2** into a reproduction signal which is output to a signal processing circuit **27**.

The thread motor **24** causes the optical pickup **23** to move to the position of the desired track of the information recording layer of the disk **2**.

The thread motor control circuit **25** causes the thread motor **24** to be driven in accordance with a command from the control circuit **28**.

The pickup control circuit **26** controls the focusing actuator and the tracking actuator in the optical pickup **23** in accordance with a command from the control circuit **28**.

The signal processing circuit **27** demodulates the reproduction signal from the optical pickup **23** and handles any signal errors. In addition, the signal processing circuit **27** detects, for example, the thickness (or type) of the substrate of the disk **2** from the RF signal level, and the detection signal is output to the control circuit **28**.

The control circuit **28** is constructed so as to output a command to the rotation control circuit **22**, the thread motor control circuit **25**, the pickup control circuit **26**, and the signal processing circuit **27**, in accordance with the command signal input through an external interface **29**. The control circuit **28** is also constructed so as to output the reproduction signal, input from the signal processing circuit **27** through the external interface **29**, to an external device.

FIG. **2** is a diagram showing the construction of the optical pickup **23** of an embodiment in accordance with the present invention.

In the optical pickup **23**, the light beam emitted from a laser diode **38** is collimated by a collimator lens **39**. The collimated light beam passes through a polarization beam splitter **33** and a ¼ wavelength plate **32**, and then impinges upon a two lens assembly comprising a first lens LA and a second lens LB having the surface facing the disk **2** formed into a planar or aspherical surface and the other surface formed into a curved, but aspherical, surface. From the two lens assembly, the light beam converges on an information recording surface of the disk **2**. In this case, a large numerical aperture NA can be obtained compared to the case where an objective lens is used singly, since the light beam is converged by the two lens assembly. In addition, recording and reproducing operations can be performed on a high-density disk.

The aforementioned light beam, reflected from the information recording surface of the disk **2** and which has passed through the two lens assembly (the second lens LB and the first lens LA) and the ¼ wavelength plate **32**, impinges upon the polarization beam splitter **33** and is reflected thereby. The reflected light passes through a focusing lens **35** and a multi-lens **36** and converges on a photodetector **37** disposed at a conjugate point in order to be converted into a reproduction signal.

The electromagnetic actuator assembly **31** comprises a focusing actuator which moves the two lens assembly in the axial direction and a tracking actuator which moves the two lens assembly so as to follow the center of a track. Therefore, the assembly **31** performs focusing servo and tracking servo operations.

FIG. **3** is an enlarged view of the actuating portion of the two lens assembly of the optical pickup **23** of FIG. **2**. In FIG. **3**, corresponding or similar parts to those of FIG. **2** are given the same reference numerals, so that descriptions thereof will be given when required.

The light beam, converged by the first lens LA, passes through the second lens LB which converges it onto a information recording surface **2***a* of the disk **2** having a substrate **2***b* formed from a light-transmitting material, such as polycarbonate, into a predetermined thickness.

The second lens LB is connected to a bobbin **101** of the first lens LA by means of an electromagnetic actuator **40**. The distance between the first lens LA and the second lens LB is controlled by the electromagnetic actuator **40** to a predetermined value, when the optical axes coincide.

A description will now be given of performing reproducing operations on two types of disks, disks **2-1** and **2—2**, having different substrate (formed from a light-transmitting material such as polycarbonate) thicknesses and numerical aperture specifications, with reference to FIGS. **4** to **7**.

FIG. **4** is a diagram showing the construction of the two lens assembly in Embodiment 1 of the present invention.

In the two lens assembly of FIG. **4**, the second lens LB-1 produces no aberration with respect to the disk **2—2** (of FIG. **5**) having a light-transmitting substrate **2—2***b* thickness of d2 and a lens numerical aperture specification of NA2, and is designed to have the numerical aperture specification value of NA2. When the first lens LA-1 is used in combination with the second lens LB-1, the first lens LA-1

produces no aberration with respect to the disk **2-1** having a light-transmitting substrate **2-1***b* thickness of d1 (where d1≦d2) and a lens numerical aperture specification value of NA1, and is designed to have the numerical aperture specification value of NA1. In the specification, "no aberration" means an aberration value which satisfies Marechal's criterion. In the present embodiment, numerical aperture NA1>numerical aperture NA2.

The change-over device **41** causes the first lens LA-1 to move in and out of the optical path, in accordance with the type of disk **2** specified by the information supplied from the pickup control circuit **26**.

More specifically, the signal processing circuit **27** detects the thickness of the substrate of the disk **2** (or type of disk **2**) from the RF signal level, and outputs the detected thickness to the control circuit **28**. In accordance with the detected thickness, the control circuit **28** supplies a predetermined control command to the change-over device **41** through the pickup control circuit **26**. As shown in FIG. **4**, the change-over device **41** causes the first lens LA-1 to move into the optical path, so that the first lens LA-1 and the second lens LB-2 of the two lens assembly are used to converge the light beam onto an information recording surface **2-1***a* of the disk **2-1** having light-transmitting substrate **2-1***b* thickness d1 and numerical aperture specification value NA1. In this case, no aberration occurs and numerical aperture specification value of NA1 is realized.

A description will now be given of the case where reproduction operations are performed on the disk **2—2**, instead of on the disk **2-1**.

In this case, the signal processing circuit **27** detects the thickness of the light-transmitting substrate of the disk **2** (or the type of disk **2**) from the RF signal level, and the detected thickness is output to the control circuit **28**. In accordance with the detected thickness, the control circuit **28** sends a predetermined control command to the change-over device **41** through the pickup control circuit **26**. In accordance with the control command, the change-over device **41** causes the first lens LA-1 to move out of the optical path, so that the optical pickup **23** is set in correspondence with the disk **2—2**, as shown in FIG. **5**.

More specifically, as shown in FIG. **5**, only the second lens LB-1 is used to converge the light beam onto the information recording surface **2—2***a* of the disk **2—2** having substrate thickness d2 and numerical aperture specification value NA2. In this case, the no aberration occurs and numerical aperture specification value of NA2 is realized.

Accordingly, it is possible to properly reproduce data on different types of disk **2** by moving the first lens LA-1 into and out of the optical path, in accordance with the disk **2** type.

FIG. **6** is a diagram showing the construction of the second lens assembly in Embodiment 2.

In the two lens assembly of FIG. **6**, the first lens LA-2 produces no aberration with respect to the disk **2—2** having substrate **2—2***b* thickness d2 and numerical aperture specification value NA2, and is designed to have numerical aperture specification value NA2 (FIG. **7**). When the second lens LB-2 is used in combination with the first lens LA-2, it produces no aberration with respect to the disk **2-1** having substrate **2-1***b* thickness d1 and numerical aperture specification value NA1, and is designed to have numerical aperture specification value NA1.

The change-over device **42** causes the second lens LB-2 to move in and out of the optical path, in accordance with the type of disk **2** specified by the information supplied from the pickup control circuit **26**.

More specifically, when the disk **2-1** is detected, the control circuit **28** controls the change-over circuit **42** through the pickup control circuit **26**, causing the second lens LB-2 to move into the optical path, as shown in FIG. **6**, so that the first lens LA-2 and the second lens LB-2 of the two lens assembly are used to converge the light beam onto the information recording surface **2-1***a* of the disk **2-1** having substrate **2-1***b* thickness d1 and numerical aperture specification value NA1. This produces no aberration and allows the numerical aperture specification of NA1 to be realized.

It will now be assumed that reproducing operations are started and performed on the disk **2—2**, instead of the disk **2-1**.

Here, in accordance with the control signal from the pickup control circuit **26**, the change-over device **42** causes the second lens LB-2 to move out of the optical path, so that the optical pickup **23** is set in correspondence with the disk **2—2**, as shown in FIG. **7**.

More specifically, as shown in FIG. **7**, only the first lens LA-2 alone is used to converge the light beam onto the information recording surface **2—2***a* of the disk **2—2** having substrate **2—2***b* thickness d2 and numerical aperture specification value NA2. This produces no aberration and allows numerical aperture specification value of NA2 to be achieved.

Accordingly, it is possible to selectively reproduce data on different disk types with the optical pickup **23** by moving the second lens LB-2 in and out of the optical path.

Although in the foregoing description, the two lens assembly comprising one second lens and one first lens was used to reproduce data on two disk types having different substrate thicknesses and numerical aperture specification values, the lens assembly may be an N lens assembly having an N number of lenses. In such a case, it is possible to reproduce data on an N number of disks having different numerical aperture specification values and substrate thicknesses with the optical pickup **23** using the lens designing method described below.

A description will now be given of the method of designing individual lenses of an N lens assembly, with reference to FIGS. **8** to **15**. FIGS. **8** to **15** illustrate the case where a two lens assembly is used to simplify the description.

A description will first be given of the method of designing the first lens LA-1 and the second lens LA-2 of the two lens assembly in the embodiments illustrated in FIGS. **4** and **5**, with reference to FIGS. **8** to **11**.

FIG. **8** shows the exact shape of a curved surface of each lens of the two lens assembly and the optical path in Embodiment 1. As shown in FIG. **8**, the light beam, which has passed through a stop **51**, passes through the first lens LA-1 and the second lens LB-1, which converge the light beam upon the disk **2-1** having numerical aperture specification value NA1 and substrate **2-1***b* thickness d1.

When the second lens LB-1 is used singly, as shown in FIG. **5**, the lens LB-1 is formed in correspondence with the disk **2—2**. Therefore, the second lens LB-1 can be designed and produced by the above-described methods involving measurement of aberration using an interferometer and modification of the die.

FIG. **9** is a diagram showing the aberration of the second lens LB-1 with respect to the thickness of the substrate **2—2***b* of the disk **2—2**, being measured with an interferometer **61**.

The light beam emitted from a light source (not shown) of the interferometer **61** passes through a reference plane **64**

and impinges upon the second lens LB-1 which converges the light beam. The converged light beam then passes through a light-transmitting substrate **63** made of the same material as that of the disk **2—2** and having substrate thickness d2, whereby an image is formed on the optical axis of the second lens LB-1. Here, the thickness d2 of the substrate **63** includes 0 thickness.

A reference spherical surface **62** whose center is defined by the imaging point located in opposing relation to the substrate **63** reflects, for example, about 4% of the total amount of the light beam. The reflected light beam travels back again through the imaging point, the substrate **63**, and the second lens LB-1, and impinges upon the reference plane **64**. The interference image on the reference plane **64** is taken by a CCD camera (not shown) of the interferometer **61**. Therefore, the aberration which occurs in the second lens LB-1 with respect to the substrate **63** can be measured in terms of the tilting of the interference image on the CCD camera.

In this way, the aberration of the second lens LB-1 with respect to the disk **2—2** (substrate **63**) is measured to modify the die of the second lens LB-1 in accordance with the measurement results. The modified die is used to repeat the step of producing the second lens LB-1 into one having a predetermined curved (aspherical) surface which sufficiently reduces aberration.

In the same way, it is possible to relatively easily produce the second lens LB-1 whose aberration is corrected with respect to the disk **2—2**.

As shown in FIG. **8**, in the case where the aberration of the first lens LA-1 alone is measured with an interferometer (with the substrate having 0 thickness) in order to form the first lens LA-1 such that it does not produce aberration when a light beam is converged onto the disk **2-1** using the two lens assembly formed by the first lens LA-1 and the second lens LB-1, it is obvious that the predetermined aberration is obtained. The aberration which occurs in such a case is illustrated in FIG. **10** showing the amount of aberration three-dimensionally in terms of height.

The aberration of the first lens LA-1 with respect to the substrate having thickness d1, is measured, while the first lens LA-1 is arranged in combination with the second lens LB-1 corrected for aberration with respect to the disk **2—2**.

FIG. **11** is a diagram showing the aberration with respect to a light-transmitting substrate **71** with a thickness of d1, being measured using the two lens assembly which is a combination of the first lens LA-1 and the second lens LB-1 previously corrected for aberration with respect to the disk **2—2**. In FIG. **11**, corresponding or similar parts to those of FIG. **9**.are given the same reference numerals, and unnecessary descriptions thereof will be omitted. Here, the thickness d1 of the substrate **71** includes zero thickness.

The substrate **71** is made of the same material and is of the same thickness as the substrate **2-1***b* of the disk **2-1**. The light beam emitted from the light source passes through the reference plane **64**, the first lens. LA-1, the second lens LB-1, and the substrate **71**, and converges on a point on the optical axis of the first lens LA-1 and the second lens LB-1. A portion of the converged light beam is reflected back by the reference spherical surface **62** through the same optical path, whereby an interference image is formed on the reference plane **64**.

In this case, the second lens LB-1 is one sufficiently corrected for aberration with respect to the substrate having thickness d2, so that the tilting of the interference image can be used to indicate the aberration of the first lens LA-1. Therefore, the die for forming a curved surface of the first lens LA-1 is modified, based on the tilting of the interference image.

Accordingly, since the aberrations of the first lens LA-1 and the second lens LB-1 of the two lens assembly can be separately determined and corrected, it is possible to easily produce the two lens assembly satisfying the specifications illustrated in FIGS. **4** and **5**. In the specifications, the first lens LA-1 and the second lens LB-1 are used to reproduce data on the disk **2-1**, while the second lens LB-1 is used to reproduce data on the disk **2—2**.

A description will now be given of the method for producing the first lens LA-2 and the second lens LB-2 of the two lens assembly in Embodiment 2 illustrated in FIGS. **6** and **7**, with reference to FIGS. **12** to **15**.

FIG. **12** is a diagram showing the exact shape of a curved surface of each lens of the two lens assembly and the optical path in Embodiment 2. As shown in FIG. **12**, the light beam, which has passed through the stop **81**, passes through the first lens LA-2 and the second lens LB-2, which converge the light beam on the disk **2-1**.

Similarly, as previously described with reference to FIG. **9**, the conventional methods are used to correct the first lens LA-2 such that it does not produce aberration with respect to the substrate with thickness d2.

More specifically, as shown in FIG. **13**, the interferometer **61** is used to measure the aberration occurring in the first lens LA-2 alone with respect to the light-transmitting substrate **63** made of the same material and having the same thickness as those of the substrate of the disk **2—2**.

The light beam, emitted from the light source, passes through the reference plane **64** and impinges upon the first lens LA-2 which converges the light beam. The converged light beam passes through the substrate **63** with thickness d2 to form an image on the optical axis of the first lens LA-2. Part of the light beam is then reflected back by the reference spherical surface **62** through the same optical path to form an interference image on the reference plane **64**.

Accordingly, the aberration occurring in the first lens LA-1 with respect to the disk **2—2** (substrate **63**), is measured in order to modify the die for forming the first lens LA-2, based on the measurement results.

As with the case illustrated in FIG. **8**, in the case where the aberration of the second lens LB-2 alone is measured with the interferometer **61** (with the substrate thickness being 0) such that the second lens LB-2 does not produce aberration when a light beam is converged onto the disk **2-1** using the two lens assembly comprising the first lens LA-2 and the second lens LB-2, the predetermined aberration is obviously obtained. The aberration which occurs in this case is illustrated in FIG. **14**.

Accordingly, the aberration of the second lens LB-2 with respect to the substrate thickness d1, is measured, while the second lens LB-2 is arranged in combination with the first lens LA-2 corrected for aberration with respect to the disk **2—2**.

FIG. **15** is a diagram illustrating the aberration of the second lens LB-2 with respect to the substrate with thickness d1, being measured using the two lens assembly which is combination of the second lens LB-2 and the first lens LA-2 previously corrected for aberration with respect to the disk **2—2**.

The light-transmitting substrate **71** is made of the same material and is of the same thickness as the substrate of the disk **2-1**. The light beam emitted from the light source

travels through the reference plane **64**, the first lens LA-2, the second lens LB-2, and the substrate **71** and converges on a point on the optical axis of the first lens LA-2 and the second lens LB-2. Then, part of the light beam is reflected back by the reference spherical surface **62** through the same path to form an interference image on the reference plane **64** in correspondence with the aberration.

In this case, the first lens LA-2 is one which has been sufficiently corrected for aberration with respect to the thickness d2 of the substrate, so that the tilting of the interference image can be used to indicate the aberration of the second lens LB-2. Therefore, the die used for forming a curved surface of the second lens LB-2 is modified based on the tilting of the interference image. Although the substrate **63** and the substrate **71** were used in the description, the same substrate may be used. In such a case, only one type of substrate is used.

Accordingly, since the aberrations of the first lens LA-2 and the second lens LB-2 of the two lens assembly can be separately determined and corrected, it is possible to easily produce the two lens assembly satisfying the specifications illustrated in FIGS. **6** and **7**. In the specifications, the first lens LA-2 and the second lens LB-2 are used to reproduce data on the disk **2-1**, while the first lens LA-2 is used to reproduce data on the disk **2—2**.

Although in the foregoing description, the lens designing method was used for a two lens assembly, the designing method may similarly be used for an N lens assembly consisting of an N number of lenses. In such a case, for example, the Nth lens opposing the disk has no aberration with respect to a predetermined substrate thickness, when it is combined with a previously corrected (N-1)th lens.

Accordingly, it is possible to separately determine the aberrations of the first lens and second lens of the two lens assembly, and easily correct the aberrations. In addition, using one pickup including the two lenses makes it possible to achieve a large numerical aperture NA in correspondence with a high-density optical disk, and moving one of the lenses in and out of the optical path allows reproducing operations to be performed on disks with different numerical aperture specification values and substrate thicknesses.

In addition, it is possible to realize a recording medium reproducing apparatus in correspondence with an N number of disks by designing the N lens assembly formed by an N number of lenses as described above.

The present invention can be applied to information recording as well as information recording or reproduction of information of recording media other than disks. In addition, the present invention can be applied to an infinite optical system as well as to a finite optical system.

What is claimed is:

1. A method for designing an objective lens apparatus including at least two lenses, a first lens and a second lens, said method comprising the steps of:

measuring aberration which occurs when a light beam is converged by said first lens;

setting said first lens such that the aberration occurring in said first lens satisfies Maréchal's criterion, in accordance with the measurement results;

measuring aberration which occurs when a light beam is converged by said first lens and said second lens; and

setting said second lens such that the aberrations occurring in said first lens and said second lens satisfy Maréchal's criterion, in accordance with the measurement results.

2. A method according to claim **1**, wherein the light beam converged by said first lens irradiates a first medium having a light-transmitting substrate with a first thickness, wherein the light beam converged by said first lens and said second lens irradiates a second medium having a light-transmitting substrate with a second thickness, and wherein the light-transmitting substrate of at least one of the first and second media has a thickness of 0.

3. A method according to claim **1**, wherein the light beam converged by said first lens irradiates a first medium having a light-transmitting substrate with a first thickness, wherein the light beam converged by said first lens and said second lens irradiates a second medium having a light-transmitting substrate with a second thickness, and wherein the light-transmitting substrates of each of the first and second media have the same thickness.

4. A method according to claim **1**, wherein the light beam converged by said first lens and the light beam converged by said first lens and said second lens irradiate the same common medium.

5. A method according to claim **1**, wherein said first lens and said second lens are arranged along the direction in which the light beam impinges upon said lenses, and wherein said second lens has the surface facing said first lens formed into an aspherical surface and the opposite surface thereof formed into a planar surface or an aspherical surface.

6. A method according to claim **5**, wherein said second lens has a smaller diameter than that of said first lens.

7. A method according to claim **1**, wherein said second lens and said first lens are arranged in the direction in which the light beam impinges upon said lenses, and wherein said first lens has the surface facing said second lens formed into an aspherical surface and the surface facing said medium formed into a planar surface or an aspherical surface.

8. A method according to claim **7**, wherein said first lens has a smaller diameter than that of said second lens.

9. A method according to claim **1**, wherein the aberration is measured with an interferometer.

10. A method according to claim **1**, wherein the aberrations of said first lens and said second lens are corrected by producing dies for molding each of said lenses.

11. An objective lens apparatus including at least two lenses, said apparatus comprising:

a first lens which is set such that aberration, occurring when light converges on a first medium having a light-transmitting substrate with a first thickness, satisfies Maréchal's criterion; and

a second lens which is set such that aberration, occurring when light converges on a second medium having a light-transmitting substrate with a second thickness by said first lens and said second lens, satisfies Maréchal's criterion.

12. An apparatus according to claim **11**, wherein said second lens is disposed between said first lens and said second medium, and wherein said first lens has the surface facing said first lens formed into an aspherical surface and the surface facing said medium formed into a planar surface or an aspherical surface.

13. An apparatus according to claim **12**, wherein said second lens has a smaller diameter than said first lens.

14. An apparatus according to claim **11**, wherein said first lens is disposed between said second lens and said second medium, and wherein said second lens has the surface facing said second lens formed into an aspherical surface and the opposite surface thereof formed into a planar surface or an aspherical surface.

15. An apparatus according to claim **14**, wherein said first lens has a smaller diameter than that of said second lens.

16. An apparatus according to claim 11, further comprising change-over means for selectively changing over optical paths, where the light beam from a light source is converged onto said medium, between a first light path where the light beam is converged by said first lens and a second light path where the light beam is converged by said first lens and said second lens.

17. An apparatus according to claim 11, further comprising moving means for moving either one of said first lens and said second lens away from the optical path where the light beam from the light source is converged on said medium.

18. An apparatus according to claim 11, further comprising actuating means for allowing said first lens and said second lens to be movably supported in the axial direction of said first lens and said second lens and in a direction perpendicular to the axial direction.

19. An apparatus according to claim 11, wherein said first lens and said second lens are supported so as to be movable relative to each other.

* * * * *

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United States Patent [19]

Komma et al.

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[45] Date of Patent: Sep. 29, 1998

[54] **COMPOUND OBJECTIVE LENS HAVING TWO FOCAL POINTS**

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[73] Assignee: **Matsushita Electric Industrial Co., Ltd.**, Osaka, Japan

[21] Appl. No.: **455,934**

[22] Filed: **May 31, 1995**

Related U.S. Application Data

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[30] **Foreign Application Priority Data**

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Aug. 4, 1993 [JP] Japan 5-193353

[51] **Int. Cl.**[6] **G02B 5/32**; G02B 3/10; G02B 3/08; G02B 7/00

[52] **U.S. Cl.** **359/19**; 359/569; 359/570; 359/721; 359/743; 369/103; 369/112; 369/44.23

[58] **Field of Search** 359/565, 566, 359/569, 570, 571, 574, 575, 721, 743, 19; 369/103, 44.23, 94, 112

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Primary Examiner—Jon W. Henry
Attorney, Agent, or Firm—Lowe Hauptman Gopstein Gilman & Berner

[57] **ABSTRACT**

A compound objective lens is composed of a hologram lens or transmitting a part of incident light without any diffraction to form a beam of transmitted light and diffracting a remaining part of the incident light to form a beam of first-order diffracted light, and an objective lens for converging the transmitted light to form a first converging spot on a front surface of a thin type of first information medium and converging the diffracted light to form a second converging spot on a front surface of a thick type of second information medium. Because the hologram selectively functions as a concave lens for the diffracted light, a curvature of the transmitted light differs from that of the diffracted light. Therefore, even though the first and second information mediums have different thicknesses, the transmitted light incident on rear surface of the first information medium is converged on the its front surface, and the diffracted light incident on a rear surface of the second information medium is converged on the its front surface. That is, the compound objective lens has two focal points.

18 Claims, 48 Drawing Sheets

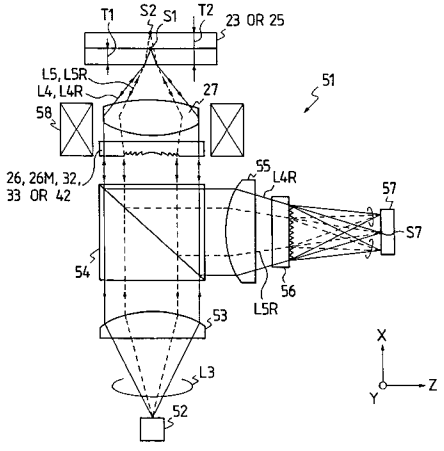

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FIG. 1
PRIOR ART

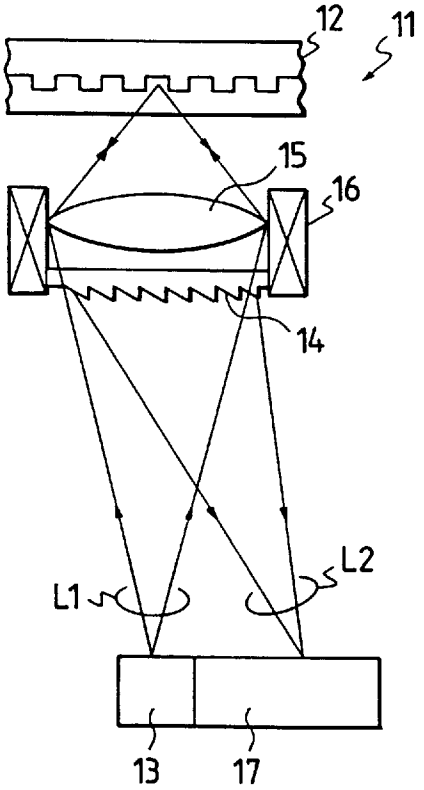


FIG. 2A
PRIOR ART

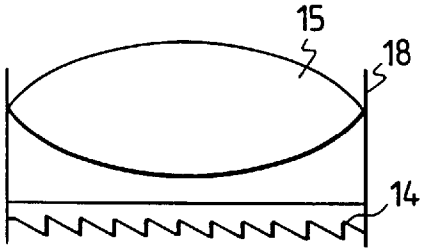


FIG. 2B
PRIOR ART

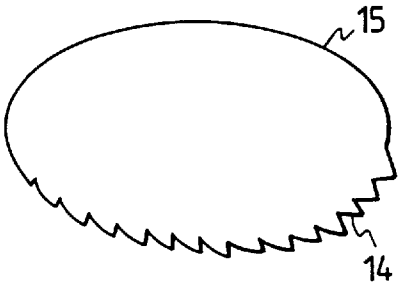


FIG. 3 PRIOR ART

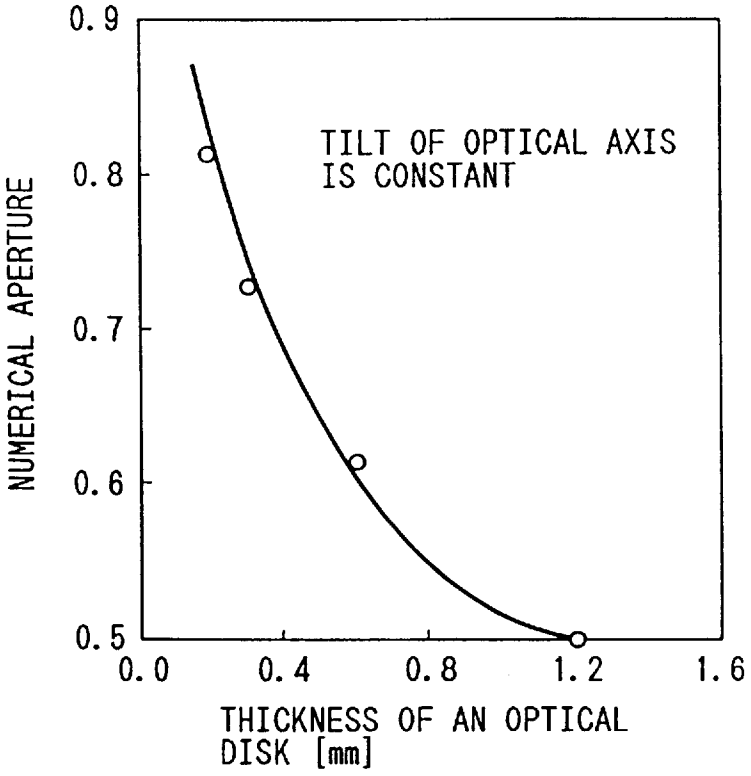


FIG. 4A

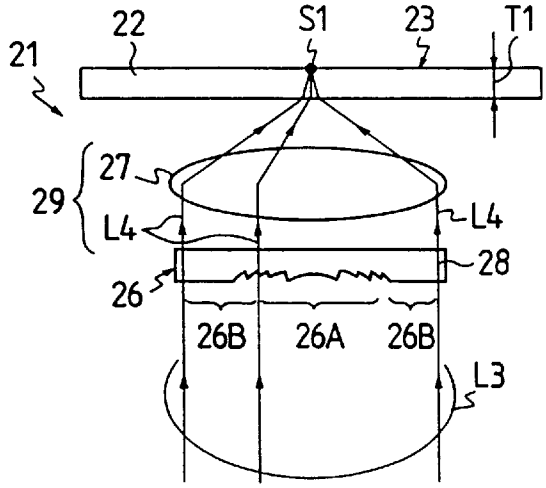


FIG. 4B

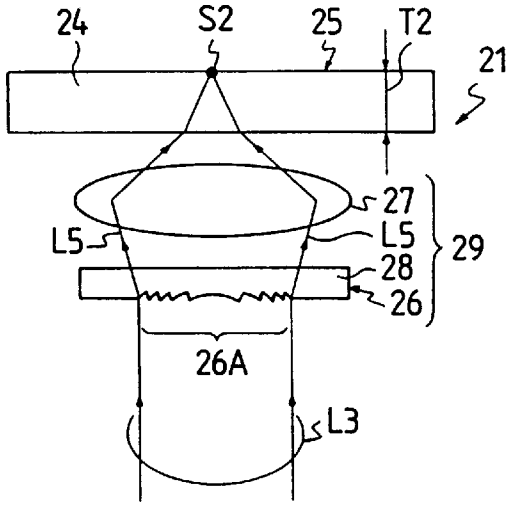


FIG. 5

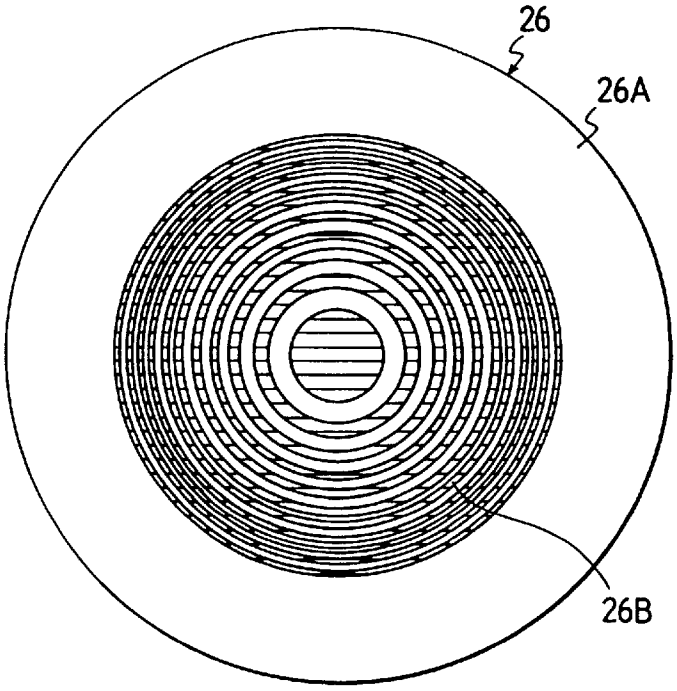


FIG. 6

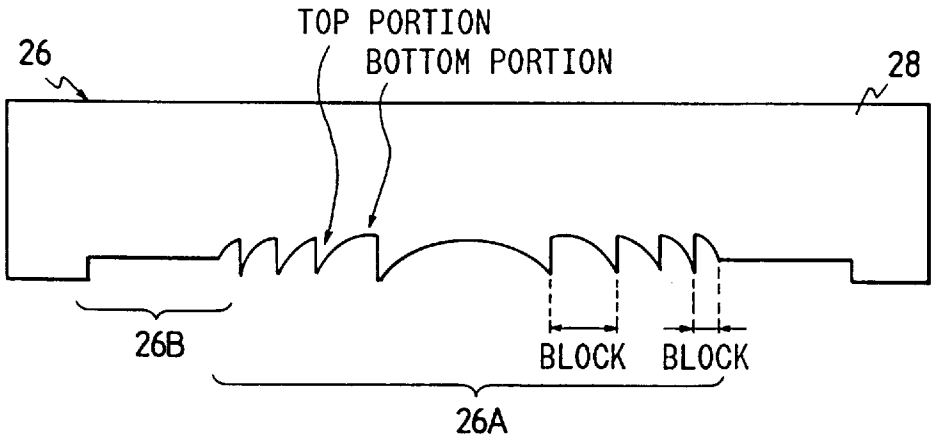

TOP PORTION
BOTTOM PORTION
26
28
26B
BLOCK
BLOCK
26A

FIG. 7

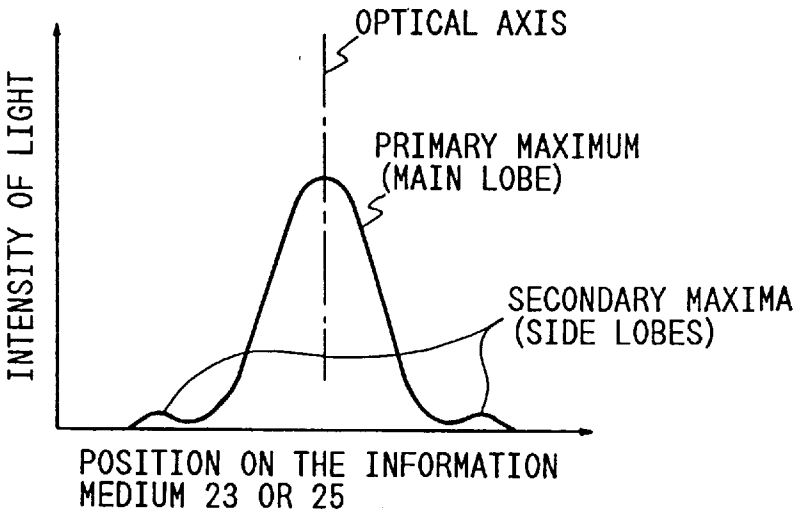

OPTICAL AXIS
PRIMARY MAXIMUM
(MAIN LOBE)
SECONDARY MAXIMA
(SIDE LOBES)
INTENSITY OF LIGHT
POSITION ON THE INFORMATION
MEDIUM 23 OR 25

FIG. 8A

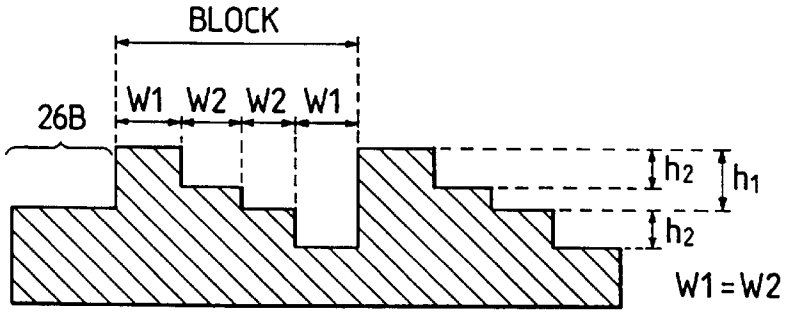


FIG. 8B

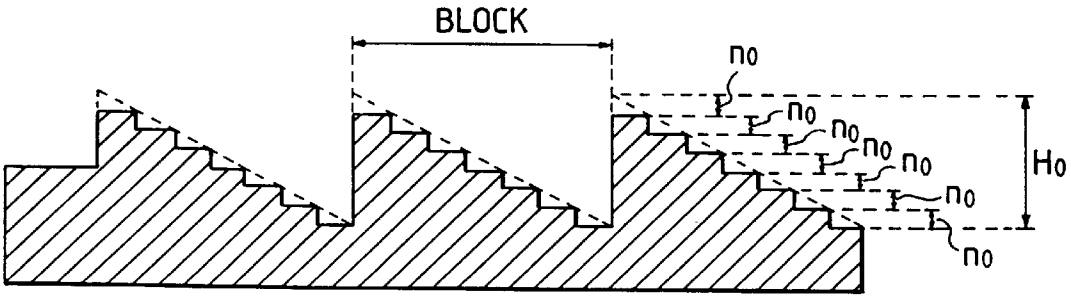


FIG. 9A

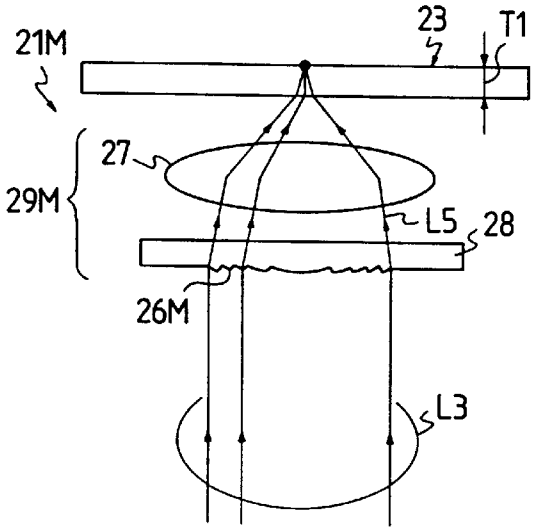


FIG. 9B

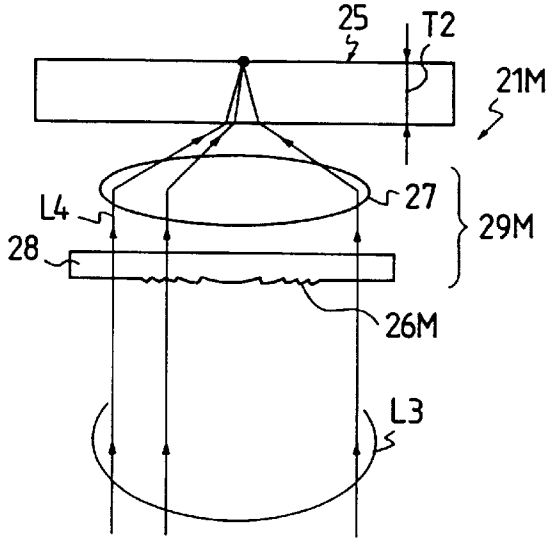


FIG. 10A

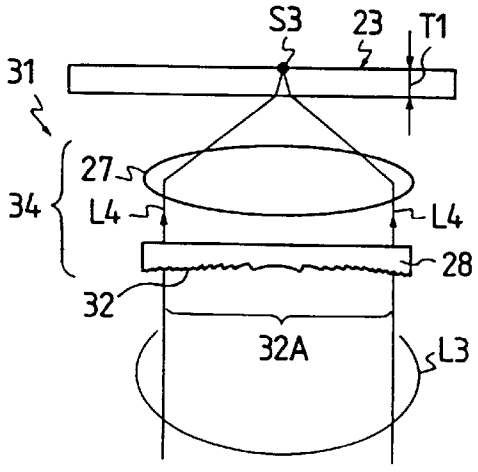


FIG. 10B

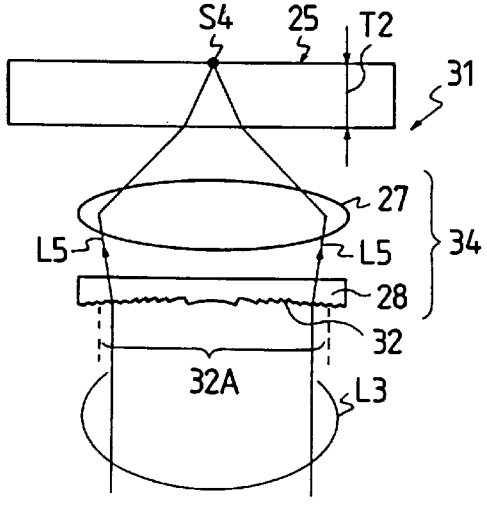


FIG. 11

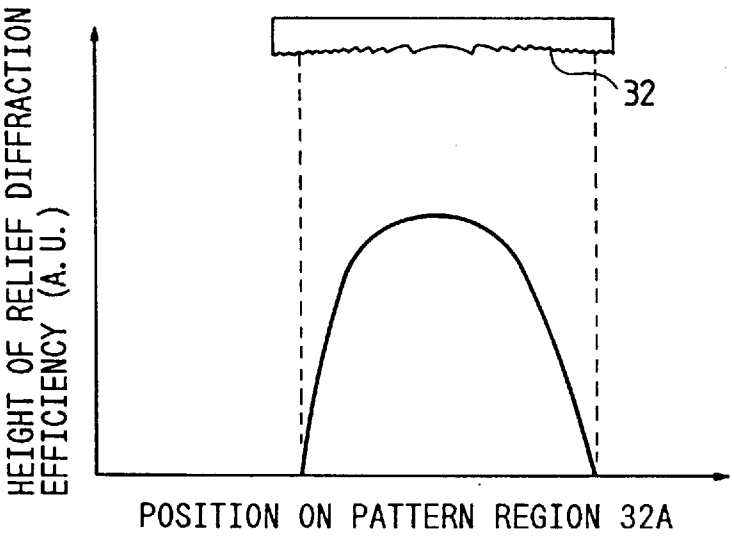

HEIGHT OF RELIEF DIFFRACTION EFFICIENCY (A.U.)
32
POSITION ON PATTERN REGION 32A

FIG. 12A

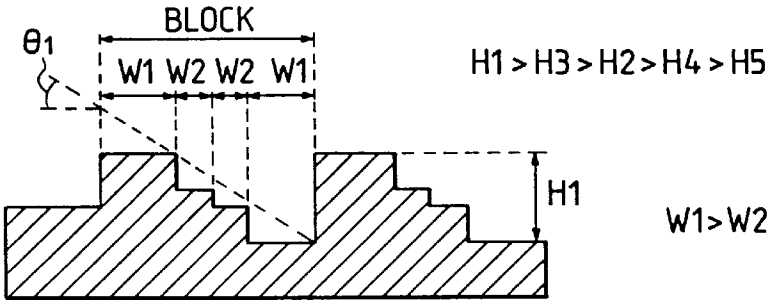


FIG. 12B

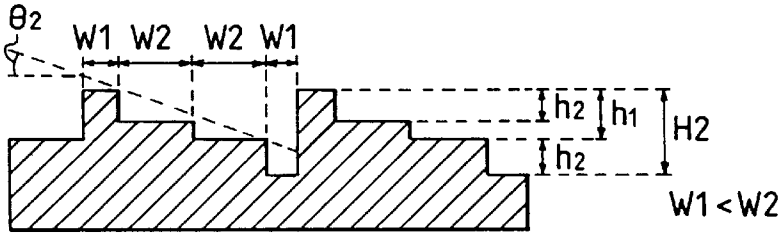


FIG. 12C

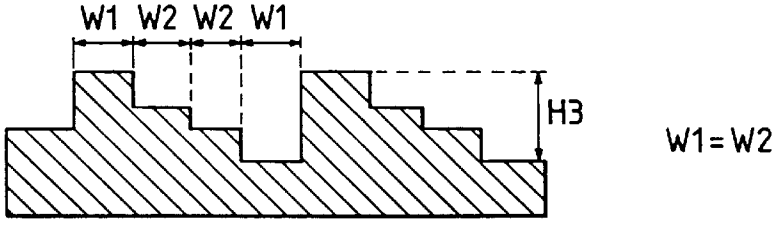


FIG. 12D

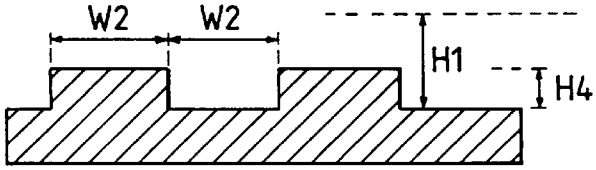


FIG. 12E

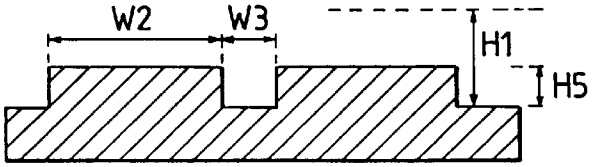


FIG. 13A

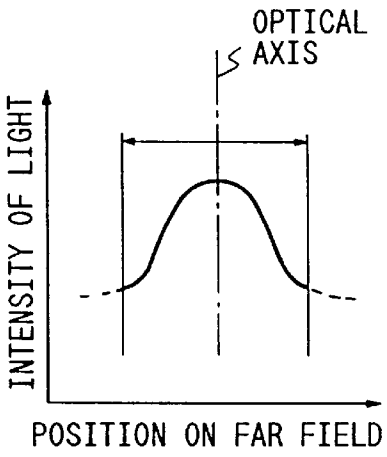


FIG. 13B

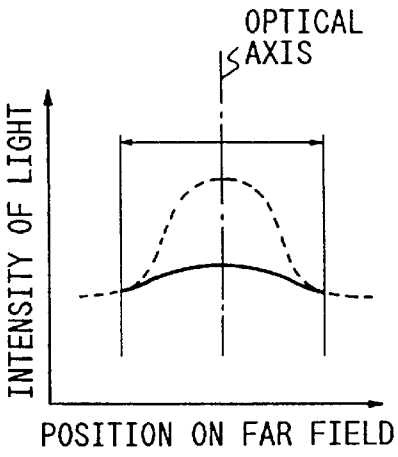


FIG. 14A

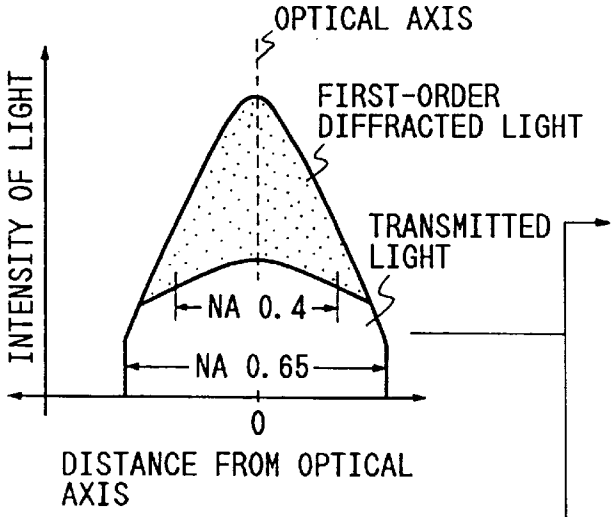


FIG. 14B

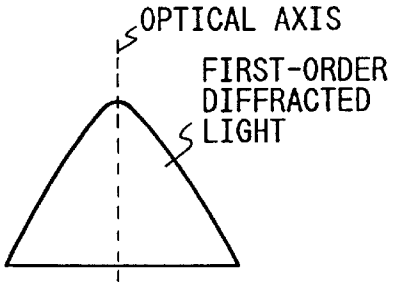


FIG. 14C

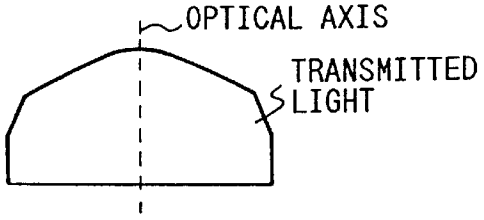


FIG. 15A

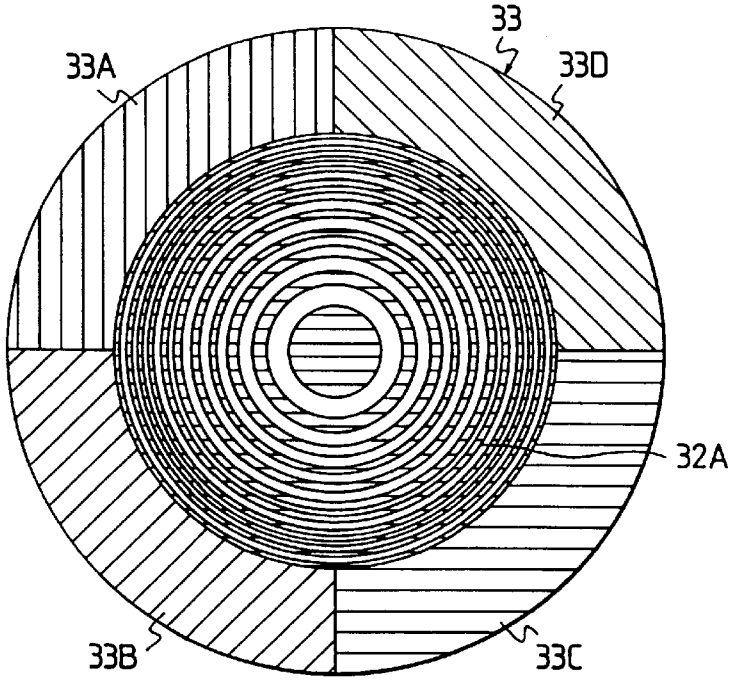


FIG. 15B

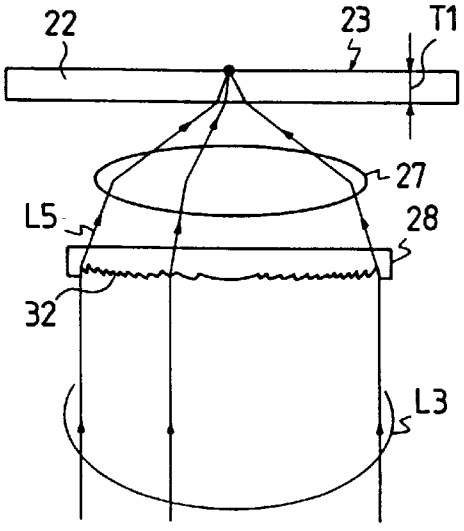


FIG. 15C

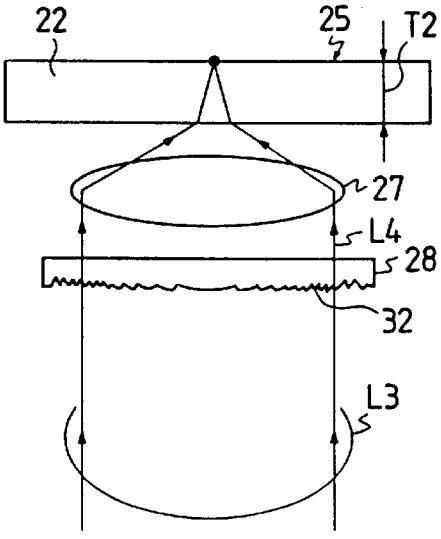


FIG. 16A

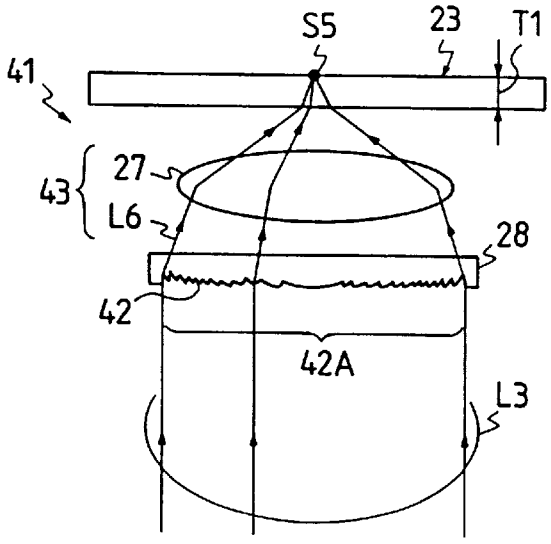


FIG. 16B

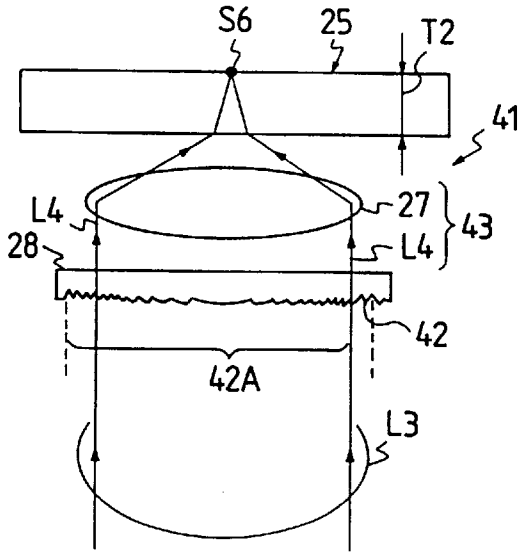


FIG. 17

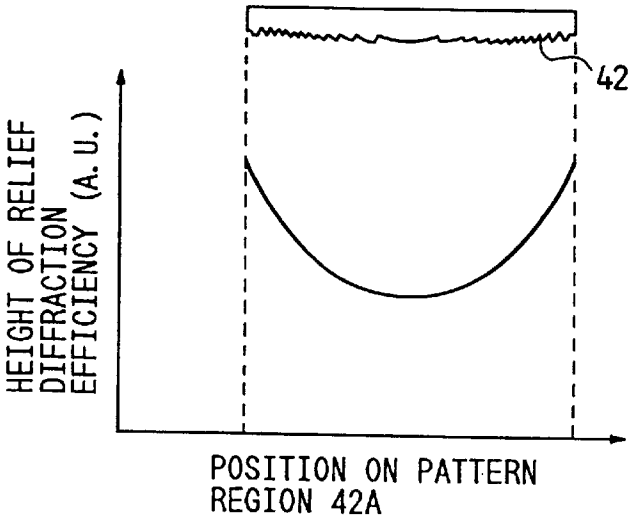


FIG. 18A

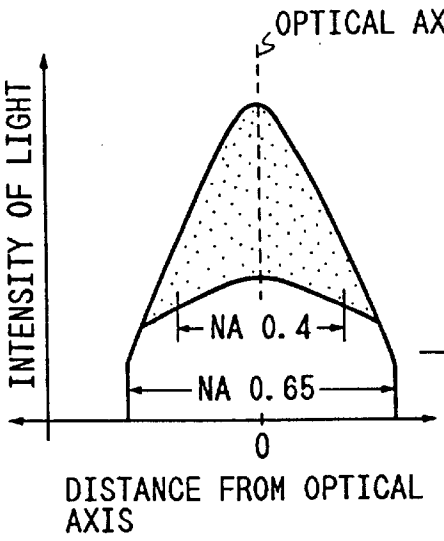


FIG. 18B

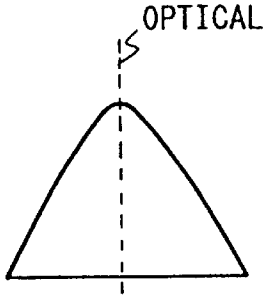


FIG. 18C

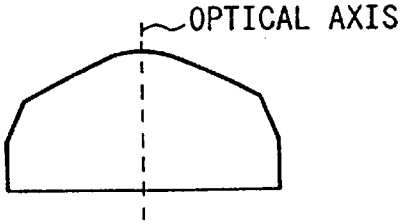


FIG. 19A

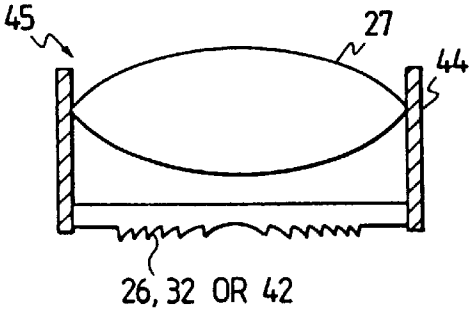


FIG. 19B

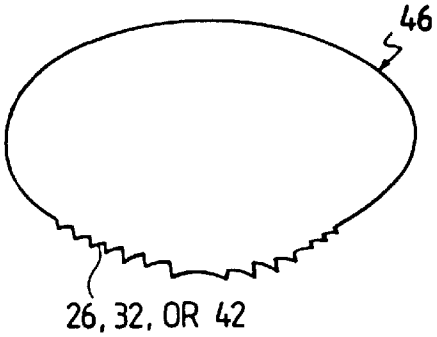


FIG. 20

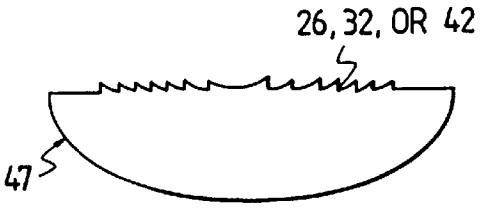


FIG. 21

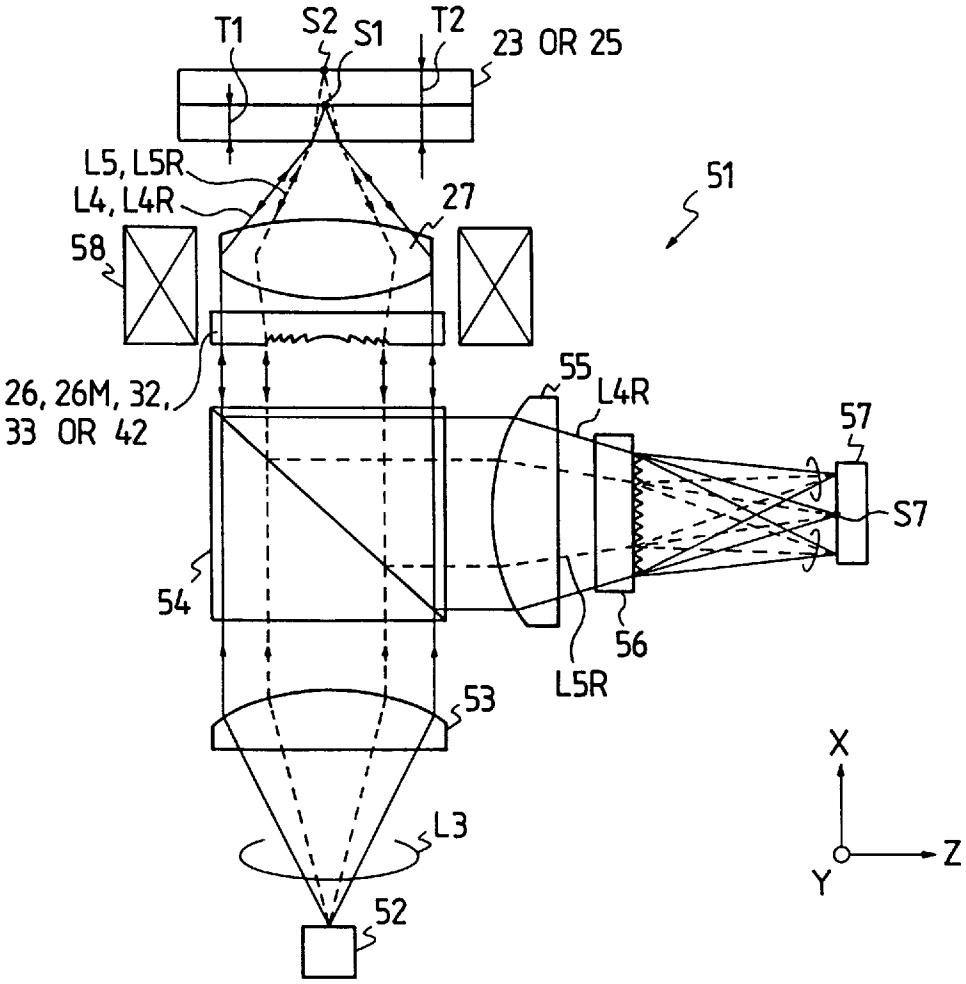

T1
S2
S1
T2
23 OR 25
L5, L5R
L4, L4R
27
51
58
26, 26M, 32,
33 OR 42
55
L4R
57
S7
54
56
L5R
53
L3
52
X
Z
Y

FIG. 22

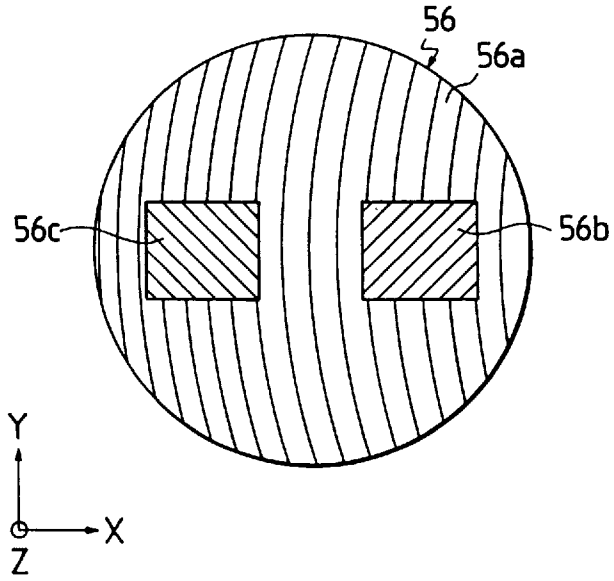


FIG. 23

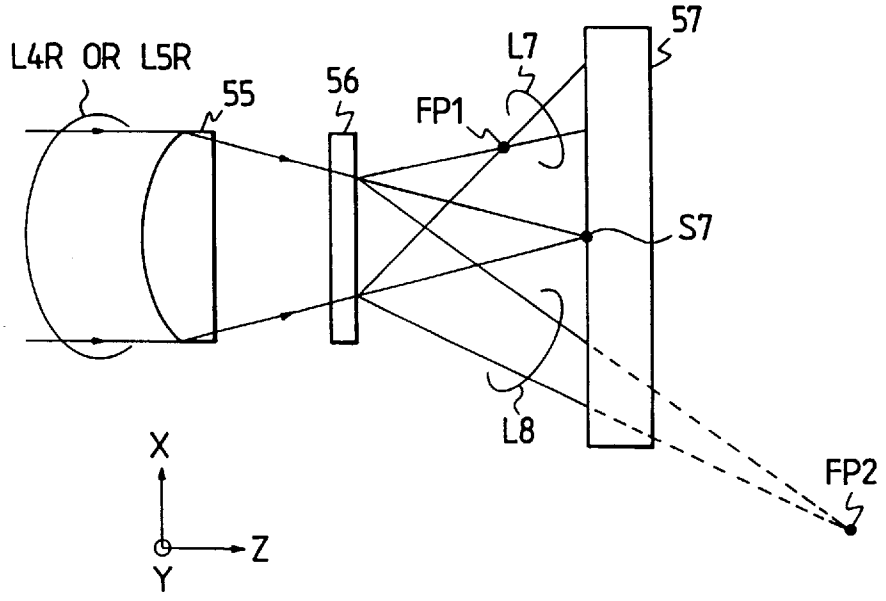


FIG. 24

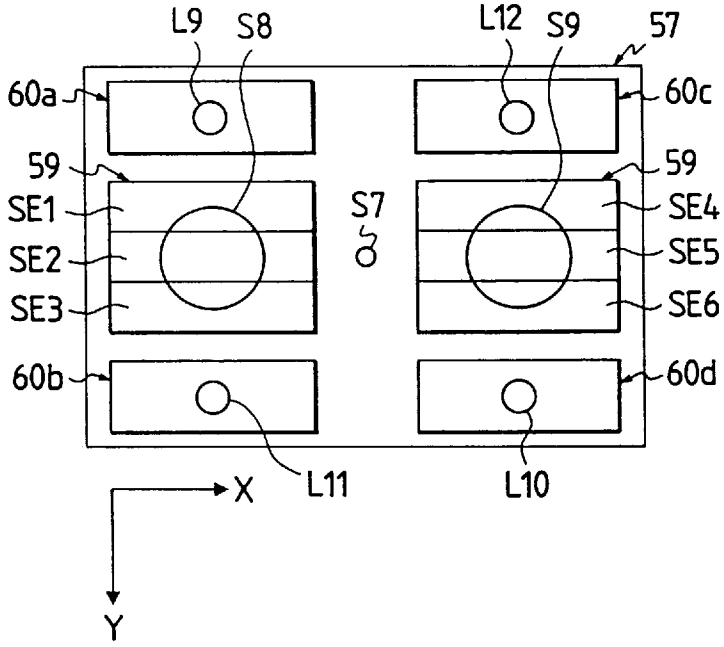


FIG. 25A

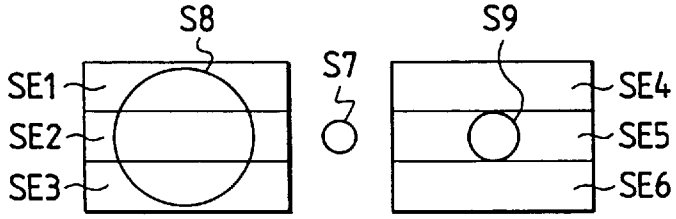


FIG. 25B

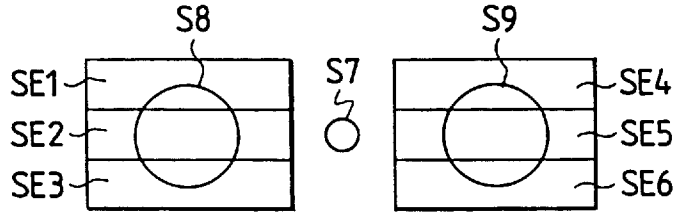


FIG. 25C

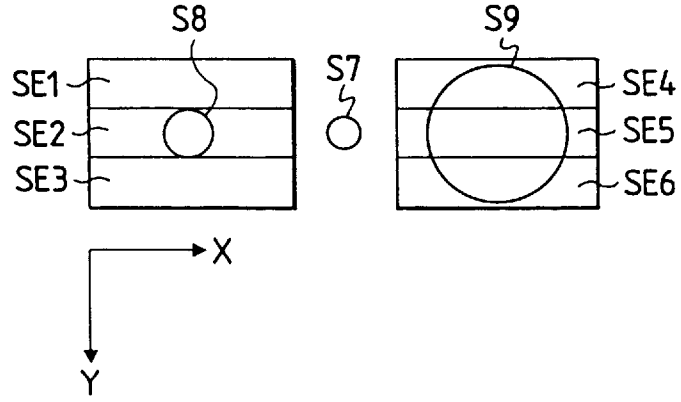
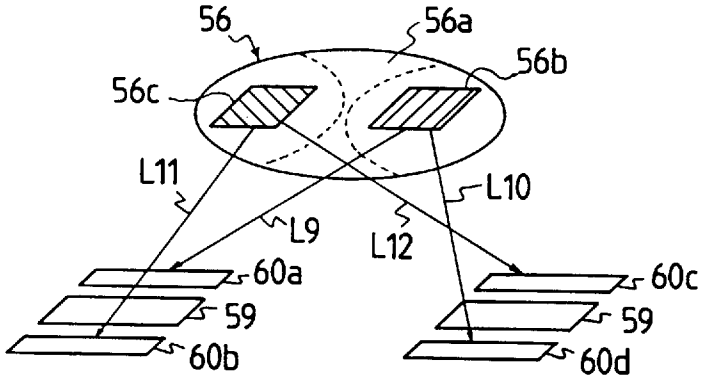


FIG. 26


56
56a
56b
56c
L11
L9
L12
L10
60a
60c
59
59
60b
60d

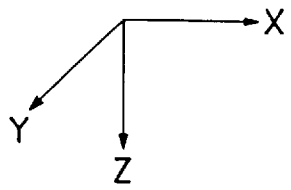

X
Y
Z

FIG. 27

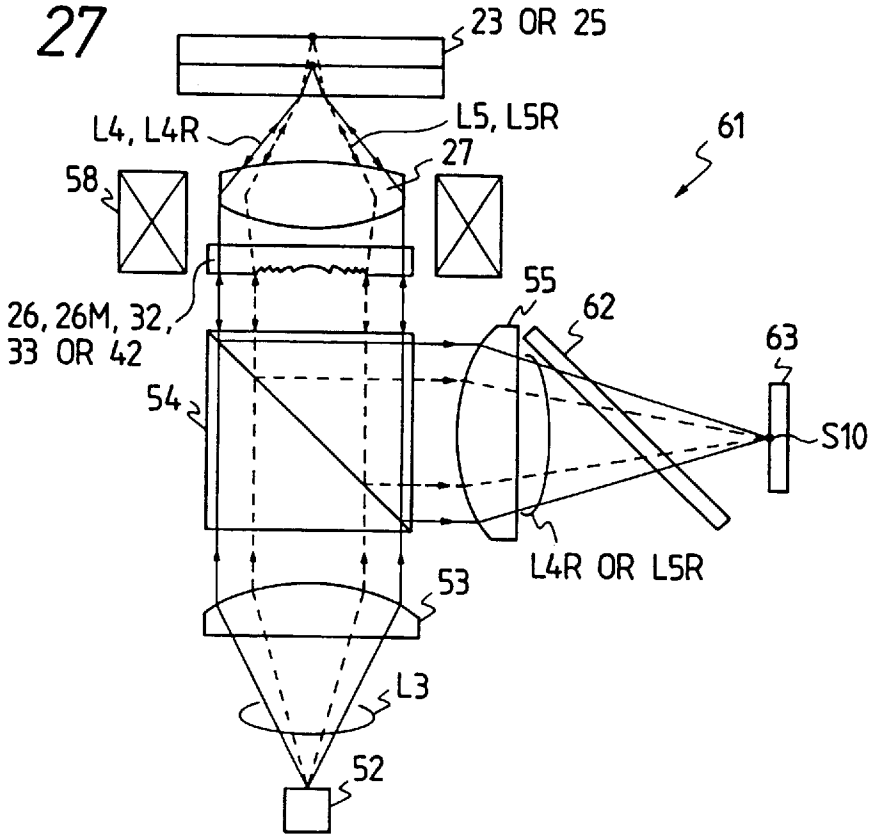

23 OR 25
L4, L4R
L5, L5R
61
27
58
55
62
63
26, 26M, 32,
33 OR 42
54
S10
L4R OR L5R
53
L3
52

FIG. 28

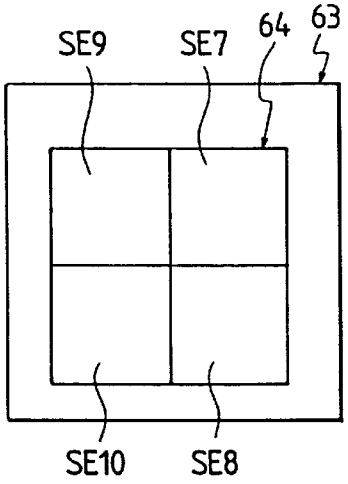


FIG. 29A

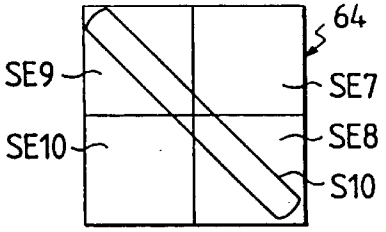


FIG. 29B

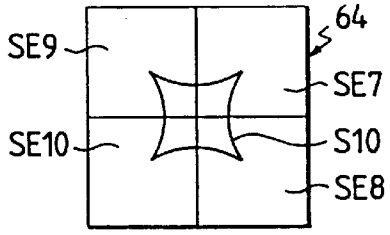


FIG. 29C

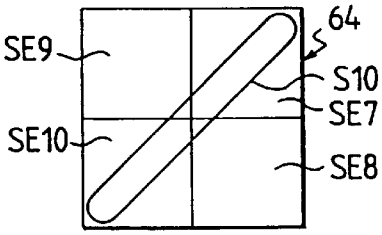


FIG. 29D

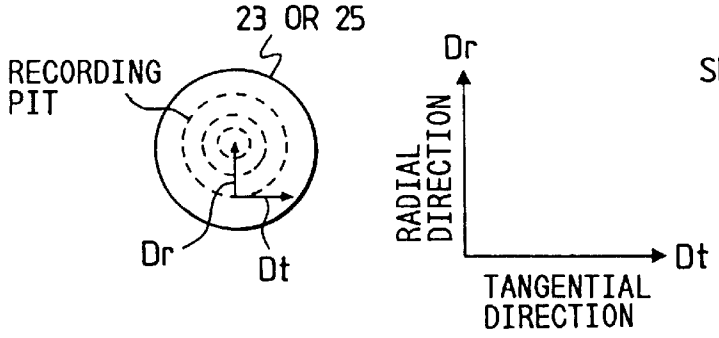


FIG. 30

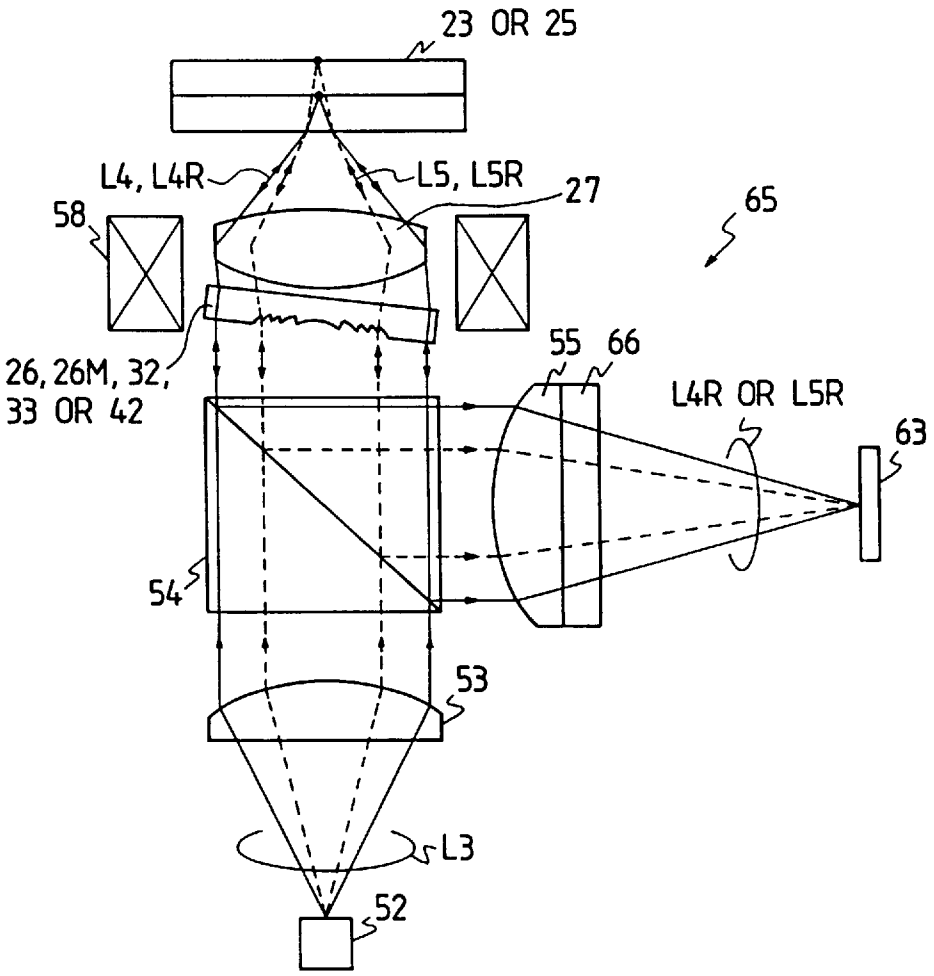

23 OR 25
L4, L4R
L5, L5R
27
65
58
26, 26M, 32,
33 OR 42
55
66
L4R OR L5R
63
54
53
L3
52

FIG. 31

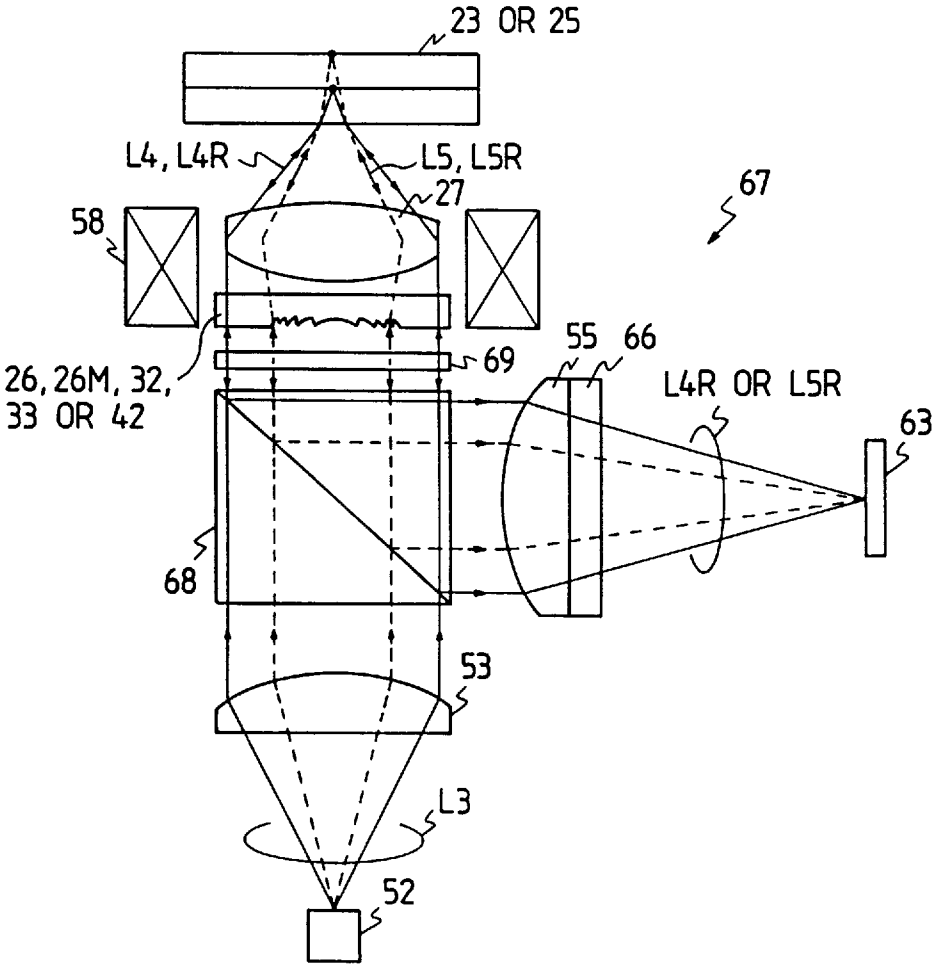

23 OR 25
L4, L4R
L5, L5R
27
67
58
55
66
69
26, 26M, 32,
33 OR 42
L4R OR L5R
63
68
53
L3
52

FIG. 32

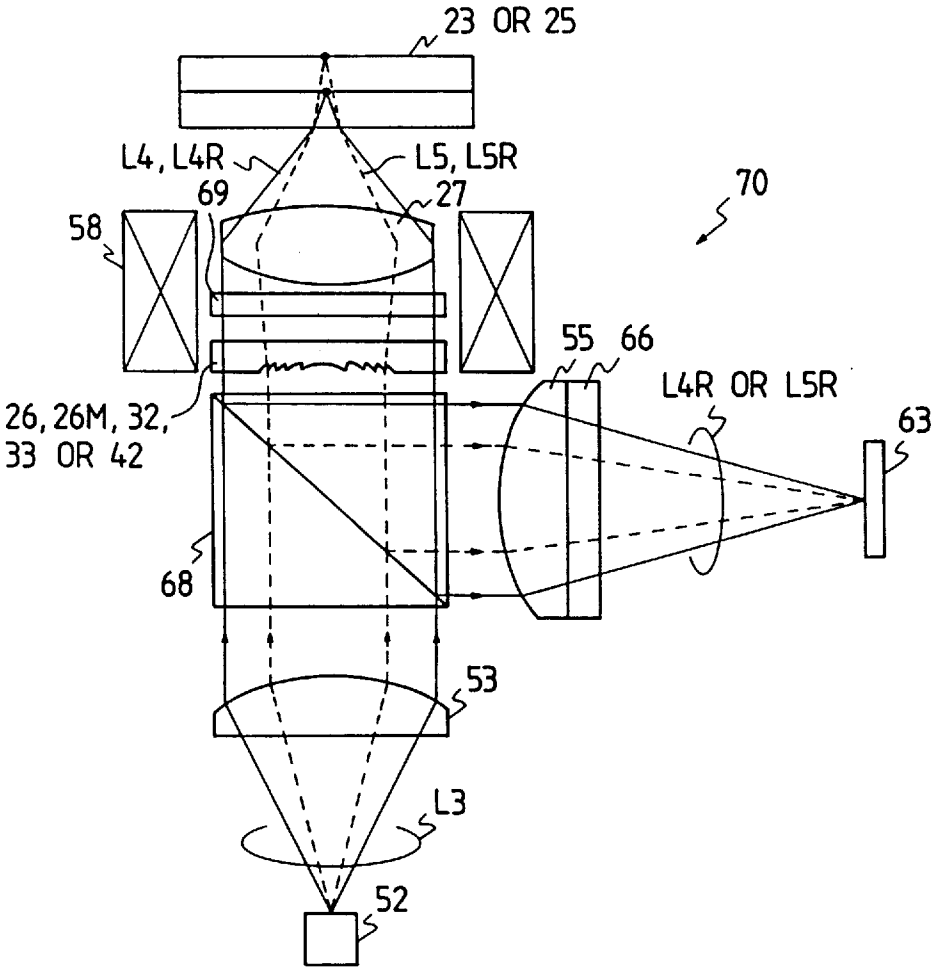

23 OR 25
L4, L4R
L5, L5R
69
27
70
58
55
66
L4R OR L5R
63
26, 26M, 32,
33 OR 42
68
53
L3
52

FIG. 33

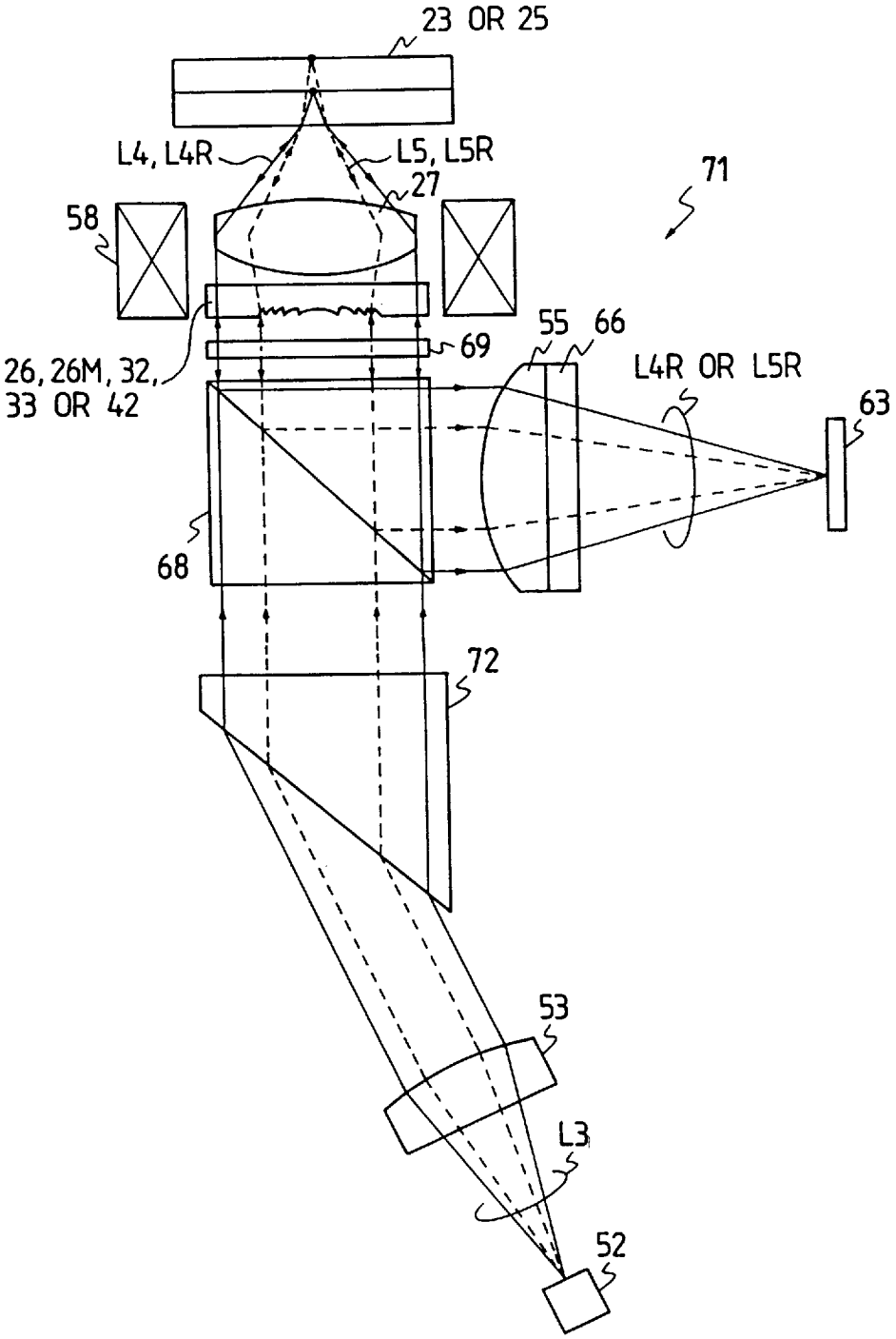

23 OR 25
L4, L4R
L5, L5R
27
71
58
55
66
69
26, 26M, 32,
33 OR 42
L4R OR L5R
63
68
72
53
L3
52

FIG. 34

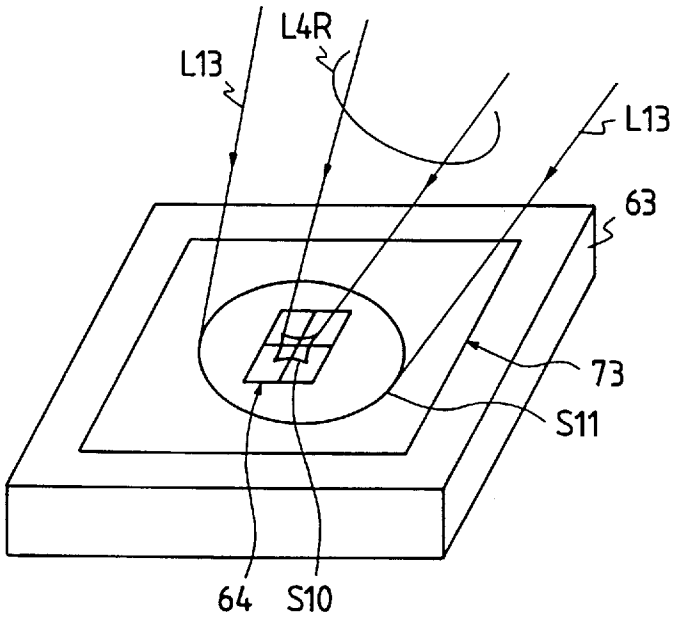

L4R
L13
L13
63
73
S11
64
S10

FIG. 37

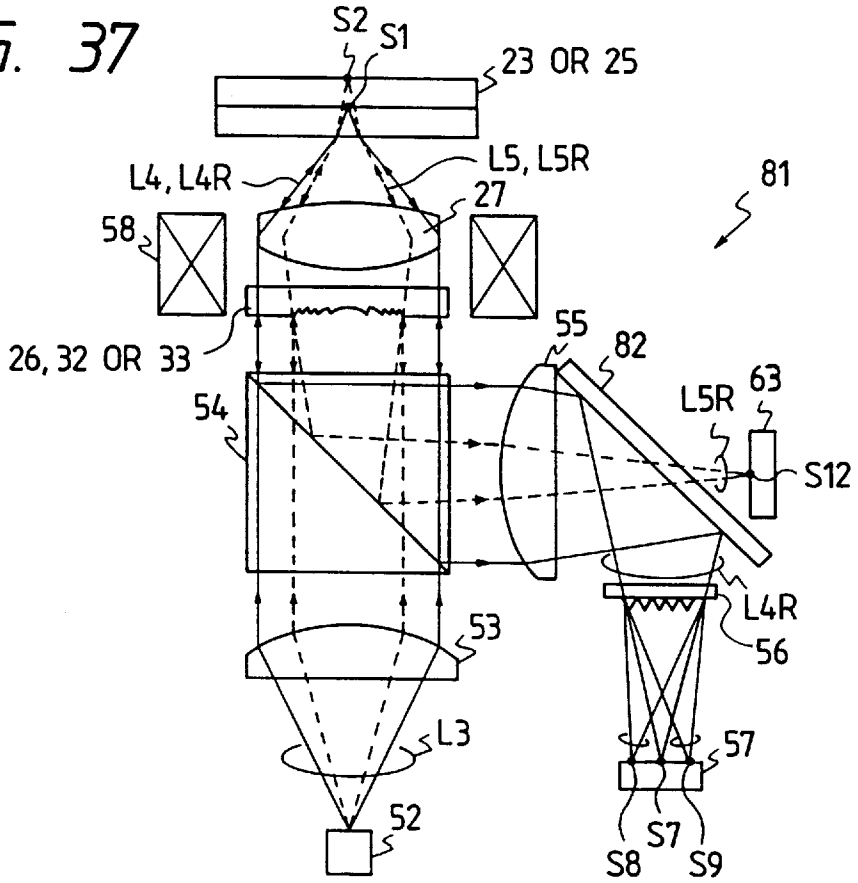

S2
S1
23 OR 25
L4, L4R
L5, L5R
27
81
58
26, 32 OR 33
55
82
54
L5R
63
S12
L4R
56
53
L3
57
52
S7
S8
S9

FIG. 35A

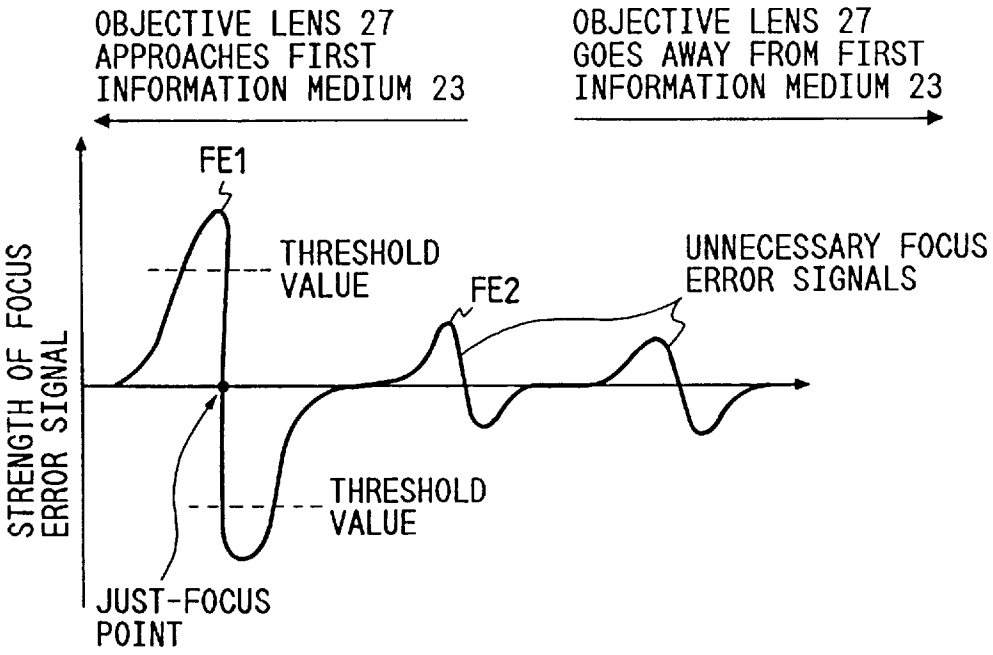


FIG. 35B

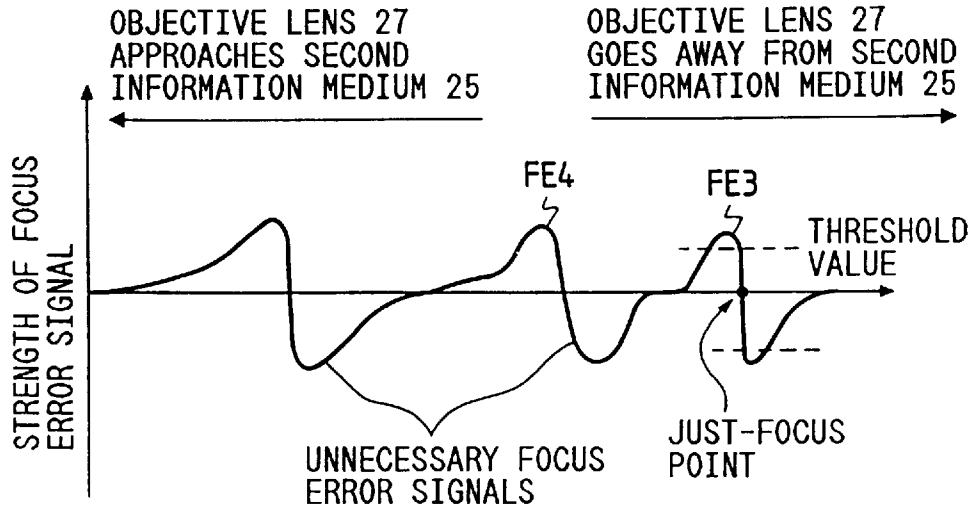


FIG. 36A

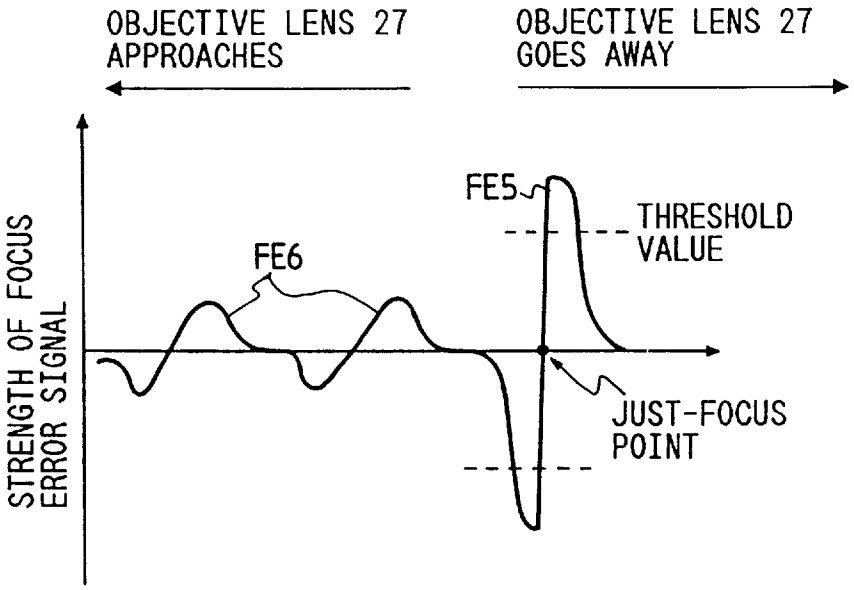


FIG. 36B

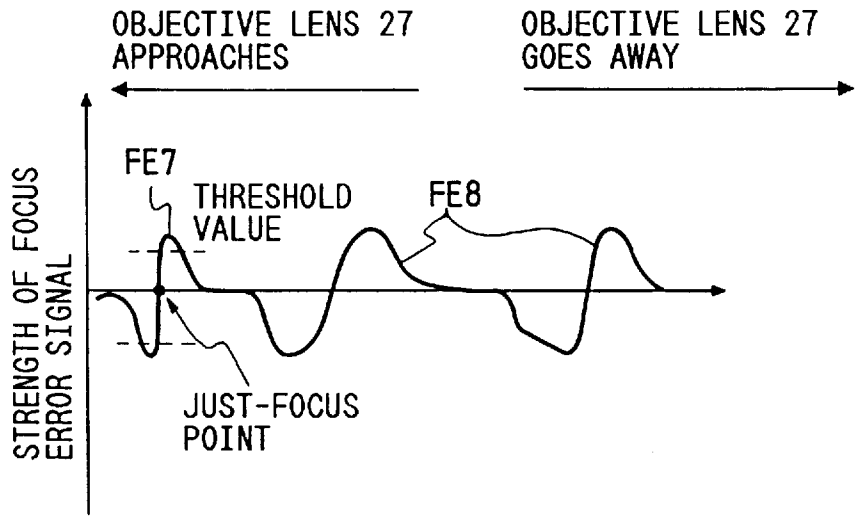


FIG. 38

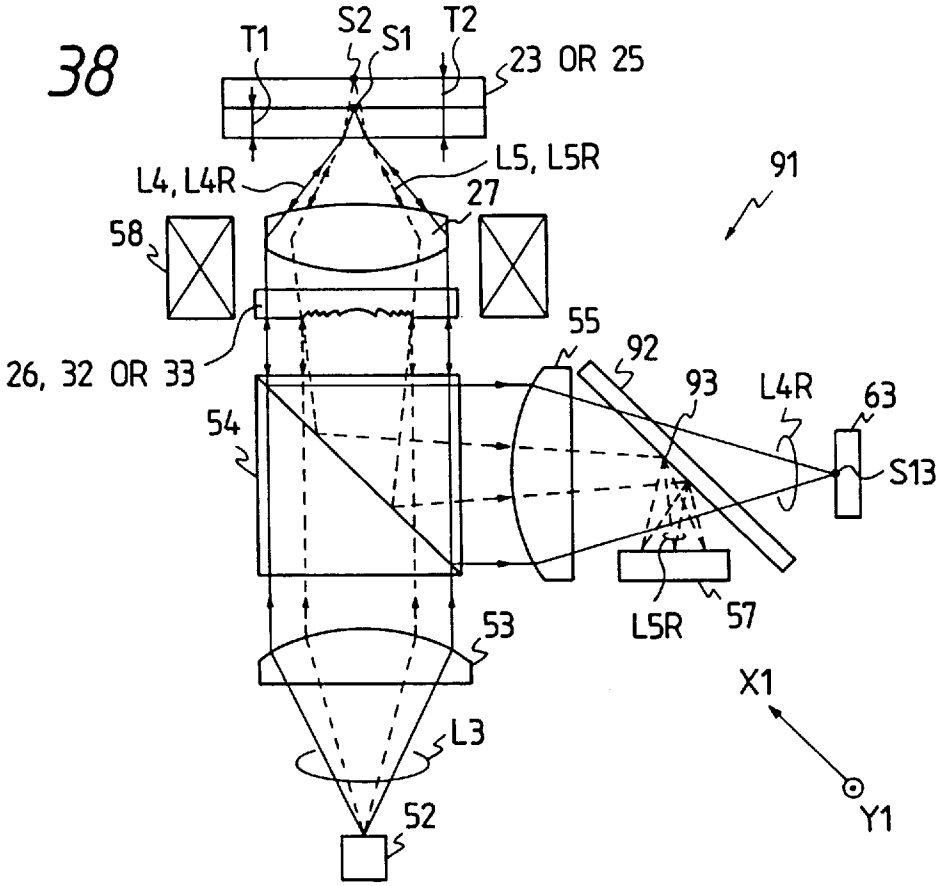

T1
S2
S1
T2
23 OR 25
L4, L4R
L5, L5R
27
91
58
55
92
26, 32 OR 33
93
L4R
63
54
S13
53
L5R
57
X1
L3
Y1
52

FIG. 39

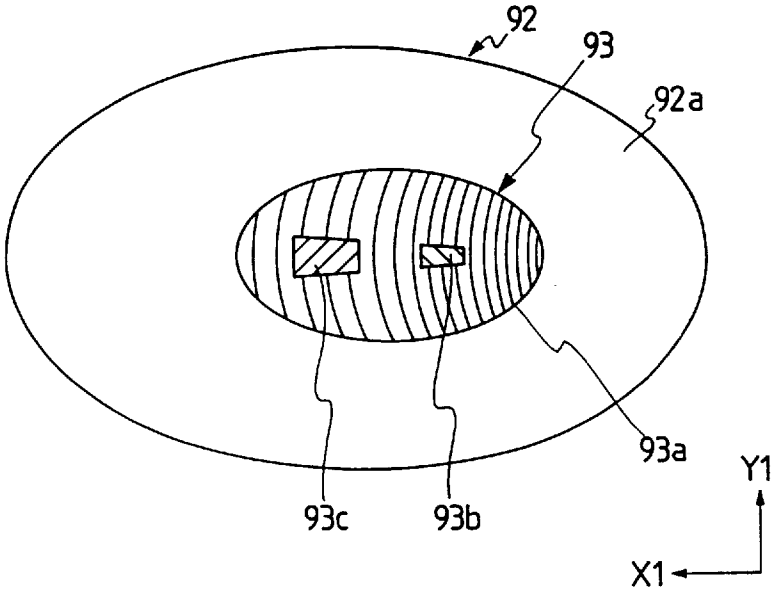

92
93
92a
93a
Y1
93c
93b
X1

FIG. 40A

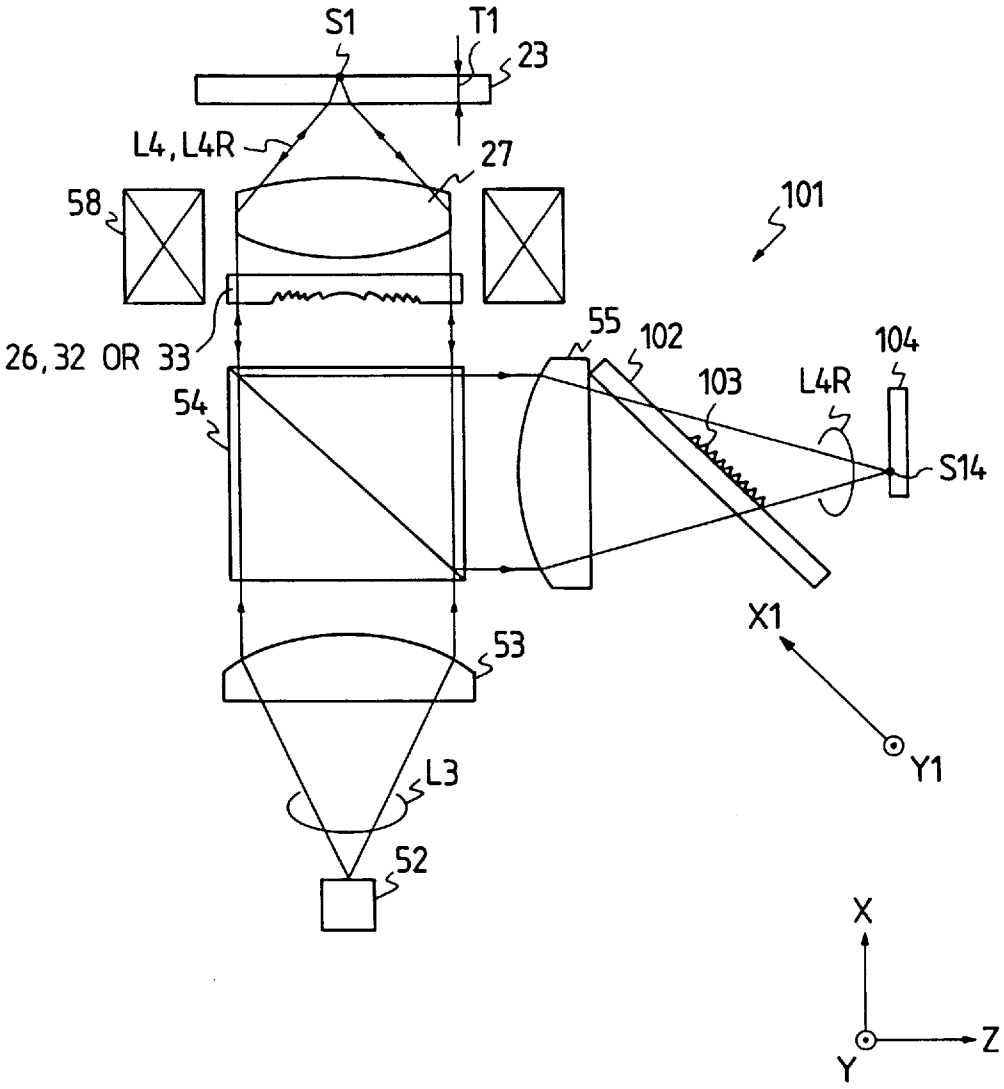

S1
T1
23
L4, L4R
27
58
101
26, 32 OR 33
55
102
104
103
L4R
54
S14
X1
53
Y1
L3
52
X
Z
Y

FIG. 40B

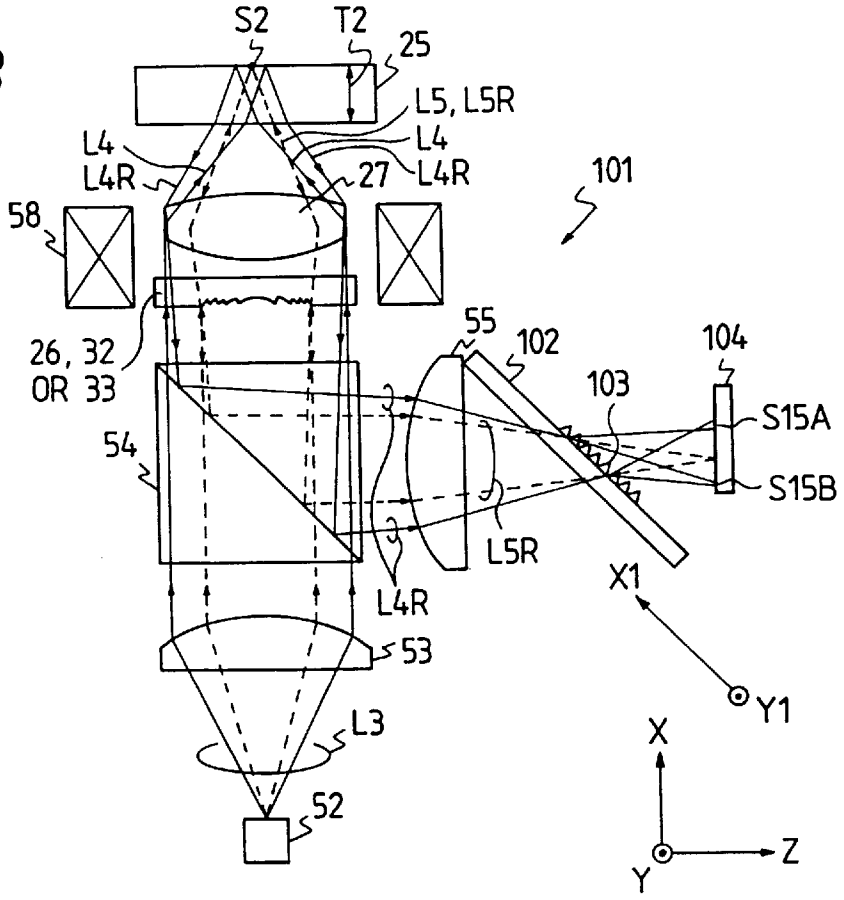


FIG. 41

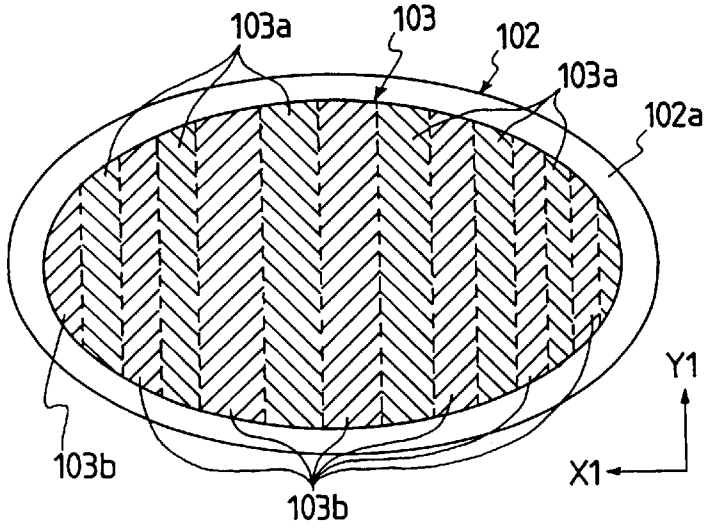


FIG. 42A

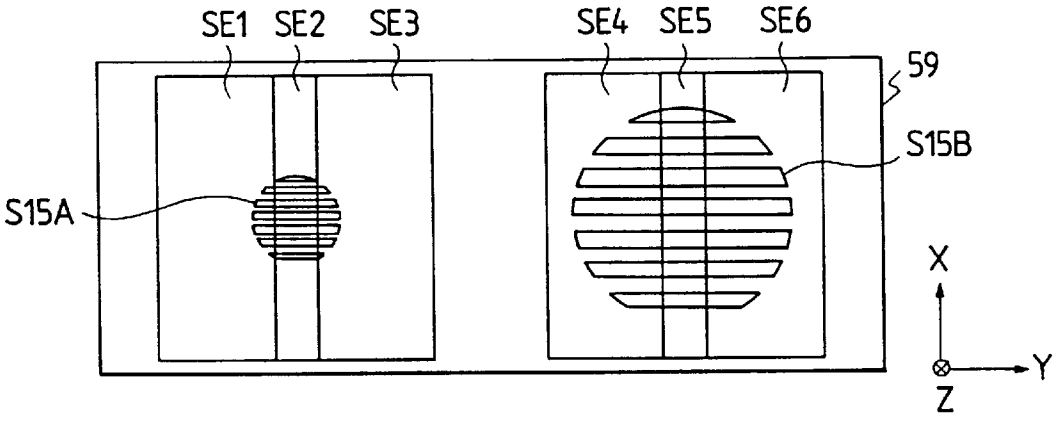


FIG. 42B

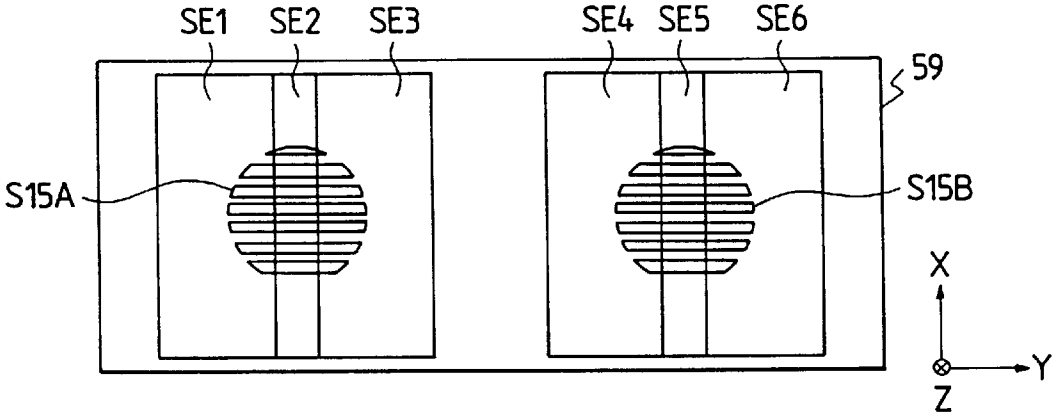


FIG. 42C

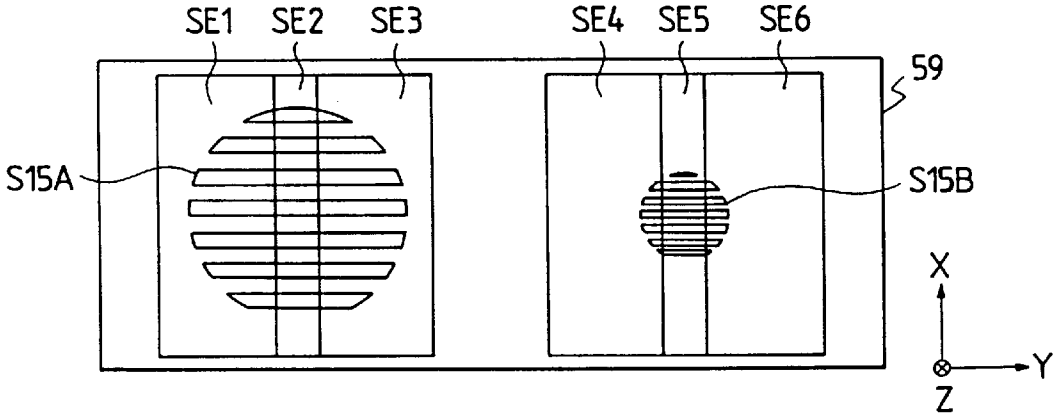


FIG. 43

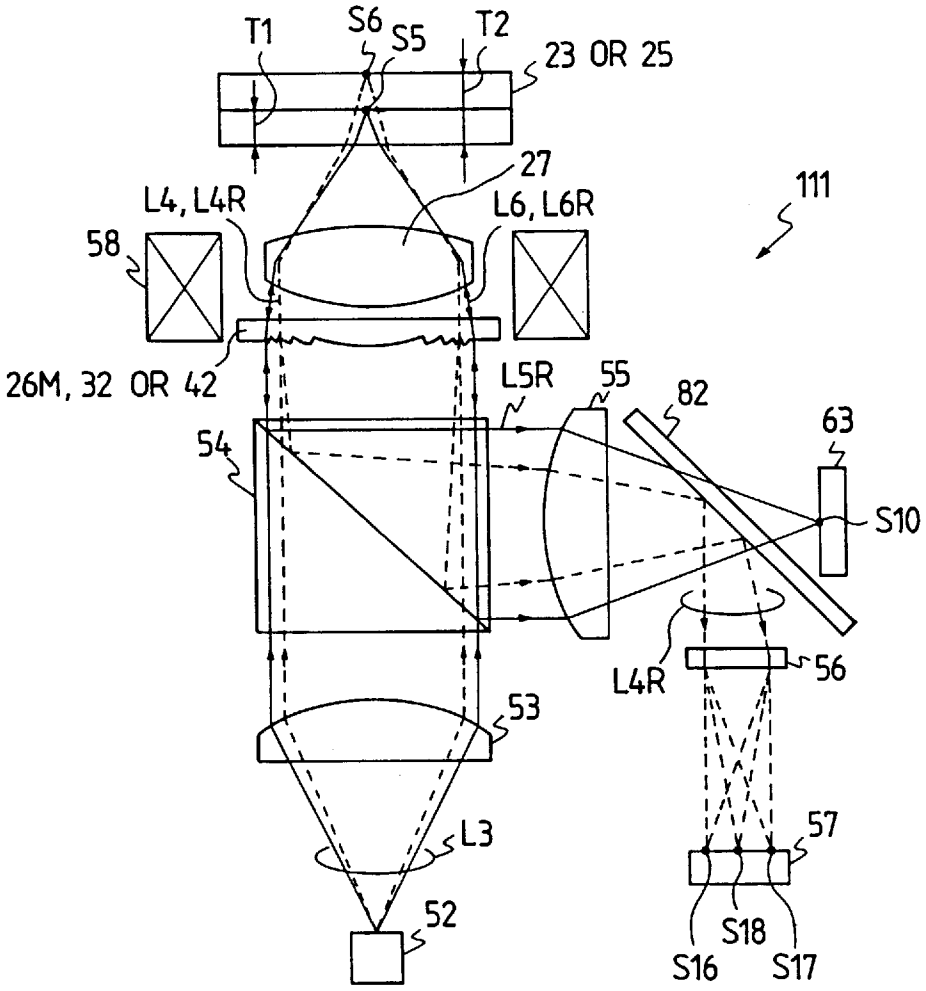

T1
S6
S5
T2
23 OR 25
27
111
L4, L4R
L6, L6R
58
26M, 32 OR 42
L5R
55
82
63
54
S10
L4R
56
53
L3
57
52
S18
S16
S17

FIG. 44

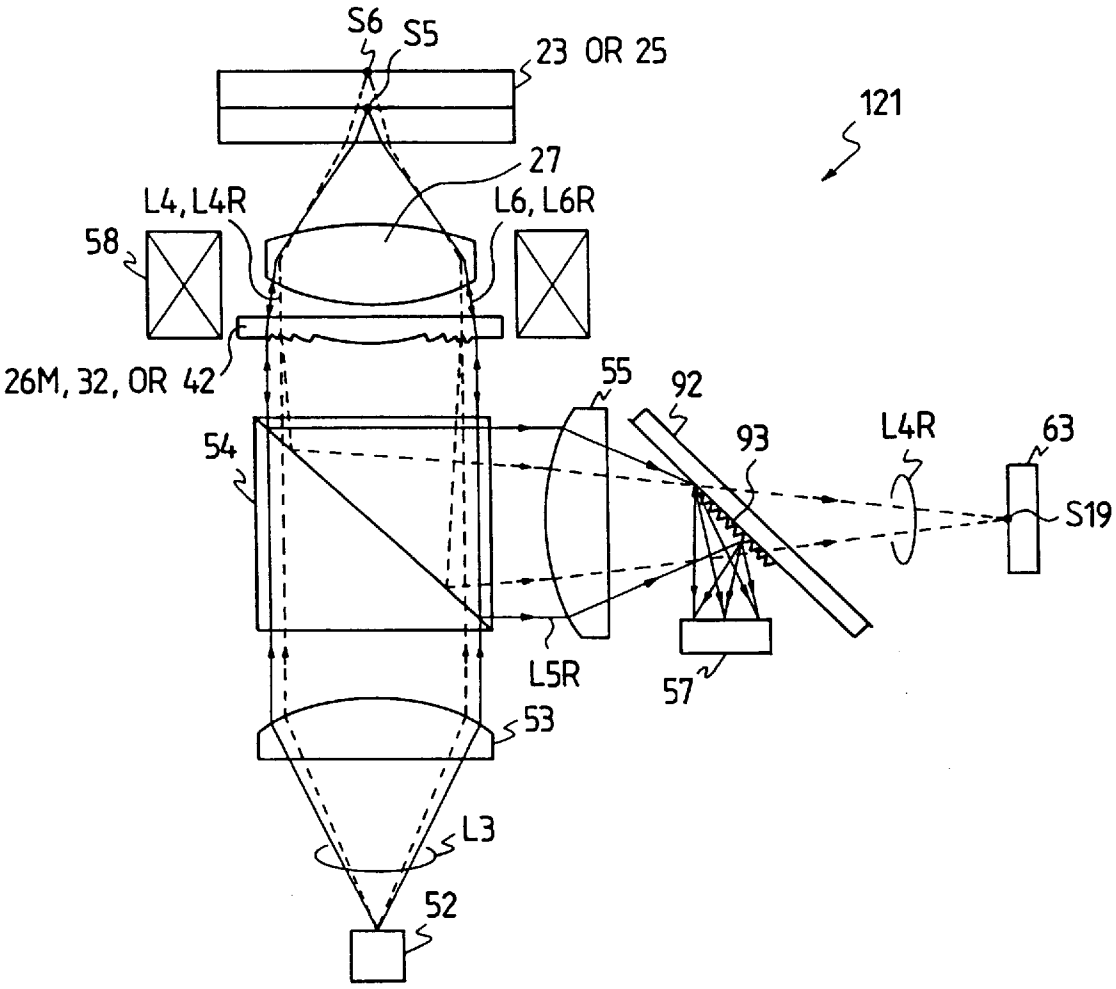

S6
S5
23 OR 25
121
27
L4, L4R
L6, L6R
58
26M, 32, OR 42
55
92
93
L4R
63
54
S19
L5R
57
53
L3
52

FIG. 45

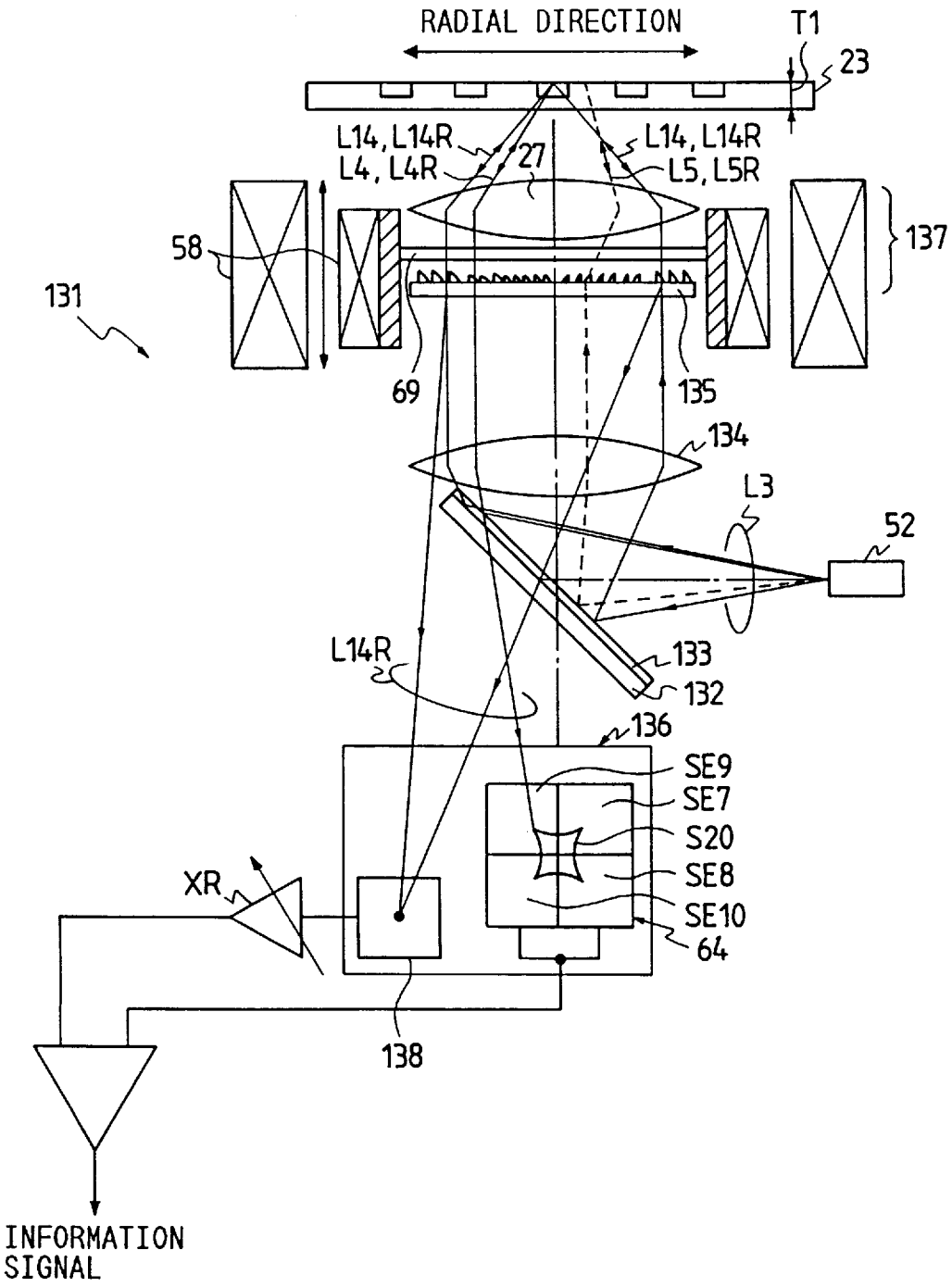

RADIAL DIRECTION
T1
23
L14, L14R
L4, L4R
27
L14, L14R
L5, L5R
58
137
131
69
135
134
L3
52
L14R
133
132
136
SE9
SE7
S20
SE8
SE10
64
XR
138
INFORMATION
SIGNAL

FIG. 46

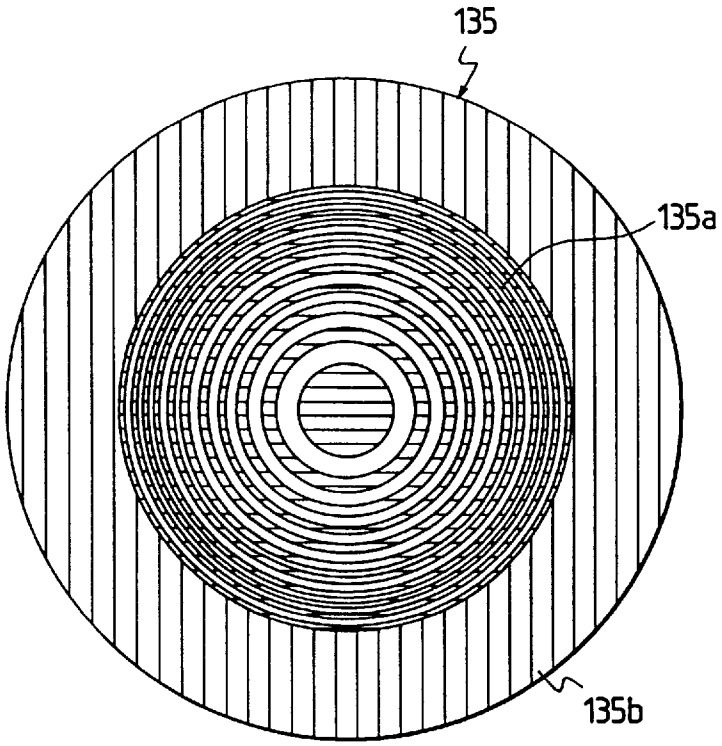


FIG. 47

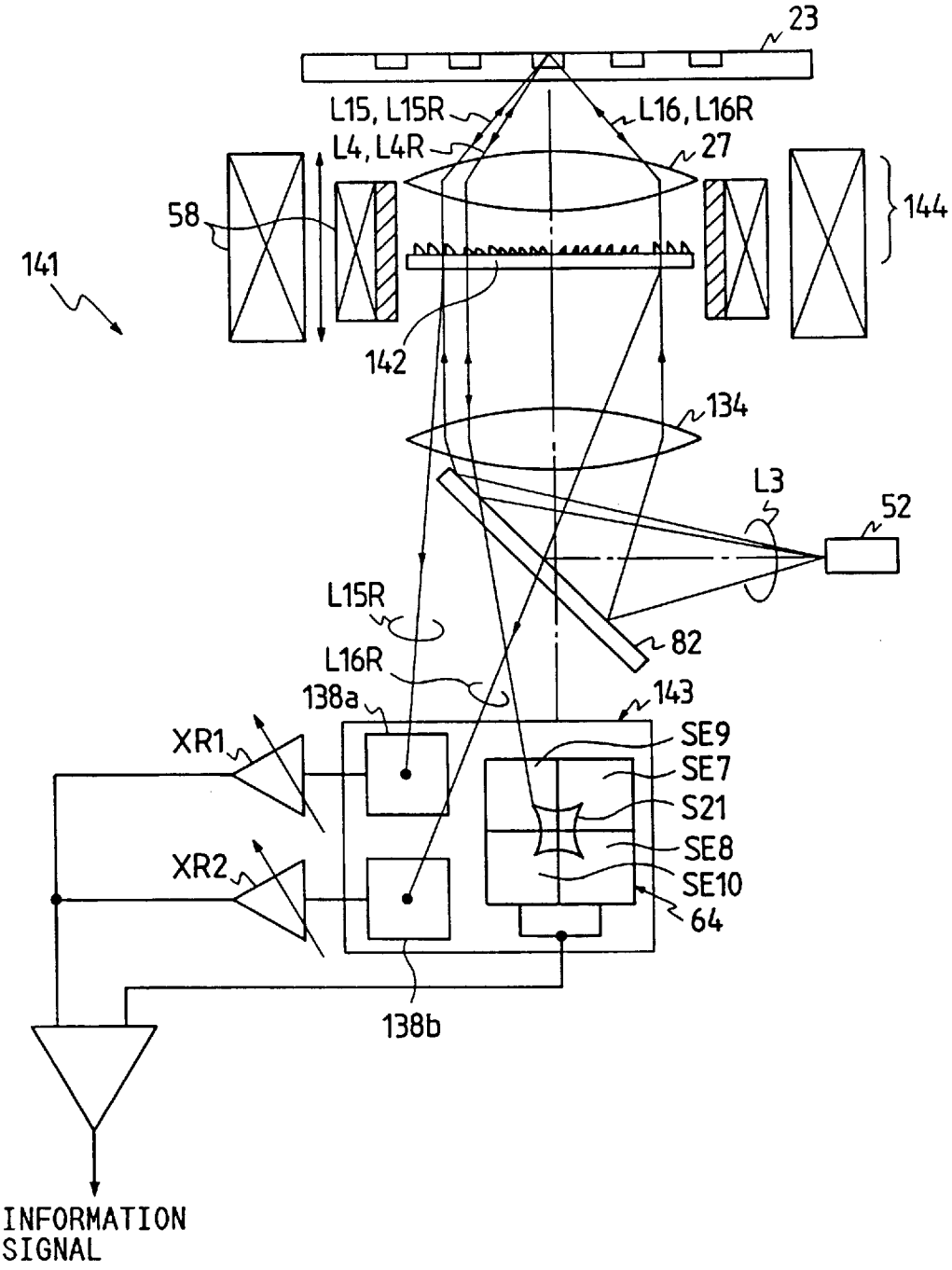

23
L15, L15R
L16, L16R
L4, L4R
27
58
144
141
142
134
L3
52
L15R
82
L16R
138a
143
XR1
SE9
SE7
S21
XR2
SE8
SE10
64
138b
INFORMATION
SIGNAL

FIG. 48

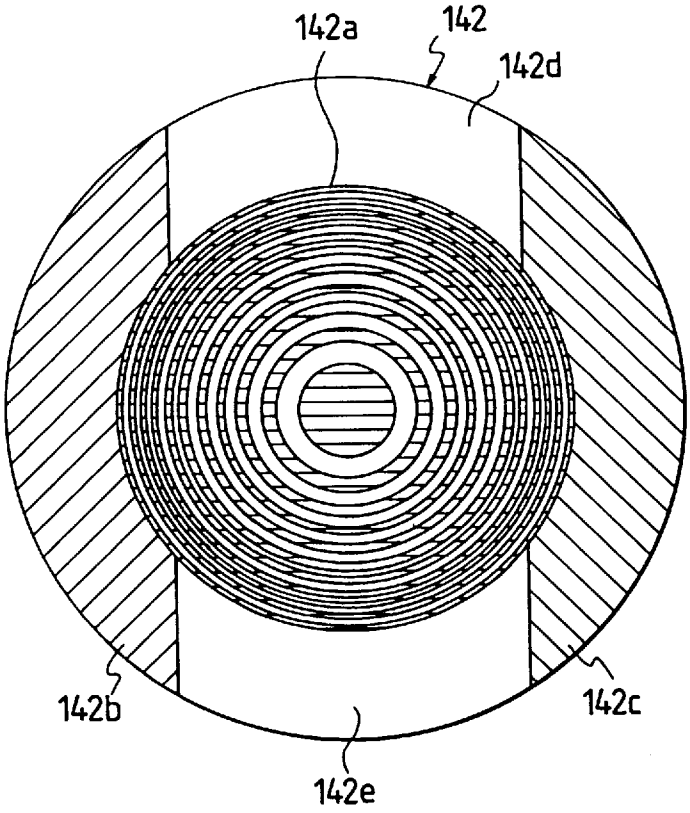


FIG. 49A

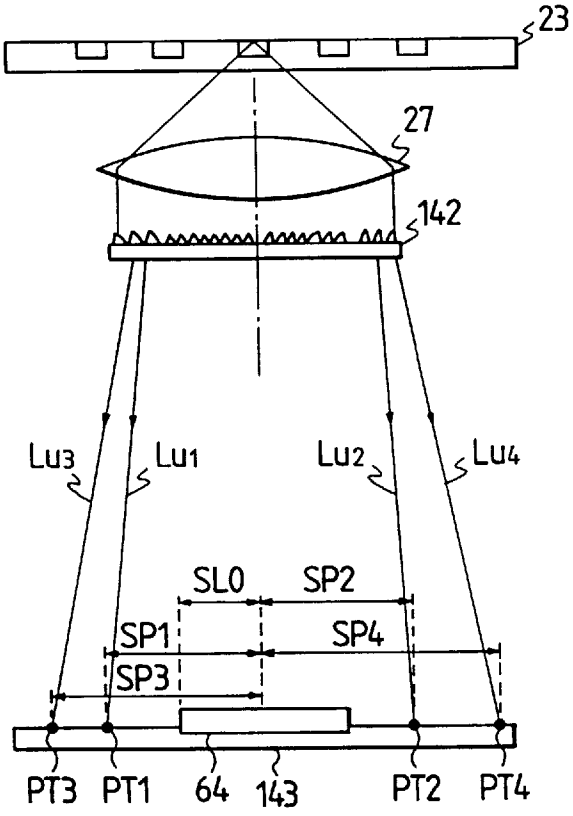


FIG. 49B

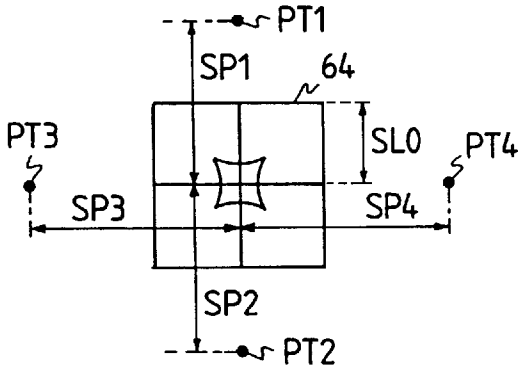


FIG. 50

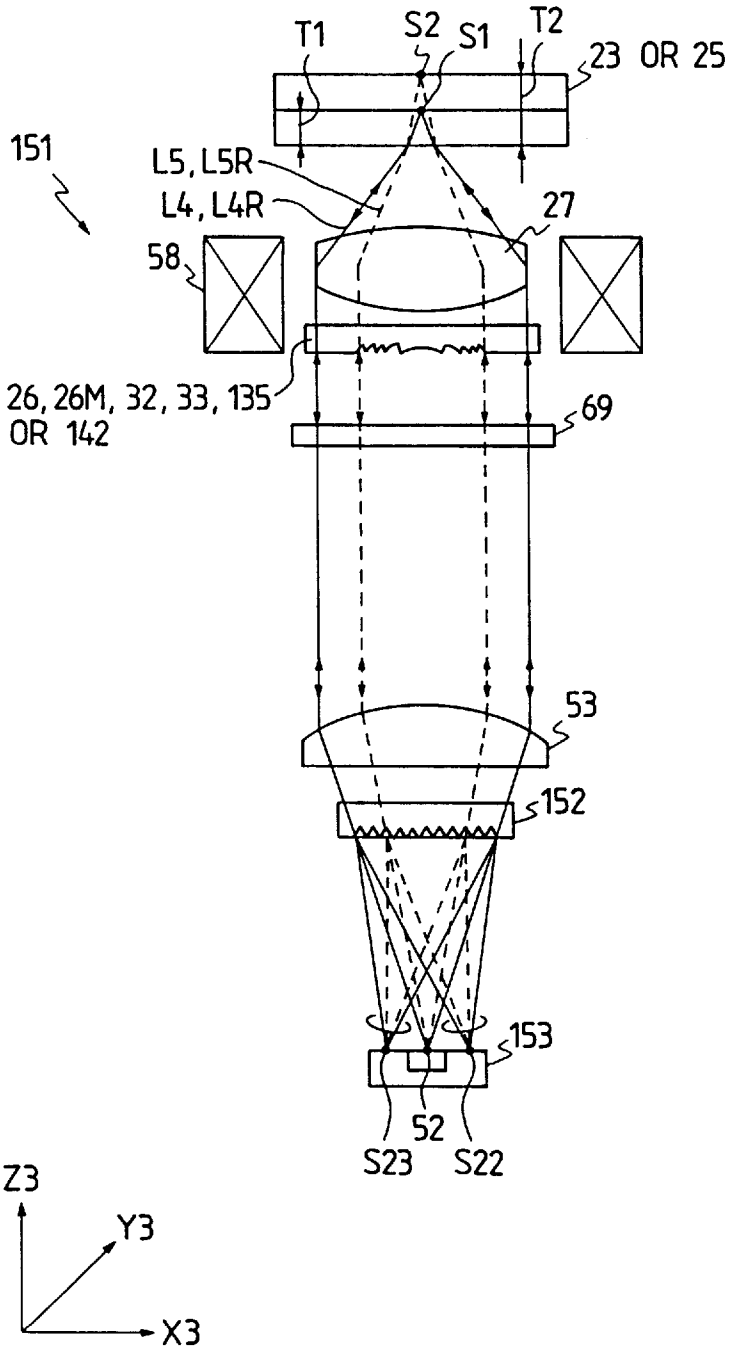

T1
S2
S1
T2
23 OR 25
151
L5, L5R
L4, L4R
27
58
26, 26M, 32, 33, 135
OR 142
69
53
152
153
52
S23
S22
Z3
Y3
X3

FIG. 51

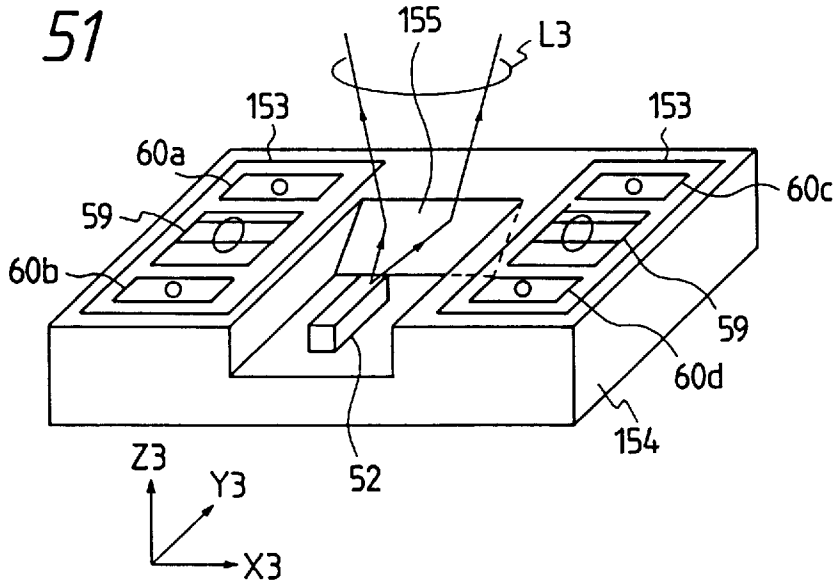

155
L3
153
153
60a
60c
59
60b
59
60d
154
52
Z3
Y3
X3

FIG. 52

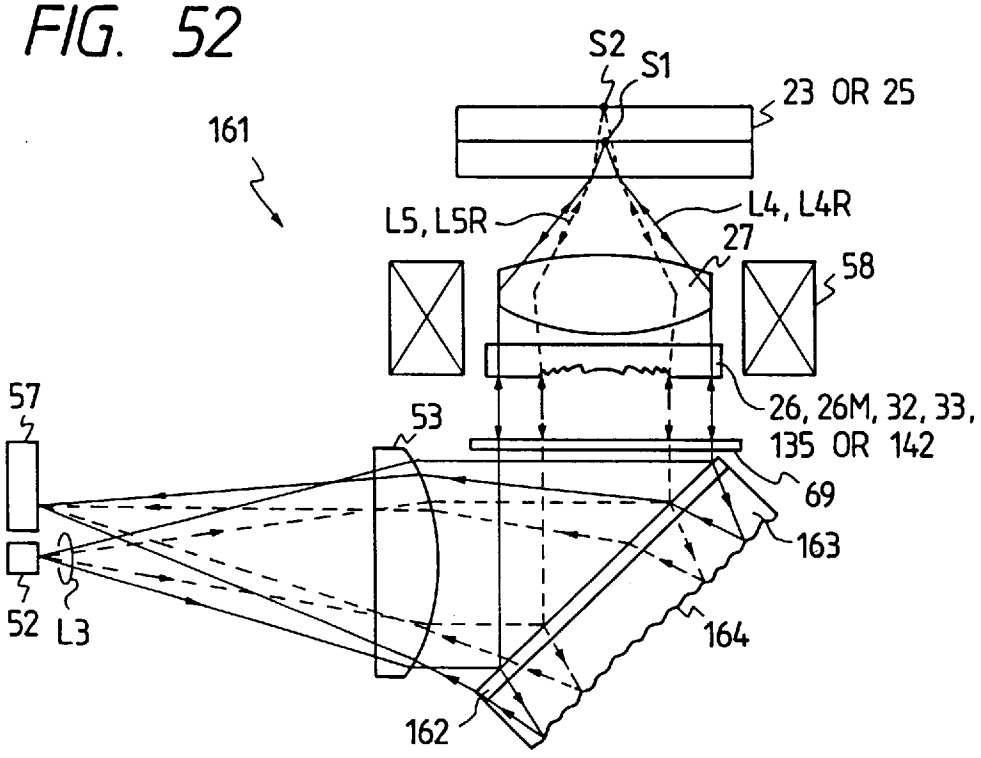

S2
S1
23 OR 25
161
L5, L5R
L4, L4R
27
58
57
53
26, 26M, 32, 33,
135 OR 142
69
163
52
L3
164
162

FIG. 53

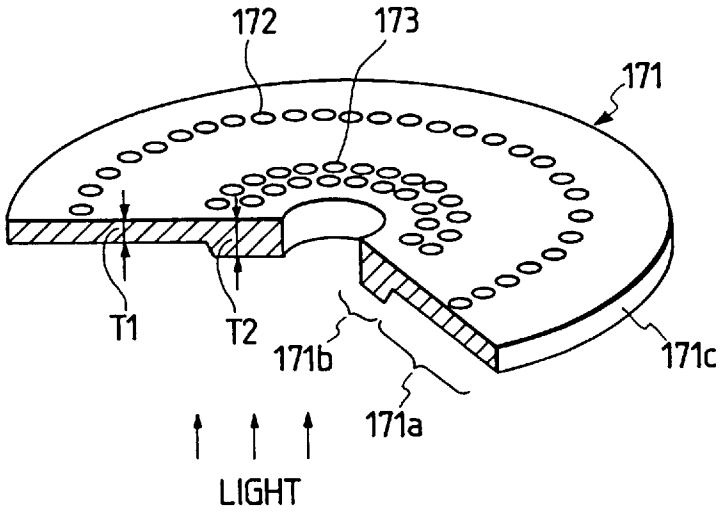

172
173
171
T1
T2
171b
171c
171a
LIGHT

FIG. 54

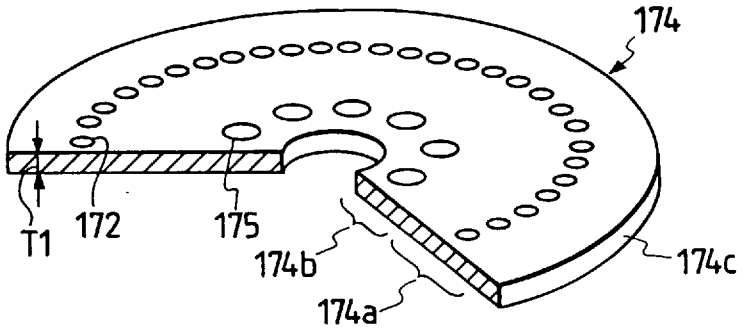

174
T1
172
175
174b
174c
174a

FIG. 55

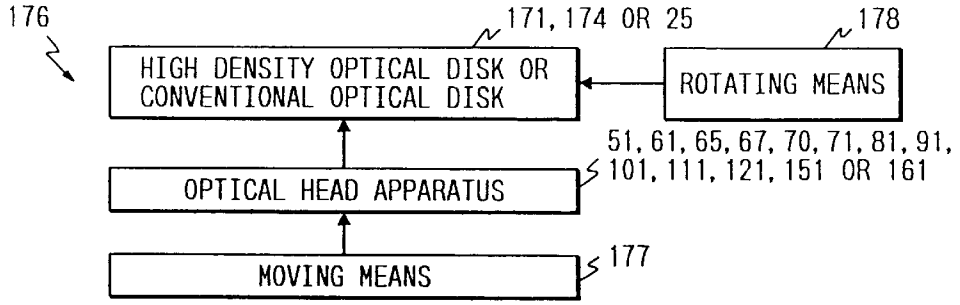

176
171, 174 OR 25
178
HIGH DENSITY OPTICAL DISK OR CONVENTIONAL OPTICAL DISK
ROTATING MEANS
51, 61, 65, 67, 70, 71, 81, 91, 101, 111, 121, 151 OR 161
OPTICAL HEAD APPARATUS
MOVING MEANS
177

FIG. 56

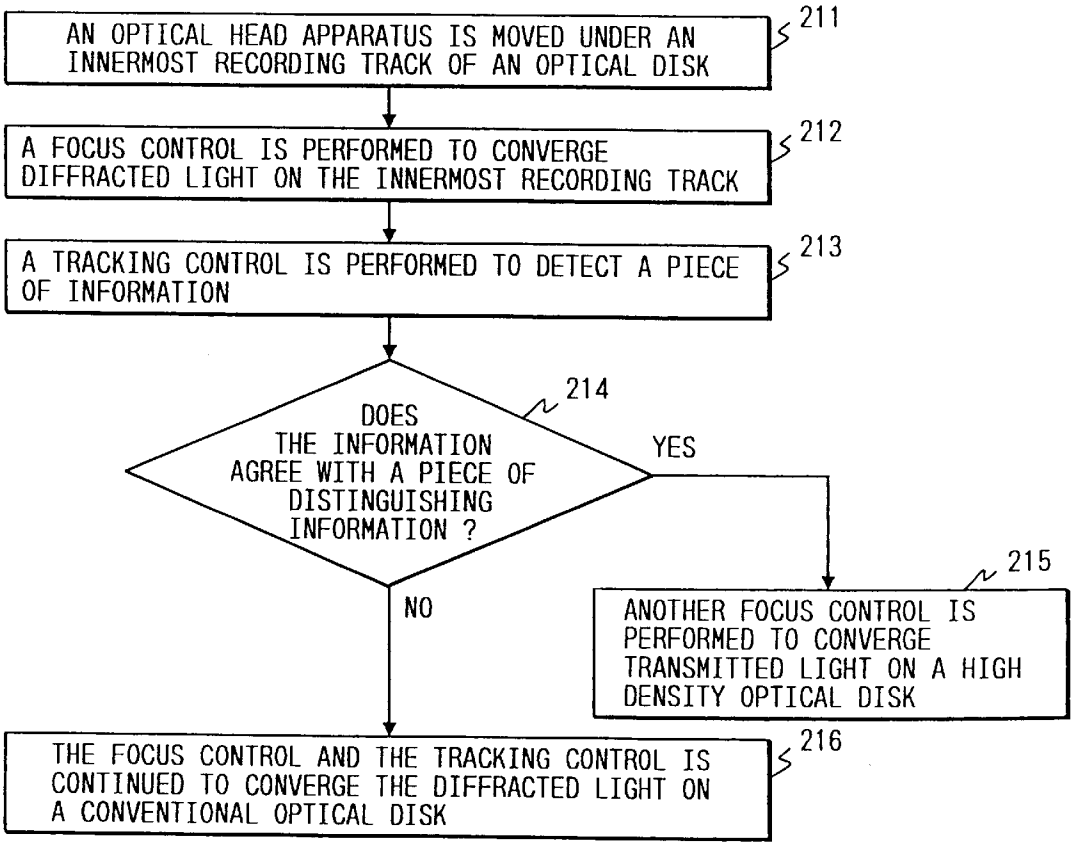

AN OPTICAL HEAD APPARATUS IS MOVED UNDER AN INNERMOST RECORDING TRACK OF AN OPTICAL DISK
211
A FOCUS CONTROL IS PERFORMED TO CONVERGE DIFFRACTED LIGHT ON THE INNERMOST RECORDING TRACK
212
A TRACKING CONTROL IS PERFORMED TO DETECT A PIECE OF INFORMATION
213
DOES THE INFORMATION AGREE WITH A PIECE OF DISTINGUISHING INFORMATION ?
214
YES
NO
ANOTHER FOCUS CONTROL IS PERFORMED TO CONVERGE TRANSMITTED LIGHT ON A HIGH DENSITY OPTICAL DISK
215
THE FOCUS CONTROL AND THE TRACKING CONTROL IS CONTINUED TO CONVERGE THE DIFFRACTED LIGHT ON A CONVENTIONAL OPTICAL DISK
216

FIG. 57

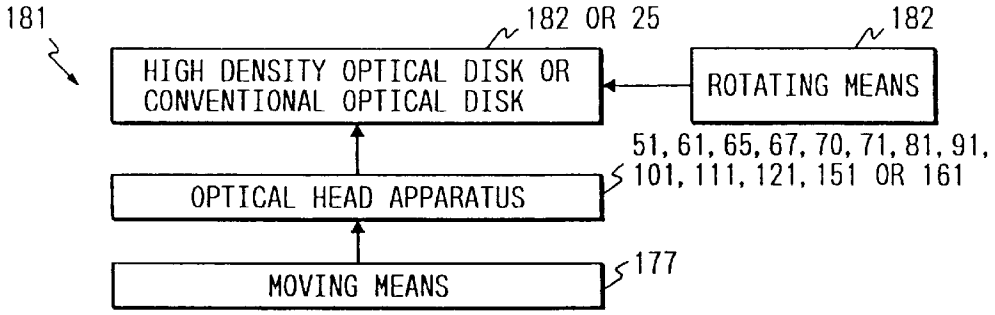

181
182 OR 25
182
HIGH DENSITY OPTICAL DISK OR CONVENTIONAL OPTICAL DISK
ROTATING MEANS
51, 61, 65, 67, 70, 71, 81, 91, 101, 111, 121, 151 OR 161
OPTICAL HEAD APPARATUS
177
MOVING MEANS

FIG. 58

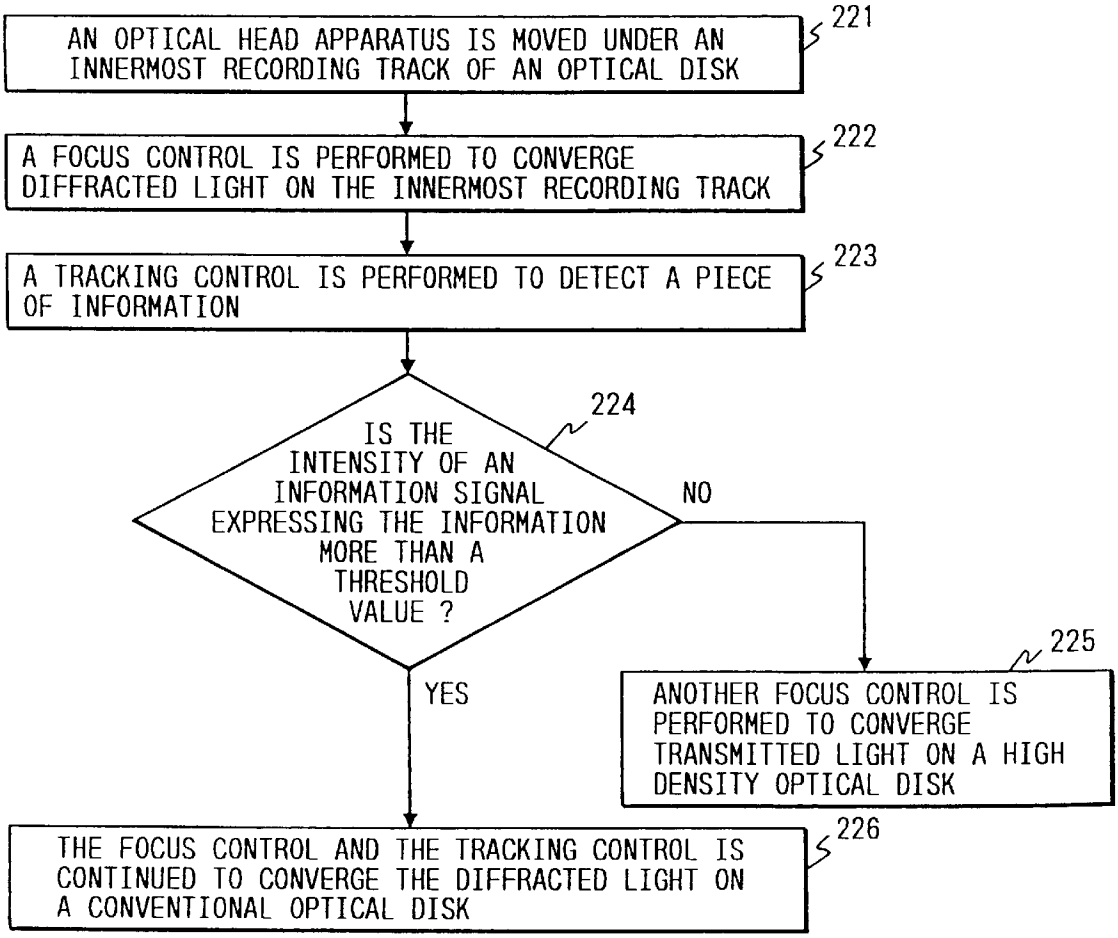

AN OPTICAL HEAD APPARATUS IS MOVED UNDER AN INNERMOST RECORDING TRACK OF AN OPTICAL DISK
221
A FOCUS CONTROL IS PERFORMED TO CONVERGE DIFFRACTED LIGHT ON THE INNERMOST RECORDING TRACK
222
A TRACKING CONTROL IS PERFORMED TO DETECT A PIECE OF INFORMATION
223
IS THE INTENSITY OF AN INFORMATION SIGNAL EXPRESSING THE INFORMATION MORE THAN A THRESHOLD VALUE ?
224
NO
YES
ANOTHER FOCUS CONTROL IS PERFORMED TO CONVERGE TRANSMITTED LIGHT ON A HIGH DENSITY OPTICAL DISK
225
THE FOCUS CONTROL AND THE TRACKING CONTROL IS CONTINUED TO CONVERGE THE DIFFRACTED LIGHT ON A CONVENTIONAL OPTICAL DISK
226

FIG. 59

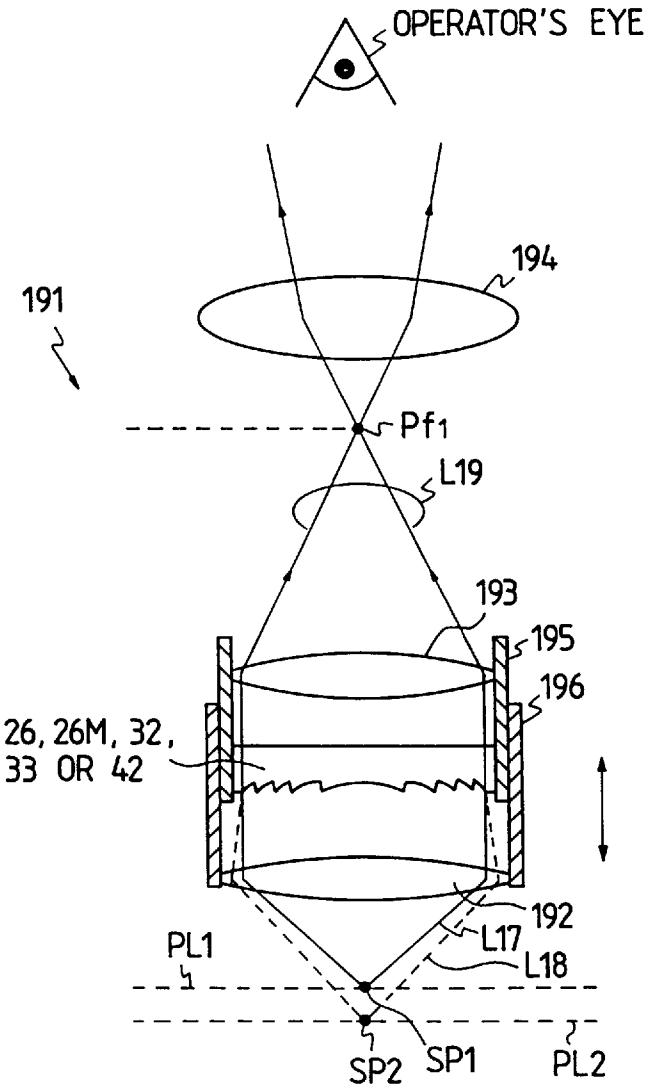

OPERATOR'S EYE
194
191
Pf1
L19
193
195
196
26, 26M, 32,
33 OR 42
192
L17
L18
PL1
SP2
SP1
PL2

FIG. 60

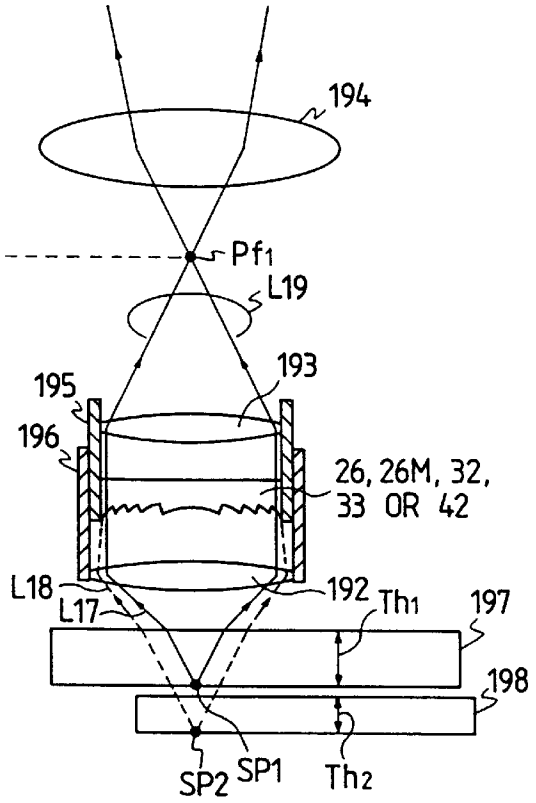

194
Pf1
L19
193
195
196
26, 26M, 32,
33 OR 42
L18
L17
192
Th1
197
198
SP2
SP1
Th2

FIG. 61

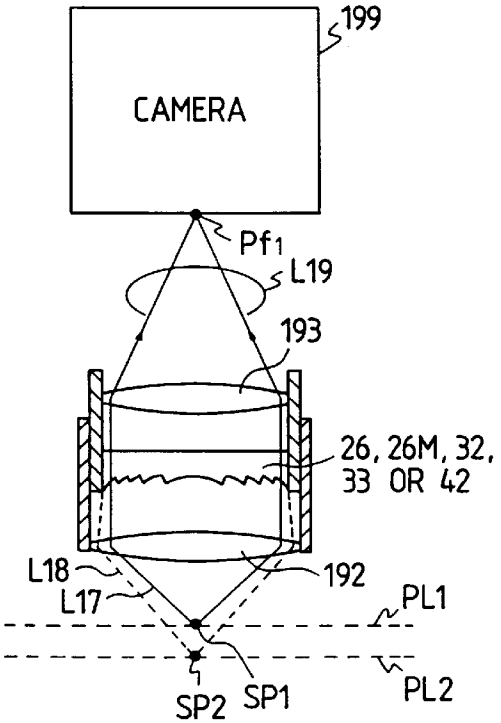

199
CAMERA
Pf1
L19
193
26, 26M, 32,
33 OR 42
L18
L17
192
PL1
PL2
SP2
SP1

FIG. 62

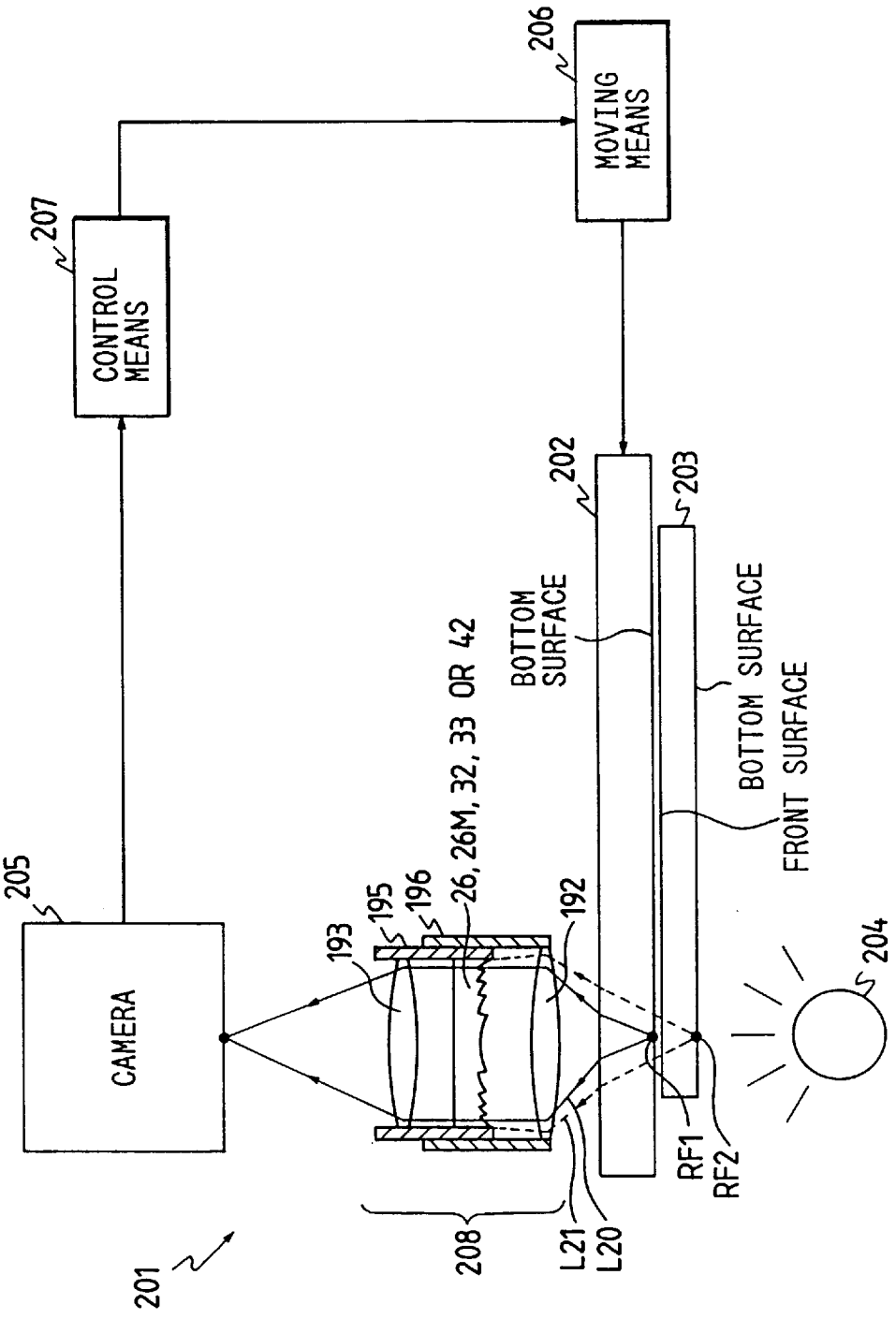

206
MOVING MEANS
207
CONTROL MEANS
202
203
BOTTOM SURFACE
BOTTOM SURFACE
FRONT SURFACE
205
CAMERA
193
195
196
26, 26M, 32, 33 OR 42
192
204
RF1
RF2
208
L21
L20
201

FIG. 63

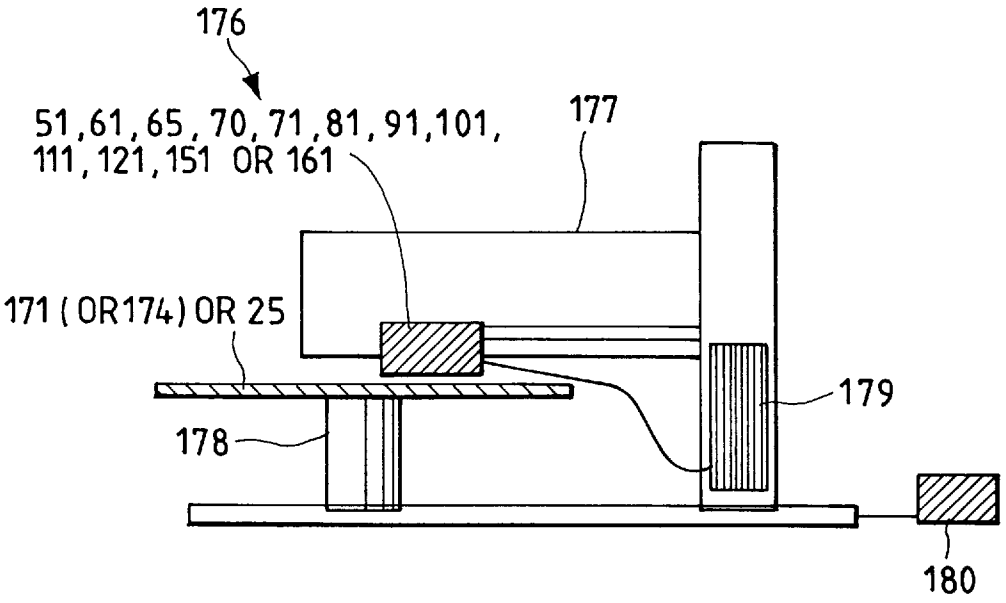

176
51,61,65,70,71,81,91,101,
111,121,151 OR 161
177
171 (OR174) OR 25
179
178
180

FIG. 64

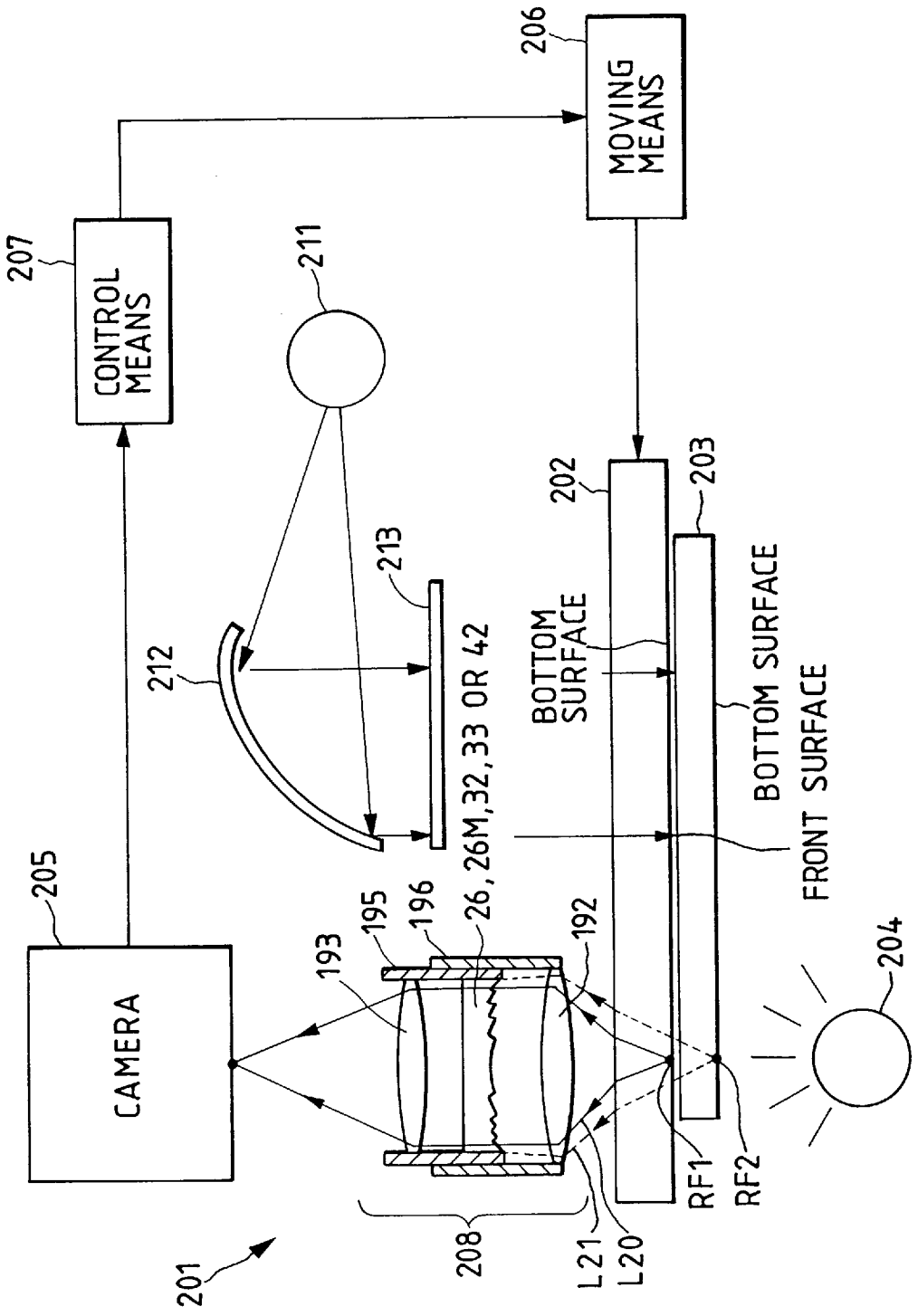

206
MOVING MEANS
207
CONTROL MEANS
211
213
212
202
203
BOTTOM SURFACE
BOTTOM SURFACE
FRONT SURFACE
26, 26M, 32, 33 OR 42
205
CAMERA
195
196
193
192
204
RF1
RF2
208
L21
L20
201

FIG. 65

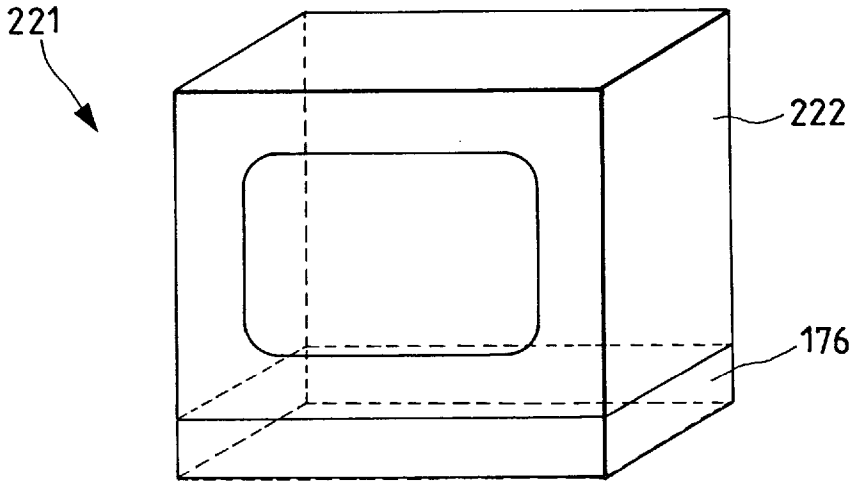


FIG. 66

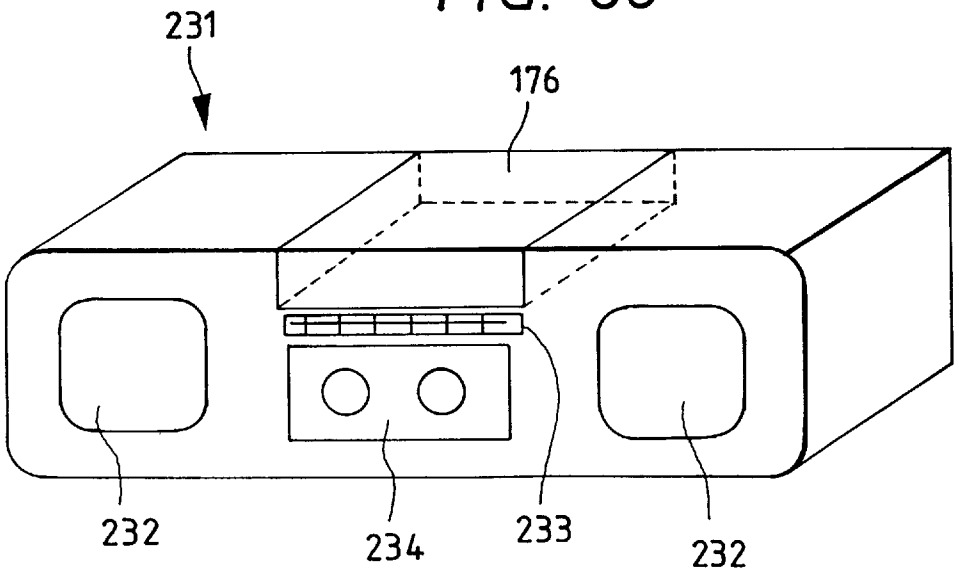


FIG. 67

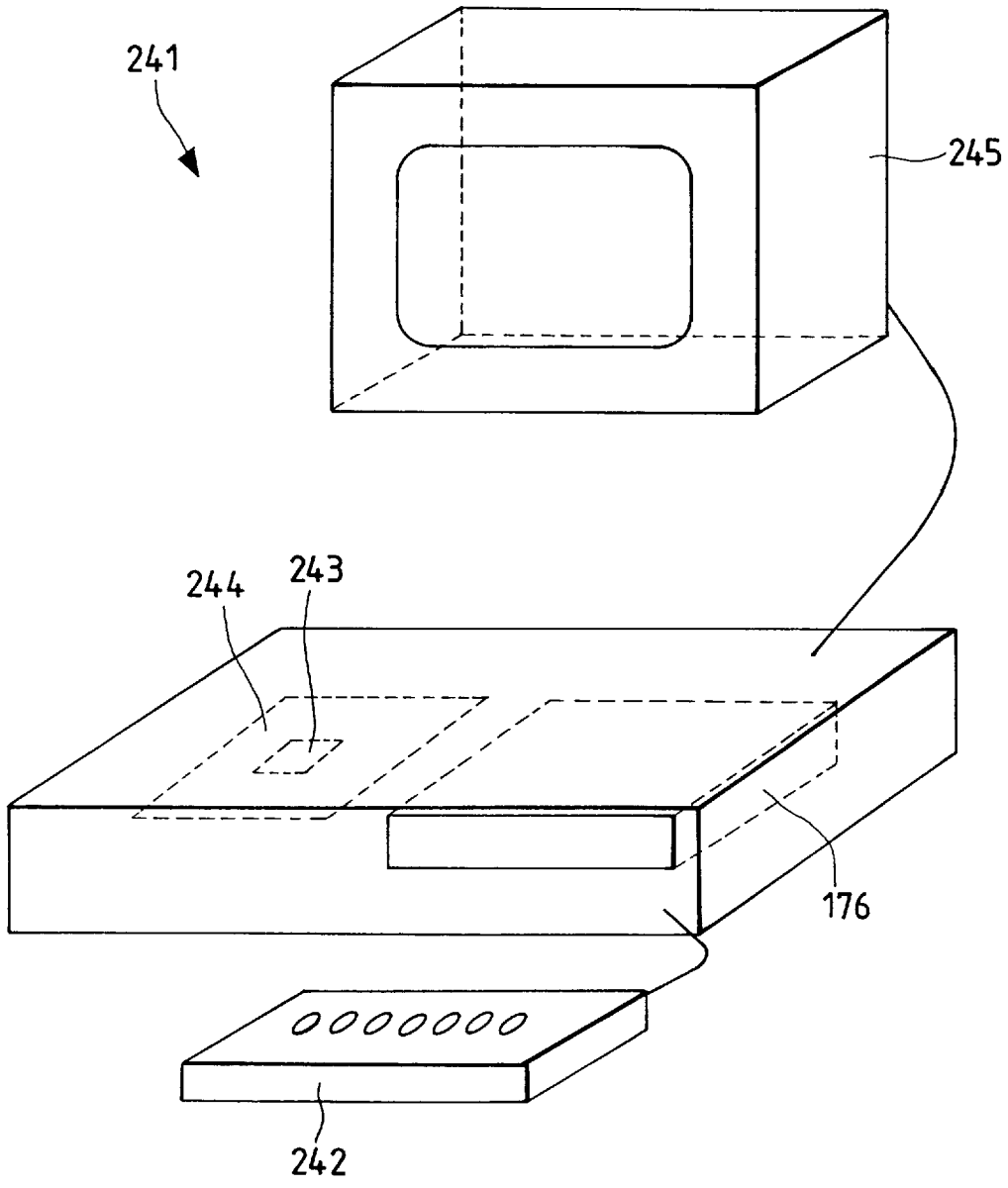
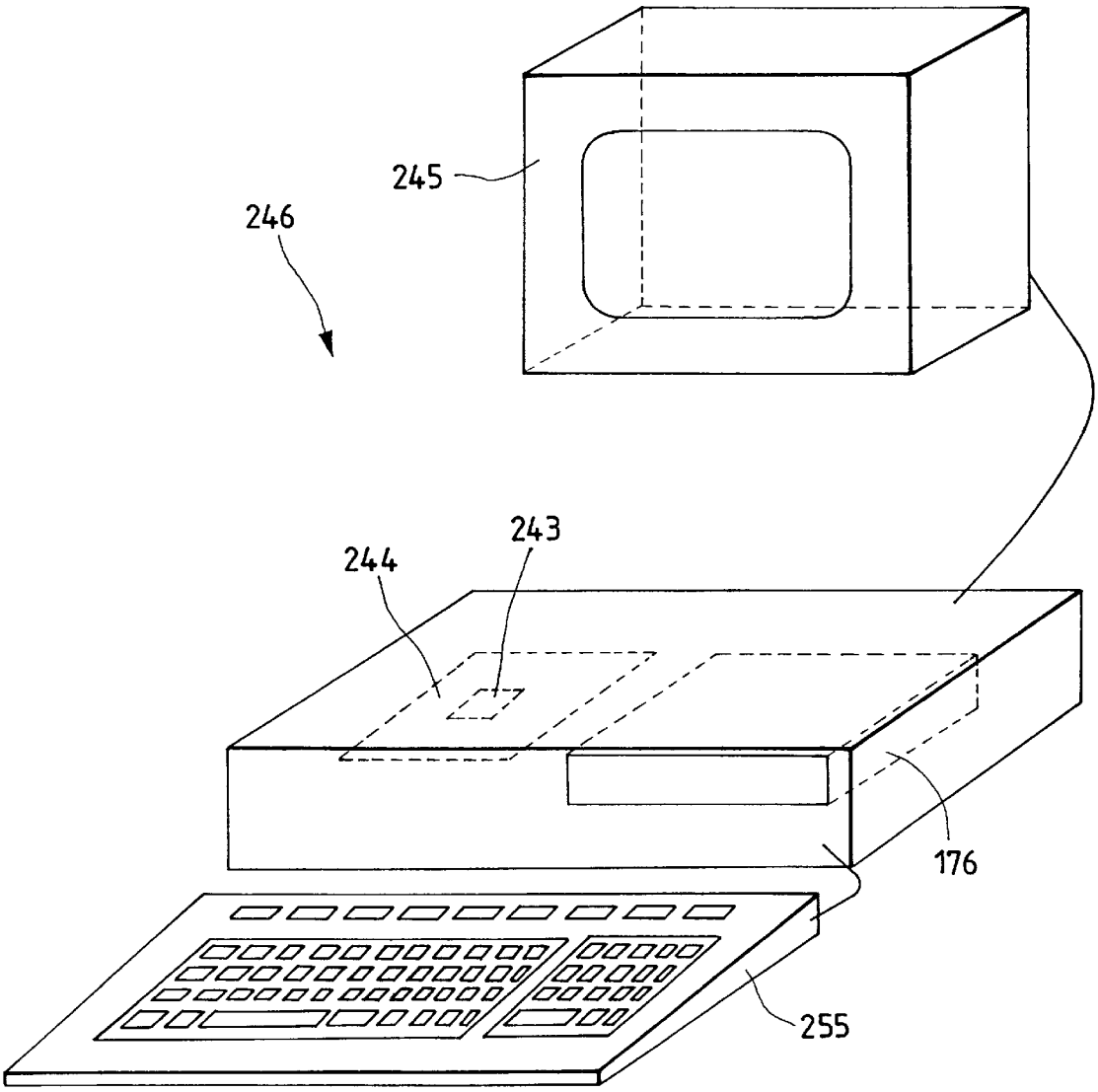


FIG. 68



COMPOUND OBJECTIVE LENS HAVING TWO FOCAL POINTS

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation-in-part of U.S. Pat. application Ser. No. 08/190,520, filed Feb. 1, 1994 now U.S. Pat. No. 5,446,565.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a compound objective lens composed of an objective lens and a hologram lens which has two focal points, an imaging optical system for converging light on two converging spots placed at different depths of an information medium with the compound objective lens, an optical head apparatus for recording, reproducing or erasing information on or from an information medium such as an optical medium or a magneto-optical medium like an optical disk or an optical card with the imaging optical system, an optical disk in which a series of high density recording pits and a series of comparatively low density recording pits are provided, an optical disk apparatus for recording or reproducing information on or from the optical disk with the compound objective lens, a binary focus microscope having two focal points in which two types of images drawn at different depths are simultaneously observed, and an alignment apparatus for aligning two types of images drawn at different depths with the binary focus microscope.

2. Description of the Related Art

An optical memory technique has been put to practical use to manufacture an optical disk in which a pit pattern formed of a series of pits is drawn to record information. The optical disk is utilized as a high density and large capacity of information medium. For example, the optical disk is utilized for a digital audio disk, a video disk, a document file disk, and a data file disk. To record information on the optical disk and to reproduce the information from the optical disk, a light beam radiated from a light source is minutely converged in an imaging optical system, and the light beam minutely converged is radiated to the optical disk through the imaging optical system. Therefore, the light beam is required to be reliably controlled in the imaging optical system with high accuracy.

The imaging optical system is utilized for an optical head apparatus in which a detecting system is additionally provided to detect the intensity of the light beam reflected from the optical disk. Fundamental functions of the optical head apparatus are classified into a converging performance for minutely converging a light beam to form a diffraction-limited micro-spot of the light beam radiated on the optical disk, a focus control in a focus servo system, a tracking control in a tracking serve system, and the detection of pit signals (or information signals) obtained by radiating the light beam on a pit pattern of the optical disk. The fundamental function of the optical head apparatus is determined by the combination of optical sub-systems and a photoelectric transfer detecting process according to a purpose and a use. Specifically, an optical head apparatus in which a holographic optical element (or hologram) is utilized to minimize and thin the optical head apparatus has been recently proposed.

2.1. Previously Proposed Art

FIG. **1** is a constitutional view of a conventional optical head apparatus proposed in Japanese Patent Application No. 46630 of 1991 which is applied by inventors of the present invention.

As shown in FIG. **1**, a conventional optical head apparatus **11** for recording or reproducing information on or from an information medium **12** such as an optical disk is provided with a light beam source **13** such as a semiconductor laser, a transmission type of blazed hologram **14** for transmitting a light beam L1 radiated from the light beam source **12** without any diffraction in an outgoing optical path and diffracting a light beam L2 reflected on the information medium **12** in a returning optical path, an objective lens **15** for converging the light beam L1 transmitting through the hologram **13** on the information medium **14** to read the information, an actuator **16** for integrally moving the objective lens **15** with the blazed hologram **13** to focus the light beam L1 on the information medium **12** with the objective lens **15**, and a photo detector **17** for detecting the intensity of the light beam L2 reflected on the information medium **12** to reproduce the information.

As shown in FIG. **2**A, a relative position between the blazed hologram **14** and the objective lens **15** is fixed by a fixing means **18**. Or, as shown in FIG. **2**B, a blazed pattern is formed on a side of the objective lens **15** to integrally form the blazed hologram **14** with the objective lens **15**.

In the above configuration, a light beam L1 (or a laser beam) radiated from the light beam source **13** is radiated to the blazed hologram **14**, and the light beam L1 mainly transmits through the blazed hologram **14** without any diffraction in an outgoing optical path. The light beam L1 transmitting through the blazed hologram **14** is called zero-order diffracted light. Thereafter, the zero-order diffracted light L1 is converged on the information medium **12** by the objective lens **15**. In the information medium **12**, information indicated by a series of patterned pits is recorded and read by the zero-order diffracted light L1. Thereafter, a beam light L2 having the information is reflected toward the objective lens **15** in a returning optical path and is incident to the blazed hologram **14**. In the blazed hologram **14**, the light L2 is mainly diffracted. The light L2 diffracted is called first-order diffracted light. Thereafter, the first-order diffracted light L2 is received in the photo detector **17**.

In the photo detector **17**, the intensity distribution of the first-order diffracted light L2 is detected. Therefore, a servo signal for adjusting the position of the objective lens **15** by the action of the actuator **16** is obtained. Also, the intensity of the first-order diffracted light L2 is detected in the photo detector **17**. Because the information medium **12** is rotated at high speed, the patterned pits radiated by the light **17** are changed so that the intensity of the first-order diffracted light L2 detected is changed. Therefore, an information signal indicating the information recorded in the information medium **12** is obtained by detecting the change in intensity of the first-order diffracted light L2.

In the above operation, a part of the light beam L1 is necessarily diffracted in the blazed hologram **14** when the light beam L1 is radiated to the blazed hologram **14** in the outgoing optical path. Therefore, unnecessary diffracted light such as first-order diffracted light and minus first-order diffracted light necessarily occurs. In cases where the hologram **14** is not blazed, the unnecessary diffracted light in the outgoing optical path also reads the information recorded in the information medium **12**, and the unnecessary light is undesirably received in the photo detector **17**. To prevent the unnecessary light from transmitting to the information medium **12**, the blazed hologram **14** is manufactured to form a blazed hologram pattern on the surface thereof, so that the intensity of the unnecessary light received in the photo detector **17** is decreased.

Also, because an objective lens of a conventional microscope has only a focal point, images placed within a focal

depth of the objective lens can be only observed with the conventional microscope.

Also, a minute circuit is formed on a semiconductor such as a group III-V compound semiconductor to form a microwave circuit, an opto-electronic detector or a solid state laser. In this case, a photo-sensitive material is coated on a sample made of the semiconductor. Thereafter, a relative position between the sample and a photo mask covering the sample is adjusted by utilizing an alignment apparatus, and the photo-sensitive material is exposed by a beam of exposure light through the photo mask to transfer a circuit pattern drawn on the photo mask to the photo-sensitive material in an exposure process by utilizing an exposure apparatus. For example, an alignment pattern is drawn on a reverse side of the sample, and a relative position between the sample and the photo mask is adjusted with high accuracy while simultaneously observing the alignment pattern of the sample and the circuit pattern of the photo mask with the conventional microscope. Thereafter, the circuit pattern of the photo mask is transferred to a front side of the sample.

In this case, because images placed within a focal depth of an objective lens utilized in the conventional microscope can be only observed with the conventional microscope, it is required to utilize the conventional microscope having a deep focal depth in the alignment apparatus in cases where the alignment pattern and the circuit pattern are simultaneously observed with the conventional microscope. Therefore, the magnification of the conventional microscope having a deep focal depth is lowered.

2.2. Problems to be Solved by the Invention

An optical disk having a high density memory capacity has been recently developed because of the improvement in a design technique of an optical system and the shortening of the wavelength of light radiated from a semiconductor laser. For example, a numerical aperture at an optical disk side of an imaging optical system in which a light beam converged on an optical disk is minutely narrowed in diameter is enlarged to obtain the optical disk having a high density memory capacity. In this case, the degree of aberration occurring in the imaging optical system is increased because an optical axis of the system tilts from a normal line of the optical disk. As the numerical aperture is increased, the degree of the aberration is enlarged. To prevent the increase of the numerical aperture, it is effective to thin the thickness of the optical disk. The thickness of the optical disk denotes a distance from a surface of the optical disk (or an information medium) radiated by a light beam to an information recording plane on which a series of patterned pits are formed.

FIG. **3** shows a relationship between the thickness of the optical disk and the numerical aperture on condition that the tilt of the optical axis is constant.

As shown in FIG. **3**, because the numerical aperture is 0.5 when the thickness of the optical disk is 1.2 mm, it is effective to thin the optical disk to 0.6 mm in thickness when the numerical aperture is increased to 0.6. In this case, even though the numerical aperture is increased on condition that the tilt of the optical axis is not changed, the degree of the aberration is not increased. Therefore, it is preferred that the thickness of the optical disk be thinned to obtain the optical disk having a high density memory capacity.

Accordingly, it is expected that the thickness of a prospective optical disk having a high density memory capacity becomes thinner than that of a present optical disk such as a compact disk appearing on the market now. For example, the thickness of the compact disk is about 1.2 mm, and the thickness of the prospective optical disk is expected to range from 0.4 mm to 0.8 mm. In this case, it is required to record or reproduce information on or from an optical disk with an optical head system regardless of whether the optical disk is the present optical disk or the prospective optical disk having a high density memory capacity. That is, an optical head apparatus having an imaging optical system in which a light beam is converged on an optical disk within the diffraction limit regardless of whether the optical disk is thick or thin is required.

However, in a conventional optical head apparatus, a piece of information is only recorded or reproduced on or from an optical disk having a fixed thickness. For example, in cases where the thickness of the information medium **12** is off a regular range by about ±0.1 mm or more, an aberration such as a spherical aberration occurs when the optical head apparatus **11** is operated. Therefore, the recording or the reproduction of the information is impossible. Accordingly, there is a drawback that an optical head apparatus in which a piece of information is recorded or reproduced on or from an optical disk regardless of whether the optical disk is the present optical disk or the prospective optical disk having a high density memory capacity cannot be manufactured in a conventional technique.

Also, there is a problem in the conventional microscope. That is, because an objective lens of the conventional microscope has only a focal point and images placed within a focal depth of the objective lens can be only observed with the conventional microscope, the magnification of the conventional microscope and an observed range in an optical axis direction are in a trade-off relationship. Therefore, there is a drawback that it is impossible to observe the images over a wide observed range in the optical axis direction at high magnification

Also, there is a problem in the alignment apparatus. That is, when a circuit pattern drawn on the photo mask is transferred to the front side of the sample after an alignment pattern is drawn on the reverse side of the sample, the alignment of the photomask and the sample is performed by simultaneously observing the circuit pattern of the photo mask and the alignment pattern of the sample with the conventional microscope having a deep focal depth and a low magnification. Therefore, because the conventional microscope has a low magnification, there is a drawback that it is impossible to align the photo mask with the sample at a high accuracy ranging within 5 μm.

SUMMARY OF THE INVENTION

A first object of the present invention is to provide, with due consideration to the drawbacks of such a conventional objective lens having a focal point, a compound objective lens having two focal points.

A second object of the present invention is to provide an imaging optical system having the compound objective lens in which light transmitting through the compound objective lens is converged at a diffraction limit on two converging spots placed at different depths of an information medium.

A third object of the present invention is to provide an optical head apparatus having the imaging optical system in which information is recorded, reproduced or erased on or from one of the converging spots of the information medium at which light is converged by the action of the imaging optical system.

A fourth object of the present invention is to provide a high density optical disk in which a series of first recording pits is formed to record pieces of information at high density on a thin substrate.

A fifth object of the present invention is to provide an optical disk apparatus in which information is recorded or reproduced on or from the optical disk with the compound objective lens regardless of whether a series of recording pits expressing pieces of information is recorded or reproduced on or from the high density optical disk having a thin thickness or a conventional compact disk having an ordinary thickness.

A sixth object of the present invention is to provide a binary focus microscope having two focal points in which two types of images drawn at different depths are simultaneously observed.

A seventh object of the present invention is to provide an alignment apparatus in which two types of images drawn at different depths are aligned with the binary focus microscope.

An eighth object of the present invention is to provide a focusing method for focusing light on an information medium with the optical head apparatus.

A ninth embodiment of the present invention is to provide an information reproducing method for reproducing a piece of recording information recorded on a high density optical disk having a thin thickness.

The first object is achieved by the provision of a compound objective lens having two focal points, comprising:

hologram means for transmitting a part of incident light without any diffraction to form a beam of transmitted light and diffracting a remaining part of the incident light to form a beam of diffracted light, the hologram means functioning as a lens for the diffracted light to diverge the diffracted light from the hologram means or converge the diffracted light; and

lens means for converging the transmitted light formed in the hologram means to form a first converging spot at a first focal point and converging the diffracted light formed in the hologram means to form a second converging spot at a second focal point, the second focal point differing from the first focal point.

In the above configuration, a part of incident light transmits through the hologram means without any diffraction. Therefore, a beam of transmitted light not diverged from the hologram means or not converging is formed. Thereafter, the transmitted light is refracted and converged by the lens means, so that the transmitted light is focused on a first converging spot positioned at a first focal point.

In contrast, a remaining part of incident light is diffracted by the hologram means. Therefore, a beam of diffracted light such as a beam of first-order diffracted light which is diverged from the hologram lens or converges is formed. Thereafter, the diffracted light is refracted and converged by the lens means, so that the diffracted light is focused on a second converging spot positioned at a second focal point.

In this case, because a propagation direction of the transmitted light differs from that of the diffracted light, the first focal point of the compound objective lens for the transmitted light differs from the second focal point of the compound objective lens for the diffracted light. Therefore, the compound objective lens has two focal points, and the incident light transmitting through the compound objective lens are converged on two converging points.

Accordingly, the incident light transmitting through the compound objective lens can be reliably converged on an information medium regardless whether the information medium has a first thickness or a second thickness.

It is preferred that a grating pattern be drawn in the hologram means in a concentric circle shape, the grating pattern of the hologram means be formed in relief to concentrically form alternating rows of bottom portions and top portions, a height H of relief in the grating pattern be set to $H < \lambda/(n(\lambda)-1)$ where a symbol λ denotes a wavelength of the incident light and a symbol $n(\lambda)$ denotes a refractive index of the hologram means made of a glass material for the incident light having the wavelength λ, and a difference in phase modulation degree between the incident light transmitting through a bottom portion of the grating pattern and the incident light transmitting through a top portion of the grating pattern be lower than 2π radians to set a diffraction efficiency of the hologram means to a value lower than 100%.

In the above configuration, because the height of the relief in the grating pattern is lower than a value $\lambda/(n(\lambda)-1)$, the difference in phase modulation degree is induced to be lower than 2π radians. Therefore, the diffraction efficiency of the hologram means is set to a value lower than 100% over the entire grating pattern, so that the transmitted light and the diffracted light are simultaneously formed in the hologram lens.

The first object is also achieved by the provision of a compound objective lens, comprising:

lens means for converging a beam of first incident light on a front surface of a first information medium having a first thickness T1 and converging a beam of second incident light on a front surface of a second information medium having a second thickness T2 (T2<T1), the first incident light passing through the first information medium from its rear surface, and the second incident light passing through the second information medium from its rear surface; and

aperture limiting means for selectively limiting an aperture of the lens means for the second incident light which is incident on the lens means, a second numerical aperture of the lens means for the second incident light which is incident on the lens means being lower than a first numerical aperture of the lens means for the first incident light which is incident on the lens means.

In the above configuration, an aperture of the lens means for the second incident light is limited by the aperture limiting means, and another aperture of the lens means for the first incident light is limited. Thereafter, the first incident light is converged by the lens means on the first information medium at a high numerical aperture, and the second incident light is converged by the lens means on the second information medium at a low numerical aperture. Accordingly, the compound objective lens has two focal points. Also, the intensity of the first incident light can be larger than that of the second incident light.

The first object is also achieved by the provision of a compound objective lens, comprising:

lens means for converging a beam of first incident light on a front surface of a first information medium having a first thickness and converging a beam of second incident light on a front surface of a second information medium having a second thickness, the first incident light passing through the first information medium from its rear surface, and the second incident light passing through the second information medium from its rear surface; and

curvature changing means for changing a curvature of spherical waves of a part of incident light to form the first incident light which is incident on the lens means and not changing a curvature of spherical waves of a remaining part of incident light to form the second incident light which is incident on the lens means.

In the above configuration, a curvature of spherical waves of a part of incident light is changed by the curvature changing means to form a beam of first incident light, and a curvature of spherical waves of a remaining part of incident light is not changed to form a beam of second incident light. Thereafter, the first incident light is converged on the first information medium, and the second incident light is converged on the second information medium.

Accordingly, the compound objective lens has two focal points.

The second object is achieved by the provision of an imaging optical system, comprising:

a light source for radiating a beam of incident light of which a far field pattern is distributed to decrease intensity of the incident light toward a peripheral portion of the beam;

hologram means for transmitting a part of the incident light radiated from the light source without any diffraction to form a beam of transmitted light and diffracting a remaining part of the incident light to form a beam of diffracted light, a grating pattern being formed in relief in the hologram means to concentrically form alternating rows of bottom portions and top portions on condition that a height H of relief in the grating pattern is set to $H < \lambda/(n(\lambda)-1)$ where a symbol λ denotes a wavelength of the incident light and a symbol $n(\lambda)$ denotes a refractive index of the hologram means made of a glass material for the incident light having the wavelength λ, a difference in phase modulation degree between the incident light transmitting through the bottom portions of the grating pattern and the incident light transmitting through the top portions of the grating pattern being lower than 2π radians to set a diffraction efficiency of the hologram means to a value lower than 100%, the height H of the relief in the grating pattern being gradually lowered toward an outer direction of a pattern region in which the grating pattern is drawn, and the diffraction efficiency of the hologram means for the incident light being gradually lowered toward the outer direction of the pattern region to distribute intensity of the transmitted light in a gently-sloping shape; and

lens means for converging the transmitted light formed in the hologram means to form a first converging spot at a first focal point and converging the diffracted light formed in the hologram means to form a second converging spot at a second focal point.

In the above configuration, a beam of incident light is radiated from a light source. A far field pattern of the incident light is distributed to decrease intensity of the incident light toward a peripheral portion of the beam. For example, the light source is a semiconductor laser, the far field pattern of the incident light is distributed in the Gaussian distribution. Thereafter, the incident light transmits through the hologram means. In this case, because a grating pattern is drawn in relief in the hologram means and because the height of the relief is lower than a value $\lambda/(n(\lambda)-1)$, the difference in phase modulation degree between the incident light transmitting through a bottom portion of the grating pattern and the incident light transmitting through a top portion of the grating pattern is induced to be lower than 2π radians. Therefore, the diffraction efficiency of the hologram means for the incident light is set to a value lower than 100% over the entire grating pattern, so that the transmitted light and the diffracted light are simultaneously formed in the hologram lens. In addition, because the height H of the relief in the grating pattern is gradually lowered toward the outer direction of the pattern region, the diffraction efficiency of the hologram means for the incident light is gradually lowered toward the outer direction of the pattern region. Therefore, the incident light positioned at a center portion of its beam are mainly changed to the diffracted light, and the incident light positioned at a peripheral portion of its beam are mainly changed to the transmitted light.

Thereafter, the transmitted light is refracted and converged by the lens means, so that the transmitted light is focused on a first converging spot positioned at a first focal point. Also, the diffracted light is refracted and converged by the lens means, so that the diffracted light is focused on a second converging spot positioned at a second focal point. In this case, because a propagation direction of the transmitted light differs from that of the diffracted light, the first focal point for the transmitted light differs from the second focal point for the diffracted light.

Accordingly, even though the far field pattern of the incident light is distributed in the Gaussian distribution, the far field pattern of the transmitted light is distributed in a gently-sloping shape. Therefore, secondary maxima (or side lobes) of the transmitted light can be prevented from occurring at the first converging spot.

Also, because the height H of the relief in the grating pattern is gradually lowered over the entire pattern region, a numerical aperture of the lens means for the diffracted light can be sufficiently heightened.

The second object is also achieved by the provision of an imaging optical system, comprising:

a light source for radiating a beam of incident light of which a far field pattern is distributed to decrease intensity of the incident light toward a peripheral portion of the beam;

hologram means for transmitting a part of the incident light radiated from the light source without any diffraction to form a beam of transmitted light and diffracting a remaining part of the incident light to form a beam of diffracted light, a grating pattern being formed in relief in the hologram means to concentrically form alternating rows of bottom portions and top portions on condition that a height H of relief in the grating pattern is set to $H < \lambda/(n(\lambda)-1)$ where a symbol λ denotes a wavelength of the incident light and a symbol $n(\lambda)$ denotes a refractive index of the hologram means made of a glass material for the incident light having the wavelength λ, a difference in phase modulation degree between the incident light passing through the bottom portions of the grating pattern and the incident light passing through the top portions of the grating pattern being lower than 2π radians to set a diffraction efficiency of the hologram means to a value lower than 100%, the height H of the relief in the grating pattern being gradually lowered toward an inner direction of a pattern region in which the grating pattern is drawn, and the diffraction efficiency of the hologram means for the incident light being gradually lowered toward the inner direction of the pattern region to distribute intensity of the diffracted light in a gently-sloping shape; and

lens means for converging the transmitted light formed in the hologram means to form a first converging spot at a first focal point and converging the diffracted light formed in the hologram means to form a second converging spot at a second focal point.

In the above configuration, the transmitted light and the diffracted light are simultaneously formed in the hologram lens in the same manner. Also, because the height H of the relief in the grating pattern is gradually lowered toward the

inner direction of the pattern region, the diffraction efficiency of the hologram means for the incident light is gradually lowered toward the inner direction of the pattern region. Therefore, the incident light positioned at a center portion of its beam are mainly changed to the transmitted light, and the incident light positioned at a peripheral portion of its beam are mainly changed to the diffracted light.

Accordingly, even though the far field pattern of the incident light is distributed in the Gaussian distribution, the far field pattern of the diffracted light is distributed in a gently-sloping shape. Therefore, secondary maxima (or side lobes) of the diffracted light can be prevented from occurring at the second converging spot.

Also, because the height H of the relief in the grating pattern is gradually lowered over the entire pattern region, a numerical aperture of the lens means for the transmitted light can be sufficiently heightened.

The third object is achieved by the provision of an optical head apparatus for recording or reproducing a piece of information on or from a thin type of first information medium having a first thickness or a thick type of second information medium having a second thickness larger than the first thickness, comprising:

a light source for radiating a beam of incident light;

hologram means for transmitting a part of the incident light radiated from the light source without any diffraction on an outgoing path to form a beam of transmitted light and diffracting a remaining part of the incident light radiated from the light source on the outgoing path to form a beam of diffracted light, the hologram means functioning as a lens for the diffracted light to diverge the diffracted light from the hologram means or converge the diffracted light;

lens means for converging the transmitted light formed in the hologram means at a first focal length on the outgoing path to form a first converging spot at a front surface of the first information medium or converging the diffracted light formed in the hologram means at a second focal length on the outgoing path to form a second converging spot at a front surface of the second information medium, the transmitted light being incident on a rear surface of the first information medium and being converged at the front surface of the first information medium, the transmitted light being reflected at the rear surface of the first information medium and again passing through the lens means and the hologram means on an incoming path, the diffracted light being incident on a rear surface of the second information medium and being converged at the front surface of the second information medium, and the diffracted light being reflected at the rear surface of the first information medium and again passing through the lens means and the hologram means on the incoming path;

wavefront changing means for changing a wavefront of the transmitted light or the diffracted light passing through the lens means and the hologram means on the incoming path to form one or more beams of information light; and

detecting means for detecting intensities of the information light formed by the wavefront changing means and generating an information signal according to the intensities of the information light, the information signal expressing a piece of information recorded on the first information medium or the second information medium.

In the above configuration, a beam of incident light is radiated from the light source, and a part of the incident light transmits through the hologram lens to form a beam of transmitted light. Also, a remaining part of the incident light is diffracted by the hologram lens to form a beam of diffracted light. Thereafter, the transmitted light and the diffracted light are converged by the converging means. In cases where a piece of information is recorded or reproduced on or from the first information medium, the transmitted light is incident on the rear surface of the first information medium and is converged at the front surface of the first information medium to form the first converging spot. Thereafter, the transmitted light is reflected at the rear surface of the first information medium and again passes through the lens means and the hologram means without any diffraction. In contrast, in cases where a piece of information is recorded or reproduced on or from the second information medium, the diffracted light is incident on the rear surface of the second information medium and is converged at the front surface of the second information medium to form the second converging spot. Thereafter, the diffracted light is reflected at the rear surface of the second information medium and again passes through the lens means. Thereafter, the diffracted light is again diffracted by the hologram means.

Thereafter, a wavefront of the transmitted light or the diffracted light is changed by the wavefront changing means to form a plurality of beams of reflected light, and the intensities of the reflected light is detected by the detecting means. Therefore, an information signal expressing the information recorded on the first or second information medium is generated according to the intensities of the reflected light.

Accordingly, because the first converging spot of the transmitted light differs from the second converging spot of the diffracted light. a compound objective lens composed of the hologram lens and the lens means has two focal points. Therefore, a piece of information can be recorded or reproduced on or from an information medium regardless of whether the information medium has the first thickness or the second thickness.

The third object is also achieved by the provision of an optical head apparatus for recording or reproducing a piece of information on or from a first information medium having a first thickness **T1** or a second information medium having a second thickness **T2** (**T1<T2**), comprising:

lens means for converging a beam of first incident light on a front surface of a first information medium having a first thickness **T1** or converging a beam of second incident light on a front surface of a second information medium having a second thickness **T2** (**T2<T1**), the first incident light passing through the first information medium from its rear surface, and the second incident light passing through the second information medium from its rear surface;

aperture limiting means for selectively limiting an aperture of the lens means for the second incident light which is incident on the lens means, a second numerical aperture of the lens means for the second incident light which is incident on the lens means being lower than a first numerical aperture of the lens means for the first incident light which is incident on the lens means, the first incident light being reflected at the front surface of the first information medium and again passing through the lens means and the aperture limiting means on an incoming path, and the second incident light being reflected at the front surface of the second information

medium and again passing through the lens means and the aperture limiting means on the incoming path;

a light source for radiating the first incident light and the second incident light to the aperture limiting means;

wavefront changing means for changing a wavefront of the first or second incident light passing through the lens means and the aperture limiting means on the incoming path to form one or more beams of information light; and

detecting means for detecting intensities of the information light formed by the wavefront changing means and generating an information signal according to the intensities of the information light, the information signal expressing a piece of information recorded on the first information medium or the second information medium.

In the above configuration, a compound objective lens composed of the lens means and the aperture limiting means has two focal points, and the intensity of the first incident light is larger than that of the second incident light.

Accordingly, a piece of information can be recorded or reproduced on or from an information medium regardless of whether the information medium has the first thickness or the second thickness. Also, a piece of information can be efficiently recorded on the first information medium with the first incident light having a high intensity, and a piece of information can be efficiently reproduced from the second information medium with the second incident light having a comparatively low intensity.

The third object is also achieved by the provision of an optical head apparatus for recording or reproducing a piece of information on or from a first information medium having a first thickness or a second information medium having a second thickness, comprising:

lens means for converging a beam of first incident light on a front surface of the first information medium and converging a beam of second incident light on a front surface of the second information medium, the first incident light passing through the first information medium from its rear surface, and the second incident light passing through the second information medium from its rear surface; and

curvature changing means for changing a curvature of spherical waves of a part of incident light to form the first incident light which is incident on the lens means and not changing a curvature of spherical waves of a remaining part of incident light to form the second incident light which is incident on the lens means, the first incident light being reflected at the front surface of the first information medium and again passing through the lens means and the curvature changing means on an incoming path, and the second incident light being reflected at the front surface of the second information medium and again passing through the lens means and the curvature changing means on the incoming path;

a light source for radiating the incident light to the curvature changing means;

wavefront changing means for changing a wavefront of the first or second incident light passing through the lens means and the curvature changing means on the incoming path to form one or more beams of information light; and

detecting means for detecting intensities of the information light formed by the wavefront changing means and generating an information signal according to the intensities of the information light, the information signal expressing a piece of information recorded on the first information medium or the second information medium.

In the above configuration, because a compound objective lens is composed of the lens means and the curvature changing means, the compound objective lens has two focal points. Accordingly, a piece of information can be recorded or reproduced on or from an information medium regardless of whether the information medium has the first thickness or the second thickness.

The fourth object is achieved by the provision of an optical disk, comprising:

an information recording substrate partitioned into a first region and a second region, the first region having a first thickness, and the second region having a second thickness smaller than the first thickness;

a plurality of first recording pits placed at the first region of the information recording substrate for recording pieces of recording information at a high recording density, the first recording pits being formed at narrow intervals; and

a plurality of second recording pits placed at the second region of the information recording substrate for recording pieces of distinguishing information at an ordinary recording density of a compact disk, the distinguishing information informing that the recording information are recorded on the information recording substrate having the first thickness, and the recording density of the recording information being higher than that of the distinguishing information.

In the above configuration, a substrate of a conventional compact disk has the same second thickness as that of the second region of the information recording substrate in the optical disk according to the present invention. Therefore, in cases where a beam of reproducing light is incident on a prescribed region of an unknown disk selected from a group of the conventional compact disk and the optical disk, the reproducing light is focused on a recording pit of the conventional compact disk or one of the second recording pits of the optical disk regardless of whether the unknown disk is the conventional compact disk or the optical disk.

In cases where the unknown disk is the optical disk, a piece of distinguishing information is read by the reproducing light. Because the distinguishing information informs that pieces of recording information are recorded on the information recording substrate having the first thickness, a curvature of the reproducing light is automatically changed to focus the reproducing light on the information recording substrate having the first thickness, and the reproducing light is automatically focused on one of the first recording pits. Therefore, a piece of recording information is reproduced.

In contrast, in cases where the unknown disk is the conventional compact disk, a piece of recording information is read by the reproducing light in the same manner as in a prior art.

Accordingly, a piece of recording information formed on an information recording substrate can be reliably reproduced even though the thickness of the information recording substrate is unknown.

The fourth object is also achieved by the provision of an optical disk, comprising:

an information recording substrate having a thin thickness, the thin thickness of the information recording substrate being thinner than that of a compact disk;

a plurality of first recording pits placed at a first region of the information recording substrate for recording

pieces of recording information at a high recording density, the first recording pits being formed at narrow intervals; and

a plurality of second recording pits placed at a second region of the information recording substrate for recording pieces of distinguishing information at a low recording density, the distinguishing information informing that the recording information are recorded on the information recording substrate having the thin thickness, the recording density of the recording information being higher than that of the distinguishing information, each of the second recording pits being larger than that of a recording pit in the compact disk, and a converging spot of a beam of reproducing light, which is converged to focus on an ordinary recording pit formed on a substrate having an ordinary thickness of the compact disk, being formed in one of the second recording pits to read the distinguishing information.

In the above configuration, a beam of reproducing light, of which a curvature is adjusted to focus the reproducing light on a recording pit formed on an information recording substrate of the compact disk, is incident on a prescribed region of an unknown disk selected from a group of the compact disk having an ordinary thickness and the optical disk according to the present invention. In cases where the unknown disk is the optical disk, the reproducing light is converged on one of the second recording pits in defocus because the information recording substrate of the optical disk has the thin thickness. However, because each of the second recording pits is large in size, a converging spot of the reproducing light is formed in the second recording pit. Therefore, a piece of distinguishing information is read by the reproducing light. Because the distinguishing information informs that pieces of recording information are recorded on the information recording substrate having the thin thickness, a curvature of the reproducing light is automatically changed to focus the reproducing light on the information recording substrate having the thin thickness, and the reproducing light is automatically focused on one of the first recording pits. Therefore, a piece of recording information is reproduced.

In contrast, in cases where the unknown disk is the compact disk, a piece of recording information is read by the reproducing light in the same manner as in a prior art.

Accordingly, a piece of recording information formed on an information recording substrate can be reliably reproduced even though the thickness of the information recording substrate is unknown.

The fifth object is achieved by the provision of an optical disk apparatus for recording or reproducing pieces of recording information on or from an optical disk in which the recording information are recorded or reproduced at a high density on or from a first substrate having a first thickness and a piece of distinguishing information informing that the recording information are recorded or reproduced on or from the first substrate having the first thickness is recorded at an ordinary density on a second substrate having a second thickness larger than the first thickness, comprising:

rotating means for rotating the optical disk at a regular speed;

a light source for radiating a beam of incident light;

hologram means for transmitting a part of the incident light radiated from the light source without any diffraction on an outgoing path to form a beam of transmitted light and diffracting a remaining part of the incident light radiated from the light source on the outgoing path to form a beam of diffracted light, the hologram means functioning as a lens for the diffracted light to diverge the diffracted light from the hologram means;

lens means for converging the transmitted light formed in the hologram means on the first substrate of the optical disk rotated by the rotating means to record or reproduce a piece of recording information on or from the optical disk and converging the diffracted light formed in the hologram means on the second substrate of the optical disk rotated by the rotating means to reproduce the distinguishing information from the optical disk, the transmitted light being reflected by the first substrate of the optical disk and again passing through the lens means and the hologram means on an incoming path, and the diffracted light being reflected by the second substrate of the optical disk and again passing through the lens means and the hologram means on the incoming path;

wavefront changing means for changing a wavefront of the transmitted light passing through the lens means and the hologram means on the incoming path to form one or more beams of recording information light and changing a wavefront of the diffracted light passing through the lens means and the hologram means on the incoming path to form one or more beams of distinguishing information light;

detecting means for detecting intensities of the recording information light formed by the wavefront changing means to generate a recording information signal according to the intensities of the recording information light and detecting intensities of the distinguishing information light formed by the wavefront changing means to generate a distinguishing information signal according to the intensities of the distinguishing information light, the distinguishing information signal expressing the distinguishing information recorded on the second substrate of the optical disk, and the recording information signal expressing the recording information recorded on the first substrate of the optical disk; and

moving means for moving an optical head apparatus comprising the light source, the hologram means, the lens means and the detecting means to converge the diffracted light formed in the hologram means on the second substrate of the optical disk and moving the optical disk, in which the diffracted light formed in the hologram means is converged on the second substrate of the optical disk, to converge the transmitted light formed in the hologram means on the first substrate of the optical disk in cases where the distinguishing information is detected in the detecting means.

In the above configuration, an optical head apparatus comprising the light source, the hologram means, the lens means and the detecting means has the same configuration as that described before. Initially, the optical head apparatus is moved by the moving means to converge in focus the diffracted light formed in the hologram means on the second substrate of the optical disk rotated by the rotating means. Therefore, the distinguishing information recorded on the second substrate is reproduced in the detecting means, and it is informed that pieces of recording information are recorded or reproduced on or from the first substrate having the first thickness. Thereafter, the optical head apparatus is moved by the moving means to converge in focus the transmitted light formed in the hologram means on the first substrate of the optical disk rotated by the rotating means. Therefore, a piece of recording information is recorded or reproduced on or from the first substrate of the optical disk.

Accordingly, even though a high density type of optical disk, in which pieces of recording information is recorded or reproduced on or from the substrate having the first thickness smaller than the second thickness of a conventional optical disk, is utilized, the recording information can be reliably recorded or reproduced.

The fifth object is also achieved by the provision of an optical disk apparatus for recording or reproducing pieces of recording information on or from an optical disk in which the recording information are recorded or reproduced at a high density on or from a first substrate having a thin thickness thinner than that of a compact disk and a piece of distinguishing information informing that the recording information are recorded or reproduced on or from the first substrate having the thin thickness is recorded at a low density on a second substrate having the thin thickness, comprising:

rotating means for rotating the optical disk at a regular speed;

a light source for radiating a beam of incident light;

hologram means for transmitting a part of the incident light radiated from the light source without any diffraction on an outgoing path to form a beam of transmitted light and diffracting a remaining part of the incident light radiated from the light source on the outgoing path to form a beam of diffracted light, the hologram means functioning as a lens for the diffracted light to diverge the diffracted light from the hologram means;

lens means for converging in focus the transmitted light formed in the hologram means on the first substrate of the optical disk rotated by the rotating means to record or reproduce a piece of recording information on or from the optical disk and converging in defocus the diffracted light formed in the hologram means on the second substrate of the optical disk rotated by the rotating means to reproduce the distinguishing information from the optical disk, the transmitted light being reflected by the first substrate of the optical disk and again passing through the lens means and the hologram means on an incoming path, and the diffracted light being reflected by the second substrate of the optical disk and again passing through the lens means and the hologram means on the incoming path;

wavefront changing means for changing a wavefront of the transmitted light passing through the lens means and the hologram means on the incoming path to form one or more beams of recording information light and changing a wavefront of the diffracted light passing through the lens means and the hologram means on the incoming path to form one or more beams of distinguishing information light;

detecting means for detecting intensities of the recording information light formed by the wavefront changing means to generate a recording information signal according to the intensities of the recording information light and detecting intensities of the distinguishing information light formed by the wavefront changing means to generate a distinguishing information signal according to the intensities of the distinguishing information light, the distinguishing information signal expressing the distinguishing information recorded on the second substrate of the optical disk, and the recording information signal expressing the recording information recorded on the first substrate of the optical disk; and

moving means for moving an optical head apparatus comprising the light source, the hologram means, the lens means and the detecting means, to converge the diffracted light formed in the hologram means in defocus on the second substrate of the optical disk and moving the optical disk, in which the diffracted light formed in the hologram means is converged on the second substrate of the optical disk in defocus, to converge the transmitted light formed in the hologram means on the first substrate of the optical disk in focus in cases where an intensity of the distinguishing information signal generated in the detecting means is larger than a threshold value.

In the above configuration, an optical head apparatus comprising the light source, the hologram means, the lens means and the detecting means has the same configuration as that described before. Initially, the optical head apparatus is moved by the moving means to converge in defocus the diffracted light formed in the hologram means on the second substrate of the optical disk rotated by the rotating means. In this case, because the distinguishing information is recorded at a low density, a plurality of recording pits expressing the distinguishing information are respectively large in size. Therefore, even though the diffracted light is converged on each of the recording pits in defocus, a converging spot of the diffracted light is formed in each of the recording pits. Therefore, the distinguishing information recorded on the second substrate is reproduced in the detecting means, and it is informed that pieces of recording information are recorded or reproduced on or from the first substrate having the thin thickness. Thereafter, the optical head apparatus is moved by the moving means to converge in focus the transmitted light formed in the hologram means on the first substrate of the optical disk rotated by the rotating means. Therefore, a piece of recording information is recorded or reproduced on or from the first substrate of the optical disk.

Accordingly, even though a high density type of optical disk, in which pieces of recording information are recorded or reproduced on or from the substrate having the thin thickness smaller than an ordinary thickness of a conventional optical disk, is utilized, the recording information can be reliably recorded or reproduced.

The sixth object is achieved by the provision of a binary focus microscope for simultaneously observing a first image put on a first image plane and a second image put on a second image plane, comprising:

an objective lens for refracting a beam of first light diverging from the first image and a beam of second light diverging from the second image, a first distance between the objective lens and the first image of the first image plane differing from a second distance between the objective lens and the second image of the second image plane;

a hologram lens for transmitting the first light refracted by the objective lens without any diffraction to form a beam of transmitted light and diffracting the second light refracted by the objective lens to form a beam of diffracted light, the hologram lens functioning as a lens for the second light to pass the diffracted light through the same optical path as the transmitted light passes through, and a beam of superposed light being formed of the transmitted light and the diffracted light;

an inner lens for converging the superposed light formed by the hologram lens at an image point of a third image plane to simultaneously form the first image and the second image enlarged on the third image plane; and

an ocular lens for converging the superposed light which is converged by the inner lens and diverges from the

image point to simultaneously form the first image and the second image moreover enlarged.

In the above configuration, a beam of first light diverging from the first image and a beam of second light diverging from the second image are refracted together by the objective lens. In this case, because a first distance between the objective lens and the first image of the first image plane differs from a second distance between the objective lens and the second image of the second image plane, a curvature of the first light refracted differs from another curvature of the second light refracted. Thereafter, the first light refracted transmits through the hologram lens without any diffraction to form a beam of transmitted light, and the second light refracted is diffracted by the hologram lens to form a beam of diffracted light. In this case, because the hologram lens functions as a lens for the diffracted light, a curvature of the diffracted light agrees with that of the transmitted light. In other words, the diffracted light passes through the same optical path as the transmitted light passes through. Therefore, a beam of superposed light is formed of the transmitted light and the diffracted light. Thereafter, the superposed light is converged by the inner lens at an image point of a third image plane, so that the first image and the second image enlarged are simultaneously formed on the third image plane. Thereafter, the superposed light diverging from the image point is converged by the ocular lens, so that the first image and the second image moreover enlarged are simultaneously formed.

Accordingly, an operator can observe the first image and the second image sufficiently enlarged.

The sixth object is also achieved by the provision of a binary focus microscope for simultaneously observing a first image put on a first image plane and a second image put on a second image plane, comprising:

an objective lens for refracting a beam of first light diverging from the first image and a beam of second light diverging from the second image, a first distance between the objective lens and the first image of the first image plane differing from a second distance between the objective lens and the second image of the second image plane;

a hologram lens for transmitting the first light refracted by the objective lens without any diffraction to form a beam of transmitted light and diffracting the second light refracted by the objective lens to form a beam of diffracted light, the hologram lens functioning as a lens for the second light to pass the diffracted light through the same optical path as the transmitted light passes through, and a beam of superposed light being formed of the transmitted light and the diffracted light;

an inner lens for converging the superposed light formed by the hologram lens at an image point of a third image plane to simultaneously form the first image and the second image enlarged on the third image plane; and

photographing means for photographing a superposed image formed of the first and second images enlarged on the third image plane by converging the superposed light in the inner lens.

In the above configuration, the first image and the second image enlarged are simultaneously formed on the third image plane in the same manner. Thereafter, the first image and the second image enlarged are photographed by the photographing means as a superposed image.

Accordingly, the first image and the second image enlarged can be observed.

The seventh embodiment is achieved by the provision of an alignment apparatus for aligning a first reference image drawn on a photomask with a second reference image drawn on a sample, comprising:

a light source for radiating beams of alignment light to illuminate the first and second reference images;

an objective lens for refracting both a beam of first alignment light diverging from the first reference image and a beam of second alignment light diverging from the second reference image which are illuminated with the alignment light radiated from the light source, a first distance between the objective lens and the first reference image of the photomask differing from a second distance between the objective lens and the second reference image of the sample;

a hologram lens for transmitting the first alignment light refracted by the objective lens without any diffraction to form a beam of transmitted light and diffracting the second alignment light refracted by the objective lens to form a beam of diffracted light, the hologram lens functioning as a lens for the second alignment light to pass the diffracted light through the same optical path as the transmitted light passes through, and a beam of superposed light being formed of the transmitted light and the diffracted light;

an inner lens for converging the superposed light formed by the hologram lens at an image point of an image plane to simultaneously form the first and second reference images enlarged on the image plane, an optical axis passing through centers of the objective lens, the hologram lens and the inner lens;

photographing means for photographing a superposed image formed of the first and second images enlarged on the image plane by converging the superposed light in the inner lens; and

moving means for moving the photomask or the sample according to the superposed image photographed by the photographing means to align the first reference image with the second reference image along the optical axis.

In the above configuration, the objective lens, the hologram lens and the inner lens are the same as those in the binary focus microscope. Therefore, the first and second images enlarged on the image plane is photographed by the photographing means as a superposed image. Thereafter, the photomask or the sample is moved in a direction perpendicular to the optical axis by the moving means to align the first reference image with the second reference image along the optical axis.

Accordingly, because the superposed image formed of the first and second reference images enlarged is photographed by the photographing means, a relative position between the first and second reference images can be accurately observed. Therefore, the first reference image can be accurately aligned with the second reference image.

The eighth embodiment is achieved by the provision of a focusing method for focusing light on a first information medium having a first thickness or a second information medium having a second thickness to record or reproduce a piece of information on or from the first information medium or the second information medium, comprising the steps of:

moving an optical head apparatus in a direction to decrease or increase the distance between the optical head apparatus and the first or second information medium, the optical head apparatus comprising

a light source for radiating a beam of incident light,

hologram means for transmitting a part of the incident light radiated from the light source without any dif-

fraction on an outgoing path to form a beam of transmitted light and diffracting a remaining part of the incident light radiated from the light source on the outgoing path to form a beam of diffracted light, the hologram means functioning as a lens for the diffracted light to diverge the diffracted light from the hologram means or converge the diffracted light,

lens means for converging the transmitted light formed in the hologram means at a first focal length on the outgoing path to form a first converging spot at a front surface of the first information medium or converging the diffracted light formed in the hologram means at a second focal length on the outgoing path to form a second converging spot at a front surface of the second information medium, the transmitted light being incident on a rear surface of the first information medium and being converged at the front surface of the first information medium, the transmitted light being reflected at the rear surface of the first information medium and again passing through the lens means and the hologram means on an incoming path, the diffracted light being incident on a rear surface of the second information medium and being converged at the front surface of the second information medium, and the diffracted light being reflected at the rear surface of the first information medium and again passing through the lens means and the hologram means on the incoming path,

wavefront changing means for changing a wavefront of the transmitted light or the diffracted light passing through the lens means and the hologram means on the incoming path to form one or more beams of information light, and

detecting means for detecting intensities of the information light formed by the wavefront changing means and generating an information signal and a focus error signal according to the intensities of the information light, the information signal expressing a piece of information recorded on the first information medium or the second information medium;

judging whether or not an intensity of the focus error signal generated in the detecting means is larger than a threshold value; and

adjusting the position of the optical head apparatus to decrease the intensity of the focus error signal to zero when the intensity of the focus error signal becomes larger than the threshold value.

In the above steps, the focusing method is performed by utilizing the optical head apparatus described above. The intensity of the focus error signal is largely increased when the distance between the lens means and the first or second information medium is near to a focal length of the lens means. Therefore, when the intensity of the focus error signal becomes larger than a threshold value, the lens means is placed near to a just-focus point in which the transmitted light or the diffracted light is converged on the first or second information medium in focus.

Accordingly, in cases where the position of the optical head apparatus is adjusted to decrease the intensity of the focus error signal to zero when the intensity of the focus error signal becomes larger than the threshold value, the transmitted light or the diffracted light can be focused on the first or second information medium.

The ninth embodiment is achieved by the provision of an information reproducing method for reproducing a piece of recording information from an optical disk in which the recording information are recorded at a high density on a first substrate having a first thickness and a piece of distinguishing information informing that the recording information are recorded on the first substrate is recorded at an ordinary density on a second substrate having a second thickness larger than the first thickness, comprising the step of:

moving an optical disk apparatus under the second substrate of the optical disk, the optical disk comprising

rotating means for rotating the optical disk at a regular speed,

a light source for radiating a beam of incident light;

hologram means for transmitting a part of the incident light radiated from the light source without any diffraction on an outgoing path to form a beam of transmitted light and diffracting a remaining part of the incident light radiated from the light source on the outgoing path to form a beam of diffracted light, the hologram means functioning as a lens for the diffracted light to diverge the diffracted light from the hologram means,

lens means for converging the transmitted light formed in the hologram means on the first substrate of the optical disk rotated by the rotating means to record or reproduce a piece of recording information on or from the optical disk and converging the diffracted light formed in the hologram means on the second substrate of the optical disk rotated by the rotating means to reproduce the distinguishing information from the optical disk, the transmitted light being reflected by the first substrate of the optical disk and again passing through the lens means and the hologram means on an incoming path, and the diffracted light being reflected by the second substrate of the optical disk and again passing through the lens means and the hologram means on the incoming path,

wavefront changing means for changing a wavefront of the transmitted light passing through the lens means and the hologram means on the incoming path to form one or more beams of recording information light and changing a wavefront of the diffracted light passing through the lens means and the hologram means on the incoming path to form one or more beams of distinguishing information light, and

detecting means for detecting intensities of the recording information light formed by the wavefront changing means to generate a recording information signal according to the intensities of the recording information light and detecting intensities of the distinguishing information light formed by the wavefront changing means to generate a distinguishing information signal according to the intensities of the distinguishing information light, the distinguishing information signal expressing the distinguishing information recorded on the second substrate of the optical disk, and the recording information signal expressing the recording information recorded on the first substrate of the optical disk; and

converging the diffracted light on the second substrate of the optical disk to reproduce the distinguishing information;

moving the optical disk apparatus to a position under the first substrate of the optical disk to converge the transmitted light on the first substrate of the optical disk when the distinguishing information is detected in the detecting means; and

reproducing the recording information by generating the recording information signal in the detecting means.

In the above steps, the information reproducing method is performed by utilizing the optical disk apparatus described above. The distinguishing information placed on the second substrate of the optical disk is reproduce with the diffracted light. In this case, because the second substrate has the second thickness, the diffracted light is just focused on the second substrate. Thereafter, when the distinguishing information is detected, the optical disk apparatus is moved to a position under the first substrate of the optical disk, and the transmitted light is converged on the first substrate of the optical disk. In this case, because the first substrate has the first thickness, the diffracted light is just focused on the first substrate.

Accordingly, the recording information can be reliably reproduced.

BRIEF DESCRIPTION OF THE DRAWINGS

The objects, features and advantages of the present invention will be apparent from the following description taken in conjunction with the accompanying drawings, in which:

FIG. **1** is a constitutional view of a conventional optical head apparatus proposed in Japanese Patent Application No. 46630 of 1991;

FIGS. **2**A, **2**B are respectively a cross sectional view of a set of an objective lens and a blazed hologram shown in FIG. **1**;

FIG. **3** shows a relationship between the thickness of an optical disk and a numerical aperture of an objective lens on condition that the tilt of the optical axis is constant;

FIG. **4**A is a constitutional view of an imaging optical system having a compound objective lens according to a first embodiment of the present invention, a beam of transmitted light not diffracted being converged on a thin type of information medium;

FIG. **4**B is a constitutional view of the imaging optical system shown in FIG. **4**A, a beam of first-order diffracted light being converged on a thick type of information medium;

FIG. **5** is a plan view of a hologram lens shown in FIGS. **4**A, **4**B, a grating pattern of the hologram lens being depicted;

FIG. **6** is a cross sectional view of the hologram lens shown in FIG. **5**, the grating pattern formed in relief on the hologram lens being shown;

FIG. **7** is an explanatory diagram showing an intensity distribution of transmitted light L4 converged on a converging spot S1 of a first information medium, a primary maximum and secondary maxima suppressed occurring in the converging spot S1;

FIG. **8**A is a cross sectional view of the hologram lens shown in FIG. **5**, the grating pattern approximating to a stepwise shape composed of four stairs being shown;

FIG. **8**B is a cross sectional view of the hologram lens shown in FIG. **5**, the grating pattern approximating to a stepwise shape composed of a plurality of stairs being shown;

FIG. **9**A is a constitutional view of an imaging optical system having a compound objective lens according to a modification of the first embodiment, a beam of first-order diffracted light being converged on a thin type of information medium;

FIG. **9**B is a constitutional view of the imaging optical system shown in FIG. **9**A, a beam of transmitted light not diffracted being converged on a thick type of information medium;

FIG. **10**A is a constitutional view of an imaging optical system having a compound objective lens according to a second embodiment of the present invention, a beam of transmitted light not diffracted being converged on a thin type of information medium;

FIG. **10**B is a constitutional view of the imaging optical system shown in FIG. **10**A, a beam of first-order diffracted light being converged on a thick type of information medium;

FIG. **11** shows a change of a diffraction efficiency of a hologram lens shown in FIGS. **10**A, **10**B;

FIGS. **12**A to **12**E are respectively a cross sectional view of the hologram lens shown in FIGS. **10**A, **10**B, the grating pattern of the hologram lens approximating to a step-wise shape;

FIG. **13**A shows an intensity distribution of incident light utilized in the second embodiment, a far field pattern of the incident light being distributed in a Gaussian distribution;

FIG. **13**B shows an intensity distribution of transmitted light transmitting through a hologram lens shown in FIGS. **10**A, **10**B, a far field pattern of the incident light being distributed in a gently-sloping shape;

FIGS. **14**A to **14**C show intensity distributions of transmitted light and diffracted light transmitting through a hologram lens shown in FIGS. **10**A, **10**B;

FIG. **15**A is a plan view of a hologram lens according to a modification of the second embodiment, a grating pattern of the hologram lens being depicted;

FIGS. **15**B, **15**C are respectively a constitutional view of an imaging optical system having a compound objective lens according to another modification of the second embodiment;

FIG. **16**A is a constitutional view of an imaging optical system having a compound objective lens according to a third embodiment of the present invention, a beam of first-order diffracted light being converged on a thin type of information medium;

FIG. **16**B is a constitutional view of the imaging optical system shown in FIG. **16**A, a beam of transmitted light not diffracted being converged on a thick type of information medium;

FIG. **17** shows a change of a diffraction efficiency of a hologram lens shown in FIGS. **16**A, **16**B;

FIGS. **18**A to **18**C show intensity distributions of transmitted light and diffracted light transmitting through a hologram lens shown in FIGS. **16**A, **16**B;

FIG. **19**A is a cross sectional view of a compound objective lens according to a fourth embodiment of the present invention;

FIG. **19**B is a cross sectional view of a compound objective lens according to a modification of the fourth embodiment of the present invention;

FIG. **20** is a cross sectional view of a compound objective lens according to a fifth embodiment of the present invention;

FIG. **21** is a constitutional view of an optical head apparatus according to a sixth embodiment of the present invention;

FIG. **22** is a plan view of a wavefront changing device utilized in the six, ninth and twelfth embodiments, a grating pattern of a hologram lens utilized as the wavefront changing device being depicted;

FIG. **23** shows a positional relation between focal points of diffracted light occurring in the wavefront changing device shown in FIG. **22** and a photo detector;

FIG. **24** is a plan view of a photo detector utilized in the six, ninth, tenth, twelfth, thirteenth and seventeenth embodiments;

FIG. **25**A and **25**C respectively show a converging spot of first-order diffracted light radiated to detecting sections SE**1**, SE**2** and SE**3** of a sextant photo-detector shown in FIG. **24** and another converging spot of minus first-order diffracted light radiated to detecting sections SE**4**, SE**5** and SE**6** of the sextant photo-detector on condition that an objective lens shown in FIG. **21** is defocused on an information medium;

FIG. **25**B shows a converging spot of first-order diffracted light radiated to the detecting sections SE**1**, SE**2** and SE**3** of the sextant photo-detector and another converging spot of minus first-order diffracted light radiated to the detecting sections SE**4**, SE**5** and SE**6** of the sextant photo-detector on condition that the objective lens is just focused on the information medium;

FIG. **26** shows a relationship between beams of diffracted light occurring in the wavefront changing device shown in FIG. **22** and the photo detector shown in FIG. **24**;

FIG. **27** is a constitutional view of an optical head apparatus according to a seventh embodiment;

FIG. **28** is a plan view of a photo detector utilized in the seven, ninth, tenth, twelfth and thirteenth embodiments;

FIGS. **29**A, **29**B, **29**C show various shapes of converging spots converged on the photo detector shown in FIG. **28**;

FIG. **29**D shows a radial direction Dr and a tangential direction Dt;

FIG. **30** is a constitutional view of an optical head apparatus according to a first modification of the seventh embodiment;

FIG. **31** is a constitutional view of an optical head apparatus according to a second modification of the seventh embodiment;

FIG. **32** is a constitutional view of an optical head apparatus according to a third modification of the seventh embodiment;

FIG. **33** is a constitutional view of an optical head apparatus according to a forth modification of the seventh embodiment;

FIG. **34** shows a beam of transmitted light not diffracted on an incoming optical path and a beam of transmitted light diffracted on the incoming optical path, the beams being utilized to detect an information signal;

FIG. **35**A graphically shows a change of a focus error signal obtained by detecting the intensity of transmitted light, the strength of the focus error signal depending on a distance between an objective lens and a first information medium;

FIG. **35**B graphically shows a change of a focus error signal obtained by detecting the intensity of diffracted light, the strength of the focus error signal depending on a distance between an objective lens and a second information medium.

FIG. **36**A graphically shows a change of a focus error signal obtained by detecting the intensity of diffracted light, the strength of the focus error signal depending on a distance between an objective lens and a first information medium;

FIG. **36**B graphically shows a change of a focus error signal obtained by detecting the intensity of transmitted light, the strength of the focus error signal depending on a distance between an objective lens and a second information medium;

FIG. **37** is a constitutional view of an optical head apparatus according to a ninth embodiment;

FIG. **38** is a constitutional view of an optical head apparatus according to a tenth embodiment;

FIG. **39** is a plan view of a beam splitter having a reflection type of hologram utilized in the optical head apparatus shown in FIG. **38**;

FIGS. **40**A, **40**B are respectively a constitutional view of an optical head apparatus according an eleventh embodiment;

FIG. **41** is a plan view of a beam splitter having a reflection type of hologram utilized in the optical head apparatus shown in FIG. **38**;

FIG. **42**A and **42**C respectively show a converging spot of first-order diffracted light radiated to detecting sections SE**1**, SE**2** and SE**3** of a sextant photo-detector shown in FIG. **24** and another converging spot of minus first-order diffracted light radiated to detecting sections SE**4**, SE**5** and SE**6** of the sextant photo-detector on condition that diffracted light is converged in defocus on a second information medium;

FIG. **42**B shows a converging spot of first-order diffracted light radiated to the detecting sections SE**1**, SE**2** and SE**3** of a sextant photo-detector shown in FIG. **24** and another converging spot of minus first-order diffracted light radiated to the detecting sections SE**4**, SE**5** and SE**6** of the sextant photo-detector on condition that diffracted light is converged in focus on a second information medium;

FIG. **43** is a constitutional view of an optical head apparatus according to a twelfth embodiment;

FIG. **44** is a constitutional view of an optical head apparatus according to a thirteenth embodiment;

FIG. **45** is a constitutional view of an optical head apparatus according to a fourteenth embodiment;

FIG. **46** is a plan view of a hologram lens utilized in the optical head apparatus shown in FIG. **45**;

FIG. **47** is a constitutional view of an optical head apparatus according to a fifteenth embodiment;

FIG. **48** is a plan view of a hologram lens utilized in the optical head apparatus shown in FIG. **47**;

FIGS. **49**A, **49**B respectively show a positional relation between unnecessary light occurring in the hologram lens shown in FIG. **48** and a photo detector shown in FIG. **47**;

FIG. **50** is a constitutional view of an optical head apparatus according to a sixteenth embodiment;

FIG. **51** is a diagonal view of a light source and photo detectors utilized in the optical head apparatus shown in FIG. **50**;

FIG. **52** is a constitutional view of an optical head apparatus according to a seventeenth embodiment;

FIG. **53** is a diagonal view of a high density optical disk according to an eighteenth embodiment, a cross sectional view of the disk being partially shown;

FIG. **54** is a diagonal view of a high density optical disk according to a nineteenth embodiment, a cross sectional view of the disk being partially shown;

FIG. **55** is a block diagram of an optical disk apparatus with one of the optical head apparatuses shown in FIGS. **21**, **27**, **30**, **31**, **32**, **33**, **37**, **38**, **40**A, **43**, **44**, **50** and **52** according to a twentieth embodiment;

FIG. **56** is a flow chart showing the operation of the optical disk apparatus shown in FIG. **55**;

FIG. **57** is a block diagram of an optical disk apparatus with one of the optical head apparatuses shown in FIGS. **21**, **27**, **30**, **31**, **32**, **33**, **37**, **38**, **40**A, **43**, **44**, **50** and **52** according to a twenty-first embodiment;

FIG. **58** is a flow chart showing the operation of the optical disk apparatus shown in FIG. **57**;

FIG. **59** is a constitutional view of a binary focus microscope according to a twenty-second embodiment;

FIG. **60** is a partial view of the binary focus microscope shown in FIG. **59** in cases where first and second samples are located at bottoms of sample holders;

FIG. **61** is a constitutional view of a binary focus microscope according to a modification of the twenty-second embodiment;

FIG. **62** is a constitutional view of an alignment apparatus according to a twenty-third embodiment;

Fig. **63** is a constitutional view of the optical disk apparatus of which the block diagram is shown in FIG. **55**;

FIG. **64** is a constitutional view of an exposure apparatus in which the alignment apparatus is included;

FIG. **65** is a diagonal view of an image reproducing apparatus for which the optical disk apparatus **176** is provided;

FIG. **66** is a diagonal view of a voice reproducing apparatus for which the optical disk apparatus **176** is provided;

FIG. **67** is a diagonal view of an information processing apparatus for which the optical disk apparatus **176** is provided; and

FIG. **68** is a diagonal view of another information processing apparatus for which the optical disk apparatus **176** is provided.

DETAIL DESCRIPTION OF THE PREFERRED EMBODIMENTS

Preferred embodiments of a compound objective lens, an imaging optical system, an optical head apparatus, an optical disk, an optical disk apparatus, a binary focus microscope and an alignment apparatus according to the present invention are described with reference to drawings.

(First Embodiment)

FIG. **4**A is a constitutional view of an imaging optical system having a compound objective lens according to a first embodiment of the present invention, a beam of transmitted light not diffracted being converged on a thin type of information medium. FIG. **4**B is a constitutional view of the imaging optical system shown in FIG. **4**A, a beam of first-order diffracted light being converged on a thick type of information medium. FIG. **5** is a plan view of a hologram lens shown in FIGS. **4**A, **4**B, a grating pattern of the hologram lens being depicted.

As shown in FIGS. **4**A, **4**B, an imaging optical system **21** for converging light on a first substrate **22** of a thin type of first information medium **23** (a thickness T1) or a second substrate **24** of a thick type of second information medium **25** (a thickness T2) to form a diffraction-limited converging spot comprises a blazed hologram lens **26** for transmitting a part of incident light **L3** radiated from a light source without any diffraction to form a beam of transmitted light **L4** and diffracting a remaining part of the incident light **L3** to form a beam of first-order diffracted light **L5**, and an objective lens **27** for converging the transmitted light **L4** on the first information medium **23** or converging the first-order diffracted light **L5** on the second information medium **25**.

The first information medium **23** represents a prospective optical disk having a high density memory capacity, and the thickness T1 of the first information medium **23** ranges from 0.4 mm to 0.8 mm. The second information medium **25** represents a compact disk or a laser disk appearing on the market now, and the thickness T2 of the second information medium **25** is about 1.2 mm.

The term "convergence" denotes in this specification that divergent light or collimated light is focused to form a diffraction-limited micro spot.

In the above configuration, a part of incident light **L3** collimated transmits through the hologram lens **26** without any diffraction, and a beam of transmitted light **L4** (that is, a beam of zero-order diffracted light **L4**) is formed. Thereafter, the transmitted light **L4** is converged by the objective lens **27**. Also, a remaining part of the incident light **L3** is diffracted and refracted by the hologram lens **26**, and a beam of first-order diffracted light **L5** is formed. In this case, the hologram lens **26** selectively functions as a concave lens for the first-order diffracted light **L5**, so that the first-order diffracted light **L5** diverges from the hologram lens **26**. Thereafter, the first-order diffracted light **L5** is converged by the objective lens **27**.

In cases where the thin type of first information medium **23** is utilized to record or reproduce pieces of information on or from a front surface of the medium **23**, as shown in FIG. **4**A, the transmitted light **L4** is incident on a rear surface of the first information medium **23** and is focused on its front surface by the objective lens **27** to form a diffraction-limited converging spot **S1** on the first information medium **23**. In contrast, in cases where the thick type of second information medium **25** is utilized to record or reproduce pieces of information on or from a front surface of the medium **25**, the diffracted light **L5** is incident on a rear surface of the second information medium **25** and is focused on its front surface to form a diffraction-limited converging spot **S2** on the second information medium **25**. Because the hologram lens **26** functions as a concave lens to diverge the first-order diffracted light **L5**, the diffraction-limited converging spots **S1**, **S2** are formed even though the thickness T1 of the first information medium **23** differs from the thickness T2 of the second information medium **25**. Therefore, a compound objective lens **29** composed of the hologram lens **26** and the objective lens **27** has substantially two focal points.

As shown in FIG. **5**, the hologram lens **26** is formed by drawing a grating pattern **P1** in a pattern region **26**A of a transparent substrate **28** in a concentric circle shape. The pattern region **26**A is positioned in a center portion of the transparent substrate **28**, and a no-pattern region **26**B is positioned in a peripheral portion of the transparent substrate **28** to surround the pattern region **26**A. An optical axis of the imaging optical system **21** passes through a central point of the grating pattern **P1** and a central axis of the objective lens **27**.

In addition, as shown in FIG. **6**, the grating pattern **P1** of the hologram lens **26** is formed in relief to produce a phase modulation type of hologram lens. That is, blocks which each are composed of a bottom portion and a top portion are concentrically formed in the grating pattern **P1**. The height H of the relief in the grating pattern **P1** is set to:

$$H < \lambda/(n(\lambda)-1), \quad (1)$$

where the symbol λ denotes a wavelength of the incident light **L3** and the symbol $n(\lambda)$ denotes a refractive index of the transparent substrate **28** for the incident light **L3**. In this case, a difference in phase modulation degree between the incident light **L3** transmitting through a bottom portion of the grating pattern **P1** and the incident light **L3** transmitting through a top portion of the grating pattern **P1** is lower than 2π radians. Therefore, a diffraction efficiency of the holo-

gram lens **26** for the incident light L3 transmitting through the grating pattern P1 is less than 100% to generate the light L4 transmitting through the grating pattern P1. Also, the incident light L3 transmitting through the no-pattern region **26**B is not diffracted. As a result, the intensity of the transmitted light L4 can be sufficient to record or reproduce pieces of information on or from the first information medium **23**.

Also, because the intensity of the transmitted light L4 is sufficient over the entire surface of the hologram lens **26**, secondary maxima (side lobes) of the transmitted light L4 undesirably occurring in the converging spot S1 can be suppressed. In detail, as an intensity distribution of the transmitted light L4 converged on the converging spot S1 is shown in FIG. **7**, a primary maximum (a main lobe) of the transmitted light L4 positioned in a center of the converging spot S1 is utilized to record or reproduce a piece of information on or from the first information medium **23**, and secondary maxima positioned around the primary maximum are unnecessary because the secondary maxima deteriorate a recording pit or a reproducing signal formed by the primary maximum.

The grating pattern P1 of hologram lens **26** formed in relief is blazed as shown in FIG. **6**, so that the occurrence of minus first-order diffracted light is considerably suppressed. Therefore, the intensity sum of the transmitted light L4 and the first-order diffracted light L5 is maximized. In other words, a utilization efficiency of the incident light L3 is enhanced.

The numerical aperture NA of the objective lens **27** is equal to or more than 0.6. Also, when the transmitted light L4 is converged by the objective lens **27**, the diffraction-limited converging spot S1 is formed on the first information medium **23** having a thickness T1.

A diameter of the hologram lens **26** is almost the same as an aperture of the objective lens **27**, so that a diameter of the pattern region **26**A is smaller than the aperture of the objective lens **27**. Because the incident light L3 transmitting through the no-pattern region **26**B is not diffracted, not only the light L4 transmitting through the pattern region **26**A but also the light L4 transmitting through the no-pattern region **26**B are converged on the first information medium **23** by the objective lens **27** having a high numerical aperture. Therefore, the intensity of the transmitted light L4 converged at the converging point S1 can be increased. In contrast to the transmitted light L4, only the incident light L3 transmitting through the pattern region **26**A of the hologram lens **26** is changed to the first-order diffracted light L5, and the first-order diffracted light L5 is converged on the second information medium **25** by the objective lens **27** having substantially a low numerical aperture.

The phase of the light L4 transmitting through the grating pattern P1 of the pattern region **26**A is determined by an average value of the phase modulation degrees in the light L4 transmitting through the bottom and top portions of the grating pattern P1. In contrast, because the height of the no-pattern region **26**B is constant, the phase of the light L4 transmitting through the no-pattern region **26**B is modulated at a phase modulation degree. Therefore, as shown in FIG. **6**, the height of the no-pattern region **26**B is set even with an average height of the grating pattern P1 to enhance the convergence function of the objective lens **27**.

For example, as shown in FIG. **8**A, in cases where each block of the grating pattern P1 in the hologram lens **26** shown in FIG. **6** approximates to a step-wise shape composed of four stairs, a first step is etched at a depth h1+h2 and a width W1, a second step is etched at a depth hi and a width W2, a third step is etched at a depth h2 and a width W2, and a fourth step is etched at a width W1. Therefore, the grating pattern P1 approximating to the step-wise shape is formed in the pattern region **26**A. Thereafter, a peripheral portion of the transparent substrate **28** is etched by a depth h1 or h2 to form the no-pattern region **26**B. Therefore, the height of the no-pattern region **26**B is almost the same as an average height of the pattern region **26**A, so that the phase of the light L4 transmitting through the pattern region **26**A is almost the same as that of the light L4 transmitting through the no-pattern region **26**B.

In addition, as shown in FIG. **8**B, an ideal blazed shape of the hologram lens **26** shown in FIG. **6** can approximate to a step-wise shape which is obtained by etching a center portion of the transparent substrate **28** many times. In this case, the height H0 of the step-wise shape is set to satisfy an equation $H0<\lambda/(n(\lambda)-1)$ so that the difference in phase modulation degree is set to a value lower than 2π radians. Specifically, in cases where the step-wise shape of the hologram lens **26** is composed of a flight of N stairs having the same difference n_o in level, the difference n_o in level is set to satisfy an equation $n_o<\lambda/\{(n(\lambda)-1)*N\}$ to set the difference in phase modulation degree of each stairs to a value lower than $2\pi/N$ radians. A peripheral portion of the transparent substrate **28** is etched to set the thickness of the no-pattern region **26**B to a thickness of the pattern region **26**A at one of the N stairs which is not the top stair or the bottom stair. Therefore, the height of the no-pattern region **26**B is almost the same as an average height of the pattern region **26**A, so that the phase of the light L4 transmitting through the pattern region **26**A is almost the same as that of the light L4 transmitting through the no-pattern region **26**B.

The grating pattern P1 of the hologram lens **26** is designed to correct any aberration occurring in the objective lens **27** and the second information medium **25**, so that the first-order diffracted light L5 transmits through the second information medium **25** having a thickness T2 and is converged on the medium **25** to form the diffraction-limited converging spot S2 without any aberration. A method for designing the hologram lens **26** having an aberration correcting function is described.

After the first-order diffracted light L5 is converged on the second information medium **25**, spherical waves diverge from the converging spot S2 and transmit through the second substrate **24** and the objective lens **27**. Thereafter, the spherical waves transmit through the transparent substrate **28** and optically interfere with the incident light L3. Therefore, an interference pattern is formed by the interference between the spherical waves and the incident light L3. The interference pattern can be calculated by subtracting the phase of the spherical waves from an inverted phase obtained by inverting the phase of the incident light L3. Accordingly, the grating pattern P1 of the hologram lens **26** which agrees with the interference pattern calculated can be easily formed according to a computer generated hologram technique.

Accordingly, because the compound objective lens **29** is composed of the objective lens **27** and the hologram lens **26** in which a part of the incident light L3 is diffracted and refracted, a diffraction-limited converging spot can be reliably formed on an information medium regardless of whether the information medium has a thickness T1 or a thickness T2. Also, two diffraction-limited converging spots can be simultaneously formed on an information medium at difference depths. In other words, the compound objective lens has substantially two focal points.

Also, because the diffraction efficiency of the hologram lens **26** is less than 100% and the intensity of the light L4

transmitting through the hologram lens **26** is sufficient to record or reproduce information on or from the first information medium **23**, the secondary maxima of the transmitted light **L4** converged on the converging spot **S1** can be suppressed.

Also, because the hologram lens **26** is blazed, the occurrence of minus first-order diffracted light can be considerably suppressed. Therefore, the intensity sum of the transmitted light **L4** and the first-order diffracted light **L5** can be maximized, and a utilization efficiency of the incident light **L3** can be enhanced.

Also, because the hologram lens **26** functions as a lens only for the first-order diffracted light, the position of the converging point **S1** formed by the transmitted light **L4** differs from that of the converging point **S2** formed by the first-order diffracted light **L5** in an optical axis direction. Therefore, when the transmitted light **L4** is converged in focus on an information recording plane of the information medium **23** to record or read a piece of information, the first-order diffracted light **L5** converged on the information medium **23** is out of focus at the information recording plane. In the same manner, when the first-order diffracted light **L5** is converged in focus on an information recording plane of the information medium **25**, the transmitted light **L4** converged on the information medium **25** is out of focus at the information recording plane. Accordingly, when the light **L4** (or **L5**) is converged on the converging spot **S1** (or **S2**) in focus to record or read the information, the light **L5** (or **L4**) not converged on the converging spot **S1** (or **S2**)in focus does not adversely influence on the recording or reading of the information. To reliably prevent the adverse influence on the recording or reading of the information, a difference in the optical axis direction between the converging spots **S1**, **S2** is required to be equal to or more than 50 μm. That is, when the difference is equal to or more than 50 μm, the light **L5** (or **L4**) largely diverges to reduce the intensity of the light **L5** (or **L4**) at an information recording plane when the light **L4** (or **L5**) is converged on the converging spot **S1** (or **S2**) of the information recording plane at a high intensity.

Also, because the thickness **T2** of the second information medium **25** representing the compact disk or the laser disk is about 1. 2 mm and because the thickness **T1** of the first information medium **23** representing a prospective optical disk ranges from 0.4 mm to 0.8 mm, the difference in the optical axis direction between the converging points **S1**, **S2** is required to be equal to or less than 1.0 mm by considering a moving range of an actuator with which the position of the compound objective lens **29** composed of the objective lens **27** and the hologram lens **26** is adjusted according to a focus servo signal. Because the hologram lens **26** functions as a concave lens for the first-order diffracted light, the difference between the converging points **S1**, **S2** can be increased to about 1 mm.

Accordingly, even though the transmitted light **L4** and the first-order diffracted light **L5** are simultaneously converged by the objective lens **27**, no adverse influence is exerted on the recording or reproduction of the information on condition that the difference between the converging points **S1**, **S2** ranges from 50 μm to 1 mm.

Examples of the utilization of the imaging optical system **21** for various types of optical disks are described.

In cases where the image optical system **21** is utilized for an optical disk device in which pieces of information recorded in a thin type of high density optical disk and a thick type of compact disk are exclusively reproduced, the diffraction efficiency of the hologram lens **26** for changing the incident light **L3** to the diffracted light **L5** is set in a range from about 20% to 70%. In this case, the intensity of the transmitted light **L4** converged on the high density optical disk is almost the same as that of the first-order diffracted light **L5** converged on the compact disk. Therefore, the output power of the incident light **L3** can be minimized.

Also, in cases where the image optical system **21** is utilized for an optical disk device in which pieces of information recorded in a thin type of high density optical disk are recorded or reproduced and pieces of information recorded in a thick type of optical disk are exclusively reproduced, the diffraction efficiency of the hologram lens **26** for changing the incident light **L3** to the first-order diffracted light **L5** is set to a value equal to or lower than 30%. In this case, even though a high intensity of transmitted light **L4** is required to record a piece of information on the high density optical disk, the recording of the information can be reliably performed without increasing the intensity of the incident light **L3** because a transmission efficiency of the hologram lens **26** for the incident light **L3** is high. In other words, a utilization efficiency of the incident light **L3** can be enhanced when a piece of information is recorded on the high density optical disk, so that the output power of the incident light **L3** can be minimized.

In the first embodiment, the hologram lens **26** functions as a concave lens for the first-order diffracted light **L5**. However, it is applicable that a hologram lens **26M** functioning as a convex lens for the first-order diffracted light **L5** be utilized in place of the hologram lens **26**. That is, as shown in FIGS. **9A**, **9B**, the diffracted light **L5** is converged on the first information medium **23** by the objective lens **27** to form the diffraction limited converging spot **S1**, and the transmitted light **L4** is converged on the second information medium **25** by the objective lens **27** to form the diffraction limited converging spot **S2**. In this case, the difference between the converging points **S1**, **S2** is required to be equal to or less than 0.5 mm by considering the moving range of the actuator. However, the occurrence of a chromatic aberration can be prevented in an imaging optical system **21M** in which the hologram lens **26M** functioning as a concave lens for the diffracted light **L5** is utilized. The achromatization function in the imaging optical system is described in detail.

When a focal length of the hologram lens **26M** for the incident light **L3** having a wavelength λ_o is represented by f_{Ho} and another focal length of the hologram lens **26M** for the incident light **L3** having a wavelength λ_l is represented by f_{Hl}, an equation (2) is satisfied.

$$f_{Hl}=f_{Ho}\times\lambda_o/\lambda_l \tag{2}$$

The focal length f_H of the hologram lens **22** is shortened as the wavelength λ of the incident light **L3** becomes longer. Also, when a refractive index of the objective lens **27** for the incident light **L3** having a wavelength λ_o is represented by $n(\lambda_o)$ and another refractive index of the objective lens **27** for the incident light **L3** having a wavelength λ_l is represented by $n(\lambda_l)$, a focal length $f_D(\lambda)$ of the objective lens **27** for the incident light **L3** having a wavelength λ is formulated by an equation (3).

$$f_D(\lambda_1)=f_D(\lambda_o)\times(n(\lambda_o)-1)/(n(\lambda_l)-1) \tag{3}$$

The focal length $f_D(\lambda)$ of the objective lens **27** is lengthened as the wavelength λ of the incident light **L3** becomes longer. That is, the dependence of the focal length $f_D(\lambda)$ on the wavelength λ in the objective lens **27** is opposite to that of the focal length f_H on the wavelength λ in the hologram lens **26M**. Therefore, a condition that the compound objective lens **29M** composed of the objective lens **27** and the

hologram lens **26**M functions as an achromatic lens is formulated by an equation (4).

$$1/f_{Ho}+1/f_D(\lambda_o)=1/f_{Hf}+1/f_D(\lambda_f)=1/(f_{Ho}\times\lambda_o/\lambda_f)+(n(\lambda_f)-1)/\{f_D(\lambda_o)\times(n(\lambda_o)-1)\} \quad (4)$$

Accordingly, because the dependence of the focal length $f_D(\lambda)$ on the wavelength λ in the objective lens **27** is opposite to that in the hologram lens **22**, the compound objective lens **29**M having an achromatic function can be formed by the combination of the lenses **26**M, **27**, and the occurrence of the chromatic aberration can be prevented. Also, even though the equation (4) is not strictly satisfied, the occurrence of the chromatic aberration can be largely suppressed.

Also, a curvature of the objective lens **27** can be small because the hologram lens **26**M functions as a convex lens for the first-order diffracted light L**5**. Also, because the hologram lens **26**M is a plane type of element, a lightweight type of compound objective lens having an achromatic function can be made in large scale manufacture. A principal of the achromatization has been proposed in a first literature (D. Faklis and M. Morris, Photonics Spectra(1991), November p.205 & December p.131), a second literature (M. A. Gan et al., S.P.I.E.(1991), Vol.1507, p.116), and a third literature (P. Twardowski and P. Meirueis, S.P.I.E.(1991), Vol.1507, p.55).

(Second Embodiment)

FIG. **10**A is a constitutional view of an imaging optical system having a compound objective lens according to a second embodiment of the present invention, a beam of transmitted light not diffracted being converged on a thin type of information medium. FIG. **10**B is a constitutional view of the imaging optical system shown in FIG. **10**A, a beam of first-order diffracted light being converged on a thick type of information medium.

As shown in FIGS. **10**A, **10**B, an imaging optical system **31** for converging light on the first substrate **22** of the first information medium **23** (the thickness T**1**) or the second substrate **24** of the second information medium **25** (the thickness T**2**) to form a diffraction-limited converging spot, comprises a blazed hologram lens **32** for transmitting a part of incident light L**3** without any diffraction to form a beam of transmitted light L**4** and diffracting a remaining part of incident light L**3** to form a beam of first-order diffracted light L**5**, and the objective lens **27** for converging the transmitted light L**4** on the first information medium **23** or converging the first-order diffracted light L**5** on the second information medium **25**.

The hologram lens **32** is formed by drawing a grating pattern P**2** in a pattern region **32**A of the transparent substrate **28** in a concentric circle shape. The pattern region **32**A is positioned in a center portion of the transparent substrate **28**. An diameter of the grating pattern P**2** is equal to or larger than an aperture of the objective lens **27**. Also, a diffraction efficiency of the hologram lens **32** for the incident light L**3** transmitting through the grating pattern P**2** is less than 100% in the same manner as in the first embodiment, so that the intensity of the transmitted light L**4** is sufficient to record or reproduce a piece of information on or from the first information medium **23**.

In addition, as shown in FIG. **11**, the diffraction efficiency in a central portion of the pattern region **32**A is high, and the diffraction efficiency is gradually decreased toward an outer direction of the pattern region **32**A. In other words, in cases where the grating pattern P**2** of the hologram lens **32** is formed in relief, the height H of the relief in the grating pattern P**2** is gradually lowered toward the outer direction of the pattern region **32**A. Or, in cases where an ideal blazed shape of the hologram lens **26** approximates to a step-wise shape, each block of the grating pattern P**2** positioned in the central portion of the transparent substrate **28** is formed in a step-wise shape shown in FIG. **12**A in which an inclined angle θ_1 of stairs is large and a relationship W**1** >W**2** between a first etching width W**1** and a second etching width W**2** is satisfied, and the grating pattern P**2** formed in the step-wise shape shown in FIG. **12**A is gradually changed by decreasing the first etching width W**1** and increasing the second etching width W**2** toward the outer direction of the pattern region **32**A while the height H of the grating pattern P**2** is gradually decreased. Therefore, each block of the grating pattern P**2** positioned in a peripheral portion of the transparent substrate **28** is formed in a step-wise shape shown in FIG. **12**B in which an inclined angle θ_2 of stairs is small and a relationship W**1**<W**1** between the etching widths is satisfied. Also, each block of the grating pattern P**2** positioned in a middle portion between the central and peripheral portions is formed in a step-wise shape shown in FIG. **12**C in which the etching widths W**1**, W**2** is the same.

In the above configuration of the imaging optical system **31**, a part of the incident light L**3** transmits through the hologram lens **32** without any diffraction to form a beam of transmitted light L**4**, and the transmitted light L**4** is converged by the objective lens **27**. Also, a remaining part of the incident light L**3** is diffracted and refracted by the hologram lens **32**. In this case, the hologram lens **32** functions as a concave lens for the incident light L**3**, so that a first-order diffracted light L**5** diverges from the hologram lens **32**. Thereafter, the first-order diffracted light L**5** is converged by the objective lens **27**.

In cases where the thin type of first information medium **23** is utilized to record or reproduce pieces of information on or from a front surface of the medium **23**, as shown in FIG. **10**A, the transmitted light L**4** is incident on a rear surface of the first information medium **23** and is focused on its front surface by the objective lens **27** to form a diffraction-limited converging spot S**3** on the first information medium **23**. In this case, because the diffraction efficiency in the central portion of the grating pattern P**2** is high and because the diffraction efficiency is gradually decreased toward the outer direction of the grating pattern P**2**, a diffraction probability of the incident light L**3** is lowered in the peripheral portion of the grating pattern P**2**. Therefore, the light L**4** transmits through the objective lens **27** on condition that the numerical aperture NA of the objective lens **27** is high.

In contrast, in cases where the thick type of second information medium **25** is utilized to record or reproduce pieces of information on or from a front surface of the medium **25**, the diffracted light L**5** is incident on a rear surface of the second information medium **25** and is focused on its front surface to form a diffraction-limited converging spot S**5** on the second information medium **25**. In this case, because the hologram lens **32** functions as a concave lens to diverge the first-order diffracted light L**5**, the diffraction-limited converging spots S**3**, S**4** are formed even though the thickness T**1** of the first information medium **23** differs from the thickness T**2** of the second information medium **25**. Therefore, a compound objective lens **34** composed of the hologram lens **32** and the objective lens **27** has substantially two focal points.

Accordingly, because the light L**4** transmits through the objective lens **27** on condition that the numerical aperture NA of the objective lens **27** is high, the intensity of the transmitted light L**4** converged on the first information medium **23** can be high.

Also, in cases where the incident light L3 is radiated from a semiconductor laser, a far field pattern of the incident light L3 is distributed in a Gaussian distribution as shown in FIG. 13A. Therefore, because the diffraction efficiency is gradually decreased toward the outer direction of the grating pattern P2, a far field pattern of the transmitted light L4 is distributed in a gently-sloping shape as shown in FIG. 13B. In contrast to the second embodiment, because the incident light L3 is not diffracted in the no-pattern region 26*b* of the hologram lens 26 in the first embodiment, the intensity of the transmitted light L4 is suddenly increased at the peripheral portion of the hologram lens 26.

Accordingly, secondary maxima of the transmitted light L4 converged on the converging spot S3 can be moreover suppressed in the second embodiment as compared with in the first embodiment. That is, the recording and reproducing of the information can be performed without any deterioration of the information by utilizing the imaging optical system 31.

In addition, in cases where the first-order diffracted light L5 is converged on the second information medium 25 to form the diffraction-limited converging spot S4, a numerical aperture of the objective lens 27 for the first-order diffracted light L5 is low because the diffraction efficiency of the hologram lens 32 is decreased toward an outer direction of the pattern region 32A. As a result, the intensity of the first-order diffracted light L5 becomes lowered. In cases where the diffraction efficiency of the hologram lens 32 is heightened to increase the intensity of the first-order diffracted light L5, the intensity of the transmitted light L4 at its inner beam portion is largely decreased, and secondary maxima (or side lobes) of the transmitted light L4 at the converging spot S3 is undesirably increased. Therefore, the incident light L3 of which the far field pattern is distributed in the Gaussian distribution is radiated to the hologram lens 32 to increase the intensity of the first-order diffracted light L5 without any increase of the second maxima. In detail, as shown in FIG. 14A, the incident light L3 distributed not only in a central portion of the Gaussian distribution but also in a peripheral portion of the Gaussian distribution transmits through the hologram lens 32 and is refracted by the objective lens 27 because the diameter of the grating pattern P2 is equal to or larger than the aperture of the objective lens 27. Therefore, a numerical aperture NA of the objective lens 27 at a light source side for the incident light L3 becomes higher than that in the first embodiment, and the diffraction efficiency of the hologram lens 32 is heightened. As a result, the intensity of the first-order diffracted light L5 converged on the second information medium 25 can be increased, as shown in FIG. 14B. Also, because the intensity of the incident light L3 at the peripheral portion of the Gaussian distribution is low and because the diffraction efficiency of the hologram lens 32 is increased toward the inner direction of the grating pattern region 32A, intensity of the transmitted light L4 is distributed in a gently-sloping shape as shown in FIG. 14C. Accordingly, secondary maxima of the transmitted light L4 at the converging spot S3 can be suppressed.

Examples of the utilization of the imaging optical system 31 for various types of optical disks are described.

In cases where the image optical system 31 is utilized for an optical disk device in which pieces of information recorded in a thin type of high density optical disk and a thick type of compact disk are exclusively reproduced, the diffraction efficiency of the hologram lens 32 for the incident light L3 is set in a range from about 20% to 70%. In this case, the intensity of the transmitted light L4 converged on the high density optical disk is almost the same as that of the first-order diffracted light L5 converged on the compact disk. Therefore, the output power of the incident light L3 can be minimized.

Also, in cases where the image optical system 31 is utilized for an optical disk device in which pieces of information recorded in a thin type of high density optical disk are recorded or reproduced and pieces of information recorded in a thick type of optical disk are exclusively reproduced, the diffraction efficiency of the hologram lens 32 for the incident light L3 is set to a value equal to or lower than 30%. In this case, even though a high intensity of transmitted light L4 is required to record a piece of information on the high density optical disk, the recording of the information can be reliably performed without increasing the intensity of the incident light L3 because a transmission efficiency of the hologram lens 32 for the incident light L3 is high. In other words, a utilization efficiency of the incident light L3 can be enhanced when a piece of information is recorded on the high density optical disk, so that the output power of the incident light L3 can be minimized.

In the second embodiment, the grating pattern P2 positioned in the central portion of the transparent substrate 28 is gradually changed toward the outer direction of the pattern region 32A from the step-wise shape shown in FIG. 12A to the step-wise shape shown in FIG. 12B through the step-wise shape shown in FIG. 12C. However, because the occurrence of unnecessary diffracted light such as minus first-order diffracted light can be effectively prevented in the middle portion of the transparent substrate 28 in which the grating pattern P2 is formed in the step-wise shape shown in FIG. 12C, it is preferred that the middle portion occupy a large part of the pattern region 32A of the hologram lens 32. In this case, the intensity sum of the transmitted light L4 and the first-order diffracted light L5 can be maximized, so that a utilization efficiency of the incident light L3 can be enhanced.

Also, because the first etching width W1 of the grating pattern P2 is gradually decreased toward the outer direction of the pattern region 32A, it is applicable that the grating pattern P2 formed in the step-wise shape shown in FIG. 12B be changed to a step-wise shape shown in FIG. 12D when the first width W1 is decreased to a value lower than about 1 μm. That is, a flight of four stairs shown in FIG. 12B is changed to a flight of two stairs. In this case, the grating pattern P2 formed in the step-wise shape shown in FIG. 12D can be easily made. In addition, in cases where a height H4 of the grating pattern P2 formed in the step-wise shape shown in FIG. 12D is moreover decreased toward the outer direction of the pattern region 32A, it is preferred that the grating pattern P2 be formed in a step-wise shape shown in FIG. 12E. That is, a third etching width W3 is gradually decreased toward the outer direction of the pattern region 32A while decreasing a height H5 of the grating pattern P2. Therefore, the diffraction efficiency of the hologram lens 32 can be gradually decreased toward the outer direction of the pattern region 32A without any manufacturing difficulty of the grating pattern P2.

In addition, as shown in FIG. 15A, it is applicable that a hologram lens 33 be formed, in place of the hologram lens 32, by placing the grating pattern P1 of the pattern region 32A in a central portion of the transparent substrate 28 and placing four types of diffraction regions 33A, 33B, 33C and 33D which surround the grating pattern P1. A part of the incident light L3 transmitting through each of the diffraction regions 33A to 33D is diffracted to control a transmission efficiency of the hologram lens 33. In this case, the intensity of the transmitted light L4 at its peripheral portion is

decreased, so that secondary maxima occurring in the converging spot S3 can be suppressed. Also, it is applicable that the grating pattern P1 of the hologram be replaced with the grating pattern P2. Also, it is applicable that grating directions of the diffraction regions 33A to 33D differ from each other. In this case, even though the first-order diffracted light L5 diffracted in the diffraction region 33A is, for example, incident on the diffraction region 33c after the diffracted light L5 is reflected by the second information medium 25, the diffracted light L5 again diffracted in the diffraction region 33c does not pass in parallel to the optical axis. Therefore, in cases where a piece of information read from the second information medium 25 is detected in a detector to reproduce the information, the first-order diffracted light L5 diffracted in the diffraction regions 33A to 33D is not detected by the detector as stray light. Accordingly, the reproduction of the information does not deteriorate.

Also, as shown in FIG. 15B, it is applicable that the hologram lens 32 function as a convex lens. In this case, the diffracted light L5 is converged on the first information medium 23, and the transmitted light L4 is converged on the second information medium 25, as shown in FIG. 15C.

(Third Embodiment)

FIG. 16A is a constitutional view of an imaging optical system having a compound objective lens according to a third embodiment of the present invention, a beam of first-order diffracted light being converged on a thin type of information medium. FIG. 16B is a constitutional view of the imaging optical system shown in FIG. 16A, a beam of transmitted light not diffracted being converged on a thick type of information medium.

As shown in FIGS. 16A, 16B, an imaging optical system 41 for converging light on the first substrate 22 of the first information medium 23 (the thickness T1) or the second substrate 24 of the second information medium 25 (the thickness T2) to form a diffraction-limited converging spot comprises a blazed hologram lens 42 for transmitting a part of incident light L3 without any diffraction to form a beam of transmitted light L4 and diffracting a remaining part of incident light L3 to form a beam of first-order diffracted light L6, and the objective lens 27 for converging the first-order diffracted light L6 on the first information medium 23 or converging the transmitted light L4 on the second information medium 25.

The hologram lens 42 is formed by drawing a grating pattern P3 in a pattern region 42A of the transparent substrate 28 in a concentric circle shape. The pattern region 42A is positioned in a center portion of the transparent substrate 28. An diameter of the grating pattern P3 is equal to or larger than an aperture of the objective lens 27. Also, a diffraction efficiency of the hologram lens 42 for the incident light L3 transmitting through the grating pattern P3 is less than 100% in the same manner as in the first embodiment, so that the intensity of the transmitted light L4 is sufficient to record or reproduce a piece of information on or from the second information medium 25.

In addition, as shown in FIG. 17, the diffraction efficiency of the hologram lens 42 is high in a peripheral portion of the pattern region 42A, and the diffraction efficiency is gradually decreased toward an inner direction of the pattern region 42A. In other words, in cases where the grating pattern P3 of the hologram lens 42 is formed in relief, the height H of the relief in the grating pattern P3 is gradually lowered toward the inner direction of the pattern region 42A. Or, in cases where an ideal blazed shape of the hologram lens 26 approximates to a step-wise shape, each pitch of the grating pattern P3 positioned in the peripheral portion of the transparent substrate 28 is formed in a step-wise shape shown in FIG. 12A in which the inclined angle θ_1 of stairs is large and the relationship W1>W2 between the first and second etching widths W1, W2 is satisfied, and the grating pattern P3 formed in the step-wise shape shown in FIG. 12A is gradually changed by decreasing the first etching width W1 and increasing the second etching width W2 toward the inner direction of the pattern region 42A while the height H of the grating pattern P3 is gradually decreased. Therefore, each pitch of the grating pattern P3 positioned in a central portion of the transparent substrate 28 is formed in a stepwise shape shown in FIG. 12B in which the inclined angle θ_2 of stairs is small and the relationship W1<W2 is satisfied. Also, each pitch of the grating pattern P3 positioned in a middle portion between the central and peripheral portions is formed in a step-wise shape shown in FIG. 12C in which the etching widths W1, W2 is the same.

In the above configuration of the imaging optical system 41, as shown in FIG. 16B, a part of the incident light L3 transmits through the hologram lens 42 without any diffraction to form a beam of transmitted light L4, and the transmitted light L4 is converged by the objective lens 27. Also, a remaining part of the incident light L3 is diffracted by the hologram lens 42 to form a beam of first-order diffracted light L6. In this case, the hologram lens 42 functions as a convex lens for the incident light L3, so that a first-order diffracted light L6 formed in the hologram lens 42 converges. Thereafter, the diffracted light L6 is converged by the objective lens 27.

In cases where the thin type of first information medium 23 is utilized to record or reproduce pieces of information on or from a front surface of the medium 23, as shown in FIG. 16A, the diffracted light L6 is incident on a rear surface of the first information medium 23 and is focused on its front surface to form a diffraction-limited converging spot S5 on the first information medium 23. In contrast, in cases where the thick type of second information medium 25 is utilized to record or reproduce pieces of information on or from a front surface of the medium 25, the transmitted light L4 is incident on a rear surface of the second information medium 25 and is focused on its front surface to form a diffraction-limited converging spot S6 on the second information medium 25.

In this case, because the hologram lens 42 functions as a convex lens to converge the diffracted light L6, the diffraction-limited converging spots S5, S6 are formed even though the thickness T1 of the first information medium 23 differs from the thickness T2 of the second information medium 25. Therefore, a compound objective lens 43 composed of the hologram lens 42 and the objective lens 27 has substantially two focal points.

Also, because the hologram lens 42 functions as a convex lens for the diffracted light L6, the diffracted light L6 transmits through the objective lens 27 on condition that the numerical aperture NA of the objective lens 27 is substantially high.

In addition, because the diffraction efficiency in the peripheral portion of the grating pattern P3 is high and because the diffraction efficiency is gradually decreased toward the inner direction of the grating pattern P3, a diffraction probability of the incident light L3 is higher in the peripheral portion of the grating pattern P3.

The grating pattern P3 of the hologram lens 42 is designed to correct any aberration occurring in the objective lens 27 and the first information medium 23, so that the diffracted light L6 transmits through the first information medium 23 having the thickness T1 and is converged on the medium 23

to form the diffraction-limited converging spot S5 without any aberration. A method for designing the hologram lens **42** having an aberration correcting function is described.

After the diffracted light L6 is converged on the first information medium **23**, spherical waves diverge from the converging spot S5 and transmit through the first substrate **22** and the objective lens **27**. Thereafter, the spherical waves transmit through the transparent substrate **28** and optically interfere with the incident light L3. Therefore, an interference pattern is formed by the interference between the spherical waves and the incident light L3. The interference pattern can be calculated by adding the phase of the spherical waves to an inverted phase obtained by inverting the phase of the incident light L3. Accordingly, the grating pattern P3 of the hologram lens **42** which agrees with the interference pattern calculated can be easily formed according to a computer generated hologram technique.

Accordingly, because the hologram lens **42** functions as a convex lens for the first-order diffracted light L6, a curvature of the objective lens **27** can be lowered. Also, a glass material having a high refractive index is not required to produce the objective lens **27**.

Also, because the first-order diffracted light L6 formed in the hologram lens **42** converges before the diffracted light L6 is incident on the objective lens **27**, the distance in an optical axis direction between the converging spots S5, S6 can be lengthened to about 1 mm. Therefore, even though the transmitted light L4 (or the first-order diffracted light L6) is converged on the converging spot S6 (or S5) in focus to record or read a piece of information, the light L6 (or L4) is not converged on the converging spot S6 (or S5) in focus to reduce the intensity of the light L6 (or L4) at the converging spot S6 (or S5). Accordingly, no adverse influence is exerted on the recording or reproduction of the information

Also, because the hologram lens **42** functions as a convex lens for the first-order diffracted light L6, the occurrence of a chromatic aberration can be prevented in the imaging optical system **41**. In detail, the focal length of the hologram lens **42** is shortened as the wavelength of the incident light L3 becomes longer. In contrast, the focal length of the objective lens **27** is lengthened as the wavelength of the incident light L3 becomes longer. That is, the dependence of the focal length on the wavelength in the objective lens **27** is opposite to that of the focal length on the wavelength in the hologram lens **42**. Therefore, the compound objective lens **43** having an achromatic function can be formed by the combination of the lenses **27**, **42**, and the occurrence of the chromatic aberration can be prevented.

Also, because the hologram lens **42** is a plane type of element, a lightweight type of compound objective lens can be made in large scale manufacture.

Also, because the diffraction efficiency of the hologram lens **42** is gradually decreased toward an inner direction of the pattern region **42**A, the numerical aperture of the objective lens **27** for the first-order diffracted light L6 becomes substantially enlarged. Therefore, the intensity of the first-order diffracted light L6 can be enlarged to record or reproduce a piece of information on or from the first information medium **23**.

Also, in cases where the incident light L3 is radiated from a semiconductor laser, a far field pattern of the incident light L3 is distributed in a Gaussian distribution as shown in FIG. **13**A. Therefore, because the diffraction efficiency of the hologram lens **42** is gradually decreased toward the inner direction of the grating pattern P2, a far field pattern of the first-order diffracted light L6 is distributed in a gently-sloping shape. Accordingly, secondary maxima of the first-order diffracted light L6 converged on the converging spot S5 can be moreover suppressed in the third embodiment as compared with in the first embodiment. That is, the recording and reproducing of the information can be performed without any deterioration of the information by utilizing the imaging optical system **41**.

In addition, in cases where the transmitted light L4 is converged on the second information medium **25** to form the diffraction-limited converging spot S6, a numerical aperture of the objective lens **27** for the transmitted light L4 is low because the diffraction efficiency of the hologram lens **42** is increased toward an outer direction of the grating pattern **42**A. As a result, the intensity of the transmitted light L4 becomes lowered. In cases where a transmission efficiency of the hologram lens **42** is heightened to increase the intensity of the transmitted light L4, the intensity of the first-order diffracted light L6 at its inner beam portion is largely decreased, and secondary maxima (or side lobes) of the first-order diffracted light L6 at the converging spot S6 is undesirably increased. Therefore, the incident light L3 of which the far field pattern is distributed in the Gaussian distribution is radiated to the hologram lens **42** to increase the intensity of the transmitted light L4 without any increase of the second maxima. In detail, as shown in FIG. **18**A, the incident light L3 distributed in not only a central portion of the Gaussian distribution but also a peripheral portion of the Gaussian distribution transmits through the hologram lens **42** and is refracted by the objective lens **27** because the diameter of the grating pattern P3 is equal to or larger than the aperture of the objective lens **27**. Therefore, a numerical aperture NA of the objective lens **27** at a light source side for the incident light L3 becomes higher than that in the first embodiment, and a transmission efficiency of the hologram lens **42** is heightened. As a result, the intensity of the transmitted light L4 converged on the second information medium **25** can be increased, as shown in FIG. **18**B. Also, because the intensity of the incident light L3 at the peripheral portion of the Gaussian distribution is low and because the diffraction efficiency of the hologram lens **42** is decreased toward the inner direction of the grating pattern **42**A, the first-order diffracted light L6 is distributed in a gently-sloping shape as shown in FIG. **18**C. Accordingly, secondary maxima of the first-order diffracted light L6 at the converging spot S5 can be suppressed.

Examples of the utilization of the imaging optical system **41** for various types of optical disks are described.

In cases where the image optical system **41** is utilized for an optical disk device in which pieces of information recorded in a thin type of high density optical disk and a thick type of compact disk are exclusively reproduced. the diffraction efficiency of the hologram lens **42** for the incident light L3 is set in a range from about 20% to 70%. In this case, the intensity of the transmitted light L4 converged on the compact disk is almost the same as that of the first-order diffracted light L6 converged on the high density optical disk. Therefore, the output power of the incident light L3 can be minimized.

Also, in cases where the image optical system **41** is utilized for an optical disk device in which pieces of information recorded in a thin type of high density optical disk are recorded or reproduced and pieces of information recorded in a thick type of optical disk are exclusively reproduced, the diffraction efficiency of the hologram lens **42** for the incident light L3 is set to a value equal to or higher than 55%. In this case, even though a high intensity of the first-order diffracted light L6 is required to record a piece of information on the high density optical disk, the recording of

the information can be reliably performed without increasing the intensity of the incident light L3 because the diffraction efficiency of the hologram lens **42** for changing the incident light L3 to the first-order diffracted light L6 is high. In other words, a utilization efficiency of the incident light L3 can be enhanced when a piece of information is recorded on the high density optical disk, so that the output power of the incident light L3 can be minimized. Also, because the diffraction efficiency of the hologram lens **42** is gradually decreased toward an inner direction of the pattern region **42**A, the numerical aperture of the objective lens **27** for the first-order diffracted light L6 becomes substantially enlarged. Therefore, the intensity of the first-order diffracted light L6 can be enlarged to record or reproduce a piece of information on or from the high density optical disk.

In the third embodiment, the grating pattern P3 positioned in the pattern region **42**A of the transparent substrate **28** is gradually changed toward the outer direction of the pattern region **42**A from the step-wise shape shown in FIG. **12**B to the step-wise shape shown in FIG. **12**A through the step-wise shape shown in FIG. **12**C while increasing the height H of the grating pattern P3. However, because the occurrence of unnecessary diffracted light such as minus first-order diffracted light can be effectively prevented in the middle portion of the transparent substrate **28** in which the grating pattern P3 is formed in the step-wise shape shown in FIG. **12**C, it is preferred that the middle portion occupy a large part of the pattern region **42**A of the hologram lens **42**. In this case, the intensity sum of the transmitted light L4 and the first-order diffracted light L6 can be maximized, so that a utilization efficiency of the incident light L3 can be enhanced.

Also, because the first etching width W1 of the grating pattern P3 is gradually decreased toward the inner direction of the pattern region **42**A, it is applicable that the grating pattern P3 formed in the step-wise shape shown in FIG. **12**B be changed to a step-wise shape shown in FIG. **12**D when the first width W1 is decreased to a value lower than about 1 μm. In this case, the grating pattern P3 formed in the step-wise shape shown in FIG. **12**D can be easily made. In addition, in cases where a height H4 of the grating pattern P3 formed in the step-wise shape shown in FIG. **12**D is moreover decreased toward the inner direction of the pattern region **42**A, it is preferred that the grating pattern P3 be formed in a step-wise shape shown in FIG. **12**E. In this case, a third etching width W3 is gradually decreased toward the inner direction of the pattern region **42**A while decreasing a height H5 of the grating pattern P3. Therefore, the diffraction efficiency of the hologram lens **42** can be gradually decreased toward the inner direction of the pattern region **42**A without any manufacturing difficulty of the grating pattern P3.

In the first to third embodiments of the image optical systems **21**, **31** and **41**, the grating patterns P1, P2 and P3 of the hologram lenses **26**, **32** and **42** are respectively formed on a front side of the transparent substrate **28** not facing the objective lens **27**. Therefore, a beam of light reflected at the front side of the transparent substrate **28** does not adversely influence as stray light on the recording or reproduction of the information. In detail, because the reflected light is diffracted by the hologram lens, the reflected light is scattered. Also, even though the first-order diffracted light L5 or L6 is reflected at a reverse side of the transparent substrate **28**, the diffracted light reflected is again diffracted by the hologram lens and is scattered. Therefore, the light reflected at the front or reverse side of the hologram lens does not adversely influence on the recording or reproduction of the information.

However, in cases where an anti-reflection film is coated on a front side of the hologram lens **28** at which the grating pattern is not formed, it is applicable that the grating patterns P1, P2 and P3 of the hologram lenses **26**, **32** and **42** be respectively formed on a reverse side of the transparent substrate **28** facing the objective lens **27**. In this case, because the first-order diffraction light L5, L6 is not refracted at the front side of the hologram lens **28**, the design of the image optical systems **21**, **31** and **41** can be simplified.

Also, in the first to third embodiments, the grating patterns P1, P2 and P3 of the hologram lenses **26**, **32** and **42** are respectively formed in relief to produce a phase modulation type of hologram lens. However, as is described in Provisional Publication No. 189504/86 (S61-189504) and Provisional Publication No. 241735/88 (S63-241735), the phase modulation type of hologram lens can be produced by utilizing a liquid crystal cell. Also, the phase modulation type of hologram lens can be produced by utilizing a birefringece material such as lithium niobate. For example, the phase modulation type of hologram lens can be produced by proton-exchanging a surface part of a lithium niobate substrate.

(Fourth Embodiment)

Also, in the first to third embodiments, the compound objective lens **29**, **34** or **43** having two focal points is composed of the objective lens **27** and the hologram lens **26**, **32** or **42**. However, as a compound objective lens according to a fourth embodiment is shown in FIG. **19**A, it is preferred that each of the hologram lenses **26**, **32** and **42** and the objective lens **27** be unified with a packaging means **44** to form a compound objective lens **45** in which a relative position between each of the hologram lenses **26**, **32** and **42** and the objective lens **27** is fixed. In this case, the transmitted light L4 and the first-order diffracted light L5, L6 can be easily converged on the first or second information medium **23**, **25** by adjusting the position of the packing means **44** with an actuator. Also, as another compound objective lens according to a modified fourth embodiment is shown in FIG. **19**B, it is preferred that each of the grating patterns P1, P2 and P3 be directly drawn on a curved side of the objective lens **27** facing a light source side to form a compound objective lens **46** in which each of the hologram lenses **26**, **32** and **42** is integrally formed with the objective lens **27**.

Accordingly, the central axis of the objective lens **27** can always agree with that of each of the hologram lenses **26**, **32** and **42**, so that abaxial aberrations of each of the hologram lenses **26**, **32** and **42** such as a coma aberration and an astigmatic aberration occurring in the first-order diffracted light can be prevented in the fourth embodiment. Also, because the hologram lens **26**, **32** or **42** is placed on a lens surface of the objective lens **27** of which a curvature is higher than those of other lens surfaces of the objective lens **27**, a sine condition for the hologram lens treated as a lens can be easily satisfied. Therefore, the degree of aberrations resulting from a constitutional error of an optical head apparatus can be sufficiently reduced.

(Fifth Embodiment)

Also, as a compound objective lens according to a fifth embodiment is shown in FIG. **20**, it is preferred that each of the grating patterns P1, P2 and P3 be directly drawn on a side of the objective lens **27** facing the information medium **23** or **25** to form a compound objective lens **47** in which each of the hologram lenses **26**, **32** and **42** is integrally formed with the objective lens **27**. In this case, a curvature at the side of the objective lens **27** can be small or in a plane shape. Therefore, each of the grating patterns P1, P2 and P3 can be made at a low cost. Also, in cases where an aberration is

caused by tilting the hologram lens from the optical axis, the aberration can be prevented by fixing the hologram lens and a light source of the incident light L3 on the same base.

(Sixth Embodiment)

An optical head apparatus with one of the compound objective lenses **29**, **29M**, **34**, **43**, **45**, **46** and **47** shown in the first to fifth embodiments is described with reference to FIGS. **21** to **26** according to a sixth embodiment of the present invention. X, Y and Z co-ordinates shown in FIGS. **21** to **26** are utilized in common.

FIG. **21** is a constitutional view of an optical head apparatus according to a sixth embodiment.

As shown in FIG. **21**, an optical head apparatus **51** for recording or reproducing pieces of information on or from the information medium **23** or **25**, comprises a light source **52** such as a semiconductor laser for radiating the incident light L3, a collimator lens **53** for collimating the incident light L3, a beam splitter **54** for transmitting the incident light L3 on an outgoing optical path and reflecting a beam of transmitted light L4 R formed by reflecting the transmitted light L4 on the information medium **23** or **25** or a beam of diffracted light L5R (or L6R) formed by reflecting the diffracted light L5 (or L6) on the information medium **23** or **25** on an incoming optical path, the compound objective lens **29** (or **29M**, **34**, **43**, **45**, **46** or **47**) composed of the hologram lens **26** (or **26M**, **32**, **33** or **42**) and the objective lens **27**, a converging lens **55** for converging the transmitted light L4R or the diffracted light L5R reflected by the beam splitter **54**, a wavefront changing device **56** such as a hologram for changing a wavefront of the transmitted light L4R or the diffracted light L5R to form a plurality of converging spots of the transmitted light L4R or the diffracted light L5R, a photo detector **57** for detecting intensities of the converging spots of the transmitted light L4R or the diffracted light L5R of which the wavefront is changed by the wavefront changing device **56** to obtain an information signal recorded on the information medium **23** or **25** and servo signals such as a focus error signal and a tracking error signal, and an actuating unit **58** for moving the compound objective lens composed of the hologram lens **26** and the objective lens **27** according to the servo signals.

In the above configuration, a beam of incident light L3 radiated from the light source **52** is collimated in the collimator lens **53** and transmits through the beam splitter **54**. Thereafter, a part of the incident light L3 transmits through the compound objective lens **29** without any diffraction, and a remaining part of the incident light L3 is diffracted.

Thereafter, in cases where a piece of information is recorded or reproduced on or from the first information medium **23**, the transmitted light L4 is converged on the first information medium **23** to form the first converging spot S1. That is, the transmitted light L4 is incident on a rear surface of the first information medium **23**, and the first converging spot S1 is formed on a front surface of the first information medium **23**. Thereafter, a beam of transmitted light L4R reflected at the front surface of the first information medium **23** passes through the same optical path in the reverse direction. That is, a part of the transmitted light L4R again transmits through the compound objective lens **29** without any diffraction and is reflected by the beam splitter **54**. In this case, the transmitted light L4R is collimated. Thereafter, the transmitted light L4R is converged by the converging lens **55**, and the wavefront of a large part of the transmitted light L4R is changed to form a plurality of converging spots on the photo detector **57**. Thereafter, the intensities of the converging spots of the transmitted light L4R are detected in the photo detector **57**. Therefore, an information signal and servo signals such as a focus error signal and a tracking error signal are obtained. The actuating unit **58** are operated according to the servo signals to move the compound objective lens **29** at high speed, so that the transmitted light L4 is converged on the first information medium **23** in focus.

Also, in cases where a piece of information is recorded or reproduced on or from the second information medium **25**, the diffracted light L5 is converged on the second information medium **25** to form the second converging spot S2. That is, the diffracted light L5 is incident on a rear surface of the second information medium **25**, and the second converging spot S2 is formed on a front surface of the second information medium **25**. Thereafter, a beam of diffracted light L5R reflected at the front surface of the second information medium **25** passes through the same optical path in the reverse direction. That is, a part of the diffracted light L5R is again diffracted by the hologram lens **26** and is reflected by the beam splitter **54**. In this case, the diffracted light L5R is collimated. Thereafter, the diffracted light L5R is converged by the converging lens **55**, and the wavefront of a large part of the diffracted light L5R is changed to form a plurality of converging spots on the photo detector **57**. In this case, the diffracted light L5R incident on the converging lens **55** is collimated in the same manner as the transmitted light L4R incident on the converging lens **55**, the converging spots of the diffracted light L5R are formed at the same positions as those of the transmitted light L4R. Thereafter, the intensities of the converging spots of the diffracted light L5R are detected in the photo detector **57**. Therefore, an information signal and servo signals such as a focus error signal and a tracking error signal are obtained. The actuating unit **58** are operated according to the servo signals to move the compound objective lens **29** at high speed, so that the diffracted light L5 is converged on the second information medium **25** in focus.

In this case, because the transmitted light L4R again transmits through the compound objective lens without any diffraction and the diffracted light L5R is again diffracted by the hologram lens **26**, the outgoing optical path agrees with the incoming optical path in a range between the information medium **23** or **25** and the beam splitter **54** even though the converging spot S1 differs from the converging spot S2. Therefore, a converging spot S7 on the photo detector **57** at which the light L4R or L5R not diffracted by the wavefront changing device **56** is converged relates to a radiation point of the light source **52** in a mirror image, so that the light L4R and L5R not diffracted by the wavefront changing device **56** are converged at the same converging point S7. In the same manner, the light L4R and L5R diffracted by the wavefront changing device **56** are converged at the same other converging points.

Accordingly, even though the compound objective lens has two focal points, the wavefront changing unit **56** and the photo detector **57** required to detect the intensity of the transmitted light L4R can be utilized to detect the intensity of the diffracted light L5R. Therefore, the number of parts required to manufacture the optical head apparatus **51** can be reduced, and a small sized optical head apparatus can be manufactured at a low cost and in light weight even though pieces of information are recorded or reproduced on or from an information medium by utilizing the optical head apparatus **51** regardless of whether the information medium is thick or thin.

In cases where the hologram lens **26** (or **32**, **33**, **42**) is integrally formed with the objective lens **27** as shown in FIG. **19A**, **19B** or **20**, each of the compound objective lenses

45, 46 and 47 can be manufactured in light weight because the hologram lens 26 (or 32, 33, 42) is a plane type of optical device. For example, the hologram lens 26 (or 32, 33, 42) is less than several tens mg in weight. Therefore, the hologram lens 26 integrally formed with the objective lens 27 can be easily moved by the actuating unit 58.

Next, a detecting method of the servo signals is described. FIG. 22 is a plan view of the wavefront changing unit 56. FIG. 23 is an enlarged view of first-order diffracted light and transmitted light detected in the photo detector 57. As shown in FIG. 22, the wavefront changing unit 56 is partitioned into as diffracted light generating region 56*a* in which a grating pattern P4 is drawn and a pair of diffracted light generating regions 55*b*, 56*c* in which a pair of grating patterns P5, P6 are drawn. The light L4R or L5R incident on the diffracted light generating region 56*a* is diffracted to obtain a focus error signal. The light L4R or L5R incident on each of the diffracted light generating regions 56*b*, 56*c* is diffracted to obtain a tracking error signal.

Initially, a spot size detection method utilized to detect a focus error signal is described as an example of a detecting method of a focus error signal. The method is proposed in Japanese Patent Application No. 185722 of 1990. In short, in cases where the method is adopted, an allowable assembly error in an optical head apparatus can be remarkably enlarged, and the servo signal such as a focus error signal can be stably obtained to adjust the position of the compound objective lens even though the wavelength of the incident light L3 varies.

In detail, as shown in FIG. 23, the grating pattern P4 is designed to change the transmitted light L4R (or the diffracted light L5R) transmitting through the diffracted light generating region 56*a* of the wavefront changing unit 56 to a beam of first-order diffracted light L7 and a beam of minus first-order diffracted light L8. The diffracted light L7, L8 are expressed by two types of spherical waves having different curvatures. That is, interference fringes are produced by actually interfering a spherical wave having a focal point FP1 in the front of the photo detector 57 with another spherical wave diverging from the converging spot S7 according to a two-beam interferometric process, so that the grating pattern P4 agreeing with the interference fringes is formed. In other case, the interference fringes are calculated according to a computer generated hologram method. As a result, the transmitted light L4R (or the diffracted light L5R) transmitting through the diffracted light generating region 56*a* of the wavefront changing unit 56 is diffracted and changed to beams of conjugate diffracted light such as a beam of first-order diffracted light L7 and a beam of minus first-order diffracted light L8. The beam of first-order diffracted light L7 has the focal point FP1 at the front surface of the photo detector 57, and the beam of minus first-order diffracted light L8 has a focal point FP2 in the rear of the photo detector 57.

As shown in FIG. 24, the photo detector 57 comprises a sextant photo-detector 59 (or a six-division photo detector) in which six detecting sections SE1, SE2, SE3, SE4, SE5 and SE6 are provided. The intensity of the first-order diffracted light L7 is detected by each of the detecting sections SE1, SE2 and SE3 of the sextant photo-detector 59 and is changed to electric current signals SC1, SC2 and SC3. Also, the intensity of the minus first-order diffracted light L8 is detected by each of the detecting sections SE4, SE5 and SE6 of the sextant photo-detector 59 and is changed to electric current signals SC4, SC5 and SC6.

FIG. 25A and 25C respectively show a converging spot of the first-order diffracted light L7 radiated to the detecting sections SE1, SE2 and SE3 of the sextant photo-detector 59 and another converging spot of the minus first-order diffracted light L8 radiated to the detecting sections SE4, SE5 and SE6 of the sextant photo-detector 59 on condition that the objective lens 27 is defocused on the information medium 23 or 25. FIG. 25B shows a converging spot of the first-order diffracted light L7 radiated to the detecting sections SE1,′ SE2 and SE3 of the sextant photo-detector 59 and another converging spot of the minus first-order diffracted light L8 radiated to the detecting sections SE4, SE5 and SE6 of the sextant photo-detector 59 on condition that the objective lens 27 is just focused on the information medium 23 or 25.

As shown in FIGS. 25A to 25C, in cases where the transmitted light L4 (or the diffracted light L5) is converged on the information medium 23 (or 25) on condition that the objective lens 27 is defocused on the information medium 23 (or 25), a converging spot S8 of the diffracted light L7 shown at the left side of FIGS. 25A, 25C is formed on the sextant photo-detector 59, and another converging spot S9 of the diffracted light L8 shown at the right side of FIG. 25A or 25C is formed on the sextant photo-detector 59. In contrast, in cases where the transmitted light L4 (or the diffracted light L5) is converged on the information medium 23 (or 25) on condition that the objective lens 27 is just focused on the information medium 23 (or 25), a converging spot S8 of the diffracted light L7 shown at the left side of FIG. 25B is formed on the sextant photo-detector 59, and another converging spot S9 of the diffracted light L8 shown at the right side of FIG. 25B is formed on the sextant photo-detector 59. The intensity of the diffracted light L7 is detected in each of the detecting sections SE1, SE2 and SE3 of the sextant photo-detector 59 and is changed to electric current signals SC1, SC2, SC3. Also, the intensity of the diffracted light L8 is detected in the detecting sections SE4, SE5 and SE6 of the sextant photo-detector 59 and is changed to electric current signals SC4, SC5 and SC6. Thereafter, a focus error signal $S_{f\theta}$. is obtained according to the spot size detection method by calculating an equation (5).

$$S_{f\theta}=(SC1+SC3-SC2)-(SC4+SC6-SC5) \quad (5)$$

Thereafter, the position of the compound objective lens is moved in a direction along an optical axis at high speed so as to minimize the absolute value of the focus error signal $S_{f\theta}$.

In the spot size detection method, the diffracted light L7, L8 are expressed by two types of spherical waves having different curvatures to detect the focus error signal $S_{f\theta}$. However, two beams of diffracted light L7, L8 radiated to the photo detector 57 are not limited to the spherical waves. That is, because the change of the diffracted light L7, L8 in a Y-direction is detected by the photo detector 57 according to the spot size detection method, it is required that a one-dimensional focal point of the diffracted light L7 is positioned in the front of the photo detector 57 and a one-dimensional focal point of the diffracted light L8 is positioned in the rear of the photo detector 57. Therefore, it is applicable that diffracted light including astigmatic aberration be radiated to the photo detector 57.

In addition, an information signal S_{in} is obtained by adding all of the electric current signals according to an equation (6).

$$S_{in}=SC1+SC2+SC3+SC4+SC5+SC6 \quad (6)$$

Because the information medium 23 or 25 is rotated at high speed, a patterned track pit radiated by the converging

spots S8, S9 of the diffracted light L7,L8 is rapidly changed one after another, so that the intensity of the information signal S_{in} is changed. Therefore, the information stored in the information medium **23** or **25** can be reproduced according to the information signal S_{in}.

Next, the detection of a tracking error signal depending on a relative position between a converging spot and a patterned track pit on the information medium **23** or **25** is described.

The grating pattern P5 drawn in the diffracted light generating region **56***b* shown in FIG. **22** is designed to change the transmitted light LR (or the diffracted light L5R) transmitting through the diffracted light generating region **56***b* of the wavefront changing unit **56** to a beam of first-order diffracted light L9 and a beam of minus first-order diffracted light L10. Also, the grating pattern P6 drawn in the diffracted light generating region **56***c* shown in FIG. **22** is designed to change the transmitted light L4R (or the diffracted light L5R) transmitting through the diffracted light generating region **56***c* of the wavefront changing unit **56** to a beam of first-order diffracted light L11 and a beam of minus first-order diffracted light L12.

As shown in FIG. **24**, the photo detector **57** further comprises four tracking photo-detectors **60***a* to **60***d* for detecting intensities of the diffracted light L9 to L12. As shown in FIG. **26**, the intensity of the diffracted light L9 is detected by the tracking photo-detector **60***a* and is changed to an electric current signal SC7, the intensity of the diffracted light L10 is detected by the tracking photo-detector **60***d* and is changed to an electric current signal SC10, the intensity of the diffracted light L11 is detected by the tracking photo-detector **60***b* and is changed to an electric current signal SC8, and the intensity of the diffracted light L12 is detected by the tracking photo-detector **60***c* and is changed to an electric current signal SC **9**. A tracking error signal $S_{t\Theta}$ is calculated according to an equation (7).

$$S_{t\Theta}=SC7-SC8-SC9+SC10 \quad (7)$$

Therefore, the asymmetry of the intensity distribution of the transmitted light L4R (or the diffracted light L5R) incident on the wavefront changing unit **56**, which changes in dependence on the positional relation between the converging spot S1 (or S2) and a patterned track pit radiated by the light L4 or L5, is expressed by the tracking error signal $S_{t\Theta}$.

Thereafter, the objective lens **27** is moved in a radial direction so as to reduce a tracking error indicated by the tracking error signal $S_{t\Theta}$. The radial direction is defined as a direction perpendicular to both the optical axis and a series of patterned track pits. Therefore, the converging spot S1 (or S2) of the transmitted light L4 (or the diffracted light L5) on the information medium **23** (or **25**) can be formed in the middle of the patterned track pit, so that the tracking error becomes zero.

Accordingly, focus and tracking servo characteristics can be stably obtained in the optical head apparatus **51**. That is, because the wavefront changing unit **56** has a wavefront changing function, a focus error signal can be easily obtained. Also, because the diffracted light generating regions **56***b*, **56***c* are provided in the wavefront changing unit **56**, a tracking error signal can be easily obtained. Therefore, the number of parts required to manufacture the optical head apparatus **51** can be reduced, and the number of manufacturing steps can be reduced. In addition, the optical head apparatus can be manufactured at a low cost and in light weight.

Also, because the compound objective lens having two focal points is utilized in the optical head apparatus **51**, pieces of information can be reliably recorded or reproduced from an information medium by utilizing the optical head apparatus **51** regardless of whether the information medium is thick or thin.

(Seventh Embodiment)

Next, an optical head apparatus in which servo signals such as a focus error signal and a tracking error signal are detected according to an astigmatic aberration method is described according to a seventh embodiment of the present invention.

FIG. **27** is a constitutional view of an optical head apparatus according to a seventh embodiment.

As shown in FIG. **27**, an optical head apparatus **61** for recording or reproducing pieces of information on or from the information medium **23** or **25**, comprises the light source **52**, the collimator lens **53**, the beam splitter **54**, the compound objective lens **29** (or **29**M, **34**, **43**, **45**, **46** or **47**) composed of the hologram lens **26** (or **26**M, **32**, **33** or **42**) and the objective lens **27**, the actuating unit **58**, the converging lens **55**, an astigmatic aberration generating unit **62** such as a plane parallel plate for generating an astigmatic aberration in the transmitted light L4R or the diffracted light L5 R converged by the converging lens **55**, and a photo detector **63** for detecting the intensity of the transmitted light L4R or the diffracted light L5R in which the astigmatic aberration is generated to obtain an information signal and servo signals such as a focus error signal and a tracking error signal.

The astigmatic aberration generating unit **62** is classified into one of the wavefront changing unit **56** because a wavefront of the transmitted light L4R or the diffracted light L5R is changed by the generating unit **62** to generate the astigmatic aberration in the light L4R or L5R. Also, a normal line of the unit **62** is tilted from an optical axis.

As shown in FIG. **28**, the photo detector **63** comprises a quadrant photo-detector **64** in which four detecting sections SE7, SE8, SE9 and SE10 are provided.

In the above configuration, the transmitted light L4R (or the diffracted light L5R) reflected by the information medium **23** (or **25**) is converged by the converging lens **55** in the same manner as in the sixth embodiment. Thereafter, the transmitted light L4R (or the diffracted light L5R) transmits through the astigmatic aberration generating unit **62** and is converged on the photo detector **57** to form a converging spot S10 on the detecting sections SE7, SE8, SE9 and SE10 of the quadrant photo-detector **64**. In this case, because the transmitted light L4R (or the diffracted light L5R) converged by the converging lens **55** is a spherical wave, an astigmatic aberration is generated in the transmitted light L4R (or the diffracted light L5R) by the astigmatic aberration generating unit **62**. Therefore, as shown in FIGS. **29**A to **29**C, the shape of the converging spot S10 considerably changes depending on a distance between the compound objective lens **29** and the information medium **23** (or **25**).

For example, in cases where the transmitted light L4 (or the diffracted light L5) is converged on the information medium **23** (or **25**) on condition that the objective lens **27** is defocused on the information medium **23** (or **25**), the converging spot S10 of the transmitted light L4R (or the diffracted light L5R) is formed on the quadrant photo-detector **64** as shown in FIGS. **29**A, **29**C. In contrast, in cases where the transmitted light L4 (or the diffracted light L5) is converged on the information medium **23** (or **25**) on condition that the objective lens **27** is just focused on the information medium **23** (or **25**), the converging spot S10 of the transmitted light L4R (or the diffracted light L5R) is formed on the quadrant photo-detector **64** as shown in FIG. **25**B.

The intensity of the transmitted light L4R (or the diffracted light L5R) is detected in the detecting sections SE7, SE8, SE9 and SE10 of the quadrant photo-detector **64** and is changed to electric current signals SC11, SC12, SC13 and SC14. Thereafter, a focus error signal $S_{f\theta}$ is obtained according to an astigmatic aberration method by calculating an equation (8).

$$S_{f\theta}=(SC11+SC14)-(SC12+SC13) \quad (8)$$

Thereafter, the position of the compound objective lens **29** is moved in a direction parallel to an optical axis at high speed so as to minimize the absolute value of the focus error signal $S_{f\theta}$.

Also, a tangential direction Dt agreeing with an extending direction of patterned recording pits and a radial direction Dr perpendicular to both the optical axis and the patterned recording pits are defined as shown in FIG. **29**D. In this case, when the quadrant photo-detector **64** is directed as shown in FIGS. **29**A to **29**C, a tracking error signal $S_{t\theta}$ is calculated according to an equation (9) by utilizing an intensity distribution change of the transmitted light L4R (or the diffracted light L5R) which depends on a positional relation between the converging spot S10 and a recording pit radiated by the light L4 or L5.

$$S_{t\theta}=SC11+SC13-(SC12+SC14) \quad (9)$$

Thereafter, the objective lens **27** is moved in the radial direction so as to reduce a tracking error indicated by the tracking error signal $S_{t\theta}$. Therefore, the converging spot S1, (or S2) of the transmitted light L4 (or the diffracted light L5) on the information medium **23** (or **25**) can be formed in the middle of the recording pit, so that the tracking error becomes zero.

In other case, the tracking error signal $S_{t\theta}$ is obtained according to a phase difference method by utilizing the result calculated in the equation (8).

In addition, an information signal S_{in} is obtained by adding all of the electric current signals according to an equation (10).

$$S_{in}=SC11+SC12+SC13+SC14 \quad (10)$$

Accordingly, focus and tracking servo characteristics can be stably obtained in the optical head apparatus **61**. That is, because an astigmatic aberration is generated in the transmitted light L4R (or the diffracted light L5R) by the astigmatic aberration generating unit **62** made of a plane parallel plate, the servo signals such as a focus error signal and a tracking error signal can be easily obtained. Therefore, the number of parts required to manufacture the optical head apparatus **61** can be reduced, and the number of manufacturing steps can be reduced. In addition, the optical head apparatus **61** can be manufactured at a low cost and in light weight.

Also, because the compound objective lens having two focal points is utilized in the optical head apparatus **61**, pieces of information can be reliably recorded or reproduced from an information medium by utilizing the optical head apparatus **61** regardless of whether the information medium is thick or thin.

In the seventh embodiment, the astigmatic aberration generating unit **62** formed out of the plane parallel plate is arranged between the converging lens **55** and the photo detector **63**. However, as an optical head apparatus **65** is shown in FIG. **30**, it is applicable that a cylindrical lens **66** integrally formed with the converging lens **55** be arranged in place of the plane parallel plate to generate an astigmatic aberration in the transmitted light L4R (or the diffracted light L5R). In this case, because the cylindrical lens **66** is integrally formed with the converging lens **55**, the optical head apparatus can be moreover manufactured at low cost. In addition, as shown in FIG. **30**, it is applicable that a normal line of the hologram lens **26** (or **32**, **33**, **42**) be tilted from an optical axis passing through the center of the objective lens **27** by about one degree to prevent stray light reflected in a surface of the hologram lens **26** from being incident on the photo detector **57** or **63**. Also, it is applicable that the hologram lens **26** (or **32**, **33**, **42**) be coated with an anti-reflection coating to prevent the occurrence of stray light.

Also, as an optical head apparatus **67** is shown in FIG. **31**, it is applicable that a polarized beam splitter **68** be arranged in place of the beam splitter **54** to perfectly transmit the incident light L3 and a ¼–λ plate **69** be additionally placed between the hologram lens **26** (or **32**, **33**, **42**) and the polarized beam splitter **68**. In this case, because the incident light L3 transmits through the ¼–λ plate **69** in an outgoing optical path and because the transmitted light L4R (or the diffracted light L5) again transmits through the ¼–λ plate **69** in an incoming optical path, the transmitted light L4R (or the diffracted light L5R) is perfectly reflected by the polarized beam splitter **68**. Accordingly, a utilization efficiency of the incident light L3 can be enhanced. Also, a signal-noise ratio of each of the servo signals and the information signal can be enhanced.

Also, as an optical head apparatus **70** is shown in FIG. **32**, it is applicable that the polarized beam splitter **68** be arranged in place of the beam splitter **54** to perfectly transmit the incident light L3 and the ¼–λ plate **69** be additionally placed between the hologram lens **26** (or **32**, **33**, **42**) and the objective lens **27**. In this case, the transmitted light L4R (or the diffracted light L5R) is perfectly reflected by the polarized beam splitter **68** in the same manner as the optical head apparatus shown in FIG. **31**. In addition, because stray light reflected from the hologram lens **26** (or **32**, **33**, **42**) transmits through the polarized beam splitter **68**, the stray light is not incident on the photo detector **63**. Accordingly, a signal-noise ratio of each of the servo signals and the information signal can be moreover enhanced.

Also, as an optical head apparatus **71** is shown in FIG. **33**, it is applicable that a wedge-like prism **72** for reshaping the incident light L3 radiated from the light source **52** be additionally placed between the collimator lens **53** and the polarized beam splitter **68**. In this case, an elliptic wavefront of the incident light L3 is reshaped to a circular wavefront by the wedge-like prism **72**. Accordingly, a utilization efficiency of the incident light L3 can be enhanced.

In the sixth and seventh embodiments, when the transmitted light L4 (that is, zero-order diffracted light L4) converged on the first information medium **23** is reflected toward the compound objective lens to reproduce a piece of information recorded on the first information medium **23**, a part of the transmitted light L4R is diffracted in the hologram lens **26** (or **32**, **33**, **42**) on the incoming optical path, so that the part of the transmitted light L4R is changed to a beam of first-order diffracted light L13. Therefore, the first-order diffracted light L13 diverges from the hologram lens **26**, and a converging spot S11 of the diffracted light L13 is formed on the photo detector **57** or **63** in a relatively large size, as shown in FIG. **34**. The size of the converging spot S11 is larger than those of the sextant photo-detector **59** and the quadrant photo-detector **64**. Therefore, there is a drawback that a signal-noise ratio in the information signal deteriorates.

To solve the drawback, it is preferred that the photo detector **57** (or **63**) further comprise an information photo-

detector **73** surrounding the sextant photo-detector **59** (or the quadrant photo-detector **64**). The size of the information photo-detector **73** is equal to or larger than a 1 mm square. Therefore, in cases where the information signal is determined by the sum of the intensity of the transmitted light L**4** detected in the sextant photo-detector **59** (or the quadrant photo-detector **64**) and the intensity of the diffracted light L**13** detected in the information photo-detector **73**, the signal-noise ratio in the information signal can be enhanced, and frequency characteristics of the information signal can be enhanced.

(Eighth Embodiment)

Next, a method of focusing performed in the optical head apparatuses **51**, **61**, **65**, **67**, **70** and **71** is described according to an eighth embodiment of the present invention.

FIG. **35**A graphically shows a change of the focus error signal obtained by detecting the intensity of the transmitted light L**4** formed in the hologram lens **26**, **32** or **33**, the strength of the focus error signal depending on a distance between the objective lens **27** and the first information medium **23**. FIG. **35**B graphically shows a change of the focus error signal obtained by detecting the intensity of the diffracted light L**5** formed in the hologram lens **26**, **32** or **33**, the strength of the focus error signal depending on a distance between the objective lens **27** and the second information medium **25**.

The intensity of the transmitted light L**4** is high because the numerical aperture of the objective lens **27** for the transmitted light L**4** is large. Therefore, as shown in FIG. **35**A, a change of a focus error signal FE**1** obtained in cases where the objective lens **27** is almost focused on the first information medium **23** is considerably large as compared with a change of an unnecessary focus error signal FE**2** obtained in cases where the objective lens **27** is defocused on the first information medium **23**. In addition, in cases where the hologram lens **26**, **32** or **33** is utilized in each of the optical head apparatuses **51**, **61**, **65**, **67**, **70** and **71**, the unnecessary focus error signal FE**2** is generated when the distance between the objective lens **27** and the first information medium **23** is larger than the focal length of the objective lens **27** for the transmitted light L**4**.

In contrast, the intensity of the diffracted light L**5** is comparatively low because the numerical aperture of the objective lens **27** for the diffracted light L**5** is comparatively small. Therefore, as shown in FIG. **35**B, a change of a focus error signal FE**3** obtained in cases where the objective lens **27** is almost focused on the second information medium **25** is almost the same as that of an unnecessary focus error signal FE**4** obtained in cases where the objective lens **27** is defocused on the second information medium **25**. In addition, in cases where the hologram lens **26**, **32** or **33** is utilized in each of the optical head apparatuses **51**, **61**, **65**, **67**, **70** and **71**, the unnecessary focus error signal FE**4** is generated when the distance between the objective lens **27** and the second information medium **25** is smaller than the focal length of the objective lens **27** for the diffracted light L**5**.

Therefore, in cases where the focusing of the transmitted light L**4** on the first information medium **23** is performed, the objective lens **27** placed far from the first information medium **23** is gradually brought near to the first information medium **23**. Thereafter, when the strength of the focus error signal reaches a threshold value, a focus servo loop provided in the photo detector **57** or **63** is set to an operation condition, so that the objective lens **27** is set to be focused on the first information medium **23**. Also, in cases where the focusing of the diffracted light L**5** on the second information medium **25** is performed, the objective lens **27** placed far from the second information medium **25** is gradually brought near to the second information medium **25** in the same manner. Thereafter, when the strength of the focus error signal reaches a threshold value, a focus servo loop provided in the photo detector **57** or **63** is set to an operation condition, so that the objective lens **27** is set to be focused on the second information medium **25**.

Accordingly, the inverse influence of the unnecessary focus error signal FE**4** on the focusing of the diffracted light L**5** can be prevented. Also, because the objective lens **27** placed far from the information medium **23** or **25** is gradually brought near to the information medium **23** or **25** regardless of whether the information medium is T**1** or T**2** in thickness, a focusing operation in each of the optical head apparatuses **51**, **61**, **65**, **67**, **70** and **71** with the hologram lens **26**, **32** or **33** can be performed according to a common procedure by changing the threshold value or performing an auto gain control in which the focus error signal is normalized by detecting the total intensity of the transmitted light L**4**R or the diffracted light L**5**R. Therefore, a control circuit required to perform the focusing operation can be made at a low cost.

FIG. **36**A graphically shows a change of the focus error signal obtained by detecting the intensity of the diffracted light L**6** formed in the hologram lens **42**, the strength of the focus error signal depending on a distance between the objective lens **27** and the first information medium **23**. FIG. **36**B graphically shows a change of the focus error signal obtained by detecting the intensity of the transmitted light L**4** formed in the hologram lens **42**, the strength of the focus error signal depending on a distance between the objective lens **27** and the second information medium **25**.

As shown in FIG. **36**A, a change of a focus error signal FE**5** obtained in cases where the objective lens **27** is almost focused on the first information medium **23** is considerably large as compared with a change of an unnecessary focus error signal FE**6** obtained in cases where the objective lens **27** is defocused on the first information medium **23**. In addition, in cases where the hologram lens **42** is utilized in each of the optical head apparatuses **51**, **61**, **65**, **67**, **70** and **71**, the unnecessary focus error signal FE**6** is generated when the distance between the objective lens **27** and the first information medium **23** is smaller than the focal length of the objective lens **27** for the diffracted light L**6**.

In contrast, as shown in FIG. **36**B, a change of a focus error signal FE**7** obtained in cases where the objective lens **27** is almost focused on the second information medium **25** is almost the same as that of an unnecessary focus error signal FE**8** obtained in cases where the objective lens **27** is defocused on the second information medium **25**. In addition, in cases where the hologram lens **42** is utilized in each of the optical head apparatuses **51**, **61**, **65**, **67**, **70** and **71**, the unnecessary focus error signal FE**8** is generated when the distance between the objective lens **27** and the second information medium **25** is larger than the focal length of the objective lens **27** for the transmitted light L**4**.

Therefore, in cases where the focusing of the diffracted light L**6** on the first information medium **23** is performed, the objective lens **27** placed near to the first information medium **23** is gradually moved away from the first information medium **23**. Thereafter, when the strength of the focus error signal reaches a threshold value, a focus servo loop provided in the photo detector **57** or **63** is set to an operation condition, so that the objective lens **27** is set to be focused on the first information medium **23**. Also, in cases where the focusing of the transmitted light L**4** on the second

information medium **25** is performed, the objective lens **27** placed near to the second information medium **25** is gradually moved away from the second information medium **25** in the same manner. Thereafter, when the strength of the focus error signal reaches a threshold value, a focus servo loop provided in the photo detector **57** or **63** is set to an operation condition, so that the objective lens **27** is set to be focused on the second information medium **25**.

Accordingly, the inverse influence of the unnecessary focus error signal FE**8** on the focusing of the transmitted light L**4** can be prevented. Also, because the objective lens **27** placed near to the information medium **23** or **25** is gradually moved away from the information medium **23** or **25** regardless of whether the information medium is T**1** or T**2** in thickness, a focusing operation in each of the optical head apparatuses **51**, **61**, **65**, **67**, **70** and **71** with the hologram lens **42** can be performed according to a common procedure by changing the threshold value or performing the auto gain control. Therefore, a control circuit required to perform the focusing operation can be made at a low cost.

(Ninth Embodiment)

An optical head apparatus with the compound objective lens **29**, **34**, **45**, **46** or **47** in which the incident light L**3** is efficiently utilized to obtain an information signal and servo signals is described with reference to FIGS. **29**, **37** according to a ninth embodiment of the present invention.

FIG. **37** is a constitutional view of an optical head apparatus according to a ninth embodiment.

As shown in FIG. **37**, an optical head apparatus **81** for recording or reproducing pieces of information on or from the information medium **23** or **25**, comprises the light source **52**, the collimator lens **53**, the beam splitter **54**, the compound objective lens the compound objective lens **29** (**34**, **45**, **46** or **47**) composed of the hologram lens **26** (or **32** or **33**) and the objective lens **27**, the actuating unit **58**, the converging lens **55**, a beam splitter **82** for transmitting a beam of diffracted light L**5**R or reflecting a beam of transmitted light L**4**R, the photo detector **63** for detecting the intensity of the diffracted light L**5**R transmitting through the beam splitter **82** to obtain servo signals and an information signal recorded on the second information medium **25**, the wavefront changing device **56** such as a hologram for changing a wavefront of the transmitted light L**4**R reflected by the beam splitter **82**, and the photo detector **57** for detecting the intensity of the transmitted light L**4**R to obtain servo signals and an information signal recorded on the first information medium **23**. The beam splitter **82** is made of a plane parallel plate of which a normal line is tilted from an optical path, so that an astigmatic aberration is generated in the diffracted light L**5**R passing through the beam splitter **82**. Also, a coating is applied on a surface of the plane parallel plate.

In the above configuration, the transmitted light L**4** (or the diffracted light L**5**) are converged by the converging lens **27** in the same manner as in the sixth embodiment. Thereafter, in cases where a piece of information is recorded or reproduced on or from the first information medium **23**, the transmitted light L**4** is converged on the first information medium **23** to form the first converging spot S**1**. Thereafter, a beam of transmitted light L**4**R reflected by the first information medium **23** passes through the same optical path in the reverse direction. That is, a great part of the transmitted light L**4**R again transmits through the compound objective lens without any diffraction and is reflected by the beam splitter **54**. Thereafter, the transmitted light L**4**R is converged by the converging lens **55**, and a part of the transmitted light L**4**R is reflected by the beam splitter **82**. Thereafter, the wavefront of a great part of the transmitted light L**4**R is changed by the wavefront changing unit **56**, and the great part of the transmitted light L**4**R is converged on the photo detector **57** to form the converging spots S**8**, S**9**. Therefore, an information signal and servo signals such as a focus error signal and a tracking error signal are obtained in the same manner as in the sixth embodiment. Also, a remaining part of the transmitted light L**4**R not changed its wavefront is converged on the photo detector **57** to form the converging spot S**7**.

In contrast, in cases where a piece of information is recorded or reproduced on or from the second information medium **25**, the diffracted light L**5** is converged on the second information medium **25** to form the second converging spot S**2**. Thereafter, a beam of diffracted light L**5**R reflected by the second information medium **25** passes through the same optical path in the reverse direction, and a great part of the diffracted light L**5**R transmits through the hologram lens **26** without any diffraction. Therefore, the diffracted light L**5**R passes through the incoming optical path differing from the outgoing optical path. Thereafter, the diffracted light L**5**R is reflected by the beam splitter **54** and is converged by the converging lens **55**. Thereafter, a part of the diffracted light L**5**R transmits through the beam splitter **82**. In this case, an astigmatic aberration is generated in the diffracted light L**5**R. Thereafter, the diffracted light L**5**R is converged on the photo detector **63** to form a converging spot S**12** of which the shape is the same as the converging spot S**10** shown in FIGS. **29**A to **29**C, and the intensity of the diffracted light L**5**R is detected in the photo detector **63**. Therefore, an information signal and servo signals such as a focus error signal and a tracking error signal are obtained in the same manner as in the seventh embodiment.

In this case, though a remaining part of the transmitted light L**4**R transmits through the beam splitter **82**, the remaining part of the transmitted light L**4**R is not converged at the converging spot S**12** because the transmitted light L**4**R passes through the same optical path. Also, though a remaining part of the diffracted light L**5**R is reflected the beam splitter **82**, the remaining part of the diffracted light L**5**R is not converged at the converging spot S**7**, S**8** or S**9** because the diffracted light L**5**R passes through the incoming optical path differing from the outgoing optical path.

In the ninth embodiment, because the diffracted light L**5**R transmits through the hologram lens **26** without any diffraction, the converging spot S**12** formed on the photo detector **63** does not relate to a radiating point of the light source **52** in a mirror image, while the converging spot S**7** formed on the photo detector **57** relates to the radiating point of the light source **52** in the mirror image. In other words, a focal point of the diffracted light L**5**R converged by the converging lens **55** differs from that of the transmitted light L**4**R converged by the converging lens **55**. Therefore, the photo detector **57** for detecting the intensity of the transmitted light L**4**R and the photo detector **63** for detecting the intensity of the diffracted light L**5**R are required.

Accordingly, because the compound objective lens having two focal points is utilized in the optical head apparatus **81**, pieces of information can be reliably recorded or reproduced on or from an information medium regardless of whether the information medium is thick or thin.

An example of the utilization of the optical head apparatus **81** for various types of optical disks is described.

In cases where the optical head apparatus **81** is utilized for an optical disk device in which pieces of information recorded in a thin type of high density optical disk **23** are recorded or reproduced and pieces of information recorded in a thick type of optical disk **25** are exclusively reproduced,

the diffraction efficiency of the hologram lens **26**, **32** or **33** in the compound objective lens **29**, **34**, **45**, **46** or **47** for changing a beam of light to a beam of first-order diffracted light is set to a value equal to or lower than 30%. Therefore, in cases where a piece of information recorded on the thick type of optical disk **25** is reproduced in the photo detector **63**, a signal-noise ratio of each of the servo signals and the information signal obtained in the photo detector **63** can be enhanced because the diffracted light L5R transmitting through the hologram lens **26**, **32** or **33** at a high transmission efficiency is utilized to obtain the servo signals and the information signal. In other words, a utilization efficiency of the incident light L3 can be enhanced when a piece of information recorded on the thick type of optical disk **25** is reproduced, so that the output power of the incident light L3 can be minimized. Also, even though a high intensity of the transmitted light L4 is required to record a piece of information on the high density optical disk **23**, the recording of the information can be reliably performed without increasing the intensity of the incident light L3 because a transmission efficiency of the hologram lens **26**, **32** or **33** for the incident light L3 is high. Also, in cases where a piece of information recorded on the high density optical disk **23** is reproduced in the photo detector **57**, a signal-noise ratio of each signal obtained in the photo detector **57** can be enhanced because the transmission efficiency of the hologram lens **26**, **32** or **33** for the light L3, L4R is high.

(Tenth Embodiment)

An optical head apparatus with the compound objective lens **29**, **34**, **45**, **46** or **47** in which the incident light L3 is efficiently utilized to obtain an information signal and servo signals is described with reference to FIGS. **38**, **39** according to a tenth embodiment of the present invention. X1 and Y1 coordinates shown in FIGS. **38**, **39** are utilized in common.

FIG. **38** is a constitutional view of an optical head apparatus according to a tenth embodiment. FIG. **39** is a plan view of a beam splitter having a reflection type of hologram utilized in the optical head apparatus shown in FIG. **38**.

As shown in FIG. **38**, an optical head apparatus **91** for recording or reproducing pieces of information on or from the information medium **23** or **25**, comprises the light source **52**, the collimator lens **53**, the beam splitter **54**, the compound objective lens **29** (or **34**, **45**, **46** or **47**) composed of the hologram lens **26** (or **32** or **33**) and the objective lens **27**, the actuating unit **58**, the converging lens **55**, a beam splitter **92** having a reflection type of hologram **93** for transmitting a large part of the transmitted light L4R or reflecting all of the diffracted light L5R incident on the hologram **93**, the photo detector **63** for detecting the intensity of the transmitted light L4R transmitting through the beam splitter **92** to obtain servo signals and an information signal recorded in the first information medium **23**, and the photo detector **57** for detecting the intensity of the diffracted light L5R to obtain servo signals and an information signal recorded in the second information medium **25**.

The beam splitter **92** is made of a plane parallel plate inclined to an optical path, so that an astigmatic aberration is generated in the transmitted light L4R passing through the beam splitter **92**. Also, as shown in FIG. **39**, the reflection type of hologram **93** is arranged at a center portion of the beam splitter **92**, and a light transmitting region **92***a* is arranged at a peripheral portion of the beam splitter **92** to surround the hologram **93**. Light incident on the light transmitting region **92***a* transmits without any diffraction. The hologram **92** is partitioned into a diffracted light generating region **93***a* in which a grating pattern P7 is drawn and a pair of diffracted light generating regions **93***b*, **93***c* in which a pair of grating patterns P8, P9 are drawn. The diffracted light L5R incident on the diffracted light generating region **93***a* is diffracted to obtain a focus error signal in the photo detector **57**. The diffracted light L5R incident on each of the diffracted light generating regions **93***b*, **93***c* is diffracted to obtain a tracking error signal in the photo detector **57**.

In the above configuration, the transmitted light L4 and the diffracted light L5 are converged by the converging lens **27** in the same manner as in the sixth embodiment. Thereafter, in cases where a piece of information is recorded or reproduced on or from the first information medium **23**, the transmitted light L4 is converged on the first information medium **23** to form the first converging spot S1. Thereafter, a beam of transmitted light L4R reflected by the first information medium **23** passes through the same optical path in the reverse direction. That is, a large part of the transmitted light L4R again transmits through the compound objective lens **29** without any diffraction and is reflected by the beam splitter **54**. Thereafter, the transmitted light L4R is converged by the converging lens **55**, and a large part of the transmitted light L4R transmits through the beam splitter **92**. In this case, an astigmatic aberration is generated in the transmitted light L4R. Thereafter, the transmitted light L4R is converged on the photo detector **63** to form a converging spot S13 of which the shape is the same as the converging spot S10 shown in FIGS. **29**A to **29**C, and the intensity of the transmitted light L4R is detected in the photo detector **63**. Therefore, an information signal and servo signals such as a focus error signal and a tracking error signal are obtained in the same manner as in the seventh embodiment.

In contrast, in cases where a piece of information is recorded or reproduced on or from the second information medium **25**, the diffracted light L5 is converged on the second information medium **25** to form the second converging spot S2. Thereafter, a beam of diffracted light L5R reflected by the second information medium **25** passes through the same optical path in the reverse direction, and a large part of the diffracted light L5R transmits through the hologram lens **26** without any diffraction. Therefore, the diffracted light L5R transmits on the incoming optical path differing from the outgoing optical path in the same manner as in the ninth embodiment. Thereafter, the diffracted light L5R is reflected by the beam splitter **54** and is converged by the converging lens **55** on the beam splitter **92** to form a converging spot on the reflection type of hologram **93** of the beam splitter **92**. Therefore, all of the diffracted light L5R is diffracted and reflected by the hologram **93** to be converged on the photo detector **57**. That is, the diffracted light L5R diffracted and reflected in the diffracted light generating region **93***a* of the hologram **93** is splitted into two beams and is converged on the detecting sections SE1 to SE6 of the sextant photo-detector **59** in the photo detector **57** in the same manner as in the sixth embodiment. Also, the diffracted light L5R diffracted and reflected in the diffracted light generating region **93***b* of the hologram **93** is splitted into two beams, and the intensity of the diffracted light L5R is detected in the tracking photo-detectors **60***a* and **60***d*. Also, the diffracted light L5R diffracted and reflected in the diffracted light generating region **93***c* of the hologram **93** is splitted into two beams, and the intensity of the diffracted light L5R is detected in the tracking photo-detectors **60***b* and **60***c*. Therefore, an information signal and servo signals such as a focus error signal and a tracking error signal are obtained in the same manner as in the sixth embodiment.

In the tenth embodiment, because the transmitted light L4R transmits through the hologram lens **26** without any

diffraction, the converging spot S13 formed on the photo detector 63 does not relate to a radiating point of the light source 52 in a mirror image. Therefore, the photo detector 57 for detecting the intensity of the diffracted light L5R and the photo detector 63 for detecting the intensity of the transmitted light L4R are required.

Accordingly, because the compound objective lens having two focal points is utilized in the optical head apparatus 91, pieces of information can be reliably recorded or reproduced on or from an information medium regardless of whether the information medium is thick or thin.

Also, because all of the diffracted light L5R is completely diffracted and reflected by the hologram 93 of the beam splitter 92, the diffracted light L5R can be utilized at high efficiency. Therefore, a signal-noise ratio of the signals obtained in the photo detector 57 can be enhanced.

An example of the utilization of the optical head apparatus 91 for various types of optical disks is described.

In cases where the optical head apparatus 91 is utilized for an optical disk device in which pieces of information recorded in a thin type of high density optical disk 23 are recorded or reproduced and pieces of information recorded in a thick type of optical disk 25 are exclusively reproduced, the diffraction efficiency of the hologram lens 26, 32 or 33 in the compound objective lens 29, 34, 45, 46 or 47 for changing a beam of light to a beam of first-order diffracted light is set to a value equal to or lower than 30%. Therefore, in cases where a piece of information recorded on the thick type of optical disk 25 is reproduced in the photo detector 57, a signal-noise ratio of each of the servo signals and the information signal obtained in the photo detector 57 can be enhanced because the diffracted light L5R transmitting through the hologram lens 26, 32 or 33 at a high transmission efficiency is utilized to obtain the servo signals and the information signal. In other words, a utilization efficiency of the incident light L3 can be enhanced when a piece of information recorded on the thick type of optical disk 25 is reproduced, so that the output power of the incident light L3 can be minimized. Also, even though a high intensity of the transmitted light L4 is required to record a piece of information on the high density optical disk 23, the recording of the information can be reliably performed without increasing the intensity of the incident light L3 because a transmission efficiency of the hologram lens 26, 32 or 33 for the incident light L3 is high. Also, in cases where a piece of information recorded on the high density optical disk 23 is reproduced in the photo detector 63, a signal-noise ratio of each signal obtained in the photo detector 63 can be enhanced because the transmission efficiency of the hologram lens 26, 32 or 33 for the light L3, L4R is high.

(Eleventh Embodiment)

An optical head apparatus with the compound objective lens 29, 34, 45, 46 or 47 in which the incident light L3 is efficiently utilized to obtain an information signal and servo signals is described with reference to FIGS. 40 to 42 according to an eleventh embodiment of the present invention. X1 and Y1 co-ordinates shown in FIGS. 40, 41 are utilized in common, and X, Y and Z co-ordinates shown in FIGS. 40, 42 are utilized in common.

FIGS. 40A, 40B are respectively a constitutional view of an optical head apparatus according an eleventh embodiment. FIG. 41 is a plan view of a beam splitter having a reflection type of hologram utilized in the optical head apparatus shown in FIG. 38.

As shown in FIGS. 40A, 40B, an optical head apparatus 101 for recording or reproducing pieces of information on or from the information medium 23 or 25, comprises the light source 52, the collimator lens 53, the beam splitter 54, the compound objective lens 29 (or 34, 45, 46 or 47) composed of the hologram lens 26 (or 32 or 33) and the objective lens 27, the actuating unit 58, the converging lens 55, a beam splitter 102 having a transmission type of hologram 103 for transmitting the transmitted light L4R converged on the first information medium 23 and the diffracted light L5R converged on the second information medium 25 and diffracting the transmitted light L4R which is converged on the second information medium 25 in defocus, a photo detector 104 for detecting the intensity of the transmitted light L4R converged on the first information medium 23 to obtain servo signals and an information signal recorded in the first information medium 23, detecting in defocus the intensity of the diffracted light L5R to obtain an information signal recorded in the second information medium 25, and detecting the intensity of the transmitted light L4R converged on the second information medium 25 in defocus to obtain a focus error signal.

The beam splitter 102 is made of a plane parallel plate inclined to an optical path, so that an astigmatic aberration is generated in the light L4R, L5R passing through the beam splitter 102. Also, as shown in FIG. 41, the transmission type of hologram 103 is arranged at a center portion of the beam splitter 102, and a light transmitting region 102*a* is arranged at a peripheral portion of the beam splitter 102 to surround the hologram 103. The transmitted light L4R incident on the light transmitting region 102*a* transmits without any diffraction. The hologram 102 is partitioned into diffracted light generating regions 103*a*, 103*b* alternately arranged to detect a focus error signal according to the spot size detection method described in the sixth embodiment. That is, a grating pattern P10 is drawn in each of the diffracted light generating regions 103*a*, and a converging spot is formed by the transmitted light L4R diffracted in the regions 103*a*. Also, a grating pattern P11 is drawn in each of the diffracted light generating regions 103*b*, and another converging spot is formed by the transmitted light L4R diffracted in the regions 103*b*.

The photo detector 104 comprises the sextant photodetector 59 in which the detecting sections SE1, SE2, SE3, SE4, SE5 and SE6 are provided in the same manner as the photo detector 57.

In the above configuration, the transmitted light L4 and the diffracted light L5 are converged by the converging lens 27 in the same manner as in the sixth embodiment. Thereafter, in cases where a piece of information is recorded or reproduced on or from the first information medium 23, as shown in FIG. 40A, the transmitted light L4 is converged on the first information medium 23 to form the first converging spot S1. Thereafter, a beam of transmitted light L4R reflected by the first information medium 23 passes through the same optical path in the reverse direction. That is, the transmitted light L4R again transmits through the compound objective lens without any diffraction and is reflected by the beam splitter 54. Thereafter, the transmitted light L4R is converged by the converging lens 55, and a major part of the transmitted light L4R transmits through the beam splitter 103. In this case, an astigmatic aberration is generated in the transmitted light L4R. Thereafter, the transmitted light L4R is converged on the photo detector 104 to form a converging spot S14 of which the shape is the same as the converging spot S10 shown in FIGS. 29A to 29C, and the intensity of the transmitted light L4R is detected in the photo detector 104. Therefore, an information signal and servo signals such as a focus error signal and a tracking error signal are obtained in the same manner as in the seventh embodiment. In this case,

because the position of the photo detector **104** detecting the transmitted light L4R relates to a radiation point of the light source **52** in a mirror image, the transmitted light L4R is converged on the photo detector **104** just in focus.

In contrast, in cases where a piece of information is recorded or reproduced on or from the second information medium **25**, as shown in FIG. **40**B, the diffracted light L5 is converged on the second information medium **25** to form the second converging spot S2. Thereafter, a beam of diffracted light L5R reflected by the second information medium **25** passes through the same optical path in the reverse direction and transmits through the hologram lens **26** without any diffraction. Therefore, the diffracted light L5R transmits on the incoming optical path differing from the outgoing optical path in the same manner as in the ninth embodiment. Thereafter, the diffracted light L5R is reflected by the beam splitter **54** and is converged by the converging lens **55**. Thereafter, a major part of the diffracted light L5R transmits through the beam splitter **102**, and the diffracted light L5R is converged on the photo detector **57**. In this case, an astigmatic aberration is generated in the diffracted light L5R. Also, because the diffracted light L5R is not diffracted by the hologram lens **26** on the incoming optical path, the position of the photo detector **104** detecting the diffracted light L5R does not relate to the radiation point of the light source **52** in the mirror image. Therefore, the diffracted light L5R is converged on the photo detector **104** in defocus. However, because the entire intensity of the diffracted light L5R converged in defocus is detected in the photo detector **104**, an information signal is obtained in the same manner as in the seventh embodiment.

Also, the transmitted light L4 is converged on the second information medium **25** in defocus as shown in FIG. **40**B. That is, the transmitted light L4 incident on the rear surface of the second information medium **25** is converged at the front surface of the second information medium **25**. Thereafter, a beam of transmitted light L4R reflected at the front surface of the second information medium **25** again transmits through the compound objective lens without any diffraction and is reflected by the beam splitter **54**. Thereafter, the transmitted light L4R is converged by the converging lens **55** on the beam splitter **102** to form a converging spot on the of hologram **103** of the beam splitter **102**. Therefore, all of the transmitted light L4R is diffracted by the hologram **103** and is converged on the photo detector **104**. That is, the transmitted light L4R diffracted in the diffracted light generating regions **103***a* of the hologram **103** is changed to a first spherical wave SW1 of which a focal point is placed at the front of the photo detector **104**, and the transmitted light L4R diffracted in the diffracted light generating regions **103***b* of the hologram **103** is changed to a second spherical wave SW2 of which a focal point is placed at the rear of the photo detector **104**. Thereafter, as shown in FIGS. **42**A to **42**C, the first spherical wave SW1 is converged on the detecting sections SE1 to SE3 of the sextant photo-detector **59** in the photo detector **104** to form a converging spot S15A, and the second spherical wave SW2 is converged on the detecting sections SE4 to SE6 of the sextant photo-detector **59** to form a converging spot S15B. Because the regions **103***a*, **103***b* are divided into many pieces, the converging spots S15A, S15B are respectively divided into many pieces.

In cases where the diffracted light L5 is converged on the information medium **25** in defocus, the converging spots S15A, S15B of the transmitted light L4R shown in FIGS. **42**A, **42**C are formed on the sextant photo-detector **59**. In contrast, in cases where the diffracted light L5 is converged on the information medium **25** in focus, the converging spots S15A, S15B of the transmitted light L4R shown in FIG. **42**B are formed on the sextant photo-detector **59**. The intensity of the transmitted light L4R is detected in each of the detecting sections SE1 to SE6 of the sextant photo-detector **59** and is changed to electric current signals SC15 to SC20. Thereafter, a focus error signal $S_{f\theta}$ is obtained according to the spot size detection method by calculating an equation (11).

$$S_{f\theta}=(SC15+SC17-SC16)-(SC18+SC20-SC19) \quad (11)$$

Thereafter, the position of the compound objective lens is moved in a direction along an optical axis at high speed so as to minimize the absolute value of the focus error signal $S_{f\theta}$. Therefore, the focus error signal is obtained in the same manner as in the sixth embodiment.

Accordingly, because the compound objective lens having two focal points is utilized in the optical head apparatus **101**, pieces of information can be reliably recorded or reproduced on or from an information medium regardless of whether the information medium is thick or thin.

Also, because all of the transmitted light L4R reflected by the second information medium **25** is completely diffracted by the hologram **103** of the beam splitter **102** to detect the focus error signal, the transmitted light L4R can be utilized at high efficiency. Therefore, a signal-noise ratio of the focus error signal obtained in the photo detector **104** can be enhanced.

Also, the information signal and the servo signals can be obtained in the photo detector **104** regardless of whether the information medium **23** or **25** is thin or thick. Therefore, the number of parts required to manufacture the optical head apparatus **101** can be reduced, and a small sized optical head apparatus can be manufactured at a low cost and in light weight even though pieces of information are recorded or reproduced on or from an information medium by utilizing the optical head apparatus **101** regardless of whether the information medium is thick or thin.

An example of the utilization of the optical head apparatus **101** for various types of optical disks is described.

In cases where the optical head apparatus **101** is utilized for an optical disk device in which pieces of information recorded in a thin type of high density optical disk **23** are recorded or reproduced and pieces of information recorded in a thick type of optical disk **25** are exclusively reproduced, the diffraction efficiency of the hologram lens **26**, **32** or **33** in the compound objective lens **29**, **34**, **45**, **46** or **47** is set to a value equal to or lower than 30%. Therefore, in cases where a piece of information recorded on the thick type of optical disk **25** is reproduced in the photo detector **104**, a signal-noise ratio of each of the servo signals and the information signal obtained in the photo detector **104** can be enhanced because the diffracted light L5R transmitting through the hologram lens **26**, **32** or **33** at a high transmission efficiency is utilized to obtain the information signal. In other words, a utilization efficiency of the incident light L3 can be enhanced when a piece of information recorded on the thick type of optical disk **25** is reproduced, so that the output power of the incident light L3 can be minimized. Also, even though a high intensity of the transmitted light L4 is required to record a piece of information on the high density optical disk **23**, the recording of the information can be reliably performed without increasing the intensity of the incident light L3 because a transmission efficiency of the hologram lens **26**, **32** or **33** for the incident light L3 is high. Also, in cases where a piece of information recorded on the high density optical disk **23** is reproduced in the photo

detector **63**, a signal-noise ratio of each signal obtained in the photo detector **63** can be enhanced because the transmission efficiency of the hologram lens **26**, **32** or **33** for the light L**3**, L**4**R is high.

(Twelfth Embodiment)

An optical head apparatus with the compound objective lens **29**M, **43**, **45**, **46** or **47** in which the incident light L**3** is efficiently utilized to obtain an information signal and servo signals is described with reference to FIG. **43** according to a twelfth embodiment of the present invention.

FIG. **43** is a constitutional view of an optical head apparatus according to a twelfth embodiment.

As shown in FIG. **43**, an optical head apparatus **111** for recording or reproducing pieces of information on or from the information medium **23** or **25**, comprises the light source **52**, the collimator lens **53**, the beam splitter **54**, the compound objective lens **29**M (or **43**, **45**, **46** or **47**) composed of the hologram lens **42** (or **26**M or **32**) and the objective lens **27**, the actuating unit **58**, the converging lens **55**, the beam splitter **82**, the photo detector **63**, the wavefront changing device **56**, and the photo detector **57**.

In the above configuration, a beam of incident light L**3** radiated from the light source **52** is collimated in the collimator lens **53** and transmits through the beam splitter **54**. Thereafter, a part of the incident light L**3** transmits through the compound objective lens **29** without any diffraction, and a remaining part of the incident light L**3** is diffracted.

Thereafter, in cases where a piece of information is recorded or reproduced on or from the first information medium **23**, the diffracted light L**6** is converged on the first information medium **23** to form the converging spot S**5**. That is, the diffracted light L**6** is incident on the rear surface of the first information medium **23**, and the converging spot S**5** is formed on the front surface of the first information medium **23**. Thereafter, a beam of diffracted light L**6**R reflected at the front surface of the first information medium **23** passes through the same optical path in the reverse direction, and a great part of the diffracted light L**6**R is again diffracted by the hologram lens **42**. Therefore, the diffracted light L**6**R transmits on the incoming optical path agreeing with the outgoing optical path. Thereafter, the diffracted light L**6**R is reflected by the beam splitter **54** and is converged by the converging lens **55**. Thereafter, a part of the diffracted light L**6**R transmits through the beam splitter **82**. In this case, an astigmatic aberration is generated in the diffracted light L**6**R. Thereafter, the diffracted light L**6**R is converged on the photo detector **63** to form the converging spot S**10** of which the shape is shown in FIGS. **29**A to **29**C, and the intensity of the diffracted light L**6**R is detected in the photo detector **63**. Therefore, an information signal and servo signals such as a focus error signal and a tracking error signal are obtained in the same manner as in the seventh embodiment.

In contrast, in cases where a piece of information is recorded or reproduced on or from the second information medium **25**, the transmitted light L**4** is converged on the second information medium **25** to form the converging spot S**6**. That is, the transmitted light L**4** is incident on the rear surface of the second information medium **25**, and the converging spot S**6** is formed on the front surface of the second information medium **25**. Thereafter, a beam of transmitted light L**4**R reflected at the front surface of the second information medium **25** passes through the same optical path in the reverse direction. That is, the transmitted light L**4**R is collimated by the objective lens **27** on the incoming optical path. Thereafter, a great part of the transmitted light L**4**R is diffracted by the hologram lens **42**. Therefore, the transmitted light L**4**R transmits on the incoming optical path differing from the outgoing optical path. Thereafter, the transmitted light L**4**R is reflected by the beam splitter **54** and is converged by the converging lens **55**. Thereafter, a part of the transmitted light L**4**R is reflected by the beam splitter **82**. Thereafter, the wavefront of a great part of the transmitted light L**4**R is changed by the wavefront changing unit **56**, and the great part of the transmitted light L**4**R is converged on the photo detector **57** to form converging spots S**16**, S**17**. Therefore, an information signal and servo signals such as a focus error signal and a tracking error signal are obtained in the same manner as in the sixth embodiment. Also, a remaining part of the transmitted light L**4**R not changed its wavefront by the wavefront changing unit **56** is converged on the photo detector **57** to form the converging spot S**18**.

In the twelfth embodiment, because the transmitted light L**4**R is diffracted by the hologram lens **42** on the incoming optical path, the converging spot S**18** formed on the photo detector **57** does not relate to a radiation point of the light source **52** in a mirror image, while the converging spot S**10** formed on the photo detector **63** relates to the radiation point of the light source **52** in the mirror image. In other words, a focal point of the transmitted light L**4**R converged by the converging lens **55** differs from that of the diffracted light L**6**R converged by the converging lens **55**. Therefore, the photo detector **57** for detecting the intensity of the transmitted light L**4**R and the photo detector **63** for detecting the intensity of the diffracted light L**6**R are required.

Accordingly, even though pieces of information are recorded or reproduced on or from an information medium, the information can be reliably recorded or reproduced on or from the information medium regardless of whether the information medium is thick or thin.

Also, because the diffracted light L**6** formed in the hologram lens **42** converges before the diffracted light L**6** is incident on the objective lens **27**, the distance in an optical axis direction between the converging spots S**5**, S**6** can be lengthened to about 1 mm. Therefore, even though the transmitted light L**4** (or the diffracted light L**6**) is converged on the converging spot S**6** (or S**5**) in focus to record or read a piece of information, the light L**6** (or L**4**) is not converged on the converging spot S**6** (or S**5**) in focus to reduce the intensity of the light L**6** (or L**4**) at the converging spot S**6** (or S**5**). Accordingly, no adverse influence is exerted on the recording or reproduction of the information

Also, because the hologram lens **42** functions as a convex lens for the first-order diffracted light L**6**, the occurrence of a chromatic aberration can be prevented in the optical head apparatus **111**.

An example of the utilization of the optical head apparatus **111** for various types of optical disks is described.

In cases where the optical head apparatus **111** is utilized for an optical disk device in which pieces of information recorded in a thin type of high density optical disk **23** are recorded or reproduced and pieces of information recorded in a thick type of optical disk **25** are exclusively reproduced, the diffraction efficiency of the hologram lens **26**M or **42** in the compound objective lens **29**M, **43**, **45**, **46** or **47** for changing a beam of light to a beam of first-order diffracted light is set to a value equal to or higher than 55%. Therefore. in cases where a piece of information recorded on the thick type of optical disk **25** is reproduced in the photo detector **57**, a signal-noise ratio of each of the servo signals and the information signal obtained in the photo detector **57** can be enhanced because the transmitted light L**4**R diffracted by the

hologram lens **26**M or **42** at a high diffraction efficiency is utilized to obtain the servo signals and the information signal. In other words, a utilization efficiency of the incident light **L3** can be enhanced when a piece of information recorded on the thick type of optical disk **25** is reproduced, so that the output power of the incident light **L3** can be minimized. Also, even though a high intensity of the diffracted light **L6** is required to record a piece of information on the high density optical disk **23**, the recording of the information can be reliably performed without increasing the intensity of the incident light **L3** because the diffraction efficiency of the hologram lens **26**M or **42** for the incident light **L3** and the diffracted light **L6**R is high. Also, in cases where a piece of information recorded on the high density optical disk **23** is reproduced in the photo detector **63**, a signal-noise ratio of each signal obtained in the photo detector **63** can be enhanced because the diffraction efficiency of the hologram lens **26**M or **42** for the light **L3**, **L6**R is high.

(Thirteenth Embodiment)

An optical head apparatus with the compound objective lens **29**M, **43**, **45**, **46** or **47** in which the incident light **L3** is efficiently utilized to obtain an information signal and servo signals is described with reference to FIG. **44** according to a thirteenth embodiment of the present invention.

FIG. **44** is a constitutional view of an optical head apparatus according to a thirteenth embodiment.

As shown in FIG. **44**, an optical head apparatus **121** for recording or reproducing pieces of information on or from the information medium **23** or **25**, comprises the light source **52**, the collimator lens **53**, the beam splitter **54**, the compound objective lens **43** (or **29**M, **45**, **46** or **47**) composed of the hologram lens **42** (or **26**M or **32**) and the objective lens **27**, the actuating unit **58**, the converging lens **55**, the beam splitter **92** having the reflection type of hologram **93**, the photo detector **63**, and the photo detector **57**.

In the above configuration, the transmitted light **L4** and the diffracted light **L6** are converged by the converging lens **27** in the same manner as in the twelfth embodiment. Thereafter, in cases where a piece of information is recorded or reproduced on or from the first information medium **23**, the diffracted light **L6** is converged on the first information medium **23** to form the converging spot **S5**. Thereafter, a beam of diffracted light **L5**R reflected by the first information medium **23** passes through the same optical path in the reverse direction, and a large part of the diffracted light **L6**R is diffracted by the hologram lens **42**. Therefore, the diffracted light **L6**R transmits on the incoming optical path agreeing with the outgoing optical path in the same manner as in the twelfth embodiment. Thereafter, the diffracted light **L6**R is reflected by the beam splitter **54** and is converged by the converging lens **55** on the beam splitter **92** to form a converging spot on the reflection type of hologram **93** of the beam splitter **92**. Therefore, all of the diffracted light **L6**R is diffracted and reflected by the hologram **93** to be converged on the photo detector **57** in the same manner as in the tenth embodiment. Therefore, an information signal and servo signals such as a focus error signal and a tracking error signal are obtained in the same manner as in the sixth embodiment.

In contrast, in cases where a piece of information is recorded or reproduced on or from the second information medium **25**, the transmitted light **L4** is converged on the second information medium **25** to form the converging spot **S6**. Thereafter, a beam of transmitted light **L4**R reflected by the second information medium **25** passes through the same optical path in the reverse direction. That is, a large part of the transmitted light **L4**R is collimated by the objective lens **27** on the incoming optical path. Thereafter, a great part of the transmitted light **L4**R is diffracted by the hologram Lens **42**. Therefore, the transmitted light **L4**R transmits on the incoming optical path differing from the outgoing optical path in the same manner as in the twelfth embodiment. Thereafter, the transmitted light **L4**R is reflected by the beam splitter **54** and is converged by the converging lens **55**. Thereafter, a large part of the transmitted light **L4**R transmits through the beam splitter **92**. In this case, an astigmatic aberration is generated in the transmitted light **L4**R. Thereafter, the transmitted light **L4**R is converged on the photo detector **63** to form a converging spot **S19** of which the shape is the same as the converging spot **S10** shown in FIGS. **29**A to **29**C, and the intensity of the transmitted light **L4**R is detected in the photo detector **63**. Therefore, an information signal and servo signals such as a focus error signal and a tracking error signal are obtained in the same manner as in the seventh embodiment.

In the thirteenth embodiment, because the transmitted light **L4**R is diffracted by the hologram lens **42**, the converging spot **S19** formed on the photo detector **63** does not relate to a radiation point of the light source **52** in a mirror image. Therefore, the photo detector **57** for detecting the intensity of the diffracted light **L6**R and the photo detector **63** for detecting the intensity of the transmitted light **L4**R are required.

Accordingly, because the compound objective lens having two focal points is utilized in the optical head apparatus **121**, pieces of information can be reliably recorded or reproduced on or from an information medium regardless of whether the information medium is thick or thin.

Also, because the diffracted light **L6** formed in the hologram lens **42** converges before the diffracted light **L6** is incident on the objective lens **27**, the distance in an optical axis direction between the converging spots **S5**, **S6** can be lengthened to about 1 mm. Therefore, even though the transmitted light **L4** (or the diffracted light **L6**) is converged on the converging spot **S6** (or **S5**) in focus to record or read a piece of information, the light **L6** (or **L4**) is not converged on the converging spot **S6** (or **S5**) in focus to reduce the intensity of the light **L6** (or **L4**) at the converging spot **S6** (or **S5**). Accordingly, no adverse influence is exerted on the recording or reproduction of the information

Also, because the hologram lens **42** functions as a convex lens for the first-order diffracted light **L6**, the occurrence of a chromatic aberration can be prevented in the optical head apparatus **121**.

An example of the utilization of the optical head apparatus **121** for various types of optical disks is described.

In cases where the optical head apparatus **121** is utilized for an optical disk device in which pieces of information recorded in a thin type of high density optical disk,**23** are recorded or reproduced and pieces of information recorded in a thick type of optical disk **25** are exclusively reproduced, the diffraction efficiency of the hologram lens **26**M or **42** in the compound objective lens **29**M, **43**, **45**, **46** or **47** for changing a beam of light to a beam of first-order diffracted light is set to a value equal to or higher than 70%. Therefore, in cases where a piece of information recorded on the thick type of optical disk **25** is reproduced in the photo detector **57**, a signal-noise ratio of each of the servo signals and the information signal obtained in the photo detector **57** can be enhanced because the transmitted light **L4**R diffracted by the hologram lens **26**M or **42** at a high diffraction efficiency is utilized to obtain the servo signals and the information signal. In other words, a utilization efficiency of the incident

light L3 can be enhanced when a piece of information recorded on the thick type of optical disk **25** is reproduced, so that the output power of the incident light L3 can be minimized. Also, even though a high intensity of the diffracted light L6 is required to record a piece of information on the high density optical disk **23**, the recording of the information can be reliably performed without increasing the intensity of the incident light L3 because the diffraction efficiency of the hologram lens **26**M or **42** for the incident light L3 and the diffracted light L6R is high. Also, in cases where a piece of information recorded on the high density optical disk **23** is reproduced in the photo detector **63**, a signal-noise ratio of each signal obtained in the photo detector **63** can be enhanced because the diffraction efficiency of the hologram lens **26**M or **42** for the light L3, L6R is high.

(Fourteenth Embodiment)

An optical head apparatus in which noises included in an information signal are reduced is described with reference to FIGS. **45**, **46** according to a fourteenth embodiment of the present invention.

FIG. **45** is a constitutional view of an optical head apparatus according to a fourteenth embodiment. FIG. **46** is a plan view of a hologram lens utilized in the optical head apparatus shown in FIG. **45**.

As shown in FIG. **45**, an optical head apparatus **131** for recording or reproducing pieces of information on or from the information medium **23** or **25**, comprises the light source **52**, a beam splitter **132** having a polarizing separation film **133** on its surface for reflecting the incident light L3 radiated from the light source **52** on an outgoing optical path and transmitting through the light L4R or L5R reflected on the information medium **23** or **25** on an incoming optical path, a collimator lens **134** for collimating the incident light L3 on the outgoing optical path and converging the light L4R or L5R on the incoming optical path, a hologram lens **135** for transmitting a part of the incident light L3 without any diffraction and diffracting a remaining part of the incident light L3, the ¼–λ plate **69**, the objective lens **27**, the actuating unit **58**, and a photo detector **136** for detecting the light transmitting through or diffracted by the hologram lens **135** on the incoming optical path.

As shown in FIG. **46**, the hologram lens **135** is formed by drawing the grating pattern P1 in a central region **135***a* of the transparent substrate **28** and a grating pattern P12 in a peripheral region **135***b* surrounding the central region **135***a*. The grating pattern P12 is drawn in a non-concentric shape. Because the grating pattern P1 are drawn in the hologram lens **135**, a compound objective lens **137** having two focal points is composed of the hologram lens **135** and the objective lens **27**. Light passing through the peripheral region **135***b* of the hologram lens **135** is detected by the photo detector **136** to cancel noises included in an information signal. An optical axis of the optical head apparatus **131** passes through a central point of the grating pattern P1 and a central axis of the objective lens **27**.

The photo detector **136** comprises the quadrant photodetector **64** having the detecting sections SE7 to SE10 and a noise cancelling photo detector **138** for detecting the intensity of light passing through the peripheral region **135***b* of the hologram lens **135**. Because the grating pattern P12 of the peripheral region **135***b* is drawn in the non-concentric shape, light diffracted in the peripheral region **135***b* is not converged on the detecting sections SE7 to SE10.

In the above configuration, the incident light L3 linearly polarized in a first direction is radiated from the light source **52** and is reflected by the beam splitter **132** because the polarizing separation film **133** functions as a mirror for the incident light L3 linearly polarized in the first direction. Therefore, the incident light L3 is directed in an upper direction and is collimated by the collimator lens **134**. Thereafter, a part of the incident light L3 incident on the central region **135***a* of the hologram lens **135** transmits through the central region **135***a* without any diffraction to form the transmitted light L4, and a remaining part of the incident light L3 incident on the central region **135***a* of the hologram lens **135** is diffracted in the central region **135***a* to form the diffracted light L5. Also, a part of the incident light L3 incident on the peripheral region **135***b* of the hologram lens **135** transmits through the peripheral region **135***b* without any diffraction to form a beam of noise cancelling light L14. Thereafter, the light L4, L5 and L14 pass through the ¼–λ plates so that the light L4, L5 and L14 linearly polarized in the first direction is changed to the light L4, L5 and L14 circularly polarized. Thereafter, the light L4, L5 and L14 are converged by the converging lens **27**.

Thereafter, in cases where a piece of information is recorded or reproduced on or from the first information medium **23** (or the second information medium **25**), the transmitted light L4 (or the diffracted light L5) is converged on the information medium **23** (or **25**) to form the converging spot S1 (or S2). Thereafter, a beam of transmitted light L4R (or a beam of diffracted light L5R) reflected by the information medium **23** (or **25**) passes through the same optical path in the reverse direction. That is, the transmitted light L4R (or the diffracted light L5R) is circularly polarized in reverse and again passes through the converging lens **27** and the ¼–λ plate **69**. Therefore, the light L4R (or L5R) is linearly polarized in a second direction perpendicular to the first direction. Thereafter, a part of the transmitted light L4R transmits through the central region **135***a* of the hologram lens **135** without any diffraction, or a part of the diffracted light L5R is again diffracted in the central region **135***a*. Thereafter, the transmitted light L4R (or the diffracted light L5R) is converged by the collimator lens **134** and passes through the beam splitter **132** without any reflection because the polarizing separation film **133** functions as a transparent plate for the light L4R (or L5R) linearly polarized in the second direction. In this case, an astigmatic aberration is generated in the transmitted light L4R (or the diffracted light L5R) in the same manner as in the seventh embodiment. Thereafter, the transmitted light L4R (or the diffracted light L5R) is incident on the detecting sections SE7 to SE10 of the photo detector **136** to form a converging spot S20 of which the shape is the same as the converging spot S10 shown in FIGS. **29**A to **29**C. The intensity of the transmitted light L4R (or the diffracted light L5R) is changed to electric current signals SC21 to SC24 in the detecting sections SE7 to SE10. Therefore, servo signals such as a focus error signal and a tracking error signal are obtained in the same manner as in the seventh embodiment, so that the position of the compound objective lens **137** is adjusted to converge the transmitted light L4 (or the diffracted light L5) on the information medium **23** (or **25**) in focus. Also, an information signal expressing a piece of information recorded on the information medium **23** (or **25**) is obtained according to an equation (12).

$$S_{in}=SC21+SC22+SC23+SC24 \quad (12)$$

Also, the noise cancelling light L14 is converged on the information medium **23** to form a converging spot surrounding the converging spot S1. Thereafter, a beam of noise cancelling light L14R reflected by the first information medium **23** passes through the same optical path in the

reverse direction. That is, the noise cancelling light L14R again passes through the converging lens **27** and the ¼-λ plate **69**, and a part of the noise cancelling light L14R is diffracted and converged in the peripheral region **135***b* of the hologram lens **135** and is incident on the noise cancelling photo detector **138**. In the photo detector **138**, an output signal SC**25** is generated according to the intensity of the noise cancelling light L14R. Thereafter, a noise cancelled information signal S_{nc} expressing a piece of information recorded on the first information medium **23** is obtained by adding all of the signals according to an equation (13):

$$S_{nc}=(SC21+SC22+SC23+SC24)+R\times SC25 \quad (13),$$

where the symbol R is a weighting factor.

In this case, because the term R×SC25 is added to obtain the information signal S_{nc}, inverse influence of noises included in the term (SC21+SC22+SC23+SC24) on the noise cancelled information signal S_{nc} can be reduced. The reason is described.

As is well known (for example, Japanese Patent Gazette No. 22452 of 1990 laid open to public inspection on Jul. 23, 1985 under Provisional Publication No. 138748 of 1985 and Published Unexamined Patent Application No. 131245 of 1986), signals expressing pieces of information recorded on an optical disk shifts to a higher frequency as the density of the information recorded becomes high. Also, the amplitude of a signal having a high frequency becomes low as compared with that of a signal having a low frequency in cases where the signals are produced according to light passing through a central region of a hologram lens. In contrast, the amplitude of a signal having a high frequency is emphasized in cases where the signal is produced according to light passing through a peripheral region of the hologram lens. Therefore, in cases where the information signal S_{nc} is obtained according to the equation (13), high frequency components included in the information signal S_{nc} is emphasized, and low frequency noise components included in the term (SC21+SC22+SC23+SC24) are comparatively reduced. As a result, a signal-noise ratio in the information signal S_{nc} can be enhanced.

Accordingly, because the compound objective lens having two focal points is utilized in the optical head apparatus **131**, pieces of information can be reliably recorded or reproduced or or from an information medium regardless of whether the information medium is thick or thin.

Also, even though pieces of information are densely recorded in a thin type of high density optical disk represented by the first information medium **23**, the information signal S_{nc} can be reliably reproduced at a high signal-noise ratio.

Also, because the intensity of the light L4R or L5R incident on the detecting sections SE7 to SE**10** of the photo detector **136** is reduced by converging the noise cancelling light L14R on the photo detector **138**, a positioning accuracy of the photo detector **136** can be coarsely lowered to 1/100.

Also, in cases where the grating pattern P12 of the peripheral region **135***b* functions as a lens for the incident light L3 diffracted in the peripheral region **135***b*, unnecessary diffracted light generated in the peripheral region **135***b* on the outgoing optical path forms a comparatively large converging spot in defocus on the first information medium **23**. Therefore, pieces of information recorded on the first information medium **23** are read by the unnecessary diffracted light, and the information are treated as a piece of averaged information in the photo detector **136** even though the unnecessary diffracted light is incident on the photo detector **136**. Accordingly, the information read by the unnecessary diffracted light does not adversely influence on the information signal S_{nc} as a noise.

Also, in cases where a transmission efficiency of the peripheral region **135***b* of the hologram lens **135** is set to agree with another transmission efficiency of the central region **135***a*, secondary maxima (or side lobes) occurring around the converging spot S1 can be lowered as compared with the first embodiment. Accordingly, a signal-noise ratio in the information signal S_{nc} can be enhanced.

(Fifteenth Embodiment)

An optical head apparatus in which noises included in an information signal are reduced is described with reference to FIGS. **47** to **49** according to a fifteenth embodiment of the present invention.

FIG. **47** is a constitutional view of an optical head apparatus according to a fifteenth embodiment. FIG. **48** is a plan view of a hologram lens utilized in the optical head apparatus shown in FIG. **47**.

As shown in FIG. **47**, an optical head apparatus **141** for recording or reproducing pieces of information on or from the information medium **23** or **25**, comprises the light source **52**, the beam splitter **82**, the collimator lens **134**, a hologram lens **142** for transmitting a part of the incident light L3 without any diffraction and diffracting a remaining part of the incident light L3, the objective lens **27**, the actuating unit **58**, and a photo detector **143** for detecting the light transmitting through or diffracted by the hologram lens **142** on the incoming optical path.

As shown in FIG. **48**, the hologram lens **142** is partitioned into a central region **142***a* in which the grating pattern P1 is drawn, a pair of side peripheral regions **142***b*, **142***c* in which grating patterns P13, P14 are drawn to cancel noises included in an information signal, and a pair of no-designed regions **142***d*, **142***e* in which no grating pattern is drawn not to reduce the intensity of light. Because the grating pattern P1 are drawn in the hologram lens **135**, a compound objective lens **144** having two focal points is composed of the hologram lens **142** and the objective lens **27**. An optical axis of the optical head apparatus **141** passes through a central point of the grating pattern P1 and a central axis of the objective lens **27**.

The photo detector **143** comprises the quadrant photodetector **64** having the detecting sections SE7 to SE**10**, a pair of noise cancelling photo detector **138***a*, **138***b* for detecting the intensity of light passing through the peripheral region **142***b*, **142***c* of the hologram lens **142**.

In the above configuration, the transmitted light L4 (or the diffracted light L5) generated in the central region **142***a* of the hologram lens **142** is converged on the first information medium **23** (or the second information medium **25**) in an outgoing optical path to form the converging spot S1 (or S2). Thereafter, the transmitted light L4R (or the diffracted light L5R) passes through the same optical path in the reverse direction. That is, the transmitted light L4R (or the diffracted light L5R) again passes through the converging lens **27**, and a part of the transmitted light L4R transmits through the central region **142***a* of the hologram lens **142** without any diffraction or a part of the diffracted light L5R is again diffracted in the central region **142***a*. Thereafter, the transmitted light L4R (or the diffracted light L5R) is converged by the collimator lens **134** and passes through the beam splitter **82**. In this case, an astigmatic aberration is generated in the transmitted light L4R (or the diffracted light L5R) in the same manner as in the seventh embodiment. Thereafter, the transmitted light L4R (or the diffracted light L5R) is incident on the detecting sections SE7 to SE**10** of the photo detector **143** to form a converging spot S21 of which the

shape is the same as the converging spot **S10** shown in FIGS. **29**A to **29**C. The intensity of the transmitted light L**4**R (or the diffracted light L**5**R) is changed to electric current signals SC**26** to SC**29** in the detecting sections SE**7** to SE**10**. Therefore, servo signals such as a focus error signal and a tracking error signal are obtained in the same manner as in the seventh embodiment, so that the position of the compound objective lens **144** is adjusted to converge the transmitted light L**4** (or the diffracted light L**5**) on the information medium **23** (or **25**) in focus. Also, an information signal recorded on the second information medium **25** is obtained according to an equation (14).

$$S_{in}=SC26+SC27+SC28+SC29 \quad (14)$$

Also, a part of the incident light L**3** incident on the peripheral region **142***b* of the hologram lens **142** transmits through the peripheral region **142***b* without any diffraction to form a beam of noise cancelling light L**15**, and a part of the incident light L**3** incident on the peripheral region **142***c* of the hologram lens **142** transmits through the peripheral region **142***c* without any diffraction to form a beam of noise cancelling light L**16**. Thereafter, the noise cancelling light L**15**, L**16** are converged on the information medium **23** to form a converging spot surrounding the converging spot S**1**. Thereafter, beams of noise cancelling light L**15**R, L**16**R reflected by the first information medium **23** passes through the same optical path in the reverse direction. That is, the noise cancelling light L**15**R, L**16**R again passes through the converging lens **27**. A part of the noise cancelling light L**15**R is diffracted and converged in the peripheral region **142***b* of the hologram lens **142** and is incident on the noise cancelling photo detector **138***a*, and a part of the noise cancelling light L**16**R is diffracted and converged in the peripheral region **142***c* of the hologram lens **142** and is incident on the noise cancelling photo detector **138***b*. In the photo detector **138***a*, an output signal SC**30** is generated according to the intensity of the noise cancelling light L**15**R. Also, an output signal SC**31** is generated according to the intensity of the noise cancelling light L**16**R in the photo detector **138***b*. Thereafter, a noise cancelled information signal S_{nc} expressing the information recorded on the first information medium **23** is obtained by adding all of the signals according to an equation (15):

$$S_{nc}=(SC26+SC27+SC28+SC29)+R\times(SC30+SC31) \quad (15),$$

where the symbol R is a weighting factor.

Accordingly, because the compound objective lens having two focal points is utilized in the optical head apparatus **141**, pieces of information can be reliably recorded or reproduced from an information medium regardless of whether the information medium is thick or thin.

Also, a signal-noise ratio in the information signal S_{nc} can be enhanced in the same manner as in the fourteenth embodiment.

Also, even though pieces of information are densely recorded in a thin type of high density optical disk represented by the first information medium **23**, the information signal S_{nc} can be reliably reproduced at a high signal-noise ratio.

Also, because the intensity of the light L**4**R or L**5**R incident on the detecting sections SE**7** to SE**10** of the photo detector **143** is reduced by converging the noise cancelling light L**15**R, L**16**R on the photo detectors **138***a*, **138***b*, a positioning accuracy of the photo detector **143** can be coarsely lowered to 1/100.

Also, in cases where the grating patterns P**13**, P**14** of the peripheral regions **142***b*, **142***c* functions as a lens for the incident light L**3** diffracted in the peripheral region **142***b*, **142***c*, unnecessary diffracted light generated by diffracting the incident light L**3** in the peripheral regions **142***b*, **142***c* on the outgoing optical path forms a comparatively large converging spot in defocus on the first information medium **23**. Also, an numerical number of each of the peripheral regions **142***b*, **142***c* is lowered as compared with that of the region **135***b* in the fourteenth embodiment because the hologram lens **142** are partitioned into many fields. Therefore, the size of the converging spot of the unnecessary diffracted light formed in defocus on the first information medium **23** becomes larger than that in the fourteenth embodiment. As a result, more pieces of information recorded on the first information medium **23** are read by the unnecessary diffracted light, and the information are treated as a piece of averaged information in the photo detector **143** even though the unnecessary diffracted light is incident on the photo detector **143**. Accordingly, the information read by the unnecessary diffracted light is moreover averaged, and the averaged information does not adversely influence on the information signal S_{nc} as a noise.

Also, as shown in FIGS. **49**A, **49**B, the unnecessary diffracted light can be prevented from being incident on the photo detector **64** in which each of the detecting sections SE**7** to SE**10** has SL**0** square in size. In detail, in cases where light generated in the peripheral region **142***c* on the outgoing optical path is again diffracted in the peripheral region **142***b* to form a beam of unnecessary diffracted light Lu_1, the light Lu_1 is converged on a first position PT**1** spaced SP**1** (SP**1**>SL**0**) from the center of the photo detector **64**. In cases where light generated in the peripheral region **142***b* on the outgoing optical path is again diffracted in the peripheral region **142***c* to form a beam of unnecessary diffracted light Lu_2, the light Lu_2 is converged on a second position PT**2** spaced SP**2** (SP**2**>SL**0**) from the center of the photo detector **64**. In cases where light generated in the peripheral regions **142***b*, **142***c* on the outgoing optical path are again diffracted in the same peripheral regions **142***b*, **142***c* to form beams of unnecessary diffracted light Lu_3, Lu_4, the light Lu_3, Lu_4 are converged on third and fourth position PT**3**, PT**4** spaced SP**3** (SP**3**>SL**0**), SP**4** (SP**4**>SL**0**) from the center of the photo detector **64**. Accordingly, the adverse influence of the unnecessary diffracted light Lu_1 to Lu_4 can be prevented.

In cases where the light source **52** is formed of a semiconductor laser, a far field pattern of the incident light L**3** incident on the hologram lens **142** is distributed in the Gaussian distribution as shown in FIG. **13**A, and a cross-sectional beam profile of the incident light L**3** distributed in the Gaussian distribution is in an elliptic shape. That is, a beam divergent angle (or a full angle at half maximum) of the incident light L**3** in a perpendicular direction is larger than that in a horizontal direction. In this embodiment, the perpendicular direction of the incident light L**3** is directed in an X2 direction shown in FIG. **48**, and the horizontal direction of the incident light L**3** is directed in a Y2 direction shown in FIG. **48**. In this case, because a transmission efficiency of the regions **142***b*, **142***c* for the incident light L**3** is smaller than that of the regions **142***d*, **142***e*, the intensity of the incident light L**3** transmitting through the hologram lens **142** without any diffraction is largely reduced in the perpendicular direction as compared with that in the horizontal direction. Therefore, the cross-sectional beam profile of the incident light L**3** is corrected to a circular shape in the hologram lens **142**. That is, the converging spot S**1** formed on the first information medium **23** is corrected to the circular shape. Accordingly, secondary maxima (or side lobes) occurring around the converging spot S**1** can be

lowered, and a signal-noise ratio of the information signal S_{nc} can be enhanced.

In the fifteenth embodiment, the noise cancelled information signal S_{nc} is obtained according to the equation (15). However, it is preferred that the noise cancelled information signal S_{nc} be obtained according to the equation (16):

$$S_{nc}=(SC26+SC27+SC28+SC29)+(R1\times SC30+R2\times SC31) \quad (16),$$

where the symbols R1, R2 are weighting factors. In this case, the noises included in the information can be moreover reduced.

(Sixteenth Embodiment)

An optical head apparatus manufactured in a small size and stably operated is described with reference to FIGS. **50**, **51** according to a sixteenth embodiment of the present invention.

FIG. **50** is a constitutional view of an optical head apparatus according to a sixteenth embodiment. FIG. **51** is a diagonal view of a light source and photo detectors utilized in the optical head apparatus shown in FIG. **50**.

As shown in FIG. **50**, an optical head apparatus **151** for recording or reproducing pieces of information on or from the information medium **23** or **25**, comprises the light source **52** for radiating the incident light L**3** linearly polarized in a non-diffracting direction parallel to an X3 axis, an holographic element **152** for transmitting through the incident light L**3** without any diffraction on an outgoing optical path and diffracting the transmitted light L**4**R or the diffracted light L**5**R linearly polarized in a diffracting direction parallel to a Y3 axis on an incoming optical path, the collimator lens **53**, the ¼–λ plate **69**, the hologram lens **26** (or **26**M, **32**, **33**, **42**, **135** or **142**), the objective lens **27**, the actuating unit **58**, and a photo detector **153** for detecting the intensity of the light L**4**R or L**5**R diffracted by the holographic element **152**.

As shown in FIG. **51**, the light source **52** and the photo detector **153** are located on a substrate **154** to precisely fix a relative position between the light source **52** and the photo detector **153**. The photo detector **153** comprises the sextant photo-detector **59** having the detecting sections SE**1** to SE**6** and the tracking photo-detectors **60***a* to **60***d*. Also, a mirror element **155** is located on the substrate **154** to direct the incident light L**3** radiated from the light source **52** in a Z**3** direction.

The holographic element **152** is produced by proton-exchanging surface parts of a lithium niobate substrate or by utilizing a liquid crystal cell, as is described in Provisional Publication No. 189504/86 (S61-189504) and Provisional Publication No. 241735/88 (S63-241735). Therefore, light linearly polarized in a non-diffracting direction parallel to an X3 axis transmits through the holographic element **152** without any diffraction. In contrast, light linearly polarized in a diffracting direction parallel to a Y3 axis which is perpendicular to the X3 axis is diffracted by the holographic element **152**.

In the above configuration, the incident light L**3** linearly polarized in a non-diffracting direction parallel to an X3 axis is radiated from the light source **52** and transmits through the holographic element **152** without any diffraction. Thereafter, the incident light L**3** is collimated by the collimator lens **53**, and the incident light L**3** linearly polarized is changed to the incident light L**3** circularly polarized by the ¼–λ plate **69**. Thereafter, a part of the incident light L**3** transmits through the hologram lens **26** without any diffraction to form the transmitted light L**4**, and a remaining part of the incident light L**3** is diffracted by the hologram lens **26** to form the diffracted light L**5**. Thereafter, the light L**4**, L**5** are converged by the objective lens **27**, and the converging spot S**1** of the transmitted light L**4** (or the converging spot S**2** of the diffracted light L**5**) is formed on the first information medium **23** (or the second information medium **25**). When the light L**4** or L**5** is reflected by the information medium **23** (or **25**) and is changed to the light L**4**R (or L**5**R), a rotational direction of the circular polarization in the light L**4** is reversed. Therefore, the light L**4**R (or L**5**R) having the reversed circular polarization passes through the same optical path in the opposite direction. That is, the transmitted light L**4**R (or the diffracted light L**5**R) again passes through the converging lens **27**, and a part of the transmitted light L**4**R transmits through the hologram lens **142** without any diffraction or a part of the diffracted light L**5**R is again diffracted by the hologram lens **142**. Thereafter, the transmitted light L**4**R (or the diffracted light L**5**R) circularly polarized in reverse is changed to the light L**4**R (or L**5**R) linearly polarized in a diffracting direction parallel to a Y3 axis by the ¼–λ plate **69**. Thereafter, the light L**4**R (or L**5**R) is converged by the collimator lens **53** and is diffracted by the holographic element **152** to form a plurality of converging spots on the photo detectors **153**. Therefore, an information signal expressing a piece of information recorded on the information medium **23** (or **25**) and servo signals such as a focus error signal and a tracking error signal are obtained in the photo detector **153** in the same manner as in the sixth embodiment.

Accordingly, because the compound objective lens having two focal points is utilized in the optical head apparatus **151**, pieces of information can be reliably recorded or reproduced or or from an information medium regardless of whether the information medium is thick or thin.

Also, because all of the incident light L**3**transmits through the holographic element **152** on the outgoing optical path and because all of the light L**4**R or L**5**R is diffracted by the holographic element **152** on the incoming optical path, a utilization efficiency of the incident light L**3** can be enhanced. Therefore, even though a radiation intensity of the incident light L**3** in the light source **52** is low, the information signal and the servo signals having a high signal-noise ratio can be reliably obtained.

Also, because no beam splitter is utilized in the optical head apparatus **151**, the optical head apparatus **151** can be manufactured at a small size, in a light weight, and at a low cost.

Also, because optical parts of the optical head apparatus **151** are located along its optical axis, the optical head apparatus **151** stably operated can be obtained even though a circumstance temperature largely varies and the apparatus is operated for a long time.

Also, because the light L**4**R or L**5**R transmitting through the holographic element **152** without any diffraction on the incoming optical path is not required, it is preferred that a diffraction efficiency of the holographic element **152** be heightened to set a transmission efficiency of the holographic element **152** to almost zero. In this case, a combination of the holographic element **152** and the ¼–λ plate **69** function functions as an isolator to prevent the light L**4**R or L**5**R from returning to the light source **52**. Therefore, in cases where a semiconductor laser is utilized as the light source **52**, any light does not return to an active layer of the semiconductor laser. Accordingly, noises induced by the light returning to the semiconductor laser can be prevented.

Also, because the light source **52** and the photo detector **153** are located on the same substrate **154**, the light source **52** and the photo detector **153** can be closely arranged each other. Therefore, a relative position between the light source **52** and the photo detector **153** can be easily set at a high

accuracy. For example, the relative position can be set at an accuracy within several μm. Accordingly, a manufacturing cost of the optical head apparatus **151** can be lowered, and the optical head apparatus **151** can be moreover manufactured at a small size, in a light weight, and at a low cost.

Also, the light source **52** is electrically connected with an external circuit through first wirings, and the photo detector **153** is electrically connected with another external circuit through second wirings. In this case, because the light source **52** and the photo detector **153** are located on the same substrate **154**, the first and second wirings can pass on an X3–Y3 plane in common. Therefore, the light source **52** and the photo detector **153** can be easily and automatically connected with the external circuits. In addition, because reference lines required to connect the light source **52** and the photo detector **153** with the external circuits are only drawn on the X3–Y3 plane, the relative position between the light source **52** and the photo detector **153** can be easily set at a high accuracy.

In the sixteenth embodiment, the optical head apparatus **151** with the holographic element **152** is described. However, in cases where the intensity of the incident light **L3** is sufficient, it is applicable that a hologram having a small grating pitch or a blazed hologram be utilized in place of the holographic element **152**. In this case, pieces of information can be reliably recorded or reproduced on or from an information medium regardless of whether the information medium is thick or thin. Also, because no beam splitter is utilized in the optical head apparatus **151**, the optical head apparatus **151** can be manufactured at a small size, in a light weight, and at a low cost. Also, because optical parts of the optical head apparatus **151** are located along its optical axis, the optical head apparatus **151** stably operated can be obtained even though a circumstance temperature largely varies and the apparatus is operated for a long time.

(Seventeenth Embodiment)

An optical head apparatus manufactured in a small size and stably operated is described with reference to FIG. **52** according to a seventeenth embodiment of the present invention.

FIG. **52** is a constitutional view of an optical head apparatus according to a seventeenth embodiment.

As shown in FIG. **52**, an optical head apparatus **161** for recording or reproducing pieces of information on or from the information medium **23** or **25**, comprises the light source **52** for radiating the incident light **L3** linearly polarized in a first direction, the collimator lens **53**, a polarizing separation film **162** formed on a front surface of a transparent substrate **162** for reflecting the incident light **L3** linearly polarized in the first direction and transmitting light linearly polarized in a second direction perpendicular to the first direction, the ¼–λ plate **69**, the hologram lens **26** (or **26M**, **32**, **33**, **42**, **135** or **142**), the objective lens **27**, the actuating unit **58**, a reflection-type hologram **164** formed on a rear surface of the transparent substrate **162** for diffracting and reflecting the light **L4R**, **L5R**, and the photo detector **57**.

In the above configuration, the incident light **L3** linearly polarized in a first direction is radiated from the light source **52** and is collimated by the collimator lens **53**. Thereafter, all of the incident light **L3** is reflected by the polarizing separation film **162** because the incident light **L3** is linearly polarized in the first direction. Therefore, the incident light **L3** is directed in an upper direction. Thereafter, the linear polarization of the incident light **L3** is changed to a circular polarization in the ¼–λ plate **69**, and a part of the incident light **L3** transmits through the hologram lens **26** to form the transmitted light **L4**. Also, a remaining part of the incident light **L3** is diffracted by the hologram lens **26** to form the diffracted light **L5**. Thereafter, the light **L4**, **L5** are converged by the objective lens **27**, and the converging spot **S1** of the transmitted light **L4** (or the converging spot **S2** of the diffracted light **L5**) is formed on the first information medium **23** (or the second information medium **25**). Thereafter, the transmitted light **L4R** (or the diffracted light **L5R**) circularly polarized in reverse again passes through the converging lens **27** in the same manner as in the sixteenth embodiment, and a part of the transmitted light **L4R** transmits through the hologram lens **26** without any diffraction or a part of the diffracted light **L5R** is again diffracted by the hologram lens **26**. Thereafter, the transmitted light **L4R** (or the diffracted light **L5R**) circularly Polarized in reverse is changed to the light **L4R** (or **L5R**) linearly polarized in a second direction perpendicular to the first direction by the ¼–λ plate **69**. Thereafter, all of the light **L4R** (or **L5R**) is refracted by the polarizing separation film **162** and is diffracted and reflected by the hologram **164**. Thereafter, the light **L4R** (or **L5R**) transmits through the polarizing separation film **162** and is converged by the collimator lens **53** to form a plurality of converging spots on the photo detector **57**. Therefore, an information signal expressing a piece of information recorded on the information medium **23** (or **25**) and servo signals such as a focus error signal and a tracking error signal are obtained in the photo detector **57** in the same manner as in the sixth embodiment.

Accordingly, because the compound objective lens having two focal points is utilized in the optical head apparatus **161**, pieces of information can be reliably recorded or reproduced on or from an information medium regardless of whether the information medium is thick or thin.

Also, because the incident light **L3** incident on the polarizing separation film **162** is collimated, a reflectivity for the incident light **L3** is uniform over the entire film **162**. Therefore, a diffraction-limited spot of the light **L4** or **L5** can be easily formed on the information medium **23** or **25**. Also, because the light **L4R**, **L5R** incident on the polarizing separation film **162** are collimated, a transmissivity for the light **L4R**, **L5R** is uniform over the entire film **162**. Therefore, an offset occurring in the servo signals can be prevented.

Also, because all of the incident light **L3** transmits through the hologram **164** on the outgoing optical path and because all of the light **L4R** or **L5R** is diffracted by the hologram **164** on the incoming optical path, a utilization efficiency of the incident light **L3** can be enhanced. Therefore, even though a radiation intensity of the incident light **L3** in the light source **52** is low, the information signal and the servo signals having a high signal-noise ratio can be reliably obtained.

Also, because a hybrid element composed of the film **162**, the substrate **163** and the hologram **164** functions as a beam splitter and a rising mirror, the optical head apparatus **161** can be manufactured at a small size, in a light weight, and at a low cost.

Also, because optical parts of the optical head apparatus **161** are located along its optical axis, the optical head apparatus **161** stably operated can be obtained even though a circumstance temperature largely varies and the apparatus is operated for a long time.

Also, a combination of the film **162** and the ¼–λ plate **69** function functions as an isolator to prevent the light **L4R** or **L5R** from returning to the light source **52**. Therefore, in cases where a semiconductor laser is utilized as the light source **52**, any light does not return to an active layer of the

semiconductor laser. Accordingly, noises induced by the light returning to the semiconductor laser can be prevented.

Also, it is preferred that the hologram **164** be blazed. In this case, because the generation of unnecessary diffracted light such as minus first-order diffracted light in the hologram **164** is prevented, a diffraction efficiency of the hologram **164** for changing light to first-order diffracted light can be set to almost 100%. Therefore, the incident light L**3** can be efficiently utilized to obtain the signals.

Also, because light incident on the hologram **164** is diffracted to first-order diffracted light, a chromatic aberration occurring in the light L**4**R, L**5**R can be compensated in the hologram **164**. Therefore, the servo signals can be stably obtained.

In the seventeenth embodiment, the collimator lens **53** is located between the light source **52** and the film **162**. However, the collimator lens **53** is not necessary in the optical head apparatus **161**.

Also, the optical head apparatus **161** with the film **162** and the ¼–λ plate **69** is described. However, in cases where the intensity of the incident light L**3** is sufficient, it is applicable that a reflection film having a reflectivity of almost ⅓ be utilized in place of the film **162** and the ¼–λ plate **69** be omitted. In this case, pieces of information can be reliably recorded or reproduced on or from an information medium regardless of whether the information medium is thick or thin. Also, because a hybrid element composed of the film **162**, the substrate **163** and the hologram **164** functions as a beam splitter and a rising mirror, the optical head apparatus **161** can be manufactured at a small size, in a light weight, and at a low cost. Also, because optical parts of the optical head apparatus **161** are located along its optical axis, the optical head apparatus **161** stably operated can be obtained even though a circumstance temperature largely varies and the apparatus is operated for a long time.

In the sixth to seventeenth embodiments, pieces of information can be reliably recorded or reproduced on or from an information medium regardless of whether the information medium represents a conventional optical disk such as a compact disk having a thickness T**2** of about 1.2 mm or a prospective high density optical disk having a thickness T**1** ranging from 0.4 mm to 0.8 mm. However, when the information recorded or reproduced on or from the information medium, it is required to examine the thickness of the information medium in advance. Therefore, in cases where a piece of distinguishing information is recorded on the information medium in advance to distinguish the thickness of the information medium, it is convenient for a user. Because no distinguishing information is recorded on the conventional optical disk, it is preferred that the distinguishing information be recorded on the prospective high density optical disk appearing on the market in. the future. Therefore, a high density optical disk with the distinguishing information is described according to eighteenth and nineteenth embodiments.

(Eighteenth Embodiment)

FIG. **53** is a diagonal view of a high density optical disk according to an eighteenth embodiment, a cross sectional view of the disk being partially shown.

As shown in FIG. **53**, a high density optical disk **171** is partitioned into an outer region **171***a* and an inner region **171***b*. The outer region **171***a* occupies a large part of the optical disk **171**, and an information recording substrate **171***c* of the outer region **171***a* has the thickness T**1**, and the information recording substrate **171***c* of the inner region **171***b* has the thickness T**2**. A plurality of first recording pits **172** are formed on the information recording substrate **171***c* of the outer region **171***a* at narrow intervals in series to record pieces of information at a high density. Also, a plurality of second recording pits **173** are formed on the information recording substrate **171***c* of the inner region **171***b* at ordinary intervals in series to record pieces of distinguishing information at an ordinary density of a compact disk. The distinguishing information inform that the optical disk **171** has the thickness T**1**. The thickness T**1** of the outer region **171***a*, for example, ranges from 0.4 mm to 0.8 mm, and the thickness T**2** of the inner region is, for example, about 1.2 mm.

In the above configuration, the diffracted light L**5** according to the first or second embodiment (or the transmitted light L**4** according to the third embodiment) is initially converged on an inner region of the information medium **23**, **25** while performing a focus control corresponding to the second information medium **25** having the thickness T**2**. In cases where the information medium **23** or **25** is the optical disk **171**, a piece of distinguishing information informing that the optical disk **171** having the thickness T**1** is converged by the light L**5** (or L**4**) is detected. Thereafter, the transmitted light L**4** (or the diffracted light L**6**) is automatically converged on the outer region **171***a* of the optical disk **171** while performing a focus control corresponding to the first information medium **23** having the thickness T**1**.

In contrast, in cases where the information medium **23** or **25** is a thick type of conventional optical disk having a thickness T**2**, no distinguishing information is detected when the light L**5** (or L**4**) is converged on the inner region **171***b* of the conventional optical disk. In this case, the focus control corresponding to the second information medium **25** is continued to detect an information signal expressing a piece of information recorded on the conventional optical disk.

Accordingly, in cases where one of the optical head apparatuses shown in FIGS. **21**, **27**, **30**, **31**, **32**, **33**, **37**, **38**, **40**A, **43**, **44**, **50** and **52** is utilized, pieces of information can be automatically recorded or reproduced on or from an information medium regardless of whether the information medium is thin or thick.

Also, because only the distinguishing information is recorded in the inner region, the inner region can be small. Therefore, a memory capacity of the optical disk **171** is not lowered by the addition of the second recording pit **173**.

(Nineteenth Embodiment)

FIG. **54** is a diagonal view of a high density optical disk according to a nineteenth embodiment, a cross sectional view of the disk being partially shown.

As shown in FIG. **54**, a high density optical disk **174** is partitioned into an outer region **174***a* and an inner region **174***b*. The outer region **174***a* occupies a large part of the optical disk **174**. The optical disk **174** has a uniform thickness of T**1**. The first recording pits **172** are formed on an information recording substrate **174***c* of the outer region **174***a* to record pieces of information at a high density. Also, a plurality of second recording pits **175** having a large size are formed on the information recording substrate **174***c* of the inner region **174***b* at wide intervals to record pieces of distinguishing information at a lower density than the ordinary density. The distinguishing information inform that the entire optical disk **174** has the thickness T**1**. The thickness T**1** of the optical disk **174**, for example, ranges from 0.4 mm to 0.8 mm.

In the above configuration, the diffracted light L**5** according to the first or second embodiment (or the transmitted light L**4** according to the third embodiment) is initially converged on an inner region of the information medium **23**

or **25** while performing a focus control corresponding to the second information medium **25** having the thickness T2. In cases where the information medium **23** or **25** is the optical disk **174**, the light L5 (or L4) is converged on each of the second recording pits **175** in defocus. However, because each of the second recording pits **175** is large in size, a converging spot of the light L5 (or L4) is reliably formed in one of the second recording pits **175**. Therefore, a piece of distinguishing information, which informs that the optical disk **174** having the thickness T1 is converged by the light L5 (or L4), is detected. Thereafter, the transmitted light L4 (or the diffracted light L6) is automatically converged on the outer region **174***a* of the optical disk **174** while performing a focus control corresponding to the first information medium **23** having the thickness T1.

In contrast, in cases where the information medium **23** or **25** is a thick type of conventional optical disk having a thickness T2, no distinguishing information is detected when the light L5 (or L4) is converged on the inner region **174***b* of the conventional optical disk. In this case, the focus control corresponding to the second information medium **25** is continued to detect an information signal expressing a piece of information recorded on the conventional optical disk.

Accordingly, in cases where one of the optical head apparatuses shown in FIGS. **21**, **27**, **30**, **31**, **32**, **33**, **37**, **38**, **40**A, **43**, **44**, **50** and **52** is utilized, pieces of information can be automatically recorded or reproduced on or from an information medium regardless of whether the information medium is thin or thick.

Also, because only the distinguishing information is recorded in the inner region of the optical disk **174**, the inner region can be small. Therefore, a memory capacity of the optical disk **174** is not lowered by the addition of the second recording pit **173**.

Also, because the thickness of the optical disk **174** is uniform, the optical disk **174** can be easily manufactured at a low cost. Also, the optical disk **174** can be thinned.

(Twentieth Embodiment)

An optical disk apparatus with one of the optical head apparatuses in which it is automatically judged whether a high density optical disk having the thickness T1 or a conventional optical disk having the thickness T2 is utilized is described.

FIG. **55** is a block diagram of an optical disk apparatus with one of the optical head apparatuses shown in FIGS. **21**, **27**, **30**, **31**, **32**, **33**, **37**, **38**, **40**A, **43**, **44**, **50** and **52** according to a twentieth embodiment. FIG. **56** is a flow chart showing the operation of the optical disk apparatus shown in FIG. **55**. FIG. **63** is a constitutional view of the optical disk apparatus of which the block diagram is shown in FIG. **55**.

As shown in FIG. **63**, an optical disk apparatus **176** for recording or reproducing pieces of information on or from the high density optical disk **171** (or **174**) or the conventional optical disk **25**, comprises the optical head apparatus **51** (or **61**, **65**, **67**, **70**, **71**, **81**, **91**, **101**, **111**, **121**, **151** or **161**), a moving means **177** such as a feed mechanism for moving the optical head apparatus **51** to a prescribed position, a rotating means **178** such as a spindle motor for rotating the high density optical disk **171** (or **174**) or the conventional optical disk **25**, an actuating means representing the actuating unit **58** (not shown in FIG. **63**), an electric circuit **179** representing a focus control means and a tracking control means for controlling the actuating means to perform a first focus control of the optical head apparatus **51** corresponding to the first thickness T1 of the optical disk **171** (or **174**) and a second focus control of the optical head apparatus **51** corresponding to the second thickness T2 of the optical disk **171** (or **174**) or **25** according to a focus error signal read by the optical head apparatus **51** and controlling the actuating means to perform a first tracking error control of the optical head apparatus **51** corresponding to the first thickness T1 and a second tracking error control of the optical head apparatus **51** corresponding to the second thickness T2 according to a tracking error signal read by the optical head apparatus **51**, and a connecting means **180** for electrically connecting the rotating means **178**, the moving means **177** and the electric circuit **179** with an electric source (not shown) to supply an electric power to the rotating means **178**, the moving means **177** and the electric circuit **179**.

In the above configuration, the high density optical disk **171** or the conventional optical disk **25** is set to a prescribed position of the optical disk apparatus **176**, and the optical disk **171** or **25** is rotated by the rotating means **178**. Thereafter, the optical head apparatus **51** is moved to a position just under an innermost recording track of the optical disk **171** or **25** by the moving means **177** in a step **211**, and the diffracted light L5 is converged on the innermost recording track of the optical disk **171** or **25** while performing a focus control corresponding to the conventional optical disk **25** of the thickness T2 in a step **212**. Thereafter, a tracking control is performed, and a piece of information recorded on the innermost recording track of the optical disk **171** or **25** is detected in a step **213**. In detail, a focus error signal and a tracking error signal corresponding to a positional relationship between the optical head apparatus **51** and the optical disk **171** or **25** are sent to the electric circuit **179**. In the electric circuit **179**, an actuating signal is generated according to the focus error signal and the tracking error signal and is sent to the actuating unit **58** to precisely move the compound objective lens **29** (or **29**M, **34**, **43**, **45**, **46** or **47**) of the optical head apparatus **51**. That is, the second focus and tracking controls of the optical head apparatus **51** corresponding to the second thickness T2 are performed to read the information. Thereafter, it is judged in a step **214** whether the information agrees with a piece of distinguishing information informing that the optical disk **171** having the thickness T1 is set to the optical disk apparatus **176**.

In cases where the high density optical disk **171** is set to the optical disk apparatus **176**, the distinguishing information is detected. Thereafter, the transmitted light L4 is automatically converged on the optical disk **171** while performing a focus control corresponding to the optical disk **171** of the thickness T1 in a step **215**. In detail, a focus error signal and a tracking error signal corresponding to a positional relationship between the optical head apparatus **51** and the optical disk **171** are sent to the electric circuit **179**. In the electric circuit **179**, an actuating signal is generated according to the focus error signal and the tracking error signal and is sent to the actuating unit **58** to precisely move the compound objective lens **29** (or **29**M, **34**, **43**, **45**, **46** or **47**) of the optical head apparatus **51**. That is, the first focus and tracking controls of the optical head apparatus **51** corresponding to the first thickness T1 are performed. Therefore, pieces of information are recorded or reproduced on or from the optical disk **171**.

In contrast, in cases where the conventional optical head **25** is set to the optical disk apparatus **176**, the distinguishing information is not detected. In this case, the convergence of the diffracted light L5 on the conventional optical disk **25** is continued while performing the focus control and the tracking control corresponding to the conventional optical disk **25** in a step **216**. Therefore, pieces of information are recorded or reproduced on or from the conventional optical disk **25**.

Accordingly, the thickness of the optical disk set in the optical disk apparatus **176** can be rapidly judged at a high accuracy. Also, pieces of information can be stably recorded or reproduced on or from an optical disk regardless of whether the optical disk is the high density optical disk **171** (or **174**) or the conventional optical disk **25**.

(Twenty-first Embodiment)

An optical disk apparatus with one of the optical head apparatuses in which it is automatically judged whether a high density optical disk having the thickness T1 or a conventional optical disk having the thickness T2 is utilized is described.

FIG. **57** is a block diagram of an optical disk apparatus with one of the optical head apparatuses shown in FIGS. **21**, **27**, **30**, **31**, **32**, **33**, **37**, **38**, **40**A, **43**, **44**, **50** and **52** according **25** to a twenty-first embodiment. FIG. **58** is a flow chart showing the operation of the optical disk apparatus shown in FIG. **57**.

As shown in FIG. **57**, an optical disk apparatus **176** for recording or reproducing pieces of information on or from a high density optical disk **182** or the conventional optical disk **25**, comprises the optical head apparatus **51** (or **61**, **65**, **67**, **70**, **71**, **81**, **91**, **101**, **111**, **121**, **151** or **161**), the moving means **177**, and a rotating means **182** such as a spindle motor for rotating the high density optical disk **182** or the conventional optical disk **25**. The high density optical disk **182** has no distinguishing information and has the thickness T1.

In the above configuration, the high density optical disk **182** or the conventional optical disk **25** is set to a prescribed position of the optical disk apparatus **181**, and the optical disk **182** or **25** is rotated by the rotating means **182**. Thereafter, the optical head apparatus **51** is moved to a position just under an innermost recording track of the optical disk **182** or **25** in a step **221** because a piece of information is reliably recorded on the innermost recording track, and the diffracted light L5 is converged on the innermost recording track of the optical disk **182** or **25** while performing a focus control corresponding to the conventional optical disk **25** of the thickness T2 in a step **222**. Thereafter, a tracking control is performed, and a piece of information recorded on the innermost recording track of the optical disk **182** or **25** is detected in a step **223**. Thereafter, it is judged in a step **224** whether the intensity of an information signal expressing the information detected is more than a threshold value. That is, the intensity of the information signal more than the threshold value denotes that the diffracted light L5 is converged in focus on the optical disk **182** or **25**, and the intensity of the information signal not more than the threshold value denotes that the diffracted light L5 is converged in defocus on the optical disk **182** or **25**.

In cases where the high density optical disk **182** is set to the optical disk apparatus **181**, the intensity of the information signal not more than the threshold value is detected. In this case, the transmitted light L4 is automatically converged on the optical disk **182** while performing a focus control corresponding to the high density optical disk **182** of the thickness T1 in a step **225**. Therefore, pieces of information are recorded or reproduced on or from the optical disk **182**.

In contrast, in cases where the conventional optical head **25** is set to the optical disk apparatus **181**, the intensity of the information signal more than the threshold value is detected. In this case, the convergence of the diffracted light L5 on the conventional optical disk **25** is continued while performing the focus control and the tracking control corresponding to the conventional optical disk **25** in a step **226**. Therefore, pieces of information are recorded or reproduced on or from the conventional optical disk **25**.

Accordingly, the thickness of the optical disk set in the optical disk apparatus **181** can be judged even though the optical disk **171** or **174** is not utilized. Also, pieces of information can be stably recorded or reproduced on or from an optical disk regardless of whether the optical disk is the high density optical disk **182** or the conventional optical disk **25**.

(Twenty-second Embodiment)

A binary focus microscope having two focal points in which two images formed on different planes are simultaneously observed is described according to a twenty-second embodiment.

FIG. **59** is a constitutional view of a binary focus microscope according to a twenty-second embodiment.

As shown in FIG. **59**, a binary focus microscope **191** for simultaneously observing a first image of a first sample SP1 put on a first sample plane PL1 and a second image of a second sample SP2 put on a second sample plane PL2, comprises an objective lens **192** having a first focal length F1 for refracting a beam of first light L17 diverging from the first image and refracting a beam of second light L18 diverging from the second image, the hologram lens **26** (or **26**M, **32**, **33** or **42**) for transmitting through a part of the first light L17 without any diffraction and diffracting a part of the second light L18 to pass the second light L18 through the same optical path as the first light L17 passes through, an inner lens **193** for converging a beam of superposed light L19 formed of the first and second light L17, L18 at an inner focal point Pf1, an ocular lens **194** for simultaneously forming the first and second images by converging the superposed light L19 diverging from the inner focal point Pf1, an inner lens-barrel **195** for moving a combination element of the inner lens **193** and the hologram lens **26** along an optical axis to adjust a distance between the combination element and the ocular lens **194**, and an outer lens-barrel **196** for moving the objective lens **192** along the optical axis to set the distance between the first sample plane PL1 and the objective lens **192** to the focal length F1 of the objective lens **192**.

The optical axis passes through the centers of the objective lens **192**, the hologram lens **26**, the inner lens **195** and the ocular lens **194**. The position of the first sample plane PL1 differs from that of the second sample plane PL2 along the optical axis.

In the above configuration, the position of the objective lens **192** is adjusted to set the distance between the first sample plane PL1 and the objective lens **192** to the first focal length F1 of the objective lens **192**. In this case, the distance between the second sample plane PL2 and the objective lens **192** is set to a second focal length F2. Also, the position of the combination element is adjusted to clearly view the first and second images. That is, a beam of first light L17 diverging from the first image on the first sample plane PL1 is collimated in the objective lens **192**, and a part of the first light L17 transmits through the hologram lens **26**. Also, a beam of second light L18 diverging from the second image on the second sample plane PL2 is refracted in the objective lens **192**, and a part of the second light L18 is diffracted in the hologram lens **26** to pass the second light L18 through the same optical path as the first light L17 passes through. Therefore, a beam of superposed light L19 is formed of the first and second light L17, L18. Thereafter, the superposed light L19 is converged by the inner lens **193** at an inner focal point Pf1 to simultaneously form the first and second images enlarged on an image plane PL3, and the superposed light L19 diverging from the point Pf1 is converged by the ocular lens **194** to simultaneously form the first and second images moreover enlarged on an operator's eye.

Accordingly, because the hologram lens **26**, **26**M, **32**, **33** or **42** is utilized to form the superposed light L**19**, the first image of the first sample SP**1** put on the first sample plane PL**1** and the second image of the second sample SP**2** put on the second sample plane PL**2** can be simultaneously observed by simultaneously focusing the binary focus microscope **191** on the first and second samples SP**1**, SP**2**.

Also, even though the intensities of the first and second light L**17**, L**18** are reduced when the light L**17**, L**18** pass through the hologram lens **26**, the intensity of the superposed light L**19** is sufficient to observe the first and second images because the intensity of the superposed light L**19** is determined by adding the intensities of the first and second light L**17**, L**18**.

Also, because the hologram lens **26** is blazed as shown in FIG. **6**, the generation of unnecessary diffracted light such as minus first-order diffracted light is reduced when the second light L**18** is diffracted in the hologram lens **26**. Therefore, the intensity of the superposed light L**19** can be increased, so that first and second images observed can be moreover brightened.

Also, as shown in FIG. **60**, in cases where the first sample SP**1** is placed at a bottom of a first sample holder **197** and in cases where the second sample SP**2** is placed at a bottom of a second sample holder **198** located under the first sample holder **197**, aberration such as a chromatic aberration is generated in the first and second light L**17**, L**18** incident on the objective lens **192** because an optical path length in the first sample holder **197** for the first light L**17** differs from that in the first and second sample holders **197**, **198** for the second light L**18**. However, the aberration can disappear in the hologram lens **26** by excessively correcting the chromatic aberration in the hologram lens **26** as is described in the first embodiment.

Also, the difference between the first and second focal lengths can be changed by moving the inner and outer lens-barrels **195**, **196** because the distance between the hologram lens **26** and the objective lens **192** is changed. Therefore, even though the thickness of the second sample holder **198** is changed, the first and second images can be reliably observed.

In the twenty-second embodiment, the ocular lens **194** is utilized in the binary focus microscope **191**. However, the ocular lens **194** is not necessarily required. Also, as shown in FIG. **61**, it is applicable that a camera **199** such as a charge-coupled device (CCD) camera be placed on the image plane PL**3** in place of the ocular lens **194**. In this case, a superposed image formed of the first and second images enlarged can be photographed with the CCD camera **199**, so that the first and second images can be simultaneously recorded.

(Twenty-third Embodiment)

In cases where a minute circuit is formed on a semiconductor wafer, a photosensitive material is coated on the semiconductor wafer, and the photosensitive material covering the semiconductor wafer is exposed to ultraviolet light through a photomask having a mask pattern in an exposure process. Therefore, the mask pattern of the photomask is transferred to the photosensitive material. In this case, the semiconductor wafer is required to be aligned with the photomask at a high accuracy in an alignment process performed prior to the exposure process. Therefore, a reference image drawn on the semiconductor wafer and the mask pattern drawn on the photomask are simultaneously observed with a conventional microscope having a deep focal depth. However, because the magnification of the conventional microscope having a deep focal depth is low, it is impossible to align the reference image and the mask pattern at an accuracy within 5 μm.

To solve the above drawback in the present invention, an alignment apparatus utilized in the alignment process in which the semiconductor wafer is aligned with the photomask at a high accuracy while simultaneously observing a reference image drawn on the semiconductor wafer and the mask pattern drawn on the photomask is described according to a twenty-third embodiment.

FIG. **62** is a constitutional view of an alignment apparatus according to a twenty-third embodiment.

As shown in FIG. **62**, an alignment apparatus **201** for aligning a first reference image RF**1** of a mask pattern drawn on a bottom surface of a photomask **202** with a second reference image RF**2** drawn on a bottom surface of a sample such as a semiconductor substrate **203**, comprises a light source **204** for radiating beams of alignment light having a particular wavelength to illuminate the first and second reference images RF**1**, RF**2**, the objective lens **192** for receiving a beam of first alignment light L**20** diverging from the first reference image RF**1** illuminated with the alignment light and receiving a beam of second alignment light L**21** diverging from the second reference image RF**2** illuminated with the alignment light, the hologram lens **26** (or **26**M, **32**, **33** or **42**) for transmitting through a part of the first alignment light L**20** without any diffraction and diffracting a part of the second alignment light L**21** to pass the second alignment light L**21** through the same optical path as the first alignment light L**20** passes through, the inner lens **193** for converging a beam of superposed alignment light L**22** formed of the first and second alignment light L**20**, L**21** at an inner focal point Pf**2**, a camera **205** such as a charge-coupled device (CCD) camera placed at the inner focal point Pf**2** for simultaneously photographing and recording the first and second reference images RF**1**, RF**2**, the inner lens-barrel **195**, the outer lens-barrel **196**, a moving means **206** for moving the photomask **202** in a horizontal direction perpendicular to an optical axis to align the first reference image RF**1** with the second reference image RF**2** along the optical axis, and a control means **207** for controlling the movement of the photomask **202** according to the first and second reference images RF**1**, RF**2** recorded in the camera **205**.

The particular wavelength of the alignment light is determined on condition that a transmissivity of the semiconductor substrate **203** for the alignment light is sufficiently high. The optical axis passes through the centers of the objective lens **192**, the hologram lens **26** and the inner lens **193**.

A binary microscope **208** is composed of the objective lens **192**, the hologram lens **26** (or **26**M, **32**, **33** or **42**), the inner lens **193**, the inner lens-barrel **195** and the outer lens-barrel **196** in the same manner as in the twenty-second embodiment.

In the above configuration, a beam of first alignment light L**20** diverging from the first reference image RF**1** is collimated in the objective lens **192**, and a part of the first alignment light L**20** transmits through the hologram lens **26**. Also, a beam of second alignment light L**21** diverging from the second reference image RF**2** is refracted in the objective lens **192**, and a part of the second alignment light L**21** is diffracted by the hologram lens **26** to pass the second alignment light L**21** through the same optical path as the first alignment light L**20** passes through. Therefore, a beam of superposed alignment light L**22** is formed of the first and second alignment light L**20**, L**21**. Thereafter, the superposed alignment light L**22** is converged at an inner focal point Pf**2** to simultaneously form the first and second reference images RF**1**, RF**2** enlarged. Thereafter, the first and second refer-

ence images RF1, RF2 enlarged are photographed and recorded by the camera **205**. Thereafter, a relative position between the first and second reference images RF1, RF2 is examined in the control means **207**, and the photomask **202** is moved in a horizontal direction by the moving means **206** under control of the control means **207** to align the first reference image RF1 with the second reference image RF2. Thereafter, as shown in FIG. **64**, a photo sensitive material coated on the semiconductor substrate **203** is exposed to exposure light radiated from an exposure light source **211** through a reflecting mirror **212** and a shutter **213**.

Accordingly, because the hologram lens **26**, **26M**, **32**, **33** or **42** is utilized to form the binary microscope **208** having two focal points, the first reference image RF1 and the second reference image RF2 can be simultaneously observed even though a focal depth of the binary microscope **208** is low. Also, because the focal depth of the binary microscope **208** can be lowered, the magnification of the binary microscope **208** can be heightened. Therefore, the first reference image RF1 of the photomask **202** can be aligned with the second reference image RF2 of the semiconductor substrate **203** at a high accuracy.

(Twenty-fourth Embodiment)

FIG. **65** is a diagonal view of an image reproducing apparatus for which the optical disk apparatus **176** is provided.

As shown in FIG. **65**, an image reproducing apparatus **221** comprises the optical disk apparatus **176** and a displaying unit **222** such as a cathode ray tube or a liquid crystal display for displaying pieces of image information recorded in the optical disk **171**, **174** or **25** of the optical disk apparatus **176** as an image.

In the above configuration, pieces of image information are recorded in the outer region **171***a* of the optical disk **171** or in the optical disk **174** at a high recording density, and the thickness T1 is, for example, 0.6 mm. Also, pieces of image information are recorded in the conventional optical disk **25** having the thickness T2 at an ordinary recording density. The conventional optical disk **25** represents a video compact disk having a thickness of 1.2 mm. Because the optical disk apparatus **176** is provided for the image reproducing apparatus **221**, regardless of whether pieces of particular image information are recorded in the optical disk **171** (or **174**) or the conventional optical disk **25**, the particular image information are read from the optical disk **171**, **174** or **25**, and a particular image can be displayed in the displaying unit **222**. Therefore, a user is not required to prepare both a conventional image reproducing apparatus for reproducing the image information recorded in the conventional optical disk **25** and an updated image reproducing apparatus for reproducing the image information recorded in an updated optical disk having a thickness of 0.6 mm.

FIG. **66** is a diagonal view of a voice reproducing apparatus for which the optical disk apparatus **176** is provided.

As shown in FIG. **66**, a voice reproducing apparatus **231** comprises the optical disk apparatus **176** and a voice reproducing unit **232** such as a speaker for reproducing pieces of voice information recorded in the optical disk **171**, **174** or **25** of the optical disk apparatus **176** as voices. The voice reproducing apparatus **231** additionally comprises a radio **233** and a cassette tape recorder **234**.

In the above configuration, pieces of voice information are recorded in the outer region **171***a* of the optical disk **171** or in the optical disk **174** at a high recording density, and the thickness T1 is, for example, 0.6 mm. Also, pieces of voice information are recorded in the conventional optical disk **25** having the thickness T2 at an ordinary recording density. The conventional optical disk **25** represents an audio compact disk having a thickness of 1.2 mm. Because the optical disk apparatus **176** is provided for the voice reproducing apparatus **231**, regardless of whether pieces of particular voice information are recorded in the optical disk **171** (or **174**) or the conventional optical disk **25**, the particular voice information are read from the optical disk **171**, **174** or **25**, and particular voices can be reproduced by the voice reproducing unit **232**. Therefore, a user is not required to prepare both a conventional voice reproducing apparatus for reproducing the voice information recorded in the conventional optical disk **25** and an updated voice reproducing apparatus for reproducing the voice information recorded in an updated optical disk having a thickness of 0.6 mm.

FIG. **67** is a diagonal view of an information processing apparatus for which the optical disk apparatus **176** is provided.

As shown in FIG. **67**, an information processing apparatus **241** comprises the optical disk apparatus **176**, an input apparatus **242** for inputting pieces of input information, a central processing unit **243** placed on a circuit substrate **244** for processing pieces of recorded information recorded in the optical disk **171**, **174** or **25** of the optical disk apparatus **176** or processing the input information to record the input information in the optical disk **171**, **174**, and a displaying unit **245** for displaying the recorded information processed in the central processing unit **243**.

In the above configuration, pieces of recorded information are recorded in the outer region **171***a* of the optical disk **171** or in the optical disk **174** at a high recording density, and the thickness T1 is, for example, 0.6 mm. Also, pieces of recorded information are recorded in the conventional optical disk **25** having the thickness T2 at an ordinary recording density. The conventional optical disk **25** represents a CD-ROM having a thickness of 1.2 mm. Because the optical disk apparatus **176** is provided for the voice reproducing apparatus **231**, regardless of whether pieces of particular recorded information are recorded in the optical disk **171** (or **174**) or the conventional optical disk **25**, the particular recorded information are read from the optical disk **171**, **174** or **25**, and a particular image can be displayed in the displaying unit **245** according to the recorded information. Also, when a user inputs pieces of input information to the inputting apparatus **242**, even though any of the optical disks **171**, **174** and **25** is set in the optical disk apparatus **176**, the input information are recorded in the optical disk **171**, **174** or **25**. Therefore, the user is not required to prepare both a conventional image reproducing apparatus for reproducing the image information recorded in the conventional optical disk **25** and an updated image reproducing apparatus for reproducing the image information recorded in an updated optical disk having a thickness of 0.6 mm.

In cases where a game program is recorded in the optical disk **171**, **174** or **25**, the user can play a game while observing a game image displayed in the displaying unit **245** and inputting pieces of operating data to the inputting apparatus **242** regardless of whether the game program is recorded in any of the optical disks **171**, **174** or **25**.

Also, in cases where the information processing apparatus **241** is utilized in a home, the information processing apparatus **241** can be utilized as an information terminal for a domestic use.

Also, as shown in FIG. **68**, in cases where a key board **245** is utilized as the inputting apparatus **242**, the information processing apparatus **241** can be utilized as a computer system **246**.

Having illustrated and described the principles of our invention in a preferred embodiment thereof, it should be readily apparent to those skilled in the art that the invention can be modified in arrangement and detail without departing from such principles. We claim all modifications coming within the spirit and scope of the accompanying claims.

What is claimed is:

1. A compound objective lens, comprising:

lens means, having a first convex surface and a second convex surface opposite to each other, for receiving a beam of incident light of one particular wavelength passing through an optical axis at the first convex surface, refracting the beam of incident light and emitting a beam of refracted light from the second convex surface; and

plural focal point generating means for receiving the beam of incident light not yet refracted by the lens means, generating from the beam of incident light a plurality of beams of divided light including a first beam of divided light and a second beam of divided light, converging the beams of divided light at a plurality of focal points which are placed on the optical axis on a side facing the second convex surface of the lens means on condition that the first beam of divided light transmits through a first substrate and is converged on an information recording plane placed at a first distance T1 from a surface of the first substrate at a diffraction limit and that the second beam of divided light transmits through a second substrate and is converged on an information recording plane placed at a second distance T2 (T1≠T2) from a surface of the second substrate at a diffraction limit.

2. A compound objective lens according to claim **1** in which the plural focal point generating means is a hologram generating from the incident light as the beams of divided light a plurality of beams of diffracted light having different diffraction orders.

3. A compound objective lens according to claim **2** in which the first beam of divided light is a beam of transmitted light which agrees with a beam of zero-order diffracted light generated by the hologram, and the second beam of divided light is a beam of first-order diffracted light generated by the hologram.

4. A compound objective lens according to claim **2** in which

the hologram is a phase modulation relief type of diffraction device,

a grating pattern of the hologram has a step-wise cross section and is formed in a concentric circle shape,

the grating pattern of the hologram is concentrically partitioned into a plurality of blocks,

a phase modulation degree of the incident light passing through the grating pattern of the hologram varies in a step-wise shape of four stairs for each of the blocks, and

a ratio of an etching width of a top stair to a length of the corresponding block and another ratio of an etching width of a bottom stair to the length of the corresponding block are respectively lowered toward an outer direction of the grating pattern of the hologram.

5. A compound objective lens according to claim **2** in which the hologram is a phase modulation relief type of diffraction device,

a grating pattern of the hologram is formed in a concentric circle shape and is concentrically partitioned into a plurality of blocks,

a phase modulation degree of the incident light passing through an inner portion of the grating pattern of the hologram varies in a step-wise shape of four inside stairs for each of the blocks,

the four inside stairs are composed of a top stair, a second stair, a third stair and a bottom stair in that order,

a ratio of an etching width of the top stair to a length of the corresponding block and another ratio of an etching width of the bottom stair to the length of the corresponding block are respectively lowered toward an outer direction of the grating pattern in the inner portion of the hologram,

another phase modulation degree of the incident light passing through an outer portion of the grating pattern of the hologram varies in a step-wise shape of two outside stairs for each of the blocks, and

a difference in width between the outside stairs is increased toward the outer direction of the grating pattern in the outer portion of the hologram.

6. A compound objective lens according to claim **2** in which

the hologram is a phase modulation relief type of diffraction device,

a grating pattern of the hologram has a step-wise cross section and is formed in a concentric circle shape,

the grating pattern of the hologram is concentrically partitioned into a plurality of blocks,

a phase modulation degree of the incident light passing through the grating pattern of the hologram varies in a step-wise shape of four stairs for each of the blocks, and

a ratio of an etching width of a top stair to a length of the corresponding block and another ratio of an etching width of a bottom stair to the length of the corresponding block are respectively lowered toward an inner direction of the grating pattern of the hologram.

7. A compound objective lens according to claim **2** in which

the hologram is a phase modulation relief type of diffraction device,

a grating pattern of the hologram is formed in a concentric circle shape and is concentrically partitioned into a plurality of blocks,

a phase modulation degree of the incident light passing through an outer portion of the grating pattern of the hologram varies in a step-wise shape of four inside stairs for each of the blocks,

the four inside stairs are composed of a top stair, a second stair, a third stair and a bottom stair in that order,

a ratio of an etching width of the top stair to a length of the corresponding block and another ratio of an etching width of the bottom stair to the length of the corresponding block are respectively lowered toward an inner direction of the grating pattern in the outer portion of the hologram,

another phase modulation degree of the incident light passing through an inner portion of the grating pattern of the hologram varies in a step-wise shape of two inside stairs for each of the blocks, and

a difference in width between the inside stairs is increased toward the inner direction of the grating pattern in the inner portion of the hologram.

8. A compound objective lens according to claim **2** in which the hologram is a phase modulation type of diffraction device and is made of a liquid crystal cell.

9. A compound objective lens according to claim 2 in which the hologram is a phase modulation type of diffraction device and is placed on a substrate of a birefringence material.

10. A compound objective lens according to claim 2 in which a positional relationship between the lens means and the hologram is fixed.

11. A compound objective lens according to claim 10 in which the hologram is formed on a lens surface of the lens means.

12. A compound objective lens according to claim 11 in which the hologram is placed on a lens surface of the lens means of which a curvature is higher than those of other lens surfaces of the lens means.

13. A compound objective lens according to claim 11 in which the hologram is placed on a lens surface of the lens means of which a curvature is lower than those of other lens surfaces of the lens means.

14. A compound objective lens according to claim 1 in which a numerical aperture of the lens means for the incident light converged at one focal point of the focal points differs from that for the incident light converged at another focal point of the focal points.

15. A compound objective lens according to claim 2 in which a grating pattern is formed in a first portion of a light-passing area of the hologram corresponding to an aperture of the lens means, and any grating pattern is not formed in a second portion of the light-passing area of the hologram.

16. A compound objective lens according to claim 15 in which a phase of the incident light passing through the second portion of the light-passing area of the hologram almost agrees with an average value of phases of the incident light passing through the first portion of the light-passing area of the hologram.

17. A compound objective lens according to claim 15 in which the grating pattern is formed in a step-wise shape having a plurality of stairs,

a surface height of the second portion of the light-passing area of the hologram in an optical direction is the same as a height of a stair selected from the stairs except a top stair and a bottom stair.

18. A compound objective lens according to claim 1 in which a numerical aperture of the lens means is equal to or higher than 0.6.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO.	:	5,815,293
DATED	:	September 29, 1998
INVENTOR(S)	:	Yoshiaki KOMMA, Sadao MIZUNO and Seiji NISHINO

It is certified that error appears in the above-indentified patent and that said Letters Patent is hereby corrected as shown below:

Title page, item [54] and col. 1, in the title should read --

--COMPOUND OBJECTIVE LENS HAVING TWO FOCAL POINTS, IMAGING OPTICAL SYSTEM FOR CONVERGING LIGHT WITH THE COMPOUND OBJECTIVE LENS, OPTICAL HEAD APPARATUS FOR RECORDING OR REPRODUCING INFORMATION WITH THE IMAGING OPTICAL SYSTEM, OPTICAL DISK HAVING TWO TYPES OF RECORDING--

Signed and Sealed this

Twentieth Day of March, 2001

Attest:

NICHOLAS P. GODICI

Attesting Officer

Acting Director of the United States Patent and Trademark Office

US005809349A

United States Patent [19]

Donner

[11] **Patent Number: 5,809,349**

[45] **Date of Patent: Sep. 15, 1998**

[54] **CAMERA WITH ADJUSTING DEVICE FOR OBJECTIVE LENS AND IMAGE CARRIER AND A FOCUSING PROCESS**

[76] Inventor: **Wilfried Donner**, Humboldtstrasse 16, D-33615 Bielefeld, Germany

[21] Appl. No.: **860,852**

[22] PCT Filed: **Jan. 10, 1996**

[86] PCT No.: **PCT/EP96/00088**

§ 371 Date: **Jul. 10, 1997**

§ 102(e) Date: **Jul. 10, 1997**

[87] PCT Pub. No.: **WO96/21882**

PCT Pub. Date: **Jul. 18, 1996**

[30] **Foreign Application Priority Data**

Jan. 10, 1995 [DE] Germany 195 00 507.4

[51] **Int. Cl.**[6] **G03B 5/00**; G03B 5/08; G03B 13/36

[52] **U.S. Cl.** **396/89**; 396/342; 396/437

[58] **Field of Search** 396/89, 342, 50, 396/437, 79, 80

[56] **References Cited**

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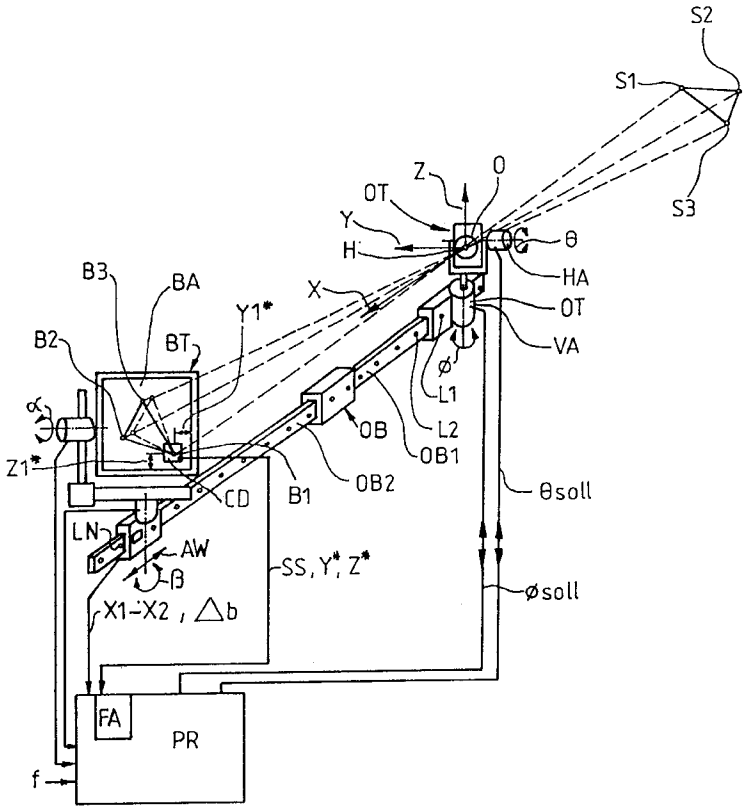
Primary Examiner—W. B. Perkey
Attorney, Agent, or Firm—Browdy and Neimark

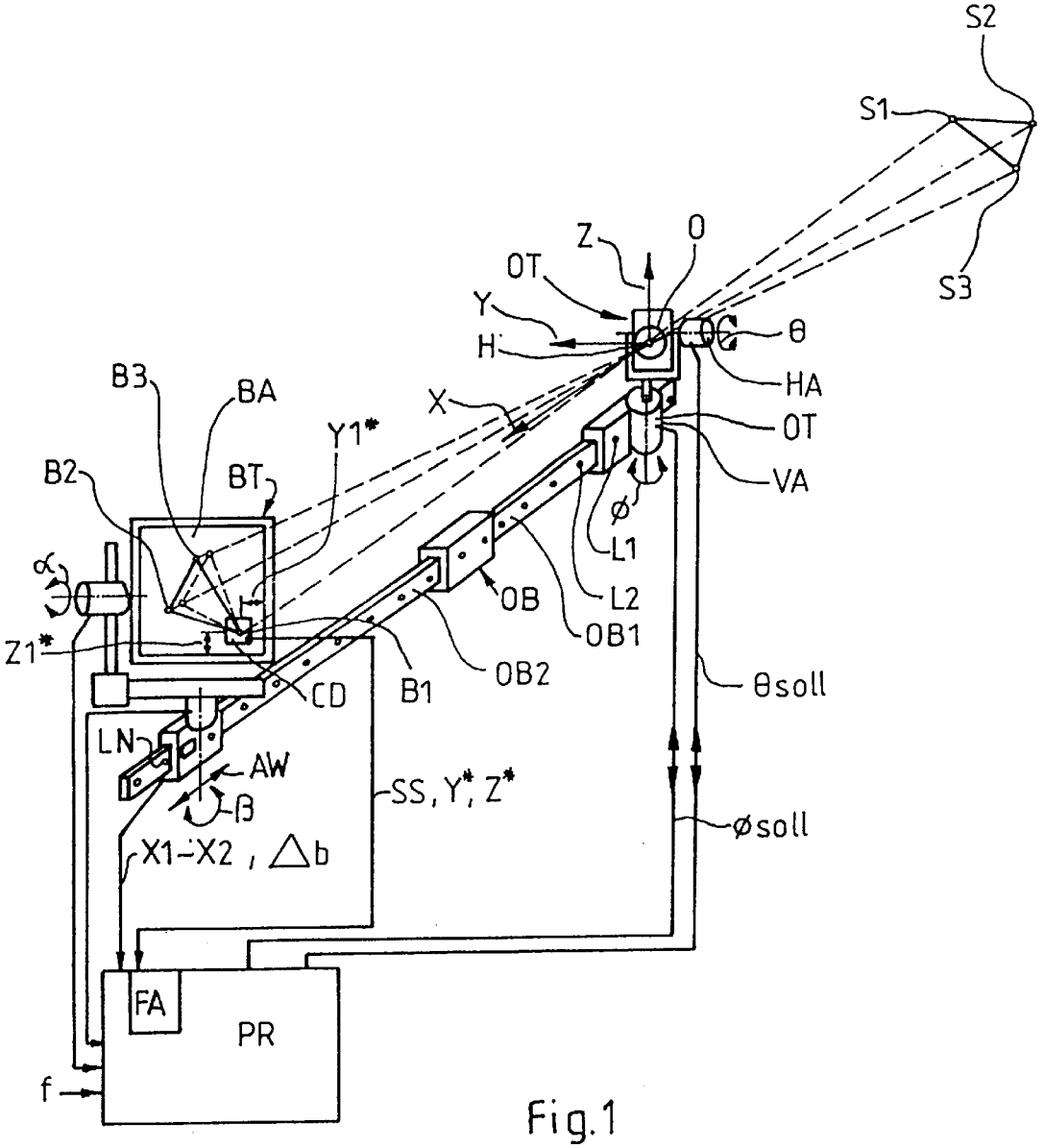
[57] **ABSTRACT**

A camera is described with objective lens and image reception carrier equipment and a focussing process. From related extension measured distances (x1–x2, x2–x3, δb), final adjusted, set-point focus values (θ_{soll}, Φ_{soll}) are obtained in the course of the focussing of various image points (B1, B2, B3) for a multiply pivotable, bellows camera which produces the pivoting angles (α, β, θ, Φ), the latter used for a double focussing compensation; by this means, the direct making of an exact spatial interval distance measurement between the objective lens carrier (OT) and the and image carrier (BT) is dispensed with, since at least a relatively accurate extension measurement (δb) at a predetermined objective lens setting is obtained and evaluated.

The optical bench (OB) can be equipped with a raster arrangement for the image carrier (B1), the objective lens carrier (OT) and be constructed in sections (OB1, OB2).

14 Claims, 5 Drawing Sheets




S2
S1
S3
Z
O
OT
Y
H
θ
HA
OT
VA
X
Y1*
B3
BA
B2
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α
Z1*
CD
B1
OB2
OB
OB1
L2
L1
ø
θsoll
øsoll
LN
AW
β
SS, Y*, Z*
X1-X2 , △b
FA
PR
f

Fig.1

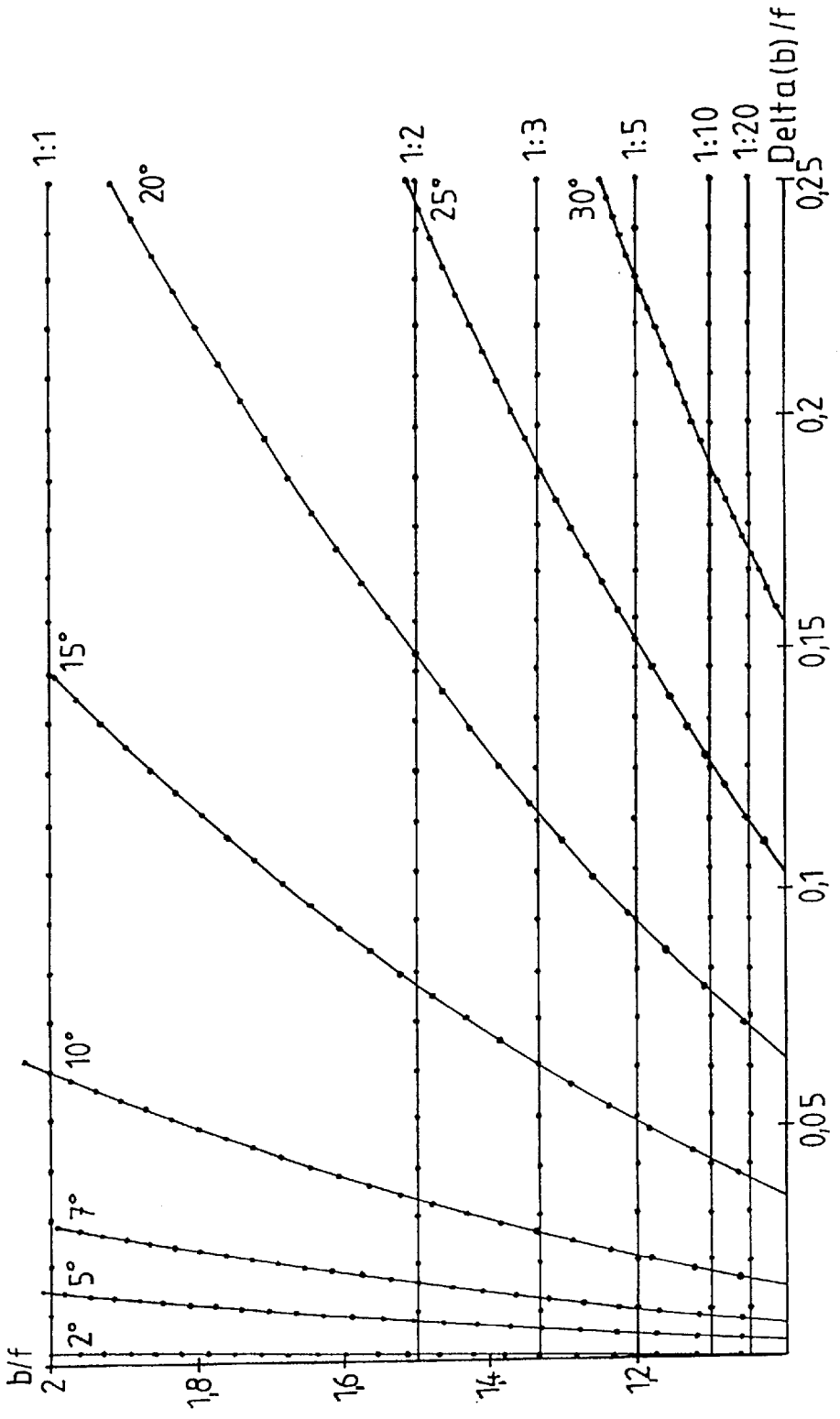
b/f
2
1,8
1,6
1,4
1,2
2°
5°
7°
10°
15°
20°
25°
30°
1:1
1:2
1:3
1:5
1:10
1:20
Delta(b)/f
0,05
0,1
0,15
0,2
0,25

Fig. 2

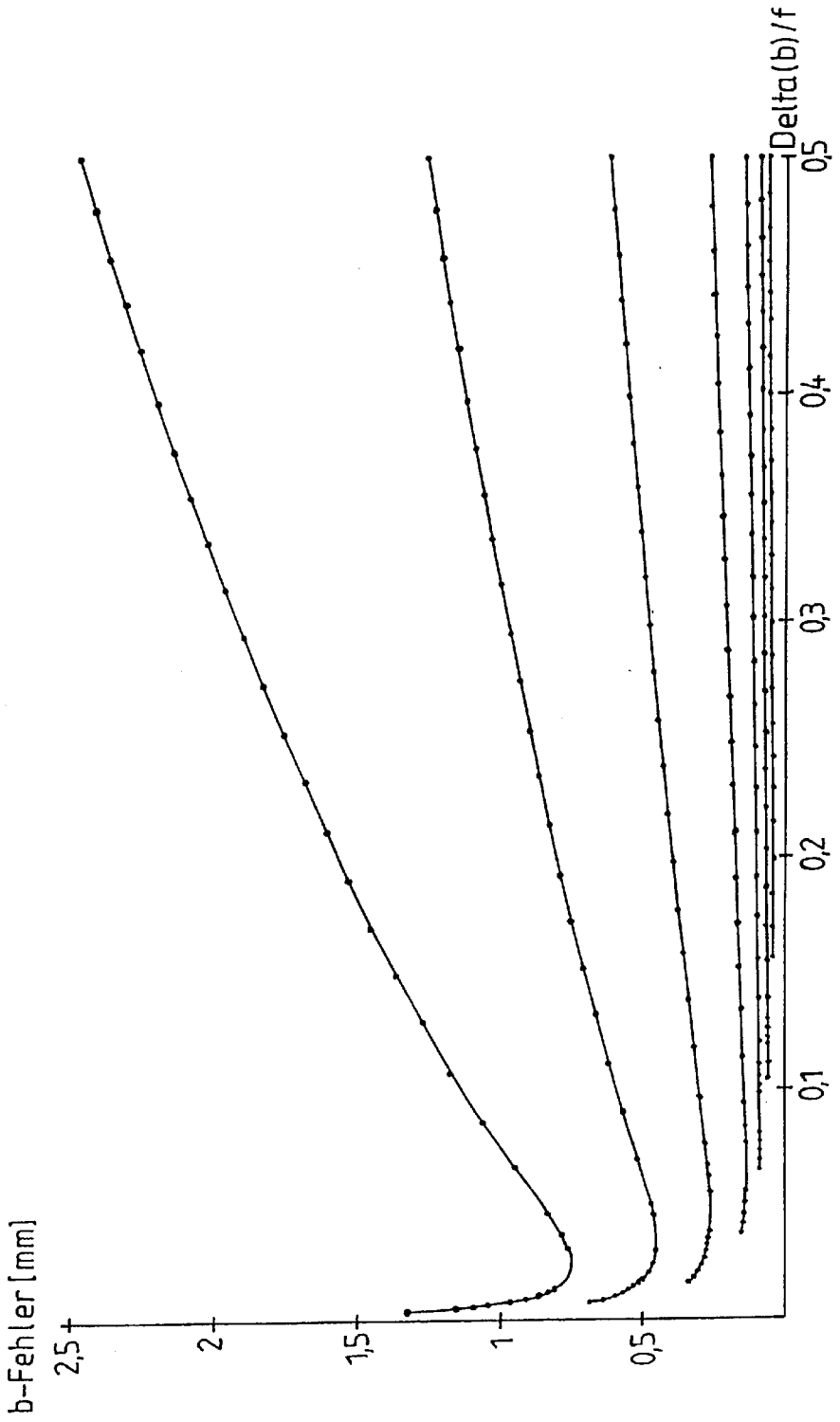

Fig. 3

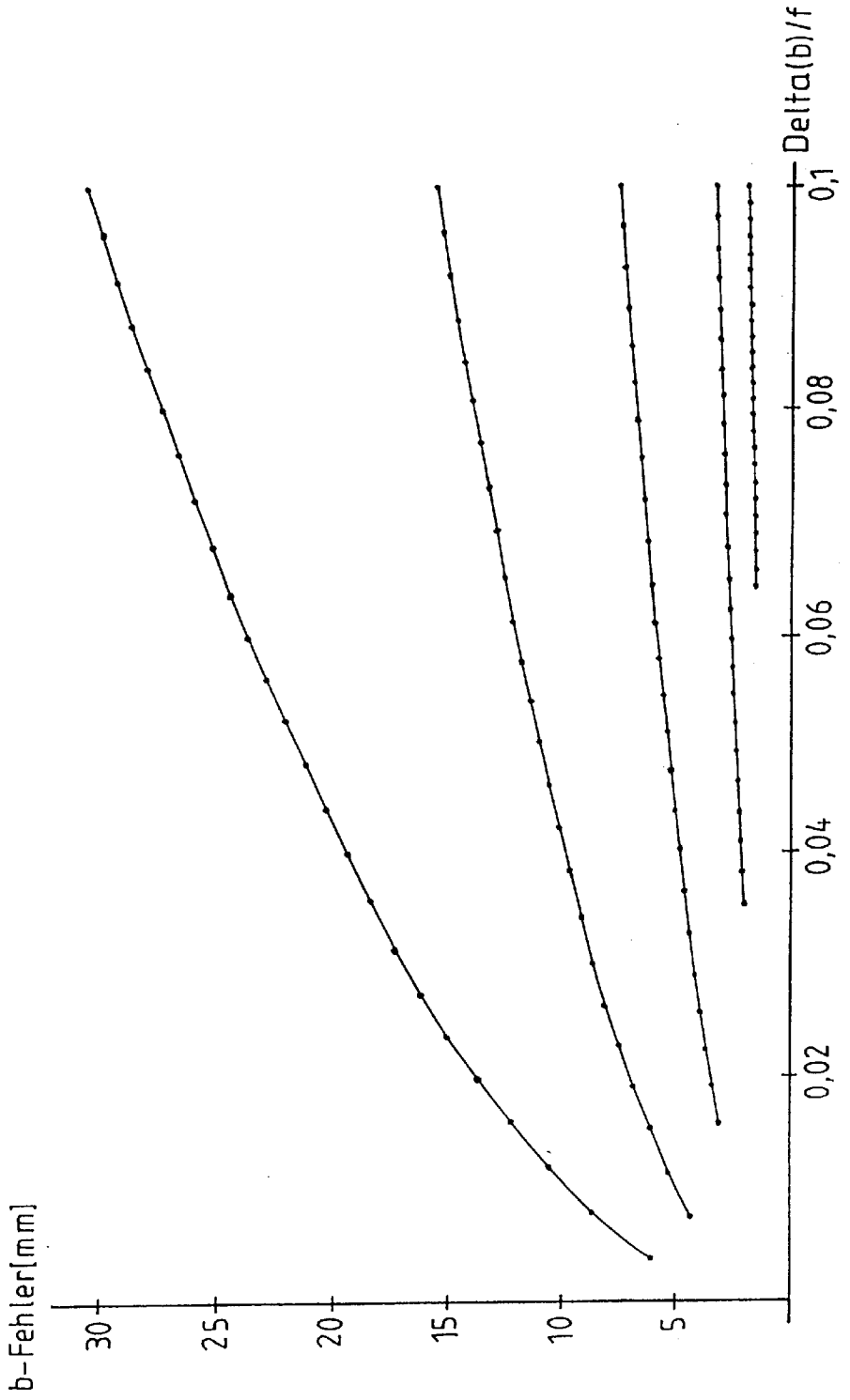
b-Fehler[mm]
30
25
20
15
10
5
0,02
0,04
0,06
0,08
0,1
Delta(b)/f
f=1800mm , $\sigma_{\Delta b}$=10µm , σ_θ=1'

Fig.4

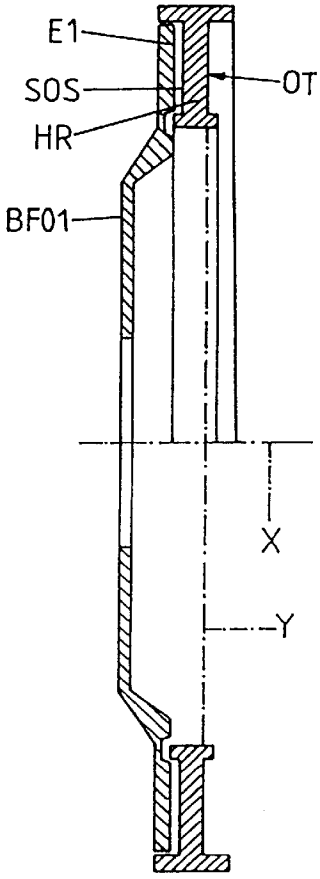

Fig.5

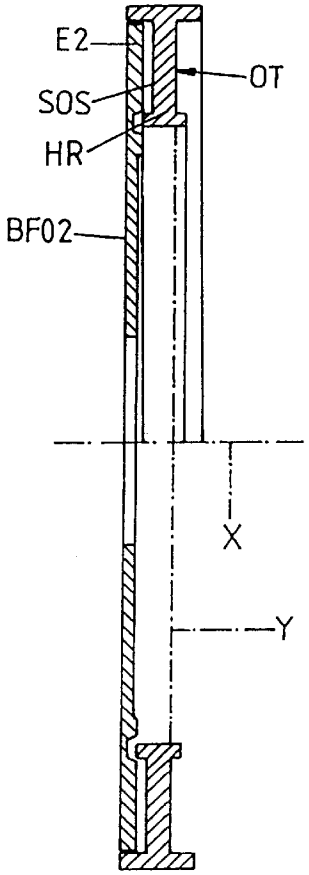

Fig.6

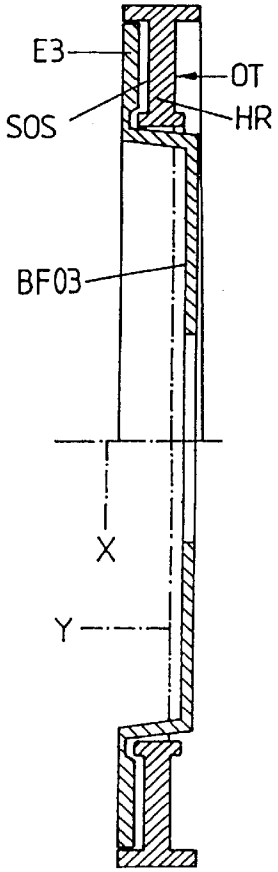

Fig.7

CAMERA WITH ADJUSTING DEVICE FOR OBJECTIVE LENS AND IMAGE CARRIER AND A FOCUSING PROCESS

The invention concerns a focusing process for a camera, said camera:

having an objective lens carrier and an image carrier, which are maintained positionally relative to one another in a straight line optical bench direction in which the spatial interval between them is variable, wherein the said interval changes are signaled to a microprocessor,

being equipped with an objective lens carrier and an objective lens secured to pivot about two axes, said axes being vertical to one another and to an optical bench, the two respective objective lens angles and the focal length of said lens being input to a processor,

possessing an image carrier in which an image screen, namely a frosted glass plate is secured, which screen is moveable about two axes vertically disposed to one another and to the direction of the bench, the two respective image reception angles being sent to the processor,

having in the image screen, a focusing adjustment sensor, which signals a degree of focus, and is positionable in two image reception coordinates which, together with the focus value, are conducted to the processor,

further possessing at least three select image point areas, which lie in a secondary image plane for the simultaneous adjustment of the focus,

having these said image point areas on the image screen subjected to determination of their respective image screen coordinates by means of a change in the interval between the image carrier and the objective lens sequentially for each area through focus adjustment, and the said positional changes of the image carrier are input to the processor,

obtaining, by means of the input data so collected, from the processor computer a determination of the positional parameters of the image screen as well as of the secondary image from which, together with a further image parameter necessary for computation, this latter originating in the solution of image equations, there will be calculated fixed adjustment values suitable for the pivoting of the objective lens carrier along with a value for the adjustment of the interval between the carriers of the image and the objective carrier, the results thereof being made available, so that the new image plane adjusted by these set-point values comes as close as possible to coinciding with the image screen.

A camera of this type is brought into common knowledge by DE 34 33 412 C2. In this case,

the objective lens focal length,

an image scale, based on

the spatial coordinates of the three select real image point areas, which were determined from the optical imagery of a scale of the image, to which purpose a focus sensor serves as an aid,

the angle adjustment of the objective lens and image screen inclinations and degrees of deviation,

and the spatial interval between the principal plane of the objective lens to the image screen,

are either input to the processor by a keyboard or provided direct with measured values.

From these data the processor computes the set point signal for the adjustment angle and the said interval. In this computation, the processor makes use of the Law of Scheimpflug according to which, the objective lens plane, the plane to which the real image belongs and the plane to which the focused image points belong, must mandatorily intersect in one straight line.

Thus, in accord with a preset adjustment, the selected image point area of the real subject, by means of the so called double focus compensation, is imaged as sharply as possible. With this apparatus, in addition the absolute space coordinates of the image points and the structural data of the imagery optics are required as starting point values for a final solution of the image equations. This is in order to find such a position of the image screen in relation to the setting of the objective lens, that the select image point areas lie with the sharpest possible focus in the image screen. This requires a substantial array of means of measurement having high requirements as to precision. Moreover, the Law of Scheimpflug, which was employed, is valid only for the imagery in a paraxial zone of a thin lens, making it of little meaning in practice.

Thus, it is the purpose of the invention, to achieve an automatic focus adjustment of a real image, using the camera described in the introductory passages, employing double focus compensation with the reduced demand for measurement equipment, simplified apparatus and an objective lens acceptable in practice.

The accomplishment of this purpose lies therein, in that one of the objective lens adjustment parameters can be altered in given quantity, and as this is carried out, for a selected image point, the extension difference of a extension adjustment apparatus lying between its two focus adjustments in the bench direction, is measured. This brings about a first set of the of the image equations by the use of the original objective lens adjustment parameters and an undetermined image distance, and a further set of image equations with the inclusion of the now varied objective lens adjustment parameters and the undetermined image distance. These two sets are equalized for the image distance as altered by the extension difference and solved for the set-point adjustment values. Another approach to solution is the functional derivation of the image comparisons with reference to the objective lens positional parameters and involving the prior adjustment changes made from time to time along with the measured extension difference, all included in the said derivations, and, in accord with the set-point parameters, solving for the said undetermined object distance.

Advantageous embodiments are described in the subordinate claims.

The new process renders the absolute distant measurement between the objective lens carrier and the image carrier superfluous. It now suffices, that the respective angular measurement equipment is at hand and the relative measurement of the interval, that is, the extension changes in the course of the various focus placements, as well as the coordinate determinations on the screen, are to be available.

The adjustment process may be summarized in the following sequence of operations:

The photographer adjusts the perspective by deflecting the screen and subsequently carries out a rough prefocusing of the image. He does this generally through altering the extension and in some cases by tilting the objective lens. The parameters "a_m" and "b_m" of the screen, which determine its normal vector, but not, however, its distance from the objective lens, which is

not necessary here, as well as the adjusted deflection angles θ_o and Φ_o of the objective lens are read off by the built-in goniometer in the computer.

The determination of the coordinates bi=(xi, yi, zi) from at least three image points by means of focusing is done with the aid of a CCD-sensor (or the equivalent thereof); meanwhile, the camera objective lens is swivelled through the angles θ_o and Φ_O. The X-axis is in this case, that axis parallel to the optical bench of the camera, and which penetrates the center of the objective lens. The Y-axis runs vertically thereto in a horizontal manner while the Z-axis stands in a vertical position.

The alignment of that plane, for which the sums of the square of the intervals of the measured image points are at a minimum. The parameters for this original image plane are a_o, b_o, d_o, which is then given

through: $=a_{ox}+b_{oy}+d_o$

The determination of the distance of image b from the difference in the extension δb by focusing a specific image point at a given objective lens pivoting angle change—in accord with the equations (5) to (7),

The determination of the distance of image b with an unpivoted objective lens in accord with equation (8),

The determination of the z-axis parameter d_o by equation (9),

The computation of the set-point objective lens adjustment angles θ_{soll}, Φ_{soll} and the screen intercepts xb_{soll} with the X-axis in accord with the equations (1), (2), and (3).

The starting screen plane will be depicted in the object space. The plane so produced, upon varied objective lens pivoting, will be re-imaged in the image space with the purpose, of aligning the newly obtained image plane parallel to the installed screen. The necessary objective lens adjustment angles, θ_{soll}, Φ_{soll} as well as the screen intercept xb_{soll} which is to be included, from the screen and X-axis, yield the following:

$$\sin\theta = -\frac{f\left(a_m^2 - a_m\frac{a_0 f + d_0\cos\theta_0\cos\phi_0}{f - d_0\sin\theta_0} + b_m^2 - b_m\frac{b_0 f + d_0\cos\theta_0\sin\phi_0}{f - d_0\sin\theta}\right)}{\frac{d_0 f}{f - d_0\sin\theta_0}(1 + a_m^2 + b_m^2)} \pm \tag{1}$$

$$\left[f^2\left[\left(a_m^2 - a_m\frac{a_0 f + d_0\cos\theta_0\cos\phi_0}{f - d_0\sin\theta_0} + b_m^2 - b_m\frac{b_0 f + d_0\cos\theta_0\sin\phi_0}{f - d_0\sin\theta_0}\right)^2 - a_m^2 + 2a_m\frac{a_0 f + d_0\cos\theta_0\cos\phi_0}{f - d_0\sin\theta_0} - \left(\frac{a_0 f + d_0\cos\theta_0\cos\phi_0}{f - d_0\sin\theta_0}\right)^2 - b_m^2 + 2b_m\frac{b_0 f + d_0\cos\theta_0\sin\phi_0}{f - d_0\sin\theta_0} - \left(\frac{b_0 f + d_0\cos\theta_0\sin\phi_0}{f - d_0\sin\theta_0}\right)^2\right] - \left(\frac{d_0 f}{f - d_0\sin\theta_0}\right)^2\right]^{\frac{1}{2}} \times \left[\frac{d_0 f}{f - d_0\sin\theta_0}(1 + a_m^2 + b_m^2)\right]^{-1}$$

$$\sin\phi = \frac{b_0 f + d_0\cos\theta_0\sin\phi_0 - b_m(f - d_0\sin\theta_0) - b_m d_0\sin 0}{d_0\cos 0} \tag{2}$$

$$x_b = -\frac{d_0 f}{f - d_0\sin\theta_0 - \frac{a_0 f + d_0\cos\theta_0\cos\phi_0}{f - d_0\sin\theta_0} d_0\cos\theta\cos\phi} \tag{3}$$

The image compensation of thin lenses serves exclusively as the physical basis for the above. It is yet to be proven, that the process lends itself in a simple manner also for the application of optional objective lenses, the optical characteristics of which may be modified through their focal length as well as the positioning of their two principal planes.

The objective lens, is now pivoted about the angles θ and Φ (in this case, θ=Φ=0, precisely the situation, in which the objective lens is positioned vertically on the optical bench of the camera.) The screen is to be displaced parallely, in such a manner that it intersects the X-axis at the value xb.

Generally, also the following transformation of the input data is carried out:

$$(\vec{b}_i, a_m, b_m, \theta_o, \phi_o) \rightarrow (a_o, b_o, d_o, a_m, b_m, \theta_o, \phi_o) \rightarrow (\theta, \Phi, I_l) \tag{4}$$

The two image equations of the original image plane and the new image plane which come to lie in the screen, are drawn from the invariant real image plane, on which account the two object planes are directly correlated. In this way, equations arise, which are not based on the principle of Scheimpflug, since no real image plane is defined, nor are the equations defined for an intersecting straight line between the real and the objective planes as well as the objective and image planes.

In the relationships (1), (2) and (3), for the adjustment of the camera, the following parameters of the original image plane, the screen and the objective lens, a_o, b_o, a_m, b_m, θ_o, ϕ_o are quite easy to determine : a_m, b_m,θ_o and ϕ_o are available directly from the readout from the standard applied goniometer, and a_o, and b_o, from the measurement of the extension upon focusing the image point Bi. The measuring of the further parameter d_o of the original image plane, however, does not evoke any insurmountable technical problems, except that the absolute value of the extension for each of the points Bi must be defined very precisely (i.e. on the basis of 50 . . . 100 μm tolerance). Since the value of the extension length runs to as much as one meter or more, this

means that the interval of the image point Bi from the objective lens must be directly measured within a possible error of maximum 0.1 promille. This is indeed possible, but technologically somewhat involved, on which account we have developed an indirect process for the determination of the extension length. Therefore, in accord with the invention, an indirect determination of this parameter has been undertaken.

The fact has been made use of, that the image length b of an imaged object point S from the objective lens changes when the lens is pivoted. The dimension of this image length variation δb depends in an unquestionable manner on the distance of the subject to lens distance s of the point S, so that the value of x can be determined from δb and the adjustment angle θ which was used. If s is known, the absolute value of b can be determined directly from the image distance equation. The absolute error for the value of b lies in the general range of the measurement error of the extension difference δb, which is very exactly determinable (up to ca. 50 μm) so that the relative error does not overstep the allowable limit.

This method is particularly simple, if one only pivots the objective lens about the Y-axis through the angle θ, (that is, I=0) and brings into play an object point S, which lies in the XY-plane. Then the interval of this point from the objective lens plane is given solely through its image distance s and the adjustment angle θ by:

$$\gamma = \frac{s\cos\theta}{f}$$

Valid for the computation of the image distance b of the image point S is:

$$b(s,\theta) = \frac{s}{1-\gamma} = \frac{fs}{fs - s\cos\theta} \tag{5}$$

The extension difference δb (s, θ) is defined by

$$\Delta b(s,\theta) = b(s,0) - b(s,\theta) = \frac{fs}{f-s} - \frac{fs}{f - s\cos\theta}\ . \tag{6}$$

From which is derived the following expression for the distance s of the real subject:

$$s = \left[\frac{\Delta bf(1+\cos\theta) \pm \sqrt{(\Delta bf(1+\cos\theta))^2 - 4bf^2(\Delta b\cos\theta - f(1-\cos\theta))}}{2(\Delta b\cos\theta - f(1-\cos\theta))} \right] \tag{7}$$

Only the solution employing the plus sign for the square root is relevant, because only this yields a value s=f, which leads to a real image of the point. The image distance of the point for θ=0, measured in relation to the extension differential δb, can be determined from:

$$b(s,\theta=0) = \frac{fs}{f-s} \tag{8}$$

It is now possible, to produce the absolute values of all other measured relative extensions (i.e. the x-coordinates of the image point Bi which is to be sharply imaged). This can be done without actually measuring any image distance directly, since the X-axis is now provided with a defined zero point. The y- and z- coordinates are simply to be derived from the position of the moveable CCD chip on the screen, the X-axis position there and the pivot angles α, β of the screen. From the now absolute definable intercept point of the oringinal image plane with the X- axis, x_o, the Z-axis intercept may be found by

$$d_o = -a_o x_o \tag{9}$$

and input into the equations (1), (2), and (3).

The precision of the process can be increased even to a higher degree, in that one has not only one, but several extension differentials measuring different adjustment angles θ and obtaining from these, values for s.

If, during the pivoting of the objective lens, the CCD chip is always maintained, by means of appropriate motorized control, on the tie line between the objective lens center and the start position (θ=O), a great number of δb-values for many different values of O can be determined during the objective lens pivoting procedure, whereby the precision becomes very great for the obtained values of the subject distance.

Should the occasion arise, that no appropriate object point which lies in the XY-plane is available, naturally, any optional object point may be used; the calculation, however, becomes a bit more complicated, since the interval of the point from the plane of the objective lens now also depends on its relationship to the Z-axis. The following equation serves this purpose:

$$\gamma = \frac{1}{f}\ (s\cos\theta - z_s\sin\theta) \tag{10}$$

and from this:

$$\Delta b(s,z_s,\theta) = fs\left(\frac{1}{f-s} - \frac{1}{f - s\cos\theta - z_s\sin\theta}\right). \tag{11}$$

It is necessary that there are at least two values for δb upon measuring different adjustment angles θ; with the readings of δb (θ) so obtained, then the equation (11), by means of variations of the free parameters s and z_s be applied. The parameter z_s is no longer needed, from s, in accord with (8), the image distance b (θ=O) can be determined. The exactitude of the applied parameter increases, of course, with the number of the measured values; also, it is possible here, to carry out the measurements very quickly by means of automatic back-check on the CCD-chip for very many values of θ.

Going from the fact, that during the determination of the extension differentials, the measuring CCD must always be set at the same position in the image, this proves useful in that one requires the complete information which the focusing process delivers. The process is based on the principle, that for the observed image region, a focusing value quantity is produced, which is dependent upon the interval of the measuring CCD (in the x direction) from the focus and is at a maximum when focusing is achieved. Outside of the focus, the number is a value for the interval of the CCD from the focus point. If one makes the most of this, one need only once, at the beginning, to run through the area of the focus, in order, for the observed image region, to ascertain the run of the focus measuring numbers in dependency of the relative position on the X-axis. From the lessening of the focus measuring number upon pivoting the objective lens, then the decision can quickly be made regarding the focus and then directly on the extension difference, without being required to refocus anew from time to time. This method of procedure enables a quicker measuring of the extension difference from δb in relation to the pivot angle θ of the objective lens.

The method presented here makes it possible to determine solely from the image information, all necessary parameters. In addition, there is avoided the determination of the image distances of the focussed, repetitively given image points through direct length measurement, which requires much time and trouble from a technical standpoint, and hence is costly to carry out. Instead of this, the object distance of a

principally optional subject point is computed through the measurement of the image distance of its image point at various objective lens adjustments and from this the absolute value of the image distance is determined in the case of a non-pivoted objective lens. The X-axis of the "bench fixed" camera-coordinate system is also provided with a zero point, the interval of which from the objective lens is very exactly known and relative to this, all further extension differentials can be measured with a high degree of exactness. The active length capacity of the displacement pickup can be only a few cm long.

Additionally, all problems are avoided, which can come up upon a direct interval length determination from thermal expansion of the optical bench or from the not entirely exact combination of a sectional optical bank which may involve several components. It is not at all important, whether the objective lens and image standards are generally connected with one another. The intervals, which in the screen plane must be still directly and absolutely determined (all lengths in y* and z* directions), lie in a cm-range and on this account are likewise easily determined by an economical motion pickup and within the required limits of precision.

It is common knowledge, that the so-called migration of the image point leads to undesirable perspective variation. This can be avoided by focusing with double focus compensation, when a thin lens is pivoted around such an axis that it intercepts the optical axis. On this account, in the case of the normally available mechanical pivot axes offset to the optical axis, virtual pivoting about the intersecting virtual axes is carried out, for which complicated compensation pivoting and displacement are necessary. In this case, undesired migration of the objective lens standard often occurs which leads to reaching the border position. Furthermore, often an undesired strong migration of the entire image to be focused occurs in the image field of the screen.

The migration occurs in still greater magnitude for the conventional objective lens as installed in practice, the image scaling behavior of which is described by means of good approximation by means of two principal planes. In this case, exhaustive computations show that migration can be avoided, if the pivoting axes intersect the optical axis in an area centrally located between the main plane and the main plane H'. The most favorable location of the intercept point of the axes is progressively advancing toward the main objective lens plane H' from the midpoint between the main plane, following the sequence: macro lens, normal objective lens II, normal objective lens I and wide angle objective lens.

Cognizance of these facts can be used to an advantageous simplification for objective lens adjustment, in that each objective lens is installed in the objective lens standard in accord with its optimal pivoted position which avoids migrations by means of an insert which holds the objective lens entry plane satisfactorily axially disposed at the receiving plane of the standard. By this means, with the pivoting of the standard, each installed objective lens moves about the optimal pivoting axis at any time without further compensation adjustments, so that migration is considerably reduced. The employment of this simple adapter insert simplifies not only the adjustment of the objective lens, but it also simplifies, in many cases, the focusing of an image point when a pivoting of the objective lens is undertaken.

Further, the measured differential extension values, which are of use in image computation, are well correlated to the respective pivoting angles, an advantage which allows correspondingly exact computation results.

The employment of the objective lens adapter insert is advantageous and inventive, independently of the use in the automatic adjustment system, since even with a manual, or semiautomatic adjustment of the objective lens, the up to now inescapable migrationing of the image is avoided thereby.

DESCRIPTION WITH ILLUSTRATION REFERENCES

Advantageous embodiments are presented in the FIGS. **1** to **7**, wherein:

FIG. **1** shows the camera in a simplified presentation, without bellows and with a schematic control apparatus,

FIG. **2** presents the functional dependency of the image distance on the extension difference upon various pivoting angles of an objective lens with normalized focal length,

FIG. **3** exhibits absolute error of the focal length upon given measuring errors for a 65 mm objective lens at varied pivoting angles,

FIG. **4** shows image distance error for a 1800 mm objective lens, and

FIGS. **5**, **6** and **7** show an objective lens standard frame with various adapter inserts.

FIG. **1** illustrates a camera with an optical bench (OB), which can also be assembled from several sections. Upon this, an objective lens carrier (OT) is mounted, which carries an objective lens (O), which is secured in such a manner that it can pivot about two axes (Y, Z). The pivoting angles (θ, I) are signaled to a processor (PR) by means of a goniometric pickup. If necessary, electrically controlled objective lens pivoting drives are provided (HA, VA) which are regulated by the processor (PR).

Further, on the optical bench (OB) an image carrier (BT) is installed, to carry an image reception surface (BA), which, in like manner to the said objective lens, is pivotable about two axes. This reception surface (BA), during the installation has a frosted glass, i.e. a screen, inserted. Also, the pivoting angles of said reception surface and screen (α, β) are communicated to the processor (PR) as above. Further, these pivotings are, if necessary, controllable by electrically controlled drives.

In the image reception surface is a positionable CCD-sensor (CD), by means of which, when called upon, two relative positional coordinates (Y1*, Z1*) on the screen can be communicated to the processor (PR). These positional coordinates can be taken from a positioning device of the CCD-measuring sensor (CD). Beyond this, the CCD-measuring sensor (CD) imparts focusing relevant, image point brightness signals (SS) of the currently selected area to the processor (PR) for evaluation of a focus criterion in conventional manner by means of a Fourier analyzer (FA).

The image carrier (BT) is mounted axially adjustably on the bench (OB) with an extension apparatus (AA), this also providing an adjustment signal to the processor (PR) which is interpreted as the extension distance. The extension adjustment apparatus (AA) has, if necessary, an electrically controlled drive, which is controlled by the processor (PR).

For an over view of the method of operation of the camera focusing adjustment, a Cartesian coordinate system has been drawn in, the X-axis of which runs through the principal point (H) of the objective lens (O) and parallel to the bench (OB). In case a pivotable bench is provided, the angular deviation of this with reference to the standard must be taken into consideration by an appropriate coordinate transformation. Extending upward is the Z-axis while the Y-axis

extends sidewards. In the simplest case, three real subject points (**S1**, **S2**, **S3**) are to be sharply imaged on the image reception surface (BA) and arranged in a definite perspective, one to the other.

In the manual presetting by hand, the three real points (**S1**, **S2**, **S3**) lie generally in a starting image surface which deviates from the screen and the corresponding three image points (**B1**, **B2**, **B3**). In the example, the first image point (**B1**) with the positional coordinates (**Y1***, **Z1***) is focused sharply on the screen by the sensor (CD). The second and third image points, (**B2**, **B3**) lie outside of the screen.

From this originating basic positioning, in the course of the process, the focusing adjustment is undertaken. For this said adjustment, repeated extension alterations are made, with the aid of the positioning of the CCD sensor (CD), on the second image point (likewise the third) which at the start is still not sharply seen on the screen, until sharp focus is attained. Thereby arise the extension difference data (**x1**–**x2**, **x2**–**x3**) for the position of the points in the X-direction. Now, the Y* and Z* position coordinates can be computed back to the screen, given the image carrier angle placements (α, β) in relative coordinates which describe the inclination of the original image plane.

For the further computations, it is foreseen to undertake an image distance determination, for which purpose, the objective lens (O) is pivoted about a given angle (θ) and a previously sharply adjusted measuring point is refocused anew, whereby the distance of extension change (δb) is determined. With the inclusion of the objective lens focal length (f), which is customarily transferred in electrically coded form from said lens to the processor (PR), the output signals (θ_{soll}, I_{soll}, xb_{soll}) ("soll" meaning "set value") which are valid for the angular deviation of the image points into the new image plane parallel to the screen and their corresponding parallel displacement in the X-direction, these can be computed into said plane and determined.

In FIG. **2**, the dependency of the image distance (b) on the extension difference (δb) is illustrated. Both quantities are normalized as to the focal length (f), whereby the graph becomes independent of (f). The pivot angle runs (from top to bottom):

θ=2°, 5°, 7°, 10°, 15°, 20°, 25° and 30°.

The greater the pivoting angle, just so much better can the the image distance be determined, since a small image distance calls up a large extension difference. If an individual value b_f is known, and for this, b_f does not allow itself within the bounds of measurement technology, to be greater than 1, and this serves for the corresponding (very large) subject distance s_f.

$$\frac{s_f}{f} = \frac{\frac{b_f}{f}}{\frac{b_f}{f} + 1} \quad \text{where } b_f < 0,\ s_f > 0 \tag{12}$$

With this subject distance, s_f can be found immediately as the image distance without further measuring of the focal distance (f).

The new type of apparatus requires thus no special lineal distance measuring equipment for the measurement of the objective lens to the screen interval distance. Accordingly, such an interval value or an image scale or the like are not present for input to the processor, since they have been replaced by the extension difference measurement. The means of measurement already provided were employed. The new computational procedure does not require the measurement of the absolute interval between the image points and the objective lens.

Adjustment of the angle and the extension in the data acquisition procedure can be carried out manually, whereby the focus value will be displayed by the processor, and, if required, the processor can output electrical positioning signals automatically. The input of the set-angle and the set-extension, i.e., the final corrected values thereof, can also be done by hand on the basis of processor produced placement displays or, if desired, be done directly by electric positioning means through said processor.

FIGS. **3** and **4** show error graphs for an objective lens with a 65 to 1800 mm focal length, whereby an extension precision of 10 μm and an angular accuracy of 1' are assumed. Further, a pivoting angle of θ=5°, 7°, 10°, 15°, 20°, 25° and 30° have been chosen as parameters. In the case of sizable pivoting angles, error, even in the case of large focal lengths is held at a low value. Since, however, relatively large extension lengths are to be measured in these procedures, it has proved advantageous, if, using the extension distance (AW) which said distance can be found with the required precision in accord with measurement technology, the x-coordinate determinations are taken therefrom employing a combination of a roughly incremental sample, but an exact standard of measurement. For this purpose, the optical bench (**03**), FIG. **1**, is provided with a mechanical incremental means, i.e. a regularly perforated, linear raster (**L1**–**L2**) that serves the incrementally exact positioning of the objective lens carrier (OT) and the image carrier (BT) on said optical bench by pin insertion.

Also, several bench sections (**OB1**, **OB2**) may be incrementally exactly linked together by means of pin insertion in the perforated segments. The x-coordinate determination is done thus, first as shown with a relatively large error, whereafter a resetting into the next neighboring incremental section is made and, in the corresponding raster measurement the remainder from the found raster point is added on, so that the absolute total error is only a little larger than that of the extension distance. This also permits working with small pivoting angles θ in the case of small extension distances, whereby, in spite of all, a high precision of the image distance determination is achieved.

The raster length will, in practice, be chosen smaller than the length of the extension distance, and a multiple greater than the greatest absolute error, which arises upon a given pivoting angle.

Through the hole and pin raster, there arises another alternative for indirect image distance or scale determination, in that the objective lens carrier (OT) is displaced by at least one increment length and before and after a focus point of a real point is made, whereby the extension length is ascertained.

The incremental divider on the optical bench and the related incremental devices on the standards and the bench connections are advantageous developments of the camera arrangement for the application of the of the new process of focusing placement.

As already mentioned, the given formulae extend themselves in the case of objective lenses with several principal planes. Besides this, it must be taken into consideration that the pivoting of the objective lens is often not about a principal plane axis, but parallely offset therefrom. By means of the interval d_h the principal plane yields a parallel offset h to the image plane in the direction out from the objective lens from the relationship $h=d_h \cos \alpha$

From this, can be evolved the parameter of the displaced image plane:

$$d_m^{\,v} = \tag{13}$$

$$d_m - h\sqrt{a_m^2 + b_m^2 + 1} = d_m - d_h(a_m\cos\Phi\cos\theta + b_m\sin\Phi\cos\theta - \sin\theta)$$

By conversion computing to the pivot point coordinate system, the parameters-of which are indicated with the raised "h" index, and upon introduction of the set-point objective lens pivot angle, there is obtained the extension adjustment for the doubled focus placement as seen in:

$$x_b = -\frac{d_m^{\,v}}{a_m} + \frac{d_h}{a_m}\,(a_m\cos\Phi_p\cos\theta_p + b_m\sin\Phi_p\cos\theta_p - \sin\theta_p) \tag{14}$$

and for the Z-axis section:

$$d_m^{\,v} = d_m^{\,H} + a_m A_1 \cos\phi_p \cos\theta_p + b_m A_1 \sin\theta_p \cos\theta_p - a_l \sin\theta_p \tag{15}$$

Wherein, A_1 is a displacement parameter and wherein the index sub "p" always represents the "set point" index in other equations.

In the above, various methods of solving are presented for the computation of the set-point adjustment value. In the case of the greatest simplification of the formulae, which are valid for the thin lenses, the differential relationship of the extension distance to a objective lens pivoting angle alteration is brought into the equations and a final solution for the sought after set-point position value results.

If more complex equations are applied, which produce a more exact definition of the image system, then two kinds of considerations for the solution of the equations appear. In the case of one method, for the related parameter pairs of the extension upon focusing, that is, the start extension and the start pivoting angle, are brought, as indeterminate quantities into a first equation system. The final extension, which is defined from the indeterminate values and the extension change, along with the final pivoting angle, is input into a second equation system. Then, by setting the two systems equal to one another, the indeterminate quantities eliminate themselves and the equations, because of their complexity cannot be normally solved, but in accord with known iteration methods the set points can be found. The equivalence setting of the two image side parts of the equation systems is possible, because the two object side portions of the equation systems in relation to the adjustment changing are invariant.

A further method does not proceed from two approaches together with the related equation systems, but from an entirely different point of view of the image equation system. The evolved results and the equations regarding the parameters to be varied, i.e. that of the variation dependent parameters, yield further equations, with the inserted real quantities of the measured dependencies, which equations are to be solved by the iteration method, in such a manner that the sought set-point values are found.

The determination of the mutual dependencies of the objective lens adjustment to the extension changes at any given time upon focusing, is technologically very simple to bring about without giving rise to image migrations.

This is the case when the objective lens is pivoted about a clearly defined pivoting axis which intersects with the optical axis at a definite point or in a closely localized zone. This zone lies, according to the type of objective lens, midway between the principal planes up to the plane H' and, is determinable for the conventional installation of an objective lens. The pivoting of the objective lens can be made about the optimal axis, when the said optimal axis does not coincide with the mechanical pivoting axis. This is accomplished by means of appropriate compensation displacements virtually about the optimal axis, which requires, however, corresponding calculation of the compensation displacement and related means of positional adjustment.

A particularly simple adjustability of the objective lens arises, when the optimal angular displacement axes coincide with the mechanical pivoting axes. To this end, the mechanical pivoting axes must meet with the optical axis at one point, and the objective lens must be so set in the objective lens standard, that its optimal pivoting axes conform with the mechanical pivoting axes.

As may be inferred from FIGS. **5**, **6**, and **7**, it is advantageously arranged, that between the lens holding elements (HR) of the objective lens holder (OT) currently an adapter set (E**1**–E**3**) is installed, so that the framing reference surface (SOS) exhibits a definite axial backstop to the current objective lens reference surface (BF**01**–BF**03**) and in accord with this, the pivoting axis (Y) of the objective lens carrier (OT) lies properly in the objective lens.

In the case of the first adapter (E**1**) in FIG. **5**, the objective lens is displaced in the direction of the subject. Where the second adapter (E**2**) is concerned, there is no axial positioning beyond the customary placement. In the third adapter (E**3**) arrangement, the objective lens is moved toward the screen. The various adapter inserts (E**1**, E**2**, E**3**) are thus flat or extend themselves inward or outward from the retaining frame (HR).

The understanding that the exceptional focussing, which is in accord with the purpose of the invention, of an already, prealigned, partially focussed image, requires only a refocussing of the camera within confined limits, was made use of. That is, in accord with the invention, subsequent to the determination of the gradients of the positioning parameters, with the aid of these said gradients, the necessary further parameters are solved for through iterative computation. In this process, and in a provable manner, a satisfactory precision is achieved.

The utmost sharp focussing, in accord with the process, now permits, as has been shown, the use of optimal aperture openings, which are chosen, on the one hand, to correlate the required depth of focus at moderate light requirement and on the other hand to avoid extensive diffraction blurring.

I claim:

1. A focusing process for a camera;

having an objective lens carrier (OT) and an image carrier (BT), which are maintained positionally relative to one another in a straight line optical bench direction (X) in which the spatial interval (x**1**–x**2**, x**2**–x**3**, δb)between them is variable, wherein the said interval changes are signaled to a microprocessor (PR),

equipping the objective lens carrier (OT) with an objective lens (O) secured to pivot about two axes (Y, Z), said axes being perpendicular to one another and to an optical bench direction (X), two respective objective lens angles (θ, Φ) and a focal length (f) of said objective lens being inputted to the microprocessor (PR),

the image carrier (BT) having a frosted glass plate image screen (BA), said screen being moveable about the two axes (Y, Z) perpendicularly disposed to one another and to the direction of the bench direction (X), and two respective image reception angles (α, β) thereof being sent to the microprocessor (PR),

the image screen (BA) having a focusing adjustment sensor (CD), which signals a degree of focus, and is positionable in two image reception coordinates (Y**1***, Z**1***) which, together with a focus value, are inputted to the microprocessor (PR),

further possessing at least three select image point areas (B1, B2, B3), which lie in a secondary image plane for the simultaneous adjustment of a focus having said image point areas and the focus adjustment sensor (CD) on the image screen (BA) subjected to determination of their respective image screen coordinates by means of a change in the interval between the image carrier (BT) and the objective lens (O) sequentially at a current time for each area of said image point areas through focus adjustment by means of the determination of the related screen coordinates (Y2*, Z2*, Y3*, Z3*), and said positional changes of the image carrier (BT), these being (x1–2x, x2–x3) and being inputted to the microprocessor,

obtaining, by means of input data collected from the microprocessor (PR) a determination of the positional parameters (a_o, b_o, a_m, b_m, θ_o, Φ_o) of the image screen (BA) as well as of the secondary image from which, together with a further image parameter necessary for computation, this latter originating in the solution of image equations, calculating such set point adjustment values (θ_{soll}, Φ_{soll}) suitable for the pivoting of the objective lens carrier (OT) along with a value for the adjustment of the interval between the image carrier (BT) and the objective carrier (OT), and the results thereof being made available, so that the new image plane adjusted by these set-point values (θ_{soll}, Φ_{soll}, xb_{soll}) comes as close as possible to coinciding with the image screen (BA),

therein characterized, in that one of the objective lens focusing adjustment parameters (θ, Φ, axial displacement) is altered by a predetermined amount, thus allowing a condition wherein, for a selected image point, can be measured an extension difference, which distance is determined by an extension apparatus AA in the bench direction (X) and a first set of the image equations with the input of the original objective lens adjustment parameters and an undetermined image distance (b) as well as a further set of image equations with the input of varied objective lens parameters (θ, Φ) and compensated by the image distance (b), changed by an extension difference (δb) and permitting determination of the set point values (θ_{soll}, Φ_{soll}, xb_{soll}),

functional derivations of the image equations having been created in regard to the objective lens focusing parameters (θ, Φ, axial displacement) and in regard to the current image distance (b) in accord with the focus at the time and the thereby arrived at focus change (θ, Φ, axial displacement) and the measured extension difference (δb), being inputted to the said derivations and solved for the set point signals (θ_{soll}, Φ_{soll}, xb_{soll}).

2. A process in accord with claim **1**, therein characterized, in that the selected image point, where the objective lens (O) has not been pivoted about the horizontal axis (Y) and lies in the horizontal XY-plane and the pivoting of the objective lens (O) takes place about the said horizontal axis (Y) by a predetermined pivoting angle (θ) for the determination of the extension difference.

3. A process in accord with claim **1**, therein characterized, in that the selected image point, is focussed by at least two pivoting angles and thereby the extension differences (AW) are measured and from a related equation (**11**) by means of which, through parameters, a real object distance (S) and therefrom the image distance (b) is calculated, which are inputted to the image equations for the solution thereof.

4. A process in accord with claim **1**, therein characterized, in that during an extension change, the current incremental extension changes from the image point signals (SS) of the corresponding focussing values of the selected image point are continually monitored and correspondingly stored in the microprocessor (PR) memory, and subsequent to the pivoting of the objective lens about the predetermined pivoting angle (θ), or after an objective lens displacement along given axial movement path, from the then produced image point signals (SS) the focus value is determined and, now having this value, from the stored data, the corresponding extension change (δb) is sought out, which serves for further computations.

5. A process in accord with claim **1** therein characterized, in that the image distance (b) is first approximated from the extension difference (δb) and the closest related raster incremental interval of the image carrier (BT) of a linear bench raster (L1–LN) from the objective lens carrier (OT) is determined to this so attained raster interval the extension differential, also corresponding to the raster, is added and this so computed image carrier-objective lens carrier interval is used for a more exact further image parameter in sequential computations.

6. A process in accord with one of the claims **1**, **4** or **5**, therein characterized, in that the objective lens displacement path amounts to one or more to the bench raster lengths.

7. A process in accord with claim **1** therein characterized, in that by means of image equations, the start image plane (B1, B2, B3) in the image space is on a new image plane, which is parallel to the image screen (BA), and will be brought back and the objective lens angles (θ_{soll}, Φ_{soll}) and subsequently the inserted intersection point (xb_{soll}) of the image reception plane (BA) is calculated with the X-axis.

8. A process in accord with claim **1** therein characterized, in that a parallel insert (h) of the image plane, dependent on a main lens plane interval (d_h) of the objective lens and an insert of the objective lens pivoting axis intersection point for the principal plane thereof, is taken into consideration in the computation for the set-point values (θ_{soll}, Φ_{soll}, xb_{soll}).

9. A camera for application with a focusing process in accord with claim **1** therein characterized, in that the bench thereof (OB) is provided with a raster with mechanical increments, in particular, hole and space increments, (L1–LN) and the objective lens carrier (OT) and the image carrier (BT) with raster apparatus are secured incrementally exact to one another in the said raster with appropriate means, namely raster pins.

10. A camera in accord with claim **9**, therein characterized, in that the optical bench (OB) is comprised of at least two bench sections (OB1, OB2), which are joined in exact incremental exactness by a connection piece possessing a raster apparatus for the given raster.

11. A camera in accord with claim **9**, therein characterized in that the raster length is shorter than a maximum extension path length.

12. A camera for application with a focusing process in accord with claim **1** therein characterized, in that the objective lens (O) is so placed in the objective lens carrier (OT), that the pivoting axes (Y, Z) of said lens intersect at a point and the point of intersection lies between the two principle planes (H, H') of the objective lens (O) .

13. A camera, in accord with claim **12**, therein characterized in that the intersection point for the axes (X, Y, Z) lies between the midpoint and the principal plane (H'), which said midpoint lies between the two principal planes (H, H').

14. A camera in accord with claim **12**, therein characterized in that between the objective lens carrier (OT) and the objective lens (O), a corresponding and suitable insert (E1, E2, E3), which possesses an axial partition between the

image reception surfaces (BF**01**, BF**02**, BF**03**, SOS) of the objective lens (O) and the objective carrier (OT), is placed in such a manner that the intersection point of the axes (X, Y, Z) is found in the optimal axial position for the objective lens (O) being used at that time and said point is between the principal planes (H, H').

* * * * *

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United States Patent [19]

Ohtaka et al.

[11] Patent Number: 5,797,049

[45] Date of Patent: Aug. 18, 1998

[54] **FOCUS DETECTION DEVICE FOR OBJECTIVE LENS**

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[73] Assignee: **Canon Kabushiki Kaisha**, Tokyo, Japan

[21] Appl. No.: **762,252**

[22] Filed: **Dec. 9, 1996**

Related U.S. Application Data

[63] Continuation of Ser. No. 241,574, May 12, 1994, abandoned.

[30] **Foreign Application Priority Data**

May 20, 1993 [JP] Japan 5-141334

[51] **Int. Cl.**[6] **G01J 1/20**

[52] **U.S. Cl.** **396/122**; 396/89; 396/111; 396/121

[58] **Field of Search** 396/89–93, 111, 396/121–123

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Primary Examiner—Daniel P. Malley

Attorney, Agent, or Firm—Fitzpatrick, Cella, Harper & Scinto

[57] **ABSTRACT**

A focus detection function is disposed on the focal plane of an objective lens. The in-focus state of the objective lens is determined with respect to a plurality of range-finding regions in a photographic range by employing the focus detection function. A correction value of the objective lens corresponding to a predetermined range-finding region among the plurality of range-finding regions is already stored, thereby finding correction values corresponding to regions other than the predetermined region. As a result, focus detection with respect to the regions other than the predetermined region can be performed.

10 Claims, 7 Drawing Sheets

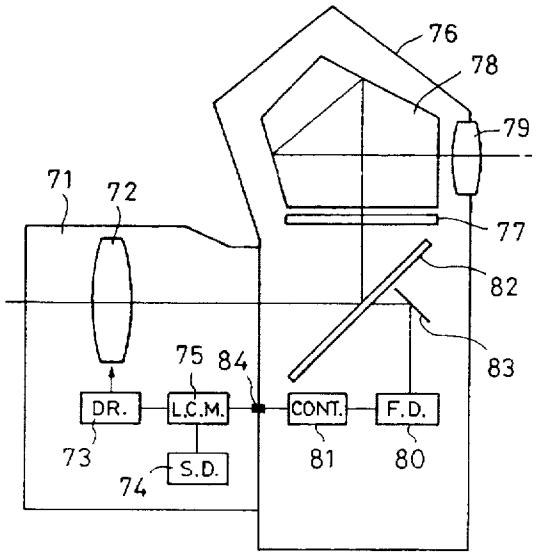


FIG. 1

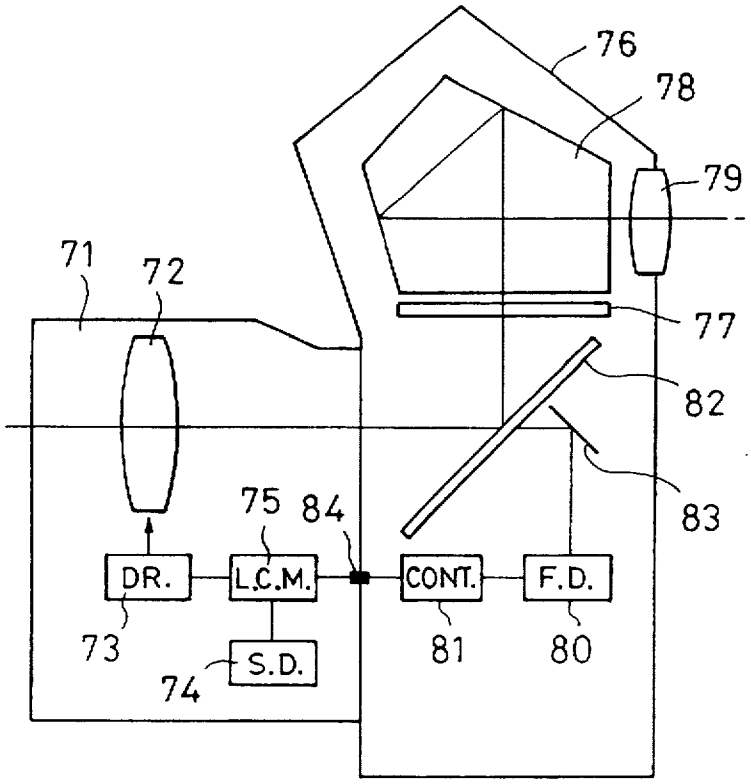


FIG. 2

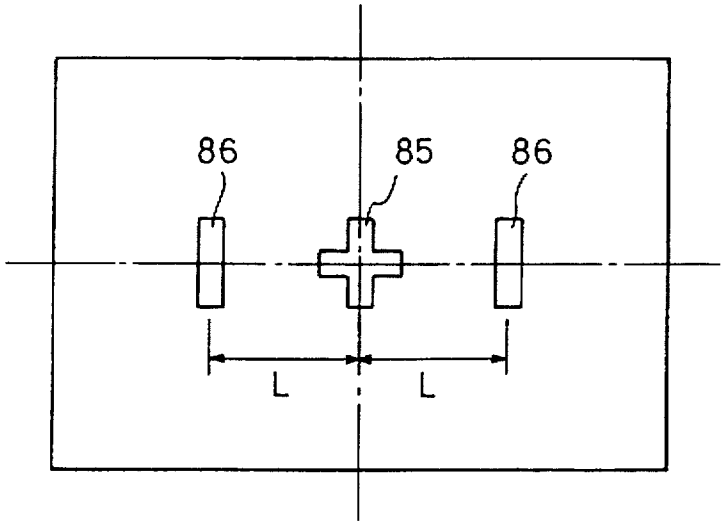


FIG. 3

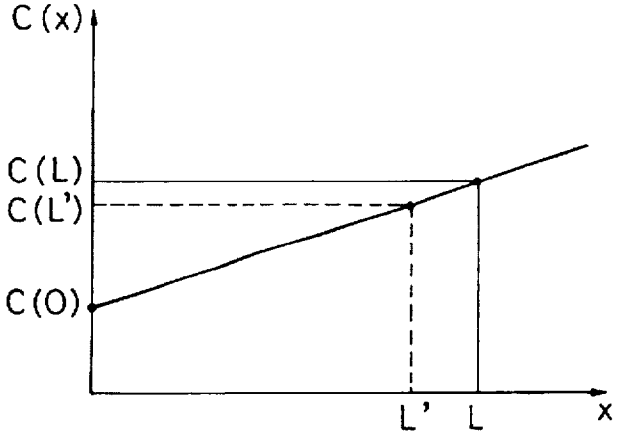


FIG. 4

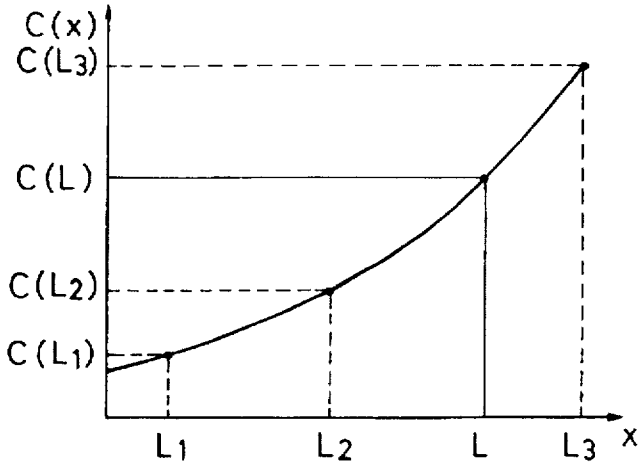


FIG. 5

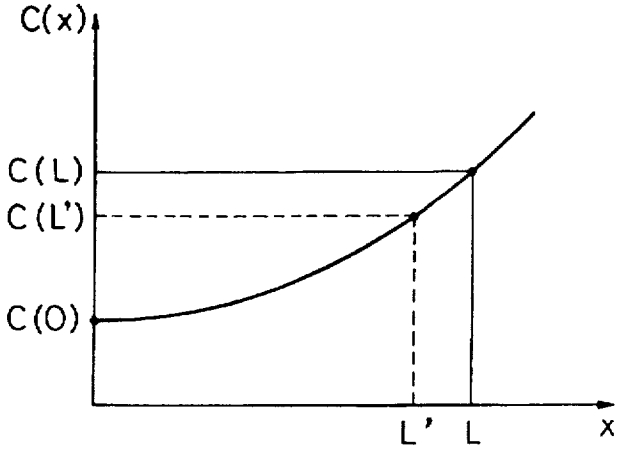


FIG. 6

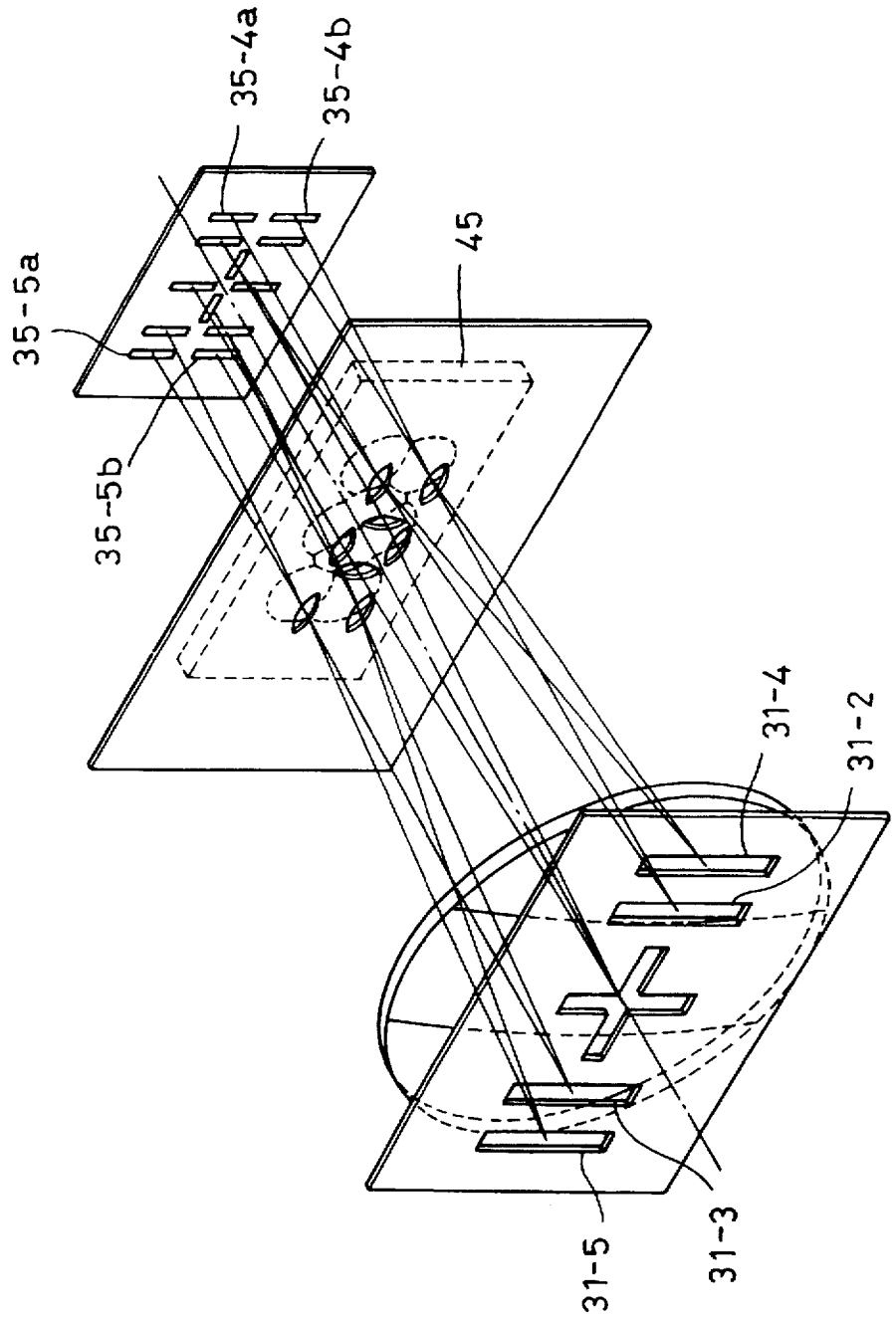
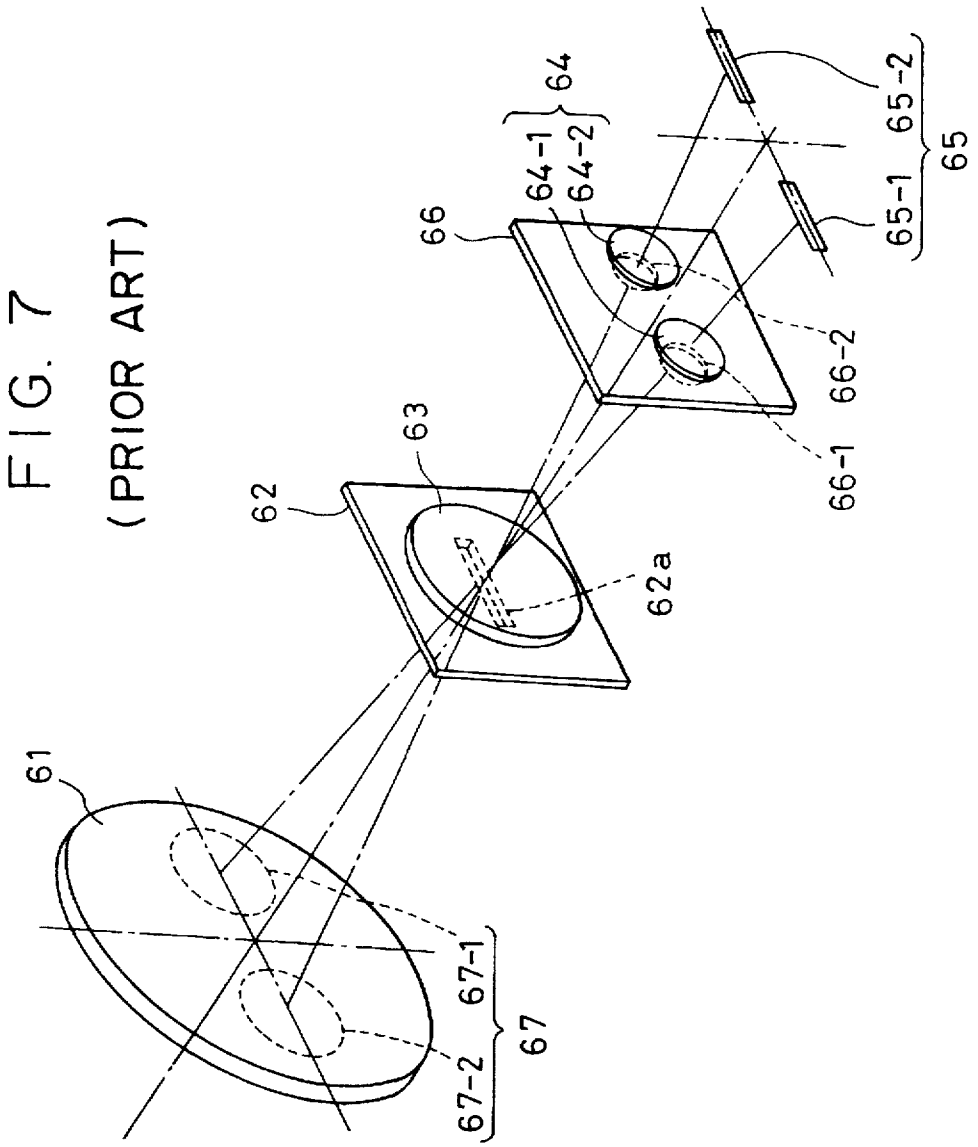


FIG. 7
(PRIOR ART)



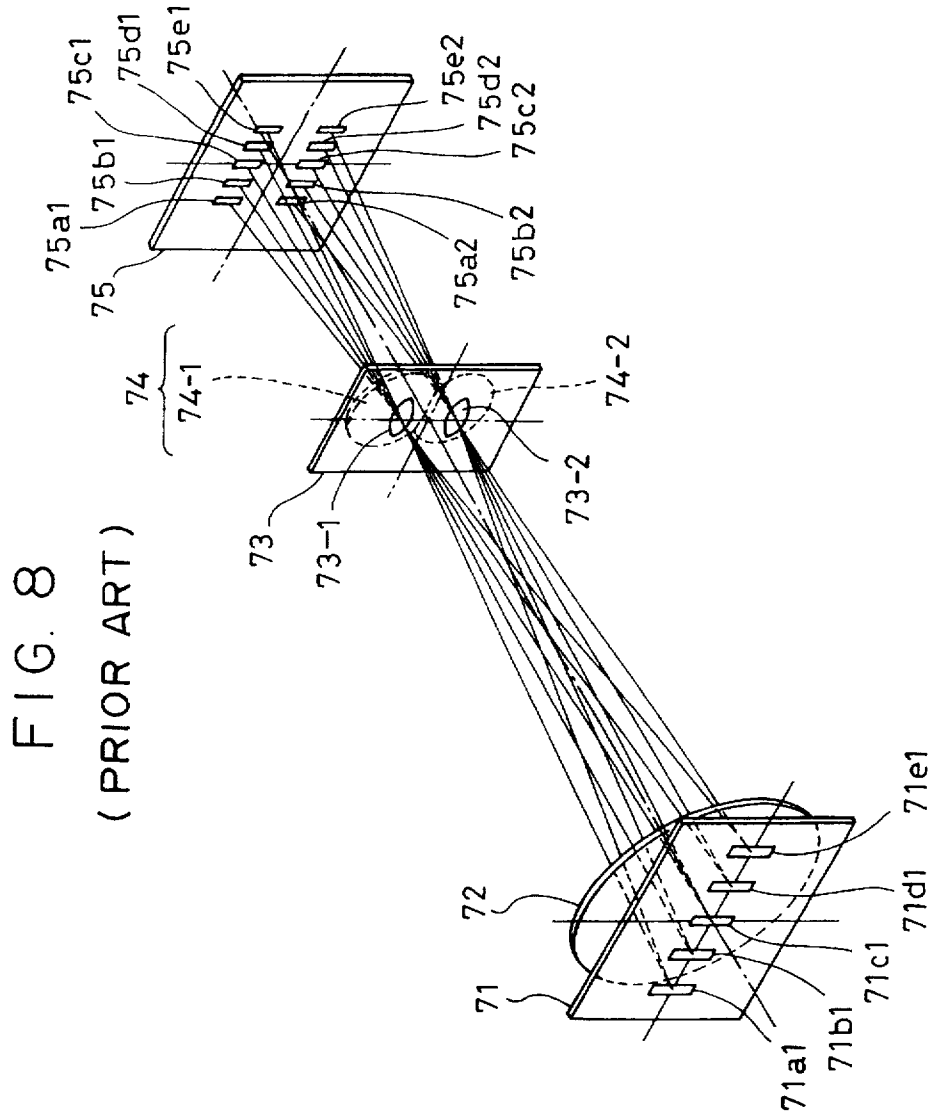


FIG. 8
(PRIOR ART)

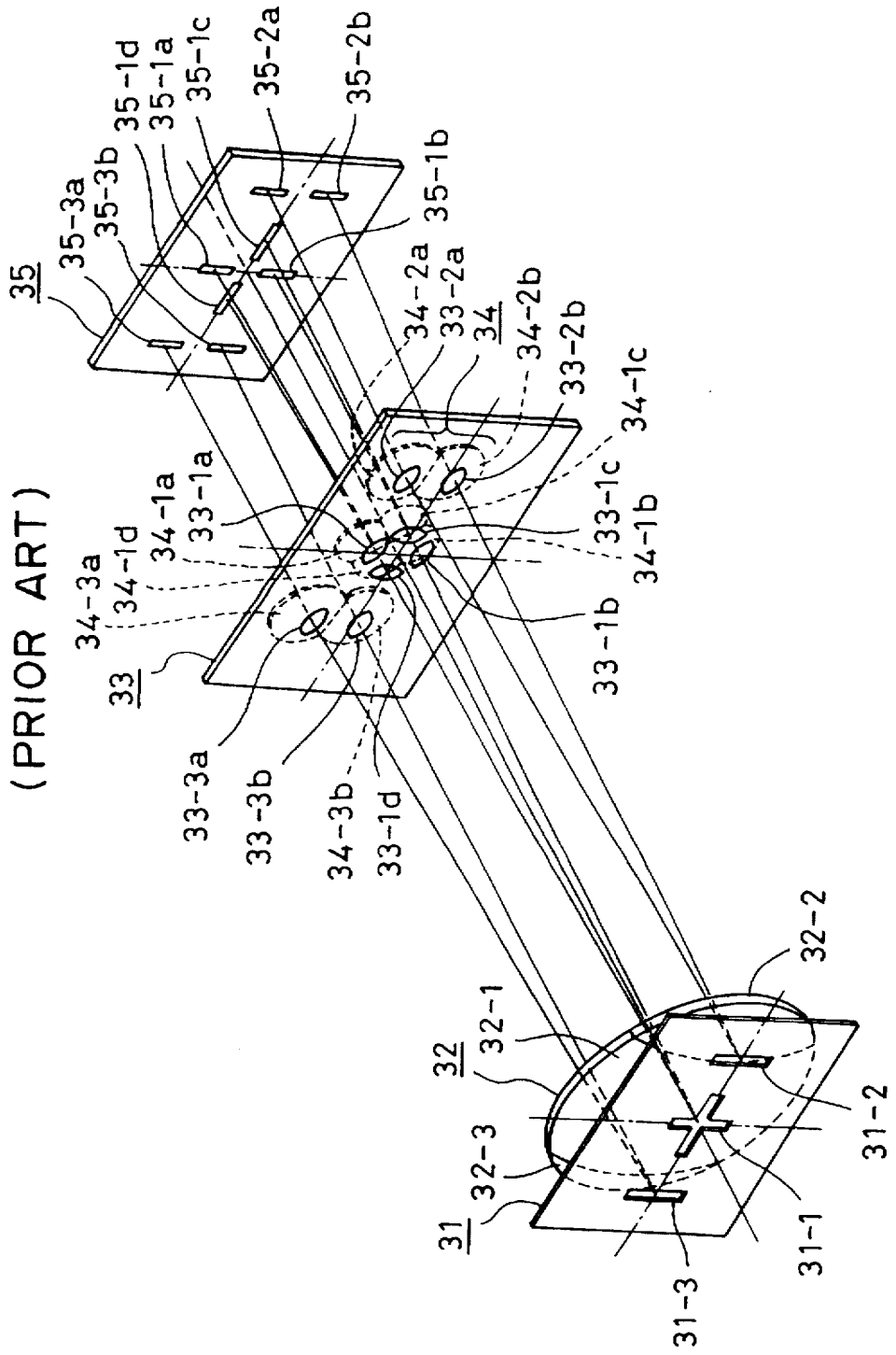
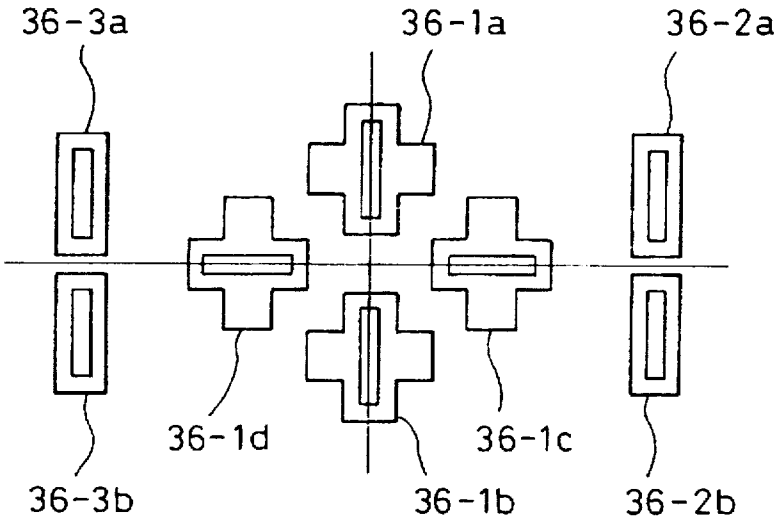


FIG. 9
(PRIOR ART)

FIG. 10
PRIOR ART



FOCUS DETECTION DEVICE FOR OBJECTIVE LENS

This application is a continuation of application Ser. No. 08/241,574, filed May 12, 1994, now abandoned.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a focus detection device suitable for photographic cameras, video cameras, and the like. More particularly, the invention relates to a focus detection device in which a pupil of an objective lens is divided into a plurality of regions and the distributions of a quantity of light with respect to a plurality of object images are formed with light transmitted through the respective regions so as to find the relative relationship of the positions of the plurality of the distributions of a quantity of light, thereby appropriately detecting an in-focus state of the objective lens with respect to the plurality of regions in the photographic range.

2. Description of the Related Art

Conventionally, the so-called "image offset method" is available for a light-receiving type focus detection method employed by utilizing light transmitted through an objective lens. The image offset method is disclosed in, for example, Japanese Patent Laid-Open Nos. 59-107311 and 59-107313.

FIG. **7** is a schematic view of an optical system of a focus detection device employing the conventional image offset method. Referring to FIG. **7**, the optical system includes an objective lens **61**, a field mask **62** placed in the vicinity of an expected focal plane of the objective lens **61**, and a field lens **63** placed in the vicinity of the expected focal plane. This system further includes a secondary optical system **64**, light-receiving means **65**, a stop **66** and an exit pupil **67** of the objective lens **61**. The secondary optical system **64** comprises two lenses **64-1** and **64-2** placed symmetrical to each other with respect to the optical axis of the objective lens **61**. The light-receiving means **65** has two arrays of light-receiving elements **65-1** and **65-2** placed to the rear of the two lenses **64-1** and **64-2**, respectively. The stop **66** has two apertures **66-1** and **66-2** in front of the two lenses **64-1** and **64-2**, respectively. The exit pupil **67** comprises two separated regions **67-1** and **67-2**.

A field lens **63** serves the function of forming an image of the apertures **66-1** and **66-2** of the stop **66** on the two regions **67-1** and **67-2** of the exit pupil **67** so that light transmitted through the respective regions **67-1** and **67-2** forms the distributions of a quantity of light on the light-receiving elements **65-1** and **65-2**, respectively.

In the focus detection device shown in FIG. **7**, when the focal point of the objective lens **61** is in front of an expected focal plane, the position of the distribution of a quantity of light with respect to the image formed on the array of the light-receiving element **65-1** is close to that formed on the array of the light-receiving element **65-2**. On the other hand, when the focal point of the objective lens **61** is behind the expected focal plane, the position of the distribution of a quantity of light with respect to the image formed on the array of the light-receiving element **65-1** is away from that formed on the array of the light-receiving element **65-2**. The displacement between the distributions of quantities of light formed on the light-receiving element **65-1** and light-receiving element **65-2** is a function of the defocusing amount of the objective lens **61**. Thus, such a defocusing amount is calculated by suitable calculation means, thereby enabling the detection of the defocusing direction and amount of movement required of the objective lens **61**.

The focus detection device shown in FIG. **7** performs range-finding corresponding to the subject which is photographed by the objective lens and is positioned substantially at the center of the subject range.

In contrast thereto, the present inventor has already proposed a focus detection device in U.S. Pat. No. 5,005,041, issued Apr. 2, 1991, which can also detect the in-focus state with respect to range-finding points other than a range-finding point at the center of the photographic range.

FIG. **8** is a schematic view of an optical system of a focus detection device for a plurality of range-finding points. Such a device is disclosed in U.S. Pat. No. 5,005,041 and includes a field mask **71**, a field lens **72**, a stop **73** having two apertures **73-1** and **73-2**, a secondary optical system **74** formed of two lenses **74-1** and **74-2**, and a sensor **75**. The objective lens **61** shown in FIG. **7** is omitted.

The field mask **71** has a plurality of apertures **71***a***1**–**71***e***1** corresponding to a plurality of fields, respectively, to be measured. Light is regulated by the field mask **71** and a plurality of pairs of the distributions of quantities of light are formed by the secondary optical system **74** so that a plurality of pairs of sensor arrays, **75***a***1** and **75***a***2**, **75***b***1** and **75***b***2**, **75***c***1** and **75***c***2**, **75***d***1** and **75***d***2**, and **75***e***1** and **75***e***2**, can receive the resulting distributions of light, respectively.

The focus detection device shown in FIG. **8** performs range-finding with respect to five regions overall, that is, a central portion and four peripheral portions of a photographing screen. It is very important that the device having such a simple construction be able to detect the in-focus state in a plurality of regions in the photograph screen when the device is applied to a camera.

Since the focus detection device shown in FIG. **8** is constructed such that two distributions of quantities of light formed on the sensor move vertically depending upon the in-focus state of the objective lens, it is only capable of range-finding with respect to objects in which the distribution of a quantity of light varies only vertically. The device is not able to perform range-finding with respect to objects in which the distribution of a quantity of light varies only horizontally, for example, a black-and-white edge pattern having a vertical boundary.

In order to solve the above-noted problems the present inventor proposes a focus detection device, which is able to perform range-finding with respect to objects in which the distribution of a quantity of light varies either only vertically or only horizontally in the central portion of the photographic region of the device and also is able to perform range-finding with respect to objects in a plurality of portions other than the central portion.

FIG. **9** is a schematic view of the focus detection device disclosed in U.S. Pat. No. 4,992,819, which issued Feb. 12, 1991.

A field mask **31** has a cross-like aperture **31-1**, two portions of which intersect with each other substantially at the center of the photographic screen formed by an objective lens (photographic lens) (not shown) and longitudinal apertures **31-2** and **31-3** at the peripheral portions of the field mask **31**. A field lens **32** comprises three regions **32-1**, **32-2** and **32-3** having respective predetermined optical characteristics corresponding to the three apertures, **31-1**, **31-2** and **31-3**, respectively, of the field mask **31**. A stop **33** comprises at the center thereof four apertures **33-1** comprising **33-1***a*, **33-1***b*, **33-1***c* and **33-1***d*, one pair at each vertical and horizontal portions at the center thereof and also one pair of apertures **33-2***a* and **33-2***b*, and another pair of apertures **33-3***a* and **33-3***b* at the peripheral portions thereof.

The regions **32-1**, **32-2** and **32-3** of the field lens **32** serve the function of forming an image of the apertures **33-1**, **33-2** and **33-3**, respectively, of the stop **33** in the vicinity of the exit pupil of the photographic lens (not shown).

A secondary optical system **34** includes a total of four pairs of secondary image-forming lenses. That is, the secondary optical system **34** comprises eight secondary image-formation lenses **34-1***a*, **34-1***b*, **34-1***c*, **34-1***d*, **34-2***a*, **34-2***b*, **34-3***a* and **34-3***b* which are placed at the rear of the respective apertures of the stop **33**.

An array of light-receiving elements (sensor) **35** has a total of 4 pairs of sensors, that is, eight sensors **35-1***a*, **35-1***b*, **35-1***c*, **35-1***d*, **35-2***a*, **35-2***b*, **35-3***a* and **35-3***b* placed in correspondence to the respective secondary image-forming lenses so that they can receive the formed image.

FIG. **10** is a schematic view of the image regions formed on the surface of the sensor **35** illustrated in FIG. **9**. Image regions **36-1***a*, **36-1***b*, **36-1***c* and **36-1***d* are the ones in which an image of the aperture **31-1** at the center of the field mask **31** is formed and show the state in which light transmitted through the central region **32-1** of the field lens **32** is regulated in the apertures **33-1***a*, **33-1***b*, **33-1***c* and **33-1***d*, respectively, of the stop **33** and an image is then formed on the surface of the sensor **35** by the secondary image-forming lenses **34-1***a*, **34-1***b*, **34-1***c* and **34-1***d*, respectively, which are placed at the rear of the respective apertures of the stop **33**.

Image regions **36-2***a* and **36-2***b* are the ones in which an image of the peripheral aperture **31-2** of the field mask **31** is formed and show the state in which light transmitted through the peripheral region **32-2** of the field lens **32** is regulated in the apertures **33-2***a* and **33-2***b*, respectively, of the stop **33** and an image is then formed on the surface of the sensor **35** by the secondary image-forming lenses **34-2***a* and **34-2***b*, respectively, placed at the rear of the respective apertures of the stop **33**.

Likewise, image regions **36-3***a* and **36-3***b* are the ones in which an image of the peripheral aperture **31-3** of the field mask **31** is formed and show the state in which light transmitted through the peripheral region **32-3** of the field lens **32** is regulated in the apertures **33-3***a* and **33-3***b*, respectively, of the stop **33** and an image is then formed on the surface of the sensor **35** by the secondary image-forming lenses **34-3***a* and **34-3***b*, respectively, placed at the rear of the respective apertures of the stop **33**.

Theoretically, the focus detection device shown in FIG. **9** detects the relative positions of the images in the direction in which a pair of arrays of sensors are disposed, in a manner similar to the conventional devices.

Since the focus detection device is constructed as described above, it is possible to perform, in the vicinity of the center of the range to be photographed or observed by the objective lens (not shown), range-finding with respect to the objects in which the distribution of a quantity of light varies either only vertically or only horizontally, and it is also possible to perform range-finding with respect to the objects positioned in correspondence to the peripheral apertures **31-2** and **31-3** of the field mask **31**.

In general, exchangeable photographic lenses used in, for example, a single-lens reflex camera, have various types of aberration inherent therein, and consequently, the amount of aberration and methods of correcting it vary depending upon the types of lenses. Hence, when the focus detection device as described above is applied to a camera including an exchangeable photographic lens and the actuation of a photographic lens (an in-focus lens) is controlled on the basis of a focus detection signal directly obtained in the focus detection device, an appropriate in-focus state may not be obtained.

In order to solve the above-mentioned problem, the following focus detection device has been proposed. A focus detection signal D, for example, representing the defocusing amount, is corrected by utilizing a correction value C inherent in each of the photographic lenses for the focus detection signal, as expressed by the following equation:

$$D_C = D - c \tag{1}$$

The actuation of the in-focus lens is controlled on the basis of the thus-obtained focus detection corrected signal D_C.

In general, the correction value C inherent in the different types of photographic lenses is also dependent upon the position of the detection region (range-finding region). Therefore, when the photographic lens has detection regions other than the center of the photographic range as shown in FIGS. **8** and **9**, it is necessary to have correction values corresponding to the respective detection regions. However, another problem arises in such a case. When the number of expected detection regions is large, a storage device with a large capacity is required in order to store correction values corresponding to all the detection regions in the photographic lens or the camera body, and the I/O control of the correction values when calculating the focus detection signals becomes complicated.

Further, a photographic system including a single-lens reflex camera or an exchangeable lens may sometimes be actuated only for a predetermined number of detection regions or placed in a predetermined position, in which case, a camera containing a focus detection device having a number of detection regions different from the predetermined number or placed in positions different from the above-described position cannot be used in such a system unless it is modified. In order to modify the above camera to make it suitable for such a system, all the new correction values must be stored in the camera body, and accordingly, a storage device having a large capacity is also required.

SUMMARY OF THE INVENTION

Accordingly, an object of the present invention is to provide a focus detection device which is capable of performing highly-precise focus detection without requiring a storage element with a high-density capacity because focus detection signals in a plurality of regions (range-finding regions) are corrected by using correction values with respect to the respective photographic lenses and employing a simple calculation process.

The invention in one aspect pertains to a focus detection device for an objective lens comprising detection means for detecting the focus state of the objective lens with respect to a plurality of regions in the field, and producing means for producing, on basis of a correction value for correcting a detection signal obtained by the detection means with respect to a predetermined region among the plurality of regions, a correction value for correcting a detection signal obtained by the detection means with respect to the region other than said predetermined region.

In order to achieve the above object, the present invention in another aspect pertains to a focus detection device comprising: an objective lens means; detection means for detecting the focus state of the objective lens means with respect to a plurality of regions in the field; storage means for storing a correction value for correcting a detection signal obtained by the detection means with respect to a predeter-

mined region among the plurality of regions; and production means for producing a correction value for correcting a detection signal obtained by the detection means with respect to each of the regions other than the predetermined region on the basis of the correction value stored in the storage means.

Further objects, features and advantages of the present invention will become apparent from the following description of the preferred embodiments with reference to the attached drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic view of a portion of a first embodiment according to the present invention;

FIG. **2** is a schematic view of the range to be found shown in FIG. **1**;

FIG. **3** is a graph illustrating the relationship between the correction value and the range to be found according to the present invention;

FIG. **4** is a graph illustrating the relationship between the correction value and the range to be found according to the present invention;

FIG. **5** is a graph illustrating the relationship between the correction value and the range to be found according to the present invention;

FIG. **6** is a schematic view of a portion of a second embodiment according to the present invention;

FIG. **7** is a schematic view of a portion of a conventional focus detection device employing the image offset method;

FIG. **8** is a schematic view of a portion of a conventional focus detection device employing the image offset method;

FIG. **9** is a schematic view of a portion of a conventional focus detection device employing the image offset method; and

FIG. **10** is a schematic view of a portion of the focus detection device shown in FIG. **9**.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. **1** is a schematic view of a first embodiment according to the present invention. FIG. **2** is an enlarged view of a portion of the first embodiment shown in FIG. **1**.

Referring to FIG. **1**, a photographic body **71** includes: a photographic lens **72**; a drive device (D.R.) **73** for shifting the entire lens system comprising the photographic lens **72** or an in-focus lens, which is a part of the lens system, so as to adjust the in-focus state of the photographic lens **72**; a storage device (S.D.) **74** such as a ROM, or the like; and lens controlling means (L.C.M.) **75** for controlling the storage device **74**.

A camera body **76** includes: a focus plate **77** on which an object image is formed by the photographic lens **72**; a pentagonal prism **78**; a finder system having an eyepiece **79**, a focus detection system having focus detection means (F.D.) **80** and control means (CONT.) **81** for controlling the detection means **80**; a main mirror **82** for introducing light from the photographic lens **72** into the finder system, and a subsidiary mirror **83** for introducing light from the photographic lens **72** to the focus detection means **80**. When connected, the photographic lens body **71** and the camera body **76** have an electric contact **84** through which information is communicated and the power is supplied.

The focus detection means **80** of this embodiment has similar components to those shown in FIG. **9** and the range-finding principle is also similar to that shown in FIG. **9**.

FIG. **2** shows the focus detection regions on the focus plate **77** illustrated in FIG. **1** when the focus detection device illustrated in FIG. **9** is employed as the detection means **80**. A cross-like region **85** at the center and peripheral narrow regions **86** the distance L away from the center form the focus detection regions corresponding to the configuration of the apertures of the field mask **31** or the arrangement of the sensor **35** shown in FIG. **9**.

The photographic lens body **71** has correction values C(O) and C(L') stored within the ROM **74** for the above focus detection signal D with respect to the central region and the peripheral regions the distance L' away from the center, respectively.

In the photographic device illustrated in FIG. **1**, when the central region, for example, is selected in advance as a focus detection region, the focus detection system is started by such means as the initial pressing of a shutter button (not shown), thereby detecting the amount of the in-focus state with respect to the central region of the photographic lens **72**, for example, the defocusing amount D(O). Subsequently, the correction value C(O) with respect to the focus detection central region stored in the ROM **74** of the photographic lens body **71** is read into the control means **81** of the focus detection system through the contact point **84**.

The final focus detection corrected signal $D_C(O)$ can be found by the following equation:

$$D_C(O)=D(O)-C(O) \tag{2}$$

The in-focus lens is actuated by the drive device **73** of the photographic lens body **71** on the basis of the above value, thereby adjusting the focus state.

Likewise, the defocusing amount D(L) is detected with respect to the focus detection peripheral regions distance L away from the center. When the following equation applies,

$$L=L' \tag{3}$$

the correction value C(L') stored within the ROM **74** of the photographic lens body **71** can be directly employed and the focus detection corrected value $D_C(L)$ can be found by the following equation:

$$D_C(L)=D(L)-C(L') \tag{4}$$

On the other hand, when the equation (3) does not apply, as being expressed by the following formula,

$$L\neq L' \tag{5}$$

the correction value C(L) is found by the following calculation in the present invention.

That is, suppose that the correction value C(x) with respect to the focus detection region distance x away from the center can be found by the following linear equation of x,

$$C(x)=ax+b \tag{6}$$

the coefficients a and b are found by the two correction values C(O) and C(L') stored within the ROM **74** of the photographic lens body **71**, thereby calculating the correction value C(x) with respect to the region any distance x away from the center.

According to the above-described simple calculation, the coefficients a and b are found by the following equations:

$$a = \frac{C(L') - C(O)}{L'} \tag{7}$$

$$b = C(O) \tag{8}$$

The equation (6) can be expressed by the following equation:

$$C(X) = \frac{C(L') - C(O)}{L'} X + C(O) \tag{9}$$

Thus, the correction value C(L) can be found by the following equation:

$$C(L) = \frac{C(L') - C(O)}{L'} L + C(O) \tag{10}$$

The focus detection corrected signal $D_C(L)$ is calculated by the above equation.

FIG. **3** is a graph illustrating the relationship of the equation (9) in which the vertical axis indicates the correction value C(x) and the horizontal axis represents the distance x. According to this equation, a correction value can be found not only when x is equal to L, but also when x is any value.

The present invention may be modified such that, for example, the following quadratic equation of x may be substituted for the linear equation including x shown in the equation (6) in another embodiment:

$$C(x)=ax^2+bx+C \tag{11}$$

Or, an equation of an even higher degree than the power of 2 may be used. Since there are three unknown coefficients in the equation (11), it is necessary to store three known correction values within the ROM **74** of the photographic lens body **71**.

If the three correction values are $C(L_1)$, $C(L_2)$, and $C(L_3)$, the coefficients of the equation (11) can be found by the following equations:

$$a = \frac{\begin{vmatrix} C(L_1) & L_1 & 1 \\ C(L_2) & L_2 & 1 \\ C(L_3) & L_3 & 1 \end{vmatrix}}{\begin{vmatrix} L_1^2 & L_1 & 1 \\ L_2^2 & L_2 & 1 \\ L_3^2 & L_3 & 1 \end{vmatrix}} \tag{12}$$

$$b = \frac{\begin{vmatrix} L_1^2 & C(L_1) & 1 \\ L_2^2 & C(L_2) & 1 \\ L_3^2 & C(L_3) & 1 \end{vmatrix}}{\begin{vmatrix} L_1^2 & L_1 & 1 \\ L_2^2 & L_2 & 1 \\ L_3^2 & L_3 & 1 \end{vmatrix}} \tag{13}$$

-continued

$$c = \frac{\begin{vmatrix} L_1^2 & L_1 & C(L_1) \\ L_2^2 & L_2 & C(L_2) \\ L_3^2 & L_3 & C(L_3) \end{vmatrix}}{\begin{vmatrix} L_1^2 & L_1 & 1 \\ L_2^2 & L_2 & 1 \\ L_3^2 & L_3 & 1 \end{vmatrix}} \tag{14}$$

wherein |A| is the determinant of the matrix A.

FIG. **4** is a graph illustrating the relationship of the equation (11) by employing the thus-obtained coefficients by way of example.

Instead of employing the three known correction values as described above, the coefficients of the square equation (11) may be determined by the two correction values C(O) and C(L') with respect to the central and peripheral regions, respectively, and on the assumption that the correction value take the extreme value with respect to the central region. According to this method, the correction value is found by the following equation:

$$C(X) = \frac{C(L') - C(O)}{L'^2} X^2 + C(O) \tag{15}$$

FIG. **5** is a graph illustrating the relationship of equation (15).

Although, in the above embodiment, the values stored in the ROM **74** of the photographic lens body **71** are used as the known correction values, the correction values may be stored in the camera body **76** and employed as the known correction values.

Also, the present invention is not limited to the above embodiment, but other forms of functions may be set according to the characteristics or the number of correction values inherent in the photographic lens body **71** or the camera body **76**.

FIG. **6** is a schematic view of a focus detection device according to another embodiment of the present invention.

In this embodiment, the secondary optical system is constructed in a manner similar to that shown in FIG. **9**. However, four apertures **31-2**, **31-3**, **31-4** and **31-5**, two each on the right and left positioned in the peripheral field are arranged, and also, the number of an array of sensors is increased to four **35-4***a*, **35-4***b*, **35-4***c* and **35-4***d*. Although the number of focus detection regions is increased, the present invention is applicable in a manner similar to the method described above.

As will be clearly understood from the foregoing description, the present invention offers the following advantages.

Since the respective components in the present invention are arranged as described above, the focus detection signals with respect to a plurality of detection regions (range-finding regions) can be corrected by employing the correction values regarding the respective photographic lenses and can be easily found by an appropriate calculation process, thus achieving a focus detection device which is capable of highly-precise focus detection without requiring a storage element with a high-density capacity.

The individual components shown in outline or designated by blocks in the Drawings are all well-known in the focus detection arts and their specific construction and operation are not critical to the operation or best mode for carrying out the invention.

While the present invention has been described with reference to what are presently considered to be the pre-

ferred embodiments, it is to be understood that the invention is not limited to the disclosed embodiments. To the contrary, the invention is intended to cover various modifications and equivalent arrangements included within the spirit and scope of the appended claims. The scope of the following claims is to be accorded the broadest interpretation so as to encompass all such modifications and equivalent structures and functions.

What is claimed is:

1. A focus detection device for an objective lens, comprising:

a storage device which contains a stored focus correction value for at least one predetermined region in a field of focus of said objective lens;

detection means for detecting a focus state of the objective lens with respect to another region located at a given distance from said predetermined region and for producing a corresponding detection signal; and

calculation means for calculating a correction value for said another region on the basis of said given distance and said stored focus correction value.

2. A focus detection device according to claim **1**, wherein said storage device contains a plurality of stored focus correction values which correspond, respectively, to each of several predetermined regions in said field of focus of said objective lens.

3. A focus detection device according to claim **1**, wherein said detection means detects the focus state of said objective lens according to a distribution of light transmitted through different regions of a pupil of the objective lens.

4. A focus detection system comprising:

objective lens means for viewing a field having a plurality of regions;

detection means for detecting the focus state of said objective lens with respect to at least one of a plurality of regions in said field, and producing a corresponding detection signal;

storage means for storing a first correction value for correcting the detection signal produced by said detection means with respect to another of said plurality of predetermined regions, said another region being located a predetermined distance from said one region; and

calculation means for calculating a second correction value for correcting said detection signal, said calculation means being constructed and arranged to calculate said second correction value based on said given distance and on said first correction value.

5. A focus detection device according to claim **1**, wherein said storage device contains a plurality of correction values corresponding, respectively, to a plurality of predetermined regions in said field of focus of said objective lens and wherein said calculation means calculates a correction value for said other region on the basis of said detection signal and on the basis of at least two of said plurality of correction values.

6. A focus detection device according to claim **5**, wherein said calculation means is constructed to calculate said correction value for said other region based on a linear equation.

7. A focus detection device according to claim **5**, wherein said calculation means is constructed to calculate said correction value for said other region based on a quadratic equation.

8. A focus detection device according to claim **5**, wherein said calculation means is constructed to calculate said correction value for said other region based on a at least three of said stored correction values.

9. A focus detection system according to claim **4**, wherein said detection means detects a focus state of said objective lens means according to a distribution of light transmitted through different regions of a pupil of said objective lens means.

10. A focus detection system according to claim **4**, wherein said storage means stores an additional correction value for another region among the plurality of regions and said calculation means calculates the second correction value on the basis of the correction values stored in said storage means.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 5,797,049

DATED : August 18, 1998

INVENTOR(S): KEIJI OHTAKA, ET AL.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

ON THE TITLE PAGE AT [56] References Cited
U.S. PATENT DOCUMENTS, "Kusaker" should read --Kusaka--.

COLUMN 2
Line 64, "each" should read --each of the--.

COLUMN 5
Line 44, "D.R." should read --DR.--.

COLUMN 8
Line 19, "value" should read --values--.

Signed and Sealed this

Twenty-seventh Day of April, 1999

Q. TODD DICKINSON

Attest:

Attesting Officer

Acting Commissioner of Patents and Trademarks

US005768035A

United States Patent [19]

Grassens et al.

[11] Patent Number: 5,768,035

[45] Date of Patent: Jun. 16, 1998

[54] **METHOD AND APPARATUS FOR ALIGNING AN OBJECTIVE LENS**

[76] Inventors: **Leonardus J. Grassens**, 19115 Pebble Beach Way, Monument, Colo. 80132; **Hollis O'Neal Hall, II**, 2935 Leoti Dr., Colorado Springs, Colo. 80922

[21] Appl. No.: **475,240**

[22] Filed: **Jun. 7, 1995**

Related U.S. Application Data

[62] Division of Ser. No. 410,698, Apr. 7, 1995.

[51] **Int. Cl.**[6] **G02B 7/02**

[52] **U.S. Cl.** **359/822**; 359/818; 359/819

[58] **Field of Search** 359/822, 819, 359/813, 814, 823, 824, 818

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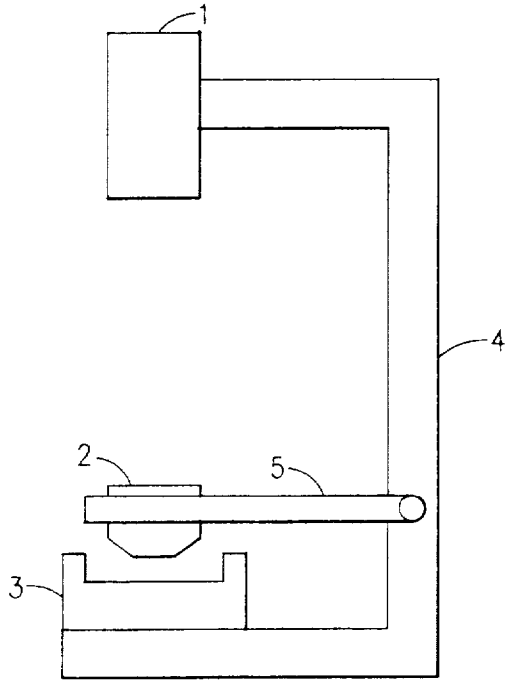
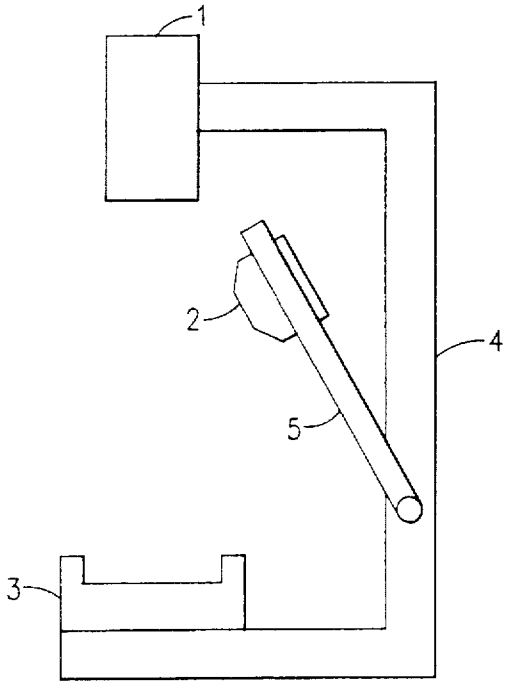
[57] **ABSTRACT**

An apparatus is described for mounting an actuator lens within an optical disc carriage held by a baseplate assembly. The apparatus includes a frame, a cradle assembly mounted to the frame with at least one degree of freedom of motion, a tower assembly mounted to the frame, a lever assembly rotatably mounted to the frame, and a gripper assembly mounted to the lever assembly. The cradle assembly includes a baseplate alignment assembly having a source of radiant energy for projecting a beam of radiant energy, means for determining the tilt alignment of the beam with respect to the tower assembly, and a plurality of tilt actuators for aligning the tilt of the beam with respect to the tower assembly. The tower assembly includes a video camera having a camera lens, a tower magnifying lens, and a monitor for displaying a presentation of a beam of radiant energy passing through the tower magnifying lens and into the video camera. A method for mounting a lens is described which includes the steps of placing a lens in the carriage, aligning the lens by moving a baseplate assembly with respect to the tower assembly, moving the objective lens assembly with respect to the tower assembly, and moving the actuator lens with respect to the tower assembly. The lens is attached to the gripper assembly and the lever moves the gripper and lens away from the carriage. Adhesive is applied to the carriage and the lever is moved back so as to place the lens on the adhesive in the aligned position.

28 Claims, 7 Drawing Sheets





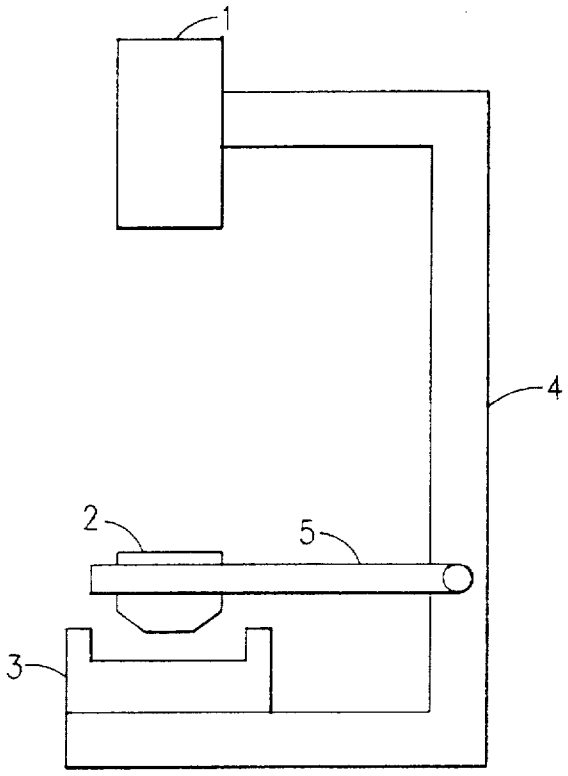


FIG.1

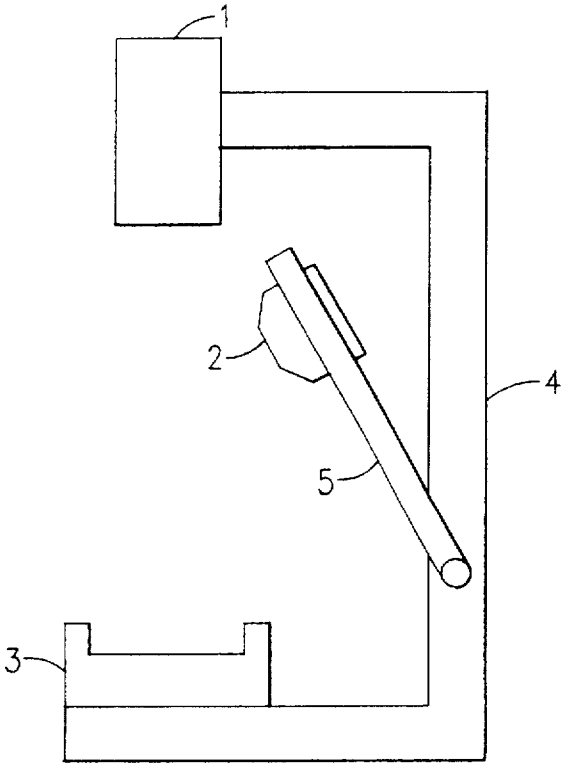


FIG.2

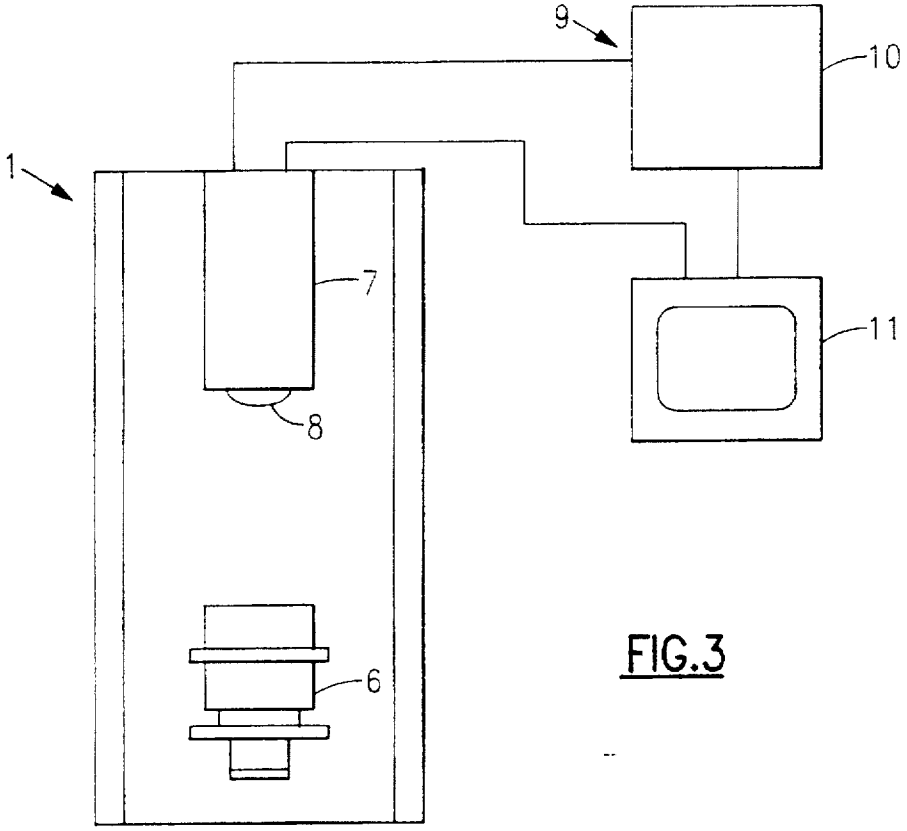


FIG.3

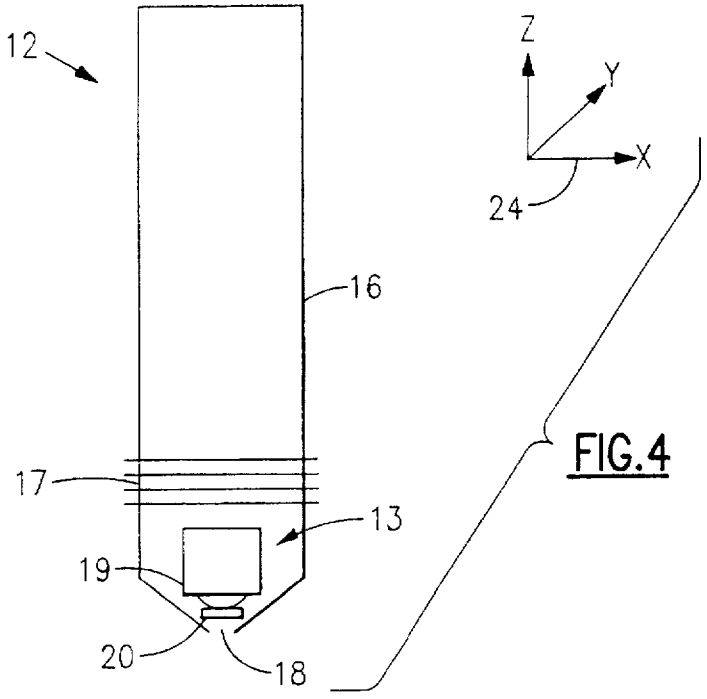
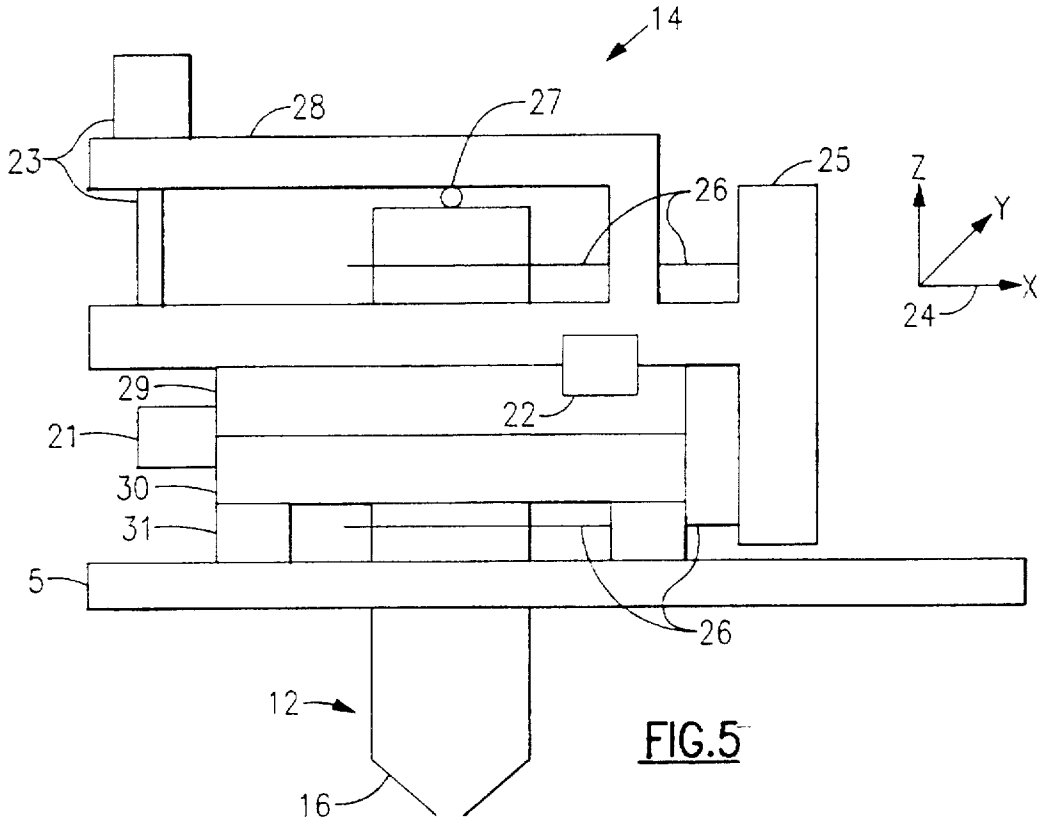


FIG.4


14
28
27
23
25
26
Z
Y
X
24
29
22
21
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31
5
26
12
16

FIG.5

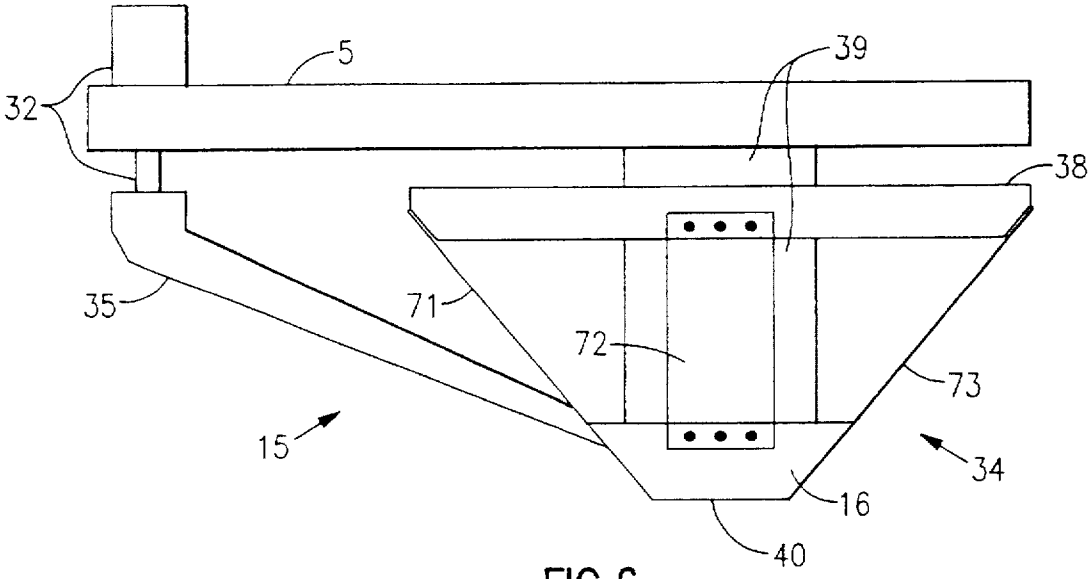
5
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FIG.6

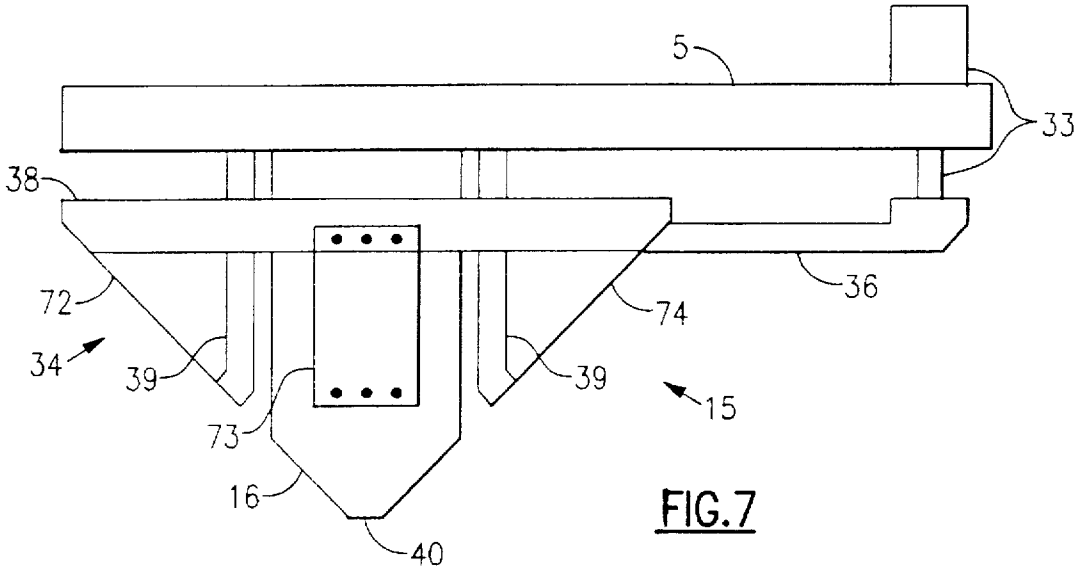


FIG.7

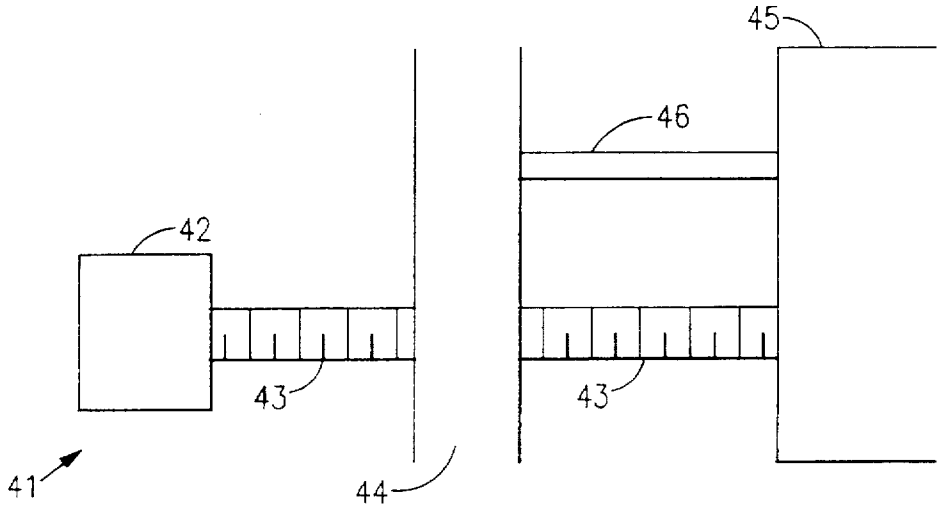
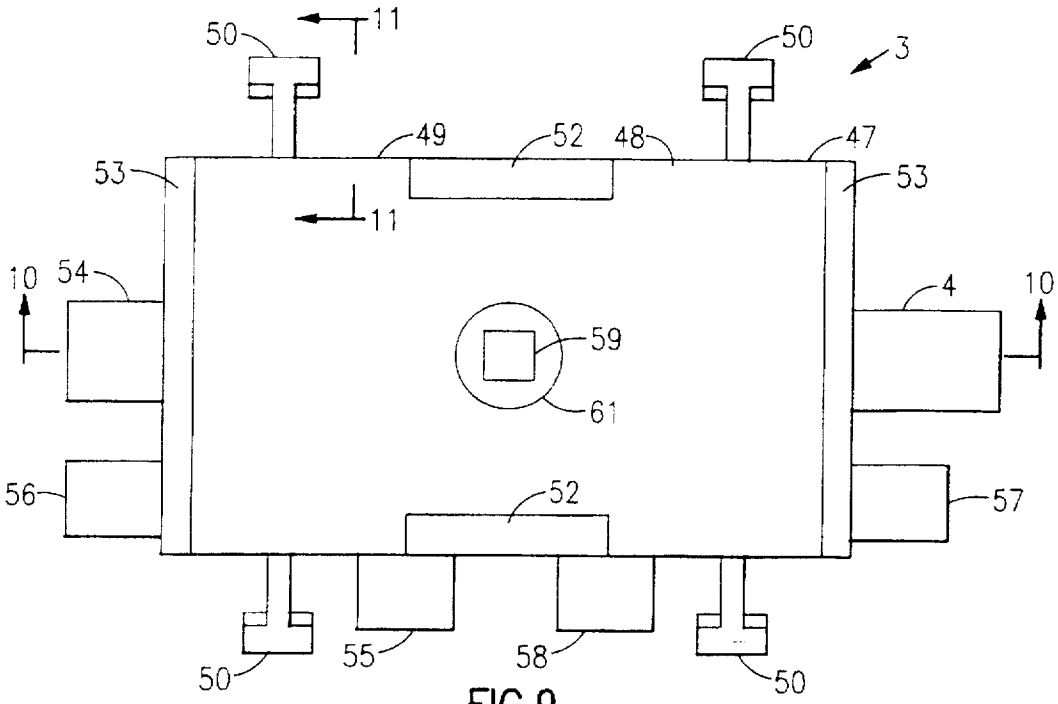


FIG.8


11
50
50
3
49
52
48
47
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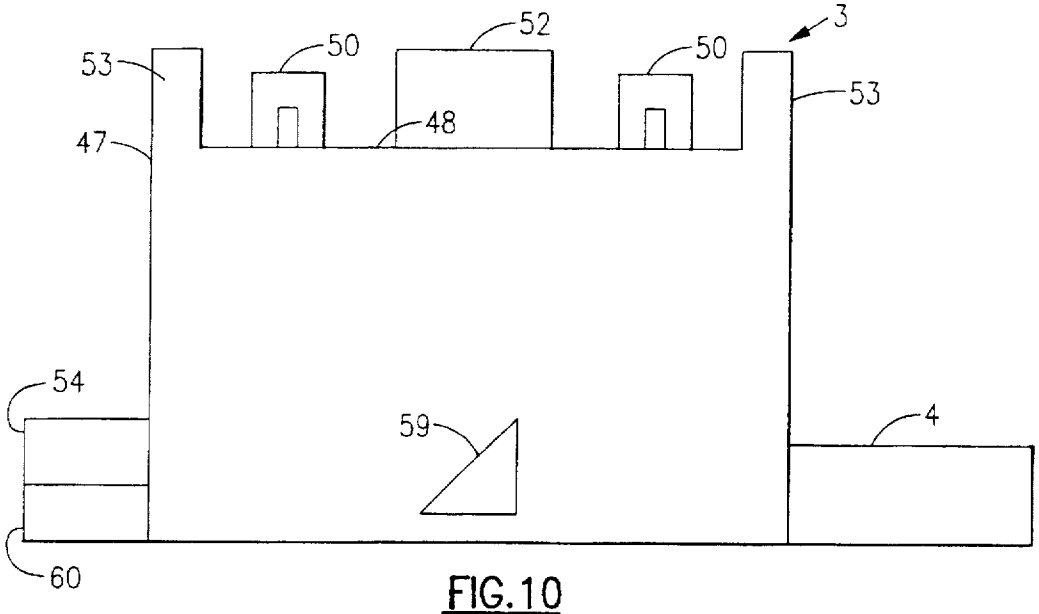
53
11
10
54
4
10
59
61
56
52
57
50
55
58
50

FIG.9


3
52
53
50
50
53
47
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59
4
60

FIG.10

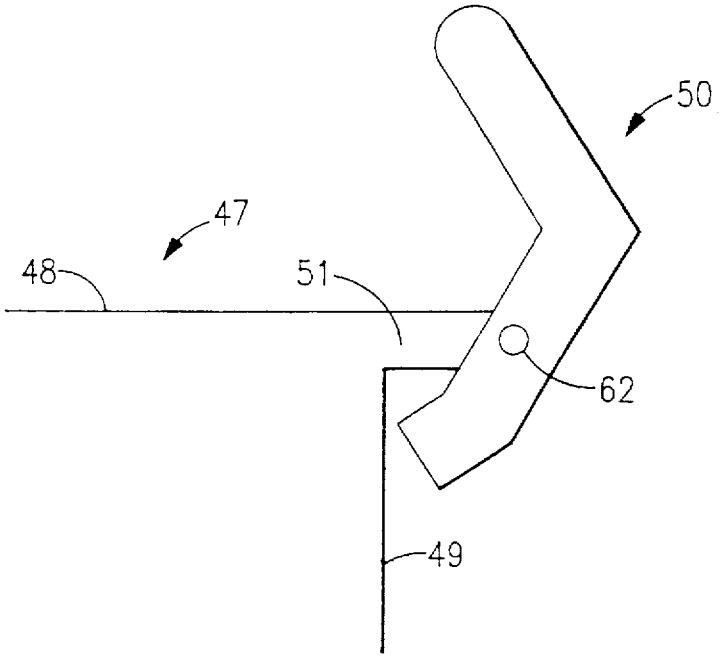

FIG.11

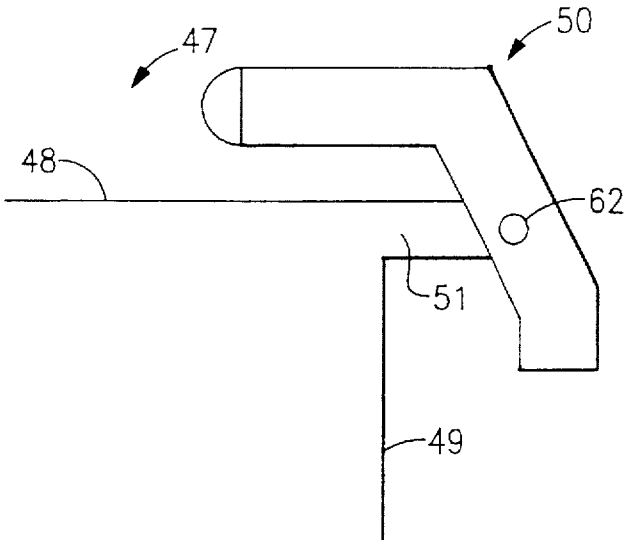

FIG.12

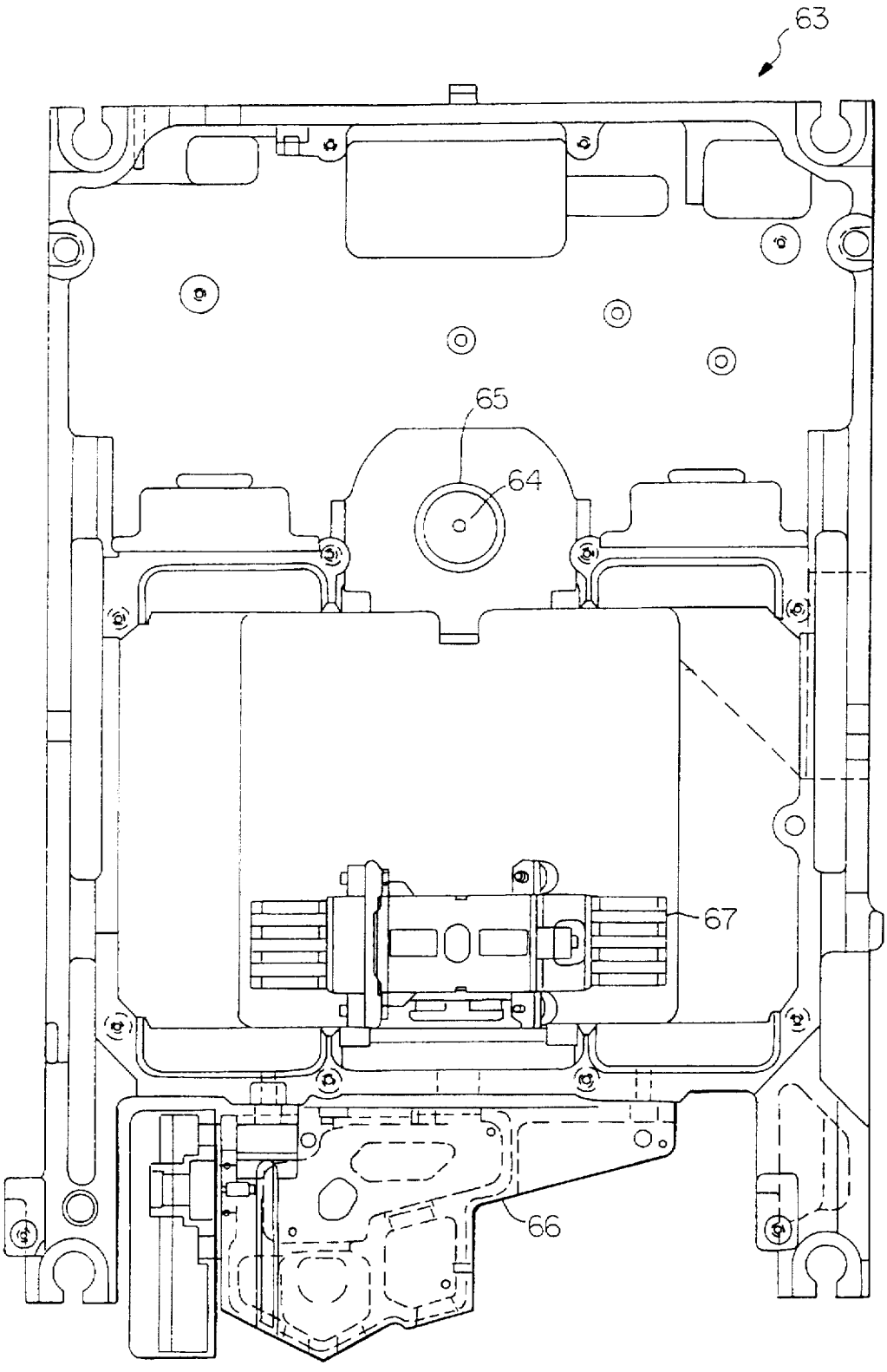

FIG.13

METHOD AND APPARATUS FOR ALIGNING AN OBJECTIVE LENS

This is a division of application Ser. No. 08/410,698, filed Apr. 7, 1995.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to manufacturing of optical systems, and, in particular, to the manipulation and alignment of an objective lens during manufacture of an optical system.

2. Description of the Related Art

In the manufacture of prior optical systems, specific alignment of the objective lens with respect to a storage medium was not critical. In those systems, a spindle which holds the storage medium is aligned with respect to guide rails. A carriage rides along the guide rails, and the objective lens is placed within the carriage. Because of the information storage densities used in such optical systems were sufficiently low, and because manufacturing tolerances of the spindle, rails, and objective lens were sufficiently high, specific alignment of the objective lens was not necessary. The objective lens was placed, then tested for alignment within tolerable limits.

Another example of a prior optical system does perform active alignment of the objective lens. However, the objective lens is fixedly mounted to an actuator, and the objective lens/actuator combination is aligned with respect to a carriage assembly. Once aligned with respect to the carriage assembly, the actuator is mounted to the carriage assembly, which is aligned with respect to the storage medium. This prior optical system requires that the actuator be alignable with respect to the carriage assembly. Additionally, the actuator/carriage assembly combination is quite large relative to such assemblies in other optical systems.

SUMMARY OF THE INVENTION

As information storage densities increase, the alignment between the objective lens and the storage medium becomes more critical. As a result, either stricter manufacturing tolerances or improved alignment of the objective lens is necessary. Because stricter manufacturing tolerances increase manufacturing cost significantly, improved alignment of the objective lens allows higher information storage densities at an economically feasible cost.

An apparatus is described which aligns such an objective lens. The apparatus comprises a frame, a cradle assembly mounted to the frame with at least one degree of freedom of motion, a tower assembly mounted to the frame, a lever assembly rotatably mounted to the frame, and a gripper assembly mounted to the lever assembly. The cradle assembly includes a baseplate alignment assembly comprising a source of radiant energy for projecting a beam of radiant energy, means for determining the tilt alignment of the beam with respect to the tower assembly, and a plurality of tilt actuators for aligning the tilt of the beam with respect to the tower assembly. The baseplate alignment assembly may further comprise means for determining the lateral alignment of the beam with respect to the tower assembly and a plurality of lateral actuators for aligning the beam laterally with respect to the tower assembly. The tower assembly comprises a video camera having a camera lens, a tower magnifying lens, and a monitor for displaying a representation of a beam of radiant energy passing through the tower magnifying lens and into the video camera.

The gripper assembly comprises an objective lens assembly, a gripper objective lens mounted to the objective lens assembly, an objective lens alignment assembly for aligning the gripper objective lens with respect to the tower assembly and the cradle assembly, and an actuator lens tilt assembly for aligning the objective lens with respect to the tower assembly and the cradle assembly. The objective lens assembly further comprises a housing having an opening at one end for receiving an objective lens and a bellows structure on its surface to allow bending of the housing, a gripper objective lens, a non-opaque substrate mounted within the housing, and a pneumatic tube attached to the housing for creating a pressure differential between the interior and the exterior of the housing sufficient to hold the actuator lens against the opening. The objective lens alignment assembly further comprises an assembly support, a first lateral alignment support slidably mounted to the assembly support, a first lateral actuator for positioning the first lateral alignment support, a second lateral alignment support slidably mounted to the first lateral alignment support, a second lateral actuator for positioning the second lateral alignment support, a support frame having a frame base and a frame extension, mounted to the second lateral actuator, a support leaf spring mounted to the support frame and biasing the housing against the frame extension, and a focus actuator for positioning the frame extension with respect to the frame base. The actuator lens tilt assembly further comprises a flexure support ring; two flexure support plates; four flexure plates mounted at equal intervals around the flexure support ring, two of which are mounted to the housing and two of which are mounted to the flexure support plates; a first lever disposed against a flexure plate; a first tilt actuator mounted against the first lever for imparting motion on the first lever which is translated into rotational motion by the flexure support ring, the flexure support plates, and the flexure plates; a second lever disposed against a flexure plate; and a second tilt actuator mounted against the second lever for imparting motion on the second lever which is translated into rotational motion by the flexure support ring, the flexure support plates, and the flexure plates.

A method for aligning an actuator lens is described comprising the steps of moving a baseplate assembly with respect to the tower assembly, moving the objective lens assembly with respect to the tower assembly, and moving the actuator lens with respect to the tower assembly. The step of moving the baseplate assembly further comprises moving the baseplate assembly laterally with respect to the tower assembly and rotating the baseplate assembly with respect to the tower assembly. The step of moving the actuator lens further comprises moving the actuator lens laterally with respect to the tower assembly and rotating the actuator lens with respect to the tower assembly. Such a method may be used with the above-described apparatus.

For a better understanding of these and other objects of the present invention, reference is made to the detailed description of the invention which is to be read in conjunction with the following drawings, wherein:

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a generalized side view of one embodiment of the invention, showing the gripper assembly in a closed position.

FIG. 2 is a generalized side view of one embodiment of the invention, showing the gripper assembly in an open position.

FIG. 3 is a cross-sectional view of the tower assembly, including an embodiment of the analysis assembly.

FIG. 4 is a cross-section view of the vacuum chuck and the microscope objective lens assembly.

FIG. 5 is a view of the microscope objective lens alignment assembly.

FIG. 6 is a side view of the actuator lens tilt assembly.

FIG. 7 is a front view of the actuator lens tilt assembly.

FIG. 8 is a view of an alignment actuator.

FIG. 9 is a top view of one embodiment of the cradle assembly.

FIG. 10 is a cross-sectional view of one embodiment of the cradle assembly, taken along line 10—10 of FIG. 9.

FIG. 11 is a cross-sectional view of one embodiment of a vacuum clamp in the open position, taken along line 11—11 of FIG. 9.

FIG. 12 is a cross-sectional view of one embodiment of a vacuum clamp in the closed position, taken along line 11—11 of FIG. 9.

FIG. 13 is a top view of a baseplate assembly.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to exemplary FIGS. 1 and 2, according to one aspect of the invention, the apparatus comprises a tower assembly 1, a gripper assembly 2, and a cradle assembly 3. The tower assembly 1 is fixedly mounted to a frame 4. The tower assembly 1 defines a tower axis. The gripper assembly 2 is fixedly mounted to a lever assembly 5, which is rotatably mounted to the frame 4. The cradle assembly 3 is mounted to the frame 4 with at least one degree of freedom of motion. A line between the tower assembly 1 and the cradle assembly 3 is referred to as an assembly axis. In the closed position, as shown in FIG. 1, the gripper assembly 2 is between the tower assembly 1 and the cradle assembly 3 along the assembly axis. In the open position, as shown in FIG. 2, the gripper assembly 2 is not along the assembly axis.

Referring to exemplary FIG. 3, a cross-section of the tower assembly 1 is shown in more detail. The tower assembly 1 comprises a tower magnifying lens 6 and a video camera 7 having a camera lens 8. The optical axes of the camera lens 8 of the video camera 7 and the tower magnifying lens 6 are the same, and are referred to collectively as the tower optical axis. The output from the video camera 7 is connected to an analysis assembly 9. The analysis assembly 9 may be any assembly suitable for analyzing the characteristics of a radiant beam of energy. In the embodiment shown in exemplary FIG. 3, the analysis assembly 9 comprises a processor 10 and a monitor 11.

Referring to exemplary FIGS. 4, 5, 6 and 7, the gripper assembly 2 comprises a vacuum chuck 12, a microscope objective lens assembly 13, a microscope objective lens alignment assembly 14, and an actuator lens tilt assembly 15. FIG. 4 shows a cross-sectional view of one embodiment of the vacuum chuck 12 and the microscope objective lens assembly 13. FIG. 5 shows a view of one embodiment of the microscope objective lens alignment assembly 14. FIGS. 6 and 7 show two views of the actuator lens tilt assembly 15.

Referring to exemplary FIG. 4, the vacuum chuck 12 comprises a housing 16, a bellows structure 17, and an actuator lens receiving opening 18. A pneumatic tube (not shown) is connected to the housing 16. In operation, an actuator lens (not shown) is placed within the actuator lens receiving opening 18 such that the actuator lens receiving opening 18 is completely covered. The actuator lens may be an objective lens. Air is then evacuated from the housing 16 through the pneumatic tube (not shown) to create a pressure differential between the interior and the exterior of the housing 16. This pressure differential operates to hold the actuator lens against the actuator lens receiving opening 18 when the gripper assembly 2 moves. The housing 16 contains a bellows structure 17 to allow the housing 16 to bend while maintaining a pressure differential.

The microscope objective lens assembly 13 comprises a microscope objective lens 19 and a substrate 20. In operation, a beam of radiant energy will enter the housing 16 through the actuator lens receiving opening 18 and, if present, through the actuator lens. The beam will pass through the substrate 20 and through the microscope objective lens 19. The beam then passes through the housing 16 and into the tower assembly 1, where it passes through the tower magnifying lens 6 and is received by the video camera 7. Together, the microscope objective lens 19 and the tower magnifying lens 6 magnify the beam and focus the beam in the video camera 7. The tower magnifying lens 6 may be a tube lens. The substrate 20 simulates the optical properties of an information-bearing disk, and the effects of those properties on the beam. The substrate 20 is mounted such that, when the gripper assembly 2 is in the closed position, the substrate 20 is orthogonal to the tower optical axis.

Referring to exemplary FIG. 5, the microscope objective lens alignment assembly 14 comprises an X-axis lateral alignment actuator 21, a Y-axis lateral alignment actuator 22, and a focus actuator 23. Referring to exemplary FIG. 5, there is shown a reference coordinate system 24. This reference coordinate system 24 is chosen for purposes of explanation only, and it will be obvious to one skilled in the art that any convenient coordinate system could be chosen without departing from the spirit and scope of the present invention.

In the embodiment particularly shown in FIG. 5, a microscope support frame 25 having a frame extension 28 supports the housing 16 by a support leaf spring 26. The support leaf spring 26 biases the housing 16 against a cylindrical bearing 27 located between the housing 16 and a frame extension 28. The focus actuator 23 is mounted to the frame extension 28, and maintains a distance between the frame extension 28 and the microscope support frame 25 along the Z-axis, as indicated by the reference coordinate system 24. Motion of the housing 16 along the Z-axis adjusts the focus of the microscope objective lens 19 in combination with the tower magnifying lens 6.

The microscope support frame 25 is mounted on a Y-axis lateral alignment support 29 such that the microscope support frame 25 may slide relative to the Y-axis lateral alignment support 29 along the Y-axis, as indicated by the reference coordinate system 24. The Y-axis lateral alignment actuator 22 is mounted to the microscope support frame 25, and will actuate the relative sliding motion along the Y-axis.

The Y-axis lateral alignment support 29 is mounted on an X-axis lateral alignment support 30 such that the Y-axis lateral alignment support 29 may slide relative to the X-axis lateral alignment support 30 along the X-axis, as indicated by the reference coordinate system 24. The X-axis lateral alignment actuator 21 is mounted to the Y-axis lateral alignment support 29, and will actuate the relative sliding motion along the X-axis.

The X-axis lateral alignment support 30 is mounted to a lateral alignment assembly support 31. The lateral alignment assembly support 31 is mounted to the lever assembly 5. It will be apparent to one skilled in the art that the mountings between the microscope support frame 25, the Y-axis lateral alignment support 29, the X-axis lateral alignment support

30, and the lateral alignment assembly support 31 may be rearranged from the above description without departing from the spirit and scope of the present invention.

Referring to exemplary FIGS. 6 and 7, there are shown two views of the actuator lens tilt assembly 15. FIG. 6 represents a left side view of the actuator lens tilt assembly 15 according to one aspect of the invention. FIG. 7 represents a front view of the same actuator lens tilt assembly 15. The actuator lens tilt assembly 15 comprises an X-axis tilt actuator 32, a Y-axis tilt actuator 33, and a flexure assembly 34. The X-axis tilt actuator 32 is mounted to the lever assembly 5 and against an X-axis lever 35. The X-axis lever 35, at the end nearest the X-axis tilt actuator 32, is biased against the lever assembly 5, and at the other end is mounted to the flexure assembly 34. The Y-axis tilt actuator 33 is mounted to the lever assembly 5 and against a Y-axis lever 36. The Y-axis lever 36, at the end nearest the Y-axis tilt actuator 33, is biased against the lever assembly 5, and at the other end is mounted to the flexure assembly 34.

The flexure assembly 34 comprises a plurality of flexure plates 37-1, 37-2, 37-3, 37-4, a flexure support ring 38, and a plurality of flexure support plates 39. Flexure plate 37-1 is mounted at one end to the flexure support ring 38, and mounted at its other end to the X-axis lever 35 and the housing 16. Flexure plate 37-3 is mounted opposite flexure plate 37-1 to the flexure support ring 38 and to the housing 16. Flexure plate 37-4 is mounted at one end to the Y-axis lever 36 and the flexure support ring 38, and mounted at its other end to a flexure support plate 39. Flexure plate 37-4 is mounted at a 90 degree interval from both flexure plate 37-1 and flexure plate 37-3. Flexure plate 37-2 is mounted opposite flexure plate 37-2 to the flexure support ring 38 and to a flexure support plate 39. The flexure support plates 39 are mounted to the lever assembly 5.

Flexure plates 37-1, 37-2, 37-3, 37-4 each lie in a separate plane. The planes in which flexure plates 37-1 and 37-3 lie intersect along a line through an intersection point 40. The planes in which flexure plates 37-2 and 37-4 lie intersection along a line through the intersection point 40. The lines may be orthogonal to each other.

The operation of the actuator lens tilt assembly 15 will be described with respect to a downward motion imparted on each of the tilt actuators, the X-axis tilt actuator 32 and the Y-axis tilt actuator 33.

A downward motion of the X-axis tilt actuator 32 imparts a downward motion on the X-axis lever 35. This downward force produces a counterclockwise rotational force on flexure plate 37-1 about the point where flexure plate 37-1 is mounted to the flexure support ring 38. The downward force also translates into a counterclockwise rotational force on flexure plate 37-3 about the point where flexure plate 37-3 is mounted to the flexure support ring 38. These two rotational forces cause rotation about the intersection of the two planes in which the flexure plates 37-1, 37-3 lie. This intersection occurs at intersection point 40.

A downward motion of the Y-axis tilt actuator 33 imparts a downward force on the Y-axis lever 36. This downward force produces a clockwise rotational force on flexure plate 37-4 about the point where flexure plate 37-4 is mounted to the flexure support plate 39. Because of the rigidity of the flexure support ring 38, this rotational force translates into a clockwise rotational force on flexure plate 37-2 about the point where flexure plate 37-2 is mounted to the flexure support plate 39. These two rotational forces cause rotation about the intersection of the two planes in which the flexure plates 37-2 and 37-4 lie. This intersection occurs at intersection point 40.

Referring to exemplary FIG. 8, there is shown one embodiment of an alignment actuator 41. The alignment actuator 41 may be a tilt actuator or a lateral alignment actuator, as described above. The alignment actuator 41 contains a handle 42 and a threaded body 43. The threaded body 43 is threadably mounted through a fixed surface 44 and against a movable surface 45. The movable surface 45 is biased toward the fixed surface 44 by a spring 46 or other suitable biasing means. The mounting of the movable surface 45 determines whether the force by the alignment actuator 41 or the biasing by the spring 46 produces a lateral or rotational force. The alignment actuator 41 may include what is commonly referred to as a micrometer stage.

Referring to exemplary FIG. 9, there is shown a top view of the cradle assembly 3. Referring to exemplary FIG. 10, there is shown a cross-sectional view of the cradle assembly 3, taken along line 10—10 of FIG. 9. The cradle assembly 3 comprises a cradle 47 having a surface 48 and a side 49, a plurality of vacuum clamps 50, and a baseplate alignment assembly (not shown). The cradle includes side walls 52 and end walls 53 for securing a baseplate assembly (not shown) in the cradle 47. In the embodiment particularly shown in exemplary FIGS. 9 and 10, the baseplate alignment assembly (not shown) comprises a source of radiant energy 54, a Y-axis source lateral actuator 55, a Z-axis source lateral actuator 56, an X-axis cradle assembly tilt actuator 57, a Y-axis cradle assembly tilt actuator 58, a mirror 59, and an alignment analyzer 60. In another embodiment, the baseplate alignment assembly (not shown) comprises a source of radiant energy 54, an X-axis cradle assembly tilt actuator 57, a Y-axis cradle assembly tilt actuator 58, a mirror 59, and an alignment analyzer 60. In both embodiments, the mirror 59 is aligned below a hole 61 in the surface 48 of the cradle 47. Additionally, the source of radiant energy 54 and the alignment analyzer 60 may be combined in an auto-collimater or an auto-collimater/telescope.

Referring to exemplary FIG. 11, a cross-sectional view of a vacuum clamp 50 is shown in the open position. Exemplary FIG. 12 shows a cross-sectional view of a vacuum clamp 50 in the closed position. The surface 48 of the cradle 47 extends laterally beyond the side 49 of the cradle 47. A vacuum clamp 50 with a U-shaped cross-section is placed over the extension of the cradle 47, with one leg of the U-shape on each side of the extension. A pivot pin 62 is placed through each leg of the U-shape and through the extension of the cradle 47. In the open position, a baseplate assembly can be placed on the cradle 47. Once in place, a pneumatic tube (not shown) biases the vacuum clamp 50 to the closed position, securing the baseplate against movement.

In operation, as shown in exemplary FIG. 13, a baseplate assembly 63 is provided. The baseplate assembly 63 contains a spindle 64 and a spindle motor 65 for rotating an information-bearing disk, and a spindle servo (not shown) for controlling the speed of the spindle motor 65. The baseplate assembly 63 further contains an optics module assembly 66. The baseplate assembly 63 also contains a carriage motor (not shown) and a carriage assembly 67 for directing a beam of radiant energy from the optics module assembly 66 toward a position on the information-bearing disk, and a carriage control servo (not shown) for controlling the position of the carriage assembly. At this point, the carriage assembly 67 does not contain an actuator lens for focussing the beam of radiant energy on the information-bearing disk. The carriage assembly 67 may be held in place relative to the spindle 64 by a carriage stop (not shown).

The baseplate assembly 63 is placed on the surface 48 of the cradle 47 and secured with the vacuum clamps 50. A test

disk of glass or other suitable material (not shown) is placed on the spindle of the baseplate assembly **63**. The gripper assembly **2** is then lowered into the closed position.

The source of radiant energy **54** radiates two cradle alignment beams of radiant energy toward the mirror **59**. The first cradle alignment beam is reflected from the mirror **59**, then passes through the hole **61** in the cradle **47** and through the baseplate assembly **63**. The first cradle alignment beam reflects off the test disk and is received by the alignment analyzer **60**. The second cradle alignment beam is reflected from the mirror **59**, then passes through the hole **61** in the cradle **47** and through the baseplate assembly **63**. The second cradle alignment beam reflects off the substrate **20** and is received by the alignment analyzer **60**. By analyzing the relative positions of the first and second cradle alignment beams, the alignment analyzer **60** determines the tilt of the test disk with respect to the substrate **20**. It will be obvious that the mirror **59** may comprise two parallel mirrors, each reflecting one of the cradle alignment beams.

Tilt between the test disk and the substrate **20** is corrected in the following manner. The X-axis cradle assembly tilt actuator **57** tilts the cradle assembly **3** about the X-axis. The Y-axis cradle assembly tilt actuator **58** tilts the cradle assembly **3** about the Y-axis. Acting together, the cradle assembly tilt actuators **57**, **58** tilt the cradle assembly **3**, including the test disk, with respect to the substrate **20**. Because the substrate **20** is orthogonal to the tower optical axis, this action tilts the cradle assembly **3** with respect to the tower optical axis. Each of the actuators **57**, **58** may be an alignment actuator **41** as shown in exemplary FIG. **8**.

In one embodiment, lateral alignment of the cradle assembly **3** with respect to the tower optical axis is done mechanically, and is not tested or measured. In another embodiment, if the cradle alignment beam is not received by the alignment analyzer **60**, or is off-center when received by the alignment analyzer **60**, the position of the source of radiant energy **54** can be moved using the Y-axis source lateral actuator **55** and the Z-axis source lateral actuator **56**. As shown best in FIG. **9**, the mirror **59** is situated such that a change in the position of the source of radiant energy **54** along the Y-axis is translated into a change in the position of the cradle alignment beam along the Y-axis as it is received by the alignment analyzer **60**. The Y-axis source lateral actuator **55** effects this change in position. Similarly, a change in the position of the source of radiant energy **54** along the Z-axis is translated into a change in the position of the cradle alignment beam along the X-axis as it is received by the alignment analyzer **60**. The Z-axis source lateral actuator **56** effects this change in position. Each of the actuators **55**, **56** may be an alignment actuator **41** as shown in exemplary FIG. **8**.

In the embodiment particularly described below, all references to a coordinate system are made in accordance with reference coordinate system **24** shown in exemplary FIG. **5**. This reference coordinate system **24** is chosen for purposes of explanation only, and it will be obvious to one skilled in the art that any convenient coordinate system could be chosen without departing from the spirit and scope of the present invention.

Once aligned, the source of radiant energy **54** is turned off and the test disk is removed. If not previously aligned, the carriage assembly of the baseplate assembly **63** is moved in approximate alignment with the assembly axis, and an actuator lens is placed within the carriage assembly of the baseplate assembly **63** and is allowed to assume a natural rest position. The lever assembly **5** is lowered to the closed position.

A pressure differential is then created between the vacuum chuck **12** and the atmosphere. This pressure differential operates to hold the actuator lens against the vacuum chuck **12**, while maintaining the orientation of the actuator lens. Additionally, the optical center of the actuator lens is maintained at the intersection point **40**. This optical center may also be substantially at the center of mass of the actuator lens.

An adjustable power supply is attached to the radiant energy source within the optics module assembly **66**. The radiant energy source projects a lens alignment beam of radiant energy into the carriage assembly. Within the carriage assembly, the lens alignment beam passes through the penta prism and through the actuator lens. The lens alignment beam then passes through the substrate **20**, through the microscope objective lens **19**, and into the tower assembly **1**, where the lens alignment beam passes through the tower magnifying lens **6** and is received by the video camera **7**. The analysis assembly **9** then displays and analyzes the spot profile of the lens alignment beam.

If the lens alignment beam is not received by the video camera **7** and passed to the analysis assembly **9**, the X-axis lateral alignment actuator **21** and the Y-axis lateral alignment actuator **22** are used to move the microscope objective lens **19** laterally with respect to the tower assembly **1**. The X-axis lateral alignment actuator **21** and the Y-axis lateral alignment actuator **22** may be alignment actuators **41** as shown in exemplary FIG. **8**.

If the lens alignment beam is not focussed properly in the video camera **7** and analysis assembly **9**, the focus actuator **23** is used to move the microscope objective lens **19** toward or away from the tower assembly **1** until the lens alignment beam is in proper focus within the video camera **7** and analysis assembly **9**. The focus actuator **23** may be an alignment actuator **41** as shown in exemplary FIG. **8**.

Once focussed properly, the analysis assembly **9** analyzes the profile of the beam for coma and astigmatism, as the cradle alignment beam was previously analyzed. If these optical aberrations occur, the actuator lens tilt assembly **15** operates to minimize these aberrations by aligning the actuator lens. As described above, the X-axis tilt actuator **32** rotates the actuator lens about the X-axis. Likewise, the Y-axis tilt actuator **33** rotates the actuator lens about the Y-axis. Together, the actuator lens tilt assembly **15** can rotate the actuator lens in any direction with respect to the lens alignment beam, while maintaining the optical center or the center of mass of the actuator lens at the intersection point **40**.

Once the misalignment is corrected to within an acceptable tolerance, the gripper assembly **2**, including the vacuum chuck **12** and the actuator lens, is raised to the open position. A fastening agent is placed on the pedestals of the carriage assembly, and the gripper assembly **2** is again lowered to the closed position. The actuator lens is secured by the fastening agent to the carriage assembly, without changing the orientation of the actuator lens established by the actuator lens tilt assembly **15**. The fastening agent may be a selectably-curable adhesive, such as ultraviolet radiation-curable adhesive.

Once the fastening agent has cured, the actuator lens is tested for alignment. As above, a lens alignment beam is radiated through the actuator lens, the substrate **20**, the microscope objective lens **19**, the tower magnifying lens **6**, and into the video camera **7**. The analysis assembly **9** then analyzes the spot profile of the lens alignment beam. Each of the alignments described above may need to be adjusted

for this testing process. Depending on its configuration, the vacuum chuck **12** may need to be retracted or removed to avoid contacting and damaging the carriage assembly.

In another embodiment of the invention, the cradle assembly **3** may comprise a plurality of cradles **47**, a plurality of vacuum clamps **50**, and a baseplate alignment assembly (not shown). The cradles **47** may be movable with respect to the tower assembly **1**, and there may be either one baseplate alignment assembly (not shown) for each cradle **47**, or a single baseplate alignment assembly (not shown) which aligns only the cradle **47** presently in position with respect to the tower assembly **1**. Further, there may be a single source of radiant energy **54** and set of actuators **55**, **56**, **57**, **58** regardless of the number of cradles **47**, with one mirror **59** associated with each cradle **47**.

According to this embodiment, there may be a second tower assembly **1** identical to the first tower assembly **1** described above. In addition, there may be a second gripper assembly **2** associated with the second tower assembly **1** as described above. The second gripper assembly **2** will not contain a vacuum chuck **12**.

In operation, the first tower assembly **1** and first gripper assembly **2** operate as described in the previous embodiment. After fastening the actuator lens to the carriage assembly with the fastening agent, the cradle **47** containing the baseplate assembly **63** is moved beneath the second tower assembly **1** and second gripper assembly **2**. Again, a lens alignment beam of radiant energy is projected by the optics module assembly **66** through the same path in the second tower assembly **1** and second gripper assembly **2** as described with respect to the first tower assembly **1** and first gripper assembly **2**. The analysis assembly **9** associated with the second tower assembly **1** analyzes the spot profile of the lens alignment beam after the actuator lens is fastened to the baseplate assembly **63**. It will be obvious to one skilled in the art that, by allowing the vacuum chuck **12** to be removable or retractable, the first tower assembly **1** and first gripper assembly **2** may function as the second tower assembly **1** and second gripper assembly **2**, respectively.

It will be obvious to one skilled in the art that modifications to the above description of the invention may be made without departing from the spirit and scope of the invention. The scope of the invention, therefore, is indicated by the appended claims rather than the above description.

While this invention has been explained with reference to the structure disclosed herein, it is not confined to the details set forth and this application is intended to cover any modifications and changes as may come within the scope of the following claims:

What is claimed is:

1. A method for mounting an actuator lens to a carriage assembly, the method comprising the steps of:

positioning the carriage assembly in a baseplate assembly;

moving the baseplate assembly with respect to a tower assembly; moving a gripper assembly with respect to the tower assembly;

moving the actuator lens with respect to the tower assembly, wherein the baseplate, gripper and actuator lens respectively, define a baseplate optical axis, a gripper optical axis and actuator lens optical axis, and whereby the baseplate gripper assembly and actuator lens optical axes are aligned with said tower optical axis;

placing the baseplate assembly in a cradle assembly;

adjusting the focus of the actuator lens;

moving the gripper to an open position out of the tower optical axis;

applying a fastening agent to said carriage assembly; and

lowering said gripper to a closed position, whereby said actuator lens is secured to said carriage assembly by said fastening agent without changing the orientation of the actuator lens.

2. A method, as defined in claim **1**, wherein the step of moving the baseplate comprises:

moving said baseplate assembly with respect to said tower assembly laterally such that said baseplate optical axis and said tower optical axis intersect at a first intersection; and

rotating a first time said baseplate assembly with respect to said tower assembly about a first rotational axis through said first intersection and orthogonal to said baseplate optical axis and said tower optical axis.

3. A method, as defined in claim **2**, wherein said step of moving the actuator lens comprises:

moving said actuator lens with respect to said tower assembly laterally such that said actuator lens optical axis and said tower optical axis intersect at a second intersection; and

rotating a second time said actuator lens with respect to said tower assembly about a second rotational axis through said second intersection and orthogonal to said actuator lens optical axis and said tower optical axis.

4. A method, as defined in claim **3**, wherein said first rotating step comprises:

rotating said baseplate assembly with respect to said tower assembly about a first reference axis through said first intersection and coplanar with said first rotational axis; and

rotating said baseplate assembly with respect to said tower assembly about a second reference axis through said first intersection and coplanar with said first rotational axis and orthogonal to said first reference axis; whereby said baseplate assembly is rotated about said first rotational axis; and

said second rotating step comprises:

rotating said actuator lens with respect to said tower assembly about a third reference axis through said second intersection and coplanar with said first rotational axis; and

rotating said actuator lens with respect to said tower assembly about a fourth reference axis through said second intersection and coplanar with said second rotational axis and orthogonal to said third reference axis;

whereby said actuator lens is rotated about said second rotational axis.

5. A method, as defined in claim **2**, wherein said first rotating step comprises:

rotating said baseplate assembly with respect to said tower assembly about a first reference axis through said first intersection and coplanar with said first rotational axis; and

rotating said baseplate assembly with respect to said tower assembly about a second reference axis through said first intersection and coplanar with said first rotational axis and orthogonal to said first reference axis;

whereby said baseplate assembly is rotated about said first rotational axis.

6. A method, as defined in claim **1**, wherein said step of moving the actuator lens comprises:

moving said actuator lens with respect to said tower assembly laterally such that said actuator lens optical axis and said tower optical axis intersect at a second intersection; and

rotating a second time said actuator lens with respect to said tower assembly about a second rotational axis through said second intersection and orthogonal to said actuator lens optical axis and said tower optical axis.

7. A method, as defined in claim **6**, wherein said second rotating step comprises:

rotating said actuator lens with respect to said tower assembly about a third reference axis through said second intersection and coplanar with said first rotational axis; and

rotating said actuator lens with respect to said tower assembly about a fourth reference axis through said second intersection and coplanar with said second rotational axis and orthogonal to said third reference axis;

whereby said actuator lens is rotated about said second rotational axis.

8. A method for installing an actuator lens into an optical disc carriage assembly, the carriage assembly including an information bearing disc having a spindle, spindle motor, and optics module; the method comprising;

moving a first time a baseplate assembly with respect to a tower assembly, said baseplate assembly defining a baseplate optical axis, said tower assembly defining a tower optical axis, whereby said first moving step aligns said baseplate optical axis and said tower optical axis;

moving a second time an objective lens assembly with respect to said tower assembly, said objective lens assembly defining an objective lens optical axis, whereby said second moving step aligns said objective lens optical axis and said tower optical axis;

moving a third time said actuator lens with respect to said tower assembly, said actuator lens defining an actuator lens optical axis, whereby said third moving step aligns said actuator lens optical axis and said tower optical axis;

mounting the carriage assembly in said baseplate assembly;

mounting the baseplate assembly on a cradle assembly, the cradle assembly having a source of radiant energy, an analyzer and a mirror;

positioning the gripper assembly in a closed position over the carriage assembly;

determining the tilt of the optical disc;

correcting the tilt of the disc;

aligning the cradle assembly with respect to a tower optical axis;

removing the optical disc from the baseplate assembly;

positioning the gripper assembly in an open position out of the tower optical axis;

placing the actuator lens in the carriage assembly;

lowering the gripper assembly to the closed position;

temporarily securing the actuator lens to the gripper assembly while maintaining the same orientation;

projecting a lens alignment beam into the carriage assembly, through the actuator lens, and through the gripper assembly to the tower assembly, the tower assembly including an optical analyzer;

analyzing the lens alignment beam;

aligning the actuator lens in response to the analysis;

moving the gripper assembly to the open position;

applying a fastening agent to the carriage assembly;

lowering the gripper to a closed position, whereby the lens is secured to the carriage assembly without changing the orientation established thereof and;

releasing the actuator lens from the gripper assembly.

9. A method, as defined in claim **8**, wherein the gripper assembly includes a microscope objective lens and substrate.

10. A method, as defined in claim **8**, wherein the step of projecting a lens alignment beam is followed by the step of analyzing the alignment of the actuator lens using the analyzer and adjusting the X-Y position of the baseplate in response thereto.

11. A method, as defined in claim **10**, comprising the step of:

moving the microscope objective lens toward or away from the tower assembly until the lens alignment beam is in proper focus.

12. A method of installing an actuator as defined in claim **8**, wherein the step of analyzing the lens alignment beam comprises the steps of: analyzing

the focus using the analyzer; and

moving the microscope objective lens in response thereto.

13. A method, as defined in claim **8**, wherein the step of analyzing the lens alignment beam comprises the step of analyzing the lens alignment beam for coma and astigmatism and aligning the actuator lens in response thereto.

14. A method, as defined in claim **8**, wherein the step of analyzing the alignment beam includes the steps of:

receiving the lens alignment beam in a video camera and in an analysis assembly contained in the tower; and

adjusting a microscope objective toward or away from the tower until the lens alignment beam is in proper focus.

15. A method, as defined in claim **8**, wherein the carriage assembly includes one or more pedestals, and wherein the step of applying a fastening agent includes the step of applying a fastening agent to the pedestal.

16. A method, as defined in claim **8**, wherein the first moving step comprises:

moving the baseplate assembly with respect to the tower assembly laterally such that the baseplate optical axis and the tower optical axis intersect at a first intersection; and

rotating a first time the baseplate assembly with respect to the tower assembly about a first rotational axis through the first intersection and orthogonal to the baseplate optical axis and the tower optical axis.

17. A method, as defined in claim **16**, wherein the first rotating step comprises:

rotating the baseplate assembly with respect to the tower assembly about a first reference axis through the first intersection and coplanar with the first rotational axis; and

rotating the baseplate assembly with respect to the tower assembly about a second reference axis through the first intersection and coplanar with the first rotational axis and orthogonal to the first reference axis;

whereby the baseplate assembly is rotated about the first rotational axis.

18. A method, as defined in claim **8**, wherein the third moving step comprises:

moving the actuator lens with respect to the tower assembly laterally such that the actuator lens optical axis and the tower optical axis intersect at a second intersection; and

rotating a second time the actuator lens with respect to the tower assembly about a second rotational axis through the second intersection and orthogonal to the actuator lens optical axis and the tower optical axis.

19. A method, as defined in claim **18**, wherein the second rotating step comprises:

rotating the actuator lens with respect to the tower assembly about a third reference axis through the second intersection and coplanar with the first rotational axis; and

rotating the actuator lens with respect to the tower assembly about a fourth reference axis through the second intersection and coplanar with the second rotational axis and orthogonal to the third reference axis;

whereby the actuator lens is rotated about the second rotational axis.

20. A method, as defined in claim **8**, wherein the third moving step comprises:

moving the actuator lens with respect to the tower assembly laterally such that the actuator lens optical axis and the tower optical axis intersect at a second intersection; and

rotating a second time the actuator lens with respect to the tower assembly about a second rotational axis through the second intersection and orthogonal to the actuator lens optical axis and the tower optical axis.

21. A method of aligning a lens, as defined in claim **8**, wherein the first rotating step comprises:

rotating the baseplate assembly with respect to the tower assembly about a first reference axis through the first intersection and coplanar with the first rotational axis; and

rotating the baseplate assembly with respect to the tower assembly about a second reference axis through the first intersection and coplanar with the first rotational axis and orthogonal to the first reference axis;

whereby the baseplate assembly is rotated about the first rotational axis; and

the second rotating step comprises:

rotating the actuator lens with respect to the tower assembly about a third reference axis through the second intersection and coplanar with the first rotational axis; and

rotating the actuator lens with respect to the tower assembly about a fourth reference axis through the second intersection and coplanar with the second rotational axis and orthogonal to the third reference axis;

whereby the actuator lens is rotated about the second rotational axis.

22. A method as defined in claim **8** wherein the step of adjusting the focus of the actuator lens comprises the steps of:

directing a beam of radiant energy from source, through the actuator lens, and to an optical analyzer in the tower; and

analyzing the focus of the beam received by the analyzer; and adjusting the position of the gripper in response to the analysis.

23. The method as defined in claim **8** wherein the step of correcting the tilt further comprises the steps of:

directing two cradle alignment beams, from the cradle assembly radiant energy source, the first beam being directed to the mirror, to the optical disc, and to the alignment analyzer;

the second beam being directed to the mirror, the gripper and to the alignment analyzer; and

comparing the relative position of the first and second beams on the alignment analyzer and adjusting the position of the cradle in response thereto.

24. An apparatus for installing an actuator lens in a carriage assembly, the actuator lens defining as actuator optical axis and an actuator optical center within a baseplate using a beam of radiant energy, comprising:

a frame;

a cradle assembly for holding the baseplate, the cradle assembly mounted to the frame with at least one degree of freedom of motion; the carriage assembly, being mounted to the baseplate, the carriage assembly including an optical disc, and spindle motor and pedestal for holding the actuator lens;

a tower assembly defining a tower axis and mounted to the frame, the cradle assembly and the tower assembly defining an assembly axis for receiving the beam of radiant energy along the tower axis and analyzing the spot profile of the beam of radiant energy;

a lever assembly positioned in a closed position, rotatably mounted to the frame; and

a gripper assembly mounted to the lever assembly, comprising:

an objective lens defining an objective optical axis;

an objective lens assembly mounted to the objective lens, for selectively holding the actuator lens stationary relative to the objective lens;

an objective lens alignment assembly for aligning the objective lens with the tower assembly and the cradle assembly by aligning the objective optical axis laterally with respect to the assembly axis when the lever assembly is in the closed position; and

an actuator lens tilt assembly for aligning the actuator lens with the tower assembly and the cradle assembly by rotating the actuator optical axis about an axis orthogonal to the assembly axis when lever assembly is in the closed position;

whereby when the lever assembly is in the closed position the gripper assembly, the tower assembly, the cradle assembly, the baseplate, and the actuator lens tilt assembly are positioned with respect to each other such that the beam of radiant energy can be used to align the actuator lens with the baseplate by adjusting the relative position of alignment of one or more of the objective lens assembly, the cradle assembly and the actuator lens with respect to the tower assembly, and whereby when the lever assembly is in the open position and the actuator lens is removed, and a fastening agent is applied to the pedestal, when the lever assembly is closed the actuator lens is secured by the fastening agent without changing the alignment of the actuator lens.

25. An apparatus as defined in claim **24**, further comprising:

a source of radiant energy for projecting the beam of radiant energy into the tower assembly along a beam axis;

means for determining the tilt alignment of the beam axis with respect to the tower axis;

a first tilt actuator for rotating the beam axis about a first repositioning axis orthogonal to the tower axis; and

a second tilt actuator for rotating the beam axis about a second repositioning axis orthogonal to the tower axis and the first repositioning axis.

26. An apparatus as defined in claim 24, further comprising:

a source of radiant energy for projecting the beam of radiant energy into the tower assembly along a beam axis;

means for determining the lateral alignment and tilt alignment of the beam axis with respect to the tower axis;

a first lateral actuator for repositioning the beam axis laterally with respect to the tower axis along a first repositioning axis orthogonal to the tower axis;

a second lateral actuator for repositioning the beam axis laterally with respect to the tower axis along a second repositioning axis orthogonal to the tower axis and the first repositioning axis;

a first tilt actuator for rotating the beam axis about the first repositioning axis; and

a second tilt actuator for rotating the beam axis about the second repositioning axis.

27. An optical disc drive system having a carriage assembly with an actuator lens mounted therein by the method according to claim 1, 8 or 24.

28. A method for installing an actuator lens into an optical disc carriage assembly, the carriage assembly including an information bearing disc having a spindle, spindle motor and optics module; the method comprising:

moving a first time said baseplate assembly with respect to a tower assembly, said baseplate assembly defining a baseplate optical axis, said tower assembly defining a tower optical axis, whereby said first moving step aligns said baseplate optical axis and said tower optical axis;

moving a second time an objective lens assembly with respect to said tower assembly, said objective lens assembly defining an objective lens optical axis, whereby said second moving step aligns said objective lens optical axis and said tower optical axis; and

moving a third time said actuator lens with respect to said tower assembly, said actuator lens defining an actuator lens optical axis, whereby said third moving step aligns said actuator lens optical axis and said tower optical axis;

positioning the carriage assembly in a baseplate assembly;

positioning the baseplate assembly on a cradle assembly, the cradle assembly having a source of radiant energy and a mirror;

positioning the gripper assembly in a closed position over the carriage assembly determine the tilt of the optical disc;

correcting the tilt of the disc;

aligning the cradle assembly with respect to a tower optical access;

removing the optical disc from the baseplate assembly;

positioning the gripper assembly in an open position out of the tower optical access;

placing the actuator lens in the carriage assembly;

lowering the gripper assembly to the closed position;

temporarily securing the actuator lens to the gripper assembly while maintaining the same orientation;

project a light beam into the carriage assembly and through the actuator lens, and through the gripper assembly to the tower assembly, the tower assembly including an optical analyzer;

analyzing the lens alignment beam (add lens above);

aligning the actuator lens in response to the analysis;

moving the gripper assembly to the open position;

applying a fastening agent to the carriage assembly;

lowering the gripper to a closed position, where by the lens is secured to the carriage assembly without changing the orientation established thereof.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 5,768,035

DATED : June 16, 1998

INVENTOR(S) : Grassens, et al

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

On the title page, under item [56], insert the following:

U. S. PATENT DOCUMENTS

EXAMINER INITIAL		PATENT NUMBER							ISSUE DATE	PATENTEE	CLASS	SUBCLASS	FILING DATE IF APPROPRIATE
		3	6	3	8	9	3	3	2/1/72	Burnette et al.			
		4	6	5	2	0	9	5	3/24/87	Mauro			
		4	7	7	2	1	0	9	9/20/88	Cutburth et al.			
		4	9	1	3	5	2	7	4/3/90	Jessop			
		3	4	0	0	5	9	7	9/10/68	Nater			
		4	7	7	2	1	2	3	9/20/88	Radner			
		5	0	7	9	6	4	1	1/7/92	Marino et al.			

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 5,768,035

DATED : June 16, 1998

INVENTOR(S) : Grassens, et al

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

FOREIGN PATENT OR PUBLISHED FOREIGN PATENT APPLICATION

		DOCUMENT NUMBER							PUBLICATION DATE	COUNTRY OR PATENT OFFICE	CLASS	SUBCLASS	TRANSLATION YES	TRANSLATION NO
		5	8	16	8	0	2	1	10/4/83	Japan				
		6	0	25	6	1	0	8	12/17/85	Japan				
		1	9	6	1	9	1	3	7/1/71	Germany				
		4	0	3	8	7	2	7	6/11/92	Germany				
		5	9	2	7	6	6		4/20/94	Europe				
		1	0	9	7	8	3	2	4/17/89	Japan				
		5	9	1	0	7	30	7	6/21/84	Japan				
		6	0	1	9	7	94	2	10/7/85	Japan				
		6	3	1	0	3	93	2	5/9/88	Japan				

Signed and Sealed this

Second Day of March, 1999

Attest:

Attesting Officer

Q. TODD DICKINSON

Acting Commissioner of Patents and Trademarks

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 5,768,035
DATED : June 16, 1998
INVENTOR(S) : Leonardus J. Grassens, et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Title page,
Item [54], delete "METHOD AND APPARATUS FOR ALIGNING AN OBJECTIVE LENS" and in place thereof insert -- METHOD AND APPARATUS FOR MOUNTING A LENS -- (in Amendment filed October 23, 1997 as well as in COMMUNICATION -- Entry of Modified Title -- filed February 18, 1998)

Item [73], add -- Assignee: Discovision Associates, Irvine, Calif. --

Item [62], delete "410,698" and in place thereof insert, -- 418,698 --
(according to Filing Receipt from USPTO received February 25, 1997)

Item [57] ABSTRACT: *Col. 2, line 15*
(Amendment filed October 23, 1997, page 2, line 12) delete "presentation" and in place thereof, insert -- *representation* -- *between "displaying a"* and *"of a beam"*.

Signed and Sealed this

Thirtieth Day of October, 2001

Attest:

Nicholas P. Godici

Attesting Officer

NICHOLAS P. GODICI
Acting Director of the United States Patent and Trademark Office

US005757552A

United States Patent [19]

Murayama et al.

[11] Patent Number: 5,757,552

[45] Date of Patent: May 26, 1998

[54] **MICROSCOPE OBJECTIVE LENS AND A MICROSCOPE INCORPORATING SAME**

[75] Inventors: **Norio Murayama**, Mitaka; **Yoshiyuki Shimizu**, Miura, both of Japan

[73] Assignee: **Nikon Corporation**, Japan

[21] Appl. No.: **611,305**

[22] Filed: **Mar. 5, 1996**

[30] **Foreign Application Priority Data**

Mar. 7, 1995 [JP] Japan 7-077319

[51] **Int. Cl.**[6] **G02B 21/02**; G02B 21/00

[52] **U.S. Cl.** **359/658**; 359/368; 359/656

[58] **Field of Search** 359/363, 368, 359/385–389, 656–661, 791–795

[56] **References Cited**

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Primary Examiner—Thong Nguyen

Attorney, Agent, or Firm—Klarquist Sparkman Campbell Leigh & Whinston, LLP

[57] **ABSTRACT**

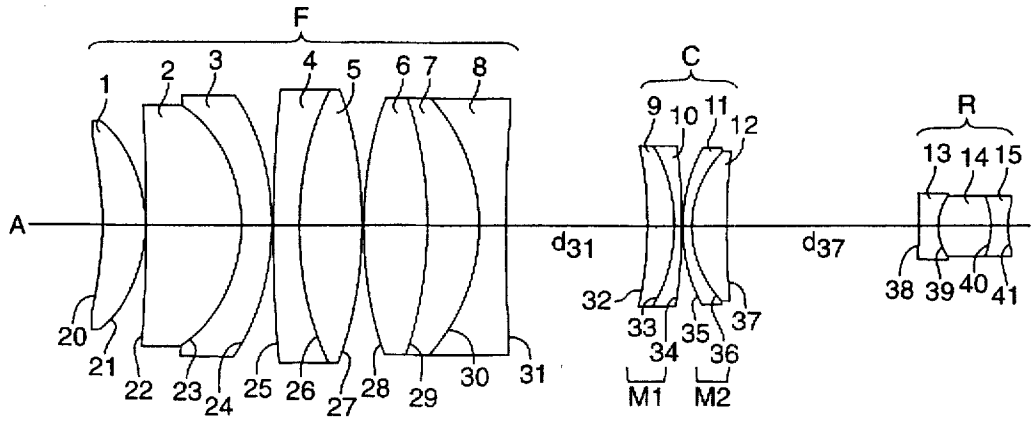
A microscope objective, and microscope incorporating same, are disclosed. A representative embodiment of the objective comprises, arranged on an optical axis, a front lens group having positive refractive power disposed on the object side, a rear lens group having negative refractive power disposed on the image side, and a corrective lens group interposed between the front and rear lens groups. The corrective lens group is axially movable and comprises a pair of meniscus lens elements each of which having a convex surface oriented toward each other. The corrective lens group serves to correct aberrations arising from a cover glass or other refractive body situated between the specimen being observed and the objective lens. To such end, the objective preferably satisfies the conditions:

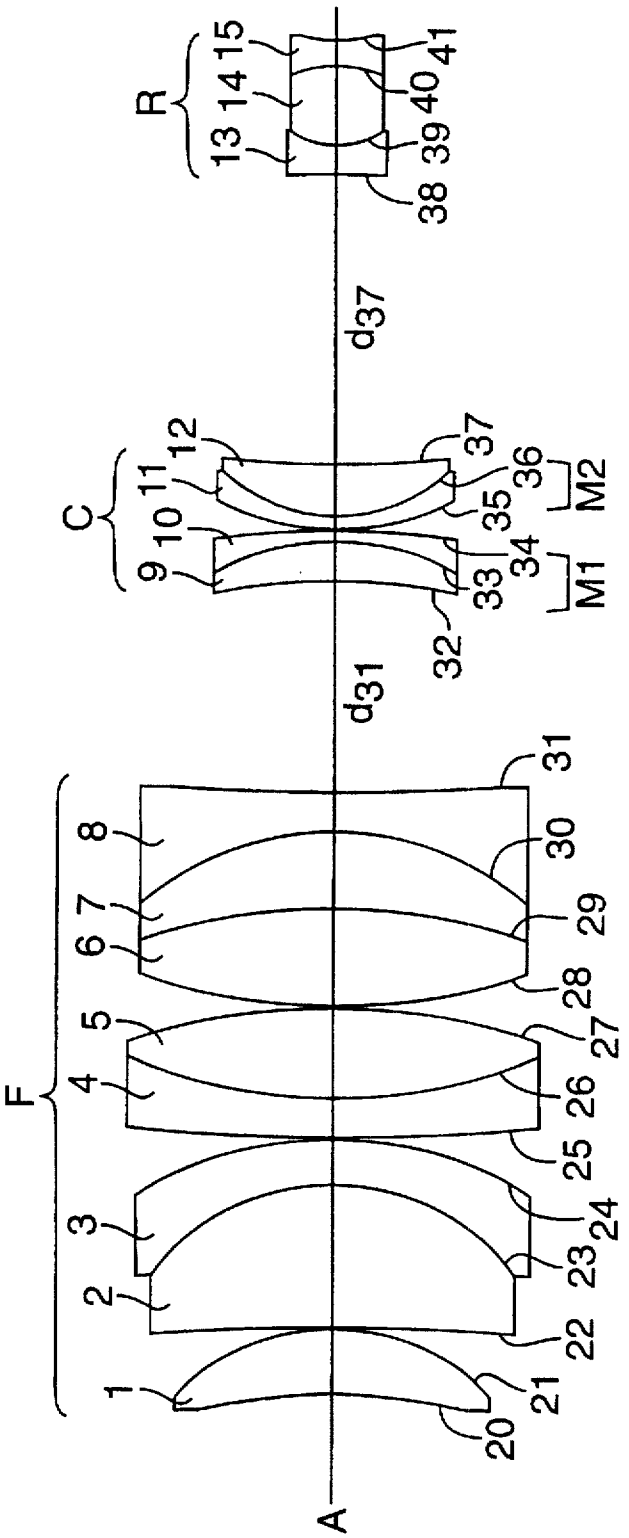
$$|1/f_c| \leqq |1/f| \times 0.02$$

$$0.95 \leqq |m| \leqq 1.05$$

wherein f is the overall refractive power of the microscope objective lens, and f_c and m are the refractive power and magnification, respectively, of the corrective lens group.

4 Claims, 11 Drawing Sheets




R
13 14 15
38 39 40 41
d37
C
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d31
F
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20 21 22 23 24 25 26 27 28 29 30 31
A

FIG. 1

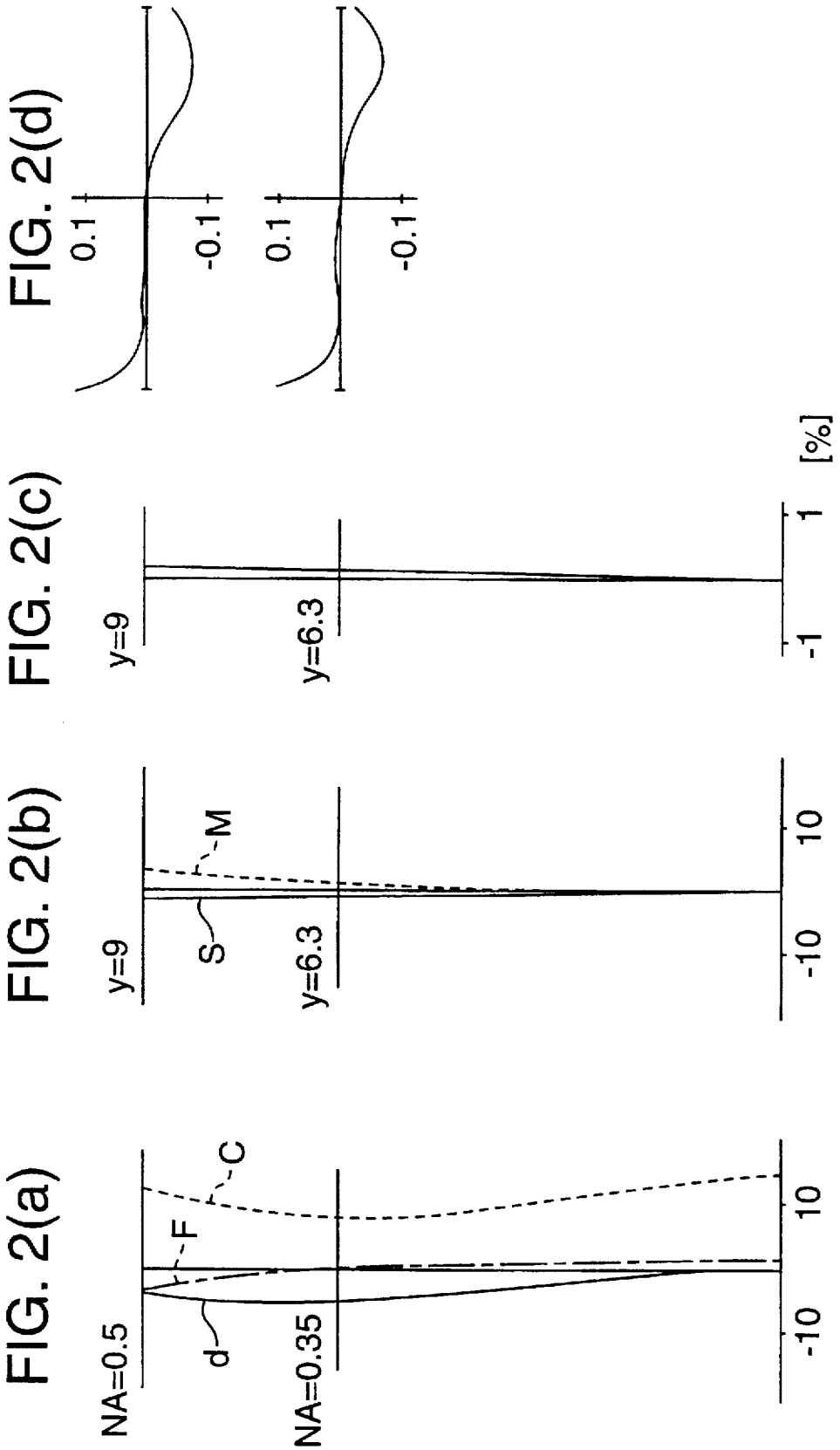


FIG. 2(a)
NA=0.5
NA=0.35
C
F
d
10
-10
10
-10
FIG. 2(b)
y=9
y=6.3
M
S
10
-10
FIG. 2(c)
y=9
y=6.3
1
-1
[%]
FIG. 2(d)
0.1
-0.1
0.1
-0.1

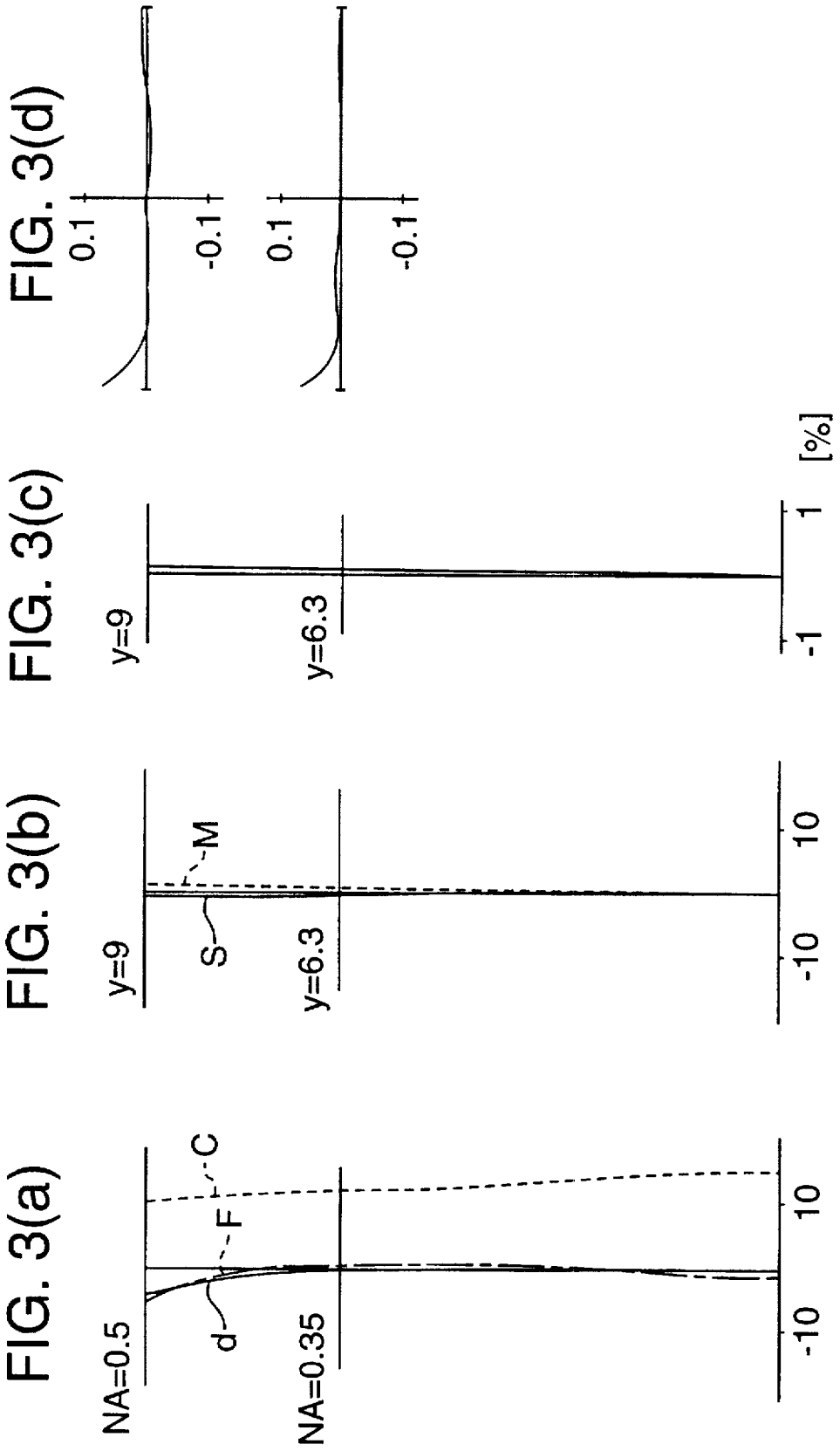


FIG. 3(a)
NA=0.5
C
F
d
NA=0.35
10
-10
FIG. 3(b)
y=9
M
S
y=6.3
10
-10
FIG. 3(c)
y=9
y=6.3
1
-1
[%]
FIG. 3(d)
0.1
-0.1
0.1
-0.1

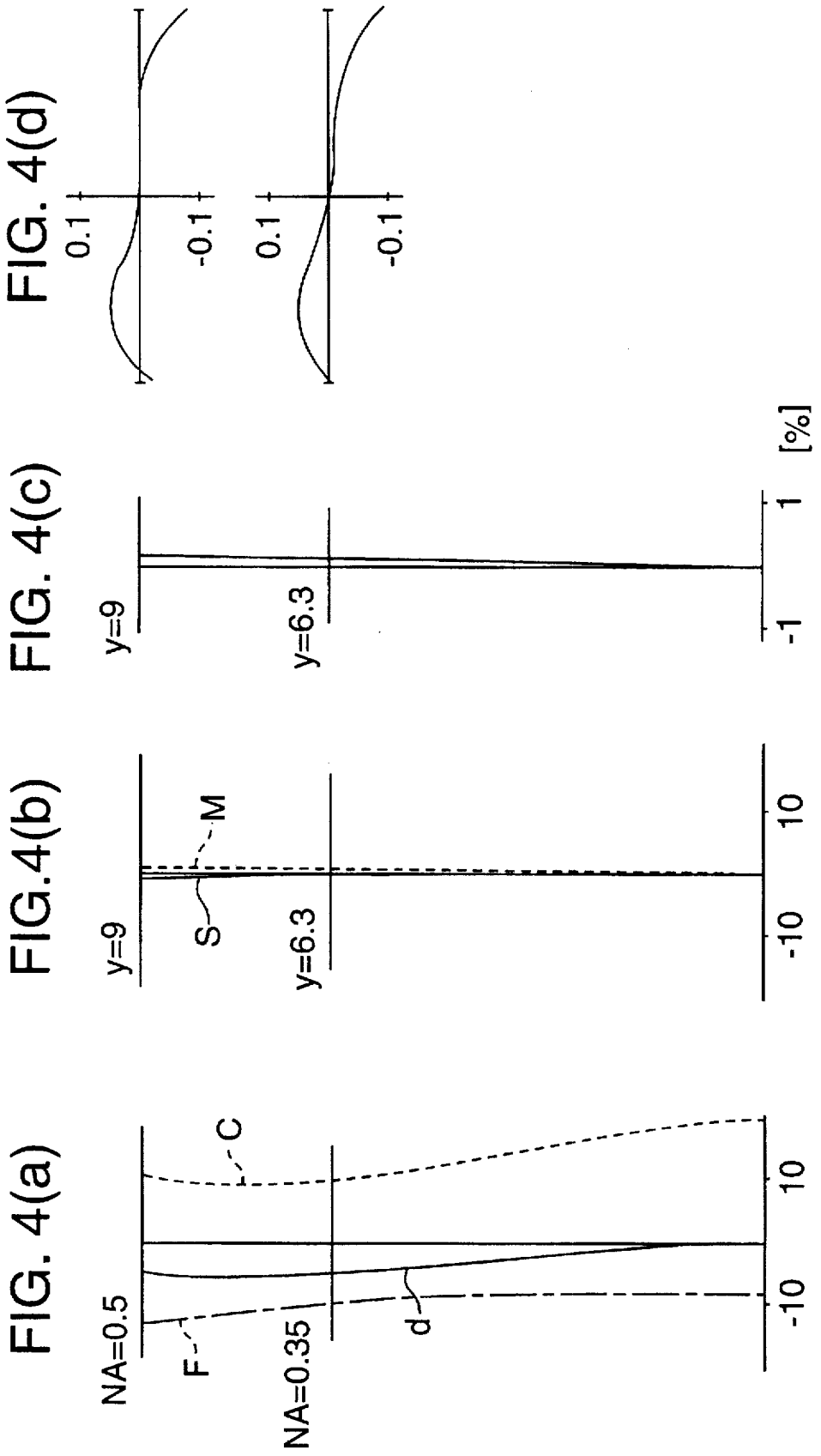
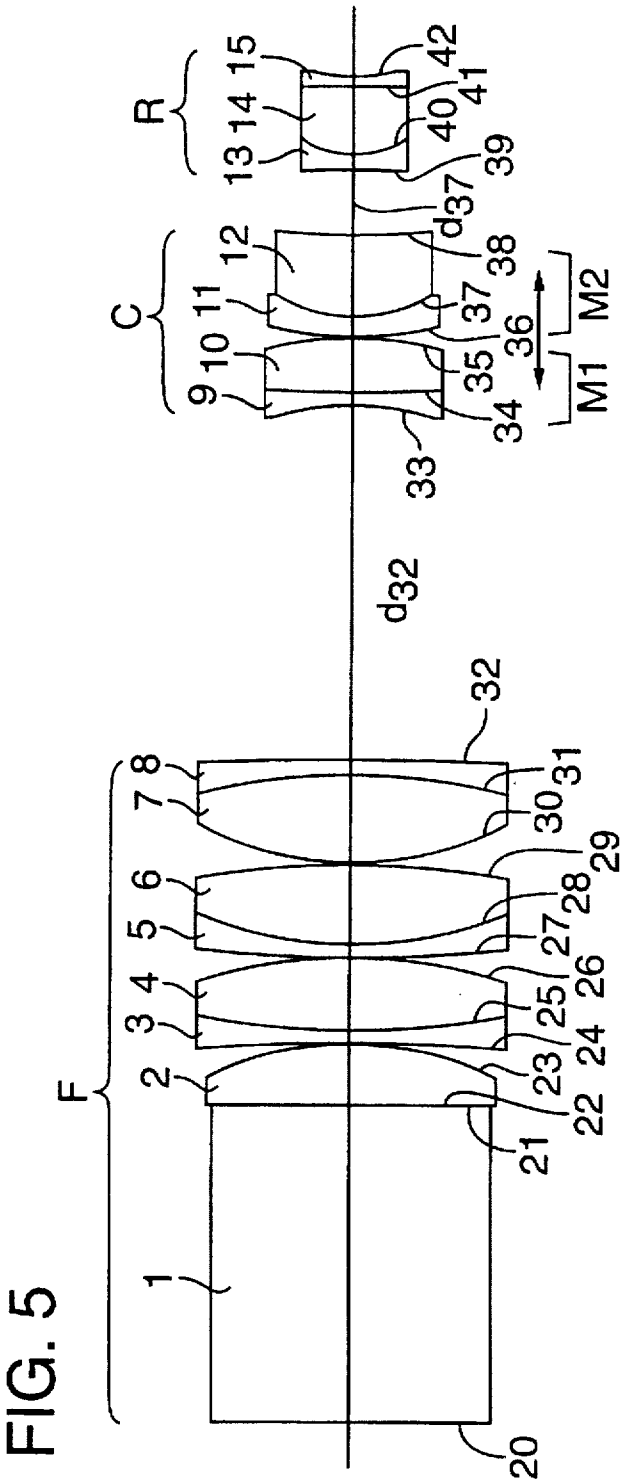


FIG. 4(a)
NA=0.5
C
F
NA=0.35
d
10
-10
FIG.4(b)
y=9
M
S
y=6.3
10
-10
FIG. 4(c)
y=9
y=6.3
1
-1
[%]
FIG. 4(d)
0.1
-0.1
0.1
-0.1


R
C
F
M1
M2
d32
d37
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
20
21
22
23
24
25
26
27
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29
30
31
32
33
34
35
36
37
38
39
40
41
42

FIG. 5

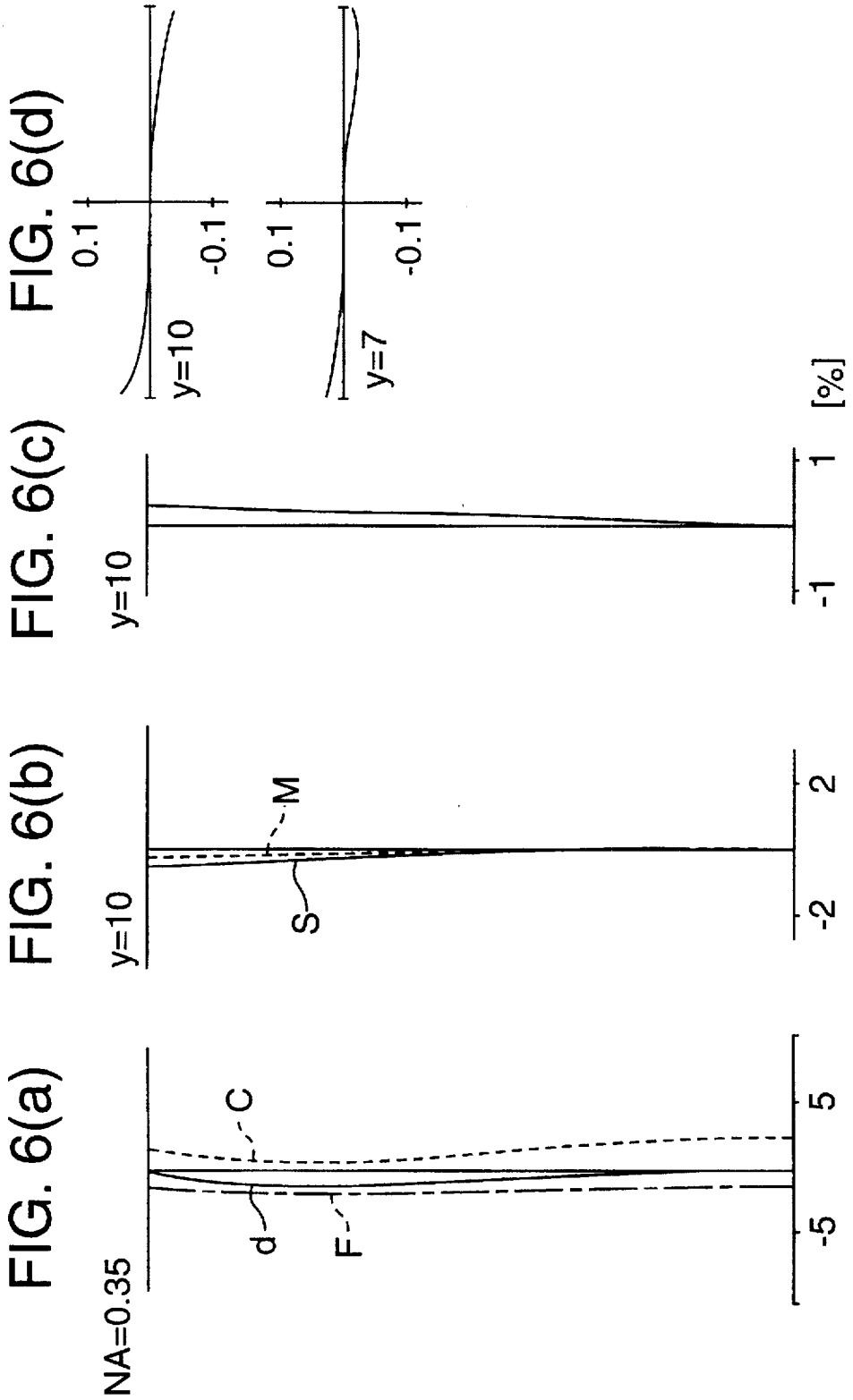
FIG. 6(a)
NA=0.35
C
d
F
FIG. 6(b)
y=10
M
S
2
-2
FIG. 6(c)
y=10
1
-1
[%]
FIG. 6(d)
0.1
-0.1
y=10
0.1
-0.1
y=7
5
-5

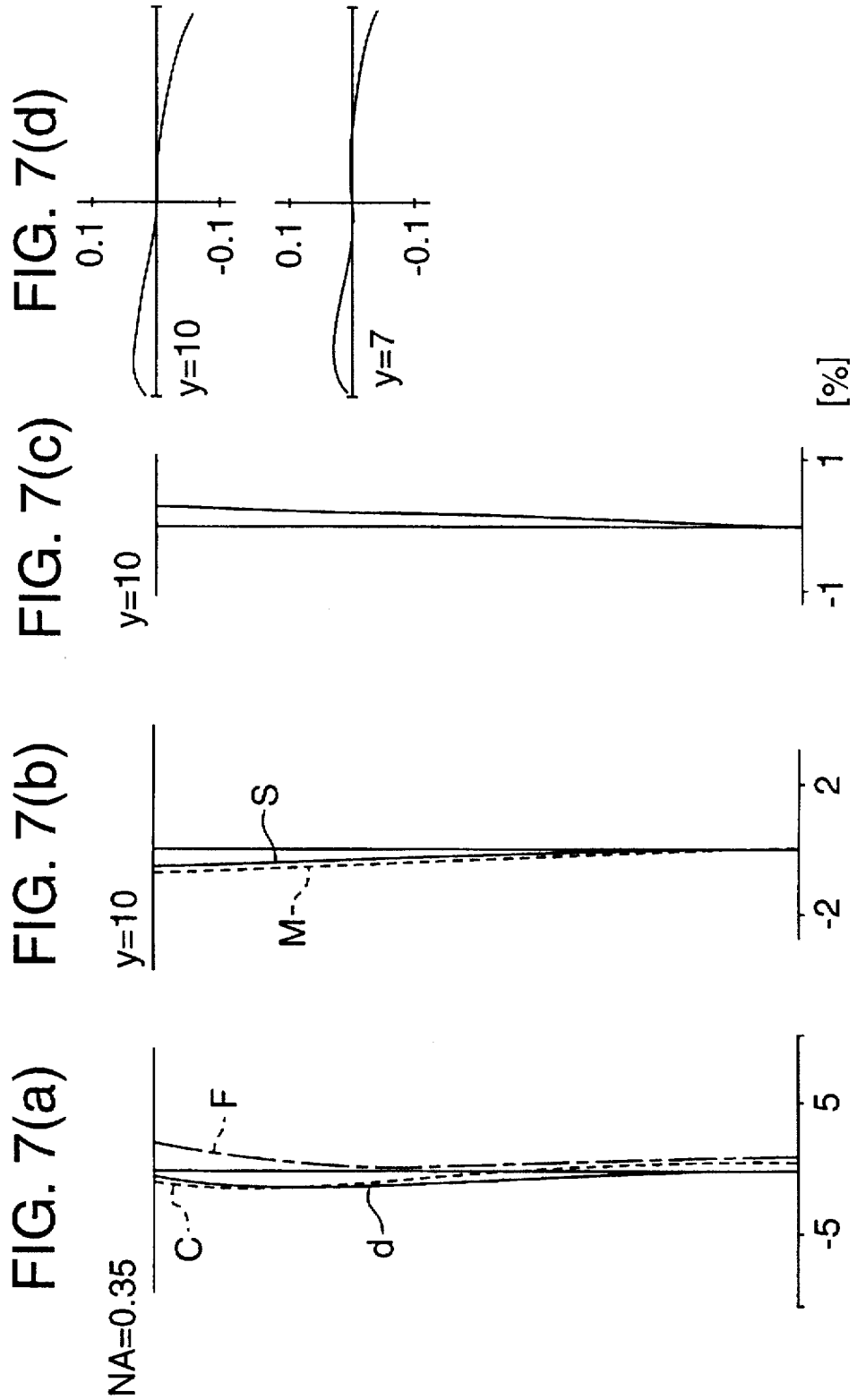
FIG. 7(a)
NA=0.35
C
F
d
FIG. 7(b)
y=10
S
M
2
-2
FIG. 7(c)
y=10
1
-1
[%]
FIG. 7(d)
0.1
-0.1
y=10
0.1
-0.1
y=7
5
-5

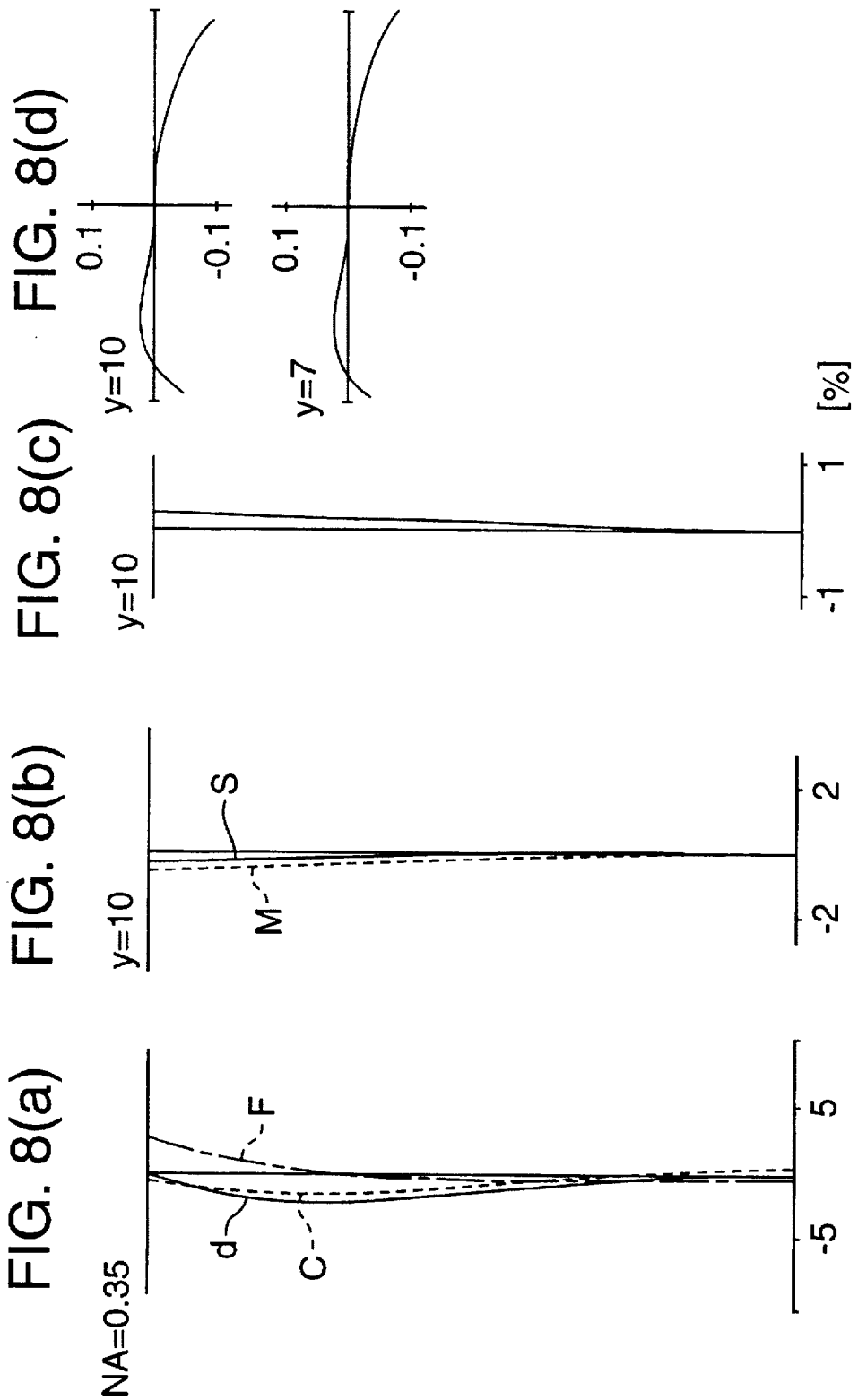
FIG. 8(a)
NA=0.35
F
d
C
5
-5
FIG. 8(b)
y=10
S
M
2
-2
FIG. 8(c)
y=10
1
-1
[%]
FIG. 8(d)
y=10
0.1
-0.1
y=7
0.1
-0.1

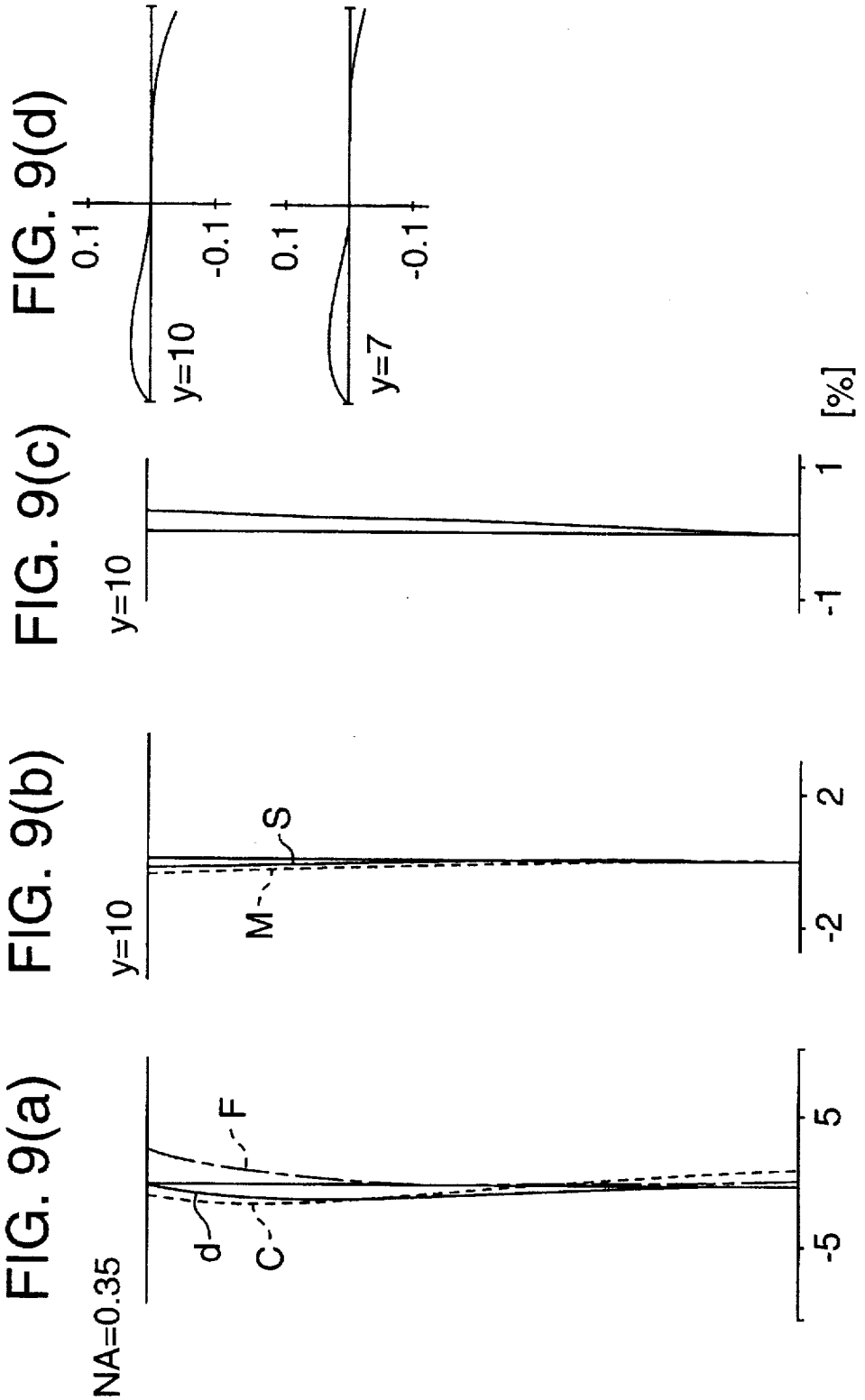
FIG. 9(a)
NA=0.35
d
C
F
5
-5
FIG. 9(b)
y=10
M
S
2
-2
FIG. 9(c)
y=10
1
-1
[%]
FIG. 9(d)
0.1
-0.1
y=10
0.1
-0.1
y=7

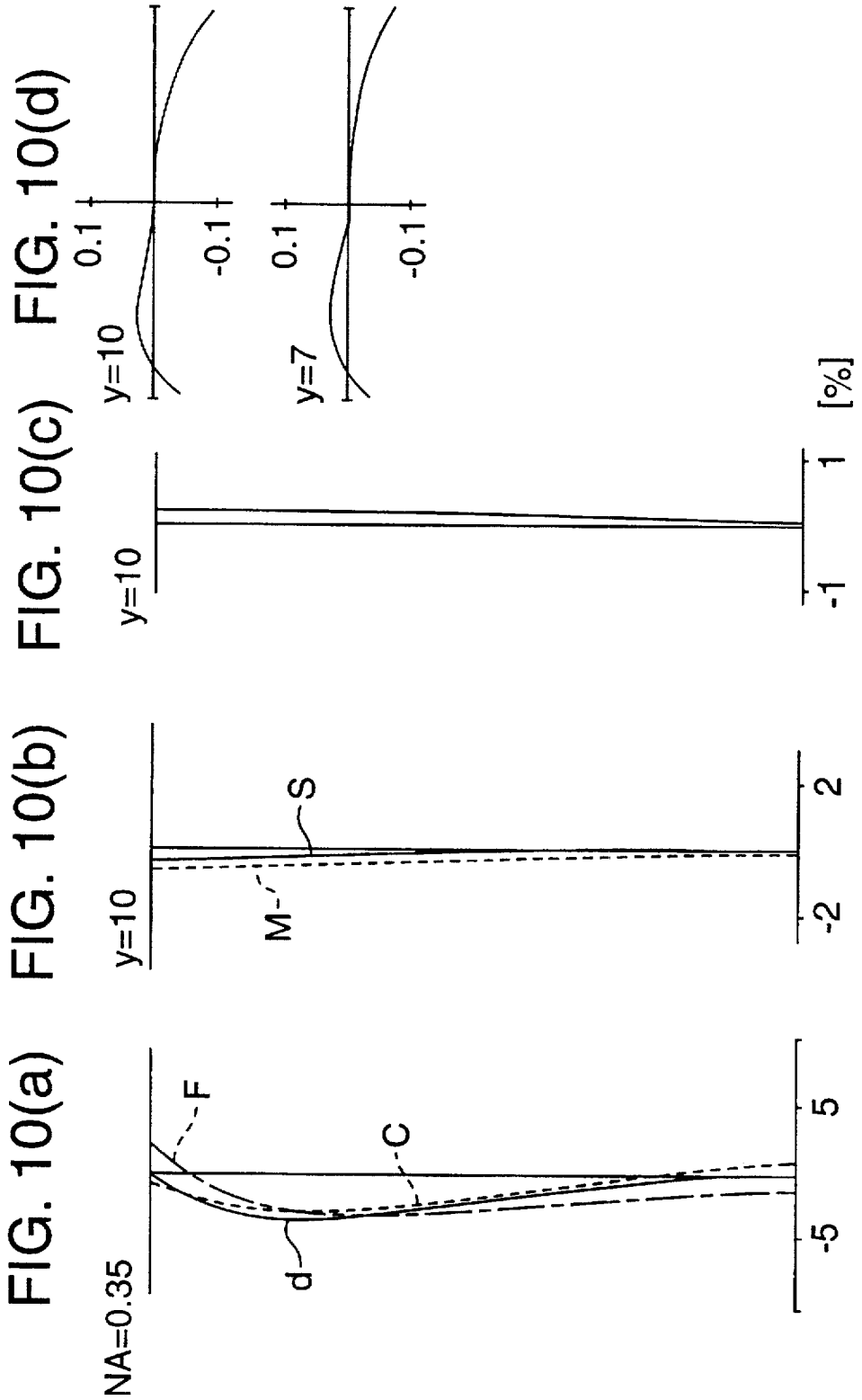
FIG. 10(a)
NA=0.35
F
C
d
5
-5
FIG. 10(b)
y=10
S
M
2
-2
FIG. 10(c)
y=10
1
-1
[%]
FIG. 10(d)
y=10
0.1
-0.1
y=7
0.1
-0.1

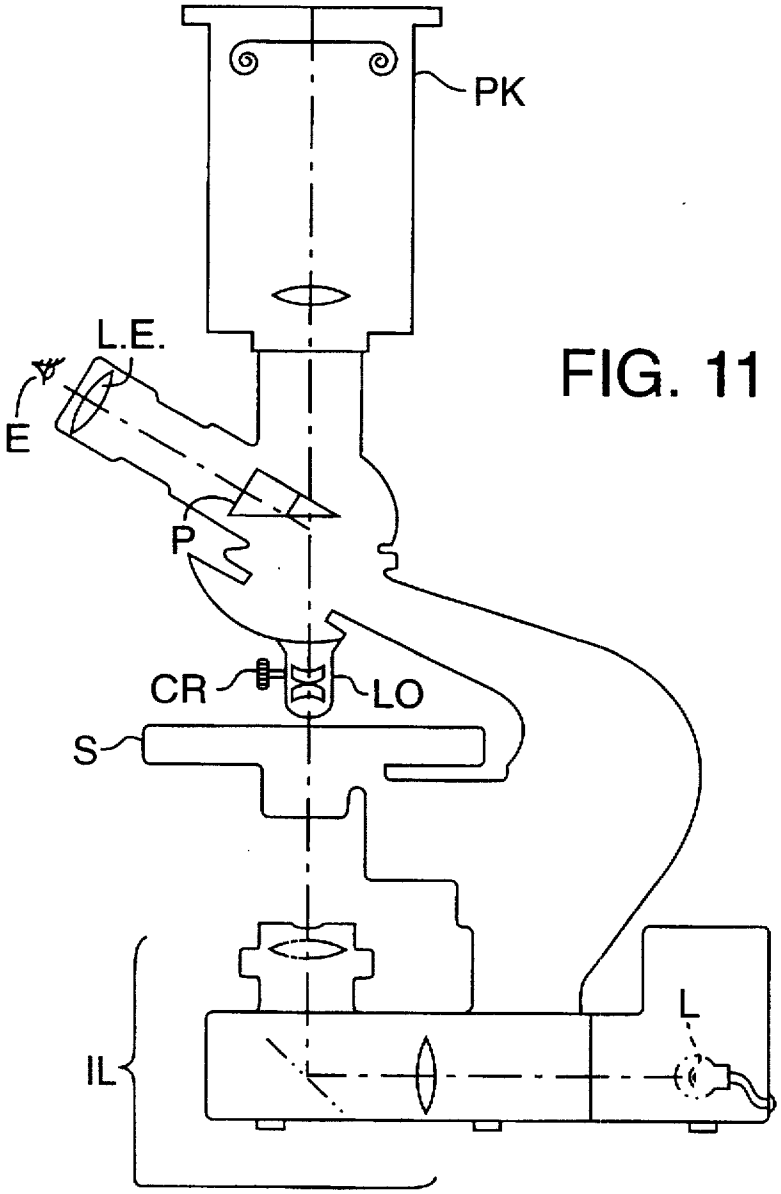

FIG. 11

MICROSCOPE OBJECTIVE LENS AND A MICROSCOPE INCORPORATING SAME

FIELD OF THE INVENTION

This invention pertains to a microscope objective lens and a microscope incorporating the objective lens. Specifically, this invention pertains to a microscope objective lens that can produce an excellent quality image of a specimen under a cover glass or other refractive body, despite any thickness variations in the refractive body.

BACKGROUND OF THE INVENTION

An objective lens on a microscope, especially a microscope used for biology or medicine, must frequently observe a specimen situated beneath a cover glass or other refractive body such as water, translucent gel or plastic, or the like. Thus, light from the specimen must pass through the thickness of the, for example, cover glass (an optical distance equal to the product of the thickness of the cover glass times the refractive index of the cover glass) and through an air layer between the cover glass and the objective. The cover glass produces a positive spherical aberration, and it is preferable that the objective lens be able to correct this aberration.

Due to manufacturing errors and/or tolerances, a cover glass can have substantial variations in thickness, although typically these variations are relatively small. Aberrations that accompany such variations in cover glass thickness are commonly corrected by moving, along an optical axis, certain lens elements or lens groups in the objective lens.

With medical and biological microscopes, substantial aberrations can also arise whenever the microscope is used to observe a specimen that is suspended in an aqueous medium in a dish such as a petri dish or cell culture dish, wherein light from the specimen must also pass through the dish before entering the objective. In such instances, the depth of the aqueous medium and thickness of the dish can vary markedly.

Japan Kôkai patent document nos. SHO 59-100409 and SHO 60-205521, (the priority documents for U.S. Pat. Nos. 4,588,264 and 4,666,256, respectively) disclose microscope objective lenses that are able to correct changes in aberrations in situations when a cover glass, a dish and water, or other variable-thickness refractive body is interposed between the specimen and the objective lens. The microscope objective lenses disclosed in these documents employ a "corrective" lens group in which a negative meniscus lens element is laminated on each side of a biconvex lens element. Such a corrective lens group, which is normally movable along the optical axis of the objective lens, is conventionally situated between a front lens group and a rear lens group in the objective lens.

Unfortunately, whereas such objective lenses provide some correction of aberrations, further improvement is desirable in view of the increasing demands placed on the performance of research microscopes. Specifically, conventional microscope objective lenses as described above can satisfactorily correct spherical and chromatic aberrations as well as image-plane distortions to a certain extent. But, coma is frequently inadequately corrected for optimum image quality under some conditions of use. In addition, conventional objectives exhibit residual movement of the image point during attempts to effect such corrections. Furthermore, the overall focal length of a conventional microscope objective lens is narrow, and the amount of variation in cover-glass thickness that can be corrected by such an objective lens is relatively small and thus inadequate for certain applications.

SUMMARY OF THE INVENTION

An object of the present invention is to provide a microscope objective lens that can sufficiently correct various aberrations and eliminate movement of the image point so as to consistently provide excellent image formation, even when the thickness of an interposed refractive body such as a cover glass, dish, or the like varies over a broad range.

Another object is to provide a microscope incorporating such an objective lens.

The foregoing objects are satisfied by a microscope objective lens, and microscope incorporating such an objective, according to the present invention.

A preferred embodiment of the objective lens comprises, in order from the object side to the image side on an optical axis, a front lens group, a rear lens group, and a corrective lens group disposed between the front and rear lens groups. The front lens group has a positive refractive power that converges light from the object. The rear lens group has a negative refractive power.

The corrective lens group is axially moveable in the air space located between the front and rear lens groups, and comprises a pair of meniscus lens elements. Each of the meniscus lens elements, which can be cemented or not cemented, has a convex surface. The meniscus lens elements are disposed on the optical axis such that the convex surfaces are oriented toward each other.

A microscope objective lens according to the present invention preferably satisfies the following conditions:

$$|1/f_c| \leqq |1/f| \times 0.02$$

$$0.95 \leqq |m| \leqq 1.05$$

wherein f is the overall refractive power of the microscope objective lens, and f_c and m are the refractive power and magnification, respectively, of the corrective lens group.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is an optical diagram showing general aspects of a preferred embodiment of a microscope objective lens according to the present invention, as well as specific aspects of Example Embodiment 1;

FIG. **2** includes various aberration diagrams for Example Embodiment 1 when used with a cover glass having "zero" thickness. Specifically, FIG. **2***a* shows spherical aberration, FIG. **2***b* shows astigmatism, FIG. **2***c* shows distortion, and FIG. **2***d* shows meriodonal coma;

FIG. **3** includes various aberration diagrams for Example Embodiment 1 when used with a cover glass having a thickness of 5 mm. Specifically, FIG. **3***a* shows spherical aberration, FIG. **3***b* shows astigmatism, FIG. **3***c* shows distortion, and FIG. **3***d* shows meriodonal coma;

FIG. **4** includes various aberration diagrams for Example Embodiment 1 when used with a cover glass having a thickness of 10 mm. Specifically, FIG. **4***a* shows spherical aberration, FIG. **4***b* shows astigmatism, FIG. **4***c* shows distortion, and FIG. **4***d* shows meriodonal coma;

FIG. **5** is an optical diagram showing specific aspects of Embodiment 2;

FIG. **6** includes various aberration diagrams for Example Embodiment 2 when used with a cover glass having "zero"

thickness. Specifically, FIG. **6***a* shows spherical aberration, FIG. **6***b* shows astigmatism, FIG. **6***c* shows distortion, and FIG. **6***d* shows meriodonal coma;

FIG. **7** includes various aberration diagrams for Example Embodiment 2 when used with a cover glass having a thickness of 9.4 mm. Specifically, FIG. **7***a* shows spherical aberration, FIG. **7***b* shows astigmatism, FIG. **7***c* shows distortion, and FIG. **7***d* shows meriodonal coma;

FIG. **8** includes various aberration diagrams for Example Embodiment 2 when used with a cover glass having a thickness of 15 mm. Specifically, FIG. **8***a* shows spherical aberration, FIG. **8***b* shows astigmatism, FIG. **8***c* shows distortion, and FIG. **8***d* shows meriodonal coma;

FIG. **9** includes various aberration diagrams for Example Embodiment 2 when used with a layer of water having a "thickness" of 10.6 mm. Specifically, FIG. **9***a* shows spherical aberration, FIG. **9***b* shows astigmatism, FIG. **9***c* shows distortion, and FIG. **9***d* shows meriodonal coma;

FIG. **10** includes various aberration diagrams for Example Embodiment 2 when used with a layer of water having a "thickness" of 16.8 mm. Specifically, FIG. **10***a* shows spherical aberration, FIG. 10*b* shows astigmatism, FIG. **10***c* shows distortion, and FIG. 10*d* shows meriodonal coma; and

FIG. **11** is an optical diagram of a representative embodiment of a microscope including an objective lens according to the present invention.

DETAILED DESCRIPTION

A "positive" distance or direction along an optical axis extends from left ("object side") to right ("image side") in an optical diagram; a "negative" distance or direction extends from right to left.

The "curvature radius" of an optical surface (such as a surface of a lens element) is "positive" whenever the center of curvature lies to the right of the surface, and "negative" whenever the center of curvature lies to the left of the surface.

An "interfacial distance" is the distance, along an optical axis, between adjacent optical surfaces on separate optical elements.

In the following description, it will be understood that a "cover glass" can be any of various refractive bodies as listed above that can be placed over a specimen for protection from physical trauma, drying, or other purpose. Other refractive bodies can also behave as a cover glass, such a clear plastic surface supporting living cells being observed using a microscope objective.

General aspects of a preferred embodiment of a microscope objective lens according to the present invention are shown in FIG. **1**. The objective lens comprises, in order from the object side to the image side on an optical axis A, a front lens group F having a positive refractive power, a rear lens group R having a negative refractive power, and a corrective lens group C interposed between the front and rear lens groups. The corrective lens group C is axially moveable in an air space located between the front and rear lens groups.

In the FIG. **1** embodiment, the corrective lens group C comprises a pair of meniscus lenses **M1**, **M2**. Each of the meniscus lenses **M1**, **M2**, which generally can be either a singlet or a cemented lens, has a convex surface **34**, **35**, respectively. The meniscus lenses **M1**, **M2** are disposed on the optical axis such that the convex surfaces **34**, **35** are oriented toward each other.

A microscope objective lens according to the present invention preferably satisfies the following conditions:

$$|1/f_c| \leq |1/f| \times 0.02$$

$$0.95 \leq |m| \leq 1.05$$

wherein f is the overall refractive power of the objective lens, and f_c and m are the refractive power and magnification, respectively, of the corrective lens group C.

The front lens group F produces a large negative spherical aberration; this negative spherical aberration is corrected a required amount by the corrective lens group C. The rear lens group R also provides spherical aberration correction, to yield an overall excellent correction of spherical aberration by the entire objective lens.

The corrective lens group C is situated in convergent light from the front lens group F. If the corrective lens group C is moved frontwardly, the height (from the axis A) of incident light entering the corrective lens group C becomes taller; thus, the corrective lens group C produces a large positive spherical aberration. Conversely, if the corrective lens group C is moved rearwardly, the height of incident light entering the corrective lens group C becomes shorter; thus, the corrective lens group C produces a small positive spherical aberration. Consequently, it is possible to correct spherical aberrations, such as spherical aberrations arising from a cover glass having a varying thickness interposed between the objective lens and an object being imaged by the objective lens, by axially moving the corrective lens group C.

The refractive power $1/f_c$ of the corrective lens group C is preferably about 2% or less of the overall refractive power 1/f of the objective lens. Thus, the corrective lens group C preferably has relatively no refractive power. Moving such a corrective lens group C along the optical axis A advantageously will effect virtually no movement of the image point, even during a change in spherical aberration.

In conventional telecentric optical systems, not limited to microscope objective lenses, used to visualize various points on an object, the effect of variations in the thickness of a cover glass or the like, disposed between the object and the optical system, on a light path is the same whether the object point is situated on- or off-axis. In other words, the optical effect of the cover glass is uniform across the entire image plane. Consequently, in a telecentric lens system, variations in the thickness of the cover glass will not directly cause coma aberration; but, coma aberration will appear to change due to the effects of changes in spherical aberration.

In addition, the thickness of a cover glass will not have any effect on the paths of principal rays in a telecentric optical system. In an objective according to the present invention, because there is virtually no movement of the image point accompanying any axial movement of the correction lens group C, there is no movement of the image point. This is because the several optical light path lengths between the object and the objective lens are always constant.

Further with respect to an objective lens according to the present invention, the front lens group F produces negative spherical aberration; but, preferably, other aberrations are preferably well corrected by this group. It is especially desirable to correct any inner and outer coma that exist at the sine condition. The corrective lens group C should also possess similar characteristics. Namely, while the corrective lens group C produces positive spherical aberration in order to correct the negative spherical aberration produced by the front lens group, other aberrations imparted by the corrective lens group C are preferably minimal; it is especially desir-

able that the corrective lens group suppress the production of inner and outer coma. In other words, it is desirable for the light flux that has passed through the cover glass, the front lens group F and the corrective lens group C to be always in the same aberration-corrected state, regardless of the thickness of the cover glass. Besides correcting spherical aberration, the corrective lens group C should not, as much as possible, produce any of its own aberrations.

For example, assuming a certain thickness of the cover glass and a certain axial position of the corrective lens group C, it is possible, by using the corrective lens group C to correct any inner coma produced by the front lens group C, to have excellent aberrational correction overall. However, if the thickness of the cover glass were to change, and if the corrective lens group C were to be moved appropriately to correct any new spherical aberration arising from the change, it is not certain that coma would remain in the same excellent state as before movement. Consequently, the corrective lens group C should suppress as much as possible the production of aberrations other than spherical aberration.

While the corrective lens group C should not produce aberrations other than spherical aberration, there is no specific restriction on the refractive power required to achieve that purpose. However, the refractive power of the corrective lens group C should be small enough so as to sufficiently minimize movement of the image point. Of course, if the corrective lens group were made of parallel planar elements rather than refractive elements, there would be no movement of the image point upon movement of the corrective lens group C. This would be due to the zero refractive power and unitary "magnification" (of an object at infinity) of planar elements. (These conditions also apply for an image magnification of 1 for an object at any object distance from the objective.) If the corrective lens group C behaved the same as parallel planar elements with respect to paraxial rays, it would be necessary for the corrective lens group C to fulfill the same conditions as parallel planar elements; i.e., it would be necessary for the refractive power of the corrective lens group C to be sufficiently small, while simultaneously having a magnification of about 1.

To perform the aberration-correction functions described above while simultaneously restricting movement of the image point, the corrective lens group C preferably comprises a pair of meniscus lenses arranged with their convex faces facing each other. Also, each meniscus lens is preferably a cemented lens so as to provide excellent correction of chromatic and spherical aberrations. Alternatively, one of the meniscus lenses can be a single lens element and the other can be a cemented lens.

In order to satisfactorily limit movement of the image point, the absolute value of the refractive power of the corrective lens group C is preferably 2% or less of the overall refractive power of the objective lens, and the magnification of the corrective lens group C is preferably within 5% of unity, i.e., in the range from 0.95 to 1.05. This is because movement of the image point becomes great if these ranges are exceeded, which increases the number of practical problems.

The magnification of the corrective lens group C when its refractive power is zero is defined as, for an object placed at infinity: (height of light rays exiting the corrective lens group)/(height of incident light rays entering the corrective lens group). The magnification of the corrective lens group C when its refractive power is not zero is defined as: (distance from the lens surface in the corrective lens group closest to the image surface to the focal point)/(focal length).

EXAMPLE EMBODIMENT 1

FIG. **1** shows specific features of Example Embodiment 1 of a microscope objective lens, comprising (in order from the object side): a front lens group F with a positive refractive power that converges the light emitted from the object, a rear lens group R with a negative refractive power, and a corrective lens group C axially interposed in the air space between the front lens group F and rear lens group R. The corrective lens group C is movable along the optical axis A.

The corrective lens group C comprises a pair of cemented meniscus lenses **M1** and **M2**, both of which being arranged on the optical axis with their respective convex faces **34**, **35** oriented toward each other. Example Embodiment 1 is telecentric on the object side, with a service magnification of 40× and an NA (numerical aperture) of 0.5.

Table 1, below, lists numeric specifications for Example Embodiment **1**. The front lens group F comprises lens elements **1** through **8**, the corrective lens group C comprises lens elements **9** through **12**, and the rear lens group comprises lens elements **13** through **15**. The interfacial distance d_{31} between the front lens group F and the corrective lens group C, and the interfacial distance d_{37} between the corrective lens group C and the rear lens group R are variable, and $d_{31}+d_{37}=38.765$. Additionally, the corrective lens group C has a focal length f_c wherein $f_c=\infty$. In other words, the refractive power ($1/f_c$) of the corrective lens group C is 0 (zero) and the magnification m of the corrective lens group C of an infinitely distant object is m=+1.000.

TABLE 1

Lens Surface No.	Curvature Radius R (mm)	Interfacial Distance d (mm)	Lens No.	Refractive Index n	Abbe No. ν_d
20	−55.609	5.2	1	1.56384	60.7
21	−17.962	0.1			
22	−230.064	11.0	2	1.49782	82.5
23	−19.417	3.5	3	1.7552	27.6
24	−31.159	0.1			
25	149.872	3.0	4	1.50137	56.4
26	41.820	7.0	5	1.59319	67.9
27	−58.179	0.2			
28	49.678	7.5	6	1.49782	82.5
29	−48.629	6.0	7	1.78472	25.8
30	−24.401	3.0	8	1.75692	31.6
31	212.618	d_{31}			
32	−53.483	3.0	9	1.59507	35.5
33	−22.606	0.8	10	1.80411	46.5
34	−90.254	0.2			
35	20.722	1.0	11	1.74950	35.2
36	13.206	4.0	12	1.49782	82.5
37	75.909	d_{37}			
38	−82.648	2.2	13	1.61266	44.4
39	6.648	6.0	14	1.74077	27.6
40	−14.121	2.0	15	1.74950	35.2
41	8.817				

Table 2 shows d_{31}, d_{37}, and the image distance (distance from the most imagewise lens surface **41** to an image plane) for cover-glass thicknesses of 0, 5, and 10. FIGS. **2***a*–**2***d*, **3***a*–**3***d*, and **4***a*–**4***d* show the corresponding aberration graphs. The refractive index n_{CG} of the cover glass in this example is $n_{CG}=1.52216$, and the Abbe number ν_d is $\nu_d=58.8$. From Table 2, it can be seen that the image distance is held constant by appropriately moving the corrective lens group C, even when there is a substantial change in the cover glass thickness. As is shown in the various aberration graphs, it can be seen that the microscope objective lens of this embodiment has superior imaging properties and performance.

TABLE 2

Cover Glass Thickness	d_{31} (mm)	d_{37} (mm)	Image Distance
0	16.312	22.453	200 mm
5	21.712	17.053	200 mm
10	30.312	8.453	200 mm

EXAMPLE EMBODIMENT 2

An objective lens configuration according to Example Embodiment 2 is shown in FIG. **5**, and the numeric specifications for this embodiment are shown in Table 3. Lens elements **1** through **8** comprise the front lens group F, lens elements **9** through **12** comprise the corrective lens group C, and lens elements **13** through **15** comprise the rear lens group R. In addition, the interfacial distance d_{32} between the front lens group F and the corrective lens group C, and the interfacial distance d_{38} between the corrective lens group C and the rear lens group R are variable; furthermore, $d_{32}+d_{38}=31.5$. The focal length f_c of the corrective lens group C is $f_c=\infty$. In other words, the refractive power ($1/f_c$) of the corrective lens group C is 0 (zero) and the magnification m of the corrective lens group C (of an infinitely distant object) is m=+1.000.

The microscope objective lens in this Example Embodiment is telecentric on the object side, with a service magnification of 20 times and a numerical aperture (NA) of 0.35.

TABLE 3

Lens Face No.	Curvature Radius R (mm)	Interfacial Distance d (mm)	Lens No.	Refractive Index n	Abbe No. ν_d
20	∞	23.2	1	1.74443	49.5
21	∞	0.2			
22	∞	4.45	2	1.62374	47.1
23	−25.082	0.1			
24	−163.174	1.0	3	1.7495	35.2
25	67.614	5.4	4	1.49782	82.2
26	−41.038	0.1			
27	163.174	1.0	5	1.61266	44.4
28	33.780	6.0	6	1.43388	95.6
29	−64.906	0.1			
30	25.749	6.5	7	1.43388	95.6
31	−48.063	1.0	8	1.713	53.9
32	−355.356	d_{32}			
33	−25.501	1.0	9	1.56384	60.7
34	107.295	4.0	10	1.56883	56.1
35	−26.400	0.1			
36	33.062	1.5	11	1.80454	39.6
37	13.865	6.0	12	1.6172	54.0
38	47.891	d_{38}			
39	−112.492	1.0	13	1.61266	44.4
40	9.332	5.0	14	1.71736	29.5
41	−151.285	0.7	15	1.713	53.9
42	14.744				

Table 4, below, shows d_{32}, d_{38}, and the image distance (distance from the most imagewise lens surface **42** to an image plane) for cover-glass thicknesses of 0, 9.4 and 15.0. FIGS. ***6a–6d***, ***7a–7d***, and ***8a–8d*** show the corresponding aberration graphs. The refractive index n_{CG} of the cover glass in this example is $n_{CG}=1.51454$, and the Abbe number ν_d is $\nu_d=54.6$. From Table 4, it can be seen that the image distance is held constant by appropriately moving the corrective lens group C, even when there is a substantial change in the cover glass thickness.

TABLE 4

Cover Glass Thickness	d_{31} (mm)	d_{37} (mm)	Image Distance
0	8.2	23.3	198.5 mm
9.4	16.5	15.0	198.5 mm
15.0	26.8	4.7	198.5 mm

Table 5, below, shows d_{32}, d_{38}, and the image distance in instances where water is used instead of a cover glass and the water thickness is either 10.6 or 16.8. FIGS. ***9a–9d***, and ***10a–10d*** show corresponding aberration graphs. The refractive index n_W of the water is $n_W=1.331$ and the Abbe number ν_d is $\nu_d=54.1$. As is shown in Table 5, it can be seen that the image distance is held constant by appropriately moving the corrective lens group C, even when there is a substantial change in the thickness of a water layer over the object.

TABLE 5

Water Thickness	d_{32} (mm)	d_{38} (mm)	Image Distance
10.6	16.5	15.0	198.5 mm
16.8	26.8	4.7	198.5 mm

As is shown in the various aberration graphs (FIGS. ***6a–6d***, ***7a–7d***, ***8a–8d***, ***9a–9d***, and ***10a–10d***), it can be seen that the microscope objective lens of this embodiment has superior imaging properties and performance.

FIG. **11** shows, in combination, a microscope and an objective lens LO according to the present invention. Referring to FIG. **11**, light flux exiting a light source L passes through an illumination optical system IL to provide Koehler illumination of the specimen (specimen not shown, but would normally be situated on the stage S beneath the microscope objective lens LO). The specimen is normally placed on a glass slide overlaid by a cover glass (not shown). The microscope objective lens LO, such as a lens according to either of Example Embodiments 1 and 2, and the eyepiece lens LE are used to observe the specimen, whereby the specimen is directly observed by the observer's eye E. The microscope in this embodiment is equipped with a light path-splitting prism P situated between the microscope objective lens LO and eyepiece lens LE, so that a light flux can be directed to a photographic camera PK if desired for photomicrography.

Further according to the present invention, any aberrations produced by the cover glass are corrected without moving the image point by axially moving the moveable lens group C shown in FIG. **1** and FIG. **5**. This can be conveniently performed by turning a correction ring CR that is operably connected to the correction lens group G.

With this invention, as described above, aberrations can be sufficiently corrected without imparting any movement of the image point, even when the thickness of a cover glass, water layer, dish bottom, etc., existing between the specimen and the objective lens varies over a substantial range. Thus, a microscope objective lens, and a microscope incorporating such a lens, are provided that produce consistently excellent images of the specimen.

The described embodiments are to be considered in all respects only as illustrative and not restrictive. The scope of the invention, therefore, resides within the text and spirit of the appended claims rather than by the foregoing description. All changes that come within the meaning and range of

equivalency of the claims are to be embraced within the scope of the claims.

What is claimed is:

1. A microscope objective lens, comprising in an order from a specimen side:

(a) a front lens group having positive refractive power, the front lens group being operable to converge light from a specimen disposed objectwise of the front lens group;

(b) a rear lens group having negative refractive power;

(c) a corrective lens group that is axially moveable and is situated in an air space located between the front and rear lens groups, the corrective lens group having a refractive power $1/f_c$ and a magnification m, and comprising first and second meniscus lenses each having a convex surface oriented toward the other convex surface; and

(d) wherein the objective lens has an overall refractive power 1/f and satisfies the conditions:

$$|1/f_c| \leqq |1/f| \times 0.02$$

$$0.95 \leqq |m| \leqq 1.05.$$

2. The microscope objective lens of claim **1**, wherein each of the first and second meniscus lenses is a cemented lens.

3. A microscope, comprising:

(a) the microscope objective lens of claim **1**; and

(b) an eyepiece lens axially disposed relative to the objective lens and operable to provide a viewable image of a specimen placed objectwise of the objective lens.

4. The microscope of claim **3**, further comprising

(a) a light source; and

(b) an illumination optical system for illuminating the specimen with light from the light source.

* * * * *

US005743846A

United States Patent [19]

Takahashi et al.

[11] Patent Number: 5,743,846

[45] Date of Patent: Apr. 28, 1998

[54] **STEREOSCOPIC ENDOSCOPE OBJECTIVE LENS SYSTEM HAVING A PLURALITY OF FRONT LENS GROUPS AND ONE COMMON REAR LENS GROUP**

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[73] Assignee: **Olympus Optical Co., Ltd.**, Tokyo, Japan

[21] Appl. No.: **404,890**

[22] Filed: **Mar. 16, 1995**

[30] **Foreign Application Priority Data**

Mar. 17, 1994 [JP] Japan 6-047189
May 17, 1994 [JP] Japan 6-103084
Oct. 27, 1994 [JP] Japan 6-264004

[51] **Int. Cl.**[6] **A61B 1/06**

[52] **U.S. Cl.** **600/166**; 600/111

[58] **Field of Search** 348/42, 45, 65, 348/75; 359/434, 435, 462; 600/111, 128, 130, 166

[56] **References Cited**

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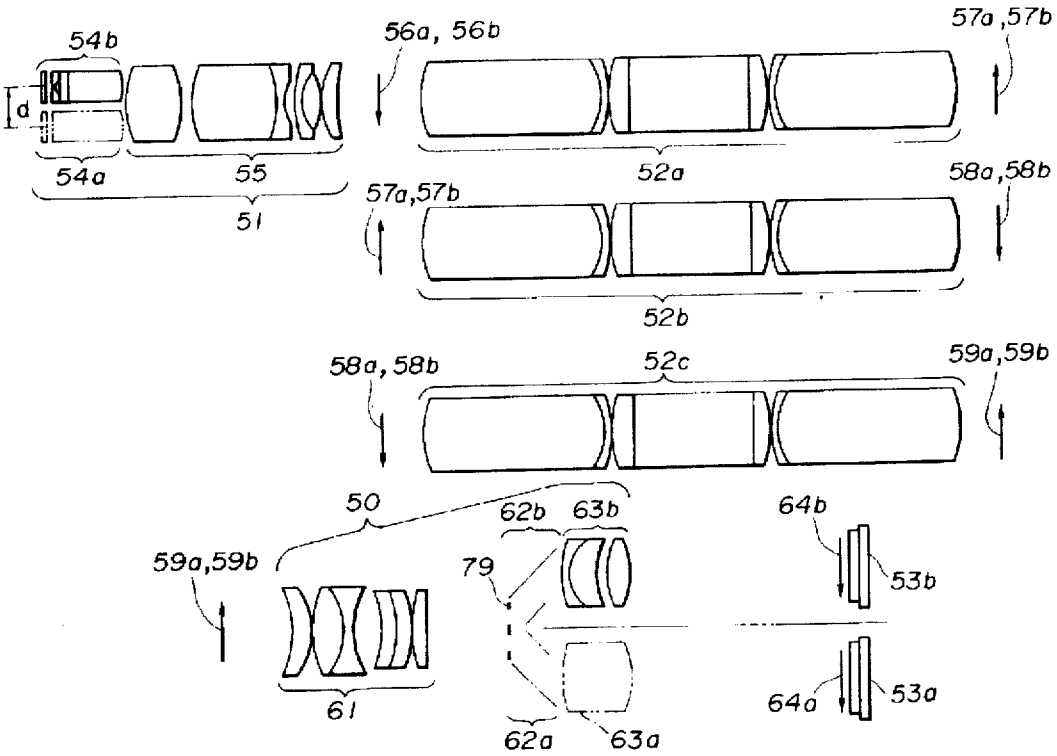
016812 1/1992 Japan 600/166

Primary Examiner—John P. Leubecker
Attorney, Agent, or Firm—Armstrong, Westerman, Hattori, McLeland & Naughton

[57] **ABSTRACT**

A stereoscopic endoscope comprises an elongate inserted section, an illuminating light system, an objective optical system at the distal end of the inserted section for forming a plurality of images having parallax between them through a plurality of incident pupils, and a common relay lens system for transmitting the plurality of images to the proximal end of the inserted section. The objective optical system includes a plurality of front lens groups and a rear lens group, wherein the plurality of front lens groups comprise two negative lens units arranged in parallel with each other and the rear lens group comprises a single positive lens group. The two negative lens units are arranged to be substantially symmetrically concentric about an optical axis of the single positive lens group and spaced to be afocal. This arrangement allows the plurality of images having parallax between them to be substantially superimposed on one another for transmission by the common relay lens system or for reception by electronic image pickup devices.

13 Claims, 51 Drawing Sheets



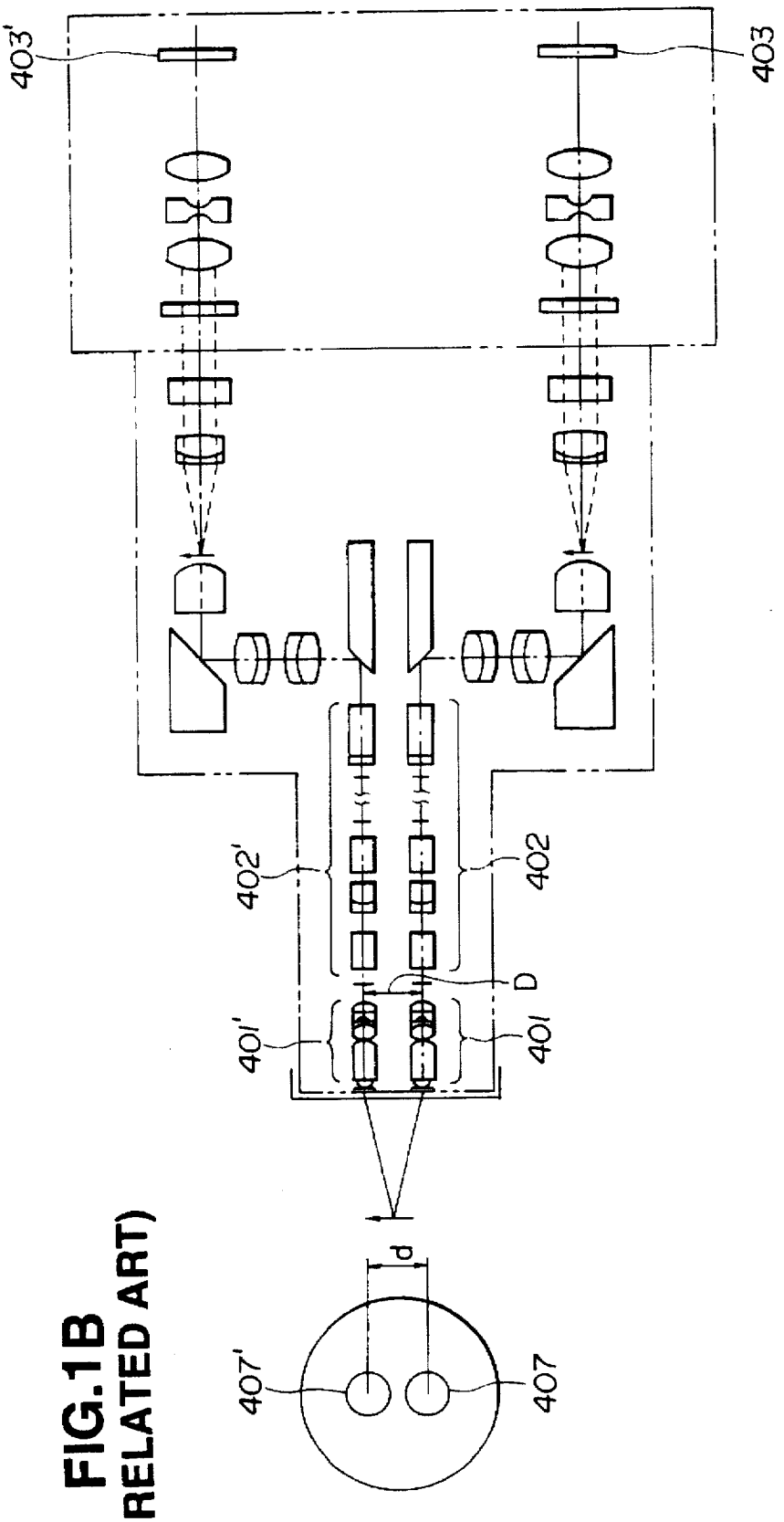


FIG.1A
(RELATED ART)

FIG.1B
(RELATED ART)

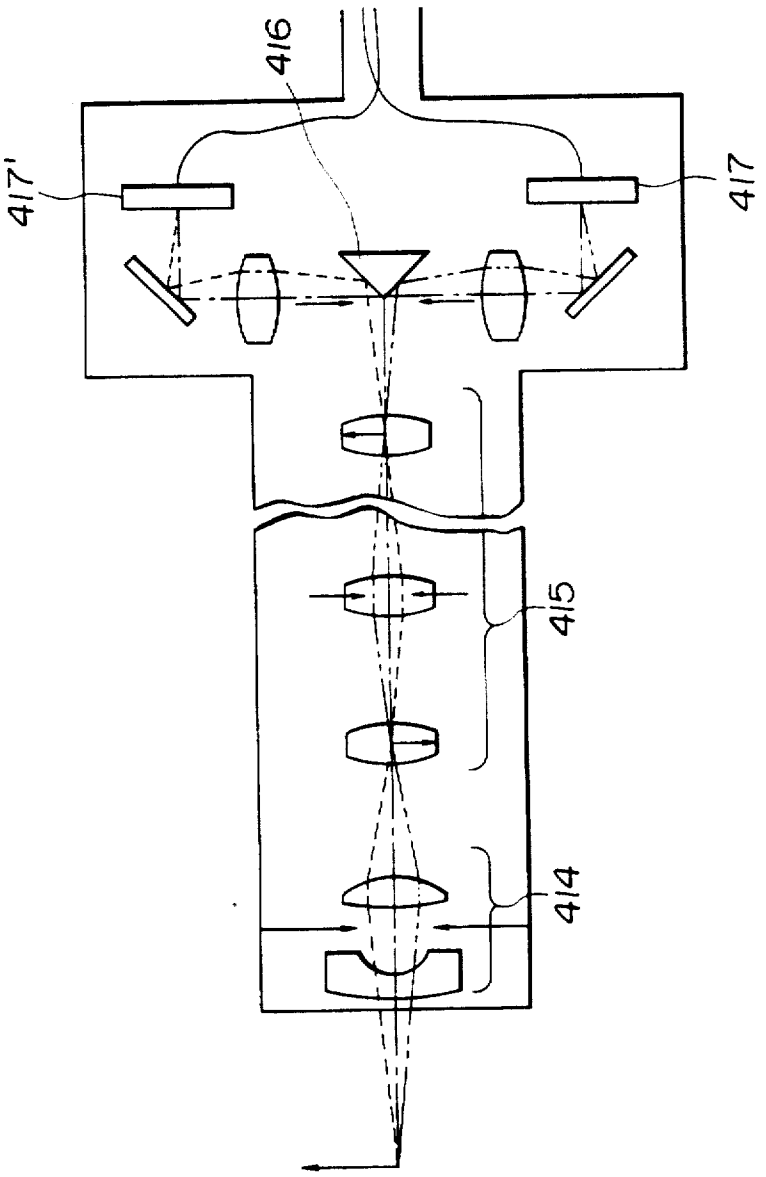


FIG.2A
(RELATED ART)

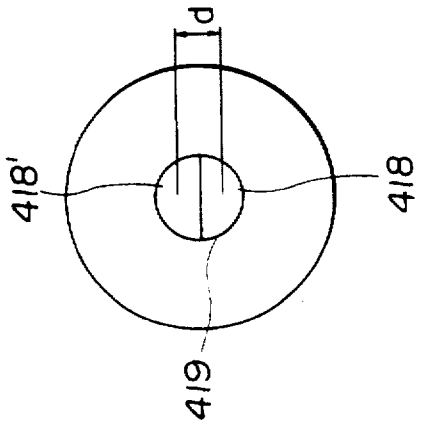


FIG.2B
(RELATED ART)

FIG.3B

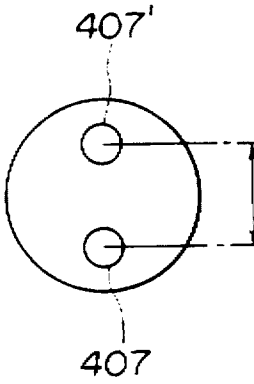


FIG.3A

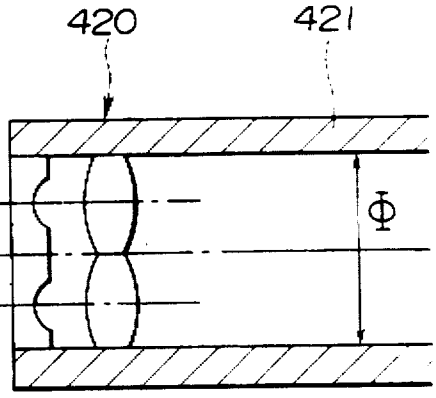


FIG.4B

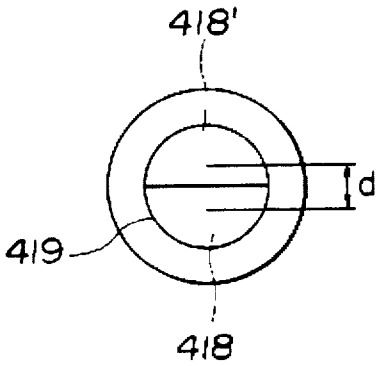


FIG.4A

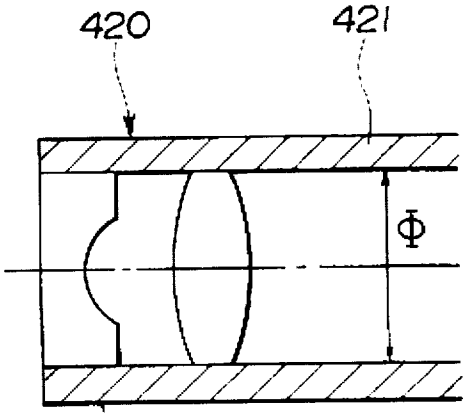


FIG.5

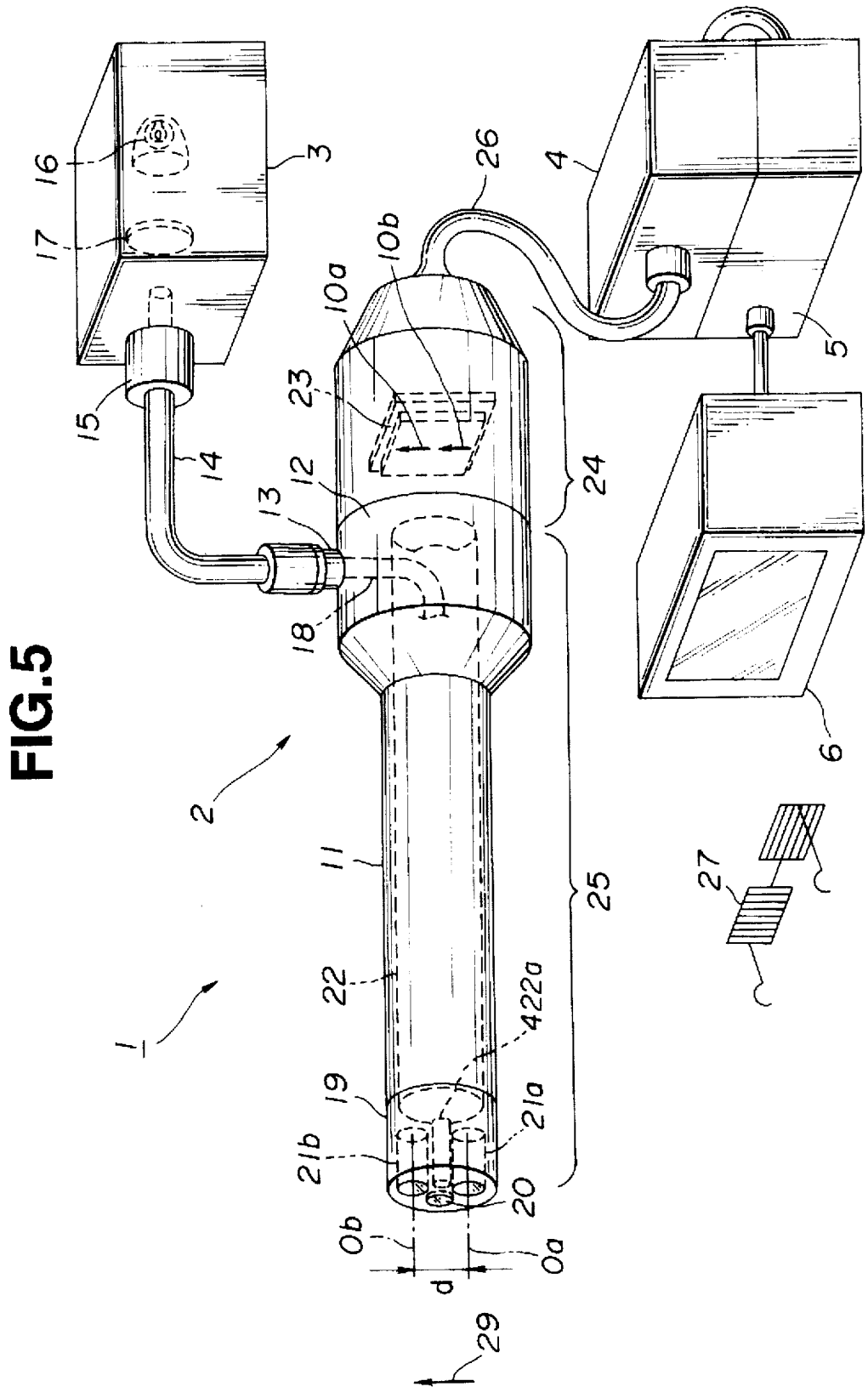

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FIG.6

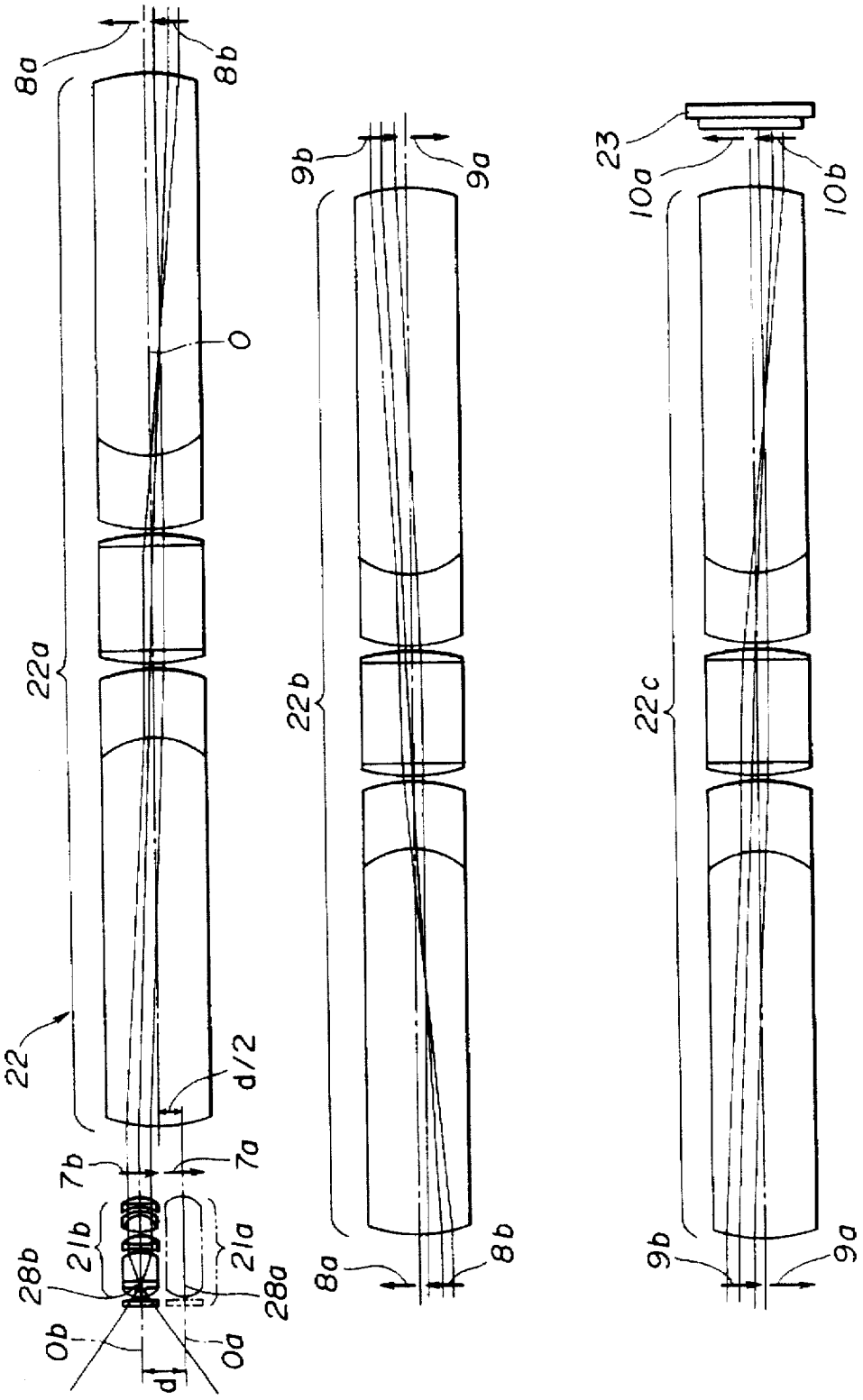
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FIG.7

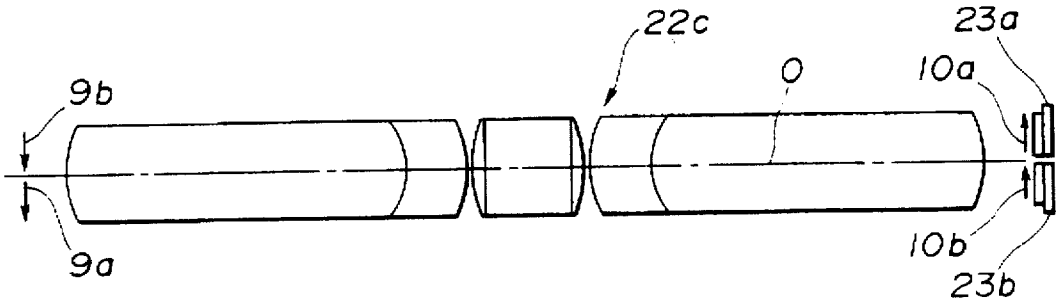

FIG.9

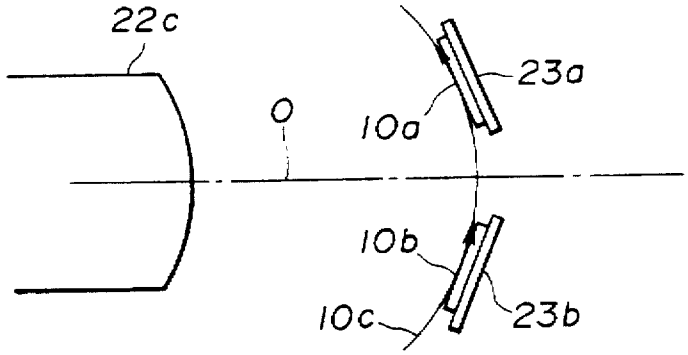

FIG.10A

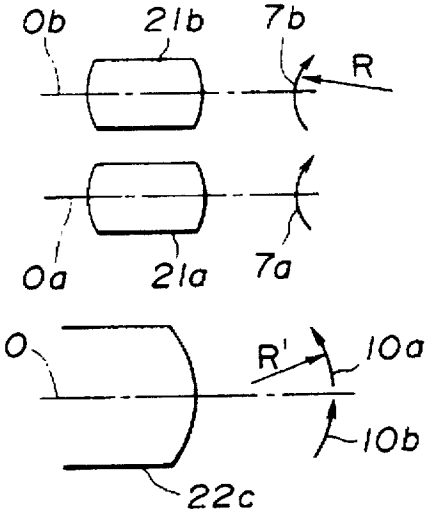

FIG.10B

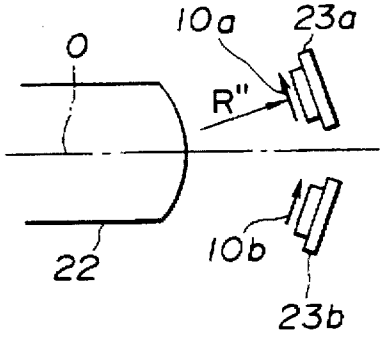

FIG.8

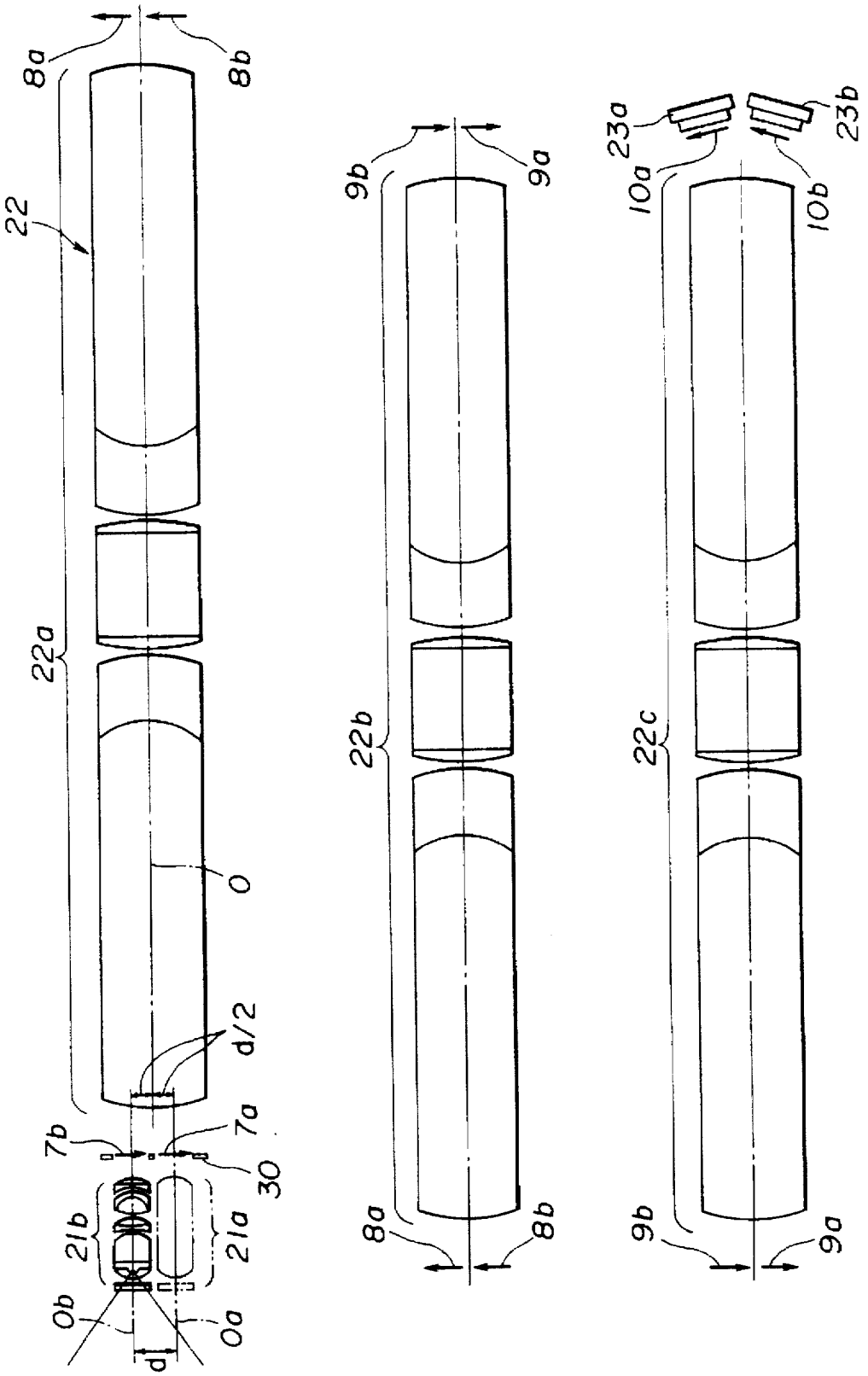
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FIG.11

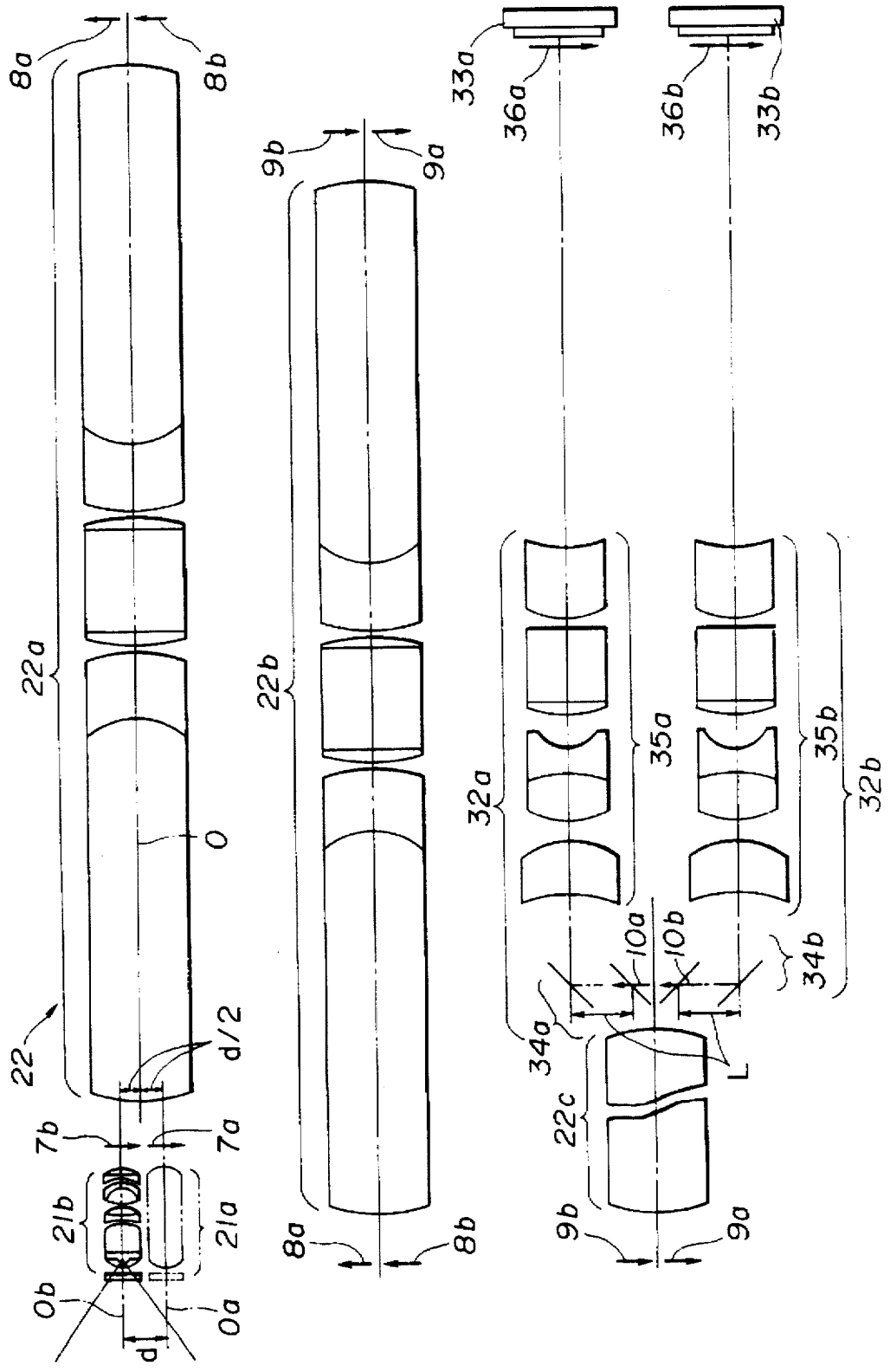
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FIG.12

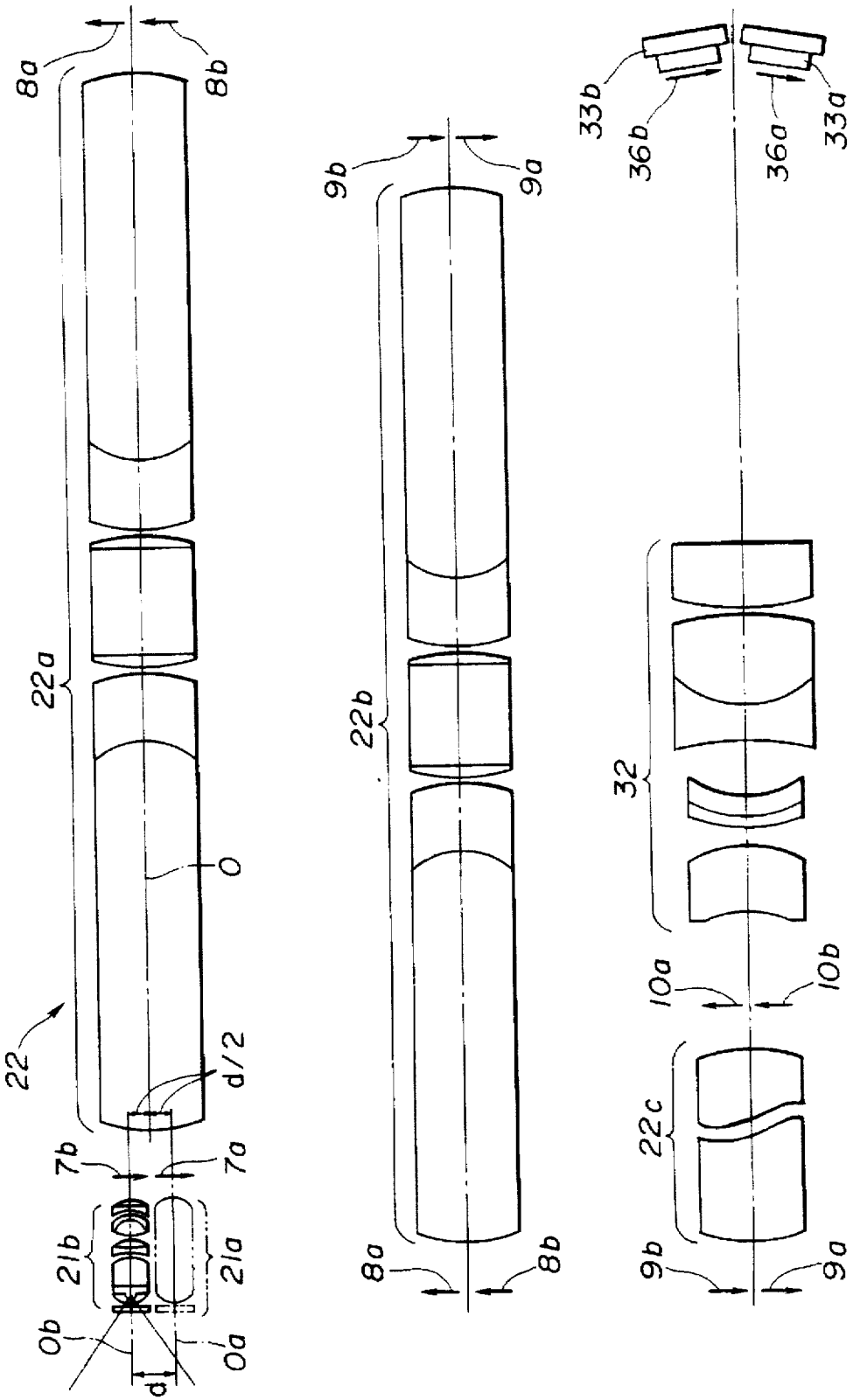
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FIG.13

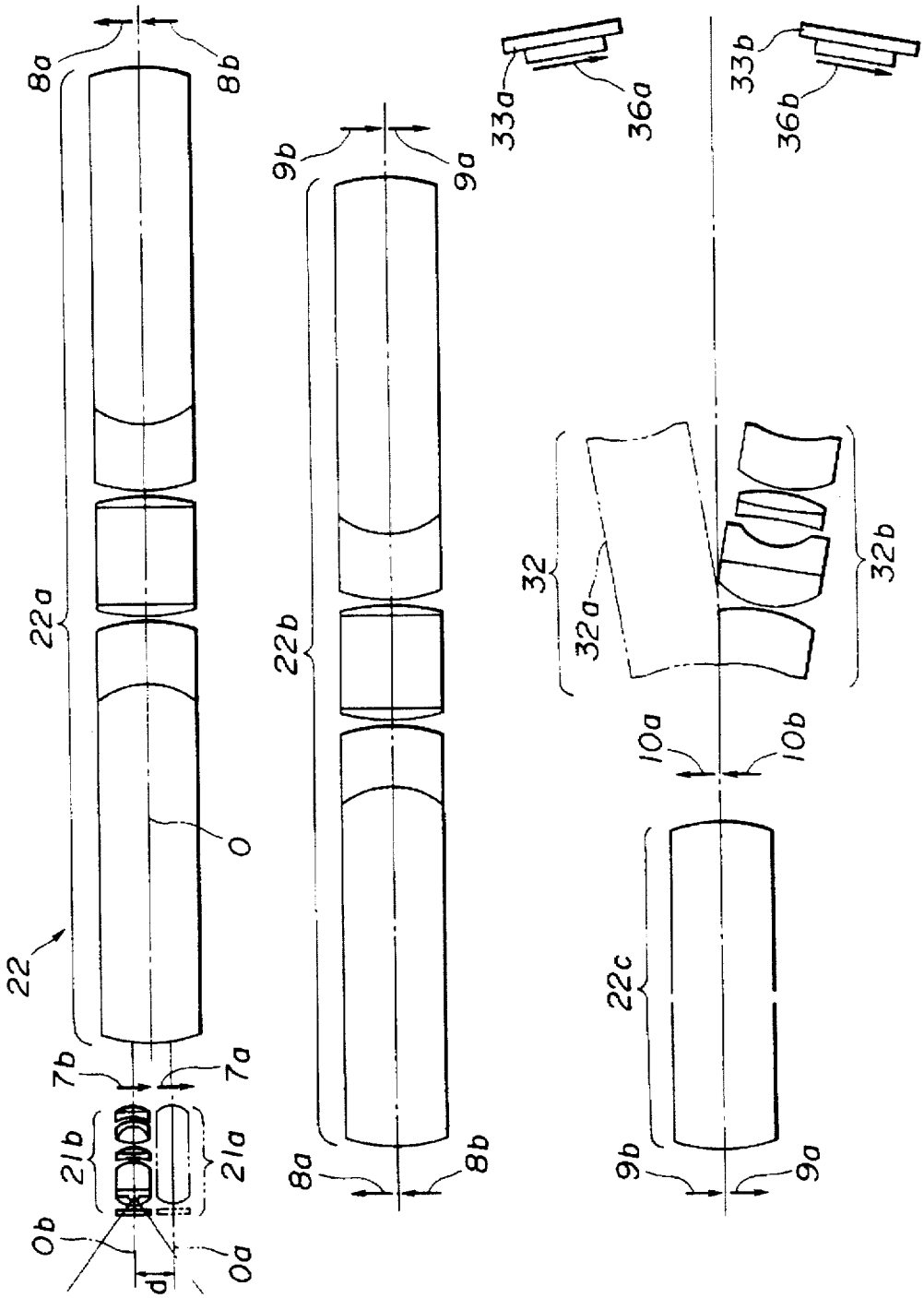
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FIG.14

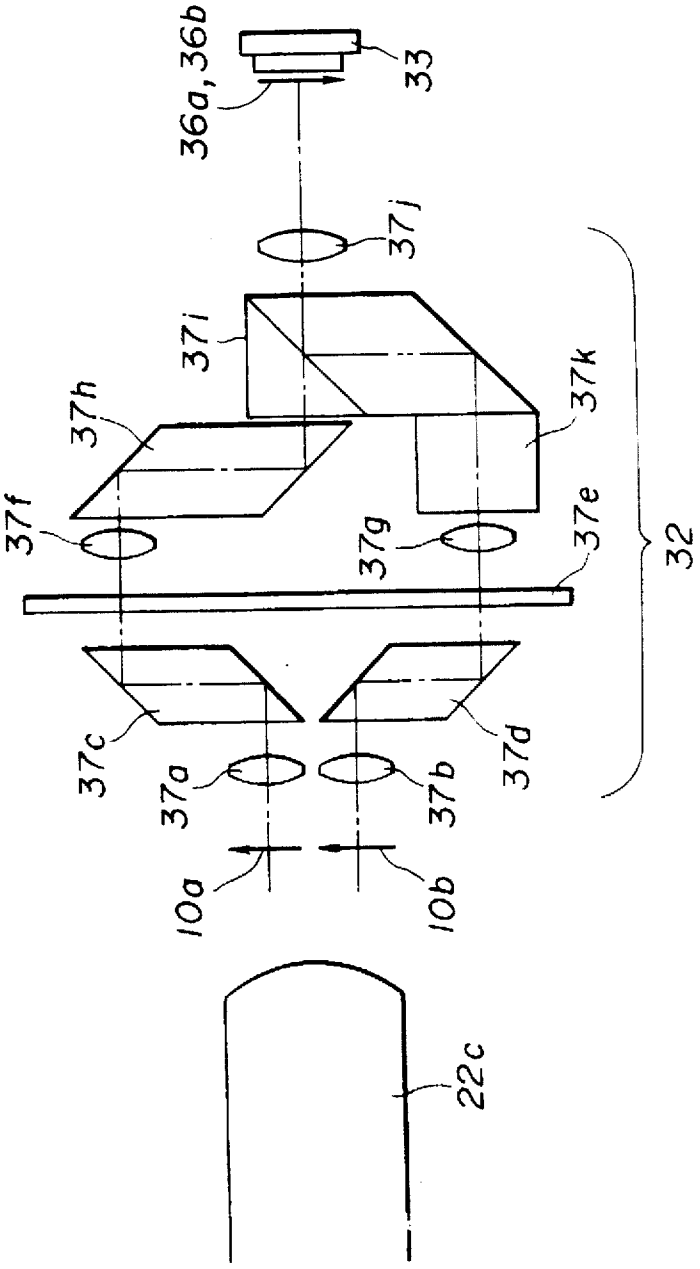
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FIG.15A

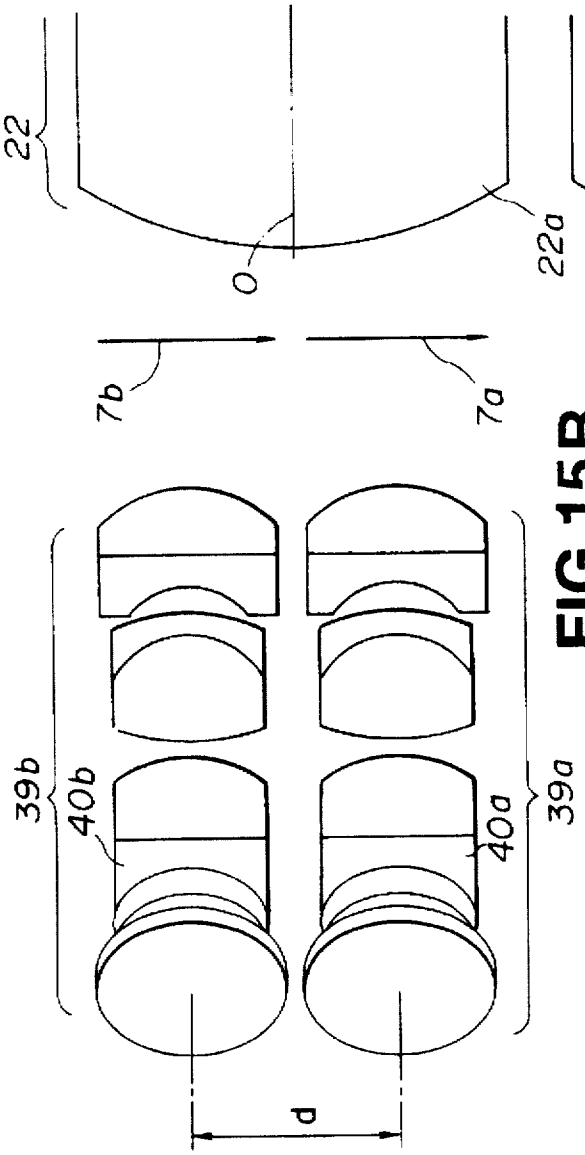


FIG.15B

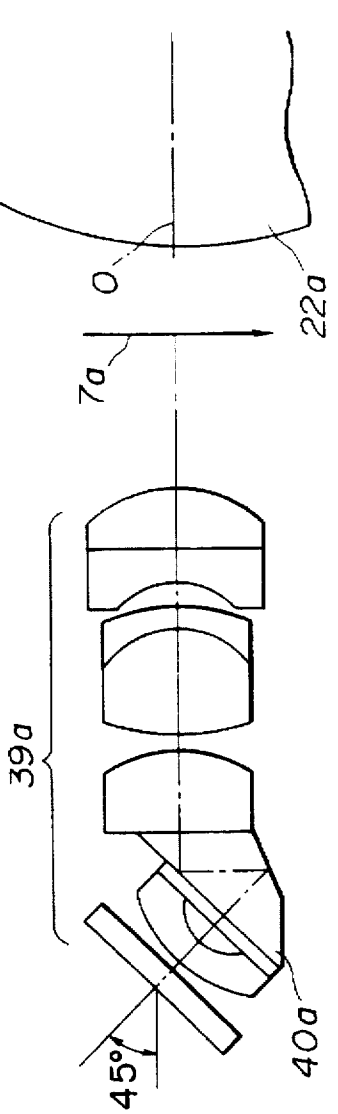


FIG.16 A

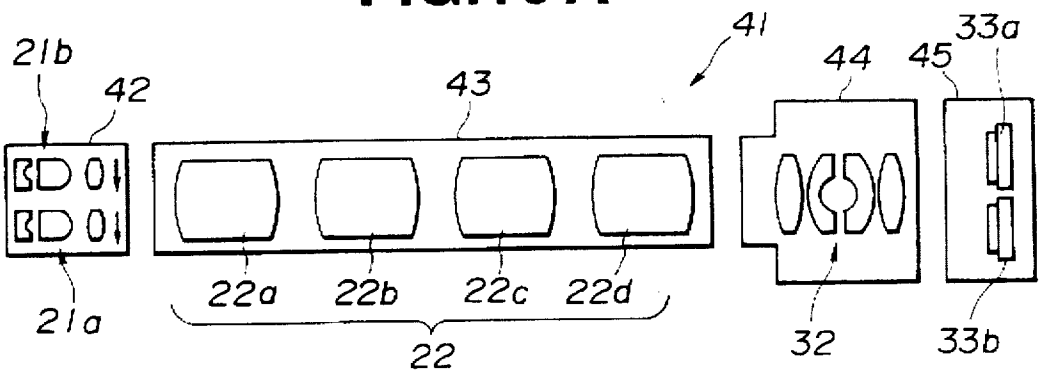


FIG.16 B

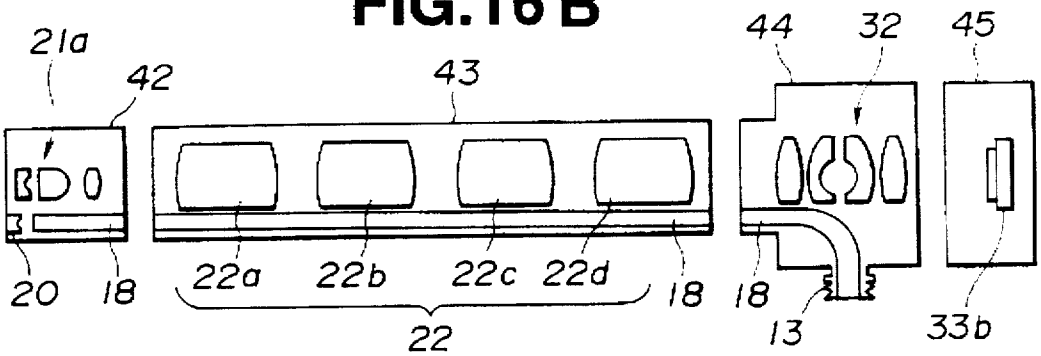


FIG.16C

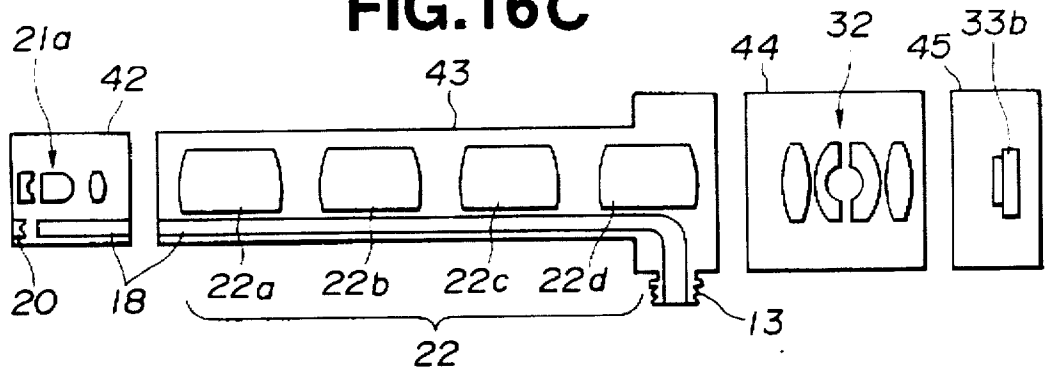


FIG.16D

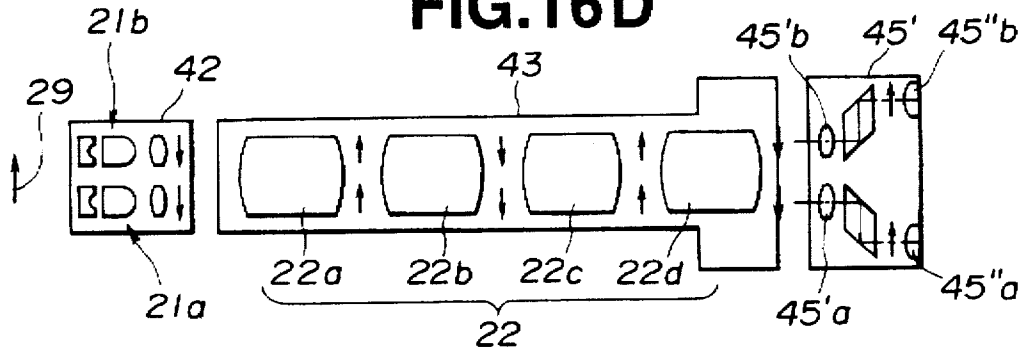


FIG.17A

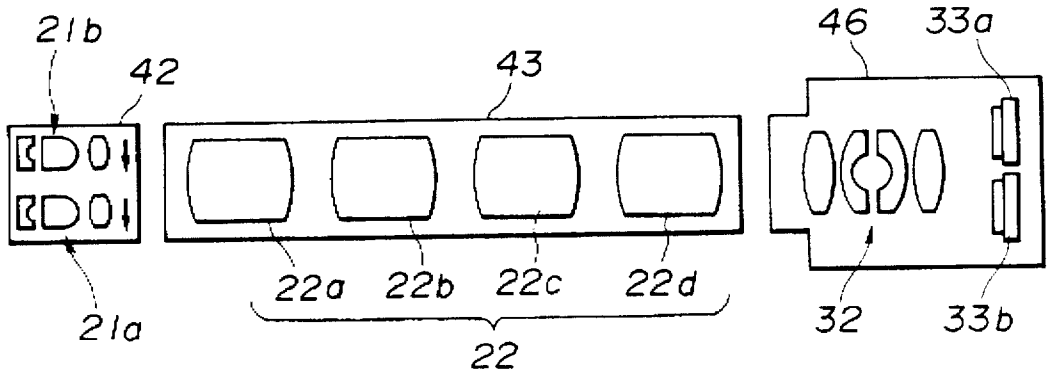


FIG.17B

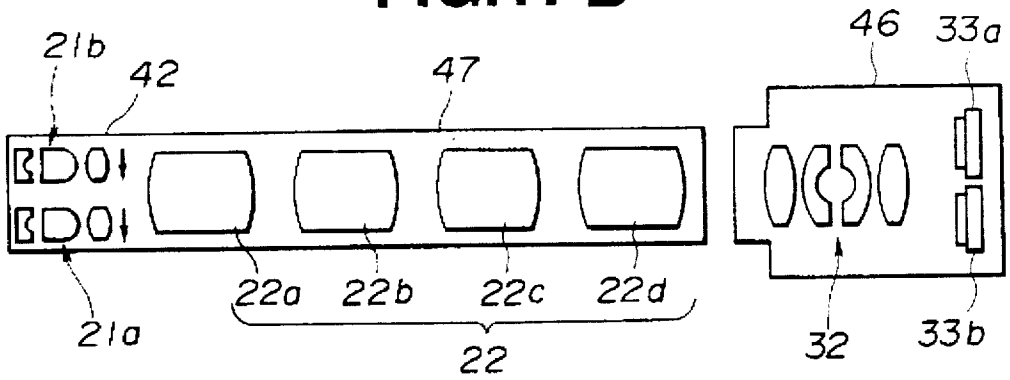


FIG.17C

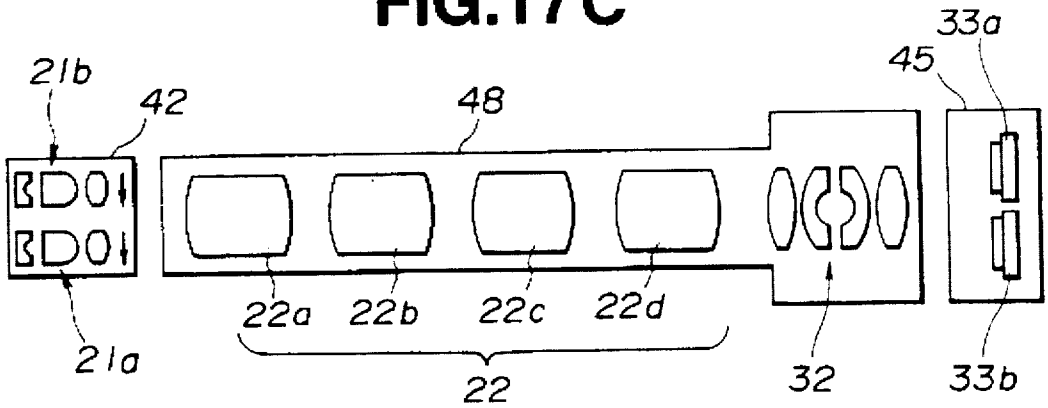


FIG.18A

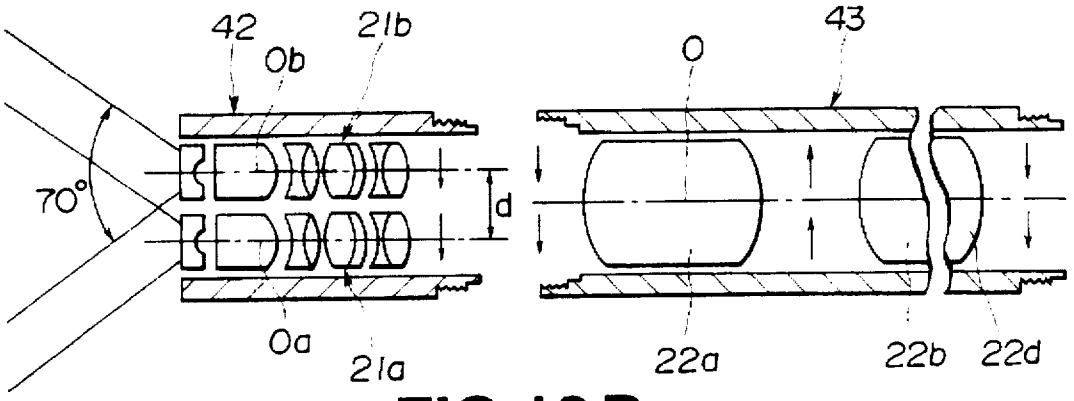


FIG.18B

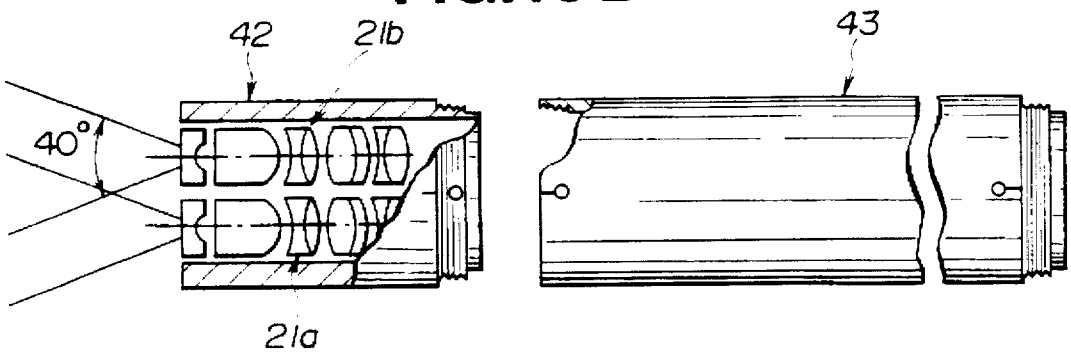


FIG.18C

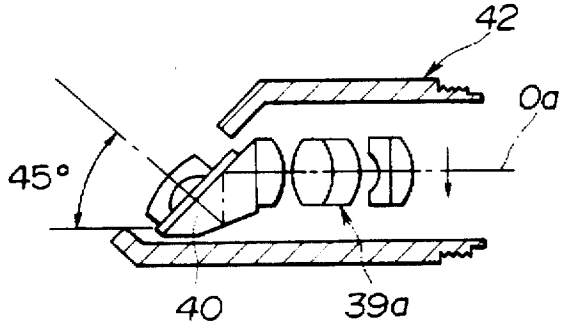


FIG.18D

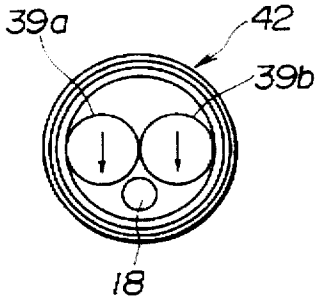
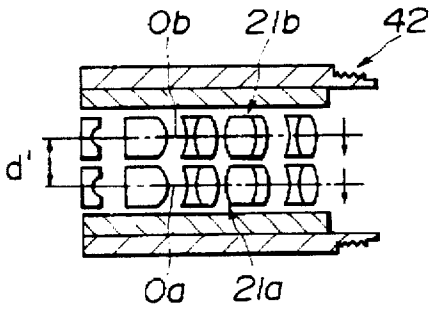


FIG.18E



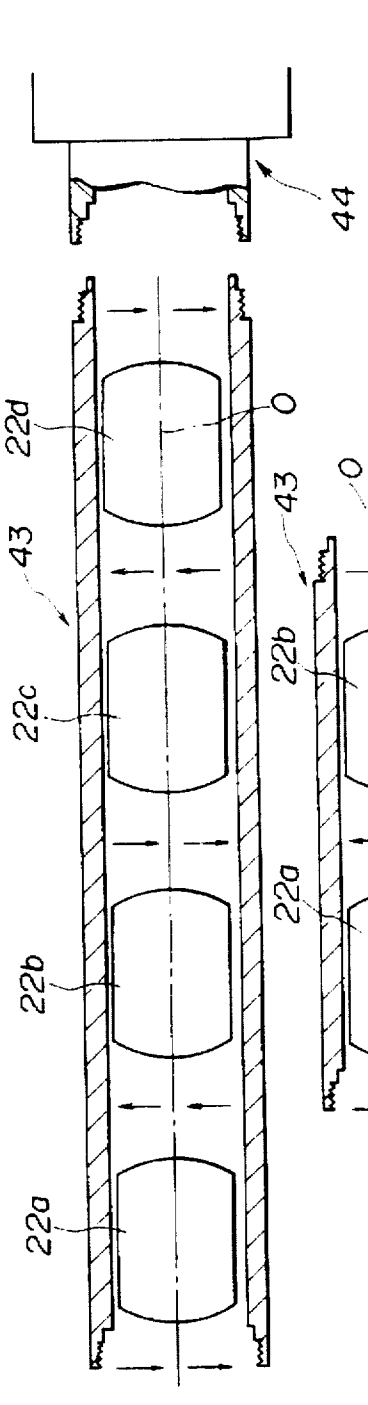


FIG.19A

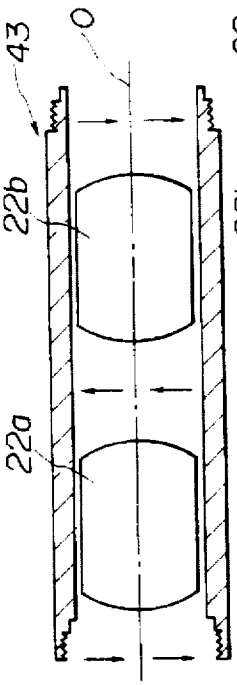


FIG.19B

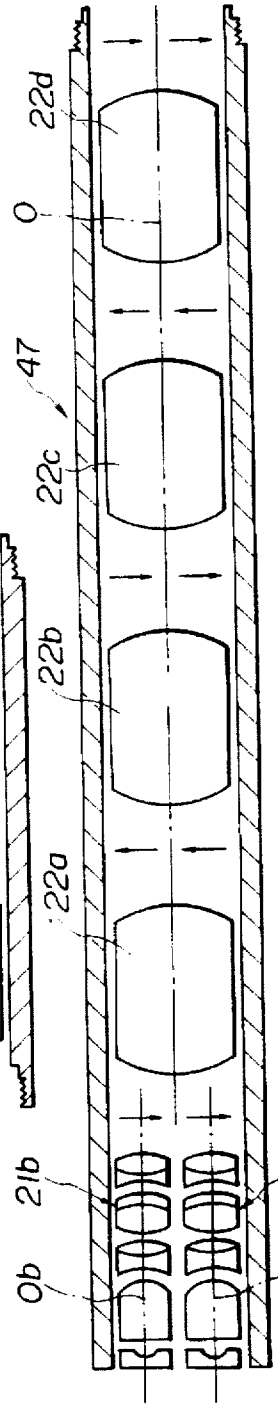


FIG.19C

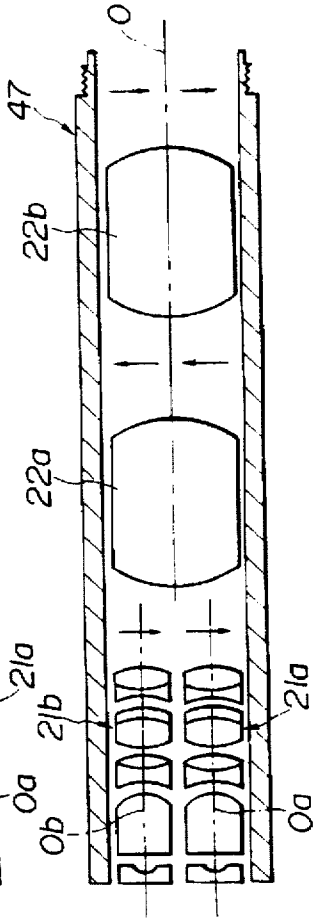


FIG.19D

FIG.20

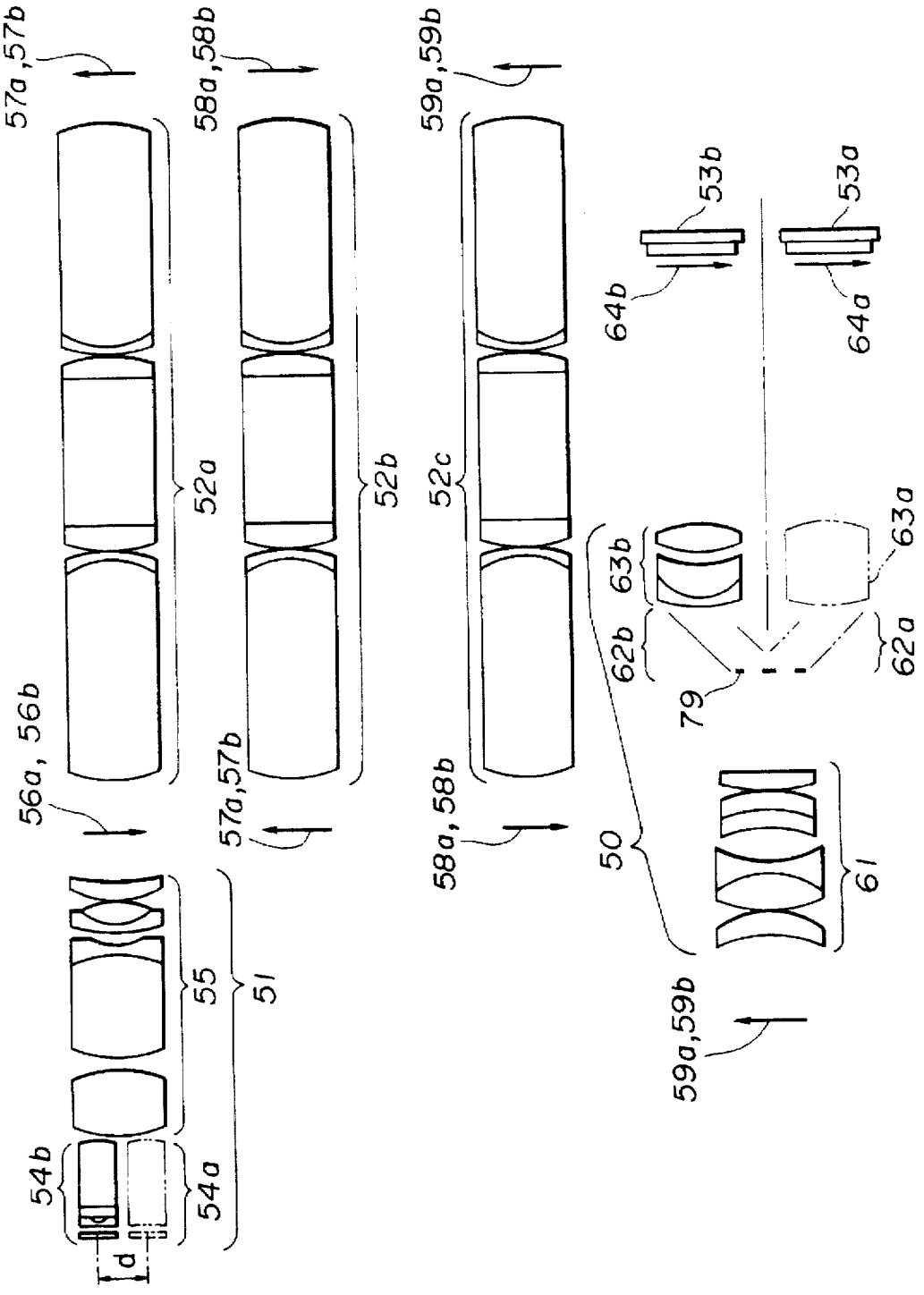

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FIG.21

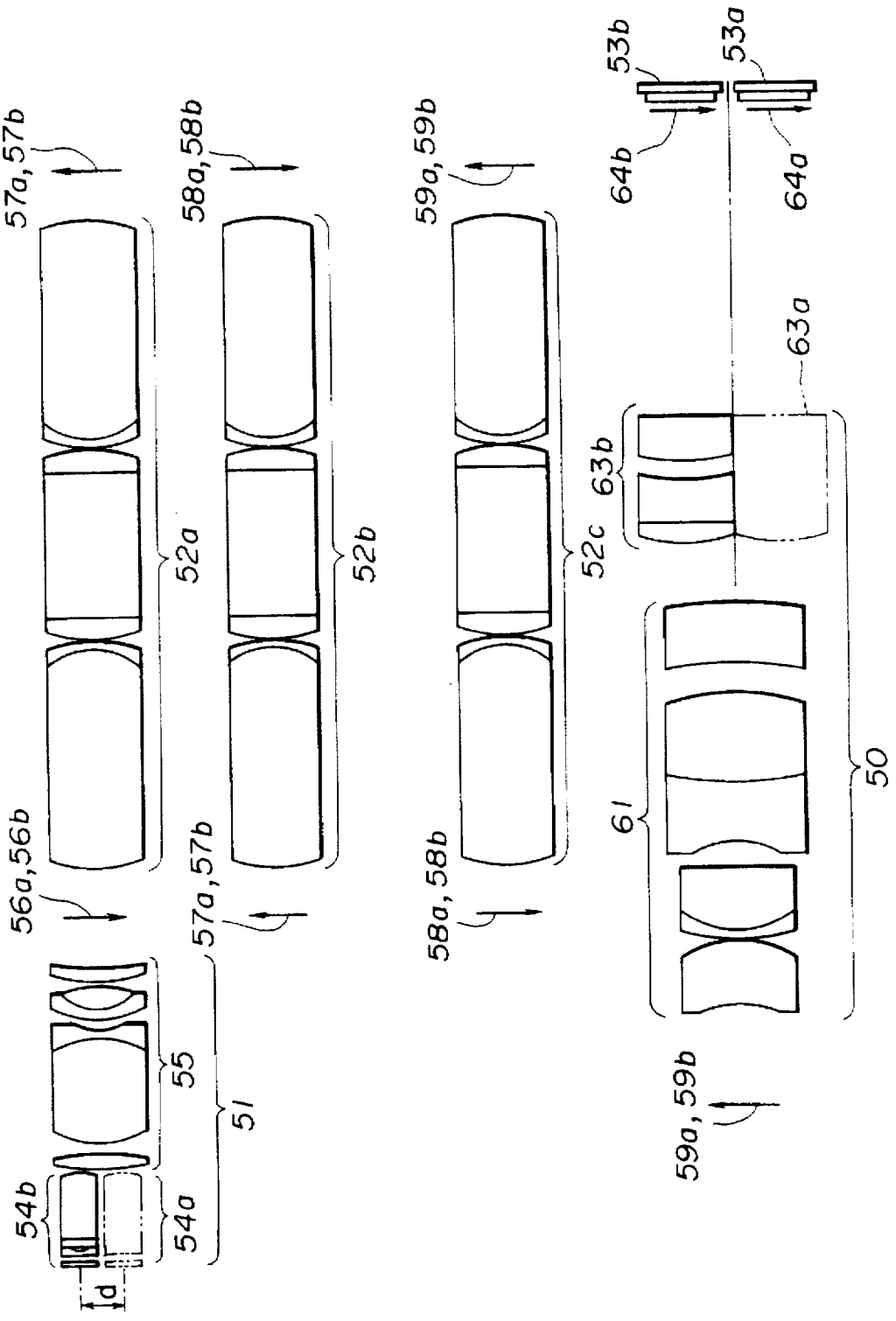
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FIG.22

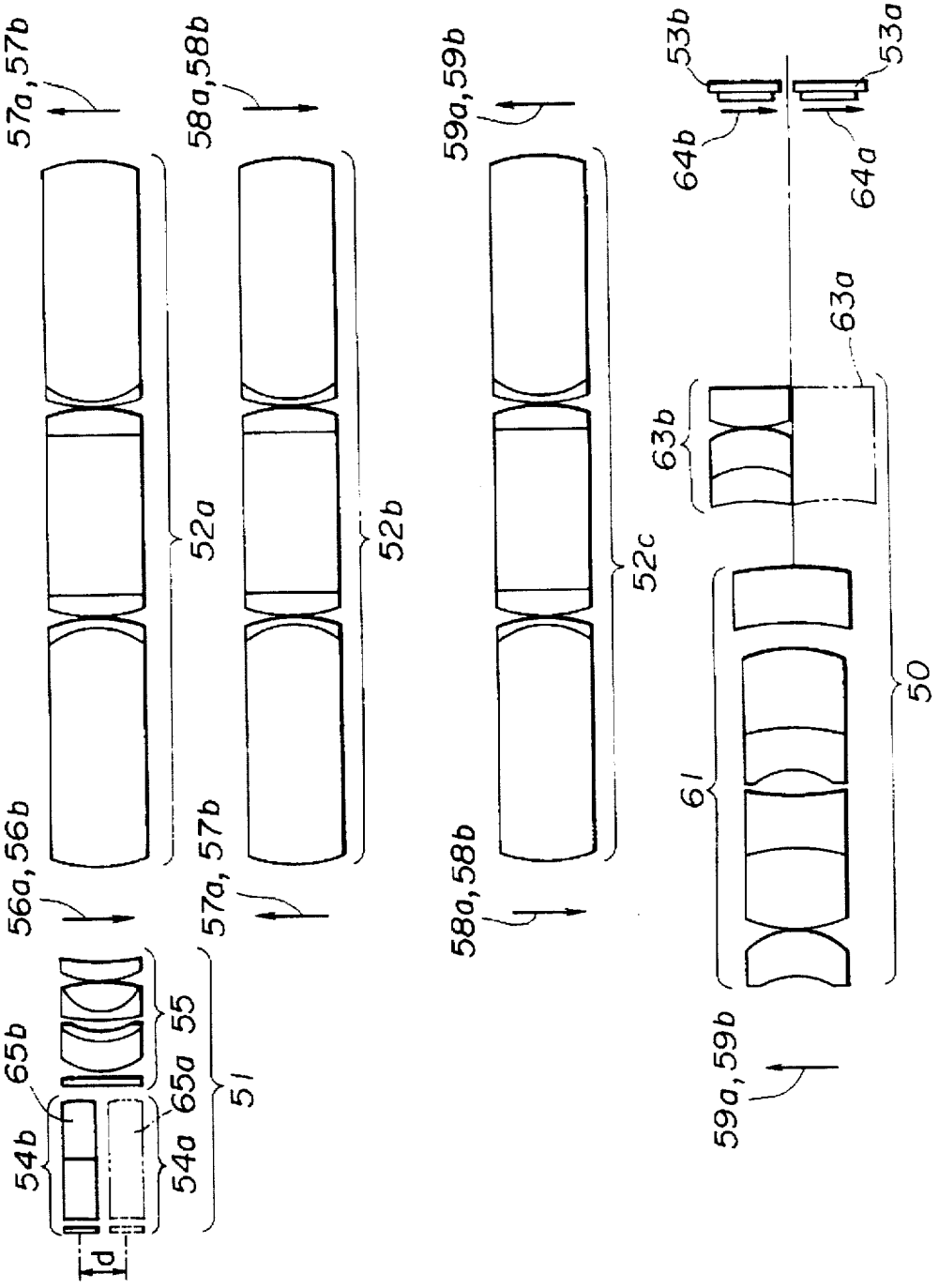
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FIG.23D

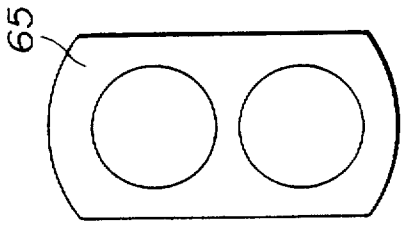


FIG.23A

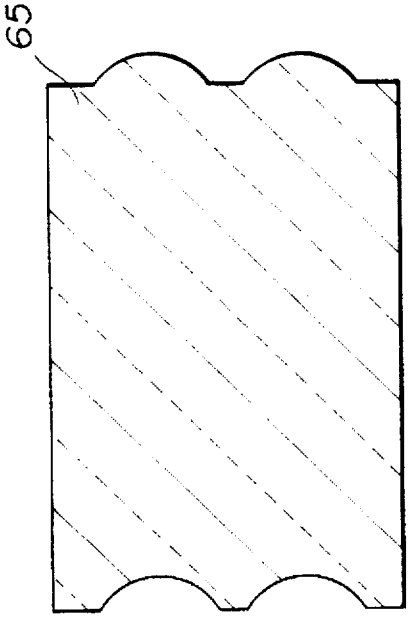


FIG.23B

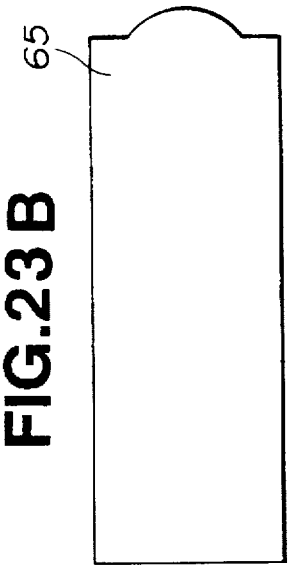


FIG.23C

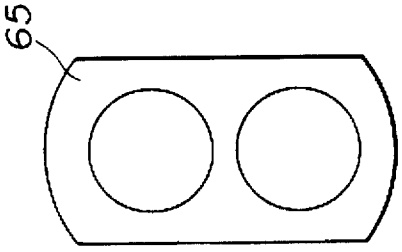
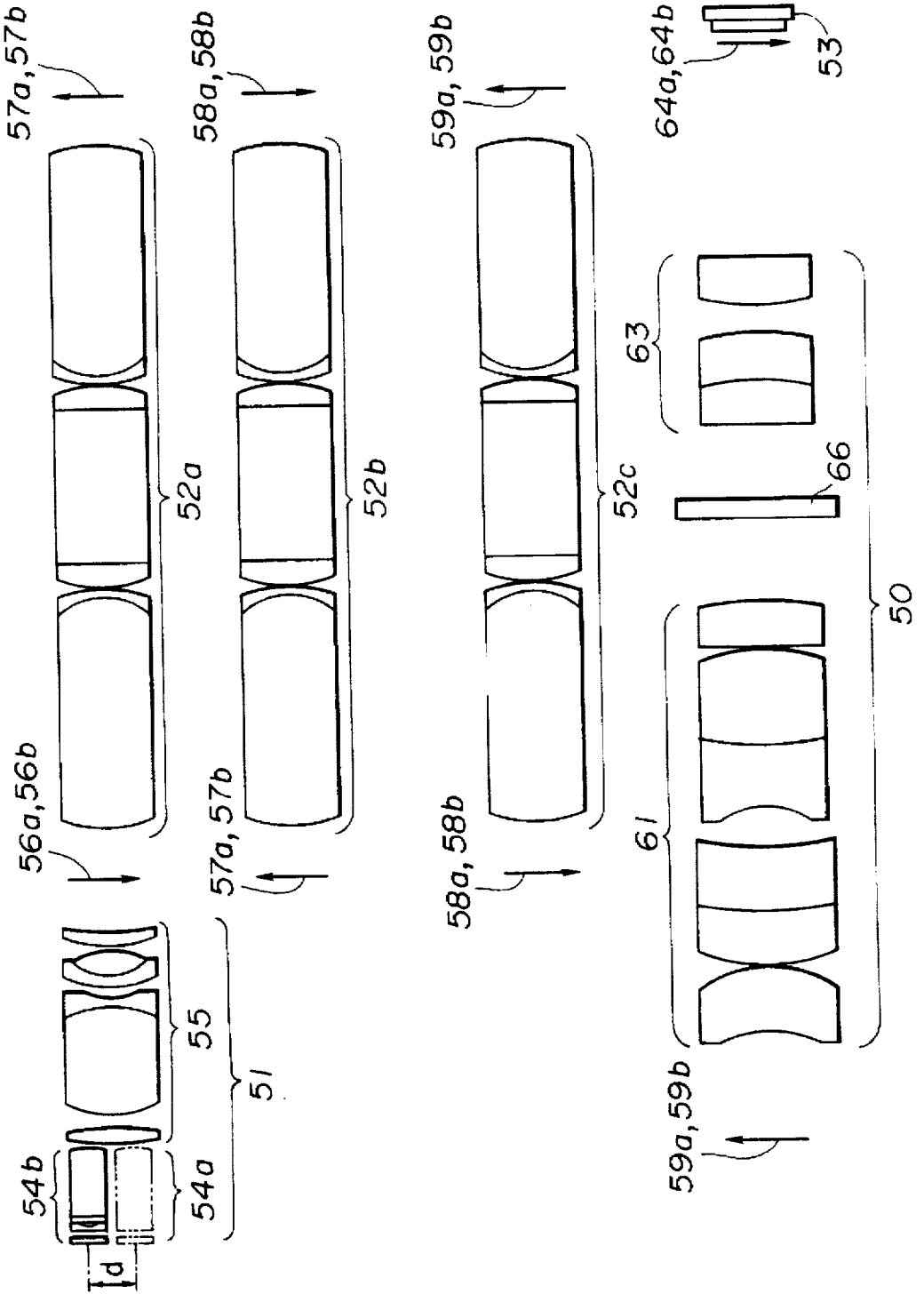


FIG.24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59a, 59b

FIG.25

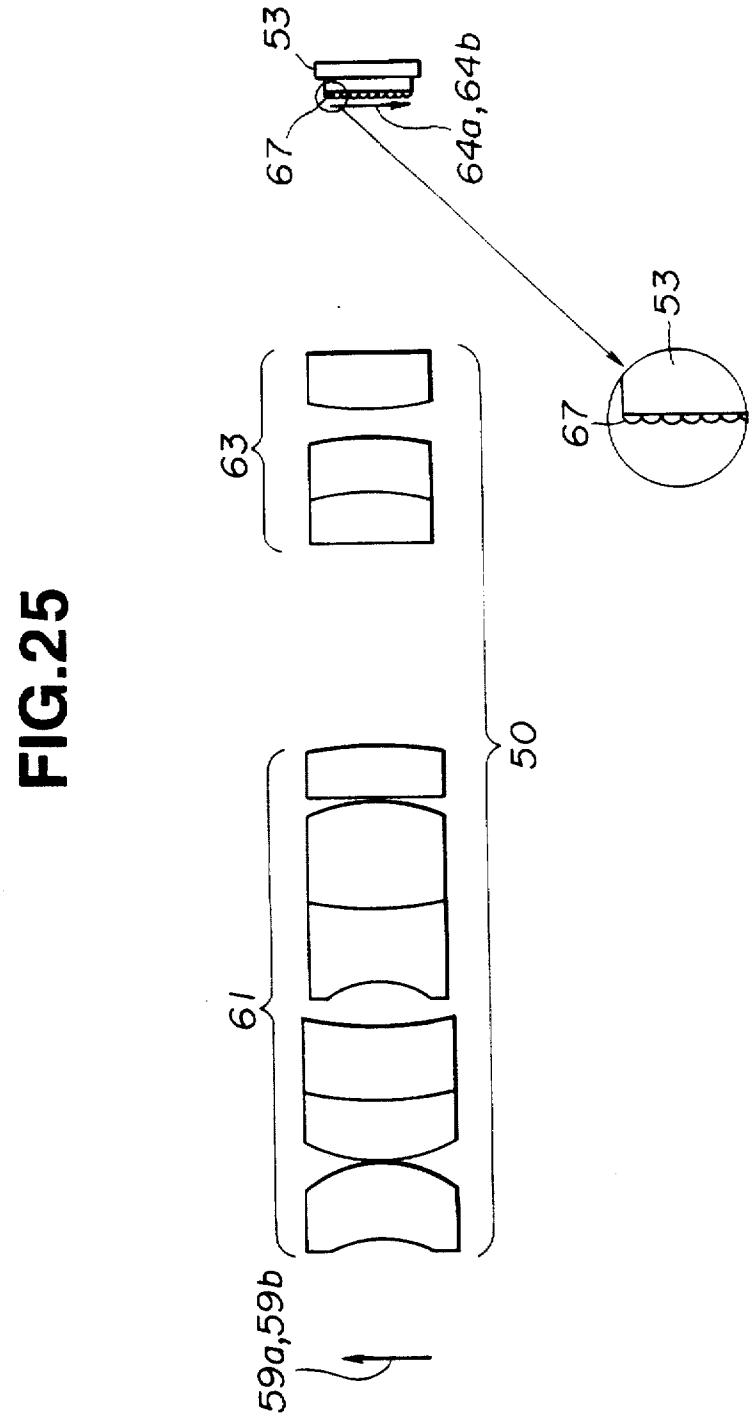


FIG.26A

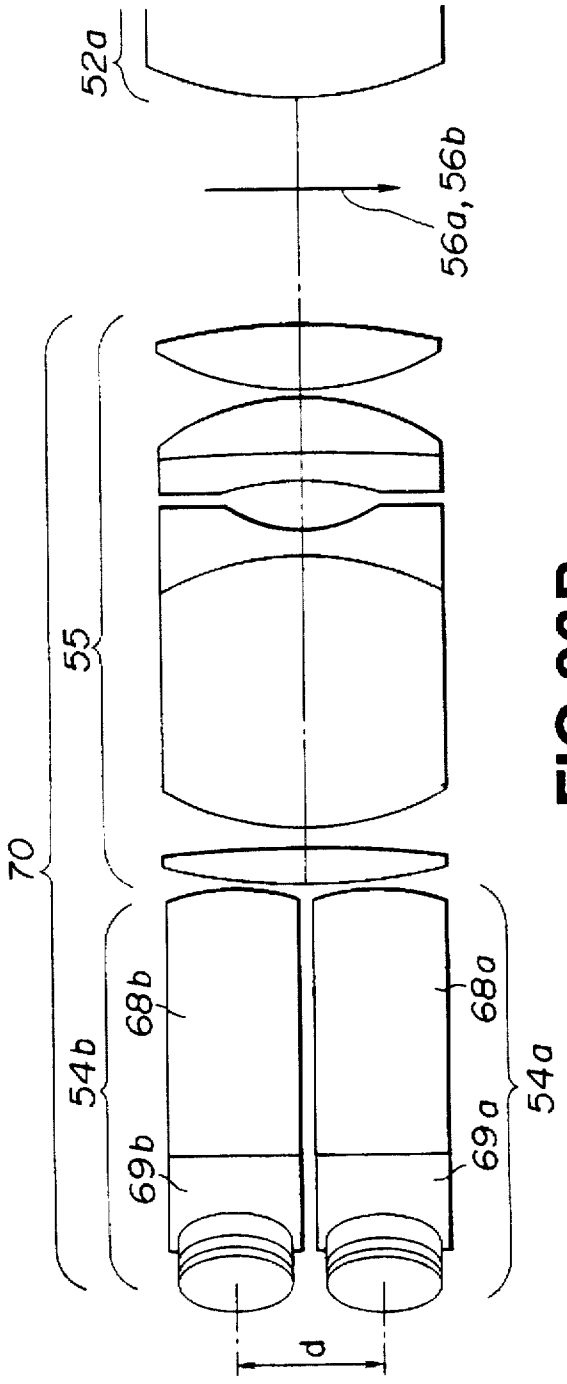


FIG.26B

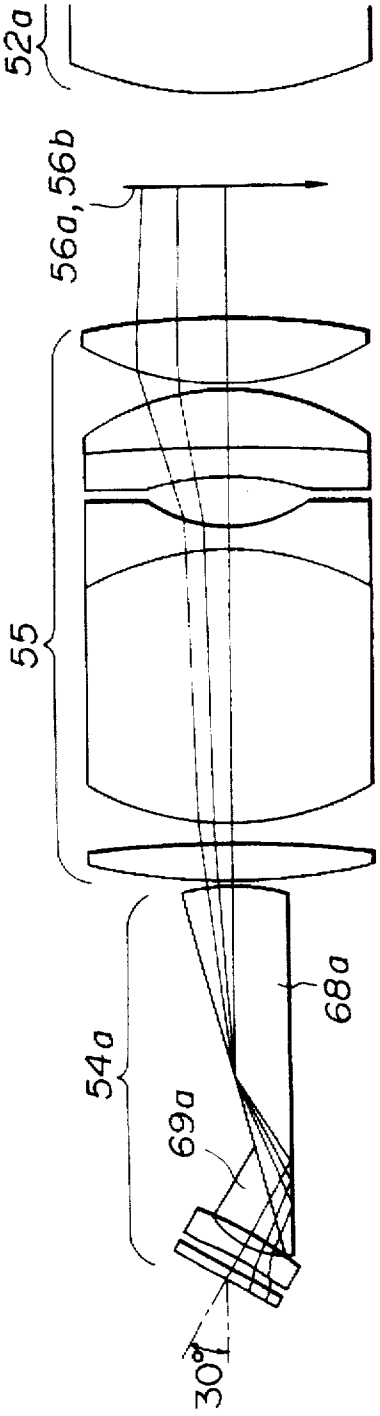


FIG.27A

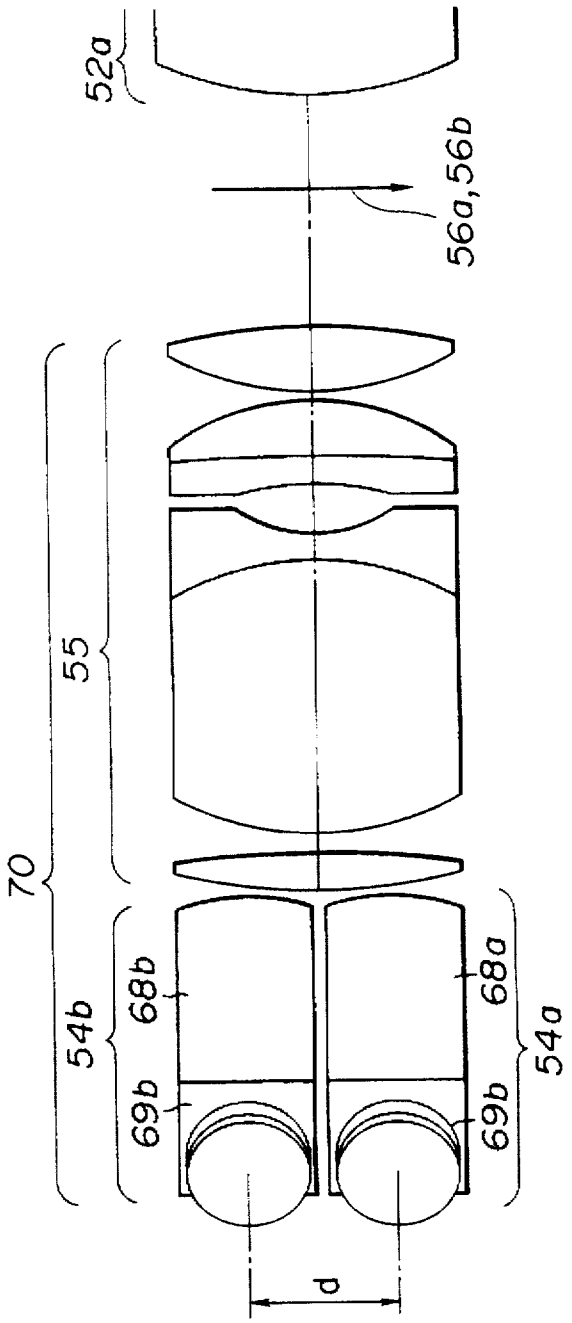


FIG.27B

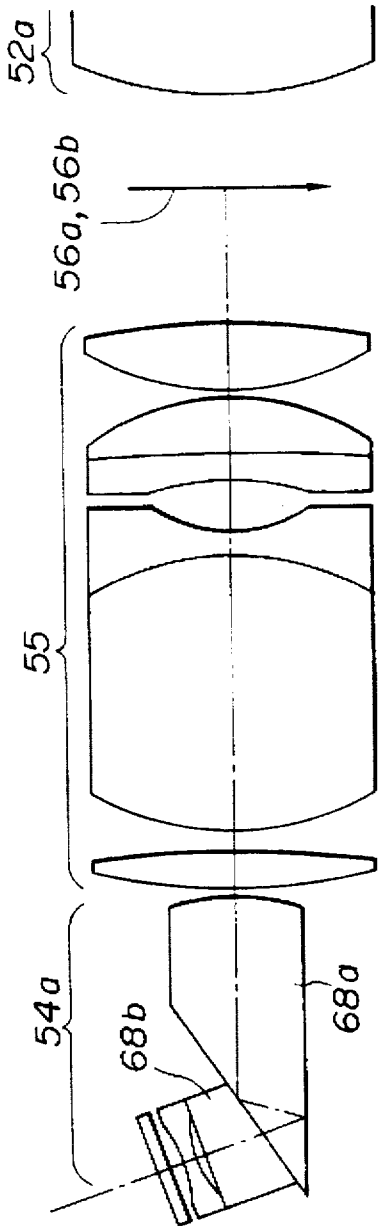


FIG.28A

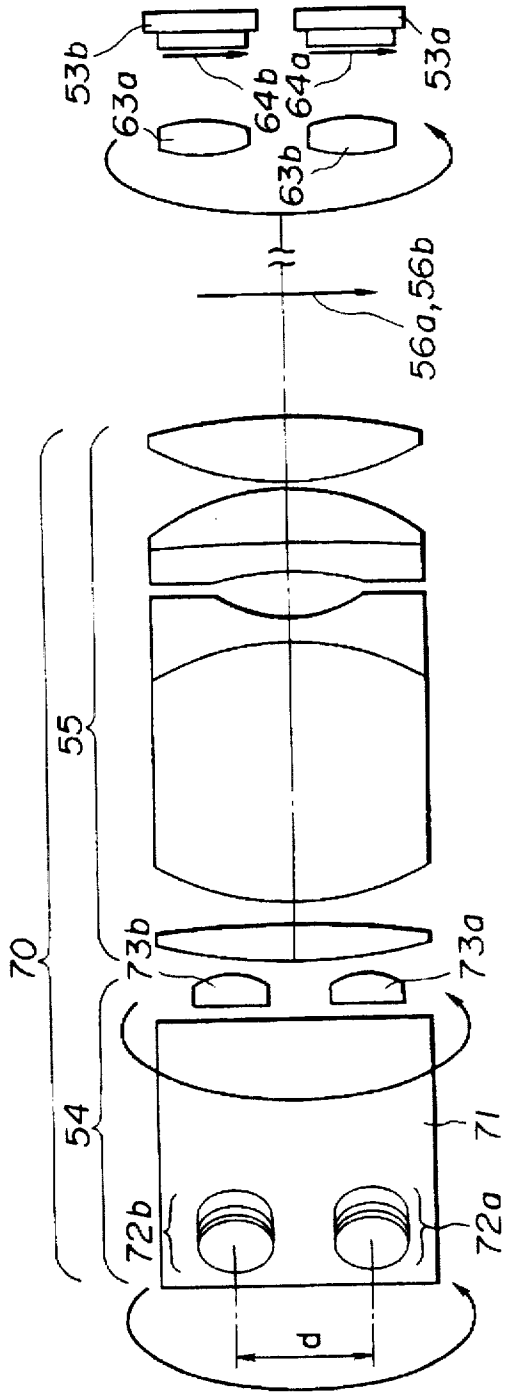


FIG.28B

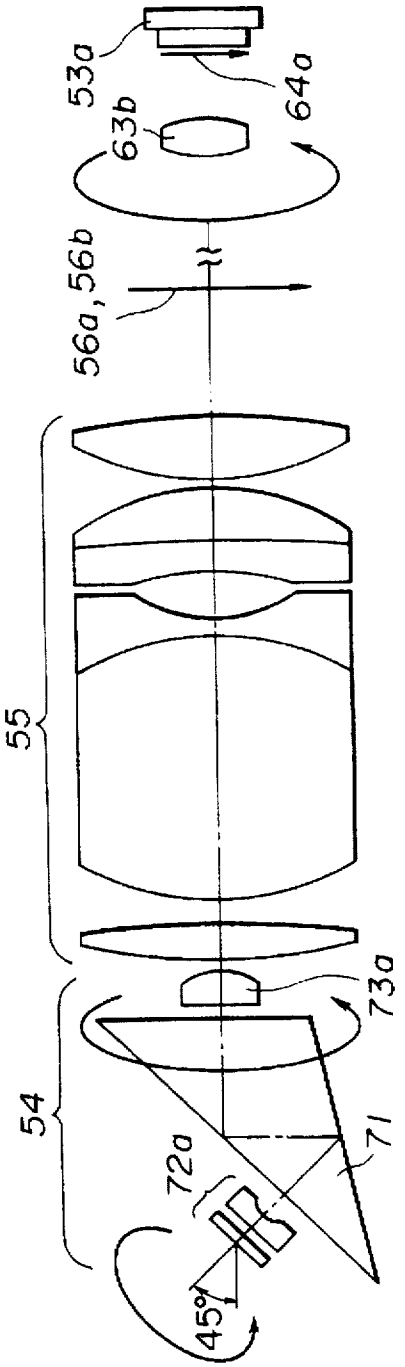


FIG.29A

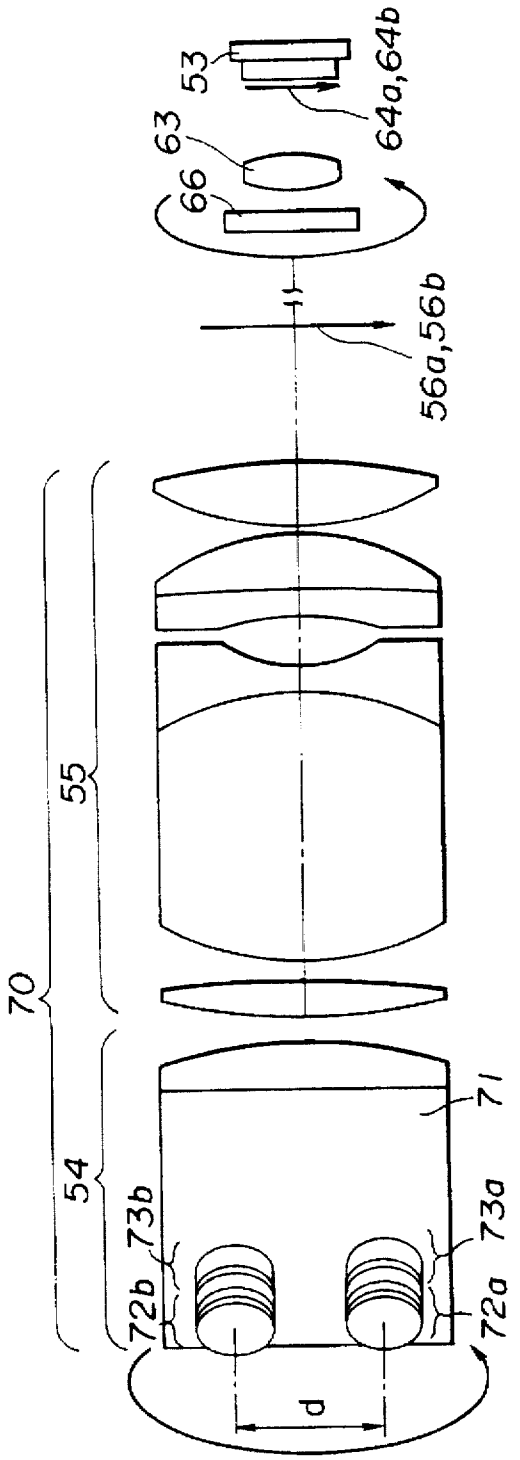


FIG.29B

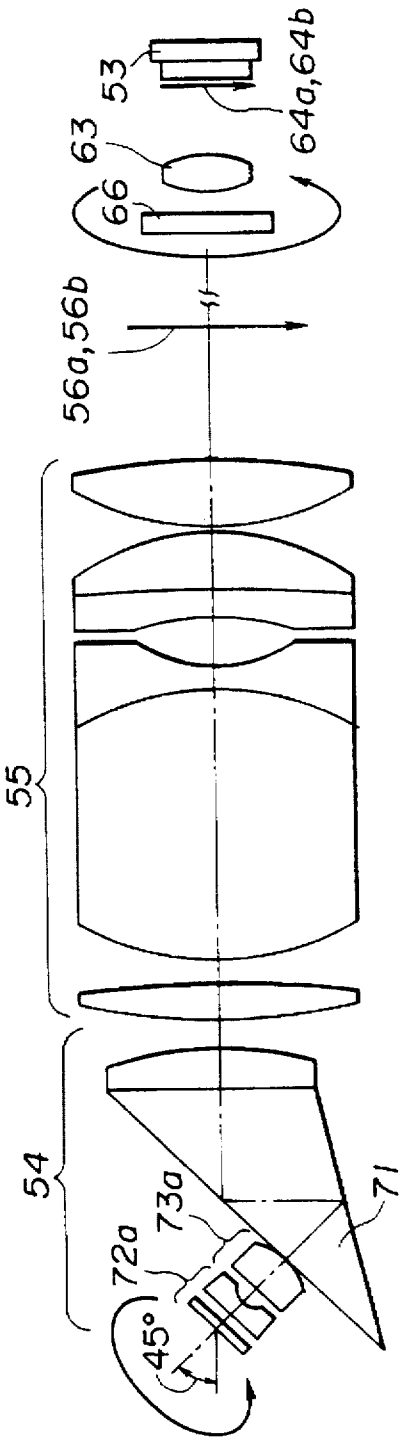


FIG.30A

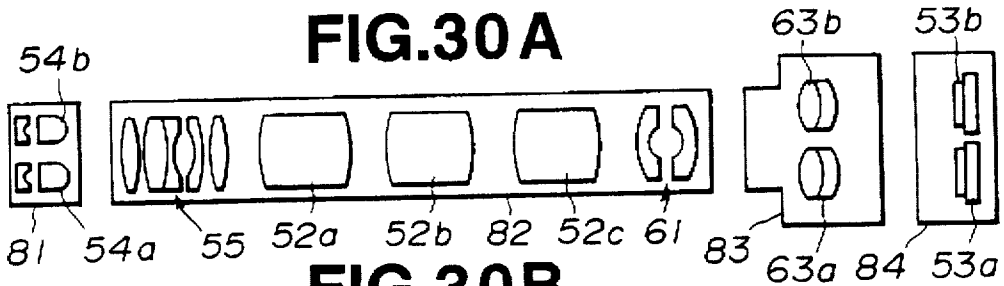


FIG.30B

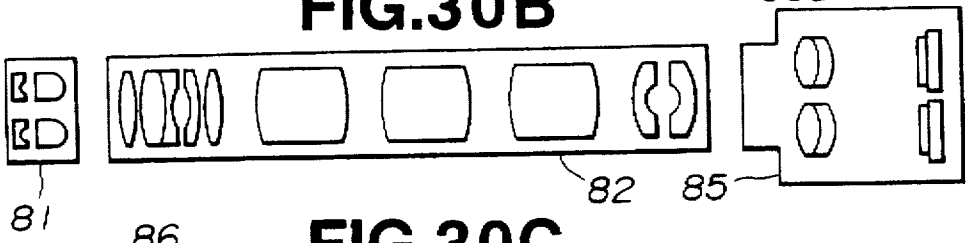


FIG.30C

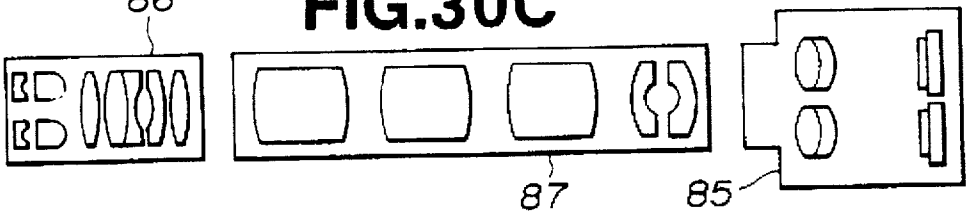


FIG.30D

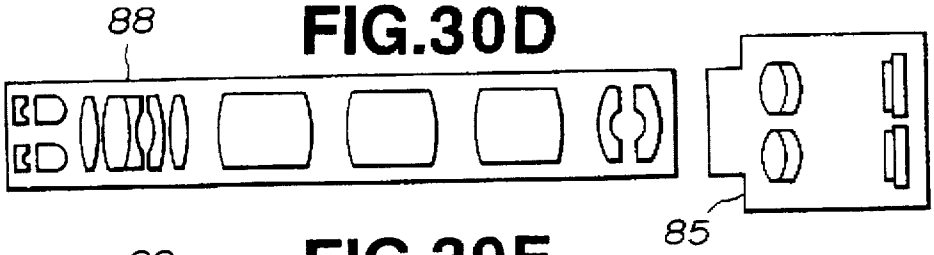


FIG.30E

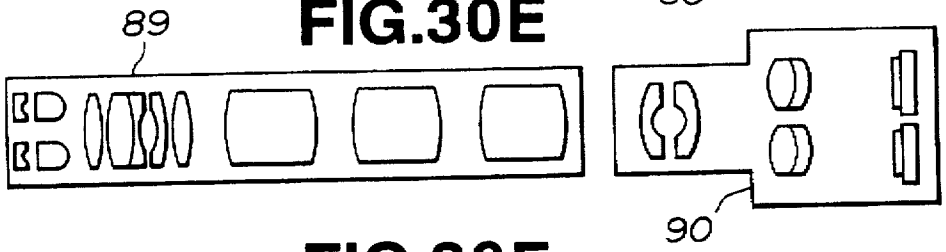


FIG.30F

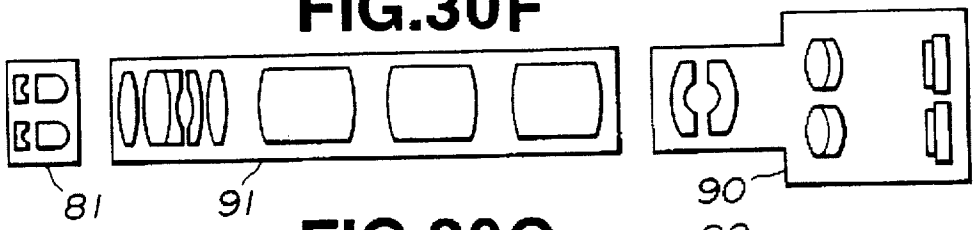


FIG.30G

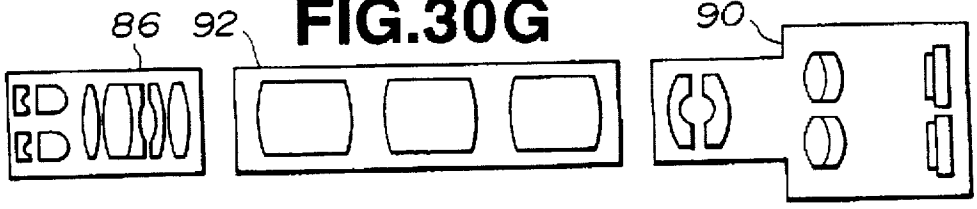


FIG.31A

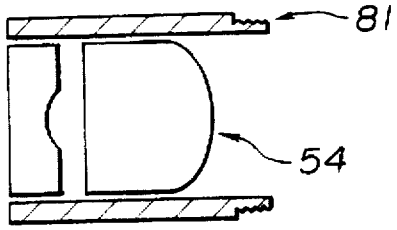


FIG.31B

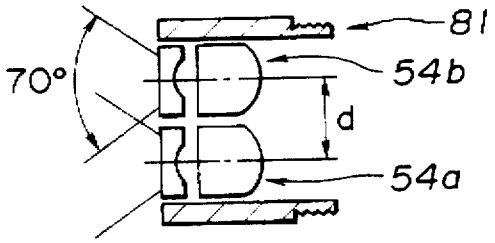


FIG.31C

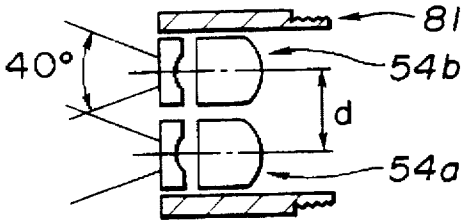


FIG.31D

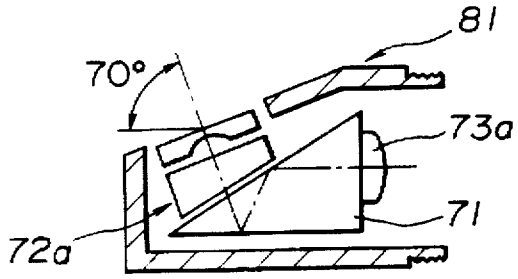


FIG.31E

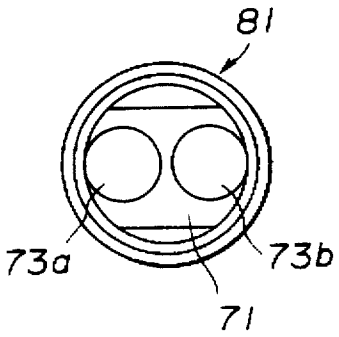


FIG.31F

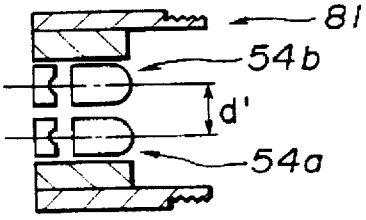


FIG.32A

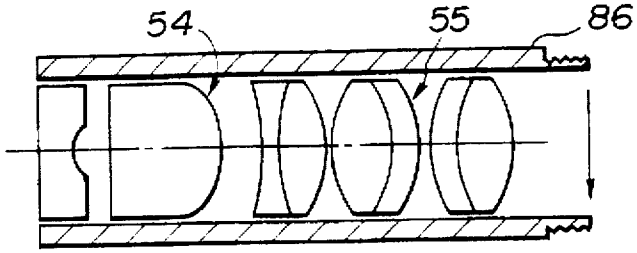


FIG.32B

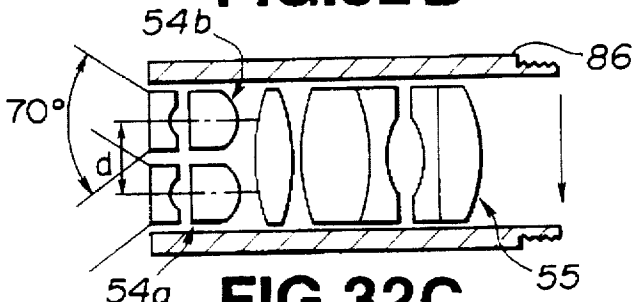


FIG.32C

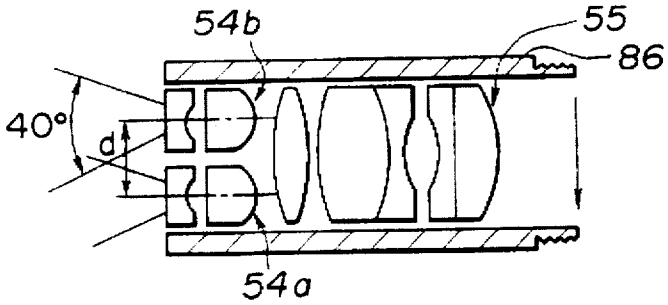


FIG.32D

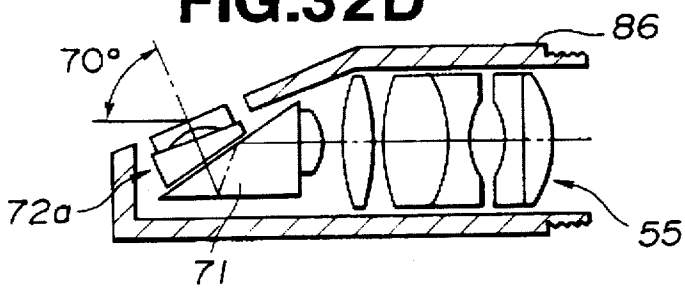


FIG.32E

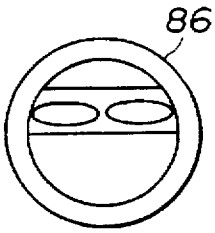
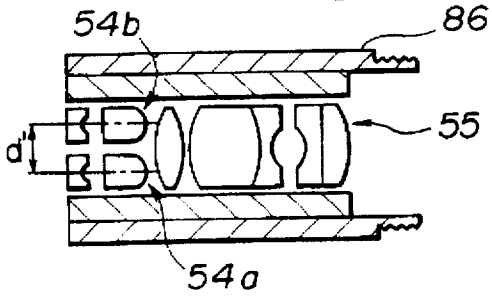


FIG.32F



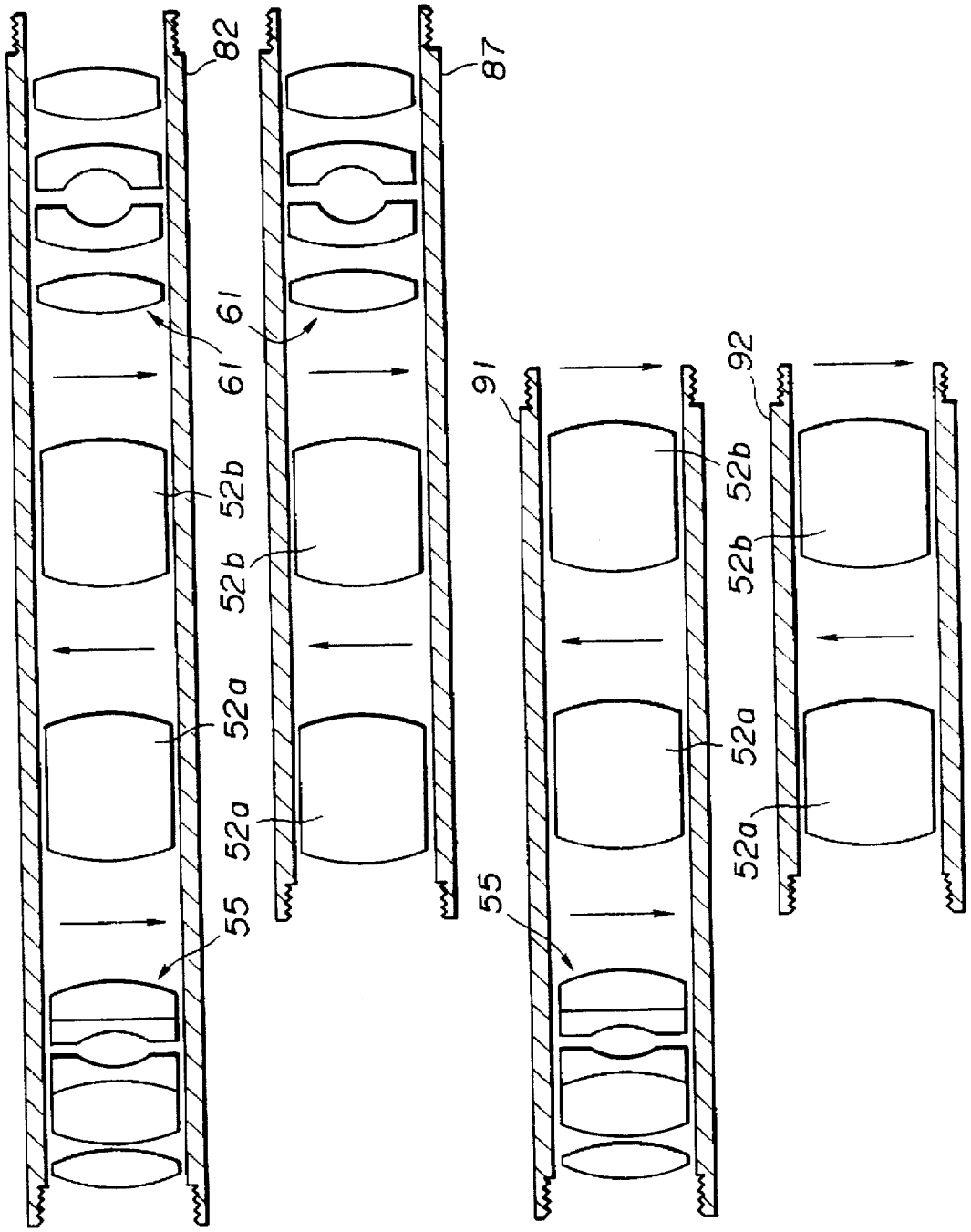


FIG.33A FIG.33B FIG.33C FIG.33D

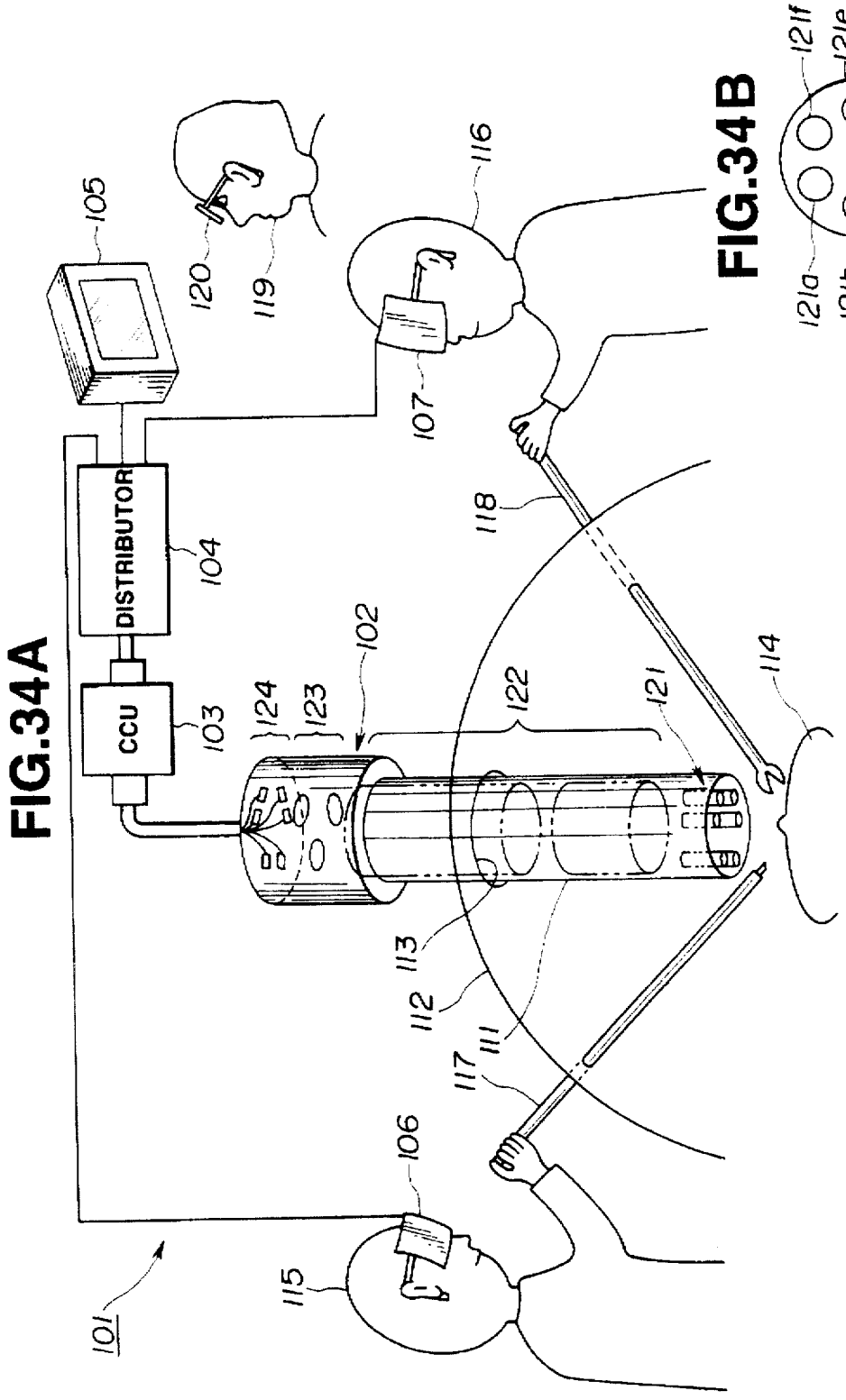


FIG.34A
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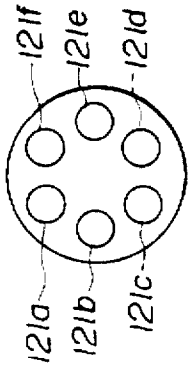
FIG.34B
121a
121b
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121e
121f

FIG.35A

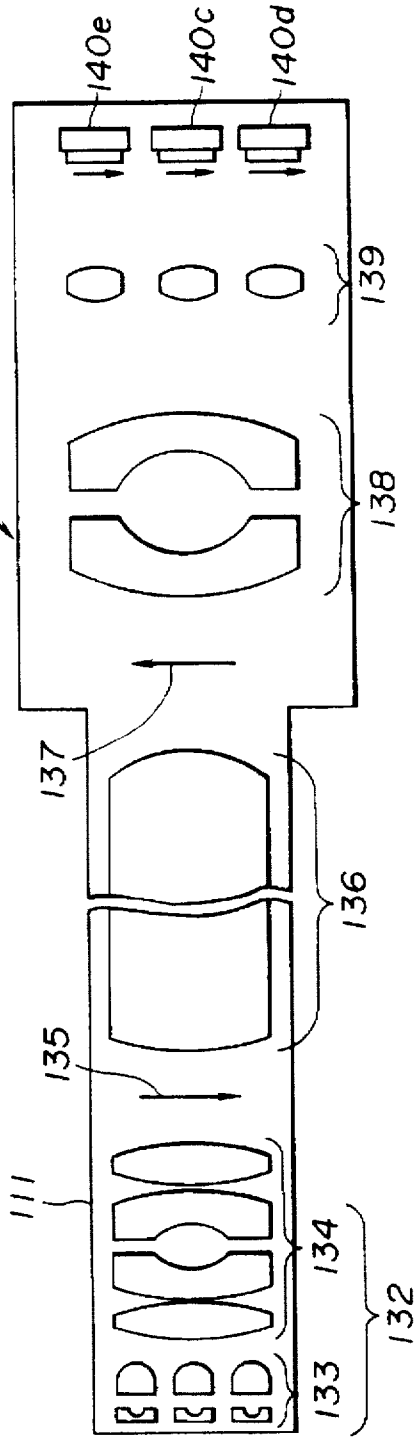


FIG.35C

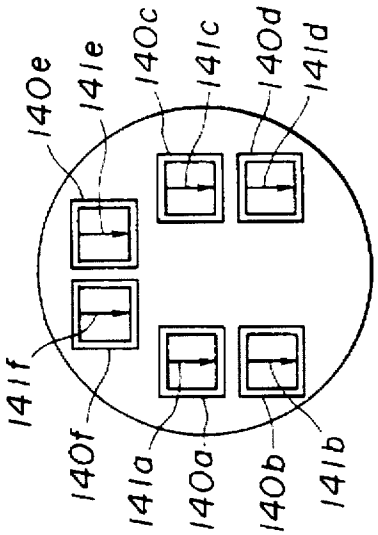


FIG.35B

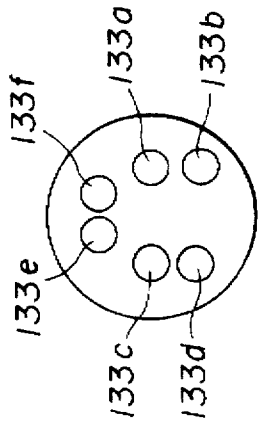


FIG.36B

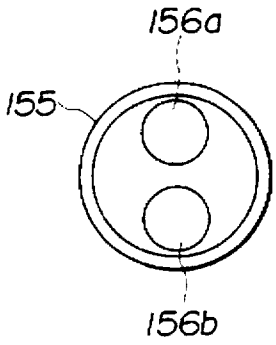


FIG.36A

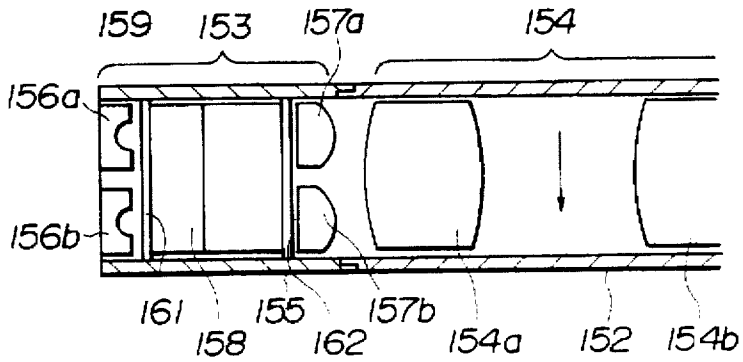


FIG.36D

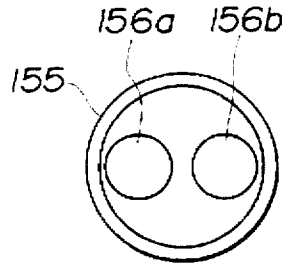


FIG.36C

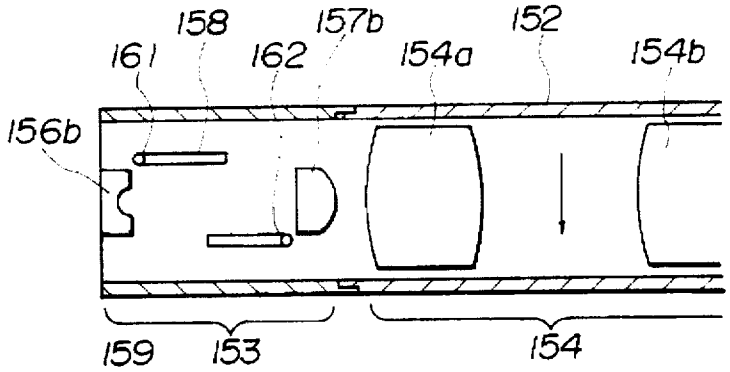


FIG.36F

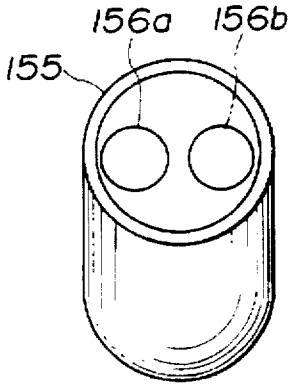


FIG.36E

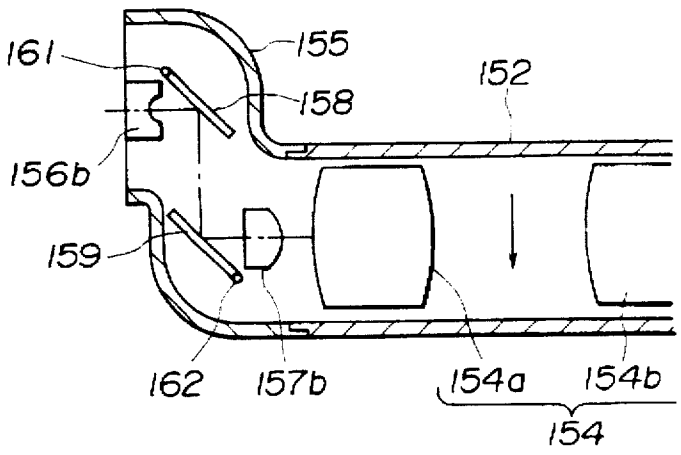


FIG.37B

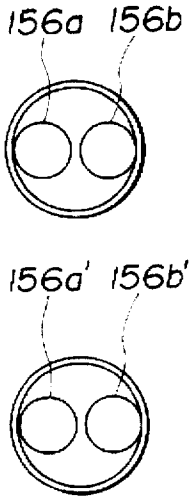


FIG.37A

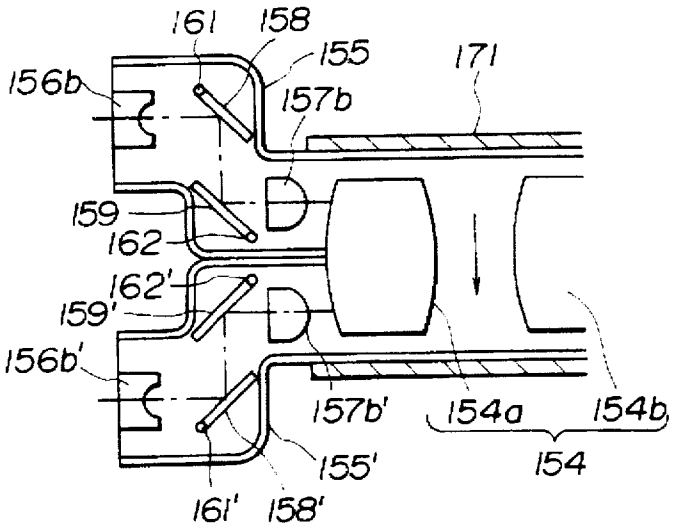


FIG.38A
(PRIOR ART)

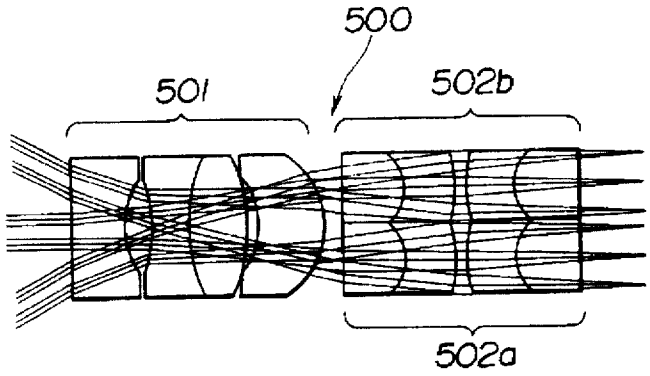


FIG.38B

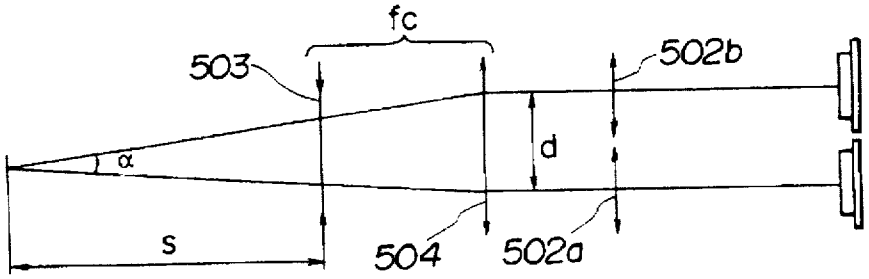
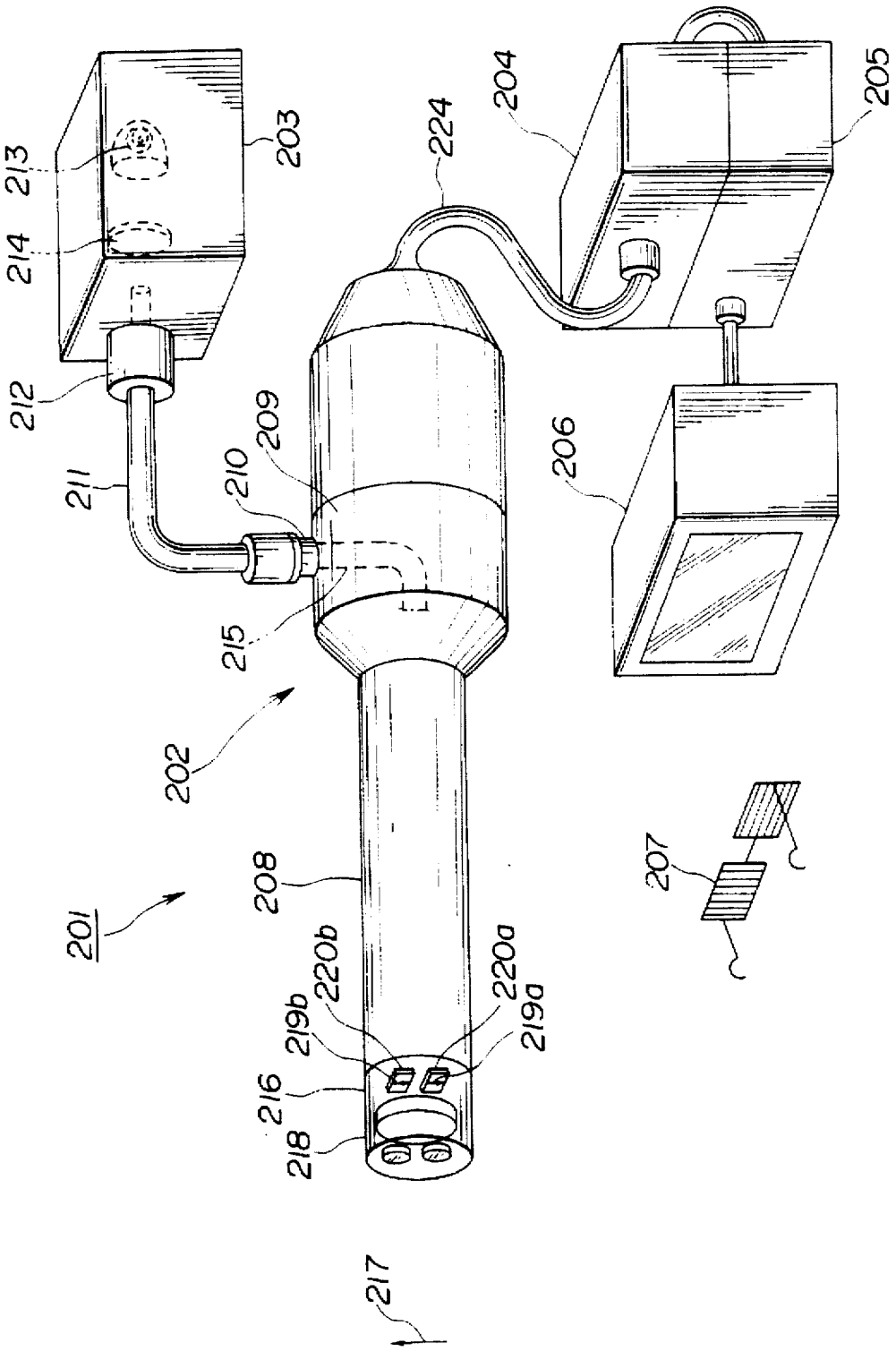


FIG.39


213
214
212
211
203
224
204
205
209
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206
215
202
207
208
201
220b
219b
220a
219a
216
218
217

FIG.40

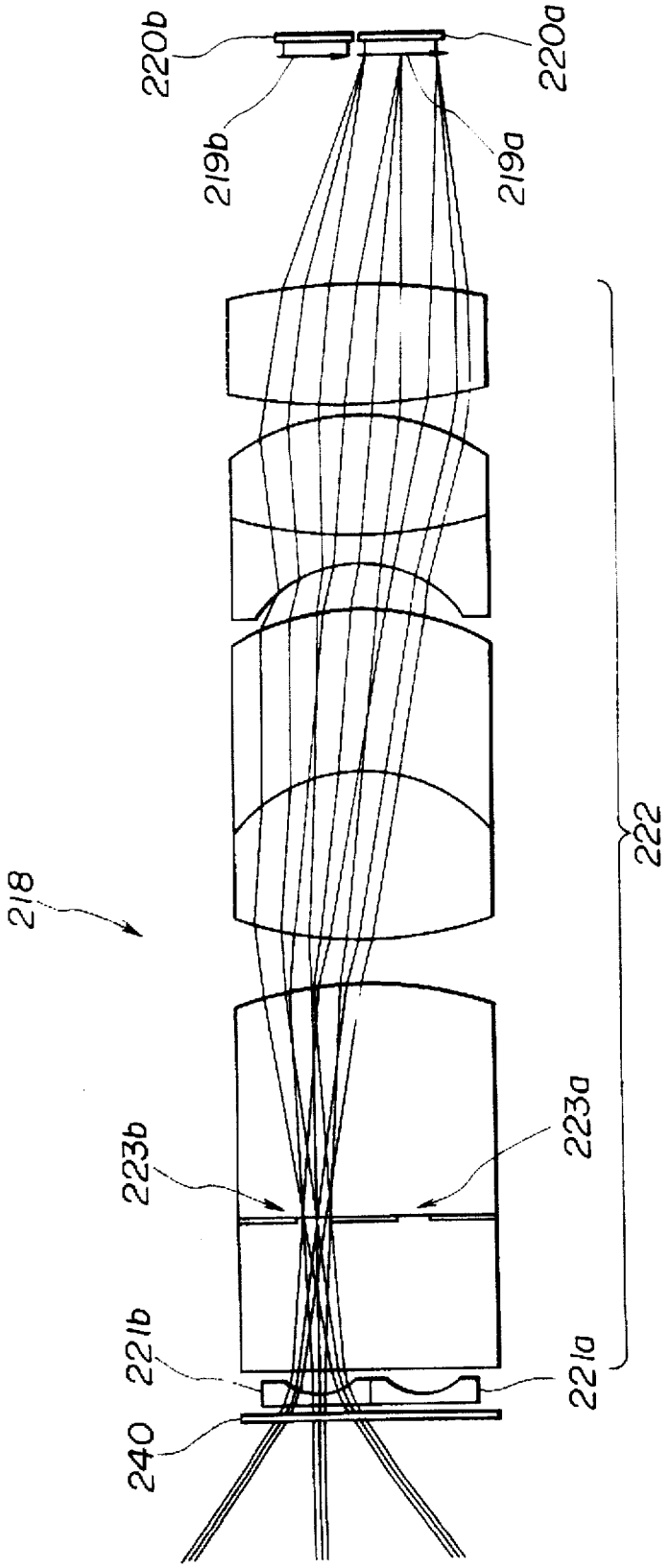


FIG.41

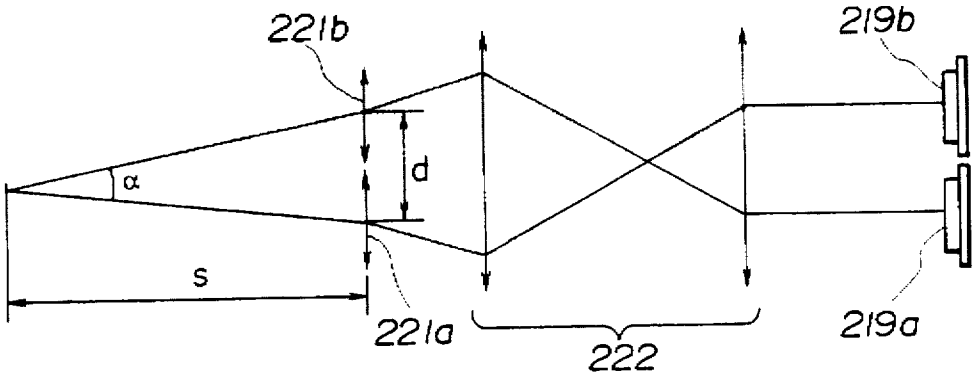
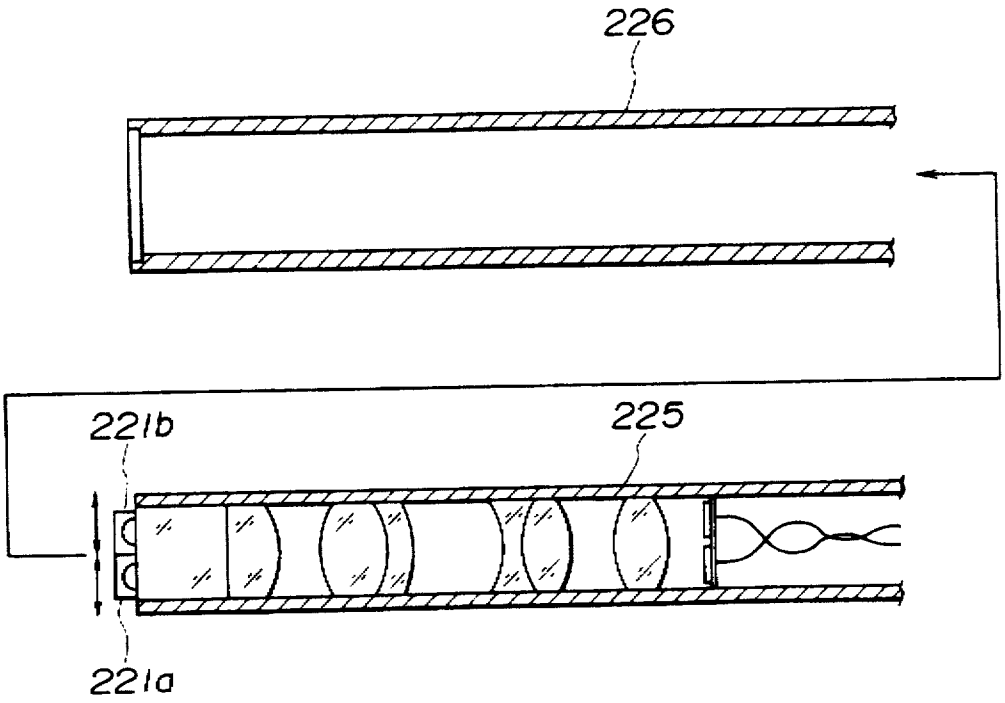


FIG.42



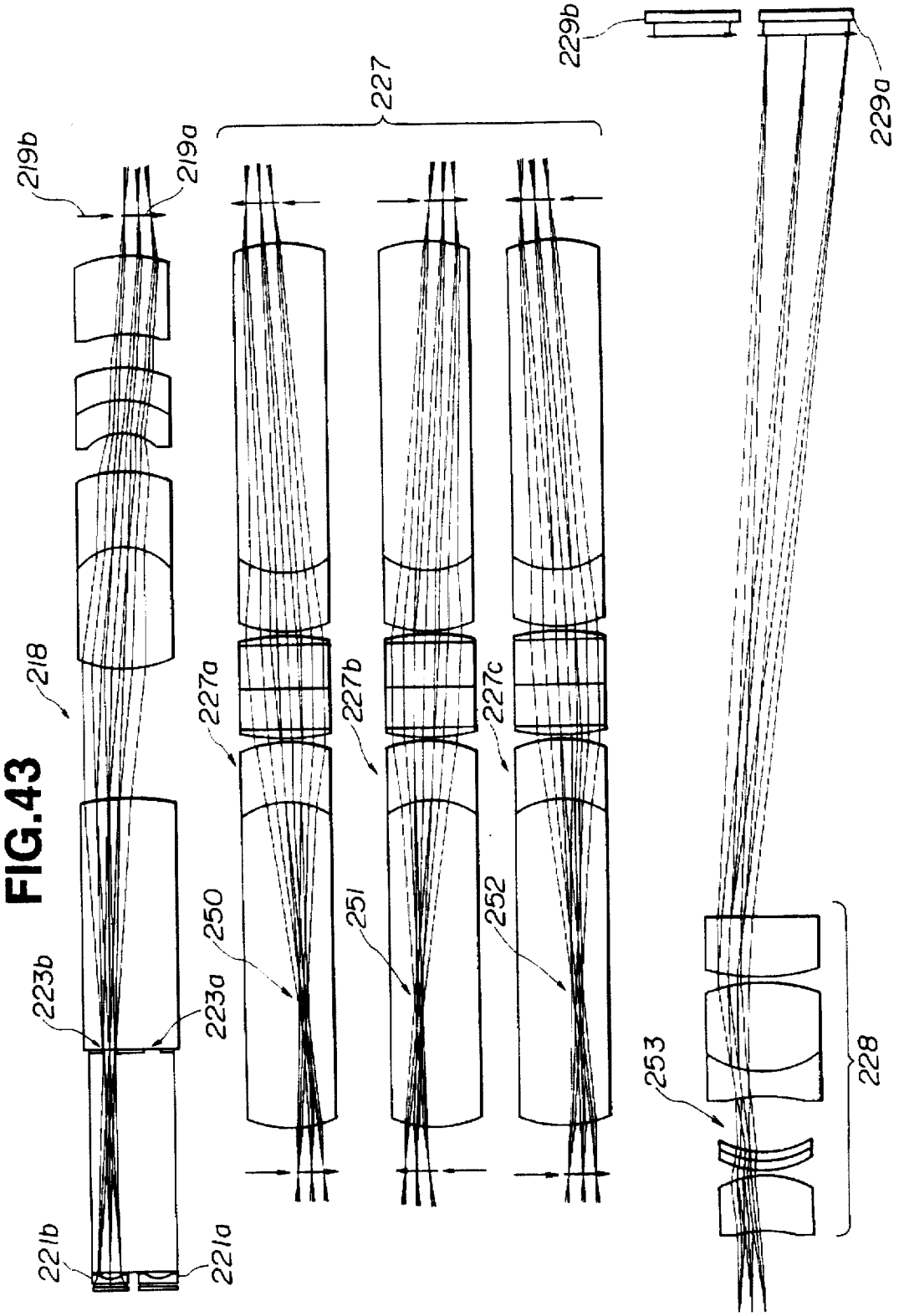

229b
227
229a
219b
219a
218
227a
227b
227c
250
251
252
223b
223a
253
228
221b
221a

FIG.43

FIG.44

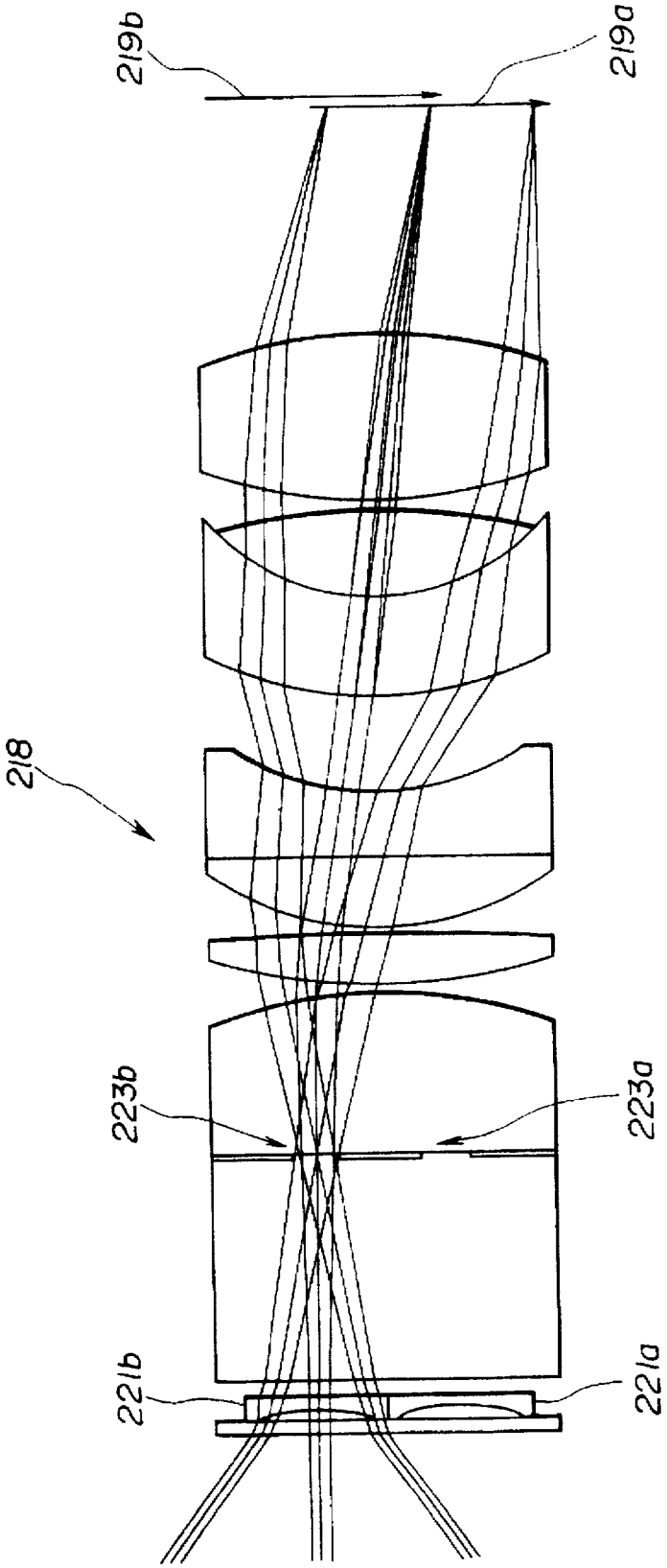


FIG.45

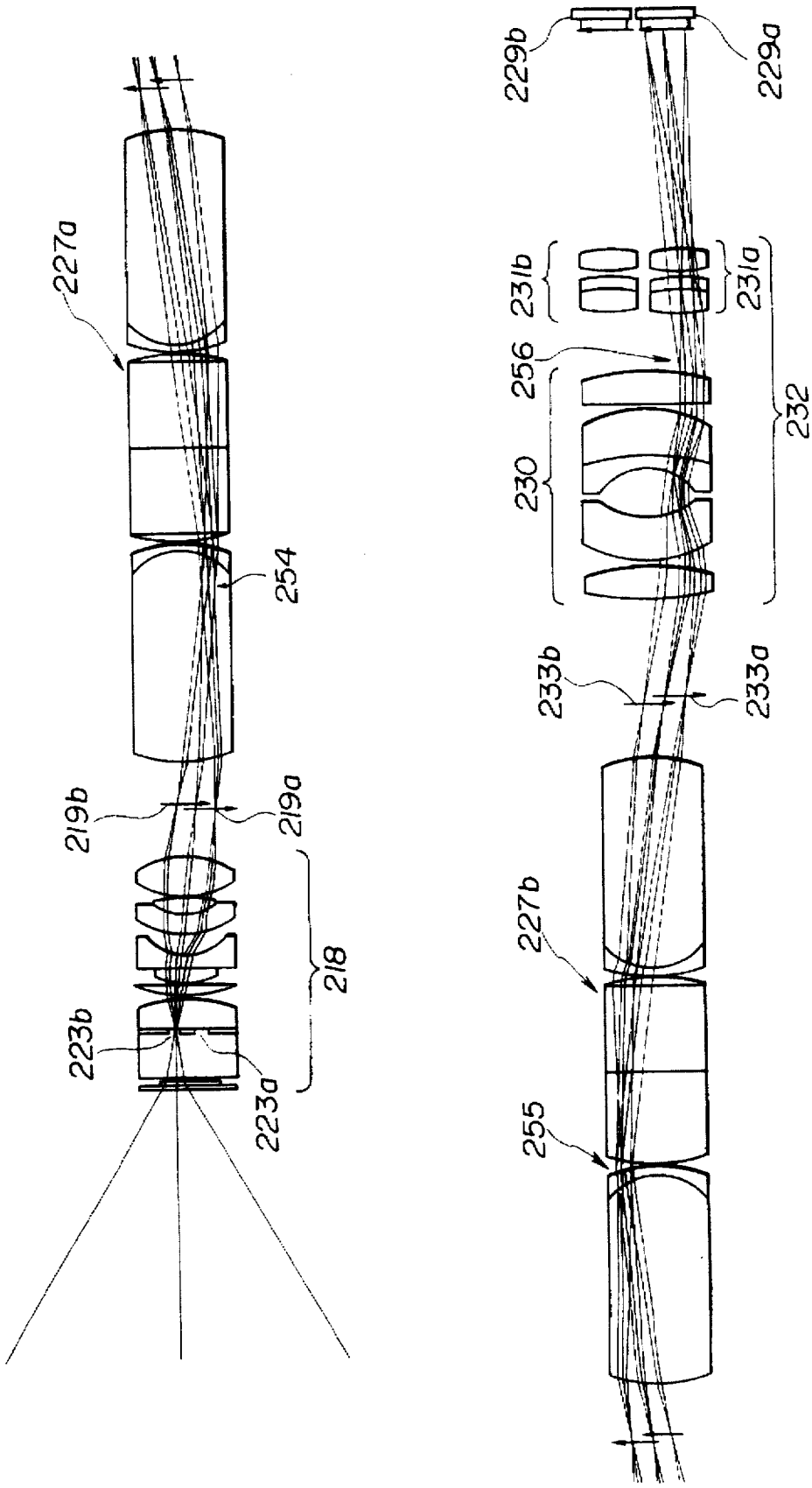

227a
254
219b
219a
218
223b
223a
229b
229a
231b
231a
256
230
232
233b
233a
227b
255

FIG.46

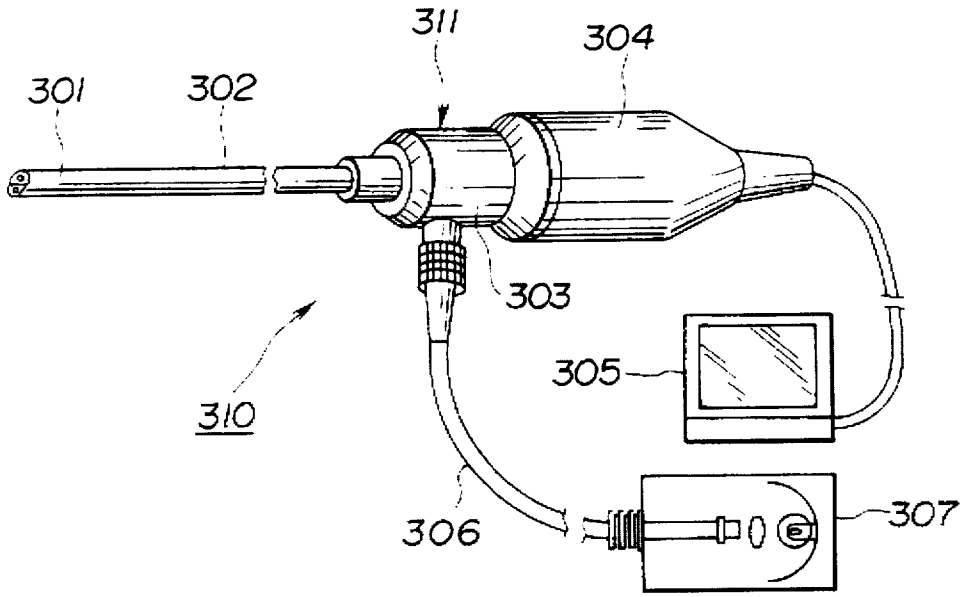


FIG.50

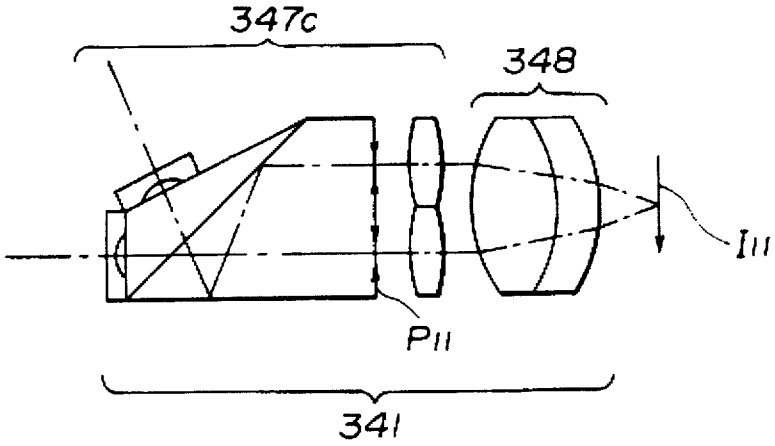


FIG.47A

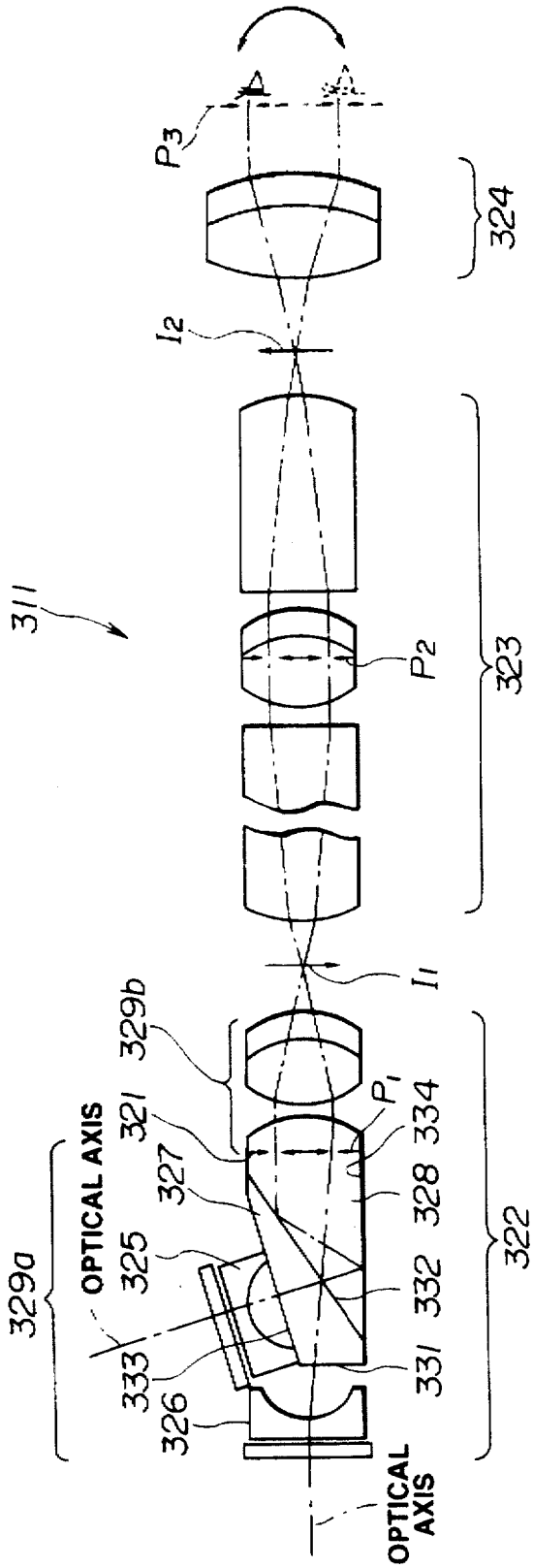


FIG.47B

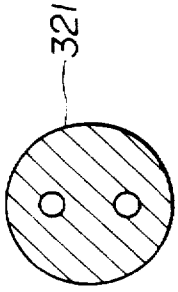


FIG.48

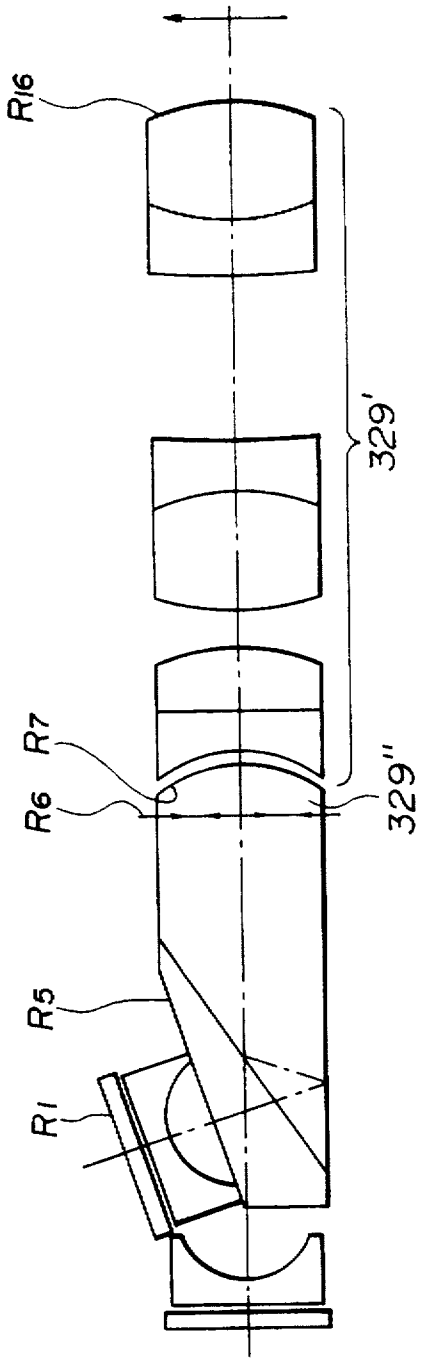


FIG.49A

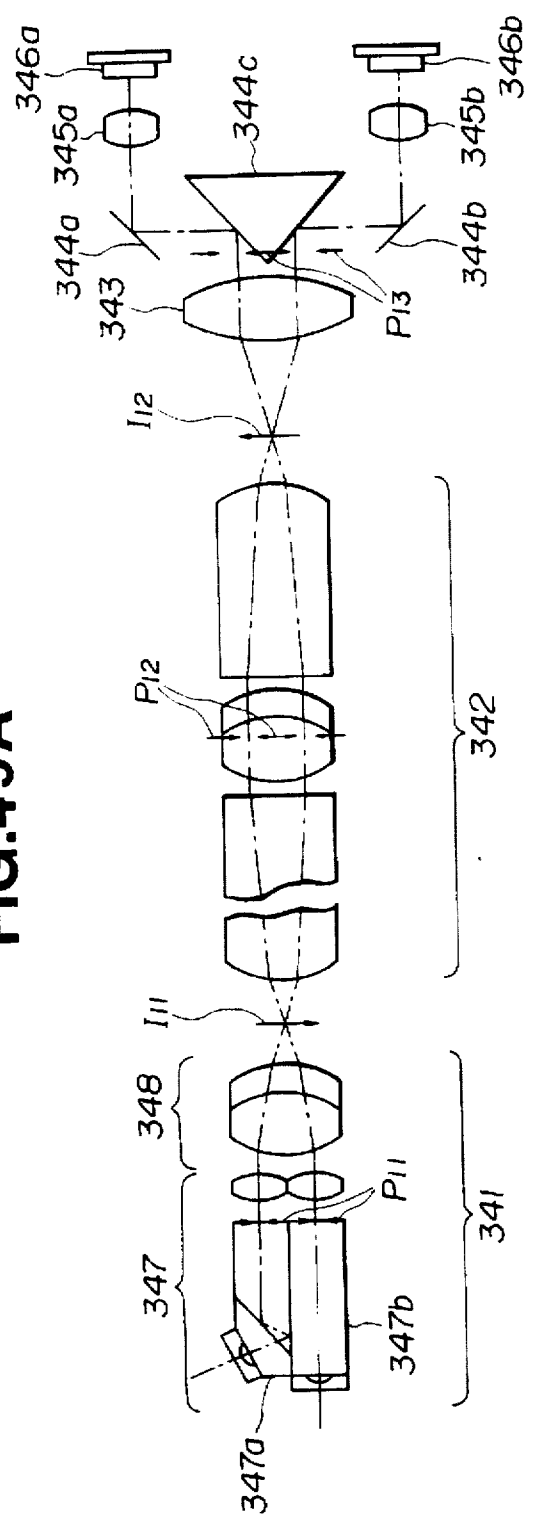


FIG.49B

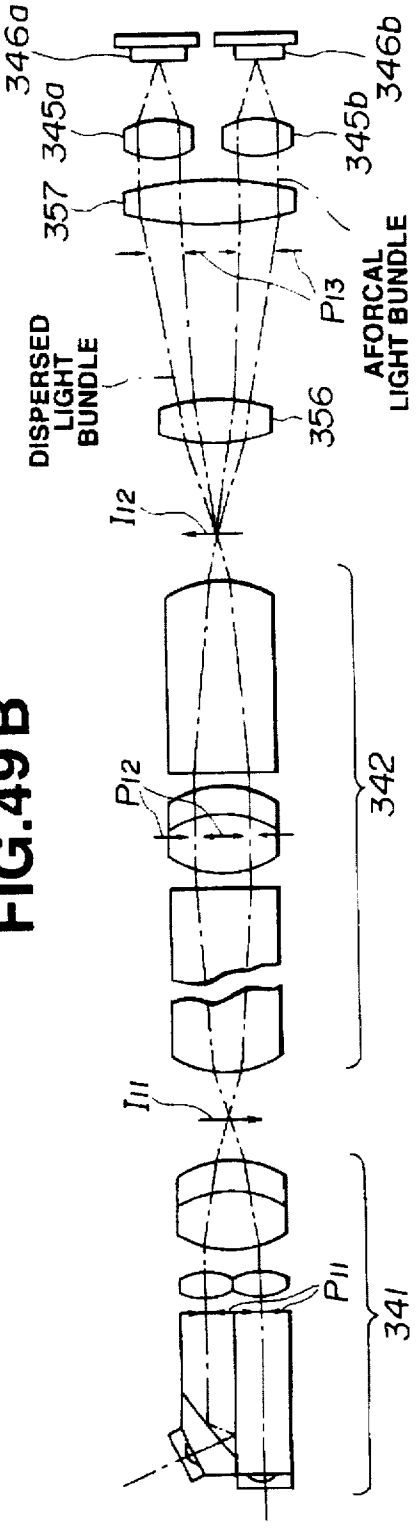


FIG.51

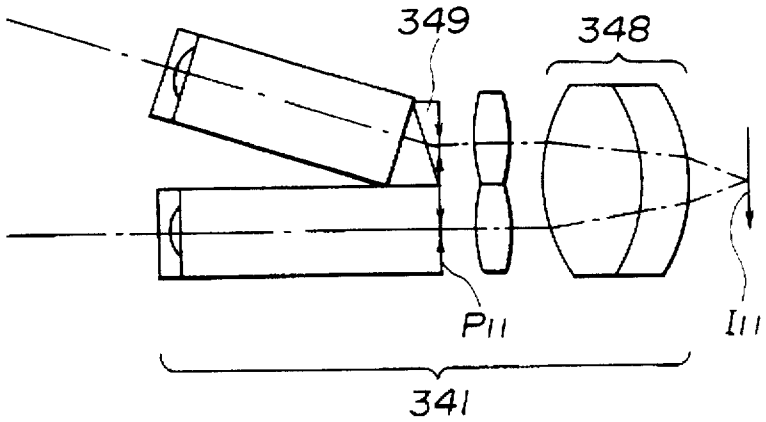


FIG.52

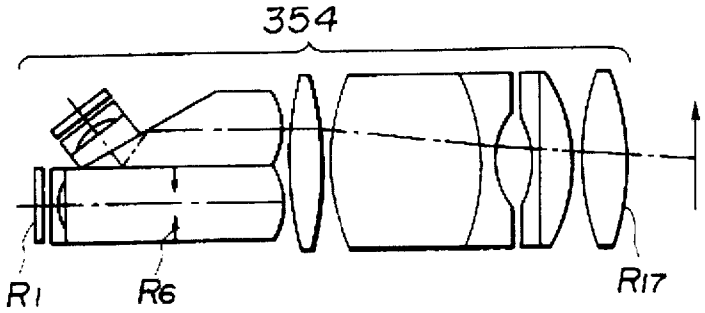


FIG.54

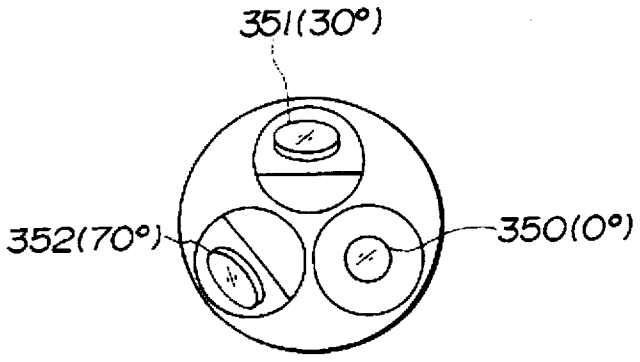


FIG.53

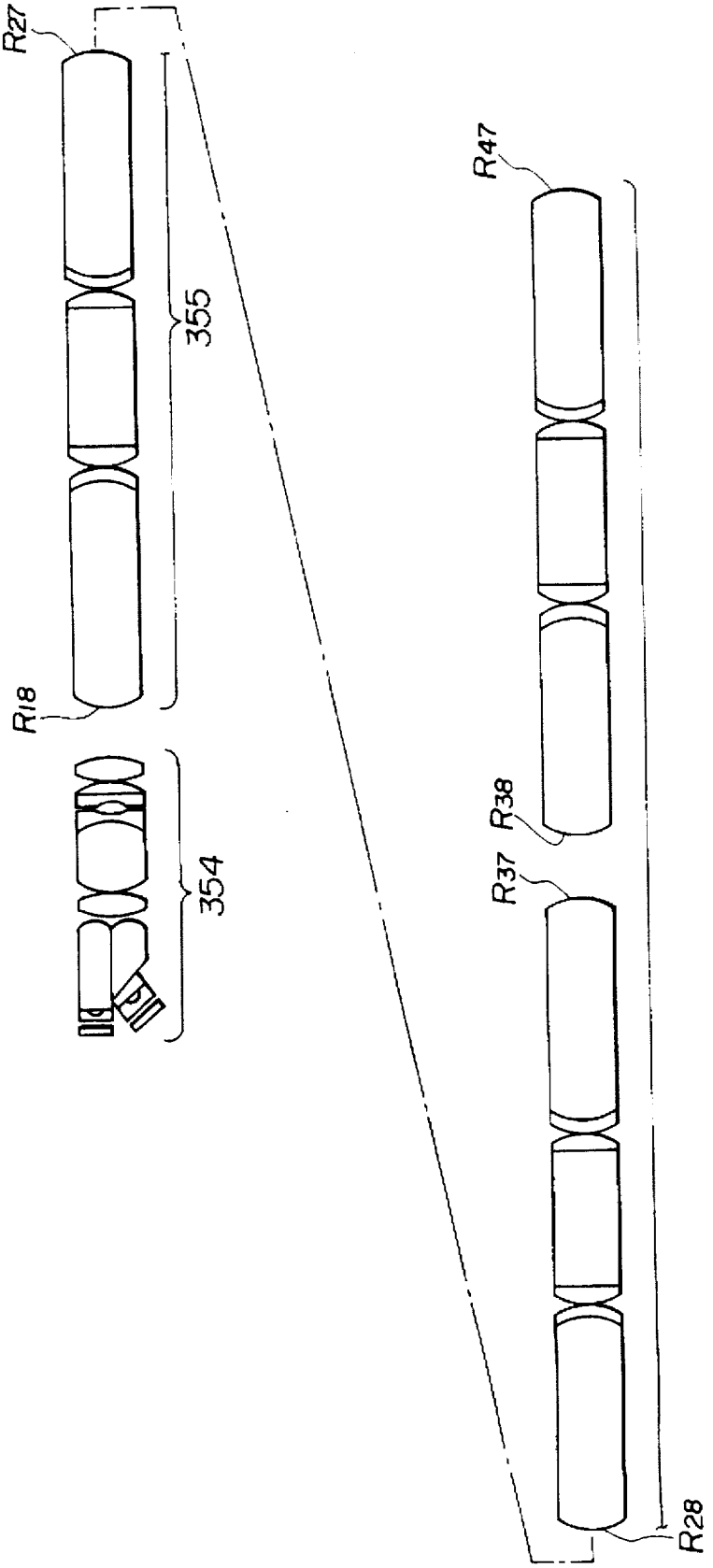


FIG.55

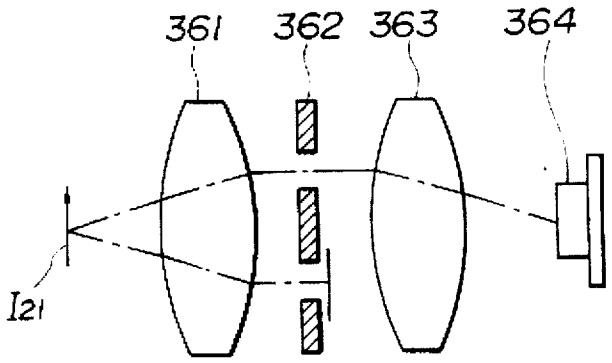


FIG.56A

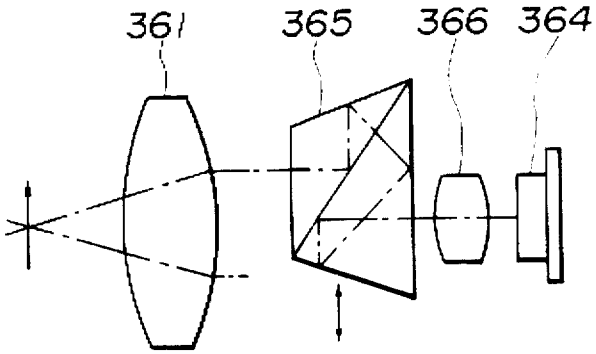


FIG.56B

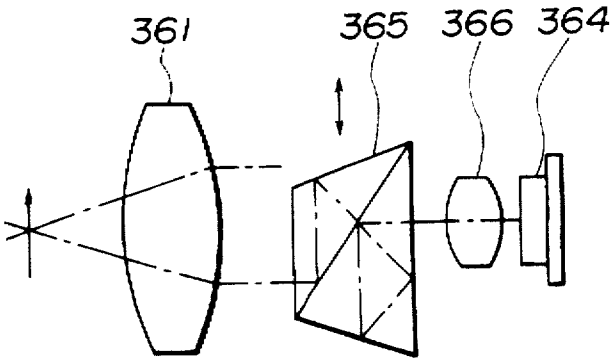


FIG.57

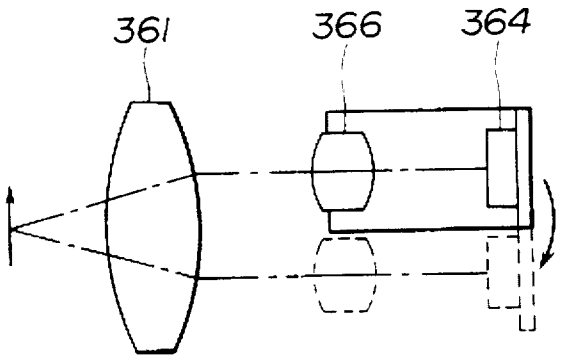


FIG.58A

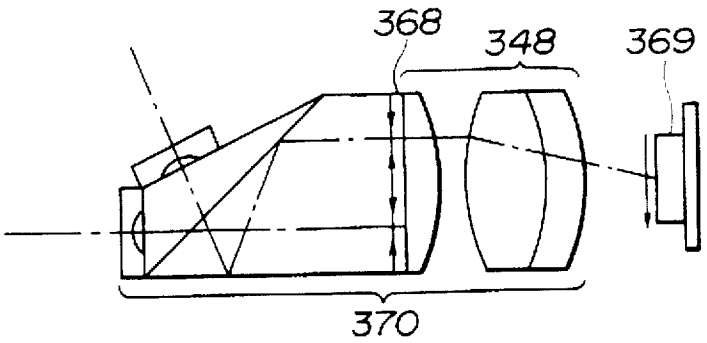


FIG.58B

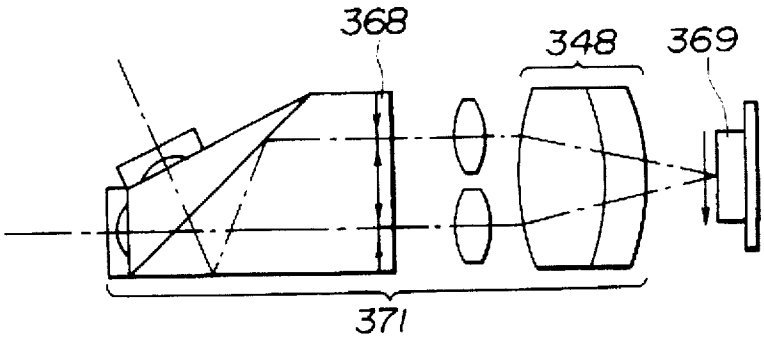


FIG.59A

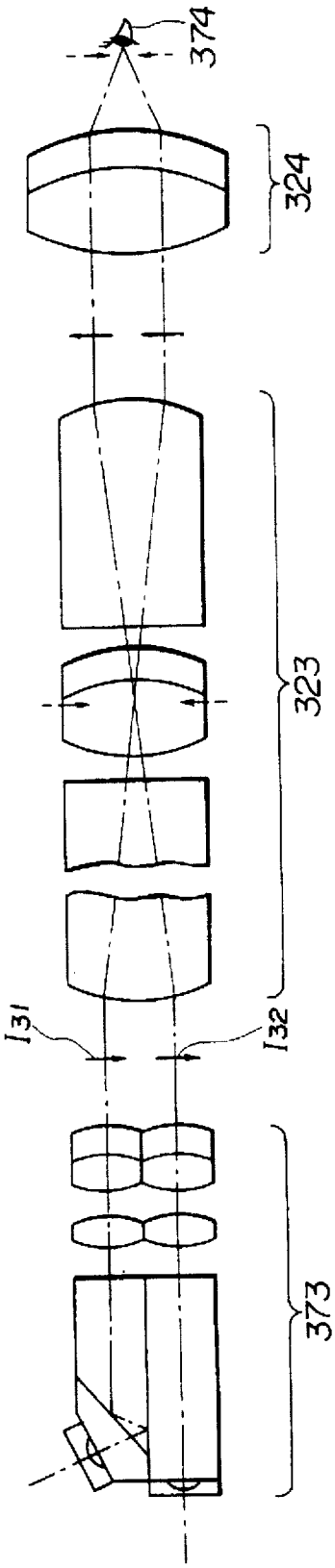


FIG.59B

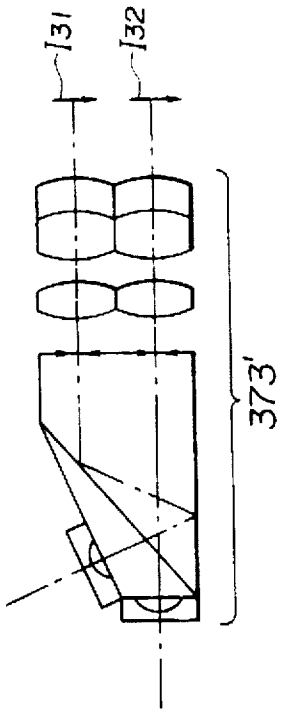


FIG.60A

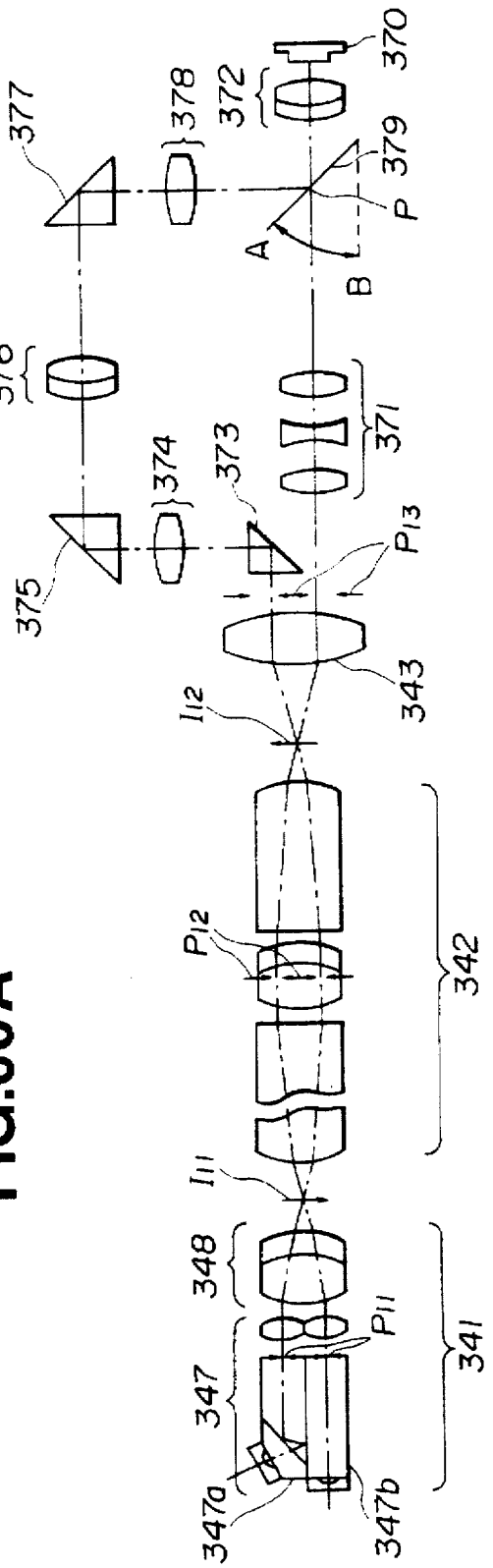
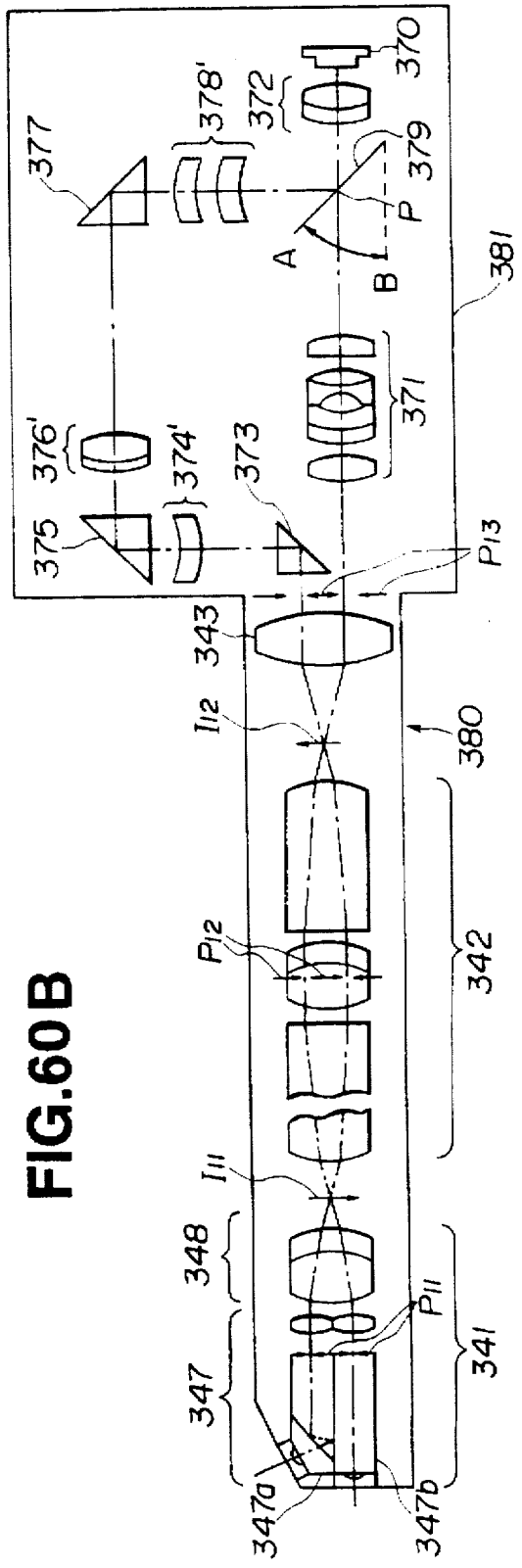


FIG.60B



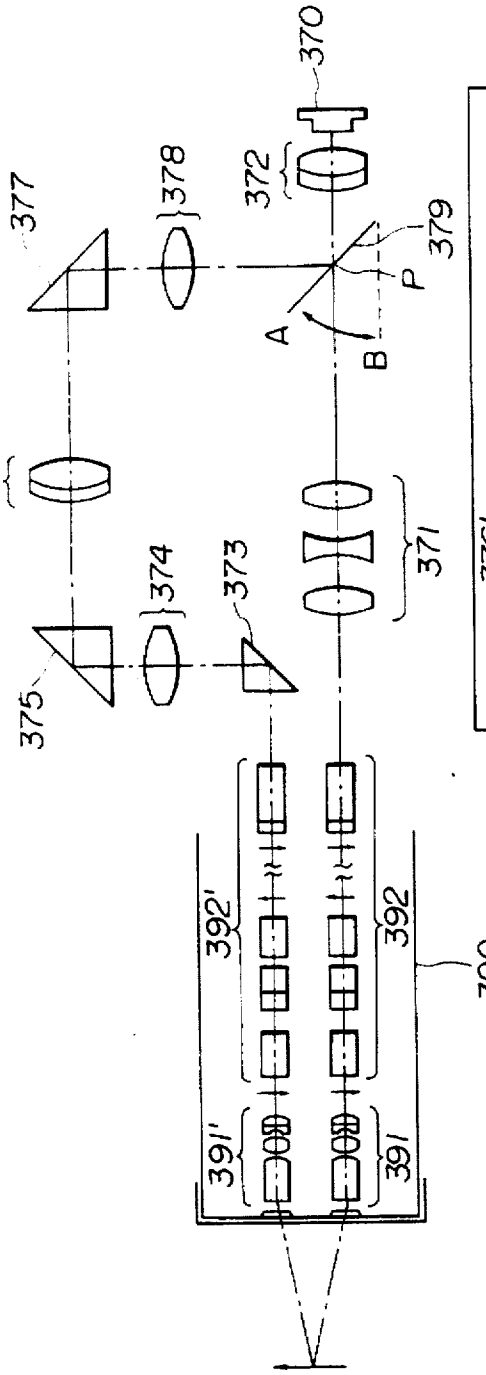


FIG.61A

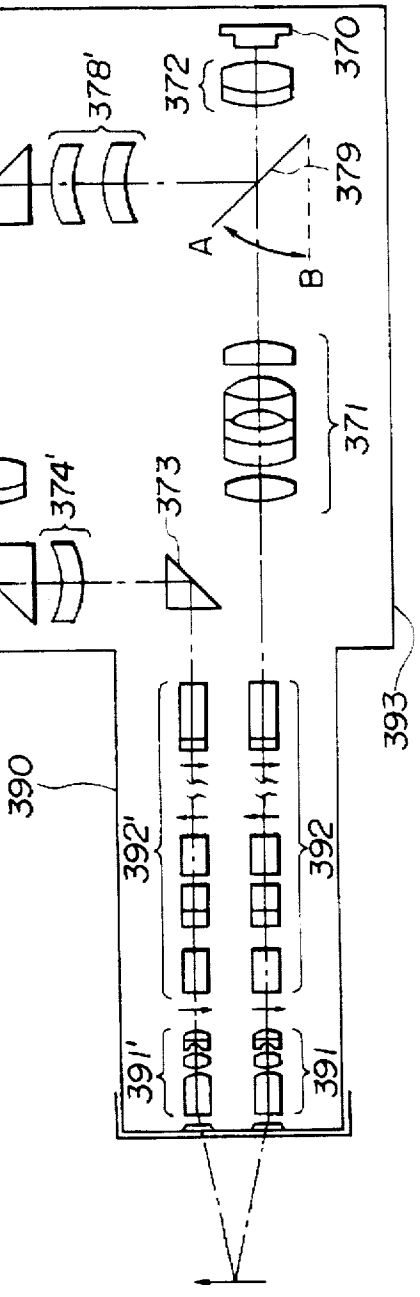


FIG.61B

STEREOSCOPIC ENDOSCOPE OBJECTIVE LENS SYSTEM HAVING A PLURALITY OF FRONT LENS GROUPS AND ONE COMMON REAR LENS GROUP

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a stereoendoscope wherein images having passed through plural incident pupils are transmitted by common relay optical systems so that an observation providing a stereo-feel may be possible.

2. Description of the Related Art

Recently, particularly in the surgical field, there is known a so-called endoscope operation wherein, in order to reduce the burden on the patient, without opening the abdomen, a small hole is made in the abdominal part, and an endoscope is inserted through the hole for the observation and treatment. In this field, the operation has been already made by directly and stereoscopically viewing the affected part with both eyes and therefore, even in the endoscope operation, stereo-inspection is strongly desired. If the stereo-inspection can be made, the operation will be easy, the operation time will be reduced and the hardship on the patient will be further reduced.

As a stereo-inspection endoscope whereby stereo-inspection is possible, there is a first related art example suggested in a Japanese patent application No.309078/1992 shown in FIG. **1A** wherein two identical optical systems are arranged in parallel and the images formed by the objective optical systems **401** and **401'** are transmitted for a predetermined distance by the transmitting optical systems **402** and **402'** (in this case, relay lens systems) and are taken by such image taking devices **403** and **403'** as CCD's.

The taken pair of the right and left images are converted to electrical signals and are displayed in a TV monitor (not illustrated). At this time, when the displayed right and left images are switched at a high speed and simultaneously shutter spectacles synchronized with the images are used, the image for the right eye will be observed with the right eye and the image for the left eye will be observed with the left eye so as to be able to be stereo-inspected.

Also, as another type stereoendoscope, there is a second related art example suggested in a Japanese patent application No.28278/1993 shown in FIG. **2A** wherein the objective optical system **414** and the relay lens system **415** which is a transmitting optical system are formed of one axially symmetrical optical system. A prism **416** is arranged at the rear end of the relay lens system **415** and a pair of right and left images having a parallax are formed and taken in the image taking devices **417** and **417'** by spatially dividing the pupil into two with the prism. FIGS. **1B** and **2B** on the left side of FIGS. **1A** and **2A** show respective incident pupils.

In order to make a stereo-inspection, it is necessary to obtain a pair of right and left images having a parallax from each other. Therefor, the incident pupil for the right image of the optical system and the incident pupil for the left image must be spatially separated. Also, the magnitude of the stereo-feel in the case of the stereo-inspection is proportional to the center distance between the right and left incident pupils.

In the two above-mentioned related art examples, in the case of the first type in which the same two optical systems are arranged, when the objective optical systems **401** and **401'** to the image taking means **403** and **403'** are separately formed and the left and right incident pupils **407** and **407'** are separately positioned, images having a parallax from each other will be obtained. The center distance d between the left and right incident pupils **407** and **407'** coincides with the optical axis distance D between the left and right objective optical systems **407** and **407'**.

In the second type in which the pupil is divided among the above-mentioned related art, the objective optical system **414** and transmitting optical system **415** are formed of one axially symmetrical optical system and the pupil is one in this part but, when this one pupil is spatially divided into two by the pupil dividing means (in the above mentioned case, the pupil dividing prism) **416** and respective images are produced, images having a parallax from each other will be obtained. The center distance d between the left and right incident pupils **418** and **418'** is ½ the size of the incident pupil **419** of the objective lens.

In the type in which the same two optical systems are arranged, as it is formed of separate right and left parts, the number of the parts is high, thereby increasing the difficulty in assembly. Also, the magnification difference between the right and left images due to the errors of the respective parts is large, the displacement of the focusing position is large, the normal stereo-inspection cannot be made and therefore a fine adjustment is necessary.

In the type of dividing pupil, there are advantages that the parts common to the right and left light paths are many, the number of parts is low and the displacement of the right and left images can be made small. On the other hand, when compared with the same thickness, the magnitude of the parallax will be smaller than in the first type and a sufficient stereo-feel will be difficult to obtain. That is to say, there is a problem in that the center distance between the right and left incident pupils is difficult to make large. This point shall be explained with reference to FIGS. **3A** to **4B**.

FIG. **3A** is a magnified view of the objective optical system on the distal end side of the first related art example. FIG. **3B** shows its incident pupil. Also, FIG. **4A** is a magnified view of the objective optical system on the distal end side of the second related art example. FIG. **4B** shows its incident pupil.

In the type in which the same two optical systems are arranged, that is, the first related art example, against the inside diameter Φ of the objective lens frame **421** of the endoscope distal end **420**, the optical axis distance between the right and left objective optical systems is substantially Φ/2. Therefore, the center distance between the right and left incident pupils **407** and **407'** is also substantially Φ/2.

On the other hand, in the type in which the pupil is divided, against the inside diameter Φ of the objective lens frame **421** at the endoscope distal end **420**, the diameter of the incident pupil **419** of the objective optical system is smaller than Φ, because the incident pupil of the objective optical system is smaller than the pupil of the relay lens system as the NA of the endoscope is limited by the outside diameter of the relay lens system and the picture angle of the objective optical system is larger than of the relay lens system.

Therefore, the center distance between the right and left incident pupils is less then Φ/2 and is usually about Φ/6 to Φ/10. Therefore, in this type, the magnitude of the parallax is about ⅓ that in the above mentioned type. Particularly, when the distal end is thin, no sufficient stereo-feel will be obtained.

SUMMARY OF THE INVENTION

In view of such circumstances, an object of this invention is to provide a stereoendoscope wherein, as in the type in

which the pupil is divided, the commonality of parts for the right and left light paths is made as high as possible, the variations of the right and left images by the production errors or the like can be made few and images having a stereo-feel by a parallax as great as of the type in which the same two optical systems are arranged are obtained.

The stereoendoscope of the present invention comprises an objective optical system which has a plurality of incident pupils formed in different positions and forms a plurality of images passing through the incident pupils and having a parallax from each other and a common image transmitting optical system which transmits the plurality of images having a parallax from each other.

When thus formed, as the objective optical system has a plurality of independent incident pupils, irrespective of the size of the diameter of the incident pupil of the objective optical system, the parallax will be able to be made large. Also, as the plurality of images and pupils are not separately transmitted by the plurality of transmitting systems but are transmitted by the common image transmitting optical system, the number of parts will be able to be reduced. Even if a production error is present in the individual image transmitting optical system, as the images are transmitted by the common image transmitting system, the variation between the plurality of transmitted images will be able to be reduced.

In order to realize such formation, there are the following two systems (a) and (b):

(a) A formation comprising an objective optical system which forms a plurality of images having parallaxes in spatially separated positions and one image transmitting optical system which transmits the plurality of incident pupils and the plurality of images of the object optical system so that the images transmitted by this image transmitting optical system may be taken finally by one or more image taking means. More specifically, the system includes:

A stereoendoscope having an objective optical system, image transmitting optical system and image taking device, where the objective optical system comprises a plurality of optical systems arranged in parallel and forms a plurality of images having a parallax from each other and the image transmitting optical system comprises an optical system arranged along one optical axis and transmits a plurality of images formed by the objective optical system.

In this formation, as the operation common to (a) and (b) is made and the image transmitted by the image transmitting optical system is also spatially separated, the image can be stereo-inspected through an image taking means taking images or an ocular optical system making observation with the naked eyes. The image taking means can use one or more image taking devices and can take a plurality of images transmitted and spatially separated by the transmitting optical system and stereo-inspection is thereby possible.

The other formation realizing such formation is as follows:

(b) A formation comprising an objective optical system forming a plurality of images having parallaxes where they spatially substantially coincide (superimposed), jetting pupils corresponding to the plurality of incident pupils of the objective optical system and one image transmitting optical system transmitting the plurality of images, wherein the images transmitted by the image transmitting optical system are taken finally by one or more image taking means.

More specifically the system includes:

A stereoendoscope having an objective optical system, image transmitting optical system and image taking device, where the objective optical system comprises a plurality of front group optical systems arranged in parallel to take in a plurality of images having a parallax from each other and rear group optical systems arranged so as to be on the same optical axis as of the image transmitting optical system and forming images of beams from the plurality of front group optical systems where the beams are substantially superimposed. The image transmitting optical system transmits the plurality of images formed by the rear group optical systems, having a parallax from each other and substantially superimposed. The jetting pupils of the objective optical system.

In this formation, because a common operation is made and images having parallaxes are transmitted to be formed where they are substantially superimposed, the diameter of the relay optical system can be made small.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. **1A** and **1B** show a first related art example, where FIG. **1A** is a formation view showing its stereoendoscope and FIG. **1B** is an explanatory view showing incident pupils.

FIGS. **2A** and **2B** show a second related art example, where FIG. **2A** is a formation view showing its stereoendoscope and FIG. **2B** is an explanatory view showing an incident pupil.

FIG. **3A** is a magnified sectioned view of an objective optical system part on the distal end side of the first related art example and FIG. **3B** is an explanatory view showing incident pupils of FIG. **3A**.

FIG. **4A** is a magnified sectioned view of an objective optical system part on the distal end side of the second related art example and FIG. **4B** is an explanatory view showing an incident pupil of FIG. **4A**.

FIGS. **5** and **6** relate to the first embodiment of the present invention, where FIG. **5** is a formation view showing the whole of a stereoendoscope apparatus provided with the first embodiment and

FIG. **6** is a formation view showing an image taking optical system in the stereoendoscope of the first embodiment of the present invention.

FIG. **7** is a formation view showing an image taking optical system in the second embodiment of the present invention.

FIG. **8** is a formation view showing an image taking optical system in the third embodiment of the present invention.

FIG. **9** is an explanatory view showing an arrangement example of an image taking device.

FIGS. **10A** and **10B** relate to a modification of the third embodiment, where FIG. **10A** is an explanatory view showing images formed by an objective optical system and relay optical system and a final image by the image transmission and FIG. **10B** is an explanatory view showing the arrangement of a final image and an image taking device arranged in the position in case the objective optical system and relay optical system of FIG. **10A** are used.

FIG. **11** is a formation view showing an image taking optical system in the fourth embodiment of the present invention.

FIG. **12** is a formation view showing an image taking optical system in the fifth embodiment of the present invention.

FIG. **13** is a formation view showing an image taking optical system in the sixth embodiment of the present invention.

FIG. 14 is a formation view showing a main part of an image taking optical system in the seventh embodiment of the present invention.

FIGS. 15A and 15B relate to the eighth embodiment of the present invention, where FIG. 15A is a plan view showing an objective optical system and FIG. 15B is a side view showing the objective optical system.

FIGS. 16A and 16B show the ninth embodiment of the present invention, where FIG. 16A is a plan view showing a unit formation of the ninth embodiment and FIG. 16B is a side view of FIG. 16A.

FIGS. 16C and 16D show a first modification of the ninth embodiment, where FIG. 16C is a plan view showing a unit formation of the first modification and FIG. 16D is a side view of FIG. 16C as an ocular adapter is connected.

FIGS. 17A to 17C are explanatory views respectively showing unit formations in the second to fourth modifications of the ninth embodiment.

FIGS. 18A to 18E are views respectively showing formations of objective optical system units.

FIGS. 19A to 19D are views respectively showing formations of relay optical system units.

FIG. 20 is a formation view showing an image taking optical system in the tenth embodiment of the present invention.

FIG. 21 is a formation view showing an image taking optical system in the eleventh embodiment of the present invention.

FIG. 22 is a formation view showing an image taking optical system in the twelfth embodiment of the present invention.

FIGS. 23A to 23D show a meniscus lens in a modification of the twelfth embodiment, where FIG. 23A is a sectioned plan view and FIG. 23B is a side view as seen from the side of FIG. 23A. FIGS. 23C and 23D are respectively a front view and back view as seen from the front surface and back surface sides.

FIG. 24 is a formation view showing an image taking optical system in the thirteenth embodiment of the present invention.

FIG. 25 is a formation view showing a main part of an image taking optical system in the fourteenth embodiment of the present invention.

FIGS. 26A and 26B show an objective optical system in the fifteenth embodiment of the present invention, where FIG. 26A is a plan view and FIG. 26B is a side view.

FIGS. 27A and 27B show an objective optical system in a modification of the fifteenth embodiment, where FIG. 27A is a plan view and FIG. 27B is a side view.

FIGS. 28A and 28B show an image taking optical system in the sixteenth embodiment, where FIG. 28A is a plan view and FIG. 28B is a side view.

FIGS. 29A and 29B show an image taking optical system in the seventeenth embodiment, where FIG. 29A is a plan view and FIG. 29B is a side view.

FIGS. 30A to 30G are explanatory views respectively showing unit formations of the eighteenth embodiment.

FIG. 31A to 31F are views respectively showing actual formations of front group units.

FIG. 32A to 32F are views respectively showing concrete formations of objective optical system units.

FIG. 33A to 33D are sectioned views respectively showing formations of rear group and relay lens system units.

FIGS. 34A and 34B relate to the nineteenth embodiment of the present invention, where FIG. 34A is a general formation view of a stereoendoscope apparatus provided with the nineteenth embodiment and FIG. 34B is a view of the arrangement of an objective optical system on the distal end surface of the stereoendoscope of the nineteenth embodiment.

FIGS. 35A to 35C relate to the twentieth embodiment of the present invention and FIG. 35A is a view showing the formation of a stereoendoscope of the twentieth embodiment. FIG. 35B is an elevation showing the arrangement of an objective optical system as seen from the distal end surface and FIG. 35C is an explanatory view showing the arrangement of an image taking device as seen from the distal end side.

FIGS. 36A to 36F show the formation on the distal end side of the twenty-first embodiment of the present invention, where FIG. 36A is a vertically sectioned view; FIG. 36B is an elevation of FIG. 36A;

FIG. 36C is a horizontally sectioned view;

FIG. 36D is an elevation of FIG. 36B;

FIG. 36E is a horizontally sectioned view; and

FIG. 36F is an elevation of FIG. 36F.

FIGS. 37A and 37B show the formation on the distal end side of the twenty-second embodiment of the present invention, where FIG. 37A is a vertically sectioned view and FIG. 37B is an elevation of FIG. 37A.

FIGS. 38A and 38B relate to a prior example, where FIG. 38A is a formation view showing the formation of an objective optical system in a stereoendoscope of the prior example and FIG. 38B is an explanatory view of a power arrangement for the objective optical system of FIG. 38A.

FIGS. 39 to 42 relate to the twenty-third embodiment of the present invention, where FIG. 39 is a general formation view of a stereoendoscope apparatus provided with the twenty-third embodiment;

FIG. 40 is a formation view of an image taking optical system including the objective optical system in the stereoendoscope of the twenty-third embodiment;

FIG. 41 is an explanatory view of a power arrangement of the objective optical system of FIG. 40; and

FIG. 42 is a sectioned view showing a frame structure at the distal end of the stereoendoscope in FIG. 39.

FIG. 43 is a formation view of the objective optical system and image transmitting optical system relating to the twenty-fourth embodiment of the present invention.

FIG. 44 is a formation view of the objective optical system in the twenty-fifth embodiment of the present invention.

FIG. 45 is a formation view of the image transmitting optical system including the objective optical system in FIG. 44.

FIGS. 46 to 48 relate to the twenty-sixth embodiment, where FIG. 46 is a general formation view of an endoscope apparatus;

FIG. 47A is a formation view of a plurality of visual field direction type endoscope;

FIG. 47B is a view showing the formation of a brightness diaphragm; and

FIG. 48 is a formation view of an objective optical system utilizing a pupil division.

FIGS. 49A to 54 relate to the twenty-seventh embodiment, where FIG. 49A is a formation view of a plural

visual field direction type endoscope including an objective optical system utilizing an eccentric optical system; FIG. **49B** is a formation view of an endoscope relating to a modification of the twenty-seventh embodiment;

FIG. **50** is a formation view of an objective optical system in which an eccentric optical system is utilized and an afocal part is partly in common;

FIG. **51** is a formation view of an objective optical system in which an eccentric optical system is utilized and a perspective is made by refraction;

FIG. **52** is a formation view of a design of an objective optical system in which an eccentric optical system is utilized;

FIG. **53** is a formation view of a design in which a relay lens system is combined with an objective optical system; and

FIG. **54** is an elevation of an objective optical system having three visual field directions.

FIGS. **55** to **58** relate to the twenty-eighth embodiment, where FIG. **55** is a formation view of a plural visual field direction type endoscope having a pupil switching apparatus;

FIGS. **56A** and **56B** are formation views of a plural visual field direction type endoscope in which the visual field direction can be switched by an image rotator;

FIG. **57** is a formation view of a plural visual field direction type endoscope in which the visual field direction can be switched by the movement of a solid state image taking device or the like;

FIG. **58A** is a formation view of a plural visual field direction type endoscope in which a pupil switching apparatus is provided near the pupil of an objective optical system; and

FIG. **58B** is a formation view of a plural visual field direction type endoscope different from that of FIG. **58A**.

FIG. **59A** is a formation view of a plural visual field direction type endoscope relating to the twenty-ninth embodiment. FIG. **59B** is a formation view of an endoscope in which the objective optical system is made partly common.

FIG. **60A** is a formation view of an optical system of a plural visual field direction type endoscope of the thirtieth embodiment.

FIG. **60B** is a formation view of an optical system of a plural visual field direction type endoscope of a modification of the thirtieth embodiment.

FIG. **61A** is a formation view of an optical system of a plural visual field direction type endoscope of the thirty-first embodiment.

FIG. **61B** is a formation view of an optical system of a plural visual field direction type endoscope of a modification of the thirty-first embodiment.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention shall be explained as follows with reference to the drawings.

The stereoendoscope in each of the first to the twenty-second embodiments is characterized by having an objective optical system which has a plurality of incident pupils formed in different positions and forms a plurality of images having passed through these incident pupils and having a parallax from each other and a common image transmitting optical system which transmits the plurality of images having a parallax from each other.

Each of the first embodiment to the modification of the ninth embodiment is of the formation (a). That is to say, images having a parallax from each other are formed in separated positions by a plurality of objective optical systems arranged at the distal end of an endoscope and the images separated from each other are transmitted by one common image transmitting optical system.

As shown in FIG. **5**, a stereoendoscope apparatus **1** comprises a stereoendoscope **2** of the first embodiment having an image taking optical system for stereo-inspection built-in, a light source apparatus **3** feeding an illuminating light to an illuminating light transmitting means provided in this stereoendoscope to transmit the illuminating light, a camera controlling unit (abbreviated as a CCU hereinafter) **4** processing signals for an image taking means built-in in this stereoendoscope **2**, a scan converter **5** converting the signal from this CCU **4** to a video signal, a color monitor **6** displaying the video signal put out of this scan converter **5** and shutter spectacles **27** having a shutter function for stereo-inspecting the image displayed in this color monitor **6**.

The stereoendoscope **2** has an elongate inserted section **11** to be inserted into a body cavity or the like and a gripped section formed to be large in the diameter at the proximal end of this inserted section so as to be gripped by the operator. This inserted section **11** is formed of a cylindrical rigid jacket tube made of metal such as stainless steel. That is to say, this stereoendoscope **2** is a rigid endoscope having the rigid inserted section **11**.

As is an ordinary endoscope, this stereoendoscope has an illuminating light transmitting means transmitting the illuminating light fed from the light source apparatus **3**, an illuminating optical system projecting this transmitted illuminating light out of an illuminating window and illuminating the object side and an observing optical system obtaining two images having a parallax so that the object illuminated by this illuminating optical system may be stereo-inspected.

By the way, in this specification, this observing optical system is mostly explained in an embodiment acting to form two images having a parallax on an image taking device provided with a photoelectrically converting function and is therefore also called an image taking optical system.

The gripped section **12** is provided with a light guide mouthpiece **13** and a light guide connector **15** at the other end of a light guide cable **14** removably connected at one end to this light guide mouthpiece **13** is removably connected to the light source apparatus **3**.

A lamp **16** generating a white illuminating light and a lens **17** condensing this white light are arranged within the light source apparatus **3**. The illuminating light condensed by this lens **17** is radiated on the end surface of the light guide connector **15**, the illuminating light radiated on this end surface is transmitted by the light guide within the light guide cable **14** and the transmitted illuminating light is fed to the light guide **18** side within the stereoendoscope **2** from the light guide mouthpiece **13**.

The light guide **18** used as an illuminating light transmitting means is bent within the gripped section **12** and is inserted through the inserted section **11**. This light guide **18** transmits the fed illuminating light and projects the illuminating light forward from the distal end surface fixed to the distal end **19** of the inserted section **11** and further through an illuminating lens **20** fitted to an illuminating window.

The respective optical images (represented by reference numerals *7a* and *7b* in FIG. **6**) of the object (represented by the arrow in FIG. **5**) **29** illuminated by this illuminating light

are formed in image forming positions by objective optical systems **21***a* and **21***b* fitted to two observing windows arranged adjacently to the illuminating window within the distal end **19**. The two objective optical systems **21***a* and **21***b* are of the same formation and are formed of optical lenses preferably of the same characteristics.

As shown in FIG. **5**, the two objective optical systems **21***a* and **21***b* have the respective optical axes Oa and Ob in parallel with the center axis of the inserted section, are arranged substantially superimposed in parallel on both sides of this center axis and are separated from each other by d in the distance (interval) between both optical axes Oa and Ob. Also, both optical axes Oa and Ob are arranged as separated in the diametral direction crossing the center axis and are therefore arranged symmetrically with the center axis. Two optical images large in the parallax can be formed by the objective optical systems **21***a* and **21***b* of the same formation with the optical axes arranged in parallel as separated by the distance d between them.

The images **7***a* and **7***b* are formed, as shown in FIG. **6**, in separate positions by the two objective optical systems **21***a* and **21***b* and are transmitted rearward by a common relay optical system **22**, that is, one image transmitting optical system or image transmitting means.

These images are both multiple-transmitted rearward by this relay optical system **22** and finally the same images **10***a* and **10***b* as the two images **7***a* and **7***b* by the two objective optical systems **21***a* and **21***b* are separately formed on a photoelectrically converting surface (image taking surface) of an image taking device **23** arranged within the gripped section **12**. For example, in FIG. **5**, if the separating direction in the two objective optical systems **21***a* and **21***b* is a horizontal direction, two images **10***a* and **10***b* will be separately formed in the horizontal direction on the image taking surface of the image taking device **23**.

As shown in FIG. **5**, the image taking device **23** has, for example, a square image taking surface and is arranged so that the vertical or horizontal direction of this image taking surface may coincide with the horizontal direction in which the two objective optical systems **21***a* and **21***b* are arranged as separated and the center of the image taking surface may be on the optical axis of the relay optical system.

By the way, the light guide **18** inserted through the inserted section **1** may be inserted through outside the relay optical system **22** (for example, like a ring). As shown in FIG. **5**, a part of the vertical direction intersecting at right angles with the horizontal direction of the relay optical system **22** may be contained in an incised groove **422***a* formed by incising in the axial direction a part of the vertical direction intersecting at right angles with the horizontal direction of the relay optical system **22**. (One incised groove **422***a* is shown in FIG. **5** but two incised grooves may be formed in the vertical direction.) When such an incised groove **422***a* is formed, the part which does not in principle substantially contribute to image transmission will be deleted, the image transmitting function will not be reduced, the illuminating light will be able to be transmitted and the inserted section **11** will be able to be made small in the diameter.

As the effective sectioned area of the relay optical system can be made large, the eccentricity (the distance d between the optical axes) of the two objective optical systems **21***a* and **21***b* arranged as opposed to each other eccentrically in the horizontal direction from the optical axis of this relay optical system **22** at the front end of this relay optical system **22**, that is, the parallax will be able to be made large and the stereo-inspecting function will be able to be improved. Further, there is a function of reducing the superimposing (cross talk) of two images.

The gripped section can be fittably separated into the output section **24** in which the image taking device **23** is built-in and the input section **25** on its forward side. The input section **25** has an image taking optical system (observing optical system) comprising the two objective optical series **21***a* and **21***b* and relay optical system **22**.

By making the output section **24** separable, there is made a flexible structure wherein the defective image taking device **23** can be easily repaired or can be replaced with one high in the sensitivity or the number of pixels to improve the performance and an ocular adapter can be connected to make stereo-inspection with the naked eyes. (The structure shown in the later described FIG. **19** may be adopted for the structure of the connecting part.)

The image taking device **23** is extended out of the rear end of the output section **24** and is connected with the CCU **4** through the signal cable **26** and the image taking signal photoelectrically converted by the image taking device **23** is processed. The image signal processed by this CCU **4** is further put into the scan converter **5**, is converted to a video signal and is then put out to the color monitor **6**. Two images corresponding to the optical images formed by the two objective optical systems **21***a* and **21***b* are alternately displayed in this color monitor **06**. By observing the images of the color monitor **6** with shutter spectacles **27**, the operator can stereo-inspect the images.

FIG. **6** shows the formations of the image taking optical systems, that is, the two objective optical systems **21***a* and **21***b* and relay optical system in the stereoendoscope **2** of the first embodiment.

The images **7***a* and **7***b* having a parallax from each other are formed by the plurality of (two in this embodiment) independent objective optical systems **21***a* and **21***b* arranged in the distal end section **19**. These images **7***a* and **7***b* separated from each other are transmitted by the relay optical system **22** as one image transmitting optical system.

As shown in FIG. **6**, the objective optical systems **21***a* and **21***b*, for example, the three relay lens systems **22***a*, **22***b* and **22***c* forming the relay optical system **22** and the image taking device **23** having a function of photoelectrically converting optical images are arranged in the order mentioned from the object side. The two images **7***a* and **7***b* having a parallax are formed in the spatially separated positions (in this case, in the positions separated from each other in the horizontal direction) by the objective optical systems **21***a* and **21***b* of the same formation arranged in parallel as separated from each other by d (for example, d=4 mm) of the distance between their optical axes.

The images **7***a* and **7***b* are both multiple-relayed by the relay lens systems **22***a*, **22***b* and **22***c* of the same formation arranged in series so that the optical axes may coincide with each other. That is to say, the images **7***a* and **7***b* formed on both left and right sides of the optical axis O of the relay optical system **22** (by the objective optical systems **21***a* and **21***b* arranged eccentrically on the left and right from this optical axis O) respectively form images **8***a* and **8***b* respectively on both right and left sides of this optical axis O in the rear side positions of the optical axis O by the relay lens system **22***a*. These images **8***a* and **8***b* respectively form images **9***a* and **9***b* on both left and right sides of this optical axis O in the rear side positions of the optical axis O by the relay lens system **22***b*. These images **9***a* and **9***b* respectively form images **10***a* and **10***b* on both right and left sides of this

optical axis O in the rear side positions of the optical axis O by the relay lens system **22***c*.

In this position, the image taking surface of the image taking device **23** is arranged and the images **10***a* and **10***b* are photoelectrically converted and put out. A masking means is provided so that the two images **10***a* and **10***b* on this image taking surface may not be superimposed. (As shown in the later described FIG. **8**, for example, a visual field diaphragm **30** may be provided on the image forming surfaces of the objective optical systems **21***a* and **21***b* to limit the visual field. The invention is not limited to this. The visual field diaphragm may be provided, for example, in the image forming position in the relay optical system **22**.)

The optical axes O of the relay lens systems **22***a*, **22***b* and **22***c* are respectively eccentric by the same amount on the right and left from the optical axes Oa and Ob of the objective optical systems **21***a* and **21***b*. The eccentricity can be selected in conformity with the desired parallax magnitude, that is, stereo-feel size and is d/2 (for example, d/2=2 mm) in this embodiment.

The number of relaying times is three times in this embodiment but can be set from one time to ten times and several other times depending on such specification as the brightness of the optical system.

By the way, in FIG. **6**, the reference numerals **28***a* and **28***b* respectively represent the positions of the incident pupils of the left and right objective optical systems **21***a* and **21***b* and the left and right images **7***a* and **7***b* are formed of the lights incident through the respective incident pupils **28***a* and **28***b*. The respective incident pupils **28***a* and **28***b* are transmitted by the relay lens systems **22***a*, **22***b* and **22***c* forming the relay optical system **22**.

During the transmission by the relay lens systems **22***a*, **22***b* and **22***c*, the two pupils may be horizontally displaced but the relay lens systems **22***a*, **22***b* and **22***c* had better be superimposed in order to be made small. Therefor, it is preferable that the two objective optical systems **21***a* and **21***b* are respectively formed to be telecentric optical systems, that is, the projecting pupils are formed to be infinitely far.

By the way, the magnitude of the parallax, that is, the center distance between the left and right incident pupils **28***a* and **28***b* is determined by the distance d between the optical axes Oa and Ob of the objective optical systems **21***a* and **21***b* and is independent of the brightness of the optical system.

According to this embodiment, as the relay optical system **22** is made common, the trouble of adjusting the lenses can be more extremely omitted than in the case that it is not made common (in the first related art) and a favorable stereo-observation can be made.

Also, as can be judged from FIG. **5**, as an image having a parallax can be obtained by arranging the two objective optical systems **21***a* and **21***b* as separated from each other, the parallax can be made larger than in the case of using a common objective optical system (in the second related art) and therefore the function of obtaining a stereo-feel can be made large. (The same stereo-feel as in the case that two optical systems are arranged as in the first related art can be obtained.)

Therefore, according to this embodiment, the common optical components can be made few, the adjusted parts can be made few, the cost can be made low and the image having the same stereo-feel as in the case that two optical systems are arranged in the related art can be obtained.

As the two images **7***a* and **7***b* having a parallax are transmitted by the relay lens systems **22***a*, **22***b* and **22***c* used in common with the axially symmetrical one, during the transmission, the qualities (the magnification, MTF, image position, chromatic aberration, coloring and the like) of the two images will lag little during the transmission.

That is to say, even if the individual characteristics of the relay lens system **22***a* and the others are dispersed by the production error, in this embodiment, as the left and right images are transmitted by the common relay lens system **22***a* and the others, the influence of the individual dispersion will not be substantially received. Therefore, the left and right images obtained by this embodiment will be images of a good quality having little lag.

In case an operation is made under the observation with this stereoendoscope, a good picture quality and a sufficient stereo-feel will be obtained, a picture image of an observation close to directly observing the affected part will be able to be realized and therefore an environment in which the operation is easy to make will be able to be provided.

Also, in this embodiment, as the left and right images **7***a* and **7***b* are formed in the positions spatially separated by the objective optical systems **21***a* and **21***b* and are formed in the positions spatially separated by the common relay optical system **22**, therefore a stereo-inspection will be able to be made with the image taking device or the like without using an image separating means newly spatially separating the images.

Also, in this embodiment, the final images **10***a* and **10***b* by the relay lens system **22***c* are taken by one image taking device **23**. Therefore, the output section **24** is very simplified in the structure and a light weight stereoendoscope can be realized.

By the way, the image taking device **23** may be any of various solid state image taking devices (known generally by the names of CCD, PCD, CMD, AMI and SIT) and image taking tubes (known generally by the names of Sachicon, Busicon and HARP TUBE).

Also, the sensitivity may be improved by utilizing an image intensifier or the like.

The image taking device **23** may be a device for taking color images with a single plate or may take colored images with a formation as a 2-plate or 3-plate camera. Also, as shown in FIG. **6**, the final images **10***a* and **10***b* by the relay lens system **22***c* are taken by the common image taking device **23** to reduce cost and weight.

In order that a stereo-feel optimum to the desire or operation type of the operator may be obtained, the distance between the respective optical axes of the two objective optical systems **21***a* and **21***b* may be made variable so that the magnitude of the parallax may be variable.

In this case, in order that the distal end section **19** may be made small, the two objective optical systems **21***a* and **21***b* may be made movable to the side opposite to one another in the horizontal direction vertical to the optical axis O of the relay lens systems **22***a*, **22***b* and **22***c*. However, in this case, when the objective optical systems **21***a* and **21***b* move, the final images **10***a* and **10***b* will be also moved by the relay lens system **22***c* and therefore, in case the image taking device **23** is fixed, the movement will be limited to be within the image taking range.

By the way, it has been explained that the image taking surface of the image taking device **23** is square. However, a rectangular surface having a long horizontal direction in which the objective optical systems **21***a* and **21***b* are arranged as separated may be used. In this case, the image taking range in which the image having a parallax is obtained will be able to be substantially expanded.

By the way, FIG. **5** shows a simultaneous illuminating and image taking system wherein a color image is taken by using the image taking device **23** in which such color separating filter as a mosaic filter is arranged under a white color light illumination. However, the invention is not limited to this. A surface sequential image taking system wherein a color image is taken by obtaining such color component image as of three primary colors by taking an image with an image taking device having no color separating filter under a surface sequential illumination in which illuminating lights of such wavelength ranges as of red, green and blue are sequentially emitted on the object side will also do.

By the way, in the first embodiment, instead of connecting the output section to the input section **25**, an ocular adapter **45'** shown in the later described FIG. **16**D is fitted so that the stereo-inspection may be made with the naked eyes. In this case, it is preferable to set the number of relaying times by the relay optical system **22** at an even number of times so that the left and right images **7***a* and **7***b* by the objective optical systems **21***a* and **21***b* may be respectively observed with the left and right ocular lenses. (In FIG. **16**D, the number of relaying times is four times.)

By the way, the lens data of the first embodiment are as in Table 1 shown later in the specification. FIG. **2** and others are collectively shown after FIG. **1**. In Tables 1 to 14, r1, r2, . . . , represent radii of curvatures of respective surfaces, d1, d2, . . . , represent surface distances, n1, n2, . . . , represent refractive indices of respective lenses and ν1, ν2, . . . , represent Abbe numbers of respective lenses.

In the following, the second to ninth embodiments are modifications of the first embodiment and, the same as in the first embodiment, the image having a parallax is formed in a position spatially separated by the objective optical systems **21***a* and **21***b*.

FIG. **7** shows a structure near the final images **10***a* and **10***b* of the relay lens system **22***c* of the image taking optical system in the stereoendoscope of the second embodiment of the present invention. The final images **10***a* and **10***b* are respectively taken by the two image taking devices **23***a* and **23***b*. Signal lines (not illustrated) are connected respectively to the two image taking devices **23***a* and **23***b* and are connected to a CCU partly different in the internal formation from the CCU **4** in FIG. **5**. The others are of the same formation as of the stereoendoscope **2** of the first embodiment.

By the way, in the CCU processing signals for the two image taking devices **23***a* and **23***b*, the same driving signal may be simultaneously applied, for example, to the two image taking devices **23***a* and **23***b*, may be simultaneously read out and may be memorized respectively in two frame memories. The same driving signal may be applied alternately respectively to the two image taking devices **23***a* and **23***b* and may be read out alternately and the image signal read out may be memorized alternately in the two frame memories.

The image signal simultaneously or alternately memorized in the two frame memories are alternately read out by the scan converter and are alternately displayed in the color monitor. The operator wears shutter spectacles **27** and can observe and stereo-inspect the image displayed in the color monitor **6**.

The stereoendoscope apparatus provided with this second embodiment can be realized in substantially the same formation as of the stereoendoscope apparatus **1** in FIG. **5**.

This second embodiment has an advantage that the image taking devices **23***a* and **23***b* can be focused respectively independently. If they are precisely adjusted, an image higher in the quality than in the case of a common image taking device **23** will be able to be made.

Also, the parallax can be made variable the same as in the first embodiment. However, this embodiment has an advantage that, when the left and right image taking devices **23***a* and **23***b* are moved as operatively connected with the movement of the objective optical systems **21***a* and **21***b*, the movement will not be restricted to be within the image taking range in the case of the common image taking device **23**.

That is to say, in the first embodiment, as the image taking device **23** is common, the moving range of the left and right images **10***a* and **10***b* is restricted to be within the image taking range. However, according to the present embodiment, in case the final images **10***a* and **10***b* are fixed, when the movement deviates (separates) from the imaging range, the two image taking devices **23***a* and **23***b* will be moved horizontally as operatively connected with the movement of the objective optical systems **21***a* and **21***b* and the final images **10***a* and **10***b* will be able to be maintained within the image taking range of the respective image taking devices **23***a* and **23***b*.

Therefore, there is a merit that a stereo-endoscope in which an image having a stereo-feel is obtained can be realized. The others have the same effects as in the first embodiment. By the way, the lens data of the second embodiment are the same as of the first embodiment.

FIGS. **8** and **9** relate to the third embodiment of the present invention. FIG. **8** shows an image taking optical system in the third embodiment. FIG. **9** shows as magnified the arrangement of the image taking devices **23***a* and **23***b*. In this embodiment, the two image taking devices **23***a* and **23***b* are used as in the second embodiment and the light receiving surfaces of the image taking devices **23***a* and **23***b* arranged not vertically to the optical axis O of the relay optical system **22** but as inclined from the vertical direction. In other words, in the central part of the light receiving surface of each of the image taking devices **23***a* and **23***b*, the optical axis vertical to this light receiving surface is arranged not to be parallel with the optical axis O of the relay optical system **22** but to make an angle greater than 0.

That is to say, when the light receiving surface of each of the two image taking devices **23***a* and **23***b* is inclined in conformity with the image surface curvature aberration **10***c* generated by the relay lens systems **22***a*, **22***b* and **22***c* and shown in FIG. **9**, the deterioration of the image by the curvature aberration will be reduced.

As the petzval of the relay lens systems **22***a*, **22***b* and **22***c* is positive, even if the image surface by the objective optical systems **21***a* and **21***b* is flat, in the case of the transmission by the relay lens systems **22***a*, **22***b* and **22***c*, the image surface will bend on the curved surface with the concave surface directed to the objective side.

Therefore, with the image taking surface or light receiving surface left to be arranged vertically to the optical axis of the relay lens systems **22***a*, **22***b* and **22***c*, a partial fog will likely be produced and it will be difficult to keep the entire image taking surface focused.

Therefore, in the third embodiment, as shown in FIG. **9**, the light receiving surface is inclined in conformity with the contact surface of the curved image surface. In FIG. **9**, the light receiving surface is inclined by 25.332 degrees to the surface vertical to the optical axis of the relay lens system **22***c*.

According to this third embodiment, not only the effects of the second embodiment are retained but also a picture

image having little curvature aberration is obtained. By the way, the lens data of the third embodiment are as in Table 2.

By the way, because the petzval sum of the relay lens systems **22***a*, **22***b* and **22***c* is a positive value, the petzval sum of the objective optical systems **21***a* and **21***b* may be made a negative value to control the image surface curvature aberration of the final images **10***a* and **10***b* having passed through the relay lens system **22***c*.

FIGS. **10**A and **10**B are of modifications showing this manner.

As shown in FIG. **10**A, the petzval sum of the objective optical systems **21***a* and **21***b* is made a negative value to form images **7***a* and **7***b* becoming concave on the rear side (the local radius of curvature of each image surface shall be represented by R). In case the image on the flat image surface is transmitted by the relay lens systems **22***a*, **22***b* and **22***c*, the local radius of curvature of the image surface of the final images **23***a* and **23***b* is represented by R' and, as shown in FIG. **10**, the light receiving surfaces of the image taking devices **23***a* and **23***b* are arranged on the contact surface of the curved surface of a local curvature 1/R"=1/R −1/R", the influence of the image surface curvature aberration will be further controlled by this embodiment than by the third embodiment.

By the way, in this case, 1/R −1/R"=0 or the absolute value of 1/R −1/R" may be made small.

FIG. **11** shows an image taking optical system in the fourth embodiment. The final images **10***a* and **10***b* of the relay lens system are relayed once more by adapter lens systems **32***a* and **32***b* forming an adapter optical system to connect images **36***a* and **36***b* and these images **36***a* and **36***b* are taken respectively by image taking devices **33***a* and **33***b*.

The adapter lens systems **32***a* and **32***b* are formed respectively of mirror parts **34***a* and **34***b* and lens parts **35***a* and **35***b*, a beam is parallel moved outside by the mirror parts **34***a* and **34***b* (in this embodiment, the displacement L is 6 mm) and the lens parts **35***a* and **35***b* act to re-form the final images **10***a* and **10***b* of the relay lens system at any magnification.

The optical axis of each of the lens parts **35***a* and **35***b* is eccentric by d/2 (2 mm) from the optical axis of the relay lens system **22***c* except the parallel moved part by the mirror parts **34***a* and **34***b*.

In this embodiment, when the parallel moving distance in the mirror sections **34***a* and **34***b* and the magnification in the lens sections **35***a* and **35***b* are properly set, images **36***a* and **36***b* optimum to any size image taking devices **33***a* and **33***b* will be able to be obtained.

Also, as the image taking devices **33***a* and **33***b* larger in the size than in the first and second embodiments can be used, those larger in the number of pixels in response to the size can be used and a favorable stereo-observed image high in the resolving degree can be obtained. The others have the same effects as in the second embodiment. The lens data of this embodiment are as in Table 3.

FIG. **12** shows an image taking optical system in the fifth embodiment. This embodiment is an improvement of the fourth embodiment.

The images **36***a* and **36***b* are respectively formed by further relaying once the final images boa and **10***b* of the relay lens system with the common adapter optical system **32** formed of one lens system and are taken by the image taking devices **33***a* and **33***b*. The adapter optical system **32** is formed of a lens system arranged so as to be of the same optical axis as of the relay lens systems **22***a*, **22***b* and **22***c*, the final images **10***a* and **10***b* of the relay lens system are formed again at any magnification and the image taking devices **33***a* and **33***b* are arranged in the image forming positions.

In this embodiment, the formation can be made simpler by the part having no mirror section within the adapter optical system **32** and has the operations and effects of the fourth embodiment. That is to say, when the magnification of the adapter optical system **32** is optionally set, the images **36***a* and **36***b* optimum to the image taking devices **33***a* and **33***b* of any size will be able to be obtained.

Also, in this embodiment, the same as in the third embodiment, the light receiving surface of each of the image taking devices **33***a* and **33***b* is inclined in conformity with the image surface curvature aberration generated by the relay lens systems **22***a*, **22***b* and **22***c* and adapter optical system **32** to control the deterioration of the image. In FIG. **12**, the light receiving surface is inclined by 11.902 degrees to the surface vertical to the optical axis of the relay lens system **22***c*. The lens data of this embodiment are shown in Table 4.

FIG. **13** shows an image taking optical system in the sixth embodiment.

The final images **10***a* and **10***b* of the relay lens system are further once relayed by the adapter lens systems **32***a* and **32***b* forming the adapter optical system **32** and are taken by the image taking devices **33***a* and **33***b*. The adapter optical system **32** is formed of the two inclined adapter lens systems **32***a* and **32***b* of the same formation. One lens system **32***b* and the image taking device **33***b* are parallel eccentric by d/2 (=2 mm) from the optical axis of the relay lens system **22***c* and are then inclined by 10.076 degrees with the point at which the optical axis of the lens system **32***b* intersects with the final image **10***b* of the relay lens system **22***c* as a center. The lens system **32***a* illustrated by the two-point chain lines is also inclined the same on the opposite side of the optical axis of the relay lens system **22***c*.

In this embodiment, too, the same as in the fifth embodiment, no mirror section is present and, by freely setting the magnification of the adapter optical system, the images **36***a* and **36***b* optimum to the image taking device of any size can be obtained. That is to say, this embodiment has substantially the same effects as in the fifth embodiment. The lens data of this embodiment are as in Table 5.

FIG. **14** shows a main part of an image taking optical system in the seventh embodiment of the present invention.

The final images **10***a* and **10***b* of the relay lens system are further once relayed by the adapter optical system **32** and are formed in the same positions and the common image taking device **33** is arranged in the image forming position in the formation.

In the adapter optical system **32**, the final images **10***a* and **10***b* of the relay lens system are led to the shutter means **37***e* side through an optical axis distance extending means comprising respectively lenses **37***a* and **37***b* and prisms **37***c* and **37***d* and are led to the opposed lens **37***f* and **37***g* side so that, when one is shielding light, the other will be passing light. A beam having passed through the lens **37***f* arranged as opposed to one side of the shutter means **37***e* passes through the prism **37***h*, half prism **37***i* and lens **37***j* and forms an image **36***a* in the position in which the image taking device **33** is arranged.

Also, a beam having passed through the lens **37***g* arranged as opposed to the other side of the shutter means **27***e* passes through the optical device **37***k*, half prism **37***i* and lens **37***j* and forms an image **36***b* in the position in which the image taking device **33** is arranged.

In this embodiment, the relayed images **36***a* and **36***b* are formed in the same position and are taken by one image taking device **33**. The shutter means **37***e* is arranged on the way of the adapter optical system **32** and alternately shields the beam so that two images may not be simultaneously formed by the image taking device **33**.

This embodiment has an advantage that one image taking device **33** will do and the cost can be reduced. The others have the same effects as of the fourth embodiment.

FIGS. **15**A and **15**B show a formation of an objective optical system in the eighth embodiment of the present invention.

In this embodiment, an objective optical system is formed of perspective objective optical systems **39***a* and **39***b* having a perspective front as a visual field.

In this embodiment, a beam incident from the diagonal front side is reflected by using reflecting prisms **40***a* and **40***b* as visual field direction changing means and is changed to be in a direction parallel to the optical axis O of the relay optical system **22** (FIGS. **15**A and **15**B show only a part of the relay lens system **22***a*). In this embodiment, the visual field direction is 45 degrees with the lengthwise direction (the optical axis direction of the relay optical system **22**) of the inserted section. The reflecting prisms **40***a* and **40***b* may be two separate bodies or one integral body.

The rear side formation of the relay optical system **22** may be the formation of any of the first to sixth embodiments. This embodiment has the same effects as in the first to seventh embodiments except that the visual field direction is different.

Other than the eighth embodiment, the visual field direction can be varied by varying the angles of the reflecting prisms **40***a* and **40***b*. Also, if the objective optical system parts are replaceably formed, various visual field directions, visual field angles and parallaxes will be able to be obtained by replacing only the objective optical system.

FIGS. **16**A to **16**D show the ninth embodiment of the present invention and a unit formation in its first modification.

The stereoendoscope **41** of the ninth embodiment shown in FIG. **16**A comprises an objective optical system unit **42**, relay optical system unit **43**, adapter optical system unit **44** and image taking device unit **45**.

The objective optical system unit **42** has objective optical systems **21***a* and **21***b* of uniform optical characteristics built-in. The relay optical system unit **43** has relay lens systems **22***a*, **22***b*, **22***c* and **22***d* of the same formation built-in. The adapter optical system unit **45** has a common adapter optical system **32** built-in. The image taking device unit **45** has image taking devices **33***a* and **33***b* of uniform characteristics built-in.

FIG. **16**A as seen from the side is as in FIG. **16**B. The objective optical system unit **42** has a distal end side section of a light guide **18** and an illuminating lens **20** built-in. The relay optical system unit **43** has an intermediate section of the light guide **18** built-in. The adapter optical system unit **44** has a rear end side section of the light guide **18** built-in. A light guide mouthpiece **13** is provided.

Also, in this embodiment, the relay lens systems **22***a*, **22***b*, **22***c* and **22***d* within the relay optical unit **43**, for example, (for example, are cut off in the lengthwise direction on the lower side to be in the direction vertical to the horizontal direction in which the objective optical systems **21***a* and **21***b* are arranged to secure a space to contain the light guide **18** and) make the inserted section small in diameter. Also, the adapter optical system **32** within the adapter optical system unit **44** is cut off on the light guide mouthpiece **13** side.

In this embodiment, the objective optical system unit **42** is connected to the distal end of the relay optical system unit **43**, the distal end of the adapter optical system unit **44** is connected to the proximal end of the relay optical system unit **43** and the image taking device unit **45** is connected to the proximal end of this adapter optical system unit **44** to form a stereoendoscope **41**.

Therefore, by combining the respective units different in the optical characteristics and image taking characteristics, stereoendoscopes of different characteristics can be simply realized. Therefore, the stereoendoscopes **41** of different characteristics can be provided.

In this embodiment, the connecting part of the proximal end of the relay optical system unit **43** and the distal end of the adapter optical system unit **44** corresponds to the border of the input section **25** and output section **24** shown in FIG. **5**.

By the way, in FIGS. **16**A and **16**B, the part after the adapter optical system unit **44** is made large in diameter. However, as shown in FIG. **16**C, the proximal end side of the relay optical system unit **43** may be made large in the diameter on the proximal end side, the proximal end side part of the light guide **18** may be built-in near this proximal end and the light guide mouth piece **13** may be provided there in the structure.

In this first modification, the light guide **18** need not be built-in in the adapter optical unit **44** and therefore the structure will be simple.

In this modification, the image taking device unit **45** may be fitted directly to the relay optical system unit **43** without using the adapter optical system unit **44** in the structure. In such a case, the formation of the second embodiment will be made. Further, in case one common image taking device is built-in as the image taking device unit **45**, the formation of the first embodiment will be made.

This first modification is higher in the freedom of combination than the ninth embodiment and can simply realize stereoendoscopes **41** different in the characteristics. Also, as shown in FIG. **16**D, when an ocular adapter **45'** is connected to the proximal end of the relay optical system unit **43**, a stereoendoscope by which stereo-inspection can be made with the naked eyes will be able to be formed.

The ocular adapter **45'** shown in FIG. **16**D has a structure whereby the final images by the relay optical system unit **43** can be magnified and observed respectively through prisms and ocular lenses **45"***a* and **45"***b* fitted to an ocular window corresponding to the distance between both eyes of the operator so that the left and right images by the objective optical systems **21***a* and **21***b* may be respectively stereo-inspected through the left and right ocular lenses **45"***a* and **45"***b*.

By the way, in this case, because the final images are inverted images, the ocular adapter **45'** is provided with lenses **45'***a* and **45'***b* as means for making them upright to form upright images in front of the ocular lenses **45"***a* and **45"***b*. Instead of providing the lenses **45'***a* and **45'***b*, the two prisms for extending the distance between the optical axes may consist of prisms for inverting images such as Porro prisms.

The ocular adapter for observation with the naked eye may be connectable to the relay optical system unit **43** in FIG. **16**A in the structure or may be connectable to the second to fourth modifications of the ninth embodiment shown in FIGS. **17**A to **17**C explained in the following.

In the second modification shown in FIG. 17A, in FIG. 16A, the adapter optical system **32** and the image taking devices **33***a* and **33***b* are formed of an adapter optical system image taking unit **46** as one unit.

In the third modification shown in FIG. 17B, in FIG. 17A, further, the objective optical systems **21***a* and **21***b* and the relay optical system **22** are formed of an objective optical system relay optical system unit **47** as one unit. In the fourth modification shown in FIG. 17C, in FIG. 16A, the relay optical systems **22** and the adapter optical system **32** are formed of a relay optical system adapter optical system unit **48** as one unit.

FIGS. **18**A to **18**E show more actual formations of various units used in the ninth embodiment and its modifications.

FIG. **18**A shows an objective optical system unit **42** of a visual field angle of 70 degrees. FIG. **18**B shows an objective optical system unit **42** of a visual field angle of 40 degrees. When they are replaced and are connected to a relay optical system unit **43**, any desired visual field angle will be obtained.

A male screw is formed at the proximal end of the jacket tube of the objective optical system unit **42** and can be removably connected by being screwed to a female screw at the distal end of the jacket tube of the relay optical system unit **43**. A projection is provided at the proximal end of the jacket tube of the objective optical system unit **43** and can be contacted with a level difference surface made by cutting off the inner peripheral surface on the distal end side of the jacket tube of the relay optical system unit **43** to determine the position in the lengthwise direction. By the way, both jacket tubes have the same outside diameter so that, in case they are connected with each other, no level difference will be made on the inserted section.

Also, a positioning mark and screw hole are provided as peripheral positioning means near the proximal end of the jacket tube of the objective optical system unit **42**. When this mark is made to meet a positioning mark at the distal end of the jacket tube of the relay optical system unit **43**, both screw holes will be able to be set to communicate with each other and will be able to be fixed with a screw (not illustrated).

By the way, the same connecting means or connecting mechanism as on the proximal end side of the jacket tube of the objective optical system unit **42** is provided on the proximal end side of the jacket tube of the relay optical system unit **43** and can be removably connected to the distal end of the jacket tube of the adapter optical system unit **44**.

FIG. **18**C shows an objective optical system unit **42** perspective in the visual field direction of 45 degrees. In FIG. **18**C, by replacing the reflecting prism **40**, the objective optical system unit **42** perspective in any visual field direction can be formed. By the way, FIG. **18**D shows FIG. **18**C as seen from the rear end side and a pair of objective optical systems **39***a* and **39***b* arranged on the left and right.

FIG. **18**E shows an objective optical system **42** in which the parallax is reduced and the optical axes of two objective optical systems **21***a* and **21***b* are near each other and the distance d' between the optical axes is d'<d. In this formation, the stereo-feeling will be reduced but, as the objective optical systems are arranged on the center axis side, a space for inserting them through other internal organs or the like will be able to be secured, therefore, for example, the cross-sectioned area of the light guide will be able to be made large, the illuminating light amount will be able to be increased and a bright image will be obtained.

By the way, when the image taking device unit or the adapter optical system unit is replaced, as required, in response to the optical axis distance and visual field angle of the objective optical systems **21***a* and **21***b*, an optimum stereoendoscope conforming to the equivalent will be able to be provided.

FIG. **19**A shows a formation of a relay optical system unit **43**. The proximal end of this relay optical system **43** can be removably connected to the distal end of the adapter optical system unit **44**. Also, the proximal end of this adapter optical system unit **44** can be removably connected to the image taking unit **45**.

As shown, for example, in FIG. **19**B, the relay optical system unit may be the relay optical system unit **43** in which the number of relaying times is doubled. Further, a relay optical system unit in which the number of relaying times is different depending on the length inserted into the body cavity or the like can be also used.

FIG. **19**C shows a formation of an objective optical system relay optical system unit **47** for integrating an objective optical system and a relay optical system. FIG. **19**D is a modification of FIG. **19**C and shows a unit in which the number of relaying times of the relay optical system is doubled. Various numbers of relaying times of the relay optical system can be prepared. A different length of the inserted section can be selected as required.

In the following, the tenth to eighteenth embodiments are embodiments of the formation (b) in the above mentioned paragraph of the summary. Images having a parallax with each other are taken into the plurality of front group optical systems of the objective optical systems arranged in the distal end section of the endoscope and a plurality of images in one rear group optical system are formed in substantially coinciding positions. These substantially superimposed images are transmitted by a common rear group optical system and a common image transmitting system coinciding with this rear group optical system in the optical axis. FIG. **20** shows an image taking optical system in the tenth embodiment.

An objective optical system **51** in which the object side opening part is separated into two parts, relay lens systems **52***a*, **52***b* and **52***c*, an adapter optical system **50** and image taking devices **53***a* and **53***b* are arranged in the order mentioned from the object side. The objective optical system **51** is formed of front group optical systems (abbreviated merely as front groups) **54***a* and **54***b* of the same formation which are arranged parallel as separated by the distance d (=4 mm) between the optical axes of each other and a rear group optical system (abbreviated merely as a rear group) **55** arranged to be of one same optical axis. Two images **56***a* and **56***b* having a parallax are formed in spatially substantially coinciding positions.

The images **56***a* and **56***b* form a relay optical system and are equally multiple-relayed by (for example, three) relay lens systems **52***a*, **52***b* and **52***c* of the same formation arranged in series so as to have the same optical axis.

That is to say, by the relay lens system **52***a*, the images **56***a* and **56***b* form images **57***a* and **57***b* with equal sizes in substantially the same positions in the rear of this relay lens system **52***a*. By the relay lens system **52***b*, these images **57***a* and **57***b* form images **58***a* and **58***b* with equal sizes in substantially the same positions in the rear of this relay lens system **52***b*. By the relay lens system **52***c*, these images **58***a* and **58***b* form images **59***a* and **59***b* with equal sizes in substantially the same positions in the rear of this relay lens system **52***c*.

The rear group **55** of the objective optical system **51** and the optical axis of the relay lens systems **52***a*, **52***b* and **52***c*

are on the same axis. This optical axis and the optical axis of the front groups **54***a* and **54***b* are respectively eccentric on the left and right.

The eccentricity can be selected in conformity with a desired size, that is, the size of the stereo-feel and is respectively d/2 (=2 mm) in this embodiment. An afocal beam may not be between the front groups **54***a* and **54***b* and the rear group **55**. However, this part may be of an afocal beam. An image formed by the objective optical system should be substantially superimposed.

For the picture angle of the ordinary relay system, the picture angle required by the endoscope is large. Because, as described above, the front groups **54***a* and **54***b* must be nearly afocal and because there must be few parts not in common, the front groups **54***a* and **54***b* must be formed of a concave group and a convex group from the object side.

When the plurality of images having a parallax and which are transmitted by the relay optical system are substantially superimposed, the relay optical system will be able to be made small in the diameter. Therefore, the projected pupil of the objective optical system **51** may be made substantially infinite. Therefore, the front side focal position of the rear group **55** of the objective optical system **51** will be the pupil position. So that the beam entering the front groups **54***a* and **54***b* from the object may be well transmitted to the rear group **55**, it is preferable to the projected pupil of the front groups **54***a* and **54***b* coincide. It is preferable that the final surfaces of the front groups **54***a* and **54***b* are arranged on the image side rather than in the front side focal position of the rear group **55**.

In this embodiment, there are three relaying times which can be selected and set to be usually one time to ten or more times depending on such specifications as the length and diameter of the inserted section of the endoscope and the brightness of the optical system.

The magnitude of the parallax, that is, the center distance between the right and left incident pupils, is determined by the optical axis distance d between the front groups **54***a* and **54***b* of the objective optical system **51** and is independent of the brightness of the optical system.

According to this embodiment, the same as in the first embodiment, the two images **56***a* and **56***b* having a parallax are transmitted by one axially symmetrical relay optical system and therefore little error will be generated in the various optical qualities (the magnification, MTF, image position, chromatic aberration, coloring and the like) of the two images being transmitted.

There are fewer non-common parts on the right and left of the objective optical system **51** than in the first embodiment. Therefore, the adjustment of lenses proves not to be troublesome and a favorable stereo-observed image can be obtained.

Further, in this embodiment, as spatially substantially superimposed images are transmitted by the relay optical system, when each of the front groups **54***a* and **54***b* is formed of an elliptic lens system in which, for example, the horizontal direction is a short axis and the vertical direction is a long axis and the pupil is also made elliptic, the objective optical system and relay optical system will be able to be made small in diameter without deteriorating the parallax, brightness and the like. In this case, the inserted section will be able to be made small in diameter from the distal end to the proximal end side and the applied range in which the endoscope can be inserted and used will be able to be expanded. Because the hole through which the inserted section is inserted into the abdominal part can be made small, the patient will experience a reduction in pain. By the way, even in the other embodiments, the objective optical system may be formed of an elliptic lens system.

In this embodiment, the final images **59***a* and **59***b* of the relay lens system **52***c* are in substantially the same position and therefore must be separated from each other by any means which is a pupil dividing image forming means.

Therefor a means for forming an image of a pupil transmitted by the relay optical system and a means for forming an image of a partial beam of this pupil and forming an image by spatially separating plural images having a parallax are required. The adapter optical system **50** formed of the pupil image forming lens system **61**, mirror parts **62***a* and **62***b* and image forming lens systems **63***a* and **63***b* arranged to be on the same optical axis as of the relay lens system **52***c* perform these functions.

The pupil image forming lens system **61** forms in spatially separated positions images of two pupils of the objective optical system **51** transmitted by the relay lens systems **52***a*, **52***b* and **52***c*. In the mirror parts **62***a* and **62***b*, the beams of the two pupils are moved outside (in this embodiment, the movement is 6 mm) in parallel and the image forming lens systems **63***a* and **63***b* form images **64***a* and **64***b* respectively in the image taking devices **53***a* and **53***b*.

The optical axes of the image forming lens systems **63***a* and **63***b* are eccentric by d/2 (=2 mm) from the optical axis of the relay lens system **52***c*, except for the part moved in parallel by the mirror parts **62***a* and **62***b*. By the way, the mirror parts **62***a* and **62***b* and image forming lens systems **63***a* and **63***b* are illustrated respectively only on one side.

Lest the right and left pupils should be finally superimposed, a brightness diaphragm **79** may be provided on the pupil surface (in this embodiment, on the projecting pupil surface of the pupil image forming lens) in any of the pupil position and its conjugate position to limit the beam.

In this embodiment, when the parallel moving distance in the mirror parts **62***a* and **62***b* and the magnification of the adapter optical system **50** are properly set, the images **64***a* and **64***b* optimum to the image taking devices **53***a* and **53***b* of any size will be able to be obtained.

As in FIG. **20**, the parallel moving direction of the mirror parts **62***a* and **62***b* may be any direction within or vertical to a plan containing the paper surface. When the focal distances of the image forming lens systems **63***a* and **63***b* are varied, the magnification will be able to be also varied.

In order to obtain the stereo-feel optimum to the operator's desire or a system, the optical axis distances between each other of the two front groups **54***a* and **54***b* may be made variable so that the magnitude of the parallax may be variable. In this case, in order to make the distal end section small, the two front groups **54***a* and **54***b* may be made movable in the directions reverse to each other vertically to the optical axis of the relay optical system.

However, in this case, because the projected pupil of the objective optical system is moved by the movement of the front groups **54***a* and **54***b*, it will be necessary to make the effective diameter of each lens rather large so that the beam may not be intercepted by the optical systems following the relay lens systems **52***a*, **52***b* and **52***c*.

The other operations and effects are the same as in the first embodiment. The lens data of this embodiment are shown in Table 6.

The following eleventh to seventeenth embodiments are made by modifying the formations of the tenth embodiment. The images having a parallax between each other are formed

in spatially substantially coinciding positions. All these objective optical systems **51** can be formed to be interchangeable with the objective lenses of the pupil dividing type stereoendoscope of the related art.

FIG. **21** shows an image taking optical system in the eleventh embodiment of the present invention. Images **64***a* and **64***b* are formed by further once relaying the final images **59***a* and **59***b* of the relay lens system with the adapter optical system **50** and are taken by the image taking devices **53***a* and **53***b*.

The adapter optical system **50** is formed of a pupil image forming lens system **61** and image forming lens systems **63***a* and **63***b* arranged to be of the same optical axis as of the relay lens system **52***c*. The optical axes of the image forming lens systems **63***a* and **63***b* are eccentric by 1.25d (=5 mm) from the optical axis of the relay lens system **22***c*.

By the way, the image forming lens system is illustrated only on one side. This embodiment is simpler than the tenth embodiment because there is no mirror part within the adapter optical system **50**. As in the tenth embodiment, when the magnification of the adapter optical system **50** is freely set, the images **64***a* and **64***b* optimum to any image taking device will be able to be obtained. The distance between the two pupils divided by the pupil image forming lens system **61** can be varied by adjusting the focal distance of this pupil image forming lens system **61**. The other operations and effects are the same as the tenth embodiment.

The lens data of this embodiment are shown in Table 7.

FIG. **22** shows an image taking optical system in the twelfth embodiment of the present invention. The front groups **54***a* and **54***b* of the objective optical system **51** are formed of meniscus lenses **65***a* and **65***b* having a concave surface on the object side. In this embodiment, because there are fewer non-common parts of the right and left light paths than in the eleventh embodiment, the error between the qualities of the two images will be less.

The lens data of this embodiment are shown in Table 8.

Further, when the meniscus lenses **65***a* and **65***b* are constructed as an integrally molded lens **65** as shown in FIGS. **23**A to **23**D, the error on the right and left from the objective optical system **51** to the pupil image forming lens system **61** will be able to be reduced to a level where the error will not be a practical problem and the trouble of adjusting the lenses will be well eliminated. The other operations and effects are the same as in the eleventh embodiment.

By the way, of FIGS. **23**A to **23**D, FIG. **23**A is a sectioned plan view, FIG. **23**B is a side view of FIG. **23**A as seen in the side direction and FIGS. **23**C and **23**D are a front view and back view, respectively, as seem from the front side and back side.

FIG. **24** shows an image taking optical system in the thirteenth embodiment of the present invention. The final images **59***a* and **59***b* of the relay lens system are further once relayed by the adapter optical system **50**. Because the adapter optical system **50** is of the same optical axis as of the relay lens system **52***c*, the relayed images **64***a* and **64***b* will be formed in substantially the same positions and will be taken by one common image taking device **53**.

A shutter **66** is arranged between the pupil image forming lens system **61** and image forming lens system **63** and alternately intercept the beam so that two images may not be simultaneously formed in the image taking device **53**.

This embodiment has an advantage in that only one image taking device **53** is required. The other effects are the same as in the twelfth embodiment.

The lens data of this embodiment are shown in Table 9.

FIG. **25** shows a main part of an image taking optical system in the fourteenth embodiment of the present invention. As in the thirteenth embodiment, because the adapter optical system **50** has the same optical axis as that of the relay lens system **52***c*, the relayed images **64***a* and **64***b* will be formed in substantially the same positions and will be taken by one image taking device **53**.

A lenticular lens **67** is arranged just before the light receiving surface of this image taking device **53** which is commonly used. When the right and left images are formed at intervals of one row or one line by the image taking device **53**, the two images will be separately taken. This embodiment has also an advantage in that only one image taking device **53** is required. The other effects are the same as in the thirteenth embodiment. By the way, the lens data of this embodiment are the same as in the thirteenth embodiment.

FIGS. **26**A and **26**B show an objective optical system in the fifteenth embodiment of the present invention. In this embodiment, the visual field direction is 30 degrees with the lengthwise direction of the endoscope (the optical axis direction of the relay lens). The reflecting prisms **68***a*, **68***b* and **69***a*, **69***b* forming the front groups **54***a* and **54***b* may be respectively two separate bodies or one integral body.

FIG. **27** shows an objective optical system in a modification of the fifteenth embodiment of the present invention. As in the fifteenth embodiment, a perspective objective optical system **70** is formed. In this modification, the visual field direction is 70 degrees with the lengthwise direction of the endoscope (the optical axis direction of the relay lens). The reflecting prisms **68***a*, **68***b* and **69***a*, **69***b* may be respectively two separate bodies or one integral body.

In the fifteenth embodiment and its modification, the visual field direction can be varied by varying the angles of the reflecting prisms **68***a*, **68***b* and **69***a*, **69***b*. Therefore, when the front group part is formed to be interchangeable, various visual field directions or visual field angles will be able to be obtained by interchanging only this front group. Needless to say, even when the entire objective optical system is formed to be interchangeable, the same effects will be obtained. The other effects are the same as in the tenth embodiment.

FIG. **28** shows an image taking optical system in the sixteenth embodiment of the present invention. As in the fifteenth embodiment, in this embodiment, the perspective objective optical system **70** is used. In this embodiment, the visual field direction is 45 degrees with the lengthwise direction of the endoscope (the optical axis direction of the relay lens). The reflecting prism **71** is integral on the right and left.

That is to say, in the illustrated tenth to fifteenth embodiments, the optical system divided into two parts of the front groups **54***a* and **54***b* is adopted. However, in this embodiment, a common reflecting prism **71** is used to form a front group **54** functioning the same as the two separated front groups **54***a* and **54***b*.

Negative lens systems **72***a* and **72***b*, such as negative power elements, and positive lens systems **73***a* and **73***b*, such as positive power elements forming the front group **54** on the left and right are formed in pairs as arranged eccentrically respectively on the left and right and are rotatable as illustrated. Therefore, the arranging direction of the two incident pupils of the objective optical system, that is, the direction of the parallax (the direction of d in FIG. **28**) can be varied and it is very effective in permitting stereo-observing of an object in many directions.

In this embodiment, with the rotation of the negative lens systems **72***a* and **72***b* and positive lens systems **73***a* and **73***b*, the incident pupil of the pupil image forming lens system **61** will also rotate. In the embodiment shown in FIG. **28**, the adapter optical system **50** shows an example in case the same formation as of the eleventh embodiment is adopted. The image forming lens systems **63***a* and **63***b* and the image taking devices **53***a* and **53***b* will synchronously rotate to prevent the beam from being intercepted.

Even in this embodiment, when the angle of the reflecting prism **71** is varied; the visual field direction will be able to be varied, when the combination of the focal distances of the negative lens and positive lens is varied, the visual field angle will be able to be varied; and when the optical axis distance between the negative lens and positive lens on the left and right is varied, the magnitude of the parallax will be able to be varied.

This embodiment can be applied to another adapter optical system. However, as mentioned above, with the rotation of the negative lens systems **72***a* and **72***b* and positive lens systems **73***a* and **73***b*, the projected pupil of the pupil image forming lens system **61** will also rotate. Therefore, it is necessary to rotate such parts having left and right separate optical axes as, for example, the mirror parts **62***a* and **62***b*, image forming lens systems **63***a* and **63***b*, image taking devices **53***a* and **53***b* and the like as synchronized in the tenth embodiment in FIG. **20**. The other effects are the same as of the tenth embodiment.

FIG. **29** shows the seventeenth embodiment of the present invention wherein the front group **54** including the negative lens systems **72***a* and **72***b* and positive lens systems **73***a* and **73***b* is arranged on the object side of the reflecting prism **71**.

In this embodiment, as the rotating parts in the front group **54** part can be concentrated in one place (in this case, on the object side of the reflecting prism **71**) as compared with the sixteenth embodiment, the formation is simple. Also, FIG. **29** shows an example wherein the adapter optical system **50** having the same formation as that of the thirteenth embodiment is used. The opening part of the shutter **66** synchronously rotates so that the beam may not be intercepted. At this time, other parts such as the image forming lens **63** and image taking device **53** may also rotate together with the shutter **66**.

FIG. **30** shows unit formations of the eighteenth embodiment of the present invention. In FIG. **30**A, the unit formation comprises the front group unit **81** having the front groups **54***a* and **54***b* built-in, the rear group—relay lens system—pupil image forming lens system unit **82** having the rear group **55**, relay lens systems **52***a*, **52***b* and **52***c* and pupil image forming lens system **61** built-in, the image forming lens system unit **83** having the image forming lens systems **63***a* and **63***b* built-in and the image taking device unit **84** having the image taking devices **53***a* and **53***b* built-in. By the way, the connecting part of the rear group—relay lens system—pupil image forming system unit **82** and the image forming lens system unit **83** corresponds to the border of the input section **25** and output section **24** shown in FIG. **5**.

FIG. **30**B shows a formation of the image forming lens system—image taking device unit **85** wherein, in FIG. **30**A, the image forming lens systems **63***a* and **63***b* and image taking devices **53***a* and **53***b* are made as one unit.

FIG. **30**C shows a formation in FIG. **30**A of the objective optical system unit **86** combining the front groups **54***a* and **54***b* in the front group unit **81** and the rear group **55** in the rear group—relay lens system—pupil image forming lens system unit **82**, the relay lens system—pupil image forming lens system unit **87** having the relay lens systems **52***a*, **52***b* and **52***c* and pupil image forming lens system **61** built-in and the image forming lens system—image taking device unit **85**, the same as in FIG. **30**B.

In FIG. **30**D, the objective optical system (that is, the front groups **54***a* and **54***b* and the rear group **55**), relay lens systems **52***a*, **52***b* and **52***c* and pupil image forming lens system **61** are formed of the objective optical system—relay lens system—pupil image forming system unit **88** and the image forming lens system—image taking device unit **85** are made as one unit.

In FIG. **30**E, the objective optical system and relay lens systems **52***a*, **52***b* and **52***c* are formed of the objective optical system—relay lens system unit **89** made one unit and the pupil image forming lens system **61**, image forming lens systems **63***a* and **63***b* and image taking devices **53***a* and **53***b* are formed of the pupil image forming lens system—image forming lens system—image taking device unit **90** are made as one unit.

In FIG. **30**F, the front group unit **81**, rear group **55** and relay lens systems **52***a*, **52***b* and **52***c* are formed of the rear group—relay lens system unit **91** and pupil image forming lens system—image forming lens system—image taking device unit **90** are made as one unit.

In FIG. **30**G, the relay lens systems **52***a*, **52***b* and **52***c* are formed of the relay lens system unit **92**, objective optical system unit **86** and pupil image forming lens system—image forming lens system—image taking device unit **90** are made as one unit. By the way, in FIGS. **30**B to **30**G, the lens system within each unit is shown with the reference numeral omitted.

Also, in FIGS. **30**A to **30**G, the ocular adapter **45'** shown in FIG. **16**D may be made connectable.

In FIG. **31**, the front group unit **81** is explained further. FIG. **31**A shows a front group unit **81** using a common front group **54**. In case it is fitted, a pupil dividing type stereoendoscope in the related art will be able to be formed.

FIG. **31**B shows the front group unit **81** of a visual field angle of 70 degrees. FIG. **31**C shows the front group unit **81** of a visual field angle of 40 degrees. When they are replaced, any desired visual field angle will be obtained.

FIGS. **31**D and **31**E show a front group perspective unit **81** of a visual field direction of 70 degrees. FIG. **31**E is a view as seen from the rear of FIG. **31**D. When the reflecting prism **71** is replaced, the front group perspective unit **81** of any visual field direction will be able to be formed.

FIG. **31**F shows the front group unit **81** in which the parallax is reduced and the optical axes of the front groups **54***a* and **54***b* are brought close to each other to make the distance d' smaller than the other optical axis distance d. In FIGS. **31**A to **31**F, if the beams from the front groups **54***a* and **54***b* are made substantially afocal beams, when the unit is displaced, a focus lag and image lag will be able to be controlled.

FIG. **32** shows a formation of the objective optical system unit.

FIG. **32**A shows an objective optical system unit **86** comprising the front group **54** and rear group **55** arranged to share the same optical axis. When it is used, the pupil dividing type stereoendoscope in the related art will be able to be formed. FIG. **32**B shows an objective optical system unit **86** having the front groups **54***a* and **54***b* of a visual field angle of 70 degrees. FIG. **32**C is of an objective optical system unit **86** having the front groups **54***a* and **54***b* of a visual field angle of 40 degrees. When these are replaced, any desired visual field angle will be obtained.

FIG. 32D is of a perspective objective optical system unit **86** of a visual field direction of 70 degrees. FIG. **32**E is a front view of FIG. **32**D. When the reflecting prism **71** is replaced, a perspective objective optical system unit of any visual field direction will be able to be formed. By the way, in FIG. **32**E, the light guide is omitted.

FIG. **32**F shows an objective optical system unit in which the parallax is reduced and the optical axes of the two front groups **54***a* and **54***b* are brought close to each other so that the optical axis distance d' may be smaller than d, for example, in FIG. **32**B and others.

FIG. **33** shows a formation of a unit including the rear group **55**, relay lens systems **52***a* and **52***b* and pupil image forming lens system **61**.

FIG. **33**A shows the rear group—relay lens system—pupil image forming lens system unit **82** including the rear group **55**, relay lens systems **52***a* and **52***b* and pupil image forming lens system **61**. FIG. **33**B shows the relay lens system—pupil image forming lens system unit **87** including the relay lens systems **52***a* and **52***b* and pupil image forming lens system **61**. FIG. **33**C shows the rear group—relay lens system unit **91** including the rear group **55** and relay lens systems **52***a* and **52***b*. FIG. **33** shows the relay lens system unit **92** comprising the relay lens systems **52***a* and **52***b*.

Any number of relaying times of the relay lens system can be used. As required, different lengths for the inserted section different can be selected.

The respective units in the eighteenth embodiment can be formed by adopting a part of the optical system of the tenth to seventeenth embodiment.

According to the eighteenth embodiment, the stereoendoscope of the formation adapted to the using object can be selected and used. The other effects are the same as the tenth to seventeenth embodiments.

The following nineteenth and twentieth embodiments are embodiments wherein formations (a) in the means and operations for solving the above mentioned problems are used. When a plurality of images taken in by an objective optical system and having a parallax between them are transmitted by a common image transmitting optical system, are taken and are selectively displayed by a displaying means, optimum stereo-images will be provided.

FIG. **34**A shows a formation of a stereoendoscope apparatus **101** provided with the nineteenth embodiment of the present invention and an operation made by using the stereoendoscope **102** of the nineteenth embodiment. FIG. **34**B shows an arrangement of an objective optical system **121** as seen from the distal end surface of the stereoendoscope **102**.

This stereoendoscope apparatus **101** comprises a stereoendoscope **102** having an image taking means for taking a plurality of images having a built-in parallax, a CCU **103** processing signals for this imaging means, a distributor **104** connected to this CCU **103** and distributing video signals, a color monitor **105** as plural displaying means displaying the video signals distributed by this distributor **104** and head mounted displays (abbreviated as HMD's) **106** and **107**.

In FIG. **34**A, a rigid inserted section **111** of the stereoendoscope **102** is inserted toward an affected part **114** from a hole **113** in an abdominal part **112** of a patient. Two operators **115** and **116** respectively fit HMD's to their head parts, observe the affected part **114** with stereo-inspection and treat the affected part **114** by using treating tools **117** and **118**. The treating tools **117** and **118** may be inserted through other holes or through channels in the stereoendoscope **102**.

Also, another observer **119** (an assistant, nurse or spectator) observes the same affected part with stereo-inspection by observing the color monitor **105** with shutter spectacles **120** fitted.

The stereoendoscope **102** comprises an objective optical system **121**, relay optical system **122**, adapter optical system **123** and image taking means **124** in the order mentioned from the object side.

At least three images having a parallax between them and formed by the objective optical system **121** are transmitted by one (or plural) relay optical system **122** and are spatially (or timely) separated and formed by respective image taking devices forming the image taking means **124**. The electrical signals of the respective images photoelectrically converted by the image taking means **124** are converted to video signals by the CCU **103**, are further divided into signals of any two images by the distributor **104** and are displayed by the color monitor **105** and HMD's **106** and **107** which are to be displaying means.

In this embodiment, when the various optical systems shown so far are used as combined with the objective optical system **121** and adapter optical system **123**, the stereo-image optimum to the respective operators and observers will be able to be effectively provided.

When a plurality of images are transmitted by one relay optical system built-in in one tubular inserted section **111**, only one hole **113** in the abdominal part **112** is required and the burden on the patient will be able to be reduced.

As shown, for example, in FIG. **34**B, the objective optical system **121** is formed of six objective lens systems **121***a* to **121***d* arranged in the positions separated by a fixed distance from the center axis at an angle of 60 degrees from the center axis of the inserted section. The six images by these objective lens systems **121***a* to **121***f* are taken, for example, by six image taking devices forming the image taking means **124** through the common relay optical system **122** and the adapter optical system **123** formed, for example, of three adapter lens systems.

According to this formation, by selecting the image, for example, by the objective lens systems **121***a* and **121***d*, a stereo-image having a large parallax can be obtained and, by selecting the image by the objective lens systems **121***b* and **121***e*, a stereo-inspection having a large parallax in the direction different by 60 degrees is possible. Further, by selecting the image by the objective lens systems **121***c* and **121***f*, a stereo-inspection having a large parallax in the direction different by 120 degrees is possible.

Further, by the combination in the above mentioned case, the parallax will become small. However, by selecting the image, for example, by the objective lens systems **121***a* and **121***c* or the objective lens systems **121***a* and **121***e*, an image having a stereo-feel in various directions can be obtained.

By the way, a remote display selecting means whereby the operator **115** using the displaying device can remotely select the two images distributed by the distributor **104** to the displaying device side of the HMD **106** or the like by a wireless remote controlling apparatus using infrared rays or ultrasonic waves may be provided.

An observing direction displaying means is provided whereby, in case the image by the objective lens systems (for example, **121***b* and **121***e*) in the parallax direction different from the parallax direction of a set of objective lens systems (for example, **121***a* and **121***d*) as a reference is selected, the parallax direction changing angle (in this case, 60 degrees) will be displayed within the displaying device so that the direction in which the operator **115** or the like is observing may be simply found.

By the way, in this embodiment, n (at least three or more) (in FIG. **34**, n=6) objective images are transmitted by one relay optical system **122** but may be transmitted by n-i relay optical systems (here, i=1 to n-1).

FIG. **35** shows a formation of the stereo-endoscope **131** of the twentieth embodiment of the present invention. FIG. **35A** shows a general formation of the stereoendoscope **131**. FIG. **35B** shows an elevation as seen from the distal end surface in FIG. **35A**. FIG. **35C** shows an arrangement of image taking devices as seen from the front surface side in FIG. **35A**. In this embodiment, too, several sets of stereo-images can be obtained.

Several front groups **133** (**133***a* to **133***f*) forming an objective optical system **132** arranged on the distal end side of the rigid inserted section **111** take in images having a parallax between them and an image **135** is formed in substantially superimposed positions by one common rear group **134**, is relayed several times by one common relay optical system and becomes a final image **137**.

This final image **137** is of several superimposed images. These images have their pupils spatially separated by a pupil image forming lens system **138** and, further, respective images **141** (**141***a* to **141***f*) are formed on CCD's **140** (**140***a* to **140***f*) by image forming lenses **139**.

In this embodiment, six images having a parallax between them can be obtained. When two of the images are selected and displayed, the images having various stereo-feels and parallaxes will be able to be stereo-inspected. Also, several persons can stereo-observe in separate directions.

FIGS. **36A** to **36F** show distal end side formations of the stereoendoscope of the twenty-first embodiment of the present invention. FIG. **36B** is an elevation of FIG. **36A**. FIG. **36C** shows an optical system as seen from the side of FIG. **36A**. FIG. **36D** is an elevation of FIG. **36C**. FIG. **36E** shows FIG. **36C** as bent. FIG. **36F** is an elevation of FIG. **36E**.

In this embodiment, the inserted section **152** can be bent on the distal end side.

A front group optical system **153**, a rear group **154***a* forming a relay optical system **154** and a relay lens system **154***b* are arranged from the distal end side within the inserted section **152**. The distal end section **155** of the inserted section covering the objective optical system **153** is formed of a tubular frame having a curvable hose structure. The proximal side from the relay optical system **154** is formed of a rigid tubular frame.

Mirrors **158** and **159** are arranged between concave lenses **156***a* and **156***b* as of a front group and convex lenses **157***a* and **157***b* forming the objective optical system **153** and are rotatable respectively around axes **161** and **162**.

When the mirrors **158** and **159** are rotated simultaneously with curving from the straight seen state in FIG. **36C**, the distal end section **155** will be curved to be bent as in FIGS. **36E** and **36F**. According to this embodiment, the observation can be made with the distal end section bent. The other effects are the same as in the first embodiment and others.

FIG. **37** shows a formation on the distal end side of the stereoendoscope of the twenty-second embodiment of the present invention. This embodiment is a combination of the twentieth embodiment wherein several sets of stereo-images can be obtained and the twenty-first embodiment having a bendable structure.

Usually, in an endoscope operation, the endoscope does not enter directly into the abdominal part but is inserted instead through a tragacanth **171**. The thinner the tragacanth **171**, the less the distress of the patient. On the other hand, in case several operators jointly operate, the observation can conveniently be made in the separate respective directions.

However, there is a limit to how much the parallax may be increased and the parallax can not be made greater than the outside diameter of the distal end section. This embodiment can cope with such circumstances and makes it possible to observe in separate directions.

In this embodiment, two bendable distal end sections **155** and **155'** are provided forward of the relay optical system **154** and objective optical systems **153** and **153'** of the same structure as in the twentieth embodiment in FIG. **36** are contained within the respective distal end sections **155** and **155'**. The same members as shown in FIG. **36** within the distal end section **155** shall bear the same reference numerals, the same members as shown in FIG. **36** within the other distal end section **155'** shall bear the same reference numerals fitted with ' and their explanation shall be omitted.

According to this embodiment, when the distal end section is inserted within the tragacanth **171**, it will be seen as straight as in FIG. **36C**. When the distal end section comes out of the tragacanth **171**, it will be bent as in FIG. **37A** and several observers will be able to observe in separate directions through one thin relay optical system **154**.

By the way, for example, in the first embodiment, each of the objective optical systems **21***a* and **21***b* may be formed of an anamorphic optical system wherein the image forming magnification in the horizontal direction can be made smaller than the image forming magnification in the vertical direction (intersecting at right angles with this horizontal direction).

In the case of this formation, particularly, in case a common image taking device **23** is adopted, the two right and left images will be able to be prevented from being superimposed and the right and left image taking ranges in the image taking device **23** will be able to be substantially expanded.

In the function of transmitting images by the relay optical system **22**, because the right and left images can be intercepted less than in the case of no anamorphic optical system, that much, the objective optical systems **21***a* and **21***b* will be able to be arranged as having increased separation from each other (with the optical axis distance d larger) and a picture image having a higher stereo-feel will be able to be obtained.

In this case, in the CCU **4**, the signal of extending the picture image in the horizontal direction or compressing the picture image in the vertical direction may be processed.

By the way, the relay optical system **22** may be also formed of an anamorphic optical system. Even in the other embodiments, the objective optical system, relay optical system and adapter optical system may be formed of anamorphic optical systems.

By the way, in the lens data of the respective embodiments, in case the same lenses are paired in the objective optical system, adapter optical system and the like, only the lens data of one of the pair will be shown. In the respective embodiments, the relay lens optical system formed of a homogeneous bar-like lens is shown. However, even in case a refractive index distributing type lens is formed of such non-homogeneous rod as of a Shelphock (trade name) and is used for the relay optical system (image transmitting optical system), the present invention will be effective.

By the way, the embodiment wherein a plurality of images having a parallax are formed in spatially separated positions

by the objective optical system and the embodiment wherein a plurality of images having a parallax are formed in spatially substantially coinciding positions have been explained above. However, the case of their intermediate functions, that is, the case where a plurality of images having a parallax are formed in spatially at least partly superimposed positions and the case that a plurality of images having a parallax are formed in spatially at least partly separated positions belong to the present invention. Also, the case of applying an image by an objective optical system to the case that the image by the objective optical system is transmitted by such image transmitting optical system as the relay optical system belongs to the present invention.

As explained above, as the stereoendoscope in the fist to twenty-second embodiments is provided with an objective optical system having a plurality of incident pupils formed in different positions and forming a plurality of images having a parallax between them having passed through these plural incident pupils and a common image transmitting optical system transmitting the plural images having a parallax between them, the parallax will be able to be made large by the optical system, a sufficient stereo-feel will be obtained, the parts of the light path transmitting a plurality of images will be able to be made common by making the image transmitting optical system common, the number of the parts will be able to be reduced and the dispersion of plural images by production errors will be able to be extremely prevented.

When a stereoendoscope is formed by providing a plurality of objective optical systems arranged in parallel, separating plural images having a parallax and forming images and a common image transmitting optical system transmitting the plurality of images, the parallax will be able to be made large by the optical system, a sufficient stereo-feel will be obtained, the parts of the light path transmitting the plurality of images will be able to be made common by making the image transmitting optical system common, the number of the parts will be able to be reduced and the dispersion of plural images by production errors will be able to be extremely prevented. Further, as the images transmitted by the image transmitting optical system are spatially separated, the stereo-inspection will be made possible by the image taking means and ocular optical system without using an image separating means.

Also, when a stereoendoscope is formed by providing several front group optical systems, common rear group optical systems forming objective optical systems forming a plurality of images having a parallax in spatially substantially coinciding positions and a common image transmitting optical system transmitting the plurality of images, the parallax will be able to be made large by the optical system, a sufficient stereo-feel will be obtained, the parts of the light path transmitting the plurality of images will be able to be made common by making the image transmitting optical system common, the number of the parts will be able to be reduced and the dispersion of the plurality of images by production errors will be able to be extremely prevented. When a common rear group optical system is used in the objective optical system part, many parts will be able to be used in common and a plurality of picture images less influenced by production errors and high in quality will be obtained.

Further, there is a stereo-inspectable endoscope in U.S. Pat. No. 5,191,203 shown in FIG. **38**A wherein an objective optical system **500** is formed of collimator lenses **501** and a pair of left and right image forming lenses **502***a* and **502***b* arranged in the order mentioned from the object side.

In the objective optical system of the stereoendoscope of this related art, there are the following three problems:

(1) When the picture angle is to be made large, the inward angle will not be able to be made large and the stereo-feel will reduce.

As in FIG. **38**B, in case the picture angle is to be made large, it will be necessary that the power arrangement of the collimator lenses **501** will be negative and positive in the order from the object side. When the power of the negative lens **503** on the object side is made large, the picture angle will be able to be made large. However, in this case, the focal distance fc of the collimator lenses **501** will become larger than the object distance s and the inward angle a will become small by the following formula:

$$\alpha=2\cdot\arctan\left(d/2\,fc\right)$$

wherein d represents an optical axis distance between the two image forming lenses **502***a* and **502***b*.

(2) A relative error between the left and right images is likely to occur.

The relative error between the right and left images is produced mostly in the parts of the left and right separate bodies by a surface shape error, surface distance error, eccentricity error or the like between right and left independent lens systems. In the prior example, the parts of the left and right separate bodies (the parts having left and right separate optical axes) correspond to the image forming lenses **502***a* and **502***b* which are so many that an error is likely to occur. When a relative lag (focusing, eccentricity or the like) is produced between the left and right images, the left and right images will become difficult to resolve, resulting in fatigue.

(3) It is difficult to adjust the eccentricity error of the left and right images.

In order to adjust the eccentricity error of the left and right images, the lens or CCD of the left and right separate body parts must be adjusted. However, in the prior example, either the lens or the CCD is in a position through the other part (in this case, the collimator lens **501**) from the distal end section of the endoscope and is difficult to adjust.

The twenty-third to twenty-fifth embodiments provide a stereoendoscope wherein the picture angle and stereo-feel (inward angle) can be set to be optimum, the error between the left and right images is small and is easily adjustable, resulting in less fatigue, which shall be explained below.

In the stereoendoscope of these embodiments, there are an elongate inserted section, an objective optical system arranged within the distal end of the inserted section and an image taking means arranged within the inserted section for taking object images formed by the objective optical system. The objective optical system is formed of two negative lenses and one coaxial positive lens arranged in parallel with each other in the order mentioned from the object side. The inward angle is determined by the optical axis distance between the two negative lenses, therefore the picture angle and stereo-feel (inward angle) can be set to be optimum, the error between the left and right images is small and is easy to adjust and the fatigue feel can be reduced. in the stereoendoscope having an elongate inserted section,

In the twenty-third embodiment, the objective optical system is applied to a so-called electronic scope having a CCD in the distal end part of the inserted section of the endoscope.

As shown in FIG. **39**, a stereoendoscope apparatus **201** comprises a stereoendoscope **202** of the twenty-third embodiment having an image taking optical system for

stereo-inspection built-in, a light source apparatus **203** feeding an illuminating light to an illuminating light transmitting means transmitting the illuminating light and provided in this stereoendoscope **202**, a camera controlling unit (abbreviated as CCU hereinafter) processing signals for an image taking means built-in in this stereoendoscope **202**, a scan converter **205** converting to a video signal the signal put out of this CCU **204**, a color monitor **206** displaying the video signal put out of this scan converter **205** and shutter spectacles **207** having a shutter function of stereo-perceiving the picture image displayed by this color monitor **206**.

The stereoendoscope **202** has an elongate inserted section **208** to be inserted into a body cavity or the like and a gripped section **209** to be gripped by the operator and formed to be thick at the proximal end of this inserted section. This inserted section **208** is formed of a cylindrical metallic hose high in the flexibility and a soft jacket tube made of a metallic mesh and resin or the like. The distal end section **216** of the inserted section **208** is formed of a cylindrical rigid jacket tube made of such metal as stainless steel. An objective optical system **218** and two image taking devices **220***a* and **220***b* (for example, CCD's) are enclosed in the distal end section **216**. By the way, the entire inserted section may be formed of a rigid jacket tube, just as in the distal end section.

This stereoendoscope has a light guide **215** as an illuminating light transmitting means transmitting the illuminating light fed from the light source apparatus **203** and an illuminating optical system (not illustrated) for emitting the transmitted illuminating light through an illuminating window just as in the ordinary endoscope. Two observed images having a parallax are obtained so that the object illuminated by this illuminating optical system may be stereo-inspected and has an observing optical system comprising the optical system **218** and two image taking devices **220***a* and **220***b*.

By the way, this embodiment includes an example wherein two images having a parallax are formed by the image taking devices **220***a* and **220***b* having a photoelectrically converting function as an observing optical system and is therefore also called an image taking optical system.

The gripped section **209** is provided with a light guide mouthpiece **210** to which a light guide cable **211** is removably connected at one end. A light guide connector **212** at the other end of the light guide cable **211** is removably connected to the light source apparatus **203**.

A lamp **213** generating a white illuminating light and a lens **214** condensing this white light are arranged within the light source apparatus **203**. The illuminating light condensed by this lens **214** is radiated on the end surface of the light guide connector **212**, is transmitted by the light guide within the light guide cable **211**, is transmitted from the light guide mouthpiece **210** to the light guide **215** side within the stereoendoscope **202** and is fed.

The light guide **215** as an illuminating light transmitting means is bent within the gripped section **209** and is inserted through the inserted section **208**. This light guide **215** transmits the fed illuminating light and emits the illuminating light forward from the distal end surface fixed to the distal end section **216** of the inserted section **216**.

An object (indicated by the arrow in FIG. **39**) **217** illuminated by this illuminating light has optical images (**219***a* and **219***b* in FIG. **39**) having a parallax between them formed in image forming positions by the objective optical system **218** fitted to an observing window arranged adjacently to the illuminating window within the distal end section. These images **219***a* and **219***b* are formed on the photoelectric converting surfaces (image taking surfaces) of the image taking devices **220***a* and **220***b* arranged the same within the distal end of the inserted section.

As shown in FIG. **40**, the objective optical system **218** is formed of left and right separate negative lenses **221***a* and **221***b* and an axially symmetrical positive lens group **222** arranged in parallel with each other in the order mentioned from the object side. The light passing through a diaphragm opening **223***b* of the light from the object forms an image on the image taking device **220***a* and the light having passed through a diaphragm opening **223***a* forms an image on the image taking device **220***b*. By the way, a cover glass **240** made of parallel plane plates is arranged on the object side of the negative lenses **221***a* and **221***b*.

Here, the lens data of the objective optical system **218** of this embodiment are shown in Table 10.

In FIG. **39**, the image taking devices **220***a* and **220***b* have, for example, square image taking surfaces. The vertical or horizontal direction of this image taking surface coincides with the horizontal direction in which the two diaphragm openings **223***a* and **223***b* are separated and arranged.

The image taking devices **220***a* and **220***b* are extended out and are connected with the CCU **204** by the signal cable **224**. The image taking signal photoelectrically converted by the image taking devices **220***a* and **220***b* is processed in the CCU **204**. The image signal processed in this CCU **4** is further put into a scan converter **205** and is converted to a video signal. The video signal is put out in a color monitor **206** in which the picture images having a parallax between each other and separately formed through the two diaphragm openings **223***a* and **223***b* are alternately displayed and the operator can observe and stereo-inspect the picture images with the shutter spectacles.

FIG. **41** shows a power arrangement of the objective optical system **218** in this embodiment. The inward angle a determining the magnitude of the stereo-feel is as follows from the optical axis distance d between the two negative lenses **221***a* and **221***b* and the object distance s:

$$\tan(\alpha/2)=d/(2s).$$

That is to say, as shown in FIG. **41**, the inward angle of the objective optical system in this embodiment is determined by the optical axis distance d between the two negative lenses and does not depend on the picture angle. Further, as the left and right separate parts are only the negative lenses **221***a* and **221***b*, no relative error will be likely to be produced. Therefore, there can be obtained the following results:

(1) As the inward angle is determined by the optical axis distance between the two negative lenses and the inward angle and picture angle can be independently set, the picture angle will be able to made large with the inward angle kept large.

(2) As the main cause of the relative error between the left and right images is only the negative lens, the relative error between the left and right images will be little.

(3) As the left and right separate parts for adjusting the error between the left and right images are on the distal end side of the endoscope, they will be easy to adjust.

FIG. **42** shows a frame structure of the distal end section **216** of the stereoendoscope **202** in this embodiment. The frame structure comprises an inner tube **225** holding lenses and a CCD and an outer tube **226** enclosing the inner tube **225**, an illuminating light guide and forceps channel not illustrated.

In the objective optical system of the prior example in FIG. **38A**, as the left and right separate bodies for adjusting the eccentricity of the left and right images are in the

positions through the collimator lens from the distal end within the inner tube, when they are to be adjusted, adjusting grooves, screws and adjusting spaces will have to be prepared in the inner tube and the inner tube will not be able to be made the inner tube **25** of such simple structure as in FIG. **42** and will be large in the outside diameter. on the other hand, in this embodiment, as the two negative lenses **221***a* and **221***b* which are the left and right separate parts to be adjusted are outside the distal end of the inner tube **225**, the positions of the negative lenses **221***a* and **221***b* will be able to be simply adjusted without requiring a special structure for the inner tube **225**. The negative lenses **221***a* and **221***b* are adjusted in the position and are then bonded and fixed and the inner tube **225** is inserted into the outer tube **226** to complete the stereoendoscope.

The twenty-fourth embodiment shall be explained in the following with reference to FIG. **43**. As the twenty-fourth embodiment is substantially the same as the twenty-third embodiment, only the different formations shall be explained.

In the twenty-fourth embodiment, the objective optical system of the stereoendoscope according to the present invention is applied to a so-called rigid endoscope wherein an image is transmitted to the proximal side by an objective optical system **218** and a transmitting optical system **227** arranged in an inserted section consisting of a cylindrical rigid jacket tube and is taken.

As shown in FIG. **43**, images **219***a* and **219***b* formed by the objective optical system **218** are relayed by relay lenses **227***a*, **227***b* and **227***c* which are of a transmitting optical system **227** and are then formed on CCD's **229***a* and **229***b* by an image taking lens **228**. All the lenses other than the negative lenses **221***a* and **221***b* at the distal end are coaxial. The images, that is, pupils of the diaphragm openings **223***a* and **223***b* are transmitted respectively to positions **250**, **251**, **252** and **253**. The other formations, operations and effects are the same as in the twenty-third embodiment.

Here, the lens data of the objective optical system **218** and transmitting optical system **227** in this embodiment are shown in Table 11.

The image taking lens **228** in this embodiment is one coaxial lens system but the two pupils are separated in the position **253**. Therefore, as the image forming lens of the image taking lens shown in the following, image forming lenses arranged in parallel with each other may be used after the pupil **253** to form images.

The twenty-fifth embodiment shall be explained in the following with reference to FIGS. **44** and **45**. As this embodiment is substantially the same as the twenty-fourth embodiment, only the different formations shall be explained.

The twenty-fifth embodiment is an embodiment as applied to a rigid endoscope just as in the twenty-fourth embodiment.

In this embodiment, as shown in FIG. **44**, the basic formation of the objective optical system **218** is the same as in the twenty-fourth embodiment. However, the image **219***a* formed of the light passing through the diaphragm opening **223***b* of the light from the object and the image **219***b* formed of the light passing through the diaphragm opening **223***a* are partially superimposed.

The images **219***a* and **219***b* formed by the objective optical system **218** are relayed by the relay lenses **227***a* and **227***b* as shown in FIG. **45**. The images are then formed to be infinite by the pupil image forming lens **230** and are formed respectively on the CCD's **229***a* and **229***b* by a pair of left and right image forming lenses **231***a* and **231***b*. The images (pupils) of the diaphragm openings **223***a* and **223***b* are transmitted respectively to the positions **254**, **255** and **256**. As the two pupils have been separated in the position **256**, the two partially superimposed images **233***a* and **233***b* relayed by the relay lenses **227***a* and **227***b* are formed separately by the image forming lenses **231***a* and **231***b*. The other formations, operations and effects are the same as in the twenty-fourth embodiment.

Here, the lens data of the objective optical system **218** and transmitting optical system **227** of this embodiment are shown in Table 12.

In the 25th embodiment, the left and right separate parts are present not only in the distal end section (the negative lenses **221***a* and **221***b*) but also within the image taking lens **232** (the image forming lenses **231***a* and **231***b*). Therefore, when the negative lenses are not adjusted but the image forming lenses are adjusted, the eccentricity error between the left and right images will be able to be adjusted.

However, in case the stereoendoscope **202** is made removable between the input section (until the transmitting optical system **227** or until the pupil image forming lens) and the output section (after the pupil image forming lens **230** or after the image forming lenses **231***a* and **231***b*), it will be necessary for the input section and output section to be independently adjusted. Therefore, even during such adjustment of the input section, the objective optical system of the present invention is very effective.

A plural visual field direction type endoscope after the 26th embodiment shall be explained in the following.

The endoscope apparatus **310** shown in FIG. **46** has an inserted section **302**, an endoscope **311** in which the visual field direction is changeable in the 26th embodiment, a camera **304**, monitor **305** and light source apparatus **307**.

An objective optical system having a plurality of visual field directions and a light guide illuminating the respective visual field directions are incorporated in the distal end section **301** of the inserted section **302** of the endoscope **311**. The inserted section **302** is provided with a relay lens system which is an image and pupil transmitting optical system following the objective optical system. An ocular optical system is arranged in the proximal section **303** of the endoscope **311**. The camera **304** can be fitted in the rear of the ocular optical system. Here, the proximal section **303** of the endoscope **311** and the camera **304** are formed to be integral or removable. The object having had the image taken by the camera **304** is displayed to be observable by the observer as an endoscope picture image finally in the monitor **305**.

The illuminating light from the light source apparatus **307** passes through the light guide cable **306** and illuminates the respective visual field directions through the proximal section **303**, inserted section **302** and distal end section **301**.

The details of the optical system of the endoscope **311** shall be explained as follows:

On the optical systems of the endoscope of the 26th embodiment, a pupil division is utilized in the objective optical system and an ocular optical system is formed.

The pupil dividing system is fundamentally formed of an optical system having one optical axis but, in order to make a plural visual field direction type, a lens group corresponding to a plurality of visual field directions is arranged in front of the optical system. The plural visual field direction type optical system having adopted this pupil dividing system is formed of a front side lens group formed the same in a plurality of visual field directions and arranged in the respective plurality of visual field directions, a prism for forming images in the plurality of visual field directions in

the rear step of the front side lens group corresponding to the plurality of visual field directions, a brightness diaphragm having a plurality of openings arranged near pupils, thereby forming a plurality of pupils and a rear side lens group forming one image of superimposed beams in the plurality of visual field directions in the order mentioned from the object side.

The inherent one beam of the optical system is divided near the pupil by the brightness diaphragm **321** having two openings and is shown in FIG. **37B**. The beam passing through one opening of the brightness diaphragm **321** is seen straight-on as it is and the beam passing through the other opening of the brightness diaphragm **321** is perspectively seen in the visual field direction by the prism. Here, the two images in the visual field direction are formed to be superimposed on the image surface.

The formation of the optical system relating to this embodiment shall be explained concretely with reference to FIG. **47A**. The optical system shown in FIG. **47A** comprises an objective optical system **322**, a set of relay lens system **323** as a transmitting optical system and an ocular optical system **324**.

The objective optical system **322** has a front side lens group **329***a* comprising two objective lenses **325** and **326** arranged in the positions nearest to the object and directed respectively in the straight seen direction and side seen direction, a first prism **327** making the beam from the two objective lenses **325** and **326** incident on different surfaces, a second prism **328** making the beam from the first prism **327** incident on the same surface and a brightness diaphragm **321** for dividing the pupil into a plurality of pupils in response to the visual field direction and has a rear side lens group **329***b* for converging the beam from the pupils and forming the object image arranged in the rear of this front side lens group **329***a*. In the drawing, the one-point chain lines represent the optical axes of the respective visual field directions.

The image in the direction as seen straight-on in this optical system is formed as follows. The rays having passed through the objective lens **326** pass through the surface **331** of the first prism **327** to the joint surface **332**. The joint surface **332** on the first prism side **327** is black-painted so as to pass no others than the rays effective to prevent detrimental flares and is made a flare diaphragm. Because the first and second prisms **327** and **328** are made of the same glass material, their refractive indices are equal and the rays pass through the surface **332** without being refracted. Then an image I1 having the lower side of the brightness diaphragm **321** as a pupil surface and having the optical axis of this rear side lens group **329***b* as a center axis by the rear side lens group **329***b* is formed.

On the other hand, the image in the perspectively seen direction is formed as follows. The rays passing through the perspectively seeing objective lens **325** pass through the surface **333** of the first prism **327** to the joint surface **332**. At this time, the rays forming the image in the perspectively seen direction proceed straight through the joint surface without being refracted the same as the straight-on seen rays.

The joint surface **332** on the first prism side **327** is made a flare diaphragm passing no others than the rays effective to prevent detrimental flares. As the optical axis in the straight-on seen direction and the optical axis in the perspectively seen direction intersect with each other on the joint surface, the same flare diaphragm will effectively function on the rays in both directions. The straight proceeding rays in the perspectively seen direction are reflected by the mirror-processed surface **334** and go again to the surface **332** on the second prism **328** side.

The surface **332** on the second prism **328** side is mirror-processed in the range of not intercepting the straight-on seen rays and perspectively seen rays separated by the pupil division and in the range of covering the reflected perspectively seen rays reflected by the surface **334**. Therefore, the rays in the perspectively seen direction reflected by the surface **334** without being perceived pass on the upper side of the brightness diaphragm **321** and are made the image II having the optical axis of the rear side lens group **329***b* as a center axis by this rear side lens group **329**, just as the straight-on seen rays and the image is formed.

The images I1 in the plurality of visual field directions made by the objective optical system **322** and the pupil P1 are transmitted in the ocular optical system direction by the relay lens system **323**. In the drawing, the reference numeral P2 represents a plurality of pupils corresponding to the respective visual field directions transmitted by the relay lens. An image I2 is formed between the relay lens system **323** and ocular optical system **324**. A plurality of pupils P3 corresponding to the respective visual field directions are obtained through the ocular optical system **324**.

When the observer moves the position of his pupil to the position of the pupil transmitted in the visual field direction he wants to observe, he will be able to select the visual field direction.

In this embodiment, the objective optical system is originally designed as a coaxial optical system but not as an eccentric optical system and is formed to be bent with a prism for a pupil in a different visual field direction. That is to say, the optical axis of the objective lens **326** is on the extended line of the optical axis of the rear side lens group **329***b* through the joint surface **332** and the optical axis of the objective lens **325** is on the extended line of the optical axis of the rear side lens group **329***b* reflected on the joint surface **332** and further reflected on the reflecting surface **334**. Therefore, between the optical system comprising two negative lenses and a prism and the optical system in the rear of it, even if the beam is not afocal, two images superimposed before the relay system will be able to be formed.

In this embodiment, as the pupil division is utilized and originally one optical system is used, with a formation of few lenses, a high picture quality will be obtained, if the means for determining plural pupils is in a position conjugate with the pupil position of the objective optical system, it may be the position of the pupil P2 of the relay system **323** or any other part and, as the objective system and transmitting optical system have no visual field direction switching apparatus, the structure will be simple and the ease of assembly will be high.

An example of designing an actual objective optical system is shown in FIG. **48** and its numerical value data are mentioned in Table 13. By the way, in the formation shown in FIG. **48**, the part shown as the rear side lens group **329***b* in FIG. **47A** is formed of a lens **329"** jointed to a prism and three jointed lenses **329'**.

In this embodiment, because the formed image is one, the following effects will be able to be obtained.

That is to say, as the objective optical system of the plural visual field direction type endoscope has a plurality of visual field directions, a plurality of pupils corresponding at 1 to 1 to the visual field directions and one image, the one image is a superimposition of images in a plurality of visual field directions, the optical axis of the plurality of visual field directions coincides with the optical axis of the transmitting system in the position of the image and, on the way of the transmission in the transmitting optical system after the image, one image and a plurality of pupils will be transmitted without being intercepted.

Therefore, in this embodiment, after the transmitting optical system, the visual field direction can be selected and no movable part is required in the objective optical system and transmitting optical system for selecting the visual field direction. Further, in this embodiment, because the objective optical system and the like have no visual field direction switching apparatus, the structure will be simple and the ease of assembly will be high. Also, because no polarization is used, there will be no deterioration of the image in the peripheral part by the rotation in the polarizing direction.

These effects will be the same even in case the pupil dividing means is in the transmitting optical system or image forming optical system.

The 27th embodiment shall be explained in the following with reference to FIGS. **49** to **54**.

In the endoscope of this embodiment, an eccentric optical system is utilized for the objective optical system, an image forming optical system and solid state image taking device are used instead of the ocular optical system in the 26th embodiment and no optical visual field direction selecting means is provided.

FIG. **49**A shows a formation of an optical system arranged within the endoscope of this embodiment.

The optical system of this embodiment comprises in the order mentioned from the distal end side an objective optical system **341**, relay lens system **342**, pupil image forming lens **343**, such reflecting members **344***a* and **344***b* as a pupil separating optical member **344***c* and mirror and two solid state image taking devices **346***a* and **346***b* as an image taking means. By the way, though only one relay lens system is shown, it is natural that a plurality of relay lens systems may be used as required. The image forming lenses **345***a* and **345***b* form the image forming optical system.

In the objective optical system **341**, a front optical system **347** comprising substantially afocal lens groups **347***a* and **347***b* independent of each other and having two straight-on seen and perspectively seen visual field directions and pupils P11 corresponding to these visual field directions is arranged in the front group and a rear side lens system **348** having a size capable of transmitting the beams from the plurality of pupils P11 to the image without being intercepted and forming one superimposed image of the beams in the plurality of visual field directions is arranged in the rear group.

The relay lens system **342** forms the images of the pupils P11 as pupils P12, forms the image I11 as an image I12 and transmits them to a pupil image forming lens **343**. The pupil image forming lens **343** transmits the pupils transmitted from the relay lens system **342** to the side of a pupil separating optical member **344***c* having a plurality of reflecting surfaces. This pupil separating optical member **344***c* receives a plurality of pupils P13 and separates and delivers them in respectively different directions, that is, to the reflecting members **344***a* and **344***b*.

The reflecting members **344***a* and **344***b* reflect the beams passing through the separated respective pupils, that is, in the illustration, the two pupils corresponding to the optical system in the straight-on seen direction and the optical system in the perspectively seen direction respectively toward the lens systems **345***a* and **345***b*. The lens systems **345***a* and **345***b* form images corresponding to the respective pupils in the solid state image taking devices **346***a* and **346***b*.

In this formation, first the rays in the respective visual field directions pass through two substantially afocal lens groups **347***a* and **347***b* forming the front optical system **347**, then the optical axes in the respective visual field directions are bent by the rear side lens system **348** and the image III is formed on the optical axis of the rear side lens system **348**.

In this embodiment, substantially the same basic formation which realizes the perspective view made by the prisms **327** and **328** in the 26th embodiment is used. Here, the perspective view prism may be a 300 prism shown in the publications of Japanese Patent Applications Laid Open Nos.140313/1985, 91333/1975 and 108013/1990 or a 700 prism or 1100 prism shown in the publication of Japanese Patent Application Laid Open No.87403/1984.

Also, the objective optical system **341** may be the front optical system **347***c* including the same prisms as the prisms **327** and **328** of the above mentioned embodiment as in FIG. **50**, that is, may be a straight-on seeing and perspectively seeing optical system in common. Or the objective optical system **341** may realize a perspective view by utilizing refraction with a wedge prism **349** placed near the pupil P11 as in FIG. **51**. In this formation, the lens group to be used respectively in the straight seen direction and the perspectively seen direction may be substantially the same lens group differing only in length, and the perspectively seeing lens group may be inclined to the straight-on seeing lens group and the wedge prism **349** may be arranged in the rear of it.

Otherwise, as shown in FIG. **54**, the objective optical system **341** may have three or more visual field directions if in a range that the image and pupil are not intercepted by the relay lens system arranged in the rear. In the illustrated example are shown the most distal end side lenses **350**, **351** and **352** forming respective lens groups respectively of 0 degrees (straight-on seen), 30 degrees (perspectively seen) and 70 degrees (perspectively seen).

As shown in FIG. **49**A, the beam from the objective optical system **341** forms an image I12 in the rear of the relay lens system just as in the 26th embodiment by the relay lens system **342**. Of the rays in the respective visual field directions forming the image I12 made in the rear of the relay lens system **342**, the beams of the two pupils differing in the visual field direction are respectively separated by the pupil separating optical member **344***c* arranged in the rear of the pupil image forming lens **343**.

This pupil separating optical member **344***c* is, for example, a prism arranged near the pupil P13 transmitted by the relay lens system **342** and formed as an image by the pupil image forming lens **343**. The separated beams in the respective visual field directions are reflected respectively by the reflecting members **344***a* and **344***b* and are formed as images respectively on the image taking devices **346***a* and **346***b* through the lens systems **345***a* and **345***b*.

In this embodiment, by the pupil image forming lens **343** forming images of pupils, the optical axes in the respective visual field directions are made substantially parallel with the optical axis of the relay lens system **342** and the object point is formed as an image to infinity. By the way, the image may be formed so as not to be superimposed on one solid state image taking device.

According to this embodiment, images differing in the visual field direction can be independently taken by a plurality of solid state image taking devices and the number of visual fields and the visual field direction can be easily selected by the objective optical system. Without an optical visual field direction switching means, images in all the visual field directions are taken in. As in the illustrated example, in the formation using a plurality of solid state image taking devices, the outputs of the respective image taking devices are selected by switching the switch and the signals are processed as determined and can be displayed.

In the formation utilizing one solid state image taking device, the respective images different in the visual field

direction may be selected by a signal processing means connected to the later step. The picture image in only one visual field direction can be displayed in a monitor.

That is to say, in this embodiment, without moving the optical system or without optically switching the visual field direction, the visual field direction can be changed. Also, depending on the way of processing the signal, a plurality of images in the visual field direction can be simultaneously displayed in one or a plurality of monitors.

An example of designing an objective optical system is shown in FIG. **52**. Also, an example of designing an objective optical system and relay lens system as combined is shown in FIG. **53**. In the drawings, the reference numeral **354** represents an objective optical system and the reference numeral **355** represents a relay lens system. The lens data are mentioned in Table 14.

By the way, just as in the 26th embodiment, the diaphragm determining the pupil may be in the objective optical system, may be in the pupil position in the conjugate relay lens system or may be in the pupil position near the pupil dividing optical member.

In FIG. **49B** is shown a modification of the 27th embodiment. In this modification, a pupil image P13 is formed of dispersed beams or converged beams by the pupil image forming lens **356** provided instead of the pupil image forming lens **343**. A focal beams are then formed by the lens **357** making the beams parallel and the beams are further formed as images by the image taking devices **346***a* and **346***b* through the image forming lenses **345***a* and **345***b*. In this modification, a reflexing prism as a pupil dividing optical member is unnecessary. The diaphragm may be arranged above the pupil position P13 in the drawing, in the relay lens system or in the pupil position in the objective optical system. The other same formations and operations as in the 27th embodiment shall bear the same reference numerals and shall not be explained here.

The 28th embodiment of the present invention shall be explained in the following with reference to FIGS. **55** to **58B**.

In the formation of the 28th embodiment, an image forming optical system and a solid state image taking device are provided the same as in the 27th embodiment and further an optical visual field direction switching means is arranged.

The objective optical system in this embodiment may be the pupil dividing system in the 26th embodiment or may be formed of the substantially afocal plurality of optical systems and rear optical systems in the 27th embodiment. This embodiment is different from the above mentioned respective embodiments in the formation of the optical system and the like arranged in the rear of the relay lens system arranged in the rear of the objective optical system.

As shown in FIG. **55**, the optical system in this embodiment comprises a lens system **361** for making the light which was once formed as an image by a relay lens system in the rear of the relay lens system (not illustrated) and then became dispersed beams in the respective visual field directions parallel with the optical axis of the relay lens, a pupil switching apparatus **362** as a selecting means switching the beams in the respective visual field directions made parallel in response to the respective pupils and arranged near the pupils to be formed as images through the lens system **361** and an image forming lens system **363** forming images of the rays selected by the pupil switching device **362** on the solid-state image taking device **364**.

The rays in the respective visual field directions forming the image I21 formed in the rear of the relay lens system are made parallel with the optical axis of the relay lens system by the lens system **361**. By the switching apparatus **362** near the pupil position, the rays passing through the other images than in the visual field direction the observer wants to observe are intercepted. The intercepting means as a selecting means may be a mechanically moved shielding plate or may be a liquid crystal shutter switch to be on/off.

The selecting means may be such image rotator **365** as in FIGS. **56A** and **56B** to be moved to switch the visual field direction. The reference numeral **366** represents an image forming lens system forming an image of the rays obtained by the image rotator **365** on the solid state image taking device. By the way, FIGS. **56A** and **56B** show that the visual field direction is switched by moving the image rotator **365**.

Also, as shown in FIG. **57**, the selecting means may be moved to the position of the visual field direction desired to be observed integrally with the image forming lens system **365** and solid state image taking device **364** to switch the visual field direction. Only the image in the selected visual field direction is formed on the solid state image forming device **364**.

The effect of this embodiment is that the visual field direction can be changed in a small space.

By the way, in case the pupil and image made by the objective optical system are transmitted by the relay lens system and the pupil dividing means is arranged after the relay lens system, the brightness diaphragm **321** can be omitted.

The formations of the 27th and 28th embodiments have an image taking means and may be applied to an outside fitted camera connectable to the ocular optical system of the 26th embodiment. In this formation, the lens system **343** or **361** is replaced with the ocular optical system **324**.

The optical system after the transmitting optical system combining utilizing the pupil division in the objective optical system and utilizing the eccentric optical system can be selected either to have the ocular optical system and optical visual field direction switching means or to have none.

In the case of either utilizing the pupil division in the objective optical system of the present invention or utilizing the eccentric optical system, when the means of intercepting the rays other than in the required visual field direction are provided near the pupils in the respective visual field directions, even if the transmitting optical system is replaced with the solid state image taking device or image guide, the visual field direction variable endoscope will be able to be realized.

In the formation shown in FIG. **58A**, a pupil switching apparatus **368** is provided near the pupil formed in the light path of the objective optical system **370** consisting of the front side lens group which is the same as the front side lens group **329***a* of the 26th embodiment and the rear side lens system **348** and a solid state image taking device **369** is arranged. The pupil switching apparatus **368** may be a liquid crystal shutter or the like.

Also, in the formation shown in FIG. **58B**, an eccentric optical system **371** including the same optical system as the front optical system **347***c* shown in FIG. **50** is utilized.

FIG. **59A** is a formation view of an optical system in the plural visual field direction type endoscope in the 29th embodiment. FIG. **59B** is a formation view of an objective optical system made partially common.

The objective optical system in the 29th embodiment is formed of a plurality of lens groups provided for respective visual fields instead of the objective optical system **322** so that a plurality of images may be formed by these lens groups. The other formations and operations which are the same as in the 26th embodiment shall bear the same reference numerals and shall not be explained here.

The objective optical system **373** shown in FIG. **59**A is formed of a plurality of (two in the illustrated example) independent lens groups. The relay lens system **323** and ocular optical system **324** are arranged in the rear of the objective optical system **373**. By the way, the relay lens system **323** and ocular optical system may be replaced with an image forming optical system and solid state image taking device.

The objective optical system **373** may be formed of an independent optical system as in FIG. **59**A and may have a part, that is, the prism on the distal end side made common as in the objective optical system **373'** shown in FIG. **59**B.

The plurality of images I31 and I32 formed by the objective optical system are transmitted rearward by the relay lens system **323** as a transmitting optical system. In the formation having the ocular optical system **324**, as in FIG. **59**A, the observer can simultaneously see the respective visual field directions with the eye placed in the pupil position **374**.

On the other hand, in the formation of the image forming optical system and solid state image taking device, the plurality of images made in the rear of the relay lens system **323** are formed on one solid state image taking device by the image forming lens. The effect by this formation can be technically comparatively easily realized by any optical system after the objective optical system and transmitting optical system.

By the way, in this embodiment, images may be formed on a plurality of solid state image taking devices with the image forming magnification made large and the solid state image taking devices placed in the positions corresponding to the plurality of images.

The 30th embodiment shall be explained with reference to FIG. **60**A. As shown in FIG. **60**A, in the optical system of this embodiment, an image is formed on the solid state image taking device **370** through the lens system **343** which is arranged in the rear of the relay lens system **342** and whereby the light once formed as an image by the relay lens system **342** and then made dispersed beams in the respective visual field directions is made parallel with the optical axes of the relay lens system **342** and optical systems arranged along two optical axes in the rear of this lens system **343**.

Multiple relay systems by the lens systems **371** and **372** are arranged along one optical axis of the two optical axes and an image is formed on the solid state image taking device **370** by the lens system **372**.

Also, multiple relay systems are arranged on the other optical axis. That is to say, the prism **373** for bending the optical axis is arranged near the pupil formed through the lens system **374** and on the rear side of this prism **373** are arranged the lens system **374**, prism **375**, lens system **376**, prism **377**, lens system **378** and mirror **379**. The beam is reflected by this mirror **379** arranged at the point P of intersection of this optical system and the other optical axis and forms an image on the solid state image taking device **370** through the lens system **372**.

This mirror **379** is rotatable as illustrated. The visual field direction can be selected by switching to either of the state A indicated by the solid line and the state B indicated by the dotted line. The other formations are the same components as are explained in FIG. **49**A.

In the inserted section of the rigid endoscope to which this embodiment is applied, the distance between the two optical axes cannot help being so small as to be several millimeters due to the restriction of the outside diameter. As the image is formed on one solid state image taking device **370** after the lens system **343**, in case one optical system is used the same as in the relay lens system **342**, the beam will diagonally project into the solid state image taking device **370** and a color shading will be generated. In order to prevent this phenomenon, in this embodiment, one of the two optical axes is bent by the prisms **373**, **375** and **377** on the rear side of the lens system **343** as in FIG. **60**A so that the beams having passed respectively through the two optical axes may project vertically onto the image taking surface of the solid state image taking device **370** and the generation of the color shading may be controlled.

FIG. **60**B shows a formation of a modification of FIG. **60**A. The optical system in FIG. **60**A is formed of expanded lens systems **374'**, **376'** and **378'** expanding respectively the lens systems **374**, **376** and **378** so that the image may be observed in a larger picture surface size with one of the optical systems having two visual field directions. When the formation is separated into the inserted section **380** and the camera adapter section **381** rotatably fitted to this inserted section **380** and the camera adapter section **381** is rotatably formed, the picture sizes in the respective visual field directions will be able to be selectively made large.

FIG. **61**A shows the 31st embodiment. In this embodiment, objective optical systems **391** and **391'** to be a pair on the respective optical axes separated by a distance D are provided on the distal end side of the inserted section **390** and the respective images by the optical objective systems **391** and **391'** are transmitted to the rear side respectively by the relay optical systems **392** and **392'**.

The image transmitted by the relay optical system **392** is formed on the solid state image taking device **370** by the multiple relay optical systems comprising the lens systems **371** and **372** the same as in FIG. **60**A.

Also, the image transmitted by the relay optical system **392'** is formed on the solid state image taking device **370** through the same relay systems as in FIG. **60**A, that is, the multiple relay systems by the prism **373**, lens system-**374**, prism **375**, lens system **376**, prism **377**, lens system **378**, mirror **379** and lens system **372**.

The same as in the embodiment in FIG. **60**A, as a means of switching the two optical systems, a mirror **379** is provided at the point P at which the two optical axes intersect with each other. The visual field direction can be selected by this mirror **379**.

In the modification shown in FIG. **61**B, the lens systems **374**, **376** and **378** forming the relay systems in FIG. **61**A are formed respectively of the expanded lens systems **374'**, **376'** and **378'** so that one optical system, that is, the objective optical system **391'** and relay optical system **392'** of the two optical systems arranged within the inserted section **390** may be made thinner, the outside diameter of the inserted section may be made smaller and the insertability may be improved.

Also, when the formation is separated into the inserted section **390** and the camera adapter section **393** rotatably fitted to the rear end of this inserted section and the camera adapter section **393** is rotatably formed, the picture size will be able to be selectively varied.

By the way, the present invention is not limited to these embodiments and modifications and any embodiment or modification formed by combining parts of them belongs to the present invention.

TABLE 1

Lens data of the first embodiment

r1 = ∞	d1 = 0.400	n1 = 1.7682	v1 = 71.8
r2 = ∞	d2 = 0.300		
r3 = 2.4658	d3 = 0.563	n2 = 1.883	v2 = 40.8
r4 = 0.7855	d4 = 0.453		
r5 = ∞	d5 = 0.400	n3 = 1.8061	v3 = 40.9
r6 = ∞ (pupil)	d6 = 3.340	n4 = 1.8061	v4 = 40.9
r7 = −2.7844	d7 = 0.300		
r8 = −4.5712	d8 = 0.400	n5 = 1.62004	v5 = 36.3
r9 = 13.1850	d9 = 0.730	n6 = 1.788	v6 = 47.4
r10 = −3.7741	d10 = 0.300		

TABLE 1-continued

Lens data of the first embodiment

r11 = 6.2003	d11 = 1.949	n7 = 1.60311	v7 = 60.7
r12 = −1.6595	d12 = 0.409	n8 = 1.84666	v8 = 23.8
r13 = −2.4812	d13 = 0.306		
r14 = −2.3688	d14 = 0.400	n9 = 1.78472	v9 = 25.7
r15 = −82.9824	d15 = 0.400	n10 = 1.6968	v10 = 55.5
r16 = −7.6931	d16 = 7.500		
r17 = 17.7721	d17 = 38.862	n11 = 1.51633	v11 = 64.1
r18 = −8.3001	d18 = 6.881	n12 = 1.85026	v12 = 32.3
r19 = −24.9616	d19 = 0.941		
r20 = 36.2005	d20 = 1.000	n13 = 1.8061	v13 = 40.9
r21 = ∞	d21 = 10.265	n14 = 1.51633	v14 = 64.1
r22 = ∞	d22 = 1.000	n15 = 1.8061	v15 = 40.9
r23 = −36.2005	d23 = 0.914		
r24 = 24.9616	d24 = 6.881	n16 = 1.85026	v16 = 32.3
r25 = 8.3001	d25 = 38.862	n17 = 1.51633	v17 = 64.1
r26 = −17.7721	d26 = 10.000		
r27 = 17.7721	d27 = 38.862	n18 = 1.51633	v18 = 64.1
r28 = −8.3001	d28 = 6.881	n19 = 1.85026	v19 = 32.3
r29 = −24.9616	d29 = 0.914		
r30 = 36.2005	d30 = 1.000	n20 = 1.8061	v20 = 40.9
r31 = ∞	d31 = 10.265	n21 = 1.51633	v21 = 64.1
r32 = ∞	d32 = 1.000	n22 = 1.8061	v22 = 40.9
r33 = −36.2005	d33 = 0.914		
r34 = 24.9616	d34 = 6.881	n23 = 1.85026	v23 = 32.3
r35 = 8.3001	d35 = 38.862	n24 = 1.51633	v24 = 64.1
r36 = −17.7721	d36 = 10.000		
r37 = 17.7721	d37 = 38.862	n25 = 1.51633	v25 = 64.1
r38 = −8.3001	d38 = 6.881	n26 = 1.85026	v26 = 32.3
r39 = −24.9616	d39 = 0.914		
r40 = 36.2005	d40 = 1.000	n27 = 1.8061	v27 = 40.9
r41 = ∞	d41 = 10.265	n28 = 1.51633	v28 = 64.1
r42 = ∞	d42 = 1.000	n29 = 1.8061	v29 = 40.9
r43 = −36.2005	d43 = 0.914		
r44 = 24.9616	d44 = 6.881	n30 = 1.85026	v30 = 32.3
r45 = 8.3001	d45 = 38.862	n31 = 1.51633	v31 = 64.1
r46 = −17.7721	d46 = 5.000		
r47 = ∞ (image position)			

TABLE 2

Lens data of the third embodiment

r1 = ∞	d1 = 0.400	n1 = 1.7682	v1 = 71.8
r2 = ∞	d2 = 0.300		
r3 = 3.8772	d3 = 1.527	n2 = 1.883	v2 = 40.8
r4 = 0.7999	d4 = 0.449		
r5 = ∞	d5 = 0.400	n3 = 1.8061	v3 = 40.9
r6 = ∞ (pupil)	d6 = 2.774	n4 = 1.8061	v4 = 40.9
r7 = −2.6393	d7 = 0.300		
r8 = −4.4440	d8 = 0.400	n5 = 1.62004	v5 = 36.3
r9 = 13.0243	d9 = 0.643	n6 = 1.788	v6 = 47.4
r10 = −3.4953	d10 = 0.300		
r11 = 6.6459	d11 = 1.858	n7 = 1.60311	v7 = 60.7
r12 = −1.6646	d12 = 0.416	n8 = 1.84666	v8 = 23.8
r13 = −2.4857	d13 = 0.300		
r14 = −2.4171	d14 = 0.400	n9 = 1.78472	v9 = 25.7
r15 = −5.1842	d15 = 0.400	n10 = 1.6968	v10 = 55.5
r16 = −5.8028	d16 = 7.500		
r17 = 17.0269	d17 = 39.876	n11 = 1.51633	v11 = 64.1
r18 = −9.1442	d18 = 6.480	n12 = 1.85026	v12 = 32.3
r19 = −25.2664	d19 = 0.300		
r20 = 38.6357	d20 = 1.000	n13 = 1.8061	v13 = 40.9
r21 = ∞	d21 = 10.000	n14 = 1.51633	v14 = 64.1
r22 = ∞	d22 = 1.000	n15 = 1.8061	v15 = 40.9
r23 = −38.6357	d23 = 0.300		
r24 = 25.2664	d24 = 6.480	n16 = 1.85026	v16 = 32.3
r25 = 9.1442	d25 = 39.876	n17 = 1.51633	v17 = 64.1
r26 = −17.0269	d26 = 10.000		
r27 = 17.0269	d27 = 39.876	n18 = 1.51633	v18 = 64.1
r28 = −9.1442	d28 = 6.480	n19 = 1.85026	v19 = 32.3
r29 = −25.2664	d29 = 0.300		
r30 = 38.6357	d30 = 1.000	n20 = 1.8061	v20 = 40.9
r31 = ∞	d31 = 10.000	n21 = 1.51633	v21 = 64.1
r32 = ∞	d32 = 1.000	n22 = 1.8061	v22 = 40.9

TABLE 2-continued

Lens data of the third embodiment

r33 = −38.6357	d33 = 0.300		
r34 = 25.2664	d34 = 6.480	n23 = 1.85026	v23 = 32.3
r35 = 9.1442	d35 = 39.876	n24 = 1.51633	v24 = 64.1
r36 = −17.0269	d36 = 10.000		
r37 = 17.0269	d37 = 39.876	n25 = 1.51633	v25 = 64.1
r38 = −9.1442	d38 = 6.480	n26 = 1.85026	v26 = 32.3
r39 = −25.2664	d39 = 0.300		
r40 = 38.6357	d40 = 1.000	n27 = 1.8061	v27 = 40.9
r41 = ∞	d41 = 10.000	n28 = 1.51633	v28 = 64.1
r42 = ∞	d42 = 1.000	n29 = 1.8061	v29 = 40.9
r43 = −38.6357	d43 = 0.300		
r44 = 25.2664	d44 = 6.480	n30 = 1.85026	v30 = 32.3
r45 = 9.1442	d45 = 39.876	n31 = 1.51633	v31 = 64.1
r46 = −17.0269	d46 = 5.001		
r47 = ∞ (image position)			

TABLE 3

Lens data of the forth embodiment

r1 = ∞	d1 = 0.400	n1 = 1.7682	v1 = 71.8
r2 = ∞	d2 = 0.300		
r3 = 2.6660	d3 = 1.000	n2 = 1.883	v2 = 40.8
r4 = 0.6568	d4 = 0.465		
r5 = ∞	d5 = 0.400	n3 = 1.883	v3 = 40.8
r6 = ∞ (pupil)	d6 = 2.938	n4 = 1.883	v4 = 40.8
r7 = −2.9259	d7 = 0.300		
r8 = −10.3818	d8 = 0.400	n5 = 1.62004	v5 = 36.3
r9 = 15.1216	d9 = 0.562	n6 = 1.788	v6 = 47.4
r10 = −4.9186	d10 = 0.300		
r11 = 6.1372	d11 = 1.797	n7 = 1.618	v7 = 63.4
r12 = −1.8144	d12 = 1.075	n8 = 1.84666	v8 = 23.8
r13 = −2.6860	d13 = 0.300		
r14 = −2.2723	d14 = 0.615	n9 = 1.78472	v9 = 25.7
r15 = −14.0716	d15 = 0.437	n10 = 1.6968	v10 = 55.5
r16 = −4.9749	d16 = 7.500		
r17 = 18.4320	d17 = 37.230	n11 = 1.51633	v11 = 64.1
r18 = −8.3411	d18 = 6.671	n12 = 1.85026	v12 = 32.3
r19 = −24.0584	d19 = 0.300		
r20 = 36.1875	d20 = 1.000	n13 = 1.8061	v13 = 40.9
r21 = ∞	d21 = 10.000	n14 = 1.51633	v14 = 64.1
r22 = ∞	d22 = 1.000	n15 = 1.8061	v15 = 40.9
r23 = −36.1875	d23 = 0.300		
r24 = 24.0584	d24 = 6.671	n16 = 1.85026	v16 = 32.3
r25 = 8.3411	d25 = 37.230	n17 = 1.51633	v17 = 64.1
r26 = −18.4320	d26 = 10.000		
r27 = 18.4320	d27 = 37.230	n18 = 1.51633	v18 = 64.1
r28 = −8.3411	d28 = 6.671	n19 = 1.85026	v19 = 32.3
r29 = −24.0584	d29 = 0.300		
r30 = 36.1875	d30 = 1.000	n20 = 1.8061	v20 = 40.9
r31 = ∞	d31 = 10.000	n21 = 1.51633	v21 = 64.1
r32 = ∞	d32 = 1.000	n22 = 1.8061	v22 = 40.9
r33 = −36.1875	d33 = 0.300		
r34 = 24.0584	d34 = 6.671	n23 = 1.85026	v23 = 32.3
r35 = 8.3411	d35 = 37.230	n24 = 1.51633	v24 = 64.1
r36 = −18.4320	d36 = 10.000		
r37 = 18.4320	d37 = 37.230	n25 = 1.51633	v25 = 64.1
r38 = −8.3411	d38 = 6.671	n26 = 1.85026	v26 = 32.3
r39 = −24.0584	d39 = 0.300		
r40 = 36.1875	d40 = 1.000	n27 = 1.8061	v27 = 40.9
r41 = ∞	d41 = 10.000	n28 = 1.51633	v28 = 64.1
r42 = ∞	d42 = 1.000	n29 = 1.8061	v29 = 40.9
r43 = −36.1875	d43 = 0.300		
r44 = 24.0584	d44 = 6.671	n30 = 1.85026	v30 = 32.3
r45 = 8.3411	d45 = 37.230	n31 = 1.51633	v31 = 64.1
r46 = −18.4320	d46 = 5.000		
r47 = ∞	d47 = 6.000 (reflection plane)		
r48 = ∞	d47 = 9.000 (reflection plane)		
r49 = −15.7631	d49 = 4.949	n32 = 1.816	v32 = 46.6
r50 = −8.9021	d50 = 2.525		
r51 = 9.9691	d51 = 4.480	n33 = 1.72916	v33 = 54.7
r52 = −16.7003	d52 = 2.578	n34 = 1.7552	v34 = 27.5
r53 = 4.2972	d53 = 3.722		
r54 = 52.6411	d54 = 1.000	n35 = 1.5927	v35 = 35.3

TABLE 3-continued

Lens data of the forth embodiment

r55 = 117.6536	d55 = 7.067	n36 = 1.618	v36 = 63.4
r56 = −77.9950	d56 = 1.037		
r57 = 8.7799	d57 = 7.000	n37 = 1.72916	v37 = 54.7
r58 = 13.9542	d58 = 49.995		
r59 = ∞ (image position)			

TABLE 4

Lens data of the fifth embodiment

r1 = ∞	d1 = 0.400	n1 = 1.7682	v1 = 71.8
r2 = ∞	d2 = 0.300		
r3 = 2.8586	d3 = 1.000	n2 = 1.883	v2 = 40.8
r4 = 0.7279	d4 = 0.466		
r5 = ∞	d5 = 0.400	n3 = 1.883	v3 = 40.8
r6 = ∞ (pupil)	d6 = 2.216	n4 = 1.883	v4 = 40.8
r7 = −2.9043	d7 = 0.300		
r8 = −5.6042	d8 = 0.400	n5 = 1.62004	v5 = 36.3
r9 = 5.6154	d9 = 0.888	n6 = 1.788	v6 = 47.4
r10 = −3.6606	d10 = 0.300		
r11 = 7.1344	d21 = 1.764	n7 = 1.618	v7 = 63.4
r12 = −1.7751	d12 = 0.597	n8 = 1.84666	v8 = 23.8
r13 = −2.5646	d13 = 0.302		
r14 = −2.1629	d14 = 0.400	n9 = 1.78472	v9 = 25.7
r15 = −4.7832	d15 = 0.400	n10 = 1.6968	v10 = 55.5
r16 = −3.9862	d16 = 7.500		
r17 = 18.1763	d17 = 37.730	n11 = 1.51633	v11 = 64.1
r18 = −8.5520	d18 = 6.670	n12 = 1.85026	v12 = 32.2
r19 = −23.4978	d19 = 0.300		
r20 = 39.1240	d20 = 1.000	n13 = 1.8061	v13 = 40.9
r21 = ∞	d21 = 10.000	n14 = 1.51633	v14 = 64.1
r22 = ∞	d22 = 1.000	n15 = 1.8061	v15 = 40.9
r23 = −39.1240	d23 = 0.300		
r24 = 23.4978	d24 = 6.670	n16 = 1.85026	v16 = 32.2
r25 = 8.5520	d25 = 37.730	n17 = 1.51633	v17 = 64.1
r26 = −18.1763	d26 = 10.000		
r27 = 18.1763	d27 = 37.730	n18 = 1.51633	v18 = 64.1
r28 = −8.5520	d28 = 6.670	n19 = 1.85026	v19 = 32.2
r29 = −23.4978	d29 = 0.300		
r30 = 39.1240	d30 = 1.000	n20 = 1.8061	v20 = 40.9
r31 = ∞	d31 = 10.000	n21 = 1.51633	v21 = 64.1
r32 = ∞	d32 = 1.000	n22 = 1.8061	v22 = 40.9
r33 = −39.1240	d33 = 0.300		
r34 = 23.4978	d34 = 6.670	n23 = 1.85026	v23 = 32.2
r35 = 8.5520	d35 = 37.730	n24 = 1.51633	v24 = 64.1
r36 = −18.1763	d36 = 10.000		
r37 = 18.1763	d37 = 37.730	n25 = 1.51633	v25 = 64.1
r38 = −8.5520	d38 = 6.670	n26 = 1.85026	v26 = 32.2
r39 = −23.4978	d39 = 0.300		
r40 = 39.1240	d40 = 1.000	n27 = 1.8061	v27 = 40.9
r41 = ∞	d41 = 10.000	n28 = 1.51633	v28 = 64.1
r42 = ∞	d42 = 1.000	n29 = 1.8061	v29 = 40.9
r43 = −39.1240	d43 = 0.300		
r44 = 23.4978	d44 = 6.670	n30 = 1.85026	v30 = 32.2
r45 = 8.5520	d45 = 37.730	n31 = 1.51633	v31 = 64.1
r46 = −18.1763	d46 = 15.000		
r47 = −15.9408	d47 = 7.000	n32 = 1.816	v32 = 46.6
r48 = −10.5614	d48 = 1.898		
r49 = 20.0434	d49 = 1.000	n33 = 1.72916	v33 = 54.7
r50 = 11.2226	d50 = 1.852	n34 = 1.7552	v34 = 27.5
r51 = 8.3607	d51 = 6.099		
r52 = −24.1926	d52 = 3.535	n35 = 1.5927	v35 = 35.3
r53 = 9.6335	d53 = 9.958	n36 = 1.618	v36 = 63.4
r54 = −27.0337	d54 = 0.300		
r55 = 22.5105	d55 = 7.000	n37 = 1.72916	v37 = 54.7
r56 = 317.0029	d56 = 102.172		
r57 = ∞ (image position)			

TABLE 5

Lens data of the sixth embodiment

r1 = ∞	d1 = 0.400	n1 = 1.7682	v1 = 71.8
r2 = ∞	d2 = 0.300		
r3 = 2.5311	d3 = 1.000	n2 = 1.883	v2 = 40.8
r4 = 0.6002	d4 = 0.483		
r5 = ∞	d5 = 0.492	n3 = 1.883	v3 = 40.8
r6 = ∞ (pupil)	d6 = 2.925	n4 = 1.883	v4 = 40.8
r7 = −2.9244	d7 = 0.300		
r8 = −20.1110	d8 = 0.500	n5 = 1.62004	v5 = 36.3
r9 = 10.9637	d9 = 0.607	n6 = 1.788	v6 = 47.4
r10 = −6.2777	d10 = 0.300		
r11 = 6.1192	d11 = 1.860	n7 = 1.618	v7 = 63.4
r12 = −1.8981	d12 = 0.810	n8 = 1.84666	v8 = 23.8
r13 = −2.7109	d13 = 0.302		
r14 = −2.2811	d14 = 0.400	n9 = 1.78472	v9 = 25.7
r15 = −13.8892	d15 = 1.289	n10 = 1.6968	v10 = 55.5
r16 = −5.4300	d16 = 7.500		
r17 = 18.4228	d17 = 37.662	n11 = 1.51633	v11 = 64.1
r18 = −8.3677	d18 = 6.665	n12 = 1.85026	v12 = 32.3
r19 = −24.4094	d19 = 0.300		
r20 = 35.7941	d20 = 1.000	n13 = 1.8061	v13 = 40.9
r21 = ∞	d21 = 10.000	n14 = 1.51633	v14 = 64.1
r22 = ∞	d22 = 1.000	n15 = 1.8061	v15 = 40.9
r23 = −35.7941	d23 = 0.300		
r24 = 24.4094	d24 = 6.665	n16 = 1.85026	v16 = 32.3
r25 = 8.3677	d25 = 37.662	n17 = 1.51633	v17 = 64.1
r26 = −18.4228	d26 = 10.000		
r27 = 18.4228	d27 = 37.662	n18 = 1.51633	v18 = 64.1
r28 = −8.3677	d28 = 6.665	n19 = 1.85026	v19 = 32.3
r29 = −24.4094	d29 = 0.300		
r30 = 35.7941	d30 = 1.000	n20 = 1.8061	v20 = 40.9
r31 = ∞	d31 = 10.000	n21 = 1.51633	v21 = 64.1
r32 = ∞	d32 = 1.000	n22 = 1.8061	v22 = 40.9
r33 = −35.7941	d33 = 0.300		
r34 = 24.4094	d34 = 6.665	n23 = 1.85026	v23 = 32.3
r35 = 8.3677	d35 = 37.662	n24 = 1.51633	v24 = 64.1
r36 = −18.4228	d36 = 10.000		
r37 = 18.4228	d37 = 37.662	n25 = 1.51633	v25 = 64.1
r38 = −8.3677	d38 = 6.665	n26 = 1.85026	v26 = 32.3
r39 = −24.4094	d39 = 0.300		
r40 = 35.7941	d40 = 1.000	n27 = 1.8061	v27 = 40.9
r41 = ∞	d41 = 10.000	n28 = 1.51633	v28 = 64.1
r42 = ∞	d42 = 1.000	n29 = 1.8061	v29 = 40.9
r43 = −35.7941	d43 = 0.300		
r44 = 24.4094	d44 = 6.665	n30 = 1.85026	v30 = 32.3
r45 = 8.3677	d45 = 37.662	n31 = 1.51633	v31 = 64.1
r46 = −18.4228	d46 = 5.000		
r47 = ∞	d47 = 11.000		
r48 = −10.3813	d48 = 5.655	n32 = 1.816	v32 = 46.6
r49 = −8.8890	d49 = 0.483		
r50 = 7.4696	d50 = 3.769	n33 = 1.72916	v33 = 54.7
r51 = 181.6429	d51 = 2.093	n34 = 1.7552	v34 = 27.5
r52 = 4.4460	d52 = 3.047		
r53 = −30.7603	d53 = 1.001	n35 = 1.5927	v35 = 353
r54 = 41.5845	d54 = 1.706	n36 = 1.618	v36 = 63.4
r55 = −17.8259	d55 = 0.342		
r56 = 7.9775	d56 = 5.749	n37 = 1.72916	v37 = 54.7
r57 = 12.6259	d57 = 39.986		
r58 = ∞ (image position)			

TABLE 6

Lens data of the tenth embodiment

r1 = ∞	d1 = 0.400	n1 = 1.7682	v1 = 71.8
r2 = ∞	d2 = 0.500		
r3 = −15.1509	d3 = 0.500	n2 = 1.883	v2 = 40.8
r4 = 1.8541	d4 = 0.400		
r5 = ∞	d5 = 1.471	n3 = 1.8061	v3 = 40.9
r6 = ∞ (pupil)	d6 = 8.000	n4 = 1.8061	v4 = 40.9
r7 = −6.3400	d7 = 0.300		
r8 = 29.8778	d8 = 6.980	n5 = 1.60311	v5 = 60.7
r9 = −76.5455	d9 = 2.000		
r10 = 11.8863	d10 = 12.000	n6 = 1.60311	v6 = 60.7
r11 = −14.2286	d11 = 1.000	n7 = 1.84666	v7 = 23.8

TABLE 6-continued

Lens data of the tenth embodiment

r12 = 6.6719	d12 = 1.327		
r13 = 16.2399	d13 = 1.000	n8 = 1.84666	v8 = 23.8
r14 = 6.8781	d14 = 2.641	n9 = 1.60311	v9 = 60.7
r15 = −16.3999	d15 = 0.300		
r16 = 9.6243	d16 = 2.045	n10 = 1.72916	v10 = 54.7
r17 = 42.1473	d17 = 12.000		
r18 = 20.3224	d18 = 28.648	n11 = 1.51633	v11 = 64.1
r19 = −9.1270	d19 = 1.000	n12 = 1.85026	v12 = 32.3
r20 = −17.5105	d20 = 0.300		
r21 = 37.3211	d21 = 2.038	n13 = 1.8061	v13 = 40.9
r22 = ∞	d22 = 25.393	n14 = 1.51633	v14 = 64.1
r23 = ∞	d23 = 2.038	n15 = 1.8061	v15 = 40.9
r24 = −37.3211	d24 = 0.300		
r25 = 17.5105	d25 = 1.000	n16 = 1.85026	v16 = 32.3
r26 = 9.1270	d26 = 28.648	n17 = 1.51633	v17 = 64.1
r27 = −20.3224	d27 = 14.000		
r28 = 20.3224	d28 = 28.648	n18 = 1.51633	v18 = 64.1
r29 = −9.1270	d29 = 1.000	n19 = 1.85026	v19 = 32.3
r30 = −17.5105	d30 = 0.300		
r31 = 37.3211	d31 = 2.038	n20 = 1.8061	v20 = 40.9
r32 = ∞	d32 = 25.393	n21 = 1.51633	v21 = 64.1
r33 = ∞	d33 = 2 038	n22 = 1.8061	v22 = 40.9
r34 = −37.3211	d34 = 0.300		
r35 = 17.5105	d35 = 1.000	n23 = 1.85026	v23 = 32.3
r36 = 9.1270	d36 = 28.648	n24 = 1.51633	v24 = 64.1
r37 = −20.3224	d37 = 14.000		
r38 = 20.3224	d38 = 28.648	n25 = 1.51633	v25 = 64.1
r39 = −9.1270	d39 = 1.000	n26 = 1.85026	v26 = 32.3
r40 = −17.5105	d40 = 0.300		
r41 = 37.3211	d41 = 2.038	n27 = 1.8061	v27 = 40.9
r42 = ∞	d42 = 25.393	n28 = 1.51633	v28 = 64.1
r43 = ∞	d43 = 2.038	n29 = 1.8061	v29 = 40.9
r44 = −37.3211	d44 = 0.300		
r45 = 17.5105	d45 = 1.000	n30 = 1.85026	v30 = 32.3
r46 = 9.1270	d46 = 28.648	n31 = 1.51633	v31 = 64.1
r47 = −20 3224	d47 = 17.000		
r48 = −14.8821	d48 = 2.846	n32 = 1.72916	v32 = 54.7
r49 = −8.8016	d49 = 0.300		
r50 = 15.1352	d50 = 4.084	n33 = 1.618	v33 = 63.4
r51 = −7.3338	d51 = 1.000	n34 = 1.5927	v34 = 35.3
r52 = 9.5056	d52 = 4.000		
r53 = −16.8952	d53 = 2.000	n35 = 1.7552	v35 = 27.5
r54 = −13.2379	d54 = 2.000	n36 = 1.72916	v36 = 54.7
r55 = −23.2387	d55 = 0.300		
r56 = 22.9913	d56 = 2.000	n37 = 1.816	v37 = 46.6
r57 = 89.7162	d57 = 15.000		
r58 = ∞	d58 = 6.000 (reflection plane)		
r59 = ∞	d59 = 4.000 (reflection plane)		
r60 = 22.5828	d60 = 1.000	n38 = 1.78472	v38 = 25.7
r61 = 6.1627	d61 = 3.276	n39 = 1.55963	v39 = 61.2
r62 = 9.4965	d62 = 1.747		
r63 = 13.6433	d63 = 3.041	n40 = 1.60311	v40 = 60.7
r64 = −11.6980	d64 = 29.780		
r65 = ∞ (image position)			

TABLE 9

Lens data of the eleventh embodiment

r1 = ∞	d1 = 0.400	n1 = 1.7682	v1 = 71.8
r2 = ∞	d2 = 0.500		
r3 = −27.1944	d3 = 0.500	n2 = 1.883	v2 = 40.8
r4 = 1.6149	d4 = 0.400		
r5 = ∞	d5 = 0.648	n3 = 1.8061	v3 = 40.9
r6 = ∞ (pupil)	d6 = 8.000	n4 = 4.8061	v4 = 40.9
r7 = −5.9410	d7 = 0.300		
r8 = 34.5218	d8 = 1.405	n5 = 1.60311	v5 = 60.7
r9 = −44.4283	d9 = 1.636		
r10 = 10.5798	d10 = 11.910	n6 = 1.60311	v6 = 60.7
r11 = −9.6402	d11 = 1.000	n7 = 1.84666	v7 = 23.8
r12 = 5.5533	d12 = 1.354		
r13 = 16.9402	d13 = 1.000	n8 = 1.84666	v8 = 23.8
r14 = 5.6237	d14 = 2.775	n9 = 1.60311	v9 = 60.7
r15 = −11.8857	d15 = 0.300		

TABLE 9-continued

Lens data of the eleventh embodiment

r16 = 9.6717	d16 = 2.054	n10 = 1.72916	v10 = 54.7
r17 = 67.8305	d17 = 12.000		
r18 = 19.4101	d18 = 30.497	n11 = 1.51633	v11 = 64.1
r19 = −9.3708	d19 = 1.000	n12 = 1.85026	v12 = 32.3
r20 = −18.4223	d20 = 0.300		
r21 = 37.3503	d21 = 1.000	n13 = 1.8061	v13 = 40.9
r22 = ∞	d22 = 29.679	n14 = 1.51633	v14 = 64.1
r23 = ∞	d23 = 1.000	n15 = 1.8061	v15 = 40.9
r24 = −37.3503	d24 = 0.300		
r25 = 18.4223	d25 = 1.000	n16 = 1.8.5026	v16 = 32.3
r26 = 9.3708	d26 = 30.497	n17 = 1.51633	v17 = 64.1
r27 = −19.4101	d27 = 14.000		
r28 = 19.4101	d28 = 30.497	n18 = 1.51633	v18 = 64.1
r29 = −9.3708	d29 = 1.000	n19 = 1.85026	v19 = 32.3
r30 = −18.4223	d30 = 0.300		
r31 = 37.3503	d31 = 1.000	n20 = 1.8061	v20 = 40.9
r32 = ∞	d32 = 29.679	n21 = 1.51633	v21 = 64.1
r33 = ∞	d33 = 1.000	n22 = 1.8061	v22 = 40.9
r34 = −37.3503	d34 = 0.300		
r35 = 18.4223	d35 = 1.000	n23 = 1.85026	v23 = 32.3
r36 = 9.3708	d36 = 30.497	n24 = 1.51633	v24 = 64.1
r37 = −19.4101	d37 = 14.000		
r38 = 19.4101	d38 = 30.497	n25 = 1.51633	v25 = 64.1
r39 = −9.3708	d39 = 1.000	n26 = 1.85026	v26 = 32.3
r40 = −18.4223	d40 = 0.300		
r41 = 37.3503	d41 = 1.000	n27 = 1.8061	v27 = 40.9
r42 = ∞	d42 = 29.679	n28 = 1.51633	v28 = 64.1
r43 = ∞	d43 = 1.000	n29 = 1.8061	v29 = 40.9
r44 = −37.3503	d44 = 0.300		
r45 = 18.4223	d45 = 1.000	n30 = 1.85026	v30 = 32.3
r46 = 9.3708	d46 = 30.497	n31 = 1.51633	v31 = 64.1
r47 = −19.4101	d47 = 19.000		
r48 = −14.3213	d48 = 7.000	n32 = 1.72916	v32 = 54.7
r49 = −11.0960	d49 = 0.300		
r50 = 33.1140	d50 = 1.047	n33 = 1.618	v33 = 63.4
r51 = 9.1082	d51 = 7.000	n34 = 1.5927	v34 = 35.3
r52 = 67.5887	d52 = 3.277		
r53 = −9.9528	d53 = 7.000	n35 = 1.7552	v35 = 27.5
r54 = 41.3894	d54 = 10.000	n36 = 1.72916	v36 = 54.7
r55 = −19.8178	d55 = 3.000		
r56 = −63.2683	d56 = 7.000	n37 = 1.816	v37 = 46.6
r57 = −41.6536	d57 = 6.621		
r58 = 20.1426	d58 = 2.426	n38 = 1.51633	v38 = 64.1
r59 = −122.3553	d59 = 5.000	n39 = 1.78472	v39 = 25.7
r60 = 32.7733	d60 = 2.000		
r61 = 21.5258	d61 = 5.000	n40 = 1.5725	v40 = 57.8
r62 = 563.4090	d62 = 36.001		
r63 = ∞ (image position)			

TABLE 8

Lens data of the twelfth embodiment

r1 = ∞	d1 = 0.400	n1 = 1.7682	v1 = 71.8
r2 = ∞	d2 = 0.500		
r3 = −5.6176	d3 = 8.000	n2 = 1.883	v2 = 40.8
r4 = ∞ (pupil)	d4 = 8.000	n3 = 1.883	v3 = 40.8
r5 = −10.6525	d5 = 1.727		
r6 = 225.1706	d6 = 1.024	n4 = 1.60311	v4 = 60.7
r7 = 794.5057	d7 = 0.803		
r8 = 7.7627	d8 = 3.448	n5 = 1.6968	v5 = 55.5
r9 = 7.0551	d9 = 1.200	n6 = 1.84666	v6 = 23.8
r10 = 6.6689	d10 = 1.754		
r11 = 21.0094	d11 = 1.000	n7 = 1.84666	v7 = 23.8
r12 = 5.2971	d12 = 3.637	n8 = 1.60311	v8 = 60.7
r13 = −17.1652	d13 = 0.300		
r14 = 9.0345	d14 = 2.401	n9 = 1.72916	v9 = 54.7
r15 = 40.5646	d15 = 12.000		
r16 = 19.9468	d16 = 30.262	n10 = 1.51633	v10 = 64.1
r17 = −9.0769	d17 = 1.018	n11 = 1.85026	v11 = 32.3
r18 = −18.5715	d18 = 0.300		
r19 = 34.7626	d19 = 3.093	n12 = 1.8061	v12 = 40.9
r20 = ∞	d20 = 19.606	n13 = 1.51633	v13 = 64.1
r21 = ∞	d21 = 3.093	n14 = 1.8061	v14 = 40.9

TABLE 8-continued

Lens data of the twelfth embodiment

r22 = −34.7626	d22 = 0.300		
r23 = 18.5715	d23 = 1.018	n15 = 1.85026	v15 = 32.3
r24 = 9.0769	d24 = 30.262	n16 = 1.51633	v16 = 64.1
r25 = −19.9468	d25 = 14.000		
r26 = 19.9468	d26 = 30.262	n17 = 1.51633	v17 = 64.1
r27 = −9.0769	d27 = 1.018	n18 = 1.85026	v18 = 32.3
r28 = −18.5715	d28 = 0.300		
r29 = 34.7626	d29 = 3.093	n19 = 1.8061	v19 = 40.9
r30 = ∞	d30 = 19.606	n20 = 1.51633	v20 = 64.1
r31 = ∞	d31 = 3.093	n21 = 1.8061	v21 = 40.9
r32 = −34.7626	d32 = 0.300		
r33 = 18.5715	d33 = 1.018	n22 = 1.85026	v22 = 32.3
r34 = 9.0769	d34 = 30.262	n23 = 1.51633	v23 = 64.1
r35 = −19.9468	d35 = 14.000		
r36 = 19.9468	d36 = 30.262	n24 = 1.51633	v24 = 64.1
r37 = −9.0769	d37 = 1.018	n25 = 1.85026	v25 = 32.3
r38 = −18.5715	d38 = 0.300		
r39 = 34.7626	d39 = 3.093	n26 = 1.8061	v26 = 40.9
r40 = ∞	d40 = 19.606	n27 = 1.51633	v27 = 64.1
r41 = ∞	d41 = 3.093	n28 = 1.8061	v28 = 40.9
r42 = −34.7626	d42 = 0.300		
r43 = 18.5715	d43 = 1.018	n29 = 1.85026	v29 = 32.3
r44 = 9.0769	d42 = 30.262	n30 = 1.51633	v30 = 64.1
r45 = −19.9468	d45 = 19.000		
r46 = −11.8408	d46 = 5.820	n31 = 1.72916	v31 = 54.7
r47 = −9.1946	d47 = 0.300		
r48 = 24.0775	d48 = 10.000	n32 = 1.618	v32 = 63.4
r49 = −26.2109	d49 = 7.000	n33 = 1.5927	v33 = 35.3
r50 = 63.4749	d50 = 3.000		
r51 = −8.3204	d51 = 5.376	n34 = 1.7552	v34 = 27.5
r52 = −38.8722	d52 = 10.000	n35 = 1.72916	v35 = 54.7
r53 = −19.1304	d53 = 3.000		
r54 = −83.1506	d54 = 7.000	n36 = 1.816	v36 = 46.6
r55 = −41.8244	d55 = 8.346		
r56 = −26.1283	d56 = 4.325	n37 = 1.51633	v37 = 64.1
r57 = −7.8805	d57 = 4.552	n38 = 1.78472	v38 = 25.7
r58 = −14.4880	d58 = 0.300		
r59 = 31.7804	d59 = 5.000	n39 = 1.5725	v39 = 57.8
r60 = 6326.3883	d60 = 36.032		
r61 = ∞ (image position)			

TABLE 9

Lens data of the thirteenth embodiment

r1 = ∞	d1 = 0.400	n1 = 1.7682	v1 = 71.8
r2 = ∞	d2 = 0.500		
r3 = 14.7408	d3 = 0.500	n2 = 1.883	v2 = 40.8
r4 = 1.5441	d4 = 0.400		
r5 = ∞	d5 = 0.572	n3 = 1.8061	v3 = 40.9
r6 = ∞ (pupil)	d6 = 7.966	n4 = 1.8061	v4 = 40.9
r7 = −5.9996	d7 = 0.300		
r8 = 38.8172	d8 = 1.360	n5 = 1.60311	v5 = 60.7
r9 = −54.0250	d9 = 1.040		
r10 = 10.8354	d10 = 11.720	n6 = 1.60311	v6 = 60.7
r11 = −36.1554	d11 = 1.000	n7 = 1.84666	v7 = 23.8
r12 = 5.7085	d12 = 1.444		
r13 = 17.6383	d13 = 1.000	n8 = 1.84666	v8 = 23.8
r14 = 5.3388	d14 = 3.339	n9 = 1.60311	v9 = 60.7
r15 = −10.4808	d15 = 0.300		
r16 = 10.4139	d16 = 2.316	n10 = 1.72916	v10 = 54.7
r17 = 1299.7086	d17 = 12.000		
r18 = 20.9531	d18 = 28.137	n11 = 1.51633	v11 = 64.1
r19 = −9.0377	d19 = 1.029	n12 = 1.85026	v12 = 32.3
r20 = −17.1424	d20 = 0.300		
r21 = 37.8341	d21 = 1.462	n13 = 1.8061	v13 = 40.9
r22 = ∞	d22 = 26.759	n14 = 1.51633	v14 = 64.1
r23 = ∞	d23 = 1.462	n15 = 1.8061	v15 = 40.9
r24 = −37.8341	d24 = 0.30.0		
r25 = 17.1424	d25 = 1 029	n16 = 1.85026	v16 = 32.3
r26 = 9.0377	d26 = 28.137	n17 = 1.51633	v17 = 64.1
r27 = −20.9531	d27 = 14.000		
r28 = 20.9531	d28 = 28.137	n18 = 1.51633	v18 = 64.1
r29 = −9.0377	d29 = 1.029	n19 = 1.85026	v19 = 32.3

TABLE 9-continued

Lens data of the thirteenth embodiment

r30 = −17.1424	d30 = 0.300		
r31 = 37.8341	d31 = 1.462	n20 = 1.8061	v20 = 40.9
r32 = ∞	d32 = 26.759	n21 = 1.51633	v21 = 64.1
r33 = ∞	d33 = 1.462	n22 = 1.8061	v22 = 40.9
r34 = −37.8341	d34 = 0.300		
r35 = 17.1424	d35 = 1.029	n23 = 1.85026	v23 = 32.3
r36 = 9.0377	d36 = 28.137	n24 = 1.51633	v24 = 64.1
r37 = −20.9531	d37 = 14.000		
r38 = 20.9531	d38 = 28.137	n25 = 1.51633	v25 = 64.1
r39 = −9.0377	d39 = 1.029	n26 = 1.85026	v26 = 32.3
r40 = −17.1424	d40 = 0.300		
r41 = 37.8341	d41 = 1.462	n27 = 1.8061	v27 = 40.9
r42 = ∞	d42 = 26.759	n28 = 1.51633	v28 = 64.1
r43 = ∞	d43 = 1.462	n29 = 1.8061	v29 = 40.9
r44 = −37.8341	d44 = 0.300		
r45 = 17.1424	d45 = 1.029	n30 = 1.85026	v30 = 32.3
r46 = 9.0377	d46 = 28.137	n31 = 1.51633	v31 = 64.1
r47 = −20.9531	d47 = 19.000		
r48 = −13.4332	d48 = 7.000	n32 = 1.72916	v32 = 54.7
r49 = −11.0047	d49 = 0.300		
r50 = 17.1878	d50 = 5.837	n33 = 1.618	v33 = 63.4
r51 = 57.8341	d51 = 7.000	n34 = 1.5927	v34 = 35.3
r52 = 38.7072	d52 = 4.174		
r53 = −8.1955	d53 = 6.919	n35 = 1.7552	v35 = 27.5
r54 = 42.2429	d54 = 10.000	n36 = 1.72916	v36 = 54.7
r55 = −19.4465	d55 = 0.300		
r56 = 944.8567	d56 = 4.699	n37 = 1.816,	v37 = 46.6
r57 = −50.3836	d57 = 18.931		
r58 = 136.6914	d58 = 5.000	n38 = 1.51633	v38 = 64.1
r59 = −21.5686	d59 = 5.000	n39 = 1.78472	v39 = 25.7
r60 = −47.7722	d60 = 3.000		
r61 = 24.4617	d61 = 5.000	n40 = 1.5725	v40 = 57.8
r62 = 207.2457	d62 = 24.000		
r63 = ∞ (image position)			

TABLE 10

Lens data of the twenty third embodiment

r1 = ∞	d1 = 0.4	n1 = 1.769000	v1 = 71.8
r2 = ∞	d2 = 0.3		
r3 = ∞	d3 = 0.5	n2 = 1.784720	v2 = 25.8
r4 = 2.18120	d4 = 0.8		
r5 = ∞	d5 = 6.524779	n3 = 1.806098	v3 = 40.9
r6 = ∞	d6 = 0.000000	n4 = 1.806098	v4 = 40.9
r7 = ∞	d7 = 10.000000	n5 = 1.806098	v5 = 40.9
r8 = −18.90821	d8 = 2.000000		
r9 = 11.34978	d9 = 7.000000	n6 = 1.589130	v6 = 61.2
r10 = −6.85269	d10 = 7.000000	n7 = 1.784718	v7 = 25.7
r11 = −9.21315	d11 = 1.757525		
r12 = −5.83605	d12 = 1.329338	n8 = 1.784718	v8 = 25.7
r13 = 21.54459	d13 = 5.000000	n9 = 1.772499	v9 = 49.6
r14 = −9.87710	d14 = 0.300000		
r15 = 23.34659	d15 = 5.000000	n10 = 1.729157	v10 = 54.7
r16 = −46.95906	d16 = 9.832604		

TABLE 11

Lens data of the twenty fourth embodiment

r1 = ∞	d1 = 0.4	n1 = 1.769000	v1 = 71.8
r2 = ∞	d2 = 0.3		
r3 = ∞	d3 = 0.5	n2 = 1.784720	v2 = 25.8
r4 = 2.24795	d4 = 0.8		
r5 = ∞	d5 = 26.000000	n3 = 1.806098	v3 = 40.9
r6 = ∞	d6 = 0.000000	n4 = 1.806098	v4 = 40.9
r7 = ∞	d7 = 28.856575	n5 = 1.806098	v5 = 40.9
r8 = −36.97230	d8 = 15.000000		
r9 = 10.27055	d9 = 13.872951	n6 = 1.496999	v6 = 31.6
r10 = −6.76542	d10 = 8.669330	n7 = 1.846660	v7 = 23.8
r11 = −12.08426	d11 = 4.358284		
r12 = −6.61021	d12 = 3.807170	n8 = 1.846660	v8 = 23.8

TABLE 11-continued

Lens data of the twenty fourth embodiment

r13 = −10.66959	d13 = 4.004968	n9 = 1.772499	v9 = 49.6
r14 = −10.95412	d14 = 3.679284		
r15 = −13.63092	d15 = 8.940710	n10 = 1.729157	v10 = 54.7
r16 = −11.40751	d16 = 9.956806		
r17 = 18.08889	d17 = 37.945337	n11 = 1.516330	v11 = 64.1
r18 = −8.56598	d18 = 6.671087	n12 = 1.850259	v12 = 32.3
r19 = −23.41526	d19 = 0.300000		
r20 = 39.63203	d20 = 1.000000	n13 = 1.806098	v13 = 40.9
r21 = ∞	d21 = 5.000000	n14 = 1.516330	v14 = 64.1
r22 = ∞	d22 = 5.00 0000	n15 = 1.516330	v15 = 64.1
r23 = ∞	d22 = 1.000000	n16 = 1.806098	v16 = 40.9
r24 = −39.63203	d23 = 0.300000		
r25 = 23.41526	d25 = 6.671087	n17 = 1.850259	v17 = 32.3
r26 = 8.56598	d26 = 37.945337	n18 = 1.516330	v18 = 64.1
r27 = −18.08889	d27 = 10.000000		
r28 = 18.08889	d28 = 37.945337	n19 = 1.516330	v19 = 64.1
r29 = −8.56598	d29 = 6.671087	n20 = 1.850259	v20 = 32.3
r30 = −23.41526	d30 = 0.300000		
r31 = 39.63203	d31 = 1.000000	n21 = 1.806098	v21 = 40.9
r32 = ∞	d32 = 5.000000	n22 = 1.516330	v22 = 64.1
r33 = ∞	d33 = 5.000000	n21 = 1.516330	v21 = 64.1
r34 = ∞	d34 = 1.000000	n22 = 1.806098	v22 = 40.9
r35 = −39.63203	d35 = 0.300000		
r36 = 23.41526	d36 = 6.671087	n25 = 1.850259	v25 = 32.3
r37 = 8.56598	d37 = 37.945337	n26 = 1.516330	v26 = 64.1
r38 = −18.08889	d38 = 10.000000		
r39 = 18.08889	d39 = 37.945337	n27 = 1.516330	v27 = 64.1
r40 = −8.56598	d40 = 6.671087	n28 = 1.850259	v28 = 32.3
r41 = −23.41526	d41 = 0.300000		
r42 = 39.63203	d42 = 1.000000	n29 = 1.806098	v29 = 40.9
r43 = ∞	d43 = 5.000000	n30 = 1.516330	v30 = 64.1
r44 = ∞	d44 = 5.000000	n31 = 1.516330	v31 = 64.1
r45 = ∞	d45 = 1.000000	n32 = 1.806098	v32 = 40.9
r46 = −39.63203	d46 = 0.300000		
r47 = 23.41526	d47 = 6.671087	n33 = 1.850259	v33 = 32.3
r48 = 8.56598	d47 = 37.945337	n34 = 1.516330	v34 = 64.1
r49 = −18.08889	d49 = 15.000000		
r50 = −15.76035	d50 = 7.000000	n35 = 1.816000	v35 = 46.6
r51 = 10.49216	d51 = 0.300000		
r52 = 19.16924	d52 = 1.000000	n36 = 1.729157	v36 = 54.7
r53 = 10.37555	d53 = 1.000000	n37 = 1.755199	v37 = 27.5
r54 = 8.20791	d54 = 6.363656		
r55 = −24.61446	d55 = 3.366619	n38 = 1.592701	v38 = 35.3
r56 = 9.99541	d56 = 9.925109	n39 = 1.618000	v39 = 63.4
r57 = −27.28005	d57 = 0.547138		
r58 = 22.89857	d58 = 7.000000	n40 = 1.729157	v40 = 54.7
r59 =465.13444	d59 = 100.501554		

TABLE 12

Lens data of the twenty fifth embodiment

R	D	N	v
r1 = ∞	d1 = 0.400000	n1 = 1.769000	v1 = 71.8
r2 = ∞	d2 = 0.300000		
r3 = −5.97394	d3 = 0.500000	n2 = 1.784720	v2 = 25.8
r4 = −81.88587	d4 = 0.400000		
r5 = ∞	d5 = 7.000000	n3 = 1.806098	v3 = 40.9
r6 = ∞	d6 = 0.000000	n4 = 1.806098	v4 = 40.9
r7 = ∞	d7 = 5.000000	n5 = 1.806098	v5 = 40.9
r8 = −19.02807	d8 = 0.300000		
r9 = 19.68776	d9 = 1.500000	n6 = 1.603112	v6 = 60.7
r10 = −143.32901	d10 = 0.300000		
r11 = 8.84970	d11 = 2.000000	n7 = 1.603112	v7 = 60.7
r12 = 205.54794	d12 = 2.000000	n8 = 1.846660	v8 = 23.8
r13 = 7.54926	d13 = 3.000000		
r14 = 11.00667	d14 = 3.000000	n9 = 1.846660	v9 = 23.8
r15 = 6.70344	d15 = 2.697123	n10 = 1.603112	v10 = 60.7
r16 = −29.22995	d16 = 0.300000		
r17 = 25.03133	d17 = 5.000000	n11 = 1.729157	v11 = 54.7
r18 = −19.09934	d18 = 14.067359		
r19 = 20.97714	d19 = 31.002854	n12 = 1.516330	v12 = 64.1
r20 = −9.61884	d20 = 1.000000	n13 = 1.850259	v13 = 32.3

TABLE 12-continued

Lens data of the twenty fifth embodiment

R	D	N	v
r21 = −18.35394	d21 = 0.300000		
r22 = 39.59182	d22 = 1.000000	n14 = 1.806098	v14 = 40.9
r23 = ∞	d23 = 12.733214	n15 = 1.516330	v15 = 64.1
r24 = ∞	d24 = 12.733214	n16 = 1.516330	v16 = 64.1
r25 = ∞	d25 = 1.000000	n17 = 1.806098	v17 = 40.9
r26 = −39.59182	d26 = 0.300000		
r27 = 18.35394	d27 = 1.000000	n18 = 1.850259	v18 = 32.3
r28 = 9.61884	d28 = 31.002854	n19 = 1.516330	v19 = 64.1
r29 = −20.97714	d29 = 13.999522		
r30 = 20.97714	d30 = 31.002854	n20 = 1.516330	v20 = 64.1
r31 = −9.61884	d31 = 1.000000	n21 = 1.850259	v21 = 32.3
r32 = −18.35394	d32 = 0.300000		
r33 = 39.59182	d33 = 1.000000	n22 = 1.806098	v22 = 40.9
r34 = ∞	d34 = 12.733214	n23 = 1.516330	v23 = 64.1
r35 = ∞	d35 = 12.733214	n24 = 1.516330	v24 = 64.1
r36 = ∞	d36 = 1.000000	n25 = 1.806098	v25 = 40.9
r37 = −39.59182	d37 = 0.300000		
r38 = 18.35394	d38 = 1.000000	n26 = 1.850259	v26 = 32.3
r39 = 9.61884	d39 = −31.002854	n27 = 1.516330	v27 = 64.1
r40 = −20.97714	d40 = 22.951000		
r41 = 51.24000	d41 = 4.900000	n28 = 1.712995	v28 = 53.9
r42 = −30.80800	d42 = 0.350000		
r43 = 15.16600	d43 = 4.930000	n29 = 1.617001	v29 = 62.8
r44 = 4.26000	d44 = 1.650000	n30 = 1.592701	v30 = 35.3
r45 = 10.61000	d45 = 7.000000		
r46 = −8.87100	d46 = 2.070000	n31 = 1.755199	v31 = 27.5
r47 = −42.79500	d47 = 7.380000	n32 = 1.696800	v32 = 56.5
r48 = −13.94800	d48 = 0.480000		
r49 = ∞	d49 = 4.700000	n33 = 1.804000	v34 = 46.6
r50 = −45.75100	d50 = 8.660000		
r51 = 47.10400	d51 = 3.500000	n34 = 1.516330	v34 = 64.1
r52 = −22.01500	d52 = 1.500000	n35 = 1.784718	v35 = 25.7
r53 = −48.13700	d53 = 1.000000		
r54 = 79.15800	d54 = 3.000000	n36 = 1.572501	v36 = 57.8
r55 = −79.15800	d55 = 32.098487		

TABLE 13

Lens data of the twenty sixth embodiment

r1 = ∞	d1 = 1.0	n1 = 1.51633	v1 = 64.15
r2 = ∞	d2 = 0.3		
r3 = ∞	d3 = 1.5	n2 = 1.72916	v2 = 54.68
r4 = 4.4560	d4 = 2.5		
r5 = ∞	d5 = 22.02	n3 = 1.88300	v3 = 40.78
r6 = ∞ (pupil)	d6 = 5.39	n4 = 1.88300	v4 = 40.78
r7 = −10.3990	d7 = 1.02		
r8 = −8.6190	d8 = 2.0	n5 = 1.62004	v5 = 36.25
r9 = ∞	d9 = 3.5	n6 = 1.788	v6 = 47.38
r10 = −14.1680	d10 = 2.28		
r11 = 24.1810	d11 = 6.14	n7 = 1.51633	v7 = 64.15
r12 = −11.7470	d12 = 3.0	n8 = 1.78472	v8 = 25.71
r13 = ∞	d13 = 8.65		
r14 = 38.2890	d14 = 3.0	n9 = 1.59551	v9 = 39.21
r15 = 11.4220	d15 = 6.0	n10 = 1.51633	v10 = 64.15
r16 = −19.2720	d16 = 10.0		

TABLE 14

Lens data of the twenty seventh embodiment

r1 = ∞	d1 = 0.4	n1 = 1.7682	v1 = 71.8
r2 = ∞	d2 = 0.5		
r3 = −12.44196	d3 = 0.5	n2 = 1.883	v2 = 40.8
r4 = 3.50665	d4 = 0.4		
r5 = ∞	d5 = 7.0	n3 = 1.80610	v3 = 40.9
r6 = ∞ (pupil)	d6 = 7.0	n4 = 1.80610	v4 = 40.9
r7 = −9.32306	d7 = 0.3		
r8 = 24.40418	d8 = 1.3301	n5 = 1.60311	v5 = 60.7
r9 = −51.70650	d9 = 0.8047		

TABLE 14-continued

Lens data of the twenty seventh embodiment

r10 = 10.49630	d10 = 10.0	n6 = 1.60311	v6 = 60.7
r11 = −12.17332	d11 = 1.0	n7 = 1.84666	v7 = 23.8
r12 = 5.56286	d12 = 1.7183		
r13 = −11.69704	d13 = 1.0	n8 = 1.84666	v8 = 23.8
r14 = −221.94536	d14 = 2.1568	n9 = 1.60311	v9 = 60.7
r15 = −8.24002	d15 = 0.3		
r16 = 10.31164	d16 = 2.3746	n10 = 1.72916	v10 = 54.7
r17 = −30.38097	d17 = 12.0		
r18 = 20.97714	d18 = 31.0029	n11 = 1.51633	v11 = 64.1
r19 = −9.61884	d19 = 1.0	n12 = 1.85026	v12 = 32.3
r20 = −18.35394	d20 = 0.3		
r21 = 39.59182	d21 = 1.0	n13 = 1.8061	v13 = 40.9
r22 = ∞	d22 = 25.4664	n14 = 1.51633	v14 = 64.1
r23 = ∞	d22 = 1.0	n15 = 1.8061	v15 = 40.9
r24 = −39.59182	d23 = 0.3		
r25 = 18.35394	d25 = 1.0	n16 = 1.85026	v16 = 32.3
r26 = 9.61884	d26 = 31.0029	n17 = 1.51633	v17 = 64.1
r27 = −20.97714	d27 = 13.9995		
r28 = 20.97714	d28 = 31.0029	n18 = 1.51633	v18 = 64.1
r29 = −9.61884	d29 = 1.0	n19 = 1.85026	v19 = 32.3
r30 = −18.35394	d30 = 0.3		
r31 = 39.59182	d31 = 1.0	n20 = 1.8061	v20 = 40.9
r32 = ∞	d32 = 25.4664	n21 = 1.51633	v21 = 64.1
r33 = ∞	d33 = 1.0	n22 = 1.8061	v22 = 40.9
r34 = −39.59182	d34 = 0.3		
r35 = 18.35394	d35 = 1.0	n23 = 1.85026	v23 = 32.3
r36 = 9.61884	d36 = 31.0029	n24 = 1.51633	v24 = 64.1
r37 = −20.97714	d37 = 13.9995		
r38 = 20.97714	d38 = 31.0029	n25 = 1.51633	v25 = 64.1
r39 = −9.61884	d39 = 1.0	n26 = 1.85026	v26 = 32.3
r40 = −18.35394	d40 = 0.3		
r41 = 39.59182	d41 = 1.0	n27 = 1.8061	v27 = 40.9
r42 = ∞	d42 = 25.4664	n28 = 1.51633	v28 = 64.1
r43 = ∞	d43 = 1.0	n29 = 1.8061	v29 = 40.9
r44 = −39.59182	d44 = 0.3		
r45 = 18.35394	d45 = 1.0	n30 = 1.85026	v30 = 32.3
r46 = 9.6188.4	d46 = 31.0029	n31 = 1.51633	v31 = 64.1
r47 = −20.97714	d47 = 7.004		

What is claimed is:

1. A stereoendoscope, comprising:

an elongate inserted section having a distal end;

an illuminating light projecting means for projecting an illuminating light from the distal end of said inserted section;

an objective optical system arranged on the distal end of said inserted section for forming the light from the object illuminated by said illuminating light as a plurality of images having a parallax between them through a plurality of incident pupils; and

one image transmitting optical system comprising one relay lens optical system contained at least partially within said inserted section for transmitting said plurality of images having a parallax between them by said objective optical system,

wherein said objective optical system is formed of two negative lens units arranged in parallel with each other and one positive lens group, said two negative lens units being arranged to be substantially symmetrically concentric about an optical axis of said one positive lens group and said image transmitting optical system, said two negative lens units being arranged nearer the object side of said distal end of said inserted section than said one positive lens group.

2. A stereoendoscope, comprising:

an elongate inserted section having a distal end;

an illuminating light projecting means for projecting an illuminating light from the distal end of said inserted section;

an objective optical system arranged on the distal end of said inserted section for forming a plurality of images having a parallax between them such that they are substantially superimposed on one another of the object illuminated by said illuminating light; and

one image transmitting optical system comprising one relay lens optical system for transmitting said plurality of images;

wherein said objective optical system comprises a plurality of front lens groups and one rear lens group positioned proximally of said plurality of front lens groups.

3. A stereoendoscope according to claim 2, comprising:

a pupil dividing and image forming means for separating and forming said plurality of images having a parallax between them formed such that they are substantially superimposed on each other on a final image surface by said image transmitting optical system; and

at least one image taking means for taking the images formed by said pupil dividing and image forming means.

4. A stereoendoscope according to claim 3,

wherein said plurality of front lens groups are formed of a negative power element and a positive power element, said negative power element being arranged nearer the object side of said distal end of said inserted section than is said positive power element.

5. A stereoendoscope according to claim 3 having an adapter optical system for separating and reforming the plurality of images having a parallax between them and made such that they are substantially superimposed on one another on a final image surface of said image transmitting optical system.

6. A stereoendoscope according to claim 3, wherein said plurality of images are simultaneously spatially separated by said pupil dividing and image forming means.

7. A stereoendoscope according to claim 3, wherein said plurality of images are alternatively formed in a time-sequential manner by said pupil dividing and image forming means.

8. A stereoendoscope according to claim 2,

wherein the space between said plurality of front lens groups and said rear lens group is afocal.

9. A stereoendoscope, comprising:

an elongate inserted section having a distal end;

an illuminating light projecting means for projecting an illuminating light from the distal end of said inserted section;

an objective optical system wherein a plurality of optical systems are arranged in parallel on the distal end of said inserted section and a plurality of images having a parallax between them are formed of the object illuminated by said illuminating light;

an image transmitting optical system comprising one relay lens optical system for transmitting the plurality of images formed by said objective optical system; and

an image taking means for taking at least two images of the plurality of images transmitted by said image transmitting optical system,

wherein said objective optical system comprises a plurality of front lens group optical systems which are arranged in parallel, and a rear lens group optical system,

wherein said plurality of front lens group optical systems is arranged to be substantially symmetrically concentric about the optical axis of said rear lens group optical system and said image transmitting optical system.

said objective optical system forming images of the beams from said plurality of front lens group optical systems in substantially superimposed positions,

said image transmitting optical system transmitting a substantially superimposed plurality of images having a parallax between them formed by said objective optical system.

10. A stereoendoscope according to claim **9**, wherein positions of pupils transmitted by said image transmitting optical system are separated from each other.

11. A stereoendoscope according to claims **9**, wherein a beam projected from said plurality of front lens group optical systems is a substantially afocal beam.

12. A stereoendoscope according to claim **9**, wherein said plurality of front lens group optical systems are arranged more on the object side than said rear group optical system and are separated more from said rear group optical system than from a front side focus position of said rear group optical system.

13. A stereoendoscope comprising:

an elongate inserted section having a distal end;

an illuminating light projecting means for projecting an illuminating light from the distal end of said inserted section;

an objective optical system arranged with the distal end of said inserted section; and

an image taking means arranged within said inserted section for taking the object image formed by said objective optical system,

said objective optical system having two negative lens units arranged in parallel with each other and one positive lens group opposed to said two negative lens units,

said two negative lens units being arranged symmetrically concentric about the central axis of said positive lens group,

said two negative lens units being arranged nearer the object side of said distal end of said inserted section than is said positive lens group.

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United States Patent [19]

Grassens et al.

[11] Patent Number: 5,742,441

[45] Date of Patent: Apr. 21, 1998

[54] **METHOD AND APPARATUS FOR ALIGNING AN OBJECTIVE LENS**

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[21] Appl. No.: **418,698**

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(Under 37 CFR 1.47)

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[52] **U.S. Cl.** **359/822**; 359/817; 359/818

[58] **Field of Search** 359/822, 817, 359/818, 813, 823; 856/138, 139.05, 139.06, 139.07, 139.08, 139.09, 399

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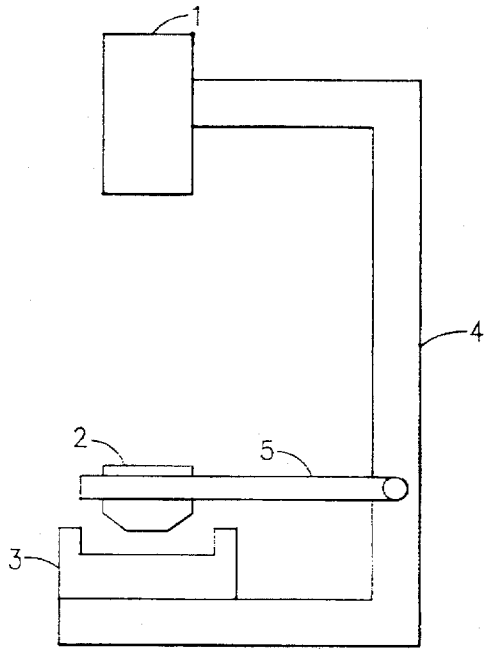
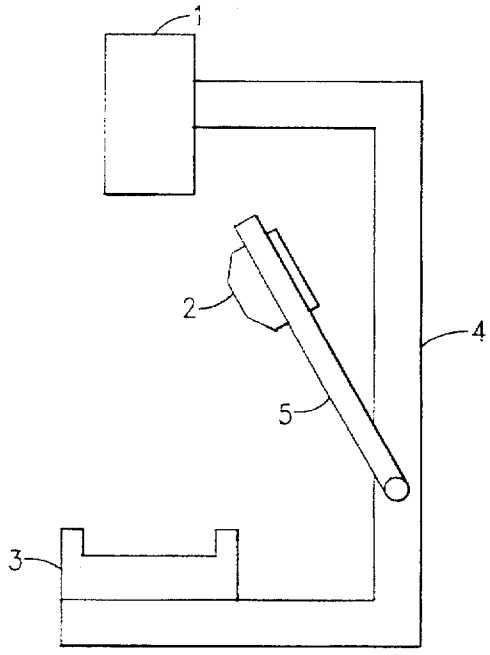
[57] **ABSTRACT**

An apparatus is described for aligning an actuator lens of an optical disk drive or the like within a baseplate assembly. The apparatus comprises a frame, a cradle assembly mounted to the frame with at least one degree of freedom of motion, a tower assembly mounted to the frame, a lever assembly rotatably mounted to the frame, and a gripper assembly mounted to the lever assembly. The cradle assembly includes a baseplate alignment assembly comprising a source of radiant energy for projecting a beam of radiant energy, means for determining the tilt alignment of the beam with respect to the tower assembly, and a plurality of tilt actuators for aligning the tilt of the beam with respect to the tower assembly. The baseplate alignment may further comprise means for determining the lateral alignment of the beam with respect to the tower assembly and a plurality of lateral actuators for aligning the beam laterally with respect to the tower assembly. The tower assembly comprises a video camera having a camera lens, a tower magnifying lens, and a monitor for displaying a representation of a beam of radiant energy passing through the tower magnifying lens and into the video camera. The gripper assembly comprises an objective lens assembly, an objective lens mounted to the objective lens assembly, an objective lens alignment assembly for aligning the objective lens with respect to the tower assembly and the cradle assembly, and an actuator lens tilt assembly for aligning the actuator lens with respect to the tower assembly and the cradle assembly.

31 Claims, 7 Drawing Sheets





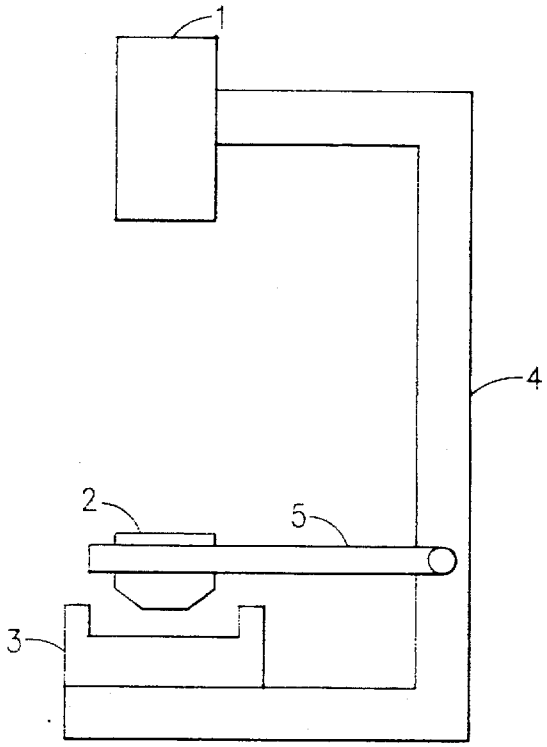


FIG.1

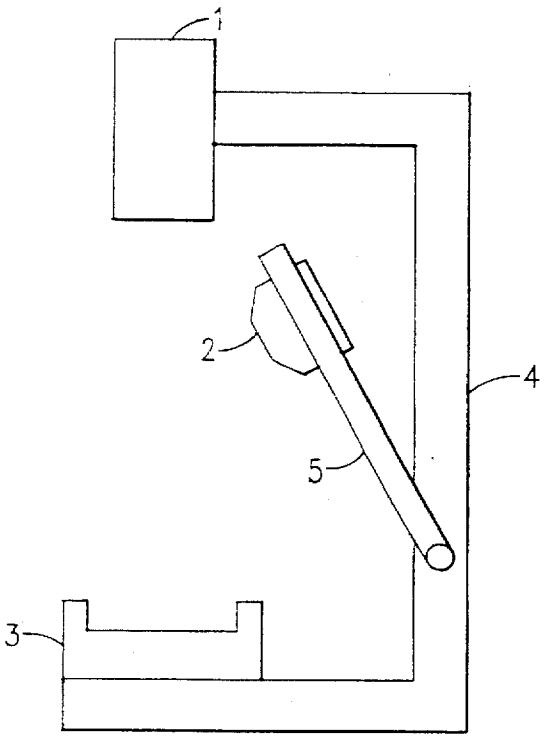


FIG.2

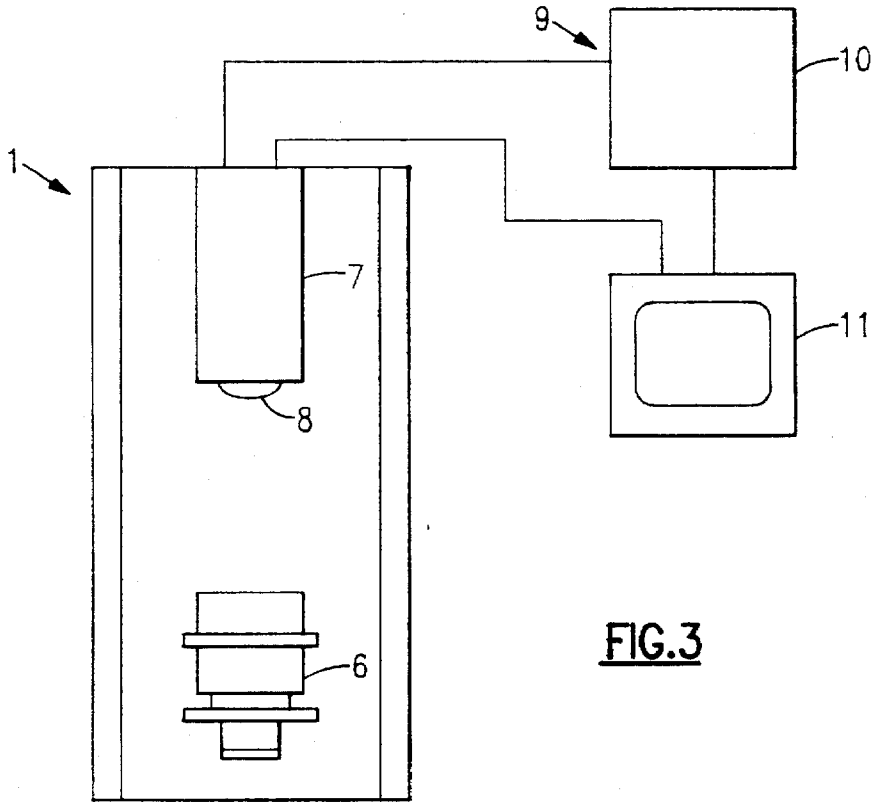


FIG.3

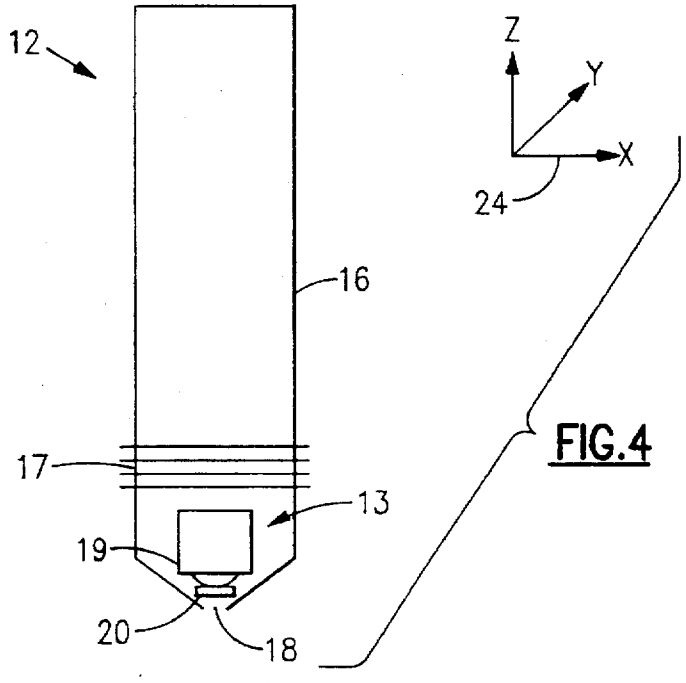


FIG.4

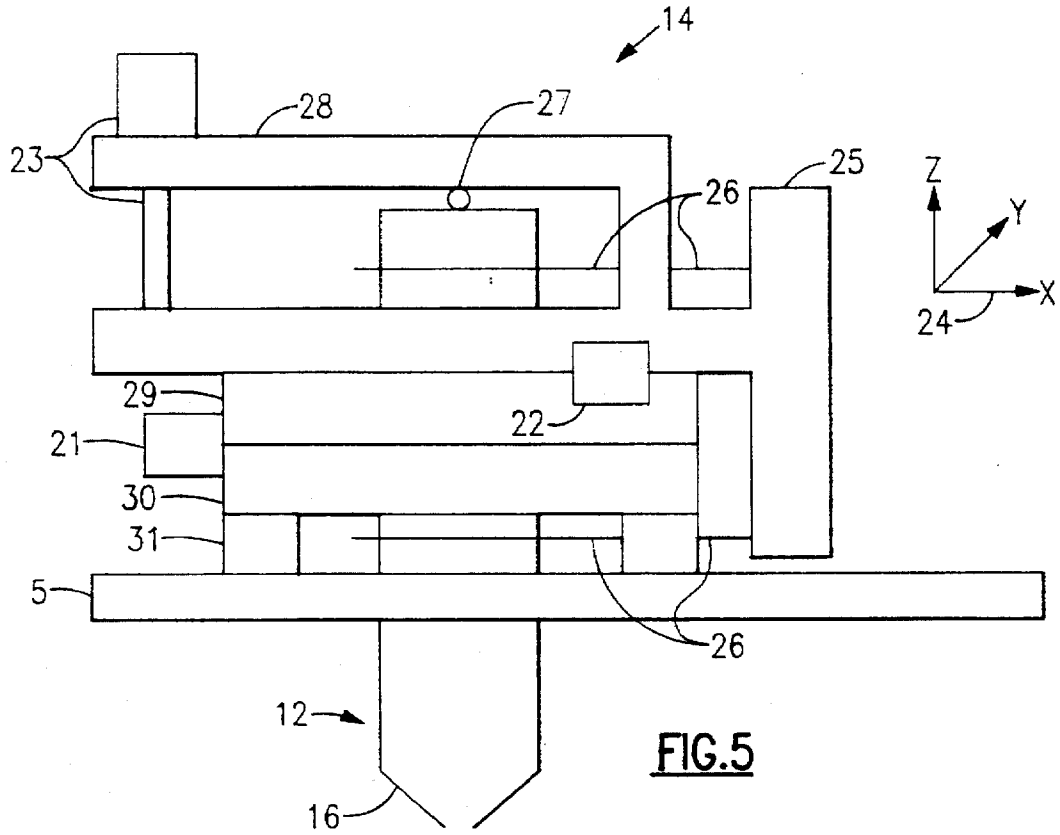

14
28
27
23
25
26
Z
Y
X
24
29
22
21
30
31
5
26
12
16

FIG.5

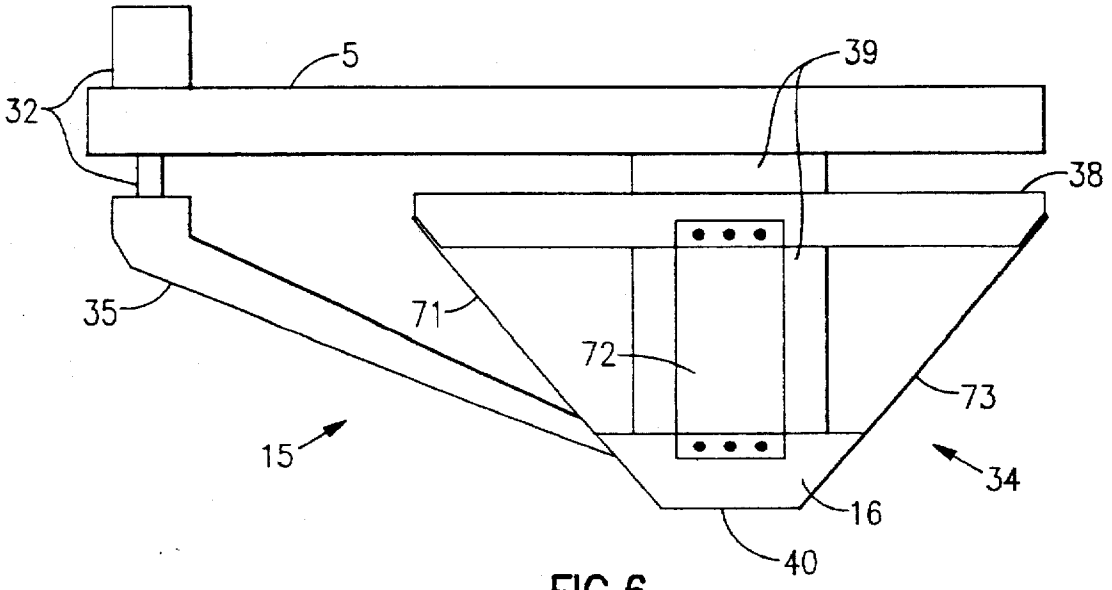

5
39
32
38
35
71
72
73
15
34
16
40

FIG.6

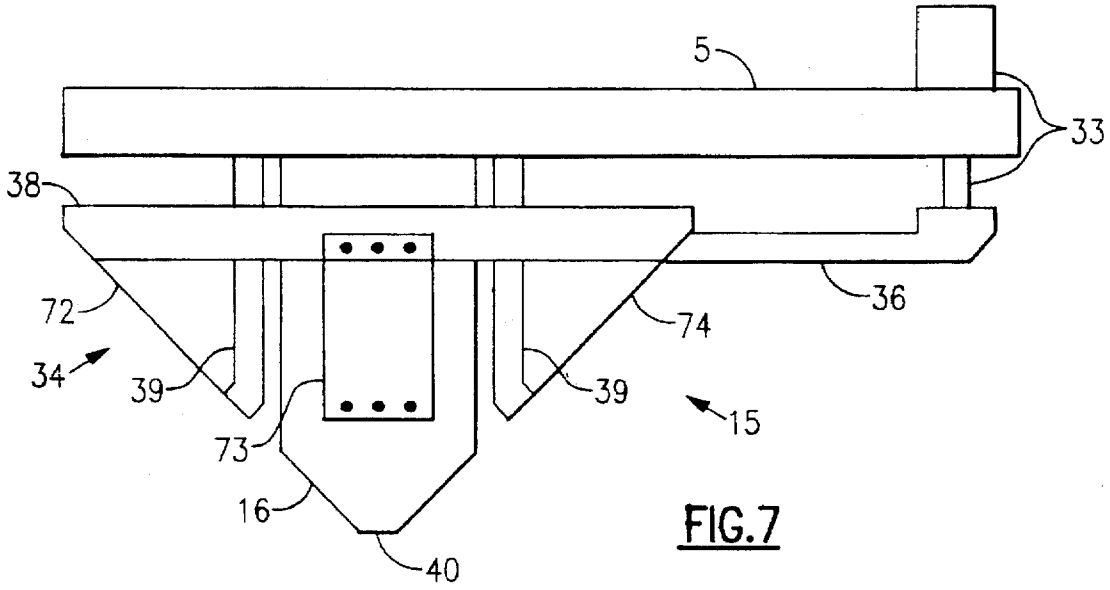


FIG.7

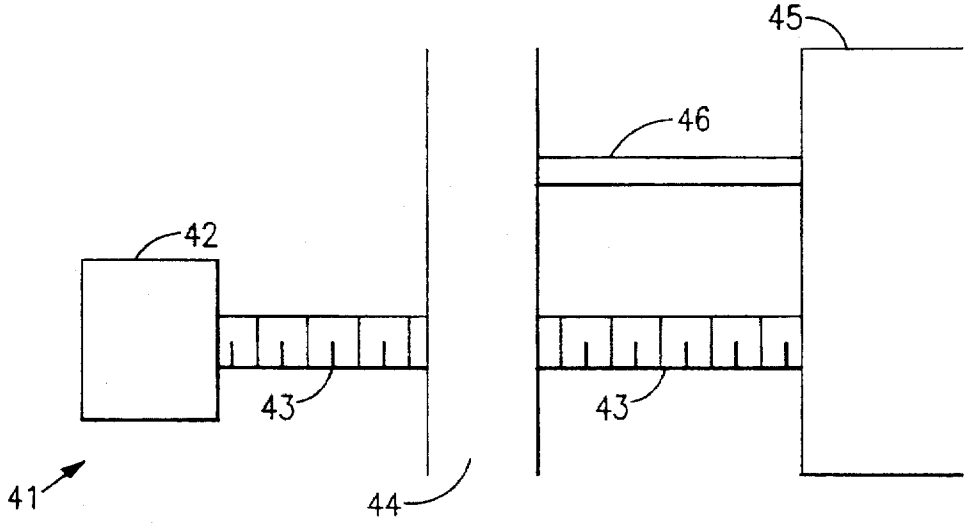


FIG.8

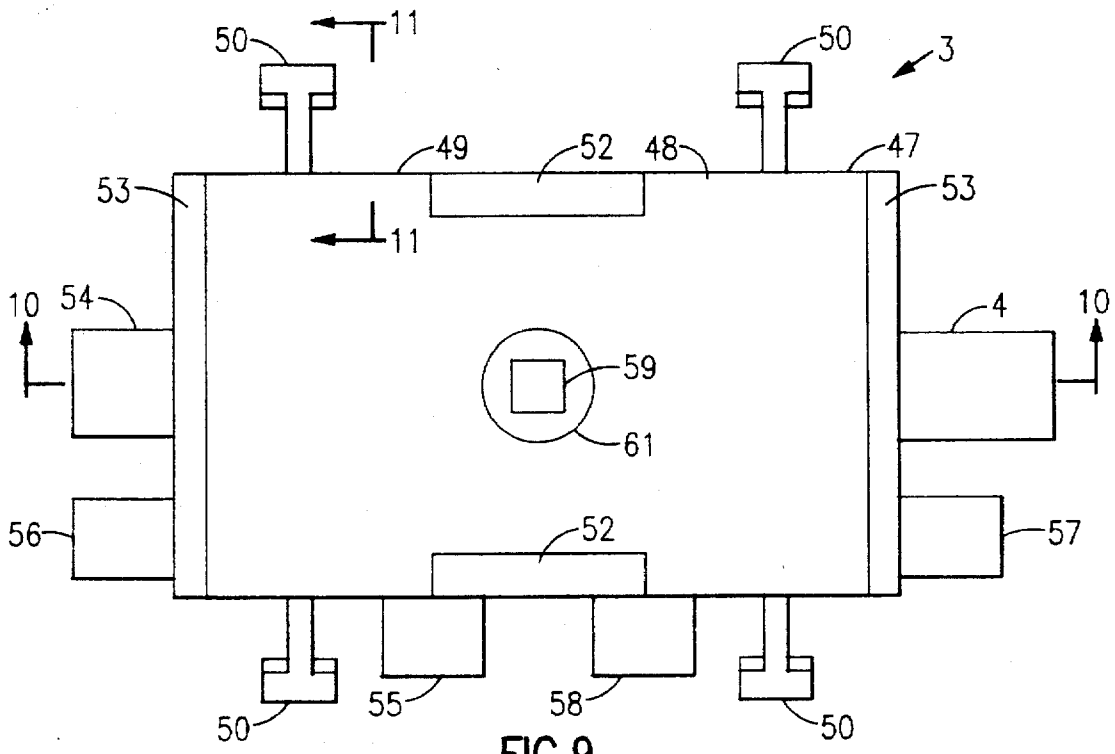

11
50
50
3
49
52
48
47
53
53
11
10
54
4
10
59
61
56
52
57
50
55
58
50

FIG.9

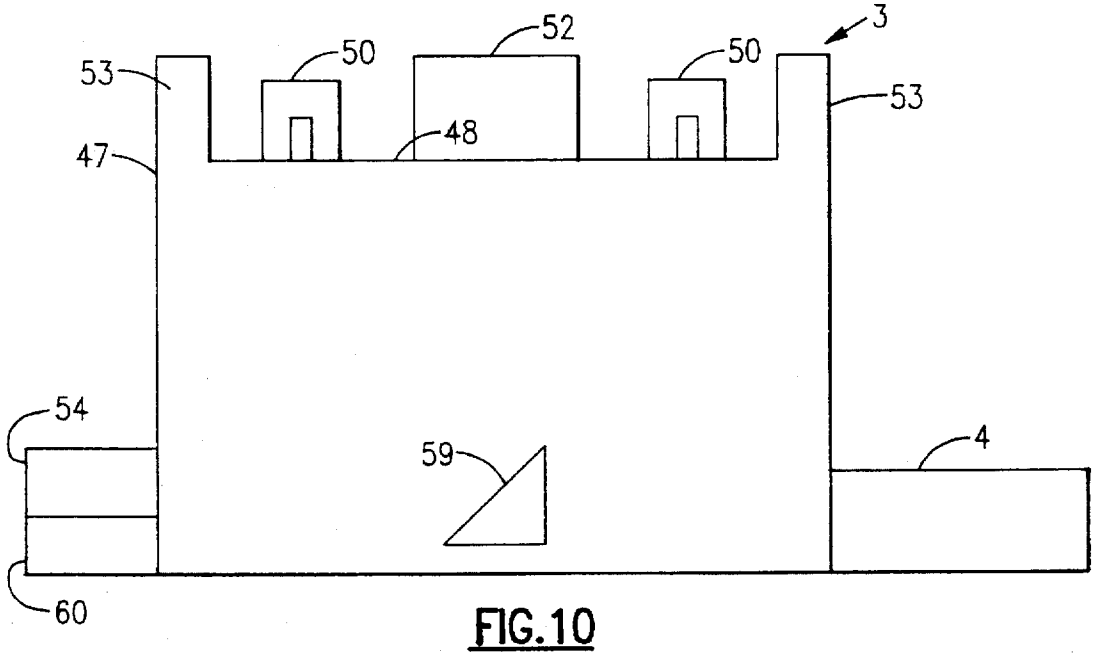

3
52
53
50
50
53
47
48
54
4
59
60

FIG.10

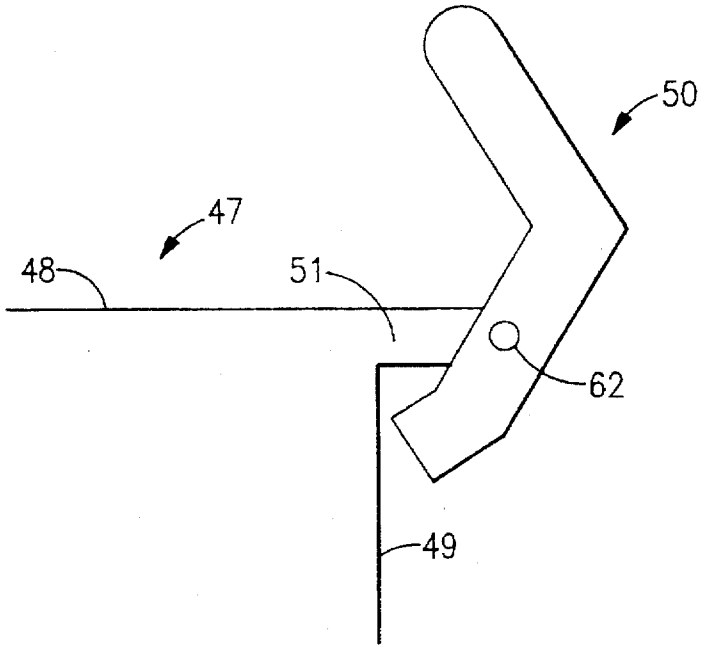


FIG.11

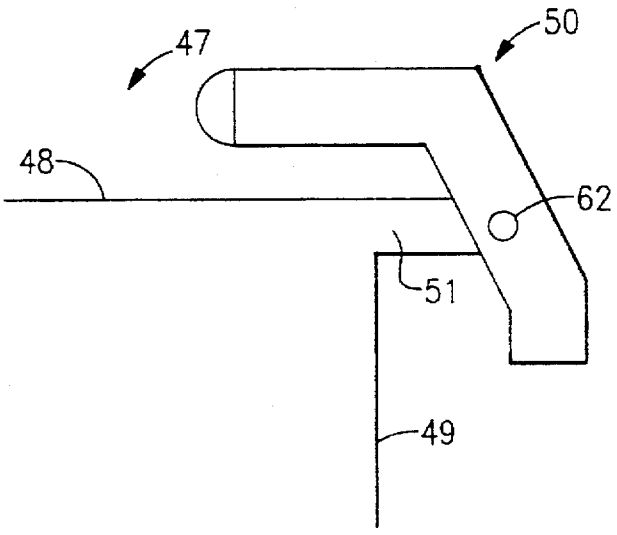


FIG.12

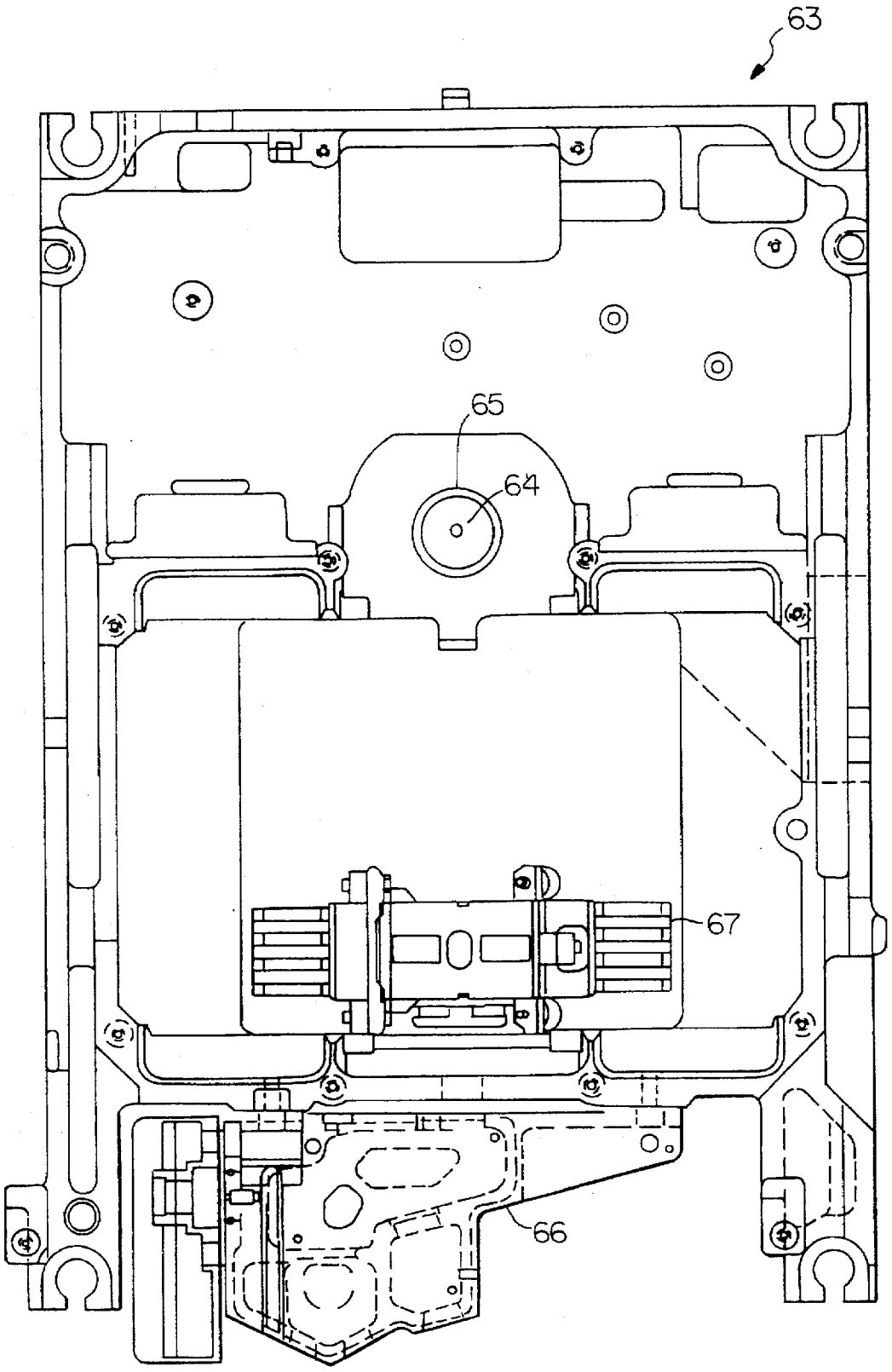


FIG.13

METHOD AND APPARATUS FOR ALIGNING AN OBJECTIVE LENS

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to manufacturing of optical systems, and, in particular, to the manipulation and alignment of an objective lens during manufacture of an optical system.

2. Description of the Related Art

In the manufacture of prior optical systems, specific alignment of the objective lens with respect to a storage medium was not critical. In those systems, a spindle which holds the storage medium is aligned with respect to guide rails. A carriage rides along the guide rails, and the objective lens is placed within the carriage. Because the information storage densities used in such optical systems were sufficiently low, and because manufacturing tolerances of the spindle, rails, and objective lens were sufficiently high, specific alignment of the objective lens was not necessary. The objective lens was placed, then tested for alignment within tolerable limits.

Another example of a prior art optical system does perform active alignment of the objective lens. However, the objective lens is fixedly mounted to an actuator, and the objective lens/actuator combination is aligned with respect to a carriage assembly. Once aligned with respect to the carriage assembly, the actuator is mounted to the carriage assembly, which is aligned with respect to the storage medium. This prior art optical system requires that the actuator be alignable with respect to the carriage assembly. Additionally, the actuator/carriage assembly combination is quite large relative to such assemblies in other optical systems.

SUMMARY OF THE INVENTION

As information storage densities increase, the alignment between the objective lens and the storage medium becomes more critical. As a result, either stricter manufacturing tolerances or improved alignment of the objective lens is necessary. Because stricter manufacturing tolerances increase manufacturing cost significantly, improved alignment of the objective lens allows higher information storage densities at an economically feasible cost.

An apparatus is described which aligns such an objective lens. The apparatus comprises a frame, a cradle assembly mounted to the frame with at least one degree of freedom of motion, a tower assembly mounted to the frame, a lever assembly rotatably mounted to the frame, and a gripper assembly mounted to the lever assembly. The cradle assembly includes a baseplate alignment assembly comprising a source of radiant energy for projecting a beam of radiant energy, means for determining the tilt alignment of the beam with respect to the tower assembly, and a plurality of tilt actuators for aligning the tilt of the beam with respect to the tower assembly. The baseplate alignment assembly may further comprise means for determining the lateral alignment of the beam with respect to the tower assembly and a plurality of lateral actuators for aligning the beam laterally with respect to the tower assembly. The tower assembly comprises a video camera having a camera lens, a tower magnifying lens, and a monitor for displaying a representation of a beam of radiant energy passing through the tower magnifying lens and into the video camera.

The gripper assembly comprises an objective lens assembly, a gripper objective lens mounted to the objective lens assembly, an objective lens alignment assembly for aligning the gripper objective lens with respect to the tower assembly and the cradle assembly, and an actuator lens tilt assembly for aligning the objective lens with respect to the tower assembly and the cradle assembly. The objective lens assembly further comprises a housing having an opening at one end for receiving an objective lens and a bellows structure on its surface to allow bending of the housing, a gripper objective lens, a non-opaque substrate mounted within the housing, and a pneumatic tube attached to the housing for creating a pressure differential between the interior and the exterior of the housing sufficient to hold the actuator lens against the opening. The objective lens alignment assembly further comprises an assembly support, a first lateral alignment support slidably mounted to the assembly support, a first lateral actuator for positioning the first lateral alignment support, a second lateral alignment support slidably mounted to the first lateral alignment support, a second lateral actuator for positioning the second lateral alignment support, a support frame having a frame base and a frame extension, mounted to the second lateral actuator, a support leaf spring mounted to the support frame and biasing the housing against the frame extension, and a focus actuator for positioning the frame extension with respect to the frame base. The actuator lens tilt assembly further comprises a flexure support ring; two flexure support plates; four flexure plates mounted at equal intervals around the flexure support ring, two of which are mounted to the housing and two of which are mounted to the flexure support plates; a first lever disposed against a flexure plate; a first tilt actuator mounted against the first lever for imparting motion on the first lever which is translated into rotational motion by the flexure support ring, the flexure support plates, and the flexure plates; a second lever disposed against a flexure plate; and a second tilt actuator mounted against the second lever for imparting motion on the second lever which is translated into rotational motion by the flexure support ring, the flexure support plates, and the flexure plates.

A method for aligning an actuator lens is described comprising the steps of moving a baseplate assembly with respect to the tower assembly, moving the objective lens assembly with respect to the tower assembly, and moving the actuator lens with respect to the tower assembly. The step of moving the baseplate assembly further comprises moving the baseplate assembly laterally with respect to the tower assembly and rotating the baseplate assembly with respect to the tower assembly. The step of moving the actuator lens further comprises moving the actuator lens laterally with respect to the tower assembly and rotating the actuator lens with respect to the tower assembly. Such a method may be used with the above-described apparatus.

For a better understanding of these and other objects of the present invention, reference is made to the detailed description of the invention which is to be read in conjunction with the following drawings, wherein:

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a generalized side view of one embodiment of the invention, showing the gripper assembly in a closed position.

FIG. 2 is a generalized side view of one embodiment of the invention, showing the gripper assembly in an open position.

FIG. 3 is a cross-sectional view of the tower assembly, including an embodiment of the analysis assembly.

FIG. 4 is a cross-section view of the vacuum chuck and the microscope objective lens assembly.

FIG. 5 is a view of the microscope objective lens alignment assembly.

FIG. 6 is a side view of the actuator lens tilt assembly.

FIG. 7 is a front view of the actuator lens tilt assembly.

FIG. 8 is a view of an alignment actuator.

FIG. 9 is a top view of one embodiment of the cradle assembly.

FIG. 10 is a cross-sectional view of one embodiment of the cradle assembly, taken along line 10—10 of FIG. 9.

FIG. 11 is a cross-sectional view of one embodiment of a vacuum clamp in the open position, taken along line 11—11 of FIG. 9.

FIG. 12 is a cross-sectional view of one embodiment of a vacuum clamp in the closed position, taken along line 11—11 of FIG. 9.

FIG. 13 is a top view of a baseplate assembly.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to exemplary FIGS. 1 and 2, according to one aspect of the invention, the apparatus comprises a tower assembly 1, a gripper assembly 2, and a cradle assembly 3. The tower assembly 1 is fixedly mounted to a frame 4. The tower assembly 1 defines a tower axis. The gripper assembly 2 is fixedly mounted to a lever assembly 5, which is rotatably mounted to the frame 4. The cradle assembly 3 is mounted to the frame 4 with at least one degree of freedom of motion. A line (not shown) between the tower assembly 1 and the cradle assembly 3 is referred to as an assembly axis. In the closed position, as shown in FIG. 1, the gripper assembly 2 is between the tower assembly 1 and the cradle assembly 3 along the assembly axis. In the open position, as shown in FIG. 2, the gripper assembly 2 is not along the assembly axis.

Referring to exemplary FIG. 3, a cross-section of the tower assembly 1 is shown in more detail. The tower assembly 1 comprises a tower magnifying lens 6 and a video camera 7 having a camera lens 8. The optical axes of the camera lens 8 of the video camera 7 and the tower magnifying lens 6 are the same, and are referred to collectively as the tower optical axis. The output from the video camera 7 is connected to an analysis assembly 9. The analysis assembly 9 may be any assembly suitable for analyzing the characteristics of a radiant beam of energy. In the embodiment shown in exemplary FIG. 3, the analysis assembly 9 comprises a processor 10 and a monitor 11.

Referring to exemplary FIGS. 4, 5, 6 and 7, the gripper assembly 2 comprises a vacuum chuck 12, a microscope objective lens assembly 13, a microscope objective lens alignment assembly 14, and an actuator lens tilt assembly 15. FIG. 4 shows a cross-sectional view of one embodiment of the vacuum chuck 12 and the microscope objective lens assembly 13. FIG. 5 shows a view of one embodiment of the microscope objective lens alignment assembly 14. FIGS. 6 and 7 show two views of the actuator lens tilt assembly 15.

Referring to exemplary FIG. 4, the vacuum chuck 12 comprises a housing 16, a bellows structure 17, and an actuator lens receiving opening 18. A pneumatic tube (not shown) is connected to the housing 16. In operation, an actuator lens (not shown) is placed within the actuator lens receiving opening 18 such that the actuator lens receiving opening 18 is completely covered. The actuator lens may be an objective lens. Air is then evacuated from the housing 16 through the pneumatic tube (not shown) to create a pressure differential between the interior and the exterior of the housing 16. This pressure differential operates to hold the actuator lens against the actuator lens receiving opening 18 when the gripper assembly 2 moves. The housing 16 contains the bellows structure 17 to allow the housing 16 to bend while maintaining a pressure differential.

The microscope objective lens assembly 13 comprises a microscope objective lens 19 and a substrate 20. In operation, a beam of radiant energy will enter the housing 16 through the actuator lens receiving opening 18 and, if present, through the actuator lens. The beam will pass through the substrate 20 and through the microscope objective lens 19. The beam then passes through the housing 16 and into the tower assembly 1, where it passes through the tower magnifying lens 6 and is received by the video camera 7. Together, the microscope objective lens 19 and the tower magnifying lens 6 magnify the beam and focus the beam in the video camera 7. The tower magnifying lens 6 may be a tube lens. The substrate 20 simulates the optical properties of an information-bearing disk, and the effects of those properties on the beam. The substrate 20 is mounted such that, when the gripper assembly 2 is in the closed position, the substrate 20 is orthogonal to the tower optical axis.

Referring to exemplary FIG. 5, the microscope objective lens alignment assembly 14 comprises an X-axis lateral alignment actuator 21, a Y-axis lateral alignment actuator 22, and a focus actuator 23. Referring to exemplary FIG. 5, there is shown a reference coordinate system 24. This reference coordinate system 24 is chosen for purposes of explanation only, and it will be obvious to one skilled in the art that any convenient coordinate system could be chosen without departing from the spirit and scope of the present invention.

In the embodiment particularly shown in FIG. 5, a microscope support frame 25 having a frame extension 28 supports the housing 16 by a support leaf spring 26. The support leaf spring 26 biases the housing 16 against a cylindrical bearing 27 located between the housing 16 and the frame extension 28. The focus actuator 23 is mounted to the frame extension 28, and maintains a distance between the frame extension 28 and the microscope support frame 25 along the Z-axis, as indicated by the reference coordinate system 24. Motion of the housing 16 along the Z-axis adjusts the focus of the microscope objective lens 19 in combination with the tower magnifying lens 6.

The microscope support frame 25 is mounted on a Y-axis lateral alignment support 29 such that the microscope support frame 25 may slide relative to the Y-axis lateral alignment support 29 along the Y-axis, as indicated by the reference coordinate system 24. The Y-axis lateral alignment actuator 22 is mounted to the microscope support frame 25, and will actuate the relative sliding motion along the Y-axis.

The Y-axis lateral alignment support 29 is mounted on an X-axis lateral alignment support 30 such that the Y-axis lateral alignment support 29 may slide relative to the X-axis lateral alignment support 30 along the X-axis, as indicated by the reference coordinate system 24. The X-axis lateral alignment actuator 21 is mounted to the Y-axis lateral alignment support 29, and will actuate the relative sliding motion along the X-axis.

The X-axis lateral alignment support 30 is mounted to a lateral alignment assembly support 31. The lateral alignment assembly support 31 is mounted to the lever assembly 5. It will be apparent to one skilled in the art that the mountings between the microscope support frame 25, the Y-axis lateral alignment support 29, the X-axis lateral alignment support 30, and the lateral alignment assembly support 31 may be rearranged from the above description without departing from the spirit and scope of the present invention.

Referring to exemplary FIGS. **6** and **7**, there are shown two views of the actuator lens tilt assembly **15**. FIG. **6** represents a left side view of the actuator lens tilt assembly **15** according to one aspect of the invention. FIG. **7** represents a front view of the same actuator lens tilt assembly **15**. The actuator lens tilt assembly **15** comprises an X-axis tilt actuator **32**, a Y-axis tilt actuator **33**, and a flexure assembly **34**. The X-axis tilt actuator **32** is mounted to the lever assembly **5** and against an X-axis lever **35**. The X-axis lever **35**, at the end nearest the X-axis tilt actuator **32**, is biased against the lever assembly **5**, and at the other end is mounted to the flexure assembly **34**. The Y-axis tilt actuator **33** is mounted to the lever assembly **5** and against a Y-axis lever **36**. The Y-axis lever **36**, at the end nearest the Y-axis tilt actuator **33**, is biased against the lever assembly **5**, and at the other end is mounted to the flexure assembly **34**.

The flexure assembly **34** comprises a plurality of flexure plates **71**, **72**, **73**, **74**, a flexure support ring **38**, and a plurality of flexure support plates **39**. Flexure plate **71** is mounted at one end to the flexure support ring **38**, and mounted at its other end to the X-axis lever **35** and the housing **16**. Flexure plate **73** is mounted opposite flexure plate **71** to the flexure support ring **38** and to the housing **16**. Flexure plate **74** is mounted at one end to the Y-axis lever **36** and the flexure support ring **38**, and mounted at its other end to a flexure support plate **39**. Flexure plate **74** is mounted at a 90 degree interval from both flexure plate **71** and flexure plate **73**. Flexure plate **72** is mounted opposite flexure plate **74** to the flexure support ring **38** and to a flexure support plate **39**. The flexure support plates **39** are mounted to the lever assembly **5**.

Flexure plates **71**, **72**, **73**, **74** each lie in a separate plane. The planes in which flexure plates **71** and **73** lie intersect along a line through an intersection point **40**. The planes in which flexure plates **72** and **74** lie intersection along a line through the intersection point **40**. The lines may be orthogonal to each other.

The operation of the actuator lens tilt assembly **15** will be described with respect to a downward motion imparted on each of the tilt actuators, the X-axis tilt actuator **32** and the Y-axis tilt actuator **33**.

A downward motion of the X-axis tilt actuator **32** imparts a downward motion on the X-axis lever **35**. This downward force produces a counterclockwise rotational force on flexure plate **71** about the point where flexure plate **71** is mounted to the flexure support ring **38**. The downward force also translates into a counterclockwise rotational force on flexure plate **73** about the point where flexure plate **73** is mounted to the flexure support ring **38**. These two rotational forces cause rotation about the intersection of the two planes in which the flexure plates **71**, **73** lie. This intersection occurs at intersection point **40**.

A downward motion of the Y-axis tilt actuator **33** imparts a downward force on the Y-axis lever **36**. This downward force produces a clockwise rotational force on flexure plate **74** about the point where flexure plate **74** is mounted to the flexure support plate **39**. Because of the rigidity of the flexure support ring **38**, this rotational force translates into a clockwise rotational force on flexure plate **72** about the point where flexure plate **72** is mounted to the flexure support plate **39**. These two rotational forces cause rotation about the intersection of the two planes in which the flexure plates **72** and **74** lie. This intersection occurs at intersection point **40**.

Referring to exemplary FIG. **8**, there is shown one embodiment of an alignment actuator **41**. The alignment actuator **41** may be a tilt actuator or a lateral alignment actuator, as described above. The alignment actuator **41** contains a handle **42** and a threaded body **43**. The threaded body **43** is threadably mounted through a fixed surface **44** and against a movable surface **45**. The movable surface **45** is biased toward the fixed surface **44** by a spring **46** or other suitable biasing means. The mounting of the movable surface **45** determines whether the force by the alignment actuator **41** or the biasing by the spring **46** produces a lateral or rotational force. The alignment actuator **41** may include what is commonly referred to as a micrometer stage.

Referring to exemplary FIG. **9**, there is shown a top view of the cradle assembly **3**. Referring to exemplary FIG. **10**, there is shown a cross-sectional view of the cradle assembly **3**, taken along line **10—10** of FIG. **9**. The cradle assembly **3** comprises a cradle **47** having a surface **48** and a side **49**, a plurality of vacuum clamps **50**, and a baseplate alignment assembly (not shown). The cradle includes side walls **52** and end walls **53** for securing a baseplate assembly (not shown) in the cradle **47**. In the embodiment particularly shown in exemplary FIGS. **9** and **10**, the baseplate alignment assembly (not shown) comprises a source of radiant energy **54**, a Y-axis source lateral actuator **55**, a Z-axis source lateral actuator **56**, an X-axis cradle assembly tilt actuator **57**, a Y-axis cradle assembly tilt actuator **58**, a mirror **59**, and an alignment analyzer **60**. In another embodiment, the baseplate alignment assembly (not shown) comprises a source of radiant energy **54**, an X-axis cradle assembly tilt actuator **57**, a Y-axis cradle assembly tilt actuator **58**, a mirror **59**, and an alignment analyzer **60**. In both embodiments, the mirror **59** is aligned below a hole **61** in the surface **48** of the cradle **47**. Additionally, the source of radiant energy **54** and the alignment analyzer **60** may be combined in an auto-collimator or an auto-collimator/telescope.

Referring to exemplary FIG. **11**, a cross-sectional view of a vacuum clamp **50** is shown in the open position. Exemplary FIG. **12** shows a cross-sectional view of a vacuum clamp **50** in the closed position. The surface **48** of the cradle **47** extends laterally beyond the side **49** of the cradle **47**. The vacuum clamp **50**, having a U-shaped cross-section, is placed over the extension **51** of the cradle **47**, with one leg of the U on each side of the extension **51**. A pivot pin **62** is placed through each leg of the U-shape and through the extension of the cradle **47**. In the open position, a baseplate assembly can be placed on the cradle **47**. Once in place, a pneumatic tube (not shown) biases the vacuum clamp **50** to the closed position, securing the baseplate against movement.

In operation, as shown in exemplary FIG. **13**, a baseplate assembly **63** is provided. The baseplate assembly **63** contains a spindle **64** and a spindle motor **65** for rotating an information-bearing disk, and a spindle servo (not shown) for controlling the speed of the spindle motor **65**. The baseplate assembly **63** further contains an optics module assembly **66**. The baseplate assembly **63** also contains a carriage motor (not shown) and a carriage assembly **67** for directing a beam of radiant energy from the optics module assembly **66** toward a position on the information-bearing disk, and a carriage control servo (not shown) for controlling the position of the carriage assembly. At this point, the carriage assembly **67** does not contain an actuator lens for focussing the beam of radiant energy on the information-bearing disk. The carriage assembly **67** may be held in place relative to the spindle **64** by a carriage stop (not shown).

The baseplate assembly **63** is placed on the surface **48** of the cradle **47** and secured with the vacuum clamps **50**. A test disk of glass or other suitable material (not shown) is placed on the spindle of the baseplate assembly **63**. The gripper assembly **2** is then lowered into the closed position.

The source of radiant energy **54** radiates two cradle alignment beams of radiant energy toward the mirror **59**. The first cradle alignment beam is reflected from the mirror **59**, then passes through the hole **61** in the cradle **47** and through the baseplate assembly **63**. The first cradle alignment beam reflects off the test disk and is received by the alignment analyzer **60**. The second cradle alignment beam is reflected from the mirror **59**, then passes through the hole **61** in the cradle **47** and through the baseplate assembly **63**. The second cradle alignment beam reflects off the substrate **20** and is received by the alignment analyzer **60**. By analyzing the relative positions of the first and second cradle alignment beams, the alignment analyzer **60** determines the tilt of the test disk with respect to the substrate **20**. It will be obvious that the mirror **59** may comprise two parallel mirrors, each reflecting one of the cradle alignment beams.

Tilt between the test disk and the substrate **20** is corrected in the following manner. The X-axis cradle assembly tilt actuator **57** tilts the cradle assembly **3** about the X-axis. The Y-axis cradle assembly tilt actuator **58** tilts the cradle assembly **3** about the Y-axis. Acting together, the cradle assembly tilt actuators **57**, **58** tilt the cradle assembly **3**, including the test disk, with respect to the substrate **20**. Because the substrate **20** is orthogonal to the tower optical axis, this action tilts the cradle assembly **3** with respect to the tower optical axis. Each of the actuators **57**, **58** may be an alignment actuator **41** as shown in exemplary FIG. **8**.

In one embodiment, lateral alignment of the cradle assembly **3** with respect to the tower optical axis is done mechanically, and is not tested or measured. In another embodiment, if the cradle alignment beam is not received by the alignment analyzer **60**, or is off-center when received by the alignment analyzer **60**, the position of the source of radiant energy **54** can be moved using the Y-axis source lateral actuator **55** and the Z-axis source lateral actuator **56**. As shown best in FIG. **9**, the mirror **59** is situated such that a change in the position of the source of radiant energy **54** along the Y-axis is translated into a change in the position of the cradle alignment beam along the Y-axis as it is received by the alignment analyzer **60**. The Y-axis source lateral actuator **55** effects this change in position. Similarly, a change in the position of the source of radiant energy **54** along the Z-axis is translated into a change in the position of the cradle alignment beam along the X-axis as it is received by the alignment analyzer **60**. The Z-axis source lateral actuator **56** effects this change in position. Each of the actuators **55**, **56** may be an alignment actuator **41** as shown in exemplary FIG. **8**.

In the embodiment particularly described below, all references to a coordinate system are made in accordance with reference coordinate system **24** shown in exemplary FIG. **5**.

Once aligned, the source of radiant energy **54** is turned off and the test disk is removed. If not previously aligned, the carriage assembly of the baseplate assembly **63** is moved in approximate alignment with the assembly axis, and an actuator lens (not shown) is placed within the carriage assembly of the baseplate assembly **63** and is allowed to assume a natural rest position. The lever assembly **5** is lowered to the closed position.

A pressure differential is then created between the vacuum chuck **12** and the atmosphere. This pressure differential operates to hold the actuator lens against the vacuum chuck **12**, while maintaining the orientation of the actuator lens. Additionally, the optical center of the actuator lens is maintained at the intersection point **40**. This optical center may also be substantially at the center of mass of the actuator lens.

An adjustable power supply is attached to the radiant energy source within the optics module assembly **66**. The radiant energy source projects a lens alignment beam of radiant energy into the carriage assembly. Within the carriage assembly, the lens alignment beam passes through a pentaprism (not shown) and through the actuator lens. The lens alignment beam then passes through the substrate **20**, through the microscope objective lens **19**, and into the tower assembly **1**, where the lens alignment beam passes through the tower magnifying lens **6** and is received by the video camera **7**. The analysis assembly **9** then displays and analyzes the spot profile of the lens alignment beam.

If the lens alignment beam is not received by the video camera **7** and passed to the analysis assembly **9**, the X-axis lateral alignment actuator **21** and the Y-axis lateral alignment actuator **22** are used to move the microscope objective lens **19** laterally with respect to the tower assembly **1**. The X-axis lateral alignment actuator **21** and the Y-axis lateral alignment actuator **22** may be alignment actuators **41** as shown in exemplary FIG. **8**.

If the lens alignment beam is not focussed properly in the video camera **7** and analysis assembly **9**, the focus actuator **23** is used to move the microscope objective lens **19** toward or away from the tower assembly **1** until the lens alignment beam is in proper focus within the video camera **7** and analysis assembly **9**. The focus actuator **23** may be an alignment actuator **41** as shown in exemplary FIG. **8**.

Once focussed properly, the analysis assembly **9** analyzes the profile of the beam for coma and astigmatism, as the cradle alignment beam was previously analyzed. If these optical aberrations occur, the actuator lens tilt assembly **15** operates to minimize these aberrations by aligning the actuator lens. As described above, the X-axis tilt actuator **32** rotates the actuator lens about the X-axis. Likewise, the Y-axis tilt actuator **33** rotates the actuator lens about the Y-axis. Together, the actuator lens tilt assembly **15** can rotate the actuator lens in any direction with respect to the lens alignment beam, while maintaining the optical center or the center of mass of the actuator lens at the intersection point **40**.

Once the misalignment is corrected to within an acceptable tolerance, the gripper assembly **2**, including the vacuum chuck **12** and the actuator lens, is raised to the open position. A fastening agent is placed on the pedestals of the carriage assembly, and the gripper assembly **2** is again lowered to the closed position. The actuator lens is secured by the fastening agent to the carriage assembly, without changing the orientation of the actuator lens established by the actuator lens tilt assembly **15**. The fastening agent may be a selectably-curable adhesive, such as ultraviolet radiation-curable adhesive.

Once the fastening agent has cured, the actuator lens is tested for alignment. As above, a lens alignment beam is radiated through the actuator lens, the substrate **20**, the microscope objective lens **19**, the tower magnifying lens **6**, and into the video camera **7**. The analysis assembly **9** then analyzes the spot profile of the lens alignment beam. Each of the alignments described above may need to be adjusted for this testing process. Depending on its configuration, the vacuum chuck **12** may need to be retracted or removed to avoid contacting and damaging the carriage assembly.

In another embodiment of the invention, the cradle assembly **3** may comprise a plurality of cradles **47**, a plurality of vacuum clamps **50**, and a baseplate alignment assembly (not shown). The cradles **47** may be movable with respect to the tower assembly **1**, and there may be either one baseplate

alignment assembly (not shown) for each cradle **47**, or a single baseplate alignment assembly (not shown) which aligns only the cradle **47** presently in position with respect to the tower assembly **1**. Further, there may be a single source of radiant energy **54** and set of actuators **55**, **56**, **57**, **58** regardless of the number of cradles **47**, with one mirror **59** associated with each cradle **47**.

According to this embodiment, there may be a second tower assembly **1** identical to the first tower assembly **1** described above. In addition, there may be a second gripper assembly **2** associated with the second tower assembly **1** as described above. The second gripper assembly **2** will not contain a vacuum chuck **12**.

In operation, the first tower assembly **1** and first gripper assembly **2** operate as described in the previous embodiment. After fastening the actuator lens to the carriage assembly with the fastening agent, the cradle **47** containing the baseplate assembly **63** is moved beneath the second tower assembly **1** and second gripper assembly **2**. Again, a lens alignment beam of radiant energy is projected by the optics module assembly **66** through the same path in the second tower assembly **1** and second gripper assembly **2** as described with respect to the first tower assembly **1** and first gripper assembly **2**. The analysis assembly **9** associated with the second tower assembly I analyzes the spot profile of the lens alignment beam after the actuator lens is fastened to the baseplate assembly **63**. It will be obvious to one skilled in the art that, by allowing the vacuum chuck **12** to be removable or retractable, the first tower assembly **1** and first gripper assembly **2** may function as the second tower assembly **1** and second gripper assembly **2**, respectively.

While this invention has been explained with reference to the structure disclosed herein, it is not confined to the details set forth and this application is intended to cover any modifications and changes as may come within the scope of the following claims:

What is claimed is:

1. An apparatus for aligning an actuator lens defining an actuator optical axis and an actuator optical center within a baseplate using a beam of radiant energy, comprising:

a frame;

a cradle assembly for holding the baseplate, said cradle assembly mounted to said frame with at least one degree of freedom of motion;

a tower assembly defining a tower axis and mounted to said frame, said cradle assembly and said tower assembly defining an assembly axis, for receiving the beam of radiant energy along said tower axis;

a lever assembly positioned in a closed position, rotatably mounted to said frame; and

a gripper assembly mounted to said lever assembly, comprising:

an objective lens defining an objective optical axis;

an objective lens assembly mounted to said objective lens, for selectively holding the actuator lens stationary relative to said objective lens;

an objective lens alignment assembly for aligning said objective lens with said tower assembly and said cradle assembly by aligning said objective optical axis laterally with respect to said assembly axis when said lever assembly is in the closed position; and

an actuator lens tilt assembly for aligning the actuator lens with said tower assembly and said cradle assembly by rotating said actuator optical axis about an axis orthogonal to said assembly axis when said lever assembly is in the closed position;

whereby when said lever assembly is in said closed position said gripper assembly, said tower assembly, said cradle assembly, said baseplate, and said actuator lens tilt assembly are positioned with respect to each other such that the beam of radiant energy can be used to align the actuator lens with said baseplate by adjusting the relative position or alignment of one or more of said objective lens assembly, said cradle assembly, and said actuator lens with respect to said tower assembly.

2. An apparatus for holding an actuator lens defining an optical center stationary with respect to an objective lens, comprising:

a housing having at least two ends and an opening at a first end for receiving an actuator lens, and having a flexible bellows structure for allowing realignment of said end of said housing with respect to a second end of said housing;

an objective lens mounted to the interior of said housing between said bellows structure and said opening, said objective lens defining an optical axis which passes through said opening;

a non-opaque substrate mounted within said housing such that said optical axis passes through said substrate; and

a pneumatic tube attached to said housing, for creating a pressure differential between the interior and the exterior of said housing sufficient to hold said actuator lens covering said opening stationary relative to said housing.

3. An apparatus for manipulating an object, comprising:

an assembly support;

a first lateral alignment support slidably mounted to said assembly support to allow sliding motion of said first lateral alignment support relative to said assembly support along a first axis;

a second lateral alignment support slidably mounted to said first lateral alignment support, to allow sliding motion of said second lateral alignment support relative to said first lateral alignment support along a second axis orthogonal to said first axis;

a support frame including a frame base and a frame extension, said support frame being mounted to said second lateral alignment support, and said frame base and said frame extension being separated by a distance along a third axis orthogonal to said first axis and said second axis;

a support leaf spring fixed to said support frame, for biasing an object toward said frame extension along said third axis;

a first lateral actuator for positioning said first lateral alignment support relative to said assembly support along said first axis;

a second lateral actuator for positioning said second lateral alignment support relative to said first lateral alignment support along said second axis; and

a third lateral actuator mounted to said frame extension and against said frame base for altering the distance between said frame extension and said frame base along said third axis.

4. An apparatus for manipulating a lens, comprising:

an assembly support;

a first lateral alignment support slidably mounted to said assembly support to allow sliding motion of said first lateral alignment support relative to said assembly support along a first axis;

a second lateral alignment support slidably mounted to said first lateral alignment support, to allow sliding motion of said second lateral alignment support relative to said first lateral alignment support along a second axis orthogonal to said first axis;

a support frame including a frame base and a frame extension, said support frame being mounted to said second lateral alignment support, and said frame base and said frame extension being separated by a distance along a third axis orthogonal to said first axis and said second axis;

a support leaf spring fixed to said support frame, for biasing a lens defining an optical axis toward said frame extension along said optical axis, said optical axis being parallel to said third axis;

a first lateral actuator for positioning said first lateral alignment support relative to said assembly support along said first axis;

a second lateral actuator for positioning said second lateral alignment support relative to said first lateral alignment support along said second axis; and

a focus actuator mounted to said frame extension and against said frame base for altering the distance between said frame extension and said frame base along said third axis.

5. An apparatus as defined in claim **1**, wherein said objective lens alignment assembly comprises:

an assembly support mounted to said lever assembly;

a first lateral alignment support slidably mounted to said assembly support to allow sliding motion of said first lateral alignment support relative to said assembly support along a first axis;

a second lateral alignment support slidably mounted to said first lateral alignment support, to allow sliding motion of said second lateral alignment support relative to said first lateral alignment support along a second axis orthogonal to said first axis;

a support frame including a frame base and a frame extension, said support frame being mounted to said second lateral alignment support, and said frame base and said frame extension being separated by a distance along a third axis orthogonal to said first axis and said second axis;

a support leaf spring fixed to said support frame, for biasing said objective lens toward said frame extension along said objective optical axis, said objective optical axis being parallel to said third axis;

a first lateral actuator for positioning said first lateral alignment support relative to said assembly support along said first axis;

a second lateral actuator for positioning said second lateral alignment support relative to said first lateral alignment support along said second axis; and

a focus actuator mounted to said frame extension and against said frame base for altering the distance between said frame extension and said frame base along said third axis.

6. An apparatus as defined in claim **2**, wherein said objective lens alignment assembly comprises:

an assembly support mounted to said lever assembly;

a first lateral alignment support slidably mounted to said assembly support to allow sliding motion of said first lateral alignment support relative to said assembly support along a first axis;

a second lateral alignment support slidably mounted to said first lateral alignment support, to allow sliding motion of said second lateral alignment support relative to said first lateral alignment support along a second axis orthogonal to said first axis;

a support frame including a frame base and a frame extension, said support frame being mounted to said second lateral alignment support, and said frame base and said frame extension being separated by a distance along a third axis orthogonal to said first axis and said second axis;

a support leaf spring fixed to said support frame, for biasing said objective lens toward said frame extension along said objective optical axis, said objective optical axis being parallel to said third axis;

a first lateral actuator for positioning said first lateral alignment support relative to said assembly support along said first axis;

a second lateral actuator for positioning said second lateral alignment support relative to said first lateral alignment support along said second axis; and

a focus actuator mounted to said frame extension and against said frame base for altering the distance between said frame extension and said frame base along said third axis.

7. An apparatus for manipulating an object, comprising:

a flexure support ring;

a first flexure plate mounted at one end to said flexure support ring, said first flexure plate defining a first plane;

a second flexure plate mounted at one end to the opposite end of said flexure support ring from said first flexure plate, said second flexure plate defining a second plane, said second flexure plate positioned relative to said first flexure plate such that said first and second planes intersect, the intersection of said first plane and said second plane defining a first line;

a support frame;

a first flexure support plate mounted at one end to the end of said first flexure plate remote from said flexure support ring, and mounted at the other end to said support frame;

a second flexure support plate mounted at one end to the end of said second flexure plate remote from said flexure support ring, and mounted at the other end to said support frame;

a first lever having a first end and a second end, said first end disposed against the juncture of said first flexure plate and said flexure support ring;

a first tilt actuator mounted on said support frame and against said second end of said first lever, for moving said first lever laterally toward or away from said first flexure plate and said flexure support ring;

a third flexure plate mounted at one end to said flexure support ring and mounted at the other end to an object, said third flexure plate defining a third plane;

a fourth flexure plate mounted at one end to said flexure support ring and mounted at the other end to said object, said fourth flexure plate defining a fourth plane, said fourth flexure plate positioned relative to said third flexure plate such that said third and fourth planes intersect, the intersection of said third plane and said fourth plane defining a second line orthogonal to said first line, the intersection of said first line and said second line defining a rotation point;

a second lever having a first end and a second end, said first end disposed against the intersection of said third flexure plate and said object; and

a second tilt actuator mounted on said support frame and against said second end of said second lever, for moving said second lever laterally toward or away from said third flexure plate;

whereby said first tilt actuator imparts a first movement on said first lever toward or away from said first flexure support plate, thereby causing rotation of said first flexure support plate, said second flexure support plate, said flexure support ring, and said object about said first axis, and said second tilt actuator imparts a second movement on said second lever toward or away from said third flexure support plate, thereby causing rotation of said third flexure support plate, said fourth flexure support plate, said flexure support ring, and said object about said second axis.

8. An apparatus as defined in claim **7**, wherein said rotation point is located at the center of mass of said object.

9. An apparatus as defined in claim **1**, wherein said actuator lens tilt assembly comprises:

a flexure support ring;

a first flexure plate mounted at one end to said flexure support ring, said first flexure plate defining a first plane;

a second flexure plate mounted at one end to the opposite end of said flexure support ring from said first flexure plate, said second flexure plate defining a second plane, said second flexure plate positioned relative to said first flexure plate such that said first and second planes intersect, the intersection of said first plane and said second plane defining a first line;

a first flexure support plate mounted at one end to the end of said first flexure plate remote from said flexure support ring, and mounted at the other end to said lever assembly;

a second flexure support plate mounted at one end to the end of said second flexure plate remote from said flexure support ring, and mounted at the other end to said lever assembly;

a first lever having a first end and a second end, said first end disposed against the juncture of said first flexure plate and said flexure support ring;

a first tilt actuator mounted on said lever assembly and against said second end of said first lever, for moving said first lever laterally toward or away from said first flexure plate and said flexure support ring;

a third flexure plate mounted at one end to said flexure support ring and mounted at the other end to said actuator lens, said third flexure plate defining a third plane;

a fourth flexure plate mounted at one end to said flexure support ring and mounted at the other end to said actuator lens, said fourth flexure plate defining a fourth plane, said fourth flexure plate positioned relative to said third flexure plate such that said third and fourth planes intersect, the intersection of said third plane and said fourth plane defining a second line orthogonal to said first line, the intersection of said first line and said second line defining a rotation point, said rotation point located at said actuator optical center;

a second lever having a first end and a second end, said first end disposed against the intersection of said third flexure plate and said actuator lens; and

a second tilt actuator mounted on said lever assembly and against said second end of said second lever, for moving said second lever laterally toward or away from said third flexure plate;

whereby said first tilt actuator imparts a first movement on said first lever toward or away from said first flexure support plate, thereby causing rotation of said first flexure support plate, said second flexure support plate, said flexure support ring, and said actuator lens about said first axis, and said second tilt actuator imparts a second movement on said second lever toward or away from said third flexure support plate, thereby causing rotation of said third flexure support plate, said fourth flexure support plate, said flexure support ring, and said actuator lens about said second axis.

10. An apparatus as defined in claim **2**, wherein said actuator lens tilt assembly comprises:

a flexure support ring;

a first flexure plate mounted at one end to said flexure support ring, said first flexure plate defining a first plane;

a second flexure plate mounted at one end to the opposite end of said flexure support ring from said first flexure plate, said second flexure plate defining a second plane, said second flexure plate positioned relative to said first flexure plate such that said first and second planes intersect, the intersection of said first plane and said second plane defining a first line;

a first flexure support plate mounted at one end to the end of said first flexure plate remote from said flexure support ring, and mounted at the other end to said lever assembly;

a second flexure support plate mounted at one end to the end of said second flexure plate remote from said flexure support ring, and mounted at the other end to said lever assembly;

a first lever having a first end and a second end, said first end disposed against the juncture of said first flexure plate and said flexure support ring;

a first tilt actuator mounted on said lever assembly and against said second end of said first lever, for moving said first lever laterally toward or away from said first flexure plate and said flexure support ring;

a third flexure plate mounted at one end to said flexure support ring and mounted at the other end to said actuator lens, said third flexure plate defining a third plane;

a fourth flexure plate mounted at one end to said flexure support ring and mounted at the other end to said actuator lens, said fourth flexure plate defining a fourth plane, said fourth flexure plate positioned relative to said third flexure plate such that said third and fourth planes intersect, the intersection of said third plane and said fourth plane defining a second line orthogonal to said first line, the intersection of said first line and said second line defining a rotation point, said rotation point located at said actuator optical center;

a second lever having a first end and a second end, said first end disposed against the intersection of said third flexure plate and said actuator lens; and

a second tilt actuator mounted on said lever assembly and against said second end of said second lever, for moving said second lever laterally toward or away from said third flexure plate;

whereby said first tilt actuator imparts a first movement on said first lever toward or away from said first flexure support plate, thereby causing rotation of said first flexure support plate, said second flexure support plate, said flexure support

ring, and said actuator lens about said first axis, and said second tilt actuator imparts a second movement on said second lever toward or away from said third flexure support plate, thereby causing rotation of said third flexure support plate, said fourth flexure support plate, said flexure support ring, and said actuator lens about said second axis.

11. An apparatus as defined in claim 5, wherein said actuator lens tilt assembly comprises:

a flexure support ring;

a first flexure plate mounted at one end to said flexure support ring, said first flexure plate defining a first plane;

a second flexure plate mounted at one end to the opposite end of said flexure support ring from said first flexure plate, said second flexure plate defining a second plane, said second flexure plate positioned relative to said first flexure plate such that said first and second planes intersect, the intersection of said first plane and said second plane defining a first line;

a first flexure support plate mounted at one end to the end of said first flexure plate remote from said flexure support ring, and mounted at the other end to said lever assembly;

a second flexure support plate mounted at one end to the end of said second flexure plate remote from said flexure support ring, and mounted at the other end to said lever assembly;

a first lever having a first end and a second end, said first end disposed against the juncture of said first flexure plate and said flexure support ring;

a first tilt actuator mounted on said lever assembly and against said second end of said first lever, for moving said first lever laterally toward or away from said first flexure plate and said flexure support ring;

a third flexure plate mounted at one end to said flexure support ring and mounted at the other end to said actuator lens, said third flexure plate defining a third plane;

a fourth flexure plate mounted at one end to said flexure support ring and mounted at the other end to said actuator lens, said fourth flexure plate defining a fourth plane, said fourth flexure plate positioned relative to said third flexure plate such that said third and fourth planes intersect, the intersection of said third plane and said fourth plane defining a second line orthogonal to said first line, the intersection of said first line and said second line defining a rotation point, said rotation point located at said actuator optical center;

a second lever having a first end and a second end, said first end disposed against the intersection of said third flexure plate and said actuator lens; and

a second tilt actuator mounted on said lever assembly and against said second end of said second lever, for moving said second lever laterally toward or away from said third flexure plate;

whereby said first tilt actuator imparts a first movement on said first lever toward or away from said first flexure support plate, thereby causing rotation of said first flexure support plate, said second flexure support plate, said flexure support ring, and said actuator lens about said first axis, and said second tilt actuator imparts a second movement on said second lever toward or away from said third flexure support plate, thereby causing rotation of said third flexure support plate, said fourth flexure support plate, said flexure support ring, and said actuator lens about said second axis.

12. An apparatus as defined in claim 6, wherein said actuator lens tilt assembly comprises:

a flexure support ring;

a first flexure plate mounted at one end to said flexure support ring, said first flexure plate defining a first plane;

a second flexure plate mounted at one end to the opposite end of said flexure support ring from said first flexure plate, said second flexure plate defining a second plane, said second flexure plate positioned relative to said first flexure plate such that said first and second planes intersect, the intersection of said first plane and said second plane defining a first line;

a first flexure support plate mounted at one end to the end of said first flexure plate remote from said flexure support ring, and mounted at the other end to said lever assembly;

a second flexure support plate mounted at one end to the end of said second flexure plate remote from said flexure support ring, and mounted at the other end to said lever assembly;

a first lever having a first end and a second end, said first end disposed against the juncture of said first flexure plate and said flexure support ring;

a first tilt actuator mounted on said lever assembly and against said second end of said first lever, for moving said first lever laterally toward or away from said first flexure plate and said flexure support ring;

a third flexure plate mounted at one end to said flexure support ring and mounted at the other end to said actuator lens, said third flexure plate defining a third plane;

a fourth flexure plate mounted at one end to said flexure support ring and mounted at the other end to said actuator lens, said fourth flexure plate defining a fourth plane, said fourth flexure plate positioned relative to said third flexure plate such that said third and fourth planes intersect, the intersection of said third plane and said fourth plane defining a second line orthogonal to said first line, the intersection of said first line and said second line defining a rotation point, said rotation point located at said actuator optical center;

a second lever having a first end and a second end, said first end disposed against the intersection of said third flexure plate and said actuator lens; and

a second tilt actuator mounted on said lever assembly and against said second end of said second lever, for moving said second lever laterally toward or away from said third flexure plate;

whereby said first tilt actuator imparts a first movement on said first lever toward or away from said first flexure support plate, thereby causing rotation of said first flexure support plate, said second flexure support plate, said flexure support ring, and said actuator lens about said first axis, and said second tilt actuator imparts a second movement on said second lever toward or away from said third flexure support plate, thereby causing rotation of said third flexure support plate, said fourth flexure support plate, said flexure support ring, and said actuator lens about said second axis.

13. An apparatus for aligning a baseplate assembly, comprising:

a lens defining an optical axis;

a source of radiant energy for projecting a radiant energy beam into said lens along a beam axis;

means for determining the tilt alignment of said beam axis with respect to said optical axis;

a first tilt actuator for rotating said beam axis about a first repositioning axis orthogonal to said optical axis; and

a second tilt actuator for rotating said beam axis about a second repositioning axis orthogonal to said optical axis and said first repositioning axis.

14. An apparatus as defined in claim **13**, further comprising a mirror disposed along said beam axis for redirecting said radiant energy beam into said lens in response to motion by one or more of said actuators.

15. An apparatus as defined in claim **1**, further comprising:

a source of radiant energy for projecting said beam of radiant energy into said tower assembly along a beam axis;

means for determining the tilt alignment of said beam axis with respect to said tower axis;

a first tilt actuator for rotating said beam axis about a first repositioning axis orthogonal to said tower axis; and

a second tilt actuator for rotating said beam axis about a second repositioning axis orthogonal to said tower axis and said first repositioning axis.

16. An apparatus as defined in claim **6**, further comprising:

a source of radiant energy for projecting said beam of radiant energy into said tower assembly along a beam axis;

means for determining the tilt alignment of said beam axis with respect to said tower axis;

a first tilt actuator for rotating said beam axis about a first repositioning axis orthogonal to said tower axis; and

a second tilt actuator for rotating said beam axis about a second repositioning axis orthogonal to said tower axis and said first repositioning axis.

17. An apparatus as defined in claim **12**, further comprising:

a source of radiant energy for projecting said beam of radiant energy into said tower assembly along a beam axis;

means for determining the tilt alignment of said beam axis with respect to said tower axis;

a first tilt actuator for rotating said beam axis about a first repositioning axis orthogonal to said tower axis; and

a second tilt actuator for rotating said beam axis about a second repositioning axis orthogonal to said tower axis and said first repositioning axis.

18. An apparatus for aligning a baseplate assembly, as defined in claim **13**, further comprising:

means for determining the lateral alignment of said beam axis with respect to said optical axis;

a first lateral actuator for repositioning said beam axis laterally with respect to said optical axis along said first repositioning axis; and

a second lateral actuator for repositioning said beam axis laterally with respect to said optical axis along said second repositioning axis.

19. An apparatus as defined in claim **18**, further comprising a mirror disposed along said beam axis for redirecting said radiant energy beam into said lens in response to motion by one or more of said actuators.

20. An apparatus as defined in claim **1**, further comprising:

a source of radiant energy for projecting said beam of radiant energy into said tower assembly along a beam axis;

means for determining the lateral alignment and tilt alignment of said beam axis with respect to said tower axis;

a first lateral actuator for repositioning said beam axis laterally with respect to said tower axis along a first repositioning axis orthogonal to said tower axis;

a second lateral actuator for repositioning said beam axis laterally with respect to said tower axis along a second repositioning axis orthogonal to said tower axis and said first repositioning axis;

a first tilt actuator for rotating said beam axis about said first repositioning axis; and

a second tilt actuator for rotating said beam axis about said second repositioning axis.

21. An apparatus as defined in claim **6**, further comprising:

a source of radiant energy for projecting said beam of radiant energy into said tower assembly along a beam axis;

means for determining the lateral alignment and tilt alignment of said beam axis with respect to said tower axis;

a first lateral repositioning actuator for repositioning said beam axis laterally with respect to said tower axis along a first repositioning axis orthogonal to said tower axis;

a second lateral repositioning actuator for repositioning said beam axis laterally with respect to said tower axis along a second repositioning axis orthogonal to said tower axis and said first repositioning axis;

a first tilt actuator for rotating said beam axis about said first repositioning axis; and

a second tilt actuator for rotating said beam axis about said second repositioning axis.

22. An apparatus as defined in claim **12**, further comprising:

a source of radiant energy for projecting said beam of radiant energy into said tower assembly along a beam axis;

means for determining the lateral alignment and tilt alignment of said beam axis with respect to said tower axis;

a first lateral repositioning actuator for repositioning said beam axis laterally with respect to said tower axis along a first repositioning axis orthogonal to said tower axis;

a second lateral repositioning actuator for repositioning said beam axis laterally with respect to said tower axis along a second repositioning axis orthogonal to said tower axis and said first repositioning axis;

a first tilt repositioning actuator for rotating said beam axis about said first repositioning axis; and

a second tilt repositioning actuator for rotating said beam axis about said second repositioning axis.

23. An apparatus as defined in claim **17**, wherein said tower assembly comprises:

a video camera having a camera lens defining a camera optical axis, said camera optical axis being parallel to said tower axis;

a tower magnifying lens defining a tower lens optical axis, said tower lens optical axis being parallel to said tower axis, for cooperating with said objective lens to focus said beam of radiant energy on said camera lens; and

a monitor for displaying a representation of said beam of radiant energy.

24. An apparatus as defined in claim **17**, further comprising:

a second cradle assembly for holding a second baseplate, said second cradle assembly mounted to said frame with at least one degree of freedom of motion;

a second source of radiant energy for projecting a second beam of radiant energy; and

a second tower assembly mounted to said frame, said second tower assembly defining a second tower axis, for receiving said second beam of radiant energy along said second tower axis and analyzing the spot profile of said second beam of radiant energy, said second cradle assembly and said second tower assembly defining a second assembly axis.

25. A method of aligning an actuator lens with respect to a baseplate assembly, comprising the steps of:

moving a first time said baseplate assembly with respect to a tower assembly, said baseplate assembly defining a baseplate optical axis, said tower assembly defining a tower optical axis, whereby said first moving step aligns said baseplate optical axis and said tower optical axis;

moving a second time an objective lens assembly with respect to said tower assembly, said objective lens assembly defining an objective lens optical axis, whereby said second moving step aligns said objective lens optical axis and said tower optical axis; and

moving a third time said actuator lens with respect to said tower assembly, said actuator lens defining an actuator lens optical axis,

whereby said third moving step aligns said actuator lens optical axis and said tower optical axis.

26. A method of aligning a lens, as defined in claim **25**, wherein said first moving step comprises:

moving said baseplate assembly with respect to said tower assembly laterally such that said baseplate optical axis and said tower optical axis intersect at a first intersection; and

rotating a first time said baseplate assembly with respect to said tower assembly about a first rotational axis through said first intersection and orthogonal to said baseplate optical axis and said tower optical axis.

27. A method of aligning a lens, as defined in claim **25**, wherein said third moving step comprises:

moving said actuator lens with respect to said tower assembly laterally such that said actuator lens optical axis and said tower optical axis intersect at a second intersection; and

rotating a second time said actuator lens with respect to said tower assembly about a second rotational axis through said second intersection and orthogonal to said actuator lens optical axis and said tower optical axis.

28. A method of aligning a lens, as defined in claim **26**, wherein said third moving step comprises:

moving said actuator lens with respect to said tower assembly laterally such that said actuator lens optical axis and said tower optical axis intersect at a second intersection; and

rotating a second time said actuator lens with respect to said tower assembly about a second rotational axis through said second intersection and orthogonal to said actuator lens optical axis and said tower optical axis.

29. A method of aligning a lens, as defined in claim **26**, wherein said first rotating step comprises:

rotating said baseplate assembly with respect to said tower assembly about a first reference axis through said first intersection and coplanar with said first rotational axis; and

rotating said baseplate assembly with respect to said tower assembly about a second reference axis through said first intersection and coplanar with said first rotational axis and orthogonal to said first reference axis;

whereby said baseplate assembly is rotated about said first rotational axis.

30. A method of aligning a lens, as defined in claim **27**, wherein said second rotating step comprises:

rotating said actuator lens with respect to said tower assembly about a third reference axis through said second intersection and coplanar with said first rotational axis; and

rotating said actuator lens with respect to said tower assembly about a fourth reference axis through said second intersection and coplanar with said second rotational axis and orthogonal to said third reference axis;

whereby said actuator lens is rotated about said second rotational axis.

31. A method of aligning a lens, as defined in claim **28**, wherein:

said first rotating step comprises:

rotating said baseplate assembly with respect to said tower assembly about a first reference axis through said first intersection and coplanar with said first rotational axis; and

rotating said baseplate assembly with respect to said tower assembly about a second reference axis through said first intersection and coplanar with said first rotational axis and orthogonal to said first reference axis;

whereby said baseplate assembly is rotated about said first rotational axis; and

said second rotating step comprises:

rotating said actuator lens with respect to said tower assembly about a third reference axis through said second intersection and coplanar with said first rotational axis; and

rotating said actuator lens with respect to said tower assembly about a fourth reference axis through said second intersection and coplanar with said second rotational axis and orthogonal to said third reference axis;

whereby said actuator lens is rotated about said second rotational axis.

* * * * *

US005742439A

United States Patent [19]

Schuster

[11] Patent Number: 5,742,439

[45] Date of Patent: Apr. 21, 1998

[54] **APOCHROMATIC WIDE-ANGLE OBJECTIVE**

[75] Inventor: **Karl-Heinz Schuster**, Bad Wurzach, Germany

[73] Assignee: **Carl-Zeiss-Stiftung**, Heidenheim, Germany

[21] Appl. No.: **529,069**

[22] Filed: **Sep. 15, 1995**

[30] **Foreign Application Priority Data**

Sep. 15, 1994 [DE] Germany 44 32 872.9

[51] **Int. Cl.**[6] **G02B 13/04**

[52] **U.S. Cl.** **359/749**; 357/752

[58] **Field of Search** 359/749, 750, 359/637, 751, 752, 753

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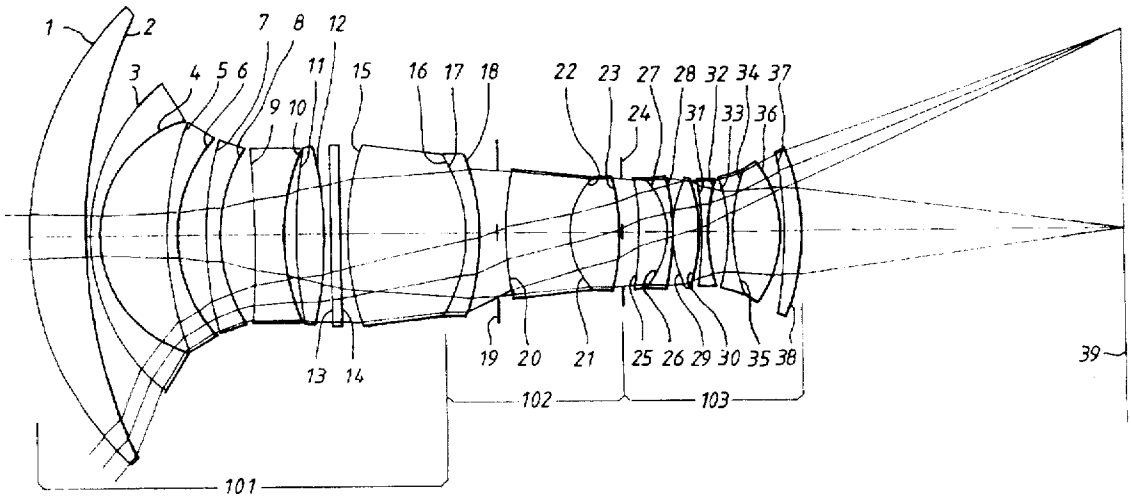
Primary Examiner—David C. Nelms
Assistant Examiner—Ricky Mack
Attorney, Agent, or Firm—Walter Ottesen

[57] **ABSTRACT**

An apochromatic wide-angle objective has an improved correction of transverse chromatic aberration while at the same providing a high correction of other errors. These corrections are obtained utilizing long-crown and short-flint glasses.

19 Claims, 6 Drawing Sheets



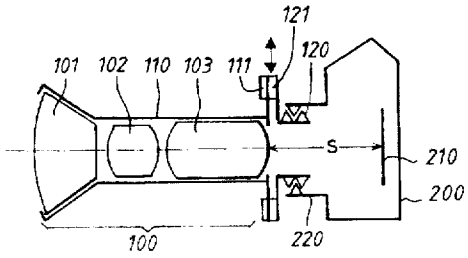
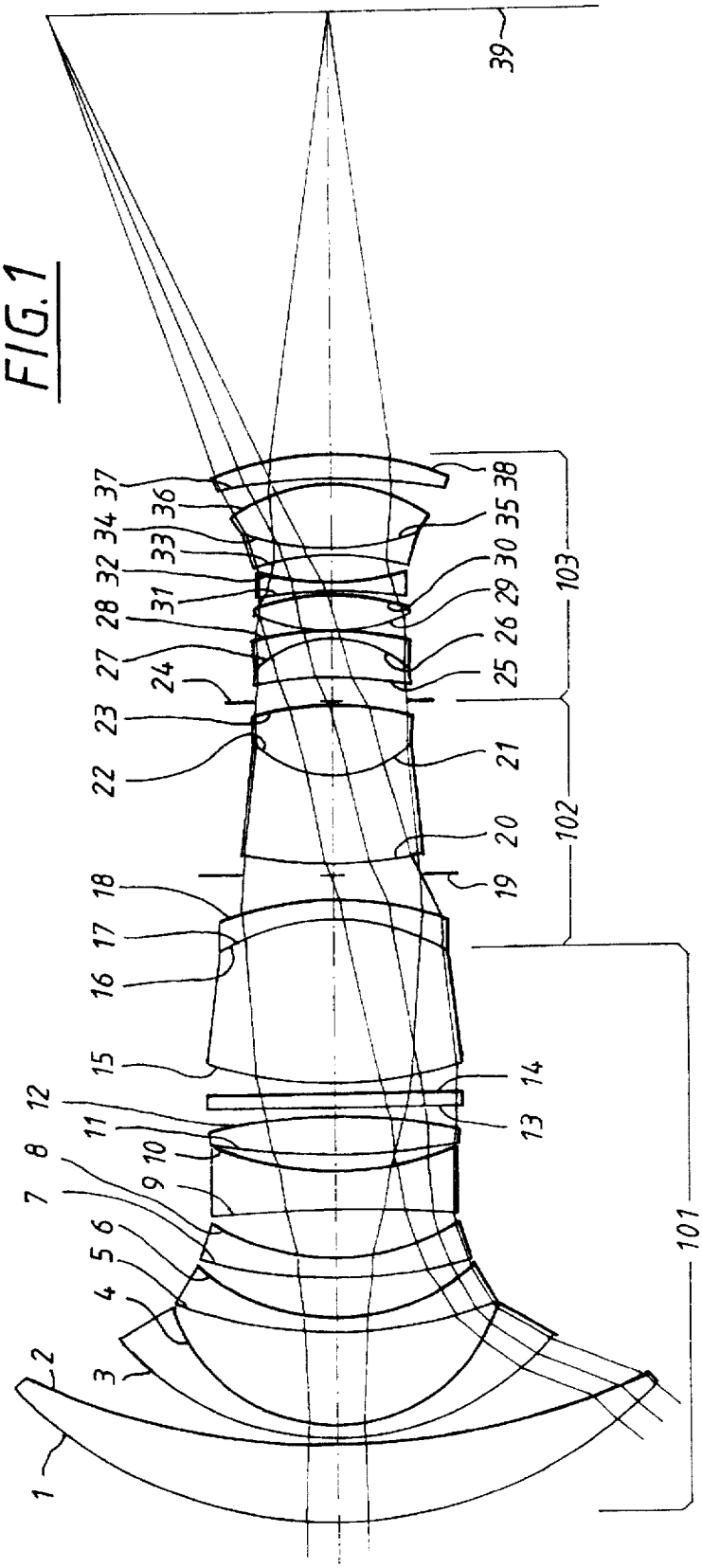


FIG. 1


39
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19
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103
102
101

FIG. 2

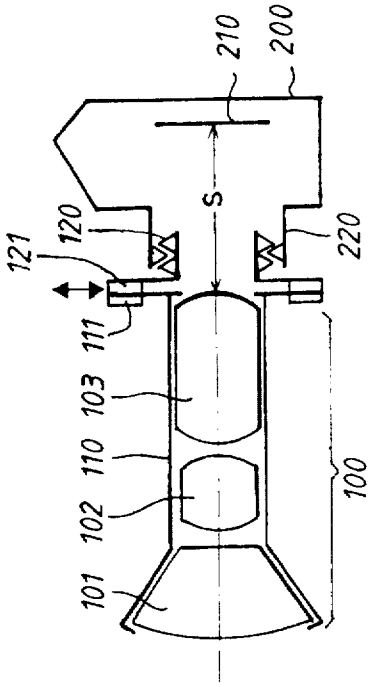
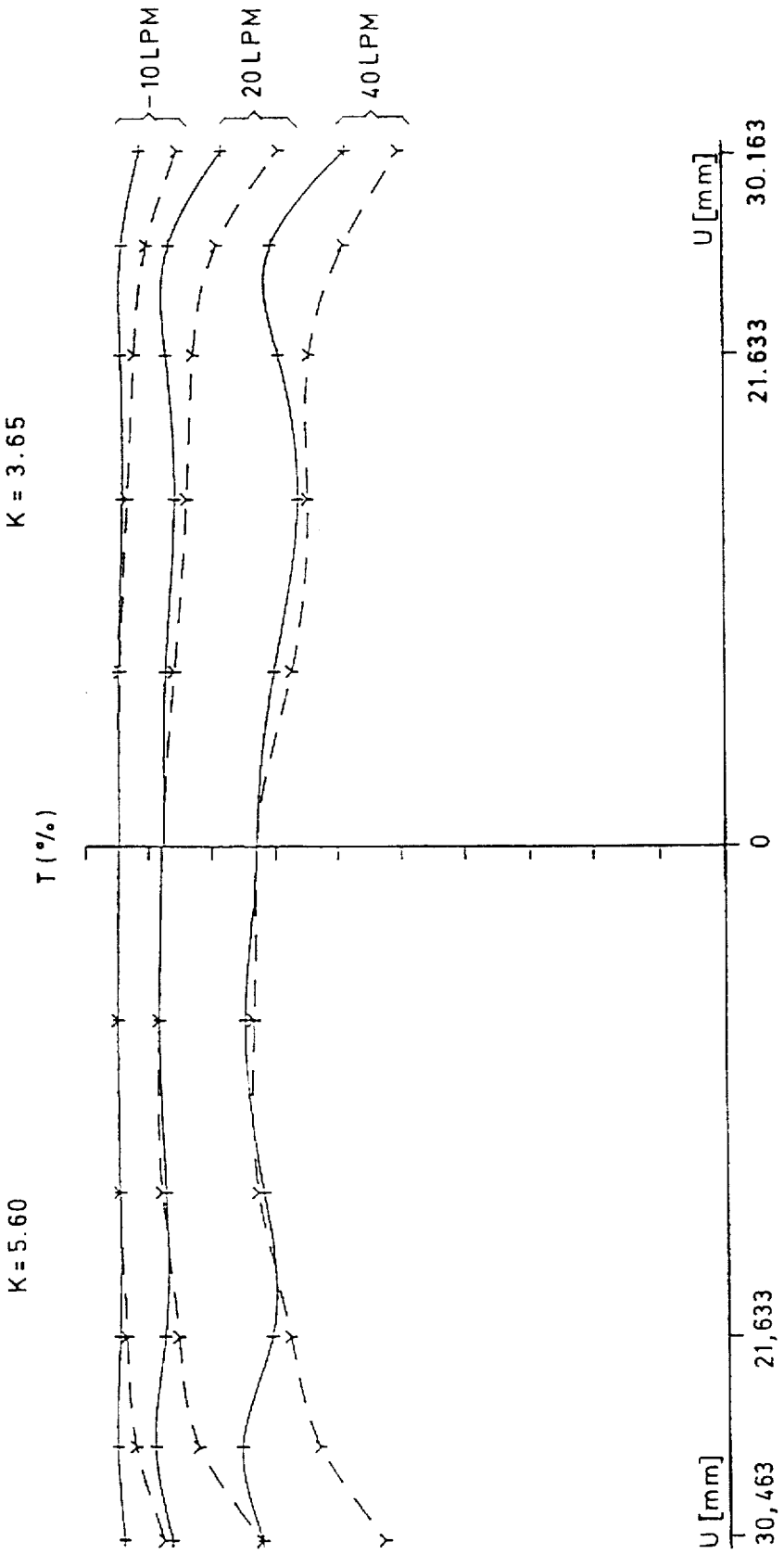

210
200
S
121
120
220
111
103
110
102
101
100

FIG. 3


10LPM
20LPM
40LPM
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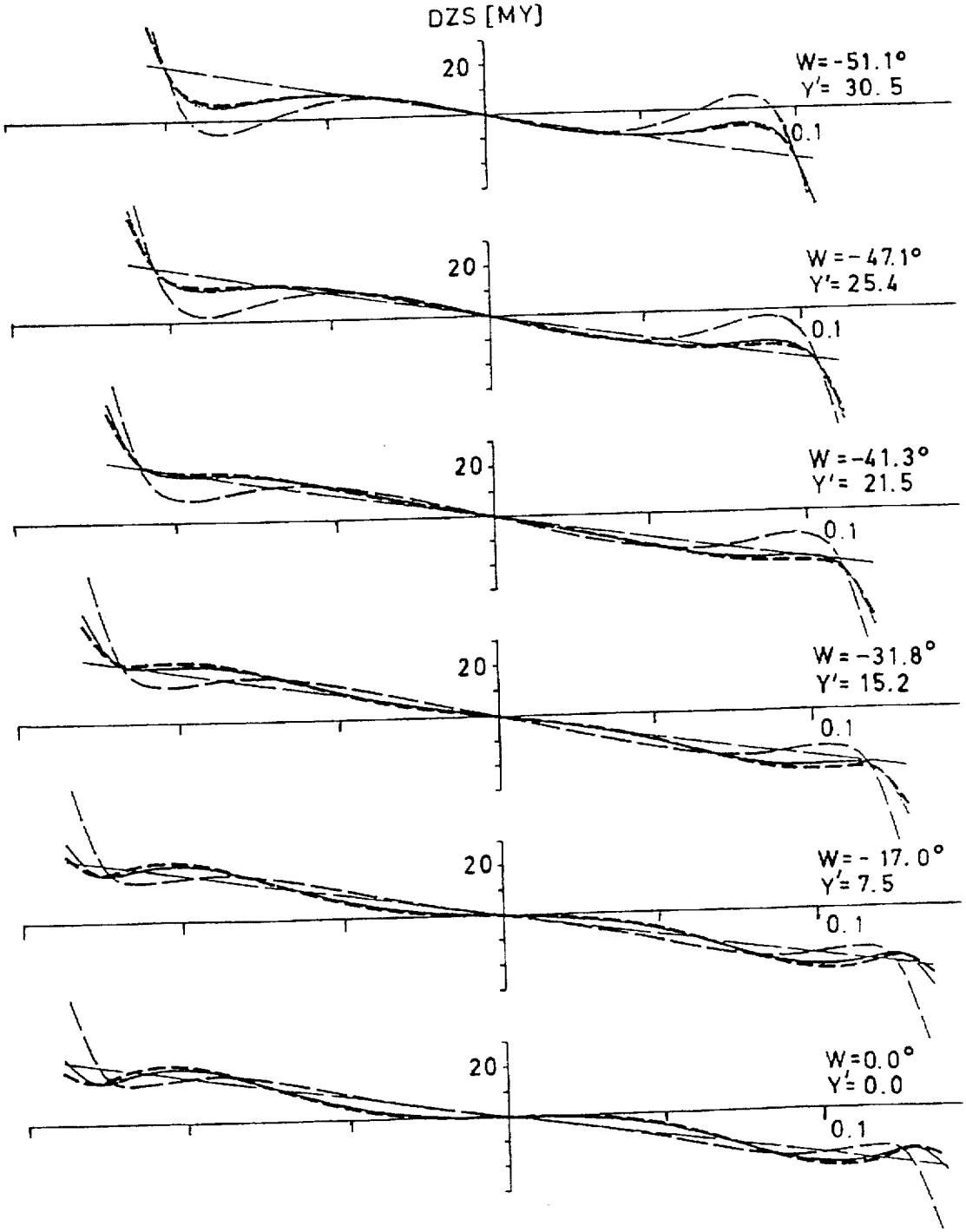
K = 5.60
T (%)
0
U [mm]
30.163
21.633
U [mm]
30,463
21,633

FIG. 4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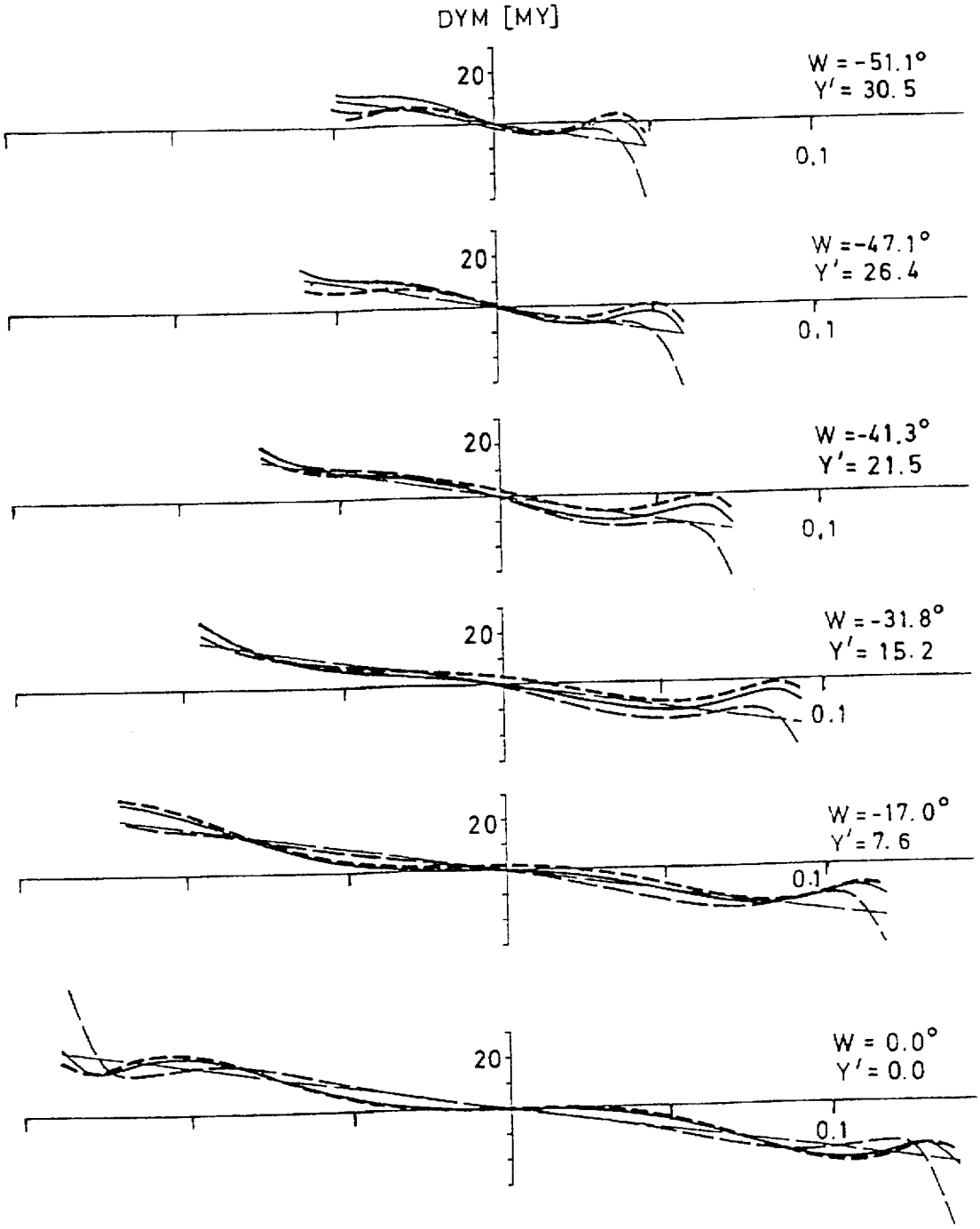
W=-47.1°
Y'= 25.4
W=-41.3°
Y'= 21.5
W=-31.8°
Y'= 15.2
W=-17.0°
Y'= 7.5
W=0.0°
Y'= 0.0

FIG. 5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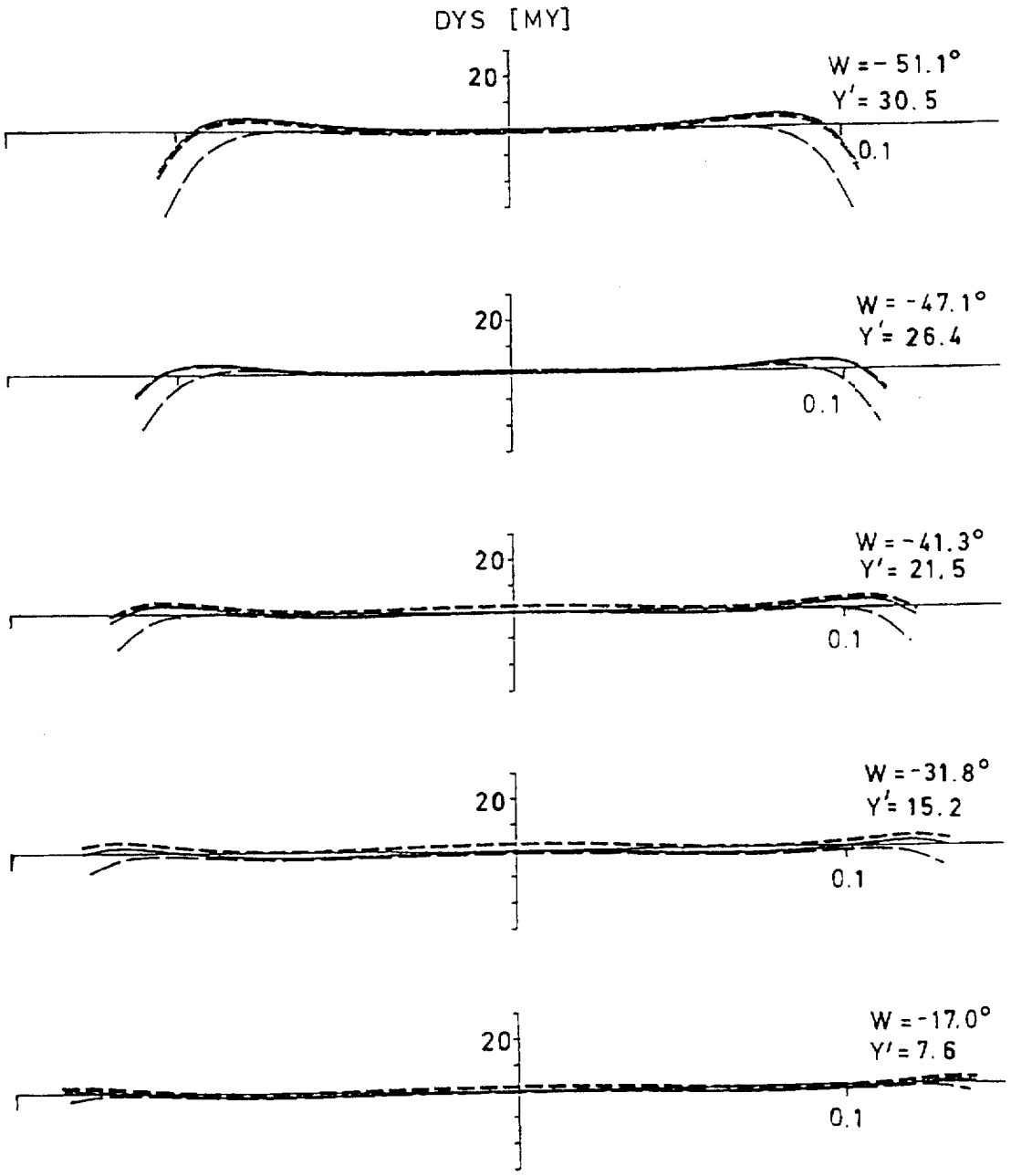
20
W = -47.1°
Y' = 26.4
0.1
20
W = -41.3°
Y' = 21.5
0.1
20
W = -31.8°
Y' = 15.2
0.1
20
W = -17.0°
Y' = 7.6
0.1
20
W = 0.0°
Y' = 0.0
0.1

FIG. 6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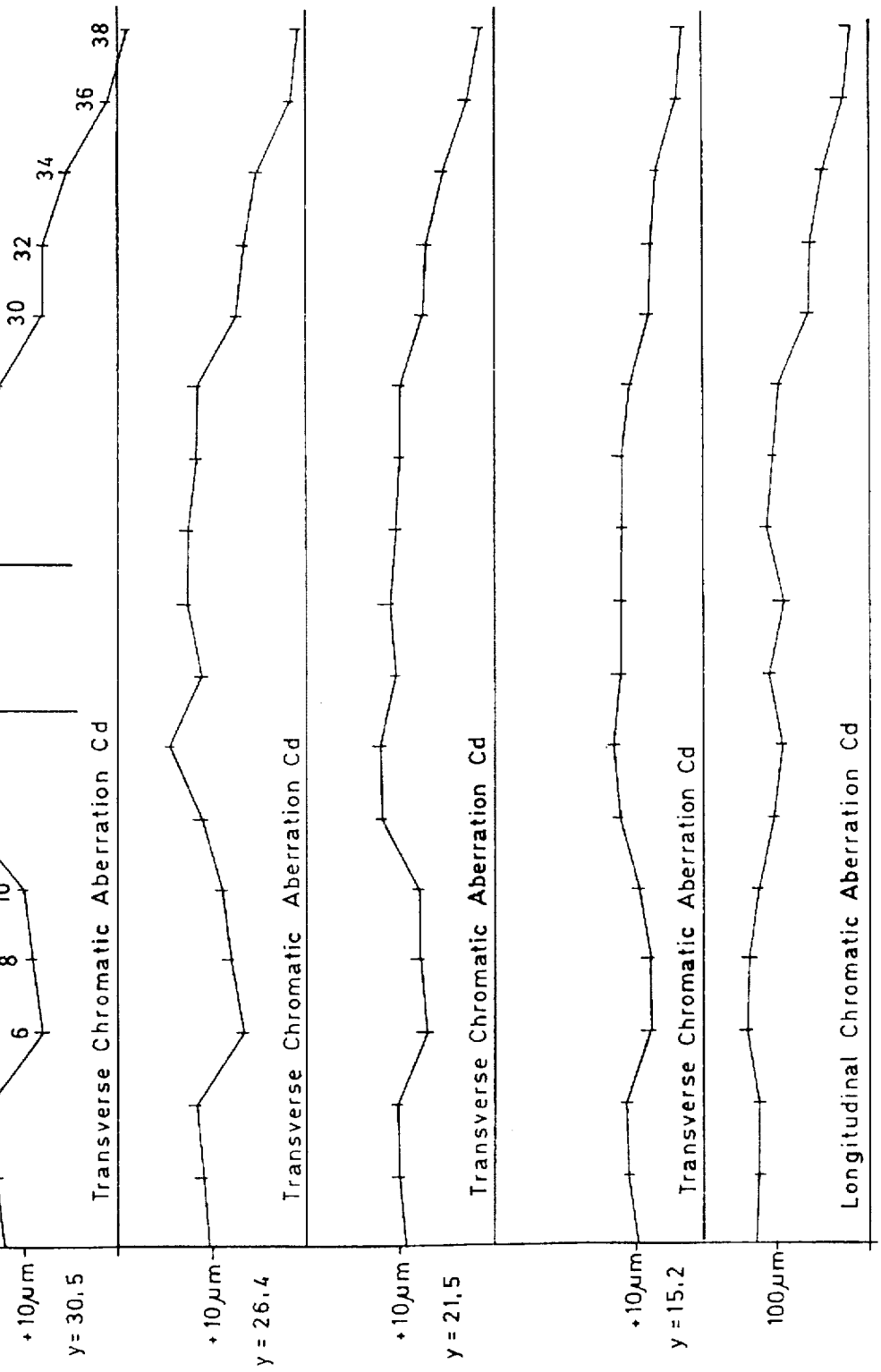
Y' = 30.5
0.1
20
W = - 47.1°
Y' = 26.4
0.1
20
W = - 41.3°
Y' = 21.5
0.1
20
W = - 31.8°
Y' = 15.2
0.1
20
W = - 17.0°
Y' = 7.6
0.1

FIG. 7


2
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32
34
36
38
+10μm
y = 30.5
Transverse Chromatic Aberration Cd
+10μm
y = 26.4
Transverse Chromatic Aberration Cd
+10μm
y = 21.5
Transverse Chromatic Aberration Cd
+10μm
y = 15.2
Transverse Chromatic Aberration Cd
100μm
Longitudinal Chromatic Aberration Cd

APOCHROMATIC WIDE-ANGLE OBJECTIVE

FIELD OF THE INVENTION

The invention relates to an apochromatic wide-angle objective wherein: the majority of the lenses have considerable anomalous partial dispersion, the majority of the converging lenses behind the system diaphragm are of the long-crown type and the majority of the convex lenses are of the short-flint type.

BACKGROUND OF THE INVENTION

An objective of this kind was presented at the "Photokina 1992" in Cologne under the designation Carl Zeiss Distagon 2.8/21 mm No. 104926 configured as a wide-angle objective for miniature cameras, such as 24×36 mm^2 cameras. In this objective, most lenses forward of the diaphragm having positive refractive power are made of glasses having anomalous partial dispersion and are of the short-flint type. Most lenses having a negative refractive power are made of the long-crown type. After the diaphragm, the association of the sign of the refractive power is inverted with respect to the glass type. In this way, the correction of the transverse chromatic aberration for three wavelengths and three image heights was made possible by continuous reduction from lens to lens.

However, in the above, it is not possible to simultaneously optimally correct the oblique spherical aberration which would require a different refractive power distribution over the lenses.

The full image quality is obtained with this objective, as with other commercially available wide-angle objectives, only after stopping down approximately two stop numbers with respect to the nominal full opening.

SUMMARY OF THE INVENTION

It is an object of the invention to provide an apochromatically corrected wide-angle objective wherein the transverse chromatic aberration and the oblique spherical aberration are corrected to a great extent. The highest image quality should already be available when the aperture is completely open, that is, the objective is set to its smallest stop number. An embodiment defining an apochromatic perspective compensating wide-angle objective is also provided.

A front lens made of glass having anomalous partial dispersion is introduced which is so configured that it generates a transverse chromatic aberration which is in addition to that which occurs for normal glass. It was surprisingly found that introducing a front lens made of this glass made it possible, together with further lenses made of such glass types, to obtain the correction of the transverse chromatic aberration and simultaneously realize a progression of the refractive powers which permits a correction of the oblique spherical aberration. Overall, a correction is possible in this manner which results in a complete image quality up to the full opening (minimum stop number). In this way, the exposure latitude available to a photographer is significantly expanded.

The apochromatic wide-angle objective of the invention is for viewing an object. The objective includes: a plurality of lenses defining an optical axis and more than half of the lenses having anomalous partial dispersion; the plurality of lenses being subdivided into first and second groups of lenses; a system diaphragm mounted on the axis between the first and second groups; the first group of lenses having a front lens facing toward the object; the front lens being a converging lens made of a long-crown type of glass; the second group of lenses including a plurality of converging lenses and a plurality of diverging lenses; and, more than half of the converging lenses of the second group being made of a long-crown type of glass and more than half of the diverging lenses of the second group being made of a short-flint type of glass.

According to another feature of the invention, a forward group, which deliberately increases the transverse chromatic aberration, and a center group, which reduces this aberration, are provided forward of the system diaphragm.

According to another feature of the invention, preferred tolerances are provided when other than long-crown or short-flint glasses are used which cannot always be avoided.

Preferably, the front lens significantly increases the transverse chromatic aberration. The front lens is preferably a meniscus having a convex front surface because the objective is then especially compact.

In an advantageous embodiment, a composite lens made of two lenses of glass is provided forward of the system diaphragm. The dispersion functions of these lenses in the spectral range used are distinguished from each other only by a constant, that is, the lenses have different refractive indices but the same Abbe number and the same anomalous partial dispersions.

In this way, a surface is made available which is without influence with respect to the chromatic errors and which can be used for correcting the remaining imaging errors.

While the front lens increases the transverse chromatic aberration, this aberration is well corrected by the entire objective in a preferred embodiment for three wavelengths over all field angles. Likewise, it is a special advantage of the invention that the oblique spherical aberration of the sagittal imaging is well corrected.

The objective is preferably configured as a retrofocus objective and especially as an interchangeable lens and is especially suited as a shift objective. The embodiment according to the invention leads to a good correction even for the problems caused by the backfocus distance which is necessarily large.

A lens made of long-crown glass Hoya ATF 2 is used or a lens made of the glass known as Hoya ADC 1. The glass Hoya ATF 2 is a long-crown glass which is known for its athermal characteristic and is used only in special objectives where this characteristic is needed. The Hoya ADC 1 glass is likewise of the long-crown type and is especially suited for the front lens. Glasses of other manufacturers having practically the same optical characteristics are likewise suitable.

The designations "long crown" and "short flint" identify optical glasses with respect to their partial dispersion. In a primary dispersion/partial dispersion diagram v, P the Abbe normal is determined by the glass pair K7, F2 (Schott). Most conventionally available optical glasses are close to this normal straight line.

Glasses of the long-crown type have a significantly lower partial dispersion. Glasses of the short-flint type have a significantly higher partial dispersion than the glasses which lie on the Abbe normal straight line, that is, they have an anomalous partial dispersion.

There are, however, various definitions of primary dispersion (v) and partial dispersion (P) in use which refer to different spectral lines. In this context, reference can be

made to the text of H. Naumann et al entitled "Bauelemente der Optik" published by Carl Hanser Verlag, Munich, 1983, pages 52 and 55. Here, it is stated that at least one type of glass having anomalous partial dispersion must be used for apochromatization.

Here, an apochromatization for the following lines is delineated:

g: blue mercury line at 435.84 nm;

d: yellow helium line at 587.56 nm; and,

C: red hydrogen line at 657.27 nm

and achromatized for g, d.

The primary dispersion is defined as:

$$\nu = \frac{n_d - 1}{n_g - n_d}$$

This equation is therefore only characterized by the indices of refraction at two lines.

The partial dispersion is defined as:

$$P = \frac{n_d - n_C}{n_g - n_d}$$

Thus, an extrapolation of the refractive index is carried out toward the third line C.

The Abbe normal straight line for K2, F7 has, with this definition, the form

$$P_n = A \cdot \nu + B$$

and the deviation therefrom as a relative partial dispersion is given as:

$$\Delta P = P - A \cdot \nu - B \text{ with}$$

$$A = 0.9007 \cdot 10^{-4} \text{ and } B = 0.2025.$$

A uniform distribution of commercially available glass types about the normal straight line results over the entire range of the primary dispersion values compared to the normal straight lines defined above and with the primary dispersion ν and partial dispersion P defined above. The distinction fixed thereby of long-crown, normal and short-flint glasses corresponds well to the requirement to select a glass for pregiven primary dispersion which has a relatively pronounced partial dispersion amongst the glasses available.

According to another feature of the invention, the selection of the glasses in accordance with the definition given above is especially advantageous.

An especially advantageous embodiment of the objective of the invention can be scaled for other focal lengths by the scale of the focal length ratio.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will now be described with reference to the drawings wherein:

FIG. **1** is a lens section view taken through an Apo-Distagon 3.5/25 mm objective according to the invention;

FIG. **2** is a schematic representation of a shift interchangeable objective mounted on a camera;

FIG. **3** is a diagram of a modulation transmission function for the objective of FIG. **1**;

FIG. **4** is a diagram of the total transverse aberration in a sagittal section for the objective of FIG. **1**;

FIG. **5** is a diagram of the total transverse aberration in the meridional section for the objective of FIG. **1**;

FIG. **6** is a diagram of the sagittal coma of the objective of FIG. **1**; and,

FIG. **7** is a diagram showing the progression of the transverse chromatic aberration and longitudinal chromatic aberration over the lenses of the objective of FIG. **1**.

DESCRIPTION OF THE PREFERRED EMBODIMENTS OF THE INVENTION

The main rays for minimum and maximum image angle are shown in the lens section of FIG. **1**. Table 1 presents the following: the radii of the surfaces **1** to **39**, the thicknesses and the glass types as well as further essential data of the objective. Surface **39** is the image plane. The cement used has the refractive index 1.57 at a wavelength of 587.6 nm.

Also presented in Table 1 are: the refractive index for the d-line (n_d), the primary dispersion (ν) and the relative partial dispersion (ΔP) in accordance with the definitions presented above. Also delineated in Table 1 are the long-crown character L or the short-flint character K of the glasses.

The planar-parallel element after surface **13** is made of normal glass and functions as an exchangeable filter. Of the 17 lenses, a total of 14 lenses have a considerable anomalous partial dispersion.

Behind the system diaphragm **24** in the base group **103**, all lenses of a positive refractive power (**25**, **29**, **35**, **37**) have a long-crown characteristic and the lenses (**27**, **33**) of negative refractive power have a short-flint characteristic as in the above-mentioned Carl Zeiss Distagon 2.8/21 mm.

The first lens **1** of the objective is a convex meniscus of positive refractive power and is on the object end of the objective. This first lens **1** has a pronounced long-crown character in contrast to the rule applied in the above-mentioned known objective. The first lens **1** is made of Hoya ADC 1, which is a glass seldom used, or a like substitute and is made with the following parameters: n_d=1.620;ν=50 and ΔP=–0.0033.

In this way, and in accordance with the invention, a transverse chromatic aberration is generated which must subsequently be corrected. This transverse chromatic aberration is greater than for a theoretical glass having the same refractive index and primary dispersion but with a vanishing relative partial dispersion. It is, however, possible in this manner to reduce the angle and elevation of the light rays in the region of lenses having surfaces (**1**, **3**, **5**, **7**) very rapidly whereby the oblique spherical aberration of the sagittal imaging is effectively reduced.

In the entire forward group **101**, the same relationship of refractive power and character of the anomalous partial dispersion is maintained as in the base group **103**. Only for the third lens having the surfaces (**5**, **6**) with a very high refractive index (n_d=1.92) and low primary dispersion (ν=15.9), only long-crown glasses which are inconsistent with the system are available so that this system deviation must be accepted.

The center group **102** is built up in an opposite manner and comprises the lenses having surfaces (**17**, **18**; **20**, **21**; **21**, **22**). Here, the lenses with surfaces (**21**, **22**) have a positive refactive power and are made of short-flint glasses and those lenses having surfaces (**17**, **18**) have a negative refractive power and are made of long-crown glasses.

The following glasses: Ohara LAH **75** (lenses having surfaces **3**, **4**; **31**, **32**); Ohara BPH 45 lenses having surfaces (**27**, **28**) and Ohara BAH 30 lenses having surfaces (**15**, **16**) all having an amount of relative partial dispersion ΔP below 2×10^{-3} can be considered as normal glasses. It is, however,

significant that the partial dispersion ΔP thereof (even when small) are in the proper direction.

The composite lens having surfaces (**20**, **22**) comprises two glasses (Hoya TAFD 30, Ohara BPH 35) with different refractive index (n) but with practically the same primary dispersion (v) and with practically the same relative partial dispersion (ΔP). The dispersion functions of both are distinguished therefore only by a constant Δn. The cement interface at surfaces (**21**, **22**) has therefore no effect with respect to spectral correction and can separately act on other errors. Overall, the composite lens having surfaces (**20**, **22**) has a positive refractive power and a short-flint character.

The system deviation of the first lens having surfaces (**20**, **21**) of the composite element lenses having surfaces (**20**, **22**) as short flint results from this special function.

The glass selection for an apochromatic wide-angle objective according to the invention then takes place as delineated below.

In the front group **101**, the transverse chromatic aberration for the red spectral range is deliberately magnified already by the first lens having surfaces (**1**, **2**). The objective here is to greatly increase the error in the external field. A demagnification of the transverse chromatic aberration would here lead to the condition that a large undercorrection in the field center (zone) would occur or that an overcorrection would occur at the edge. The rule therefore states for the forward group:

lenses of positive refractive power are made of long-crown glass; and,

lenses of negative refractive power are made of short-flint glass.

The refractive index and primary dispersion are, however, pregiven by the primary requirements of the achromatic correction. For this reason, the situation can occur that for the lenses having surfaces (**5**, **6**), no suitable glass is available in the marketplace and nonconforming glass must be utilized, for example, a lens having surfaces (**5**, **6**) of negative refractive power made of long-crown glass.

In the center group **102**, the objective is the reduction of transverse chromatic aberration in the entire field and, for this purpose, the rule is the opposite as for the first group **101** and is as follows:

lenses of positive refractive power are made of short-flint glass; and,

lenses of negative refractive power are made of long-crown glass.

It is necessary that one lens having surfaces (**20**, **21**) not adhere to the rule in the context of the special configuration of the composite element lenses having surfaces (**20**, **21**, **22**) already described.

In the base group **103**, and after the system diaphragm **24**, it is the objective to completely eliminate the remaining transverse chromatic aberration in the red spectral range, that is, for the C-line.

The rule here is as follows:

lenses of positive refractive power are made of long-crown glass; and,

lenses of negative refractive power are made of short-flint glass.

The glasses of higher anomalous partial dispersion ΔP are preferably provided in the center of the base group **103** and this is realized by lenses having surfaces (**29**, **30**) which drastically reduce the transverse chromatic aberration over all image heights (see FIG. **7**). The rule is maintained in the embodiment shown. Since the remaining image errors must also be corrected, a smaller transverse chromatic aberration remains in the center of the field (zone).

FIG. **7** shows the transverse chromatic aberration for lines (C, d) plotted as a function of the lenses of the objective for various ray elevations (y). In this, the above color correction can be clearly seen. For comparison, the longitudinal chromatic aberration is also shown. The chromatic aberration is shown in the image plane **39** for simulation computations. In these equations, all lenses are made of glass (which is not really available) having the same refractive index and primary dispersion as presented in the table for the embodiment, but with vanishing relative partial dispersion (ΔP=0).

For focusing the objective, the backfocus distance (spacing **38**, **39**) is changed, that is, the entire objective is displaced and, at the same time, the front group **101** is shifted with respect to the following center and base groups (**102**, **103**) as a "floating element". The air spacings (**18** to **20**) and (**38**, **39**) are changed at the same time.

FIG. **2** shows the objective **100** of the invention mounted on a camera **200**. The objective includes lens groups (**101**, **102**, **103**) and the frame **110** and is attached with an adapter **120** to adapter **220** of the camera **200**. The adapter is shown schematically as screw thread. Since the backfocus distance S of the objective **100** (the spacing of the last lens apex of the base group **103** to the image plane **210** in the camera **200**) is greater than the spacing of the adapters (**120**, **220**) to the image plane **210**, the objective **100** of the invention can be equipped with a shift device (**111**, **121**) to prevent tumbling lines (perspective-compensating wide-angle objective).

The excellent overall quality of the wide-angle objective of Table 1 which is obtained is shown in FIG. **3** wherein the modulation transmission T is shown as a function of the image height (u) for 10, 20 and 40 lines per mm (LPM) sagittally (solid lines) and tangentially (shown dotted) and to the right for the maximum aperture K=3.65, to the left for K=5.6, therefore stopped down by two stop numbers, for white light comprising ten wavelengths from 404.7 nm to 656.3 nm and distance to object is infinity.

The exceptionally stable trace of the modulation transmission T up to large image heights is especially very useful for the embodiment (see FIG. **2**) in the form of a shift objective.

FIG. **4** shows a diagram of the total transverse aberration (DZS) in the sagittal section for the same objective for six different image heights (y') or image angles (W) as a function of the tangent of the aperture angle tan DW' for the three spectral lines (d shown as a solid line, g shown as a broken line of long segments and C as a broken line of short segments). The line of the adjusting plane is shown diagonally.

FIG. **5** shows the same but for the meridional section (DYM, total meridional transverse aberration) and FIG. **6** shows the sagittal aberration (DYS) for the same parameters.

All of these errors are well corrected up to large aperture angles and image heights.

It is understood that the foregoing description is that of the preferred embodiments of the invention and that various changes and modifications may be made thereto without departing from the spirit and scope of the invention as defined in the appended claims.

TABLE 1

Surface	Radius	Thickness	Refractive Power	Glass	Type	n_d	v	P*10⁴
0								
1	50.2529	8.700	+	Hoya ADC1	L	1.62000	50.1	−33
2	92.0163	.050						
3	32.0126	1.000	−	Ohara LAH75	K	1.87400	27.4	+8
4	18.6988	10.510						
5	54.5994	1.500	−	Ohara PBH71	L	1.92286	15.9	−55
6	21.9437	4.850						
7	62.7726	1.500	−	Hoya TAFD30	K	1.88300	32.1	+28
8	23.1902	5.380						
9	−176.8511	4.150	−	Ohara LAM54	K	1.75700	38.1	+26
10	35.9626	1.920						
11	97.3607	4.000	+	Ohara PBH71	L	1.92286	15.9	−55
12	−77.8342	1.180						
13	infinite	1.500	0	Ohara NSL51		Filter		
14	infinite	1.180						
15	42.2118	17.870	+	Ohara BAH30	L	1.65016	30.7	−11
16	−23.5400	.010		Cement				
17	−23.5300	2.150	−	Ohara PBH71	L	1.92286	15.9	−55
18	−32.4246	2.510						
19	infinite	1.490						
20	78.2780	9.490	−	Hoya TAFD30	K	1.88300	32.2	+28
21	12.2789	.010		Cement				
22	12.2811	7.404	+	Ohara BPH35	K	1.64450	32.1	+29
23	−40.1660	.500						
24	infinite	2.560		Diaphragm				
25	−45.2866	4.500	+	Hoya ADC1	L	1.62000	50.1	−33
26	−11.5460	.010		Cement				
27	−11.5430	.740	−	Ohara BPH45	K	1.71850	25.9	+8
28	−29.6646	.060						
29	26.5153	3.840	+	Hoya ATF2	L	1.65052	29.1	−71
30	−25.9265	.180						
31	−56.0023	.960	−	Ohara LAH75	K	1.87400	27.4	+8
32	29.9968	3.250						
33	−21.5144	.690	−	Hoya TAFD30	K	1.88300	32.2	+28
34	28.9861	.010		Cement				
35	29.0109	6.890	+	Ohara FPL51	L	1.49700	66.2	−142
36	−18.0911	.250						
37	−95.1794	3.000	+	Ohara FPL51	L	1.49700	66.2	−142
38	−31.5296							
39		47.791		(backfocus distance S)				

What is claimed is:

1. An apochromatic wide-angle objective for viewing an object, the objective comprising:

a plurality of lenses defining an optical axis and more than half of said lenses having anomalous partial dispersion;

said plurality of lenses being subdivided into forward, center and base groups of lenses;

a system diaphragm mounted on said axis between said center group and said base group;

said base group including a first plurality of converging lenses and a second plurality of diverging lenses;

more than half of said converging lenses of said base group being made of a long-crown type glass and more than half of said diverging lenses of said base group being made of short-flint type glass;

said forward group having a third plurality of lenses having a positive refractive power and a fourth plurality of lenses having a negative refractive power;

more than half of the lenses of said third plurality of lenses including a front lens being made of long-crown type of glass and more than half of the lenses of said fourth plurality of lenses being made of short-flint type glass;

said center group having a fifth plurality of lenses having a positive refractive index and a sixth plurality of lenses having a negative refractive index; and,

more than half of lenses of said fifth plurality of glasses being made of short-flint type glass and more than half of the lenses of said sixth plurality being made of long-crown type glass.

2. The apochromatic wide-angle objective of claim 1, wherein said forward and center groups comprise up to seven lenses; and, at most two of said lenses of said forward and center groups are missing the rules given in claim 1 for more than half of each of the first to sixth pluralities of lenses.

3. The apochromatic wide-angle objective of claim 1, wherein said forward and center groups comprise more than seven lenses; and, at most three of said lenses of said forward and center groups are missing the rules given in claim 1 for more than half of each of the first to sixth pluralities of lenses.

4. The apochromatic wide-angle objective of claim 1, said forward group of lenses having a front lens facing toward the object; said front lens being made of a long-crown type of glass and generating a transverse chromatic aberration which is greater than for a conventional glass otherwise having the same characteristics.

5. The apochromatic wide-angle objective of claim 1, said front lens being a meniscus having a convex front surface.

6. The apochromatic wide-angle objective of claim 1, said center group including a composite lens having two component lenses made of glasses having dispersion functions $(n, (\lambda))$ which differ only by a constant in the spectral range used.

7. The apochromatic wide-angle objective of claim 1, wherein said transverse chromatic aberration is corrected for three wavelengths (g, d, C) over all field angles.

8. The apochromatic wide-angle objective of claim 7, wherein said transverse chromatic aberration is corrected with an error less than ±5 micrometers.

9. The apochromatic wide-angle objective of claim 7, wherein the oblique spherical aberration of sagittal imaging is well corrected.

10. The apochromatic wide-angle objective of claim 1, wherein said objective is configured as a retrofocus objective.

11. The apochromatic wide-angle objective of claim 10, wherein said objective is an exchangeable objective adapted for mounting on a camera; said objective and said camera conjointly defining a device for connecting said objective to said camera; said camera having an image plane and said objective having a last lens facing toward said image plane; and, said last lens having an apex which does not extend beyond said device.

12. The apochromatic wide-angle objective of claim 10, wherein said objective is configured as a shift objective.

13. The apochromatic wide-angle objective of claim 1, wherein at least one of said lenses has characteristics of a glass Hoya ATF2.

14. The apochromatic wide-angle objective of claim 1, wherein at least one of said lenses has characteristics of a glass Hoya ADC1.

15. The apochromatic wide-angle objective of claim 1, comprising a focal length of 25 mm; a numerical aperture of 0.14; an image end back focal distance of 48 mm; and, for all image angles up to 51° in the spectral range of the lines g to C, a total transverse aberration (DZS) in the sagittal section of less than 30 μm for all tangents of the aperture angle (tanDW') less than 0.1; a total transverse aberration DYM) in the meridional section less than 30 μm for all tangents of the aperture angle (tanDW') less than 0.5; and, a sagittal coma (DYS) less than 30 μm for all tangents of the aperture angle (tanDW') less than 0.1.

16. The apochromatic wide-angle objective of claim 1, wherein up to fully opened diaphragm K=3.65 for white light in the spectral range of the lines g to C, the modulation transfer (T) sagittally and tangentially for 10 lines per mm up to an image height (YB) of 20 mm is greater than 90%, up to an image height (YB) of 30 mm is still greater than 80%, and for 40 lines per mm up to an image height (YB) of 20 mm is greater than 60%, and for an image height (YB) of 30 mm is still greater than 50%.

17. The apochromatic wide-angle objective of claim 1, wherein: the refractive index for the wavelength 435.84 nm is n_g; the refractive index for the wavelength 587.56 nm is n_d; the refractive index for the wavelength 657.27 nm is n_C; with the definition of the primary dispersion being given by:

$$\nu = \frac{n_d - 1}{n_g - n_d}$$

with the definition of the partial dispersion being given by

$$P = \frac{n_d - n_C}{n_g - n_d}$$

and the Abbe normal for the glasses (K2, F7) being given by:

$$P_n = A\,\nu + B$$

wherein:

A=0.9007·10^{-4} and B=0.2025 and the deviation from the normal

$$\Delta P = P - P_n = P - A\nu - B$$

wherein:

ΔP is negative for all long crown glass;

ΔP is positive for all short flint glass;

all glasses used having an amount ΔP greater than 8·10^{-4}; and, at least half the glasses an amount ΔP greater than 2.5·10^{-3}.

18. An objective comprising the following characteristics:

focal length 25 mm

largest diaphragm 3.65

Surface	Radius	Thickness	Glass	Type
1	50.2529	8.70	Hoya ADC1	L
2	92.0163	.05		
3	32.0126	1.00	Ohara LAH75	K
4	18.6988	10.51		
5	54.5994	1.50	Ohara PBH71	L
6	21.9437	4.85		
7	62.7726	1.50	Hoya TAFD30	K
8	23.1902	5.38		
9	−176.8511	4.15	Ohara LAM54	K
10	35.9626	1.92		
11	97.3607	4.00	Ohara PBH71	L
12	−77.8342	1.18		
13	infinite	1.50	Ohara NSL51	
14	infinite	1.18	(Filter)	
15	42.2118	17.87	Ohara BAH30	L
16	−23.5400	.01	Cement	
17	−23.5300	2.15	Ohara PBH71	L
18	−32.4246	2.51		
19	infinite	1.49		
20	78.2780	9.49	Hoya TAFD30	K
21	12.2789	.01	Cement	
22	12.2811	7.40	Ohara BPH35	K
23	−40.1660	.50		
24	infinite	2.56	System Diaphragm	
25	−45.2866	4.50	Hoya ADC1	L
26	−11.5460	.01	Cement	
27	−11.5430	.74	Ohara BPH45	K
28	−29.6646	.06		
29	26.5153	3.84	Hoya ATF2	L
30	−25.9265	.18		
31	−56.0023	.96	Ohara LAH75	N
32	29.9968	3.25		
33	−21.5144	.69	Hoya TAFD30	K
34	28.9861	.01	Cement	
35	29.0109	6.89	Ohara FPL51	L
36	−18.0911	.25		
37	−95.1794	3.00	Ohara FPL51	L
38	−31.5296			
39		47.79	(backfocus distance)	

or a different focal length with all radii and distances changed in proportion thereto.

19. An apochromatic wide-angle objective for viewing an object, the objective comprising:

a plurality of lenses defining an optical axis and more than half of said lenses having anomalous partial dispersion;

said plurality of lenses being subdivided into first and second groups of lenses;

a system diaphragm mounted on said axis between said first and second groups;

said first group of lenses having a front lens facing toward the object;

said front lens being a converging lens made of a long-crown type of glass;

said second group of lenses including a plurality of converging lenses and a plurality of diverging lenses; and,

more than half of said converging lenses of said second group being made of a long-crown type of glass and more than half of said diverging lenses of said second group being made of a short-flint type of glass.

* * * * *

US005734511A

United States Patent [19]

Braat

[11] **Patent Number: 5,734,511**

[45] **Date of Patent: Mar. 31, 1998**

[54] **WIDE ANGLE OBJECTIVE SYSTEM**

[75] Inventor: **Josephus J. M. Braat**, Eindhoven, Netherlands

[73] Assignee: **U.S. Philips Corporation**, New York, N.Y.

[21] Appl. No.: **408,756**

[22] Filed: **Mar. 22, 1995**

[30] **Foreign Application Priority Data**

Jul. 25, 1994 [EP] European Pat. Off. 94202161

[51] **Int. Cl.**[6] **G02B 13/18**; G02B 7/02; G02B 9/12; G02B 13/04

[52] **U.S. Cl.** **359/716**; 359/753; 359/784; 359/820

[58] **Field of Search** 359/716, 661, 359/784, 820, 713, 714, 715, 749, 750, 751, 752, 753

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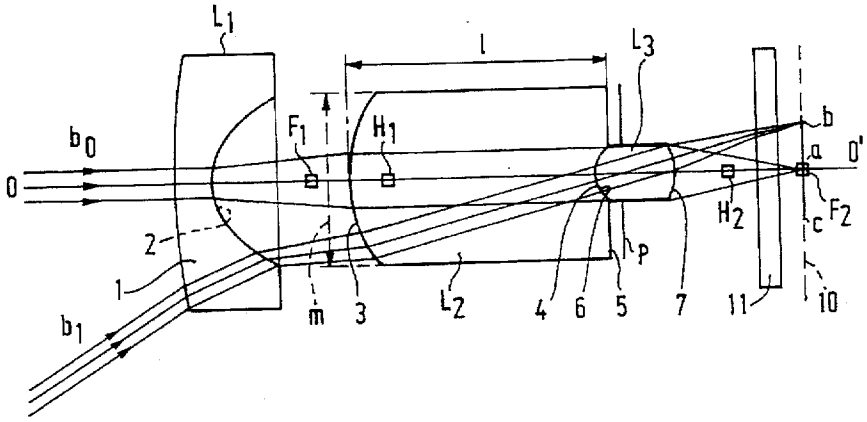
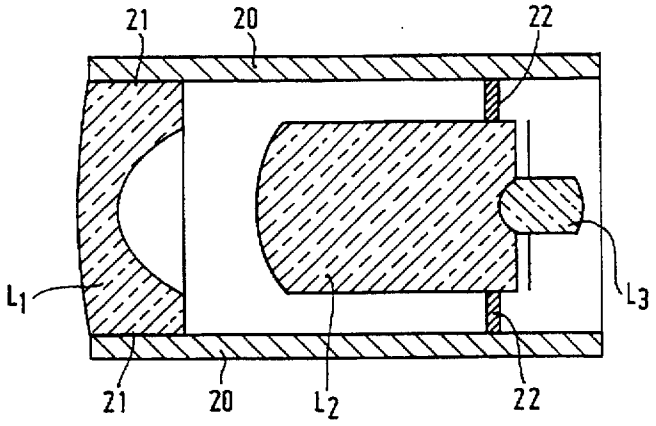
Primary Examiner—Scott J. Sugarman
Attorney, Agent, or Firm—Walter M. Egbert, III

[57] **ABSTRACT**

A wide angle objective system is described for, inter alia CCD cameras, which system is compact, inexpensive and satisfactorily corrected. It comprises a front meniscus lens (L_1), a thick convex-concave central lens element (L_2) and a biconvex lens element (L_3), the two last-mentioned elements preferably being cemented together, the pupil (P) being present at the area of the exit surface (4) of the second lens element and the first and the third element (L_1,L_3) being made of, for example PMMA and the second element (L_2) being made of, for example PC.

18 Claims, 2 Drawing Sheets





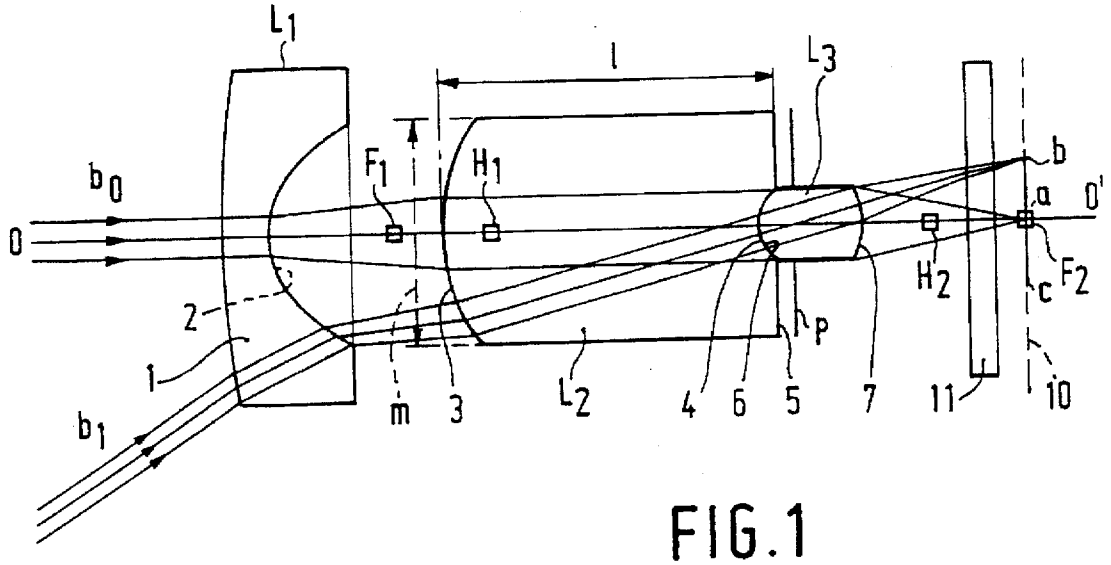


FIG.1

GEOMETRICAL MTF-CURVES

N.A.	X	Y	FREQ(1/MM)
0.225	0.00000	1.95620	12.5

VIGNETTING(%): 2.9

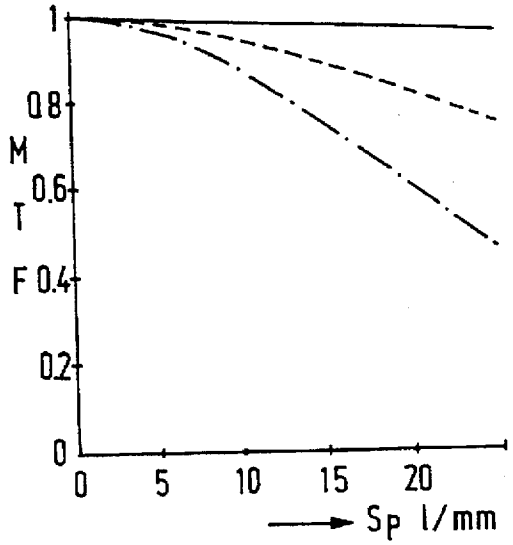


FIG.2a

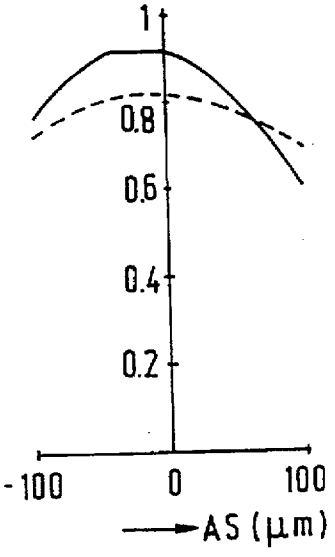


FIG.2b

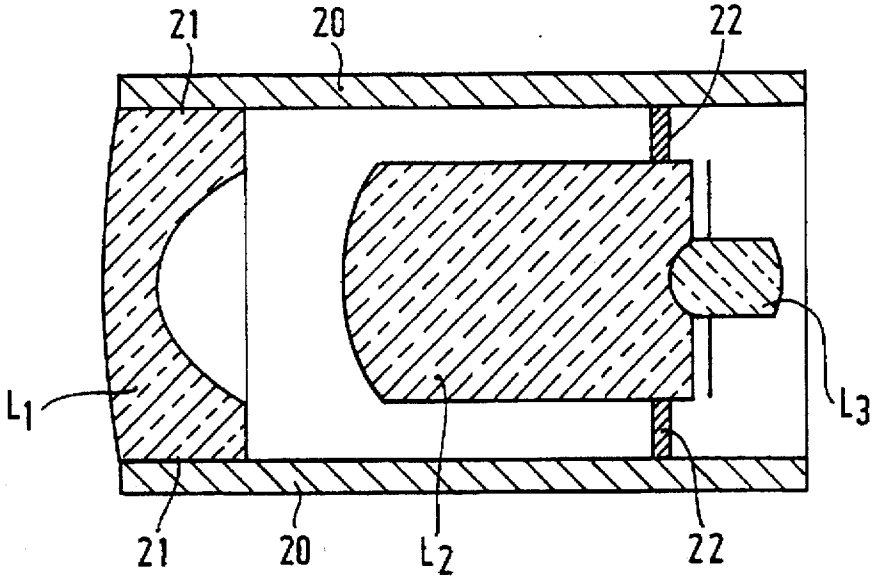


FIG.3

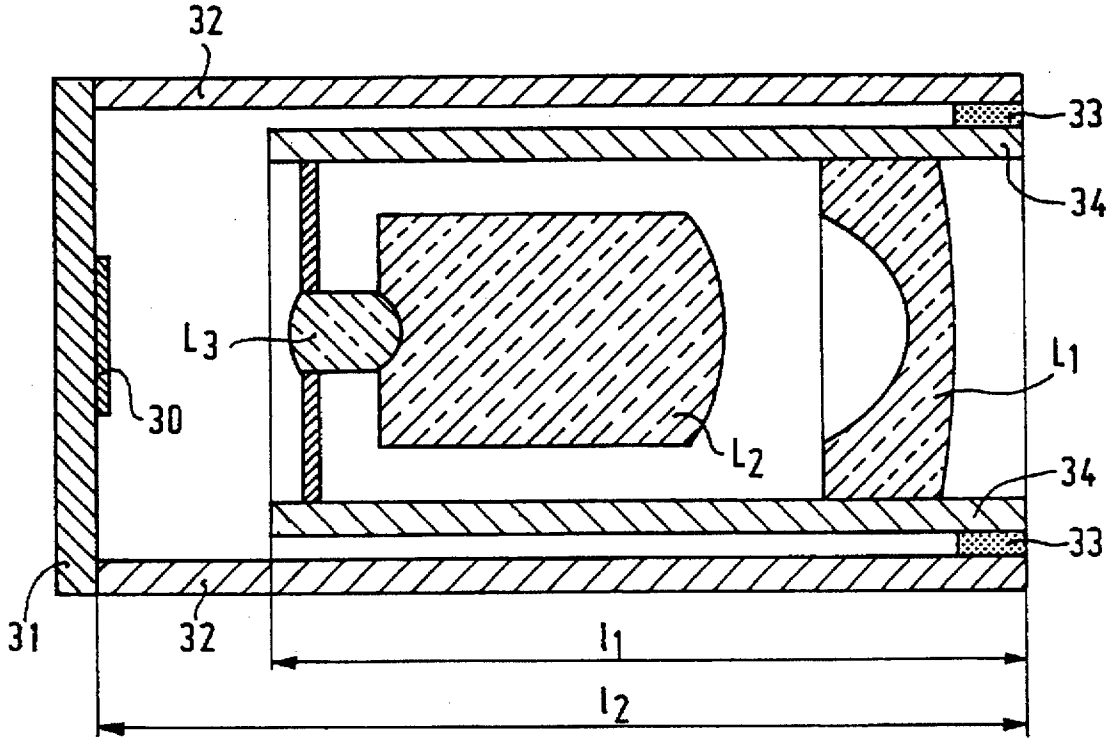


FIG.4

WIDE ANGLE OBJECTIVE SYSTEM

The invention relates to an objective system having a large angular aperture for demagnified imaging a scene in an image plane, which system, viewed from the object side, successively comprises:

- a first lens element having a first and a second convex refractive surface,
- a second lens element having a third, convex refractive surface and a fourth refractive surface,
- a third lens element having a fifth refractive surface and a sixth refractive surface.

The invention also relates to an image pick-up device provided with such an objective system.

BACKGROUND OF THE INVENTION

Such an objective system having, however, an extremely large angular aperture ranging between 125° and 150°, which can be used in a CCD camera, is described in U.S. Pat. No. 5,251,073. This system is of the retrofocus type, which is also referred to as inverse telephoto type, which means that it has a relatively large front focal length at the image side. The known objective system has an F number of F/2.0 and comprises at least four and preferably six glass lens elements. In the known system, the entrance pupil between the first and the second lens element is located in air.

The objective system of the present invention is intended for mass application and for combination with, for example an electronic image sensor, or CCD sensor, having a photosensitive surface diagonal of, for example 4 mm. If the objective system is inexpensive enough, such a combination may be used in a monitoring camera, in a videophone or in a camera which is associated with a personal computer working station coupled to other such stations, so that visual data can be transmitted together with the actual data from one station to other stations. These data can be obtained by scanning a document, also referred to as bitmapping. For said applications, the objective system should have a field of view of the order of 2×35° or more, a focal length of, for example 3 mm dependent on the surface of the image sensor for a CCD image sensor having a diagonal of 2 mm and an F number of, for example F/2.5 so as to pick up scenes of sufficient quality, even at low light levels. Such an objective system cannot be made in accordance with the design described in U.S. Pat. No. 5,251,073 because it would then be too expensive. Moreover, this system has a resolving power which is too small and exhibits too much spherical aberration and astigmatism, the latter effect being particularly troublesome in said bitmapping application.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide an objective system for, inter alia said application, which system is inexpensive and compact, has a satisfactory colour correction and little astigmatism and distortion, and a satisfactory resolving power. This objective system is characterized in that the sixth refractive surface is concave, in that the pupil of the lens system is present at the area of, or very proximate to the fourth refractive surface, and in that the first and the third lens element are manufactured from the same first material having a first refractive index, and the second lens element is manufactured from a second material having a second refractive index which is different from the first refractive index.

At the area of the fourth surface the angles of incidence of the imaging beam, which angles are determined by the first and second lens elements, are considerably reduced as compared with those of the beam incident on the first lens surface. Since the transition of the second lens element having the second refractive index to the third lens element having the first refractive index is present at the location of the pupil, which transition has a correcting effect for the longitudinal colour error, this error is satisfactorily corrected for all angles of incidence of the imaging beam. Such an effective correction is not realised in the objective system in accordance with U.S. Pat. No. 5,251,073, in which the pupil is not present at the location of, or very proximate to a correction element. The longitudinal colour error is understood to mean that the position of the image plane is dependent on the colour, or wavelength, of the beam or the beam components.

By making use of a thick second lens element having the second refractive index, the transversal colour error of the first lens element having the first refractive index is corrected. The transversal colour error is understood to mean the colour, or wavelength-dependent magnification of the objective system.

The first and third lens elements may be separated from each other by a narrow air gap. An embodiment of the objective system, which is preferred from a manufacturing-technical point of view and as regards stability, is, however, characterized in that the fourth and the fifth refractive surface have the same curvature and are cemented together.

Use is made of a cementing material whose refractive index is in the range between a value which is slightly larger than the smallest of said first and second refractive indices and a value which is slightly larger than the largest of said refractive indices.

This embodiment is preferably further characterized in that it satisfies the conditions

$$0.20 \leqq \frac{K_+}{K_{tot}} \leqq 0.60$$

in which K_+ is the positive focal power of the assembly of the second and the third lens element and K_{tot} is the total focal power of the lens system.

An inexpensive embodiment of the objective system having a satisfactory quality is characterized in that the lens elements are entirely manufactured of a synthetic material.

Since all lens elements consist of a transparent synthetic material, the objective system is inexpensive, while it still has the imaging quality desired for said applications. Moreover, lens elements made of such synthetic materials can easily be provided with aspherical surfaces by making use of aspherically profiled moulds for manufacturing the lens elements.

It is to be noted that an objective system for use in a CCD camera and consisting of synthetic material elements is known per se from the abstract of Japanese Patent Application 4-107407. However, this system comprises only two lens elements, a negative meniscus lens and a biconvex lens, in which the meniscus lens does not have an aspherical surface. The abstract neither states that the materials of the lens elements are different. The quality of this objective system cannot match that of the objective system according to the present invention, not only in the field but also on the axis.

A preferred embodiment of the objective system using synthetic material elements is characterized in that the first and the third lens element are manufactured of polymethyl methacrylate and the second lens element is manufactured of polycarbonate. Practice has proved that these materials

having a refractive index of 1.49 and 1.58, respectively, are materials having a good optical quality.

In this embodiment the fourth and the fifth lens surface are convex, as viewed from the object side.

The objective system is preferably further characterized in that the fourth lens surface is aspherical.

An aspherical lens surface is understood to mean a surface whose fundamental shape is spherical but whose real shape deviates to a slight extent so as to correct for the spherical aberrations of the fundamental shape of the lens. Since the aspherical surface is present at the location of, or proximate to the pupil of the lens system, it can satisfactorily correct for all angles of incidence of the imaging beam. Since the fourth surface also ensures the correction of the longitudinal colour error, this surface thus has a double correction function in the relevant lens system.

If the objective system is further characterized in that at least one of the first and the second lens surface is aspherical, this system is satisfactorily free from distortion.

By giving also the sixth refractive surface an aspherical shape, an objective system is obtained which has a large F number of the order of F/2.5 with sufficiently small spherical aberrations.

The invention also relates to an image pick-up device provided with an objective system and an opto-electronic image sensor for converting images formed by the objective system into an electronic image signal. This image pick-up device is characterized in that the objective system is a system as described hereinbefore.

If this image pick-up device is further characterized in that the image sensor is a CCD sensor, this device can be implemented in a compact and inexpensive way.

The synthetic materials, abbreviated to PMMA and PC, have a greater temperature sensitivity than glass. To minimize the effect of this temperature sensitivity and those of the holder accommodating the lens elements on the supplied image signal, the image pick-up device may be further characterized in that the sensor is provided with a fitting for accomodating a lens holder in which the lens elements of the objective system are secured and in that the thermal coefficient of expansion of said fitting is larger than that of the lens holder.

BRIEF DESCRIPTION OF THE DRAWING FIGURES

These and other aspects of the invention will be apparent from and elucidated with reference to the embodiments described hereinafter.

In the drawings

FIG. **1** shows an embodiment of the objective system according to the invention,

FIGS. **2***a* and **2***b* show the modulation transfer curve and an aberration curve of this system,

FIG. **3** shows this system accommodated in a holder, and

FIG. **4** shows an image pick-up device provided with such an objective system.

DESCRIPTION OF THE INVENTION

The objective system shown in a cross-section in FIG. **1** comprises a first lens element L_1, a second lens element L_2 and a third lens element L_3. The scene to be imaged is at the left-hand side in FIG. **1** and the image plane **10** is at the right-hand side. The first lens element has the shape of a meniscus lens having a slightly curved exit surface **2**. This element ensures that a beam portion b_0 entering along the optical axis **00'** becomes divergent and that a peripheral beam portion b_1 entering at a relatively large angle α is deflected in such a way that it will extend more parallel to the optical axis and becomes divergent. The lens element L_2 has an entrance surface **3** with such a radius of curvature that it has a collimating effect so that all beam portions can be combined on the exit surface **4** which has a smaller diameter and a smaller radius of curvature than the entrance surface **3**. The surface portions **5** at both sides of the exit surface **4** of the lens element L_2 may be plane. The exit surface **4** itself has a diverging effect which is overcompensated by the third lens element so that the beam portions b_0 and b_1 are focused at the points a and b of the image plane **10**. All beam portions incident under the optical axis **00'** at angles between 0° and α° are focused at points located between the points a and b. The peripheral beam portion incident above the optical axis at an angle $-\alpha$ is focused at a point c in the image plane which is symmetrical with respect to the point b. The beam portions which are incident above the optical axis at angles between 0° and $-\alpha$° are focused at points between said point c and point a. The third lens element has an entrance surface **6** and an opposite curved exit surface **7**. The surface **4** of element L_2 is preferably cemented against surface **6** of element L_3. However, these surfaces may also be separated by a narrow air gap.

In FIG. **1**, the references H_1 and H_2 denote the main planes of the objective system, F_2 denotes the image focal point and p denotes the exit pupil. For the sake of completeness, a glass plate **11** is also shown which may be located in front of a sensor and which should be taken into account in designing the objective system.

The refractive indices of the lens element materials, the curvatures of these elements and the distances between these surfaces are preferably chosen to be such that it holds for the focal powers that:

$$0.20 \leqq \frac{K_+}{K_{tot}} \leqq 0.60$$

in which K_+ is the positive power of the assembly of element L_2 and element L_3, and K_{tot} is the total power of the objective system.

To be able to keep the price of the objective system as low as possible, the lens elements are preferably manufactured of a synthetic material. The first and the third lens element L_1 and L_3 are manufactured of the same transparent synthetic material, preferably polymethyl methacrylate (PMMA) having a refractive index n_1=1.49, while the second lens element is manufactured of a different synthetic material having a different refractive index, for example polycarbonate (PC) having a refractive index n_2=1.58. With this choice of synthetic materials, surface **4** is concave and surface **6** is convex, as is shown in FIG. **1**. With a different choice of synthetic materials, may become convex and surface **6** may become concave. Instead of PMMA, another similar polymer may be used and instead of PC, for example styrene or the material CA-**39**. The second lens element is a thick element, i.e. its length 1 is considerably larger than the diameter m of its first lens surface **3**. With this element of, for example PC the transversal colour error of the negative front element L_1 of, for example PMMA can be corrected. Moreover, the longitudinal colour error is corrected at the transition between the refractive surface **4** of the lens element L_2 and the refractive surface **6** of the lens element L_3, hence at an internal refractive surface.

This internal refractive surface is present in or proximate to the pupil of the objective system, hence at a position

where the axes of the different beam portions extend at small angles to the optical axis **00'** of the system, so that this correction for these beam portions is equally satisfactory.

The surface **4** is preferably aspherical so that at the location of the pupil it is also possible to correct for the aspherical aberration, which correction is again substantially identical for all beam portions. The surface **4** then has a dual correcting effect. An aspherical surface may be characterized by

$$Z = \Sigma A_{2i} \cdot Y^{2i}$$

in which Y is the distance between a point on the aspherical surface and the optical axis of the lens element, Z is the distance between the projection on the optical axis of this point and the point of intersection of the optical axis with the aspherical surface and A_{2i} are the aspherical coefficients.

By giving the surface **2** or surface **1** an aspherical shape, the distortion of the objective system can be maintained sufficiently small. By giving also the surface **7** an aspherical shape, the spherical aberration of the system can even be better corrected so that the system is sufficiently free from spherical aberration, also for the relatively large F number: $F_{2.5}$.

For an embodiment of the objective system in accordance with FIG. **1**, having three aspherical surfaces in which the lens elements L_1 and L_3 are made of PMMA and the lens element L_2 is made of PC, the following values, computed from the object side, apply for the axial surface curvatures C_1, the axial distances d between these surfaces and the refractive indices n:

		c (mm^{-1})	d(mm)	n
	1	0.03078		
L_1			1.5	1.49
	2	0.33483		
			5.346	1
	3	0.17400		
L_2			10.055	1.58
	4/6	0.49336		
L_3			3.2118	1.49
	7	−0.46157		

while the aspherical coefficients A_{2i} of the surfaces **2**, **4** and **7** are equal to:

1. $A_2=0.167446.10^0$
   $A_4=0.410699.10^{-2}$
   $A_6=-0.361459.10^{-3}$
   $A_8=0.332931.10^{-4}$
   $A_{10}=-0.942326.10^{-6}$
4. $A_2=0.246681.10^0$
   $A_4=0.163018.10^0$
   $A_6=-0283456.10^{-1}$
   $A_8=0.332336.10^{-1}$
7. $A_2=-0.230787.10^0$
   $A_4=-0.904503.10^{-2}$
   $A_6=0.433596.10^{-2}$
   $A_8=-0.444410.10^{-2}$
   $A_{10}=-0.841075.10^{-3}$

If a glass plate **11** having a thickness of 0.19 mm and a refractive index of 1.51 is arranged between the lens surface **7** and the image plane **10**, the image field is located at a distance of 5.3132 mm from this lens surface.

This objective system has a focal length of 3 mm, an image diagonal of 4.02 mm, an F number $F_{2.5}$, a field of view of 2×38° and a resolving power of more than 50% for a structure of 40 lines/mm. The system is satisfactorily corrected for colour in a wavelength band between 500 and 900 nm.

FIG. **4** shows diagrammatically an embodiment of an image pick-up device according to the invention which comprises the above-described objective system and an image sensor **30**, preferably in the form of a CCD sensor as its basic elements.

The objective system has a total power of $K_{tot}=0.333$ mm^{-1}, the power of the lens element L_1 K being 0.16 mm^{-1} and the power of the assembly of the lens elements L_2, L_3: K_+ being 0.13 mm^{-1}.

FIG. **2***a* shows the modulation transfer function (MTF) of this embodiment of the objective system as a function of the spatial frequency SP (expressed in lines per mm) while FIG. **2***b* shows the MTF as a function of the distance AS to the optical axis for a spatial frequency of 12.5 lines per mm. It appears that the astigmatism is only small and that the MTF is 50% for a spatial frequency of **40** lines per mm.

In practice, the separate lens elements are accommodated in a common holder **20**, as is shown in FIG. **3**.

The synthetic materials preferably used for the lens elements L_1, L_2 and L_3 have a larger thermal coefficient of expansion than glass. Moreover, their refractive index is temperature-dependent. Consequently, the optical behavior of the objective system might change when the ambient temperature varies so that the scene would be imaged out of focus on the image sensor. To prevent this, a material having such a thermal coefficient of expansion may be chosen for the lens holder **20** that the equivalent coefficient of expansion of the objective system causing the change of optical behaviour of this system as a function of the temperature and being determined by:

- the coefficients of expansion of the materials of the lens elements,
- the refractive indices of these materials and their variations with temperature, and
- the dimensions of the lens elements is equal to the coefficient of expansion of the holder material which is present between the fixations **21**, **22** on the holder of the two outer elements of the objective system.

This provides a compensation for temperature variations in the objective system itself. For the principle and further elaboration of this temperature compensation, reference is made to U.S. Pat. No. 4,855,987 in which a temperature-compensated radiation source unit and an optical scanning unit are described.

FIG. **4** shows diagrammatically an embodiment of an image pick-up device according to the invention, which comprises the above-described objective system and an image sensor **30**, preferably in the form of a CCD sensor as its basic elements. This sensor is arranged on a holder **31**. To be able to correct for temperature variations, a bush **32** may be secured to the holder **31** as an alternative to the compensation described with reference to FIG. **3**. This bush is connected at the points **33** to an inner bush **34** within which the lens system L_1, L_2, L_3 is arranged. The thermal coefficient of expansion α_1 of the bush **32** is larger than that, α_2, of the bush **33**. If the length of the bush **32** is l_1 and that of the bush **34** is l_2, an offset ΔZ of the objective system with respect to the sensor **30** will occur at a temperature variation of ΔT, which offset is given by

$$\Delta z=(l_{1\alpha 1}-l_{2\alpha 2})\Delta T$$

This offset can correct the offset of the focal point of the objective system occurring as a result of the temperature variation ΔT.

I claim:

1. An objective system having a large angular aperture for demagnified imaging a scene in an image plane, which system, viewed from the object side, successively comprises:

a first lens element having a first convex surface and a second concave surface,

a second lens element having a third convex surface and a fourth refractive surface,

a third lens element having a fifth refractive surface and a sixth convex surface,

a pupil of the lens system being positioned proximate the fourth refractive surface, and wherein the first and the third lens element are manufactured from a first material having a first refractive index, and the second lens element is manufactured from a second material having a second refractive index different from the first refractive index.

2. An objective system as claimed in claim 1, wherein the fourth and the fifth refractive surface have the same curvature and are cemented together.

3. An objective system as claimed in claim 2, satisfying the conditions

$$0.20 \leqq \frac{K_+}{K_{tot}} \leqq 0.60$$

in which K_+ is the positive focal power of the assembly of the second and third lens element and K_{tot} is the total focal power of the lens system.

4. An objective as claimed in claim 3, wherein the lens elements are entirely manufactured of a synthetic material.

5. An objective system as claimed in claim 4, wherein the first and the third lens elements are manufactured of polymethyl methacrylate and the second lens element is manufactured of polycarbonate.

6. An objective system as claimed in claim 5, wherein the fourth lens surface is aspherical.

7. An objective system as claimed in claim 6, wherein at least one of the first and the second lens surface is aspherical.

8. An objective system as claimed in claim 7, wherein the sixth lens surface is aspherical.

9. An objective system as claimed in claim 1, and including a holder for accommodating the lens elements, the lens holder being manufactured of a material having a thermal coefficient of expansion so that the equivalent coefficient of expansion of the lens system causes a change of optical behavior of said lens system as a function of the temperature and being determined by:

the coefficients of expansion of the materials of the lens elements,

the refractive indices of said materials and their variations with temperature, and

the dimensions of the lens elements is equal to the coefficient of expansion of the holder material which is present between the fixations on the holder of the two outer lens elements.

10. An image pickup device provided with an objective system as claimed in claim 1 and an opto-electronic image sensor for converting images of a scene formed by the objective system into an electronic image signal.

11. An image pick-up device as claimed in claim 10, wherein the image sensor is a CCD sensor.

12. An image pick-up device as claimed in claim 10, wherein the sensor is provided with a fitting for accommodating a lens holder in which the lens elements of the objective system are secured and in that the thermal coefficient of expansion of said fitting is larger than that of the lens holder.

13. An objective as claimed in claim 1, wherein the lens elements are entirely manufactured of a synthetic material.

14. An objective system as claimed in claim 13, wherein the first and the third lens elements are manufactured of polymethyl methacrylate and the second lens element is manufactured of polycarbonate.

15. An objective system as claimed in claim 1, wherein the fourth lens surface is aspherical.

16. An objective system as claimed in claim 15, wherein at least one of the first and the second lens surface is aspherical.

17. An objective system as claimed in claim 16, wherein the sixth lens surface is aspherical.

18. An objective system as claimed in claim 1, wherein the pupil is located intermediate the fourth and the sixth refractive surfaces.

* * * * *

US005708532A

United States Patent [19]

Wartmann

[11] Patent Number: 5,708,532

[45] Date of Patent: Jan. 13, 1998

[54] **DOUBLE-SIDED TELECENTRIC MEASUREMENT OBJECTIVE**

[75] Inventor: **Rolf Wartmann**, Hallgarten, Germany

[73] Assignee: **Jos. Schneider Optische Werke Kreuznach GmbH & Co. KG**, Kreuznach, Germany

[21] Appl. No.: **659,044**

[22] Filed: **Jun. 3, 1996**

[30] **Foreign Application Priority Data**

Jun. 3, 1995 [EP] European Pat. Off. 95108559

[51] **Int. Cl.**[6] **G02B 13/22**; G02B 21/02

[52] **U.S. Cl.** **359/663**; 359/362; 359/658; 359/756

[58] **Field of Search** 359/362, 363, 359/642, 649, 663, 793, 656–658, 733, 754, 755, 756, 771–783

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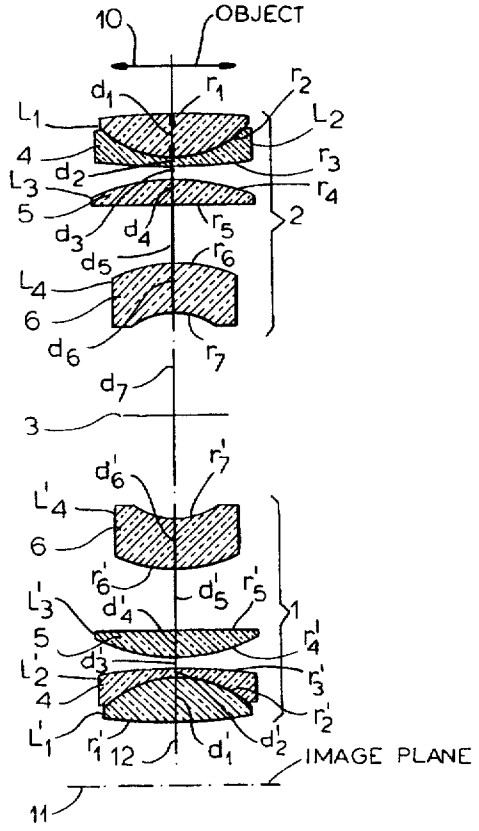
Primary Examiner—Thong Nguyen

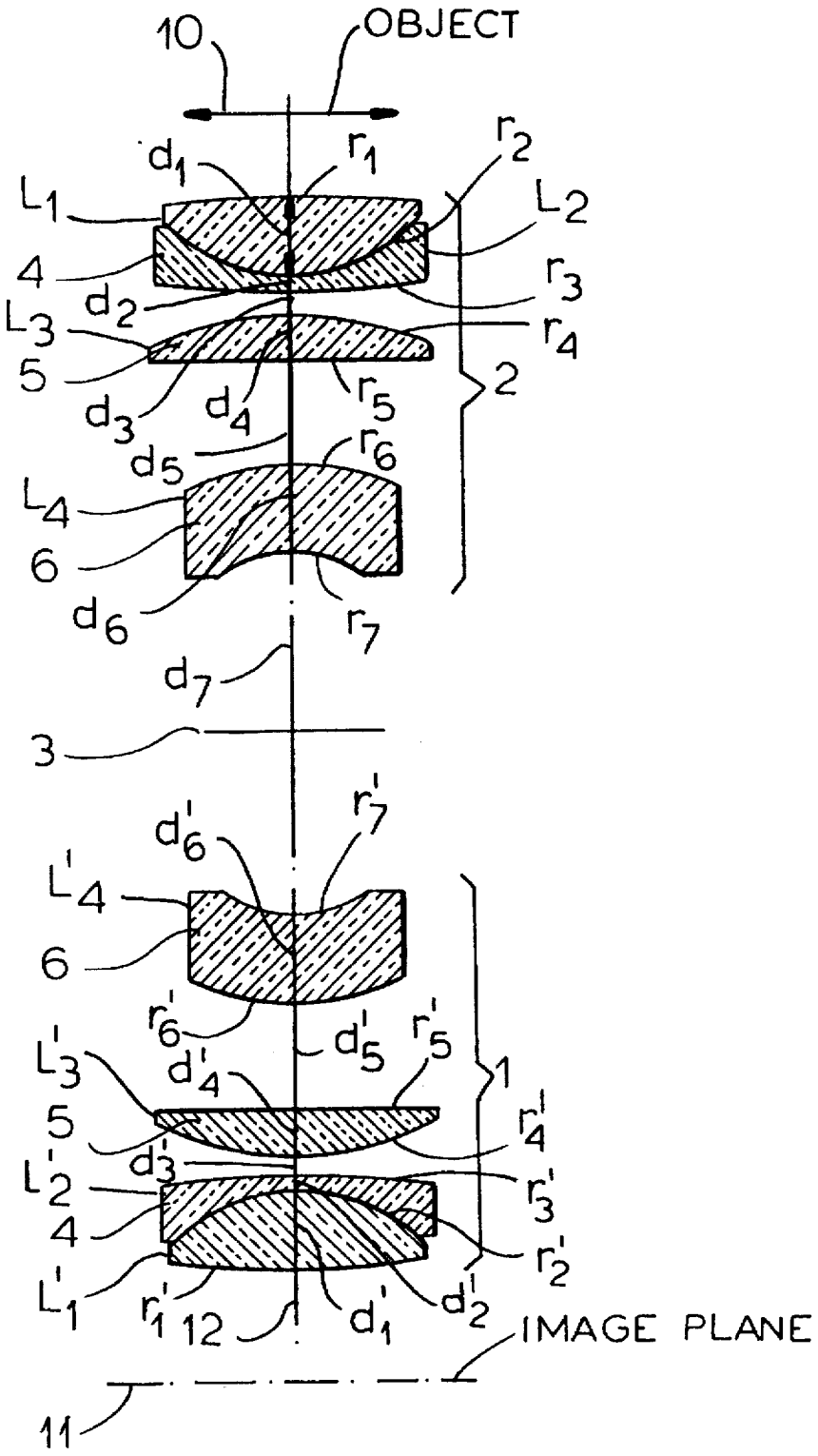
Attorney, Agent, or Firm—Herbert Dubno

[57] **ABSTRACT**

A double sided telecentic measurement objective for contactless length measurement in two-dimensional and three-dimensional space. The objective has an image-side optical system consisting of three elements equivalent to those of an object-side optical system but in the reverse order, including a cemented positively refracting lens element turned toward the object of image respectively, a collecting lens spaced by an air gap from the cemented lens, and a dispersive meniscus spaced by an air gap from the collecting lens. The widths of the air gaps between the collecting lenses and the meniscus are substantially greater than the widths of air gaps between the cemented lens elements and the collecting lenses.

4 Claims, 3 Drawing Sheets

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r_1
r_2
L_1
L_2
4
r_3
d_2
L_3
r_4
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d_3
d_4
r_5
d_5
r_6
L_4
6
d_6
r_7
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d'_6
r'_7
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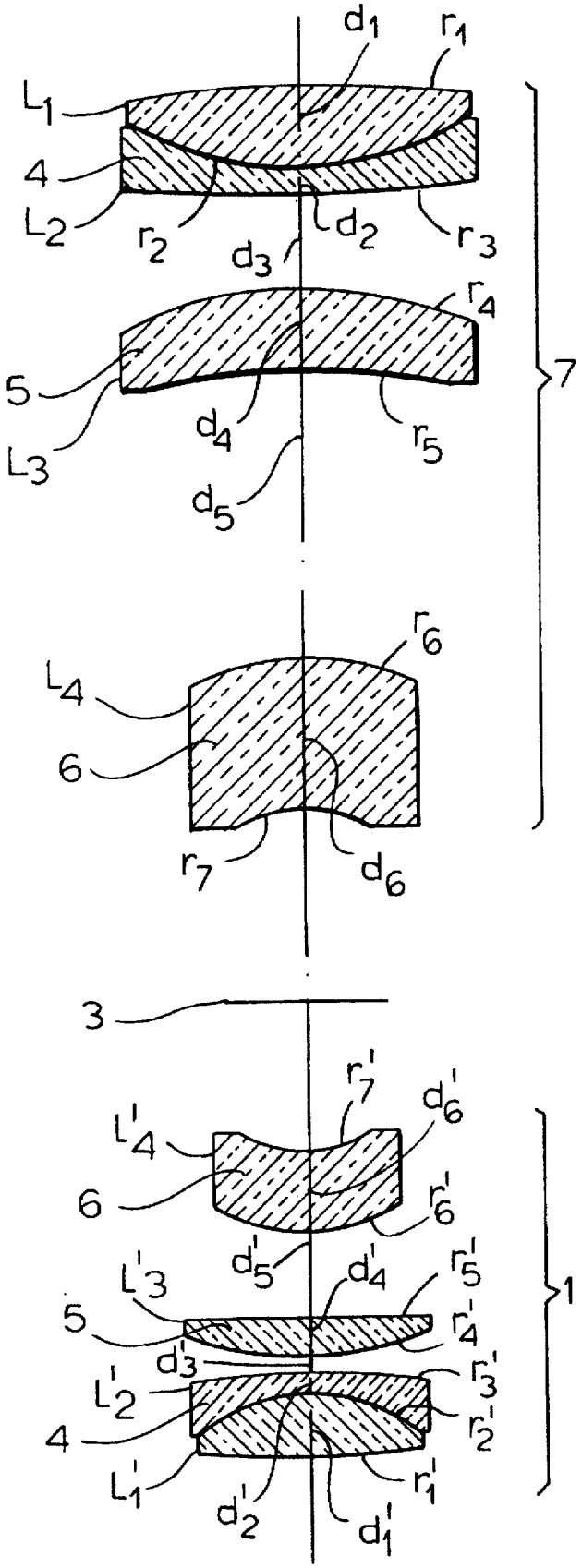
L'_3
d'_4
1
5
r'_4
d'_3
L'_2
r'_3
4
r'_2
L'_1
r'_1
12
d'_1
d'_2
IMAGE PLANE
11

FIG.1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L1
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L2
r2
d2
r3
d3
r4
5
L3
d4
r5
d5
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L4
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r7
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L'4
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d'4
r'5
L'3
5
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r'3
L'2
4
r'2
L'1
r'1
d'2
d'1
1

FIG. 2

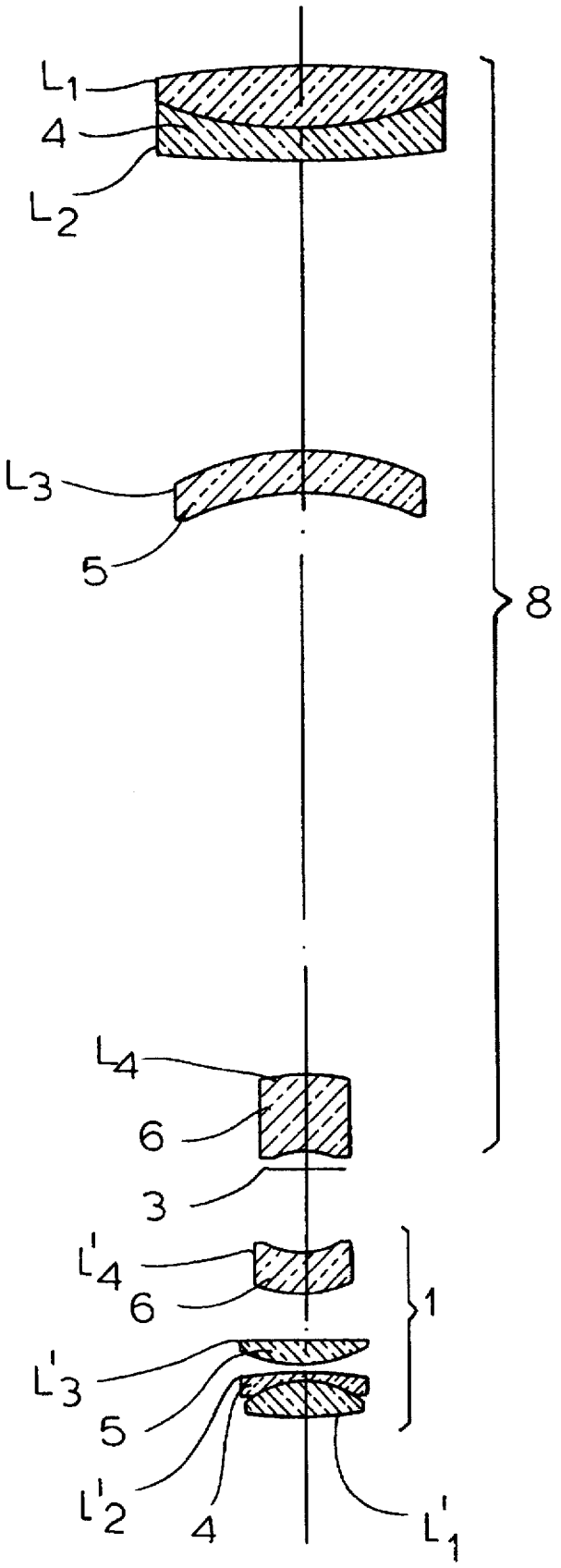

FIG.3

DOUBLE-SIDED TELECENTRIC MEASUREMENT OBJECTIVE

FIELD OF THE INVENTION

My present invention relates to a double-sided telecentric measuring objective for contactless length measurements in two-dimensional and three-dimensional space.

BACKGROUND OF THE INVENTION

For the contactless measurement of objectives in automatic product lines, video cameras are increasingly of interest as pick-ups for measurement systems. A measuring camera, for example, is described in U.S. Pat. No. 5,453,785.

The measurement principle utilizes the central projection of object points in an image plane. The image is then digitalized and the digitized image is interpreted in an image-processing computer and stretches between contour features of the object in the image are measured. A precondition for this type of measurement approach, of course, is a sufficiently precisely defined set of chamber constants and position of the main points photogram-metric. These parameters define the so-called internal orientation of the measurement camera (see the aforementioned patent).

The measurement precision in video measurement techniques is directly dependent upon the precision and stability of the parameters of the internal orientation. These parameters give the correlation between the measured image size and the geometry of the object. They may be determined by a camera calibration procedure.

When a measuring system is intended not only for a single kind of measurement and the position of the article to be measured cannot be maintained with a high level of precision, camera calibration must be frequent and is expensive and time-consuming since it must be carried out with each change in the article to be measured or each change in the position of the article.

It is known to avoid such camera calibration or at last to reduce the frequency of such calibration by providing telecentric objectives. The use of a telecentric objective makes the image size independent from the object distance and does not require as meticulous adjustment of the measuring unit. By providing telecentric objectives in automatic production lines, the effective quality control can be substantially simplified. Nevertheless, even with such optical systems, the measurement system must be calibrated and in particular, the dependency of the reduction scale or ratio of the image to the object size must be determined for the selected image plane position.

It has already been proposed to completely eliminate the need for camera calibration by providing double-sided telecentric optical systems. Such objectives are comprised of two distinct optical systems or partial systems aligned along a common optical axis which have the same general constructions and between which an iris diaphragm is disposed. The lens elements of the second optical system are disposed in an opposite or reverse order from the sequence of the lens elements of the first optical system. Such telecentric measuring objectives are afocal and have a fixed image ratio or reduction which is independent not only of the object position but also of the image position.

One such afocal and telecentric objective is described in SU Patent 935 099. Because of the construction of this objective, pupil aberration exists, i.e. in spite of the afocal construction, not all of the major rays are telecentric. The pupil aberration results in a change of distortion upon shifting of the object plane or image plane. This objective is, therefore, unsuitable for measurement purposes. In GB Patent 1,423,597, afocal systems for transcription of markings is described. This system does not permit correction of pupil aberration and of coma. It is also unsuitable as a measurement objective.

EP 0 299 473 A2 describes a system which, as a consequence of its construction, allows only small variation of the object plane or image plane. The optical system of this patent also is not highly suitable for measurement purposes since control of the sharpness is not possible and a scale of reproduction which deviates significantly from −1 cannot be achieved with high image quality. This objective is also costly to produce and with significant variations of the object plane positions, cause a considerable loss of imaging quality.

OBJECTS OF THE INVENTION

It is, therefore, the principal object of the present invention to provide a double-sided measurement objective for contactless measurement systems which makes superfluous internal calibration of the camera, is of simple construction and can ensure high image quality even for a substantial range in variation of the object plane position.

Another object of this invention is to provide a telecentric objective for the purposes described whereby drawbacks of the earlier systems described can be avoided.

Still another object of the invention is to provide a telecentric objective for a measurement camera which is of simple and economical construction.

SUMMARY OF THE INVENTION

These objects and others which will become apparent hereinafter in a telecentric lens system of the double-sided type having the object-side optical part system and the image-side optical systems as described, each with three lens elements of which a cemented lens element is turned toward the object side or the image side of the respective system, a collecting lens is spaced by an air gap from the cemented lens element and a dispersive meniscus lens is spaced by an air gap from the collecting lens, the image-side optical system thus having lenses equivalent to those of the object-side system but in the reverse order.

According to the invention, the cemented positively refracting lens element has a dispersive cemented surface and is made up of a convergent lens and a divergent lens cemented thereto.

According to the invention, moreover, the two optical systems are so arranged that the back focal point of the first optical system coincides with the front focal point of the second optical system along the optical axis. The image scale (or magnification or reduction ratio) of the total system is equal to the ratio of the focal lengths of the optical part-systems.

It has been found to be important to the invention that the third element of each optical system is a dispersive meniscus whose convex side is turned toward the object.

With a construction of this type, a wide range of variation is possible in the selection of the location of the object and image planes.

Even in the event that the object or image plane positions are not selected to be optimum, the image can remain free from coma so that a high measurement precision is assured within the total band width of the possible object/image relationship.

An optical system according to the invention has, if applied to scaled down imaging, and allows an image size aperture of at least 0.14. It is corrected for an image circle diameter of 0.2·f'2 where f'2 is the focal length of the image-side optical system.

A variation of the object plane position in the range of

$$\pm 3\ \text{mm} \cdot \left(\frac{f1}{f2}\right)^2$$

is possible without loss of image quality. In this relationship f'1 is the focal length of the object-side optical system.

By appropriate selection of the optical systems which are applicable, objectives with various focal lengths for the image-side or the object-side optical systems can be provided and the measurement objective can be of the double sided telecentric type for different magnification ratios.

BRIEF DESCRIPTION OF THE DRAWING

The above and other objects, features, and advantages will become more readily apparent from the following description, reference being made to the accompanying drawing in which:

FIG. **1** is a diagram of a measurement objective for a magnification or reproduction ratio of −1 according to the invention;

FIG. **2** is a diagram of a measurement objective for a magnification or reproduction ratio of −0.5 according to the invention; and

FIG. **3** is a diagram of a measurement objective for a magnification or reproduction ratio of −0.25 according to the invention.

SPECIFIC DESCRIPTION

FIG. **1** shows a double-sided telecentric objective for use in a measurement camera, e.g. of the type described in U.S. Pat. No. 5,453,785, which comprises an image-side optical system **1** and an object-side optical system **2** for the measurement of an object **10** and reproduction thereof in an image plane **11**. The two optical systems are arrayed along a common optical axis **12** and, in the embodiment of FIG. **1** which is entirely symmetrical, midway between the optical systems, an iris diaphragm **3** is provided. The objective of FIG. **1** has a magnification ratio of −1 and an image size aperture of 0.14.

Each optical system **1**, **2** is comprised of a cemented element **4** turned toward the object to be measured and the image plane, respectively, with a positive refractivity and a dispersive cemented surface (the surfaces with radii r_2 and r_2', respectively. The intermediate lens element of both the object-side and the image-side systems **2**, **1**, are collecting lenses **5** of a highly respective crown glass. Lying directly opposite the Iris diaphragm **3** are respective dispersive meniscuses **6** whose convex side is turned toward the object and the image respectively. For a two sided telecentic measurement objective with a magnification ratio −1 with a symmetrical configuration of the lenses, the object-image distance may be 284 and a range of object positions between **71** and **77** from the objective can be sustained without a detrimental effect upon the image quality when the image-side optical system has for its four lenses L_1' to L_4', the radii r_1' to r_7' and thicknesses of the lenses and air gaps d_1' to d_6', refractive indices and Abbé numbers as given in the following table:

Lens	Radius	Thickness	n_e	ν_e
	$r_1' = 130.882$			
L_1'		$d_1' = 9.60$	1.4891	70.2
	$r_2' = -22.140$			
L_2'		$d_2' = 2.00$	1.6072	37.8
	$r_3' = -127.464$			
		$d_3' = 3.10$		
	$r_4' = 40.965$			
L_3'		$d_4' = 5.70$	1.6413	55.1
	$r_5' = -597.046$			
		$d_5' = 13.50$		
	$r_6' = 28.247$			
L_4'		$d_6' = 11.39$	1.5848	40.6
	$r_7' = 15.845$			

focal length: 57

distance to back focal point: 23.20 all thicknesses, radii, distances and lengths being in the same distance units.

In the symmetrical lens system of FIG. **1**, the lenses L_1 through L_4 for radii r_4 to r_7 and thicknesses d_1 to d_6, refraction indices and Abbé numbers correspond to the numerical valves of the foregoing table as well.

Throughout this application, r refers to the radius of curvature of the respective lens surfaces, n_e to the refractive index and ν_e to the Abbé number for the wavelength e=546 nm of the glass from which the lenses are constituted and d represents distances between the respective lens surfaces as measured along the optical axis.

In FIG. **2**, there is shown an embodiment of a double sided telecentric measuring objective with a magnification ratio of −0.5 and an image-side aperture of 0.14. The position of the object plane can vary within a distance range of 185 to 209 without detriment to the image quality. The object/image distance can then vary between **467** and **485** all thicknesses, radii, distances and lengths being in the same distance units. In this case, for the same construction of the image-side optical system as in FIG. **1**, the numerical data of the object-side optical system can correspond to the following table:

Lens	Radius	Thickness	n_e	ν_e
	$r_1 = 163.039$			
L_1		$d_1 = 12.00$	1.4891	70.2
	$r_2 = -42.468$			
L_2		$d_2 = 4.00$	1.6072	37.8
	$r_3 = -219.485$			
		$d_3 = 14.72$		
	$r_4 = 53.840$			
L_3		$d_4 = 11.40$	1.6413	55.1
	$r_5 = -96.899$			
		$d_5 = 42.58$		
	$r_6 = 38.188$			
L_4		$d_6 = 22.78$	1.5848	40.6
	$r_7 = 20.358$			

focal length: 114

distance to back focal point: 28.07 all thicknesses, radii, distances and lengths being in the same distance units.

In the third embodiment illustrated in FIG. **3**, for a measuring objective with a magnification ratio of −0.25 and an image-side aperture of 0.14, the position of the object plane can vary at a distance of **246** through **342** from the objective without detriment to imaging quality. The object/image distance then varies between **505** and **595**. While the image side optical system **1** corresponds to that given in connection with FIG. **1**, the object side optical system **8** corresponds to the following numerical data:

Lens	Radius	Thickness	n_e	υ_e
L_1	r_1 = 243,547	d_1 = 17.00	1.4996	66.7
	r_2 = −88.326			
L_2		d_2 = 8.60	1.6072	37.8
	r_3 = −342.441			
		d_3 = 82.40		
	r_4 = 72.157			
L_3		d_4 = 12.00	1.6413	55.1
	r_5 = −78.537			
		d_5 = 163.70		
	r_6 = 47.746			
L_4		d_6 = 22.80	1.5848	40.6
	r_7 = 29.641			

focal length: 228

distance to back focal point: 4.75 all thicknesses, radii, distances and lengths being in the same distance units.

I claim:

1. A double-sided telecentric measurement objective for contactless length measurement in two-dimensional and three-dimensional space, said objective comprising:

two optical systems, each comprising three lenses aligned along an optical axis and constituted of an object-side optical system and an image-side optical system,

said object-side optical system having in succession from a side turned toward an object:

a cemented positively refracting lens element and a dispersive cemented surface formed by a convergent lens L_1 with radii of curvature r_1 and r_2 and a thickness d_1 and a divergent lens L_2 with radii of curvature r_2 and r_3 and a thickness d_2,

a collecting lens L_3 spaced by an air gap of a thickness d_3 from said cemented lens element and having radii of curvature r_4 and r_5 and a thickness d_4 of a highly refractive crown glass, and

a dispersive meniscus lens L_4 spaced by an air gap of thickness d_5 from said collecting lens and having radii of curvature of r_6 and r_7 and a thickness d_6;

and an image-side optical system having in succession from a side turned away from said object:

a cemented positively refracting lens element and a dispersive cemented surface formed by a convergent lens L_1' with radii of curvature r_1' and r_2' and a thickness d_1' and a divergent lens L_2' with radii of curvature r_2' and r_3' and a thickness d_2',

a collecting lens L_3' spaced by an air gap of a thickness d_3' from said cemented lens element and having radii of curvature r_4' and r_5' and a thickness d_4' of a highly refractive crown glass, and

a dispersive meniscus lens L_4' spaced by an air gap of thickness d_5' from said collecting lens and having radii of curvature of r_6' and r_7' and a thickness d_6' with a convex side turned away from said object;

widths of air gaps between the respective collecting lenses and the respective meniscuses being substantially greater than widths of air gaps between the cemented lens elements and the respective collecting lenses;

a back focal point of said object-side optical system coinciding with a front focal point of said image-side optical system so that a reproduction scale of the objective is equal to a ratio of front and back focal lengths of said optical systems, said image-side optical system having substantially the following numerical parameters wherein n_e and ν_e are respectively the refractive indices and Abbé numbers of the respective lenses:

Lens	Radius	Thickness	n_e	υ_e
L_1'	r_1' = 130.882	d_1' = 9.60	1.4891	70.2
	r_2' = −22.140			
L_2'		d_2' = 2.00	1.6072	37.8
	r_3' = −127.464			
		d_3' = 3.10		
	r_4' = 40.965			
L_3'		d_4' = 5.70	1.6413	55.1
	r_5' = −597.046			
		d_5' = 13.50		
	r_6' = 28.247			
L_4'		d_6' = 11.39	1.5848	40.6
	r_7' = 15.845			

focal length: 57

distance to back focal point: 23.20.

2. The objective defined in claim 1 wherein the lenses L_1 through L_4 have radii of curvature r_1 through r_7 and thicknesses d_1' through d_6, refractive indices and Abbé numbers corresponding to those of the lenses L_1' to L_4' for the radii r_1' through r_7' and thicknesses d_1' through d_6', and the respective refractive indices and Abbé numbers.

3. The objective defined in claim 1 wherein the object-side optical system has the following numerical parameter:

Lens	Radius	Thickness	n_e	υ_e
L_1	r_1 = 163.039	d_1 = 12.00	1.4891	70.2
	r_2 = −42.468			
L_2		d_2 = 4.00	1.6072	37.8
	r_3 = −219.485			
		d_3 = 14.72		
	r_4 = 53.840			
L_3		d_4 = 11.40	1.6413	55.1
	r_5 = −96.899			
		d_5 = 42.58		
	r_6 = 38.188			
L_4		d_6 = 22.78	1.5848	40.6
	r_7 = 20.358			

focal length: 114

distance to back focal point: 28.07.

4. The objective defined in claim 1 wherein said object-side optical system has the following numerical parameter:

Lens	Radius	Thickness	n_e	υ_e
L_1	r_1 = 243,547	d_1 = 17.00	1.4996	66.7
	r_2 = −88.326			
L_2		d_2 = 8.60	1.6072	37.8
	r_3 = −342.441			
		d_3 = 82.40		
	r_4 = 72.157			
L_3		d_4 = 12.00	1.6413	55.1
	r_5 = −78.537			
		d_5 = 163.70		
	r_6 = 47.746			
L_4		d_6 = 22.80	1.5848	40.6
	r_7 = 29.641			

focal length: 228

distance to back focal point: 4.75.

* * * * *

US005707925A

United States Patent [19]

Akada et al.

[11] Patent Number: 5,707,925

[45] Date of Patent: Jan. 13, 1998

[54] **IMAGE FORMATION ON OBJECTIVE BODIES**

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[73] Assignee: **Dai Nippon Insatsu Kabushiki Kaisha**, Japan

[21] Appl. No.: **470,208**

[22] Filed: **Jun. 6, 1995**

Related U.S. Application Data

[62] Division of Ser. No. 395,850, Feb. 28, 1995, which is a continuation of Ser. No. 034,186, Mar. 18, 1993, Pat. No. 5,451,560, which is a continuation of Ser. No. 467,415, Jan. 19, 1990, abandoned, which is a division of Ser. No. 138,384, Dec. 8, 1987, Pat. No. 4,923,848.

[30] **Foreign Application Priority Data**

Apr. 11, 1986	[JP]	Japan	61-81988
Apr. 11, 1986	[JP]	Japan	61-81989
Sep. 24, 1986	[JP]	Japan	61-223896
Sep. 24, 1986	[JP]	Japan	61-225473
Oct. 1, 1986	[JP]	Japan	61-231224

[51] **Int. Cl.**[6] **B41M 5/035**; B41M 5/38

[52] **U.S. Cl.** **503/227**; 428/195; 428/913; 428/914

[58] **Field of Search** 8/471; 428/195, 428/913, 914; 503/227

[56] **References Cited**

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62-66997	3/1987	Japan	503/227

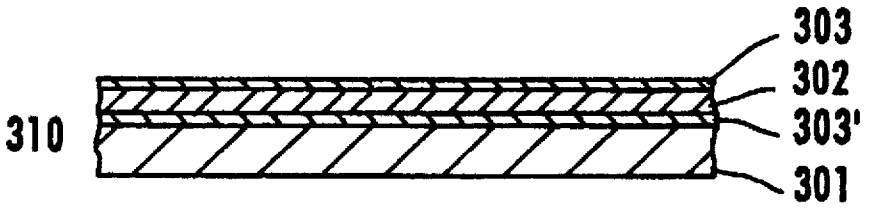
Primary Examiner—Bruce H. Hess

Attorney, Agent, or Firm—Parkhurst, Wendel & Burr, L.L.P.

[57] **ABSTRACT**

The present invention relates to image-formation on any selected kind of objective body. The characterizing features reside in such that, based upon fed image data, required images are formed on an image-transferable sheet acting for image carry-over service and in reliance on sublimation image transfer technique, and then, by the use of said sheet with said images thus formed thereon, the formed images thereon are transferringly applied on the objective body. By adopting the above measures, the objective body can be formed sharply and clearly with any desired images, irrespective of kind and configuration thereof, with such superior results of highly improved unity and solidability between the formed images and the objective body to be decorated with.

9 Claims, 16 Drawing Sheets



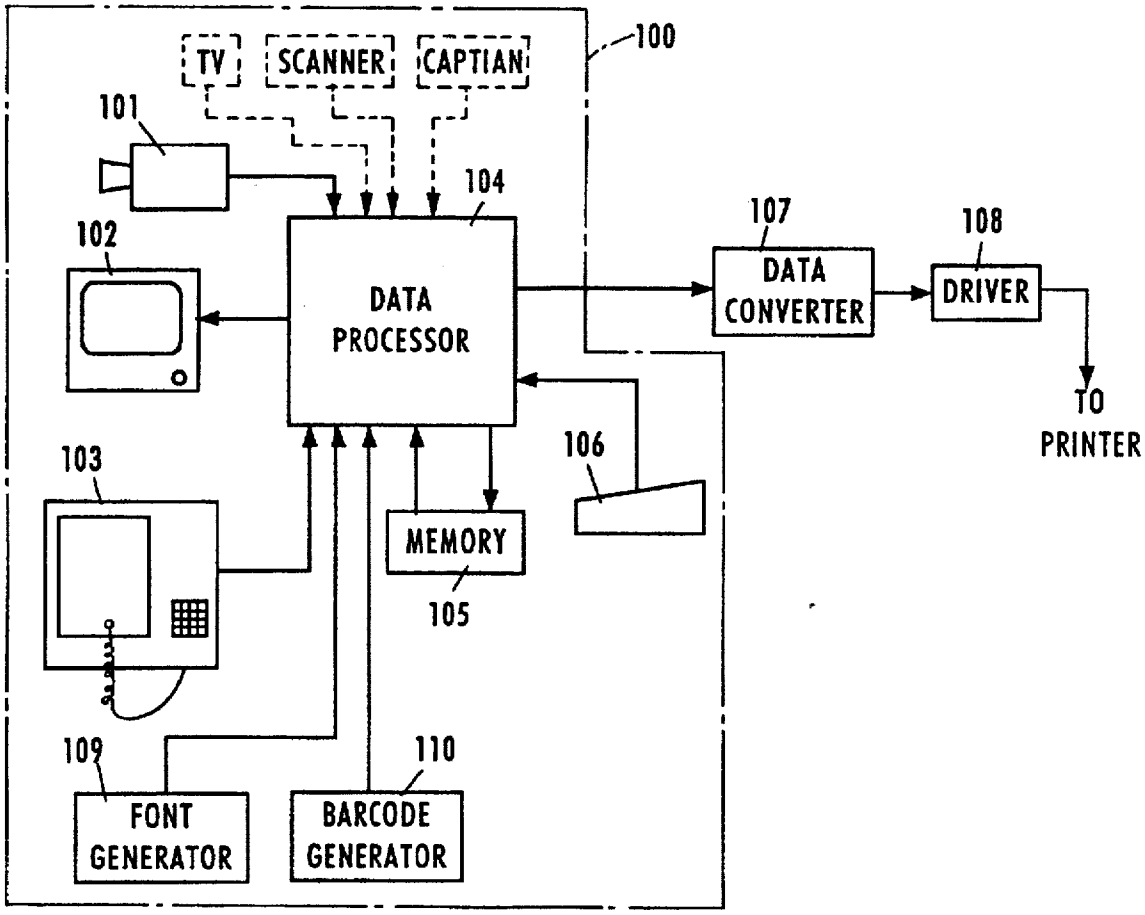

100
TV
SCANNER
CAPTIAN
101
102
104
DATA PROCESSOR
107
DATA CONVERTER
108
DRIVER
TO PRINTER
103
106
MEMORY
105
109
FONT GENERATOR
110
BARCODE GENERATOR

FIG. 1A

FIG. 1B

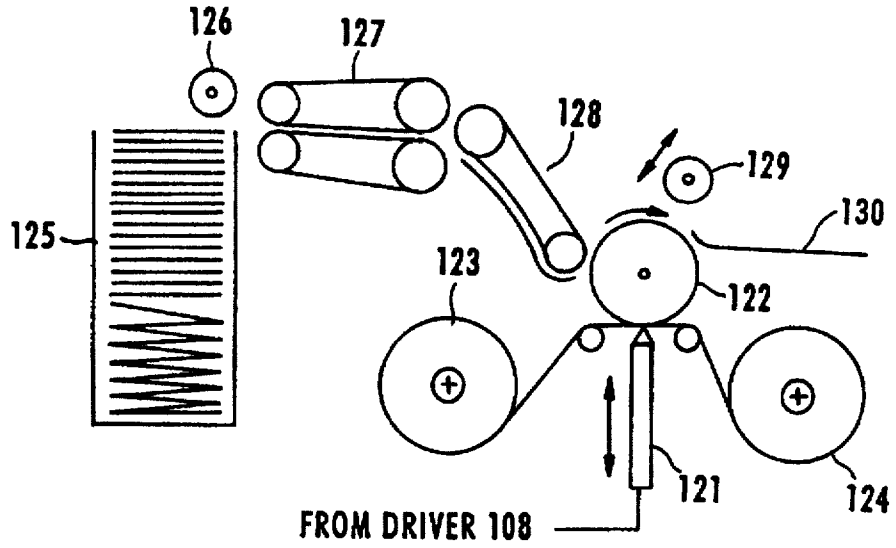


FIG. 1C

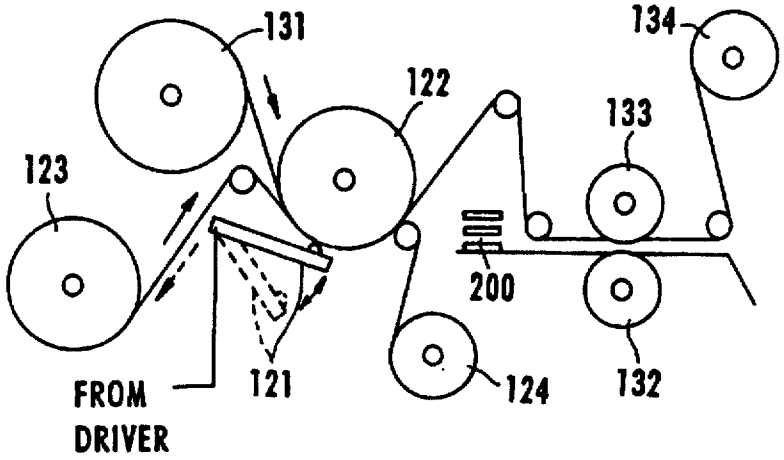
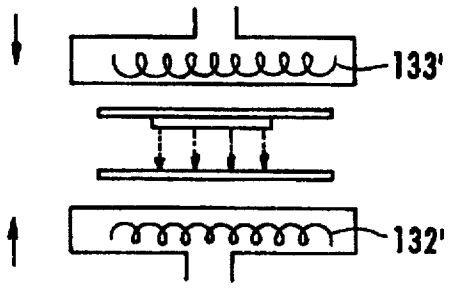


FIG. 1D



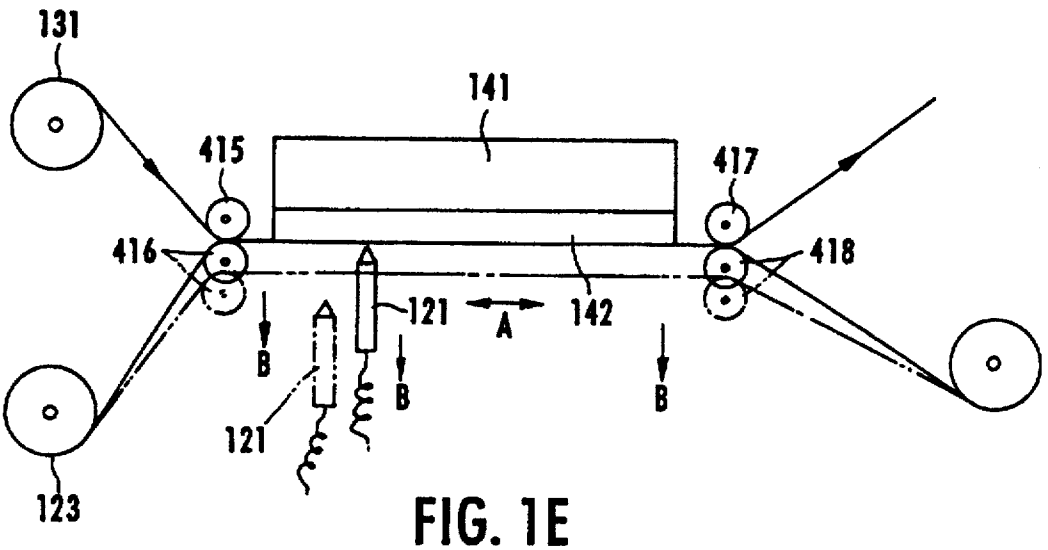


FIG. 1E

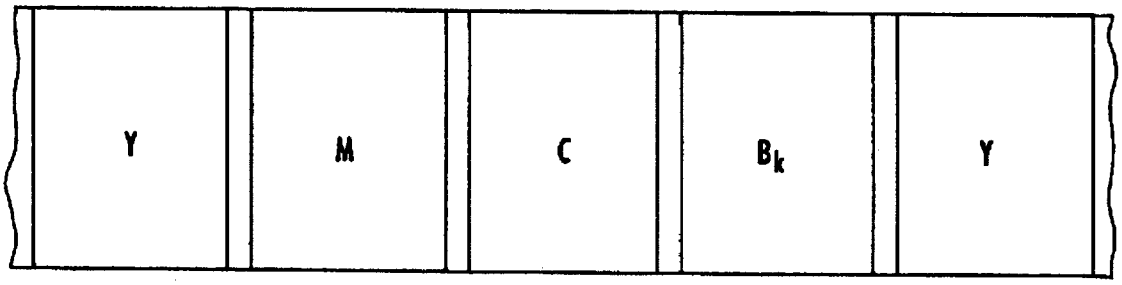


FIG. 1F

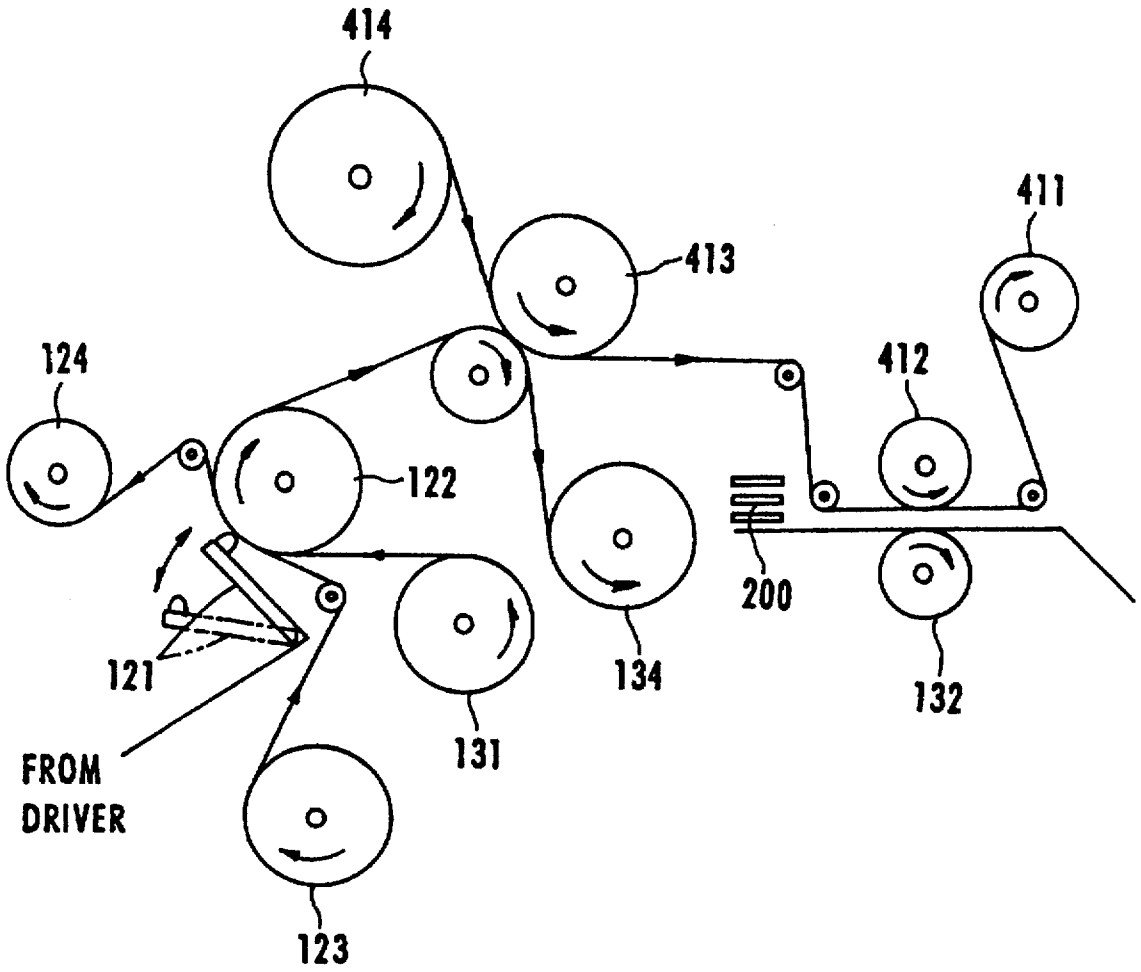


FIG. 1G

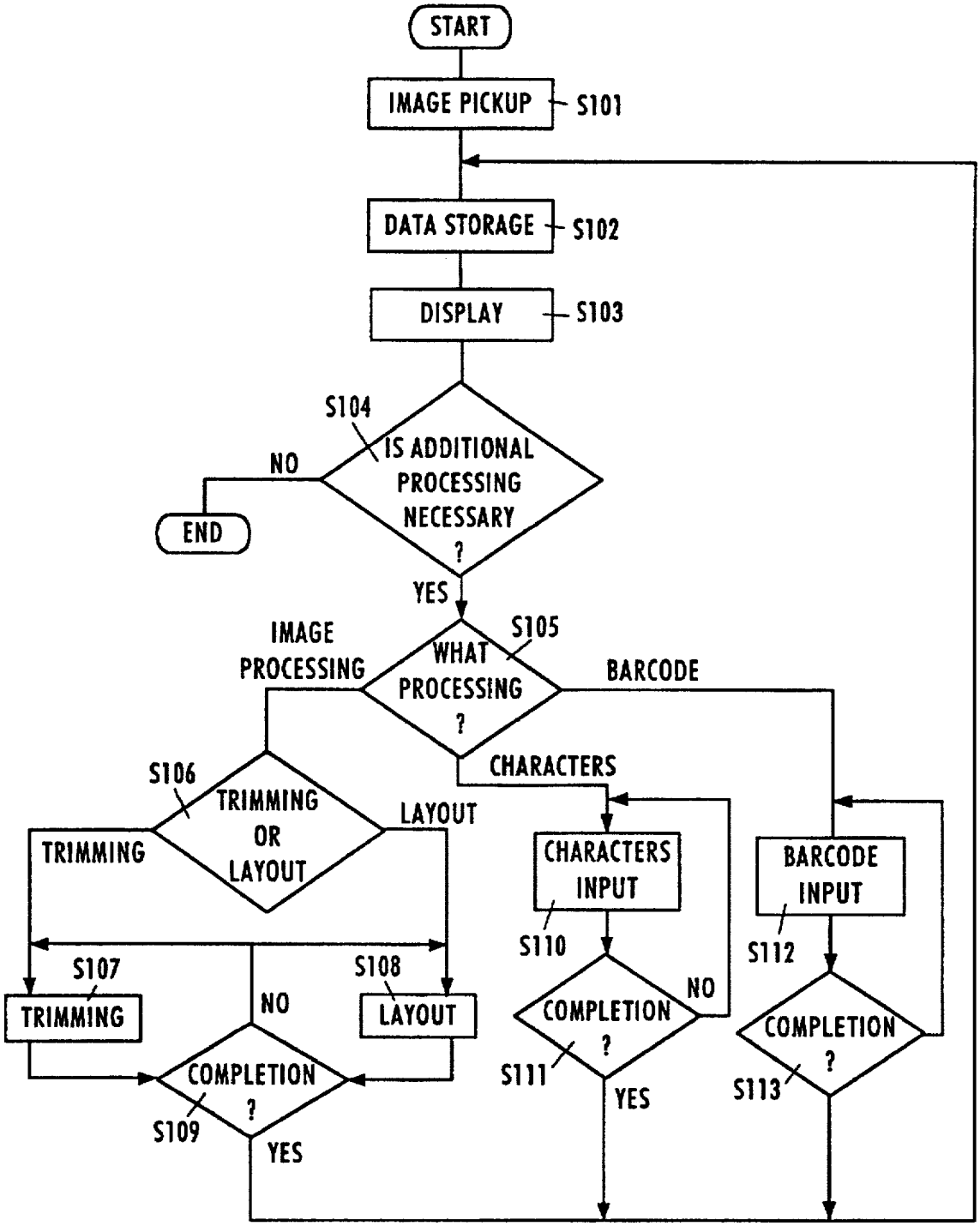

START
IMAGE PICKUP
S101
DATA STORAGE
S102
DISPLAY
S103
S104
IS ADDITIONAL PROCESSING NECESSARY ?
NO
END
YES
IMAGE PROCESSING
S105
WHAT PROCESSING ?
BARCODE
CHARACTERS
S106
TRIMMING OR LAYOUT
TRIMMING
LAYOUT
CHARACTERS INPUT
BARCODE INPUT
S110
S112
S107
TRIMMING
S108
LAYOUT
NO
COMPLETION ?
S111
NO
COMPLETION ?
S113
S109
COMPLETION ?
YES
YES

FIG. 2

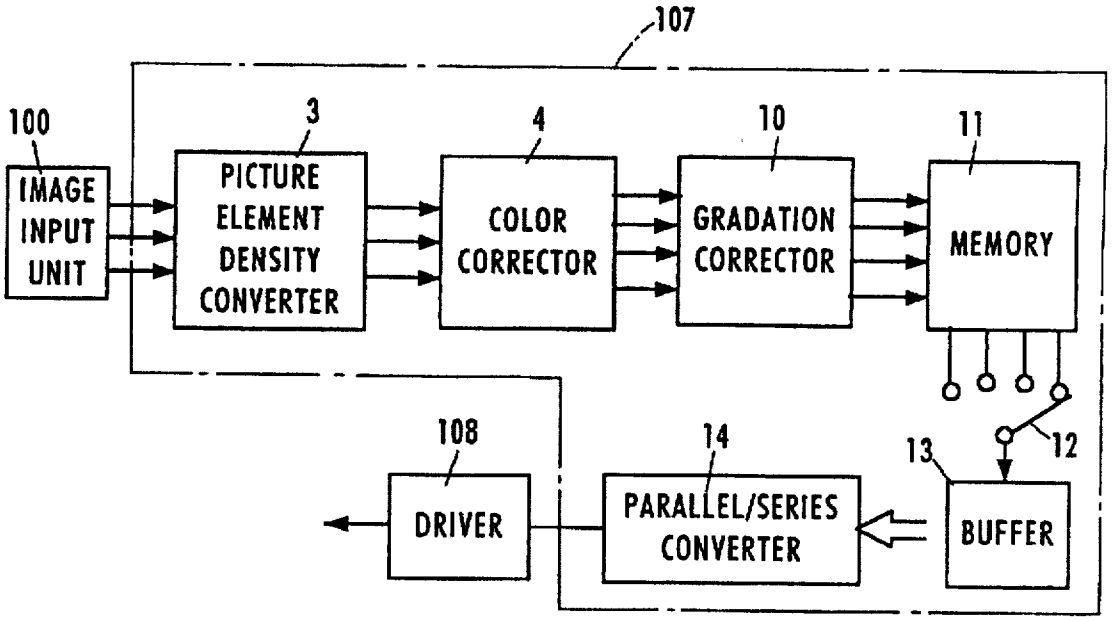

107
100
IMAGE INPUT UNIT
3
PICTURE ELEMENT DENSITY CONVERTER
4
COLOR CORRECTOR
10
GRADATION CORRECTOR
11
MEMORY
108
DRIVER
14
PARALLEL/SERIES CONVERTER
13
BUFFER
12

FIG. 3A

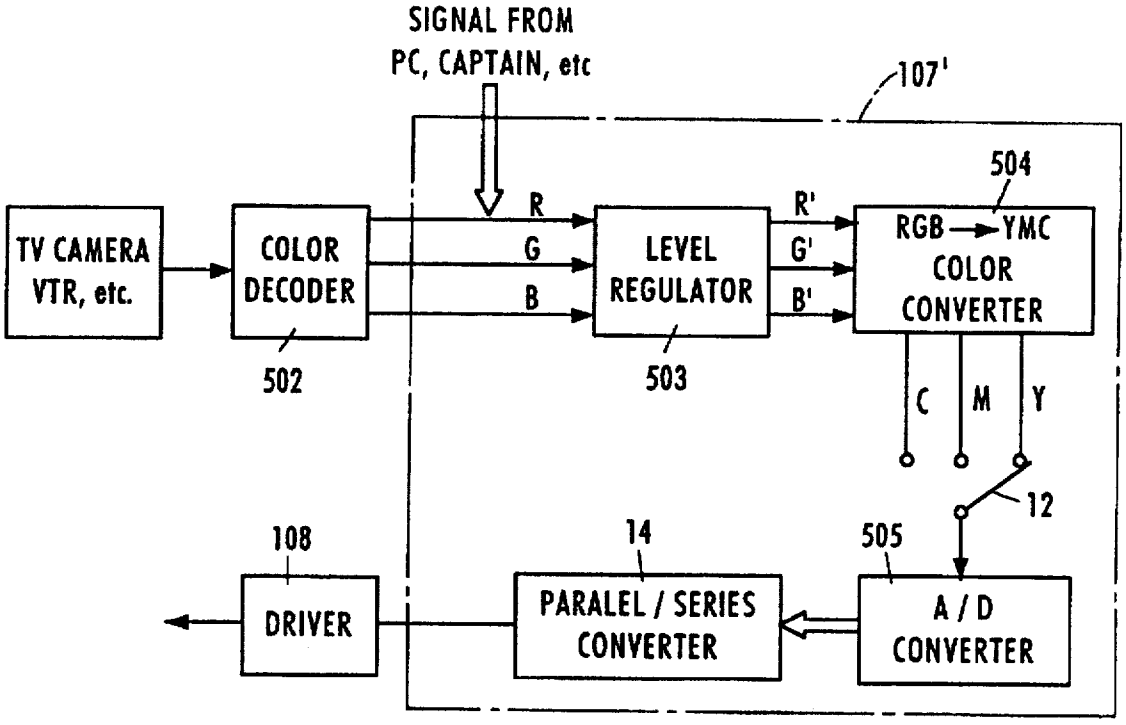

SIGNAL FROM PC, CAPTAIN, etc
107'
TV CAMERA VTR, etc.
COLOR DECODER
502
R
G
B
LEVEL REGULATOR
503
R'
G'
B'
504
RGB → YMC COLOR CONVERTER
C
M
Y
12
108
DRIVER
14
PARALEL / SERIES CONVERTER
505
A / D CONVERTER

FIG. 3B

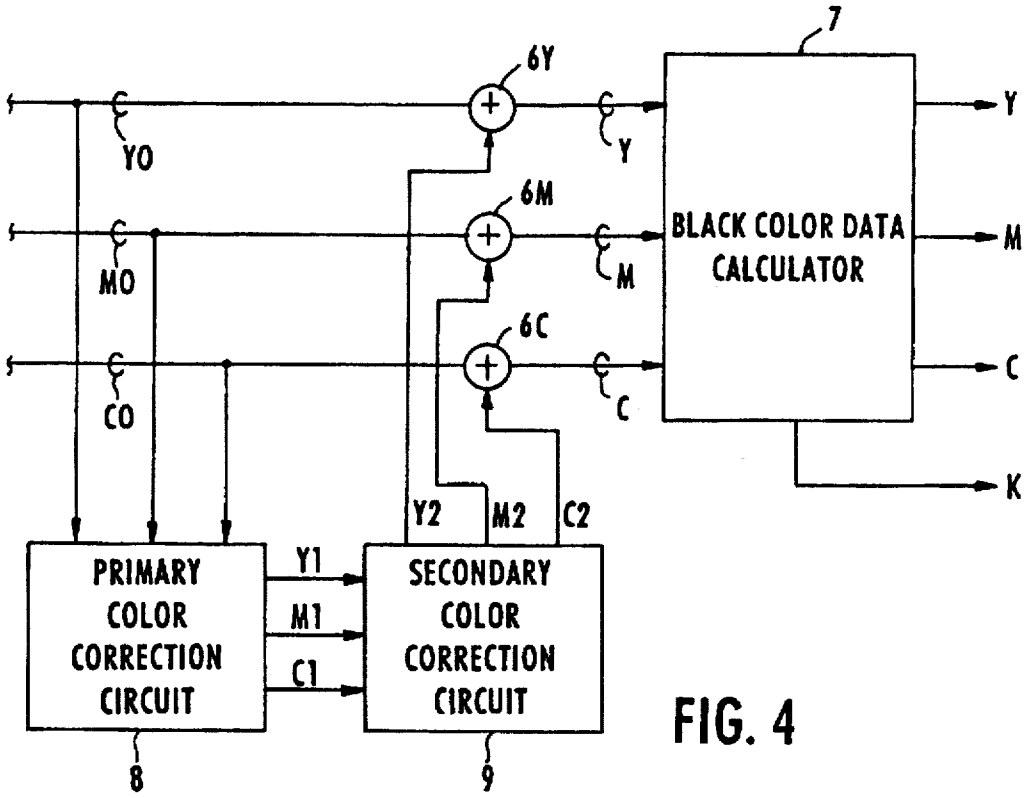

7
6Y
YO
Y
Y
6M
MO
M
M
6C
CO
C
C
BLACK COLOR DATA CALCULATOR
Y
M
C
K
Y2
M2
C2
PRIMARY COLOR CORRECTION CIRCUIT
Y1
M1
C1
SECONDARY COLOR CORRECTION CIRCUIT
8
9

FIG. 4

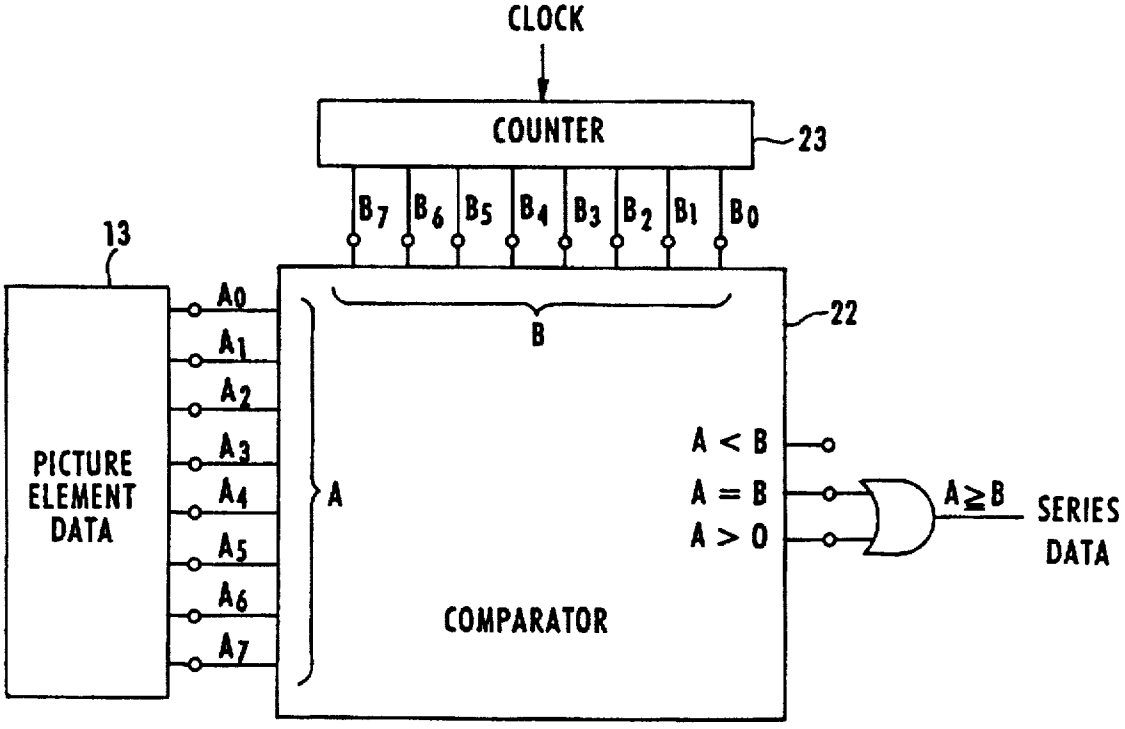

CLOCK
COUNTER
23
B7 B6 B5 B4 B3 B2 B1 B0
13
A0
A1
A2
A3
A4
A5
A6
A7
A
B
22
PICTURE ELEMENT DATA
A < B
A = B
A > 0
A≥B
SERIES DATA
COMPARATOR

FIG. 5

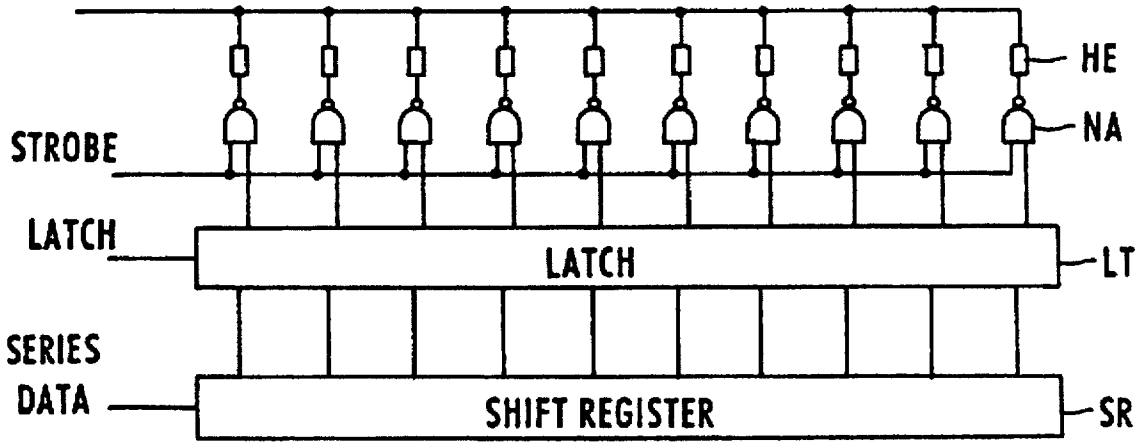

HE
NA
STROBE
LATCH
LATCH
LT
SERIES
DATA
SHIFT REGISTER
SR

FIG. 6

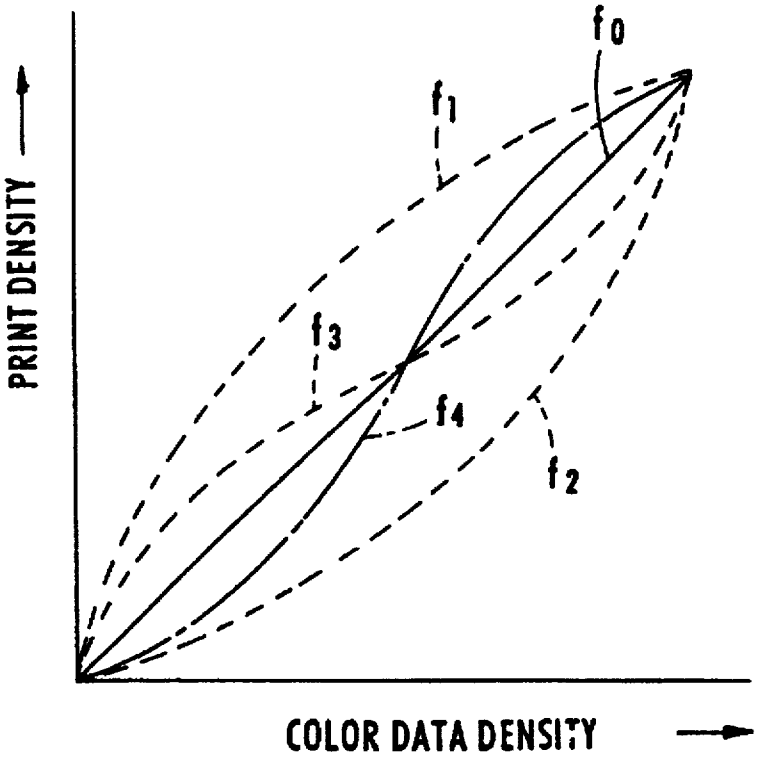

f0
f1
f3
f4
f2
PRINT DENSITY
COLOR DATA DENSITY

FIG. 7

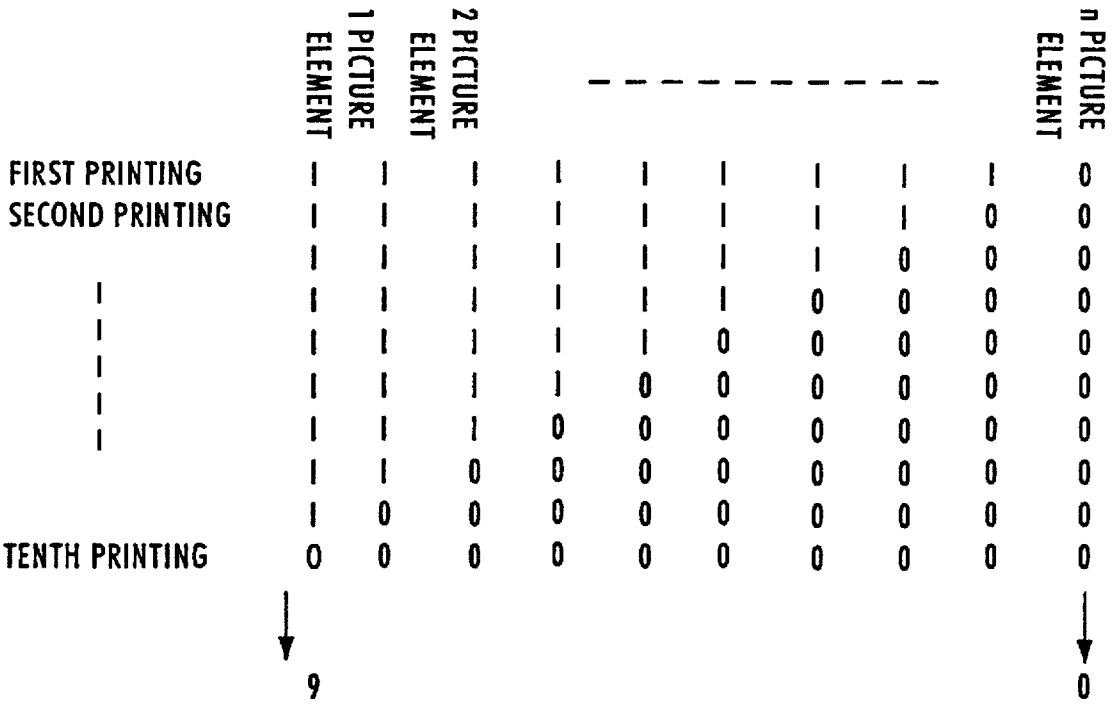

1 PICTURE ELEMENT
2 PICTURE ELEMENT
n PICTURE ELEMENT
FIRST PRINTING
SECOND PRINTING
TENTH PRINTING
9
0

FIG. 8

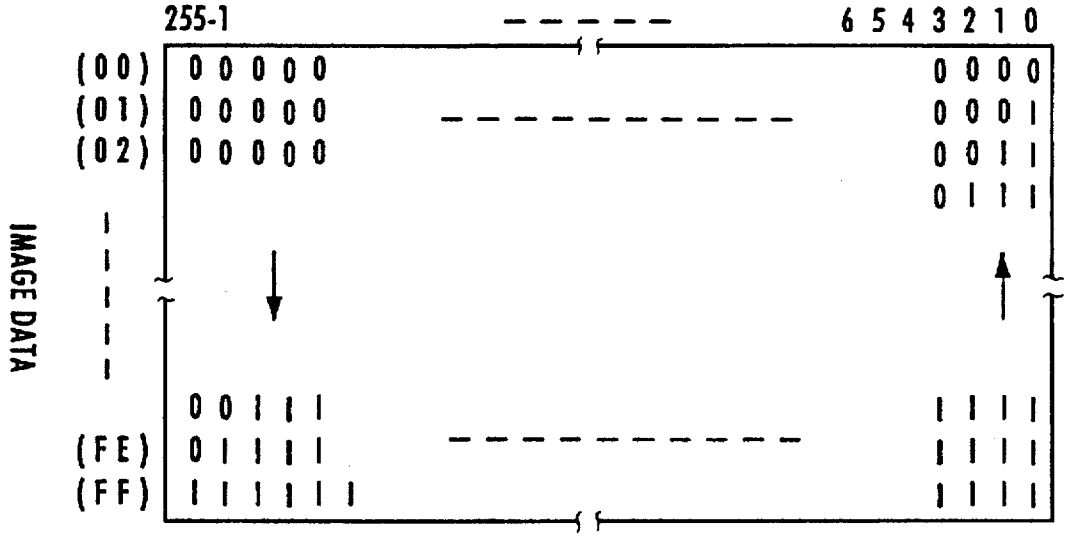

255-1
6 5 4 3 2 1 0
(00)
(01)
(02)
(FE)
(FF)
IMAGE DATA

FIG. 9

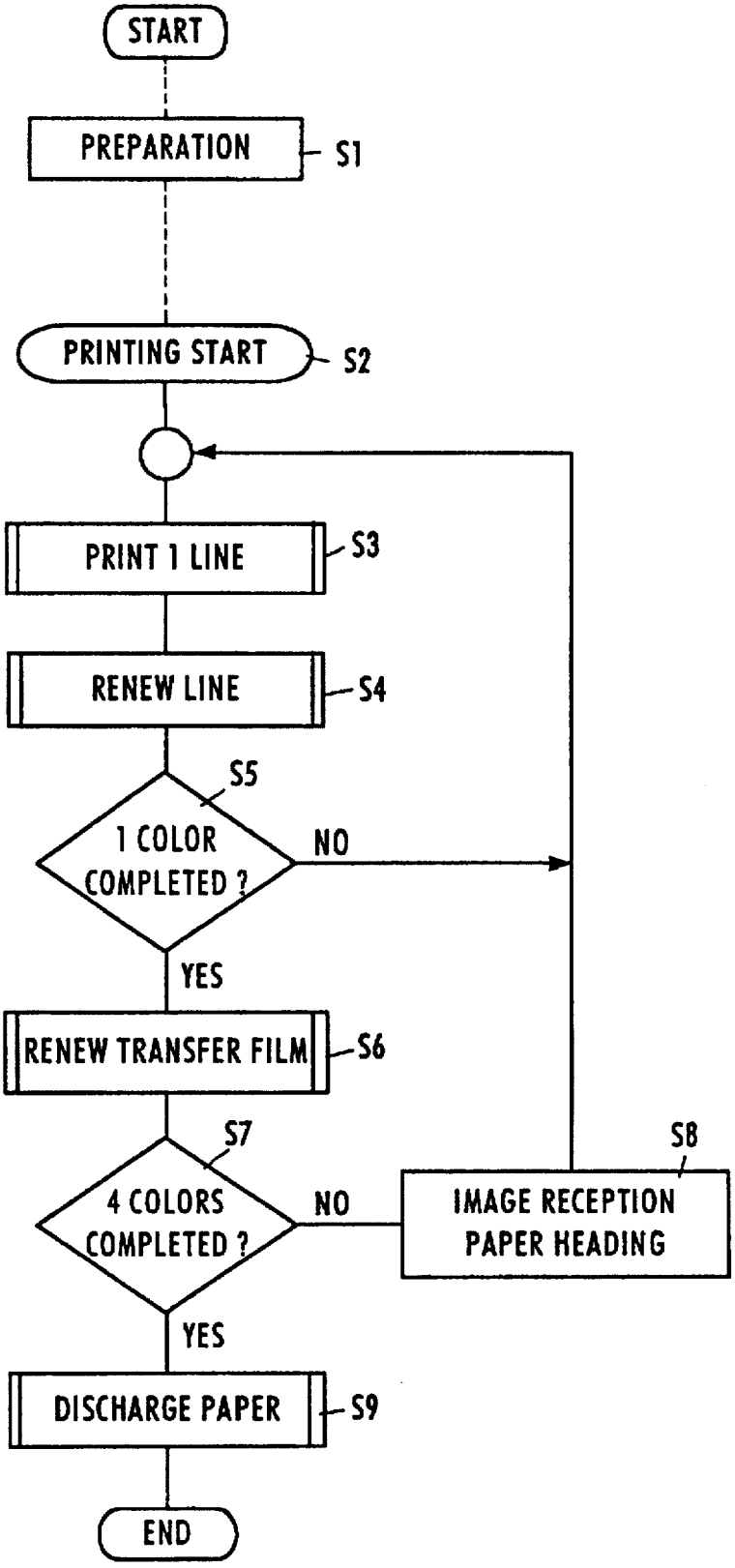

START
PREPARATION
S1
PRINTING START
S2
PRINT 1 LINE
S3
RENEW LINE
S4
S5
1 COLOR COMPLETED ?
NO
YES
RENEW TRANSFER FILM
S6
S7
4 COLORS COMPLETED ?
NO
S8
IMAGE RECEPTION PAPER HEADING
YES
DISCHARGE PAPER
S9
END

FIG. 10

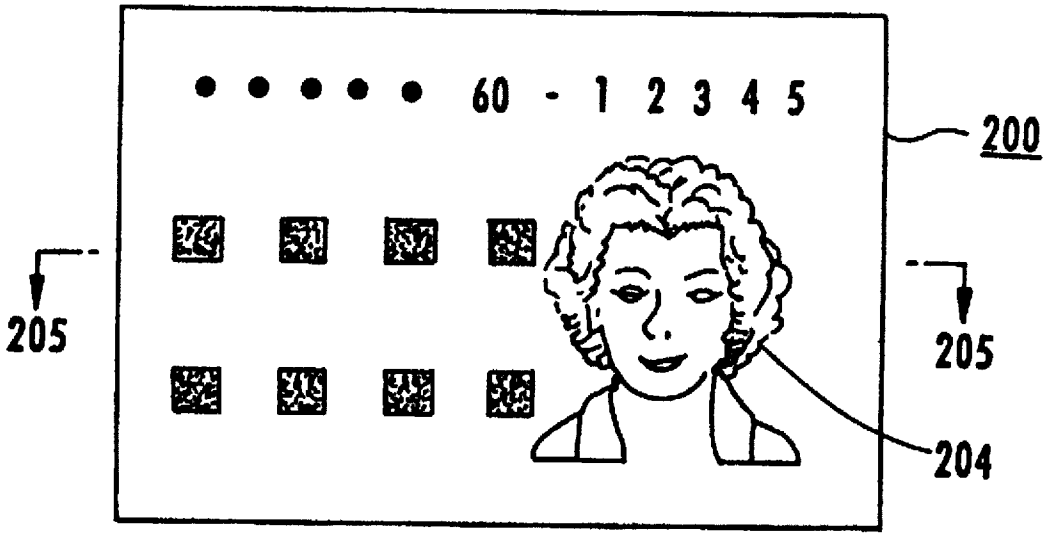


FIG. 11

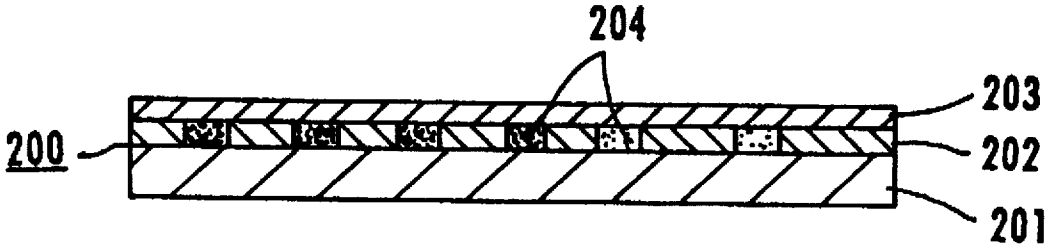


FIG. 12

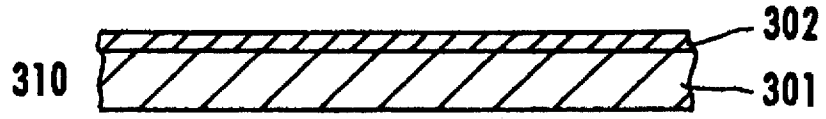


FIG. 13

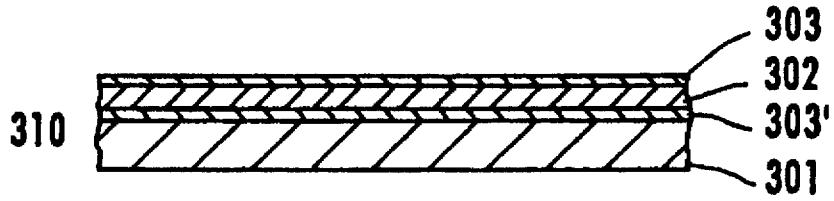


FIG. 14

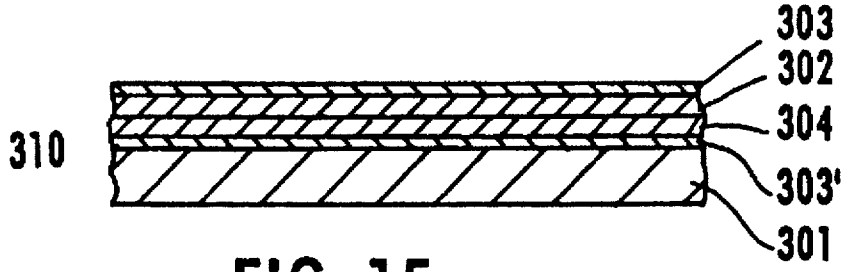


FIG. 15

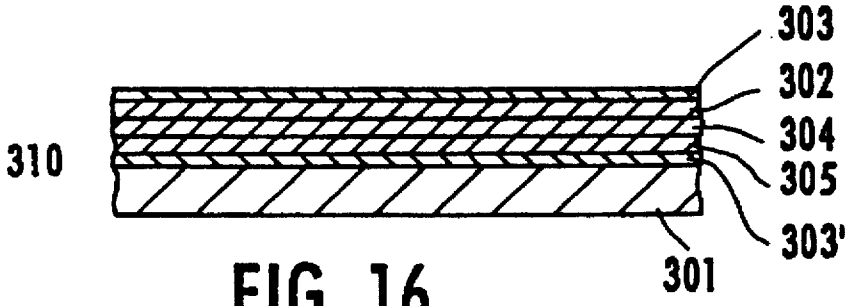


FIG. 16

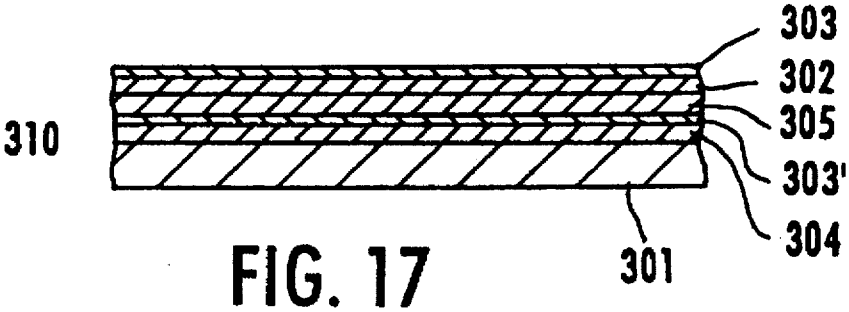


FIG. 17

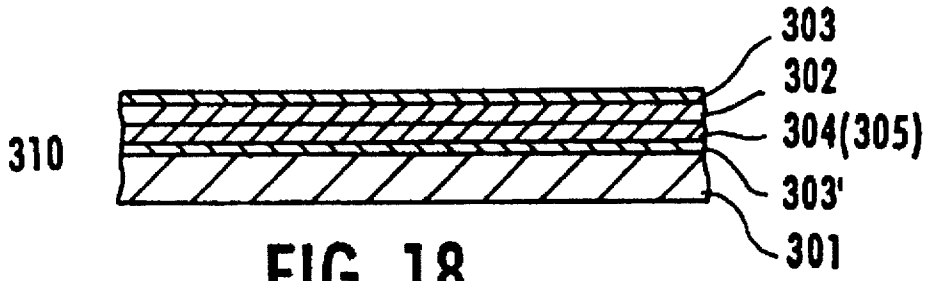


FIG. 18

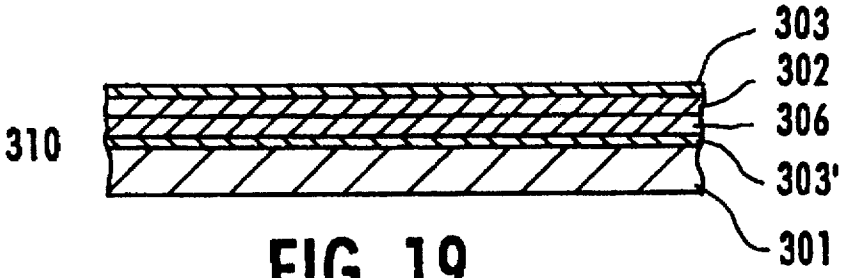


FIG. 19

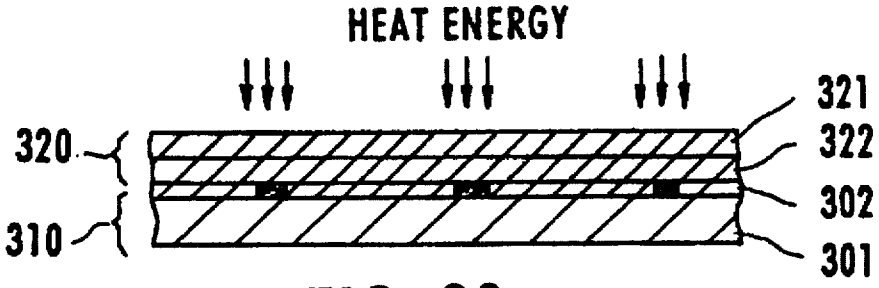


FIG. 20

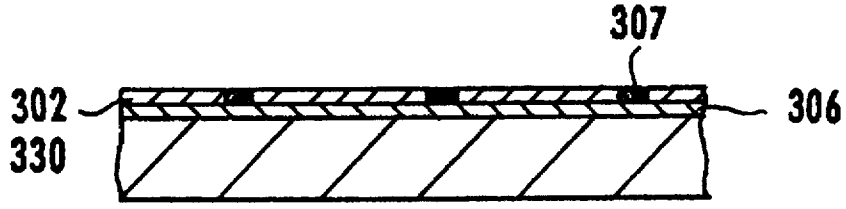


FIG. 21

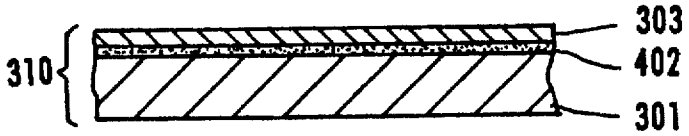


FIG. 22

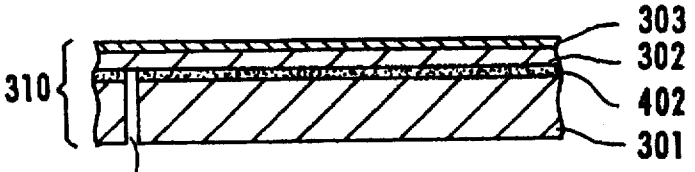


FIG. 23

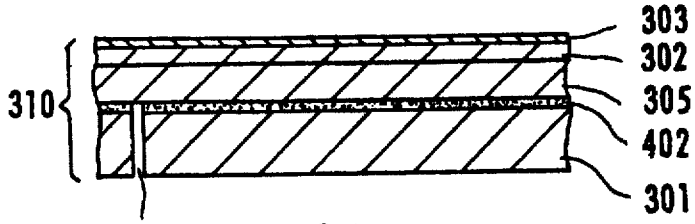


FIG. 24

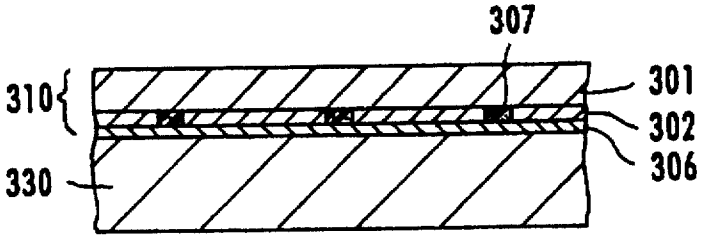


FIG. 25

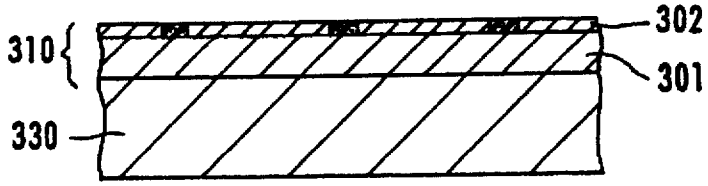


FIG. 26

FIG. 27

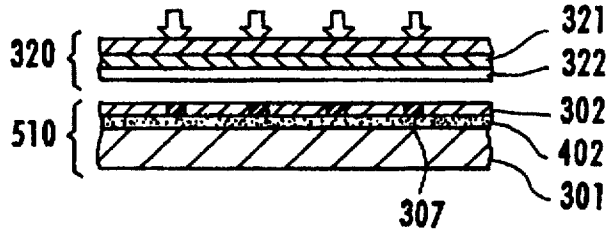


FIG. 28

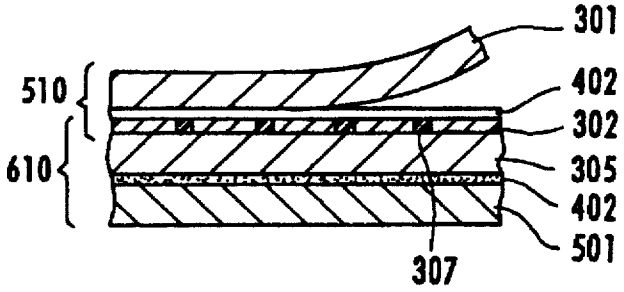


FIG. 29

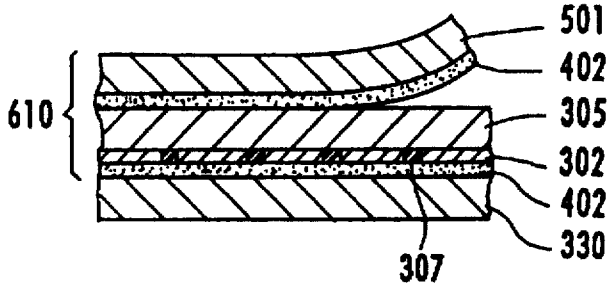


FIG. 30

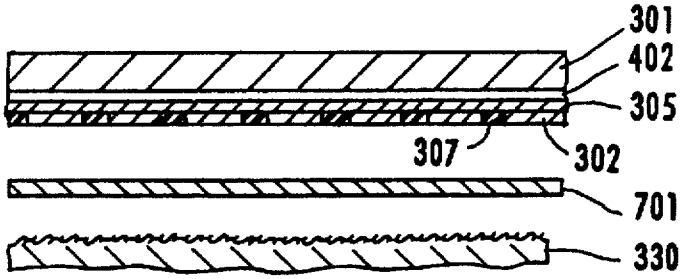


FIG. 31

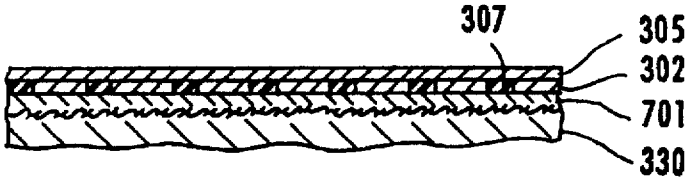


FIG. 32(a)

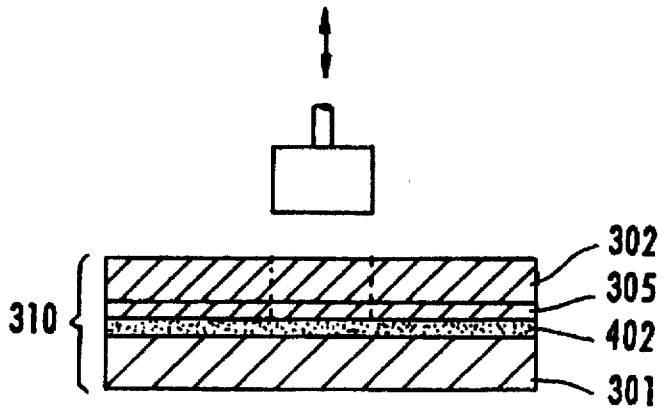


FIG. 32(b)

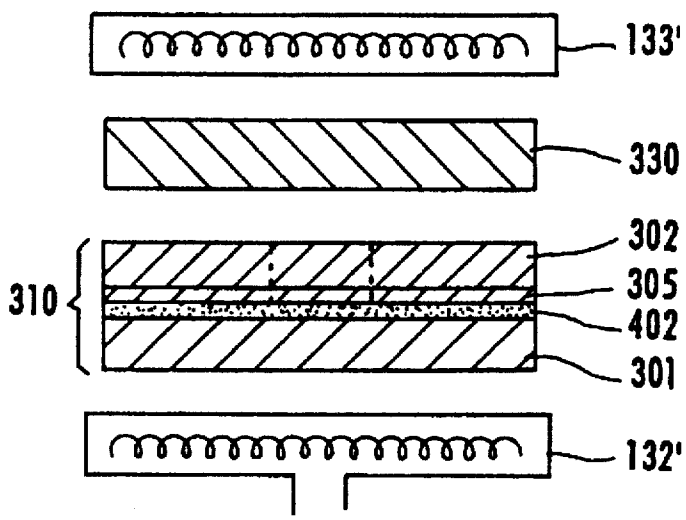


FIG. 32(c)

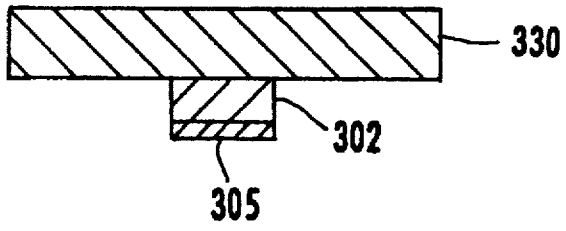


IMAGE FORMATION ON OBJECTIVE BODIES

This is a Division of application Ser. No. 08/395,850 filed Feb. 28, 1995, now pending, which in turn is a continuation of application Ser. No. 08/034,186 filed Mar. 18, 1993, now U.S. Pat. No. 5,451,560, which in turn is a continuation of application Ser. No. 07/467,415 filed Jan. 19, 1990, now abandoned, which in turn is a division of application Ser. No. 07/138,384 filed Dec. 8, 1987, now U.S. Pat. No. 4,923,848.

TECHNICAL FIELD

This invention relates to methods and apparatus for the formation of images as prints on objective bodies through transfer of images preformed by the sublimation transfer technique, and more specifically it relates to such systems as adapted for the formation of images on any selected objective body, such as cards, clothes, papers, and transparent sheets, although these are not limitative to the present invention.

BACKGROUND ART

Reliance is made generally upon the normal printing technique for formation of images on objective bodies. For the execution of the printing technique, provision and use of printing plates (forms or blocks) are requisite. No matter how simple the image-printing is, the plate-making is a very time-consuming and laborious procedure. This is much more so in the printing of various and complexed image combinations, such as those of graphic or portrait images combined with characters, letters or barcodes, as an example, representing extremely complicated and troublesome work.

Further, in the normal printing operation, various operating conditions, including ink selection and the like, must be carefully considered, depending upon the kind and nature of the printing object, thus the best selection thereof is highly delicate and not as simple as expected.

The present invention is proposed upon careful consideration of the foregoing facts, and an object of the invention is to provide a unique process for the formation of sharp and clear images regardless of the kind and nature of the object to be printed upon, and usable and effective materials and apparatuses for carrying out this unique process.

The method of thermal image transfer (sublimation image transfer) on clothes or fabrics with the use of thermal transfer dyestuffs has been practiced for a long time. In this conventional process, a dyestuff picture layer carrying thermal transfer dyestuff is formed on a substrate sheet which is then subjected to heat in an overlapped state on a cloth or fabric, the dyestuff thereby being transferred thermally onto the latter for forming the desired images thereon. By utilizing this technique, and with recent development of the image forming technology concerning fine thermal printers and the like, various fine image forming processes have been proposed to provide fine images which are comparable to photographic images and are transferred onto plastic films from thermal transfer sheets carrying thermal transfer dyestuffs.

According to these recently proposed processes, various images of cameras, or TVs, graphic images of personal computers and the like can be reproduced easily in the form of hard copies on the surface of a transferred material such as a paper or the like sheet carrying thereon a fixedly attached layer of polyester resin, as an example. These

images thus reproduced represent an amply high level comparable to those obtained by photography or fine printing arts.

The thermal transfer process so far set forth has an advantage in that it can form any image in a convenient manner yet entails a problem in that it is limited to image-transferred products preferably of polyester and the like materials which must be dyed with thermal transfer dyes. On the other hand, the image-transferred products must be limited to specifically selected shapes, preferably film, sheet or the like configuration, and thus, such materials as wood, metal, glass or ceramics cannot be formed with images in this way. Further, even if the material is plastics such as polyester or the like, and when the image-forming surface is curved or undulated, or physical body other than sheet, even if it represents a plane surface, it is almost impossible to reproduce images precisely thereon, which naturally constitutes a grave problem in the art.

With recent development and enlargement of utilizing fields of various card-style products, such as cash-cards, telephone-cards, prepayment cards; and ID-cards, there are increasing demands for providing these cards with images, symbols and codes, so as to give various other functional and/or decorative effects. Most of these cards are of planar form, but they are frequently not pliable and/or have uneven rough portions due to provision of characters and symbols, resulting in great difficulty in the scheduled image formation relying upon the thermal image transfer process.

There is therefore an urgent demand among those skilled in the art for the provision of a unique technique capable of forming sharp and clear images of desired patterns on the surface of an objective body of any preferred kind of material and having any shape and configuration and surface condition of any kind, and indeed, for combining and unifying image- and decoration effects.

DISCLOSURE OF THE INVENTION

The present invention is basically based on such a principle that a first image transfer pattern is formed on an image transfer material, preferably an image transfer sheet, and in the form of dyestuff images through the sublimation image transfer process executed by first image transfer means, depending upon given image data, preferably including those of letters, characters, symbols, line images, graduated graphic representations, and then the first transfer pattern is transferred to second transfer means for retransferring the images onto an objective body So as to provide a final product.

Based upon the image data fed from various image data input means and at the first image-transfer means, a thermal head is actuated to execute printing operation through a dyestuff film (thermal image-transfer sheet) on an image-transfer material (or more specifically on an image-transferable material which means an image-transferable sheet,. This image-printing is carried out according to the sublimation or sublimative image transfer technique. Thus, in this case, the dyestuff on the dyestuff film is transferred or shifted under the influence of heat energy from the thermal head onto the image-transfer material through sublimation, thus providing the first image-transferred means. Since this first image-transferred means has been thus formed with the images by the sublimated dyestuff, they are, then, transferred onto the second image-transferable means which will be brought into tight contact with the object to be decorated and subjected to heat and pressure for execution of further image-transfer operation to provide the final desired product.

In the present invention, the image-transfer material (image-transferable sheet) is, as above referred to, formed with images by the sublimative image transfer technique for providing first image-transfer means which has highly sharp and clear images as the operation and results of the characterizing feature of the sublimation image-transfer technique. Therefore, because of the transfer of such sharp and clear images onto the object, it becomes possible to form the images thereon, and indeed, practically irrespective of the kind and nature of the object. In this way, thus, fine image-formation is assured onto practically any objective substance.

And further, by execution of control of the thermal energy applied during- the sublimative image-transfer step, the resulting color effect is superior and the image quality is good.

The images sublimatingly applied and formed in the foregoing way are subjected to a further transfer, and onto a substrate product, for providing a final decorative product as desired. In this final product, it should be noted that the underlying layer underneath the images during the sublimative image-transfer stage appears now at the top, acting thus as a kind of protecting layer upon up-and-down positional conversion during execution of the second and final image-transfer stage, resulting in realization of various and numerous effects. As an example, attainment of substantial reduction of contamination, improvement of light resistance, weather resistance and chemical resistance; substantial reduction of color fading; provision of glazing effect; easier and simpler introduction of granular and/or undulated image appearance.

The inventive process is carried into effect basically in such a manner that an image-reception layer provided on one surface of an image-transferable sheet is subjected to an image-forming step with the use of dyestuff capable of depositing therein depending upon the fed image data, so as to form the required images, and then, the image-reception layer of the image-transferable sheet, having been image-fixed and thus now image-carrying, is stuck onto the surface of the object to be decorated upon.

As for the image-transferable sheet adapted for use in the image-transfer during execution of the inventive process, it consists basically of a sheet-like substrate and a reception layer attached, however, in a separable manner, onto one surface thereof. As a modification of the inventive process from the basic mode set forth above, the sheet-like substrate is caused to remain, even after completion of the image-transfer step, as may be occasionally required. In this modified case, it is unnecessary to make the image-reception layer of the image-transfer sheet separable.

Under occasion, the inventive process may be brought into effect in such a way that the image-reception layer of the image-transfer sheet is transferred upon execution of the image-forming step, and indeed, once onto an intermediate image-transfer substrate which is then retransferred, together with the once transferred image-reception layer, onto the surface of an object to be decorated on; and thus, in a retransferring manner.

BRIEF DESCRIPTION OF THE DRAWINGS

In the accompanying drawings:

FIG. 1A is a block diagram, showing a preferred embodiment of the apparatus according to the present invention;

FIG. 1B is a schematic view illustrating at (a), (b) and (c), several image-transfer steps for the execution of a process according to the invention;

FIG. 1C is a schematic view of an image-transfer step, using a platen roll;

FIG. 1D is a plan view of part of a multi-color dyestuff film adapted for use in an image-forming step;

FIG. 1E is a schematic view for the illustration of several image-transfer steps;

FIG. 2 is a flow chart of successive operation steps with use of a data-processor, shown in FIG. 1, functioning as an operating center;

FIG. 3A is a schematic block diagram, showing a data-processor for the printer;

FIG. 3B is a block diagram of a sublimative image-transferring printer adopted in the present invention, as a preferred embodiment thereof;

FIG. 4 is a schematic block diagram, showing a color correction unit shown in FIG. 3A, and several related parts cooperating therewith;

FIG. 5 is a schematic block diagram of a comparator and several related parts cooperating therewith;

FIG. 6 is a circuit block diagram of an image-transfer head shown in FIG. 1B;

FIG. 7 is a graph showing operational characteristics of a color tone or -gradation corrector unit shown in FIG. 3A;

FIG. 8 is a table for the illustration, as an example, of picture- or image-elements, as expressed in binary signals;

FIG. 9 is a table showing a conversion operation, as an example, of a parallel/series converter shown in FIG. 3A;

FIG. 10 is a flow chart, illustrating the operation of the sublimative image transfer printer;

FIG. 11 is a plan view of a final decorative product prepared according to the inventive technique;

FIG. 12 is a sectional view of the product card shown in FIG. 11, and taken along a section line A—A shown therein;

FIGS. 13 through 31 are a series of sectional views, respectively illustrating several structural examples of image-transferable sheets, suitable for use in the invention; and

FIGS. 32 (*a*), (*b*), and (*c*) are sectional views, indicating final transfer steps.

BEST MODES FOR CARRYING OUT THE INVENTION

Referring now to FIG. 1A and FIG. 1B, (a), (b) and (c), a basic scheme of the inventive image data processing and image formation will be illustrated. First, in FIG. 1A, numeral **101** represents an image input means which is adapted for forming image data based upon optical and the like inputs delivered from a TV-camera, line sensor or the like. Other than those above enlisted only by way of example, video; CD; TV; scanner; personal computer, captain system, capable of providing R.G.B.—and picture image and the like signals may also be utilized in a similar way. The image signal data delivered from the image input means are fed through a data processor **104** to a memory **105** for being stored therein. These stored data can be taken out from the memory and fed through data processor **104** to display means **102** for being displayed thereat.

To the data processer **104**, a mouth/tablet digitizer and/or the like position data processer **103** is electrically connected for introducing position data concerning displayed images appearing at the display **102**. In addition, key board and the like character data input means **106** and font generator **109** are provided for introducing character data. Still further, a barcode generator **110** is provided for introducing barcode

when necessary. By the use of these means and units, various additional processing modes can be executed.

The thus processed data are subjected to conversion at a data converter **107** into proper data adapted for operating a sublimation transfer printer and fed forward through a driver **108** to the thermal head.

In this case, by controlling the current duration period to the thermal element of the thermal head, the transfer quantity from the dyestuff film (thermal transfer sheet) is controlled depending upon the thermal energy of the element for realization of the desired gradation degree of concentration on the transfer sheet. There are two different modes of such control of current duration period as follows:

(a) A method for controlling the pulse length corresponding to the picture element in the impressed data to the thermal element of the thermal head or, more specifically, a series data introduced as input to the shift register shown in FIG. **6** and to be described more specifically hereinafter.

(b) A method for controlling the number of pulses of the pulse series corresponding to the picture elements of the data impressed upon the thermal element in the thermal head (in this case, the pulse length being constant).

The degree of gradation of the transfer image can be controlled in the above mentioned way by the regulation of the current-conducting period depending upon the desired gradation degree. On the other hand, the image concentration can be controlled by adjusting the pulse length or the number of pulses contained in the pulse series in correspondence to the picture elements contained in the data as introduced in the shift register and depending upon the driving mode of the thermal head. Further in this case, if the number of gradation of introduced image data is larger than that which can be expressed by the printer unit, a proper conversion operation can be performed by the known strobe control method. As an example, in such case, the conversion of gradation number 256 to 64 may be executed by a ROM, and the thus reduced gradation number can be used as output.

Next, referring to FIG. 1B at (a) and (b), reference numeral **121** represents a thermal head which receives signals from the driver **108** shown in FIG. 1A. This thermal head **121** is arranged in opposition to platen roll **122**, forming the printing position therebetween. The dyestuff film (thermal transfer sheet) is fed from a delivery roll **123** to a winding roll **124** through this printing position, these structural and functional features being commonly employed in both the arrangements shown in FIG. 1B at (a) and (b).

In the case of FIG. **1B**, (a), the mechanism is so arranged that card or sheet style transfer sheets are printed with dyestuff images.

On the other hand, in the case of FIG. **1B**, (b), the mechanism is so arranged that cards are continuously produced with the use of a film style transfer sheet and a dyestuff film in combination.

Now turning back to FIG. 1B, (a), a number of transfer sheets (cards, sheets or the like) have been stacked and stored within a storage casing **125** and are being thrust upward from below by a spring so that the uppermost sheet is kept in pressure contact with a take-out roll **126**. With the rotation of the roll **126**, the sheets are successively delivered from the casing **125** by conveyer belts **127**, **128** onto a platen roll **122**. Each one of the sheets is fixed on the peripheral surface of the platen roll, now positionally indexed, by means of a gripper or the like mechanical attaching and separating means, static attracting means, or electromagnetic attaching means. Then, the roll **122** is so rotated that the transfer sheet is positioned at the ready-for-printing-position.

Next, the thermal head **121** is brought into pressure contact with the transfer sheet through the intermediary of the dyestuff film, and then the thermal head **121** is energized with electric current while the dyestuff film and platen roll **122** are moved in synchronism for the execution of image transfer (first image transfer).

Upon execution of the image transfer, the platen roll **122** is rotated, the gripper is released and the take-out roll **129** is rotated and brought into pressure contact for taking out the image transfer sheet onto a tray **130**.

The thus taken-out sheet is brought into overlapped state with a new image transfer sheet, not shown, and then, both the sheets are fusingly united together by pressure application of a heated roll, not shown, for execution of a second transfer step job. The whole operation has thus been completed. Before the fusion process, the sheets may be subjected to punching, trimming and/or the like processing, if necessary.

By execution of the foregoing operational steps, a monocolor printing operation has been completed. However, in the case of multicolor printing, use is made of tricolored or quadruple colored dyestuff film and the corresponding printing operations must be repeated. In this case, upon completion of a single monocolor printing procedure, the platen roll is rotated without contact of the take-out roll **129**, until it arrives again at the printing-initiation position, and so on.

In the following, a tricolor printing job will be illustrated with reference to FIG. 1B, (b), and with use of three different series color zones, of cyan, magenta and yellow.

First, a platen roll **122** is positionally indexed, and an image transfer sheet taken out from the roll **131** and a dyestuff film taken out from the roll **123** are brought into pressure contact in an overlapped state. Then a thermal head **121** is pressed against the platen roll **122** through the intermediary of the overlapped sheets. At this stage, the platen roll **122** is rotated counterclockwise while synchronism is kept between the platen roll **122** and the dyestuff film, and the thermal head **121** is kept electrically energized. In this way, the first color printing is executed.

Further, the dyestuff film is fed to the second color zone position, and then, the platen roll **122**, the dyestuff film and the image transfer sheet are fed forward clockwise around the center roll **122**. Thus a second color printing step is executed.

Further, the print-serviced two color sections of the film is fed back counter clockwise around the center of the platen roll **122** for the execution of a third color printing step. Then, each card sheet is taken out from the stack **200** under the action of take-out rolls or the like, not shown, towards and between a pair of thermal transfer rolls **132**, **133**, brought into overlapping state with the image transfer sheet positionally indexed and already subjected to image transfer steps as was described above, and finally subjected to a picture printing operation by pressurizing application of the thermal image transfer rolls **132**, **133** from both sides of each taken-out card, and so on.

The color-printing step with the use of the thermal head is carried into effect in the following manner, as an example.

(First color printing)

Platen roll, image transfer sheet and dyestuff film perform the printing while they are moved in the counterclockwise direction.

(Second color printing)

Platen roll and image transfer sheet are moved in the clockwise direction while the dyestuff film is moved at the same speed and in the counterclockwise direction for performing the color printing under consideration.

(Third color printing)

Platen roll, image transfer sheet and dyestuff film are moved in the counterclockwise direction for execution of the color printing under consideration.

In the modified arrangement shown in FIG. **1B**, (c), thermal image transfer rolls **132**, **133** have been replaced by a flat press type image transfer head having up-and-down movable flat printer elements **132'**, **133'**.

It should be noted that in the course of the foregoing first and second image transfer steps, image reversal phenomenon is necessarily brought about upon execution of each image transfer step. In other words and more specifically, when two successive image transfer steps in the foregoing sense are executed, reverse images which have once appeared will return to the original normal images. Therefore, when the printed-out products are to be provided upon execution of the first image transfer step, it is necessary to provide reversed image data in the signal processing system. For this purpose, it is only necessary to reverse the addressing order at the data introduction or readout stage into or from the memory.

In the modified arrangement shown in FIG. **1C**, the foregoing platen roll means has been replaced by a metal block **141** lined with a rubber plate **142** in an overlapped manner. The image transfer sheet and dyestuff film are fed out from respective rolls **131** and **123**. With the use of this modified arrangement, the dyestuff surface layer of the dyestuff film can be brought into tight contact with the image-receiving surface layer of the image transfer sheet, and thermal energy will be transferred evenly form the thermal head **121** to the dyestuff film.

In this case, the image transfer sheet is delivered from the roll **131**, and the desired zone or region of the sheet is set underneath the rubber plate **142** (step **1**).

At the same time, the dyestuff film shown in FIG. **1D** on an enlarged scale is delivered from the roll **123** and a selected one of the different color regions is set underneath the rubber plate **142** (step **2**).

Next, the thermal head **121** is brought into the rear surface of the dyestuff film which is the opposite surface to the dyestuff-coated front layer, and the head **121** is driven while it is being translated in the direction shown by an arrow A, images thereby being formed at the specifically allocated zone(s) or region(s) of the image transfer sheet (step **3**).

Further, the thermal-head **121** and rolls **416** and **418** are shifted downwards as shown by arrows B, so as to form an idle gap between the image transfer sheet and the dyestuff film for allowing the latter to shift towards the next following color region (step **4**).

Further, the thermal head **121** and rolls **416** and **418** are returned to their original positions, whereupon the third and further succeeding steps are repeatedly executed until a certain predesired number of color printings are completed.

As shown in FIG. **1D**, the dyestuff film is colored to have several different color regions denoted by Y (yellow), M (magenta), C (cyan) and Bk (black). However, the arrangement order is not limited to that shown: Y; M; C and Bk. In addition, as occasionally required, the Bk-region may be dispensed with. Further, as the color elements to be adopted in the Y, M, C-system may not be limited to the three primary colors provided by the subtractive color mixture. On occasion, a characterizing color which means such a color as preadjusted to provide an objective specifically selected one may be used to form the images concerned. As a further modification, the arrangement shown in FIG. **1C** may be so modified that the traveling direction of the image transfer sheet is selected to be perpendicular to that of the dyestuff film.

FIG. **2** is an operation flow chart for showing schematically operational modes taking the data processor **104** adopted in the embodiment shown in FIG. **1** as the centrum of description. The operational contents several working parts downstream of the data converter **107** will be set forth separately hereinbelow. Now referring to FIG. **2**, in combination with FIG. **1** and at the step of **S101**, image pickup operation is carried out by means of the image pickup means **101**. For execution of this step, it may be better to pick up the face of a person per se which is to be represented on the card, or alternatively, a photograph, portrait or imagery product thereof will do. Depending upon the nature of the object, a TV camera, line sensor or the like instrument may naturally be selectively utilized.

The data taken by the image pickup means **101** are stored through the data processor **104** at a memory **105** (**S102**). By the use of these stored data, image or images is/are displayed at the display **102** (**S103**). Since this display image is not yet subjected to any processing, it is generally unsuitable for representing on the card. However, under certain circumstances, it may be represented thereon as it is.

Then, the operator observed the displayed image or images on the display unit **102** and adjudges whether additional processing is necessary or not (**S104**). If it is not necessary, he will manipulate the key board **106** to make a certain operation, resulting in the termination of processing at the data processing unit **104**, data being fed out therefrom to the succeeding data converter **107**.

On the contrary, when additional processing is necessary, the operator-observes carefully the displayed image or images on the unit **102** and adjudges whether the picture image data, or character data or barcode data should be processed. If the picture image data should be processed, such an operation is made for selecting the proper mass of trimming or layout within the menu range of position-data input means **103**. By the execution of this operation, functions and operations at steps **S105** and **S106** can be executed at one stroke. If trimming is taken as an example, the next step is executed in such a way that position data are fed from the position input means **103** to the data-processer **104** with the use of a carsor. When a tablet digitizer is used as the position data input means, the carsor image displayed in an overlapped manner on the displayed picture image appearing at the display unit **102** by carsor manipulation is positionally specified beforehand in registration with the specified position on the card, for determining the trimming range. Then the operation is carried out in such a way that the picture image data outside the specified trimming range are canceled. By completing these operations, data processing operations relating to step **107** are executed, and, then, the mass for completion of the menu range is selected out. By these measures, steps progress through **S109** to **S102**, and data storing is executed, and further, display representation is brought about through step **S103**. If there is no need for additional processing, an operation termination manipulation is carried out as before at key board **106**, and further operations will be made through data converter **107**.

As for the layout, the operation is carried out with the position data input means **103**, similarly as in the foregoing trimming operation. More specifically, layout is selected out in the menu range of position data input means **103**, and the

overall configuration of the card and the display position of picture image are shown at display unit **102**. Then, image inclination correcting operation and the like are carried out so as to realize correspondence thereof with the displayed positional information, the processing operations relating to step **S108** thereby being brought about. After completion of these operations, the mass for the ending in the menu range is selected.

In this way, when selection is made from the menu range by reliance on the position data input means **103**, trimming or layout operation can be brought about. At this stage, when manual operation is carried out at the key board **106**, introduction of character data is executed (**S110**). As the character data in this sense, in the case of ID card, as an example, the name and/or birthday, month and year of the owner may be used. The data introduced from the key board **106** in accordance with the output character style from the font generator **109** are shown at the display unit **102** in the specified positions on the displaying surface and respectively arranged in accordance with display items. The operator acknowledges these items and detailed displays of the represented images. When he acknowledges them as being true, he will operate the key board **106** for showing the operation ending (**S111**).

Upon ending the operations as described above, the data are stored in memory **105** (**S102**) and represented at the display **102**. The operator will acknowledge again this fact, and upon the execution of this, the operations are terminated.

As for the barcode introduction, the data are subjected to inputing at steps **S112** and **S113**, as in a manner similar to the character data introduction as set forth above. The barcodes and the like data may be introduced separately through printing or other mechanical method.

In FIG. **3A**, a data processing circuitry usable in the sublimation image transfer printing method is shown only schematically. As shown, the circuitry **107** comprises a picture element density converter **3**; a color corrector **4**; a gradation corrector **10**; a memory **11**; a switch **12**; a buffer **13** and parallel/series converter **14**. The picture element density converter **3** is connected to a picture image input unit **100**.

The unit **100** serves for generation of three primary color data of R.G.B.- or Y.M.C.-mode from original picture images and is connected through the picture element density converter **3** to the color corrector **4**. The converter **3** converts the picture element density of the image data fed from the unit **100** to the desired one, by subtracting or supplementing, as the case may be, image data for each color element. It should be mentioned that for attaining high quality hard copies, conversion of the picture element density to at least 10 lines/mm or so is preferable.

Color corrector **4** consists preferably of a color decoder, level adjuster or color converter, and serves to correct three primary color data converted to those of a predetermined density of picture elements in consideration of characteristics of the image transfer ink in the image transfer sheet and in addition to provide black color data.

The data processing circuitry **107** is connected through a driver **108** to the sublimation image transfer printer.

In FIG. **4**, an example of the color corrector **4** is shown schematically in structure. As shown, it comprises adders **6Y**; **6M** and **6C**, a black color data calculator **7**, and primary and secondary color correction circuits **8** and **9**. Primary color correction circuit **8** serves for making correction of turbidity of the image transfer ink, while secondary color correction circuit **9** provides a capability of arbitrary and selective correction control relative to specifically selected color hue.

The gradation corrector **10** is so arranged as to make correction of the gradation of the data for each color Y, M, C or K (representing black color) fed from the foregoing color corrector **4** when necessary. For this purpose, the corrector **10** includes a gradation circuit (not shown) and the like, whereby a certain mode of highlight stressing or shadow stressing is introduced and realized.

The memory **11** functions to preserve temporarily the data of each color delivered from the gradation corrector **10**, a selection switch **12** being provided at the output side of the memory for selective writing-in of the data of each color to the buffer **13**. The buffer **13** is capable of writing-in the data of one line of the image transfer head **16** and kept in connection with the parallel/series converter **14** adapted for converting parallel data into series data. Additionally, in the simplified machine, black color data series is dispensed with in some instances.

In FIG. **5**, a schematic construction of the parallel/series converter **14** is shown. As shown, parallel data delivered from the buffer **13** are fed to an input side of a comparator **22**, while outputs from a counter **23** are fed to another input side of the comparator **22** which delivers the converted series data to the driver **15** for driving a thermal head **121**.

If necessary, however, the comparator **22** may be replaced by a converter table, not shown, utilizing a parallel/series converting ROM.

In FIG. **6**, a detailed circuit scheme of the thermal head **121** is shown. As shown, series data delivered from the comparator **22** are fed into a shift register SR and thence, after being subjected to latching at a latch circuit LT, fed to thermal elements HE through NAND gates NA which are fed at respective one side inlets with strobe signals.

Next, referring to FIG. **3A**, the operation of the data processing circuitry **107** will be described more specifically.

First, when three primary color image data are fed from the picture image inlet circuit **100** to the picture element density converter **3**, the latter converts these three primary color data to those which represent a predetermined picture element density and then are fed to the color correction unit **4**. In this case, it is assumed that the unit **4** is fed with three primary color data expressed in respective concentration signals, which are of yellow: **Y0**; of magenta: **M0** and of cyan: **C0**, respectively, in the present example.

These data: **Y0**; **M0** and **C0** are, as shown in FIG. **4**, fed through respective adders **6Y**; **6M** and **6C** to the black color data calculator **7**, to provide a K-output as expressed mathematically by the following formula:

$$K=\min(Y, M, C)$$

wherein, "min" represents a function which provides a possible minimum value.

These data: **Y0**, **M0** and **C0** are fed from the converter **3** to the primary color correction circuit **8** to provide primarily corrected data **Y1**, **M1** and **C1** which are thence fed to the secondary color correction circuit **9** to provide, through calculation, secondarily corrected data: **Y2**, **M2** and **C2**, respectively. These are then fed to respective adders **6Y**, **6M** and **6C**, which add them to respective data **Y0**, **M0** and **C0**, to provide respectively added output data Y, M, and C to be fed to the gradation correcter circuit **10**, respectively, after being utilized for calculation of the K-output signal value.

The primary color correction circuit **8** serves to calculate primarily corrected data: **Y1**, **M1** and **C1** which are necessarily utilized for correct-out of transfer ink turbit. In this case, the original data: **Y0**, **M0** and **C0** are subjected to matrix calculation to provide the primarily corrected data **Y1**, **M1** and **C1**, as folows:

$$Y1=k_{11}\cdot C0-k_{12}\cdot M0+k_{13}\cdot Y0$$

$$M1=k_{21}\cdot C0+k_{22}\cdot M0-k_{23}\cdot Y0$$

$$C1=k_{31}\cdot C0+k_{32}\cdot M0-k_{33}\cdot Y0$$

where, k_{ij} represents weight coefficients:

i=1–3; and

j=1–3.

The secondary color correction circuit **9** serves to calculate secondary color correction data **Y2**, **M2** and **C2** from primary color correction data **Y1**, **M1** and **C1** by modifying the latter to make certain thereto by performing matrix calculations so as to provide a capability for making an arbitral and selective color control at a certain specifically selected-out color hue, in the following manner:

$$Y2=Y1+l_{11}\cdot\Delta B+l_{12}\cdot\Delta C+l_{13}\cdot\Delta G+l_{14}\cdot\Delta Y+l_{15}\cdot\Delta R+l_{16}\cdot\Delta M$$

$$M2=M1+l_{21}\cdot\Delta B+l_{22}\cdot\Delta C+l_{23}\cdot\Delta G+l_{24}\cdot\Delta Y+l_{25}\cdot\Delta R+l_{26}\cdot\Delta M, \text{ and}$$

$$C2=C1+l_{31}\cdot\Delta B+l_{32}\cdot\Delta C+l_{33}\cdot\Delta G+l_{34}\cdot\Delta Y+l_{35}\cdot\Delta R+l_{36}\cdot\Delta M$$

wherein, l_{ij} represents weight coefficients:

i=1–3;

j=1–6;

ΔB, ΔC, ΔG, ΔY, ΔR, ΔM:

characterizing color data.

Thus, when these-secondary correction data **Y2**, **M2** and **C2** are added to the corresponding original data **Y0**, **M0** and **C0** by means of respective adders **6Y**, **6M** and **6C** and under proper selection of weight coefficients k_{ij} for primary color correction circuit **8**, any color discrepancy of the ideal color of the ink appearing on the printed picture images under the action of the sublimation transfer printer can be arbitrarily ammended. In this case, when the weight coefficients l_{ij} for the secondary correction circuit **9** are selected out properly, the color tone of the printing picture images can be modified to an arbitrary degree.

Further, as for the black color data K, correction data K2 can be calculated by the following formula. With use of these correction data K2, which are added to the original black color data K, the desired correction can be executed in a similar manner.

$$K2=K+m1\cdot\Delta B+m2\cdot\Delta C+m3\cdot\Delta G+m4\cdot\Delta Y+m5\cdot\Delta R+m6\cdot\Delta M$$

wherein, Mi represents weight coefficients:

i=1–6.

In this way, output data: Y, M, C and K delivered from the color correction circuit **4** are introduced into the gradation corrector **10** as inputs thereof, and each constituent of these data can be subjected to correction as desired.

FIG. **7** shows several characteristic curves illustrating corrections by means of the gradation corrector **10**. More specifically, **f0** represents a standard characteristic curve; **f1** a highlight-stressing operation curve; **f2** a shadow-stressing operation curve; **f3** a highlight-and-shadow stressing operation curve; and **f4** a medium tone stressing operation curve.

As indicated in FIG. **7**, by presetting, as necessary, the tone-reproducing characteristics, which determine the relationship between that concentration of color data and that of the prints printed by means of a sublimation image transferring printer, a color tone similar to that possessed by the original image can be reproduced. More specifically, when no correction is adopted, the curve **f0** is used, while in the case of correction, any selected one of these curves **f1** to **f4** may be utilized depending upon the part of gradation to be stressed. Further, it should be noted that the tone reproducing characteristic curves are not exclusively limited to those which have been specifically shown and described above. As an example, the control of gradation correction by color tone reproducing characteristic mentioned above is executed by a gradation circuit, not shown, and the setting of the color tone reproducing characteristic is brought about by manipulation of any selected one of the control knobs, not shown, which are provided separately for "highlight"; "medium tone" and "shadow".

Y.M.C.K.-data subjected to correction by the gradation corrector **10** are once stored in the memory unit **11**. The thus stored data may be read out from the memory for each color by manipulation of the selection switch **12** and, after provisional storing, per one line of transfer head **16**, at the buffer **13**, introduced into the parallel/series converter **14** for conversion thereby into corresponding series data.

Another example of the data processing circuit for the sublimation transfer printer is shown only schematically in FIG. **3B**. As shown, the processing circuit in **107'** comprises a level regulator **503**; a color converter **504**; an A/D converter **505** and a parallel/series converter **14**.

As the image data introduced into the processing circuit **107'**, those which have been subjected to conversion into R.G.B.-signals in the color decoder **502** from composite video signals delivered from a T.V. camera, VTR or the like are used. On the other hand, R.G.B.-signals delivered from a personal computer, captain system or the like means are introduced as input into the level adjuster **503**.

As the color correction method with the use of the foregoing arrangements, it is possible, more specifically, to adjust the hue saturation and/or brightness in the color decoder **502**, or to adjust the signal level of each color light of R.G.B.-system in the level regulator **503**.

As an example, the color conversion from R.G.B.- to Y.M.C.-system can be executed in the color converter **504**. The simplest possible method in this color conversion is to procure the opposite color to each of the normal colors.

The thus produced color signals of Y.M.C.-system is subjected to A/D conversion and then fed successively through the parallel/series converter **14** and the driver **108** to the thermal head, not shown, to carry out printing in the sublimation transfer principle.

Additionally, in normal cases, with the use of the foregoing system composition, input image data must be of static mode. However, by provision of memory means in front of the color decoder or at an intermediate position between the A/D converter and parallel/series converter, animating images can be processed.

The series data converted in the foregoing manner in the data converter **107** or **107'** are fed to the shift register SR shown in FIG. **6** by n-image elements and then, upon being subjected to latching in the latch circuit LT are further delivered to NAND gate NA as its inputs. When a strobe signal ST is fed as input to the NAND gate NA, the foregoing n-image element data is fed to the thermal element HE.

FIG. **8** is a schematic diagram, showing signals for respective image elements. The gradation has been so selected that the first image element is at the highest gradation level, while the n-th image element corresponds to the lowest gradation level, and that the second to (n–1)th image elements vary linearly in gradation levels, so as to provide representatively a better understandable example of the invention.

Next, the operation of the parallel/series converter **14** will be described.

First, as shown in FIG. **5**, image elements data A, consisting of parallel data, more specifically, comprising paral-

lel eight bit data A0–A7, are fed to one-side inputs of comparator 22, while another side inputs thereof are fed with outputs B, comprising eight bit increment outputs B0–B7, of counter 23. The counter 23 counts clock signals in increments, the outputs B0–B7 being successively varied.

The comparator 22 performs comparison between the two inputs A and B, so as to deliver successively outputs of binary "1" until the increment output B is brought into coincidence with image elements data A, or more specifically, under the condition of A>B and A=B, while, thereafter, binary "0"-outputs are delivered therefrom. More specifically, comparator 22 will continue to deliver binary "1" until an increment value which corresponds to the weight of concentration of image element data A is given thereto. As an example, if the image element data A has a concentration of gradation 128 of a total 256, output "1" will be repeated to deliver 128 times first and then, output "0" will follow after again 128 times, so as to provide in total a specific series data peculiarly in this case.

These series data are taken out from the comparator 22 in the form of A>B- and A≥B-outputs and of A=B-outputs through an attributed OR-gate 24, and in the present example, the gradation consists of 256 steps or increments. However, in practice, the gradation may represent a smaller number of steps. As an example, if the incrementing bit is B1 instead of hitherto employed B0, the gradation will have 128 steps; and if B2 employed, it will have only 64 steps. In this way, the gradation setting may be varied in a simple manner.

When in the foregoing way, the output B from the counter 23 is stepwise incremented, such series data consisting of a first series of "1" will be delivered until the relationship between the image elements data A and the output B from counter 23 becomes A=B, and of a second series of "0" issued thereafter, as shown in FIG. 8.

In FIG. 9, a conversion mode at the parallel/series converter 14, which, however, is different from that shown in FIG. 8, as an example, is shown again in the form of a matrix. As-shown, when the image data are of 8-bit parallel kind, as an example, the gradation data are ranged from 0 to 255, providing, therefore, binary series data from "00 . . . 00" to "11 . . . 11".

In this way, the data, per line in the transfer head 16, kept preserved in the buffer 13 are fed to the parallel/series converter 14 for providing as outputs therefrom into corresponding series data which are then delivered through the driver 15 to the transfer head 16 and thus recorded on a print paper P supported on the transfer drum 17.

FIG. 10 represents a flow chart illustrating the operation of the sublimate printer as employed in the present invention.

At the first step S1, print papers are set in position and the printing ribbon is also set in position ready for performing the required procedure.

At the second step S2, printing operation is initiated, and line printings are executed, line by line, accompanying necessary intermittent line shifts, with relation to any selected one of four colors: C (cyan); M (magenta); Y (yellow) and K (black) being carried out. Refer to S3 and S4. When line printings with the selected-out single color have been completed (S5), the image transfer sheet is replaced by another color sheet (S6) and so on. In this way, line printings are completed in all four colors. In this case, it is naturally most preferable to use a long extended single transfer sheet on which four color ink regions are repeatedly printed in a certain predetermined pattern. The image reception paper is initiated to make print from a certain prescribed position for each of these colors (S8). When all of the printing steps have been completed with the four colors, the paper is discharged from position (S9) and the printing operation is terminated to be repeated.

In FIG. 11, a card style sample of the final products according to this invention is shown in front view at 200. FIG. 12 is a sectional view thereof. Numeral 201 represents the substrate material of the card; 202 a display layer; 203 a surface protecting layer; and 204 a display image as an example. Depending upon the kind of usage and when necessary, the protecting layer 203 may be dispensed with. It should be noted that the display image 204 on the display layer 202 is represented by a sublimative dyestuff, as a characterizing feature of the present invention.

As the main and substantial material of the image transfer sheet, various plain papers, convertea papers, plastic resin sheets or the like may be used per se or in combination. When a plastic resin sheet which can be colored directly with a sublimative dye or dyes is used, these image transfer substrates (articles or objects) as at 201 can be united each with the display layer 202. Each of these substrate materials, when it is of the card style, may have generally such dimensions: thickness of 0.68 to 0.80 mm and size: 11 to 8×8 to 5 cm.

As the material of the display layer 202, various known materials which may be colored with sublimative dyestuffs, such as polyethylene, polypropylene, polyester, ABS, AS, polyvinylchloride, polyvinyl/vinyl acetate copolymer, polystyrene, polyacrylate, polyester, polyamide, polyurethane and the like plastic material, may be advantageously utilized. As will be more specifically described hereinafter, this material layer can be united with the substrate material layer 201. In the case of such unified structure with substrate layer 201, the thickness and size dimensions may be substantially as the same as before. However, when normal and/or converted papers or metals, which are practically impossible to color with sublimative dyestuffs, are used as the substrate layer 201, various methods can be utilized for desired coloring. As an example, a solution including at least any selected one of plastic resin materials capable of coloring with sublimative dyestuffs may be coated on the substrate surface, or alternatively used in the form of a film which is laminated thereon. This kind of film preferably has a thickness of about 3 to 50 μm or so. One of main characterizing features represented in and by the final products 200 is that the appearing display image or images as at 204 is/are formed at least partially or wholly with a sublimative dyestuff or dyestuffs. Additionally, the process for formation of such images can be executed in the conventional art.

As an example, the processing method may be executed conventionally as follows.

As an example, a sublimative image transferable sheet, such as a paper sheet, plastic resin film or sheet capable of acting as the carrier is coated on its surface with any suitable binder resin carrier carrying a sublimative a dyestuff or dyestuffs under heat, is overlapped on the display layer 202 and then subjected to heat from behind the heat-transferable sheet, preferably in the pattern mode, so as to transfer the dyestuff or dyestuffs into the display layer 202. It is proper to select the molecular weight of 250 or larger of the dyestuff, for improving the fastness thereof. However, a molecular weight higher than 370 is more favorable. In the case of provision of the surface protecting layer, there is practically no limitation to the selectability of the dyestuff molecular weight.

The sublimative image transfer may be executed directly on the surface of substrate 201 provided with the display

layer **202**. Or alternatively, a carrying, image transferable sheet is prepared separately and, after formation of the image **204** thereon, may be stuck onto or laminated on the substrate **201**.

Image-Carrying and Image-Transferable Sheet

In the following, structure, material, usage and application purpose of the image-transferable sheet to be employed in the present invention will be described in detail:

FIG. **13** illustrates Only basically and in schematic sectional view the image-transferable sheet adopted in the present invention, while FIGS. **14** through **19** and **22** through **24** illustrate preferable embodiments thereof.

The basic structure of the image transferable sheet **310** is characterized in that, as shown in FIG. **13**, a sheet-like substrate **301** is provided at its one surface with an image-reception layer **302** capable of peel-off from the substrate. By adopting such a structural configuration of the image-transferable sheet, the image-reception layer **302** can be formed with the required image or images with the use of an image transferable sheet having thermally shiftable dyestuff, and then, the image-formed, image-reception layer **302** is peeled off from substrate **301** and attached firmly, preferably as by sticking, on the surface of any selected object or article with use of any suitable means. In this way, various conventional drawbacks inherent in the comparative conventional technique can be basically overcome.

More specifically, as the material of the aforementioned image-reception layer **302**, limitation must be imposed to those which can be colored with thermally shiftable or transferable dyestuff. However, upon Eormation of necessary images and upon peel-off from the sheet-like substrate **301**, the image-reception layer **302** may be attached fixedly onto the surface of glass-made, metal-made or wooden-made products or plastic-resin made ones which are very difficult to color with thermally shiftable and transferable dyestuffs, indeed, by reliance on conventional sticking techniques as properly adopted in consideration of the specific nature and kind of the material of decorative products to be ornamented. Further, the image-formed and peeled-off, image-reception layer **302** from the sheet substrate **301**, is highly thin and thus sufficiently pliable so that it may be applied even onto any uneven and complicated surface of a product to be decorated or ornamented, having undulations, convexities, concavities, recesses and projections. Therefore, a maximum possible better fitness of the image-reception layer to be ornamented is attained and guaranteed by the present invention. Thus, practically no limitation in the attaching use thereof may be encountered. Further, in sharp contrast to conventional sealing seals and the like, the very thin image-reception layer bearing necessary images can be applied easily to the product per se in a very uniform manner, thus providing no raised and thickened feeling, and giving rise to no foreign feeling upon attachment.

FIG. **14** shows a further example of the image transferable sheet **310**. In this case, there is provided a parting agent layer **303** on the surface of image-reception layer **302**. Between the latter and the sheet substrate **301**, there is provided a parting agent layer **303'**. If necessary, however, any one of the two layers **303**; **303'** may be dispensed with.

The first parting agent layer **303** is provided for prevention of thermal fusion between the image-reception layer **302** and an image transferable sheet, not shown, as may occur during image transfer and formation on the first layer **302** through transfer of thermally transferable dyestuff from the said transferable sheet to the first layer. If there is no risk of such thermal fusion of the above nature, or when the image-transferable sheet has been already provided with such a parting agent layer, the present provision thereof may be unnecessary. As for another parting agent layer **303'**, it is for the purpose of making the latter peel-off operation, to be executed after image-forming step, easier. When the sheet-like substrate **301** is made of polyester or the like material which has, as it is, sufficient separability from image-reception layer **302**, provision of parting agent layer may naturally be dispensed with.

FIG. **15** illustrates a still further example of image transferable sheet **310**,. In this case, between the image-reception **302** and the sheet-like substrate **301**, an intermediate layer **304** and/or parting agent layer **303'** is/are provided. The laminating order is optional and thus not binding. The intermediate layer **304** will serve to assist the image formation to be rather firm and beautiful, the image formation being carried out by transferring the thermally shifting and transferring dyestuff from the image transferable sheet to the image-reception layer **302**. For this purpose, the intermediate layer **304** may take, for example, the form of a cushioning layer or heat insulating layer. When a cushioning layer is provided as the intermediate layer **304**, the cohesion between the image transferable sheet and the image reception layer **302** is greatly improved and the thermal shift and transfer of the dyestuff during image formation with the use of a thermal head is evenly executed, the image formation thereby being carried out amply in correspondence with the supplied image signals. Further, when a heat insulating layer consisting of a highly heat-insulative material is used as the intermediate layer **304**, ineffective release of the heat applied during shift and transfer of the dyestuff from the image transferable sheet to the image-reception layer **302** can be reduced to a minimum possible, the effective thermal efficiency thereby being correspondingly improved and ample image formation being accelerated. If necessary, however, these cushioning layer and heat-insulating layer can be prepared independently and arranged concurrently in any arranging order.

Additionally, when the intermediate layer **304** is arranged at a higher level than the parting agent layer **303'**, the intermediate layer **304** will be conjointedly peeled off in the case of peel-off of the image-reception layer **302**. On the contrary, when the intermediate layer **304** is arranged at a lower level than the parting agent layer **303'**, the intermediate layer will remain on the sheet-like substrate **301** after execution of the separation of image-reception layer **302**. In this case, therefore, the intermediate layer **304** may be made preferably and at least substantially transparent, when the peeled-off image-reception layer **302** is stuck on a decorative product, while directing the surface of parting agent layer **303** towards the latter.

In the modifications shown in FIGS. **16**, **17**, and. **18**, modified from the foregoing embodiment shown in FIG. **15**, a further protecting layer **305** is provided between the image-reception layer **302** and the sheet-like substrate **301**. This protecting layer **305** serves to prevent deterioration of the formed images in the image-reception layer **302** when the latter is stuck on the decorating product while directing the surface (more specifically the image-formed surface) towards the product. For example, this protecting layer **305** is prepared from a superior material which exhibits at least one of desirous properties such as antiwearing, light-fast, weather proofing and anti-chemical qualities. With the use of the protecting layer **305** having these superior qualities, the images can represent improved fastness in the above various aspects, even after execution of the foregoing sticking procedure.

In the modification shown in FIG. **16**, the protecting layer **305** is arranged between the intermediate layer **304** and the parting agent layer **303'**.

In the further modification shown in FIG. **17**, the protecting layer **305** is arranged between the image-reception layer **302** and the parting agent layer **303'**.

In still another modification shown in FIG. **18**, the intermediate layer **304** takes the role of the protecting layer **305**.

In each of these modifications, the protecting layer **305** is arranged in neighboring relationship with the partition agent layer **303'**, whereby the image-formed and remotely arranged, image-reception layer **302**, kept in its up-and-down reversed state, is capable of adhering securely to the decorative product, so as to be positioned as an uppermost layer, as may be required. In a still further modification shown in FIG. **19**, derived from that shown in FIG. **14**, a sticking layer **306** is further provided between the image-reception layer **302** and the partition agent layer **303**. It should be noted, however, that such a sticking layer as at **306** may be provided in any one of other foregoing examples and modifications, if necessary, in neighboring relationship with the parting agent layer **303'**.

The provision of such a sticking layer as at **306** is highly valuable when the image-f6rmed and peeled-off, image-reception layer is adhering without position reversal onto the decorative product. With this arrangement mode, the protecting layer **305** shown in FIGS. **16**, **17**, and **18** may be dispensed with. If, however, the protecting layer **305** is composed of a material in the form of a sheet-like substrate, the part to be peeled off is thereby strengthed, the peel-off procedure thus being greatly facilitated.

By previous provision of the sticking layer **306**, the image-formed and peeled-off, image-reception sheet **302** can be caused to adhere as it is onto the decorative product without use of a separate sticking agent. As the sticking layer **306**, an ordinary sticking agent which is active at room temperature can be used. Or alternatively, a heat-sensible or light-sensitive sticking agent may be used, if necessary.

In the foregoing, the main structure of the image transferable sheet employed in the present invention has been described in detail. However, other structural modes than those set forth hereinbefore which occur easily to those skilled in the art may be employable in the invention, and thus. they may be included within the scope of the invention without departing from the appended claims.

It should be further noted that, in the present invention, the sheet-like substrate may be provided on its one surface with an image-transferable layer capable of peeling off through the intermediary of only one weakly sticking layer.

FIG. **22** shows only schematically in a sectional view a preferred embodiment of such an image-transferable sheet, denoted with same reference numeral **310**.

As shown in FIG. **22**, the image-transferable sheet **310** represents a basic structural characteristic such that any suitable sheet-like substrate **301** is provided on one of the surfaces with an image-reception layer **302** through an only weakly sticking intermediate layer **402**, the layer **302** thus being easily peeled-off when desired. By providing the image-transferable sheet with such a structural characteristic as set forth above, desired positive or negative images are formed by transferring thermally shiftable and transferable dyestuff from the image heat transferable sheet to the image-reception layer **302**, and the thus image-formed layer is peeled off from the sheet-like substrate **381** and then attached onto any suitably selected product with the use of proper means or attached per se thereon without the peeling-off operation, the substrate then being peeled off, whereby an image-formed final product can be obtained.

In the foregoing example, it should be noted that the image reception sheet **302** per se has only a thin thickness and thus represents only poor feedability during the sheet-feeding period within the printer at the time of image formation, insufficient cushioning effect and only insufficient thermal efficiency during the printing operation, and further, it is very difficult to treat in advance of as well as after execution of the image formation. Therefore, the coexistence of the image-reception layer **302** and the sheet-like substrate **301** is absolutely necessary. In addition, it is a requisite requirement that the image reception layer **302** be easily peeled off from the sheet-like substrate **301** upon execution of the image-forming operation, and thus, the layer **302** and the sheet **301** should not be stuck too strongly together. In order to satisfy this requirement, provision is made of weakly stuck layer **402** therebetween. Thus, it should be noted that the term "weakly stuck" employed in this specification and appended claims may be defined as "to be separable by finger's end and the like means from each other without entailing destruction or breakage of the parts originally stuck together". It is worthwhile to say, in considering the relative relationship between the image-reception layer **302** and the sheet-like substrate **301**, there is no necessity to provide the weakly-stuck layer **402** if the aforementioned peeling-off is very easy to bring about.

FIG. **23** illustrates still another modification of the image-transferable sheet **310** denoted by the same reference numeral **310** only for simplicity and convenience, wherein a further parting agent layer **303** is provided on the surface of image-reception layer **302**.

This layer **302** is provided for occasional thermal sticking between the thermal image transferable sheet, not shown, and the image reception layer **302** in the progress of thermal shift and transfer of the dyestuff from the sheet to the layer **302**. This provision of the parting agent layer **303** may be dispensed with if there is no risk of occurrence of such disadvantageous sticking attachment or the sheet under consideration has already been fitted with such a parting agent layer.

A modification shown in FIG. **24** from that shown in FIG. **23** has such a modified structure that a protecting layer **305** is provided between the image-reception layer **302** and the weakly stuck layer **305**. This layer **305** serves to prevent otherwise occurring deterioration of the images at the image-reception layer **302** which has been formed with preferably reversed images and subjected to peeling-off, together with protecting layer **305**, preferably a plastic sheet layer, from the sheet-like substrate **301** and finally stuck onto the decorative product, while directing the image-formed surface of the image-reception layer towards the product. The protecting layer **305** is made of a material having various excellent physical properties, such as anti-wearing-, light-fastness and antichemical characteristics. Provision of such a protecting layer improves various fastness performances of the formed images after sticking attachment of the image-reception layer **302**.

When necessary, a separate parting agent layer, not shown, may be provided between the protecting layer **305** and the weakly stuck layer **402** for providing easy peel-off capability between these two layers **305** and **402**, as being applicable to the example shown in FIG. **24**. If the surface of the protecting layer **305** should have sufficient peel-off capability, it is natural to provide such an intermediate parting agent layer as above.

Further, in the case of the image-transferable sheet **310**, it is naturally easy to separate from each other through a peel-off operation, upon the formation of necessary images thereon and before practical use thereof as the image-transfer sheet, and a cut-out slit as at **407** in the sheet-like substrate **301** may be provided for attaining such an easy separation as stated above at a portion of the sheet **310** in proximity to one end thereof. Upon the provision of such a cut-out slit as at **407**, the thus formed flap-like portion can be easily folded out by the operator's finger-tip, thereby affording convenience in a peel-off operation.

The usable materials and composing methods of the foregoing image transferable sheets will now be described.

As a material usable for the sheet-like substrate may be any one or any combination of the following categories:

(1) synthetic paper (polyolefin-series; polystyrene series and the like);

(2) fine quality paper; art paper; coated paper; cast-coated paper, wall paper; back-up paper; backing paper; resin-, emulsion- or synthetic rubber-imprignated paper; resin-admixed paper; paper board; cellulose fiber paper;

(3) polyolefin-, polyvinyl chloride-, polyethylene terephthalate; polystyrene; polymethacrylate; polycarbonate and the like plastic film or sheet.

Use of the synthetic paper belonging to the foregoing category (1) is highly suitable for the purpose of the present invention since the surface thereof generally represents a microvoid layer which provides a low heat conductivity and thus a high heat-insulating peformance. A laminated material representing any combination of the foregoing categories (1), (2) and (3) can be used in the present invention. A representative and recommendable example of such a laminate is that of cellulose fiber paper and synthetic paper or that of cellulose fiber paper and plastic resin film or sheet. Among others, use of the first mentioned kind of laminate will provide an advantage in that the thermal instability such as thermal elongation or shrinkage possessed by the synthetic paper component is compensated for by the cellulose fiber paper, whereby a high thermal sensibility is demonstrated during the printing step due to low thermal conductivity of the synthetic paper component. Further, in the case of the present paper combination, however, a further modified combination of a three-layer laminate: synthetic paper-cellulose fiber paper-synthetic paper may be more advantageously employed for making the frequently appearing lesser by providing a well-balanced structure between both the surfaces of the final laminate.

As the synthetic paper mentioned above, any suitable one usable as a synthetic paper substrate used as a component of the image-transferable sheet layer may be used. As a recommendable example thereof, having a fine porous fine paper structure layer, the synthetic paper called "YUPO", manufactured and sold by Oji Yuka Goseishi Kabushiki Kaisha, Tokyo, may be mentioned. This paper layer having a fine pore structure may be prepared in such a way that a suitable plastic resin material containing a filler of finely divided state is subjected to a mechanical elongation step. When the image-transferable sheet composed of the synthetic paper sheet containing finely divided air as above mentioned is formed with images through a thermal image transfer setp, the concentration of the thus formed images is surprisingly high and no fluctuation of image configuration and concentration is encountered, thanks to the heat insulation effect provided by the very existence of fine air pores, in addition to the improved thermal energy efficiency. Especially, due to the advantageous cushioning effect provided by the air-filled fine pores, the image-receiving layer is supposed to be rather advantageously affected during the image formation step. As an alternative measure, the paper-like layer containing the above-mentioned fine air pores may be, if desired, provided directly with the core material consisting of the cellulose fiber paper or the like.

It is further possible to use plastic film in addition to the cellulose fiber paper in the laminate described above. Still further, a laminate of said cellulose fiber paper and plastic film composed together can be used.

As the method for co-sticking of synthetic paper and cellulose fiber paper, use of a known adhesive agent is naturally adopted, as an example. Or alternatively, the extrusion-laminating, heat-adhesion, or the like process may be relied upon, as the case may be. On the other hand, as the sticking-process between the synthetic paper and the plastic film, the lamination process to be carried out simultaneously with the formation of the film may be adopted. Calendering or the like method may be utilized for the same purpose. Selection of any suitable one of the several foregoing sticking processes depends upon the kind of material or the like condition of the partner member to be stuck together with the synthetic paper. As for the adhesive agent mentioned above, emulsion adhesive such as ethylene-vinyl acetate copolymer, polyvinyl acetate or the like, aqueous solution type adhesive polyester containing carboxyl radicals; or the like may be mentioned. On the other hand, as the laminating use adhesive, organic solvent solution type one such as polyurethane-, acrylic- or the like, may be mentioned.

The material for the image-reception layer must be suitable for reception of heat-transfer dyestuff, such as sublimative disperse dye from the image transfer sheet and holding and maintaining the thus formed images thereon. From the view point of image-holding and blocking prevention, use of such synthetic resin as having glass transition temperature higher than 40° C. may be advantageous. For example, the synthetic resins set forth in the following items (a) through (e) may be used separately or in combination.

(a) Ester bond-bearing resins:

Polyester resin; polyacrylic ester resin; polycarbonate resin; polyvinyl acetate resin; styrene acrylate resin; vinyltoluene acrylate resin and the like.

(b) Urethane bond-bearing resins:

Polyurethane resin and the like.

(c) Amide-bond carrying resins:

Polyamide resins (nylons).

(d) Urea-bond carrying resins:

Urea resins and the like.

(e) Other high polar-bond carrying substances:

Polycaprolactorc resin; polystyrene resin; polyvinylchloride resin; polyacrylonitrile resin and the like.

The image-reception layer may be prepared from a resin mixture of saturated polyester and vinylchloride-vinyl acetate copolymer. As the saturated polyester, such commercialized products: "Vylon 200"; "Vylon 290"; "Vylon 600"; "Vylon 103" and the like, manufactured and sold by Toyoboseki K.K., Osaka, Japan; "KA-1038C" (manufactured and sold by Arakawa Kagaku K.K., Osaka, Japan; "TP 220"; "TP 235", manufactured and sold by Nippon Gosei K.K., Osaka, Japan; may be advantageously used. The vinyl chloride-vinyl acetate copolymer may have preferably 85–97 wt. % of vinyl chloride component, the polymerization degree being between about 200 and 880. The vinyl chloride-vinyl acetate copolymer may further contain a vinyl alcohol

component, maleic acid component within the purpose of the invention in addition to the main components. According to our experiments, it has been found that these modified copolymers should have rather superior compatibility with polyester resin. The image-reception layer may be, if necessary, composed of polystyrene resin, for example, in this case, styrene monomer, preferably styrene, α-methyl styrene, and vinyl toluene may be used separately or in the form of copolymer or saying in general sense polystyrene resin. Further, such styrene copolymer resin may be used as specifically recommendable material in the above sense, comprising said styrene monomer(s) with other monomer, preferably for example, acrylic acid ester, methacrylic acid ester, acrylonitrile, methacrylonitrile and the acrylic or methacrylic monomer, or further styrene copolymer resin comprising maleic acid anhydride.

It should be noted, however, that among others, polyester series resin is especially superior for the purpose of the present invention.

In any of the foregoing embodiments, however, white pigment is preferably admixed with the material of the image-reception layer for improving the whiteness thereof and further accentuating the sharpness and fineness of the images when transferred thereto and to provide a manually writing-on performance. As the white pigment for this purpose, the following materials may be used separately or in any combination: titanium oxide; zinc oxide; china clay calcium carbonate; finely divided silica and the like.

For further improving the whiteness fluorescent whiteness-increasing agent or -bleaching agent may be added to. Further, for improving the light fastness of transferred images, ultraviolet absorption agent and/or photostabilizing agent may be added to, preferably in a quantity of 0.05 to 10 and 0.5 to 3 weight parts per 100 weight parts of the material resin composing the image-reception layer.

The image-transferable sheet used in the present invention is preferably constituted for improving the separability from the image-transfer sheet in such a way that the surface of the image-reception layer is formed with a partition agent layer, or instead, such agent is admixed to the image-reception layer. As for the partition agent to be used for this purpose, polyethylene wax; Amido Wax, Teflon Powder or the like solid wax; surface active agents such as fluorine-contained agent or phosphoric acid ester series surfactant; silicone oil or the like may be selectively used. Among others, silicone oil may be advantageously utilized.

The silicone oil may be used in oily state, but a hardenable type thereof may be rather advantageous. As the hardenable silicone oil, reaction-hardening one, photo-hardening one, catalytically hardening or the like one may be used selectively according to necessity. However, use of the reaction-hardenable one is most highly recommendable. Silicone oil of this type may be obtained, as example, by reacting amino-modified silicone oil with epoxy-modified silicone oil to obtain a reaction-hardened product. As for the amino-modified silicone oil, "KF-394", "KF-857", "KF-858"; and "X-22-3680"; "X-22-3801C" (manufactured and sold by Shinetsu Kagaku Kogyo K.K., (Tokyo, Japan)) and equivalents thereof may be used. As for the epoxy-modified silicone oil, "KF-100T"; "KF-101"; "KF-60-164"; and "KF-103" (manufactured by Shinetsu, above mentioned) and equivalents thereof may be used. Further, as the catalytically hardenable and photohardenable silicone oils in the above sense, "KS-705F"; "KS-770" of the catalytic hardenable or hardened silicone oils, manufactured by Shinetsu; and "KS-720" and "KS-774" of the photo-hardenable or hardened silicone oils (manufactured equally by Shinetsu) and equivalents thereof may be used. The adding quantity of each of these hardenable or hardened silicone oils may advantageously range from 0.5 to 30 wt. % depending on the material of the resin composing the image-reception layer.

At least a part of the image-reception layer is coated with a solution or dispersion of any of the foregoing partition agents in a suitable solvent and dried and further treated, a suitable parting layer being provided thereon. A-particularly suitable partition agent for the formation of this kind of partition layer is the aforementioned reaction type hardenable one obtainable by reacton of an amine-modified silicone oil with an epoxy-modified one. The thickness of the partition layer is 0.01–5μ, preferably 0.05–2μ.

It should be noted that when silicone oil is admixed during formation of the image-reception layer, the silicone oil will bleed out after coating and the parting agent layer can be formed by the hardening even after such bleeding. In order to improve the parting ability between the image transferable layer and sheet-like substrate, it is possible to provide a parting layer consisting of a heat-hardenable resin, preferably of the melamine series, and having better affinity for the image transferable layer compositions. For the same purpose as above, however, without special provision of the parting layer, a protecting layer consisting of polymethyl methacrylate resin or cellulose acetate propionate can be provided.

For the formation of the image transferable layer, a solution or dispersion of a material composition suitable for the purpose is applied on the sheet-like substrate through conventional coating or printing. As an alternative way, a separate film or sheet for the image transferable layer **302** is formed preparatorily on a provisional carrier sheet or film and then, as a succeeding step, subjected to an image-transfer onto the substrate.

The intermediate layer is made of either a cushioning or a porous material. In some cases, the intermediate layer may additionally function as the adhesive layer.

The cushioning layer is mainly composed of such a resin which has a value of 100%-modulus as defined at JIS-K-6031 (Japanese Industrial Standard) of less than 100 kg/cm^2. If this value should exceed the above prescribed value, the rigidity will become much higher than that recommended for the intermediate layer. When the layer is formed with such disadvantageous material resin, sufficient adhesion between the heat image-transfer sheet and the image-reception layer cannot be maintained during the printing step. The lower limit of the prescribed 100%-modulus is of the order of 0.5 kg/cm^2 in actual practice.

Preferable kinds of resin to be used for the above purpose, may be enlisted as follows:

polyurethane resin; polyester resin; polybutadine resin; polyacrylic acid ester resin; epoxy resin; polyamide resin; rosin-modified phenol resin; terpene phenol resin; ethylene/vinylacetate copolymer resin; and the like.

These resins can be used independently or in combination of two or more kinds. Since these resins are rather viscous and tend to give rise to manufacturing troubles inorganic additives may be admixed, such as, for example, silica; alumina; clay; calcium carbonate; amide series substance such as amide stearate; and/or the like.

The cushioning layer is preferably formed with the use of one or more of the above specified resins, occasionally with the addition of suitable additive(s); solvent or diluent, prepared into a coating agent or printing ink which is then applied on, according to a known coating or printing process and then subjected to drying to provide a coating. The

thickness of the coating should be between 0.5–50 μm, preferably 2–20 μm or so. With a thickness less than 0.5 μm, the coating will not be able to compensate for the surface irregularities on the substrate, thus being ineffective for the desired purpose. On the other hand, when the thickness exceeds the above specified maximum value or more specifically 50 μm, the overall thickness of the image-transferable layer becomes much too large, so that handling troubles may be encountered during wind-up and overlapping procedures, without attaining further effect as desired. In addition, in this case, a loss of production economy will be inevitably introduced.

The thus obtainable improvement of intimate adhesion between the heat-image transfer sheet and the thermally image-transferable sheet by the provision of the above intermediate layer may be conceivably attributed to the lower rigidity of the intermediate layer per se, whereby it is liably to be deformed under the influence of the printing pressure, and further to the generally relatively low glass transition temperature and softening temperature of the aforementioned kinds of resin resulting in further lowering of rigidity and tendency to deform than at room temperatures upon reception of heat energy during the image printing step.

The porous layer may be formed generally in the following four ways: 1) through 4).

1) Emulsion of polyurethane or the like resin, methylmethacrylate-butadiene series synthetic rubber latex is foamed by mechanical agitation, coated, and dried on the sheet substrate into a layer.

2) The synthetic resin emulsion or synthetic rubber latex is admixed with a foaming agent and the liquid mixture is coated and dried on the substrate into a layer.

3) Vinyl chloride-plastisol, polyurethane or the like synthetic resin or styrene-butadiene series or the like synthetic rubber is added with a foaming agent and the liquid mixture is coated on the substrate and subjected to heating to provide a foamed layer formed thereon.

4) A thermoplastic resin or synthetic rubber is dissolved in an organic solvent to provide a solution, and a non-solvent (including that containing aqueous main component), and the latter solution are mixed together to provide a liquid mixture, said nonsolvent being less volatile than the organic solvent and having a considerable mutual solubility with the solvent, and showing, however, non-solubility with the thermoplastic resin or synthetic rubber. The thus prepared liquid mixture is then coated on the sheet-like substrate and dried, to provide a porous membrane upon micro-coagulation of the constituents. The resulting microporous layer can be utilized for the above purpose.

It should be noted that the layers produced by any of the foregoing three processes 1) to 3) have rather large foams contained therein, and thus when the foaming solution for the image-transferable layer is applied thereon and dried, the latter may exhibit excessively coarse surface conditions. Therefore., in order to obtain an optimumly image-transferable smooth surface capable of providing transferred images of high uniformity, provision of the micro-porous layer prepared by the process as set forth in the foregoing item 4) is highly recommendable.

As the thermoplastic resin suitable for the formation of the above porous layer, saturated polyester; polyurethane; vinylchloride-vinylacetate copolymer; cellulose acet0propionate and the like can be used. Further, as the synthetic rubber usable for the same purpose, those of styrene-butadiene series, isoprene series, urethane and the like series may be used. Still further, as the organic solvent and non-solvent liquid used for the formation of the microporous layer, various known substances may be used. Generally speaking, however, methyl ethyl ketone; alcohol and the like are representatively used. On the other hand, as the non-solvent, water is mostly used.

The thickness of the porous layer usable in the present invention is preferably greater than 3 μm, especially preferably in the range of 5 to 20 μm. With the use of a porous layer having a thickness of less than 3 μm, the desired cushioning and heat-insulating effects cannot be attained.

As was referred to hereinbefore in the description stage for the formation of the image-transferable layer, the intermediate layer may act simultaneously as the sticking layer in some cases.

This kind of intermediate layer(s) may be provided on one or both of the surfaces of the thermally image-transferable sheet.

In practice, however, an electrostatic charge may accumulate in the material of the thermally image-transferable sheet during its processing step or during running through the printer. As a countermeasure, a proper antistatic agent may be applied on one surface of the image-transferable-layer or on the bottom surface of the thermally image-transferable sheet or it can be included in the material of the image-transferable layer. As the antistatic agent in this sense, a surfactant such as a cation-exchange agent (for example, a quaternary ammonium salt, polyamide derivatives and the like) may be advantageously used. Further, an anion exchange type surfactant, such as alkyl sulfonate may be used. Otherwise, amphoteric ion type surfactants or even, non-ionic surfactants may be used for the same purpose.

On the other hand, the antistatic agents may be coated on the surface of image-reception layer by gravure-coating, bar-coating or the like process or alternatively, these agents may be kneaded with the material resin and then subjected to transfer towards the surface during the coating formation and drying step for preparing and providing the image-transferable layer. As the antistatic agents to be admixed with the image-transferable layer material resin, cation-type acrylic polymers may be employed.

The protecting layer is peeled off together with the image-transferred layer, from the sheet-like substrate, and then stuck, in inverted reversed state, onto any desired decorative object, the protecting layer thereby being positioned at the uppermost position, for improving the anti-wearing-light-proofing and anti-chemical performances of the image-bearing layer. As the material adapted for the formation of the protecting layer, for example, alkyd resin; phenol-modified alkyd resin; aminoalkyd resin; phenol resin; urea resin, melamine resin; silicone resin, thermoserring acryl resin, thermosetting polyurethane resin and the like thermosetting resin or normal temperature setting resin; further, ultraviolet hardenable resin; electron ray hardenable and the like activating energy flux hardenable resins or thermoplastic resins such as polyester-; polyurethane-; polyvinyl acetate resin; vinyl chloride-vinyl acetate copolymer resin; polyolefin resin, acryl resin and the like, can be used.

Preparation and use of a protecting layer comprising one or more of the above-mentioned resins are made in such a way that the material resin is dissolved in a properly selected solvent according to the necessity, so as to provide a coating liquid or ink, as the case may be, which is provided between the parting layer and the image transferable layer. The thickness thereof is generally 0.5 to 20 μm. It is also possible to form the protecting layer with the use of a resin film which consists of polyester-; acryl-; acrylpolyol-; polyvinyl chloride-; olefin resin or the like resin. It is further possible

advantageously to admix an ultraviolet ray absorbing agent and/or photostabilizer to the material of the protecting layer.

The protecting layers prepared and formed in the foregoing way are thus not made integral with the sheet-like substrate or parting layer and, therefore, the peel-off operation of the sheet-like substrate upon execution of the image transfer is very simple and easy.

It is further recommendable, if necessary, to provide a slip-promoting layer on the bottom surface of the sheet-like substrate, which surface is naturally the one opposite to the image-transferable layer side, so as to properly adjust the friction between the image-transferable sheet and feed roll paper or carrier belt acting during passage through the printer and to improve the running performance of the thermally image-transferable sheet in the printer.

The slip-promoting layer can be formed by adding an organic powder such as polyethylene wax fluorine resin powder or an inorganic powder such as talc, according to necessity, to a resin such as polymethyl methacrylate resin; vinyl chloride-vinylacetate copolymer; vinyl chloride copolymer; cellulose acetate butyrate; cellulose acetate propionate; styrene-acryl series or the like resin and kneading the resulting mixture to prepare a composition, applying this composition as a coating on the sheet substrate either directly or after application of a suitable primer treatment, and drying the coating thus applied. A suitable quantity of the slip-promoting layer is 0.5 to 5 g/m^2 after drying.

In the embodiments-shown in FIGS. **22**, **23**, and **24**, as the adhesive agent to be used in the slightly weak or weak adhesive layer, it should be noted that those conventionally used adhesives for adhesive tapes and seals can all be used. Preferred examples are polyisoprene rubber; polyisobutyl rubber; styrene butadiene rubber; butadiene acrylonitrile rubber and the like rubber-series resins; (meth)acrylic acid ester-series resins; polyvinyl ether-series resins; polyvinyl acetate-series resins; vinylchloride-acetate copolymer series resins; polystyrene-series resins; polyester-series resins; polyamide-series resins; polychlorinated olefin-series resins; and polyvinyl butyrol-series resins. To the suitably selected adherent may be added a proper quantity of a stickness improver, such as rosin; dammar; polymerized rosin; partially hydrogenated rosin; ester rosin; polyterpene-series resins, terpene-modified substances; petroleum-originated resins; cyclopentadiene series resins; phenol resins; styrene resins; xylene resins; and coumarone-indene resin. Further, when necessary, to the mixture may be added a softening agent, filler; antiaging substance or the like conventional agent(s). As the material for the formation of slightly or weak-adherent layer said above, emulsion type adhesive, preferably of acryl acid ester series can be used. As for the parting function after a long time of preservation, emulsion type adhesives are highly recommendable. These adhesive agents are easily procurable from market.

When necessary, these adhesives are added with proper organic solvent(s) for the adjustment of the viscosity, and then applied by roll coating, die-coating, knife coating, gravure coating or the like conventional technique on the surface of the sheet-like substrate, image-reception layer or protecting layer, so as to provide an adhesive agent layer. The thus formed adhesive layer is preferably of a thickness of 1–50 μm, although this is not limitative.

Formation of Images

In the following, the decorating process according to this invention will be set forth in detail. Utilization of the image-transferable sheet according to this invention constitutes an important main feature thereof.

In FIGS. **20** and **21**, basic practising processes will be described first.

The embodiment shown in FIG. **20** is a result of the use of the transferable sheet shown in FIG. **13**. First, a known transfer sheet **320** is applied onto the image-transferable sheet **310** in an overlapped manner such that the dye-carrying layer **321** is kept in opposition to the image-reception layer **302** of image-transfer sheet **320**, and heat energy is applied, as schematically shown by a plurality of arrows, in accordance with image signals fed at a thermal head, not. shown, from the side of image-transferable sheet **310**, or preferably, from the side of the image-transfer sheet **320**, thereby forming the desired images as at **307** in the image-reception layer **302**. Next, the image-reception layer **302** formed therein with the desired images **307** is peeled off from sheet-like substrate **301** and stuck onto the decorative product **306**. Or alternatively, both the sheets **302**; **301** are stuck onto the product **306** without preparatory peeling-off. In the latter case, the peel-off step may be executed after execution of the stickingly attaching step. In the above former case, and in such a case where an adhesive agent layer **306** has preparatorily provided between image-reception layer **302** and sheet-like substrate **301** as was set forth hereinbefore, the sticking attachment is carried into effect in such a way that the adhesive layer **306** iS kept in opposing contact with the product **330**, and then the sticking operation is brought about by application of heat and pressure or light and pressure, depending upon the nature and structure of the layer **306**. In this way, the decoration according to the present invention is completed as a preferred one mode thereof.

On the other hand, if there is no preparatory provision of the adhesive layer, either the surface of product **330** or of the peeled-off image reception layer **302**, may be coated with the adhesive agent, and the latter layer **302** per se or otherwise in the up-and-down reversed state may be stickingly attached onto the product **330** (refer to FIG. **21**).

Since the image-reception layer **302** is composed generally of such thermoplastic resin material as is liable to be colored with thermally transferable dyestuff, it can be thermally and fusingly attached to plastic resin-made formlings, clothes or metals even with provision of an adhesive layer, if necessary.

In this case, the image-bearing layer **302**, the image thereof having been formed in the aforementioned way, is stuck on, through the intermediary of the adhesive agent layer **306** as shown in FIG. **25**, while retaining the sheet-like substrate **301** on the surface of the image-reception layer **302**.

A modification of the last-mentioned mode is shown in FIG. **26**. In this case, sheet-like substrate **301** is formed on the surface of the product **330** and the image-reception layer **302** is formed as the outermost layer. Further, in this case, sheet-like substrate **301** and product **330** may be stuck together, and, through the intermediary of a suitable adhesive layer, sticking layer or heat-sealable sheet or the like.

As for the transparent film usable as the said sheet-like substrate, it must be transparent to such a degree as not to conceal the images formed in the image-reception layer, and, in addition, it must have superior surface properties such as, for instance, antiwearing characteristics. As an example, polyolefine; polyvinyl chloride; polyethylene terephthalate; polystyrene; polymethacrylate; polycarbonate and the like plastic resin-made films may be used upon variously surface conditioning. If these transparent films should be too thick, the images will be raised, and the unitary feelings may be

lost when these are stuck on respective products to be decorated. Therefore, the film thickness is preferably of the order of 0.5 to 50 μm.

In the case of a further embodiment of the present invention, the image reception layer of image transferable sheet which has been, however, formed with necessary images is subjected to image transfer treatment onto an intermediate image transferable substrate, the latter is then subjected to an image-retransfer with the images, and the thus retransferred images are again transferred onto the surface of the product to be decorated. In the following, this image transfer mode will be set forth in detail.

Embodiments shown in FIGS. **27**, **28** and **29** represent such a process for execution of image transfer operation as by the intermediary of intermediate image transfer sheet **510**. First, as shown in FIG. **27**, a thermally image-transfer sheet **320** having a thermal transferable dyestuff layer **321** is overlapped to image-transfer sheet **510** which is, at this stage, not formed with images **307** and thus consists of a thermal image-transferable sheet, in such a way that the dyestuff layer **321** or more specifically the parting layer **322** is in opposition to the image-reception layer **302** of the foregoing sheet **510**. In such a case, however, that heat energy is supplied in accordance with image-forming signals delivered from the thermal head, not shown, and, indeed, preferably from the side of the sheet **320** as hinted by a plurality of double-line arrows for thermal formation of desired images (positive images) as at **307** in the image-reception layer **302**, it is highly recommendable to provide an adhesive layer **402** between the layer **302** and sheet-like substrate **301**.

Then, with the use of the image transfer sheet **510** formed with positive images **307**, the images of layer **302** are transferred, as shown in FIG. **28**, to a separate intermediate substrate **501**, which is, however, fitted with a protecting film layer **305**, thus, the transfer being carried out, in fact, onto the latter, and indeed, with the correspondingly inverted images, attached with same reference numeral only for convenience, from the foregoing layer **302**. In this case, it is preferable to subject the adhesive layer **402** of the image-transfer sheet **510** to the image-transfer operation, together with the image-reception layer **302**. Further, as for the intermediate image-transfer substrate **501**, it is recommendable to provide the protecting film layer **305** through the intermediary of a weak-adhesive layer **402'** as shown. The thus provided intermediate image-transfer sheet **610** represents generally the image-transferable sheet.

FIG. **29** illustrates the step for transfer of the image-reception layer **302** now carrying positive images **307** onto the object **330** to be decorated and under utilization of the previously described intermediate image-transfer sheet **610**.

More specifically, the intermediate image-transfer sheet **610** is overlapped onto the said object **330** in such a way that the adhesive layer **402** of the former in opposition to the surface of the object **330** and pressurized together. Then, the intermediate transfer substrate **501** together with the weak-adhesive layer **402'** is peeled off from the remainder of the thus-pressurized assembly, the now image-carrying layer **302** formed with positive images **307** covered with protecting the film layer **305** thereby remaining in the transferred state on the product **330**. In the case of no provision of the protecting film layer **305** on the intermediate image-transferable sheet **610**, the layer **302** remains in an exposed state. Therefore, an overcoat layer, if necessary, can be provided on the now image-carrying layer **302**.

The previously set forth process carried out by the use of said intermediate image-transferable sheet can be executed by means of the apparatus which is shown schematically in FIG. **1E**.

In this apparatus, more specifically, there is provided a carrier system comprising a series of rolls **411**, **412**, **413** and **414** for conveying the intermediate transfer substrate (sheet), arranged in addition to the apparatus shown in FIG. **1B**. More specifically, the substrate is drawn out from feed roll **414**, conveyed through successive rolls **413**; **412** and retransferred onto one of the products **200**. Other operations are same as set forth hereinbefore with reference to FIG. **1B**. Further, in the case of FIG. **1E**, the final product may take the form of a roll-like substrate which is subjected to an image transfer operation through the intermediate substrate, by transferring its image-carrying, image-transferable layer, for later being punched out properly. Alternatively, under occasion, it may be subjected to half-cut operations downstream of roll **122**.

As was set forth herein above, the preferable method for the formation of desired images on the image-transferable sheet is carried out by use of a heat image-transfer sheet comprising a sheet-like substrate having a layer including a thermally transferable dye (evaporative dye). The heat image-transfer sheet which can be utilized in this method is known per se. And almost every kind of these known sheets can be useful in the practice of the present invention. It should be noted that by employing the foregoing image-transfer method, mono-color or full-color images can be easily formed as occasion may desire.

It should be further noted that details of such heat image-transferable sheet can be easily understood with reference to our U.S. patent application Ser. No. 833,039. As for the heat image-transferable sheet usable in the present invention, the coating layer of the sheet (coating film) may include a parting agent. By adopting this measure, the image-reception layer of the image-transferable sheet or the surface thereof, to be subjected to sublimative image-transfer, must not have a separate parting agent layer, the adhesive ability between the image-reception and the surface of object to be decorated can be still further improved upon execution of the sublimative image-transfer and image-formation at the image-reception layer and adherent attachment thereof to the object. As the parting agent to be included in the coating layer of the thermally image-transferable sheet (coating film), silicone oil; silicone resin; phosphoric ester or the like surfactant; and/or chelate- and the like agents, may be selectively utilized. These agents, upon mixed, will ooze out from inside to the outer surface of the coating layer, resulting in providing a better parting quality. However, it is preferable to properly select the kind and nature of the parting agent to be used for this purpose, being such that the agent cannot transfer to the image-reception layer of the image-transferable sheet during the sublimating image-transfer stage. The adding quantity of the parting agent may preferably be 3–25 wt. parts based upon the total amount of resin and coating composing the coating layer taken as 100 wt. %.

In practice, any kind of conventionally known heat transfer sheets is overlapped on the thermally image-transfer sheet employed in the present invention, and then necessary heat energy of 5–100 mJ/mm^2 is applied by use of a conventionally known heat transfer unit, for instance, "Video-printer: VY-100" manufactured and sold by Hitachi Seisakusho, Tokyo, or its equivalent machine, for the formation of necessary images on the image-reception layer of the image-transfer sheet as set forth hereinbefore.

Peel-off operation for removal of the image-reception layer formed with necessary images in the above manner may be carried into effect in a very easy manner, so as to provide it in a thin film carrying the images thereon. In case where the thus-peeled off film carrying the images is pro-

vided beforehand with an adhesive layer, composed of a suitable adhesive agent as was referred to, at the opposite surface to the image-carrying one, the peeled-off film can be, as it is, stuck on the object to be decorated. It is natural that this adhesive attachment procedure can be performed only partially and locally on selected part of the whole surface of the object, or totally thereon, as the case may be. On the contrary, if the peel-off film is provided beforehand with no adhesive layer, the film can be subjected occasionally to a heat fusion onto the surface of the object, if the physical properties or material kind thereof is suitable for such kind of thermal fusion. Or alternatively, a properly selected adhesive agent can be preparatorily applied onto the surface of the film or object, and then, the stick-on job can be executed.

If the image-reception layer is provided preparatorily with a parting layer thereon, as was referred to, the latter layer can be removed off partially or wholly, by grinding or rubbing operation after execution of the sublimating image-transfer job, for avoiding otherwise occurrence of ill effect by the very presence of parting layer in the adhesive attachment of the image-carrying layer film onto the decorative object.

In case of that where the image-transferable sheet is provided with a protecting layer and the latter is composed of a plastic resin film, this film may preferably be cut into pieces or subjected to punch-cuttings.

FIG. **32** illustrates successive die-cutting steps in sectional views, serving for the above purpose. In this case, as shown in FIG. **32** at (a), only image-reception layer **305** of the image-transferable sheet **310**, which has been image-formed through the way of the foregoing image-transfer step, are die-cut by operation of a cutter **801**. Next, as shown in FIG. **32** at (b), a pair of hot stamps **132'**; **133'** are used to execute a pressurizing job under heat from opposite sides, thereby the decorative product **330** being processed into a final product provided tightly with an image-reception layer and a protecting layer, as shown in FIG. **32** at (c).

Further, when occasion desires, the image-carrying film is reversed up-and-down in position after execution of the peel-off job, and, the film is stuck onto the product to be decorated in such a state that the image-carrying surface of the film is kept in direct opposition to the product's decorating surface. In this case, however, it would be rather preferable that in advance of preparatory peel-off of the image-reception layer, the image-carrying transferable sheet is stuck onto the surface of the product to be decorated, and indeed, preferably with use of an adhesive agent, in such a way that the image-carrying layer is kept in direct opposition to the product surface and finally, the sheet-like substrate is peeled off, so as to leave the image-carrying surface on the product's surface.

As in the foregoing, when the images are once reversed and then stuck onto the object to be decorated, the forming images are preferable to reverse in mode (mirror-like relationship) the original to those of reversed mode.

It is further possible that the transfer or sticking-on of the image-carrying layer is carried out through the intermediary of a separate fusing sheet.

In FIG. **30**, use of such fusing sheet **701** for reimage-transfer operation of image-carrying layer **2** already formed with necessary images **307**, however, of reversed mode, and onto the surface of a product.

More specifically, the image-transferable sheet **310** is overlapped onto the product **330** to be decorated in such a way that the image-reception layer **302** carrying the necessary images **307** is kept in opposition to the surface of the product, and indeed, through the intermediary of a fusing seat **701** and then these three components are pressurized together. Further, sheet-like substrate **301**, together with parting layer **303'**, is peeled off, thereby the image-reception layer **302**, now having positive images **307** formed thereon, and protecting the latter, being transferred onto the product **330**. It will be seen in this case, that there is no need for this transfer job, to provide in advance on adhesive layer on the surface of image-reception layer **302** and/or on the surface of the product **330**, and further that a direct heat fusion onto the surface of the product **330** which may be composed of plastic resin, textile fabric, metal or the like common material, however, through the intermediary of a heat-fusible or heat-sealable sheet.

In case where the protecting layer **305** is of plastic resin, similar composing technique as mentioned above may be employed by substituting a weak-sticking layer **402'** for parting layer **303'**.

As the heat-fusible or heat-sealable sheet as at **701** employable in the present invention, it may be composed of one or other material capable of adhering under heat, pressure or both, especially suitable one of those which become soft to be adhesive upon heating. These heat adhering materials in the form of sheets will be, upon softening, charge the pores, meshes or stitches of the product material composed preferably of textiles, woven or non-woven; knits, rough-surface papers or meshed materials, thereby the surface of the product becoming highly smooth for well receiving the image-reception layer **302** for desired image-retransfer with trouble, which effect is superior in the art.

On the contrary, when such heat-fusible or heat adhesive sheet materials which may be called "heat bond sheets" as at **701** are not utilized, it is highly difficult to realize the image-retransfer operation onto certain kind of objects such as rough-surfaced or rough-meshed fabric or the like. Even if the retransfer job could be executed, the obtained images may be blurred and the adhesive may be insufficient, on account of the very thin thickness of the image-reception layer **302**, thus giving rise to technical and commercial troubles.

As for the heat fusible sheet **701** to be used in the foregoing manner, ethylene/vinyl acetate copolymer, nylon copolymer; epoxy/phenol copolymer; epoxy/vinyl copolymer; acrylic resin; polyester resin; or polyolefin resin and the like thermoplastic resins (heat sensible adhesive agents) which are formed into sheets or films may be used. These materials must be softened at 100°–250° C. or so to represent viscous adhesive characteristics. These materials are, when used, capable of being stuck to both the image-transferred product **330** and the image-carrying layer **302**.

These heat bond sheets **701** have generally thickness of 1–200 μm. When the surface of the product **330** to be decorated is relatively smooth, the sheet selected out may be of relatively thin thickness, while, on the contrary, when the surface of the decorative product **330** is relatively rough, as in the case of textile fabrics, unwoven fabrics, meshed fabrics or the like, use of thicker heat bond sheets is rather recommendable.

As set forth above, the use of heat bond sheets is highly recommendable in the decorative image-transfer onto rough surface products, such as those of rough fabrics, woven or non-woven, knitted clothes, meshed one or the like, thereby a better quality image-transfer being executed, in spite of the meshed or highly undulating surface conditions of the objects to be decorated.

Further in the present invention, during the adhering attachment of the image-reception layer already formed with

necessary images onto the object or product, an additional processing step is preferably introduced for prevention of occasional interference in the foregoing adhering attachment step, by rubbing-off or grinding-off part or whole of the parting layer, provided on the surface of the now image-carrying layer, upon completion of the sublimating image-transfer step.

Still further, in such a case that the image-transferable sheet is fitted with a protecting layer which is composed of a plastic resin film, the latter must in advance be subjected to punching or the like cutting step for cutting the film into desirously sized pieces.

FIG. **32** represents such a die-cut (half-cut) process in sectional schema. In this case, at first, as shown at (a) of FIG. **32**, the image-reception layer **302** of an image-transferable sheet **310**, now formed with necessary images through a sublimative image-transfer step, and the protecting layer **305**, are subjected to a die-cutting process by means of a cutter **801** to shape a desired shape. And then, as shown at (b) in FIG. **32**, the cut-out piece is subjected to a pressurizing step under heat by means of a pair of hot stamps **132'**; **133'** to provide a final decorative object, as shown at (c) in FIG. **32**, which is composed of a product **330** to be decorated, however, now attached integrally and jointly with image-carrying layer **302** and protecting layer **305**.

Applied Products

The products applicable with the inventive process for decorating purposes are not limited to occasionally employed kind, shape and nature of the materials. Preferred examples of the usable product may be: cartons; vessels or packages; bags; cassette cases; cassette halves; floppy cases; paper packages and envelopes; stock certificates; personal and bank cheques; bills; bonds; certificates; notifications; car tickets; travel tickets; betting tickets; tax stamps; postage stamps; entrance tickets, money-exchangeable papers and documents; cashcards, credit cards, orange cards, telephone cards; member's cards; greeting cards; postcards, name cards; driver's certificates; IC-cards; optical cards and the like various cards; accounting cards and documents-envelopes; tags; OHP-sheets; slide films; bookmark slips; calendars; posters; pamphlets; menus; passports; POP-goods and articles; coasters; displays; nameplates; keyboards; cosmetics; personal ornaments (watches; cigarette lighters); stationaries; construction materials; radio-receiving sets; T.V.-sets; speakers; table calculators; automotive gauge boards; emblems; keys; clothes; wearing commodities; footwears; appliances; OA-instruments; sample books; tickets in general; albums; computer graphic and/or medicare graphic image printouts; and the like, where the material kinds, sizes and configurations are regardless for purposes of the invention.

The aforementioned goods and instruments may have printed or the like other images in advance of execution of the process of the invention. Or conversely, the goods and instruments can be formed with necessary images in accordance with the present process, and then, additional images may be formed in conventional printing or the like process.

As an example, when the invention is applied to a card style intermediate product, it is possible to combine image-forming means of the present invention with conventional recording means. As the latter, magnetic recording by use of a magnetic material layer; optical recording by use of an optical recording layer; preferably composed of a membrane having low melting point metal; application of hologram; embossing formation of characters and numerals; application of personal face photograph; engraved formation of personal face or the like; human signatures; recorded information with use of IC-memory; mechanical printing; formation of bar codes; formation of characters and patterns by use of printer, typewriter or pen plotter may be used independently or in any combination.

In the following, the present invention will be more fully described by way of preferred embodiments. In these embodiments, parts or % will be given by weight, not otherwise specifically referred to.

As the image transfer film (dye film) used for sublimating transfer onto the image-transferable sheets, a polyester film, 6 μm thick, subjected to a heat-resisting treatment on one surface thereof only, and bearing color ink composition areas of yellow, magenta and cyan, respectively, was used. The coating rate of the color ink composition was 1.0 g/m^2 when measuring at the dry state.

These color ink compositions were as follows.

Yellow Ink Composition

polyvinyl butyral resin ("Eslek-BX-1", manufactured and sold by Sekisui Kagaku K.K., Tokyo)	4.80 parts
dispersion dye ("PTY-52, Disperse Yellow-141", manufactured and sold by Mitsubishi Kasei Kogyo Co., Ltd., Tokyo)	5.50 parts;
methyl ethyl ketone	55.00 parts;
toluene	34.70 parts;
(parting agent	1.03 parts)

Magenta Ink Composition

polyvinyl butyral resin (same as above in the case of yellow color ink)	3.92 parts;
dispersion dye ("MS Red G, disperse red 60", manufactured and sold by Mitsui Toatsu K.K.)	2.60 parts;
dispersion dye ("Macrolex Red Violet R, Disperse Violet 26", manufactured and sold by Beyer A.G., West Germany)	1.40 parts;
methyl ethyl ketone	43.34 parts;
toluene	43.34 parts;
(parting agent	0.40 part)

Cyan color Ink Composition

polyvinyl butyral resin (same as in said yellow color ink composition)	3.92 parts;
dispersion dye ("Kayaset Blue-714, solvent blue-63", manufactured and sold by Nippon Kayaku K.K., Tokyo)	5.50 parts;
methyl ethyl ketone	68.18 parts;
(parting agent	0.94 parts)

Each of the foregoing color ink compositions was prepared wihh and without addition of parting agent.

As the parting agent occasionally used in each of the foregoing color ink compositions, any of the following specific agents may be employed:

(a) silicone alkyd-parting agent, "KR-5206", manufactured and sold by Shinetsu Kagaku Kogyo K.K., Tokyo;

(b) graft polymer of. silicone and acryl, "GS-30", manufactured and sold by Toa Gosei Kagaku K.K.;

(c) silicone graft polymer, "US-3000", manufactured and sold by the above company;

(d) phosphoric acid ester, natrium salt, "RE-410", manufactured and sold by Toho Kagaku Kogyo K.K.;

(e) natural phosphoric acid ester, "Lecytin", manufactured and sold by Ajinomoto Co., Ltd., Tokyo;

(f) silicone oil, "KF 412", manufactured and sold by Shinetsu Kagaku Kogyo K.K., Tokyo;

(g) aluminum chelate agent, "ALM", manufactured and sold by Ajinomoto; and

(h) titanium chelate agent, "TTS", manufactured and sold by Nippon Soda K.K., Tokyo.

EXAMPLE A-1

As the substrate, a laminate of a synthetic paper, "Yupo FPG 150 μm thick" manufactured and sold by Oji Yuka Co., Ltd., Tokyo, and a polyester film, 6 μm thick, was prepared and coated on the polyester film side surface by a wire bar with a mixture of pull-separating varnish, "Hakurinisu 45" manufactured and sold by Showa Ink Co., Ltd., Tokyo, with an ultra-violet absorbing agent, or more specifically, 2.5-bis (5'-tert-butylbenzoxazolyl (2))-thiofin, 0.5% based on the resin content of the varnish, and dried up to provide a protecting layer of 1 g/m^2, when weighed upon drying.

Then, on the surface of the foregoing protecting layer, an ink composition adapted for the formation of an image-reception layer was coatingly applied and dried up. The applied quantity amounted to 7 g/m^2 when measured upon drying.

Ink composition for the Formation of Image-Reception Layer

polyester resin (manufactured and sold by Toyobo K.K.)	100 parts;
amino-modified silicone ("KF-393", manufactured and sold by Shinetsu Kagaku Kogyo K.K., Tokyo)	5 parts;
epoxy-modified silicone ("X-22-343", manufactured and sold by Shinetsu Kagaku Kogyo)	5 parts;
solvent (methyl ethyl ketone/toluene/ cyclohexanon 4/2/2)	900 parts.

The ink composition was coated, dried up and cured one day under normal temperature. Then, the layer was kept at 100° C. for 30 minutes under heat, for letting the silicone to bleed up to the surface, to provide an image-transferable layer formed on its surface with a hardened silicone layer.

On the thus-provided image-reception layer, a sublimating image-transfer film was overlapped which is composed of cyan color sublimative dye (molecular weight being higher than 250) carried by a proper binder resin and thermal energy is fed thereon from a thermal head adapted for receiving electric signals representing cyan color components. obtained by a color analysis of a portrait photograph, as an example, for providing portrait images corresponding thereto. Then, two successive sublimative image-transfer jobs were executed with use of respective sublimating image-transfer films carrying sublimative magenta and yellow color dyes, each molecular weight being higher than 250, and substantially in the manner set forth above. In this way, after all, an overall combined display image composed of a full color portrait, in combination with several characters and graphics, was provided.

The image-reception layer of the sheet, now carrying these display images, was overlapped on the card substrate composed of a polyester resin sheet, 100 μm thick, which had been primed to white-opaque state, and pressurized together at 160° C. by means of heated pressure rolls. Then, the polyester film was peeled off at the interface with the protecting layer, thereby providing a final product card transferred with image-reception layer now carrying the desired image display.

It was found that the overall surface of the product card was generally smooth and showing no raised feeling of the thus-formed and displaying images. Even upon an accelerated testing of the product card for three months held in an atmosphere of 40° C., the images showed no blurtings as well as no interlayer separation. Further, according to an accelerated light-proof test carried out as prescribed in JIS-Standard with use of a carbon arc lamp, the results showed to be classified to JIS-4 or -5 corresponding to an acceptable superior performance. Additionally, a surface scratch test and the like showed also superior durability.

EXAMPLE A-2

The foregoing image-transferable sheet, now image-carrying, as processed in Example A-1, is then subjected to a peel-off operation for separating the image-carrying layer from the sheet. Then, an adhesive agent of polyester series was coated on the exposed surface of the peeled-off film, and stuck under pressure on a curved surface part of a telephone set. The images could follow up to the stuck curvature into a unitary solid mass, and indeed, without inviting any stuck-on feeling, contrary to the case when a sticky loose-leaf stamp should have been stuck on. In this way, miracle viewing feelings as obtainable with direct-printing operation only, were created and maintained.

EXAMPLE A-3

A white polyester film, baked on one surface thereof with melamine coating, "E 20", 100 μm thick, manufactured and sold by Toray Co., Ltd. Tokyo, is formed on the opposite surface with a slipping layer, same as in the following Example C-2, through application of polyurethane primer. And an identification mark was provided thereon through the way of regular printing technique. On the melamine resin-baked surface of the white polyester resin film, a layer of peeling varnish (of polymethyl methacrylate-series), manufactured and sold by Showa Inku. Co., Ltd., Tokyo) was applied in dry quantity of 2 g/m^2 and dried up to provide a definite layer.

On the thus-formed protecting layer, the following image-reception layer-forming composition was coated and dried up, so as to form an image-heat transferable sheet. The coated composition was in quantity of 6 g/m^2 by dry weight.

Image-Reception Layer-Forming Composition

polyester resin ("Vylon 600", Tg: 47° C., manufactured and sold by Toyobo, Osaka)	80 parts;
polyester resin ("Vylon 290", Tg: 77° C., manufactured and sold by Toyobo)	20 parts;
amino-modified silicone ("KF-393", manufactured and sold by Shinetsu Kagaku Kogyo)	7 parts;
epoxy-modified silicone ("X-22-343", manufactured and sold by Shinetsu Kagaku Kogyo)	7 parts;
solvent (methyl ethyl ketone/toluene = 1/1)	800 parts.

On the image-reception layer of the foregoing heat image-transferable sheet, reversed images composed of full color portrait images together with characters and graphics by use of a thermal head, as in the same way with Example A-1, were formed.

Next, the image-reception layer, however, now carrying the reversed images formed in the foregoing manner was brought into contacting and overlapping State with the image displayable surface on a card style substrate made of white color polyester resin, 125 μm thick, preparatorily primer treated as before, and pressurized together under the action of thermal rolls, and the white polyester film, 100 μm, was peeled off between the protecting layer and the melamine-baked layer, thus providing a final card-style product transferred with the image-reception layer now carrying the necessary images.

The surface of the final card style product represented a smooth and slippery, without fear of interlayer separation and with superior light resistant power.

EXAMPLE A-4

A white foam polyester resin film, "Merinex", 125 μm thick, manufactured and sold by ICI, was provided with an identification mark on one surface thereof, with regular printing technique.

Then, on the opposite surface of the white foam polyester resin film to the foregoing surface formed with the identification mark, a coating of a polyurethane-series primer was applied and dried up. Further, the following protecting layer-forming composition was applied in dry quantity of 3 g/m^2 and dried up to form a protecting layer.

Protecting Layer-Forming Composition

acrylic polyole ("Acrit 6416MA", manufactured and sold by Taisei Kako K.K.)	41 parts;
toluene	36 parts;
methyl ethyl ketone	27 parts;
diisocyanate ("Colonate", manufactured and sold by Nippon Polyurethane K.K.)	6 parts.

On the above protecting layer, the following composition was applied in dry quantity of 3 g/m^2 and dried up, to provide an intermediate layer.

Intermediate Layer-Forming Composition

polyester resin ("Vylon 290", manufactured and sold by Toyo Boseki (Toyobo) K.K., Osaka)	15 parts;
toluene/methyl ethyl ketone = 1/1	85 parts.

On the thus-formed intermediate layer, an image-reception layer which is substantially same with that in the foregoing Example A-3 was provided, so as to form an image-transferable sheet. Then, as same in the foregoing Example A-3, correspondingly inverted images were formed on the image-reception layer and further then, subjected to transfer onto the card substrate by use of thermal rollers. In this way, a final product card, having an image transferable, yet now image-formed layer, was provided.

This card showed favorable results of light-resisting test. Further, it showed a better scratch test result than the foregoing card obtained in Example A-3.

EXAMPLE A-5

Substrate

A white polyester film, "E-20", 100 μm thick, manufactured and sold by Toray Co., Ltd., Tokyo, was used.

Intermediate Layer-Forming Composition

Polyester resin ("Vylon 600", manufactured and sold by Toyo Boseki K.K., Osaka)	15 parts;
toluene/methyl ethyl ketone = 1/1 (dry weight: 5 g/m^2)	85 parts.

Protecting Layer-Forming Composition

"Hakuri-Nisu" (acrylic resin varnish, manufactured and sold by Showa Ink K.K.) (dry weight)	2 g/m^2

Image-Reception Layer-Forming Composition

polyester resin ("Vylon 600", manufactured and sold by Toyo Boseki K.K., Osaka)	10 parts;
polyester resin ("Vylon 200", supplied by Toyo Boseki K.K.)	5 parts;
toluene/methyl ethyl ketone = 1/1	85 parts;
amino-modified silicone ("KF-393", manufactured and sold by Shinetsu Kagaku Kogyo)	1 part;
epoxy-modified silicone ("X-22-343", supplied by Shinetsu Kagaku Kogyo)	1 part.
(coated quantity (dry) 5 g/m^2)	

With use of the foregoing composition and processed in similar way as in Example A-3, to provide a final card product, having an image-reception layer transferred with necessary images.

EXAMPLE A-6

Substrate

White polyester resin film, "E-20", 100 μm thick, manufactured and sold by Toray was coated with polyurethane-series primer and dried up.

Parting Layer-Forming Composition

melamine resin ("Meran 45", manufactured and sold by Hitachi Kasei)	100 parts;
hardener (para-toluenesulfonic acid)	20 parts;
(coating quantity (dry), 2 g/m^2)	

Protecting Layer-Forming Composition

vinylchloride-vinylacetate ("Vinylite VYHH", manufactured and sold by Union Carbide Corp.)	15 parts;
methyl ethyl ketone = 2/1	85 parts;
(coating quantity (dry): 2 g/m^2)	

Intermediate Layer-Forming Composition

polyurethane resin ("Takelac T-3350", manufactured and sold by Takeda Pharmaceutical Company, Osaka, of 23% - concentration)	50 parts;
isopropyl alcohol	15 parts;
toluene	25 parts;
methyl ethyl ketone	10 parts.
(coating quantity (dry) 5 g/m^2)	

Image-Reception Layer Composition

polystyrene resin ("Picolastic D125" (Tg = 53° C., manufactured and sold by Hercules	15 parts;
toluene/methyl ethyl ketone = 1/1	85 parts;
amino-modified silicone ("KF-393", manufactured and sold by Shinetsu Kagaku)	1 part;
epoxy-modified silicone ("X-22-343", manufactured and sold by Shinetsu Kagaku)	1 part.
(coating quantity (dry): 6 g/m^2)	

The foregoing composition was prepared and used as in the same manner with Example A-3, to provide a card with the image-reception layer subjected to image-transfer as desired.

EXAMPLE B-1

As the substrate, a polyester resin film, 6 μm thick, was used and a polyester resin-series primer was coated on one surface thereof and dried up. Further, the following ink composition was applied and dried up. The coating quantity of the composition was set to about 7 g/m^2.

Image-Reception Layer-Forming Composition

polyester resin ("Vylon 200", manufactured and sold by Toyo Boseki K.K.)	100 parts;
amino-modified silicone ("KF-393", manufactured and sold by Shinetsu Kagaku)	5 parts;
epoxy-modified silicone ("X-22-343", manufactured and sold by Shinetsu Kagaku)	5 parts;
solvent (methyl ethyl ketone/toluene/ cyclohexanone = 4/2/2)	900 parts.

The ink composition was coated, dried up and left standing for a full day, and then subjected to heat treatment at 100° C. for 30 minutes, so as to bleed the silicone towards the film surface for providing thereon an acceptable image-reception layer composing the active surface.

Then, a sublimative image-transferable film, composed of a resin binder evenly mixed with a proper amount of sublimative cyanic dye, the molecular weight being higher than 250, was overlapped on the above image-reception layer and applied with heat energy by means of a thermal head supplied with electric signals corresponding to cyanic color components of a portrait full color photograph as determined by regular color analysis, thus providing cyanic color component images.

Next, as for magenta and yellow color components, similar respective processings were executed and finally, full color display portrait images could be formed.

Then, the exposed surface of image-reception layer of the thus-display image-formed film was overlapped on a card substrate composed of a white opaque, hard vinyl chloride resin sheet, 100 μm thick and pretreated with a conventional primer, and then this assembly was subjected to heat and pressure by means of a pair of heated rolls. In this way, a card product stuck with an image-transferable and now carrying layer was provided.

The surface of this card was generally smooth and slippy, the thus-formed images thereon providing no raised feelings. In an accelerated test of these formed images in hot atmosphere of 40° C. for a continuous period of three months, there were no appreciable image blurring and interlayer separation. Upon execution of a light exposure test in accordance with prescribed conditions in JIS with use of an arc lamp, the results were classified to JIS-4 to 5 Classes which means as acceptable and better image quality. Scratch test results were also superior.

EXAMPLE B-3

A sticking layer, 1 μm thick, was formed with a polyamide resin sticking agent on the image-carrying surface of the image-transferable sheet, image-formed in the manner as described in foregoing Example B-1, and the thus provided sheet was stuck on the curved surface of a glass tumbler. These images express practically no stuck-on feelings, rather providing such a touch and viewing feeling as if they had been formed by the regular and direct printing technique.

EXAMPLE C-1

With use of the image-transferable sheet prepared in the foregoing Example A-1, images were formed substantially in accordance with procedures mentioned therein, however, with exception of the formation of reversed images, and then, the image-carrying layer was, without execution of the foregoing peel-off operation, stuck on a portion of curved outer surface of a glass tumbler, whereupon the sheet-like substrate was peeled off, together with the weak-sticking layer. The thus-applied images represent almost no sticking-

on grip and viewing feeling, as if they should have been applied through regular and direct-printing technique.

EXAMPLE C-2

On the surface of a transparent polyester film, 12 μm thick, employed as a protecting film, the following image-reception layer forming composition was applied to form a coated layer (in quantity of 6 g/m^2 when measuring upon drying), dried up and left as it was for full one day. Then, it was held at 100° C. for 30 minutes, to form an image-reception layer. On the surface thereof, a parting surface layer was found to exist, which was composed of a combined hardened product of amino-modified silicone resin and epoxy-modified silicone resin.

Image-Reception Layer-Forming Composition

polyester resin ("Vylon 600", manufactured and sold by Toyo Boseki)	100 parts;
amino-modified silicone resin ("KF-393", manufactured and sold by Shinetsu)	7 parts;
epoxy-modified silicone resin ("X-22-343", manufactured and sold by Shinetsu)	5 parts;
solvent (methyl ethyl ketone/toluene = 1/1)	800 parts.

As the substrate, on the other hand, white polyester resin film, "E-20", 75 μm, manufactured and sold by Toray, was used and coated on one surface thereof with a polyurethane-series primer and dried up. Then, the following composition (in the dried quantity of 1 g/m^2) and dried up, so as to provide a smooth and stick layer.

Smooth Layer-Forming Composition

polymethyl methacrylate resin ("Dianal BR-85", manufactured and sold by Mitsubishi Rayon Co., Ltd., Tokyo)	12 parts;
polyethylene wax ("MF8F", manufactured and sold by Dulacon Co.)	0.5 part;
toluene/methyl ethyl ketone = 1/1	85 parts.

On the opposite surface of the-white-polyester resin sheet to the smoothed surface there, a primer coating of polyurethane-series is applied and dried up, and further coated thereon with the following composition, in quantity of 3 g/m^2, so as to provide a weak-sticky layer.

Weak-Sticky Layer-Forming Composition

weak-sticky adhering agent ("Esdyme AE-206", manufactured and sold by Sekisui Kagaku Kogyo K.K., Tokyo)	50 parts;
water	50 parts.

The weak-sticky adhering layer is brought into contact with the protecting film consisting of a polyester film, 12 μm thick, at the opposite surface to the image-reception layer, and then subjected to heat and pressure, to provide an image-transferable sheet. Upon bringing the image-reception layer of the image-transferable sheet and the dyestuff layer of the heat-image transfer sheet into contact with each other, heat energy was applied from a thermal head, as in the similar manner mentioned in the foregoing Example A-1, and thus heat image-transfer job was executed, so as to provide reversed mode images for expressing a full color portrait as well as characters and graphics.

Next, the image-reception layer formed with the reversed images thereon was overlapped onto the image-displayable surface of a card style substrate, 100 μm thick, made of a white color polyester resin material preparatorily applied with a primer layer by coating a composition, consisting of "Vylon 200", 100 μm thick, manufactured and sold by Toyo Boseki K.K., and then subjected together to heat and pressure by means of at least a heated roll at 160° C. Then, the white polyester film, 75 μm thick, and the weak-sticky adhesive layer were peeled off in unison, for providing a final decorative product card having the image-reception layer transferred with images and carrying dislay images.

This card had a highly smooth surface and was not liable to invite any interlayer separation and showed superior light fastness.

In place of white color polyester-made card substrate preparatorily formed with a primer layer, such a modification was prepared and experimented that the white polyester sheet was formed on its rear surface with a magnetic layer, while, on its front surface there is formed with a write-on layer which consists of proper filler and resin as conventionally, so as to provide a telephone card. This processed telephone card had the write-on layer provided with display images formed by image-transfer.

EXAMPLE C-3

On the surface of a transparent polyester film, 9 μm thick, used as the protecting layer, an intermediate layer was provided by coating. The coated amount was 5 g/m^2 as measured upon being dried up.

Intermediate Layer-Forming Composition

polyurethane resin ("Takelack T-3350", solid content 23%, manufactured and sold by Takeda Pharmaceutical Co., Ltd., Osaka)	50 parts;
isopropyl alcohol	15 parts;
toluene	25 parts;
methyl ethyl ketone	10 parts.

Onto the intermediate layer, the following composition was applied for the formation of an image-reception layer. The coated quantity was 5 g/m^2 as measured upon being dried up.

Image-Reception Layer-Forming Composition

polyester resin ("Vylon 600", manufactured and sold by Toyo Boseki)	10 parts;
polyester resin ("Vylon 200", manufactured and sold by Toyo Boseki)	5 parts;
amino-modified silicone ("KF-393", manufactured and sold by Shinetsu)	1 part;

-continued

epoxy-modified silicone ("X-22-343", manufactured and sold by Shinetsu)	1 part;
solvent (methyl ethyl ketone/toluene = 1/1)	85 parts.

On the other hand, a white color polyester film, which was similar to that employed in the foregoing Example C-2 was formed with a slidingly smooth layer, as well as a weak-sticking adhesive layer, the latter being brought into intimate contact with a transparent polyester film, 9 μm thick, at the opposite surface to the image-reception layer and then, subjected to heat and pressure, for providing a heat image-transferable sheet. As further processed in the similar manner in the foregoing Example C-2, full-color photographic images (reversed images) were thus formed on the image-reception surface. In this way, a final product card, having its image-reception layer transferringly formed with display images.

EXAMPLE C-4

Substrate

White color polyester sheet, "E-20", 100 μm thick, manufactured and sold by Toray was formed thereon with a polyurethane-series primer coating. Then, a weak-sticking layer was applied thereon with use of the following composition.

Weak-Sticking Layer-Forming Composition

weak-sticking agent ("Esdyne AE-206", manufactured and sold by Sekisui Kagaku Kogyo K.K., Tokyo)	50 parts;
water	50 parts.

Protecting Layer-Forming Composition

polyester resin ("Vylon-200", manufactured and sold by Toyo Boseki)	15 parts;
diisocyanate ("Colonate L", manufactured and sold by Nippon Polyurethane Co., Ltd.)	1 part;
toluene/methyl ethyl ketone = 1/1	84 parts.

Image-Reception Layer-Forming Composition

polyester resin ("Vylon 600", manufactured and sold by Toyo Boseki K.K.)	10 parts;
vinyl chloride-vinyl acetate copolymer resin ("Vinylite VAGH" (Tg = 79° C.), manufactured and sold by Union Carbide Corp)	5 parts;
toluene/methyl ethyl ketone = 1/1	85 parts;
amino-modified silicone ("KF-393", manufactured and sold by Shinetsu)	1 part;
epoxy-modified silicone ("X-22-343", manufactured and sold by Shinetsu)	1 part.

With use of the above composition and processed substantially same as in the foregoing Example C-2, a final card product was obtained.

EXAMPLE D-1

An image-transferable sheet was prepared as in the foregoing Example A-1 and thermally image-transferred with reversed mode images of a full color portrait photograph, to provide an intermediate image-transfer medium. The latter is overlapped by its image-reception layer onto the surface of a sheet of rough-textured cotton cloth, however, through the intermediary of an acrylic acid ester-vinyl acetate copolymer sheet, 100 μm thick. Then, the assembly was subjected to heat and pressure. Then, the substrate sheet and weak-sticky adhesive layer, together, were peeled off. The thus transfeted images have sufficient surface smoothness, showing superior surface conditions.

Without use of the bond-attaching sheet in the above process and when similar image-transfer job as above was performed, the resulted images followed the surface undulations appearing disadvantageously on the material product of the rough fabrics and thus were highly uneven, and further, on account of insufficient adhering performance acting between the image-receiving layer and the woven fabrics serving as product material, easy and frequent separations took place therebetween.

EXAMPLE D-2

In the similar way as was disclosed in the foregoing Example D-1, an intermediate image-transfer medium carrying reversed images was prepared and overlapped on a polymethacrylate board preparatorily subjected to surface-toughening operation through a conventional sandblasting step, and through the intermediary of a bond-adhering sheet pressurized together under heat, as was employed in Example D-1. Then, the sheet-like substrate was peeled off, together with the weak adhesive layer. The thus-provided images were highly smooth and even in spite of the highly rough and undulating conditions at the surface to be image-transferred. In addition, the image-carrying surface showed superior results in various resisting tests.

Without use of the foregoing bond-sticking layer, the similarly transferred images showed considerable undulations and distortions. Further, on account of insufficient adhering performance, easy and frequent peel-offs of applied images were feared.

EXAMPLE D-3

On the surface of a polyester resin film, 25 μm thick, the following composition adapted for the formation of bond-sticking layer was coated and dried up, in dried quantity of 5 g/m^2, to provide a film formed thereon a bond sticking sheet.

Bond-Sticking Sheet-Forming Composition

polyester resin ("Vylon 600", manufactured and sold by Toyo Boseki)	15 parts;
methyl ethyl ketone/toluene = 1/1	84 parts.

The bond-sticking sheet surface, together the polyester resin film proper, was brought into contact with the image-representing surface of a white color polyester made-card substrate, 25 μm thick, and then, subjected to heat and pressure by means of at least a heat roll kept at 200° C, arranged to supply heat energy from the side of the polyester resin surface, thereby heat bonding the bond-sticking sheet onto the card surface, whereupon the polyester resin film being forcedly peeled off.

Further then, as in the similar way as adopted in foregoing Examples C-2; A-3; A-4 and C-3, use is made of the image-reception layers representing reversed images thereon, the respective image-reception layers were whereupon brought into contact with the card's bond-sticking surface of the card and subjected to heat and pressure by use of at least a heat roll kept at 200° C. Then, the white color polyester resin substrate was peeled off, together with the weak-sticky adhering layer. In this way, a final product card displaying the portrait photograph was obtained.

EXAMPLE D-4

Substrate

A white color polyester resin sheet, "E-20", 100 μm thick, manufactured and sold by Toray Co. Ltd., was coated with a polyurethane-series primer. On the surface of the thus precoated sheet, the following composition was coated to form a weak-sticking adhesive layer.

Weak-Sticking Adhesive Component

weak-sticking adhesive agent, ("Esdyne AE-206", manufactured and sold by Sekisui Kagaku)	50 parts.

Image-Reception Layer-Forming Composition

polyester resin ("Vylon 200", manufactured and sold by Toyo Boseki)	7.5 parts;
polyester resin ("Vylon 290", manufactured and sold by Toyo Boseki)	7.5 parts;
toluene/methyl ketone = 1/1	85 parts;
amino-modified silicone ("KF-393", manufactured and sold by Shinetsu)	1 part;
epoxy-modified silicone ("X-22-343", manufactured and sold by Shinetsu)	1 part.

The foregoing compositions were prepared. On the other hand, a polyester resin film, 25 μm thick, was coated on one surface thereof with a 15%-solution of polyester resin, "Vylon 200", manufactured and sold by Toyo Boseki, in toluene/methyl ethyl ketone=1/1 and dried up. The coating quantity was adjusted to 5 g/m^2 when measuring in dried state. In this way, a bond-sticking sheet was provided.

Then, the coated surface of the thus prepared bond-sticking sheet was brought into contact with the image display surface of a card style substrate of white color hard vinyl chloride or the like resin material preparatorily subjected to a primer coating treatment in overlapping state and then, the whole assembly was subjected to heat and pressure with use of at least a heated roll to 130° C., thus the bond-sticking layer being stuck on the card surface. Under this condition, the polyester resin film, 25 μm thick, was peeled off.

Then, the image-reception layer, now carrying thereon reversed images, was brought into contact with the bond-sticking sheet and the resulted whole was subjected to heat and pressure by use of at least a heated roll and the white color polyester resin substrate, together with the weak-sticking adhesive layer, was peeled off. In this way, the card, now displaying the portrait images, was provided.

EXAMPLE D-5

Substrate

Same as in the foregoing Example D-4.

Weak-Sticking Adhesive Layer

Same as in the foregoing Example D-4.

Protecting Layer-Forming Composition

polyester resin ("Vylon 200", manufactured and sold by Toyo Boseki)	15 parts;
diisocyanate ("Colonate L", manufactured and sold by Nippon Polyurethane)	1 part;
toluene/methyl ethyl ketone = 1/1	84 parts.

Image-Reception Layer-Forming Composition

polyester resin ("Vylon 600", manufactured and sold by Toyo Boseki)	10 parts;
toluene/methyl ethyl ketone = 1/1	85 parts;
amino-modified silicone ("KF-393", manufactured and sold by Shinetsu)	1 part;
epoxy-modified silicone ("X-22-343", manufactured and sold by Shinetsu)	1 part.

With use of the foregoing materials and compositions, the processings were carried out as in the foregoing Example D-4, to provide a final product card displaying portrait images as was desired.

EXAMPLE D-6

Substrate

Same as in the foregoing Example D-4.

Weak-Sticking Adhesive-Layer

Same as in the foregoing Example D-4.

Image-Reception Layer Forming Composition

polyester resin ("Vylon 600", manufactured and sold by Toyo Boseki)	10 parts;
vinyl chloride-vinyl acetate copolymer resin ("Vinylite VAGH", manufactured and sold by Union Carbide Corp.)	5 parts;
toluene/methyl ethyl ketone = 1/1	85 parts.

The foregoing materials and compositions were prepared and processed in the similar way as in the foregoing Example D-4, to provide a final product card, displaying the desired portrait images as were desired.

EXAMPLE E-1

On a polyethylene terephthalate film, 9 μm thick, a solution of saturated polyester resin, "Vylon 600", manufactured and sold by Toyo Boseki, in toluene/methyl ethyl ketone=1/1, was coated by reliance of the known reverse roll-coating process, and dried up. The coated quantity was 7 g/m^2 when measuring in dry condition. In this way, a weak-sticking adhesive layer could be formed.

On the weak-sticking adhesive layer, the following composition, 3 g/m^2 (dry), was coated by means of an oblique-lined gravure roll for solid and full printing use and in the reverse roll-coating process, and then dried up, to provide an image-reception layer.

Image-Reception Layer-Forming Composition

polyester resin ("Vylon 200", manufactured and sold by Toyo Boseki)	70 parts;
polyester resin, ("Vylon 290", manufactured and sold by Toyo Boseki)	30 parts;
amino-modified silicone ("KF-393", manufactured and sold by Shinetsu)	5 parts;
epoxy-modified silicone ("X-22-343", manufactured and sold by Shinetsu)	5 parts;
methyl ethyl ketone (wt. ratio 1/1)	700 parts.

On the opposite surface to the image-reception layer of the thus-prepared image-transferable sheet, a synthetic paper substrate, "Yupo FPG 110", 110 μm thick, manufactured and sold by Oji Yuka K.K., coated with "Vylon 600" as the adhesive agent in quantity of 10 g/m^2 (dry) was stuck intimately together.

On the other hand, a polyethylene terephthalate film substrate, 6 μm thick, preparatorily provided on one surface thereof with a heat-resisting layer was used and the following composition was applied on the opposite surface of the substrate with use of a wire bar and dried up, in the quantity of 1 g/m^2 (dry), so as to provide a dyestuff layer. In this way, a heat image-transferable sheet was prepared and provided.

Dyestuff Layer-Forming Composition

dispersion dye ("Kayaseo Blue-136", manufactured and sold by Nippon Kayaku K.K.)	4 parts;
ethylhydroxyethyl cellulose	6 parts;
methylethylketone/toluene (wt. ratio: 1/1)	90 parts.

The dyestuff layer of the foregoing heat image-transfer sheet was brought into contact with the image-reception layer of the image-transferable sheet in overlapping manner, then, heat energy was applied from a thermal head from the side of heat-resisting layer of the heat image-transfer sheet, thereby dyestuff being transferred to the image-reception layer of image-transferable sheet, and indeed, for the formation of positive images.

Then, the image-transferable sheet, now carrying the required positive images was stuck together under heat and pressure at 140° C. for 5 seconds on the intermediate image-transfer substrate prepared in the following manner, in mutually opposed manner. Then, the synthetic paper "Yupo" was peeled off at the intersurface between the polyester resin film and the "Vylon 600" layer. In thus way, the inventive image-transfer sheet (intermediate image-transfer medium) carrying the corresponding reverse images was provided.

Method for the Preparation of Intermediate Image-Transfer Substrate

A sheet of fine quality or stick paper, unit weight: 82 g/m^2 was applied with a coating, about 20 μm thick, of polyethylene resin through conventional extrusion coating process. Thereon, further, a catalyst-added toluene solution of a parting agent silicone, "KS-707", manufactured and sold by Shinetsu was applied and dried up in quantity of about 2 g/m^2 (dry), for the purpose of curing. Thereon, still further, the following coating liquid composition was applied by means of a conventional coating bar and dried up, to provide an intermediate image transfer substrate. The thus coated and dried resin quantity was measured to 7 g/m^2.

Coating Liquid Composition

polyester resin ("Vylon 200", manufactured and sold by Toyo Boseki)	100 parts;
methyl ethyl ketone/toluene (mixing ratio by weight: 1/1)	700 parts.

A sheet of coated paper, pretreated for pore-filling, was coated, in the similar manner as above, with the foregoing liquid composition, to provide an image-transferable medium. On and with the presently coated surface, the image carrying surface of the foregoing intermediate image-transfer medium is brought into opposing contact and stuck together under heat and pressure at 140° C. for 7 seconds. Finally, the laminate of fine-quality paper and polyethylene was peeled off, to provide a final decorative product now displaying the positive images as required.

It will thus be seen that by adopting the above processing steps, the positive images formed under the action of the thermal head are transferred, through the intermediary of intermediate image transfer medium, onto the final object to be decorated, and indeed, in the form of positive mode. It

will be further seen that, since the dyestuff is well distributed within the image-reception layer, the transferred positive images are highly sharp and fresh, in addition to much profundities.

Since a resin layer was overlappingly applied on the thus-formed images, weather fastness, frictional durability and light-fastness of the finally formed images could be highly and amazingly improved. When suitable ultraviolet absorbing agent, antioxydant, quenching agent and/or radical scavenger is added to, further improvement of the light-fastness can be attained.

EXAMPLE E-2

The substrate of image-transferable medium adopted in the foregoing Example E-1 was replaced by a hard polyvinyl chloride card, 100 μm thick, and other processing modes were same as in Example E-1. In this way, a high quality, positive-image transferred, decorative final product was successfully provided. When the image include human portrait photograph, the final product was highly useful for ID-card.

EXAMPLE E-3

The substrate of image-transferable medium adopted in the foregoing Example E-1 was replaced by a transparent polyester film, and other processing modes were same as employed therein. In this way, a transparent film formed with the wanted positive images of better quality as before was obtained. This film was highly useful in OHP-services.

EXAMPLE E-4

A sheet of high quality paper, unit weight: 104 g/m^2, was coated with a layer of polypropylene resin, thickness: about 20 μm, through the way of conventional extrusion coating technique, then the coating was further coated with a silicone solution for use in parting service and hardenable under electron rays and dried up. The quantity of the coating silicone was about 1 g/m^{2}upon drying. In this way, an electron-hardened, provisional substrate was provided. On this substrate, the following, image-reception layer-forming composition was applied as a layer by use of a coating bar, and then dried up, for providing an image-reception layer. The coated resin quantity in the above last step amounted about 5 g/m^2.

Image-Reception Layer-Forming Composition

polystyrene ("Picolastic D 150" (Tg = 69° C.), manufactured and sold by Rika-Hercules Co., Ltd.	100 parts;
amino-modified silicone ("KF-393", manufactured and sold by Shinetsu)	7 parts;
epoxy-modified silicone ("X-22-343", manufactured and sold by Shinetsu)	7 parts.

Further processing was carried out as was set forth in the foregoing Example E-2, for providing a final product card, carrying thereon the wanted positive images of same superior quality, as was in Example E-2.

EXAMPLE E-5

On the image transferable medium used in the foregoing Example E-4, however, in the present Example, a thermoplastic resin, adhesive, polyolefine-series film, "Adwin 500", manufactured and sold by Showa Denko K.K., Tokyo, was applied as a layer. Other materials were used and processed as set forth therein. In this way, a decorative final product formed with necessary positive was obtained with superior results.

INDUSTRIAL AVAILABILITIES

As will be well understood from the foregoing detailed description of the invention, it is possible according to the present inventive system, to form highly easily and evenly the desired images sharply and attractingly on any product and object to be decorated or graphically ornamented, substantially irrespective of material kind and configuration thereof, and indeed, with a surprising unitary touch and feeling with the substrate. Therefore, the invention can be utilized broadly and conveniently in such various industrial fields, where unitary formation of various images, characters, symbols, numerals and graphics, on and to the articles, objects and substrate products to a sufficiently miracle and attracting degree.

We claim:

1. An image-transferable sheet for image-transfer onto the surface of an objective body, comprising a substrate sheet, an image-reception layer separably provided on one surface of said substrate, and a parting agent layer provided on the surface of said image-reception layer.

2. The image-transferable sheet of claim **1**, further comprising at least one of a parting agent layer, an intermediate layer and a protecting layer, provided between said image-reception layer and said substrate sheet.

3. The image-transferable sheet of claim **1**, further comprising an adhesively sticking layer provided between said image-reception layer and said substrate sheet.

4. The image-transferable sheet of claim **1**, further comprising a parting agent layer provided between said image-reception layer and said substrate sheet and an adhesively sticking layer provided on said parting agent layer which is in contact with said image-reception layer.

5. The image-transferable sheet of claim **1**, wherein said image-reception layer is composed of a material on or in which at least a thermally transferable dye-stuff can be deposited.

6. The image-transferable sheet of claim **1**, wherein said image-reception layer is provided in a separable manner, through the intermediary of a weak-sticking adhesive layer, on one surface of said substrate sheet.

7. The image-transferable sheet of claim **6**, wherein a parting agent layer is provided on one surface of said image-reception layer.

8. The image-transferable layer of claim **6**, wherein a protecting film layer is provided between said image-reception layer and said weak-sticking adhesive layer.

9. The image-transferable sheet of claim **8**, wherein the inter-relationship between said protecting film layer and said weak-sticking adhesive layer is a separable relationship.

* * * * *

US005696634A

United States Patent [19]

Watanabe et al.

[11] Patent Number: 5,696,634

[45] Date of Patent: Dec. 9, 1997

[54] **OBJECTIVE LENS FOR IMAGE PICKUP APPARATUS WITH SIZE OF IMAGE PICKUP SURFACE CHANGEABLE BETWEEN ASPECT RATIOS**

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[73] Assignee: **Canon Kabushiki Kaisha**, Tokyo, Japan

[21] Appl. No.: **580,277**

[22] Filed: **Dec. 27, 1995**

[30] **Foreign Application Priority Data**

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Dec. 28, 1994	[JP]	Japan	6-339058
Jan. 20, 1995	[JP]	Japan	7-26059
Jan. 25, 1995	[JP]	Japan	7-30138

[51] **Int. Cl.**[6] **G02B 15/14**

[52] **U.S. Cl.** **359/694**; 359/696; 359/697

[58] **Field of Search** 359/694, 696, 359/697

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Primary Examiner—Georgia Y. Epps
Assistant Examiner—Ricky Mack
Attorney, Agent, or Firm—Fitzpatrick, Cella, Harper & Scinto

[57] **ABSTRACT**

An objective lens for application to an image apparatus of which the size of the image pickup surface is changeable over between a first mode of a first aspect ratio and a second mode of a second aspect ratio has first optical member for extending the focal length of the objective lens, second optical member for shrinking the focal length of the objective lens, an operating member, and a transmitting mechanism for transmitting the operating force of the operating member to the first optical member under the first mode, and transmitting the operating force to the first and second optical member under the second mode, and by the operation of the operating member, under the first mode, the first optical member is removably insertable into the optical path of the objective lens, and under the second mode, the first and second optical member are removably insertable into the optical path of the objective lens.

6 Claims, 26 Drawing Sheets

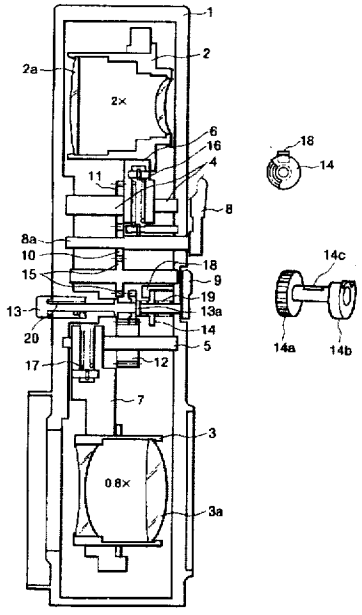


FIG. 1

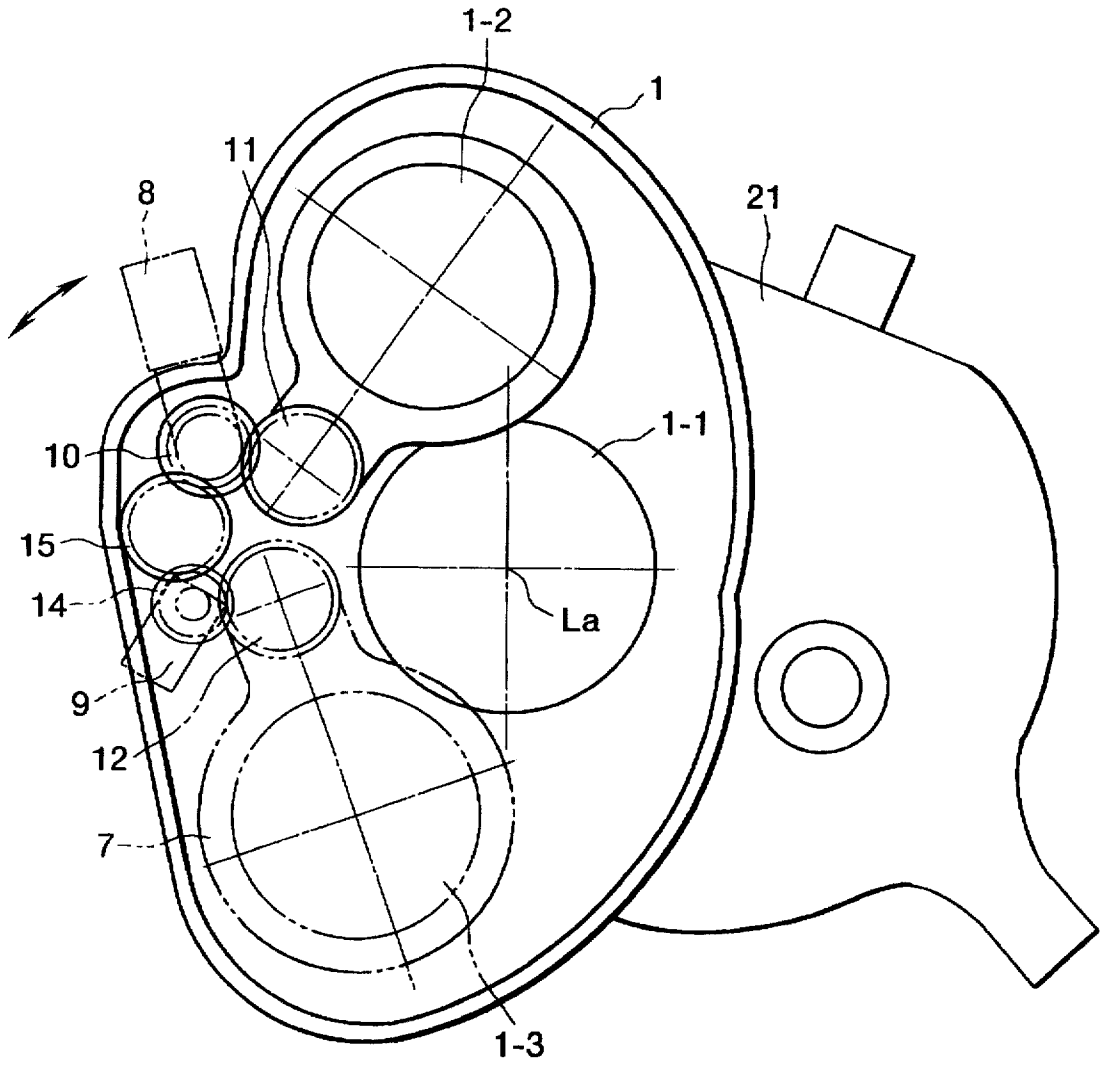


FIG. 2A

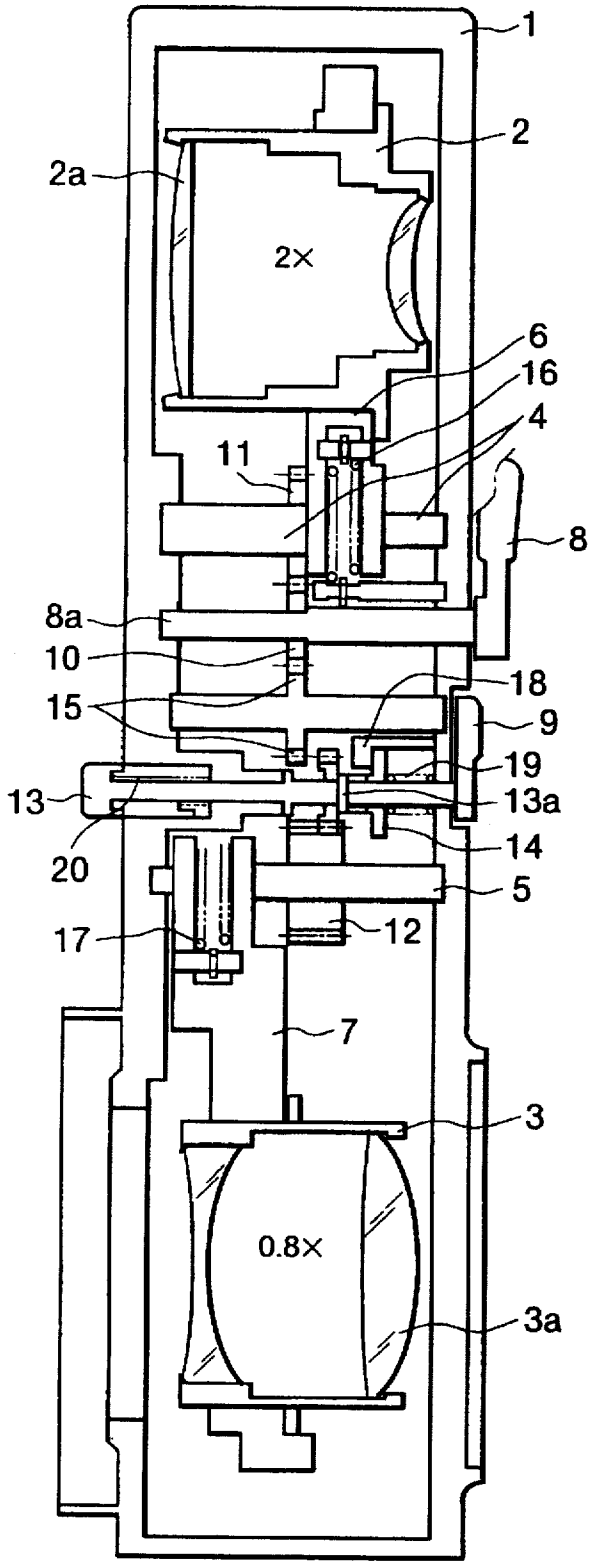


FIG. 2B

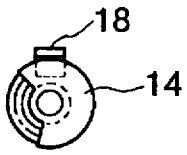
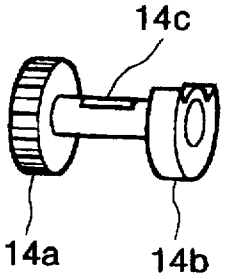


FIG. 2C



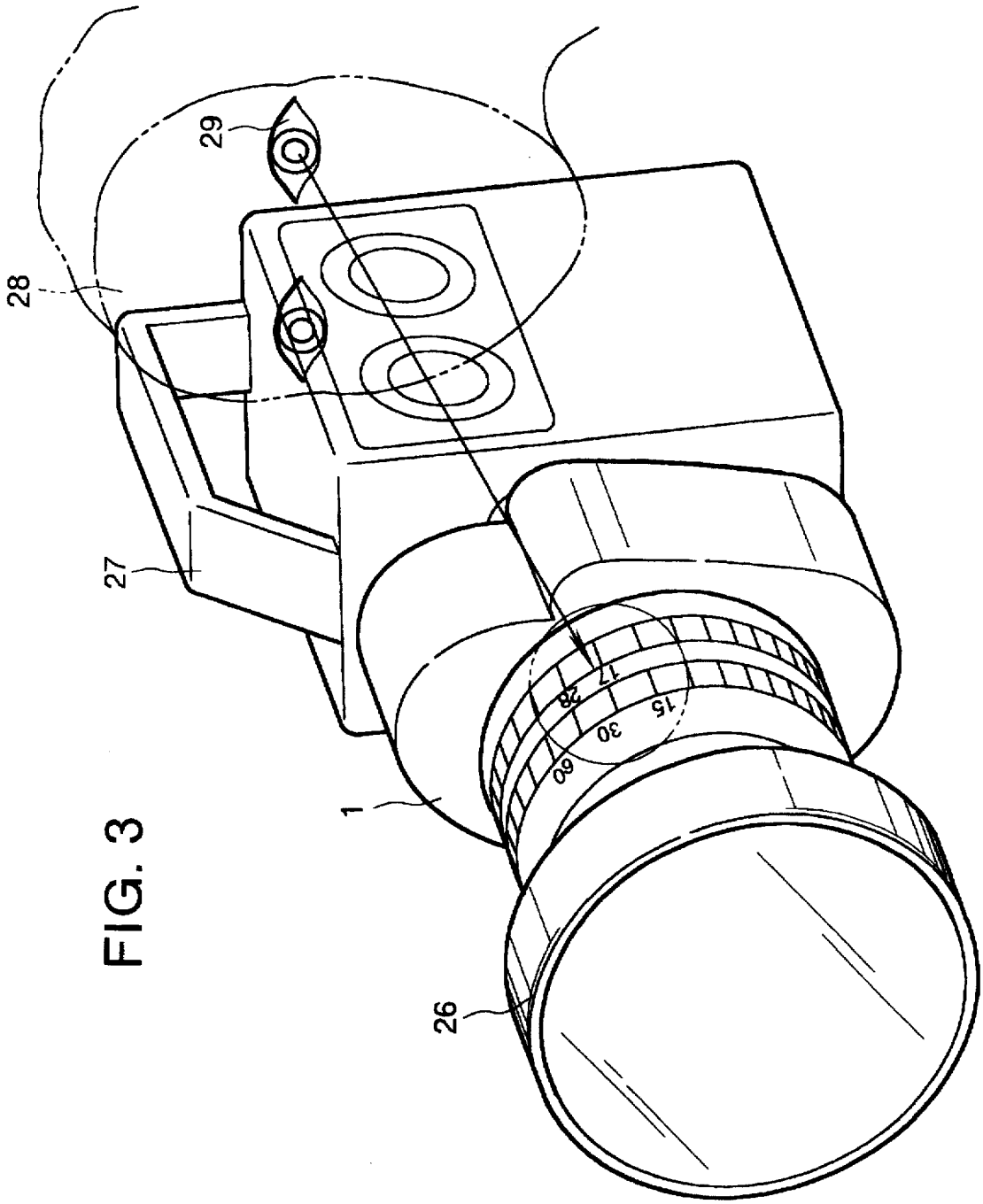


FIG. 3

FIG. 4

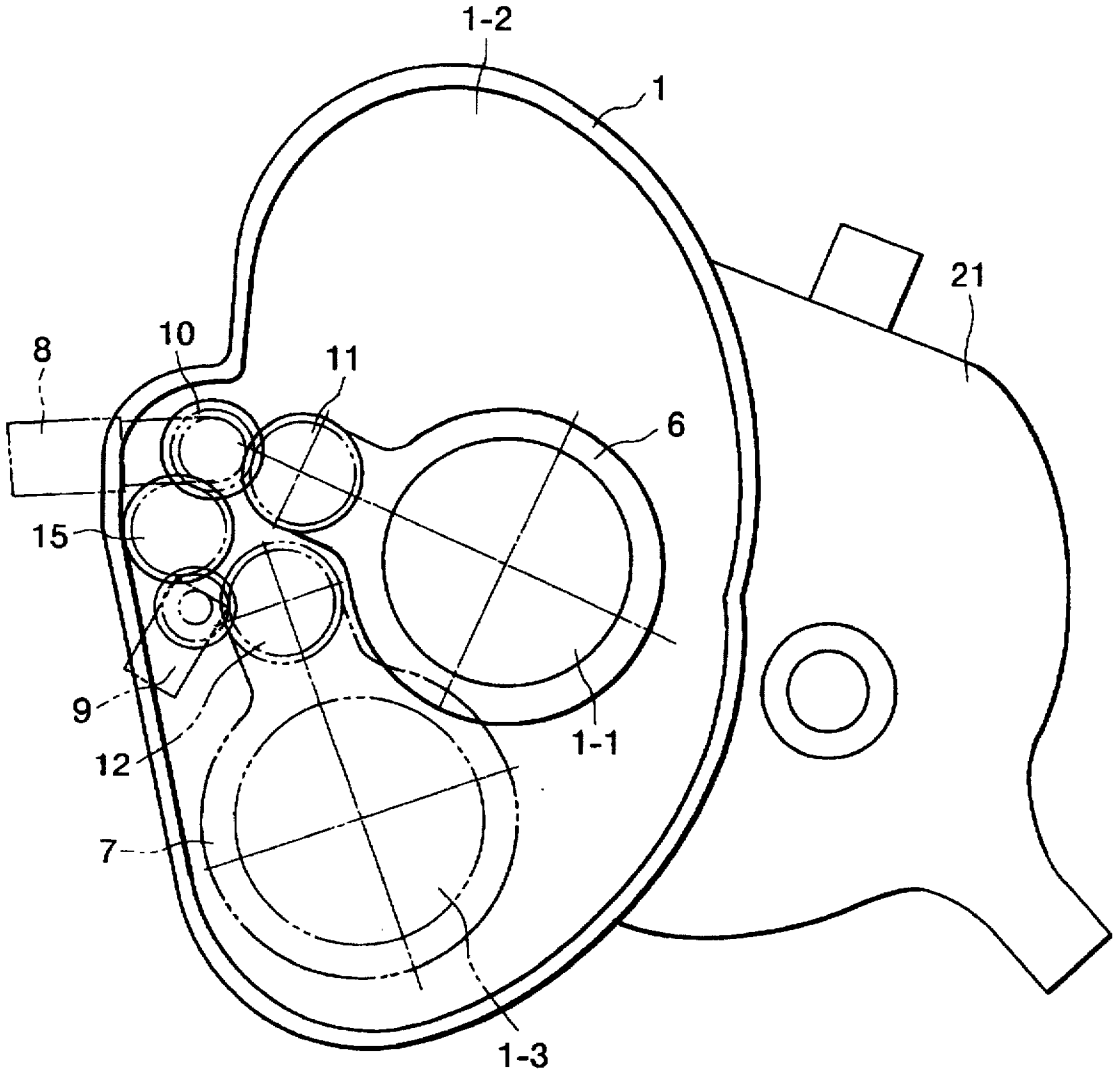


FIG. 5

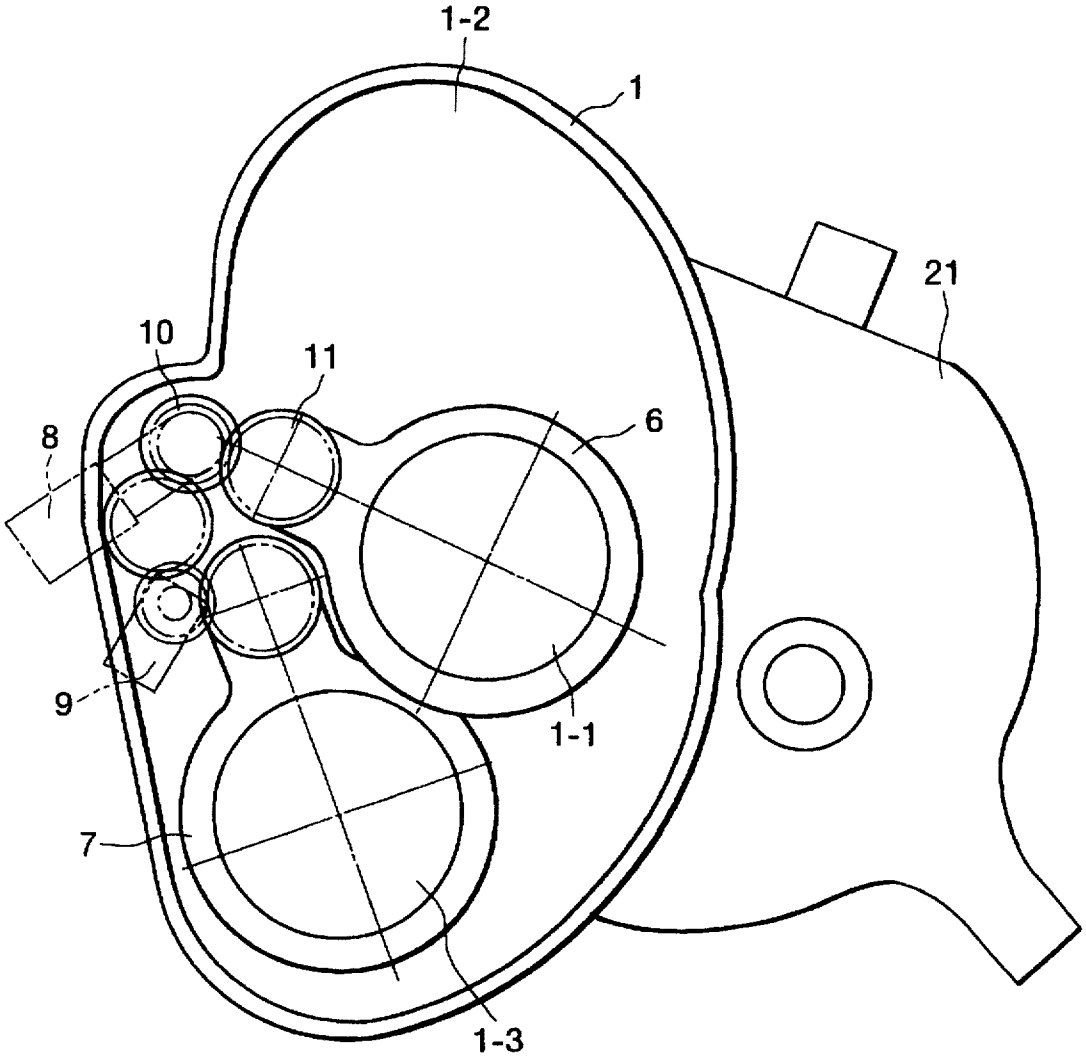


FIG. 6

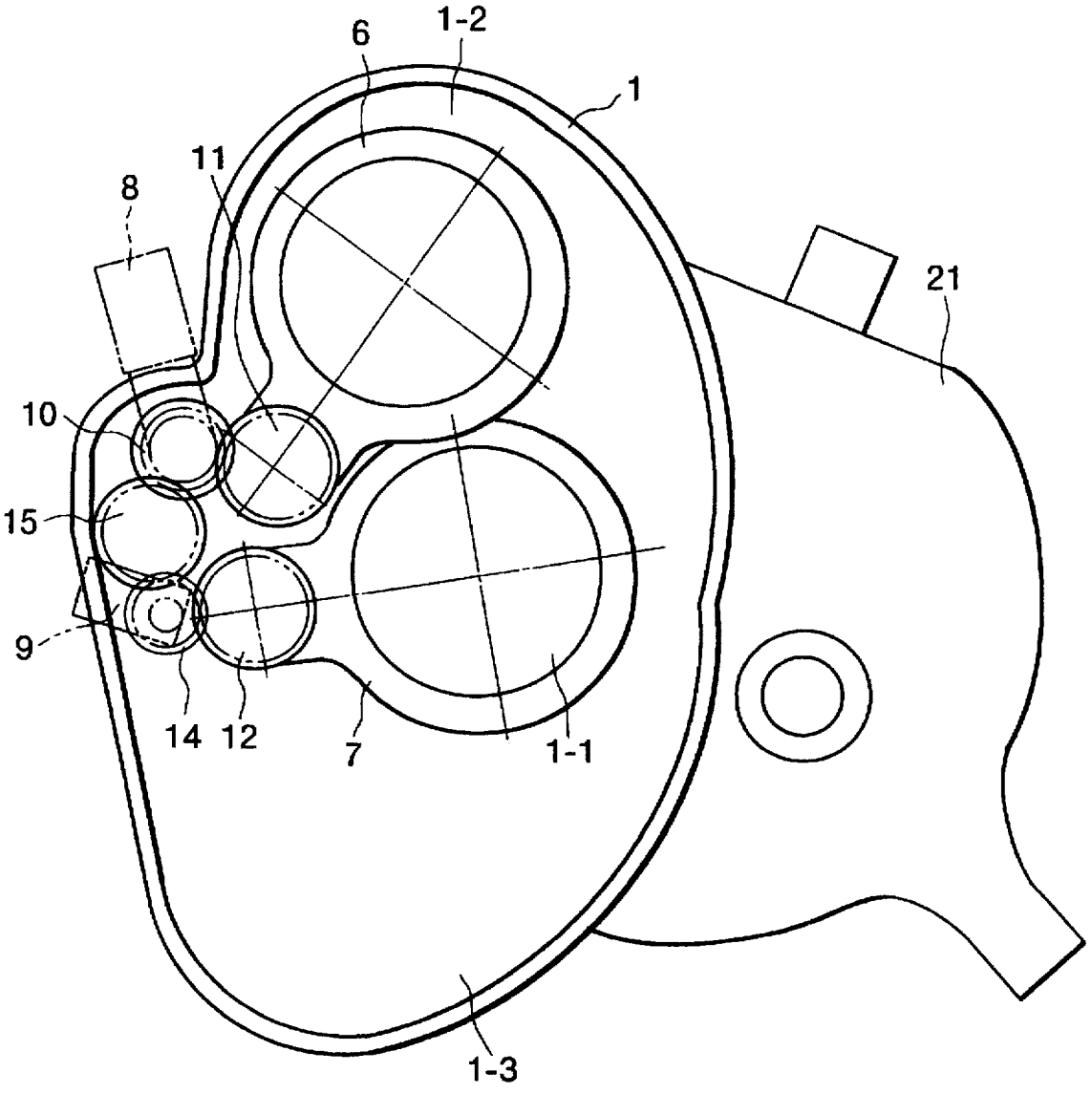


FIG. 7

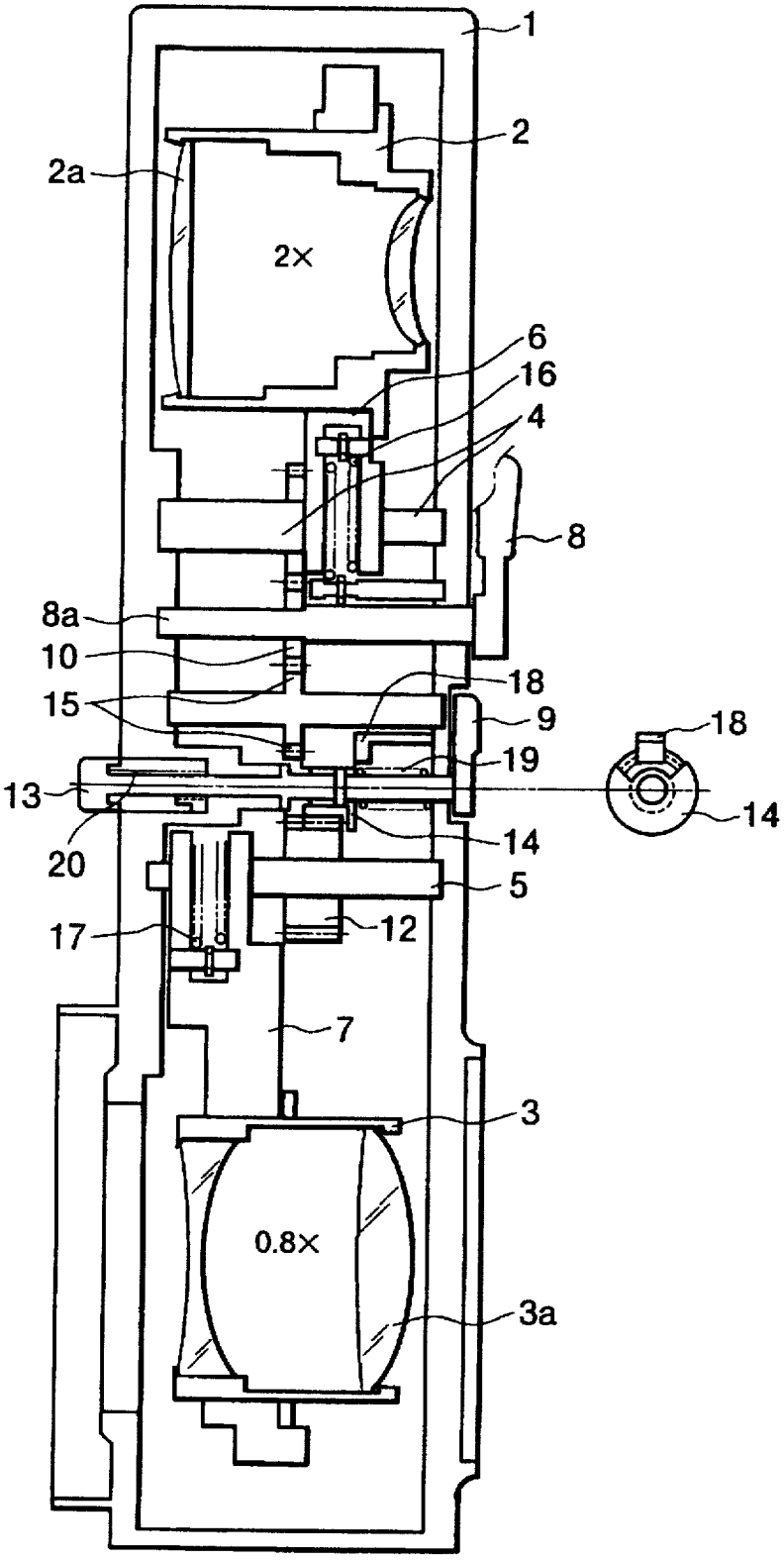


FIG. 8

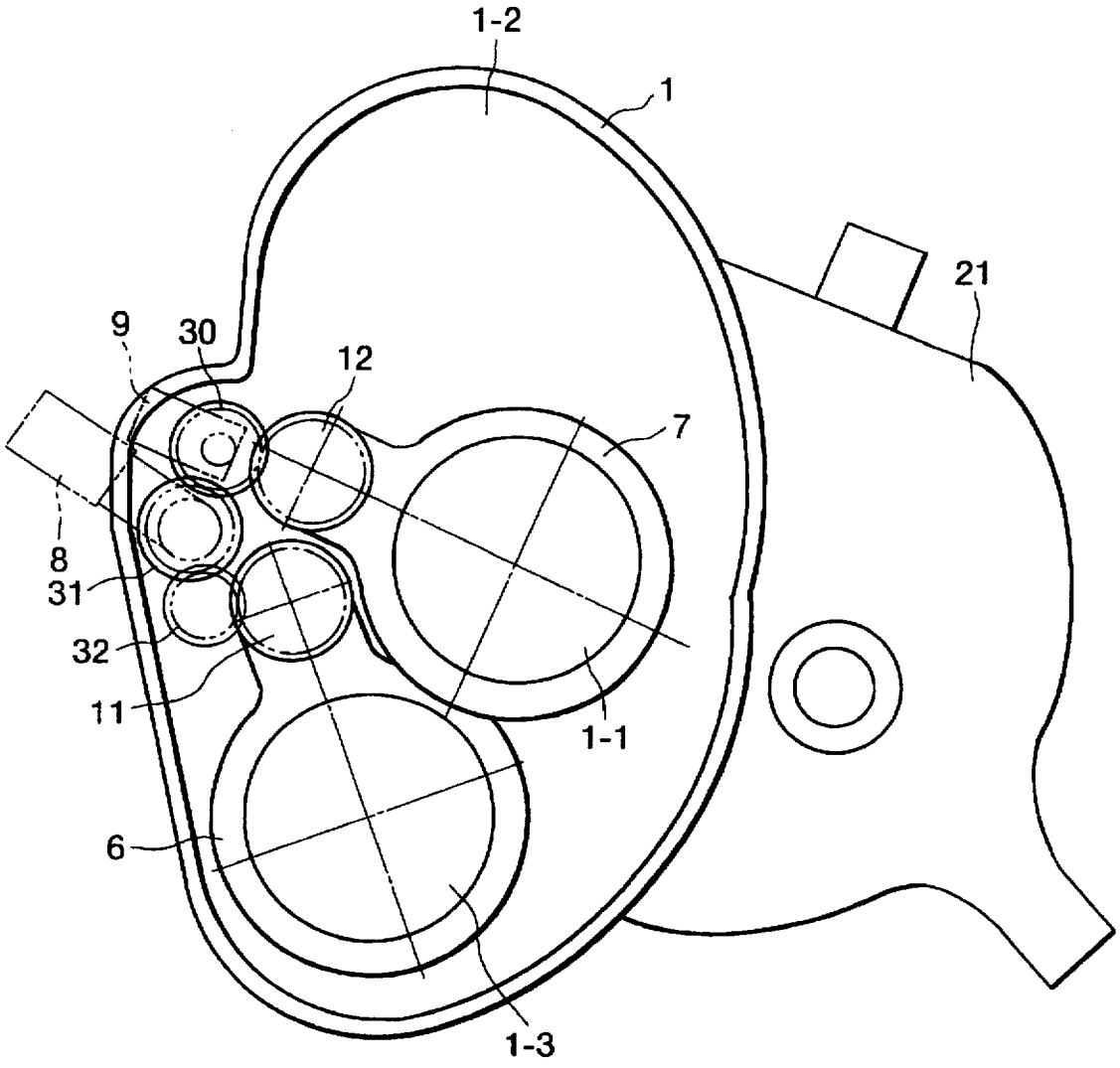


FIG. 9

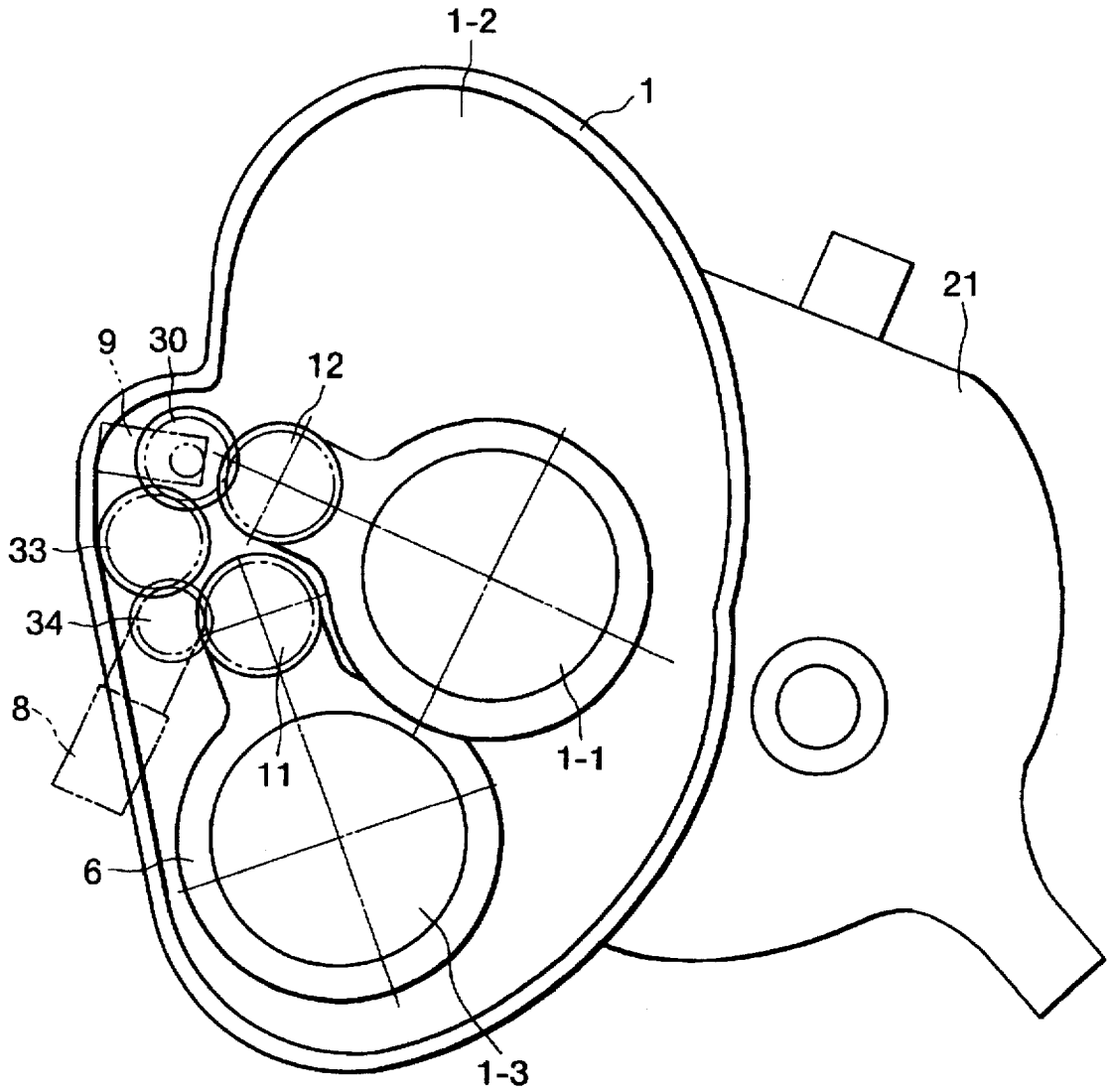


FIG. 10

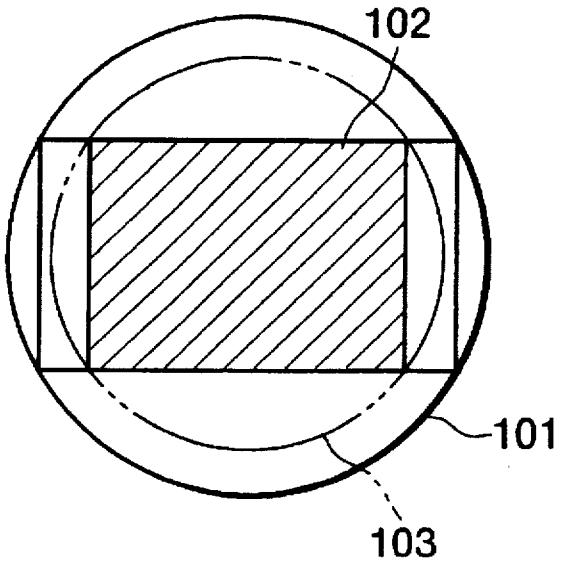


FIG. 11

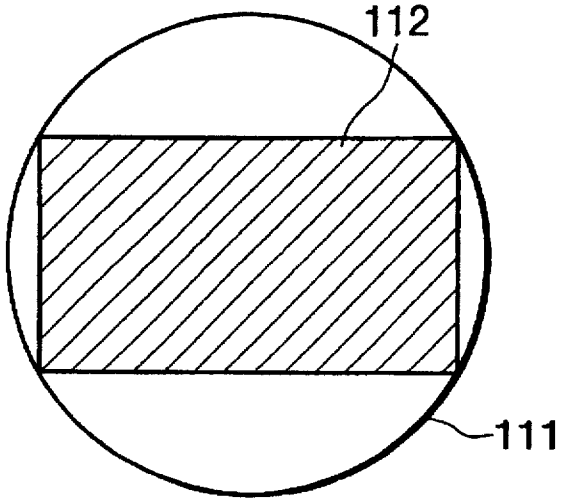


FIG. 12

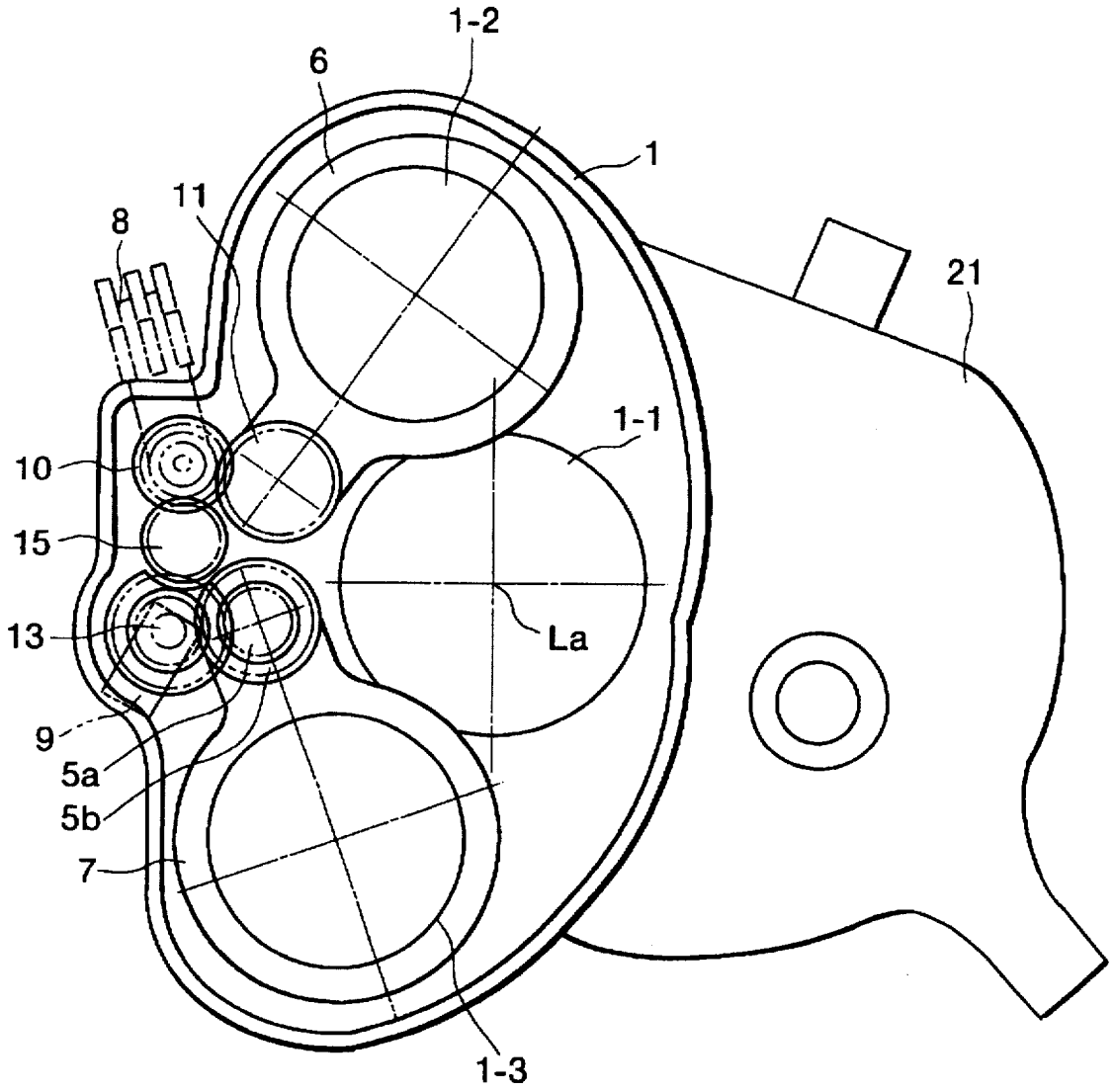


FIG. 13A

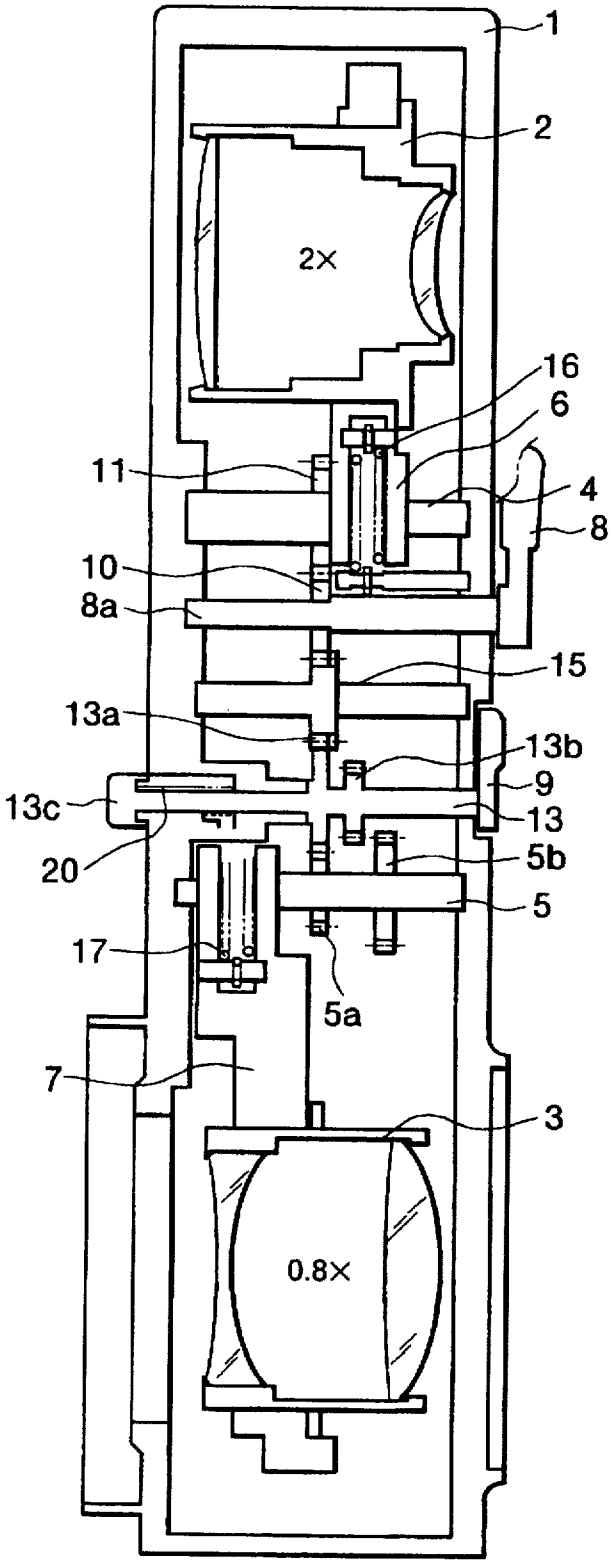


FIG. 13B

FIG. 14

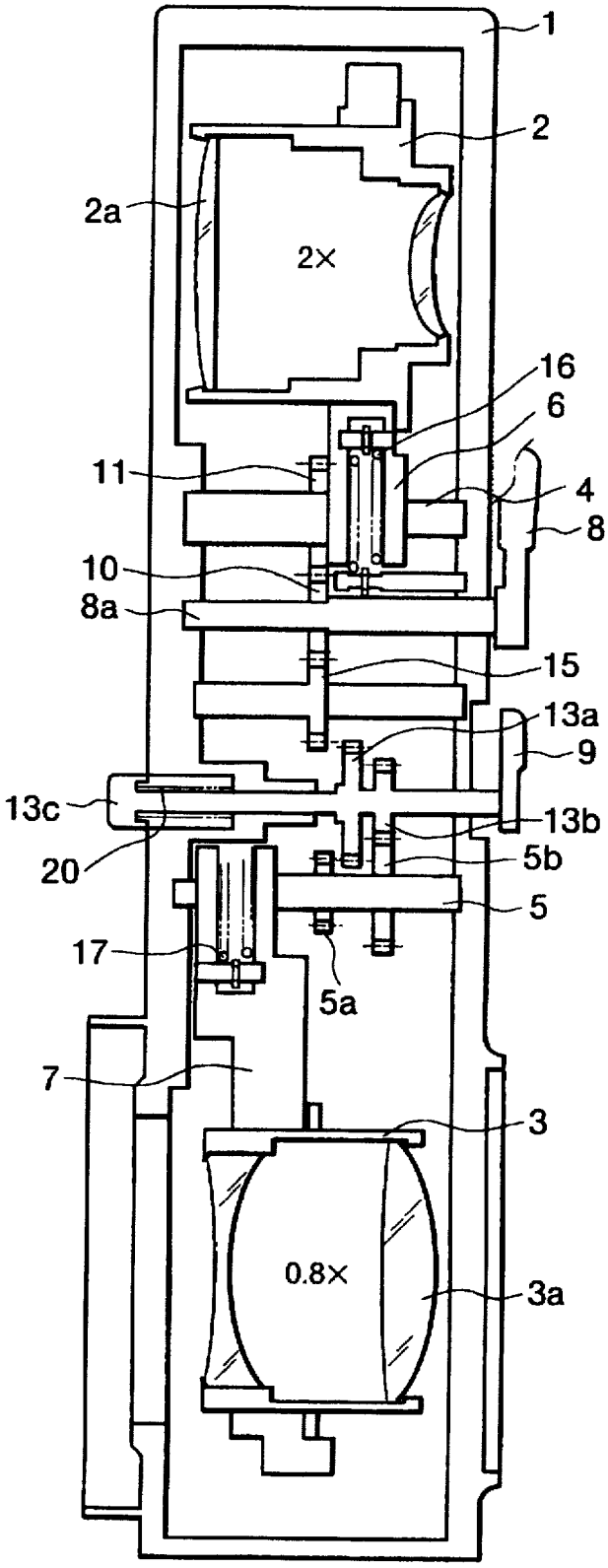


FIG. 15

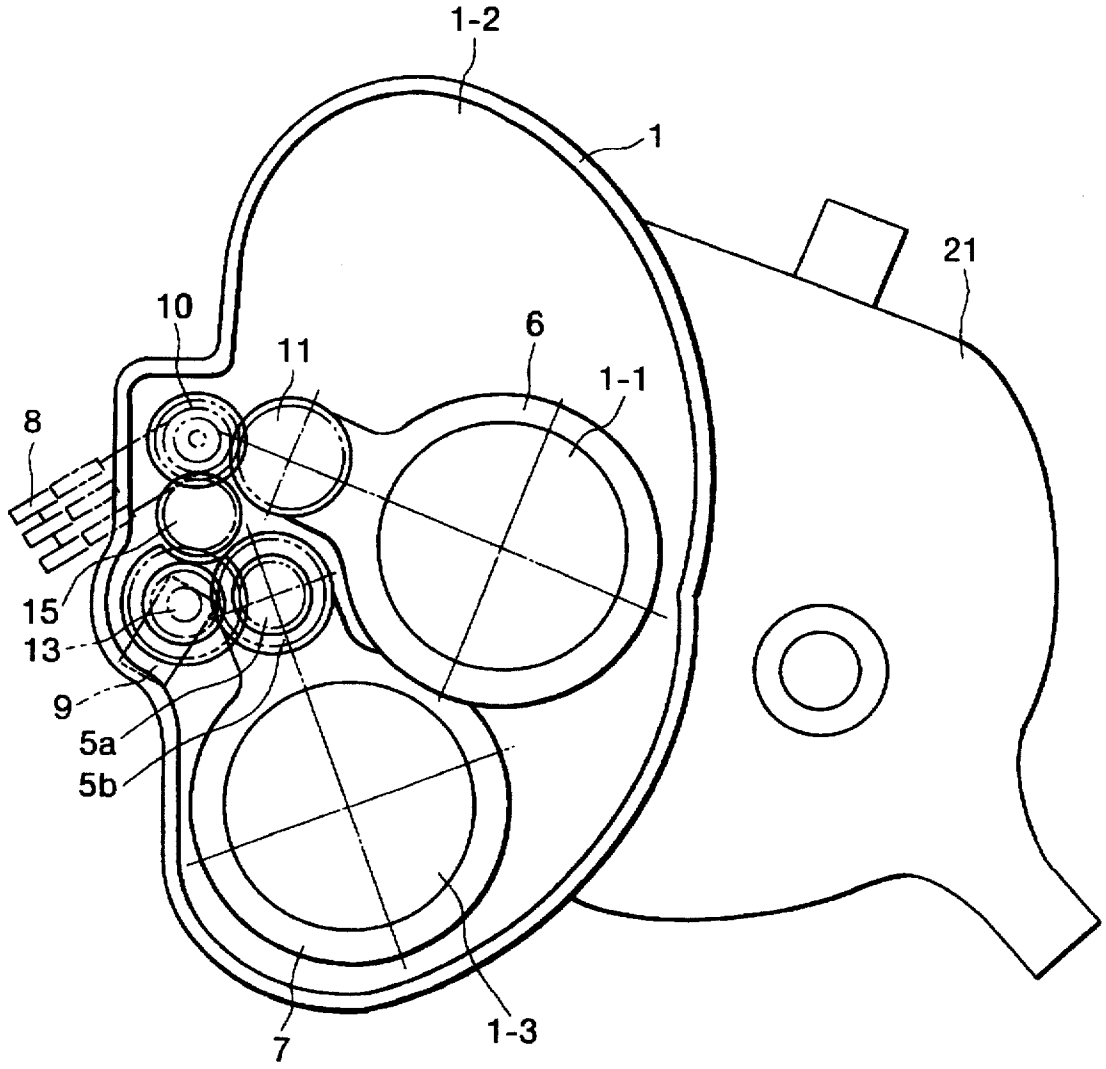


FIG. 16

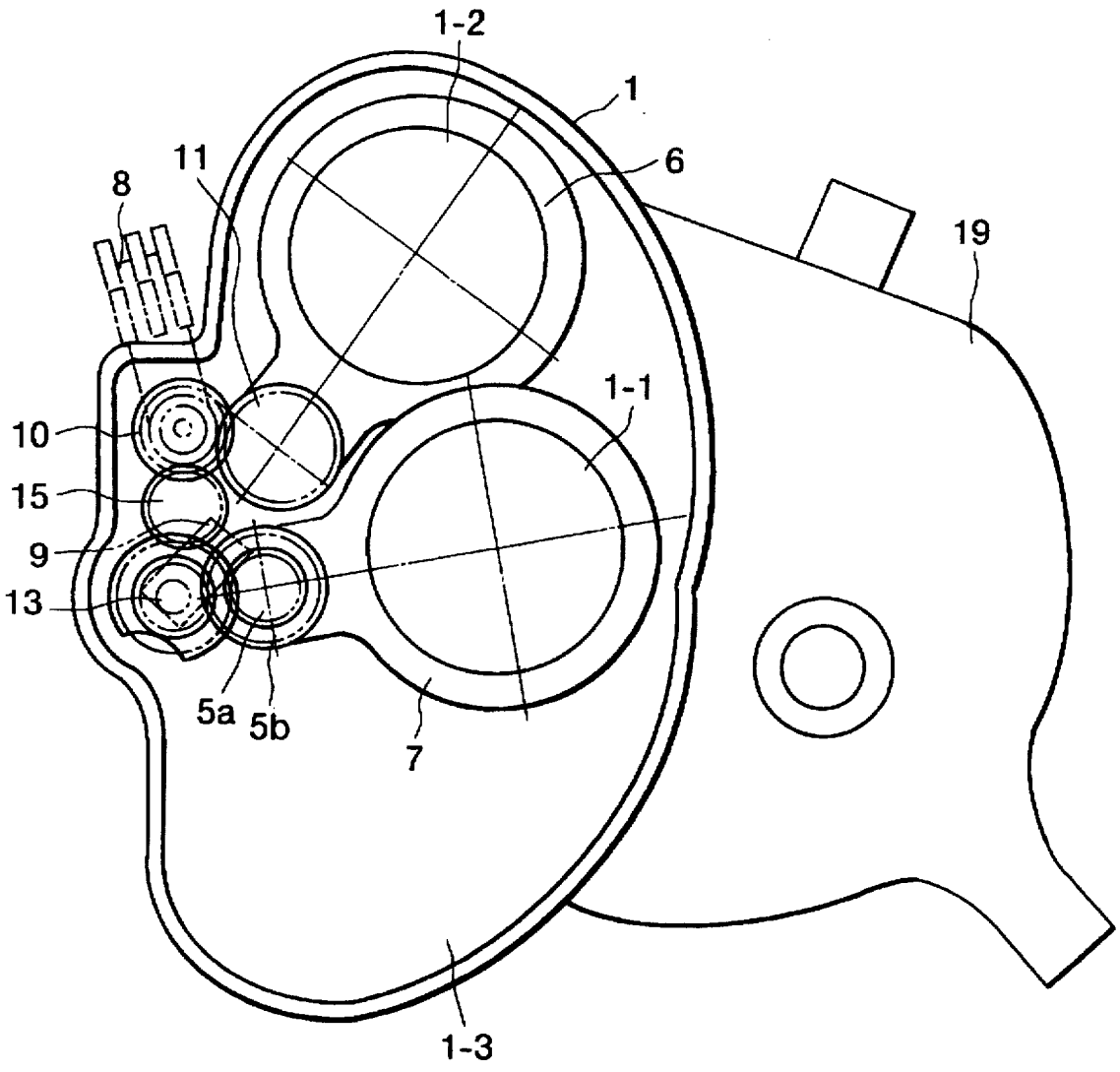


FIG. 17

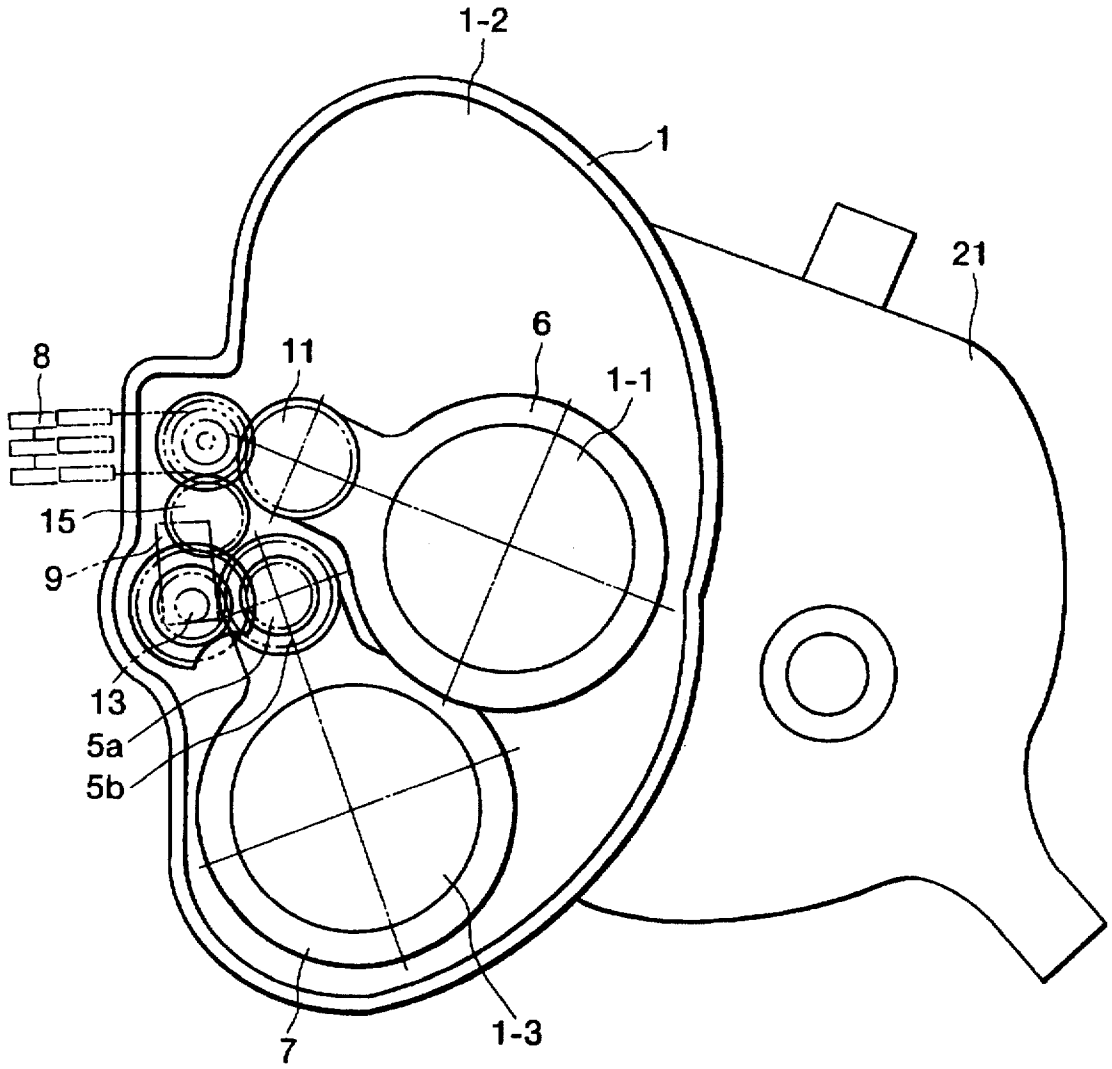


FIG. 18

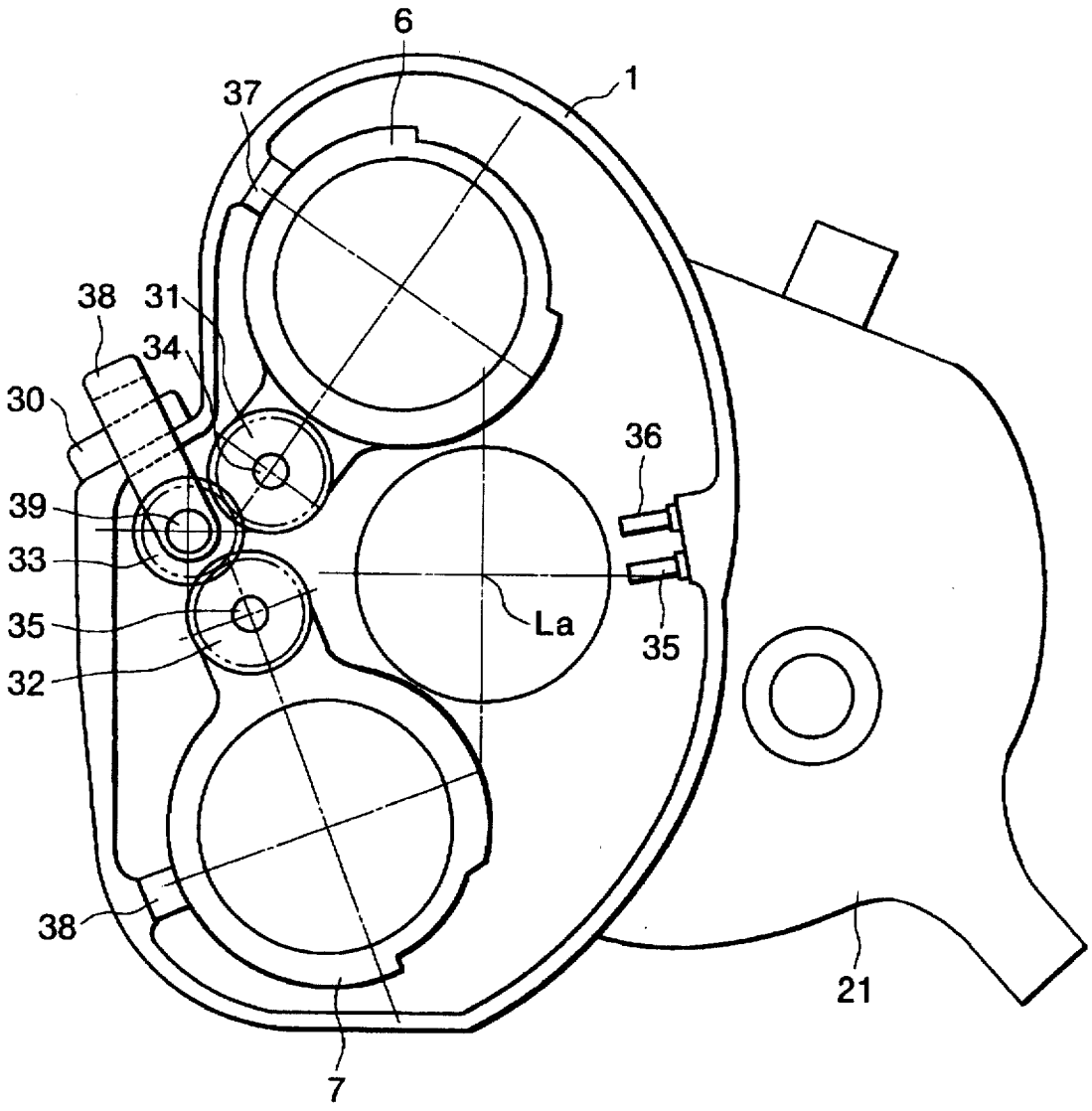


FIG. 19A

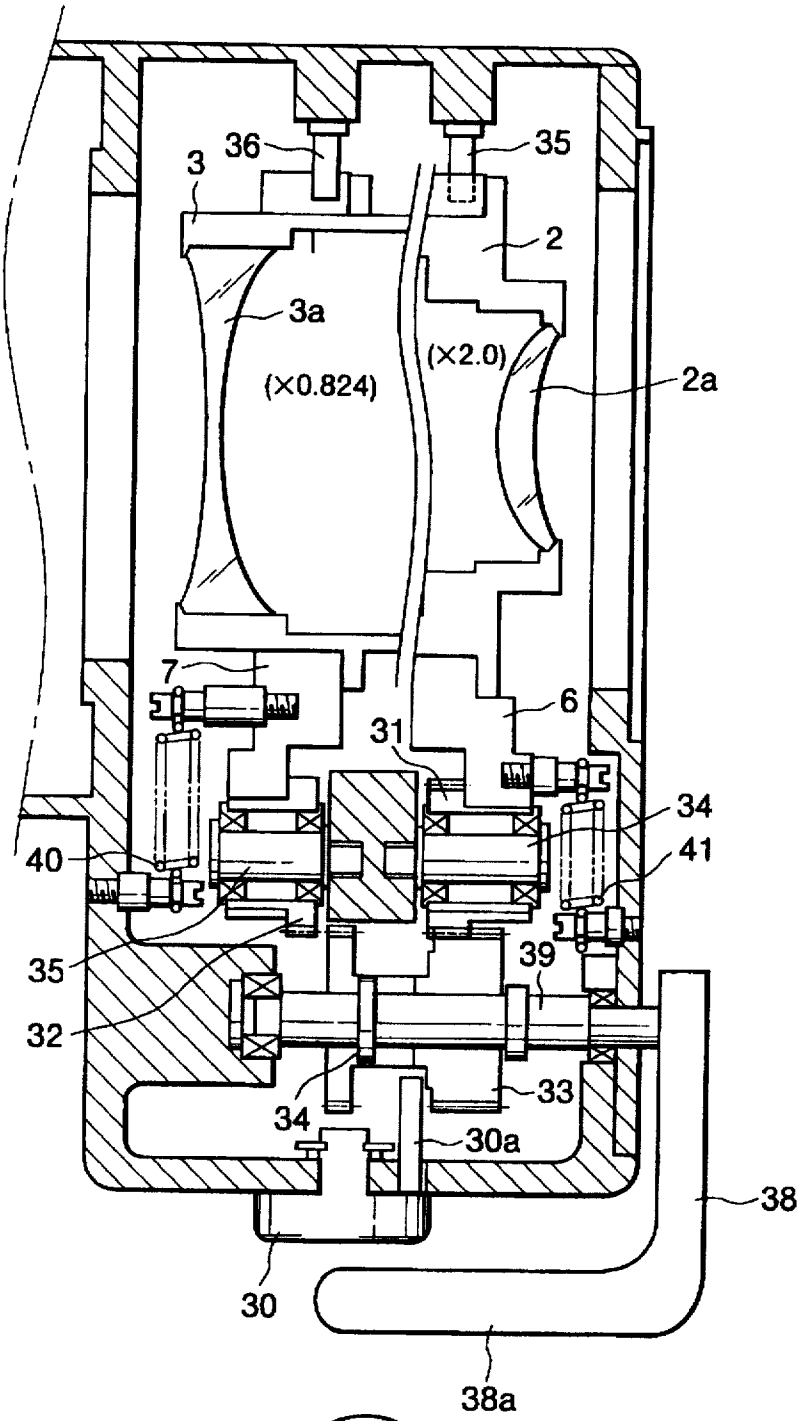


FIG. 19B

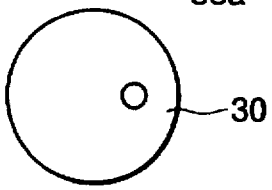


FIG. 20

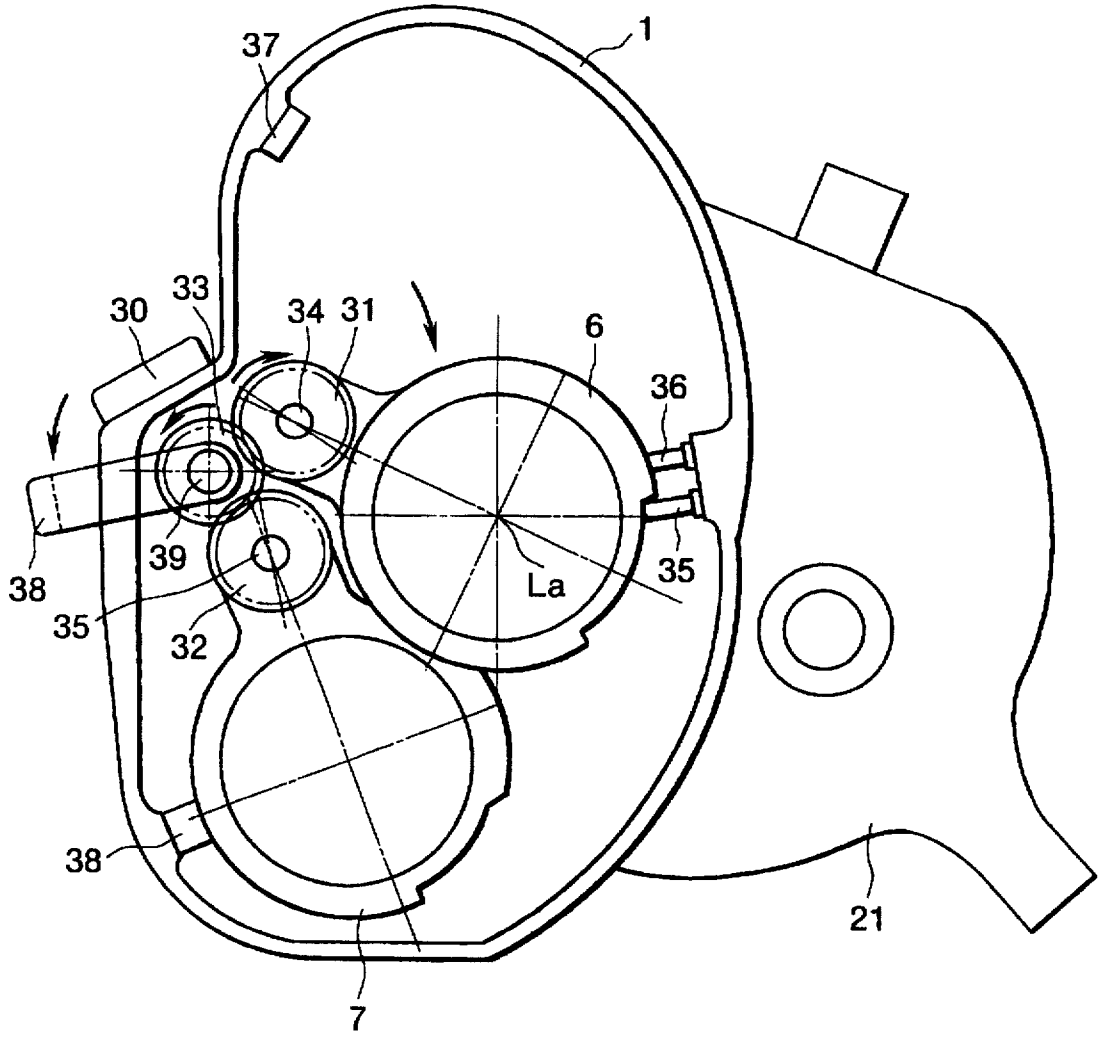


FIG. 21A

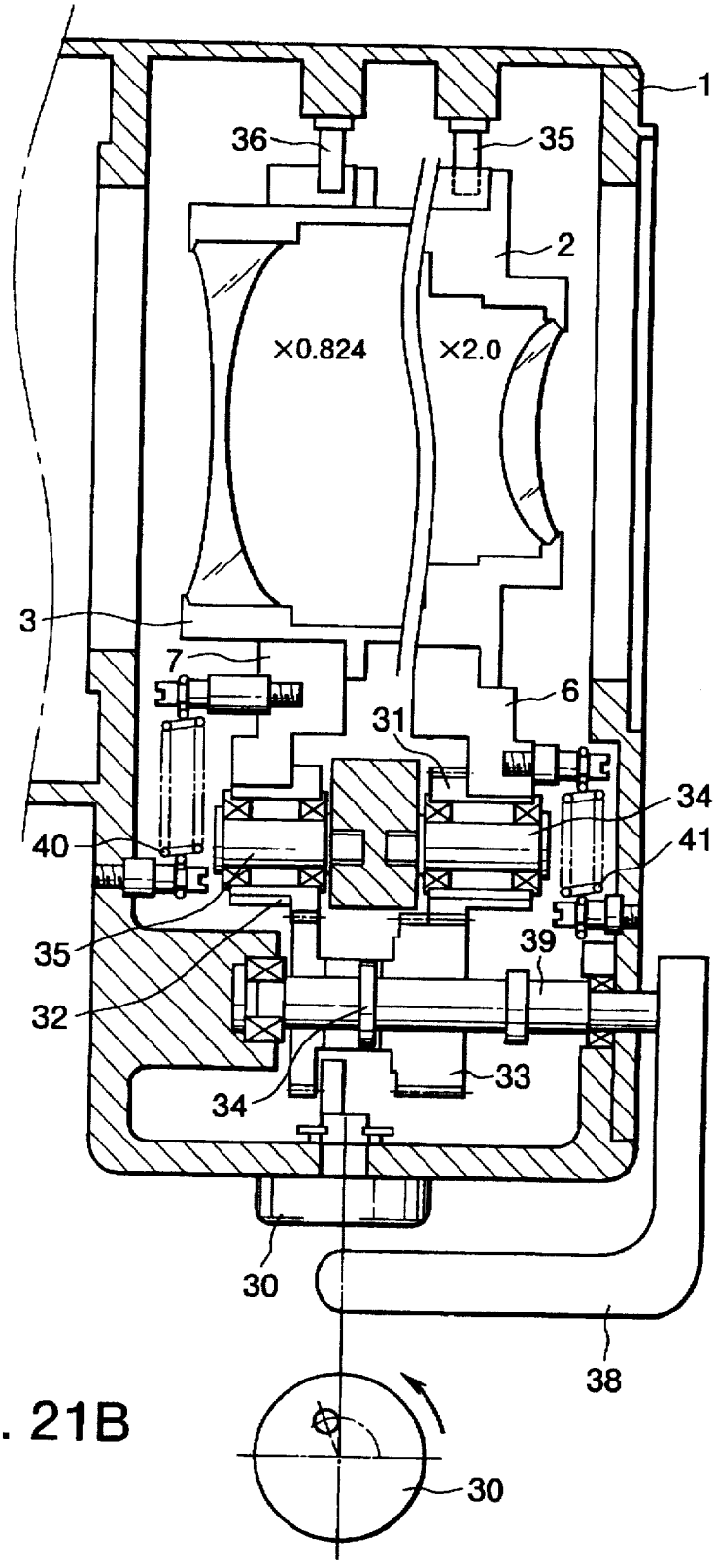


FIG. 21B

FIG. 22

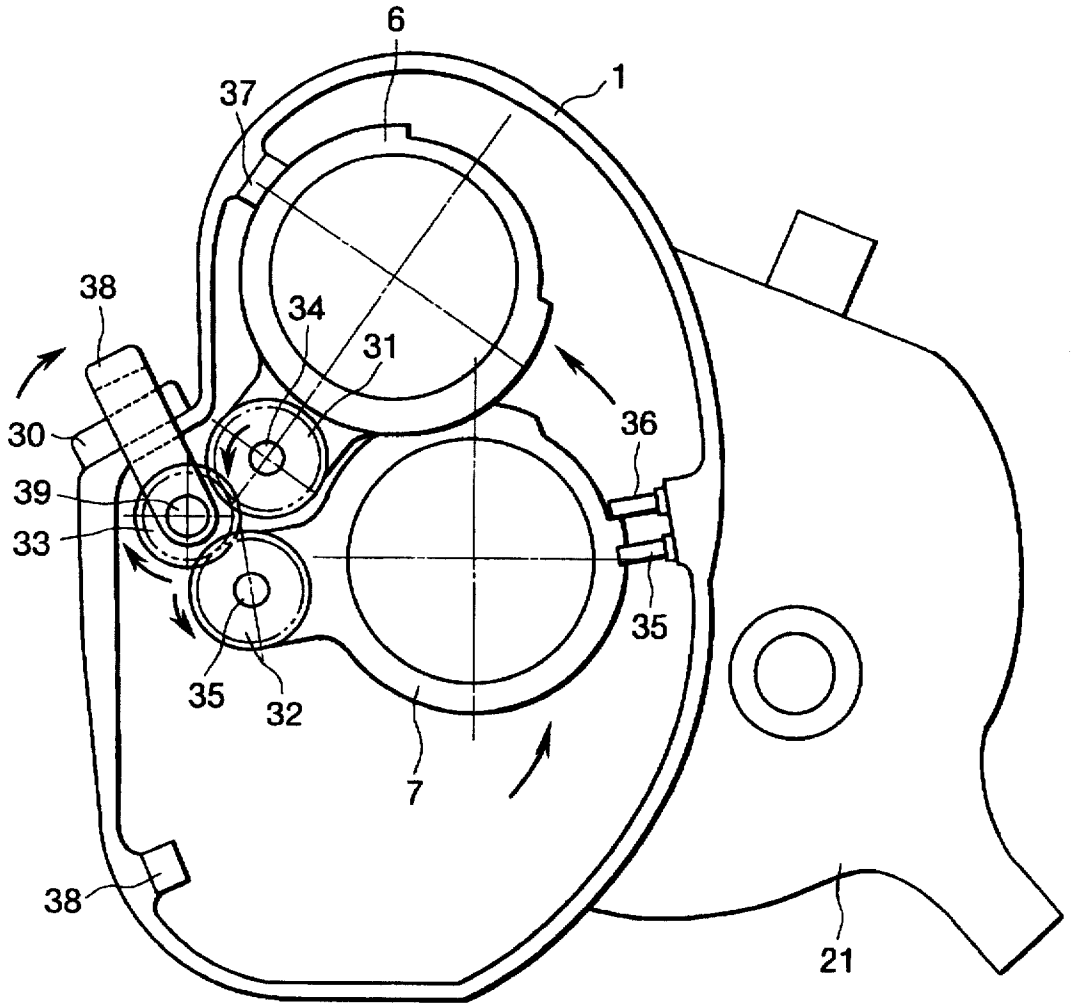


FIG. 23

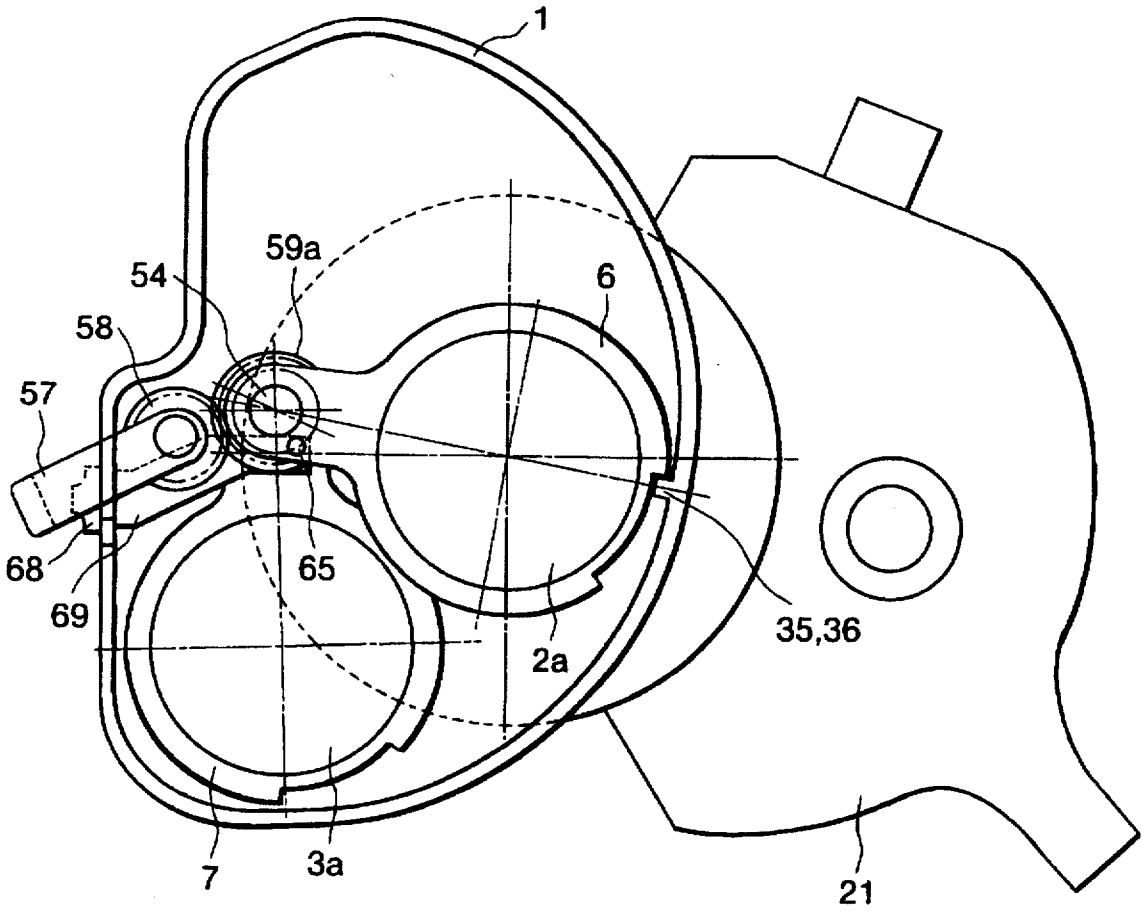
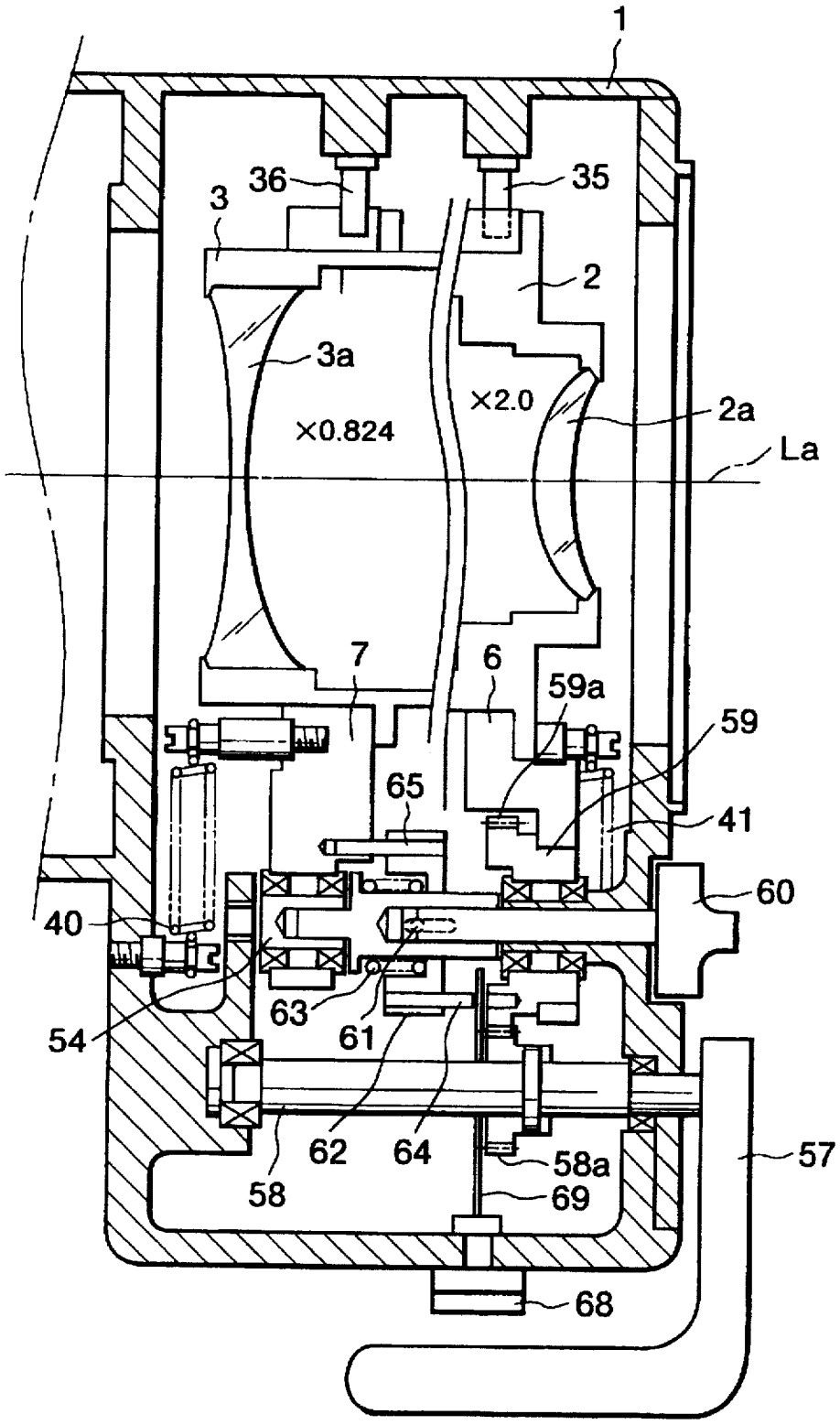


FIG. 24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×2.0
2a
×0.824
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FIG. 25

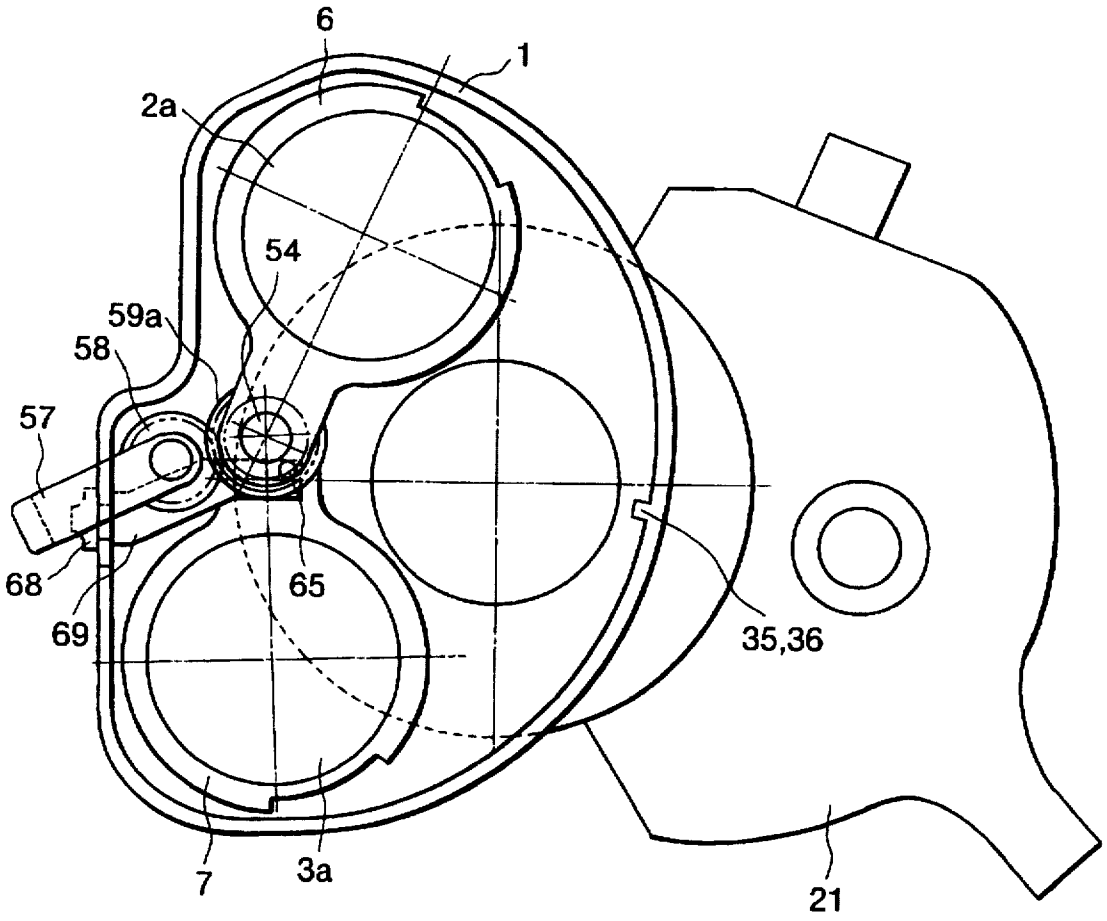

FIG. 26

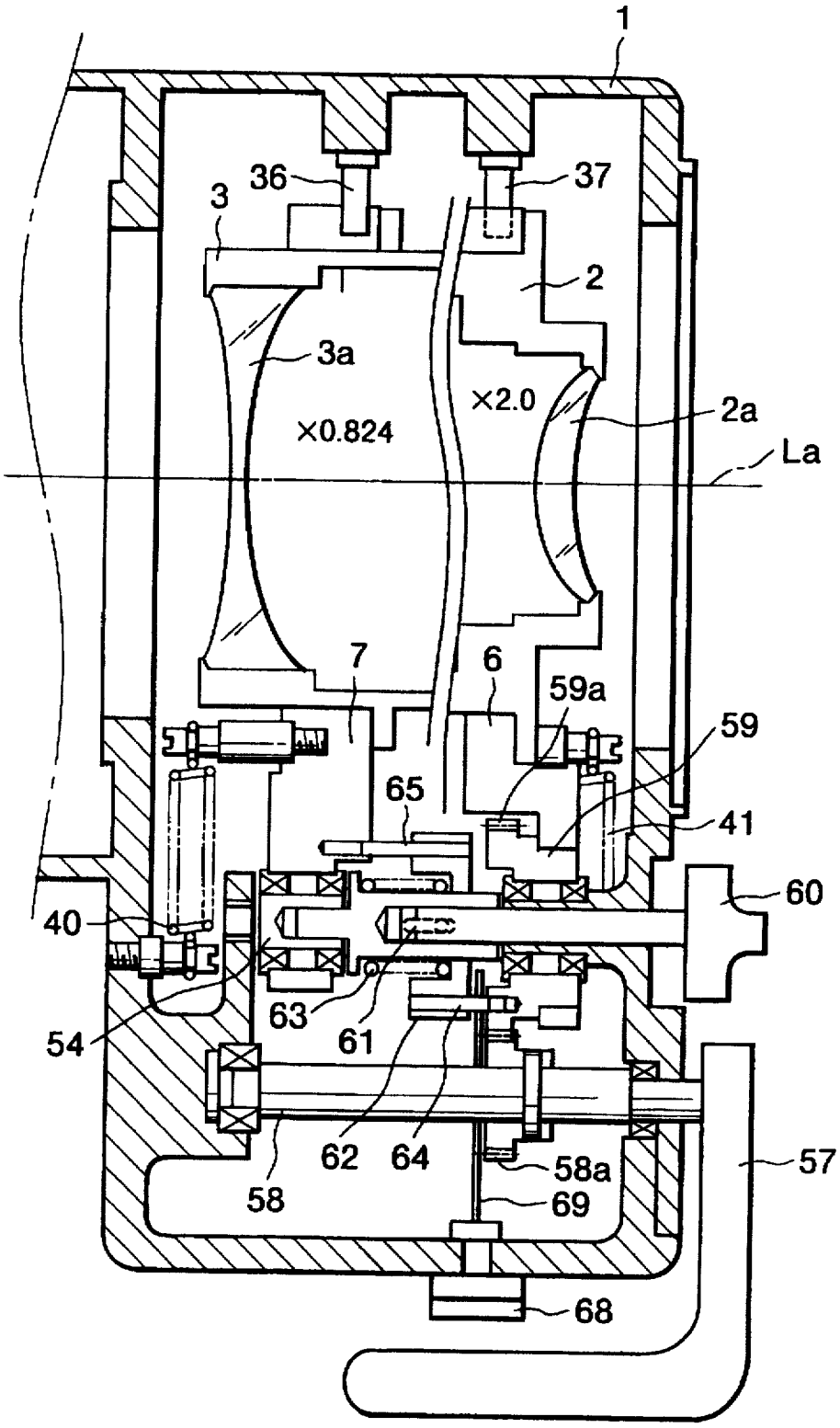
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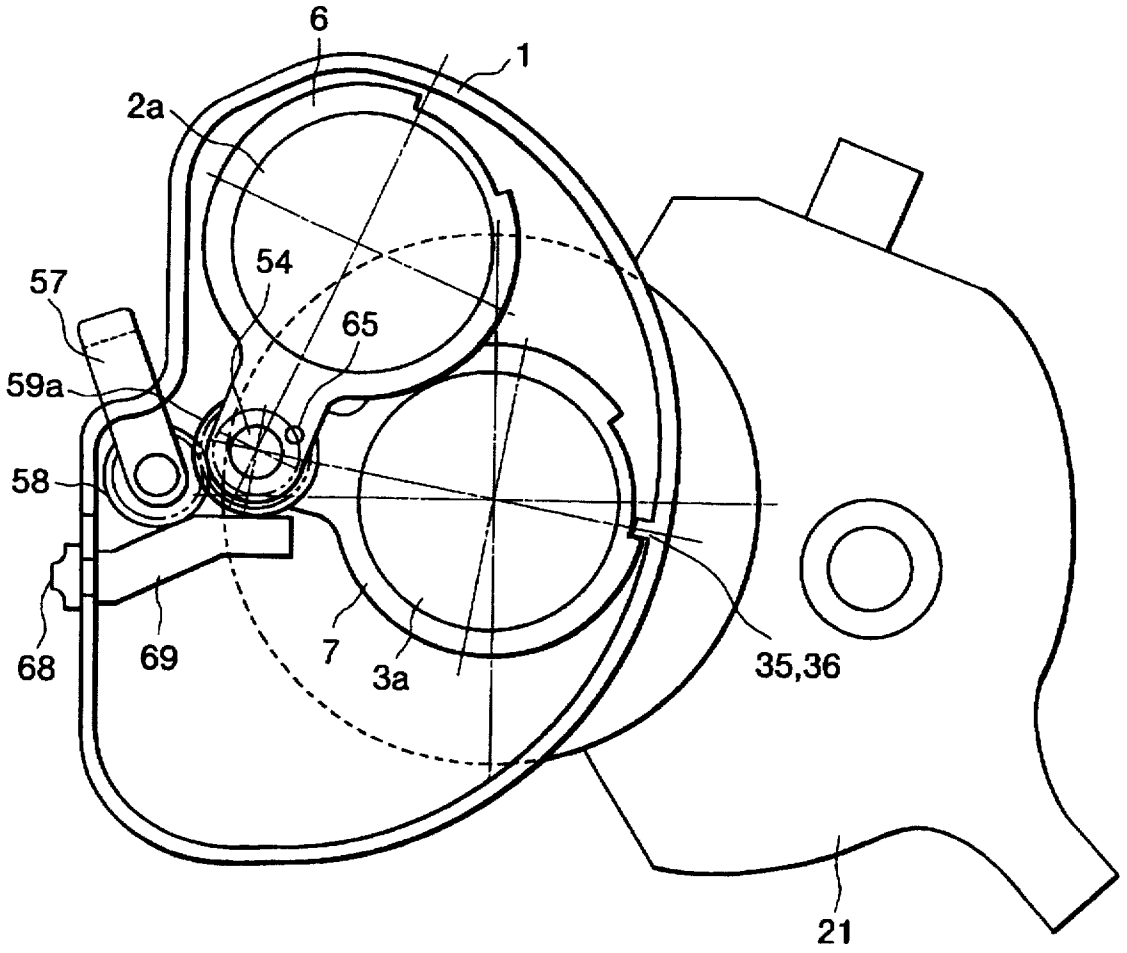
FIG. 27



OBJECTIVE LENS FOR IMAGE PICKUP APPARATUS WITH SIZE OF IMAGE PICKUP SURFACE CHANGEABLE BETWEEN ASPECT RATIOS

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to a lens barrel applicable to an image pickup apparatus capable of changing an aspect ratio, and particularly to a lens barrel in which a converting lens unit for changing over the aspect ratio is adapted to be removably provided in a portion of a photo-taking system when, for example, the aspect ratio of an effective image field is reversibly changed from 4:3 to 16:9.

2. Related Background Art

The width to length ratio, the so-called aspect ratio of the effective image pickup surface (image field) of an ordinary television camera, a video camera or the like is 4:3. In contrast with this, recently, the EDTV system having the aspect ratio of image field of 16:9 is being put into practical use as the broadcasting system of the next generation. Therefore, recently, in order to cope with both of the ordinary TV system and the EDTV system of the aspect ratio 16:9, there have been proposed various cameras (image pickup apparatuses) which can selectively use the aspect ratio 16:9 and the aspect ratio 4:3.

For example, in a camera of the image pickup tube type, the deflection area of an electron beam is electrically changed over to thereby change the width to length ratio (the aspect ratio) while keeping the diagonal length of the image field. However, to carry out this system by the use of a solid state image pickup element such as a CCD element, it is necessary to do as follows.

In a camera using a CCD element in which as shown in FIG. **11** of the accompanying drawings, the original aspect ratio of an image pickup surface **111** is 16:9, use is made of the whole area **112** of an image field of an aspect ratio 16:9. On the other hand, when an image field of an aspect ratio 4:3 which is a part area of an image pickup element of this size is to be photographed, as shown in FIG. **10** of the accompanying drawings, the right and left of a photo-taking surface **101** is not used, but only the area **102** of an image field of an aspect ratio 4:3 in the central portion is used.

When the image pickup surface of the image pickup element is thus partly used, the diagonal length of the image field becomes short and therefore, an image obtained by a photo-taking lens cannot be effectively used, and this leads to the disadvantage that the diagonal angle of view becomes narrow or sensitivity is reduced. That is, supposing that only the aspect ratio is simply changed, there axises the problem that the angle of view varies on a monitor.

Heretofore, in a TV camera or the like, use has been made of a system in which an extender is removably inserted into a portion of a photo-taking system (zoom lens) to thereby vary the focal length range of the whole system. In an extender constructed with a view to extend the focal length of the whole system to a longer one, the fact that the aspect ratio is changed, thereby the diagonal image field becomes narrow means that the focal length is apparently further extended. This poses no problem because in a state in which the extender is used, the focal length is in a direction to become longer, but in a state in which the extender is not used, the focal length on the wide angle side shifts to the telephoto side, and this becomes a great problem.

In contrast, in Japanese Laid-Open Patent Application No. 6-230279, there is proposed a method of disposing a lens unit for changing the image size (for example, an image field **103** indicated by dots-and-dash line in FIG. **10**) on a turret provided for an extender, and removably inserting a converting lens unit for shrinking the focal length by the rotation of the turret (hereinafter referred to as the "shrinker") into an optical path to thereby avoid the above-noted disadvantage. That is, a lens for preventing any variation in the angle of view even if the aspect ratio varies is prepared on the turret.

In the method proposed in the above-mentioned Japanese Laid-Open Patent Application No. 6-230279, the turret system is used for the changeover of the extender. Therefore, this system is very effective in the case of a large photo-taking lens like, for example, a lens for a studio camera.

However, in a camera system like a portable handy camera wherein a photographer effects photographing carrying the camera on his shoulder, it is usual to manually change over the extender and therefore, the new provision of the turret leads to the arising of the following problems.

(i) The addition of the turret and a rotating mechanism therefor to the photo-taking system greatly increases the weight of the handy camera system.

(ii) Heretofore, in a photo-taking lens for a handy camera, the changeover of the extender has been realized by the vertical or horizontal changeover operation of a changeover lever. To rotate the turret, it is usual to accomplish it by rotating a dial, a knob or the like connected to the turret. By this operation, not only the shrinker but also the extender are changed over, and this gives a feeling of physical disorder to the photographer accustomed to the conventional lens operation, while it takes much time to effect the changeover, and a hindrance comes to arise when a scene quick in movement is to be photographed.

(iii) The changeover mechanism becomes bulky and the area of the track on which the photo-taking lens moves is enlarged and therefore, when the focusing, zooming or iris operation is to be manually performed, an index provided on the circumference of the lens becomes difficult to see and a hindrance arises in the operation.

(iv) After the aspect ratio has once been selected on the camera side during photographing, if the photographer, in spite of having been conscious of only the selection of one-to-one magnification and the extender as before without being conscious of the presence or absence of the shrinker, makes a mistake in the selection, the image field will be eclipsed in some cases. That is, under a mode of an aspect ratio of 16:9, if the shrinker is inserted into the optical path, there will arise the inconvenience that the phenomenon of the light around the image field being eclipsed occurs. Accordingly, a photographer who performs the manual operation must constantly take care of the relation between the aspect ratio and the shrinker even during photographing.

SUMMARY OF THE INVENTION

It is a first object of the present invention to provide a relatively compact lens barrel applicable to a photographing apparatus of which the aspect ratio of the image pickup surface is changeable over.

It is a second object of the present invention to improve the operability of the changeover of a mode in which the aspect ratio varies.

According to a preferred embodiment of the present invention, an objective lens applicable to an image pickup apparatus of which the size of the image pickup surface is changeable over between a first mode of a first aspect ratio and a second mode of a second aspect ratio has first optical

means for extending the focal length of said objective lens, second optical means for shrinking the focal length of said objective lens, an operating member, and a transmitting mechanism for transmitting the operating force of said operating member to said first optical means under said first mode, and transmitting the operating force of said operating member to said first and second optical means under said second mode, and by the operation of said operating member, under said first mode, said first optical means is removably insertable into the optical path of said objective lens, and under said second mode, said first and second optical means are removably insertable into the optical path of said objective lens.

Further features of the present invention will become apparent from the following detailed description taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a cross-sectional view of a lens barrel according to an embodiment of the present invention.

FIGS. **2A**, **2B** and **2C** are a side cross-sectional view and the like of the lens barrel according to an embodiment of the present invention (when the aspect ratio is 16:9).

FIG. **3** is a perspective view of the whole of a camera according to an embodiment of the present invention.

FIG. **4** is a cross-sectional view of the lens barrel according to an embodiment of the present invention.

FIG. **5** is a cross-sectional view of the lens barrel according to an embodiment of the present invention.

FIG. **6** is a cross-sectional view of the lens barrel according to an embodiment of the present invention.

FIG. **7** is a side cross-sectional view of the lens barrel according to an embodiment of the present invention (when the aspect ratio is 4:3).

FIG. **8** is a cross-sectional view of a lens barrel according to an embodiment of the present invention.

FIG. **9** is a cross-sectional view of a lens barrel according to an embodiment of the present invention.

FIG. **10** shows an image circle at an aspect ratio of 4:3.

FIG. **11** shows an image circle at an aspect ratio of 16:9.

FIG. **12** is a cross-sectional view of a lens barrel according to another embodiment of the present invention.

FIGS. **13A** and **13B** are side cross-sectional views of the lens barrel according to another embodiment of the present invention.

FIG. **14** is a side cross-sectional view of a lens barrel according to another embodiment of the present invention.

FIG. **15** is a cross-sectional view of the lens barrel according to another embodiment of the present invention.

FIG. **16** is a cross-sectional view of a lens barrel according to another embodiment of the present invention.

FIG. **17** is a cross-sectional view of the lens barrel according to another embodiment of the present invention.

FIG. **18** is a cross-sectional view of a lens barrel according to still another embodiment of the present invention.

FIGS. **19A** and **19B** are side cross-sectional views of the lens barrel according to still another embodiment of the present invention.

FIG. **20** is a cross-sectional view of the lens barrel according to still another embodiment of the present invention.

FIGS. **21A** and **21B** are cross-sectional views of the lens barrel according to still another embodiment of the present invention.

FIG. **22** is a side cross-sectional view of the lens barrel according to still another embodiment of the present invention.

FIG. **23** is a cross-sectional view of a lens barrel according to still another embodiment of the present invention.

FIG. **24** is a side cross-sectional view of the lens barrel according to still another embodiment of the present invention.

FIG. **25** is a cross-sectional view of the lens barrel according to still another embodiment of the present invention.

FIG. **26** is a side cross-sectional view of the lens barrel according to still another embodiment of the present invention.

FIG. **27** is a cross-sectional view of the lens barrel according to still another embodiment of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. **1** is a cross-sectional view of the essential portions of Embodiment 1 of the present invention, FIGS. **2A**, **2B** and **2C** are side views of the essential portions of FIG. **1**, FIG. **3** is a pictorial view of the essential portions of an image pickup apparatus according to the present invention, and FIGS. **4** and **5** are illustrations of Embodiment 1 of the present invention.

FIGS. **2A**, **2B** and **2C** show the case of an aspect ratio 16:9 and one-to-one magnification mode (mode A) (both of an extender and a shrinker are absent in an optical path).

FIG. **4** shows the case of an aspect ratio 16:9 and two times mode (mode B) (the extender is inserted in the optical path).

FIG. **5** shows the case of an aspect ratio 4:3 and 2.427 times mode (mode D) (the extender is inserted in the optical path).

FIG. **6** shows the case of an aspect ratio 4:3 and one-to-one magnification mode (mode C) (the shrinker is inserted in the optical path).

In the figures, the reference numeral **1** designates a housing containing an interchangeable lens unit therein. The housing **1** contains therein an extender **2***a* for enlarging the focal length and a shrinker **3***a* for shrinking the focal length shown in FIG. **7**. The housing **1** is provided between a photo-taking lens body **26** having a zoom lens and a camera body **27** (FIG. **3**).

In FIG. **3**, the reference numeral **28** denotes a photographer, and the reference numeral **29** designates the photographer's eyeballs. In FIG. **1**, the reference numeral **1-1** denotes a photo-taking optical path area, and La designates the optical axis thereof. The reference numeral **1-2** denotes an upper retraction area, and the reference numeral **1-3** designates a lower retraction area.

In FIGS. **2A**, **2B** and **2C**, the reference numeral **2** denotes an extender barrel having an extender unit **2***a*. In these figures, there is shown a case where the extender is comprised of an enlarging system lens having two times the photographing magnification and the focal length range of the whole system is varied to two times toward a longer one (two times mode). The reference numeral **3** designates a shrinker barrel holding a converting lens **3***a* to be inserted into an optical path correspondingly to the time when an image size (aspect ratio) is converted. In these figures, there is shown a case where the shrinker is comprised of a shrinking system lens having 0.824 times as the photograph-

ing magnification. Accordingly, in the mode A and mode C which will be described later, substantially the same angle of view is maintained in spite of the aspect ratio having been varied.

The reference numeral **4** denotes a rotary shaft which corresponds to the center of rotation of the extender barrel **2**. The reference numeral **5** designates a rotary shaft which corresponds to the center of rotation of the shrinker barrel **3**. The reference numeral **6** denotes a sector which fixes the rotary shaft **4** and the extender barrel **2**. The reference numeral **7** designates a sector which fixes the rotary shaft **5** and the shrinker barrel **3**. The reference numeral **8** denotes a changeover lever as an operating member for selectively removably inserting the extender barrel **2** and the shrinker barrel **3** into the optical path. The reference character **8***a* designates a lever shaft on which the changeover lever **8** is mounted. The reference numeral **9** denotes a lever for changing over the mode from a mode of an aspect ratio (second aspect ratio) 4:3 to a mode of an aspect ratio (first aspect mode) 16:9 or conversely. The reference numeral **10** designates a gear fixedly mounted on the lever shaft **8***a*. The reference numeral **11** denotes a gear constituting an element of extender changeover means. The gear **11** is fixed to the sector **6** and is in meshing engagement with the gear **10**. The reference numeral **12** designates a gear as shrinker changeover means. The gear **12** is fixed to the sector **7** and is in meshing engagement with a clutch gear **14**.

The clutch gear **14** constitutes an element of connecting means, is slidable in the axial direction of a shaft **13** and is rotatable with the rotation of the lever **9**. That is, the clutch gear **14**, as shown in FIG. **2**C, has a slot **14***c* in the central portion thereof, and a pin **13***a* fixed to the shaft **13** is engaged with the slot **14***c* so that the clutch gear may be slidable only in the axial direction. A gear **14***b* at the right of the clutch gear has a cut-away portion in a portion thereof and is adapted to be connected and disconnected with a stopper **18** which will be described later. The gear **14***a* of the clutch gear is normally in meshing engagement with the gear **12** and slides to thereby mesh with both of the gear **12** and an idler gear **15** and connect these two gears together. The idler gear **15** is normally in meshing engagement with the gear **10**. The reference numeral **16** denotes a spring resiliently holding the extender barrel **2** and the sector **6**. The reference numeral **17** designates a spring resiliently holding the shrinker barrel **3** and the sector **7**. The reference numeral **18** denotes a stopper as connection releasing means provided in the housing **1**. The stopper **18** regulates the meshing engagement between the gear **14** and the idler gear **15** and the releasing thereof. The reference numeral **19** designates a spring biasing the clutch gear **14** leftwardly as viewed in FIG. **2**A. The reference numeral **20** denotes a spring biasing the shaft **13** leftwardly as viewed in FIG. **2**A. The reference numeral **21** (FIG. **1**) designates a driving grip provided sideways of the photo-taking lens **26**.

In the present embodiment, the conversion of the aspect ratio and the enlargement (magnification) of the zoom range are coped with in a state in which one of the extender and the shrinker is removably inserted into a portion of the zoom lens (photo-taking system) **26**, for example, the optical path of a relay lens or in a state in which none of the extender and the shrinker is inserted. The construction of the used states of the extender and the shrinker in each mode at this time is as shown in Table 1 below.

TABLE 1

Aspect ratio	Enlargement magnification of zoom range	Lens unit disposed on the optical axis (area 1-1) of a portion (relay lens) of photo-taking system	Area 1–2	Area 1–3	Mode symbol	Corresponding figure
16:9	one-to-one	none	extender 2	Shrinker 3	mode A	FIG. 1
16:9	two times	extender 2	none	shrinker 3	mode B	FIG. 4
4:3	one-to-one (0.824 time at 16:9)	shrinker 3	extender 2	none	mode C	FIG. 6 (FIG. 7)
4:3	2.427 times	extender 2	none	shrinker 3	mode D	FIG. 5 (FIG. 7)

As shown in Table 1, there are four modes (photographing conditions) for two aspect ratios desired by the photographer. Actually, there are three kinds of disposition, i.e., a case where the extender and the shrinker are absent in the optical path (mode A), a case where the extender is disposed in the optical path (mode B, mode D), and a case where the shrinker is disposed in the optical path (mode C). As described with respect to the prior art, this is from the judgment that from the situation of use of the extender, the correction in a direction to extend the focal length is unnecessary. Accordingly, even when the same extender of two times is used, in the case of a mode of use of an extender of an aspect ratio 4:3, from

2/0.824=2.427,

the focal length of the whole photo-taking system becomes a focal length of apparently 2.427 times.

Operation will now be described.

FIGS. **1**, **2**A, **2**B and **2**C show a case where the aspect ratio is 16:9 and the whole system not using the extender is in mode A of one-to-one magnification (aspect ratio 16:9, one-to-one magnification mode). In this case, as shown in Table 1, the extender barrel **2** and the shrinker barrel **3** are both disposed at positions retracted from the optical axis La.

When in this state, the changeover lever **8** is operated, the lever shaft **8***a* on which the changeover lever **8** is mounted is rotated and the gear **10** is also rotated. Since the gear **10** is in meshing engagement with the gear **11**, the gear **11** is rotated to thereby rotate the sector **6**. Thereby, as shown in FIG. **4**, the extender barrel **2** is disposed on the optical axis La. At this time, the mode becomes mode B (aspect ratio 16:9, two times mode) in which the aspect ratio is 16:9 and the focal length of the whole system has been enlarged to two times.

Also, when conversely, the changeover lever **8** is returned, the same member is reversely rotated and the extender barrel **2** retracts from the optical axis La. In the case of this mode of the aspect ratio 16:9, the gear **14***a* of the clutch gear and the gear **15** provided on the shrinker barrel **3** side do not touch each other at all. Accordingly, the shrinker barrel **3** remains retracted from the optical path. At this time, the mode returns to the mode (aspect ratio 16:9, one-to-one magnification mode) in which the aspect ratio is 16:9 and the focal length range of the whole system is one-to-one magnification free of any variation.

Thus, the present embodiment adopts a construction in which when the mode of the aspect ratio (first aspect ratio)

16:9 is selected, the shrinker is inhibited from entering and only the extender barrel **2** can be changed over by the changeover lever **8**.

Accordingly, under this mode, any reduction in the quantity of light around the image field is prevented by the insertion of the shrinker into the optical path.

Description will now be made of the case of a mode of the aspect ratio (second aspect ratio) 4:3.

Description will first be made of the changeover from the mode A to the mode C when the aspect ratio is changed on the camera body side with the photo-taking system being in one-to-one magnification state.

For the changeover from the mode A shown in FIGS. **1**, **2A**, **2B** and **2C** to the mode C shown in FIG. **6**, the mode changeover lever **9** is rotated. Thereupon, immediately before the rotating operation of the lever **9** is terminated, the clutch gear **14** so far regulated by the stopper **18** comes out of engagement with the stopper **18** and is moved to the left of the shaft **13** as viewed in FIG. **2A** by the biasing force of the spring **19**, and the gear **14***a* of the clutch gear comes into meshing engagement with the gear **15**. Thereby, the extender barrel **2** and the shrinker barrel **3** are connected together. The rotation of the lever **9** is transmitted to the gear **12** by the gear **14***a* of the clutch gear and the center of the optical axis of the shrinker barrel **3** is moved to a position which coincides with the center of the optical axis La, through the sector **7**. Thereby, the mounting of the shrinker **2***a* onto the optical axis is effected and the changeover from the mode A to the mode C is effected.

In this state (mode C), as previously described, the operating force of the operating lever **8** is always transmitted to the shrinker **3***a* through a connecting mechanism. That is, since the gear **14***a* of the clutch gear is in meshing engagement with the gear **12**, the shrinker **3***a* becomes operatively associated with the extender by the operating lever **8** being rotatively operated, and the changeover from the mode C to the mode D becomes possible. Of course, the changeover from the mode D to the mode C can also be accomplished by the operation of the operating lever **8**.

Description will now be made of the changeover from the mode C to the mode A in which nothing is inserted into the optical path and a mechanism therefor. For the changeover from the mode C shown in FIG. **6** to the mode A, the shaft **13** shown in FIG. **7** is pressed and moved rightwardly as viewed in the figure by fingers, while the lever **9** fixed to the same shaft is rotated in the original direction. By the shaft **13** being deviated, the clutch gear **14** is also moved rightwardly as viewed in the figure against the force of the spring **19** and comes out of meshing engagement with the idler gear **15**. Thereafter, the lever **9** is rotated to its original position, whereby the gear **14***a* of the clutch gear is normally in meshing engagement with the gear **12** and therefore, through the sector **7**, the shrinker barrel **3** comes to the area **1-3** in which it was originally positioned. On the other hand, the gear **14***b* is again caught by the stopper **18** due to its axial movement and rotation, and by releasing the fingers, the shaft **13** is returned to its original position by the spring **20** after the rotation of the lever **9**, and stays in a position shown in FIGS. **2A** to **2C**. Thereby, the changeover of the aspect ratio from the mode C to the mode A is effected.

What has been described above is the changeover of the aspect ratio. By this and the above-described extender changeover method, the changeover of all modes is made possible.

The mutual changeover between the mode B and the mode D is effected by electrical processing in the camera body with the extender **2***a* disposed in the optical path.

In the present embodiment, as described above, the changeover to each mode is made easy by the construction in which:

- provision is made of the connecting means and connection releasing means which makes the operation of only changing over the shrinker and the extender by only one changeover operation of the operating means in accordance with the aspect ratio and which can be selected by the photographer;
- provision is made of the connecting means and connection releasing means which can effect the extender changeover operation and the connecting lens unit changeover operation at a time by the converting lens unit changeover operation;
- the center of the rotational movement during the changeover of the extender and the converting lens unit is divided and the retraction location of the lens unit from the optical axis is secured at a position whereat the photographer can confirm the index and a numerical value corresponding thereto;
- some of the gears change their positions in parallelism to the rotary shaft to thereby come out of meshing engagement and effect connection and the releasing of the connection; and
- provision is made of the shaft and the gear movable in the axial direction and transmitting only the rotational force and weighted by the spring and having a convex portion formed on a portion outside the rotary shaft, and the convex portion interferes with the stopper by the angle of rotation of the gear to thereby change the position of the gear.

FIG. **8** is a schematic view of the essential portions of Embodiment 2 of the present invention. This embodiment, as compared with Embodiment 1, is one in which the disposition of the barrels is vertically reversed (in this state, one-to-one magnification of an aspect ratio 4:3). That is, design is made such that the extender barrel **2** is retracted downwardly (the area **1-3**) and the shrinker barrel **3** is retracted upwardly (the area **1-2**). The reference numerals in this figure designate the same parts as those in Embodiment 1.

The reference numeral **30** designates a gear corresponding to the gear **14** in Embodiment 1 and movable in the thrust direction, the reference numeral **31** denotes a gear corresponding to the gear **10** and fixed to the extender changeover lever, and the reference numeral **32** designates an idler gear which is normally in meshing engagement with the gear **11** and the gear **31**. The operation and the movement of the barrels are the same as those in Embodiment 1, and the internal mechanism is also the same as that in Embodiment 1 except the position of the idler and therefore, detailed description of the operation need not be made.

As described above, the disposition of the barrels can be done anyway, depending on the positional relation of the idler gear.

FIG. **9** is a schematic view of the essential portions of Embodiment 3 of the present invention. This embodiment, as compared with Embodiment 2 of FIG. **8**, is one in which the operating system is vertically reversed (in this state, one-to-one magnification of an aspect ratio 4:3). The reference numerals in this embodiment designates the same parts as those in Embodiments 1 and 2. The reference numeral **33** denotes an idler gear corresponding to the idler gear **15** in Embodiment 1, and the reference numeral **34** designates a gear corresponding to the gear **10** and fixed to the extender changeover lever. The only difference of this embodiment

from Embodiment 2 is that the changeover direction of the extender is converse, and the operation of this embodiment is similar to that of Embodiment 2 and therefore need not be described. As described above, the direction of operation can be anyway, depending on the positional relation of the idler gear.

In Embodiment 1, the magnification of the extender has been described with respect to the case of two times, but may be any other magnification. Also, when for a camera having an image pickup element of which the aspect ratio of the image pickup surface is 4:3, an image field of an aspect ratio 16:9 which is an area thereof is to be photographed, a vertical portion of the image field is not used, but the area of 16:9 of the central portion may be used, or in such case, the magnification of the shrinker may be changed to 0.917 time and may be made to correspond thereto. Also, even when the aspect ratio differs, a shrinker magnification corresponding thereto may likewise be adopted and may be made to correspond thereto.

According to the present invention, as described above, in the photo-taking system having the converting lens (shrinker) for the changeover of the aspect ratio and the extender, there can be achieved an image pickup apparatus capable of changing over the aspect ratio in which a driving mechanism for effecting the removable insertion of both lenses into the optical path is appropriately set, whereby irrespective of the use or non-use of the shrinker, by only the operation of removably inserting the extender into the optical path, photographing can be effected easily at one-to-one magnification or a different magnification (focal length range).

Particularly, the present invention can cope with a camera with the aspect ratio changeover function which enables the quick extender operation by the operation of the changeover lever similar to that in the prior art to be performed without giving a feeling of physical disorder to a photographer accustomed to the photographing operation of a zoom lens for the conventional handy camera with an extender.

Also, the photographer, after he has once selected an aspect ratio, can be conscious of only the selection of one-to-one magnification and the extender as before and therefore, these makes it unnecessary for the photographer to newly learn to use the new function of changing over the aspect ratio, and can effectively prevent the eclipse of the photographed image which is a mistake absolutely unallowable in photographing.

Also, it becomes possible to minimize the area of the movement locus of the lens and very much simplify the entire changeover mechanism and therefore, as compared with the turret type according to the prior art, it is possible to make the entire photographing system light in weight. At the same time, the shape made compact as compared with the turret type does not spoil the visual confirmability of a scale for operation, index lines, etc. disposed on the circumference of the lens.

An embodiment improved over the above-described embodiments will now be described with reference to FIGS. **12** to **17**. The improved points are that the clutch gear **14** and the stopper **18** in the above-described embodiments are eliminated and that the shaft **5** is improved to thereby improve the operability. The members designated by the other reference numerals perform the same functions and therefore need not be described in detail.

The reference character **5***a* designates a small gear as an element of converting lens changeover means. The small gear **5***a* is fixed to the rotary shaft **5**.

The reference character **5***b* denotes a large gear as an element of the converting lens changeover means. The large gear **5***b* is fixed to the rotary shaft **5**. The reference numeral **13** designates a shaft gear constituting an element of connecting means and fixed to the lever **9**. A large gear **13***a* and a small gear **13***b* are secured to the shaft **13***c* of the shaft gear **13**. The small gear **5***a*, the large gear **5***b* and the shaft gear **13** together constitute an element of a speed reducing mechanism. The gear **13***a*, as shown in FIG. **13B**, has a cut-away portion in a portion thereof, and this cut-away portion is in such relationship as not to mesh with the gear **15** in the case of a mode of 16:9.

The shaft **13***c* is slidable in the axial direction thereof and is rotatable with the rotation of the lever **9**. The shaft **13***c* is such that by its sliding, the large gear **13***a* meshes with the idler gear **15** and the small gear **5***a* (FIGS. **13A** and **13B**) or the small gear **13***b* meshes with the large gear **5***b* (FIG. **14**). The idler gear **15** is normally in meshing engagement with the gear **10**.

The construction of the used states of the extender and the shrinker in each mode at this time is as follows when shown analogically to the table shown below.

TABLE 2

Aspect ratio	Enlargement magnification of zoom range	Lens unit disposed on the optical axis (area 1-1) of a portion (relay lens) of photo-taking system	Area 1–2	Area 1–3	Mode symbol	Corresponding figure
16:9	one-to-one	none	extender 2	shrinker 3	mode A	FIG. 12 FIG. 14
16:9	two times	extender 2	none	shrinker 3	mode B	FIG. 15
4:3	one-to-one (0.824 time at 16:9)	shrinker 3	extender 2	none	mode C	FIGS. 13A, 13B FIG. 16
4:3	2.427 times	extender 2	none	shrinker 3	mode D	FIG. 17

Under such a construction, when the aspect ratio is 16:9, the gear **13***a* and the gear **15** are not in meshing engagement with each other and therefore, by the operating lever **8** being rotated, only the extender **2** of two times becomes removably insertable onto the optical axis La (FIGS. **12**, **13A**, **13B** and **15**). That is, the changeover of the mode A and the mode B becomes possible by the operation of the operating lever **8**.

Description will now be made of the operation of changing over the mode from the mode of the aspect ratio 16:9 to the mode of the aspect ratio 4:3. The changeover from the mode A (the converting lens is absent on the optical axis La) to the mode C is effected as follows.

The shaft **13** is first pressed and slidden by fingers against the spring **20** to thereby bring the small gear **13***a* into meshing engagement with the gear **5***b*. Subsequently, the lever **9** is rotated to thereby insert the shrinker **3** into the optical path (the mode C). By releasing the fingers, the shaft slides leftwardly and now the gear **13***a* comes into meshing engagement with the gear **15** and thus, the rotative operation of the operating lever **8** is transmitted to the shrinker **3**.

That is, the rotation of the operating lever **8** is transmitted to the gears **15**, **13***a* and **5***a*, and the extender and the shrinker are always operatively associated with each other, and the changeover from the mode C to the mode D or the converse mode changeover becomes possible.

Conversely, for the changeover from the mode of the aspect ratio 4:3 to the mode of the aspect ratio 16:9, the mode is first set to the mode C, whereafter the shaft **13***c* is pressed by fingers and the gear **13***b* is brought into meshing engagement with the gear **5***b*, whereafter the lever **8** is rotated to its original position, whereupon the shrinker is retracted from the optical axis La. By releasing the fingers, the original state is restored.

In the present embodiment, the diameter of the gear **13***b* of the gears meshing with each other during the changeover of the aspect ratio is made smaller than the diameter of the gear **5***a*, whereby the operating force required to removably insert the shrinker can be made small and the operability is successfully improved.

An embodiment of another form will now be described with reference to FIGS. **18** to **22**.

FIG. **18** is a cross-sectional view of the essential portions of the present embodiment, FIGS. **19**A and **19**B are side views of the essential portions of FIG. **18**, and FIGS. **20** to **22** are illustrations of the present embodiment.

FIGS. **19**A and **19**B show the case of the aspect ratio 16:9 and one-to-one magnification mode (both of the extender and the shrinker are absent in the optical path).

FIG. **20** shows the case of the aspect ratio 16:9 and two times mode (the extender is inserted in the optical path).

FIGS. **21**A and **21**B show the case of the aspect ratio 4:3 and 2.427 times mode (the extender is inserted in the optical path).

FIG. **22** shows the case of the aspect ratio 4:3 and one-to-one magnification mode (the shrinker is inserted in the optical path).

Elements designated by the same reference characters as in the aforedescribed embodiment perform similar functions and therefore need not be described.

In FIGS. **18** to **22**, the reference numeral **34** designates a rotary shaft which corresponds to the center of rotation of the extender barrel **2**. The reference numeral **35** denotes a rotary shaft which corresponds to the center of rotation of the shrinker barrel **3**. The reference numeral **6** designates a sector which holds the rotary shaft **34** and the extender lens **2**. The reference numeral **7** denotes a sector which holds the rotary shaft **35** and the shrinker lens **3**. The reference numeral **38** designates a changeover lever as an operating member which selectively removably mounts the extender lens **2** and the shrinker lens **3** in the optical path. The reference numeral **39** denotes a lever shaft on which the changeover lever **38** is mounted. The reference numeral **30** designates a changeover knob as an element of connection releasing means and aspect ratio setting means. The changeover knob **30** is operated with the changeover from the mode of the aspect ratio (second aspect ratio) 4:3 to the mode of the aspect ratio (first aspect ratio) 16:9. The reference numeral **31** denotes a gear as extender changeover means. The gear **31** is fixed to the sector **6** and in FIG. **18**, it is in meshing engagement with a clutch gear (connecting means) **33**. The reference numeral **32** designates a gear as converting lens changeover means. The gear **32** is fixed to the sector **7** and is capable of meshing with the clutch gear **33**.

The clutch gear **33** is slidable in the axial direction of the lever shaft **39** and rotatable with the rotation of the lever shaft **39**. The clutch gear **33** slides to thereby mesh with only the gear **31** or with both of the gear **31** and the gear **32**. The reference numeral **34** denotes a pin which transmits the rotation of the lever shaft **39** to the clutch gear **33**. The reference numeral **35** designates a stopper which holds the sector **6** for holding the extender barrel **2** on the optical axis.

The reference numeral **36** denotes a stopper which holds the sector **7** for holding the shrinker barrel **3** on the optical axis. The reference numeral **37** designates a stopper which holds the sector **6** in a position wherein the extender barrel **2** is retracted from the optical axis. The reference numeral **38** denotes a stopper which holds the sector **7** in a position wherein the shrinker barrel **3** is retracted from the optical axis La of the photo-taking system. The reference numeral **41** designates a spring which resiliently holds the extender barrel **2** and the sector **6**. The reference numeral **40** denotes a spring which resiliently holds the shrinker barrel **3** and the sector **7**.

In the present embodiment, with one of the extender and the shrinker removably inserted or neither of them inserted in a portion of the zoom lens (photo-taking system), for example, the optical path of a relay lens, the changeover of the aspect ratio and the enlargement (magnification) of the zoom range are coped with. The construction of the used states of the extender and shrinker in each mode at this time is as shown in the table below.

TABLE 3

Aspect ratio	Enlargement magnification of zoom range	Lens unit disposed on the optical axis of a portion (relay lens) of photo-taking system	Corresponding figure
16:9	one-to-one	none	FIG. 18
16:9	two times	extender	FIG. 20
4:3	one-to-one	shrinker	FIG. 22
4:3	2.427 times	extender	FIGS. 21A, 21B

As shown in this table, there are four modes (photographing conditions) for two aspect ratios desired by the photographer. Actually, there are three kinds of disposition, i.e., a case where the extender and the shrinker are absent in the optical path, a case where the extender is disposed in the optical path, and a case where the shrinker is exposed in the optical path. As described with respect to the prior art, this is from the judgment that from the situation of use of the extender, the correction in a direction to extend the focal length is unnecessary. Accordingly, even when the same extender of two times is used, in the case of a mode of use of an extender of the aspect ratio 4:3, from

$$2/0.824=2.427,$$

the focal length of the whole photo-taking system becomes a focal length of apparently 2.427 times.

In the case of a mode in which the aspect ratio is 16:9 (a mode of the aspect ratio 16:9), the shrinker barrel **3** is always in a state retracted from the optical axis La. By the extender changeover lever **38** being operated, only the extender barrel **2** is removably inserted onto the optical axis to thereby vary the focal length range of the whole system to one-to-one magnification (one-to-one magnification mode) and two times (two times mode). Also, in the case of a mode in which the aspect ratio is 4:3 (a mode of the aspect ratio 4:3), the extender changeover means **31** and the shrinker changeover means **32** are connected together by the connecting means **33** which is a clutch gear so that one of the shrinker barrel **3** and the extender barrel **2** may be disposed on the optical axis La without fail by one operation of the operating member **38**. That is, the shrinker barrel **3** and the extender barrel **2** are connected together by the clutch gear **33** so as to be moved at a time by one operation of the changeover lever **38**.

The operation at this time will now be described in accordance with the operation of the changeover lever **38**.

FIGS. **18**, **19**A and **19**B show cases where the aspect ratio is 16:9 and the whole system not using the extender is at one-to-one magnification (the aspect ratio 16:9, one-to-one magnification mode). At this time, as shown in the table above, the extender barrel **2** and the shrinker barrel **3** are both disposed at positions retracted from the optical axis La.

When in this state, the changeover lever **38** is operated, the lever shaft **39** on which the changeover lever **38** is mounted is rotated and the clutch gear **33** is also rotated therewith through the pin **34**. Since the clutch gear **33** is in meshing engagement with the gear **31**, the gear **31** is rotated to thereby rotate the sector **6**. Thereby, as shown in FIG. **20**, the extender barrel **2** is disposed on the optical axis La. At this time, the mode becomes a mode in which the aspect ratio is 16:9 and the focal length range of the whole system has been enlarged to two times (the aspect ratio 16:9, two times mode).

Also, when conversely, the changeover lever **38** is returned to its original position, the same member is reversely rotated to thereby retract the extender barrel **2** from the optical axis La. In the meantime, the clutch gear **33** does not at all touch the gear **32** provided on the shrinker barrel **3** side and accordingly, the shrinker barrel **3** remains retracted from the optical path. At this time, the mode becomes a mode in which the aspect ratio is 16:9 and the focal length range of the whole system is unchanged, i.e., one-to-one magnification (the aspect ratio 16:9, one-to-one magnification mode).

As described above, in the present embodiment, when the aspect ratio (first aspect ratio) 16:9 mode is selected, only the extender lens is changed over by the changeover lever **38**.

Description will now be made of the case of a mode of the aspect ratio (second aspect ratio) 4:3.

As previously described, in the present invention, mode changeover is effected by the aspect ratio setting means **30** with the extender **2***a* disposed on the optical axis La and therefore, the changeover lever **38** is once operated to thereby dispose the extender barrel **2** on the optical axis La.

Here, the changeover knob **30** is rotated to effect mode changeover and the clutch gear **33** is pushed leftwardly as viewed in FIG. **19**A by a projection **30***a* provided integrally with the changeover knob **30**. As a result, as shown in FIGS. **21**A and **21**B, the clutch gear **33** slides on the lever shaft **39** and is fixed at a position in which it meshes with the gear **32** disposed in advance so as to mesh with the clutch gear **33**. In this state, the changeover lever **38** is in the position of extender ON and therefore, when it is returned to its original position, the extender barrel **2** is retracted from the optical axis by the transmission of the rotation of the clutch gear **33** and the gear **31** as in the case of the aspect ratio 16:9 mode.

The rotation is likewise transmitted to another gear **32** with which the clutch gear **33** is in meshing engagement, and the sector **7** is rotated about the rotary shaft **35** through the gear **32**, and the shrinker barrel **3** becomes operatively associated with the extender barrel **2**, whereby the extender barrel **2** is moved toward the optical axis conversely to being retracted from the optical axis, and becomes positioned on the optical axis. Here, the angles by which the sector **6** and the sector **7** are rotatable are substantially the same and the speed reduction ratios of the clutch gear **33** and the gear **31** and of the clutch gear **33** and the gear **32** are the same.

Also, the meshing engagement among the gears **31**, **32** and **33** is provided with a play sufficient to absorb the irregularity of the angle of rotation of each sector in the manufacture thereof. Therefore, design is made such that the sector **7** reliably strikes against the stopper **38** when the stopper **35** for positioning the extender barrel **2** at a position on the optical axis La is regulating the rotation of the sector **6**.

Also, design is made such that the sector **6** reliably strikes against the stopper **7** when the stopper **36** for positioning the shrinker barrel **3** at a position on the optical axis La is regulating the rotation of the sector **7**.

Thus, as shown in FIG. **22**, the changeover knob **30** is rotated, whereafter the changeover lever **38** is operated, whereby the extender barrel **2** may be retracted from the optical axis and at the same time, the shrinker barrel **3** may be disposed on the optical axis. Thereby, there is brought about a mode of an aspect ratio 4:3 and one-to-one magnification (the aspect ratio 4:3, one-to-one magnification mode).

When from this state, the changeover lever **38** is again returned to its original position, the shrinker barrel **3** is retracted from the optical axis and at the same time, the extender barrel **2** becomes again positioned on the optical axis. Thereby, there is brought about a mode in which the aspect ratio is 4:3 and the focal length range of the whole system has been displaced by 2.427 times toward a longer one (the aspect ratio 4:3, 2.427 times mode).

In the present embodiment, even in the case of a photographing mode of the aspect ratio 4:3, the shrinker barrel **3** and the extender barrel **2** become removably inserted in operatively associated relationship with each other, and after a mode has once been set, as in the case of the aspect ratio 16:9, the extender operation is made possible by only the operation of the changeover lever **38**, like the prior-art photo-taking lens which does not constitute a shrinker. After the extender has been returned onto the optical axis, the mode changeover knob **30** is again rotated, that is, the connection of the connecting means **33** is released to return it to its original position, whereupon photographing at the aspect ratio 16:9 again becomes possible.

It has been described that when the mode changeover knob **30** is operated when the extender barrel **2** is on the optical axis as described above, the mode changeover of the aspect ratio 16:9 and the aspect ratio 4:3 is possible, but when the photographer effects mode changeover by mistake during photographing in the aspect ratio 16:9 mode and at one-to-one magnification, the extender barrel **2** and the shrinker barrel **3** will become operatively associated with each other while being both retracted from the optical axis, and the changeover lever **38** will become unmovable in any direction.

In order to avoid the photographer's wrong operation so as not to fall into such a state, in the present embodiment, when as shown in FIGS. **21**A and **21**B, the changeover lever **38** is in one-to-one magnification position, a portion (inhibiting means) **38***a* of this changeover lever **38** is disposed so as to cover the mode changeover knob **30**. Thus, design is made such that the changeover during one-to-one magnification which poses a problem in operation is made impossible and the photographer never operates wrongly.

While in the present embodiment, the angle of retraction at which the extender barrel **2** is retracted from the optical axis and the angle at which the shrinker barrel **3** is retracted from the optical axis have been described as being substantially the same, a great angle of retraction may be secured for only the extender barrel **2** or only the shrinker barrel **3**, and the speed reduction ratios between the clutch gear **33** and the gear **31** and between the clutch gear **33** and the gear **32** referred to in FIGS. **19**A and **19**B may be changed to ones conforming to the angle of retraction.

FIG. **25** shows the case of the aspect ratio 16:9, one-to-one magnification mode (neither of the extender **2***a* and the shrinker (converting lens) **3***a* is present in the optical path).

FIGS. **23** and **24** show the case of the aspect ratio 16:9, two times mode (the extender is inserted in the optical path).

FIGS. **26** and **27** show the case of the aspect ratio 4:3, one-to-one magnification mode (the shrinker is inserted in the optical path).

The reference numeral **54** designates a rotary shaft which corresponds to the center of rotation of the extender barrel **2** and of the shrinker barrel **3**. The reference numeral **6** denotes a sector which fixes the rotary shaft **54** and the extender barrel **2**. The reference numeral **7** designates a sector which files the rotary shaft **54** and the shrinker barrel **3**. The reference numeral **57** denotes a changeover lever as an operating member on which the extender barrel **2** and the shrinker barrel **3** are mounted for selective removable insertion into the optical path. The reference numeral **58** designates a lever shaft on which the changeover lever **57** is mounted.

The lever shaft **58** has a gear **58***a* thereon. The reference numeral **59** denotes a gear member fixed to the rotary shaft **54**. A gear **59***a* provided on the outer periphery of the gear member **59** is shown as being in meshing engagement with the gear **58***a* on the lever shaft **58** in FIGS. **23** and **24**. The rotary shaft **54**, the sector **6** and the gear member **59** together constitute an element of extender changeover means. The rotary shaft **54**, the sector **7**, etc. together constitute an element of converting lens changeover means.

The reference numeral **60** designates a clutch knob. The reference numeral **61** denotes a connecting pin which connects a clutch body **62** and the clutch knob **60** together. The clutch body **62** is operatively associated with the rotation of the clutch knob **60** and the connecting pin **61** and is rotatable about the rotary shaft **54**. The reference numeral **63** designates a spring which biases the clutch body **62** toward the optical axis La. The reference numeral **64** denotes a clutch pin fixed to the clutch body **62**. The clutch pin **64** slides in the direction of the optical axis to thereby effect the connection thereof to the gear member **59** and the release of the connection. The reference numeral **65** designates a clutch pin fixed to the clutch body **62** and connected to the sector **7**.

The reference numeral **68** denotes a mode fixing switch, and the reference numeral **69** designates a mode fixing plate which is fixed to the mode fixing switch **68** and prevents the connection between the clutch pin **64** and the gear member **59**. The mode fixing switch **68**, the clutch knob **60** and the clutch body **62** together constitute an element of mode changeover means.

In the present embodiment, the construction of the used states of the extender and shrinker in each mode is as shown in the table below.

TABLE 4

Aspect ratio	Enlargement magnification of zoom range	Lens unit disposed on the optical axis of a portion (relay lens) of photo-taking system	Corresponding figure
16:9	one-to-one	none	FIG. 25
16:9	two times	extender	FIGS. 23 and 24
4:3	one-to-one	shrinker	FIGS. 26 and 27
4:3	2.427 times	extender	FIGS. 23 and 24
4:3	1.214 times	none	FIG. 25

In the present embodiment, as shown in the table above, there are five modes (photographing conditions) for two aspect ratios desired by the photographer. Actually, there are three kinds of disposition, i.e., a case where the extender and the shrinker are absent in the optical path, a case where the extender is disposed in the optical path, and a case where the shrinker is disposed in the optical path. As described with respect to the conventional art, this is from the judgment that from the situation of use of the extender, the correction in a direction to extend the focal length is unnecessary. Accordingly, even when the same extender of two times is used, in the case of a mode of use of an extender of the aspect ratio 4:3, from

2/0.824=2.427,

the focal length of the whole photo-taking system becomes a focal length of apparently 2.427 times.

Also, in the case of the mode of the aspect ratio 4:3, if the extender and the shrinker are both retracted from the optical path, as the reason why the shrinker is required, the focal length will extend toward the telephoto side as previously described and therefore, a hindrance will occur in the photographing at a wide angle. However, if the shrinker is constructed and this problem is solved, it will **6**e possible to utilize this nature as in the present embodiment and utilize an extender of apparently low magnification as being inserted. In this case, the apparent magnification of the extender is 1.214 times which is an inverse number of the magnification of the shrinker.

In the present embodiment, when a mode in which the aspect ratio is 16:9 (the aspect ratio 16:9 mode) is set by aspect ratio setting means (not shown) on the camera body side, the shrinker barrel **3** is always in its retracted state from the optical axis La.

The changeover lever **57** is operated to thereby removably insert only the extender barrel **2** onto the optical axis and vary the focal length range of the whole system to the one-to-one magnification (one-to-one magnification mode) of FIG. **25** and the two times (two times mode) of FIG. **23**. Also, in the case of the mode in which the aspect ratio is 4:3 (the aspect ratio 4:3 mode), by the operation of the changeover lever **57**, the shrinker barrel **3** or the extender barrel **2** may be positioned on the optical axis or both of them may be positioned off the optical axis. That is, by the operation of the changeover lever **57**, their positions are changed to those of FIGS. **23**, **25** and **27**.

The operation at this time will now be described in accordance with the operation of the changeover lever **57**.

FIGS. **23** and **24** show a case where the aspect ratio is 16:9, the extender is used and the whole system is at two times (the aspect ratio 16:9, two times mode). At this time, as shown in the previous table, the extender barrel **2** is disposed on the optical axis and the shrinker barrel **3** is disposed in a position retracted from the optical axis La.

When in this state, the changeover lever **57** is operated, the lever shaft **58** on which the changeover lever **57** is mounted is rotated and the gear **59***a* is also rotated therewith through the gear **58***a*. Since the gear member **59** is fixed to the sector **6**, it rotates the sector **6**. Thereby, as shown in FIG. **25**, the extender barrel **2** is retracted from the optical axis La. At this, the mode becomes a mode in which the aspect ratio is 16:9 and the focal length range of the whole system is one-to-one magnification (the aspect ratio 16:9, one-to-one magnification mode).

When conversely, the changeover lever **57** is returned to its original position, the same member is reversely rotated and the extender barrel **2** is positioned on the optical axis La. In the meantime, the clutch pin **64** provided on the clutch body **62** operatively associated with the shrinker barrel **3** side is prevented from being connected to the gear member **59** by the mode fixing plate **69**. Accordingly, the shrinker

barrel **3** remains retracted from the optical path. At this time, the mode becomes a mode in which the aspect ratio is 16:9 and the focal length range of the whole system is two times (the aspect ratio 16:9, two times mode).

As described above, in the present embodiment, when the aspect ratio (first aspect ratio) 16:9 mode is selected, the operation of the extender is effected by only the changeover operation of the changeover lever **57** as in the prior-art photo-taking lens which does not constitute a shrinker.

Description will now be made of the case of the mode of the aspect ratio (second aspect ratio) 4:3.

When the aspect ratio 4:3 mode is selected by the aspect ratio setting means (not shown) on the camera body side or the lens side, the mode fixing switch **58** is released on the lens side and the mode fixing plate **69** is slidden and retracted. The clutch knob **60** is then rotated to thereby fit the clutch pin **64** biased by the spring **63** into an aperture formed in the gear member **59**. Thereby, the connection between the converting lens changeover means and the extender changeover means or the operating member is effected (when the aspect ratio is 16:9, the clutch knob **60** is slidden in the direction of the optical axis against the force of the spring **63** to thereby release the connection between the clutch pin **64** and the gear member **59**, and then the mode fixing switch **68** is changed over to thereby release the connection between the converting lens changeover means and the extender changeover means.

First, the retraction of the extender barrel **2** from the optical axis to the positions of FIGS. **23** to **25** is effected by rotating the changeover lever **57** as in the aspect ratio 16:9 mode previously described. However, as shown in the previous table, in the aspect ratio 4:3 mode, use is made with the case of FIG. **25** where the extender is absent as 1.214 times, and with the case of FIG. **23** where the extender is present as 2.427 times.

The changeover lever **57** is then further rotated from the state of FIG. **25**. By this operation of the changeover lever **57**, the lever shaft **58** is rotated and the clutch body **62** and the sector **7** are rotated about the rotary shaft **54** through the gear **58***a* and the clutch pin **64**, whereby the shrinker barrel **3** is disposed on the optical axis.

Thereby, as shown in FIG. **26**, the shrinker barrel **3** is positioned on the optical axis. At this time, the mode is a one-to-one magnification mode of the aspect ratio 4:3.

If the mode fixing switch **68** is changed over by a procedure converse to the above-described operation, the mode can be returned to the mode of the aspect ratio 16:9.

In the present invention, design is made such that the changeover shaft of the changeover lever **57** is left of the optical axis as viewed from the camera side, but alternatively, design may be made such that the changeover shaft is right of the optical axis. Also, design may be made such that the shrinker barrel **3** is retracted upwardly and the extender barrel **2** is retracted downwardly.

In the present embodiment, the magnification of the extender has been described as two times, but the extender may be designed at any other magnification. Also, when for a camera having an image pickup element of which the aspect ratio of the image pickup surface is 4:3, the image field of the aspect ratio 16:9 which is an area thereof is to be photographed, a vertical portion of the image field is not used, but the central area of the aspect ratio 16:9 may be used or in this case, the magnification of the shrinker may be changed to 0.917 times, thereby coping with it. Also, even when the aspect ratio differs, a shrinker magnification conforming thereto may likewise be adopted to thereby cope with it.

According to the present invention, as described above, there can be achieved an image pickup apparatus capable of changing over the aspect ratio wherein in a photo-taking system having a converting lens (shrinker) and an extender for the changeover of the aspect ratio, a driving mechanism for effecting the removable insertion of the both lenses into the optical path is appropriately set, whereby the extender or the shrinker may easily or may not be positioned in the optical path and photographing can be effected easily at a predetermined aspect ratio and one-to-one magnification or different magnifications (focal length range).

Particularly, the present invention can cope with a camera with the aspect ratio changeover function which does not give a feeling of physical disorder to any photographer accustomed to the photographing operation of a zoom lens for a prior-art handy camera with an extender and which enables a quick extender operation by the operation of a changeover lever similar to that of the prior art.

Also, after the photographer has once selected an aspect ratio, he can be conscious of only the selection of one-to-one magnification and the extender as in the prior art and therefore, these make it unnecessary for the photographer to newly learn to use the new function of changing over the aspect ratio, and the eclipse of a photographed image which is a mistake absolutely unallowable in photographing can be effectively prevented.

Also, in the photographing in the aspect ratio 4:3 mode, the extender function of the order of 1.2 times can be realized without newly adding any optical system besides the shrinker prepared for one-to-one magnification. Thus, even when during photographing in a dark place, the use of an extender of two times reduces the quantity of light to half and therefore it is difficult to enlarge the focal length, it becomes possible to minimize the reduction in the quantity of light and make the focal length on the telephoto side equal to that of a lens ranking above by one class, and an extender of a little over 2.4 times can be provided and the range of selection can be more widened for the photographer.

What is claimed is:

1. An objective lens for application to an image pickup apparatus of which the size of the image pickup surface is changeable over between a first mode having a first aspect ratio and a second mode having a second aspect ratio, said objective lens comprising:

first optical means for extending the focal length of said objective lens;

second optical means for shrinking the focal length of said objective lens;

an operating member; and

a transmitting mechanism for transmitting the operating force of said operating member to said first optical means under said first mode, and transmitting the operating force of said operating member to said first and second optical means under said second mode;

wherein by the operation of said operating member, under said first mode, said first optical means is removably insertable into the optical path of said objective lens,

and under said second mode, each of said first and second optical means is removably insertable into the optical path of said objective lens.

2. An objective lens according to claim 1, wherein said first optical means is rotatable about a first shaft, said second optical means is rotatable about a second shaft, and said first and second optical means are rotated about said first and second shafts, respectively, whereby they are removably insertable into the optical path of said objective lens.

3. An objective lens according to claim 1, wherein the first aspect ratio is 16:9.

4. An objective lens according to claim 1, wherein the second aspect ratio is 4:3.

5. An objective lens according to claim 1, wherein said transmitting mechanism inhibits the transmission of the operating force of said operating member under said first mode.

6. An objective lens according to claim 2, wherein the center of rotation of said operating member has a rotatable gear thereon, said first and second shafts have a first gear and a second gear, respectively, thereon, the teeth of said rotatable gear and said first gear normally mesh with one another, and under said second mode, said rotatable gear and said second gear mesh with each other.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 5,696,634 Page 1 of 3

DATED : December 9, 1997

INVENTOR(S) : ITARU WATANABE, ET AL.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Title page, item

[56] References Cited (U.S. PATENT DOCUMENTS)

"Matsubsita" should read --Matsushita--.

[56] References Cited (OTHER PUBLICATIONS)

"No. 18," should be deleted.

COLUMN 1

Line 22, "of the " should read --the--.
Line 50, "axises" should read --arises--.

COLUMN 4

Line 30, "of an" should read --an--.
Line 67, "as the" should read --the--.

COLUMN 8

Line 62, "designates" should read --designate--.

COLUMN 9

Line 4, "anyway" should read --any way--.
Line 41, "these" should read --this--.

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

DATED : December 9, 1997

INVENTOR(S) : ITARU WATANABE, ET AL.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

COLUMN 10

Line 55, "slidden" should read --slid--.

COLUMN 11

Line 22, "of the" should read --the--.
Line 63, "both of" should read --both--.

COLUMN 15

Line 13, "files" should read --fixes--.

COLUMN 16

Line 20, "6e" should read --be--.

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 5,696,634 Page 3 of 3

DATED : December 9, 1997

INVENTOR(S) : ITARU WATANABE, ET AL.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

COLUMN 17

Line 15, "slidden" should read --slid--.
Line 21, "slidden" should read --slid--.

COLUMN 18

Line 11, "the both" should read --both--.
Line 39, "when" should be deleted.

Signed and Sealed this

Twenty-second Day of September, 1998

Attest:

BRUCE LEHMAN

Attesting Officer

Commissioner of Patents and Trademarks

US005692061A

United States Patent [19]

Sasada et al.

[11] Patent Number: 5,692,061

[45] Date of Patent: Nov. 25, 1997

[54] **METHOD OF UTILIZING A TWO-DIMENSIONAL IMAGE FOR DETECTING THE POSITION, POSTURE, AND SHAPE OF A THREE-DIMENSIONAL OBJECTIVE**

[75] Inventors: **Katsuhiro Sasada; Tomoharu Nakahara; Hidekazu Araki**, all of Kadoma, Japan

[73] Assignee: **Matsushita Electric Works, Ltd.**, Osaka, Japan

[21] Appl. No.: **391,006**

[22] Filed: **Feb. 21, 1995**

[30] **Foreign Application Priority Data**

Feb. 23, 1994 [JP] Japan 6-025731
Dec. 20, 1994 [JP] Japan 6-317279

[51] **Int. Cl.**[6] **G06K 9/00**

[52] **U.S. Cl.** **382/106**; 382/154

[58] **Field of Search** 382/103, 106, 382/154, 291; 348/42, 135; 356/12, 20

[56] **References Cited**

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6-29695 4/1994 Japan G01B 11/00

Primary Examiner—Andrew Johns
Attorney, Agent, or Firm—Burns, Doane, Swecker & Mathis, L.L.P.

[57] **ABSTRACT**

A method for recognizing a three-dimensional objective in which a two-dimensional image is obtained from the same viewing point as a distance image obtained by picking up the objective in a three-dimensional space and the two-dimensional image is utilized to previously limit an existence zone of the objective under detection for the distance image and to perform objective detecting operation over the partial distance image in the limited zone, thereby realizing a sufficiently high speed detection of, in particular, the three-dimensional objective.

8 Claims, 58 Drawing Sheets

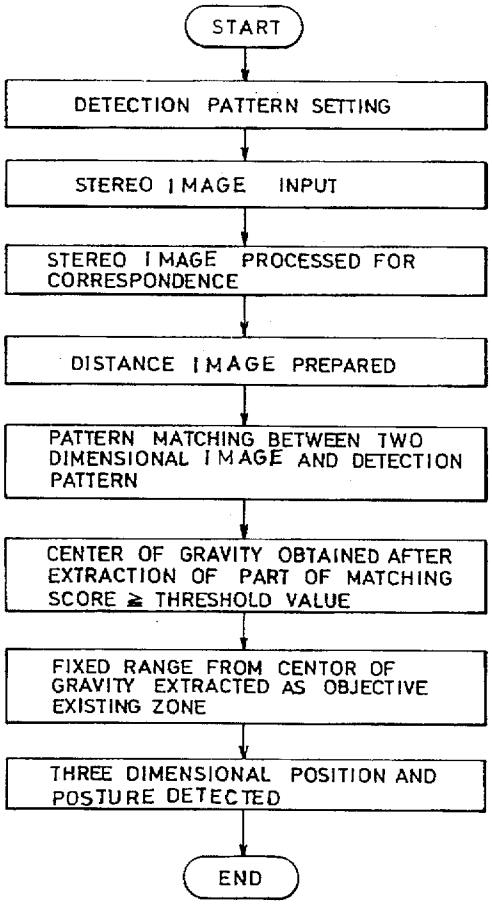


FIG. 1

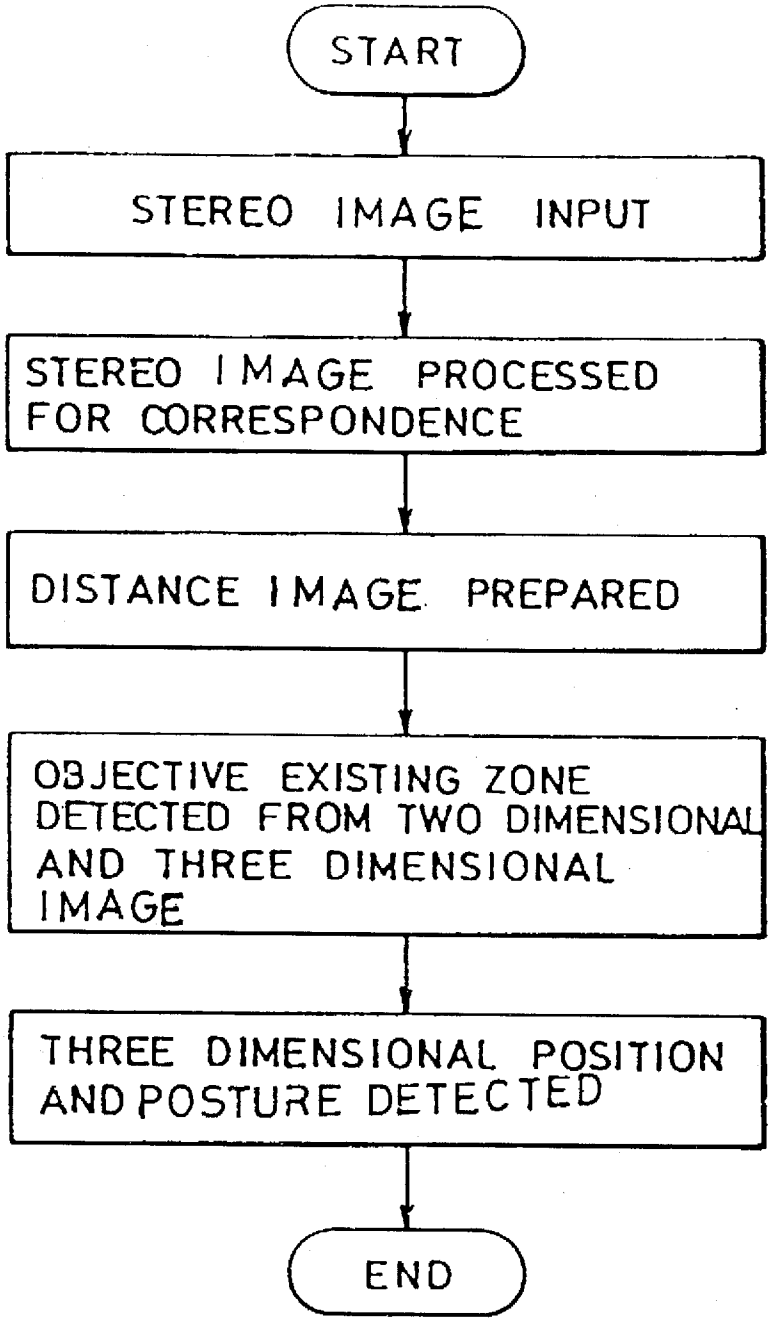

START
STEREO IMAGE INPUT
STEREO IMAGE PROCESSED FOR CORRESPONDENCE
DISTANCE IMAGE PREPARED
OBJECTIVE EXISTING ZONE DETECTED FROM TWO DIMENSIONAL AND THREE DIMENSIONAL IMAGE
THREE DIMENSIONAL POSITION AND POSTURE DETECTED
END

FIG. 2

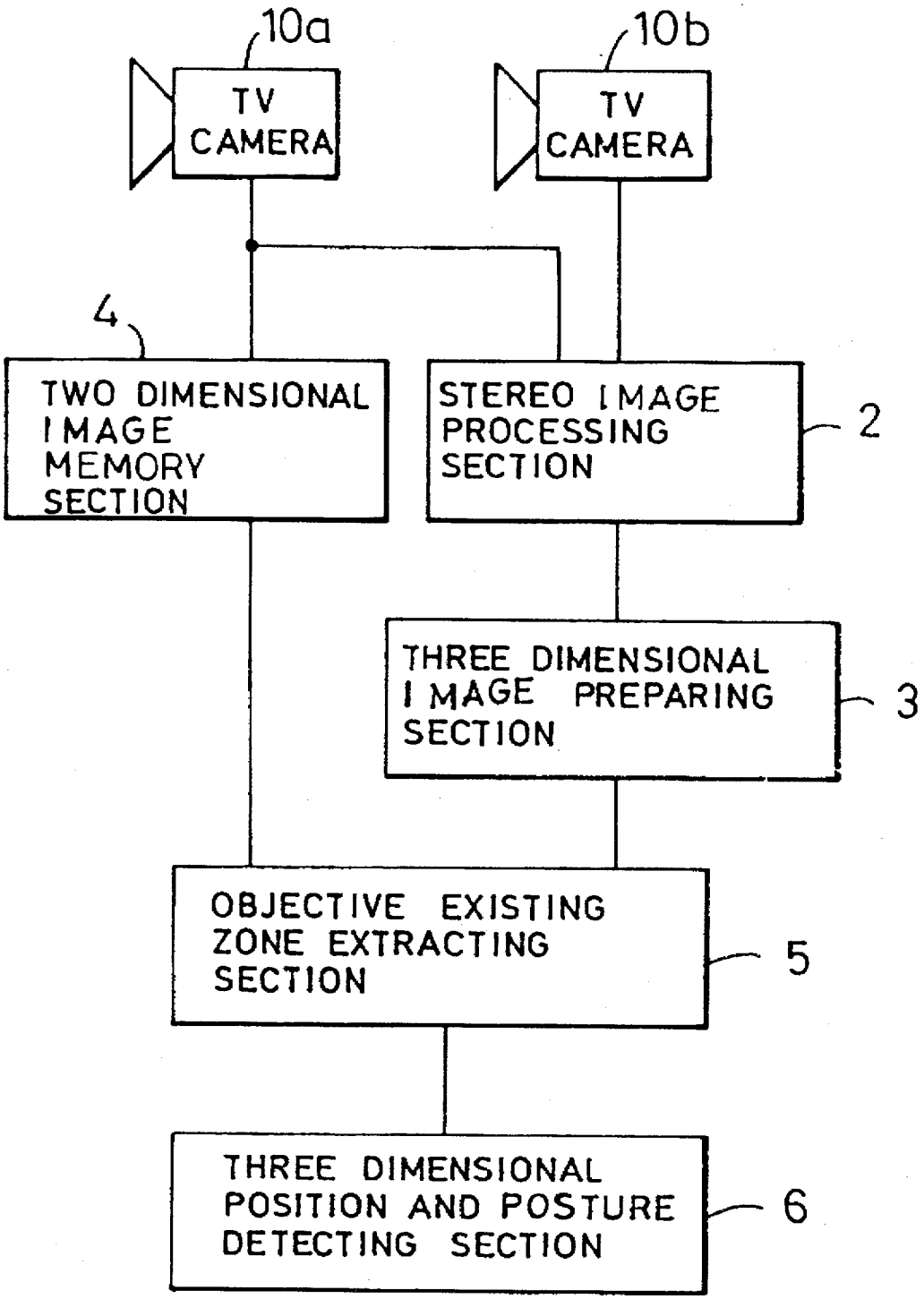

10a
10b
TV CAMERA
TV CAMERA
4
TWO DIMENSIONAL IMAGE MEMORY SECTION
STEREO IMAGE PROCESSING SECTION
2
THREE DIMENSIONAL IMAGE PREPARING SECTION
3
OBJECTIVE EXISTING ZONE EXTRACTING SECTION
5
THREE DIMENSIONAL POSITION AND POSTURE DETECTING SECTION
6

FIG. 3

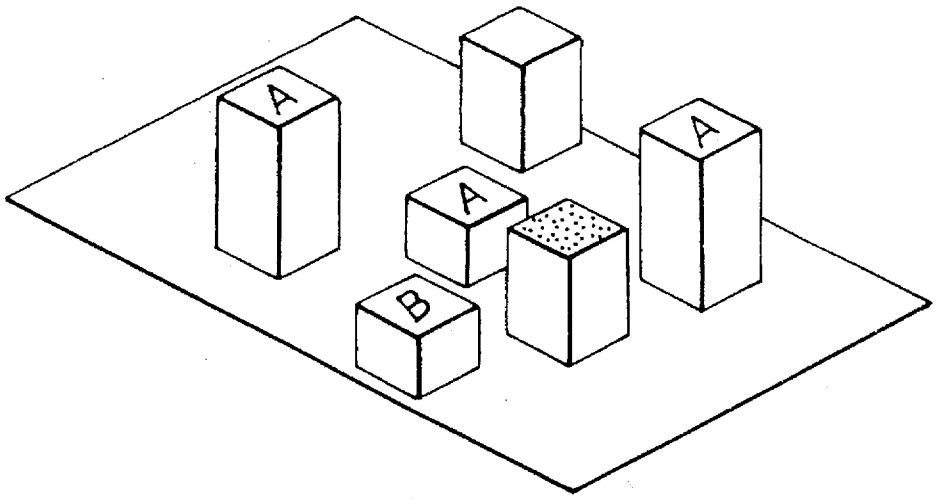


FIG. 4a

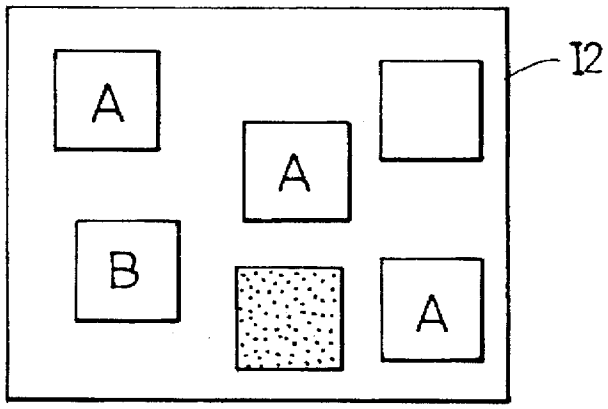


FIG. 4b

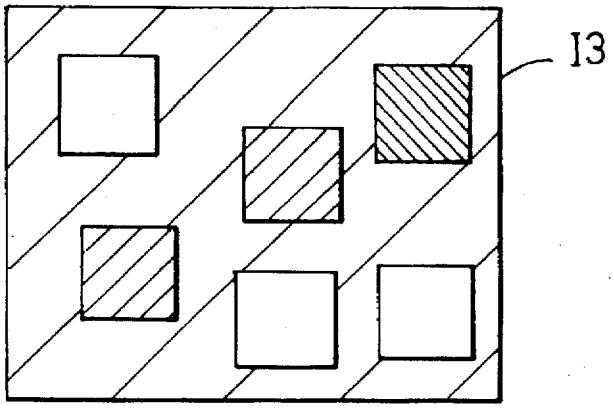


FIG. 5

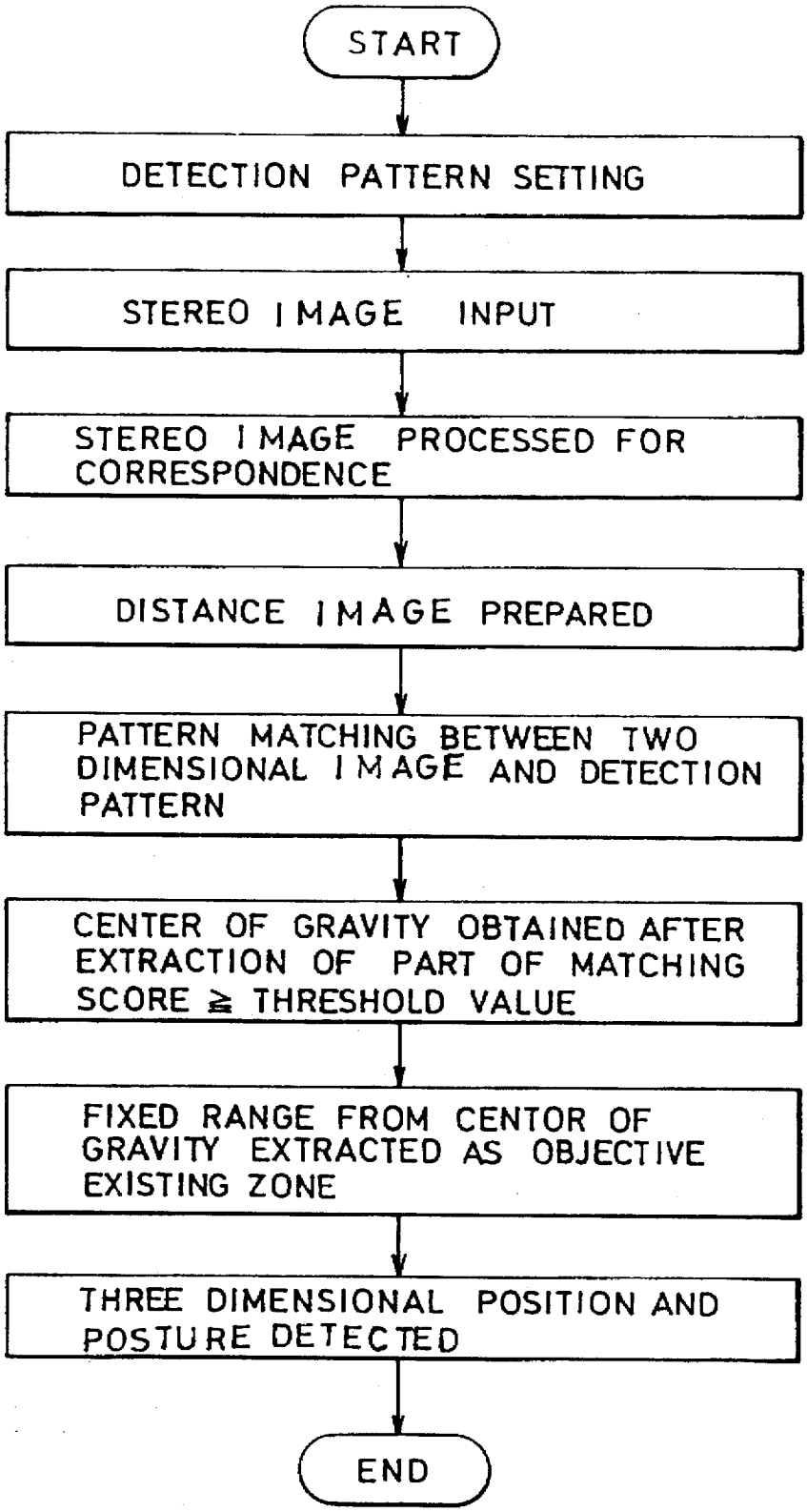

START
DETECTION PATTERN SETTING
STEREO IMAGE INPUT
STEREO IMAGE PROCESSED FOR CORRESPONDENCE
DISTANCE IMAGE PREPARED
PATTERN MATCHING BETWEEN TWO DIMENSIONAL IMAGE AND DETECTION PATTERN
CENTER OF GRAVITY OBTAINED AFTER EXTRACTION OF PART OF MATCHING SCORE ≧ THRESHOLD VALUE
FIXED RANGE FROM CENTOR OF GRAVITY EXTRACTED AS OBJECTIVE EXISTING ZONE
THREE DIMENSIONAL POSITION AND POSTURE DETECTED
END

FIG. 6

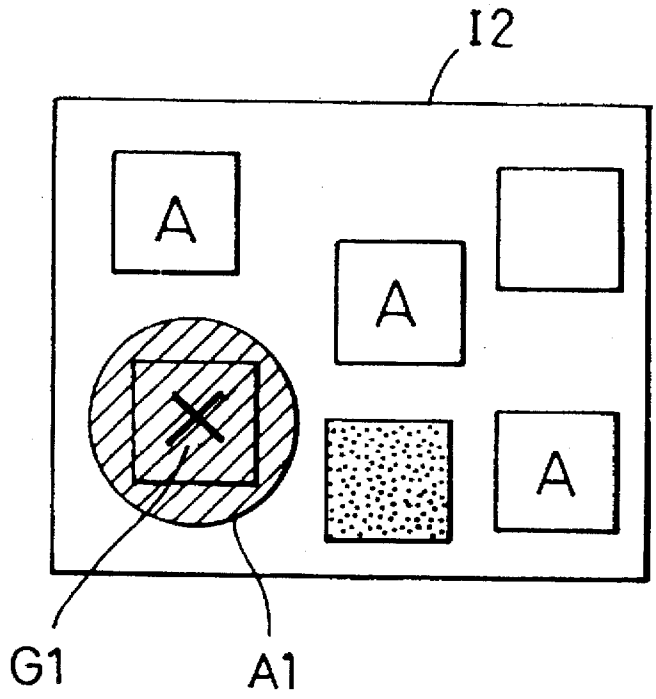


FIG. 8

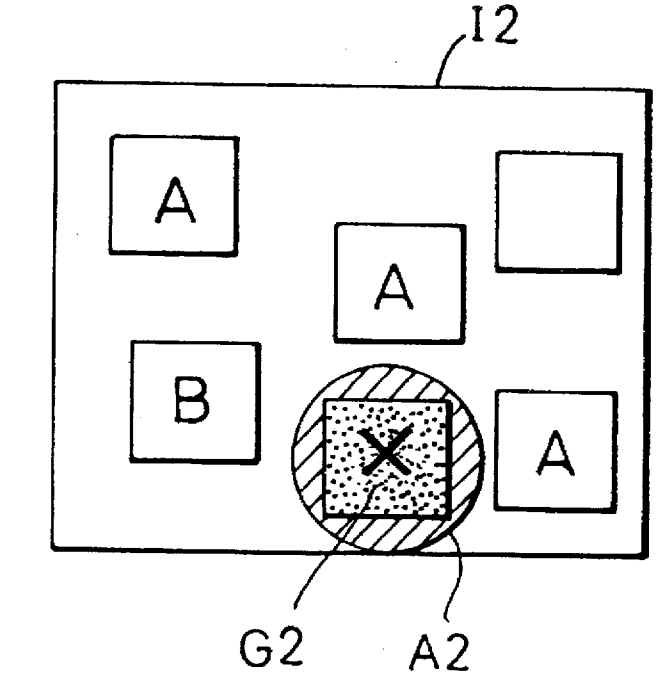


FIG. 7

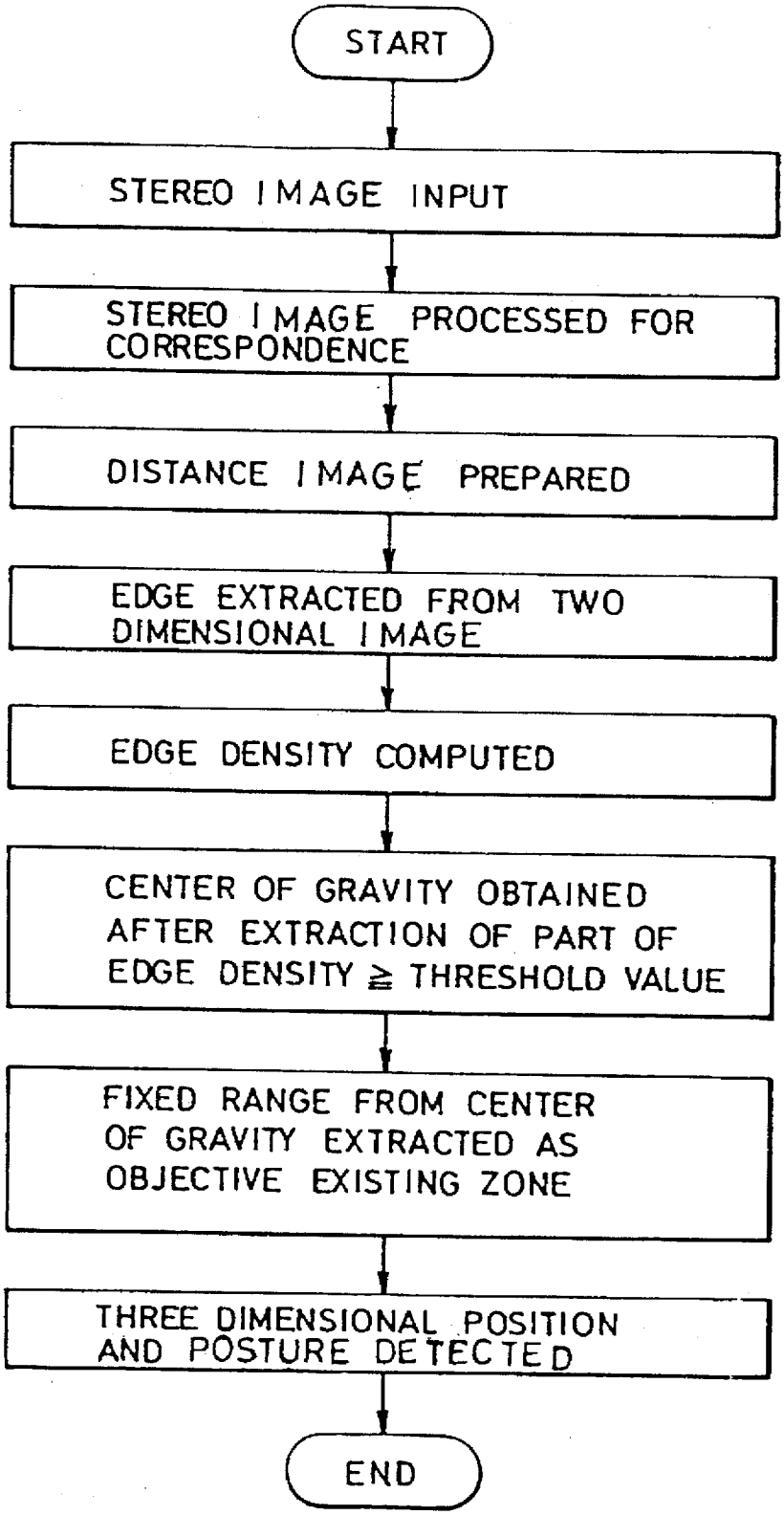

START
STEREO IMAGE INPUT
STEREO IMAGE PROCESSED FOR CORRESPONDENCE
DISTANCE IMAGE PREPARED
EDGE EXTRACTED FROM TWO DIMENSIONAL IMAGE
EDGE DENSITY COMPUTED
CENTER OF GRAVITY OBTAINED AFTER EXTRACTION OF PART OF EDGE DENSITY ≧ THRESHOLD VALUE
FIXED RANGE FROM CENTER OF GRAVITY EXTRACTED AS OBJECTIVE EXISTING ZONE
THREE DIMENSIONAL POSITION AND POSTURE DETECTED
END

FIG. 9

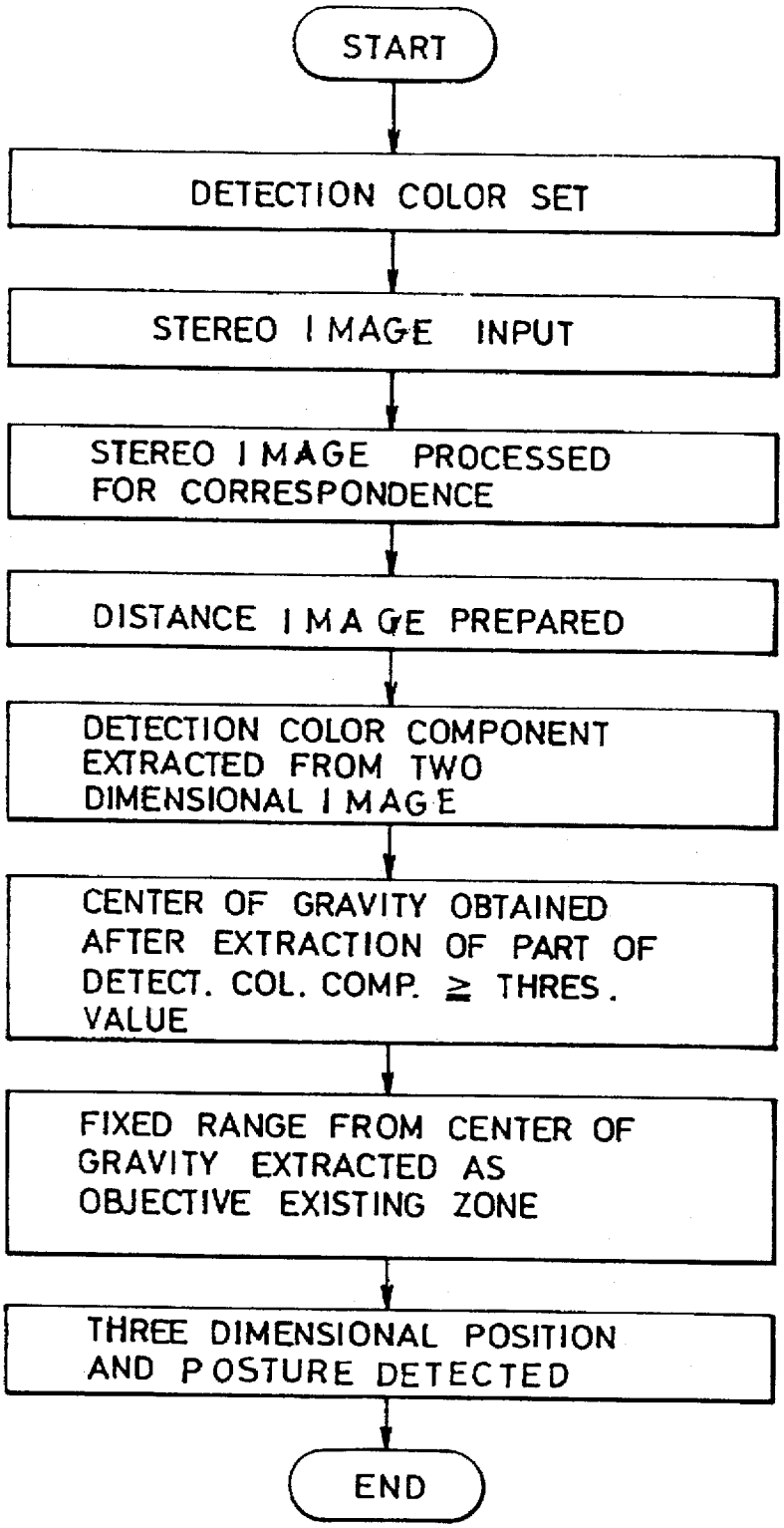

START
DETECTION COLOR SET
STEREO IMAGE INPUT
STEREO IMAGE PROCESSED FOR CORRESPONDENCE
DISTANCE IMAGE PREPARED
DETECTION COLOR COMPONENT EXTRACTED FROM TWO DIMENSIONAL IMAGE
CENTER OF GRAVITY OBTAINED AFTER EXTRACTION OF PART OF DETECT. COL. COMP. ≧ THRES. VALUE
FIXED RANGE FROM CENTER OF GRAVITY EXTRACTED AS OBJECTIVE EXISTING ZONE
THREE DIMENSIONAL POSITION AND POSTURE DETECTED
END

FIG. 10

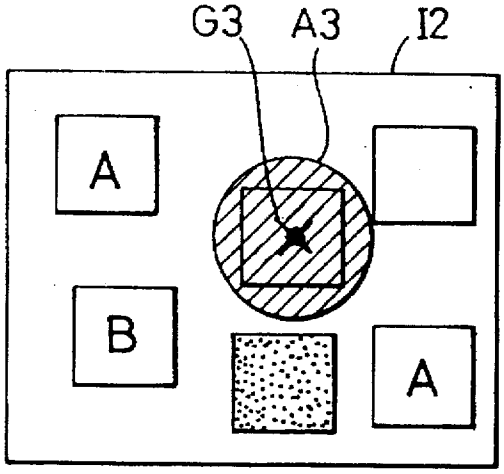


FIG. 12

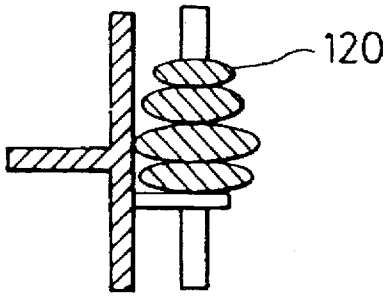


FIG. 13 a

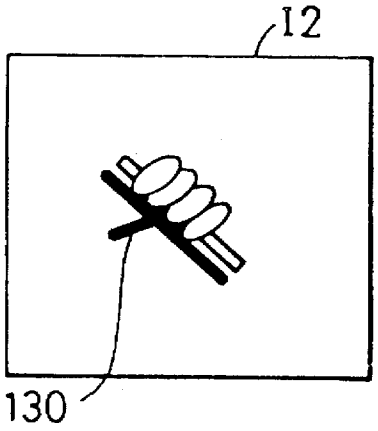


FIG. 13b

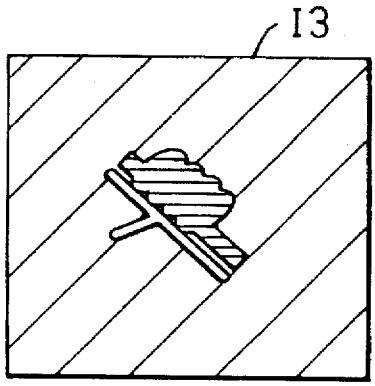


FIG. 14

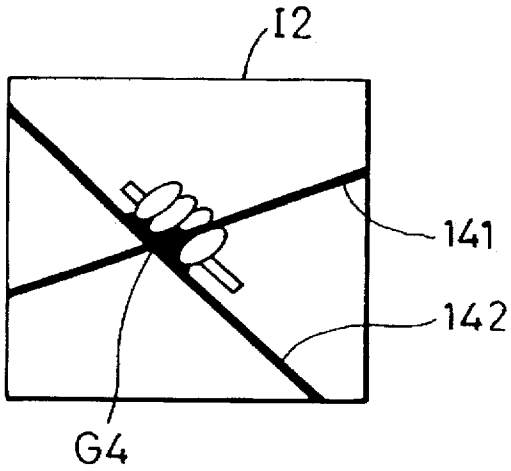


FIG. 11

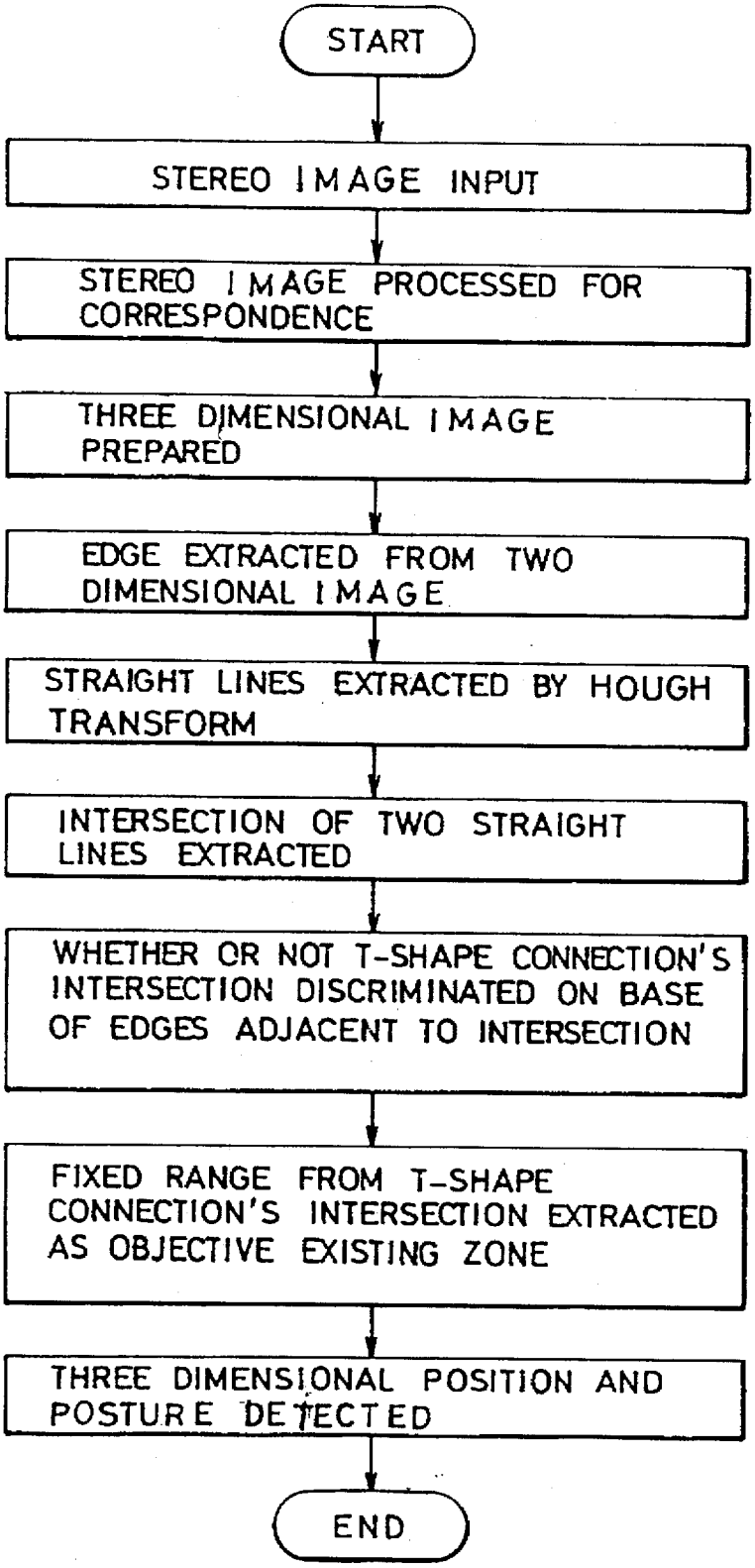

START
STEREO IMAGE INPUT
STEREO IMAGE PROCESSED FOR CORRESPONDENCE
THREE DIMENSIONAL IMAGE PREPARED
EDGE EXTRACTED FROM TWO DIMENSIONAL IMAGE
STRAIGHT LINES EXTRACTED BY HOUGH TRANSFORM
INTERSECTION OF TWO STRAIGHT LINES EXTRACTED
WHETHER OR NOT T-SHAPE CONNECTION'S INTERSECTION DISCRIMINATED ON BASE OF EDGES ADJACENT TO INTERSECTION
FIXED RANGE FROM T-SHAPE CONNECTION'S INTERSECTION EXTRACTED AS OBJECTIVE EXISTING ZONE
THREE DIMENSIONAL POSITION AND POSTURE DETECTED
END

FIG. 15

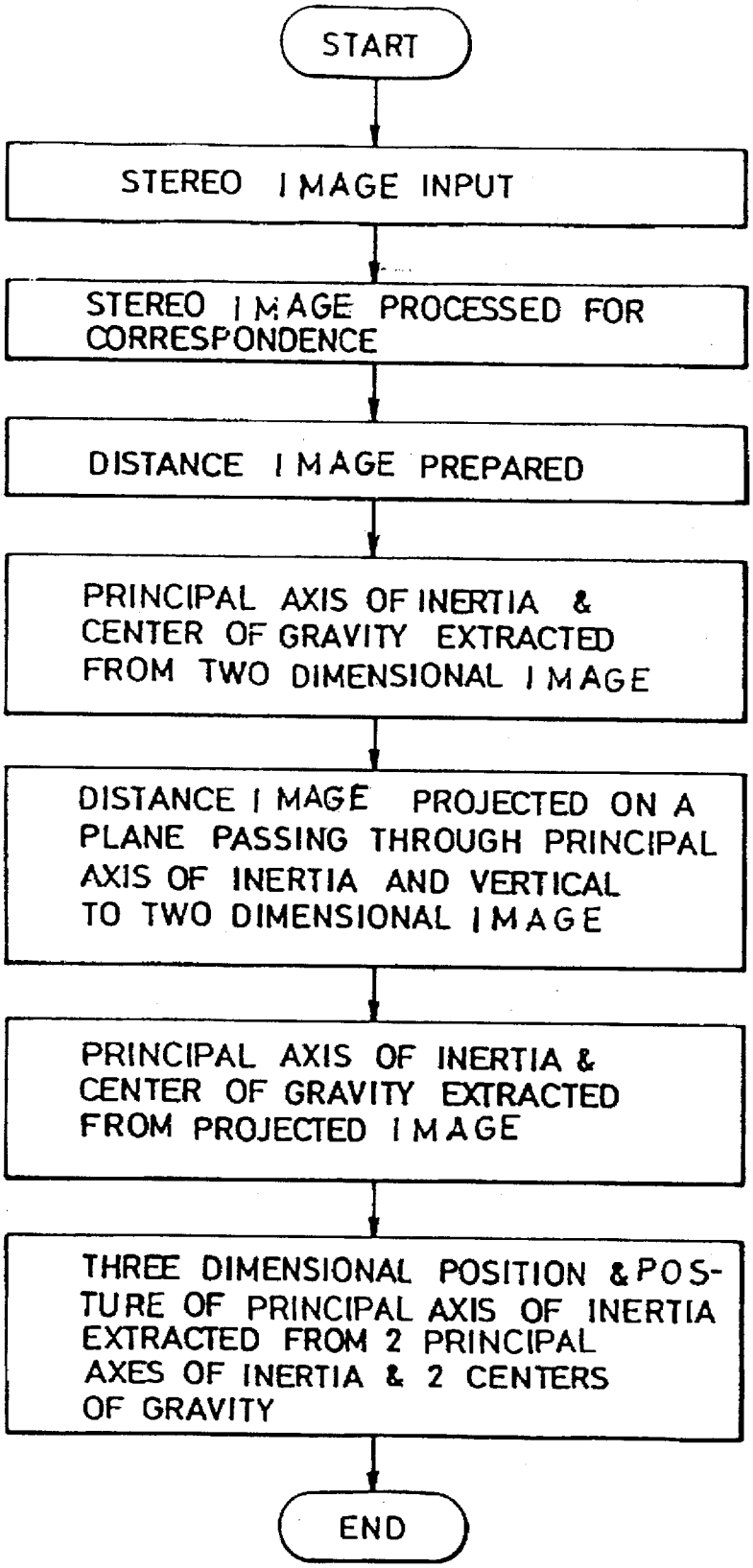

START
STEREO IMAGE INPUT
STEREO IMAGE PROCESSED FOR CORRESPONDENCE
DISTANCE IMAGE PREPARED
PRINCIPAL AXIS OF INERTIA & CENTER OF GRAVITY EXTRACTED FROM TWO DIMENSIONAL IMAGE
DISTANCE IMAGE PROJECTED ON A PLANE PASSING THROUGH PRINCIPAL AXIS OF INERTIA AND VERTICAL TO TWO DIMENSIONAL IMAGE
PRINCIPAL AXIS OF INERTIA & CENTER OF GRAVITY EXTRACTED FROM PROJECTED IMAGE
THREE DIMENSIONAL POSITION & POSTURE OF PRINCIPAL AXIS OF INERTIA EXTRACTED FROM 2 PRINCIPAL AXES OF INERTIA & 2 CENTERS OF GRAVITY
END

FIG. 16

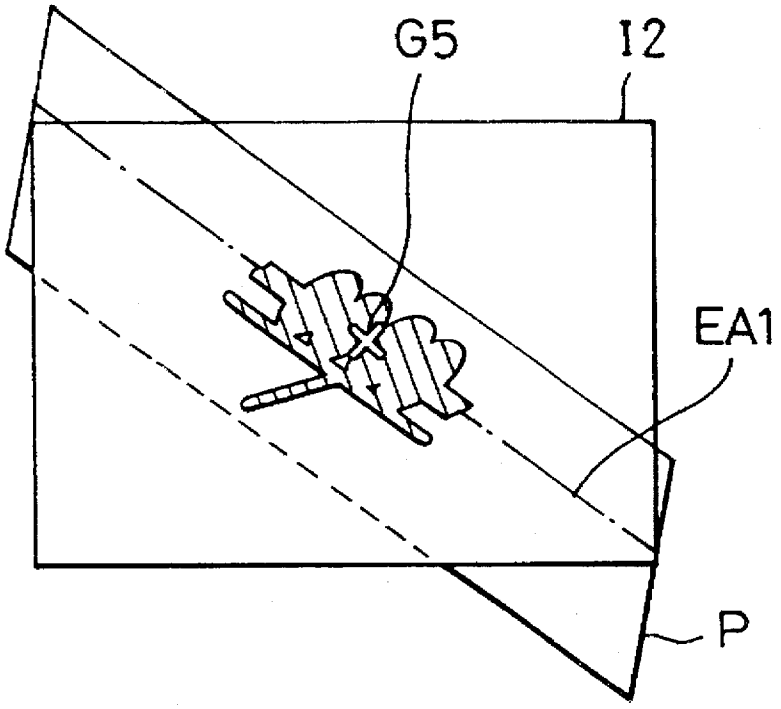


FIG. 17

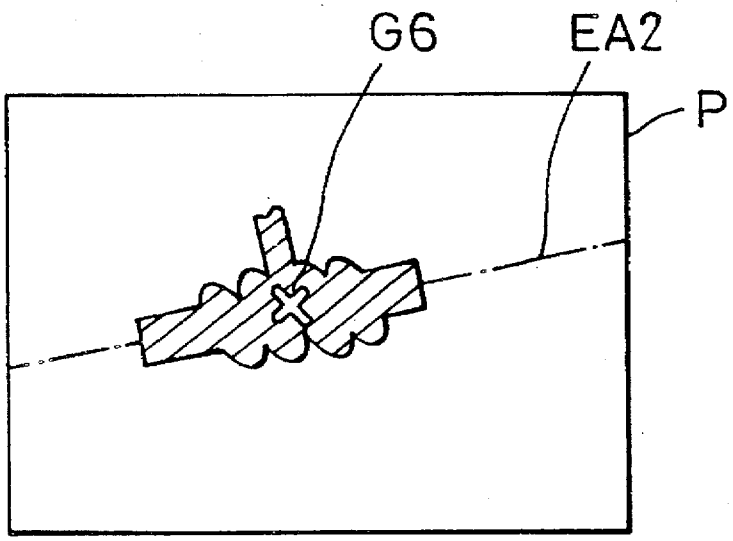


FIG. 18

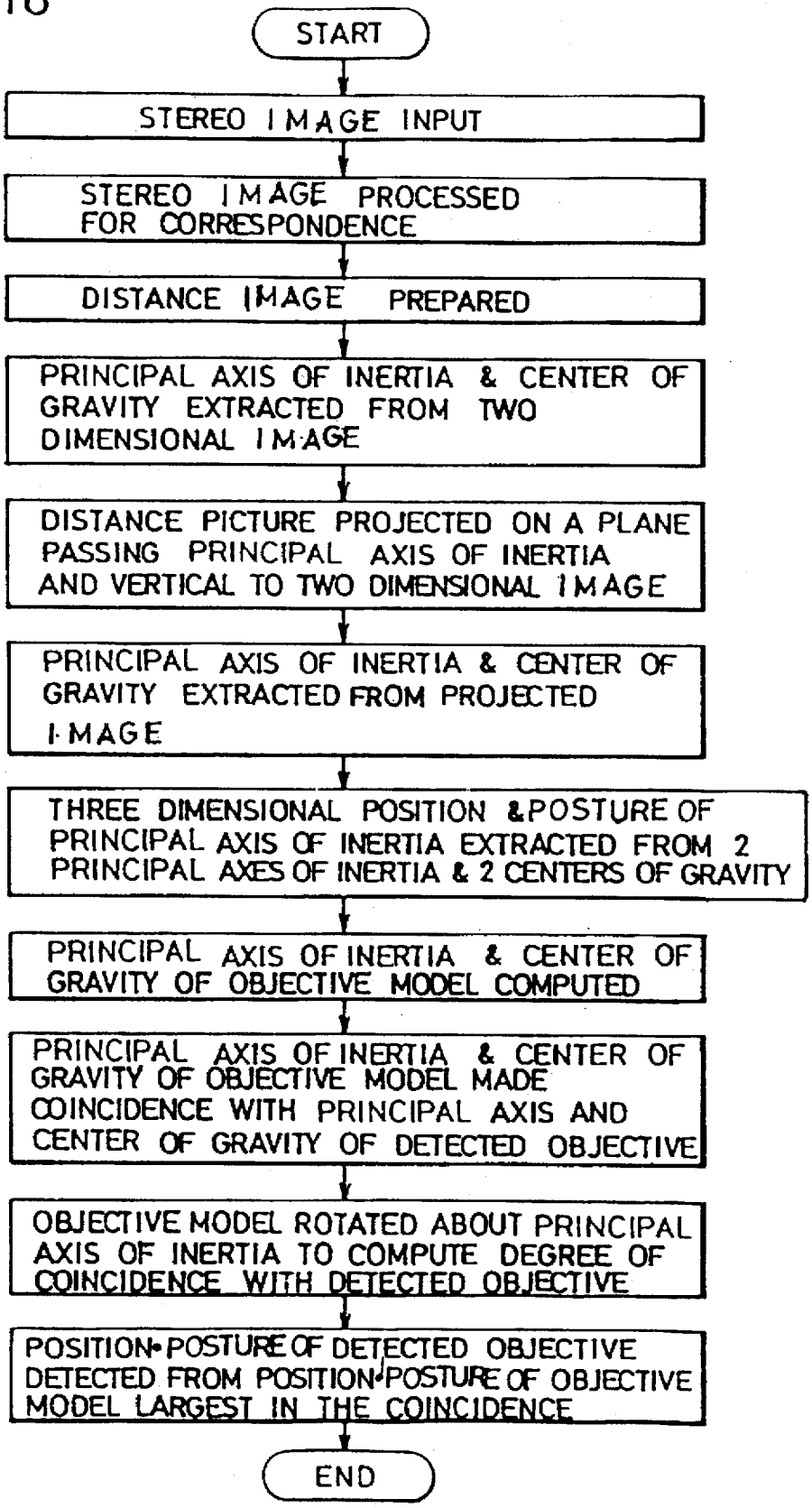

START
STEREO IMAGE INPUT
STEREO IMAGE PROCESSED FOR CORRESPONDENCE
DISTANCE IMAGE PREPARED
PRINCIPAL AXIS OF INERTIA & CENTER OF GRAVITY EXTRACTED FROM TWO DIMENSIONAL IMAGE
DISTANCE PICTURE PROJECTED ON A PLANE PASSING PRINCIPAL AXIS OF INERTIA AND VERTICAL TO TWO DIMENSIONAL IMAGE
PRINCIPAL AXIS OF INERTIA & CENTER OF GRAVITY EXTRACTED FROM PROJECTED IMAGE
THREE DIMENSIONAL POSITION & POSTURE OF PRINCIPAL AXIS OF INERTIA EXTRACTED FROM 2 PRINCIPAL AXES OF INERTIA & 2 CENTERS OF GRAVITY
PRINCIPAL AXIS OF INERTIA & CENTER OF GRAVITY OF OBJECTIVE MODEL COMPUTED
PRINCIPAL AXIS OF INERTIA & CENTER OF GRAVITY OF OBJECTIVE MODEL MADE COINCIDENCE WITH PRINCIPAL AXIS AND CENTER OF GRAVITY OF DETECTED OBJECTIVE
OBJECTIVE MODEL ROTATED ABOUT PRINCIPAL AXIS OF INERTIA TO COMPUTE DEGREE OF COINCIDENCE WITH DETECTED OBJECTIVE
POSITION•POSTURE OF DETECTED OBJECTIVE DETECTED FROM POSITION•POSTURE OF OBJECTIVE MODEL LARGEST IN THE COINCIDENCE
END

FIG. 19

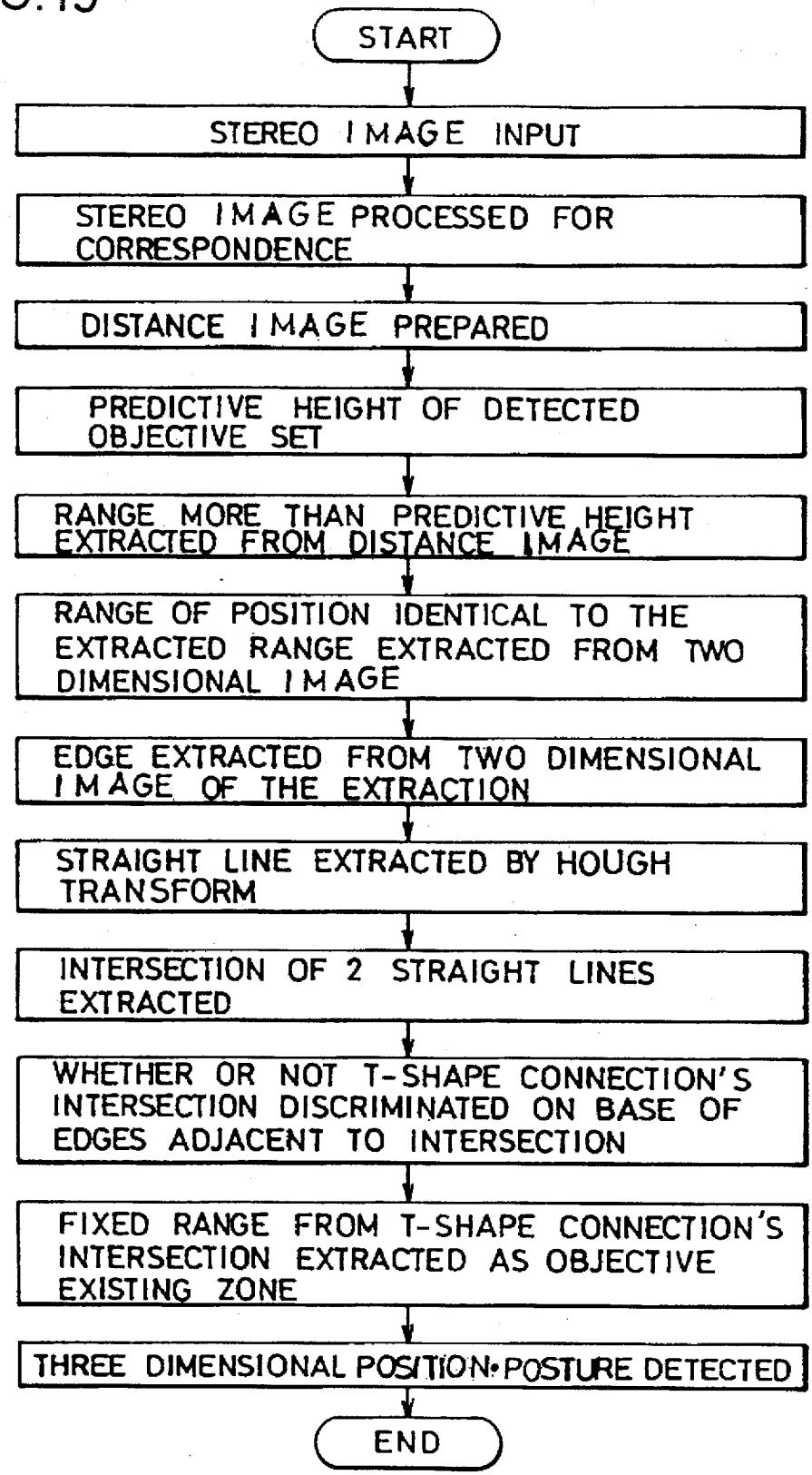

START
STEREO IMAGE INPUT
STEREO IMAGE PROCESSED FOR CORRESPONDENCE
DISTANCE IMAGE PREPARED
PREDICTIVE HEIGHT OF DETECTED OBJECTIVE SET
RANGE MORE THAN PREDICTIVE HEIGHT EXTRACTED FROM DISTANCE IMAGE
RANGE OF POSITION IDENTICAL TO THE EXTRACTED RANGE EXTRACTED FROM TWO DIMENSIONAL IMAGE
EDGE EXTRACTED FROM TWO DIMENSIONAL IMAGE OF THE EXTRACTION
STRAIGHT LINE EXTRACTED BY HOUGH TRANSFORM
INTERSECTION OF 2 STRAIGHT LINES EXTRACTED
WHETHER OR NOT T-SHAPE CONNECTION'S INTERSECTION DISCRIMINATED ON BASE OF EDGES ADJACENT TO INTERSECTION
FIXED RANGE FROM T-SHAPE CONNECTION'S INTERSECTION EXTRACTED AS OBJECTIVE EXISTING ZONE
THREE DIMENSIONAL POSITION·POSTURE DETECTED
END

FIG. 20a

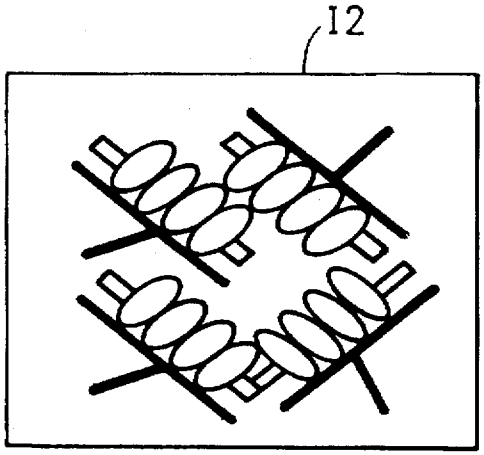


FIG. 20b

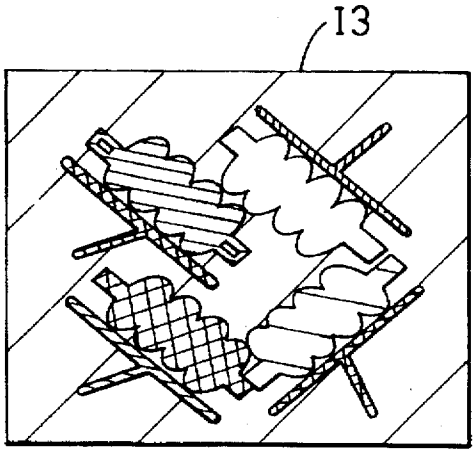


FIG. 21a

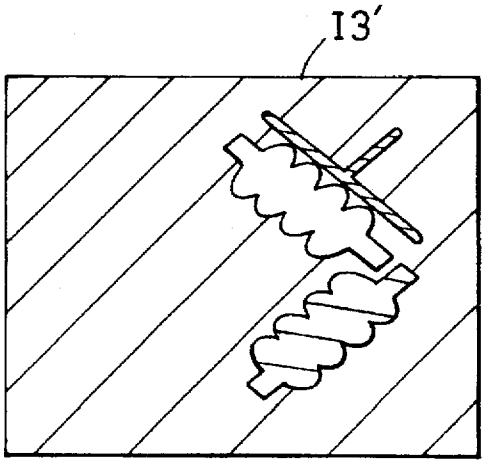


FIG. 21b

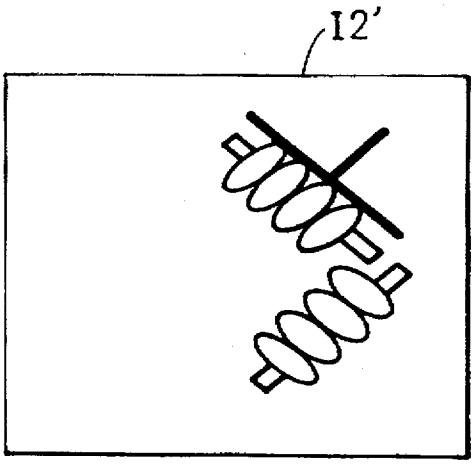


FIG. 22

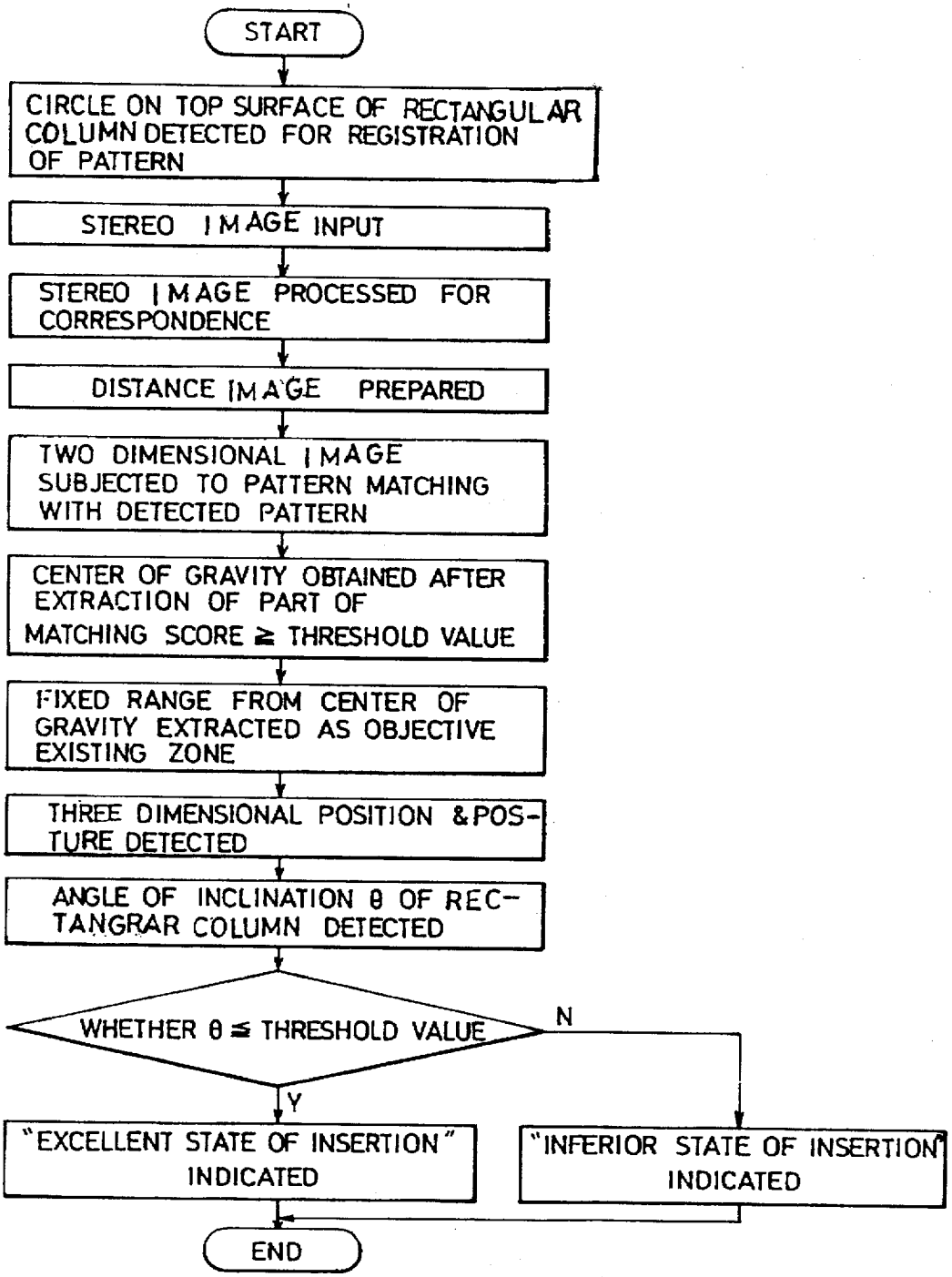

START
CIRCLE ON TOP SURFACE OF RECTANGULAR COLUMN DETECTED FOR REGISTRATION OF PATTERN
STEREO IMAGE INPUT
STEREO IMAGE PROCESSED FOR CORRESPONDENCE
DISTANCE IMAGE PREPARED
TWO DIMENSIONAL IMAGE SUBJECTED TO PATTERN MATCHING WITH DETECTED PATTERN
CENTER OF GRAVITY OBTAINED AFTER EXTRACTION OF PART OF MATCHING SCORE ≧ THRESHOLD VALUE
FIXED RANGE FROM CENTER OF GRAVITY EXTRACTED AS OBJECTIVE EXISTING ZONE
THREE DIMENSIONAL POSITION & POSTURE DETECTED
ANGLE OF INCLINATION θ OF RECTANGRAR COLUMN DETECTED
WHETHER θ ≦ THRESHOLD VALUE
N
Y
"EXCELLENT STATE OF INSERTION" INDICATED
"INFERIOR STATE OF INSERTION" INDICATED
END

FIG. 23

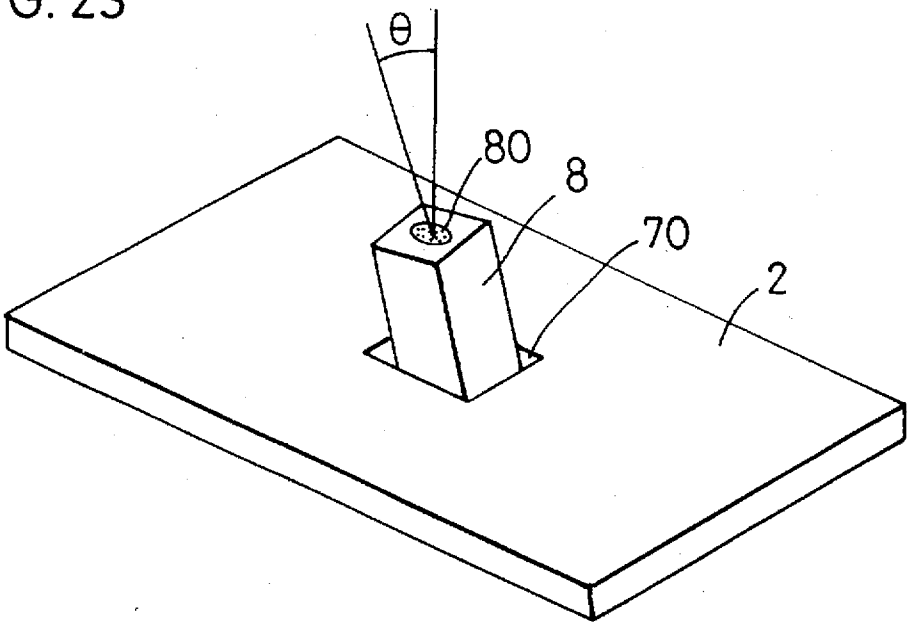


FIG. 24a

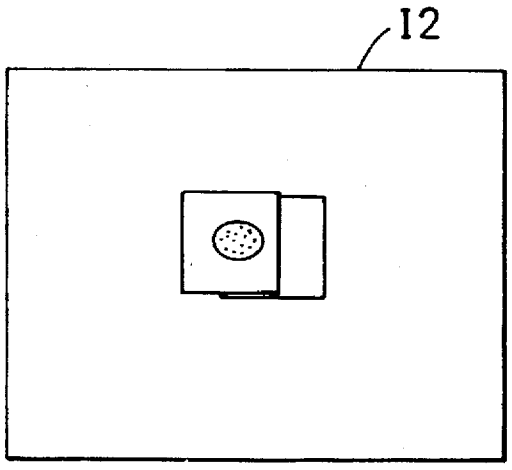


FIG. 24b

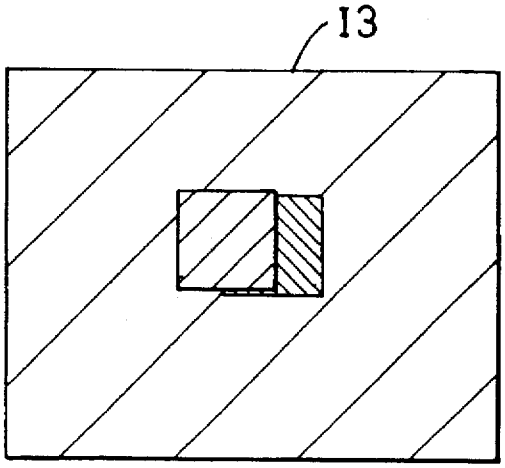


FIG. 25

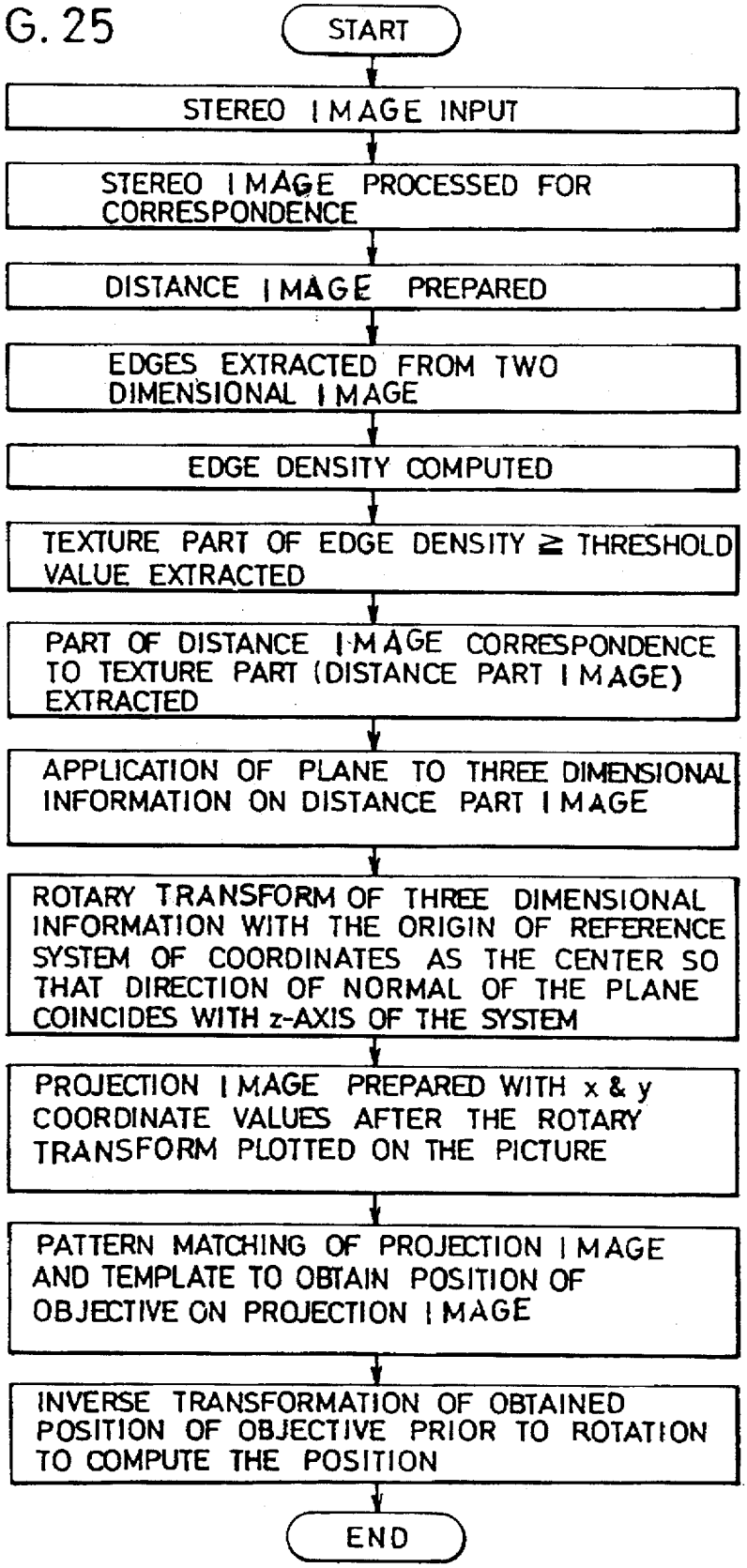

START
STEREO IMAGE INPUT
STEREO IMAGE PROCESSED FOR CORRESPONDENCE
DISTANCE IMAGE PREPARED
EDGES EXTRACTED FROM TWO DIMENSIONAL IMAGE
EDGE DENSITY COMPUTED
TEXTURE PART OF EDGE DENSITY ≧ THRESHOLD VALUE EXTRACTED
PART OF DISTANCE IMAGE CORRESPONDENCE TO TEXTURE PART (DISTANCE PART IMAGE) EXTRACTED
APPLICATION OF PLANE TO THREE DIMENSIONAL INFORMATION ON DISTANCE PART IMAGE
ROTARY TRANSFORM OF THREE DIMENSIONAL INFORMATION WITH THE ORIGIN OF REFERENCE SYSTEM OF COORDINATES AS THE CENTER SO THAT DIRECTION OF NORMAL OF THE PLANE COINCIDES WITH z-AXIS OF THE SYSTEM
PROJECTION IMAGE PREPARED WITH x & y COORDINATE VALUES AFTER THE ROTARY TRANSFORM PLOTTED ON THE PICTURE
PATTERN MATCHING OF PROJECTION IMAGE AND TEMPLATE TO OBTAIN POSITION OF OBJECTIVE ON PROJECTION IMAGE
INVERSE TRANSFORMATION OF OBTAINED POSITION OF OBJECTIVE PRIOR TO ROTATION TO COMPUTE THE POSITION
END

FIG. 26

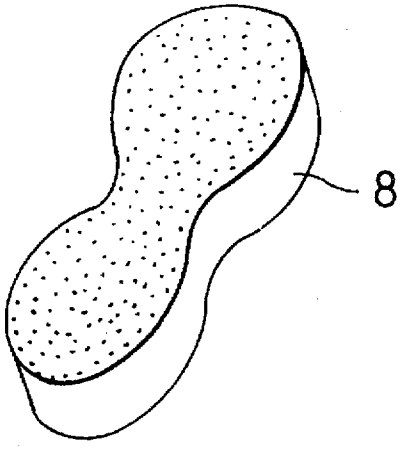
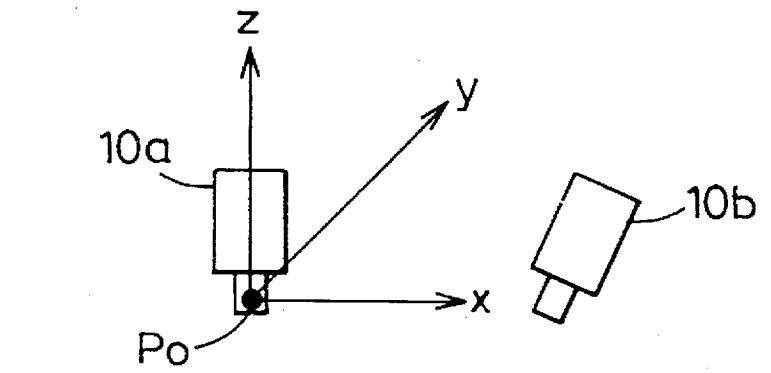


FIG. 27



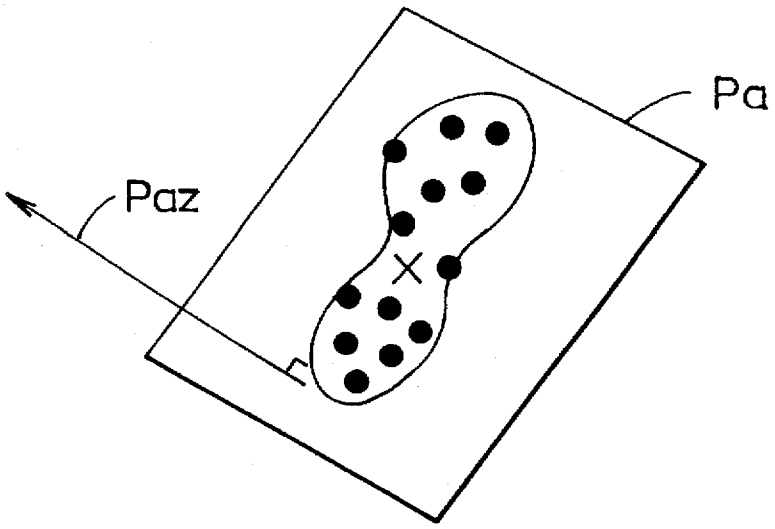


FIG. 28a

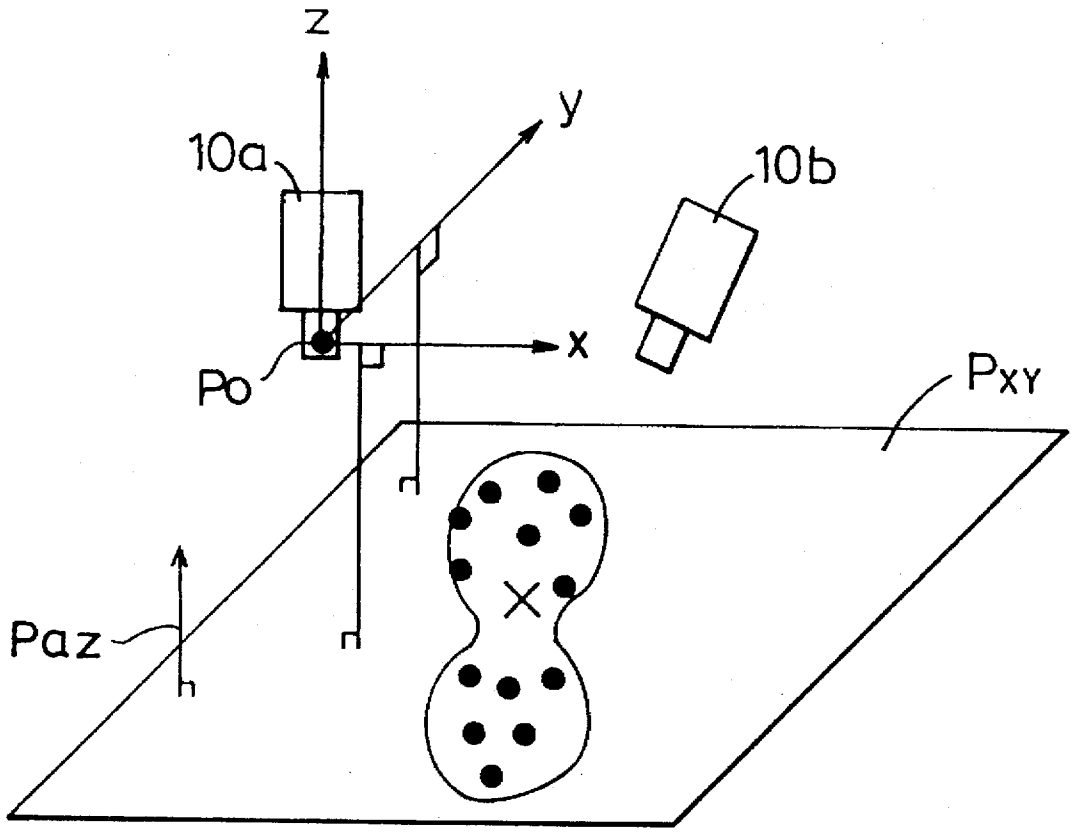


FIG. 28b

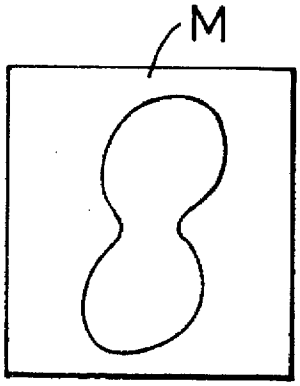
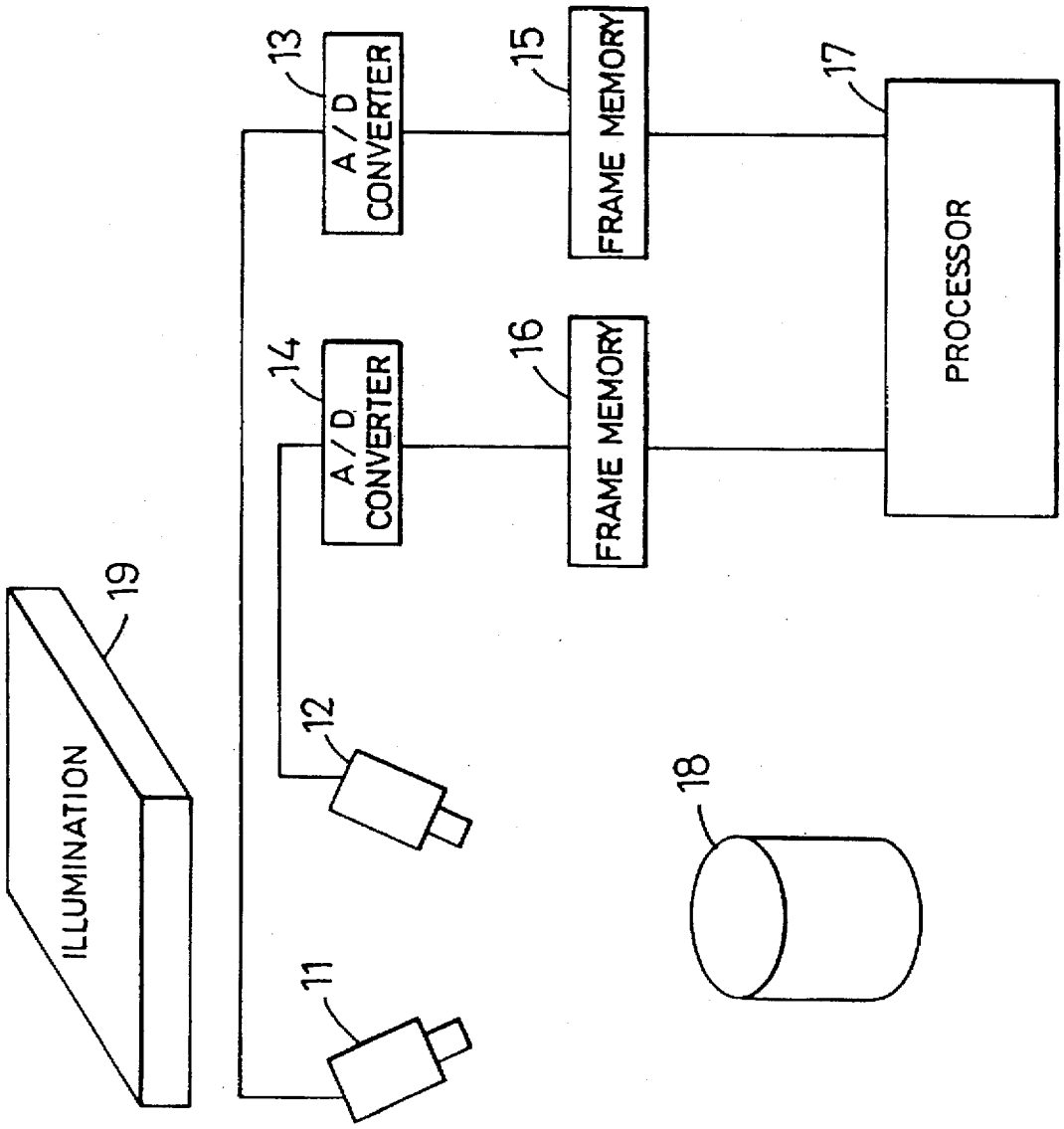


FIG. 29


13
A/D CONVERTER
15
FRAME MEMORY
17
PROCESSOR
14
A/D CONVERTER
16
FRAME MEMORY
19
ILLUMINATION
12
18
11

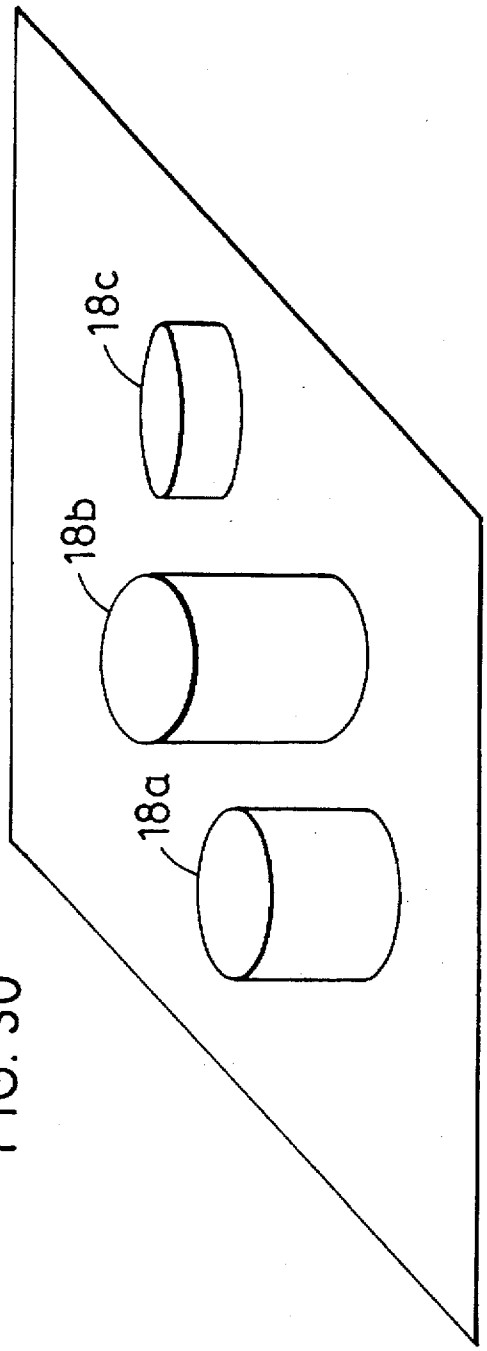


FIG. 30

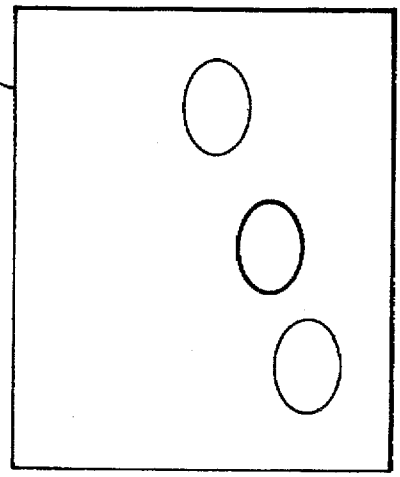


FIG. 31b

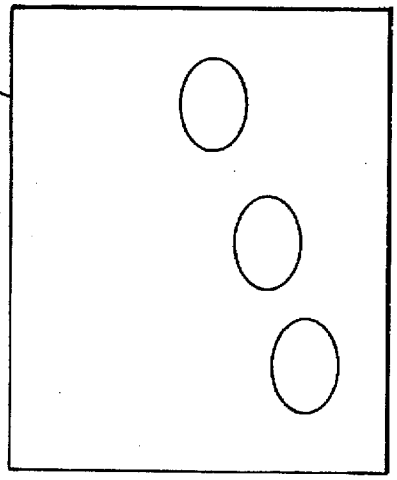


FIG. 31a

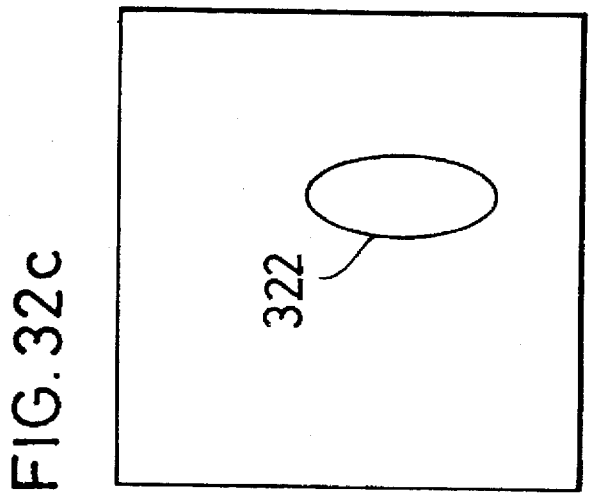


FIG. 32c

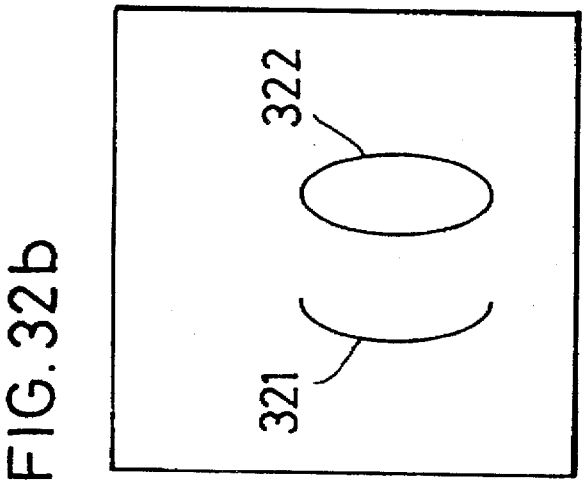


FIG. 32b

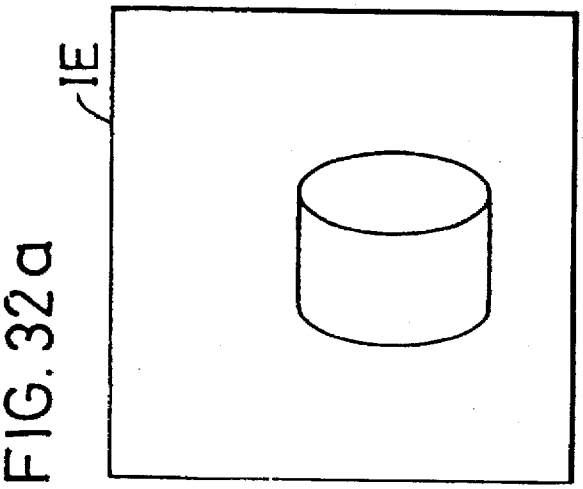


FIG. 32a

FIG. 33

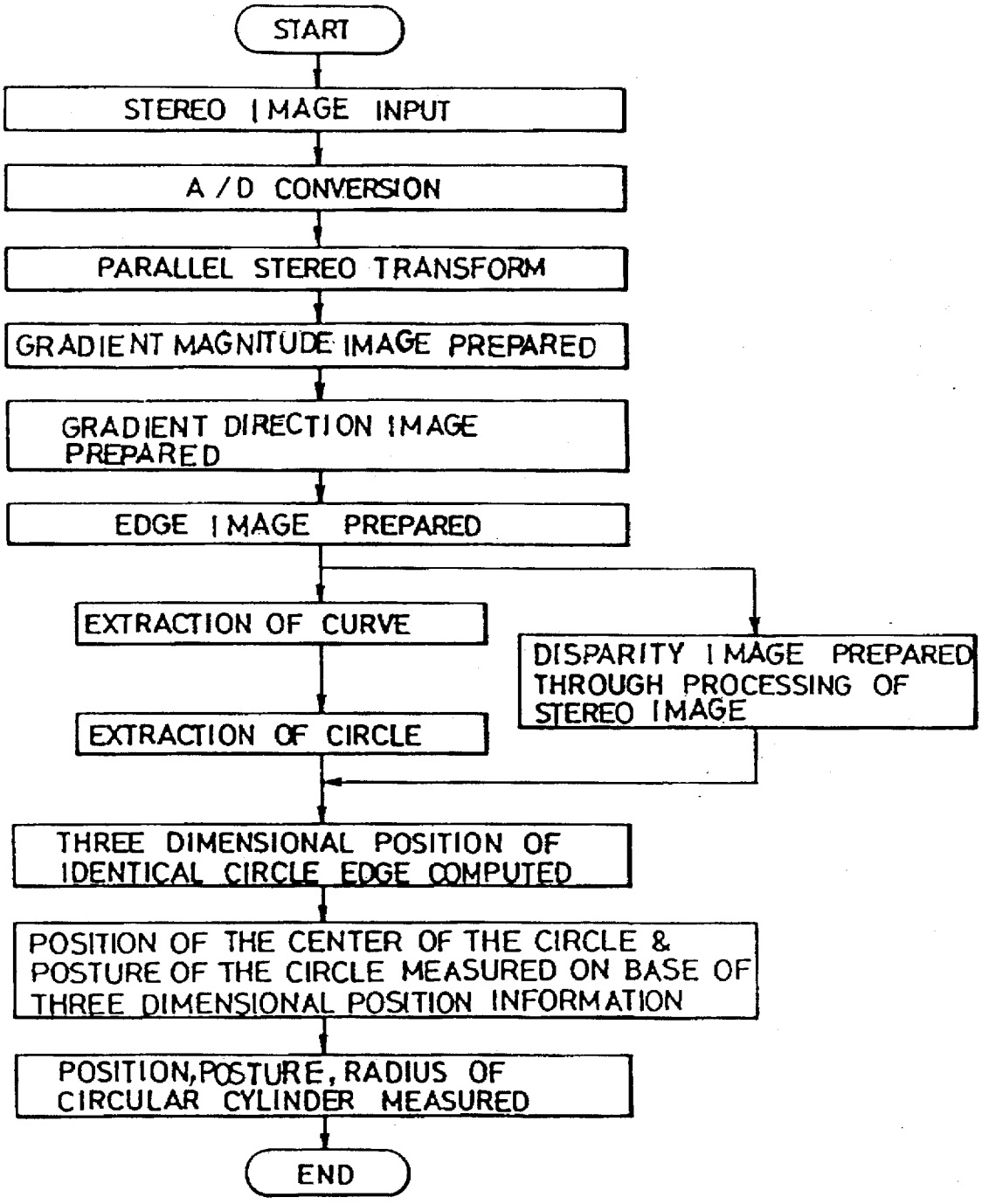

START
STEREO IMAGE INPUT
A/D CONVERSION
PARALLEL STEREO TRANSFORM
GRADIENT MAGNITUDE IMAGE PREPARED
GRADIENT DIRECTION IMAGE PREPARED
EDGE IMAGE PREPARED
EXTRACTION OF CURVE
EXTRACTION OF CIRCLE
DISPARITY IMAGE PREPARED THROUGH PROCESSING OF STEREO IMAGE
THREE DIMENSIONAL POSITION OF IDENTICAL CIRCLE EDGE COMPUTED
POSITION OF THE CENTER OF THE CIRCLE & POSTURE OF THE CIRCLE MEASURED ON BASE OF THREE DIMENSIONAL POSITION INFORMATION
POSITION, POSTURE, RADIUS OF CIRCULAR CYLINDER MEASURED
END

FIG. 34

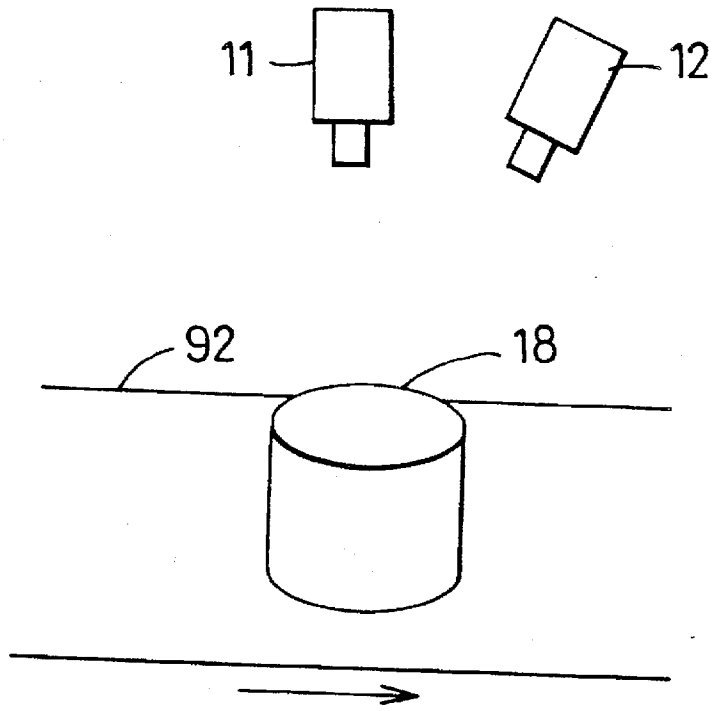


FIG. 35

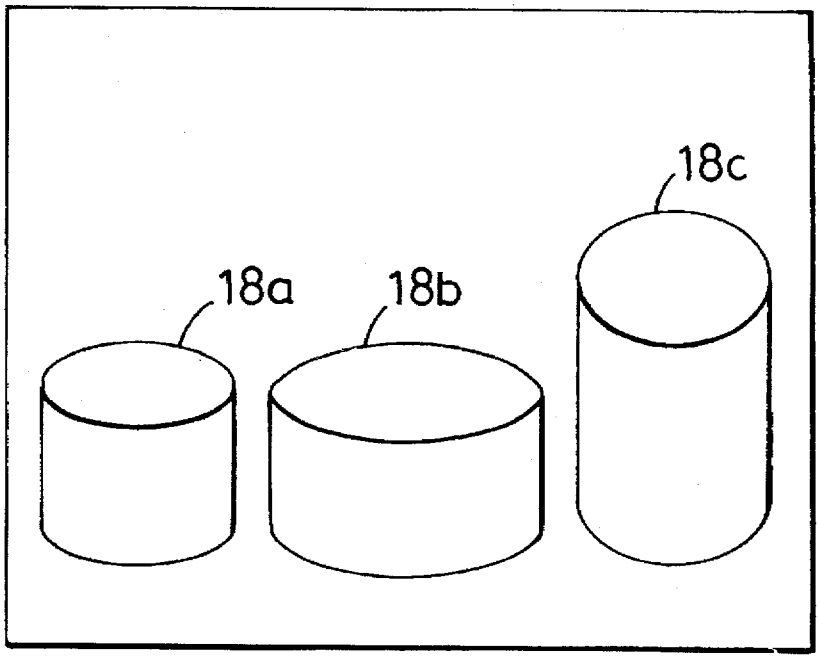


FIG. 36a

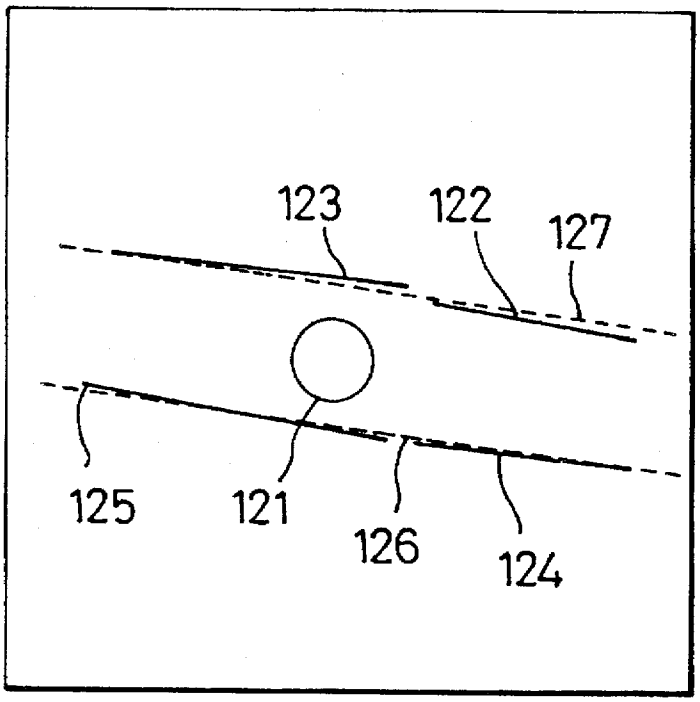


FIG. 36b

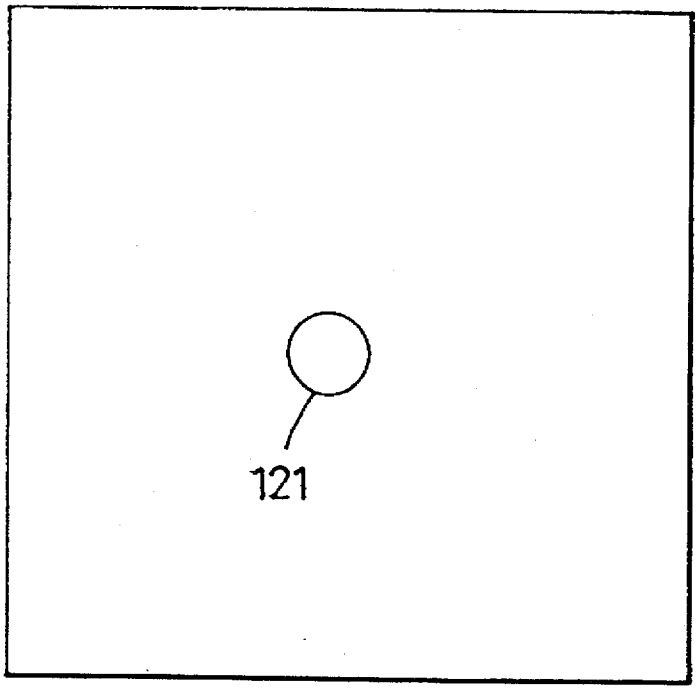


FIG. 37

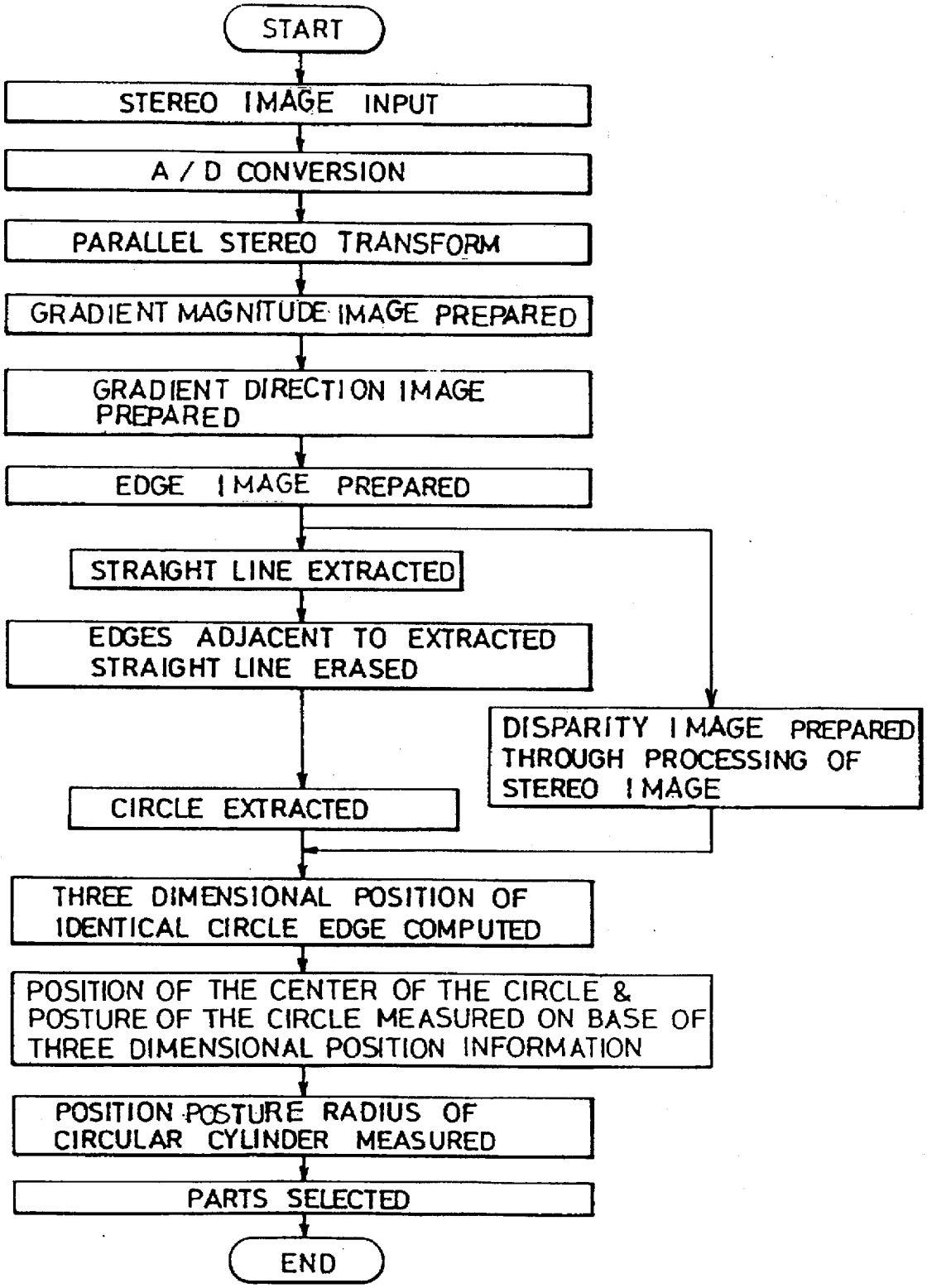

START
STEREO IMAGE INPUT
A / D CONVERSION
PARALLEL STEREO TRANSFORM
GRADIENT MAGNITUDE IMAGE PREPARED
GRADIENT DIRECTION IMAGE PREPARED
EDGE IMAGE PREPARED
STRAIGHT LINE EXTRACTED
EDGES ADJACENT TO EXTRACTED STRAIGHT LINE ERASED
DISPARITY IMAGE PREPARED THROUGH PROCESSING OF STEREO IMAGE
CIRCLE EXTRACTED
THREE DIMENSIONAL POSITION OF IDENTICAL CIRCLE EDGE COMPUTED
POSITION OF THE CENTER OF THE CIRCLE & POSTURE OF THE CIRCLE MEASURED ON BASE OF THREE DIMENSIONAL POSITION INFORMATION
POSITION POSTURE RADIUS OF CIRCULAR CYLINDER MEASURED
PARTS SELECTED
END

FIG. 38

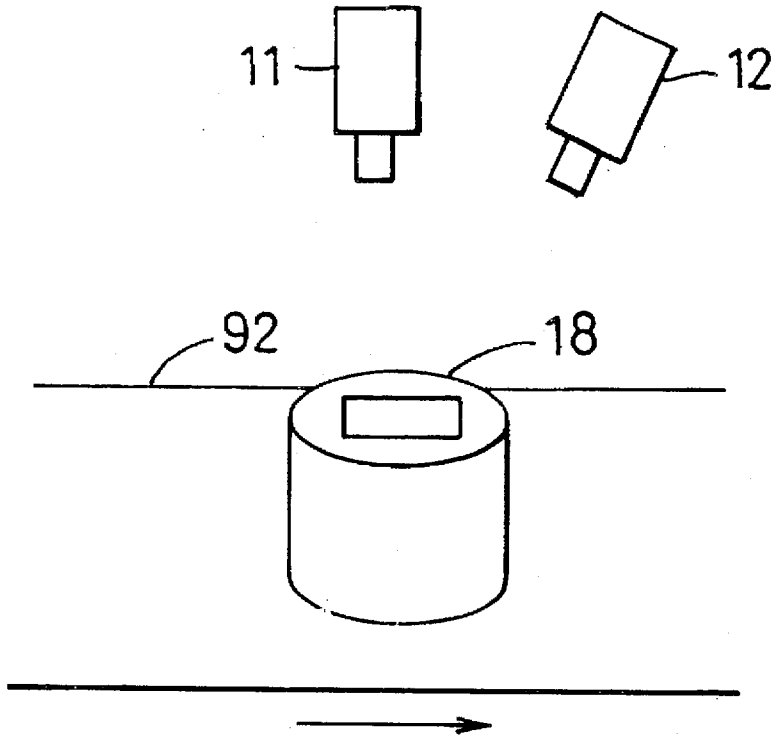


FIG. 39

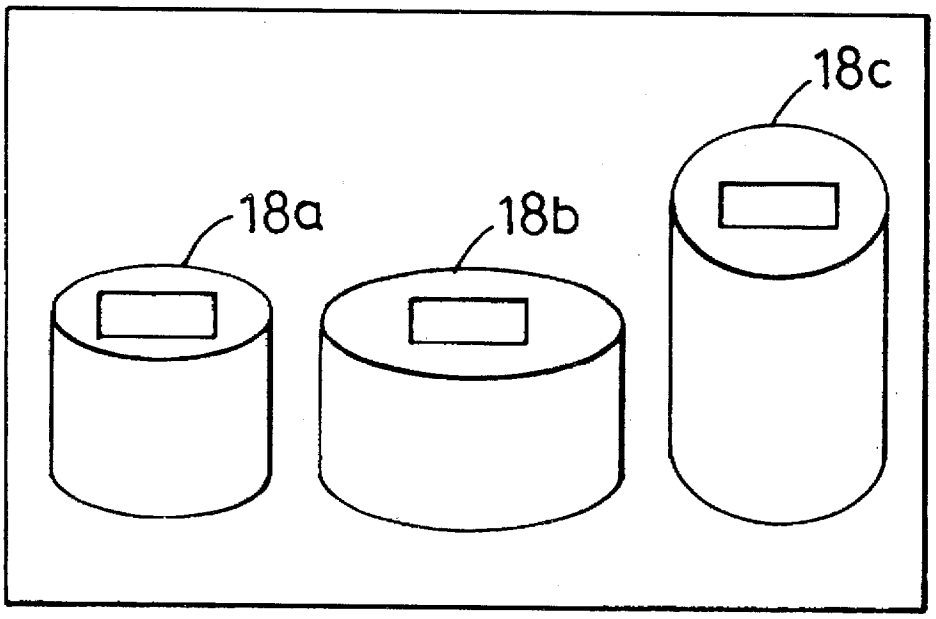


FIG. 40a

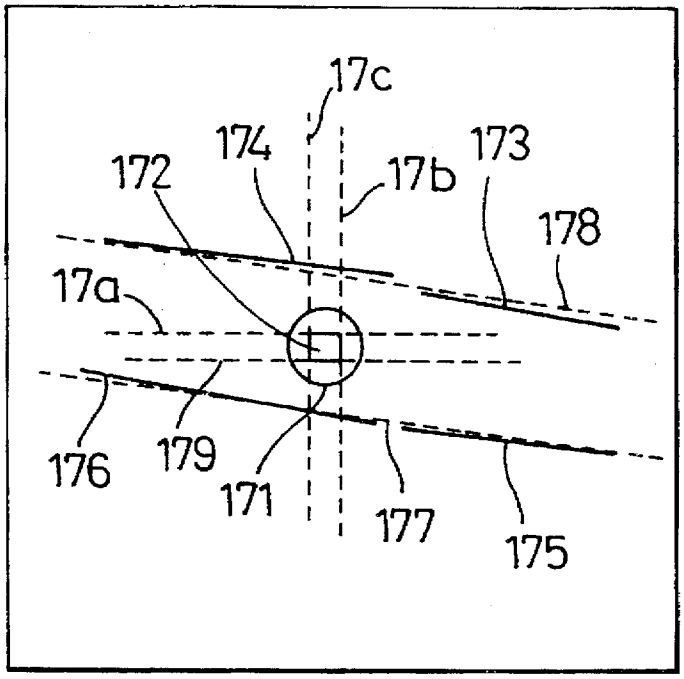


FIG. 40b

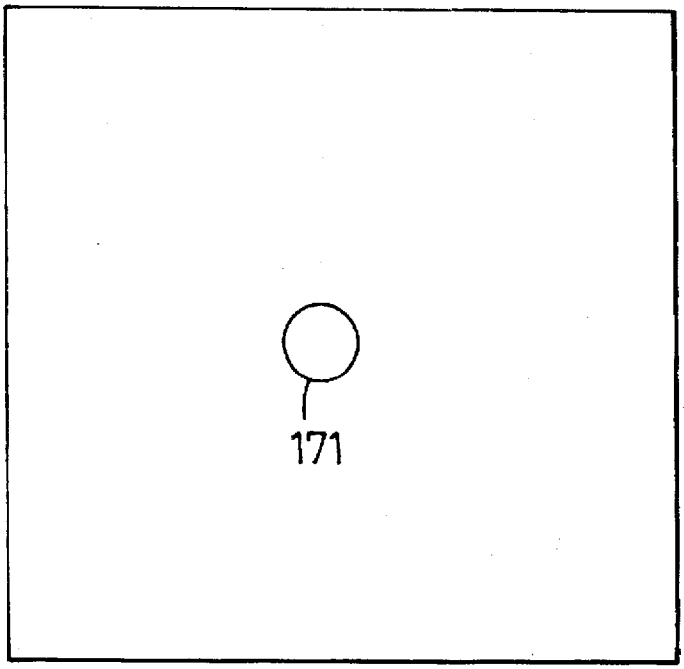


FIG. 41

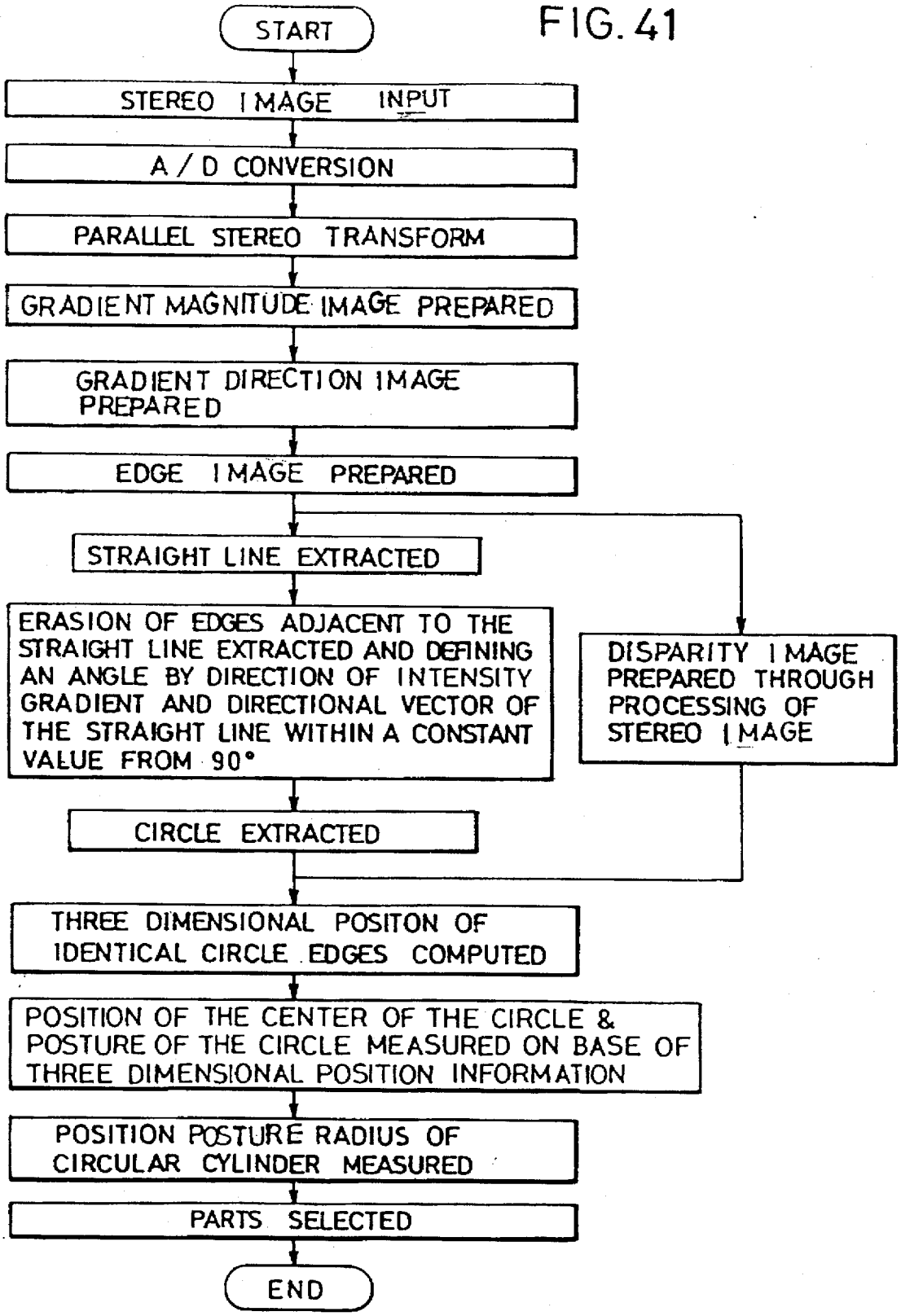
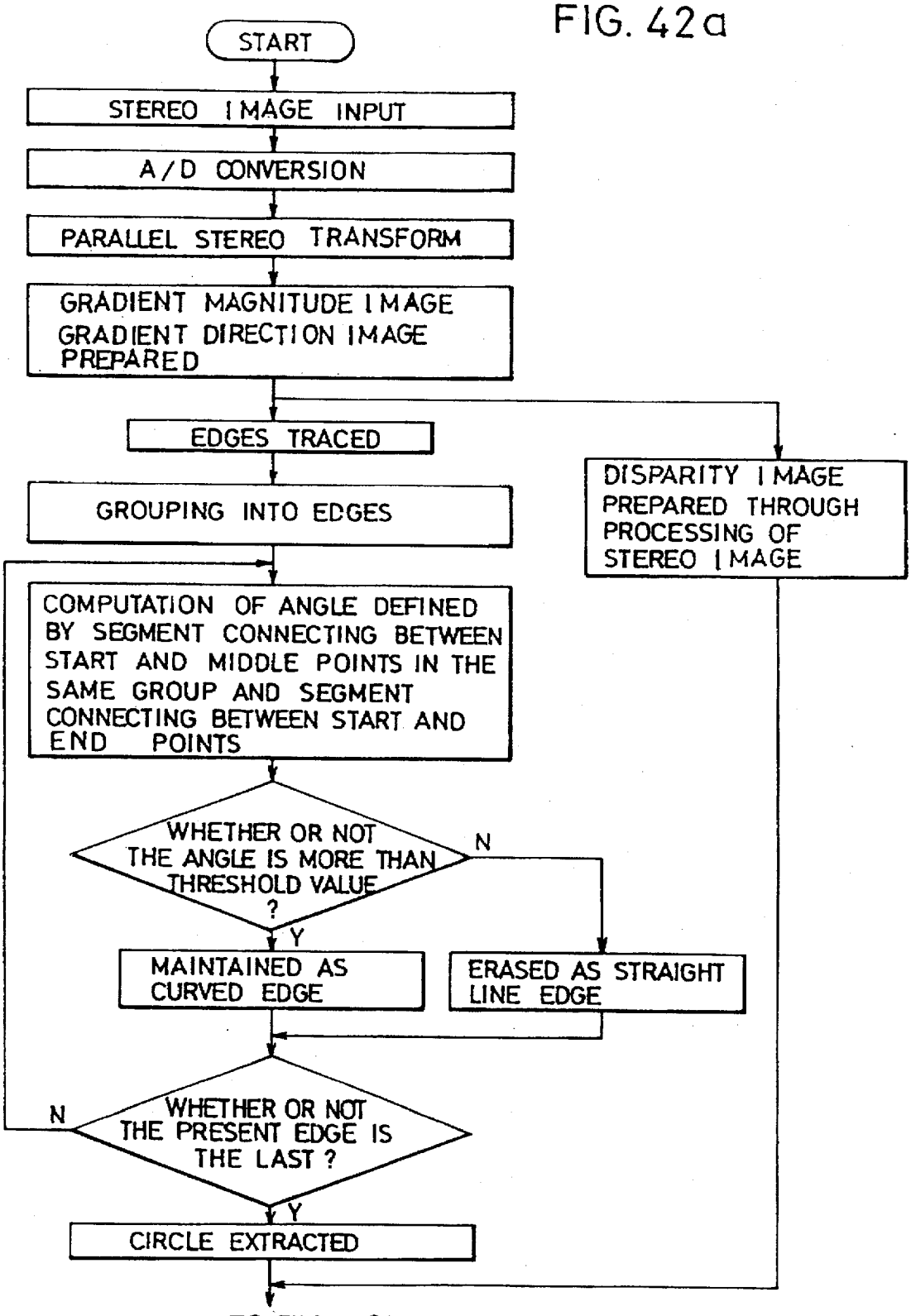

START
STEREO IMAGE INPUT
A / D CONVERSION
PARALLEL STEREO TRANSFORM
GRADIENT MAGNITUDE IMAGE PREPARED
GRADIENT DIRECTION IMAGE PREPARED
EDGE IMAGE PREPARED
STRAIGHT LINE EXTRACTED
ERASION OF EDGES ADJACENT TO THE STRAIGHT LINE EXTRACTED AND DEFINING AN ANGLE BY DIRECTION OF INTENSITY GRADIENT AND DIRECTIONAL VECTOR OF THE STRAIGHT LINE WITHIN A CONSTANT VALUE FROM 90°
DISPARITY IMAGE PREPARED THROUGH PROCESSING OF STEREO IMAGE
CIRCLE EXTRACTED
THREE DIMENSIONAL POSITON OF IDENTICAL CIRCLE EDGES COMPUTED
POSITION OF THE CENTER OF THE CIRCLE & POSTURE OF THE CIRCLE MEASURED ON BASE OF THREE DIMENSIONAL POSITION INFORMATION
POSITION POSTURE RADIUS OF CIRCULAR CYLINDER MEASURED
PARTS SELECTED
END

FIG. 42a



TO FIG. 42b

FIG. 42b

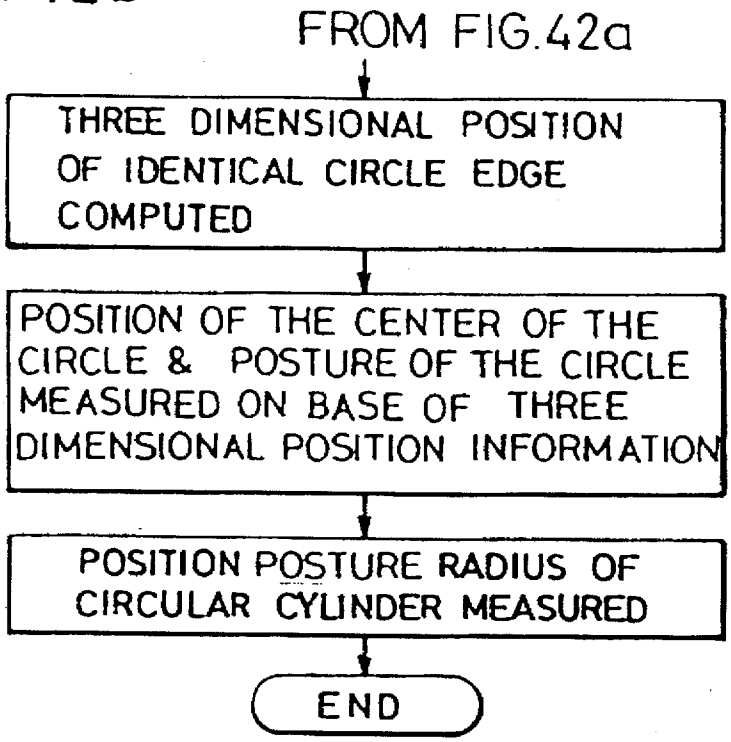


FIG. 42

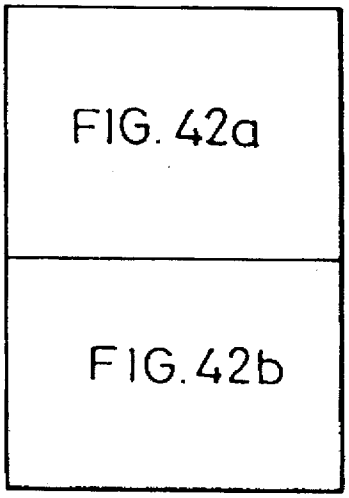


FIG. 43a

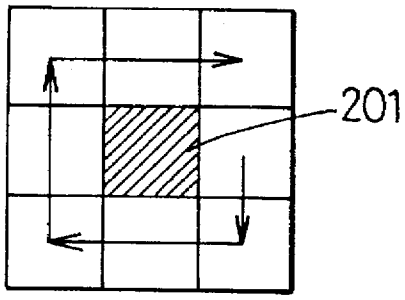


FIG. 43b

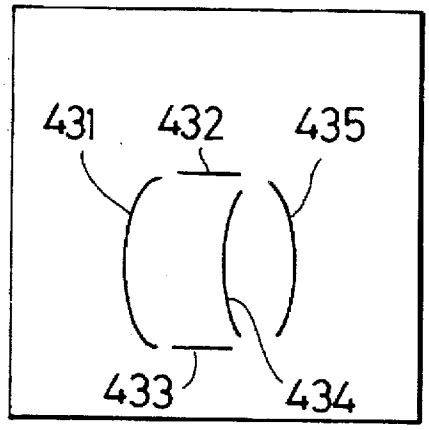


FIG. 44

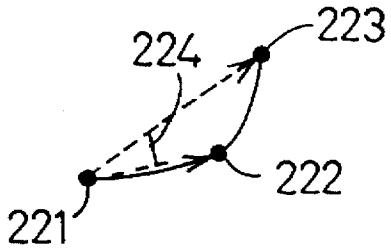


FIG. 45a

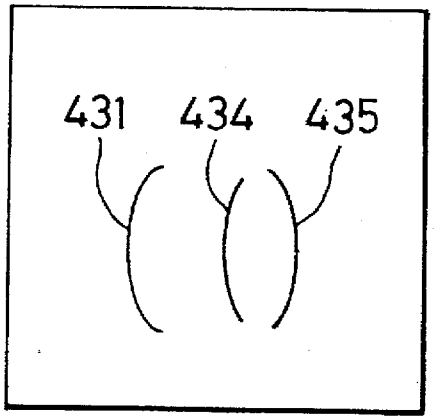


FIG. 45b

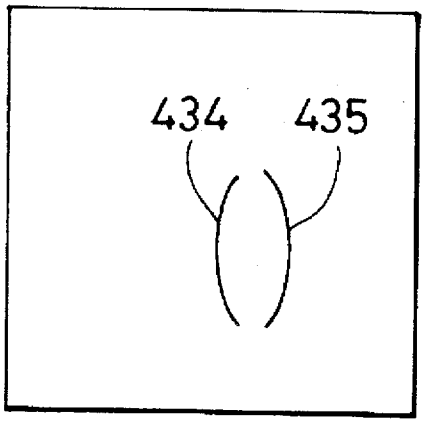


FIG. 46

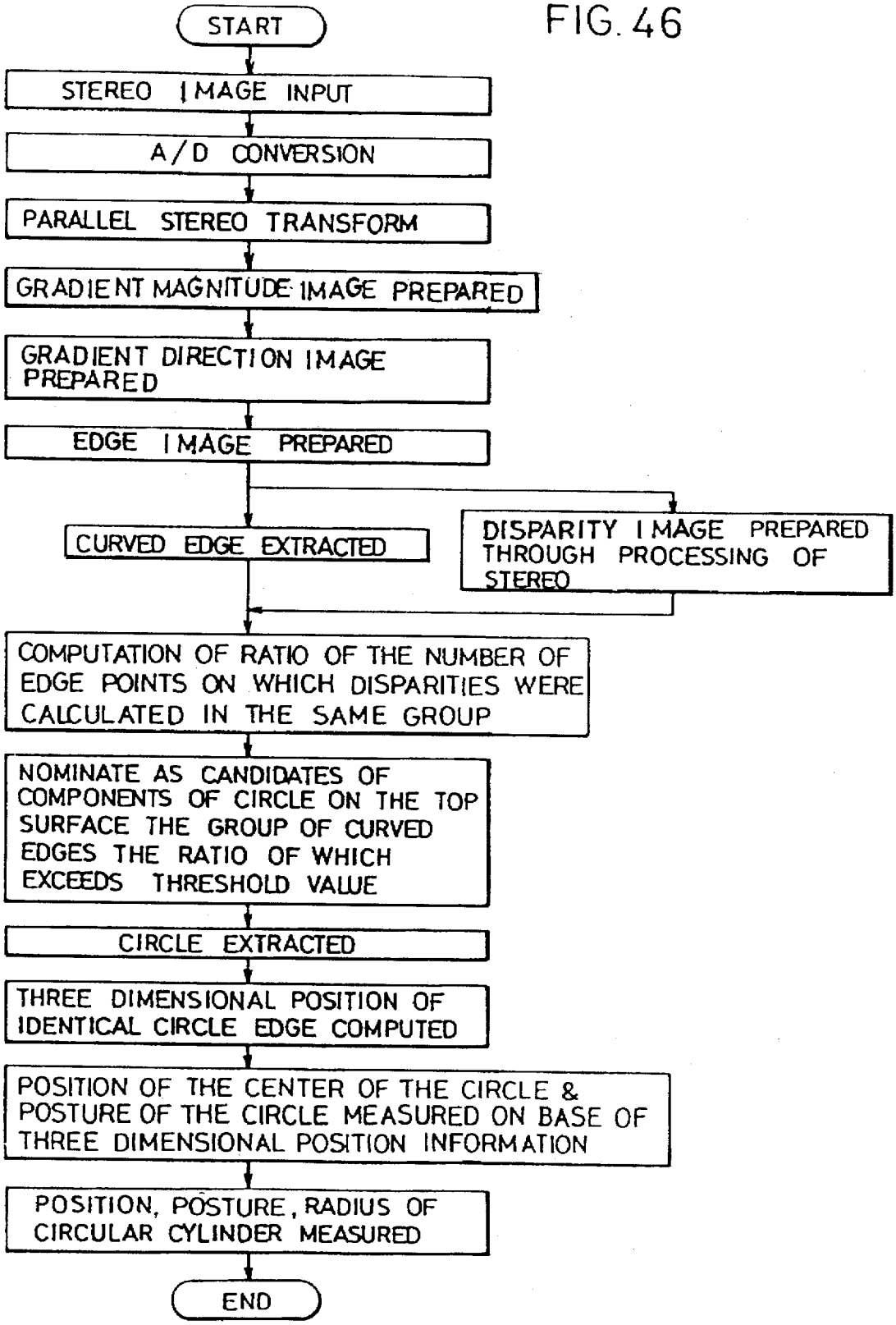

START
STEREO IMAGE INPUT
A/D CONVERSION
PARALLEL STEREO TRANSFORM
GRADIENT MAGNITUDE IMAGE PREPARED
GRADIENT DIRECTION IMAGE PREPARED
EDGE IMAGE PREPARED
CURVED EDGE EXTRACTED
DISPARITY IMAGE PREPARED THROUGH PROCESSING OF STEREO
COMPUTATION OF RATIO OF THE NUMBER OF EDGE POINTS ON WHICH DISPARITIES WERE CALCULATED IN THE SAME GROUP
NOMINATE AS CANDIDATES OF COMPONENTS OF CIRCLE ON THE TOP SURFACE THE GROUP OF CURVED EDGES THE RATIO OF WHICH EXCEEDS THRESHOLD VALUE
CIRCLE EXTRACTED
THREE DIMENSIONAL POSITION OF IDENTICAL CIRCLE EDGE COMPUTED
POSITION OF THE CENTER OF THE CIRCLE & POSTURE OF THE CIRCLE MEASURED ON BASE OF THREE DIMENSIONAL POSITION INFORMATION
POSITION, POSTURE, RADIUS OF CIRCULAR CYLINDER MEASURED
END

FIG. 47a

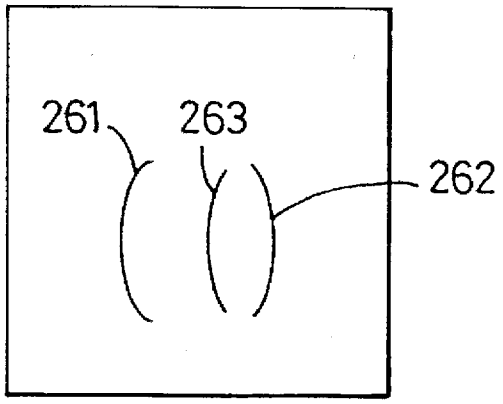


FIG. 47b

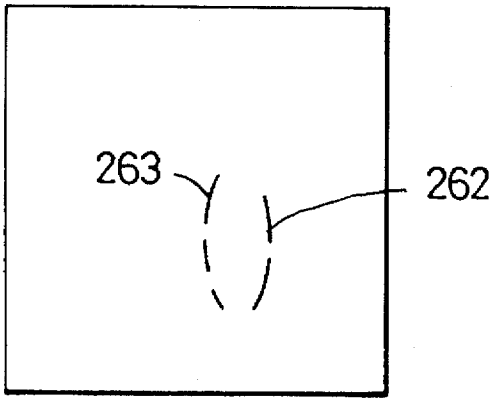


FIG. 47c

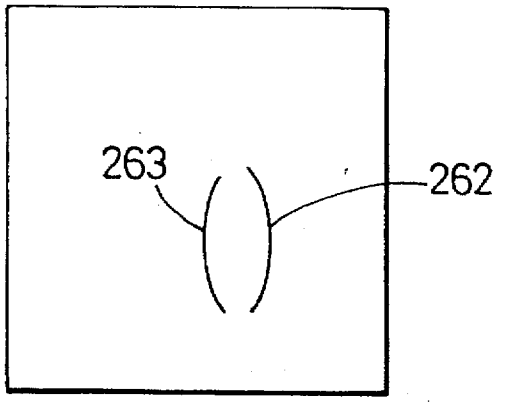


FIG. 48a

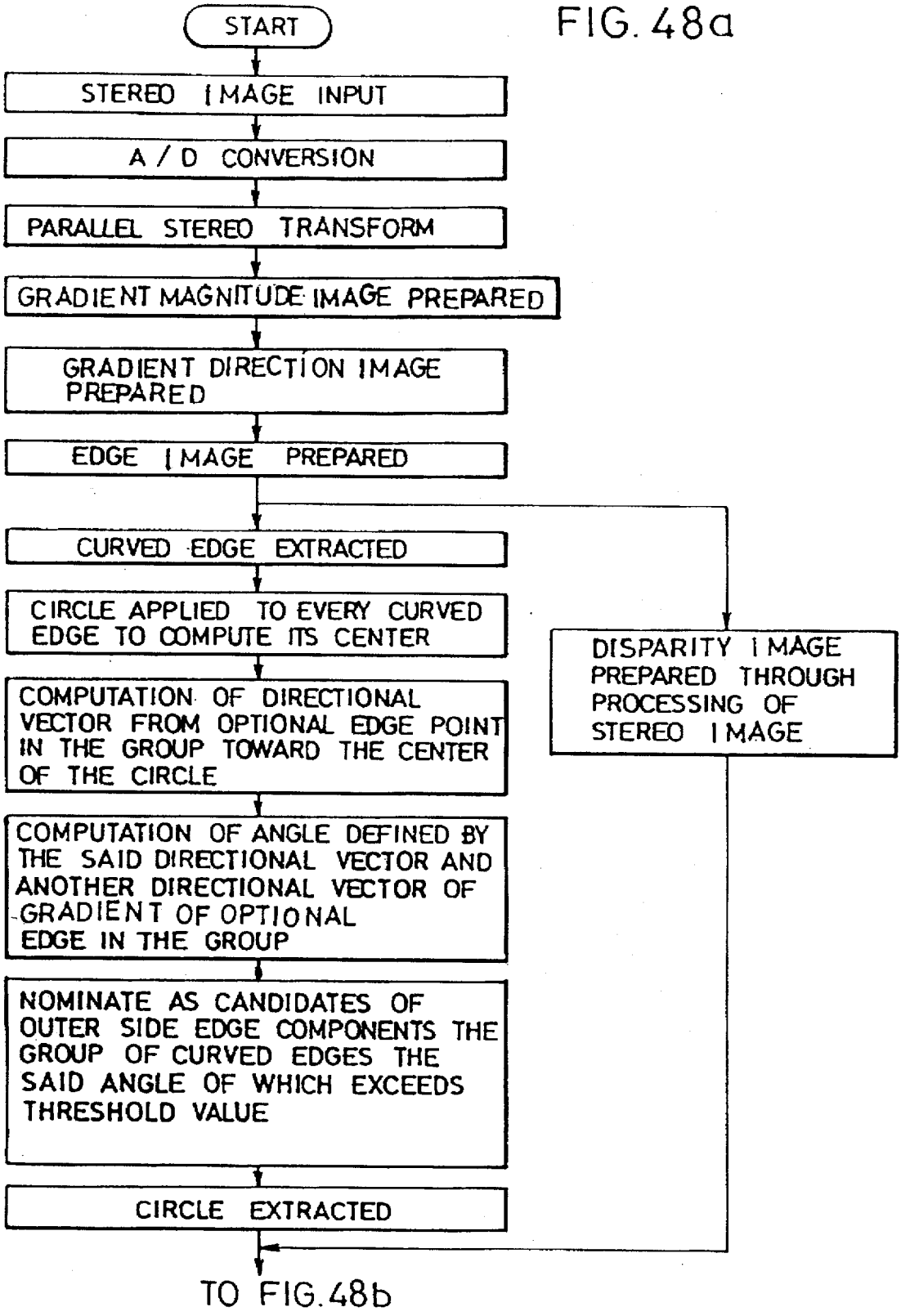

START
STEREO IMAGE INPUT
A / D CONVERSION
PARALLEL STEREO TRANSFORM
GRADIENT MAGNITUDE IMAGE PREPARED
GRADIENT DIRECTION IMAGE PREPARED
EDGE IMAGE PREPARED
CURVED EDGE EXTRACTED
CIRCLE APPLIED TO EVERY CURVED EDGE TO COMPUTE ITS CENTER
COMPUTATION OF DIRECTIONAL VECTOR FROM OPTIONAL EDGE POINT IN THE GROUP TOWARD THE CENTER OF THE CIRCLE
COMPUTATION OF ANGLE DEFINED BY THE SAID DIRECTIONAL VECTOR AND ANOTHER DIRECTIONAL VECTOR OF GRADIENT OF OPTIONAL EDGE IN THE GROUP
NOMINATE AS CANDIDATES OF OUTER SIDE EDGE COMPONENTS THE GROUP OF CURVED EDGES THE SAID ANGLE OF WHICH EXCEEDS THRESHOLD VALUE
CIRCLE EXTRACTED
DISPARITY IMAGE PREPARED THROUGH PROCESSING OF STEREO IMAGE
TO FIG. 48b

FIG. 48b

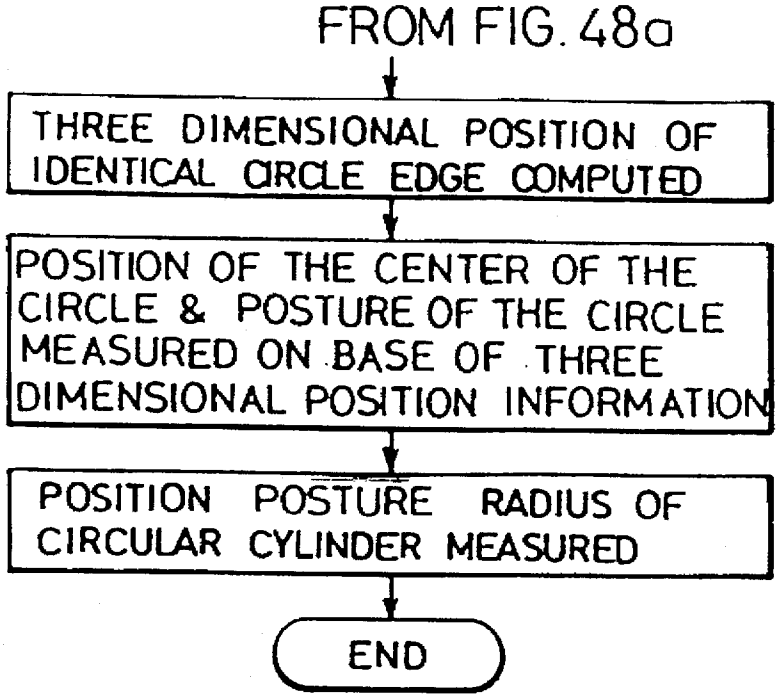
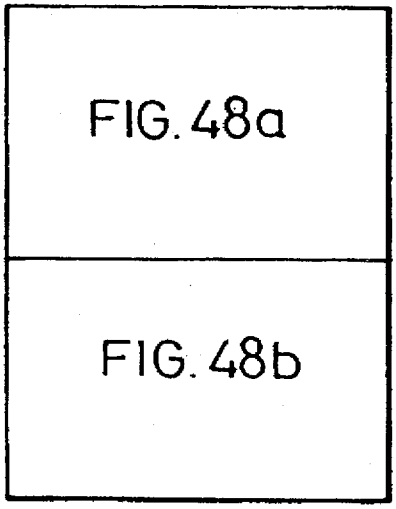


FIG. 48



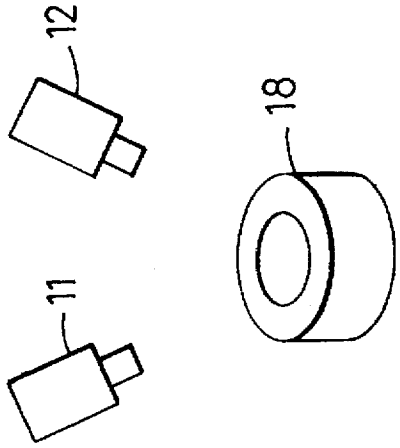


FIG. 49

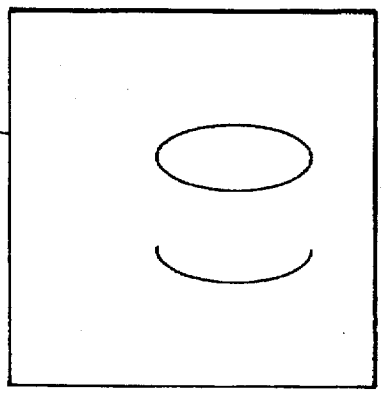


FIG. 50c

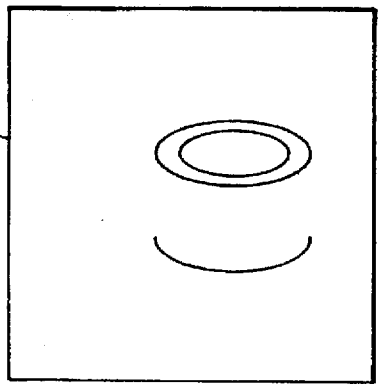


FIG. 50b

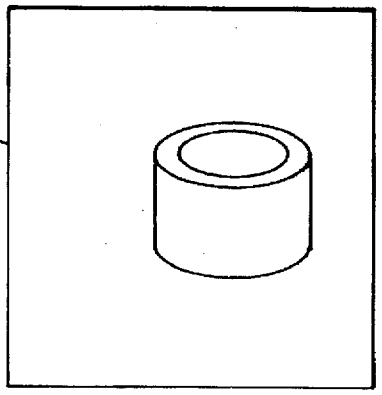


FIG. 50a

FIG. 51

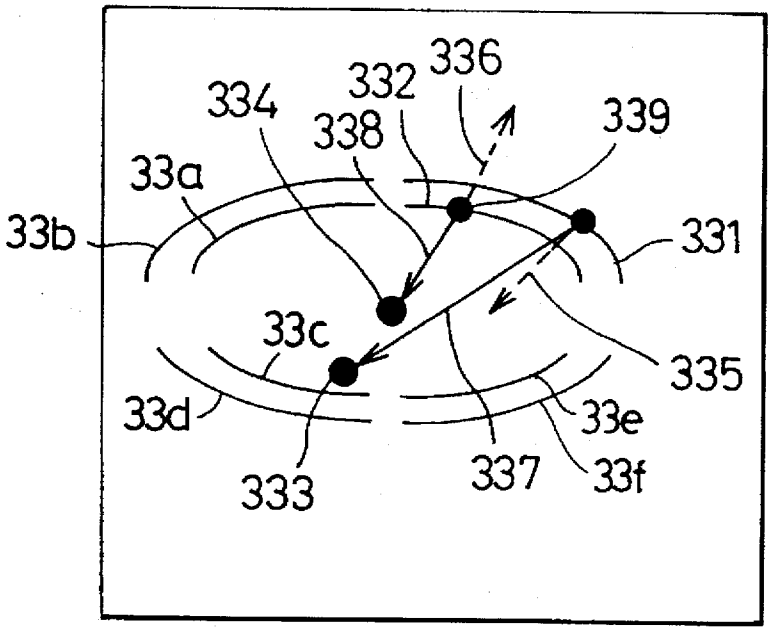
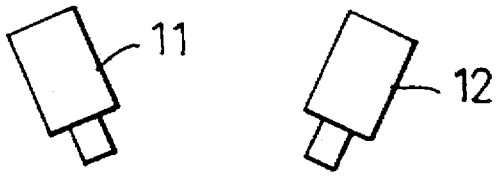

336
332
334
338
339
33a
33b
331
33c
335
33d
33e
337
33f
333

FIG. 53


11
12

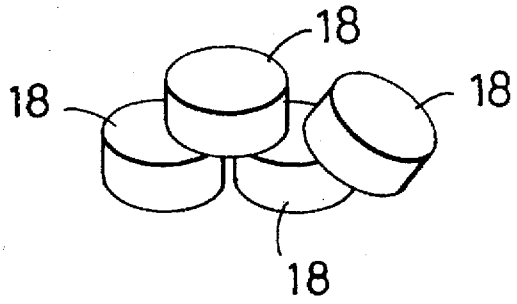
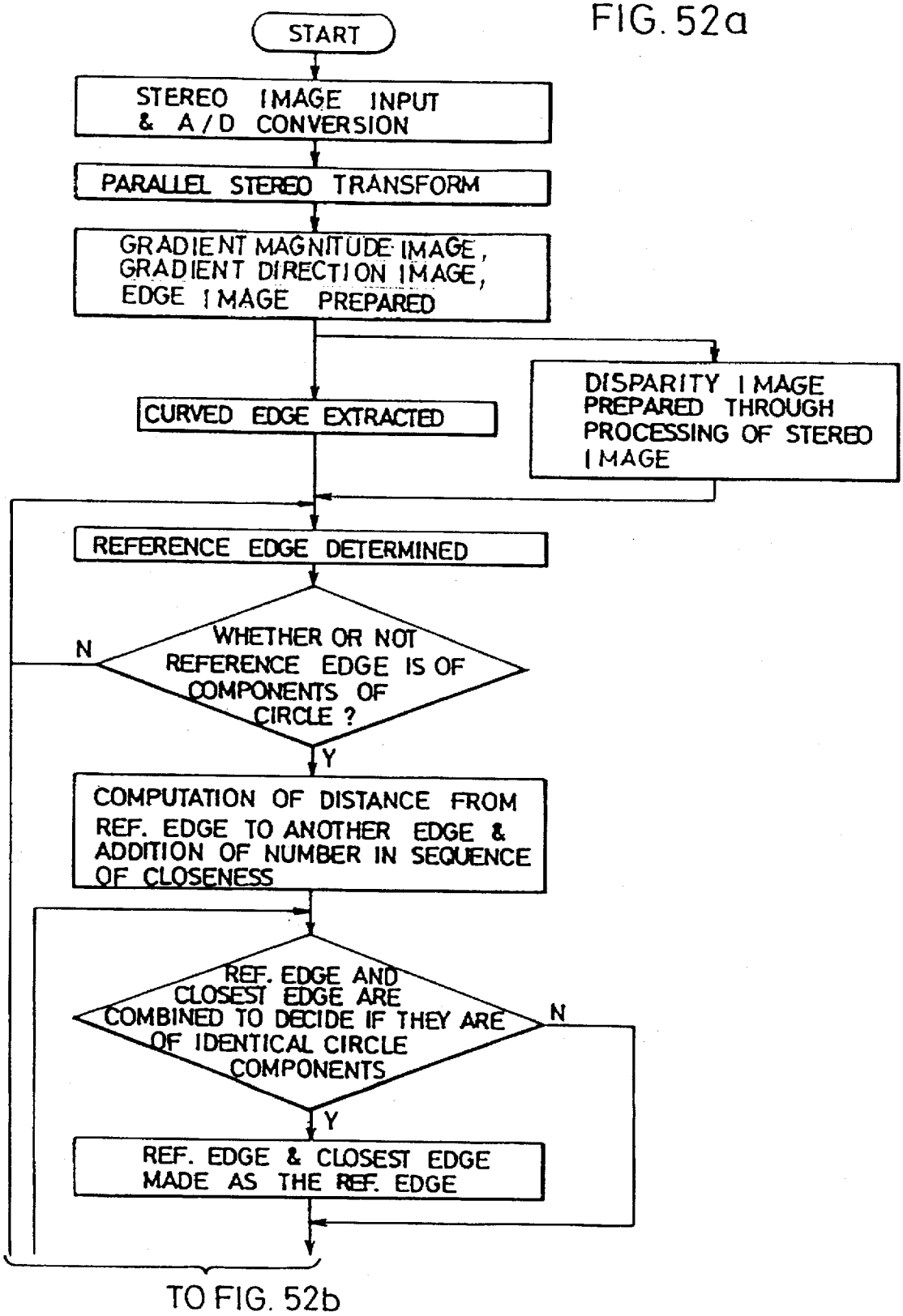

18
18
18
18

FIG. 52a


START
STEREO IMAGE INPUT & A/D CONVERSION
PARALLEL STEREO TRANSFORM
GRADIENT MAGNITUDE IMAGE, GRADIENT DIRECTION IMAGE, EDGE IMAGE PREPARED
CURVED EDGE EXTRACTED
DISPARITY IMAGE PREPARED THROUGH PROCESSING OF STEREO IMAGE
REFERENCE EDGE DETERMINED
WHETHER OR NOT REFERENCE EDGE IS OF COMPONENTS OF CIRCLE ?
N
Y
COMPUTATION OF DISTANCE FROM REF. EDGE TO ANOTHER EDGE & ADDITION OF NUMBER IN SEQUENCE OF CLOSENESS
REF. EDGE AND CLOSEST EDGE ARE COMBINED TO DECIDE IF THEY ARE OF IDENTICAL CIRCLE COMPONENTS
N
Y
REF. EDGE & CLOSEST EDGE MADE AS THE REF. EDGE
TO FIG. 52b

FROM FIG. 52a

FIG. 52b

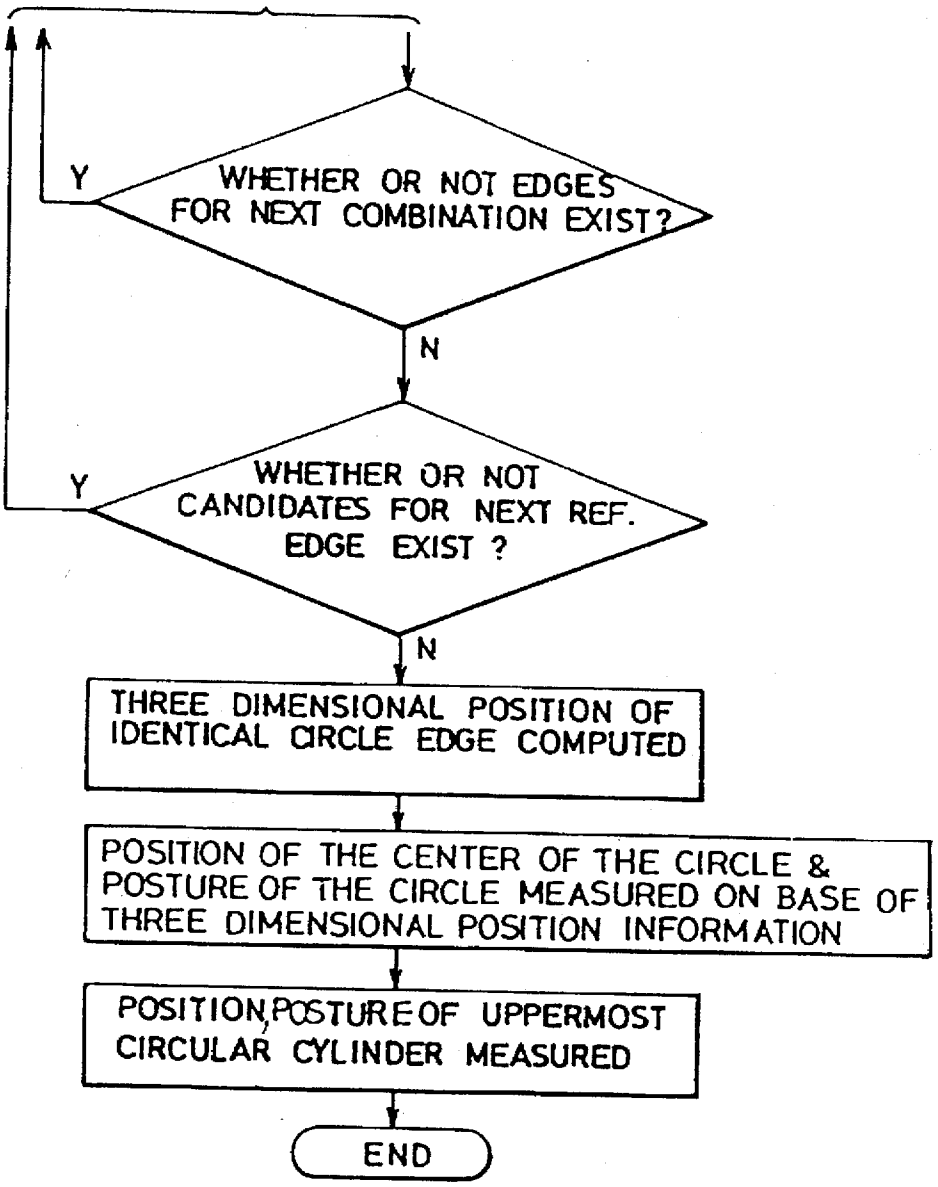


FIG. 52

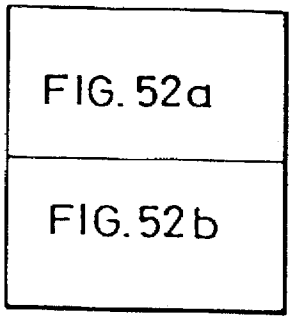


FIG. 54a

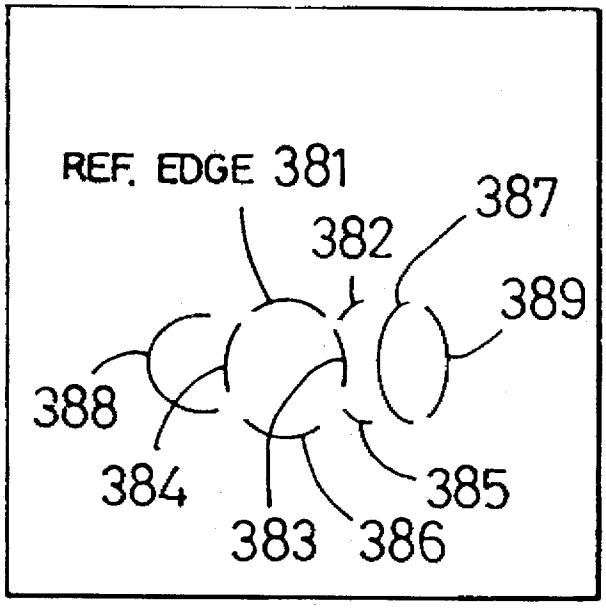


FIG. 54b

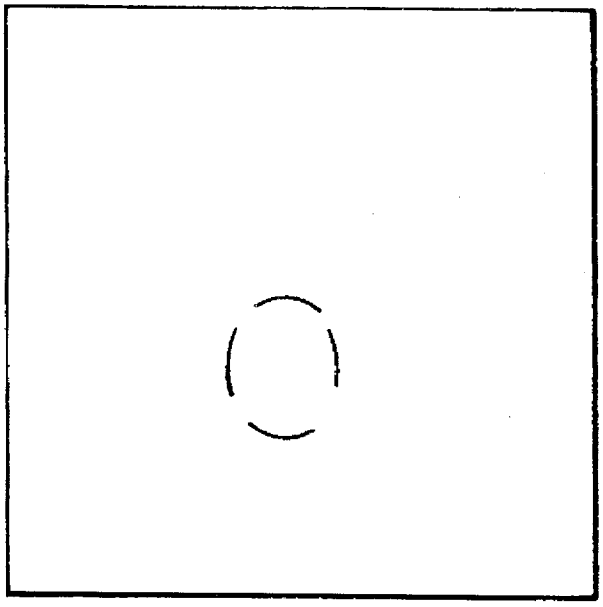


FIG. 55a

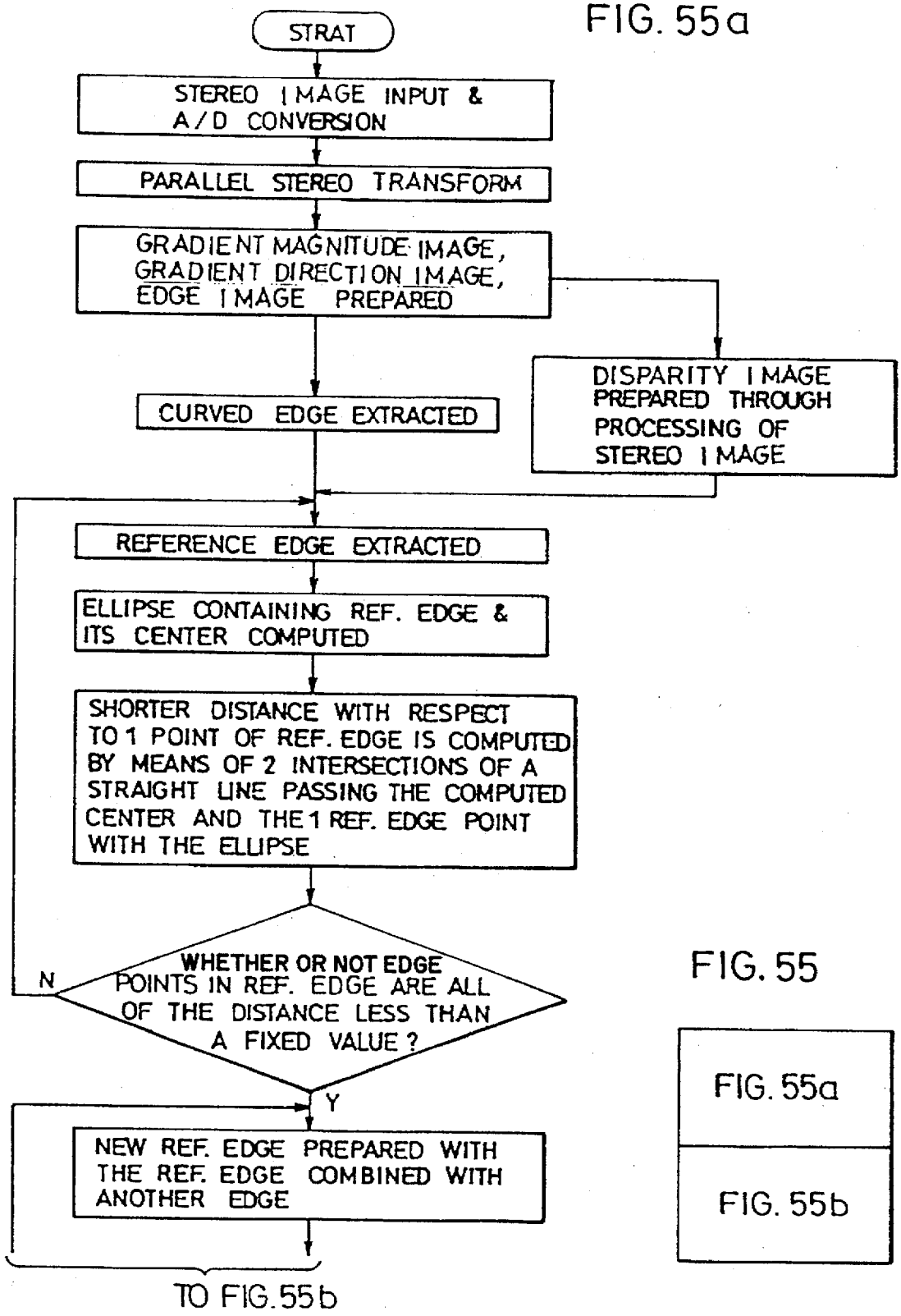


FIG. 55

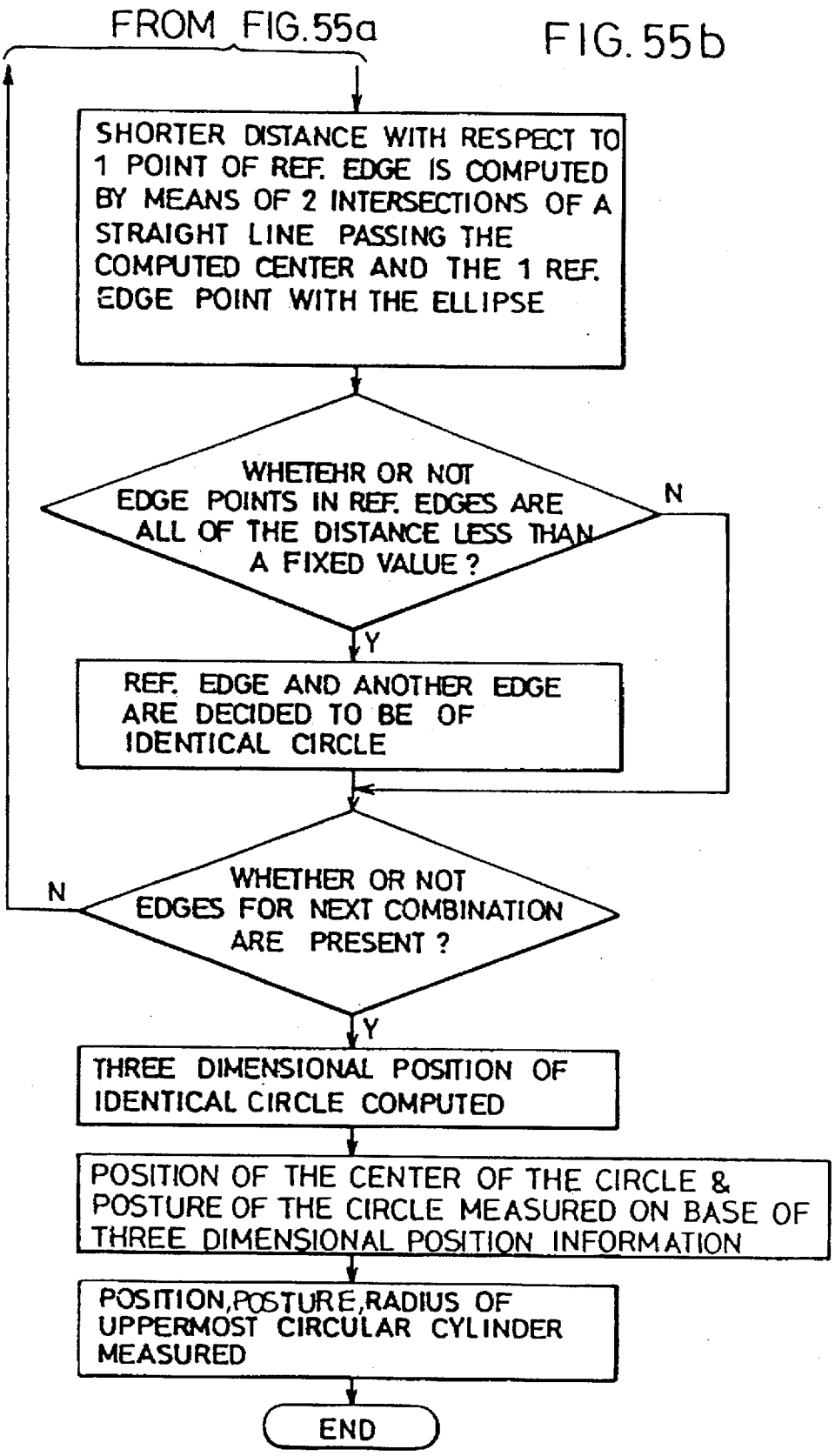

FROM FIG.55a
SHORTER DISTANCE WITH RESPECT TO 1 POINT OF REF. EDGE IS COMPUTED BY MEANS OF 2 INTERSECTIONS OF A STRAIGHT LINE PASSING THE COMPUTED CENTER AND THE 1 REF. EDGE POINT WITH THE ELLIPSE
WHETEHR OR NOT EDGE POINTS IN REF. EDGES ARE ALL OF THE DISTANCE LESS THAN A FIXED VALUE ?
N
Y
REF. EDGE AND ANOTHER EDGE ARE DECIDED TO BE OF IDENTICAL CIRCLE
WHETHER OR NOT EDGES FOR NEXT COMBINATION ARE PRESENT ?
N
Y
THREE DIMENSIONAL POSITION OF IDENTICAL CIRCLE COMPUTED
POSITION OF THE CENTER OF THE CIRCLE & POSTURE OF THE CIRCLE MEASURED ON BASE OF THREE DIMENSIONAL POSITION INFORMATION
POSITION,POSTURE,RADIUS OF UPPERMOST CIRCULAR CYLINDER MEASURED
END

FIG. 55b

FIG. 56

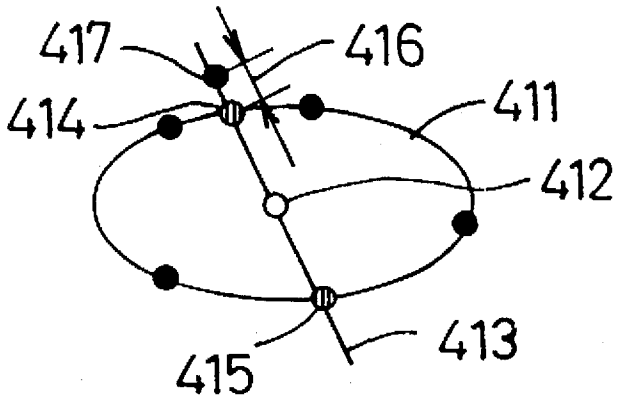


FIG. 58

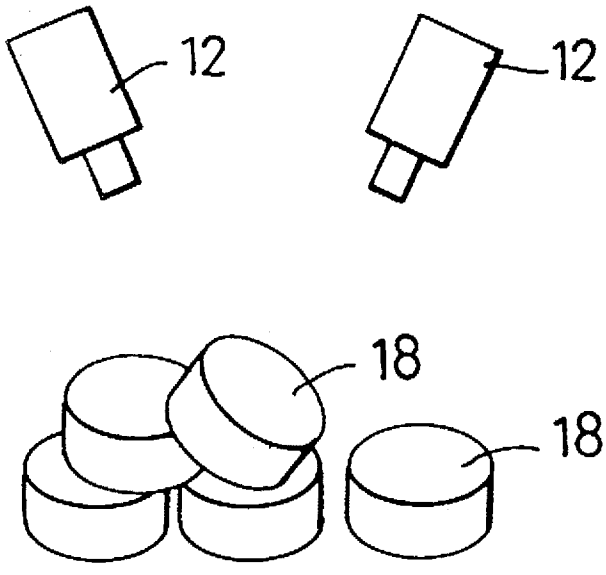
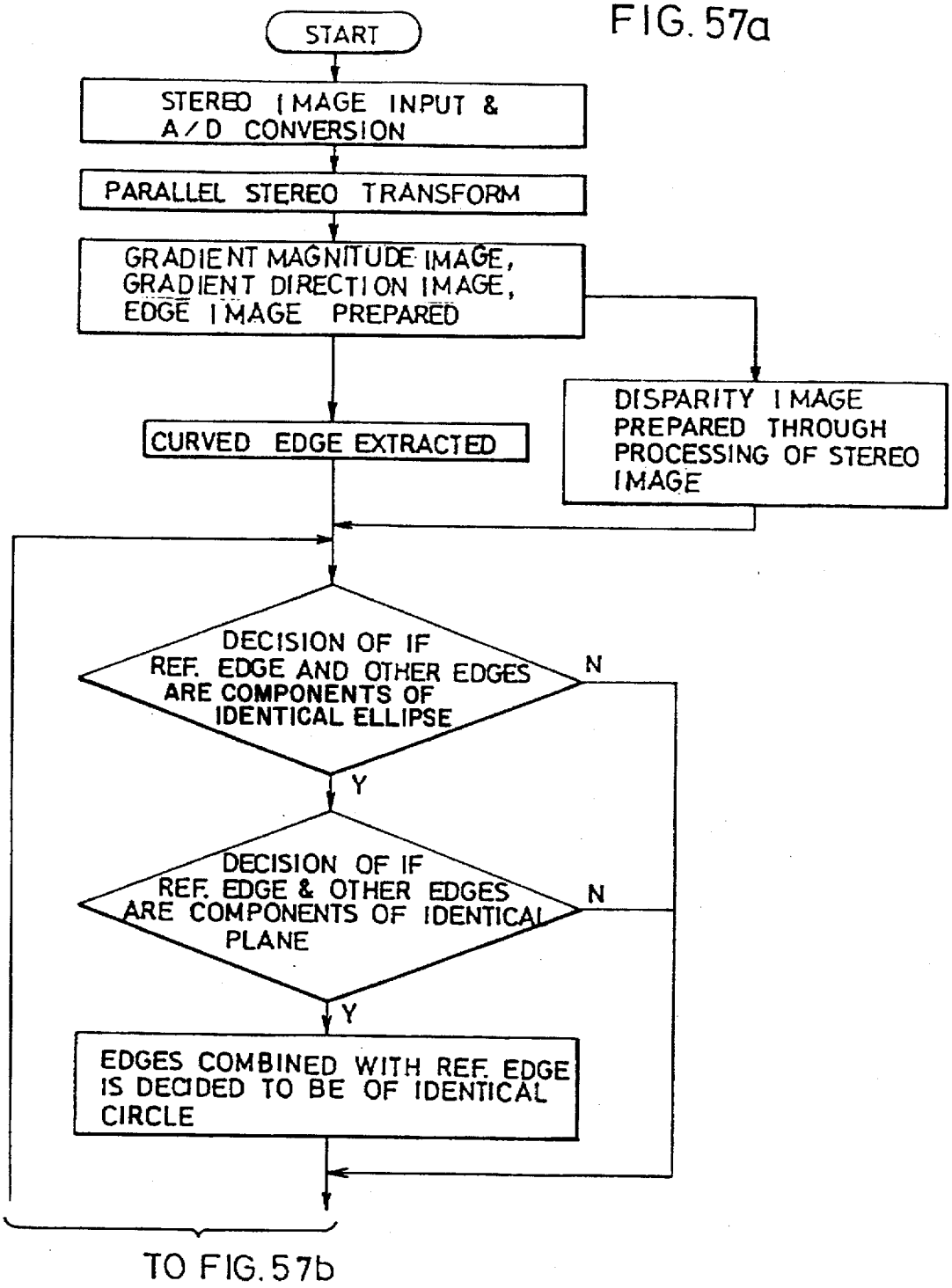


FIG. 57a


START
STEREO IMAGE INPUT & A/D CONVERSION
PARALLEL STEREO TRANSFORM
GRADIENT MAGNITUDE IMAGE, GRADIENT DIRECTION IMAGE, EDGE IMAGE PREPARED
DISPARITY IMAGE PREPARED THROUGH PROCESSING OF STEREO IMAGE
CURVED EDGE EXTRACTED
DECISION OF IF REF. EDGE AND OTHER EDGES ARE COMPONENTS OF IDENTICAL ELLIPSE
N
Y
DECISION OF IF REF. EDGE & OTHER EDGES ARE COMPONENTS OF IDENTICAL PLANE
N
Y
EDGES COMBINED WITH REF. EDGE IS DECIDED TO BE OF IDENTICAL CIRCLE
TO FIG. 57b

FROM FIG. 57a

FIG. 57b

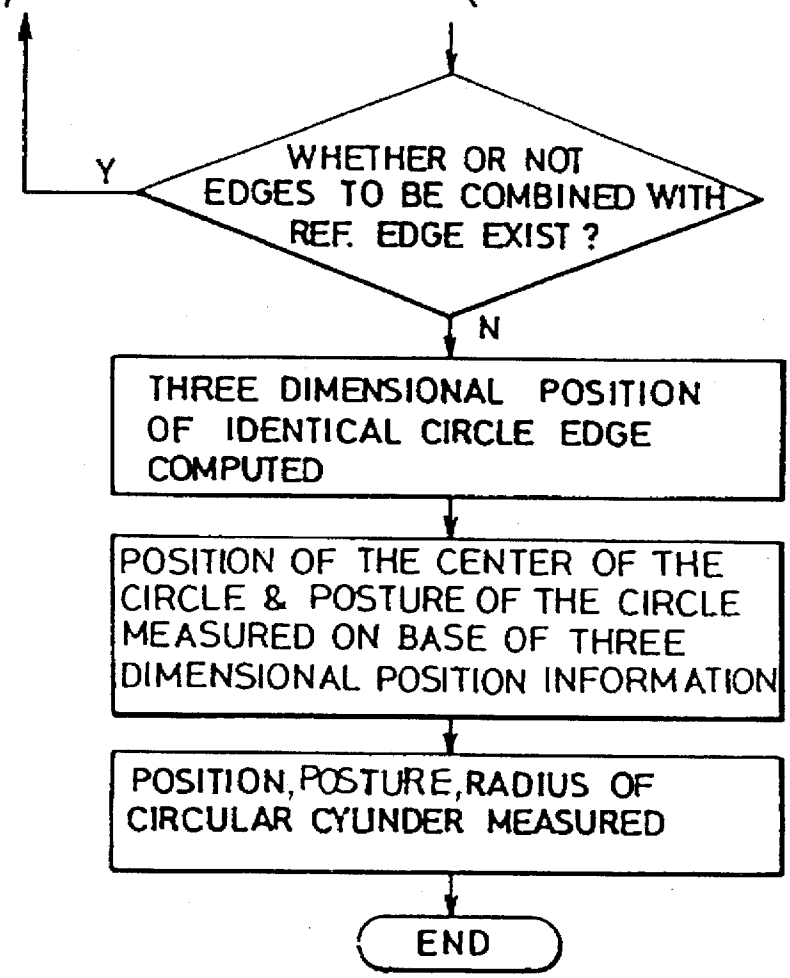


FIG. 57

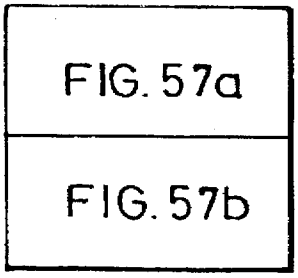


FIG. 59a

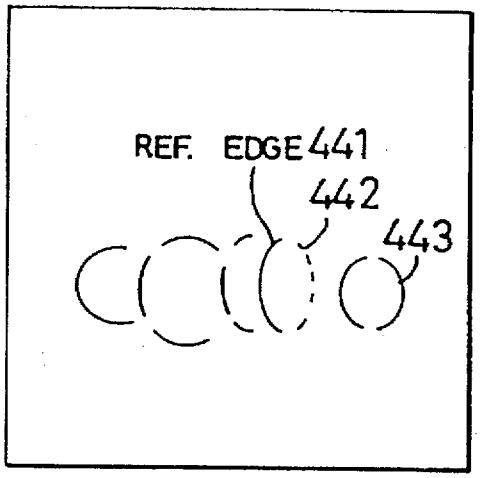


FIG. 59b

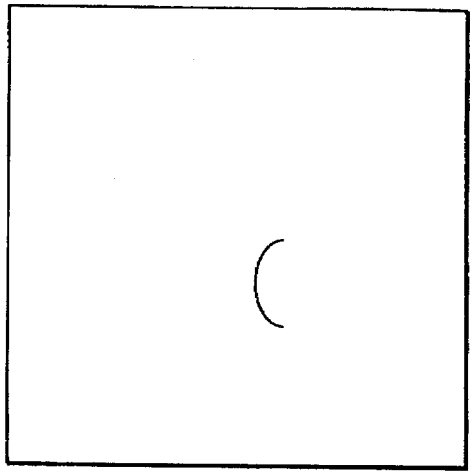


FIG. 60

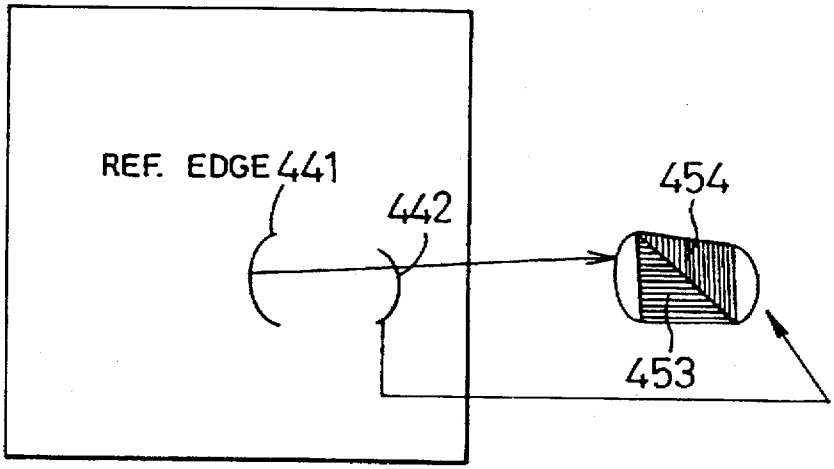


FIG. 61a

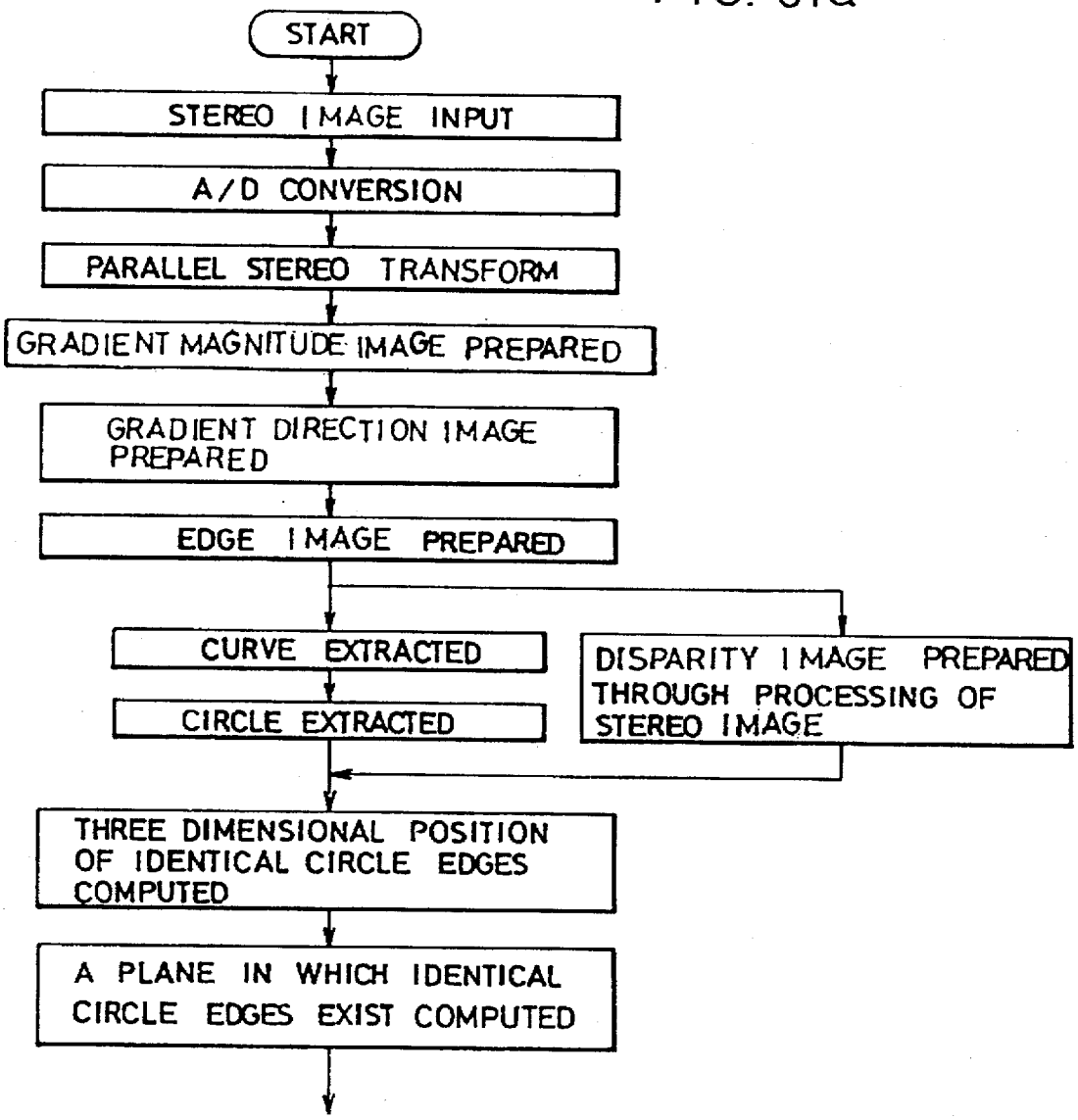

START
STEREO IMAGE INPUT
A/D CONVERSION
PARALLEL STEREO TRANSFORM
GRADIENT MAGNITUDE IMAGE PREPARED
GRADIENT DIRECTION IMAGE PREPARED
EDGE IMAGE PREPARED
CURVE EXTRACTED
CIRCLE EXTRACTED
DISPARITY IMAGE PREPARED THROUGH PROCESSING OF STEREO IMAGE
THREE DIMENSIONAL POSITION OF IDENTICAL CIRCLE EDGES COMPUTED
A PLANE IN WHICH IDENTICAL CIRCLE EDGES EXIST COMPUTED
TO FIG. 61b

FIG. 61 b

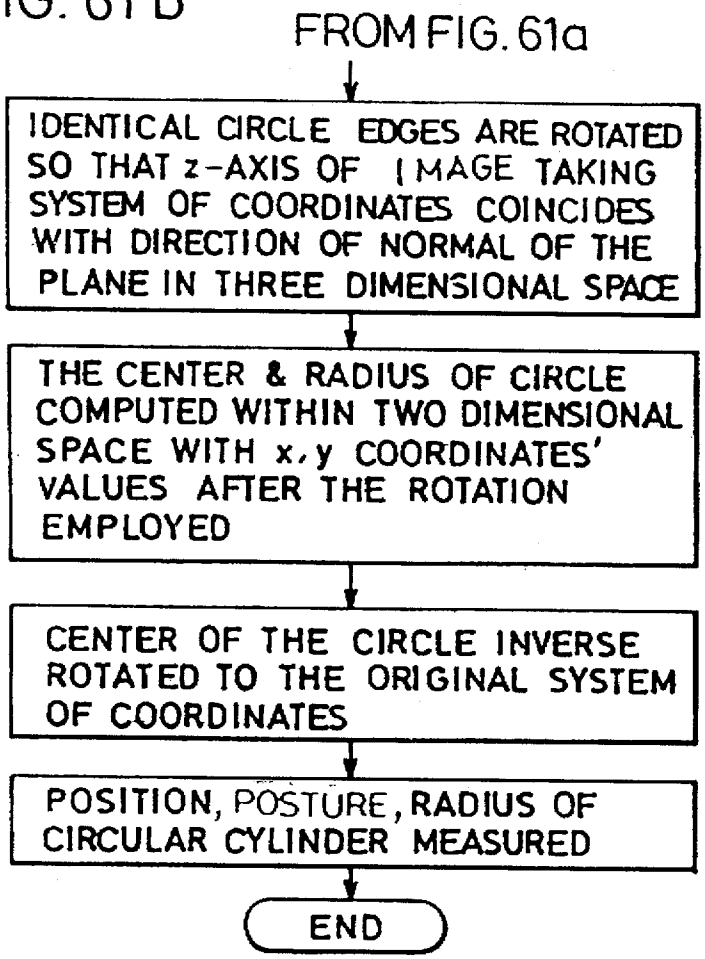


FIG. 61

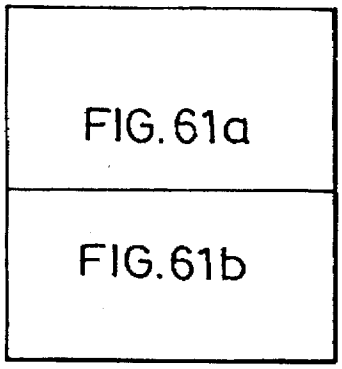


FIG. 62

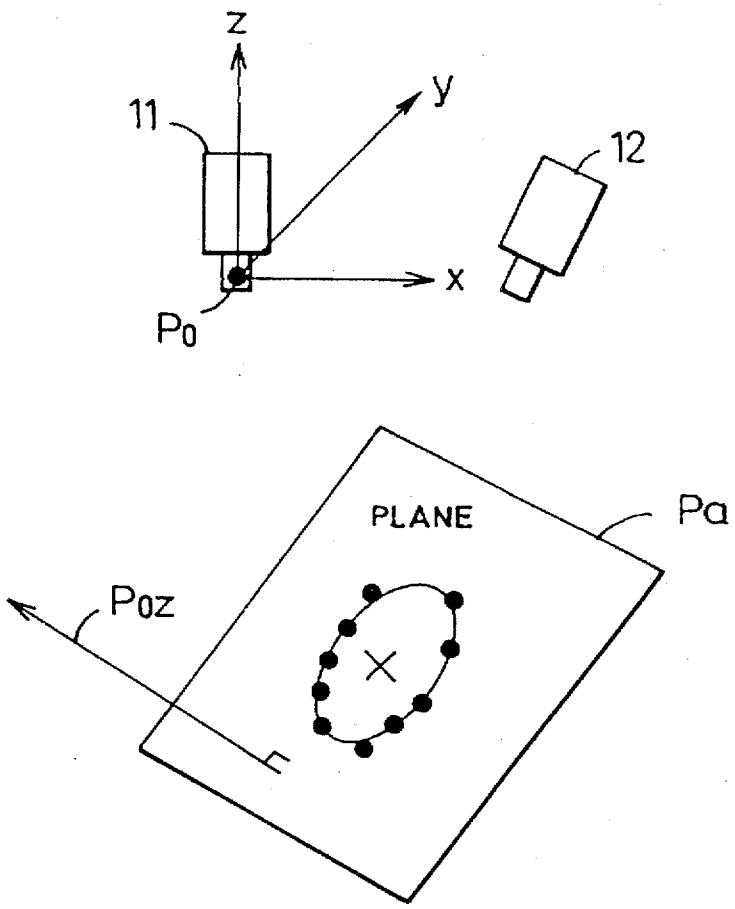


FIG. 63

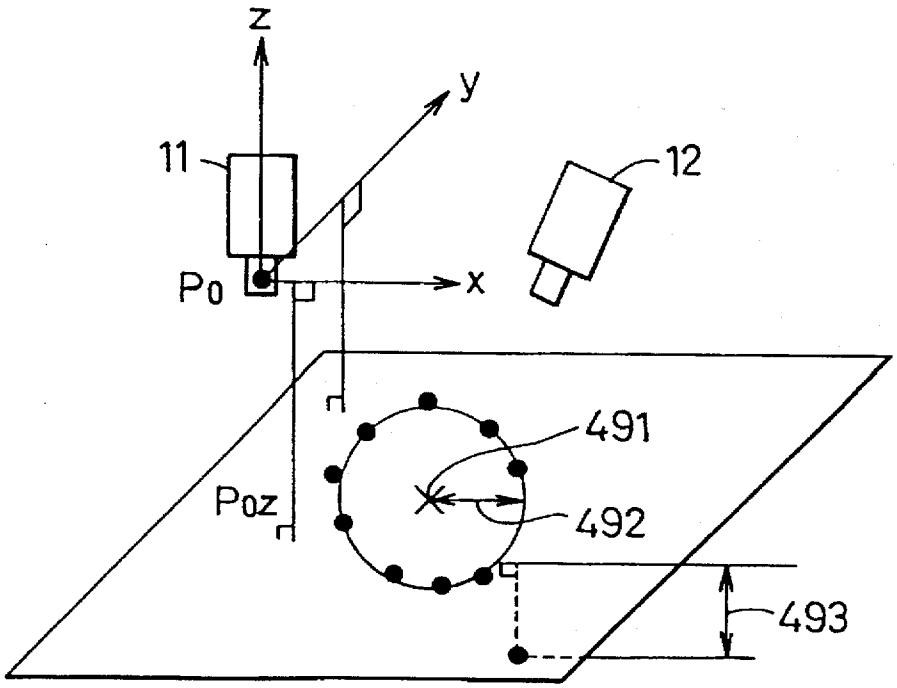
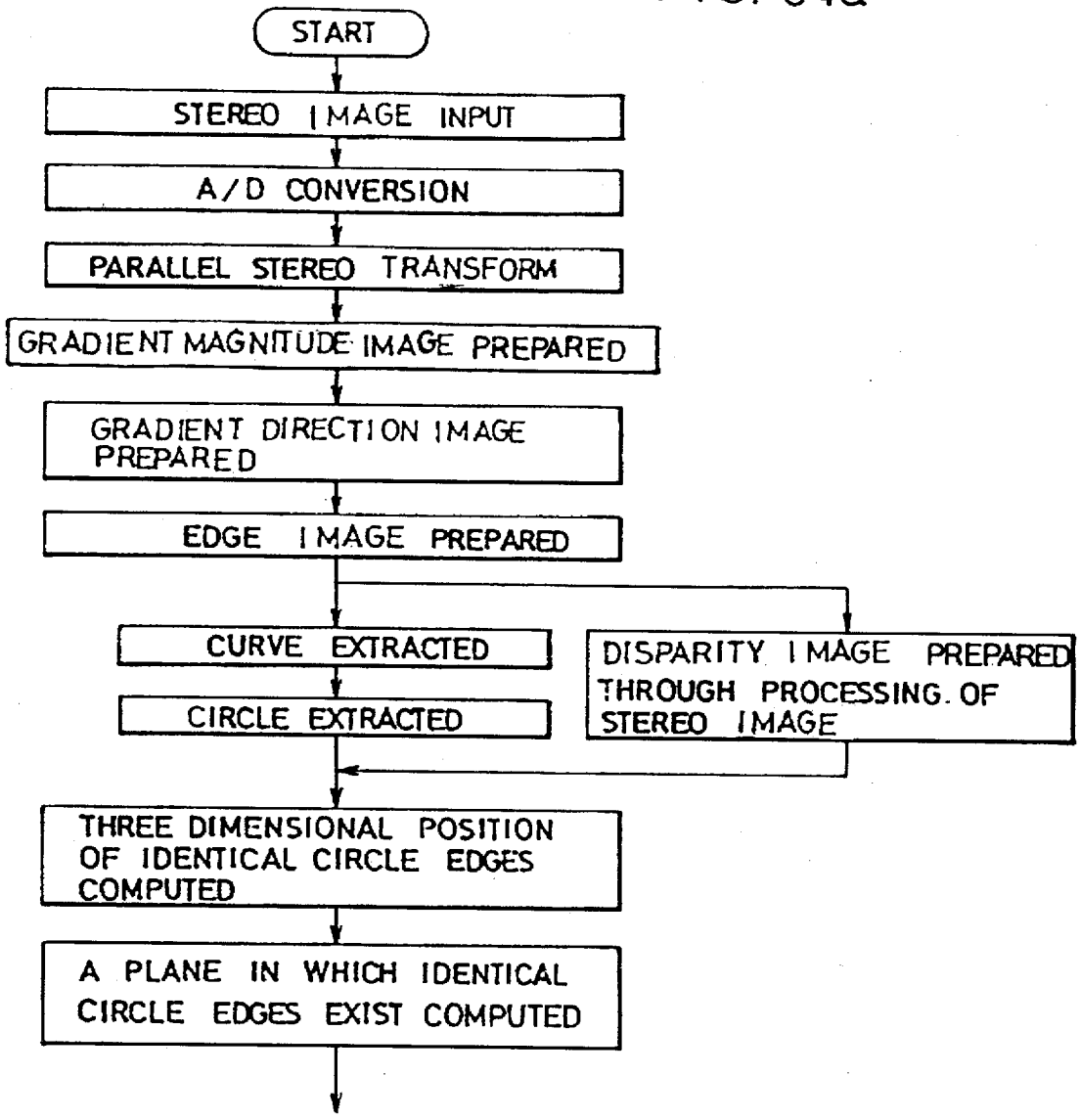


FIG. 64a



TO FIG. 64b

FIG. 64b

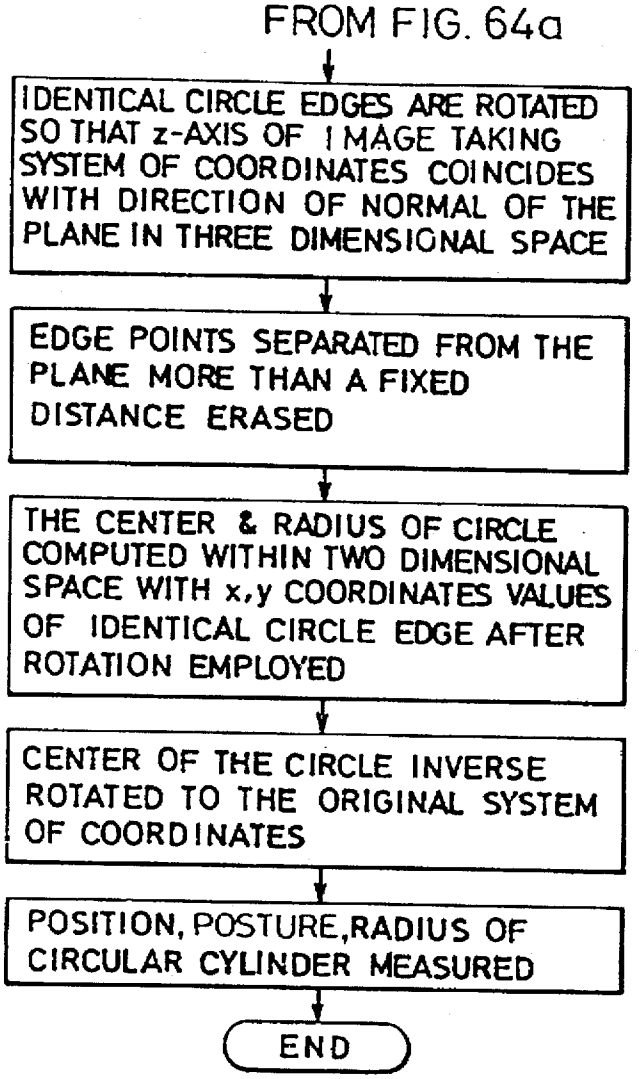


FIG. 64

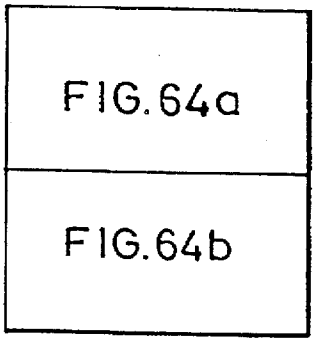
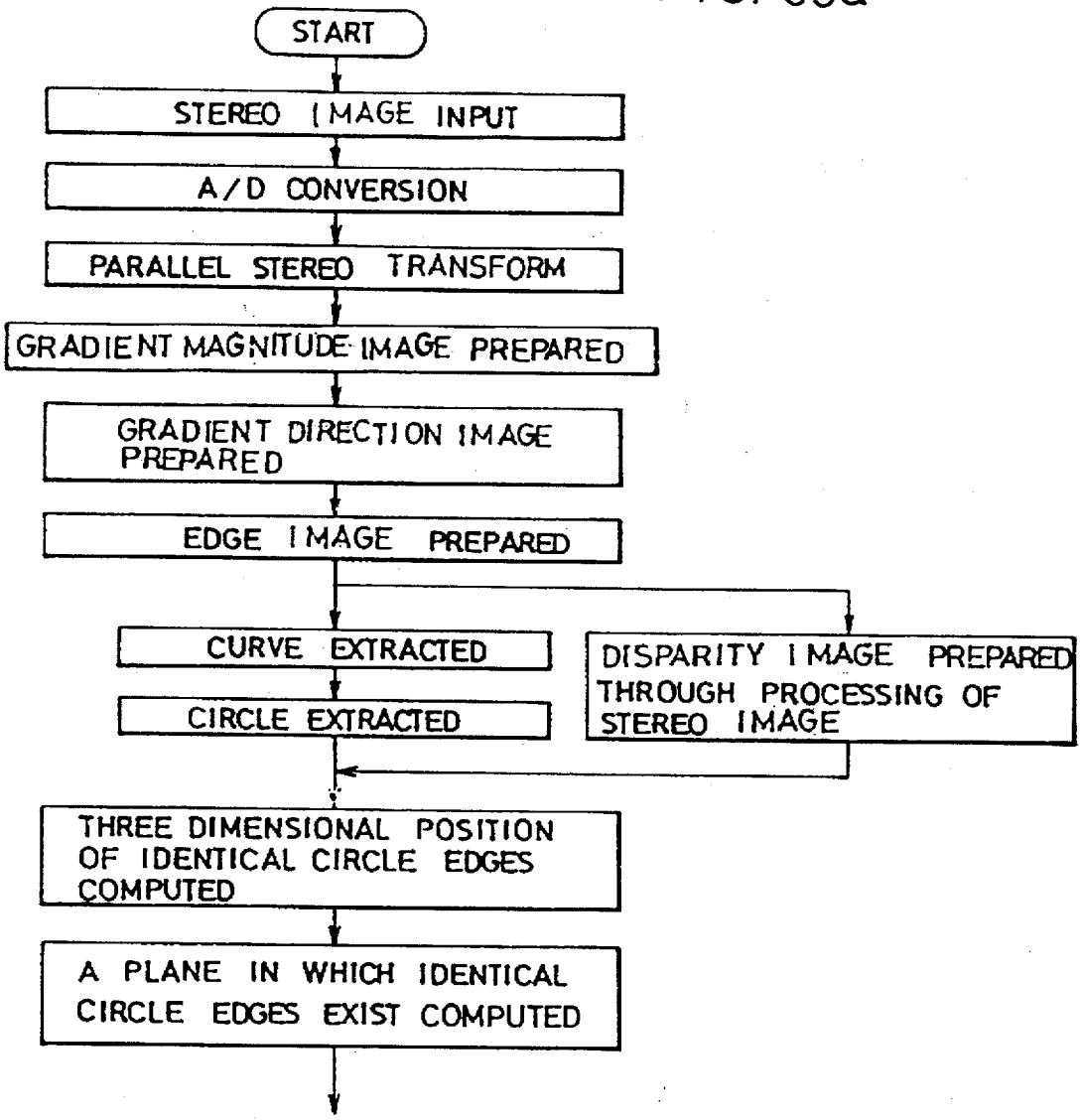


FIG. 65a



TO FIG. 65b

FIG. 65b

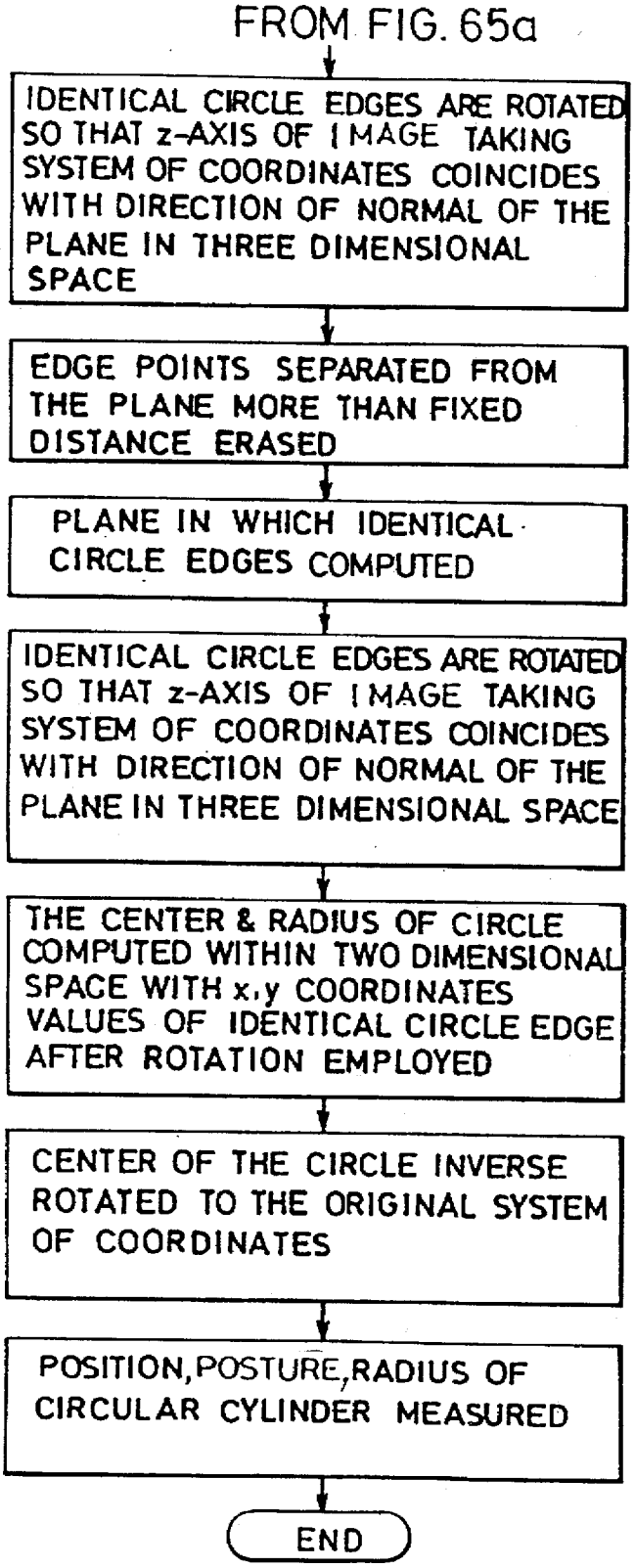


FIG. 65

FIG.65a
FIG.65b

FIG. 66

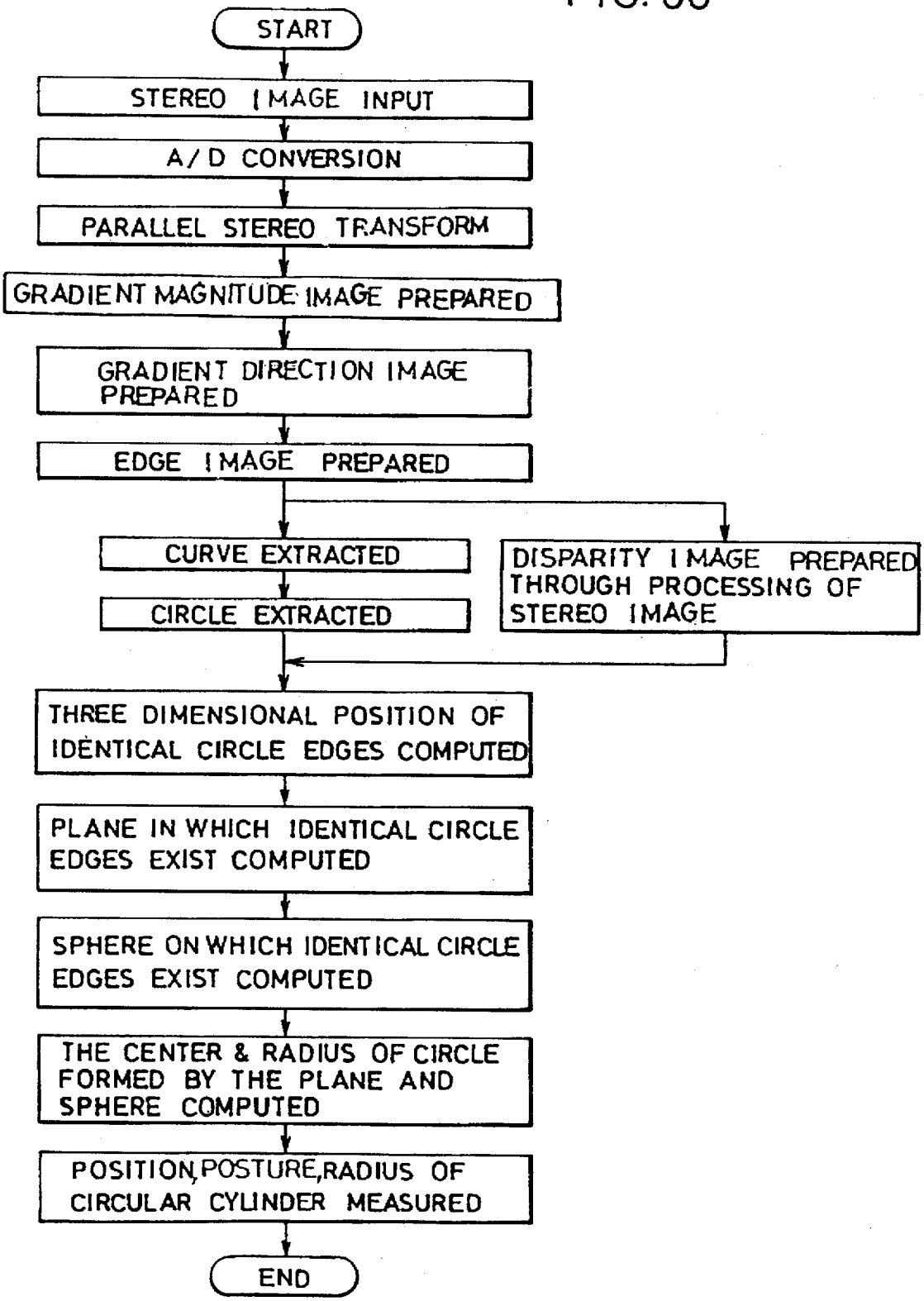

START
STEREO IMAGE INPUT
A/D CONVERSION
PARALLEL STEREO TRANSFORM
GRADIENT MAGNITUDE IMAGE PREPARED
GRADIENT DIRECTION IMAGE PREPARED
EDGE IMAGE PREPARED
CURVE EXTRACTED
CIRCLE EXTRACTED
DISPARITY IMAGE PREPARED THROUGH PROCESSING OF STEREO IMAGE
THREE DIMENSIONAL POSITION OF IDENTICAL CIRCLE EDGES COMPUTED
PLANE IN WHICH IDENTICAL CIRCLE EDGES EXIST COMPUTED
SPHERE ON WHICH IDENTICAL CIRCLE EDGES EXIST COMPUTED
THE CENTER & RADIUS OF CIRCLE FORMED BY THE PLANE AND SPHERE COMPUTED
POSITION, POSTURE, RADIUS OF CIRCULAR CYLINDER MEASURED
END

FIG. 67

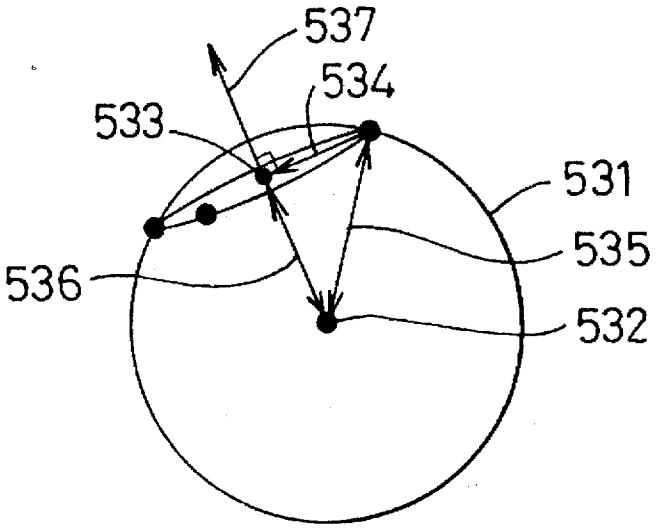


FIG. 69

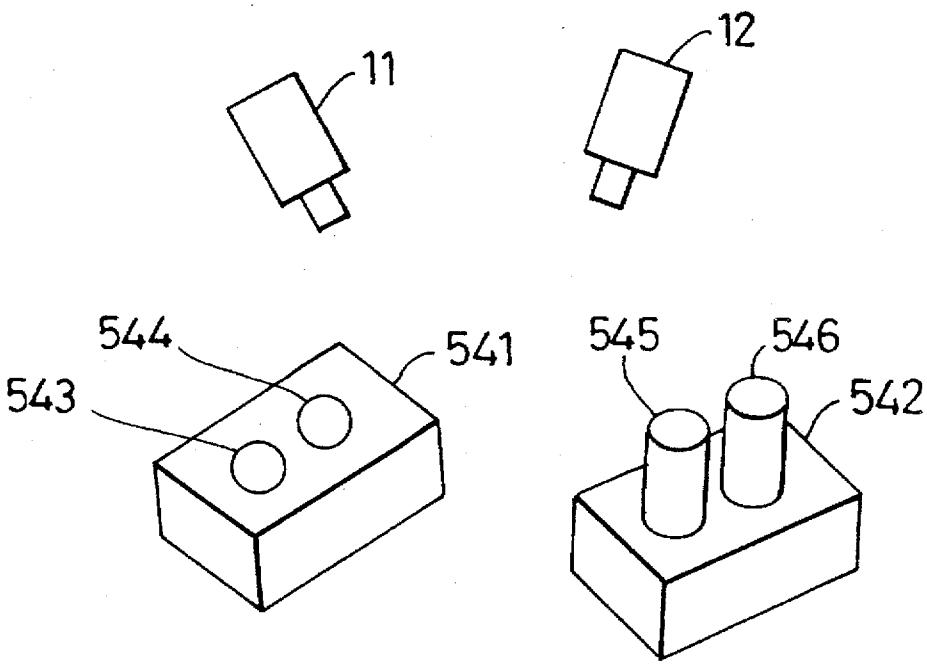


FIG. 68

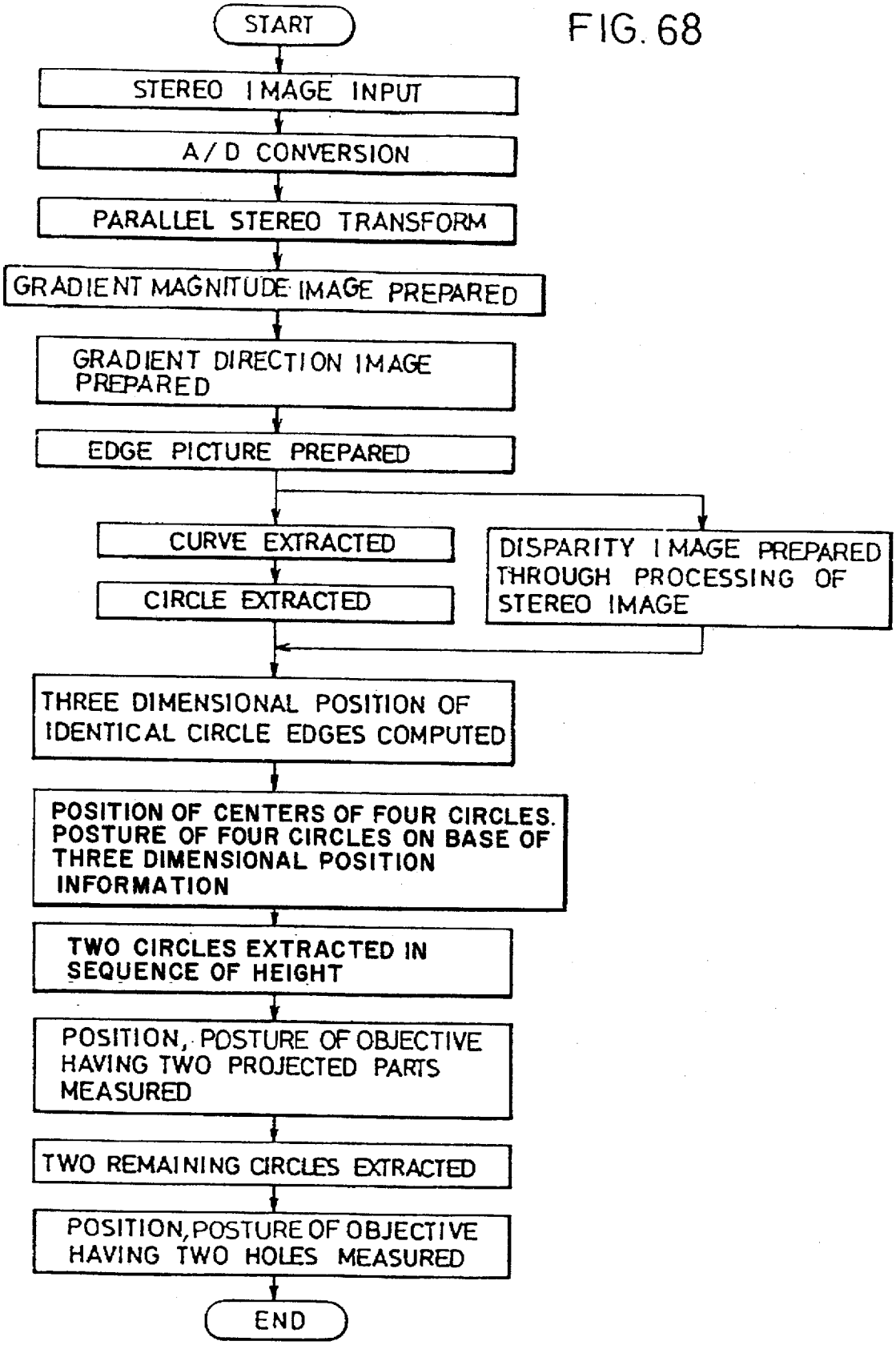

START
STEREO IMAGE INPUT
A/D CONVERSION
PARALLEL STEREO TRANSFORM
GRADIENT MAGNITUDE IMAGE PREPARED
GRADIENT DIRECTION IMAGE PREPARED
EDGE PICTURE PREPARED
CURVE EXTRACTED
CIRCLE EXTRACTED
DISPARITY IMAGE PREPARED THROUGH PROCESSING OF STEREO IMAGE
THREE DIMENSIONAL POSITION OF IDENTICAL CIRCLE EDGES COMPUTED
POSITION OF CENTERS OF FOUR CIRCLES. POSTURE OF FOUR CIRCLES ON BASE OF THREE DIMENSIONAL POSITION INFORMATION
TWO CIRCLES EXTRACTED IN SEQUENCE OF HEIGHT
POSITION, POSTURE OF OBJECTIVE HAVING TWO PROJECTED PARTS MEASURED
TWO REMAINING CIRCLES EXTRACTED
POSITION, POSTURE OF OBJECTIVE HAVING TWO HOLES MEASURED
END

FIG. 70a

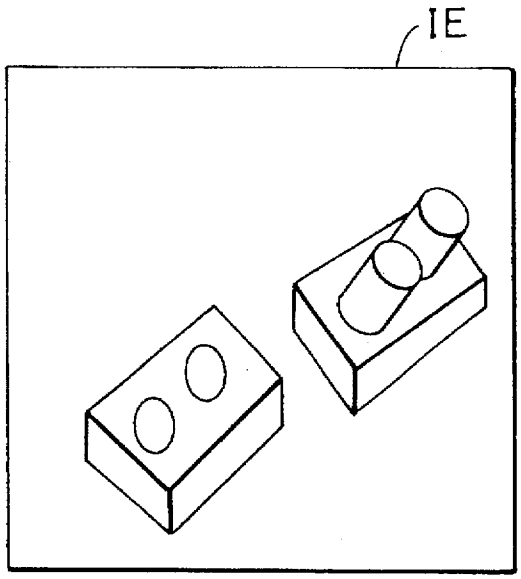


FIG. 70b

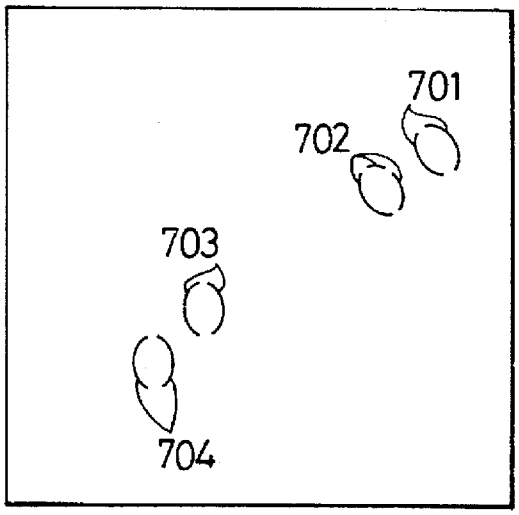
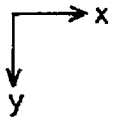


FIG. 71

-1	0	1
-2	0	2
-1	0	1

Gx



1	2	1
0	0	0
-1	-2	-1

Gy

METHOD OF UTILIZING A TWO-DIMENSIONAL IMAGE FOR DETECTING THE POSITION, POSTURE, AND SHAPE OF A THREE-DIMENSIONAL OBJECTIVE

BACKGROUND OF THE INVENTION

The present invention relates to a method for recognizing an objective in a three-dimensional space and, more particularly, an objective recognition method for detecting the position, attitude or posture and shape of an objective.

DESCRIPTION OF RELATED ART

For recognizing a three-dimensional objective, there have conventionally been suggested a method in which objective position detection is carried out by extracting a cluster in a space of parameters indicative of the positional posture of an objective obtained based on correspondences between all edge segments in an image and all arris or ridge lines of an objective model as disclosed in Japanese Patent Laid-Open Publication No. 2-230478. In another method an objective to be checked is considered to be an objective model comprising a plurality of rigid bodies and joints having degrees of freedom of rotation connected to the bodies. Posture candidates for each of the rigid bodies are found based on correspondences between features (such as designated segments or designated points) in an image and the objective model. An image of the objective image is estimated from the respective posture candidates and collated with the image to thereby determined a suitable posture as disclosed in Japanese Patent Laid-Open Publication No. 4-54409.

In the former method, it is necessary to make correspondences between all the edge segments in the image and all the arris lines of the objective model. Thus, when the target objective has a complicated shape, the number of edge segments in an image and the number of arris lines in an objective model become large, which disadvantageously results in that a lot of time is required for making the correspondences and a detection accuracy becomes bad. Even in the latter method, when an objective has a flexible structure, the numbers of rigid bodies and joints become large. So final detection of the three-dimensional posture of an objective requires lots of time.

Meanwhile, for the purpose of recognizing an objective having such a shape as a cylindrical shape, there is suggested such a method for realizing high-speed detection of an objective as shown in Japanese Patent Laid-Open Publication No. 6-29695. In this method, an objective to be checked is photographed obliquely by two image pick-up means to obtain two images. Curve edges are extracted from the two images, some of the curve edges when located within a predetermined distance range being regarded as edges in an identical elliptical line. The center of a right circle is regarded as photographed as the center of the ellipse in the images. The centers of the upper and lower ellipses are calculated and made associated with each other from the two images. The centers of right circles corresponding to the upper and lower ellipses are calculated based on the trigonometrical survey. The orientation or direction of a line segment connecting the calculated two centers is calculated to find a central line for the cylinder, thereby determining the position and posture of the cylindrical body.

However, this method has a problem that, when it is desired to recognize a ring-shaped objective or a plurality of cylindrical objectives, combinations of curve edges not in an identical circle are erroneously regarded as in the identical circle, and some edges in the lower cylindrical surface

become positioned off the screen, leading to the fact that it becomes impossible to measure the direction of the central line of the cylindrical objective, i.e., its posture. Further, when the center of a circle is projected to an image, the center will be projected as offset from the circle center in the image so long as the plane containing the circle is not perpendicular to the optical axis of the image pick-up means. Furthermore, since nearly half of edges of the lower circle are hidden as unseen, the center accuracy of the circle calculated based on such edges tends to be low. Accordingly, the values of the position and posture thus obtained have been low in accuracy and reliability.

SUMMARY OF THE INVENTION

It is therefore an object of the present invention to provide an objective recognition method for realizing high-speed detection with a high accuracy.

In accordance with an aspect of the present invention, the above objective is attained by providing an objective recognition method which comprises the steps of obtaining a two-dimensional image from the same viewing point as a distance image obtained by photographing an objective in a three-dimensional space, specifying a partial image for the two-dimensional image, applying the specified two-dimensional partial image to the distance image to extract a partial image for the distance image, and subjecting the distance partial image to an objective detecting operation.

In accordance with another aspect of the present invention, there is provided an objective recognition method wherein a two-dimensional image is obtained from the same viewing point as a distance image obtained by photographing an objective in a three-dimensional space, an inertia principal axis and gravity center of a target objective image in the two-dimensional image, the distance image is projected onto a plane passing through the inertia principal axis and perpendicular to the two-dimensional image, an inertia principal axis and gravity center of a target objective image in a projected plane, and a position and posture of an inertia principal axis of the target objective in the three-dimensional space is detected from the 2 obtained inertia principal axes and the 2 obtained gravity centers.

In accordance with yet a further aspect of the present invention, there is provided an objective recognition method wherein an edge image and an intensity gradient direction image are obtained from gray images obtained by photographing an objective having a circular shape in a three-dimensional space from a plurality of directions, an edge image as a reference is created through stereo image processing and a disparity image is created from the reference image and the other edge image, only curved edges are extracted from the reference edge image, a circle is extracted from the curved edges, and a position and posture of the extracted circle are detected with use of three-dimensional information found from the disparity of edge points of the extracted circle.

In the present invention, in the objective detecting operation, the two-dimensional image is utilized to previously restrict the existence zone of the objective under detection in the distance image, and the objective detecting operation is carried out over the distance partial image of the restricted zone. Thus, the present invention can realize the high-speed detecting operation when compared to the prior art wherein detecting operation is carried out over all zones of the distance image. In this case, the specification of the partial image of the two-dimensional image may be carried out on the basis of the shape pattern of the surface of the

target objective, the statistical image feature of texture, the color or brightness classification, or the two-dimensional geometrical feature derived from the three-dimensional geometrical feature of the target objective.

While the present invention is susceptible of various modifications and alternative constructions, certain illustrated embodiments hereof have been shown in the drawings and will be described below in detail. It should be understood, however, that there is no intention to limit the invention to specific forms disclosed, but on the contrary, the intention is to cover all modifications, alternative constructions and equivalents falling within the spirit and scope of the invention.

BRIEF EXPLANATION OF THE DRAWINGS

These and other features of the present invention will become apparent from the following description, with reference to the accompanying drawings, in which:

FIG. **1** is a flowchart for explaining the operation of an embodiment of a system of the present invention;

FIG. **2** is a block diagram of the system of the embodiment of FIG. **1**;

FIG. **3** is a perspective view of an example of objectives under detection in the embodiment of FIG. **1**;

FIG. **4***a* is a diagram for explaining a two-dimensional image of the exemplary objectives in the embodiment of FIG. **1**;

FIG. **4***b* is a diagram for explaining a distance image of the exemplary objectives in the embodiment of FIG. **1**;

FIG. **5** is a flowchart for explaining the operation of a more specific variation of the embodiment of FIG. **1**;

FIG. **6** is a diagram for explaining the operation of the variation of FIG. **5**;

FIG. **7** is a flowchart for explaining the operation of another specific variation of the embodiment of FIG. **1**;

FIG. **8** is a diagram for explaining the operation of the variation of FIG. **7**;

FIG. **9** is a flowchart for explaining the operation of a further specific variation of the embodiment of FIG. **1**;

FIG. **10** is a diagram for explaining the operation of the variation of FIG. **9**;

FIG. **11** is a flowchart for explaining the operation of yet a further specific variation of the embodiment of FIG. **1**;

FIG. **12** is a front view of an example of a detection objective in the variation of FIG. **11**;

FIG. **13***a* is a diagram for explaining a two-dimensional image in the variation of FIG. **11**;

FIG. **13***b* is a diagram for explaining a distance image in the variation of FIG. **11**;

FIG. **14** is a diagram for explaining the operation of the variation of FIG. **11**;

FIG. **15** is a flowchart for explaining the operation of another embodiment of the present invention;

FIG. **16** is a diagram for explaining one operation of the embodiment of FIG. **15**;

FIG. **17** is a diagram for explaining another operation of the embodiment of FIG. **15**;

FIG. **18** is a flowchart for explaining the operation of a further embodiment of the present invention;

FIG. **19** is a flowchart for explaining the operation of yet another embodiment of the present invention;

FIG. **20***a* is a diagram for explaining a two-dimensional image in the embodiment of FIG. **19**;

FIG. **20***b* is a diagram for explaining a distance image in the embodiment of FIG. **19**;

FIG. **21***a* is a diagram for explaining the distance image after subjected to a pre-processing operation in the embodiment of FIG. **19**;

FIG. **21***b* is a diagram for explaining the two-dimensional image after subjected to a pre-processing operation in the embodiment of FIG. **19**;

FIG. **22** is a flowchart for explaining the operation of an embodiment to which the inspection method according to the present invention is applied;

FIG. **23** is a perspective view of an objective to be inspected in the embodiment of FIG. **23**;

FIG. **24***a* is a diagram for explaining a two-dimensional image in the embodiment of FIG. **22**;

FIG. **24***b* is a diagram for explaining a distance image in the embodiment of FIG. **22**;

FIG. **25** is a flowchart for explaining the operation of another embodiment of the present invention to find a position and posture of a target objective;

FIG. **26** is a perspective view of an example of the target objective in FIG. **25**;

FIG. **27** is a diagram for explaining a plane onto which the upper surface of the target objective in the embodiment of FIG. **25** is applied;

FIG. **28***a* is a diagram showing a rotated state of the plane in the embodiment of FIG. **25**;

FIG. **28***b* is a diagram for explaining a template image;

FIG. **29** is a block diagram of a system in which the present invention is employed and an objective to be detected has a cylindrical shape;

FIG. **30** shows perspective views of an example of the detection objective in the system of FIG. **29**;

FIG. **31***a* is a diagram for explaining an edge image in a stereo reference image in the system of FIG. **30**;

FIG. **31***b* is a diagram for explaining a disparity image in the system of FIG. **30**;

FIG. **32***a* is a diagram for explaining an example of an edge image in the system of FIG. **30**;

FIG. **32***b* is a diagram for explaining curve edges in the system of FIG. **30**;

FIG. **32***c* is a diagram for explaining a circular edge extracted in the system of FIG. **30**;

FIG. **33** is a flowchart for explaining the operation of a variation of the present invention;

FIG. **34** is a perspective view of other embodiment of the present invention;

FIG. **35** shows perspective views of an objective in the embodiment of FIG. **34**;

FIG. **36***a* is a diagram for explaining an edge image in the embodiment of FIG. **35**;

FIG. **36***b* is a diagram for explaining a circular edge extracted in the embodiment of FIG. **35**;

FIG. **37** is a flowchart for explaining the operation of another variation of the present invention;

FIG. **38** is a perspective view of an image acquisition state of other embodiment of the present invention;

FIG. **39** shows perspective views of an objective in the embodiment of FIG. **38**;

FIG. **40***a* is a diagram for explaining an edge image in the embodiment of FIG. **38**;

FIG. **40***b* is a diagram for explaining an extracted circular edge in the embodiment of FIG. **38**;

FIG. **41** is a flowchart for explaining the operation of another variation of the present invention;

FIGS. **42**, **42**A and **42**B are a flowchart for explaining the operation of other embodiment of the present invention;

FIG. **43***a* is a diagram for explaining how to search edge points in the embodiment of FIG. **42**;

FIG. **43***b* is a diagram for explaining extracted edges in the embodiment of FIG. **42**;

FIG. **44** is a diagram for explaining how to extract a curved edge in the embodiment of FIG. **42**;

FIG. **45***a* is a diagram for explaining extracted curved edges in the embodiment of FIG. **42**;

FIG. **45***b* is a diagram explaining extracted curved edges in the embodiment of FIG. **42**;

FIG. **46** is a flowchart for explaining the operation of a variation of other embodiment of the present invention;

FIG. **47***a* is a diagram for explaining extracted curved edges in the embodiment of FIG. **46**;

FIG. **47***b* is a diagram for explaining a binary image of edges with disparities calculated in the embodiment of FIG. **46**;

FIG. **47***c* is a diagram for explaining extracted circular edges in the embodiment of FIG. **46**;

FIGS. **48**, **48**A and **48**B show a flowchart for explaining the operation of a variation of other embodiment of the present invention;

FIG. **49** is a perspective view of an objective in the embodiment of FIG. **48**;

FIG. **50***a* is a diagram for explaining an edge image in the embodiment of FIG. **48**;

FIG. **50***b* is a diagram for explaining extracted curved edges in the embodiment of FIG. **48**;

FIG. **50***c* is a diagram for explaining extracted curved edges in the embodiment of FIG. **48**;

FIG. **51** is a diagram for explaining how to select curved edges in the embodiment of FIG. **48**;

FIGS. **52**, **52**A and **52**B show a flowchart for explaining the operation of other embodiment of the present invention;

FIG. **53** shows perspective views of an objective in the embodiment of FIG. **52**;

FIG. **54***a* is a diagram for explaining edge images in the embodiment of FIG. **52**;

FIG. **54***b* is a diagram for explaining extracted circular edges in the embodiment of FIG. **52**;

FIGS. **55**, **55**A and **55**B show a flowchart for explaining the operation of a variation of other embodiment of the present invention;

FIG. **56** is a flowchart for explaining the extracting operation of the embodiment of FIG. **55**;

FIGS. **57**, **57**A and **57**B show a flowchart for explaining the operation of a variation of other embodiment of the present invention;

FIG. **58** is a perspective view of objectives in the embodiment of FIG. **57**;

FIG. **59***a* is a diagram for explaining edge images in the embodiment of FIG. **57**;

FIG. **59***b* is a diagram for explaining an extracted circular edge in the embodiment of FIG. **57**;

FIG. **60** is a diagram for explaining how to extract a circular edge in the embodiment of FIG. **57**;

FIGS. **61**, **61**A and **61**B show a flowchart for explaining the operation of a variation of other embodiment of the present invention;

FIG. **62** is a diagram showing a plane of an objective when viewed from its upper side in the embodiment of FIG. **61**;

FIG. **63** is a diagram for explaining a state of the plane when rotated in the embodiment of FIG. **61**;

FIGS. **64**, **64**A and **64**B show a flowchart for explaining the operation of a variation of other embodiment of the present invention;

FIGS. **65**, **65**A and **65**B show a flowchart for explaining the operation of other embodiment;

FIG. **66** is a flowchart for explaining the operation of a variation of other embodiment;

FIG. **67** is a diagram for explaining a form of the operation of the embodiment of FIG. **66**;

FIG. **68** is a flowchart for explaining the operation of an embodiment of the present invention which can be applied to an assembly control system;

FIG. **69** is a perspective view of objectives in the embodiment of FIG. **68**;

FIG. **70***a* is a diagram for explaining edge images in the embodiment of FIG. **68**;

FIG. **70***b* is a diagram for explaining extracted circular edges in the embodiment of FIG. **68**; and

FIG. **71** is a diagram for explaining a Sobel operator used, for example, in the embodiments of FIGS. **29** to **31**.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention will be detailed in connection with illustrated embodiments. First and second features of the present invention involving using a distance image and a two-dimensional image photographed from the same viewing point as the distance image. Though there are various ways of creating the distance image, explanation will be made in connection with a case where the distance image is created from a stereoscopic image, i.e., from two-dimensional images. In FIG. **2**, reference symbols **10***a* and **10***b* denote television cameras for capturing stereo images. An image photographed by one **10***a* of the television cameras **10***a* and **10***b* connected to a two-dimensional image memory **4** is used as a stereo reference image. Images photographed by the television cameras **10***a* and **10***b* are associated with each other in a stereo image processor **2**, and distances calculated based on the associated result are mapped onto the stereo reference image to generate a distance image in a three-dimensional image generator **3**. The two-dimensional image acquired by one television camera **10***a* is stored in the two-dimensional image memory **4**. An objective existence zone extractor **5**, on the basis of the two-dimensional image and distance image, extracts an objective existence zone in which the objective is present, and a three-dimensional position/posture detector **6** detects a three-dimensional position or posture of the objective based on the objective existence zone and the distance image in its vicinity.

FIG. **3** shows an example of objectives to be detected, FIG. **4***a* is a two-dimensional image I2 of the exemplary objectives, and FIG. **4***b* is a distance image I3 thereof. Areas which are differently hatched in the distance image I3 stand for different heights of the objectives. This representation is also applied to cases which will be described later.

Explanation will first be made as to how to extract an objective existence zone using a shape pattern present on a surface of an objective under detection undetectable from the distance image. The extraction of an objective existence

zone by the objective existence zone extractor **5** is carried out by means of pattern matching in the case of FIG. **5**. For example, when a letter "B" is present on a surface of an objective under detection, the letter "B" is used as a detection pattern. Pattern matching is carried out between the two-dimensional image **I2** and the detection pattern to extract a part corresponding to a matching score equal to or larger than a threshold value and to use as an objective existence zone **A1** a zone including the extracted part and covering a circle having a center corresponding to a gravity center **G1** of the extracted part as shown in FIG. **6**. An objective detecting operation is carried out over a partial image of the distance image **I3** corresponding to the objective existence zone **A1**. This objective detecting operation may be realized not only by the two methods already explained in connection with the prior art but also by another method which will be explained later.

For setting the objective existence zone **A2**, as shown in FIGS. **7** and **8**, edges may be extracted from the two-dimensional image **I2**, a part corresponding to an edge intensity equal to or larger than a threshold value may be extracted, an objective existence zone **A2** having a center corresponding to a gravity center **G2** of the extracted part may be set, and objective detecting operation may be carried out over a partial image of the distance image **I3** corresponding to the objective existence zone **A2**. This objective detecting operation utilizes the fact that differences in the statistical image features of the objective texture appear as different edge densities in the two-dimensional image **I2**.

When only one of a plurality of rectangular parallelopipeds located in their center is red in color and the other rectangular parallelopipeds are blue, as shown in FIG. **9**, color extraction (red extraction in the illustrated example) may be carried out from the two-dimensional image **I2** to extract a part having a red component equal to or larger than a threshold value. And as shown in FIG. **10**, an objective existence zone **A3** having a center corresponding to a gravity center **G3** of the extracted part may be set and objective detecting operation may be performed over a partial image of the distance image **I3** corresponding to the objective existence zone **A3**. It goes without saying that a specific part may be extracted based on its brightness in place of the color. In this case, it will be noted that an objective existence zone is set on the basis of an extracted part of a two-dimensional image having a target component equal to or larger than its threshold value and an image corresponding to the set zone is used as a partial image of the two-dimensional image.

In addition to the above, the existence zone of an objective under detection may be previously limited by utilizing two-dimensional geometrical features derived from three-dimensional geometrical features. FIG. **11** shows a case where a two-dimensional geometrical feature comprised of two straight lines connected in the form of a letter T is utilized. More specifically, first, an objective **120** shown in FIG. **12** is photographed to obtain such a two-dimensional image **I2** as shown in FIG. **13***a* and such a distance image **I3** as shown in FIG. **13***b*. In this case, a two-dimensional geometrical feature appears as such a T-shape connection of two straight lines as shown by a reference numeral **130**. Next, edges are extracted from the two-dimensional image **I2** and subjected to a Hough transform to detect straight lines, an intersection point of the detected lines is extracted, the presence or absence of a T-shaped connection is judged, whereby an intersection point **G4** in the T-shaped connection is extracted as shown in FIG. **14**. And a zone having a predetermined range and having a center corresponding to the intersection point **G4** of the T-shaped connection is applied to a distance image **I3** to detect a three-dimensional position or posture of the objective from a distance partial image.

As shown in FIGS. **15** and **16**, an inertia principal axis **EA1** and a gravity center **G5** are detected from the two-dimensional image **I2**, and the distance image **I3** is projected onto a plane P passing through the Inertia principal axis **EA1** and perpendicular to the two-dimensional image **I2**. When an inertia principal axis **EA2** and a gravity center **G6** are detected from the projected image as shown in FIG. **17**, the posture of the inertia principal axis can be detected from the two inertia principal axes **EA1** and **EA2** and the position of the inertia principal axis can be detected from the gravity centers **G5** and **G6**.

Further, as shown in FIG. **18**, after the posture and position of the inertia principal axis are detected as mentioned above, an inertia principal axis and gravity center for the objective model are found and made to coincide with the posture and position of the detected inertia principal axis, the objective model is rotated on the inertia principal axis to find a coincidence or matching degree between the objective model and target objective, and a three-dimensional position and posture of the objective can be detected on the basis of the position and posture of the target model when the matching degree becomes maximum. In this case, since the position and posture of the inertia principle axis representative of the position and posture of the objective in the three-dimensional space are used as fixed references, that is, since 5 of 6 degrees of freedom of the objective in the three-dimensional space are restricted, the position and posture of the objective in the three-dimensional space can be accurately detected at a high speed.

As will be seen from a two-dimensional image **I2** shown in FIG. **20***a* and from a distance image **I3** shown in FIG. **20***b*, when a plurality of such objectives as shown in FIG. **12** are piled, a predicted height of an existence position of an objective to be detected is set as a pre-processing, a zone higher than the predicted height is extracted from the distance image **I3** (see FIG. **21***a*), and a zone having the same position as in the image is extracted from the two-dimensional image **I2** (see FIG. **21***b*), as shown in FIG. **19**. Thereafter, the zone restricted by the predicted height references of a two-dimensional image **I2'** and distance image **I3'** is subjected to such processing as mentioned above (in the illustrated example, which is the same as the processing shown in FIG. **11**) to detect a three-dimensional position and posture of the objective.

Such a three-dimensional objective recognition method can be applied to objective inspection situations. For example, FIG. **23** shows a case where a rectangular column **8** is inserted into a square hole **70** of a base **2** and it is desired to examine whether or not the rectangular column **8** was inserted in the square hole perpendicularly (θ=90°) to the base **2**. FIG. **22** shows a flowchart for explaining the operation when the aforementioned pattern matching is employed. That is, such a two-dimensional image **I2** as shown in FIG. **24***a* and such a distance image **I3** as shown in FIG. **24***b* are obtained from stereo images of two television cameras. In more detail, a circle **80** (which may be replaced by an opening or a screw hole) on the top surface of the rectangular column **8** is used as a detection pattern, an objective existence zone is restricted in a similar way to the foregoing embodiment, and then a position and posture of the rectangular column **8** in the three-dimensional space are detected. On the basis of the detection result, a tilt θ of the rectangular column **8** is found to judge whether the inserted state is good or not.

FIGS. **25** to **28** show an example of a detection method in which a position and posture of an objective are detected based on a distance partial image extracted by utilizing the aforementioned texture. More specifically, when such an objective **8** as shown in FIG. **26** is present, a partial image corresponding to the top surface of the objective **8** is extracted from a distance image obtained by photographing the objective **8** and based on the texture, and three-dimensional information obtained from the partial image is applied to find a plane Pa containing the top surface of the objective **8** in the three-dimensional space as shown in FIG. **27**. The plane Pa can be obtained by calculating coefficients a, b and c in the following equation by the least squares method.

$$ax+by+cz+1=0$$

Next, as shown in FIG. **27**, three-dimensional positions of points on the top surface of the objective are rotated on an origin Po of a camera image coordinate system so that a normal Paz of the plane Pa coincides with a Z axis of the image coordinate system as shown in FIG. **28***a*, and the positions are then projected onto a plane (in this case, an X-Y plane Pxy of the above image coordinate system) of a reference coordinate system with use of x and y coordinate values of the points on the top surface of the objective after rotated. A projected image thus obtained and a previously-registered template image M (such as shown in FIG. **28***b*) are subjected to a pattern matching therebetween to find a position and posture of the objective of the projected image. The found objective position is subjected to an inverse transformation to find a position and posture of the top surface of the objective before the above rotation. In order to detect the position and posture of the objective on the two-dimensional image, the pattern matching with the template image has been employed in the illustrated example, but it goes without saying that another method such as a generalized Hough transform can be employed.

In the foregoing embodiment, the two-dimensional image has been obtained from the same viewing point as the distance image obtained by picking up the objective in the three-dimensional space, the zone to be subjected to the detecting operation of the position and posture of the target objective has been extracted and restricted, and the inertia principal axis and gravity center of the target objective have been extracted on the basis of two-dimensional image. However, when he target objective has such a shape as a circular cylinder, a circular part is extracted by utilizing an edge image, and a position, posture and radius of the circle are measured to realize higher speed recognition of the objective.

In this case, such a system as shown in FIG. **29** comprises two cameras **11** and **12** for photographing an objective **18** illuminated by an illuminator **19**, A/D converters **13** and **14** for converting analog image signals from the both cameras **11** and **12** into digital image signals, frame memories **15** and **16** for storing the digital image signals therein, and a processor **17** connected to the frame memories **15** and **16**. With this system, parallel stereo conversion is carried out through the stereo image processing of an edge image, that is, the two cameras **11** and **12** are matched in their orientation and focal distance, the image signals are converted into images so that the corresponding pixels of the two images coincide with each other in the Y coordinate value to thereby realize efficient corresponding point search, and a disparity corresponding to a difference between the X coordinate values of the two calculated images is photographed by the camera **11** and mapped onto an extracted edge image (stereo reference image) to create a disparity image. When a distance image is required, conversion from disparity to distance is added. For example, in the case where circular cylindrical objectives **18***a*, **18***b* and **18***c* having different heights are located as shown in FIG. **30**, when the objectives are photographed from their upper side by the two cameras, such an edge image IE for the stereo reference image as shown in FIG. **31***a* and such a disparity image ID as shown in FIG. **31***b* are obtained. In FIG. **31***b*, a thicker line indicates a higher objective.

The images stored in the frame memories **15** and **16** through the image acquisition are subjected to the parallel stereo conversion to obtain an edge image and a gradient direction image based on the converted image. In order to extract edges from the images, a Sobel operator as shown in FIG. **71** is used. Upon application of this operator, the center of the operator is moved to a target pixel, the intensity values of pixels adjacent to the target pixel are multiplied by the values of the operator, whereby gradient magnitudes Gx and Gy in the X and Y directions, gradient intensity |G| and gradient direction θ are calculated with respect to all the pixels. When I(x,y) denotes the intensity of a pixel at a coordinate point [x,y], the gradient magnitudes Gx and Gy in the X and Y directions are expressed by the following equations.

$$Gx(x,y)=\{I(x+1,y-1)+2I(x+1,y)+I(x+1,y+1)\}-\{I(x-1,y-1)+2I(x-1,y)+I(x-1,y+1)\}$$

$$Gy(x,y)=\{I(x-1,y-1)+2I(x,y-1)+I(x+1,y-1)\}-\{I(x-1,y+1)+2I(x,y+1)+I(x+1,y+1)\}$$

Using Gx and Gy, the gradient intensity |G| and the gradient direction θ at each pixel position are found as follows. Images of pixels having such values are referred to as gradient intensity image and gradient direction image, respectively.

$$|G|=(Gx^2+Gy^2)^{1/2}$$

$$\theta=\tan^{-1}(Gy/Gx)$$

After a threshold value is provided for the value of the gradient intensity |G| and the gradient intensities for pixels having gradient intensities lower than the threshold value are set at 0, points having the highest gradient intensities in the vicinity, i.e., the gradient intensities in the form of a ridge line are extracted as edge points, such an edge image IE as shown in FIG. **32***a* is obtained. And only curved components **321** and **322** are extracted from the edge image of the stereo reference image as shown in FIG. **32***b*, and a circular component **322** is extracted from the extracted curved components as shown in FIG. **32***c*.

A disparity is calculated in the aforementioned manner on the basis of the two stereo edge images through the stereo image processing, the calculated disparity is mapped onto the edge image of the stereo reference image to create a disparities image, three-dimensional positions at points on the circular edge are calculated from the corresponding parts of the circular disparities image extracted in the aforementioned manner, and a central position and posture of a circle of the top surface of the circular cylindrical objective **18** are measured based on the calculated three-dimensional position information to thereby recognize a position and posture of the objective **18**.

The extraction of only the curved components from the edge image of the stereo reference image can be carried out,

for example, by extracting straight lines through Hough transform and by erasing edges present within a predetermined distance from the extracted straight lines. Explanation will be made as to the case where three types of such objectives **18***a*. **18***b* and **18***c* as shown in FIG. **35** are conveyed along a conveyor **92** and the target objective **18** is one of three types of such objectives, and as to how to select the target objective from the three types of objectives. As shown in FIG. **37**, an edge image is created through parallel stereo conversion and creation of a gradient magnitude image and a gradient direction image. In this case, a camera **11** for photographing an image to be used as a stereo reference image acquires the image of the objective **18** nearly right from its top, whereupon such an edge image as shown in FIG. **36***a* is obtained. When the edge image is subjected to a Hough transform to extract straight lines therefrom and edges present within a predetermined distance from extracted straight lines **126** and **127** are erased, edges **122** to **125** resulting from the conveyor **92** can be erased. Thus only a circular edge **121** of the top surface of the objective **18** can be extracted. And when three-dimensional positions at points on the circular edge are calculated from the disparity of the extracted circle and when a central position and radius of the circle of the top surface of the objective **18** are measured from the calculated three-dimensional position information, the objective **18** can be specified as one of the three types of objectives shown in FIG. **35** on the basis of the measured central position (height) and radius.

Meanwhile, when the circular cylindrical objectives **18**, **18***a*, **18***b* and **18***c* have straight line components in the edges of their top surface as shown in FIGS. **38** and **39**, mere erasing of edges present within a predetermined distance from the extracted straight lines also causes part of curved lines to be erased. To avoid such disadvantage, as shown in FIGS. **40** and **41**, it is arranged to erase edges which are present within a predetermined distance from extracted straight lines **177**, **178**, **179**, **17***a*, **17***b* and **17***c* and which have values within a predetermined value from 90° in the angle between their gradient direction and straight line direction vector. This enables realization of erasure of straight line edges while preventing partial erasing of a circular edge **171** as shown in FIG. **40***b*.

The erasure of straight line components from the edge image while leaving curve components may be realized by such a method as shown in FIGS. **42** to **45**. That is, edge points are found from an edge image of a stereo reference image for storage, points surrounded by a found target edge point **201** are searched clockwise from its right side to find the presence of another edge point as shown in FIG. **43***a*, storing operation of an edge point which gradient direction is different from the gradient direction of the previously-stored edge point **201** by a predetermined value or less as the next target edge point is continued, in the presence of the edge point, until no edge point is found at the points around the target edge point **201**. When the number of such edge points stored exceeds a predetermined value, such edge points are assembled into edge groups **431** to **435** as shown in FIG. **43***b*. For each edge group, as shown in FIG. **44**, an angle **224** made between a segment connecting an edge start point **221** and a middle point **222** and a segment connecting the edge start point **221** and an end point **223** is examined so that, when only such an edge that has the angle exceeding a predetermined value is left, only curved edges **431**, **434** and **435** can be extracted as shown in FIG. **45***a* and such circular edges **434** and **435** as shown in FIG. **45***b* can be extracted from the edges of FIG. **45***a*.

The extraction of circular edges from curved edges may be carried out in the following manner. First, a method shown in FIG. **46** utilizes the fact that the objective **18** has in its lower side substantially no corresponding parts in its left and right side images and thus its disparity detection ratio becomes considerably low. When the calculated disparities of curved edges **261**, **262** and **263** are examined from such an edge image having only curved edges as shown in FIG. **47***a*, the curved edges **262** and **263** are almost calculated in their disparity as shown by a binary image of edge points with the disparities calculated in FIG. **47***b*. Since the curved edge **261** has no corresponding parts in the left and right side images and its disparity is not calculated yet, when curved edges whose already-calculated disparity ratios are smaller than a predetermined value are deleted, the curved edge **261** is deleted, which results in that only the curved edges **262** and **263** on the top surface of the objective can remain left as shown in FIG. **47***c*, from which the edges **262** and **263** can be extracted to form a circle.

When the objective **18** has such a ring shape as shown in FIG. **49**, since the top surface of the objective has two circular edges, only one (the outer circular edge in FIG. **49**) of the circular edges is extracted. More specifically, an edge image IE for the objective **18** is as shown in FIG. **50***a* and, when straight line components are erased from the edge image, such an edge image IE2 as shown in FIG. **50***b* is obtained. When the objective **18** is seen bright on the background, and a gradient direction **335** of an edge **331** for the outer ring is directed inwardly of the circle while a gradient direction **336** of an edge **332** for the outer ring is directed outwardly of the circle as shown in FIG. **51**, coefficients a and b and constant r can be found by the least squares method in accordance with a right-circle application equation which follows.

$$X^2+Y^2+ax+by+r=0$$

When the right-circle application equation is applied to the single edge **332** of the top surface to calculate a center (−a/2,−b/2) **334** of the circle, any one **339** of points of the right-circle edge is selected, a direction toward the calculated center **334** of the circle from the selected point **339** is found, and such an edge of the top surface is extracted that a difference between the direction **338** and the gradient direction **336** of the selected point is a predetermined value (90 °) or less. Even with respect to edges **331**, **33***a*, **33***b*, **33***c*, **33***d*, **33***e* and **33***f* of the top surface other than the edge **332**, when the aforementioned operation is carried out to calculate a difference between the direction of gradient of a point of each edge and the direction from the point toward the center of the right circle, and when edges of the top surface having such differences of a predetermined value (90°) or less are extracted, such an edge image IE3 of a stereo reference image with the inner-side circular edges **332**, **33***a*, **33***c* and **33***e* removed as shown in FIG. **50***c* can be obtained. In this connection, when the predetermined value for the difference is selected to be higher than 90°, the outer-side circular edges **331**, **33***b*, **33***d* and **33***f* are erased while the inner-side circular edges **332**, **33***a*, **33***c* and **33***e* are left.

An embodiment of FIG. **52** is designed so that, when such circular cylindrical objectives **18** as shown in FIG. **53** are piled and thus its edge image IE is as shown in FIG. **54***a*, a highest-level one of the piled objectives is detected to measure its position and posture. Among a plurality of curved edges present in the edge image, an edge having the maximum disparity because of its highest-level location is selected and the selected edge is set to be a reference edge

381 as shown in FIG. 54*a*, and it is examined whether or not the reference edge 381 forms part of a circle. When the reference edge cannot be regarded as part of the circle, the edge having a disparity larger next to the edge 381 is selected as a reference edge and it is examined whether or not the edge forms part of the circle. The above operation is repeated until the reference edge capable of forming part of the circle is found. Thereafter, the other edges are denoted by reference numerals 382, 383, . . . in an increasing order of the distance from the reference edge 381 and it is examined in the above numeral order whether or not the other edges form part of the same circle. Those of the edges judged to form part of the same circle as the reference edge are contained in the same group as the reference edge. Such processing is also carried out over other edges having distances of a predetermined value or less from the reference edge so that edges 381. 383. 384 and 386 having the same circle are assembled as shown in FIG. 54*b*, on the basis of which a position and posture of the highest-level objective 18 can be detected.

In an embodiment of FIG. 55, an edge having the largest disparity due to the highest-level location of the target objective is selected from the edge image of FIG. 54*a*. The selected edge is used as a reference edge 381, and the other edges are denoted by reference numerals 382, 383, . . . in an increasing order of the distance from the reference edge 381. Thereafter, coefficients a, b, h, g and f are found by the least squares method in accordance with an equation (to be applied to ellipse) which follows.

$$ax^2+by^2+2hxy+2gx+2fy=1$$

An ellipse is applied to the reference edge 381 to calculate its center coordinate point (xo,yo). As shown in FIG. 56, a straight line 413 passing through a point 417 of the reference edge and a center 412 of an ellipse 411 intersects the ellipse at two intersection points 414 and 415, and, when a distance 416 of one 414 of the two intersection points closer to the edge point 417 therefrom exceeds a predetermined value at any points of the reference edge, the reference edge is not regarded as a circle component and a next reference edge is arbitrarily selected. When the distance does not exceed the predetermined value, on the other hand, the reference edge is regarded as a circle component, the reference edge 381 is combined with the edge 382 in the vicinity thereof, and the coefficients a, b, h, g and f are found in the above equation by the least squares method, whereby the ellipse is applied to the reference edge to calculate its center coordinate point (xo,yo). And distances between the points of the reference edge 381 and edge 382 in its vicinity and the found ellipse are found. When the found distances are all less than a predetermined value, the reference edge 381 and the edge 382 in its vicinity are judged to form part of the same circle. When even a single one of the distances is not less than the predetermined value, the edges are judged not to form part of the same circle and the reference edge 381 is combined with the next edge 383 in its vicinity to perform the aforementioned operation. When a series of operations is repeated until edges to be combined become null, edges belonging to the same circle can be combined into one. In this conjunction, the center coordinate point (xo,yo) of the above ellipse is expressed as follows.

$$xo=(hf/bg)/(ab-h^2)$$

$$yo=(hg/af)/(ab-h^2)$$

An embodiment shown in FIG. 57 is also intended to detect a highest-level one of a plurality of circular cylindrical objectives 18 piled as shown in FIG. 58. FIG. 59*a* shows an edge image IE of such objectives of FIG. 58. In FIG. 59*a*, a reference edge 441 corresponds to the highest-level edge having the maximum disparity. In this case, according to the method of the above embodiment, when the edge 442 to be detected as part of the same circle as the reference edge 441 cannot be detected due to the tilted objective or the like, it may be erroneously judged that the edge 443 is to be combined with the reference edge 441. In the illustrated example, in order to avoid such error, when the reference edge 441 and the edge 443 are judged to form part of the same circle according to the method of the above embodiment, final judgement of the same circle is carried out only when a difference is within a predetermined range between the direction of a normal of a plane 453 made with use of three-dimensional information found based on the disparity of any two points of the reference edge 441 and any one point of the other edge 443 and the direction of a normal of a plane 454 made with use of three-dimensional information found based on the disparity of any two points of the edge 443 and any one point of the reference edge 441 except for the selected two points, as shown in FIG. 60. Through the above operation, the circular edge 441 of the top surface of the highest-level objective can be extracted as shown in FIG. 59*b*.

Explanation will be directed to the operation after the extraction of the circular edges of the top surface of the circular cylindrical objective. In an embodiment of FIGS. 61 to 63, as in the case of FIG. 25, three-dimensional positions of points are calculated based on the disparity of the extracted circle edges, and coefficients a, b and c are calculated by the least squares method in accordance with the following equation (to be applied to plane).

$$ax+by+cz+1=0$$

Then, a plane Pa containing the top surface of the objective 18 is found as shown in FIG. 62, three-dimensional positions of points in the top surface of the objective are rotated on an origin po of a camera coordinate system so that a normal Paz of the plane Pa coincides with the Z axis of the camera coordinate system as shown in FIG. 63, and coefficients a, b and constant r are found by the least squares method in accordance with the following equation (to be applied to right circle) to calculate a center position 491 and radius 492 of the right circle after the rotation.

$$x^2+y^2+ax+by+r=0$$

In the illustrated example, the camera coordinate system is employed as a reference coordinate system. A center position 486 of the right circle of the top surface of the objective 18 is calculated through inverse transformation (to before the rotation) of the center position 491 of the calculated right circle to obtain a position, posture and radius of the objective 18. In the calculation of the right circle after the coordinate system rotation, coefficients a, b, h, g and f are found in the above ellipse application equation by the least squares method and conversion to a standard ellipse is carried out to obtain a position and posture of the elliptical cylinder as well as a major and minor radii thereof.

In an embodiment of FIG. 64, three-dimensional positions of points on the top surface of the objective are rotated on the origin po of the above image coordinate system as

mentioned above so that the normal Paz of the plane Pa coincides with the Z axis of the coordinate system, after which certain edge points are removed so that a distance **493** (difference from the Z coordinate value) of the found plane Pa from the edge points of the circle after the rotation in the three-dimensional space exceeds a predetermined value. With use of the x and y coordinate values of edge points of the top surface of the objective **18** after the rotation except for the above edge points, coefficients a and b and constant r are found by the least squares method in accordance with the right-circle application equation to calculate a center position **491** and radius **492** of the right circle after the rotation. In this connection, the camera coordinate system is used as a reference coordinate system. And a center position **486** of the right circle of the top surface of the objective **18** is calculated through inverse transformation (to before the rotation) of the center position **491** of the calculated right circle to obtain a position, posture and radius of the objective **18** after the coordinate system rotation. In the calculation of the right circle after the coordinate system rotation, further, coefficients a, b, h, g and f are found by the least squares method in accordance with the aforementioned ellipse application equation; and a position and posture of the elliptical cylinder as well as a major and minor radii thereof are obtained through conversion to standard ellipse.

In an embodiment of FIG. **65**, three-dimensional positions of points on the top surface of the objective are rotated on the origin po of the above image coordinate system as mentioned above so that the normal Paz of the plane Pa coincides with the Z axis of the coordinate system, after which certain points are so removed that a distance (difference from the Z coordinate value) of the found plane Pa from the edge points of the circle after the rotation in the three-dimensional space exceeds a predetermined value, a plane Pa in the three-dimensional space containing the edge of the top surface of the circular cylindrical objective **18** is again found by the least squares method, and three-dimensional positions of points of the top surface of the objective are rotated on the origin po of the camera coordinate system so that the normal Paz of the found plane Pa coincides with the Z axis of the coordinate system. Thereafter, with use of the x and y coordinate values of edge points of the top surface of the objective **18** after the rotation except for the above edge points, coefficients a and b and constant r are found by the least squares method in accordance with the right-circle application equation to calculate a center position **491** and radius **492** of the right circle after the rotation. And a center position **486** of the right circle of the top surface of the objective **18** is calculated through inverse transformation before the rotation) of the center position **491** of the calculated right circle to obtain a position, posture and radius of the objective **18** after the coordinate system rotation. Even in this case, in the calculation of the right circle after the coordinate system rotation, further, coefficients a, b, h, g and f are found by the least squares method in accordance with the aforementioned ellipse application equation, and a position and posture of the elliptical cylinder as well as a major and minor radii thereof are obtained through conversion to standard ellipse.

In an embodiment of FIG. **66**, three-dimensional positions of points are calculated based on the disparity of the extracted circle edges as mentioned above, and coefficients a, b and c are calculated by the least squares method in accordance with the aforementioned plane applying equation to find a plane Pa containing the top surface of the objective **18**. Further, as shown in FIG. **67**, a sphere **531** containing the right circle of the top surface of an objective **18** in a three-dimensional space is found by the least squares method. When a sphere is applied, since the right circle of the top surface is present on the same plane, the sphere is not uniquely determined. However, the center of the sphere is restricted to the extent that the center is present on a straight line perpendicular to the above plane Pa and passing through the center of the right circle present on the plane. Further, since the found sphere may be any sphere so long as its radius is larger than the right circle of the top surface and the sphere contains the right circle of the top surface, when any one value of any one of center coordinate axes of the sphere is fixed, the sphere can be determined. In the present embodiment, the Z coordinate value of the center of the sphere was fixed to a Z coordinate value c_o different by more than the radius of the right circle from the Z coordinate values of the objective existence zone. In other words, an equation for the sphere was expressed as follows to find coefficients a and b and constant R by the least squares method.

$$x^2+y^2+z^2+ax+by-2c_oz+R=0$$

A center **533** of the right circle of the top surface of the circular cylindrical objective **18** is found by calculating an intersection point between the plane Pa and a straight line passing through a center **532** of the sphere and having the same direction vector as a normal vector **537** of the plane Pa. A radius **534** is found by subtracting a square of a distance **536** between the center of the sphere and the center of the right circle from a square of a radius **535** of the sphere to find a subtraction and then by finding a square root of the subtraction. Accordingly, even in this case, a position, posture and radius of the objective **18** can be found.

An embodiment of FIGS. **68** to **70** shows an example where the present invention is applied to automatic assembling work. More in detail, as shown in FIG. **69**, when it is desired to assemble a part **541** having two holes and a part **542** having two projections by means of robot, positions and posture of the holes and projections are detected to detect positions and postures of the parts **541** and **542**.

More specifically, an edge image IE (see FIG. **70***a*) of a stereo reference image, a gradient direction image and a disparity image are created and curved edges are extracted from the edge image. That is, such 4 circular edges **701** to **704** as shown in FIG. **70***b* are extracted. When the direction of a segment connecting the middle point and centers of corresponding 4 circles **543** to **546** in a three-dimensional space as well as the direction of a normal of a plane defined by the 2 circles are calculated from the 4 circle edges, the position and posture of the part **542** having the two projections are determined. When the similar operation is carried out for the remaining 2 circles, the position and posture of the part having the two holes are determined.

In accordance with the present invention, as has been explained in the foregoing, a two-dimensional image is obtained from the same viewing point as a distance image obtained by photographing an objective in a three-dimensional space, a partial image in the two-dimensional image is specified, the specified two-dimensional partial image is applied to the distance image to extract a partial image from the distance image, and objective detecting operation is carried out over the distance partial image. That is, upon the objective detecting operation, an existence zone of the objective under detection in the distance image is previously restricted by utilizing the two-dimensional image, and the objective detecting operation is carried out over a distance partial image of the restricted zone. As a

result, it will be appreciated that the present invention can realize a relatively high detecting operation when compared with the prior art for performing detecting operation over all the zones of the distance image.

What is claimed is:

1. A method for detecting a position, posture and shape of an objective, the method comprising the steps of:

obtaining a two-dimensional image of the objective from the same viewing point as a distance image obtained by photographing the objective in a three-dimensional space;

specifying a partial image in the two-dimensional image;

extracting a partial image of a distance image at a position corresponding to the position of the specified partial image of the two-dimensional image; and

subjecting the partial image of the distance image to an objective detecting operation.

2. The objective recognition method as set forth in claim 1, wherein the step of specifying the partial image for the two-dimensional image is carried out based on shape pattern.

3. The objective recognition method as set forth in claim 1, wherein the step of specifying the partial image for the two-dimensional image is carried out based on statistical image features of texture.

4. The objective recognition method as set forth in claim 1, wherein the step of specifying the partial image for the two-dimensional image is carried out based on color or brightness.

5. The objective recognition method as set forth in claim 1, wherein the step of specifying the partial image for the two-dimensional image is carried out based on two-dimensional geometrical feature derived from three-dimensional geometrical feature of the target objective.

6. The objective recognition method as set forth in claim 1, wherein, as a pre-processing, a specific zone indicative of a specified height is extracted from the distance image and the partial image is specified from a two-dimensional image for the specified zone.

7. The objective recognition method as set forth in claim 1, wherein, upon objective detecting operation, three-dimensional information obtained from a distance partial image is applied to a plane, the three-dimensional information is rotated on an origin of a camera coordinate system to cause a normal of the plane to coincide with a Z axis of the camera coordinate system, the three-dimensional information after the rotation is projected onto an X-Y plane of the coordinate system, a projected image is collated with a previously-registered model to find a temporary position and posture of the target objective, the temporary position and posture are subjected to an inverse transformation to calculate a position and posture of the target objective before the rotation.

8. An objective recognition method comprising the steps of:

obtaining a two-dimensional image from the same viewing point as a distance image obtained by photographing an objective in a three-dimensional space;

specifying a partial image for the two-dimensional image;

applying the specified two-dimensional partial image to the distance image to extract a partial image for the distance image; and

subjecting the distance partial image to an objective detecting operation, wherein three-dimensional information obtained from the distance partial image is applied to a plane, the three-dimensional information is rotated on an origin of a camera coordinate system to cause a normal of the plane to coincide with a Z axis of the camera coordinate system, the three-dimensional information is then projected onto an X-Y plane of the coordinate system, a projected image is collated with a previously-registered model to find a temporary position and posture of the target objective, the temporary position and posture are subjected to an inverse transformation to calculate a position and posture of the target objective before the rotation.

* * * * *

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United States Patent [19]

Kimura et al.

[11] Patent Number: 5,682,269

[45] Date of Patent: Oct. 28, 1997

[54] **OBJECTIVE LENS DEVICE**

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[73] Assignee: **Canon Kabushiki Kaisha**, Tokyo, Japan

[21] Appl. No.: **687,023**

[22] Filed: **Jul. 25, 1996**

[30] **Foreign Application Priority Data**

Jul. 31, 1995 [JP] Japan 7-214195

[51] **Int. Cl.**[6] **G02B 9/60**; G02B 9/62; G02B 13/04

[52] **U.S. Cl.** **359/770**; 359/752; 359/753; 359/761

[58] **Field of Search** 359/761, 770, 359/752, 753

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Primary Examiner—Scott J. Sugarman

Attorney, Agent, or Firm—Fitzpatrick, Cella, Harper & Scinto

[57] **ABSTRACT**

An objective lens device comprising in order from the lens closest to an object side, a negative meniscus first lens whose concave side faces the object side; a positive second lens; a positive meniscus third lens whose convex side faces an image side; a negative meniscus fourth lens whose concave side faces the object side; a negative meniscus fifth lens whose convex side faces the object side; and a positive sixth lens. The fifth and sixth lenses are cemented together to form a cemented lens subunit. The objective lens device contains six lenses in its entire lens structure, has a long back focus, and provides excellent optical properties over an entire field.

7 Claims, 3 Drawing Sheets

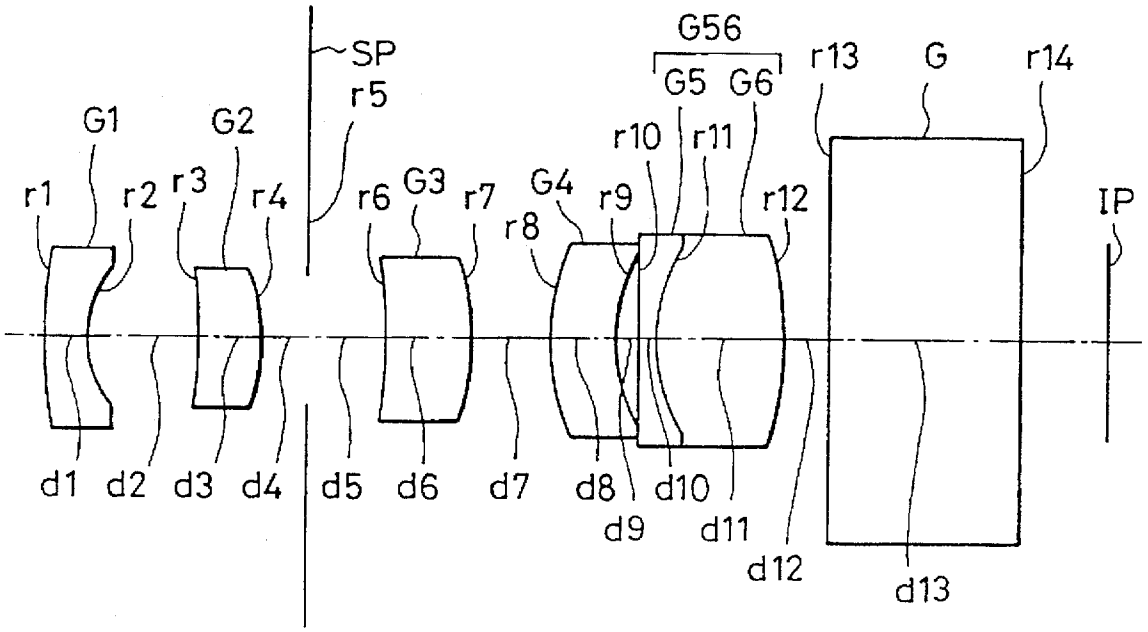


FIG. 1

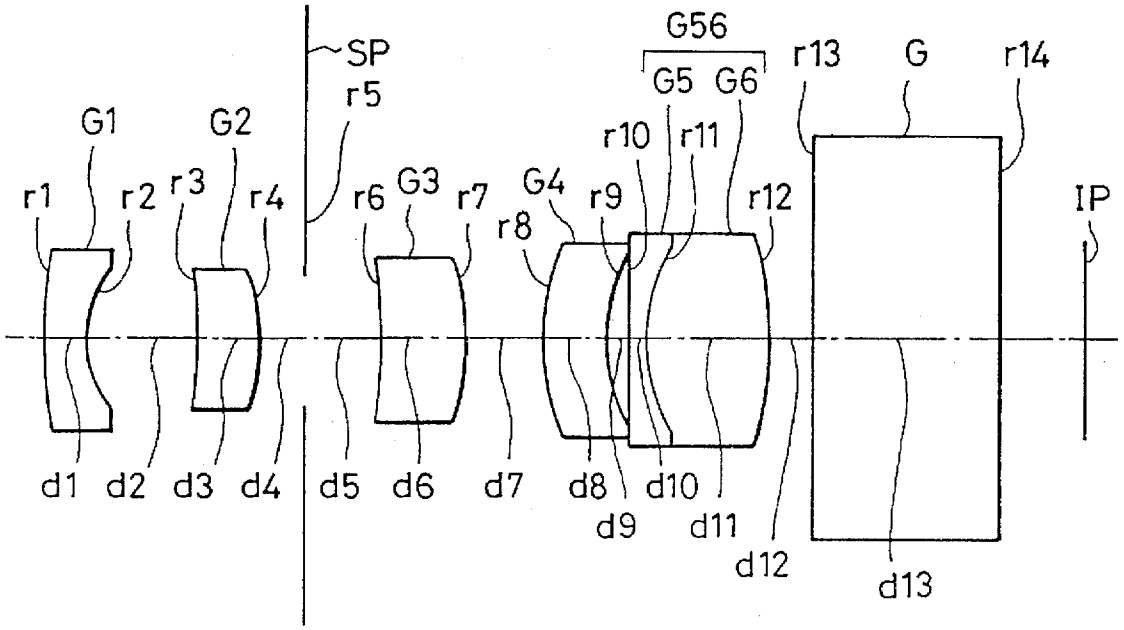


FIG. 2A

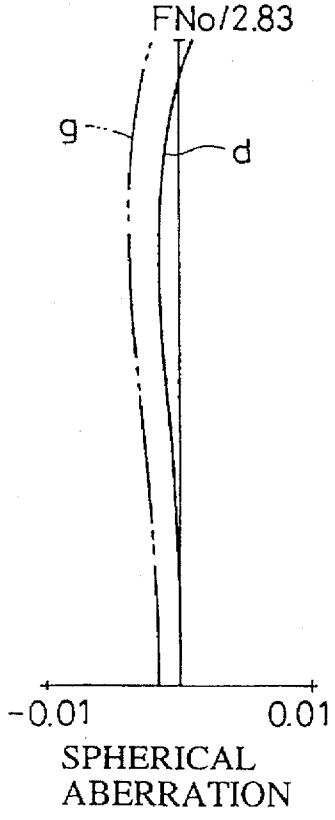


FIG. 2B

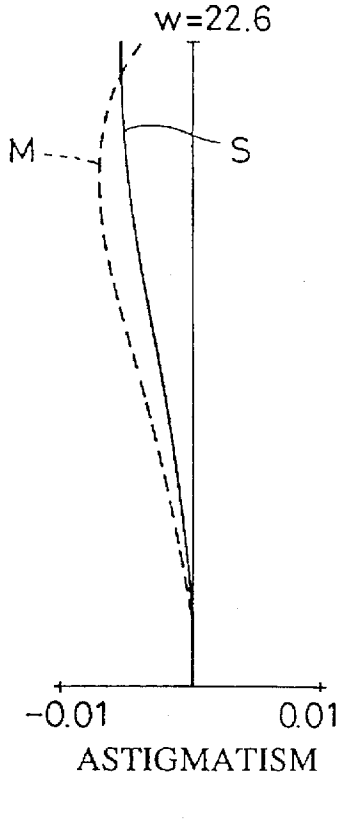


FIG. 2C

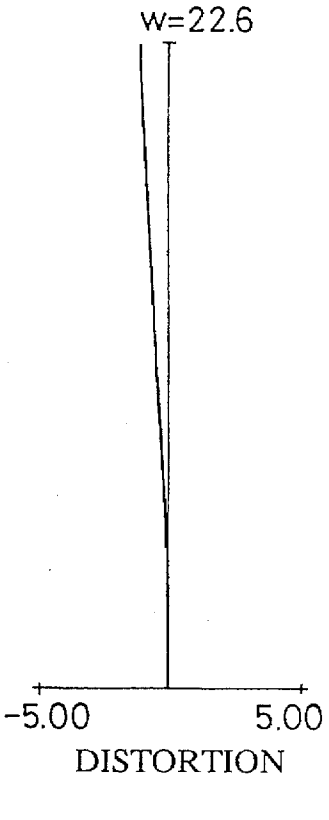


FIG. 3

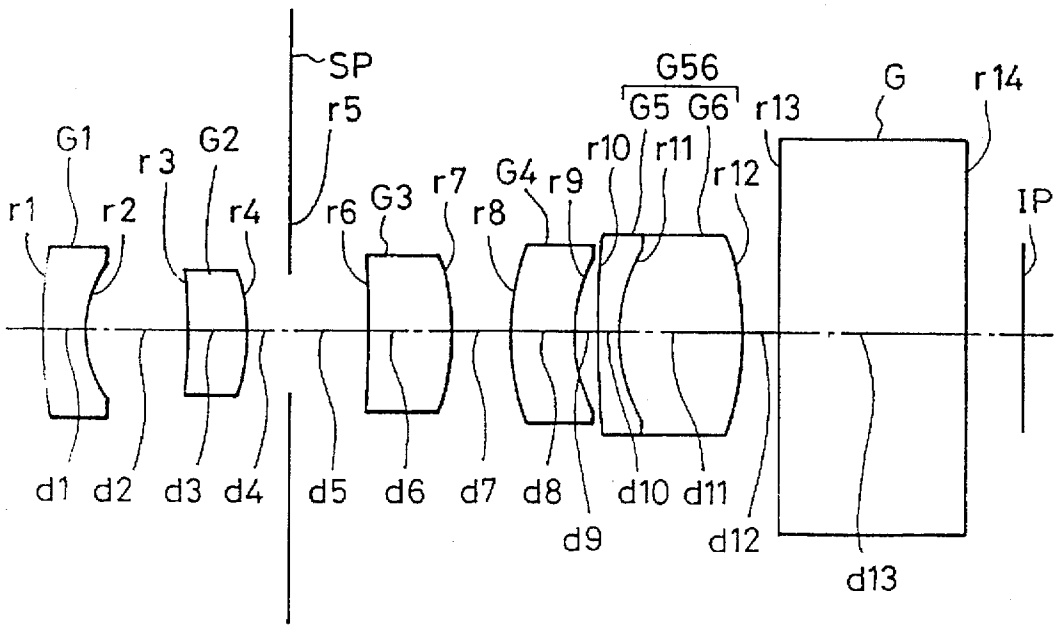


FIG. 4A

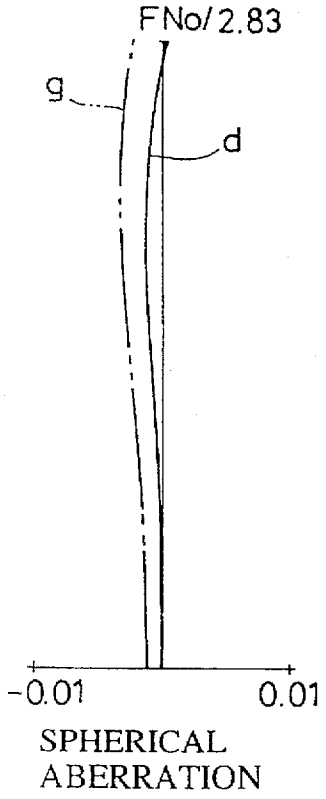


FIG. 4B

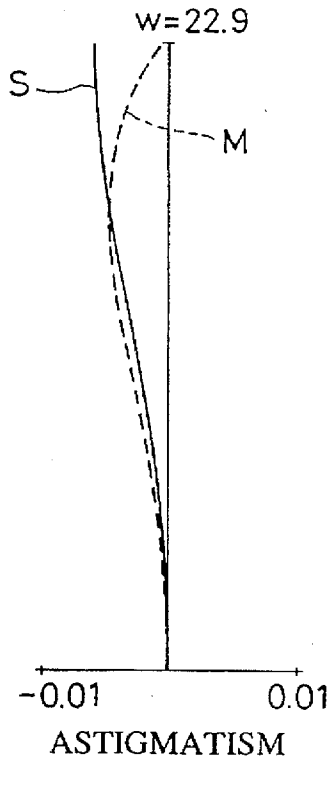


FIG. 4C

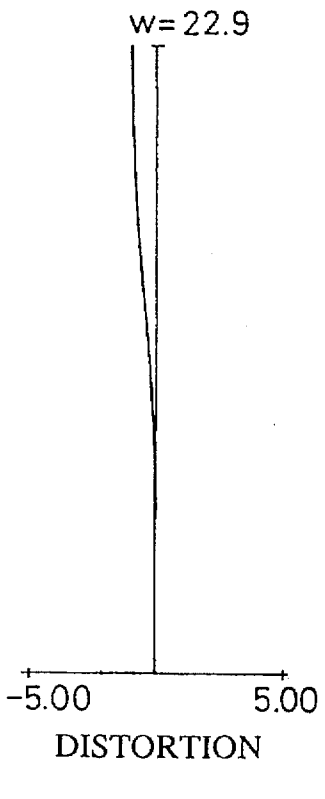


FIG. 5

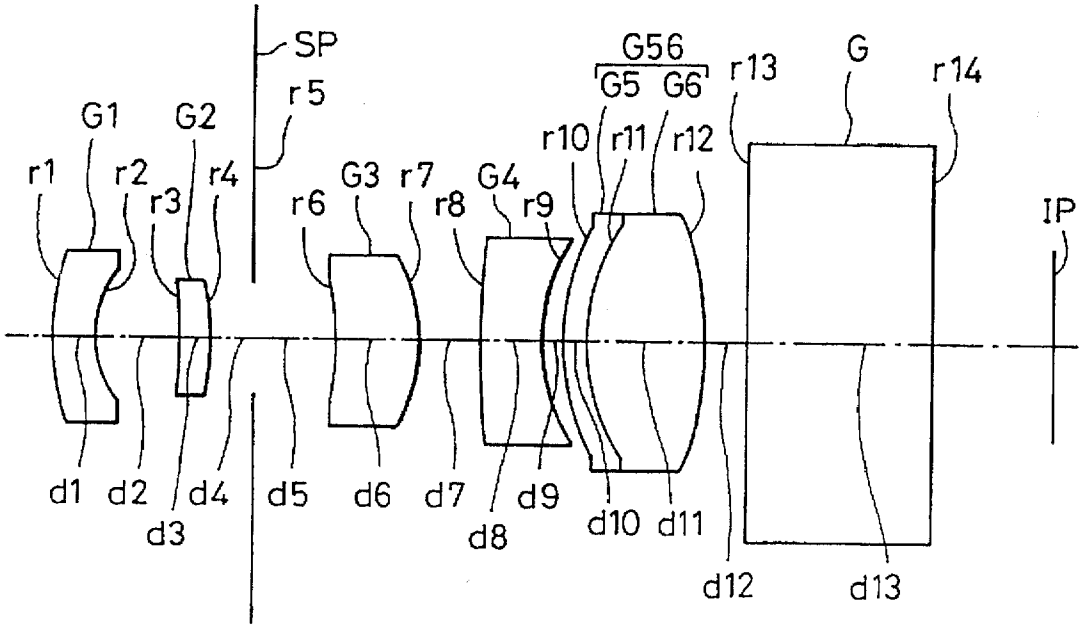


FIG. 6A

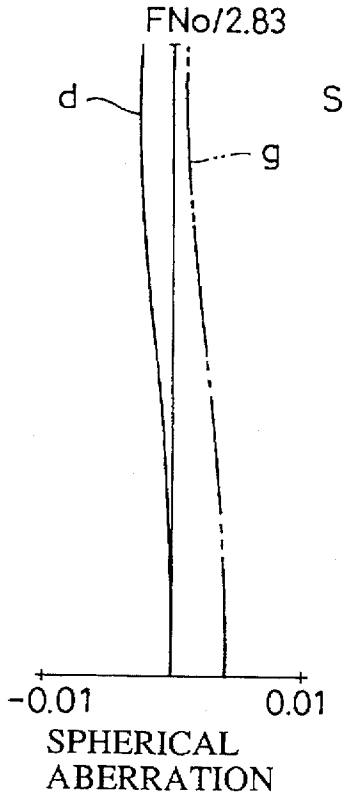


FIG. 6B

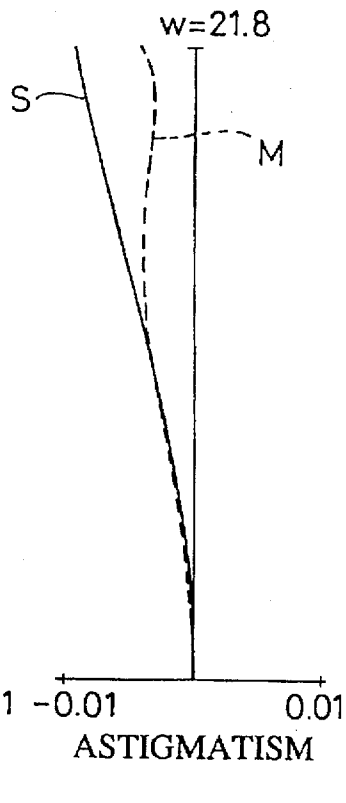
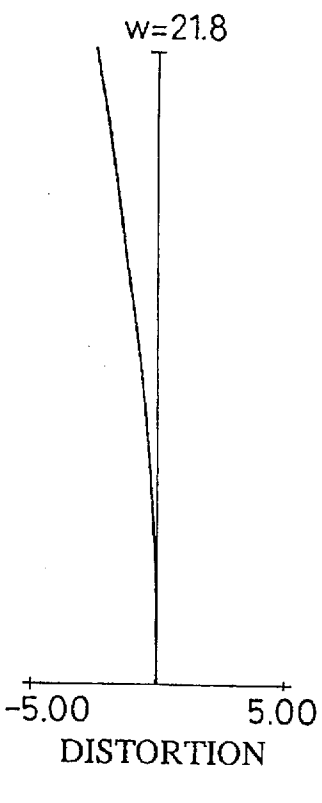


FIG. 6C



OBJECTIVE LENS DEVICE

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to an objective lens device with a photographic field angle of about 45 degrees and an f-number of about 2.8, and, more particularly, to a retrofocusing type objective lens device suitable for use in a small camera utilizing a solid-state image pick-up device, having a long back focus, and good optical properties over an entire field.

2. Description of the Related Art

In recent years, the production of smaller cameras such as video cameras utilizing a solid-state image pickup device has caused a demand for smaller and brighter objective lens devices. In such cameras, it is necessary to dispose various optical members, such as lowpass filters or color-correcting filters, between the rearmost portion of the lens device and image pickup device. Therefore, objective lens devices need to have a relatively long back focus. In the case of cameras utilizing a color image pickup device, it is desirable that they provide excellent telecentric properties at an image side in order to prevent color shading.

Hitherto, wide angle lens devices as objective lens devices utilizing 6 to 7 lenses in their lens structure and having a long back focus have been disclosed, for example, in Japanese Patent Laid-Open Nos. 54-151442, 55-45007, and 56-22406. Objective lens devices have also been disclosed, for example, in Japanese Patent Laid-Open No. 1-214812 and U.S. Pat. No. 3,297,394, in which aberrations are corrected by a negative meniscus lens whose convex side faces an object, or by a cemented lens subunit. These objective lens devices are designed primarily for 35-mm film cameras, so that these lens devices cannot be regarded as satisfactory objective lens devices utilizing a solid-state image pickup device because they do not have a sufficiently long back focus and sufficient telecentric properties.

Objective lens devices with a simple lens construction and having sufficiently long and satisfactory telecentric properties have been disclosed, for example, in Japanese Patent Laid-Open Nos. 64-61714, 61-123810, and 63-81309. The objective lens devices disclosed in Japanese Patent Laid-Open Nos. 64-61714 and 61-123810 are wide angle objective lens devices, and the objective lens device disclosed in Japanese Patent Laid-Open No. 63-81309 is a standard angle objective lens device. Japanese Patent Publication No. 58-40166 discloses a retrofocusing type telecentric lens system having a back focus that is longer than the focal distance.

Generally, in order for the back focus to be long, it is desirable to construct the lens system into a retrofocusing type lens system in which the front lens unit has a strong negative refractive power and the rear lens unit has a positive refractive power. However, various aberrations, such as spherical aberration, coma, distortion, astigmatism, etc. occur more frequently because the entire lens system becomes asymmetrical when it is a retrofocusing type, and the absolute value of the negative refractive power of the front lens unit must be made larger in order for the back focus to be long. This has made it extremely difficult to correct each of the various aberrations satisfactorily.

Attempting to obtain a sufficiently long back focus results in such problems as a longer overall length of the objective lens device and a larger diameter of the front lens unit.

In addition, for an objective lens device utilizing a color image pickup device, the lens units near the object side tend to be large, when an attempt is made to make the optical system into one that is telecentric at an object side. This causes nonaxial aberration to occur more often.

SUMMARY OF THE INVENTION

Accordingly, an object of the present invention is to form a suitable lens structure in order to provide an objective lens device having a back focus long enough to allow various optical members, such as a filter, to be disposed between the rear end of the lens and an imaging plane, having a smaller first focusing lens unit, being telecentric at an image side, having a photographic angle of about 45 degrees and an f-number of about 2.8, and which is corrected for various aberrations over an entire field.

To this end, the present invention provides an objective lens device which comprises in order from the lens closest to an object side, a negative meniscus first lens whose convex side faces the object side, a positive second lens, a positive meniscus third lens whose convex side faces an image side, a negative meniscus fourth lens whose convex side faces the object side, a negative meniscus fifth lens whose convex side faces the object side, and a positive sixth lens. The fifth lens and the sixth lens are cemented together, forming a cemented lens subunit.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a cross sectional view of a lens device of Numerical Example 1 of the present invention.

FIGS. **2A**, **2B**, and **2C** illustrate graphs showing the aberrations of the lens device of Numerical Example 1 of the present invention.

FIG. **3** is a cross sectional view of a lens device of Numerical Example 2 of the present invention.

FIGS. **4A**, **4B**, and **4C** illustrate graphs showing the aberrations of the lens device of Numerical Example 2 of the present invention.

FIG. **5** is a cross sectional view of a lens device of Numerical Example 3 of the present invention.

FIGS. **6A**, **6B**, and **6C** illustrate graphs of the aberrations of the lens device of Numerical Example 3 of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. **1** is a cross sectional view of a lens device of Numerical Example 1 of the present invention, while FIGS. **2A**, **2B**, and **2C** illustrate graphs of the aberrations of the lens device of Numerical Example 1 when an object is at infinity. FIG. **3** is a cross sectional view of a lens device of Numerical Example 2 of the present invention, while FIGS. **4A**, **4B**, and **4C** illustrate graphs of the aberrations of the lens device of Numerical Example 2 when the object is at infinity. FIG. **5** is a cross sectional view of a lens device of Numerical Example 3 of the present invention, while FIGS. **6A**, **6B**, and **6C** illustrate graphs showing the aberrations of the lens device of Numerical Example 3 when the object is at infinity.

According to the present invention, the objective lens device comprises six lenses. They are, in order from the lens closest to an object side, a negative meniscus first lens **G1**, a positive second lens **G2**, a positive meniscus third lens **G3** whose convex side faces an image side, a negative meniscus fourth lens **G4** whose convex side faces the object side, a negative meniscus fifth lens **G5** whose convex side faces the object side, and a positive biconvex sixth lens **G6**. The fifth

lens G5 and the sixth lens G6 are cemented together to form a cemented lens subunit G56. A stop SP is disposed between the second lens G2 and the third lens G3. In the figures, G denotes a glass block such as a face plate or an optical filter, and IP denotes an image plane.

The objective lens device of the present embodiment is formed by two retrofocusing lens units, one composed of the negative first lens G1 and the positive second lens G2, and the other composed of the negative third lens G3, the negative fourth lens G4, and the cemented lens subunit G56. By virtue of such a construction, the back focus can be made sufficiently long such that the principal point at the image side is positioned closer to the image side.

Here, the lens system is considered as being formed by two lens units, a front lens unit composed of the first lens G1 and the second lens G2, and a rear lens unit composed of the third to sixth lenses G3 to G6. The front lens unit is a substantially afocal system which consists of negative first lens G1 and positive second lens G2. The air gap between the first lens G1 and the second lens G2 can be reduced by setting the refractive powers of the negative first lens G1 and the positive second lens G2 at high values, with the afocal magnification maintained, which leads to reduction of the diameter of the first lens G1. When the refractive powers are set at high values, the high refractive power of the second lens G2 causes a large astigmatism. The astigmatism of the second lens G2 is corrected by the negative fourth meniscus lens G4 whose convex side faces the object side. Comatic aberration of the first lens G1 and that of the second lens G2 are also corrected by the fourth lens G4. Oblique aberration is corrected by the cemented lens subunit formed by cementing the fifth lens G5 and the sixth lens G6 and having the convex side facing the object side.

In the present embodiment, by virtue of the above-described lens structure, the objective lens device contains relatively few lenses, aberrations are properly corrected over the entire field, and the objective lens device is particularly suitable for a photographic system utilizing a solid-state image pickup device, has a relatively long back focus, and is telecentric at the image side.

In the present embodiment, the objective lens device has long back focus and good optical properties from its particular shape.

It is to be noted that in order for the back focus to be easily set to a predetermined value, for oblique aberrations, such as distortion, to be properly corrected, and for the optical properties over the entire field to be satisfactorily corrected, only at least one of the following conditions need to be satisfied.

$$(1\text{-}1)\quad -7 < \frac{R9+R8}{R9-R8} < -1 \qquad (1)$$

where R8 and R9 represent the radius of curvature of the surface at the object side and that at the image side of the fourth lens, respectively.

Condition 1 is related to the shape of the negative meniscus fourth lens G4. When the ratio is less than the lower limit and the meniscus fourth lens G4 is more curved, not only are astigmatism and coma corrected excessively, but also higher-order aberration occurs. On the other hand, when the value exceeds the upper limit and the fourth lens G4 becomes a plano-convex lens, the fourth lens G4 no longer is effective in correcting astigmatism and coma. Therefore, it is not preferable that the ratio be less than the lower limit or be greater than the upper limit.

$$(1\text{-}2)\quad N1 < N2 \qquad (2)$$

where N1 and N2 denote, respectively, the refractive indices of the materials of the first lens and the second lens, with the second lens being a meniscus-shaped lens whose convex side faces an image side.

Coma occurring at the surface at the image side of the first lens G1 is corrected by the second lens G2 which is formed into a meniscus lens whose convex side faces an image side. It corrects coma along with the fourth lens G4 which is also formed into a meniscus lens.

Condition 2 is related to the refractive indices of the materials of the first lens G1 and the second lens G2. In common retrofocusing type lens systems, the Petzval's sum tends to be too small. But in the lens structure of the present invention, the Petzval's sum tends to be positively large. The Petzval's sum is a proper value when the material of the second lens G2 has a higher refractive index than the first lens G1. When N1 becomes greater than N2, and the refractive index of the material of the first lens G1 becomes high, the Petzval's sum increases in the positive direction, thus increasing the curvature of field. Therefore, it is not desirable that N1 be greater than N2.

$$(1\text{-}3)\quad 0.1 < D3/R4 < 0.3 \qquad (3)$$

where D3 represents the thickness of the second lens, and R4 denotes the radius of curvature of the lens surface at the image side of the second lens.

Condition 3 is related to the thickness (of the center) of the second lens G2. When the second lens G2 is of the proper thickness, distortion that occurs in the negative first lens G1 is corrected. When the value is less than the lower limit, and the second lens G2 is thinner, it becomes difficult to produce the lens because the edge thickness becomes smaller. In addition, when the value becomes less than the lower limit of Condition 3, and the curvature of the lens surface at the image side is low, distortion is not sufficiently corrected. On the other hand, when the value is greater than the upper limit, and the second lens G2 is thicker, the size of the lens system becomes larger. In addition, when the value exceeds the upper limit of Condition 3, and the curvature of the lens surface at the image side becomes too large, not only is distortion corrected in excess, but also higher order aberration occurs. Therefore, it is not preferable that the value be greater than the upper limit or be less than the lower limit.

(1-4) When an object at infinity is in focus, and a nearby object is to be brought into focus, the entire lens system or the third to sixth lenses are integrally moved toward the object side.

In changing the focusing object from an object at infinity to a nearby object by an objective lens device in the present embodiment, good optical properties are provided by moving the entire lens system to an object side. The first lens G1 and the second lens G2 are as a whole substantially afocal, so that focusing is performed by integrally moving the lens unit composed of the third lens G3 to the sixth lens G6, whereby variations in aberration that occur during focusing are properly corrected. The lens unit has a focusing sensitivity of about 1.

(1-5) Either light control means used by an iris stop, or light control means by switching various apertures, or light control means with a fixed aperture is disposed between the second lens and the third lens, or between the third lens and the fourth lens.

An iris stop, or a so-called turret-type stop used by switching various apertures, or a fixed aperture type stop is disposed in front of or behind the third lens G3 in order to facilitate exposure control, without any shading, and to obtain good optical properties over the entire field. When a color image-pickup device is used as the image pickup means, it is desirable that the lens system be telecentric at the image side. This is achieved by disposing a stop, as mentioned above, as a result of which aberrations are properly corrected.

$$(1\text{-}6)\quad 3<|tk/f| \qquad (4)$$

where tk denotes the position of the exit pupil of the system, measured from the sixth lens surface at the image plane side, and f denotes the focal length of the entire lens system.

Condition 4 is related to the position of the exit pupil of the lens system, measured from the surface of the last lens in the objective lens device. When the tk/f ratio is less than the lower limit of Condition 4 and the exit pupil is closer to the lens system, color shading or the like occurs in a camera using a color image pickup device. Therefore, it is not preferable that the tk/f ratio be less than the lower limit.

Numerical examples of the present invention will now be described. In the numerical examples, Ri denotes the radius of curvature of a surface of an i-th lens surface in order of lenses from the lens closest to an object side, Di denotes the thickness of an i-th lens in order of lenses from the lens closest to the object side and air gap, and Ni and Vi denote, respectively, the refractive index and the Abbe constant of a glass of an i-th lens in order of lenses from the lens closest to the object side. R13 and R14 each represent the radius of curvature of a surface of a glass block, such as a face plate or an optical filter. The relationships between each of the above-described conditions and the numerical values of the numerical examples are given below in Table 1.

(Numerical Example 1)
F = 5.75 FNo = 1:2.83 2ω = 45.3

R1 =	14.30	D1 = 1.00	N1 = 1.60311	ν1 = 60.7
R2 =	2.91	D2 = 2.54		
R3 =	−22.50	D3 = 1.50	N2 = 1.69680	ν2 = 55.5
R4 =	−5.32	D4 = 1.05		
R5 =	(stop)	D5 = 1.86		
R6 =	−14.51	D6 = 2.00	N3 = 1.69680	ν3 = 55.5
R7 =	−6.60	D7 = 1.82		
R8 =	6.10	D8 = 1.50	N4 = 1.84666	ν4 = 23.8
R9 =	4.36	D9 = 0.51		
R10 =	37.44	D10 = 0.50	N5 = 1.84666	ν5 = 23.8
R11 =	4.81	D11 = 3.00	N6 = 1.77250	ν6 = 49.6
R12 =	−8.07	D12 = 1.00		
R13 =	∞	D13 = 4.50	N7 = 1.51633	ν7 = 64.2
R14 =	∞			

(Numerical Example 2)
F = 5.68 FNo = 1:2.83 2ω = 45.8

R1 =	14.52	D1 = 1.00	N1 = 1.60311	ν1 = 60.7
R2 =	3.00	D2 = 2.45		
R3 =	−27.67	D3 = 1.50	N2 = 1.69680	ν2 = 55.5
R4 =	−5.48	D4 = 1.00		
R5 =	(stop)	D5 = 2.00		
R6 =	−17.96	D6 = 2.00	N3 = 1.69680	ν3 = 55.5
R7 =	−6.64	D7 = 1.49		
R8 =	6.57	D8 = 1.50	N4 = 1.84666	ν4 = 23.8
R9 =	4.44	D9 = 0.58		
R10 =	20.92	D10 = 0.50	N5 = 1.84666	ν5 = 23.8
R11 =	4.55	D11 = 3.00	N6 = 1.77250	ν6 = 49.6
R12 =	−9.07	D12 = 1.00		
R13 =	∞	D13 = 4.50	N7 = 1.51633	ν7 = 64.2
R14 =	∞			

-continued

(Numerical Example 3)
F = 6.00 FNo = 1:2.83 2ω = 43.6

R1 =	7.74	D1 = 1.00	N1 = 1.60311	ν1 = 60.7
R2 =	2.93	D2 = 1.99		
R3 =	−21.25	D3 = 0.80	N2 = 1.69680	ν2 = 55.5
R4 =	−6.08	D4 = 1.00		
R5 =	(stop)	D5 = 2.00		
R6 =	−8.13	D6 = 2.00	N3 = 1.69680	ν3 = 55.5
R7 =	−5.18	D7 = 1.48		
R8 =	20.64	D8 = 1.50	N4 = 1.84666	ν4 = 23.8
R9 =	5.23	D9 = 0.50		
R10 =	7.09	D10 = 0.50	N5 = 1.84666	ν5 = 23.8
R11 =	5.53	D11 = 3.00	N6 = 1.77250	ν6 = 49.6
R12 =	−8.36	D12 = 1.00		
R13 =	∞	D13 = 4.50	N7 = 1.51633	ν7 = 64.2
R14 =	∞			

TABLE 1

		Numerical Example		
Formula		1	2	3
(1)	$\frac{R9+R8}{R9-R8}$	−6.03	−5.16	−1.68
(2)	N1	1.603	1.603	1.603
	N2	1.697	1.697	1.697
(3)	|D3/R4|	0.28	0.27	0.13
(4)	|tk/f|	3.88	3.70	12.13

As can be understood from the foregoing description, according to the present invention, a proper lens structure makes it possible to provide an objective lens device having a back focus that is long enough to allow various optical members, such as a filter, to be disposed between the objective lens device and an imaging plane, having a smaller front lens unit diameter, having telecentric properties at an image side, having a photographic field angle of about 45 degrees, having an f-number of about 2.8, and excellent optical properties, with the various aberrations corrected over the entire field.

What is claimed is:

1. An objective lens device comprising in order from the lens closest to an object side:

a negative meniscus first lens whose convex side faces the object side;

a positive second lens;

a positive meniscus third lens whose convex side faces an image side;

a negative meniscus fourth lens whose convex side faces the object side;

a negative meniscus fifth lens whose convex side faces the object side; and

a positive sixth lens;

wherein said fifth lens and said sixth lens are cemented together to form a cemented lens subunit.

2. An objective lens device according to claim **1**, satisfying the condition

$$-7<\frac{R9+R8}{R9-R8}<-1,$$

wherein **R8** and **R9** represent the radius of curvature of a surface at the object side of said fourth lens and the radius of curvature of a surface at the image side of said fourth lens, respectively.

3. An objective lens device according to claim **1**, further satisfying the condition **N1<N2**, wherein **N1** and **N2** denote

the refractive indices of the materials of said first lens and said second lens, respectively, with said second lens being a meniscus lens whose convex side faces the image side.

4. An objective lens device according to claim 1, further satisfying the condition $0.1<|D3/R4|<0.3$, wherein D3 represents the thickness of said second lens, and R4 represents the radius of curvature of a surface at the image side of said second lens.

5. An objective lens device according to claim 1, wherein when an object at infinity is in focus and a nearby object is to be brought into focus, an entire lens system is moved, or said third lens to sixth lens are integrally moved toward the object side.

6. An objective lens device according to any one of claims 1 to 5, further comprising one of light control means including an iris stop, light control means including switching of a plurality of apertures, and light control means with a fixed aperture, said light control means being disposed between said second lens and third lens, or between said third lens and said fourth lens.

7. An objective lens device according to claim 1, further satisfying the condition $3<|tk/f|$, wherein tk represents the position of an exit pupil of the lens system, measured from a surface at the image side of said sixth lens, and wherein f represents a focal length of the entire lens system.

* * * * *

US005673147A

United States Patent [19]

McKinley

[11] Patent Number: 5,673,147

[45] Date of Patent: Sep. 30, 1997

[54] **STEREO VIDEO ENDOSCOPE OBJECTIVE LENS SYSTEMS**

[75] Inventor: **Harry R. McKinley**, Southampton, Mass.

[73] Assignee: **McKinley Optics, Inc.**, Southampton, Mass.

[21] Appl. No.: **424,704**

[22] Filed: **Apr. 18, 1995**

[51] **Int. Cl.**[6] **G02B 27/22**

[52] **U.S. Cl.** **359/462**; 359/376; 359/466; 359/475

[58] **Field of Search** 359/462, 466, 359/470, 473, 475–477, 643, 656, 661, 664, 376–378; 250/208.1

[56] **References Cited**

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4,651,201	3/1987	Schoolman	348/45
4,710,000	12/1987	Spitznas et al.	350/516
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0 211 783	7/1986	European Pat. Off. .

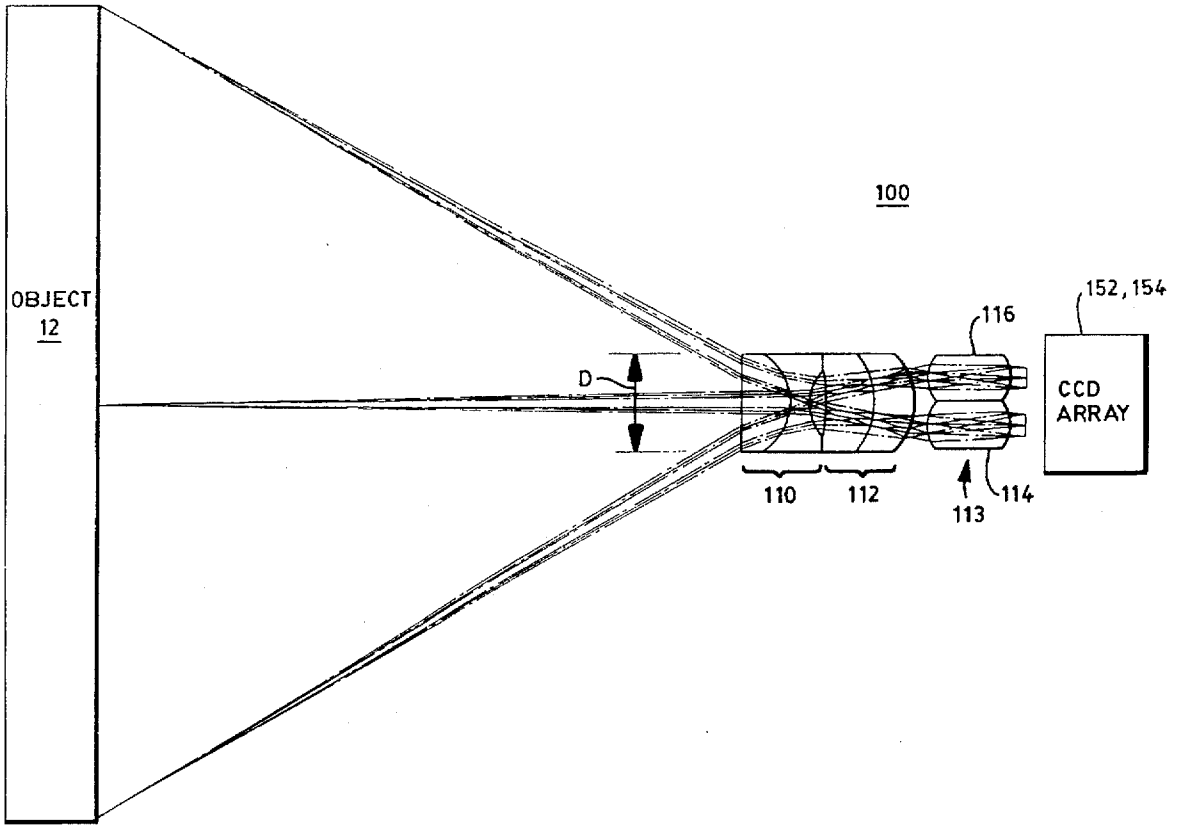
Primary Examiner—John D. Lee

Attorney, Agent, or Firm—Lappin & Kusmer LLP

[57] **ABSTRACT**

A stereoscopic objective lens system for video endoscopes and borescopes includes two full-diameter doublets and two identical half-diameter ball lenses. The full-diameter doublets collimate object points, imaging object points to infinity. The full-diameter doublets present equal-angle pairs from symmetrically disposed object points to the ball lenses. This equal-angle property enables accurate object/image mapping onto the final stereo image pair such that all parts of each left/right image can be mapped to within a fraction of a video pixel to each other.

12 Claims, 5 Drawing Sheets



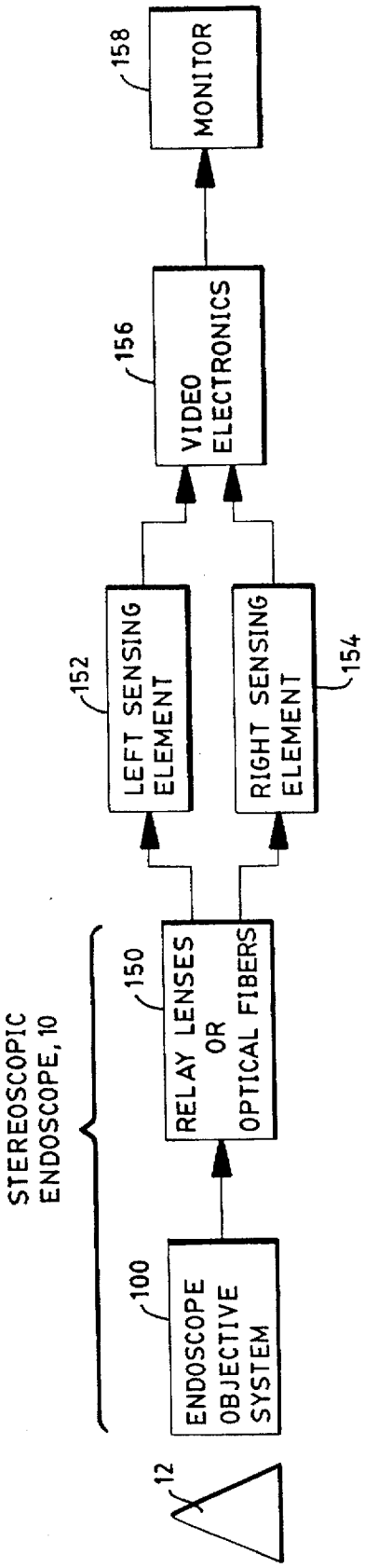

158
MONITOR
156
VIDEO ELECTRONICS
152
LEFT SENSING ELEMENT
154
RIGHT SENSING ELEMENT
1
150
RELAY LENSES OR OPTICAL FIBERS
STEREOSCOPIC ENDOSCOPE, 10
100
ENDOSCOPE OBJECTIVE SYSTEM
12

FIG. 1

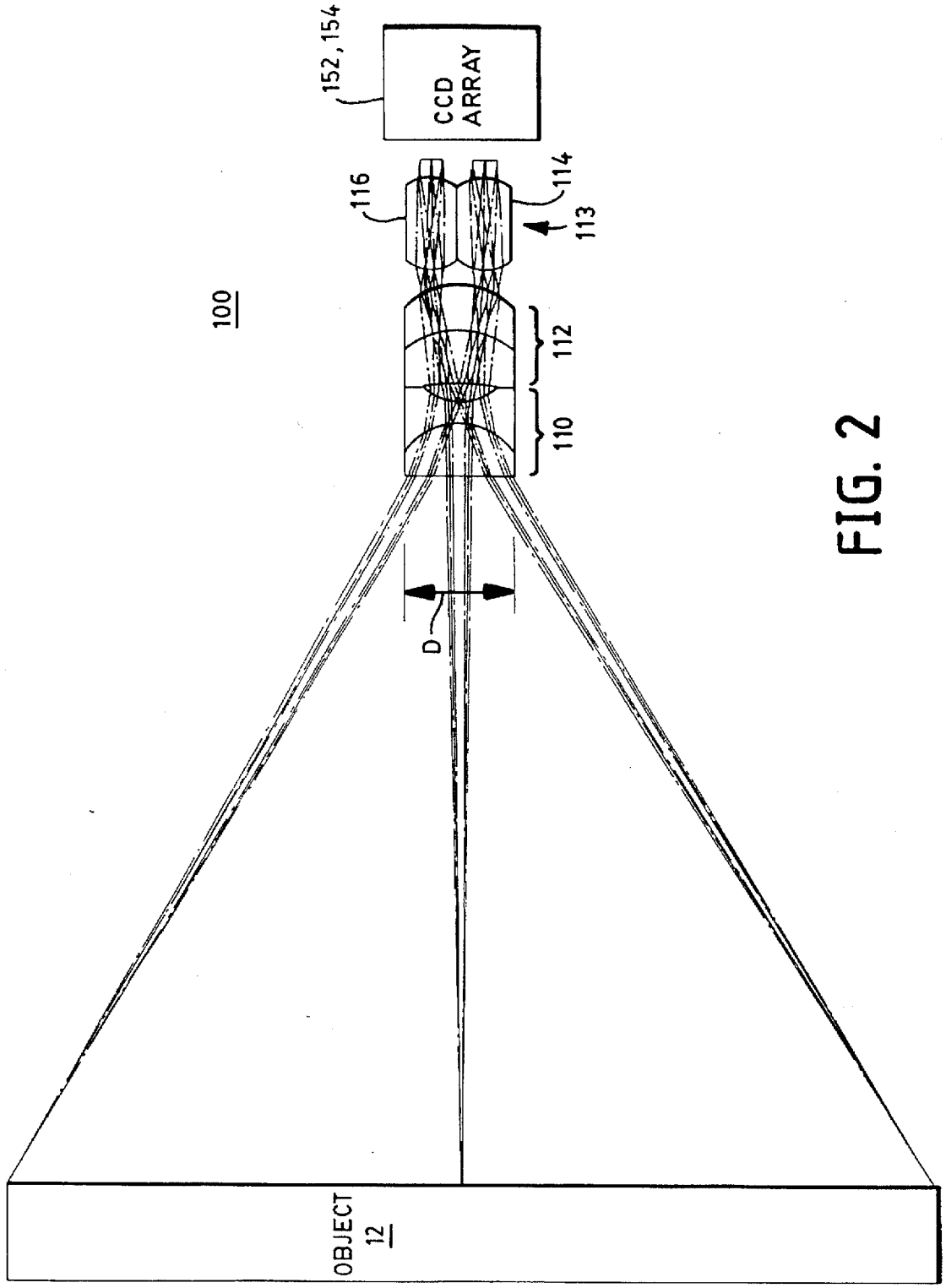


FIG. 2

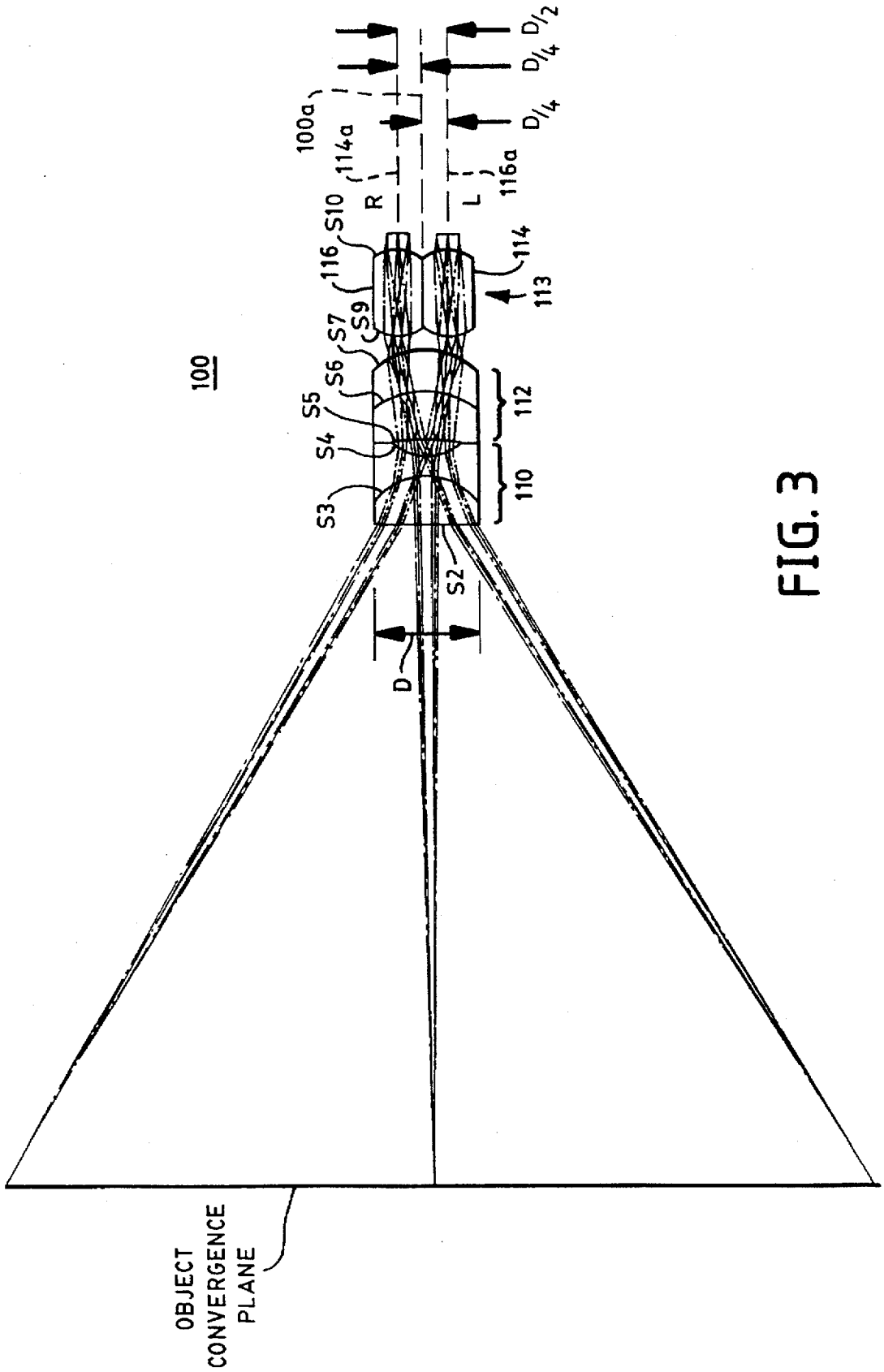

100
100a
114a
116a
R
L
D/2
D/4
D/4
S10
116
S7
S9
S6
S5
S4
S3
S2
114
113
112
110
D
OBJECT CONVERGENCE PLANE

FIG. 3

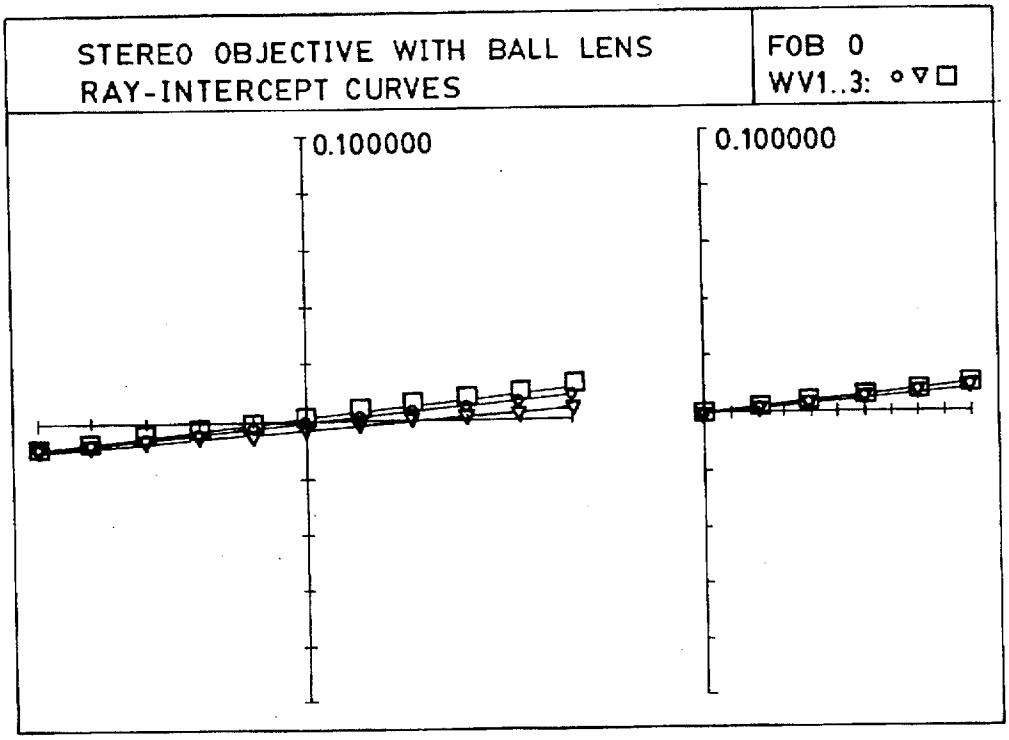

STEREO OBJECTIVE WITH BALL LENS
RAY-INTERCEPT CURVES
FOB 0
WV1..3:
0.100000
0.100000

FIG. 4A

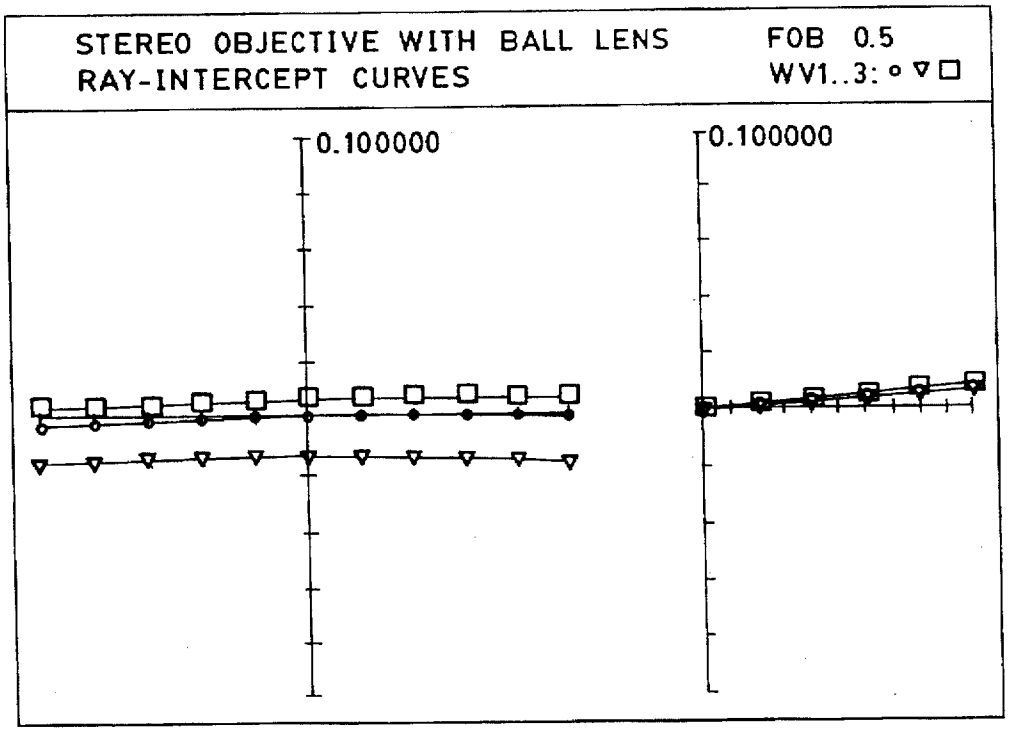

STEREO OBJECTIVE WITH BALL LENS
RAY-INTERCEPT CURVES
FOB 0.5
WV1..3:
0.100000
0.100000

FIG. 4B

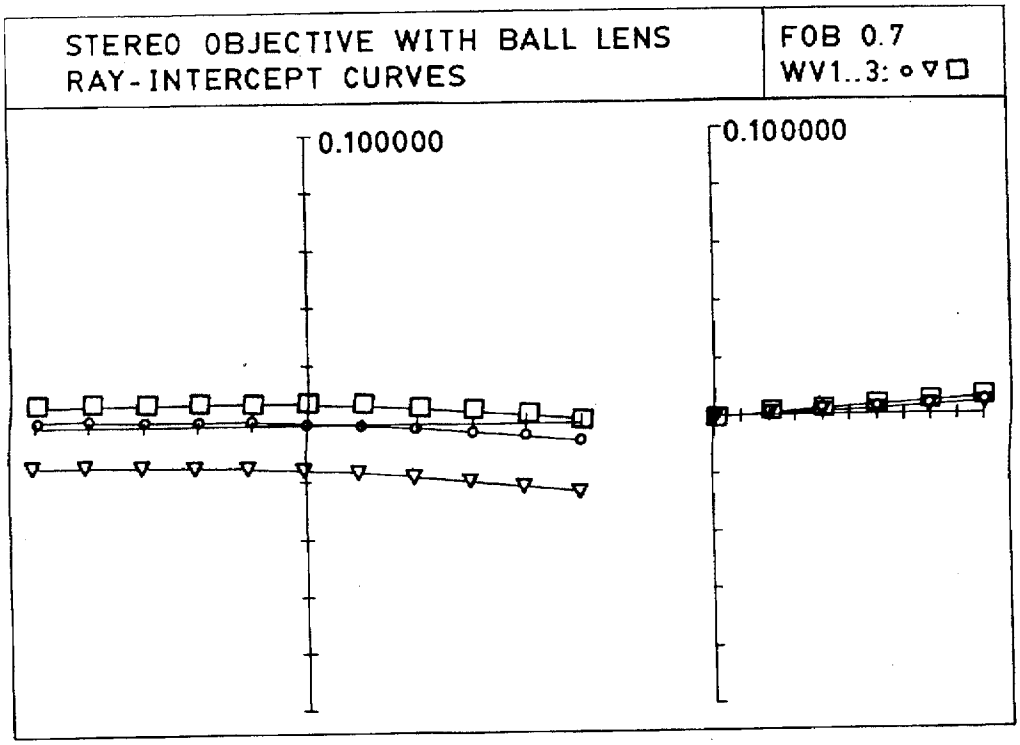

STEREO OBJECTIVE WITH BALL LENS
RAY-INTERCEPT CURVES
FOB 0.7
WV1..3:
0.100000
0.100000

FIG. 4C

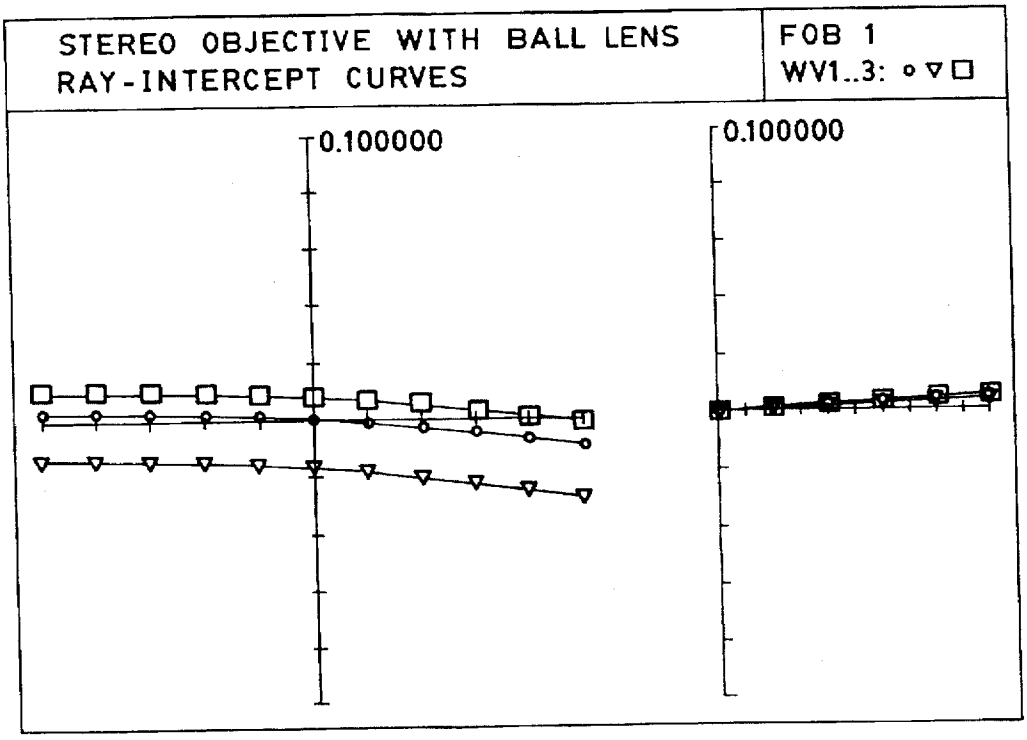

STEREO OBJECTIVE WITH BALL LENS
RAY-INTERCEPT CURVES
FOB 1
WV1..3:
0.100000
0.100000

FIG. 4D

STEREO VIDEO ENDOSCOPE OBJECTIVE LENS SYSTEMS

BACKGROUND OF THE INVENTION

This invention relates generally to optical lens systems, and, more particularly, relates to stereoscopic objective lens designs adapted for use in stereo video endoscopes.

Medical endoscopes are widely utilized to view internal regions of the human body during diagnostic, surgical, and other medical procedures. Endoscopes typically include a long, thin, rigid or semi-rigid optical cylinder affixed to a viewing mechanism. The cylinder is sufficiently narrow to be inserted through a small opening in the body, which may be natural or surgical. When the endoscope is inserted and positioned for use, an image of the object being viewed is formed at an inserted end of the endoscope by an objective lens. The image passes through a series of relay lenses down the cylinder to an eye lens or video camera at a viewing end of the endoscope.

In recent years, researchers have attempted to improve the imaging available through endoscopic devices by developing stereoscopic video endoscopes. These endoscopes present an apparently three-dimensional image on a video monitor. The stereoscopic effect is created by producing two optical images—a left image and a right image—through the endoscope. The left and right optical images are presented by the endoscope to left and right image sensors, which may be charge-coupled device (CCD) cameras or other image sensing devices. The sensing devices convert the left and right optical images into left and right video images which are then presented as alternating left/right images on a monitor, at a switching rate higher than the flicker-sensing limit of the human eye, so that observed images appear flicker-free.

The images are alternately switched from a left-hand polarization mode to a right-hand polarization mode, such that, for example, the left image has a left-hand polarization and the right image has a right-hand polarization. In accord with this example, the observer wears polarized glasses in which the left lens has the left-hand polarization and the right lens has the right-hand polarization. Thus, the left eye sees only images from the left channel of the endoscope system and the right eye sees only images from the right channel, resulting in stereoscopic viewing.

The following United States and foreign patents disclose examples of stereo endoscopes, some of which utilize video imaging and display elements:

U.S. Pat. No. 4,061,135
U.S. Pat. No. 4,615,332
U.S. Pat. No. 4,651,201
U.S. Pat. No. 4,862,873
U.S. Pat. No. 4,873,572
U.S. Pat. No. 4,895,431
U.S. Pat. No. 5,122,650
U.S. Pat. No. 5,191,203
EP Patent No. 211,783

In particular, U.S. Pat. No. 4,061,135 discloses a binocular endoscope in which images are transmitted from the viewed object to the viewing station through an optical system utilizing a dove prism and mechanical linkage to compensate for rotation effects.

U.S. Pat. No. 4,615,332 discloses a binocular endoscope having flexible light guides and binocular eyepieces.

U.S. Pat. No. 4,651,201 discloses a stereoscopic video endoscope including two image guides and an illumination light guide. The image guides are optically coupled to a stereoscopic viewer for three dimensional viewing. The viewer includes couplings for attaching miniature video camera that can be connected to a head mounted stereoscopic video display.

U.S. Pat. No. 4,862,873 discloses a stereo endoscope having two light guides for carrying images of an object an electro-optical imaging assembly. A lens system directs light from the object to the objective end of the light guides. Illuminating light is transmitted to the object from the opposite end of one light guide, thereby illuminating the object. Simultaneously, the image transmitted through the other optical guide is conducted to the imaging assembly.

U.S. Pat. No. 4,873,572 discloses a stereo endoscope having a CCD camera module and two image-forming lens systems that form two object images. The object images are integrated and directed to the CCD camera to provide a stereoscopic output. The lens systems include red, green, and blue color filters disposed at the camera imaging surface.

U.S. Pat. No. 4,895,431 discloses an endoscope apparatus that generates a three-dimensional image of an object from overlapping images recorded by a camera. The endoscope includes an insertion module and a movable end section capable of being deflected through an angle. A first image is recorded with the end section positioned at a first angle. A second image, partially overlapping the first image, is recorded after moving the end section to a second angle. The relative position of the movable end section is detected by an encoder that generates position signals for input to a microprocessor, which utilizes the position signals to generate a three-dimensional image of the object.

U.S. Pat. No. 5,122,650 discloses a stereo video endoscope objective lens system using six doublet lenses to generate pixel mapped left-right images for stereo viewing.

U.S. Pat. No. 5,191,203 discloses a stereo video endoscope objective lens system using lenses having a graded index of refraction to generate pixel mapped left-right images for stereo viewing.

European Patent No. 211,783 discloses a stereo video endoscope in which two light pipes deliver two images of the same object. These images are presented by a binocular device to the user's eyes to show a three dimensional image of the target. The apparatus includes two television cameras and video recorders for recording the images. The recorded images can be displayed on separate screens and viewed by a binocular viewing system.

Most conventional stereo endoscopes, however, share a number of deficiencies associated with their objective lens systems. These problems include a bulky and unwieldy configuration; high cost and complexity of fabricating the objective lens system; and the less than optimal optical performance afforded by conventional objective lens systems.

An additional problem associated with conventional stereo video endoscope objectives involves the requirement that all portions of each left/right image be mapped to within a fraction of a video pixel to each other. This pixel mapping condition is a significant optical design constraint, because the object-to-image ray paths through the lens system are quite different for the left and right image points associated with a common object point.

Accordingly, it is a general object of the present invention to provide improved stereo endoscope objective lens systems that overcome the problems associated with conventional designs.

A more specific object is to provide an improved stereo endoscope objective lens system having optical elements that facilitate assembly of the system.

It is another object of the invention to provide an improved stereo endoscope objective lens system having elements that are substantially less expensive to manufacture than the elements of conventional systems.

A further object is to provide an improved stereo endoscope objective lens system having optical performance characteristics that are substantially superior to the performance characteristics of conventional systems.

Another object of the invention is to provide a stereo objective lens system affording a pixel mapped image.

The above and other objects and advantages of this invention will become more readily apparent when the following description is read in conjunction with the accompanying drawings.

SUMMARY OF THE INVENTION

The foregoing objects are attained by the invention, which provides an improved stereo endoscope objective lens system for video imaging in medical endoscopes and industrial borescopes.

One aspect of the invention includes two full-diameter (D) doublets disposed along an optical axis, and a left/right stereo lens pair. The stereo lens pair includes a set of two spherical, or ball lenses, each having a cylindrical lateral surface with a circular cross-section having a diameter D/2. The full-diameter doublets substantially collimate object points, i.e., image them substantially to infinity. The stereo lens pair is disposed to collect light from the second doublet, with the optical axis of each ball lens being substantially parallel, and offset by D/4 from the optical axis of the doublets.

The doublets and the stereo lens pair cooperate so that the doublets present equal angle light ray pairs from symmetrically disposed object points to the ball lenses of the stereo lens pair. The left and right ball lenses generate left and right images respectively, at an image plane, where corresponding portions of those images are mapped to within a selected distance of each other.

In a further aspect of the invention, the ball lenses are particularly advantageous compared to the prior art, because they can be most economically fabricated in production quantities. This is advantageous because these small lenses are inherently difficult to manufacture.

In another aspect of the invention, the large collimator doublets provide accurate object/image mapping onto the final stereo image pair. In this design, the larger, and hence easier to fabricate doublets carry the corrective burden, so that the smaller, more difficult to manufacture lenses can be made a simple as possible.

The invention will next be described in connection with certain illustrated embodiments; however, it should be clear to those skilled in the art that various modifications, additions and subtractions can be made without departing from the spirit or scope of the claims.

The invention will next be described in connection with certain illustrated embodiments; however, it should be clear to those skilled in the art that various modifications, additions and subtractions can be made without departing from the spirit or scope of the claims.

BRIEF DESCRIPTION OF THE DRAWING

For a fuller understanding of the nature and objects of the invention, reference should be made to the following detailed description and the accompanying drawings, in which:

FIG. **1** is a schematic diagram depicting a stereo video endoscope utilizing an objective lens system constructed in accordance with the invention;

FIG. **2** is an optical schematic diagram depicting an objective lens system constructed in accordance with the invention, showing light rays transmitted through the system;

FIG. **3** is an optical schematic diagram depicting an objective lens system constructed in accordance with the invention, identifying optical surfaces, and

FIGS. **4A–4D** show ray intercept and optical path difference curves the embodiment of FIGS. **2** and **3**.

DESCRIPTION OF ILLUSTRATED EMBODIMENTS

FIG. **1** depicts the invention, an endoscope objective system **100**, utilized in a stereo video endoscopy system **1** for generating stereoscopic images of an object **12**. The system **1** principally includes a stereoscopic endoscope **10** containing objective system **100**; sensing modules **152, 154**; switching module **156**; and a monitor **158**. In addition to objective lens system **100**, the endoscope **10** includes conventional relay lenses or optical fibers **150** for transmitting light collected by the endoscope objective system **100** to light sensing modules **152, 154**.

The endoscope objective system **100** generates left and right optical images of the object **12** that are processed by sensing elements **152, 154** and video switching module **156** in a known manner to display an apparently three-dimensional image of the object **12** on video monitor **158**.

The stereoscopic effect is created by producing two optical images—a left image and a right image —through the endoscope objective system **100**. The left and right optical images generated by the objective system **100** are presented by the relay lens or optical fiber system **150** to left and right image sensors **152, 154**, which can be conventional charge-coupled device (CCD) cameras or other image sensing devices. The CCD elements operate in a known manner to convert the light collected by the objective system **100**, and transmitted by the relay lenses or optical fibers **150**, into electrical signals representative of the left and right optical images of the object **12**.

Conventional video switching circuitry **156** transmits the electronic signals representative of left and right video images as alternating left-right images on the monitor **158**. In accord with known video practice, these alternating images are presented at a switching rate higher than the flicker-sensing limit of the human eye, so that observed images appear flicker-free.

Moreover, the images can be alternately switched from a left-hand polarization mode to a right-hand polarization mode, such that, for example, the left image has a left-hand polarization and the right image has a right-hand polarization. The observer wears polarized glasses in which the left lens has the left-hand polarization and the right lens has the right-hand polarization. Thus, when the observer views the monitor **158**, the left eye sees only images from the left channel of the endoscope system and the right eye sees only images from the right channel, resulting in stereoscopic viewing. Video switching and display equipment of this type is commercially available from Stereographics, Inc. of San Rafael, Calif.; and from Tektronix Corp., of Beaverton, Oreg.

The accuracy and quality of the image displayed on monitor **158** is controlled by the performance of the endo-

scope objective system **100**, which is the subject of the present invention.

FIGS. **2** and **3** depict an objective lens system **100** constructed in accordance with the invention, showing light rays transmitted through the system.

The objective system **100** of FIGS. **2** and **3** include a first doublet **110** and a second doublet **112** positioned in sequence along and centered about a common system axis **100***a*, followed by a stereo lens set **113**. Both doublets have circular cross sections with a diameter D. The lens set **113** includes a pair of matched, cylindrical side wall ball lenses **114**, **116**, each having a circular cross-section with diameter D/2, extending along an associated one of ball lens axes **114***a* and **116***a* which are parallel to, and spaced apart by D/2 from, the system axis **100***a*. The two doublets **112**, **114** cooperate to collimate object points, i.e., image them to infinity.

Those skilled in the art will appreciate that the lenses of the objective system **100** depicted in FIGS. **2** and **3** define a sequence of **12** optical surfaces. A working example of a set of lenses for objective system **100** is set forth below in Table A. Reference numerals S2–S7, S9 and S10 shown in FIG. **3** correspond to numerals **2–7**, **9** and **10** respectively in the "SURFACE" column of Table A. As those skilled in the an will appreciate, surfaces **1**, **8**, **11**, and **12** do not correspond to physical surfaces and are indicated in Table A for convenience of analysis. FIG. **3** shows reference designations S2–S7, S9 and S10 overlaid onto the system of FIG. **2**.

TABLE A

SURFACE	RADIUS	THICKNESS	GLASS
1	—	−3.678088	AIR
2	—	3.000000	SIO2 C
3	−3.650000	1.200000	SF1 C
4	3.101000	0.983255	AIR
5	15.121014	3.000000	LAKN12 C
6	−5.000000	2.500000	F4 C
7	−4.443995	1.400000	AIR
8	—	2.200000	AIR
9	2.500000	5.000000	BK7 C
10	−2.500000	1.046744	AIR
11	—	0.001000	BK7 C
12	—	—	AIR

In Table A, the numerical values in the "RADIUS" and "THICKNESS" columns are set forth in millimeters. The "GLASS" descriptions are standard optical glass characterizations as found in the product catalog of the Schott Glass Company of Germany. The "THICKNESS" column refers to the distance to the next optical surface. The "RADIUS" column refers to the radii of curvature of the respective curved surfaces. For example, Table A describes lens **116** as a ball lens because surfaces **9** and **10** have 2.5, and −2.5 millimeter radii of curvature, respectively, and the distance between surfaces **9** and **10** is 5 millimeters. Lenses **114** and **116** are ball (or spherical) lenses that have been ground to have cylindrical lateral surfaces, with a circular cross-section (transverse to the respective axes **114**A and **116**A) having a diameter that is one half of the diameter of doublets **110** and **112**.

In this working example, the diameters are 6.0 millimeters for the doublets **110** and **112**, and 3.0 millimeters for the ball lenses **114** and **116**. The image diameters are 1.5 millimeters.

The system **100** is designed so that all parts of each left/right image are mapped to within a selected distance of each other such that stereoscopic image quality is maintained. For video applications, this selected distance is typically a fraction of a video pixel. This is a difficult condition to satisfy, because the object-to-image ray paths through the lens system are quite different for the left and right image points of a common object point. The ray paths shown in FIG. **2** demonstrate how differently an object point is imaged through the lens elements for the left and right images.

The objective system **100** depicted in FIGS. **2** and **3** is able to map all parts of each left/right image to within a fraction of a video pixel to each other, because the large collimator doublets present equal-angle pairs from symmetrically disposed object points to the small ball lenses **114**, **116**. This exact equal-angle solution results in an accurate object/image mapping onto the final stereo image pair.

The accuracy and minimized distortion of the system of Table A is shown in the respective ray intercept curves shown in FIGS. **4**A–**4**D. In each of those figures, for an identified object point the ray intercepts are shown as a function of relative aperture height.

Objective system **100**, as described in Table A and shown in FIGS. **2** and **3**, achieves accurate object/image mapping with simpler and fewer components than those used in prior art devices. Doublets **110** and **112** are relatively easy to manufacture compared to those used in prior art systems because they do not have any highly curved surfaces, nor do they have any curved surfaces that are nearly planer. Further, lenses **114** and **116** are identical and are made from widely available ball or spherical lenses.

As indicated in FIG. **1**, the endoscope objective system **100** can be utilized in connection with optical fiber elements or a set of relay lenses **150**, an example of which is described in the above-referenced U.S. Pat. No. 5,122,650.

Alternatively, an endoscope constructed in accordance with the invention can employ a conventional CCD array mounted within the same housing as the objective system. The CCD array can include left and right sensing elements **152**, **154**, disposed to receive the optical images generated at the output of ball lenses **114**, **116** i.e. at surface **12**. The design and construction of CCD elements having more than one photosensitive region in a monolithic package is well known in the art. The electrical signals generated by the CCD array can be conducted from the housing by a conventional conduit. This configuration eliminates the requirement for a relay lens system or optical fibers.

The system **100** depicted in FIGS. **2** and **3** offers advantages for use in medical endoscopes and industrial borescopes. The configuration offers the advantage of being adaptable to fit into a small tube diameter, as small as 2 millimeters. The design also affords high resolution and low distortion for diagnostic and surgical use, and for high-accuracy industrial measurement applications. The design is also relatively easy and inexpensive to produce.

The invention may be embodied in other specific forms without departing from the spirit or essential characteristics thereof. The present embodiments are therefore to be considered in all respects as illustrative and not restrictive, the scope of the invention being indicated by the appended claims rather than by the foregoing description, and all changes which come within the meaning and range of equivalency of the claims are therefore intended to be embraced therein.

Having described the invention, what is claimed as new and secured by Letters Patent is:

1. A stereoscopic objective lens system for a stereo video endoscope, the objective lens system converting light propa-

gated from an object and received at an objective end of the objective system to pixel-mapped left and right optical images of said object at an image plane end of the objective system, the objective lens system comprising:

A. a first collimator doublet lens element proximate to the objective end for collecting light from points on the object, said first doublet lens having a first optical axis, a selected diameter and a selected optical power,

B. a second collimator doublet lens for collecting light from said first collimator doublet lens, said second collimator doublet lens being disposed adjacent to said first collimator doublet lens and having an optical axis substantially collinear with the optical axis of the first collimator doublet lens, said second collimator doublet lens having a selected diameter and a selected optical power, whereby said first and second collimator doublet lenses cooperate to image the object points substantially to infinity so that light transmitted by the second collimator doublet lens from the object points is substantially collimated,

C. a right/left stereo lens pair, said pair including a right ball lens and a left ball lens, said right and left ball lenses being adjacent to said second collimator doublet lens and disposed for collecting light from said second collimator doublet lens, said right ball lens and said left ball lens each having a respective optical axis substantially parallel to the optical axis of the second collimator doublet lens,

wherein said first and second collimator doublet lenses and said right/left stereo lens pair cooperate so that the first and second collimator doublet lenses present equal-angle light ray pairs from symmetrically disposed object points to the ball lenses of said right/left stereo lens pair,

whereby said right ball lens generates a right image at the image plane, and said left ball lens generates a left image at the image plane, such that corresponding portions of each right/left image are mapped to within a selected distance of each other.

2. A lens system according to claim **1** wherein the diameter of said second collimator doublet lens is approximately equal to the diameter of said first collimator doublet lens.

3. A lens system according to claim **2** wherein said right ball lens is substantially identical to said left ball lens.

4. A lens system according to claim **3** wherein said left ball lens and said right ball lens each have a circular cross-section transverse to the respective optical axes of said right ball lens and said left ball lens.

5. A lens system according to claim **3** wherein the diameters of said right ball lens and said left ball lens are substantially equal to one-half the diameter of said first and second collimator doublet lenses, and said optical axes of said right ball lens and said left ball lens are off-set from said optical axis of said first and second collimator doublet lenses by one-fourth the diameter of said first and second collimator doublet lenses.

6. A lens system according to claim **5** wherein said left ball lens and said right ball lens each have a circular cross-section transverse to the respective optical axes of said right ball lens and said left ball lens.

7. A stereoscopic objective lens system for a stereo video endoscope, the objective lens system converting light propagated from an object and received at an objective end of the objective system to pixel-mapped left and right optical images at an image plane end of the objective system, the objective lens system comprising:

A. a collimator lens system proximate to the objective end for collecting light propagated from points on the object, said collimator lens system having a defined optical axis, a selected diameter and a selected optical power, whereby said collimator lens system images the object points substantially to infinity so that light transmitted by said collimator lens system from the object points is substantially collimated,

B. a right/left stereo lens pair, said pair including a right ball lens and a left ball lens, said right and left ball lenses being adjacent to said collimator lens system and disposed for collecting light from said collimator lens system, said right ball lens and said left ball lens each having a respective optical axis substantially parallel to the optical axis of the collimator lens system,

wherein said collimator lens system and said right/left stereo lens pair cooperate so that the collimator lens system presents equal-angle light ray pairs from symmetrically disposed object points to the ball lenses of said right/left stereo lens pair,

whereby said right ball lens generates a right image at the image plane, and said left ball lens generates a left image at the image plane, such that corresponding portions of each right/left image are mapped to within a selected distance of each other.

8. A lens system according to claim **7** wherein said collimator lens system comprises a first collimator doublet lens and a second collimator doublet lens, the diameter of said second collimator doublet lens being approximately equal to the diameter of said first collimator doublet lens.

9. A lens system according to claim **8** wherein said right ball lens is substantially identical to said left ball lens.

10. A lens system according to claim **9** wherein said left ball lens and said right ball lens each have a circular cross-section transverse to the respective optical axes of said right ball lens and said left ball lens.

11. A lens system according to claim **8** wherein the diameters of said right ball lens and said left ball lens are substantially equal to one-half the diameter of said first and second collimator doublet lenses, and said optical axes of said right ball lens and said left ball lens are off-set from said optical axis of said first and second collimator doublet lenses by one-fourth the diameter of said first and second collimator doublet lenses.

12. A lens system according to claim **11** wherein said left ball lens and said right ball lens each have a circular cross-section transverse to the respective optical axes of said right ball lens and said left ball lens.

* * * * *

US005668669A

United States Patent [19]

Ohtake et al.

[11] Patent Number: 5,668,669

[45] Date of Patent: *Sep. 16, 1997

[54] **COMPACT WIDE-ANGLE OBJECTIVE LENS**

[75] Inventors: **Motoyuki Ohtake**, Ohmiya; **Motohisa Mori**, Yokohama, both of Japan

[73] Assignee: **Nikon Corporation**, Tokyo, Japan

[*] Notice: The term of this patent shall not extend beyond the expiration date of Pat. No. 5,528,428.

[21] Appl. No.: **636,946**

[22] Filed: **Apr. 24, 1996**

Related U.S. Application Data

[63] Continuation of Ser. No. 173,084, Dec. 27, 1993, Pat. No. 5,528,428, which is a continuation-in-part of Ser. No. 80,971, Jun. 24, 1993, abandoned, which is a continuation of Ser. No. 973,614, Nov. 9, 1992, abandoned.

[30] **Foreign Application Priority Data**

Nov. 13, 1991 [JP] Japan 3-297444
May 13, 1993 [JP] Japan 5-111289

[51] **Int. Cl.**[6] **G02B 15/14**; G02B 9/00

[52] **U.S. Cl.** **359/684**; 359/691; 359/740; 359/751

[58] **Field of Search** 359/684, 691, 359/740, 770, 746, 657, 661, 749, 750, 751, 755

[56] **References Cited**

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FOREIGN PATENT DOCUMENTS

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Primary Examiner—Georgia Y. Epps
Assistant Examiner—Evelyn A. Lester
Attorney, Agent, or Firm—Shapiro and Shapiro

[57] **ABSTRACT**

A wide-angle objective lens is comprised, from the object side, of a first lens component which is a negative meniscus lens having its convex surface facing the object side, a second lens component which is a meniscus lens having its convex surface facing the object side and having positive refractive power, a third lens component which is a cemented meniscus lens comprising a positive lens and a negative lens cemented together and having its convex surface facing the object side and having positive refractive power, a fourth lens component which is a positive meniscus lens having its concave surface facing the object side, and a fifth lens component which is a negative meniscus lens having its concave surface facing the object side. The wide-angle objective lens has a stop disposed between the second lens component and third lens component, and satisfies predetermined conditions.

7 Claims, 10 Drawing Sheets

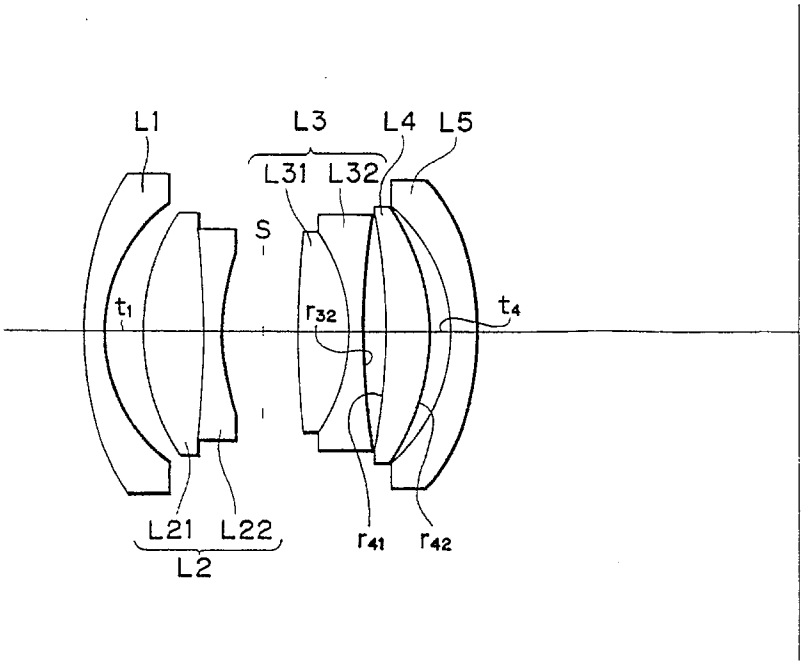


FIG. 1

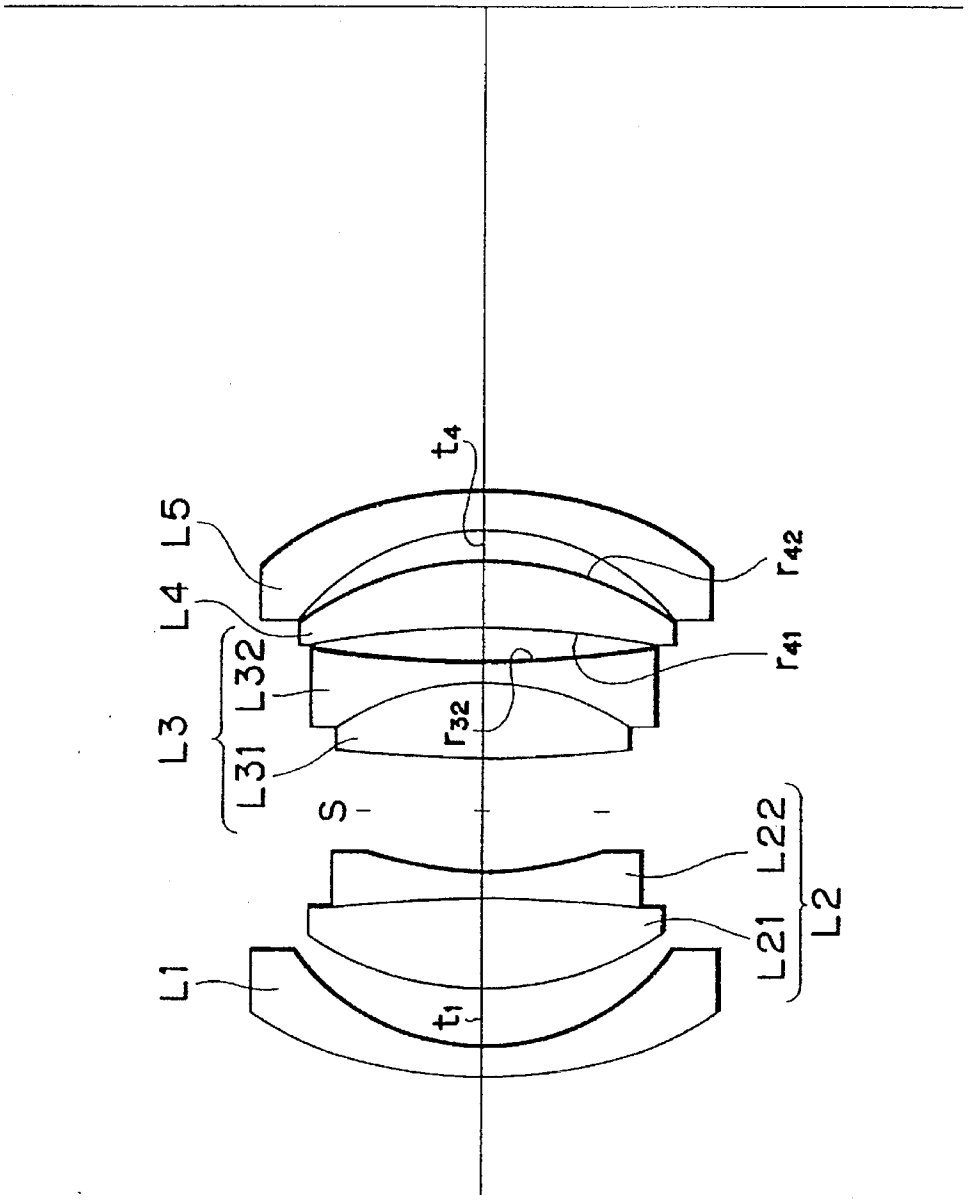


FIG. 2

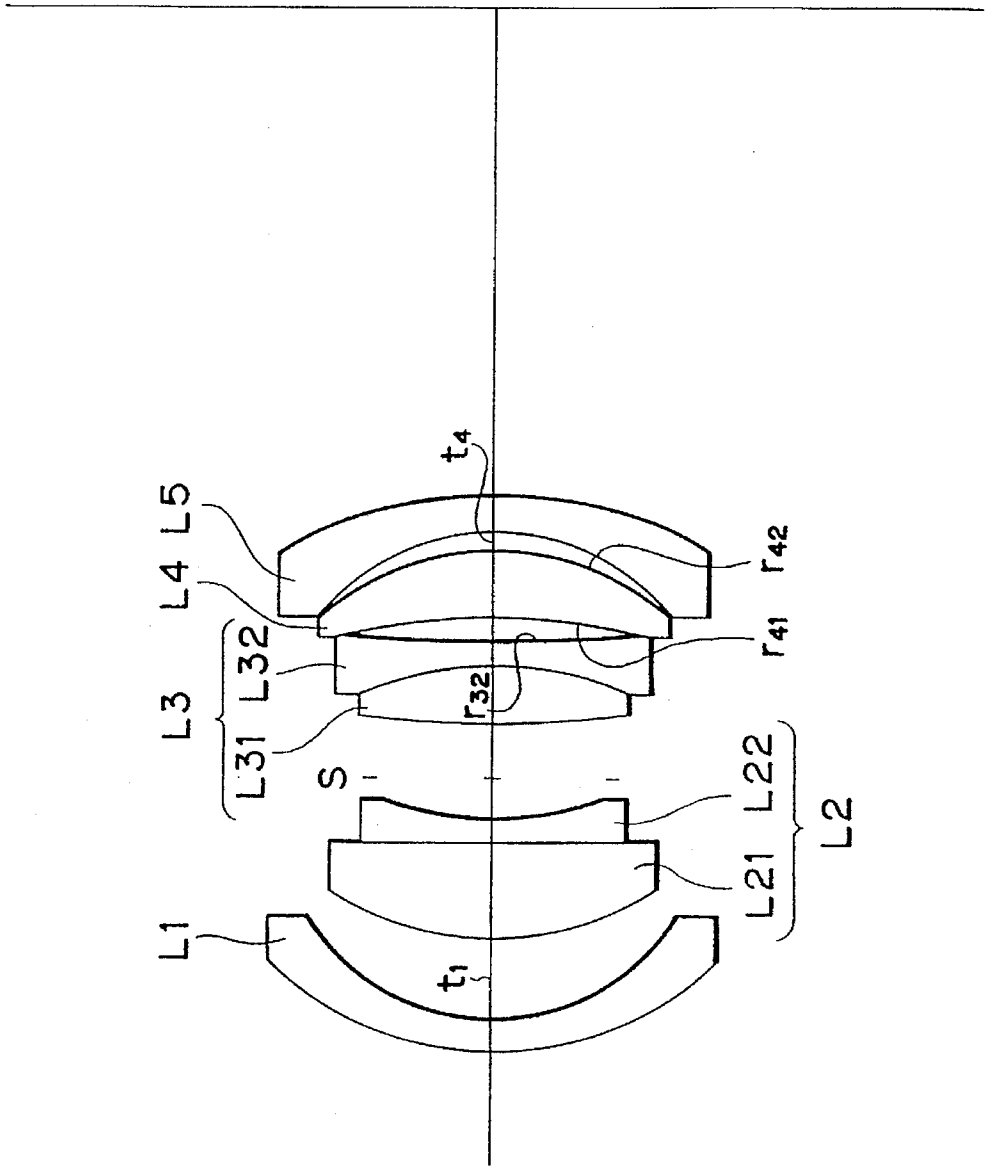


FIG. 3

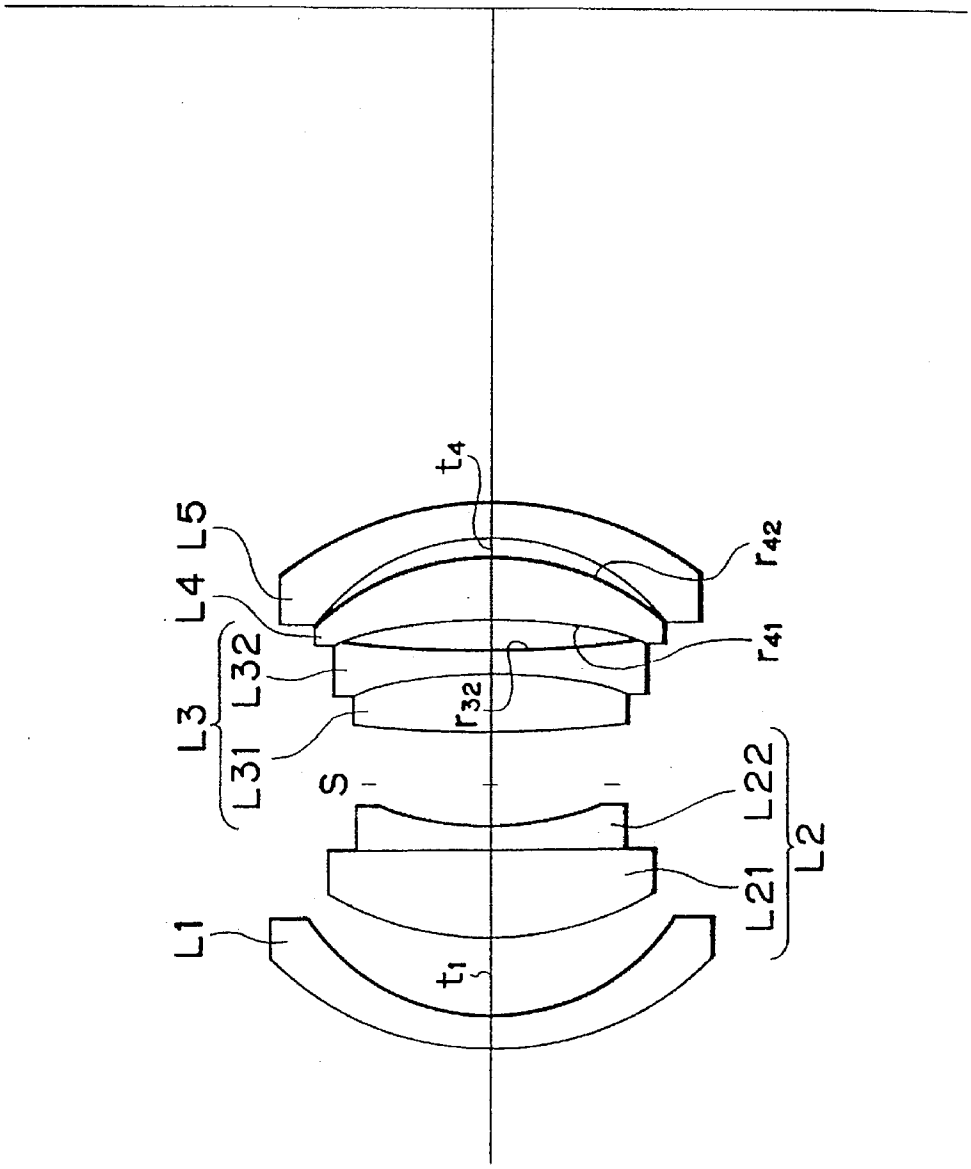


FIG. 4

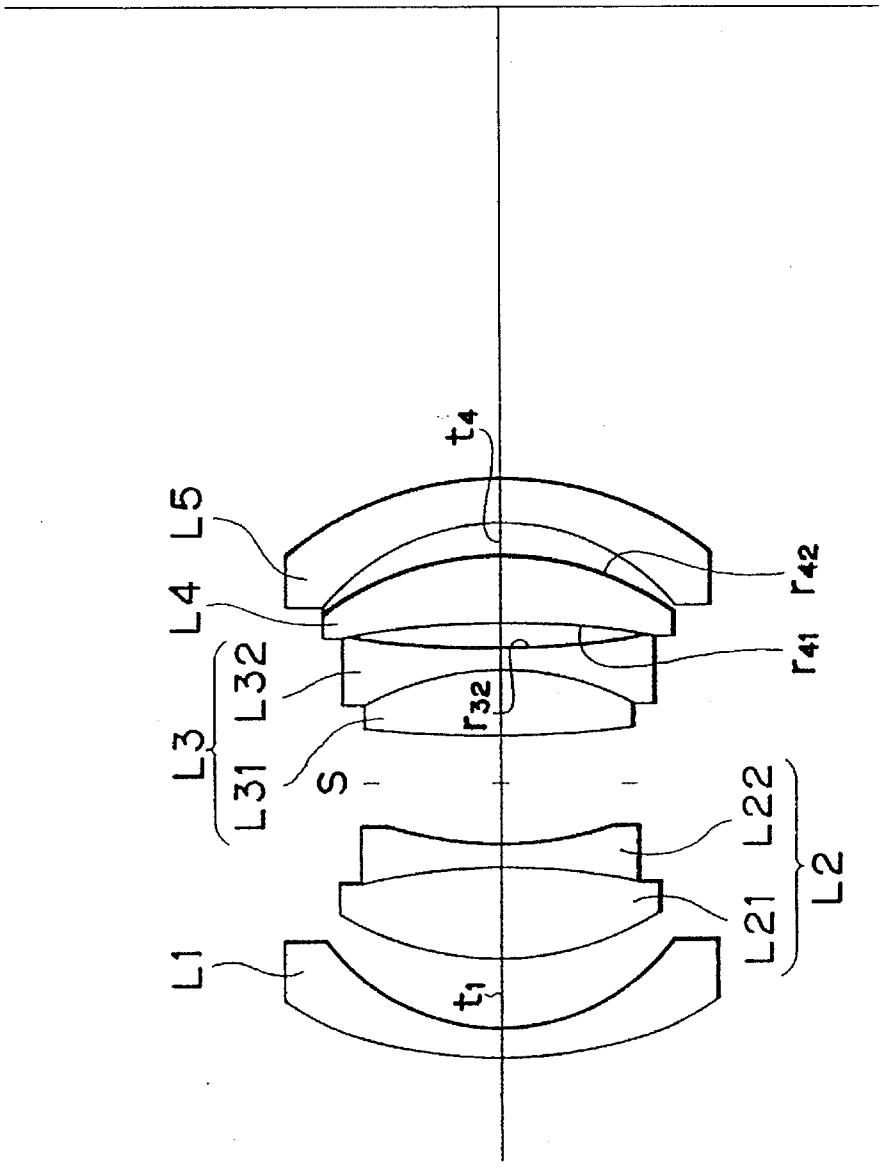


FIG. 5

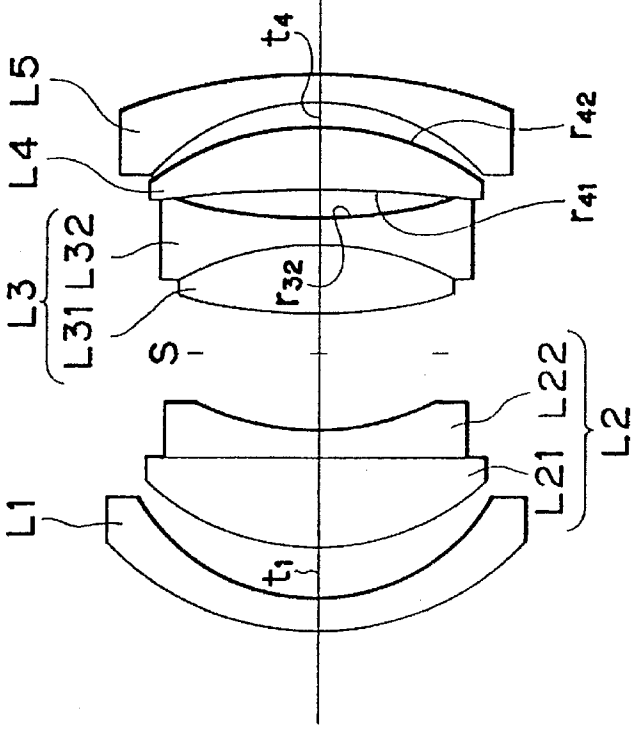


FIG. 6

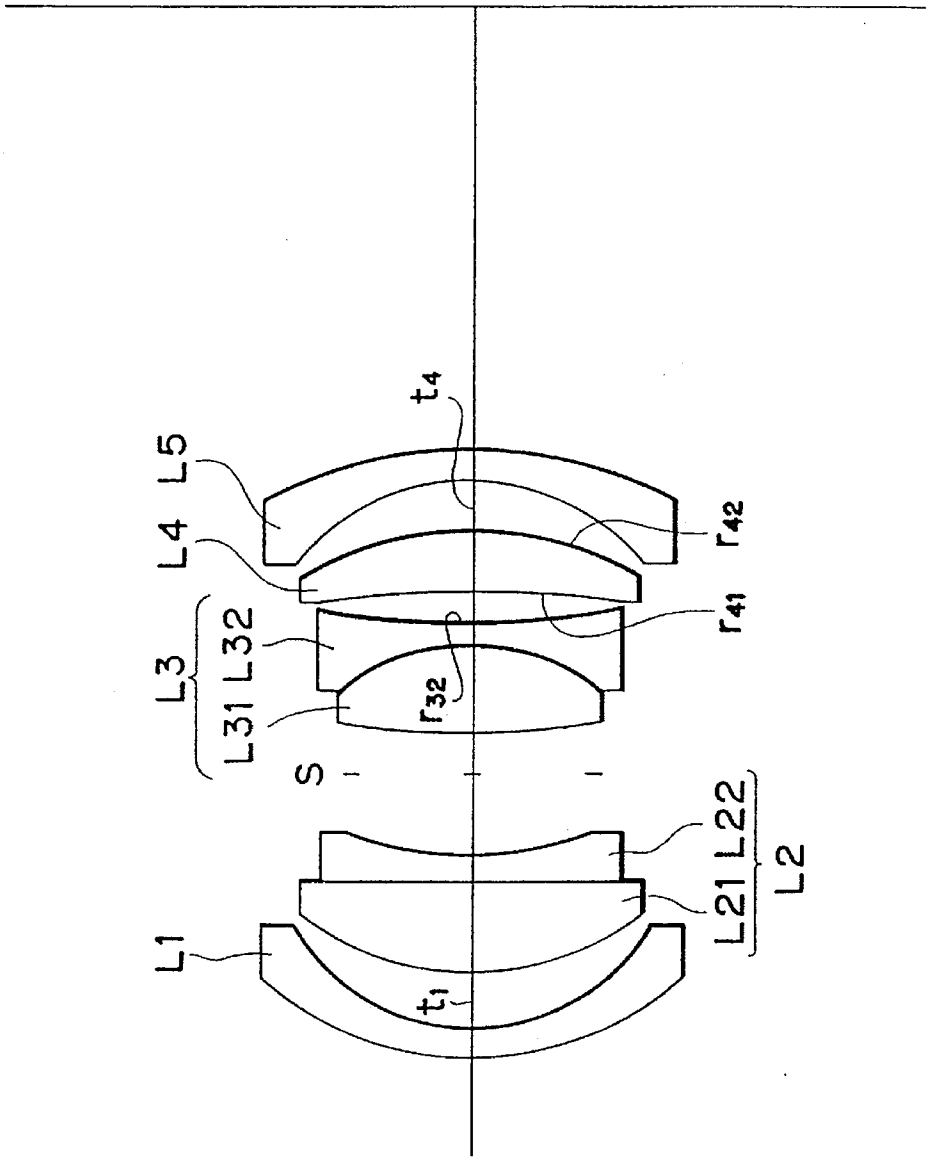


FIG. 7

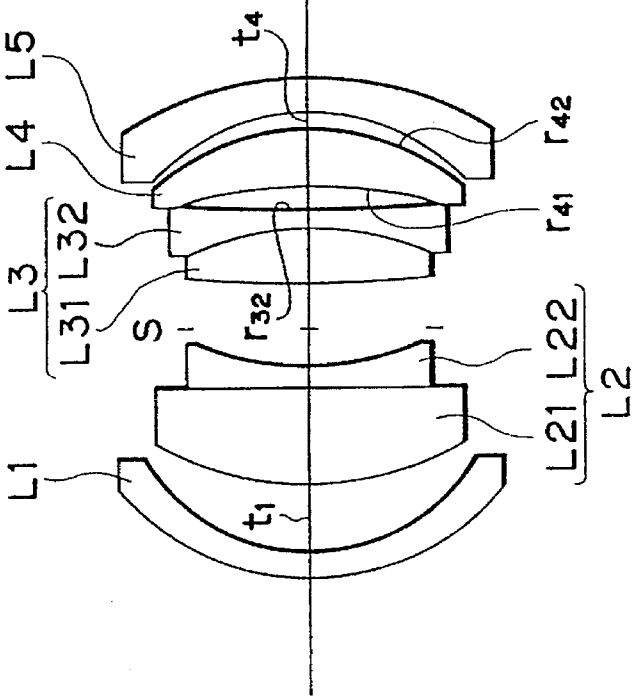


FIG. 8

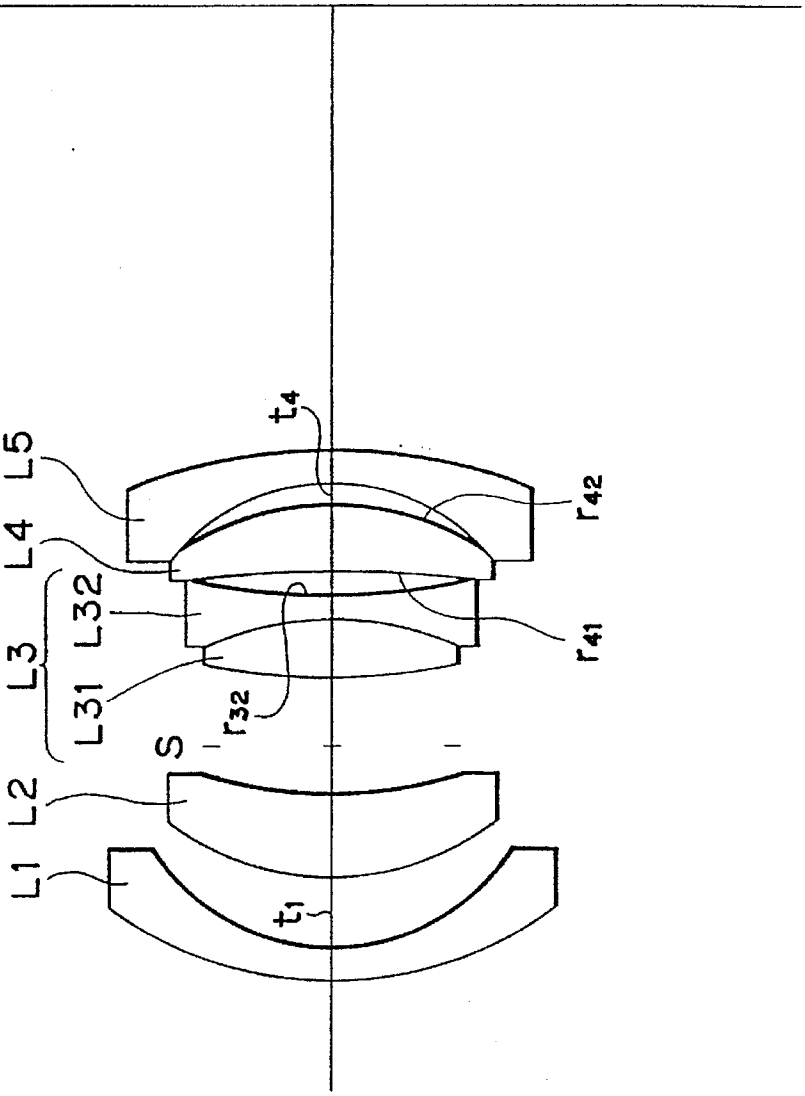


FIG. 9A

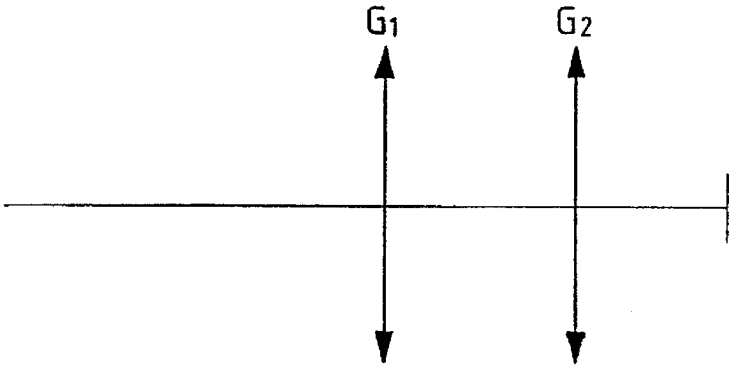


FIG. 9B

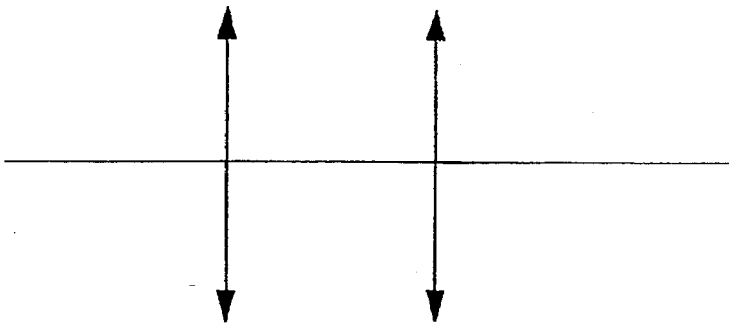


FIG. 10

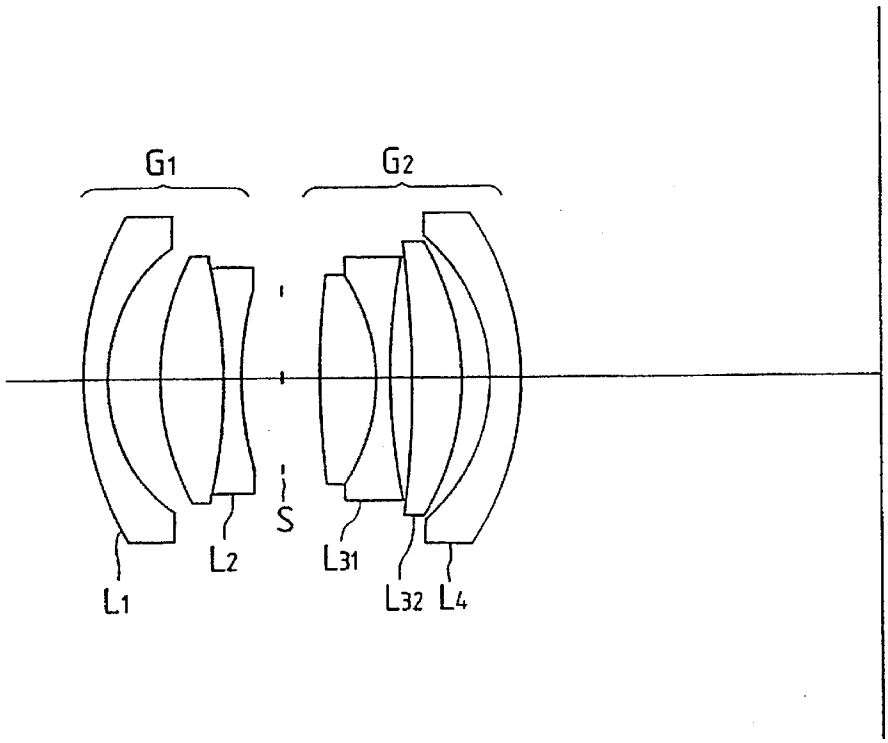
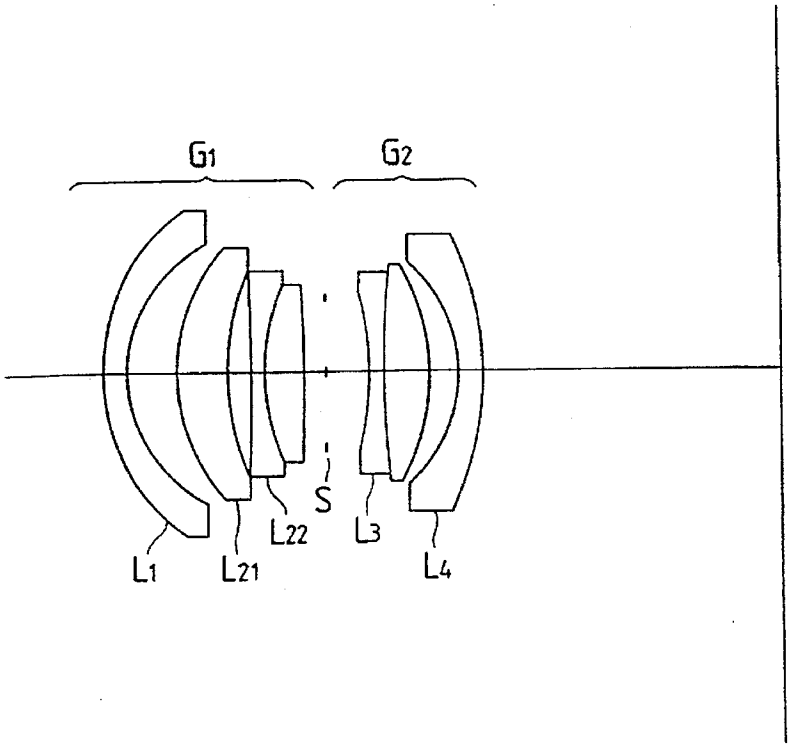


FIG. 11



COMPACT WIDE-ANGLE OBJECTIVE LENS

This is a continuation of application Ser. No. 08/173,084 filed Dec. 27, 1993 (U.S. Pat. No. 5,528,428), which is a continuation-in-part of application Ser. No. 08/080,971 filed Jun. 24, 1993 (abandoned), which is a continuation of application Ser. No. 07/973,614 filed Nov. 9,1992 (abandoned).

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to a wide-angle objective lens for cameras, and particularly to a compact, large aperture, wide-angle objective lens suitable for use in a 35 mm format lens shutter camera or a 35 mm format camera with a range finder.

2. Related Background Art

Biogon type, abiogon type, etc. are known as symmetrical type wide-angle lenses having a negative, positive, negative refractive power distribution. The biogon type wide-angle lens can cover a wide angle of view and can make distortion small. Also, its refractive power distribution is a negative, positive, negative refractive power distribution and therefore, as compared with a symmetrical type wide-angle lens of a positive, negative, positive refractive power distribution such as a topogon type wide-angle lens, the biogon type wide-angle lens has an advantage that the quantity of marginal light is great and moreover the diameters of fore and rear lenses can be made small.

Various wide-angle lenses of negative, positive, negative construction are known as the developed types of the biogon type wide-angle lens. They are known, for example, from Japanese Utility Model Publication No. 43-30782, U.S. Pat. No. 3,829,198, U.S. Pat. No. 4,211,472, Japanese Laid-Open Patent Application No. 56-140311, etc.

Examples in which the F-number is made small are shown in Japanese Utility Model Publication No. 43-30782 and U.S. Pat. No. 4,211,472. Examples which comprise a small number of lens components are shown in U.S. Pat. No. 3,829,198 and Japanese Laid-Open Patent Application No. 56-140311.

However, the biogon type wide-angle lens generally suffers from the disadvantages that the total thickness of the lens system (the thickness from that surface of the lens which is most adjacent (nearest) to the object side to that surface of the lens which is most adjacent to the image side) is great and that the F-number is large.

In the lens systems shown in U.S. Pat. No. 3,829,198 and Japanese Laid-Open Patent Application No. 56-140311, the number of lens components is small but the correction of spherical aberration is deficient and therefore, the F-number cannot provide a large aperture. They also have suffered from the disadvantages that the total thickness of the lens system is very great and that the spacing between the front unit and the rear unit of the lens system in which a diaphragm is placed is too narrow and therefore great limitations must be imposed upon the structure of an aperture stop, a shutter unit, a lens barrel, etc.

In the lens system shown in Japanese Utility Model Publication No. 43-30782, the total thickness of the lens system is very great. Moreover the diameters of the fore and rear lenses are great. This is against the desire to make the lens system compact. In the lens system shown in U.S. Pat. No. 4,211,472, the F-number provides a large aperture but the total thickness of the lens system is great, and this is against the desire to make the lens compact. Also, the shape of coma is bad and therefore, if the lens system is left in its original condition, it is necessary to apply a limitation to the light beam and the quantity of marginal light becomes very small, and this has not been preferable.

Further, in the lens system of Japanese Laid-Open Pat. No. Application No. 54-70826, the symmetry of the refractive power distributions on both sides of a stop is destroyed, the air space between a negative lens component disposed on the object side and a positive lens component and the air space between the positive lens component and a negative lens component disposed on the image side are both widened and, a wide-angle of view and a large aperture can be obtained. However, this lens system has the disadvantages that the great air spaces result in a great total thickness of the lens system and that the height of a ray of light passing through the lens component remote from the stop becomes far from the optical axis and therefore the effective diameter of each lens becomes large.

Further, Gaussian type, Topogon type, etc. are known as symmetrical type lenses having positive, negative, positive refractive power distribution.

The positive, negative, positive symmetrical type lens is advantageous for large aperture, but cannot cover a wide-angle of view, and conversely, the aforedescribed negative, positive, negative symmetrical lens can cover a wide-angle of view, but has the disadvantage for large aperture.

In the positive, negative, positive symmetrical type lens, the off-axis light beam passing through the lens component remote from the stop passes a location remote from the optical axis and therefore, when an attempt is made to achieve a wide-angle, the effective diameters of the front and rear lenses become large, and this results in the bulkiness of the optical system. Accordingly, when an attempt is made to achieve a wide-angle, a negative, positive, negative symmetrical type lens is desirable.

Thus, it has been difficult to provide an optical system which satisfies the condition that a wide-angle can be achieved by a symmetrical type lens and the optical system is compact with a large aperture.

The positive, negative, positive symmetrical type lens and the negative, positive, negative symmetrical type lens are generally of a construction advantageous in the correction of distortion and chromatic aberration. When in such symmetrical type lenses, the whole lens system is axially moved to effect focusing (so-called whole axial movement system), the fluctuation of off-axis aberration can be suppressed to a certain degree.

However, where the whole axial movement system is used in the optical system as disclosed in Japanese Laid-Open Pat. No. Application No. 54-70826 wherein the symmetry of the refractive power arrangement of the negative, positive, negative symmetrical type lens is greatly destroyed in order to make the optical system bright, there has been a problem that the fluctuation of off-axis aberration becomes great.

SUMMARY OF THE INVENTION

Accordingly, it is an object of the present invention to solve the above-noted problems peculiar to the prior art and to provide a symmetrical type wide-angle lens which realizes the small total thickness and great aperture of the lens system and which is compact and bright as well as small in distortion.

To achieve the above object, a wide-angle objective lens according to the present invention comprises, in succession

from the object side, a first lens component comprising a negative meniscus single lens having its convex surface facing the object side, a meniscus-shaped second lens component having its convex surface facing the object side and having positive refractive power, a stop, a third lens component comprising a cemented meniscus lens comprising a positive lens and a negative lens cemented together and having its convex surface facing the object side and having positive refractive power, a fourth lens component comprising a positive meniscus single lens having its concave surface facing the object side, and a fifth lens component comprising a negative meniscus single lens having its concave surface facing the object side, and is constructed into a negative, positive, negative refractive power arrangement as a whole, and when the focal length of said first lens component is f_1 and the focal length of said fifth lens component is f_5 and the radius of curvature of that surface of said third lens component which is most adjacent to the image side is r_{32} and the radius of curvature of that surface of said fourth lens component which is most adjacent to the object side is r_{41}, said wide-angle objective lens is designed to satisfy at least one of the following conditions:

$$0.02 \leqq |t_1/f_1| \leqq 0.1$$

$$0.01 \leqq |t_4/f_5| \leqq 0.08$$

$$-0.85 \leqq (r_{32}+r_{41})/(r_{32}-r_{41}) < 0.90,$$

where

t_1: the air space on the optical axis from that surface of the first lens component which is most adjacent to the image side to that surface of the second lens component which is most adjacent to the object side,

t_4: the air space on the optical axis from that surface of the fourth lens component which is most adjacent to the image side to that surface of the fifth lens component which is most adjacent to the object side.

By constructing the objective lens as described above, it becomes possible to correct, in particular, curvature of image field, astigmatism and coma, and a wide-angle lens which is compact, large aperture and high in performance can be realized.

It is a further object of the present invention to provide a wide-angle lens which suffers little from the fluctuation of off-axis aberration caused by focusing and which is compact with a large aperture and covers a wide-angle of view.

To achieve the above object, the present invention has a stop, and a first lens unit and a second lens unit that are disposed on the object side of the stop and on the image side of the stop, respectively. The first lens unit and the second lens unit are designed such that, during focusing, the first and second lens units are moved on the optical axis toward the object side and the amounts of movement of the lens units on the optical axis differ from each other.

Other objects, features and effects of the present invention will become fully apparent from the following detailed description of the invention taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** shows the lens construction of a first embodiment of the present invention.

FIG. **2** shows the lens construction of a second embodiment of the present invention.

FIG. **3** shows the lens construction of a third embodiment of the present invention.

FIG. **4** shows the lens construction of a fourth embodiment of the present invention.

FIG. **5** shows the lens construction of a fifth embodiment of the present invention.

FIG. **6** shows the lens construction of a sixth embodiment of the present invention.

FIG. **7** shows the lens construction of a seventh embodiment of the present invention.

FIG. **8** shows the lens construction of an eighth embodiment of the present invention.

FIGS. **9**A and **9**B are schematic views schematically showing the refractive power arrangements in ninth to thirteenth embodiments of the present invention and in which objects are at infinity and a near distance, respectively.

FIG. **10** shows the lens construction of the ninth to twelfth embodiments of the present invention.

FIG. **11** shows the lens construction of the thirteenth embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Some embodiments of the present invention will hereinafter be described in detail with reference to the accompanying drawings.

FIGS. **1** to **8** show the lens constructions of first to eighth embodiments, respectively, of the present invention. The wide-angle lenses according to the present invention, as shown in FIGS. **1** to **8**, comprise, in succession from the object side, a first lens component **L1** comprising a negative meniscus single lens having its convex surface facing the object side, a meniscus-shaped second lens component **L2** having its convex surface facing the object side and having positive refractive power, a third lens component **L3** comprising a cemented meniscus lens comprising a positive lens and a negative lens cemented together and having its convex surface facing the object side and having positive refractive power, a fourth lens component **L4** comprising a positive meniscus single lens having its concave surface facing the object side, a fifth lens component **L5** comprising a negative meniscus single lens having its concave surface facing the object side, and a stop between the second lens component **L2** and the third lens component **L3**, is constructed into a negative, positive, negative refractive power arrangement as a whole, and is designed to satisfy at least one of the following conditions:

$$0.02 \leqq |t_1/f_1| \leqq 0.1 \quad (1)$$

$$0.01 \leqq |t_4/f_5| \leqq 0.08 \quad (2)$$

$$-0.85 \leqq (r_{32}+r_{41})/(r_{32}-r_{41}) \leqq 0.90 \quad (3)$$

where

t_1: the air space on the optical axis from that surface of the first lens component **L1** which is most adjacent to the image side to that surface of the second lens component **L2** which is most adjacent to the object side,

t_4: the air space on the optical axis from that surface of the fourth lens component **L4** which is most adjacent to the image side to that surface of the fifth lens component **L5** which is most adjacent to the object side,

f_1: the focal length of the first lens component **L1**,

f_5: the focal length of the fifth lens component **L5**,

r_{32}: the radius of curvature of that surface of the third lens component **L3** which is most adjacent to the image side,

r_{41}: the radius of curvature of that surface of the fourth lens component L4 which is most adjacent to the object side.

As described above, the lens construction of the present invention is comprised of the first lens component L1 and the fifth lens component L5 each having negative refractive power, and the second lens component L2, the third lens component L3 and the fourth lens component L4 each having positive refractive power, and is a negative, positive, negative refractive power arrangement as a whole.

The first lens component L1 and the fifth lens component L5 each are a negative meniscus lens having its concave surface facing the stop S to sufficiently correct curvature of image field and astigmatism. By the negative meniscus lenses being thus used, it becomes possible to make the angle of view greater and increase the quantity of marginal light.

In a lens having a great angle of view, the correction of astigmatism and curvature of image field is important and it is necessary that the Petzval sum be an appropriate value.

Generally, in case of a lens of a negative, positive, negative refractive power arrangement having symmetry with respect to the stop S, as the air space between a lens unit adjacent to the object side and a positive lens unit and between a negative lens unit adjacent to the image side and the positive lens unit become wider, the degree of freedom of aberration correction increases more, and the Patzval sum can be made into an appropriate value.

However, where these air spaces are made great, the Patzval sum can be made into an appropriate value and this is advantageous for aberration correction, but the diameters of the fore and rear lenses become large and this is not preferable. Conversely, where these air spaces are made small, the Patzval sum increases to the positive and the correction of negative astigmastism and curvature of image field becomes difficult. So, where the refractive power of the first lens component L1 and of the fifth lens component L5 is made great to alleviate the Patzval sum, it will adversely affect coma, and this is not preferable.

The Patzval sum which is the cause of these problems can be improved to a certain degree by setting the refractive indices of the positive lens and the negative lens to appropriate values.

According to the present invention, in the symmetrical type wide-angle lens as disclosed in Japanese Utility Model Publication No. 43-30782, it becomes possible to divide the cemented positive lens disposed rearwardly of the stop into two lens components L3 and L4, effect the correction of spherical aberration by that surface r_{32} of the third lens component L3 which is most adjacent to the image side and that surface r_{41} of the fourth lens component L4 which is most adjacent to the object side, and make the F-number small. Further, since the cemented positive lens is divided into two lens components, the degree of freedom of aberration correction increases and it is possible to correct curvature of image field and astigmatism better.

The aforementioned conditional expressions of the present invention will hereinafter be described in detail.

Conditional expressions (1) and (2) are conditions regarding the correction of astigmatism and curvature of image field and compactness.

If the lower limit of conditional expression (1) is exceeded, the following two cases ① and ② are conceivable.

① A case where the air space t_1 between the first lens component L1 and the second lens component L2 is small; and

② A case where the focal length f_1 of the first lens component L1 is great.

In case ①, positive distortion increases and the correction of spherical aberration becomes impossible, and the F-number cannot be made small. In case ②, the Patzval sum increases to the positive and therefore, the correction of negative astigmastism and curvature of image field becomes impossible.

On the other hand, if the upper limit of conditional expression (1) is exceeded, the following two cases ③ and ④ are conceivable.

③ A case where the air space t_1 between the first lens component L1 and the second lens component L2 is great; and

④ A case where the focal length f_1 of the first lens component L1 is small.

In case ③, there is an advantage in aberration correction, but the diameter of the fore lens and the total thickness of the lens system become great and this is against the desire for compactness, and thus is not preferable. In case ④, the Patzval sum decreases, but the coma under the principal ray increases to the negative in a portion which is great in the angle of view, and this is not preferable.

If the lower limit of conditional expression (2) is exceeded, the following two cases ⑤ and ⑥ are conceivable.

⑤ A case where the air space t_4 between the fourth lens component L4 and the fifth lens component L5 is small; and

⑥ A case where the focal length f_5 of the fifth lens component L5 is great.

In case ⑤, the correction of spherical aberration becomes impossible and the F-number cannot be made small. In case ⑥, the Patzval sum increases to the positive and the correction of negative astigmatism and curvature of image field becomes impossible, and a good image plane cannot be obtained.

On the other hand, if the upper limit of conditional expression (2) is exceeded, the following two cases ⑦ and ⑧ are conceivable.

⑦ A case where the air space t_4 between the fourth lens component L4 and the fifth lens component L5 is great; and

⑧ A case where the focal length f_5 of the fifth lens component L5 is small.

In case ⑦ the degree of freedom with which the Patzval sum is made into an appropriate value increases and this is advantageous in correcting astigmatism and curvature of image field, but the total thickness of the lens system becomes great and this is against the desire for compactness, and thus is not preferable. In case ⑧, the correction of spherical aberration becomes impossible and further, the fluctuation of the coma above the principal ray by the angle of view becomes great and this is not preferable.

Conditional expression (3) is a condition regarding the shape of the air space between the third lens component L3 and the fourth lens component L4, and is concerned with coma, curvature of image field and astigmatism.

If the upper limit of conditional expression (3) is exceeded, the Patzval sum will increase to the positive and cannot be made into an appropriate value and the correction of astigmatism and curvature of image field will become difficult, and a good image plane cannot be obtained. Also, the shape of coma will exhibit a sharp tendency toward inner coma, and this is not preferable.

If conversely, the lower limit of conditional expression (3) is exceeded, a good Patzval sum will be obtained, but aberrations of high orders will occur in a portion which is great in the angle of view and astigmatism will become

great. Also, the shape of coma will exhibit a great tendency toward outer coma, and this is not preferable.

It is desirable that in order to correct spherical aberration, curvature of image field and astigmatism and to form the lens compactly, the wide-angle lens according to the present invention be designed to further satisfy the following conditions:

$$0.20 \leqq |r_{42}/f| \leqq 0.55 \quad (4)$$

$$0.40 \leqq D/f \leqq 1.00, \quad (5)$$

where

f: the focal length of the entire lens system,

r_{42}: the radius of curvature of that surface of the fourth lens component **L4** which is most adjacent to the image side,

D: total thickness of the lens system.

Conditional expression (4) is concerned with the correction of spherical aberration.

If the upper limit value of conditional expression (4) is exceeded, it will become impossible to correct positive spherical aberration, and this is not preferable.

If, conversely, the lower limit value of conditional expression (4) is exceeded, it will become impossible to correct negative spherical aberration, and this is not preferable.

Now, the wide-angle lens of the present invention is characterized in that, as compared with popular symmetrical type wide-angle lenses, its back focal length differs little, but the total thickness of the lens is very small. This makes it possible to make the lens barrel into the sunk barrel type to thereby contain it compactly when the lens of the present invention is used in a compact lens shutter camera or a camera with a range finder, and it is more realistic and effective to make the total thickness of the lens system small than to shorten the back focal length.

So, conditional expression (5) sets a condition for prescribing the total thickness of the lens system, i.e., the length from that surface of the first lens component **L1** which is most adjacent to the object side to that surface of the fifth lens component **L5** which is not adjacent to the image side.

If the lower limit value of conditional expression (5) is exceeded, the difference in height between the on-axis ray and the off-axis ray will become small in the lens far from the stop S and the degree of freedom will be deficient and thus, it will become impossible to correct the on-axis aberration and the off-axis aberration independently of each other.

If conversely, the upper limit value of conditional expression (5) is exceeded, the Patzval sum can be made into an appropriate value and a better image plane performance will be obtained, but this is against the desire for compactness and is therefore against an object of the present invention.

Also, it is desirable that in order to correct curvature of image field and astigmatism better, the first lens component **L1**, the third lens component **L3** and the fifth lens component **L5** be designed to satisfy the following conditions:

$$0.04 < N_{31} - N_{32} < 0.25 \quad (6)$$

$$N_1 < 1.70 \quad (7)$$

$$N_5 < 1.70, \quad (8)$$

where

N_{31}: the refractive index of the positive lens **L3** disposed on the object side in the third lens component **L3** for d-line,

N_{32}: the refractive index of the negative lens disposed on the image side in the third lens component **L3** for d-line,

N_1: the refractive index of the first lens component **L1** for d-line,

N_5: the refractive index of the fifth lens component **L5** for d-line.

Conditional expression (6) represents the difference between the refractive indices of the position lens disposed on the object side in the third lens component **L3** and the negative lens disposed on the image side in the third lens component **L3** for d-line.

If the lower limit value of conditional expression (6) is exceeded, the Patzval sum will increase to the positive and therefore, it will become impossible to correct negative curvature of image field and astigmatism.

If conversely, the upper limit value of conditional expression (6) is exceeded, a better Patzval sum will be obtained, but aberrations of high orders will occur in a portion which is great in the angle of view and astigmatic difference will be created, and this is not preferable.

Conditional expressions (7) and (8) are concerned with curvature of image field and astigmatism.

If the upper limit values of these conditional expressions are exceeded, the Patzval sum will increase to the positive and therefore, the correction of curvature of image field and negative astigmatism will become impossible and a good image plane will not be obtained.

Another embodiment of the present invention has a first lens unit and a second lens unit disposed with a stop interposed therebetween, on the object side of the stop and on the image side of the stop, respectively, said first lens unit comprising, in succession from the object side, a first lens component of negative refractive power and a second lens component of positive refractive power, said second lens unit comprising a third lens component of positive refractive power and a fourth lens component of negative refractive power, said first lens unit and said second lens unit being designed such that during focusing, they are moved on the optical axis toward the object side and the amounts of movement of said lens units on the optical axis differ from each other.

The present invention as a whole is of a negative, positive, negative refractive power arrangement. The first lens component of negative refractive power in the first lens unit disposed at a location remote from the stop and the fourth lens component of negative refractive power in the second lens unit are negative meniscus lenses having their concave surfaces facing the stop in order to sufficiently correct curvature of image field and astigmatism. The use of the negative meniscus lenses leads to the achievement of a wider angle and the provision of the action of increasing the quantity of marginal light.

The present invention makes the first lens unit and the second lens unit take their share of the correction of on-axis aberration and the correction of off-axis aberration. Specifically, there are the following two kinds of sharing:

(a) To achieve a wide-angle and yet make the refractive power of the first lens unit small in the positive, thereby correcting the off-axis aberration well with the first lens unit, and make the refractive power of the second lens unit great in the positive and divide the positive lens component in the second lens unit into two lens components, thereby correcting the on-axis aberration well with the second lens unit and making the optical system bright.

(b) To achieve a wide-angle and yet make the refractive power of the second lens unit small in the positive,

thereby correcting the off-axis aberration well with the second lens unit, and make the refractive power of the first lens unit great in the positive and divide the positive lens component in the first lens unit into two lens components, thereby correcting the on-axis aberration well with the first lens unit and making the optical system bright.

In the present invention, as described in items (a) and (b) above, the lens units forward and rearward of the stop S are made to take their share of the correction of the on-axis aberration and the correction of the off-axis correction to thereby enable the optical system to be bright, but correspondingly thereto, the symmetry of the refractive power on both sides of the stop is destroyed. Therefore, when focusing is effected by the use of the whole axial movement system, it becomes impossible to suppress the fluctuation of the off-axis aberration well.

So, the fluctuation of the off-axis aberration, when focusing is effected by the use of the whole axial movement system, will hereinafter be considered with respect to the following two types of optical systems in which the refractive power distribution on both sides of the stop is asymmetrical,

(I) Petrofocus Type; and

(II) Telephoto Type.

In the case of (I) above, the refractive power arrangement on both sides of the stop is negative and positive and the pupil magnification exceeds 1. Therefore, when the object position moves from the infinity state to a short distance, positive astigmatism occurs.

In the case of (II) above, the refractive power arrangement on both sides of the stop is positive and negative and the pupil magnification is smaller than 1. Therefore, when the object position moves from the infinity state to a short distance, negative astigmatism occurs.

In the present embodiment, when focusing by the whole axial movement is effected, the construction of item (a) above corresponds to (I) above, and when the object position moves from the infinity state to a short distance, positive astigmatism occurs. According to the definition of the third-order aberration coefficient in *Lens Designing Method* by Yoshiya Matsui, the third-order aberration coefficient III of the second lens unit exhibits the positive (+). Therefore, if the amount of axial movement of the second lens unit is made small relative to the amount of axial movement of the first lens unit, positive astigmatism could be suppressed well and the fluctuation of off-axis aberration caused during focusing could be suppressed.

Conversely, the construction of item (b) above corresponds to (II) above, and when the object position moves from the infinity state to a short distance, negative astigmatism occurs. At this time, the third-order aberration coefficient III of the second lens unit exhibits the negative (−). Therefore, if the amount of axial movement of the second lens unit is made great relative to the amount of axial movement of the first lens unit, the fluctuation of off-axis aberration caused during focusing could be alleviated.

As described above, the present invention effects focusing by the use of the so-called floating system that makes the amounts of axial movement of the first lens unit and the second lens unit different from each other during focusing, thereby enabling the fluctuation of off-axis aberration caused by focusing to be suppressed well.

In the present invention, it is desirable that with the above-described construction, the following conditional expression (9) or (10) be satisfied.

$$0<\Delta\cdot\phi/(\phi_a-\phi_b)<0.2 \quad (9)$$

$$0.3<|\phi 1/\phi|<0.95 \quad (10)$$

where

ϕ_a: the refractive power of the first lens unit,

ϕ_b: the refractive power of the second lens unit,

ϕ: the refractive power of the whole lens system,

Δ: an amount defined by the following equation:

$$\Delta=(\delta 1-\delta 2)/67\ 2$$

when the amount of movement of the first lens unit during focusing is $\delta 1$ and the amount of movement of the second lens unit is $\delta 2$,

$\phi 1$:the refractive power of the first lens component.

Conditional expression (9) is a condition for suppressing the fluctuation of aberration in short distance focusing very well.

If the upper limit value of conditional expression (9) is exceeded, the correction of the fluctuation of off-axis aberration caused by focusing will become excessive. If conversely, the lower limit value of conditional expression (9) is exceeded, the correction of the fluctuation of off-axis aberration caused by focusing will become deficient. Accordingly, it is preferable that the range of this condition be satisfied.

Conditional expression (10) is a condition for achieving the balance of the shortening of the full length and the effective diameter of the front lens.

If the upper limit value of conditional expression (10) is exceeded, the refractive power of the first lens component will become great to the negative and therefore, the diverging action will become strong and the back focal length will become too great. If conversely, the lower limit value of conditional expression (10) is exceeded, the refractive power of the first lens component will become small to the negative and the height of the ray of off-axis light passing through the first lens component will become far from the optical axis, and if an attempt is made to obtain the amount of marginal light, the effective diameter of the front lens will become great, which will lead to the bulkiness of the optical system, and this is not preferable.

The lens constructions of the embodiments of the present invention will hereinafter be described in greater detail.

All of Embodiments 1 to 7, as shown in FIGS. **1** to **7**, are lens systems of two groups G1 and G2 constituting component construction comprising, in succession from the object side, a first lens component L1 which is a negative meniscus lens having its convex surface facing the object side, a second lens component L2 which is a cemented positive meniscus lens comprising a biconvex lens and a biconcave lens, a stop S, a third lens component L3 which is a cemented positive meniscus lens comprised of a biconvex lens and a biconcave lens, a fourth lens component L4 which is a positive meniscus lens having its concave surface facing the object side, and a fifth lens component L5 which is a negative meniscus lens having its concave surface facing the object side.

Also, Embodiment 8, as shown in FIG. **8**, is a lens of five-unit six-component construction comprising, in succession from the object side, a first lens component L1 which is a negative meniscus lens having its convex surface facing the object side, a second lens component L2 which is a positive meniscus lens having its convex surface facing the object side, a stop S, a third lens component L3 which is a cemented positive meniscus lens comprised of a biconvex lens and a biconcave lens, a fourth lens component L4 which is a positive meniscus lens having its concave surface facing

the object side, and a fifth lens component L5 which is a negative meniscus lens having its concave surface facing the object side.

The numerical data of the respective embodiments of the present invention will be shown in Tables 1 to 8 below. In these tables, f represents the focal length, F_{NO} represents F-number and 2_{ω} represents the angle of view. The numbers at the left end represent the order from the object side, r represents the radius of curvature of each lens surface, d represents the spacing between adjacent lens surfaces, and the refractive index n and Abbe number ν are values for d-line (λ=587.6 nm).

TABLE 1

(Numerical Data of Embodiment 1)
f = 28.9
F_{NO} = 2.88
2ω = 73.8°

	r	d	n	ν
1	17.100	1.50	1.54739	53.5
2	9.282	2.70		
3	12.910	3.90	1.84042	43.3
4	−60.183	1.10	1.62588	35.7
5	14.650	5.00		
6	50.105	3.30	1.79668	45.4
7	−10.659	1.00	1.67270	32.2
8	43.956	1.40		
9	−36.842	3.00	1.79668	45.4
10	−13.025	1.50		
11	−9.805	1.50	1.58144	40.8
12	−14.846	20.83		

The condition-corresponding values of the above data are shown below.

(1) $|t_1/f_1|$=0.068
(2) $|t_4/f_5|$=0.027
(3) $(r_{32}+r_{41})/(r_{32}-r_{41})$=0.088
(4) $|r_{42}/f|$=0.451
(5) D/f=0.897
(6) $N_{31}-N_{32}$=0.123
(7) N_1=1.547
(8) N_5=1.581

TABLE 2

(Numerical Data of Embodiment 2)
f = 28.9
F_{NO} = 2.87
2ω = 73.0°

	r	d	n	ν
1	12.475	1.50	1.57550	41.6
2	8.882	3.10		
3	12.551	4.40	1.84042	43.3
4	−1631.732	1.00	1.64831	33.8
5	12.856	4.00		
6	43.791	2.50	1.79668	45.4
7	−13.768	1.00	1.67270	32.2
8	77.172	1.10		
9	−25.300	2.70	1.79668	45.4
10	−10.647	1.00		
11	−8.993	1.50	1.58144	40.8
12	−17.685	20.51		

The condition-corresponding values of the above data are shown below.

(1) $|t_1/f_1|$=0.051
(2) $|t_4/f_5|$=0.024
(3) $(r_{32}+r_{41})/(r_{32}-r_{41})$=0.506
(4) $|r_{42}/f|$=0.369
(5) D/f=0.824
(6) $N_{31}-N_{32}$=0.056
(7) N_1=1.532
(8) N_5=1.581

TABLE 3

(Numerical Data of Embodiment 3)
f = 28.9
F_{NO} = 2.87
2ω = 74.0°

	r	d	n	ν
1	12.422	1.50	1.53172	49.1
2	8.919	3.37		
3	12.829	3.87	1.84042	43.3
4	−1726.972	1.00	1.64831	33.8
5	12.785	4.00		
6	51.931	2.50	1.81600	46.8
7	−17.040	1.00	1.61750	30.8
8	54.857	1.31		
9	−21.730	2.95	1.79668	45.4
10	−10.479	0.80		
11	−8.874	1.50	1.59507	35.5
12	−13.780	20.96		

The condition-corresponding values of the above data are shown below.

(1) $|t_1/f_1|$=0.048
(2) $|t_4/f_5|$=0.017
(3) $(r_{32}+r_{41})/(r_{32}-r_{41})$=0.433
(4) $|r_{42}/f|$=0.363
(5) D/f=0.824
(6) $N_{31}-N_{32}$=0.199
(7) N_1=1.532
(8) N_5=1.595

TABLE 4

(Numerical Data of Embodiment 4)
f = 28.9
F_{NO} = 2.87
2ω = 73.4°

	r	d	n	ν
1	18.080	1.50	1.56384	60.9
2	9.401	3.26		
3	13.713	4.18	1.80218	44.7
4	−28.737	1.10	1.61293	37.0
5	17.068	5.00		
6	48.775	3.14	1.80218	44.7
7	−11.832	0.00	1.68893	31.1
8	38.220	1.22		
9	−40.592	3.30	1.79668	45.4
10	−12.910	1.60		
11	−9.672	2.00	1.58144	40.8
12	—13.780	20.96		

The condition-corresponding values of the above data are shown below.

(1) $|t_1/f_1|$=0.088
(2) $|t_4/f_5|$=0.028
(3) $(r_{32}+r_{41})/(r_{32}-r_{41})$=−0.030
(4) $|r_{42}/f|$=0.447
(5) D/f=0.945

(6) $N_{31}-N_{32}=0.113$

(7) $N_1=1.564$

(8) $N_5=1.582$

TABLE 5

(Numerical Data of Embodiment 5)
f = 35.0
F_{NO} = 2.80
2ω = 62.4°

	r	d	n	ν
1	13.804	1.40	1.67025	57.6
2	9.560	2.50		
3	11.800	4.20	1.79668	43.3
4	−1901.932	1.20	1.68893	31.2
5	12.250	5.75		
6	23.817	3.30	1.72000	50.3
7	−12.861	1.20	1.62588	35.6
8	23.478	1.25		
9	−92.286	3.20	1.79631	40.9
10	−13.150	1.00		
11	−10.885	1.40	1.67003	47.1
12	−26.314	22.10		

The condition-corresponding values of the above data are shown below.

(1) $|t_1/f_1|=0.047$

(2) $|t_4/f_5|=0.035$

(3) $(r_{32}+r_{41})/(r_{32}-r_{41})=0.595$

(4) $|r_{42}/f|=0.376$

(5) D/f=0.747

(6) $N_{31}-N_{32}=0.094$

(7) $N_1=1.670$

(8) $N_5=1.670$

TABLE 6

(Numerical Data of Embodiment 6)
f = 35.0
F_{NO} = 2.80
2ω = 62.4°

	r	d	n	ν
1	15.140	1.40	1.51680	64.1
2	9.852	2.60		
3	13.541	4.20	1.79668	45.4
4	−1960.755	1.20	1.67270	32.1
5	16.374	5.75		
6	38.906	4.20	1.79668	45.4
7	−9.900	1.20	1.67270	32.1
8	39.474	1.40		
9	−56.315	3.00	1.74950	35.2
10	−15.623	2.30		
11	−10.487	1.40	1.53172	49.1
12	−22.411	20.87		

The condition-corresponding values of the above data are shown below.

(1) $|t_1/f_1|=0.043$

(2) $|t_4/f_5|=0.060$

(3) $(r_{32}+r_{41})/(r_{32-r41})=-0.176$

(4) $|r_{42}/f|=0.446$

(5) D/f=0.819

(6) $N_{31}-N_{32}=0.124$

(7) $N_1=1.517$

(8) $N_5=1.532$

TABLE 7

(Numerical Data of Embodiment 7)
f = 35.0
F_{NO} = 2.80
2ω = 62.6°

	r	d	n	ν
1	11.026	1.50	1.57501	41.6
2	8.859	3.28		
3	14.478	4.60	1.84042	43.3
4	−226.717	1.00	1.64831	33.8
5	13.585	4.00		
6	78.289	2.50	1.80411	46.4
7	−13.768	1.00	1.67270	32.2
8	100.000	1.15		
9	−20.464	2.95	1.79668	45.4
10	−10.474	0.80		
11	−9.468	1.50	1.58267	46.5
12	−16.567	25.07		

The condition-corresponding values of the above data are shown below.

(1) $|t_1/f_1|=0.031$

(2) $|t_4/f_5|=0.019$

(3) $(r_{32}+r_{41})/(r_{32}-r_{41})=0.660$

(4) $|r_{42}/f|=0.299$

(5) D/f=0.694

(6) $N_{31}-N_{32}=0.131$

(7) $N_1=1.575$

(8) $N_5=1.583$

TABLE 8

(Numerical Data of Embodiment 8)
f = 28.9
F_{NO} = 2.88
2ω = 73.8°

	r	d	n	ν
1	14.953	1.50	1.59507	35.5
2	8.621	2.94		
3	10.597	3.76	1.80411	46.4
4	17.712	5.00		
5	24.439	2.50	1.79668	45.4
6	−12.240	1.00	1.67270	32.2
7	25.235	1.10		
8	−49.274	2.90	1.79631	40.9
9	−11.514	1.00		
10	−8.160	1.50	1.58144	40.8
11	−21.421	19.32		

The condition-corresponding values of the above data are shown below.

(1) $|t_1/f_1|=0.078$

(2) $|t_4/f_5|=0.042$

(3) $(r_{32}+r_{41})/(r_{32-r41})=-0.323$

(4) $|r_{42}/f|=0.399$

(5) D/f=0.803

(6) $N_{31}-N_{32}=0.124$

(7) $N_1=1.595$

(8) $N_5=1.581$

By using popular aspherical lenses, it is of course possible to introduce an aspherical surface into the first lens component **L1** or the fifth lens component **L5** of the present invention to thereby correct astigmatism and curvature of

image field better and achieve a wide-angle, and to introduce an aspherical surface into the second lens component L2, the third lens component L3 or the fourth lens component L4 to thereby further correct spherical aberration and achieve a great relative aperture.

FIGS. 9A and 9B schematically show the refractive power arrangements of ninth to thirteenth embodiment of the present invention. FIG. 9A shows the refractive power arrangement when the object position is in the infinity state, and FIG. 9B shows the refractive power arrangement when the object position is in a short distance state. It is shown in FIGS. 9A and 9B that as the object position moves from the infinity to the short distance, the first lens unit G1 and the second lens unit G2 move toward the object side.

Each of the ninth to twelfth embodiments, as shown in FIG. 10, is of a construction which comprises, in succession from the object side, a first lens component L1 which is a negative meniscus lens having its convex surface facing the object side, a second lens component L2 which is a cemented lens of positive refractive power comprising a biconvex lens and a biconcave lens cemented together and having its convex surface facing the object side as a whole, a third lens component L3 comprising a cemented lens component of positive refractive power comprising a biconvex lens having its convex surface of sharper curvature facing the image side and a biconcave lens cemented thereto and having its convex surface facing the object side as a whole, a fourth lens component L4 which is a positive lens component having its concave surface facing the object side, and a fifth lens component L5 which is a negative meniscus lens having its convex surface facing the image side, a stop S being disposed between the second lens component L2 and the third lens component L3.

The numerical data of the ninth to twelfth embodiments of the present invention are given below. In the data Tables below, the numbers at the left end represents the order from the object side, r represents the radius of curvature of each lens surface, d represents the spacing between adjacent lens surface, and the refractive index n and Abbe number ν are values for d-line (λ=587.6 nm).

TABLE 9

Numerical Data of the Ninth Embodiment
f = 28.6
FNO = 2.88
2ω = 74.0°

	r	d	n	ν
1	17.9178	1.500	1.58913	61.2
2	9.1148	3.000		
3	14.8517	4.000	1.79668	45.4
4	−22.6769	1.300	1.60342	38.0
5	19.6186	2.000		
6	∞	(d6)	(stop)	
7	85.5391	3.000	1.79668	45.4
8	−12.4521	1.300	1.67270	32.2
9	44.1538	1.300		
10	−49.9974	2.500	1.74810	52.3
11	−13.6254	2.700		
12	−9.5518	2.000	1.64831	33.8
13	−13.0360	(Bf)		

Variations in the spacing when the photographing distance is infinity (∞) and a short distance (300 mm) are shown below.

TABLE 10

Photographing Distance	Infinity	300 mm
d6	3.000	2.651
Bf	21.891	25.382

The condition-corresponding values of the above data are shown below.

(1) $\Delta\cdot(\phi_a-\phi_b)/\phi=0.071$

(2) $|\phi 1/\phi|=0.851$

TABLE 11

Numerical Data of the Tenth Embodiment
f = 28.9
FNO = 2.88
2ω = 73.8°

	r	d	n	ν
1	17.8000	1.500	1.58913	61.2
2	9.3309	3.100		
3	13.9124	3.900	1.79668	45.4
4	−29.7570	1.100	1.60342	38.1
5	17.4563	(d5)		
6	∞	2.400	(stop)	
7	49.4089	3.600	1.79668	45.4
8	−10.5646	1.000	1.67270	32.2
9	35.7839	1.400		
10	−47.3829	3.300	1.79668	45.4
11	−13.1267	1.600		
12	−9.9212	2.000	1.60432	38.1
13	−15.6720	(Bf)		

Variations in the spacing when the photographing distance is infinity (∞) and a short distance (300 mm) are shown below.

TABLE 12

Photographing Distance	Infinity	300 mm
d5	2.600	2.369
Bf	21.940	24.832

The condition-corresponding values of the above data are shown below.

(1) $\Delta\cdot\phi/(\phi_a-\phi_b)=0.061$

(2) $|\phi 1/\phi|=0.811$

TABLE 13

Numerical Data of the Eleventh Embodiment
f = 28.9
FNO = 2.88
2ω = 73.8°

	r	d	n	ν
1	12.5065	1.500	1.53172	49.1
2	8.7834	3.450		
3	12.5521	3.950	1.84042	43.3
4	−1626.4800	1.000	1.64831	33.8
5	12.6942	(d5)		
6	∞	2.350	(stop)	
7	45.2763	2.500	1.80411	46.3
8	−13.7592	1.000	1.67270	32.2
9	56.7133	1.150		
10	−25.5838	2.950	1.79668	45.4

TABLE 13-continued

Numerical Data of the Eleventh Embodiment
f = 28.9
FNO = 2.88
2ω = 73.8°

	r	d	n	ν
11	−10.3313	0.800		
12	−8.8304	1.500	1.58144	40.8
13	−16.1578	(Bf)		

Variations in the spacing when the photographing distance is infinity (∞) and a short distance (300 mm) are shown below.

TABLE 14

Photographing Distance	Infinity	300 mm
d5	1.650	1.545
Bf	20.514	24.033

The condition-corresponding values of the above data are shown below.

(1) $\Delta\cdot\phi/(\phi_a-\phi_b)=0.022$

(2) $|\phi 1/\phi|=0.447$

TABLE 15

Numerical Data of the Twelfth Embodiment
f = 28.9
FNO = 2.88
2ω = 73.8°

	r	d	n	ν
1	17.1000	1.500	1.54739	53.6
2	9.2824	2.700		
3	12.9097	3.900	1.84042	43.3
4	−60.1829	1.100	1.62588	35.6
5	14.6504	(d5)		
6	∞	2.400	(stop)	
7	50.3000	3.300	1.79668	45.4
8	−10.6591	1.000	1.67270	32.2
9	43.9560	1.400		
10	−36.8415	3.000	1.79668	45.4
11	−13.0249	1.500		
12	−9.8051	1.500	1.58144	40.8
13	−14.8205	(Bf)		

Variations in the spacing when the photographing distance is infinity (∞) and a short distance (300 mm) are shown below.

TABLE 16

Photographing Distance	Infinity	300 mm
d5	2.600	2.427
Bf	20.830	25.727

The condition-corresponding values of the above data are shown below.

(1) $\Delta\cdot(\phi_a-\phi_b)/\phi=0.046$

(2) $|\phi 1/\phi|=0.726$

The thirteenth embodiment, as shown in FIG. **11**, is of a construction which comprises, in succession from the object side, a first lens component **L1** which is a negative meniscus lens having its convex surface facing the object side, a second lens component **L2** which is a positive meniscus lens having its convex surface of sharp curvature facing the object side, a third lens component **L3** which is and a positive lens component comprising a biconcave lens having its concave surface of sharper curvature facing the image side and a biconvex lens having its convex surface of sharper curvature facing the object side, said biconcave lens and said biconvex lens being cemented together, a fourth lens component **L4** of positive refractive power comprising a biconcave lens and a biconvex lens cemented together and having its convex surface facing the image side as a whole, and a fifth lens component **L5** which is a negative meniscus lens having its convex surface facing the image side, a stop S being disposed between the third lens component **L3** and the fourth lens component **L4**.

The numerical data of the thirteenth embodiment of the present invention are given below. In the data Table below, the numbers at the left end represents the order from the object side, r represents the radius of curvature of each lens surface, d represents the spacing between adjacent lens surfaces, and the refractive index n and Abbe number ν are values for d-line (λ=587.6 nm).

TABLE 17

Numerical Data of the Thirteenth Embodiment
f = 28.9
FNO = 2.88
2ω = 73.8°

	r	d	n	ν
1	11.8420	1.500	1.59507	36.6
2	8.4410	2.998		
3	10.9528	3.300	1.79668	27.8
4	15.7309	1.354		
5	−449.9259	1.000	1.67270	40.5
6	13.7678	2.500	1.80411	46.3
7	−117.2633	(d7)		
8	∞	2.650	(stop)	
9	−24.4051	1.000	1.64831	38.4
10	45.0605	2.973	1.84042	29.2
11	−12.1107	1.674		
12	−8.8483	1.500	1.59507	36.6
13	−18.9952	(Bf)		

Variations in the spacing when the photographing distance is infinity (∞) and a short distance (300 mm) are shown below.

TABLE 18

Photographing Distance	Infinity	300 mm
d7	1.350	1.492
Bf	18.460	21.287

The condition-corresponding values of the above data are shown below.

(1) $\Delta\cdot(\phi_a-\phi_b)/\phi=0.012$

(2) $|\phi 1/\phi|=0.489$

By using popular aspherical lenses in the ninth to thirteenth embodiments of the present invention, introducing an aspherical surface into the first lens component **L1** or the fifth lens component **L5**, it is possible to correct astigmatism and curvature of image field better and achieve a wider angle. By introducing an aspherical surface also into the second lens component **L2**, the third lens component **L3**, or the fourth lens component **L4**, it is of course possible to correct spherical aberration further and achieve a greater aperture.

According to the present invention, there can be achieved a wide-angle lens which is compact and high in performance

and as small as the order of F 2.8. The present invention can be used not only in 35 mm format cameras, but also in large format cameras. Further, when focusing is effected by general axial movement, the fluctuations of aberrations are very small and a good performance can be obtained.

What is claimed is:

1. A wide-angle objective lens system comprising, in the order from an object side:

a first negative lens component having a concave surface facing an image side;

a second lens component having positive refractive power and having a convex surface facing the object side;

a third lens component having a convex surface facing the object side;

a fourth lens component including a positive meniscus single lens having a concave surface facing the object side; and

a fifth lens component including a negative meniscus single lens having a concave surface facing the object side,

wherein said lens system satisfies the following condition:

$$0.40 \leqq D/f \leqq 1.00$$

where

f: the focal length of the entire lens system,

D: the total thickness of the lens system.

2. A wide-angle objective lens system according to claim **1**, wherein said lens system satisfies the following condition:

$$0.20 \leqq |r_{42}/f| \leqq 0.55$$

where

r_{42}: the radius of curvature of a surface of the fourth lens component which is nearest to the image side.

3. A wide-angle objective lens system comprising, in order from an object side:

a first negative lens component having a concave surface facing an image side;

a meniscus-shaped second lens component having positive refractive power and having a convex surface facing the object side;

a meniscus-shaped third lens component having a convex surface facing the object side;

a fourth lens component including a positive meniscus single lens having a concave surface facing the object side; and

a fifth lens component including a negative meniscus single lens having a concave surface facing the object side,

wherein said lens system satisfies the following condition:

$$0.40 \leqq D/f \leqq 1.00$$

where

f: the focal length of the entire lens system,

D: the total thickness of the lens system.

4. A wide-angle objective lens system according to claim **3**, wherein said lens system satisfies the following condition:

$$0.20 \leqq |r_{42}/f| \leqq 0.55$$

where

r_{42}: the radius of curvature of a surface of the fourth lens component which is nearest to the image side.

5. A wide-angle objective lens system comprising, in order from an object side:

a first lens unit including, in order from the object side, a first lens component having negative refractive power and a second lens component having positive refractive power;

a stop; and

a second lens unit having positive refractive power,

wherein said lens system consists of seven lenses and satisfies the following condition:

$$0.4 < D/f \leqq 1.0$$

where

f: the focal length of the entire lens system,

D: the total thickness of the lens system.

6. A wide-angle objective lens system according to claim **5**, wherein said lens system satisfies the following condition:

$$0.3 < |\phi 1/\phi| < +0.95$$

where

$\phi 1$: the refractive power of the first lens component,

ϕ: the refractive power of the whole lens system.

7. A wide-angle objective lens system according to claim **6**, wherein said lens system satisfies the following conditions:

$$0.02 \leqq |t1/f1| \leqq 0.1$$

$$N1 < 1.70$$

where

t1: an air space on an optical axis of the lens system between a surface of the first lens component which is nearest to an image side and a surface of the second lens component which is nearest to the object side,

f1: the focal length of the first lens component,

N1: the refractive index of the first lens component for d-line.

* * * * *

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United States Patent [19]

Suzuki

[11] Patent Number: 5,659,425

[45] Date of Patent: Aug. 19, 1997

[54] **IMMERSION MICROSCOPE OBJECTIVE**

[75] Inventor: **Toshinobu Suzuki**, Hachioji, Japan

[73] Assignee: **Olympus Optical Co., Ltd.**, Tokyo, Japan

[21] Appl. No.: **420,680**

[22] Filed: **Apr. 12, 1995**

[30] **Foreign Application Priority Data**

Apr. 13, 1994 [JP] Japan 6-074679

[51] **Int. Cl.**^{6} **G02B 21/02**

[52] **U.S. Cl.** **359/658**; 359/656

[58] **Field of Search** 359/658, 656

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Primary Examiner—Georgia Y. Epps
Assistant Examiner—Ricky Mack
Attorney, Agent, or Firm—Cushman, Darby & Cushman IP Group of Pillsbury Madison & Sutro LLP

[57] **ABSTRACT**

The invention provides an immersion microscope objective which has a magnification of about 100× and a high numerical aperture of the order of 1.65, and is particularly excellent in axial optical properties. The first lens unit G_1 consists of a cemented doublet of a plano-convex lens and a meniscus lens concave on the object side and a positive meniscus lens concave on the object side, three in all; the second lens unit G_2 consists of a cemented triplet of double-convex, double-concave and double-convex lenses; the third lens unit G_3 consists of a cemented doublet of double-convex and double-concave lenses; the fourth lens unit G_4 consists of a cemented doublet of a double-convex lens and a negative meniscus lens concave on the object side; the fifth lens unit G_5 consists of a cemented doublet of double-convex and double-concave lenses; and the sixth lens unit G_6 consists of a cemented doublet of double-concave and double-convex lenses. The lens located on the side proximate to the object has a refractive index of at least 1.6.

16 Claims, 4 Drawing Sheets

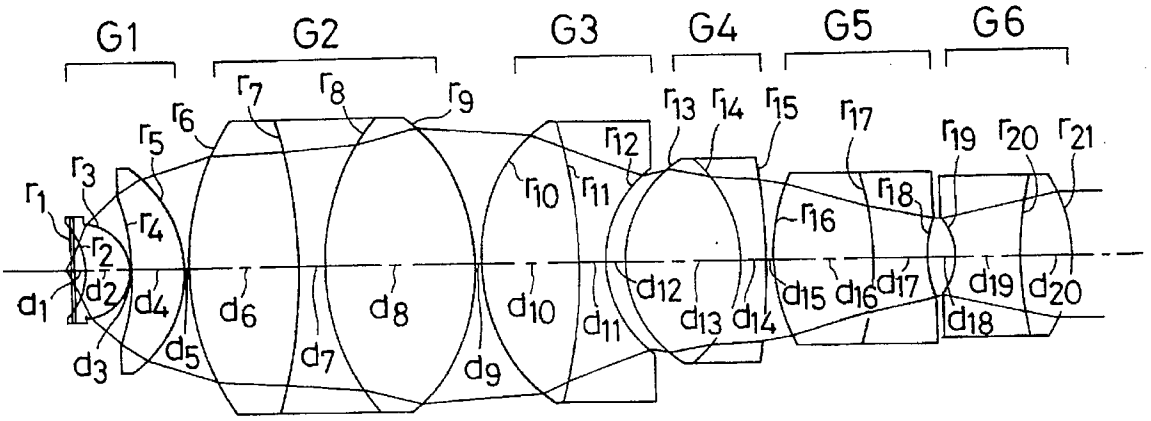

FIG. 1

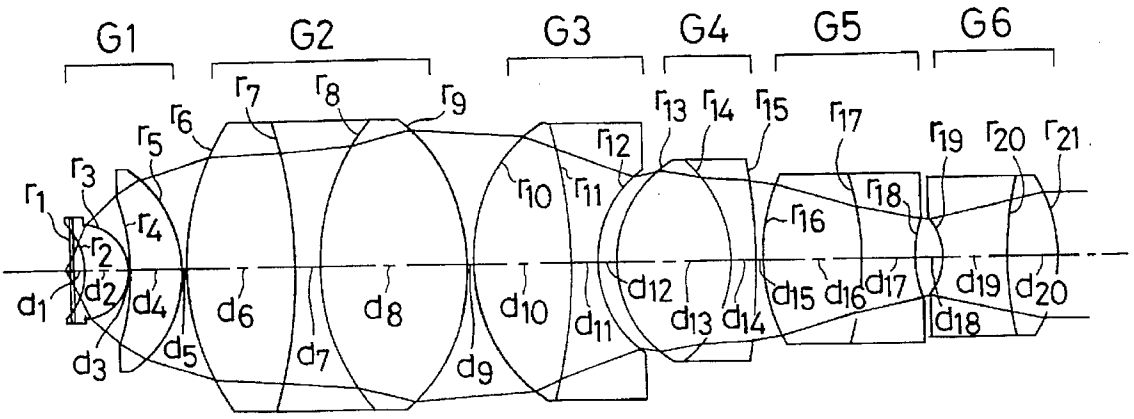
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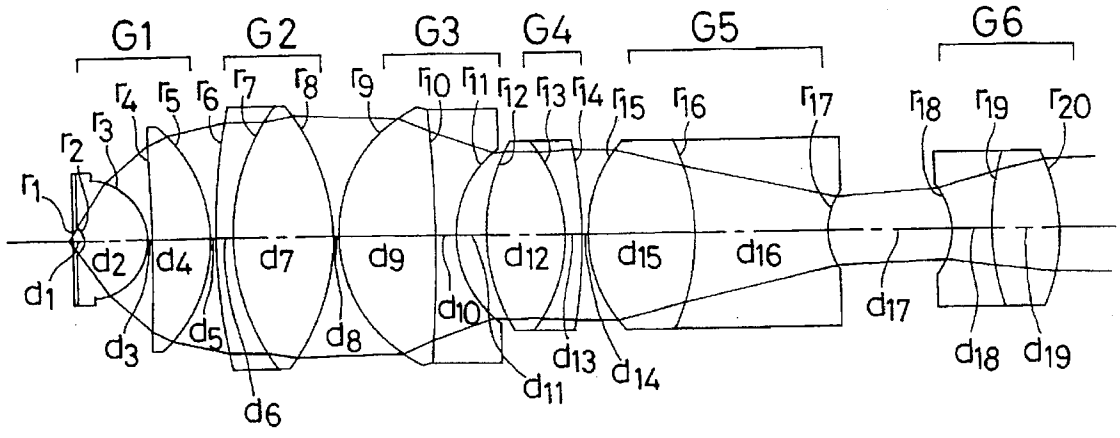
FIG. 2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r7
r8
r9
r10
r11
r12
r13
r14
r15
r16
r17
r18
r19
r20
d1
d2
d3
d4
d5
d6
d7
d8
d9
d10
d11
d12
d13
d14
d15
d16
d17
d18
d19

FIG. 3

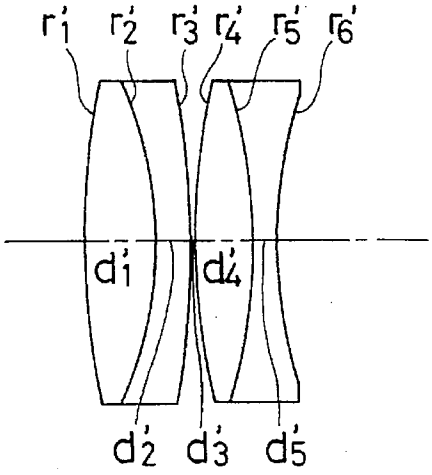


FIG. 4(a)

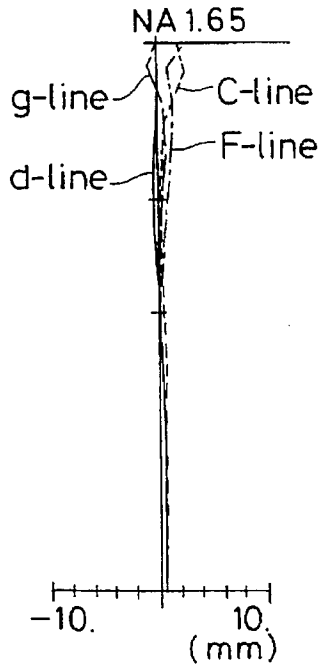


FIG. 4(b)

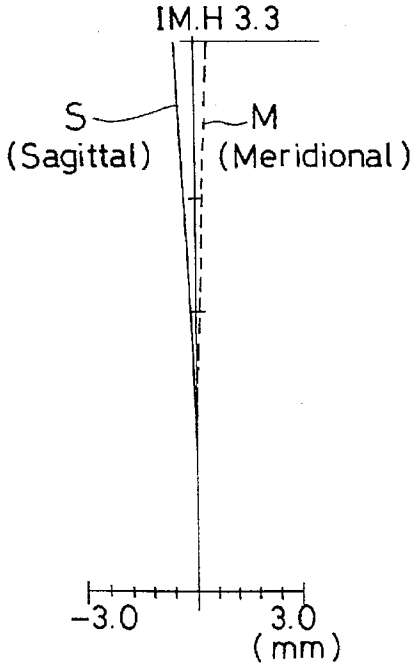


FIG. 4(c)

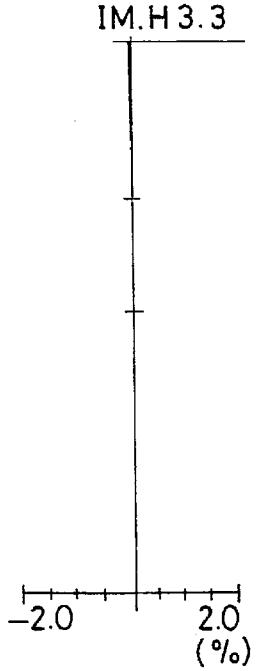


FIG. 5 (a)

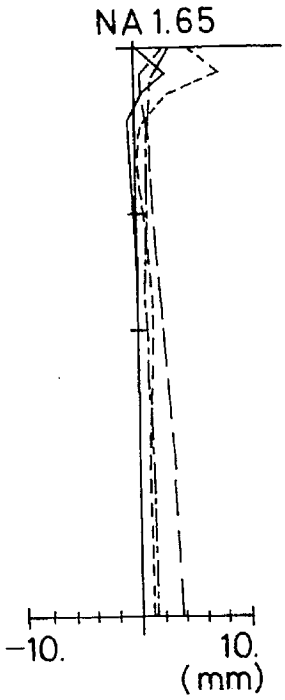


FIG. 5 (b)

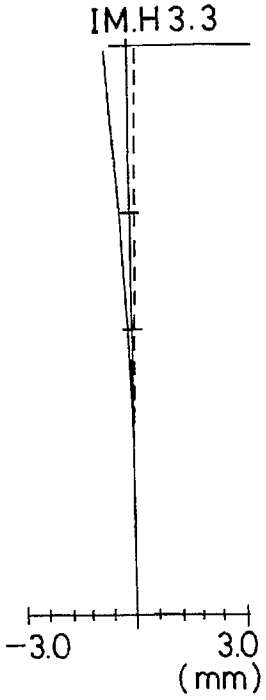


FIG. 5 (c)

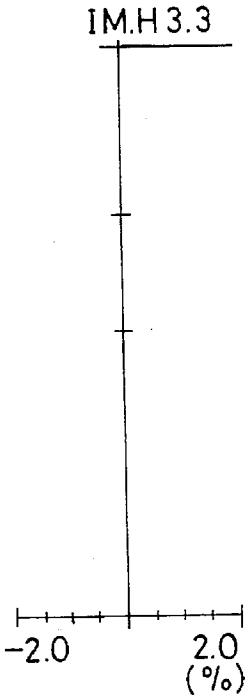


FIG. 6 (a)

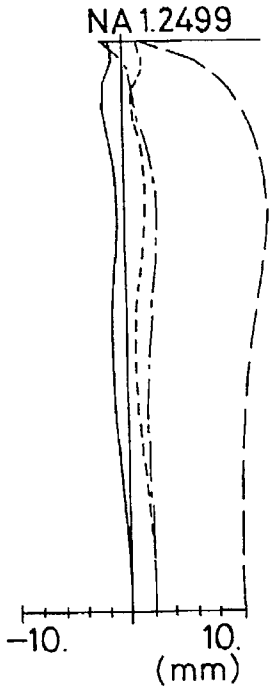


FIG. 6 (b)

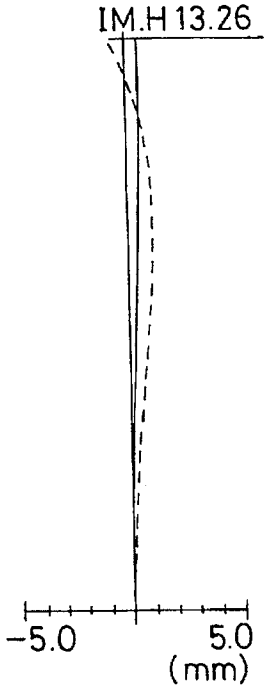


FIG. 6 (c)

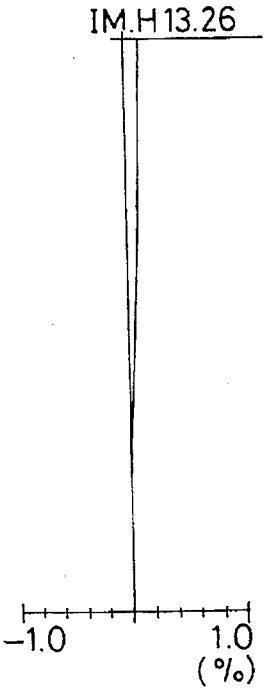


FIG. 7 (a)

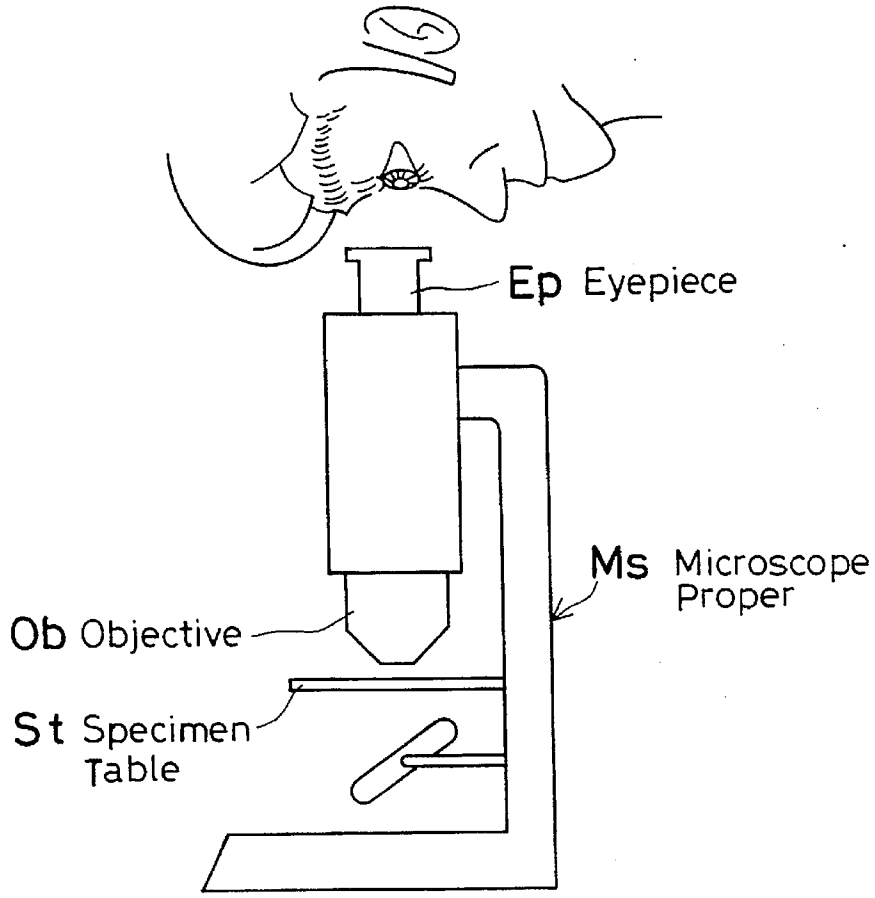
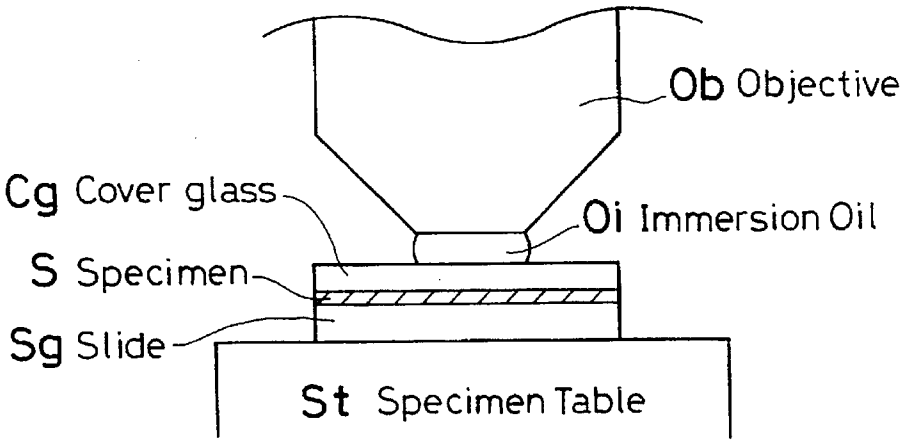

Ep Eyepiece
Ms Microscope Proper
Ob Objective
St Specimen Table

FIG. 7 (b)


Ob Objective
Cg Cover glass
Oi Immersion Oil
S Specimen
Sg Slide
St Specimen Table

IMMERSION MICROSCOPE OBJECTIVE

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to an immersion microscope objective, and more particularly to an immersion microscope objective of the apochromatic class which enables the numerical aperture (NA) to exceed 1.4.

2. Prior Art

Of vital importance for a microscope objective is to allow it to have a high numerical aperture (NA), thereby increasing the resolving power. In this regard, numerous proposals have so far been made in the art. For instance, JP-A 61(1986)-275813 and 4(1992)-311703 disclose microscope objectives which have a numerical aperture of 1.4, are well corrected in terms of chromatic aberration, and are improved in terms of the flatness of image surface as well. Since the immersion oil used has a refractive index of about 1.52, however, it is virtually impossible to achieve a further high numerical aperture, because the axial bundle from an object point on the axis is so diffused that much difficulty is involved in lens design per se. Thus, no objective with NA>1.4 is available.

An objective with NA>1.4 belongs virtually to an unheard-of technology. In recent years, however, microscopes have been used in various ways and differential interference has been used in high-tech fields so that the image can be magnified for video camera observation. The objective of the present invention, as will be explained later, can find some way to the realm of the unknown.

Set out below are objectives which are different in specifications from, but similar in construction to, the microscope objective according to the present invention. JM-B 41(1966)-12378 is not directed to an immersion objective, as can be seen from an NA of 0.8 and a magnification of 65×, but the third lens unit disclosed is similar in shape to the third lens unit of the invention which is one feature of the present invention. It is here to be understood that the present invention distinguishes over JM-B 41-12378 in that the first lens unit does not include a cemented doublet with the cemented surface being concave on the object side and the second lens unit includes no cemented triplet.

U.S. Pat. Nos. 3,700,311 and 4,373,785 are directed to an immersion objective having an NA of 1.3 and a magnification of 100×, which is identical with the present invention in terms of the first, fifth and sixth lens units and similar to the present invention in terms of the shape of the third and fourth lens units as well. However, the present invention distinguishes over them in that the second lens unit includes no cemented triplet and the third lens unit has positive refracting power. In this connection, it is to be noted that the third lens unit of the present invention is characterized by having negative refracting power.

SUMMARY OF THE INVENTION

The present invention has been made in view of such problems as mentioned in association with the prior art, and has for its object the provision of an immersion microscope objective which can have a numerical aperture higher than a conventionally achieved numerical aperture of 1.4 and has particularly improved axial optical performance.

According to one aspect of the present invention, the above-mentioned object is achieved by the provision of an immersion microscope objective which comprises, in order from the object side, a first lens unit having positive refracting power in its entirety and including a cemented lens with the cemented surface being concave on the object side; a second lens unit including a cemented lens of two or more lens components and having positive refracting power in its entirety; a third lens unit including a convex surface on its side proximate to the object, with the surface proximate to the image being strongly concave on the image side, and having negative refracting power in its entirety; a fourth lens unit including a strongly convex surface on its side proximate to the object and having positive refracting power in its entirety; a fifth lens unit including a convex surface on its side proximate to the object, with the surface proximate to the image being concave on the image side; and a sixth lens unit including a concave surface on its side proximate to the object, with the surface proximate to the image being convex on the image side.

According to another aspect of the present invention, there is provided an immersion microscope objective which comprises, in order from the object side, a first lens unit having positive refracting power in its entirety and including a cemented lens with the cemented surface being concave on the object side; a second lens unit including a cemented lens of two or more lens components and having positive refracting power in its entirety; a third lens unit including a convex surface on its side proximate to the object, with the surface proximate to the image being strongly concave on the image side, and having negative refracting power in its entirety; a fourth lens unit including a convex surface on its side proximate to the object and having positive refracting power in its entirety; a fifth lens unit including a convex surface on its side proximate to the object, with the surface proximate to the image being concave on the image side; and a sixth lens unit including a concave surface on its side proximate to the object, with the surface proximate to the image being convex on the image side, said immersion microscope objective further conforming to the following condition (1):

$$0.2<R_3/R_4<1.3 \quad (1)$$

where R_3 is the radius of curvature of the surface of the third lens unit that is proximate to the image side and R_4 is the radius of curvature of the surface of the fourth lens unit that is proximate to the object side.

Still another aspect of the present invention, there is provided an immersion microscope objective including a plurality of lens units with an immersion oil being applied to the object side of the lens surface proximate to the object for observation, characterized in that the lens proximate to the object side has an index of refraction of at least 1.6.

Preferably, the immersion microscope objective comprises, in order from the object side, a first lens unit having positive refracting power in its entirety and including a cemented lens with the cemented surface being concave on the object side, a second lens unit having positive refracting power in its entirety, a third lens unit having negative refracting power in its entirety, a fourth lens unit having positive refracting power in its entirety, a fifth lens unit with the concave surface being located on the image side, and a sixth lens unit with the concave surface being located on the object side.

Preferably, the second lens unit includes a cemented triplet.

Preferably, the second lens unit includes a cemented triplet consisting of positive, negative and positive lenses, and has positive refracting power in its entirety.

Preferably, the third lens unit includes a convex surface on its side proximate to the object with the surface proximate to the image being strongly concave on the image side, and has negative refracting power in its entirety.

Preferably, the fourth lens unit includes a convex surface on its side proximate to the object, and has positive refracting power in its entirety.

Preferably, the fifth lens unit includes a convex surface on its side proximate to the object with the surface proximate to the image being concave on the image side.

Preferably, the sixth lens unit includes a concave surface on its side proximate to the object with the surface proximate to the image being convex on the image side.

It is then preferable to conform the following condition (1):

$$0.2<R_3/R_4<1.3 \quad (1)$$

where R_3 is the radius of curvature of the surface of the third lens unit that is proximate to the image side and R_4 is the radius of curvature of the surface of the fourth lens unit that is proximate to the object side.

It is also preferable to conform to the following condition (2):

$$f/f_3<-0.01 \quad (2)$$

where f_3 is the focal length of the third lens unit and f is the overall focal length of the objective lens system.

A detailed account will now be given of why the above-mentioned lens arrangements are used and how they work.

To impart a high numerical aperture to the microscope objective an immersion oil having an index of refraction of at least 1.6 is used, and to reduce the occurrence of spherical aberration the index of refraction of the lens proximate to the object side must be at least 1.6.

In the present invention, the front lens of the first lens unit is formed of a cemented lens, while the index of refraction of the object-side lens is made as high as possible with the cemented surface being concave on the object side. This is to reduce the quantity of spherical aberration produced as much as possible.

Within the second lens unit there is disposed a cemented lens consisting of two or more lens components. This is effective for correction for axial chromatic aberration. With a luminous flux incident on the third lens unit, the flux is converged by the convex surface proximate to the object side and negative refracting power is exerted by the surface proximate to the image side, which is strongly concave on the image side. The flux is then diffused by this negative refracting power, but it is again converged by the convex surface of the fourth lens unit that is proximate to the object side. In the case of such a high-magnification and high-numerical aperture type objective, some considerable negative spherical aberration occurs because the overall positive refracting power of the lens system is strong. A point important for objective design is how negative refracting power is ensured for correction for spherical aberration. In the present invention, this is achieved by the so-called air lens effect of the negative refracting power, while an air separation is located between the surface of the third lens unit proximate to the image side and the surface of the fourth lens unit proximate to the object side.

The flux is further converged by the fourth lens unit of positive refracting power, and then allowed to be incident on so-called Gauss lens units, i.e., the fifth and sixth lens units, so that the flatness of the resultant image surface can be secured.

For satisfactory correction for aberrations, it is required to comply with the following condition (1):

$$0.2<R_3/R_4<1.3 \quad (1)$$

where R_3 is the radius of curvature of the surface of the third lens unit that is proximate to the image side and R_4 is the radius of curvature of the surface of the fourth lens unit that is proximate to the object side.

The ratio of R_3 and R_4 should lie within the range defined by condition (1), partly because negative refracting power is needed for correction for spherical aberration and partly because too strong negative refracting power puts the whole aberrations in an ill-balanced state. When the upper limit of 1.3 is exceeded, the whole aberrations are ill balanced because the positive refracting power of the surface of the fourth lens unit proximate to the object side becomes too strong. When the lower limit of 0.2 is not reached, the whole aberrations are again ill balanced because the negative refracting power of the surface of the third lens unit proximate to the image side becomes too strong.

To secure the negative refracting power required for correction for spherical aberration, it is effective to comply with the following condition (2):

$$f/f_3<-0.01 \quad (2)$$

where f_3 is the focal length of the third lens unit and f is the overall focal length of the objective lens system.

In this connection, the value corresponding to condition (2) in JM-B 41-12378 is −0.0031, indicating weak negative refracting power. All other conventional objectives have positive refracting power and so depart from condition (2).

Still other objects and advantages of the invention will in part be obvious and will in part be apparent from the specification.

The invention accordingly comprises the features of construction, combinations of elements, and arrangement of parts which will be exemplified in the construction hereinafter set forth, and the scope of the invention will be indicated in the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a sectional view of Example 1 of the immersion microscope objective according to the present invention,

FIG. **2** is a sectional view of Example 3 of the immersion microscope objective according to the present invention,

FIG. **3** is a sectional view of an image formation lens used in combination with the objective of each example,

FIGS. **4**(*a*) to **4**(*c*) are aberration diagrams showing the spherical aberration, astigmatism and distortion of Example 1,

FIGS. **5**(*a*) to **5**(*c*) are aberration diagrams showing the spherical aberration, astigmatism and distortion of Example 2,

FIGS. **6**(*a*) to **6**(*c*) are aberration diagrams showing the spherical aberration, astigmatism and distortion of Example 3, and

FIGS. **7**(*a*) and **7**(*b*) schematically show the construction of a microscope with which the inventive objective is used, and illustrate the end portion of the objective on an enlarged scale.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Examples 1 to 3 of the immersion microscope objective according to the present invention will now be explained by way of example but not by way of limitation.

Lens data on each example will be enumerated later. FIG. **1** is a sectional view of the lens arrangement of Example 1. Example 2 is substantially similar in construction to Example 1, and so is not illustrated. FIG. **2** is a sectional view of the lens arrangement of Example 3.

In each of Examples 1 and 2, the first lens unit G_1 consists of a cemented doublet of a plano-convex lens and a meniscus lens concave on the object side and a positive meniscus lens concave on the object side, three in all; the second lens unit G_2 consists of a cemented triplet of double-convex, double-concave and double-convex lenses; the third lens unit G_3 consists of a cemented doublet of double-convex and double-concave lenses; the fourth lens unit G_4 consists of a cemented doublet of a double-convex lens and a negative meniscus lens with the concave surface being located on the object side; the fifth lens unit G_5 consists of a cemented doublet of double-convex and double-concave lenses; and the sixth lens unit G_6 consists of a cemented doublet of double-concave and double-convex lenses.

In Example 3, the first lent unit G_1 consists of a cemented doublet of a plano-convex lens and a meniscus lens with the concave surface being located on the object side and a positive meniscus lens with the concave surface being located on the object side, three in all; the second lens unit G_2 consists of a cemented doublet of a negative meniscus lens with the convex surface being located on the object side and a double-convex lens, two in all; the third lens unit G_3 consists of a cemented doublet of double-concave and double-convex lenses; the fourth lens unit G_4 consists of a cemented doublet of a double-convex lens and a negative meniscus lens with the concave surface being located on the object side; the fifth lens unit G_5 consists of a cemented doublet of double-convex and double-concave lenses; and the sixth lens unit G_6 consists of a cemented doublet of double-concave and double-convex lenses.

Enumerated below will be numerical data on each example. The symbols used hereinafter but not hereinbefore have the following meanings:

r_1, r_2, . . . the radii of curvature of the lens surfaces as indicated in order from the object side

d_1, d_2, . . . the separations between the lens surfaces as indicated in order from the object side

n_{d1}, n_{d2}, . . . the d-line indices of refraction of the lenses as indicated in order from the object side

ν_{d1}, ν_{d2}, . . . the Abbe's number of the lenses as indicated in order from the object side.

In both Examples 1 and 2, the focal length is f=1.8, the magnification is 100×, the numerical aperture is NA=1.65, and the working distance is 0.1289. They are both of the immersion type, and the refractive indices of the immersion oil used here are n_d=1.78035, n_C=1.76883, n_F=1.80975 and n_g=1.83503. Notice that the affixes d, C, F and g represent values with respect to the d-, C-, F- and g-lines. The d-line index of refraction, Abbe's number and thickness of the cover glass used are designed to be n_d=1.7865, ν_d=50.0 and d=0.17 mm.

In Example 3, the focal length is f=1.8, the magnification is 100×, the numerical aperture is NA=1.25, and the working distance is 0.1329. This is again of the immersion type, and the indices of refraction of the immersion oil used are n_d=1.51548, n_C=1.51198, n_F=1.52394 and n_g=1.53088. The d-line index of refraction, Abbe's number and thickness of the cover glass used are designed to be n_d=1.521, ν_d=56.02 and d=0.17 mm.

EXAMPLE 1

$r_1 = \infty$	$d_1 = 0.5100$	$n_{d1} = 1.78650$	$\nu_{d1} = 50.00$
$r_2 = -3.4374$	$d_2 = 2.1700$	$n_{d2} = 1.88300$	$\nu_{d2} = 40.78$
$r_3 = -2.2093$	$d_3 = 0.1325$		
$r_4 = -10.9949$	$d_4 = 2.4500$	$n_{d3} = 1.88300$	$\nu_{d3} = 40.78$
$r_5 = -5.8271$	$d_5 = 0.1997$		
$r_6 = 12.6750$	$d_6 = 5.3200$	$n_{d4} = 1.43875$	$\nu_{d4} = 94.97$
$r_7 = -22.9089$	$d_7 = 1.2000$	$n_{d5} = 1.71300$	$\nu_{d5} = 53.84$
$r_8 = 10.1935$	$d_8 = 7.3000$	$n_{d6} = 1.43875$	$\nu_{d6} = 94.97$
$r_9 = -9.0192$	$d_9 = 0.2000$		
$r_{10} = 8.0162$	$d_{10} = 4.8000$	$n_{d7} = 1.61800$	$\nu_{d7} = 63.38$
$r_{11} = -20.6259$	$d_{11} = 1.2500$	$n_{d8} = 1.74000$	$\nu_{d8} = 31.71$
$r_{12} = 5.2036$	$d_{12} = 1.0000$		
$r_{13} = 5.6171$	$d_{13} = 5.4000$	$n_{d9} = 1.43875$	$\nu_{d9} = 94.97$
$r_{14} = -6.1286$	$d_{14} = 1.2000$	$n_{d10} = 1.64450$	$\nu_{d10} = 40.82$
$r_{15} = -28.4328$	$d_{15} = 0.2334$		
$r_{16} = 8.1214$	$d_{16} = 4.9000$	$n_{d11} = 1.43875$	$\nu_{d11} = 94.97$
$r_{17} = -13.9811$	$d_{17} = 2.6848$	$n_{d12} = 1.61340$	$\nu_{d12} = 43.84$
$r_{18} = 6.8433$	$d_{18} = 1.3000$		
$r_{19} = -2.6403$	$d_{19} = 3.0112$	$n_{d13} = 1.64450$	$\nu_{d13} = 40.82$
$r_{20} = 14.3617$	$d_{20} = 2.5400$	$n_{d14} = 1.80518$	$\nu_{d14} = 25.43$
$r_{21} = -7.4872$			

$R_3 = 5.2036$
$R_4 = 5.6171$
$f_3 = -33.621$
(1) $R_3/R_4 = 0.926$
(2) $f/f_3 = -0.054$

EXAMPLE 2

$r_1 = \infty$	$d_1 = 0.5100$	$n_{d1} = 1.78650$	$\nu_{d1} = 50.00$
$r_2 = -3.5000$	$d_2 = 2.1700$	$n_{d2} = 1.88300$	$\nu_{d2} = 40.78$
$r_3 = -2.2069$	$d_3 = 0.1325$		
$r_4 = -7.6704$	$d_4 = 2.4500$	$n_{d3} = 1.88300$	$\nu_{d3} = 40.78$
$r_5 = -5.1439$	$d_5 = 0.1997$		
$r_6 = 11.5611$	$d_6 = 5.3200$	$n_{d4} = 1.43875$	$\nu_{d4} = 94.97$
$r_7 = -126.3986$	$d_7 = 1.2000$	$n_{d5} = 1.71300$	$\nu_{d5} = 53.84$
$r_8 = 10.0151$	$d_8 = 7.3000$	$n_{d6} = 1.43875$	$\nu_{d6} = 94.97$
$r_9 = -10.1436$	$d_9 = 0.2000$		
$r_{10} = 8.8086$	$d_{10} = 4.8000$	$n_{d7} = 1.61800$	$\nu_{d7} = 63.38$
$r_{11} = -11.6721$	$d_{11} = 1.2500$	$n_{d8} = 1.74000$	$\nu_{d8} = 31.71$
$r_{12} = 6.2427$	$d_{12} = 0.9000$		
$r_{13} = 5.4730$	$d_{13} = 5.4000$	$n_{d9} = 1.43875$	$\nu_{d9} = 94.97$
$r_{14} = -6.5046$	$d_{14} = 1.2000$	$n_{d10} = 1.64450$	$\nu_{d10} = 40.82$
$r_{15} = -26.5678$	$d_{15} = 0.2334$		
$r_{16} = 9.2718$	$d_{16} = 4.9000$	$n_{d11} = 1.43875$	$\nu_{d11} = 94.97$
$r_{17} = -3.0588$	$d_{17} = 1.0000$	$n_{d12} = 1.61340$	$\nu_{d12} = 43.84$
$r_{18} = 7.4439$	$d_{18} = 1.3000$		
$r_{19} = -2.5688$	$d_{19} = 1.7556$	$n_{d13} = 1.74000$	$\nu_{d13} = 31.71$
$r_{20} = 93.1630$	$d_{20} = 2.5400$	$n_{d14} = 1.80518$	$\nu_{d14} = 25.43$
$r_{21} = -5.1322$			

$R_3 = 6.2427$
$R_4 = 5.473$
$f_3 = -37.433$
(1) $R_3/R_4 = 1.14$
(2) $f/f_3 = -0.048$

EXAMPLE 3

$r_1 = \infty$	$d_1 = 0.4300$	$n_{d1} = 1.51633$	$\nu_{d1} = 64.15$
$r_2 = -0.7360$	$d_2 = 3.4356$	$n_{d2} = 1.78650$	$\nu_{d2} = 50.00$
$r_3 = -2.9864$	$d_3 = 0.1992$		
$r_4 = -107.1427$	$d_4 = 3.1452$	$n_{d3} = 1.56907$	$\nu_{d3} = 71.30$
$r_5 = -7.3492$	$d_5 = 0.1999$		
$r_6 = 26.1330$	$d_6 = 1.0000$	$n_{d4} = 1.78650$	$\nu_{d4} = 50.00$
$r_7 = 10.1905$	$d_7 = 5.3000$	$n_{d5} = 1.43875$	$\nu_{d5} = 94.97$
$r_8 = -10.0289$	$d_8 = 0.2000$		
$r_9 = 7.0602$	$d_9 = 5.0826$	$n_{d6} = 1.43875$	$\nu_{d6} = 94.97$
$r_{10} = -69.6153$	$d_{10} = 1.0954$	$n_{d7} = 1.64450$	$\nu_{d7} = 40.82$
$r_{11} = 5.3372$	$d_{11} = 1.5962$		
$r_{12} = 9.7321$	$d_{12} = 4.0024$	$n_{d8} = 1.43875$	$\nu_{d8} = 94.97$
$r_{13} = -7.7983$	$d_{13} = 0.9000$	$n_{d9} = 1.64450$	$\nu_{d9} = 40.82$

-continued

r_{14} = −28.1461	d_{14} = 0.3000		
r_{15} = 6.6682	d_{15} = 5.5793	n_{d10} = 1.43875	ν_{d10} = 94.97
r_{16} = −10.9329	d_{16} = 7.0984	n_{d11} = 1.52944	ν_{d11} = 51.72
r_{17} = 3.6004	d_{17} = 6.3491		
r_{18} = −3.7102	d_{18} = 2.1182	n_{d12} = 1.50378	ν_{d12} = 66.81
r_{19} = 13.3645	d_{19} = 3.6566	n_{d13} = 1.63636	ν_{d13} = 35.37
r_{20} = −8.3730			

R_3 = 5.3372
R_4 = 9.7321
f_3 = −33.789
(1) R_3/R_4 = 0.548
(2) f/f_3 = −0.053

Each of the above-exemplified objective is used in combination with an image-formation lens the data on which are given below by way of example, and one section of which is shown in FIG. **3**. In the data, r_1', r_2', . . . are the radii of the lens surfaces as indicated in order from the object side; d_1', d_2', . . . are the separations between the lens surfaces as indicated in order from the object side; n_{d1}', n_{d2}', . . . are the d-line indices of refraction of the lenses as indicated in order from the object side; and ν_{d1}', ν_{d2}', . . . are the Abbe's number of the lenses as indicated in order from the object side.

r_1'=68.7541, d_1'=7.7321, n_{d1}'=1.48749, ν_{d1}'=70.20
r_2'=−37.5679, d_2'=3.4742, n_{d2}'=1.80610, ν_{d2}'=40.95
r_3'=−102.8477, d_3'=0.6973
r_4'=84.3099, d_4'=6.0238, n_{d3}'=1.83400, ν_{d3}'=37.16
r_5'=−50.7100, d_5'=3.0298, n_{d4}'=1.64450, ν_{d4}'=40.82
r_6'=40.6619

The separation between each objective and the image-formation lens of FIG. **3** may lie somewhere between 50 mm and 170 mm. The spherical aberrations (a), astigmatisms (b) and distortions (c) of Examples 1, 2 and 3 at a typical separation of 105 mm are shown in FIGS. **4**, **5** and **6**. However, it is to be understood that similar aberrations are observed at separations of 50 mm to 170 mm.

A brief account will now be given of the schematic construction and action of the microscope on which the inventive immersion microscope objective is used. The immersion microscope is schematically shown in FIG. **7**(*a*), and an end portion of the objective is shown in FIG. **7**(*b*) on an enlarged scale. A microscope proper Ms is made up of an objective Ob, an eyepiece Ep, a specimen table St, and the like. An immersion oil Oi is added dropwise onto a cover glass Cg, while placed on the specimen table St is a specimen S held between a slide Sg and the cover glass Cg. As the objective Ob is brought close to the cover glass Cg, the gap between the objective Ob and the cover glass Cg is filled with the immersion oil Oi. With the gap between the objective Ob and the specimen S filled with the immersion oil Oi, it is possible to observe the image of the specimen with a magnification higher than would be possible with a dry objective system including an air gap layer, because a high-NA luminous flux from the specimen S is incident on the objective lens, contributing to image formation. In addition, the resultant image is improved in view of aberrations.

According to the present invention as explained above, it is possible to provide an immersion microscope objective which can have a magnification of about 100× and a high NA of the order of 1.65 and is particularly improved in terms of axial optical properties.

What we claims is:

1. An immersion microscope objective comprising, in order from an object side:

a first lens unit having positive refracting power as a whole, said first lens unit including a cemented lens with a cemented surface being concave on an object side;

a second lens unit having positive refracting power as a whole and including a cemented lens of at least two lens components;

a third lens unit having negative refracting power as a whole, said third lens unit including a convex surface on an object side, and said third lens unit being concave on an image side surface;

a fourth lens unit having positive refracting power as a whole and including a convex surface on an object side;

a fifth lens unit including a convex surface on an object side, and said fifth lens unit being concave on an image side; and

a sixth lens unit including a concave surface on an object side, said sixth lens unit being convex on an image side.

2. An immersion microscope objective comprising, in order from an object side:

a first lens unit having positive refracting power as a whole and including a cemented lens with a cemented surface being concave on an object side;

a second lens unit having positive refracting power as a whole and including a cemented lens of at least two lens components;

a third lens unit having negative refracting power as a whole, said third lens unit including a convex surface on an object side, and said third lens unit being concave on an image side surface;

a fourth lens unit having positive refracting power as a whole and including a convex surface on an object side surface;

a fifth lens unit including a convex surface on an object side, said fifth lens unit being concave on an image side; and

a sixth lens unit including a concave surface on an object side, said sixth lens unit being convex on an image side;

said immersion microscope objective further conforming to the following condition (1):

$$0.2<R_3/R_4<1.3 \quad (1)$$

where R_3 is a radius of curvature of said image side surface of said third lens unit, and R_4 is a radius of curvature of said object side surface of said fourth lens unit.

3. An immersion microscope objective comprising:

a plurality of lens units with an immersion oil being applied to a lens surface of a foremost object side for observation;

a foremost object side lens of said plurality of lens units having an index of refraction of at least 1.6.

4. An immersion microscope objective comprising, in order from an object side:

a first lens unit having positive refracting power as a whole and including a cemented lens with a cemented surface being concave on an object side;

a second lens unit having positive refracting power as a whole;

a third lens unit having negative refracting power as a whole;

a fourth lens unit having positive refracting power as a whole;

a fifth lens unit with a concave surface being located on an image side; and

a sixth lens unit with a concave surface being located on an object side.

5. The immersion microscope objective according to claim 3, wherein said plurality of lens units comprise, in order from an object side:

a first lens unit having positive refracting power as a whole and including a cemented lens with a cemented surface being concave on an object side;

a second lens unit having positive refracting power as a whole;

a third lens unit having negative refracting power as a whole;

a fourth lens unit having positive refracting power as a whole;

a fifth lens unit with a concave surface being located on an image side; and

a sixth lens unit with a concave surface being located on an object side.

6. The immersion microscope objective according to claim 4, wherein:

said second lens unit includes a cemented triplet.

7. The immersion microscope objective according to claim 3, wherein:

said plurality of lens units include a first lens unit on an object side of said immersion microscope objective, said first lens unit having a positive refracting power as a whole and including a cemented lens with a cemented surface being concave on an object side.

8. The immersion microscope objective according to claim 4, 5 or 6, wherein:

said second lens unit includes a cemented triplet consisting of a positive lens, a negative lens, and a positive lens.

9. The immersion microscope objective according to claim 4, 5 or 6, wherein:

said third lens unit includes a convex surface on an object side, said third lens unit being concave on an image side.

10. The immersion microscope objective according to claim 4, 5 or 6, wherein:

said fourth lens unit includes a convex surface on an object side.

11. The immersion microscope objective according to claim 4, 5 or 6, wherein:

said fifth lens unit includes a convex surface on an object side.

12. The immersion microscope objective according to claim 4, 5 or 6, wherein:

said sixth lens unit is convex on an image side.

13. The immersion microscope objective according to claim 4, 5 or 6, said immersion microscope objective satisfying the following condition (1):

$$0.2<R_3/R_4<1.3 \quad (1)$$

where R_3 is a radius of curvature of an image side surface of said third lens unit, and R_4 is a radius of curvature of an object side surface of said fourth lens unit.

14. The immersion microscope objective according to claim 4, 5 or 6, said immersion microscope objective satisfying the following condition (2):

$$f/f_3<-0.01 \quad (2)$$

where f_3 is a focal length of said third lens unit, and f is an overall focal length of said immersion microscope objective.

15. An immersion microscope objective according to claim 3, wherein:

said foremost object side lens of said plurality of lens units has an index of refraction of at least 1.7.

16. An immersion microscope objective according to claim 7, wherein:

said foremost object side lens of said plurality of lens units has an index of refraction of at least 1.7.

* * * * *

US005657158A

United States Patent [19]

Baumann et al.

[11] Patent Number: 5,657,158

[45] Date of Patent: Aug. 12, 1997

[54] **MICROSCOPE HAVING AN OBJECTIVE CORRECTED TO INFINITY**

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[73] Assignee: **Carl Zeiss Jena GmbH**, Jena, Germany

[21] Appl. No.: **631,363**

[22] Filed: **Apr. 12, 1996**

[30] **Foreign Application Priority Data**

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[51] **Int. Cl.**[6] **G02B 21/20**; G02B 21/36; G02B 23/04

[52] **U.S. Cl.** **359/363**; 359/384; 359/793; 359/795; 359/375

[58] **Field of Search** 359/363, 368, 359/384, 375–377, 793, 795

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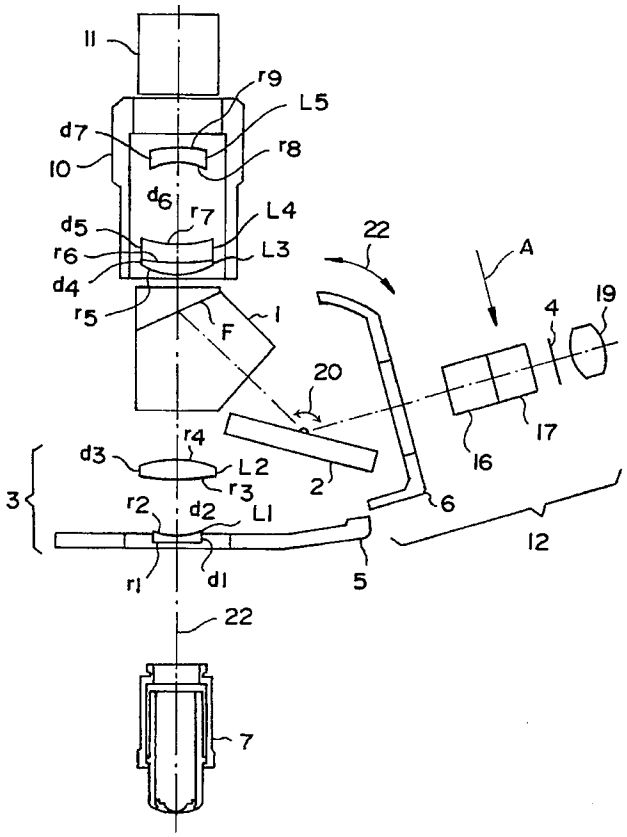
Primary Examiner—Jon W. Henry
Attorney, Agent, or Firm—Walter Ottesen

[57] **ABSTRACT**

The invention is directed to a microscope having an objective corrected to infinity and a pivotable binocular viewing unit. A tube lens is arranged downstream of the objective. The microscope includes at least one two-lens tube lens having a focal intercept greater than 200 mm as well as a tiltable mirror element and a further deflecting element mounted between the tube lens and the binocular viewing unit.

7 Claims, 3 Drawing Sheets



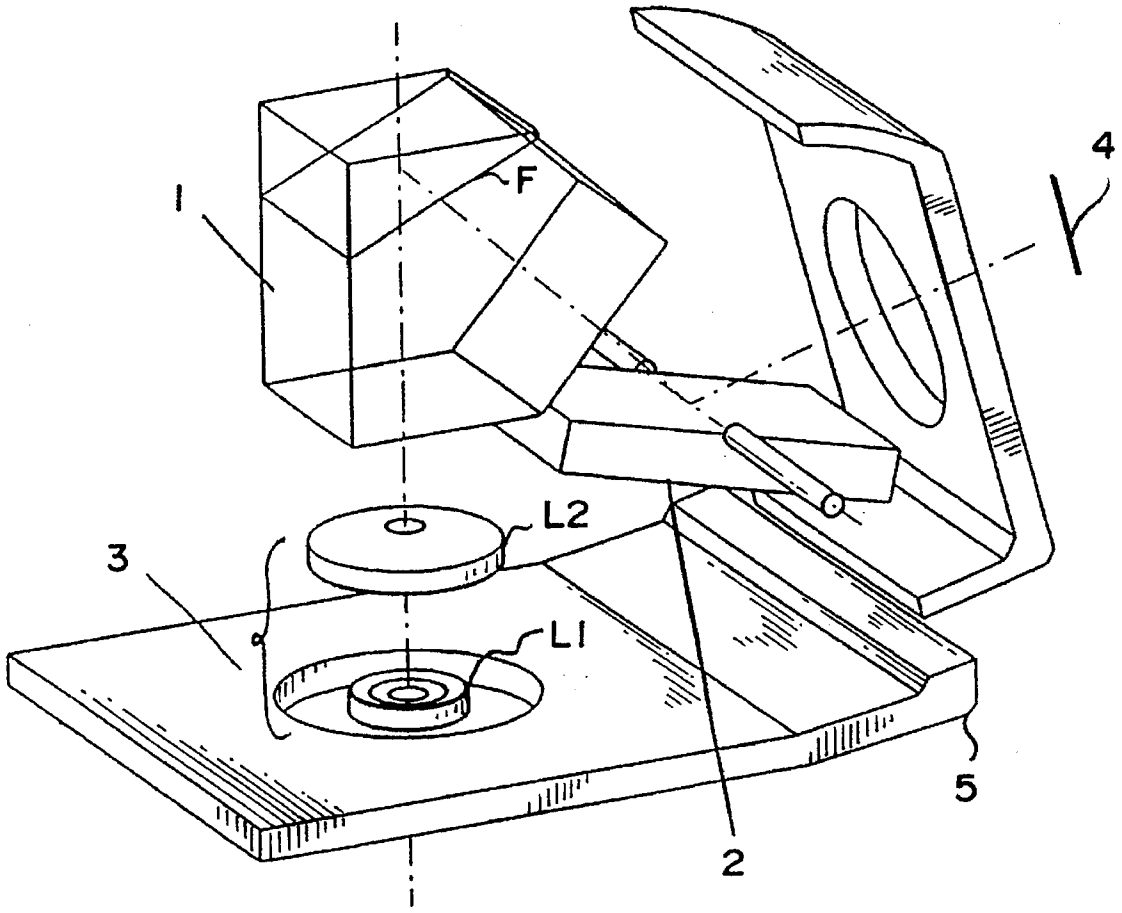


FIG. 1

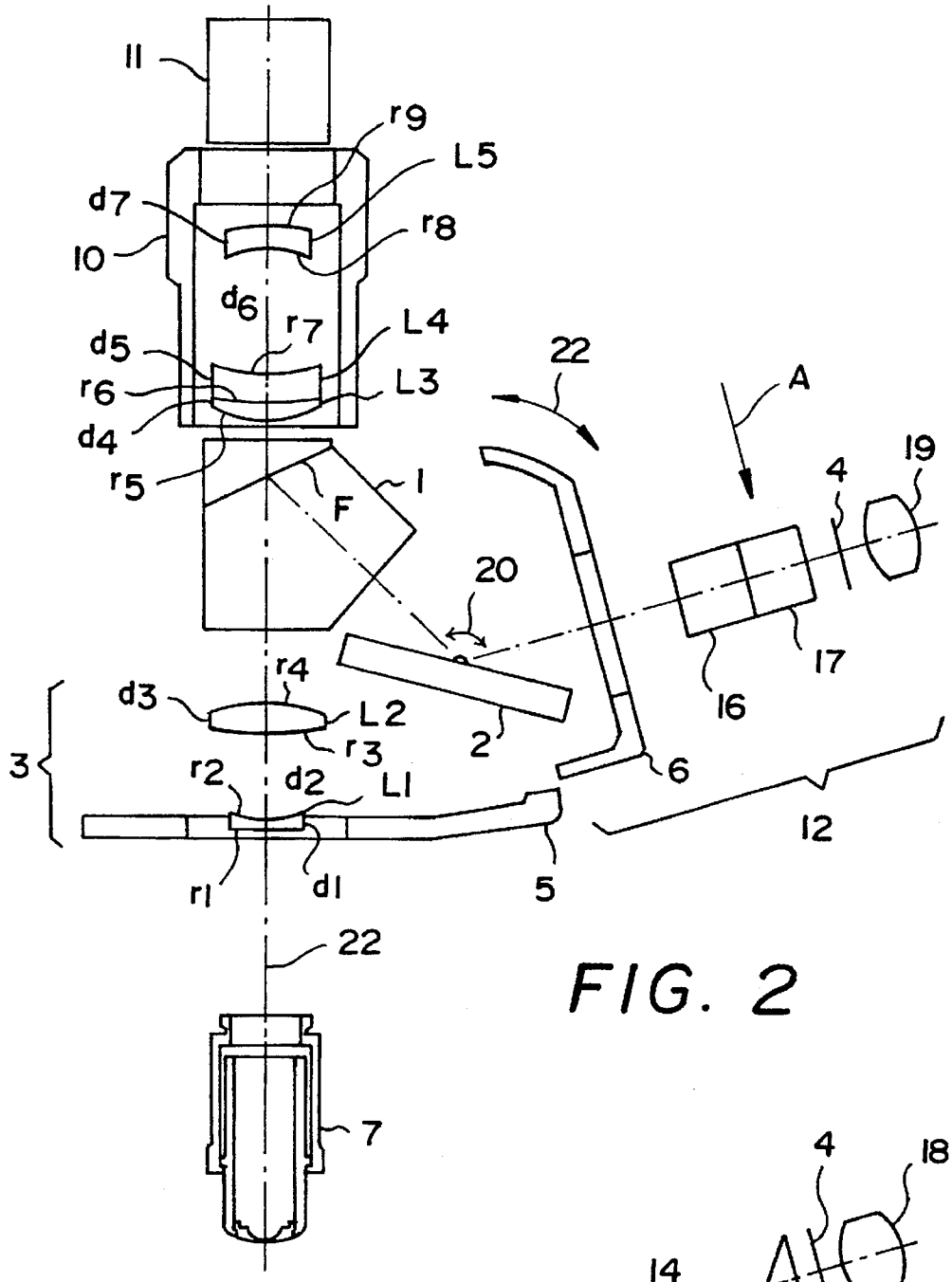

11
r9
L5
d7
r8
10
d6
r7
L4
d5
r6
L3
d4
r5
F
1
22
A
19
4
20
17
16
r4
d3
L2
r3
2
6
3
r2
d2
L1
12
r1
d1
5
22
7

FIG. 2

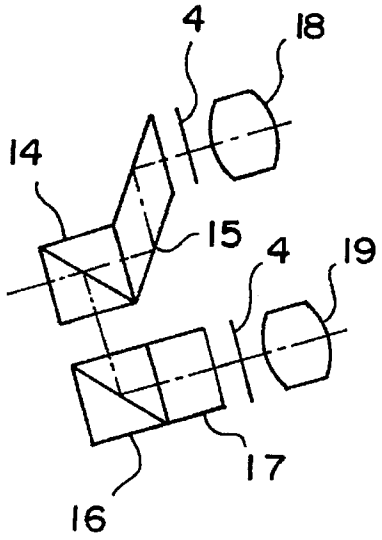

4
18
14
15
4
19
17
16

FIG. 3

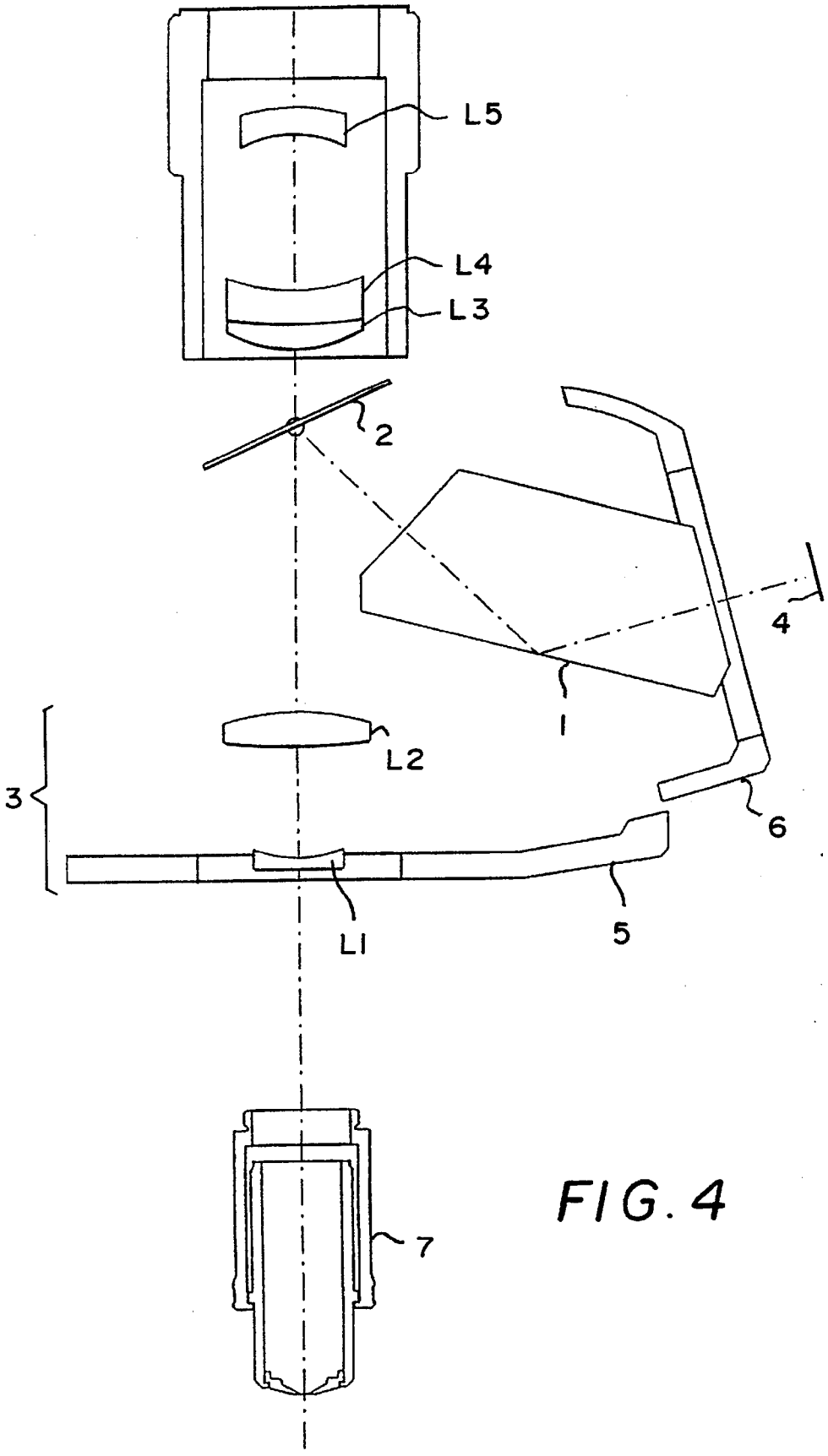


FIG. 4

MICROSCOPE HAVING AN OBJECTIVE CORRECTED TO INFINITY

FIELD OF THE INVENTION

The invention relates to a microscope having an objective corrected to infinity and a tube lens for generating an intermediate image in the intermediate image plane of a binocular viewing unit.

BACKGROUND OF THE INVENTION

Microscopes of this kind are offered as basic equipment by many microscope manufacturers. An inverted and reversed image is provided in the ocular because of the simple configuration which enables transmission of an image via two fixed deflections by a Bauernfeind prism. In this configuration, the movement of the object and of the ocular intermediate-image are mutually opposing and the users of these apparatus have become accustomed thereto.

For ergonomic reasons, there is a need for the user to have the viewing elevation and viewing angle so as to be changeable. For this purpose, many solutions for microscopes having objectives corrected to form an image in a finite focal plane are known wherein a variation of viewing elevation and viewing angle is provided. These apparatus have a common mirror surface which is also pivoted by about half of the angle when pivoting the binocular viewing unit containing the ocular. In this connection, reference can be made to German published patent application 3,334,690 as well as German Patent 1,098,233, German patent publication 218,692 and German utility model registration 7,931, 427. Reference can also be made to U.S. Pat. Nos. 4,798, 451; 4,643,541; and 4,576,450. A binocular viewing unit of this kind, which is configured in a simple manner, is disclosed in European published patent application 0,627, 642 for a stereomicroscope; however, here too, the objective is without a tube lens and is corrected to form an image in a finite focal plane.

Except for different basic configurations, all these solutions however have at least one of the following disadvantages:

(a) a high number of optical elements and the complexity associated therewith as well as possible image errors and contrast reduction;

(b) an additional intermediate image which is required because of the long optical path whereby the ocular intermediate image is generated so as to be erect and laterally correct in an unaccustomed manner;

(c) high mechanical complexity because several elements on different axes must be moved coupled to each other and at precise angles;

(d) a tube factor of greater than 1 because the path to the intermediate image is too long; and,

(e) the inability to realize an output for a camera in a simple manner.

One problem in this context is that conventional single-lens tube lenses, which are adapted to the microscope, have a focal length in the range of approximately 160 to 200 mm with a body magnification of 1 being pregiven. This relatively high focal length is countered by the requirement that an adapter between the body tube of the microscope and the camera should be realized with the shortest structural length possible.

The focal intercept (approximately 160 mm) of the tube lenses which are conventional for this type of microscope does not permit the image to be transmitted into the intermediate image plane when additional optical planar surfaces such as mirrors or prisms are required for pivoting the binocular viewing unit.

SUMMARY OF THE INVENTION

In view of the foregoing, it is an object of the invention to enable the viewing elevation and viewing angle of the binocular viewing unit holding the oculars to be changed and nonetheless maintain the total number of optically effective surfaces and mechanical rotational axes at a minimum. It is a further object of the invention to maintain the image position which is customary for the basic equipment, that is, inverted and reversed. It is still another object of the invention that the tube lens unit directly downstream of the objective have a magnification (tube factor) of 1 without intermediate imaging and to realize a compact camera adapter in a simple manner. The configuration of the invention is compact and space saving.

The microscope of the invention is for viewing an object and includes: an objective defining an optical axis and conducting a light beam coming from the object; the objective being corrected to infinity; a frame; a binocular viewing unit pivotally mounted on the frame so as to pivot through a predetermined angle relative to the frame; a tube lens unit mounted on the frame and arranged on the optical axis downstream of the objective as seen in the direction of the light beam; the tube lens unit including at least a first lens and a second lens arranged on said optical axis and having a focal intercept of greater than 200 mm; a first deflecting element mounted downstream of the tube lens unit for deflecting at least a component beam of the beam out of the optical axis; and, a second deflecting element pivotally mounted on the frame for deflecting the component beam into the binocular viewing unit.

A pivotal binocular viewing unit is realized with the microscope of the invention for which only two deflections and one rotational axis are adequate and wherein a magnification of 1 is nonetheless maintained without it being necessary to generate an intermediate image.

For this purpose, the deflection element (fixed or switchable) is configured as a mirror or a deflecting prism if a simple binocular viewing unit per se is desired or as a partially-transmitting mirror or splitting cube if a binocular tube with a camera adapter is desired in addition to the simple binocular viewing unit.

The tiltable mirror is entrained in a manner known per se via suitable gearing and tilts by an angular amount half of the tilt of the binocular viewing unit as disclosed, for example, in U.S. Pat. No. 2,132,122 incorporated herein by reference.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will now be described with reference to the drawings wherein:

FIG. **1** is a schematic perspective view of a first embodiment of the microscope of the invention;

FIG. **2** is a side elevation schematic view of the microscope shown in FIG. **1** equipped with an adapter for a camera;

FIG. **3** is a schematic plan view of the binocular viewing unit of the microscope of FIG. **2** as seen in the direction of arrow A thereof; and,

FIG. **4** is a schematic of a further embodiment of the microscope of the invention also equipped with an adapter.

DESCRIPTION OF THE PREFERRED EMBODIMENTS OF THE INVENTION

A tube lens unit **3** includes the lenses **L1** and **L2** and is mounted on a tube support **5** downstream of the microscope

objective **7** (see FIG. **2**). The objective **7** defines an optical axis **22** and conducts a light beam coming from an object (not shown) and the lenses L1 and L2 are arranged on this axis.

A deflection prism **1** includes a partially-transmitting face F at which the light beam coming from an object is split into a first component beam and a second component beam. The first component beam is deflected at the face F and the second component beam passes through the face F to a camera adapter **10** mounted downstream of the partially-transmitting face F. The camera adapter **10** comprises three lenses L3, L4 and L5. A camera **11** is shown mounted on the adapter **10** in FIG. **2**.

After being deflected at face F, the first component beam reaches the intermediate image plane **4** of the oculars via a tilt mirror **2** and the support **6** of a binocular viewing unit **12**. As shown in FIG. **3**, the binocular viewing unit **12** includes a beam splitter **14** for splitting the first component beam deflected by tilt mirror **2** into first and second subcomponent beams for respective ones of the oculars **18** and **19**. The first subcomponent beam passes via deflecting prism **15** to ocular **18** and the second subcomponent beam is deflected by deflecting cube **16** into glass cube **17** and then to ocular **19**.

The tilt mirror **2** is coupled so as to pivot (arrow **20**) with the pivoting movement of the binocular viewing unit **12** and tilts by half the pivot angle of the binocular viewing unit **12**. The tilting movement of binocular viewing unit **12** is schematically represented by double arrow **22**. This tilting movement and associated coupling of the tilt mirror is well known in the art and is described, for example, in U.S. Pat. No. 2,132,122, incorporated herein by reference.

The binocular tube assembly includes the binocular viewing unit **12**, tilt mirror **2**, prism **1** and tube lens unit **3** and has a tube length which extends from binocular viewing unit **12** to the tube lens unit **3**. The binocular tube assembly includes the tube lens unit **3** in order to adapt the assembly to the tube length and should not affect the overall magnification of the microscope. For this reason, the tube lens unit **3** has a magnification of one (1).

The tube lens unit **3** (lenses L1 and L2) generates the required long intercept distance (focal intercept) for the visual output in that the two lenses L1 and L2 are so configured that the amounts of the individual focal lengths thereof are 0.4±0.05 of the total focal length (that is, the focal length of the composite of lenses L1 and L2). The first lens L1 (viewed in the direction of light) is a diverging lens made of flint glass having a refractive index of 1.55±0.05 and an Abbe number of **43** to **47** and the lens L2 is a converging lens made of crown glass of Abbe number **65** to **69** and the distance of the mutually adjacent principal planes is 0.15 to 0.19 of the total focal length of the tube lens unit **3**.

In this way, and except for the image plane displacement, an excellent image correction is obtained, that is, axial and off-axis image errors such as chromatic aberration and spherical aberration in the image center, color magnification difference, distortion, coma, and astigmatism up to the field edge are eliminated.

The binocular viewing unit **12** is configured to have the longest possible focal intercept. In contrast, adapter **10** is configured to have the shortest possible focal intercept in order to keep its overall structural length, measured along the optical axis, at a minimum.

Furthermore, with the given individual focal lengths, the Petzval sum is zero as a condition for field flattening. The lens system L3 to L5 of adapter **10** functions to realize the conventional coupling dimension for the camera output and generates a short focal intercept by displacing the common principal plane. The common principal plane here is the plane common to the entire lens system (L3, L4 and L5) of the adapter **10**. The common principal plane lies forward of the intermediate image and is that plane in which the image side principal point is disposed. The principal plane in the following embodiment lies forward of lens L3.

A first element (L3, L4) is a converging composite lens having the focal length of 1.1 to 1.2 of the total focal length and the second element L5 is at least one diverging individual lens made of crown glass having the refractive index of 1.48 to 1.53 with the Abbe number **68** to **72** and a focal length of 0.5 to 0.6 of the total focal length. The principal plane spacing is 0.18 to 0.22 of the total focal length. In this way, the same imaging quality is obtained as at the visual output.

The principal plane spacing here is the spacing between the principal plane of composite lens (L3, L4) and the principal plane of the individual lens L5. The intermediate image generated by the adapter **10** lies in the spacing of the focal intercept which is in the plane of the film of the camera **11**.

The following table provides data on an advantageous embodiment of the lens systems (L1, L2) as well as (L3 to L5). The intercept distance here is 238 mm.

Lens	Glass Type	Radius of Curvature	Distance (mm)
L1	LLF1	r1 = infinite	d1 = 2.5
		r2 = 34.475	
			d2 = 26.4
L2	BK10	r3 = 124.099	d3 = 4.0
		r4 = −44.342	
L3	FK5	r5 = 24.939	d4 = 4.2
		r6 = 87.217	
L4	BaF52	r7 = 33.741	d5 = 5.9
			d6 = 30.9
L5	FK5	r8 = −18.970	d8 = 4.5
		r9 = −34.975	

In FIG. **4**, a tilt mirror **2** is mounted in the beam path downstream of the tube lens unit **3**. The tilt mirror **2** is configured so as to be partially transmitting for generating a camera beam path with the lens system of the invention. The deflecting prism **1** follows the tilt mirror **2**. In this case, the prism executes a movement coupled directly to the movement of the support **6** of the binocular viewing unit (not shown in FIG. **4**). Reference numeral **7** identifies the microscope objective of the microscope.

It is understood that the foregoing description is that of the preferred embodiments of the invention and that various changes and modifications may be made thereto without departing from the spirit and scope of the invention as defined in the appended claims.

What is claimed is:

1. A microscope for viewing an object comprising:

an objective defining an optical axis and conducting a light beam coming from the object;

said objective being corrected to infinity;

a frame;

a binocular viewing unit pivotally mounted on said frame so as to pivot through a predetermined angle relative to said frame;

a tube lens unit mounted on said frame and arranged on said optical axis downstream of said objective as seen in the direction of said light beam;

said tube lens unit including at least a first lens and a second lens arranged on said optical axis and having a focal intercept of greater than 200 mm;

a first deflecting element mounted downstream of said tube lens unit for deflecting at least a component beam of said beam out of said optical axis; and,

a second deflecting element pivotally mounted on said frame for deflecting said component beam into said binocular viewing unit.

2. The microscope of claim **1**, wherein said first deflecting element is a deflecting prism and said second deflecting element is a tiltable mirror.

3. The microscope of claim **2**, further comprising:

an adapter for interfacing a camera with said microscope;

said adapter being arranged on said optical axis downstream of said deflecting prism;

said component beam being a first component beam and said deflecting prism having a partially-transmitting surface whereat said light beam is split to form said first component beam deflected toward said mirror and a second component beam passing through said partially-transmitting surface along said optical axis and into said adapter; and,

said adapter including first and second lenses for transmitting said second component beam into the camera.

4. The microscope of claim **1**, wherein said first deflecting element is a tiltable mirror and said second deflecting element is a deflecting prism.

5. The microscope of claim **4**, further comprising:

an adapter for interfacing a camera with said microscope;

said adapter being arranged on said optical axis downstream of said tiltable mirror;

said component beam being a first component beam and said tiltable mirror being a partially-transmitting mirror whereat said light beam is split to form said first component beam deflected toward said deflecting prism and a second component beam passing through said partially-transmitting mirror along said optical axis and into said adapter; and,

said adapter including first and second lenses for transmitting said second component beam into the camera.

6. The microscope of claim **1**, said tube lens unit including first and second lenses having first and second individual focal lengths and said first and second lenses conjointly defining a total focal length; said first and second lenses being so configured that said individual focal lengths are each 0.4±0.05 of said total focal length; said first lens being the first lens in said direction of said light beam and said first lens being a diverging lens made of flint glass having a refractive index of 1.55±0.05 and an Abbe number in the range of 43 to 47; and, said second lens being a converging lens made of crown glass having an Abbe number in the range of 65 to 69; and, said first and second lenses defining mutually adjacent respective principal planes conjointly defining a spacing therebetween corresponding to 0.19 of said total focal length.

7. The microscope of claim **3**, said adapter including a first lens having a first focal length and a second lens having a second focal length; said first and second lenses conjointly defining a total focal length; said first and second lenses defining mutually adjacent respective principal planes which are shifted to provide a short focal intercept in that said first lens is a converging composite lens with said first focal length being 1.1 to 1.2 of said total focal length and said second lens is a diverging lens made of crown glass having a refractive index of 1.48 to 1.53 and an Abbe number in the range of 68 to 72 and said second focal length being 0.5 to 0.6 of said total focal length; and, said principal planes conjointly defining a spacing therebetween corresponding to 0.18 to 0.22 of said total focal length.

* * * * *

US005640270A

United States Patent [19]

Aziz et al.

[11] Patent Number: 5,640,270

[45] Date of Patent: Jun. 17, 1997

[54] **ORTHOGONAL-SCANNING MICROSCOPE OBJECTIVE FOR VERTICAL-SCANNING AND PHASE-SHIFTING INTERFEROMETRY**

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[21] Appl. No.: **613,462**

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[51] **Int. Cl.**[6] **G02B 21/00**; G02B 21/36; G02B 26/08; G01B 11/24

[52] **U.S. Cl.** **359/368**; 359/370; 359/372; 359/234; 359/236; 359/369; 359/583; 356/345; 356/346; 356/360; 250/559.22; 250/201.3

[58] **Field of Search** 359/368, 370, 359/372, 384, 235, 236, 234, 369, 583; 356/4.5, 345, 346, 348, 359, 360, 355; 250/559.22, 201.3

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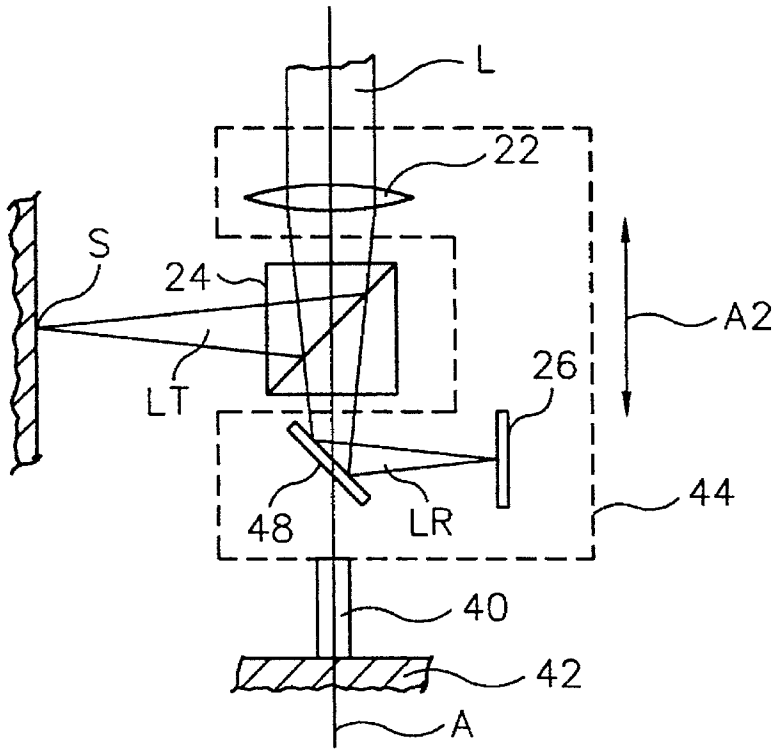
[57] **ABSTRACT**

A broad-bandwidth interferometric device is adapted for longitudinal insertion into a cylinder cavity to produce irradiance signals at multiple vertical-scanning positions as a function of optical path differences between a reference mirror incorporated in the probe and the cylinder-wall surface. The light-source beam is passed through an objective lens placed longitudinally in the cylinder and then divided by a beam splitter disposed in fixed relation to the cylinder wall to produce a test beam directed radially to the wall and a reference beam directed axially to a reference mirror disposed in fixed relation to the lens. During scanning, the objective lens and reference mirror are translated together, while the beam splitter remains stationary with respect to the cylinder wall, thereby varying the position of the focal point of the test beam and providing the vertical-scanning effect required to produce interference fringes and a corresponding map of the tested cylinder surface. In order to reduce the length of the instrument, the reference beam may be folded to the side by a reflective surface and the reference mirror may be positioned perpendicularly to the main axis of the instrument. In that case, the lens, fold mirror and reference mirror are all translated together, while the beam splitter remains stationary and fixed with the test surface.

27 Claims, 4 Drawing Sheets



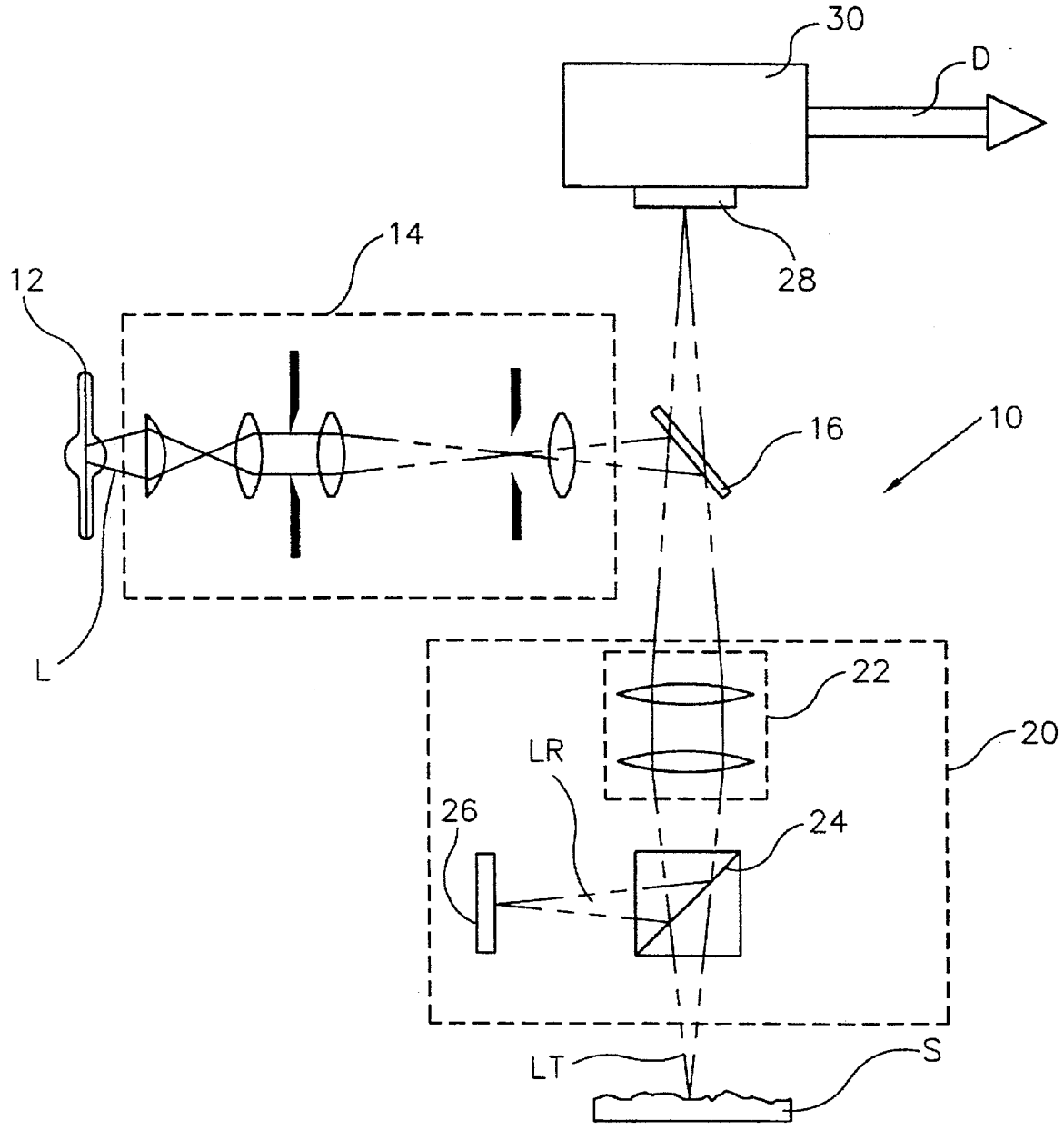


FIG. 1 (PRIOR ART)

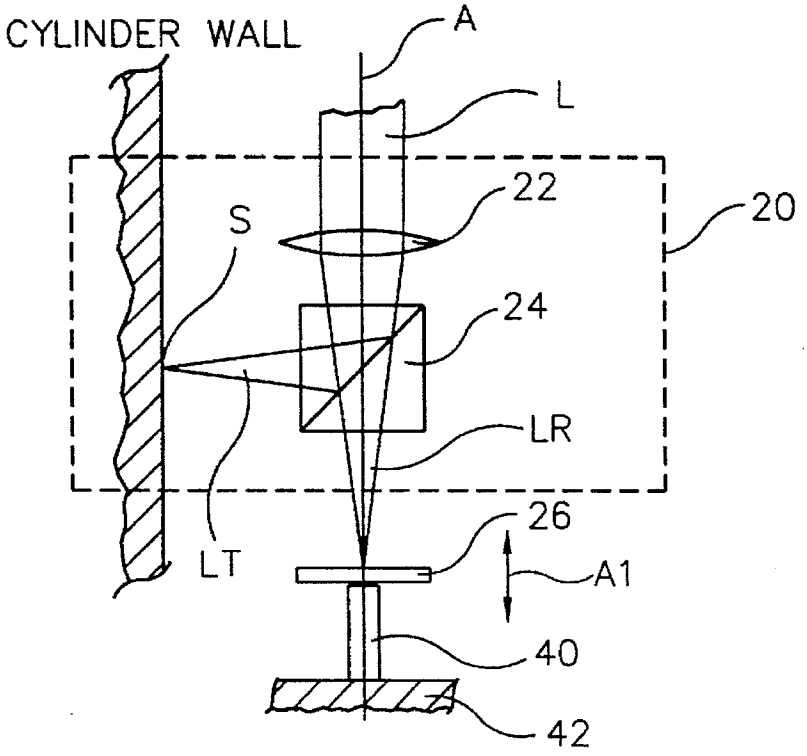

CYLINDER WALL
A
L
22
20
S
24
LR
26
LT
A1
40
42

FIG. 2

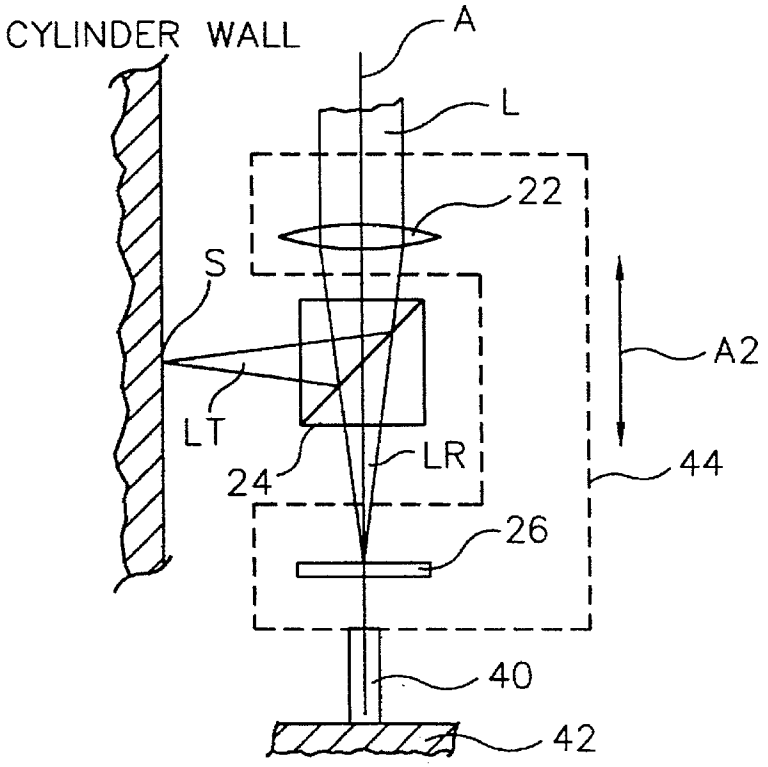

CYLINDER WALL
A
L
22
S
A2
LT
LR
24
44
26
40
42

FIG. 3

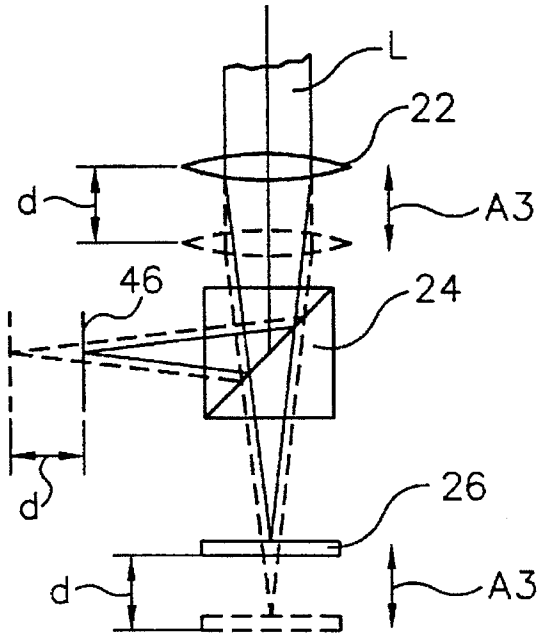


FIG. 4

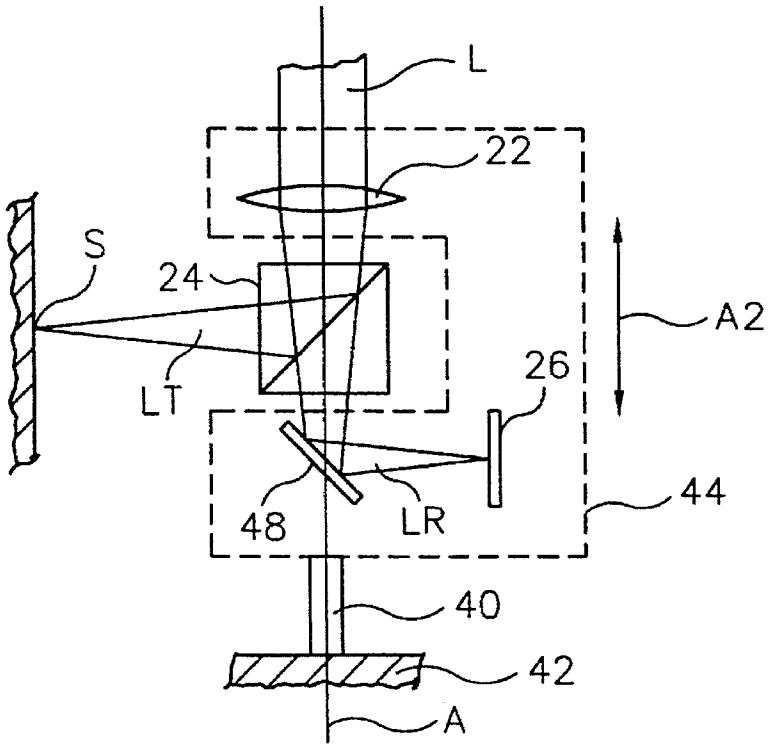


FIG. 5

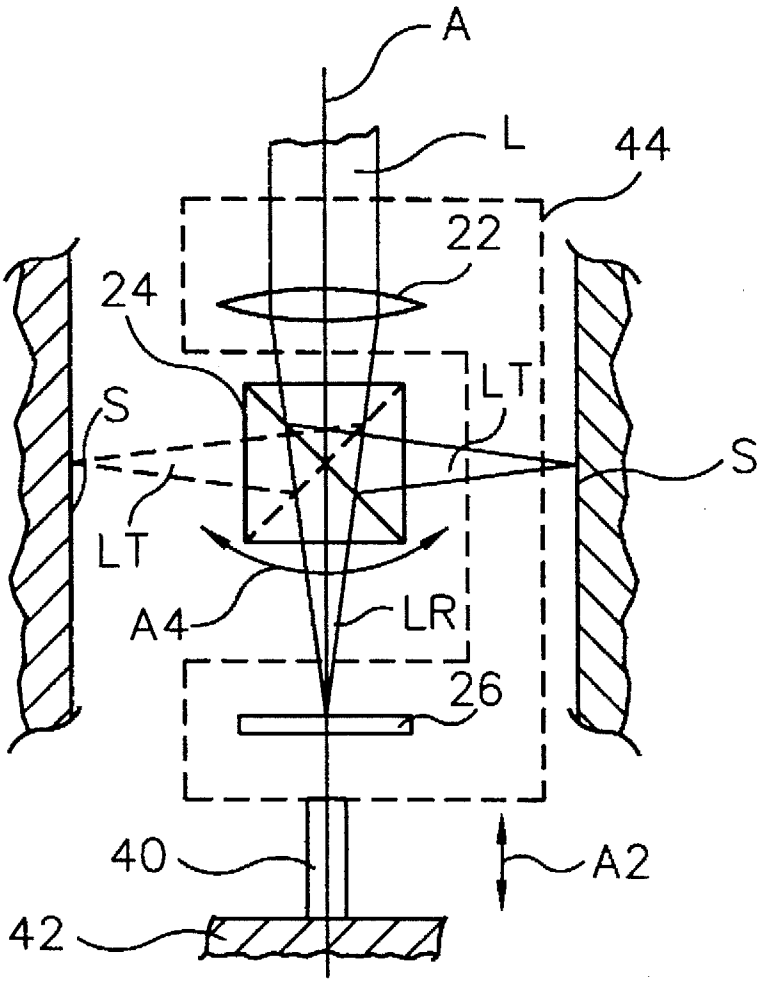


FIG. 6

ORTHOGONAL-SCANNING MICROSCOPE OBJECTIVE FOR VERTICAL-SCANNING AND PHASE-SHIFTING INTERFEROMETRY

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention is related in general to the field of interferometry and, in particular, to a novel device for measuring the surface roughness of cylinder walls in internal combustion engines.

2. Description of the Related Art

The surface roughness of cylinder walls in internal combustion engines is critical to good performance and durability. When the surface is too smooth, engine oil is thoroughly cleaned away by the recurring scraping action of piston rings over the cylinder walls, thereby greatly reducing lubrication to the parts and correspondingly increasing wear and tear. On the other hand, when the surface is too rough, the rings abut unevenly against the cylinder walls creating nonuniform lubricant distribution, which results in lubricant losses and nonuniform pressure distribution between the abutting surfaces, in turn also producing excessive wear and tear. In the ideal situation, the interior walls of cylinders have a very uniform surface with sufficient microscopic roughness to retain lubricant particles within uniformly-distributed recesses in the wall, such that the surface is never fully depleted of lubricant by the scraping action of the rings. Experience has shown that an average roughness of about 0.2 to 1.5 microns is desirable for standard automobile and truck internal-combustion engines.

In view of this objective, engine manufacturers inspect cylinder walls and measure their surface roughness as normal quality-control steps. The instruments used consist of borescopes, optical devices capable of showing small details of internal features, including imperfections and cracks, and stylus profilometers, mechanical devices for measuring the topography of the cylinder wall, typically with a limited three-dimensional resolution. Boroscopes are not very useful in testing for surface roughness because their resolution is not sufficient to identify problem spots; in addition, they provide a view of the cylinder wall but do not produce a quantified profile of the tested surface. The stylus instruments operate on contact, thereby affecting the tested surface, and have no ability to perform three-dimensional measurements.

Accordingly, there is a need for a better instrument for the purpose of rapidly, reliably and non-destructively measuring the roughness of cylinder walls. This invention is directed at providing a novel instrument and procedure based on non-contact interferometric principles for measuring the surface roughness of cylinder walls.

BRIEF SUMMARY OF THE INVENTION

One primary goal of this invention is an interferometer suitable for scanning a test surface placed orthogonally from, or at an angle with, the direction of motion of the scanning mechanism.

Another important object of the invention is a non-contact instrument and method for mapping the surface profile of a cylinder wall over a large scanning range, preferably up to several millimeters.

Another basic objective is a technique for cylinder walls based on optical measurements that permit higher vertical resolution than currently available with stylus-profilometry technology.

Another objective is a device and a method for measuring surface-roughness of cylinder walls more rapidly and reliably than with prior-art procedures.

Another goal is an instrument that makes it possible to obtain three-dimensional measurements of the profile of a test surface.

Finally, another goal is a method and apparatus that are suitable for implementation with relatively minor modifications to existing interferometric surface profilers.

Therefore, according to these and other objectives, the principle of interferometry, in particular vertical scanning interferometry (VSI), is applied to measuring the relative height of peaks and valleys in the surface of a cylinder wall to produce a topographic map of the tested area. The invention consists preferably of a broad-bandwidth interferometric device or probe adapted for longitudinal insertion into a cylinder cavity to produce irradiance signals at multiple vertical-scanning positions as a function of optical path differences between a reference mirror incorporated in the probe and the cylinder-wall surface. The light-source beam is passed through an objective lens placed longitudinally in the cylinder and then divided by a beam splitter disposed in fixed relation to the cylinder wall to produce a test beam directed radially to the wall and a reference beam directed axially to a reference mirror disposed in fixed relation to the lens. During scanning, the objective lens and reference mirror are translated together, while the beam splitter remains stationary with respect to the cylinder wall, thereby varying the position of the focal point of the test beam and providing the vertical-scanning effect required to produce interference fringes and a corresponding map of the tested cylinder surface. In order to reduce the length of the instrument, the reference beam may be folded to the side by a reflective surface and the reference mirror may be positioned perpendicularly to the main axis of the instrument. In that case, the lens, fold mirror and reference mirror are all translated together, while the beam splitter remains stationary and fixed with respect to the test surface.

Various other purposes and advantages of the invention will become clear from its description in the specification that follows and from the novel features particularly pointed out in the appended claims. Therefore, to the accomplishment of the objectives described above, this invention consists of the features hereinafter illustrated in the drawings, fully described in the detailed description of the preferred embodiment and particularly pointed out in the claims. However, such drawings and description disclose but one of the various ways in which the invention may be practiced.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a simplified schematic representation of a conventional vertical-scanning interferometer.

FIG. **2** is a schematic representation of the interference microscope objective portion of a cylinder-bore scanner according to one embodiment of the present invention, wherein the reference mirror is translated vertically to perform vertical-scanning interferometric measurements on a stationary cylinder wall placed at right angle to the axis of the stationary objective lens and beam splitter.

FIG. **3** is a schematic representation of the interference microscope objective portion of a cylinder-bore scanner according to the preferred embodiment of the present invention, wherein the objective lens and reference mirror are translated vertically to perform vertical-scanning interferometric measurements on a stationary cylinder wall placed at right angle to the axis of the objective lens through a stationary beam splitter.

FIG. 4 is a schematic representation of the optical effect of scanning the device of FIG. 3.

FIG. 5 is a variation of the device of FIG. 3 comprising a fold mirror reflecting the reference beam to the side of the objective's optical axis in order to shorten the length of the instrument.

FIG. 6 is another variation of the device of FIG. 3, wherein the bean splitter is rotatable about the optical axis of the instrument, thereby enabling it to view and test sample surfaces in all radial directions.

DESCRIPTION OF THE PREFERRED EMBODIMENTS OF THE INVENTION

The heart of this invention lies in the recognition that vertical-scanning interferometry can be performed on the surface of the interior wall of an internal-combustion cylinder by modifying a conventional interference microscope objective so that the objective lens and the reference mirror are translated together along the optical axis in the longitudinal direction of the cylinder, while the beam splitter is kept stationary with respect to the test surface, that is, the cylinder wall, which is disposed orthogonally to the direction of scanning. Such configuration results in vertical scanning of the wall surface even though no radial movement occurs within the cylinder.

The invention is applicable to both vertical scanning-interferometry (VSI) and phase-shifting interferometry (PSI), but it is mostly practical only when a rough surface is being measured; that is, when VSI is the suitable interferometric method. Therefore, the invention will be described in terms of vertical-scanning interferometry but it is understood that it should not be so limited.

Vertical scanning interferometry is a technique where broad bandwidth light, such as white light, is used as a light source in an interferometer and the degree of modulation, or contrast, of interference fringes produced by the instrument is measured for various distances between a test surface and the reference surface of the interferometer (each distance corresponding to a different optical path difference, OPD) to determine surface height. The method typically involves vertical scanning of a reference arm of the interferometer with respect to a stationary sample and calculation of the relative modulation of the intensity signal as a function of vertical position.

As illustrated in simple schematic form in FIG. 1, typical interferometric equipment **10** comprises a light source **12** directing a beam L of light through an illuminator **14** toward a beam splitter **16**, which reflects the light downward in the direction of a test surface S. The light reflected by the beam splitter **16** passes through an objective lens **22** focused on the test surface S. The objective lens **22**, a beam splitter **24** and a reference mirror together **26** constitute an interference microscope assembly **20** adapted for relative movement with respect to the test surface, so that two light beams LR and LT are generated for producing interference fringes. The reference beam LR is focused on the surface of the reference surface **26**, while the test beam LT is focused on the test or sample surface S. Note that the test beam LT is shown for simplicity as coaxial with the optical axis of the objective lens **22**, but in practice it may be shifted either by design or by optics imperfections to a parallel or slightly angular position by the beam splitter **24**, as would be obvious to one skilled in the art. The beams reflected from the reference mirror **26** and the test surface S pass back up through the optics of the objective lens **22** and upward through the beam splitter **16** to a solid-state detector array **28** in a camera **30** in coaxial alignment with the objective **22**, so that two light beams produce interference fringes as a result of the optical path difference between the reference mirror and the test surface S. The imaging array **28** normally consists of individual charge-coupled-device (CCD) cells or other sensing apparatus adapted to detect and record a two-dimensional array of signals corresponding to interference effects produced by the interferometer as a result of light reflected at individual x-y-coordinate pixels in the surface S and received at corresponding individual cells in the array. Appropriate electronic hardware is provided to process the signals generated by each cell and transmit digitized light-intensity data D to a microprocessor for processing. The reference arm **20**, containing the microscope objective **22**, beam splitter **24** and reference surface **26** incorporated within it, is adapted for vertical movement (along the z coordinate) to focus the image of the sample surface S on the detector array **28**. Thus, an interference-fringe map is generated by detecting the intensity of the light signal received in each cell of the array **28**.

In conventional vertical-scanning interferometry, a profile of the surface S is produced by repeating irradiance measurements at different, normally constant-interval OPD's between the microscope objective **20** and the test surface S (that is, at different elevations of the scanning unit), so as to provide information concerning the variation of light intensity at each pixel as the corresponding optical path difference is varied systematically with respect to an initial reference point. Thus, the position of the scanning unit corresponding to maximum interference at each pixel is determined and used, based on the distance from the reference point, to calculate the height of the surface at that pixel. Either the interference microscope assembly **20** or the test surface S is moved vertically (vertical scanning) to produce these repeated measurements. It is noted that this type of interference microscope conforms to the configuration of a special type of Michelson interferometer.

The prior art discloses various ways by which VSI may be implemented to determine surface height by calculating the degree of fringe modulation, or contrast, of the interference fringes produced at the light detector for various OPD's between the test surface and the reference surface of the interferometer. All methods involve vertical scanning of the interference microscope assembly (or its equivalent components, in the case of other types of interferometers) with respect to a stationary sample, or viceversa. The components of the interference microscope objective **20** (lens **22**, beam splitter **24** and reference mirror **26**) are kept in fixed relation and move together to maintain a fixed focused optical path to the reference mirror while the sample S is scanned. This arrangement allows large vertical scans (in the order of hundreds of microns, up to several millimeters, depending on the scanning mechanism utilized); this scanning range ensures that different portions of the sample S, successively appearing within the focal depth of the lens **22**, produce observable interference fringes during the entire scan.

In order to measure the roughness of a cylinder wall with an interferometric device adapted to scan vertically along the cylinder's main axis and test a surface disposed orthogonally thereto, the positions of the test and reference surfaces in FIG. 1 necessarily would have to be inverted, as shown in the schematic view of FIG. 2, to reflect the coaxial position of the cylinder wall with respect to the optical axis A of the objective lens **22**. According to one aspect of the present invention, such a configuration (shown for simplicity with a single objective lens **22** receiving collimated light L) could

be used to perform vertical scanning interferometry by translating the reference surface **26** in the direction of arrows A1 along the optical axis of the objective lens using a scanning mechanism **40** fixedly mounted on a support surface **42**, but the scanning range of such a device would be limited to a fraction of the depth of focus of the lens **22**. When scanning outside the focal depth, in practice no useful fringes are produced because the vertical resolution is greatly degraded. Therefore, while viable as a solution for measuring a relatively smooth surface (for example, an F/4 objective lens will provide a useful scanning range of about 10 microns with visible light), the configuration of FIG. **2** is not practical for cylinder walls with greater peak-to-valley roughness.

The main aspect of the present invention concerns the idea of performing vertical scanning by translating the objective lens **22** and the reference mirror **26** together, while keeping the beam splitter **24** fixed with respect to the test surface S (i.e., with respect to the cylinder wall). As shown in the schematic representation of FIG. **3**, the objective-lens/mirror assembly **44** is translated in the direction of arrows A2 along the optical axis of the objective lens using a scanning mechanism **40** fixedly mounted on a support surface **42**. Because of the fixed distance between the lens **22** and the reference mirror **26**, the mirror remains in focus during the entire range of translation. At the same time, as the distance between the lens **22** and the splitter **24** varies, so will the position of the focal plane of the test beam LT, thereby providing a variable OPD for producing fringes during scanning.

FIG. **4** illustrates the effect of the simultaneous and equal translation of the objective lens **22** and the reference mirror **26** along the direction of arrows A3. The initial position, shown in solid line, results in a test focal plane **46** determined by the initial distance between the lens and the beam splitter **24**. As the lens **22** is moved closer to the splitter **24** by a distance d (the result is shown in broken line), the reference mirror **26** remains in the reference focal plane because the distance between the lens and the mirror is unchanged, but the test focal plane is shifted away. Thus, during the translation corresponding to the two lens and reference mirror positions indicated in FIG. **4**, the focal plane of the test beam travels through the same distance d and successively produces interference fringes corresponding to points found in focus on the scanned surface. Therefore, the scanning range can be extended as needed to cover the roughness of the sample surface.

According to this principle, the preferred embodiment of the present invention consists of an interferometric probe adapted for longitudinal insertion in the cavity of a cylinder and comprising a microscope objective lens and a reference surface disposed in fixed relation to one another and adapted to translate together along the cylinder's axis during vertical scanning. The probe also comprises a stationary beam splitter to produce a test beam projecting radially (orthogonally to the optical axis of the objective lens) and focused on the cylinder wall. In operation, the probe of the invention is inserted longitudinally into the cavity of a cylinder such that the optical axis of the objective lens **22** is parallel to the main axis of the cylinder. As would be obvious to those skilled in the art of interferometry, the probe must be rigidly secured to a supporting structure so that its position relative to the target surface can be finely adjusted. The probe is placed in such a way that the target surface on the wall of the cylinder is within the focal depth of the test beam LT. Conventional VSI is then carried out by translating the objective-lens/mirror assembly **44** in the direction of arrows A2 (FIG. **3**) and the relative height of each surface pixel is measured by estimating the peak of the corresponding modulation envelope from the intensity measurements collected during scanning. Note that the curvature of the test surface (the internal wall of a cylinder) is accounted for and eliminated by appropriate software that is conventionally used when interferometric measurements are performed on curved surfaces. It is also noted that the interferometric arrangement of FIG. **3** can be used for phase-shifting measurements as well when a smooth surface is being tested. In such cases, though, conventional configurations would be just as effective and probably preferred.

As those skilled in the art would readily understand, the concept of this invention could be applied as well in a system where the test beam is projected at an angle (which may or may not be 90 degrees) from the optical axis A of the objective lens and from the scanning direction of the interferometer, and where the test beam is then focused on a test surface placed perpendicularly to the test beam. The principles of the invention apply to any such configuration as well because a vertical translation of the objective-lens/mirror assembly **44** in the direction of arrows A2 will produce the same amount of translation of the focal plane **46** along the test beam's axis, such that height measurements can be made of a test surface lying within that plane. In practice, though, if the angle between the optical axis of the objective lens and the test beam is small (measured with respect to the direction of the lens' focal point), the test and reference surfaces will be too close to each other for practical implementation. In addition, the beam splitter would have to be very large to reflect the test beam at a small angle with respect to the reference beam. If the angle is large, the test beam will be reflected back toward the objective lens, with comparable undesirable effects. Therefore, for optimal performance the test beam should be close to orthogonal to the optical axis of the objective lens. In practice, it is expected that any angle between about 25 and 155 degrees could be implemented in a straightforward manner for most applications. Smaller and larger angles would require special design configurations that may be harder to implement and, therefore, not preferred.

The concept of the invention could also be implemented by directing the reference beam LR out of the beam splitter **24** at an angle with respect to the optical axis A of the objective lens **22**. This configuration would require coordinating the translation of the objective lens and of reference mirror in such a way that the reference mirror would remain in focus throughout the scanning procedure, while the beam splitter would remain stationary. As well understood in the art, this could be accomplished by translating the objective lens and the reference mirror vertically by different amounts (the relative motion would depend on the geometry and optical characteristics of the beam splitter), or by translating each along its respective axis by the same amount. The relationship between the vertical movement of the objective lens and the vertical movement of the reference beam's focal plane is a function of the structural configuration of the beam splitter **24** and is well understood in the art. Accordingly, appropriate correction would be made as a function of the angle between the reference beam and the optical axis of the objective lens to account for the proportionate (but unequal) vertical displacement of the focal plane with respect to that of the objective lens. Note that the term "vertical" is used here to indicate the direction of scanning of the interferometer, but any other scanning direction would be equivalent for the purposes of this invention.

FIG. **5** illustrates a refinement of the concept of the present invention which may be preferred for applications

where the length of the probe is crucial and needs to be as compact as possible to conform to limited space requirements. In order to shorten the tip of the probe, a fold mirror **48** is placed within the reference beam LR to divert it to the side (preferably, but not necessarily, at 90 degrees). This allows the placement of the reference mirror **26** at the focal length in a direction appropriate for shortening the physical length of the probe. Obviously, this embodiment of the invention is optically equivalent to the one illustrated in FIG. **3**.

In still another embodiment of the invention illustrated schematically in FIG. **6**, the beam splitter **24**, which is stationary along the optical axis A of the objective lens **22**, is made rotatable around such axis (arrows A4) so as to provide flexibility with respect to the radial direction of the test beam LT. This feature enables use of the probe of the invention to project the test beam in any direction on a plane perpendicular to the lens' optical axis and scan any surface placed in parallel to the probe. For example, it can be used to test the entire circumference of the inside wall of a cylinder, as shown in the figure where dotted and solid lines correspond to two alternative positions of the beam splitter **24**. Note that this feature is illustrated in FIG. **6** with reference to the embodiment of FIG. **3**, but it could be implemented in equivalent fashion with the probe of FIG. **5**.

Thus, the present invention exploits the optical effect of translating a microscope objective lens and a reference mirror together along the lens' optical axis while maintaining a beam splitter in stationary position to reflect the test beam radially therefrom to carry out vertical scanning interferometry on a test surface disposed in parallel to the direction of scanning. This procedure is not limited by the focal depth of the objective lens and, therefore, it can be implemented over a wide scanning range, constrained only by the characteristics of the mechanism utilized to effect the scanning translation. With the motorized devices recently introduced in the art, the present invention has been used over a scanning range of about one millimeter and it is expected that VSI will soon be carried out reliably over a scanning of several millimeters.

Various changes in the details, steps and components that have been described may be made by those skilled in the art within the principles and scope of the invention herein illustrated and defined in the appended claims. Therefore, while the present invention has been shown and described herein in what is believed to be the most practical and preferred embodiments, it is recognized that departures can be made therefrom within the scope of the invention, which is not to be limited to the details disclosed herein but is to be accorded the full scope of the claims so as to embrace any and all equivalent processes and products.

We claim:

1. In a device for executing interferometric measurements at multiple distances between a reference surface and a test surface disposed in aligned optical paths to a light-intensity sensor, wherein a scanning means is used to effect a relative translation between the reference surface and the test surface to achieve said multiple distances at which light-intensity outputs are produced, wherein said light-intensity outputs are used to calculate a surface-height output corresponding to a profile of the test surface, and wherein the test surface is disposed orthogonally to a direction forming a first angle with a scanning direction of the interferometer, an interference microscope that comprises:

(a) an objective lens having an optical axis and a focal plane;

(b) a beam splitter aligned with the optical axis of the objective lens, said beam splitter producing a reference beam and producing a test beam directed substantially along said direction forming a first angle with the scanning direction of the interferometer and toward said test surface placed substantially within the focal plane of said test beam;

(c) a reference surface disposed substantially within the focal plane of said reference beam; and

(d) scanning means for translating the objective lens and the reference surface together while the beam splitter and test surface remain stationary.

2. The device of claim **1**, wherein said beam splitter is rotatable around said optical axis.

3. The device of claim **1**, wherein said first angle is substantially 90 degrees.

4. The device of claim **2**, wherein said first angle is substantially 90 degrees.

5. The device of claim **1**, further comprising a fold mirror placed between the beam splitter and the reference surface in fixed relation to the objective lens to divert the reference beam toward a direction at a second angle with said optical axis of the objective lens.

6. The device of claim **5**, wherein said first angle is substantially 90 degrees.

7. The device of claim **5**, wherein said second angle is substantially 90 degrees.

8. The device of claim **5**, wherein said first angle is substantially 90 degrees and said second angle is substantially 90 degrees.

9. The device of claim **5**, wherein said beam splitter is rotatable around said optical axis.

10. The device of claim **9**, wherein said first angle is substantially 90 degrees.

11. The device of claim **9**, wherein said second angle is substantially 90 degrees.

12. The device of claim **9**, wherein said first angle is substantially 90 degrees and said second angle is substantially 90 degrees.

13. In a device for executing interferometric measurements at multiple distances between a reference surface and a test surface disposed in aligned optical paths to a light-intensity sensor, wherein a scanning means is used to effect a relative translation between the reference surface and the test surface to achieve said multiple distances at which light-intensity outputs are produced, wherein said light-intensity outputs are used to calculate a surface-height output corresponding to a profile of the test surface, and wherein the test surface is disposed orthogonally to a scanning direction of the interferometer, an interference microscope that comprises:

(a) an objective lens having an optical axis and a focal plane;

(b) a beam splitter aligned with the optical axis of the objective lens, said beam splitter producing a reference beam directed substantially along said optical axis and producing a test beam directed substantially along said direction forming a first angle with the scanning direction of the interferometer and toward said test surface placed substantially within the focal plane of said test beam;

(c) a reference surface disposed in fixed relation to the objective lens and substantially within the focal plane of said reference beam; and

(d) scanning means for translating the objective lens and the reference surface together along said optical axis while the beam splitter and test surface remain stationary.

14. A method of executing interferometric measurements at multiple distances between a reference surface and a test surface disposed in aligned optical paths to a light-intensity sensor, wherein a scanning means is used to effect a relative translation between the reference surface and the test surface to achieve said multiple distances at which light-intensity outputs are produced, wherein said light-intensity outputs are used to calculate a surface-height output corresponding to a profile of the test surface, and wherein the test surface is disposed orthogonally to a direction forming a first angle with a scanning direction of the interferometer, said method comprising the following steps:

(a) providing an objective lens having an optical axis and a focal plane;

(b) providing a beam splitter aligned with the optical axis of the objective lens and adapted to produce a reference beam directed along said optical axis and a test beam directed along said direction forming a first angle with the scanning direction of the interferometer toward said test surface;

(c) providing a reference surface disposed in fixed relation to the objective lens and substantially within the focal plane of said reference beam;

(d) providing scanning means for translating the objective lens and reference surface together along said optical axis;

(e) placing a test surface substantially within the focal plane of said test beam; and

(f) translating said objective lens and reference surface together along said optical axis to perform interferometric measurements while the beam splitter and test surface remain stationary.

15. The method of claim 14, wherein said first angle is substantially 90 degrees.

16. The method of claim 14, wherein said beam splitter is rotatable around said optical axis.

17. The method of claim 16, wherein said first angle is substantially 90 degrees.

18. The method of claim 14, wherein said step (c) further comprises providing a fold mirror placed between the beam splitter and the reference surface in fixed relation to the objective lens to divert the reference beam toward a direction at a second angle with said optical axis of the objective lens; and wherein said step (f) further comprises translating the fold mirror together with the objective lens and the reference surface.

19. The method of claim 18, wherein said first angle is substantially 90 degrees.

20. The method of claim 18, wherein said second angle is substantially 90 degrees.

21. The method of claim 18, wherein said first angle is substantially 90 degrees and said second angle is substantially 90 degrees.

22. The method of claim 18, wherein said beam splitter is rotatable around said optical axis.

23. The method of claim 22, wherein said first angle is substantially 90 degrees.

24. The method of claim 22, wherein said second angle is substantially 90 degrees.

25. The method of claim 22, wherein said first angle is substantially 90 degrees and said second angle is substantially 90 degrees.

26. A method of executing vertical-scanning interferometric measurements at multiple distances between a reference surface and a test surface disposed in aligned optical paths to a light-intensity sensor, wherein a scanning means is used to effect a relative translation between the reference surface and the test surface to achieve said multiple distances at which light-intensity outputs are produced, wherein said light-intensity outputs are used to calculate a surface-height output corresponding to a profile of the test surface, and wherein the test surface is disposed in parallel to the scanning direction of the interferometer, said method comprising the following steps:

(a) providing an objective lens having an optical axis and a focal plane;

(b) providing a beam splitter disposed in fixed relation to the objective lens, aligned with the optical axis thereof, and adapted to produce a reference beam directed along said optical axis and a test beam directed radially from the optical axis toward a test surface;

(c) providing a reference surface substantially within the focal plane of said reference beam;

(d) providing scanning means for translating the reference surface along said optical axis; and

(e) placing a test surface substantially within the focal plane of said test beam; and

(f) translating said reference surface along said optical axis to perform vertical-scanning while the objective lens and the beam splitter remain stationary.

27. The method of claim 26, wherein said beam splitter is rotatable around said optical axis.

* * * * *

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United States Patent [19]

Neil

[11] Patent Number: 5,638,215

[45] Date of Patent: Jun. 10, 1997

[54] **OBJECTIVE LENS SYSTEM**

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[73] Assignee: **Panavision International, L.P.**, Tarzana, Calif.

[21] Appl. No.: **492,838**

[22] Filed: **Jun. 20, 1995**

[51] **Int. Cl.**[6] **G02B 1/06**; G02B 3/12

[52] **U.S. Cl.** **359/665**; 359/666

[58] **Field of Search** 359/666, 665

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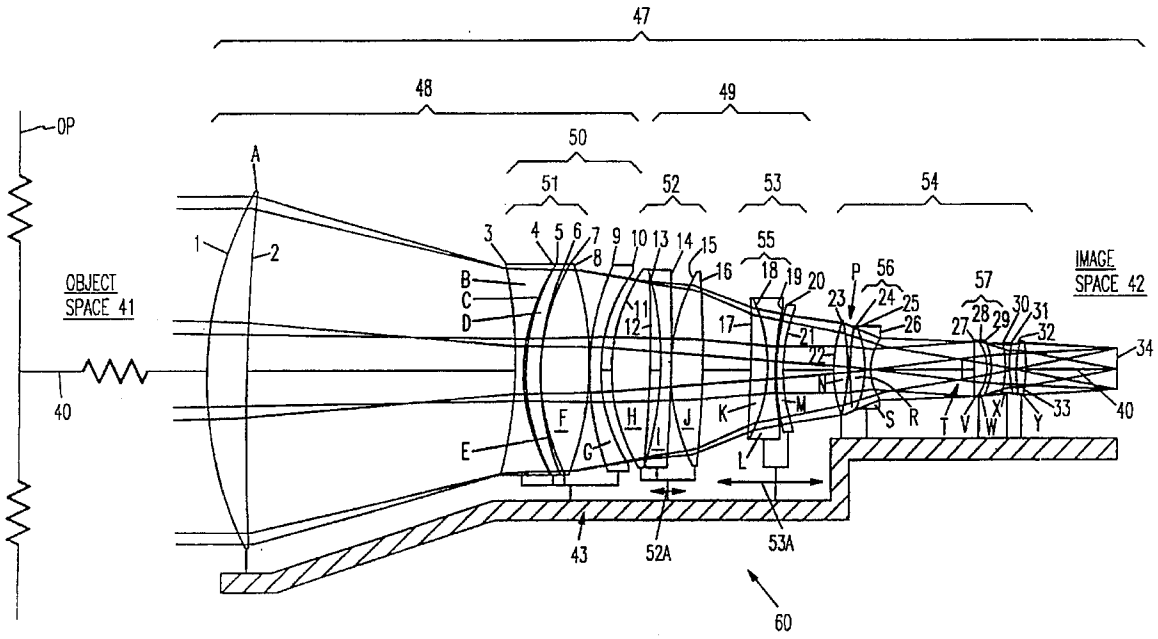
Primary Examiner—Scott J. Sugarman
Attorney, Agent, or Firm—Lyon & Lyon

[57] **ABSTRACT**

A high performance, large aperture, long focal length visible waveband objective lens system (**60**) comprises a telephoto objective lens group (**48**) spaced from a focusing lens group (**49**) and an auxiliary lens group (**54**), all supported in a support assembly (**43**) of fixed length. The lens groups are aligned on a common optical axis (**40**) and arranged to form a real image (**34**) in image space (**42**) from radiation entering the system (**60**) from a real object in object space (**41**). The telephoto objective lens group (**48**) is stationary and comprises a positively powered lens element (A) and a negatively powered lens sub-group (**50**) containing a quintuplet lens group (**51**) with lens elements (B, C, D, E, F) and a lens element (G). The quintuplet lens group includes two lens elements (C and E) of liquid materials which exhibit highly abnormal partial dispersions and one solid glass lens element (F) which exhibits slightly abnormal partial dispersion In addition, the liquid materials of lens elements (C) and (E) exhibit very large changes in refractive index with temperature and the material of lens element (F) exhibits a compensating large change in refractive index with temperature. The remaining lens elements of the system are common optical glass and exhibit substantially normal partial dispersions.

27 Claims, 3 Drawing Sheets



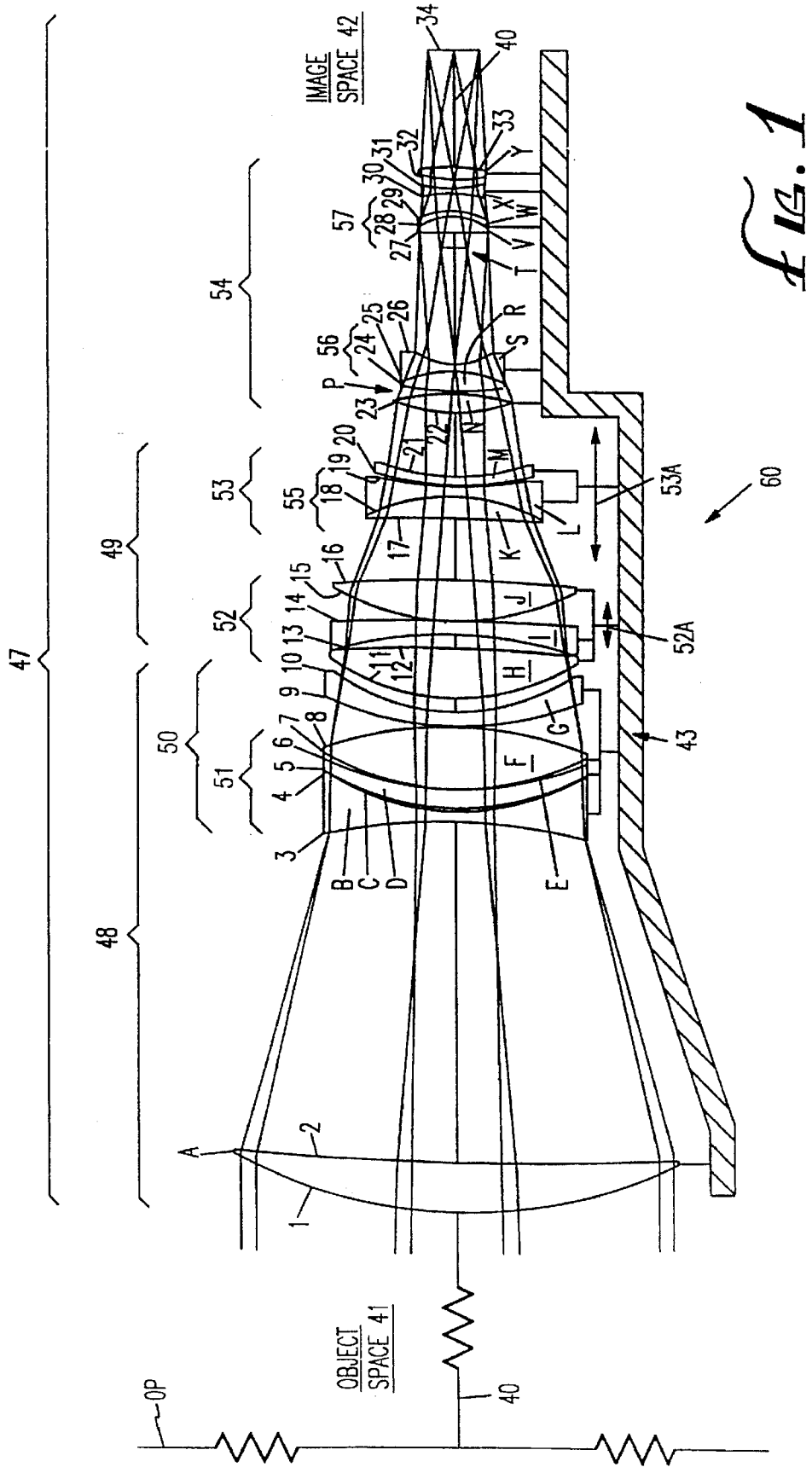


IMAGE SPACE 42
OBJECT SPACE 41
OP
47
48
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50
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57
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53A
52A
43
60
A
B
C
D
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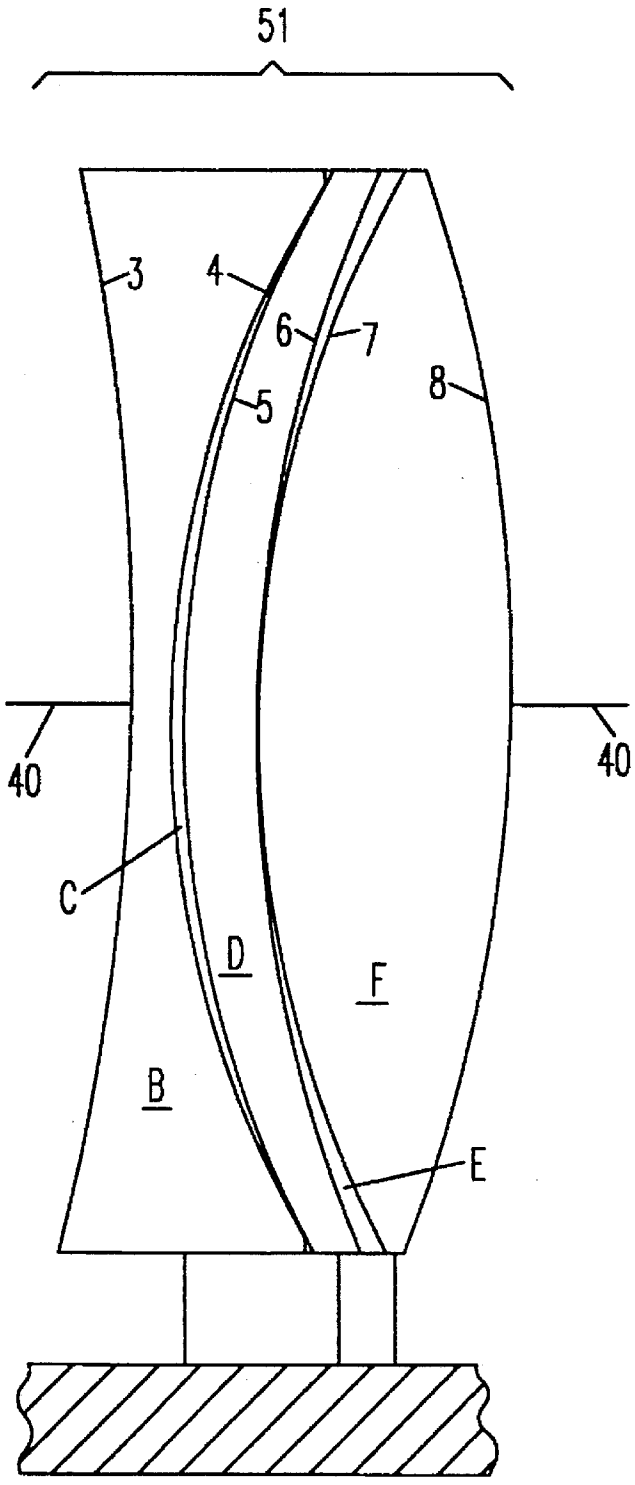
FIG. 1

FIG. 2



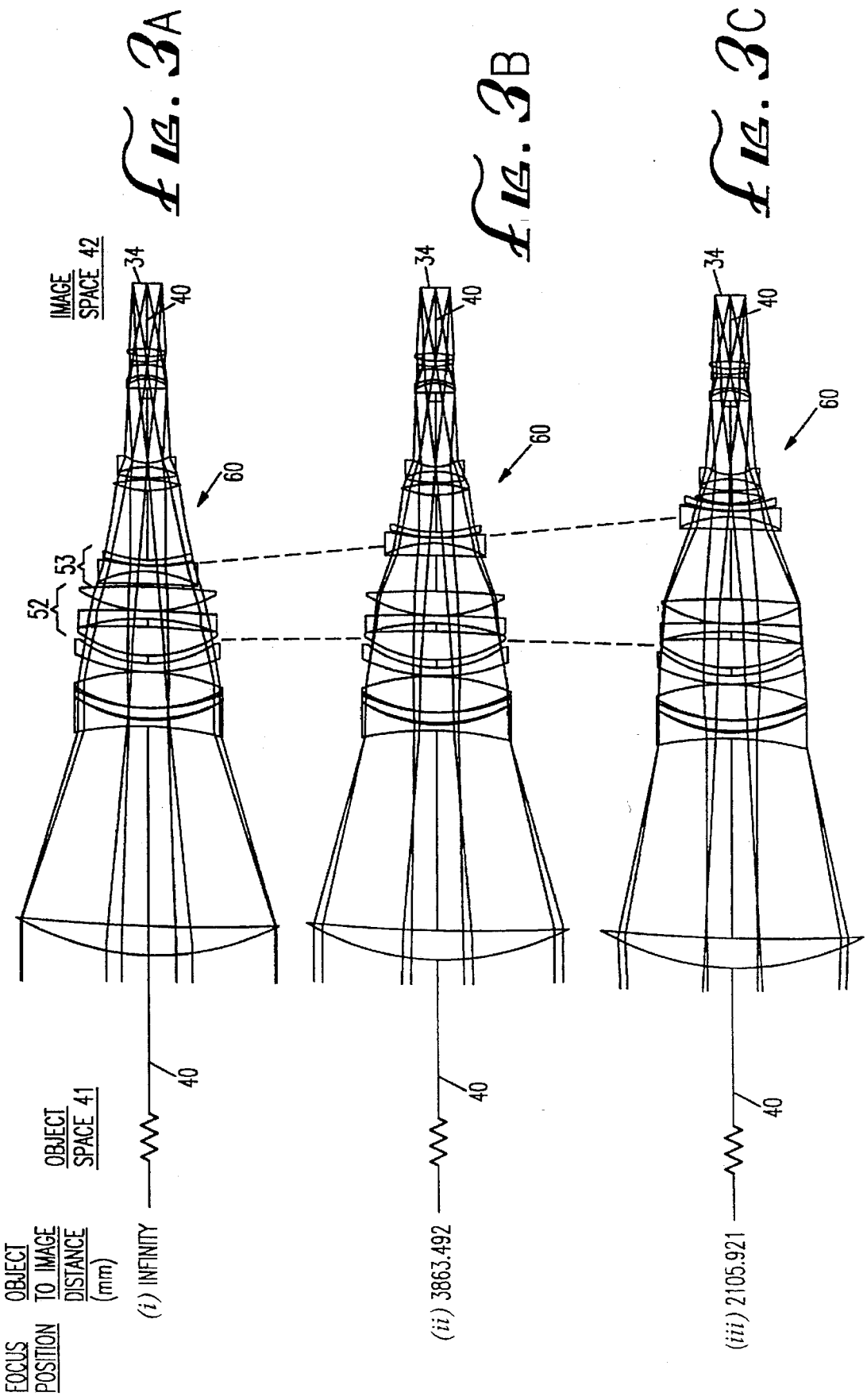


FIG. 3A
FIG. 3B
FIG. 3C
IMAGE SPACE 42
OBJECT SPACE 41
FOCUS POSITION
OBJECT TO IMAGE DISTANCE (mm)
(i) INFINITY
(ii) 3863.492
(iii) 2105.921
34
40
60
52
53

OBJECTIVE LENS SYSTEM

This invention relates to an optical objective lens system for cameras and the like and, in particular, to a large aperture, high performance, long focal length lens system using a combination of solid lenses and liquid lenses.

BACKGROUND OF THE INVENTION

High performance optical systems, such as for cinematography, require superior polychromatic optical performance and athermal characteristics. Previously, the design of large aperture, high performance, long focal length lens systems for the visible waveband has been limited by practical issues concerning length, volume, weight, cost and the availability of large dimensional sizes of raw material, especially glasses that exhibit abnormal dispersion characteristics. Catadioptric lenses do offer a significant reduction in overall length but they have the disadvantage of producing donut shaped images of out of focus point objects which, in many applications including cinematography, high definition television ("HDTV") and advanced television ("ATV") is unnatural and highly distracting or even disturbing to a viewer. In comparison, telephoto lenses offer reasonable compactness in terms of length and volume but demand multiple lens elements in the front objective grouping. These elements, apart from producing large weight, necessitate the use of abnormal dispersion glass or crystalline materials which are high in cost with limited availability or which may even be unavailable in large sizes. Aspheric surfaces can be used in the front objective grouping to reduce the quantity of lens elements required but aspheric surfaces are difficult to manufacture, are high in cost and do not eliminate the need for abnormal dispersion materials. Liquid optical materials which exhibit abnormal and highly abnormal dispersion characteristics, sometimes referred to as abnormal dispersion liquids (ADLs), offer an alternative to using abnormal dispersion glasses and crystals. However, liquid lens elements need to be supported and sealed by solid elements, for example, between two glass elements in a glass/liquid/glass cell which can be heavy in weight, especially when located in the front objective grouping because of the large diameter of the elements. If two compensating ADLs are employed, then the weight will be increased even more by the two glass/liquid/glass elements. In addition, liquid optical materials tend to exhibit large changes in refractive index with temperature changes, as compared to solid lens materials, which causes defocusing as well as loss of chromatic aberration control thus making the liquid lens system unusable at elevated and depressed temperatures.

SUMMARY OF THE INVENTION

It is an object of this invention to provide a large aperture, high performance, long focal length lens system for the visible waveband that is low in weight, relatively inexpensive, athermal and has superior polychromatic optical performance. For accomplishing that object, the lens system of this invention comprises a stationary telephoto objective lens grouping incorporating two liquid lens elements, a movable first focus lens grouping, a movable second focus lens grouping and a stationary auxiliary lens grouping which internally houses an optical stop or iris, all aligned on a common optical axis. By virtue of the telephoto objective design configuration, which contains a single spherically surfaced primary objective lens element and a rear telephoto lens grouping formed by quintuplet and singlet lenses, the system is compact and inexpensive with low weight.

The two independently movable focus lens groupings provide continuous focusing at a constant aperture over a focus range extending from an infinity object distance to a close focus object to image distance with an object to image magnification ratio of less than 3:1.

The two liquid elements, because of their highly abnormal dispersions, have low optical powers and therefore do not significantly affect the monochromatic aberration balance of the system. However, the system is well corrected for chromatic aberration. Furthermore, because the two liquid lens elements have opposite powers, they substantially compensate and correct the system as a whole for thermally induced defocus and aberration variations caused mainly by the very large changes in refractive index with temperature of the liquid materials. Although, the quintuplet lens group is formed by five elements, three glass and two liquid, the very thin liquid elements contribute very little to the overall weight of the quintuplet lens. The rear element of the quintuplet, which is farthest from the primary objective element, is preferably made of a glass or crystalline material that exhibits slightly abnormal dispersion and change in refractive index with temperature thus providing the system with a more consistent level of high performance at all operating temperatures. Apart from the two liquid elements and one rear element of the quintuplet lens, all remaining elements of the system can be made of standard glasses or other types of material which are low in cost and readily available from various vendors.

Another object of the present invention is to provide a large aperture high performance, long focal length lens system with a compact telephoto objective lens configuration which utilizes two abnormal dispersion liquid elements and one partly abnormal dispersion glass element. A still further object of the present invention is to provide a long focal length lens system which is low in weight and cost and provides a close focusing capability from an infinity object distance to a minimum focus distance magnification, object to image, of less than 3:1. A further object of the present invention is to provide a long focal length lens system which is substantially passively athermal both in constancy of image focus and quality over an extended range of object to image focus distances.

Other objects and advantages of the present invention will appear from the following description of a preferred embodiment and the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is an optical diagram of the objective lens system of the present invention;

FIG. **2** is an enlarged diagrammatic view of a portion of the lens system shown in FIG. **1**; and

FIGS. **3A**, **3B** and **3C** are optical diagrams of the optical system shown in FIG. **1** with the focus lens groupings adjusted to different positions for three representative focus positions.

DESCRIPTION OF A PREFERRED EMBODIMENT OF THE INVENTION

A preferred embodiment of the present invention is now described by way of a design example with accompanying Figures and Tables.

As depicted in FIG. **1**, an optical system **60** comprises an objective lens arrangement **47** containing a plurality of spherically surfaced lens elements in lens groupings **48**, **49**, **54** aligned on an optical axis **40** wherein a positively

powered, stationary, primary telephoto objective lens element "A" with refractive surfaces **1**, **2** collects radiation from an object plane OP in object space **41** and relays said radiation to a negatively powered, stationary, secondary telephoto objective group **50**, which relays said radiation to a positively powered, axially movable first focus group **52**, which relays said radiation to a negatively powered, axially movable second focus group **53**, which relays said radiation to a weakly powered, stationary, auxiliary lens group **54** which produces a real image at image plane **34** in image space **42**. The real image at plane **34** may be received by film in a camera or the like in a conventional manner. The shapes of the lens elements illustrated in the FIGS. are only generally representative of the exact shapes, radii, thicknesses and sizes which are set forth below in Table I, to be discussed below. FIGS. **1**, **3A**, **3B** and **3C** include representative ray trace lines extending from immediately in front of lens element A through the optical system **60** to image plane **34**.

The secondary telephoto objective group **50**, comprises a quintuplet lens sub-group **51** as depicted in greater detail in FIG. **2**, with lens elements B, C, D, E, F having lens refractive surfaces **3**, **4**, **5**, **6**, **7**, **8** and a singlet lens G with refractive surfaces **9**, **10**. It should be noted that for convenient reference, the two refractive "surfaces" of each of the two liquid lens elements C and E have been designated by the same reference number as the solid lens element refractive surface that contains that liquid because they are coincidental and coextensive therewith, such as, rear surface **4** of solid lens element B is the front surface **4** of liquid lens element C, rear surface **5** of liquid lens element C is the front surface **5** of solid lens element D, etc., whereby there are only six numerals 3–8 for the ten refractive surfaces of the five lens elements. The lens elements C and E are of liquid optical materials known as abnormal dispersion liquids (ADLs), as described below more fully, and the lens elements B, D and F are of solid lens material. The liquid lens element C is captured between solid lens elements B and D and the liquid lens element E is captured between solid lens elements D and F, with the five lens elements permanently assembled, in a conventional manner, to form the quintuplet (i.e. five integrated lenses) lens subgroup **51**. The liquid materials for the liquid lens elements C and E are selected to be complimentary or self-compensating for their respective optical characteristics (as well as the optical characteristics of the system). Specifically, it is preferred that liquid lens C be an ADL that provides chromatic correction, such as an ADL manufactured by Cargille Laboratories, Inc., Cedar Grove, N.J., USA and marketed by Lockheed Martin under the Code No. 642134. However, the ADL for liquid lens C also has the characteristic of causing substantial defocusing, as compared with glass lens materials, in response to temperature changes. Thus, the ADL for liquid lens element E is selected to provide optical power which compensates for the defocusing by liquid lens element C caused by temperature changes, such as an ADL manufactured by Cargille Laboratories, Inc. and marketed by Lockheed Martin under the Code No. 295990. However, the ADL for lens element E degrades the chromatic correction accomplished by lens element C and, therefore, the specific ADLs selected for lens elements C and E cannot completely compensate for both temperature changes (i.e. the system is not athermal) and chromatic aberrations (i.e. image quality). Thus, it is preferred that solid lens element F be made from a glass or crystalline having a refractive index and thermal expansion which are relatively moderately temperature sensitive and a dispersion which is relatively partly abnormal, such as a glass made and sold by Ohara Corp. under the Code No. 438950 and name FPL **53** or the equivalent. In the preferred embodiment, the remaining solid lens elements B and D of the quintuplet lens **51** are preferably made from an inexpensive optical glass. It is to be understood that one or more of the other lens elements B, D or G of the secondary telephoto objective group **50** or the primary telephoto objective lens element A or even the lens elements of the first focus group **52** may be made of glass or crystalline material having the afore-described properties of lens element F rather than or in addition to lens element F for providing the thermal, chromatic and other corrections not compensated for by the liquid lens elements C and E without departing from the present invention.

The first focus group **52** comprises three lens elements H, I, J with refractive surfaces **11**, **12**, **13**, **14**, **15**, **16** and the second focus group **53** comprises three lens elements K, L, M with surfaces **17**, **18**, **19**, **20**, **21** wherein the lens elements K, L form a doublet lens **55**. Again, as with the quintuplet lens **51**, the identical facing surfaces of lens elements K and L that are joined are identified as a single refractive surface **18**. The auxiliary group **54** comprises a first singlet lens N with refractive surfaces **22**, **23**, an optical stop or iris P, a first doublet lens **56** formed by lens elements R, S with refractive surfaces **24**, **25**, **26**, a field stop T, a second doublet lens **57** formed by lens elements V, W with refractive surfaces **27**, **28**, **29**, a second singlet lens X with refractive surfaces **30**, **31** and a third singlet lens Y with refractive surfaces **32**, **33**. As noted above, all of the lens elements H-N, R, S, V, W, X and Y may be of a common optical glass material. The optical system **60** is supported by a structure **43** which preferably is made of a light weight material, such as aluminum.

The construction of the optical system **60** is such that the distance on the optical axis **40** between the vertex of refractive surface **1** of lens element A to the real image plane **34** is fixed and remains constant, except for thermal expansion and contraction in the support structure **43**. The first focus group **52** and the second focus group **53** are axially movable along the optical axis **40**, as shown by the arrows **52A** and **53A**, respectively, in FIG. **1**, in a conventional manner by conventional mechanisms without changing the length of the optical system **60**. The supporting structure **43** is constructed to support all of the lens elements (A-N, R, S, V, W, X and Y) in series in that order on the optical axis **40** and at a maximum aperture diameter.

FIGS. **3A**, **3B** and **3C** diagrammatically illustrate the optical system **60** with the first focus group **52** and the second focus group **53** moved to their respective positions for three different representative distances from the object plane OP to the image plane **34**. Specifically, FIG. **3A** shows the focus positions (i) of the first and second focus groups **52** and **53** for an object to image distance of infinity, FIG. **3B** shows the focus positions (ii) of the first and second focus groups **52** and **53** with an object to image distance of 3863.492 mm, and FIG. **3C** shows the focus positions (iii) of the first and second focus groups **52** and **53** for an object image distance of 2105.921 mm, which is the minimum focus distance for the optical system **60** to provide high performance optical characteristics. The positions of the first and second focus groups **52** and **53** and the respective object to image distances shown in FIGS. **3A**, **3B** and **3C**, respectively, correspond to the Separation distances set forth in Table I (described and set forth below). The difference in the respective numbers for object to image distance in FIGS. **3B** and **3C** and the Separation between the Object Plane OP and refractive surface **1** of lens element A in Table I is simply

the length (668 mm) of the optical system **60** between the vertex of refractive surface **1** of lens element A to the image plane **34**. The second focus group **53** moves over a substantial range of approximately 67 mm for providing most of the focusing function of the optical system **60** while the first focus group **52** moves only a small amount of less than 4 mm for refining the focus by correcting or balancing aberrations that result from the substantial movement of the second focus group **53**, which distances are also represented in Table I below, and from the lens group **48**, as shown by the different positions of the ray trace lines through lens group **48** in FIGS. 3A, 3B and 3C.

Specific data for all of the lens elements of optical system **60**, including surface separations, radii, material (type, code and name) and aperture diameter are set forth in the following Table I, wherein "Separation" is the distance between one Surface and the next Surface (objective plane OP, refractive surfaces **1–33** and image plane **34**), and the "Type" of the "Material" is the material between that surface and the next surface progressing downwardly in Table I. The Separation for surfaces OP, **10**, **16** and **21** are given at three representative focus distances, assuming the overall length of optical system **60** from the vertex of surface **1** of lens element A to the image plane **34** remains constant at 668 mm (i.e. ignoring thermal changes), and those focus distances are specifically set forth in the Separation column, opposite Object Plane OP. In other words, for example, for an intermediate focus distance of 3195.492 mm from the object plane OP to the refractive surface **1** of lens element A, the distance between the rear refractive surface **10** of the lens element G to the front refractive surface **11** of the lens element H is 8.168 mm and the latter distance changes as the focus distance changes because the first focus group **52** which includes lens element H moves axially for focusing. The "Aperture Diameter" at the Image Plane **34** given in Table I is actually the image diameter based on paraxial data. All data in Table I is given at a temperature of 20° C. (68° F.).

TABLE I

Item	Group	Subgroup	Surface	Separation (mm)	Radius of Curvature (mm)	Material Type	Material Code	Material Name	Aperture Diameter (mm)
Object Plane			OP	Infinite 3195.482 1437.921	Flat	Air			
A			1	29.350	295.058	Glass	723380	BAH28	252.00
			2	194.046	2147.773	Air			250.18
B	50	51	3	6.650	−336.508	Glass	667331	PBM39	144.90
C	50	51	4	1.939	142.976	Liquid	642134	None	144.17
D	50	51	5	10.660	154.354	Glass	516642	BSL7	144.17
E	50	51	6	0.300	187.120	Liquid	295990	None	144.83
F	50	51	7	36.110	158.264	Glass	438950	FPL53	145.71
	50	51	8	1.000	−217.194	Air			146.39
G	50		9	7.100	197.008	Glass	773496	LAH66	142.52
	50		10	7.319 8.168 4.884	120.250	Air			136.43
H	52		11	26.650	131.697	Glass	571508	BAL2	137.30
	52		12	8.342	−997.410	Air			136.07
I	52		13	6.700	−253.396	Glass	667331	PBM39	135.37
	52		14	1.000	−7530.388	Air			134.64
J	52		15	21.990	153.695	Glass	583594	BAL42	133.14
	52		16	3.606 35.321 73.727	−1143.000	Air			131.160
K	53	55	17	12.770	−1774.180	Glass	762401	LAM55	96.45
L	53	55	18	5.100	−114.090	Glass	805254	TIH6	95.07
	53	55	19	1.000	217.156	Air			86.92
M	53		20	4.900	180.721	Glass	569563	BAL14	86.17
	53		21	70.712 38.148 3.026	120.764	Air			83.06
N	54		22	10.040	116.519	Glass	720437	LAM52	64.04
	54		23	0.800	−194.521	Air			62.84
P	54		Iris	1.328	Flat	Air			59.25
R	54	56	24	10.960	153.440	Glass	626357	PBM1	55.16
S	54	56	25	4.480	−73.718	Glass	773496	LAH66	52.33
	54	56	26	67.521	38.575	Air			42.70
T	54		Field Stop	8.644	Flat	Air			36.00
V	54	57	27	10.310	407.198	Glass	720347	BPH8	37.52
W	54	57	28	2.600	−30.434	Glass	785257	TIH11	37.71
	54	57	29	10.600	−55.689	Air			38.36
X	54		30	2.800	−67.564	Glass	804466	LAH65	33.61
	54		31	5.732	57.597	Air			33.74
Y	54		32	6.940	67.910	Glass	717295	PBH1	37.06
	54		33	68.000	−114.579	Air			37.26
Image Plane			34	0.000	Flat	Air			28.90

The "Radius of Curvature" values set forth in Table I have a positive value when the center of the radius of curvature of that refractive surface is closer to the image space **42** than is the vertex of that refractive surface and a negative value when the center of the radius curvature of that refractive surface is closer to the object space **41** than is the vertex of that refractive surface.

In Table I, the Code and Name of the Material for all of the solid lens elements are based on glass lenses manufactured and marketed by Ohara Corporation but many of the glasses are available from other sources and may be substituted if such glasses are substantially similar in optical and mechanical properties, especially refractive index, dispersion, thermal expansion and change of refractive index with temperature. The liquid lens elements C and E in Table I are manufactured by Cargille Laboratories, Inc. and marketed by Lockheed Martin, but any equivalent ADLs may be used. The refractive indices of the ADLs, as supplied by Lockheed Martin from actual test data, for the liquid lens elements C and E for five representative wavelengths and at three different temperatures are set forth in the following Table II.

TABLE II

Liquid Lens	Temperature		Refractive Indices at wavelengths (nanometers)				
Element	°C.	°F.	656.3	587.6	546.1	486.1	435.8
C	20	68	1.630387	1.642690	1.653508	1.678028	1.716612
C	40	104	1.619870	1.631899	1.642414	1.666424	1.704113
C	0	32	1.640904	1.653481	1.664602	1.689632	1.729111
E	20	68	1.296909	1.297816	1.298522	1.299864	1.301440
E	40	104	1.289842	1.290744	1.291448	1.292759	1.294264
E	0	32	1.303976	1.304888	1.305596	1.306969	1.308616

The image quality of the optical system **60** has been computed theoretically in accordance with accepted optical principles and programs to provide image quality data in terms of modulation, i.e. contrast, of the modulation transfer function (commonly known by the acronym MTF), the results of which are shown in the following Table III. The image quality data in terms of MTF was calculated on the basis of a temperature of 20° C. for three focal distances and at temperatures of 0° C. and 40° C. at the nominal design focus distance, as shown in Table III, and the data assumed an all aluminum support structure **43**. The glass coefficients of refractive index and expansion with temperature were obtained from commonly available data publications produced by the vendor, Ohara Corporation. The refractive index of the two liquid lens elements C and E were obtained from the vendor, Lockheed Martin. The liquid thermal expansion coefficients of the ADLs of the two liquid lens elements C and E are of no consequence and were not considered because the ADLs are constrained by the surrounding glass elements and conventional mounting elements that include bellows or reservoirs (external to the optical area of use) that accommodate the volumetric change in the ADLs. With these parameters, the approximate polychromatic MTF performance (all at the best focus averaged over the field) in terms of percent (%) Modulation at Radial (R) and Tangential (T) azimuths for wavelengths of 656.3, 587.6, 546.1, 486.1 and 435.8 nanometers with respective weightings of 70, 80, 90, 75, 60 and full field % distortion and % relative illumination, with a normalized field position for maximum image heights equal to 14.45 mm are shown in Table III.

TABLE III

Object to Image Distance	Temperature		0	½		¾		Full			% Relative
(mm)	°C.	°F.	R & T	R	T	R	T	R	T	% Distortion	Illumination
Infinity	20	68	82.1	82.5	81.8	84.4	77.0	84.6	67.9	0.4	51
3863.94	20	68	84.2	84.7	83.2	84.2	79.1	83.1	71.6	0.4	56
2105.92	20	68	75.1	74.1	75.0	75.6	75.6	77.6	71.9	0.4	57
3863.94	40	104	60.6	62.2	62.4	64.2	60.0	67.1	54.2	0.4	55
3863.94	0	32	72.4	70.1	70.7	68.0	68.0	65.2	62.8	0.4	56

Table III illustrates that the optical system **60** is optimized for maximum performance at object to image distances from about three meters to infinity at a temperature of 20° C. (68° F.). The system full aperture is f/2.75 at all focus distances and temperatures. The spectral waveband of the optical system is 435.8 to 656.3 nanometers. At 20° C. (68° F.) and for an object at infinity distance, the effective focal length (EFL) of this optical system is approximately 692.9 mm. The telephoto ratio of the EFL to the overall length of approximately 668 mm (measured from the vertex of surface **1** of lens element A to the image surface **34**) is 668/692.9 equals 0.964. Generally, for a lens to be considered telephoto, the telephoto ratio should be less than 1.0. Although the telephoto ratio of 0.964 of the optical system **60** is not much less than 1.0, this is the result of optionally

selected design features of the internal housing optics that consume considerable length along the optical axis **40**, such as the first and second independently movable focus groups **52** and **53**. The telephoto ratio can easily be reduced to less than 0.9 by excluding one or more of the optional design features described above. The focus range of the optical system **60**, as measured axially from the object to the image plane **34** at 20° C. is from infinity to 2.106 meters (6'10.9") and has a close focus magnification of 2.53:1 (object:image). The temperature range of the optical system **60**, as designed and described above, is 0° C. (32° F.) to 40° C. (104° F.) with a nominal design temperature of 20° C. (68° F.). However, this optical system will maintain a high level of performance over at least an extended temperature range of −10° C. to +50° C., although some degradation of image quality may be observed at high temperatures. It should be noted that within the temperature range of −10° C. to +50° C., the ADLs of the liquid lens elements C and E will not solidify and, of course, the solid lens elements will not liquify. The optical system **60** provides the required "high performance" as measured by the polychromatic MTF being greater than 70% and preferably greater than 80% (on axis) and 60% to 70% (off axis) over the field, as shown by the values set forth in Table III.

It should be noted that while the liquid materials or ADLs of the liquid lens elements C and E have been described as partly or highly "abnormal" and the material of the solid lens element F has been described as a glass or crystalline that is relatively moderately temperature sensitive and relatively partly "abnormal" that these descriptions relate to the differences in characteristics of those materials from normal, classical or standard optical materials, usually glass. Here, the material of solid lens element F is described as having a dispersion which is relatively partly abnormal only by comparison to the liquid material of liquid lens element C which is highly abnormal compared to other glasses but indeed the solid lens element F is substantially abnormal when compared to normal glasses. It will readily appear to those skilled in the art from the teachings of this invention that numerous variations in the materials for the liquid lens elements and the solid lens elements, whether available now or in the future, may be adopted without departing from the teachings of this invention so long as the resultant optical system **60** is athermal and corrected for chromatic aberrations and other aberrations.

What is claimed is:

1. A visible waveband optical system comprising, an objective lens for delivering visible radiation emanating from an object space to a radiation detecting device, said objective lens including a plurality of lens elements in a plurality of lens groupings mounted in spaced apart relationship on a common support assembly and aligned on a common optical axis, a first lens grouping adjacent the object space formed by a telephoto objective lens comprising primary and secondary lens groups, said first lens grouping arranged to accept visible radiation from the object space and remaining lens groupings are sequentially arranged to accept and relay said radiation from the first lens grouping to form a real image thereof at an external image surface, said primary lens group formed by a single lens element, said secondary lens group formed by a quintuplet lens and a singlet lens element, said primary lens group being positively powered and made of a glass material having a refractive index and expansion which are substantially temperature insensitive and a dispersion which is substantially normal, the secondary lens group being negatively powered with said quintuplet lens being formed by a sandwich of three solid lens elements and two liquid lens elements in a solid/liquid/solid/liquid/solid configuration, said liquid lens elements being separate from each other, two of said solid lens elements made of glass materials having a refractive index and expansion which are substantially temperature insensitive and a dispersion which is substantially normal, a third solid lens element of said three solid lens elements made of at least one of either a glass or crystalline material having a refractive index and expansion which are temperature sensitive and a dispersion which is abnormal, said two liquid lens elements being visibly transmissive optical liquids having refractive indices which are temperature sensitive and the dispersions which are abnormal, and said singlet lens element of said secondary lens group is made of glass material having a refractive index and expansion which are substantially temperature insensitive and a dispersion which is substantially normal, said optical system being such that chromatic and thermal aberrations introduced by lens element refractive index, dispersion and expansion and displacements caused by the expansion of said support assembly are compensated by said two liquid lens elements and said third solid lens element of glass or crystalline material so that the optical system is rendered substantially passively athermal both in constancy of image position and image quality.

2. The optical system of claim **1** further comprising an internal focusing lens group.

3. The optical system of claim **1**, further comprising two internal focusing lens groups.

4. The optical system of claim **2** or **3**, wherein said focusing lens groups are internally movable relative to the support assembly, said support assembly having a fixed length.

5. The optical system of claim **4**, further comprising an auxiliary lens group for forming an image.

6. The optical system of claim **5** wherein said lens groups are arranged on the common axis in the order of said primary lens group, said quintuplet lens, said singlet lens element, said two focusing lens groups, and said auxiliary lens group.

7. The optical system of claim **1**, wherein said singlet lens element is made of one of either a glass or a crystalline material having a refractive index and expansion which are temperature sensitive and a dispersion which is abnormal, and said quintuplet lens has three solid elements made of glasses, the refractive index and expansion of which are substantially temperature insensitive and the dispersions of which are substantially normal.

8. The optical system as claimed in claim **1**, wherein said common support assembly is made of aluminum.

9. A visible waveband optical system, comprising, an objective lens group having a single lens element and a quintuplet lens aligned on a common axis and substantially spaced from each other with said quintuplet lens being closer to an image plane, said quintuplet lens comprised of first, second and third solid lens elements and first and second liquid lens elements with said first liquid lens element formed between said first and second solid lens elements and said second liquid lens element formed between said second and third solid lens elements, said first and second liquid lens elements being of two different visibly transmissive optical liquids having temperature sensitive refractive indices and abnormal dispersions for producing chromatic and thermal aberration corrections, two of said solid lens elements being of glass materials having refractive indexes and coefficients of thermal expansion which are substantially temperature insensitive, and the remaining one of the three solid lens elements having a refractive index and a coefficient of thermal expansion which are temperature

sensitive for producing chromatic and thermal aberration corrections that are uncorrected by said two liquid lens elements.

10. The optical system of claim **9**, wherein said single lens element is positively powered for receiving radiation from an object and transmitting the radiation to said quintuplet lens.

11. The optical system of claim **9** or **10**, wherein said quintuplet lens is negatively powered.

12. The optical system of claim **11**, further comprising a focusing lens group.

13. The optical system of claim **11**, further comprising two focusing lens groups, wherein each focusing lens group is independently movable along the common axis.

14. The optical system of claim **13**, further comprising an auxiliary lens group for forming an image on said image plane.

15. The optical system of claim **14**, wherein said lens groups are arranged on the common axis in the order of said single positively powered lens element, said quintuplet lens, said two focusing lens groups, and said auxiliary lens group.

16. The optical system of claim **9**, wherein said optical liquid of said first liquid lens element has a refractive index and abnormal dispersion for producing primarily chromatic correction, and said optical liquid of said second liquid lens element has characteristics for producing primarily thermal aberration correction.

17. The optical system of claim **16**, wherein said optical liquid of said second liquid lens primarily corrects thermal aberrations created by said first liquid lens.

18. The optical system of claim **16**, wherein said first liquid lens is located on a side of said second solid lens that is closer to said single lens element.

19. The optical system of claim **9** or **18**, wherein said remaining one of the three solid lens elements is located on a side of said quintuplet lens farther than said two solid lens elements from said single lens element.

20. A visible waveband optical system, comprising, an objective lens group having a single lens element and a quintuplet lens aligned on a common axis and substantially spaced from each other with said quintuplet lens being closer to an image plane, said quintuplet lens comprised of first, second and third solid lens elements and first and second liquid lens elements with said first liquid lens elements formed between said first and second solid lens elements and said second liquid lens element formed between said second and third solid lens elements, said first and second liquid lens elements being of two different visibly transmissive optical liquids having temperature sensitive refractive indices and abnormal dispersions for producing chromatic and thermal aberration corrections, said objective lens group also having a second single lens and a focusing lens group, at least one lens element of said single lens element, second single lens element, first, second and third solid lens elements and said focusing lens group being of a solid material having a refractive index and a coefficent of thermal expansion for producing chromatic and thermal aberration corrections that are uncorrected by said two liquid lens elements.

21. The optical system of claim **20**, wherein said single lens element is positively powered for receiving radiation from an object and transmitting the radiation to said quintuplet lens, and said quintuplet lens is negatively powered.

22. The optical system of claim **21**, wherein said second single lens is said one lens element.

23. The optical system of claim **22** wherein said lens groups and elements are arranged on the common axis in the order of said single lens element, said quintuplet lens, said second single lens and said focusing lens group.

24. The optical system of claim **20**, wherein said optical liquid of said first liquid lens element has a refractive index and abnormal dispersion for producing primarily chromatic correction, and said optical liquid of said second liquid lens element has characteristics for producing primarily thermal aberration correction.

25. The optical system of claim **24**, wherein said optical liquid of said second liquid lens primarily corrects thermal aberrations created by said first liquid lens.

26. The optical system of claim **24**, wherein said first liquid lens is located on a side of said second solid lens that is closer to said single lens element.

27. A visible waveband optical system comprising:

lens elements, groups and subgroups supported and arranged on a common axis from an end closer to an object to an end closer to an image formed by the optical system, in the following order;

a first single lens A,

a quintuplet lens having lens elements B, C, D, E and F,

a second single lens G,

a first focusing lens group having lens elements H, I and J,

a second focusing lens group having lens elements K, L and M, and

an auxiliary lens group having a lens element N, an iris P, lens elements R and S, a field stop T, and lens elements V, W, X and Y;

wherein said lens elements C and E are of optical liquid materials and the remaining lens elements are of solid materials, and

wherein the lens elements, groups and subgroups have characteristics with respect to an object plane and an image plane at three representative focus distances, as follows;

Item	Group	Subgroup	Surface	Separation (mm)	Radius of Curvature (mm)	Material Type	Material Code	Material Name	Aperture Diameter (mm)
Object Plane			OP	Infinite 3195.492 1437.921	Flat	Air			
A			1	29.350	295.058	Glass	723380	BAH28	252.00
			2	194.046	2147.773	Air			250.18
B	50	51	3	6.650	−336.508	Glass	667331	PBM39	144.90
C	50	51	4	1.939	142.976	Liquid	642134	None	144.17
D	50	51	5	10.660	154.354	Glass	516642	BSL7	144.17
E	50	51	6	0.300	187.120	Liquid	295990	None	144.83

-continued

Item	Group	Subgroup	Surface	Separation (mm)	Radius of Curvature (mm)	Material Type	Material Code	Material Name	Aperture Diameter (mm)
F	50	51	7	36.110	158.264	Glass	438950	FPL53	145.71
	50	51	8	1.000	−217.194	Air			146.39
G	50		9	7.100	197.008	Glass	773496	LAH66	142.52
	50		10	7.319	120.250	Air			136.43
				8.168					
				4.884					
H	52		11	26.650	131.697	Glass	571508	BAL2	137.30
	52		12	8.342	−997.410	Air			136.07
I	52		13	6.700	−253.396	Glass	667331	PBM39	135.37
	52		14	1.000	−7530.388	Air			134.64
J	52		15	21.990	153.695	Glass	583594	BAL42	133.14
	52		16	3.606	−1143.000	Air			131.160
				35.321					
				73.727					
K	53	55	17	12.770	−1774.180	Glass	762401	LAM55	96.45
L	53	55	18	5.100	−114.090	Glass	805254	TIH6	95.07
	53	55	19	1.000	217.156	Air			86.92
M	53		20	4.900	180.721	Glass	569563	BAL14	86.17
	53		21	70.712	120.764	Air			83.06
				38.148					
				3.026					
N	54		22	10.040	116.519	Glass	720437	LAM52	64.04
	54		23	0.800	−194.521	Air			62.84
P	54		Iris	1.328	Flat	Air			59.25
R	54	56	24	10.960	153.440	Glass	626357	PBM1	55.16
S	54	56	25	4.480	−73.718	Glass	773496	LAH66	52.33
	54	56	26	67.521	38.575	Air			42.70
T	54		Field Stop	8.644	Flat	Air			36.00
V	54	57	27	10.310	407.198	Glass	720347	BPH8	37.52
W	54	57	28	2.600	−30.434	Glass	785257	TIH11	37.71
	54	57	29	10.600	−55.689	Air			38.36
X	54		30	2.800	−67.564	Glass	804466	LAH65	33.61
	54		31	5.732	57.597	Air			33.74
Y	54		32	6.940	67.910	Glass	717295	PBH1	37.06
	54		33	68.000	−114.579	Air			37.26
Image Plane			34	0.000	Flat	Air			28.90

* * * * *

US005636058A

United States Patent [19]

Amemiya

[11] Patent Number: 5,636,058

[45] Date of Patent: Jun. 3, 1997

[54] **MICROSCOPE OBJECTIVE LENS AND MICROSCOPE USING THE SAME**

[75] Inventor: **Noboru Amemiya**, Fujisawa, Japan

[73] Assignee: **Nikon Corporation**, Japan

[21] Appl. No.: **443,226**

[22] Filed: **May 17, 1995**

[30] **Foreign Application Priority Data**

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Jan. 6, 1995 [JP] Japan 7-000871

[51] **Int. Cl.**[6] **G02B 21/02**

[52] **U.S. Cl.** **359/656**; 359/657

[58] **Field of Search** 359/656, 657, 359/658, 659, 660, 661

[56] **References Cited**

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Primary Examiner—Scott J. Sugarman
Assistant Examiner—Jordan M. Schwartz
Attorney, Agent, or Firm—Pennie & Edmonds

[57] **ABSTRACT**

This invention has as its object to eliminate flare light as a cause of low contrast. A microscope objective lens has, in the following order from the object side, a front group having positive refracting power to convert a beam from an object into a convergent beam, and having a positive meniscus lens element with a concave surface facing the object side, and a cemented lens component disposed at the image side of the positive meniscus lens, and a rear group having negative refracting power, constituted by cementing a negative lens element and a positive lens element, and disposed at the image side of the front group. A last cemented lens component, disposed nearest to the image side, of the cemented lens component in the front group satisfies:

$$|R_1|/f>100 \quad (1)$$

$$|R_2|/f>20 \quad (2)$$

where R_1 is the radius of curvature of a lens surface on the object side of the last cemented lens component, R_2 is the radius of curvature of a lens surface on the image side of the last cemented lens component, and f is the focal length of the microscope objective lens.

10 Claims, 14 Drawing Sheets

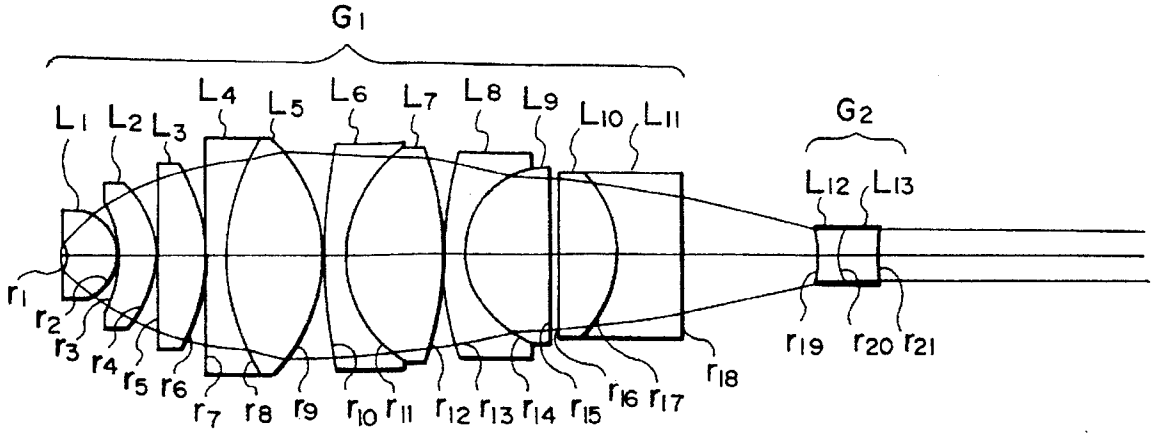
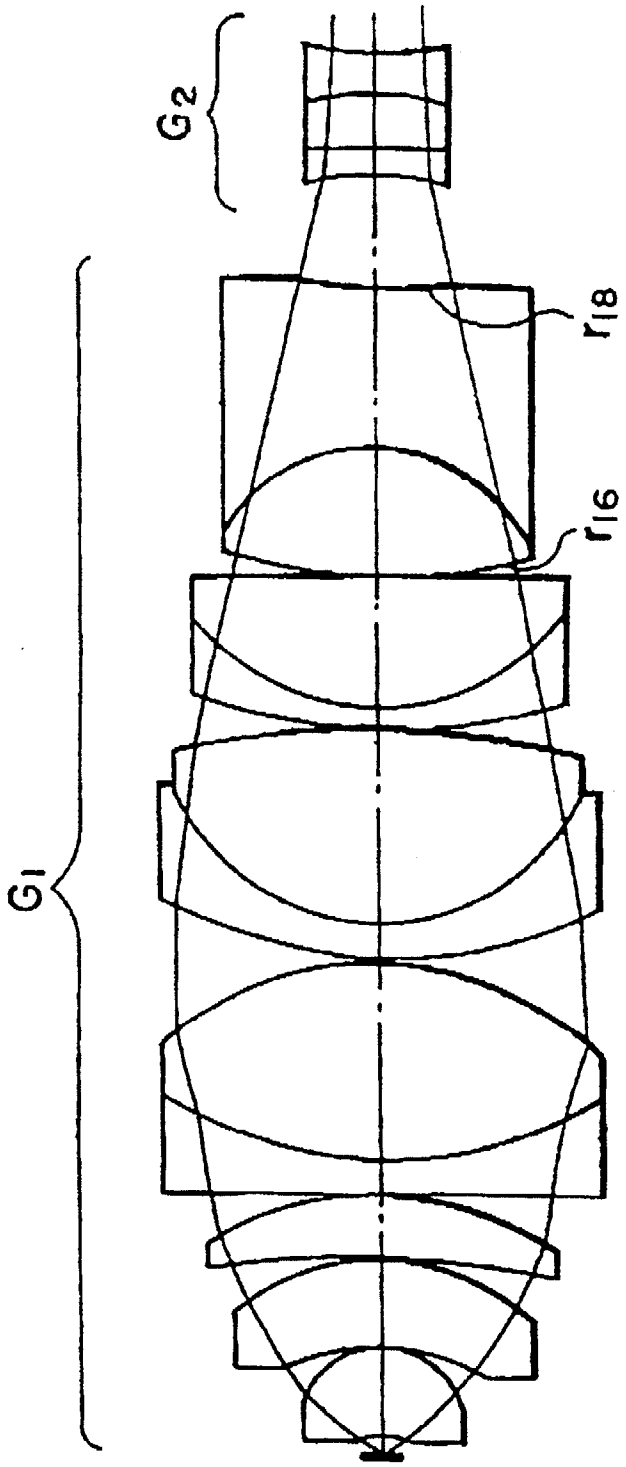


Fig. 1



(PRIOR ART)

Fig. 2

(PRIOR ART)

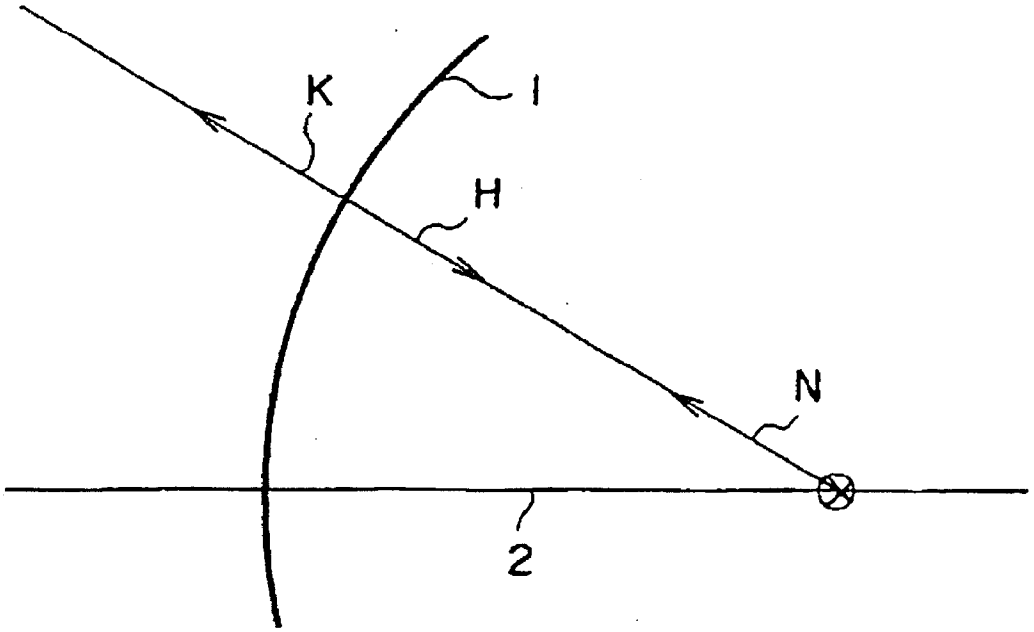


Fig. 3

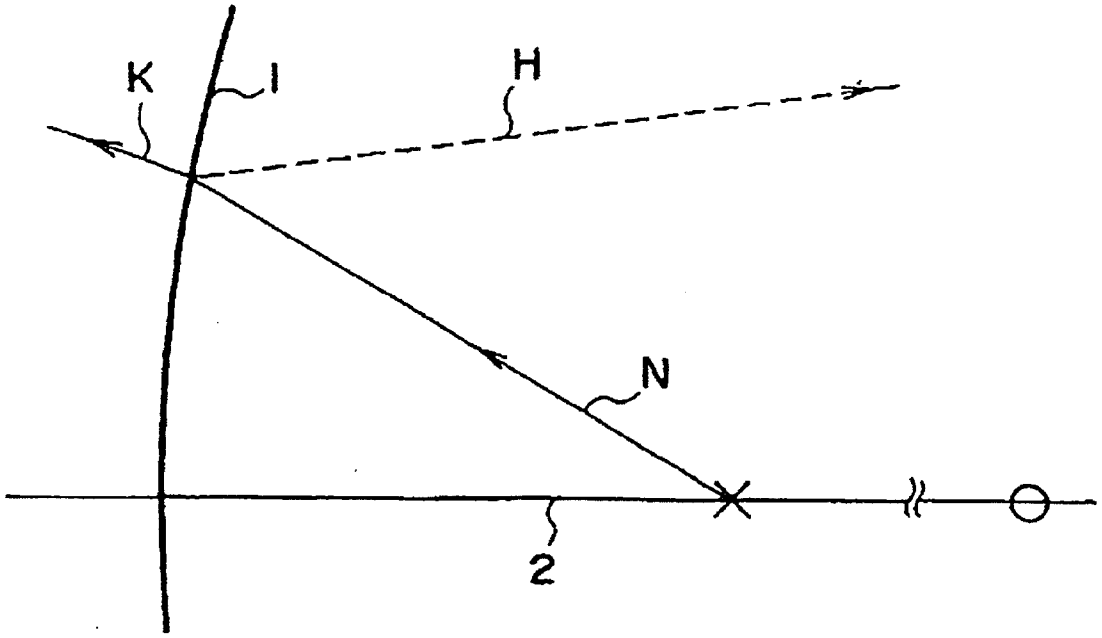


Fig. 4

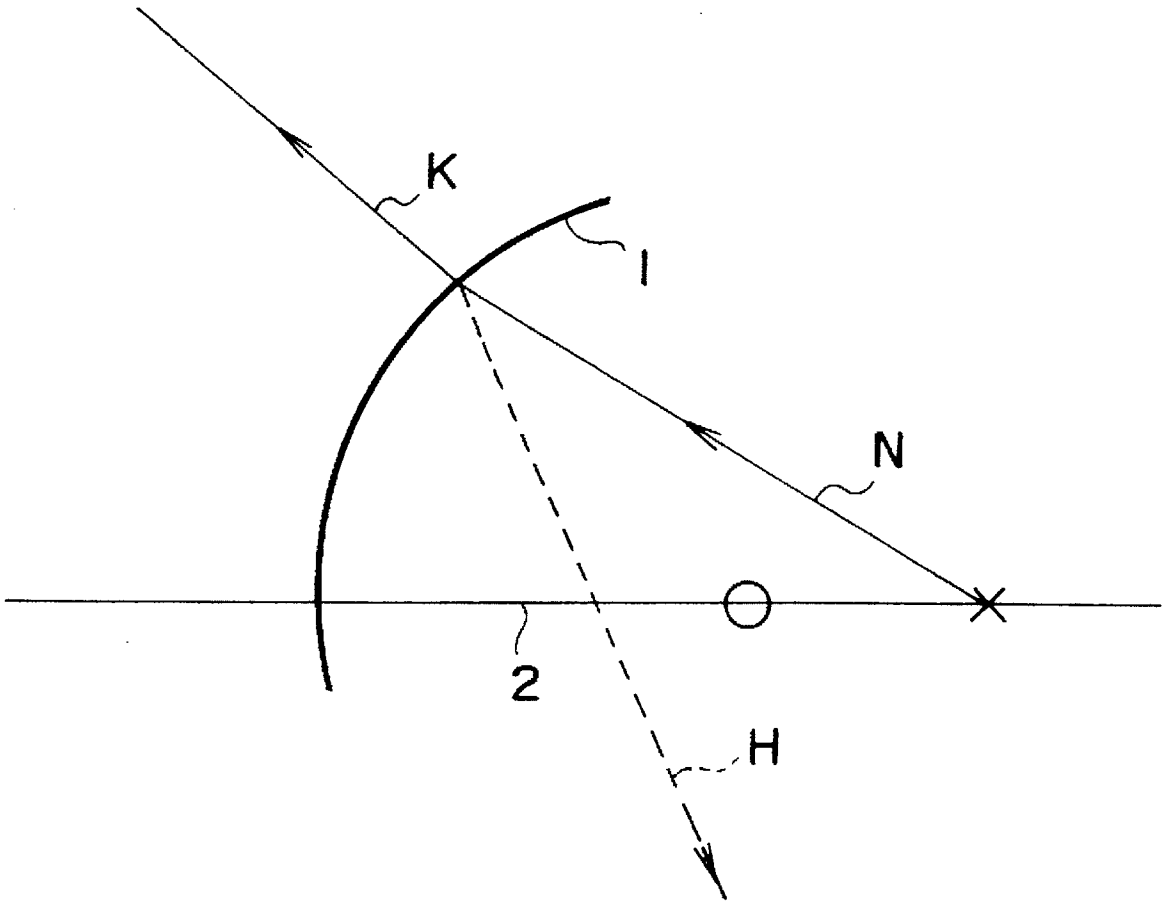


Fig. 5

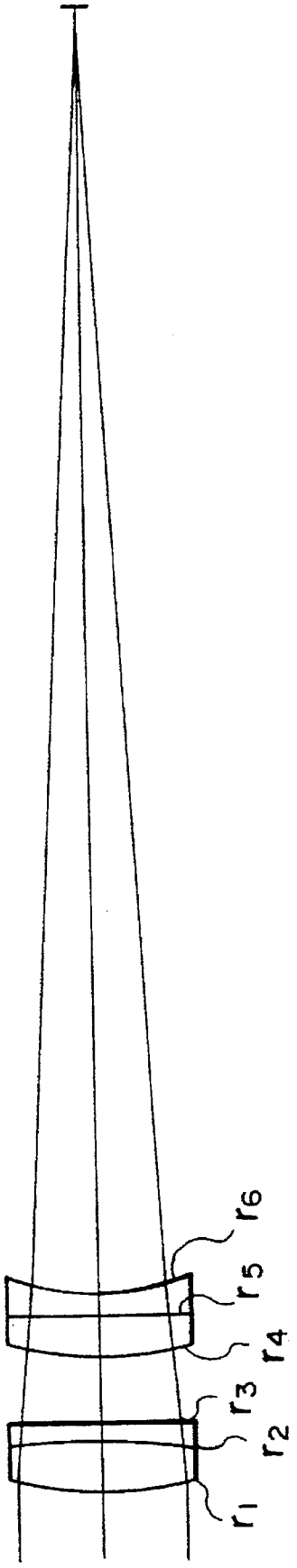


Fig. 6

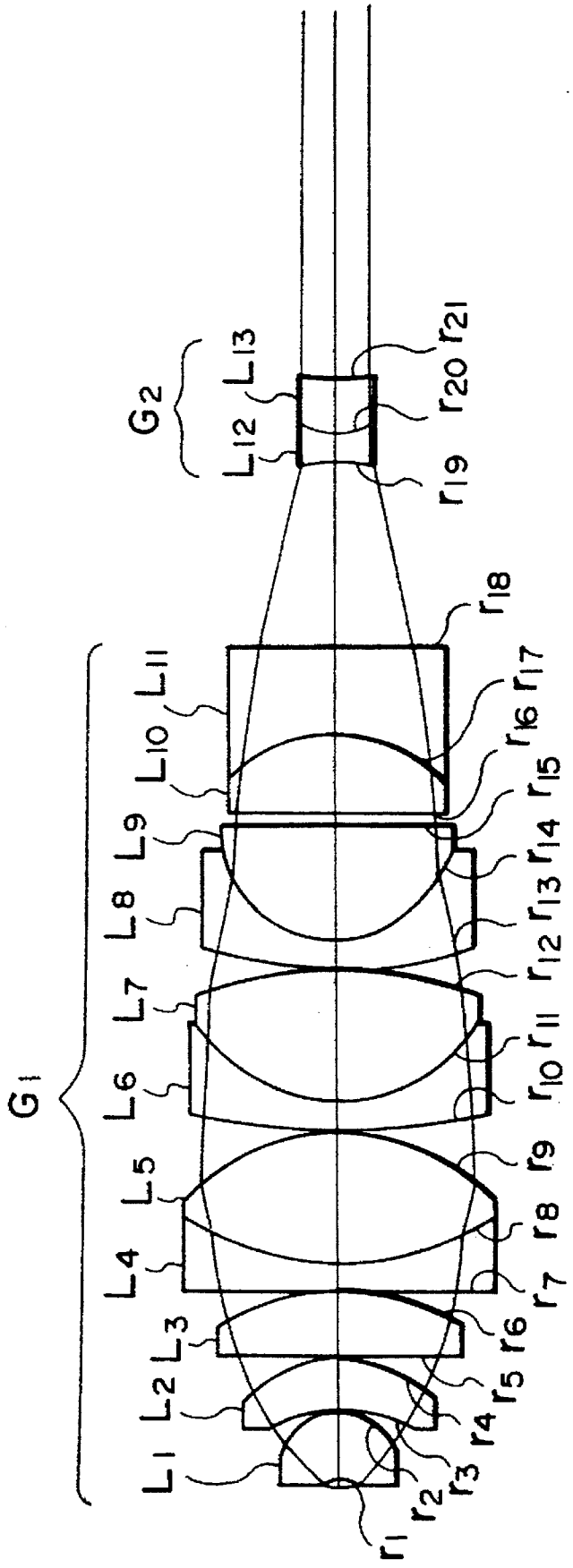

G1
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Fig. 7

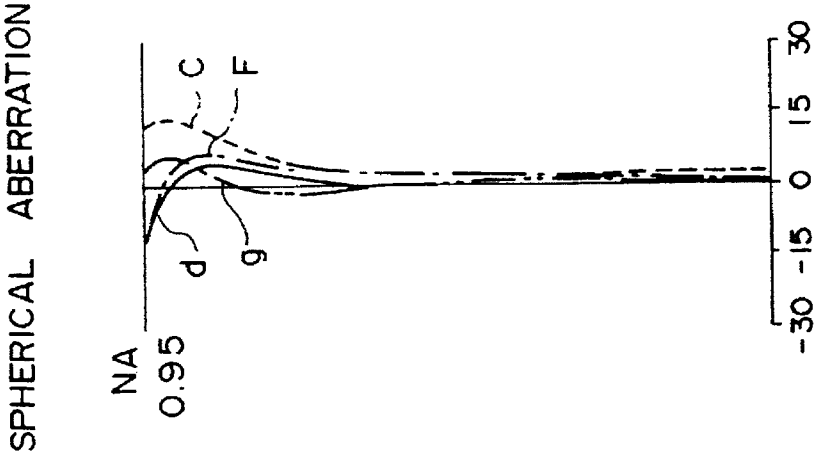
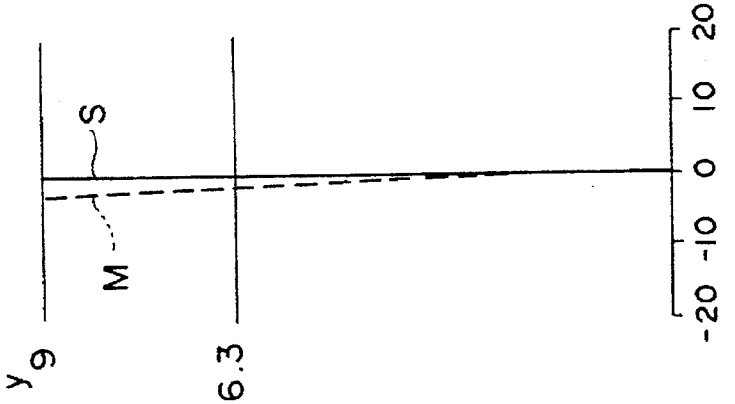


Fig. 8



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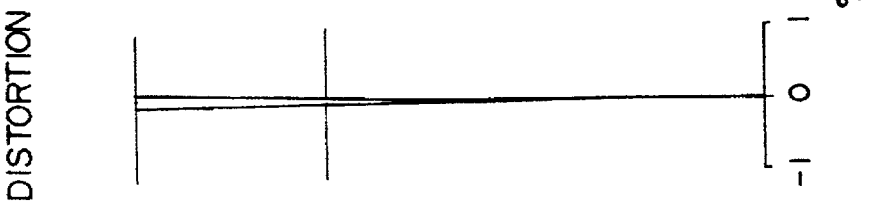

Fig. 10

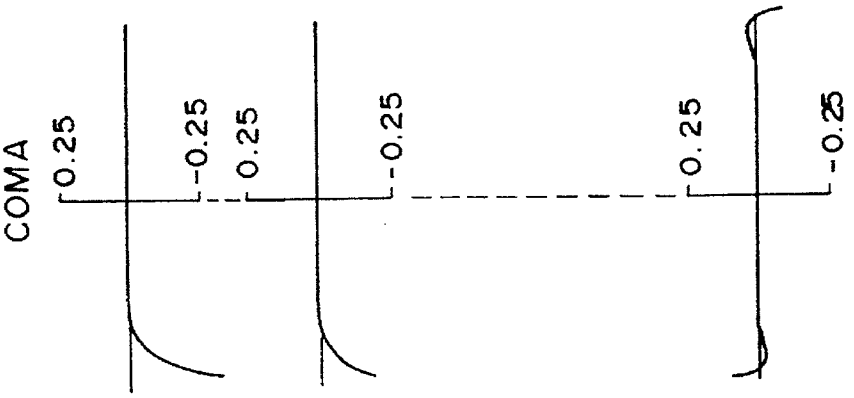

Fig. 11

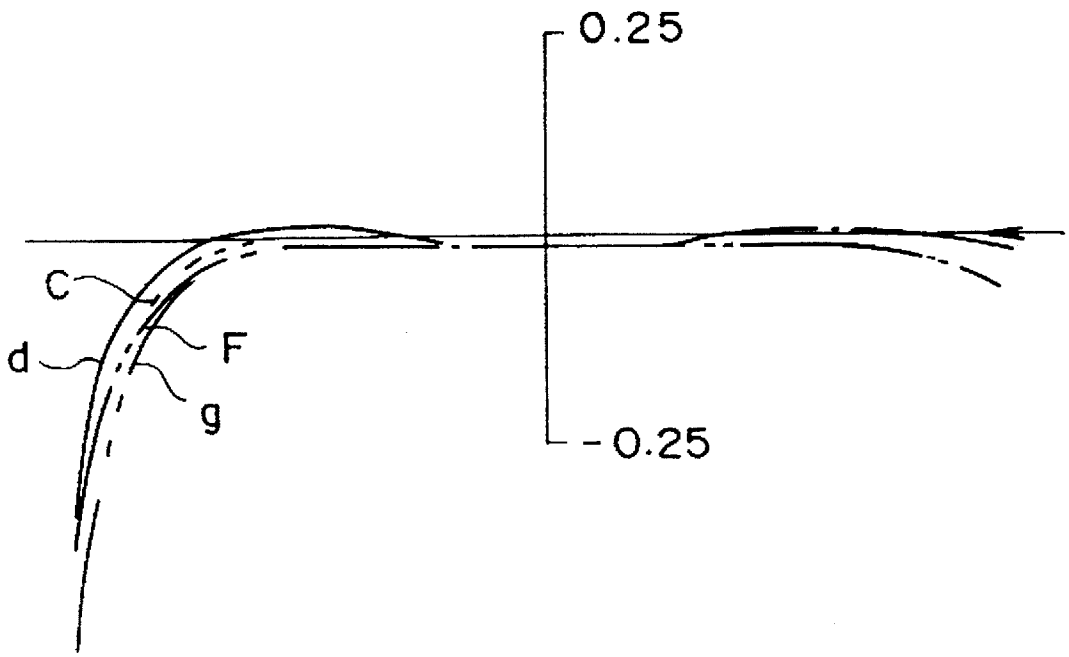

Fig. 12

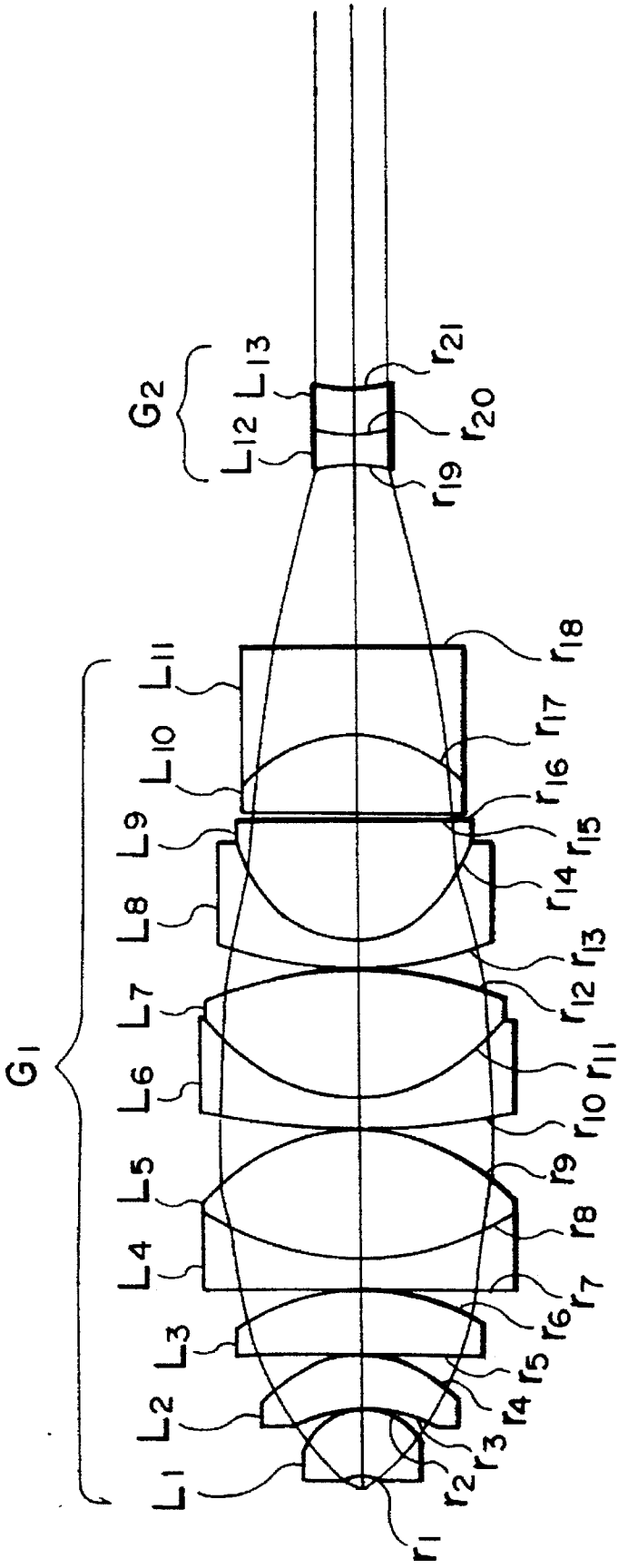
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Fig. 16

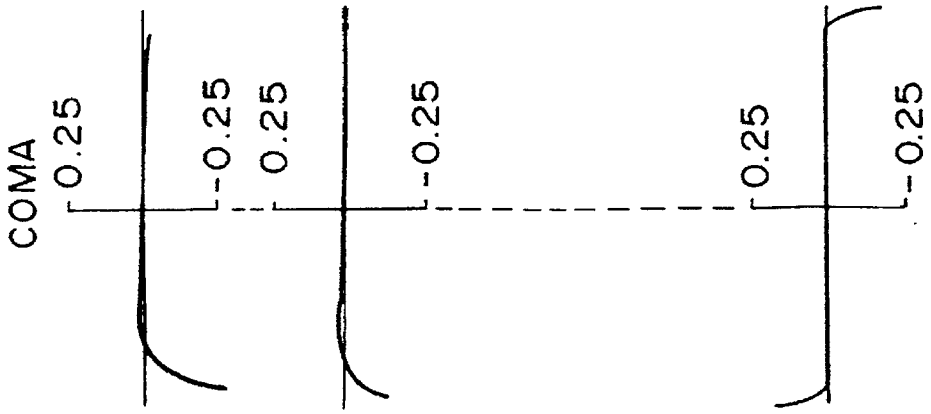


Fig. 15

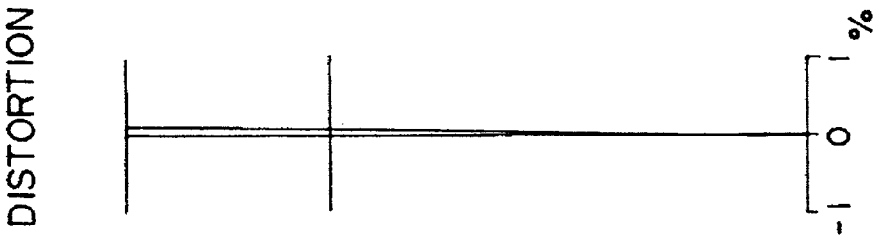


Fig. 14

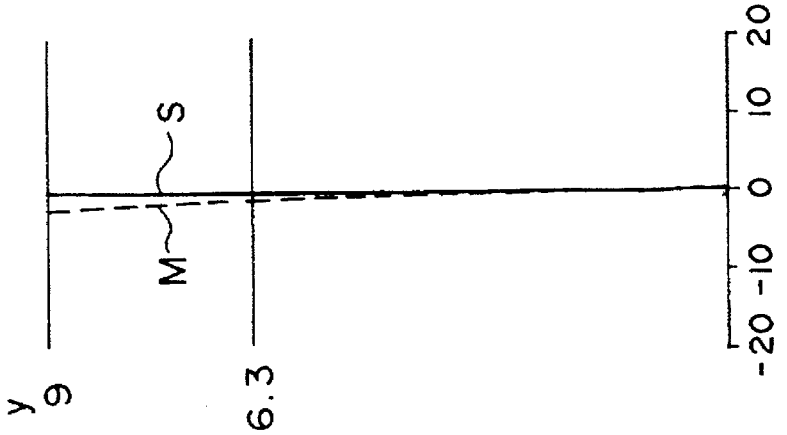


Fig. 13

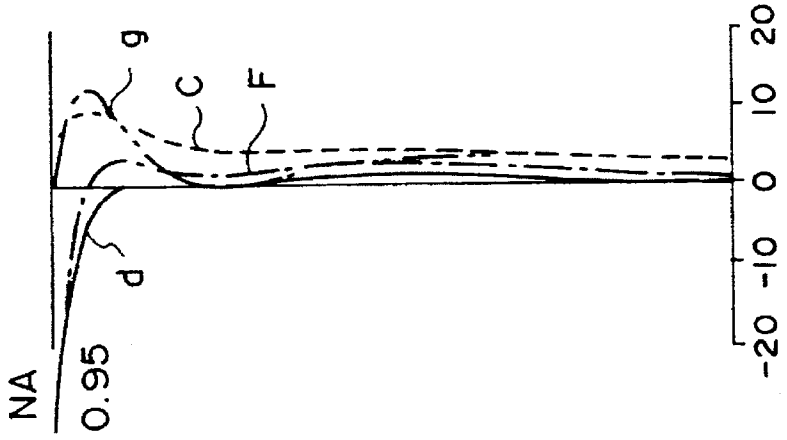
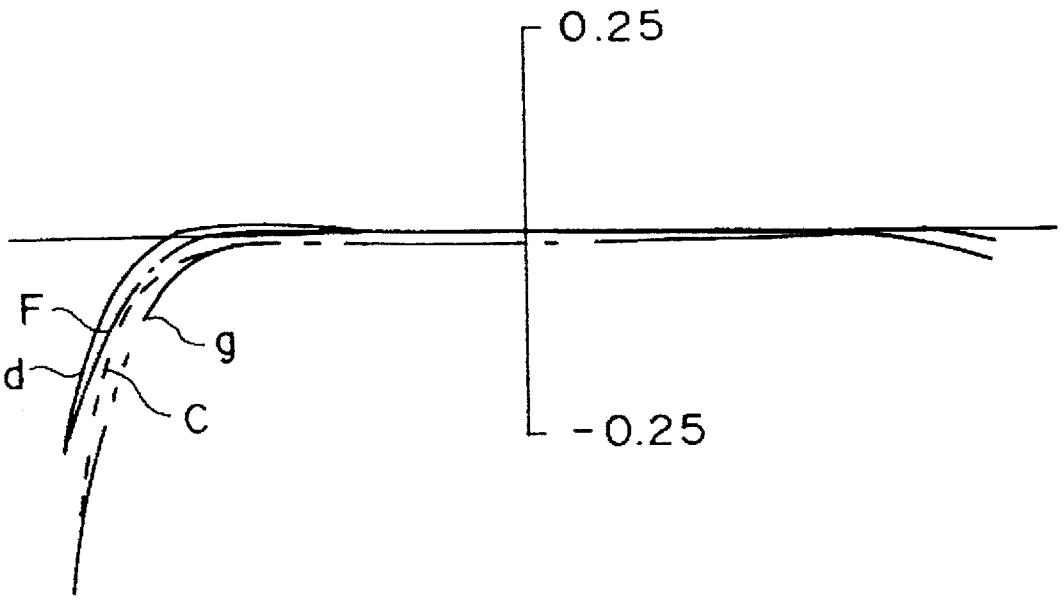


Fig. 17



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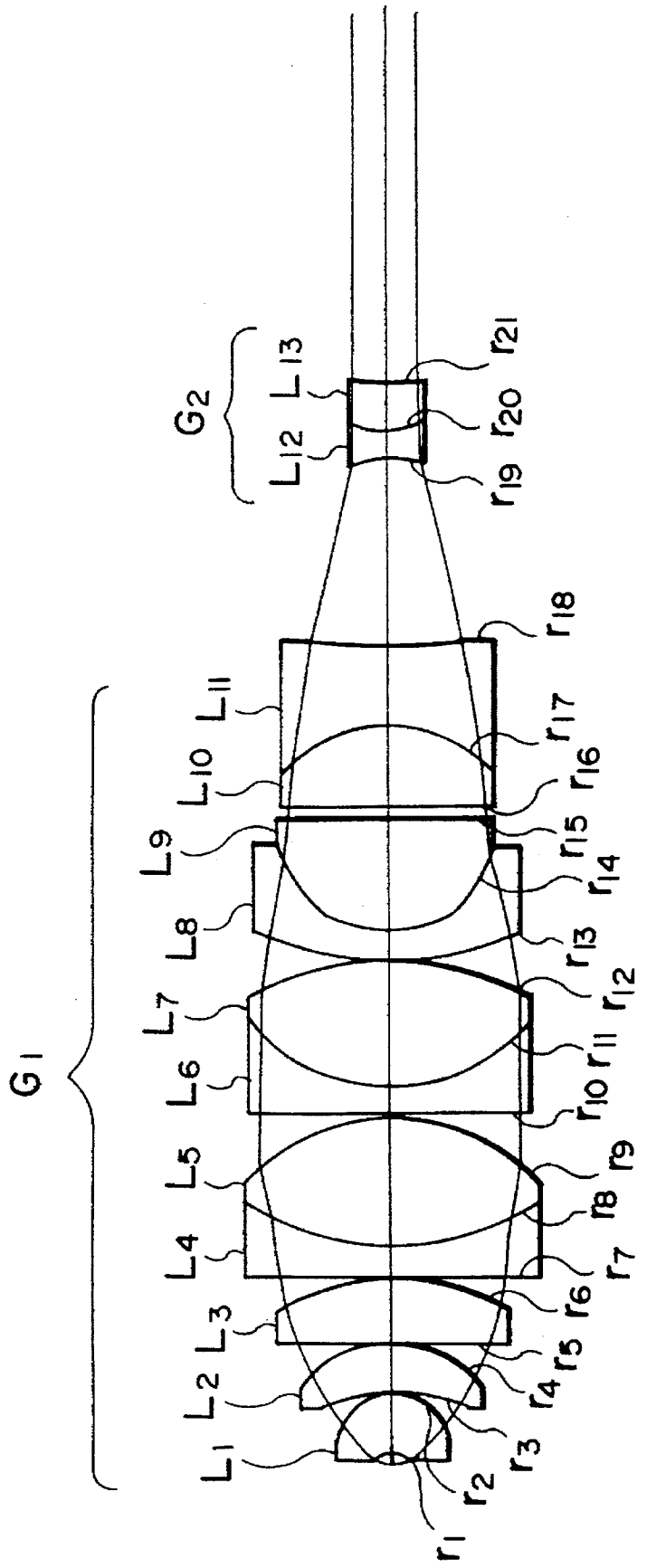
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Fig. 19

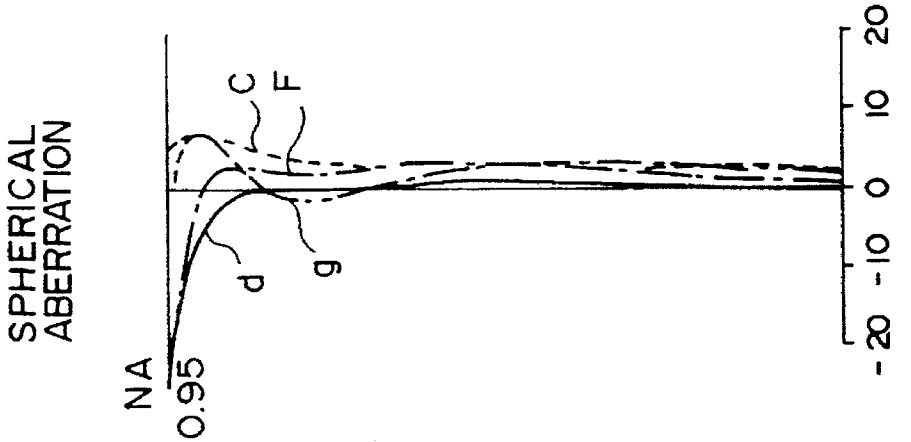


Fig. 20

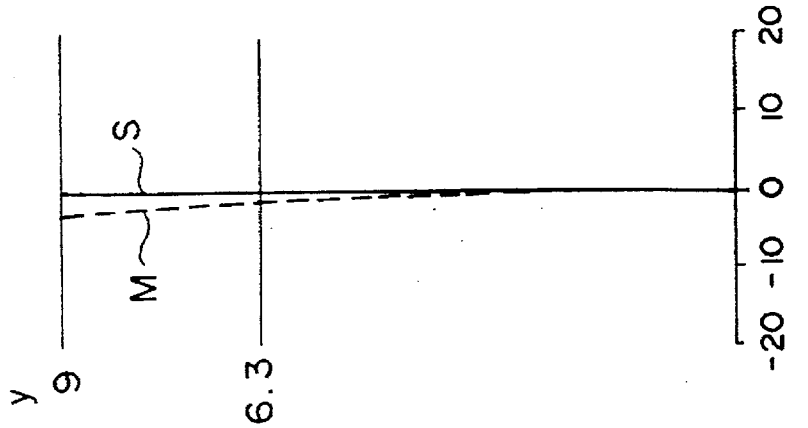


Fig. 21

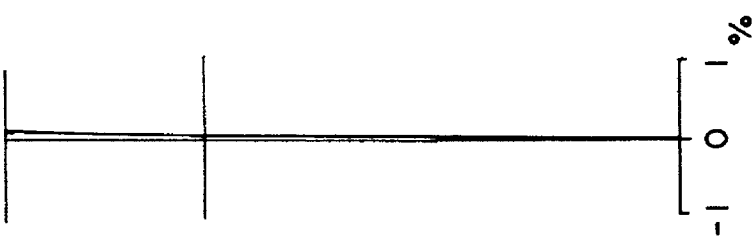


Fig. 22

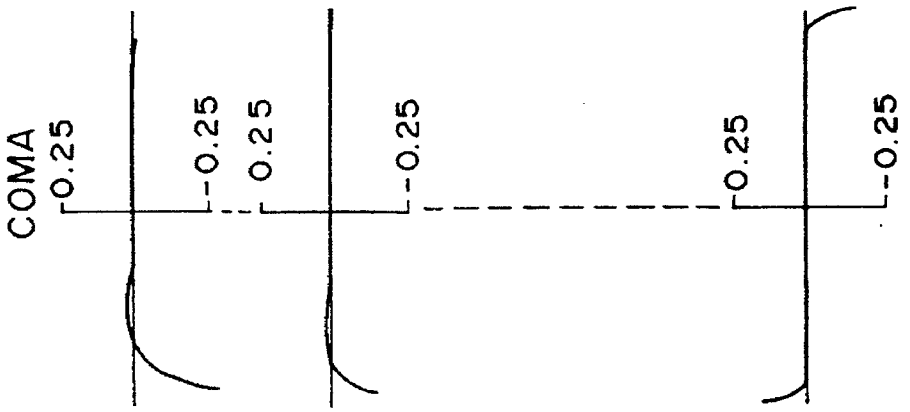


Fig. 23

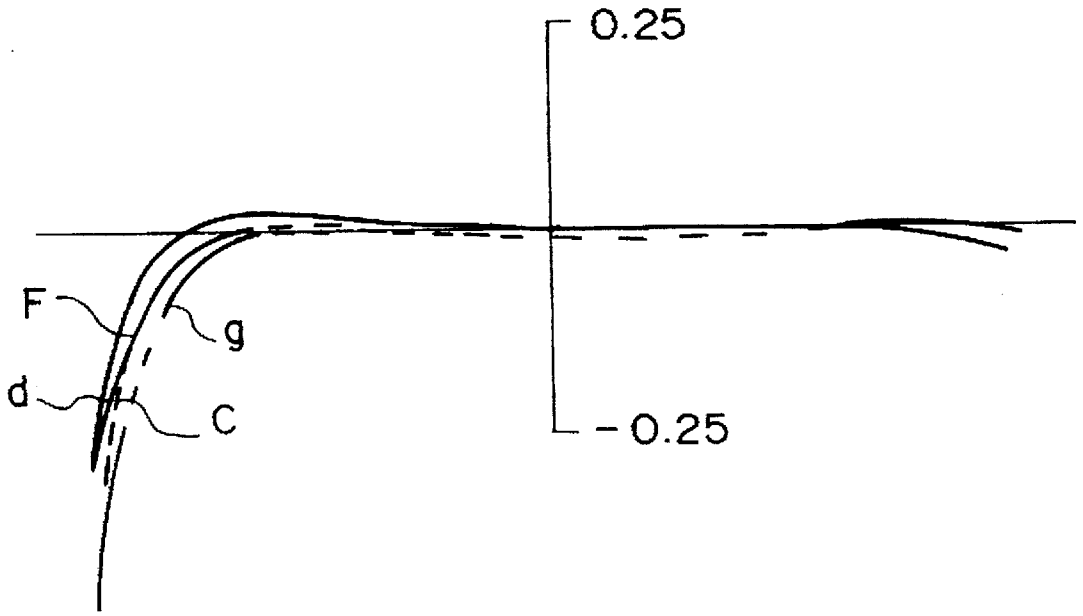
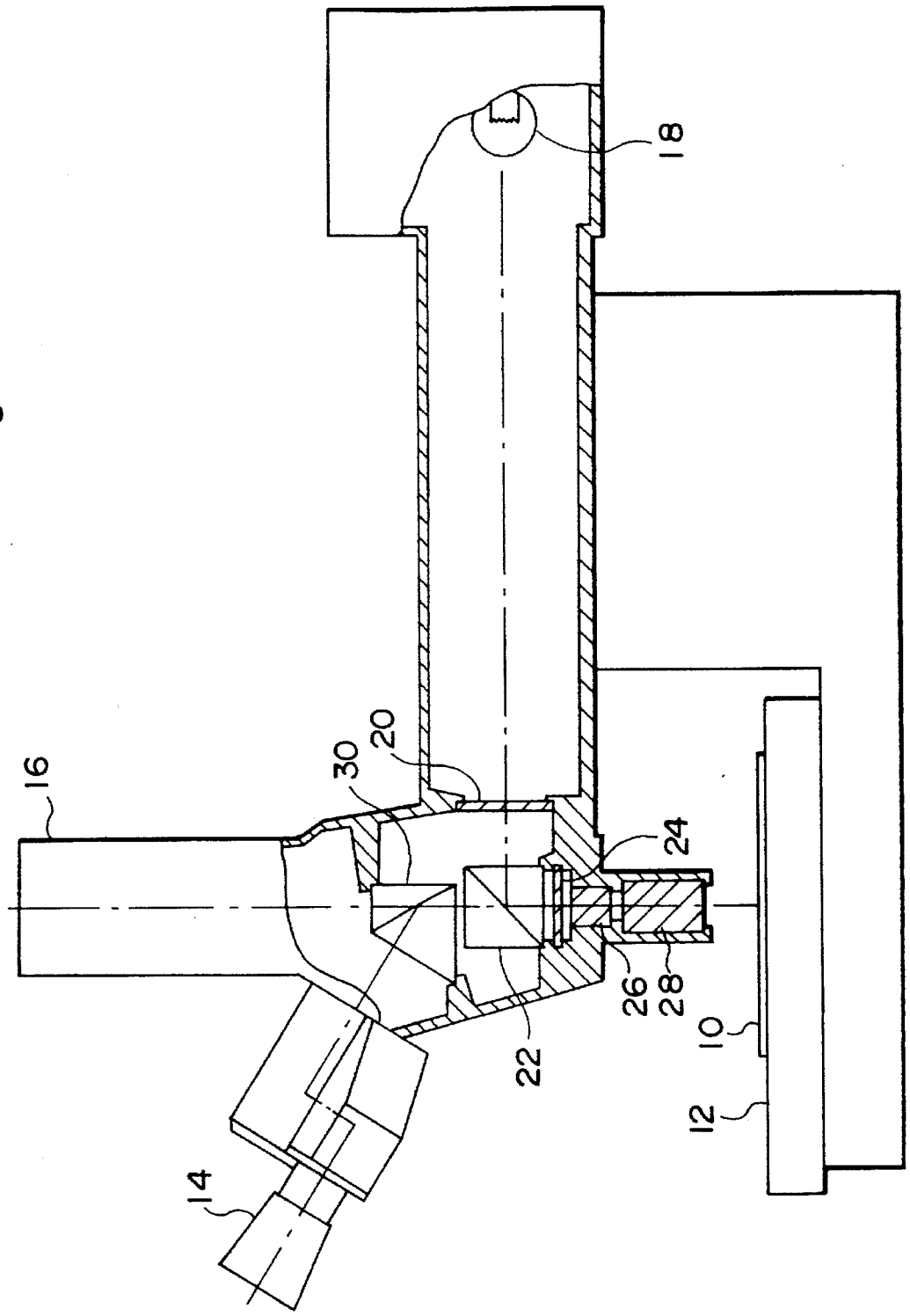


Fig. 24



MICROSCOPE OBJECTIVE LENS AND MICROSCOPE USING THE SAME

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a microscope objective lens and, more particularly, to a metal microscope objective lens. Furthermore, the present invention relates to a microscope using the microscope objective lens.

2. Related Background Art

A conventional dry-system microscope objective lens has a lens arrangement disclosed in, e.g., Japanese Patent Publication No. 4-26446.

More specifically, a conventional dry-system microscope objective lens has a front group G_1 having positive refracting power and a rear group G_2 having negative refracting power, as shown in FIG. **1**. Furthermore, the front group G_1 having positive refracting power has, in the following order from the object side, a positive meniscus lens element with a concave surface facing the object side, a positive cemented lens component, and a meniscus lens component with a convex surface facing the object side. The rear group G_2 having negative refracting power has a cemented lens of two negative lenses and one positive lens.

As shown in FIG. **1**, in the front group G_1, a lens nearest to the image side is a meniscus lens with a concave surface facing the object side, which is obtained by cementing a biconvex single lens and a biconcave single lens to each other. The cemented lens, nearest to the image side, in the front group G_1 has almost no refraction effect, as can be seen from FIG. **1**.

SUMMARY OF THE INVENTION

According to the present invention, there is provided a microscope objective lens which comprises, in the following order from the object side, a front group of positive refracting power which has a positive meniscus lens element with a concave surface facing the object side, and a cemented lens component, and converts beams from an object into convergent beams, and a rear group of negative refracting power, which is disposed at the image side of the front group and has a cemented lens of a negative lens element and a positive lens element, wherein a cemented lens, nearest to the image side, out of the cemented lens component in the front group satisfies:

$$|R_1|/f>100 \quad (1)$$

$$|R_2|/f>20 \quad (2)$$

where R_1 is the radius of curvature of a lens surface, nearest to the object side, of the cemented lens, nearest to the image side, in the front group, R_2 is the radius of curvature of a lens surface, nearest to the image side, of the cemented lens, nearest to the image side, in the front group, and f is the focal length of the microscope objective lens.

The microscope objective lens of the present invention preferably satisfies:

$$\nu_{21}>50 \quad (3)$$

$$\nu_{22}>50 \quad (4)$$

where ν_{21} is the Abbe's number of the negative lens element in the rear group, and ν_{22} is the Abbe's number of the positive lens element in the rear group.

Furthermore, in order to achieve an apochromatic microscope objective lens, the positive meniscus lens component with the concave surface facing the object side in the front group has at least three positive meniscus lens elements, and at least two positive meniscus lenses of the at least three positive meniscus lenses preferably satisfy:

$$\nu>90 \quad (5)$$

where ν is the Abbe's number of each of the at least two positive meniscus lenses.

The present invention will be more fully understood from the detailed description given hereinbelow and the accompanying drawings, which are given by way of illustration only and are not to be considered as limiting the present invention.

Further scope of applicability of the present invention will become apparent from the detailed description given hereinafter. However, it should be understood that the detailed description and specific examples, while indicating preferred embodiments of the invention, are given by way of illustration only, since various changes and modifications within the spirit and scope of the invention will be apparent to those skilled in the art from this detailed description.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a drawing to show the conventional dry-system microscope objective lens.

FIGS. **2** to **4** are drawings to explain the relation among a refraction surface, an incident light ray and a reflected light ray.

FIG. **5** is a drawing to show an imaging lens.

FIG. **6** is a view showing the lens arrangement of the embodiment 1.

FIGS. **7** to **10** are graphs to show various aberrations of the embodiment 1.

FIG. **11** is a graph to show chromatic coma at the maximum incident height in the embodiment 1.

FIG. **12** is a view showing the lens arrangement of the embodiment 2.

FIGS. **13** to **16** are graphs to show various aberrations of the embodiment 2.

FIG. **17** is a graph to show chromatic coma at the maximum incident height in the embodiment 2.

FIG. **18** is a view showing the lens arrangement of the embodiment 3.

FIGS. **19** to **22** are graphs to show various aberrations of the embodiment 3.

FIG. **23** is a graph to show chromatic coma at the maximum incident height in the embodiment 3.

FIG. **24** is a sectional view to show an example of a metal microscope using the objective lens shown in FIG. **6**.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

In general, in a metal microscope, a microscope objective lens also serves as an illumination optical system for the microscope since an object to be examined is observed with reflected light. More specifically, in a general microscope objective lens, light rays propagate only from the object side toward the image side, while in a metal microscope objective lens, light rays propagate not only from the object side toward the image side, but also from the image side toward the object side.

The conventional dry-system microscope objective lens shown in FIG. **1** is applied to a metal microscope objective

lens. When observation light from an object to be examined propagates through the conventional dry-system microscope objective lens shown in FIG. 1, no problem is posed. However, when illumination light propagates through the conventional dry-system microscope objective lens shown in FIG. 1 in a direction opposite to the observation light from the object to be examined, the illumination light is reflected by a specific surface, and flare light is generated. As a result, the contrast is lowered, resulting in difficult observation. Note that in this specification, flare light means stray light which reaches an image upon reflection by a lens surface.

In the case of the conventional dry-system microscope objective lens shown in FIG. 1, boundary surfaces r_{16} and r_{18} of the cemented lens, nearest to the image side, in the front group G_1 with the air cause harmful reflections. As described above, the cemented lens, nearest to the image side, in the front group has almost no refraction effect. For this reason, light rays, which are incident from the image side on the cemented lens, nearest to the image side, in the front group as illumination light, are reflected by a refraction surface in the same direction as the incident light rays, as can be seen from FIG. 1.

The above-mentioned phenomenon will be explained in detail below with reference to FIG. 2. FIG. 2 shows a case wherein the center of the curvature (indicated by a mark ○ in FIG. 2), on an optical axis 2, of a refraction surface 1 agrees with the central position (indicated by a mark x in FIG. 2), on the optical axis 2, where an incident light ray N diverges (or converges). In this case, a refracted light ray K which is incident on and refracted by the refraction surface 1 does not undergo refraction by the refraction surface 1 at all, and its state is equivalent to that of the incident light ray N which is transmitted through the refraction surface 1. Also, in this case, a reflected light ray H which is incident on and reflected by the refraction surface 1 propagates along the same optical path as the incident light ray N in a direction opposite thereto. This is because the normal to the refraction surface 1 coincides with the incident light ray N, and the incident light ray N is perpendicularly incident on the incident point on the refraction surface 1.

When the center of the curvature of the refraction surface substantially coincides with the central position where the incident light ray diverges (or converges), the central position where the reflected light ray reflected by the refraction surface converges (or diverges) also substantially coincides with the center of the curvature of the refraction surface.

In this manner, the reflected light, which is reflected in the same direction as the incident light ray, forms an image together with the observation light. The contrast of the formed image is lowered due to the presence of such flare light, resulting in very poor appearance of the image upon actual observation.

In the present invention, as shown in FIG. 3, the center of the curvature of the refraction surface does not coincide with the central position where a light ray diverges (or converges). In this manner, the present invention can eliminate flare light.

In FIG. 3, the central position (indicated by a mark x in FIG. 3), on the optical axis 2, where the light ray diverges is present between the center of the curvature (indicated by a mark ○ in FIG. 3) of the refraction surface 1, and the refraction surface 1. In this case, an incident light ray N incident on the refraction surface 1 is reflected in a direction to separate from the optical axis 2, as shown in FIG. 3. A reflected light ray H which is incident on and reflected by the refraction surface 1 finally reaches the inner wall of the lens barrel of a microscope. Note that the inner wall of the lens barrel of the microscope is painted in black or is lined with filling, and the light ray which has reached the inner wall of the lens barrel of the microscope disappears.

Conditions (1) and (2) above quantitatively define the above-mentioned requirements. If the objective lens satisfies these conditions (1) and (2), a microscope objective lens which can eliminate flare light can be realized. If conditions (1) and (2) are not satisfied, as described above, a light ray which is incident as illumination light is reflected in substantially the same direction as an incident light ray, and is combined with observation light, thus increasing flare light. When the lower limit of condition (1) is set to be 150, and the lower limit of condition (2) is set to be 25, better results are expected. Furthermore, when the lower limit of condition (1) is set to be 200, and the lower limit of condition (2) is set to be 30, very good results are expected.

Furthermore, in the present invention, conditions (3) and (4) above are preferably satisfied. Conditions (3) and (4) are those for eliminating flare light generated at the cemented surfaces in the rear group. In the case of the conventional dry-system microscope objective lens shown in FIG. 1 as well, the rear group G_2 generates flare light, which is smaller than that generated by the cemented lens, nearest to the image side, in the front group G_1. In a method of eliminating flare light in this case, as shown in FIG. 4, in principle, the central position (indicated by a mark x in FIG. 4) where an incident light ray N diverges is located at a side opposite to the refraction surface 1 with respect to the center of the curvature of the refraction surface 1. In a case shown in FIG. 4, the incident light ray N incident on the refraction surface 1 is reflected in a direction toward the optical axis 2. The reflected light ray finally reaches the inner wall of the lens barrel of the microscope, which wall is painted in black or is lined with filling, and disappears. Thus, the amount of flare light generated at the cemented surfaces can be reduced. If conditions (3) and (4) are not satisfied, flare light increases inconveniently.

As another method of eliminating flare light generated at the cemented surfaces, a method of setting the refractive index difference before and after the cemented surface to be zero or nearly zero is available. However, when the refractive index difference is set to be zero or nearly zero, the cemented surface inconveniently loses its effect of deflecting a light ray, and the degree of freedom of aberration correction decreases by one.

Furthermore, in the present invention, condition (5) above is preferably satisfied. Condition (5) is one for achieving an apochromatic microscope objective lens with high magnification. If condition (5) is not satisfied, chromatic coma increases, and an apochromatic microscope objective lens cannot be achieved. If chromatic coma increases, an image suffers color smearing, resulting in very poor appearance of the image. In this specification, the chromatic coma means coma with respect to respective wavelengths (colors).

In the present invention, condition (6) below is preferably satisfied:

$$|R_3/f|<5 \quad (6)$$

where R_3 is the radius of curvature of a cemented surface of the cemented lens, nearest to the image side, in the front group.

Condition (6) is one for satisfactorily correcting various aberrations. When the range of this condition is exceeded, especially chromatic aberration increases, and an apochromatic microscope objective lens with high magnification as

the object of the present invention cannot be achieved. When the upper limit of condition (6) is set to be 4.6, a better result is expected. Furthermore, when the upper limit of condition (6) is set to be 4.2, a very good result is expected.

The embodiments of the present invention will be described hereinafter. All the embodiments are designed as infinity systems. When a microscope objective lens of each embodiment is actually used, an imaging lens shown in, e.g., FIG. **5** is disposed at the image side of the objective lens. Table 1 below summarizes data of the imaging lens shown in FIG. **5**.

TABLE 1

Surface Number No.	Radius of Curvature r	Central Thickness Interval d	Refractive Index n_d	Abbe's Number ν_d
1	52.00	6.50	1.61720	54.0
2	−87.00	2.00	1.74950	35.2
3	350.00	8.50		
4	49.00	5.00	1.66755	42.0
5	0.00	2.50	1.61266	44.4
6	31.00	158.78		

Focal Length f = 204

Tables 2 to 4 presented later summarize data of Embodiments 1 to 3. In each table, numerals in the leftmost column represent the order of lens surfaces from the object side, and n_d and ν_d are respectively the refractive index and Abbe's number for the d-line (λ=587.6 nm). Also, W.D. represents a value corresponding to the operating distance, i.e., the distance between the object surface and the apex of the frontmost lens surface. The value of the focal length is one defined by data without using an imaging lens.

FIGS. **7** to **10**, FIGS. **13** to **16**, and FIGS. **19** to **22** respectively graphs showing various aberrations of the respective embodiments at the respective use magnifications when an imaging lens is also used. These graphs show spherical aberration, astigmatism, coma, and distortion for the d-line (λ=587.6 nm), and graphs showing spherical aberration also show curves for the C-line (λ=656.3 nm), the F-line (λ=486.1 nm), and the g-line (λ=435.8 nm).

Furthermore, FIGS. **11**, **17**, and **23** show chromatic coma at the maximum incident height in the respective embodiments. Each of FIGS. **11**, **17**, and **23** shows not only a curve for the d-line (λ=587.6 nm), but also curves for the C-line (λ=656.3 nm), the F-line (λ=486.1 nm), and the g-line (λ=435.8 nm), as in graphs showing spherical aberration.

EMBODIMENT 1

FIG. **6** is a view showing the lens arrangement of this embodiment. The lens arrangement will be described below with reference to FIG. **6**.

A front group G_1 has, in the following order from the object side, positive meniscus lens elements: a first positive meniscus lens L_1 with a concave surface facing the object side, and second and third positive meniscus lenses L_2 and L_3 each with a concave surface facing the object side as positive meniscus lens elements; and cemented lens components: a first cemented lens consisting of a negative lens L_4 with a concave surface facing the image side and a biconvex positive lens L_5, a second cemented lens consisting of a negative lens L_6 with a concave surface facing the image side and a biconvex positive lens L_7, a third cemented lens consisting of a negative lens L_8 with a concave surface facing the object side and a biconvex positive lens L_9, and a fourth cemented lens consisting of a biconvex positive lens L_{10} and a biconcave negative lens L_{11}. A rear group G_2 has a negative lens constituted by cementing a biconcave negative lens L_{12} as a negative lens element, and a positive meniscus lens L_{13} with a concave surface facing the image side as a positive lens element.

Table 2 below summarizes data of Embodiment 1. FIGS. **7** to **10** are graphs showing various aberrations of the lens of this embodiment, and FIG. **11** is a graph showing chromatic coma at the maximum incident height in this embodiment.

TABLE 2

Surface Number No.	Radius of Curvature r	Central Thickness Interval d	Refractive Index n_d	Abbe's Number ν_d		
1	−2.10	2.49	1.76684	46.8	L_1	G_1
2	−2.38	0.05				
3	−6.92	2.00	1.43388	95.6	L_2	
4	−4.80	0.05				
5	−235.08	2.30	1.43388	95.6	L_3	
6	−9.86	0.10				
7	704.79	1.00	1.79504	28.6	L_4	
8	10.65	5.00	1.49782	86.5	L_5	
9	−8.06	0.10				
10	26.72	1.10	1.61266	44.4	L_6	
11	6.68	4.80	1.49782	82.5	L_7	
12	−17.50	0.10				
13	16.37	1.10	1.68893	31.1	L_8	
14	4.62	4.50	1.49782	82.5	L_9	
15	−164.01	0.50				
16	874.78	3.00	1.78472	25.8	L_{10}	
17	−5.25	3.40	1.67025	57.5	L_{11}	
18	146.43	7.00				
19	−4.25	1.00	1.58913	61.1	L_{12}	G_2
20	3.26	2.00	1.74810	52.3	L_{13}	
21	10.19					

Focal Length f = 1.33
N.A. = 0.95
Magnification: 150
W.D. = 0.4
R_1/f = 658
R_2/f = 110
R_3/f = −3.95

EMBODIMENT 2

FIG. **12** is a view showing the lens arrangement of this embodiment. The lens arrangement will be described below with reference to FIG. **12**.

A front group G_1 has, in the following order from the object side, positive meniscus lens elements: a first positive meniscus lens L_1 with a concave surface facing the object side, and second and third positive meniscus lenses L_2 and L_3 each with a concave surface facing the object side as positive meniscus lens elements; and cemented lens components: a first cemented lens consisting of a biconcave negative lens L_4 and a biconvex positive lens L_5, a second cemented lens consisting of a negative meniscus lens L_6 with a concave surface facing the image side and a biconvex positive lens L_7, a third cemented lens consisting of a negative meniscus lens L_8 with a concave surface facing the image side and a positive meniscus lens L_9 with a concave surface facing the image side, and a fourth cemented lens consisting of a positive meniscus lens L_{10} with a concave surface facing the object side and a biconcave negative lens L_{11}. A rear group G_2 has a negative lens constituted by cementing a biconcave negative lens L_{12} as a negative lens element, and a positive meniscus lens L_{13} with a concave surface facing the image side as a positive lens element.

Table 3 below summarizes data of Embodiment 2. FIGS. **13** to **16** are graphs showing various aberrations of the lens

of this embodiment, and FIG. **17** is a graph showing chromatic coma at the maximum incident height in this embodiment.

TABLE 3

Surface Number No.	Radius of Curvature r	Central Thickness Interval d	Refractive Index n_d	Abbe's Number ν_d		
1	−2.10	2.49	1.76684	46.8	L_1	G_1
2	−2.38	0.05				
3	−7.00	2.00	1.43388	95.6	L_2	
4	−4.69	0.05				
5	−68.57	2.30	1.43388	95.6	L_3	
6	−9.34	0.10				
7	−336.00	1.00	1.79504	28.6	L_4	
8	10.96	5.00	1.49782	86.5	L_5	
9	−8.10	0.10				
10	31.86	1.10	1.61266	44.4	L_6	
11	7.06	4.80	1.49782	82.5	L_7	
12	−15.56	0.10				
13	13.88	1.10	1.68893	31.1	L_8	
14	4.57	4.50	1.49782	82.5	L_9	
15	85.72	0.50				
16	−362.00	3.00	1.78472	25.8	L_{10}	
17	−5.25	3.40	1.67025	57.5	L_{11}	
18	1000.00	7.00				
19	−4.33	1.00	1.58913	61.1	L_{12}	G_2
20	3.20	2.00	1.74810	52.3	L_{13}	
21	9.68					

Focal Length f = 1.33
N.A. = 0.95
Magnification: 150
W.D. = 0.4
$R_1/f = -272$
$R_2/f = 752$
$R_3/f = -3.95$

EMBODIMENT 3

FIG. **18** is a view showing the lens arrangement of this embodiment. The lens arrangement will be described below with reference to FIG. **18**.

A front group G_1 has, in the following order from the object side, positive meniscus lens elements: a first positive meniscus lens L_1 with a concave surface facing the object side, and second and third positive meniscus lenses L_2 and L_3 each with a concave surface facing the object side as positive meniscus lens elements; and cemented lens components: a first cemented lens consisting of a biconcave negative lens L_4 and a biconvex positive lens L_5, a second cemented lens consisting of a negative lens L_6 with a concave surface facing the image side and a biconvex positive lens L_7, a third cemented lens consisting of a negative lens L_8 with a concave surface facing the image side and a positive meniscus lens L_9 with a concave surface facing the image side, and a fourth cemented lens consisting of a biconvex positive lens L_{10} and a biconcave negative lens L_{11}. A rear group G_2 has a negative lens constituted by cementing a biconcave negative lens L_{12} as a negative lens element, and a positive meniscus lens L_{13} with a concave surface facing the image side as a positive lens element.

Table 2 below summarizes data of Embodiment 3. FIGS. **19** to **22** are graphs showing various aberrations of the lens of this embodiment, and FIG. **23** is a graph showing chromatic coma at the maximum incident height in this embodiment.

TABLE 4

Surface Number No.	Radius of Curvature r	Central Thickness Interval d	Refractive Index n_d	Abbe's Number ν_d		
1	−2.10	2.49	1.76684	46.8	L_1	G_1
2	−2.38	0.05				
3	−7.06	2.00	1.43388	95.6	L_2	
4	−4.71	0.05				
5	−86.06	2.30	1.43388	95.6	L_3	
6	−9.25	0.10				
7	−300.34	1.00	1.79504	28.6	L_4	
8	10.80	5.00	1.49782	86.5	L_5	
9	−8.11	0.10				
10	53.77	1.10	1.61266	44.4	L_6	
11	7.39	4.80	1.49782	82.5	L_7	
12	−14.73	0.10				
13	12.94	1.10	1.68893	31.1	L_8	
14	4.68	4.50	1.49782	82.5	L_9	
15	3165.50	0.50				
16	773.81	3.00	1.78472	25.8	L_{10}	
17	−5.40	3.40	1.67025	57.5	L_{11}	
18	50.00	7.00				
19	−4.23	1.00	1.58913	61.1	L_{12}	G_2
20	3.31	2.00	1.74810	52.3	L_{13}	
21	10.64					

Focal Length f = 1.33
N.A. = 0.95
Magnification: 150
W.D. = 0.4
$R_1/f = 582$
$R_2/f = 38$
$R_3/f = -4.06$

Furthermore, Table 5 below summarizes the flare coefficients of the respective embodiments. The flare coefficient is defined by (the amount of light which is reflected by a given surface whose reflectance is assumed to be 100%, and reaches a detection system)/(the amount of light incident on the surface). Note that the product of the flare coefficient and the reflectance of the surface corresponds to the actual flare amount.

TABLE 5

	Embodiment 1	Embodiment 2	Embodiment 3
r_{16}	0.005	0.005	0.005
r_{18}	0.005	0.005	0.009
r_{19}	0.001	0.001	0.001
r_{20}	0.001	0.001	0.001
r_{21}	0.069	0.061	0.069
Total	0.153	0.141	0.157

As can be seen from Table 5, the objective lenses of Embodiments 1 to 3 generate very small flare light.

As can be seen from FIGS. **7** to **10**, FIGS. **13** to **16**, and FIGS. **19** to **22**, respective aberrations are satisfactorily corrected. In particular, on-axis chromatic aberration is corrected very satisfactorily.

Furthermore, as can be seen from the chromatic coma states in the respective embodiments shown in FIGS. **11**, **17**, and **23**, chromatic coma is corrected very satisfactorily.

As described above, according to the embodiments described above, an apochromatic objective lens with high magnification free from flare light can be realized.

Note that the present invention is not limited to the above-mentioned embodiments. In each of the above embodiments, an infinity-system objective lens has been

exemplified. However, by slightly modifying the rear group G_2, a finite-system objective lens can be easily realized. Needless to say, a microscope objective lens according to the present invention can be used not only in a metal microscope but also generally in a dry-system microscope.

FIG. **24** is a sectional view showing an example of a metal microscope using the objective lens shown in FIG. **6**. Referring to FIG. **24**, an object **10** to be observed such as a wafer is placed on a stage **12**, and it can be observed via an eyepiece lens **14** or photographed by a camera attached to a camera attachment portion **16**. The object **10** to be observed is supported by the stage **12** to be movable in two directions perpendicular to the optical axis indicated by an alternate long and short dash line, and in a direction parallel to the optical axis. The arrangement of the metal microscope will be described below.

A halogen lamp **18** emits a light beam for illuminating the object **10** to be observed, and illumination light is polarized by a polarization filter **20**. The optical path of the illumination light which is converted into predetermined polarized light via the polarization filter **20** is deflected through 90° by a polarization beam splitter **22**. The illumination light is transmitted through a quarter-wave plate **24**, is transmitted through an imaging lens **26** shown in FIG. **5**, and is then transmitted through an objective lens **28** shown in FIG. **6**. The illumination light emerging from the objective lens **28** illuminates the surface of the object **10** to be observed. Observation light reflected by the surface of the object **10** to be observed is transmitted through the objective lens **28**, the imaging lens **26**, and the quarter-wave plate **24** in a direction opposite to that described above. Since this light beam is transmitted through the quarter-wave plate **24** twice, it is transmitted through the polarization beam splitter **22** this time. The observation light transmitted through the polarization beam splitter **22** is split into two light beams by a prism **30** having a semi-transparent reflection film. One light beam reaches the eyepiece lens **14**, and the other light beam reaches the camera attachment portion **16**. Since the prism **30** is constituted by combining two prisms, the optical path of the observation light which propagates toward the camera attachment portion **16** is not deflected by the prism **30**.

From the invention thus described, it will be obvious that the invention may be varied in many ways. Such variations are not to be regarded as a departure from the spirit and scope of the invention, and all such modifications as would be obvious to one skilled in the art are intended for inclusion within the scope of the following claims.

What is claimed is:

1. A microscope objective lens comprising:

a front group having positive refracting power to convert a beam from an object into a convergent beam, and having a positive meniscus lens element with a concave surface facing the object side, and a plurality of cemented lens components disposed at the image side of said positive meniscus lens; and

a rear group having negative refracting power, having a negative lens element and a positive lens element which is cemented with said negative lens element, and disposed at the image side of said front group,

wherein said cemented lens component disposed nearest to the image side in said front group satisfies:

$$|R_1|/f>100$$

$$|R_2|/f>20$$

where R_1 is a radius of curvature of a lens surface on the object side of said last cemented lens component, R_2 is a radius of curvature of a lens surface on the image side of said last cemented lens component, and f is a focal length of said microscope objective lens.

2. A microscope objective lens according to claim **1**, wherein said microscope objective lens satisfies:

$$\nu_{21}>50$$

$$\nu_{22}>50$$

where ν_{21} is an Abbe's number of said negative lens element in said rear group, and ν_{22} is an Abbe's number of said positive lens element in said rear group.

3. A microscope objective lens according to claim **1**, wherein said positive meniscus lens element with the concave surface facing the object side in said front group comprises at least three positive meniscus lenses, and

at least two positive meniscus lenses of said at least three positive meniscus lenses satisfy:

$$\nu>90$$

where ν is an Abbe's number of each of said at least two positive meniscus lenses.

4. A microscope objective lens according to claim **2**, wherein said positive meniscus lens element with the concave surface facing the object side in said front group comprises at least three positive meniscus lenses, and

at least two positive meniscus lenses of said at least three positive meniscus lenses satisfy:

$$\nu>90$$

where ν is an Abbe's number of each of said at least two positive meniscus lenses.

5. A microscope objective lens according to claim **1**, wherein said objective lens is used with an imaging lens, disposed at the image side of said objective lens, for focusing a beam emerging from said rear group.

6. A microscope comprising:

a stage for supporting an object to be observed;

a light source system for supplying illumination light for illuminating the object to be observed supported by said stage;

light guide means for deflecting an optical path of the illumination light emitted from said light source system in a direction of the object to be observed; and

a microscope objective lens for guiding the illumination light from said light guide means toward the object to be observed, and acting on light reflected by the object to be observed,

wherein said light guide means guides light reflected by the object to be observed and transmitted through said microscope objective lens in a direction different from the direction of said light source system, and

said microscope objective lens comprises:

a front group having positive refracting power to convert a beam from the object to be observed into a convergent beam, and having a positive meniscus lens element with a concave surface facing the object to be observed, and a plurality of cemented lens components disposed at the image side of said positive meniscus lens; and

a rear group having negative refracting power, having a negative lens element and a positive lens element which is cemented with said negative lens element, and disposed at the image side of said front group,

in which said cemented lens component disposed nearest to the image side in said front group satisfies:

$$|R_1|/f>100$$

$$|R_2|/f>20$$

where R_1 is a radius of curvature of a lens surface on the side of the object to be observed of said last cemented lens component, R_2 is a radius of curvature of a lens surface on the image side of said last cemented lens component, and f is a focal length of said microscope objective lens.

7. A microscope according to claim **6**, further comprising an imaging lens for focusing a beam emerging from said rear group.

8. A microscope according to claim **6**, further comprising:

a polarization filter disposed between said light source system and said light guide means; and

a quarter-wave plate disposed between said light guide means and said microscope objective lens, and

wherein said light guide means comprises a polarization beam splitter.

9. A microscope according to claim **6**, further comprising an eyepiece lens for receiving light reflected by the object to be observed and transmitted through said microscope objective lens and said light guide means.

10. A microscope according to claim **6**, further comprising a camera attachment portion to which a camera for photographing the object to be observed based on light reflected by the object to be observed and transmitted through said microscope objective lens and said light guide means is attached.

* * * * *

US005632718A

United States Patent [19]

Igarashi et al.

[11] Patent Number: 5,632,718

[45] Date of Patent: May 27, 1997

[54] **NON-FLEXIBLE ENDOSCOPE WITH OBJECTIVE LENS SYSTEM AND RELAY LENS SYSTEM**

[75] Inventors: **Tsutomu Igarashi**; **Noriyuki Tateyama**, both of Hachioji, Japan

[73] Assignee: **Olympus Optical Co., Ltd.**, Tokyo, Japan

[21] Appl. No.: **396,428**

[22] Filed: **Feb. 28, 1995**

[30] **Foreign Application Priority Data**

Mar. 11, 1994 [JP] Japan 6-066493
Apr. 8, 1994 [JP] Japan 6-093920
Sep. 2, 1994 [JP] Japan 6-232433

[51] **Int. Cl.**[6] **A61B 1/002**

[52] **U.S. Cl.** **600/160**; 600/130; 359/434

[58] **Field of Search** 600/170–172, 600/167, 160, 161, 138, 130, 101, 105, 135; 385/902; 359/434, 435, 795, 798, 362, 661, 663

[56] **References Cited**

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Primary Examiner—Richard J. Apley
Assistant Examiner—John P. Leubecker
Attorney, Agent, or Firm—Cushman, Darby & Cushman IP Group of Pillsbury Madison & Sutro LLP

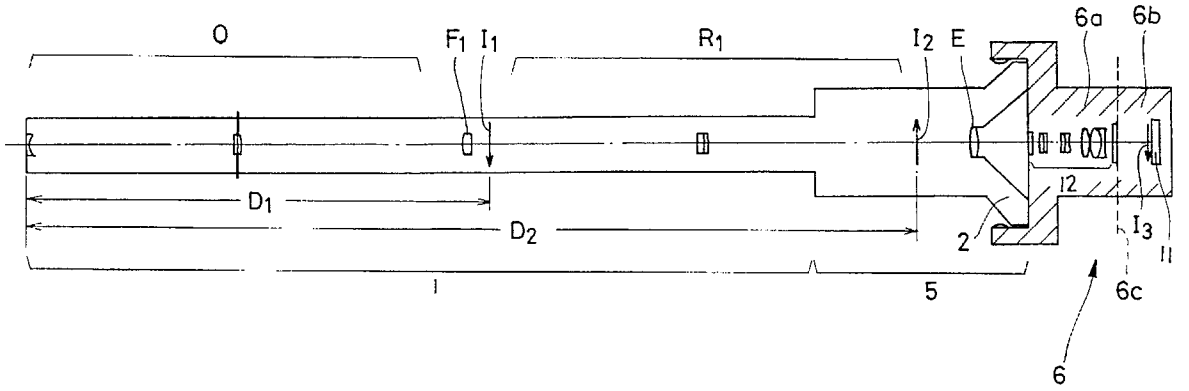
[57] **ABSTRACT**

A non-flexible endoscope comprises a slender insert section which is capable of being inserted from a leading end thereof into cavities of living bodies, an objective lens system for forming a primary image within the insert section, and a relay lens system for transmitting said primary image so as to form a secondary image, wherein the insert section satisfies the following condition:

$$0.3<D_1/D_2<0.7$$

wherein the reference symbol D_1 represents a distance as measured from a first surface of the objective lens system to the primary image and the reference symbol D_2 designates a distance as measure from the first surface of the objective lens system to the secondary image.

16 Claims, 45 Drawing Sheets



PRIOR ART

FIG. 1

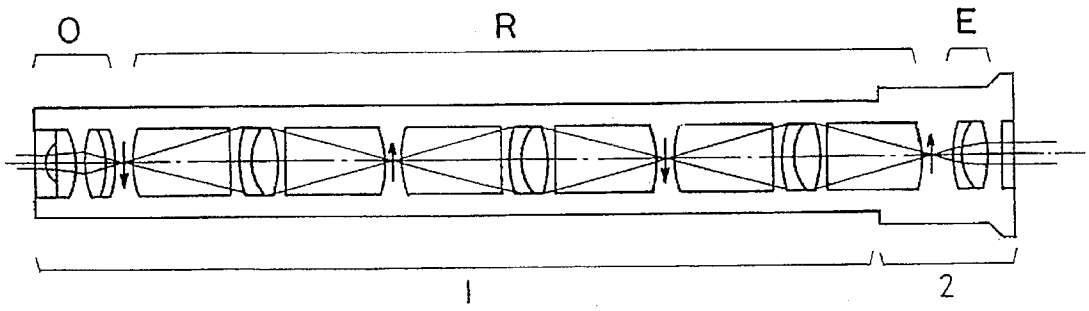


FIG. 2

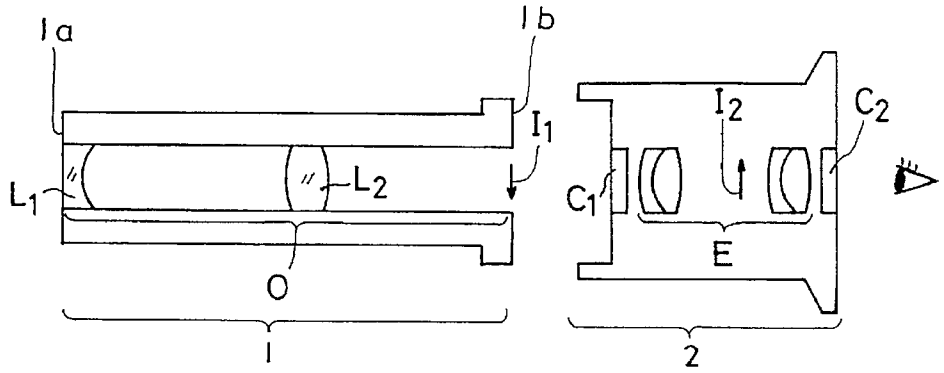


FIG. 3

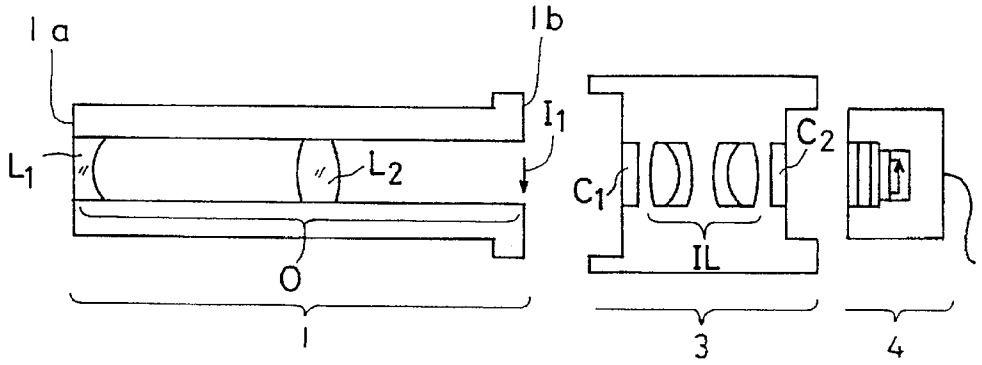


FIG. 4

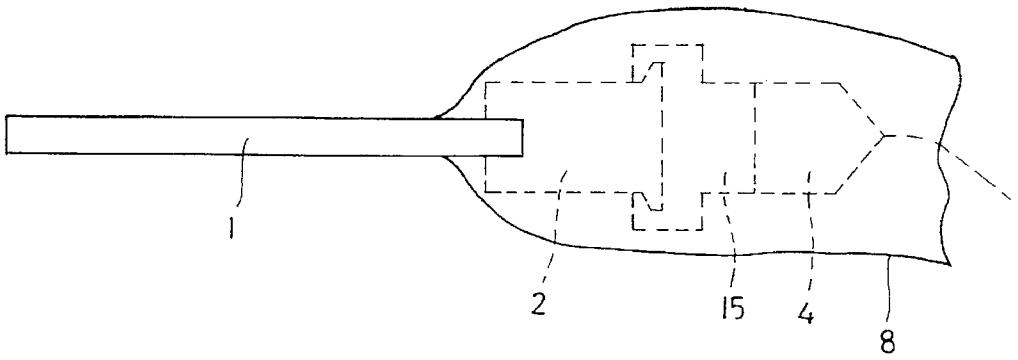


FIG. 5A

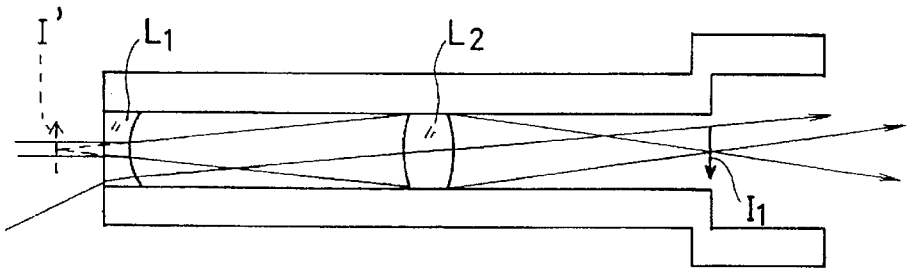


FIG. 5B

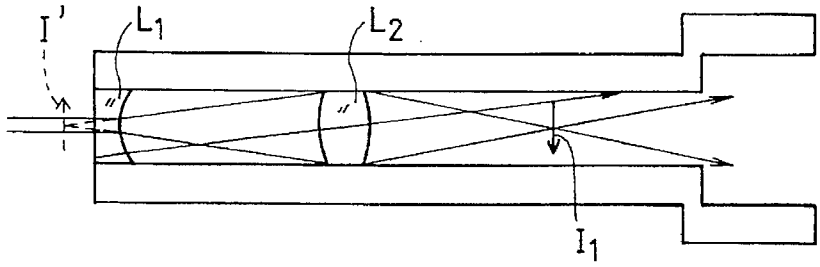


FIG. 5C

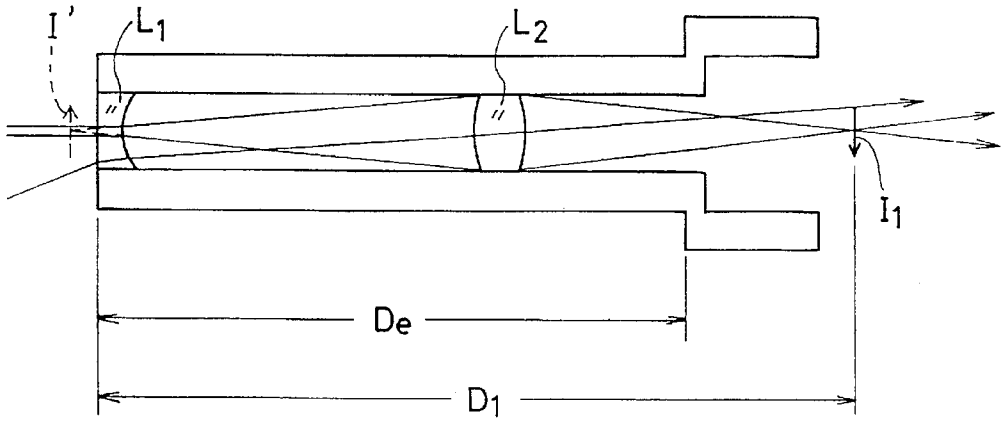


FIG. 6A

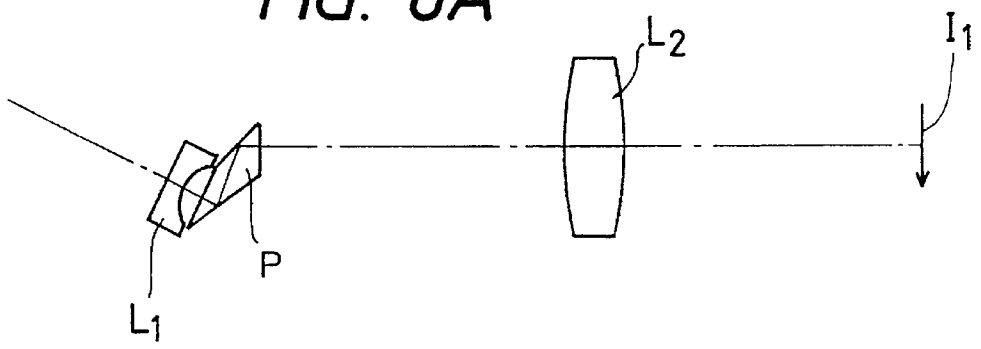


FIG. 6B

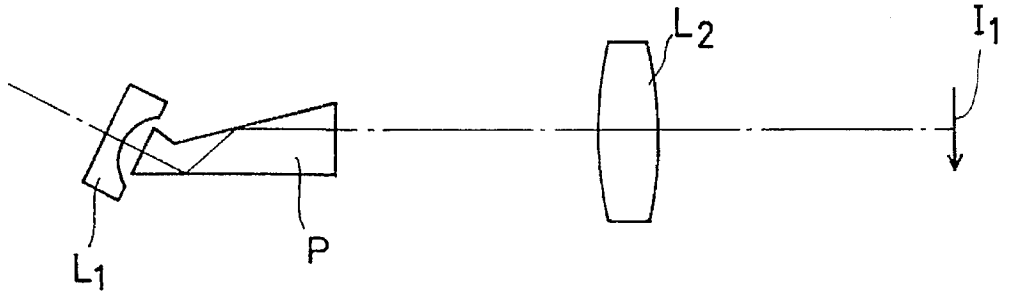


FIG. 7

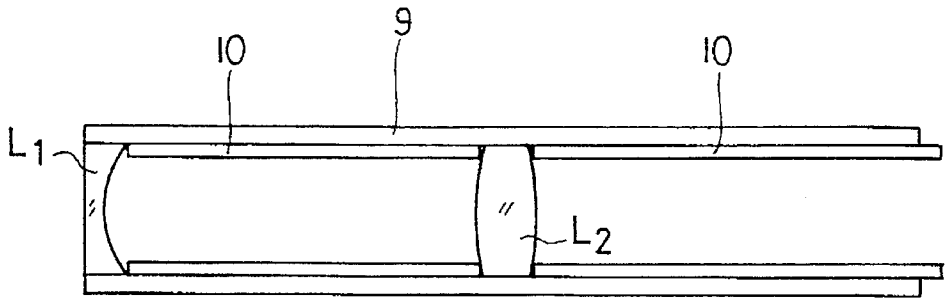
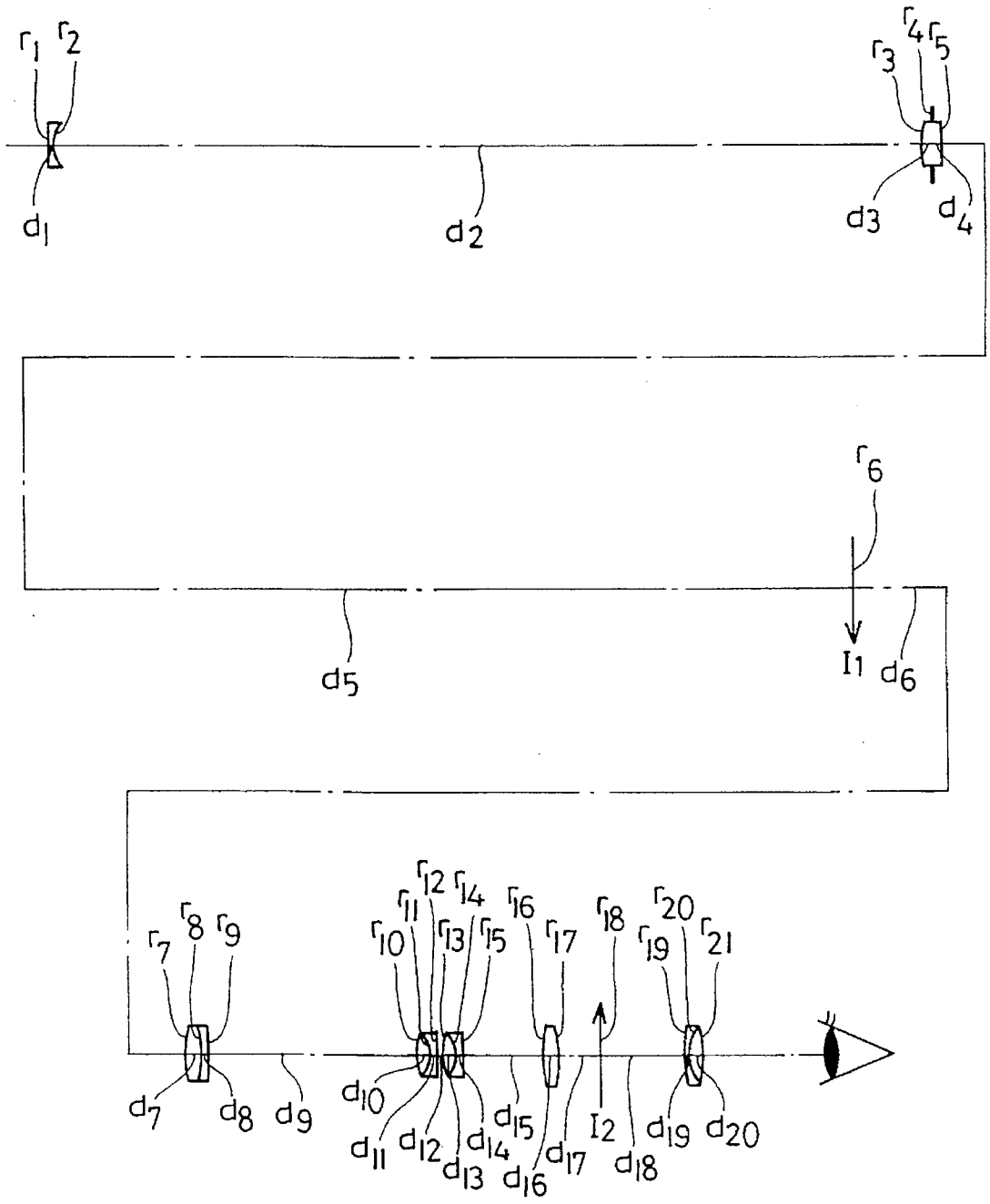


FIG. 8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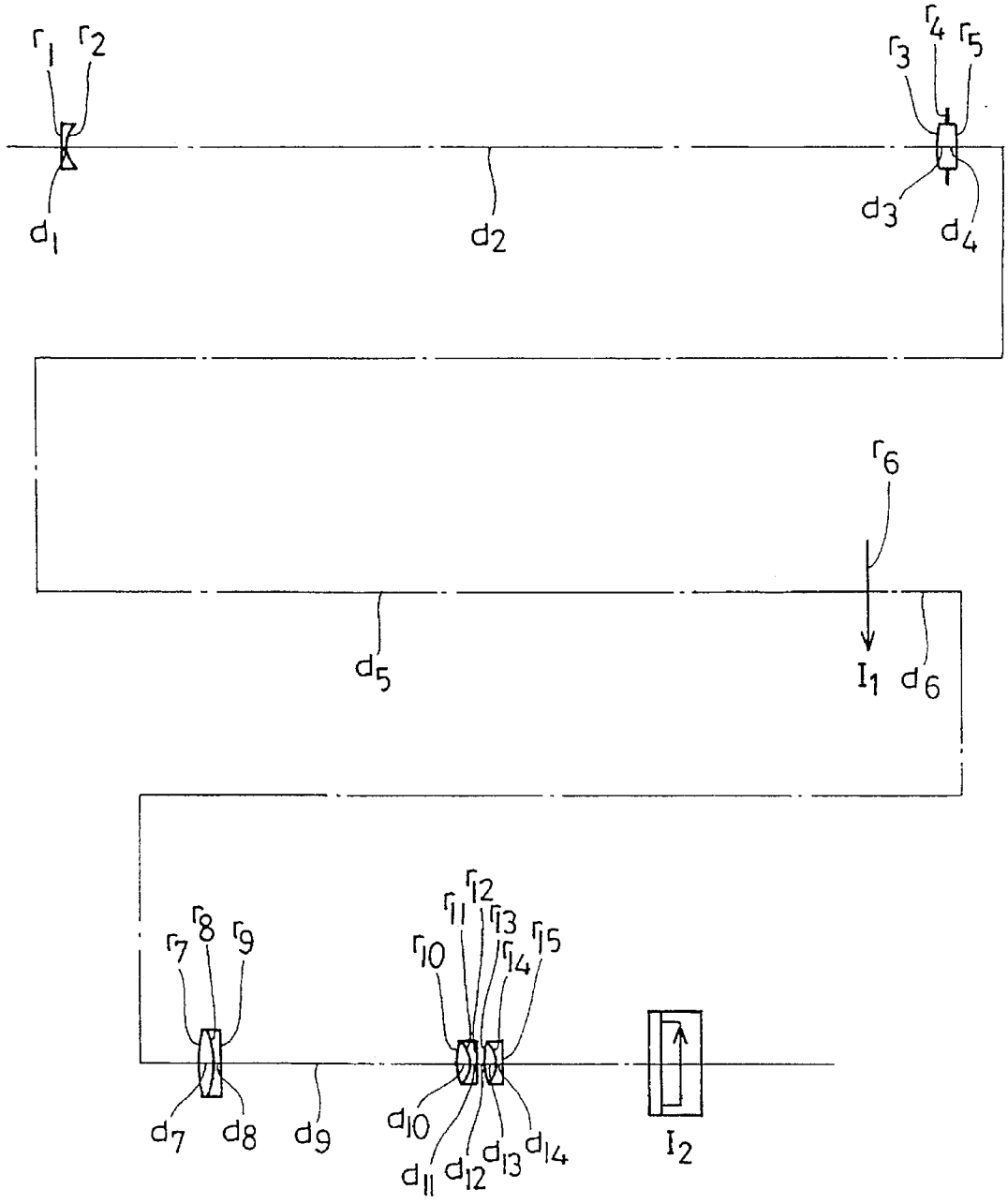
r6
r7 r8 r9
r10 r11 r12 r13 r14 r15 r16 r17 r18 r19 r20 r21
d1 d2 d3 d4 d5 I1 d6
d7 d8 d9 d10 d11 d12 d13 d14 d15 d16 d17 I2 d18 d19 d20

FIG. 9


r1
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r3
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r12
r13
r14
r15
d1
d2
d3
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I1
d6
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d8
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d13
d14
I2

FIG. 10

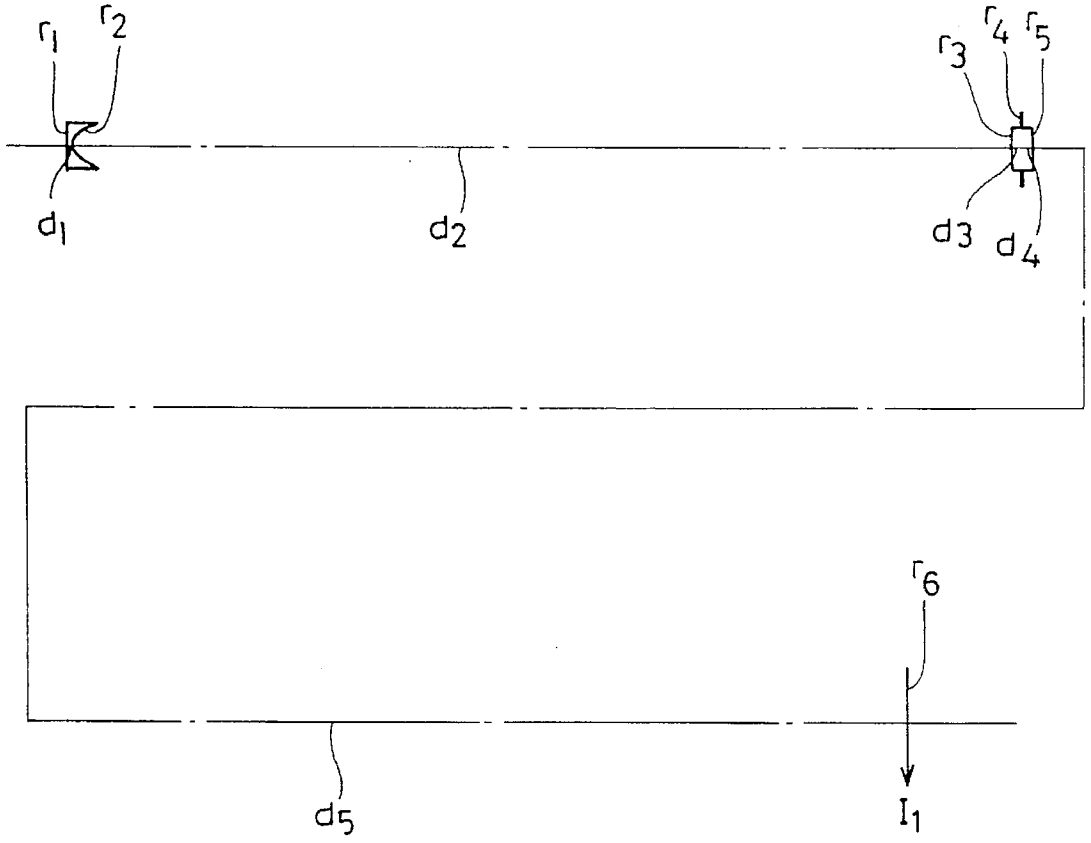


FIG. 11

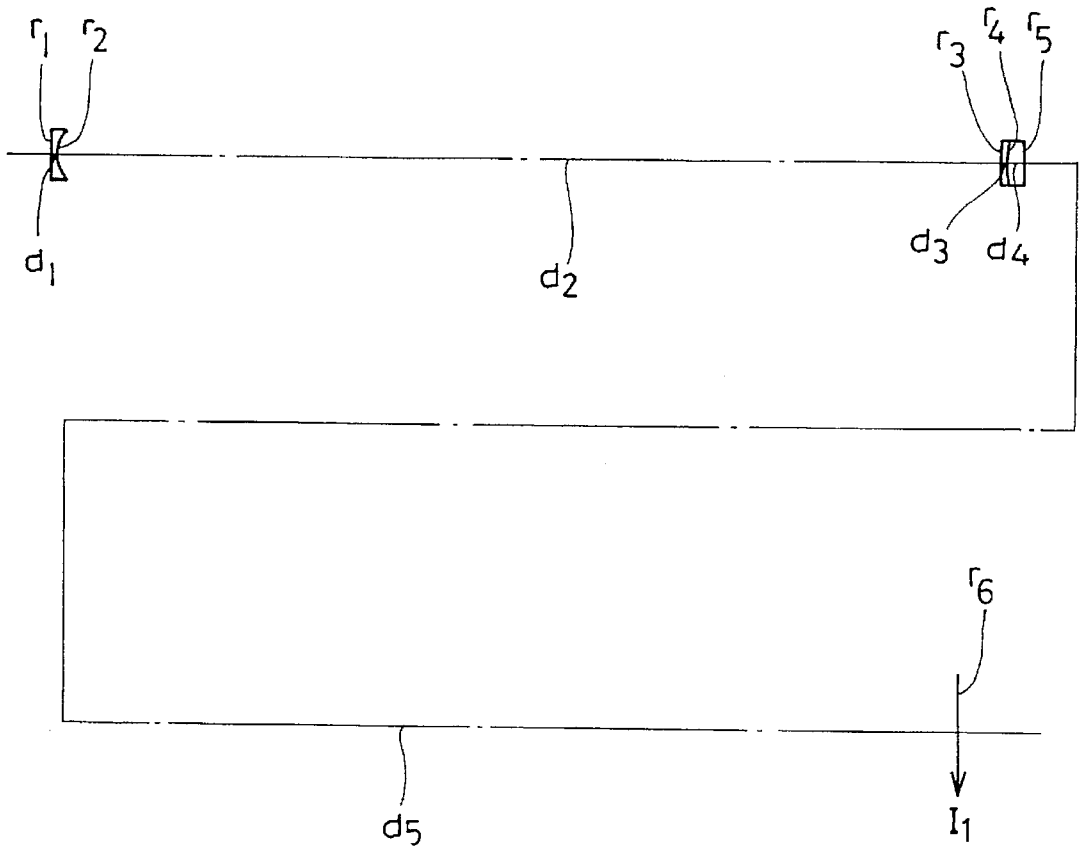


FIG. 12

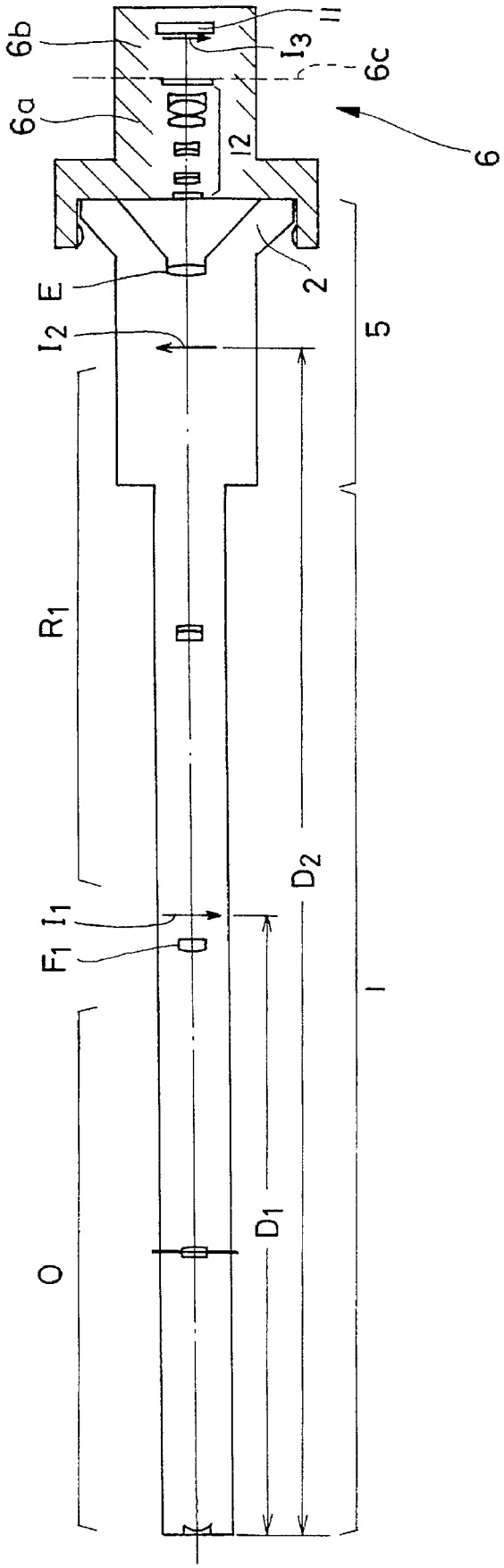


FIG. 13A

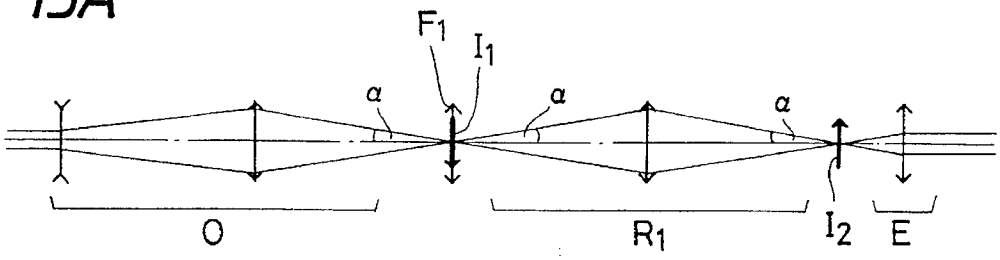


FIG. 13B

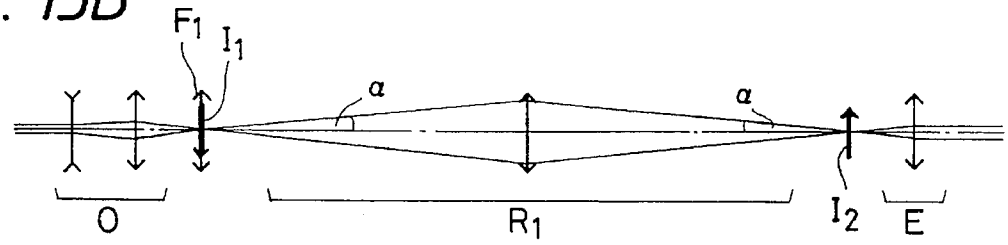


FIG. 13C

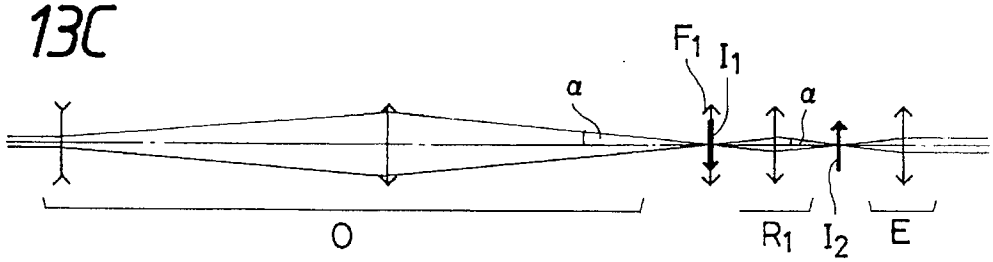
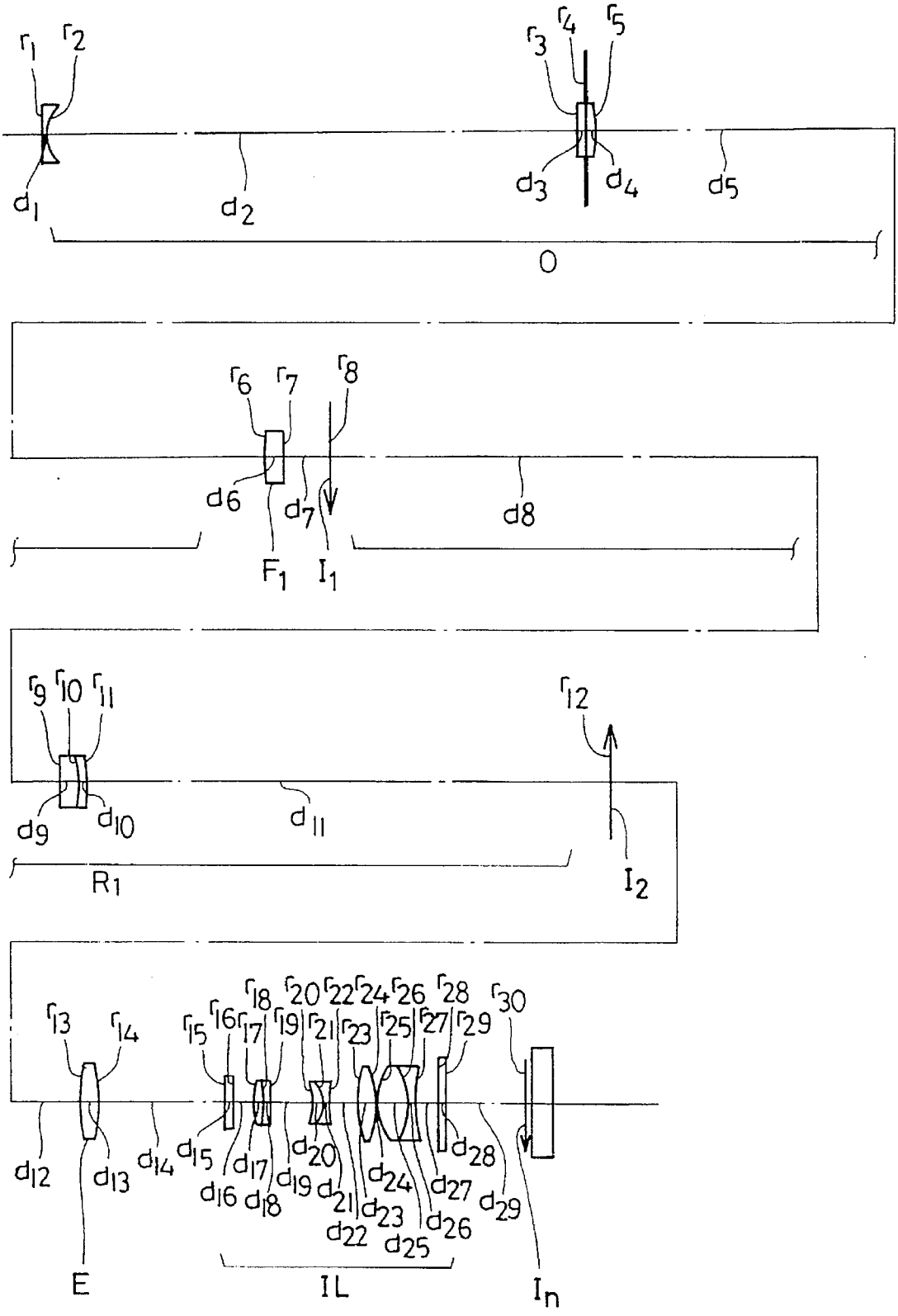


FIG. 14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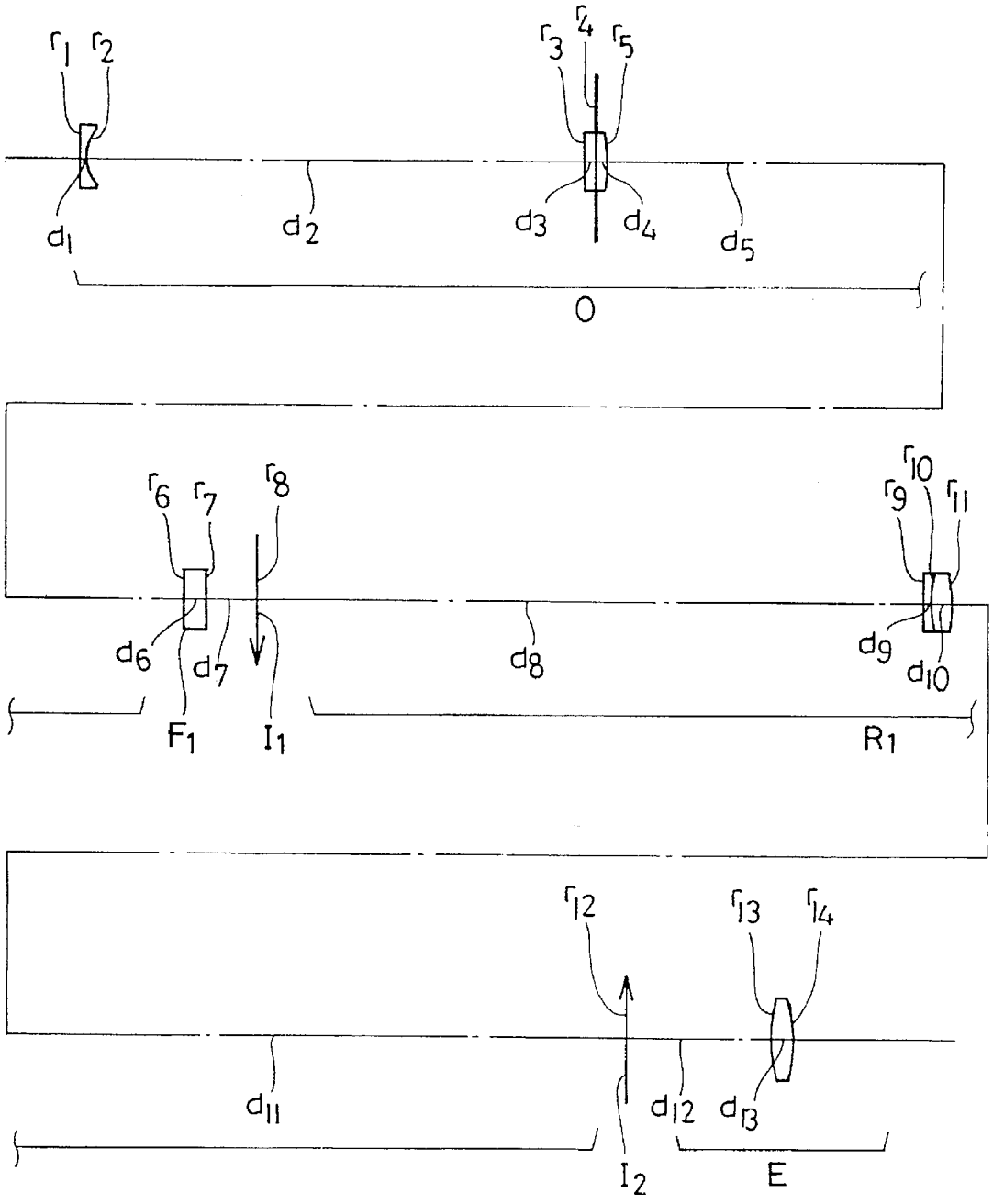
d1 d2 d3 d4 d5
O
r6 r7 r8
d6 d7 d8
F1 I1
r9 r10 r11 r12
d9 d10 d11
R1 I2
r13 r14 r15 r16 r17 r18 r19 r20 r21 r22 r23 r24 r25 r26 r27 r28 r29 r30
d12 d13 d14 d15 d16 d17 d18 d19 d20 d21 d22 d23 d24 d25 d26 d27 d28 d29
E IL In

FIG. 15


r1 r2
r3 r4 r5
d1
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d5
O
r6 r7 r8
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d6
d7
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d10
F1
I1
R1
r12
r13 r14
d11
d12
d13
I2
E

FIG. 16

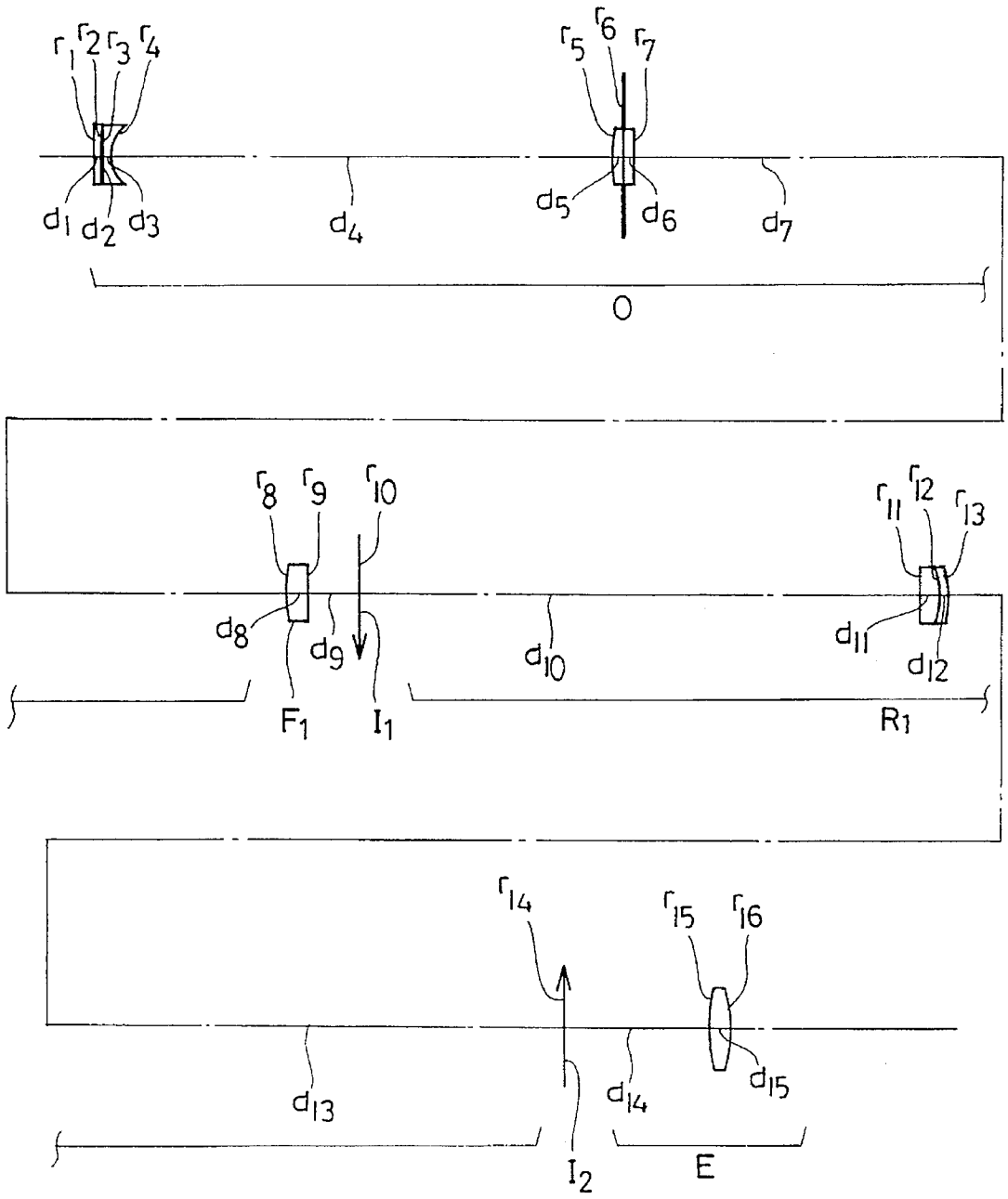

r1 r2 r3 r4
r5 r6 r7
d1 d2 d3
d4
d5 d6
d7
O
r8 r9 r10
r11 r12 r13
d8 d9
d10
d11 d12
F1 I1
R1
r14
r15 r16
d13
d14 d15
I2
E

FIG. 17

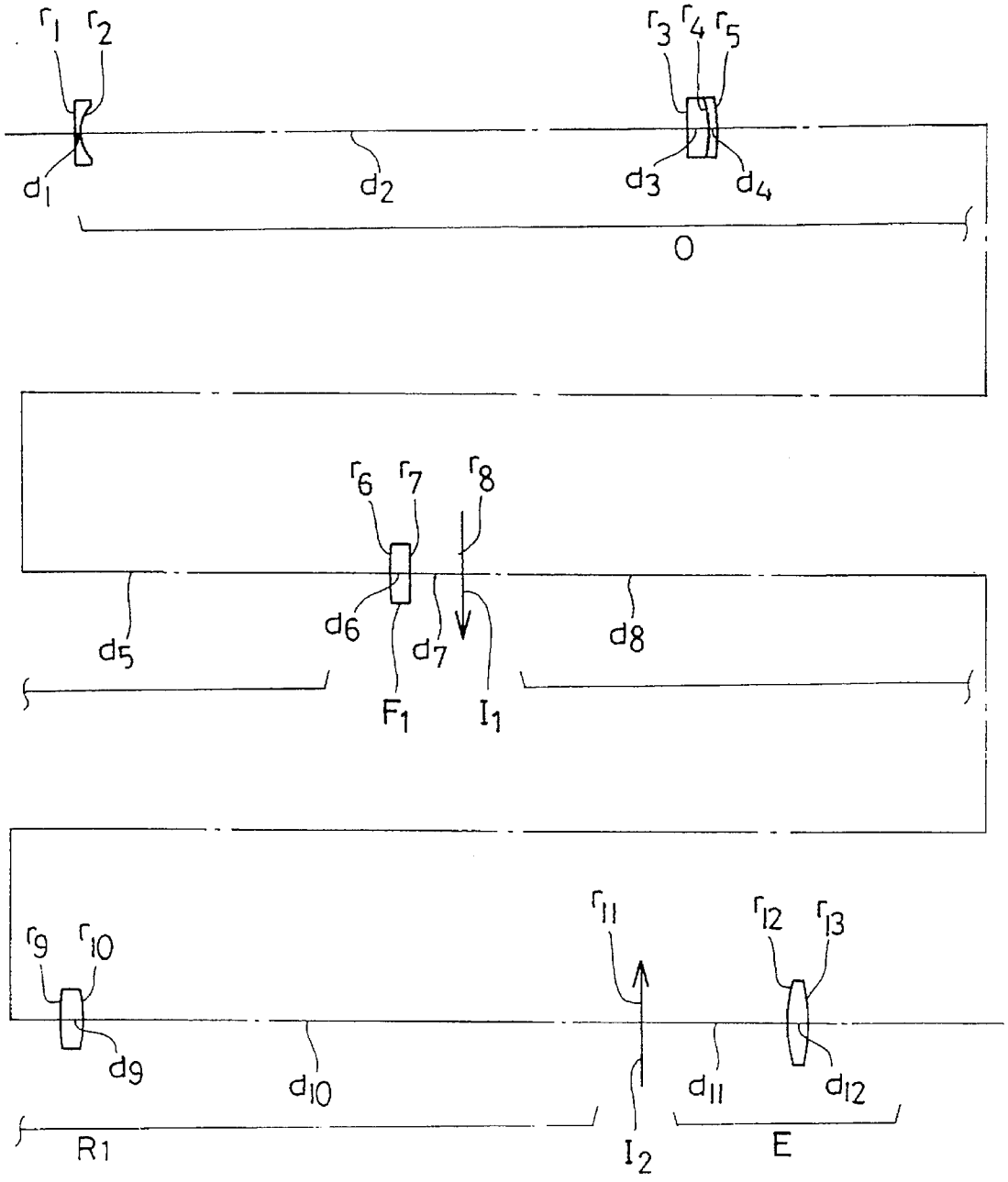
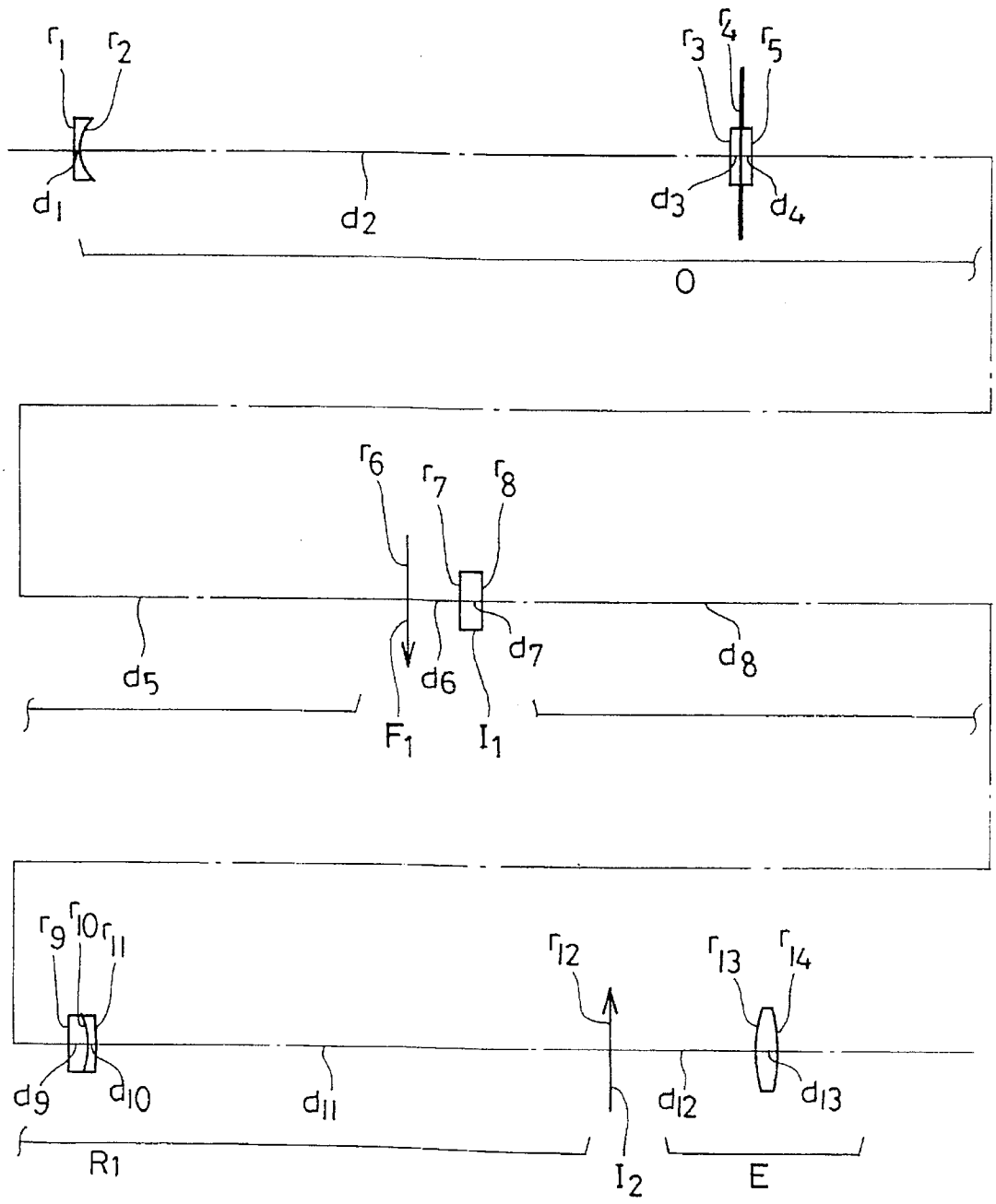

r1 r2
r3 r4 r5
d1
d2
d3
d4
O
r6 r7 r8
d5
d6
d7
d8
F1
I1
r9 r10
r11
r12 r13
d9
d10
d11
d12
R1
I2
E

FIG. 18


r1
r2
r3
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r5
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d3
d4
O
r6
r7
r8
d5
d6
d7
d8
F1
I1
r9
r10
r11
r12
r13
r14
d9
d10
d11
d12
d13
R1
I2
E

FIG. 19

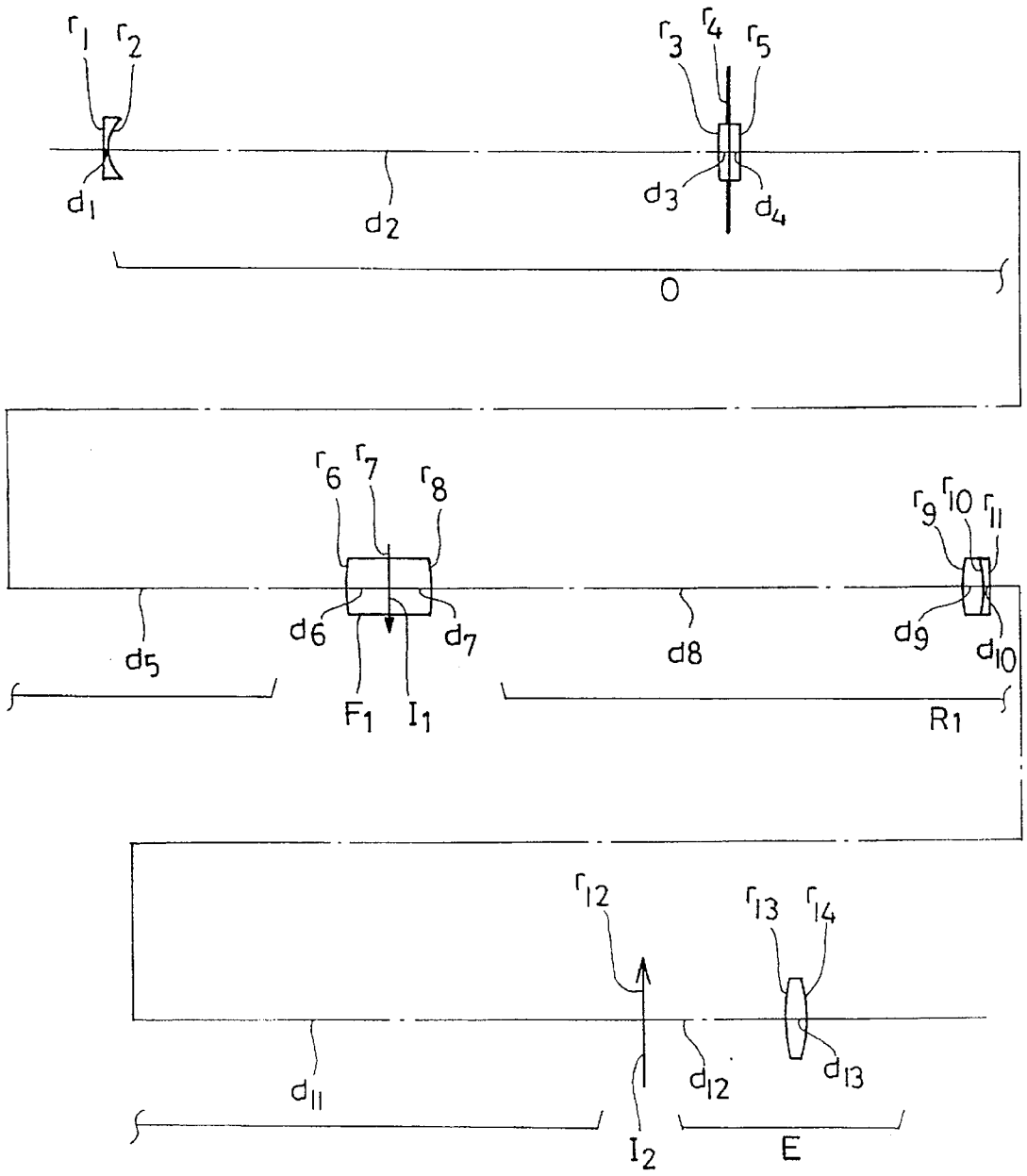
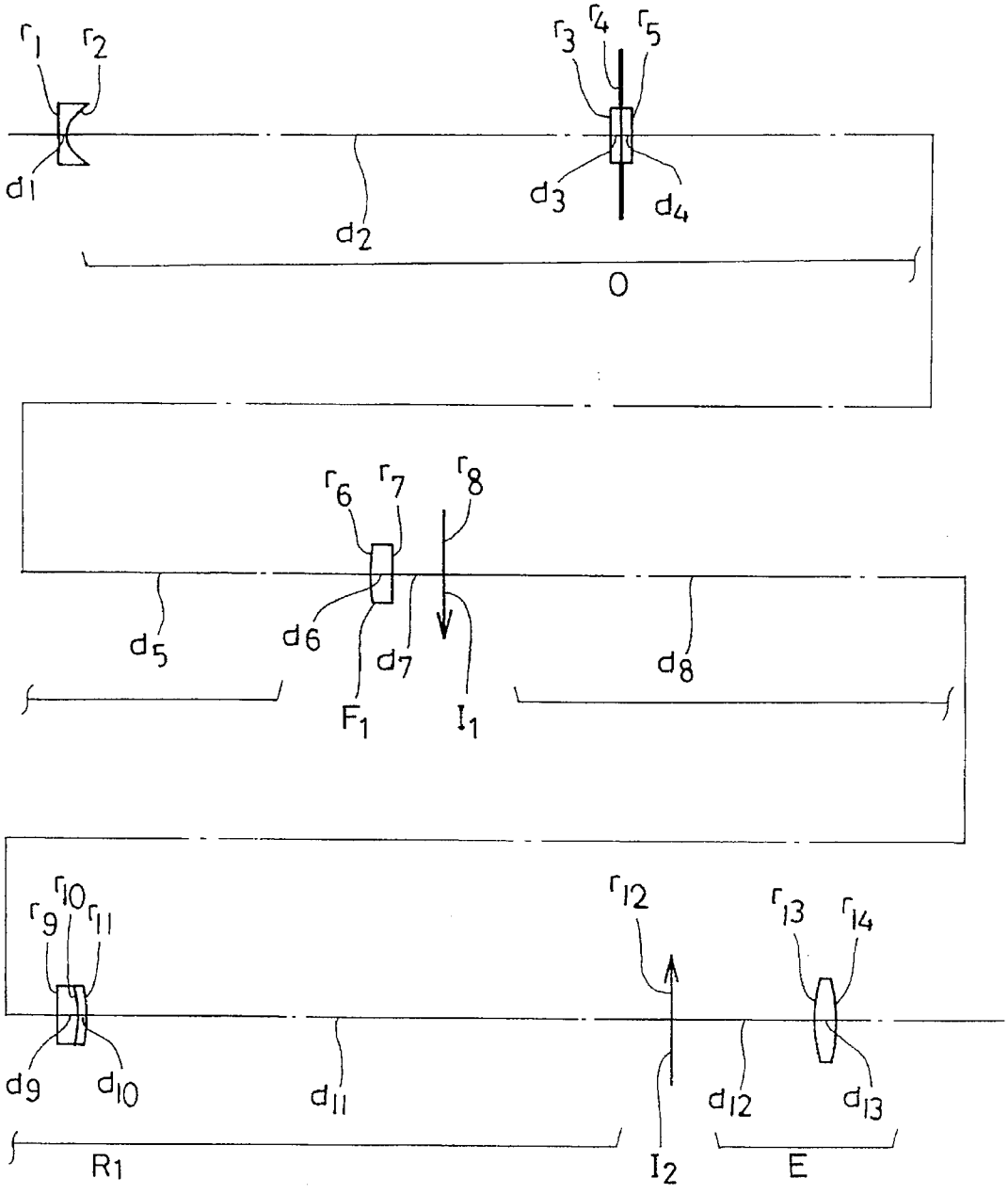

r1 r2
r3 r4 r5
d1
d2
d3
d4
O
r6 r7 r8
r9 r10 r11
d5
d6
d7
d8
d9
d10
F1
I1
R1
r12
r13 r14
d11
d12
d13
I2
E

FIG. 20


r1
r2
r3
r4
r5
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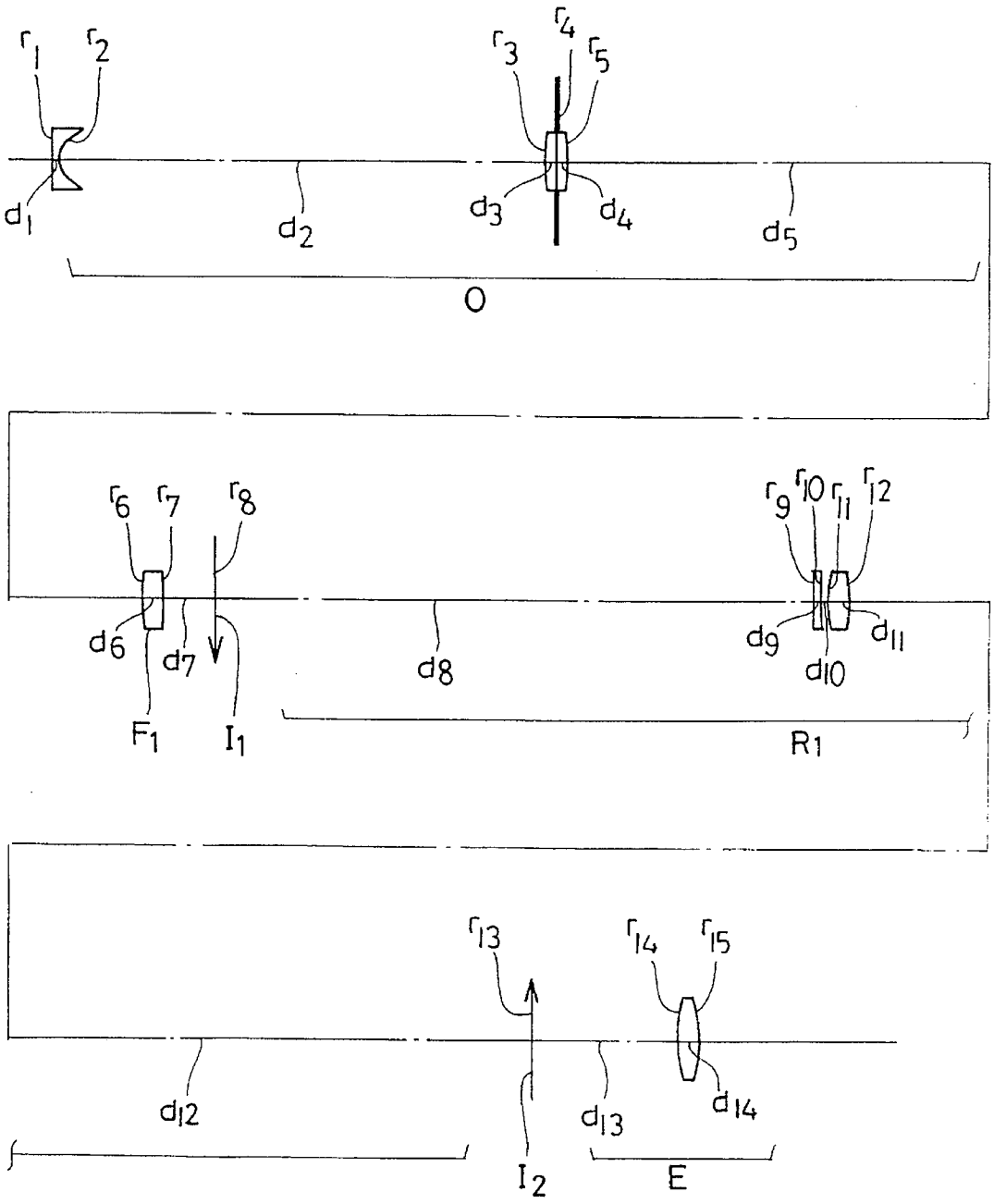
d2
d3
d4
O
r6
r7
r8
d5
d6
d7
d8
F1
I1
r9
r10
r11
r12
r13
r14
d9
d10
d11
d12
d13
R1
I2
E

FIG. 21


r1
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d5
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r11
r12
d6
d7
d8
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F1
I1
R1
r13
r14
r15
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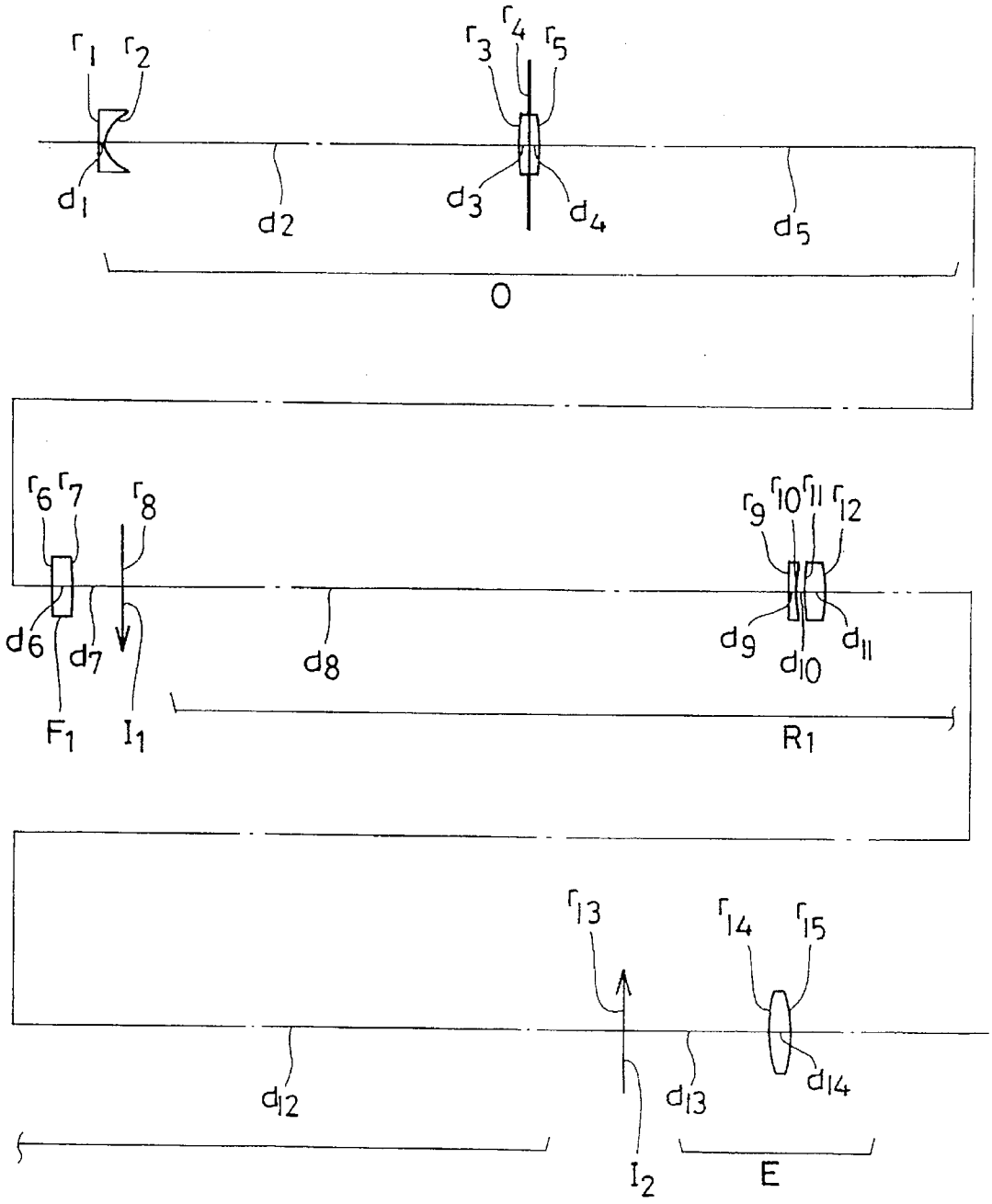
d14
I2
E

FIG. 22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d5
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r8
r9 r10 r11 r12
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d7
d8
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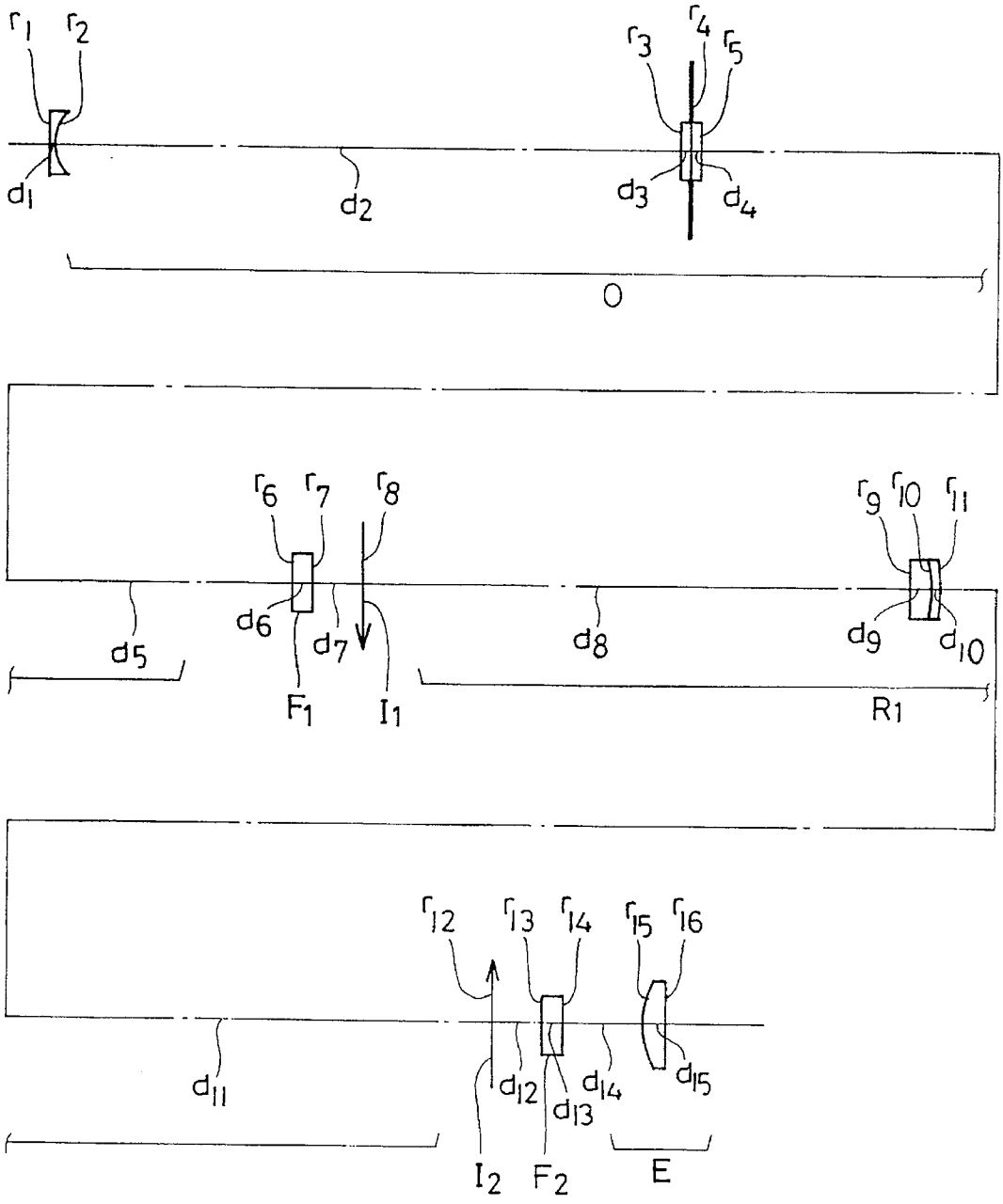
d10
d11
F1
I1
R1
r13
r14 r15
d12
d13
d14
I2
E

FIG. 23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d3
d4
O
r6 r7 r8
r9 r10 r11
d5
d6
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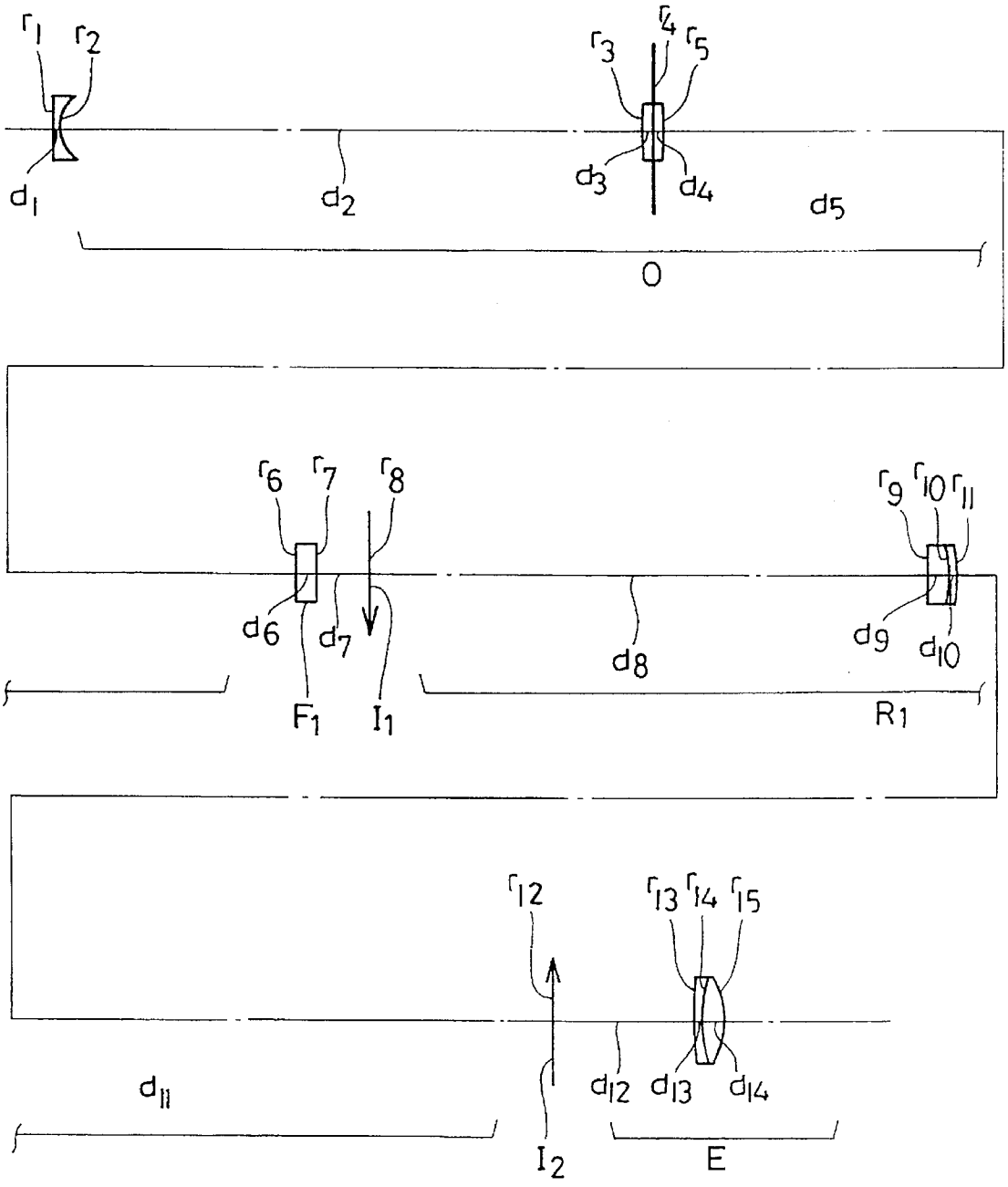
d9
d10
F1
I1
R1
r12 r13 r14 r15 r16
d11
d12
d13
d14
d15
I2
F2
E

FIG. 24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O
r6 r7 r8
r9 r10 r11
d6
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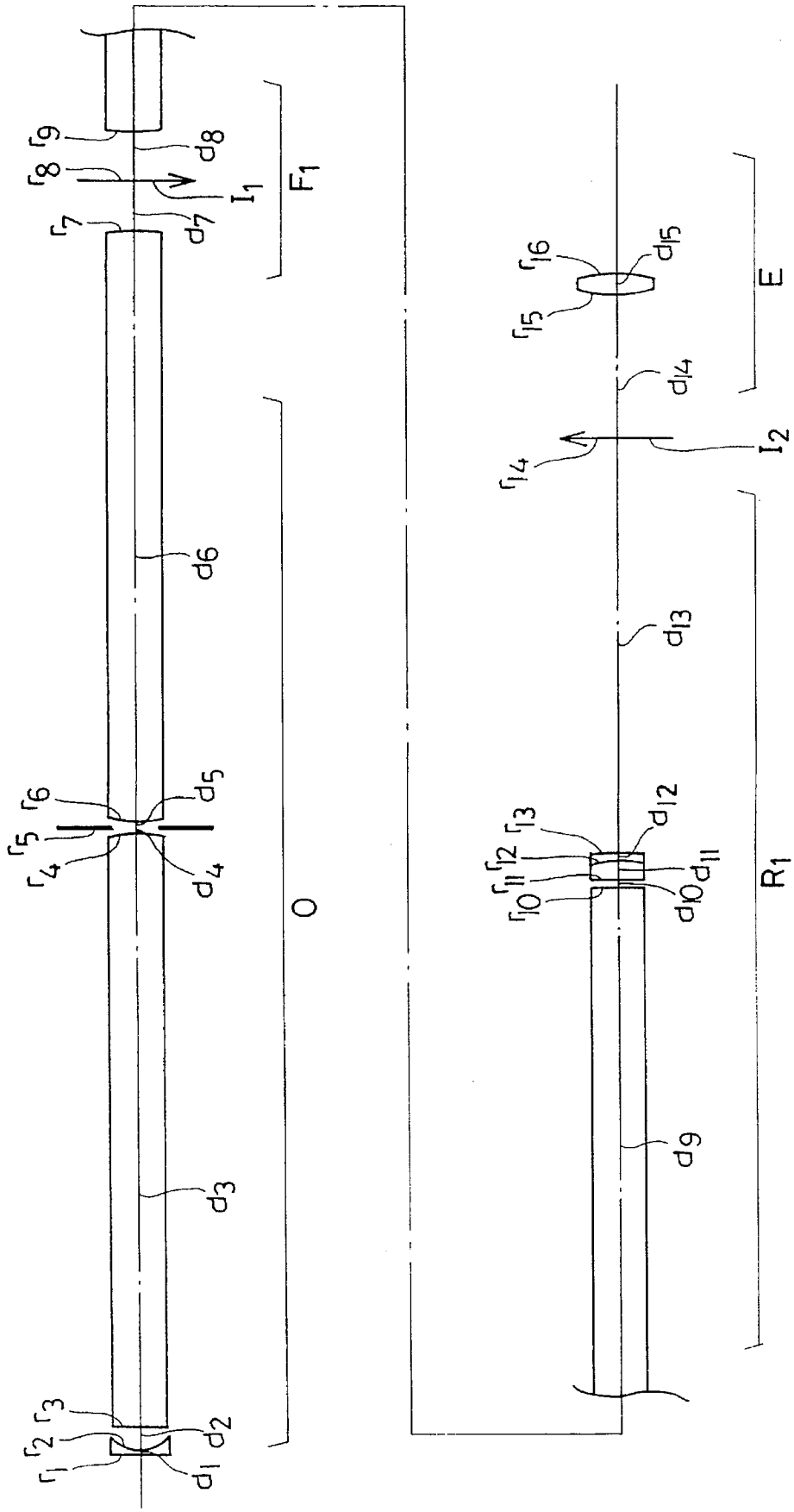
d8
d9
d10
F1
I1
R1
r12
r13 r14 r15
d11
d12
d13
d14
I2
E

FIG. 25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d2
d3
r4
r5
r6
d4
d5
d6
r7
d7
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d8
I1
F1
O
r10
r11
r12
r13
d10
d11
d12
d13
r14
r15
r16
d14
d15
I2
E
R1
d9

FIG. 26

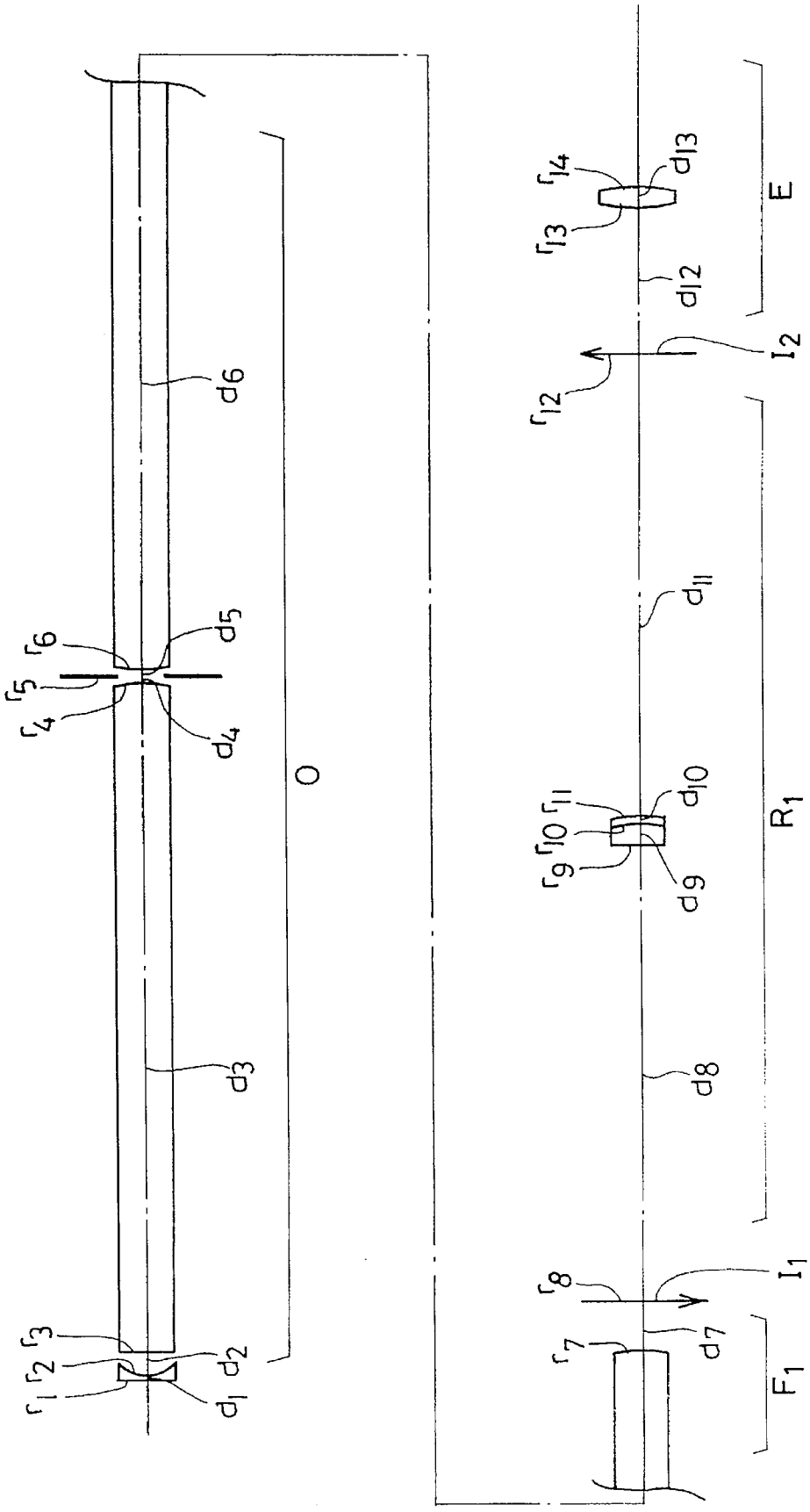

r1
r2
r3
d1
d2
d3
r4
r5
r6
d4
d5
d6
O
r7
r8
d7
I1
F1
d8
r9
r10
r11
d9
d10
d11
R1
r12
r13
r14
d12
d13
I2
E

FIG. 27

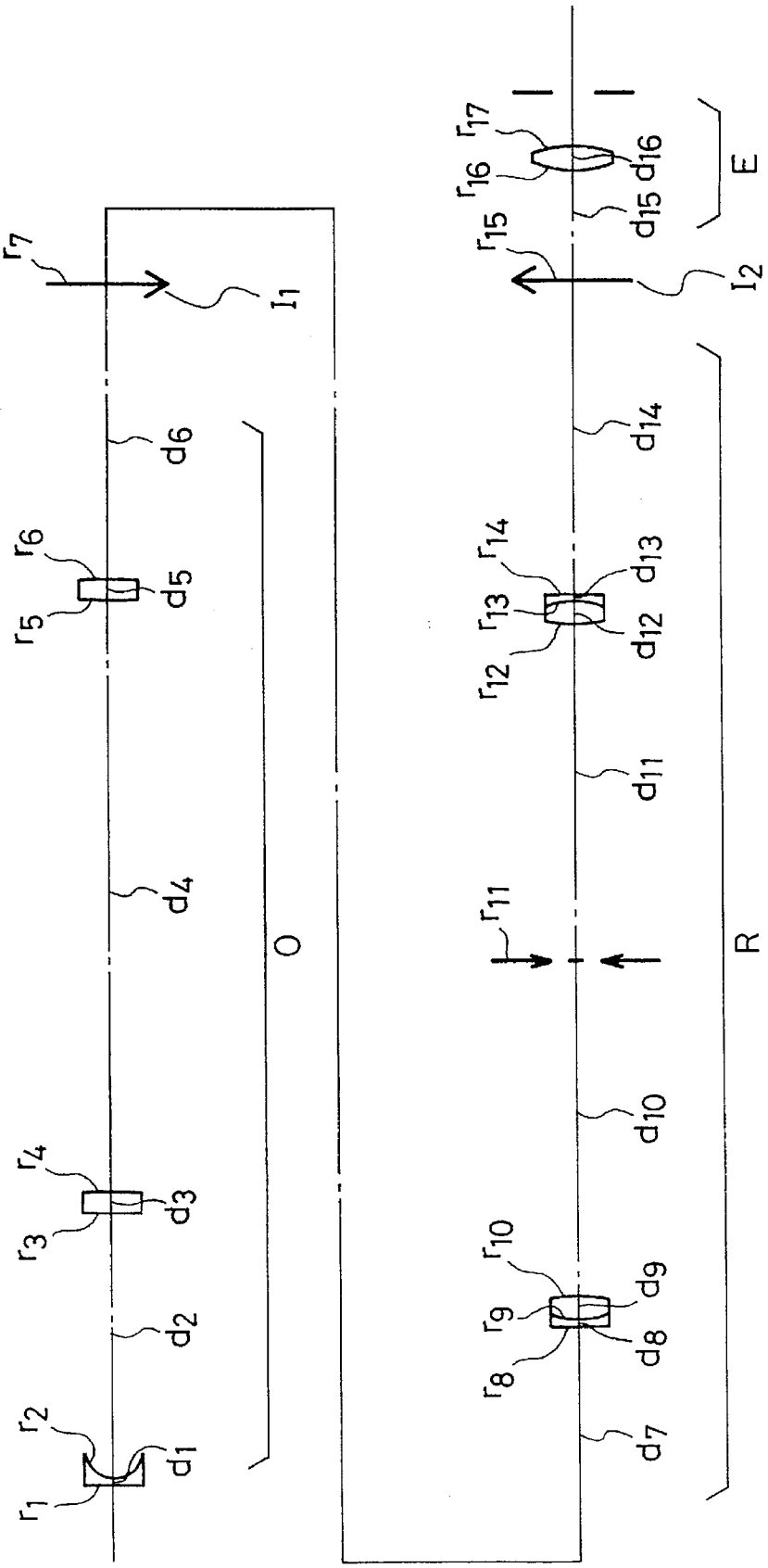

r1
r2
d1
d2
r3
r4
d3
d4
r5
r6
d5
d6
r7
I1
O
r8
r9
r10
d7
d8
d9
d10
r11
d11
r12
r13
r14
d12
d13
d14
r15
r16
r17
d15
d16
I2
E
R

FIG. 28

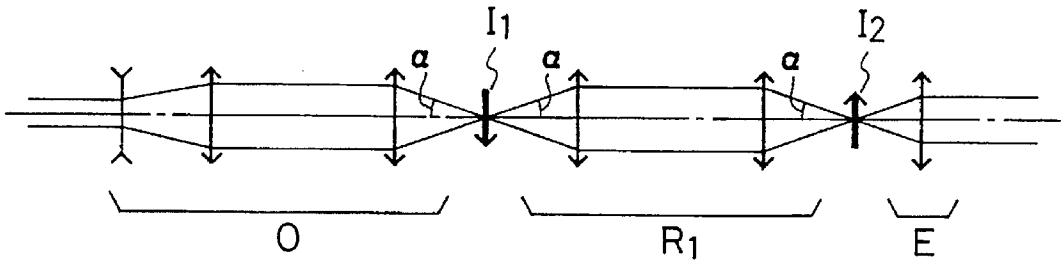


FIG. 29A

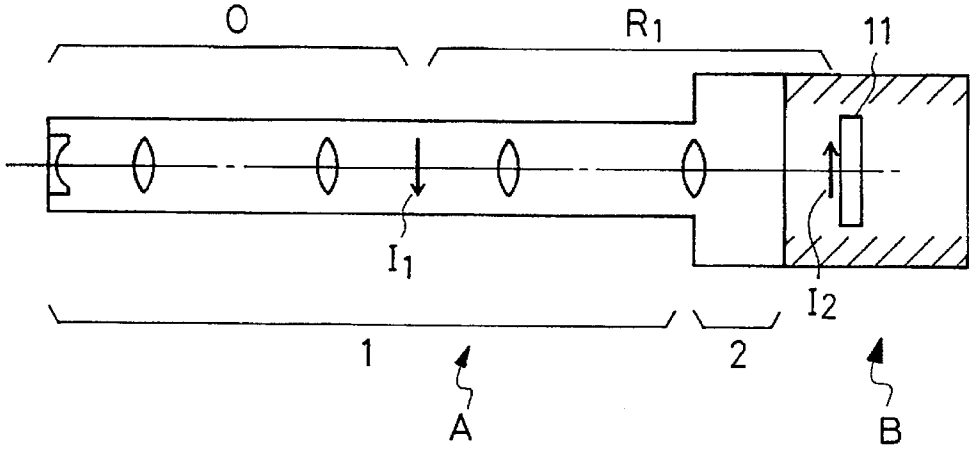
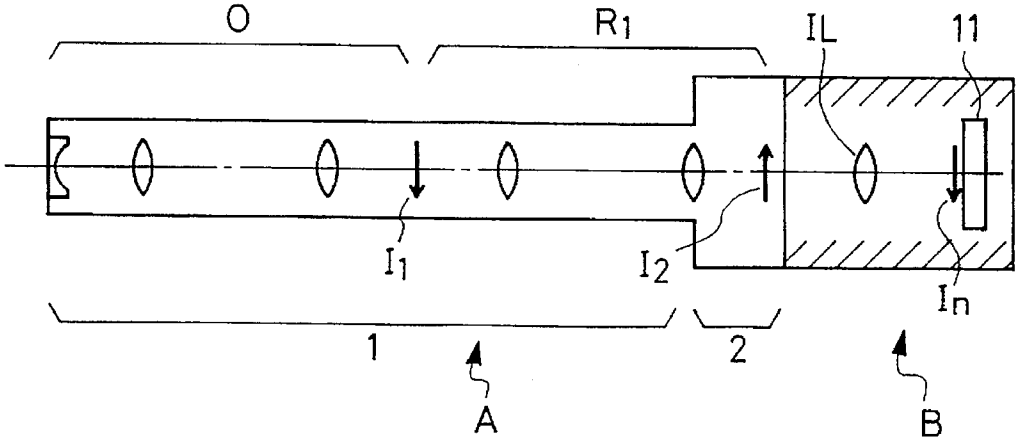


FIG. 29B



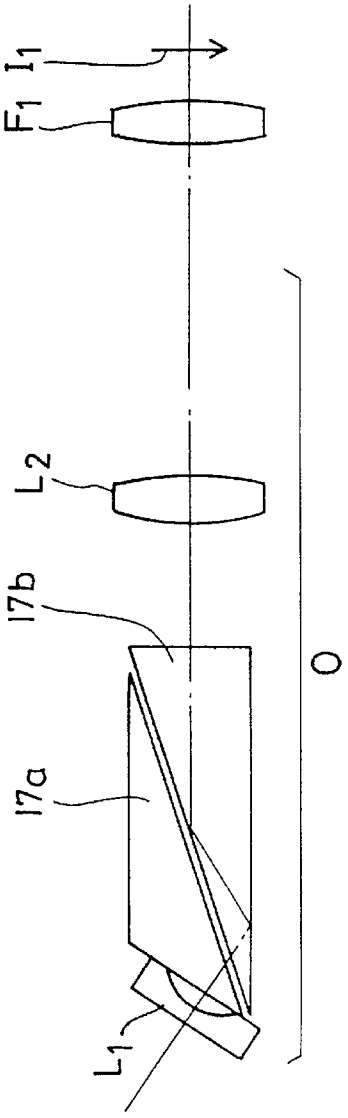


FIG. 30

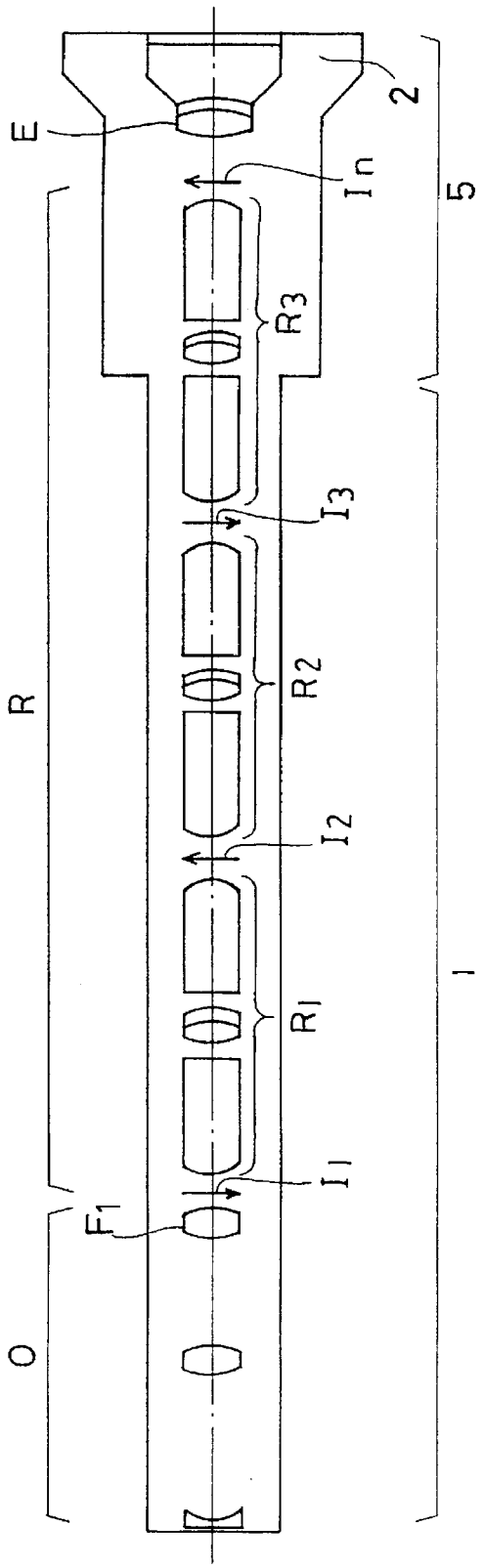
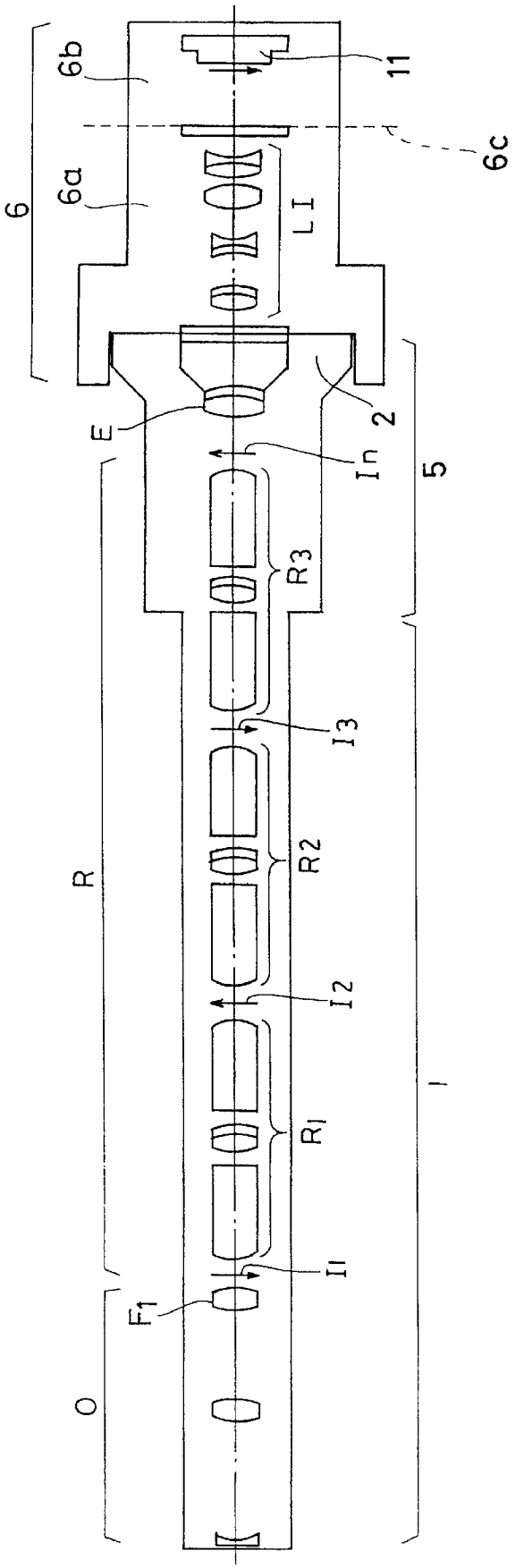


FIG. 31

FIG. 32



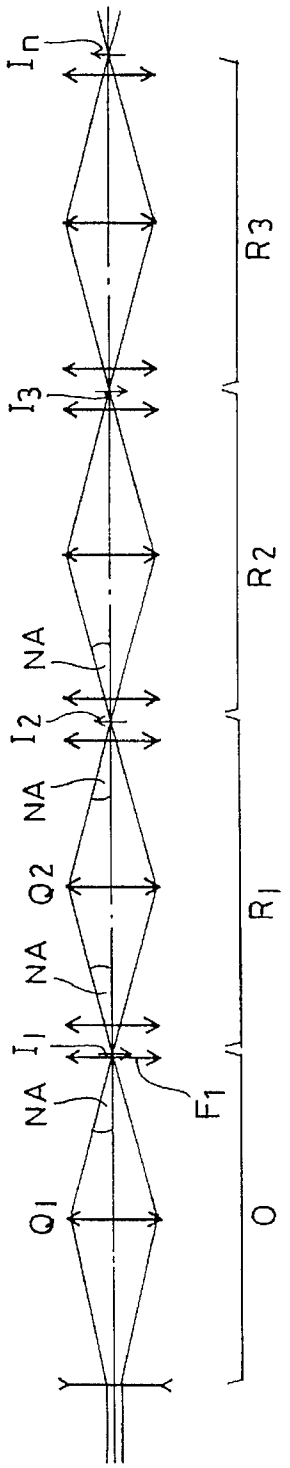


FIG. 33A

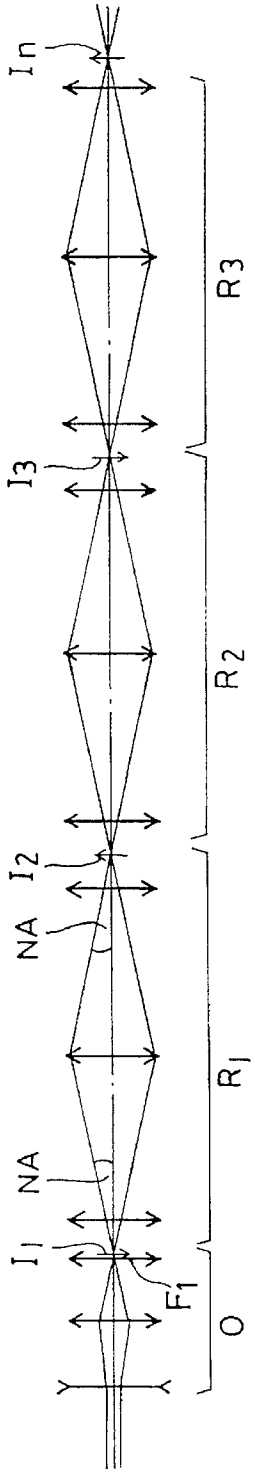


FIG. 33B

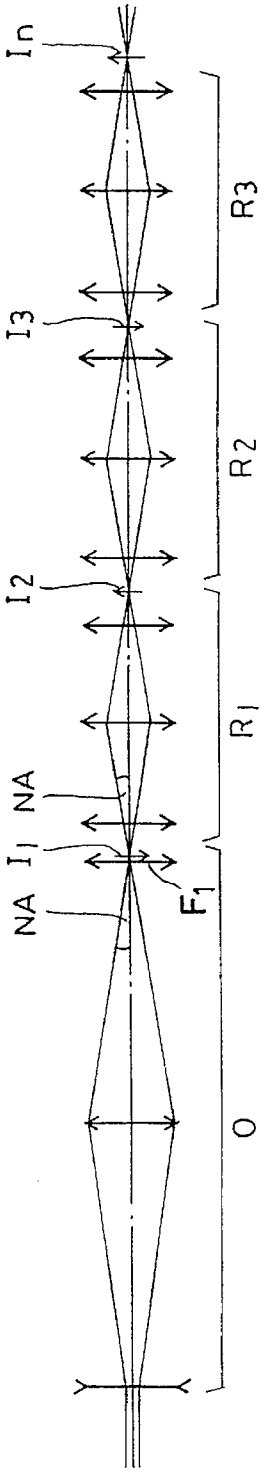


FIG. 33C

FIG. 34

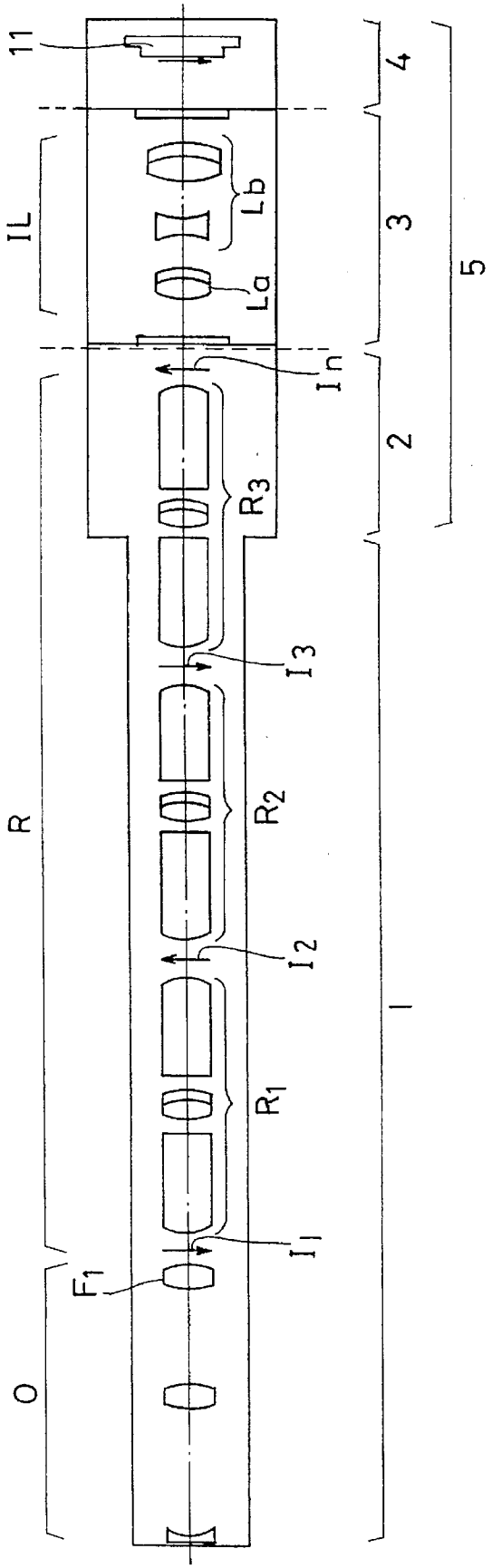
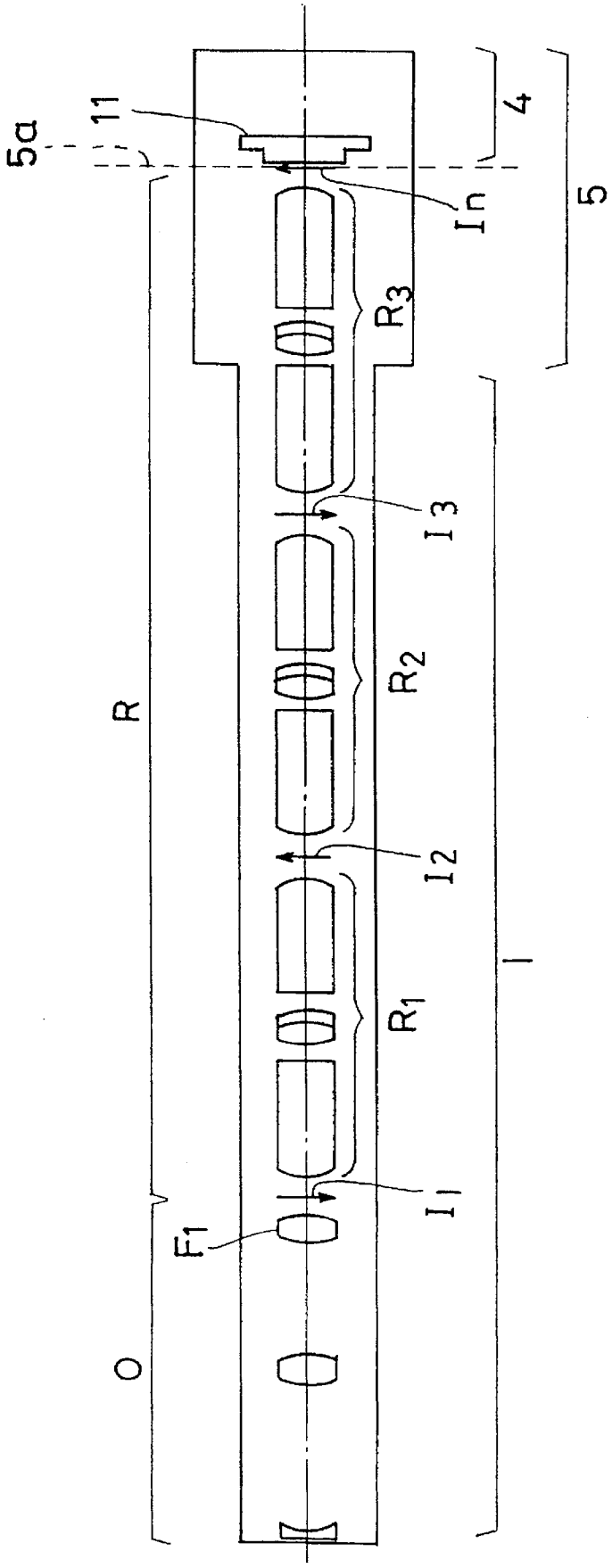


FIG. 35



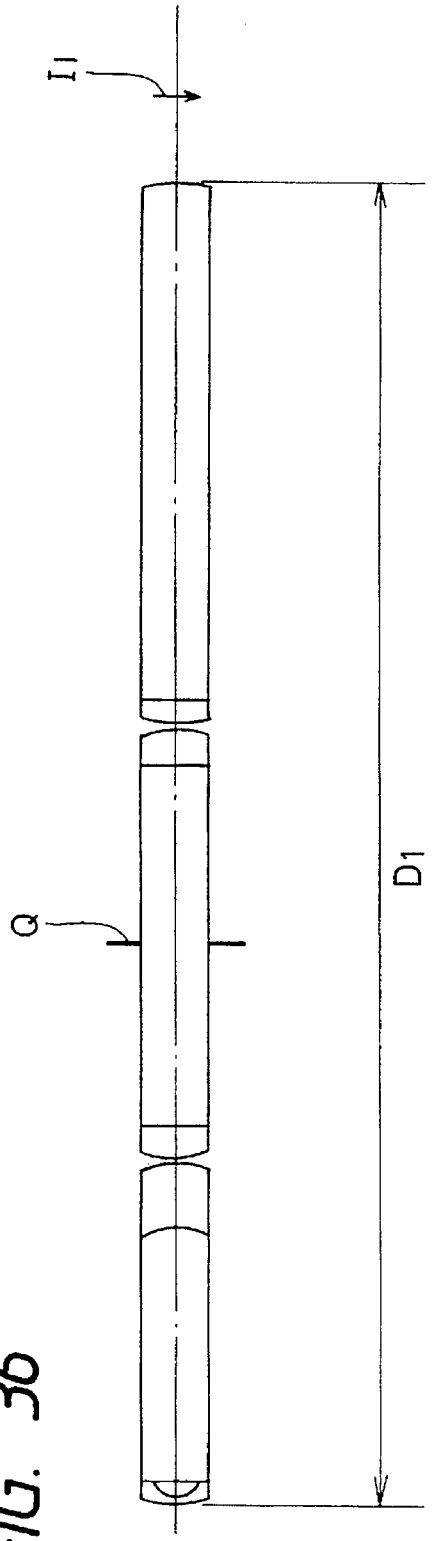


FIG. 36

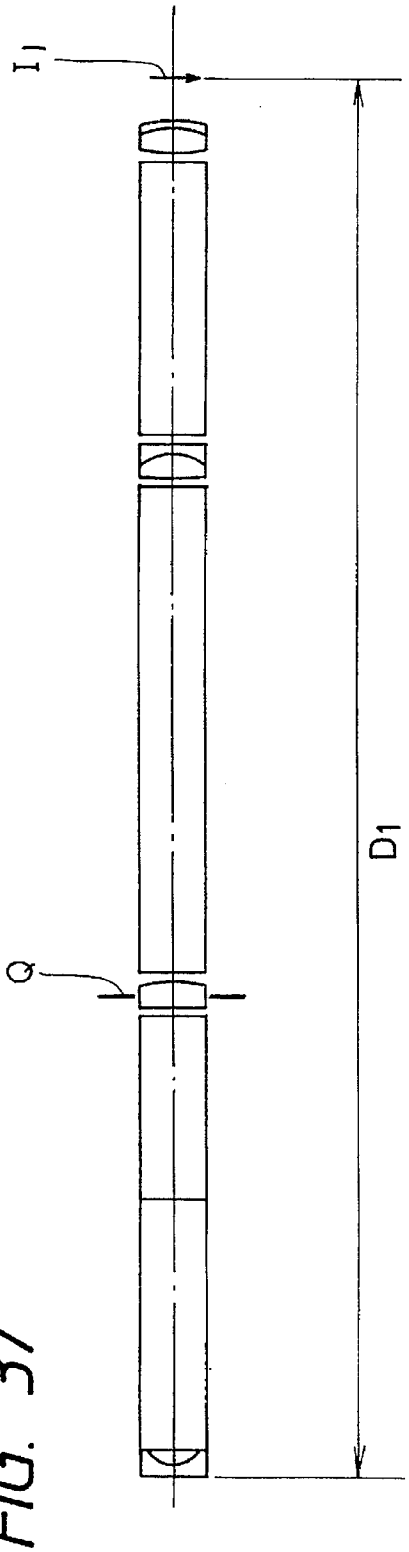


FIG. 37

FIG. 38

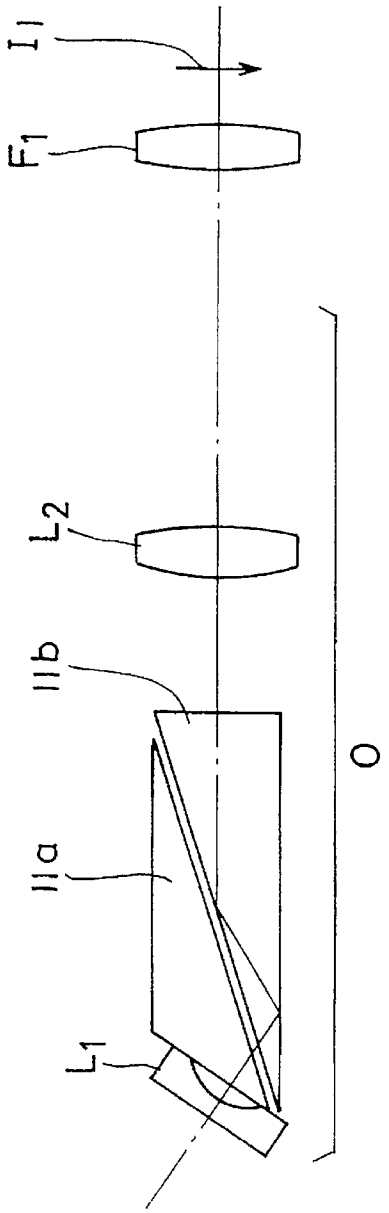


FIG. 39

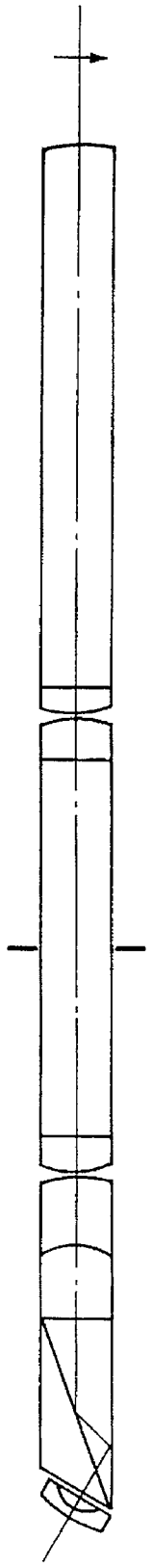


FIG. 40

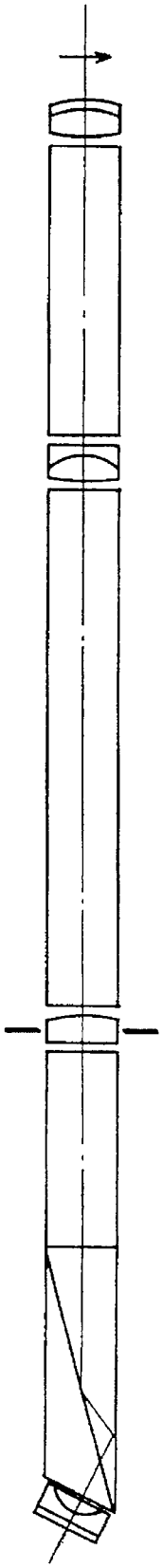


FIG. 41

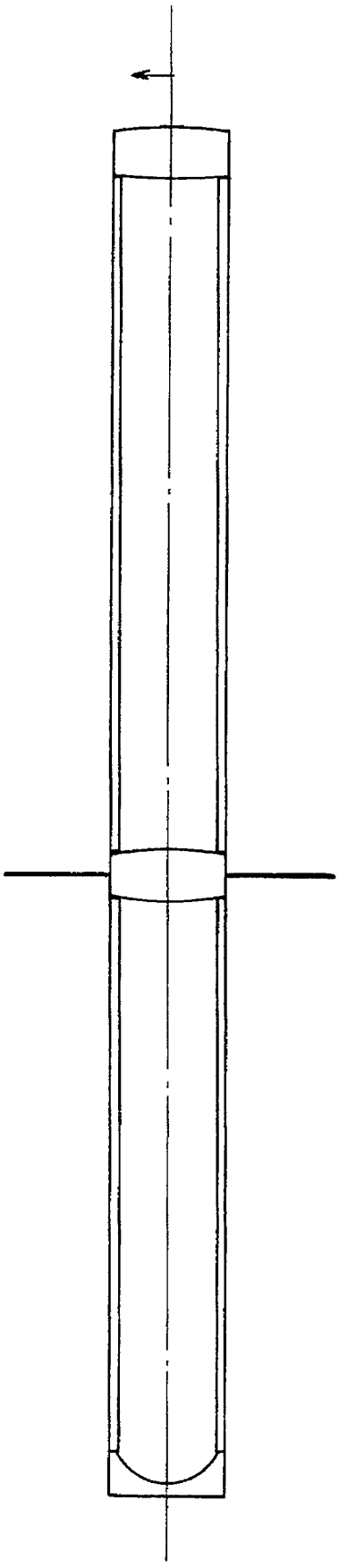


FIG. 42

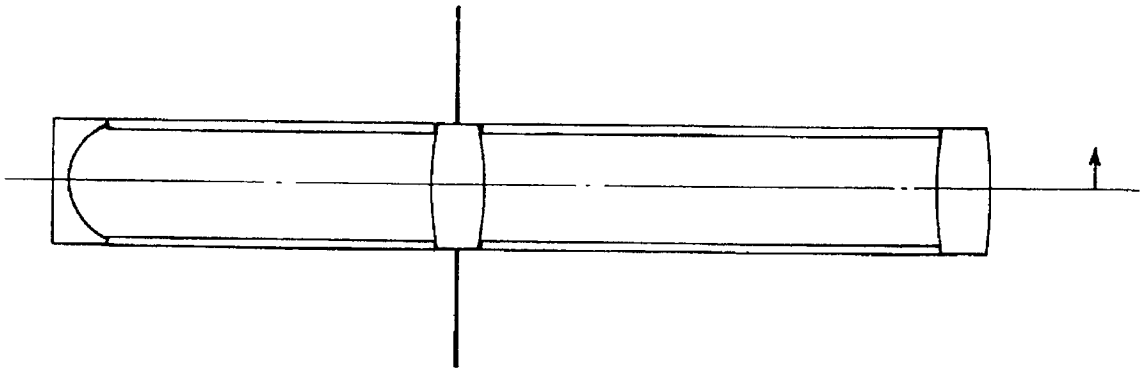


FIG. 43A

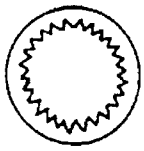


FIG. 43B

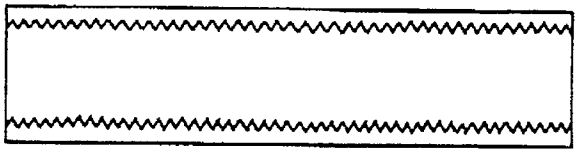


FIG. 44

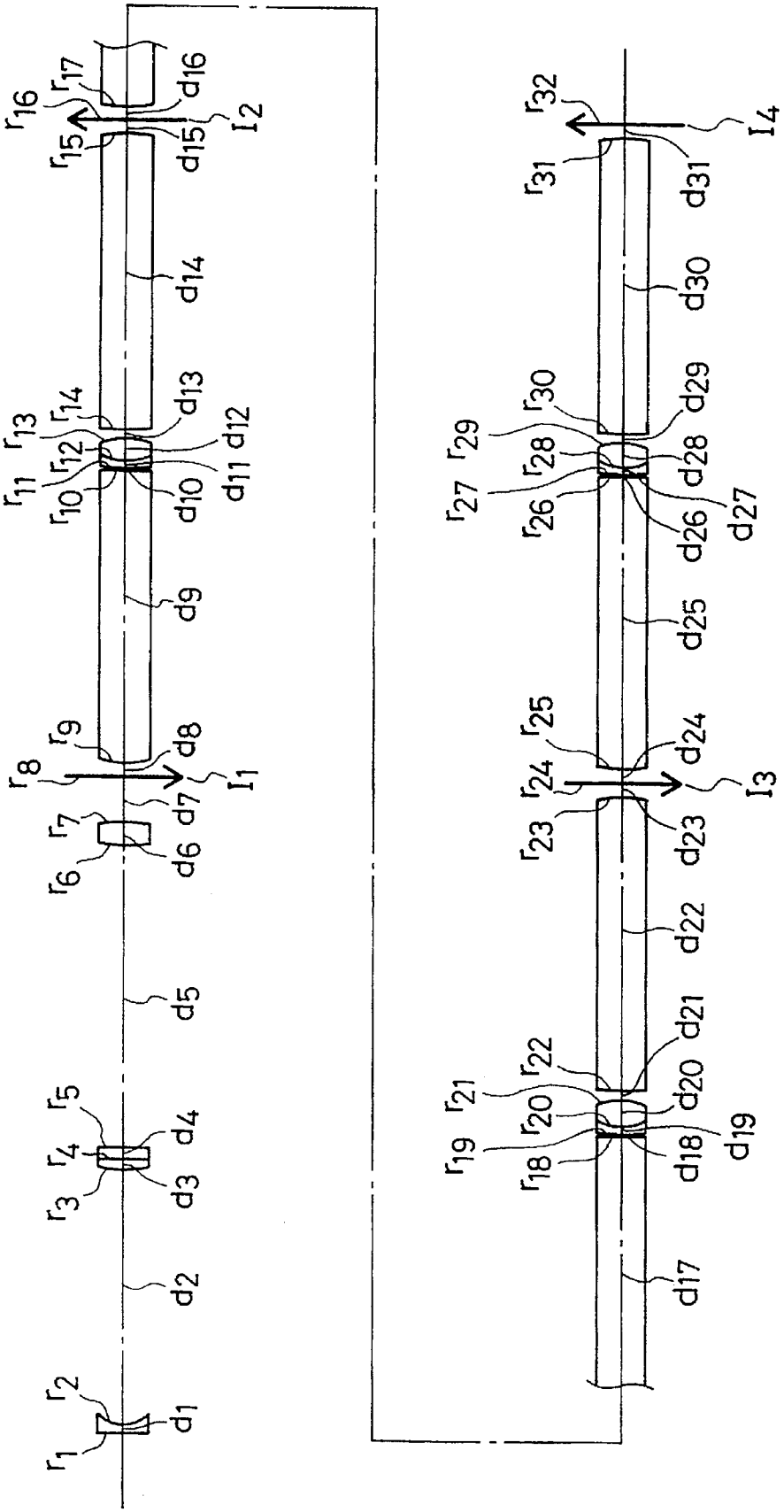

r1
r2
d1
d2
r3
r4
r5
d3
d4
d5
r6
r7
d6
d7
r8
r9
d8
I1
d9
r10
r11
r12
r13
r14
d10
d11
d12
d13
d14
r15
r16
r17
d15
d16
I2
r19
r20
r21
r22
d17
d18
d19
d20
d21
d22
r23
r24
r25
d23
d24
I3
r26
r27
r28
r29
r30
d25
d26
d27
d28
d29
d30
r31
r32
d31
I4

FIG. 45

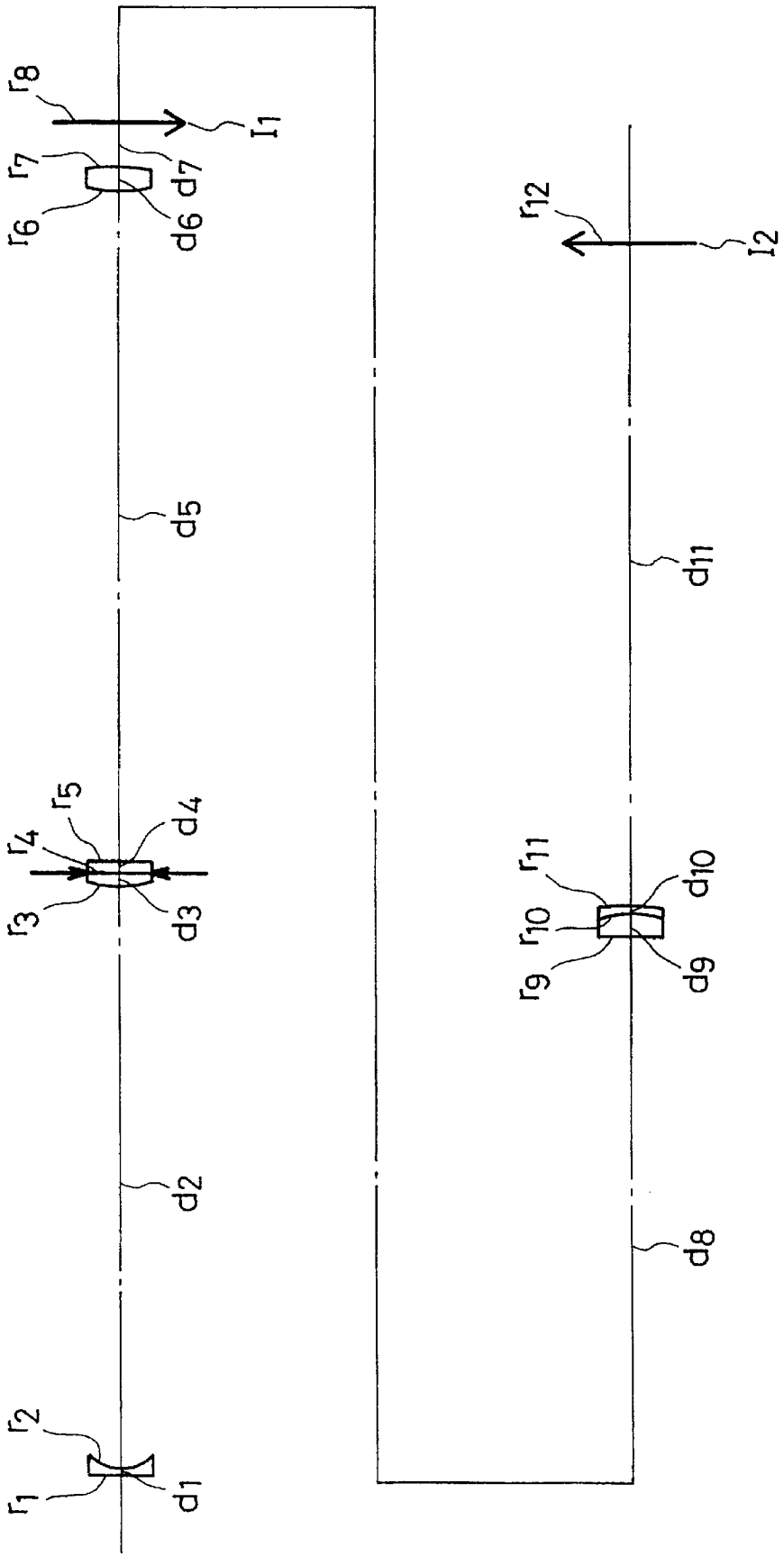

r8
I1
r7
d7
r6
d6
d5
r12
I2
d11
r5
r4
d4
r3
d3
r11
d10
r10
r9
d9
d2
d8
r2
r1
d1

FIG. 46A FIG. 46B FIG. 46C FIG. 46D

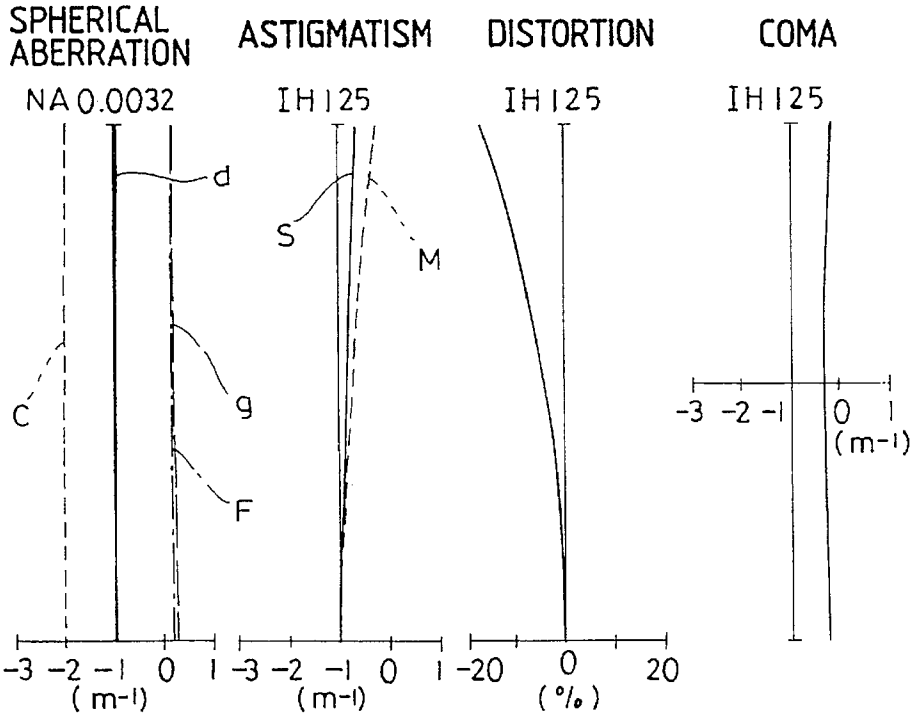


FIG. 47A FIG. 47B FIG. 47C FIG. 47D

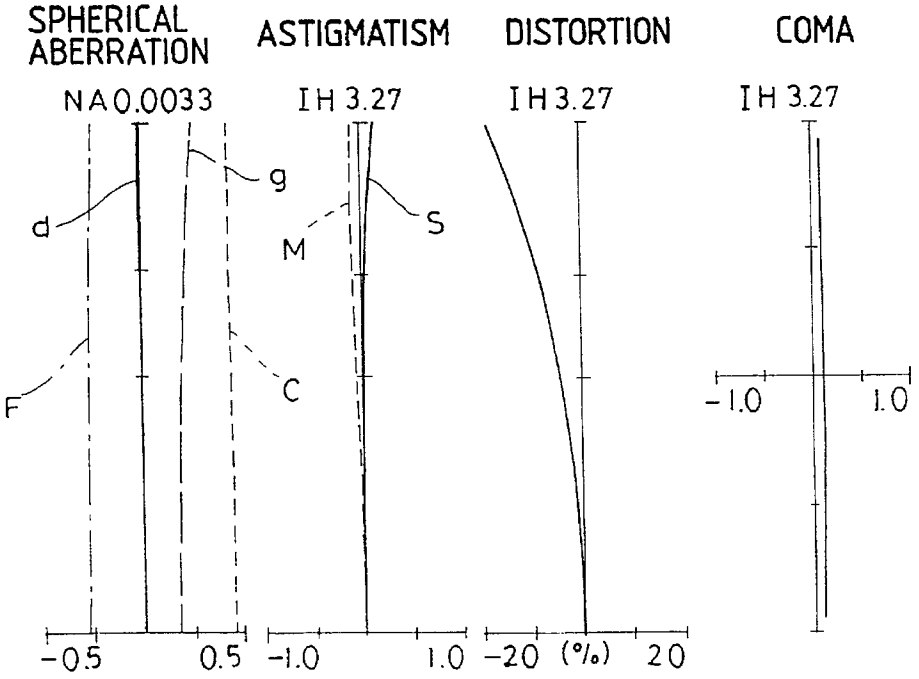


FIG. 48A FIG. 48B FIG. 48C FIG. 48D

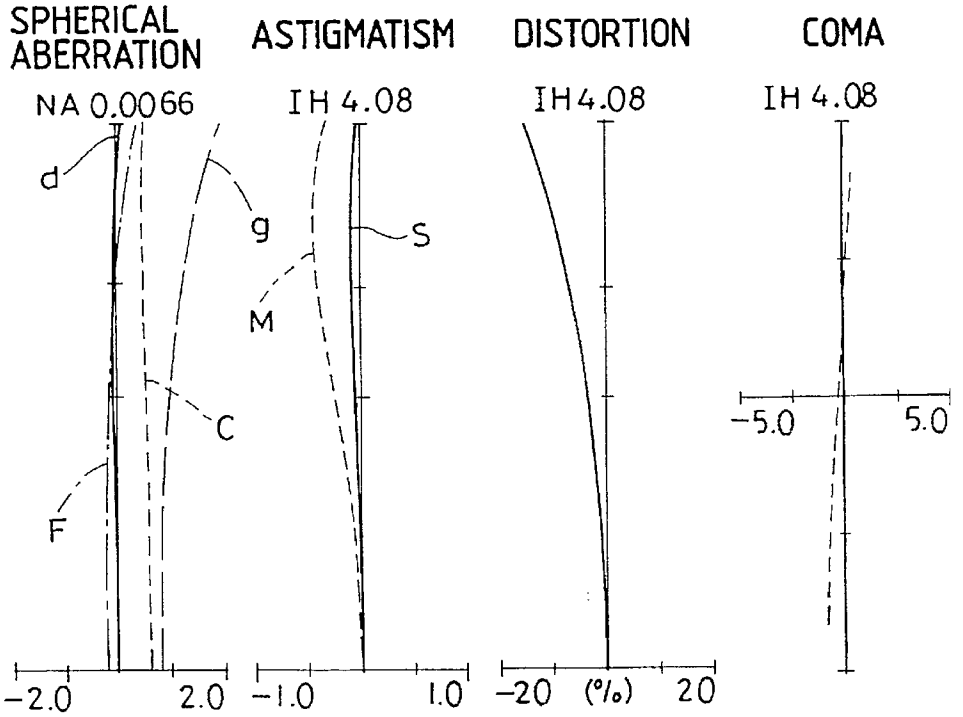


FIG. 49A FIG. 49B FIG. 49C FIG. 49D

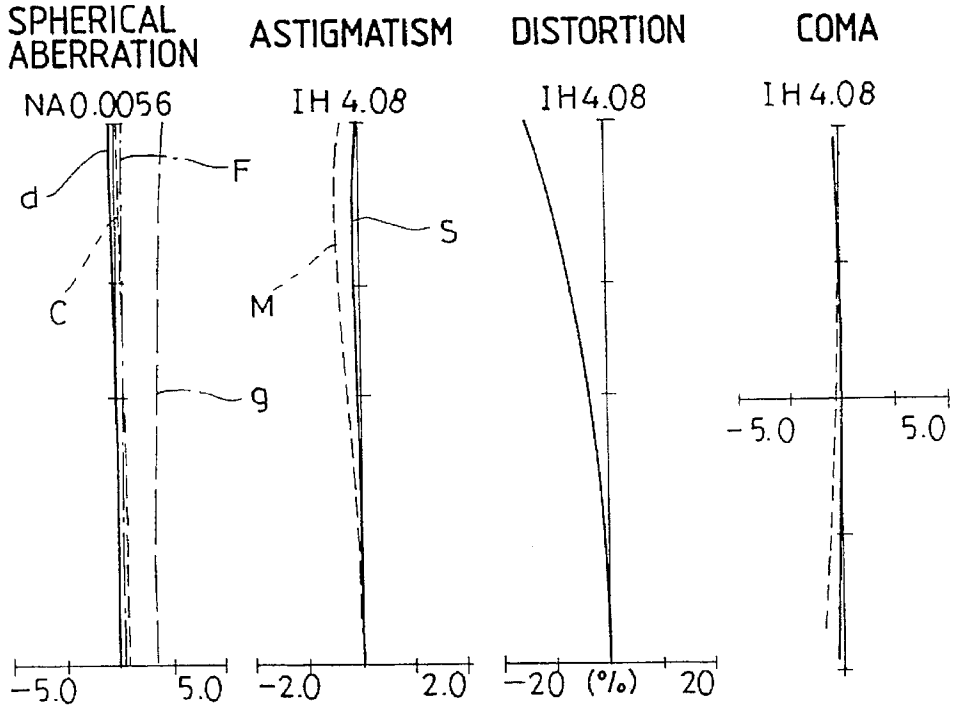


FIG. 50A FIG. 50B FIG. 50C FIG. 50D

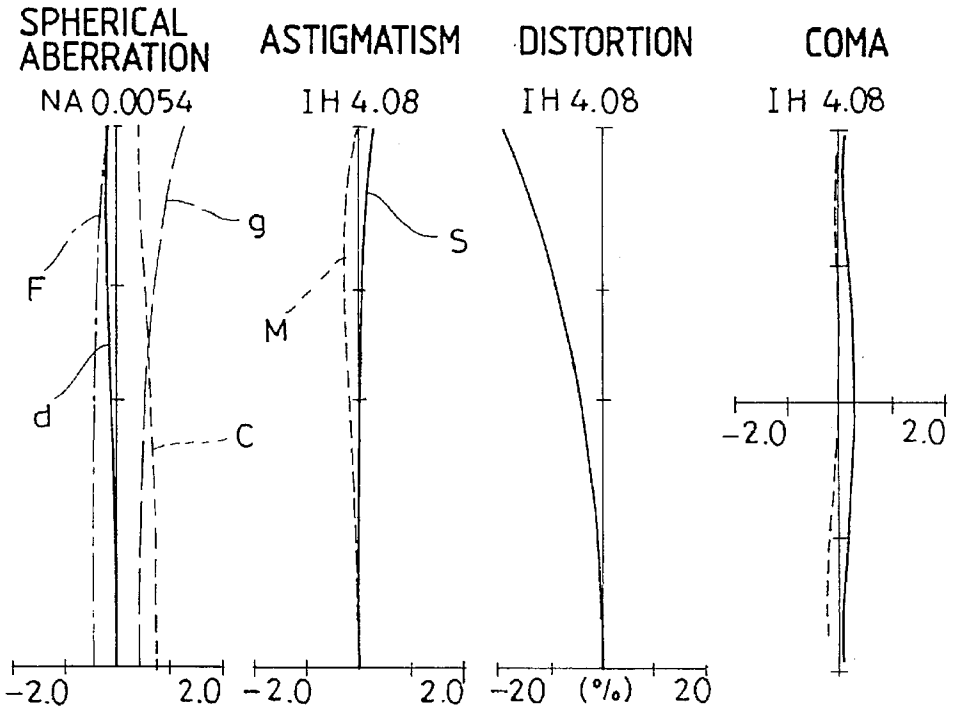


FIG. 51A FIG. 51B FIG. 51C FIG. 51D

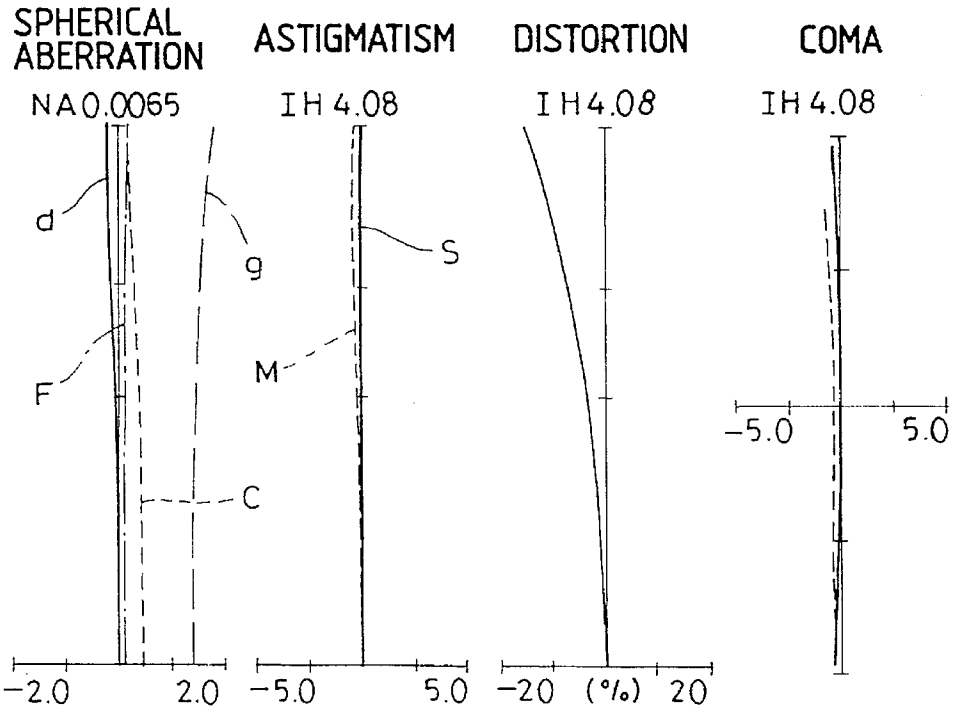


FIG. 52A FIG. 52B FIG. 52C FIG. 52D

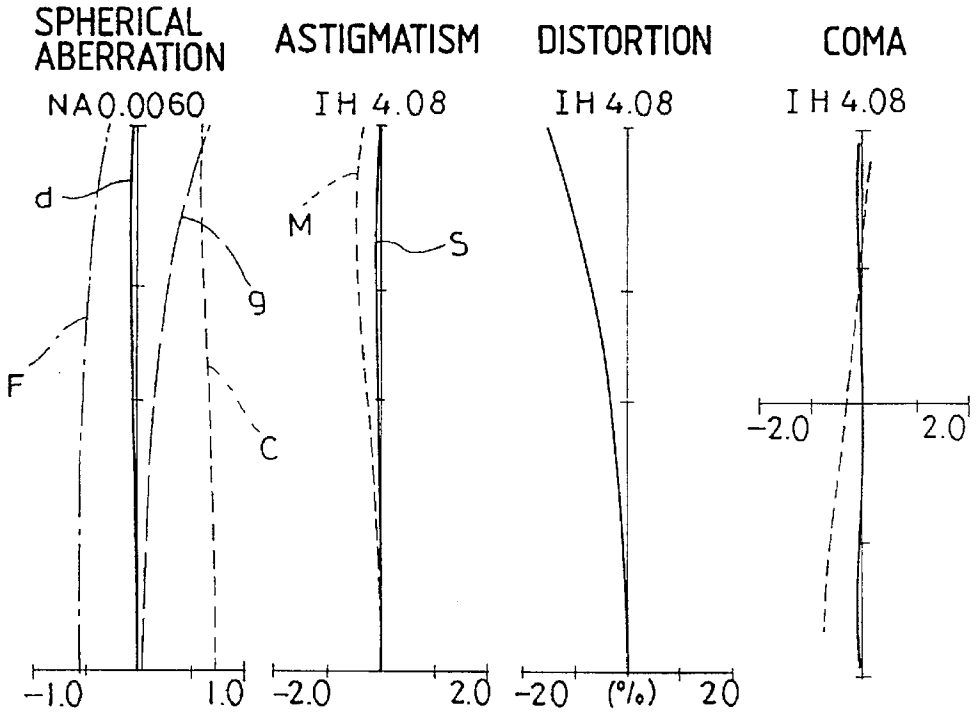


FIG. 53A FIG. 53B FIG. 53C FIG. 53D

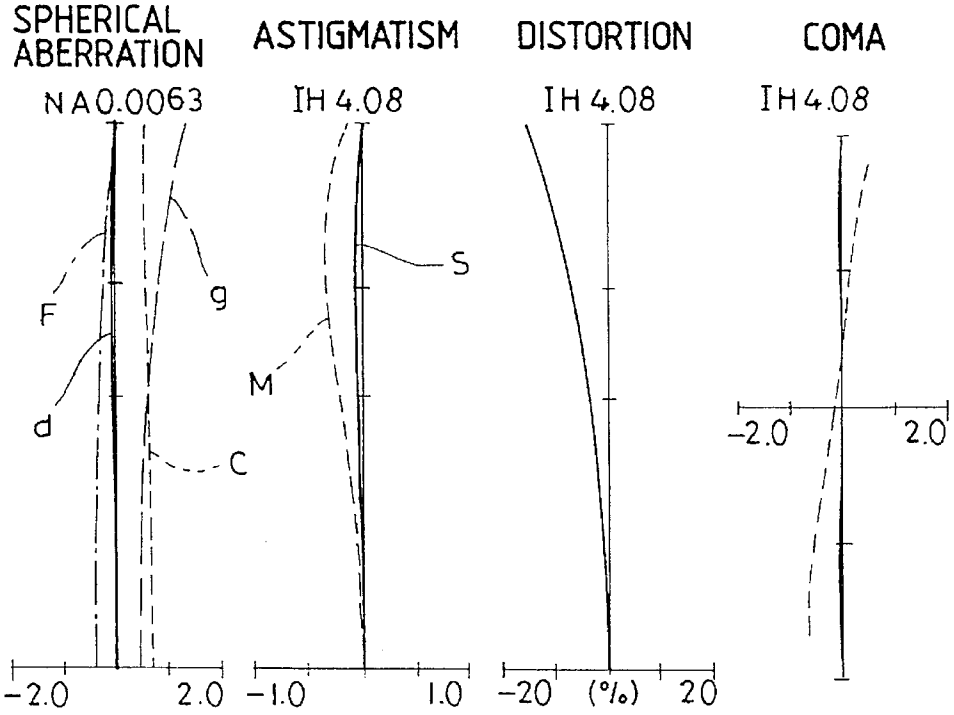


FIG. 54A FIG. 54B FIG. 54C FIG. 54D

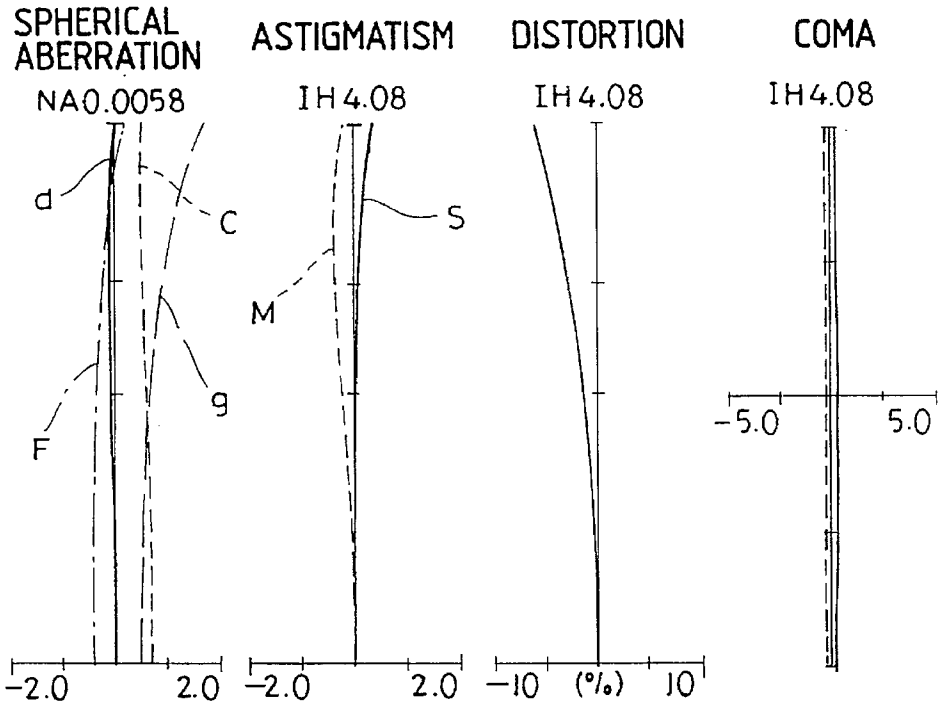


FIG. 55A FIG. 55B FIG. 55C FIG. 55D

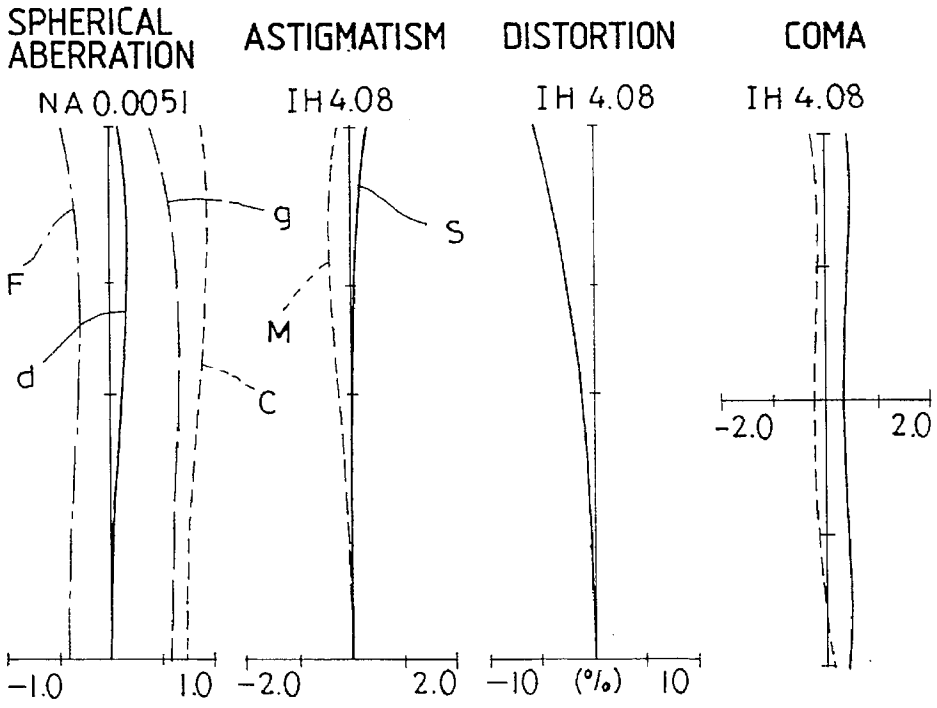


FIG. 56A FIG. 56B FIG. 56C FIG. 56D

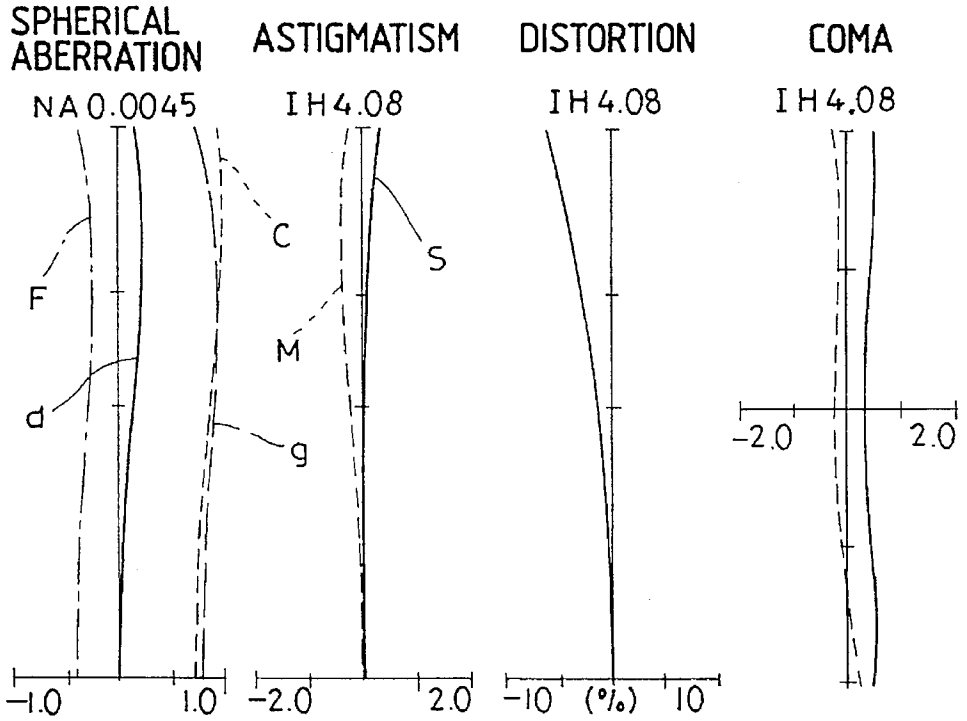


FIG. 57A FIG. 57B FIG. 57C FIG. 57D

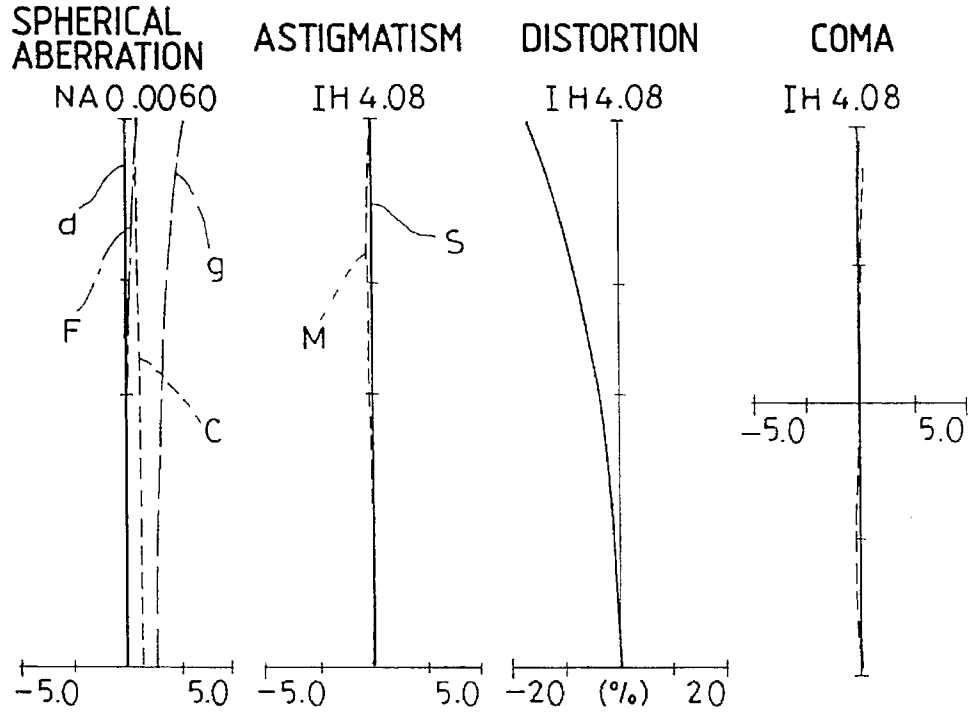


FIG. 58A FIG. 58B FIG. 58C FIG. 58D

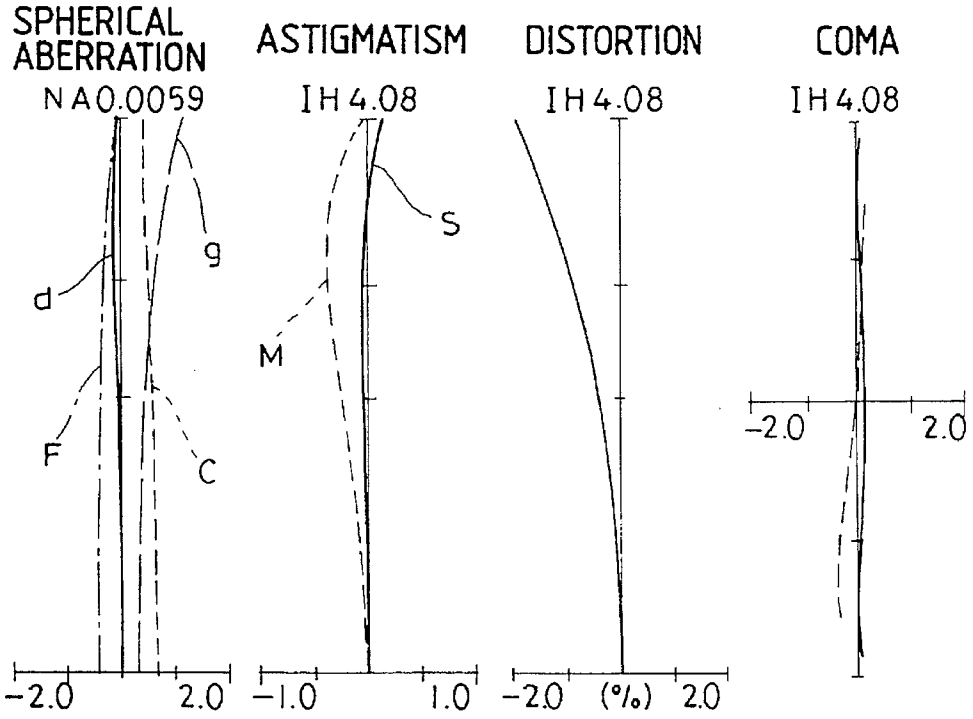


FIG. 59A FIG. 59B FIG. 59C FIG. 59D

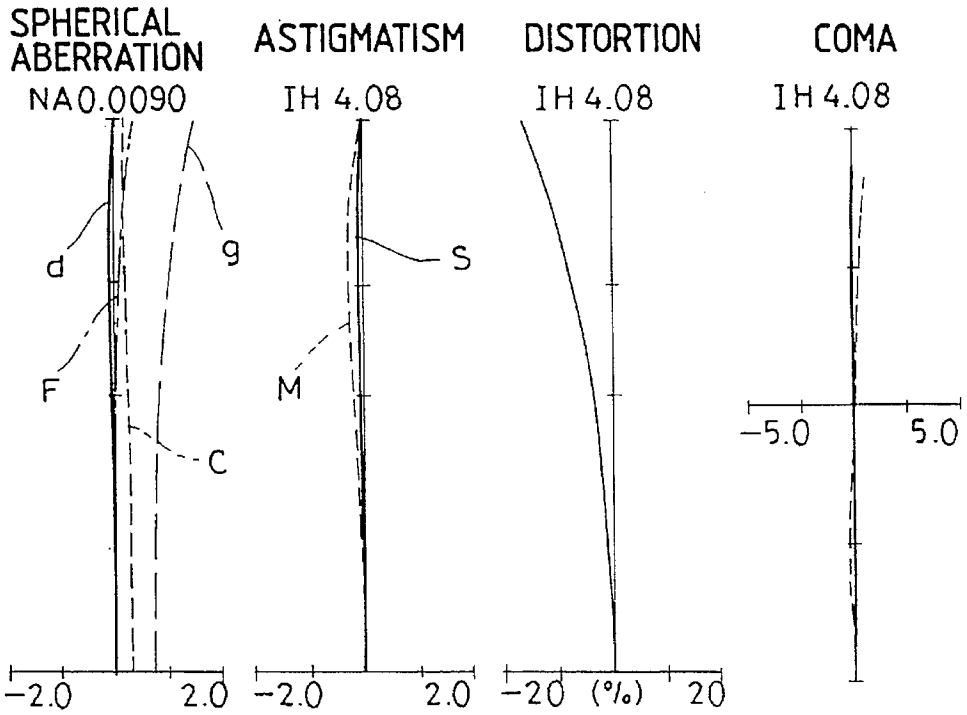


FIG. 60A FIG. 60B FIG. 60C FIG. 60D

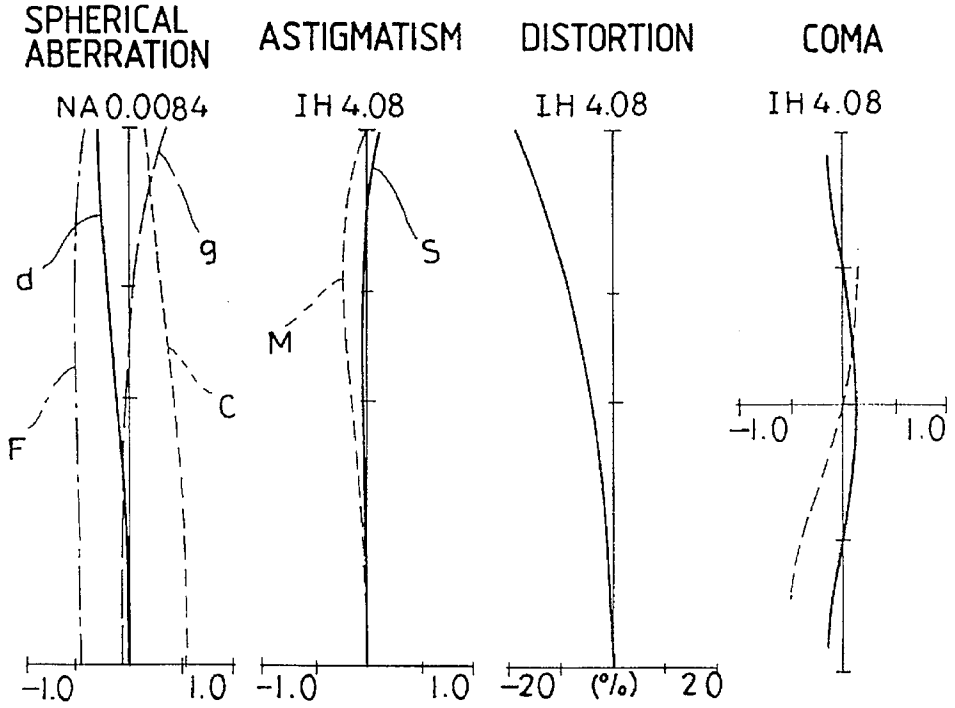


FIG. 61A FIG. 61B FIG. 61C FIG. 61D

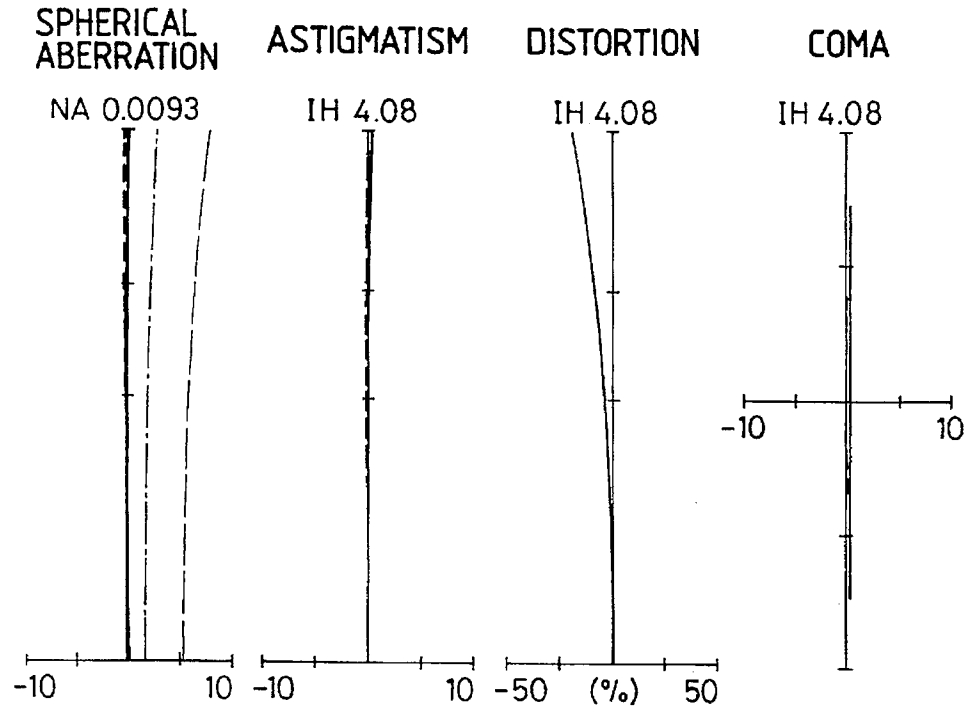
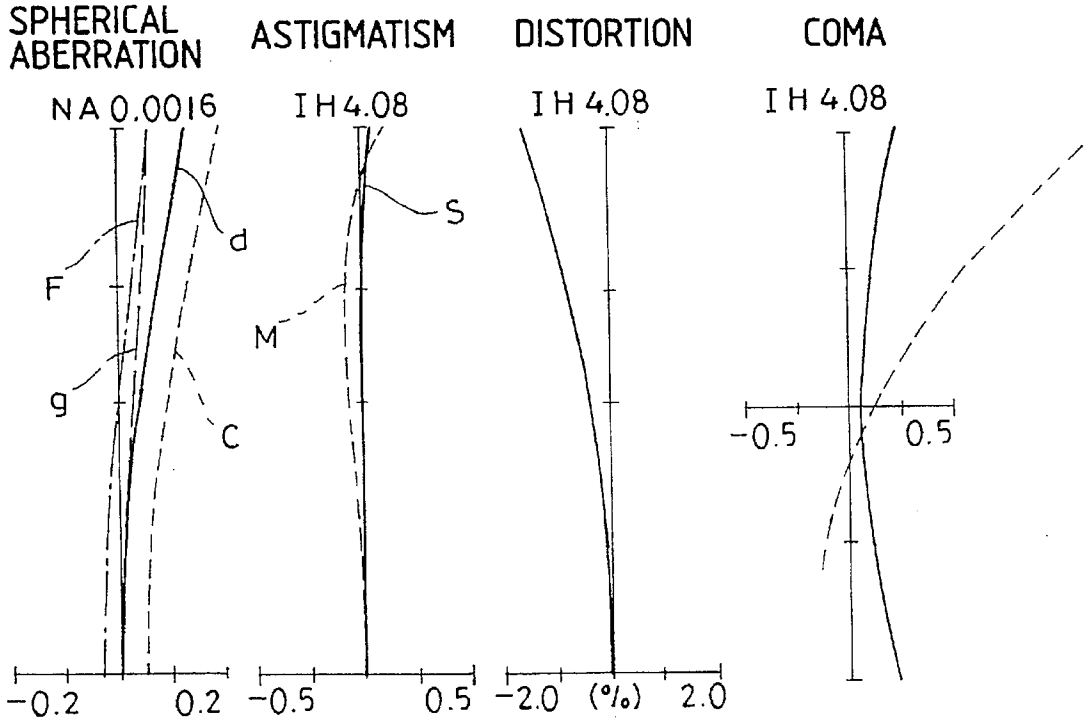


FIG. 62A FIG. 62B FIG. 62C FIG. 62D



NON-FLEXIBLE ENDOSCOPE WITH OBJECTIVE LENS SYSTEM AND RELAY LENS SYSTEM

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a non-flexible endoscope to be used widely in the medical field, and mainly a non-flexible endoscope which can be manufactured at a cost low enough to be disposable.

2. Description of the Prior Art

In the recent trend of surgical operations in the medical field, medical techniques are exercised increasingly in conditions of minimum contacts with higher parasites by using endoscopes and treating tools developed exclusively for operations in such conditions. Since affected parts which conventionally required laparotomy for medical treatments can now be treated in the conditions of minimum contacts with the higher parasites under observation through endoscopes for lessening burdens of patients by reducing days of hospitalization, etc., further development is expected for the surgical operations under observation through endoscopes.

Dependently on structures of insert sections of endoscopes which are to be inserted into body cavities, the endoscopes are classified into two types: flexible endoscopes and non-flexible endoscopes. Out of these two types, the non-flexible endoscopes which provide images of higher qualities are used for surgical operations under observation. The non-flexible endoscopes has another merit that they are bearable of autoclaving.

In the recent days where a serious problem is posed by hospital infections, it is remarkably important to sterilize medical tools and instruments, and autoclaving apparatuses are more widespread than the other types of sterilizers. It is therefore necessary to configure the endoscopes so as to have structures bearable of autoclaving.

For the non-flexible endoscopes which have no flexible section, it is rather easy to select materials and structures which are bearable of autoclaving. It is therefore general in practice to repeatedly use non-flexible endoscopes bearable of autoclaving while sterilizing these instruments after individual uses.

On the other hand, attempts are made to configure the non-flexible endoscopes themselves so as to be disposable for preventing hospital infections from being caused through repeated use of the non-flexible endoscopes. In order to configure the non-flexible endoscopes so as to be disposable, it is necessary to configure them so that they can be manufactured as low costs while maintaining practical utilities thereof.

FIG. 1 shows a conventional non-flexible endoscope and an observation optical system used therein. The conventional optical system of this conventional non-flexible endoscope consists of a short objective lens system O disposed in a leading end of an insert section 1 to be inserted into body cavities and a relay lens system R disposed in the insert section 1 almost over the entire length thereof, and an eyepiece lens system E disposed in a grip section 2: these lens systems being integrated with one another in a main body of the non-flexible endoscope.

This conventional non-flexible endoscope is configured so as to permit observing, through the eyepiece lens system E, an image which is formed by the objective lens system O and relayed ordinarily in three cycles by the relay lens system R. This relay lens system consists of fundamental lens units each being symmetrical with regard to a vertical axis perpendicular to the right-to-left direction and is configured so as to relay an image in a plurality of cycles.

It is for the purpose of obtaining required brightness in an optical system that an image is relayed in a plurality of cycles in the optical system for the non-flexible endoscopes such as the conventional example described above.

Since insert sections of non-flexible endoscopes have small outside diameters and large effective lengths, it is necessary for maintaining brightness of images transmitted through the insert sections to enlarge numerical apertures of relay lens systems by increasing numbers of relay cycles. In case of an optical system which uses an insert section having a given effective length in combination with a relay lens system having a given fundamental composition and a given outside diameter, a numerical aperture of the relay lens system is determined dependently on a length required for a single relay cycle and therefore proportional to a number of relay cycles to be performed by the relay lens systems.

The conventional non-flexible endoscope shown in FIG. 1 hardly allows the main body thereof to be disposable due to a fact that the relay lens system R used for composing the optical system thereof comprises a large number of lens elements and the optical system requires too high a manufacturing cost. When the manufacturing cost of the optical system is reduced simply by reducing the number of relay cycles or the number of the lens elements disposed in the relay lens system as a whole, the length required for a single relay cycle is shortened, thereby reducing the numerical aperture of the relay lens system.

For the reason described above, the optical system for the conventional non-flexible endoscope does not allow to lower the manufacturing cost thereof while reserving the brightness required therein.

SUMMARY OF THE INVENTION

A primary object of the present invention is to provide a non-flexible endoscope using an optical system which comprises an extremely small number of lens elements to be discarded, or is configured so as to prevent an operating cost thereof from being enhanced by discarding the lens elements.

Another object of the present invention is to provide a non-flexible endoscope using an optical system which comprises a small number of lens elements, can be manufactured at a low cost and is bright enough for practical use.

A still another object of the present invention is to provide a non-flexible endoscope using an optical system which has a numerical aperture of brightness enlarged or enhanced by prolonging an objective lens system so as to shorten a distance for transmission of an image through a relay lens system.

The non-flexible endoscope according to the present invention has a far end (an end farthest from an observer) and a near end (an end nearest the observer), and comprises an insert section which is used for inserting the far end of the non-flexible endoscope into body cavities to be observed and an eyepiece section which is to be connected to a near end of the insert section. The insert section accommodates an objective lens system, whereas the eyepiece section accommodates an eyepiece lens system which directly receives rays from a primary image formed by the objective lens system and allows these rays to emerge therefrom as rays nearly in parallel with one another. The insert section and the eyepiece section are attachable and detachable to and from each other.

In an optical system which is to be used in the non-flexible endoscope according to the present invention, the objective lens system consists of a first negative lens component and a second positive lens component which has a magnification satisfying the following condition (1):

$$0.7<|\beta_2|<1.5 \quad (1)$$

wherein the reference symbol β_2 represents the magnification of the second lens component.

Further, it is desirable that the objective lens system forms a primary image at a position located in the vicinity of the near end of the insertion section, or satisfies the following condition (2):

$$0.7<D_1/D_e<1.5 \quad (2)$$

wherein the reference symbol D_1 represents a distance as measured from a first surface of the objective lens system to the primary image and the reference symbol D_e designates an effective length of the insert section. Meant by "an effective length of the insert section" is a length of a section which has a small outside diameter and is to be inserted into a truncal or a sheath.

Further, it is desirable for correction of chromatic aberration to configure the objective lens system so as to satisfy the following condition (3):

$$n_1>n_2,\ \nu_1<\nu_2 \quad (3)$$

wherein the reference symbols n_1 and n_2 represent refractive indices of the first lens component and the second lens component respectively, and the reference symbols ν_1 and ν_2 designate Abbe's numbers of the first lens component and the second lens component respectively.

Furthermore, it is desirable to compose the first lens component of the objective lens system of a single plano-convex lens element, and configure the second lens component as a cemented lens component which consists of a positive lens element and a negative lens element, and satisfies the following condition (4):

$$n_p<n_N,\ \nu_P>\nu_N \quad (4)$$

wherein the reference symbols n_p and n_N represent refractive indices of the positive lens element and the negative lens element respectively of the second lens component, and the reference symbol ν_P and ν_N designate Abbe's numbers of the positive lens element and the negative lens element respectively of the second lens component.

Moreover, the non-flexible endoscope according to the present invention consists of a slender insertion section which is to be inserted into cavities of living bodies for observing these cavities and a grip section which is to be kept outside the cavities: and comprises an optical system which consists of an objective lens system disposed on the side of the leading end in the insert section for forming primary image in the insert section, a relay lens system disposed in the insert section for relaying the primary image for forming a secondary image at a near end (an end located on the side opposite to the leading end) of the insert section or in the grip section and an eyepiece lens system disposed in the grip section for deflecting rays coming from the secondary image so as to be parallel with one another or in an observable condition; and is configured so as to satisfy the following condition (5):

$$0.3<D_1/D_2<0.7 \quad (5)$$

wherein the reference symbol D_2 represents a distance as measured from a first surface to the secondary image.

Moreover, it is desirable that an optical system which is to be used in the non-flexible endoscope according to the present invention (an optical system of a type comprising a relay lens system) adopts an objective lens system composed of a first lens component consisting only of a single negative lens element and a second lens component consisting only of a positive lens element which satisfies the following condition (6):

$$0.5<|\beta_2|<2.0 \quad (6)$$

wherein the reference symbol β_2 represents a magnification of the second lens component.

For the optical system of the non-flexible endoscope according to the present invention of the type which comprises the relay lens system as described above, it is desirable to dispose a primary field lens component in the vicinity of the primary image at a location satisfying the following condition (7):

$$|D_3/D_2|\leqq 0.1 \quad (7)$$

wherein the reference symbol D_3 represents a spacing to be reserved between the primary image and the field lens component.

Moreover, it is desirable to control the relay lens system so as to have a magnification β_R satisfying the following condition (8):

$$-2<\beta_R<-0.5 \quad (8)$$

In addition, when the optical system of the non-flexible endoscope according to the present invention is of a type which uses a relay lens system configured so as to perform a single cycle of image relaying or a plurality of cycles of image relaying, it is desirable for shortening the relay lens system to satisfy the following condition (9):

$$0.3<D_1/D_R<2.0 \quad (9)$$

wherein the reference symbol D_R represents a distance required for a single cycle of image relaying.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** shows a sectional view illustrating a composition of a conventional optical system for non-flexible endoscopes;

FIG. **2** shows a sectional view illustrating a configuration of the non-flexible endoscope according to the present invention;

FIG. **3** shows a sectional view illustrating another example of the non-flexible endoscope according to the present invention;

FIG. **4** shows a sectional view illustrating a configuration of the non-flexible endoscope shown in FIG. **3** when it is protected with a sterilizing cover;

FIG. **5**A, FIG. **5**B and FIG. **5**C show diagrams illustrating relationship between locations of lens components in an objective lens system to be used in the non-flexible endoscope according to the present invention and those of primary images to be formed by the objective lens systems;

FIG. 6A and FIG. 6B show sectional views exemplifying prisms for oblique viewing which are to be used in an objective lens system of the optical system of the non-flexible endoscope according to the present invention;

FIG. 7 shows a sectional view exemplifying a frame structure for an insert section of the non-flexible endoscope according to the present convention;

FIG. 8 shows a sectional view illustrating a composition of a first embodiment of the non-flexible endoscope according to the present invention;

FIG. 9 shows a sectional view illustrating a composition of a second embodiment of the non-flexible endoscope according to the present invention;

FIG. 10 shows a sectional view illustrating a composition of a third embodiment of the non-flexible endoscope according to the present invention;

FIG. 11 shows a sectional view illustrating a composition of a fourth embodiment of the non-flexible endoscope according to the present invention;

FIG. 12 shows a sectional view illustrating an optical system for the non-flexible endoscope according to the present invention which comprises a relay lens system;

FIG. 13A, FIG. 13B and FIG. 13C show diagrams visualizing relationship between locations of primary images in non-flexible endoscopes and numerical apertures thereof;

FIG. 14 shows a sectional view illustrating a composition of a fifth embodiment of the non-flexible endoscope according to the present invention;

FIG. 15 shows a sectional view illustrating a composition of a sixth embodiment of the non-flexible endoscope according to the present invention;

FIG. 16 shows a sectional view illustrating a composition of a seventh embodiment of the non-flexible endoscope according to the present invention;

FIG. 17 shows a sectional view illustrating a composition of an eighth embodiment of the non-flexible endoscope according to the present invention;

FIG. 18 shows a sectional view illustrating a composition of a ninth embodiment of the non-flexible endoscope according to the present invention;

FIG. 19 shows a sectional view illustrating a composition of a tenth embodiment of the non-flexible endoscope according to the present invention;

FIG. 20 shows a sectional view illustrating a composition of an eleventh embodiment of the non-flexible endoscope according to the present invention;

FIG. 21 shows a sectional view illustrating a composition of a twelfth embodiment of the non-flexible endoscope according to the present invention;

FIG. 22 shows a sectional view illustrating a composition of a thirteenth embodiment of the non-flexible endoscope according to the present invention;

FIG. 23 shows a sectional view illustrating a composition of a fourteenth embodiment of the non-flexible endoscope according to the present invention;

FIG. 24 shows a sectional view illustrating a composition of a fifteenth embodiment of the non-flexible endoscope according to the present invention;

FIG. 25 shows a sectional view illustrating a composition of a sixteenth embodiment of the non-flexible endoscope according to the present invention;

FIG. 26 shows a sectional view illustrating a composition of a seventeenth embodiment of the non-flexible endoscope according to the present invention;

FIG. 27 shows a sectional view illustrating a composition of an eighteenth embodiment of the non-flexible endoscope according to the present invention;

FIG. 28 shows a sectional view visualizing relationship between a primary image and a numerical aperture in the fourteenth embodiment of the present invention;

FIG. 29A and FIG. 29B show sectional views exemplifying non-flexible endoscopes comprising no eyepiece lens system;

FIG. 30 shows a sectional view illustrating a configuration of prisms which are to be employed when the non-flexible endoscope according to the present invention is to be used for oblique viewing;

FIG. 31 shows a sectional view illustrating a composition of a nineteenth embodiment of the non-flexible endoscope according to the present invention;

FIG. 32 shows a sectional view illustrating a twentieth embodiment of the non-flexible endoscope according to the present invention;

FIG. 33A, FIG. 33B and FIG. 33C show diagrams visualizing relationship between locations of primary images in an optical system for endoscopes which is configured so as to perform three cycles of image relaying and numerical apertures thereof;

FIG. 34 shows a sectional view illustrating a composition of a twenty-first embodiment of the non-flexible endoscope according to the present invention;

FIG. 35 shows a sectional view illustrating a composition of a twenty-second embodiment of the non-flexible endoscope according to the present invention;

FIG. 36 shows a sectional view illustrating another example of the objective lens system to be used in the optical system of the non-flexible endoscope according to the present invention;

FIG. 37 shows a sectional view illustrating a still another example of the objective lens system to be used in the optical system of the non-flexible endoscope according to the present invention;

FIG. 38 shows a sectional view illustrating a composition of an objective lens system for oblique viewing to be used in the optical system of the non-flexible endoscopes according to the present invention;

FIG. 39 shows a sectional view illustrating a composition of the objective lens system shown in FIG. 36 for the non-flexible endoscope according to the present invention when the objective lens system is modified for oblique viewing;

FIG. 40 shows a sectional view illustrating a composition of the objective lens system shown in FIG. 37 for the non-flexible endoscope according to the present invention when the objective lens system is modified for oblique viewing;

FIG. 41 shows a sectional view illustrating a composition of an objective lens system which is to be used in combination with a relay lens system performing three cycles of image relaying;

FIG. 42 shows a sectional view illustrating a composition of an objective lens system which is to be used in combination with a relay lens system performing five cycles of image relaying;

FIG. 43A and FIG. 43B show sectional views illustrating a spacing tube to be used in the non-flexible endoscope according to the present invention;

FIG. 44 shows a sectional view illustrating a composition of an optical system to be used in a twenty-third embodiment of the non-flexible endoscope according to the present invention;

FIG. **45** shows a sectional view illustrating a composition of an optical system to be used in a twenty-fourth embodiment of the non-flexible endoscope according to the present invention;

FIG. **46**A, FIG. **46**B, FIG. **46**C and FIG. **46**D show curves visualizing aberration characteristics of an optical system used in the first embodiment of the non-flexible endoscope according to the present invention;

FIG. **47**A, FIG. **47**B, FIG. **47**C and FIG. **47**D show curves visualizing aberration characteristics of an optical system used in the second embodiment of the non-flexible endoscope according to the present invention;

FIG. **48**A, FIG. **48**B, FIG. **48**C and FIG. **48**D show curves visualizing aberration characteristics of an optical system used in the fifth embodiment of the non-flexible endoscope according to the present invention;

FIG. **49**A, FIG. **49**B, FIG. **49**C and FIG. **49**D show curves visualizing aberration characteristics of an optical system used in the sixth embodiment of the non-flexible endoscope according to the present invention;

FIG. **50**A, FIG. **50**B, FIG. **50**C and FIG. **50**D show curves visualizing aberration characteristics of an optical system used in the seventh embodiment of the non-flexible endoscope according to the present invention;

FIG. **51**A, FIG. **51**B, FIG. **51**C and FIG. **51**D show graphs illustrating aberration characteristics of an optical system used in the eighth embodiment of the non-flexible endoscope according to the present invention;

FIG. **52**A, FIG. **52**B, FIG. **52**C and FIG. **52**D show graphs illustrating aberration characteristics of an optical system used in the ninth embodiment of the non-flexible endoscope according to the present invention;

FIG. **53**A, FIG. **53**B, FIG. **53**C and FIG. **53**D show graphs illustrating aberration characteristics of an optical system used in the tenth embodiment of the non-flexible endoscope according to the present invention;

FIG. **54**A, FIG. **54**B, FIG. **54**C and FIG. **54**D show curves illustrating aberration characteristics of an optical system used in the eleventh embodiment of the non-flexible endoscope according to the present invention;

FIG. **55**A, FIG. **55**B, FIG. **55**C and FIG. **55**D show curves illustrating aberration characteristics of an optical system used in the twelfth embodiment of the non-flexible endoscope according to the present invention;

FIG. **56**A, FIG. **56**B, FIG. **56**C and FIG. **56**D show graphs visualizing aberration characteristics of an optical system employed in the thirteenth embodiment of the non-flexible endoscope according to the present invention;

FIG. **57**A, FIG. **57**B, FIG. **57**C and FIG. **57**D show graphs visualizing aberration characteristics of an optical system employed in the fourteenth embodiment of the non-flexible endoscope according to the present invention;

FIG. **58**A, FIG. **58**B, FIG. **58**C and FIG. **58**D show graphs visualizing aberration characteristics of an optical system employed in the fifteenth embodiment of the non-flexible endoscope according to the present invention;

FIG. **59**A, FIG. **59**B, FIG. **59**C and FIG. **59**D show graphs visualizing aberration characteristics of an optical system employed in the sixteenth embodiment of the non-flexible endoscope according to the present invention;

FIG. **60**A, FIG. **60**B, FIG. **60**C and FIG. **60**D show graphs visualizing aberration characteristics of an optical system employed in the seventeenth embodiment of the non-flexible endoscope according to the present invention;

FIG. **61**A, FIG. **61**B, FIG. **61**C and FIG. **61**D show curves illustrating aberration characteristics of an optical system used in the eighteenth embodiment of the non-flexible endoscope according to the present invention; and

FIG. **62**A, FIG. **62**B, FIG. **62**C and FIG. **62**D show graphs illustrating aberration characteristics of an imaging lens system to be used in the optical systems of the non-flexible endoscope according to the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Now, the non-flexible endoscope according to the present invention will be described more detailedly below with reference to the preferred embodiments illustrated in the accompanying drawings.

FIG. **2** shows an embodiment of the non-flexible endoscope according to the present invention. In this drawing, the reference numeral **1** represents a cylindrical insert section which has a far end **1***a* and a near end **1***b*, and accommodates an objective lens system O. Further, the reference numeral **2** designates an eyepiece section which is attachable and detachable to and from the near end **1***b* of the insert section **1**, and accommodates an eyepiece lens system E. The reference symbols C_1 and C_2 denote cover glass plates which are disposed before and after the eyepiece lens system E. This non-flexible endoscope is to be inserted, from the side of the far end **1***a* of the insert section, into a location such as a body cavity or the similar part to be observed so that the objective lens system O forms an image of an object to be observed (image I_1) in the vicinity of the near end **1***b* of the insert section. Rays coming from this image are incident directly, or without passing through a relay lens system, onto the objective lens system disposed in the vicinity of the near end of the insert section and reimaged in the eyepiece lens system E by a front lens component of the eyepiece lens system E (image I_2). Rays coming from the image I_2 emerge from the eyepiece lens system E as rays nearly in parallel with one another so that an observer can receive these rays or observe an image of the object.

FIG. **3** shows a non-flexible endoscope which is configured for TV monitoring and uses an insert section **1** having the same composition as that of the insert section **1** shown in FIG. **2**, but can be equipped with a TV camera adaptor **3** and a TV camera **4** in place of the eyepiece section **2** shown in FIG. **2**. The TV camera adaptor **3** comprises an imaging lens system IL, whereas the TV camera **4** comprises an image pickup means such as a solid-state image pickup device. An objective lens system O forms an image of an object in the vicinity of a near end **1***b* of the insert section (image I_1). Rays coming from this image are incident directly, or without passing through a relay lens system, on the imaging lens system IL disposed in the TV camera adaptor **3**, which reimages an image of an object on a solid-state image pickup device disposed in the TV camera **4**. This image is presented on a display means such as a TV monitor for observation. In addition, the TV camera adaptor **3** and the TV camera **4** are attachable and detachable to and from each other.

Since the insert section **1** of the non-flexible endoscope shown in FIG. **2** or FIG. **3** can be detached from the eyepiece section **2** or the TV camera adaptor **3**, the insert section **1** can be discarded after it is practically used and contaminated. Further, the eyepiece section **2** or the TV camera adaptor **3** and the TV camera **4** can be reused in combination with a new insert section.

The non-flexible endoscope shown in FIG. **2** or FIG. **3** allows the eyepiece section or the TV camera adaptor and

the TV camera other than the insert section to be covered with a strilizing cover **8** as shown in FIG. **4**. The sterilizing cover **8** is integrated at one end thereof with the insert section **1** in FIG. **4**. Alternately, the sterilizing cover **8** may be elastically fitted over the insert sectional or fixed to the insert section **1** by an adequate fixing means. The sterilizing cover has a large opening at the other end.

When the sterilizing cover **8** is integrated with the insert section **1**, the eyepiece section or the TV camera adaptor, etc. can be protected with the sterilizing cover **8** by inserting the eyepiece section or the TV camera adaptor, etc. through the opening located at the other end and connecting the TV camera adaptor or the TV camera adaptor, etc. to the insert section **1**. When the sterilizing cover **8** is separate from the insertion section **1**, it is connected to the eyepiece section or the TV camera adaptor, etc., and then the sterilizing cover **8** is placed on the near end of the insert section **1** so as to cover the eyepiece section or the TV camera adaptor, etc. for maintenance in cleaner conditions. In FIG. **4**, the reference numeral **2** represents the eyepiece section shown in FIG. **2**, and the reference numeral **15** designates an adaptor for TV photographing which is detachable from the eyepiece section **2** and accommodates an imaging lens system for imaging nearly parallel rays emerging from an eyepiece lens system. A TV camera **4** shown in FIG. **4** is quite the same as that illustrated in FIG. **3**.

Now, an optical system to be used in the non-flexible endoscope according to teh present invention will be described detailedly below:

First, description will be made of an objective lens system to be disposed in the optical system. The objective lens system to be used in the non-flexible endoscope according to the present invention is long enough to extend almost over the entire length of the insertion section **1** and therefore has a composition which is largely different from that of an ordinary objective lens system for non-flexible endoscopes (an objective lens system for non-flexible endoscopes which uses a relay lens system for transmitting an image).

The objective lens system to be used in the non-flexible endoscope according to the present invention consists of a first lens component L_1 which is disposed in the vicinity of a far end **1***a* of an insert section **1** and has a negative refractive power, and a second lens component L_2 which is disposed at a middle location in the insert section **1** and has a positive refractive power.

In the objective lens system having the composition described above, the first lens component L_1 forms, in the vicinity of the far end **1***a* of the insert section **1**, a virtual image I' which is contracted on the order of an outside diameter of this lens component or smaller and the second lens component L_2 reimages the virtual image I' so as to form a primary image I_1 in the vicinity of the near end **1***b* of the insert section **1**. When the objective lens system comprises no aperture stop, a margin (a side surface) of the second lens component L_2 or a portion of a lens barrel functions as an aperture stop. When the first lens component L_1 is not disposed in the vicinity of the far end **1***a* and does not have a negative refractive power as shown in FIG. **5A**, it will undesirably hinder offaxial rays from passing through a pipe of the insert section. When the second lens component L_2 does not have a positive refractive power, it can hardly reimage the virtual image I' or when the second lens component L_2 is not disposed in the middle section of the insertion section **1**, brightness will be undesirably lowered due to eclipse of the offaxial rays or reduction of a numerical aperture.

Further, it is desirable that the second lens component L_2 satisfies the above-mentioned condition (1).

If $|\beta_2|$ exceeds the lower limit of 0.7 of the condition (1), a light bundle obtained on the object side will undesirably be thin, thereby lowering brightness in the optical system. If $[\beta_2]$ exceeds the upper limit of 1.5 of the condition (1), in contrast, the offaxial rays will be undesirably eclipsed, thereby producing eclipse of an image.

Further, it is desirable that the objective lens system forms the primary image in the vicinity of the near end **1***b* of the insert section **1**. For this reason, it is desirable to configure the objective lens system so as to satisfy the above-mentioned condition (2).

If D_1/D_e has a value smaller than the lower limit of 0.7 of the condition (2), the primary image I_1 will be formed in the pipe of the insert section **1**, whereby the offaxial rays will be eclipsed. If D_1/D_e has a value exceeding the upper limit of 1.5 of the condition (2), in contrast, the light bundle obtained on the object side will be thin and the objective lens system will have a small numerical aperture, thereby lowering brightness in the optical system.

For the objective lens system to be used in the non-flexible endoscope according to the present invention, it is desirable to compose the first lens component L_1 and the second lens component L_2 of small numbers of lens elements or select simple compositions for these lens components so that the insert section can be manufactured at a low cost. For this reason and for suppression of offaxial aberrations, it is desirable to compose the first lens component L_1 of a single negative lens element having a concave surface on the image side. Further, it is more desirable to configure this negative lens element so as to have a planar surface on the object side. Furthermore, it is desirable to configure the second lens component L_2 as a positive lens component consisting of a single positive lens element or a positive cemented lens component. The lens elements may be made of a glass material or a plastic material.

FIG. **6A** and FIG. **6B** show examples of objective lens systems to be used in the non-flexible endoscope according to the present invention in each of which a visual field changing prism for oblique viewing is disposed in a tip of the objective lens system and composed of a single prism as shown in the drawing. An ordinary visual field changing prism is composed of two or more prisms and requires a high manufacturing cost. For reducing a manufacturing cost of the objective lens system and configuring the insert section which comprises the prism in addition to the objective lens system so as to be disposable, it is desirable to compose the prism P of a single prism and dispose it after the first lens component L_1 as shown in FIG. **6A** or FIG. **6B**.

A first embodiment of the optical system which has the configuration described above for use in the non-flexible endoscope according to the present invention has a composition illustrated in FIG. **8** and numerical data listed below:

Embodiment 1

object distance = −30 (viewing diopter = $1m^{-1}$),
NA for incidence = 0.0032,
field angle = 60.2° image height = 125

$r_1 = \infty$			
	$d_1 = 0.8000$	$n_1 = 1.80610$	$\nu_1 = 40.95$
$r_2 = 5.1410$			
	$d_2 = 167.5000$		
$r_3 = 87.1610$			
	$d_3 = 2.000$	$n_2 = 1.51633$	$\nu_2 = 64.15$
$r_4 = \infty$ (stop)			
	$d_4 = 2.0000$	$n_3 = 1.51633$	$\nu_3 = 64.15$
$r_5 = -87.8610$			
	$d_5 = 167.6300$		

-continued

Embodiment 1

$r_6 = \infty$			
	$d_6 = 30.0000$		
$r_7 = 24.6552$			
	$d_7 = 3.0000$	$n_4 = 1.69680$	$\nu_4 = 55.52$
$r_8 = -17.2217$			
	$d_8 = 1.0000$	$n_5 = 1.69895$	$\nu_5 = 30.12$
$r_9 = -560.9511$			
	$d_9 = 40.4125$		
$r_{10} = 8.8507$			
	$d_{10} = 3.0000$	$n_6 = 1.51633$	$\nu_6 = 64.15$
$r_{11} = -5.2344$			
	$d_{11} = 1.0000$	$n_7 = 1.71736$	$\nu_7 = 29.51$
$r_{12} = 59.7461$			
	$d_{12} = 1.0000$		
$r_{13} = 8.8507$			
	$d_{13} = 3.0000$	$n_8 = 1.51633$	$\nu_8 = 64.15$
$r_{14} = -5.2344$			
	$d_{14} = 1.0000$	$n_9 = 1.71736$	$\nu_9 = 29.51$
$r_{15} = 59.7461$			
	$d_{15} = 15.5875$		
$r_{16} = 23.5293$			
	$d_{16} = 3.0000$	$n_{10} = 1.51633$	$\nu_{10} = 64.15$
$r_{17} = -24.0097$			
	$d_{17} = 8.0000$		
$r_{18} = \infty$			
	$d_{18} = 16.2546$		
$r_{19} = 21.2180$			
	$d_{19} = 0.9000$	$n_{11} = 1.78472$	$\nu_{12} = 25.71$
$r_{20} = 8.1750$			
	$d_{20} = 2.6000$	$n_{12} = 1.66672$	$\nu_{12} = 48.32$
$r_{21} = -18.7960$			

$D_1 = 339.6$ mm, $D_e = 300$ mm, $D_1/D_e = 1.132$, $\beta_2 = -0.958$

wherein the reference symbols r_1, r_2, . . . represent radii of curvature on surfaces of respective lens elements, the reference symbols d_1, d_2, . . . designate thicknesses of the respective lens elements and air-spaces reserved therebetween, the reference symbols n_1, n_2, . . . denote refractive indices of the respective lens elements, and the reference symbols ν_1, ν_2, . . . represent Abbe's numbers of the respective lens elements.

In the numerical data listed above, r_1 through r_5 correspond to the objective lens system, r_7 through r_{21} correspond to the eyepiece lens system, $r_4=\infty$ represents an imaginary stop, $r_6=\infty$ designates the primary image and $r_{18}=\infty$ denotes the secondary image.

In the first embodiment of the optical system of the non-flexible endoscope according to the present invention, the objective lens system and the eyepiece lens system are disposed in the insert section and the eyepiece section respectively which are located on both sides of the primary image (r_6). Since the first embodiment uses no relay lens system, it comprises lens elements in a remarkably reduced number and the insert section accommodates only the objective lens system which is composed of an extremely small number of lens elements. Further, the optical system composed of the objective lens system and the eyepiece lens system adopted for the first embodiment has aberrations favorably corrected as illustrated in FIG. **46**A, FIG. **46**B, FIG. **46**C and FIG. **46**D. In these drawings, diopter is taken as the abscissa for visualizing each of spherical aberration, astigmatism and coma.

FIG. **9** shows a second embodiment of the optical system to be used in the non-flexible endoscope according to the present invention. The second embodiment is configured for use in the non-flexible endoscope according to the present invention which is of the type shown in FIG. **3**. The non-flexible endoscope shown in FIG. **3** has the insert section **1** which is to be connected to the TV camera adaptor **3** and further to the TV camera **4** as described above, and permits detaching the insert section **1** for discarding it after use. The TV camera adaptor and the TV camera may be integrated with each other so as to compose a TV camera comprising an imaging lens system so that the insert section **1** can be detachably connected to the TV camera and detached from the TV camera for discarding after use.

Each of the first embodiment and the second embodiment described above is configured on an assumption that the objective lens system is composed of the first lens component and the second lens component which consist of a single plano-concave lens element and a single biconvex lens element respectively made of multi-component type glass materials. The second biconvex lens element adopted as the second lens component is a symmetrical lens element which has the same radius of curvature on both surfaces thereof and requires no discrimination between a front surface and a rear surface thereof at an assembly stage thereof. Even when an asymmetrical lens element such as a plano-convex lens element is used as the second lens component and disposed mistaking its front surface for its rear surface, however, no serious problem is posed by variations of aberrations since the second lens component has a magnification nearly equal to 1× and functions also as an aperture stop. Accordingly, the second lens component requires nearly no consideration for its direction even when it has an asymmetrical shape.

In each of the first embodiment and the second embodiment, the plano-concave lens element used as the first lens component is made of a glass material which has a high refractive index and a medium dispersing power, whereas the biconvex lens element adopted as the second lens component is made of a glass material which has a low refractive index and a low dispersing power. In other words, the objective lens system is configured so as to satisfy the following condition (3):

$$n_1>n_2,\ \nu_1<\nu_2 \tag{3}$$

wherein the reference symbols n_1 and n_2 represent refractive indices of the first lens component and the second lens component respectively, and the reference symbols ν_1 and ν_2 designate Abbe's number of the first lens component and the second lens component respectively.

For the first lens component, it is suitable to select a glass material having a high refractive index for obtaining a low curvature on the concave surface thereof and a dispersing power which is not too strong to suppress lateral chromatic aberration. Further, for the second lens component which is composed of a single lens element, it is unnecessary to select a glass material which has an exceptionally low refractive index, but a glass material having a low dispersing power should desirably be selected for suppressing production of longitudinal chromatic aberration.

The second embodiment of the optical system for non-flexible endoscope which consists of the objective lens system and the imaging lens system has the numerical data which are listed below:

Embodiment 2

object distance = −30,
NA for incidence = 0.0033 (F number = 28.574)
field angle = 61.3° image height = 3.27

$r_1 = \infty$			
	$d_1 = 0.8000$	$n_1 = 1.80610$	$\nu_1 = 40.95$
$r_2 = 5.1410$			
	$d_2 = 167.5000$		
$r_3 = 87.8610$			
	$d_3 = 2.0000$	$n_2 = 1.51633$	$\nu_2 = 64.15$
$r_4 = \infty$ (stop)			
	$d_4 = 2.0000$	$n_3 = 1.51633$	$\nu_3 = 64.15$

-continued

Embodiment 2

$r_5 = -87.8610$			
	$d_5 = 167.6300$		
$r_6 = \infty$			
	$d_6 = 30.0000$		
$r_7 = 25.3040$			
	$d_7 = 3.0000$	$n_4 = 1.69680$	$\nu_4 = 55.52$
$r_8 = -15.5040$			
	$d_8 = 1.0000$	$n_5 = 1.69895$	$\nu_5 = 30.12$
$r_9 = \infty$			
	$d_9 = 45.2800$		
$r_{10} = 9.0340$			
	$d_{10} = 3.0000$	$n_6 = 1.51633$	$\nu_6 = 64.15$
$r_{11} = -5.9710$			
	$d_{11} = 1.0000$	$n_7 = 1.71736$	$\nu_7 = 29.51$
$r_{12} = 49.0230$			
	$d_{12} = 1.0000$		
$r_{13} = 9.0340$			
	$d_{13} = 3.0000$	$n_8 = 1.51633$	$\nu_8 = 64.15$
$r_{14} = -5.9710$			
	$d_{14} = 1.0000$	$n_9 = 1.71736$	$\nu_9 = 29.51$
$r_{15} = 49.0230$			

$D_1 = 339.6$ mm, $D_e = 300$ mm, $D_1/D_e = 1.132$, $\beta_2 = -0.958$

In the numerical data of the second embodiment described above, r_1 through r_5 correspond to the objective lens system and r_7 through r_{15} correspond to the imaging lens system for the TV camera. Further, r_4 represents an imaginary stop and r_6 designates a primary image.

The optical system preferred as the second embodiment of the present invention uses the objective lens system which is quite the same as that adopted for the first embodiment. Accordingly, the second embodiment uses no relay lens system and comprises an extremely small number of lens elements in the insert section thereof. The second embodiment has aberrations which are corrected favorably as illustrated in FIG. **47**A, FIG. **47**B, FIG. **47**C and FIG. **47**D.

FIG. **10** and FIG. **11** show a third embodiment and a fourth embodiment respectively of the optical system to be used in the non-flexible endoscope according to the present invention. Numerical data of these embodiments are listed below:

Embodiment 3

object distance = −30, NA for incidence = 0.002,
field angle = 70°

$r_1 = \infty$			
	$d_1 = 0.8000$	$n_1 = 1.49216$	$\nu_1 = 57.50$
$r_2 = 1.6894$ (aspherical surface)			
	$d_2 = 167.5000$		
$r_3 = 83.1893$			
	$d_3 = 2.0000$	$n_2 = 1.49216$	$\nu_2 = 57.50$
$r_4 = \infty$ (stop)			
	$d_4 = 2.0000$	$n_3 = 1.49216$	$\nu_3 = 57.50$
$r_5 = -83.1893$			
	$d_5 = 167.5000$		
$r_6 = \infty$			

$D_1 = 339.8$ mm, $D_e = 300$ mm, $D_1/D_e = 1.133$, $\beta_2 = -0.978$
aspherical surface coefficient
$P = 0.0500$

Embodiment 4

object distance = −30, NA for incidence = 0.0033,
field angle = 60°

$r_1 = \infty$			
	$d_1 = 0.8000$	$n_1 = 1.80610$	$\nu_1 = 40.95$
$r_2 = 5.1692$			
	$d_2 = 167.5000$		
$r_3 = 71.8444$			
	$d_3 = 1.0000$	$n_2 = 1.64769$	$\nu_2 = 33.80$
$r_4 = 29.4929$ (stop)			
	$d_4 = 3.0000$	$n_3 = 1.51633$	$\nu_3 = 64.15$
$r_5 = -71.8444$			
	$d_5 = 167.5000$		
$r_6 = \infty$			

$D_1 = 339.8$ mm, $D_e = 300$ mm, $D_1/D_e = 1.133$, $\beta_2 = -0.957$

Only objective lens systems used in the third embodiment and the fourth embodiment are represented by FIG. **10**, FIG. **11** and the numerical data listed above. In the numerical data of the third embodiment, r_4 represents an imaginary stop and r_6 designates a primary image. In the numerical data of the fourth embodiment, r_4 represents an imaginary stop and r_6 designates a primary image.

The objective lens system used in the third embodiment is composed of lens elements made of plastic materials which may be acrylic resin materials or other plastic materials so far as they are optical materials having low dispersing powers. Further, the first lens component is a single plano-concave lens element having an image side concave surface which has such an aspherical surface as to lower curvature from an optical axis toward a margin thereof. The aspherical surface which has such a shape as to lower curvature from the optical axis toward the margin thereof is selected for correcting astigmatism and distortion by this aspherical surface itself. When the optical system is composed of lens elements which have only spherical surfaces, astigmatism will be remarkably overcorrected and barrel distortion will be produced. In the third embodiment, distortion is corrected to −1% at a maximum image height of the primary image. Furthermore, the second lens component is configured as a single biconvex lens element r_3, r_5 having the same radius of curvature on both surfaces thereof.

The aspherical surface used in the third embodiment has a shape expressed by the following formula (a):

$$z = \frac{y^2/r}{1+\sqrt{1-Py^2/r^2}} \qquad (a)$$

wherein the reference symbol z represents a distance as measured, in a direction along the optical axis of the aspherical surface, from an intersection between the aspherical surface and the optical axis, the reference symbol y designates a distance as measured from the optical axis, the reference symbol r denotes a radius of curvature on the reference sphere of the aspherical surface, and the reference symbol p represents a parameter expressing a shape of a guadratic surface.

This aspherical surface has no term of high order and is selectable for manufacturing aspherical lens elements at low costs.

The objective lens system adopted for the fourth embodiment of the optical system for non-flexible endoscope according to the present invention is composed of a first lens component consisting of a single plano-concave lens element and a second lens component consisting of a biconvex cemented lens component. Though the objective lens system adopted for the fourth embodiment which uses the second cemented lens component requires an additional lens element, it has a merit to favorably correct longitudinal chromatic aberration and spherical aberration. The cemented lens component is composed of a positive lens element which has a relatively low refractive index and a weak

dispersing power, and a negative lens element which has a high refractive index and a strong dispersing power.

In other words, this cemented lens component is configured so as to satisfy the following condition (4):

$$n_P<n_N,\ \nu_P>\nu_N \quad (4)$$

wherein the reference symbols n_P and n_N represent refractive indices of the positive lens element and the negative lens element respectively disposed in the cemented lens component, and the reference symbols ν_P and ν_N designate Abbe's numbers of the positive lens element and the negative lens element respectively disposed in the cemented lens component.

In the cemented lens component, the negative lens element may be disposed on the object side as shown in FIG. **11** or on the image side. Further, the cemented lens component may have a plano-convex or meniscus shape instead of the biconvex shape selected for the fourth embodiment.

FIG. **7** exemplifies a frame structure for the objective lens system. A tube **9** of an observation system shown in this drawing consists of a pipe which has an inside diameter just fitting over an outside diameters of the lens components and accommodates the objective lens system fixed with spacers **10**. The spacers **10** are made of a metal or a synthetic resin material and have inside surfaces which should desirably be treated into rougthened surfaces, preferably in black. If the spacers have inside surfaces which are specular surfaces having high reflectance, rays reflected by the inside surfaces of the spacers will reach an image surface, thereby undesirably producing flare.

Then, description will be made of an eyepiece lens system and an imaging lens system which are to be used in the optical system of the non-flexible endoscope according to the present invention.

The eyepiece lens system to be used in the optical system of the non-flexible endoscope according to the present invention has a composition illustrated in FIG. **8** (r_7 through r_{21}), for example, and has a role of a magnifying lens for observing a primary image I_1 (r_6) which is formed by the objective lens system. However, the objective lens system forms an inverted image and it is necessary to obtain an erect image with the optical system as a whole including the objective lens system. For this reason, the eyepiece lens system to be used in the optical system of the non-flexible endoscope according to the present invention is configured so as to perform a single cycle of image relaying within the eyepiece lens system itself and then form a secondary mage I_2 (r_{18}) which is to be observed. In other words, an image to be observed will undesirably be inverted when the secondary image I_2 is not formed in the eyepiece lens system itself. Further, the objective lens system has the simple composition and can hardly correct aberrations sufficiently by itself. Accordingly, the optical system of the non-flexible endoscope according to the present invention is configured so as to correct aberrations in the optical system as a whole including the objective lens system and the eyepiece lens system. That is to say, the eyepiece lens system is configured so as to correct mainly aberrations which cannot be corrected by the objective lens system.

In the first embodiment of the optical system of the non-flexible endoscope according to the present invention, for example, the objective lens system is composed only of a single lens component and undercorrects longitudinal chromatic aberration. For correcting this undercorrected longitudinal chromatic aberration, at least two cemented lens components are used in the eyepiece lens system so as to overcorrect longitudinal chromatic aberration in the eyepiece lens system, whereby the optical system as a whole favorably corrects longitudinal chromatic aberration by cancelling the longitudinal chromatic aberration undercorrected by the objective lens system with the longitudinal chromatic aberration overcorrected by the eyepiece lens system.

Further, when manufacturing precisions of parts are lowered for reducing a manufacturing cost of the objective lens system, positional variations of the primary image will be large in a direction along the optical axis, thereby degrading focusing accuracy. For correcting such degradation of focusing accuracy, it is desirable to equip the eyepiece lens system with a focusing mechanism. As the focusing mechanism for the eyepiece lens system, it can be considered to adopt a mechanism for moving the eyepiece lens system as a whole along the optical axis or an inner-focus type mechanism for moving some of lens components disposed in the eyepiece lens system along the optical axis.

Furthermore, it is desirable to dispose a field stop at a location of the secondary image I_2 or the primary image I_1 since a field stop disposed at such a location is capable of preventing a border of visual field being dim and hindering flare from being produced due to rays coming from outside the visual field.

Now, description will be made of the imaging lens system to be used in the non-flexible endoscope according to the present invention which is configured for observation on a TV monitor. This imaging lens system has a composition illustrated as r_7 through r_{15} in FIG. **9**, for example, and a role to relay the primary image I_1 formed by the objective lens system onto an image pickup surface of a solid-state image pickup device. Like the eyepiece lens system described above, the imaging lens system is configured so as to correct aberrations in the optical system as a whole including the objective lens system. Therefore, the imaging lens system is configured so as to correct aberrations which cannot be corrected by the objective lens system. Longitudinal chromatic aberration, in particular, is overcorrected by using at least two cemented lens components in the imaging lens system so that longitudinal chromatic aberration undercorrected by the objective lens system is corrected favorably in the optical system as a whole.

Also in case of the non-flexible endoscope configured for observation on a TV monitor, it is desirable to equip the TV camera adaptor with a focusing mechanism. It is possible to select, as the focusing mechanism, a mechanism for moving the imaging lens system as a whole or an inner-focus type mechanism for moving some of lens components disposed in the imaging lens system. Further, it is possible to prevent a border of a visual field from being dim and hinder flare from being produced due to rays coming from outside the visual field by disposing a stop at a location of the primary image.

Though the non-flexible endoscope according to the present invention is configured mainly for making certain parts thereof (the insert section) disposable, the configuration of the non-flexible endoscope according to the present invention is applicable also to non-flexible endoscopes which are configured to use parts thereof repeatedly without discarding them for lowering cost prices thereof. It is sufficient for such application to integrate the insert section **1** and the eyepiece section **2** so as to be inseparable from each other in the configuration illustrated in FIG. **2**. In case of the configuration illustrated in FIG. **3**, it is sufficient to integrate the insert section **1** and the TV camera adaptor **3** so as to be inseparable from each other. Further, it is possible

to integrate all of the insert section **1**, the TV camera adaptor **3** and the TV camera **4** so as to be inseparable from one another.

That is to say, it is possible to integrate the insert section with a photographing section accommodating the imaging lens system and a solid-state image pickup device so that they have an inseparable unit structure.

Even for the non-flexible endoscopes which are configured to use parts thereof repeatedly, the reduction in numbers of optical elements realized by the omission of relay lens systems provides merits from viewpoints of cost prices and assembling convenience thereof.

The non-flexible endoscope according to the present invention has the fundamental configuration which is characterized in that only the objective lens system is disposed in the insert section to be inserted into a location to be observed and that the objective lens system forms the primary image in the vicinity of the near end (an end surface located on the side opposite to the leading end) of the insert section. That is to say, the non-flexible endoscope according to the present invention is configured so as to permit composing an observation optical sysem by attaching the insert section comprising the objective lens system to the eyepiece section comprising the eyepiece lens system for observation of the object side or attaching a TV camera to the eyepiece section for picking up an image or observation on a TV monitor. However, the non-flexible endoscopes according to the present invention is essentially characterized in that the objective lens system is disposed in the insert section or the like described above so as to form a primary image at the near end (the end surface located on the side opposite to the leading end) of the insert section, thereby accomplishing the objects of the present invention.

Now, description will be made of a configuration of the non-flexible endoscope according to the present invention of a type which comprises a relay lens system disposed in an optical system thereof.

An optical system of the non-flexible endoscope according to the present invention which is of the type comprising a relay lens system consists of a slender insert section which is to be inserted into body cavities for observing interiors thereof and a grip section which is to be kept outside the cavities even during observation. Accommodated in the insert section are an objective lens system which is disposed on the side of a leading end of the insert section for forming a primary image and a relay lens system which serves for relaying the primary image so as to form a secondary image in the vicinity of a near end of the insert section or in the grip section, whereas the grip section accommodates an eyepiece lens system which receives rays coming from the secondary image and allows rays to emerge therefrom in a condition where they are made parallel with one another so as to be observable by human eyes. This optical system is characterized in that it satisfies the following condition (5):

$$0.3<D_1/D_2<0.7 \quad (5)$$

wherein the reference symbol D_1 represents a distance as measured from a leading end surface of the objective lens system to the primary image and the reference symbol D_2 designates a distance as measured from the leading end surface to the secondary image.

Speaking more concretely, the non-flexible endoscope according to the present invention described above has a configuration illustrated in FIG. **12**, for example, or consists of a slender insert section **1** which is to be inserted into cavities of living bodies and the like, and a grip section which is to be kept outside the cavities even during use of the non-flexible endoscope and comprises an eyepiece section **2** disposed in a near end thereof. Further, accommodated in the insert section **1** are an objective lens system O which is disposed in the leading end thereof, a primary field lens F_1 which is disposed in the vicinity of a primary image I_1 formed by the objective lens system O, and a relay lens unit R_1 which serves for relaying the primary image I_1 so as to form a secondary image I_2. Further, disposed in the grip section **5** is an eyepiece lens system E which converts rays coming from the secondary image I_2 into rays which are nearly parallel with one another so as to be observable by naked eyes. Furthermore, it is possible to attach the eyepiece section **2** to a TV camera system **6** for endoscopes which is configured as a separate unit comprising a solid-state image pickup device **11** and an imaging lens system IL.

Though the TV camera system **6** is mechanically integrated in FIG. **12**, it is possible to compose this system of a section **6*a*** comprising the imaging lens system IL and another section **6*b*** comprising the solid-state image pickup device so that the system is separable along the dashed line 6C shown in FIG. **12** into the two sections which are mechanically attachable and detachable to and from each other. In this case, the section **6*a*** which comprises the imaging lens system IL has a role of an adaptor for attaching the section **6*b***, or a TV camera head, to the non-flexible endoscope. When the TV camera **6** is configured so as to have a separable configuration described above, it provides a convenience to use various combinations of adaptors and TV camera heads which are prepared in plural kinds respectively.

A greatest characteristic of the optical system of the non-flexible endoscope according to the present invention which has the configuration described above lies in that a relay lens unit is configured so as to perform image relaying only in one cycle for reducing a number of lens elements to be used in the non-flexible endoscope and the objective lens system is configured so as to form the primary image nearly in the middle of a section from the leading end of the endoscope to the secondary image for preventing a numerical aperture from being reduced by the image relaying.

The optical system of the non-flexible endoscope according to the present invention comprises, in order from the side of the leading end thereof, the objective lens system O, the primary field lens F_1, the relay lens unit R_1 and the eyepiece lens system E: the objective lens system O serves for forming the primary image I_1 in the insertion section and the relay lens R_1 serves for forming the secondary image I_2 in the grip section **5** as described above. The primary field lens F_1 is disposed in the vicinity of the primary image I_1.

When a primary field lens is to be disposed on the side of the objective lens system O of a primary image I_1, it may be regarded as a lens component of the objective lens system O or when the primary field lens F_1 is to be disposed on the side of a relay lens unit R_1 of the primary image I_1, it may be considered as a lens component of the relay lens unit R_1.

In an ordinary case where a final image which is formed on the object side of the eyepiece lens system E is located in the vicinity of a near end of an insert section or in the grip section, the secondary image I_2 is formed as a final image on the optical system of the non-flexible endoscope according to the present invention. Accordingly, the distance as measured from the leading end of the insert section to the secondary image must be equal or longer to or than an effective length of the insert section. Though a smaller effective length of the insert section makes it possible to obtain a brighter optical system, the insert section has an

effective length which is determined almost dependently only on a length required for handling of a non-flexible endoscope and cannot be shorter than this length.

Since the location of the secondary image, out of the two images formed in the non-flexible endoscope according to the present invention, is determined as described above, the present invention selects a location of the primary image which is suited for obtaining a bright optical system.

FIG. **13**A, FIG. **13**B and FIG. **13**C show diagrams visualizing variations of numerical apertures to be caused by changing a location of a primary image. FIG. **13**A illustrates a case where the primary image I_1 is located in the middle between the leading end of the objective lens system O and the secondary image I_2 by prolonging the objective lens system O, FIG. **13**B visualizes a case where the location of the primary image I_1 is shifted toward the leading end by shortening the objective lens system O and FIG. **13**C shows a case where the location of the primary image I_1 is shifted toward the secondary image I_2 by remarkably prolonging the objective lens system O. Out of these drawings, FIG. **13**A shows a refractive power distribution which is most desirable for accomplishing the objects of the present invention, whereas FIG. **13**B shows a composition which is similar to that in the conventional optical system for non-flexible endoscopes which uses a short objective lens system O.

In each of FIG. **13**A, FIG. **13**B and FIG. **13**C wherein a relay lens unit R_1 has a magnification set at 1× and a primary field lens F_1 is overlapped with the primary image I_1, the objective lens system O has a numerical aperture on the side of incidence which is equal to a numerical aperture thereof on the side of emergence.

Numerical apertures are determined dependently on angles α which are formed between marginal rays and optical axes as shown in FIG. **13**A, FIG. **13**B and FIG. **13**C. Speaking concretely, a numerical aperture is defined as NA=sin α and a larger angle α makes it possible to obtain a brighter optical system.

Though the marginal rays are traced at an equal maximum height in FIG. **13**A, FIG. **13**B and FIG. **13**C, it is apparent that the angle α is the largest and permits obtaining a brightest optical system in the case shown in FIG. **13**A since a lens system which determines a limit of heights of the marginal rays is not either one of the objective lens system O and the relay lens unit R_1 in this case. In the case illustrated in FIG. **13**B, a limit of heights of the marginal rays is determined by the relay lens system R_1 only and the angle α is determined by a length of the relay lens unit R_1. In the case visualized in FIG. **13**C, a limit of heights of the marginal rays is determined by the objective lens system O only and the angle α is determined by a length of the objective lens system O. In the case illustrated in FIG. **13**A, in contrast, a limit of heights of the marginal rays is determined by both the objective lens system O and the relay lens unit R_1 either of which has a length shorter than that of the relay lens unit R_1 shown in FIG. **13**B or that of the objective lens system O shown in FIG. **13**C, whereby the location of the primary image I_1 shown in FIG. **13**A allows to form a large angle α which makes it possible to obtain a brightest optical system when outside diameters of the lens systems are predetermined to a definite value.

Apart from the qualitative description of the optical system of the non-flexible endoscope according to the present invention, it is quantitatively sufficient to configure the optical system so as to satisfy the abovementioned condition (5).

The reference symbol D_1/D_2 used in the condition (5) represents a parameter for varying brightness in the optical system and has a value of 0.5 in the condition illustrated in FIG. **13**A which permits configuring the optical system so as to be brightest.

Accordingly, brightness in the optical system will be lowered if D_1/D_2 has a value larger or smaller than 0.5. When brightness at D_1/D_2 is taken as 1, brightness at various values of D_1/D_2 is expressed by an equation of $1/\{1+|1-(2D_1/D_2)|\}^2$ or calculated as listed below:

D_1/D_2	Brightness
0.1, 0.9	0.31
0.2, 0.8	0.39
0.3, 0.7	0.51
0.4, 0.6	0.69
0.5	1

As is understood from the values tabulated above, brightness at D_1/D_2=0.3 or 0.7 is 0.51 times as high as that at D_1/D_2=0.5, or brightness is halved by lowering D_1/D_2 from 0.5 to 0.3 or enhancing it from 0.5 to 0.7. Since brightness is not allowed to be lower than that at D_1/D_2=0.3 or 0.7, it is necessary that the optical system satisfies the abovementioned condition (5). If the lower limit of 0.3 of the condition (5) is exceeded, the optical system will be set in the condition shown in FIG. **13**B or if the upper limit of 0.7 of the condition (5) is exceeded, the optical system will be set in the condition shown in FIG. **13**C, whereby brightness will be lowered to about ½ of that at D_1/D_2=0.5 or the optical system will be too dark for practical use.

It is possible to obtain at least 70% of the brightness at D_1/D_2=0.5 when the above-mentioned condition (5) is modified so as to have a lower limit of 0.4 and an upper limit of 0.6. It is therefore more desirable to configure the optical system so as to satisfy the following condition:

$$0.4<D_1/D_2<0.6$$

In FIG. **12**, the primary field lens F_1 is disposed in the vicinity of the primary image I_1 for transmitting a pupil of the objective lens system O to the relay lens unit R_1. Since a principal ray which emerges from the objective lens system O travels in a direction away from the optical axis, the principal ray cannot pass through the relay lens unit R_1 if the field lens is not disposed in the vicinity of the primary image, whereby an image will be eclipsed at a marginal portion of a visual field. For this reason, the primary field lens F_1 must be disposed in the vicinity of the primary image. When a surface of the field lens F_1 is overlapped with the primary image, however, dust or injury existing on the surface of the field lens F_1 will be imaged. It is therefore desirable to dispose the field lens F_1 so as to have air-contact surfaces located with narrow spacings reserved from the primary image I_1.

It is possible to carry out observation on a TV monitor which is essential for surgical operations under observation through an endoscope when a TV camera system for non-flexible endoscope is attached to a non-flexible endoscope comprising an optical system of the type which uses a relay lens system as described above. For such observation on a TV monitor, it is sufficient to connect a TV camera system **6** to a grip section **2** of a non-flexible endoscope as in the case of the non-flexible endoscope shown in FIG. **12**, for example, so that an imaging lens system IL disposed in the TV camera system for non-flexible endoscope forms a ternary image I_3 at a location coincident with a light receiving surface of a solid-state image pickup device for allowing this device to pick up the image.

Now, description will be made of an optical system which is of a type desirable for use in the non-flexible endoscope according to the present invention and comprises not only the objective lens system O described above but also a relay lens unit R_1. It is desirable to compose the objective lens system O of a first lens component which is disposed in the leading end of an insert section and has a negative refractive power and a second lens component which is disposed between the first lens component and a primary field lens, and has a positive refractive power. Such a refractive power distribution is selected for the objective lens system O so that a number of lens components to be disposed in the objective lens system O is reduced while required field angle thereof. The negative refractive power is imparted to the first lens component for allowing it to have a function for widening a field angle and the positive refractive power is imparted to the second lens component for allowing it to relay a virtual image formed by the first lens component so as to form a real image. The first lens component of the objective lens system O has the strongest negative refractive power out of lens components disposed in an observation optical system and is therefore effective also for correction of curvature of field. Further, the second lens component of the objective lens system O has a role of a pupil in the objective lens system. The refractive power distribution described above permits minimizing a number of lens components to be disposed in the objective lens system O, or allows this lens system to have a simplest composition.

In the configuration shown in FIG. **12**, the objective lens system is composed only of two lens elements, or a first lens component consisting of a single negative lens element and a second lens component consisting only of a positive lens element. However, a refractive power of the first lens component which consists of the single negative lens element may be insufficient for certain specifications of the optical system such as a field angle thereof and the first lens component can comprise an additional lens element having a negative refractive power. Further, the first lens component can comprise a lens element having a positive refractive power or be configured as a cemented lens component for favorably correcting lateral chromatic aberration and astigmatism. When the objective lens system is composed only of spherical lens elements, it produces barrel distortion. For correcting this distortion, it is sufficient to use an aspherical surface in the first lens component, on which the principal ray is high, so as to prevent the principal ray from being refracted excessively. Further, for correcting longitudinal chromatic aberration by the second lens component, it is sufficient to configure it so as to comprise a negative lens element having a strong dispersing power, or have a composition consisting of a positive lens element and a negative lens element. In this case, the positive lens element and the negative lens element may be cemented to each other or disposed as separate lens elements. It is most desirable that the second lens component has a magnification of approximately −1× or it should preferably have a magnification within a range from −2× to −0.5×. The objective lens system will have a pupil at a location largely apart from a middle between the leading end thereof and the primary image, whereby offaxial rays will undesirably be eclipsed if the second lens component has a magnification within a range defined by the following condition (6):

$$0.5<|\beta_2|<2.0 \tag{6}$$

wherein the reference symbol β_2 represents the magnification of the second lens component.

Next, a primary field lens may be disposed on either side of the primary image, i.e., on the side of the objective lens system or on the side of the relay lens, or so as to locate the primary image therein. When the primary field lens is too far from the primary image, however, an image will be eclipsed or intensities of the marginal rays will be lowered. Therefore, it is desirable that a distance D_3 as measured from the primary field lens to the primary image is within 10% of a value of D_2 mentioned above.

In other words, it is desirable to configure the objective lens system so as to satisfy the following condition (7):

$$|D_3/D_2|\leqq 0.1 \tag{7}$$

If the distance as measured from the primary field lens to the primary image exceeds 10% of D_2, the primary field lens itself will eclipse the offaxial rays, thereby causing eclipse of an image at marginal portions of a visual field or lowering of intensities of the marginal rays. The primary field lens must have a positive refractive power for transmitting a pupil and can have a function sufficient for this purpose when it is composed of a single positive lens element. For correcting lateral chromatic aberration and astigmatism, however, it is desirable to configure the primary field lens as a cemented lens component consisting of a positive lens element and a negative lens element.

Further, a relay lens unit need not have a symmetrical shape or a complicated composition, unlike the relay lens system used in the conventional optical system for non-flexible endoscopes which is configured so as to perform a plurality of image relay cycles.

The relay lens unit to be used in the optical system of the non-flexible endoscope according to the present invention can be composed simply by disposing a lens component having a positive refractive power nearly in the middle between the primary image and the secondary image, and this lens component has a role of a pupil of the relay lens unit. This lens component having the positive refractive power may be composed of a single positive lens element, but for correction of longitudinal chromatic aberration it is to be composed of a positive lens element and a negative lens element. The positive lens element and the negative lens element may be cemented to each other or disposed separately.

In the optical system of the non-flexible endoscope according to the present invention in which both the second lens component of the objective lens system and the relay lens unit have roles of pupils in an observation optical system, it is sufficient for correction of longitudinal chromatic aberration in the observation optical system to compose at least either of the second lens component and the relay lens unit of a combination of a positive lens element and a negative lens element.

In the optical system of the endoscope shown in FIG. **12**, the relay lens unit is configured as a cemented lens component consisting of a positive lens element and a negative lens element for correcting longitudinal chromatic aberration, whereas the second lens component of the objective lens system is composed of a single lens element.

In a case where aspherical surfaces are to be used for correcting spherical aberration, it is sufficient to configure at least either of the second lens component of the objective lens system or the relay lens unit so as to have an aspherical surface which has such a shape as to lower curvature toward a marginal portion thereof. As already described above, the relay lens unit should desirably have a magnification of approximately −1× or within a range defined by the following condition (8):

$-2<\beta_R<-0.5$

wherein the reference symbol β_2 represents the magnification of the relay lens system.

If the relay lens unit has a magnification largely deviated from the range defined above, the relay lens unit will have a pupil at a location largely deviated from the middle between the primary image and the secondary image, whereby the offaxial rays will be eclipsed.

The eyepiece lens system has a positive refractive power and can be composed sufficiently of a single positive lens element. For correcting lateral chromatic aberration and astigmatism, however, the eyepiece lens system may be composed of a positive lens element and a negative lens element which may be cemented to each other or disposed separately.

In the fundamental composition of the optical system of the non-flexible endoscope according to the present invention, no particular consideration is taken for an eye point of the eyepiece lens system. When positional control of the eye point is important in actual lens design, however, it is allowable to dispose a secondary field lens in the vicinity of the secondary image for positional control of the eye point by using a refractive power of the secondary field lens.

In the conventional non-flexible endoscope, a visual field mask is disposed at an imaging location for clarifying a range of a visual field to be observed. A visual field mask can be disposed also in the optical system of the non-flexible endoscope according to the present invention. In such a case, it is most desirable to dispose a visual field mask composed of a thin black metal sheet or the similar material at a location of the secondary image which imposes a weak spatial restriction, but such a visual field mask may be disposed at a location of the primary image or in the first lens component of the objective lens system on which the principal ray is low.

Listed below are numerical data of the preferred embodiments of the optical system of the non-flexible endoscape according to the present invention which is of the type described above (characterized in that it comprises at least an objective lens system and a relay lens system):

Embodiment 5

f = 8.130 mm, object distance = −30 mm
maximum image height on TV camera side = 4.08 mm,
F number on TV camera side = 17.83, field angle = 60°

$r_1 = \infty$			
	$d_1 = 0.8000$	$n_1 = 1.80610$	$\nu_{1 = 40.95}$
$r_2 = 5.1239$			
	$d_2 = 80.2734$		
$r_3 = 46.7013$			
	$d_3 = 1.5000$	$n_2 = 1.51633$	$\nu_2 = 64.15$
$r_4 = \infty$ (stop)			
	$d_4 = 1.5000$	$n_3 = 1.51633$	$\nu_3 = 64.15$
$r_5 = -46.7013$			
	$d_5 = 85.1824$		
$r_6 = 45.0033$			
	$d_6 = 3.0000$	$n_4 = 1.51633$	$\nu_4 = 64.15$
$r_7 = -45.0033$			
	$d_7 = 7.0000$		
$r_8 = \infty$			
	$d_8 = 77.6197$		
$r_9 = 68.6864$			
	$d_9 = 3.0000$	$n_5 = 1.58913$	$\nu_5 = 61.18$
$r_{10} = -11.2095$			
	$d_{10} = 1.0000$	$n_6 = 1.76182$	$\nu_6 = 26.55$
$r_{11} = -23.7341$			
	$d_{11} = 79.1246$		
$r_{12} = \infty$			
	$d_{12} = 20.1878$		

-continued

Embodiment 5

$r_{13} = 21.8541$			
	$d_{13} = 3.0000$	$n_7 = 1.51633$	$\nu_7 = 64.15$
$r_{14} = -21.8541$			
	$d_{14} = 19.2020$		
$r_{15} = \infty$			
	$d_{15} = 1.0000$	$n_8 = 1.51633$	$\nu_8 = 64.15$
$r_{16} = \infty$			
	$d_{16} = 3.1818$		
$r_{17} = 13.7100$			
	$d_{17} = 1.3700$	$n_9 = 1.72000$	$\nu_9 = 50.25$
$r_{18} = -13.7100$			
	$d_{18} = 1.0000$	$n_{10} = 1.78472$	$\nu_{10} = 25.71$
$r_{19} = \infty$			
	$d_{19} = 6.6282$		
$r_{20} = -6.8120$			
	$d_{20} = 1.5000$	$n_{11} = 1.84666$	$\nu_{11} = 23.78$
$r_{21} = -3.7050$			
	$d_{21} = 0.8000$	$n_{12} = 1.62374$	$\nu_{12} = 47.10$
$r_{22} = 8.7190$			
	$d_{22} = 4.5260$		
$r_{23} = 18.9290$			
	$d_{23} = 2.7600$	$n_{13} = 1.62041$	$\nu_{13} = 60.06$
$r_{24} = -13.4420$			
	$d_{24} = 0.2000$		
$r_{25} = 9.1970$			
	$d_{25} = 4.7100$	$n_{14} = 1.51633$	$\nu_{14} = 64.15$
$r_{26} = -9.1970$			
	$d_{26} = 0.8000$	$n_{15} = 1.85026$	$\nu_{15} = 32.28$
$r_{27} = 23.0810$			
	$d_{27} = 3.5960$		
$r_{28} = \infty$			
	$d_{28} = 1.0000$	$n_{16} = 1.51633$	$\nu_{16} = 64.15$
$r_{29} = \infty$			
	$d_{29} = 14.1000$		
$r_{30} = \infty$			

$D_1 = 179.26$ mm, $D_2 = 340$ mm, $D_1/D_2 = 0.527$,
$\beta_2 = -1.12$, $\beta_R = -1.00$

Embodiment 6

object distance = −30 mm,
maximum image height on TV camera side = 4.08 mm,
F number on TV camera side = 20.71, field angle = 60°

$r_1 = \infty$			
	$d_1 = 0.8000$	$n_1 = 1.80610$	$\nu_1 = 40.95$
$r_2 = 5.1763$			
	$d_2 = 68.4331$		
$r_3 = 40.1441$			
	$d_3 = 1.5000$	$n_2 = 1.51633$	$\nu_2 = 64.15$
$r_4 = \infty$ (stop)			
	$d_4 = 1.5000$	$n_3 = 1.51633$	$\nu_3 = 64.15$
$r_5 = -40.1441$			
	$d_5 = 71.3720$		
$r_6 = 43.6088$			
	$d_6 = 3.0000$	$n_4 = 1.51633$	$\nu_4 = 64.15$
$r_7 = -43.6088$			
	$d_7 = 7.0000$		
$r_8 = \infty$			
	$d_8 = 91.7825$		
$r_9 = 29.9977$			
	$d_9 = 1.0000$	$n_5 = 1.76182$	$\nu_5 = 26.55$
$r_{10} = 14.1459$			
	$d_{10} = 3.0000$	$n_6 = 1.58913$	$\nu_6 = 61.18$
$r_{11} = -68.4094$			
	$d_{11} = 90.6124$		
$r_{12} = \infty$			
	$d_{12} = 20.1530$		
$r_{13} = 21.8162$			
	$d_{13} = 3.0000$	$n_7 = 1.51633$	$\nu_7 = 64.15$
$r_{14} = -21.8162$			

$D_1 = 153.61$ mm, $D_2 = 340$ mm, $D_1/D_2 = 0.452$,
$\beta_2 = -1.11$, $\beta_R = -1.00$

Embodiment 7

object distance = −30 mm,
maximum image height on TV camera side = 4.08 mm,
F number on TV camera side = 19.21, field angle = 70°

$r_1 = \infty$			
	$d_1 = 0.8000$	$n_1 = 1.51633$	$\nu_1 = 64.15$
$r_2 = 14.4251$			
	$d_2 = 0.6000$		
$r_3 = \infty$			
	$d_3 = 0.8000$	$n_2 = 1.80610$	$\nu_2 = 40.95$
$r_4 = 4.3308$			
	$d_4 = 69.9342$		
$r_5 = 44.5266$			
	$d_5 = 1.5000$	$n_3 = 1.51633$	$\nu_3 = 64.15$
$r_6 = \infty$ (stop)			
	$d_6 = 1.5000$	$n_4 = 1.51633$	$\nu_4 = 64.15$
$r_7 = -44.5266$			
	$d_7 = 92.6837$		
$r_8 = 46.8089$			
	$d_8 = 3.0000$	$n_5 = 1.51633$	$\nu_5 = 64.15$
$r_9 = -46.8089$			
	$d_9 = 7.0000$		
$r_{10} = \infty$			
	$d_{10} = 78.3941$		
$r_{11} = 64.2273$			
	$d_{11} = 3.0000$	$n_6 = 1.58913$	$\nu_6 = 61.18$
$r_{12} = -10.9857$			
	$d_{12} = 1.0000$	$n_7 = 1.76182$	$\nu_7 = 26.55$
$r_{13} = -24.1056$			
	$d_{13} = 79.7881$		
$r_{14} = \infty$			
	$d_{14} = 20.1825$		
$r_{15} = 21.8483$			
	$d_{15} = 3.0000$	$n_8 = 1.51633$	$\nu_8 = 64.15$
$r_{16} = -21.8483$			

$D_1 = 177.82$ mm, $D_2 = 340$ mm, $D_1/D_2 = 0.523$,
$\beta_2 = -1.39$, $\beta_R = -1.00$

Embodiment 8

object distance = −30 mm,
maximum image height on TV camera side = 4.08 mm,
F number on TV camera side = 18.17, field angle = 60°

$r_1 = \infty$			
	$d_1 = 0.8000$	$n_1 = 1.80610$	$\nu_1 = 40.95$
$r_2 = 5.1142$			
	$d_2 = 82.0469$		
$r_3 = 47.8629$			
	$d_3 = 3.0000$	$n_2 = 1.58913$	$\nu_2 = 61.18$
$r_4 = -13.2592$ (stop)			
	$d_4 = 1.0000$	$n_3 = 1.76182$	$\nu_3 = 26.55$
$r_5 = -34.2575$			
	$d_5 = 87.7317$		
$r_6 = 45.1573$			
	$d_6 = 3.0000$	$n_4 = 1.51633$	$\nu_4 = 64.15$
$r_7 = -45.1573$			
	$d_7 = 7.0000$		
$r_8 = \infty$			
	$d_8 = 76.2107$		
$r_9 = 39.3499$			
	$d_9 = 3.0000$	$n_5 = 1.51633$	$\nu_5 = 64.15$
$r_{10} = -39.3499$			
	$d_{10} = 76.2107$		
$r_{11} = \infty$			
	$d_{11} = 20.1992$		
$r_{12} = 21.8665$			
	$d_{12} = 3.0000$	$n_6 = 1.51633$	$\nu_6 = 64.15$
$r_{13} = -21.8665$			

$D_1 = 184.58$ mm, $D_2 = 340$ mm, $D_1/D_2 = 0.543$,
$\beta_2 = -1.12$, $\beta_R = -1.00$

Embodiment 9

object distance = −30 mm,
maximum image height on TV camera side = 4.08 mm,
F number on TV camera side = 19.54, field angle = 60°

$r_1 = \infty$			
	$d_1 = 0.8000$	$n_1 = 1.80518$	$\nu_1 = 25.43$
$r_2 = 5.0888$			
	$d_2 = 89.1783$		
$r_3 = 46.7638$			
	$d_3 = 1.5000$	$n_2 = 1.51633$	$\nu_2 = 64.15$
$r_4 = \infty$ (stop)			
	$d_4 = 1.5000$	$n_3 = 1.51633$	$\nu_3 = 64.15$
$r_5 = -46.7638$			
	$d_5 = 87.0248$		
$r_6 = \infty$			
	$d_6 = 7.0000$		
$r_7 = 44.3580$			
	$d_7 = 3.0000$	$n_4 = 1.51633$	$\nu_4 = 64.15$
$r_8 = -44.3580$			
	$d_8 = 75.2496$		
$r_9 = 48.0450$			
	$d_9 = 3.0000$	$n_5 = 1.58913$	$\nu_5 = 61.18$
$r_{10} = -10.6465$			
	$d_{10} = 1.0000$	$n_6 = 1.76182$	$\nu_6 = 26.55$
$r_{11} = -25.7579$			
	$d_{11} = 70.7473$		
$r_{12} = \infty$			
	$d_{12} = 20.2187$		
$r_{13} = 21.8878$			
	$d_{13} = 3.0000$	$n_7 = 1.51633$	$\nu_7 = 64.15$
$r_{14} = -21.8878$			

$D_1 = 180$ mm, $D_2 = 340$ mm, $D_1/D_2 = 0.529$,
$\beta_2 = -0.92$, $\beta_R = -0.82$

Embodiment 10

object distance = −30 mm,
maximum image height on TV camera side = 4.08 mm,
F number on TV camera side = 18.72, field angle = 60°

$r_1 = \infty$			
	$d_1 = 0.8000$	$n_1 = 1.80610$	$\nu_1 = 40.95$
$r_2 = 5.1065$			
	$d_2 = 85.2715$		
$r_3 = 45.9553$			
	$d_3 = 1.5000$	$n_2 = 1.51633$	$\nu_2 = 64.15$
$r_4 = \infty$ (stop)			
	$d_4 = 1.5000$	$n_3 = 1.51633$	$\nu_3 = 64.15$
$r_5 = -45.9553$			
	$d_5 = 83.3820$		
$r_6 = 41.9389$			
	$d_6 = 6.0000$	$n_4 = 1.51633$	$\nu_4 = 64.15$
$r_7 = \infty$			
	$d_7 = 6.0000$	$n_5 = 1.51633$	$\nu_5 = 64.15$
$r_8 = -41.9389$			
	$d_8 = 75.0594$		
$r_9 = 57.8740$			
	$d_9 = 3.0000$	$n_6 = 1.58913$	$\nu_6 = 61.18$
$r_{10} = -10.9911$			
	$d_{10} = 1.0000$	$n_7 = 1.76182$	$\nu_7 = 26.55$
$r_{11} = -24.5483$			
	$d_{11} = 76.4871$		
$r_{12} = \infty$			
	$d_{12} = 20.1964$		
$r_{13} = 21.8634$			
	$d_{13} = 3.0000$	$n_8 = 1.51633$	$\nu_8 = 64.15$
$r_{14} = -21.8634$			

$D_1 = 178.45$ mm, $D_2 = 340$ mm, $D_1/D_2 = 0.525$,
$\beta_2 = -0.97$, $\beta_R = -0.95$

Embodiment 11

object distance = −30 mm,
maximum image height on TV camera side = 4.08 mm,
F number on TV camera side = 18.26, field angle = 60°

$r_1 = \infty$
$d_1 = 0.8000$ $n_1 = 1.49216$ $\nu_1 = 57.50$
$r_2 = 2.4305$ (aspherical surface)
$d_2 = 74.6460$
$r_3 = 43.1965$ (aspherical surface)
$d_3 = 1.5000$ $n_2 = 1.49216$ $\nu_2 = 57.50$
$r_4 = \infty$ (stop)
$d_4 = 1.5000$ $n_3 = 1.49216$ $\nu_3 = 57.50$
$r_5 = -43.1965$ (aspherical surface)
$d_5 = 88.0859$
$r_6 = 43.7851$
$d_6 = 3.0000$ $n_4 = 1.49216$ $\nu_4 = 57.50$
$r_7 = -43.7851$
$d_7 = 7.0000$
$r_8 = \infty$
$d_8 = 79.0426$
$r_9 = 64.0973$
$d_9 = 3.0000$ $n_5 = 1.58913$ $\nu_5 = 61.18$
$r_{10} = -10.9645$
$d_{10} = 1.0000$ $n_6 = 1.76182$ $\nu_6 = 26.55$
$r_{11} = -24.2504$
$d_{11} = 80.4254$
$r_{12} = \infty$
$d_{12} = 20.2086$
$r_{13} = 20.8614$
$d_{13} = 3.0000$ $n_7 = 1.49216$ $\nu_7 = 57.50$
$r_{14} = -20.8614$

aspherical surface cofficients

(2nd surface) P = 0.2285, (3rd surface) P = 1.5536,
(5th surface) P = 1.5536
$D_1 = 176.53$ mm, $D_2 = 340$ mm, $D_1/D_2 = 0.519$,
$\beta_2 = -1.25$, $\beta_R = -1.00$

Embodiment 12

object distance = −30 mm,
maximum image height on TV camera side = 4.08 mm,
F number on TV camera side = 20.83, field angle = 60°

$r_1 = \infty$
$d_1 = 0.8000$ $n_1 = 1.49216$ $\nu_1 = 57.50$
$r_2 = 2.4413$ (aspherical surface)
$d_2 = 67.2311$
$r_3 = 39.1495$
$d_3 = 1.5000$ $n_2 = 1.49216$ $\nu_2 = 57.50$
$r_4 = \infty$ (stop)
$d_4 = 1.5000$ $n_3 = 1.49216$ $\nu_3 = 57.50$
$r_5 = -39.1495$
$d_5 = 78.7484$
$r_6 = 42.1398$
$d_6 = 3.0000$ $n_4 = 1.49216$ $\nu_4 = 57.50$
$r_7 = -42.1398$
$d_7 = 7.0000$
$r_8 = \infty$
$d_8 = 83.0137$
$r_9 = -38.7763$
$d_9 = 1.0000$ $n_5 = 1.76182$ $\nu_5 = 26.55$
$r_{10} = 38.7763$
$d_{10} = 1.0000$
$r_{11} = 16.8362$ (aspherical surface)
$d_{11} = 3.0000$ $n_6 = 1.49216$ $\nu_6 = 57.50$
$r_{12} = -16.8362$ (aspherical surface)
$d_{12} = 92.2068$
$r_{13} = \infty$
$d_{13} = 20.1708$
$r_{14} = 20.8221$
$d_{14} = 3.0000$ $n_7 = 1.49216$ $\nu_7 = 57.50$
$r_{15} = -20.8221$

-continued

Embodiment 12

aspherical surface coefficient

(2nd surface) P = 0.2230, (11th surface) P = −0.7877,
(12th surface) P = −0.7877
$D_1 = 159.78$ mm, $D_2 = 340$ mm, $D_1/D_2 = 0.470$
$\beta_2 = -1.25$, $\beta_R = -1.00$

Embodiment 13

object distance = −30 mm,
maximum image height on TV camera side = 4.08 mm,
F number on TV camera side = 23.67, field angle = 60°

$r_1 = \infty$
$d_1 = 0.8000$ $n_1 = 1.49216$ $\nu_1 = 57.50$
$r_2 = 2.4989$ (aspherical surface)
$d_2 = 57.0401$
$r_3 = 33.5464$
$d_3 = 1.5000$ $n_2 = 1.49216$ $\nu_2 = 57.50$
$r_4 = \infty$ (stop)
$d_4 = 1.5000$ $n_3 = 1.49216$ $\nu_3 = 57.50$
$r_5 = -33.5464$
$d_5 = 65.5966$
$r_6 = 39.9491$
$d_6 = 3.0000$ $n_4 = 1.49216$ $\nu_4 = 57.50$
$r_7 = -39.9491$
$d_7 = 7.0000$
$r_8 = \infty$
$d_8 = 93.8257$
$r_9 = -28.0116$
$d_9 = 1.0000$ $n_5 = 1.58423$ $\nu_5 = 30.30$
$r_{10} = 28.0116$
$d_{10} = 1.0000$
$r_{11} = 16.9806$ (aspherical surface)
$d_{11} = 3.0000$ $n_6 = 1.49216$ $\nu_6 = 57.50$
$r_{12} = -16.9806$ (aspherical surface)
$d_{12} = 104.7376$
$r_{13} = \infty$
$d_{13} = 20.1462$
$r_{14} = 20.7965$
$d_{14} = 3.0000$ $n_7 = 1.49216$ $\nu_7 = 57.50$
$r_{15} = -20.7965$

aspherical surface coefficients

(2nd surface) P = 0.2408, (11th surface) P = −0.5399,
(12th surface) P = −0.5399
$D_1 = 136.44$ mm, $D_2 = 340$ mm, $D_1/D_2 = 0.401$,
$\beta_2 = -1.24$, $\beta_R = -1.00$

Embodiment 14

object distance = −30 mm,
maximum image height on TV camera side = 4.08 mm,
F number on TV camera side = 19.87, field angle = 60°

$r_1 = \infty$
$d_1 = 0.8000$ $n_1 = 1.80400$ $\nu_1 = 46.57$
$r_2 = 5.0891$
$d_2 = 86.7040$
$r_3 = 47.6811$
$d_3 = 1.5000$ $n_2 = 1.51633$ $\nu_2 = 64,15$
$r_4 = \infty$ (stop)
$d_4 = 1.5.000$ $n_3 = 1.51633$ $\nu_3 = 64.15$
$r_5 = -47.6811$
$d_5 = 81.9098$
$r_6 = 43.6719$
$d_6 = 3.,0000$ $n_4 = 1.51633$ $\nu_4 = 64.15$
$r_7 = -43.6719$
$d_7 = 7.0000$

-continued

Embodiment 14

$r_8 = \infty$
$d_8 = 76.5667$
$r_9 = 39.9780$
$d_9 = 3.0000$ $n_5 = 1.58913$ $\nu_5 = 61.18$
$r_{10} = -12.5062$
$d_{10} = 1.0000$ $n_6 = 1.76182$ $\nu_6 = 26.55$
$r_{11} = -30.4039$
$d_{11} = 76.8498$
$r_{12} = \infty$
$d_{12} = 7.0000$
$r_{13} = 96.5673$
$d_{13} = 3.0000$ $n_7 = 1.78472$ $\nu_7 = 25.71$
$r_{14} = -96.5673$
$d_{14} = 11.3766$
$r_{15} = 12.0529$
$d_{15} = 3.0000$ $n_8 = 1.51633$ $\nu_8 = 64.15$
$r_{16} = -157.9337$

$D_1 = 182.41$ mm, $D_2 = 340$ mm, $D_1/D_2 = 0.537$
$\beta_2 = -1.01$, $\beta_R = -1.00$

Embodiment 15

object distance = −30 mm,
maximum image height on TV camera side = 4.08 mm,
F number on TV camera side = 17.62, field angle = 70°

$r_1 = \infty$
$d_1 = 0.8000$ $n_1 = 1.80610$ $\nu_1 = 40.95$
$r_2 = 4.3638$
$d_2 = 79.1915$
$r_3 = 46.7018$
$d_3 = 1.5000$ $n_2 = 1.51633$ $\nu_2 = 64.15$
$r_4 = \infty$ (stop)
$d_4 = 1.5000$ $n_3 = 1.51633$ $\nu_3 = 64.15$
$r_5 = -46.7018$
$d_5 = 87.4834$
$r_6 = 45.2400$
$d_6 = 3.0000$ $n_4 = 1.51633$ $\nu_4 = 64.15$
$r_7 = -45.2400$
$d_7 = 7.0000$
$r_8 = \infty$
$d_8 = 77.0461$
$r_9 = 65.5076$
$d_9 = 3.0000$ $n_5 = 1.58913$ $\nu_5 = 61.18$
$r_{10} = -11.2103$
$d_{10} = 1.0000$ $n_6 = 1.76182$ $\nu_6 = 26.55$
$r_{11} = -23.8871$
$d_{11} = 78.4789$
$r_{12} = \infty$
$d_{12} = 19.5030$
$r_{13} = 49.7945$
$d_{13} = 1.0000$ $n_7 = 1.72916$ $\nu_7 = 54.68$
$r_{14} = 18.6044$
$d_{14} = 3.0000$ $n_8 = 1.51823$ $\nu_8 = 58.96$
$r_{15} = -12.2921$

$D_1 = 180.47$ mm, $D_2 = 340$ mm, $D_1/D_2 = 0.531$,
$\beta_2 = -1.17$, $\beta_R = -1.00$

Embodiment 16

object distance = −30 mm,
maximum image height on TV camera side = 4.08 mm,
F number on TV camera side = 13.28, field angle = 60°

$r_1 = \infty$
$d_1 = 0.8000$ $n_1 = 1.80518$ $\nu_1 = 25.43$
$r_2 = 4.9043$
$d_2 = 3.0000$

-continued

Embodiment 16

$r_3 = 34.9905$
$d_3 = 84.4997$ $n_2 = 1.51633$ $\nu_2 = 64.15$
$r_4 = -41.4453$
$d_4 = 1.0000$
$r_5 = \infty$ (stop)
$d_5 = 1.0000$
$r_6 = 27.6766$
$d_6 = 84.3592$ $n_3 = 1.51633$ $\nu_3 = 64.15$
$r_7 = -29.6190$
$d_7 = 7.0000$
$r_8 = \infty$
$d_8 = 7.0000$
$r_9 = 30.9409$
$d_9 = 87.2633$ $n_4 = 1.51633$ $\nu_4 = 64.15$
$r_{10} = \infty$
$d_{10} = 1.0000$
$r_{11} = 36.4798$
$d_{11} = 3.0000$ $n_5 = 1.58913$ $\nu_5 = 61.18$
$r_{12} = -10.8874$
$d_{12} = 1.0000$ $n_6 = 1.76182$ $\nu_6 = 26.55$
$r_{13} = -24.1409$
$d_{13} = 59.0777$
$r_{14} = \infty$
$d_{14} = 20.2847$
$r_{15} = 21.8841$
$d_{15} = 3.0000$ $n_7 = 1.51454$ $\nu_7 = 54.69$
$r_{16} = -21.8841$

$D_1 = 181.66$ mm, $D_2 = 340$ mm, $D_1/D_2 = 0.534$,
$\beta_2 = -0.97$, $\beta_R = -0.88$

Embodiment 17

object distance = −30 mm,
maximum image height on TV camera side = 4.08 mm,
F number on TV camera side = 14.47, field angle = 60°

$r_1 = \infty$
$d_1 = 0.8000$ $n_1 = 1.80610$ $\nu_1 = 40.95$
$r_2 = 4.8021$
$d_2 = 3.0000$
$r_3 = 27.9253$
$d_3 = 93.1871$ $n_2 = 1.51633$ $\nu_2 = 64.15$
$r_4 = -38.3056$
$d_4 = 1.0000$
$r_5 = \infty$ (stop)
$d_5 = 1.0000$
$r_6 = 37.4772$
$d_6 = 102.2232$ $n_3 = 1.51633$ $\nu_3 = 64.15$
$r_7 = -18.4422$
$d_7 = 7.0000$
$r_8 = \infty$
$d_8 = 63.4974$
$r_9 = 41.4556$
$d_9 = 3.0000$ $n_4 = 1.58913$ $\nu_4 = 61.18$
$r_{10} = -11.2437$
$d_{10} = 1.0000$ $n_5 = 1.76182$ $\nu_5 = 26.55$
$r_{11} = -23.5963$
$d_{11} = 64.2923$
$r_{12} = \infty$
$d_{12} = 20.2460$
$r_{13} = 21.9177$
$d_{13} = 3.0000$ $n_6 = 1.51633$ $\nu_6 = 64.15$
$r_{14} = -21.9177$

$D_1 = 208.21$ mm, $D_2 = 340$ mm, $D_1/D_2 = 0.612$,
$\beta_2 = -1.26$, $\beta_R = -1.00$

Embodiment 18

object distance = −30 mm,
maximum image height on TV camera side = 4.08 mm,
F number on TV camera side = 13.87, field angle = 60°

r_1 = ∞		
d_1 = 0.8000	n_1 = 1.80610	ν_1 = 40.95
r_2 = 3.5575		
d_2 = 35.6752		
r_3 = 41.1433		
d_3 = 3.0000	n_2 = 1.51633	ν_2 = 64.15
r_4 = −41.1433		
d_4 = 78.3719		
r_5 = 41.1433		
d_5 = 3.0000	n_3 = 1.51633	ν_3 = 64.15
r_6 = −41.1433		
d_6 = 39.1529		
r_7 = ∞		
d_7 = 41.3193		
r_8 = 147.2366		
d_8 = 1.0000	n_4 = 1.78472	ν_4 = 25.71
r_9 = 17.9531		
d_9 = 3.0000	n_5 = 1.51633	ν_5 = 64.15
r_{10} = −16.3775		
d_{10} = 44.6807		
r_{11} = ∞ (stop)		
d_{11} = 44.6807		
r_{12} = 16.3775		
d_{12} = 3.0000	n_6 = 1.51633	ν_6 = 64.15
r_{13} = −17.9531		
d_{13} = 1.0000	n_7 = 1.78472	ν_7 = 25.71
r_{14} = −147.2366		
d_{14} = 41.3193		
r_{15} = ∞		
d_{15} = 14.6359		
r_{16} = 15.9009		
d_{16} = 3.0000	n_8 = 1.51633	ν_8 = 64.15
r_{17} = −15.9009		

D_1 = 160 mm, D_2 = 340 mm, D_1/D_2 = 0.471,
β_R = −1.00

wherein the reference symbols r_1, r_2, . . . represent radii of curvature on surfaces of respective lens elements, the reference symbols d_1, d_2, . . . designate thicknesses of the respective lens elements and air-spaces reserved therebetween, the reference symbols n_1, n_2, . . . denote refractive indices of the respective lens elements, and the reference symbols ν_1, ν_2. . . represent Abbe's numbers of the respective lens elements.

The fifth embodiment of the present invention has a configuration shown in FIG. **12** and uses an optical system which has a composition illustrated in FIG. **14** on an enlarged scale. The fifth embodiment consists of: an objective lens system O (r_1 through r_5) which is composed of a first lens component consisting of a single negative plano-concave lens element and a second lens component consisting of a single biconvex positive lens element having the same radius of curvature on both surfaces thereof; a primary field lens F_1 (r_6 and r_7) which consists of a single positive biconvex lens element having the same radius of curvature on both surfaces thereof; a relay lens system R_1 (r_9 through r_{11}) which is composed of a cemented lens component having a positive refractive power, and consisting of a positive lens element and a negative lens element; and an eyepiece lens system (r_{13} and r_{14}) which is composed of a single biconvex lens element having the same radius of curvature on both surfaces thereof. The fifth embodiment is composed only of the six lens element for manufacturing at a low cost. Further, all the lens elements other than the plano-concave lens element and those used for composing the cemented lens component are symmetrical with regard to vertical axes perpendicular to the right-to-left direction and require no discrimination between sides to be set on the object side and the image side, thereby facilitating assembling procedures. Furthermore, a distance as measured from r_1 to r_8 corresponds to D_1, whereas a distance as measured from r_1 to r_{12} corresponds to D_2 when the fifth embodiment is combined with the imaging lens system IL (r_{15} through r_{29}) shown in FIG. **14**, the optical system has aberration characteristics illustrated in FIG. **48**A, FIG. **48**B, FIG. **48**C and FIG. **48**D. The reference symbol r_{30} used in FIG. **14** represents an imaging location I_n.

The sixth embodiment has a composition illustrated in FIG. **15** which is similar to that of the fifth embodiment, except for a cemented lens surface (r_{10}) which is set in an opposite direction. Aberration characteristics of the sixth embodiment are illustrated in FIG. **49**A, FIG. **49**B, FIG. **49**C and FIG. **49**D.

The seventh embodiment has a composition illustrated in FIG. **16** which is similar to that of the fifth embodiment, except for a first lens component of the objective lens system O which is composed of two negative plano-concave lens elements in the seventh embodiment. Speaking more concretely of the seventh embodiment, r_1 through r_7 correspond to the objective lens system O, r_8 and r_9 correspond to a primary field lens F_1, r_{11} through r_{13} correspond to a relay lens system R_1, r_{15} and r_{16} correspond to and eyepiece lens system E; r_{10} represents a primary image I_1, r_{14} designates a secondary image I_2, a distance as measured from r_1 to r_{10} corresponds to D_1, and a distance as measured from r_1 to r_{14} corresponds to D_2.

The seventh embodiment has aberration characteristics illustrated in FIG. **50**A, FIG. **50**B, FIG. **50**C and FIG. **50**D.

The eighth embodiment has a composition illustrated in FIG. **17** and is different from the fifth embodiment in that a second lens component of an objective lens system O is a positive cemented lens component consisting of a positive lens element and a negative lens element, and a relay lens system R_1 is composed of a single positive biconvex lens element having the same radius of curvature on both surfaces thereof in the eighth embodiment. In other words, the composition of the eighth embodiment is obtained by using the cemented lens component which is disposed in the relay lens system R_1 as the second lens component of the objective lens system O in the composition of the fifth embodiment. Accordingly, r_1 through r_5 corresponds to the objective lens system O, r_6 and r_7 corerspnod to a primary field lens F_1, r_9 and r_{10} correspond to a relay lens system R_1, and r_{12} and r_{13} correspond to an eyepiece lens system E in the eighth embodiment. Further, r_8 represents a primary image I_1, r_{11} designates a secondary image I_2, a distance as measured from r_1 to r_8 corresponds to D_1, and a distance as measured from r_1 to r_{11} corresponds to D_2.

The eighth embodiment has aberration characteristics which are visualized in FIG. **51**A, FIG. **51**B, FIG. **51**C and FIG. **51**D.

The ninth embodiment has a composition illustrated in FIG. **18** which is similar to that of the fifth embodiment, except for a primary field lens F_1 which is disposed on the side of a relay lens system R_1, or the right side of a primary image I_1 in the ninth embodiment. Speaking concretely, r_1 through r_5 correspond to an objective lens system O, r_7 and r_8 correspond to the primary field lens F_1, r_9 through r_{11} correspond to the relay lens system R_1, and r_{13} and r_{14} correspond to an eyepiece lens system E in the ninth embodiment. Further, a distance as measured from r_1 to r_6 corresponds to D_1 and a distance as measured from r_1 to r_{12} corresponds to D_2.

Aberration characteristics of the ninth embodiment are visualized in FIG. **52**A, FIG. **52**B, FIG. **52**C and FIG. **52**D.

The tenth embodiment has a composition illustrated in FIG. **19** which is characterized in that a primary image is formed in a primary field lens F_1. Accordingly, r_1 through r_5

correspond to an objective lens system O, r_6 through r_8 correspond to the primary field lens F_1, r_9 through r_{11} correspond to a relay lens system R_1, and r_{13} and r_{14} correspond to an eyepiece lens system E. Further, r_{17} represents a primary image I_1 formed in the primary field lens F_1 and r_{12} designates a secondary image I_2.

The tenth embodiment has aberration characteristics visualized in FIG. **53**A, FIG. **53**B, Fib. **53**C and FIG. **53**D.

The eleventh embodiment has a composition illustrated in FIG. **20** which is similar to that of the fifth embodiment wherein a distance as measured from r_1 to r_8 corresponds to D_1 and a distance as measured from r_1 to r_{12} corresponds to D_2. The eleventh embodiment uses aspherical surfaces on a first lens component and a second lens component of an objective lens system. Speaking more concretely, the eleventh embodiment adopts the aspherical surfaces as a surface r_2 of the first lens component which is disposed on the side of the second lens component and both r_3, r_5 surface of the second lens component. Further, the eleventh embodiment is designed on an assumption that all the lens elements other than those used for composing the cemented lens comopnent are to be made of an acrylic plastic material for reducing a manufacturing cost of the non-flexible endoscope according to the present invention through mass production. Furthermore, a concave surface r_2 of the first lens component of the objective lens system is configured as an aspherical surface having such a shape as to lower curvature toward a margin thereof for correcting distortion.

The aspherical surfaces used in the eleventh embodiment have shapes which are expressed by the above-mentioned formula (a).

Aspherical surfaces used in the other embodiments of the present invention also have shapes expressed by this formula.

The eleventh embodiment has aberration characteristics shown in FIG. **54**A, FIG. **54**B, FIG. **54**C and FIG. **54**D.

The twelfth embodiment has a composition visualized in FIG. **21** and is different from the fifth embodiment in that the twelfth embodiment uses a relay lens unit R_1 which is composed on a negative lens element and a positive lens element disposed separately, and has a positive refractive power. Speaking concretely, r_1 through r_5 correspond to an objective lens system O, r_6 and r_7 represent a primary field lens F_1, r_9 through r_{12} correspond to the relay lens unit R_1, and r_{14} and r_{15} designate an eyepiece lens system E. Further, r_8 denotes a primary image I_1, r_{13} represents a secondary image I_2, a distance as measured from r_1 to r_8 corresponds to D_1 and a distance as measured from r_1 to r_{13} corresponds to D_2. Furthermore, a concave surface r_2 of a first lens component of the objective lens system O which is located on the side of a second lens component, and both surfaces r_{11} and r_{12} of the positive lens element of the relay lens unit R_1 are configured as aspherical surfaces. Moreover, all the lens elements other than the negative lens element (r_9 and r_{10}) of the relay lens unit R_1 are made of an acrylic plastic material for reduction of the manufacturing cost of the non-flexible endoscope according to the present invention through mass production. Like the eleventh embodiment, the twelfth embodiment uses an aspherical surface as a concave surface r_2 of the first lens component which is disposed on the side of the second lens component for correcting distortion.

The twelfth embodiment has aberration characteristics visualized in FIG. **55**A, FIG. **55**B, FIG. **55**C and FIG. **55**D.

The thirteenth embodiment has a composition illustrated in FIG. **22** and uses, like the twelfth embodiment, a relay lens unit R_1 which is composed of a negative lens element and a positive lens element disposed separately. Speaking concretely, r_1 through r_5 correspond to an objective lens system O, r_6 and r_7 represent a primary field lens F_1, r_9 through r_{12} correspond to the relay lens unit R_1, r_{14} and r_{15} designate an eyepiece lens system E, r_8 denotes a primary image I_1, r_{13} represents a secondary image I_2, a distance as measured from r_1 to r_8 corresponds to D_1, and a distance as measured from r_1 to r_{13} corresponds to D_2. Further, a surface r_2 of a first lens component of the objective lens system O which is disposed on the side of a second lens component thereof, and both surfaces r_{11} and r_{12} of the positive lens elemenet of the relay lens unit R_1 are configured as aspherical surfaces. The thirteenth embodiment is configured on an assumption that all lens elements to be used for composing the optical system are to be made of plastic materials: the negative lens element of the relay lens system R_1 which is disposed on the side of the primary image I_1 to be made of a polycarbonate material and the other lens elements to be made of an acrylic plastic material.

Aberration characteristics of the thirteenth embodiment are visualized in FIG. **56**A, FIG. **56**B, FIG. **56**C and FIG. **56**D.

The fourteenth embodiment has a composition illustrated in FIG. **23** and is different from the fifth embodiment in that the fourteenth embodiment uses a secondary field lens F_2 (r_{13} and r_{14}) which is disposed on the side of an eyepiece lens system E, or right side, of a secondary image r_{12}. In the fourteenth embodiment, r_1 through r_5 correspond to an objective lens system O, r_6 and r_7 represent a primary field lens F_1, r_9 through r_{11} correspond to a relay lens unit R_1, r_{13} and r_{14} designate the above-mentioned secondary field lens F_2, r_{15} and r_{16} denote an eyepiece lens system E, r_8 represents a primary image I_1, r_{12} designates a secondary image I_2, a distance as measured from r_1 to r_8 corresponds to D_1, and a distance as measured from r_1 to r_{12} corresponds to D_2.

The fourteenth embodiment which uses the secondary field lens F_2 permits controlling a distance as measured from the eyepiece lens system E to an eyepiece attaching surface, or allows this distance to be shorter than the distances corresponding thereto in the other embodimetns.

The fourteenth embodiment has aberration characteristics which are visualized in FIG. **57**A, FIG. **57**B, FIG. **57**C and FIG. **57**D.

The fifteenth embodiment has a composition illustrated in FIG. **24** and is characterized in that an eyepiece lens system E is composed of a cemented lens component consisting of a negative lens element and a positive lens element. Speaking concretely of the fifteenth embodiment, r_1 through r_5 correspond to an objective lens system O, r_6 and r_7 represent a primary field lens F_1, r_9 through r_{11} correspond to a relay lens unit R_1, and r_{13} through r_{15} correspond to an eyepiece lens system E. Further, r_8 represents a primary image I_1, r_{12} represents a secondary image I_2, a dsitance as measured from r_1 to r_8 corresponds to D_1 and a distance as measured from r_1 to r_{12} corresponds to D_2.

Aberratin characteristics of the fifteenth embodiment are illustrated in FIG. **58**A, FIG. **58**B, FIG. **58**C and FIG. **58**D.

The sixteenth embodiment has a composition illustrated in FIG. **25** and is characterized in that an objective lens system O and a relay lens unit R_1 thereof comprise long rod-shaped lens components. Speaking concretely of the optical system preferred as the sixteenth embodiment, the objective lens system and the eyepiece lens system are composed of a negative plano-concave lens element, a first biconvex rod-shaped lens component, a second biconvex rod-shaped lens component, a third convex-planar rod-shaped lens component, and a cemented lens component

consisting of a positive lens element and a negative lens element. A pupil is located between the first and second rod-shaped lens components.

In the sixteenth embodiment, certain lens elements are replaced with air lenses. An airspace reserve between a surface of emergence (r_4) of the first rod-shaped lens component and a surface of incidence (r_6) of the second rod-shaped lens component functions as a biconcave air lens having a positive refractive power so that the objective lens system O is composed of a first lens component which consists of the plano-concave lens element (r_1 and r_2) and a surface of incidence of the first rod-shaped lens component, and a second lens component which consists of the air lens. Further, an airspace reserved between a surface of emergence (r_7) of the second rod-shaped lens component and a surface of incidence (r_9) of the third rod-shaped lens component forms rather a thick biconcave air lens which functions as a primary field lens F_1 in which a primary image I_1 is to be formed. The relay lens unit R_1 is composed of a surface of emergence (r_{10}) of the third rod-shaped lens component and a cemented lens component (r_{11} through r_{13}) to which all of a refractive power of the relay lens unit is imparted.

In addition, an eyepiece lens system E is composed of a positive biconvex lens element (r_{15} and r_{16}). The reference symbol r_8 represents a primary image I_1, the reference symbol r_{14} designates a secondary image I_2, a distance as measured from r_1 to r_8 corresponds to D_1 and a distance as measured from r_1 to r_{14} corresponds to D_2.

In the field of optical systems for non-flexible endoscopes, it is conventionally known that brightness can be enhanced by filling internal spaces thereof with glass materials and this conventional technique is applies to the sixteenth embodiment of the present invention.

The sixteenth embodiment, in which the airspaces reserved in each of the fifth to fifteenth embodiments are filled with a glass material having a high refractive index, provides an effect equivalent to shortening of an effective length of an insert section calculated in terms of an optical path length, whereby the sixteenth embodiment has a larger numerical aperture or is a brighter optical system. The sixteenth embodiment actually has an F number which is smaller than the F number of any one of the fifth to fifteenth embodiments.

Though the objective lens system O, the primary field lens F_1 and the relay lens unit R_1 are composed of the thin lens elements in each of the fifth to fifteenth embodiments, it is possible to use air lenses formed among three long rod-shaped lens components as in the case of the sixteenth embodiment.

From a fact that the sixteenth embodiment has a composition which is similar to that illustrated in FIG. **13**A when it is decomposed into the individual refracting surfaces, it will be understood that the sixteenth embodiment can accomplish the objects of the present invention.

The sixteenth embodiment has aberration characteristics which are visualized in FIG. **59**A, FIG. **59**B, FIG. **59**C and FIG. **59**D.

The seventeenth embodiment has a composition illustrated in FIG. **26**. From a viewpoint of the composition, the seventeenth embodiment is equivalent to the sixteenth embodiment in which the third rod-shaped lens component is omitted. Accordingly, an objective lens system O is composed of a first lens component which consists of a single negative plano-concave lens element (r_1 and r_2) and a surface of incidence (r_3) of a first rod-shaped lens component, and a second lens component which consists of an air lens (r_4 and r_6) formed between the first rod-shaped lens component and a second rod-shaped lens component in the seventeenth embodiment. A first field lens F_1 is composed of a surface of emergence (r_7) of the second rod-shaped lens component. In the specification of the non-flexible endoscope according to the present invention, a term "lens" may be used for expressing a refracting surface which has a refractive power. A relay lens unit R_1 is composed of a cemented lens component (r_9 through r_{11}) which consists of a positive lens element and a negative lens element. An eyepiece lens system E_1 is composed of a single positive biconvex lens element which has the same radius of curvature on both surfaces thereof.

The seventeenth embodiment is configured so as to have an F number which is as small as that of the sixteenth embodiment by composing the objective lens system O and the primary field lens F_1 of the long rod-shaped lens components. Though the primary field lens F_1 is composed not of a single lens element but of a single refracting surface, the seventeenth embodiment has such a refractive power distribution as that shown in FIG. **13**A and can accomplish the objects of the present invention.

In addition, a distance as measured from r_1 to r_8 corresponds to D_1 and a distance as measured from r_1 to r_{12} corresponds to D_2. Aberration characteristics of the seventeenth embodiment are visualized in FIG. **60**A, FIG. **60**B, FIG. **60**C and FIG. **60**D.

The sixteenth embodiment and the seventeenth embodiment use the long rod-shaped lens components. These long rod-shaped lens components need not be used as described with reference to these embodiments, but may be optionally disposed between the first lens component of the objective lens system and the secondary image I_2. These long rod-shaped lens components may be used so as to fill almost all spaces reserved between the first lens component of the objective lens system and the secondary image for brightening the optical systems or so as to fill only portions of the spaces so far as refractive power distributions are such as that shown in FIG. **13**A.

The eighteenth embodiment has a composition illustrated in FIG. **27**. In the eighteenth embodiment, an objective lens system O (r_1 through r_6) is composed of a first lens component consisting of a negative plano-concave lens element and a biconvex lens element, and a second lens component consisting of a single biconvex lens element; a relay lens unit R_1 (r_8 through r_{14}) is composed of a positive cemented lens component consisting of a negative lens element and a positive lens element, and a positive cemented lens component consisting of a positive lens element and a negative lens element; and an eyepiece lens system E (r_{16} and r_{17}) is composed of a positive lens element.

The eighteenth embodiment uses no primary field lens and has aberration characteristics visualized in FIG. **61**A, FIG. **61**B, FIG. **61**C and FIG. **61**D.

FIG. **47**A, FIG. **47**B, FIG. **47**C and FIG. **47**D through FIG. **61**A, FIG. **61**B, FIG. **61**C and FIG. **61**D, i.e., the graphs illustrating the aberration characteristics of the sixth through eighteenth embodiments, visualize aberration characteristics of the optical systems composed of sections from the objective lens systems to the eyepiece lens system when they are combined with the imaging lens system (r_{15} through r_{30}) used in the fifth embodiment.

Aberration characteristics only of the imaging lens system disposed in the TV camera (the imaging lens system IL shown in FIG. **14**) has aberration characteristics illustrated in FIG. **62**A, FIG. **62**B, FIG. **62**C and FIG. **62**D.

Since each of the embodiments is configured so as to correct aberrations sufficiently in the optical system consid-

ered as an independent section in the non-flexible endoscope according to the present invention, the optical system as a whole has favorable aberration characteristics even when it is combined with the imaging lens system.

The above-mentioned distance D_3, which is a distance as measured from the primary field lens F_1 to the primary image I_1, is defined as an optical path length as measured from the primary image to a refracting surface which is disposed at a shortest distance therefrom and has a positive refractive power. In such a case as the fifth embodiment wherein the field lens F_1 is disposed on the side of the objective lens system of the primary image I_1, the distance D_3 corresponds to a distance as measured from a surface of the primary field lens F_1 which is located on the side of the relay lens unit R_1 to the primary image. Further, in such a case as the ninth embodiment wherein the primary field lens F_1 is disposed on the side of the relay lens unit R_1 of the primary image, the distance D_3 corresponds to a distance as measured from the primary image to a surface of the primary field lens F_1 which is located on the side of the objective lens system O. Furthermore, in such a case as the tenth embodiment wherein the primary field lens F_1 is disposed at a location of the primary image I_1 or such a case as the sixteenth embodiment wherein an air lens is used as the primary field lens F_1, the distance D_3 corresponds to a distance, expressed in terms of an optical path length as measured from the primary image to one of surfaces of the primary field lens whichever is nearer the primary image. In addition, in the case of the eleventh embodiment or the sixteenth embodiment wherein the primary iamge I_1 is formed between both surfaces of the primary field lens, the distance may be measured from either of the surfaces to the primary image so far as it is unnecessary to consider a positive or negative sign of the distance D_3. In the seventeenth embodiment wherein the surface r_7 has a refractive power which has a role of the primary field lens F1, the distance D_3 corresponds to a distance as mesaured from the surface r_7 to the primary image.

Though all of the fifth through seventeenth embodiments are configured for straight viewing, the optical systems preferred as these embodiments are usable also for oblique viewing. FIG. **30** shows a sectional view illustrating the composition of an objective lens system of the non-flexible endoscope configured for straight viewing which can be modified for oblique viewing by disposing prisms **17***a* and **17***b* for oblique viewing on the side of the first lens component of the objective lens system in a section between the first lens component and the second lens component thereof. A narrow space reserved between the prism **17***a* and the prism **17***b* is filled with a medium such as air or a cementing agent having a low refractive index.

Rays coming from an object pass through the first lens component of the objective lens system O and the prism **17***a*, transmit through the medium having the low refractive index used for filling a space between the prism **17***a* and the prism **17***b*, and are reflected by a bottom surface of the prism **17***b* so as to reach a slant surface of the prism **17***b*, where the rays are totally reflected by a boundary surface between the slant surface and the medium having the low refractive index so as to travel toward the second lens component of the objective lens system. Though it is desirable to coat the bottom surface of the prism **17***b* with a reflective film of a metal such a aluminium, such a metallic film is unnecessary in a case where the rays can be totally reflected by using a prism having a high refractive index. Though it is desirable to select materials having high refractive indices for the prisms **17***a* and **17***b*, such materials are limited to glass materials and hardly allow to reduce manufacturing costs of the prisms. When the non-flexible endoscope according to the present invention is to be configured so as to be disposable, a manufacturing cost thereof can be reduced by selecting optical plastic materials such as acrylic plastic materials for the prisms **17***a* and **17***b*, and manufacturing these prisms by injection molding. Since the prisms made of such materials have low refractive indices, it is necessary for assuring total reflection on the slant surface of the prism **17***b* to fill an airspace reserved between the prisms **17***a* and **17***b* with air.

Though it is difficult to configure the objective lens system for the optical system of the non-flexible endoscope according to the present invention, in which heights of rays are larger than those in the objective lens system for the conventional non-flexible endoscope, so as to allow to dispose prisms for oblique viewing therein, it is possible to design an optical system for oblique viewing non-flexible endoscopes by selecting the composition described above which permits reserving sufficient effective diameters in prisms.

The optical system of the non-flexible endoscope according to the present invention of the type which accommodates the objective lens system and the relay lens system also comprises the eyepiece lens system E as shown in FIG. **28**. That is to say, the eyepiece lens system E is disposed after the secondary image I_2 as shown in FIG. **28**. However, the eyepiece lens system E may not be used as illustrated in FIG. **29**A and FIG. **29**B. In other words, the secondary image I_2 can be picked up directly by the solid-state image pickup device **11**. In this case, the observation optical system disposed in an non-flexible endoscope consists only of the objective lens system O and the relay lens system R_1, and the solid-state image pickup device **11** is disposed in the TV camera B for directly picking up the secondary image I_2.

By selecting the configuration described above for the non-flexible endoscope from which the insertion section **1**, the grip section **5** and the TV camera system **6** are detachable, it is pssible to obtain a merit that the endoscope has a simple configuration and is disposable at a low cost. Even when the non-flexible endoscope is not discarded, it can be exchanged with another non-flexible endoscope. Further, the endoscope can be configured so as to be bearable of autoclaving since it can have a configuration comprising no electrical system. Moreover, it is possible to obtain a non-flexible video scope by integrating the non-flexible endoscope with the TV camera.

FIG. **29**B shows an optical system which is configured so as to perform an additional relay cycle for the secondary image I_2 before image pickup. Speaking concretely, an imaging lens system IL is disposed in a TV camera B so as to allow an image pickup device **11** to pickup an image. The configuration illustrated in FIG. **29**B like that shown in FIG. **29**A, allows the TV camera to be detached from the non-flexible endoscope or to integrate the TV camera with the non-flexible endoscope.

The above-mentioned condition (9) should be satisfied also in the configuration illustrated in FIG. **29**A or FIG. **29**B. In this case, the optical system of the non-flexible endoscope according to the present invention comprises an objective lens system and a relay lens system which are disposed in order from the leading end in a slender insert section; is configured so that the objective lens system forms a primary image in the insert section and the relay lens system forms a secondary image by relaying the primary image; and satisfies the condition (9). Further, the non-flexible endoscope according to the present invention can comprise an

image pickup device for picking up the secondary image or an imaging lens system for further relaying the secondary image and an image pickup device for picking up an image I_n formed by the imaging lens system. Each of the non-flexible endoscopes satisfies the condition (5).

Now, description will be made of another type of optical system which is desirable for use in the non-flexible endoscope according to the present invention and comprises a relay lens system performing a single of a plurality of cycles of image relayings.

The optical system of the non-flexible endoscope according to the present invention of the type using the above-mentioned relay lens system consists of: an objective lens system which is disposed in a leading end of a slender insert section to be inserted into cavities of living bodies for observing interiors thereof so as to form a primary image; and a relay lens system which is disposed in the insert section so as to relay the primary image in a single or a plurality of cycles for forming a final image in the vicinity of a near end of the insert section or in a grip section attached to the insert section. This optical system is also configured so as to satisfy the above-mentioned condition (9).

The non-flexible endoscope according to the present invention which uses the optical system described above is similar to the conventional endoscope having the eyepiece section **2** illustrated in FIG. **1**. That is to say, the non-flexible endoscope according to the present invention which uses the optical system described above has a configuration shown in FIG. **31** wherein the endoscope consists of a slender insert section **1** to be inserted into cavities of living bodies and the like, and a grip section **5** which is to be kept outside the cavities even during use of the non-flexible endoscope and has a near end configured as an eyepiece section **2**.

The optical system of the non-flexible endoscope according to the present invention consists, for example, of an objective lens system O disposed in the leading end of the insert section **1**, a relay lens system R for relaying a primary image I_1 formed by the objective lens system O and an eyepiece lens system E disposed in the eyepiece section **2** for forming a nearly parallel light bundle from rays which come from a final image I_n formed by the relay lens system R.

Further, the non-flexible endoscope according to the present invention permits attaching a TV camera system **6** for endoscopes which is configured separately from the grip section **5** to the eyepiece section **2** as shown in FIG. **32**. Disposed in this TV camera system **6** are an imaging lens system IL and a solid-state image pickup device **11**. Though the non-flexible endoscope shown in FIG. **32** uses the TV camera system **6** which is mechanically integrated, this TV camera system may be divided along a dashed line **6***c* shown in FIG. **32** so as to compose an adaptor **6***a* comprising the imaging lens system IL and a TV camera head **6***b* comprising the solid-state image pickup device **11**, and the adaptor **6***b* and the TV camera head **6***b* can be configured so as to be mechanically attachable and detachable to and from each other. When the adaptor **3** and the TV camera head **6***a* are configured so as to be attachable and detachable, it is possible to perform photographing by using various combinations of these members each of which is prepared in a plurality of kinds.

The optical system of the non-flexible endoscope according to the present invention is composed, as shown in FIG. **31** or FIG. **32** for example, of the objective lens system O which is disposed on the side of the leading end in the insert section **1** for forming the primary image I_1 in the insert section **1**, a relay lens system R for relaying the primary image I_1 in a single or a plurality of cycles so as to form a final image I_n in the near end of the insert section **1** or the grip section **5**, and an eyepiece lens system E which is disposed in the eyepiece section **2** of the grip section **5** for allowing rays incident from the final image I_n to emerge in a condition of a nearly parallel light bundle which is observable by naked eyes.

Now, description will be made of the optical system for the non-flexible endoscope which has the composition described above and is configured so as to perform three cycles of image relaying as shown in FIG. **31** or FIG. **32**. The optical system of the non-flexible endoscope according to the present invention is characterized in that the above-mentioned distances D_1 and D_R are nearly equal to each other for enlarging a numerical aperture or obtaining a bright optical system while reserving a length (an effective length) of the insert section required for the non-flexible endoscope.

As in an ordinary case where a final image which must be formed on the object side of an eyepiece lens system E is formed in the vicinity of an insertion section **1**, a quaternary image shown in FIG. **31** or FIG. **32** corresponds to the final image I_n in the optical system of the non-flexible endoscope according to the present invention and is formed, for example, in the grip section **5** as shown in FIG. **31** or FIG. **32**. Accordingly, it is necessary that a distance as measured from the leading end of the insert section to the final image I_n must be equal to or longer than an effective length of the insert section. Though a shorter distance as measured from the leading end of the insert section to the final image permits configuring a brighter optical system, the effective length of the insert section is determined nearly dependently only on a length required for surgical operations and cannot be shorter than this length.

When the optical system of the non-flexible endoscope according to the present invention is configured so as to perform three cycles of image relaying, it forms four images including the final image I_n which is formed at the location determined as described above. Further, a relay lens system R is composed of relay lens unit R_1, R_2, . . . each of which relays an image at a magnification of 1× and the present invention provides a bright optical system by using the relay lens units repeatedly, and adequately selecting an objective lens system and a relay lens system as described below.

When the optical system of the non-flexible endoscope according to the present invention is configured so as to peform three cycles of image relaying as described above, for example, it forms four images including a secondary image, an intermediate image and a final image which are to be formed at locations determined for the reasons described above. Therefore, the present invention selects an adequate location for a primary image so as to obtain a bright optical system.

FIG. **33**A, FIG. **33**B and FIG. **33**C show diagrams illustrating variaitons of numerical apertures to be caused by changing a location of the primary image in a typical optical system of the non-flexible endoscope according to the present invention which is configured to perform three cycles of image relaying.

FIG. **33**A shows a case where the objective lens system O is prolonged so as to have a length D_1 which is equal to a length D_R of each of relay lens units R_1, R_2 and R_3 required for a single cycle of image relaying, FIG. **33**B illustrates a case where the objective lens system is shortened so as to form a primary image I_1 at a location shifted toward the leading end, and FIG. **33**C visualizes a case where the objective lens system O is remarkably prolonged so as to form the primary image I_1 at a location shifted toward an intermediate image I_2. Out of the three cases shown in FIG.

33A, FIG. 33B and FIG. 33C, a refractive power distribution which is most desirable for accomplishing the objects of the present invention is obtained in the case shown in FIG. 33A. The case shown in FIG. 33B corresponds to a composition which is similar to that of the conventional optical system for non-flexible endoscopes using a short objective lens system.

In each of FIG. 33A, FIG. 33B and FIG. 33C, numerical apertures are equal to each other between a side of incidence and a side of emergence at the location of the primary image I_1 formed by the objective lens system O since each of the relay lens untis R_1, R_2 and R_3 of the relay lens system R is set at a magnification of 1× and the primary field lens F_1 is disposed at a location coincident with the primary image I_1. A "numerical aperture" means an angle which is formed between a marginal ray and an optical axis.

Though maximum heights of marginal rays are traced equal in FIG. 33A, FIG. 33B and FIG. 33C, it is apparent that the optical system shown in FIG. 33A has a largest numerical aperture or is brightest since a limit for heights of the marginal rays is not determined only either one of the objective lens system and the relay lens system. In the case shown in FIG. 33B, a limit for heights of the marginal rays is determined by the relay lens system and a numerical aperture is determined dependently only on a length of the relay lens system. In the case shown in FIG. 33C, in contrast, a limit for heights of the marginal rays is determiend by the objective lens system and a numerical aperture is determined dependently on a length of the objective lens system.

In the case shown in FIG. 33A, the limit for heights of the marginal rays is determiend by both the objective lens system and the relay lens system, either of which has a length larger than that of the relay lens system shown in FIG. 33B or that of the objective lens system shown in FIG. 33C, thereby allowing an optical system having a given outside diameter to have a large numerical aperture.

The condition (9) is required for obtaining a large numerical aperture.

D_1/D_R used in the condition (9) is a parameter for varying brightness and brightness is maximum at D_1/D_R=1.0 which corresponds to the condition shown in FIG. 33A. When D_1/D_R is deviated from 1.0, brightness is lowered to values listed below which are expressed taking brightness at D_1/D_R=1.0 as 1:

(When D_1/D_R<1.0) $[\{1+(N-1)\times D_R/D_1\}/N]^2$

(When D_1/D_R>1.0) $[\{1+D_1/(N-1)/D_R\}\times(N-1)/N]^2$

wherein the reference symbol N represents a number of imaging cycles to be performed by the relay lens system.

For the optical system of the non-flexible endoscope according to the present invention which has the typical composition for three cycles of image relaying, or N=4, ratios of brightness at various values of D_1/D_R relative to brightness at D_1/D_R=1 are calculated as listed below:

D_1/D_R	Ratio in brightness
0.01 and 1.42	0.57
0.33 and 1.29	0.69
1.0	1.0

As is seen from the calculation values listed above, D_1/D_R having a value of 0.01 or 1.42 lowers brightness to a half of that at D_1/D_R=1.0 below which brightness is allowed to be lowered. That is to say, if the lower limit or the upper limit of the condition (9) is exceeded, the optical system will be set in the condition shown in FIG. 33B or FIG. 33C, whereby the optical system will have brightness lower than a maximum level which is available with the utmost capability thereof and is not bright enough for practical use. Further, it is desirable, for obtaining at least 70% of the brightness available with the utmost capability of the optical system, to configure it so as to satisfy, instead of the condition (9), the following condition:

$$0.33<D_1/D_R<1.29$$

In the optical system shown in FIG. 31, the primary field lens F_1 which is disposed in the vicinity of the primary image I_1 has a function to relay a pupil of the objective lens system O to the relay lens system R. Since a principal ray emerging from the objective lens system O travels in a direction away from the optical axis, the principal ray cannot pass through the relay lens system R and an image will be eclipsed at a marginal portion of a visual field if the primary field lens F_1 is not disposed in the vicinity of the primary image I_1. It is therefore necessary to dispose the field lens F_1 in the vicinity of the primary image I_1. When an air-contact surface of the primary field lens F_1 is overlapped with the primary image I_1, however, dust or injury on the surface of the primary field lens F_1 will be imaged. It is therefore desirable to dispose the field lens F_1 so as to have air-contact surfaces located slightly apart from the primary image I_1.

The foregoing description which is made of the typical relay lens system configured for three cycles of image relaying (N=4) is applicable also to relay lens systems which are configured for two cycles, three cycles, four cycles, . . . n cycles of image relaying. It is desirable to select values of D_1/D_R within ranges defined below so that the optical system has brightness of at least 70% of that available with the maximum capability thereof when they are configured for numbers of imaging cycles of 2, 3, 4, . . . to 10:

TABLE 3

N (number of imaging cycle)	
2	$0.66 < D_1/D_R < 1.5$
3	$0.56 < D_1/D_R < 1.29$
4	$0.33 < D_1/D_R < 1.29$
5	$0.3 < D_1/D_R < 1.26$
6	$0.3 < D_1/D_R < 1.25$
7	$0.3 < D_1/D_R < 1.25$
8	$0.3 < D_1/D_R < 1.24$
9	$0.3 < D_1/D_R < 1.22$
10	$0.3 < D_1/D_R < 1.2$

By attaching a TV camera system for non-flexible endoscopes to the optical system of the non-flexible endoscope according to the present invention which has the fundamental composition described above, it is possible to carry out observation on a TV monitor indispensable to surgical operations under observation through endoscopes. For such observation on a TV monitor, it is sufficient to attach a TV camera system **6** to a grip section **1** as in the non-flexible endoscope shown in FIG. **31** so that an imaging lens system IL disposed in this TV camera system forms a final image I_n at a location coincident with a light receiving surface of a solid-state image pickup device **5** for picking up the final image I_n.

Now, description will be made below of a composition desirable for the objective lens system which is to be used in the optical system of the non-flexible endoscope according to the present invention. Speaking concretely, it is desirable to compose the objective lens system, in order from the object side, of a first lens component which is disposed in the leading end of an insert section and has a

negative refractive power, and a second lens component which is disposed between the first lens component and a primary field lens F_1, and has a positive refractive power. This refractive power distribution in the objective lens system is desirable for composing the lens system of a reduced number of lens elements while reserving a field angle required for the objective lens system. The negative refractive power of the first lens component has a function to widen a field angle, whereas the positive refractive power of the second lens component has a role to form a real primary image by imaging a virtual image of an object which is formed by the first lens component. Since the first lens component of the objective lens system has the strongest refractive power among those of lens components disposed in an observation optical system which consists of the objective lens system and a relay lens system, the first lens component has a function to correct curvature of field. Further, the second lens component has a role to determine a pupil in the objective lens system. Accordingly, the refractive power distribution described above permits minimizing a number of lens elements required for composing the objective lens system.

The objective lens system of the optical system shown in FIG. **31**, for example, is composed of the first lens component which consists of a single negative lens element and the second lens component which consists of a single positive lens element. In a case where the first lens component which consists of the single negative lens element has a refractive power insufficient for a certain specification item such as a field angle of the objective lens system, it is allowable to dispose an additional lens element having a negative refractive power in the first lens component. Further, it is allowable to dispose a lens element having a positive refractive power or use a cemented lens component for favorably correcting lateral chromatic aberration and astigmatism.

For correcting barrel distortion produced by an objective lens system which is composed only of spherical lens elements, it is sufficient to prevent a principal ray from being refracted excessively by using an aspherical surface in the first lens component on which the principal ray is high. Further, it is necessary for correcting longitudinal chromatic aberration by the second lens component to use a negative lens element having a high dispersing power and it is sufficient for this purpose to compose the second lens component of a combination of a positive lens element and a negative lens element. In such a case, the positive lens element and the negative lens element may be cemented to each other or disposed separately from each other. For the second lens component for which a magnification of approximately $-1\times$ is most desirable, it is sufficient to select a magnification within a range from $-2\times$ to $-0.5\times$. If the second lens component has a magnification outside the range from $-2\times$ to $-0.5\times$, the objective lens system will have a pupil at a location largely deviated from the middle between the leading end and a primary image, whereby marginal rays will undesirably be eclipsed.

Since the objective lens system which is to be used in the optical system of the non-flexible endoscope according to the present invention is configured so as to be long and have a numerical aperture nearly equal to that of a relay lens system, it is necessary to transmit a pupil together with an image. An image cannot be relayed with unchanged brightness unless a diameter of a light bundle which has passed through the pupil Q_2 of the relay lens system R is changed from that of the light bundle at a stage where it has passed through the pupil Q_1 of the objective lens system. Accordingly, it is desirable that a diameter ϕ_1 of the light bundle as measured at the pupil Q_1 of the objective lens system and a diameter ϕ_2 of the light bundle as measured at the pupil Q_2 of the relay lens system satisfy the following condition (10):

$$0.5<\phi_1/\phi_2<1.5 \tag{10}$$

Further, when a distance D_4 as measured from the pupil Q_1 of the objective lens system O to the primary image I_1 is nearly equal to a distance D_5 as measured from the pupil Q_2 of the relay lens system R to the primary image I_1, the pupil Q_1 and the pupil Q_2 are located nearly symmetrical with regard to the primary image I_1, whereby a pupil can be relayed favorably with little loss of light intensity. Further, the primary field lens F_1 may be disposed on the side of the objective lens system O or the side of the relay lens system R of the primary image or can be located so as to comprise the primary field lens F_1 therein. However, intensity of marginal rays will be lowered when the primary field lens F_1 is too far from the primary image I_1. It is therefore desirable to dispose the primary field lens F_1 so as to reserve, between the primary field lens F_1 and the primary image I_1, a distance which is shorter than 10% of D_3. If the distance reserved between the primary field lens F_1 and the primary image I_1 exceeding 10% of D_3, the primary field lens F_1 itself will eclipse the offaxial rays, thereby eclipsing an image at a marginal portion of a visual field or lowering intensity of the marginal rays. The primary field lens F_1 must have a positive refractive power for transmitting a pupil and can be composed of a singel positive lens element so as to have a sufficient function thereof. When the primary field lens F_1 is to be used for correcting lateral chromatic aberration and astigmatism, however, it may be composed of a cemented lens component consisting of a positive lens element and a negative lens element.

Like the conventional non-flexible endoscope which uses a visual field mask disposed at an imaging location for clarifying a range of a visual field to be observed, the non-flexible endoscope according to the present invention may comprise a visual field mask. In such a case, it is most desirable to dispose a visual field mask consisting of a thin black metal sheet or the like at a location of a final intermediate image I_n at which a spatial restriction is minimum. However, a visual field mask may be disposed at a location of the primary image I_1, any one of the other intermediate images I_2, I_3, . . . or in the first lens component of the objective lens system O on which the marginal rays are low and the principal ray is high.

Now, description will be made of an optical system which is to be used in the non-flexible endoscope according to the present invention and of a type comprising an objective lens system and a plurality of relay lens units.

The nineteenth embodiment of the present invention has a configuration illustrated in FIG. **31** which has already been described above. Speaking concretely, the nineteenth embodiment consists of an insert section **1** which is to be inserted into cavities of living bodies and the like, and a grip section **2** which is to be kept outside the cavities and comprises an eyepiece section **2** disposed in the vicinity of a near end thereof. An objective lens system is disposed in the leading end of the insert section **1** of the non-flexible endoscope, a relay lens system R for relaying a primary image I_1 of an object formed by the objective lens system O is disposed in the insert section **1**, and an eyepiece lens system E which converts a light bundle coming from a final image I_n into a nearly parallel light bundle is disposed in the eyepiece section **2**.

The relay lens system R which is used in the optical system of the non-flexible endoscope preferred as the nineteenth embodiment illustrated in FIG. **31** is composed of relay lens units R_1, R_2 and R_3 for relaying an image in three cycles.

The optical system preferred as the nineteenth embodiment is configured so that a ratio between the length D_1 and D_R, i.e., the parameter (D_1/D_R) expressing a ratio between the length D_1 as measured from the leading end of the objective lens system O to the primary image I_1 and the distance as measured from the primary image I_1 to the next image I_2, satisfies the condition (9).

The twentieth embodiment illustrated in FIG. **32** has a configuration which is obtained by connecting a TV camera system **6** to the grip section **5** of the nineteenth embodiment, and uses on objective lens system O, a relay lens system R and an eyepiece lens system E which are the same as those disposed in the nineteenth embodiment. The TV camera system **6** comprisees an imaging lens system IL and a solid-state image pickup device **11** disposed at a location of an image formed by the imaging lens system IL.

When the TV camera system **6** is detachable from the grip section **5** in the twentieth embodiment, it is usable in various modes while exchanging the TV camera system **6** with different types of TV camera systems. Further, when the TV camera system **6** is configured so as to be dividable along a dashed line **6***c*, the twentieth embodiment can be used in a variety of modes by using a large number of combinations of a multiple kinds of adaptors **3***a* comprising imaging lens systems IL and a multiple kinds of TV camera heads **4***b* which are prepared at hand.

Furthermore, the twentieth embodiment can have a focusing fucntion and a vari-focal function which provide convenient adjustments of focusing positions and image surface sizes when lens elements to be disposed in the imaging lens system IL are configured so as to be movable in the adaptor **3***a*.

The twenty-first embodiment of the present invention has a configuration illustrated in FIG. **34**, or consists of an insert section **1**, a grip section **5**, an adaptor **3** connected to the grip section **5** and a TV camera head **4**. An objective lens system O and a relay lens system R are disposed in the insertion sect **1** and the grip section **5**, whereas an imaging lens system IL is disposed in the adaptor **3** for reimaging a final image I_n formed by the relay lens system R onto a light receiving surface of an image pickup device **11** disposed in the TV camera head **4**.

Unlike the nineteenth embodiment or the twentieth embodiment, the twenty-first embodiment uses no eyepice lens system, and therefore permits configuring a non-flexible endoscope and a TV adaptor compacter. Further, when the twenty-first embodiment is configured so as to permit detaching the insert section **1**, the adaptor **3** and the TV camera head **4** from one another, it is usable in a variety of modes by using a large number of combinations of adaptors and TV camera heads which are prepared in a pluralities of kinds.

The twenty-first embodiment can have a focusing function and a vari-focal function for permitting adjustments of focusing locations and image surface sizes when a lens element L_a or L_b which is used for composing the imaging lens system IL disposed in the adaptor **3** is movable.

The twenty-second embodiment of the present invention has a configuration illustrated in FIG. **35**, or consists of an insert section **1** and a grip section **5**. An objective lens system O and a relay lens system R are disposed in the insert section **1** and the grip section **5** respectively. Further, disposed in the grip section **5** is a solid-state image pickup device **11** for reimaging a final image I_n formed in the optical system onto a light receiving surface of the solid-state image pickup device **11**. Accordingly, the twenty-second embodiment permits configuring a TV observation system for the non-flexible endoscope compacter and enhancing operability thereof.

The twenty-second embodiment also permits configuring a TV camera head **4** so as to be detachable from the other sections and exchangeable with another.

FIG. **36** and FIG. **37** exemplify objective lens systems which are composed of long rod-shaped lens components. When an objective lens system having a large total length is composed of a small number of lens components, it requires very long spacing rings for reserving required airspaces among the lens components. An optical system can be brightened by filling these airspaces with a glass material as in the conventional endoscope.

The objective lens systems illustrated in FIG. **36** and FIG. **37**, in which the airspaces filled with air in the embodiment described above are filled with glass materials having high refractive indices, provide an effect equivalent to that available by shortening an effective length by prolonging an optical path length, thereby enabling to obtain optical systems which have enlarged numerical apertures or are brighter.

FIG. **38** and FIG. **39** illustrate oblique viewing optical systems for non-flexible endoscopes. These optical systems are usable also for straight viewing.

FIG. **38** is a sectional view illustrating an objective lens system O for the oblique viewing optical system for non-flexible endoscopes wherein oblique viewing prisms **11***a* and **11***b* are disposed on the side of a first lens component in a section between the first lens component and a second lens component of the objective lens system for configuring the optical system for oblique viewing. A space reserved between the prisms **11***a* and **11***b* is filled with air or an optical cementing agent which has a refractive index lower than a material of the prisms.

In this objective lens system, a light bundle incident thereon from an object passes through the first lens component and the prism **11***a*, transmits through a layer of the medium having the low refractive index, passes into the prism **11***b*, is totally reflected by a bottom surface of the prism **11***b*, reaches a slant surface of the prism **11***b*, and is reflected totally by a boundary between the layer of the medium having the low refractive index and the slant surface so as to travel toward the second lens component. It is desirable to coat the bottom surface of the prism **11***b* with a reflective film of a metal such as aluminium, but such a reflective metal film is unnecessary when a prism having high refractive index is used for total reflection. Though it is desirable to make the prisms **11***a* and **11***b* of a material having a high refractive index, such a material is limited to one of glass materials and can hardly allow manufacturing costs thereof to be reduced. Therefore, it is desirable for obtaining disposable prisms to select an optical plastic material such as an acrylic plastic material for the prisms **11***a* and **11***b*, and manufacture them by injection molding for reduction of manufacturing cost thereof. In this case, the prisms have a low refractive index and it is sufficient for total reflection on the slant surface of the prism **11***b* to reserve a space between the prisms **11***a* and **11***b* so as to form an air layer.

FIG. **39** and FIG. **40** show examples of oblique viewing objective lens systems which are obtained by modifying the objective lens systems illustrated in FIG. **36** and FIG. **37** respectively, and have compositions which can be realized by using oblique viewing prisms (the prisms **17***a* and **17***b* shown in FIG. **38**) in place of the bar-shaped lens component disposed after the first lens component (the concave lens component) out of the bar-shaped lens components in the objective lens system shown in FIG. **36** or FIG. **37** in which spaces are filled with an optical material.

It is rather hard to design oblique viewing prisms for the objective lens system to be used in the optical system of the non-flexible endoscope according to the present invention in which rays are higher in the first lens component than the rays in the first lens component of the conventional objective lens systems which has a small total length. However, the

composition which is described above permits reserving a sufficient effective diameter in prisms and makes it possible to design objective lens systems for oblique viewing non-flexible endoscopes.

As is seen from FIG. **41** (illustraing an objective lens system for endoscopes performing three cycles of image relaying) and FIG. **42** (showing an objective lens system for non-flexible endoscopes performing five cycles of image relaying), the objective lens systems which are to be used in the optical system of the non-flexible endoscope according to the present invention comprise airspaces which are remarkably wider than those reserved in the conventional objective lens system for non-flexible endoscopes. It is therefore undesirable to use metallic spacing rings for holding the lens components at predetermined spacings in the objective lens systems for the non-flexible endoscope according to the present invention since such metallic spacing rings have inside surfaces which allow detrimental rays to be incident due to reflection thereon, thereby producing flare. The objective lens systems for the optical system of the non-flexible endoscope according to the present invention use spacing rings having inside surfaces which are roughened or sand-blasted so as to lower reflection thereon and prevent production of flare. Further, it is possible to obtain spacing rings having roughened inside surfaces by fabricating them with synthetic resin materials and mixing a foreign matter such as glass with the synthetic resin material at molding stages. These spacing rings can prevent produciton of flare.

Though the lens components to be used for composing the optical system of the non-flexible endoscope according to the present invention are ordinarily made of glass materials, a manufacturing cost of the optical system can be lowered by manufacturing the lens components by injection molding of optical plastic materials such a acrylic materials. It is desirable to compose each of the lens components of a single lens element and two lens elements may be disposed separately with a slight airspace reserved therebetween when a cemented lens component is required for composing the optical system.

In the objective lens system shown in FIG. **36** or FIG. **37**, the location of the pupil Q is shifted toward the first lens component (the concave lens component) so that a small virtual image is formed in the vicinity of the first lens component and the principal ray is low on this lens component, thereby preventing a visual field from being eclipsed.

FIG. **44** and FIG. **45** (Embodiemnt 23 and Embodiment 24) show concrete examples of optical systems of the non-flexible endoscopes according to the present invention which are configured so as to perform a single image relaying cycle or a plurality of image relaying cycles, uses relay lens systems having shortened lengths and have numerical data listed below:

Embodiment 23

object distance = −30 mm, F No. = 7.16
image height = 2.18 mm, field angle = 60°
effective diameter of lens element = ϕ5.8 mm

$r_1 = \infty$		
$d_1 = 0.8000$	$n_1 = 1.80610$	$\nu_1 = 40.95$
$r_2 = 3.5063$		
$d_2 = 34.6896$		
$r_3 = 22.3925$		
$d_3 = 1.5000$	$n_2 = 1.51633$	$\nu_2 = 64.15$
$r_4 = \infty$		
$d_4 = 1.5000$	$n_3 = 1.51633$	$\nu_3 = 64.15$

-continued

Embodiment 23

$r_5 = -22.3258$		
$d_5 = 40.0104$		
$r_6 = 42.0295$		
$d_6 = 3.0000$	$n_4 = 1.51633$	$\nu_4 = 64.15$
$r_7 = -42.2079$		
$d_7 = 6.0000$		
$r_8 = \infty$		
$d_8 = 1.6886$		
$r_9 = 17.0754$		
$d_9 = 39.1310$	$n_5 = 1.62004$	$\nu_5 = 36.26$
$r_{10} = \infty$		
$d_{10} = 0.2955$		
$r_{11} = 20.9646$		
$d_{11} = 1.0000$	$n_6 = 1.80610$	$\nu_6 = 40.95$
$r_{12} = 5.7017$		
$d_{12} = 3.0000$	$n_7 = 1.65160$	$\nu_7 = 58.52$
$r_{13} = -10.5362$		
$d_{13} = 1.5653$		
$r_{14} = \infty$		
$d_{14} = 39.1310$	$n_8 = 1.62004$	$\nu_8 = 36.26$
$r_{15} = -17.0754$		
$d_{15} = 1.6886$		
$r_{16} = \infty$		
$d_{16} = 1.6886$		
$r_{17} = 17.0754$		
$d_{17} = 39.1310$	$n_9 = 1.62004$	$\nu_9 = 36.26$
$r_{18} = \infty$		
$d_{18} = 0.2955$		
$r_{19} = 20.9646$		
$d_{19} = 1.0000$	$n_{10} = 1.80610$	$\nu_{10} = 40.95$
$r_{20} = 5.7017$		
$d_{20} = 3.0000$	$n_{11} = 1.65160$	$\nu_{11} = 58.52$
$r_{21} = -10.5362$		
$d_{21} = 1.5653$		
$r_{22} = \infty$		
$d_{22} = 39.1310$	$n_{12} = 1.62004$	$\nu_{12} = 36.26$
$r_{23} = -17.0754$		
$d_{23} = 1.6886$		
$r_{24} = \infty$		
$d_{24} = 1.6886$		
$r_{25} = 17.0754$		
$d_{25} = 39.1310$	$n_{13} = 1.62004$	$\nu_{13} = 36.26$
$r_{26} = \infty$		
$d_{26} = 0.2955$		
$r_{27} = 20.9646$		
$d_{27} = 1.0000$	$n_{14} = 1.80610$	$\nu_{14} = 40.95$
$r_{28} = 5.7017$		
$d_{28} = 3.0000$	$n_{15} = 1.65160$	$\nu_{15} = 58.52$
$r_{29} = -10.5362$		
$d_{29} = 1.5653$		
$r_{30} = \infty$		
$d_{30} = 39.1310$	$n_{16} = 1.62004$	$\nu_{16} = 36.26$
$r_{31} = -17.0754$		
$d_{31} = 1.6886$		
$r_{32} = \infty$		

$D_1 = 87.5$ mm, $D_2 = 87.5$ mm, $D_1/D_2 = 1$

Embodiment 24

object distance = −30 mm, F No. = 11.62,
image height = 2.9, field angle = 60°
effective diameter of lens element = ϕ7.4 mm

$r_1 = \infty$		
$d_1 = 0.8000$	$n_1 = 1.80610$	$\nu_1 = 40.95$
$r_2 = 5.1100$		
$d_2 = 75.7700$		
$r_3 = 45.3700$		
$d_3 = 1.5000$	$n_2 = 1.51633$	$\nu_2 = 64.15$
$r_4 = \infty$		
$d_4 = 1.5000$	$n_3 = 1.51633$	$\nu_3 = 64.15$
$r_5 = -45.3700$		
$d_5 = 86.4200$		
$r_6 = 44.1060$		

-continued

Embodiment 24		
$d_6 = 3.0000$	$n_4 = 1.51633$	$\nu_4 = 64.15$
$r_7 = -44.1060$		
$d_7 = 6.0000$		
$r_8 = \infty$		
$d_8 = 85.6300$		
$r_9 = 30.7220$		
$d_9 = 3.0000$	$n_5 = 1.51633$	$\nu_5 = 64.15$
$r_{10} = -14.7370$		
$d_{10} = 1.0000$	$n_6 = 1.78472$	$\nu_6 = 25.71$
$r_{11} = -31.7910$		
$d_{11} = 85.3600$		
$r_{12} = \infty$		
$D_1 = 174.99$ mm, $D_2 = 174.99$ mm, $D_1/D_2 = 1$		

Out of the optical system described above, an optical system which performs three cycles of image relaying is illustrated in FIG. **44** and an optical system which performs a single cycle of image relaying is shown in FIG. **45**. These optical systems are configured so as to satisfy the condition (9).

The present invention provide an optical system for non-flexible endoscopes which is bright or has a numerical aperture enlarged by determining a location of a primary image to be formed by an objective lens system so as to shorten a length required for relaying the primary image by one cycle.

We claim:

1. A non-flexible endoscope comprising: an insert section for insertion from a leading end thereof into cavities of an object to be observed for observing interiors thereof, and a grip section which is to be connected to an end of said insert section located on a side opposite to said leading end and always kept outside the cavities during observation, wherein said insert section comprises an objective lens system having a first surface disposed at said leading end for forming a primary image, and a relay lens system for transmitting said primary image so as to form a secondary image in the vicinity of a connecting position between said insert section and said grip section or in said grip section, wherein said grip section comprises an eyepiece lens system for making said secondary image visible, and wherein said insert section satisfies the following condition (5):

$$0.3<D_1/D_2<0.7 \quad (5)$$

wherein the reference symbol D_1 represents a distance as measured from the first surface of said objective lens system to said primary image and the reference symbol D_2 designates a distance as measured from the first surface of said objective lens system to said secondary image.

2. A non-flexible endoscope comprising: an insert section for insertion from a leading end thereof into cavities of an object to be observed for observing interiors thereof, a grip section which is to be connected to an end of said insert section located on a side opposite to said leading end and always kept outside the cavities during observation, and a TV camera system which is to be attached to said grip section, wherein said insert section comprises an objective lens system having a first surface disposed at said leading end for forming a primary image, and a relay lens system for transmitting said primary image so as to form a secondary image in the vicinity of a connecting position between said insert section and said grip section, wherein said grip section comprises an eyepiece lens system for converting rays coming from said secondary image into a nearly parallel light bundle, and wherein said TV camera system comprises an imaging lens system for imaging the nearly parallel light bundle emerging from said eyepiece lens system and an image pickup device for picking up an image formed by said imaging lens system, and wherein said insert section satisfies the following condition (5):

$$0.3<D_1/D_2<0.7 \quad (5)$$

wherein the reference symbol D_1 represents a distance as measured from the first surface of said objective lens system and the reference symbol D_2 designates a distance as measured from the first surface of said objective lens system to said secondary image.

3. A non-flexible endoscope comprising: an insert section for insertion from a leading end thereof into cavities of an object to be observed for observing interiors thereof, wherein said insert section comprises an objective lens system having a first surface disposed at said leading end for forming a primary image, and a relay lens system which is disposed on the image side of said objective lens system for relaying said primary image so as to form a secondary image, and wherein said insert section satisfies the following condition (5):

$$0.3<D_1/D_2<0.7 \quad (5)$$

wherein the reference symbol D_1 represents a distance as measured from the first surface of said objective lens system to the primary image and the reference symbol D_2 designates a distance as measured from the first surface of said objective lens system to the secondary image.

4. A non-flexible endoscope according to claim **3** further comprising an image pickup device disposed at a location of said secondary image.

5. A non-flexible endoscope according to claim **3** further comprising an imaging lens system for reimaging said secondary image and an image pickup device disposed at a location of an image formed by said imaging lens system.

6. A non-flexible endoscope according to claim **2**, **3**, **4** or **5** wherein said objective lens system is composed of a first negative lens component and a second positive lens component, and wherein said second lens component satisfies the following condition (6):

$$0.5<|\beta_2|<2.0 \quad (6)$$

wherein the reference symbol β_2 represents a magnification of said second lens component.

7. A non-flexible endoscope according to claim **6** wherein said first lens component is composed of a single negative lens element and wherein said second lens component is composed of a single positive lens element.

8. A non-flexible endoscope according to claim **6** wherein said first lens component is composed of a single negative lens element and wherein said second lens component is composed of a positive lens element and a negative lens element.

9. A non-flexible endoscope according to claim **1**, **2** or **3** comprising a primary field lens disposed in the vicinity of said primary image.

10. A non-flexible endoscope according to claim **9** satisfying the following condition (7):

$$|D_3/D_2|\leqq 0.1 \quad (7)$$

wherein the reference symbol D_2 represents a distance as measured from a first surface of said objective lens system to said secondary image and the reference symbol D_3 designates a distance as measured from said primary field lens to said primary image.

11. A non-flexible endoscope comprising: an insert section for insertion from a leading end thereof into cavities of an object to be observed for observing interiors thereof, and a grip section which is to be connected to an end of said insert section located on a side opposite to said leading end, wherein said insert section comprises an objective lens system having a first surface disposed in said leading end for forming a primary image and a relay lens system for relaying said primary image in a single cycle or a plurality of cycles so as to form a final image in the vicinity of a connecting position of said insert section or in said grip section, and wherein said insert section satisfies the following condition (9):

$$0.3<D_1/D_R<2.0 \quad (9)$$

wherein the reference symbol D_1 represents a distance as measured from the first surface of said objective lens system to said primary image and the reference symbol D_R designates a distance which is required for relaying said primary image in a single cycle by said relay lens system.

12. A non-flexible endoscope according to claim **11** satisfying the following condition (10):

$$0.5<\phi_1/\phi_2<1.5 \quad (10)$$

wherein the reference symbol ϕ_1 represents a diameter of a light bundle at a location of a pupil of said objective lens system and the reference symbol ϕ_2 designates a diameter of the light bundle at a location of a pupil of said relay lens system.

13. A non-flexible endoscope according to claim **11** wherein said grip section comprises an eyepiece lens system for converting rays coming from the final image formed by said relay lens system into a nearly parallel light bundle which is visible by eyes.

14. A non-flexible endoscope according to claim **13** comprising a TV camera system to be attached to said grip section, wherein said TV camera system comprises an imaging lens system for reimaging said final image and an image pickup device disposed at a location of an image formed by said imaging lens system.

15. A non-flexible endoscope according to claim **13** further comprising a TV camera to be attached to said grip section, wherein said TV camera comprises an imaging lens system for imaging rays emerging from said eyepiece lens system and an image pickup device disposed at a location of an image formed by said imaging lens system.

16. A non-flexible endoscope according to claim **11** comprising an image pickup device disposed at a location of the final image formed by said relay lens system.

* * * * *

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United States Patent [19]

Weber et al.

[11] Patent Number: 5,630,771

[45] Date of Patent: May 20, 1997

[54] **COARSE AND FINE DRIVES FOR AN OBJECTIVE**

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[73] Assignee: **Carl-Zeiss-Stiftung**, Heidenheim, Germany

[21] Appl. No.: **406,412**

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[30] **Foreign Application Priority Data**

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[52] **U.S. Cl.** **475/338**; 475/339; 475/349; 475/288; 359/822; 359/823

[58] **Field of Search** 475/288, 289, 475/311, 312, 338, 339, 346, 349; 354/195; 359/822, 823

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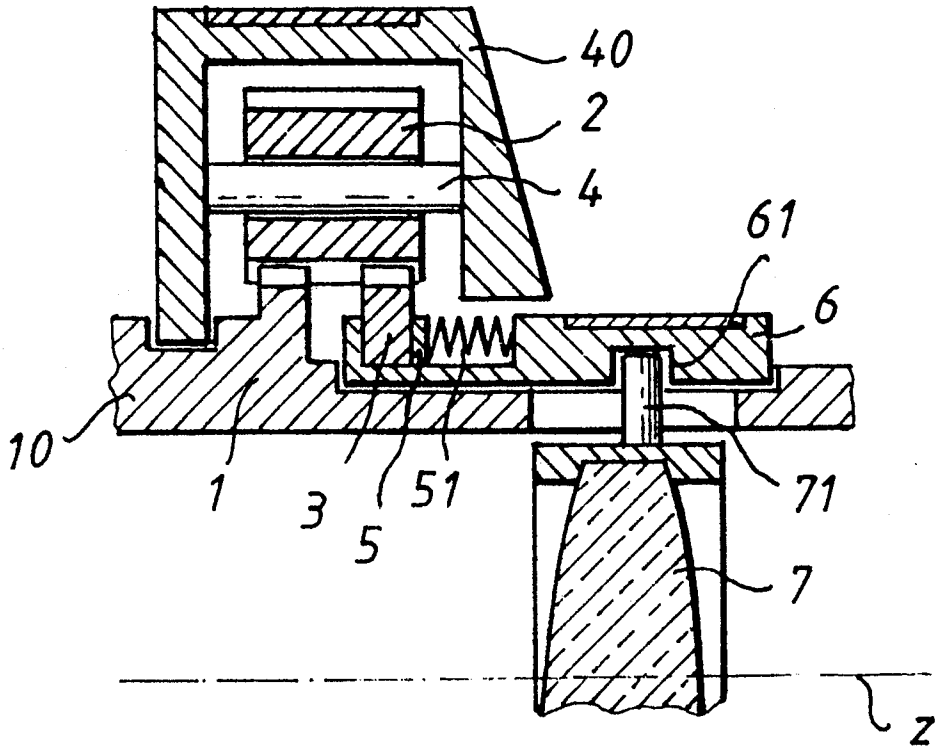
Primary Examiner—Charles A. Marmor
Assistant Examiner—Peter Kwon
Attorney, Agent, or Firm—Walter Ottesen

[57] **ABSTRACT**

The invention is directed to an arrangement for displacing the parts of an objective with at least one adjusting ring **6**. A fine adjusting ring **40** is also provided and there is no switchover device which must be actuated by the operator. The fine adjusting ring **40** is at standstill when it is not actively rotated by the operator. A coarse adjusting ring **6** is rotatably journalled in the housing **10** of an objective. A transmission or gearing for suitably fine adjusting this coarse adjusting ring **6** includes a sun gear wheel **1** mounted fixedly on the objective housing **10**, a fine adjusting ring **40** which includes a shaft pin **4** on which planetary gear wheels **2** are journalled and an output gear wheel **3** rotatably mounted on the coarse adjusting ring **6** via a slip clutch **5**.

6 Claims, 1 Drawing Sheet



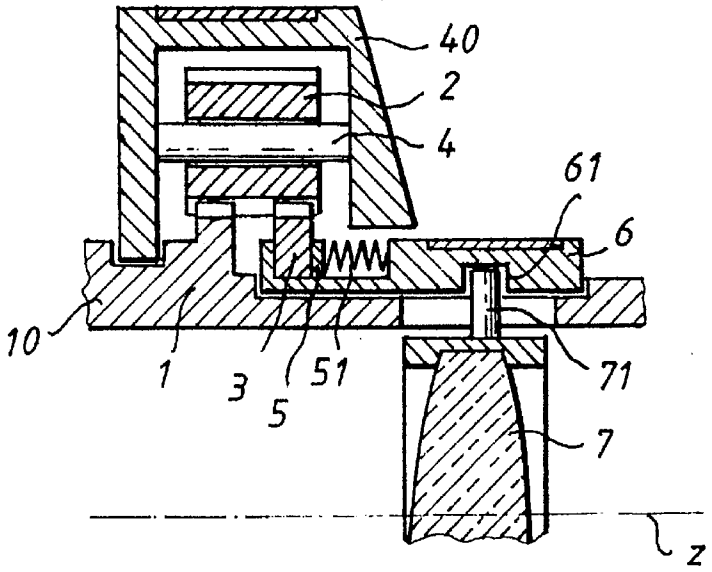


FIG. 1

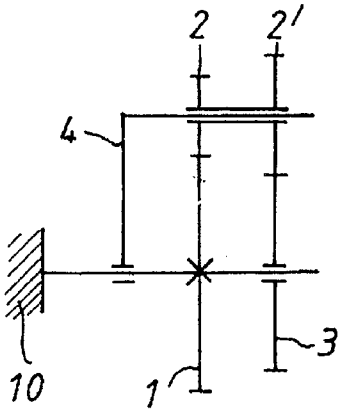


FIG. 2

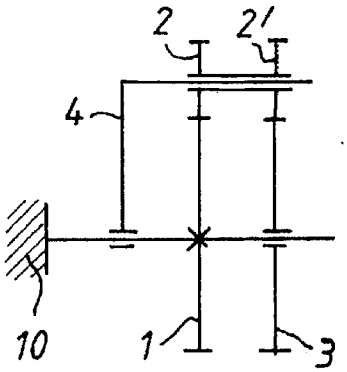


FIG. 3

COARSE AND FINE DRIVES FOR AN OBJECTIVE

FIELD OF THE INVENTION

The invention relates to an arrangement for displacing at least one part of an objective with at least one adjusting ring and also relates to a transmission for the fine displacement of a coarse adjusting ring. The coarse adjusting ring is rotatably journalled in the housing of the objective.

BACKGROUND OF THE INVENTION

It is known to selectively derive a movement of an objective from two different drive sources such as a motor and a manual adjusting ring. U.S. Pat. No. 4,200,377 discloses a focusing mechanism for a camera objective wherein the drives are decoupled via a slip clutch. Published German patent application 4,331,650 discloses a planetary transmission. The inactive drive is brought to standstill by the action of a friction brake.

A manual focusing by adjusting the object spacing (object to lens distance) with two different transmission ratios (coarse and fine drives) is normal for microscopes (that is, very different mechanical conditions); however, this manual focusing is exceptional for photo and film objectives and is only purposeful in a given area of application, namely, for a long focal length telephoto lens for sport (rapid) and nature photography (fine). Photo and film objectives usually have a single distance rotation ring. For rapid focusing, a small rotational angle is advantageous and for sensitive focusing a larger rotational angle is advantageous.

Various manufacturers of objectives offer therefore a range switchover especially for long focal length objectives wherein, with a switch or rotational ring, a distance range can be preselected and thereafter a sharp focusing is made within this range with a distance rotational ring over a larger rotational angle. However, this requires that the photographer must know ab initio in which range the work will be performed.

This is most of all critical at the range boundaries. If the photographer has preselected a range and attempts to sharply focus the object, but cannot attain the point of sharp focus because of the range boundary, the photographer must first change the range and then again search for the point of sharp focus with the distance ring. This is inconvenient and time consuming.

SUMMARY OF THE INVENTION

In view of the foregoing, it is an object of the invention to provide a user-friendly gearing solution for a manual coarse and fine drive for focusing the objective.

The invention provides a user-friendly, rapid and precise focusing. The objective is equipped with two distance adjusting rings which both provide the capability of focusing from the near range to infinity. The first distance adjusting ring (coarse adjusting ring) has a small rotational angle and functions for rapid focusing, for example, to make sport photographs and for coarse prefocusing such as for subjects in nature. The second distance adjusting ring (the fine adjusting ring) can be rotated through a large rotational angle (several rotations of the ring from the near range to infinity) and functions for fine focusing such as when photographing subjects as they are found in nature.

The photographer first attempts to come close to the sharp focusing point with the coarse adjusting ring and then reaches with the hand to the fine adjusting ring in order to precisely adjust the sharp focus.

The coarse adjusting ring directly drives the optical member which is to be displaced linearly. The coarse adjusting ring does this via a thread or a cam (coarse drive). The fine adjusting ring is connected to the coarse adjusting ring via a reduction transmission and a slip clutch. The reduction converts a large rotational angle of the fine adjusting ring into a small rotational angle of the coarse adjusting ring. The distance scale provided on the coarse adjusting ring is therefore also applicable to the indirect drive thereof via the fine adjusting ring.

For higher reductions of the transmission, the fine adjusting ring should not be moved at high rotational speed with the actuation of the coarse adjusting ring. Also, the transmission is self retarding for the translation into the slower rotational speed because the slight frictional torque in the bearing locations of the toothed wheels is sufficient in order to block the transmission. For this reason, a slip clutch is provided between the output wheel of the fine drive and the coarse adjusting ring. The slip clutch is so configured that it transmits the torque of the output wheel of the fine drive to the coarse adjusting ring when the fine adjusting ring is actuated. The transferable torque of the slip clutch must therefore be greater than the drive torque of the coarse drive. The gearing blocks the fine drive when the coarse adjusting ring is actuated and the slip clutch slips. Furthermore, the slip clutch protects the gearing of the fine drive against damage when both coarse and fine adjusting rings are actuated at the same time and when reaching the stops in the end positions with the fine drive.

An especially advantageous embodiment provides for only one planetary gear wheel for transmitting from the sun gear to the output gear wheel. A plurality of such planetary gear wheels can be distributed about the periphery. This is possible when the sun gear wheel and the output gear wheel each have many teeth. The number of teeth differs only slightly and one of the sets of teeth has a profile shift.

In this way, the assembly is facilitated because instead of two pinions, only one pinion is seated on each shaft pin. In the case of two pinions, all planetary gear wheels distributed over the periphery must be precisely adjusted with respect to rotation.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will now be described with reference to the drawings wherein:

FIG. **1** is a schematic section view taken through a transmission according to the invention;

FIG. **2** is a gearing schematic of a planetary transmission in accordance with an embodiment of the invention; and,

FIG. **3** is a preferred embodiment of the gearing arrangement of the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS OF THE INVENTION

In FIG. **1**, the objective housing **10** includes a fixed sun gear wheel **1** formed thereon and having a positive profile shift. A planetary gear wheel **2** is rotatably journalled on the shaft pin **4** which, in turn, is part of a fine adjusting ring **40** and is rotatably journalled on the objective housing **10** for rotation about the main axis Z of the housing. A plurality of planetary gear wheels **2** is distributed about the periphery and there are preferably three in number. The planetary gear wheel **2** furthermore meshes with the output gear wheel **3** (unmodified gear wheel) which is rotatably connected via a slip clutch **5** to the coarse adjusting ring **6**. The slip clutch

5 has a load spring 51. Other varieties of slip clutches 5 can also be used such as those using hydraulic or pneumatic means or media of special or variable viscosity.

The coarse adjusting ring 6 is rotatably journalled on the objective housing 10 to rotate about the main axis Z thereof and has a control cam 61. A cam follower 71 of a slide member 7 engages the control cam 61. A rotational movement of the coarse adjusting ring 6 is converted into a focusing movement along the main axis Z by the cam transmission configured in the manner described above and known per se.

When actuated by the output gear wheel 3, the planetary gear (1, 2, 3, 4) is self-locking as the low friction torques at the fine adjusting ring 40 side of the planetary gear (1, 2, 3, 4) are transformed into a high braking torque because of the high transmission ratio of the planetary gear (1, 2, 3, 4). The slide clutch 5 is suitably adjusted so that the braking torque at the output gear wheel 3 cannot be transmitted from the coarse adjusting ring 6 to the output gear wheel 4. Accordingly, the fine adjusting ring 40 remains stationary when the coarse adjusting ring 6 is actuated.

When the fine adjusting ring 40 is rotated, then the planetary gear wheel 2 rolls on the stationary sun gear 1 and entrains the output gear wheel 3 because of the different tooth number. The output gear wheel 3 is connected to the coarse adjusting ring 6 via the slip clutch 5. The coarse adjusting ring 6 is entrained and effects the displacement of the slide member 7 as described above.

The planetary transmission (1, 2, 3, 4) is again shown in FIG. 2 as a gearing schematic in its normal base form. Two planetary gear wheels (2, 2') are mounted on the shaft pin 4 and are rigidly connected to each other. The planetary gear wheels (2, 2') have the number of revolutions N_4 and have tooth numbers (Z_2, $Z_{2'}$), respectively. The stationary sun gear wheel 1 has the tooth number Z_1. The output wheel 3 has the tooth number Z_3 and the number of revolutions N_3.

The transmission ratio is $N_3/N_4=1-(Z_1 \cdot Z_{2'}/Z_2 \cdot Z_3)$. The output gear wheel 3 (that is, the coarse adjusting ring 6) and the shaft pin 4 (that is, the fine adjusting ring 40) rotate in the same direction when Z_1 is less than Z_3.

The less the difference of the tooth numbers Z_1 and Z_2, the greater is the reduction. By advancing the pinion 2 on the gear wheels 1 and 3, the transmission can be adjusted without play. The planetary gear wheels (2, 2') should be three in number and evenly distributed about the periphery so that no one-sided forces can occur in the transmission. For this reason, the tooth number difference of Z_1 and Z_3 must be a multiple of 3.

The teeth of the planetary gear wheels (2, 2') must be precisely aligned to each other. In order to avoid this and to simplify the assembly of the transmission, a departure in accordance with FIG. 3 is presented which is already considered in FIG. 1. Here, $Z_2=Z_{2'}$, that is, only a single through pinion is provided as the planetary gear wheel 2 and this pinion meshes with the sun gear wheel 1 and the output gear wheel 3. This is possible because: the sun gear wheel 1 and the output gear wheel 3 have many teeth; the respective tooth numbers (Z_1, Z_3) of these wheels differ from each other only slightly; and, the sun gear wheel 1 ($Z_1<Z_3$) has a positive profile shift of the tooth profile (the effective running circle diameter in the first pair (sun gear wheel 1/planet gear wheel 2) differs from the effective running circle diameter of the second pair (output gear wheel 3/planetary gear wheel 2), The transmission ratio is then $N_3/N_4=1-Z_1/Z_3$.

A specific embodiment has the following data for the planetary transmission: number of teeth $Z_1=237$ of the sun gear wheel 1, The number of teeth $Z_3=Z_1+3=240$ for the output gear wheel 3 because three planetary gear wheels 2 are distributed about the periphery for transmitting torque, The number of teeth $Z_2=20$ for the planetary gear wheel 2, Module 0.5. The transmission ratio is then $N_3/N_4=1/80$.

The coarse drive comprising the coarse adjusting ring 6 having the control cam 61, cam follower 71 and displacing member 7 is configured as a screw drive having a rotational angle of 120° and a stroke of 20 mm. A rotation on the coarse adjusting ring 6 of 1° therefore effects a displacement of the displacing member 7 of 0.17 mm.

A rotation on the fine adjusting ring 40 of 1° effects only a displacement of the displacing member 7 of 0.002 mm, that is, 1/80 of the above value.

In lieu of the gear wheel transmission, the planetary transmission (1, 2, 3, 4) of FIG. 2 can be provided with a friction wheel transmission. Here, the two planetary gear wheels (2, 2') can be joined to define a bevel gear.

It is understood that the foregoing description is that of the preferred embodiments of the invention and that various changes and modifications may be made thereto without departing from the spirit and scope of the invention as defined in the appended claims.

What is claimed is:

1. An arrangement displacing at least a part of an objective, the arrangement comprising:

a housing defining a longitudinal axis;

a holding member for holding said one part and being displaceable along said axis;

a coarse adjusting ring rotatably mounted on said housing so as to be rotatable by an operator;

conversion means operatively connecting said coarse adjusting ring to said holding member for converting a rotatable movement of said coarse adjusting ring to a linear displacement of said holder and said part along said axis;

a fine adjusting ring mounted on said housing so as to be rotatable relative thereto by an operator through a first rotational angle;

interface means operatively connecting said fine adjusting ring to said coarse adjusting ring to effect a rotation thereof through a second rotational angle when said fine adjusting ring is rotated by the operator;

said interface means including: means for decoupling said fine adjusting ring from said coarse adjusting ring when said coarse adjusting ring is rotated by the operator whereby said fine adjusting ring remains at standstill; and, rotation reduction means for making said second rotational angle of said coarse adjusting ring a fraction of said first rotational angle whereby a fine adjustment of said linear displacement is obtained when said fine adjusting ring is rotated by the operator.

2. A transmission for adjusting at least a part of an objective mounted in an objective housing defining a longitudinal axis, the transmission comprising:

a coarse adjusting ring rotatably journalled on the housing so as to rotate about said longitudinal axis;

a holding member for holding said one part and being displaceable along said axis;

a coarse adjusting ring rotatably mounted on said housing so as to be movably rotatable by an operator;

conversion means operatively connecting said coarse adjusting ring to said holding member for converting a rotational movement of said coarse adjusting ring to a linear displacement of said holder and said part along said axis;

a sun gear wheel fixedly mounted on said housing;

a fine adjusting ring disposed in surrounding spaced relationship to said housing;

planetary gear means rotatably journalled in said fine adjusting ring for meshing with said sun gear wheel;

an output gear wheel rotatably mounted on said coarse adjusting ring and meshed with said planetary gear means whereby a manual rotation of said fine adjusting ring imparts a rotational movement to said output gear wheel; and,

slip clutch means interposed between said output gear wheel and said coarse adjusting ring for transmitting a torque from said output gear wheel to said coarse adjusting ring when an operator manually rotates said fine adjusting ring and for decoupling said output gear wheel from said coarse adjusting ring when the operator rotates said coarse adjusting ring.

3. The transmission of claim **2**, wherein said planetary gear means comprises a plurality of one-piece pinions uniform throughout and rotatably journalled in said fine adjusting ring so as to mesh with said sun gear wheel and said output gear wheel; and, one of said sun gear wheel and said output gear wheel having a profile shift.

4. An arrangement displacing at least a part of an objective, the arrangement comprising:

a housing defining a longitudinal axis;

a holder for holding said one part and being displaceable along said axis;

a coarse adjusting ring rotatably mounted on said housing so as to be rotatable by an operator;

an angular-to-linear drive operatively connecting said coarse adjusting ring to said holder for converting a rotational movement of said coarse adjusting ring to a linear displacement of said holder and said part along said axis;

a fine adjusting ring mounted on said housing so as to be rotatable relative thereto by an operator through a first rotational angle;

a reduction gear operatively connecting said fine adjusting ring to said coarse adjusting ring to effect a rotation thereof through a second rotational angle when said fine adjusting ring is rotated by the operator;

said reduction gear including: a clutch decoupling said fine adjusting ring from said coarse adjusting ring when said coarse adjusting ring is rotated by the operator whereby said fine adjusting ring remains at standstill; and, rotation reduction gear wheels for making said second rotational angle of said coarse adjusting ring a fraction of said first rotational angle whereby a fine adjustment of said linear displacement is obtained when said fine adjusting ring is rotated by the operator.

5. A transmission for adjusting at least a part of an objective mounted in an objective housing defining a longitudinal axis, the transmission comprising:

a coarse adjusting ring rotatably journalled on the housing so as to rotate about said longitudinal axis;

a holder for holding said one part and being displaceable along said axis;

a coarse adjusting ring rotatably mounted on said housing so as to be movably rotatable by an operator;

an angular-to-linear drive operatively connecting said coarse adjusting ring to said holder for converting a rotational movement of said coarse adjusting ring to a linear displacement of said holder and said part along said axis;

a sun gear wheel fixedly mounted on said housing;

a fine adjusting ring disposed in surrounding spaced relationship to said housing;

planetary gear wheels rotatably journalled in said fine adjusting ring for meshing with said sun gear wheel;

an output gear wheel rotatably mounted on said coarse adjusting ring and meshed with said planetary gear means whereby a manual rotation of said fine adjusting ring imparts a rotational movement to said output gear wheel; and,

a slip clutch interposed between said output gear wheel and said coarse adjusting ring for transmitting a torque from said output gear wheel to said coarse adjusting ring when an operator manually rotates said fine adjusting ring and for decoupling said output gear wheel from said coarse adjusting ring when the operator rotates said coarse adjusting ring.

6. The transmission of claim **5**, wherein said planetary gear wheels are one-piece pinions uniform throughout and rotatably journalled in said fine adjusting ring so as to mesh with said sun gear wheel and said output gear wheel; and, one of said sun gear wheel and said output gear wheel having a profile shift.

* * * * *

US005629259A

United States Patent [19]

Akada et al.

[11] Patent Number: 5,629,259

[45] Date of Patent: May 13, 1997

[54] **IMAGE FORMATION ON OBJECTIVE BODIES**

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[73] Assignee: **Dai Nippon Insatsu Kabushiki Kaisha**, Japan

[21] Appl. No.: **395,850**

[22] Filed: **Feb. 28, 1995**

Related U.S. Application Data

[63] Continuation of Ser. No. 34,186, Mar. 18, 1993, Pat. No. 5,451,560, which is a continuation of Ser. No. 467,415, Jan. 19, 1990, abandoned, which is a division of Ser. No. 138,384, filed as PCT/JP87/00228, Apr. 10, 1987, Pat. No. 4,923,848.

[30] **Foreign Application Priority Data**

Apr. 11, 1986	[JP]	Japan	61-81988
Apr. 11, 1986	[JP]	Japan	61-81989
Sep. 24, 1986	[JP]	Japan	61-223896
Sep. 24, 1986	[JP]	Japan	61-225473
Oct. 1, 1986	[JP]	Japan	61-231224
Jan. 14, 1987	[JP]	Japan	62-5066

[51] **Int. Cl.**[6] **B41M 5/035**; B41M 5/38

[52] **U.S. Cl.** **503/227**; 428/195; 428/913; 428/914

[58] **Field of Search** 8/471; 428/195, 428/913, 914; 503/227

[56] **References Cited**

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60-203494	10/1985	Japan	503/227

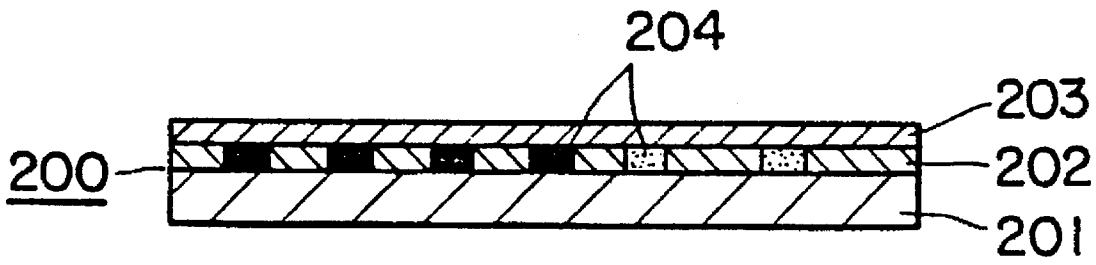
Primary Examiner—Bruce H. Hess

Attorney, Agent, or Firm—Parkhurst, Wendel & Burr, L.L.P.

[57] **ABSTRACT**

The present invention relates to image-formation on any selected kind of objective body. The characterizing features reside in such that, based upon fed image data, required images are formed on an image-transferable sheet acting for image carry-over service and in reliance on sublimation image transfer technique, and then, by the use of said sheet with said images thus formed thereon, the formed images thereon are transferringly applied on the objective body. By adopting the above measures, the objective body can be formed sharply and clearly with any desired images, irrespective of kind and configuration thereof, with such superior results of highly improved unity and solidability between the formed images and the objective body to be decorated with.

6 Claims, 16 Drawing Sheets



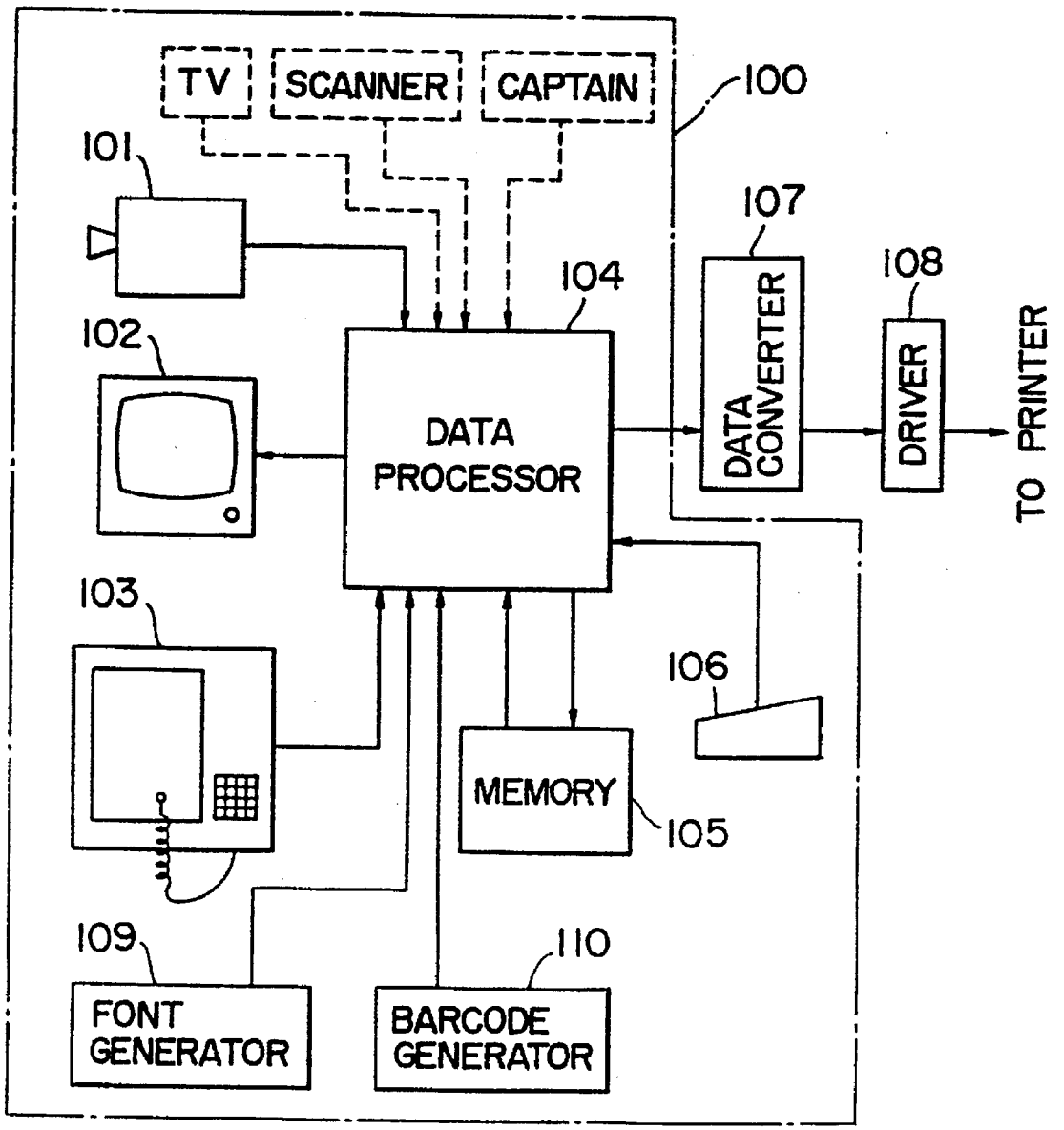

TV
SCANNER
CAPTAIN
100
101
107
104
108
102
DATA PROCESSOR
DATA CONVERTER
DRIVER
TO PRINTER
103
106
MEMORY
105
109
110
FONT GENERATOR
BARCODE GENERATOR

FIG. 1A

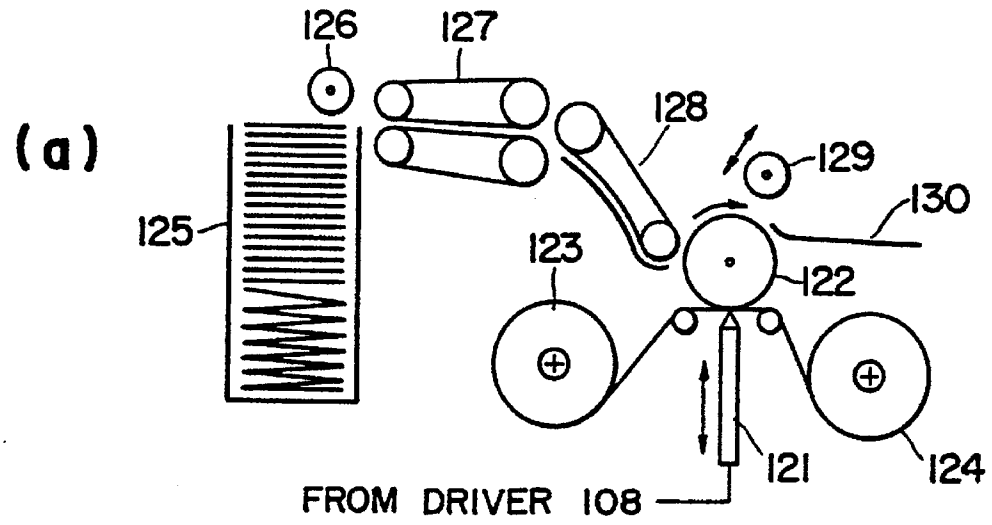

(a)
126
127
128
129
130
125
123
122
121
124
FROM DRIVER 108
(b)
131
134
122
133
123
200
121
124
132
FROM DRIVER
(c)
133'
132'

FIG. 1B

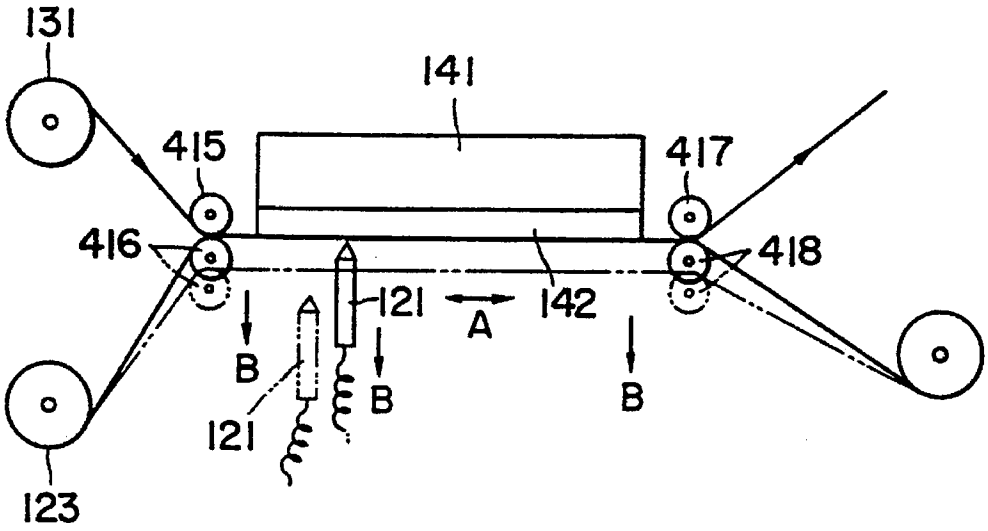


FIG. 1C

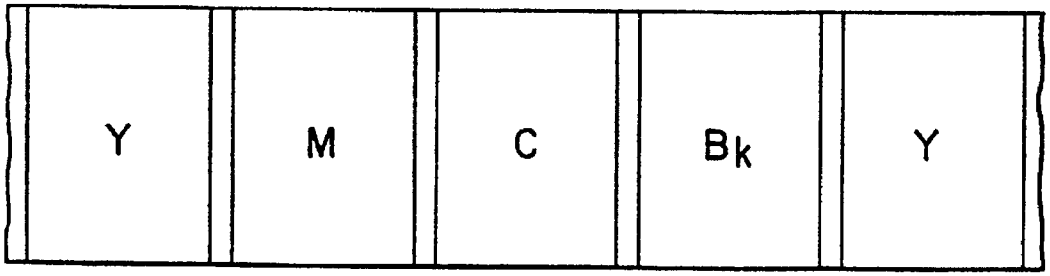


FIG. 1D

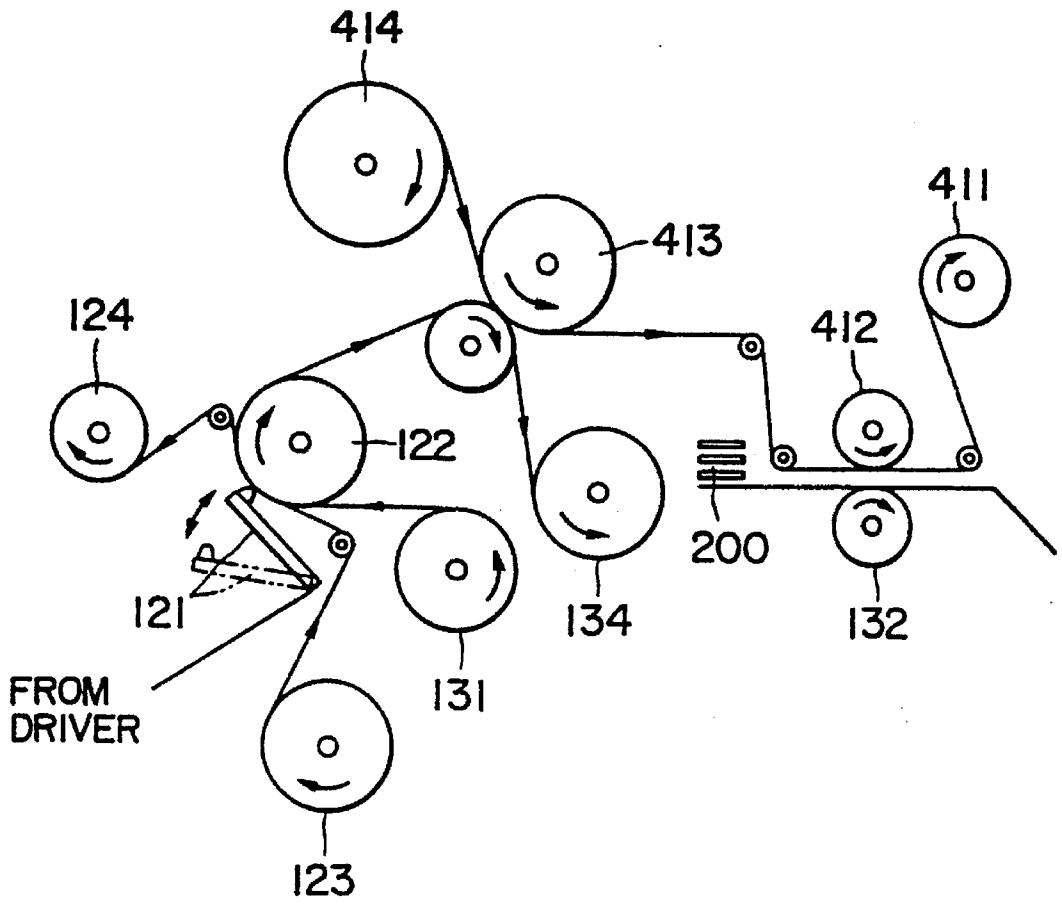


FIG. 1E

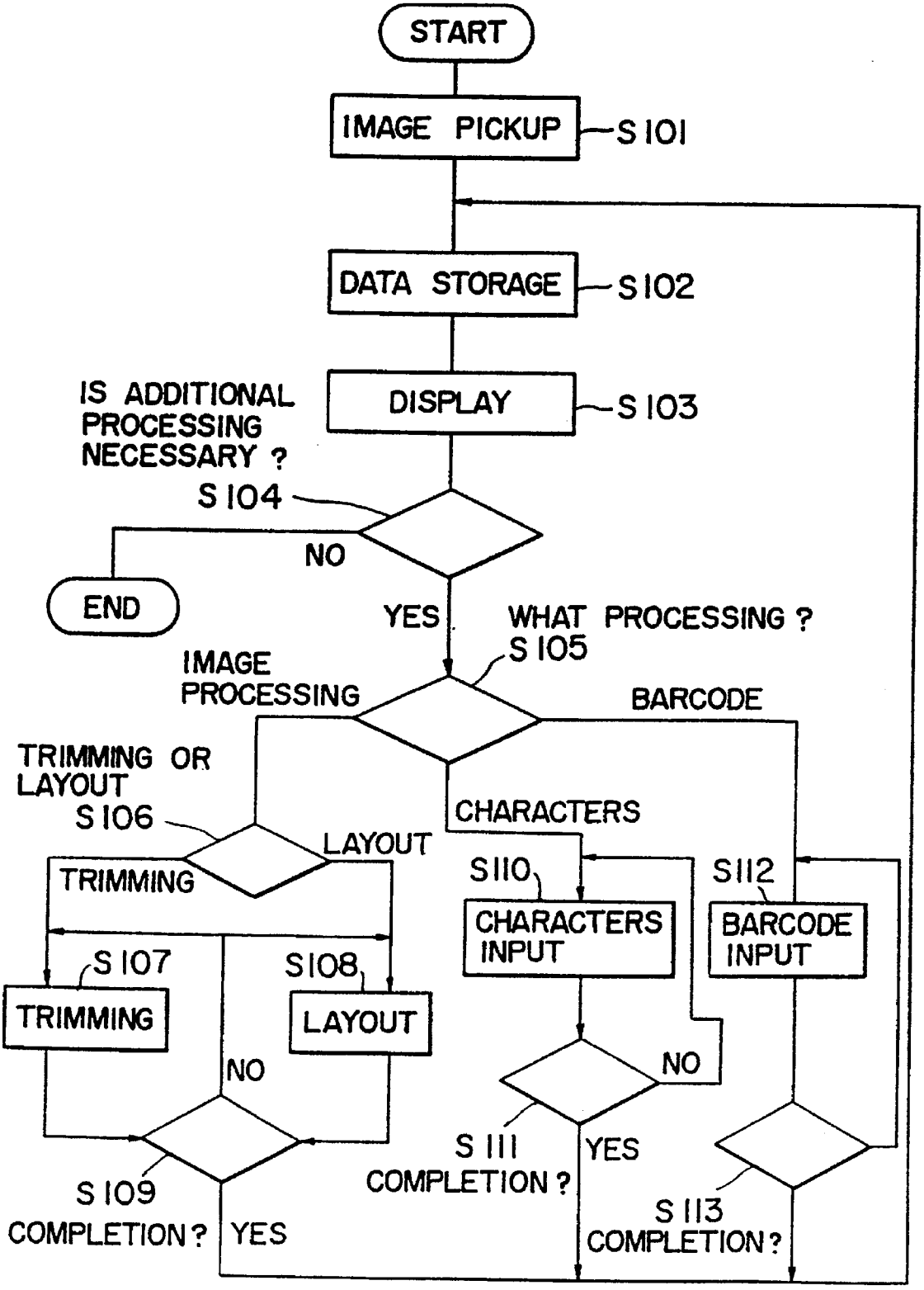

START
IMAGE PICKUP
S101
DATA STORAGE
S102
DISPLAY
S103
IS ADDITIONAL PROCESSING NECESSARY ?
S104
NO
END
YES
WHAT PROCESSING ?
S105
IMAGE PROCESSING
BARCODE
CHARACTERS
TRIMMING OR LAYOUT
S106
LAYOUT
TRIMMING
S110
S112
CHARACTERS INPUT
BARCODE INPUT
S107
TRIMMING
S108
LAYOUT
NO
NO
S111
COMPLETION ?
YES
S109
COMPLETION ?
YES
S113
COMPLETION ?

FIG. 2

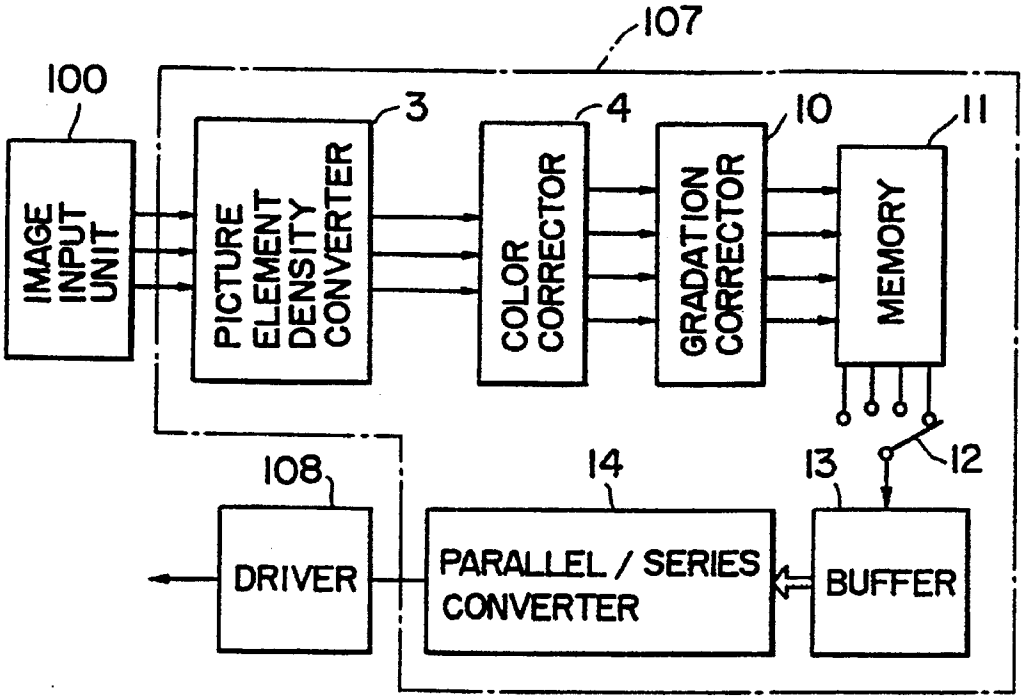

107
100
3
4
10
11
IMAGE INPUT UNIT
PICTURE ELEMENT DENSITY CONVERTER
COLOR CORRECTOR
GRADATION CORRECTOR
MEMORY
108
14
13
12
DRIVER
PARALLEL / SERIES CONVERTER
BUFFER

FIG. 3A

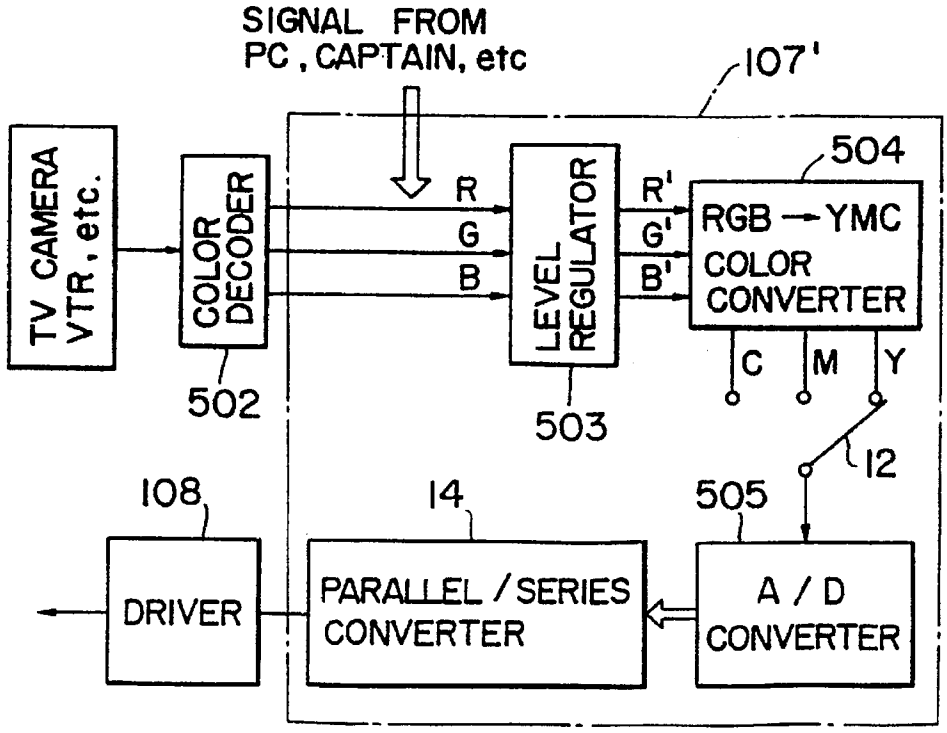

SIGNAL FROM PC, CAPTAIN, etc
107'
504
TV CAMERA VTR, etc.
COLOR DECODER
R
G
B
LEVEL REGULATOR
R'
G'
B'
RGB → YMC COLOR CONVERTER
C
M
Y
502
503
12
108
14
505
DRIVER
PARALLEL / SERIES CONVERTER
A / D CONVERTER

FIG. 3B

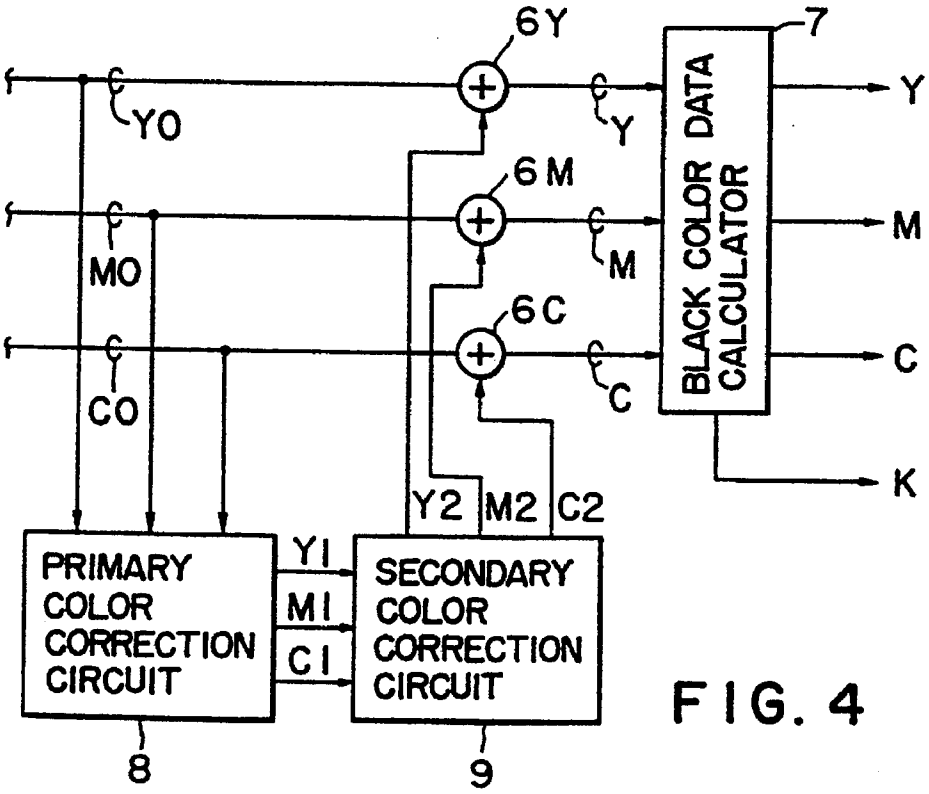

6Y
7
Y0
Y
BLACK COLOR DATA CALCULATOR
Y
6M
M0
M
M
6C
C0
C
C
C
K
Y2
M2
C2
PRIMARY COLOR CORRECTION CIRCUIT
Y1
M1
C1
SECONDARY COLOR CORRECTION CIRCUIT
8
9

FIG. 4

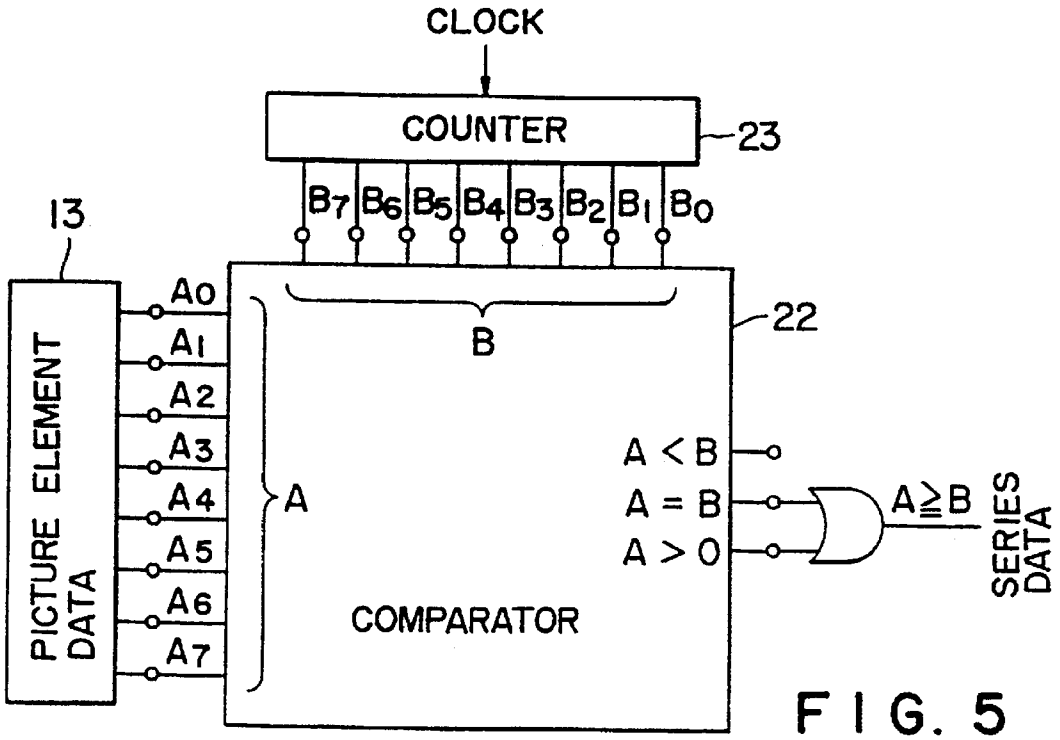

CLOCK
COUNTER
23
B7 B6 B5 B4 B3 B2 B1 B0
13
A0
A1
A2
A3
A4
A5
A6
A7
A
B
22
A < B
A = B
A > 0
A≧B
SERIES DATA
PICTURE ELEMENT DATA
COMPARATOR

FIG. 5

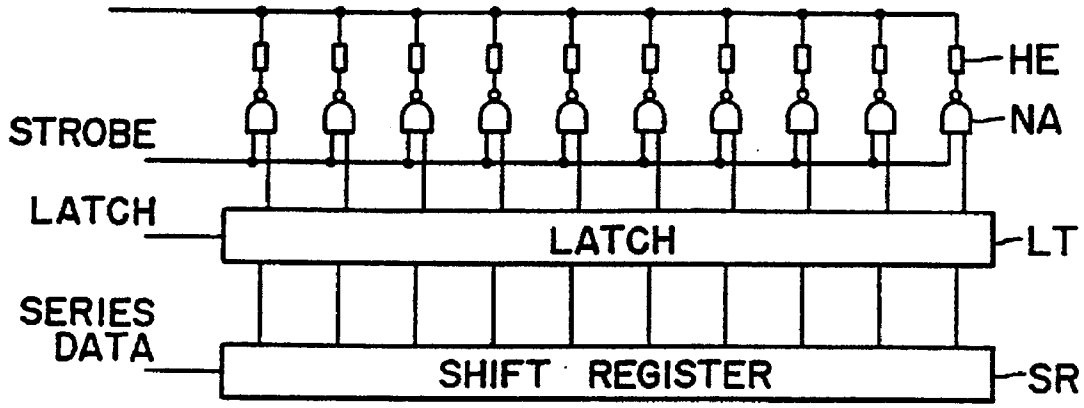

HE
NA
STROBE
LATCH
LATCH
LT
SERIES DATA
SHIFT REGISTER
SR

FIG. 6

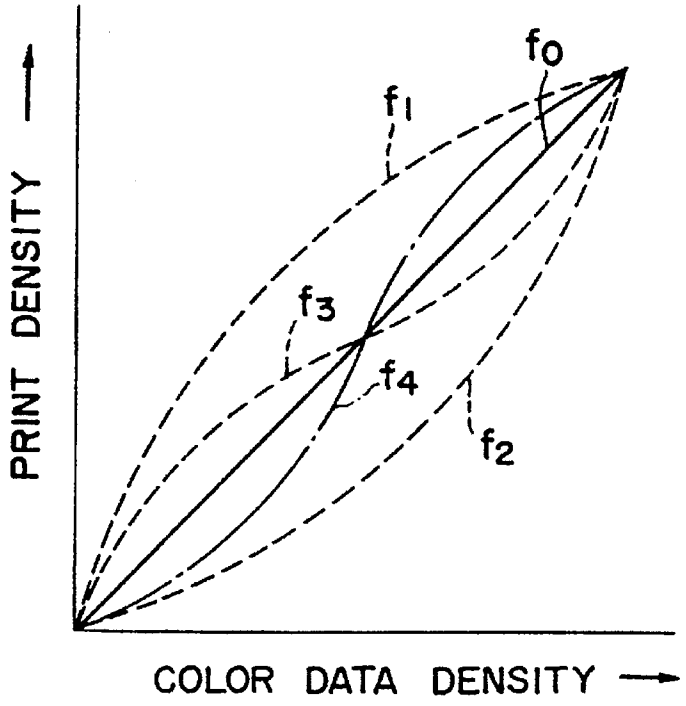

f0
f1
f3
f4
f2
PRINT DENSITY
COLOR DATA DENSITY

FIG. 7

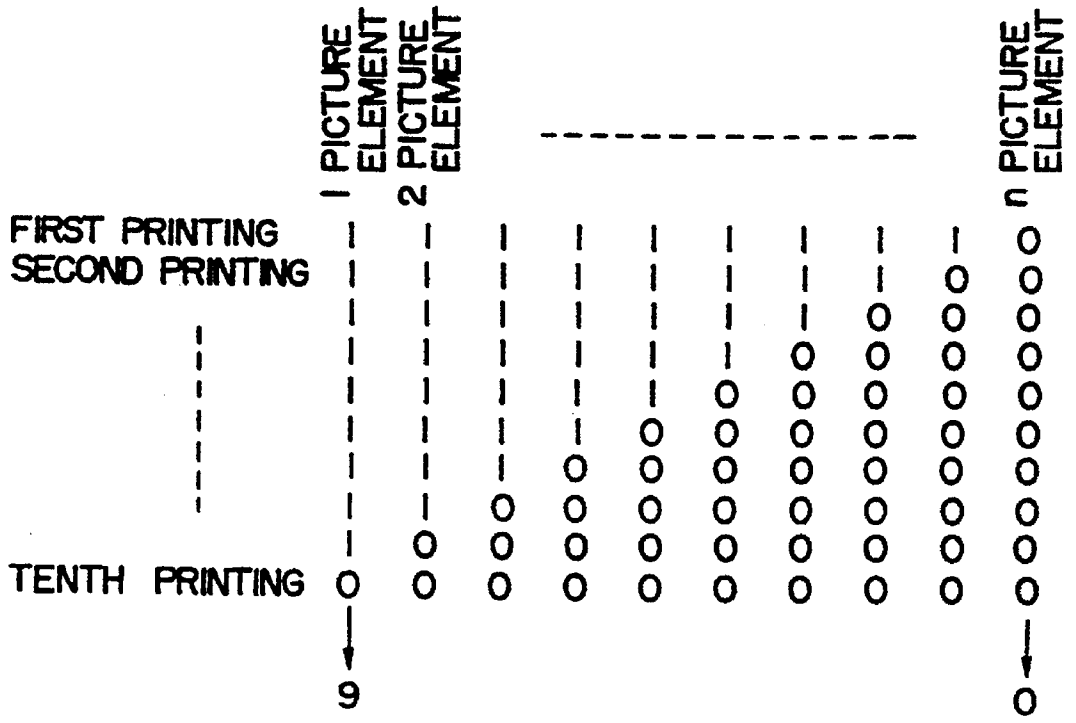

1 PICTURE ELEMENT
2 PICTURE ELEMENT
n PICTURE ELEMENT
FIRST PRINTING
SECOND PRINTING
TENTH PRINTING
9
0

FIG. 8

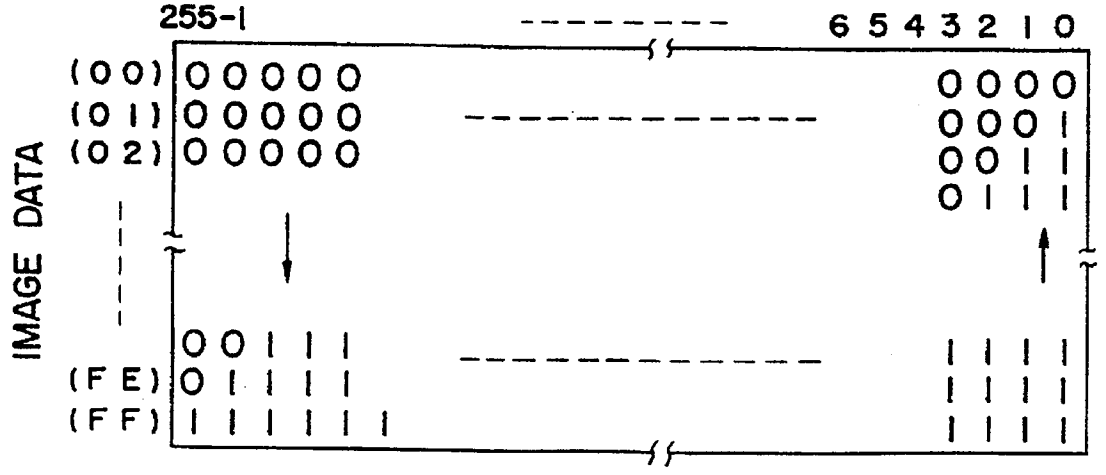

255-1
6 5 4 3 2 1 0
(0 0)
(0 1)
(0 2)
(F E)
(F F)
IMAGE DATA

FIG. 9

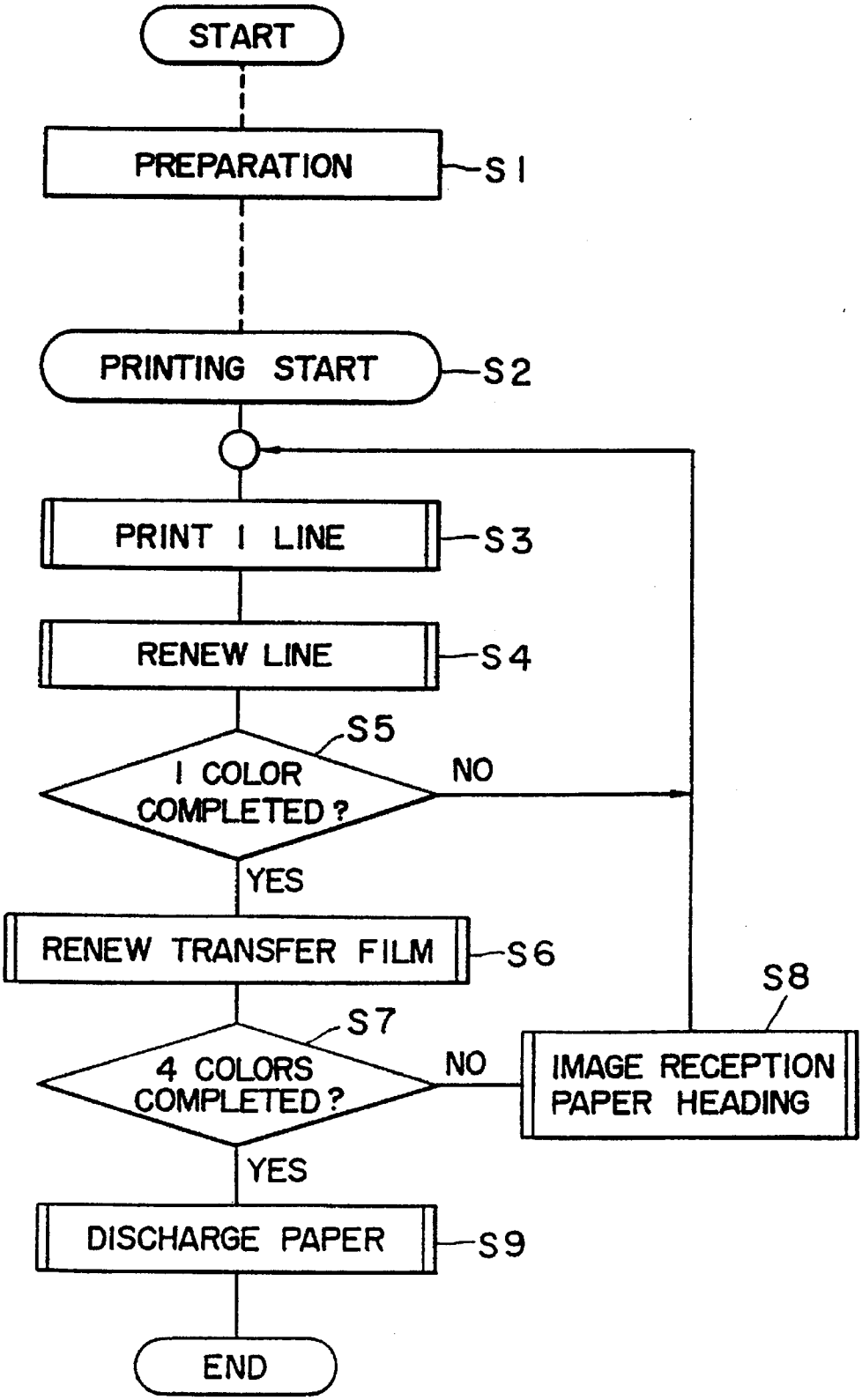

START
PREPARATION
S1
PRINTING START
S2
PRINT 1 LINE
S3
RENEW LINE
S4
S5
1 COLOR COMPLETED?
NO
YES
RENEW TRANSFER FILM
S6
S8
S7
4 COLORS COMPLETED?
NO
IMAGE RECEPTION PAPER HEADING
YES
DISCHARGE PAPER
S9
END

FIG. 10

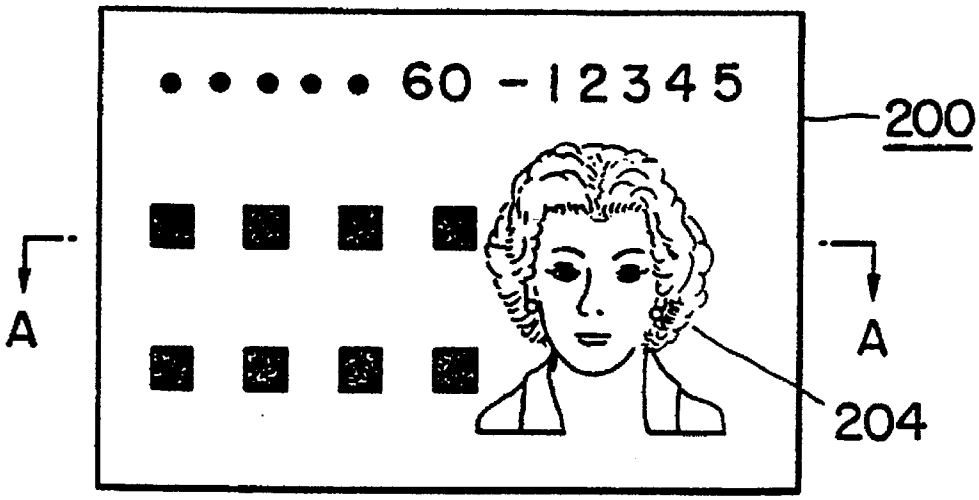


FIG. 11

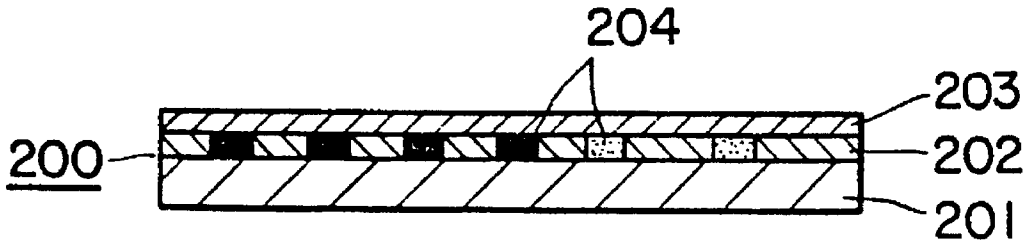


FIG. 12

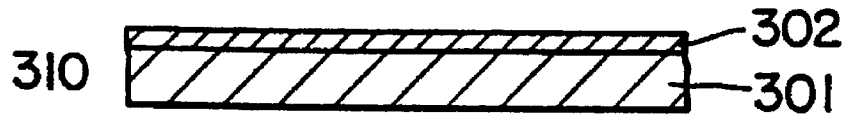


FIG. 13

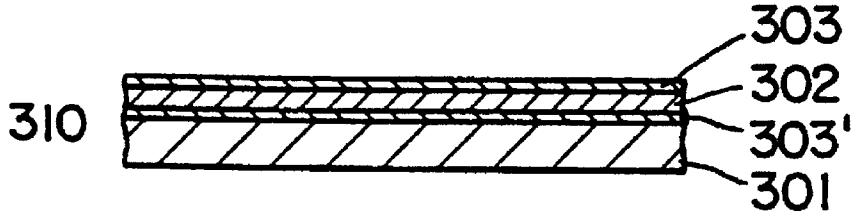


FIG. 14

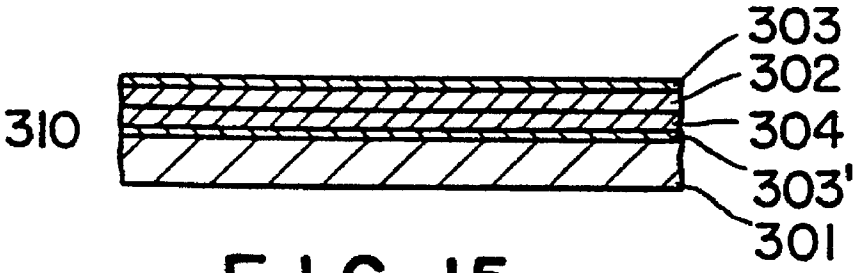


FIG. 15

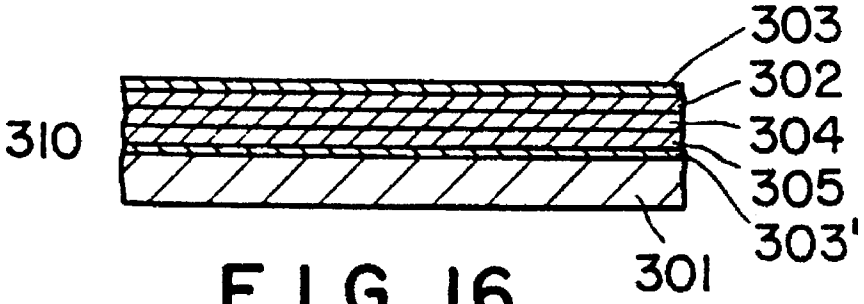


FIG. 16

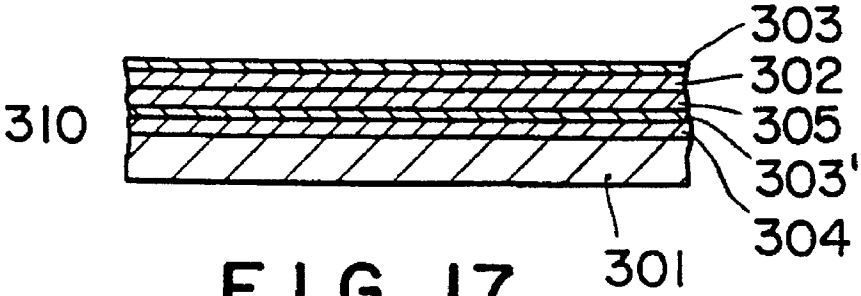


FIG. 17

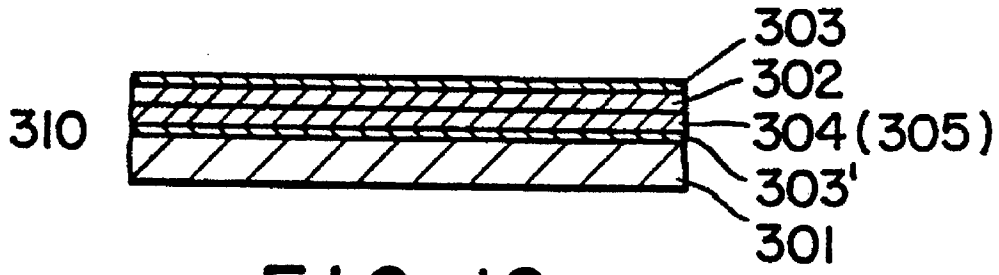


FIG. 18

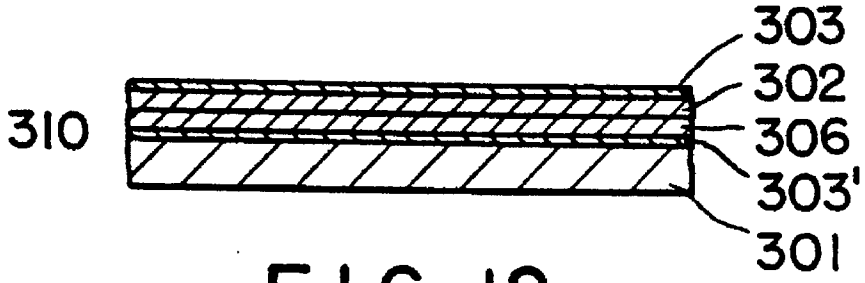


FIG. 19

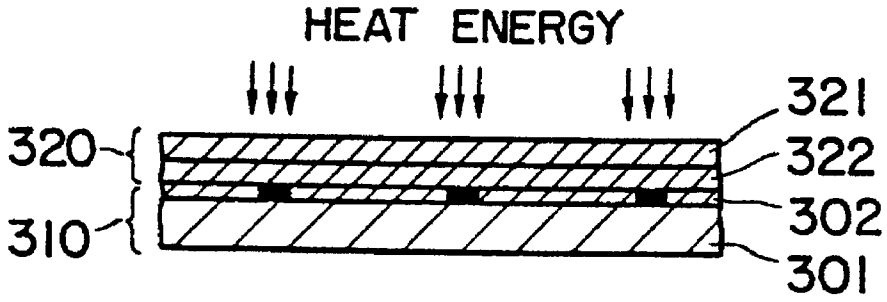


FIG. 20

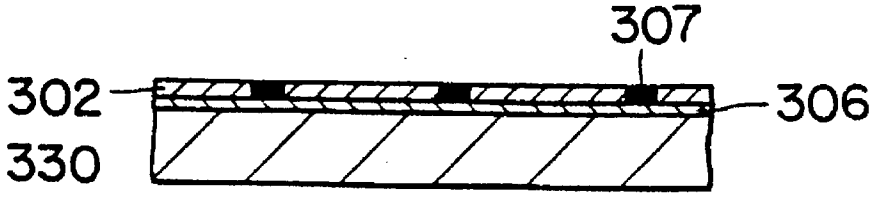


FIG. 21

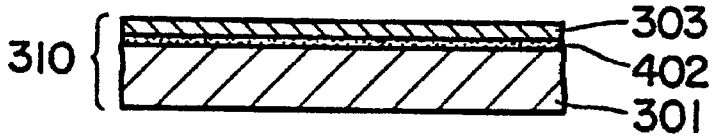


FIG. 22

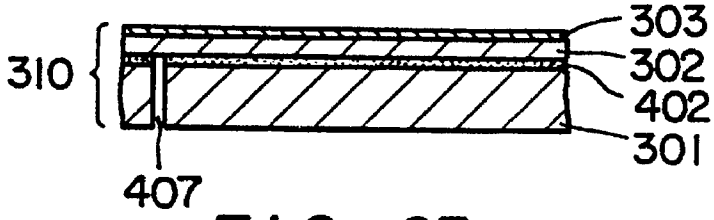


FIG. 23

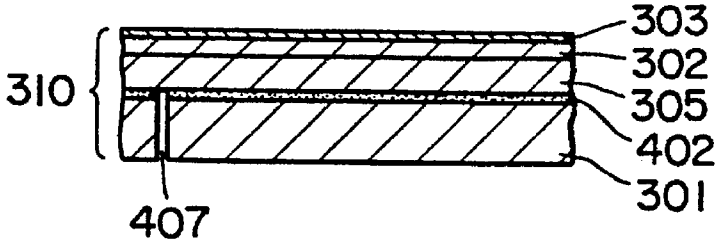


FIG. 24

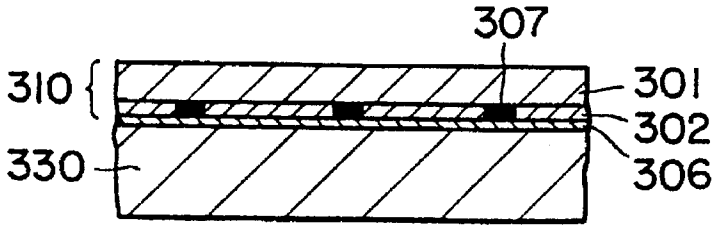


FIG. 25

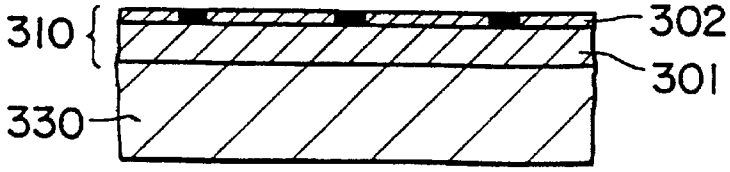


FIG. 26

FIG. 27

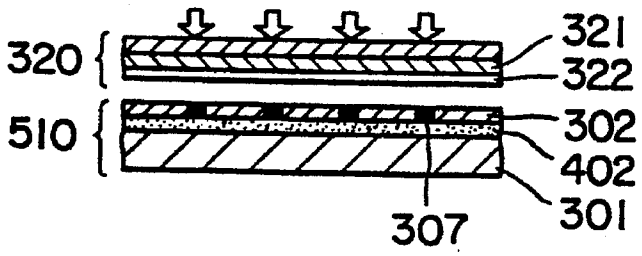


FIG. 28

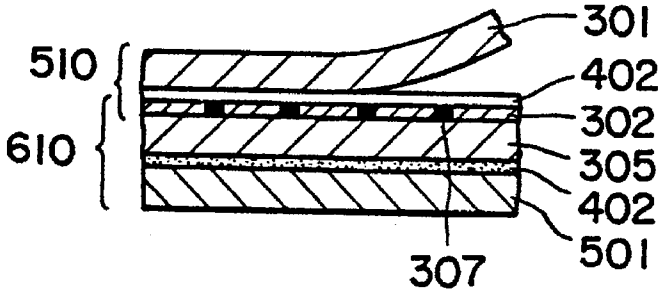


FIG. 29

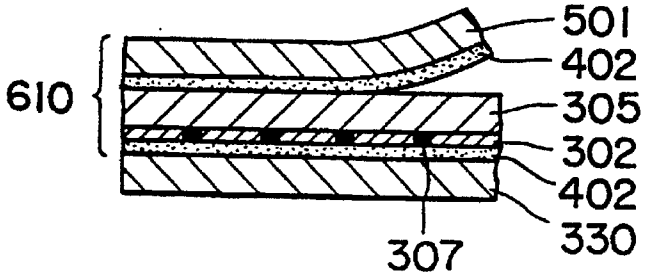


FIG. 30

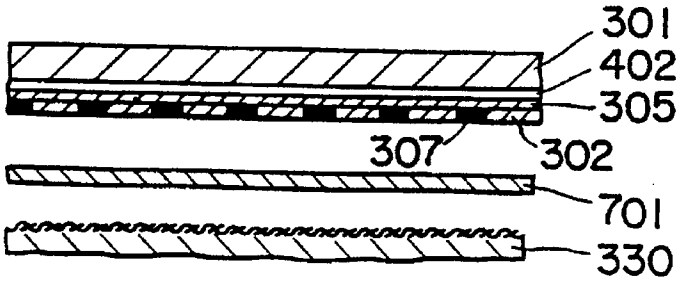
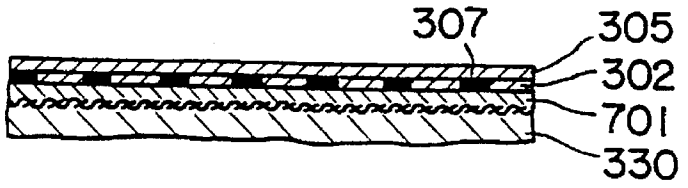


FIG. 31



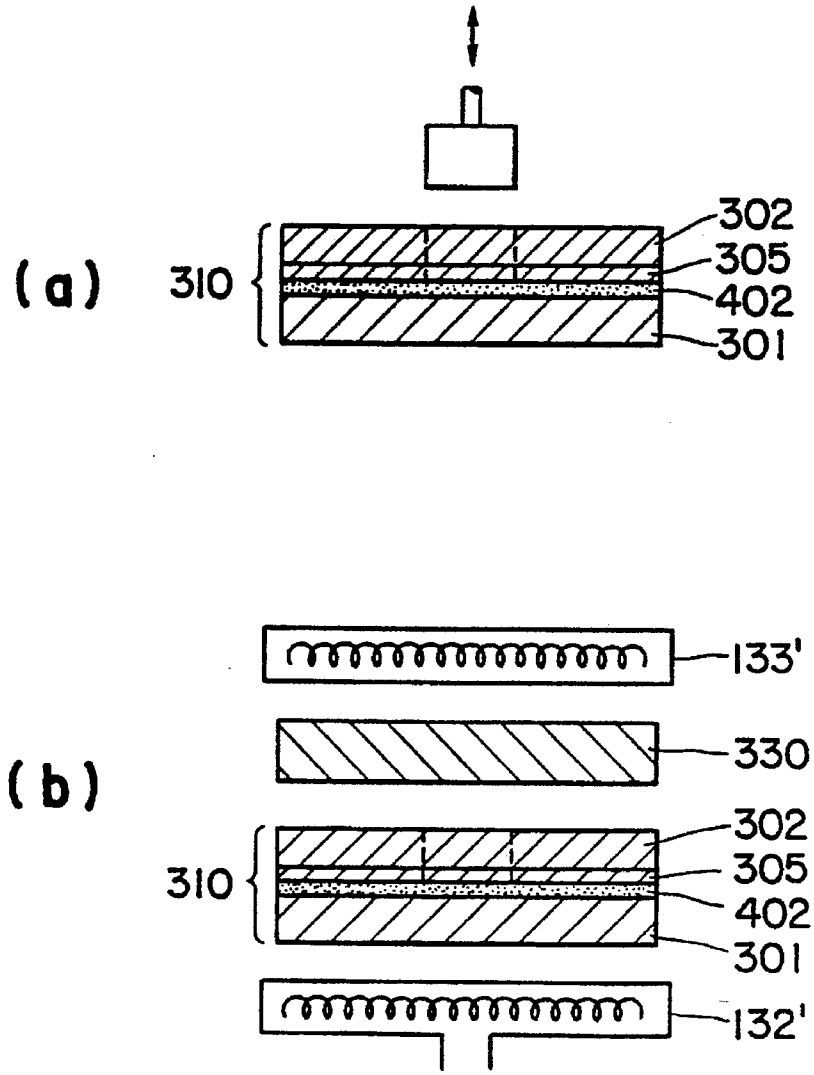

(a)
310
302
305
402
301
(b)
133'
330
310
302
305
402
301
132'
(c)
330
302
305

FIG. 32

IMAGE FORMATION ON OBJECTIVE BODIES

This is a continuation of application Ser. No. 08/034,186 filed Mar. 18, 1993, now U.S. Pat. No. 5,451,560, which in turn is a continuation of Ser. No. 07/467,415, filed Jan. 19, 1990, now abandoned, which in turn is a divisional of Ser. No. 07/138,384, filed as PCT/JP87/00228, Apr. 10, 1987, now U.S. Pat. No. 4,923,848, issued May 8, 1990.

TECHNICAL FIELD

This invention relates to methods and apparatus for the formation of images as prints on objective bodies through transfer of images preformed by the sublimation transfer technique, and more specifically it relates to such systems as adapted for the formation of images on any selected objective body, such as cards, clothes, papers, and transparent sheets, although these are not limitative to the present invention.

BACKGROUND ART

Reliance is made generally upon the normal printing technique for formation of images on objective bodies. For the execution of the printing technique, provision and use of printing plates (forms or blocks) are requisite. No matter how simple the image-printing is, the plate-making is a very time-consuming the laborious procedure. This is much more so in the printing of various and complexed image combinations, such as those of graphic or portrait images combined with characters, letters or barcodes, as an example, representing extremely complicated and troublesome work.

Further, in the normal printing operation, various operating conditions, including ink selection and the like, must be carefully considered, depending upon the kind and nature of the printing object, thus the best selection thereof is highly delicate and not as simple as expected.

The present invention is proposed upon careful consideration of the foregoing facts, and an object of the invention is to provide a unique process for the formation of sharp and clear images regardless of the kind and nature of the object to be printed upon, and usable and effective materials and apparatuses for carrying out this unique process.

The method of thermal image transfer (sublimation image transfer) on clothes or fabrics with the use of thermal transfer dyestuffs has been practiced for a long time. In this conventional process, a dyestuff picture layer carrying thermal transfer dyestuff is formed on a substrate sheet which is then subjected to heat in an overlapped state on a cloth or fabric, the dyestuff thereby being transferred thermally onto the latter for forming the desired images thereon. By utilizing this technique, and with recent development of the image forming technology concerning fine thermal printers and the like, various fine image forming processes have been proposed to provide fine images which are comparable to photographic images and are transferred onto plastic films from thermal transfer sheets carrying thermal transfer dyestuffs.

According to these recently proposed processes, various images of cameras, or TVs, graphic images of personal computers and the like can be reproduced easily in the form of hard copies on the surface of a transferred material such as a paper or the like sheet carrying thereon a fixedly attached layer of polyester resin, as an example. These images thus reproduced represent an amply high level comparable to those obtained by photography or fine printing arts.

The thermal transfer process so far set forth has an advantage in that it can form any image in a convenient manner yet entails a problem in that it is limited to image-transferred product preferably of polyester and the like materials which must be dyed with thermal transfer dyes. On the other hand, the image-transferred products must be limited to specifically selected shapes, preferably film, sheet or the like configuration, and thus, such materials as wood, metal, glass or ceramics cannot be formed with images in this way. Further, even if the material is plastics such as polyester or the like, and when the image-forming surface is curved or undulated, or physical body other than sheet, even if it represents a plane surface, it is almost impossible to reproduce images precisely thereon, which naturally constitutes a grave problem in the art.

With recent development and enlargement of utilizing fields of various card-style products, such as cash-cards, telephone-cards, prepayment cards; and ID-cards, there are increasing demands for providing these cards with images, symbols and codes, so as to give various other functional and/or decorative effects. Most of these cards are of planar form, but they are frequently not pliable and/or have uneven rough portions due to provision of characters and symbols, resulting in great difficulty in the scheduled image formation relying upon the thermal image transfer process.

There is therefore an urgent demand among those skilled in the art for the provision of a unique technique capable of forming sharp and clear images of desired patterns on the surface of an objective body of any preferred kind of material and having any shape and configuration and surface condition of any kind, and indeed, for combining and unifying image- and decoration effects.

DISCLOSURE OF THE INVENTION

The present invention is basically based on such a principle that a first image transfer pattern is formed on an image transfer material, preferably an image transfer sheet, and in the form of dyestuff images through the sublimation image transfer process executed by first image transfer means, depending upon given image data, preferably including those of letters, characters, symbols, line images, graduated graphic representations, and then the first transfer pattern is transferred to second transfer means for retransferring the images onto an objective body so as to provide a final product.

Based upon the image data fed from various image data input means and at the first image-transfer means, a thermal head is actuated to execute printing operation through a dyestuff film (thermal image-transfer sheet) on an image-transfer material (or more specifically on an image-transferable material which means an image-transferable sheet. This image-printing is carried out according to the sublimation or sublimative image transfer technique. Thus, in this case, the dyestuff on the dyestuff film is transferred or shifted under the influence of heat energy from the thermal head onto the image-transfer material through sublimation, thus providing the first image-transferred means. Since this first image-transferred means has been thus formed with the images by the sublimated dyestuff, they are, then, transferred onto the second image-transferable means which will be brought into tight contact with the object to be decorated and subjected to heat and pressure for execution of further image-transfer operation to provide the final desired product.

In the present invention, the image-transfer material (image-transferable sheet) is, as above referred to, formed

with images by the sublimative image tansfer technique for providing first image-transfer means which has highly sharp and clear images as the operation and results of the characterizing feature of the sublimation image-transfer technique. Therefore, because of the transfer of such sharp and clear images onto the object, it becomes possible to form the images thereon, and indeed, practically irrespective of the kind and nature of the object. In this way, thus, fine image-formation is assured onto practically any objective substance.

And further, by execution of control of the thermal energy applied during the sublimative image-transfer step, the resulting color effect is superior and the image quality is good.

The images sublimatingly applied and formed in the foregoing way are subjected to a further transfer, and onto a substrate product, for providing a final decorative product as desired. In this final product, it should be noted that the underlying layer underneath the images during the sublimative image-transfer stage appears now at the top, acting thus as a kind of protecting layer upon up-and-down positional conversion during execution of the second and final image-transfer stage, resulting in realization of various and numerous effects. As an example, attainment of substantial reduction of contamination, improvement of light resistance, weather resistance and chemical resistance; substantial reduction of color fading; provision of glazing effect; easier and simpler introduction of granular and/or undulated image appearance.

The inventive process is carried into effect basically in such a manner that an image-reception layer provided on one surface of an image-transferable sheet is subjected to an image-forming step with the use of dyestuff capable of depositing therein depending upon the fed image data, so as to form the required images, and then, the image-reception layer of the image-transferable sheet, having been image-fixed and thus now image-carrying, is stuck onto the surface of the object to be decorated upon.

As for the image-transferable sheet adapted for use in the image-transfer during execution of the inventive process, it consists basically of a sheet-like substrate and a reception layer attached, however, in a separable manner, onto one surface thereof. As a modification of the inventive process from the basic mode set forth above, the sheet-like substrate is caused to remain, even after completion of the image-transfer step, as may be occasionally required. In this modified case, it is unnecessary to make the image-reception layer of the image-transfer sheet separable.

Under occasion, the inventive process may be brought into effect in such a way that the image-reception layer of the image-transfer sheet is transferred upon execution of the image-forming step, and indeed, once onto an intermediate image-transfer substrate which is then retransferred, together with the once transferred image-reception layer, onto the surface of an object to be decorated on, and thus, in a retransferring manner.

BRIEF DESCRIPTION OF THE DRAWINGS

In the accompanying drawings:

FIG. **1A** is a block diagram, showing a preferred embodiment of the apparatus according to the present invention;

FIG. **1B** is a schematic view illustrating at (*a*), (*b*) and (*c*), several image-transfer steps for the execution of a process according to the invention;

FIG. **1C** is a schematic view of an image-transfer step, using a platen roll;

FIG. **1D** is a plan view of part of a multi-color dyestuff film adapted for use in an image-forming step;

FIG. **1E** is a schematic view for the illustration of several image-transfer steps;

FIG. **2** is a flow chart of successive operation steps with use of a data-processor, shown in FIG. **1**, functioning as an operating center;

FIG. **3A** is a schematic block diagram, showing a data-processor for the printer;

FIG. **3B** is a block diagram of a sublimative image-transferring printer adopted in the present invention, as a preferred embodiment thereof;

FIG. **4** is a schematic block diagram, showing a color correction unit shown in FIG. **3A**, and several related parts cooperating therewith;

FIG. **5** is a schematic block diagram of a comparator and several related parts cooperating therewith;

FIG. **6** is a circuit block diagram of an image-transfer head shown in FIG. **1B**;

FIG. **7** is a graph showing operational characteristics of a color tone or -gradation corrector unit shown in FIG. **3A**;

FIG. **8** is a table for the illustration, as an example, of picture- or image-elements, as expressed in binary signals;

FIG. **9** is a table showing a conversion operation, as an example, of a parallel/series converter shown in FIG. **3A**;

FIG. **10** is a flow chart, illustrating the operation of the sublimative image transfer printer;

FIG. **11** is a plan view of a final decorative product prepared according to the inventive technique;

FIG. **12** is a sectional view of the product card shown in FIG. **11**, and taken along a section line A—A shown therein;

FIGS. **13** through **31** are a series of sectional views, respectively illustrating several structural examples of image-transferable sheets, suitable for use in the invention; and

FIGS. **32** (*a*), (*b*), and (*c*) are sectional views, indicating final transfer steps.

BEST MODES FOR CARRYING OUT THE INVENTION

Referring now to FIG. **1A** and FIG. **1B**, (*a*), (*b*) and (*c*), a basic schema of the inventive image data processing and image formation .will be illustrated. First, in FIG. **1A**, numeral **101** represents an image input means which is adapted for forming image data based upon optical and the like inputs delivered from a TV-camera, line sensor or the like. Other than those above enlisted only by way of example, video; CD; TV; scanner; personal computer, captain system, capable of providing R.G.B.- and picture image and the like signals may also be utilized in a similar way. The image signal data delivered from the image input means are fed through a data processor **104** to a memory **105** for being stored therein. These stored data can be taken out from the memory and fed through data processor **104** to display means **102** for being displayed thereat.

To the data processer **104**, a mouth/tablet digitizer and/or the like position data processer **103** is electrically connected for introducing position data concerning displayed images appearing at the display **102**. In addition, key board and the like character data input means **106** and font generator **109** are provided for introducing character data. Still further, a barcode generator **110** is provided for introducing barcode when necessary. By the use of these means and units, various additional processing modes can be executed.

The thus processed data are subjected to conversion at a data converter **107** into proper data adapted for operating a sublimation transfer printer and fed forward through a driver **108** to the thermal head.

In this case, by controlling the current duration period to the thermal element of the thermal head, the transfer quantity from the dyestuff film (thermal transfer sheet) is controlled depending upon the thermal energy of the element for realization of the desired gradation degree of concentration on the transfer sheet. There are two different modes of such control of current duration period as follows:

(a) A method for controlling the pulse length corresponding to the picture element in the impressed data to the thermal element of the thermal head or, more specifically, a series data introduced as input to the shift register shown in FIG. **6** and to be described more specifically hereinafter.

(b) A method for controlling the number of pulses of the pulse series corresponding to the picture elements of the data impressed upon the thermal element in the thermal head (in this case, the pulse length being constant).

The degree of gradation of the transfer image can be controlled in the above mentioned way by the regulation of the current-conducting period depending upon the desired gradation degree. On the other hand, the image concentration can be controlled by adjusting the pulse length or the number of pulses contained in the pulse series in correspondence to the picture elements contained in the data as introduced in the shift register and depending upon the driving mode of the thermal head. Further in this case, if the number of gradation of introduced image data is larger than that which can be expressed by the printer unit, a proper conversion operation can be performed by the known strobe control method. As an example, in such case, the conversion of gradation number 256 to 64 may be executed by a ROM, and the thus reduced gradation number can be used as output.

Next, referring to FIG. **1B** at (*a*) and (*b*), reference numeral **121** represents a thermal head which receives signals from the driver **108** shown in FIG. 1A. This thermal head **121** is arranged in opposition to platen roll **122**, forming the printing position therebetween. The dyestuff film (thermal transfer sheet) is fed from a delivery roll **123** to a winding roll **124** through this printing position, these structural and functional features being commonly employed in both the arrangements shown in FIG. **1B** at (*a*) and (*b*).

In the case of FIG. **1B**, (*a*), the mechanism is so arranged that card or sheet style transfer sheets are printed with dyestuff images.

On the other hand, in the case of FIG. **1B**, (b), the mechanism is so arranged that cards are continuously produced with the use of a film style transfer sheet and a dyestuff film in combination.

Now turning back to FIG. **1B**, (a), a number of transfer sheets (cards, sheets or the like) have been stacked and stored within a storage casing **125** and are being thrust upward from below by a spring so that the uppermost sheet is kept in pressure contact with a take-out roll **126**. With the rotation of the roll **126**, the sheets are successively delivered from the casing **125** by conveyer belts **127**, **128** onto a platen roll **122**. Each one of the sheets is fixed on the peripheral surface of the platen roll, now positionally indexed, by means of a gripper or the like mechanical attaching and separating means, static attracting means, or electromagnetic attaching means. Then, the roll **122** is so rotated that the transfer sheet is positioned at the ready-for-printing-position.

Next, the thermal head **121** is brought into pressure contact with the transfer sheet through the intermediary of the dyestuff film, and then the thermal head **121** is energized with electric current while the dyestuff film and platen roll **122** are moved in synchronism for the execution of image transfer (first image transfer).

Upon execution of the image transfer, the platen roll **122** is rotated, the gripper is released and the take-out roll **129** is rotated and brought into pressure contact for taking out the image transfer sheet onto a tray **130**.

The thus taken-out sheet is brought into overlapped state with a new image transfer sheet, not shown, and then, both the sheets are fusingly united together by pressure application of a heated roll, not shown, for execution of a second transfer step job. The whole operation has thus been completed. Before the fusion process, the sheets may be subjected to punching, trimming and/or the like processing, if necessary.

By execution of the foregoing operational steps, a monocolor printing operation has been completed. However, in the case of multicolor printing, use is made of tricolored or quadruple colored dyestuff film and the corresponding printing operations must be repeated. In this case, upon completion of a single monocolor printing procedure, the platen roll is rotated without contact of the take-out roll **129**, until it arrives again at the printing-initiation position, and so on.

In the following, a tricolor printing job will be illustrated with reference to FIG. **1B**, (*b*), and with use of three different series color zones, of cyan, magenta and yellow.

First, a platen roll **122** is positionally indexed, and an image transfer sheet taken out from the roll **131** and a dyestuff film taken out from the roll **123** are brought into pressure contact in an overlapped state. Then a thermal head **121** is pressed against the platen roll **122** through the intermediary of the overlapped sheets. At this stage, the platen roll **122** is rotated counterclockwise while synchronism is kept between the platen roll **122** and the dyestuff film, and the thermal head **121** is kept electrically energized. In this way, the first color printing is executed.

Further, the dyestuff film is fed to the second color zone position, and then, the platen roll **122**, the dyestuff film and the image transfer sheet are fed forward clockwise around the center roll **122**. Thus a second color printing step is executed.

Further, the print-serviced two color sections of the film is fed back counter clockwise around the center of the platen roll **122** for the execution of a third color printing step. Then, each card sheet is taken out from the stack **200** under the action of take-out rolls or the like, not shown, towards and between a pair of thermal transfer rolls **132**, **133**, brought into overlapping state with the image transfer sheet positionally indexed and already subjected to image transfer steps as was described above, and finally subjected to a picture printing operation by pressurizing application of the thermal image transfer rolls **132**, **133** from both sides of each taken-out card, and so on.

The color-printing step with the use of the thermal head is carried into effect in the following manner, as an example.

(First color printing)

Platen roll, image transfer sheet and dyestuff film perform the printing while they are moved in the counterclockwise direction.

(Second color printing)

Platen roll and image transfer sheet are moved in the clockwise direction while the dyestuff film is moved at the same speed and in the counterclockwise direction for performing the color printing under consideration.

(Third color printing)

Platen roll, image transfer sheet and dyestuff film are moved in the counterclockwise direction for execution of the color printing under consideration.

In the modified arrangement shown in FIG. **1**B, (*c*), thermal image transfer rolls **132**, **133** have been replaced by a flat press type image transfer head having up-and-down movable flat printer elements **132'**, **133'**.

It should be noted that in the course of the foregoing first and second image transfer steps, image reversal phenomenon is necessarily brought about upon execution of each image transfer step. In other words and more specifically, when two successive image transfer steps in the foregoing sense are executed, reverse images which have once appeared will return to the original normal images. Therefore, when the printed-out products are to be provided upon execution of the first image transfer step, it is necessary to provide reversed image data in the signal processing system. For this purpose, it is only necessary to reverse the addressing order at the data introduction or readout stage into or from the memory.

In the modified arrangement shown in FIG. **1**C, the foregoing platen roll means has been replaced by a metal block **141** lined with a rubber plate **142** in an overlapped manner. The image transfer sheet and dyestuff film are fed out from respective rolls **131** and **123**. With the use of this modified arrangement, the dyestuff surface layer of the dyestuff film can be brought into tight contact with the image-receiving surface layer of the image transfer sheet, and thermal energy will be transferred evenly form the thermal head **121** to the dyestuff film.

In this case, the image transfer sheet is delivered from the roll **131**, and the desired zone or region of the sheet is set underneath the rubber plate **142** (step **1**).

At the same time, the dyestuff film shown in FIG. **1**D on an enlarged scale is delivered from the roll **123** and a selected one of the different color regions is set underneath the rubber plate **142** (step **2**).

Next, the thermal head **121** is brought into the rear surface of the dyestuff film which is the opposite surface to the dyestuff-coated front layer, and the head **121** is driven while it is being translated in the direction shown by an arrow A, images thereby being formed at the specifically allocated zone(s) or region(s) of the image transfer sheet (step **3**).

Further, the thermal head **121** and rolls **416** and **418** are shifted downwards as shown by arrows B, so as to form an idle gap between the image transfer sheet and the dyestuff film for allowing the latter to shift towards the next following color region (step **4**).

Further, the thermal head **121** and rolls **416** and **418** are returned to their original positions, whereupon the third and further succeeding steps are repeatedly executed until a certain predesired number of color printings are completed.

As shown in FIG. **1**D, the dyestuff film is colored to have several different color regions denoted by Y (yellow), M (magenta), C (cyan) and Bk (black). However, the arrangement order is not limited to that shown: Y; M; C and Bk. In addition, as occasionally required, the Bk-region may be dispensed with. Further, as the color elements to be adopted in the Y, M, C-system may not be limited to the three primary colors provided by the subtractive color mixture. On occasion, a characterizing color which means such a color as preadjusted to provide an objective specifically selected one may be used to form the images concerned. As a further modification, the arrangement shown in FIG. **1**C may be so modified that the traveling direction of the image transfer sheet is selected to be perpendicular to that of the dyestuff film.

FIG. **2** is an operation flow chart for showing schematically operational modes taking the data processor **104** adopted in the embodiment shown in FIG. **1** as the centrum of description. The operational contents of several working parts downstream of the data converter **107** will be set forth separately hereinbelow. Now referring to FIG. **2**, in combination with FIG. **1** and at the step of **S101**, image pickup operation is carried out by means of the image pickup means **101**. For execution of this step, it may be better to pick up the face of a person per se which is to be represented on the card, or alternatively, a photograph, portrait or imagery product thereof will do. Depending upon the nature of the object, a TV camera, line sensor or the like instrument may naturally be selectively utilized.

The data taken by the image pickup means **101** are stored through the data processor **104** at a memory **105** (**S102**). By the use of these stored data, image or images is/are displayed at the display **102** (**S103**). Since this display image is not yet subjected to any processing, it is generally unsuitable for representing on the card. However, under certain circumstances, it may be represented thereon as it is.

Then, the operator observed the displayed image or images on the display unit **102** and adjudges whether additional processing is necessary or not (**S104**). If it is not necessary, he will manipulate the key board **106** to make a certain operation, resulting in the termination of processing at the data processing unit **104**, data being fed out therefrom to the succeeding data converter **107**.

On the contrary, when additional processing is necessary, the operator observes carefully the displayed image or images on the unit **102** and adjudges whether the picture image data, or character data or barcode data should be processed. If the picture image data should be processed, such an operation is made for selecting the proper mass of trimming or layout within the menu range of position-data input means **103**. By the execution of this operation, functions and operations at steps **S105** and **S106** can be executed at one stroke. If trimming is taken as an example, the next step is executed in such a way that position data are fed from the position input means **103** to the data-processer **104** with the use of a carsor. When a tablet digitizer is used as the position data input means, the carsor image displayed in an overlapped manner on the displayed picture image appearing at the display unit **102** by carsor manipulation is positionally specified beforehand in registration with the specified position on the card, for determining the trimming range. Then the operation is carried out in such a way that the picture image data outside the specified trimming range are canceled. By completing these operations, data processing operations relating to step **107** are executed, and, then, the mass for completion of the menu range is selected out. By these measures, steps progress through **S109** to **S102**, and data storing is executed, and further, display representation is brought about through step **S103**. If there is no need for additional processing, an operation termination manipulation is carried out as before at key board **106**, and further operations will be made through data converter **107**.

As for the layout, the operation is carried out with the position data input means **103**, similarly as in the foregoing trimming operation. More specifically, layout is selected out in the menu range of position data input means **103**, and the overall configuration of the card and the display position of picture image are shown at display unit **102**. Then, image inclination correcting operation and the like are carried out so as to realize correspondence thereof with the displayed positional information, the processing operations relating to step **S108** thereby being brought about. After completion of these operations, the mass for the ending in the menu range is selected.

In this way, when selection is made from the menu range by reliance on the position data input means **103**, trimming or layout operation can be brought about. At this stage, when manual operation is carried out at the key board **106**, introduction of character data is executed (S110). As the character data in this sense, in the case of ID card, as an example, the name and/or birthday, month and year of the owner may be used. The data introduced from the key board **106** in accordance with the output character style from the font generator **109** are shown at the display unit **102** in the specified positions on the displaying surface and respectively arranged in accordance with display items. The operator acknowledges these items and detailed displays of the represented images. When he acknowledges them as being true, he will operate the key board **106** for showing the operation ending (S111).

Upon ending the operations as described above, the data are stored in memory **105** (S102) and represented at the display **102**. The operator will acknowledge again this fact, and upon the execution of this, the operations are terminated.

As for the barcode introduction, the data are subjected to inputing at steps S112 and S113, as in a manner similar to the character data introduction as set forth above. The barcodes and the like data may be introduced separately through printing or other mechanical method.

In FIG. 3A, a data processing circuitry usable in the sublimation image transfer printing method is shown only schematically. As shown, the circuitry **107** comprises a picture element density converter **3**; a color corrector **4**; a gradation corrector **10**; a memory **11**; a switch **12**; a buffer **13** and parallel/series converter **14**. The picture element density converter **3** is connected to a picture image input unit **100**.

The unit **100** serves for generation of three primary color data of R.G.B.- or Y.M.C.-mode from original picture images and is connected through the picture element density converter **3** to the color corrector **4**. The converter **3** converts the picture element density of the image data fed from the unit **100** to the desired one, by subtracting or supplementing, as the case may be, image data for each color element. It should be mentioned that for attaining high quality hard copies, conversion of the picture element density to at least 10 lines/mm or so is preferable.

Color corrector **4** consists preferably of a color decoder, level adjuster or color converter, and serves to correct three primary color data converted to those of a predetermined density of picture elements in consideration of characteristics of the image transfer ink in the image transfer sheet and in addition to provide black color data.

The data processing circuitry **107** is connected through a driver **108** to the sublimation image transfer printer.

In FIG. **4**, an example of the color corrector **4** is shown schematically in structure. As shown, it comprises adders **6Y**; **6M** and **6C**, a black color data calculator **7**, and primary and secondary color correction circuits **8** and **9**. Primary color correction circuit **8** serves for making correction of turbidity of the image transfer ink, while secondary color correction circuit **9** provides a capability of arbitrary and selective correction control relative to specifically selected color hue.

The gradation corrector **10** is so arranged as to make correction of the gradation of the data for each color Y, M, C or K (representing black color) fed from the foregoing color corrector **4** when necessary. For this purpose, the corrector **10** includes a gradation circuit (not shown) and the like, whereby a certain mode of highlight stressing or shadow stressing is introduced and realized.

The memory **11** functions to preserve temporarily the data of each color delivered from the gradation corrector **10**, a selection switch **12** being provided at the output side of the memory for selective writing-in of the data of each color to the buffer **13**. The buffer **13** is capable of writing-in the data of one line of the image transfer head **16** and kept in connection with the parallel/series converter **14** adapted for converting parallel data into series data. Additionally, in the simplified machine, black color data series is dispensed with in some instances.

In FIG. **5**, a schematic construction of the parallel/series converter **14** is shown. As shown, parallel data delivered from the buffer **13** are fed to an input side of a comparator **22**, while outputs from a counter **23** are fed to another input side of the comparator **22** which delivers the converted series data to the driver **15** for driving a thermal head **121**.

If necessary, however, the comparator **22** may be replaced by a converter table, not shown, utilizing a parallel/series converting ROM.

In FIG. **6**, a detailed circuit schema of the thermal head **121** is shown. As shown, series data delivered from the comparator **22** are fed into a shift register SR and thence, after being subjected to latching at a latch circuit LT, fed to thermal elements HE through NAND gates NA which are fed at respective one side inlets with strobe signals.

Next, referring to FIG. **3A**, the operation of the data processing circuitry **107** will be described more specifically.

First, when three primary color image data are fed from the picture image inlet circuit **100** to the picture element density converter **3**, the latter converts these three primary color data to those which represent a predetermined picture element density and then are fed to the color correction unit **4**. In this case, it is assumed that the unit **4** is fed with three primary color data expressed in respective concentration signals, which are of yellow: **Y0**; of magenta: **M0** and of cyan: **C0**, respectively, in the present example.

These data: **Y0**; **M0** and **C0** are, as shown in FIG. **4**, fed through respective adders **6Y**; **6M** and **6C** to the black color data calculator **7**, to provide a K-output as expressed mathematically by the following formula:

$$K=\min(Y, M, C)$$

wherein, "min" represents a function which provides a possible minimum value.

These data: **Y0**, **M0** and **C0** are fed from the converter **3** to the primary color correction circuit **8** to provide primarily corrected data **Y1**, **M1** and **C1** which are thence fed to the secondary color correction circuit **9** to provide, through calculation, secondarily corrected data: **Y2**, **M2** and **C2**, respectively. These are then fed to respective adders **6Y**, **6M** and **6C**, which add them to respective data **Y0**, **M0** and **C0**, to provide respectively added output data Y, M, and C to be fed to the gradation correcter circuit **10**, respectively, after being utilized for calculation of the K-output signal value.

The primary color correction circuit **8** serves to calculate primarily corrected data: **Y1**, **M1** and **C1** which are necessarily utilized for correct-out of transfer ink turbit. In this case, the original data: **Y0**, **M0** and **C0** are subjected to matrix calculation to provide the primarily corrected data **Y1**, **M1** and **C1**, as folows:

$$Y1=k_{11}\cdot C0-k_{12}\cdot M0+k_{13}\cdot Y0$$

$$M1=k_{21}\cdot C0+k_{22}\cdot M0-k_{23}\cdot Y0$$

$$C1=k_{31}\cdot C0+k_{32}\cdot M0-k_{33}\cdot Y0$$

where, k_{ij} represents weight coefficients:

i=1–3; and

j=1–3.

The secondary color correction circuit **9** serves to calculate secondary color correction data **Y2**, **M2** and **C2** from primary color correction data **Y1**, **M1** and **C1** by modifying the latter to make certain thereto by performing matrix calculations so as to provide a capability for making an arbitral and selective color control at a certain specifically selected-out color hue, in the following manner:

$$Y2=Y1+l_{11}\cdot\Delta B+l_{12}\cdot\Delta C+l_{13}\cdot\Delta G+l_{14}\cdot\Delta Y+l_{15}\cdot\Delta R+l_{10}\cdot\Delta M$$

$$M2=M1+l_{21}\cdot\Delta B+l_{22}\cdot\Delta C+l_{23}\cdot\Delta G+l_{24}\cdot\Delta Y+l_{25}\cdot\Delta R+l_{26}\cdot\Delta M, \text{ and}$$

$$C2=C1+l_{31}\cdot\Delta B+l_{32}\cdot\Delta C+l_{33}\cdot\Delta G+l_{34}\cdot\Delta Y+l_{35}\cdot\Delta R+l_{36}\cdot\Delta M$$

wherein, l_{ij} represents weight coefficients:

i=1–3;

j=1–6;

ΔB, ΔC, ΔG, ΔY, ΔR, ΔM: characterizing color data.

Thus, when these-secondary correction data **Y2**, **M2** and **C2** are added to the corresponding original data **Y0**, **M0** and **C0** by means of respective adders **6Y**, **6M** and **6C** and under proper selection of weight coefficients k_{ij} for primary color correction circuit **8**, any color discrepancy of the ideal color of the ink appearing on the printed picture images under the action of the sublimation transfer printer can be arbitrarily ammended. In this case, when the weight coefficients l_{ij} for the secondary correction circuit **9** are selected out properly, the color tone of the printing picture images can be modified to an arbitrary degree.

Further, as for the black color data K, correction data **K2** can be calculated by the following formula. With use of these correction data **K2**, which are added to the original black color data K, the desired correction can be executed in a similar manner.

$$K2=K+\mathrm{ml}\cdot\Delta B+m2-\Delta C+m3\cdot\Delta G+m4\cdot\Delta Y+m5\cdot\Delta R+m6\cdot\Delta\mathrm{M}$$

wherein, Mi represents weight coefficients:

i=1–6.

In this way, output data: Y, M, C and K delivered from the color correction circuit **4** are introduced into the gradation corrector **10** as inputs thereof, and each constituent of these data can be subjected to correction as desired.

FIG. **7** shows several characteristic curves illustrating corrections by means of the gradation corrector **10**. More specifically, **f0** represents a standard characteristic curve; **f1** a highlight-stressing operation curve; **f2** a shadow-stressing operation curve; **f3** a highlight-and-shadow stressing operation curve; and **f4** a medium tone stressing operation curve.

As indicated in FIG. **7**, by presetting, as necessary, the tone-reproducing characteristics, which determine the relationship between that concentration of color data and that of the prints printed by means of a sublimation image transferring printer, a color tone similar to that possessed by the original image can be reproduced. More specifically, when no correction is adopted, the curve **f0** is used, while in the case of correction, any selected one of these curves **f1** to **f4** may be utilized depending upon the part of gradation to be stressed. Further, it should be noted that the tone reproducing characteristic curves are not exclusively limited to those which have been specifically shown and described above. As an example, the control of gradation correction by color tone reproducing characteristic mentioned above is executed by a gradation circuit, not shown, and the setting of the color tone reproducing characteristic is brought about by manipulation of any selected one of the control knobs, not shown, which are provided separately for "highlight"; "medium tone" and "shadow".

Y.M.C.K.-data subjected to correction by the gradation corrector **10** are once stored in the memory unit **11**. The thus stored data may be read out from the memory for each color by manipulation of the selection switch **12** and, after provisional storing, per one line of transfer head **16**, at the buffer **13**, introduced into the parallel/series converter **14** for conversion thereby into corresponding series data.

Another example of the data processing circuit for the sublimation transfer printer is shown only schematically in FIG. **3B**. As shown, the processing circuit in **107'** comprises a level regulator **503**; a color converter **504**; an A/D converter **505** and a parallel/series converter **14**.

As the image data introduced into the processing circuit **107'**, those which have been subjected to conversion into R.G.B.-signals in the color decoder **502** from composite video signals delivered from a T.V. camera, VTR or the like are used. On the other hand, R.G.B.-signals delivered from a personal computer, captain system or the like means are introduced as input into the level adjuster **503**.

As the color correction method with the use of the foregoing arrangements, it is possible, more specifically, to adjust the hue saturation and/or brightness in the color decoder **502**, or to adjust the signal level of each color light of R.G.B.-system in the level regulator **503**.

As an example, the color conversion from R.G.B.- to Y.M.C.-system can be executed in the color converter **504**. The simplest possible method in this color conversion is to procure the opposite color to each of the normal colors.

The thus produced color signals of Y.M.C.-system is subjected to A/D conversion and then fed successively through the parallel/series converter **14** and the driver **108** to the thermal head, not shown, to carry out printing in the sublimation transfer principle.

Additionally, in normal cases, with the use of the foregoing system composition, input image data must be of static mode. However, by provision of memory means in front of the color decoder or at an intermediate position between the A/D converter and parallel/series converter, animating images can be processed.

The series data converted in the foregoing manner in the data converter **107** or **107'** are fed to the shift register SR shown in FIG. **6** by n-image elements and then, upon being subjected to latching in the latch circuit LT are further delivered to NAND gate NA as its inputs. When a strobe signal ST is fed as input to the NAND gate NA, the foregoing n-image element data is fed to the thermal element HE.

FIG. **8** is a schematic diagram, showing signals for respective image elements. The gradation has been so selected that the first image element is at the highest gradation level, while the n-th image element corresponds to the lowest gradation level, and that the second to (n–1)th image elements vary linearly in gradation levels, so as to provide representatively a better understandable example of the invention.

Next, the operation of the parallel/series converter **14** will be described.

First, as shown in FIG. **5**, image elements data A, consisting of parallel data, more specifically, comprising parallel eight bit data **A0–A7**, are fed to one-side inputs of comparator **22**, while another side inputs thereof are fed with outputs B, comprising eight bit increment outputs **B0–B7**, of counter **23**. The counter **23** counts clock signals in increments, the outputs **B0–B7** being successively varied.

The comparator **22** performs comparison between the two inputs A and B, so as to deliver successively outputs of binary "1" until the increment output B is brought into coincidence with image elements data A, or more specifically, under the condition of A>B and A=B, while, thereafter, binary "0"-outputs are delivered therefrom. More specifically, comparator **22** will continue to deliver binary "1" until an increment value which corresponds to the weight of concentration of image element data A is given thereto. As an example, if the image element data A has a concentration of gradation 128 of a total 256, output "1" will be repeated to deliver 128 times first and then, output "0" will follow after again 128 times, so as to provide in total a specific series data peculiarly in this case.

These series data are taken out from the comparator **22** in the form of A>B- and A≦B-outputs and of A=B–outputs through an attributed OR-gate **24**, and in the present example, the gradation consists of 256 steps or increments. However, in practice, the gradation may represent a smaller number of steps. As an example, if the incrementing bit is **B1** instead of hitherto employed **B0**, the gradation will have 128 steps; and if **B2** is employed, it will have only 64 steps. In this way, the gradation setting may be varied in a simple manner.

When in the foregoing way, the output B from the counter **23** is stepwise incremented, such series data consisting of a first series of "1" will be delivered until the relationship between the image elements data A and the output B from counter **23** becomes A=B, and of a second series of "0" issued thereafter, as shown in FIG. **8**.

In FIG. **9**, a conversion mode at the parallel/series converter **14**, which, however, is different from that shown in FIG. **8**, as an example, is shown again in the form of a matrix. As-shown, when the image data are of 8-bit parallel kind, as an example, the gradation data are ranged from 0 to 255, providing, therefore, binary series data from "00 . . . 00" to "11 . . . 11".

In this way, the data, per line in the transfer head **16**, kept preserved in the buffer **13** are fed to the parallel/series converter **14** for providing as outputs therefrom into corresponding series data which are then delivered through the driver **15** to the transfer head **16** and thus recorded on a print paper P supported on the transfer drum **17**.

FIG. **10** represents a flow chart illustrating the operation of the sublimate printer as employed in the present invention.

At the first step **S1**, print papers are set in position and the printing ribbon is also set in position ready for performing the required procedure.

At the second step **S2**, printing operation is initiated, and line printings are executed, line by line, accompanying necessary intermittent line shifts, with relation to any selected one of four colors: C (cyan); M (magenta); Y (yellow) and K (black) being carried out. Refer to **S3** and **S4**. When line printings with the selected-out single color have been completed (**S5**), the image transfer sheet is replaced by another color sheet (**S6**) and so on. In this way, line printings are completed in all four colors. In this case, it is naturally most preferable to use a long extended single transfer sheet on which four color ink regions are repeatedly printed in a certain predetermined pattern. The image reception paper is initiated to make print from a certain prescribed position for each of these colors (**S8**). When all of the printing steps have been completed with the four colors, the paper is discharged from position (**S9**) and the printing operation is terminated to be repeated.

In FIG. **11**, a card style sample of the final products according to this invention is shown in front view at **200**. FIG. **12** is a sectional view thereof. Numeral **201** represents the substrate material of the card; **202** a display layer; **203** a surface protecting layer; and **204** a display image as an example. Depending upon the kind of usage and when necessary, the protecting layer **203** may be dispensed with. It should be noted that the display image **204** on the display layer **202** is represented by a sublimative dyestuff, as a characterizing feature of the present invention.

As the main and substantial material of the image transfer sheet, various plain papers, converted papers, plastic resin sheets or the like may be used per se or in combination. When a plastic resin sheet which can be colored directly with a sublimative dye or dyes is used, these image transfer substrates (articles or objects) as at **201** can be united .each with the display layer **202**. Each of these substrate materials, when it is of the card style, may have generally such dimensions: thickness of 0.68 to 0.80 mm and size: 11 to 8×8 to 5 cm.

As the material of the display layer **202**, various known materials which may be colored with sublimative dyestuffs, such as polyethylene, polypropylene, polyester, ABS, AS, polyvinylchloride, polyvinyl/vinyl acetate copolymer, polystyrene, polyacrylate, polyester, polyamide, polyurethane and the like plastic material, may be advantageously utilized. As will be more specifically described hereinafter, this material layer can be united with the substrate material layer **201**. In the case of such unified structure with substrate layer **201**, the thickness and size dimensions may be substantially as the same as before. However, when normal and/or converted papers or metals, which are practically impossible to color with sublimative dyestuffs, are used as the substrate layer **201**, various methods can be utilized for desired coloring. As an example, a solution including at least any selected one of plastic resin materials capable of coloring with sublimative dyestuffs may be coated on the substrate surface, or alternatively used in the form of a film which is laminated thereon. This kind of film preferably has a thickness of about 3 to 50 μm or so. One of main characterizing features represented in and by the final products **200** is that the appearing display image or images as at **204** is/are formed at least partially or wholly with a sublimative dyestuff or dyestuffs. Additionally, the process for formation of such images can be executed in the conventional art.

As an example, the processing method may be executed conventionally as follows.

As an example, a sublimative image transferable sheet, such as a paper sheet, plastic resin film or sheet capable of acting as the carrier is coated on its surface with any suitable binder resin carrier carrying sublimative a dyestuff or dyestuffs under heat, is overlapped on the display layer **202** and then subjected to heat from behind the heat-transferable sheet, preferably in the pattern mode, so as to transfer the dyestuff or dyestuffs into the display layer **202**. It is proper to select the molecular weight of 250 or larger of the dyestuff, for improving the fastness thereof. However, a molecular weight higher than 370 is more favorable. In the

case of provision of the surface protecting layer, there is practically no limitation to the selectability of the dyestuff molecular weight.

The sublimative image transfer may be executed directly on the surface of substrate **201** provided with the display layer **202**. Or alternatively, a carrying, image transferable sheet is prepared separately and, after formation of the image **204** thereof, may be stuck onto or laminated on the substrate **201**.

Image-carrying and image-transferable sheet

In the following, structure, material, usage and application purpose of the image-transferable sheet to be employed in the present invention will be described in detail:

FIG. **13** illustrates only basically and in schematic sectional view the image-transferable sheet adopted in the present invention, while FIGS. **14** through **19** and **22** through **24** illustrate preferable embodiments thereof.

The basic structure of the image transferable sheet **310** is characterized in that, as shown in FIG. **13**, a sheet-like substrate **301** is provided at its one surface with an image-reception layer **302** capable of peel-off from the substrate. By adopting such a structural configuration of the image-transferable sheet, the image-reception layer **302** can be formed with the required image or images with the use of an image transferable sheet having thermally shiftable dyestuff, and then, the image-formed, image-reception layer **302** is peeled off from substrate **301** and attached firmly, preferably as by sticking, on the surface of any selected object or article with use of any suitable means. In this way, various conventional drawbacks inherent in the comparative conventional technique can be basically overcome.

More specifically, as the material of the aforementioned image-reception layer **302**, limitation must be imposed to those which can be colored with thermally shiftable or transferable dyestuff. However, upon formation of necessary images and upon peel-off from the sheet-like substrate **301**, the image-reception layer **302** may be attached fixedly onto the surface of glass-made, metal-made or wooden-made products or plastic-resin made ones which are very difficult to color with thermally shiftable and transferable dyestuffs, indeed, by reliance on conventional sticking techniques as properly adopted in consideration of the specific nature and kind of the material of decorative products to be ornamented. Further, the image-formed and peeled-off, image-reception layer **302** from the sheet substrate **301**, is highly thin and thus sufficiently pliable so that it may be applied even onto any uneven and complicated surface of a product to be decorated or ornamented, having undulations, convexities, concavities, recesses and projections. Therefore, a maximum possible better fitness of the image-reception layer to be ornamented is attained and guaranteed by the present invention. Thus, practically no limitation in the attaching use thereof may be encountered. Further, in sharp contrast to conventional sealing seals and the like, the very thin image-reception layer bearing necessary images can be applied easily to the product per se in a very uniform manner, thus providing no raised and thickened feeling, and giving rise to no foreign feeling upon attachment.

FIG. **14** shows a further example of the image transferable sheet **310**. In this case, there is provided a parting agent layer **303** on the surface of image-reception layer **302**. Between the latter and the sheet substrate **301**, there is provided a parting agent layer **303'**. If necessary, however, any one of the two layers **303**; **303'** may be dispensed with.

The first parting agent layer **303** is provided for prevention of thermal fusion between the image-reception layer **302** and an image transferable sheet, not shown, as may occur during image transfer and formation on the first layer **302** through transfer of thermally transferable dyestuff from the said transferable sheet to the first layer. If there is no risk of such thermal fusion of the above nature, or when the image-transferable sheet has been already provided with such a parting agent layer, the present provision thereof may be unnecessary. As for another parting agent layer **303'**, it is for the purpose of making the latter peel-off operation, to be executed after image-forming step, easier. When the sheet-like substrate **301** is made of polyester or the like material which has, as it is, sufficient separability from image-reception layer **302**, provision of parting agent layer may naturally be dispensed with.

FIG. **15** illustrates a still further example of image transferable sheet **310**. In this case, between the image-reception **302** and the sheet-like substrate **301**, an intermediate layer **304** and/or parting agent layer **303'** is/are provided. The laminating order is optional and thus not binding. The intermediate layer **304** will serve to assist the image formation to be rather firm and beautiful, the image formation being carried out by transferring the thermally shifting and transferring dyestuff from the image transferable sheet to the image-reception layer **302**. For this purpose, the intermediate layer **304** may take, for example, the form of a cushioning layer or heat insulating layer. When a cushioning layer is provided as the intermediate layer **304**, the cohesion between the image transferable sheet and the image reception layer **302** is greatly improved and the thermal shift and transfer of the dyestuff during image formation with the use of a thermal head is evenly executed, the image formation thereby being carried out amply in correspondence with the supplied image signals. Further, when a heat insulating layer consisting of a highly heat-insulative material is used as the intermediate layer **304**, ineffective release of the heat applied during shift and transfer of the dyestuff from the image transferable sheet to the image-reception layer **302** can be reduced to a minimum possible, the effective thermal efficiency thereby being correspondingly improved and ample image formation being accelerated. If necessary, however, these cushioning layer and heat-øinsulating layer can be prepared independently and arranged concurrently in any arranging order.

Additionally, when the intermediate layer **304** is arranged at a higher level than the parting agent layer **303'**, the intermediate layer **304** will be conjointedly peeled off in the case of peel-off of the image-reception layer **302**. On the contrary, when the intermediate layer **304** is arranged at a lower level than the parting agent layer **303'**, the intermediate layer will remain on the sheet-like substrate **301** after execution of the separation of image-reception layer **302**. In this case, therefore, the intermediate layer **304** may be made preferably and at least substantially transparent, when the peeled-off image-reception layer **302** is stuck on a decorative product, while directing the surface of parting agent layer **303** towards the latter.

In the modifications shown in FIGS. **16**, **17**, and **18**, modified from the foregoing embodiment shown in FIG. **15**, a further protecting layer **305** is provided between the image-reception layer **302** and the sheet-like substrate **301**. This protecting layer **305** serves to prevent deterioration of the formed images in the image-reception layer **302** when the latter is stuck on the decorating product while directing the surface (more specifically the image-formed surface) towards the product. For example, this protecting layer **305** is prepared from a superior material which exhibits at least one of desirous properties such as antiwearing, light-fast, weather proofing and anti-chemical qualities. With the use of

the protecting layer **305** having these superior qualities, the images can represent improved fastness in the above various aspects, even after execution of the foregoing sticking procedure.

In the modification shown in FIG. **16**, the protecting layer **305** is arranged between the intermediate layer **304** and the parting agent layer **303'**.

In the further modification shown in FIG. **17**, the protecting layer **305** is arranged between the image-reception layer **302** and the parting agent layer **303'**.

In still another modification shown in FIG. **18**, the intermediate layer **304** takes the role of the protecting layer **305**.

In each of these modifications, the protecting layer **305** is arranged in neighboring relationship with the partition agent layer **303'**, whereby the image-formed and remotely arranged, image-reception layer **302**, kept in its up-and-down reversed state, is capable of adhering securely to the decorative product, so as to be positioned as an uppermost layer, as may be required. In a still further modification shown in FIG. **19**, derived from that shown in FIG. **14**, a sticking layer **306** is further provided between the image-reception layer **302** and the partition agent layer **303**. It should be noted, however, that such a sticking layer as at **306** may be provided in any one of other foregoing examples and modifications, if necessary, in neighboring relationship with the parting agent layer **303'**.

The provision of such a sticking layer as at **306** is highly valuable when the image-formed and peeled-off, image-reception layer is adhering without position reversal onto the decorative product. With this arrangement mode, the protecting layer **305** shown in FIGS. **16**, **17**, and **18** may be dispensed with. If, however, the protecting layer **305** is composed of a material in the form of a sheet-like substrate, the part to be peeled off is thereby strengthed, the peel-off procedure thus being greatly facilitated.

By previous provision of the sticking layer **306**, the image-formed and peeled-off, image-reception sheet **302** can be caused to adhere as it is onto the decorative product without use of a separate sticking agent. As the sticking layer **306**, an ordinary sticking agent which is active at room temperature can be used. Or alternatively, a heat-sensible or light-sensitive sticking agent may be used, if necessary.

In the foregoing, the main structure of the image transferable sheet employed in the present invention has been described in detail. However, other structural modes than those set forth hereinbefore which occur easily to those skilled in the art may be employable in the invention, and thus they may be included within the scope of the invention without departing from the appended claims.

It should be further noted that, in the present invention, the sheet-like substrate may be provided on its one surface with an image-transferable layer capable of peeling off through the intermediary of only one weakly sticking layer.

FIG. **22** shows only schematically in a sectional view a preferred embodiment of such an image-transferable sheet, denoted with same reference numeral **310**.

As shown in FIG. **22**, the image-transferable sheet **310** represents a basic structural characteristic such that any suitable sheet-like substrate **301** is provided on one of the surfaces with an image-reception layer **302** through an only weakly sticking intermediate layer **402**, the layer **302** thus being easily peeled-off when desired. By providing the image-transferable sheet with such a structural characteristic as set forth above, desired positive or negative images are formed by transferring thermally shiftable and transferable dyestuff from the image heat transferable sheet to the image-reception layer **302**, and the thus image-formed layer is peeled off from the sheet-like substrate **301** and then attached onto any suitably selected product with the use of proper means or attached per se thereon without the peeling-off operation, the substrate then being peeled off, whereby an image-formed final product can be obtained.

In the foregoing example, it should be noted that the image reception sheet **302** per se has only a thin thickness and thus represents only poor feedability during the sheet-feeding period within the printer at the time of image formation, insufficient cushioning effect and only insufficient thermal efficiency during the printing operation, and further, it is very difficult to treat in advance of as well as after execution of the image formation. Therefore, the coexistence of the image-reception layer **302** and the sheet-like substrate **301** is absolutely necessary. In addition, it is a requisite requirement that the image reception layer **302** be easily peeled off from the sheet-like substrate **301** upon execution of the image-forming operation, and thus, the layer **302** and the sheet **301** should not be stuck too strongly together. In order to satisfy this requirement, provision is made of weakly stuck layer **402** therebetween. Thus, it should be noted that the term "weakly stuck" employed in this specification and appended claims may be defined as "to be separable by finger's end and the like means from each other without entailing destruction or breakage of the parts originally stuck together". It is worthwhile to say, in considering the relative relationship between the image-reception layer **302** and the sheet-like substrate **301**, there is no necessity to provide the weakly-stuck layer **402** if the aforementioned peeling-off is very easy to bring about.

FIG. **23** illustrates still another modification of the image-transferable sheet **310** denoted by the same reference numeral **310** only for simplicity and convenience, wherein a further parting agent layer **303** is provided on the surface of image-reception layer **302**.

This layer **302** is provided for occasional thermal sticking between the thermal image transferable sheet, not shown, and the image reception layer **302** in the progress of thermal shift and transfer of the dyestuff from the sheet to the layer **302**. This provision of the parting agent layer **303** may be dispensed with if there is no risk of occurrence of such disadvantageous sticking attachment or the sheet under consideration has already been fitted with such a parting agent layer.

A modification shown in FIG. **24** from that shown in FIG. **23** has such a modified structure that a protecting layer **305** is provided between the image-reception layer **302** and the weakly stuck layer **305**. This layer **305** serves to prevent otherwise occurring deterioration of the images at the image-reception layer **302** which has been formed with preferably reversed images and subjected to peeling-off, together with protecting layer **305**, preferably a plastic sheet layer, from the sheet-like substrate **301** and finally stuck onto the decorative product, while directing the image-formed surface of the image-reception layer towards the product. The protecting layer **305** is .made of a material having various excellent physical properties, such as anti-wearing-, light-fastness and antichemical characteristics. Provision of such a protecting layer improves various fastness performances of the formed images after sticking attachment of the image-reception layer **302**.

When necessary, a separate parting agent layer, not shown, may be provided between the protecting layer **305** and the weakly stuck layer **402** for providing easy peel-off capability between these two layers **305** and **402**, as being applicable to the example shown in FIG. **24**. If the surface of the protecting layer **305** should have sufficient peel-off

capability, it is natural to provide such an intermediate parting agent layer as above.

Further, in the case of the image-transferable sheet **310**, it is naturally easy to separate from each other through a peel-off operation, upon the formation of necessary images thereon and before practical use thereof as the image-transfer sheet, and a cut-out slit as at **407** in the sheet-like substrate **301** may be provided for attaining such an easy separation as stated above at a portion of the sheet **310** in proximity to one end thereof. Upon the provision of such a cut-out slit as at **407**, the thus formed flap-like portion can be easily folded out by the operator's finger-tip, thereby affording convenience in a peel-off operation.

The usable materials and composing methods of the foregoing image transferable sheets will now be described.

As a material usable for the sheet-like substrate may be any one or any combination of the following categories:

(1) synthetic paper (polyolefin-series; polystyrene series and the like);

(2) fine quality paper; art paper; coated paper; cast-coated paper, wall paper; back-up paper; backing paper; resin-, emulsion- or synthetic rubber-imprignated paper; resin-admixed paper; paper board; cellulose fiber paper;

(3) polyolefin-, polyvinyl chloride-, polyethylene terephthalate; polystyrene; polymethacrylate; polycarbonate and the like plastic film or sheet.

Use of the synthetic paper belonging to the foregoing category (1) is highly suitable for the purpose of the present invention since the surface thereof generally represents a microvoid layer which provides a low heat conductivity and thus a high heat-insulating peformance. A laminated material representing any combination of the foregoing categories (1), (2) and (3) can be used in the present invention. A representative and recommendable example of such a laminate is that of cellulose fiber paper and synthetic paper or that of cellulose fiber paper and plastic resin film or sheet. Among others, use of the first mentioned kind of laminate will provide an advantage in that the thermal instability such as thermal elongation or shrinkage possessed by the synthetic paper component is compensated for by the cellulose fiber paper, whereby a high thermal sensibility is demonstrated during the printing step due to low thermal conductivity of the synthetic paper component. Further, in the case of the present paper combination, however, a further modified combination of a three-layer laminate: synthetic paper-cellulose fiber paper-synthetic paper may be more advantageously employed for making the frequently appearing lesser by providing a well-balanced structure between both the surfaces of the final laminate.

As the synthetic paper mentioned above, any suitable one usable as a synthetic paper substrate used as a component of the image-transferable sheet layer may be used. As a recommendable example thereof, having a fine porous fine paper structure layer, the synthetic paper called "YUPO", manufactured and sold by Oji Yuka Goseishi Kabushiki Kaisha, Tokyo, may be mentioned. This paper layer having a fine pore structure may be prepared in such a way that a suitable plastic resin material containing a filler of finely divided state is subjected to a mechanical elongation step. When the image-transferable sheet composed of the synthetic paper sheet containing finely divided air as above mentioned is formed with images through a thermal image transfer setp, the concentration of the thus formed images is surprisingly high and no fluctuation of image configuration and concentration is encountered, thanks to the heat insulation effect provided by the very existence of fine air pores, in addition to the improved thermal energy efficiency. Especially, due to the advantageous cushioning effect provided by the air-filled fine pores, the image-receiving layer is supposed to be rather advantageously affected during the image formation step. As an alternative measure, the paper-like layer containing the above-mentioned fine air pores may be, if desired, provided directly with the core material consisting of the cellulose fiber paper or the like.

It is further possible to use plastic film in addition to the cellulose fiber paper in the laminate described above. Still further, a laminate of said cellulose fiber paper and plastic film composed together can be used.

As the method for co-sticking of synthetic paper and cellulose fiber paper, use of a known adhesive agent is naturally adopted, as an example. Or alternatively, the extrusion-laminating, heat-adhesion, or the like process may be relied upon, as the case may be. On the other hand, as the sticking-process between the synthetic paper and the plastic film, the lamination process to be carried out simultaneously with the formation of the film may be adopted. Calendering or the like method may be utilized for the same purpose. Selection of any suitable one of the several foregoing sticking processes depends upon the kind of material or the like condition of the partner member to be stuck together with the synthetic paper. As for the adhesive agent mentioned above, emulsion adhesive such as ethylene-vinyl acetate copolymer, polyvinyl acetate or the like, aqueous solution type adhesive polyester containing carboxyl radicals; or the like may be mentioned. On the other hand, as the laminating use adhesive, organic solvent solution type one such as polyurethane-, acrylic- or the like, may be mentioned.

The material for the image-reception layer must be suitable for reception of heat-transfer dyestuff, such as sublimative disperse dye from the image transfer sheet and holding and maintaining the thus formed images thereon. From the view point of image-holding and blocking prevention, use of such synthetic resin as having glass transition temperature higher than 40° C. may be advantageous. For example, the synthetic resins set forth in the following items (a) through (e) may be used separately or in combination.

(a) Ester bond-bearing resins:

Polyester resin; polyacrylic ester resin; polycarbonate resin; polyvinyl acetate resin; styrene acrylate resin; vinyltoluene acrylate resin and the like.

(b) Urethane bond-bearing resins:

Polyurethane resin and the like.

(c) Amide-bond carrying resins:

Polyamide resins (nylons).

(d) Urea-bond carrying resins:

Urea resins and the like.

(e) Other high polar-bond carrying substances:

Polycaprolacton resin; polystyrene resin; polyvinylchloride resin; polyacrylonitrile resin and the like.

The image-reception layer may be prepared from a resin mixture of saturated polyester and vinyl chloride-vinyl/acetate copolymer. As the saturated polyester, such commercialized products: "Vylon 200"; "Vylon 290"; "Vylon 600"; "Vylon 103" and the like, manufactured and sold by Toyoboseki K.K., Osaka, Japan; "KA-1038C" (manufactured and sold by Arakawa Kagaku K.K., Osaka, Japan; "TP 220"; "TP 235", manufactured and sold by Nippon Gosei K.K., Osaka, Japan; may be advantageously used. The vinyl chloride-vinyl acetate copolymer may have preferably 85–97 wt. % of vinyl chloride component, the polymerization degree being between about 200 and 800. The vinyl chloride-vinyl acetate copolymer may further contain a vinyl alcohol

component, maleic acid component within the purpose of the invention in addition to the main components. According to our experiments, it has been found that these modified copolymers should have rather superior compatibility with polyester resin. The image-reception layer may be, if necessary, composed of polystyrene resin, for example, in this case, styrene monomer, preferably styrene, α-methyl styrene, and vinyl toluene may be used separately or in the form of copolymer or saying in general sense polystyrene resin. Further, such styrene copolymer resin may be used as specifically recommendable material in the above sense, comprising said styrene monomer(s) with other monomer, preferably for example, acrylic acid ester, methacrylic acid ester, acrylonitrile, methacrylonitrile and the acrylic or methacrylic monomer, or further styrene copolymer resin comprising maleic acid anhydride.

It should be noted, however, that among others, polyester series resin is especially superior for the purpose of the present invention.

In any of the foregoing embodiments, however, white pigment is preferably admixed with the material of the image-reception layer for improving the whiteness thereof and further accentuating the sharpness and fineness of the images when transferred thereto and to provide a manually writing-on performance. As the white pigment for this purpose, the following materials may be used separately or in any combination: titanium oxide; zinc oxide; china clay calcium carbonate; finely divided silica and the like.

For further improving the whiteness fluorescent whiteness-increasing agent or -bleaching agent may be added to. Further, for improving the light fastness of transferred images, ultraviolet absorption agent and/or photostabilizing agent may be added to, preferably in a quantity of 0.05 to 10 and 0.5 to 3 weight parts per 100 weight parts of the material resin composing the image-reception layer.

The image-transferable sheet used in the present invention is preferably constituted for improving the separability from the image-transfer sheet in such a way that the surface of the image-reception layer is formed with a partition agent layer, or instead, such agent is admixed to the image-reception layer. As for the partition agent to be used for this purpose, polyethylene wax; Amido Wax, Teflon Powder or the like solid wax; surface active agents such as fluorine-contained agent or phosphoric acid ester series surfactant; silicone oil or the like may be selectively used. Among others, silicone oil may be advantageously utilized.

The silicone oil may be used in oily state, but a hardenable type thereof may be rather advantageous. As the hardenable silicone oil, reaction-hardening one, photo-hardening one, catalytically hardening or the like one may be used selectively according to necessity. However, use of the reaction-hardenable one is most highly recommendable. Silicone oil of this type may be obtained, as example, by reacting amino-modified silicone oil with epoxy-modified silicone oil to obtain a reaction-hardened product. As for the amino-modified silicone oil, "KF-394", "KF-857", "KF-858"; and "X-22-3680"; "X-22-3801C" (manufactured and sold by Shinetsu Kagaku Kogyo K.K., (Tokyo, Japan)) and equivalents thereof may be used. As for the epoxy-modified silicone oil, "KF-100T"; "KF-101"; "KF-60-164"; and "KF-103" (manufactured by Shinetsu, above mentioned) and equivalents thereof may be used. Further, as the catalytically hardenable and photohardenable silicone oils in the above sense, "KS-705F"; "KS-770" of the catalytic hardenable or hardened silicone oils, manufactured by Shinetsu; and "KS-720" and "KS-774" of the photo-hardenable or hardened silicone oils (manufactured equally by Shinetsu) and equivalents thereof may be used. The adding quantity of each of these hardenable or hardened silicone oils may advantageously range from 0.5 to 30 wt. % depending on the material of the resin composing the image-reception layer.

At least a part of the image-reception layer is coated with a solution or dispersion of any of the foregoing partition agents in a suitable solvent and dried and further treated, a suitable parting layer being provided thereon. A particularly suitable partition agent for the formation of this kind of partition layer is the aforementioned reaction type hardenable one obtainable by reacton of an amine-modified silicone oil with an epoxy-modified one. The thickness of the partition layer is 0.01–5 μ, preferably 0.05–2 μ.

It should be noted that when silicone oil is admixed during formation of the image-reception layer, the silicone oil will bleed out after coating and the parting agent layer can be formed by the hardening even after such bleeding. In order to improve the parting ability between the image transferable layer and sheet-like substrate, it is possible to provide a parting layer consisting of a heat-hardenable resin, preferably of the melamine series, and having better affinity for the image transferable layer compositions. For the same purpose as above, however, without special provision of the parting layer, a protecting layer consisting of polymethyl methacrylate resin or cellulose acetate propionate can be provided.

For the formation of the image transferable layer, a solution or dispersion of a material composition suitable for the purpose is applied on the sheet-like substrate through conventional coating or printing. As an alternative way, a separate film or sheet for the image transferable layer **302** is formed preparatorily on a provisional carrier sheet or film and then, as a succeeding step, subjected to an image-transfer onto the substrate.

The intermediate layer is made of either a cushioning or a porous material. In some cases, the intermediate layer may additionally function as the adhesive layer.

The cushioning layer is mainly composed of such a resin which has a value of 100%-modulus as defined at JIS-K-6031 (Japanese Industrial Standard) of less than 100 kg/cm^2. If this value should exceed the above prescribed value, the rigidity will become much higher than that recommended for the intermediate layer. When the layer is formed with such disadvantageous material resin, sufficient adhesion between the heat image-transfer sheet and the image-reception layer cannot be maintained during the printing step. The lower limit of the prescribed 100%-modulus is of the order of 0.5 kg/cm^2 in actual practice.

Preferable kinds of resin to be used for the above purpose, may be enlisted as follows:

polyurethane resin; polyester resin; polybutadine resin; polyacrylic acid ester resin; epoxy resin; polyamide resin; rosin-modified phenol resin; terpene phenol resin; ethylene/vinylacetate copolymer resin; and the like.

These resins can be used independently or in combination of two or more kinds. Since these resins are rather viscous and tend to give rise to manufacturing troubles inorganic additives may be admixed, such as, for example, silica; alumina; clay; calcium carbonate; amide series substance such as amide stearate; and/or the like.

The cushioning layer is preferably formed with the use of one or more of the above specified resins, occasionally with the addition of suitable additive(s); solvent or diluent, prepared into a coating agent or printing ink which is then applied on, according to a known coating or printing process and then subjected to drying to provide a coating. The

thickness of the coating should be between 0.5–50 μm, preferably 2–20 μm or so. With a thickness less than 0.5 μm, the coating will not be able to compensate for the surface irregularities on the substrate, thus being ineffective for the desired purpose. On the other hand, when the thickness exceeds the above specified maximum value or more specifically 50 μm, the overall thickness of the image-transferable layer becomes much too large, so that handling troubles may be encountered during wind-up and overlapping procedures, without attaining further effect as desired. In addition, in this case, a loss of production economy will be inevitably introduced.

The thus obtainable improvement of intimate adhesion between the heat-image transfer sheet and the thermally image-transferable sheet by the provision of the above intermediate layer may .be conceivably attributed to the lower rigidity of the intermediate layer per se, whereby it is liably to be deformed under the influence of the printing pressure, and further to the generally relatively low glass transition temperature and softening temperature of the aforementioned kinds of resin resulting in further lowering of rigidity and tendency to deform than at room temperatures upon reception of heat energy during the image printing step.

The porous layer may be formed generally in the following four ways: 1) through 4).

1) Emulsion of polyurethane or the like resin, methylmethacrylate-butadiene series synthetic rubber latex is foamed by mechanical agitation, coated, and dried on the sheet substrate into a layer.

2) The synthetic resin emulsion or synthetic rubber latex is admixed with a .foaming agent and the liquid mixture is coated and dried on the substrate into a layer.

3) Vinyl chloride-plastisol, polyurethane or the like synthetic resin or styrene-butadiene series or the like synthetic rubber is added with a foaming agent and the liquid mixture is coated on the substrate and subjected to heating to provide a foamed layer formed thereon.

4) A thermoplastic resin or synthetic rubber is dissolved in an organic solvent to provide a solution, and a non-solvent (including that containing aqueous main component), and the latter solution are mixed together to provide a liquid mixture, said nonsolvent being less volatile than the organic solvent and having a considerable mutual solubility with the solvent, and showing, however, non-solubility with the thermoplastic resin or synthetic rubber. The thus prepared liquid mixture is then coated on the sheet-like substrate and dried, to provide a porous membrane upon micro-coagulation of the constituents. The resulting microporous layer can be utilized for the above purpose.

It should be noted that the layers produced by any of the foregoing three processes 1) to 3) have rather large foams contained therein, and thus when the foaming solution for the image-transferable layer is applied thereon and dried, the latter may exhibit excessively coarse surface conditions. Therefore, in order to obtain an optimumly image-transferable smooth surface capable of providing transferred images of high uniformity, provision of the micro-porous layer prepared by the process as set forth in the foregoing item 4) is highly recommendable.

As the thermoplastic resin suitable for the formation of the above porous layer, saturated polyester; polyurethane; vinylchloride-vinylacetate copolymer; cellulose acetopropionate and the like can be used. Further, as the synthetic rubber usable for the same purpose, those of styrene-butadiene series, isoprene series, urethane and the like series may be used. Still further, as the organic solvent and non-solvent liquid used for the formation of the microporous layer, various known substances may be used. Generally speaking, however, methyl ethyl ketone; alcohol and the like are representatively used. On the other hand, as the non-solvent, water is mostly used.

The thickness of the porous layer usable in the present invention is preferably greater than 3 μm, especially preferably in the range of 5 to 20 μm. With the use of a porous layer having a thickness of less than 3 μm, the desired cushioning and heat-insulating effects cannot be attained.

As was referred to hereinbefore in the description stage for the formation of the image-transferable layer, the intermediate layer may act simultaneously as the sticking layer in some cases.

This kind of intermediate layer(s) may be provided on one or both of the surfaces of the thermally image-transferable sheet.

In practice, however, an electrostatic charge may accumulate in the material of the thermally image-transferable sheet during its processing step or during running through the printer. As a countermeasure, a proper antistatic agent may be applied on one surface of the image-transferable layer or on the bottom surface of the thermally image-transferable sheet or it can be included in the material of the image-transferable layer. As the antistatic agent in this sense, a surfactant such as a cation-exchange agent (for example, a quaternary ammonium salt, polyamide derivatives and the like) may be advantageously used. Further, an anion exchange type surfactant, such as alkyl sulfonate may be used. Otherwise, amphoteric ion type surfactants or even, nonionic surfactants may be used for the same purpose.

On the other hand, the antistatic agents may be coated on the surface of image-reception layer by gravure-coating, bar-coating or the like process or alternatively, these agents may be kneaded with the material resin and then subjected to transfer towards the surface during the coating formation and drying step for preparing and providing the image-transferable layer. As the antistatic agents to be admixed with the image-transferable layer material resin, cation-type acrylic polymers may be employed.

The protecting layer is peeled off together with the image-transferred layer, from the sheet-like substrate, and then stuck, in inverted reversed state, onto any desired decorative object, the protecting layer thereby being positioned at the uppermost position, for improving the anti-wearing-light-proofing and anti-chemical performances of the image-bearing layer. As the material adapted for the formation of the protecting layer, for example, alkyd resin; phenol-modified alkyd resin; aminoalkyd resin; phenol resin; urea resin, melamine resin; silicone resin, thermosetting acryl resin, thermosetting polyurethane resin and the like thermosetting resin or normal temperature setting resin; further, ultraviolet hardenable resin; electron ray hardenable and the like activating energy flux hardenable resins or thermoplastic resins such as polyester-; polyurethane-; polyvinyl acetate resin; vinyl chloride-vinyl acetate copolymer resin; polyolefin resin, acryl resin and the like, can be used.

Preparation and use of a protecting layer comprising one or more of the above-mentioned resins are made in such a way that the material resin is dissolved in a properly selected solvent according to the necessity, so as to provide a coating liquid or ink, as the case may be, which is provided between the parting layer and the image transferable layer. The thickness thereof is generally 0.5 to 20 m. It is also possible to form the protecting layer with the use of a resin film which consists of polyester-; acryl-; acrylpolyol-; polyvinyl chloride-; olefin resin or the like resin. It is further possible

advantageously to admix an ultraviolet ray absorbing agent and/or photostabilizer to the material of the protecting layer.

The protecting layers prepared and formed in the foregoing way are thus not made integral with the sheet-like substrate or parting layer and, therefore, the peel-off operation of the sheet-like substrate upon execution of the image transfer is very simple and easy.

It is further recommendable, if necessary, to provide a slip-promoting layer on the bottom surface of the sheet-like substrate, which surface is naturally the one opposite to the image-transferable layer side, so as to properly adjust the friction between the image-transferable sheet and feed roll paper or carrier belt acting during passage through the printer and to improve the running performance of the thermally image-transferable sheet in the printer.

The slip-promoting layer can be formed by adding an organic powder such as polyethylene wax fluorine resin powder or an inorganic powder such as talc, according to necessity, to a resin such as polymethyl methacrylate resin; vinyl chloride-vinylacetate copolymer; vinyl chloride copolymer; cellulose acetate butylate; cellulose acetate propionate; styrene-acryl series or the like resin and kneading the resulting mixture to prepare a composition, applying this composition as a coating on the sheet substrate either directly or after application of a suitable primer treatment, and drying the coating thus applied. A suitable quantity of the slip-promoting layer is 0.5 to 5 g/m^2 after drying.

In the embodiments shown in FIGS. **22**, **23**, and **24**, as the adhesive agent to be used in the slightly weak or weak adhesive layer, it should be noted that those conventionally used adhesives for adhesive tapes and seals can all be used. Preferred examples are polyisoprene rubber; polyisobutyl rubber; styrene butadiene rubber; butadiene acrylonitrile rubber and the like rubber-series resins; (meth)acrylic acid ester-series resins; polyvinyl ether-series resins; polyvinyl acetate-series resins; vinylchloride-acetate copolymer series resins; polystyrene-series resins; polyester-series resins; polyamide-series resins; polychlorinated olefin-series resins; and polyvinyl butyrol-series resins. To the suitably selected adherent may be added a proper quantity of a stickness improver, such as rosin; dammar; polymerized rosin; partially hydrogenated rosin; ester rosin; polyterpene-series resins, terpene-modified substances; petroleum-originated resins; cycropentadiene-series resins; phenol resins; styrene resins; xylene resins; and coumarone-indene resin. Further, when necessary, to the mixture may be added a softening agent, filler; antiaging substance or the like conventional agent(s). As the material for the formation of slightly or weak-adherent layer said above, emulsion type adhesive, preferably of acryl acid ester series can be used. As for the parting function after a long time of preservation, emulsion type adhesives are highly recommendable. These adhesive agents are easily procurable from market.

When necessary, these adhesives are added with proper organic solvent(s) for the adjustment of the viscosity, and then applied by roll coating, die-coating, knife coating, gravure coating or the like conventional technique on the surface of the sheet-like substrate, image-reception layer or protecting layer, so as to provide an adhesive agent layer. The thus formed adhesive layer is preferably of a thickness of 1–50 μm, although this is not limitative.

Formation of Images

In the following, the decorating process according to this invention will be set forth in detail. Utilization of the image-transferable sheet according to this invention constitutes an important main feature thereof.

In FIGS. **20** and **21**, basic practising processes will be described first.

The embodiment shown in FIG. **20** is a result of the use of the transferable sheet shown in FIG. **13**. First, a known transfer sheet **320** is applied onto the image-transferable sheet **310** in an overlapped manner such that the dye-carrying layer **321** is kept in opposition to the image-reception layer **302** of image-transfer sheet **320**, and heat energy is applied, as schematically shown by a plurality of arrows, in accordance with image signals fed at a thermal head, not shown, from the side of image-transferable sheet **310**, or preferably, from the side of the image-transfer sheet **320**, thereby forming the desired images as at **307** in the image-reception layer **302**. Next, the image-reception layer **302** formed therein with the desired images **307** is peeled off from sheet-like substrate **301** and stuck onto the decorative product **306**. Or alternatively, both the sheets **302**; **301** are stuck onto the product **306** without preparatory peeling-off. In the latter case, the peel-off step may be executed after execution of the stickingly attaching step. In the above former case, and in such a case where an adhesive agent layer **306** has preparatorily provided between image-reception layer **302** and sheet-like substrate **301** as was set forth hereinbefore, the sticking attachment is carried into effect in such a way that the adhesive layer **306** is kept in opposing contact with the product **330**, and then the sticking operation is brought about by application of heat and pressure or light and pressure, depending upon the nature and structure of the layer **306**. In this way, the decoration according to the present invention is completed as a preferred one mode thereof.

On the other hand, if there is no preparatory provision of the adhesive layer, either the surface of product **330** or of the peeled-off image reception layer **302**, may be coated with the adhesive agent, and the latter layer **302** per se or otherwise in the up-and-down reversed state may be stickingly attached onto the product **330** (refer to FIG. **21**).

Since the image-reception layer **302** is composed generally of such thermoplastic resin material as is liable to be colored with thermally transferable dyestuff, it can be thermally and fusingly attached to plastic resin-made formlings, clothes or metals even with provision of an adhesive layer, if necessary.

In this case, the image-bearing layer **302**, the image thereof having been formed in the aforementioned way, is stuck on, through the intermediary of the adhesive agent layer **306** as shown in FIG. **25**, while retaining the sheet-like substrate **301** on the surface of the image-reception layer **302**.

A modification of the last-mentioned mode is shown in FIG. **26**. In this case, sheet-like substrate **301** is formed on the surface of the product **330** and the image-reception layer **302** is formed as the outermost layer. Further, in this case, sheet-like substrate **301** and product **330** may be stuck together, and, through the intermediary of a suitable adhesive layer, sticking layer or heat-sealable sheet or the like.

As for the transparent film usable as the said sheet-like substrate, it must be transparent to such a degree as not to conceal the images formed in the image-reception layer, and, in addition, it must have superior surface properties such as, for instance, antiwearing characteristics. As an example, polyolefine; polyvinyl chloride; polyethylene terephthalate; polystyrene; polymethacrylate; polycarbonate and the like plastic resin-made films may be used upon variously surface conditioning. If these transparent films should be too thick, the images will be raised, and the unitary feelings may be lost when these are stuck on respective products to be decorated. Therefore, the film thickness is preferably of the order of 0.5 to 50 μm.

In the case of a further embodiment of the present invention, the image reception layer of image transferable sheet which has been, however, formed with necessary images is subjected to image transfer treatment onto an intermediate image transferable substrate, the latter is then subjected to an image-retransfer with the images, and the thus retransferred images are again transferred onto the surface of the product to be decorated. In the following, this image transfer mode will be set forth in detail.

Embodiments shown in FIGS. **27**, **28** and **29** represent such a process for execution of image transfer operation as by the intermediary of intermediate image transfer sheet **510**. First, as shown in FIG. **27**, a thermally image-transfer sheet **320** having a thermal transferable dyestuff layer **321** is overlapped to image-transfer sheet **510** which is, at this stage, not formed with images **307** and thus consists of a thermal image-transferable sheet, in such a way that .the dyestuff layer **321** or more specifically the parting layer **322** is in opposition to the image-reception layer **302** of the foregoing sheet **510**. In such a case, however, that heat energy is supplied in accordance with image-forming signals delivered from the thermal head, not shown, and, indeed, preferably from the side of the sheet **320** as hinted by a plurality of doubleline arrows for thermal formation of desired images (positive images) as at **307** in the image-reception layer **302**, it is highly recommendable to provide an adhesive layer **402** between the layer **302** and sheet-like substrate **301**.

Then, with the use of the image transfer sheet **510** formed with positive images **307**, the images of layer **302** are transferred, as shown in FIG. **28**, to a separate intermediate substrate **501**, which is, however, fitted with a protecting film layer **305**, thus, the transfer being carried out, in fact, onto the latter, and indeed, with the correspondingly inverted images, attached with same reference numeral only for convenience, from the foregoing layer **302**. In this case, it is preferable to subject the adhesive layer **402** of the image-transfer sheet **510** to the image-transfer operation, together with the image-reception layer **302**. Further, as for the intermediate image-transfer substrate **501**, it is recommendable to provide the protecting film layer **305** through the intermediary of a weak-adhesive layer **402'** as shown. The thus provided intermediate image-transfer sheet **610** represents generally the image-transferable sheet.

FIG. **29** illustrates the step for transfer of the image-reception layer **302** now carrying positive images **307** onto the object **330** to be decorated and under utilization of the previously described intermediate image-transfer sheet **610**.

More specifically, the intermediate image-transfer sheet **610** is overlapped onto the said object **330** in such a way that the adhesive layer **402** of the former in opposition to the surface of the object **330** and pressurized together. Then, the intermediate transfer substrate **501** together with the weak-adhesive layer **402'** is peeled off from the remainder of the thus-pressurized assembly, the now image-carrying layer **302** formed with positive images **307** covered with protecting the film layer **305** thereby remaining in the transferred state on the product **330**. In the case of no provision of the protecting film layer **305** on the intermediate image-transferable sheet **610**, the layer **302** remains in an exposed state. Therefore, an overcoat layer, if necessary, can be provided on the now image-carrying layer **302**.

The previously set forth process carried out by the use of said intermediate image-transferable sheet can be executed by means of the apparatus which is shown schematically in FIG. **1E**.

In this apparatus, more specifically, there is provided a carrier system comprising a series of rolls **411**, **412**, **413** and **414** for conveying the intermediate transfer substrate (sheet), arranged in addition to the apparatus shown in FIG. **1B**. More specifically, the substrate is drawn out from feed roll **414**, conveyed through successive rolls **413**; **412** and retransferred onto one of the products **200**. Other operations are same as set forth hereinbefore with reference to FIG. **1B**. Further, in the case of FIG. **1E**, the final product may take the form of a roll-like substrate which is subjected to an image transfer operation through the intermediate substrate, by transferring its image-carrying, image-transferable layer, for later being punched out properly. Alternatively, under occasion, it may be subjected to half-cut operations downstream of roll **122**.

As was set forth herein above, the preferable method for the formation of desired images on the image-transferable sheet is carried out by use of a heat image-transfer sheet comprising a sheet-like substrate having a layer including a thermally transferable dye (evaporative dye). The heat image-transfer sheet which can be utilized in this method is known per se. And almost every kind of these known sheets can be useful in the practice of the present invention. It should be noted that by employing the foregoing image-transfer method, mono-color or full-color images can be easily formed as occasion may desire.

It should be further noted that details of such heat image-transferable sheet can be easily understood with reference to our U.S. patent application Ser. No. 833039. As for the heat image-transferable sheet usable in the present invention, the coating layer of the sheet (coating film) may include a parting agent. By adopting this measure, the image-reception layer of the image-transferable sheet or the surface thereof, to be subjected to sublimative image-transfer, must not have a separate parting agent layer, the adhesive ability between the image-reception and the surface of object to be decorated can be still further improved upon execution of the sublimative image-transfer and image-formation at the image-reception layer and adherent attachment thereof to the object. As the parting agent to be included in the coating layer of the thermally image-transferable sheet (coating film), silicone oil; silicone resin; phosphoric ester or the like surfactant; and/or chelate- and the like agents, may be selectively utilized. These agents, upon mixed, will ooze out from inside to the outer surface of the coating layer, resulting in providing a better parting quality. However, it is preferable to properly select the kind and nature of the parting agent to be used for this purpose, being such that the agent cannot transfer to the image-reception layer of the image-transferable sheet during the sublimating image-transfer stage. The adding quantity of the parting agent may preferably be 3–25 wt. parts based upon the total amount of resin and coating composing the coating layer taken as 100 wt. %.

In practice, any kind of conventionally known heat transfer sheets is overlapped on the thermally image-transfer sheet employed in the present invention, and then necessary heat energy of 5–100 mJ/mm^2 is applied by use of a conventionally known heat transfer unit, for instance, "Video-printer: VY-100" manufactured and sold by Hitachi Seisakusho, Tokyo, or its equivalent machine, for the formation of necessary images on the image-reception layer of the image-transfer sheet as set forth hereinbefore.

Peel-off operation for removal of the image-reception layer formed with necessary images in the above manner may be carried into effect in a very easy manner, so as to provide it in a thin film carrying the images thereon. In case where the thus-peeled off film carrying the images is provided beforehand with an adhesive layer, composed of a suitable adhesive agent as was referred to, at the opposite

surface to the image-carrying one, the peeled-off film can be, as it is, stuck on the object to be decorated. It is natural that this adhesive attachment procedure can be performed only partially and locally on selected part of the whole surface of the object, or totally thereon, as the case may be. On the contrary, if the peel-off film is provided beforehand with no adhesive layer, the film can be subjected occasionally to a heat fusion onto the surface of the object, if the physical properties or material kind thereof is suitable for such kind of thermal fusion. Or alternatively, a properly selected adhesive agent can be preparatorily applied onto the surface of the film or object, and then, the stick-on job can be executed.

If the image-reception layer is provided preparatorily with a parting layer thereon, as was referred to, the latter layer can be removed off partially or wholly, by grinding or rubbing operation after execution of the sublimating image-transfer job, for avoiding otherwise occurrence of ill effect by the very presence of parting layer in the adhesive attachment of the image-carrying layer film onto the decorative object.

In case of that where the image-transferable sheet is provided with a protecting layer and the latter is composed of a plastic resin film, this film may preferably be cut into pieces or subjected to punch-cuttings.

FIG. **32** illustrates successive die-cutting steps in sectional views, serving for the above purpose. In this case, as shown in FIG. **32** at (a), only image-reception layer **305** of the image-transferable sheet **310**, which has been image-formed through the way of the foregoing image-transfer step, are die-cut by operation of a cutter **801**. Next, as shown in FIG. **32** at (b), a pair of hot stamps **132'**; **133'** are used to execute a pressurizing job under heat from opposite sides, thereby the decorative product **330** being processed into a final product provided tightly with an image-reception layer and a protecting layer, as shown in FIG. **32** at (c).

Further, when occasion desires, the image-carrying film is reversed up-and-down in position after execution of the peel-off job, and, the film is stuck onto the product to be decorated in such a state that the image-carrying surface of the film is kept in direct opposition to the product's decorating surface. In this case, however, it would be rather preferable that in advance of preparatory peel-off of the image-reception layer, the image-carrying transferable sheet is stuck onto the surface of the product to be decorated, and indeed, preferably with use of an adhesive agent, in such a way that the image-carrying layer is kept in direct opposition to the product surface and finally, the sheet-like substrate is peeled off, so as to leave the image-carrying surface on the product's surface.

As in the foregoing, when the images are once reversed and then stuck onto the object to be decorated, the forming images are preferable to reverse in mode (mirror-like relationship) the original to those of reversed mode.

It is further possible that the transfer or sticking-on of the image-carrying layer is carried out through the intermediary of a separate fusing sheet.

In FIG. **30**, use of such fusing sheet **701** for reimage-transfer operation of image-carrying layer **2** already formed with necessary images **307**, however, of reversed mode, and onto the surface of a product.

More specifically, the image-transferable sheet **310** is overlapped onto the product **330** to be decorated in such a way that the image-reception layer **302** carrying the necessary images **307** is kept in opposition to the surface of the product, and indeed, through the intermediary of a fusing seat **701** and then these three components are pressurized together. Further, sheet-like substrate **301**, together with parting layer **303'**, is peeled off, thereby the image-reception layer **302**, now having positive images **307** formed thereon, and protecting the latter, being transferred onto the product **330**. It will be seen in this case, that there is no need for this transfer job, to provide in advance on adhesive layer on the surface of image-reception layer **302** and/or on the surface of the product **330**, and further that a direct heat fusion onto the surface of the product **330** which may be composed of plastic resin, textile fabric, metal or the like common material, however, through the intermediary of a heat-fusible or heat-sealable sheet.

In case where the protecting layer **305** is of plastic resin, similar composing technique as mentioned above may be employed by substituting a weak-sticking layer **402'** for parting layer **303'**.

As the heat-fusible or heat-sealable sheet as at **701** employable in the present invention, it may be composed of one or other material capable of adhering under heat, pressure or both, especially suitable one of those which become soft to be adhesive upon heating. These heat adhering materials in the form of sheets will be, upon softening, charge the pores, meshes or stitches of the product material composed preferably of textiles, woven or non-woven; knits, rough-surface papers or meshed materials, thereby the surface of the product becoming highly smooth for well receiving the image-reception layer **302** for desired image-retransfer with trouble, which effect is superior in the art.

On the contrary, when such heat-fusible or heat adhesive sheet materials which may be called "heat bond sheets" as at **701** are not utilized, it is highly difficult to realize the image-retransfer operation onto certain kind of objects such as rough-surfaced or rough-meshed fabric or the like. Even if the retransfer job could be executed, the obtained images may be blurred and the adhesive may be insufficient, on account of the very thin thickness of the image-reception layer **302**, thus giving rise to technical and commercial troubles.

As for the heat fusible sheet **701** to be used in the foregoing manner, ethylene/vinyl acetate copolymer, nylon copolymer; epoxy/phenol copolymer; epoxy/vinyl copolymer; acrylic resin; polyester resin; or polyolefin resin and the like thermoplastic resins (heat sensible adhesive agents) which are formed into sheets or films may be used. These materials must be softened at 100°–250° C. or so to represent viscous adhesive characteristics. These materials are, when used, capable of being stuck to both the image-transferred product **330** and the image-carrying layer **302**.

These heat bond sheets **701** have generally thickness of 1–200 μm. When the surface of the product **330** to be decorated is relatively smooth, the sheet selected out may be of relatively thin thickness, while, on the contrary, when the surface of the decorative product **330** is relatively rough, as in the case of textile fabrics, unwoven fabrics, meshed fabrics or the like, use of thicker heat bond sheets is rather recommendable.

As set forth above, the use of heat bond sheets is highly recommendable in the decorative image-transfer onto rough surface products, such as those of rough fabrics, woven or non-woven, knitted clothes, meshed one or the like, thereby a better quality image-transfer being executed, in spite of the meshed or highly undulating surface conditions of the objects to be decorated.

Further in the present invention, during the adhering attachment of the image-reception layer already formed with necessary images onto the object or product, an additional processing step is preferably introduced for prevention of occasional interference in the foregoing adhering attachment

step, by rubbing-off or grinding-off part or whole of the parting layer, provided on the surface of the now image-carrying layer, upon completion of the sublimating image-transfer step.

Still further, in such a case that the image-transferable sheet is fitted with a protecting layer which is composed of a plastic resin film, the latter must in advance be subjected to punching or the like cutting step for cutting the film into desirously sized pieces.

FIG. **32** represents such a die-cut (half-cut) process in sectional schema. In this case, at first, as shown at (a) of FIG. **32**, the image-reception layer **302** of an image-transferable sheet **310**, now formed with necessary images through a sublimative image-transfer step, and the protecting layer **305**, are subjected to a die-cutting process by means of a cutter **801** to shape a desired shape. And then, as shown at (b) in FIG. **32**, the cut-out piece is subjected to a pressurizing step under heat by means of a pair of hot stamps **132'**; **133'** to provide a final decorative object, as shown at (c) in FIG. **32**, which is composed of a product **330** to be decorated, however, now attached integrally and jointly with image-carrying layer **302** and protecting layer **305**.

Applied Products

The products applicable with the inventive process for decorating purposes are not limited to occasionally employed kind, shape and nature of the materials. Preferred examples of the usable product may be: cartons; vessels or packages; bags; cassette cases; cassette halves; floppy cases; paper packages and envelopes; stock certificates; personal and bank cheques; bills; bonds; certificates; notifications; car tickets; travel tickets; betting tickets; tax stamps; postage stamps; entrance tickets, money-exchangeable papers and documents; cash-cards, credit cards, orange cards, telephone cards; member's cards; greeting cards; postcards, name cards; driver's certificates; IC-cards; optical cards and the like various cards; accounting cards and documents-envelopes; tags; OHP-sheets; slide films; bookmark slips; calendars; posters; pamphlets; menus; passports; POP-goods and articles; coasters; displays; nameplates; keyboards; cosmetics; personal ornaments (watches; cigarette lighters); stationaries; construction materials; radio-receiving sets; T.V.-sets; speakers; table calculators; automotive gauge boards; emblems; keys; clothes; wearing commodities; footwears; appliances; CA-instruments; sample books; tickets in general; albums; computer graphic and/or medicare graphic image printouts; and the like, where the material kinds, sizes and configurations are regardless for purposes of the invention.

The aforementioned goods and instruments may have printed or the like other images in advance of execution of the process of the invention. Or conversely, the goods and instruments can be formed with necessary images in accordance with the present process, and then, additional images may be formed in conventional printing or the like process.

As an example, when the invention is applied to a card style intermediate product, it is possible to combine image-forming means of the present invention with conventional recording means. As the latter, magnetic recording by use of a magnetic material layer; optical recording by use of an optical recording layer; preferably composed of a membrane having low melting point metal; application of hologram; embossing formation of characters and numerals; application of personal face photograph; engraved formation of personal face or the like; human signatures; recorded information with use of IC-memory; mechanical printing; formation of bar codes; formation of characters and patterns by use of printer, typewriter or pen plotter may be used independently or in any combination.

In the following, the present invention will be more fully described by way of preferred embodiments. In these embodiments, parts or % will be given by weight, not otherwise specifically referred to.

As the image transfer film (dye film) used for sublimating transfer onto the image-transferable sheets, a polyester film, 6 μm thick, subjected to a heat-resisting treatment on one surface thereof only, and bearing color ink composition areas of yellow, magenta and cyan, respectively, was used. The coating rate of the color ink composition was 1.0 g/m^2 when measuring at the dry state.

These color ink compositions were as follows.

Yellow ink composition	
polyvinyl butyral resin ("Eslek-BX-l", manufactured and sold by Sekisui Kagaku K. K., Tokyo)	4.80 parts
dispersion dye ("PTY-52, Disperse Yellow-141", manufactured and sold by Mitsubishi Kasei Kogyo Co., Ltd., Tokyo)	5.50 parts;
methyl ethyl ketone	55.00 parts;
toluene	34.70 parts;
(parting agent	1.03 parts)

Magenta ink composition	
polyvinyl butyral resin (same as above in the case of yellow color ink)	3.92 parts;
dispersion dye ("MS Red G, disperse red 60", manufactured and sold by Mitsui Toatsu K. K.)	2.60 parts;
dispersion dye ("Macrolex Red Violet R, Disperse Violet 26", manufactured and sold by Beyer A. G., West Germany)	1.40 parts;
methyl ethyl ketone	43.34 parts;
toluene	43.34 parts;
(parting agent	0.40 part)

Cyan color ink composition	
polyvinyl butyral resin (same as in said yellow color ink composition)	3.92 parts;
dispersion dye ("Kayaset Blue-714, solvent blue-63", manufactured and sold by Nippon Kayaku K. K., Tokyo)	5.50 parts;
methyl ethyl ketone	68.18 parts;
(parting agent	0.94 parts)

Each of the foregoing color ink compositions was prepared with and without addition of parting agent.

As the parting agent occasionally used in each of the foregoing color ink compositions, any of the following specific agents may be employed:

(a) silicone alkyd parting agent, "KR-5206", manufactured and sold by Shinetsu Kagaku Kogyo K.K., Tokyo;

(b) graft polymer of silicone and acryl, "GS-30", manufactured and sold by Toa Gosei Kagaku K.K.;

(c) silicone graft polymer, "US-3000", manufactured and sold by the above company;

(d) phosphoric acid ester, natrium salt, "RE-410", manufactured and sold by Toho Kagaku Kogyo K.K.;

(e) natural phosphoric acid ester, "Lecytin", manufactured and sold by Ajinomoto Co., Ltd., Tokyo;

(f) silicone oil, "KF 412", manufactured and sold by Shinetsu Kagaku Kogyo K.K., Tokyo;

(g) aluminum chelate agent, "ALM", manufactured and sold by Ajinomoto; and

(h) titanium chelate agent, "TTS", manufactured and sold by Nippon Soda K.K., Tokyo.

Example A-1

As the substrate, a laminate of a synthetic paper, "Yupo FPG 150 μm thick" manufactured and sold by Oji Yuka Co., Ltd., Tokyo, and a polyester film, 6 μm thick, was prepared and coated on the polyester film side surface by a wire bar with a mixture of pull-separating varnish, "Hakurinisu 45" manufactured and sold by Showa Ink Co., Ltd., Tokyo, with an ultra-violet absorbing agent, or more specifically, 2.5-bis (5'-tert-butylbenzoxazolyl (2))-thiofin, 0.5% based on the resin content of the varnish, and dried up to provide a protecting layer of 1 g/m^2, when weighed upon drying.

Then, on the surface of the foregoing protecting layer, an ink composition adapted for the formation of an image-reception layer was coatingly applied and dried up. The applied quantity amounted to 7 g/m^2 when measured upon drying.

Ink composition for the formation of image-reception layer	
polyester resin (manufactured and sold by Toyobo K. K.)	100 parts;
amino-modified silicone ("KF-393", manufactured and sold by Shinetsu Kagaku Kogyo K. K., Tokyo)	5 parts;
epoxy-modified silicone ("X-22-343", manufactured and sold by Shinetsu Kagaku Kogyo)	5 parts;
solvent (methyl ethyl ketone/toluene/ cyclohexanon 4/2/2)	900 parts.

The ink composition was coated, dried up and cured one day under normal temperature. Then, the layer was kept at 100° C. for 30 minutes under heat, for letting the silicone to bleed up to the surface, to provide an image-transferable layer formed on its surface with a hardened silicone layer.

On the thus-provided image-reception layer, a sublimating image-transfer film was overlapped which is composed of cyan color sublimative dye (molecular weight being higher than 250) carried by a proper binder resin and thermal energy is fed thereon from a thermal head adapted for receiving electric signals representing cyan color components obtained by a color analysis of a portrait photograph, as an example, for providing portrait images corresponding thereto. Then, two successive sublimative image-transfer jobs were executed with use of respective sublimating image-transfer films carrying sublimative magenta and yellow color dyes, each molecular weight being higher than **250**, and substantially in the manner set forth above. In this way, after all, an overall combined display image composed of a full color portrait, in combination with several characters and graphics, was provided.

The image-reception layer of the sheet, now carrying these display images, was overlapped on the card substrate composed of a polyester resin sheet, 100 μm thick, which had been primed to white-opaque state, and pressurized together at 160° C. by means of heated pressure rolls. Then, the polyester film was peeled off at the interface with the protecting layer, thereby providing a final product card transferrd with image-reception layer now carrying the desired image display.

It was found that the overall surface of the product card was generally smooth and showing no raised feeling of the thus-formed and displaying images. Even upon an accelerated testing of the product card for three months held in an atmosphere of 40° C., the images showed no blurrings as well as no interlayer separation. Further, according to an accelerated light-proof test carried out as prescribed in JIS-Standard with use of a carbon arc lamp, the results showed to be classified to JIS-4 or -5 corresponding to an acceptable superior performance. Additionally, a surface scratch test and the like showed also superior durability.

Example A-2

The foregoing image-transferable sheet, now image-carrying, as processed in Example A-1, is then subjected to a peel-off operation for separating the image-carrying layer from the sheet. Then, an adhesive agent of polyester series was coated on the exposed surface of the peeled-off film, and stuck under pressure on a curved surface part of a telephone set. The images could follow up to the stuck curvature into a unitary solid mass, and indeed, without inviting any stuck-on feeling, contrary to the case when a sticky loose-leaf stamp should have been stuck on. In this way, miracle viewing feelings as obtainable with direct-printing operation only, were created and maintained.

Example A-3

A white polyester film, baked on one surface thereof with melamine coating, "E 20", 100 μm thick, manufactured and sold by Toray Co., Ltd. Tokyo, is formed on the opposite surface with a slipping layer, same as in the following Example C-2, through application of polyurethane primer. And an identification mark was provided thereon through the way of regular printing technique. On the melamine resin-baked surface of the white polyester resin film, a layer of peeling varnish (of polymethyl methacrylate-series), manufactured and sold by Showa Inku. Co., Ltd., Tokyo) was applied in dry quantity of 2 g/m^2 and dried up to provide a definite layer.

On the thus-formed protecting layer, the following image-reception layer-forming composition was coated and dried up, so as to form an image-heat transferable sheet. The coated composition was in quantity of 6 g/m^2 by dry weight.

Image-reception layer-forming composition	
polyester resin ("Vylon 600", Tg: 47° C., manufactured and sold by Toyobo, Osaka)	80 parts;
polyester resin ("Vylon 290", Tg: 77° C., manufactured and sold by Toyobo)	20 parts;
amino-modified silicone ("KF-393", manufactured and sold by Shinetsu Kagaku Kogyo)	7 parts;
epoxy-modified silicone ("X-22-343", manufactured and sold by Shinetsu Kagaku Kogyo)	7 parts;
solvent (methyl ethyl ketone/toluene = 1/1)	800 parts.

On the image-reception layer of the foregoing heat image-transferable sheet, reversed images composed of full color portrait images together with characters and graphics by use of a thermal head, as in the same way with Example A-1, were formed.

Next, the image-reception layer, however, now carrying the reversed images formed in the foregoing manner was brought into contacting and overlapping state with the image displayable surface on a card style substrate made of white

color polyester resin, 125 μm thick, preparatorily primer treated as before, and pressurized together under the action of thermal rolls, and the white polyester film, 100 μm, was peeled off between the protecting layer and the melamine-baked layer, thus providing a final card-style product transferred with the image-reception layer now carrying the necessary images.

The surface of the final card style product represented a smooth and slippery, without fear of interlayer separation and with superior light resistant power.

Example A-4

A white foam polyester resin film, "Merinex", 125 μm thick, manufactured and sold by ICI, was provided with an identification mark on one surface thereof, with regular printing technique.

Then, on the opposite surface of the white foam polyester resin film to the foregoing surface formed with the identification mark, a coating of a polyurethane-series primer was applied and dried up. Further, the following protecting layer-forming composition was applied in dry quantity of 3 g/m^2 and dried up to form a protecting layer.

Protecting layer-forming composition	
acrylic polyole ("Acrit 6416MA", manufactured and sold by Taisei Kako K. K.)	41 parts;
toluene	36 parts;
methyl ethyl ketone	27 parts;
diisocyanate ("Colonate", manufactured and sold by Nippon Polyurethane K. K.)	6 parts.

On the above protecting layer, the following composition was applied in dry quantity of 3 g/m^2 and dried up, to provide an intermediate layer.

Intermediate layer-forming composition	
polyester resin ("Vylon 290", manufactured and sold by Toyo Boseki (Toyobo) K. K., Osaka)	15 parts;
toluene/methyl ethyl ketone = 1/1	85 parts.

On the thus-formed intermediate layer, an image-reception layer which is substantially same with that in the foregoing Example A-3 was provided, so as to form an image-transferable sheet. Then, as same in the foregoing Example A-3, correspondingly inverted images were formed on the image-reception layer and further then, subjected to transfer onto the card substrate by use of thermal rollers. In this way, a final product card, having an image transferable, yet now image-formed layer, was provided.

This card showed favorable results of light-resisting test. Further, it showed a better scratch test result than the foregoing card obtained in Example A-3.

Example A-5

Substrate

A white polyester film, "E-20", 100 μm thick, manufactured and sold by Toray Co., Ltd., Tokyo, was used.

Intermediate layer-forming composition	
Polyester resin ("Vylon 600", manufactured and sold by Toyo Boseki K. K., Osaka)	15 parts;
toluene/methyl ethyl ketone = 1/1 (dry weight: 5 g/m^2)	85 parts.

Protecting layer-forming composition	
"Hakuri-Nisu" (acrylic resin varnish, manufactured and sold by Showa Ink K. K.) (dry weight)	2 g/m^2

Image-reception layer-forming composition	
polyester resin ("Vylon 600", manufactured and sold by Toyo Boseki K. K., Osaka)	10 parts;
polyester resin ("Vylon 200", supplied by Toyo Boseki K. K.)	5 parts;
toluene/methyl ethyl ketone = 1/1	85 parts;
amino-modified silicone ("KF-393", manufactured and sold by Shinetsu Kagaku Kogyo)	1 part;
epoxy-modified silicone ("X-22-343", supplied by Shinetsu Kagaku Kogyo)	1 part.
(coated quantity (dry)	5 g/m^2)

With use of the foregoing composition and processed in similar way as in Example A-3, to provide a final card product, having an image-reception layer transferred with necessary images.

Example A-6

Substrate

White polyester resin film, "E-20", 100 μm thick, manufactured and sold by Toray was coated with polyurethane-series primer and dried up.

Parting layer-forming composition	
melamine resin ("Meran 45", manufactured and sold by Hitachi Kasei)	100 parts;
hardener (para-toluenesulfonic acid)	20 parts;
(coating quantity (dry), 2 g/m^2)	

Protecting layer-forming composition	
vinylchloride-vinylacetate ("Vinylite VYHH", manufactured and sold by Union Carbide Corp.)	15 parts;
methyl ethyl ketone = 2/1	85 parts;
(coating quantity (dry): 2 g/m^2)	

Intermediate layer-forming composition	
polyurethane resin ("Takelac T-3350", manufactured and sold by Takeda Pharmaceutical Company, Osaka, of 23%-concentration)	50 parts;
isopropyl alcohol	15 parts;
toluene	25 parts;
methyl ethyl ketone	10 parts.
(coating quantity (dry) 5 g/m^2)	

Image-reception layer composition	
polystyrene resin ("Picolastic D125" (Tg = 53° C.), manufactured and sold by Hercules	15 parts;
toluene/methyl ethyl ketone = 1/1	85 parts;
amino-modified silicone ("KF-393", manufactured and sold by Shinetsu Kagaku)	1 part;
epoxy-modified silicone ("X-22-343", manufactured and sold by Shinetsu Kagaku)	1 part.
(coating quantity (dry): 6 g/m^2)	

The foregoing composition was prepared and used as in the same manner with Example A-3, to provide a card with the image-reception layer subjected to image-transfer as desired.

Example B-1

As the substrate, a polyester resin film, 6 μm thick, was used and a polyester resin-series primer was coated on one surface thereof and dried up. Further, the following ink composition was applied and dried up. The coating quantity of the composition was set to about 7 g/m^2.

Image-reception layer-forming composition	
polyester resin ("Vylon 200", manufactured and sold by Toyo Boseki K. K.)	100 parts;
amino-modified silicone ("KF-393", manufactured and sold by Shinetsu Kagaku)	5 parts;
epoxy-modified silicone ("X-22-343", manufactured and sold by Shinetsu Kagaku)	5 parts;
solvent (methyl ethyl ketone/toluene/ cyclohexanone = 4/2/2)	900 parts.

The ink composition was coated, dried up and left standing for a full day, and then subjected to heat treatment at 100° C. for 30 minutes, so as to bleed the silicone towards the film surface for providing thereon an acceptable image-reception layer composing the active surface.

Then, a sublimative image-transferable film, composed of a resin binder evenly mixed with a proper amount of sublimative cyanic dye, the molecular weight being higher than 250, was overlapped on the above image-reception layer and applied with heat energy by means of a thermal head supplied with electric signals corresponding to cyanic color components of a portrait full color photograph as determined by regular color analysis, thus providing cyanic color component images.

Next, as for magenta and yellow color components, similar respective processings were executed and finally, full color display portrait images could be formed.

Then, the exposed surface of image-reception layer of the thus-display image-formed film was overlapped on a card substrate composed of a white opaque, hard vinyl chloride resin sheet, 100 μm thick and pretreated with a conventional primer, and then this assembly was subjected to heat and pressure by means of a pair of heated rolls. In this way, a card product stuck with an image-transferable and now carrying layer was provided.

The surface of this card was generally smooth and slippy, the thus-formed images thereon providing no raised feelings. In an accelerated test of these formed images in hot atmosphere of 40° C. for a continuous period of three months, there were no appreciable image blurring and interlayer separation. Upon execution of a light exposure test in accordance with prescribed conditions in JIS with use of an arc lamp, the results were classified to JIS-4 to 5 Classes which means as acceptable and better image quality. Scratch test results were also superior.

Example B-3

A sticking layer, 1 μm thick, was formed with a polyamide resin sticking agent on the image-carrying surface of the image-transferable sheet, image-formed in the manner as described in foregoing Example B-1, and the thus provided sheet was stuck on the curved surface of a glass tumbler. These images express practically no stuck-on feelings, rather providing such a touch and viewing feeling as if they had been formed by the regular and direct printing technique.

Example C-1

With use of the image-transferable sheet prepared in the foregoing Example A-1, images were formed substantially in accordance with procedures mentioned therein, however, with exception of the formation of reversed images, and then, the image-carrying layer was, without execution of the foregoing peel-off operation, stuck on a portion of curved outer surface of a glass tumbler, whereupon the sheet-like substrate was peeled off, together with the weak-sticking layer. The thus-applied images represent almost no sticking-on grip and viewing feeling, as if they should have been applied through regular and direct-printing technique.

Example C-2

On the surface of a transparent polyester film, 12 μm thick, employed as a protecting film, the following image-reception layer forming composition was applied to form a coated layer (in quantity of 6 g/m^2 when measuring upon drying), dried up and left as it was for full one day. Then, it was held at 100° C. for 30 minutes, to form an image-reception layer. On the surface thereof, a parting surface layer was found to exist, which was composed of a combined hardened product of amino-modified silicone resin and epoxy-modified silicone resin.

Image-reception layer-forming composition	
polyester resin ("Vylon 600", manufactured and sold by Toyo Boseki)	100 parts;
amino-modified silicone resin ("KF-393", manufactured and sold by Shinetsu)	7 parts;
epoxy-modified silicone resin ("X-22-343", manufactured and sold by Shinetsu)	5 parts;
solvent (methyl ethyl ketone/toluene = 1/1)	800 parts.

As the substrate, on the other hand, white polyester resin film, "E-20", 75 μm, manufactured and sold by Toray, was used and coated on one surface thereof with a polyurethane-series primer and dried up. Then, the following composition (in the dried quantity of 1 g/m^2) and dried up, so as to

provide a smooth and stick layer.

Smooth layer-forming composition	
polymethyl methacrylate resin ("Dianal BR-85", manufactured and sold by Mitsubishi Rayon Co., Ltd., Tokyo	12 parts;
polyethylene wax ("MF8F", manufactured and sold by Dulacon Co.)	0.5 part;
toluene/methyl ethyl ketone = 1/1	85 parts.

On the opposite surface of the white-polyester resin sheet to the smoothed surface there, a primer coating of polyurethane-series is applied and dried up, and further coated thereon with the following composition, in quantity of 3 g/m^2, so as to provide a weak-sticky layer.

Weak-sticky layer-forming composition	
weak-sticky adhering agent ("Esdyme AE-206", manufactured and sold by Sekisui Kagaku Kogyo K. K., Tokyo)	50 parts;
water	50 parts.

The weak-sticky adhering layer is brought into contact with the protecting film consisting of a polyester film, 12 μm thick, at the opposite surface to the image-reception layer, and then subjected to heat and pressure, to provide an image-transferable sheet. Upon bringing the image-reception layer of the image-transferable sheet and the dyestuff layer of the heat-image transfer sheet into contact with each other, heat energy was applied from a thermal head, as in the similar manner mentioned in the foregoing Example A-1, and thus heat image-transfer job was executed, so as to provide reversed mode images for expressing a full color portrait as well as characters and graphics.

Next, the image-reception layer formed with the reversed images thereon was overlapped onto the image-displayable surface of a card style substrate, 100 μm thick, made of a white color polyester resin material preparatorily applied with a primer layer by coating a composition, consisting of "Vylon 200", 100 μm thick, manufactured and sold by Toyo Boseki K.K., and then subjected together to heat and pressure by means of at least a heated roll at 160° C. Then, the white polyester film, 75 μm thick, and the weak-sticky adhesive layer were peeled off in unison, for providing a final decorative product card having the image-reception layer transferred with images and carrying dislay images.

This card had a highly smooth surface and was not liable to invite any interlayer separation and showed superior light fastness.

In place of white color polyester-made card substrate preparatorily formed with a primer layer, such a modification was prepared and experimented that the white polyester sheet was formed on its rear surface with a magnetic layer, while, on its front surface there is formed with a write-on layer which consists of proper filler and resin as conventionally, so as to provide a telephone card. This processed telephone card had the write-on layer provided with display images formed by image-transfer.

Example C-3

On the surface of a transparent polyester film, 9 μm thick, used as the protecting layer, an intermediate layer was provided by coating. The coated amount was 5 g/m^2 as measured upon being dried up.

Intermediate layer-forming composition	
polyurethane resin ("Takelack T-3350", solid content 23%, manufactured and sold by Takeda Pharmaceutical Co., Ltd., Osaka)	50 parts;
isopropyl alcohol	15 parts;
toluene	25 parts;
methyl ethyl ketone	10 parts.

Onto the intermediate layer, the following composition was applied for the formation of an image-reception layer. The coated quantity was 5 g/m^2 as measured upon being dried up.

Image-reception layer-forming composition	
polyester resin ("Vylon 600", manufactured and sold by Toyo Boseki)	10 parts;
polyester resin ("Vylon 200", manufactured and sold by Toyo Boseki)	5 parts;
amino-modified silicone ("KF-393", manufactured and sold by Shinetsu)	1 part;
epoxy-modified silicone ("X-22-343", manufactured and sold by Shinetsu)	1 part;
solvent (methyl ethyl ketone/toluene = 1/1)	85 parts.

On the other hand, a white color polyester film, which was similar to that employed in the foregoing Example C-2 was formed with a slidingly smooth layer, as well as a weak-sticking adhesive layer, the latter being brought into intimate contact with a transparent polyester film, 9 μm thick, at the opposite surface to the image-reception layer and then, subjected to heat and pressure, for providing a heat image-transferable sheet. As further processed in the similar manner in the foregoing Example C-2, full-color photographic images (reversed images) were thus formed on the image-reception surface. In this way, a final product card, having its image-reception layer transferringly formed with display images.

Example C-4

Substrate

White color polyester sheet, "E-20", 100 μm thick, manufactured and sold by Toray was formed thereon with a polyurethane-series primer coating. Then, a weak-sticking layer was applied thereon with use of the following composition.

Weak-sticking layer-forming composition	
weak-sticking agent ("Esdyne AE-206", manufactured and sold by Sekisui Kagaku Kogyo K. K., Tokyo)	50 parts;
water	50 parts.

Protecting layer-forming composition	
polyester resin ("Vylon-200", manufactured and sold by Toyo Boseki)	15 parts;
diisocyanate ("Colonate L", manufactured and sold by Nippon Polyurethane Co., Ltd.)	1 part;
toluene/methyl ethyl ketone = 1/1	84 parts.

Image-reception layer-forming composition	
polyester resin ("Vylon 600", manufactured and sold by Toyo Boseki K. K.)	10 parts;
vinyl chloride-vinyl acetate copolymer resin ("Vinylite VAGH" (Tg = 79° C.), manufactured and sold by Union Carbide Corp)	5 parts;
toluene/methyl ethyl ketone = 1/1	85 parts;
amino-modified silicone ("KF-393", manufactured and sold by Shinetsu)	1 part;
epoxy-modified silicone ("X-22-343", manufactured and sold by Shinetsu)	1 part.

With use of the above composition and processed substantially same as in the foregoing Example C-2, a final card product was obtained.

Example D-1

An image-transferable sheet was prepared as in the foregoing Example A-1 and thermally image-transferred with reversed mode images of a full color portrait photograph, to provide an intermediate image-transfer medium. The latter is overlapped by its image-reception layer onto the surface of a sheet of rough-textured cotton cloth, however, through the intermediary of an acrylic acid ester-vinyl acetate copolymer sheet, 100 μm thick. Then, the assembly was subjected to heat and pressure. Then, the substrate sheet and weak-sticky adhesive layer, together, were peeled off. The thus transfered images have sufficient surface smoothness, showing superior surface conditions.

Without use of the bond-attaching sheet in the above process and when similar image-transfer job as above was performed, the resulted images followed the surface undulations appearing disadvantageously on the material product of the rough fabrics and thus were highly uneven, and further, on account of insufficient adhering performance acting between the image-receiving layer and the woven fabrics serving as product material, easy and frequent separations took place therebetween.

Example D-2

In the similar way as was disclosed in the foregoing Example D-1, an intermediate image-transfer medium carrying reversed images was prepared and overlapped on a polymethacrylate board preparatorily subjected to surface-roughening operation through a conventional sand-blasting step, and through the intermediary of a bond-adhering sheet pressurized together under heat, as was employed in Example D-1. Then, the sheet-like substrate was peeled off, together with the weak adhesive layer. The thus-provided images were highly smooth and even in spite of the highly rough and undulating conditions at the surface to be image-transferred. In addition, the image-carrying surface showed superior results in various resisting tests.

Without use of the foregoing bond-sticking layer, the similarly transferred images showed considerable undulations and distortions. Further, on account of insufficient adhering performance, easy and frequent peel-offs of applied images were feared.

Example D-3

On the surface of a polyester resin film, 25 μm thick, the following composition adapted for the formation of bond-sticking layer was coated and dried up, in dried quantity of 5 g/m^2, to provide a film formed thereon a bond sticking sheet.

Bond-sticking sheet-forming composition	
polyester resin ("Vylon 600", manufactured and sold by Toyo Boseki)	15 parts;
methyl ethyl ketone/toluene = 1/1	84 parts.

The bond-sticking sheet surface, together the polyester resin film proper, was brought into contact with the image-representing surface of a white color polyester made-card substrate, 25 μm thick, and then, subjected to heat and pressure by means of at least a heat roll kept at 200° C., arranged to supply heat energy from the side of the polyester resin surface, thereby heat bonding the bond-sticking sheet onto the card surface, whereupon the polyester resin film being forcedly peeled off.

Further then, as in the similar way as adopted in foregoing Examples C-2; A-3; A-4 and C-3, use is made of the image-reception layers representing reversed images thereon, the respective image-reception layers were whereupon brought into contact with the card's bond-sticking surface of the card and subjected to heat and pressure by use of at least a heat roll kept at 200° C. Then, the white color polyester resin substrate was peeled off, together with the weak-sticky adhering layer. In this way, a final product card displaying the portrait photograph was obtained.

Example D-4

Substrate

A white color polyester resin sheet, "E-20" 100 μm thick, manufactured and sold by Toray Co. Ltd., was coated with a polyurethane-series primer. On the surface of the thus precoated sheet, the following composition was coated to form a weak-sticking adhesive layer.

Weak-sticking adhesive component	
weak-sticking adhesive agent, ("Esdyne AE-206", manufactured and sold by Sekisui Kagaku)	50 parts.

Image-reception layer-forming composition	
polyester resin ("Vylon 200", manufactured and sold by Toyo Boseki)	7.5 parts;
polyester resin ("Vylon 290", manufactured and sold by Toyo Boseki)	7.5 parts;
toluene/methyl ketone = 1/1	85 parts;
amino-modified silicone ("KF-393", manufactured and sold by Shinetsu)	1 part;
epoxy-modified silicone ("X-22-343", manufactured and sold by Shinetsu)	1 part.

The foregoing compositions were prepared. On the other hand, a polyester resin film, 25 μm thick, was coated on one

surface thereof with a 15%-solution of polyester resin, "Vylon 200", manufactured and sold by Toyo Boseki, in toluene/methyl ethyl ketone=1/1 and dried up. The coating quantity was adjusted to 5 g/m^2 when measuring in dried state. In this way, a bond-sticking sheet was provided.

Then, the coated surface of the thus prepared bond-sticking sheet was brought into contact with the image display surface of a card style substrate of white color hard vinyl chloride or the like resin material preparatorily subjected to a primer coating treatment in overlapping state and then, the whole assembly was subjected to heat and pressure with use of at least a heated roll to 130° C., thus the bond-sticking layer being stuck on the card surface. Under this condition, the polyester resin film, 25 μm thick, was peeled off.

Then, the image-reception layer, now carrying thereon reversed images, was brought into contact with the bond-sticking sheet and the resulted whole was subjected to heat and pressure by use of at least a heated roll and the white color polyester resin substrate, together with the weak-sticking adhesive layer, was peeled off. In this way, the card, now displaying the portrait images, was provided.

Example D-5

Substrate

Same as in the foregoing Example D-4.

Weak-sticking adhesive layer

Same as in the foregoing Example D-4.

Protecting layer-forming composition	
polyester resin ("Vylon 200", manufactured and sold by Toyo Boseki)	15 parts;
diisocyanate ("Colonate L", manufactured and sold by Nippon Polyurethane)	1 part;
toluene/methyl ethyl ketone = 1/1	84 parts.

Image-reception layer-forming composition	
polyester resin ("Vylon 600", manufactured and sold by Toyo Boseki)	10 parts;
toluene/methyl ethyl ketone = 1/1	85 parts;
amino-modified silicone ("KF-393", manufactured and sold by Shinetsu)	1 part;
epoxy-modified silicone ("X-22-343", manufactured and sold by Shinetsu)	1 part.

With use of the foregoing materials and compositions, the processings were carried out as in the foregoing Example D-4, to provide a final product card displaying portrait images as was desired.

Example D-6

Substrate

Same as in the foregoing Example D-4.

Weak-sticking adhesive layer

Same as in the foregoing Example D-4.

Image-reception layer-forming composition	
polyester resin ("Vylon 600", manufactured and sold by Toyo Boseki)	10 parts;
vinyl chloride-vinyl acetate copolymer resin ("Vinylite VAGH", manufactured and sold by Union Carbide Corp.)	5 parts;
toluene/methyl ethyl ketone = 1/1	85 parts.

The foregoing materials and compositions were prepared and processed in the similar way as in the foregoing Example D-4, to provide a final product card, displaying the desired portrait images as were desired.

Example E-1

On a polyethylene terephthalate film, 9 μm thick, a solution of saturated polyester resin, "Vylon 600", manufactured and sold by Toyo Boseki, in toluene/methyl ethyl ketone=1/1, was coated by reliance of the known reverse roll-coating process, and dried up. The coated quantity was 7 g/m^2 when measuring in dry condition. In this way, a weak-sticking adhesive layer could be formed.

On the weak-sticking adhesive layer, the following composition, 3 g/m^2 (dry), was coated by means of an oblique-lined gravure roll for solid and full printing use and in the reverse roll-coating process, and then dried up, to provide an image-reception layer.

Image-reception layer-forming composition	
polyester resin ("Vylon 200", manufactured and sold by Toyo Boseki)	70 parts;
polyester resin, ("Vylon 290", manufactured and sold by Toyo Boseki)	30 parts;
amino-modified silicone ("KF-393", manufactured and sold by Shinetsu)	5 parts;
epoxy-modified silicone ("X-22-343", manufactured and sold by Shinetsu)	5 parts;
methyl ethyl ketone (wt. ratio 1/1)	700 parts.

On the opposite surface to the image-reception layer of the thus-prepared image-transferable sheet, a synthetic paper substrate, "Yupo FPG 110", 110 μm thick, manufactured and sold by Oji Yuka K.K., coated with "Vylon 600" as the adhesive agent in quantity of 10 g/m^2 (dry) was stuck intimately together.

On the other hand, a polyethylene terephthalate film substrate, 6 μm thick, preparatorily provided on one surface thereof with a heat-resisting layer was used and the following composition was applied on the opposite surface of the substrate with use of a wire bar and dried up, in the quantity of 1 g/m^2 (dry), so as to provide a dyestuff layer. In this way, a heat image-transferable sheet was prepared and provided.

Dyestuff layer-forming composition	
dispersion dye ("Kayaseo Blue-136", manufactured and sold by Nippon Kayaku K. K.)	4 parts;
ethylhydroxyethyl cellulose	6 parts;
methylethylketone/toluene (wt. ratio: 1/1)	90 parts.

The dyestuff layer of the foregoing heat image-transfer sheet was brought into contact with the image-reception layer of the image-transferable sheet in overlapping manner, then, heat energy was applied from a thermal head from the side of heat-resisting layer of the heat image-transfer sheet, thereby dyestuff being transferred to the image-reception layer of image-transferable sheet, and indeed, for the formation of positive images.

Then, the image-transferable sheet, now carrying the required positive images was stuck together under heat and pressure at 140° C. for 5 seconds on the intermediate image-transfer substrate prepared in the following manner, in mutually opposed manner. Then, the synthetic paper "Yupo" was peeled off at the intersurface between the polyester resin film and the "Vylon 600" layer. In thus way, the inventive image-transfer sheet (intermediate image-transfer medium) carrying the corresponding reverse images was provided.

Method for the preparation of intermediate image-transfer substrate

A sheet of fine quality or stick paper, unit weight: 82 g/m^2 was applied with a coating, about 20 μm thick, of polyethylene resin through conventional extrusion coating process. Thereon, further, a catalyst-added toluene solution of a parting agent silicone, "KS-707", manufactured and sold by Shinetsu was applied and dried up in quantity of about 2 g/m^2 (dry), for the purpose of curing. Thereon, still further, the following coating liquid composition was applied by means of a conventional coating bar and dried up, to provide an intermediate image transfer substrate. The thus coated and dried resin quantity was measured to 7 g/m^2.

Coating liquid composition	
polyester resin ("Vylon 200", manufactured and sold by Toyo Boseki)	100 parts;
methyl ethyl ketone/toluene (mixing ratio by weight: 1/1)	700 parts.

A sheet of coated paper, pretreated for pore-filling, was coated, in the similar manner as above, with the foregoing liquid composition, to provide an image-transferable medium. On and with the presently coated surface, the image carrying surface of the foregoing intermediate image-transfer medium is brought into opposing contact and stuck together under heat and pressure at 140° C. for 7 seconds. Finally, the laminate of fine-quality paper and polyethylene was peeled off, to provide a final decorative product now displaying the positive images as required.

It will thus be seen that by adopting the above processing steps, the positive images formed under the action of the thermal head are transferred, through the intermediary of intermediate image transfer medium, onto the final object to be decorated, and indeed, in the form of positive mode. It will be further seen that, since the dyestuff is well distributed within the image-reception layer, the transferred positive images are highly sharp and fresh, in addition to much profundities.

Since a resin layer was overlappingly applied on the thus-formed images, weather fastness, frictional durability and light-fastness of the finally formed images could be highly and amazingly improved. When suitable ultraviolet absorbing agent, antioxydant, quenching agent and/or radical scavenger is added to, further improvement of the light-fastness can be attained.

Example E-2

The substrate of image-transferable medium adopted in the foregoing Example E-1 was replaced by a hard polyvinyl chloride card, 100 μm thick, and other processing modes were same as in Example E-1. In this way, a high quality, positive-image transferred, decorative final product was successfully provided. When the image include human portrait photograph, the final product was highly useful for ID-card.

Example E-3

The substrate of image-transferable medium adopted in the foregoing Example E-1 was replaced by a transparent polyester film, and other processing modes were same as employed therein. In this way, a transparent film formed with the wanted positive images of better quality as before was obtained. This film was highly useful in OHP-services.

Example E-4

A sheet of high quality paper, unit weight: 104 g/m^2, was coated with a layer of polypropylene resin, thickness: about 20 μm, through the way of conventional extrusion coating technique, then the coating was further coated with a silicone solution for use in parting service and hardenable under electron rays and dried up. The quantity of the coating silicone was about 1 g/m^2 upon drying. In this way, an electron-hardened, provisional substrate was provided. On this substrate, the following, image-reception layer-forming composition was applied as a layer by use of a coating bar, and then dried up, for providing an image-reception layer. The coated resin quantity in the above last step amounted about 5 g/m^2.

Image-reception layer-forming composition	
polystyrene ("Picolastic D 150" (Tg = 69° C.), manufactured and sold by Rika-Hercules Co., Ltd.	100 parts;
amino-modified silicone ("KF-393", manufactured and sold by Shinetsu)	7 parts;
epoxy-modified silicone ("X-22-343", manufactured and sold by Shinetsu)	7 parts.

Further processing was carried out as was set forth in the foregoing Example E-2, for providing a final product card, carrying thereon the wanted positive images of same superior quality, as was in Example E-2.

Example E-5

On the image transferable medium used in the foregoing Example E-4, however, in the present Example, a thermoplastic resin, adhesive, polyolefine-series film, "Adwin

500", manufactured and sold by Showa Denko K.K., Tokyo, was applied as a layer. Other materials were used and processed as set forth therein. In this way, a decorative final product formed with necessary positive was obtained with superior results.

Industrial Availabilities

As will be well understood from the foregoing detailed description of the invention, it is possible according to the present inventive system, to form highly easily and evenly the desired images sharply and attractingly on any product and object to be decorated or graphically ornamented, substantially irrespective of material kind and configuration thereof, and indeed, with a surprising unitary touch and feeling with the substrate. Therefore, the invention can be utilized broadly and conveniently in such various industrial fields, where unitary formation of various images, characters, symbols, numerals and graphics, on and to the articles, objects and substrate products to a sufficiently miracle and attracting degree.

We claim:

1. A sublimatingly image transferred product comprising:

a plastic card; and

an image-reception layer containing a releasing agent provided on said plastic card,

said image-reception layer being directly formed on said plastic card by thermal fusion, and said image-reception layer having a transferred image formed by sublimation transfer, said transferred image being formed on the plastic card surface side.

2. The sublimatingly image transferred product of claim **1**, further comprising a protective layer formed on said image-reception layer.

3. The sublimatingly image transferred product of claim **2**, wherein said protective layer contains an ultraviolet absorbing agent and/or a photostabilizer.

4. The sublimatingly image transferred product of claim **2**, wherein said protective layer comprises a resin selected from the group consisting of an alkyd resin, a phenol-modified alkyd resin, an aminoalkyd resin, a phenol resin, a urea resin, a melamine resin, a silicone resin, a thermosetting resin, a cold setting resin, an actinic lay hardenable resin, and a thermoplastic resin.

5. The sublimatingly image transferred product of claim **4**, wherein said thermoplastic resin comprises a resin selected from the group consisting of a polyester resin, a polyurethane resin, a polyvinyl acetate resin, a vinyl chloride-vinyl acetate copolymer, a polyolefin resin, and an acrylic resin.

6. The sublimatingly image transferred product of claim **1**, wherein said image-reception layer comprises a resin selected from the group consisting of a polyester resin, a polyacrylic ester resin, a polycarbonate resin, a polyvinyl acetate resin, a styrene-acrylate resin, a vinyltoluene-acrylate resin, a polyurethane resin, a polyamide resin, a polycaprolactone resin, a polystyrene resin, a polyvinylchloride resin, and a polyacrylonitrile resin.

* * * * *

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United States Patent [19]

Estelle et al.

[11] Patent Number: 5,589,989

[45] Date of Patent: * Dec. 31, 1996

[54] **COMPACT OBJECTIVE LENS SYSTEM**

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[73] Assignee: **Eastman Kodak Company**, Rochester, N.Y.

[*] Notice: The term of this patent shall not extend beyond the expiration date of Pat. No. 5,572,369.

[21] Appl. No.: **84,387**

[22] Filed: **Jun. 29, 1993**

[51] **Int. Cl.**[6] **G02B 9/14**

[52] **U.S. Cl.** **359/785**; 359/788; 359/790

[58] **Field of Search** 359/785, 788, 359/790

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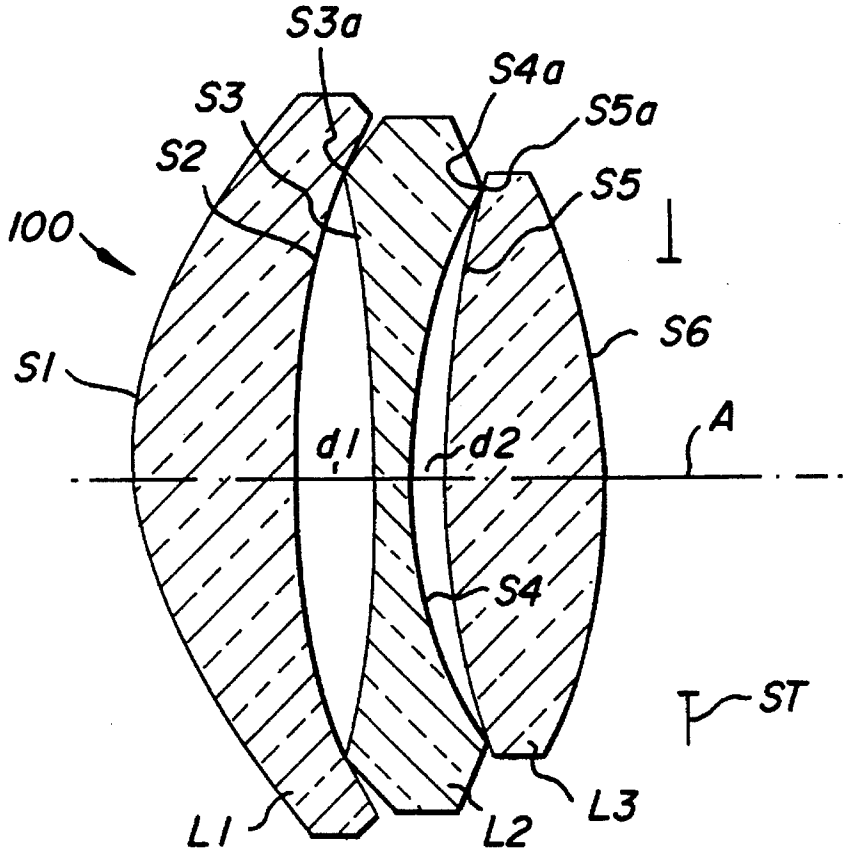
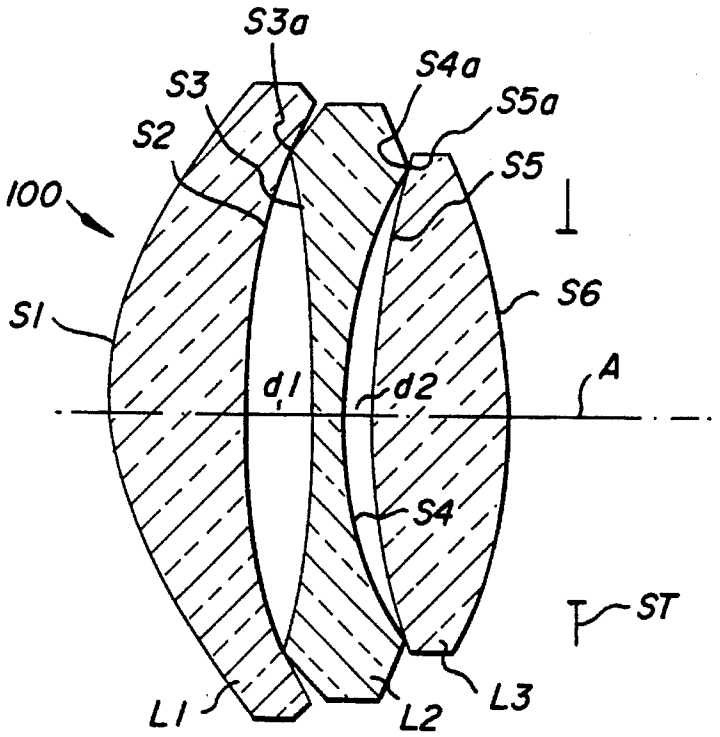
Primary Examiner—Georgia Y. Epps
Assistant Examiner—Jacqueline M. Steady
Attorney, Agent, or Firm—Svetlana Z. Short

[57] **ABSTRACT**

A compact objective lens with a diaphragm arranged behind the lens system suitable for use in very compact photographic cameras. The objective lens comprises a plurality of components arranged in a triplet or a triplet type configuration and is capable of covering at least a 55 degree field of view.

34 Claims, 6 Drawing Sheets

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S4a
S5a
S3
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S6
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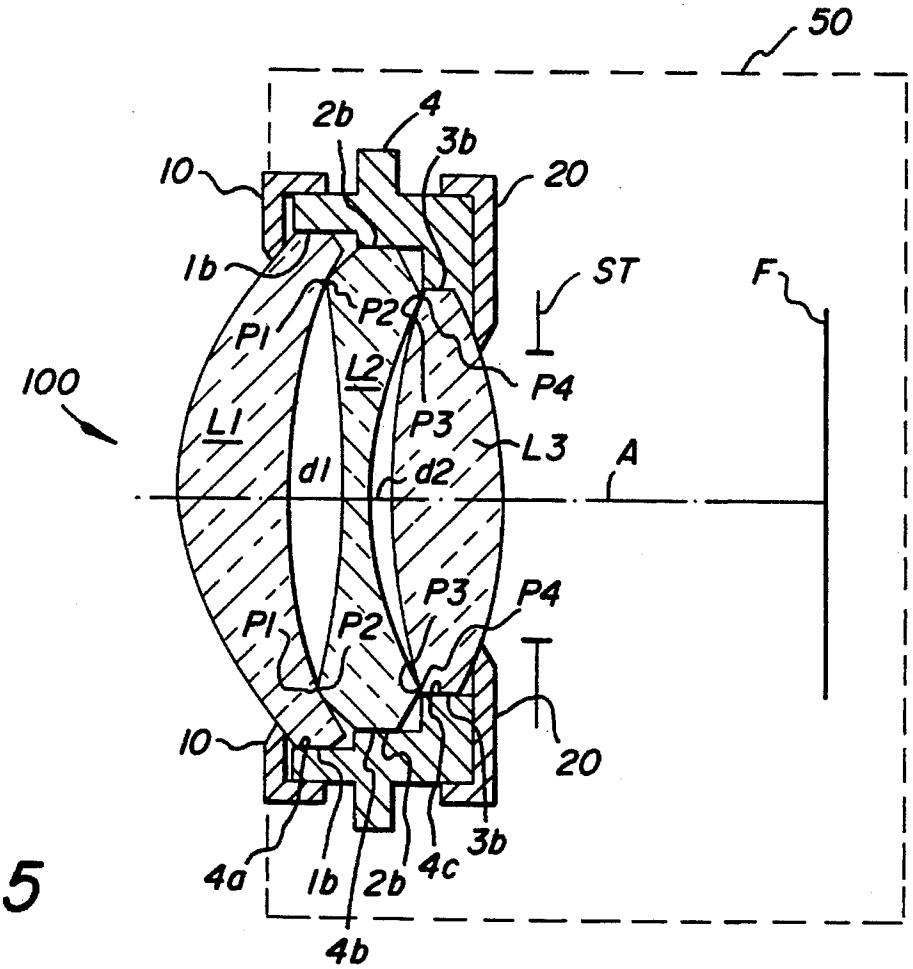
d1
d2
S4
ST
L1
L2
L3

FIG. 1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1b
ST
F
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L1
P3
L3
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d1
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P4
P1
P2
10
20
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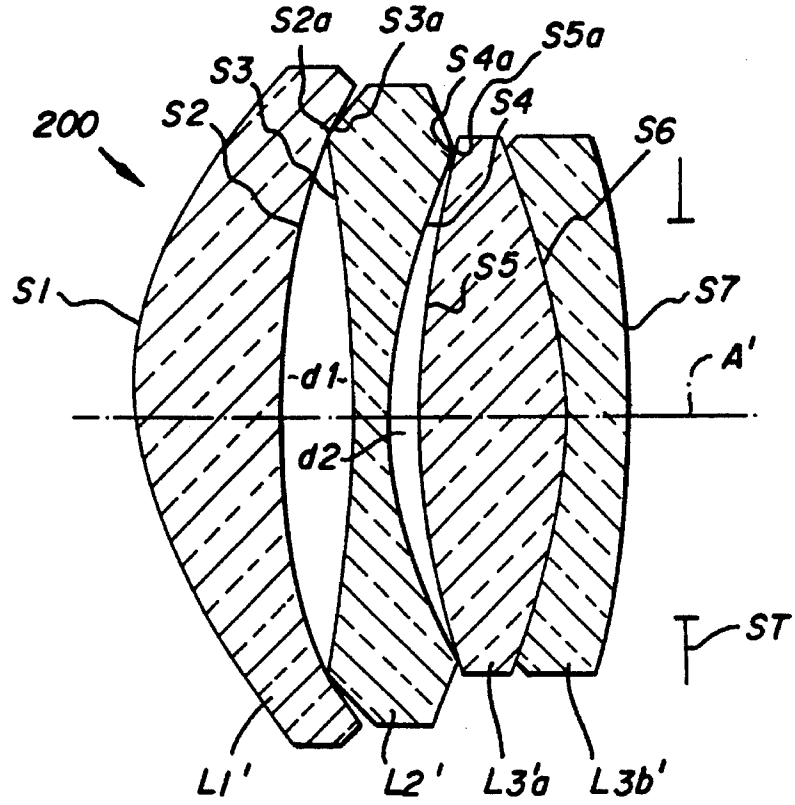
4a
1b
2b
4c
4b

FIG. 5


S2a
S3a
S5a
S3
S4a
S4
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S2
S6
S5
S1
S7
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d1
d2
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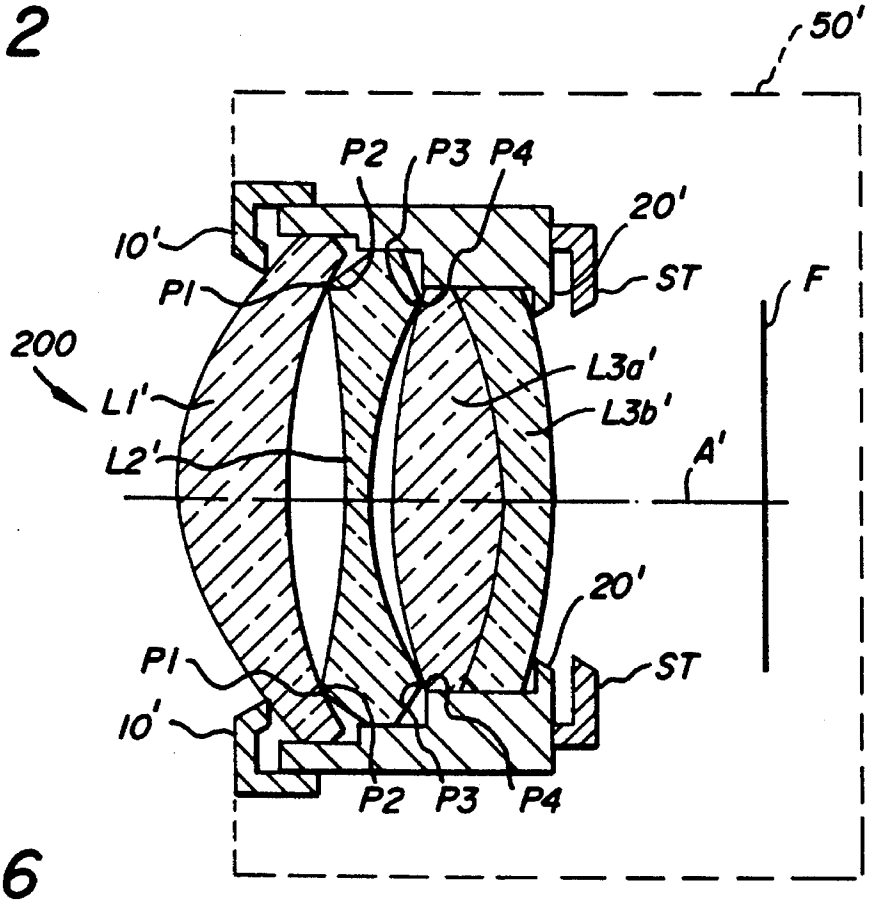
L1'
L2'
L3'a
L3b'

FIG. 2


50'
P2
P3
P4
20'
10'
ST
P1
F
200
L3a'
L1'
L3b'
L2'
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P3
P4

FIG. 6

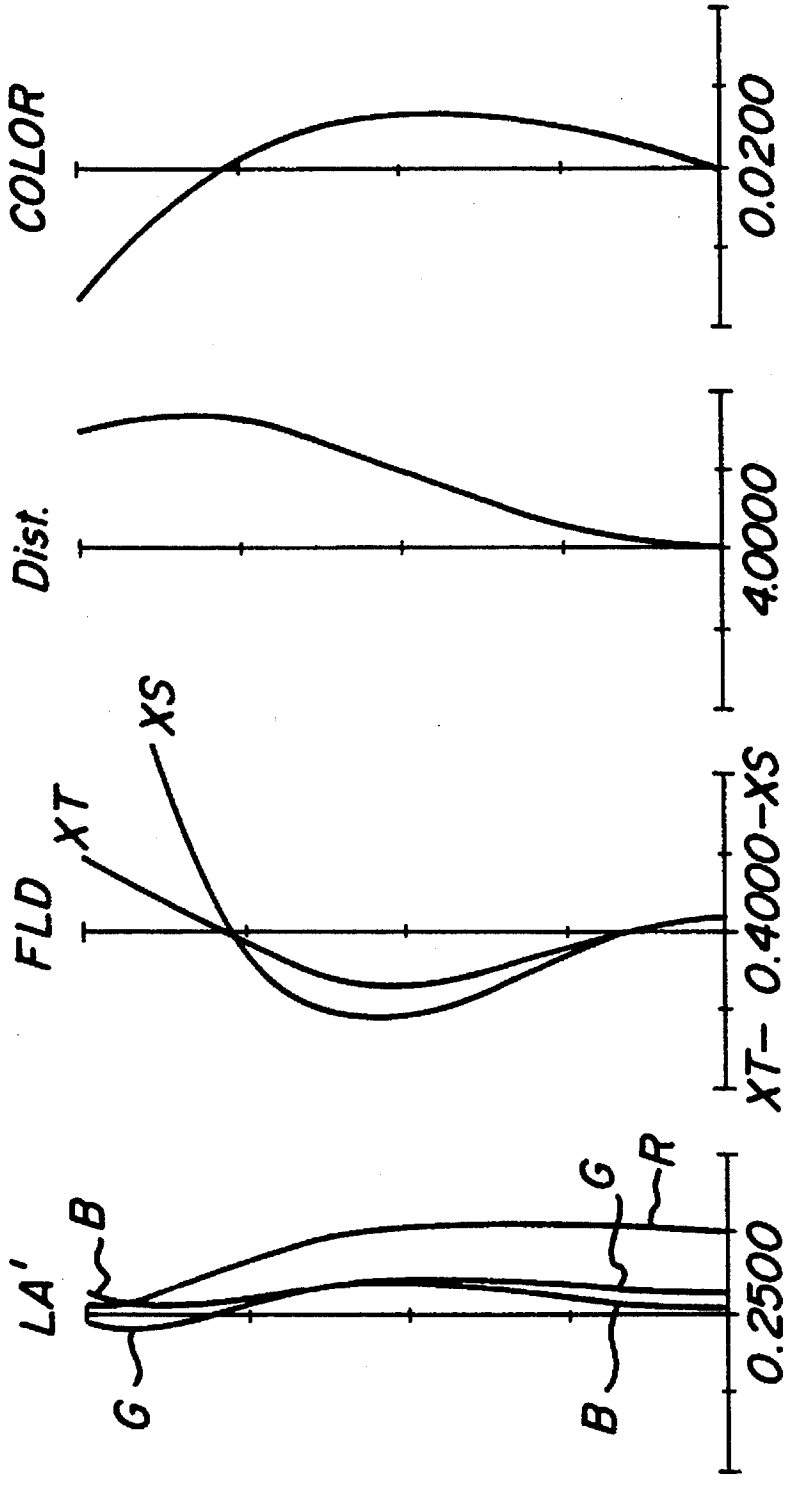

FIG. 3d FIG. 3c FIG. 3b FIG. 3a

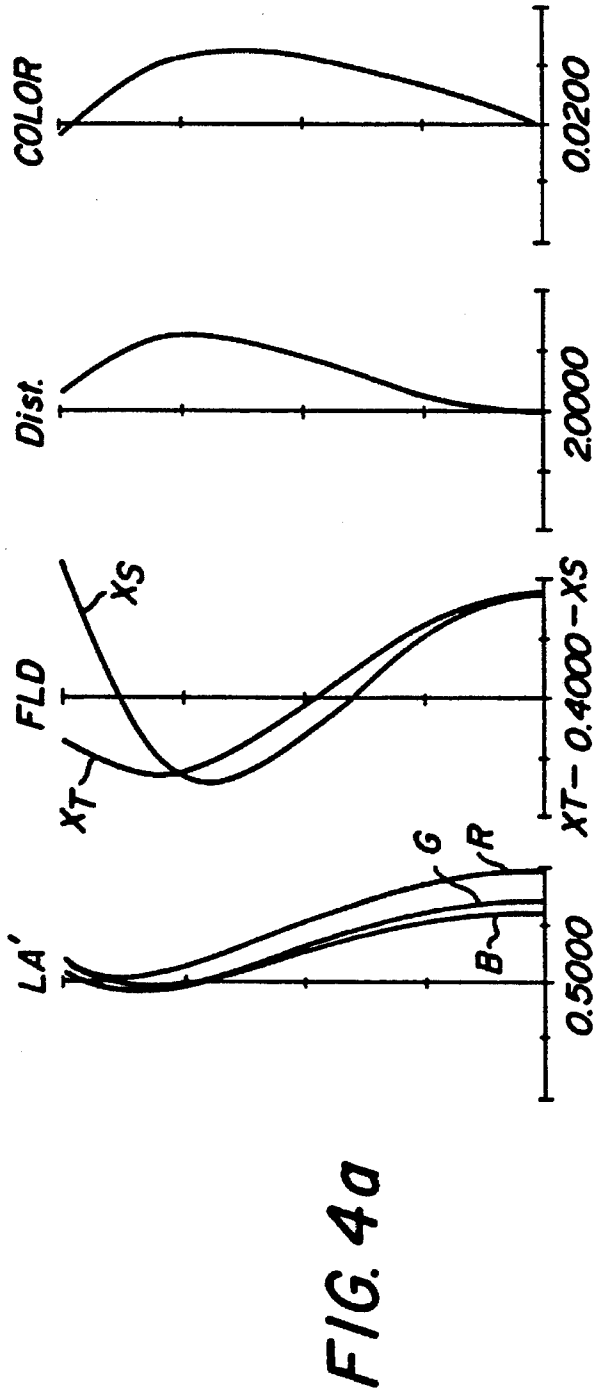

FIG. 4a

FIG. 4b

FIG. 4c

FIG. 4d

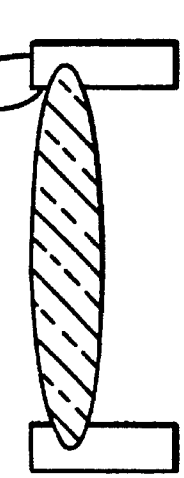

FIG. 12b

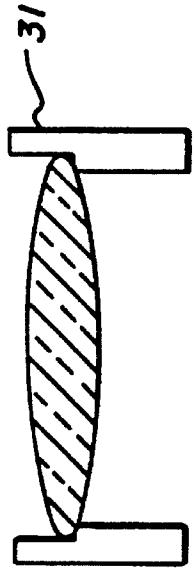

FIG. 12a

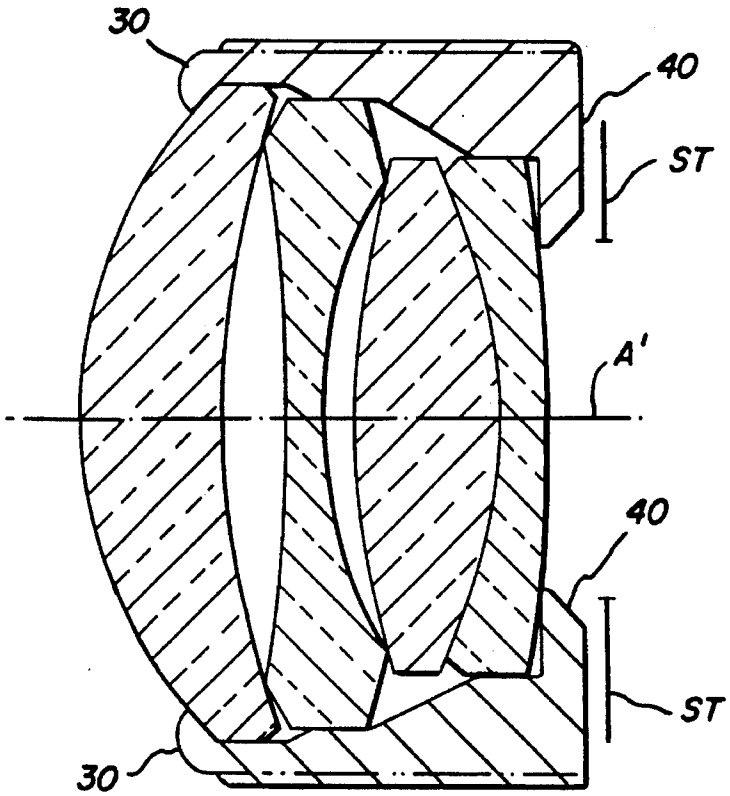

FIG. 11

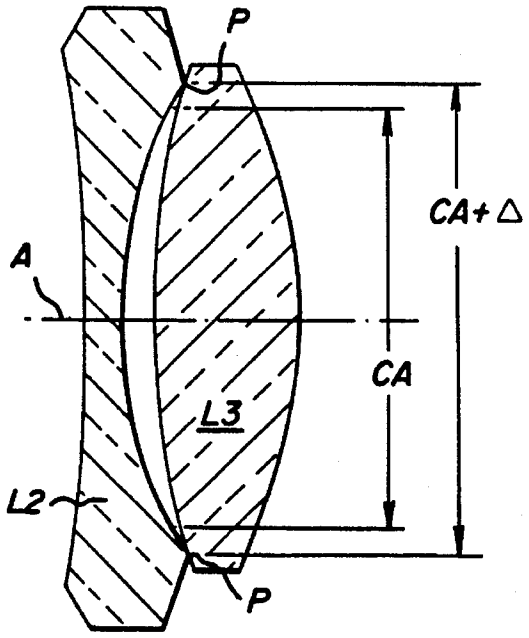

FIG. 7

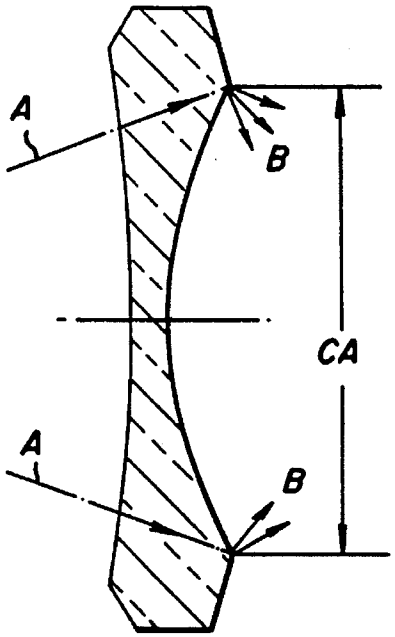

FIG. 8

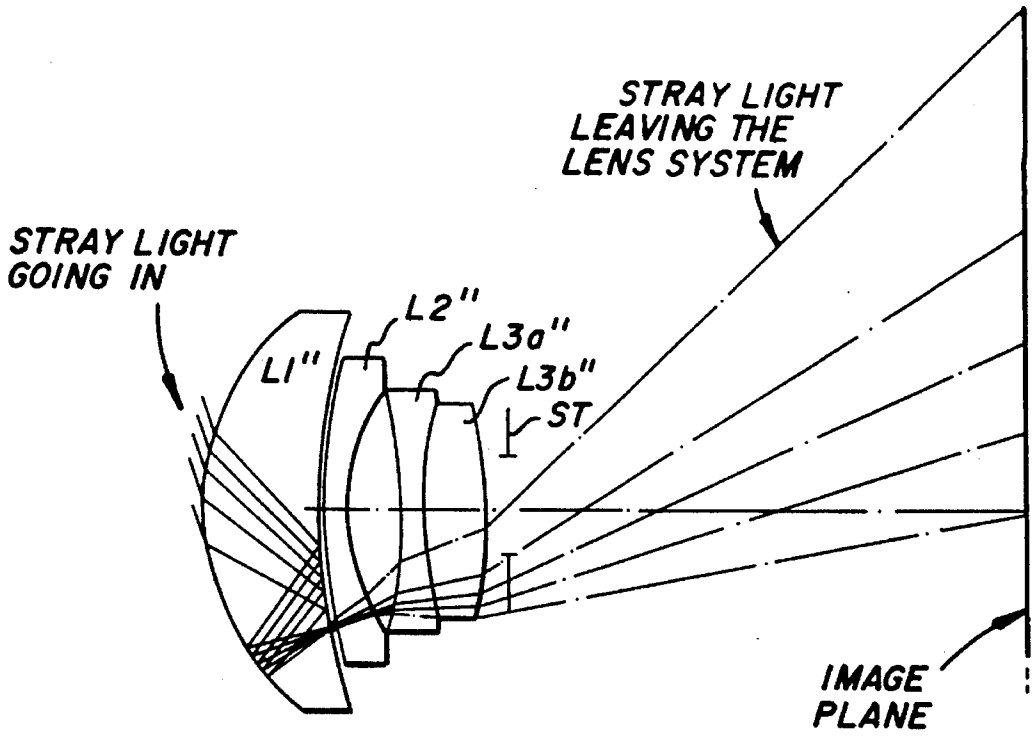
STRAY LIGHT
LEAVING THE
LENS SYSTEM
STRAY LIGHT
GOING IN
L2"
L3a"
L1"
L3b"
ST
IMAGE
PLANE

FIG. 9

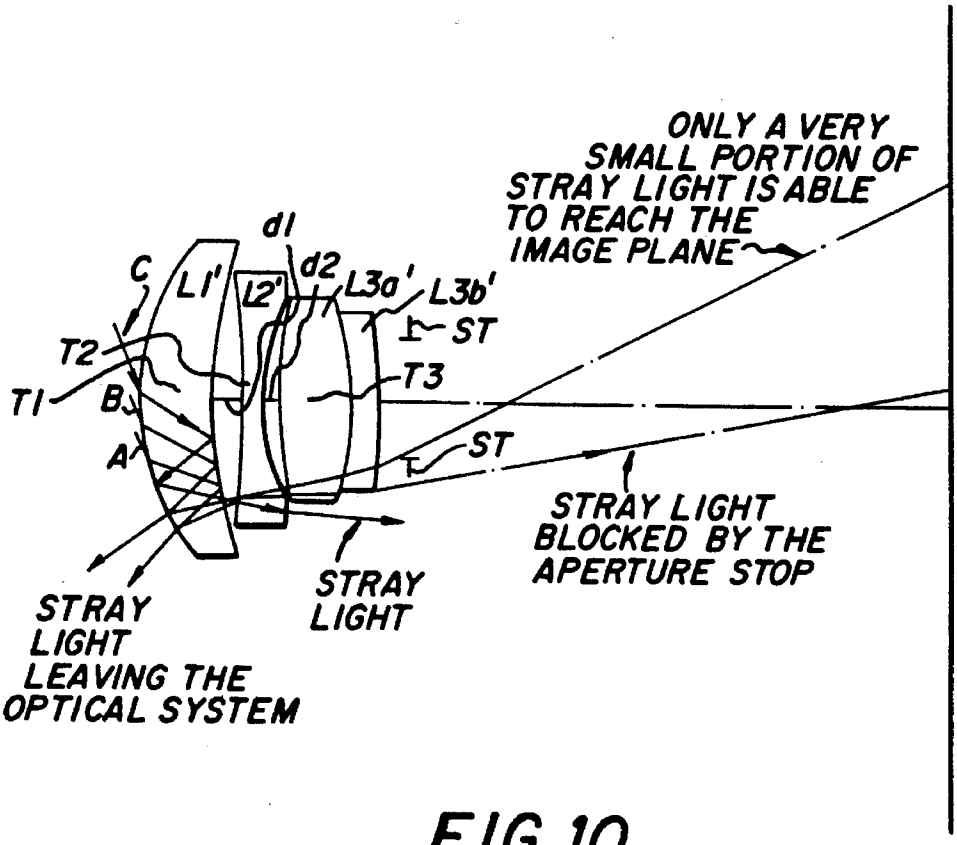
ONLY A VERY
SMALL PORTION OF
STRAY LIGHT IS ABLE
TO REACH THE
IMAGE PLANE
d1
C
L1'
L2'
d2
L3a'
L3b'
ST
T2
T3
T1
B
A
ST
STRAY LIGHT
BLOCKED BY THE
APERTURE STOP
STRAY
LIGHT
STRAY
LIGHT
LEAVING THE
OPTICAL SYSTEM

FIG. 10

COMPACT OBJECTIVE LENS SYSTEM

CROSS-REFERENCE TO RELATED APPLICATION(S)

This application is related to U.S. patent application Ser. No. 08/084,380, filed Jun. 29, 1993, and entitled A TRIPLET-TYPE LENS FOR USE IN A COMPACT PHOTOGRAPHIC CAMERA, filed in the names of Lee R. Estelle and William T. Goosey, Jr.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a lens system suitable for use as an objective or taking lens for compact photographic cameras and providing a field coverage of at least 55 degrees and preferably 60 degrees or higher.

2. Description of the Prior Art

With the increasing demand for manufacturing smaller, more compact photographic cameras at a lower cost, there is an increased need for use of smaller and less costly lens systems. Triplet or a Tessar-type lens systems are good candidates for such use because these systems have relatively few lens elements.

Triplet-type or triplet derivatives such as Tessar-type lenses have been used in photographic apparatus for many years. Moreover, the objectives having a triplet-type lens system with the diaphragm arranged either in front of the first lens element or behind the last lens element are also well known, and such lens systems are disclosed in U.S. Pat. Nos. 3,910,685, 4,886,342, 4,892,398, 4,676,607, 3,967,884, 3,895,857 and 3,784,287. Such objectives have an advantage of being compact, having relatively few lens elements and eliminating the costs of "split" barrels.

However, many of these lens systems are assembled in their optical barrels with spacers such as spacer rings or shims placed between the optical components. This is disadvantageous because the spacers may cause tolerance build-up on thicknesses as well as tolerance build-ups due to spacer wedge. In addition, there is an increased cost due to extra parts.

The need for the spacers or shims can be eliminated when the elements are made of plastic and mounted as shown in U.S. Pat. Nos. 4,886,342 and 3,784,287, but this severely limits the choice of the optical materials of which the lens elements are made. For example, certain index ranges and V number materials may be required by the photographic lens system, in order to enhance its performance, but such materials are available in optical grade are glass and not in plastic.

Finally, there is a problem if the edge contact is established too far from the clear aperture, the lens element diameter will increase, the lens elements thickness will increase and the compactness of the overall optical system will be compromised.

Thus, there is a growing demand for more compact photographic cameras and correspondingly, there exists a need to further improve and simplify the lens system for use in such cameras, and to lower the cost of making such lens systems by making them less expensive to assemble while maintaining or improving their imaging quality.

SUMMARY OF THE INVENTION

An object of the present invention is to produce a photographic lens device of high quality which includes a lens system which is uniquely suited for use in compact photographic cameras and which is relatively inexpensive to produce and to assemble.

Yet, another object of the present invention is to provide a lens system that is easy to assemble and the configuration of which promotes lens elements to self-center and also eliminates the need of spacers while maintaining the lens system's compactness.

These and other objects of the invention have been attained by a lens system comprising from the object side: a first positive meniscus lens component having foremost lens surface convex to the object side; a second bi-concave lens component; a third bi-convex lens component; and a diaphragm arranged behind the rear-most lens element of the the lens system, wherein the lens system fulfills the following conditions:

$$N_3 - N_1 \leqq 0.1$$

$$\frac{N_1}{N_2} \geqq 0.9$$

$$0.25f < \Sigma d < 0.35f$$

where f is the composite focal length of the lens system; Σd is the distance from the vertex of the foremost lens surface to the vertex of the last lens surface; N_1 represents the refractive index of the positive lens element forming the first lens component; N_2 represents the refractive index of the negative lens element forming the second lens component; N_3 represents the refractive index of the positive lens element forming the third lens component. These relationships help maintain the aberration's balance while maintaining the compactness of the optical system.

According to another aspect of the present invention, a lens system comprises: a first outer lens component, the first outer lens component being a positive lens component; a negative lens component located between and airspaced from the first outer lens component and a second outer lens component; a positive power second outer lens component; and an aperture stop, said aperture stop located on the outer side of one of said outer lens components, wherein the airspaces between said components are so arranged that there exists an edge contact between the lens components at less than 3 mm and preferably less than 2 mm beyond clear aperture.

According to yet another aspect of the present invention, a compact lens system for use in a compact photographic camera comprises: a plurality of optical elements spaced in a close proximity to one another, the plurality of lens elements having sufficient powers and spacings to enable said lens system to cover a field of view of at least 55 degrees, said plurality of lens elements including at least one positive lens element and one negative lens element wherein the airspace between said positive lens element and said negative lens element is smaller than the thickness of said positive lens element; and the lens system in order to be suitable for use in a compact camera satisfies the following parameters:

$$20 \leqq f \leqq 30$$

$$5 \leqq BF \leqq 24.85$$

$$2 \times f/No.|_{min.} \leqq 5.6,$$

where f is the focal length of the lens system, BF is the back focus of the lens system. $f/No.|_{min}$ is the f/No. that the system is intended to perform at without being stopped down.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a simplified cross-sectional view of a lens system corresponding to a first embodiment of the invention.

FIG. **2** is a simplified cross-sectional view of a lens system corresponding to a second embodiment of the invention.

FIGS. **3***a*–**3***d* represent the aberration curves of the lens system corresponding to the first embodiment.

FIGS. **4***a*–**4***d* represent the aberration curves of the lens system corresponding to the second embodiment.

FIGS. **5** and **6** are cross-sectional views in schematic of a photographic device showing the objective lens systems of FIGS. **1** and **2** and their respective mounting structure.

FIG. **7** illustrates the requirements of the edge contact as they apply to the rear surface of a negative lens element.

FIG. **8** illustrates formation and propagation of unwanted light if the edge contact points are located at the clear aperture of the surface.

FIG. **9** illustrates how rays of stray light propagate in an optical system that does not form an embodiment of this invention.

FIG. **10** illustrates a lens system of FIG. **2** and how it substantially eliminates light flare or stray light problems.

FIG. **11** is a cross-sectional view of the lens system of FIG. **2** and showing a mounted objective lens system in a barrel utilizing a heat-seal ring retainer.

FIGS. **12***a* and **12***b* illustrate steps in the formation of a heat-seal retainer for an optical mount such as one illustrated in FIG. **11**.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to FIGS. **1** and **5**, a photographic device, such as a compact photographic camera **55**, includes a barrel **4** and a three-component lens system **100** retained on the lens barrel **4** and including, in order from an object side, a first, second and third lens elements **L1**, **L2** and **L3**, respectively, in appropriately spaced axial alignment and forming a taking lens system for focusing light onto a photographic film F located by suitable means (not shown) at the focal plane of the camera. An aperture stop ST is located behind the rear lens element **L3**. The f/No. of the lens system may be determined by the opening in the diaphragm ST. As the opening is reduced, the f/No. increases. The particular lens mount **4** is shown for illustrative purposes only and this is but one type of mount which may be used with the lens system disclosed. Since the lens system is primarily intended for use in connection with very compact photographic cameras which are fabricated on a high volume production basis, it is preferred that the lens mount be compact and also be constructed so that its manufacture is adapted to the assembly of the lens components therein for mass production. In this particular embodiment, the first lens component is positive and is in the form of a single lens element **L1** which has a meniscus shape and has a convex first surface **S1** and a concave second surface **S2**. The second lens component is in the form of a bi-concave lens element having a front surface **S3** and a rear surface **S4**. A third lens component is in the form of a bi-convex single lens element and it has a front surface **S5** and a rear surface **S6**. The focal lengths of the first, second and third lens components are 19.86,–8.31 and 10.04 respectively. The absolute value of the ratio of the focal length of the middle component to the total lens system focal length is 0.325. It is important in order to fill the film plane, that the compact lens system according to this invention is capable of covering at least a 55 degree field of view and preferably a field of view of 60 degrees or more and most preferably, a field of 65 degrees or greater. In particular, the lens system of this embodiment is capable of maintaining an excellent performance over a 67 or 68 degree field of view. The lens system satisfies the following conditions and definitions:

$$N_3 - N_1 \leqq 0.1;$$

$$\frac{N_1}{N_2} \geqq 0.9;$$

and more preferably $0.9<N_2/N_1<1.0$;

$$0.22f<\Sigma d<0.38f$$

where f is the composite focal length of the lens system; Σd is the distance from the vertex of the foremost lens surface to the vertex of the last lens surface; N_1 represents the refractive index of a positive lens element forming the first lens component; N_2 represents the refractive index of a negative lens element forming the second lens component; and N_3 represents the refractive index of a positive lens element forming the third lens component.

The significance of the above-mentioned conditions is as follows: It is advantageous to have high index glasses in the positive lens elements, because it helps to keep the Petzval sum low. Also, with the higher index of refraction, the lens element may be made with weaker radii of curvature, thus, the lens system can be made more compact. In addition, in order to correct the Petzval sum, it is advantageous to have the index N_2 of the negative lens element as low as possible. However, typically in flint glasses, the lower the index of refraction is, the higher the V number; and, in order to correct color aberrations, we need a low V number. Thus, the first two requirements help us balance the Petzval sum and color correction in the lens system. The last condition helps to keep the lens compact and is also a condition for well-corrected coma aberration for a wide angle system as ours. The performance of the lens system of the first embodiment is illustrated in FIGS. **3***a*–**3***d*.

FIG. **3***a* is a graph of longitudinal spherical aberration (in mm) with respect to aperture is in three wavelengths. The graph shows well corrected spherical aberration and the axial color which is corrected at approximately the 0.9 aperture.

FIG. **3***b* is a graph of the tangential and sagittal coddington field curvature (in mm). It can be seen that there is a node beyond the 0.6 field and the astigmatism is well balanced.

FIG. **3***c* is a graph that plots the percent distortion with respect to relative image height. It can be seen that the distortion is not greater than 2% at any point in the field.

FIG. **3***d* shows a plot of lateral color (in mm) as a function of relative field. It shows that the lateral color is well balanced and does not vary by more than 5 microns through most of the field.

Although in principal the lens elements can be made of plastic, the lens elements of this embodiment are all made from glass. This eliminates some of the distortion problems referred to in U.S. Pat. No. 4,886,342. The lens elements powers, shapes and the airspaces between the lens elements of lens system **100** are arranged so that there exists an edge or other contact between mutually contacting lens elements at less than Δ=3 mm and preferably at less than Δ=2 mm beyond the clear aperture CA. (See FIG. **7** for illustration of

Δ.) The "clear aperture" of a surface of a lens element in the lens system is basically a minimum size aperture of the lens element that allows all of the desired bundles of light rays to go through the lens system to the image plane. These desired bundles of rays are often determined by other surfaces of the lens system. The clear aperture of a surface of a lens element in the lens system is defined as the necessary minimum size openings on the lens surfaces of the lens system that must satisfy both of the following conditions: a) it must be large enough to satisfy the minimum f/No. required; and b) it must be large enough to transmit the required amount of light in the comers of the field at the maximum field coverage. If the clear apertures are too small, then there will be unacceptable vignetting; and if they are too large, poorly corrected light could reach the image plane. Also, if they are too large, the lens system will not be compact as desired, and may exhibit stray light problems. The section outside the clear aperture may be masked off or otherwise treated so that light striking outside of the clear aperture would be prevented from propagating through the lens system.

The pairs of mutually contacting surfaces are S2*a* and S3*a*; S4*a* and S5*a*. These surfaces do not have to be flat, vertical surfaces and they do not need to be cemented together. Surfaces S2*a*, S3*a*, S4*a* and S5*a* are segments of the surfaces S2, S3, S4 and S5, respectively.

Having an edge contact allows all of the elements to be placed next to each other so they physically touch each other as in glass-to-glass contact thus eliminating the costly need for superfluous spacers. No adhesive is usually necessary. However, where a thin layer of adhesive is used, this may still be considered to be edge contact in accordance with the invention. This edge contact also eliminates tolerance build-up on the thickness of spacers as well as tolerance build-up on spacer wedge. The manufacturing errors on spacer thickness and spacer wedge angle also cause misalignment of the lens components with respect to each other. This results in the degredation in the performance of the lens system. As stated above, by maintaining the contact between the lens elements, the need for spacers is eliminated which also results in improved performance of the optical system. As an additional benefit of the edge contact, the lens components tend to self align or self center, thus, eliminating a need for complex alignment procedures. The importance of achieving an edge contact at points P on a circle of diameter (CA+Δ), where Δ is in the range of or less than 3 mm, and more preferably 2 mm or less beyond the clear aperture CA (FIG. 7), is that the lens diameter will be held at a minimum. This requirement also tends to minimize the thicknesses of the lens elements and the airspaces between them and thus produces the overall lens system which is very compact and also less expensive to manufacture. On the other hand, it is preferable not to have an edge contact exactly at the clear aperture (i.e. Δ≈0.0 mm beyond the clear apeture) because digs and chips from beveling operation can cause unwanted sparkling. That is, the digs, scratches, bubbles, and chips, etc. at the resulting edge contact cause the impinging light A to disperse (FIG. 8). The (unwanted) dispersed light B then may propagate through the lens system and impinge on the imaging medium such as film. With the stop outside the lens system, the cost of "split" barrels is also eliminated.

The requirement that the airspace d_1 between the first and the second elements L1 and L2 be smaller than the first element's thickness T_1 and that the airspace d_2 between the second lens element L2 and the third lens element L3 be smaller than the thickness T_3 of the third lens element L3 facilitates the compactness of the lens system and helps maintain the edge contact between the lens elements. It is preferable that the following relationship be maintained, $T_1 \geqq 2d_1$ and $T_3 \geqq 2d_2$ and more preferably that $T_1 \geqq 2d_1$ and $T_3 \geqq 3d_2$. In this first embodiment,

$$\frac{T_1}{d_1} = 2.9 \text{ and } \frac{T_3}{d_2} = 3.5.$$

The dimensions d_1, d_2, T_1 and T_3 are taken along the optical axis A. In addition, in order to facilitate lens system compactness, one may specify that at least one airspace between the positive lens element and the second or middle lens element be smaller than the thickness of said second lens element. It should be also noted, the requirements that

$$0.275 \leqq \frac{|f_2|}{f} \leqq 0.375$$

and that

$$1.5 \leqq \frac{f_1}{f_3}$$

(where f_1, f_2 and f_3 are the focal length of the first, second and third lens components respectfully, and f is the focal length of the lens system) help to maintain a nice aberration balance while keeping the lens system compact.

Finally, by placing the aperture stop (or diapragm) at the rear of the lens system, it is protected from dust and dirt. Placement of the aperture stop (i.e. diapragm) in front of the optical system, requires that a cover glass be placed in front of the aperture stop to keep dust and dirt out. Therefore, by placing the aperture stop at the rear of the optical system (i.e. towards the image plane), eliminates the need for the cover glass.

This design is extremely compact as can be determined by a vertex-to-film plane distance which is short—i.e. only 27.26 mm when the focal length is 25.6 mm. The size of the front clear aperture is 9.9 mm and the system f/No. is 4.5. In designing the lens system for the compact camera, it has been determined that the focal length range needs to be between 20 and 30 mm in order to make the lens system more compact and that the focal range should preferably be between 22 and 28 mm and more preferably between 25 and 27 mm. We determined that a short focal length (i.e. f<20 mm) tends to require more elements because the field angle has to increase to cover the same image size, and this causes the aberration correction to become increasingly difficult. In particular, such aberrations as distortion and astigmatism become predominant. On the other hand, a lens system having the same f/No., but a longer focal length (i.e. f>30) will tend to make all elements larger and the front vertex to image plane longer thus producing a more bulky lens. The advantages provided by edge contact would also be jeopardized. In addition, the back focal length BF, (back focal length is the distance as measured from the rear vertex of the rear surface of the last lens element to the image plane) needs to be between 5 mm and 24.85 mm . Placing a lens element closer than approximately 5 mm to the image plane when stopping the lens down to f/16 or greater results in small artifacts on the lens surface near the image plane to be visible at the image plane. Thus, it is found that a lens system satisfying the following parameters or requirements is particularly suited for use in very compact cameras:

$$20 \leqq f \leqq 30, \quad (1)$$

$$5 \leqq BF \leqq 24.85 \quad (2)$$

and

$2 \leqq f/No.|_{min.} \leqq 5.6,$ (3)

where f is the focal length of the lens system, BF is the back focus of the lens system. $f/No.|_{min}$ is the f/No. that the system is intended to perform at without being stepped down. Alternatively, in the lens system which can be used in lower cost cameras, the f/No. may be slower, thus, the third requirement can be altered to 3<f/No.<16 where f/No. is the lens system's F-number.

FIG. **5** illustrates the lens elements **L1**, **L2** and **L3** of lens system **100** are freely placed in the lens barrel **4**. Their optical axes are aligned without a need to cement these elements to each other. All of the lens components are pressed against the lens barrel. In this embodiment, the three lens components are mounted in the cylindrical recess surface of the lens barrel and have outer annual barrel contacting surfaces **1***b*, **2***b* and **3***b* respectively which fit within hollow cylindrical surfaces **4***a*, **4***b* and **4***c* forming the inner surfaces of the barrel **4**. The lens elements have just enough clearance to move within the barrel so as to be positioned within the barrel. Finally, the lens system **100** is securely retained within the lens barrel **4** by a pressing member **10** for pressing the first lens element **L1** against the second lens element **L2**, and by a pressing member **20** for pressing the third lens element **L3** against the second lens element **L2**.

In the photographic lens devices, the lens components can be readily slipped inside the lens barrel **4**. Once the edge contact is established between the lens elements, the lens elements align themselves with a high degree of accuracy and are then retained in the barrel in that alignment by the pressing members **10** and **20** which are adjacent to lens elements **1** and **3** respectively.

Finally, it is preferred that high index materials be used for outer elements in a design of this lens system. Some of the reasons are reduced field curvature and spherical aberration correction. In addition, the edge contact properties are closely related to a best choice of high index glass. (This is all related to f/No., field coverage and focal length range requirements discussed above.) If low indices are used, the powers and radii of the outer elements are redefined in such a way that it becomes more difficult to achieve edge conditions.

Constructional values for the first preferred embodiment of the invention is shown in Table 1 below, in which the lens elements are numbered from front to rear, N is the index of refraction for the d line of the spectrum, V is the Abbe number, R is the radius of curvature of the lens surface, T is the axial thickness of the lens element, and d is the axial separation between the lens elements.

TABLE 1

f = 25.57; BF = 20.68; semifield angle = 33.58°.
Maximum aperture with no vignetting corresponds to f/4.5.

Lens		Clear			Material	
Element	Surface	Aper.	Radius	Thickness	N_d	V
L1	S1	9.90	R_1 = 7.4251	T_1 = 2.852	1.713	53.8
	S2	7.90	R_2 = 13.046	d_1 = 0.974		
L2	S3	7.90	R_3 = –21.793	T_2 = 0.520	1.699	30.1
	S4	6.86	R_4 = 8.0817	d_2 = 0.533		
L3	S5	6.79	R_5 = 15.453	T_3 = 1.862	1.786	44.2
	S6	6.28	R_6 = –15.453	d_3 = 1.000		
		4.40	DIAPHRAGM			

The second embodiment of the present invention is shown in FIGS. **2**, **6** and **11**. Referring to FIGS. **2**, **6** and **11**, a photographic device includes a barrel (**4**A, **4**B) and a three component lens system **200** retained on the lens barrel. The lens system **200** parameters are provided in Table 2.

The second embodiment is similar to the first embodiment in that it is also a behind-stop type lens system for photographic cameras and in that it also comprises three lens components (arranged in positive-negative-positive configuration). Thus, this lens constitutes a triplet derivative. However, unlike the first embodiment, this embodiment comprises four lens elements. They are, in succession from the object side, a first lens component that is in the form of a first lens element **L1'** which is a positive meniscus lens element having its convex surface facing the object side, a second lens component that is in the form of a second lens element **L2'** which is biconcave, a third lens component that is in the form of a third lens element **L3***a*' which is biconvex and a fourth lens element **L3***b*' which is a negative meniscus lens element having its convex surface facing the image side. The third and the fourth lens elements **L3***a*' and **L3***b*' are joined together to form a positive cemented doublet lens component. The lens system **200** has a stop ST in position most adjacent to the rear surface **S7'** of the fourth or rear-most lens element **L3***b*'. It is important that the lens system has a field of view of at least 55 degrees, preferably over 60 degrees and most preferably 65 or more degrees. Accordingly, the lens system of this embodiment has a full field of over 67 degrees. The lens system **200** was found, as in the previous embodiment, that having

$$0.275 \leqq \frac{|f_2|}{f} \leqq 0.375 \text{ and } 1.5 \leqq \frac{f_1}{f_3}$$

helped maintain the aberration balance while keeping the lens system compact. The lens system of the second embodiment also satisfies the following conditions:

$$20 \leqq f \leqq 30$$

$$5 \leqq BF \leqq 24.85$$

$$3 \leqq f/No. \leqq 16,$$

more specifically, the parameters of the lens system are provided in the following table.

TABLE 2

f' = 25.56; BF = 20.31; semifield angle = 33.58°; f/No. = 3.5.

Lens		Clear			Material	
Element	Surface	Aper.	Radius	Thickness	N_d	V
L1'	S1'	10.53	R_1 = 8.02940	T_1 = 2.500	1.734	51.8
	S2'	8.80	R_2 = 15.8029	d_1 = 1.102		
L2'	S3'	8.23	R_3 = −31.7598	T_2 = 0.668	1.689	31.2
	S4'	6.76	R_4 = 8.18380	d_2 = 0.577		
L3a'	S5'	6.60	R_5 = 15.8680	T_3 = 2.565	1.788	47.5
L3b'	S6'	6.11	R_6 = −9.92860	T_4 = 0.850	1.569	56.1
	S7'	5.91	R_7 = −31.4600	d_3 = 1.000		
		6.14[1]	DIAPHRAGM[1]			

[1]THE DIAPHRAM ACTS AS A BAFFLE WHEN THE LENS OPERATES AT f/3.5 AND APERTURE HOLD ON SURFACE S7' BECOMES THE STOP.

All of the above dimentions, for radii, thickness and clear apertures are in millimeters.

The performance of this lens system **200** is illustrated in FIGS. *4a–4d*.

FIG. *4a* is the graph of longitudinal spherical aberration (in mm) with respect to aperture in three wavelengths. The graph shows well corrected spherical aberration and the axial color is corrected at approximately the 0.9 aperture.

FIG. *4b* is a graph of the tangential and sagittal coddington field curvature (in mm). It can be seen that there is a node beyond the 0.6 field and the astigmatism is well balanced.

FIG. *4c* is a graph that plots the percent distortion with respect to relative image height. The distortion is less than approximately 0.5% at any point in the field.

FIG. *4d* shows a plot of lateral color (in mm) as a function of relative field. It shows that the lateral color is well balanced and does not vary by more than 5 microns through most of the field.

FIGS. **6** and **11** illustrate that the lens elements L1, L2, L3 and L4 of lens system **200** are freely placed in the camera's lens barrels. Their optical axes A' are aligned without a need to cement these elements to each other. All of the lens components are pressed against the respective lens barrel inner walls. In each embodiment, the three lens components are mounted in cylindrical recess surfaces of the lens barrel and have outer annual barrel contacting surfaces *1b'*, *2b'* and *3b'* respectively. The lens elements have just enough clearance to move within the barrel so as to be positioned within the barrel. Finally, the lens system **200** is securely retained within the lens barrel by a pressing member **10** for pressing the first lens element L1 against the second lens element L2, and by a pressing member **20** for pressing the third lens element L3 against the second lens element L2.

In the photographic lens devices, the lens components can be readily slipped inside the lens barrel **4**. Once the edge contact is established between the lens elements, the lens elements align themselves, i.e. self-center, with a high degree of accuracy and are then retained in the barrel in that alignment by pressure means such as the pressing members **10'** and **20'** or the barrel surfaces **30** and **40** which are adjacent to lens elements L1 and L4 respectively.

Finally, it is preferred that high index materials be used for outer elements in a design of this lens system. Some of the masons are reduced field curvature and spherical aberration correction. In addition, the edge contact properties are closely related to a best choice of high index glass. (This is all related to f/No., field coverage and focal length range requirements discussed above.) If low indices are used, the powers and radii of the outer elements are redefined in such a way that it becomes more difficult to achieve edge conditions.

The lens system assembly is done in the following fashion. At first, the rear component is dropped into the lens barrel where it is retained by front and rear pressing members **20** or **40** and the barrel walls. The second component is dropped in second. It contacts physically with the rear lens component establishing the edge contact. Once the edge contact is established, the airspace d_2 between the second and the rear lens component is automatically set with the required precision without any further involvement on the part of the assembly personnel. Lastly, the front component corresponding to the lens element **L1** is dropped into the lens barrel. Once the edge contact between the front component and the second component is established, the distance between these components is accurately set. Finally, with all lens components nested against each other in a barrel, pressure means is applied to the front lens element to permanently keep the lens system elements in an optical, axially aligned relationship with each other and to prevent lens elements from movement. This may be done by use of a pressure member **10'** (FIG. **6**), or alternatively by use of a heat seal retainer **30** (FIG. **11**). The heat seal retainer **30** may be formed (FIG. **12**) by applying sufficient sonic energy to create heat which softens a plastic lip **31** which forms a ring **32** and extends round the edge of a lens element. A metal tool then presses the ring over and down upon the upper surface of the lens element, permanently retaining it in the barrel.

As in the previous embodiment, the airspaces between the lens elements are arranged so that there exists an edge contact between the lens elements at Δ equal to about 2 mm, or Δ less than 2 mm beyond the clear aperture CA. This insures that the lens elements can be placed next to each other in glass-to-glass (i.e. lens element-to-lens element) contact thus eliminating the costly need for superfluous spacers while having a compact lens system which can be used in a compact photographic camera. With the stop outside the lens system and this combination of lens elements, the cost of "split" barrels is eliminated. When two lens elements are to be edge contacted to eliminate the need for a spacer, it is advantageous to have both lens elements have a finished diameter that extends beyond the edge contact points and then precision bevel one of the elements (usually the element with the concave surface). The bevel is placed at the precise distance from the lens element's center so that its sag, when edge contacted with another lens element (as done during the assembly of lens elements into the barrel), will accurately define the desired airspace between the two elements. In addition, manufacturing the precision bevel in this manner reduces the amount of edge chips and hence reduces the effects of unwanted stray light.

The requirement that the airspace d **1** between the first and the second lens elements **L1'** and **L2'** be smaller than the first lens element's thickness T_1 and that the airspace d_2 between the second lens element **L2** and the third lens element **L3*a***' be smaller than the thickness T_3 of the third lens element **L3*a***' facilitates the compactness of the lens system and helps maintain the edge contact between the lens elements. It is preferable that the following relationship be maintained, $T_1 \leqq 2d_1$ and $T_3 \leqq 2d_2$ and more preferably that $T_1 \leqq 2d_1$ and $T_3 > 3d_2$. In this first embodiment,

$$\frac{T_1}{d_1} = 2.2 \text{ and } \frac{T_3}{d_2} = 4.4.$$

In addition, in order to facilitate lens system compactness, one may specify that at least one airspace between the positive lens element and the second or middle lens element be smaller than the thickness of said second lens element.

This arrangement also enhances the unique method of utilizing the rear surface of which lens of the lens system to act as the stop when the lens system is operating in a wide open or fast mode (i.e. low f/No.) and enabling the "true" diaphragm; i.e. the aperture stop, to act as a baffle to control the upper rays at the f/3.5 opening (see FIG. **6**). For f/Nos. slower than f/3.5, the diaphragm acts as the true stop.

Furthermore, by placing a limiting clear aperture at surface **S5** controls upper rays at the mid obliquities thus improving their image quality.

An important consideration is the reduction of light coming from overhead and through multiple reflections eventually exposing the film. This condition is illustrated in FIG. **9**. FIG. **9** shows that a double reflection condition for a light source at 72 degree azimuth angle allowing bundles of light striking high in the aperture to easily bounce twice within the front lens and then make it through a lens system to the image plane, resulting in an unacceptable picture quality.

Therefore, the first and the second lens components corresponding to lens elements **L1** and **L2'** are configured so as to minimize the upward slope of the stray rays after the reflection from the front surface of the front lens element **L1'** (i.e. the 2nd reflection within the first lens element). This change results in fewer stray light rays passing through the aperture stop opening. The diaphragm walls of the aperture stop will thus block the rest of the unwanted or stray light. The shape of the second component also permits the shape of the first lens component **L1** to be configured to minimize the angle of incidence of the rays for controlling internal reflections, with the result that the high incident overhead light (ray C in FIG. **10**) that enters the front surface of **S1'** above the optical axis does not propagate towards the opening in the diaphragm and instead will be limited by the diaphragm wall. Thus, total internal reflections that will send light rays towards the image plane is minimized.

The lens system **200** of the second preferred embodiment illustrates the result of designing for stray light minimization. The stray bundles of light D do not make it through the lens system unless they strike the front most lens surface of the lens system below the optical axis resulting in near grazing incidence thus reducing the intensity of the light that is refracted. The refracted bundle is then vignetted before it reaches the image.

Thus, in this second embodiment, the shape of the second element **L2'** is configured to eliminate double and triple reflections that results in undesirable light flare at the image plane from a bright overhead object, such as the sun, when it is subtending an angle from 55 to 75 degrees. When the sun is lower in the horizon (i.e. when it subtends an angle less than 55 degrees) it would be seen in the viewfinder and the camera sensor would be eliminated as a potential camera shot. If the sun is higher than 75 degrees, then them is no chance of double reflection due to high grazing angles of the light. FIG. **9** shows the stray ray bundles and illustrates this effect. FIG. **10** shows how this effect has been controlled.

Finally, the lens systems described herein are particularly advantageous when used in the focal length range 24 mm to 27 mm and for covering half fields of at least 34 degrees.

The invention has been described in detail with particular reference to preferred embodiments thereof, but it will be understood that variations and modifications can be effected within the spirit and scope of the invention.

I claim:

1. A lens system comprising from an object side:

a first positive power meniscus lens component having a foremost lens surface convex to the object side;

a second bi-concave lens component engaging said first lens component and defining with said first lens component an airspace separating said second lens component from said first component;

a third bi-convex lens component engaging said second lens component and defining with said second lens component an airspace between said third lens component from said second lens component; and

a diaphragm arranged behind the rear-most lens element of the lens system, wherein all of the airspaces between said lens components are so arranged that there exists between all of adjacent lens components an edge contact located only at points located within the region from over 0.0 mm at a position to sufficiently eliminate stray light to about 2 mm beyond clear aperture diameter, and wherein the lens system fulfills the following conditions:

$$N_3 - N_1 \leqq 0.1$$

$$\frac{N_1}{N_2} \geqq 0.9$$

$$0.25f < \Sigma d < 0.35f$$

where:

f is the composite focal length of the lens system;

Σd is the distance from the vertex of the foremost lens surface to the vertex of the last lens surface;

N_1 represents the refractive index of a positive lens element forming the first lens component;

N_2 represents the refractive index of a negative lens element forming the second lens component; and

N_3 represents the refractive index of a positive lens element forming the third lens component.

2. A lens system as claimed in claim **1**, wherein:

$$T_1 \geqq 2d_1$$

and

$$T_3 \geqq 3d_2.$$

where:

d_1 is an airspace between the first and the second lens component;

d_2 is an airspace between the second and the third lens component;

T_1 is the thickness of said first positive lens element forming the first lens component; and

T_3 is the thickness of said positive lens element forming the third lens component.

3. A lens system according to claim 1 wherein:

$$0.275 \leqq \frac{|f_2|}{f} < 0.375\ 1.5 \leqq \frac{f_1}{f_3}$$

where:

f_1 represents the focal length of the first lens component;

f_2 represents the focal length of the second lens component; and

f_3 represents the focal length of the third lens component.

4. A lens according to claim 1, wherein:

$$0.3 \leqq \frac{|f_2|}{f} \leqq 0.36$$

and

$$1.6 \leqq \frac{f_1}{|f_2|} \leqq 2.0.$$

5. A photographic device according to claim 1, wherein said first lens component is a singlet lens element, said second lens component is a single lens element; and said third lens component is a cemented doublet.

6. A photographic device according to claim 5, wherein said cemented doublet comprises a front biconvex positive lens element and a rear meniscus negative lens element.

7. A lens system comprising a plurality lens of components arranged in order from an object side:

a first positive power meniscus lens component having an object type surface convex to the object side;

a second bi-concave lens component engaging said first lens component and having an airspace separating said second lens component from said first component;

a third bi-convex lens component engaging said second lens component and having an airspace separating said third lens component from said second lens component, said plurality of lens components having radii of curvature, thicknesses and airspaces to enable the lens to cover at least 55 degree field of view, wherein all of the airspaces between said lens components are so arranged that there exists between all of adjacent lens components an edge contact located only at points located within the region from over 0.0 mm at a position to sufficiently eliminate stray light to about 2 mm beyond clear aperture diameter; and

a diaphragm arranged behind a rear-most lens element of a lens system, and wherein said lens system fulfills the following conditions:

$$T_1 \geqq 2d_1$$

and

$$T_3 \geqq 2d_2.$$

where:

d_1 is an airspace between a first and a second lens element;

d_2 is an airspace between the second and a third lens element;

T_1 is the thickness of the first lens element; and

T_3 is the thickness of the third lens element.

8. A lens system according to claim 7, wherein all of the lens elements are glass lens elements.

9. A lens system according to claim 7, wherein:

$$0.275 \leqq \frac{|f_2|}{f} < 0.375\ 1.5 \leqq \frac{f_1}{f_3}$$

where:

f_2 represents the focal length of the second lens component;

f_1 represents the focal length of the first lens component; and

f is the focal length of the lens system.

10. A photographic device according to claim 7, wherein two of said lens components each consist of a single lens element; and one of said lens components is a cemented doublet.

11. A lens system comprising in order from an object side:

a first positive power lens component;

a negative power lens component located between and airspaced from said first positive power lens component and a second positive power lens component;

the second positive power lens component located behind said negative power lens component;

an aperture stop, said aperture stop located on an outer side of one of said positive power lens components; and

wherein all of airspaces between said lens components are so arranged that there exists an edge contact between all of the adjacent lens components so that there are contacting lens surfaces and said edge contact exists only at points located within the region from 0.0 mm at a position to sufficiently eliminate stray light to less than 3 mm beyond a clear aperture diameter of each of said contacting lens surfaces.

12. A lens system according to claim 11, wherein said edge contact is at less than 2 mm beyond said clear aperture.

13. A lens system according to claims 12, wherein:

$$0.275 \leqq \frac{|f_2|}{f} \leqq 0.375,$$

where f_2 represents the focal length of the negative power lens component and f is the focal length of the lens system.

14. A lens according to claim 12, wherein:

$$0.3 \leqq \frac{|f_2|}{f} \leqq 0.36,$$

where f_2 represents the focal length of the negative power lens component and f is the focal length of the lens system.

15. A compact lens system according to claim 11, wherein said aperture stop being arranged behind a rearmost lens element from an object side.

16. A compact lens system according to claim 11 having the following parameters:

$$22 \leqq f \leqq 28$$

$$5 \leqq BF \leqq 23$$

$$2 \leqq f/No._{min.} \leqq 5.6,$$

where f is the focal length of the lens system, BF is the back focus of the lens system and $f/No._{min.}$ is the F-number that the lens system performs at without being stepped down.

17. A compact lens system according to claim 11, wherein the rear lens of positive power component is a cemented doublet.

18. A compact lens system according to claim **16**, wherein there is an edge contact between all of the lens components at more than 0.0 mm so as to sufficiently eliminate stray light to less than 3 mm beyond clear aperture, and

$$0.275 \leqq \frac{|f_2|}{f} \leqq 0.375,$$

where f_2 represents the focal length of the negative power lens component and f is the focal length of the lens system.

19. A photographic device according to claim **11**, wherein two of said lens components each consist of a single lens element; and one of said lens components is a cemented doublet.

20. A compact lens system for use in a compact photographic camera comprising:

a plurality of lens elements forming lens components and spaced in a close proximity to one another, said plurality of lens elements having sufficient powers and spacings to enable said lens system to cover a field of view of at least 55 degrees, said plurality of lens elements including at least one positive power lens element and one negative power lens element wherein an airspace between said positive power lens element and said negative power lens element is smaller than a thickness of said positive lens element, wherein all of airspaces between the lens components are so arranged that there exists between all adjacent lens components an edge contact located only at points located within the region from over 0.0 mm at a position to sufficiently eliminate stray light to about 2 mm beyond clear aperture diameter; and

the lens system being suited for use in a compact camera and satisfying the following parameters:

$20 \leqq f \leqq 30$

$5 \leqq BF \leqq 24.85$

$2 \leqq f/No.|_{min.} \leqq 5.6,$

where f is the focal length of the lens system, BF is the back focus of the lens system and $f/No.|_{min.}$ is the F-number that the lens system performs at without being stopped down.

21. A compact lens system according to claim **20**, wherein said plurality of lens elements are only three lens components arranged in order from an object side, a first positive power lens component that includes said one positive power lens element, a second negative power lens component that includes said negative power lens element, and a third positive power lens component.

22. A compact lens system according to claim **20** further comprising an aperture stop arranged behind a rearmost lens element from an object side.

23. A compact lens system according to claim **21** further comprising an aperture stop arranged behind a rearmost lens element from the object side.

24. A photographic device according to claim **20**, wherein said first lens component is a singlet lens element, said second lens component is a single lens element; and said third lens component is a cemented doublet.

25. A compact lens system for use as a taking lens in a compact camera, the lens system comprising no more than four lens elements centered on an optical axis and grouped together in a 3 lens component lens group with an aperture stop arranged outside of the lens group; said lens elements arranged so that there is edge contact among all of the adjacent and uncemented lens elements and the lens elements have cooperating edge surfaces to self-center said lens elements, wherein all of airspaces between said adjacent and uncemented lens elements are so arranged that said edge contact exits only at points located within a region from over 0.0 mm at a position to eliminate stray light to about 2 mm beyond clear aperture diameter, said lens components being a front positive power lens component, a negative power lens component and a rear positive power lens component wherein said rear positive power lens component is a cemented doublet comprising one positive lens element and one negative lens element.

26. A compact lens system according to claim **25** further having the following parameters:

f' = 25.56; BF = 20.31; semifield angle = 33.58°; f/No. = 3.5.

Lens		Clear			Material	
Element	Surface	Aper.	Radius	Thickness	N_d	V
L1'	S1'	10.53	R_1 = 8.02940	T_1 = 2.500	1.734	51.8
	S2'	8.80	R_2 = 15.8029	d_1 = 1.102		
L2'	S3'	8.23	R_3 = −31.7598	T_2 = 0.668	1.689	31.2
	S4'	6.76	R_4 = 8.18380	d_2 = 0.577		
L3a'	S5'	6.60	R_5 = 15.8680	T_3 = 2.565	1.788	47.5
L3b'	S6'	6.11	R_6 = −9.92860	T_4 = 0.850	1.569	56.1
	S7'	5.91	R_7 = −31.4600	d_3 = 1.000		
		6.14[(1)]	DIAPHRAGM[(1)]			

[(1)]THE DIAPHRAM ACTS AS A BAFFLE WHEN THE LENS OPERATES AT f/3.5 AND APERTURE HOLD ON SURFACE S7' BECOMES THE STOP.

where f' is the composite focal length of the lens system: BF is the back focal length of the lens system: F/No. is the F-number of the lens system: Li' is the lens element number i: and Si' is the lens surface number i.

27. A compact lens system according to claim **25** further having the following parameters:

$f = 25.57$; BF = 20.68; semifield angle = 33.58°.
Maximum aperture with no vignetting corresponds to f/4.5.

Lens		Clear			Material	
Element	Surface	Aper.	Radius	Thickness	N_d	V
L1	S1	9.90	$R_1 = 7.4251$	$T_1 = 2.852$	1.713	53.8
	S2	7.90	$R_2 = 13.046$	$d_1 = 0.974$		
L2	S3	7.90	$R_3 = -21.793$	$T_2 = 0.520$	1.699	30.1
	S4	6.86	$R_4 = 8.0817$	$d_2 = 0.533$		
L3	S5	6.79	$R_5 = 15.453$	$T_3 = 1.862$	1.786	44.2
	S6	6.28	$R_6 = -15.453$	$d_3 = 1.000$		
		4.40	DIAPHRAGM			

Where f' is the composite focal length of the lens system: BF is the back focal length of the lens system: F/No. is the F-number of the lens system: Li' is the lens element number i: and Si' is the lens surface number i.

28. A compact lens system for use in a compact camera comprising:

a plurality of optical elements spaced in close proximity to one another, said plurality of lens elements having sufficient powers and spacings to enable said lens system to cover a field of view of at least 55 degrees, said plurality of lens elements including at least one positive lens element and one negative lens element wherein an airspace between said positive lens element and said negative lens element is smaller than a thickness of said positive lens element, wherein all of airspaces between all of adjacent lens elements are so arranged that there exists an edge contact located only at points located within the region from over 0.0 mm at a position to sufficiently eliminate stray light to about 2 mm beyond clear aperture diameter; and

the lens system being suited for use in a compact camera and satisfying the following parameters:

$$2 \leqq f/No.|_{min.} \leqq 5.6$$

$$20 \leqq f \leqq 30,$$

where:

f is the focal length of the lens system; and

$f/No.|_{min.}$ is the F-number that the lens system performs at without being stopped down.

29. A compact lens system for use in a compact photographic camera comprising:

a plurality of lens elements forming a plurality of lens components and spaced in a close proximity to one another, said plurality of lens elements having sufficient powers and spacings to enable said lens system to cover a field of view of at least 50 degrees, said plurality of lens elements including at least one positive power lens element and one negative power lens element wherein an airspace between said positive power lens element and said negative power lens element is smaller than a thickness of said positive lens element, wherein all of airspaces between the lens components are so arranged that there exists between all adjacent lens components an edge contact located only at points located within the region from over 0.0 mm at a position to sufficiently eliminate stray light to about 2 mm beyond clear aperture diameter; and

the lens system being suited for use in a compact camera and satisfying the following parameters:

$$20 \leqq f \leqq 30$$

$$5 \leqq BF \leqq 24.25$$

$$3 \leqq f/No.|_{min.} \leqq 16,$$

where f is the focal length of the lens system, BF is the back focus of the lens system, all distances are in mm, and the f/No. is the f number of the lens system.

30. A compact lens system according to claim **29**, wherein said plurality of lens elements are only three lens components arranged in order from an object side, a first positive power lens component that includes said one positive power lens element, a second negative power lens component that includes said negative power lens element, and a third positive power lens component.

31. A compact lens system according to claim **29** further comprising an aperture stop arranged behind a rearmost lens element from an object side.

32. A compact lens system according to claim **30** further comprising an aperture stop arranged behind a rearmost lens element from the object side.

33. A lens system according to claim **29**, wherein all of airspaces between said lens components are so arranged that there exists an edge contact between all of the lens components at less than 2 mm beyond a clear aperture of any contacting surface.

34. A lens system according to claim **30**, wherein all of airspaces between said lens components are so arranged that there exists an edge contact between all of the lens components at less than 2 mm beyond a clear aperture of any contacting surface.

* * * * *

US005583690A

United States Patent [19]

Andrae et al.

[11] **Patent Number: 5,583,690**

[45] **Date of Patent: Dec. 10, 1996**

[54] **FARADAY MICROSCOPE WITH MAGNETO-OPTICAL INDICATOR AS TERMINATING ELEMENT OF OBJECTIVE LENS**

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[73] Assignee: **Carl Zeiss Jena GmbH**, Jena, Germany

[21] Appl. No.: **379,318**

[22] Filed: **Jan. 25, 1995**

[30] **Foreign Application Priority Data**

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[51] **Int. Cl.**^{6} **G02B 21/00**

[52] **U.S. Cl.** **359/368**; 359/484

[58] **Field of Search** 359/368, 371, 359/382, 383, 385, 386, 484, 488, 494, 656

[56] **References Cited**

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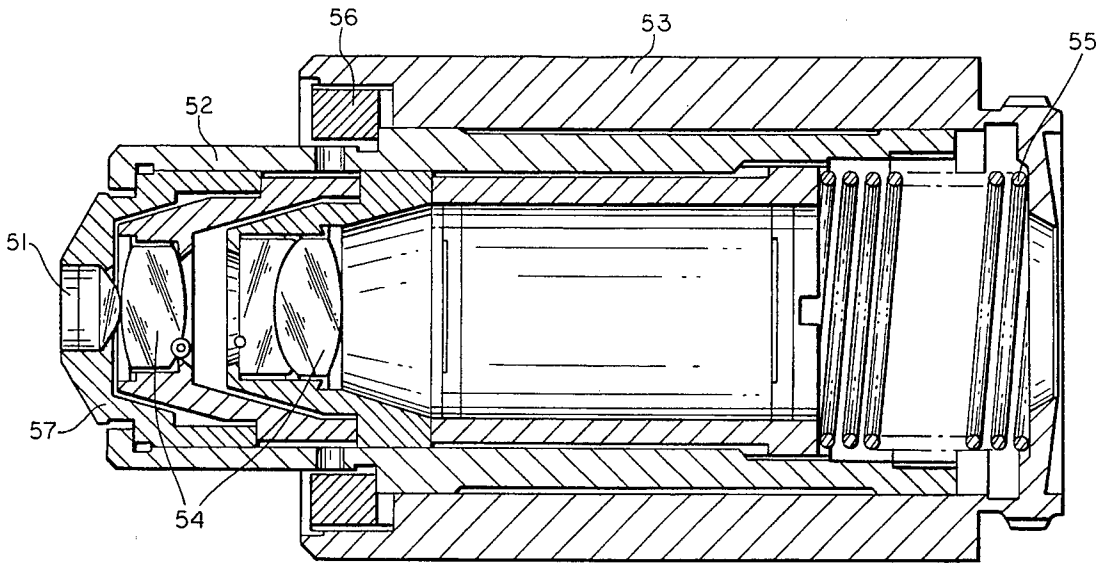
5,420,717 5/1995 Tabata 359/371

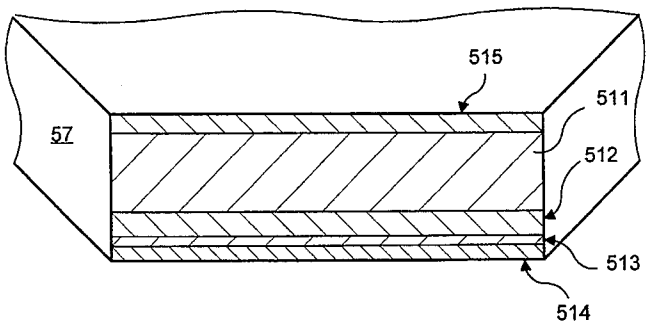
Primary Examiner—Timothy P. Callahan
Assistant Examiner—Jeffrey Zweizig
Attorney, Agent, or Firm—McAulay Fisher Nissen Goldberg & Kiel, LLP

[57] **ABSTRACT**

In a Faraday microscope for examining specimens with stray magnetic fields in a reflected light beam path with a magnetic indicator film arranged in front of the specimen, the influence of the specimen on the indicator film is evaluated with the indicator film arranged as the termination of the microscope objective, the indicator film advantageously being arranged on an optically transparent substrate. The indicator film and substrate are taken into account in the optical calculation of the microscope objective.

26 Claims, 3 Drawing Sheets





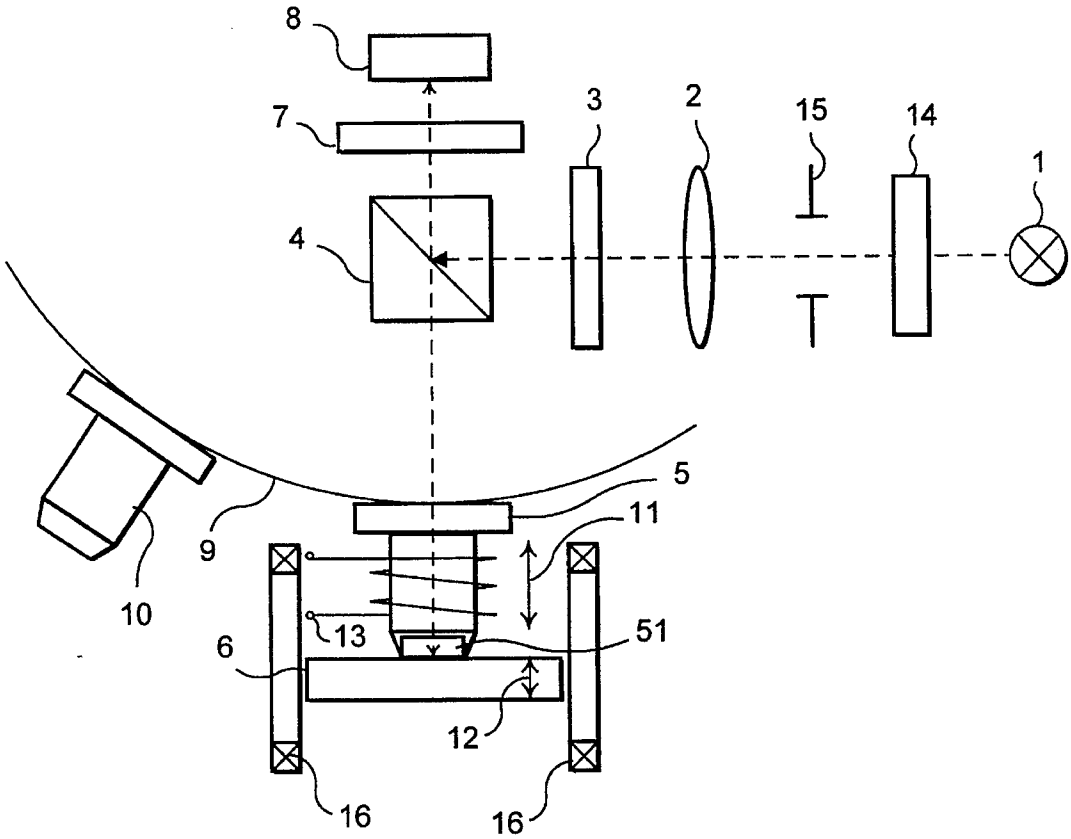


FIG. 1

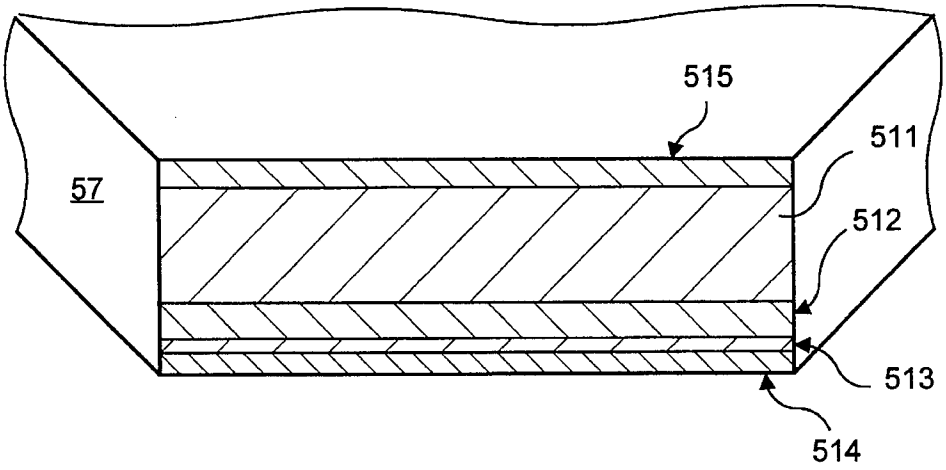


FIG. 3

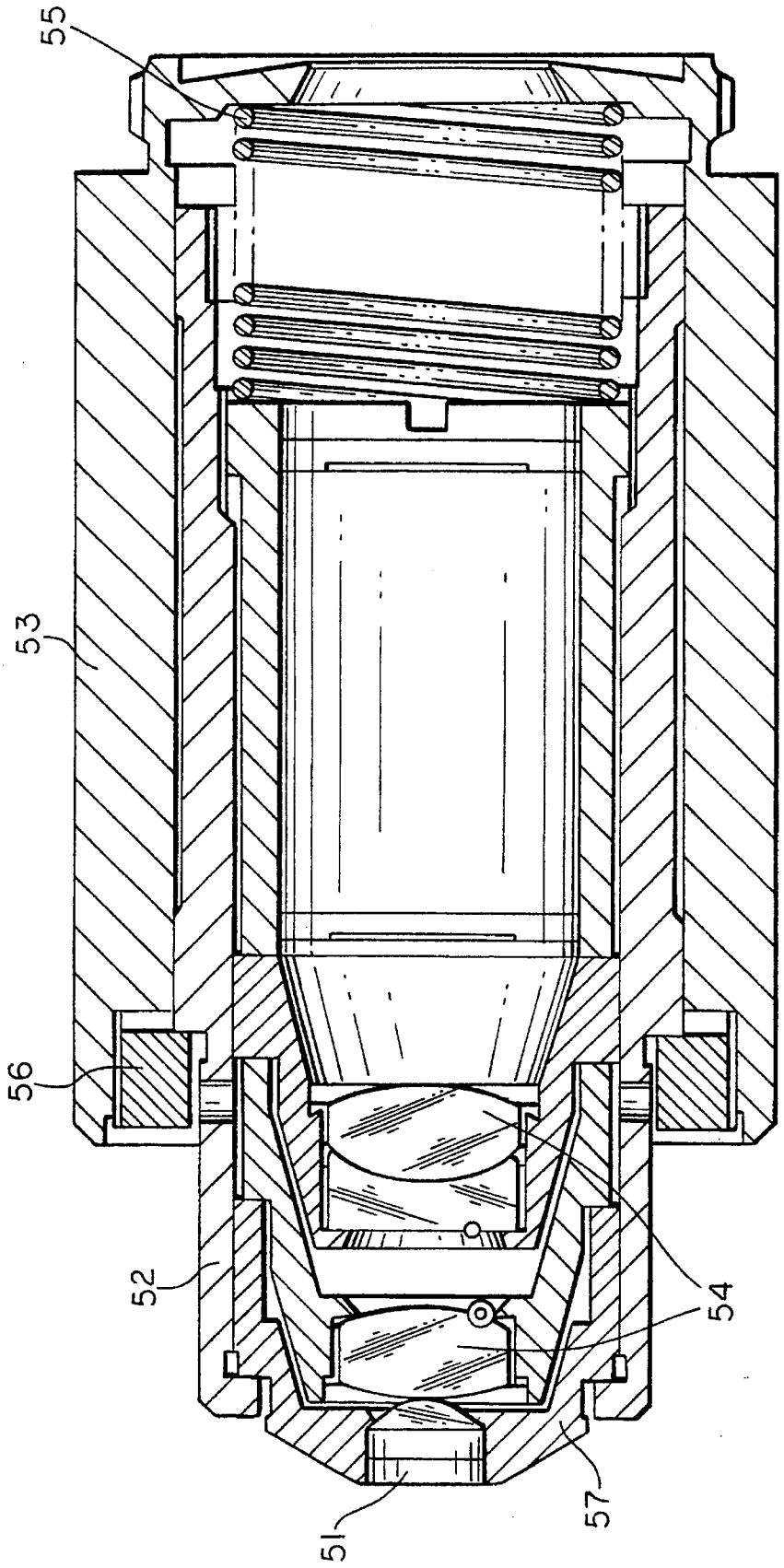
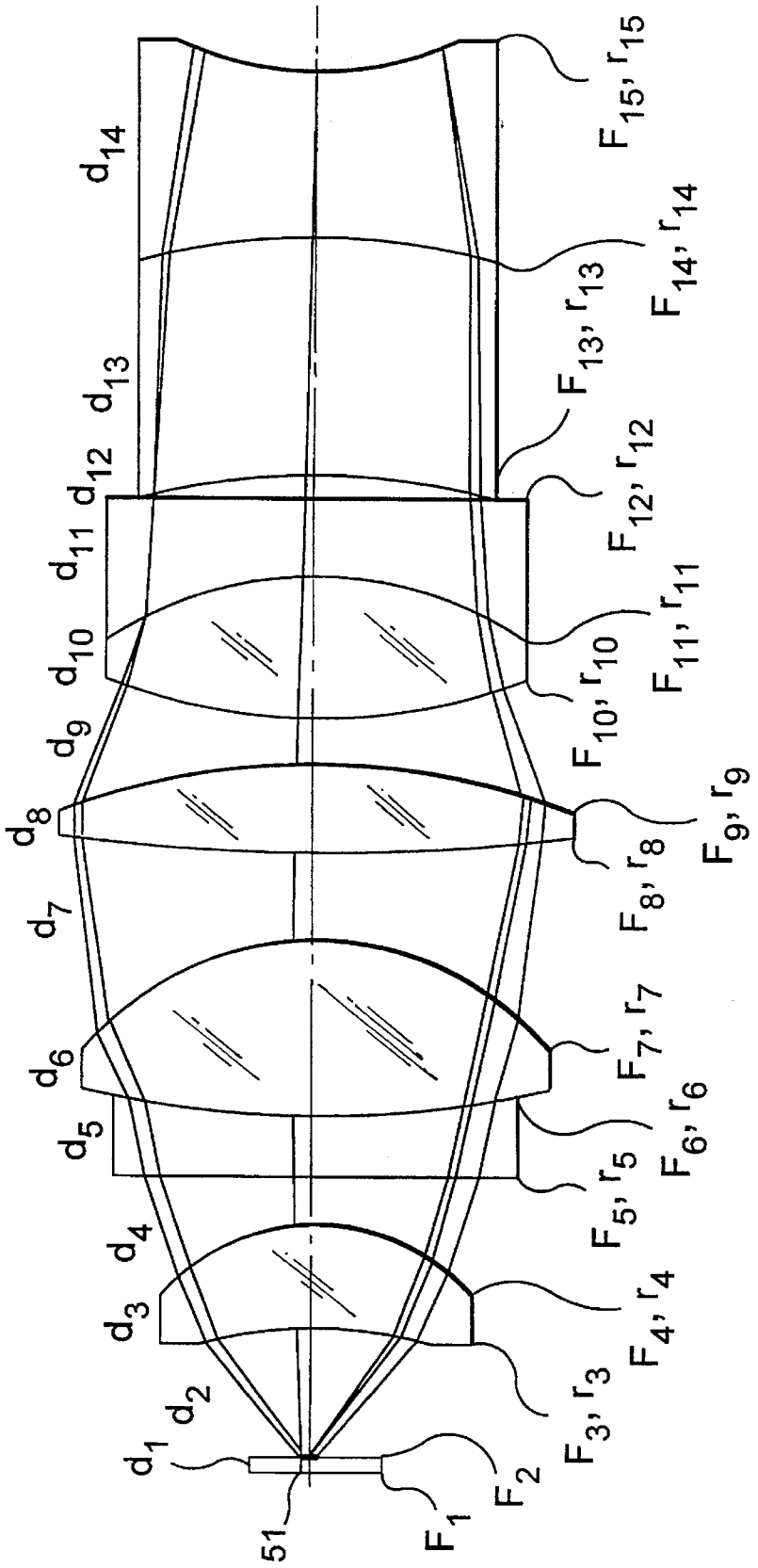


FIG. 2


d14
d13
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d11
d10
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F2
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F5, r5
F6, r6
F7, r7
F8, r8
F9, r9
F10, r10
F11, r11
F12, r12
F13, r13
F14, r14
F15, r15

FIG. 4

FARADAY MICROSCOPE WITH MAGNETO-OPTICAL INDICATOR AS TERMINATING ELEMENT OF OBJECTIVE LENS

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention is directed to a Faraday microscope for examining specimens with stray magnetic fields in a reflected light beam path, wherein a magneto-optical film is arranged in front of the specimen and the influence of the specimen on the indicator film is evaluated with respect to optical polarization, and to a process for adjusting the Faraday microscope.

2. Background of the Invention

Arrangements of this type are known from (1) B. Ludescher, et al., "Faraday Low-Temperature Microscope for Observing Dynamic Magnetization Processes in Superconductors [Faraday-Tieftemperatur-Mikroskop zur Beobachtung dynamischer Magnetisierungsvorgänge in Supraleitern]", *Laser und Optoelektronik* 23 (1991), pages 54–58; (2) L. A. Dorosinskii, et al., *Physica C* 203 (1992) , page 149; (3) M. V. Indenbohm, et al., *Physica C* 209 (1993), page 295.

A device for detecting magneto-optical anisotropism, particularly of magnetic recording media, is described in U.S. Pat. No. 4,410,227.

A laser polarizing microscope for observing magnetic domains is known from JP 3-185338 (A).

A Kerr microscope for examining current paths utilizing the polar Kerr effect is known from DE 4027049.

The magneto-optical Faraday effect causes a rotation of the polarization plane of polarized light at angle w as it passes through a magneto-optical material of thickness d according to the equation

$$w=RM(x)d,$$

where R represents a material constant of the magneto-optical material and M(x) represents the magnetization component at point x parallel to the light path.

The rotation of the plane of polarization is visible by observing the light at the polarizer-analyzer intersection. For example, with the aid of the Faraday effect, dynamic processes in superconductors and magnetic structures in magnetic storage media can be examined. In general, the constant R is so small that the Faraday effect is observed only in special materials.

A "Faraday microscope" in which a magneto-optically active film is vacuum-deposited on the superconductor to be examined is known (see 1 above). Since the Faraday rotation which can be achieved is very small, the interference between the light beams reflected at the surface of the magneto-optical film and those reflected in regions at the surface of the superconductor which are free of magnetic fields is used for evaluation. It is disadvantageous that every specimen to be analyzed must first be vacuum-deposited.

It is known (see 2, 3 above) to place thin magneto-optical indicator plates on the specimen to be analyzed, since the lateral resolution and sensitivity of the indicator decreases sharply with increasing distance from the specimen. In so doing, there is a risk that the specimen will be scratched. Moreover, a large indicator plate must be used when analyzing specimens extending over a surface area in order to avoid repeated placement. However, large indicator plates

are expensive and difficult to produce. The indicator plate is formed by a substrate (garnet) on which the actual magneto-optical indicator film has been deposited. The substrate has a high index of refraction (n=approximately 2) so that the optical imaging is impaired when observing the magneto-optical indicator film.

OBJECT AND SUMMARY OF THE INVENTION

The primary object of the present invention is to realize an improved Faraday microscope for examining specimens with stray magnetic fields. In particular, damage to the surface of specimens is substantially prevented and different specimens may be examined. Further, the invention makes it possible to bring the indicator film as close as possible to the analyzed region of the surface of the specimen which is generally not perfectly planar.

According to the invention, this object is met in a Faraday microscope for examining specimens with stray magnetic fields in a reflected-light beam path, wherein a magneto-optical indicator film is arranged in front of the specimen and the influence of the specimen on the indicator film is evaluated with respect to optical polarization, the improvement comprising that the indicator film is arranged at the end of a microscope objective. Preferred further embodiments and an adjustment process for the microscope objective are within the scope of the invention. A preferred embodiment of a microscope objective is also within the scope of the invention.

A strain-free, (reflected-light) microscope objective suitable for polarization and having a magneto-optical indictor plate as its terminating element is particularly advantageous. The indicator plate is taken into account in the optical calculation for the microscope objective. Further, the objective has an arrangement for protecting the specimen and objective.

Operation of this objective is further facilitated by the use of automatic focussing. In so doing, focussing on the specimen is first effected automatically by a different objective with a reduced depth of field, the location on the object to be examined is selected, whereupon the objective with the indicator plate is switched to. The focussing device now automatically moves the objective with the indicator plate to a minimum distance from the specimen. For this purpose, it is necessary to determine and store the difference between the balanced length of the objective with the reduced depth of field and that of the objective with the indicator plate in an adjustment process following assembly of the microscope.

The indicator plate normally has a reflective layer. A transparent indicator plate without a reflective layer can also be used in an advantageous manner with favorably reflecting, optically isotropic specimens. The specimen can be observed first without a polarizer so that a bright-field image is achieved. When the polarizer/analyzer is switched on, an imaging of the magnetic properties of the specimen is achieved. In this way, a correlation between the surface structure of the specimen and magnetic field contrast is made possible without the use of an additional objective.

When highly reflective optically isotropic specimens are used, the indicator plate can also advantageously have a semi-transparent reflective layer. The semi-transparent reflective layer can be used in the bright field without polarizers for interferometric adjustment of the distance between the indicator plate and the surface of the specimen. The interference can also be used to detect the correlation

between surface topology and magnetic contrast when a polarizer/analyzer is used.

Further, the objective according to the invention is advantageously surrounded by a current coil or Helmholtz coil. A magnetic field (along the optical axis) can be generated and modulated with the current coil, which can be used to improve contrast (e.g., elimination of earth field) and to influence the specimen in situ. A magnetic field can be produced vertically to the optical axis with a Helmholtz coil to homogenize the indicator plate.

Further, the microscope is advantageously outfitted with a monochromator (e.g., exchangeable interference filters) to make use of the dispersion of the Faraday rotation.

Further, the microscope advantageously has an aperture stop which is adjustable vertically to the optical axis so that in-plane magnetization components of the specimen can also be detected by oblique incidence of light with eccentric aperture stop.

The invention is explained more fully in the following with reference to the schematic drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings:

FIG. **1** illustrates a schematic construction of a microscope according to the invention;

FIG. **2** illustrates a diagram of the objective according to the invention;

FIG. **3** illustrates a variant of an indicator plate in accordance with the invention; and

FIG. **4** illustrates an example of a microscope with integrated indicator plate.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The general construction of the microscope according to the invention is shown schematically in FIG. **1**. The light from a light source **1** with associated illuminating optics **2** is linearly polarized in a polarizer **3**. A deflecting element or beam splitter **4** deflects the light into the objective **5** according to the invention. A Berek prism is advantageously provided as beam splitter, since this ensures a homogeneous polarization field with high-intensity illumination and, accordingly, optimal contrast can be achieved at light intensities which are frequently low.

Due to its magnetic field components, the magnetic specimen **6** causes a rotation of the plane of polarization of light in the indicator plate **51**. The light is reflected at the reflective layer of the indicator plate **51**, passes through the objective and reaches the analyzer **7** via the beam splitter. If the analyzer **7** is crossed with the polarizer **3**, light only enters through the analyzer when a Faraday rotation has taken place. Accordingly, the light which reaches the video camera **8** or is observed visually via imaging optics contains an image of the magnetic characteristics of the specimen.

One or both of the polars are advantageously constructed so as to be rotatable so as to enable variation in contrast.

The construction of the objective according to the invention is shown schematically in FIG. **2**. The objective contains the indicator plate **51** as terminating element. The entire lens system **54** including the indicator plate **51** is arranged in a sliding tube **52**. The sliding tube **52** is guided in a stationary tube **53** and is pressed against a stop **56** by a spring **55**. This arrangement protects the specimen and objective and ensures contact between the indicator plate and specimen. The front barrel or mount **57** can be produced from a softer material, e.g., Teflon.

A variant of the construction of the indicator plate **51** is shown schematically in FIG. **3**. The magneto-optical film **512** is deposited on a suitable, often monocrystalline, substrate **511** followed by a reflective layer **513** which is protected by a protective layer **514**. Another advantage of the reflective layer consists in that the light passes twice through the magneto-optical indicator film so that the rotation of the plane of polarization is doubled. The objective **5** is so dimensioned in the optics calculation that the object plane lies in the reflective layer.

The indicator plate advantageously supports an anti-reflection coating **515** because the substrate often has a high refractive index and accordingly high inherent reflection. The anti-reflection coating **515** improves contrast.

When highly reflective, optically isotropic specimens are used, the indicator plate can also advantageously have a semi-transparent reflective layer **513**. The semi-transparent reflective layer can be used in the bright field without polarizer **2** for interferometric adjustment of the distance between the indicator plate and the surface of the specimen. The interference can also be used to detect the correlation between surface topology and magnetic contrast when the polarizer/analyzer is switched on.

Further, the objective **5** according to the invention is advantageously surrounded by a small current coil **13**. A magnetic field can be generated along the optical axis and modulated with the current coil, which can be used to improve contrast (e.g., elimination of earth field) and to influence the specimen in situ. A magnetic field can be produced vertically to the optical axis, i.e., parallel to the surface of the specimen, with a Helmholtz coil **16** which can be used to homogenize the indicator plate. If the microscope is equipped with automatic focussing acting on the objective focussing arrangement **11** or stage focussing arrangement **12**, the difference between the balanced length of the objective **10** with reduced depth of field and that of the objective **5** with the indicator plate is first determined and stored in an adjustment process following assembly of the microscope. Then, focussing on the specimen is first effected automatically by the objective **10** with reduced depth of field, the location on the object to be examined is selected, and the objective turret **9** is switched to the objective **5** with indicator plate. The focussing device now automatically moves the objective **5** with indicator plate to the minimum optimum distance from the specimen.

The microscope is advantageously outfitted with a monochromator **14** (e.g., exchangeable interference filters) to make use of the dispersion of the Faraday rotation. Accordingly, the wavelength at which the magneto-optical film **512** has its maximum Faraday rotation can be used.

Further, the microscope advantageously has an aperture stop **15** which is adjustable vertically to the optical axis so that in-plane magnetization components of the specimen can also be detected by oblique incident light with eccentric aperture stop.

FIG. **4** shows an advantageous example of a microscope objective with integrated indicator plate with surfaces F1, F2 and lens surfaces F3–F15 with distances d1–d14 and radii of curvature r1–r15. The optical parameters are:

Surface no.	Radius	Distance	Glass type	Refractive index
1	infinite			1.0000
		0.50000	garnet	1.9740
2	infinite	4.33505		1.0000
3	−18.73716	3.29010	psk1	1.54979
4	−7.25655	1.50822		1.0000
5	392.44918	1.50000	sf4	1.761670
6	18.64128	6.00000	fk51	1.48794
7	−11.16745	3.70000		1.00000
8	56.63752	2.95000	lask3	1.734438
9	−21.36052	1.77000		1.00000
10	19.47278	4.80000	fk51	1.48794
11	−11.12580	2.500000	sf4	1.76167
12	−664.96261	0.75000		1.00000
13	−21.41133	8.25000	sf4	1.76167
14	−9.30821	5.35000	bk3	1.500140
15	9.88940			

within a tolerance of 20%.

While the foregoing description and drawings represent the preferred embodiments of the present invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the true spirit and scope of the present invention.

What is claimed is:

1. In a Faraday microscope for examining specimens with stray magnetic fields in a reflected-light beam path, wherein a magneto-optical indicator film is arranged in front of the specimen and the influence of the specimen on the indicator film is evaluated with respect to optical polarization, the improvement comprising that the indicator film is arranged at the end of a microscope objective as a terminating element of said objective.

2. The Faraday microscope according to claim **1**, wherein the indicator film is arranged on an optically transparent supporting substrate, the indicator film and substrate being taken into account in the optical calculation of the microscope objective.

3. The Faraday microscope according to claim **2**, wherein the indicator film is a component part of an indicator plate which is arranged along with the optical elements of the microscope objective in a common housing.

4. The Faraday microscope according to claim **3**, wherein the indicator plate is provided with a protective layer in the direction of the specimen.

5. The Faraday microscope according to claim **2**, wherein an anti-reflection coating is provided in front of the supporting substrate in the direction of light.

6. The Faraday microscope according to claim **1**, wherein an anti-reflection coating is provided subsequent to the indicator film in the direction of light.

7. The Faraday microscope according to claim **4**, wherein the protective layer is formed as an anti-reflection coating.

8. The Faraday microscope according to claim **2**, wherein the supporting substrate is a monocrystalline substrate.

9. The Faraday microscope according to claim **1**, wherein a reflective layer is arranged subsequent to the indicator film in the direction of light.

10. The Faraday microscope according to claim **9**, wherein the reflective layer is arranged between the indicator film and the protective layer.

11. The Faraday microscope according to claim **9**, wherein the reflective layer is semi-transparent.

12. The Faraday microscope according to claim **1**, wherein the microscope objective with the indicator film is arranged in a sliding tube which is guided in an outer tube so as to be displaceable.

13. The Faraday microscope according to claim **12**, wherein the sliding tube is supported in a springing manner and its displacement is limited by a stop.

14. The Faraday microscope according to claim **3**, wherein a crossed polarizer/analyzer arrangement is provided for detecting rotation of the polarization plane by the indicator plate, at least one of the polars being rotatable for the purpose of variation in contrast.

15. The Faraday microscope according to claim **3**, wherein the indicator plate is arranged in the immediate vicinity of the specimen.

16. The Faraday microscope according to claim **3**, wherein the indicator plate is placed on the specimen.

17. The Faraday microscope according to claim **1**, including means for providing a magnetic field in the vicinity of the microscope objective to influence the magnetic properties of the specimen.

18. The Faraday microscope according to claim **17**, wherein the microscope objective is surrounded by said means which includes a current-conducting coil for generating a magnetic field parallel to the optical axis.

19. The Faraday microscope according to claim **17**, said means for providing a magnetic field includes a Helmholtz coil, said field being generated vertically to the optical axis.

20. The Faraday microscope according to claim **19**, wherein a monochromator with adjustable wavelength is provided in the optical path of the microscope.

21. The Faraday microscope according to claim **1**, wherein an adjustable aperture stop is provided in the beam path.

22. The Faraday microscope according to claim **1**, wherein the illuminating beam path and the analysis beam path are united via a beam splitter.

23. The Faraday microscope according to claim **22**, wherein the beam splitter is a Berek prism.

24. The Faraday microscope according to claim **1**, wherein said microscope objective has the following optical parameters with lens surfaces with surface numbers **3–15** and distances **d1–d14** and wherein an indicator plate is arranged in front of the objective with surface numbers **1** and **2**:

Surface no.	Radius (mm)	Distance d (mm)	Glass type	Refractive index
1	infinite			1.0000
		0.50000	garnet	1.9740
2	infinite	4.33505		1.0000
3	−18.73716	3.29010	psk1	1.54979
4	−7.25655	1.50822		1.0000
5	392.44918	1.50000	sf4	1.761670
6	18.64128	6.00000	fk51	1.48794
7	−11.16745	3.70000		1.00000
8	56.63752	2.95000	lask3	1.734438
9	−21.36052	1.77000		1.00000
10	19.47278	4.80000	fk51	1.48794
11	−11.12580	2.500000	sf4	1.76167
12	−664.96261	0.75000		1.00000
13	−21.41133	8.25000	sf4	1.76167
14	−9.30821	5.35000	bk3	1.500140
15	9.88940			

within a tolerance of 20%.

25. A process for adjusting a Faraday microscope objective with integrated indicator plate relative to the surface of a superconducting specimen, comprising the steps of: focusing a different objective with reduced depth of field on the specimen surface in a first step, and placing the microscope objective with integrated indicator plate in the beam path and adjusting the objective to a minimum distance from the specimen in a second step.

26. The process according to claim **25**, including the step of determining the difference between the balanced length of the objective with reduced depth of field and that of the objective with integrated indicator plate during adjustment and taking said differences into account when setting the minimum distance from the specimen.

* * * * *

US005553052A

United States Patent [19]

Oono et al.

[11] Patent Number: 5,553,052

[45] Date of Patent: Sep. 3, 1996

[54] **INCLINATION OF AN OBJECTIVE LENS IN AN OPTICAL INFORMATION SYSTEM**

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[73] Assignee: **Asahi Kogaku Kogyo Kabushiki Kaisha**, Tokyo, Japan

[21] Appl. No.: **204,655**

[22] Filed: **Aug. 2, 1994**

[30] **Foreign Application Priority Data**

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Mar. 2, 1993	[JP]	Japan	5-066010
Mar. 2, 1993	[JP]	Japan	5-066011
Mar. 2, 1993	[JP]	Japan	5-066012
Mar. 19, 1993	[JP]	Japan	5-085637
Apr. 14, 1993	[JP]	Japan	5-111103

[51] **Int. Cl.**[6] **G11B 7/00**; G02B 7/00

[52] **U.S. Cl.** **369/112**; 369/44.15; 369/219; 359/813

[58] **Field of Search** 369/44.16, 44.14, 369/44.15, 112, 219, 215; 359/811, 813, 814, 819, 823

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Primary Examiner—Georgia Y. Epps
Assistant Examiner—Kim-Kwok Chu
Attorney, Agent, or Firm—Greenblum & Bernstein P.L.C.

[57] **ABSTRACT**

A detecting apparatus which detects an inclination of an objective lens relative to a reference surface is provided. The objective lens is part of an optical data recording and reproducing apparatus in which data is optically recorded on and reproduced from a recording medium which is placed parallel to the reference surface. The apparatus includes a transparent parallel plate which is opposite the objective lens, parallel to the reference surface, and made of a material that is substantially optically equivalent to a transparent material of the recording medium. The apparatus further includes a reflecting mechanism for reflecting coherent light which has passed through the objective lens and the transparent parallel plate back towards the transparent parallel plate and the objective lens, and a beam splitting mechanism for splitting the coherent light into a first beam and a second beam. The apparatus further includes a wavefront rotating mechanism for rotating the first beam and the second beam about an optical axis in a manner such that the first beam and the second beam are rotated through 180 degrees with respect to one another, and a mechanism for superposing the first beam and the second beam to produce an optical interference.

50 Claims, 32 Drawing Sheets

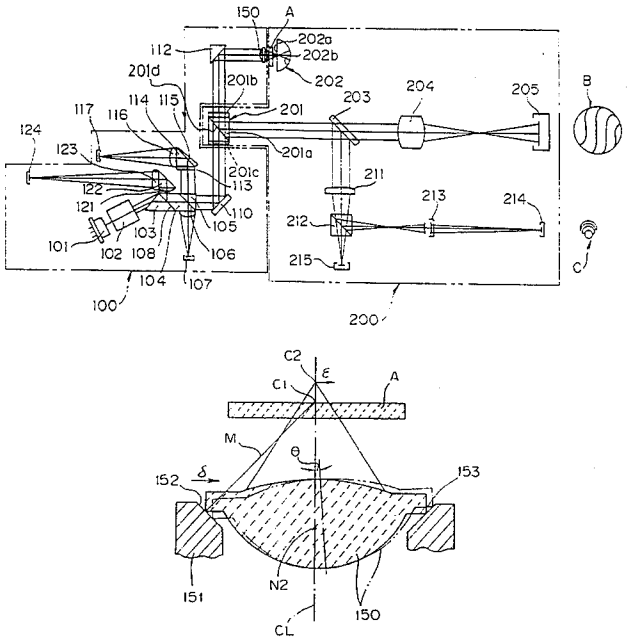

Fig. 1

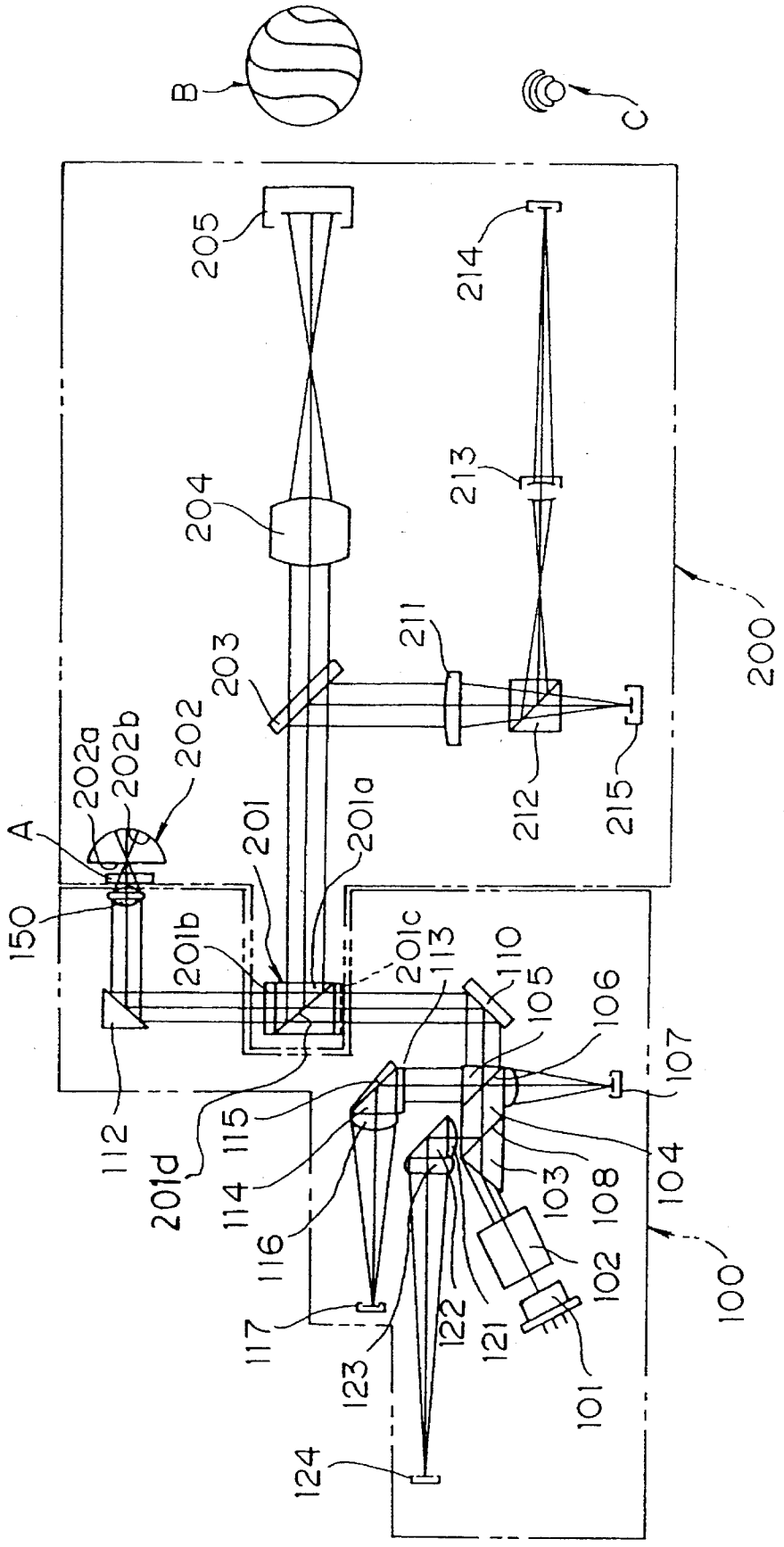
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Fig. 2

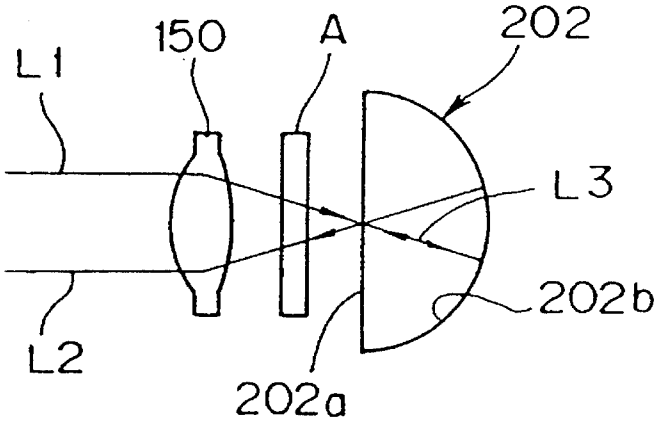

Fig. 3

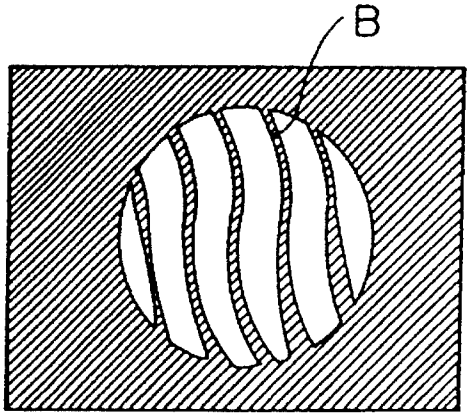

Fig. 4

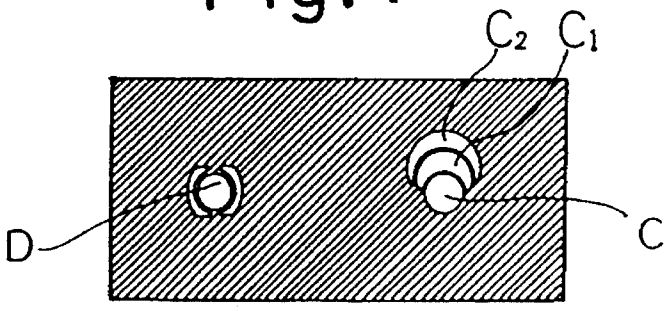

Fig. 5

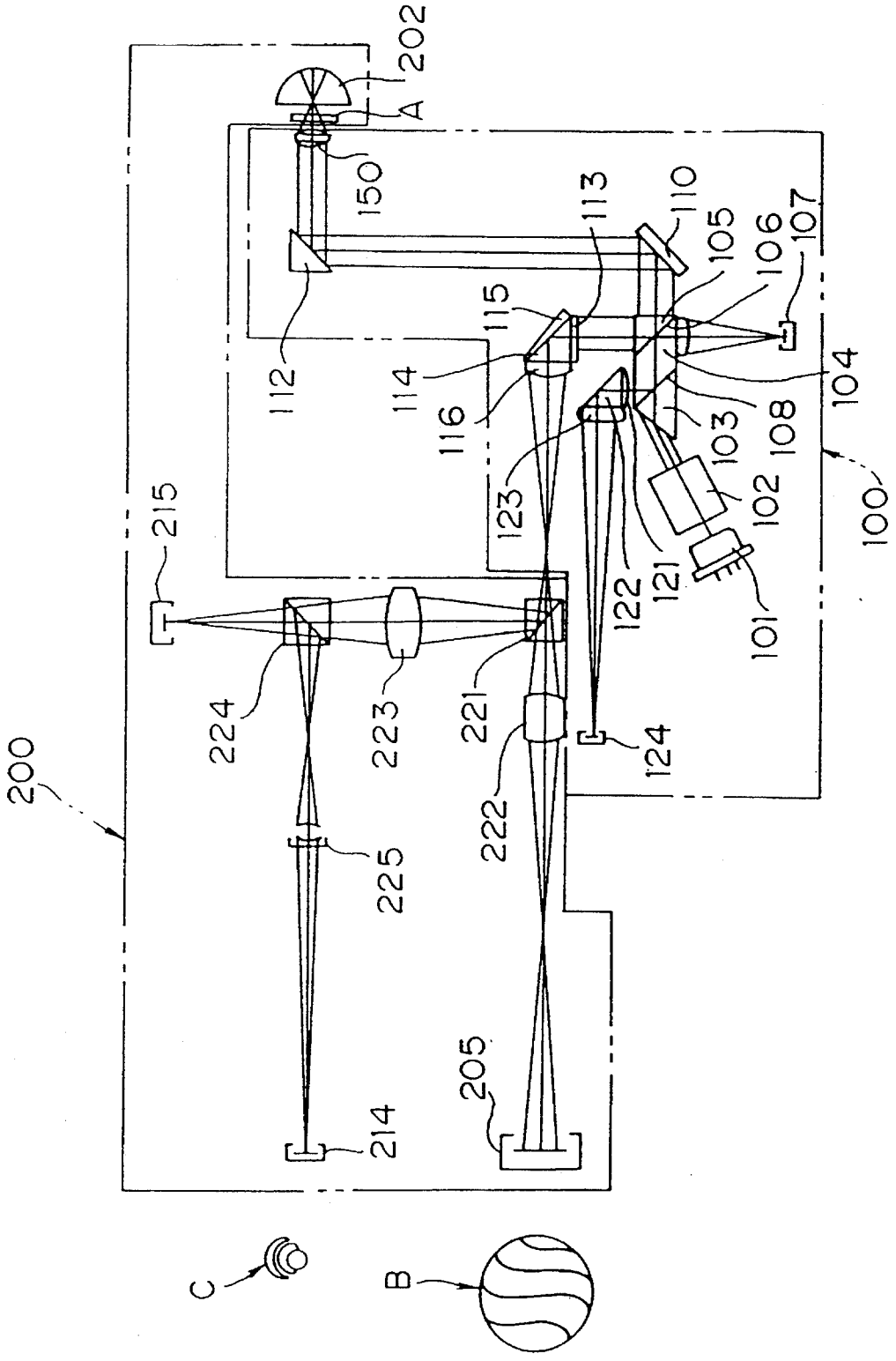
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Fig. 6

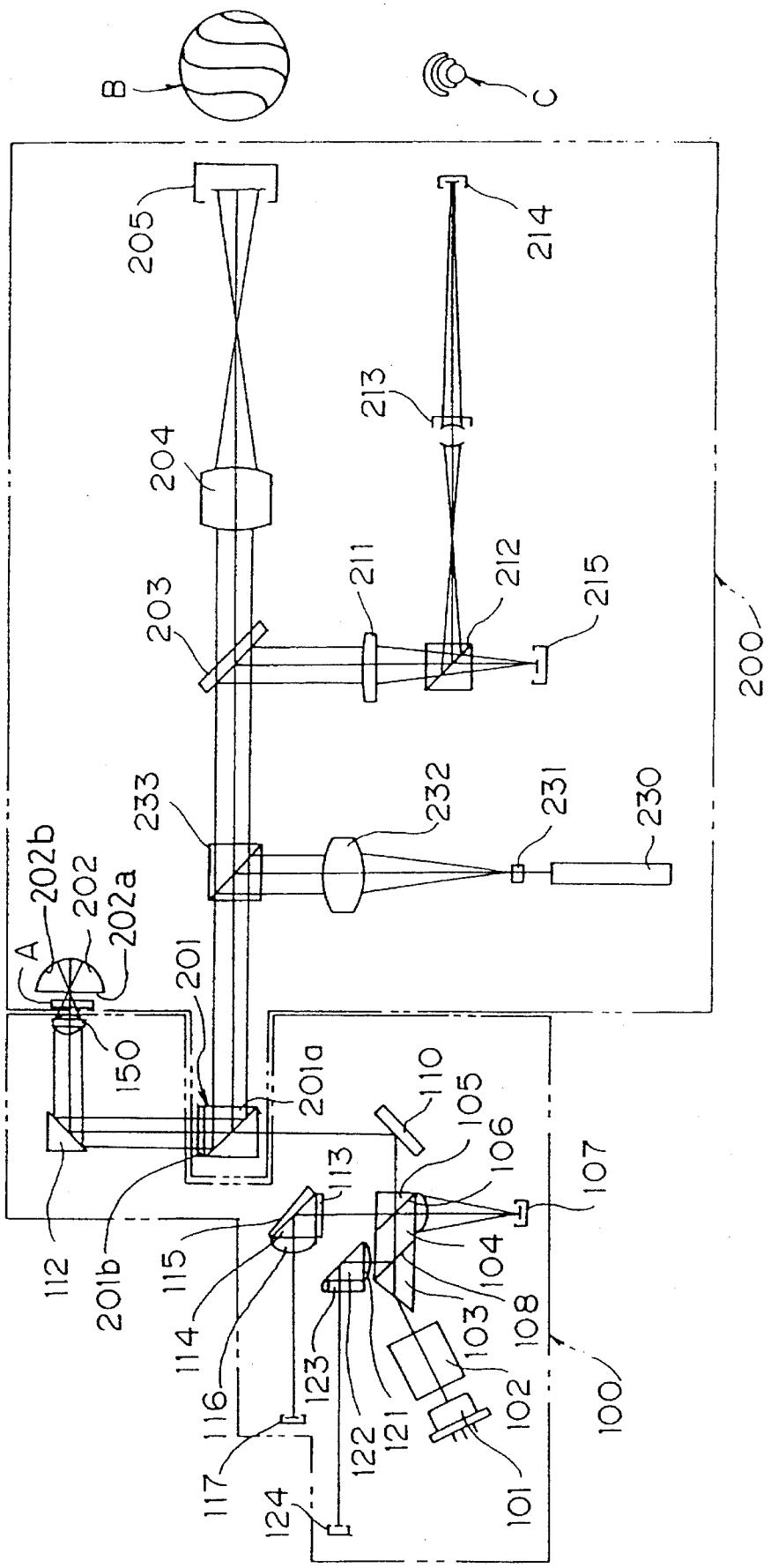
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Fig. 7

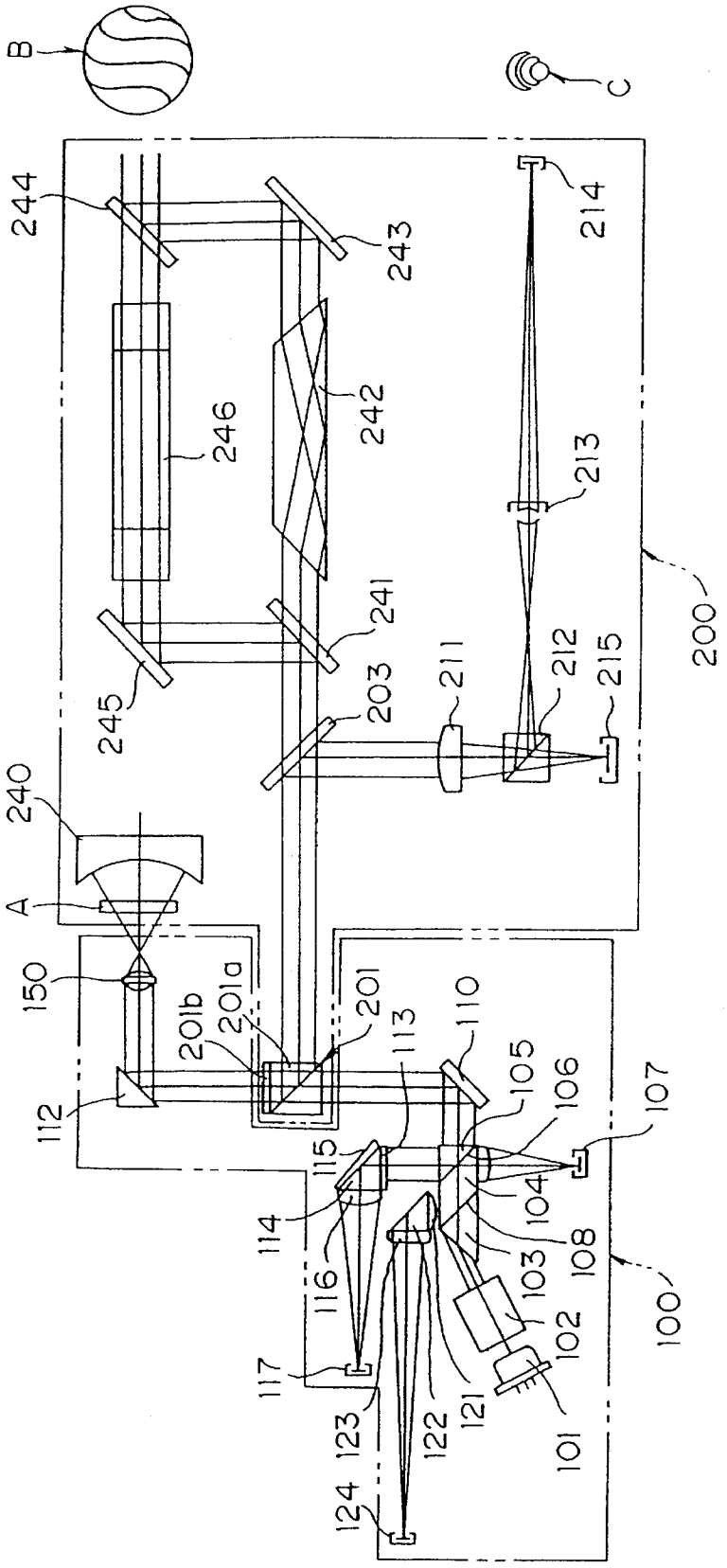
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Fig. 8

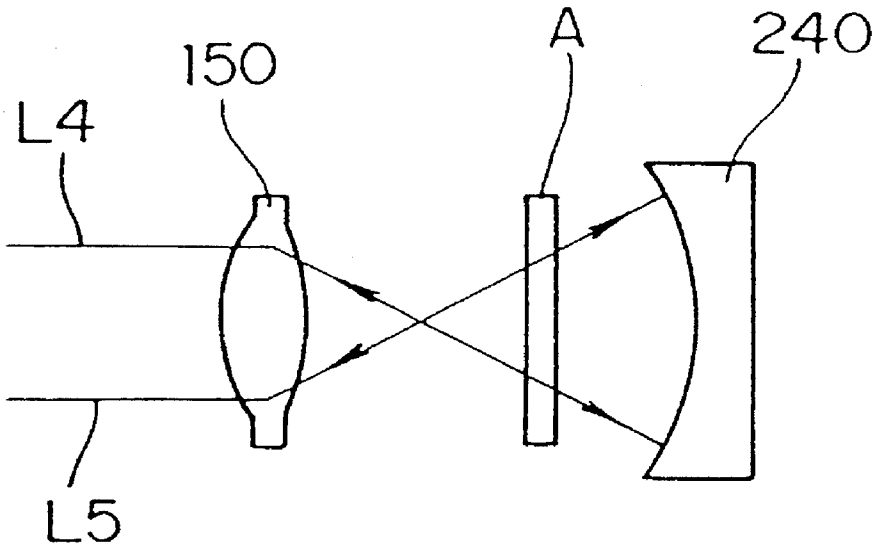

Fig. 9

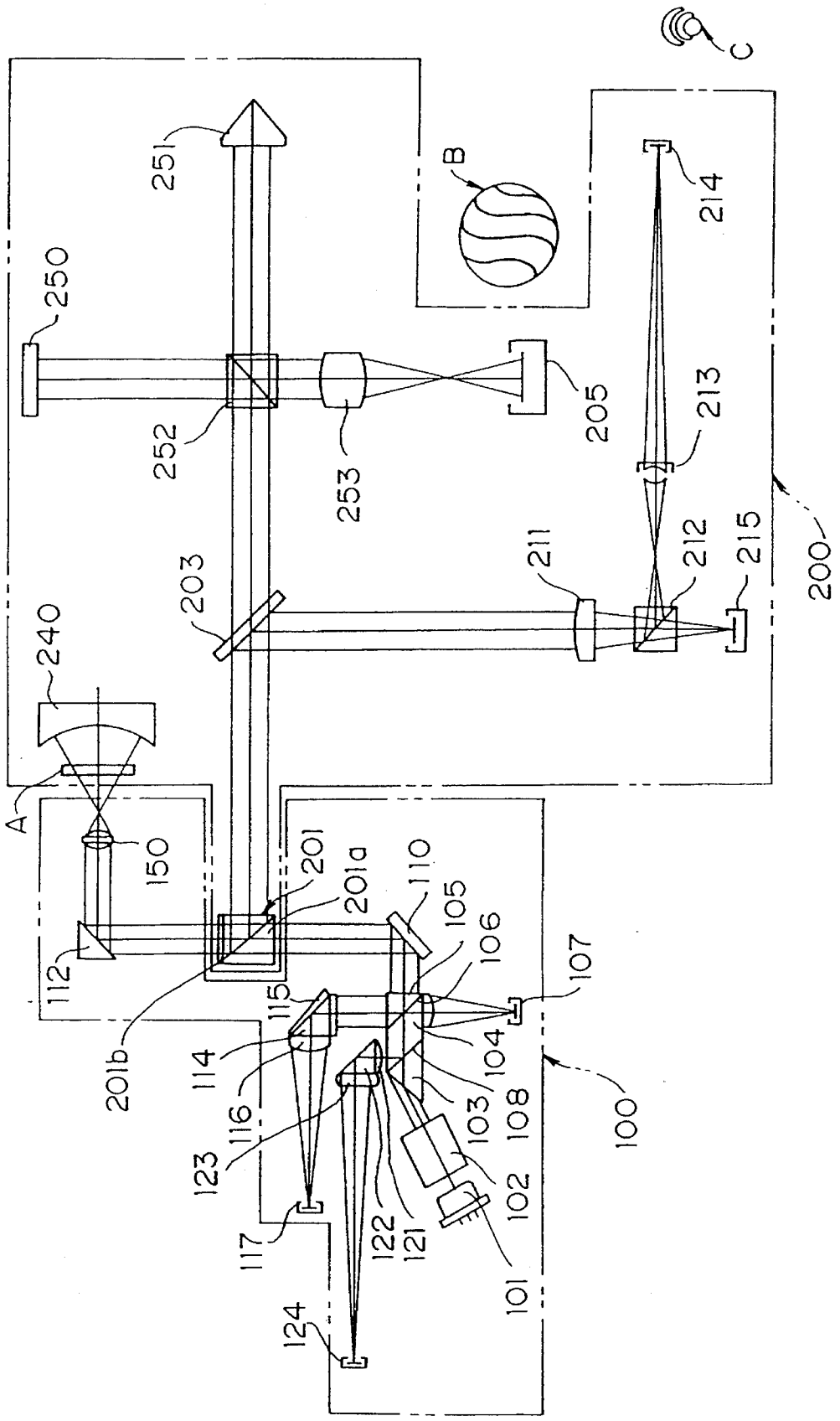
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Fig. 10

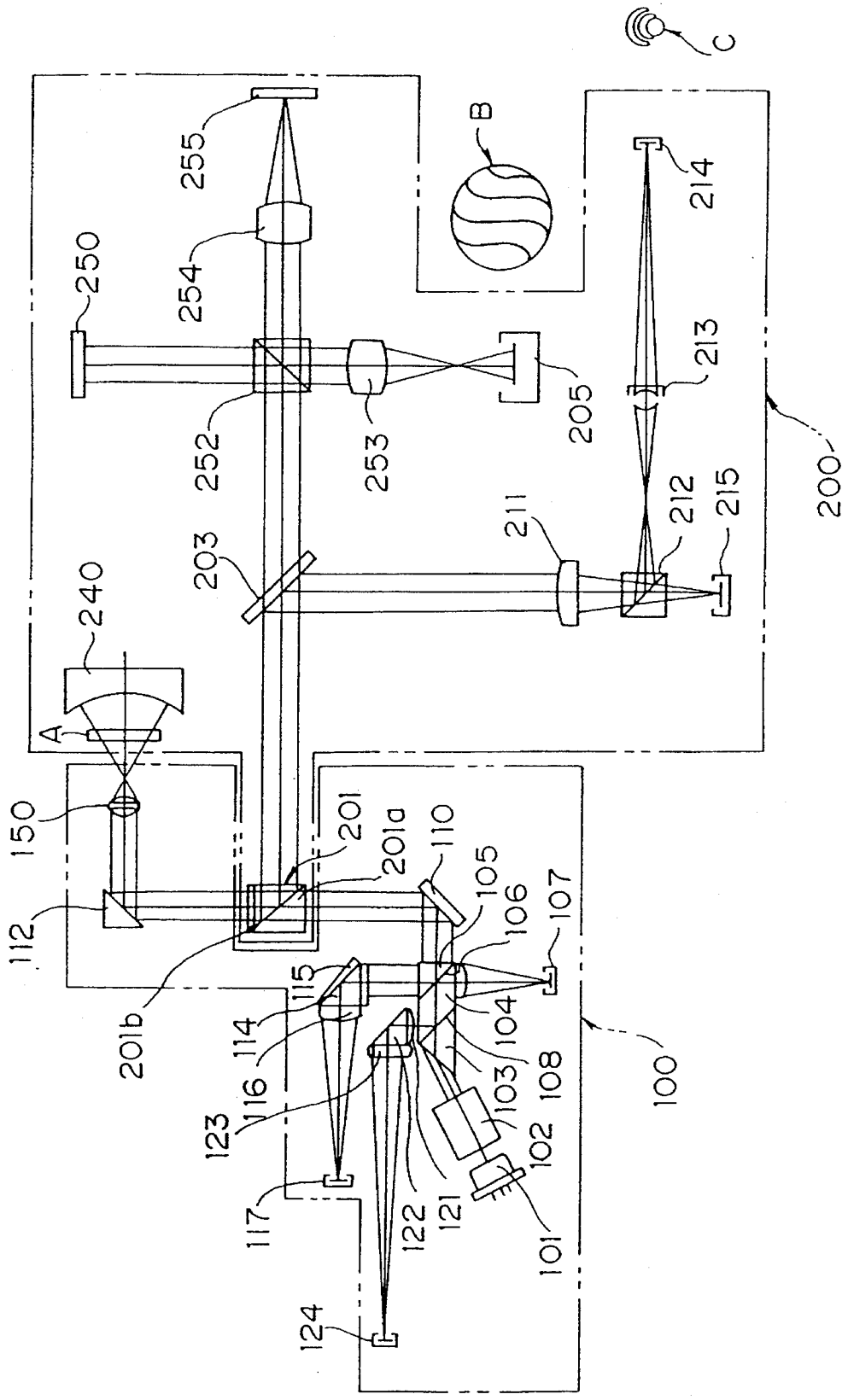
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Fig. 11

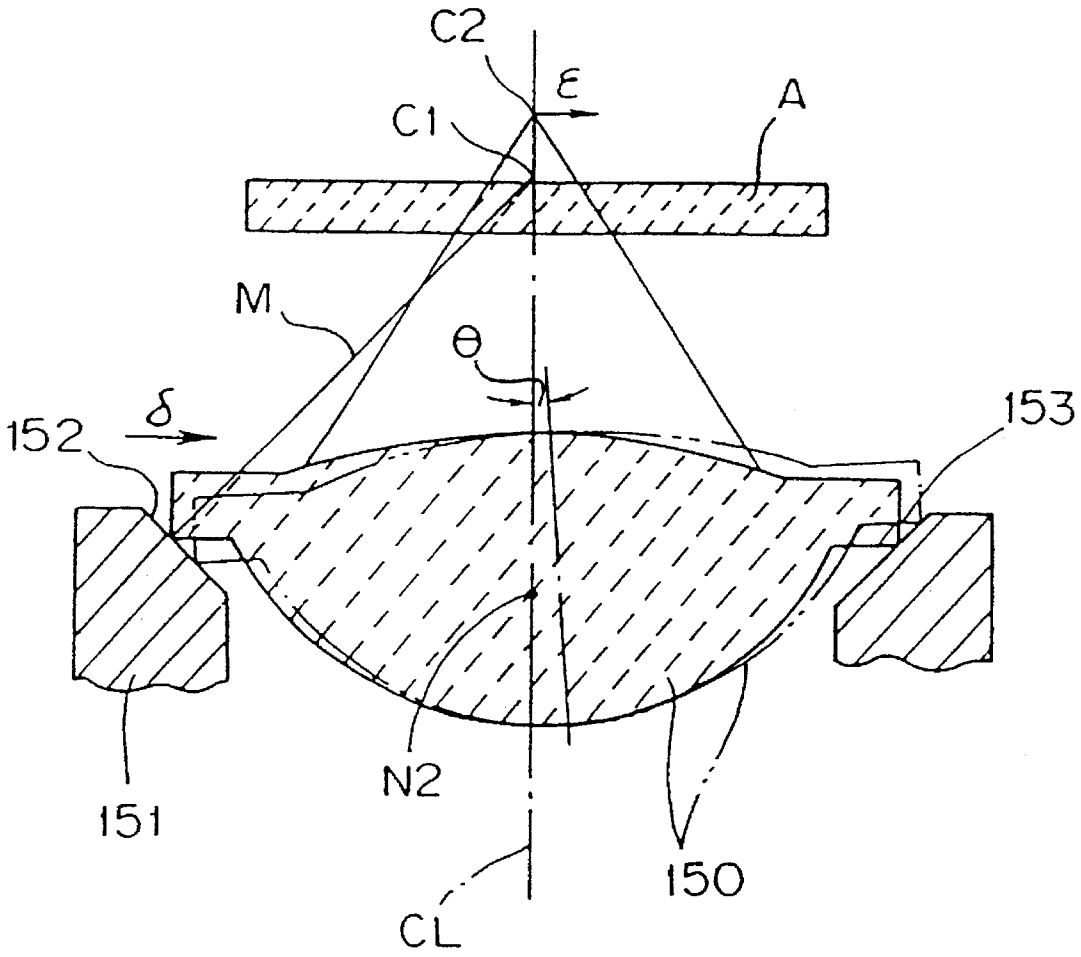

Fig. 12

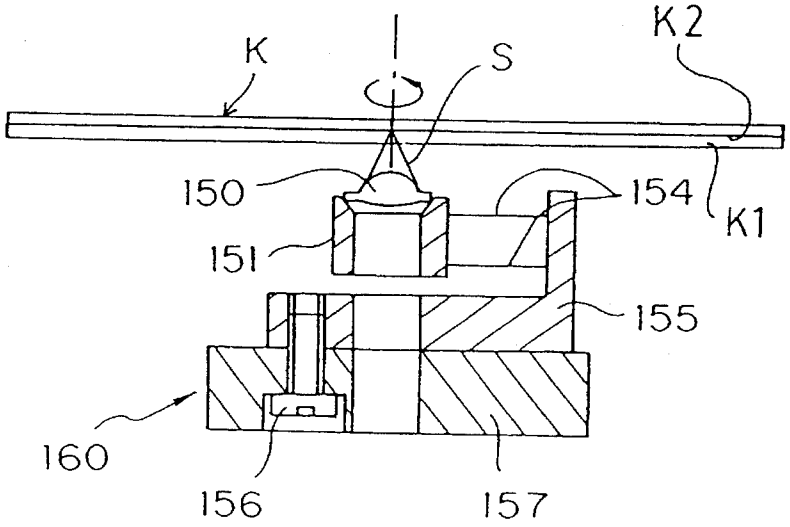
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Fig. 13

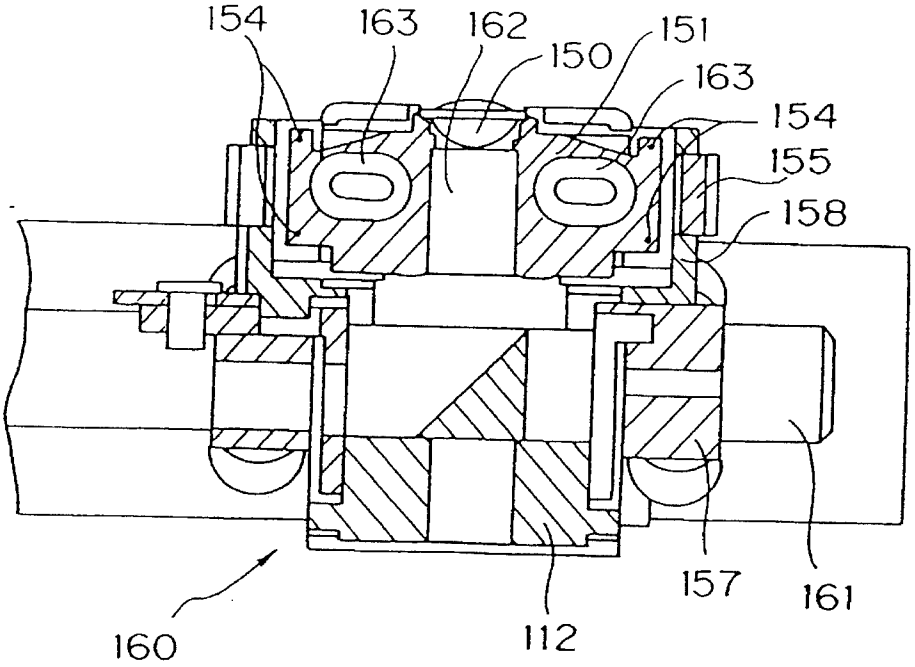
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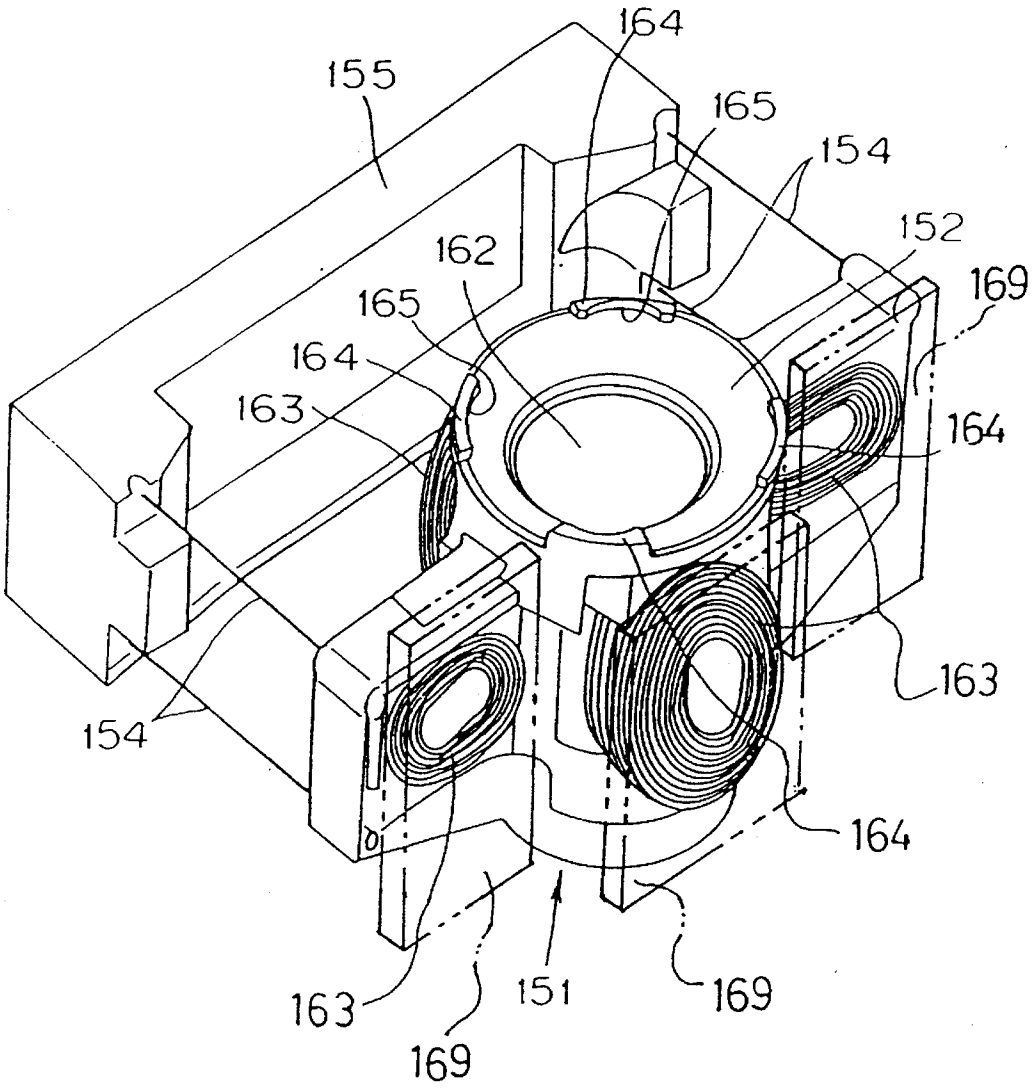
Fig. 14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169
169

Fig. 15

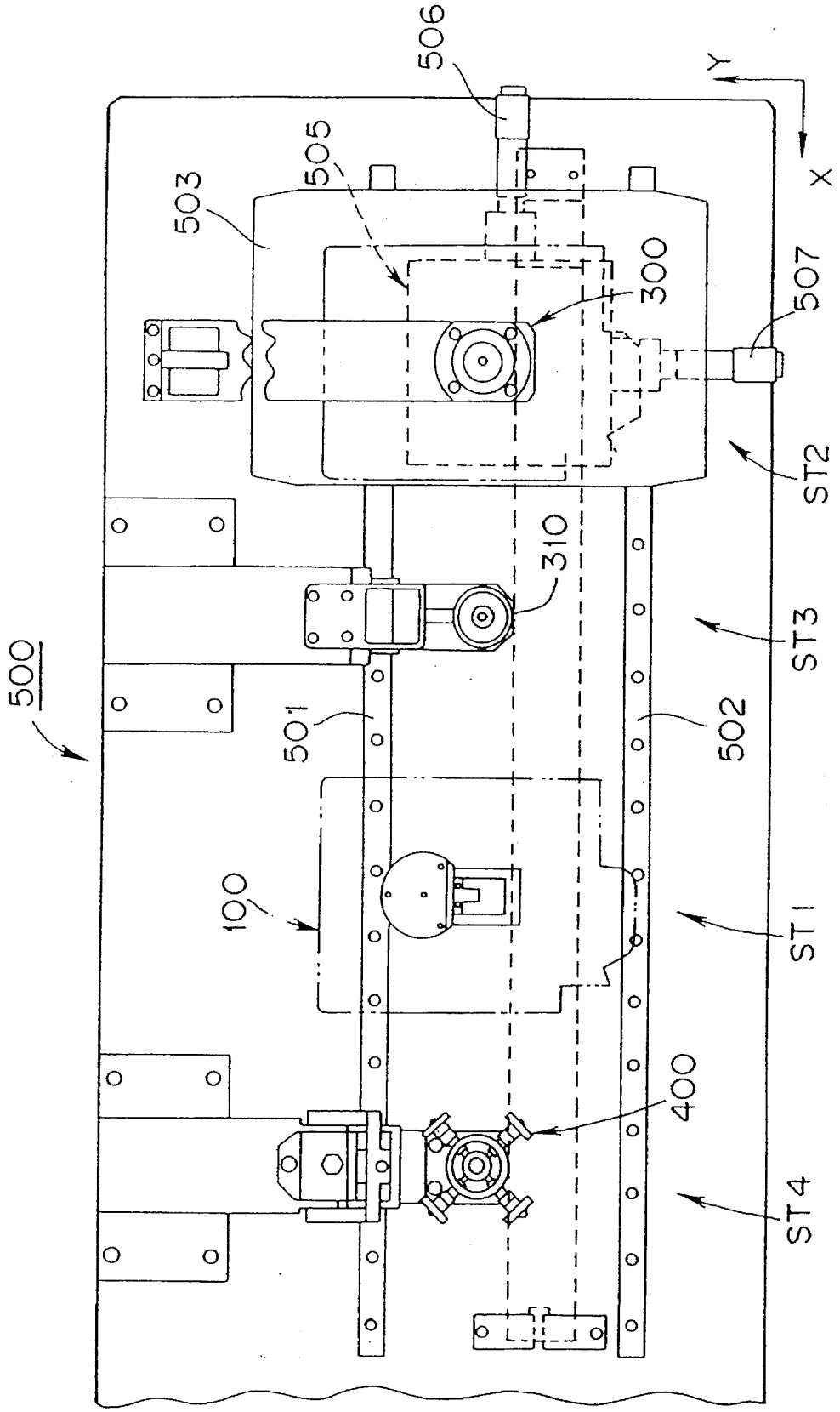


Fig.16

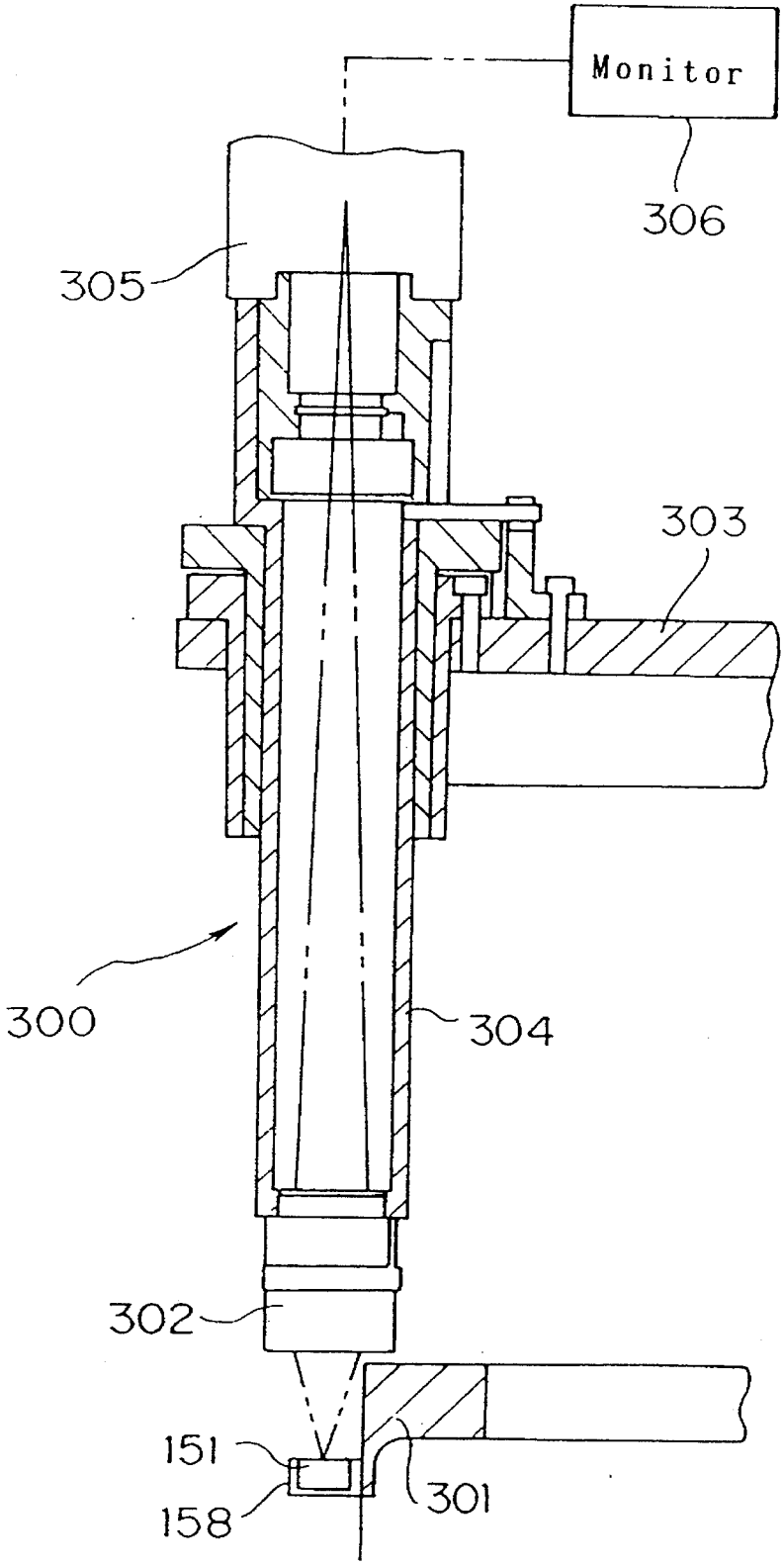


Fig.17

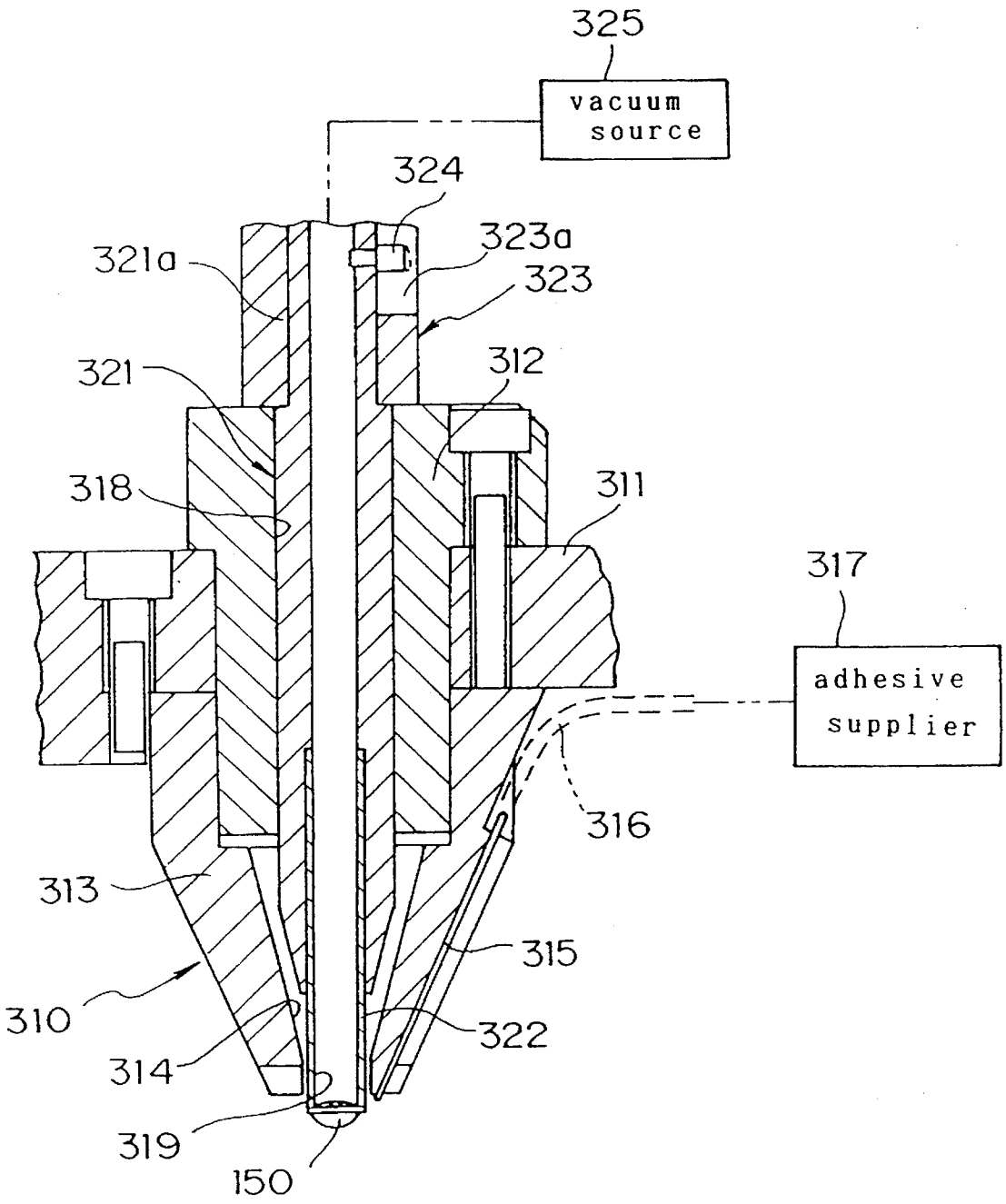

325
vacuum source
324
323a
321a
323
321
312
318
311
317
adhesive supplier
316
313
315
310
322
314
319
150

Fig.18

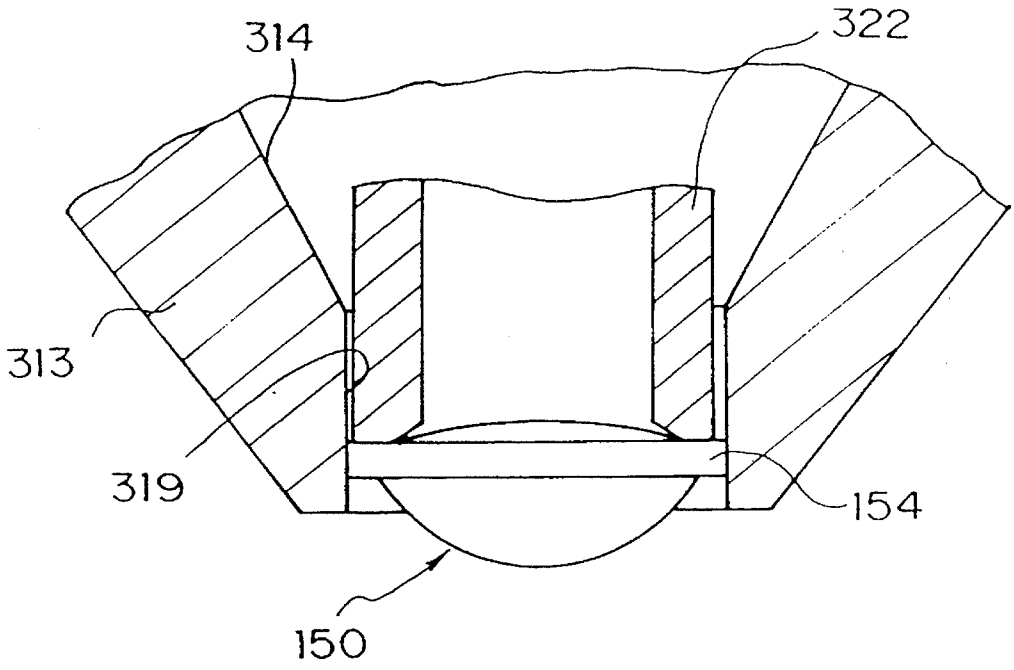


Fig.19

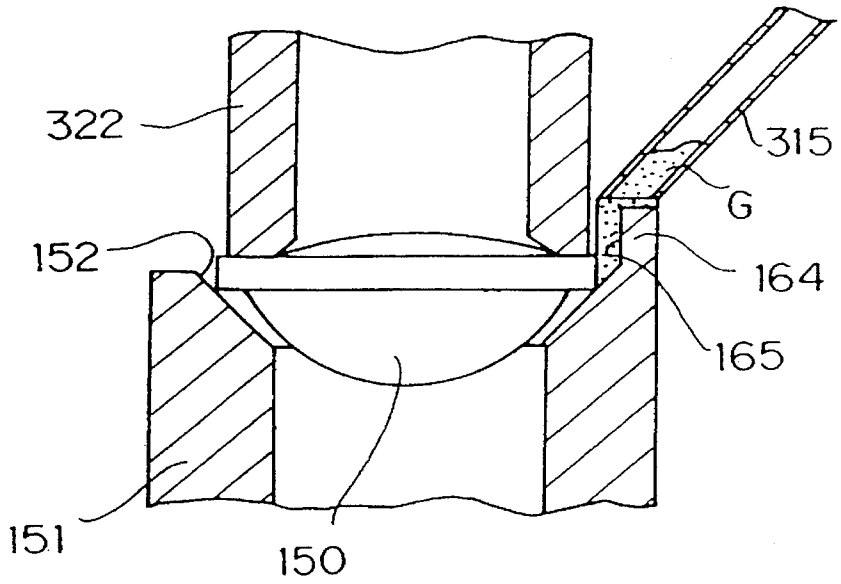


FIG.20

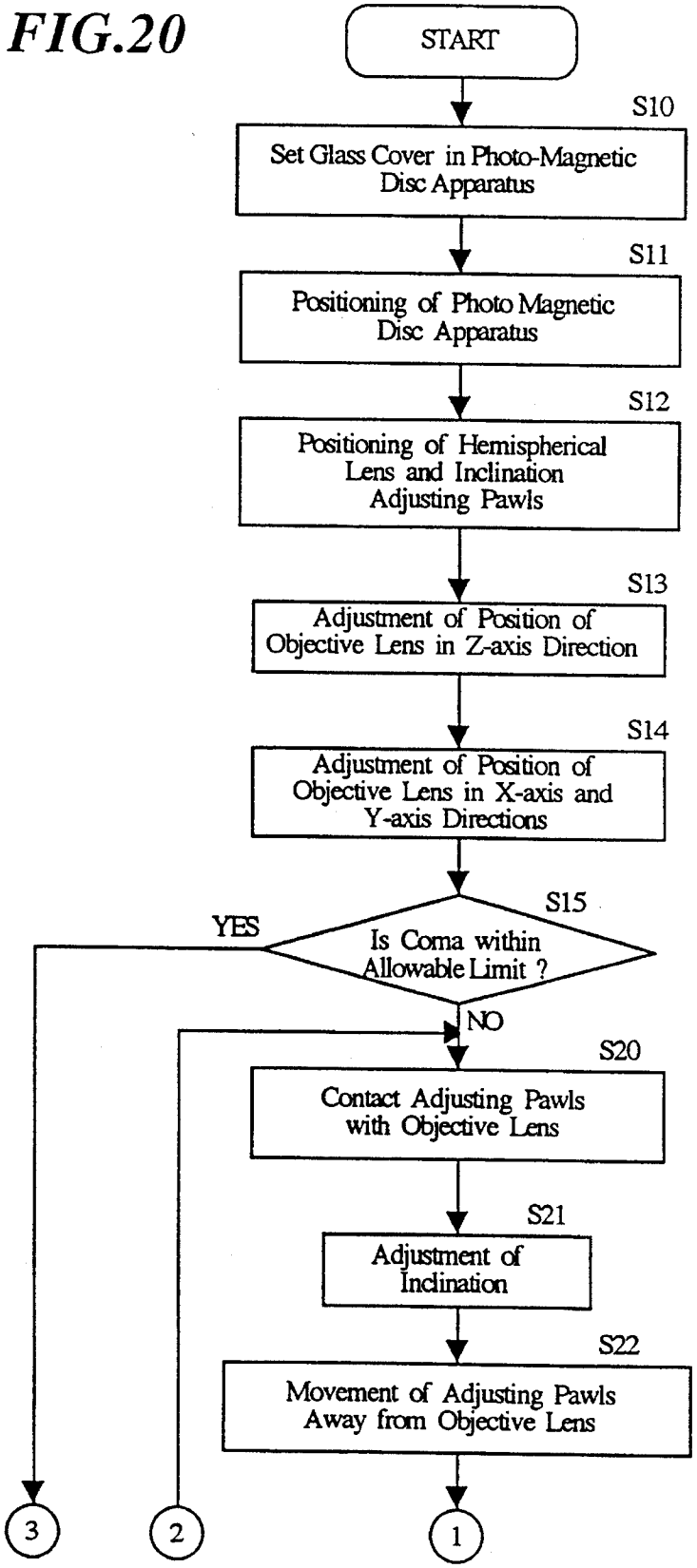

START
S10
Set Glass Cover in Photo-Magnetic Disc Apparatus
S11
Positioning of Photo Magnetic Disc Apparatus
S12
Positioning of Hemispherical Lens and Inclination Adjusting Pawls
S13
Adjustment of Position of Objective Lens in Z-axis Direction
S14
Adjustment of Position of Objective Lens in X-axis and Y-axis Directions
S15
Is Coma within Allowable Limit ?
YES
NO
S20
Contact Adjusting Pawls with Objective Lens
S21
Adjustment of Inclination
S22
Movement of Adjusting Pawls Away from Objective Lens
3
2
1

FIG.21

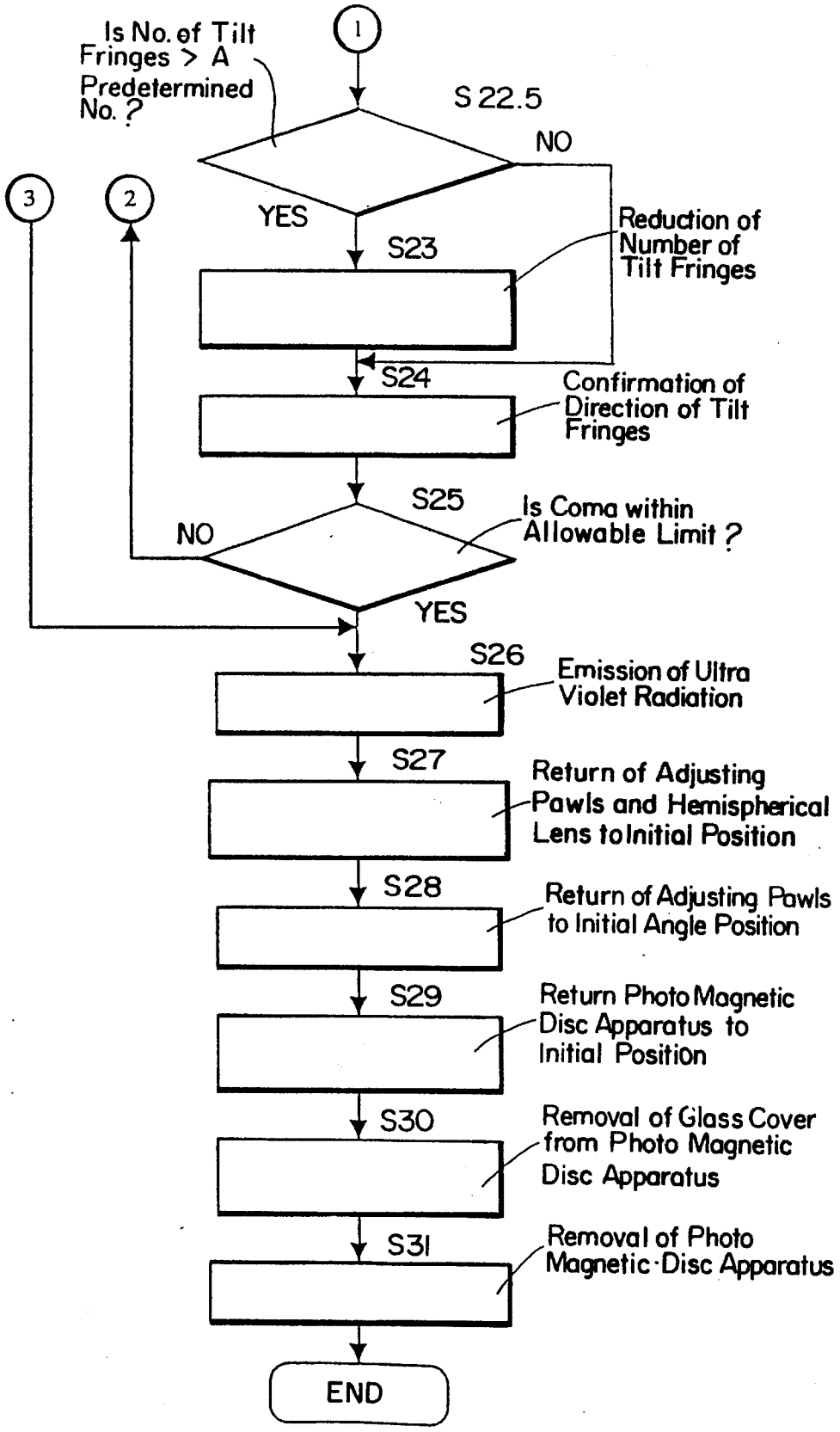

1
Is No. of Tilt Fringes > A Predetermined No. ?
S 22.5
NO
YES
3
2
S23
Reduction of Number of Tilt Fringes
S24
Confirmation of Direction of Tilt Fringes
S25
Is Coma within Allowable Limit ?
NO
YES
S26
Emission of Ultra Violet Radiation
S27
Return of Adjusting Pawls and Hemispherical Lens to Initial Position
S28
Return of Adjusting Pawls to Initial Angle Position
S29
Return Photo Magnetic Disc Apparatus to Initial Position
S30
Removal of Glass Cover from Photo Magnetic Disc Apparatus
S31
Removal of Photo Magnetic Disc Apparatus
END

FIG.22

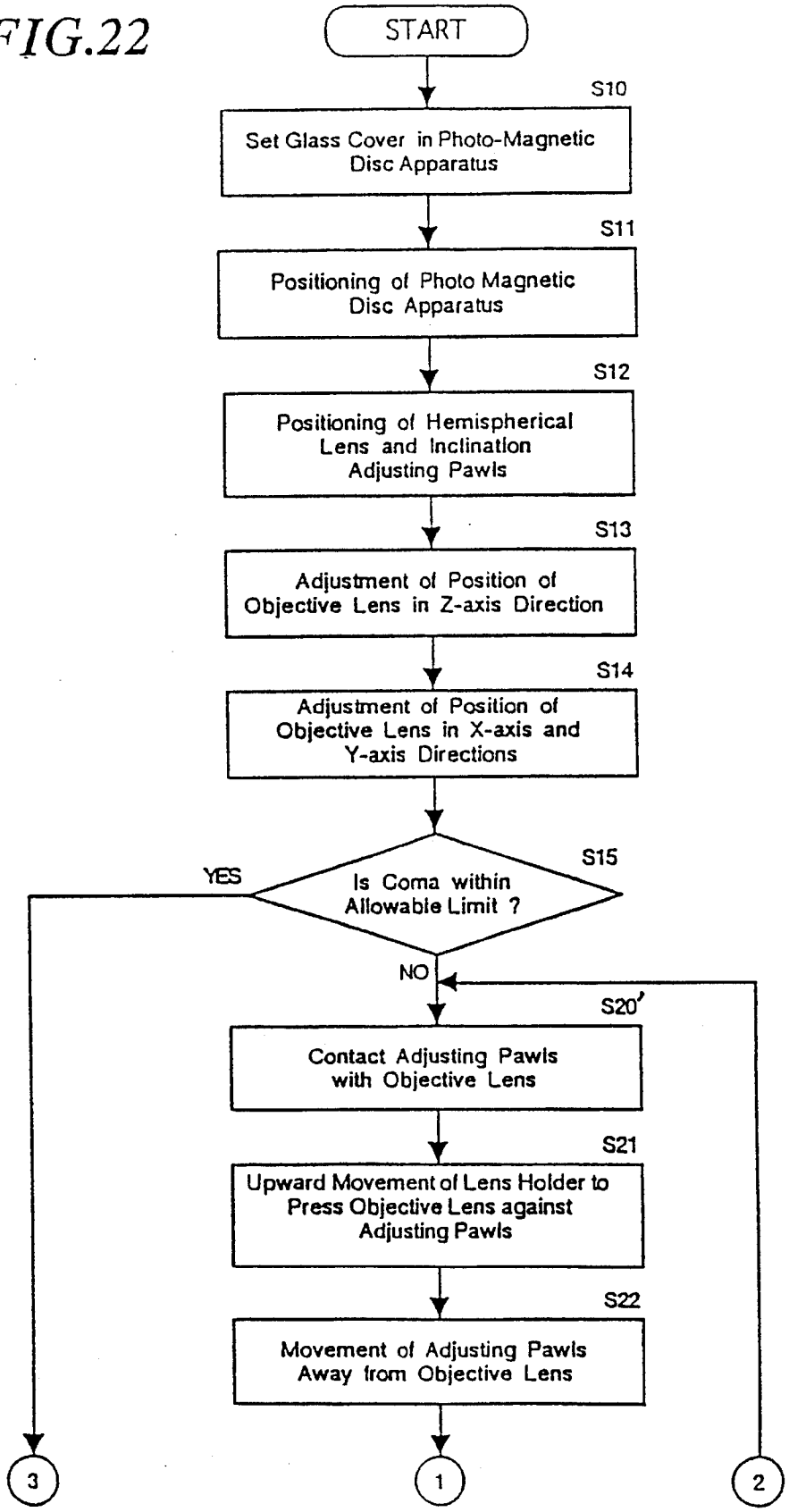

START
S10
Set Glass Cover in Photo-Magnetic Disc Apparatus
S11
Positioning of Photo Magnetic Disc Apparatus
S12
Positioning of Hemispherical Lens and Inclination Adjusting Pawls
S13
Adjustment of Position of Objective Lens in Z-axis Direction
S14
Adjustment of Position of Objective Lens in X-axis and Y-axis Directions
S15
Is Coma within Allowable Limit ?
YES
NO
S20'
Contact Adjusting Pawls with Objective Lens
S21
Upward Movement of Lens Holder to Press Objective Lens against Adjusting Pawls
S22
Movement of Adjusting Pawls Away from Objective Lens
3
1
2

FIG.23

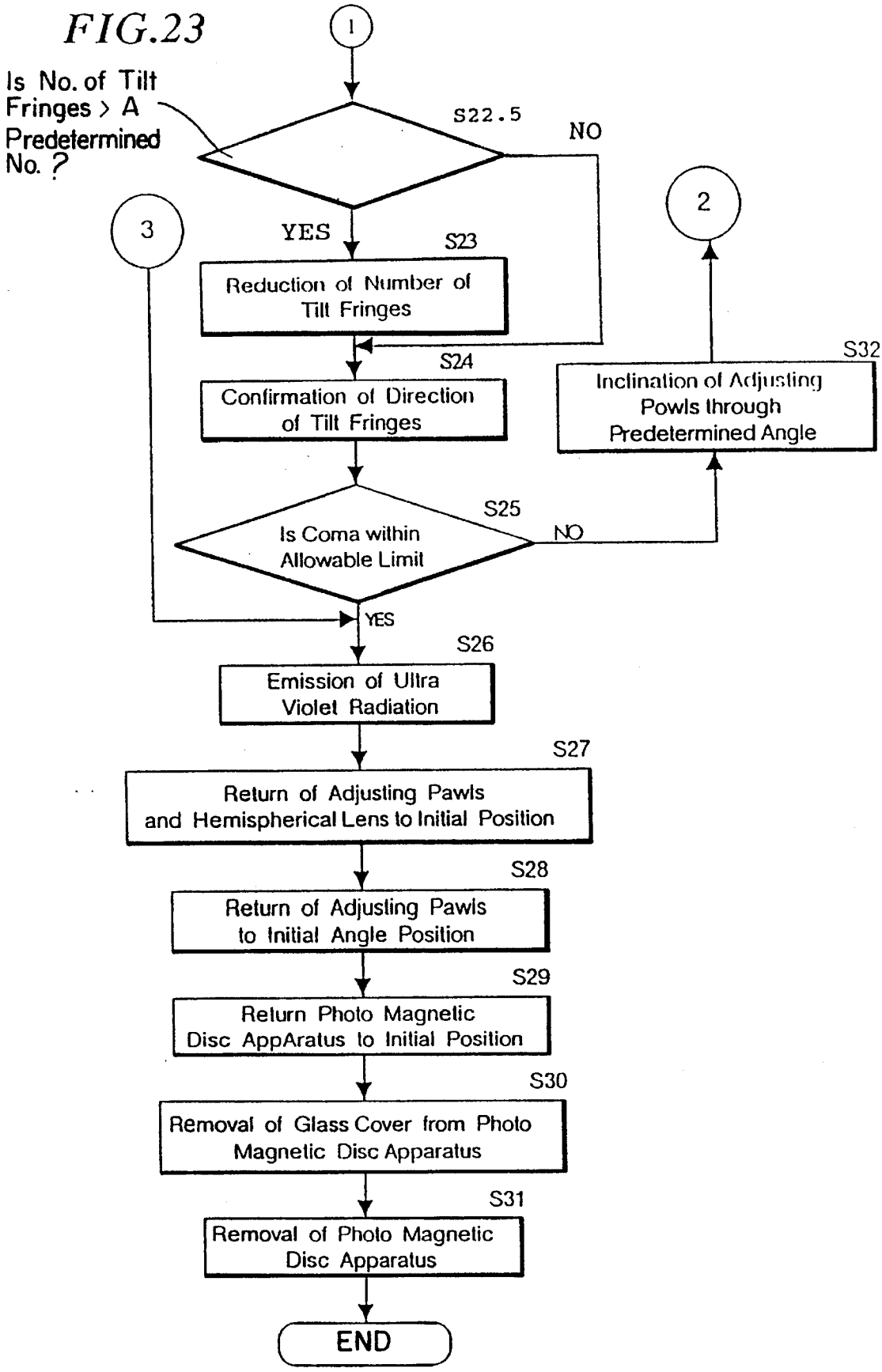

1
Is No. of Tilt Fringes > A Predetermined No. ?
S22.5
NO
YES
3
2
S23
Reduction of Number of Tilt Fringes
S24
Confirmation of Direction of Tilt Fringes
S32
Inclination of Adjusting Powls through Predetermined Angle
S25
Is Coma within Allowable Limit
NO
YES
S26
Emission of Ultra Violet Radiation
S27
Return of Adjusting Pawls and Hemispherical Lens to Initial Position
S28
Return of Adjusting Pawls to Initial Angle Position
S29
Return Photo Magnetic Disc AppAratus to Initial Position
S30
Removal of Glass Cover from Photo Magnetic Disc Apparatus
S31
Removal of Photo Magnetic Disc Apparatus
END

FIG. 24

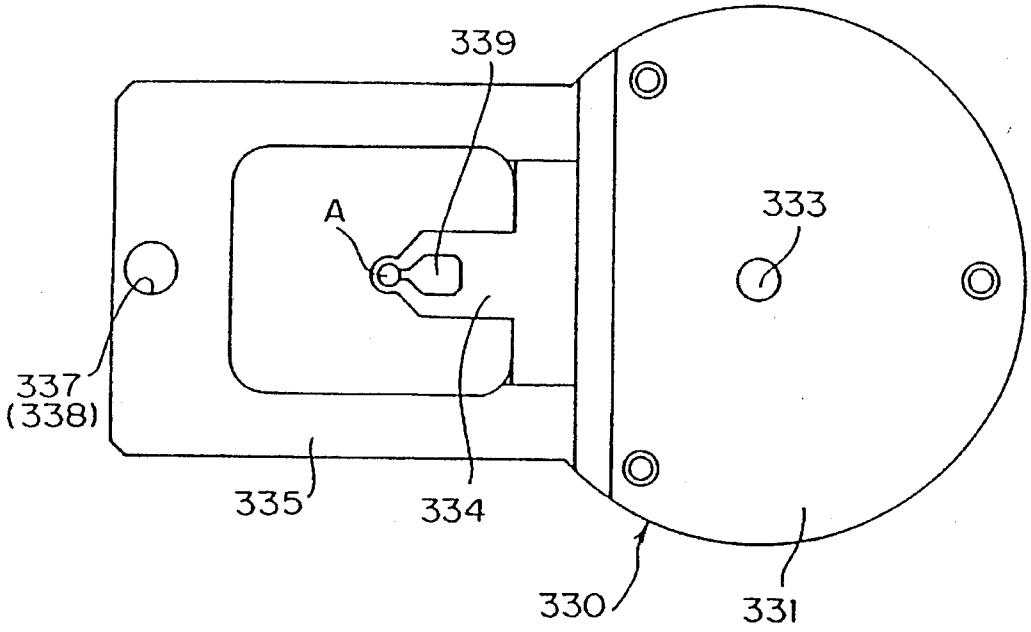

339
A
333
337
(338)
335
334
330
331

FIG. 25

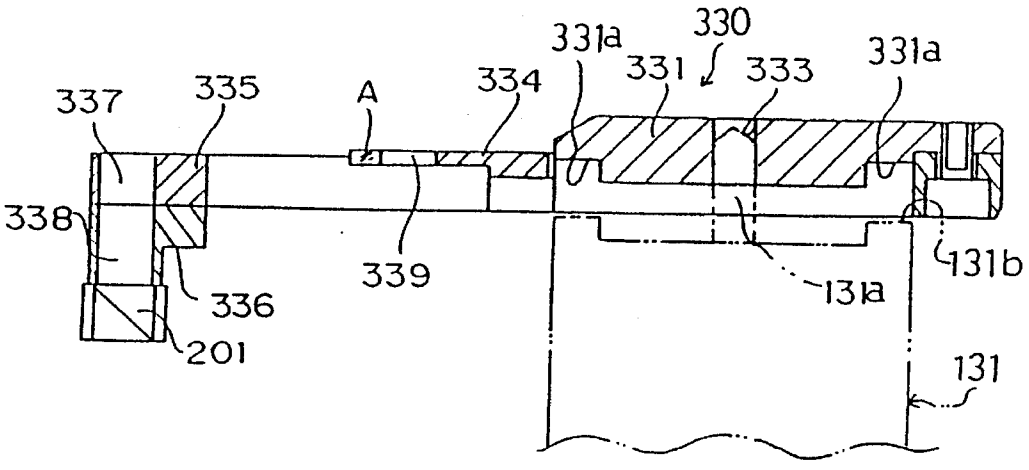

331a
330
331
333
331a
337
335
A
334
338
339
336
201
131a
131b
131

FIG. 26

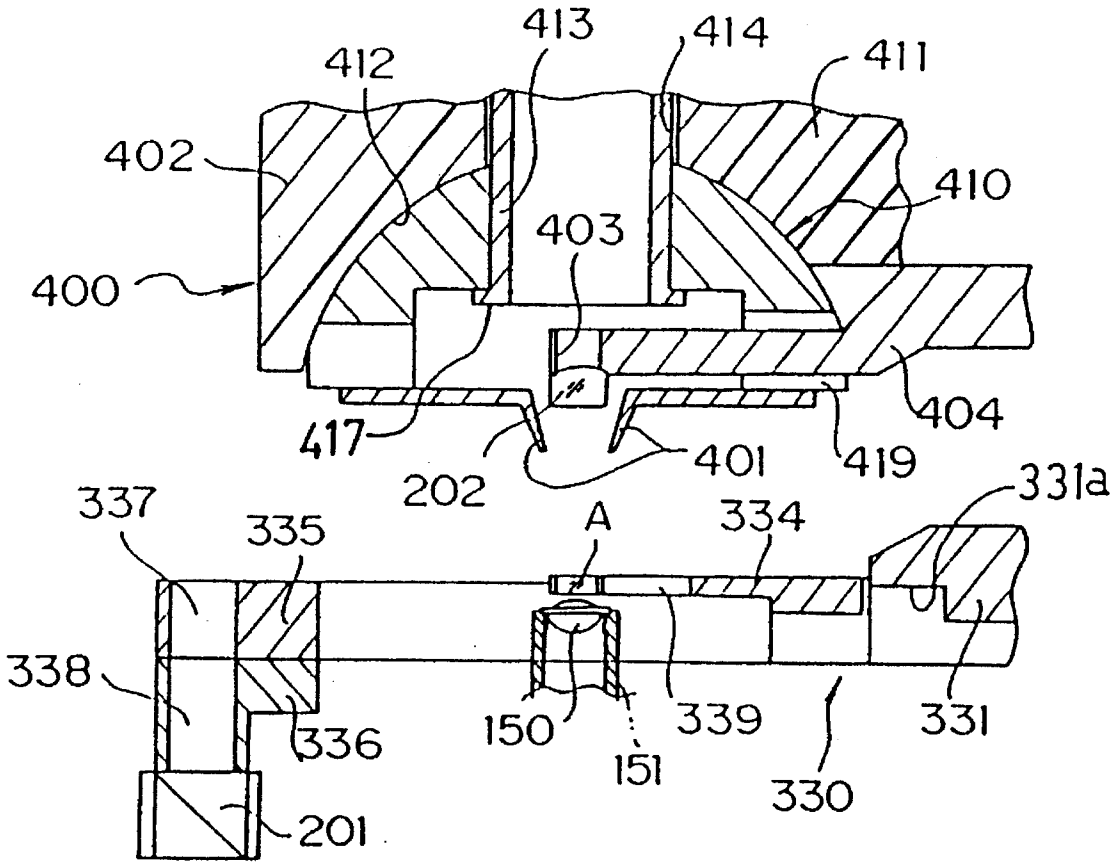

413
414
412
411
402
410
403
400
404
417
401
419
202
331a
337
335
A
334
338
336
150
339
331
151
330
201

FIG. 27

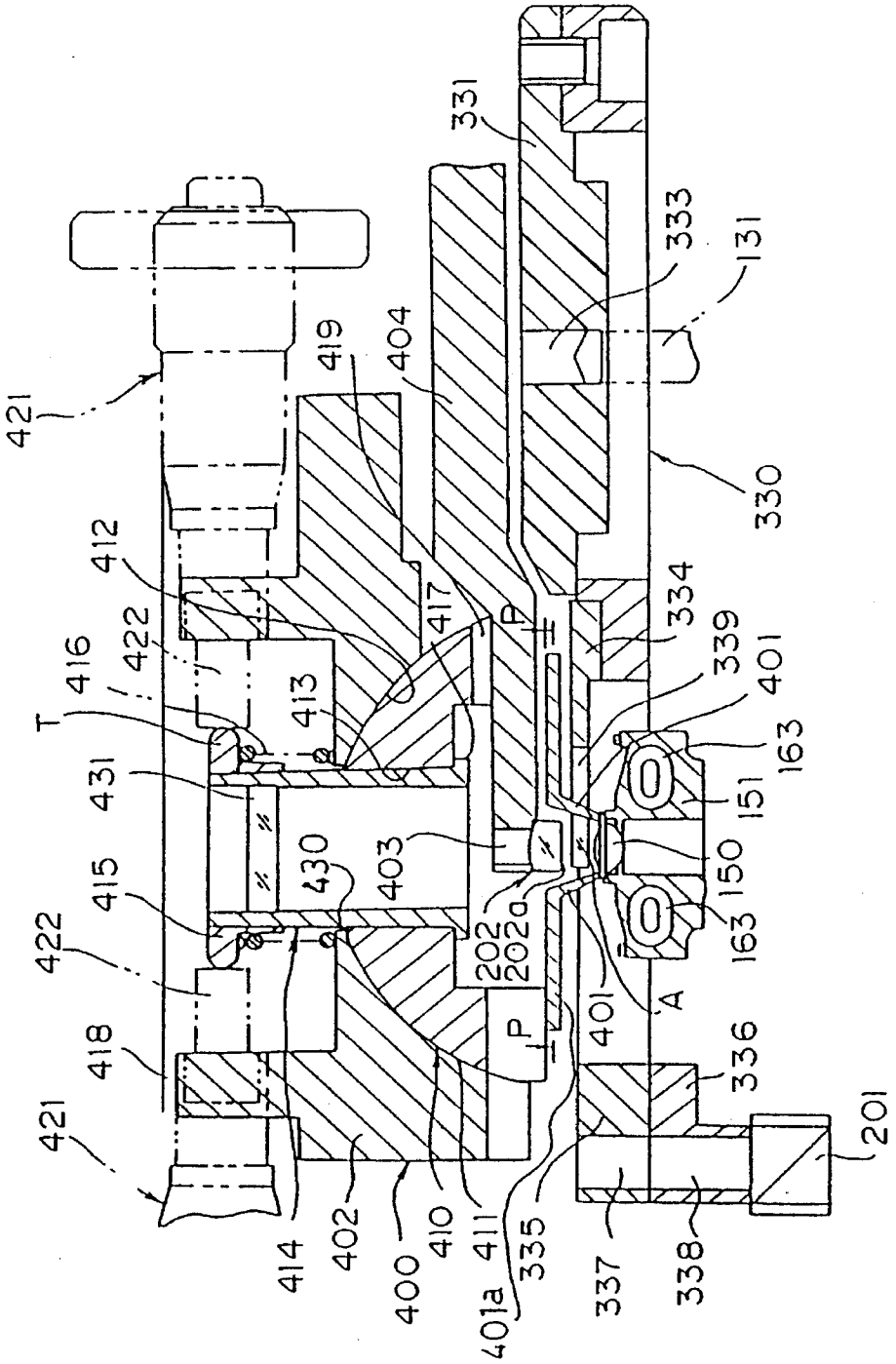

331
333
131
421
419
404
330
412
334
417
P
422
339
401
416
T
413
163
431
151
430
403
150
415
202
202a
163
422
A
401
418
P
336
201
421
414
402
400
410
411
335
337
338
401a

FIG. 28

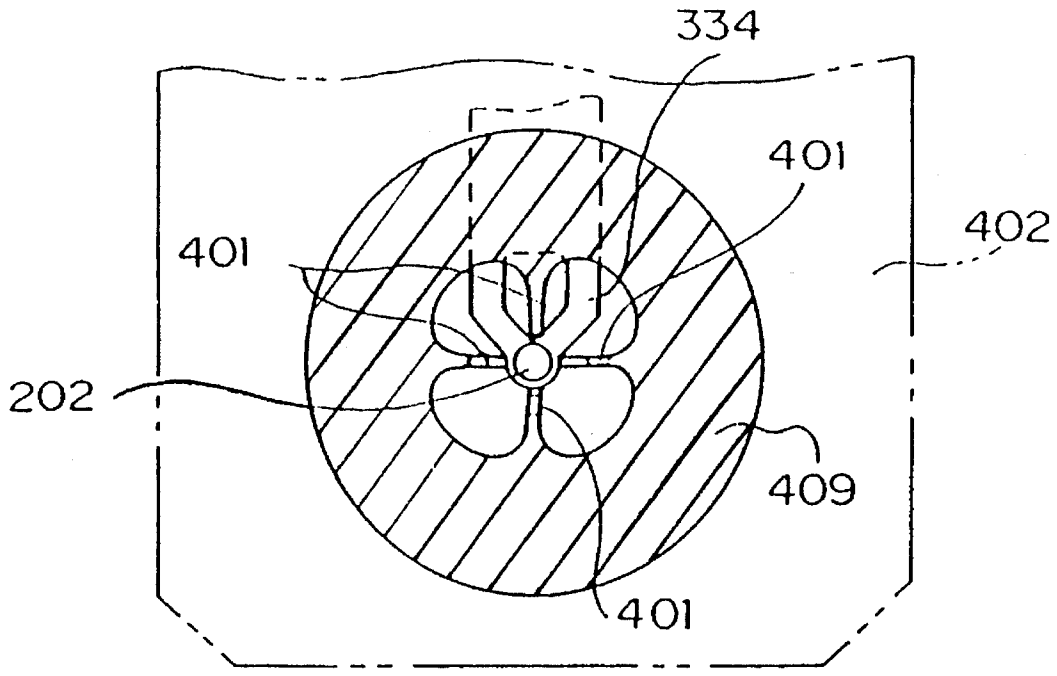


FIG. 29

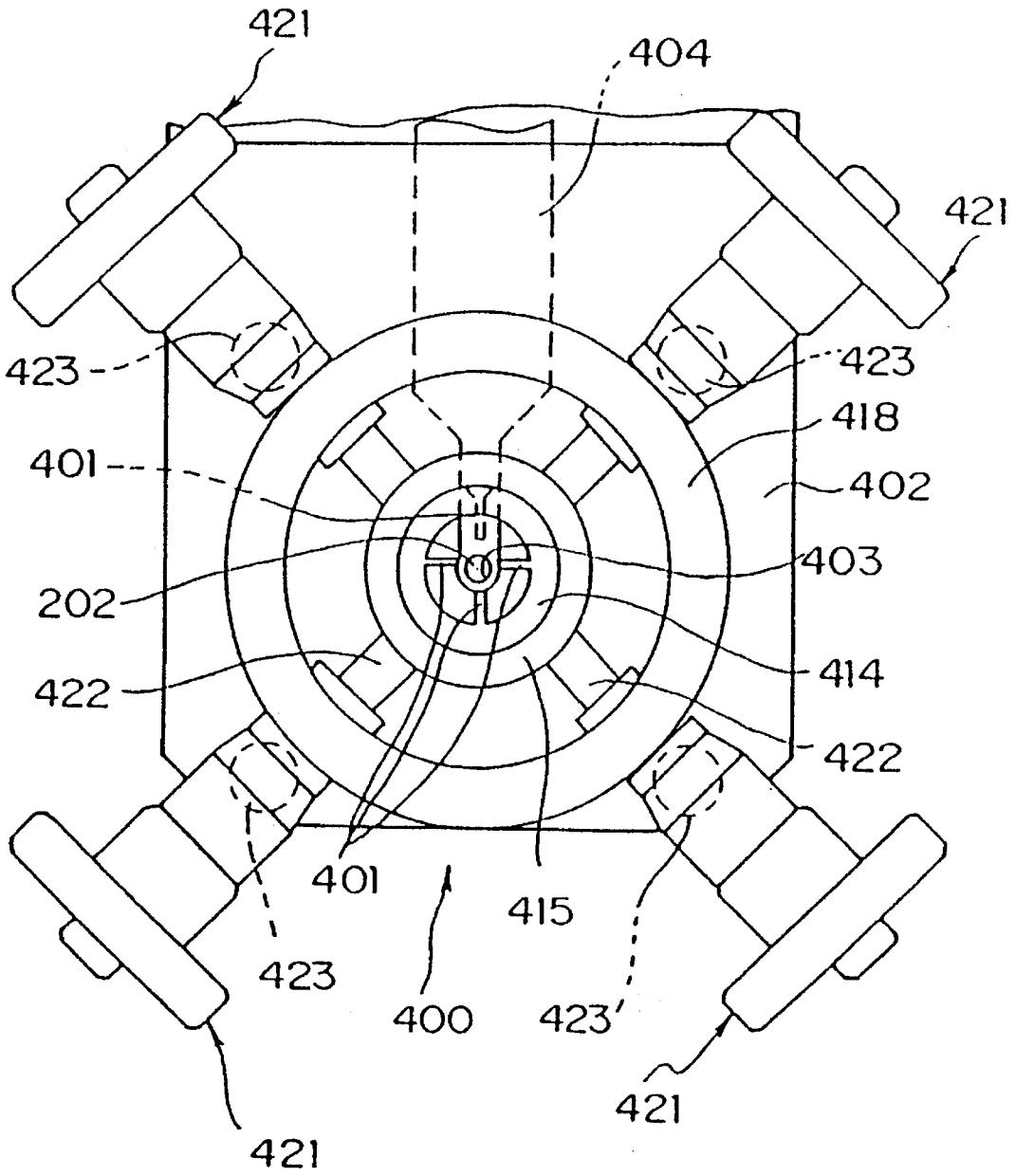

421
404
421
423
423
418
401
402
403
202
414
422
422
401
415
423
400
423
421
421

FIG. 30

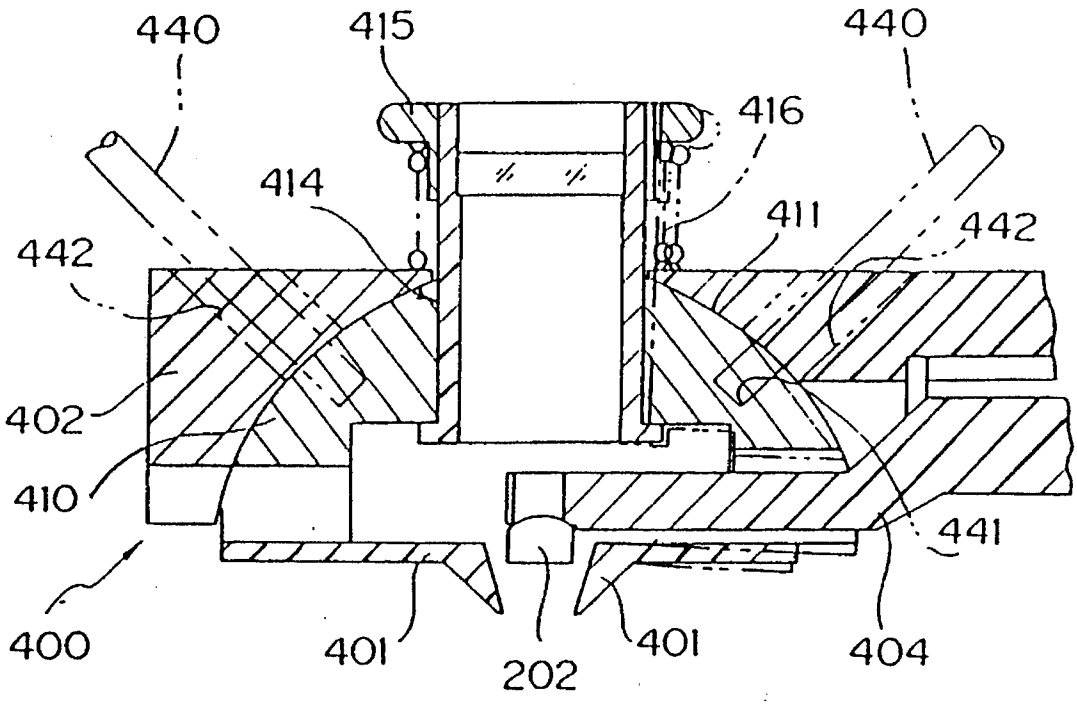

440
415
440
416
414
411
442
442
402
410
441
400
401
202
401
404

FIG. 31

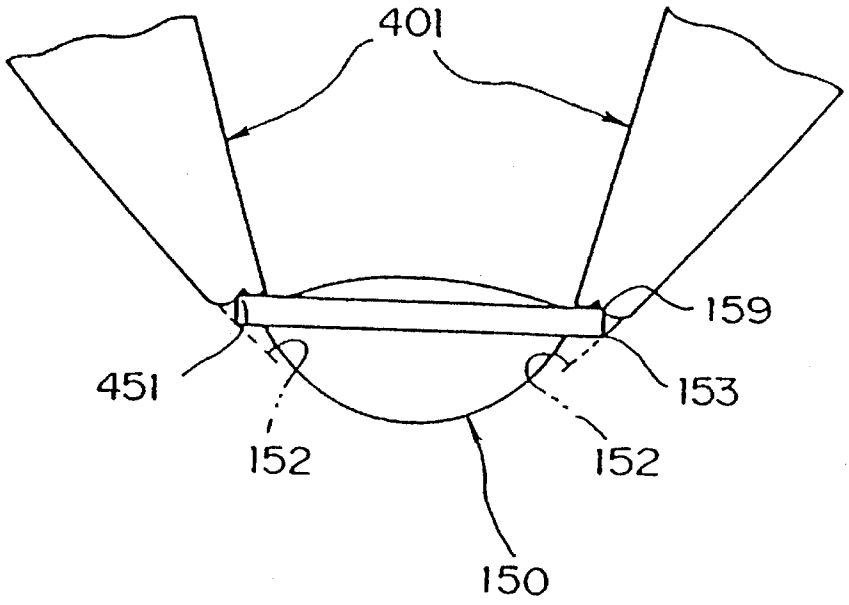

401
159
451
153
152
152
150

Fig.32

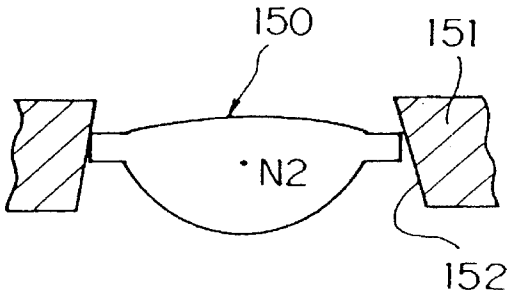


Fig.33

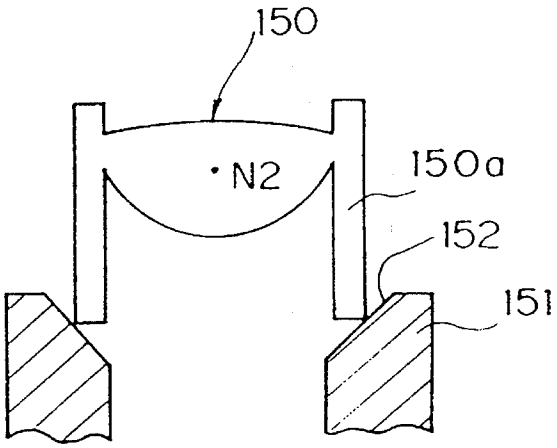


Fig.34

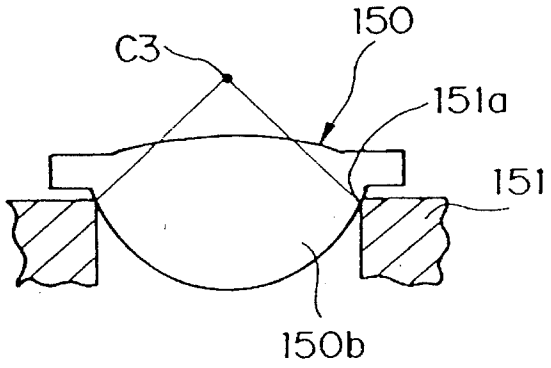


Fig.35

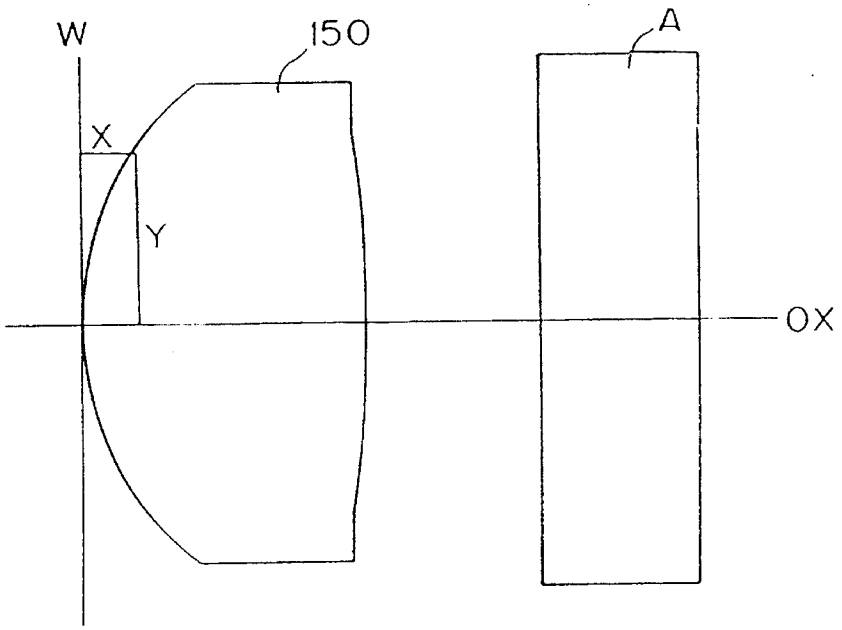

W
150
A
X
Y
OX

Fig.36

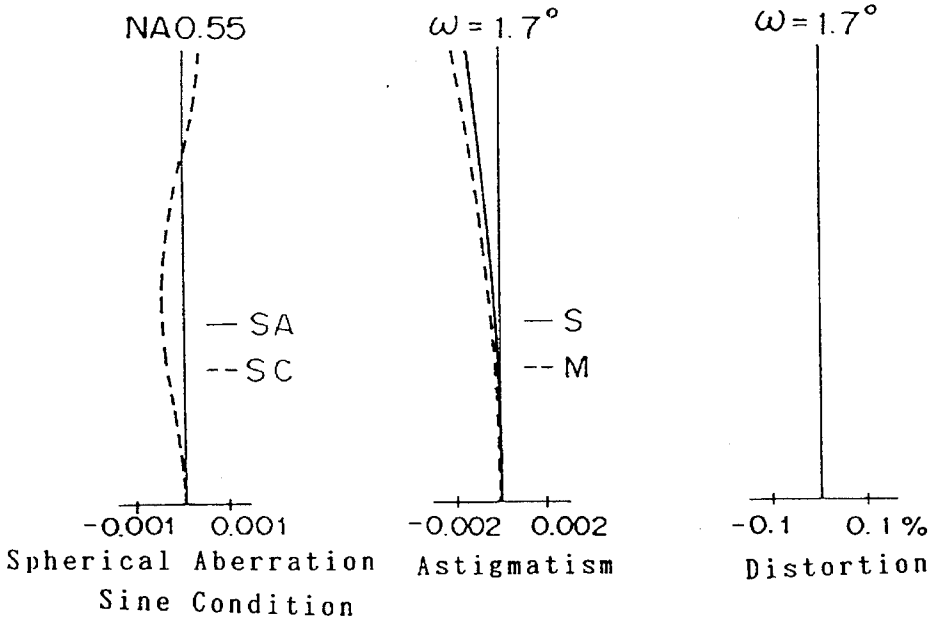

NA0.55
ω = 1.7°
ω = 1.7°
— SA
--SC
— S
-- M
-0.001 0.001
-0.002 0.002
-0.1 0.1%
Spherical Aberration
Sine Condition
Astigmatism
Distortion

Fig.37

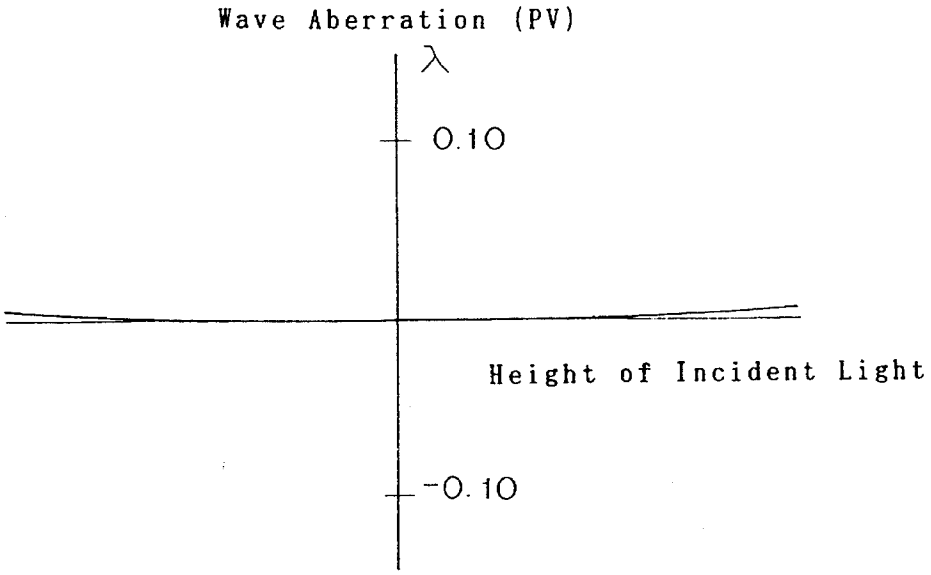

Wave Aberration (PV)
λ
0.10
Height of Incident Light
-0.10

Fig.38

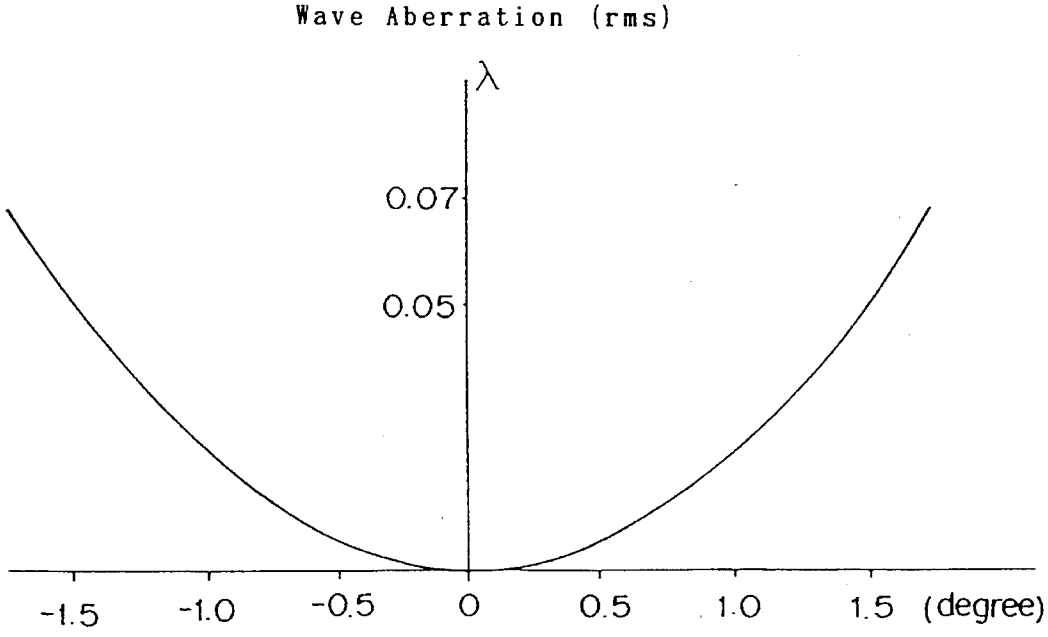

Wave Aberration (rms)
λ
0.07
0.05
-1.5
-1.0
-0.5
0
0.5
1.0
1.5
(degree)

Fig.39

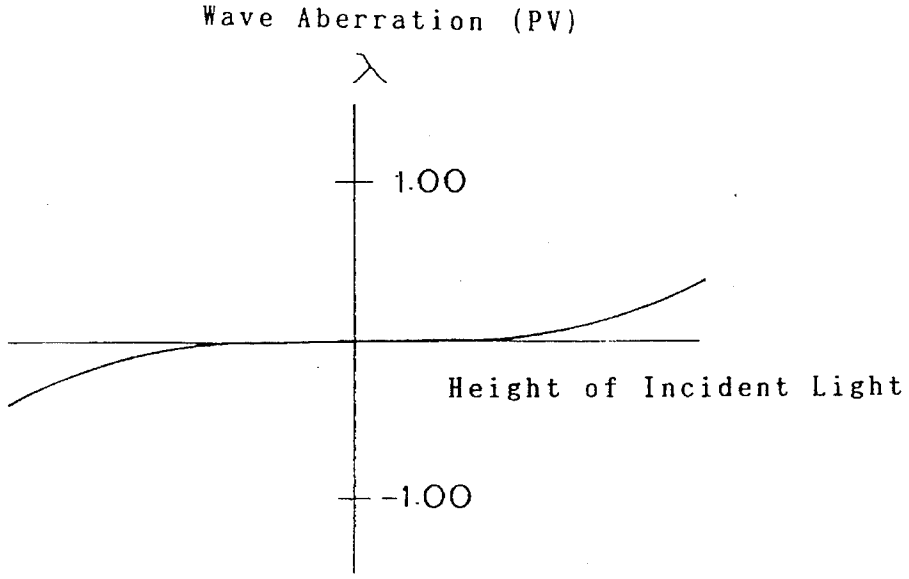

Wave Aberration (PV)
λ
1.00
Height of Incident Light
-1.00

Fig.40

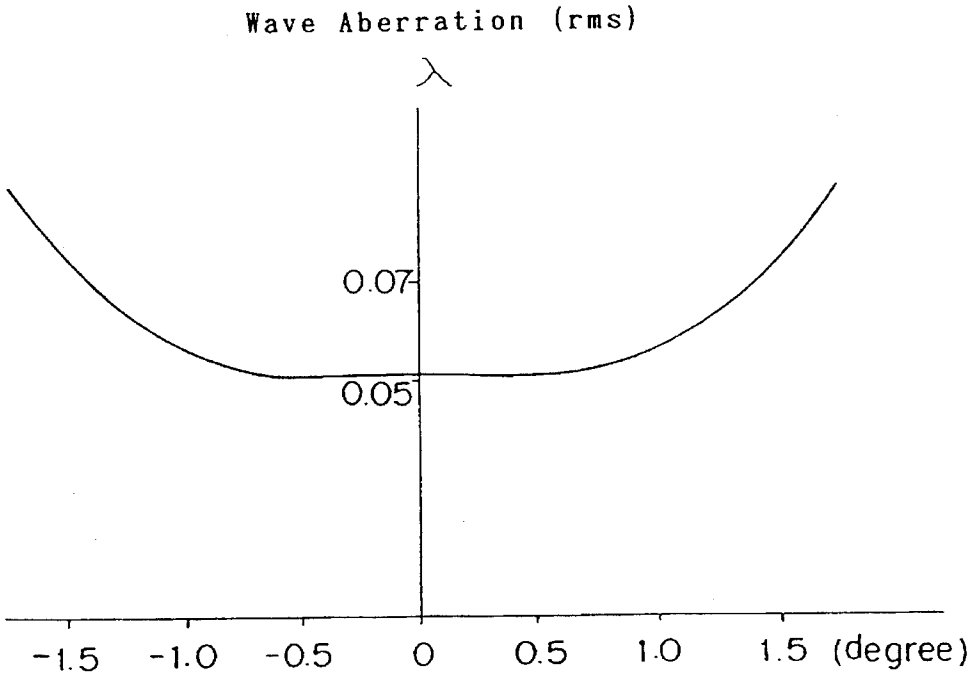

Wave Aberration (rms)
λ
0.07
0.05
-1.5
-1.0
-0.5
0
0.5
1.0
1.5 (degree)

Fig.41

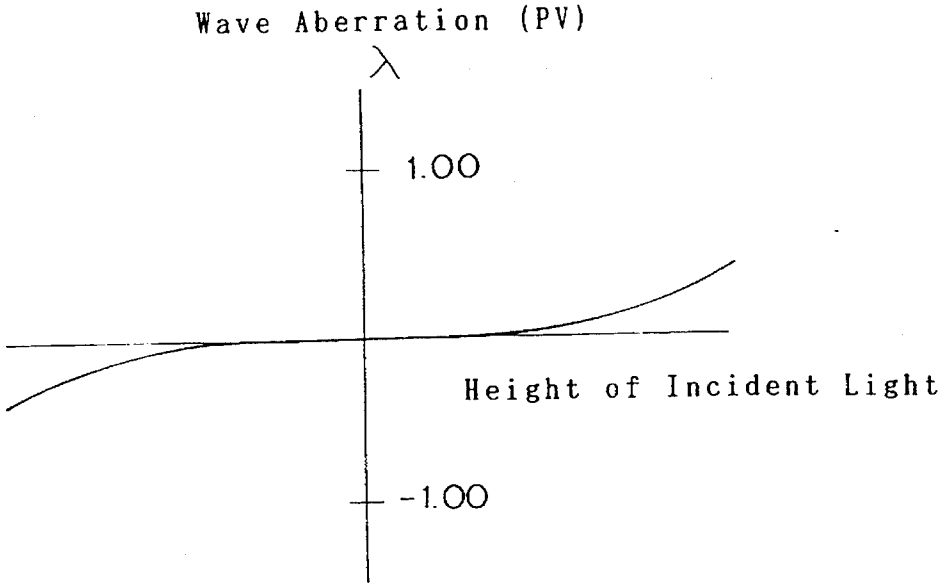

Wave Aberration (PV)
λ
1.00
Height of Incident Light
-1.00

Fig.42

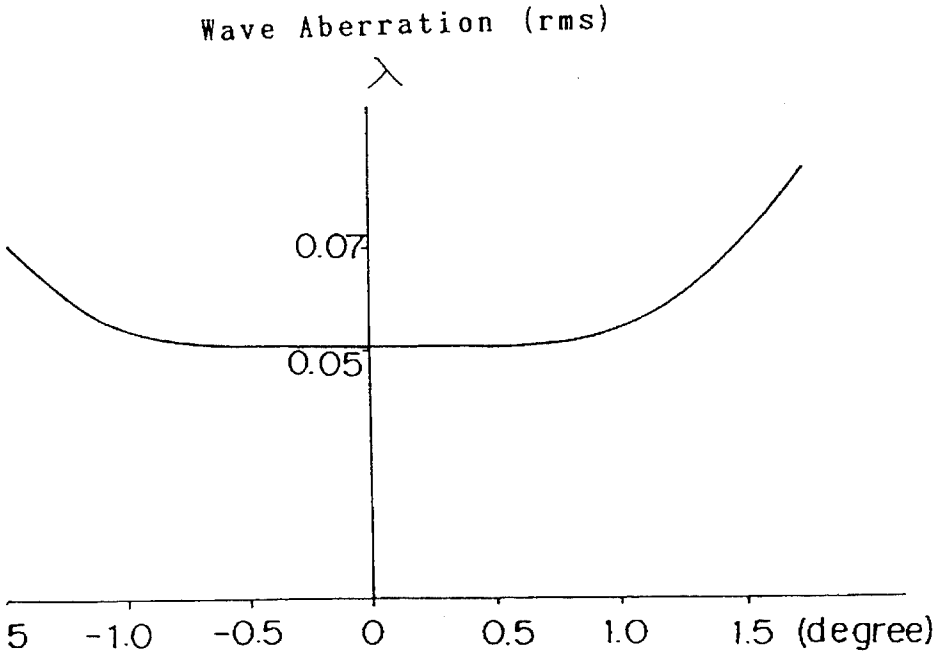

Wave Aberration (rms)
λ
0.07
0.05
5
-1.0
-0.5
0
0.5
1.0
1.5 (degree)

Fig. 43

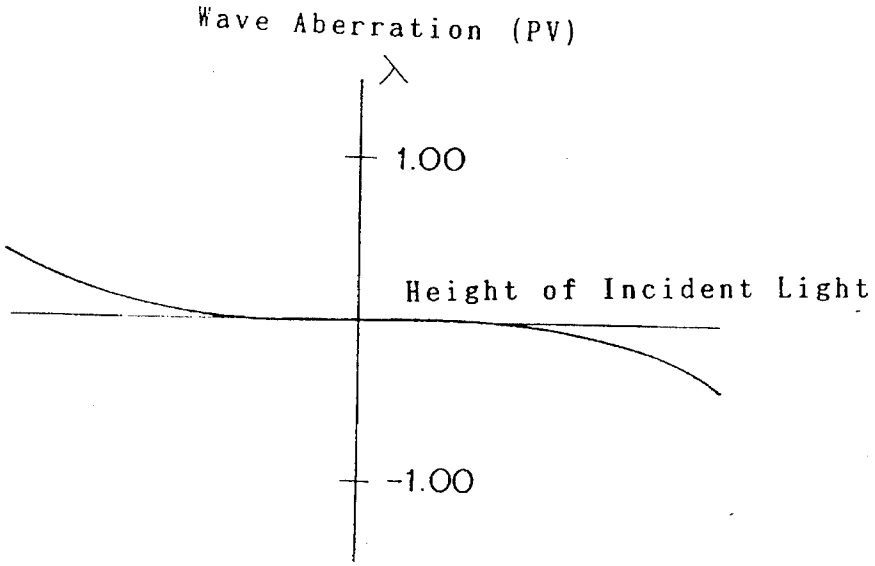

Wave Aberration (PV)
1.00
Height of Incident Light
-1.00

Fig. 44

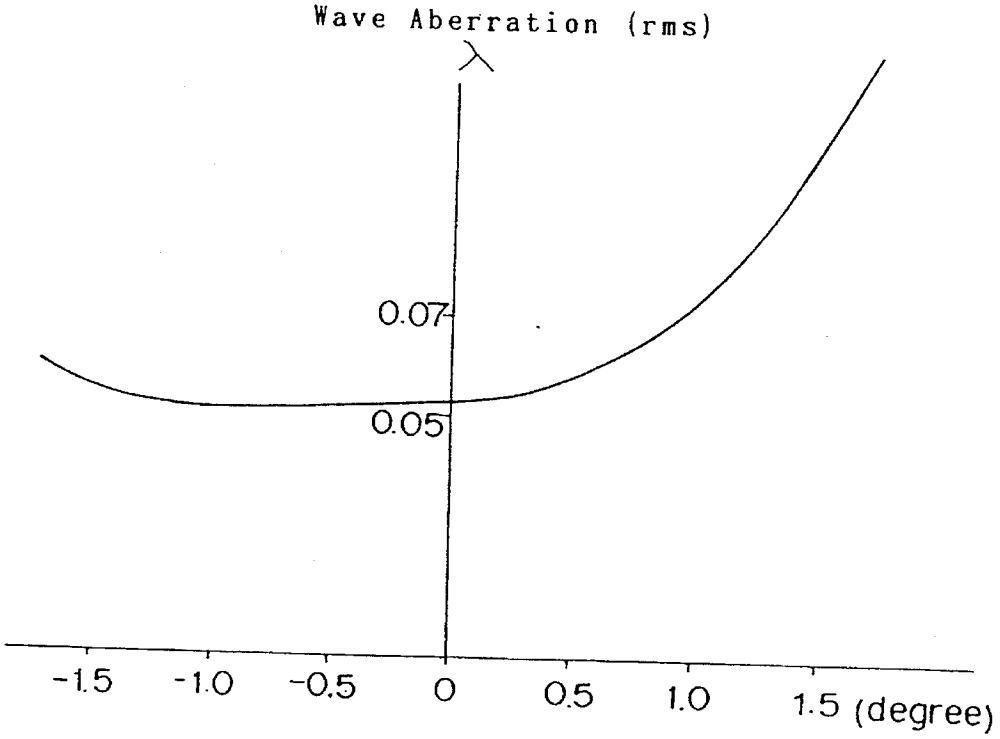

Wave Aberration (rms)
0.07
0.05
-1.5
-1.0
-0.5
0
0.5
1.0
1.5 (degree)

Fig.45

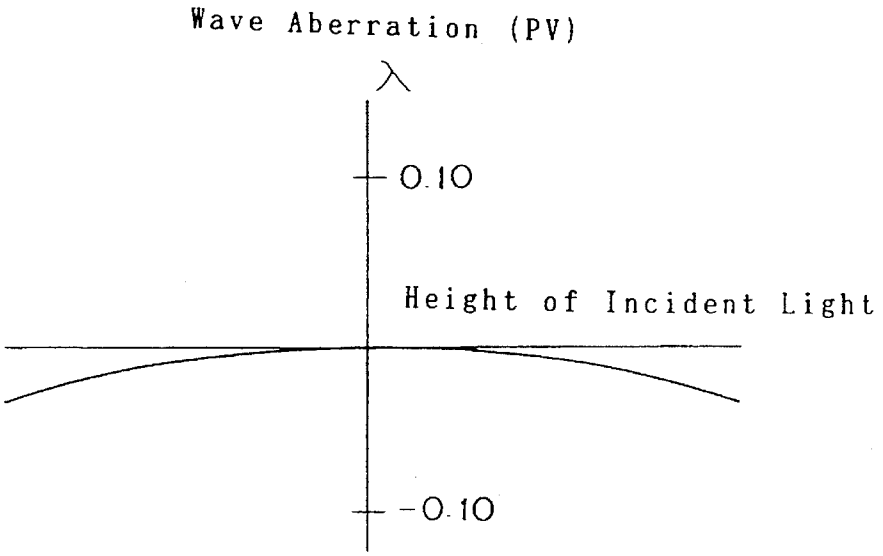
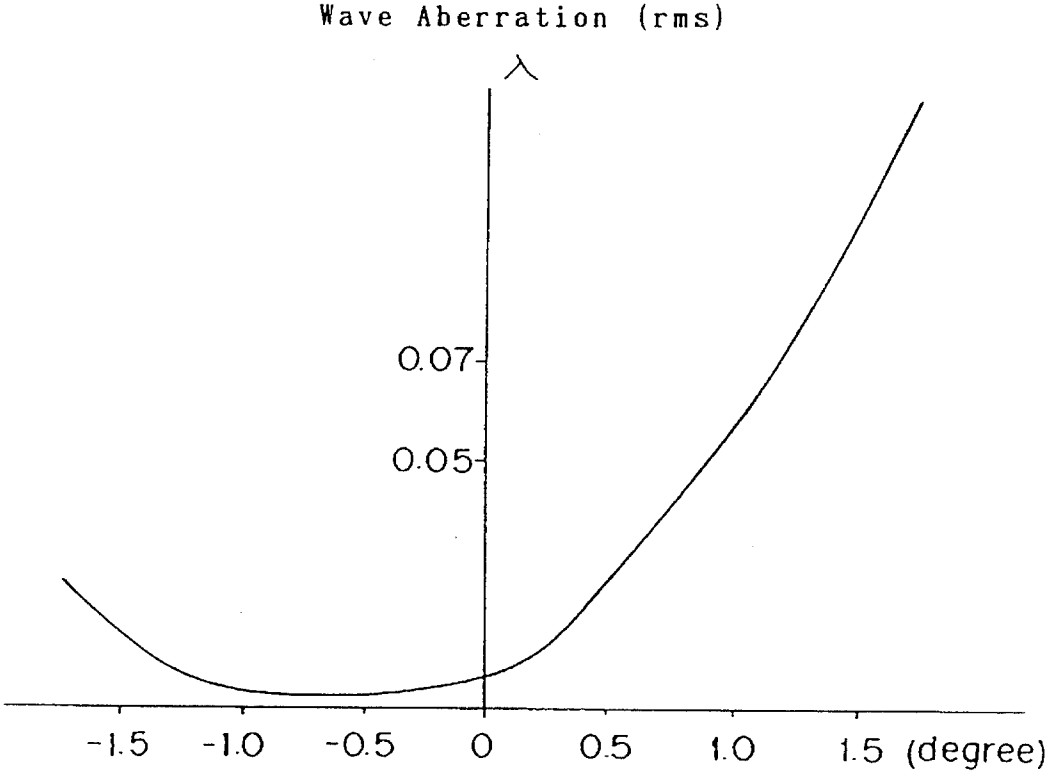

Wave Aberration (PV)
λ
0.10
Height of Incident Light
-0.10

Fig.46


Wave Aberration (rms)
λ
0.07
0.05
-1.5
-1.0
-0.5
0
0.5
1.0
1.5 (degree)

INCLINATION OF AN OBJECTIVE LENS IN AN OPTICAL INFORMATION SYSTEM

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to an apparatus and method for adjusting an optical system.

2. Description of Related Art

In a conventional optical data recording and reproducing apparatus in which a laser beam is used to record data onto a recording medium, such as a photo magnetic disc (magneto-optical disc), and to read and reproduce the recorded data from the recording medium, it is necessary to converge the laser beam onto the recording medium so as to form a beam spot. The beam spot is made as small as possible to thereby correctly write data onto and read data from the recording medium. However, if the optical axis of the objective lens is not normal to the recording medium, coma occurs. The coma makes it impossible to correctly converge the laser beam onto the recording medium to form a small beam spot, resulting in a restriction of the amplitude of reading signals or an increase of jitters, and thus leading to a failure to correctly reproduce the recorded data.

To this end, it is necessary to precisely adjust the posture of the objective lens so that the optical axis thereof is normal to the recording medium, in the course of the manufacturing process of the optical data recording and reproducing apparatus. The allowable inclination of the optical axis of the objective lens with respect to the recording medium decreases as the numerical aperture (NA) of the objective lens increases. The objective lens used in recent optical data recording and reproducing apparatuses has a large numerical aperture to enhance the data recording density.

The U.S. Pat. No. 5,157,459 has disclosed an inclination adjusting device of an objective lens for adjusting an inclination of the objective lens relative to a recording medium. The adjusting device can be attached to the optical data recording and reproducing apparatus. The device is positioned opposite to the objective lens of the data recording and reproducing apparatus. In other words, adjustment can be performed with a master glass, which corresponds to an optical disc (i.e., the recording medium), positioned opposite to the objective lens. This inclination adjusting device takes in coherent light that is emitted from a laser light source in the optical data recording and reproducing apparatus, and enables the adjustment of the objective lens inclination relative to the master glass in accordance with the interference fringes of the coherent light.

The device, however, cannot adjust the inclination of the objective lens while monitoring the inclination from the recording medium side because a comatic aberration detecting system having a plurality of optical elements is positioned opposite and close to the objective lens. In other words, since there is little space between the comatic aberration detecting system and the objective lens, the comatic aberration detecting system prevents the device from being capable of adjusting the inclination of the objective lens while monitoring the inclination of the objective lens. Due to this inconvenience in prior art, after the inclination of the objective lens is detected in accordance with the interference fringes, the inclination adjusting device has to be removed from the optical data recording and reproducing apparatus to actually adjust the objective lens. This means that it was impossible to adjust the inclination of the objective lens while monitoring the inclination of the objective lens, i.e., whenever an inclination adjustment was carried out, the adjusting device is first attached to the optical data recording and reproducing apparatus, and then removed after the inclination data is obtained to carry out the actual adjustment of the inclination of the objective lens.

The optical system in the optical data recording and reproducing apparatus is usually comprised of various optical elements. It is necessary for the optical system to have an extremely high performance with respect to the diffraction limit (resolution limit). Accordingly, the optical elements which constitute the optical system must be extremely precisely machined or produced. For instance, a single aspherical objective lens, which is provided on opposite sides thereof with aspherical lens surfaces and which has a numerical aperture NA of about 0.55, the wavefront aberration (coma) of the objective lens caused by the deviation of the optical system, etc., would amount to around 0.9 λ (λ=wavelength of light) which is represented by the PV value (difference between the maximum value and the minimum value), assuming that the parallel or transverse deviation (decentering) of one of the aspherical lens surfaces is 10 μm.

To prevent such a large wavefront aberration from occurring, not only must high precision machines be employed to produce or machine the optical elements, but the optical system also must be very carefully assembled. This increases the manufacturing cost of the optical system in the optical data recording and reproducing apparatus. Moreover, the assembling and adjustment of the optical system require a long time and a highly skilled artisan.

SUMMARY OF THE INVENTION

The primary object of the present invention is to provide a detecting apparatus which detects an inclination of an objective lens to adjust the same. In particular, the present invention is directed to a detecting apparatus in which an inclination adjustment of the objective lens can be easily performed from a position opposite the objective lens.

To achieve the object mentioned above, according to the present invention, there is provided a detecting apparatus which detects an inclination of an objective lens relative to a reference surface, the objective lens being part of an optical data recording and reproducing apparatus in which data is optically recorded on and reproduced from a recording medium which is placed parallel to the reference surface. The apparatus includes a transparent parallel plate which is opposite the objective lens, parallel to the reference surface, and made of a material that is substantially optically equivalent to a transparent material of the recording medium; a reflecting mechanism for reflecting coherent light which has passed through the objective lens and the transparent parallel plate back towards the transparent parallel plate and the objective lens; a beam splitting mechanism for splitting the coherent light into a first beam and a second beam; a wavefront rotating mechanism for rotating the first beam and the second beam about an optical axis in a manner such that the first beam and the second beam are rotated through 180 degrees with respect to one another; and, a mechanism for superposing the first beam and the second beam to produce an optical interference.

Another object of the present invention is to provide a lens supporting apparatus which makes it possible to reduce the number of components of an optical pickup to thereby reduce the weight of the same and enable a fast tracking operation (i.e., high-speed tracking).

To achieve the object mentioned above, there is provided a lens supporting apparatus which supports an objective lens of an optical data recording and reproducing apparatus, in which data is optically recorded on and reproduced from a recording medium placed parallel to a reference surface. The apparatus includes an oblique annular lens supporting surface which is inclined relative to a peripheral edge of the objective lens. The annular lens supporting surface supports the objective lens in a manner such that the inclination of the objective lens can be adjusted with respect to the reference surface. The apparatus further includes a mechanism for moving the lens supporting surface to bring a peripheral edge of the objective lens into contact with an external object to thereby move the objective lens along the lens supporting surface in order to vary an inclination of the objective lens relative to the reference surface.

Still another object of the present invention is to provide a lens adjusting method for adjusting the inclination of a lens with respect to a lens holder.

To achieve the object mentioned above, there is provided an inclination adjusting method for adjusting an inclination, relative to a reference surface, of an objective lens of an optical data recording and reproducing apparatus in which data is optically recorded on and reproduced from a recording medium which is positioned parallel to the reference surface. The inclination adjusting method includes the steps of positioning a lens supporting member which supports the objective lens at a predetermined position; placing the objective lens on the lens supporting member; adjusting the inclination of the objective lens while observing interference fringes to reduce a coma, the interference fringes being caused by an inclination of the objective lens relative to a transparent plate, and the transparent plate being positioned parallel to the reference surface and made of a material that is substantially optically equivalent to the recording medium; and, fixing the objective lens to the lens supporting member.

Yet another object of the present invention is to provide a lens positioning apparatus, a lens adjusting apparatus and a method for smoothly adjusting the inclination of a lens supported on a lens holder.

To achieve the object mentioned above, a positioning apparatus, which positions a lens relative to a lens supporting member, is provided. The position apparatus includes a sucking tube which holds the lens by a vacuum force, and a guide portion which has a circular hole. An inner surface of the circular hole guides the lens in a radial direction of the sucking tube so as to position the lens in the radial direction when the sucking tube is inserted into the circular hole. The circular hole is formed in a manner such that a diameter of the circular hole is larger than a diameter of the sucking tube and substantially corresponds to a diameter of the lens.

According to still another aspect of the present invention, an inclination adjusting apparatus is provided with a body, and an oblique annular lens supporting surface which is inclined relative to a peripheral edge of the objective lens and which supports the objective lens in a manner such that the objective lens can be inclined with respect to the lens supporting surface. The inclination adjusting apparatus includes a rotational portion which is rotatably supported by the body in a manner such that a rotational center of the rotational portion is positioned in the vicinity of a rotational center of the lens when the lens is inclined with respect to the lens supporting surface. An adjusting pawl, which is supported by the rotational portion for engaging with a peripheral edge of the lens, is also provided.

According to yet another aspect of the present invention, there is provided an inclination adjusting method for adjusting an inclination of a lens which is supported on ah oblique annular lens supporting surface inclined relative to a peripheral edge of the lens. The lens is displaced by an inclination adjusting member on the oblique annular lens supporting surface thereby inclining the lens at a predetermined angle. The inclination adjusting method includes a first step of determining an angle at which the lens is to be inclined; a second step of inclining the inclination adjusting member at the angle; a third step of bringing the inclination adjusting member into contact with the lens; and, a fourth step of moving the oblique annular lens supporting surface toward the inclination adjusting member to abut the lens against the inclination adjusting member.

According to yet another aspect of the present invention, there is provided an inclination adjusting apparatus which adjusts an inclination of a lens. The inclination adjusting apparatus includes a lens supporting member having an oblique annular supporting surface which supports the lens in a manner such that the lens can be inclined with respect to the supporting surface. The inclination adjusting apparatus further includes an inclination adjusting member which comes into contact with a surface of the lens, the surface being located opposite to the lens supporting member. An inclination defining member for defining an inclination of the inclination adjusting member, and a biasing mechanism for biasing the lens supporting member towards the inclination adjusting member while bringing a part of the inclination adjusting member into contact with the lens to thereby abut the lens against the inclination adjusting member.

Another object of the present invention is to provide a coma compensating method in which imprecise optical elements, such as a lens which has been incorrectly manufactured, can be used, and in which assembling operation of the optical system can be simplified.

To achieve the object mentioned above, a lens adjusting method, in an optical apparatus in which coherent light emitted from a light source is made incident upon a recording medium through an optical system including an objective lens and a plurality of optical elements so as to reproduce data recorded on the recording medium based upon light reflected by the recording medium, is provided. The lens adjusting method includes a first step of adjusting a relative inclination between the objective lens and the recording medium on a lens supporting member which supports the objective lens to compensate a coma occurring in the optical system; and, a second step of securing the objective lens to the lens supporting member by an adhesive applied between the objective lens and the lens supporting member.

The present disclosure relates to subject matter contained in Japanese patent application Nos. 5-66009, 5-66010, 5-66011, 5-66012 (all filed on Mar. 2, 1993), 5-85637 (filed on Mar. 19, 1993), and No. 5-111103 (filed on Apr. 14, 1993) which are expressly incorporated herein by reference in their entirety.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be described below in detail with reference to the accompanying drawings, in which;

FIG. **1** is a conceptual view of a first embodiment of a lens inclination detecting apparatus according to the present invention;

FIG. **2** is a conceptual view of an optical path of an optical system including an objective lens, a glass cover, and a hemispherical lens;

FIG. **3** is a schematic view of interference fringes indicated in a monitor of an interference fringe viewing portion;

FIG. **4** is a schematic view of image points indicated in a monitor of a image point viewing portion;

FIG. **5** is a conceptual view of a second embodiment of a lens inclination detecting apparatus according to the present invention;

FIG. **6** is a conceptual view of a third embodiment of a lens inclination detecting apparatus according to the present invention;

FIG. **7** is a conceptual view of a fourth embodiment of a lens inclination detecting apparatus according to the present invention;

FIG. **8** is a conceptual view of an optical path of an optical system including an objective lens, a glass cover, and a concave mirror;

FIG. **9** is a conceptual view of a fifth embodiment of a lens inclination detecting apparatus according to the present invention;

FIG. **10** is a conceptual view of a sixth embodiment of a lens inclination detecting apparatus according to the present invention;

FIG. **11** is an explanatory view of an occurrence of a deviated image point when an objective lens is inclined on a lens holder;

FIG. **12** is a schematic view of a mounting portion of an objective lens to a tracking mechanism;

FIG. **13** is a sectional view of a tracking mechanism;

FIG. **14** is a perspective view of a lens holder;

FIG. **15** is a schematic plan view of an optical disc apparatus mounting device;

FIG. **16** is a sectional view of a positioning device;

FIG. **17** is a sectional view of a lens feeding device;

FIG. **18** is a schematic view of a guide mechanism having an oblique guide surface for an objective lens;

FIG. **19** is an explanatory view of an adhesive reservoir in which an adhesive is introduced by an adhesive application member;

FIGS. **20** and **21** are flow charts of an inclination adjusting operation;

FIGS. **22** and **23** are flow charts of another inclination adjusting operation;

FIG. **24** is a plan view of an inserting member;

FIG. **25** is a sectional view of an inserting member;

FIG. **26** is a sectional view of an inclination adjusting apparatus in an initial position;

FIG. **27** is a sectional view of an inclination adjusting apparatus in an operative position in which the inclination of an objective lens is adjusted;

FIG. **28** is a sectional view taken along the line P—P in FIG. **27**;

FIG. **29** is a plan view of an inclination adjusting apparatus;

FIG. **30** is a sectional view of another embodiment of an inclination adjusting apparatus;

FIG. **31** is a view of another example of inclination adjusting pawls;

FIGS. **32, 33** and **34** are schematic views of three different examples of an objective lens;

FIG. **35** is a schematic view of an objective lens and glass cover used in a simulation;

FIG. **36** shows diagrams of optical characteristics of an objective lens shown in FIG. **35**;

FIG. **37** is a diagram of a wavefront aberration on an optical axis, that is represented by the PV value when there is no inclination of an objective lens with respect to a glass cover;

FIG. **38** is a diagram of a wavefront aberration that is varied by the change in the angle of incident light with respect to the optical axis when there is no inclination of an objective lens with respect to a glass cover;

FIG. **39** is a diagram similar to FIG. **37**, when a first lens surface of an objective lens is decentered from the optical axis;

FIG. **40** is a diagram similar to FIG. **38**, when a first lens surface of an objective lens is decentered from the optical axis;

FIG. **41** is a diagram similar to FIG. **37**, when a first lens surface of an objective lens is inclined;

FIG. **42** is a diagram similar to FIG. **38**, when a first lens surface of an objective lens is inclined;

FIG. **43** is a diagram similar to FIG. **37**, when an objective lens is inclined at 25 minutes (') with respect to a glass cover;

FIG. **44** is a diagram similar to FIG. **38**, when an objective lens is inclined at 25 minutes (') with respect to a glass cover;

FIG. **45** is a diagram similar to FIG. **37**, when an objective lens is inclined with respect to a glass cover to compensate a wavefront aberration which is caused when a first lens surface of an objective lens is decentered from the optical axis; and,

FIG. **46** is a diagram similar to FIG. **38**, when an objective lens is inclined with respect to a glass cover to compensate a wavefront aberration which is caused when a first lens surface of an objective lens is decentered from the optical axis.

DESCRIPTION OF THE PREFERRED EMBODIMENT

FIG. **1** shows a first embodiment of a lens inclination detecting apparatus **200** which detects an inclination of an objective lens **150** in a photo magnetic disc apparatus **100**.

The photo magnetic disc apparatus **100** constitutes an optical data recording and reproducing apparatus which records (or writes) data onto a recording medium which is in the form of a photo magnetic disc(magneto-optical disc), and reads and reproduces the recorded data from the photo magnetic disc. The optical system of the optical data recording and reproducing apparatus will be discussed below.

A divergent laser beam (i.e., coherent light) emitted from a light source **101**, such as a semiconductor laser or laser diode (LD), is collimated by a collimating lens **102**. The cross sectional shape of the collimated light is converted to a circular shape by a beam shaping prism (i.e., anamorphic prism) **103**. The beam shaping prism **103** is provided with beam splitting prisms **104** and **105** secured thereto. The laser beam transmitted through the beam shaping prism **103** and reflected by a beam splitter **106**, which is defined between the beam splitting prisms **104** and **105**, is made incident upon a light sensor **107** which detects the quantity of light outputted from the LD **101**, so that the adjustment is carried out until the quantity of light received by the light sensor **107** is a predetermined value.

The laser beam transmitted through the beam splitter **106** is reflected by a mirror **110**; transmitted through an insertion prism **201** (beam splitting means) of the inclination detecting apparatus **200**; reflected by a mirror **112**; and made incident upon an objective lens **150**.

The objective lens **150** is opposite a glass cover (i.e., transparent parallel plate) "A". The glass cover "A" is made of a material which is optically equivalent to that of a transparent plate K1 of the photo magnetic disc K shown in FIG. **12**. When the inclination of the objective lens **150** is adjusted, the cover glass "A" is disposed at a position that is substantially equivalent to the location where transparent plate K1 of the photo magnetic disc K is disposed during normal use of the photo magnetic disc apparatus **100**. In normal use, the photo magnetic disc K is set when the recording and reproducing operation are performed by the photo magnetic disc apparatus **100**. When the photo magnetic disc K is set in during normal use, the disc K is disposed parallel to a reference plane of the photo magnetic disc apparatus **100**. Accordingly, when the cover glass "A" is disposed during the adjustment of the objective lens **150**, the cover glass "A" is oriented parallel to the reference plane.

The signal detecting system of the photo magnetic disc apparatus **100** will be explained hereinafter in the state in which the glass cover "A", instead of a magnetic disc, is positioned opposite the objective lens **150**.

The laser beam reflected by the photo magnetic disc is transmitted through the objective lens **150**; reflected by the mirror **112** and the mirror **110**; and made incident upon the beam splitting prisms **104** and **105**. The laser beam reflected by the beam splitter **106** provided between the beam splitting prisms **104** and **105** is transmitted through a ½ wave plate **113** where the direction of polarization thereof is rotated by 45 degrees. Thereafter, the light is incident upon a polarization beam splitter which is comprised of a prism **114** and a wedge prism **115**. The light incident upon the polarization beam splitter is split into P-polarized and S-polarized light components that are transmitted through a condenser lens **116** and converged onto a signal detector **117** having two data sensors for obtaining photo magnetic signals, etc.

The light transmitted through the beam splitter **106** is reflected by a beam splitter **108** located between the beam shaping prism **103** and the beam splitting prism **104** and is received by a condenser lens **121**. The light is then reflected by a prism **122**; transmitted through a cylindrical lens **123**; and received by an error detector **124**. Namely, the light has an astigmatic difference caused by the condenser lens **121** and the cylindrical lens **123** and is converged onto the error detector **124** where tracking error signals and focusing error signals are obtained by a push-pull method and an astigmatism correction method, respectively.

The following discussion will be directed to the optical system of the lens inclination detecting apparatus **200**.

The hemispherical lens **202** is located next to the glass cover "A" on the side opposite;to the objective lens **150** with respect to the glass cover "A". The insertion prism **201** is inserted between the mirrors **110** and **112** of the photo magnetic disc apparatus, i.e., within the optical path of the collimated light. The insertion prism **201** includes a polarization beam splitter (PBS) **201***a* which is precisely machined so as not to produce a wavefront aberration, and a ¼ wave plate **201***b* which is located on the side of the PBS **201***a* next to the objective lens **150**. Of the linearly polarized light incident upon the insertion prism **201**, light that is linearly polarized in the same plane as the P polarized light is converted to circularly polarized light by the ¼ wave plate **201***b*. The circularly polarized light is reflected by the hemispherical lens **202** and is transformed back into linearly polarized light when the circularly polarized light again passes through the ¼ wave plate **201***b*. This change of circularly polarized light to linearly polarized light causes a total internal reflection of the linearly polarized light at the insertion prism **201** towards the lens inclination detecting apparatus **200** because the phases of the circularly polarized light and the linearly polarized light differ by 180 degrees. This is a result of the light passing through the ¼ wave plate **201***b* twice. Therefore, there is no return light towards the LD **101** from the insertion prism **201**, and no occurrence of noise due to the return light.

It is possible to provide a ½ wave plate **201***c* on the side of the polarization beam splitter **201***a* nearest the LD **101**. Since the polarization direction of light from the LD **101** can be optionally selected by properly selecting the mounting state of the ½ wave plate **201***c* to the PBS **201***a*, the light reflected from the hemispherical lens **202** can be appropriately received by the detecting apparatus **200** regardless of the location of the detecting apparatus **200**, even if the direction of the incident polarized light lies on a plane which includes the optical axis and the line normal to the reflecting surface of the insertion prism.

The light reflected by the insertion prism **201** is partly transmitted through a half mirror **203** and is made incident upon an interference fringe viewing portion **205** through an imaging lens **204**. The interference fringe viewing portion **205** is provided with, for example, a CCD camera and a monitor (not shown). In the interference fringe viewing portion **205**, interference fringes B which are caused by an interference of the beam transmitted through the objective lens **150** and the glass cover "A" and reflected by the flat surface **202***a* of the hemispherical lens **202**, and the beam transmitted through the objective lens **150** and the glass cover "A" and reflected by the spherical surface **202***b* of the hemispherical lens **202** are viewed. A reflecting mechanism includes the flat surface **202***a* and the spherical surface **202***b*. A beam splitting mechanism includes the flat surface **202***a* and the spherical surface **202***b*. An superposing mechanism includes the flat surface **202***a* and the spherical surface **202***b*. A wavefront rotating mechanism includes the flat surface **202***a*. The distortion of the interference fringes B is due to a coma which is in turn caused by the inclination of the objective lens **150** with respect to the glass cover "A".

The light reflected by the half mirror **203** is made incident upon a condenser lens **211**. The light transmitted through the condenser lens **211** is split into two beams by a beam splitter **212**. One of the beams is received by a image point viewing portion **214** through a magnifying lens **213**, and the other beam is received by an alignment detector **215**. The image point viewing portion **214** and the alignment detector **215** are each provided with, for example, a CCD camera and a monitor (not shown).

In the image point viewing portion **214**, the magnified image (point image) of light reflected by the flat surface **202***a* of the hemispherical lens **202** and the magnified image (point image) C of light reflected by the spherical surface **202***b* of the hemispherical lens **202** are viewed. The image point formed by the flat surface **202***a* does not contain a coma component which is asymmetrical in 180 degree directions with respect to the optical axis. However, the image point C formed by the spherical surface **202***b* contains the coma component.

The alignment detector **215** is provided to adjust the relative positional relationship among the convergence point

of the beam incident upon the objective lens **150**, the flat surface **202***a* of the hemispherical lens **202**, and the center of curvature of the spherical surface **202***b* of the hemispherical lens **202**, the center being located on the flat surface **202***a* so as to effectively view the interference fringes and the image points. As will be discussed hereinafter, the alignment detector **215** is used, for example, upon commencement of the adjustment of the inclination of the objective lens **150**, upon setting the relative position between the hemispherical lens **202** and the photo magnetic disc apparatus **100**, or upon the adjustment of the inclination of the objective lens **150**, etc.

The detection sensitivity of the coma component of the wavefront aberration (referred to as coma) will be discussed below with reference to FIG. **2**.

In FIG. **2**, the light L1 transmitted through the objective lens **150** and the glass cover "A" is partly reflected by the flat surface **202***a* of the hemispherical lens **202** in a direction symmetrical thereto with respect to the optical axis of the objective lens **150**. The reflected light is indicated at L2. Of the coherent light which has passed through the objective lens **150** and the glass cover "A" once, all the rays which are reflected by the flat surface **202***a* are reflected back through the glass cover "A", the objective lens **150**, and along a path that is symmetrical to the incoming path with respect to the optical axis. Due to this reflection, if the flat surface **202***a* is viewed from the objective lens **150** along the light path, the wavefront of the reflected coherent light is observed as being turned by 180 degrees.

The light transmitted through the flat surface **202***a* is partly reflected by the spherical surface **202***b* of the hemispherical lens **202**, as indicated at L3. The reflected light L3 is transmitted along the same optical path as the incident light and emitted from the objective lens **150**. Of the coherent light having passed once through the objective lens **150** and the glass cover "A", the rays that are reflected by the spherical surface **202***b* are reflected by the spherical surface **202***b* back through the glass cover "A", the objective lens **150**, and along the same light path as the incoming light path. As a result of this reflection by the spherical surface **202***b*, the wavefront of the reflected coherent light is observed from the objective lens **150** along the light path as being returned to the objective lens **150** without being rotated. The two wavefronts of reflected light at the flat surface **202***a* and at the spherical surface **202***b* are rotated relative to one another through 180 degrees around the optical axis of the objective lens **150**. Accordingly, the only aberration that is observed is the comatic aberration.

A coma, which is rotationally symmetrical with respect to the optical axis, does not appear in the wavefront which has been transmitted through the. objective lens **150** and the glass cover "A", and reflected by the flat surface **202***a* back towards and through the glass cover "A" and the objective lens **150**. On the other hand, the wavefront reflected by the spherical surface **202***b* of the hemispherical lens **202** and transmitted again through the objective lens **150** contains a coma that is double that of the coma of the wavefront that passes the objective lens **150** and the glass cover "A" once, since the first-mentioned wavefront passes the objective lens **150** and the glass cover "A" twice. The interference fringes are caused by the interference of the two kinds of wavefront mentioned above. Thus, the coma caused by the passage through the objective lens **150** and the glass cover "A" can be viewed with double sensitivity in the interference fringe viewing portion **205**. In other words, one interference fringe appears in the interference fringe viewing portion **205** when the coma, which is caused due to the inclination of the objective lens **150** with respect to the glass cover "A", is $\lambda/2$ (λ=wavelength of light transmitted through the objective lens).

The following discussion will be addressed to the adjustment of the inclination of the objective lens, with reference to FIGS. **1**, **3** and **4**, according to the present invention. The objective lens **150** is disposed on a lens holder (not shown), and the glass cover "A" is disposed at an appropriate position with reference to a contacting surface **131***b* (FIG. **25**) of the spindle motor **131**.

Thereafter, the relative position of the hemispherical lens **202** and the objective lens **150** in the optical axis direction is adjusted so as to obtain a clear image point of light condensed by the objective lens **150** and reflected by the flat surface **202***a* of the hemispherical lens **202**, while observing the image point viewed in the alignment detector **215** and the image point viewing portion **214**. After that, the relative position of the hemispherical lens **202** and the objective lens **150** in the direction perpendicular to the optical axis is adjusted so that the image point of light condensed by the objective lens **150** and reflected by the spherical surface **202***b* of the hemispherical lens **202** is located at the position of the image point formed by the flat surface **202***a* of the hemispherical lens **202**, while observing the image point in the alignment detector **215**. When the glass cover "A" is arranged adjacent to the flat surface **202***a*, the positional relationship between the glass cover "A" and the flat surface **202***a* becomes similar to the relationship between the transparent plate K1 and the data recording surface K2 (see FIG. **12**) of an actual photo magnetic disc. If the glass cover "A" is brought into contact with the flat surface **202***a*, additional light reflection may occur other than the reflection at the flat surface **202***a* and the flat surface **202***b*. This additional reflection at the contacting surface may bring about an adverse effect on the interference fringe observation. To prevent such from occurring, in the present embodiment, the glass cover "A" and the flat surface **202***a* are disposed with a predetermined distance therebetween.

The interference fringes B, as shown in FIG. **3**, are displayed in the monitor of the interference fringe viewing portion **205**. The image points C and D, as shown in FIG. **4**, are indicated in the monitors of the alignment detector **215** and the image point viewing portion **214**. The distortion of the interference fringes B is caused by the coma and increases as the inclination of the objective lens **150** relative to the glass cover "A" increases. The image point C is formed by light reflected by the spherical surface **202***b* of the hemispherical lens **202** and has an outstanding coma. The image point D is formed by light reflected by the flat surface **202***a* of the hemispherical lens **202** and has no coma. There is a difference in magnification of the image to be viewed between the alignment detector **215** and the image point viewing portion **214**. Both the image points C and D are magnified at a large magnification rate in the image point viewing portion **214** and can be clearly viewed.

If the distortion of the interference fringes B is above a predetermined value (e.g., $\lambda/4$, in other words ½ fringe), the inclination of the objective lens **150** is adjusted to substantially eliminate the distortion, so that the interference fringes are linear. If the adjustment of the objective lens **150** causes the convergence point of light by the objective lens **150** to be considerably deviated from the center of curvature of the spherical surface **202***b* of the hemispherical lens **202**, there will be too many tilt fringes, making it difficult to determine the degree of the distortion of the interference fringes B. In such case, the objective lens **150** (or the whole photo magnetic disc apparatus **100**) or the hemispherical lens **202**

is displaced in a direction perpendicular to the optical axis of the objective lens **150** to reduce the number of the tilt fringes B to an appropriate number (for example, 3 or 4 fringes). Thereafter, coma caused by the relative inclination of the objective lens with respect to the glass cover is observed. Consequently, the inclination of the objective lens **150** is adjusted so that the interference fringes B become linear again. The above-mentioned operations are repeated to correctly adjust the inclination of the objective lens **150**.

In the above-mentioned embodiment, the hemispherical lens **202** is provided on the side opposite to the objective lens **150** with respect to the glass cover "A", so that the relative inclination between the objective lens **150** and the glass cover "A" is detected in accordance with the interference fringes B caused by the light reflected by the hemispherical lens **202**. Accordingly, it is substantially only the hemispherical lens **202** which serves as the optical system to obtain the interference fringes B on the right side of the glass cover "A" in FIG. **5**. Consequently, the portion of the detecting apparatus **200** containing the hemispherical lens **202** is made small. This makes it possible to adjust the objective lens **150** from the side of the hemispherical lens **202**. Accordingly, there is no restriction to the mounting mechanism of the objective lens **150** to a lens holder or support (not shown). Namely, if a mounting structure of the objective lens **150** to the focusing and tracking mechanism, as shown in FIGS. **11** through **14** is used to lighten the whole focusing and tracking device in the photo magnetic disc apparatus, it is possible to easily adjust the inclination of the objective lens **150**.

In the above-mentioned embodiment, the light transmitted through the objective lens **150** is reflected and split by the hemispherical lens **202**, so that the light is separated into the above-noted two bundles of rays. The wavefronts of the two bundles of rays which are rotated through 180 degrees around the optical axis in a relative manner are superposed to thereby produce the interference fringes. Namely, the reflection, separation, rotation and superimposition of beams are effected by the single member. Consequently, no harmful external light tends to enter the above-noted superimposed bundles of rays. Accordingly, stable interference fringes B are obtained, resulting in an easy adjustment of the inclination, in comparison with an arrangement in which a concave mirror and a Dove prism are used in combination, as will be discussed hereinafter.

Also, in this embodiment, since the hemispherical lens **202** is used, the adjustment of the relative position between the hemispherical lens **202** and the objective lens **150** (i.e., the alignment adjustment) can be easily effected. Namely, since the center of curvature of the spherical surface portion **202*b*** of the hemispherical lens **202** is located on the flat surface portion **202*a***, the adjustment of the hemispherical lens **202** in the axial direction can be completed only by making the convergence point of the objective lens **150** coincidental with the flat surface portion **202*a***. Thereafter, the adjustment of the hemispherical lens **202** or the objective lens **150** (or, the photo magnetic disc apparatus **100**) with respect to the optical axis in the vertical direction (i.e., perpendicular to the optical axis) is carried out by making the convergence point of the objective lens **150** coincidental with the center of curvature of the spherical surface **202*b***.

In the first embodiment, the coma produced in the optical system of the photo magnetic disc apparatus **100** and the lens inclination detecting apparatus **200** can be substantially eliminated only by adjusting the relative inclination of the objective lens **150** and the glass cover "A" provided in the terminal stage of the optical system. Namely, in this embodiment, the coma produced in the optical system can be eliminated by adjusting the relative inclination of the objective lens **150** and the glass cover "A" without increasing the assembly accuracy of the optical elements of the optical system, according to the first embodiment.

When the adjustment of the inclination of the objective lens **150** is completed, as mentioned above, the photo magnetic disc apparatus is moved to a subsequent assembling or checking station.

FIG. **5** shows a second embodiment of a lens inclination detecting apparatus **200**, according to the present invention.

In the second embodiment, the insertion prism of the first embodiment is not provided, so that the light reflected from the hemispherical lens **202** is detected by the signal detecting system of the photo magnetic disc apparatus **100**. Namely, the light reflected from the hemispherical lens **202** is reflected by the prism **114** and introduced into the inclination detecting apparatus **200**. The light is split into two beams by the beam splitter **221** in the lens inclination detecting apparatus **200**. One of the split beams is made incident upon the interference fringe viewing portion **205** through the image forming lens **222** and the other split beam is transmitted through the condenser lens **223** and is made incident upon the beam splitter **224**. One of the beams split by the beam splitter **224** is introduced into the image point viewing portion **214** through the magnifying lens **225**, and the other split beam is made incident upon the alignment detecting portion **215**.

The remaining structure of the optical arrangement shown in FIG. **5** is same as the first embodiment.

In the second embodiment, the absence of the insertion prism between the mirrors **110** and **112** attenuates the disturbance of the wavefront of light towards the hemispherical lens **202**. Consequently, the inclination of the objective lens **150** can be more accurately detected in the second embodiment than the first embodiment.

FIG. **6** shows a third embodiment of a lens inclination detecting apparatus **200**, according to the present invention.

In the third embodiment, the interference fringes B, which are employed to detect the inclination of the objective lens **150**, are formed by the laser beam emitted from the He-Ne (helium-neon) laser source **230** provided in the lens inclination detecting apparatus **200**, unlike the first embodiment. Namely, the laser beam emitted from the He-Ne laser source **230** is converted to divergent light by a beam expander **231** and collimated by the collimating lens **232**, and is then made incident upon the insertion prism **201** (which has the same function as a mirror in this embodiment) through the beam splitter **233**.

The remaining structure of the third embodiment is the same as the first embodiment. Namely, the light incident upon the lens inclination detecting apparatus **200** through the insertion prism **201** is partly transmitted through the half mirror **203** to reach the interference fringe viewing portion **205** through the image forming lens **204**, and is partly reflected by the half mirror **203** to be made incident upon the condenser lens **211**. The light emitted from the condenser lens **211** is split into two bundles of rays by the beam splitter **212**. One of the split beams is made incident upon the image point viewing portion **214** through the magnifying lens **213** and the other split beam is made incident upon the alignment detector **215**. The thickness of the glass cover "A" in the third embodiment is determined in accordance with the wavelength of the laser beam emitted by the He-Ne laser source **230**.

According to the third embodiment, since the visible light is emitted from the laser source **230**, the interference fringes

B and the image points C and D can be directly viewed by a viewer without relying upon the CCD camera. Consequently, the adjustment of the inclination of the objective lens **150** can be much more simplified. Moreover, in comparison with the arrangement in which the semiconductor laser source **101** within the photo magnetic disc apparatus **100** is employed, no aberration is caused in the light path between the LD source **101** and the insertion prism **201**. Accordingly, a higher detection accuracy of the inclination of the objective lens **150** is obtained.

FIG. **7** shows a fourth embodiment of a lens inclination detecting apparatus **200**, according to the present invention.

In the fourth embodiment, there is provided a concave mirror **240** instead of the hemispherical lens. The light reflected by the concave mirror **240** is transmitted through the glass cover "A" and the objective lens **150** and is made incident upon the mirror **112**.

The light reflected by the beam splitter of the insertion prism **201** is partly transmitted through the half mirror **203** where the light is split. A half mirror (i.e., a reflecting means) **241** is provided for partially transmitting and partially reflecting light. A beam splitting means includes the half mirror **241**. The light transmitted through the half mirror **241** is incident upon the first Dove prism **242** which is per se known. Namely, when the light passes through the Dove prism **242**, the beam is inverted with respect to the first axis normal to the sheet of the drawings. The beam is then reflected by the mirror **243** and made incident upon the half mirror (i.e., a superposing means) **244**. The first Dove prism **242** and the second Dove prism **246** together constitute a wavefront rotating means. Light reflected by the half mirror **241** is reflected by the mirror **245** and is transmitted through the second Dove prism **246**, so that the beam is inverted with respect to the vertical axis (i.e., a second axis perpendicular to the first axis of the first Dove prism **242**) in FIG. **7** to reach the half mirror **244**.

The two beams are rotated by approximately 180 degrees about the optical axis by the first and second Dove prisms **242** and **246**, so that the two bundles are superimposed. Consequently, the interference fringes B are produced due to the coma which is the asymmetric aberration in 180 degrees directions with respect to the optical axis. The interference fringes B are converged as an image in the interference fringe viewing portion (not shown).

The remaining structure of the fourth embodiment is the same as the first embodiment.

The detection sensitivity of the coma in the fourth embodiment will be discussed below with reference to FIG. **8**.

In FIG. **8**, the light rays L4 and L5 transmitted through the objective lens **150** and the glass cover "A" are reflected by the concave mirror **240** and are returned along the same optical paths and emitted from the objective lens **150**.

The degree of coma contained in the wavefront reflected by the concave mirror **240** and transmitted through the objective lens **150** is twice that of the wavefront transmitted once through the objective lens **150** and the glass cover "A", since the return light passes twice through the objective lens **150** and the glass cover "A". The wavefront containing the "double" coma is split into two wavefronts which are relatively turned by 180 degrees with respect to the optical axis by the Dove prisms to be superimposed. Consequently, the coma caused by the transmission of the wavefront through the objective lens **150** and the glass cover "A" can be viewed at a fourfold sensitivity. Namely, one interference fringe is viewed when the coma caused by the inclination of the objective lens **150** with respect to the glass cover "A" is $\lambda/4$. Thus, the coma can be detected at very high sensitivity.

FIG. **9** shows a fifth embodiment of a lens inclination detecting apparatus **200**, according to the present invention.

The fifth embodiment is different from the fourth embodiment in that light transmitted through the half mirror **203** is split into two bundles or rays by the beam splitter **252**. The two types of bundle of rays are made incident upon the reflecting mirror **250** and the corner-cube prism **251**, respectively.

The bundle of rays reflected by the reflecting mirror **250** has the same direction as the light reflected by the concave mirror **240** with respect to the optical axis and is transmitted through the beam splitter **252** (i.e., a beam splitting means and a beam superposing means) to be made incident upon the image forming lens **253**. The bundle of rays reflected by the corner-cube prism (i.e., a wavefront rotating means) **251** corresponds to light reflected by the concave mirror **240** and the wavefront of the bundle of rays is rotated by 180 degrees with respect to the optical axis and is reflected by the beam splitter **252** to be made incident upon the image forming lens **253**. Consequently, the interference fringes B caused by the coma can be viewed in the interference fringe viewing portion **205**. The coma can be detected at high sensitivity similar to the fourth embodiment.

FIG. **10** shows a sixth embodiment of a lens inclination detecting apparatus **200**, according to the present invention.

In the sixth embodiment, the corner-cube prism **251** in the fifth embodiment is replaced with the condenser lens **254** and the reflecting mirror **255**. Namely, the condenser lens **254** and the reflecting mirror **255** has the same function as the corner-cube prism **251** in the fifth embodiment.

Consequently, one of the bundles of rays obtained by splitting light incident upon the beam splitter **252** is rotated through 180 degrees about the optical axis by the condenser lens **254** and the reflecting mirror **255**. This bundle of rays is superposed with another bundle of rays which is reflected by the reflecting mirror **250** at the beam splitter **252**. The superposition of the bundles of rays produces interference fringes. The condenser lens **254** and reflecting mirror **255** together constitute a wavefront rotating means. The other structure and operation of the sixth embodiment are the same as those in the fifth embodiment. Namely, the coma can be detected at high sensitivity similar to the fifth embodiment.

FIGS. **11** through **14** show the mounting structure of the objective lens **150** to the focusing and tracking mechanism of the photo magnetic disc apparatus **100**.

As shown in FIG. **11**, the objective lens **150** is supported by the lens supporting surface **152** of the lens supporting member (lens holder) **151**. The supporting surface **152** is a conically oblique surface. The objective lens **150** is, for example, a single glass mold lens with opposite aspherical lens surfaces. The single objective lens **150** is provided on the outer peripheral surface thereof with a peripheral or annular flange **153** which comes into contact with the supporting surface **152**. The lens supporting surface **152** may be spherical.

It is now assumed that the center line CL of the supporting surface **152** is identical to the optical axis of the objective lens **150** and that the objective lens **150** is parallel with the glass cover "A". If the objective lens **150** is displaced by the lateral force applied thereto through a displacement δ, the displacement of the flange **153** of the lens **150** takes place along the supporting surface **152**, so that the objective lens **150** is rotated about the intersecting point C1 of the straight

line M normal to the supporting surface **152** and the center axis CL in a cross section, as indicated at two-dotted and dashed line in FIG. **11**. Namely, there is an inclination angle θ of the optical axis of the objective lens **150**, and the convergence point C2 of the objective lens is moved, so that the deviation ϵ of the image point occurs. The inclination θ causes the coma, so that the distortion of the interference fringes B (FIG. **1**) increases.

Furthermore, the number of the tilt fringes (interference fringes B) is increased by the deviation ϵ of the image point. This makes it difficult for an operator to observe the magnitude of the distortion of the interference fringes. To prevent this, it is desirable that only the inclination θ occurs without causing the deviation ϵ of the image point, upon the adjustment of the inclination of the objective lens **150**.

No deviation ϵ of the image point occurs due to the inclination of the objective lens **150**, when the objective lens **150** is rotated about the rear principal point (i.e., principal point adjacent to the image) N2 thereof, provided that the incident light is collimated light. However, in case where the objective lens **150** is displaced with respect to the supporting surface **152**, as mentioned above, the intersecting point C1 of the optical axis and the straight line which passes through the contacting point of the supporting surface **152** and the flange **153** and which is perpendicular to the supporting surface **152** must coincide with the center line CL which contains the rear principal point N2, in order that the objective lens **150** rotates about the rear principal point N2. It is however difficult to support the objective lens in such an arrangement. Therefore, in the first through sixth embodiments, if the number of the interference fringes increases due to the occurrence of the deviation ϵ of the image point during the adjustment of the inclination of the lens, so that it is difficult to measure or detect the magnitude or degree of the coma, the whole lens inclination detecting apparatus **200** or the hemispherical lens **202** (or the concave mirror **240**) is displaced in the direction perpendicular to the optical axis of the objective lens to attenuate the deviation ϵ of the image point or reduce the number of the interference fringes to thereby measure the coma. The adjustment of the inclination of the objective lens **150** will be discussed hereinafter.

FIG. **12** schematically shows the mounting structure of the objective lens **150** to the focusing and tracking mechanism **160**.

The focusing and tracking mechanism (i.e., coarse actuator) **160** is provided below the photo magnetic disc K, so that the objective lens **150** emits the laser beam S towards the photo magnetic disc K from the lower side thereof. The lens holder (fine actuator) **151** is connected to the securing member **155** through the springs **154**. The securing member **155** is secured to the movable member **157** by the screw **156**. Consequently, the lens holder **151** is displaced with respect to the securing member **155** when an elastic deformation of the springs **154** takes place. As mentioned above, since the inclination of the objective lens **150** is adjustable with respect to the lens holder **151** and the securing member **155** is integrally connected to the movable member **157**, it is not necessary to provide a mechanism which relatively inclines the securing member **155** or the movable member **157**, unlike prior art in which such a mechanism is indispensable. Thanks to this, it is not necessary to provide any component which provides for inclinable movement of the securing member **155** with respect to the movable member **157**. Consequently, not only can the focusing and tracking mechanism **160** be considerably lightened, but also the speed of the tracking operation for the photo magnetic disc can be increased.

FIG. **13** shows the internal structure of the split type focusing and tracking mechanism **160** of photo magnetic disc apparatus.

The movable member **157** is movably supported on rails **161**, for example, through a ball bearing (not shown), so that the movable member **157** is moved along the rail **161** to a position corresponding to a predetermined track of the photo magnetic disc apparatus. The movable member **157** is provided with the mirror **112** (FIG. **1**) through which the laser beam is made incident upon the objective lens **150** and the laser beam emitted from the objective lens **150** is made incident upon the detecting system (not shown). The securing member **155** is secured to the movable member **157** through the connecting member **158**. Note that the connecting member **158** is not shown in FIG. **12**.

The springs **154** extend in the direction perpendicular to the sheet of the drawings in FIG. **13**. The lens holder **151** is spaced from the securing member **155** and the connecting member **158**, and is supported only by the springs **154**. The lens holder **151** is provided with a hole **162** which extends in the vertical direction under the objective lens **150**. There are a plurality of solenoid coils **163** surrounding the hole **162**. The connecting member **158** is provided with magnets **169** (FIG. **14**) corresponding to the solenoid coils **163**. As is well known, to record or reproduce data on or from the photo magnetic disc K, the solenoid coils **163** are selectively activated or energized in accordance with the tracking error signals or focusing error signals, so that a slight displacement of the lens holder **151** occurs to adjust the relative positional relationship between the objective lens **150** and the focus position and the track position of the photo magnetic disc K.

The mounting mechanism of the objective lens **150** is not limited to that shown in FIGS. **12** and **13**, and the present invention can be applied to any type of adjusting apparatuses which adjust the relative inclination of the objective lens and the photo magnetic disc.

FIG. **14** shows the lens holder **151**, in which the supporting surface **152** on which the objective lens **150** is supported and the surroundings thereof are exaggerated.

The conical lens supporting surface **152** is made of a part of a cone whose apex is located on the center axis of the hole **162**. The diameter of the conical supporting surface **152** decreases towards the lower end (inner end) thereof. There are four projections **164** which project upward from the outer peripheral edge (upper edge) of the supporting surface **152**. The projections **164** are spaced at an equi-angular distance and are provided on inner surfaces thereof with recessed portions **165** which form adhesive reservoirs. The adhesive reservoirs **165** receive an excess amount of adhesive between the objective lens **150** and the supporting surface **152**. Namely, if the adhesive expands when it sets, the excess adhesive can be absorbed by the adhesive reservoirs **165**, so that no adhesive is discharged onto the lens surface of the objective lens **150**.

The following discussion will be directed to the adjusting operation of the inclination of the objective lens **150** that is disposed on the lens holder **151**, with reference to FIGS. **15** through **29**.

FIG. **15** shows a plan view of the mounting apparatus **500** of the photo magnetic disc apparatus. The mounting apparatus **500** includes a pair of parallel guide members **501** and **502** on which a pallet **503** is slidably supported. The photo magnetic disc apparatus **100** is disposed on the pallet **503** at a first stage ST1.

Thereafter, the pallet **503** is transferred in the right direction in FIG. **15** and stopped at a second stage ST2 at which

a positioning apparatus **300** is provided, as shown in FIG. **16**. The positioning apparatus **300** is adapted to determine the position of the lens holder **151** with respect to the rails **161** (FIG. **13**). The rails **161** extend in the left and right directions in FIG. **13**. A stop **301** is provided on the mounting apparatus **500** to restrict the movement of the lens holder **151** with respect to the rails **161**, so that the connecting member **158** abuts against the stop **301** to carry out the substantial positioning of the lens holder **151**. Thereafter, a lock mechanism (not shown) is actuated to lock the focusing and tracking mechanism **160** to the rails **161**, and the stop **301** is rotated upward to disconnect the same from the connecting member **158**.

To confirm the positioning state, there is a microscopic objective lens **302** above the front end of the stop **301**. The microscopic objective lens **302** is secured to the lower end of the cylindrical holder **304** mounted to a securing plate **303**. The holder **304** is provided on the upper end thereof with a CCD camera **305** to which the monitor **306** is connected. If the image of the lens holder **151** does not concur with a mark which represents a predetermined position (i.e., reference position) of the lens holder in the monitor, the fine adjustment of the position of the photo magnetic disc apparatus **100** is carried out to adjust the lens holder **151** by a horizontal position adjusting mechanism **505** (FIG. **15**) so as to make the image coincidental with the reference mark.

The horizontal position adjusting mechanism **505** is provided on the lower surface of the pallet **503** so as to move the photo magnetic disc apparatus **100** with respect to the pallet **503** in the X-axis direction parallel with the guide members **501** and **502** and the Y-axis directions perpendicular to the X-axis direction. Namely, when an X-axis adjusting knob **506** is rotated about the axis thereof, the fine adjustment of the photo magnetic disc apparatus **100** in the X-axis direction is effected, and when a Y-axis adjusting knob **507** is rotated about the axis thereof, the fine adjustment of the photo magnetic disc apparatus **100** in the Y-axis direction is effected, respectively.

Thereafter, the pallet **503** and, accordingly, the photo magnetic disc apparatus **100** is moved to the left (with respect to FIG. **15**) along the guide members **501** and **502**, and is stopped at a third stage ST3. At the third stage ST3, the objective lens **150** is disposed on the lens holder **151** by the lens feeding apparatus **310** which will be discussed below, and the adhesive is supplied between the lens holder **151** and the objective lens **150**.

FIG. **17** shows the lens feeder **310** provided at the third stage ST3.

A cylindrical bearing member **312** is secured to the securing plate **311** to project therefrom. The projecting end of the bearing member **312** from the securing plate **311** is fitted in the hollow conical guide member **313**. The guide member **313** is provided with a inner conical surface **314**. The guide member **313** is provided on the outer periphery thereof with four adhesive applying members **315** which are spaced at an equi-angular distance about the center axis of the guide member **313**. Each of the adhesive applying members **315** is made of an elongated tube which is connected to an adhesive supplier **317** through a flexible tube **316**. The adhesive supplier **317** is controlled to supply a predetermined amount of adhesive.

An insertion tube **321** having a sucking tube **322** at the front end thereof is slidably fitted in the inner wall surface **318** of the bearing member **312**. The insertion tube **321** is connected to a vacuum source **325**, so that the objective lens **150** can be held at and by the front end of the sucking tube **322** with the help of the vacuum. The base end **321***a* of the insertion tube **321** is slidably supported by and in a supporting pipe **323** which is provided with a guide groove **323***a* in which a bolt **324** secured to the base end **321***a* is engaged. Namely, the bolt **324** is guided in the guide groove **323***a* so that the insertion tube **321** is relatively movable with respect to the supporting tube **323** in the axial direction.

The supporting tube **323**, the insertion tube **321**, and the sucking tube **322** are originally detached from the bearing member **312**. In this state, the objective lens **150** is picked up at the front end of the sucking tube **322**. When the objective lens **150** is held by the front end of the sucking tube **322**, the insertion tube **321** and the sucking tube **322** are inserted in the bearing member **312** and the guide member **313**. During the insertion, the outer peripheral surface **154** of the objective lens **150** is guided by the tapered surface **314** of the guide member **313** and the circular hole **319** at the front end thereof, as shown in FIG. **18**. Consequently, the positioning of the objective lens **150** relative to the circular hole **319** in the radial direction, i.e., the centering of the objective lens **150** is executed. Further insertion of the insertion tube **321** and the sucking tube **322** causes the lower end of the supporting pipe **323** to come into contact with the upper end of the bearing member **312**. Consequently, the front end of the sucking tube **322**, and accordingly, the objective lens **150** project downward from the circular hole **319** of the guide member **313**, as shown in FIG. **17**.

Thereafter, the insertion tube **321** and the sucking tube **322** are moved downward with respect to the supporting pipe **323**, the bearing member **312** and the guide member **313**, so that the objective lens **150** is disposed on the supporting surface **152** of the lens holder **151**. As soon as the vacuum supply to the insertion tube **321** and the sucking tube **322** is stopped, the sucking tube **322** is slightly separated from the objective lens **150**. In this state, the front ends of the four adhesive applying members **315** are opposed to the center portions of the upper surfaces of the corresponding projections **164** of the lens holder **151**. A predetermined amount of adhesive G is fed from the adhesive applying members **315** into the respective adhesive reservoirs **165** that are spaced at an equi-angular distance. It should be appreciated here that since the adhesive G is introduced in the adhesive reservoirs **165**, the adhesive G can be uniformly applied to the outer peripheral edge of the objective lens **150** supported on the supporting surface **152** of the lens holder **151**. In the illustrated embodiment, the adhesive G is an ultra violet setting type adhesive.

After the adhesive G has been applied, the insertion tube **321** and the sucking tube **322** are moved upward to come away from the objective lens **150** by a return spring (not shown) and are stopped at a position away from the objective lens **150**.

Thereafter, at a fourth stage ST4, the inclination of the objective lens **150** is adjusted, and the adhesive G is set to secure the objective lens **150** to the lens holder **151**. The adjustment of the inclination of the objective lens **150** will be discussed below with reference to FIGS. **20** and **21** which show flow charts of the adjusting operation.

At step S10, an insertion member **330**, as shown in FIGS. **24** and **25** is attached to the photo magnetic disc apparatus **100** which has been transferred again to the first stage ST1 after the operation at the third stage ST3 has been completed (FIGS. **26** and **27**).

The insertion member **330** has a cylindrical body **331** which is provided on the center portion thereof with a center

hole **333** in which an output shaft **131***a* of a spindle motor **131** is fitted. A first arm **334** projects from the cylindrical body **331** in the radial direction. The glass cover "A" is attached to the front end of the first arm **334**. In the insertion member **330**, a contacting surface **331***a* of the cylindrical body **331** abuts a contacting surface **131***b* of the spindle motor **131** to make the glass cover "A" parallel to a reference surface (i.e., the contacting surface **131***b*). The contacting surface **131***b* is arranged parallel to the photo magnetic disc K.

A second arm **335** which is in the form of a rectangle to surround the first arm **334** as viewed from above is provided on the front end thereof with a supporting portion **336** which extends downward therefrom. The insertion prism **201** is attached to the supporting portion **336**. Namely, the insertion prism **201** is located below the glass cover "A". Note that the front end of the second arm **335** and the supporting portion **336** have holes **337** and **338** through which light reflected by the insertion prism **201** passes, respectively. The first arm **334** is provided with an opening **339** through which the inclination adjusting pawl **401** can extend.

At step **S11**, the photo magnetic disc apparatus **100** is conveyed to the fourth stage ST4 where the inclination adjusting apparatus **400** is provided. The inclination adjusting apparatus **400** which is adapted to adjust the inclination of the objective lens **150** with respect to the glass cover "A" includes the hemispherical lens **202** and the inclination adjusting pawls **401**. In the state shown in FIG. **27**, the flat surface portion **202***a* of the hemispherical lens **202** is parallel with the glass cover "A". Note that the inclination adjusting apparatus **400** will be discussed hereinafter.

The photo magnetic disc apparatus **100** is secured at a predetermined position underneath the inclination adjusting apparatus **400**. The inclination adjusting apparatus **400** which has been originally located above and away from the objective lens **150**, as shown in FIG. **26**, is moved down at step **S12** to a position close to the objective lens **150**, as shown in FIG. **27**. In this state, the positioning of the hemispherical lens **202** in the axis direction is executed, and the inclination adjusting pawls **401** are located close to the objective lens **150**.

At step **S13**, the fine adjustment of the objective lens **150** in the optical axis direction (Z-axis direction) thereof is effected so that the image point (FIG. **4**) indicated in the alignment detector **215** (FIG. **1**) and the image point D indicated in the image point viewing portion **214** are clear spot images, i.e., the convergence point of the objective lens **150** is located on the flat surface portion **202***a* of the hemispherical lens **202**. This fine adjustment is carried out by controlling the activation of the solenoid coils **163** (FIG. **14**) to move the objective lens **150** only or moving the whole photo magnetic disc apparatus **100** by a driver (not shown), while observing the monitors of the alignment detector **215** and the image point viewing portion **214**. The fine adjustment of the objective lens **150** can be replaced with the fine adjustment of the hemispherical lens **202** in the optical axis direction.

At step **S14**, the fine adjustment of the objective lens **150** in the direction normal to the optical axis is carried out so that the convergence point of the objective lens **150** concurs with the center of curvature of the spherical surface portion **202***b* of the hemispherical lens **202**, while observing the interference fringes B and the image points C and D (FIG. **3**) displayed in the monitors of the interference fringe viewing portion **205**, the image point viewing portion **214**, and the alignment detector **215**, respectively. Namely, the fine adjustment causes the image point C to move close to the image point D. This fine adjustment is effected by the slight displacement of the photo magnetic disc apparatus **100** in the X-axis direction and the Y-axis direction by the horizontal position adjusting mechanism **505**. As a result, an appropriate number of tilt fringes (for example, three tilt fringes) and the coma are added to the interference fringes B, so that the distortion of the interference fringes, i.e., the coma can be easily and clearly viewed. It is alternatively possible to execute a fine adjustment of the hemispherical lens **202** in the X-axis direction and Y-axis direction, instead of the fine adjustment of the objective lens **150**.

At step **S15**, the tilt fringe(s) of an optional direction indicated in the monitor of the interference fringe viewing portion **205** is (or are) selected and observed to measure the degree of the coma contained in the light emitted from the objective lens **150**. If the degree of the coma is not within an allowable limit, i.e., if the magnitude of the distortion of the interference fringes B is above a predetermined value, it is determined that the inclination of the objective lens **150** with respect to the glass cover "A" is too large. Consequently, the inclination of the objective lens **150** is adjusted by the inclination adjusting apparatus **400** in steps subsequent to step **S20**. Conversely, if the coma is within the allowable limit, no adjustment of the inclination of the objective lens **150** is carried out, and the control proceeds to step **S26**.

The structure of the inclination adjusting apparatus **400** will be described below, referring to FIGS. **27** through **29**.

There is a hemispherical lens holder **404** provided on the lower surface of the body **402** of the inclination adjusting apparatus **400**. The hemispherical lens holder **404** is provided on the front end thereof with the vertically extending hole **403**. The hemispherical lens **202** is secured to the lower end of the hole **403**.

As can be seen in FIG. **28**, the four adjusting pawls **401** are formed by cutting the center portion of the circular disc plate **409** into a predetermined shape. The adjusting pawls **401** extend in the radial directions. The circular disc plate **409** is attached to the lower surface of a hemispherical rotatable member **410**. The center of the circular disc **409** is located within the hemispherical lens **202**. The adjusting pawls **401** are spaced at an equi-angular distance of 90 degrees, and are bent at the front ends thereof to project below the level of the hemispherical lens **202**. The front ends of the adjusting pawls **401** extend to the vicinity of the center of curvature of the hemispherical outer peripheral surface of the rotatable member **410**, so that the front ends are located below the level of the lower surface of the glass cover "A" upon adjustment of the inclination of the objective lens **150**, as shown in FIG. **27**.

One of the four adjusting pawls **401** is located within the opening **339** of the first arm **334**. The rotatable member **410** is provided with a cut-away portion **419** which prevents the hemispherical lens holder **404** from interfering with the rotatable member **410**.

The hemispherical outer peripheral surface **411** of the rotatable member **410** is slidably supported in and by the hemispherical recess **412** formed on the lower surface of the body **402**. The center of curvature of the hemispherical outer peripheral surface **411** and the corresponding hemispherical recess **412** is located on the optical axis of the objective lens **150** in the vicinity of the center of rotation C1 of the objective lens **150** (FIG. **11**). Namely, the center of rotation of the rotatable member **410** is located in the vicinity of the center of rotation C1 (FIG. **11**) of the objective lens **150**, the center of rotation C1 being located on the optical axis of the objective lens **150**.

The rotatable member **410** is provided with a vertically extending connecting hole **413** in which a hollow cylindrical operation shaft **414** is fitted. The operation shaft **414** is provided on the lower end thereof with a flange **417** whose diameter is larger than the diameter of the connecting hole **413**, so that the flange **417** comes into surface contact with the lower surface of the rotatable member **410**. The operation shaft **414** projects upward from the connecting hole **413** and extends through a passage **430** formed on the body **402**. An annular pressing member **415** is fitted to the upper end of the operation shaft **414**. Between the pressing member **415** and the body **402** is provided a spring **416** which continuously biases the rotatable member **410** upwardly through the pressing member **415**.

The operation shaft **414** is provided therein with a parallel plate (transparent glass) **431** which is in parallel with a reference surface of the adjusting pawls **401**. The parallel plate **431** is adapted to confirm an initial position of the inclination of the adjusting pawls **401** at step **S12** in the inclination adjusting operation of the objective lens **150**.

There are four microadjusters **421** screwed in the cylindrical wall **418** provided on the upper end of the body **411** to surround the pressing member **415**. A spindle **422** of each microadjuster **421** extends inward through a cylindrical wall **418** to abut against the outer peripheral surface of the pressing member **415**. The rotation of the microadjusters **421** about the respective axes causes the handles to move in the respective axial directions to vary the length of the inward projection of the microadjusters **421** from the cylindrical wall **418**. Consequently, the pressing member **415** can be displaced in the horizontal direction by decreasing the length of projection of two of the microadjusters **421** and increasing the length of projection of the remaining two microadjusters **421**, so that the operation shaft **414** is inclined to rotate the rotatable member **410**. The rotation of the rotatable member **410** varies the inclination of the adjusting pawls **401** to adjust the inclination of the objective lens **150**, as will be discussed hereinafter.

The distance between the center of rotation of the rotatable member **410** and the contact portions T of the microadjusters **421** and the pressing member **415** is larger than (for example, about ten times) the distance between the center of rotation **C1** of the objective lens **150** and the supporting surface **152** (FIG. **11**). Consequently, when the axial displacement of the microadjusters **421** caused by the rotation thereof takes place, the displacement of the objective lens **150** is about one-tenth (1/10) the displacement of the handles **421**. Thus, the fine adjustment of the inclination of the objective lens **150** can be accurately effected by the microadjusters **421**.

As may be seen in FIG. **29**, there are springs **423** within the body **402** to correspond to the microadjusters **421**. The springs **423** abut at one end thereof, for example, against the outer peripheral surface of the circular disc **409**, and abut at the other ends thereof against the upper portion of the body **402**, respectively. The rotatable member **410** is continuously biased upwards by the springs **423**, so that the rotatable member **410** can be stably held in the inclined state.

Turning back to FIGS. **20** and **21**, the inclination of the objective lens **150** is carried out as follows.

At step **S20**, the inclination adjusting apparatus **400** slightly descends until the adjusting pawls **401** come into contact with the outer peripheral edge of the objective lens **150**. At step **S21**, the microadjusters **421** are rotated to rotate the rotatable member **410** to thereby incline the adjusting pawls **401**. The direction and degree of the inclination of the adjusting pawls **401** are determined in accordance with the interference fringes B viewed at step **S20**. Namely, if it is detected from the interference fringes B that the coma appears inclined, for example, at 45 degrees from the X-axis direction in the horizontal plane, the adjusting pawls **401** are inclined in that direction. As a result, the objective lens **150** is displaced along the supporting surface **152** to vary the contact portion of the objective lens **150** with the supporting surface **152** to thereby adjust the inclination of the objective lens **150**. At step **S22**, a slight upward movement of the inclination adjusting apparatus **400** takes place to move the adjusting pawls **401** away from the objective lens **150**.

At step **S21**, the convergence point **C2** of the objective lens **150** is displaced as a result of the inclination of the objective lens **150**, as mentioned above with reference to FIG. **11**. Consequently, the number of the tilt fringes of the interference fringes B is increased. The increase in the number of the tilt fringes may make it difficult for an operator to determine the degree of coma. Thereafter, at step **S22.5**, the number of the tilt fringes of the interference fringes B is checked to see if the number is too large to measure the coma. If the number is too large, the photo magnetic disc apparatus **100**, and accordingly, the objective lens **150** are moved in the direction to reduce the number of the tilt fringes (step **S23**), i.e., in the direction opposite to the direction of the inclination of the adjusting pawls **401** at step **S21** by actuating the horizontal position adjusting mechanism **505**. Alternatively, it is possible to move the hemispherical lens **202**. If the number is not too large, the operation proceeds directly to step **S24**. At step **S24**, the direction of the maximum coma is detected by the fine adjustment of the horizontal position adjusting mechanism **505** to check whether or not the coma is still present.

At step **S25**, whether or not the coma is within the allowable limit is checked, similar to step **S15**. If the coma is not within the allowable limit, the operations at steps **S20** through **S24** are performed again.

Consequently, if the coma is attenuated to be within the allowable limit, the control proceeds to step **S26** at which the periphery of the objective lens **150** is illuminated with the ultra violet radiation to set the adhesive G. As a result, the objective lens **150** is secured to the supporting surface **152** of the lens holder **151**.

At step **S27**, the inclination adjusting apparatus **400** and the hemispherical lens holder **404** are moved upward to retract the inclination adjusting pawls **401** from the objective lens **150**. Namely, the inclination adjusting apparatus **400** is returned to the initial position shown in FIG. **26**. At step **S28**, the four handles **421** are rotated to adjust the adjusting pawls **401** whose inclination is returned to the reference position, i.e., the position in which reference plate **401*a***, which is integral with adjusting pawls **401**, is parallel to the contacting surface **131*b*** of the spindle motor **131** (FIG. **25**). In the course of the adjustment of the reference plate **401*a***, the laser beam is emitted towards the parallel plate **431**, so that the laser beam reflected by the parallel plate **431** is made coincident with the reference mark provided in the monitor. In this state, the parallel plate **431** and the adjusting pawl reference plate **401*a*** are parallel with the contacting surface **131*b*** and the glass cover "A".

Thereafter, at step **S29**, the photo magnetic disc apparatus **100** is returned to the initial position, i.e., the first stage **ST1**. At step **S30**, the insertion member **330**, and accordingly, the glass cover "A" and the insertion prism **201** are removed from the photo magnetic disc apparatus **100**. Thereafter, at step **S31**, the photo magnetic disc apparatus **100** is removed

from the optical disc apparatus mounting apparatus **500**. Thus, the adjustment of the inclination of the objective lens **150** of the photo magnetic disc apparatus **100** is completed.

As can be understood from the foregoing, according to the inclination adjusting method as shown in FIGS. **20** and **21**, the inclination of the objective lens **150** with respect to the lens holder **151** can be easily and accurately adjusted since the adjustment of **150** is carried out on a real-time basis while the variation of the coma is being observed. Moreover, although the inclination detecting apparatus **200** (FIG. **1**) according to the first embodiment is used to effect the inclination method, the adjusting method can be equally applied also to the inclination detecting apparatuses shown in the second through sixth embodiments.

FIG. **30** shows another embodiment of the inclination adjusting apparatus **400**.

In this embodiment, the microadjusters **421** shown in FIG. **27** are replaced with sticks **440** which extend in the radial directions of the rotatable member **410**. The sticks **440** are secured at the lower ends thereof to corresponding holes **441** formed in the hemispherical outer surface **411** of the rotatable member **410**. The body **402** is provided with openings **442** through which the sticks **440** extend. The sticks **440** project outward from the openings **442** of the body **402**. The diameter of the openings **442** is larger than the diameter of the sticks **440**, so that the sticks **442** are movable (swingable) within the respective openings **440** about the center of curvature of the rotatable member **410**. The remaining structure of the apparatus shown in FIG. **30** is the same as that shown in FIG. **27**.

In the embodiment illustrated in FIG. **27**, the rotatable member **410** is rotated when the microadjusters **421** are selectively rotated to vary the projection length of the spindle **422** thereof, as mentioned above. Consequently, if the direction in which the objective lens **150** is to be inclined to eliminate the coma is identical to the axial direction of none of the four microadjusters **421**, it is necessary to actuate all the microadjusters **421** in combination to thereby incline the rotatable member **410** in the desired direction.

In the embodiment illustrated in FIG. **30**, the sticks **440** are selectively inclined in the direction in which the rotatable member **410** is to be rotated. Namely, the sticks **440** allow for a more precise and easier adjustment than the microadjusters **421**, since the rotatable member **410** is directly rotated.

FIG. **31** shows another embodiment of the adjusting pawls **401** whose front ends are different in shape from those in FIGS. **26** and **27**.

In the arrangement shown in FIG. **31**, the adjusting pawls **401** are provided on the front ends thereof with recesses (notches) **451** in which the upper corner or edge portion **159** of the objective lens **150** is engaged. When the objective lens **150** is pressed by the adjusting pawls **401** to move the lens holder **151** downward, the objective lens **150** tends to laterally slide. However, the engagement of the upper corner edge **159** in the recesses **451** prevents the objective lens **150** from moving in the transverse direction. Consequently, it is ensured that a smooth inclination of the objective lens **150** takes place and the lens holder **151** is returned to the initial position by the restoring force of the spring **154**.

FIGS. **32** through **34** show different examples of the objective lens **150** and the lens holders **151**.

As mentioned above, in the embodiment shown in FIG. **11**, the objective lens **150** is supported on the tapered supporting surface **152** of the lens holder **151**. Consequently, the center of rotation of the objective lens **150** is located at a level higher than the objective lens **150** during the adjustment of the inclination of the objective lens **150**. Therefore, the inclination of the objective lens **150** causes the convergence point C2 to move, thus resulting in the occurrence of the deviation ϵ of the image point. This results in an increase in the number of the interference fringes B. One of the solutions to such a deviation of the image point is to provide a conical supporting surface **152** which expands downward (i.e., in the direction opposite to the convergence point of the objective lens **150**), as shown in FIG. **32**. Namely, the diameter of the conical supporting surface **152** increases towards the lower end thereof. In the arrangement shown in FIG. **32**, the center of rotation of the objective lens **150** is located in the vicinity of the rear principal point N2 of the objective lens **150**. Note that, in the modification shown in FIG. **32**, it is necessary to always suck the objective lens **150** from the upper side thereof, for example, by the use of vacuum in the course of the inclination adjustment of the objective lens.

Also, in another solution shown in FIG. **33**, the center of rotation of the objective lens **150** is located in the vicinity of the rear principal point N2 of the objective lens **150**. Namely, in FIG. **33**, the supporting surface **152** of the lens holder **151** is defined by a conical surface which expands towards the upper end thereof (i.e., towards the convergence point of the objective lens), similar to the supporting surface shown in FIG. **11**. The difference between the arrangements shown in FIG. **11** and FIG. **33** resides in the annular or cylindrical holding ring **150*a*** provided on the peripheral edge of the objective lens **150** and having a center located on the optical axis of the objective lens **150** in FIG. **33**. The lower end of the holding ring **150*a*** is supported on and by the supporting surface **152** of the lens holder **151**. The objective lens **150** with the holding ring **150*a*** is integrally made of a plastic lens which is molded, for example, in an injection molding process.

FIG. **34** shows a modified embodiment of the objective lens **150**. The objective lens **150** shown in FIG. **34** has a lower surface **150*b*** which is supported on and by a tapered inner peripheral edge **151*a*** of the lens holder **151**. In this arrangement, it is impossible to incline (or rotate) the objective lens **150** about the rear principal point N2 of the objective lens **150**, but the center of rotation C3 of the objective lens is located closer to the rear principal point N2 than the embodiment shown in FIG. **11**.

FIGS. **22** and **23** show flow charts of the inclination adjusting operations of the objective lens **150** different from those shown in FIGS. **20** and **21**. The operations up to steps **S15** are the same as those in FIGS. **20** and **21**, and accordingly, no explanation therefor will be given herein below. Accordingly, the following explanation will begin with step **S20**. Note that in the flow charts shown in FIGS. **22** and **23**, although the inclination detecting apparatus **200** of the objective lens shown in FIG. **1**, according to the first embodiment mentioned above is used, it goes without saying that the inclination detecting apparatus according to any one of the second through sixth embodiments can be also equally used.

At step **S20**, the inclination adjusting apparatus **400** is slightly moved downward until the inclination adjusting pawls **401** come into contact with the peripheral edge of the objective lens **150**. Thereafter, at step **S21**, the solenoid coils **163** are activated to bias the lens holder **151** upward. As a result, the upward movement of the lens holder **151** takes place, so that the objective lens **150** is pressed against the adjusting pawls **401**. Namely, the objective lens **150** is held between the adjusting pawls **401** and the lens holder **151**

(FIG. 27), so that the objective lens **150** can be smoothly displaced on the supporting surface **152** to be inclined at an inclination angle identical to the inclination angle of the adjusting pawls **401**. At step S22, the slight upward movement of the inclination adjusting apparatus **400** occurs to move the adjusting pawls **401** away from the objective lens **150**.

As a result of the inclination of the objective lens **150** at step S21', the convergence point C2 of the objective lens **150** is displaced, as mentioned above with reference to FIGS. **11**, and consequently, an operator may have difficulty in measuring the degree of coma, due to the increase in the number of the tilt fringes of the interference fringes B. To prevent this, at step S22.5, whether or not the there are too many tilt fringes to measure the coma is checked. If the number of the tilt fringes is above a predetermined value, the photo magnetic disc apparatus **100**, and accordingly, the objective lens **150** are moved by the operation of the horizontal position adjusting mechanism **505** in the direction to reduce the number of the tilt fringes (step S23), i.e., in the direction opposite to the direction of the inclination of the objective lens obtained at step S21'. Alternatively, it is possible to move the hemispherical lens **202**. If the number of the tilt fringes is not above a predetermined value, the operation proceeds directly to step S24.

At step S24, the fine adjustment of the horizontal position adjusting mechanism **505** varies the direction of the tilt fringes of the interference fringes B to find the direction of the maximum coma to check whether or not the coma is still present.

At step S25, the magnitude of the coma is determined, similar to step S15. If the coma is not within a predetermined limit, the control proceeds to step S32 to incline the adjusting pawls **401** by a predetermined angle. The angle by which the adjusting pawls **401** are to be inclined, corresponding to the inclination angle of the objective lens **150**, is determined in accordance with the distortion of the interference fringes B measured at step S23. The relationship between the variation of the inclination angle of the objective lens **150** and the variation of the coma (distortion of the interference fringes B) is obtained in advance by experiments or calculation. Namely, one variation of the inclination angle of the objective lens **150** corresponds to one variation of the coma (i.e., 1:1). For example, in case of the objective lens **150** whose NA is 0.55 (NA=0.55), it is necessary to incline the objective lens **150** by about 34' (minutes) in order to vary one interference fringe. This value is arrived at by dividing the magnitude of the curvature or inclination of the interference fringes B by the distance or pitch of the interference fringes B. Note that the calculation of the variation of the inclination angle of the objective lens **150** and the variation of the coma is per se known. Also, note that the direction of the adjusting pawls **401** has been already obtained at step S24.

The following discussion will be addressed to the adjusting operation of the inclination of the adjusting pawls **401** at step S32 in more detail.

The laser beam is emitted from the upper side of the parallel plate **431** (FIG. **27**) and a image point of the light reflected therefrom is observed in the monitor (not shown). The image point is displaced in the monitor in accordance with the inclination angle of the adjusting pawls. The reference mark provided in the monitor is adapted to detect or measure the displacement of the image point, i.e., the inclination angle of the adjusting pawls **401**. Namely, the inclination of the adjusting pawls **401** is carried out by rotating the rotatable member **410** which is in turn rotated by the rotation of the microadjusters **421**, while observing the image point in the monitor.

The inclination angle of the adjusting pawls **401** can be detected by a special angle detector which is additionally provided, instead of the measurement of the image point of the light reflected from the parallel plate **431**.

After the operation at step S32 is completed, the control is returned to step S20 in which the adjusting pawls **401** are brought into contact again with the objective lens **150**, and then, the lens holder **151** is biased upward at step S21. Consequently, the objective lens **150** is held between the adjusting pawls **401** and the lens holder **151**, and is displaced along the supporting surface **152** of the lens holder **151** to be inclined at an inclination angle identical to that of the adjusting pawls **401**. As a result of the inclination of the objective lens **150**, the image point of the light reflected from the spherical surface portion **202***b* of the hemispherical lens **202** is displaced in the monitor of the alignment detector **215** (FIG. **1**). Also, in the monitor of the interference fringe viewing portion **205**, the number of the tilt fringes of the interference fringes B is increased owing to the occurrence of the deviation ϵ of the image point (FIG. **11**). If there are too many tilt fringes to measure the coma, the control proceeds to step S23 to reduce the number of the tilt fringes, and thereafter, whether or not the coma is within the allowable limit is checked at step S25. If the displacement of the image point caused by the change of the inclination angle of the objective lens **150** at step S21 is small in the monitor of the alignment detector **215**, it is possible to measure the displacement of the image point in the monitor of the image point viewing portion **214**.

If the coma is within the allowable limit, the control proceeds to step S26 where the peripheral edge of the objective lens **150** is illuminated with the ultra violet radiation through the parallel plate **431** to set the adhesive G. Consequently, the objective lens **150** is secured to the supporting surface **152** of the lens holder **151**.

Thereafter, at step S27, the inclination adjusting apparatus **400** and the hemispherical lens holder **404** are moved upward to retract the adjusting pawls **401** from the objective lens **150**. Namely, the inclination adjusting apparatus **400** is returned to the initial position as shown in FIG. **26**. Thereafter, at step S28, the adjusting pawls **401** are returned to the initial position (horizontal position) by rotating the four microadjusters **421**. During the return operation, the adjustment is effected such that the image point of the light reflected from the parallel plate **431** comes to a predetermined position in the monitor. Thereafter, at step S29, the photo magnetic disc apparatus **100** is returned to the initial position, i.e., the first stage ST1. At step S30, the insertion member **330**, i.e., the glass cover "A" and the insertion prism **201** are removed from the photo magnetic disc apparatus **100**. Thereafter, at step S31, the photo magnetic disc apparatus **100** is removed from the optical disc apparatus mounting apparatus **500**. Thus, the adjustment of the inclination of the objective lens **150** of the photo magnetic disc apparatus **100** is completed.

As can be understood from the foregoing, according to the inclination adjusting method as shown in FIGS. **22** and **23**, the inclination angle of the objective lens **150** is determined in accordance with the distortion of the interference fringes B to incline the objective lens **150** by the inclination angle thus determined, without changing the inclination angle of the adjusting pawls **401** while observing the distortion of the interference fringes B. The inclination angle can be detected

by the displacement of the image point in the monitor. In the case that the inclination of the objective lens **150** which is made of a single glass mold lens with opposite aspheric lens surfaces as used in the illustrated embodiments is adjusted by an inclined supporting surface, the deviation ϵ of the image point corresponding to the value of the inclination to be adjusted to eliminate the coma is large, thus resulting in an increased displacement of the image point in the monitor. Namely, there is a relatively large displacement of the image point with respect to the magnitude of the coma to be eliminated, so that the adjustment of the inclination angle can be easily effected.

In this embodiment, the objective lens **150** is held between the lens holder **151** which is biased towards the adjusting pawls **401** whose inclination angle has been adjusted and the adjusting pawls **401**, so that the objective lens **150** is rotated and displaced on the supporting surface **152** of the lens holder **151**. Accordingly, the objective lens **150** can be smoothly inclined in accordance with the inclination of the adjusting pawls **401**, against the spring **154** provided between the lens holder **151** and the securing member **155**.

The inclination adjusting apparatus and method according to the present invention are not limited to those for the photo magnetic disc apparatus and can be applied to adjust the inclination of a lens in other optical instruments.

As can be seen from the foregoing, according to the lens inclination detecting apparatuses of the above first, second, forth, fifth, and sixth embodiments of the present invention, the coherent light which is emitted from the semi-conductor laser beam source **101** and transmitted through the objective lens **150** and the cover glass "A" can be introduced, at a point far from the objective lens **150** within the optical system of the optical data recording and reproducing apparatus **100**, to the optical system of the lens inclination detecting apparatus **200** by reflecting the coherent light at the hemispherical lens **202** or the concave mirror **240** to return the same to the optical system of the optical data recording and reproducing apparatus.

Moreover, according to the lens inclination detecting apparatus of the third embodiment of the present invention, the coherent light which is emitted from the He-Ne laser beam source **230** and transmitted through the objective lens **150** and the cover glass "A" can be introduced, at point far from the objective lens **150** within the optical system of the optical data recording and reproducing apparatus **100**, to the optical system of the lens inclination detecting apparatus **200** by reflecting the coherent light at the hemispherical lens **202** to return the same to the optical system of the optical data recording and reproducing apparatus.

In the lens inclination detecting apparatus **200**, as is above explained, the cover glass "A" and the hemispherical lens **202** (or the concave mirror **240**), both of which can be made small in size, are placed opposite the objective lens **150**, while an interference fringe optical system including the interference fringe observing portion **205** is located far from the position opposite to the objective lens **150**. This arrangement results in a large space opposite the objective lens **150** outside of the optical data recording and reproducing apparatus **150**. Accordingly, the inclination adjusting apparatus **400** can be positioned in the large space. Furthermore, the inclination of the objective lens **150** can be adjusted from a position at which the optical magnetic disc K is normally placed when the optical recording and reproducing apparatus **100** is used. In this adjustment operation, the adjusting pawls **401** of the inclination adjusting apparatus **400** are inserted between the cover glass "A" and the objective lens **150**. As a result, adjustment of the inclination of the objective lens **150** can be effectively carried out while observing interference fringes.

The elimination of coma by the adjustment of the inclination of the objective lens **150** will be discussed below, with reference to simulation results.

FIG. **35** shows the shape of the objective lens **150** which is in the form of a single lens having opposite aspheric surfaces and the glass cover "A" used in the simulations.

Numerical data of the objective lens **150** used in the simulations is as follows:

NA (numerical aperture)=0.55; focal length=3.3 mm; ω (angle of view)=1.7°; paraxial radius of curvature of the first lens surface=2.124 mm; paraxial radius of curvature of the second lens surface=−6.837 mm; lens thickness=2.180 mm; and, refractive index=1.53677.

Data for the glass cover "A" used in the simulation is as follows:

thickness=1.200 mm and refractive index=1.57346.

The aspheric surface of the objective lens **150** is defined by the following equation:

$$X=CxY^2/(1+(1-(1+K)\times C^2\times Y^2)^{1/2})+A_4\times Y^4+A_6\times Y^6+A_8\times Y^8\times A_{10}\times Y^{10}$$

wherein "X" designates the distance from the tangential plane W; "Y" the distance from the optical axis OX; and, "C" the curvature of the aspherical apex; respectively. The constant of cone K and the constants of the aspheric surface A_4, A_6, A_8, and A_{10} are as follows;

for the first lens surface,

$K=-0.4377$; $A_4=-0.7167\times10^{-3}$; $A_6=-0.6080\times10^{-4}$; $A_8=-0.1060\times10^{-4}$; and, $A_{10}=-0.2730\times10^{-5}$

and for the second lens surface,

$K=0.0000$; $A_4=0.1665\times10^{-1}$; $A_6=-0.3180\times10^{-2}$; $A_8=0.5060\times10^{-3}$; and, $A_{10}=-0.3960\times10^{-4}$

FIG. **36** shows the optical characteristics of the objective lens **150**, i.e., the spherical aberration, the sine condition, and the astigmatism. As can be seen from FIG. **36**, the objective lens **150** has the corrected sine condition, etc., and accordingly has little or no aberration.

FIG. **37** shows the wave aberration on the optical axis, that is represented by PV value (difference between the maximum value and the minimum value) when the inclination of the objective lens **150** with respect to the glass cover "A" is zero.

FIG. **38** shows the variation of the wave aberration which is represented by rms (root mean square) when the inclination of incident light with respect to the optical axis changes. As can be seen in FIGS. **37** and **38**, the objective lens **150** is an aplanatic lens having a corrected sine condition. If the incident light is inclined at about 1.5 degrees with respect to the optical axis, the wave aberration is smaller than ¼ of λ.

FIGS. **39** and **40** show the wave aberration when there is a manufacturing error in the objective lens **150**, i.e., when the first lens surface thereof is decentered from the optical axis by 10 μm in the vertical direction. FIGS. **39** and **40** correspond to FIGS. **37** and **38**, respectively. Namely, in FIGS. **39** and **40**, the wave aberration is represented by PV value and rms, respectively. As may be seen in FIGS. **39** and **40**, the manufacturing error of the objective lens **150** has a considerable influence on the wave aberration. In FIG. **39**, the wave aberration is 0.9 λ (PV value) .

FIGS. **41** and **42** show the wave aberration when the first lens surface is inclined at 4 minutes, as a manufacturing error of the objective lens **150**. In FIGS. **41** and **42**, the wave

aberration is represented by PV value and rms, respectively. As may be seen in FIGS. **41** and **42**, if the first lens surface of the objective lens **150** is inclined, there is a large wave aberration, similar to the case where the first lens surface is decentered. The tendency of the wave aberration in FIGS. **41** and **42** is similar to that in FIGS. **39** and **40**. Such a tendency occurs in a lens having a corrected sine condition.

FIGS. **43** and **44** show the wave aberration when the objective lens **15** fails to be located at a correct position. Namely, the objective lens **150** is inclined at an angle of 25 minutes with respect to the glass cover "A". In FIGS. **43** and **44**, the wave aberration is represented by PV value and rms, respectively. As can be seen in FIG. **43**, a coma occurs when the objective lens **150** is inclined with respect to the glass cover "A". The wave aberration in FIG. **43** is identical in magnitude to that in FIG. **39** or **41** and is symmetrical with respect to the optical axis. Moreover, since the incident light upon the objective lens **150** is inclined with respect thereto, the wave aberration by rms value with respect to the incident angle is not symmetrical with respect to the optical axis, as shown in FIG. **44**.

FIGS. **45** and **46** show the wave aberration which is caused when the first lens surface of the objective lens **150** is decentered by 10 μm from the optical axis in the vertical direction and which is corrected by inclining the objective lens **150** at an angle of 24.6 minutes with respect to the glass cover "A". In FIGS. **45** and **46**, the wave aberration is represented by PV value and rms, respectively. As can be seen in FIGS. **45** and **46**, the wave aberration due to the manufacturing error (assembly error) of the objective lens **150** can be substantially eliminated by inclining the objective lens **150** with respect to the glass cover. In FIG. **45**, although a slight wave aberration remains, since the slight wave aberration arises mainly due to the defocus (out of focus) component, substantially no deterioration of the image occurs.

In FIG. **46**, the minimum wave aberration occurs approximately at −0.5 degrees, and the wave aberration by rms is asymmetric with respect to the ordinate. This is because the light incident upon the objective lens **150** is inclined relative to the optical axis by the inclination of the objective lens **150**. In the adjustment to eliminate the wave aberration, since the adjustment is effected such that the wave aberration on the optical axis is reduced to be a predetermined value, there is no problem with the asymmetrical wave aberration with respect to the ordinate.

It can be understood from the simulations mentioned above that the wave aberration can be varied by the inclination of the objective lens **150** with respect to the glass cover "A" (FIGS. **43** and **44**). Therefore, even if there is a wave aberration caused by the first lens surface of the objective lens **150** decentered from the optical axis due to a manufacturing error as seen in FIGS. **39** and **40**, the wave aberration can be eliminated by inclining the objective lens **150** (FIGS. **45** and **46**).

If the first lens surface is inclined by the manufacturing error (FIGS. **41** and **42**), the wave aberration due to the inclination of the first lens surface can be compensated by varying the inclination of the objective lens **150**. The same would be true for the second lens surface of the objective lens **150**. Furthermore, a wave aberration caused by a manufacturing error of an optical element (for example, collimating lens) other than the objective lens **150** or by a positioning error of any optical elements, etc., can also be corrected.

Namely, the coma (wave aberration) which is produced in the optical system can be cancelled by the coma (wave aberration) that is identical in magnitude and opposite in direction to the first-mentioned coma and that is positively produced in the optical system by the adjustment of the relative inclination of the objective lens and the glass cover.

Consequently, the wave aberration (coma) produced in the optical system can be eliminated merely by adjusting the inclination angle of the objective lens which is located at the terminal stage of the optical system **150** without increasing the tolerance of the optical elements of the optical system. Furthermore, since it is only necessary to adjust the inclination angle of the objective lens in order to eliminate the aberration, the assembling operation and the adjusting operation of the optical system are simplified and require less time.

As can be understood from the above discussion, according to the present invention, not only can the adjustment of the inclination of the objective lens with respect to the recording medium be performed from the side of the objective lens opposite to the recording medium, but also there is no restriction to the mounting mechanism of the objective lens. Moreover, in the supporting apparatus of the objective lens according to the present invention, the number of the elements of the optical pick-up can be reduced, thus resulting in a light-weight pick-up and a fast tracking operation.

In the optical data recording and reproducing apparatus of the present invention, the fine adjustment of the objective lens relative to the recording medium can be executed to eliminate the tracking error and focusing error which would be otherwise caused upon recording and reproducing data on and from the recording medium. Namely, the supporting member (lens holder) of the objective lens is elastically connected to the securing member through an elastic means, such as a spring. Accordingly, the objective lens is slightly displaceable through the elastic deformation of the elastic means, for example, when the electromagnetic force is applied. In the optical data recording and reproducing apparatus, if the objective lens is disposed on the movable lens holder and is engaged at the upper surface thereof by the adjusting member to adjust the inclination of the objective lens with respect to the lens holder, it is impossible to smoothly move the objective lens with respect to the lens holder since the lens holder is displaced by the deformation of the spring which is caused when the lens holder is pressed. However, in the positioning apparatus of the present invention, the inclination of the objective lens can be easily and smoothly adjusted with respect to the lens holder.

Furthermore, in the adjusting method to correct the coma according to the present invention, not only can the optical elements having less manufacturing accuracy than the prior art be used, but also the assembling operation of the optical elements can be simplified.

Although the invention has been described with reference to particular means, materials and embodiments, it is to be understood that the invention is not limited to the particulars disclosed and extends to all equivalents within the scope of the claims.

We claim:

1. A detecting apparatus for detecting an inclination of an objective lens relative to a reference surface, said objective lens being part of an optical data recording and reproducing apparatus in which data is optically recorded on and reproduced from a recording medium which is placed parallel to said reference surface, comprising;

a transparent parallel plate which is opposite said objective lens, parallel to said reference surface, and made of a material that is substantially optically equivalent to a transparent material of said recording medium;

reflecting means for reflecting a coherent light which has passed through said objective lens and said transparent parallel plate back towards said transparent parallel plate and said objective lens;

beam splitting means for splitting said coherent light into a first beam and a second beam;

wavefront rotating means for rotating said first beam and said second beam about an optical axis in a manner such that said first beam and said second beam are rotated through 180 degrees with respect to one another; and,

means for superposing said first beam and said second beam to produce an optical interference.

2. The detecting apparatus of claim **1**, wherein said reflecting means, said beam splitting means, said wavefront rotating means, and said superposing means comprise a single hemispherical lens positioned adjacent to said transparent parallel plate on the opposite side of said objective lens.

3. The detecting apparatus of claim **2**, wherein said hemispherical lens comprises a flat reflecting surface and a spherical reflecting surface whose center of curvature is located on said flat reflecting surface, and wherein said hemispherical lens splits said coherent light by reflecting segments of said coherent light at said flat reflecting surface and said spherical reflecting surface, thereby creating said first beam and said second beam, respectively.

4. The detecting apparatus of claim **3**, further comprising:

an interference fringe observing portion for observing interference fringes which are produced by said superposing means, and a prism for introducing said first beam and said second beam, which have been reflected by said hemispherical lens toward said objective lens and superposed with each other by said hemispherical lens, to said interference fringe observing portion from an optical path of an optical system of said optical data recording and reproducing apparatus, wherein said prism is an insertion prism which is inserted into said optical path so as to split said first and said second beams from said optical path.

5. The detecting apparatus of claim **3**, further comprising:

an interference fringe observing portion for observing interference fringes which are produced by said superposing means, and a beam splitter for introducing said first beam and said second beam, which have been reflected by said hemispherical lens toward said objective lens and superposed with each other by said hemispherical lens, to said interference fringe observing portion from an optical path of an optical system of said optical data recording and reproducing apparatus, wherein said beam splitter introduces said first and second beams, which have been split from said optical path to be emitted to the outside of said optical data recording and reproducing apparatus, to said interference fringe observing portion.

6. The detecting apparatus of claim **3**, wherein said recording medium is a photo magnetic disc, and wherein said flat reflecting surface corresponds to a data recording surface of said photo magnetic disc, and further wherein said objective lens is adjusted in a manner such that a converging point of said objective lens is coincident with said center of curvature of said spherical reflecting surface.

7. The detecting apparatus of claim **3**, further comprising:

an alignment detector for detecting a positional relationship between a convergence point of light converged by said objective lens and said flat reflecting surface.

8. The detecting apparatus of claim **7**, wherein said coherent light reflected by said reflecting means and transmitted through a signal detecting system of said optical data recording and reproducing apparatus is introduced to said alignment detector from said optical data recording and reproducing apparatus.

9. The detecting apparatus of claim **8**, further comprising:

an image point observing portion for observing a coma component contained in said coherent light reflected by said reflecting means, wherein said coherent light reflected by said reflecting means and transmitted through said signal detecting system is introduced into said alignment detector.

10. The detecting apparatus of claim **1**, wherein said reflecting means is a concave mirror for reflecting said coherent light back towards said transparent parallel plate.

11. The detecting apparatus of claim **10**, wherein said beam splitting means is a half mirror for splitting coherent light, which has been reflected by said reflecting means and has passed through said objective lens and said transparent parallel plate twice, into said first beam and said second beam.

12. The detecting apparatus of claim **11**, wherein said wavefront rotating means comprises two Dove prisms positioned in such a manner that, when said first beam and said second beam split by said half mirror pass through said two Dove prisms, said beams are rotated through 180 degrees with respect to one another.

13. The detecting apparatus of claim **11**, wherein said wavefront rotating means includes a corner-cube prism for rotating a wavefront of one of said first beam or of said second beam about said optical axis by 180 degrees.

14. The detecting apparatus of claim **11**, wherein said wavefront rotating means includes a condenser lens and a reflecting mirror for rotating said first beam or said second beam about said optical axis by 180 degrees, wherein said reflecting mirror is positioned at a converging point of said condenser lens.

15. The detecting apparatus of claim **1**, further comprising:

an interference fringe observing portion for observing interference fringes which are produced by said superposing means.

16. The detecting apparatus of claim **15**, wherein said coherent light, which has passed through said superposing means said optical system of said optical data recording and reproducing apparatus, and has proceeded outside of said optical data recording and reproducing apparatus, is introduced to said interference fringe observing portion.

17. The detecting apparatus of claim **15**, wherein said optical data recording and reproducing apparatus includes a semiconductor laser light source which emits said coherent light.

18. The detecting apparatus of claim **17**, wherein said detecting apparatus further includes a He-Ne lapser source for introducing a visible light portion of a spectrum of said coherent light to said objective lens.

19. The detecting apparatus of claim **17**, further comprising means for introducing said coherent light emitted by said semiconductor laser light source into said objective lens, for reflecting said coherent light by a half-mirror within an optical path of an optical system of said optical data recording and reproducing apparatus, said coherent light having been reflected by said reflecting means and having twice passed through said objective lens and said transparent parallel plate, and for introducing said coherent light reflected by said half-mirror into said interference fringe observing portion.

20. The detecting apparatus of claim 19, wherein said second beam splitting means is a prism, which is positioned within a parallel bundle of rays of said optical system, for preventing said coherent light from returning to said semiconductor laser light source.

21. The detecting apparatus of claim 19, wherein said second beam splitting means comprises a wave plate for enabling selecting a polarization direction of said coherent light emitted from said semiconductor laser light source.

22. A lens supporting apparatus which supports an objective lens of an optical data recording and reproducing apparatus in which data is optically recorded on and reproduced from a recording medium, which is placed parallel to a reference surface, comprising:

an oblique annular lens supporting surface inclined relative to a peripheral edge of said objective lens for supporting said objective lens in a manner such that an inclination of said objective lens can be adjusted with respect to said reference surface;

means for moving said lens supporting surface to bring a peripheral edge of said objective lens into contact with an adjusting device to thereby move said objective lens along said lens supporting surface in order to vary an inclination of said objective lens relative to said reference surface.

23. The lens supporting apparatus of claim 22, further comprising:

a lens supporting member connected to a securing portion of said optical data recording and reproducing apparatus, said lens supporting surface formed on said lens supporting member.

24. The lens supporting apparatus of claim 23, said moving means comprises a solenoid coil provided on said lens supporting member, and a magnet provided on said securing portion, and wherein said lens supporting member is moved by energizing said solenoid coil.

25. The lens supporting apparatus of claim 23, wherein said objective lens is provided on a peripheral edge thereof with a flange supported by said lens supporting surface.

26. The lens supporting apparatus of claim 25, wherein said peripheral edge of said objective lens is integrally provided with a plurality of cylindrical portions extending parallel to said optical axis, said cylindrical portions being supported at one of ends thereof by said lens supporting surface.

27. The lens supporting apparatus of claim 26, wherein a rotational center of said objective lens with respect to said lens supporting surface is positioned by said plurality of said cylindrical portions to make said rotational center substantially coincident with a rear principal point of said objective lens.

28. The lens supporting apparatus of claim 22, wherein said lens supporting surface is tapered in a direction away from a position at which said recording medium is placed.

29. The lens supporting apparatus of claim 22, wherein said lens supporting surface is tapered in a direction towards a position at which said recording medium is placed, and wherein said tapered lens supporting surface is formed in a manner such that said objective lens can be rotated about a center which is substantially coincident with a rear principal point of said objective lens.

30. The lens supporting apparatus of claim 22, wherein said lens supporting surface is a conical section.

31. The lens supporting apparatus of claim 22, wherein said lens supporting surface is a spherical section.

32. The lens supporting apparatus of claim 22, wherein said objective lens is rotatable about a rotational center thereof, said rotational center being substantially coincident with a rear principal point of said objective lens.

33. A lens supporting apparatus for supporting an objective lens of an optical data recording and reproducing apparatus in which data is optically recorded on and reproduced from a recording medium placed parallel to a reference surface, comprising:

an annular supporting portion for supporting said objective lens;

a supported surface formed on said objective lens and supported on said annular supporting portion in a manner such that said supported surface can be moved on said annular supporting portion to be inclined relative to said reference surface; and

means for moving said annular supporting portion to bring a peripheral edge of said objective lens into contact with an adjusting device to thereby move said objective lens along said annular supporting portion in order to vary an inclination of said objective lens relative to said reference surface.

34. An inclination adjusting method for adjusting an inclination, relative to a reference surface, of an objective lens of an optical data recording and reproducing apparatus in which data is optically recorded on and reproduced from a recording medium which is positioned parallel to said reference surface, comprising:

a first step of positioning a lens supporting member which supports said objective lens at a predetermined position;

a second step of placing said objective lens on said lens supporting member;

a third step of adjusting said inclination of said objective lens while observing interference fringes to reduce a coma, said interference fringes being caused by an inclination of said objective lens relative to a transparent plate, said transparent plate being positioned parallel to said reference surface and made of a material that is substantially optically equivalent to said recording medium; and,

a fourth step of fixing said objective lens to said lens supporting member.

35. The inclination adjusting method of claim 34, wherein said second step further includes a step of introducing an adhesive, which solidifies when ultraviolet rays are applied thereto, between said objective lens and said lens supporting member, and wherein, in said fourth step, said objective lens is fixed to said lens supporting member by applying ultraviolet rays to said adhesive so as to solidify said adhesive.

36. The adjusting method of claim 34, wherein said lens placing step comprises positioning said objective lens relative to a sucking tube which holds said objective lens by a vacuum force and which places said objective lens on said lens supporting member by releasing the vacuum force.

37. A positioning apparatus which positions a lens relative to a lens supporting member, comprising:

a sucking tube which holds said lens by a vacuum force; and,

a guide portion which has a circular hole, an inner surface of said circular hole guiding said lens in a radial direction of said sucking tube so as to position said lens in said radial direction when said sucking tube is inserted into said circular hole, wherein said circular hole is formed in a manner such that a diameter of said circular hole is larger than a diameter of said sucking tube and substantially corresponds to a diameter of said lens.

38. The positioning apparatus of claim 37, wherein said guide portion further includes a tapered portion having a conical shape for introducing said sucking tube into said circular hole, and an adhesive applying member provided in an outer circumferential portion of said guide portion for applying an adhesive to secure said lens, whose position relative to said lens supporting member has been adjusted, to said lens supporting member.

39. The positioning apparatus of claim 38, further comprising a plurality of said adhesive applying member, said plurality of said adhesive applying members being provided at equal intervals around a center axis of said guiding portion.

40. An inclination adjusting apparatus, comprising:

a body;

an oblique annular lens supporting surface which is inclined relative to a peripheral edge of an objective lens and which supports said objective lens in a manner such that said objective lens can be inclined with respect to said lens supporting surface;

a rotational portion which is rotatably supported by said body in a manner such that a rotational center of said rotational portion is positioned in the vicinity of a rotational center of said lens when said lens is inclined with respect to said lens supporting surface; and

an adjusting pawl which is supported by said rotational portion for engaging with a peripheral edge of said lens;

wherein said rotational portion comprises a rotatable member having a spherical surface to which said adjusting pawl is secured, and a recess having a spherical surface formed in said body to slidably support said rotatable member having a spherical surface.

41. The inclination adjusting apparatus of claim 40, wherein said adjusting pawl is provided with a recess with which an upper corner of said peripheral edge of said lens can be engaged.

42. The inclination adjusting apparatus of claim 40, wherein said rotational portion comprises a passage formed on said recess having a spherical surface; a pressed member which passes through said passage to be connected to said rotatable member having a spherical surface; and, a microadjuster which abuts against said pressed member in a plurality of directions to move said pressed member, wherein said rotatable member having a spherical surface is rotated when said pressed member is moved by operating said microadjuster.

43. The inclination adjusting apparatus of claim 42, wherein a distance between a rotational center of said rotatable member having a spherical surface and a contacting portion of said microadjuster which abuts against said pressed member is set larger than a distance between a peripheral edge of said lens and a rotational center of said lens.

44. The inclination adjusting apparatus of claim 40, wherein said rotational portion comprises a passage formed on said recess having a spherical surface, and a rod which passes through said passage and is connected to said rotatable member having a spherical surface, and wherein said rotatable member having a spherical surface is rotated by moving said rod.

45. The inclination adjusting apparatus of claim 40, further comprising a detecting means for detecting state in which said adjusting pawl is located at a reference position.

46. The inclination adjusting apparatus of claim 45, wherein said detecting means comprises a transparent glass sheet that is parallel with a reference plate of said adjusting pawl, and wherein said adjusting pawl is initially positioned with respect to said lens based upon a bundle of rays reflected on said transparent glass sheet.

47. An inclination adjusting method for adjusting an inclination of a lens which is supported on an oblique annular lens supporting surface that is inclined relative to a peripheral edge of said lens, wherein said lens is positioned by an inclination adjusting member on said oblique annular lens supporting surface to incline said lens at a predetermined angle, comprising:

determining an angle at which said lens is to be inclined;

inclining said inclination adjusting member at said angle;

contacting said inclination adjusting member with said lens; and

displacing said oblique annular lens supporting surface in a direction toward said inclination adjusting member to abut said lens against said inclination adjusting member.

48. An inclination adjusting apparatus which adjusts an inclination of a lens, comprising:

a lens supporting member having an oblique annular supporting surface which supports said lens in a manner such that said lens can be inclined with respect to said supporting surface;

an inclination adjusting member which comes into contact with a surface of said lens, the surface being located opposite to said lens supporting member;

alignment detector for defining an inclination of said inclination adjusting member; and,

biasing means for biasing said lens supporting member towards said inclination adjusting member while bringing a part of said inclination adjusting member into contact with said lens to thereby abut said lens against said inclination adjusting member.

49. The inclination adjusting apparatus of claim 48, wherein said lens supporting member is connected to a securing portion of an optical data recording and reproducing apparatus through a biasing means in a manner such that said lens supporting member can be moved with respect to said securing portion.

50. The inclination adjusting apparatus of claim 49, wherein said biasing means comprises a solenoid coil provided on said lens supporting member, and a magnet provided on said securing portion, so that when said solenoid coil is energized, said lens supporting member is moved to incline said lens to thereby abut said lens against said inclination adjusting member.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 5,553,052
DATED : September 3, 1996
INVENTOR(S) : M. OONO et al.

It is certified that error appears in the above-indentified patent and that said Letters Patent is hereby corrected as shown below:

On cover page, in item [22], change "Aug. 2, 1994" to ---Mar. 2, 1994---.

At column 32, line 54 (claim 2, line 18), change "lapser" to ---laser---.

At column 36, line 5 (claim 45, line 2), delete "a" (first occurrence).

At column 36, line 5 (claim 45, line 2), before "state" insert --a---.

Signed and Sealed this

Twenty-fifth Day of February, 1997

Attest:

BRUCE LEHMAN

Attesting Officer

Commissioner of Patents and Trademarks

US005528428A

United States Patent [19]

Ohtake et al.

[11] **Patent Number: 5,528,428**

[45] **Date of Patent: Jun. 18, 1996**

[54] **COMPACT WIDE-ANGLE OBJECTIVE LENS**

[75] Inventors: **Motoyuki Ohtake**, Ohmiya; **Motohisa Mori**, Yokohama, both of Japan

[73] Assignee: **Nikon Corporation**, Tokyo, Japan

[21] Appl. No.: **173,084**

[22] Filed: **Dec. 27, 1993**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 80,971, Jun. 24, 1993, abandoned, which is a continuation of Ser. No. 973,614, Nov. 9, 1992, abandoned.

[30] **Foreign Application Priority Data**

Nov. 13, 1991 [JP] Japan 3-297444
May 13, 1993 [JP] Japan 5-111289

[51] **Int. Cl.**[6] **G02B 15/14**; G02B 9/00

[52] **U.S. Cl.** **359/684**; 359/691; 359/740; 359/770

[58] **Field of Search** 359/740, 746, 359/770, 684, 691

[56] **References Cited**

FOREIGN PATENT DOCUMENTS

54-70826 6/1979 Japan .

0279815 12/1986 Japan 359/740

Primary Examiner—George Y. Epps
Assistant Examiner—Evelyn A. Lester
Attorney, Agent, or Firm—Shapiro and Shapiro

[57] **ABSTRACT**

A wide-angle objective lens is comprised, from the object side, of a first lens component which is a negative meniscus lens having its convex surface facing the object side, a second lens component which is a meniscus lens having its convex surface facing the object side and having positive refractive power, a third lens component which is a cemented meniscus lens comprising a positive lens and a negative lens cemented together and having its convex surface facing the object side and having positive refractive power, a fourth lens component which is a positive meniscus lens having its concave surface facing the object side, and a fifth lens component which is a negative meniscus lens having its concave surface facing the object side. The wide-angle objective lens has a stop disposed between the second lens component and third lens component, and satisfies predetermined conditions.

22 Claims, 10 Drawing Sheets

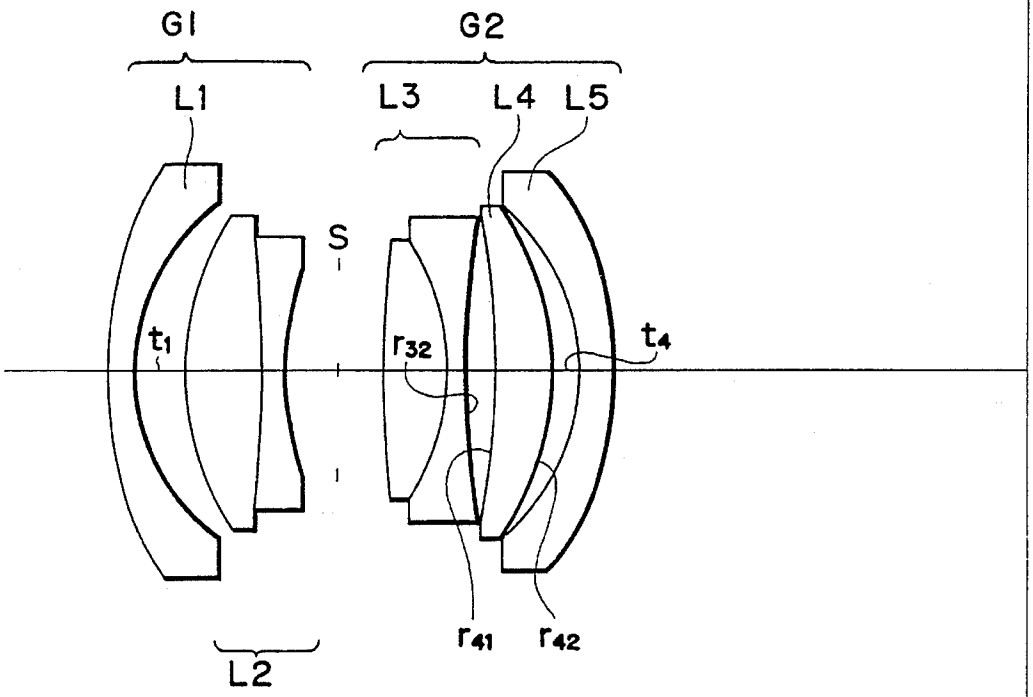


FIG. 1

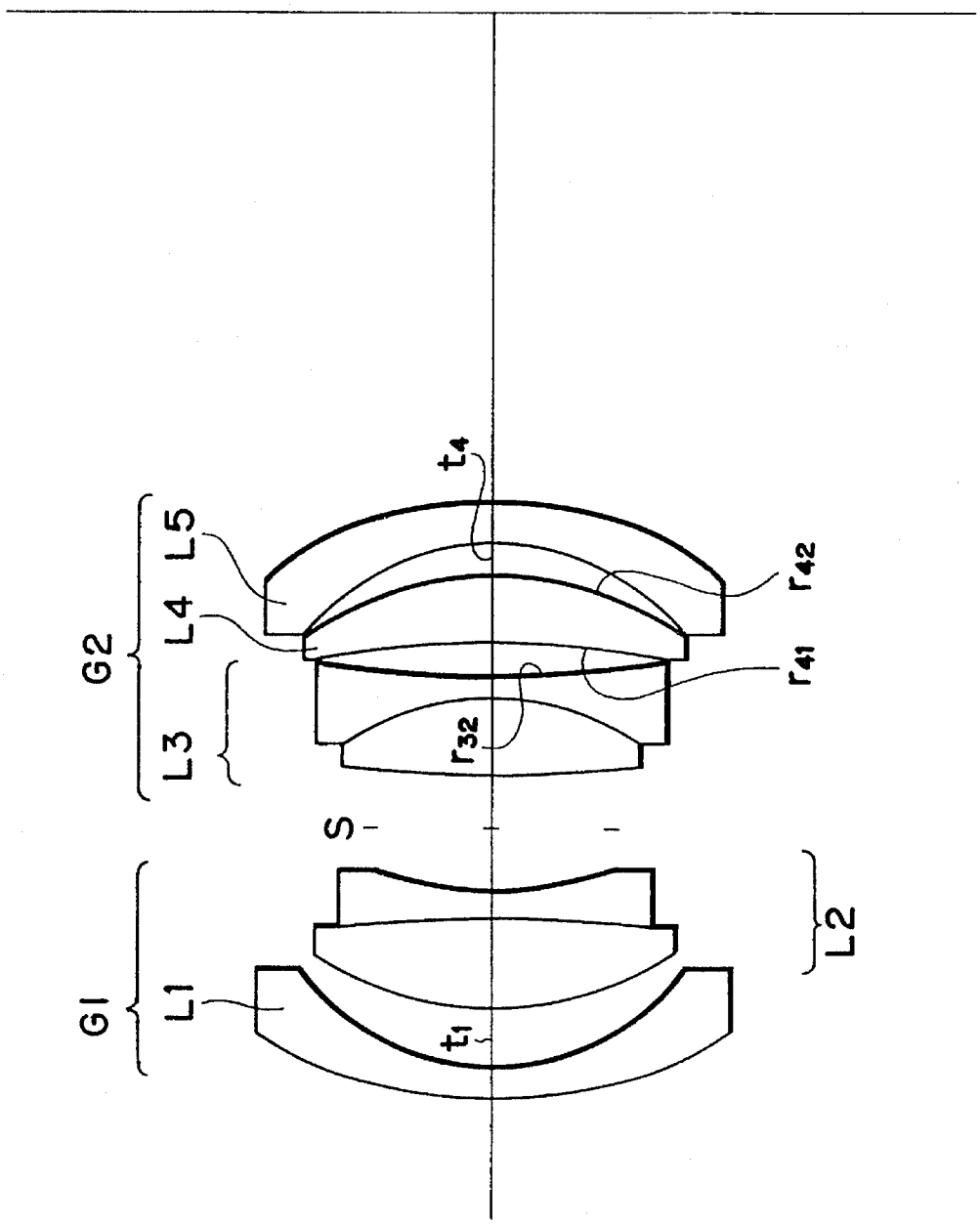


FIG. 2

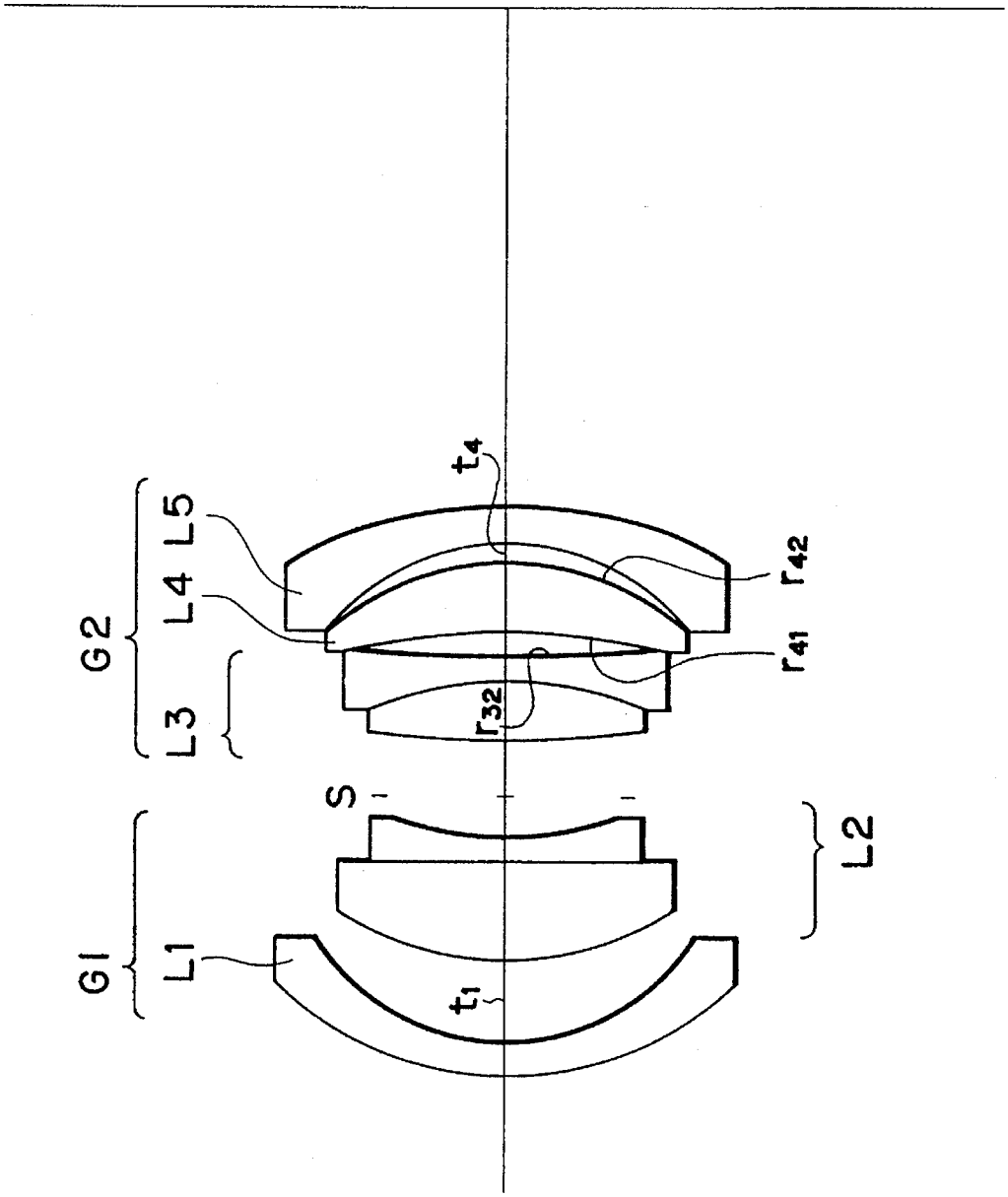


FIG. 3

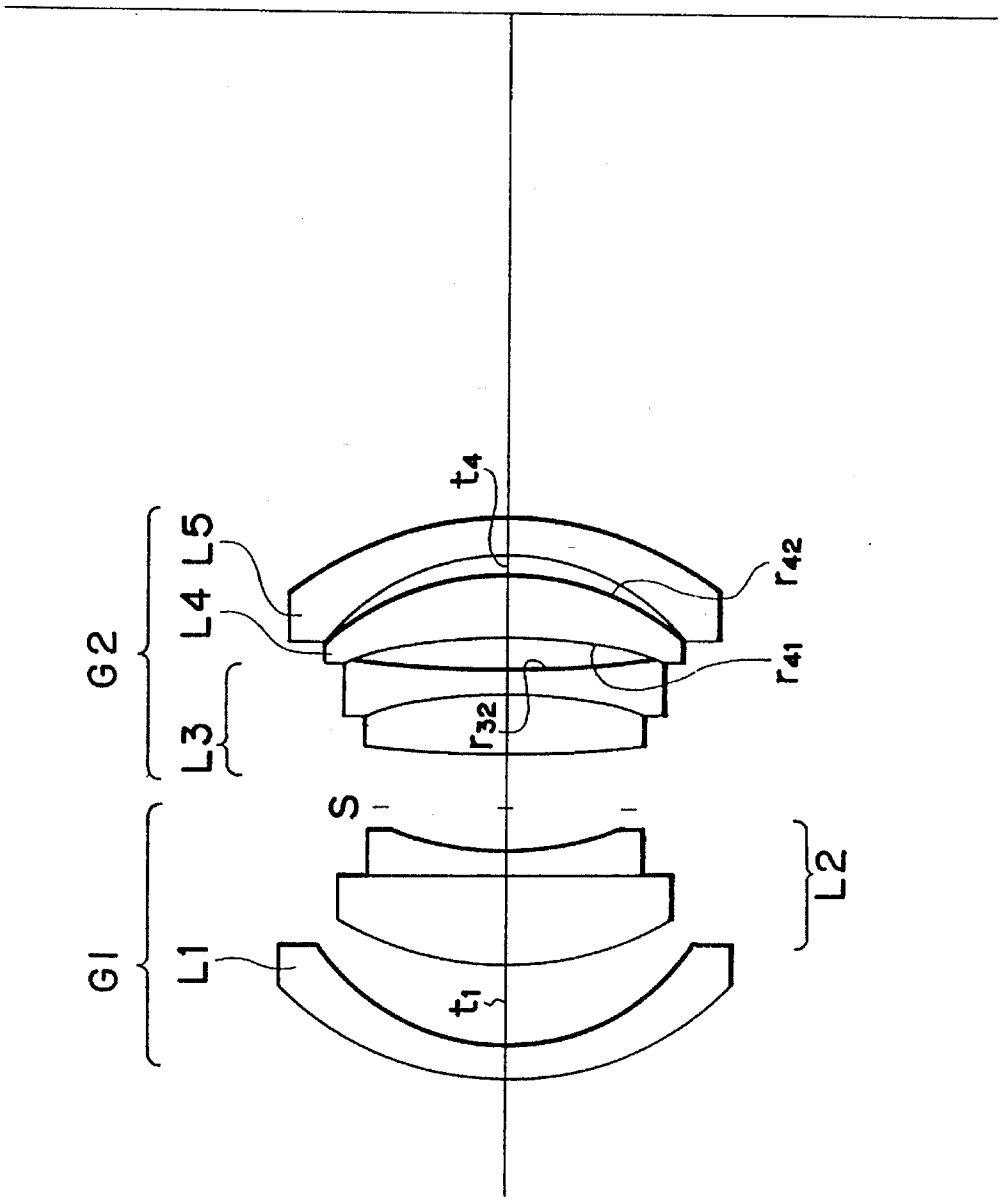


FIG. 4

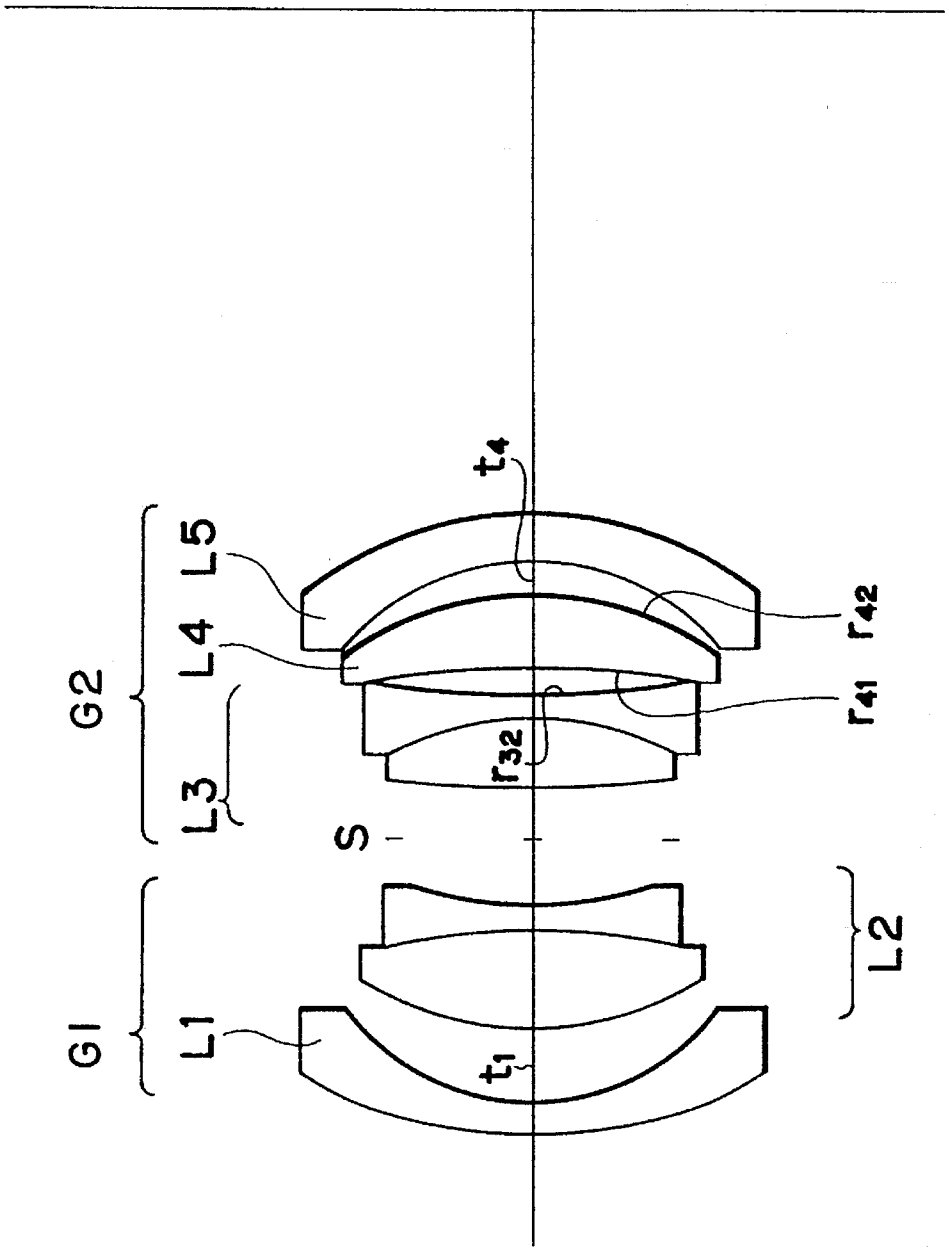


FIG. 5

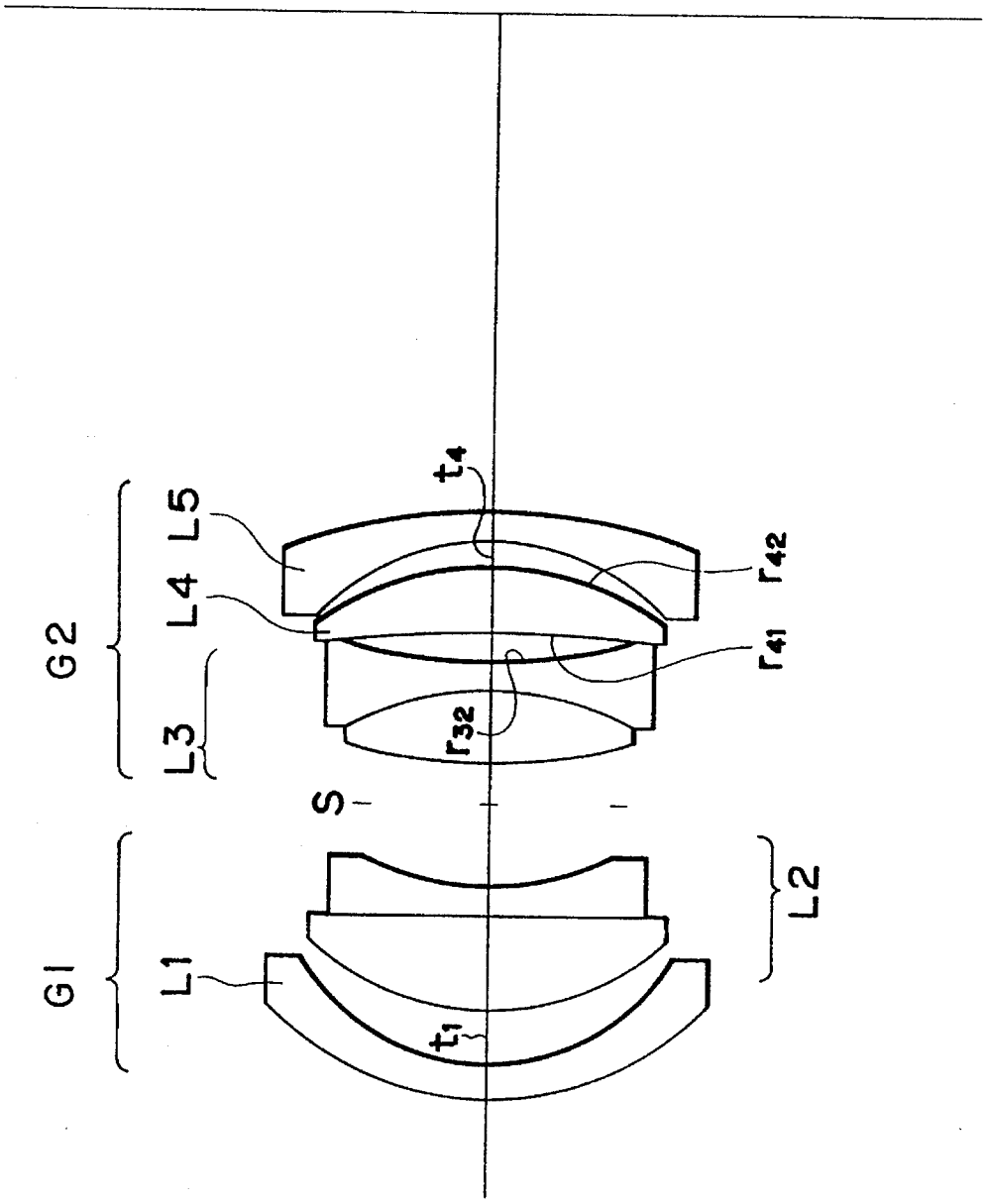


FIG. 6

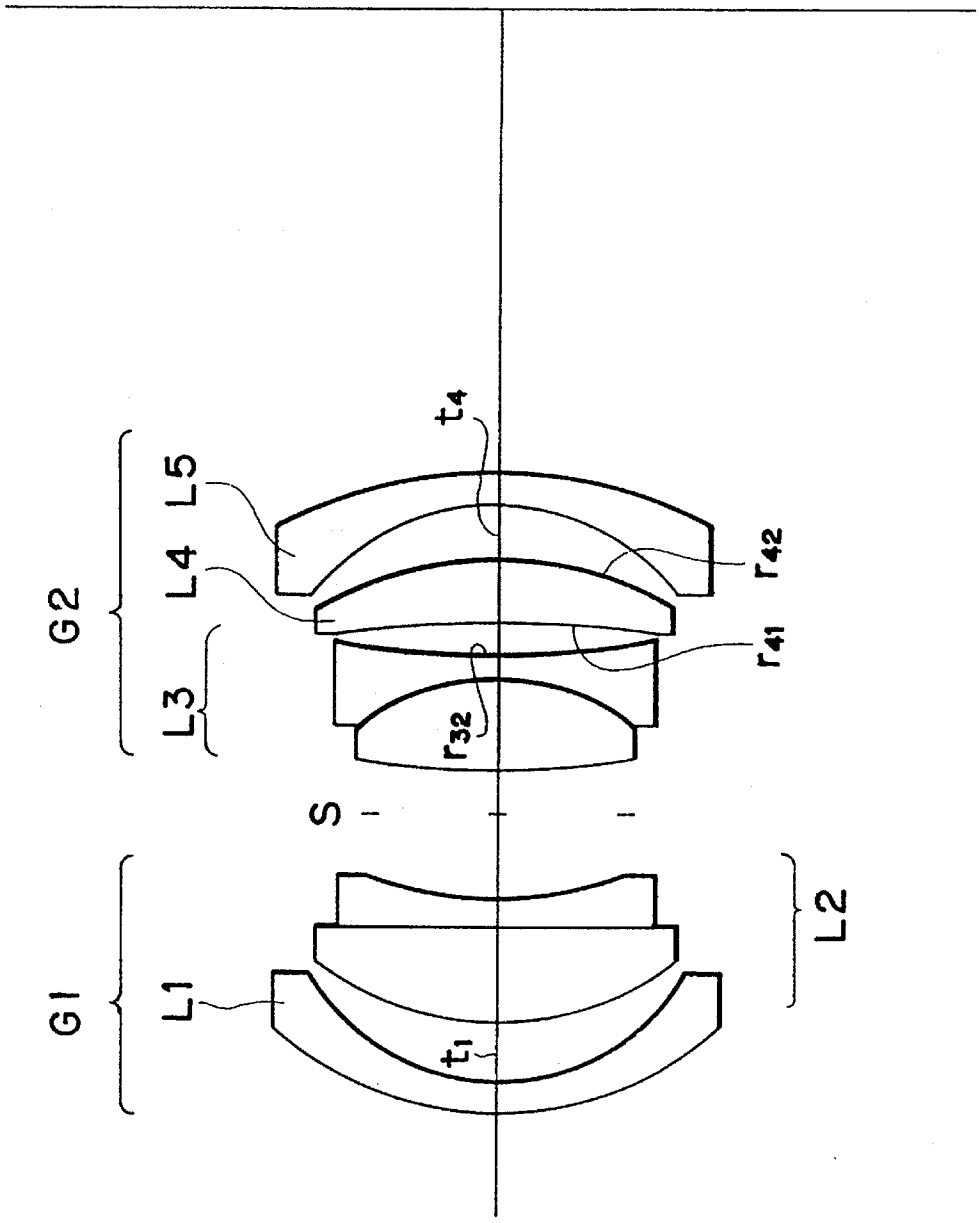


FIG. 7

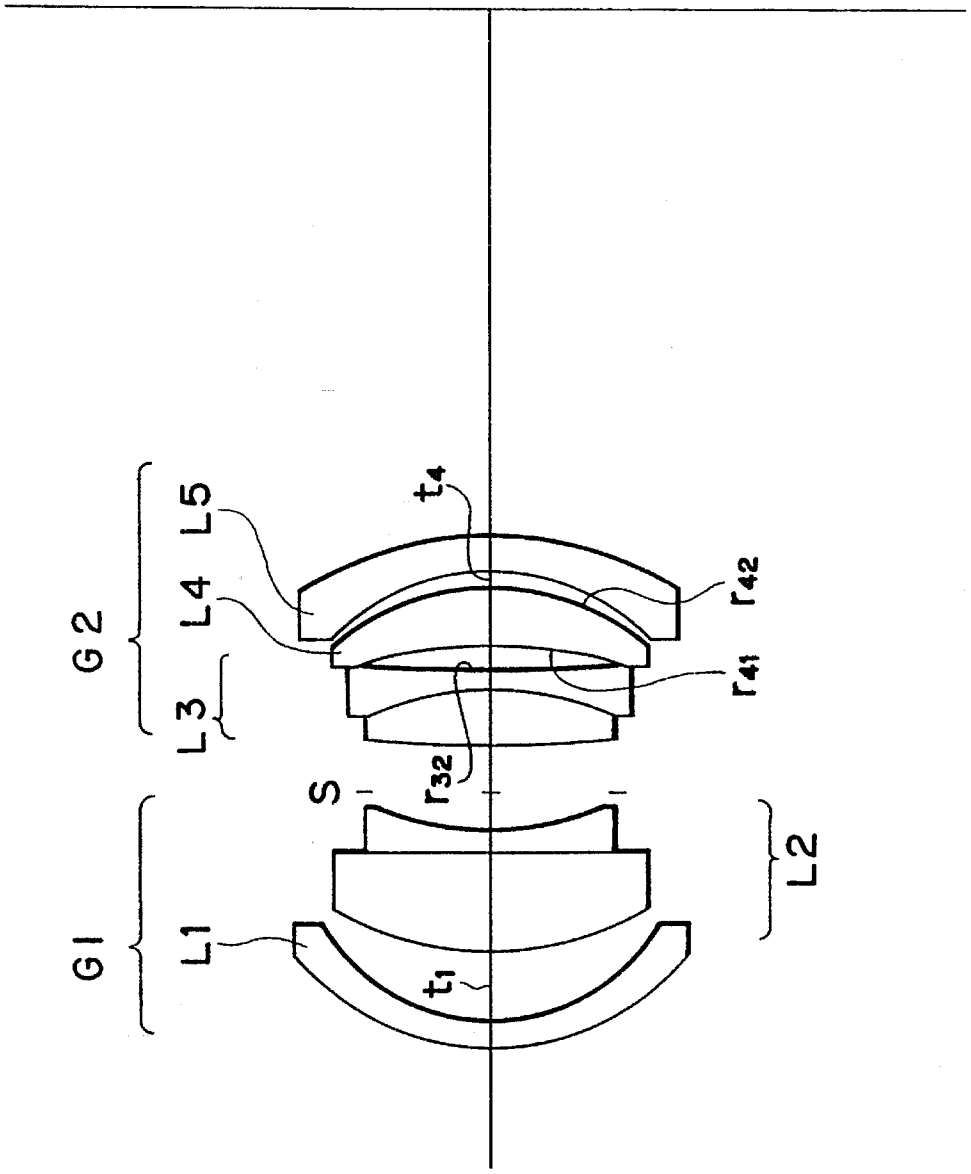


FIG. 8

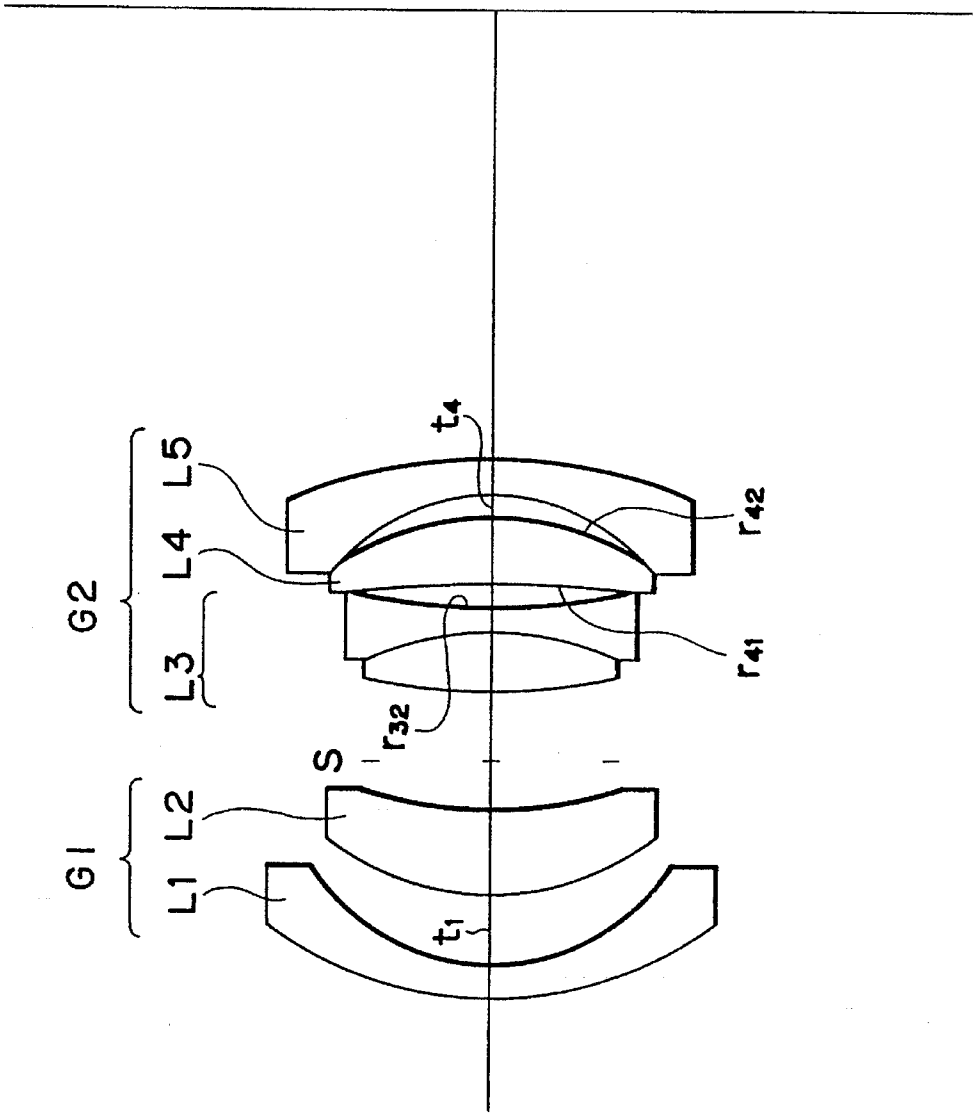


FIG. 9A

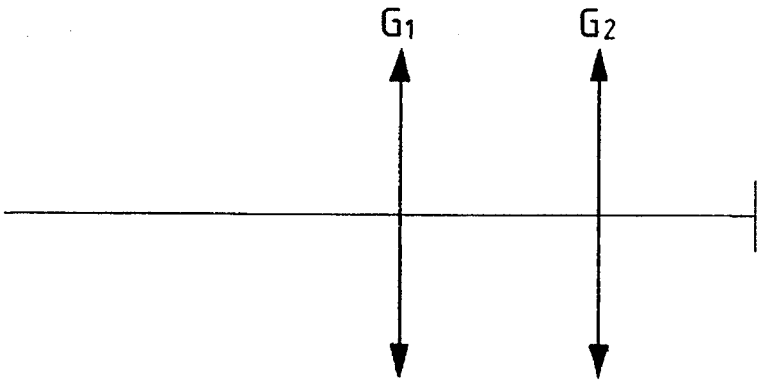


FIG. 9B

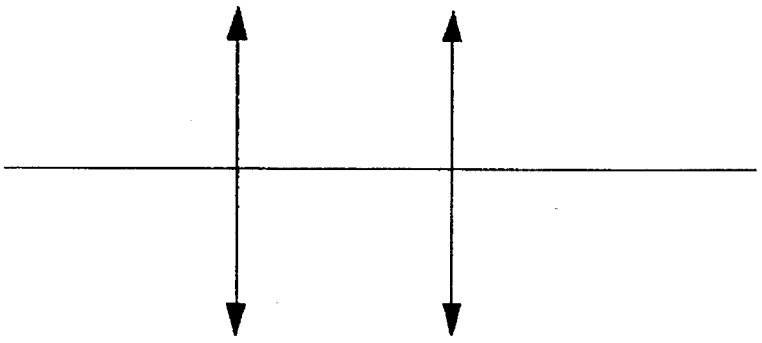


FIG. 10

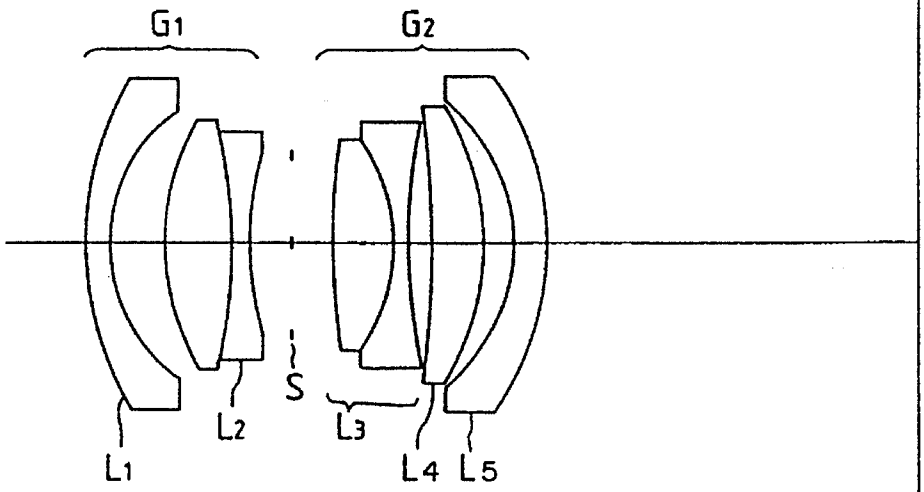
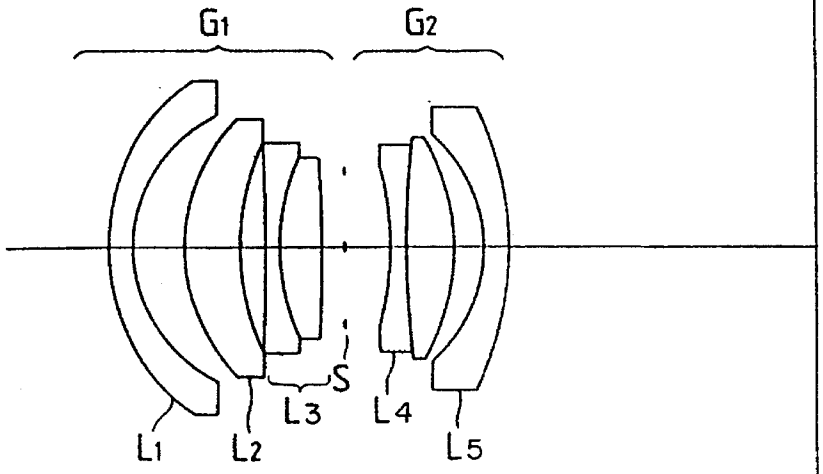


FIG. 11



COMPACT WIDE-ANGLE OBJECTIVE LENS

This is a continuation-in-part of application Ser. No. 080,971 filed Jun. 24, 1993, which is a continuation of application Ser. No. 973,614 filed Nov. 9, 1992, both now abandoned.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to a wide-angle objective lens for cameras, and particularly to a compact, large aperture, wide-angle objective lens suitable for use in a 35 mm format lens shutter camera or a 35 mm format camera with a range finder.

2. Related Background Art

Biogon type, abiogon type, etc. are known as symmetrical type wide-angle lenses having a negative, positive, negative refractive power distribution. The biogon type wide-angle lens can cover a wide angle of view and can make distortion small. Also, its refractive power distribution is a negative, positive, negative refractive power distribution and therefore, as compared with a symmetrical type wide-angle lens of a positive, negative, positive refractive power distribution such as a topogon type wide-angle lens, the biogon type wide-angle lens has an advantage that the quantity of marginal light is great and moreover the diameters of fore and rear lenses can be made small.

Various wide-angle lenses of negative, positive, negative construction are known as the developed types of the biogon type wide-angle lens. They are known, for example, from Japanese Utility Model Publication No. 43-30782, U.S. Pat. No. 3,829,198, U.S. Pat. No. 4,211,472, Japanese Laid-Open Patent Application No. 56-140311, etc.

Examples in which the F-number is made small are shown in Japanese Utility Model Publication No. 43-30782 and U.S. Pat. No. 4,211,472 and examples which comprise a small number of lens components are shown in U.S. Pat. No. 3,829,198 and Japanese Laid-Open Patent Application No. 56-140311.

However, the biogon type wide-angle lens generally suffers from the disadvantages that the total thickness of the lens system (the thickness from that surface of the lens which is most adjacent (nearest) to the object side to that surface of the lens which is most adjacent to the image side) is great and that the F-number is large.

In the lens systems shown in U.S. Pat. No. 3,829,198 and Japanese Laid-Open Patent Application No. 56-140311, the number of lens components is small but the correction of spherical aberration is deficient and therefore, the F-number cannot provide a large aperture. They also have suffered from the disadvantages that the total thickness of the lens system is very great and that the spacing between the front unit and the rear unit of the lens system in which a diaphragm is placed is too narrow and therefore great limitations must be imposed upon the structure of an aperture stop, a shutter unit, a lens barrel, etc.

In the lens system shown in Japanese Utility Model Publication No. 43-30782, the total thickness of the lens system is very great. Moreover the diameters of the fore and rear lenses are great. This is against the desire to make the lens system compact. In the lens system shown in U.S. Pat. No. 4,211,472, the F-number provides a large aperture but the total thickness of the lens system is great, and this is against the desire to make the lens compact. Also, the shape of coma is bad and therefore, if the lens system is left in its original condition, it is necessary to apply a limitation to the light beam and the quantity of marginal light becomes very small, and this has not been preferable.

Further, in the lens system of Japanese Laid-Open Patent Application No. 54-70826, the symmetry of the refractive power distributions on both sides of a stop is destroyed, the air space between a negative lens component disposed on the object side and a positive lens component and the air space between the positive lens component and a negative lens component disposed on the image side are both are widened, and a wide-angle of view and a large aperture can be obtained. However, this lens system has the disadvantages that the great air spaces result in a great total thickness of the lens system and that the height of a ray of light passing through the lens component remote from the stop becomes far from the optical axis and therefore the effective diameter of each lens becomes large.

Further, Gaussian type, Topogon type, etc. are known as symmetrical type lenses having positive, negative, positive refractive power distribution.

The positive, negative, positive symmetrical type lens is advantageous for large aperture, but cannot cover a wide-angle of view, and conversely, the aforedescribed negative, positive, negative symmetrical lens can cover a wide-angle of view, but has the disadvantage for large aperture.

In the positive, negative, positive symmetrical type lens, the off-axis light beam passing through the lens component remote from the stop passes a location remote from the optical axis and therefore, when an attempt is made to achieve a wide-angle, the effective diameters of the front and rear lenses become large, and this results in the bulkiness of the optical system. Accordingly, when an attempt is made to achieve a wide-angle, a negative, positive, negative symmetrical type lens is desirable.

Thus, it has been difficult to provide an optical system which satisfies the condition that a wide-angle can be achieved by a symmetrical type lens and the optical system is compact with a large aperture. The positive, negative, positive symmetrical type lens and the negative, positive, negative symmetrical type lens are generally of a construction advantageous in the correction of distortion and chromatic aberration. When in such symmetrical type lenses, the whole lens system is axially moved to effect focusing (so-called whole axial movement system), the fluctuation of off-axis aberration can be suppressed to a certain degree.

However, where the whole axial movement system is used in the optical system as disclosed in Japanese Laid-Open Patent Application No. 54-170826 wherein the symmetry of the refractive power arrangement of the negative, positive, negative symmetrical type lens is greatly destroyed in order to make the optical system bright, there has been a problem that the fluctuation of off-axis aberration becomes great.

SUMMARY OF THE INVENTION

Accordingly, it is an object of the present invention to solve the above-noted problems peculiar to the prior art and to provide a symmetrical type wide-angle lens which realizes the small total thickness and great aperture of the lens system and which is compact and bright as well as small in distortion.

To achieve the above object, a wide-angle objective lens according to the present invention comprises, in succession from the object side, a first lens component comprising a

negative meniscus single lens having its convex surface facing the object side, a meniscus-shaped second lens component having its convex surface facing the object side and having positive refractive power, a stop, a third lens component comprising a cemented meniscus lens comprising a positive lens and a negative lens cemented together and having its convex surface facing the object side and having positive refractive power, a fourth lens component comprising a positive meniscus single lens having its concave surface facing the object side, and a fifth lens component comprising a negative meniscus single lens having its concave surface facing the object side, and is constructed into a negative, positive, negative refractive power arrangement as a whole, and when the focal length of said first lens component is f_1 and the focal length of said fifth lens component is f_5 and the radius of curvature of that surface of said third lens component which is most adjacent to the image side is r_{32} and the radius of curvature of that surface of said fourth lens component which is most adjacent to the object side is r_{41}, said wide-angle objective lens is designed to satisfy at least one of the following conditions:

$$0\ 02 \leqq |t_1/f_1| \leqq 0.1$$

$$0.01 \leqq |t_4/f_5| \leqq 0.08$$

$$-0.85 \leqq (r_{32}+r_{41})/(r_{32}-r_{41}) \leqq 0.90,$$

where

t_1: the air space on the optical axis from that surface of the first lens component which is most adjacent to the image side to that surface of the second lens component which is most adjacent to the object side,

t_4: the air space on the optical axis from that surface of the fourth lens component which is most adjacent to the image side to that surface of the fifth lens component which is most adjacent to the object side.

By constructing the objective lens as described above, it becomes possible to correct, in particular curvature of image field, astigmatism and coma, and a wide-angle lens which is compact, large aperture and high in performance can be realized.

It is a further object of the present invention to provide a wide-angle lens which suffers little from the fluctuation of off-axis aberration caused by focusing and which is compact with a large aperture and covers a wide-angle of view.

To achieve the above object, the present invention has a stop, and a first lens unit and a second lens unit that are disposed on the object side of the stop and on the image side of the stop respectively. The first lens unit and the second lens unit are designed such that, during focusing, the first and second lens units are moved on the optical axis toward the object side and the amounts of movement of the lens units on the optical axis differ from each other.

Other objects, features and effects of the present invention will become fully apparent from the following detailed description of the invention taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** shows the lens construction of a first embodiment of the present invention.

FIG. **2** shows the lens construction of a second embodiment of the present invention.

FIG. **3** shows the lens construction of a third embodiment of the present invention.

FIG. **4** shows the lens construction of a fourth embodiment of the present invention.

FIG. **5** shows the lens construction of a fifth embodiment of the present invention.

FIG. **6** shows the lens construction of a sixth embodiment of the present invention.

FIG. **7** shows the lens construction of a seventh embodiment of the present invention.

FIG. **8** shows the lens construction of an eighth embodiment of the present invention.

FIGS. **9**A and **9**B are schematic views schematically showing the refractive power arrangements in ninth to thirteenth embodiments of the present invention and in which objects are at infinity and a near distance, respectively.

FIG. **10** shows the lens construction of the ninth to twelfth embodiments of the present invention.

FIG. **11** shows the lens construction of the thirteenth embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Some embodiments of the present invention will hereinafter be described in detail with reference to the accompanying drawings.

FIGS. **1** to **8** show the lens constructions of first to eighth embodiments, respectively, of the present invention. The wide-angle lenses according to the present invention, as shown in FIGS. **1** to **8**, comprise, in succession from the object side, a first lens component **L1** comprising a negative meniscus single lens having its convex surface facing the object side, a meniscus-shaped second lens component **L2** having its convex surface facing the object side and having positive refractive power, a third lens component **L3** comprising a cemented meniscus lens comprising a positive lens and a negative lens cemented together and having its convex surface facing the object side and having positive refractive power, a fourth lens component **L4** comprising a positive meniscus single lens having its concave surface facing the object side, a fifth lens component **L5** comprising a negative meniscus single lens having its concave surface facing the object side, and a stop between the second lens component **L2** and the third lens component **L3**, is constructed into a negative, positive, negative refractive power arrangement as a whole, and is designed to satisfy at least one of the following conditions:

$$0.02 \leqq |t_1/f_1| \leqq 0.1 \quad (1)$$

$$0.01 \leqq |t_4/f_5| \leqq 0.08 \quad (2)$$

$$-0.85 \leqq (r_{32}+r_{41})/(r_{32}-r_{41}) \leqq 0.90, \quad (3)$$

where

t_1: the air space on the optical axis from that surface of the first lens component **L1** which is most adjacent to the image side to that surface of the second lens component **L2** which is most adjacent to the object side,

t_4: the air space on the optical axis from that surface of the fourth lens component **L4** which is most adjacent to the image side to that surface of the fifth lens component **L5** which is most adjacent to the object side,

f_1: the focal length of the first lens component **L1**,

f_5: the focal length of the fifth lens component **L5**,

r_{32}: the radius of curvature of that surface of the third lens component L3 which is most adjacent to the image side,

r_{41}: the radius of curvature of that surface of the fourth lens component L4 which is most adjacent to the object side.

As described above, the lens construction of the present invention is comprised of the first lens component L1 and the fifth lens component L5 each having negative refractive power, and the second lens component L2, the third lens component L3 and the fourth lens component L4 each having positive refractive power, and is a negative, positive, negative refractive power arrangement as a whole.

The first lens component L1 and the fifth lens component L5 each are a negative meniscus lens having its concave surface facing the stop S to sufficiently correct curvature of image field and astigmatism. By the negative meniscus lenses being thus used, it becomes possible to make the angle of view greater and increase the quantity of marginal light.

In a lens having a great angle of view, the correction of astigmatism and curvature of image field is important and it is necessary that the Petzval sum be an appropriate value.

Generally, in case of a lens of a negative, positive, negative refractive power arrangement having symmetry with respect to the stop S, as the air space between a lens unit adjacent to the object side and a positive lens unit and between a negative lens unit adjacent to the image side and the positive lens unit become wider, the degree of freedom of aberration correction increases more, and the Petzval sum can be made into an appropriate value.

However, where these air spaces are made great, the Petzval sum can be made into an appropriate value and this is advantageous for aberration correction, but the diameters of the fore and rear lenses become large and this is not preferable. Conversely, where these air spaces are made small, the Petzval sum increases to the positive and the correction of negative astigmastism and curvature of image field becomes difficult. So, where the refractive power of the first lens component L1 and of the fifth lens component L5 is made great to alleviate the Petzval sum, it will adversely affect coma, and this is not preferable.

The Petzval sum which is the cause of these problems can be improved to a certain degree by setting the refractive indices of the positive lens and the negative lens to appropriate values.

According to the present invention, in the symmetrical type wide-angle lens as disclosed in Japanese Utility Model Publication No. 43-30782, it becomes possible to divide the cemented positive lens disposed rearwardly of the stop into two lens components L3 and L4, effect the correction of spherical aberration by that surface r_{32} of the third lens component L3 which is most adjacent to the image side and that surface r_{41} of the fourth lens component L4 which is most adjacent to the object side, and make the F-number small. Further, since the cemented positive lens is divided into two lens components, the degree of freedom of aberration correction increases and it is possible to correct curvature of image field and astigmatism better.

The aforementioned conditional expressions of the present invention will hereinafter be described in detail.

Conditional expressions (1) and (2) are conditions regarding the correction of astigmatism and curvature of image field and compactness.

If the lower limit of conditional expression (1) is exceeded, the following two cases ① and ② are conceivable.

① A case where the air space t_1 between the first lens component L1 and the second lens component L2 is small; and

② A case where the focal length f_1 of the first lens component L1 is great.

In case ①, positive distortion increases and the correction of spherical aberration becomes impossible, and the F-number cannot be made small. In case ②, the Petzval sum increases to the positive and therefore, the correction of negative astigmastism and curvature of image field becomes impossible.

On the other hand, if the upper limit of conditional expression (1) is exceeded, the following two cases ③ and ④ are conceivable.

③ A case where the air space t_1 between the first lens component L1 and the second lens component L2 is great; and

④ A case where the focal length f_1 of the first lens component L1 is small.

In case ③, there is an advantage in aberration correction, but the diameter of the fore lens and the total thickness of the lens system become great and this is against the desire for compactness, and thus is not preferable. In case ④, Petzval sum decreases, but the coma under the principal ray increases to the negative in a portion which is great in the angle of view, and this is not preferable.

If the lower limit of conditional expression (2) is exceeded, the following two cases ⑤ and ⑥ are conceivable.

⑤ A case where the air space t_4 between the fourth lens component L4 and the fifth lens component L5 is small; and

⑥ A case where the focal length f_5 of the fifth lens component L5 is great.

In case ⑤, the correction of spherical aberration becomes impossible and the F-number cannot be made small. In case ⑥, the Petzval sum increases to the positive and the correction of negative astigmatism and curvature of image field becomes impossible, and a good image plane cannot be obtained.

On the other hand, if the upper limit of conditional expression (2) is exceeded, the following two cases ⑦ and ⑧ are conceivable.

⑦ A case where the air space t_4 between the fourth lens component L4 and the fifth lens component L5 is great; and

⑧ A case where the focal length f_5 of the fifth lens component L5 is small.

In case ⑦, the degree of freedom with which the Petzval sum is made into an appropriate value increases and this is advantageous in correcting astigmatism and curvature of image field, but the total thickness of the lens system becomes great and this is against the desire for compactness, and thus is not preferable. In case ⑧, the correction of spherical aberration becomes impossible and further, the fluctuation of the coma above the principal ray by the angle of view becomes great and this is not preferable.

Conditional expression (3) is a condition regarding the shape of the air space between the third lens component L3 and the fourth lens component L4, and is concerned with coma, curvature of image field and astigmatism.

If the upper limit of conditional expression (3) is exceeded, the Petzval sum will increase to the positive and cannot be made into an appropriate value and the correction of astigmatism and curvature of image field will become difficult, and a good image plane cannot be obtained. Also, the shape of coma will exhibit a sharp tendency toward inner coma, and this is not preferable.

If conversely, the lower limit of conditional expression (3) is exceeded, a good Petzval sum will be obtained, but

aberrations of high orders will occur in a portion which is great in the angle of view and astigmatism will become great. Also, the shape of coma will exhibit a great tendency toward outer coma, and this is not preferable.

It is desirable that in order to correct spherical aberration, curvature of image field and astigmatism and to form the lens compactly, the wide-angle lens according to the present invention be designed to further satisfy the following conditions:

$$0.20 \leqq |r_{42}/f| \leqq 0.55 \quad (4)$$

$$0.40 \leqq D/f \leqq 1.00, \quad (5)$$

where

f: the focal length of the entire lens system,

r_{42}: the radius of curvature of that surface of the fourth lens component L4 which is most adjacent to the image side,

D: total thickness of the lens system. Conditional expression (4) is concerned with the correction of spherical aberration.

If the upper limit value of conditional expression (4) is exceeded, it will become impossible to correct positive spherical aberration, and this is not preferable.

If conversely, the lower limit value of conditional expression (4) is exceeded, it will become impossible to correct negative spherical aberration, and this is not preferable.

Now, the wide-angle lens of the present invention is characterized in that, as compared with popular symmetrical type wide-angle lenses, its back focal length differs little, but the total thickness of the lens is very small. This makes it possible to make the lens barrel into the sunk barrel type to thereby contain it compactly when the lens of the present invention is used in a compact lens shutter camera or a camera with a range finder, and it is more realistic and effective to make the total thickness of the lens system small than to shorten the back focal length.

So, conditional expression (5) sets a condition for prescribing the total thickness of the lens system, i.e., the length from that surface of the first lens component L1 which is most adjacent to the object side to that surface of the fifth lens component L5 which is not adjacent to the image side.

If the lower limit value of conditional expression (5) is exceeded, the difference in height between the on-axis ray and the off-axis ray will become small in the lens far from the stop S and the degree of freedom will be deficient and thus, it will become impossible to correct the on-axis aberration and the off-axis aberration independently of each other.

If conversely, the upper limit value of conditional expression (5) is exceeded, the Petzval sum can be made into an appropriate value and a better image plane performance will be obtained, but this is against the desire for compactness and is therefore against an object of the present invention.

Also, it is desirable that in order to correct curvature of image field and astigmatism better, the first lens component L1, the third lens component L3 and the fifth lens component L5 be designed to satisfy the following conditions:

$$0.04 < N_{31} - N_{32} < 0.25 \quad (6)$$

$$N_1 < 1.70 \quad (7)$$

$$N_5 < 1.70, \quad (8)$$

where

N_{31}: the refractive index of the positive lens L3 disposed on the object side in the third lens component L3 for d-line, the refractive index of the negative

N_{32}: the refractive index of the negative lens disposed on the image side in the third lens component L3 for d-line,

N_1: the refractive index of the first lens component L1 for d-line,

N_5: the refractive index of the fifth lens component L5 for d-line.

Conditional expression (6) represents the difference between the refractive indices of the position lens disposed on the object side in the third lens component L3 and the negative lens disposed on the image side in the third lens component L3 for d-line.

If the lower limit value of conditional expression (6) is exceeded, the Petzval sum will increase to the positive and therefore, it will become impossible to correct negative curvature of image field and astigmatism.

If conversely, the upper limit value of conditional expression (6) is exceeded, a better Petzval sum will be obtained, but aberrations of high orders will occur in a portion which is great in the angle of view and astigmatic difference will be created, and this is not preferable.

Conditional expressions (7) and (8) are concerned with curvature of image field and astigmatism.

If the upper limit values of these conditional expressions are exceeded, the Petzval sum will increase to the positive and therefore, the correction of curvature of image field and negative astigmatism will become impossible and a good image plane will not be obtained.

Another embodiment of the present invention has a first lens unit and a second lens unit disposed with a stop interposed therebetween, on the object side of the stop and on the image side of the stop, respectively, said first lens unit comprising, in succession from the object side, a first lens component of negative refractive power and a second lens component of positive refractive power, said second lens unit comprising a third lens component of positive refractive power and a fourth lens component of negative refractive power, said first lens unit and said second lens unit being designed such that during focusing, they are moved on the optical axis toward the object side and the amounts of movement of said lens units on the optical axis differ from each other.

The present invention as a whole is of a negative, positive, negative refractive power arrangement. The first lens component of negative refractive power in the first lens unit disposed at a location remote from the stop and the fourth lens component of negative refractive power in the second lens unit are negative meniscus lenses having their concave surfaces facing the stop in order to sufficiently correct curvature of image field and astigmatism. The use of the negative meniscus lenses leads to the achievement of a wider angle and the provision of the action of increasing the quantity of marginal light.

The present invention makes the first lens unit and the second lens unit take their share of the correction of on-axis aberration and the correction of off-axis aberration. Specifically, there are the following two kinds of sharing:

(a) To achieve a wide-angle and yet make the refractive power of the first lens unit small in the positive, thereby correcting the off-axis aberration well with the first lens unit, and make the refractive power of the second lens unit great in the positive and divide the positive lens component in the second lens unit into two lens components, thereby correcting the on-axis aberration well with the second lens unit and making the optical system bright.

(b) To achieve a wide-angle and yet make the refractive power of the second lens unit small in the positive,

thereby correcting the off-axis aberration well with the second lens unit, and make the refractive power of the first lens unit great in the positive and divide the positive lens component in the first lens unit into two lens components, thereby correcting the on-axis aberration well with the first lens unit and making the optical system bright.

In the present invention, as described in items (a) and (b) above, the lens units forward and rearward of the stop S are made to take their share of the correction of the on-axis aberration and the correction of the off-axis correction to thereby enable the optical system to be bright, but correspondingly thereto, the symmetry of the refractive power on both sides of the stop is destroyed. Therefore, when focusing is effected by the use of the whole axial movement system, it becomes impossible to suppress the fluctuation of the off-axis aberration well.

So, the fluctuation of the off-axis aberration, when focusing is effected by the use of the whole axial movement system, will hereinafter be considered with respect to the following two types of optical systems in which the refractive power distribution on both sides of the stop is asymmetrical,

(I) Petrofocus Type; and

(II) Telephoto Type.

In the case of (I) above, the refractive power arrangement on both sides of the stop is negative and positive and the pupil magnification exceeds **1**. Therefore, when the object position moves from the infinity state to a short distance, positive astigmatism occurs.

In the case of (II) above, the refractive power arrangement on both sides of the stop is positive and negative and the pupil magnification is smaller than **1**. Therefore, when the object position moves from the infinity state to a short distance, negative astigmatism occurs.

In the present embodiment, when focusing by the whole axial movement is effected, the construction of item (a) above corresponds to (I) above, and when the object position moves from the infinity state to a short distance, positive astigmatism occurs. According to the definition of the third-order aberration coefficient in Lens Designing Method by Yoshiya Matsui, the third-order aberration coefficient III of the second lens unit exhibits the positive (+). Therefore, if the amount of axial movement of the second lens unit is made small relative to the amount of axial movement of the first lens unit, positive astigmatism could be suppressed well and the fluctuation of off-axis aberration caused during focusing could be suppressed.

Conversely, the construction of item (b) above corresponds to (II) above, and when the object position moves from the infinity state to a short distance, negative astigmatism occurs. At this time, the third-order aberration coefficient III of the second lens unit exhibits the negative (–). Therefore, if the amount of axial movement of the second lens unit is made great relative to the amount of axial movement of the first lens unit, the fluctuation of off-axis aberration caused during focusing could be alleviated.

As described above, the present invention effects focusing by the use of the so-called floating system that makes the amounts of axial movement of the first lens unit and the second lens unit different from each other during focusing, thereby enabling the fluctuation of off-axis aberration caused by focusing to be suppressed well.

In the present invention, it is desirable that with the above-described construction, the following conditional expression (9) or (10) be satisfied.

$$0<\Delta\cdot\phi/(\phi_a-\phi_b)<0.2 \quad (9)$$

$$0.3<|\phi 1/\phi|<0.95 \quad (10)$$

where

ϕ_a: the refractive power of the first lens unit,

ϕ_b: the refractive power of the second lens unit,

ϕ: the refractive power of the whole lens system,

Δ: an amount defined by the following equation:

$$\Delta=(\delta 1-\delta 2)/\delta 2$$

when the amount of movement of the first lens unit during focusing is $\delta 1$ and the amount of movement of the second lens unit is $\delta 2$,

$\phi 1$: the refractive power of the first lens component.

Conditional expression (9) is a condition for suppressing the fluctuation of aberration in short distance focusing very well.

If the upper limit value of conditional expression (9) is exceeded, the correction of the fluctuation of off-axis aberration caused by focusing will become excessive. If conversely, the lower limit value of conditional expression (9) is exceeded, the correction of the fluctuation of off-axis aberration caused by focusing will become deficient. Accordingly, it is preferable that the range of this condition be satisfied.

Conditional expression (10) is a condition for achieving the balance of the shortening of the full length and the effective diameter of the front lens.

If the upper limit value of conditional expression (10) is exceeded, the refractive power of the first lens component will become great to the negative and therefore, the diverging action will become strong and the back focal length will become too great. If conversely, the lower limit value of conditional expression (10) is exceeded, the refractive power of the first lens component will become small to the negative and the height of the ray of off-axis light passing through the first lens component will become far from the optical axis, and if an attempt is made to obtain the amount of marginal light, the effective diameter of the front lens will become great, which will lead to the bulkiness of the optical system, and this is not preferable.

The lens constructions of the embodiments of the present invention will hereinafter be described in greater detail.

All of Embodiments 1 to 7, as shown in FIGS. **1** to **7**, are lens systems of two groups **G1** and **G2** constituting is a lens of five-unit seven-component construction comprising, in succession from the object side, a first lens component **L1** which is a negative meniscus lens having its convex surface facing the object side, a second lens component **L2** which is a cemented positive meniscus lens comprising a biconvex lens and a biconcave lens, a stop S, a third lens component **L3** which is a cemented positive meniscus lens comprised of a biconvex lens and a biconcave lens, a fourth lens component **L4** which is a positive meniscus lens having its concave surface facing the object side, and a fifth lens component **L5** which is a negative meniscus lens having its concave surface facing the object side.

Also, Embodiment 8, as shown in FIG. **8**, is a lens of five-unit six-component construction comprising, in succession from the object side, a first lens component **L1** which is a negative meniscus lens having its convex surface facing the object side, a second lens component **L2** which is a positive meniscus lens having its convex surface facing the object side, a stop S, a third lens component **L3** which is a cemented positive meniscus lens comprised of a biconvex lens and a biconcave lens, a fourth lens component **L4** which is a positive meniscus lens having its concave surface facing

the object side, and a fifth lens component L5 which is a negative meniscus lens having its concave surface facing the object side.

The numerical data of the respective embodiments of the present invention will be shown in Tables 1 to 8 below. In these tables, f represents the focal length, F_{NO} represents F-number and 2ω represents the angle of view. The numbers at the left end represent the order from the object side, r represents the radius of curvature of each lens surface, d represents the spacing between adjacent lens surfaces, and the refractive index n and Abbe number ν are values for d-line (λ=587.6 nm).

TABLE 1

(Numerical Data of Embodiment 1)
f = 28.9
F_{NO} = 2.88
2ω = 73.8°

	r	d	n	ν
1	17.100	1.50	1.54739	53.5
2	9.282	2.70		
3	12.910	3.90	1.84042	43.3
4	−60.183	1.10	1.62588	35.7
5	14.650	5.00		
6	50.105	3.30	1.79668	45.4
7	−10.659	1.00	1.67270	32.2
8	43.956	1.40		
9	−36.842	3.00	1.79668	45.4
10	−13.025	1.50		
11	−9.805	1.50	1.58144	40.8
12	−14.846	20.83		

The condition-corresponding values of the above data are shown below.

(1) $|t_1/f_1|$=0.068
(2) $|t_4/f_5|$=0.027
(3) $(r_{32}+r_{41})/(r_{32}-r_{41})$=0.088
(4) $|r_{42}/f|$=0.451
(5) D/f=0.897
(6) $N_{31}-N_{32}$=0.123
(7) N_1=1.547
(8) N_5=1.581

TABLE 2

(Numerical Data of Embodiment 2)
f = 28.9
F_{NO} = 2.87
2ω = 73.0°

	r	d	n	ν
1	12.475	1.50	1.57501	41.6
2	8.882	3.10		
3	12.551	4.40	1.84042	43.3
4	−1631.732	1.00	1.64831	33.8
5	12.856	4.00		
6	43.791	2.50	1.79668	45.4
7	−13.768	1.00	1.67270	32.2
8	77.172	1.10		
9	−25.300	2.70	1.79668	45.4
10	−10.647	1.00		
11	−8.993	1.50	1.58144	40.8
12	−17.685	20.51		

The condition-corresponding values of the above data are shown below.

(1) $|t_1/f_1|$=0.051
(2) $|t_4/f_5|$=0.024
(3) $(r_{32}+r_{41})/(r_{32}-r_{41})$=0.506
(4) $|r_{42}/f|$=0.369
(5) D/f=0.824
(6) $N_{31}-N_{32}$=0.056
(7) N_1=1.532
(8) N_5=1.581

TABLE 3

(Numerical Data of Embodiment 3)
f = 28.9
F_{NO} = 2.87
2ω = 74.0°

	r	d	n	ν
1	12.422	1.50	1.53172	49.1
2	8.919	3.37		
3	12.829	3.87	1.84042	43.3
4	−1726.972	1.00	1.64831	33.8
5	12.785	4.00		
6	51.931	2.50	1.81600	46.8
7	−17.040	1.00	1.61750	30.8
8	54.857	1.31		
9	−21.730	2.95	1.79668	45.4
10	−10.479	0.80		
11	−8.874	1.50	1.59507	35.5
12	−13.780	20.96		

The condition-corresponding values of the above data are shown below.

(1) $|t_1/f_1|$=0.048
(2) $|t_4/f_5|$=0.017
(3) $(r_{32}+r_{41})/(r_{32}-r_{41})$=0.433
(4) $|r_{42}/f|$=0.363
(5) D/f=0.824
(6) $N_{31}-N_{32}$=0.199
(7) N_1=1.532
(8) N_5=1.595

TABLE 4

(Numerical Data of Embodiment 4)
f = 28.9
F_{NO} = 2.87
2ω = 73.4°

	r	d	n	ν
1	18.080	1.50	1.56384	60.9
2	9.4013.26			
3	13.713	4.18	1.80218	44.7
4	−28.737	1.10	1.61293	37.0
5	17.068	5.00		
6	48.775	3.14	1.80218	44.7
7	−11.832	1.00	1.68893	31.1
8	38.220	1.22		
9	−0.592	3.30	1.79668	45.4
10	−12.910	1.60		
11	−9.672	2.00	1.58144	40.8
12	−13.780	20.96		

The condition-corresponding values of the above data are shown below.

(1) $|t_1/f_1|$=0.088
(2) $|t_4/f_5|$=0.028
(3) $(r_{32}+r_{41})/(r_{32}-r_{41})$=−0.030
(4) $|r_{42}/f|$=0.447
(5) D/f=0.945
(6) $N_{31}-N_{32}$=0.113

(7) N_1=1.564

(8) N_5=1.582

TABLE 5

(Numerical Data of Embodiment 5)
f = 35.0
F_{NO} = 2.80
2ω = 62.4°

	r	d	n	υ
1	13.804	1.40	1.61025	57.6
2	9.560	2.50		
3	11.800	4.20	1.79668	43.3
4	−1901.932	1.20	1.68893	31.2
5	12.250	5.75		
6	23.817	3.30	1.72000	50.3
7	−12.861	1.20	1.62588	35.6
8	23.478	1.25		
9	−92.286	3.20	1.79631	40.9
10	−13.150	1.00		
11	−10.885	1.40	1.67003	47.1
12	−26.314	22.10		

The condition-corresponding values of the above data are shown below.

(1) $|t_1/f_1|$=0.047

(2) $|t_4/f_5|$=0.035

(3) $(r_{32}+r_{41})/(r_{32}-r_{41})$=−0.595

(4) $|r_{42}/f|$=0.376

(5) D/f=0.747

(6) $N_{31}-N_{32}$=0.094

(7) N_1=1.670

(8) N_5=1.670

TABLE 6

(Numerical Data of Embodiment 6)
f = 35.0
F_{NO} = 2.80
2ω = 62.4°

	r	d	n	υ
1	15.140	1.40	1.51680	64.1
2	9.852	2.60		
3	13.541	4.20	1.79668	45.4
4	−1960.755	1.20	1.67270	32.1
5	16.374	5.75		
6	38.906	4.20	1.79668	45.4
7	−9.900	1.20	1.67270	32.1
8	39.474	1.40		
9	−56.315	3.00	1.74950	35.2
10	−15.623	2.30		
11	−10.487	1.40	1.53172	49.1
12	−22.411	20.87		

The condition-corresponding values of the above data are shown below.

(1) $|t_1/f_1|$=0.043

(2) $|t_4/f_5|$=0.060

(3) $(r_{32}+r_{41})/(r_{32}-r_{41})$=−0.176

(4) $|r_{42}/f|$=0.446

(5) D/f=0.819

(6) $N_{31}-N_{32}$=0.124

(7) N_1=1.517

(8) N_5=1.532

TABLE 7

(Numerical Data of Embodiment 7)
f = 35.0
F_{NO} = 2.80
2ω = 62.6°

	r	d	n	υ
1	11.026	1.50	1.57501	41.6
2	8.859	3.28		
3	14.478	4.60	1.84042	43.3
4	−226.717	1.00	1.64831	33.8
5	13.585	4.00		
6	78.289	2.50	1.80411	46.4
7	−13.768	1.00	1.67270	32.2
8	100.000	1.15		
9	−20.464	2.95	1.79668	45.4
10	−10.474	0.80		
11	−9.468	1.50	1.58267	46.5
12	−16.567	25.07		

The condition-corresponding values of the above data are shown below.

(1) $|t_1/f_1|$=0.031

(2) $|t_4/f_5|$=0.019

(3) $(r_{32}+r_{41})/(r_{32}-r_{41})$=0.660

(4) $|r_{42}/f|$=0.299

(5) D/f=0.694

(6) $N_{31}-N_{32}$=0.131

(7) N_1=1.575

(8) N_5=1.583

TABLE 8

(Numerical Data of Embodiment 8)
f = 28.9
F_{NO} = 2.88
2ω = 73.8°

	r	d	n	υ
1	14.953	1.50	1.59507	35.5
2	8.621	2.94		
3	10.597	3.76	1.80411	46.4
4	17.712	5.00		
5	24.439	2.50	1.79668	45.4
6	−12.240	1.00	1.67270	32.2
7	25.235	1.10		
8	−49.274	2.90	1.79631	40.9
9	−11.514	1.00		
10	−8.160	1.50	1.58144	40.8
11	−21.421	19.32		

The condition-corresponding values of the above data are shown below.

(1) $|t_1/f_1|$=0.078

(2) $|t_4/f_5|$=0.042

(3) $(r_{32}+r_{41})/(r_{32}-r_{41})$=−0.323

(4) $|r_{42}/f|$=0.399

(5) D/f=0.803

(6) $N_{31}-N_{32}$=0.124

(7) N_1=1.595

(8) N_5=1.581

By using popular aspherical lenses, it is of course possible to introduce an aspherical surface into the first lens component **L1** or the fifth lens component **L5** of the present invention to thereby correct astigmatism and curvature of image field better and achieve a wide-angle, and to introduce an aspherical surface into the second lens component **L2**, the third lens component **L3** or the fourth lens component **L4** to

thereby further correct spherical aberration and achieve a great relative aperture.

FIGS. **9**A and **9**B schematically show the refractive power arrangements of ninth to thirteenth embodiment of the present invention. FIG. **9**A shows the refractive power arrangement when the object position is in the infinity state, and FIG. **9**B shows the refractive power arrangement when the object position is in a short distance state. It is shown in FIGS. **9**A and **9**B that as the object position moves from the infinity to the short distance, the first lens unit **G1** and the second lens unit **G2** move toward the object side.

Each of the ninth to twelfth embodiments, as shown in FIG. **10**, is of a construction which comprises, in succession from the object side, a first lens component **L1** which is a negative meniscus lens having its convex surface facing the object side, a second lens component **L2** which is a cemented lens of positive refractive power comprising a biconvex lens and a biconcave lens cemented together and having its convex surface facing the object side as a whole, a third lens component **L3** comprising a cemented lens component of positive refractive power comprising a biconvex lens having its convex surface of sharper curvature facing the image side and a biconcave lens cemented thereto and having its convex surface facing the object side as a whole, a fourth lens component **L4** which is a positive lens component having its concave surface facing the object side, and a fifth lens component **L5** which is a negative meniscus lens having its convex surface facing the image side, a stop **S** being disposed between the second lens component **L2** and the third lens component **L3**.

The numerical data of the ninth to twelfth embodiments of the present invention are given below. In the data Tables below, the numbers at the left end represents the order from the object side, r represents the radius of curvature of each lens surface, d represents the spacing between adjacent lens surface, and the refractive index n and Abbe number ν are values for d-line (λ=587.6 nm).

TABLE 9

Numerical Data of the Ninth Embodiment
f = 28.6
FNO = 2.88
2ω = 74.0°

	r	d	n	ν
1	17.9178	1.500	1.58913	61.2
2	9.1148	3.000		
3	14.8517	4.000	1.79668	45.4
4	−22.6769	1.300	1.60342	38.0
5	19.6186	2.000		
6	∞	(d6)	(stop)	
7	85.5391	3.000	1.79668	45.4
8	−12.4521	1.300	1.67270	32.2
9	44.1538	1.300		
10	−49.9974	2.500	1.74810	52.3
11	−13.6254	2.700		
12	−9.5518	2.000	1.64831	33.8
13	−13.0360	(Bf)		

Variations in the spacing when the photographing distance is infinity (∞) and a short distance (300 mm) are shown below.

TABLE 10

Photographing Distance	Infinity	300 mm
d6	3.000	2.651
Bf	21.891	25.382

The condition-corresponding values of the above data are shown below.

$\Delta\cdot(\phi_a-\phi_b)/\phi=0.071$ (1)

$|\phi 1/\phi|=0.051$ (2)

TABLE 11

Numerical Data of the Tenth Embodiment
f = 28.9
FNO = 2.88
2ω = 73.8°

	r	d	n	ν
1	17.8000	1.500	1.58913	61.2
2	9.3309	3.100		
3	13.9124	3.900	1.79668	45.4
4	−29.7570	1.100	1.60342	38.1
5	17.4563	(d5)		
6	∞	2.400	(stop)	
7	49.4089	3.600	1.79668	45.4
8	−10.5646	1.000	1.67270	32.2
9	35.7839	1.400		
10	−47.3829	3.300	1.79668	45.4
11	−13.1267	1.600		
12	−9.9212	2.000	1.60432	38.1
13	−15.6720	(Bf)		

Variations in the spacing when the photographing distance is infinity (∞) and a short distance (300 mm) are shown below.

TABLE 12

Photographing Distance	Infinity	300 mm
d5	12.600	2.369
Bf	21.940	24.832

The condition-corresponding values of the above data are shown below.

$\Delta\cdot\phi/(\phi_a-\phi_b)=0.061$ (1)

$|\phi 1/\phi|=0.811$ (2)

TABLE 13

Numerical Data of the Eleventh Embodiment
f = 28.9
FNO = 2.88
2ω = 73.8°

	r	d	n	ν
1	12.5065	1.500	1.53172	49.1
2	8.7834	3.450		
3	12.5521	3.950	1.84042	43.3
4	−1626.4800	1.000	1.64831	33.8
5	12.6942	(d5)		
6	∞	2.350	(stop)	
7	45.2763	2.500	1.80411	46.3
8	−13.7592	1.000	1.67270	32.2
9	56.7133	1.150		
10	−25.5838	2.950	1.79668	45.4
11	−10.3313	0.800		
12	−8.8304	1.500	1.58144	40.8
13	−16.1578	(Bf)		

Variations in the spacing when the photographing distance is infinity (∞) and a short distance (300 mm) are shown below.

TABLE 14

Photographing Distance	Infinity	300 mm
d5	1.650	1.545
Bf	20.514	24.033

The condition-corresponding values of the above data are shown below.

$\Delta\cdot\phi/(\phi_a-\phi_b)=0.022$ (1)

$|\phi 1/\phi|=0.447$ (2)

TABLE 15

Numerical Data of the Twelfth Embodiment
f = 28.9
F_{NO} = 2.88
2ω = 73.8°

	r	d	n	υ
1	17.1000	1.500	1.54739	53.6
2	9.2824	2.700		
3	12.9097	3.900	1.84042	43.3
4	−60.1829	1.100	1.62588	35.6
5	14.6504	(d5)		
6	∞	2.400	(stop)	
7	50.3000	3.300	1.79668	45.4
8	−10.6591	1.000	1.67270	32.2
9	43.9560	1.400		
10	−36.8415	3.000	1.79668	45.4
11	−13.0249	1.500		
12	−9.8051	1.500	1.58144	40.8
13	−14.8205	(Bf)		

Variations in the spacing when the photographing distance is infinity (∞) and a short distance (300 mm) are shown below.

TABLE 16

Photographing Distance	Infinity	300 mm
d5	2.600	2.427
Bf	20.830	5.727

The condition-corresponding values of the above data are shown below.

$\Delta\cdot(\phi_a-\phi_b)/\phi=0.046$ (1)

$|\phi 1/\phi|=0.726$ (2)

The thirteenth embodiment, as shown in FIG. **11**, is of a construction which comprises, in succession from the object side, a first lens component **L1** which is a negative meniscus lens having its convex surface facing the object side, a second lens component **L2** which is a positive meniscus lens having its convex surface of sharp curvature facing the object side, a third lens component **L3** which is a positive lens component comprising a biconcave lens having its concave surface of sharper curvature facing the image side and a biconvex lens having its convex surface of sharper curvature facing the object side, said biconcave lens and said biconvex lens being cemented together, a fourth lens component **L4** of positive refractive power comprising a biconcave lens and a biconvex lens cemented together and having its convex surface facing the image side as a whole, and a fifth lens component **L5** which is a negative meniscus lens having its convex surface facing the image side, a stop S being disposed between the third lens component **L3** and the fourth lens component **L4**.

The numerical data of the thirteenth embodiment of the present invention are given below. In the data Table below, the numbers at the left end represents the order from the object side, r represents the radius of curvature of each lens surface, d represents the spacing between adjacent lens surfaces, and the refractive index n and Abbe number ν are values for d-line (λ=587.6 nm).

TABLE 17

Numerical Data of the Thirteenth Embodiment
f = 28.9
F_{NO} = 2.88
2ω = 73.8°

	r	d	n	υ
1	11.8420	1.500	1.59507	36.6
2	8.4410	2.998		
3	10.9528	3.300	1.79668	27.8
4	15.7309	1.354		
5	−449.9259	1.000	1.67270	40.5
6	13.7678	2.500	1.80411	46.3
7	−117.2633	(d7)		
8	∞	2.650	(stop)	
9	−24.4051	1.000	1.64831	38.4
10	5.0605	2.973	1.84042	29.2
11	−12.1107	1.674		
12	−8.8483	1.500	1.59507	36.6
13	−18.9952	(Bf)		

Variations in the spacing when the photographing distance is infinity (∞) and a short distance (300 mm) are shown below.

TABLE 18

Photographing Distance	Infinity	300 mm
d7	1.350	1.492
Bf	18.460	21.287

The condition-corresponding values of the above data are shown below.

$\Delta\cdot(\phi_a-\phi_b)/\phi=0.012$ (1)

$|\phi 1/\phi|=0.489$ (2)

By using popular aspherical lenses in the ninth to thirteenth embodiments of the present invention, introducing an aspherical surface into the first lens component **L1** or the fifth lens component **L5**, it is possible to correct astigmatism and curvature of image field better and achieve a wider angle. By introducing an aspherical surface also into the second lens component **L2**, the third lens component **L3**, or the fourth lens component **L4**, it is of course possible to correct spherical aberration further and achieve a greater aperture.

According to the present invention, there can be achieved a wide-angle lens which is compact and high in performance and as small as the order of F 2.8. The present invention can be used not only in 35 mm format cameras, but also in large format cameras. Further, when focusing is effected by general axial movement, the fluctuations of aberrations are very small and a good performance can be obtained.

What is claimed is:

1. A wide-angle objective lens system comprising, in order from an object side:

a first lens component including a negative meniscus single lens having a convex surface facing the object side;

a meniscus-shaped second lens component having positive refractive power and having a convex surface facing the object side;

a stop;

a third lens component including a cemented meniscus lens having positive refractive power, having a positive lens and a negative lens cemented together, and having a convex surface facing the object side;

a fourth lens component including a positive meniscus single lens having a concave surface facing the object side; and

a fifth lens component including a negative meniscus single lens having a concave surface facing the object side,

said lens system satisfying at least one of the following conditions:

$$0.02 \leqq |t_1/f_1| \leqq 0.1$$

$$0.01 \leqq |t_4/f_5| \leqq 0.08$$

$$-0.85 \leqq (r_{32}+r_{41})/(r_{32}-r_{41}) \leqq 0.90$$

where

t_1: an air space on an optical axis of the lens system between a surface of the first lens component which is nearest to an image side and a surface of the second lens component which is nearest to the object side,

f_1: the focal length of the first lens component,

t_4: an air space on said optical axis between a surface of the fourth lens component which is nearest to the image side and a surface of the fifth lens component which is nearest to the object side,

f_5: the focal length of the fifth lens component,

r_{32}: the radius of curvature of a surface of the third lens component which is nearest to the image side,

r_{41}: the radius of curvature of a surface of the fourth lens component which is nearest to the object side.

2. A wide-angle objective lens system according to claim **1**, wherein said fourth lens component and the total thickness of the lens system satisfy the following conditions:

$$0.20 \leqq |r_{42}/f| \leqq 0.55$$

$$0.40 \leqq D/f \leqq 1.00$$

where

f: the focal length of the entire lens system,

r_{42}: the radius of curvature of a surface of the fourth lens component which is nearest to the image side,

D: the total thickness of the lens system.

3. A wide-angle objective lens system according to claim **1**, wherein said first lens component, said third lens component and said fifth lens component satisfy the following conditions:

$$0.04 < N_{31} - N = 21\ 0.25$$

$$N_1 < 1.70$$

$$N_5 < 1.70$$

where

N_{31}: the refractive index of the positive lens of the third lens component for d-line,

N_{32}: the refractive index of the negative lens of third lens component for d-line,

N_1: the refractive index of the first lens component for d-line,

N_5: the refractive index of the fifth lens component for d-line.

4. A wide-angle objective lens system according to claim **1**, wherein said second lens component and said third lens component each include a cemented meniscus lens having a biconvex lens and a biconcave lens cemented together and having a convex surface facing the object side, said stop being disposed in the air space between said biconcave lens in said second lens component and said biconvex lens in said third lens component.

5. A wide-angle objective lens system according to claim **1**, wherein said second lens component includes a positive meniscus single lens having a convex surface facing the object side, said third lens component includes a cemented meniscus lens having a biconvex lens and a biconcave lens cemented together and having a convex surface facing the object side, and said stop is disposed in the air space between said positive meniscus single lens in said second lens component and said biconvex lens in said third lens component.

6. A wide-angle objective lens system according to claim **1**, which is designed in accordance with the following data:

F = 28.9
F_{NO} = 2.88
2ω = 73.8°

	r	d	n	υ
1	17.100	1.50	1.54739	53.5
2	9.282	2.70		
3	12.910	3.90	1.84042	43.3
4	−60.183	1.10	1.62588	35.7
5	14.650	5.00		
6	50.105	3.30	1.79668	45.4
7	−10.659	1.00	1.67270	32.2
8	43.956	1.40		
9	−36.842	3.00	1.79668	45.4
10	13.025	1.50		
11	−9.805	1.50	1.58144	40.8
12	−14.846	20.83		

(1) $|t_1/f_1| = 0.068$
(2) $|t_4/f_5| = 0.027$
(3) $(r_{32} + r_{41})/(r_{32} - r_{41}) = 0.088$
(4) $|r_{42}/f| = 0.451$
(5) $D/f = 0.897$
(6) $N_{31} - N_{32} = 0.123$
(7) $N_1 = 1.547$
(8) $N_5 = 1.581$

where f represents the focal length, F_{NO} represents the F-number, 2ω represents the angle of view, the numbers at the left end represent the order from the object side, r represents the radius of curvature of each lens surface, d represents the spacing between adjacent lens surfaces, and n and ν represent the refractive index and Abbe number, respectively, for d-line (λ=587.6 nm),

r_{42}: the radius of curvature of a surface of the fourth lens component which is nearest to the image side,

D: the total thickness of the lens system,

N_{31}: the refractive index of the positive lens of the third lens component for d-line,

N_{32}: the refractive index of the negative lens of the third lens component for d-line,

N_1: the refractive index of the first lens component for d-line,

N_5: the refractive index of the fifth lens component for d-line.

7. A wide-angle objective lens system according to claim **1**, which is designed in accordance with the following data:

f = 28.9
F_{NO} = 2.87
2ω = 73.0°

	r	d	n	υ
1	12.475	1.50	1.57501	41.6
2	8.882	3.10		
3	12.551	4.40	1.84042	43.3
4	−1631.732	1.00	1.64831	33.8
5	12.856	4.00		
6	43.791	2.50	1.79668	45.4
7	−13.768	1.00	1.67270	32.2
8	77.172	1.10		
9	−25.300	2.70	1.79668	45.4
10	−10.647	1.00		
11	−8.993	1.50	1.58144	40.8
12	−17.685	20.51		

(1) $|t_1 / f_1| = 0.051$
(2) $|t_4 / f_5| = 0.024$
(3) $(r_{32} + r_{41}) / (r_{32} - r_{41}) = 0.506$
(4) $|r_{42} / f| = 0.369$
(5) $D / f = 0.824$
(6) $N_{31} - N_{32} = 0.056$
(7) $N_1 = 1.532$
(8) $N_5 = 1.581$

where f represents the focal length, F_{NO} represents the F-number, 2ω represents the angle of view, the numbers at the left end represent the order from the object side, r represents the radius of curvature of each lens surface, d represents the spacing between adjacent lens surfaces, and n and ν represent the refractive index and Abbe number, respectively, for d-line (λ=587.6 nm),

r_{42}: the radius of curvature of a surface of the fourth lens component which is nearest to the image side,

D: the total thickness of the lens system,

N_{31}: the refractive index of the positive lens of the third lens component for d-line,

N_{32}: the refractive index of the negative lens of the third lens component for d-line,

N_1: the refractive index of the first lens component for d-line,

N_5: the refractive index of the fifth lens component for d-line.

8. A wide-angle objective lens system according to claim **1**, which is designed in accordance with the following data:

f = 28.9
F_{NO} = 2.87
2ω = 74.0°

	r	d	n	υ
1	12.422	1.50	1.53172	49.1
2	8.919	3.37		
3	12.829	3.87	1.84042	43.3
4	−1726.972	1.00	1.64831	33.8
5	12.785	4.00		
6	51.931	2.50	1.81600	46.8
7	−17.040	1.00	1.61750	30.8
8	54.857	1.31		
9	−21.730	2.95	1.79668	45.4
10	−10.479	0.80		
11	−8.874	1.50	1.59507	35.5
12	−13.780	20.96		

(1) $|t_1 / f_1| = 0.048$
(2) $|t_4 / f_5| = 0.017$
(3) $(r_{32} + r_{41}) / (r_{32} - r_{41}) = 0.433$
(4) $|r_{42} / f| = 0.363$
(5) $D / f = 0.824$

-continued

f = 28.9
F_{NO} = 2.87
2ω = 74.0°

	r	d	n	υ

(6) $N_{31} - N_{32} = 0.199$
(7) $N_1 = 1.532$
(8) $N_5 = 1.595$

where f represents the focal length, F_{NO} represents the F-number, 2ω represents the angle of view, the numbers at the left end represent the order from the object side, r represents the radius of curvature of each lens surface, d represents the spacing between adjacent lens surfaces, and n and ν represent the refractive index and Abbe number, respectively, for d-line (λ=587.6 nm),

r_{42}: the radius of curvature of a surface of the fourth lens component which is nearest to the image side,

D: the total thickness of the lens system,

N_{31}: the refractive index of the positive lens of the third lens component for d-line,

N_{32}: the refractive index of the negative lens of the third lens component for d-line,

N_1: the refractive index of the first lens component for d-line,

N_5: the refractive index of the fifth lens component for d-line.

9. A wide-angle objective lens system according to claim **1**, which is designed in accordance with the following data:

f = 28.9
F_{NO} = 2.87
2ω = 73.4°

	r	d	n	υ
1	18.080	1.50	1.56384	60.9
2	9.401	3.26		
3	13.713	4.18	1.80218	44.7
4	−28.737	1.10	1.61293	37.0
5	17.068	5.00		
6	48.775	3.14	1.80218	44.7
7	−11.832	1.00	1.68893	31.1
8	38.220	1.22		
9	−40.592	3.30	1.79668	45.4
10	−12.910	1.60		
11	−9.672	2.00	1.58144	40.8
12	−13.780	20.96		

(1) $|t_1 / f_1| = 0.088$
(2) $|t_4 / f_5| = 0.028$
(3) $(r_{32} + r_{41}) / (r_{32} - r_{41}) = -0.030$
(4) $|r_{42} / f| = 0.447$
(5) $D / f = 0.945$
(6) $N_{31} - N_{32} = 0.113$
(7) $N_1 = 1.564$
(8) $N_5 = 1.582$

where f represents the focal length, F_{NO} represents the F-number, 2ω represents the angle of view, the numbers at the left end represent the order from the object side, r represents the radius of curvature of each lens surface, d represents the spacing between adjacent lens surfaces, and n and ν represent the refractive index and Abbe number, respectively, for d-line (λ=587.6 nm),

r_{42}: the radius of curvature of a surface of the fourth lens component which is nearest to the image side,

D: the total thickness of the lens system,

N_{31}: the refractive index of the positive lens of the third lens component for d-line,

N_{32}: the refractive index of the negative lens of the third lens component for d-line,

N_1: the refractive index of the first lens component for d-line,

N_5: the refractive index of the fifth lens component for d-line.

10. A wide-angle objective lens system according to claim **1**, which is designed in accordance with the following data:

f = 35.0
F_{NO} = 2.80
2ω = 62.4°

	r	d	n	υ
1	13.804	1.40	1.67025	57.6
2	9.560	2.50		
3	11.800	4.20	1.79668	43.3
4	−1901.932	1.20	1.68893	31.2
5	12.250	5.75		
6	23.817	3.30	1.72000	50.3
7	−12.861	1.20	1.62588	35.6
8	23.478	1.25		
9	−92.286	3.20	1.79631	40.9
10	−13.150	1.00		
11	−10.885	1.40	1.67003	47.1
12	−26.314	22.10		

(1) $|t_1 / f_1| = 0.047$
(2) $|t_4 / f_5| = 0.035$
(3) $(r_{32} + r_{41}) / (r_{32} - r_{41}) = -0.595$
(4) $|r_{42} / f| = 0.376$
(5) $D / f = 0.747$
(6) $N_{31} - N_{32} = 0.094$
(7) $N_1 = 1.670$
(8) $N_5 = 1.670$

where f represents the focal length, F_{NO} represents the F-number, 2ω represents the angle of view, the numbers at the left end represent the order from the object side, r represents the radius of curvature of each lens surface, d represents the spacing between adjacent lens surfaces, and n and ν represent the refractive index and Abbe number, respectively, for d-line (λ=587.6 nm),

r_{42}: the radius of curvature of a surface of the fourth lens component which is nearest to the image side,

D: the total thickness of the lens system,

N_{31}: the refractive index of the positive lens of the third lens component for d-line,

N_{32}: the refractive index of the negative lens of the third lens component for d-line,

N_1: the refractive index of the first lens component for d-line,

N_5: the refractive index of the fifth lens component for d-line.

11. A wide-angle objective lens system according to claim **1**, which is designed in accordance with the following data:

f = 35.0
F_{NO} = 2.80
2ω = 62.4°

	r	d	n	υ
1	15.140	1.40	1.51680	64.1
2	9.852	2.60		
3	13.541	4.20	1.79668	45.4
4	−1960.755	1.20	1.67270	32.1
5	16.374	5.75		
6	38.906	4.20	1.79668	45.4
7	−9.900	1.20	1.67270	32.1
8	39.474	1.40		
9	−56.315	3.00	1.74950	35.2
10	−15.623	2.30		
11	−10.487	1.40	1.53172	49.1
12	−22.411	20.87		

(1) $|t_1 / f_1| = 0.043$
(2) $|t_4 / f_5| = 0.060$
(3) $(r_{32} + r_{41}) / (r_{32} - r_{41}) = -0.176$
(4) $|r_{42} / f| = 0.446$
(5) $D / f = 0.819$
(6) $N_{31} - N_{32} = 0.124$
(7) $N_1 = 1.517$
(8) $N_5 = 1.532$

where f represents the focal length, F_{NO} represents the F-number, 2ω represents the angle of view, the numbers at the left end represent the order from the object side, r represents the radius of curvature of each lens surface, d represents the spacing between adjacent lens surfaces, and n and ν represent the refractive index and Abbe number, respectively, for d-line (λ=587.6 nm),

r_{42}: the radius of curvature of a surface of the fourth lens component which is nearest to the image side,

D: the total thickness of the lens system,

N_{31}: the refractive index of the positive lens of the third lens component for d-line,

N_{32}: the refractive index of the negative lens of the third lens component for d-line,

N_1: the refractive index of the first lens component for d-line,

N_5: the refractive index of the fifth lens component for d-line.

12. A wide-angle objective lens system according to claim **1**, which is designed in accordance with the following data:

f = 35.0
F_{NO} = 2.80
2ω = 62.6°

	r	d	n	υ
1	11.026	1.50	1.57501	41.6
2	8.859	3.28		
3	14.478	4.60	1.84042	43.3
4	−226.717	1.00	1.64831	33.8
5	13.585	4.00		
6	78.289	2.50	1.80411	46.4
7	−13.768	1.00	1.67270	32.2
8	100.000	1.15		
9	−20.464	2.95	1.79668	45.4
10	−10.474	0.80		
11	−9.468	1.50	1.58267	46.5
12	−16.567	25.07		

(1) $|t_1 / f_1| = 0.031$
(2) $|t_4 / f_5| = 0.019$
(3) $(r_{32} + r_{41}) / (r_{32} - r_{41}) = 0.660$
(4) $|r_{42} / f| = 0.299$
(5) $D / f = 0.694$
(6) $N_{31} - N_{32} = 0.131$
(7) $N_1 = 1.575$
(8) $N_5 = 1.583$

where f represents the focal length, F_{NO} represents the F-number, 2ω represents the angle of view, the numbers at the left end represent the order from the object side, r represents the radius of curvature of each lens surface, d represents the spacing between adjacent lens surfaces, and n

and ν represent the refractive index and Abbe number, respectively, for d-line (λ=587.6 nm),

r_{42}: the radius of curvature of a surface of the fourth lens component which is nearest to the image side,

D: the total thickness of the lens system,

N_{31}: the refractive index of the positive lens of the third lens component for d-line,

N_{32}: the refractive index of the negative lens of the third lens component for d-line,

N_1: the refractive index of the first lens component for d-line,

N_5: the refractive index of the fifth lens component for d-line.

13. A wide-angle objective lens system according to claim **1**, which is designed in accordance with the following data:

f = 28.9
F_{NO} = 2.88
2ω = 73.8°

	r	d	n	ν
1	14.953	1.50	1.59507	35.5
2	8.621	2.94		
3	10.597	3.76	1.80411	46.4
4	17.712	5.00		
5	24.439	2.50	1.79668	45.4
6	−12.240	1.00	1.67270	32.2
7	25.235	1.10		
8	−49.274	2.90	1.79631	40.9
9	−11.514	1.00		
10	−8.160	1.50	1.58144	40.8
11	−21.421	19.32		

(1) $|t_1/f_1| = 0.078$
(2) $|t_4/f_5| = 0.042$
(3) $(r_{32}+r_{41})/(r_{32}-r_{41}) = -0.323$
(4) $|r_{42}/f| = 0.399$
(5) $D/f = 0.803$
(6) $N_{31}-N_{32} = 0.124$
(7) $N_1 = 1.595$
(8) $N_5 = 1.581$

where f represents the focal length, F_{NO} represents the F-number, 2ω represents the angle of view, the numbers at the left end represent the order from the object side, r represents the radius of curvature of each lens surface, d represents the spacing between adjacent lens surfaces, and n and ν represent the refractive index and Abbe number, respectively, for d-line (λ=587.6 nm),

r_{42}: the radius of curvature of a surface of the fourth lens component which is nearest to the image side,

D: the total thickness of the lens system,

N_{31}: the refractive index of the positive lens of the third lens component for d-line,

N_{32}: the refractive index of the negative lens of the third lens component for d-line,

N_1: the refractive index of the first lens component for d-line,

N_5: the refractive index of the fifth lens component for d-line.

14. A wide-angle objective lens comprising, in order from an object side:

a first lens component including a negative meniscus lens having a convex surface facing the object side;

a second lens component having a convex surface facing the object side and having positive refractive power;

a third lens component which is a cemented lens having positive refractive power, the cemented lens consisting of, in order from the object side, a positive lens and a negative lens;

a fourth lens component having a convex surface facing an image side and having positive refractive power; and

a fifth lens component including a negative meniscus lens having a convex surface facing the image side,

said wide-angle objective lens system satisfying the following condition:

$$0.04<N_{31}-N_{32}<0.25$$

where

N_{31}: the refractive index of the positive lens of the third lens component for d-line;

N_{32}: the refractive index of the negative lens of the third lens component for d-line.

15. A wide-angle objective lens system according to claim **14**, wherein a stop is disposed between said second lens component and said third lens component, and said wide-angle objective lens satisfies the following condition:

$$-0.85\leqq(r_{32}+r_{41})/(r_{32}-r_{41})\leqq0.90$$

where

r_{32}: the radius of curvature of a surface of the third lens component which is nearest to the image side;

r_{41}: the radius of curvature of a surface of the fourth lens component which is nearest to the object side.

16. A wide-angle objective lens system according to claim **14**, wherein, when the total thickness of the lens system is D and the focal length of the whole lens system is f, said wide-angle objective lens satisfies the following condition:

$$0.4<D/f\leqq1.0.$$

17. A wide-angle objective lens system according to claim **14**, wherein a stop is disposed between said second lens component and said third lens component and, when focusing is performed, a lens unit disposed on the object side of the stop and a lens unit disposed on the image side of the stop are designed so as to move different distances on the optical axis.

18. A wide-angle objective lens system comprising, in order from an object side:

a first lens unit including, in order from the object side, a first lens component having negative refractive power and a second lens component having positive refractive power;

a stop; and

a second lens unit having positive refractive power,

said first lens unit and said second lens unit moving different distances on an optical axis of the lens system when moved toward the object side during focusing.

19. A wide-angle objective lens system according to claim **18**, satisfying the following condition:

$$0<\Delta\cdot\phi/(\phi_a-\phi_b)<0.2$$

where

ϕ_a: the refractive power of said first lens unit,

ϕ_b: the refractive power of said second lens unit,

ϕ: the refractive power of the whole lens system,

Δ: an amount defined by the following equation:

$$\Delta=(\delta1-\delta2)/\delta2$$

when the amount of movement of the first lens unit during focusing is $\delta 1$ and the amount of movement of the second lens unit during focusing is $\delta 2$.

20. A wide-angle objective lens system according to claim **19**, wherein, when the refractive power of said first lens component is $\phi 1$ and the refractive power of the whole lens system is ϕ, said wide-angle objective lens satisfies the following condition:

$$0.3<|\phi 1/\phi|<0.95.$$

21. A wide-angle objective lens system according to claim **18**, wherein said second lens unit has a negative lens component nearest to the image side.

22. A wide-angle objective lens system according to claim **18**, wherein, when the total thickness of the lens system is D and the focal length of the whole lens system is f, said wide-angle objective lens system satisfies the following condition:

$$0.4<D/f\leqq 1.0.$$

* * * * *

US005491528A

United States Patent [19]

Takato et al.

[11] Patent Number: 5,491,528

[45] Date of Patent: Feb. 13, 1996

[54] **REAL IMAGE MODE FINDER OPTICAL SYSTEM HAVING AN OBJECTIVE LENS INTEGRATED AS A PRISM WITH A REFLECTIVE SURFACE**

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[73] Assignee: **Olympus Optical Co., Ltd.**, Tokyo, Japan

[21] Appl. No.: **226,850**

[22] Filed: **Apr. 13, 1994**

[30] **Foreign Application Priority Data**

Apr. 14, 1993 [JP] Japan 5-087503

[51] **Int. Cl.**[6] **G03B 13/08**

[52] **U.S. Cl.** **354/225**; 354/224; 359/726; 359/835

[58] **Field of Search** 354/219, 224, 354/225, 222, 166; 359/726, 793, 794, 834, 835

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4-019705	1/1992	Japan .

Primary Examiner—David C. Nelms
Assistant Examiner—Andrew Q. Tran
Attorney, Agent, or Firm—Cushman, Darby & Cushman

[57] **ABSTRACT**

A real image mode finder optical system includes an objective lens, an image inverting optical member for erecting an object image formed by the objective lens, and an eyepiece for observing the object image. The objective lens has a reflecting surface and satisfies a condition:

$$0.1<D/f<0.4$$

where D is the distance between the exit surface of the objective lens and the entrance surface of the image inverting optical member and f is the focal length of the objective lens. Thus, the real image mode finder optical system are constructed with a small number of parts and compact design.

6 Claims, 5 Drawing Sheets

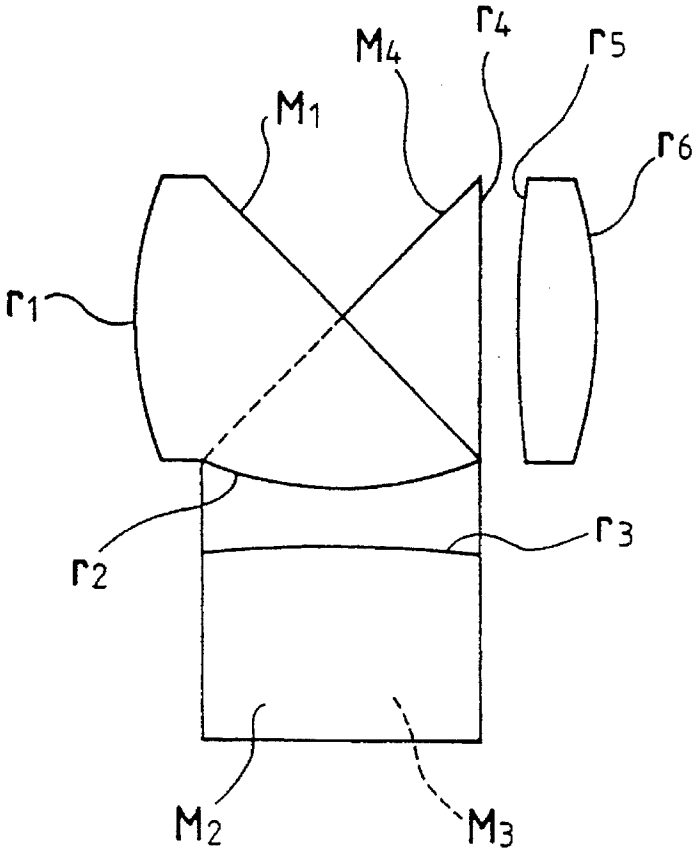


FIG. 1 PRIOR ART

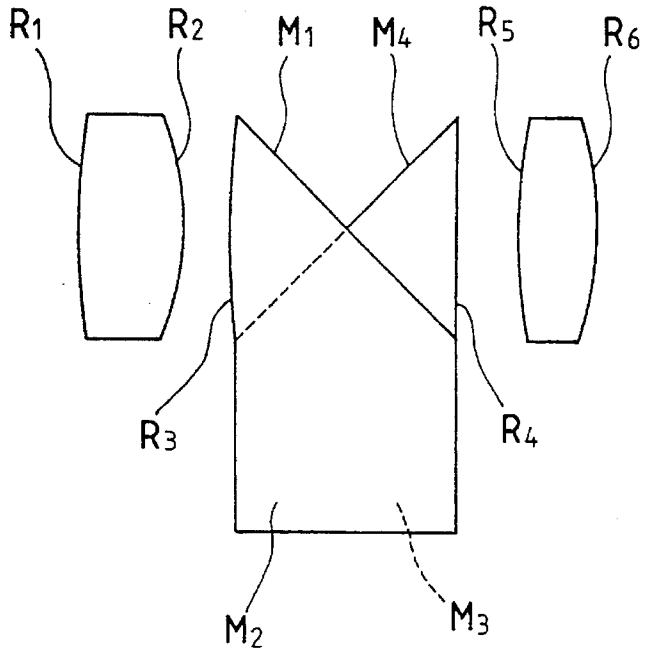


FIG. 3

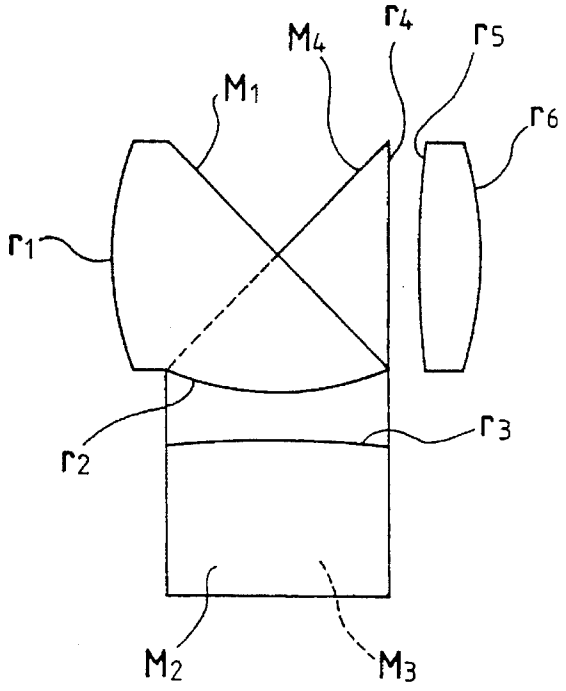


FIG. 2

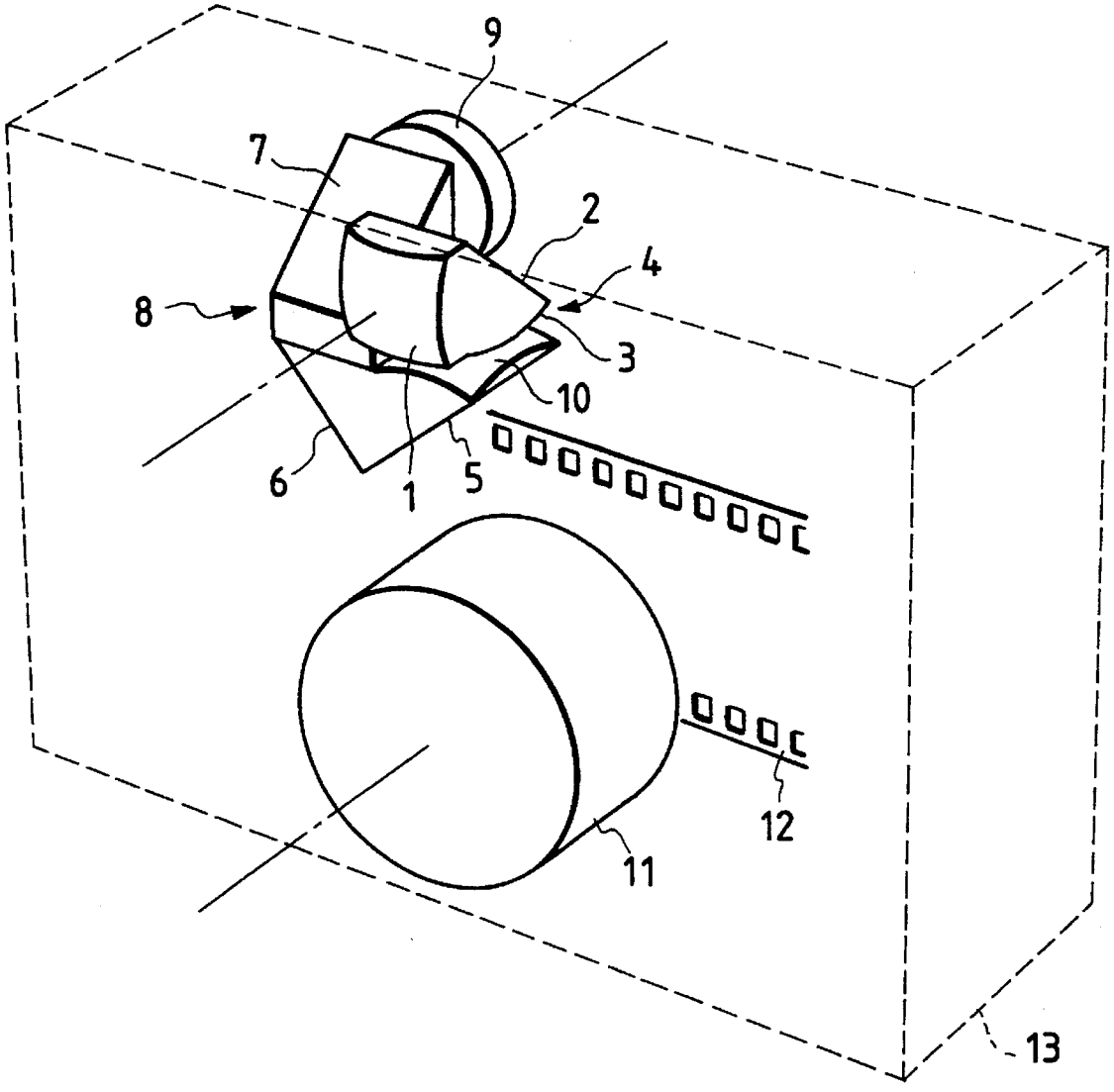


FIG. 4

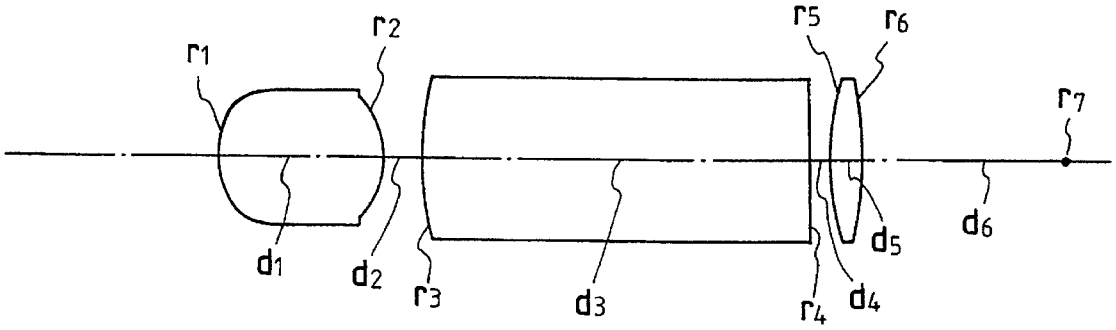


FIG. 5A

SPHERICAL ABERRATION
PUPIL DIAMETER = 2.0 mm

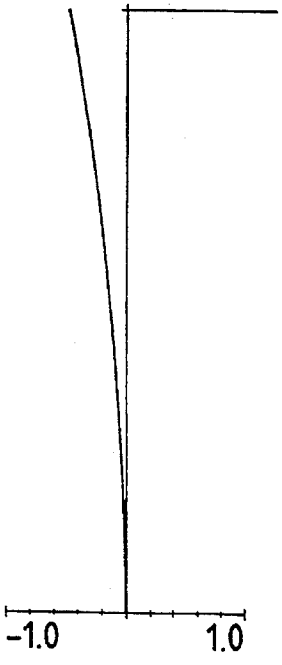


FIG. 5B

ASTIGMATISM
ω=30.2°

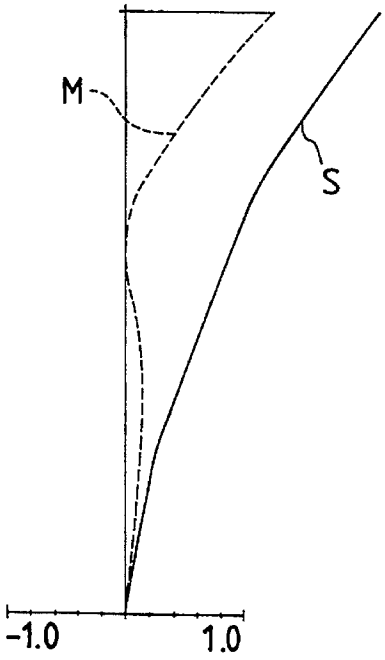


FIG. 5C

DISTORTION
ω=30.2°

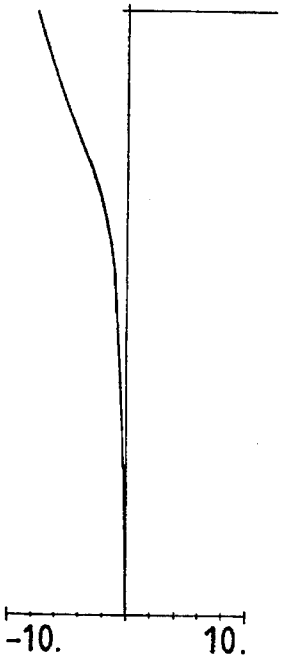


FIG. 6

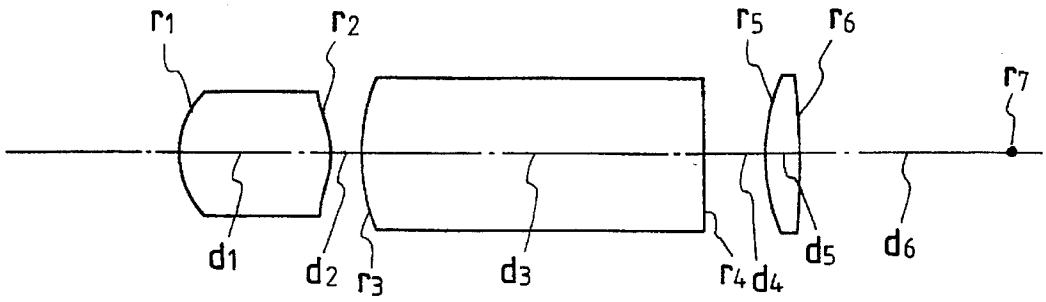


FIG. 7A

SPHERICAL ABERRATION
PUPIL DIAMETER = 2.0 mm

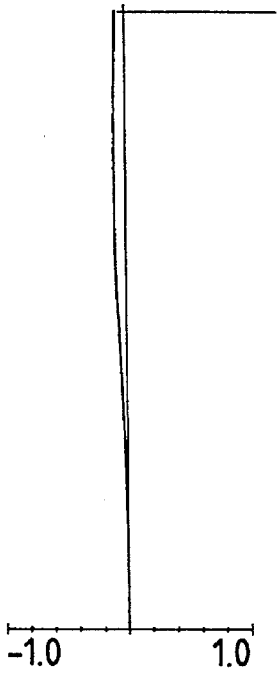


FIG. 7B

ASTIGMATISM
ω = 27.4°

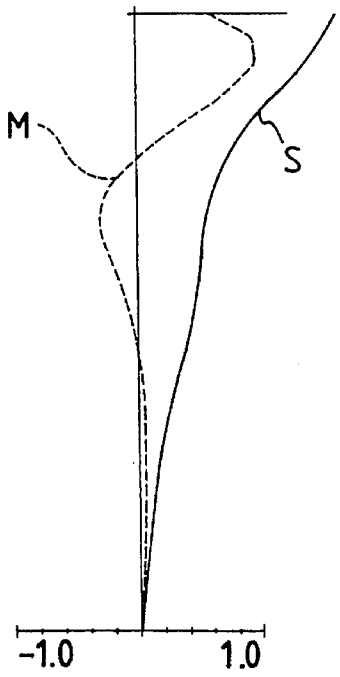


FIG. 7C

DISTORTION
ω = 27.4°

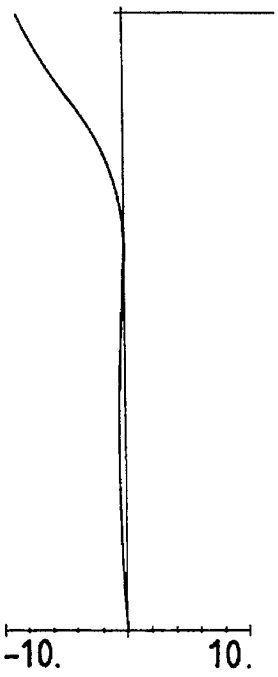


FIG. 8

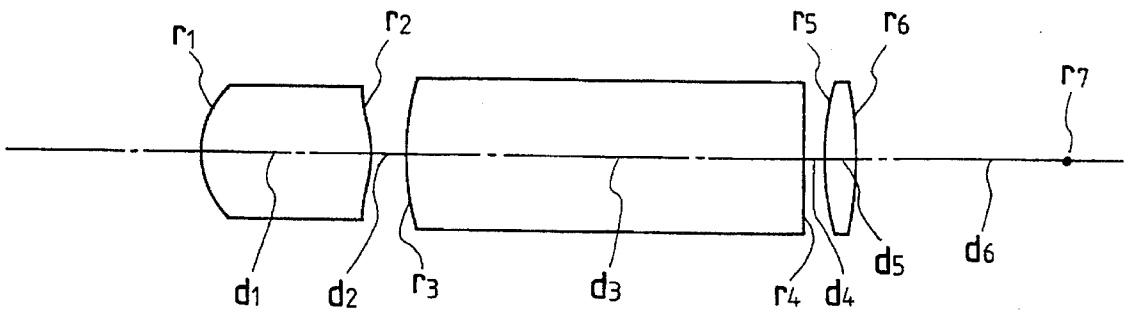


FIG. 9A

SPHERICAL ABERRATION
PUPIL DIAMETER = 2.0 mm

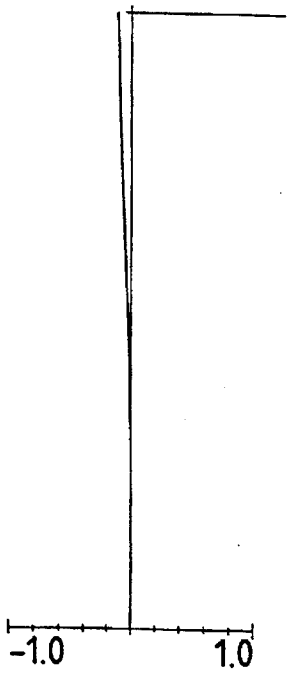


FIG. 9B

ASTIGMATISM
ω = 28.1°

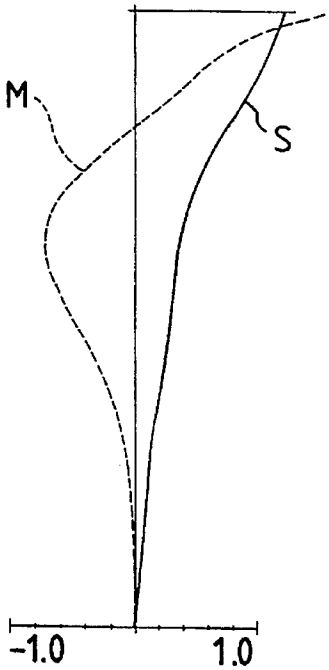
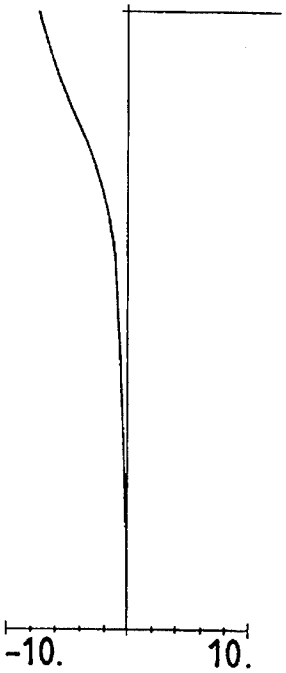


FIG. 9C

DISTORTION
ω = 28.1°



REAL IMAGE MODE FINDER OPTICAL SYSTEM HAVING AN OBJECTIVE LENS INTEGRATED AS A PRISM WITH A REFLECTIVE SURFACE

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to a real image mode finder optical system which is suitable for compact cameras such as photographic cameras and video cameras.

2. Description of the Related Art

In general, finder optical systems are available in virtual image modes, such as Albada and inverse Galilean types, and real image modes, such as Keplerjan types. The finder optical systems of conventional compact cameras has found many uses for virtual image modes. It is for this reason that the virtual image mode finder optical system brings about a wide field angle with comparative ease, has a smaller number of parts because it dispenses with an image erecting means, and allows its length along the optical axis to be reduced. Recently, on the other hand, the real image mode finder optical system has undergone many improvements such that an indicating member, like a field frame, is made easy to see, the effective diameters of lenses can be reduced, and an image inverting optical member, like a Porro prism, can be integrally molded of plastic. Consequently, real image mode finder optical systems (such as those set forth, for example, in Japanese Patent Preliminary Publication Nos. Sho 63-44616 and Sho 61-156018) have come into prominent use.

With the conventional real image mode finder optical systems as mentioned above, however, when an attempt is made to secure a relatively wide field angle, the height of an object image formed by an objective system will inevitably increase. Thus, for compactness of the optical system, the refracting power of the objective system need be increased. This causes the degradation of aberration. Hence, in order to improve the performance of the optical system, it is indispensable to increase the number of lenses of the objective system and lessen the refracting power of each lens. As a consequence of this, the problem is raised that the number of parts used in the optical system increases and its arrangement is complicated. Moreover, the position of the object image formed by the objective system is located in front of the image inverting optical member, and an eyepiece is located behind it.

FIG. **1** show the arrangement of the conventional real image mode finder optical system. This optical system includes an objective lens having lens surfaces R_1 and R_2; an image inverting optical member having lens surfaces R_3 and R_4 and reflecting surfaces M_1, M_2, M_3, and M_4; and an eyepiece having lens surfaces R_5 and R_6. Thus, when the finder optical system is actually disposed in a camera body, the objective lens and the eyepiece, as shown in FIG. **1**, are situated in front of and behind the Porto prism of the image inverting optical member, no matter how the arrangement of the optical system is simplified. Hence, the corresponding thickness of the optical system is imperatively needed, and there is a limit to the reduction of the length along the optical axis.

In order to solve such a problem, optical systems, such as those disclosed in Japanese Patent Preliminary Publication Nos. Sho 63-226616 and Hei 1-255825, are available. These optical systems are designed so that the position of an object image formed by an objective lens is located inside an image inverting optical member to thereby intend the reduction of the overall length. Such prior art, however, develops the defect that because an optical member, such as a field frame, is disposed at the imaging position, the image inverting optical member, such as the Porto prism which can be integrally molded originally, must be divided into two, with a resulting increase in the number of parts.

SUMMARY OF THE INVENTION

It is, therefore, an object of the present invention to provide a real image mode finder optical system in which compactness can be realized by a simple arrangement, without increasing the number of parts, the field angle covers a wide range, and the overall length can be reduced.

In order to achieve this object, the real image mode finder optical system according to the present invention includes an objective lens, an image inverting optical member for erecting an object image formed by the objective lens, and an eyepiece for observing the object image. The objective lens has a reflecting surface and satisfies the condition:

$$0.1<D/f<0.4 \quad (1)$$

where D is the distance between the exit surface of the objective lens and the entrance surface of the image inverting optical member and f is the focal length of the objective lens. The objective lens is constructed so that the conventional objective lens and the first refleeting surface of the conventional image inverting optical member are integrally configured as a prism.

FIG. **2** shows a state where the finder optical system of the present invention is incorporated in a camera. The finder optical system comprises an objective lens **4** shaped into a prism form, having an entrance surface **1**, a reflecting surface **2**, and an exit surface **3**; an image inverting prism **8** having three reflecting surfaces **5**, **6**, and **7**; and an eyepiece **9**. Each of the entrance surface **1** and the exit surface **3** of the objective lens **4**, followed by the entrance surface **10** of the image inverting prism **8**, is configured as a curved surface with a positive power.

In the finder optical system, an image of an object is formed by the combined refracting power of the objective lens **4** and the entrance surface of the image inverting prism **8**, and is observed through the eyepiece **9**. Further, the reflecting surface **2** of the objective lens **4** and the three reflecting surfaces of the image inverting prism **8** have the same configuration as those of the Porro prism, and these four reflecting surfaces invert the image to form an erect image.

Apart from the finder optical system, a photographic lens **11** is disposed nearly parallel to the optical axis of the finder optical system. Reference numeral **12** represents film. These components are arranged, together with others, inside a camera body **13**.

In this way, the real image mode tinder optical system according to the present invention, as shown in FIG. **2**, is compactly incorporated in the camera body, and thus it does away with the corresponding thickness required for the objective lens of the conventional finder optical system such as shown in FIG. **1**. The arrangement of the finder optical system can thus be simplified to reduce the overall length.

In the real image mode finder optical system of the present invention, the distance D between the exit surface of the objective lens and the entrance surface of the image inverting optical member needs some degree of space to correct

for aberration. For its limit, it is desirable to satisfy Eq. (1). This is because if the value of Eq. (1) exceeds the lower limit, the ability to correct for aberration will decrease at the surface on the image side of the objective lens, and in particular the degradation of astigmatism will be caused, while if the value of Eq. (1) passes the upper limit, a compact arrangement of the entire finder optical system becomes impossible.

Further, it is desirable that the finder optical system of the present invention provides the entrance and exit surfaces of the objective lens with curvatures, satisfying conditions:

$$f/r1>0.9 \quad (2)$$

$$f/r2>-0.7 \quad (3)$$

where r_1 and r_2 are radii of curvature of surfaces on the objective and image sides of the objective lens, respectively. If the value of each of Eqs. (2) and (3) exceeds the lower limit of f/**r1** or the upper limit of f/**r2**, the refracting power of the objective lens will decline. This makes it difficult to bring about the finder optical system which has a simple arrangement and a wide field angle as in the present invention. Hence, by providing curvatures within the limits of the values satisfying Eqs. (2) and (3), the objective lens can hold a positive power of moderate strength, with a wide field angle.

If, however, the refracting power of the objective lens is extremely high, it is difficult to secure a finder optical system of high performance. Thus, in the above-mentioned finder optical system, if either the entrance or exit surface of the objective lens, or both, are made aspherical, aberrations can be favorably corrected and a finder optical system of high performance can also be realized. Additionally, if the entrance surface of the image inverting optical member is provided with curvature, an entrance pupil can be situated adjacent to the lens system. In this way, the height of a ray through the objective lens can be held low, which situation is effective for compactness of the objective lens.

This and other objects as well as the features and advantages of the present invention will become apparent from the following detailed description of the preferred embodiments when taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a sectional view showing the arrangement of a real image mode finder optical system of prior art;

FIG. **2** is a view showing a state where a real image mode finder optical system according to the present invention is incorporated in a camera;

FIG. **3** is a sectional view showing a fundamental arrangement of the optical system of the present invention:

FIG. **4** is a developed view of the optical system in a first embodiment of the present invention;

FIGS. **5**A, **5**B, and **5**C are aberration curve diagrams in the first embodiment;

FIG. **6** is a developed view of the optical system in a second embodiment of the present invention;

FIGS. **7**A, **7**B, and **7**C are aberration curve diagrams in the second embodiment;

FIG. **8** is a developed view of the optical system in a third embodiment of the present invention; and

FIGS. **9**A, **9**B, and **9**C are aberration curve diagrams in the third embodiment.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

In accordance with the embodiments shown, the present invention will be explained in detail below. FIG. **3** shows the fundamental arrangement of the present invention, and FIG. **4** is a developed view in the first embodiment of the present invention. The optical system of one first embodiment includes an objective lens having a first lens surface **r1**, a first reflecting surface M_1, and a second lens surface r_2; an image inverting optical member having a third lens surface r_3, a second reflecting surface face M_2, a third reflecting surface M_3, a fourth reflecting surface M_4, and a fourth lens surface r_4; and an eyepiece having a fifth lens surface r_5 and a sixth lens surface r_6. Of these surfaces, the third lens surface r_3 constituting the image inverting optical member is provided with curvature to transmit a pupil and assumes the role of a field lens. FIGS. **5**A, **5**B, and **5**C are the aberration curve diagrams of the first embodiment.

The numerical data of the first embodiment are shown below.

Finder magnification = 0.4x
Half field angle of incidence $\omega = 30.2°$
$r_1 = 6.1989$ (aspherical)
$d_1 = 12.4315$ $n_1 = 1.4924$ $\nu_1 = 57.7$
$r_2 = -4.9467$ (aspherical)
$d_2 = 2.991$
$r_3 = 21.5324$
$d_3 = 28.7940$ $n_3 = 1.4924$ $\nu_3 = 57.7$
$r_4 = \infty$
$d_4 = 1.4830$
$r_5 = 17.4342$ (aspherical)
$d_5 = 2.4950$ $n_5 = 1.4924$ $\nu_5 = 57.7$
$r_6 = -26.5239$
$d_6 = 15.0000$
r_7 = (pupil)

Aspherical coefficients

First surface

$P = 0.076$
$E = -0.23077 \times 10^{-2}$, $F = 0.36733 \times 10^{-3}$,
$G = -0.30451 \times 10^{-4}$, $H = 0.94683 \times 10^{-6}$

Second surface

$P = 0.9521$
$E = 0.16652 \times 10^{-2}$, $F = 0.14210 \times 10^{-4}$,
$G = -0.11044 \times 10^{-4}$, $H = 0.33959 \times 10^{-6}$

Fifth surface

$P = 3.6453$
$E = -0.17402 \times 10^{-3}$, $F = 0.21924 \times 10^{-6}$,
$G = -0.10042 \times 10^{-7}$, $H = 0.94956 \times 10^{-10}$

The values of Eqs. (1), (2), and (3) in the first embodiment are as follows:

D/f=0.338

f/**r1**=1.428

f/**r2**=−1.783

FIG. **6** and FIGS. **7**A, **73**, and **7**C are the developed view and aberration curve diagrams of the second embodiment, respectively. The numerical data of this embodiment are shown below.

Finder magnification = 0.36x
Half field angle of incidence $\omega = 27.4°$
$r_1 = 4.6532$ (aspherical)
$d_1 = 10.954$ $n_1 = 1.4924$ $\nu_1 = 57.7$
$r_2 = -5.1387$ (aspherical)
$d_2 = 2.252$
$r_3 = 14.4746$
$d_3 = 24.535$ $n_3 = 1.4924$ $\nu_3 = 57.7$
$r_4 = \infty$
$d_4 = 4.495$
$r_5 = 12.6655$ (aspherical)
$d_5 = 2.495$ $n_5 = 1.4924$ $\nu_5 = 57.7$
$r_6 = -70.549$
$d_6 = 15.000$
r_7 = (pupil)

Aspherical coefficients

First surface

$P = 0.3235$
$E = -0.20256 \times 10^{-2}$, $F = 0.11492 \times 10^{-3}$,
$G = -0.35607 \times 10^{-5}$, $H = 0.43666 \times 10^{-7}$

Second surface

$P = 1.4247$
$E = 0.12102 \times 10^{-2}$, $F = 0.12589 \times 10^{-2}$,
$G = -0.13793 \times 10^{-3}$, $H = 0.47637 \times 10^{-5}$

Fifth surface

$P = 3.0260$
$E = -0.28238 \times 10^{-3}$, $F = 0.38424 \times 10^{-5}$,
$G = -0.30426 \times 10^{-6}$, $H = 0.45719 \times 10^{-8}$

The values of Eqs. (1), (2), and (3) in the second embodiment are as follows:

D/f=0.286

f/r1=1.689

f/r2=−1.530

FIG. **8** and FIGS. **9**A, **9**B, and **9**C are the developed view and aberration curve diagrams of the third embodiment, respectively. The numerical data of this embodiment are shown below.

Finder magnification = 0.45x
Half field angle of incidence $\omega = 28.1°$
$r_1 = 5.4622$ (aspherical)
$d_1 = 12.446$ $n_1 = 1.4924$ $\nu_1 = 57.7$
$r_2 = -9.8755$ (aspherical)
$d_2 = 2.601$
$r_3 = 21.5326$
$d_3 = 28.500$ $n_3 = 1.4924$ $\nu_3 = 57.7$
$r_4 = \infty$
$d_4 = 1.500$
$r_5 = 17.4342$ (aspherical)
$d_5 = 2.4950$ $n_5 = 1.4924$ $\nu_5 = 57.7$
$r_6 = -26.5239$
$d_6 = 15.000$
r_7 = (pupil)

Aspherical coefficients

First surface

$P = 0.2243$
$E = -0.11644 \times 10^{-2}$, $F = 0.53422 \times 10^{-4}$,
$G = -0.11963 \times 10^{-5}$, $H = 0.99294 \times 10^{-8}$

Second surface

$P = 1.9306$
$E = 0.11786 \times 10^{-2}$, $F = 0.90395 \times 10^{-4}$,
$G = -0.10352 \times 10^{-4}$, $H = 0.32060 \times 10^{-6}$

Fifth surface

$P = 0.9985$
$E = -0.57527 \times 10^{-3}$, $F = 0.1924 \times 10^{-6}$,
$G = -0.10042 \times 10^{-7}$, $H = 0.94956 \times 10^{-10}$

The values of Eqs. (1), (2), and (3) the third embodiment are as follows:

D/f=0.267

f/r1=1.786

f/r2=−0.980

In each embodiment mentioned above, r1, r2, . . . represent radii of curvature of individual lens surfaces; d1, d2, . . . are the thicknesses of individual lenses or spaces therebetween; n1, n3, . . . are the refractive indices of individual lenses; and ν1, ν3, . . . , represent Abbe's numbers of individual lenses.

Also, the configurations of aspherical surfaces in each embodiment are expressed by the following equation using the aspherical coefficients:

$$X = \frac{CS^2}{1+\sqrt{1-PC^2S^2}} + ES^4 + FS^6 + GS^8 + HS^{10}$$

where X represents the coordinates in the direction of the optical axis, S the coordinates in the direction normal to the optical axis, C the curvature (=1/r) at the vertex of the aspherical surface, and P the conic constant.

What is claimed:

1. A real image mode finder optical system comprising, in order from an object side thereof:

an objective lens;

an image inverting optical member for erecting an object image formed by said objective lens; and

an eyepiece for observing said object image;

wherein said objective lens has a reflecting surface and satisfies a condition:

$0.1 < D/f < 0.4$

where D is a distance between an exit surface of said objective lens and an entrance surface of said image inverting optical member and f is a focal length of said objective lens.

2. A real image mode finder optical system comprising, in order from an object side thereof:

an objective lens;

an image inverting optical member having a plurality of reflecting surfaces for erecting an image, by reflections caused at said plurality of reflecting surfaces;

an eyepiece disposed after said image inerting optical member;

wherein at least one of the reflecting surfaces of said image inverting optical member is disposed inside said objective lens;

wherein the reflecting surfaces, exclusive of said at least one reflecting surface disposed within said objective lens, are integrally configured as a prism, and disposed after said objective lens; and

wherein said objective lens satisfies a condition:

$0.1 < D/f < 0.4$

where D is a distance between an exit surface of said objective lens and an entrance surface of said prism and f is a focal length of said objective lens.

3. A real image mode finder optical system according to claim **2**, wherein said objective lens comprises a lens having an entrance surface, a reflecting surface, and an exit surface, and satisfies conditions:

$$f/r1>0.9$$

$$f/r2>-0.7$$

where **r1** and **r2** are radii of curvature of the entrance surface and the exit surface of said lens, respectively.

4. A real image mode finder optical system according to claim **3**, wherein the entrance surface of said prism is a curved surface.

5. A real image mode finder optical system according to claim **3**, wherein one of the entrance surface and the exit surface of said objective lens is aspherical.

6. A real image mode finder optical system according to claim **3**, wherein both the entrance surface and the exit surface of said objective lens are aspherical.

* * * * *

US005451560A

United States Patent [19]

Akada et al.

[11] Patent Number: 5,451,560

[45] Date of Patent: Sep. 19, 1995

[54] **IMAGE FORMATION ON OBJECTIVE BODIES**

[75] Inventors: **Masanori Akada; Yoshikazu Ito; Jumpei Kanto,** all of Tokyo; **Mitsuru Takeda,** Yokohama; **Masaki Kutsukake,** Tokyo; **Noritaka Egashira,** Ichikawa; **Shunsuke Mukasa,** Tokyo; **Takao Suzuki,** Kawagoe; **Hideo Hosoi,** Tokyo; **Yasuo Otatsume,** Chiba, all of Japan

[73] Assignee: **Dai Nippon Insatsu Kabushiki Kaisha,** Japan

[21] Appl. No.: **34,186**

[22] Filed: **Mar. 18, 1993**

Related U.S. Application Data

[60] Continuation of Ser. No. 467,415, Jan. 19, 1990, abandoned, which is a division of Ser. No. 138,384, Dec. 8, 1987, Pat. No. 4,923,848.

[30] **Foreign Application Priority Data**

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Apr. 11, 1986	[JP]	Japan	61-81989
Sep. 24, 1986	[JP]	Japan	61-223896
Sep. 24, 1986	[JP]	Japan	61-225473
Oct. 1, 1986	[JP]	Japan	61-231224
Jan. 14, 1987	[JP]	Japan	62-5066
Apr. 10, 1987	[WO]	WIPO	PCT/JP87/00228

[51] **Int. Cl.**[6] **B41M 5/035;** B41M 5/38

[52] **U.S. Cl.** **503/227;** 428/195; 428/203; 428/913; 428/914; 156/235; 156/240

[58] **Field of Search** 8/471; 156/235, 239, 156/240; 428/195, 206, 207, 913, 914, 201, 203, 204; 503/227

[56] **References Cited**

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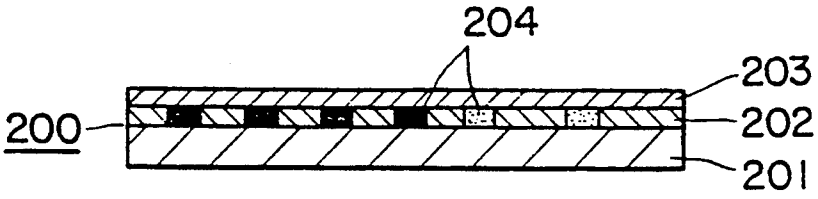
Primary Examiner—B. Hamilton Hess
Attorney, Agent, or Firm—Parkhurst, Wendel & Rossi

[57] **ABSTRACT**

The present invention relates to image-formation on any selected kind of objective body. The characterizing features reside in such that, based upon fed image data, required images are formed on an image-transferable sheet acting for image carry-over service and in reliance on sublimation image transfer technique, and then, by the use of said sheet with said images thus formed thereon, the formed images thereon are transferringly applied on the objective body. By adopting the above measures, the objective body can be formed sharply and clearly with any desired images, irrespective of kind and configuration thereof, with such superior results of highly improved unity and solidability between the formed images and the objective body to be decorated with.

5 Claims, 16 Drawing Sheets



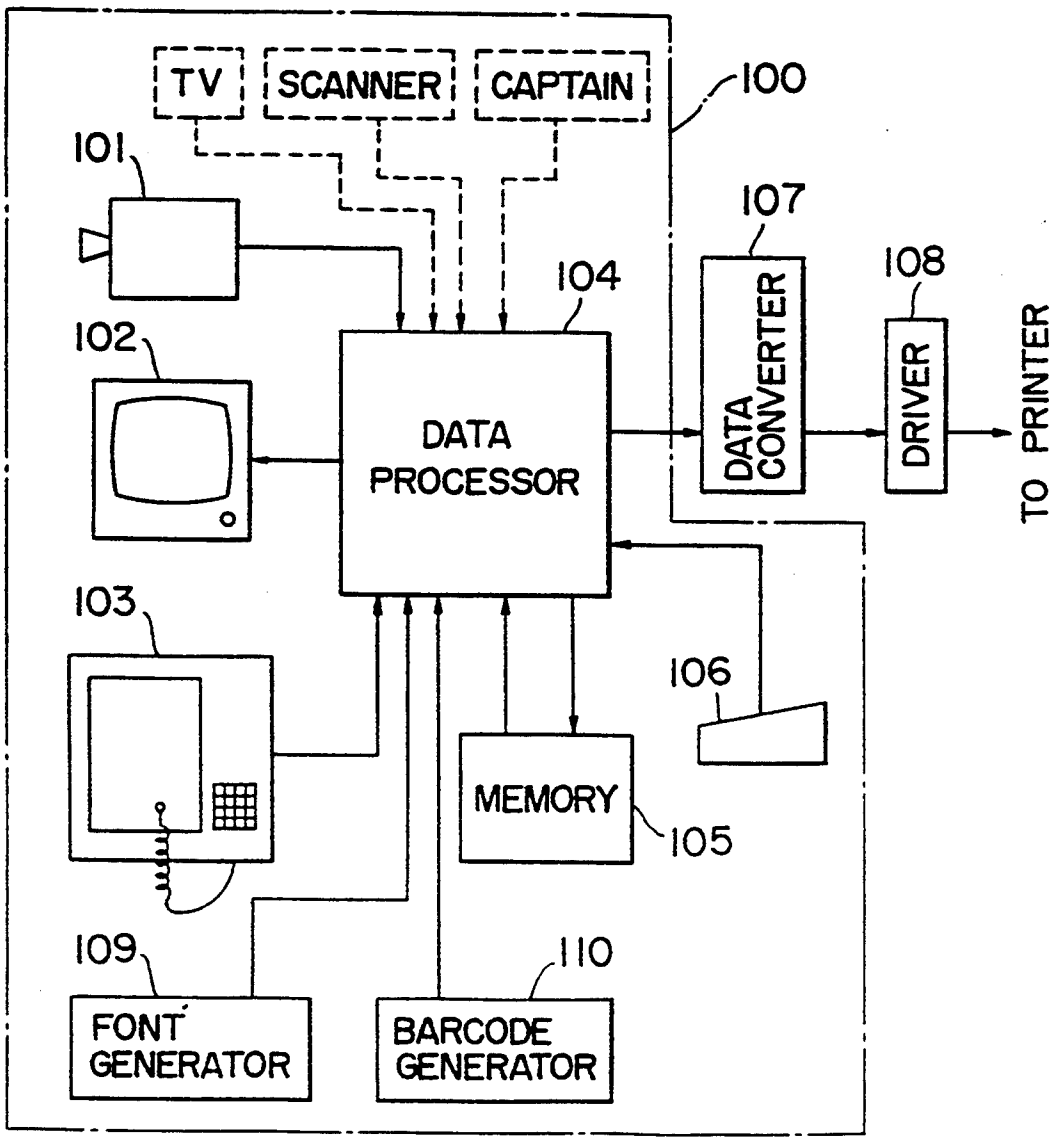

TV
SCANNER
CAPTAIN
100
101
107
108
104
102
DATA PROCESSOR
DATA CONVERTER
DRIVER
TO PRINTER
103
106
MEMORY
105
109
110
FONT GENERATOR
BARCODE GENERATOR

FIG. 1A

FIG. 1B-1

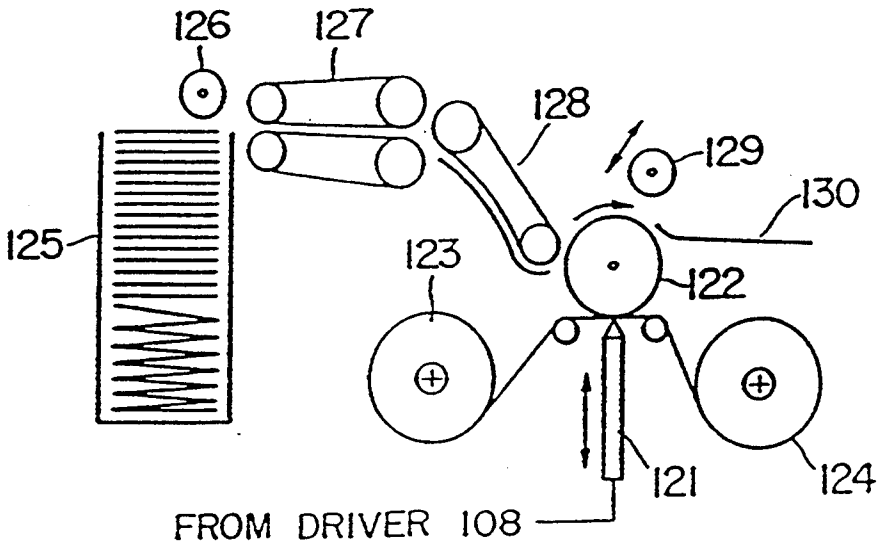


FIG. 1B-2

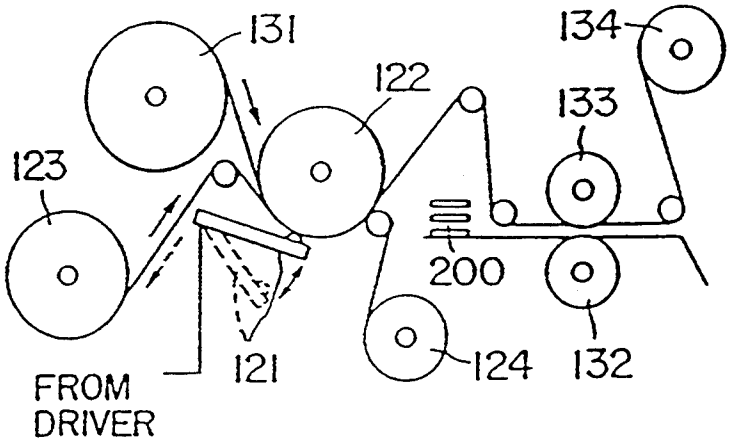
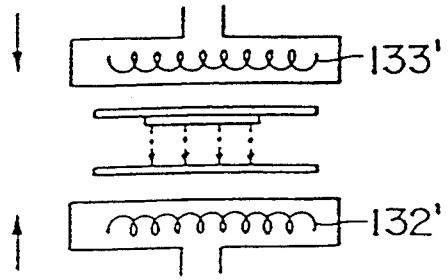


FIG. 1B-3



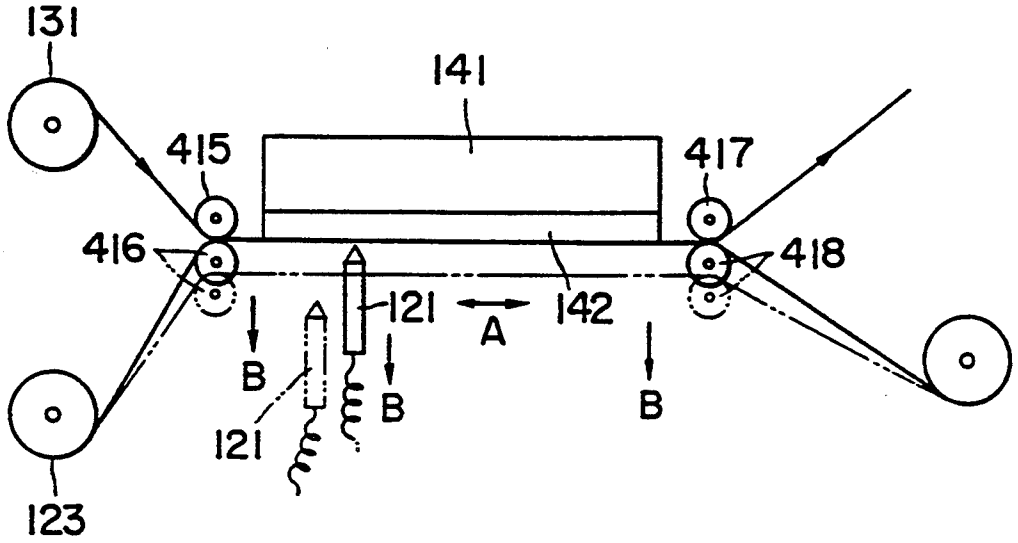


FIG. 1C

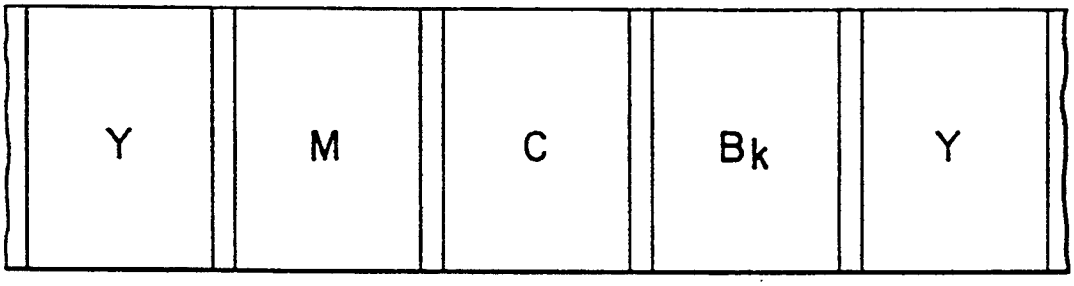


FIG. 1D

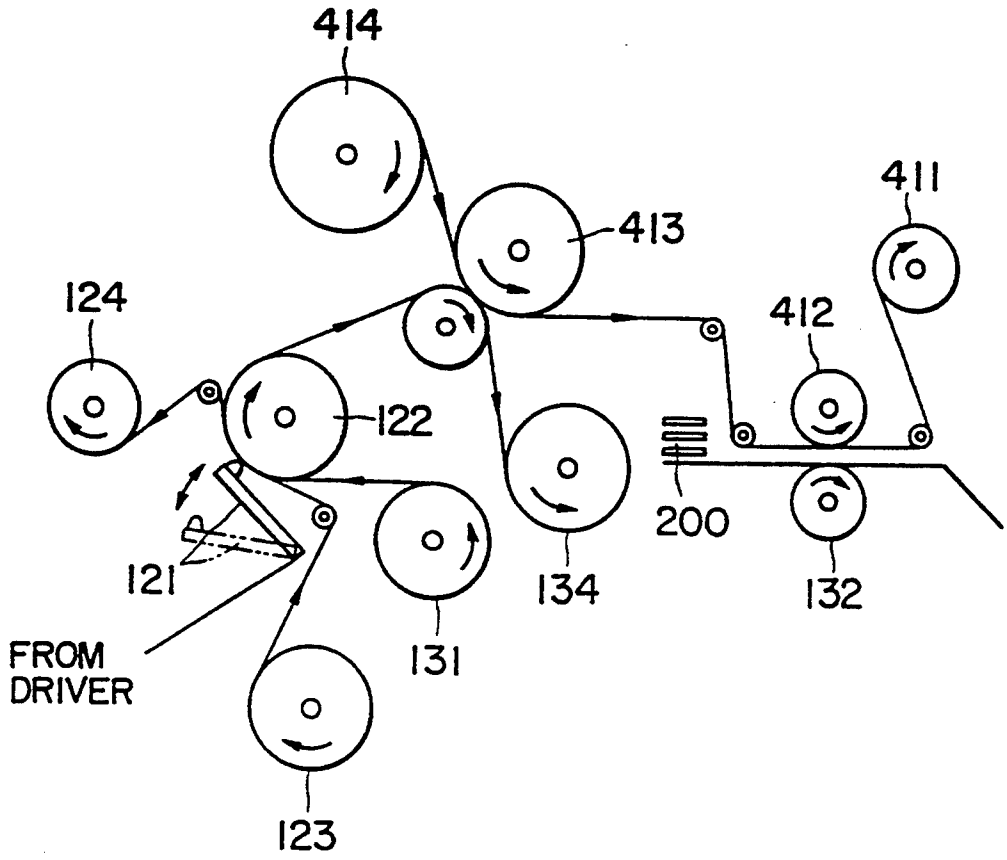


FIG. 1E

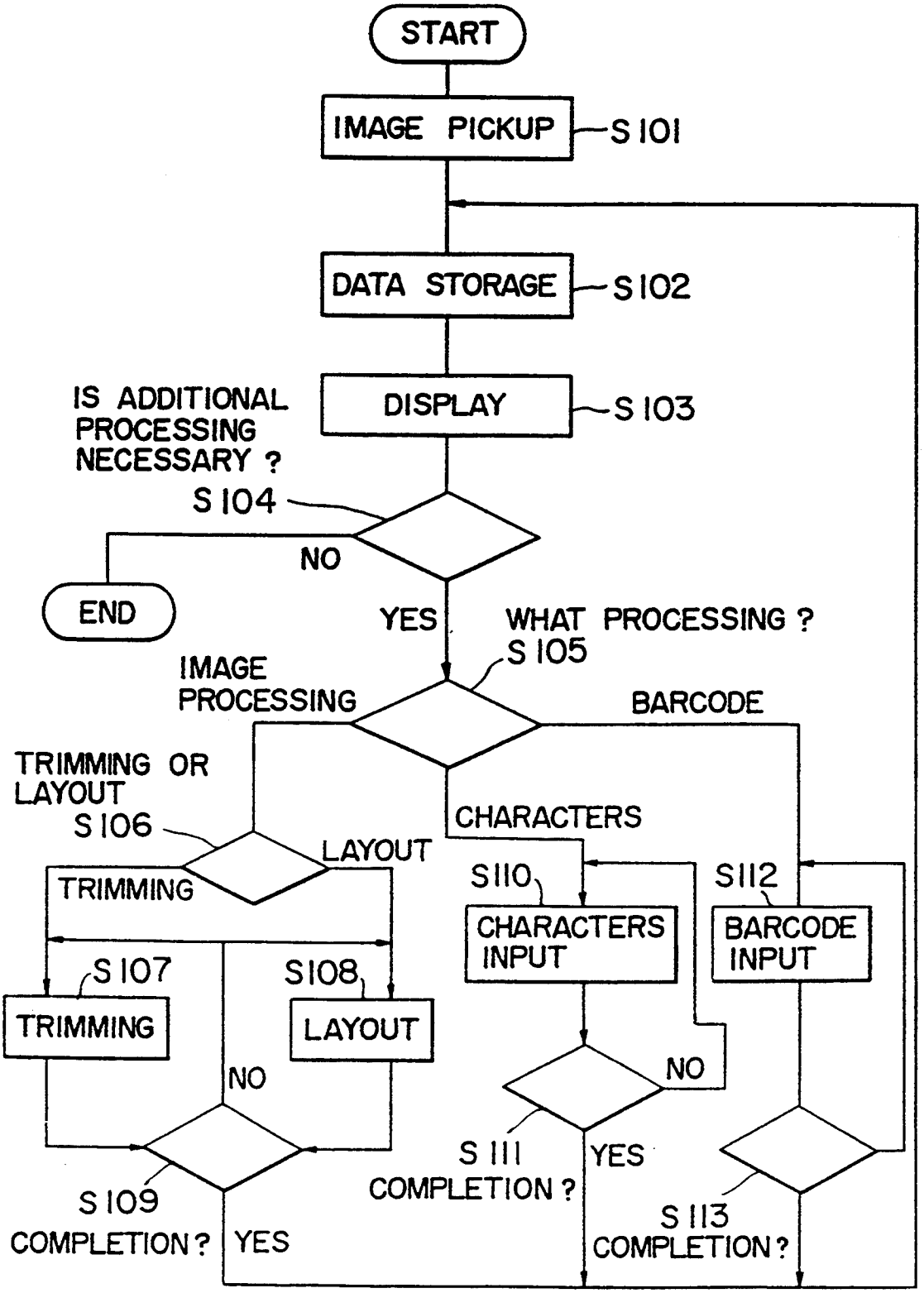

START
IMAGE PICKUP
S101
DATA STORAGE
S102
DISPLAY
S103
IS ADDITIONAL PROCESSING NECESSARY ?
S104
NO
END
YES
WHAT PROCESSING ?
S105
IMAGE PROCESSING
BARCODE
CHARACTERS
TRIMMING OR LAYOUT
S106
LAYOUT
TRIMMING
S110
S112
CHARACTERS INPUT
BARCODE INPUT
S107
S108
TRIMMING
LAYOUT
NO
NO
S111
COMPLETION ?
YES
S109
COMPLETION ?
YES
S113
COMPLETION ?

FIG. 2

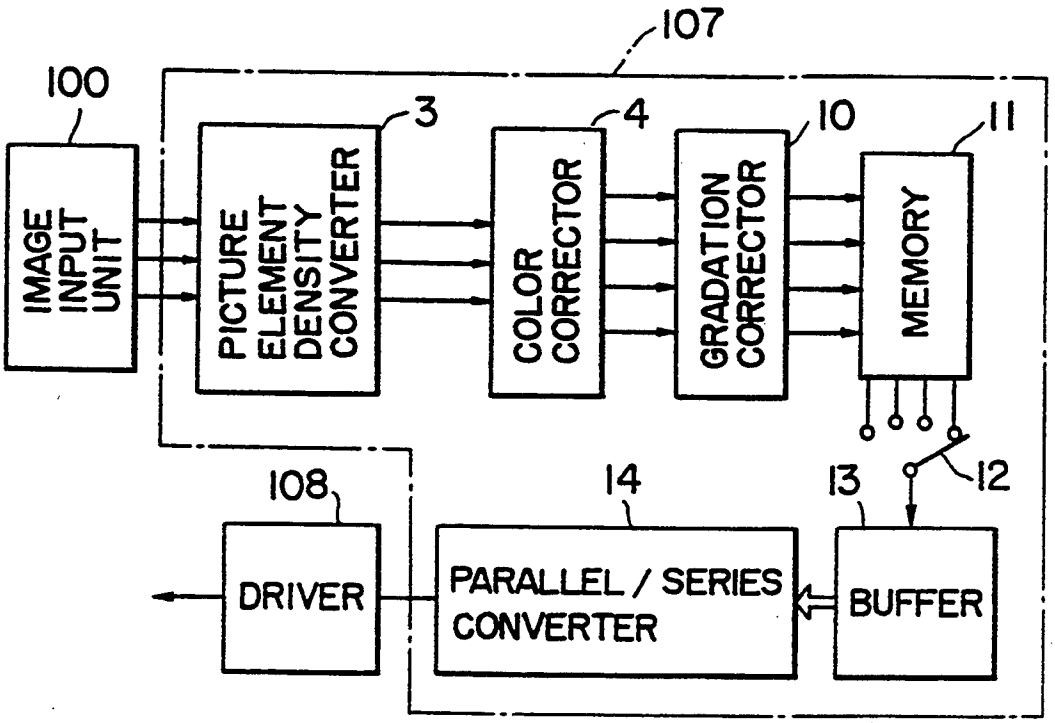

107
100
3
4
10
11
IMAGE INPUT UNIT
PICTURE ELEMENT DENSITY CONVERTER
COLOR CORRECTOR
GRADATION CORRECTOR
MEMORY
108
14
13
12
DRIVER
PARALLEL / SERIES CONVERTER
BUFFER

FIG. 3A

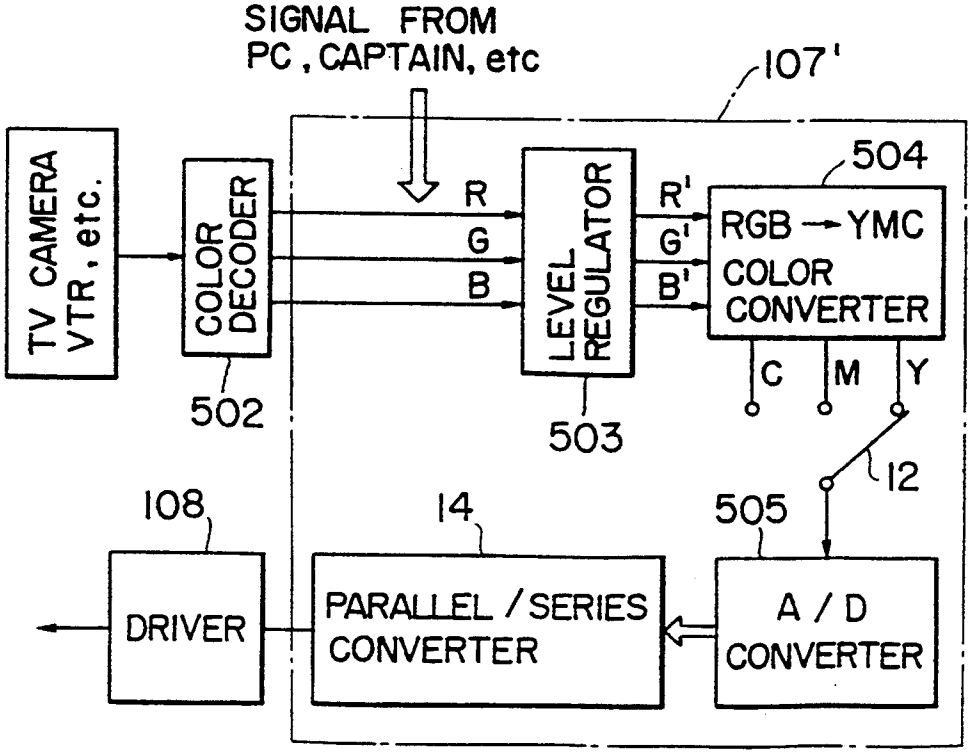

SIGNAL FROM PC, CAPTAIN, etc
107'
504
TV CAMERA VTR, etc.
COLOR DECODER
R
G
B
LEVEL REGULATOR
R'
G'
B'
RGB → YMC COLOR CONVERTER
C
M
Y
502
503
12
108
14
505
DRIVER
PARALLEL / SERIES CONVERTER
A / D CONVERTER

FIG. 3B

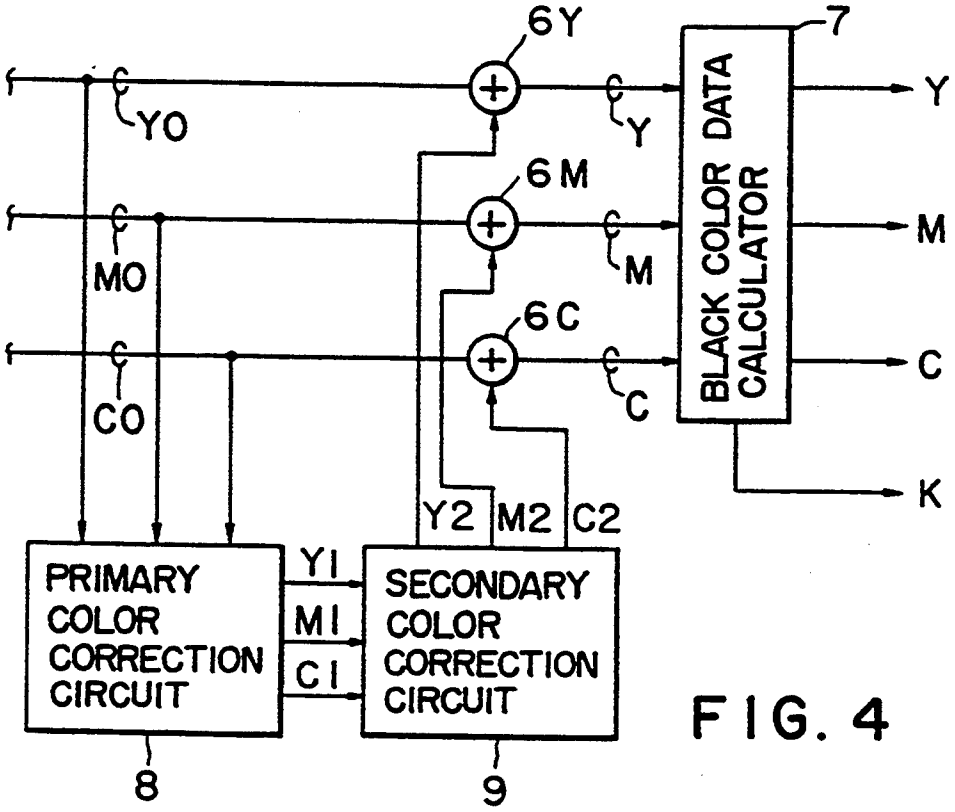

6Y
7
YO
Y
Y
6M
MO
M
M
6C
CO
C
C
BLACK COLOR DATA CALCULATOR
K
Y2
M2
C2
PRIMARY COLOR CORRECTION CIRCUIT
Y1
M1
C1
SECONDARY COLOR CORRECTION CIRCUIT
8
9

FIG. 4

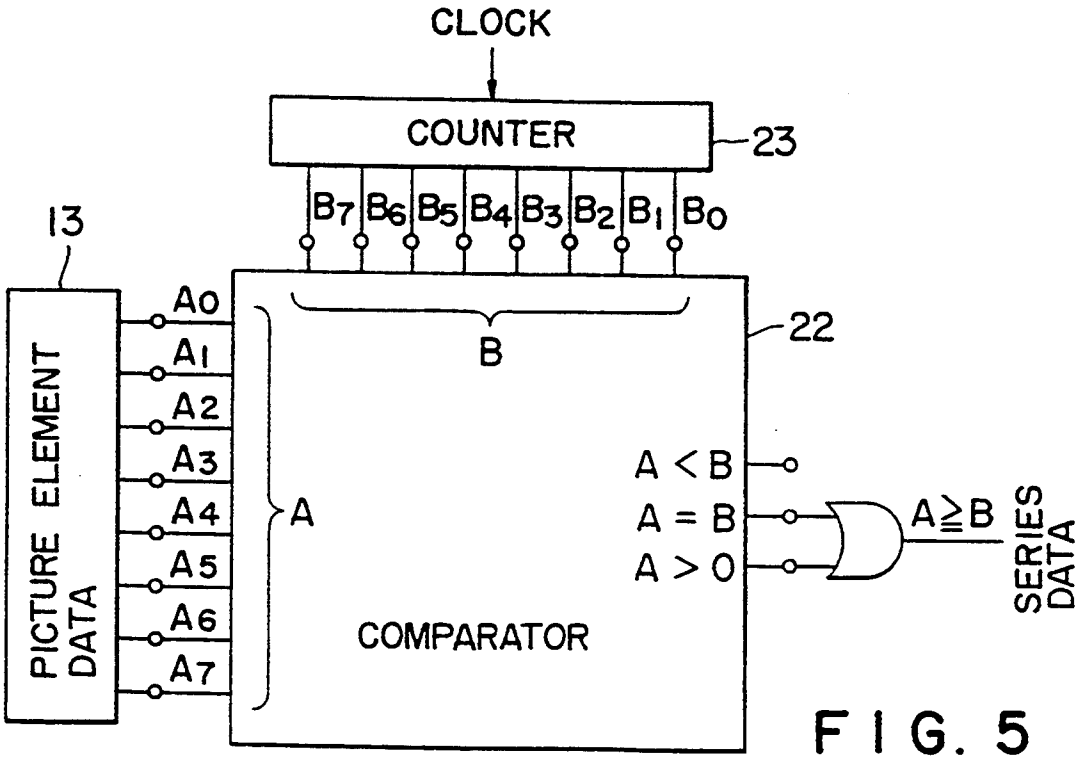

CLOCK
COUNTER
23
B7 B6 B5 B4 B3 B2 B1 B0
13
A0
A1
A2
A3
A4
A5
A6
A7
A
B
22
A < B
A = B
A > 0
A≧B
SERIES DATA
PICTURE ELEMENT DATA
COMPARATOR

FIG. 5

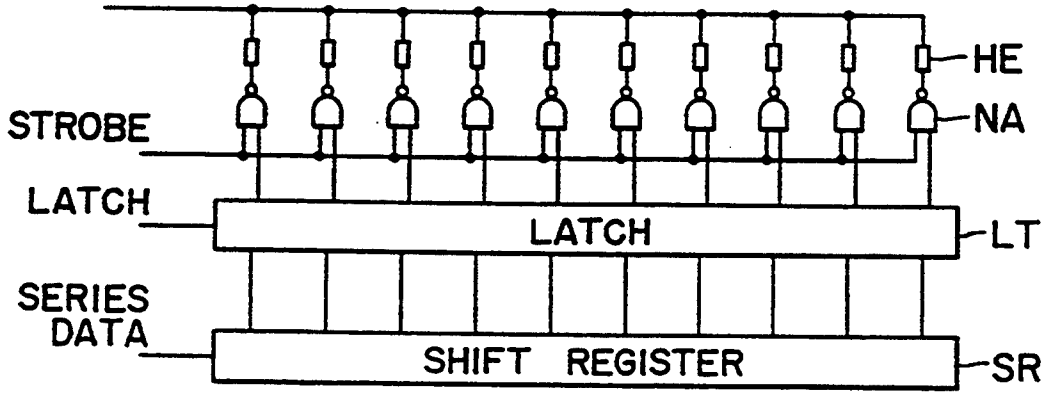

HE
NA
STROBE
LATCH
LATCH
LT
SERIES DATA
SHIFT REGISTER
SR

FIG. 6

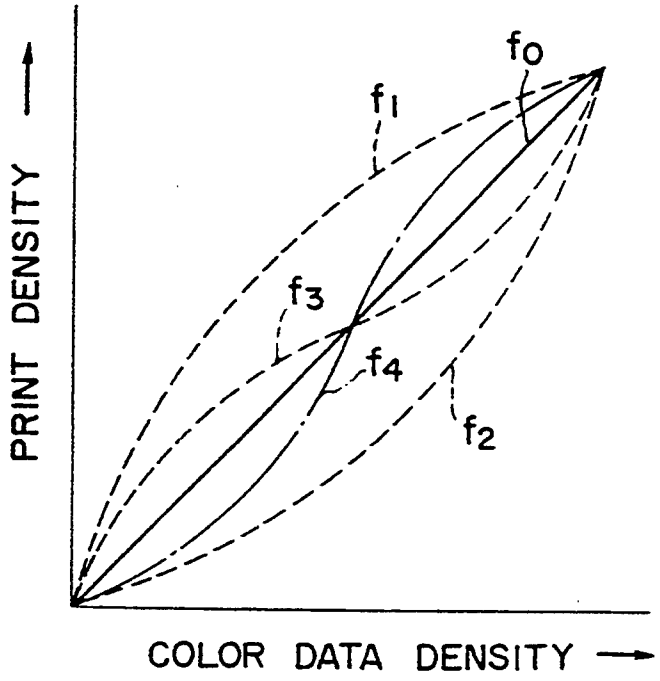

f0
f1
f3
f4
f2
PRINT DENSITY
COLOR DATA DENSITY

FIG. 7

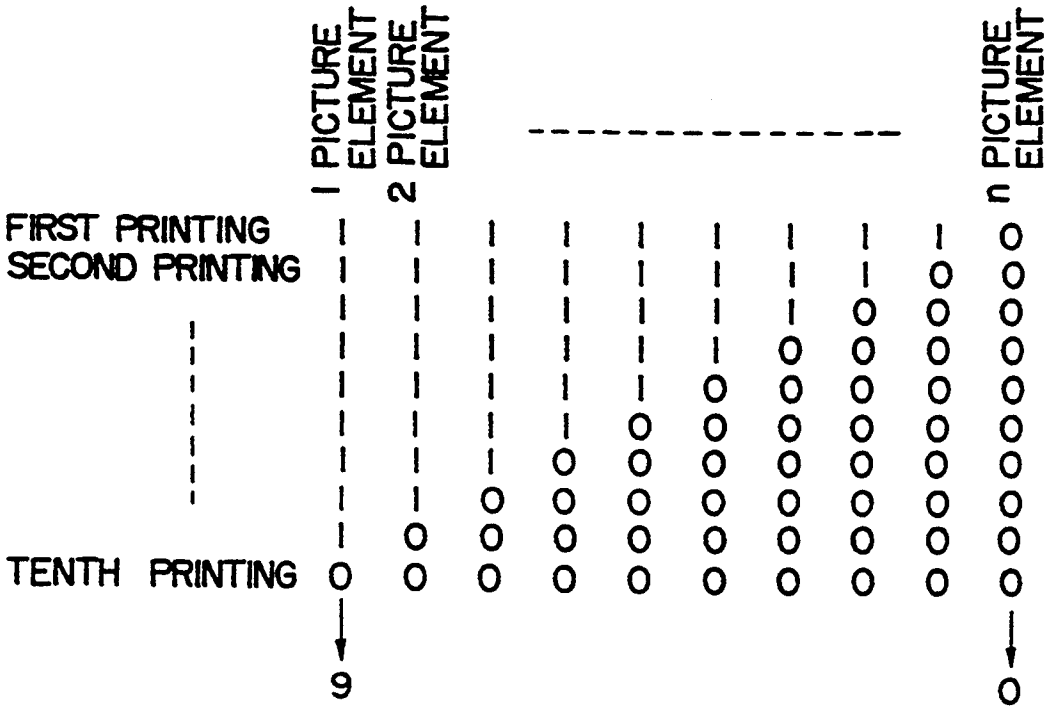

1 PICTURE ELEMENT
2 PICTURE ELEMENT
n PICTURE ELEMENT
FIRST PRINTING
SECOND PRINTING
TENTH PRINTING
9
0

FIG. 8

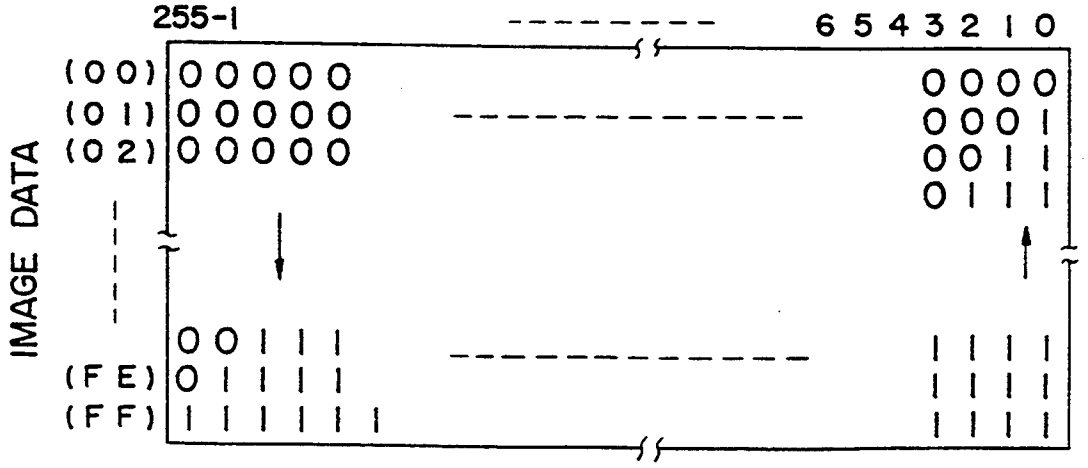

255-1
6 5 4 3 2 1 0
(0 0)
(0 1)
(0 2)
(F E)
(F F)
IMAGE DATA

FIG. 9

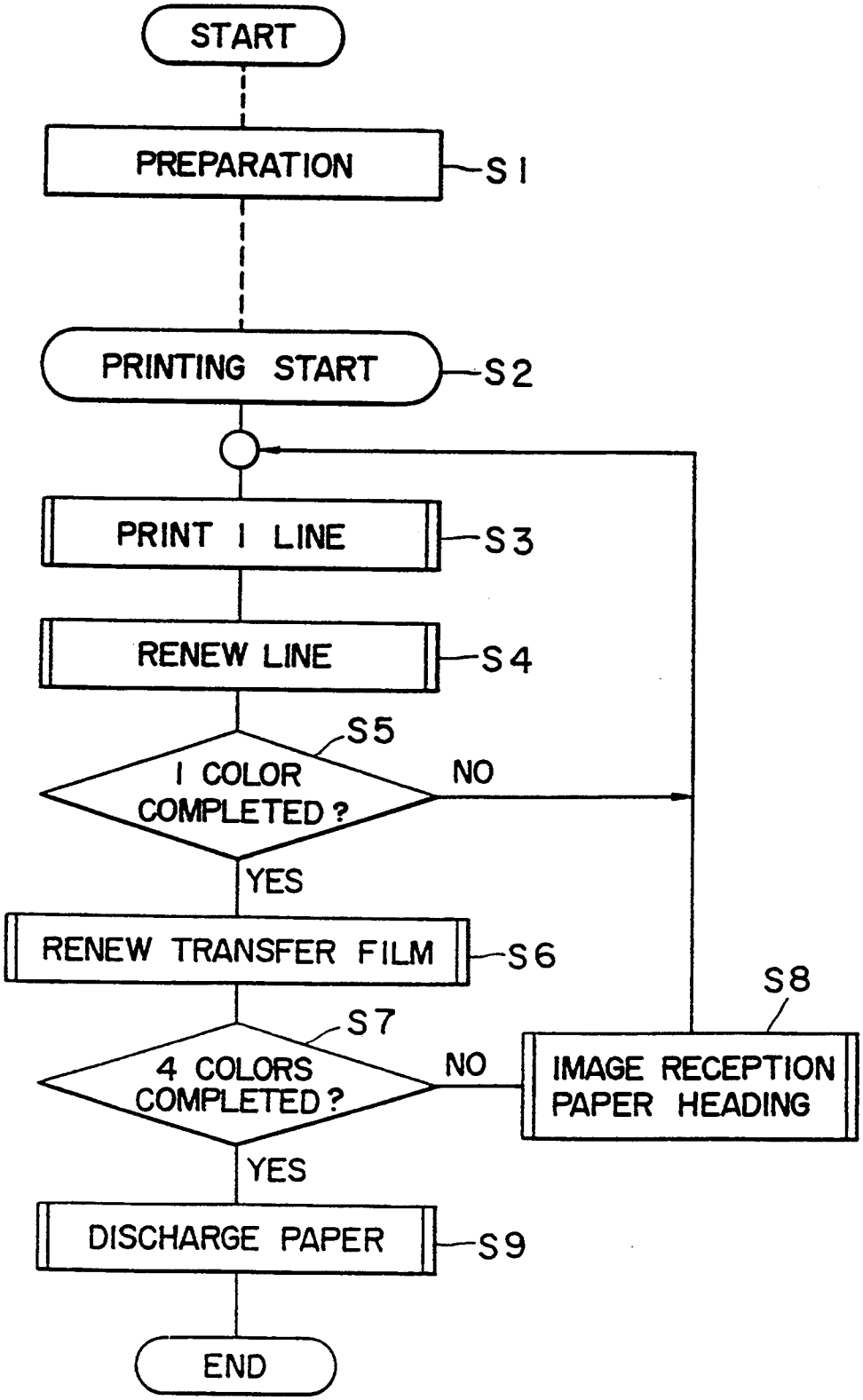

START
PREPARATION
S1
PRINTING START
S2
PRINT 1 LINE
S3
RENEW LINE
S4
S5
1 COLOR COMPLETED?
NO
YES
RENEW TRANSFER FILM
S6
S7
4 COLORS COMPLETED?
NO
S8
IMAGE RECEPTION PAPER HEADING
YES
DISCHARGE PAPER
S9
END

FIG. 10

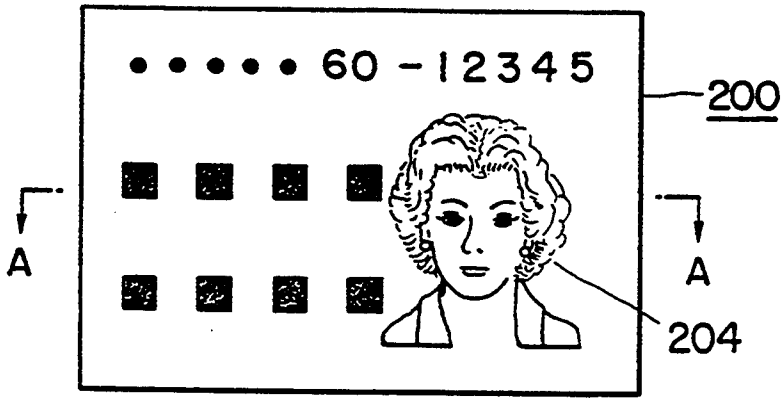


FIG. 11

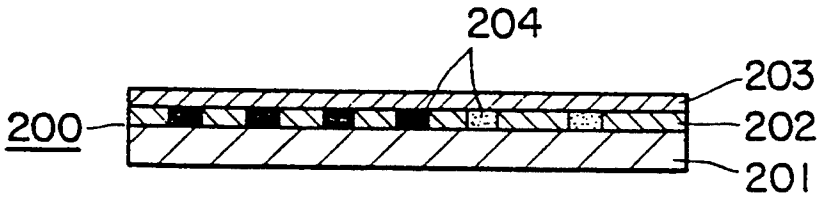


FIG. 12

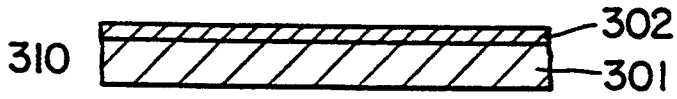


FIG. 13

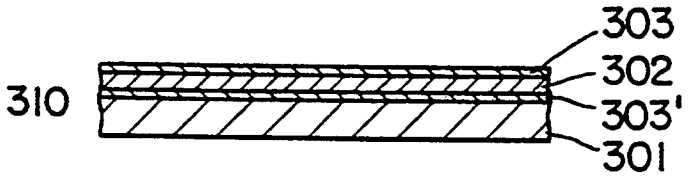


FIG. 14

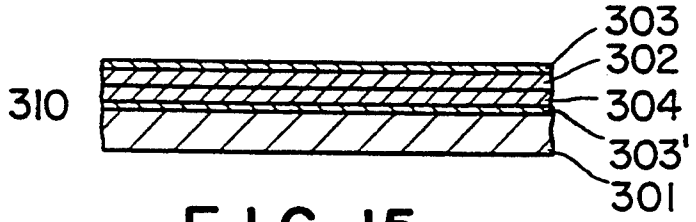


FIG. 15

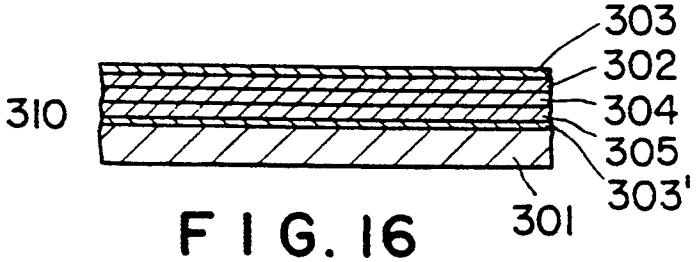


FIG. 16

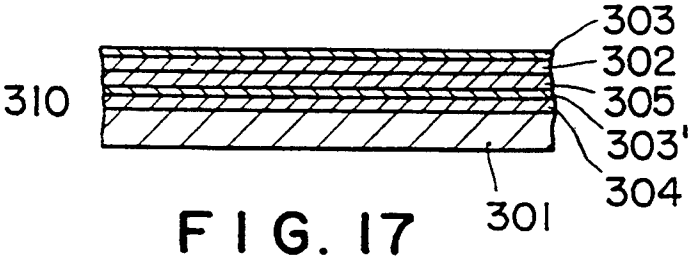


FIG. 17

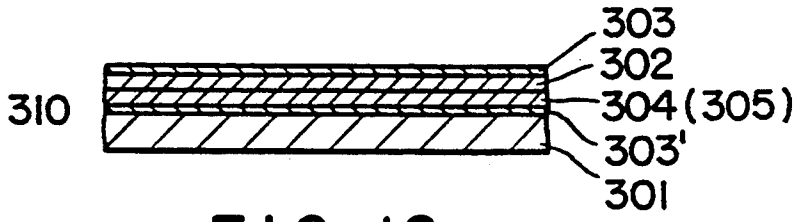


FIG. 18

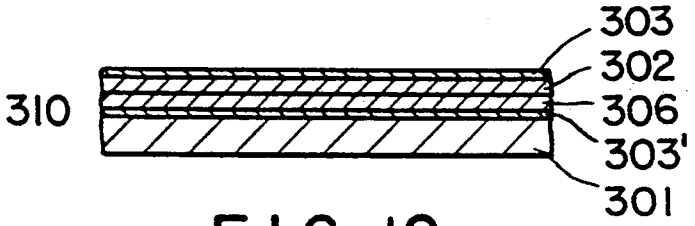


FIG. 19

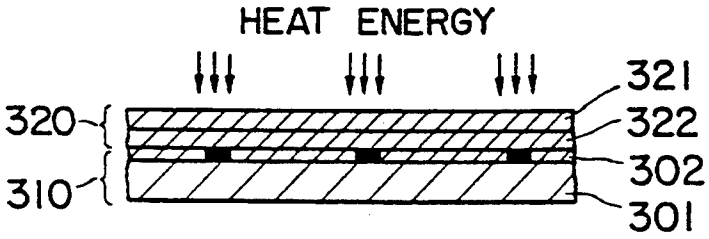


FIG. 20

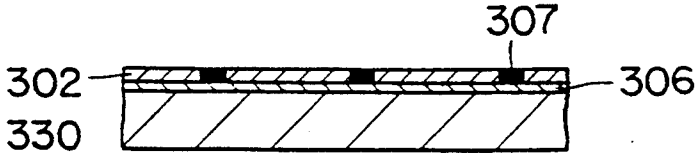


FIG. 21

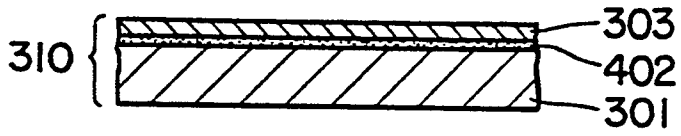


FIG. 22

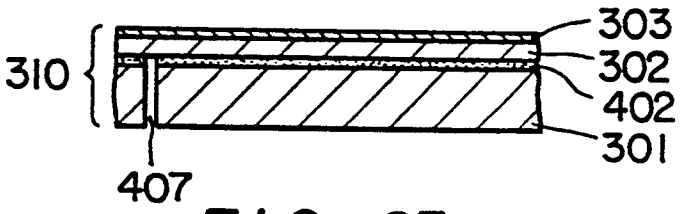


FIG. 23

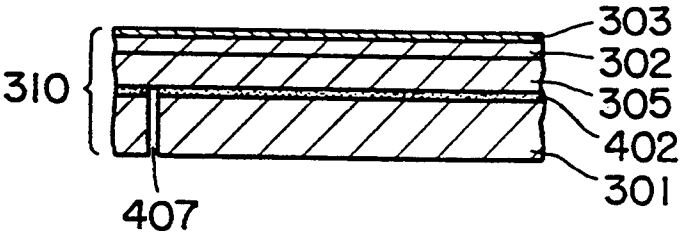


FIG. 24

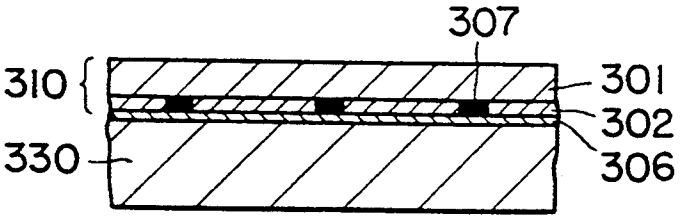


FIG. 25

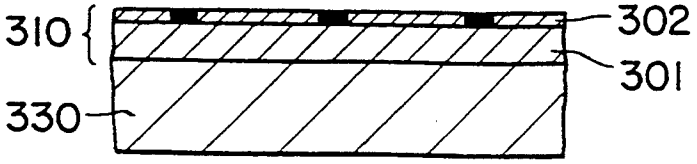


FIG. 26

FIG. 27

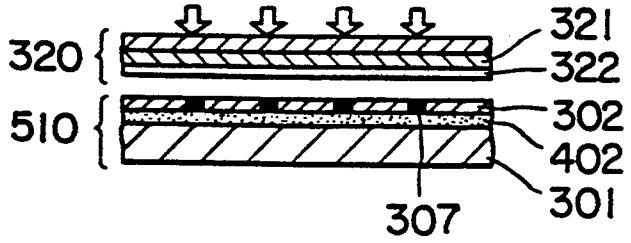


FIG. 28

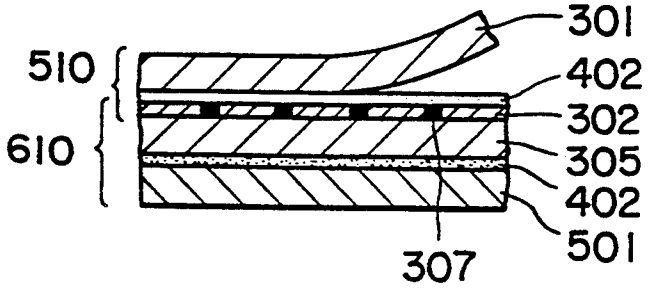


FIG. 29

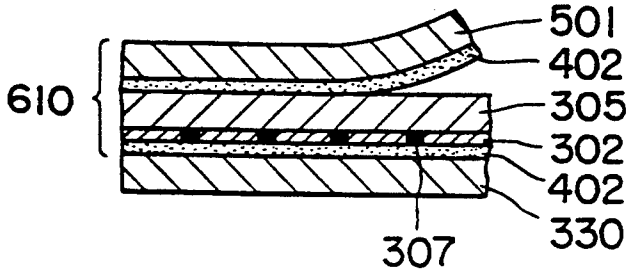


FIG. 30

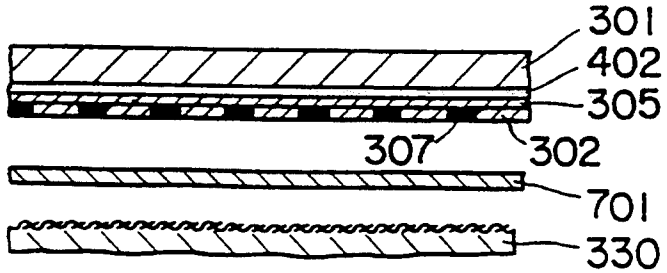


FIG. 31

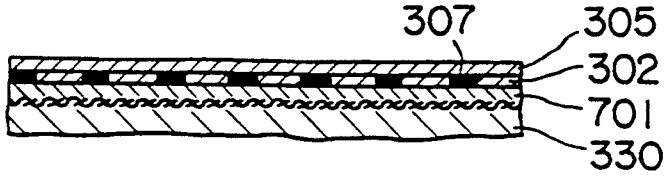


FIG. 32 (a)

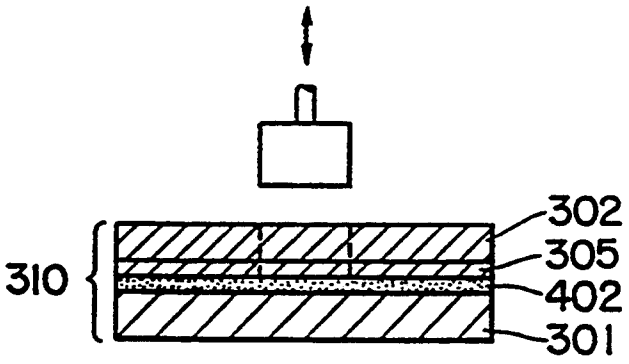


FIG. 32 (b)

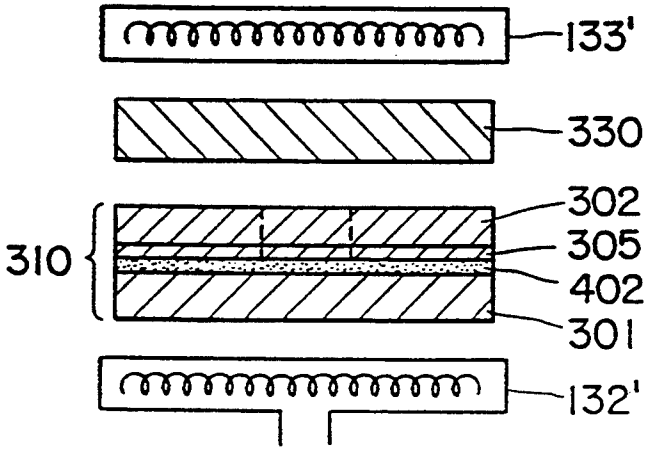


FIG. 32 (c)

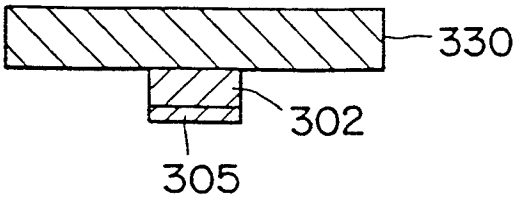


IMAGE FORMATION ON OBJECTIVE BODIES

This is a Continuation of application Ser. No. 07/467,415 filed Jan. 19,1990, now abandoned, which, in turn, is a division of application Ser. No. 07/138,384 filed Dec. 8, 1987, now U.S. Pat. No. 4,923,848 issued May 8, 1990.

TECHNICAL FIELD

This invention relates to methods and apparatus for the formation of images as prints on objective bodies through transfer of images preformed by the sublimation transfer technique, and more specifically it relates to such systems as adapted for the formation of images on any selected objective body, such as cards, clothes, papers, and transparent sheets, although these are not limitative to the present invention.

BACKGROUND ART

Reliance is made generally upon the normal printing technique for formation of images on objective bodies. For the execution of the printing technique, provision and use of printing plates (forms or blocks) are requisite. No matter how simple the image-printing is, the plate-making is a very time-consuming and laborious procedure. This is much more so in the printing of various and complexed image combinations, such as those of graphic or portrait images combined with characters, letters or barcodes, as an example, representing extremely complicated and troublesome work.

Further, in the normal printing operation, various operating conditions, including ink selection and the like, must be carefully considered, depending upon the kind and nature of the printing object, thus the best selection thereof is highly delicate and not as simple as expected.

The present invention is proposed upon careful consideration of the foregoing facts, and an object of the invention is to provide a unique process for the formation of sharp and clear images regardless of the kind and nature of the object to be printed upon, and usable and effective materials and apparatuses for carrying out this unique process.

The method of thermal image transfer (sublimation image transfer) on clothes or fabrics with the use of thermal transfer dyestuffs has been practiced for a long time. In this conventional process, a dyestuff picture layer carrying thermal transfer dyestuff is formed on a substrate sheet which is then subjected to heat in an overlapped state on a cloth or fabric, the dyestuff thereby being transferred thermally onto the latter for forming the desired images thereon. By utilizing this technique, and with recent development of the image forming technology concerning fine thermal printers and the like, various fine image forming processes have been proposed to provide fine images which are comparable to photographic images and are transferred onto plastic films from thermal transfer sheets carrying thermal transfer dyestuffs.

According to these recently proposed processes, various images of cameras, or TVs, graphic images of personal computers and the like can be reproduced easily in the form of hard copies on the surface of a transferred material such as a paper or the like sheet carrying thereon a fixedly attached layer of polyester resin, as an example. These images thus reproduced represent an amply high level comparable to those obtained by photography or fine printing arts.

The thermal transfer process so far set forth has an advantage in that it can form any image in a convenient manner yet entails a problem in that it is limited to image-transferred products preferably of polyester and the like materials which must be dyed with thermal transfer dyes. On the other hand, the image-transferred products must be limited to specifically selected shapes, preferably film, sheet or the like configuration, and thus, such materials as wood, metal, glass or ceramics cannot be formed with images in this way. Further, even if the material is plastics such as polyester or the like, and when the image-forming surface is curved or undulated, or physical body other than sheet, even if it represents a plane surface, it is almost impossible to reproduce images precisely thereon, which naturally constitutes a grave problem in the art.

With recent development and enlargement of utilizing fields of various card-style products, such as cash-cards, telephone-cards, prepayment cards; and ID-cards, there are increasing demands for providing these cards with images, symbols and codes, so as to give various other functional and/or decorative effects. Most of these cards are of planar form, but they are frequently not pliable and/or have uneven rough portions due to provision of characters and symbols, resulting in great difficulty in the scheduled image formation relying upon the thermal image transfer process.

There is therefore an urgent demand among those skilled in the art for the provision of a unique technique capable of forming sharp and clear images of desired patterns on the surface of an objective body of any preferred kind of material and having any shape and configuration and surface condition of any kind, and indeed, for combining and unifying image- and decoration effects.

DISCLOSURE OF THE INVENTION

The present invention is basically based on such a principle that a first image transfer pattern is formed on an image transfer material, preferably an image transfer sheet, and in the form of dyestuff images through the sublimation image transfer process executed by first image transfer means, depending upon given image data, preferably including those of letters, characters, symbols, line images, graduated graphic representations, and then the first transfer pattern is transferred to second transfer means for retransferring the images onto an objective body so as to provide a final product.

Based upon the image data fed from various image data input means and at the first image-transfer means, a thermal head is actuated to execute printing operation through a dyestuff film (thermal image-transfer sheet) on an image-transfer material (or more specifically on an image-transferable material which means an image-transferable sheet). This image-printing is carried out according to the sublimation or sublimative image transfer technique. Thus, in this case, the dyestuff on the dyestuff film is transferred or shifted under the influence of heat energy from the thermal head onto the image-transfer material through sublimation, thus providing the first image-transferred means. Since this first image-transferred means has been thus formed with the images by the sublimated dyestuff, they are, then, transferred onto the second image-transferable means which will be brought into tight contact with the object to be decorated and subjected to heat and pressure for execu-

tion of further image-transfer operation to provide the final desired product.

In the present invention, the image-transfer material (image-transferable sheet) is, as above referred to, formed with images by the sublimative image transfer technique for providing first image-transfer means which has highly sharp and clear images as the operation and results of the characterizing feature of the sublimation image-transfer technique. Therefore, because of the transfer of such sharp and clear images onto the object, it becomes possible to form the images thereon, and indeed, practically irrespective of the kind and nature of the object. In this way, thus, fine image-formation is assured onto practically any objective substance.

And further, by execution of control of the thermal energy applied during the sublimative image-transfer step, the resulting color effect is superior and the image quality is good.

The images sublimatingly applied and formed in the foregoing way are subjected to a further transfer, and onto a substrate product, for providing a final decorative product as desired. In this final product, it should be noted that the underlying layer underneath the images during the sublimative image-transfer stage appears now at the top, acting thus as a kind of protecting layer upon up-and-down positional conversion during execution of the second and final image-transfer stage, resulting in realization of various and numerous effects. As an example, attainment of substantial reduction of contamination, improvement of light resistance, weather resistance and chemical resistance; substantial reduction of color fading; provision of glazing effect; easier and simpler introduction of granular and/or undulated image appearance.

The inventive process is carried into effect basically in such a manner that an image-reception layer provided on one surface of an image-transferable sheet is subjected to an image-forming step with the use of dyestuff capable of depositing therein depending upon the fed image data, so as to form the required images, and then, the image-reception layer of the image-transferable sheet, having been image-fixed and thus now image-carrying, is stuck onto the surface of the object to be decorated upon.

As for the image-transferable sheet adapted for use in the image-transfer during execution of the inventive process, it consists basically of a sheet-like substrate and a reception layer attached, however, in a separable manner, onto one surface thereof. As a modification of the inventive process from the basic mode set forth above, the sheet-like substrate is caused to remain, even after completion of the image-transfer step, as may be occasionally required. In this modified case, it is unnecessary to make the image-reception layer of the image-transfer sheet separable.

Under occasion, the inventive process may be brought into effect in such a way that the image-reception layer of the image-transfer sheet is transferred upon execution of the image-forming step, and indeed, once onto an intermediate image-transfer substrate which is then retransferred, together with the once transferred image-reception layer, onto the surface of an object to be decorated on, and thus, in a retransferring manner.

BRIEF DESCRIPTION OF THE DRAWINGS

In the accompanying drawings:

FIG. **1A** is a block diagram, showing a preferred embodiment of the apparatus according to the present invention;

FIG. **1B** is a schematic view illustrating at B-1, B-2 and B-3, several image-transfer steps for the execution of a process according to the invention;

FIG. **1C** is a schematic view of an image-transfer step, using a platen roll;

FIG. **1D** is a plan view of part of a multi-color dyestuff film adapted for use in an image-forming step;

FIG. **1E** is a schematic view for the illustration of several image-transfer steps;

FIG. **2** is a flow chart of successive operation steps with use of a data-processor, shown in FIG. **1**, functioning as an operating center;

FIG. **3A** is a schematic block diagram, showing a data-processor for the printer;

FIG. **3B** is a block diagram of a sublimative image-transferring printer adopted in the present invention, as a preferred embodiment thereof;

FIG. **4** is a schematic block diagram, showing a color correction unit shown in FIG. **3A**, and several related parts cooperating therewith;

FIG. **5** is a schematic block diagram of a comparator and several related parts cooperating therewith;

FIG. **6** is a circuit block diagram of an image-transfer head shown in FIG. **1B**;

FIG. **7** is a graph showing operational characteristics of a color tone or -gradation corrector unit shown in FIG. **3A**;

FIG. **8** is a table for the illustration, as an example, of picture- or image-elements, as expressed in binary signals;

FIG. **9** is a table showing a conversion operation, as an example, of a parallel/series converter shown in FIG. **3A**;

FIG. **10** is a flow chart, illustrating the operation of the sublimative image transfer printer;

FIG. **11** is a plan view of a final decorative product prepared according to the inventive technique;

FIG. **12** is a sectional view of the product card shown in FIG. **11**, and taken along a section line A—A shown therein;

FIGS. **13** through **31** are a series of sectional views, respectively illustrating several structural examples of image-transferable sheets, suitable for use in the invention; and

FIGS. **32** (*a*), (*b*), and (*c*) are sectional views, indicating final transfer steps.

BEST MODES FOR CARRYING OUT THE INVENTION

Referring now to FIG. **1A** and FIG. **1B**, **1B-1**, **1B-2** and **1B-3**, a basic scheme of the inventive image data processing and image formation will be illustrated. First, in FIG. **1A**, numeral **101** represents an image input means which is adapted for forming image data based upon optical and the like inputs delivered from a TV-camera, line sensor or the like. Other than those above enlisted only by way of example, video; CD; TV; scanner;-personal computer, captain system, capable of providing R.G.B.- and picture image and the like signals may also be utilized in a similar way. The image signal data delivered from the image input means are fed through a data processor **104** to a memory **105** for being stored therein. These stored data can be taken out from the memory and fed through data processor **104** to display means **102** for being displayed thereat.

To the data processer **104**, a mouth/tablet digitizer and/or the like position data processer **103** is electrically connected for introducing position data concerning displayed images appearing at the display **102**. In addition, key board and the like character data input means **106** and font generator **109** are provided for introducing character data. Still further, a barcode generator **110** is provided for introducing barcode when necessary. By the use of these means and units, various additional processing modes can be executed.

The thus processed data are subjected to conversion at a data converter **107** into proper data adapted for operating a sublimation transfer printer and fed forward through a driver **108** to the thermal head.

In this case, by controlling the current duration period to the thermal element of the thermal head, the transfer quantity from the dyestuff film (thermal transfer sheet) is controlled depending upon the thermal energy of the element for realization of the desired gradation degree of concentration on the transfer sheet. There are two different modes of such control of current duration period as follows:

(a) A method for controlling the pulse length corresponding to the picture element in the impressed data to the thermal element of the thermal head or, more specifically, a series data introduced as input to the shift register shown in FIG. **6** and to be described more specifically hereinafter.

(b) A method for controlling the number of pulses of the pulse series corresponding to the picture elements of the data impressed upon the thermal element in the thermal head (in this case, the pulse length being constant).

The degree of gradation of the transfer image can be controlled in the above mentioned way by the regulation of the current-conducting period depending upon the desired gradation degree. On the other hand, the image concentration can be controlled by adjusting the pulse length or the number of pulses contained in the pulse series in correspondence to the picture elements contained in the data as introduced in the shift register and depending upon the driving mode of the thermal head. Further in this case, if the number of gradation of introduced image data is larger than that which can be expressed by the printer unit, a proper conversion operation can be performed by the known strobe control method. As an example, in such case, the conversion of gradation number **256** to **64** may be executed by a ROM, and the thus reduced gradation number can be used as output.

Next, referring to FIG. **1B** at **1B-1** and **1B-2**, reference numeral **121** represents a thermal head which receives signals from the driver **108** shown in FIG. **1A**. This thermal head **121** is arranged in opposition to platen roll **122**, forming the printing position therebetween. The dyestuff film (thermal transfer sheet) is fed from a delivery roll **123** to a winding roll **124** through this printing position, these structural and functional features being commonly employed in both the arrangements shown in FIG. **1B** at **1B-1** and **1B-2**.

In the case of FIG. **1B-1**, the mechanism is so arranged that card or sheet style transfer sheets are printed with dyestuff images.

On the other hand, in the case of FIG. **1B-2**, the mechanism is so arranged that cards are continuously produced with the use of a film style transfer sheet and a dyestuff film in combination.

Now turning back to FIG. **1B-1**, a number of transfer sheets (cards, sheets or the like) have been stacked and stored within a storage casing **125** and are being thrust upward from below by a spring so that the uppermost sheet is kept in pressure contact with a take-out roll **126**. With the rotation of the roll **126**, the sheets are successively delivered from the casing **125** by conveyer belts **127, 128** onto a platen roll **122**. Each one of the sheets is fixed on the peripheral surface of the platen roll, now positionally indexed, by means of a gripper or the like mechanical attaching and separating means, static attracting means, or electromagnetic attaching means. Then, the roll **122** is so rotated that the transfer sheet is positioned at the ready-for-printing-position.

Next, the thermal head **121** is brought into pressure contact with the transfer sheet through the intermediary of the dyestuff film, and then the thermal head **121** is energized with electric current while the dyestuff film and platen roll **122** are moved in synchronism for the execution of image transfer (first image transfer).

Upon execution of the image transfer, the platen roll **122** is rotated, the gripper is released and the take-out roll **129** is rotated and brought into pressure contact for taking out the image transfer sheet onto a tray **130**.

The thus taken-out sheet is brought into overlapped state with a new image transfer sheet, not shown, and then, both the sheets are fusingly united together by pressure application of a heated roll, not shown, for execution of a second transfer step job. The whole operation has thus been completed. Before the fusion process, the sheets may be subjected to punching, trimming and/or the like processing, if necessary.

By execution of the foregoing operational steps, a monocolor printing operation has been completed. However, in the case of multicolor printing, use is made of tricolored or quadruple colored dyestuff film and the corresponding printing operations must be repeated. In this case, upon completion of a single monocolor printing procedure, the platen roll is rotated without contact of the take-out roll **129**, until it arrives again at the printing-initiation position, and so on.

In the following, a tricolor printing job will be illustrated with reference to FIG. **1B-2**, and with use of three different series color zones, of cyan, magenta and yellow.

First, a platen roll **122** is positionally indexed, and an image transfer sheet taken out from the roll **131** and a dyestuff film taken out from the roll **123** are brought into pressure contact in an overlapped state. Then a thermal head **121** is pressed against the platen roll **122** through the intermediary of the overlapped sheets. At this stage, the platen roll **122** is rotated counterclockwise while synchronism is kept between the platen roll **122** and the dyestuff film, and the thermal head **121** is kept electrically energized. In this way, the first color printing is executed.

Further, the dyestuff film is fed to the second color zone position, and then, the platen roll **122**, the dyestuff film and the image transfer sheet are fed forward clockwise around the center roll **122**. Thus a second color printing step is executed.

Further, the print-serviced two color sections of the film is fed back counter clockwise around the center of the platen roll **122** for the execution of a third color printing step. Then, each card sheet is taken out from the stack **200** under the action of take-out rolls or the like, not shown, towards and between a pair of thermal transfer rolls **132, 133**, brought into overlapping state

with the image transfer sheet positionally indexed and already subjected to image transfer steps as was described above, and finally subjected to a picture printing operation by pressurizing application of the thermal image transfer rolls **132, 133** from both sides of each taken-out card, and so on.

The color-printing step with the use of the thermal head is carried into effect in the following manner, as an example.

(First color printing)

Platen roll, image transfer sheet and dyestuff film perform the printing while they are moved in the counterclockwise direction.

(Second color printing)

Platen roll and image transfer sheet are moved in the clockwise direction while the dyestuff film is moved at the same speed and in the counterclockwise direction for performing the color printing under consideration.

(Third color printing)

Platen roll, image transfer sheet and dyestuff film are moved in the counterclockwise direction for execution of the color printing under consideration.

In the modified arrangement shown in FIG. **1B-3**, thermal image transfer rolls **132, 133** have been replaced by a flat press type image transfer head having up-and-down movable flat printer elements **132'**, **133'**.

It should be noted that in the course of the foregoing first and second image transfer steps, image reversal phenomenon is necessarily brought about upon execution of each image transfer step. In other words and more specifically, when two successive image transfer steps in the foregoing sense are executed, reverse images which have once appeared will return to the original normal images. Therefore, when the printed-out products are to be provided upon execution of the first image transfer step, it is necessary to provide reversed image data in the signal processing system. For this purpose, it is only necessary to reverse the addressing order at the data introduction or readout stage into or from the memory.

In the modified arrangement shown in FIG. **1C**, the foregoing platen roll means has been replaced by a metal block **141** lined with a rubber plate **142** in an overlapped manner. The image transfer sheet and dyestuff film are fed out from respective rolls **131** and **123**. With the use of this modified arrangement, the dyestuff surface layer of the dyestuff film can be brought into tight contact with the image-receiving surface layer of the image transfer sheet, and thermal energy will be transferred evenly form the thermal head **121** to the dyestuff film.

In this case, the image transfer sheet is delivered from the roll **131**, and the desired zone or region of the sheet is set underneath the rubber plate **142** (step **1**).

At the same time, the dyestuff film shown in FIG. **1D** on an enlarged scale is delivered from the roll **123** and a selected one of the different color regions is set underneath the rubber plate **142** (step **2**).

Next, the thermal head **121** is brought into the rear surface of the dyestuff film which is the opposite surface to the dyestuff-coated front layer, and the head **121** is driven while it is being translated in the direction shown by an arrow A, images thereby being formed at the specifically allocated zone(s) or region(s) of the image transfer sheet (step **3**).

Further, the thermal head **121** and rolls **416** and **418** are shifted downwards as shown by arrows B, so as to form an idle gap between the image transfer sheet and the dyestuff film for allowing the latter to shift towards the next following color region (step **4**).

Further, the thermal head **121** and rolls **416** and **418** are returned to their original positions, whereupon the third and further succeeding steps are repeatedly executed until a certain predesired number of color printings are completed.

As shown in FIG. **1D**, the dyestuff film is colored to have several different color regions denoted by Y (yellow), M (magenta), C (cyan) and Bk (black). However, the arrangement order is not limited to that shown: Y; M; C and Bk. In addition, as occasionally required, the Bk-region may be dispensed with. Further, as the color elements to be adopted in the Y, M, C-system may not be limited to the three primary colors provided by the subtractive color mixture. On occasion, a characterizing color which means such a color as preadjusted to provide an objective specifically selected one may be used to form the images concerned. As a further modification, the arrangement shown in FIG. **1C** may be so modified that the traveling direction of the image transfer sheet is selected to be perpendicular to that of the dyestuff film.

FIG. **2** is an operation flow chart for showing schematically operational modes taking the data processor **104** adopted in the embodiment shown in FIG. **1** as the centrum of description. The operational contents of several working parts downstream of the data converter **107** will be set forth separately hereinbelow. Now referring to FIG. **2**, in combination with FIG. **1** and at the step of **S101**, image pickup operation is carried out by means of the image pickup means **101**. For execution of this step, it may be better to pick up the face of a person per se which is to be represented on the card, or alternatively, a photograph, portrait or imagery product thereof will do. Depending upon the nature of the object, a TV camera, line sensor or the like instrument may naturally be selectively utilized.

The data taken by the image pickup means **101** are stored through the data processor **104** at a memory **105** (**S102**). By the use of these stored data, image or images is/are displayed at the display **102** (**S103**). Since this display image is not yet subjected to any processing, it is generally unsuitable for representing on the card. However, under certain circumstances, it may be represented thereon as it is.

Then, the operator observed the displayed image or images on the display unit **102** and adjudges whether additional processing is necessary or not (**S104**). If it is not necessary, he will manipulate the key board **106** to make a certain operation, resulting in the termination of processing at the data processing unit **104**, data being fed out therefrom to the succeeding data converter **107**.

On the contrary, when additional processing is necessary, the operator observes carefully the displayed image or images on the unit **102** and adjudges whether the picture image data, or character data or barcode data should be processed. If the picture image data should be processed, such an operation is made for selecting the proper mass of trimming or layout within the menu range of position-data input means **103**. By the execution of this operation, functions and operations at steps **S105** and **S106** can be executed at one stroke. If trimming is taken as an example, the next step is executed in such a way that position data are fed from the position input means **103** to the data-processer **104** with the use of a carsor. When a tablet digitizer is used as the position data input means, the carsor image displayed in

an overlapped manner on the displayed picture image appearing at the display unit **102** by carsor manipulation is positionally specified beforehand in registration with the specified position on the card, for determining the trimming range. Then the operation is carried out in such a way that the picture image data outside the specified trimming range are canceled. By completing these operations, data processing operations relating to step **107** are executed, and, then, the mass for completion of the menu range is selected out. By these measures, steps progress through **S109** to **S102**, and data storing is executed, and further, display representation is brought about through step **S103**. If there is no need for additional processing, an operation termination manipulation is carried out as before at key board **106**, and further operations will be made through data converter **107**.

As for the layout, the operation is carried out with the position data input means **103**, similarly as in the foregoing trimming operation. More specifically, layout is selected out in the menu range of position data input means **103**, and the overall configuration of the card and the display position of picture image are shown at display unit **102**. Then, image inclination correcting operation and the like are carried out so as to realize correspondence thereof with the displayed positional information, the processing operations relating to step **S108** thereby being brought about. After completion of these operations, the mass for the ending in the menu range is selected.

In this way, when selection is made from the menu range by reliance on the position data input means **103**, trimming or layout operation can be brought about. At this stage, when manual operation is carried out at the key board **106**, introduction of character data is executed (**S110**). As the character data in this sense, in the case of ID card, as an example, the name and/or birthday, month and year of the owner may be used. The data introduced from the key board **106** in accordance with the output character style from the font generator **109** are shown at the display unit **102** in the specified positions on the displaying surface and respectively arranged in accordance with display items. The operator acknowledges these items and detailed displays of the represented images. When he acknowledges them as being true, he will operate the key board **106** for showing the operation ending (**S111**).

Upon ending the operations as described above, the data are stored in memory **105** (**S102**) and represented at the display **102**. The operator will acknowledge again this fact, and upon the execution of this, the operations are terminated.

As for the barcode introduction, the data are subjected to inputing at steps **S112** and **S113**, as in a manner similar to the character data introduction as set forth above. The barcodes and the like data may be introduced separately through printing or other mechanical method.

In FIG. **3A**, a data processing circuitry usable in the sublimation image transfer printing method is shown only schematically. As shown, the circuitry **107** comprises a picture element density converter **3**; a color corrector **4**; a gradation corrector **10**; a memory **11**; a switch **12**; a buffer **13** and parallel/series converter **14**. The picture element density converter **3** is connected to a picture image input unit **100**.

The unit **100** serves for generation of three primary color data of R.G.B.- or Y.M.C.-mode from original picture images and is connected through the picture element density converter **3** to the color corrector **4**. The converter **3** converts the picture element density of the image data fed from the unit **100** to the desired one, by subtracting or supplementing, as the case may be, image data for each color element. It should be mentioned that for attaining high quality hard copies, conversion of the picture element density to at least **10** lines/mm or so is preferable.

Color corrector **4** consists preferably of a color decoder, level adjuster or color converter, and serves to correct three primary color data converted to those of a predetermined density of picture elements in consideration of characteristics of the image transfer ink in the image transfer sheet and in addition to provide black color data.

The data processing circuitry **107** is connected through a driver **108** to the sublimation image transfer printer.

In FIG. **4**, an example of the color corrector **4** is shown schematically in structure. As shown, it comprises adders **6Y**; **6M** and **6C**, a black color data calculator **7**, and primary and secondary color correction circuits **8** and **9**. Primary color correction circuit **8** serves for making correction of turbidity of the image transfer ink, while secondary color correction circuit **9** provides a capability of arbitrary and selective correction control relative to specifically selected color hue.

The gradation corrector **10** is so arranged as to make correction of the gradation of the data for each color Y, M, C or K (representing black color) fed from the foregoing color corrector **4** when necessary. For this purpose, the corrector **10** includes a gradation circuit (not shown) and the like, whereby a certain mode of highlight stressing or shadow stressing is introduced and realized.

The memory **11** functions to preserve temporarily the data of each color delivered from the gradation corrector **10**, a selection switch **12** being provided at the output side of the memory for selective writing-in of the data of each color to the buffer **13**. The buffer **13** is capable of writing-in the data of one line of the image transfer head **16** and kept in connection with the parallel/series converter **14** adapted for converting parallel data into series data. Additionally, in the simplified machine, black color data series is dispensed with in some instances.

In FIG. **5**, a schematic construction of the parallel/series converter **14** is shown. As shown, parallel data delivered from the buffer **13** are fed to an input side of a comparator **22**, while outputs from a counter **23** are fed to another input side of the comparator **22** which delivers the converted series data to the driver **15** for driving a thermal head **121**.

If necessary, however, the comparator **22** may be replaced by a converter table, not shown, utilizing a parallel/series converting ROM.

In FIG. **6**, a detailed circuit scheme of the thermal head **121** is shown. As shown, series data delivered from the comparator **22** are fed into a shift register SR and thence, after being subjected to latching at a latch circuit LT, fed to thermal elements HE through NAND gates NA which are fed at respective one side inlets with strobe signals.

Next, referring to FIG. **3A**, the operation of the data processing circuitry **107** will be described more specifically.

First, when three primary color image data are fed from the picture image inlet circuit **100** to the picture element density converter **3**, the latter converts these three primary color data to those which represent a predetermined picture element density and then are fed to the color correction unit **4**. In this case, it is assumed that the unit **4** is fed with three primary color data expressed in respective concentration signals, which are of yellow: **Y0**; of magenta: **M0** and of cyan: **C0**, respectively, in the present example.

These data: **Y0**; **M0** and **C0** are, as shown in FIG. **4**, fed through respective adders **6Y**; **6M** and **6C** to the black color data calculator **7**, to provide a K-output as expressed mathematically by the following formula:

$$K=\min(Y, M, C)$$

wherein, "min" represents a function which provides a possible minimum value.

These data: **Y0**, **M0** and **C0** are fed from the converter **3** to the primary color correction circuit **8** to provide primarily corrected data **Y1**, **M1** and **C1** which are thence fed to the secondary color correction circuit **9** to provide, through calculation, secondarily corrected data: **Y2**, **M2** and **C2**, respectively. These are then fed to respective adders **6Y**, **6M** and **6C**, which add them to respective data **Y0**, **M0** and **C0**, to provide respectively added output data Y, M, and C to be fed to the gradation correcter circuit **10**, respectively, after being utilized for calculation of the K-output signal value.

The primary color correction circuit **8** serves to calculate primarily corrected data: **Y1**, **M1** and **C1** which are necessarily utilized for correct-out of transfer ink turbit. In this case, the original data: **Y0**, **M0** and **C0** are subjected to matrix calculation to provide the primarily corrected data **Y1**, **M1** and **C1**, as folows:

$$Y1=k_{11}\cdot C0-k_{12}\cdot M0+k_{13}\cdot Y0$$

$$M1=k_{21}\cdot C0+k_{22}\cdot M0-k_{23}\cdot Y0$$

$$C1=k_{31}\cdot C0+k_{32}\cdot M0-k_{33}\cdot Y0$$

where,

k_{ij} represents weight coefficients:

i=1–3; and

j=1–3.

The secondary color correction circuit **9** serves to calculate secondary color correction data **Y2**, **M2** and **C2** from primary color correction data **Y1**, **M1** and **C1** by modifying the latter to make certain thereto by performing matrix calculations so as to provide a capability for making an arbitral and selective color control at a certain specifically selected-out color hue, in the following manner:

$$Y2=Y1+l_{11}\cdot\Delta B+l_{12}\cdot\Delta C+l_{13}\cdot\Delta G+l_{14}\cdot\Delta Y+l_{15}l_{15}\cdot\Delta+\cdot\Delta M$$

$$M2=M1+l_{21}\cdot\Delta B+l_{22}\cdot\Delta C+l_{23}\cdot\Delta G+l_{24}\cdot\Delta Y+l_{25}\cdot\Delta R+l_{26}\cdot\Delta M,$$

and

$$c2=C1+l_{31}\cdot\Delta B+l_{32}\cdot\Delta C+l_{33}\cdot\Delta G+l_{34}\cdot\Delta Y+l_{35}\cdot\Delta R+l_{36}\cdot\Delta M$$

wherein,

l_{ij} represents weight coefficients:

i=**1–3**;

j=**1–6**;

ΔB, ΔC, ΔG, ΔY, ΔR, ΔM:

characterizing color data.

Thus, when these secondary correction data **Y2**, **M2** and **C2** are added to the corresponding original data **Y0**, **M0** and **C0** by means of respective adders **6Y**, **6M** and **6C** and under proper selection of weight coefficients k_{ij} for primary color correction circuit **8**, any color discrepancy of the ideal color of the ink appearing on the printed picture images under the action of the sublimation transfer printer can be arbitrarily ammended. In this case, when the weight coefficients l_{ij} for the secondary correction circuit **9** are selected out properly, the color tone of the printing picture images can be modified to an arbitrary degree.

Further, as for the black color data K, correction data **K2** can be calculated by the following formula. With use of these correction data **K2**, which are added to the original black color data K, the desired correction can be executed in a similar manner.

$$K2=K+m1\cdot\Delta B+m2\cdot\Delta C+m3\cdot\Delta G+m4\cdot\Delta Y+m5\cdot\Delta R+m6\cdot\Delta M$$

wherein,

Mi represents weight coefficients:

i=**1–6**.

In this way, output data: Y, M, C and K delivered from the color correction circuit **4** are introduced into the gradation corrector **10** as inputs thereof, and each constituent of these data can be subjected to correction as desired.

FIG. **7** shows several characteristic curves illustrating corrections by means of the gradation corrector 10. More specifically, **f0** represents a standard characteristic curve; **f1** a highlight-stressing operation curve; f2 a shadow-stressing operation curve; **f3** a highlight-and-shadow stressing operation curve; and **f4** a medium tone stressing operation curve.

As indicated in FIG. **7**, by presetting, as necessary, the tone-reproducing characteristics, which determine the relationship between that concentration of color data and that of the prints printed by means of a sublimation image transferring printer, a color tone similar to that possessed by the original image can be reproduced. More specifically, when no correction is adopted, the curve **f0** is used, while in the case of correction, any selected one of these curves **f1** to **f4** may be utilized depending upon the part of gradation to be stressed. Further, it should be noted that the tone reproducing characteristic curves are not exclusively limited to those which have been specifically shown and described above. As an example, the control of gradation correction by color tone reproducing characteristic mentioned above is executed by a gradation circuit, not shown, and the setting of the color tone reproducing characteristic is brought about by manipulation of any selected one of the control knobs, not shown, which are provided separately for "highlight"; "medium tone" and "shadow".

Y.M.C.K.-data subjected to correction by the gradation corrector **10** are once stored in the memory unit 11. The thus stored data may be read out from the memory for each color by manipulation of the selection switch **12** and, after provisional storing, per one line of transfer head **16**, at the buffer **13**, introduced into the parallel/series converter **14** for conversion thereby into corresponding series data.

Another example of the data processing circuit for the sublimation transfer printer is shown only schematically in FIG. 3B. As shown, the processing circuit in **107'** comprises a level regulator **503**; a color converter **504**; an A/D converter **505** and a parallel/series converter **14**.

As the image data introduced into the processing circuit **107'** those which have been subjected to conversion into R.G.B.-signals in the color decoder **502** from composite video signals delivered from a T.V. camera, VTR or the like are used. On the other hand, R.G.B.-signals delivered from a personal computer, captain system or the like means are introduced as input into the level adjuster **503**.

As the color correction method with the use of the foregoing arrangements, it is possible, more specifically, to adjust the hue saturation and/or brightness in the color decoder **502**, or to adjust the signal level of each color light of R.G.B.-system in the level regulator **503**.

As an example, the color conversion from R.G.B.- to Y.M.C.-system can be executed in the color converter **504**. The simplest possible method in this color conversion is to procure the opposite color to each of the normal colors.

The thus produced color signals of Y.M.C.-system is subjected to A/D conversion and then fed successively through the parallel/series converter **14** and the driver **108** to the thermal head, not shown, to carry out printing in the sublimation transfer principle.

Additionally, in normal cases, with the use of the foregoing system composition, input image data must be of static mode. However, by provision of memory means in front of the color decoder or at an intermediate position between the A/D converter and parallel/series converter, animating images can be processed.

The series data converted in the foregoing manner in the data converter **107** or **107'** are fed to the shift register SR shown in FIG. **6** by n-image elements and then, upon being subjected to latching in the latch circuit LT are further delivered to NAND gate NA as its inputs. When a strobe signal ST is fed as input to the NAND gate NA, the foregoing n-image element data is fed to the thermal element HE.

FIG. **8** is a schematic diagram, showing signals for respective image elements. The gradation has been so selected that the first image element is at the highest gradation level, while the n-th image element corresponds to the lowest gradation level, and that the second to (n−1)th image elements vary linearly in gradation levels, so as to provide representatively a better understandable example of the invention.

Next, the operation of the parallel/series converter **14** will be described.

First, as shown in FIG. **5**, image elements data A, consisting of parallel data, more specifically, comprising parallel eight bit data **A0–A7**, are fed to one-side inputs of comparator **22**, while another side inputs thereof are fed with outputs B, comprising eight bit increment outputs **B0–B7**, of counter **23**. The counter **23** counts clock signals in increments, the outputs **B0–B7** being successively varied.

The comparator **22** performs comparison between the two inputs A and B, so as to deliver successively outputs of binary "1" until the increment output B is brought into coincidence with image elements data A, or more specifically, under the condition of A>B and A=B, while, thereafter, binary "0"-outputs are delivered therefrom. More specifically, comparator **22** will continue to deliver binary "1" until an increment value which corresponds to the weight of concentration of image element data A is given thereto. As an example, if the image element data A has a concentration of gradation 128 of a total 256, output "1" will be repeated to deliver 128 times first and then, output "0" will follow after again 128 times, so as to provide in total a specific series data peculiarly in this case.

These series data are taken out from the comparator **22** in the form of A>B- and A≧B-outputs and of A=B-outputs through an attributed OR-gate **24**, and in the present example, the gradation consists of **256** steps or increments. However, in practice, the gradation may represent a smaller number of steps. As an example, if the incrementing bit is **B1** instead of hitherto employed **B0**, the gradation will have **128** steps; and if **B2** is employed, it will have only **64** steps. In this way, the gradation setting may be varied in a simple manner.

When in the foregoing way, the output B from the counter **23** is stepwise incremented, such series data consisting of a first series of "1" will be delivered until the relationship between the image elements data A and the output B from counter **23** becomes A=B, and of a second series of "0" issued thereafter, as shown in FIG. **8**.

In FIG. **9**, a conversion mode at the parallel/series converter **14**, which, however, is different from that shown in FIG. **8**, as an example, is shown again in the form of a matrix. As shown, when the image data are of 8-bit parallel kind, as an example, the gradation data are ranged from 0 to 255, providing, therefore, binary series data from "00 . . . . 00" to "11 . . . . 11".

In this way, the data, per line in the transfer head **16**, kept preserved in the buffer **13** are fed to the parallel/series converter **14** for providing as outputs therefrom into corresponding series data which are then delivered through the driver **15** to the transfer head **16** and thus recorded on a print paper P supported on the transfer drum **17**.

FIG. **10** represents a flow chart illustrating the operation of the sublimate printer as employed in the present invention.

At the first step **S1**, print papers are set in position and the printing ribbon is also set in position ready for performing the required procedure.

At the second step **S2**, printing operation is initiated, and line printings are executed, line by line, accompanying necessary intermittent line shifts, with relation to any selected one of four colors: C (cyan); M (magenta); Y (yellow) and K (black) being carried out. Refer to **S3** and **S4**. When line printings with the selected-out single color have been completed (**S5**), the image transfer sheet is replaced by another color sheet (**S6**) and so on. In this way, line printings are completed in all four colors. In this case, it is naturally most preferable to use a long extended single transfer sheet on which four color ink regions are repeatedly printed in a certain predetermined pattern. The image reception paper is initiated to make print from a certain prescribed position for each of these colors (**S8**). When all of the printing steps have been completed with the four colors, the paper is discharged from position (**S9**) and the printing operation is terminated to be repeated.

In FIG. **11**, a card style sample of the final products according to this invention is shown in front view at **200**. FIG. **12** is a sectional view thereof. Numeral **201** represents the substrate material of the card; **202** a display layer; **203** a surface protecting layer; and **204** a

display image as an example. Depending upon the kind of usage and when necessary, the protecting layer **203** may be dispensed with. It should be noted that the display image **204** on the display layer **202** is represented by a sublimative dyestuff, as a characterizing feature of the present invention.

As the main and substantial material of the image transfer sheet, various plain papers, converted papers, plastic resin sheets or the like may be used per se or in combination. When a plastic resin sheet which can be colored directly with a sublimative dye or dyes is used, these image transfer substrates (articles or objects) as at **201** can be united leach with the display layer **202**. Each of these substrate materials, when it is of the card style, may have generally such dimensions: thickness of 0.68 to 0.80 mm and size: 11 to 8×8 to 5 cm.

As the material of the display layer **202**, various known materials which may be colored with sublimative dyestuffs, such as polyethylene, polypropylene, polyester, ABS, AS, polyvinylchloride, polyvinyl/vinyl acetate copolymer, polystyrene, polyacrylate, polyester, polyamide, polyurethane and the like plastic material, may be advantageously utilized. As will be more specifically described hereinafter, this material layer can be united with the substrate material layer **201**. In the case of such unified structure with substrate layer **201**, the thickness and size dimensions may be substantially as the same as before. However, when normal and/or converted papers or metals, which are practically impossible to color with sublimative dyestuffs, are used as the substrate layer **201**, various methods can be utilized for desired coloring. As an example, a solution including at least any selected one of plastic resin materials capable of coloring with sublimative dyestuffs may be coated on the substrate surface, or alternatively used in the form of a film which is laminated thereon. This kind of film preferably has a thickness of about 3 to 50 μm or so. One of main characterizing features represented in and by the final products **200** is that the appearing display image or images as at **204** is/are formed at least partially or wholly with a sublimative dyestuff or dyestuffs. Additionally, the process for formation of such images can be executed in the conventional art.

As an example, the processing method may be executed conventionally as follows.

As an example, a sublimative image transferable sheet, such as a paper sheet, plastic resin film or sheet capable of acting as the carrier is coated on its surface with any suitable binder resin carrier carrying a sublimative dyestuff or dyestuffs under heat, is overlapped on the display layer **202** and then subjected to heat from behind the heat-transferable sheet, preferably in the pattern mode, so as to transfer the dyestuff or dyestuffs into the display layer **202**. It is proper to select the molecular weight of **250** or larger of the dyestuff, for improving the fastness thereof. However, a molecular weight higher than **370** is more favorable. In the case of provision of the surface protecting layer, there is practically no limitation to the selectability of the dyestuff molecular weight.

The sublimative image transfer may be executed directly on the surface of substrate **201** provided with the display layer **202**. Or alternatively, a carrying, image transferable sheet is prepared separately and, after formation of the image **204** thereon, may be stuck onto or laminated on the substrate **201**.

Image-carrying and image-transferable sheet

In the following, structure, material, usage and application purpose of the image-transferable sheet to be employed in the present invention will be described in detail:

FIG. **13** illustrates only basically and in schematic sectional view the image-transferable sheet adopted in the present invention, while FIGS. **14** through **19** and **22** through **24** illustrate preferable embodiments thereof.

The basic structure of the image transferable sheet **310** is characterized in that, as shown in FIG. **13**, a sheet-like substrate **301** is provided at its one surface with an image-reception layer **302** capable of peel-off from the substrate. By adopting such a structural configuration of the image-transferable sheet, the image-reception layer **302** can be formed with the required image or images with the use of an image transferable sheet having thermally shiftable dyestuff, and then, the image-formed image-reception layer **302** is peeled off from substrate **301** and attached firmly, preferably as by sticking, on the surface of any selected object or article with use of any suitable means. In this way, various conventional drawbacks inherent in the comparative conventional technique can be basically overcome.

More specifically, as the material of the aforementioned image-reception layer **302**, limitation must be imposed to those which can be colored with thermally shiftable or transferable dyestuff. However, upon formation of necessary images and upon peel-off from the sheet-like substrate **301**, the image-reception layer **302** may be attached fixedly onto the surface of glass-made, metal-made or wooden-made products or plastic-resin made ones which are very difficult to color with thermally shiftable and transferable dyestuffs, indeed, by reliance on conventional sticking techniques as properly adopted in consideration of the specific nature and kind of the material of decorative products to be ornamented. Further, the image-formed and peeled-off, image-reception layer **302** from the sheet substrate **301**, is highly thin and thus sufficiently pliable so that it may be applied even onto any uneven and complicated surface of a product to be decorated or ornamented, having undulations, convexities, concavities, recesses and projections. Therefore, a maximum possible better fitness of the image-reception layer to be ornamented is attained and guaranteed by the present invention. Thus, practically no limitation in the attaching use thereof may be encountered. Further, in sharp contrast to conventional sealing seals and the like, the very thin image-reception layer bearing necessary images can be applied easily to the product per se in a very uniform manner, thus providing no raised and thickened feeling, and giving rise to no foreign feeling upon attachment.

FIG. **14** shows a further example of the image transferable sheet **310**. In this case, there is provided a parting agent layer **303** on the surface of image-reception layer **302**. Between the latter and the sheet substrate **301**, there is provided a parting agent layer **303'**. If necessary, however, any one of the two layers **303**; **303'** may be dispensed with.

The first parting agent layer **303** is provided for prevention of thermal fusion between the image-reception layer **302** and an image transferable sheet, not shown, as may occur during image transfer and formation on the first layer **302** through transfer of thermally transferable dyestuff from the said transferable sheet to the first layer. If there is no risk of such thermal fusion of the above nature, or when the image-transferable sheet has

been already provided with such a parting agent layer, the present provision thereof may be unnecessary. As for another parting agent layer **303'**, it is for the purpose of making the latter peel-off operation, to be executed after image-forming step, easier. When the sheet-like substrate **301** is made of polyester or the like material which has, as it is, sufficient separability from image-reception layer **302**, provision of parting agent layer may naturally be dispensed with.

FIG. **15** illustrates a still further example of image transferable sheet **310**. In this case, between the image-reception **302** and the sheet-like substrate **301**, an intermediate layer **304** and/or parting agent layer **303'** is/are provided. The laminating order is optional and thus not binding. The intermediate layer **304** will serve to assist the image formation to be rather firm and beautiful, the image formation being carried out by transferring the thermally shifting and transferring dyestuff from the image transferable sheet to the image-reception layer **302**. For this purpose, the intermediate layer **304** may take, for example, the form of a cushioning layer or heat insulating layer. When a cushioning layer is provided as the intermediate layer **304**, the cohesion between the image transferable sheet and the image reception layer **302** is greatly improved and the thermal shift and transfer of the dyestuff during image formation with the use of a thermal head is evenly executed, the image formation thereby being carried out amply in correspondence with the supplied image signals. Further, when a heat insulating layer consisting of a highly heat-insulative material is used as the intermediate layer **304**, ineffective release of the heat applied during shift and transfer of the dyestuff from the image transferable sheet to the image-reception layer **302** can be reduced to a minimum possible, the effective thermal efficiency thereby being correspondingly improved and ample image formation being accelerated. If necessary, however, these cushioning layer and heat-insulating layer can be prepared independently and arranged concurrently in any arranging order.

Additionally, when the intermediate layer **304** is arranged at a higher level than the parting agent layer **303'**, the intermediate layer **304** will be conjointedly peeled off in the case of peel-off of the image-reception layer **302**. On the contrary, when the intermediate layer **304** is arranged at a lower level than the parting agent layer **303'** the intermediate layer will remain on the sheet-like substrate **301** after execution of the separation of image-reception layer **302**. In this case, therefore, the intermediate layer **304** may be made preferably and at least substantially transparent, when the peeled-off image-reception layer **302** is stuck on a decorative product, while directing the surface of parting agent layer **303** towards the latter.

In the modifications shown in FIGS. **16**, **17**, and **18**, modified from the foregoing embodiment shown in FIG. **15**, a further protecting layer **305** is provided between the image-reception layer **302** and the sheet-like substrate **301**. This protecting layer **305** serves to prevent deterioration of the formed images in the image-reception layer **302** when the latter is stuck on the decorating product while directing the surface (more specifically the image-formed surface) towards the product. For example, this protecting layer **305** is prepared from a superior material which exhibits at least one of desirous properties such as antiwearing, light-fast, weather proofing and anti-chemical qualities. With the use of the protecting layer **305** having these superior qualities, the images can represent improved fastness in the above various aspects, even after execution of the foregoing sticking procedure.

In the modification shown in FIG. **16**, the protecting layer **305** is arranged between the intermediate layer **304** and the parting agent layer **303'**.

In the further modification shown in FIG. **17**, the protecting layer **305** is arranged between the image-reception layer **302** and the parting agent layer **303'**.

In still another modification shown in FIG. **18**, the intermediate layer **304** takes the role of the protecting layer **305**.

In each of these modifications, the protecting layer **305** is arranged in neighboring relationship with the partition agent layer **303'**, whereby the image-formed and remotely arranged, image-reception layer **302**, kept in its up-and-down reversed state, is capable of adhering securely to the decorative product, so as to be positioned as an uppermost layer, as may be required. In a still further modification shown in FIG. **19**, derived from that shown in FIG. **14**, a sticking layer **306** is further provided between the image-reception layer **302** and the partition agent layer **303**. It should be noted, however, that such a sticking layer as at **306** may be provided in any one of other foregoing examples and modifications, if necessary, in neighboring relationship with the parting agent layer **303'**.

The provision of such a sticking layer as at **306** is highly valuable when the image-formed and peeled-off, image-reception layer is adhering without position reversal onto the decorative product. With this arrangement mode, the protecting layer **305** shown in FIGS. **16**, **17**, and **18** may be dispensed with. If, however, the protecting layer **305** is composed of a material in the form of a sheet-like substrate, the part to be peeled off is thereby strengthed, the peel-off procedure thus being greatly facilitated.

By previous provision of the sticking layer **306**, the image-formed and peeled-off, image-reception sheet **302** can be caused to adhere as it is onto the decorative product without use of a separate sticking agent. As the sticking layer **306**, an ordinary sticking agent which is active at room temperature can be used. 0r alternatively, a heat-sensible or light-sensitive sticking agent may be used, if necessary.

In the foregoing, the main structure of the image transferable sheet employed in the present invention has been described in detail. However, other structural modes than those set forth hereinbefore which occur easily to those skilled in the art may be employable in the invention, and thus-they may be included within the scope of the invention without departing from the appended claims.

It should be further noted that, in the present invention, the sheet-like substrate may be provided on its one surface with an image-transferable layer capable of peeling off through the intermediary of only one weakly sticking layer.

FIG. **22** shows only schematically in a sectional view a preferred embodiment of such an image-transferable sheet, denoted with same reference numeral **310**.

As shown in FIG. **22**, the image-transferable sheet **310** represents a basic structural characteristic such that any suitable sheet-like substrate **301** is provided on one of the surfaces with an image-reception layer **302** through an only weakly sticking intermediate layer **402**, the layer **302** thus being easily peeled-off when desired. By providing the image-transferable sheet with such a

structural characteristic as set forth above, desired positive or negative images are formed by transferring thermally shiftable and transferable dyestuff from the image heat transferable sheet to the image-reception layer **302**, and the thus image-formed layer is peeled off from the sheet-like substrate **301** and then attached onto any suitably selected product with the use of proper means or attached per se thereon without the peeling-off operation, the substrate then being peeled off, whereby an image-formed final product can be obtained.

In the foregoing example, it should be noted that the image reception sheet **302** per se has only a thin thickness and thus represents only poor feedability during the sheet-feeding period within the printer at the time of image formation, insufficient cushioning effect and only insufficient thermal efficiency during the printing operation, and further, it is very difficult to treat in advance of as well as after execution of the image formation. Therefore, the coexistence of the image-reception layer **302** and the sheet-like substrate **301** is absolutely necessary. In addition, it is a requisite requirement that the image reception layer **302** be easily peeled off from the sheet-like substrate **301** upon execution of the image-forming operation, and thus, the layer **302** and the sheet **301** should not be stuck too strongly together. In order to satisfy this requirement, provision is made of weakly stuck layer **402** therebetween. Thus, it should be noted that the term "weakly stuck" employed in this specification and appended claims may be defined as "to be separable by finger's end and the like means from each other without entailing destruction or breakage of the parts originally stuck together". It is worthwhile to say, in considering the relative relationship between the image-reception layer **302** and the sheet-like substrate **301**, there is no necessity to provide the weakly-stuck layer **402** if the aforementioned peeling-off is very easy to bring about.

FIG. **23** illustrates still another modification of the image-transferable sheet **310** denoted by the same reference numeral **310** only for simplicity and convenience, wherein a further parting agent layer **303** is provided on the surface of image-reception layer **302**.

This layer **302** is provided for occasional thermal sticking between the thermal image transferable sheet, not shown, and the image reception layer **302** in the progress of thermal shift and transfer of the dyestuff from the sheet to the layer **302**. This provision of the parting agent layer **303** may be dispensed with if there is no risk of occurrence of such disadvantageous sticking attachment or the sheet under consideration has already been fitted with such a parting agent layer.

A modification shown in FIG. **24** from that shown in FIG. **23** has such a modified structure that a protecting layer **305** is provided between the image-reception layer **302** and the weakly stuck layer **305**. This layer **305** serves to prevent otherwise occurring deterioration of the images at the image-reception layer **302** which has been formed with preferably reversed images and subjected to peeling-off, together with protecting layer **305**, preferably a plastic sheet layer, from the sheet-like substrate **301** and finally stuck onto the decorative product, while directing the image-formed surface of the image-reception layer towards the product. The protecting layer **305** is made of a material having various excellent physical properties, such as anti-wearing-, light-fastness and antichemical characteristics. Provision of such a protecting layer improves various fastness performances of the formed images after sticking attachment of the image-reception layer **302**.

When necessary, a separate parting agent layer, not shown, may be provided between the protecting layer **305** and the weakly stuck layer **402** for providing easy peel-off capability between these two layers **305** and **402**, as being applicable to the example shown in FIG. **24**. If the surface of the protecting layer **305** should have sufficient peel-off capability, it is natural to provide such an intermediate parting agent layer as above.

Further, in the case of the image-transferable sheet **310**, it is naturally easy to separate from each other through a peel-off operation, upon the formation of necessary images thereon and before practical use thereof as the image-transfer sheet, and a cut-out slit as at **407** in the sheet-like substrate **301** may be provided for attaining such an easy separation as stated above at a portion of the sheet **310** in proximity to one end thereof. Upon the provision of such a cut-out slit as at **407**, the thus formed flap-like portion can be easily folded out by the operator's finger-tip, thereby affording convenience in a peel-off operation.

The usable materials and composing methods of the foregoing image transferable sheets will now be described.

As a material usable for the sheet-like substrate may be any one or any combination of the following categories:

(1) synthetic paper (polyolefin-series; polystyrene series and the like);

(2) fine quality paper; art paper; coated paper; cast-coated paper, wall paper; back-up paper; backing paper; resin-, emulsion- or synthetic rubber-imprignated paper; resin-admixed paper; paper board; cellulose fiber paper;

(3) polyolefin-, polyvinyl chloride-, polyethylene terephthalate; polystyrene; polymethacrylate; polycarbonate and the like plastic film or sheet.

Use of the synthetic paper belonging to the foregoing category (1) is highly-suitable for the purpose of the present invention since the surface thereof generally represents a microvoid layer which provides a low heat conductivity and thus a high heat-insulating peformance. A laminated material representing any combination of the foregoing categories (1), (2) and (3) can be used in the present invention. A representative and recommendable example of such a laminate is that of cellulose fiber paper and synthetic paper or that of cellulose fiber paper and plastic resin film or sheet. Among others, use of the first mentioned kind of laminate will provide an advantage in that the thermal instability such as thermal elongation or shrinkage possessed by the synthetic paper component is compensated for by the cellulose fiber paper, whereby a high thermal sensibility is demonstrated during the printing step due to low thermal conductivity of the synthetic paper component. Further, in the case of the present paper combination, however, a further modified combination of a three-layer laminate: synthetic paper-cellulose fiber paper-synthetic paper may be more advantageously employed for making the frequently appearing lesser by providing a well-balanced structure between both the surfaces of the final laminate.

As the synthetic paper mentioned above, any suitable one usable as a synthetic paper substrate used as a component of the image-transferable sheet layer may be used. As a recommendable example thereof, having a fine porous fine paper structure layer, the synthetic

paper called "YUPO", manufactured and sold by Oji Yuka Goseishi Kabushiki Kaisha, Tokyo, may be mentioned. This paper layer having a fine pore structure may be prepared in such a way that a suitable plastic resin material containing a filler of finely divided state is subjected to a mechanical elongation step. When the image-transferable sheet composed of the synthetic paper sheet containing finely divided air as above mentioned is formed with images through a thermal image transfer setp, the concentration of the thus formed images is surprisingly high and no fluctuation of image configuration and concentration is encountered, thanks to the heat insulation effect provided by the very existence of fine air pores, in addition to the improved thermal energy efficiency. Especially, due to the advantageous cushioning effect provided by the air-filled fine pores, the image-receiving layer is supposed to be rather advantageously affected during the image formation step. As an alternative measure, the paper-like layer containing the above-mentioned fine air pores may be, if desired, provided directly with the core material consisting of the cellulose fiber paper or the like.

It is further possible to use plastic film in addition to the cellulose fiber paper in the laminate described above. Still further, a laminate of said cellulose fiber paper and plastic film composed together can be used.

As the method for co-sticking of synthetic paper and cellulose fiber paper, use of a known adhesive agent is naturally adopted, as an example. Or alternatively, the extrusion-laminating, heat-adhesion, or the like process may be relied upon, as the case may be. On the other hand, as the sticking-process between the synthetic paper and the plastic film, the lamination process to be carried out simultaneously with the formation of the film may be adopted. Calendering or the like method may be utilized for the same purpose. Selection of any suitable one of the several foregoing sticking processes depends upon the kind of material or the like condition of the partner member to be stuck together with the synthetic paper. As for the adhesive agent mentioned above, emulsion adhesive such as ethylene-vinyl acetate copolymer, polyvinyl acetate or the like, aqueous solution type adhesive polyester containing carboxyl radicals; or the like may be mentioned. On the other hand, as the laminating use adhesive, organic solvent solution type one such as polyurethane-, acrylic- or the like, may be mentioned.

The material for the image-reception layer must be suitable for reception of heat-transfer dyestuff, such as sublimative disperse dye from the image transfer sheet and holding and maintaining the thus formed images thereon. From the view point of image-holding and blocking prevention, use of such synthetic resin as having glass transition temperature higher than 40° C. may be advantageous. For example, the synthetic resins set forth in the following items (a) through (e) may be used separately or in combination.

(a) Ester bond-bearing resins:
Polyester resin; polyacrylic ester resin; polycarbonate resin; polyvinyl acetate resin; styrene acrylate resin; vinyltoluene acrylate resin and the like.

(b) Urethane bond-bearing resins:
Polyurethane resin and the like.

(c) Amide-bond carrying resins:
Polyamide resins (nylons).

(d) Urea-bond carrying resins:
Urea resins and the like.

(e) Other high polar-bond carrying substances:
Polycaprolactone resin; polystyrene resin; polyvinylchloride resin; polyacrylonitrile resin and the like.

The image-reception layer may be prepared from a resin mixture of saturated polyester and vinyl chloride-vinyl acetate copolymer. As the saturated polyester, such commercialized products: "Vylon 200"; "Vylon 290"; "Vylon 600"; "Vylon 103" and the like, manufactured and sold by Toyoboseki K.K., Osaka, Japan; "KA-1038C" (manufactured and sold by Arakawa Kagaku K.K., Osaka, Japan; "TP 220"; "TP 235", manufactured and sold by Nippon Gosei K.K., Osaka, Japan; may be advantageously used. The vinyl chloride-vinyl acetate copolymer may have preferably 85–97 wt. % of vinyl chloride component, the polymerization degree being between about 200 and 800. The vinyl chloride-vinyl acetate copolymer may further contain a vinyl alcohol component, maleic acid component within the purpose of the invention in addition to the main components. According to our experiments, it has been found that these modified copolymers should have rather superior compatibility with polyester resin. The image-reception layer may be, if necessary, composed of polystyrene resin, for example, in this case, styrene monomer, preferably styrene, a-methyl styrene, and vinyl toluene may be used separately or in the form of copolymer or saying in general sense polystyrene resin. Further, such styrene copolymer resin may be used as specifically recommendable material in the above sense, comprising said styrene monomer(s) with other monomer, preferably for example, acrylic acid ester, methacrylic acid ester, acrylonitrile, methacrylonitrile and the acrylic or methacrylic monomer, or further styrene copolymer resin comprising maleic acid anhydride.

It should be noted, however, that among others, polyester series resin is especially superior for the purpose of the present invention.

In any of the foregoing embodiments, however, white pigment is preferably admixed with the material of the image-reception layer for improving the whiteness thereof and further accentuating the sharpness and fineness of the images when transferred thereto and to provide a manually writing-on performance. As the white pigment for this purpose, the following materials may be used separately or in any combination: titanium oxide; zinc oxide; china clay calcium carbonate; finely divided silica and the like.

For further improving the whiteness fluorescent whiteness-increasing agent or -bleaching agent may be added to. Further, for improving the light fastness of transferred images, ultraviolet absorption agent and/or photostabilizing agent may be added to, preferably in a quantity of 0.05 to 10 and 0.5 to 3 weight parts per 100 weight parts of the material resin composing the image-reception layer.

The image-transferable sheet used in the present invention is preferably constituted for improving the separability from the image-transfer sheet in such a way that the surface of the image-reception layer is formed with a partition agent layer, or instead, such agent is admixed to the image-reception layer. As for the partition agent to be used for this purpose, polyethylene wax; Amido Wax, Teflon Powder or the like solid wax; surface active agents such as fluorine-contained agent or phosphoric acid ester series surfactant; silicone oil or the like may be selectively used. Among others, silicone oil may be advantageously utilized.

The silicone oil may be used in oily state, but a hardenable type thereof may be rather advantageous. As the hardenable silicone oil, reaction-hardening one, photohardening one, catalytically hardening or the like one may be used selectively according to necessity. However, use of the reaction-hardenable one is most highly recommendable. Silicone oil of this type may be obtained, as example, by reacting amino-modified silicone oil with epoxy-modified silicone oil to obtain a reaction-hardened product. As for the amino-modified silicone oil, "KF-394", "KF-857", "KF-858"; and "X-22-3680"; "X-22-3801C" (manufactured and sold by Shinetsu Kagaku Kogyo K.K., (Tokyo, Japan)) and equivalents thereof may be used. As for the epoxy-modified silicone oil, "KF-100T"; "KF-101"; "KF-60-164"; and "KF-103" (manufactured by Shinetsu, above mentioned) and equivalents thereof may be used. Further, as the catalytically hardenable and photohardenable silicone oils in the above sense, "KS-705F"; "KS-770" of the catalytic hardenable or hardened silicone oils, manufactured by Shinetsu; and "KS-720" and "KS-774" of the photohardenable or hardened silicone oils (manufactured equally by Shinetsu) and equivalents thereof may be used. The adding quantity of each of these hardenable or hardened silicone oils may advantageously range from 0.5 to 30 wt. % depending on the material of the resin composing the image-reception layer.

At least a part of the image-reception layer is coated with a solution or dispersion of any of the foregoing partition agents in a suitable solvent and dried and further treated, a suitable parting layer being provided thereon. A particularly suitable partition agent for the formation of this kind of partition layer is the aforementioned reaction type hardenable one obtainable by reacton of an amine-modified silicone oil with an epoxy-modified one. The thickness of the partition layer is 0.01–5 μ, preferably 0.05–2 μ.

It should be noted that when silicone oil is admixed during formation of the image-reception layer, the silicone oil will bleed out after coating and the parting agent layer can be formed by the hardening even after such bleeding. In order to improve the parting ability between the image transferable layer and sheet-like substrate, it is possible to provide a parting layer consisting of a heat-hardenable resin, preferably of the melamine series, and having better affinity for the image transferable layer compositions. For the same purpose as above, however, without special provision of the parting layer, a protecting layer consisting of polymethyl methacrylate resin or cellulose acetate propionate can be provided.

For the formation of the image transferable layer, a solution or dispersion of a material composition suitable for the purpose is applied on the sheet-like substrate through conventional coating or printing. As an alternative way, a separate film or sheet for the image transferable layer **302** is formed preparatorily on a provisional carrier sheet or film and then, as a succeeding step, subjected to an image-transfer onto the substrate.

The intermediate layer is made of either a cushioning or a porous material. In some cases, the intermediate layer may additionally function as the adhesive layer.

The cushioning layer is mainly composed of such a resin which has a value of 100%-modulus as defined at JIS-K-6031 (Japanese Industrial Standard) of less than 100 kg/cm^2. If this value should exceed the above prescribed value, the rigidity will become much higher than that recommended for the intermediate layer. When the layer is formed with such disadvantageous material resin, sufficient adhesion between the heat image-transfer sheet and the image-reception layer cannot be maintained during the printing step. The lower limit of the prescribed 100%-modulus is of the order of 0.5 kg/cm^2 in actual practice.

Preferable kinds of resin to be used for the above purpose, may be enlisted as follows:

polyurethane resin; polyester resin; polybutadine resin; polyacrylic acid ester resin; epoxy resin; polyamide resin; rosin-modified phenol resin; terpene phenol resin; ethylene/vinylacetate copolymer resin; and the like.

These resins can be used independently or in combination of two or more kinds. Since these resins are rather viscous and tend to give rise to manufacturing troubles inorganic additives may be admixed, such as, for example, silica; alumina; clay; calcium carbonate; amide series substance such as amide stearate; and/or the like.

The cushioning layer is preferably formed with the use of one or more of the above specified resins, occasionally with the addition of suitable additive(s); solvent or diluent, prepared into a coating agent or printing ink which is then applied on, according to a known coating or printing process and then subjected to drying to provide a coating. The thickness of the coating should be between 0.5–50 μm, preferably 2–20 μm or so. With a thickness less than 0.5 μm, the coating will not be able to compensate for the surface irregularities on the substrate, thus being ineffective for the desired purpose. On the other hand, when the thickness exceeds the above specified maximum value or more specifically 50 μm, the overall thickness of the image-transferable layer becomes much too large, so that handling troubles may be encountered during wind-up and overlapping procedures, without attaining further effect as desired. In addition, in this case, a loss of production economy will be inevitably introduced.

The thus obtainable improvement of intimate adhesion between the heat-image transfer sheet and the thermally image-transferable sheet by the provision of the above intermediate layer may be conceivably attributed to the lower rigidity of the intermediate layer per se, whereby it is liably to be deformed under the influence of the printing pressure, and further to the generally relatively low glass transition temperature and softening temperature of the aforementioned kinds of resin resulting in further lowering of rigidity and tendency to deform than at room temperatures upon reception of heat energy during the image printing step.

The porous layer may be formed generally in the following four ways: 1) through 4).

1) Emulsion of polyurethane or the like resin, methylmethacrylate-butadiene series synthetic rubber latex is foamed by mechanical agitation, coated, and dried on the sheet substrate into a layer.
2) The synthetic resin emulsion or synthetic rubber latex is admixed with a foaming agent and the liquid mixture is coated and dried on the substrate into a layer.
3) Vinyl chloride-plastisol, polyurethane or the like synthetic resin or styrene-butadiene series or the like synthetic rubber is added with a foaming agent and the liquid mixture is coated on the substrate and subjected to heating to provide a foamed layer formed thereon.

4) A thermoplastic resin or synthetic rubber is dissolved in an organic solvent to provide a solution, and a non-solvent (including that containing aqueous main component), and the latter solution are mixed together to provide a liquid mixture, said nonsolvent being less volatile than the organic solvent and having a considerable mutual solubility with the solvent, and showing, however, non-solubility with the thermoplastic resin or synthetic rubber. The thus prepared liquid mixture is then coated on the sheet-like substrate and dried, to provide a porous membrane upon microcoagulation of the constituents. The resulting microporous layer can be utilized for the above purpose.

It should be noted that the layers produced by any of the foregoing three processes 1) to 3) have rather large foams contained therein, and thus when the foaming solution for the image-transferable layer is applied thereon and dried, the latter may exhibit excessively coarse surface conditions. Therefore, in order to obtain an optimumly image-transferable smooth surface capable of providing transferred images of high uniformity, provision of the micro-porous layer prepared by the process as set forth in the foregoing item 4) is highly recommendable.

As the thermoplastic resin suitable for the formation of the above porous layer, saturated polyester; polyurethane; vinylchloride-vinylacetate copolymer; cellulose acetopropionate and the like can be used. Further, as the synthetic rubber usable for the same purpose, those of styrene-butadiene series, isoprene series, urethane and the like series may be used. Still further, as the organic solvent and non-solvent liquid used for the formation of the microporous layer, various known substances may be used. Generally speaking, however, methyl ethyl ketone; alcohol and the like are representatively used. On the other hand, as the nonsolvent, water is mostly used.

The thickness of the porous layer usable in the present invention is preferably greater than 3 μm, especially preferably in the range of 5 to 20 μm. With the use of a porous layer having a thickness of less than 3 μm, the desired cushioning and heat-insulating effects cannot be attained.

As was referred to hereinbefore in the description stage for the formation of the image-transferable layer, the intermediate layer may act simultaneously as the sticking layer in some cases.

This kind of intermediate layer(s) may be provided on one or both of the surfaces of the thermally image-transferable sheet.

In practice, however, an electrostatic charge may accumulate in the material of the thermally image-transferable sheet during its processing step or during running through the printer. As a countermeasure, a proper antistatic agent may be applied on one surface of the image-transferable layer or on the bottom surface of the thermally image-transferable sheet or it can be included in the material of the image-transferable layer. As the antistatic agent in this sense, a surfactant such as a cation-exchange agent (for example, a quaternary ammonium salt, polyamide derivatives and the like) may be advantageously used. Further, an anion exchange type surfactant, such as alkyl sulfonate may be used. Otherwise, amphoteric ion type surfactants or even, non-ionic surfactants may be used for the same purpose.

On the other hand, the antistatic agents may be coated on the surface of image-reception layer by gravure-coating, bar-coating or the like process or alternatively, these agents may be kneaded with the material resin and then subjected to transfer towards the surface during the coating formation and drying step for preparing and providing the image-transferable layer. As the antistatic agents to be admixed with the image-transferable layer material resin, cation-type acrylic polymers may be employed.

The protecting layer is peeled off together with the image-transferred layer, from the sheet-like substrate, and then stuck, in inverted reversed state, onto any desired decorative object, the protecting layer thereby being positioned at the uppermost position, for improving the anti-wearing-light-proofing and anti-chemical performances of the image-bearing layer. As the material adapted for the formation of the protecting layer, for example, alkyd resin; phenol-modified alkyd resin; aminoalkyd resin; phenol resin; urea resin, melamine resin; silicone resin, thermosetting acryl resin, thermosetting polyurethane resin and the like thermosetting resin or normal temperature setting resin; further, ultraviolet hardenable resin; electron ray hardenable and the like activating energy flux hardenable resins or thermoplastic resins such as polyester-; polyurethane-; polyvinyl acetate resin; vinyl chloride-vinyl acetate copolymer resin; polyolefin resin, acryl resin and the like, can be used.

Preparation and use of a protecting layer comprising one or more of the above-mentioned resins are made in such a way that the material resin is dissolved in a properly selected solvent according to the necessity, so as to provide a coating liquid or ink, as the case may be, which is provided between the parting layer and the image transferable layer. The thickness thereof is generally 0.5 to 20 μm. It is also possible to form the protecting layer with the use of a resin film which consists of polyester-; acryl-; acrylpolyol-; polyvinyl chloride-; olefin resin or the like resin. It is further possible advantageously to admix an ultraviolet ray absorbing agent and/or photostabilizer to the material of the protecting layer.

The protecting layers prepared and formed in the foregoing way are thus not made integral with the sheet-like substrate or parting layer and, therefore, the peel-off operation of the sheet-like substrate upon execution of the image transfer is very simple and easy.

It is further recommendable, if necessary, to provide a slip-promoting layer on the bottom surface of the sheet-like substrate, which surface is naturally the one opposite to the image-transferable layer side, so as to properly adjust the friction between the image-transferable sheet and feed roll paper or carrier belt acting during passage through the printer and to improve the running performance of the thermally image-transferable sheet in the printer.

The slip-promoting layer can be formed by adding an organic powder such as polyethylene wax fluorine resin powder or an inorganic powder such as talc, according to necessity, to a resin such as polymethyl methacrylate resin; vinyl chloride-vinylacetate copolymer; vinyl chloride copolymer; cellulose acetate butyrate; cellulose acetate propionate; styrene-acryl series or the like resin and kneading the resulting mixture to prepare a composition, applying this composition as a coating on the sheet substrate either directly or after application of a suitable primer treatment, and drying the coating thus applied. A suitable quantity of the slip-promoting layer is 0.5 to 5 g/m^2 after drying.

In the embodiments-shown in FIGS. **22**, **23**, and **24**, as the adhesive agent to be used in the slightly weak or weak adhesive layer, it should be noted that those conventionally used adhesives for adhesive tapes and seals can all be used. Preferred examples are polyisoprene rubber; polyisobutyl rubber; styrene butadiene rubber; butadiene acrylonitrile rubber and the like rubber-series resins; (meth)acrylic acid ester-series resins; polyvinyl ether-series resins; polyvinyl acetate-series resins; vinyl-chloride-acetate copolymer series resins; polystyrene-series resins; polyester-series resins; polyamide-series resins; polychlorinated olefin-series resins; and polyvinyl butyrol-series resins. To the suitably selected adherent may be added a proper quantity of a stickness improver, such as rosin; dammar; polymerized rosin; partially hydrogenated rosin; ester rosin; polyterpene-series resins, terpene-modified substances; petroleum-originated resins; cyclopentadiene-series resins; phenol resins; styrene resins; xylene resins; and coumarone-indene resin. Further, when necessary, to the mixture may be added a softening agent, filler; antiaging substance or the like conventional agent(s). As the material for the formation of slightly or weak-adherent layer said above, emulsion type adhesive, preferably of acryl acid ester series can be used. As for the parting function after a long time of preservation, emulsion type adhesives are highly recommendable. These adhesive agents are easily procurable from market.

When necessary, these adhesives are added with proper organic solvent(s) for the adjustment of the viscosity, and then applied by roll coating, die-coating, knife coating, gravure coating or the like conventional technique on the surface of the sheet-like substrate, image-reception layer or protecting layer, so as to provide an adhesive agent layer. The thus formed adhesive layer is preferably of a thickness of 1–50 μm, although this is not limitative.

Formation of Images

In the following, the decorating process according to this invention will be set forth in detail. Utilization of the image-transferable sheet according to this invention constitutes an important main feature thereof.

In FIGS. **20** and **21**, basic practising processes will be described first.

The embodiment shown in FIG. **20** is a result of the use of the transferable sheet shown in FIG. **13**. First, a known transfer sheet **320** is applied onto the image-transferable sheet **310** in an overlapped manner such that the dye-carrying layer **321** is kept in opposition to the image-reception layer **302** of image-transfer sheet **320**, and heat energy is applied, as schematically shown by a plurality of arrows, in accordance with image signals fed at a thermal head, not shown, from the side of image-transferable sheet **310**, or preferably, from the side of the image-transfer sheet **320**, thereby forming the desired images as at **307** in the image-reception layer **302**. Next, the image-reception layer **302** formed therein with the desired images **307** is peeled off from sheet-like substrate **301** and stuck onto the decorative product **306**. Or alternatively, both the sheets **302**; **301** are stuck onto the product **306** without preparatory peeling-off. In the latter case, the peel-off step may be executed after execution of the stickingly attaching step. In the above former case, and in such a case where an adhesive agent layer **306** has preparatorily provided between image-reception layer **302** and sheet-like substrate **301** as was set forth hereinbefore, the sticking attachment is carried into effect in such a way that the adhesive layer **306** is kept in opposing contact with the product **330**, and then the sticking operation is brought about by application of heat and pressure or light and pressure, depending upon the nature and structure of the layer **306**. In this way, the decoration according to the present invention is completed as a preferred one mode thereof.

On the other hand, if there is no preparatory provision of the adhesive layer, either the surface of product **330** or of the peeled-off image reception layer **302**, may be coated with the adhesive agent, and the latter layer **302** per se or otherwise in the up-and-down reversed state may be stickingly attached onto the product **330** (refer to FIG. **21**).

Since the image-reception layer **302** is composed generally of such thermoplastic resin material as is liable to be colored with thermally transferable dyestuff, it can be thermally and fusingly attached to plastic resin-made formlings, clothes or metals even with provision of an adhesive layer, if necessary.

In this case, the image-bearing layer **302**, the image thereof having been formed in the aforementioned way, is stuck on, through the intermediary of the adhesive agent layer **306** as shown in FIG. **25**, while retaining the sheet-like substrate **301** on the surface of the image-reception layer **302**.

A modification of the last-mentioned mode is shown in FIG. **26**. In this case, sheet-like substrate **301** is formed on the surface of the product **330** and the image-reception layer **302** is formed as the outermost layer. Further, in this case, sheet-like substrate **301** and product **330** may be stuck together, and, through the intermediary of a suitable adhesive layer, sticking layer or heat-sealable sheet or the like.

As for the transparent film usable as the said sheet-like substrate, it must be transparent to such a degree as not to conceal the images formed in the image-reception layer, and, in addition, it must have superior surface properties such as, for instance, antiwearing characteristics. As an example, polyolefine; polyvinyl chloride; polyethylene terephthalate; polystyrene; polymethacrylate; polycarbonate and the like plastic resin-made films may be used upon variously surface conditioning. If these transparent films should be too thick, the images will be raised, and the unitary feelings may be lost when these are stuck on respective products to be decorated. Therefore, the film thickness is preferably of the order of 0.5 to 50 μm.

In the case of a further embodiment of the present invention, the image reception layer of image transferable sheet which has been, however, formed with necessary images is subjected to image transfer treatment onto an intermediate image transferable substrate, the latter is then subjected to an image-retransfer with the images, and the thus retransferred images are again transferred onto the surface of the product to be decorated. In the following, this image transfer mode will be set forth in detail.

Embodiments shown in FIGS. **27**, **28** and **29** represent such a process for execution of image transfer operation as by the intermediary of intermediate image transfer sheet **510**. First, as shown in FIG. **27**, a thermally image-transfer sheet **320** having a thermal transferable dyestuff layer **321** is overlapped to image-transfer sheet **510** which is, at this stage, not formed with images **307** and thus consists of a thermal image-transferable sheet, in such a way that the dyestuff layer 321 or more specifically the parting layer **322** is in opposition to the image-reception layer **302** of the foregoing

sheet **510**. In such a case, however, that heat energy is supplied in accordance with image-forming signals delivered from the thermal head, not shown, and, indeed, preferably from the side of the sheet **320** as hinted by a plurality of double-line arrows for thermal formation of desired images (positive images) as at **307** in the image-reception layer **302**, it is highly recommendable to provide an adhesive layer **402** between the layer **302** and sheet-like substrate **301**.

Then, with the use of the image transfer sheet **510** formed with positive images **307**, the images of layer **302** are transferred, as shown in FIG. **28**, to a separate intermediate substrate **501**, which is, however, fitted with a protecting film layer **305**, thus, the transfer being carried out, in fact, onto the latter, and indeed, with the correspondingly inverted images, attached with same reference numeral only for convenience, from the foregoing layer **302**. In this case, it is preferable to subject the adhesive layer **402** of the image-transfer sheet **510** to the image-transfer operation, together with the image-reception layer **302**. Further, as for the intermediate image-transfer substrate **501**, it is recommendable to provide the protecting film layer **305** through the intermediary of a weak-adhesive layer **402'** as shown. The thus provided intermediate image-transfer sheet **610** represents generally the image-transferable sheet.

FIG. **29** illustrates the step for transfer of the image-reception layer **302** now carrying positive images **307** onto the object **330** to be decorated and under utilization of the previously described intermediate image-transfer sheet **610**.

More specifically, the intermediate image-transfer sheet **610** is overlapped onto the said object **330** in such a way that the adhesive layer **402** of the former in opposition to the surface of the object **330** and pressurized together. Then, the intermediate transfer substrate **501** together with the weak-adhesive layer **402'** is peeled off from the remainder of the thus-pressurized assembly, the now image-carrying layer **302** formed with positive images **307** covered with protecting the film layer **305** thereby remaining in the transferred state on the product **330**. In the case of no provision of the protecting film layer **305** on the intermediate image-transferable sheet **610**, the layer **302** remains in an exposed state. Therefore, an overcoat layer, if necessary, can be provided on the now image-carrying layer **302**.

The previously set forth process carried out by the use of said intermediate image-transferable sheet can be executed by means of the apparatus which is shown schematically in FIG. **1E**.

In this apparatus, more specifically, there is provided a carrier system comprising a series of rolls **411, 412, 413** and **414** for conveying the intermediate transfer substrate (sheet), arranged in addition to the apparatus shown in FIG. **1B**. More specifically, the substrate is drawn out from feed roll **414**, conveyed through successive rolls **413**; **412** and retransferred onto one of the products **200**. Other operations are same as set forth hereinbefore with reference to FIG. **1B**. Further, in the case of FIG. **1E**, the final product may take the form of a roll-like substrate which is subjected to an image transfer operation through the intermediate substrate, by transferring its image-carrying, image-transferable layer, for later being punched out properly. Alternatively, under occasion, it may be subjected to half-cut operations downstream of roll **122**.

As was set forth herein above, the preferable method for the formation of desired images on the image-transferable sheet is carried out by use of a heat image-transfer sheet comprising a sheet-like substrate having a layer including a thermally transferable dye (evaporative dye). The heat image-transfer sheet which can be utilized in this method is known per se. And almost every kind of these known sheets can be useful in the practice of the present invention. It should be noted that by employing the foregoing image-transfer method, mono-color or full-color images can be easily formed as occasion may desire.

It should be further noted that details of such heat image-transferable sheet can be easily understood with reference to our U.S. patent application Ser. No. 833,039. As for the heat image-transferable sheet usable in the present invention, the coating layer of the sheet (coating film) may include a parting agent. By adopting this measure, the image-reception layer of the image-transferable sheet or the surface thereof, to be subjected to sublimative image-transfer, must not have a separate parting agent layer, the adhesive ability between the image-reception and the surface of object to be decorated can be still further improved upon execution of the sublimative image-transfer and image-formation at the image-reception layer and adherent attachment thereof to the object. As the parting agent to be included in the coating layer of the thermally image-transferable sheet (coating film), silicone oil; silicone resin; phosphoric ester or the like surfactant; and/or chelate- and the like agents, may be selectively utilized. These agents, upon mixed, will ooze out from inside to the outer surface of the coating layer, resulting in providing a better parting quality. However, it is preferable to properly select the kind and nature of the parting agent to be used for this purpose, being such that the agent cannot transfer to the image-reception layer of the image-transferable sheet during the sublimating image-transfer stage. The adding quantity of the parting agent may preferably be 3–25 wt. parts based upon the total amount of resin and coating composing the coating layer taken as 100 wt. %.

In practice, any kind of conventionally known heat transfer sheets is overlapped on the thermally image-transfer sheet employed in the present invention, and then necessary heat energy of 5–100 mJ/mm^2 is applied by use of a conventionally known heat transfer unit, for instance, "Video-printer: VY-100" manufactured and sold by Hitachi Seisakusho, Tokyo, or its equivalent machine, for the formation of necessary images on the image-reception layer of the image-transfer sheet as set forth hereinbefore.

Peel-off operation for removal of the image-reception layer formed with necessary images in the above manner may be carried into effect in a very easy manner, so as to provide it in a thin film carrying the images thereon. In case where the thus-peeled off film carrying the images is provided beforehand with an adhesive layer, composed of a suitable adhesive agent as was referred to, at the opposite surface to the image-carrying one, the peeled-off film can be, as it is, stuck on the object to be decorated. It is natural that this adhesive attachment procedure can be performed only partially and locally on selected part of the whole surface of the object, or totally thereon, as the case may be. On the contrary, if the peel-off film is provided beforehand with no adhesive layer, the film can be subjected occasionally to a heat fusion onto the surface of the object, if the physical properties or material kind thereof is suitable for such kind of thermal fusion. **0**r alternatively,

a properly selected adhesive agent can be preparatorily applied onto the surface of the film or object, and then, the stick-on job can be executed.

If the image-reception layer is provided preparatorily with a parting layer thereon, as was referred to, the latter layer can be removed off partially or wholly, by grinding or rubbing operation after execution of the sublimating image-transfer job, for avoiding otherwise occurrence of ill effect by the very presence of parting layer in the adhesive attachment of the image-carrying layer film onto the decorative object.

In case of that where the image-transferable sheet is provided with a protecting layer and the latter is composed of a plastic resin film, this film may preferably be cut into pieces or subjected to punch-cuttings.

FIG. **32** illustrates successive die-cutting steps in sectional views, serving for the above purpose. In this case, as shown in FIG. **32** at (*a*), only image-reception layer **305** of the image-transferable sheet **310**, which has been image-formed through the way of the foregoing image-transfer step, are die-cut by operation of a cutter **801**. Next, as shown in FIG. **32** at (*b*), a pair of hot stamps **132'**; **133'** are used to execute a pressurizing job under heat from opposite sides, thereby the decorative product **330** being processed into a final product provided tightly with an image-reception layer and a protecting layer, as shown in FIG. **32** at (*c*).

Further, when occasion desires, the image-carrying film is reversed up-and-down in position after execution of the peel-off job, and, the film is stuck onto the product to be decorated in such a state that the image-carrying surface of the film is kept in direct opposition to the product's decorating surface. In this case, however, it would be rather preferable that in advance of preparatory peel-off of the image-reception layer, the image-carrying transferable sheet is stuck onto the surface of the product to be decorated, and indeed, preferably with use of an adhesive agent, in such a way that the image-carrying layer is kept in direct opposition to the product surface and finally, the sheet-like substrate is peeled off, so as to leave the image-carrying surface on the product's surface.

As in the foregoing, when the images are once reversed and then stuck onto the object to be decorated, the forming images are preferable to reverse in mode (mirror-like relationship) the original to those of reversed mode.

It is further possible that the transfer or sticking-on of the image-carrying layer is carried out through the intermediary of a separate fusing sheet.

In FIG. **30**, use of such fusing sheet **701** for reimage-transfer operation of image-carrying layer **2** already formed with necessary images **307**, however, of reversed mode, and onto the surface of a product.

More specifically, the image-transferable sheet **310** is overlapped onto the product **330** to be decorated in such a way that the image-reception layer **302** carrying the necessary images **307** is kept in opposition to the surface of the product, and indeed, through the intermediary of a fusing seat **701** and then these three components are pressurized together. Further, sheet-like substrate **301**, together with parting layer **303'**, is peeled off, thereby the image-reception layer **302**, now having positive images **307** formed thereon, and protecting the latter, being transferred onto the product **330**. It will be seen in this case, that there is no need for this transfer job, to provide in advance on adhesive layer on the surface of image-reception layer **302** and/or on the surface of the product **330**, and further that a direct heat fusion onto the surface of the product **330** which may be composed of plastic resin, textile fabric, metal or the like common material, however, through the intermediary of a heat-fusible or heat-sealable sheet.

In case where the protecting layer **305** is of plastic resin, similar composing technique as mentioned above may be employed by substituting a weak-sticking layer **402'** for parting layer **303'**.

As the heat-fusible or heat-sealable sheet as at **701** employable in the present invention, it may be composed of one or other material capable of adhering under heat, pressure or both, especially suitable one of those which become soft to be adhesive upon heating. These heat adhering materials in the form of sheets will be, upon softening, charge the pores, meshes or stitches of the product material composed preferably of textiles, woven or non-woven; knits, rough-surface papers or meshed materials, thereby the surface of the product becoming highly smooth for well receiving the image-reception layer **302** for desired image-retransfer with trouble, which effect is superior in the art.

On the contrary, when such heat-fusible or heat adhesive sheet materials which may be called "heat bond sheets" as at **701** are not utilized, it is highly difficult to realize the image-retransfer operation onto certain kind of objects such as rough-surfaced or rough-meshed fabric or the like. Even if the retransfer job could be executed, the obtained images may be blurred and the adhesive may be insufficient, on account of the very thin thickness of the image-reception layer **302**, thus giving rise to technical and commercial troubles.

As for the heat fusible sheet **701** to be used in the foregoing manner, ethylene/vinyl acetate copolymer, nylon copolymer; epoxy/phenol copolymer; epoxy/vinyl copolymer; acrylic resin; polyester resin; or polyolefin resin and the like thermoplastic resins (heat sensible adhesive agents) which are formed into sheets or films may be used. These materials must be softened at 100°–250° C. or so to represent viscous adhesive characteristics. These materials are, when used, capable of being stuck to both the image-transferred product **330** and the image-carrying layer **302**.

These heat bond sheets **701** have generally thickness of 1–200 μm. When the surface of the product **330** to be decorated is relatively smooth, the sheet selected out may be of relatively thin thickness, while, on the contrary, when the surface of the decorative product **330** is relatively rough, as in the case of textile fabrics, unwoven fabrics, meshed fabrics or the like, use of thicker heat bond sheets is rather recommendable.

As set forth above, the use of heat bond sheets is highly recommendable in the decorative image-transfer onto rough surface products, such as those of rough fabrics, woven or non-woven, knitted clothes, meshed one or the like, thereby a better quality image-transfer being executed, in spite of the meshed or highly undulating surface conditions of the objects to be decorated.

Further in the present invention, during the adhering attachment of the image-reception layer already formed with necessary images onto the object or product, an additional processing step is preferably introduced for prevention of occasional interference in the foregoing adhering attachment step, by rubbing-off or grinding-off part or whole of the parting layer, provided on the surface of the now image-carrying layer, upon completion of the sublimating image-transfer step.

Still further, in such a case that the image-transferable sheet is fitted with a protecting layer which is composed of a plastic resin film, the latter must in advance be subjected to punching or the like cutting step for cutting the film into desirously sized pieces.

FIG. **32** represents such a die-cut (half-cut) process in sectional schema. In this case, at first, as shown at (*a*) of FIG. **32**, the image-reception layer **302** of an image-transferable sheet **310**, now formed with necessary images through a sublimative image-transfer step, and the protecting layer **305**, are subjected to a die-cutting process by means of a cutter **801** to shape a desired shape. And then, as shown at (*b*) in FIG. **32**, the cut-out piece is subjected to a pressurizing step under heat by means of a pair of hot stamps **132'**; **133'** to provide a final decorative object, as shown at (*c*) in FIG. **32**, which is composed of a product **330** to be decorated, however, now attached integrally and jointly with image-carrying layer **302** and protecting layer **305**. Applied Products

The products applicable with the inventive process for decorating purposes are not limited to occasionally employed kind, shape and nature of the materials. Preferred examples of the usable product may be: cartons; vessels or packages; bags; cassette cases; cassette halves; floppy cases; paper packages and envelopes; stock certificates; personal and bank cheques; bills; bonds; certificates; notifications; car tickets; travel tickets; betting tickets; tax stamps; postage stamps; entrance tickets, money-exchangeable papers and documents; cash-card, credit cards, orange cards, telephone cards; member's cards; greeting cards; postcards, name cards; driver's certificates; IC-cards; optical cards and the like various cards; accounting cards and documents-envelopes envelopes; tags; OHP-sheets; slide films; bookmark slips; calendars; posters; pamphlets; menus; passports; POP-goods and articles; coasters; displays; nameplates; keyboards; cosmetics; personal ornaments (watches; cigarette lighters); stationaries; construction materials; radio-receiving sets; T.V.-sets; speakers; table calculators; automotive gauge boards; emblems; keys; clothes; wearing commodities; footwears; appliances; CA-instruments; sample books; tickets in general; albums; computer graphic and/or medicare graphic image printouts; and the like, where the material kinds, sizes and configurations are regardless for purposes of the invention.

The aforementioned goods and instruments may have printed or the like other images in advance of execution of the process of the invention. Or conversely, the goods and instruments can be formed with necessary images in accordance with the present process, and then, additional images may be formed in conventional printing or the like process.

As an example, when the invention is applied to a card style intermediate product, it is possible to combine image-forming means of the present invention with conventional recording means. As the latter, magnetic recording by use of a magnetic material layer; optical recording by use of an optical recording layer; preferably composed of a membrane having low melting point metal; application of hologram; embossing formation of characters and numerals; application of personal face photograph; engraved formation of personal face or the like; human signatures; recorded information with use of IC-memory; mechanical printing; formation of bar codes; formation of characters and patterns by use of printer, typewriter or pen plotter may be used independently or in any combination.

In the following, the present invention will be more fully described by way of preferred embodiments. In these embodiments, parts or % will be given by weight, not otherwise specifically referred to.

As the image transfer film (dye film) used for sublimating transfer onto the image-transferable sheets, a polyester film, 6 μm thick, subjected to a heat-resisting treatment on one surface thereof only, and bearing color ink composition areas of yellow, magenta and cyan, respectively, was used. The coating rate of the color ink composition was 1.0 g/m^2 when measuring at the dry state.

These color ink compositions were as follows.

Yellow ink composition		
polyvinyl butyral resin ("Eslek-BX-1", manufactured and sold by Sekisui Kagaku K.K., Tokyo)	4.80	parts
dispersion dye ("PTY-52, Disperse Yellow-141", manufactured and sold by Mitsubishi Kasei Kogyo Co., Ltd., Tokyo)	5.50	parts;
methyl ethyl ketone	55.00	parts;
toluene	34.70	parts;
(parting agent	1.03	parts)
Magenta ink composition		
polyvinyl butyral resin (same as above in the case of yellow color ink)	3.92	parts;
dispersion dye ("MS Red G, disperse red 60", manufactured and sold by Mitsui Toatsu K.K.)	2.60	parts;
dispersion dye ("Macrolex Red Violet R, Disperse Violet 26", manufactured and sold by Beyer A.G., West Germany)	1.40	parts;
methyl ethyl ketone	43.34	parts;
toluene	43.34	parts;
(parting agent	0.40	part)
Cyan color ink composition		
polyvinyl butyral resin (same as in said yellow color ink composition)	3.92	parts;
dispersion dye ("Kayaset Blue-714, solvent blue-63", manufactured and sold by Nippon Kayaku K.K., Tokyo)	5.50	parts;
methyl ethyl ketone	68.18	parts;
(parting agent	0.94	parts)

Each of the foregoing color ink compositions was prepared with and without addition of parting agent.

As the parting agent occasionally used in each of the foregoing color ink compositions, any of the following specific agents may be employed:

(a) silicone alkyd parting agent, "KR-5206", manufactured and sold by Shinetsu Kagaku Kogyo K.K., Tokyo;

(b) graft polymer of, silicone and acryl, "GS-30", manufactured and sold by Toa Gosei Kagaku K.K.;

(c) silicone graft polymer, "US-3000", manufactured and sold by the above company;

(d) phosphoric acids ester, natrium salt, "RE-410", manufactured and sold by Toho Kagaku Kogyo K.K.;

(e) natural phosphoric acid ester, "Lecytin", manufactured and sold by Ajinomoto Co., Ltd., Tokyo;

(f) silicone oil, "KF 412", manufactured and sold by Shinetsu Kagaku Kogyo K.K., Tokyo;

(g) aluminum chelate agent, "ALM", manufactured and sold by Ajinomoto; and
(h) titanium chelate agent, "TTS", manufactured and sold by Nippon Soda K.K., Tokyo.

EXAMPLE A-1

As the substrate, a laminate of a synthetic paper, "Yupo FPG 150 μm thick" manufactured and sold by Oji Yuka Co., Ltd., Tokyo, and a polyester film, 6 μm thick, was prepared and coated on the polyester film side surface by a wire bar with a mixture of pull-separating varnish, "Hakurinisu **45**" manufactured and sold by Showa Ink Co., Ltd., Tokyo, with an ultra-violet absorbing agent, or more specifically, 2.5-bis(5'-tert-butylbenzoxazolyl (2))-thiofin, 0.5% based on the resin content of the varnish, and dried up to provide a protecting layer of 1 g/m^2, when weighed upon drying;

Then, on the surface of the foregoing protecting layer, an ink composition adapted for the formation of an image-reception layer was coatingly applied and dried up. The applied quantity amounted to 7 g/m^2 when measured upon drying.

Ink composition for the formation of image-reception layer	
polyester resin (manufactured and sold by Toyobo K.K.)	100 parts;
amino-modified silicone ("KF-393", manufactured and sold by Shinetsu Kagaku Kogyo K.K., Tokyo)	5 parts;
epoxy-modified silicone ("X-22-343", manufactured and sold by Shinetsu Kagaku Kogyo)	5 parts;
solvent (methyl ethyl ketone/toluene/ cyclohexanon 4/2/2)	900 parts.

The ink composition was coated, dried up and cured one day under normal temperature. Then, the layer was kept at 100° C. for 30 minutes under heat, for letting the silicone to bleed up to the surface, to provide an image-transferable layer formed on its surface with a hardened silicone layer.

On the thus-provided image-reception layer, a sublimating image-transfer film was overlapped which is composed of cyan color sublimative dye (molecular weight being higher than 250) carried by a proper binder resin and thermal energy is fed thereon from a thermal head adapted for receiving electric signals representing cyan color components obtained by a color analysis of a portrait photograph, as an example, for providing portrait images corresponding thereto. Then, two successive sublimative image-transfer jobs were executed with use of respective sublimating image-transfer films carrying sublimative magenta and yellow color dyes, each molecular weight being higher than 250, and substantially in the manner set forth above. In this way, after all, an overall combined display image composed of a full color portrait, in combination with several characters and graphics, was provided.

The image-reception layer of the sheet, now carrying these display images, was overlapped on the card substrate composed of a polyester resin sheet, 100 μm thick, which had been primed to white-opaque state, and pressurized together at 160° C. by means of heated pressure rolls. Then, the polyester film was peeled off at the interface with the protecting layer, thereby providing a final product card transferred with image-reception layer now carrying the desired-image display.

It was found that the overall surface of the product card was generally smooth and showing no raised feeling of the thus-formed and displaying images. Even upon an accelerated testing of the product card for three months held in an atmosphere of 40° C. the images showed no blurrings as well as no interlayer separation. Further, according to an accelerated light-proof test carried out as prescribed in JIS-Standard with use of a carbon arc lamp, the results showed to be classified to JIS-4 or -5 corresponding to an acceptable superior performance. Additionally, a surface scratch test and the like showed also superior durability.

EXAMPLE A-2

The foregoing image-transferable sheet, now image-carrying, as processed in Example A-1, is then subjected to a peel-off operation for separating the image-carrying layer from the sheet. Then, an adhesive agent of polyester series was coated on the exposed surface of the peeled-off film, and stuck under pressure on a curved surface part of a telephone set. The images could follow up to the stuck curvature into a unitary solid mass, and indeed, without inviting any stuck-on feeling, contrary to the case when a sticky loose-leaf stamp should have been stuck on. In this way, miracle viewing feelings as obtainable with direct-printing operation only, were created and maintained.

EXAMPLE A-3

A white polyester film, baked on one surface thereof with melamine coating, "E 20", 100 μm thick, manufactured and sold by Toray Co., Ltd. Tokyo, is formed on the opposite surface with a slipping layer, same as in the following Example C-2, through application of polyurethane primer. And an identification mark was provided thereon through the way of regular printing technique. On the melamine resin-baked surface of the white polyester resin film, a layer of peeling varnish (of polymethyl methacrylate-series), manufactured and sold by Showa Inku. Co., Ltd., Tokyo) was applied in dry quantity of 2 g/m^2 and dried up to provide a definite layer.

On the thus-formed protecting layer, the following image-reception layer-forming composition was coated and dried up, so as to form an image-heat transferable sheet. The coated composition was in quantity of 6 g/m^2 by dry weight.

Image-reception layer-forming composition	
polyester resin ("Vylon 600", Tg: 47° C., manufactured and sold by Toyobo, Osaka)	80 parts;
polyester resin ("Vylon 290", Tg: 77° C., manufactured and sold by Toyobo)	20 parts;
amino-modified silicone ("KF-393", manufactured and sold by Shinetsu Kagaku Kogyo)	7 parts;
epoxy-modified silicone ("X-22-343", manufactured and sold by Shinetsu Kagaku Kogyo)	7 parts;
solvent (methyl ethyl ketone/toluene = 1/1)	800 parts.

On the image-reception layer of the foregoing heat image-transferable sheet, reversed images composed of

full color portrait images together with characters and graphics by use of a thermal head, as in the same way with Example A-1, were formed.

Next, the image-reception layer, however, now carrying the reversed images formed in the foregoing manner was brought into contacting and overlapping state with the image displayable surface on a card style substrate made of white color polyester resin, 125 μm thick, preparatorily primer treated as before, and pressurized together under the action of thermal rolls, and the white polyester film, 100 μm, was peeled off between the protecting layer and the melamine-baked layer, thus providing a final card-style product transferred with the image-reception layer now carrying the necessary images.

The surface of the final card style product represented a smooth and slippery, without fear of interlayer separation and with superior light resistant power.

EXAMPLE A-4

A white foam polyester resin film, "Merinex", 125 μm , thick, manufactured and sold by ICI, was provided with an identification mark on one surface thereof, with regular printing technique.

Then, on the opposite surface of the white foam polyester resin film to the foregoing surface formed with the identification mark, a coating of a polyurethane-series primer was applied and dried up. Further, the following protecting layer-forming composition was applied in dry quantity of 3 g/m^2 and dried up to form a protecting layer.

Protecting layer-forming composition	
acrylic polyole ("Acrit 6416MA", manufactured and sold by Taisei Kako K.K.)	41 parts;
toluene	36 parts;
methyl ethyl ketone	27 parts;
diisocyanate ("Colonate", manufactured and sold by Nippon Polyurethane K.K.)	6 parts.

On the above protecting layer, the following composition was applied in dry quantity of 3 g/m^2 and dried up, to provide an intermediate layer.

Intermediate layer-forming composition	
polyester resin ("Vylon 290", manufactured and sold by Toyo Boseki (Toyobo) K.K., Osaka)	15 parts;
toluene/methyl ethyl ketone = 1/1	85 parts.

On the thus-formed intermediate layer, an image-reception layer which is substantially same with that in the foregoing Example A-3 was provided, so as to form an image-transferable sheet. Then, as same in the foregoing Example A-3, correspondingly inverted images were formed on the image-reception layer and further then, subjected to transfer onto the card substrate by use of thermal rollers. In this way, a final product card, having an image transferable, yet now image-formed layer, was provided.

This card showed favorable results of light-resisting test. Further, it showed a better scratch test result than the foregoing card obtained in Example A-3.

EXAMPLE A-5

Substrate

A white polyester film, "E-20", 100 μm thick, manufactured and sold by Toray Co., Ltd., Tokyo, was used.

Intermediate layer-forming composition	
Polyester resin ("Vylon 600", manufactured and sold by Toyo Boseki K.K., Osaka)	15 parts;
toluene/methyl ethyl ketone = 1/1 (dry weight: 5 g/m^2)	85 parts.
Protecting layer-forming composition	
"Hakuri-Nisu" (acrylic resin varnish, manufactured and sold by Showa Ink K.K.) (dry weight)	2 g/m^2
Image-reception layer-forming composition	
polyester resin ("Vylon 600", manufactured and sold by Toyo Boseki K.K., Osaka)	10 parts;
polyester resin ("Vylon 200", supplied by Toyo Boseki K.K.)	5 parts;
toluene/methyl ethyl ketone = 1/1	85 parts;
amino-modified silicone ("KF-393", manufactured and sold by Shinetsu Kagaku Kogyo)	1 part;
epoxy-modified silicone ("X-22-343", supplied by Shinetsu Kagaku Kogyo)	1 part.
(coated quantity (dry)	5 g/m^2)

With use of the foregoing composition and processed in similar way as in Example A-3, to provide a final card product, having an image-reception layer transferred with necessary images.

EXAMPLE A-6

Substrate

White polyester resin film, "E-20", 100 μm thick, manufactured and sold by Toray was coated with polyurethane-series primer and dried up.

Parting layer-forming composition	
melamine resin ("Meran 45", manufactured and sold by Hitachi Kasei)	100 parts;
hardener (para-toluenesulfonic acid)	20 parts;
(coating quantity (dry), 2 g/m^2)	
Protecting layer-forming composition	
vinylchloride-vinylacetate ("Vinylite VYHH", manufactured and sold by Union Carbide Corp.)	15 parts;
methyl ethyl ketone = 2/1	85 parts;
(coating quantity (dry): 2 g/m^2)	
Intermediate layer-forming composition	
polyurethane resin ("Takelac T-3350", manufactured and sold by Takeda Pharmaceutical Company, Osaka, of 23%-concentration)	50 parts;
isopropyl alcohol	15 parts;
toluene	25 parts;
methyl ethyl ketone	10 parts.
(coating quantity (dry) 5 g/m^2)	
Image-reception layer composition	
polystyrene resin ("Picolastic D125" (Tg = 53° C.), manufactured and sold by Hercules	15 parts;
toluene/methyl ethyl ketone = 1/1	85 parts;
amino-modified silicone ("KF-393", manufactured and sold by Shinetsu Kagaku)	1 part;

-continued

epoxy-modified silicone ("X-22-343", manufactured and sold by Shinetsu Kagaku) (coating quantity (dry): 6 g/m^2)	1 part.

The foregoing composition was prepared and used as in the same manner with Example A-3, to provide a card with the image-reception layer subjected to image-transfer as desired.

EXAMPLE B-1

As the substrate, a polyester resin film, 6 μm thick, was used and a polyester resin-series primer was coated on one surface thereof and dried up. Further, the following ink composition was applied and dried up. The coating quantity of the composition was set to about 7 g/m^2.

Image-reception layer-forming composition	
polyester resin ("Vylon 200", manufactured and sold by Toyo Boseki K.K.)	100 parts;
amino-modified silicone ("KF-393", manufactured and sold by Shinetsu Kagaku)	5 parts;
epoxy-modified silicone ("X-22-343", manufactured and sold by Shinetsu Kagaku)	5 parts;
solvent (methyl ethyl ketone/toluene/ cyclohexanone = 4/2/2)	900 parts.

The ink composition was coated, dried up and left standing for a full day, and then subjected to heat treatment at 100° C. for 30 minutes, so as to bleed the silicone towards the film surface for providing thereon an acceptable image-reception layer composing the active surface.

Then, a sublimative image-transferable film, composed of a resin binder evenly mixed with a proper amount of sublimative cyanic dye, the molecular weight being higher than 250, was overlapped on the above image-reception layer and applied with heat energy by means of a thermal head supplied with electric signals corresponding to cyanic color components of a portrait full color photograph as determined by regular color analysis, thus providing+cyanic color component images.

Next, as for magenta and yellow color components, similar respective processings were executed and finally, full color display portrait images could be formed.

Then, the exposed surface of image-reception layer of the thus-display image-formed film was overlapped on a card substrate composed of a white opaque, hard vinyl chloride resin sheet, 100 μm thick and pretreated with a conventional primer, and then this assembly was subjected to heat and pressure by means of a pair of heated rolls. In this way, a card product stuck with an image-transferable and now carrying layer was provided.

The surface of this card was generally smooth and slippy, the thus-formed images thereon providing no raised feelings. In an accelerated test of the se formed images in hot atmosphere of 40° C. for a continuous period of three months, the re were no appreciable image blurring and interlayer separation. Upon execution of a light exposure test in accordance with prescribed conditions in JIS with use of an arc lamp, the results were classified to JIS-4 to 5 Classes which means as acceptable and better image quality. Scratch test results were also superior.

EXAMPLE B-3

A sticking layer, 1 μm thick, was formed with a polyamide resin sticking agent on the image-carrying surface of the image-transferable sheet, image-formed in the manner as described in foregoing Example B-1, and the thus provided sheet was stuck on the curved surface of a glass tumbler. These images express practically no stuck-on feelings, rather providing such a touch and viewing feeling as if they had been formed by the regular and direct printing technique.

EXAMPLE C-1

With use of the image-transferable sheet prepared in the foregoing Example A-1, images were formed substantially in accordance with procedures mentioned therein, however, with exception of the formation of reversed images, and then, the image-carrying layer was, without execution of the foregoing peel-off operation, stuck on a portion of curved outer surface of a glass tumbler, whereupon the sheet-like substrate was peeled off, together with the weak-sticking layer. The thus-applied images represent almost no sticking-on grip and viewing feeling, as if they should have been applied through regular and direct-printing technique.

EXAMPLE C-2

On the surface of a transparent polyester film, 12 μm thick, employed as a protecting film, the following image-reception layer forming composition was applied to form a coated layer (in quantity of 6 g/m^2 when measuring upon drying), dried up and left as it was for full one day. Then, it was held at 100° C. for 30 minutes, to form an image-reception layer. On the surface thereof, a parting surface layer was found to exist, which was composed of a combined hardened product of amino-modified silicone resin and epoxy-modified silicone resin.

Image-reception layer-forming composition	
polyester resin ("Vylon 600", manufactured and sold by Toyo Boseki)	100 parts;
amino-modified silicone resin ("KF-393", manufactured and sold by Shinetsu)	7 parts;
epoxy-modified silicone resin ("X-22-343", manufactured and sold by Shinetsu)	5 parts;
solvent (methyl ethyl ketone/toluene = 1/1)	800 parts.

As the substrate, on the other hand, white polyester resin film, "E-20", 75 μm, manufactured and sold by Toray, was used and coated on one surface thereof with a polyurethane-series primer and dried up. Then, the following composition (in the dried quantity of 1 g/m^2) and dried up, so as to provide a smooth and stick layer.

Smooth layer-forming composition	
polymethyl methacrylate resin ("Dianal BR-85", manufactured and sold by Mitsubishi Rayon Co., Ltd.,	12 parts;

-continued

Smooth layer-forming composition	
Tokyo)	
polyethylene wax ("MF8F", manufactured and sold by Dulacon Co.)	0.5 part;
toluene/methyl ethyl ketone = 1/1	85 parts.

On the opposite surface of the white-polyester resin sheet to the smoothed surface the re, a primer coating of polyurethane-series is applied and dried up, and further coated thereon with the following composition, in quantity of 3 g/m^2, so as to provide a weak-sticky layer.

Weak-sticky layer-forming composition	
weak-sticky adhering agent ("Esdyme AE-206", manufactured and sold by Sekisui Kagaku Kogyo K.K., Tokyo)	50 parts;
water	50 parts.

The weak-sticky adhering layer is brought into contact with the protecting film consisting of a polyester film, 12 μm thick, at the opposite surface to the image-reception layer, and then subjected to heat and pressure, to provide an image-transferable sheet. Upon bringing the image-reception layer of the image-transferable sheet and the dyestuff layer of the heat-image transfer sheet into contact with each other, heat energy was applied from a thermal head, as in the similar manner mentioned in the foregoing Example A-1, and thus heat image-transfer job was executed, so as to provide reversed mode images for expressing a full color portrait as well as characters and graphics.

Next, the image-reception layer formed with the reversed images thereon was overlapped onto the image-displayable surface of a card style substrate, 100 μm thick, made of a white color polyester resin material preparatorily applied with a primer layer by coating a composition, consisting of "Vylon 200", 100 μm thick, manufactured and sold by Toyo Boseki K.K., and then subjected together to heat and pressure by means of at least a heated roll at 160° C. Then, the white polyester film, 75 μm thick, and the weak-sticky adhesive layer were peeled off in unison, for providing a final decorative product card having the image-reception layer transferred with images and carrying dislay images.

This card had a highly smooth surface and was not liable to invite any interlayer separation and showed superior light fastness.

In place of white color polyester-made card substrate preparatorily formed with a primer layer, such a modification was prepared and experimented that the white polyester sheet was formed on its rear surface with a magnetic layer, while, on its front surface there is formed with a write-on layer which consists of proper filler and resin as conventionally, so as to provide a telephone card. This processed telephone card had the write-on layer provided with display images formed by image-transfer.

EXAMPLE C-3

On the surface of a transparent polyester film, 9 μm thick, used as the protecting layer, an intermediate layer was provided by coating. The coated amount was 5 g/m^2 as measured upon being dried up.

Intermediate layer-forming composition	
polyurethane resin ("Takelack T-3350", solid content 23%, manufactured and sold by Takeda Pharmaceutical Co., Ltd., Osaka)	50 parts;
isopropyl alcohol	15 parts;
toluene	25 parts;
methyl ethyl ketone	10 parts.

Onto the intermediate layer, the following composition was applied for the formation of an image-reception layer. The coated quantity was 5 g/m^2 as measured upon being dried up.

Image-reception layer-forming composition	
polyester resin ("Vylon 600", manufactured and sold by Toyo Boseki)	10 parts;
polyester resin ("Vylon 200", manufactured and sold by Toyo Boseki)	5 parts;
amino-modified silicone ("KF-393", manufactured and sold by Shinetsu)	1 part;
epoxy-modified silicone ("X-22-343", manufactured and sold by Shinetsu)	1 part;
solvent (methyl ethyl ketone/toluene = 1/1)	85 parts.

On the other hand, a white color polyester film, which was similar to that employed in the foregoing Example C-2 was formed with a slidingly smooth layer, as well as a weak-sticking adhesive layer, the latter being brought into intimate contact with a transparent polyester film, 9 μm thick, at the opposite surface to the image-reception layer and then, subjected to heat and pressure, for providing a heat image-transferable sheet. As further processed in the similar manner in the foregoing Example C-2, full-color photographic images (reversed images) were thus formed on the image-reception surface. In this way, a final product card, having its image-reception layer transferringly formed with display images.

EXAMPLE C-4

Substrate

White color polyester sheet, "E-20", 100 μm thick, manufactured and sold by Toray was formed thereon with a polyurethane-series primer coating. Then, a weak-sticking layer was applied thereon with use of the following composition.

Weak-sticking layer-forming composition	
weak-sticking agent ("Esdyne AE-206", manufactured and sold by Sekisui Kagaku Kogyo K.K., Tokyo)	50 parts;
water	50 parts.
Protecting layer-forming composition	
polyester resin ("Vylon-200", manufactured and sold by Toyo Boseki)	15 parts;
diisocyanate ("Colonate L", manufactured and sold by Nippon Polyurethane Co., Ltd.)	1 part;
toluene/methyl ethyl ketone = 1/1	84 parts.
Image-reception layer-forming composition	
polyester resin	10 parts;

-continued

("Vylon 600", manufactured and sold by Toyo Boseki K.K.)	
vinyl chloride-vinyl acetate copolymer resin ("Vinylite VAGH" (Tg = 79° C.), manufactured and sold by Union Carbide Corp)	5 parts;
toluene/methyl ethyl ketone = 1/1	85 parts;
amino-modified silicone ("KF-393", manufactured and sold by Shinetsu)	1 part;
epoxy-modified silicone ("X-22-343", manufactured and sold by Shinetsu)	1 part.

With use of the above composition and processed substantially same as in the foregoing Example C-2, a final card product was obtained.

EXAMPLE D-1

An image-transferable sheet was prepared as in the foregoing Example A-1 and thermally image-transferred with reversed mode images of a full color portrait photograph, to provide an intermediate image-transfer medium. The latter is overlapped by its image-reception layer onto the surface of a sheet of rough-textured cotton cloth, however, through the intermediary of an acrylic acid ester-vinyl acetate copolymer sheet, 100 μm thick. Then, the assembly was subjected to heat and pressure. Then, the substrate sheet and weak-sticky adhesive layer, together, were peeled off. The thus transfered images have sufficient surface smoothness, showing superior surface conditions.

Without use of the bond-attaching sheet in the above process and when similar image-transfer job as above was performed, the resulted images followed the surface undulations appearing disadvantageously on the material product of the rough fabrics and thus were highly uneven, and further, on account of insufficient adhering performance acting between the image-receiving layer and the woven fabrics serving as product material, easy and frequent separations took place therebetween.

EXAMPLE D-2

In the similar way as was disclosed in the foregoing Example D-1, an intermediate image-transfer medium carrying reversed images was prepared and overlapped on a polymethacrylate board preparatorily subjected to surface-toughening operation through a conventional sand-blasting step, and through the intermediary of a bond-adhering sheet pressurized together under heat, as was employed in Example D-1. Then, the sheet-like substrate was peeled off, together with the weak adhesive layer. The thus-provided images were highly smooth and even in spite of the highly rough and undulating conditions at the surface to be image-transferred. In addition, the image-carrying surface showed superior results in various resisting tests.

Without use of the foregoing bond-sticking layer, the similarly transferred images showed considerable undulations and distortions. Further, on account of insufficient adhering performance, easy and frequent peel-offs of applied images were feared.

EXAMPLE D-3

On the surface of a polyester resin film, 25 μm thick, the following composition adapted for the formation of bond-sticking layer was coated and dried up, in dried quantity of 5 g/m^2 to provide a film formed thereon a bond sticking sheet.

Bond-sticking sheet-forming composition	
polyester resin ("Vylon 600", manufactured and sold by Toyo Boseki)	15 parts;
methyl ethyl ketone/toluene = 1/1	84 parts.

The bond-sticking sheet surface, together the polyester resin film proper, was brought into contact with the image-representing surface of a white color polyester made-card substrate, 25 μm thick, and then, subjected to heat and pressure by means of at least a heat roll kept at 200° C., arranged to supply heat energy from the side of the polyester resin surface, thereby heat bonding the bond-sticking sheet onto the card surface, whereupon the polyester resin film being forcedly peeled off.

Further then, as in the similar way as adopted in foregoing Examples C-2; A-3; A-4 and C-3, use is made of the image-reception layers representing reversed images thereon, the respective image-reception layers were whereupon brought into contact with the card's bond-sticking surface of the card and subjected to heat and pressure by use of at least a heat roll kept at 200° C. Then, the white color polyester resin substrate was peeled off, together with the weak-sticky adhering layer. In this way, a final product card displaying the portrait photograph was obtained.

EXAMPLE D-4

Substrate

A white color polyester resin sheet, "E-20", 100 μm thick, manufactured and sold by Toray Co. Ltd., was coated with a polyurethane-series primer. On the surface of the thus precoated sheet, the following composition was coated to form a weak-sticking adhesive layer.

Weak-sticking adhesive component	
weak-sticking adhesive agent, ("Esdyne AE-206", manufactured and sold by Sekisui Kagaku)	50 parts.
Image-reception layer-forming composition	
polyester resin ("Vylon 200", manufactured and sold by Toyo Boseki)	7.5 parts;
polyester resin ("Vylon 290", manufactured and sold by Toyo Boseki)	7.5 parts;
toluene/methyl ketone = 1/1	85 parts;
amino-modified silicone ("KF-393", manufactured and sold by Shinetsu)	1 part;
epoxy-modified silicone ("X-22-343", manufactured and sold by Shinetsu)	1 part.

The foregoing compositions were prepared. On the other hand, a polyester resin film, 25 μm thick, was coated on one surface thereof with a 15%-solution of polyester resin, "Vylon 200", manufactured and sold by Toyo Boseki, in toluene/methyl ethyl ketone=1/1 and dried up. The coating quantity was adjusted to 5 g/m^{2}when measuring in dried state. In this way, a bond-sticking sheet was provided.

Then, the coated surface of the thus prepared bond-sticking sheet was brought into contact with the image display surface of a card style substrate of white color

hard vinyl chloride or the like resin material preparatorily subjected to a primer coating treatment in overlapping state and then, the whole assembly was subjected to heat and pressure with use of at least a heated roll to 130° C., thus the bond-sticking layer being stuck on the card surface. Under this condition, the polyester resin film, 25 μm thick, was peeled off.

Then, the image-reception layer, now carrying thereon reversed images, was brought into contact with the bond-sticking sheet and the resulted whole was subjected to heat and pressure by use of at least a heated roll and the white color polyester resin substrate, together with the weak-sticking adhesive layer, was peeled off. In this way, the card, now displaying the portrait images, was provided.

EXAMPLE D-5

Substrate

Same as in the foregoing Example D-4.

Weak-sticking adhesive layer

Same as in the foregoing Example D-4.

Protecting layer-forming composition	
polyester resin ("Vylon 200", manufactured and sold by Toyo Boseki)	15 parts;
diisocyanate ("Colonate L", manufactured and sold by Nippon Polyurethane)	1 part;
toluene/methyl ethyl ketone = 1/1	84 parts.
Image-reception layer-forming composition	
polyester resin ("Vylon 600", manufactured and sold by Toyo Boseki)	10 parts;
toluene/methyl ethyl ketone = 1/1	85 parts;
amino-modified silicone ("KF-393", manufactured and sold by Shinetsu)	1 part;
epoxy-modified silicone ("X-22-343", manufactured and sold by Shinetsu)	1 part.

With use of the foregoing materials and compositions, the processings were carried out as in the foregoing Example D-4, to provide a final product card displaying portrait images as was desired.

EXAMPLE D-6

Substrate

Same as in the foregoing Example D-4.

Weak-sticking adhesive layer

Same as in the foregoing Example D-4.

Image-reception layer-forming composition	
polyester resin ("Vylon 600", manufactured and sold by Toyo Boseki)	10 parts;
vinyl chloride-vinyl acetate copolymer resin ("Vinylite VAGH", manufactured and sold by Union Carbide Corp.)	5 parts;
toluene/methyl ethyl ketone = 1/1	85 parts.

The foregoing materials and compositions were prepared and processed in the similar way as in the foregoing Example D-4, to provide a final product card, displaying the desired portrait images as were desired.

EXAMPLE E-1

On a polyethylene terephthalate film, 9 μm thick, a solution of saturated polyester resin, "Vylon 600", manufactured and sold by Toyo Boseki, in toluene/methyl ethyl ketone = 1/1, was coated by reliance of the known reverse roll-coating process, and dried up. The coated quantity was 7 g/m^2 when measuring in dry condition. In this way, a weak-sticking adhesive layer could be formed.

On the weak-sticking adhesive layer, the following composition, 3 g/m^2 (dry), was coated by means of an oblique-lined gravure roll for solid and full printing use and in the reverse roll-coating process, and then dried up, to provide an image-reception layer.

Image-reception layer-forming composition	
polyester resin ("Vylon 200", manufactured and sold by Toyo Boseki)	70 parts;
polyester resin ("Vylon 290", manufactured and sold by Toyo Boseki)	30 parts;
amino-modified silicone ("KF-393", manufactured and sold by Shinetsu)	5 parts;
epoxy-modified silicone ("X-22-343", manufactured and sold by Shinetsu)	5 parts;
methyl ethyl ketone (wt. ratio 1/1)	700 parts.

On the opposite surface to the image-reception layer of the thus-prepared image-transferable sheet, a synthetic paper substrate, "Yupo FPG 110", 110 μm thick, manufactured and sold by Oji Yuka K.K., coated with "Vylon 600" as the adhesive agent in quantity of 10 g/m^2 (dry) was stuck intimately together.

On the other hand, a polyethylene terephthalate film substrate, 6 μm thick, preparatorily provided on one surface thereof with a heat-resisting layer was used and the following composition was applied on the opposite surface of the substrate with use of a wire bar and dried up, in the quantity of 1 g/m^2 (dry), so as to provide a dyestuff layer. In this way, a heat image-transferable sheet was prepared and provided.

Dyestuff layer-forming composition	
dispersion dye ("Kayaseo Blue-136", manufactured and sold by Nippon Kayaku K.K.)	4 parts;
ethylhydroxyethyl cellulose	6 parts;
methylethylketone/toluene (wt. ratio: 1/1)	90 parts.

The dyestuff layer of the foregoing heat image-transfer sheet was brought into contact with the image-reception layer of the image-transferable sheet in overlapping manner, then, heat energy was applied from a thermal head from the side of heat-resisting layer of the heat image-transfer sheet, thereby dyestuff being transferred to the image-reception layer of image-transferable sheet, and indeed, for the formation of positive images.

Then, the image-transferable sheet, now carrying the required positive images was stuck together under heat and pressure at 140° C. for 5 seconds on the intermediate image-transfer substrate prepared in the following manner, in mutually opposed manner. Then, the synthetic paper "Yupo" was peeled off at the intersurface between the polyester resin film and the "Vylon 600" layer. In thus way, the inventive image-transfer sheet

(intermediate image-transfer medium) carrying the corresponding reverse images was provided.

Method for the preparation of intermediate image-transfer substrate

A sheet, of fine quality or stick paper, unit weight: 82 g/m^2 was applied with a coating, about 20 μm thick, of polyethylene resin through conventional extrusion coating process. Thereon, further, a catalyst-added toluene solution of a parting agent silicone, "KS-707", manufactured and sold by Shinetsu was applied and dried up in quantity of about 2 g/m^2 (dry), for the purpose of curing. Thereon, still further, the following coating liquid composition was applied by means of a conventional coating bar and dried up, to provide an intermediate image transfer substrate. The thus coated and dried resin quantity was measured to 7 g/m^2.

Coating liquid composition	
polyester resin ("Vylon 200", manufactured and sold by Toyo Boseki)	100 parts;
methyl ethyl ketone/toluene (mixing ratio by weight: 1/1)	700 parts.

A sheet of coated paper, pretreated for pore-filling, was coated, in the similar manner as above, with the foregoing liquid composition, to provide an image-transferable medium. On and with the presently coated surface, the image carrying surface of the foregoing intermediate image-transfer medium is brought into opposing contact and stuck together under heat and pressure at 140° C. for 7 seconds. Finally, the laminate of fine-quality paper and polyethylene was peeled off, to provide a final decorative product now displaying the positive images as required.

It will thus be seen that by adopting the above processing steps, the positive images formed under the action of the thermal head are transferred, through the intermediary of intermediate image transfer medium, onto the final object to be decorated, and indeed, in the form of positive mode. It will be further seen that, since the dyestuff is well distributed within the image-reception layer, the transferred positive images are highly sharp and fresh, in addition to much profundities.

Since a resin layer was overlappingly applied on the thus-formed images, weather fastness, frictional durability and light-fastness of the finally formed images could be highly and amazingly improved. When suitable ultraviolet absorbing agent, antioxydant, quenching agent and/or radical scavenger is added to, further improvement of the light-fastness can be attained.

EXAMPLE E-2

The substrate of image-transferable medium adopted in the foregoing Example E-1 was replaced by a hard polyvinyl chloride card, 100 μm thick, and other processing modes were same as in Example E-1. In this way, a high quality, positive-image transferred, decorative final product was successfully provided. When the image include human portrait photograph, the final product was highly useful for ID-card.

EXAMPLE E-3

The substrate of image-transferable medium adopted in the foregoing Example E-1 was replaced by a transparent polyester film, and other processing modes were same as employed the rein. In this way, a transparent film formed with the wanted positive images of better quality as before was obtained. This film was highly useful in OHP-services.

EXAMPLE E-4

A sheet of high quality paper, unit weight: 104 g/m^2, was coated with a layer of polypropylene resin, thickness: about 20 μm, through the way of conventional extrusion coating technique, then the coating was further coated with a silicone solution for use in parting service and hardenable under electron rays and dried up. The quantity of the coating silicone was about 1 g/m^{2}upon drying. In this way, an electron-hardened, provisional substrate was provided. On this substrate, the following, image-reception layer-forming composition was applied as a layer by use of a coating bar, and then dried up, for providing an image-reception layer. The coated resin quantity in the above last step amounted about 5 g/m^2.

Image-reception layer-forming composition	
polystyrene ("Picolastic D 150" (Tg = 69° C.), manufactured and sold by Rika-Hercules Co., Ltd.	100 parts;
amino-modified silicone ("KF-393", manufactured and sold by Shinetsu)	7 parts;
epoxy-modified silicone ("X-22-343", manufactured and sold by Shinetsu)	7 parts.

Further processing was carried out as was set forth in the foregoing Example E-2, for providing a final product card, carrying thereon the wanted positive images of same superior quality, as was in Example E-2.

EXAMPLE E-5

On the image transferable medium used in the foregoing Example E-4, however, in the present Example, a thermoplastic resin, adhesive, polyolefine-series film, "Adwin 500", manufactured and sold by Showa Denko K.K., Tokyo, was applied as a layer. Other materials were used and processed as set forth the rein. In this way, a decorative final product formed with necessary positive was obtained with superior results.

Industrial Availabilities

As will be well understood from the foregoing detailed description of the invention, it is possible according to the present inventive system, to form highly easily and evenly the desired images sharply and attractingly on any product and object to be decorated or graphically ornamented, substantially irrespective of material kind and configuration thereof, and indeed, with a surprising unitary touch and feeling with the substrate. Therefore, the invention can be utilized broadly and conveniently in such various industrial fields, where unitary formation of various images, characters, symbols, numerals and graphics, on and to the articles, objects and substrate products to a sufficiently miracle and attracting degree.

We claim:

1. A sublimatingly image-transferred product comprising:

a plastic card;

an image-reception layer provided on said plastic card, said image-reception layer having an antistatic agent applied on the surface of the image-recep-

tion layer located between said plastic card and said image-reception layer; and

a transferred image formed between said plastic card and said image-reception layer having said antistatic agent applied thereon;

said image-transferred product being formed by a two transfer step process comprising (1) sublimation transferring by thermal energy an image on an image-receiving sheet comprising a substrate and the image-reception layer having an antistatic agent applied thereon and thereafter (2) transferring said image-reception layer having the transferred image formed by the sublimation transfer step (1) from said image-receiving sheet onto said plastic card, transferring step (2) occurring by adhesion of thermal fusion between the surface of said plastic card and said image-reception layer and peeling off the substrate from the image-receiving sheet thereby to form said transferred image on the interface side between the plastic card and the image-reception layer.

2. The sublimatingly image-transferred product of claim **1**, further comprising a protecting layer on the surface of said image-reception layer.

3. The sublimatingly image-transferred product of claim **1**, further comprising a parting agent layer is provided on the surface of said image-reception layer or between the latter and the card.

4. The sublimatingly image-transferred product of claim **1**, wherein said card is a transparent card.

5. The sublimatingly image-transferred product of claim **1**, wherein a protecting layer is provided on the substrate and the image-reception layer is provided on the protecting layer, both the protecting layer and the image-reception layer being retained after transferring step (2).

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United States Patent [19]

Komma et al.

[11] **Patent Number: 5,446,565**

[45] **Date of Patent: Aug. 29, 1995**

[54] **COMPOUND OBJECTIVE LENS HAVING TWO FOCAL POINTS**

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[21] Appl. No.: **190,520**

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Aug. 4, 1993 [JP] Japan 5-193353

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[52] **U.S. Cl.** **359/19**; 369/44.23; 369/94; 369/103; 369/112

[58] **Field of Search** 359/15, 16, 19; 369/94, 369/103, 109, 112, 44.23

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[57] **ABSTRACT**

A compound objective lens is composed of a hologram lens for transmitting a part of incident light without any diffraction to form a beam of transmitted light and diffracting a remaining part of the incident light to form a beam of first-order diffracted light, and an objective lens for converging the transmitted light to form a first converging spot on a front surface of a thin type of first information medium and converging the diffracted light to form a second converging spot on a front surface of a thick type of second information medium. Because the hologram lens selectively functions as a concave lens for the diffracted light, a curvature of the transmitted light differs from that of the diffracted light. Therefore, even though the first and second information mediums have different thicknesses, the transmitted light incident on a rear surface of the first information medium is converged on the its front surface, and the diffracted light incident on a rear surface of the second information medium is converged on the its front surface. That is, the compound objective lens has two focal points.

34 Claims, 43 Drawing Sheets

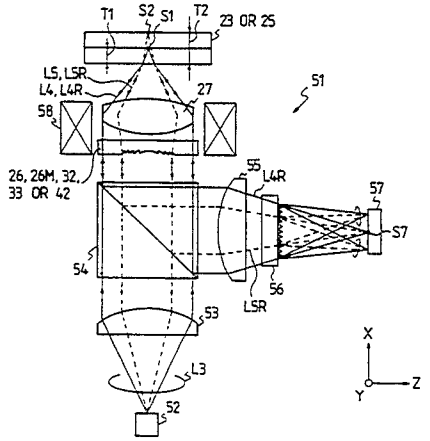

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FIG. 1
PRIOR ART

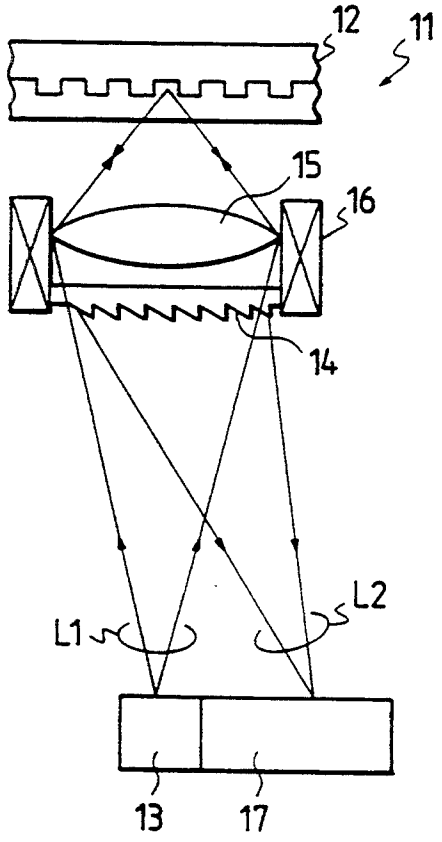


FIG. 2A
PRIOR ART

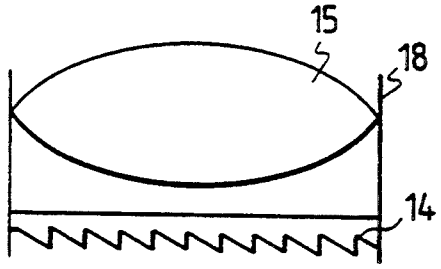


FIG. 2B
PRIOR ART

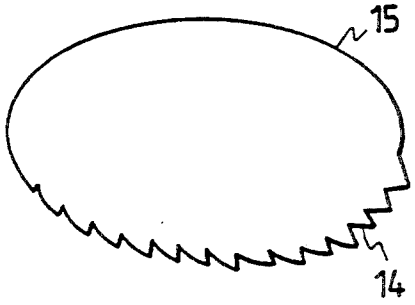


FIG. 3 PRIOR ART

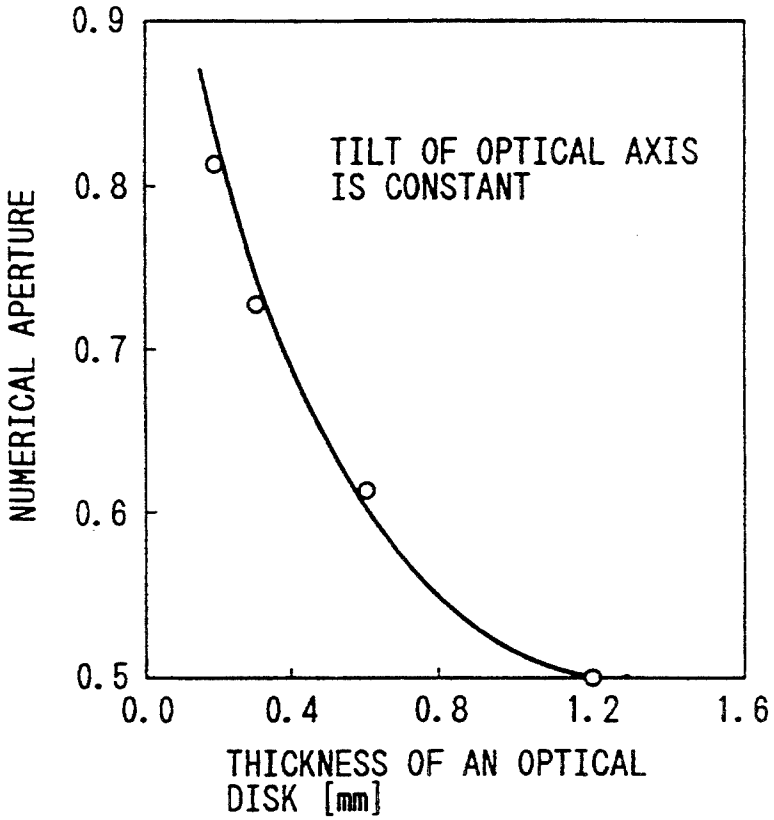


FIG. 4A

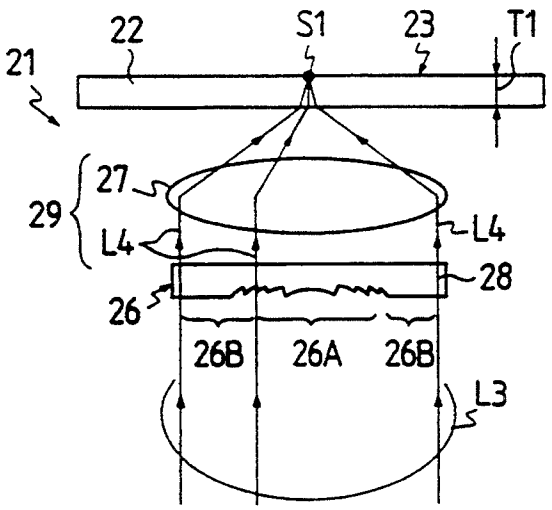


FIG. 4B

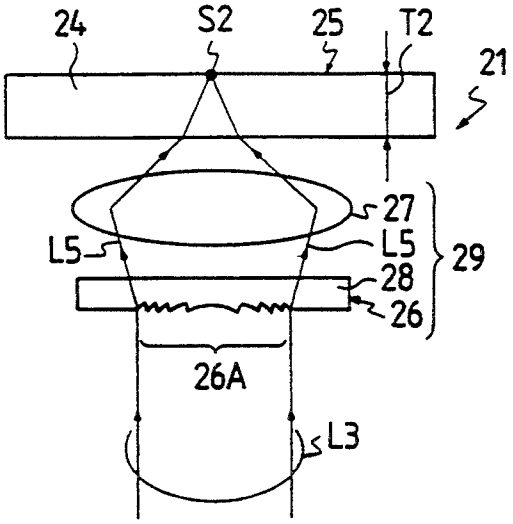


FIG. 5

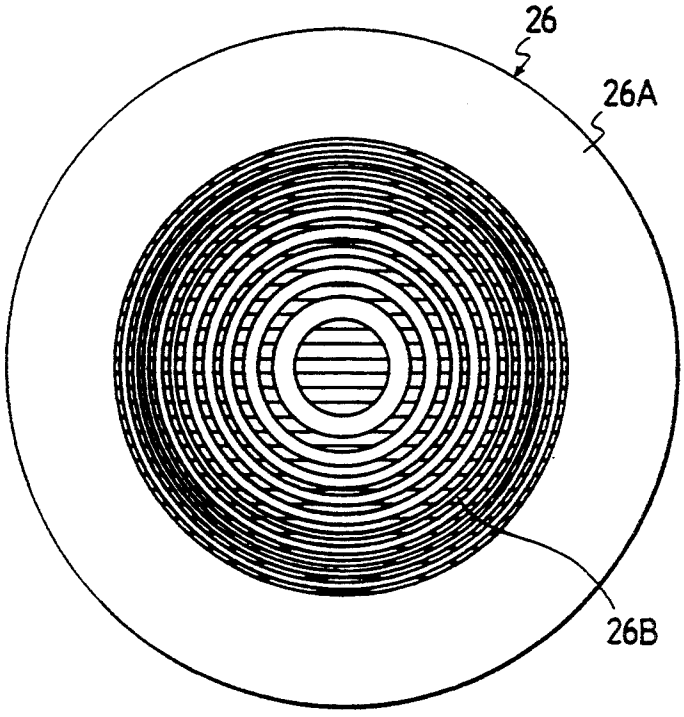


FIG. 6

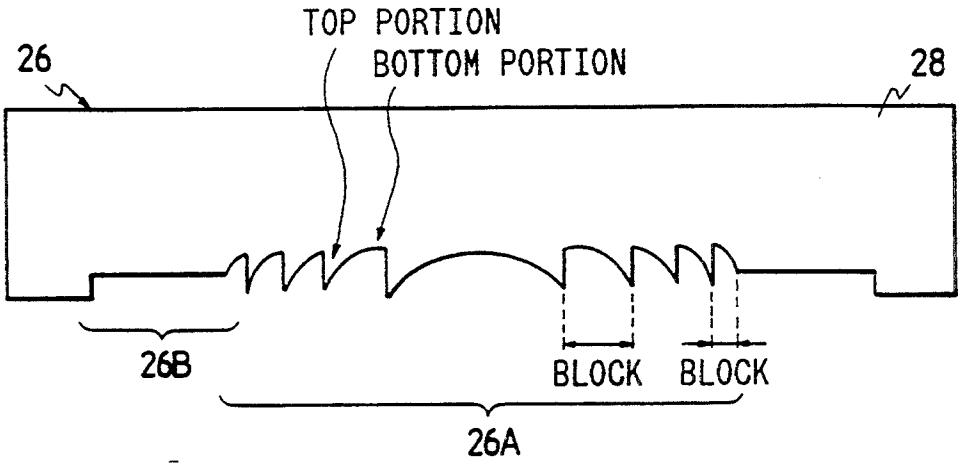

TOP PORTION
BOTTOM PORTION
26
28
26B
BLOCK
BLOCK
26A

FIG. 7

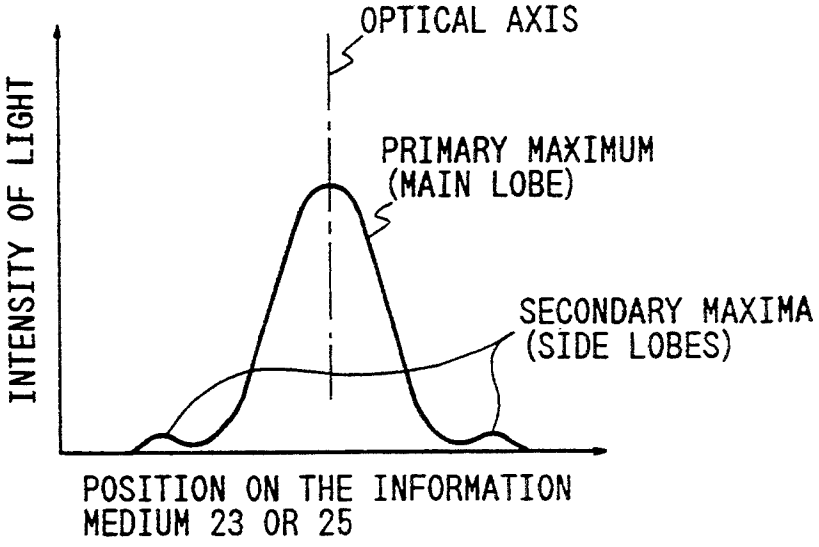

OPTICAL AXIS
PRIMARY MAXIMUM
(MAIN LOBE)
SECONDARY MAXIMA
(SIDE LOBES)
INTENSITY OF LIGHT
POSITION ON THE INFORMATION
MEDIUM 23 OR 25

FIG. 8A

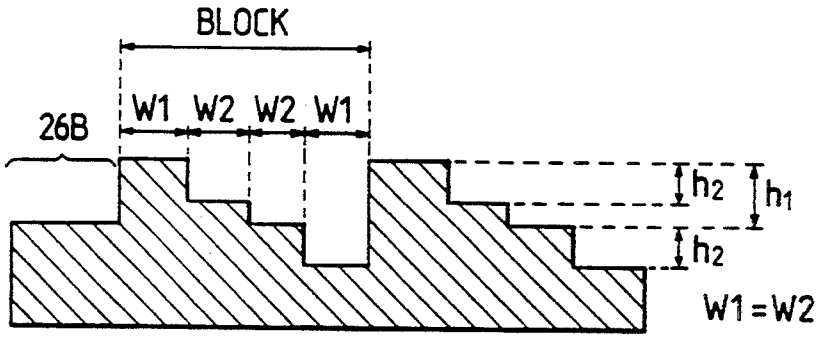


FIG. 8B

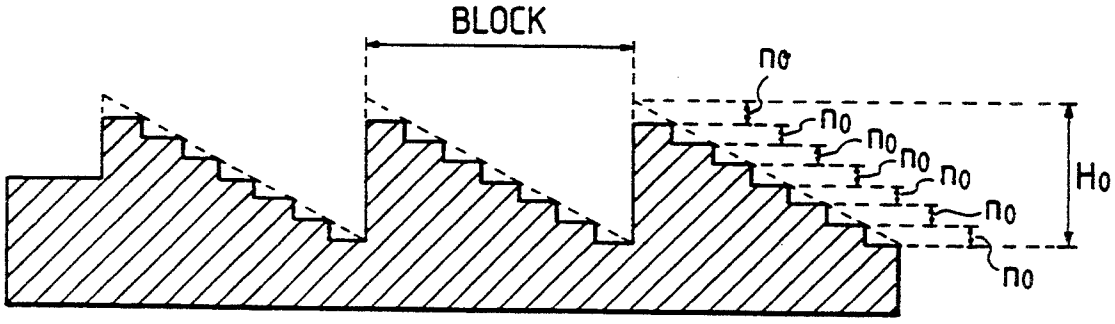


FIG. 9A

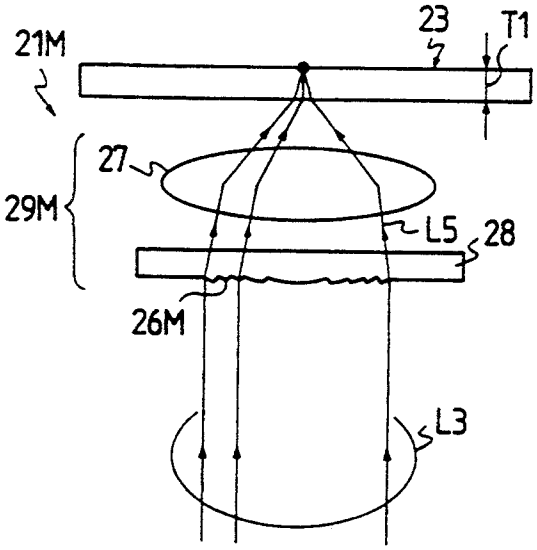


FIG. 9B

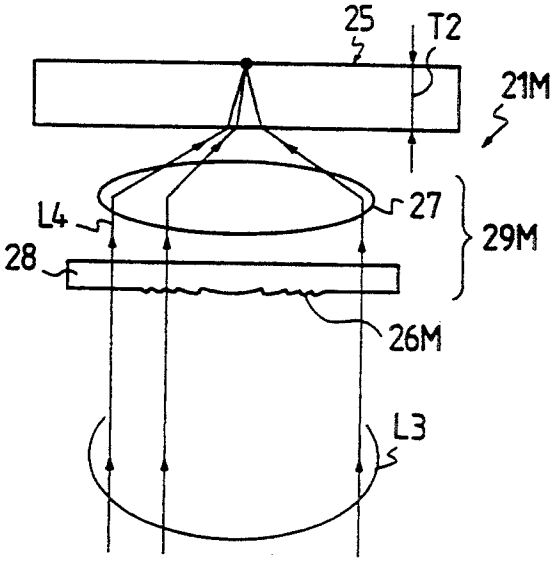


FIG. 10A

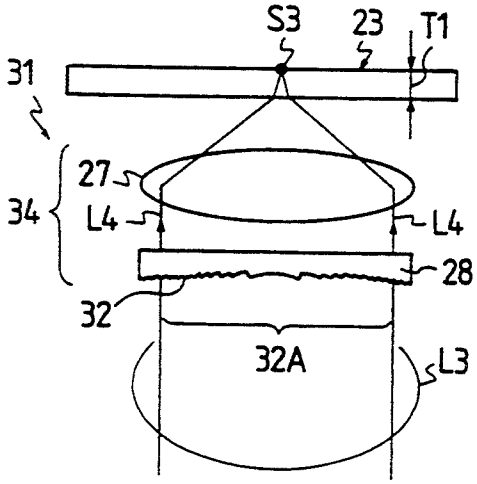


FIG. 10B

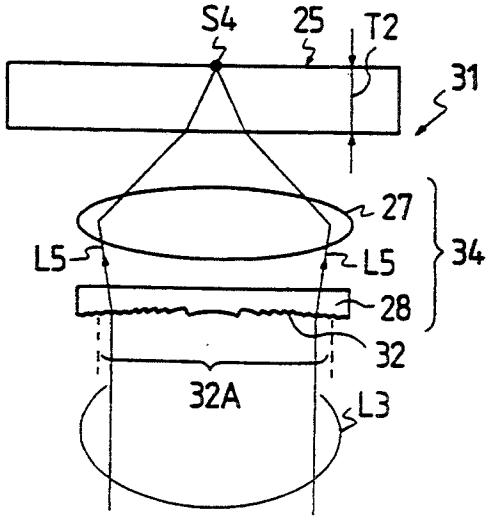


FIG. 11

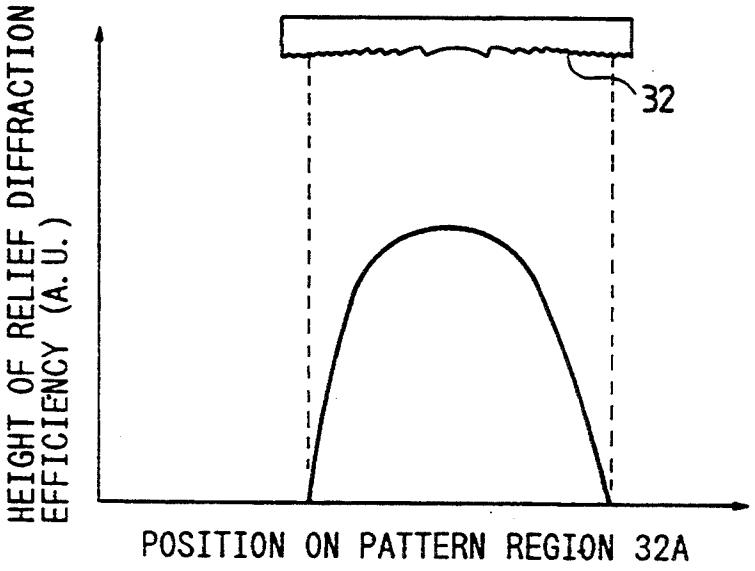

HEIGHT OF RELIEF DIFFRACTION EFFICIENCY (A.U.)
32
POSITION ON PATTERN REGION 32A

FIG. 12A

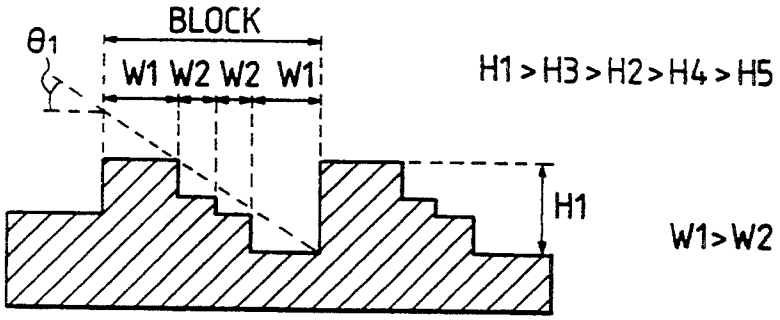


FIG. 12B

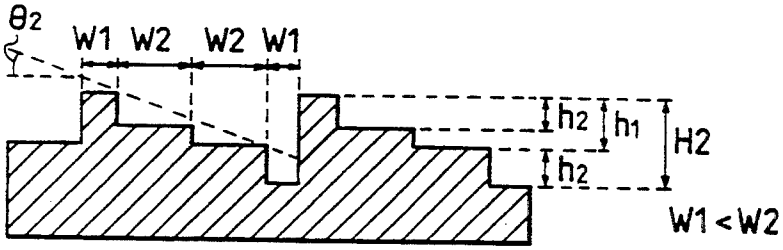


FIG. 12C

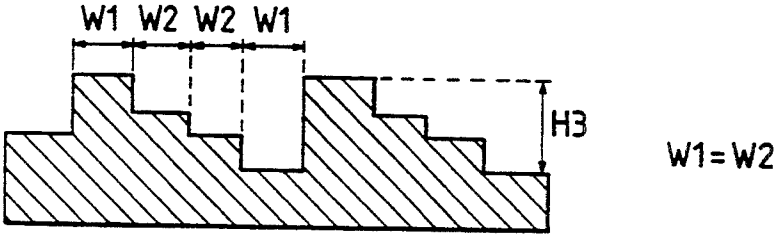


FIG. 12D

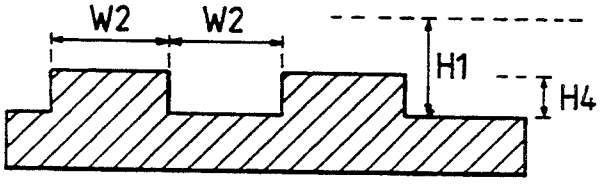


FIG. 12E

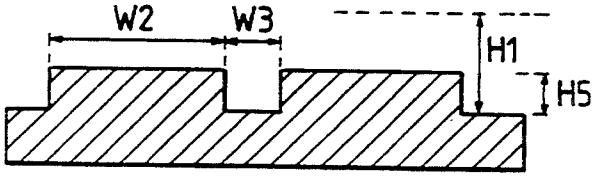


FIG. 13A

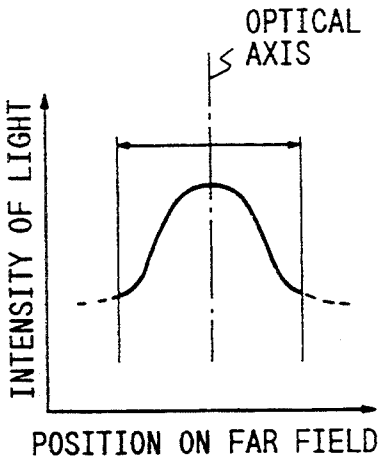


FIG. 13B

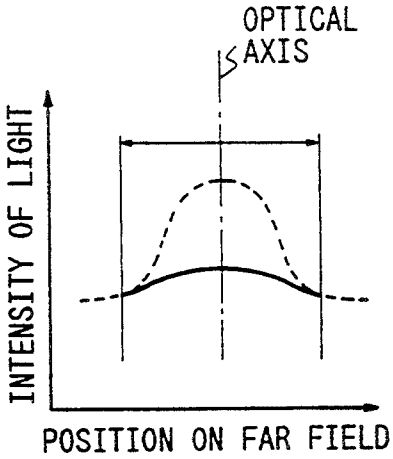


FIG. 14A

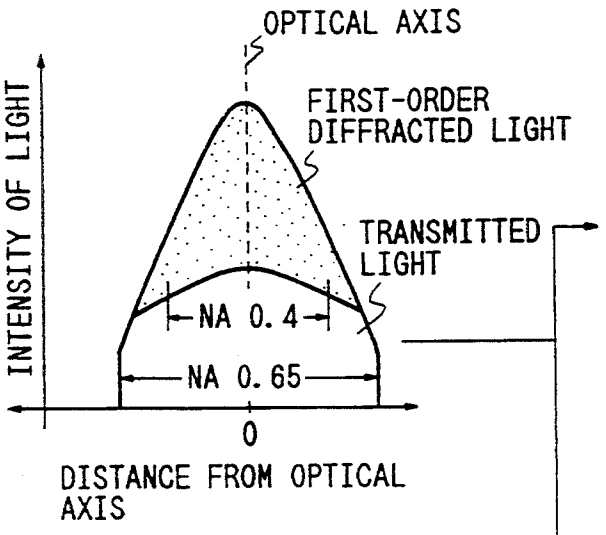


FIG. 14B

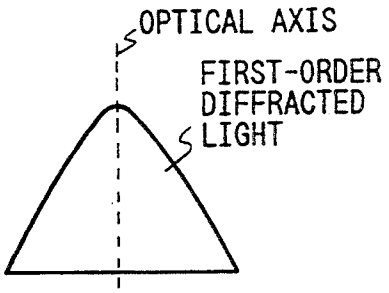


FIG. 14C

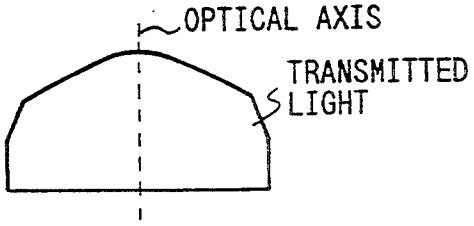


FIG. 15A

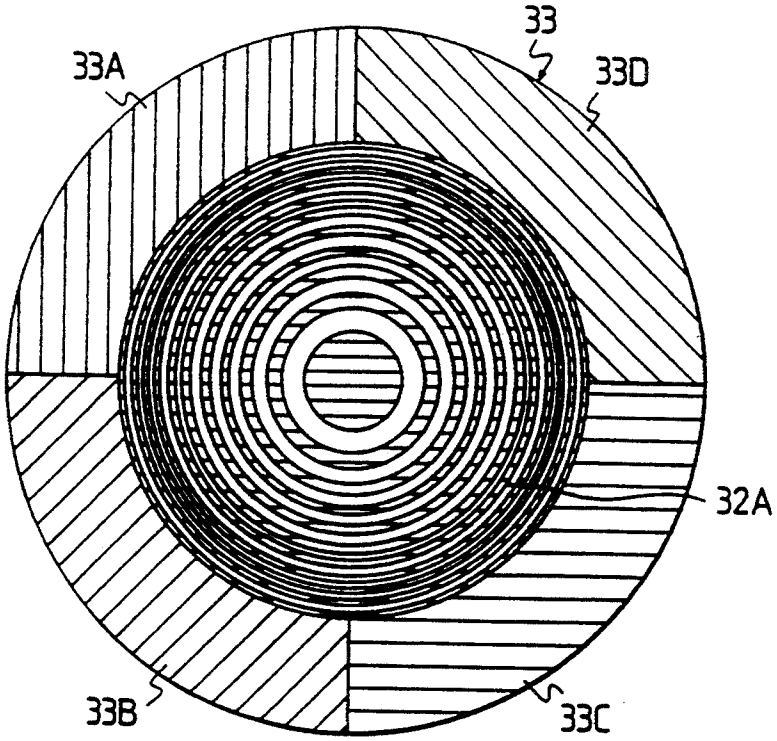


FIG. 15B

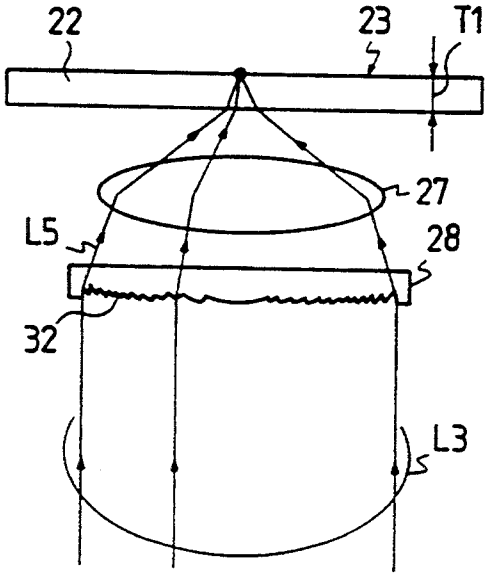


FIG. 15C

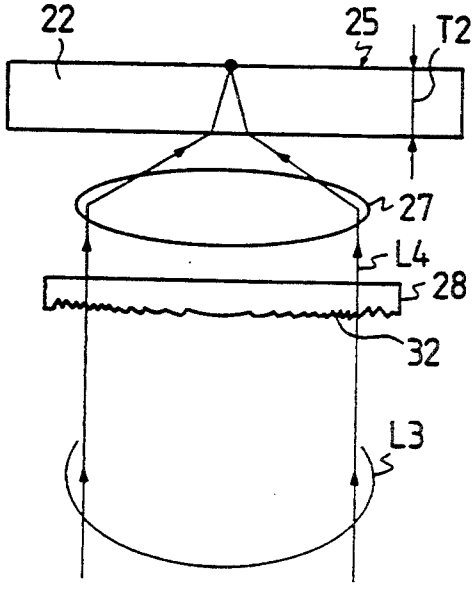


FIG. 16A

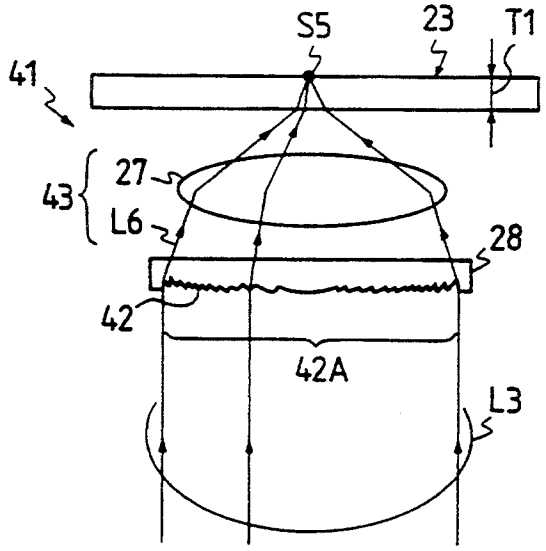


FIG. 16B

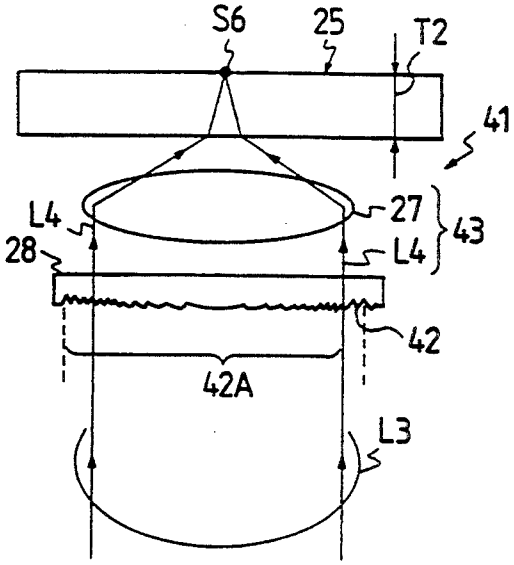


FIG. 17

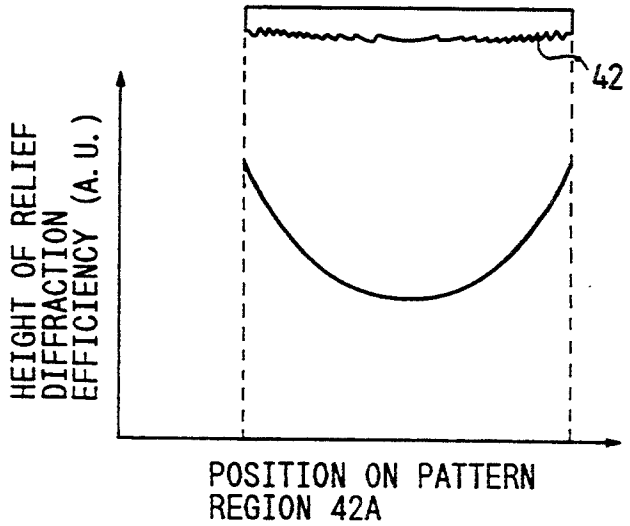


FIG. 18A

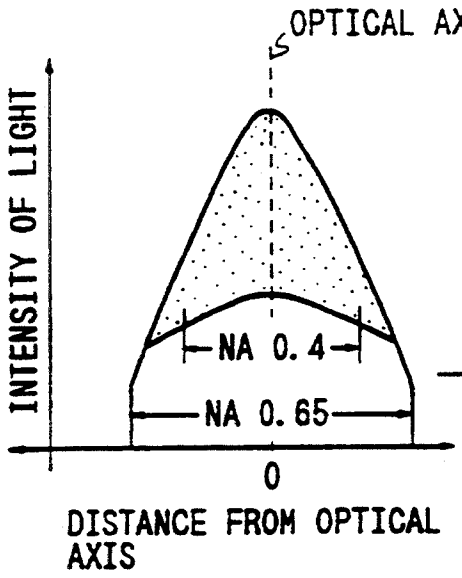


FIG. 18B

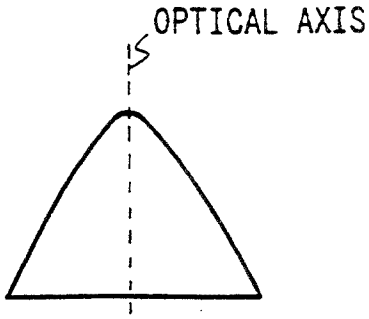


FIG. 18C

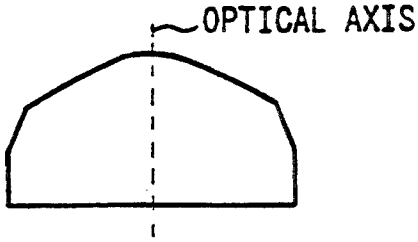


FIG. 19A

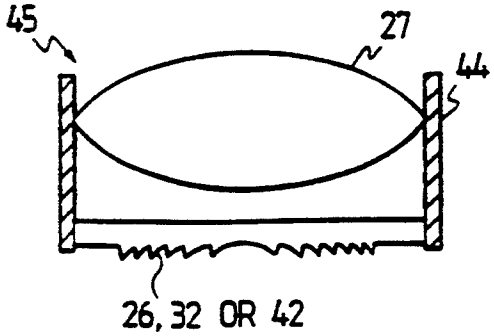


FIG. 19B

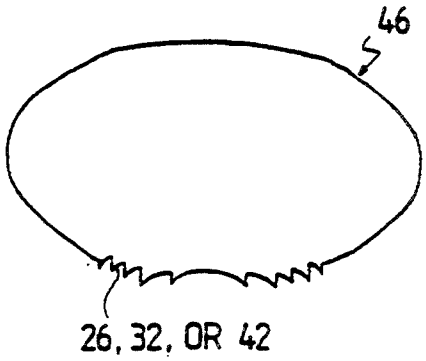


FIG. 20

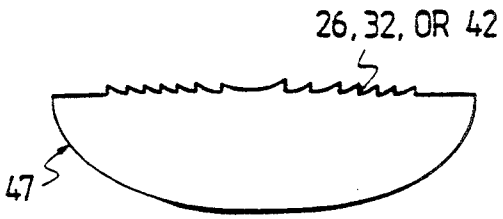


FIG. 21

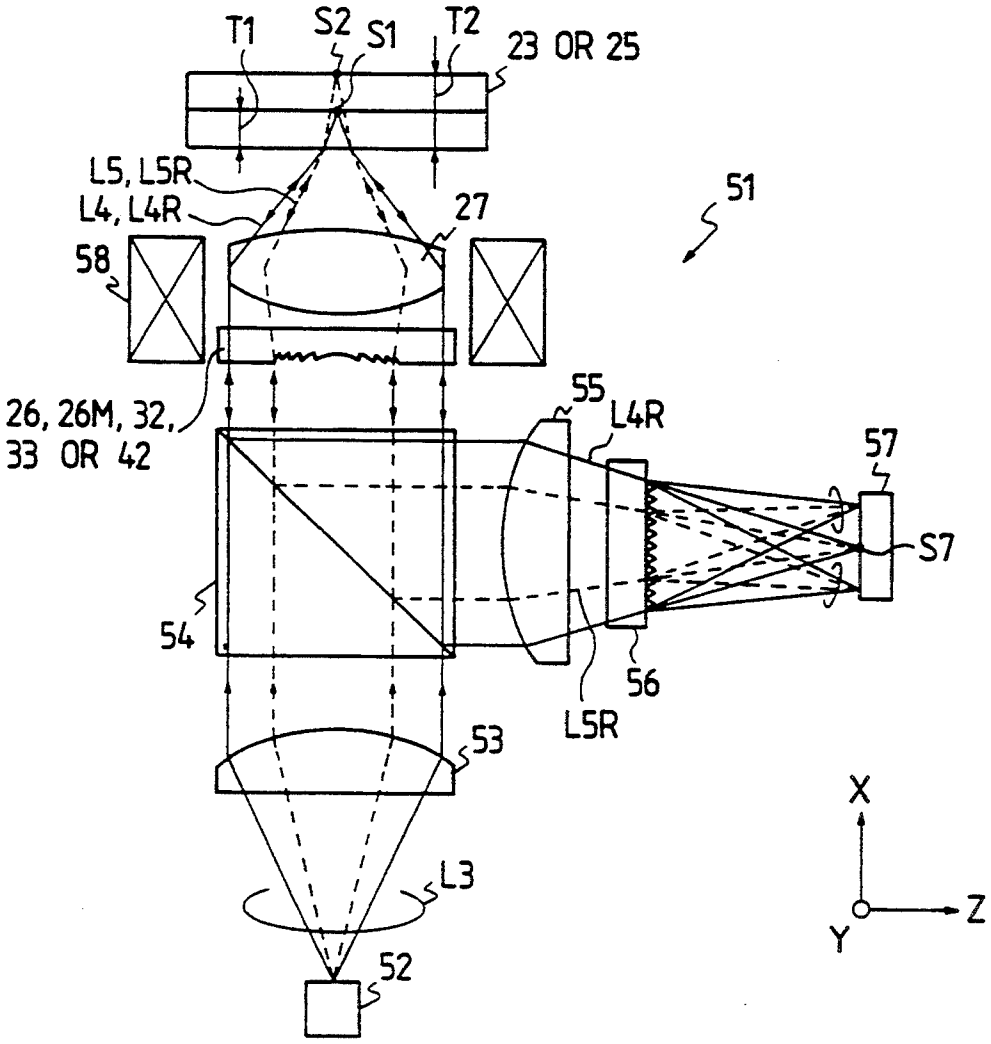

T1
S2
S1
T2
23 OR 25
L5, L5R
L4, L4R
27
51
58
26, 26M, 32,
33 OR 42
55
L4R
57
S7
54
56
L5R
53
L3
52
X
Z
Y

FIG. 22

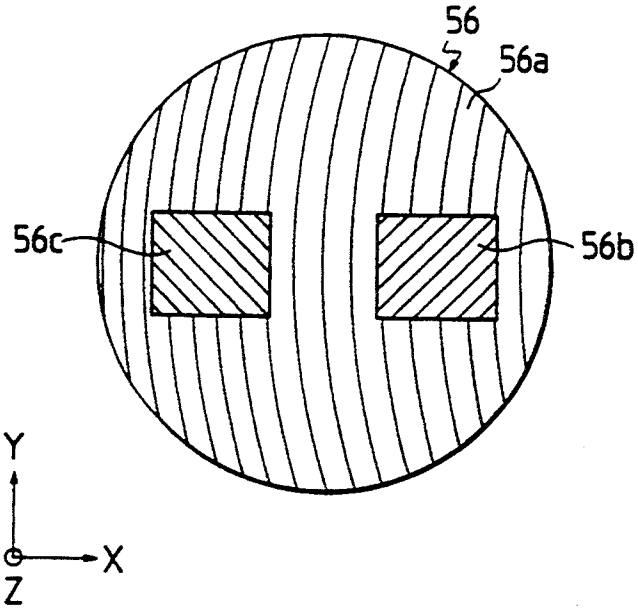


FIG. 23

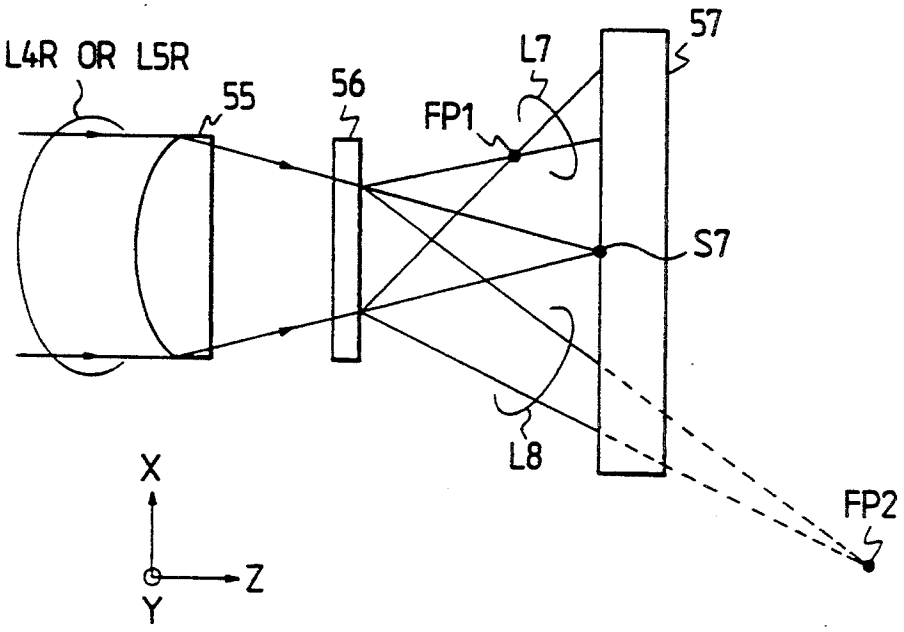


FIG. 24

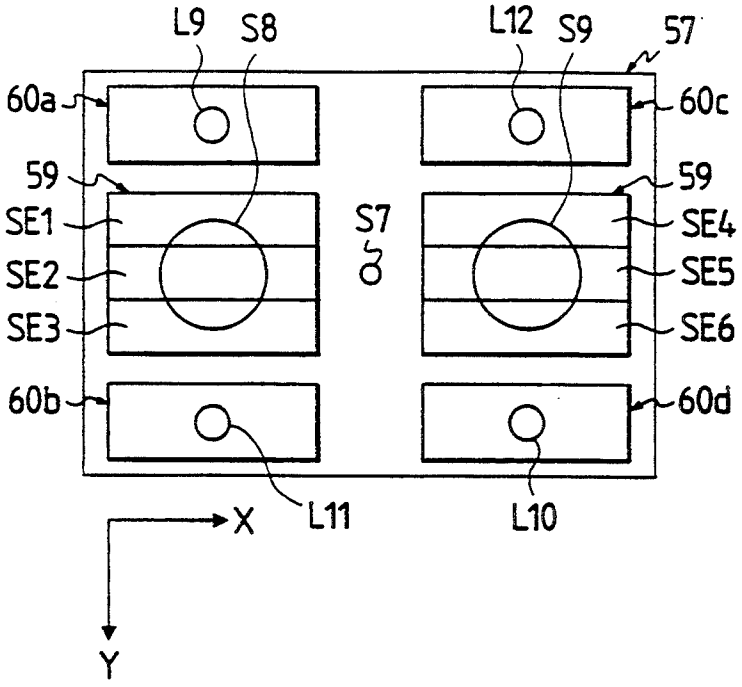


FIG. 25A

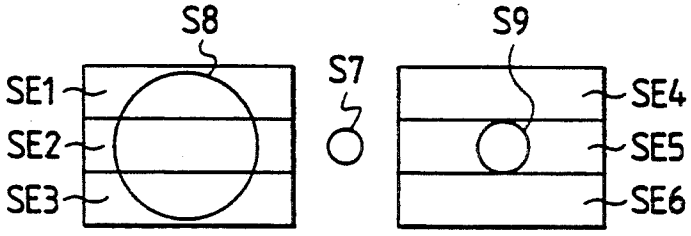


FIG. 25B

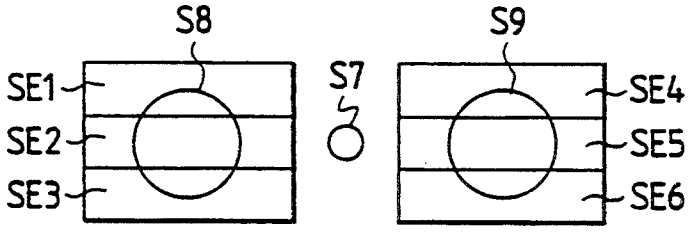


FIG. 25C

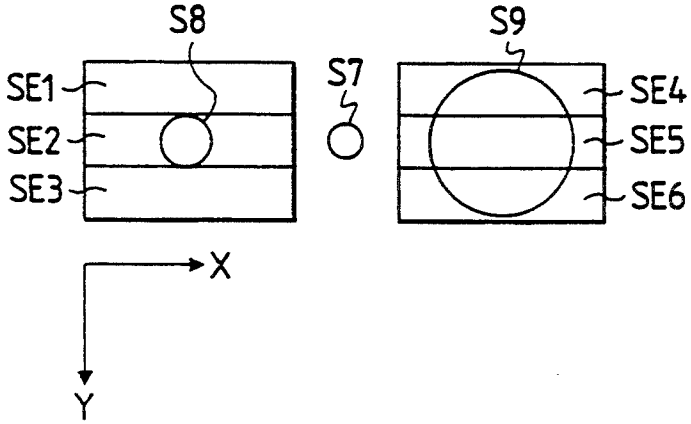


FIG. 26

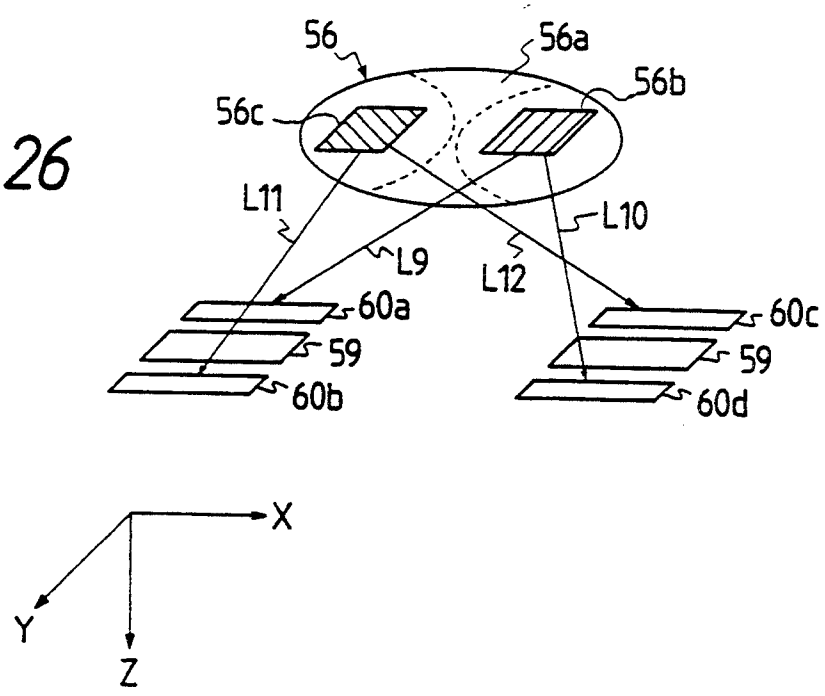

56
56a
56b
56c
L11
L10
L9
L12
60a
60c
59
59
60b
60d
X
Y
Z

FIG. 27

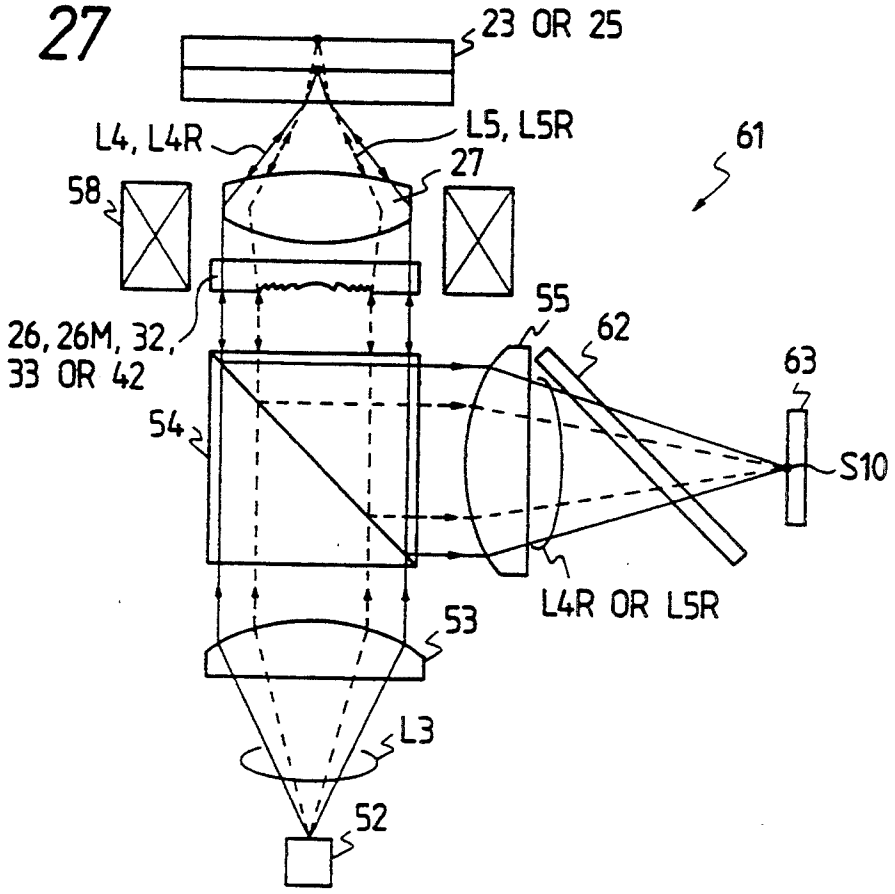

23 OR 25
L4, L4R
L5, L5R
27
61
58
55
62
63
26, 26M, 32,
33 OR 42
54
S10
L4R OR L5R
53
L3
52

FIG. 28

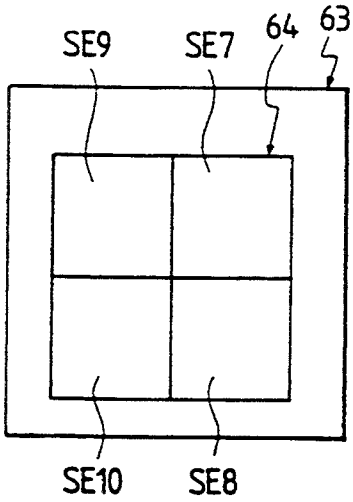


FIG. 29A

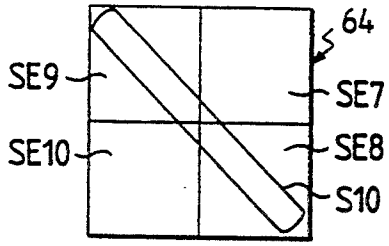


FIG. 29B

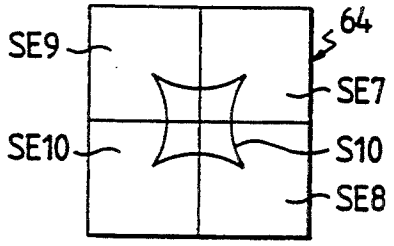


FIG. 29C

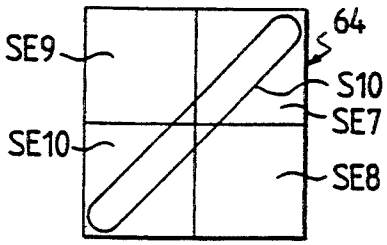


FIG. 29D

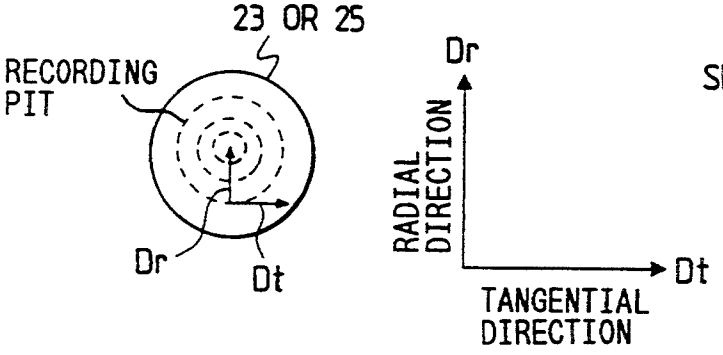


FIG. 30

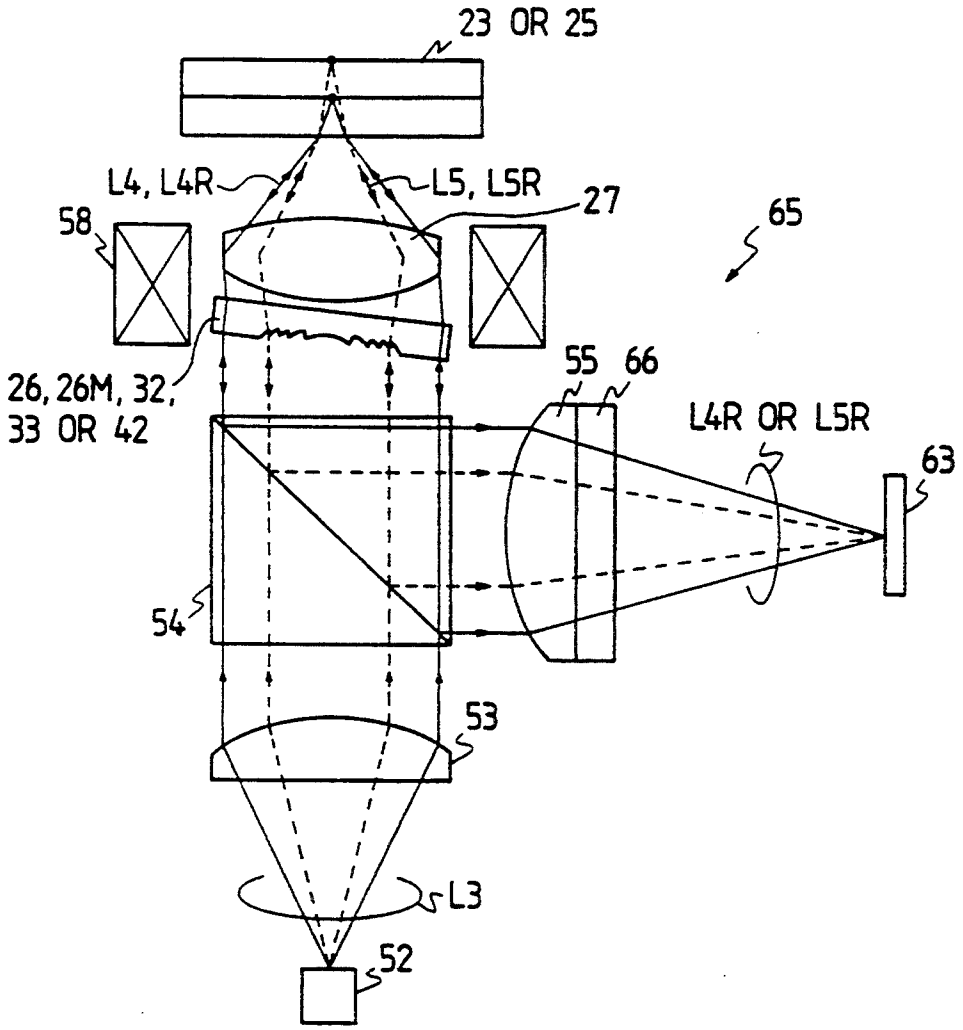

23 OR 25
L4, L4R
L5, L5R
27
58
65
26, 26M, 32,
33 OR 42
55
66
L4R OR L5R
63
54
53
L3
52

FIG. 31

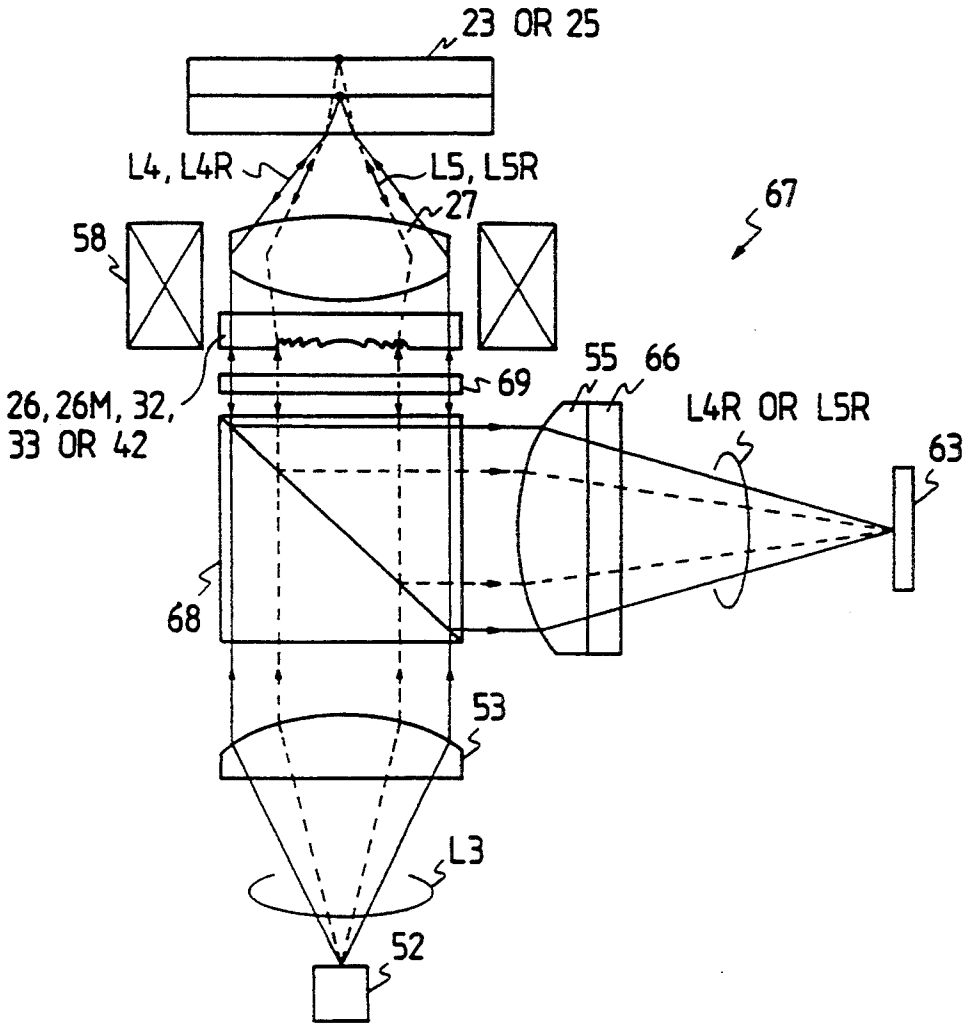

23 OR 25
L4, L4R
L5, L5R
27
67
58
55
66
69
26, 26M, 32,
33 OR 42
L4R OR L5R
63
68
53
L3
52

FIG. 32

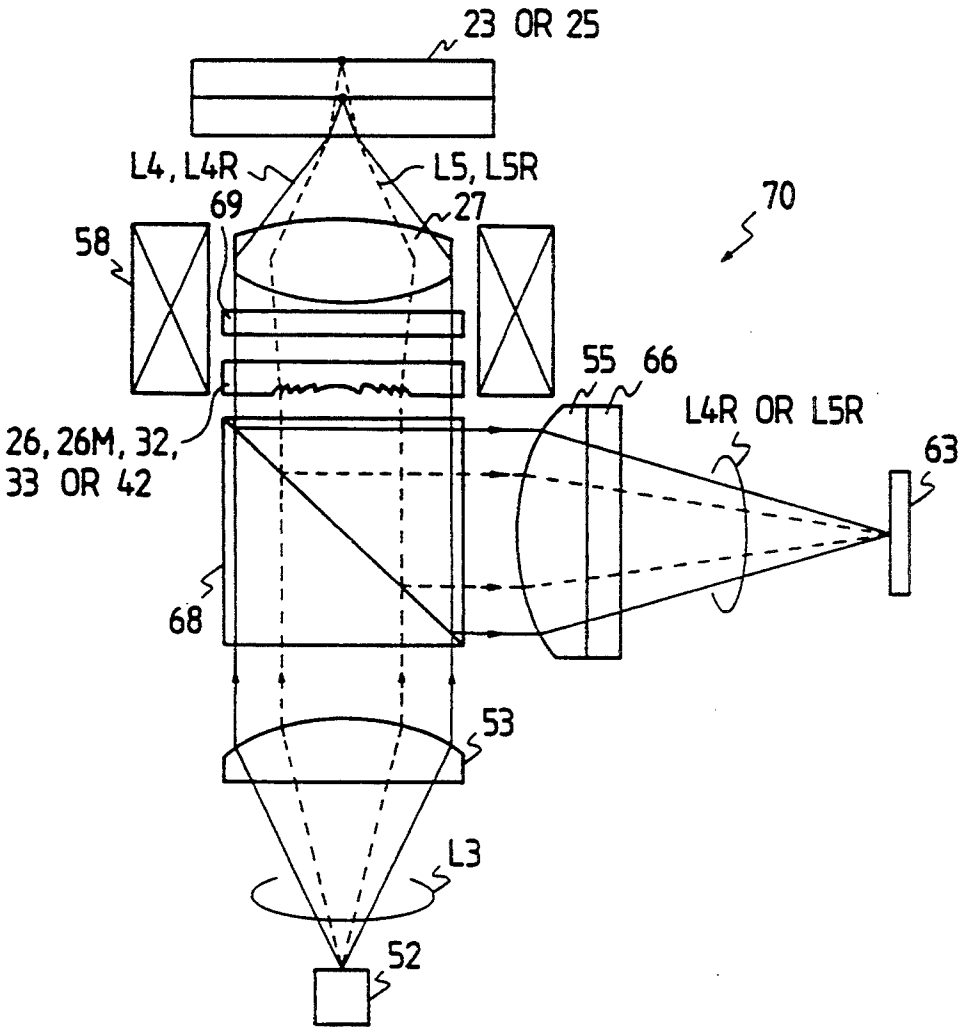

23 OR 25
L4, L4R
L5, L5R
69
27
70
58
55
66
L4R OR L5R
63
26, 26M, 32,
33 OR 42
68
53
L3
52

FIG. 33

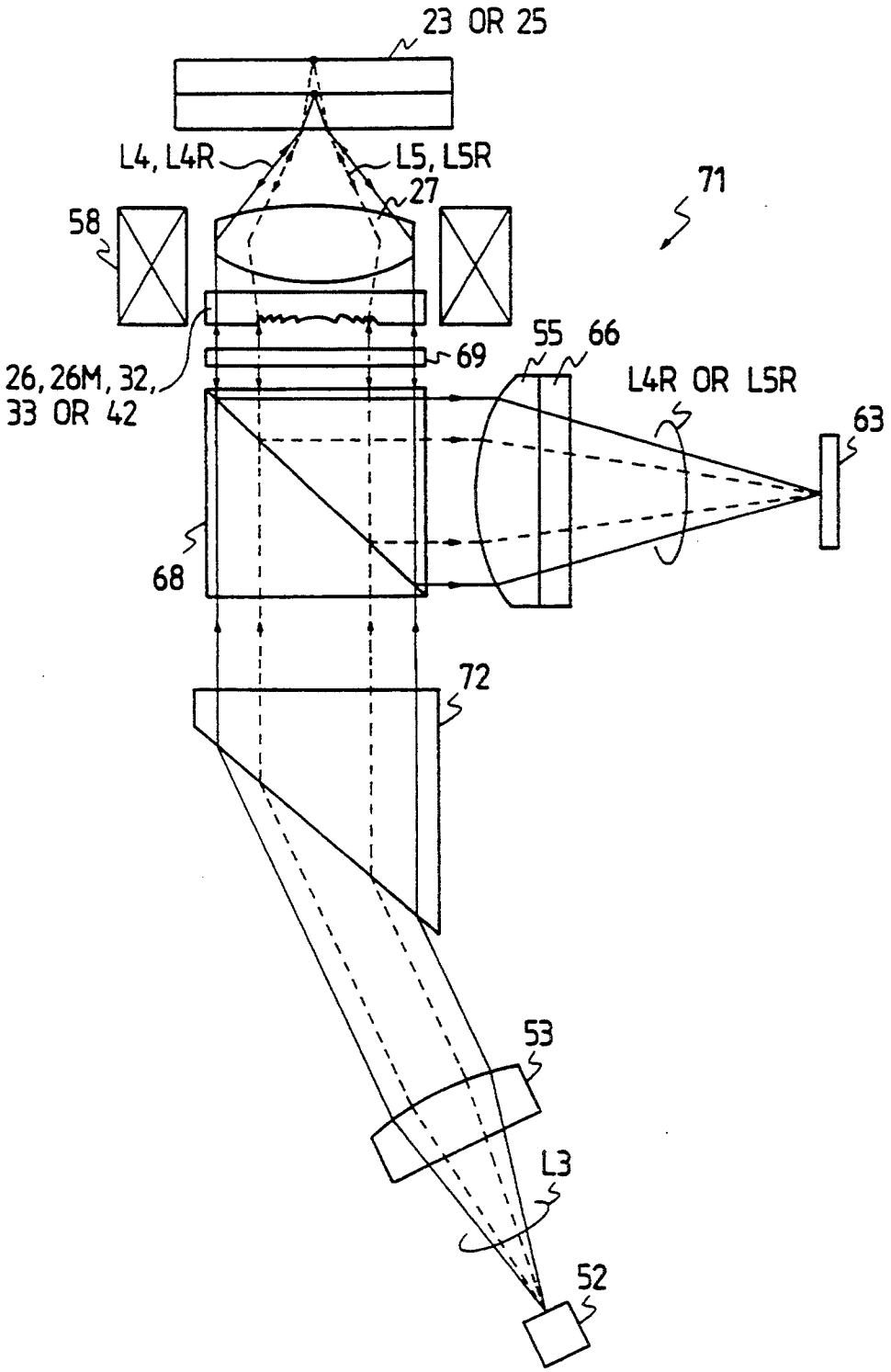

23 OR 25
L4, L4R
L5, L5R
27
71
58
55
66
69
26, 26M, 32,
33 OR 42
L4R OR L5R
63
68
72
53
L3
52

FIG. 34

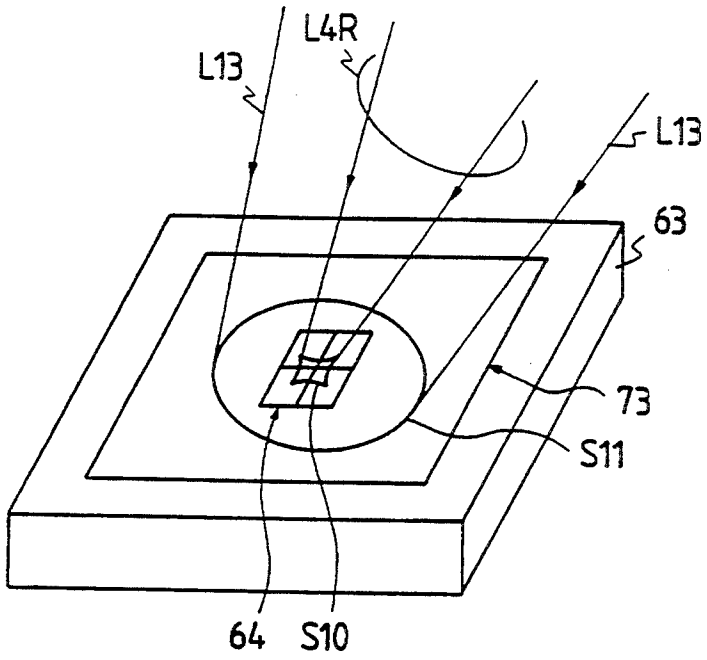

L4R
L13
L13
63
73
S11
64
S10

FIG. 37

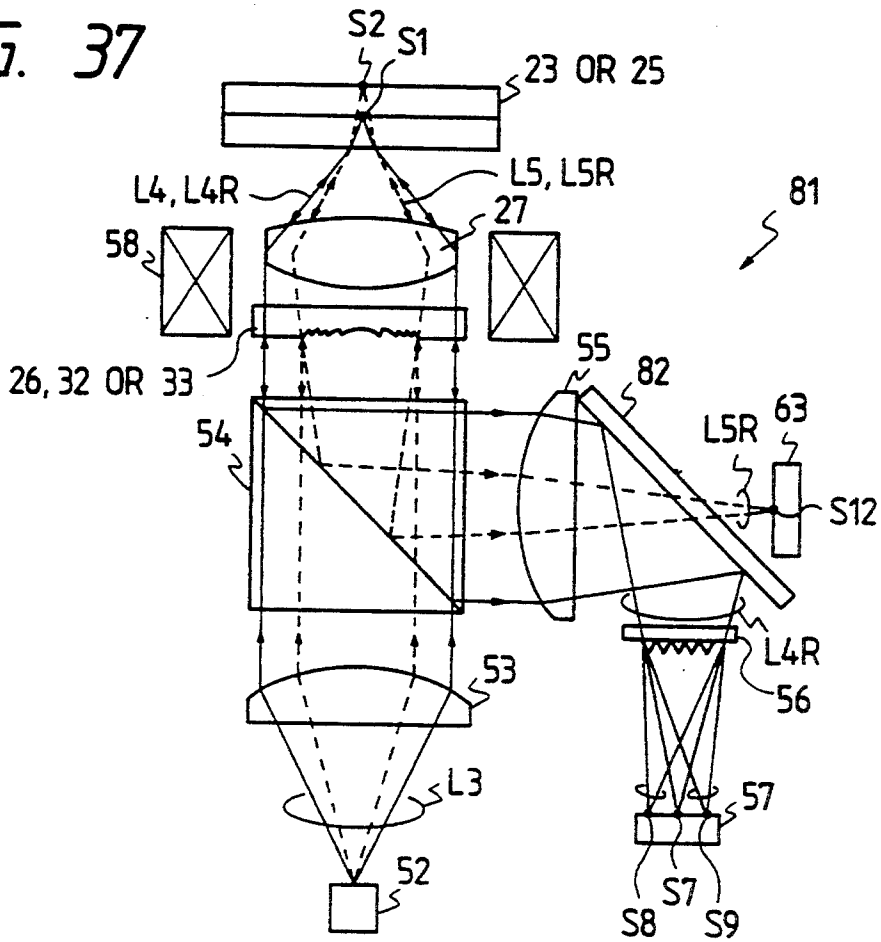

S2
S1
23 OR 25
L4, L4R
L5, L5R
27
81
58
26, 32 OR 33
55
82
54
L5R
63
S12
L4R
56
53
L3
57
52
S8
S7
S9

FIG. 35A

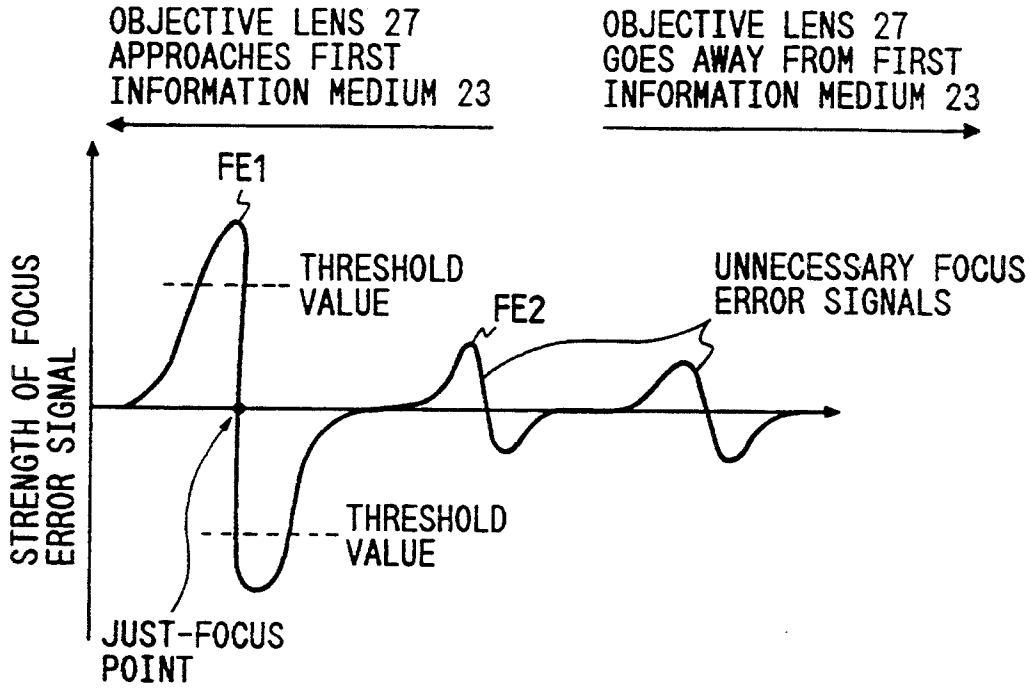


FIG. 35B

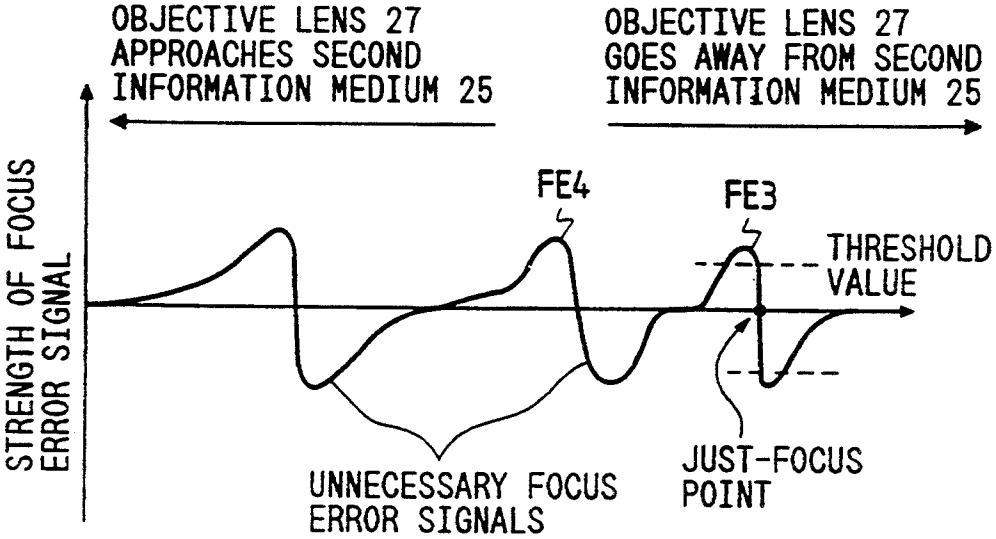


FIG. 36A

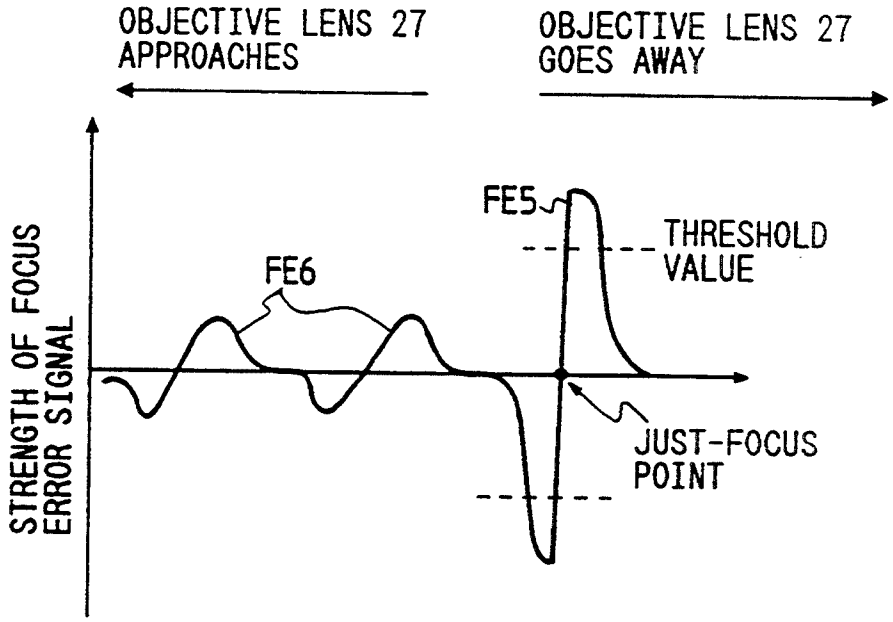


FIG. 36B

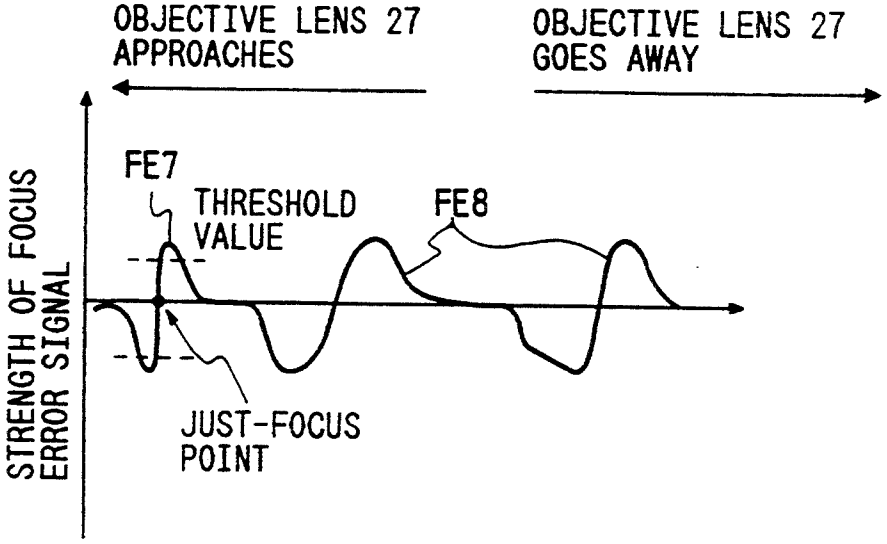


FIG. 38

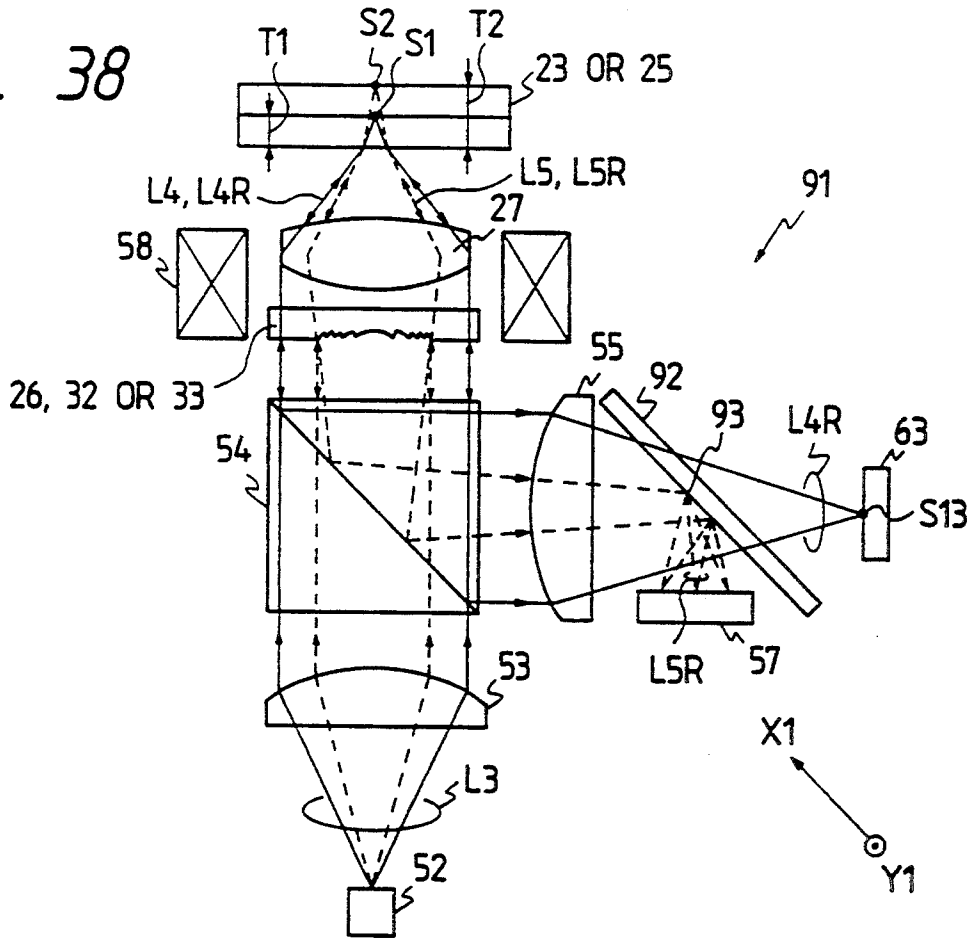

T1
S2
S1
T2
23 OR 25
L4, L4R
L5, L5R
27
91
58
55
92
26, 32 OR 33
93
L4R
63
54
S13
53
L5R
57
X1
L3
Y1
52

FIG. 39

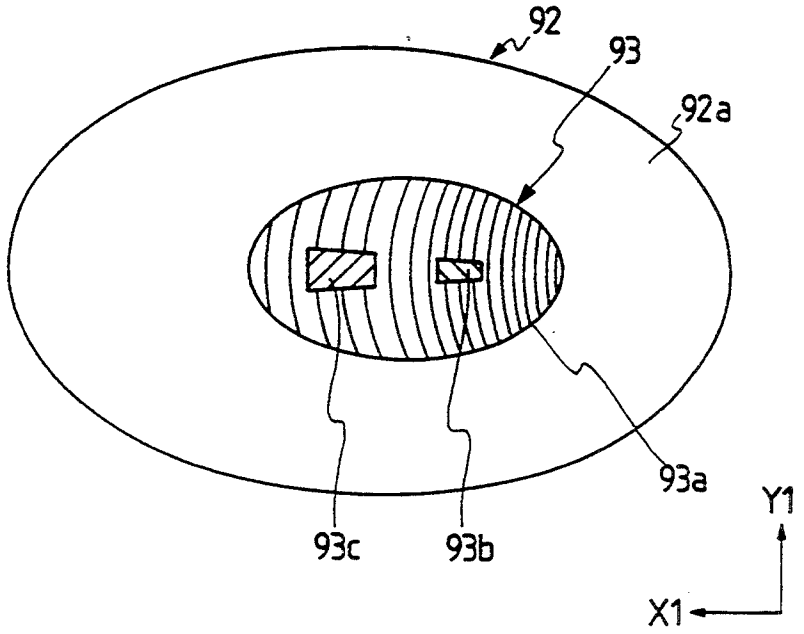

92
93
92a
93a
Y1
93c
93b
X1

FIG. 40A

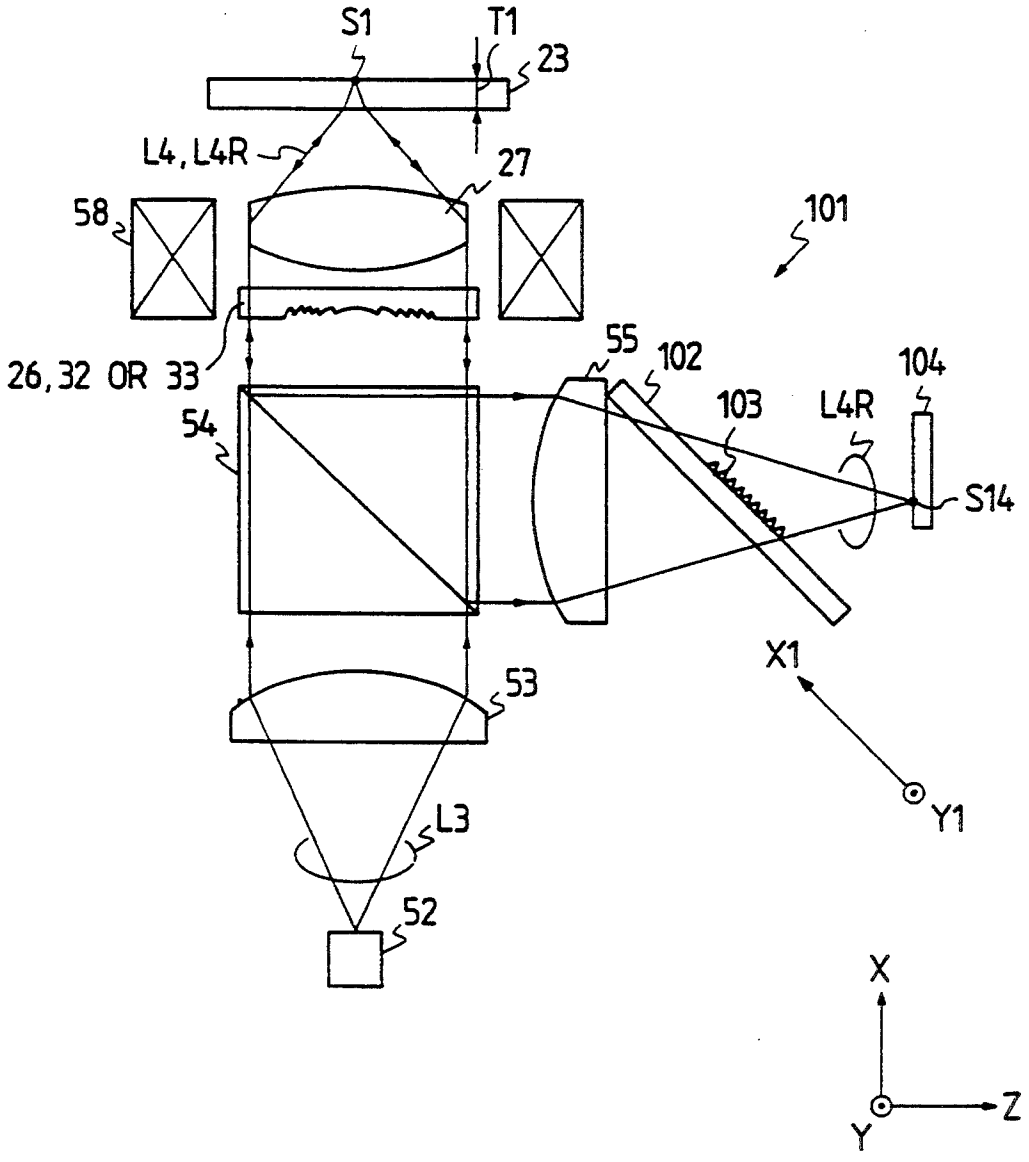

S1
T1
23
L4, L4R
27
58
101
26, 32 OR 33
55
102
104
103
L4R
54
S14
X1
53
Y1
L3
52
X
Z
Y

FIG. 40B

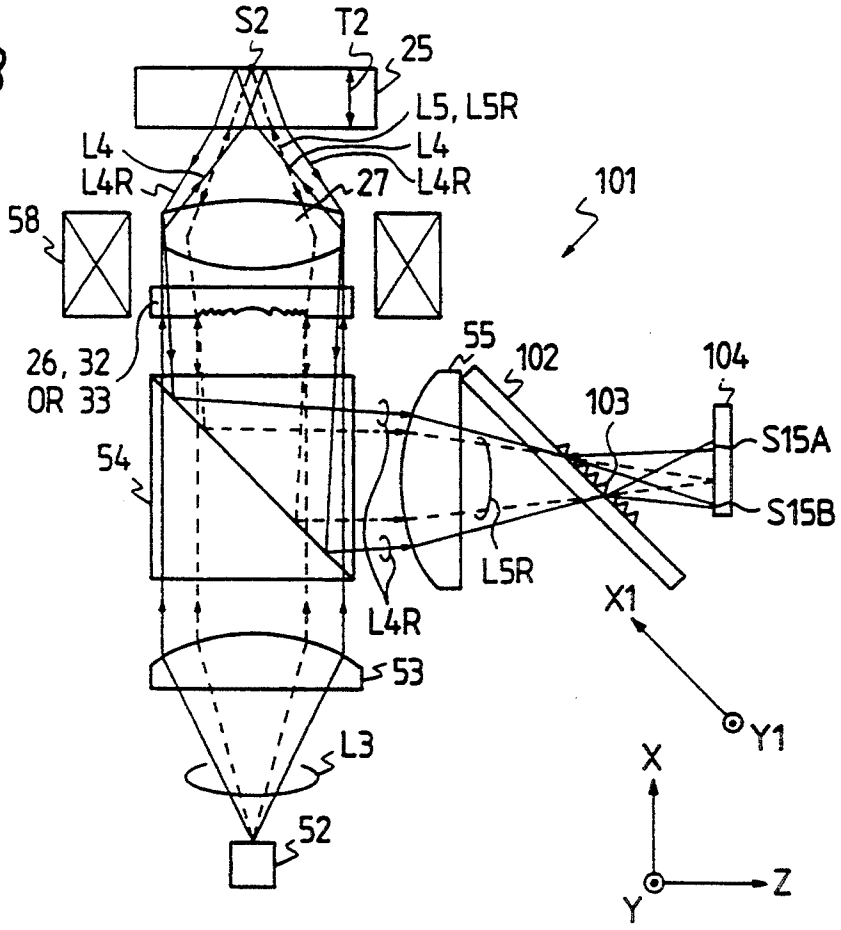


FIG. 41

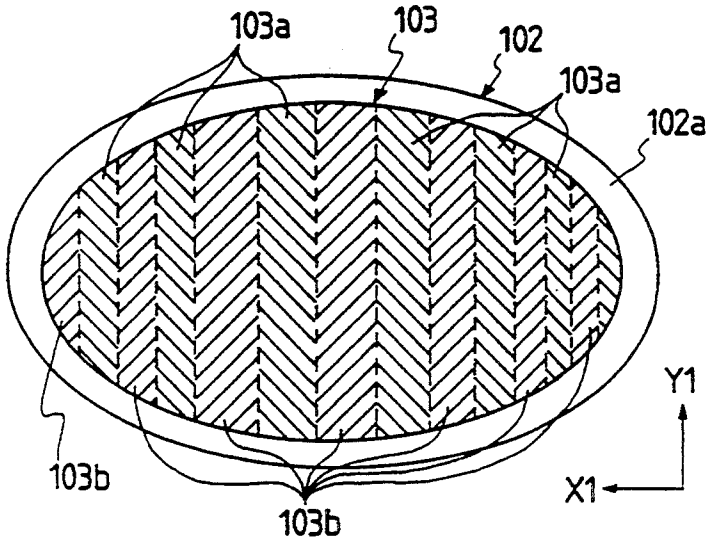


FIG. 42A

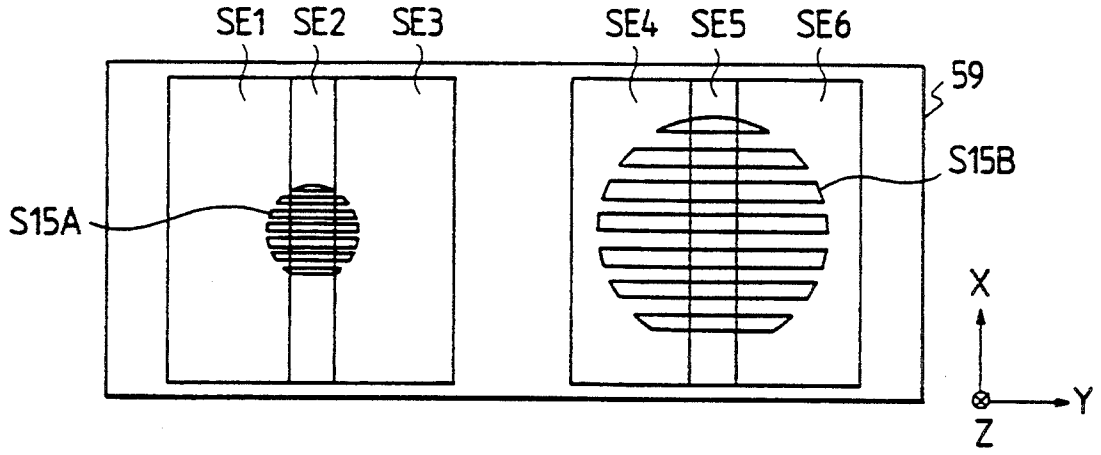


FIG. 42B

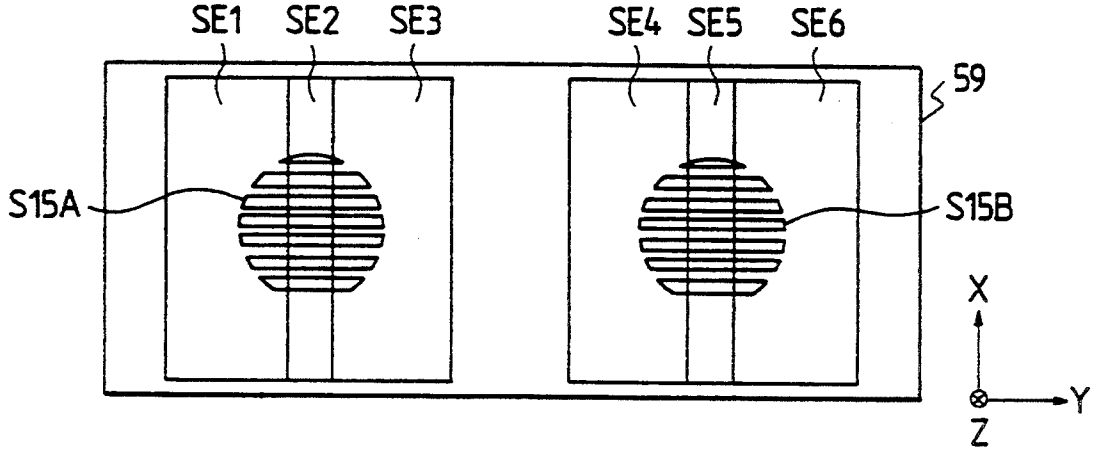


FIG. 42C

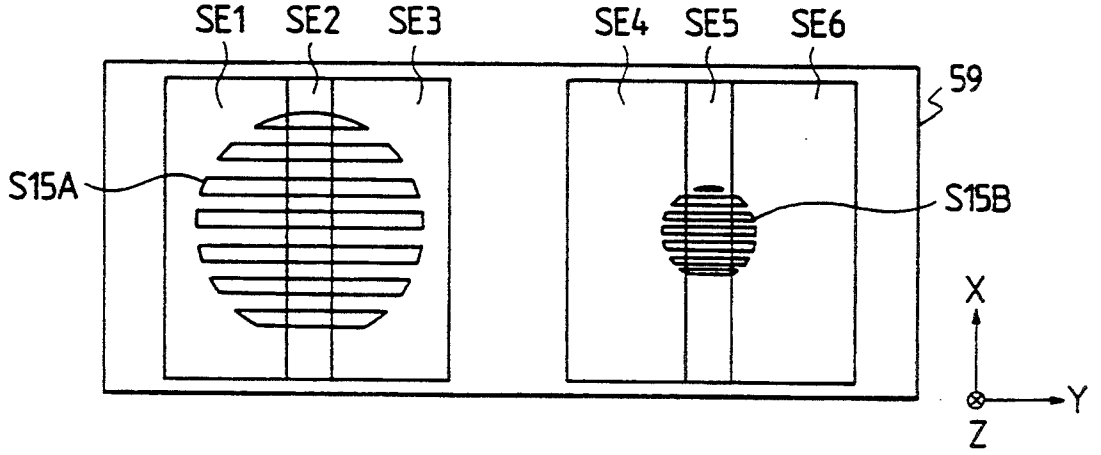


FIG. 43

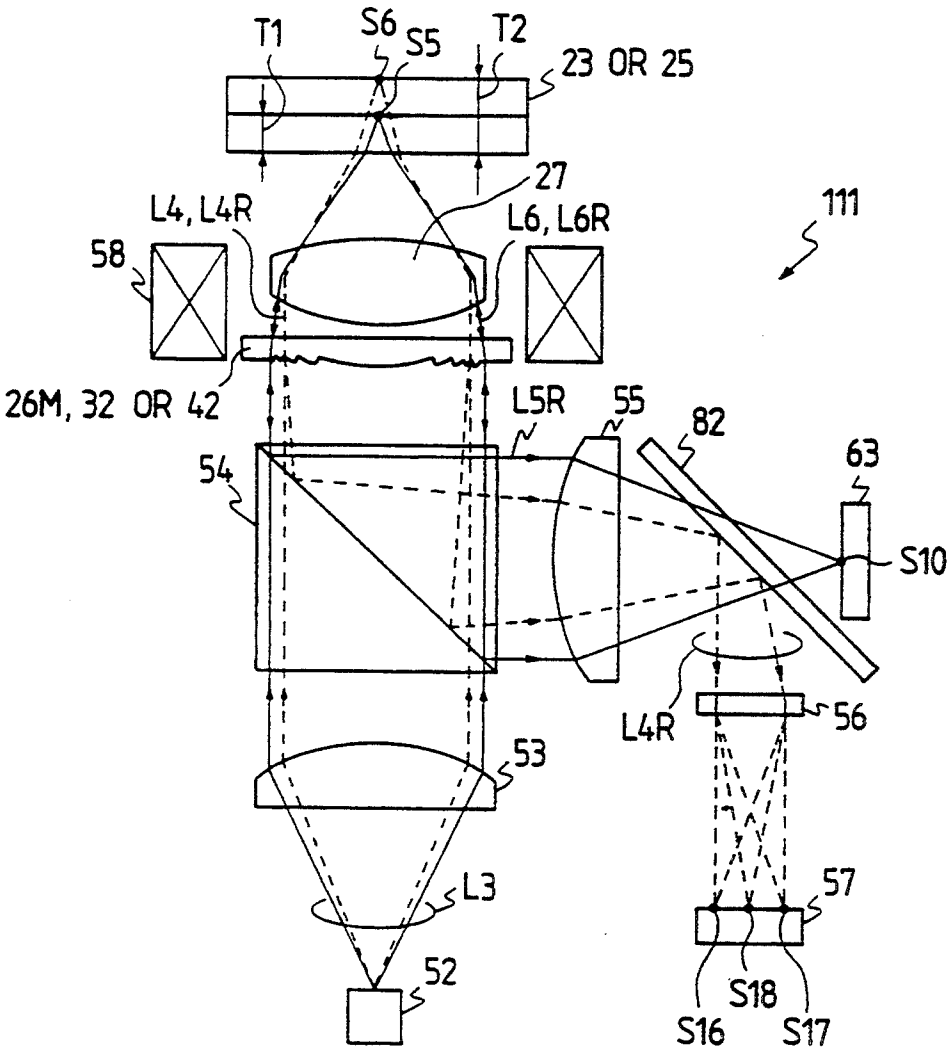

T1
S6
S5
T2
23 OR 25
27
L4, L4R
L6, L6R
58
111
26M, 32 OR 42
L5R
55
82
63
54
S10
L4R
56
53
L3
57
52
S18
S16
S17

FIG. 44

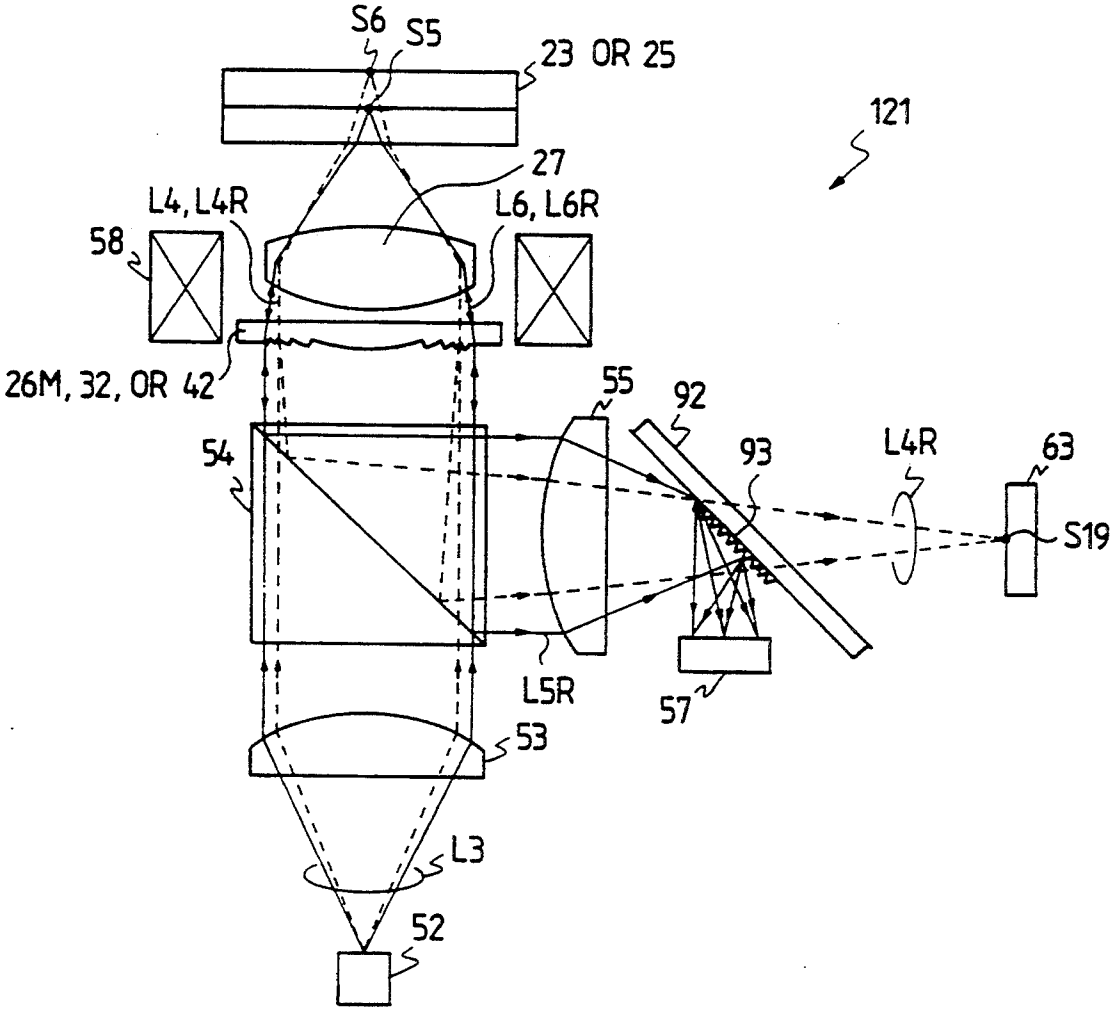

S6
S5
23 OR 25
121
27
L4, L4R
L6, L6R
58
26M, 32, OR 42
55
92
54
93
L4R
63
S19
L5R
57
53
L3
52

FIG. 45

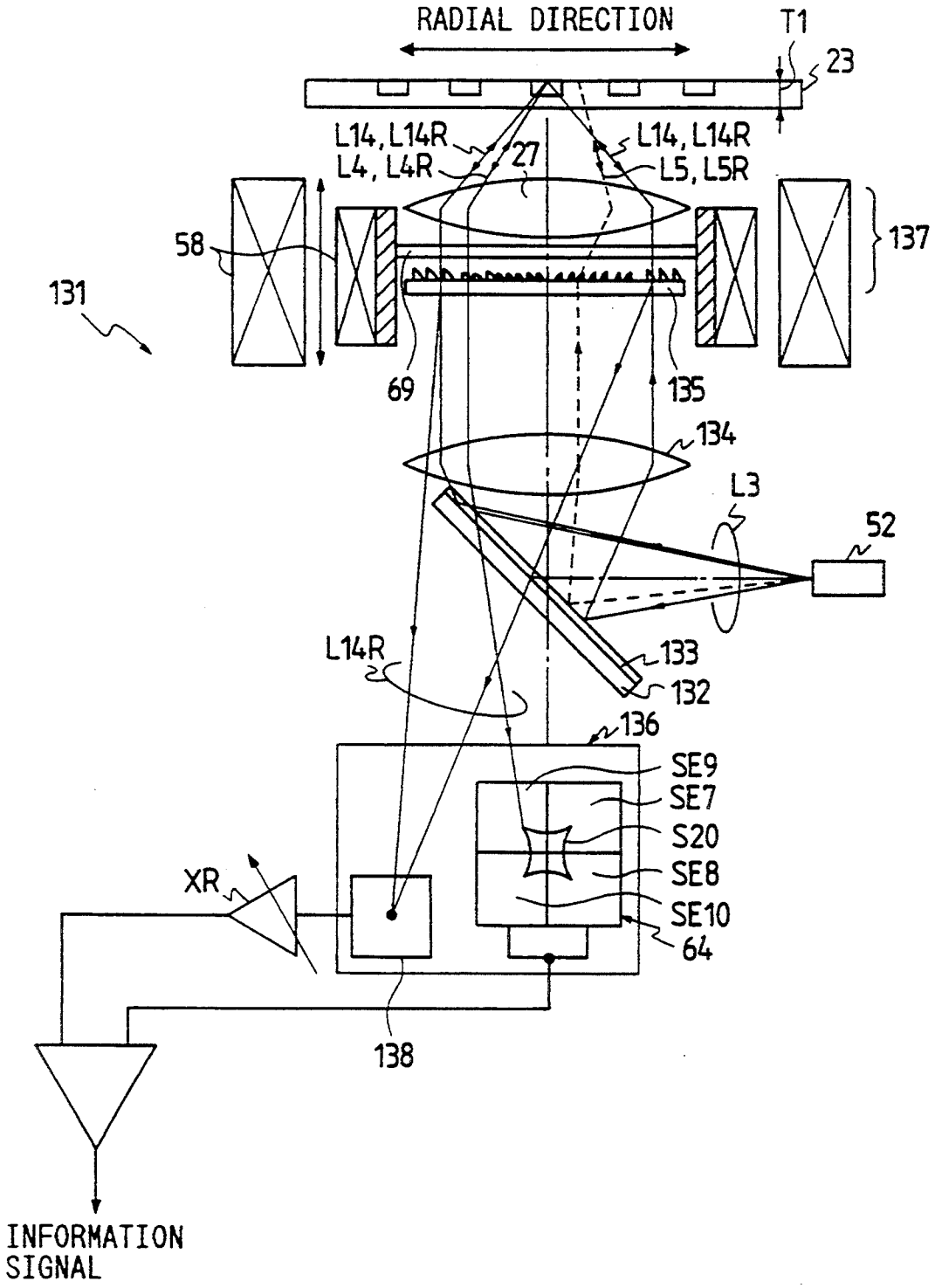

RADIAL DIRECTION
T1
23
L14, L14R
L4, L4R
27
L14, L14R
L5, L5R
58
137
131
69
135
134
L3
52
L14R
133
132
136
SE9
SE7
S20
SE8
SE10
64
XR
138
INFORMATION
SIGNAL

FIG. 46

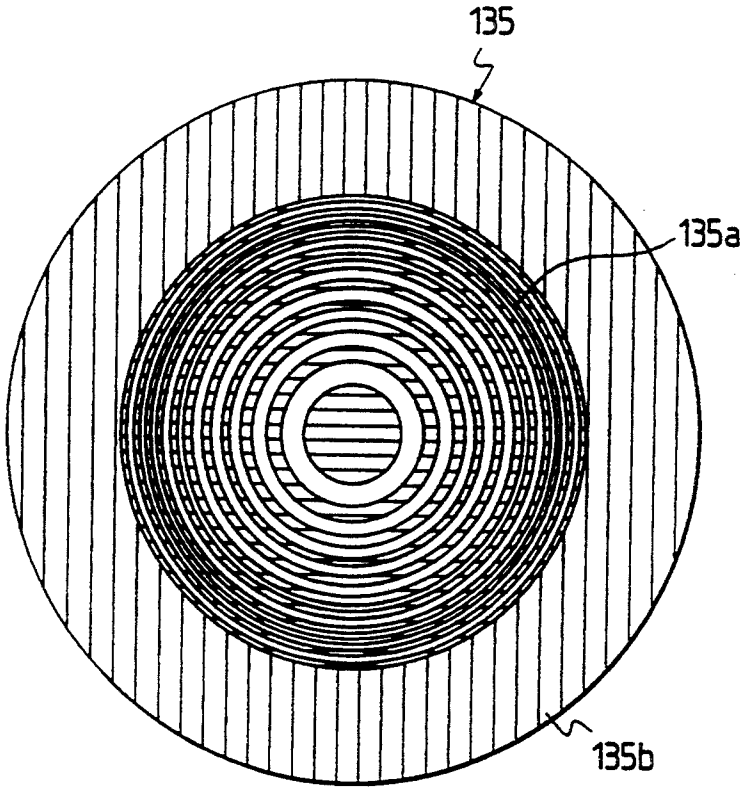


FIG. 47

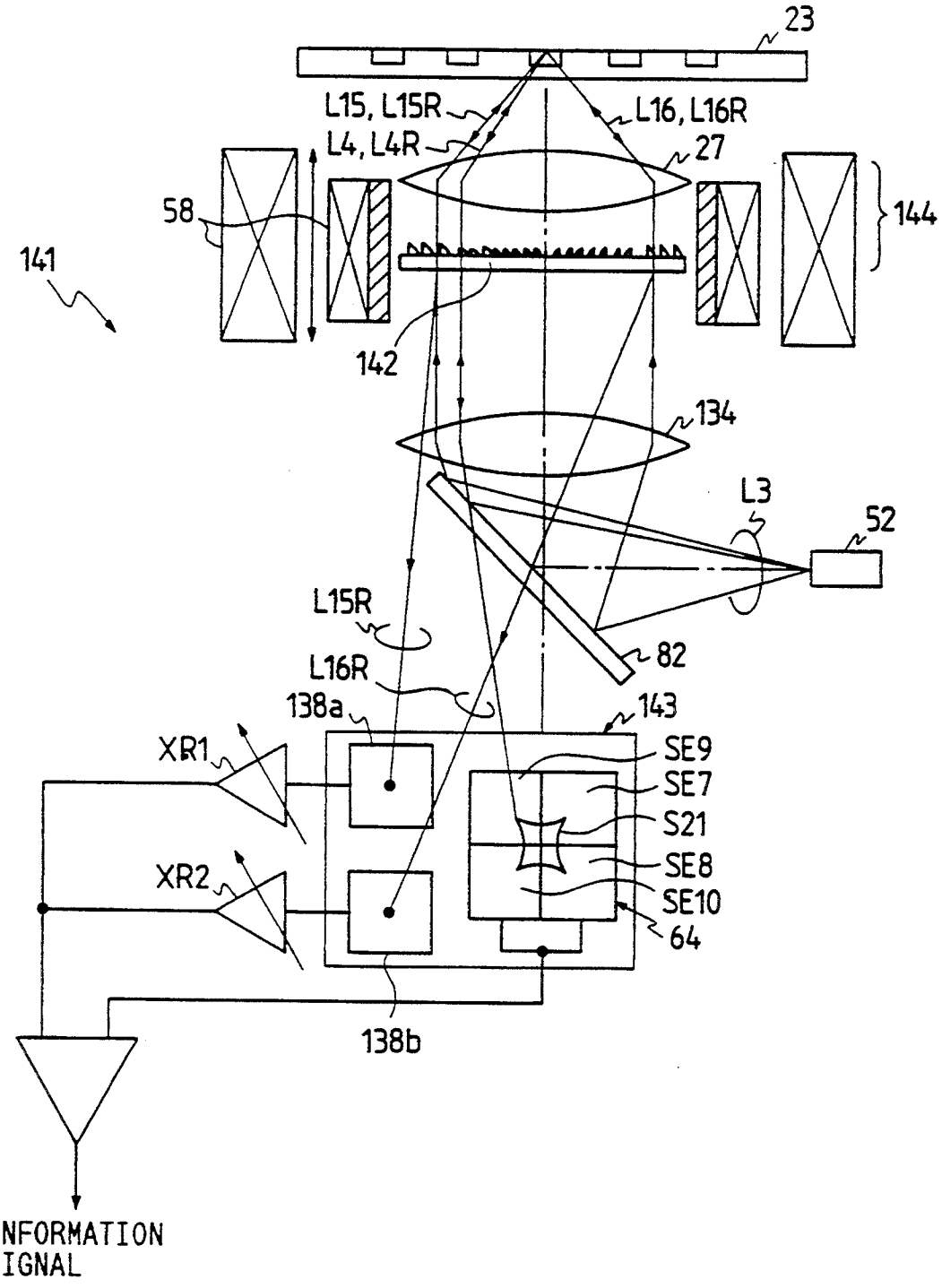
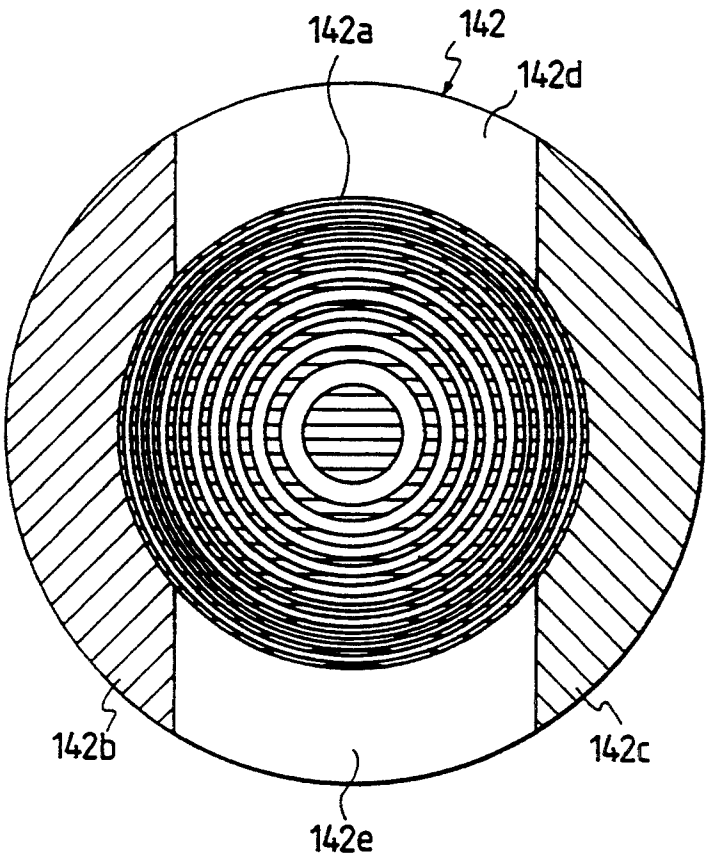

23
L15, L15R
L16, L16R
L4, L4R
27
58
144
141
142
134
L3
52
L15R
82
L16R
138a
143
XR1
SE9
SE7
S21
XR2
SE8
SE10
64
138b
INFORMATION
SIGNAL

FIG. 48



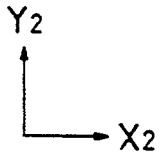


FIG. 49A

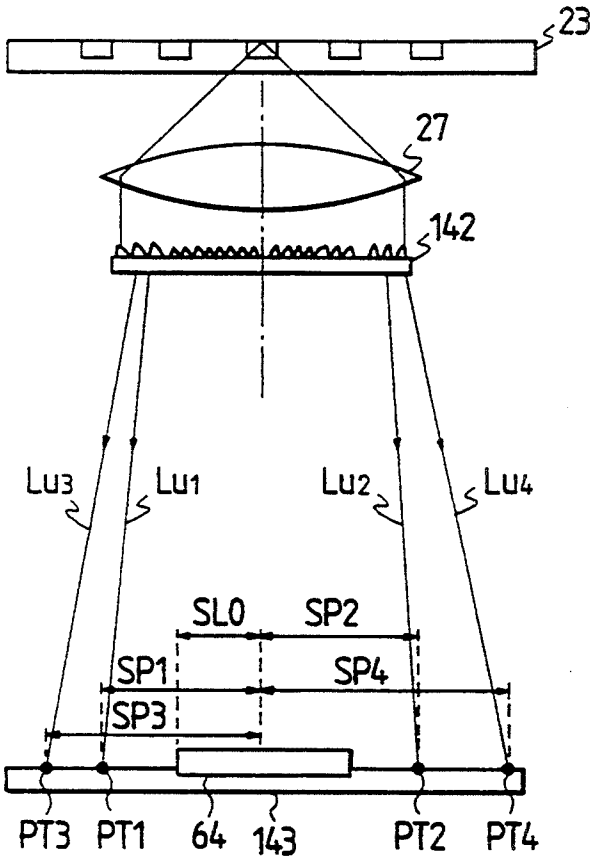


FIG. 49B

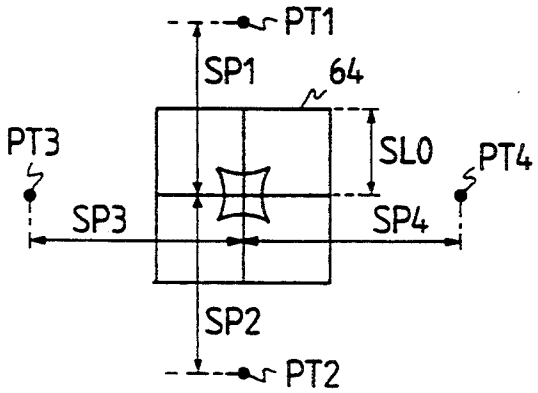


FIG. 50

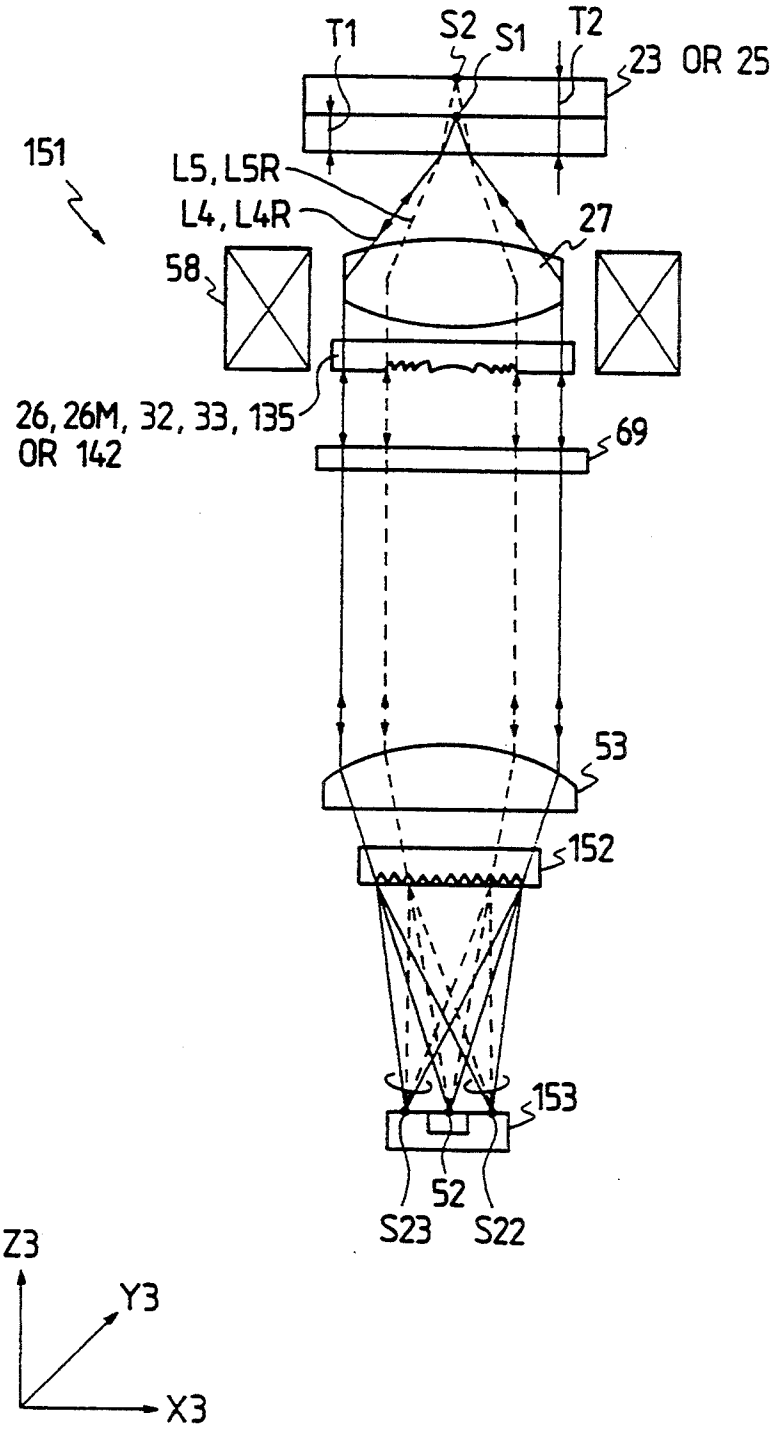

T1
S2
S1
T2
23 OR 25
151
L5, L5R
L4, L4R
27
58
26, 26M, 32, 33, 135
OR 142
69
53
152
153
52
S23
S22
Z3
Y3
X3

FIG. 51

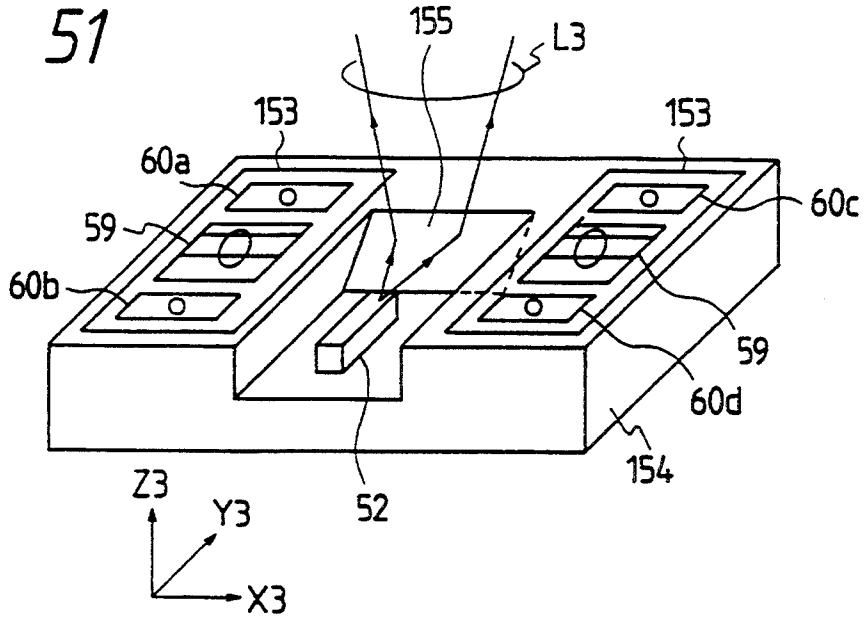

155
L3
153
153
60a
60c
59
60b
59
60d
154
52
Z3
Y3
X3

FIG. 52

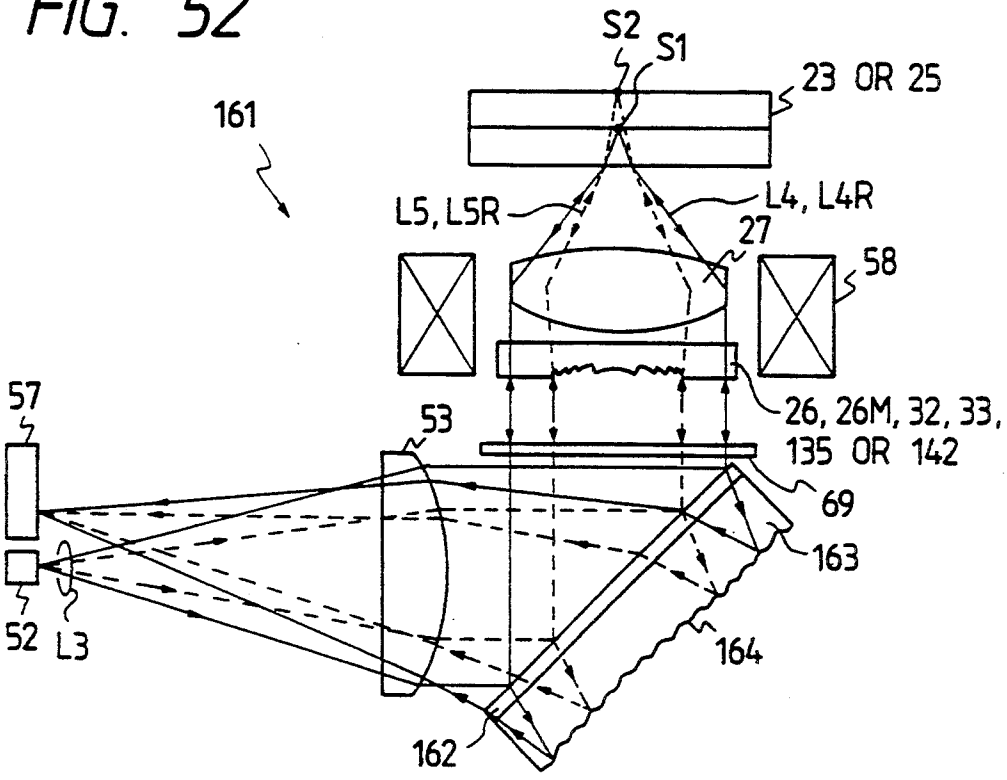

S2
S1
23 OR 25
161
L5, L5R
L4, L4R
27
58
57
53
26, 26M, 32, 33,
135 OR 142
69
163
52
L3
164
162

FIG. 53

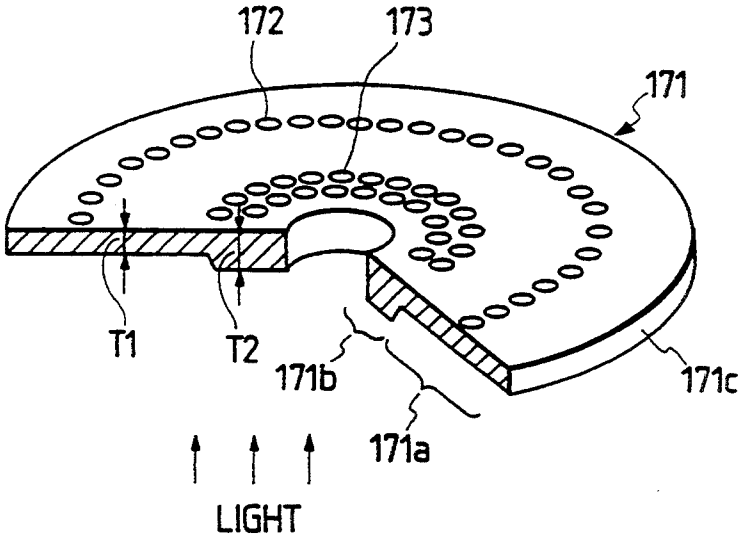

172
173
171
T1
T2
171b
171c
171a
LIGHT

FIG. 54

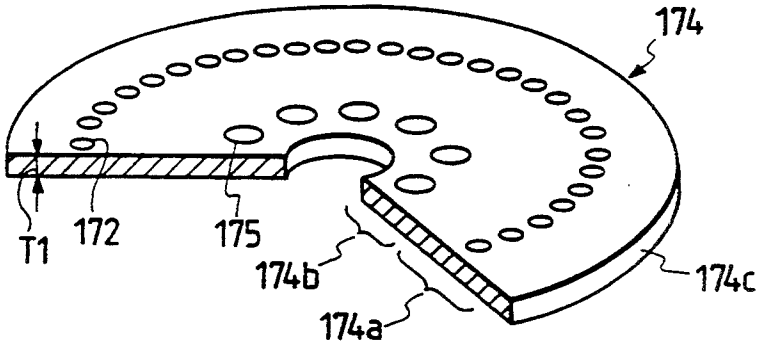

174
T1
172
175
174b
174c
174a

FIG. 55

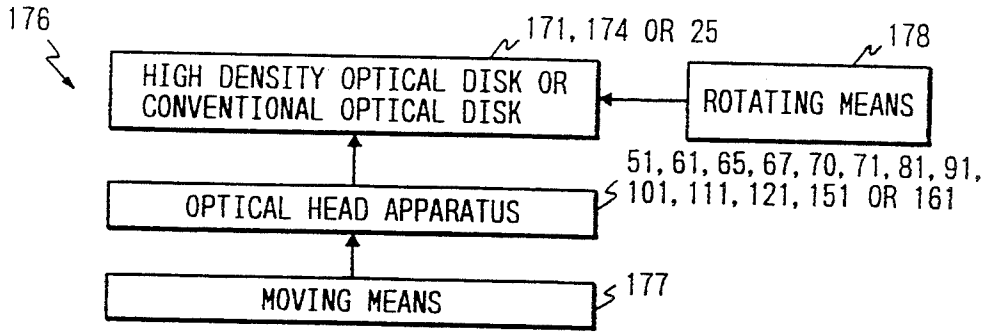

176
171, 174 OR 25
178
HIGH DENSITY OPTICAL DISK OR CONVENTIONAL OPTICAL DISK
ROTATING MEANS
51, 61, 65, 67, 70, 71, 81, 91, 101, 111, 121, 151 OR 161
OPTICAL HEAD APPARATUS
MOVING MEANS
177

FIG. 56

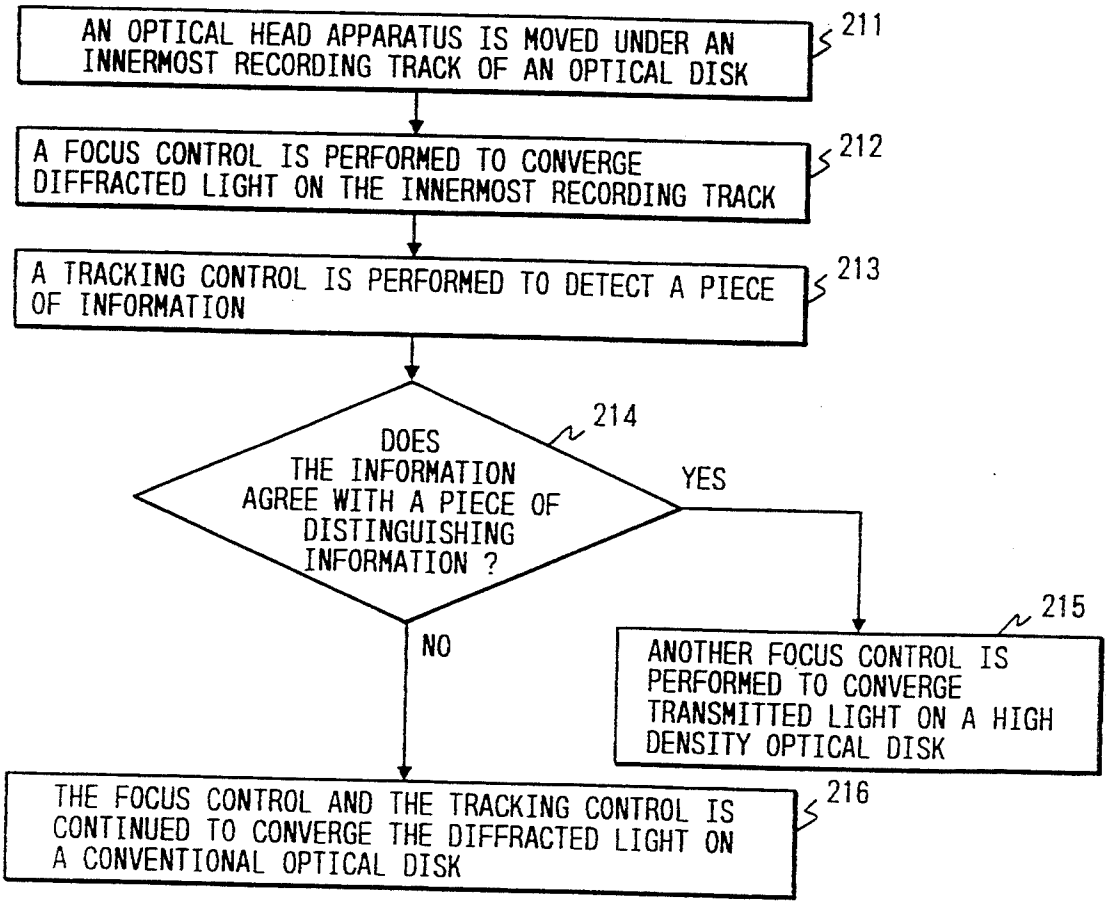

AN OPTICAL HEAD APPARATUS IS MOVED UNDER AN INNERMOST RECORDING TRACK OF AN OPTICAL DISK
211
A FOCUS CONTROL IS PERFORMED TO CONVERGE DIFFRACTED LIGHT ON THE INNERMOST RECORDING TRACK
212
A TRACKING CONTROL IS PERFORMED TO DETECT A PIECE OF INFORMATION
213
DOES THE INFORMATION AGREE WITH A PIECE OF DISTINGUISHING INFORMATION ?
214
YES
NO
ANOTHER FOCUS CONTROL IS PERFORMED TO CONVERGE TRANSMITTED LIGHT ON A HIGH DENSITY OPTICAL DISK
215
THE FOCUS CONTROL AND THE TRACKING CONTROL IS CONTINUED TO CONVERGE THE DIFFRACTED LIGHT ON A CONVENTIONAL OPTICAL DISK
216

FIG. 57

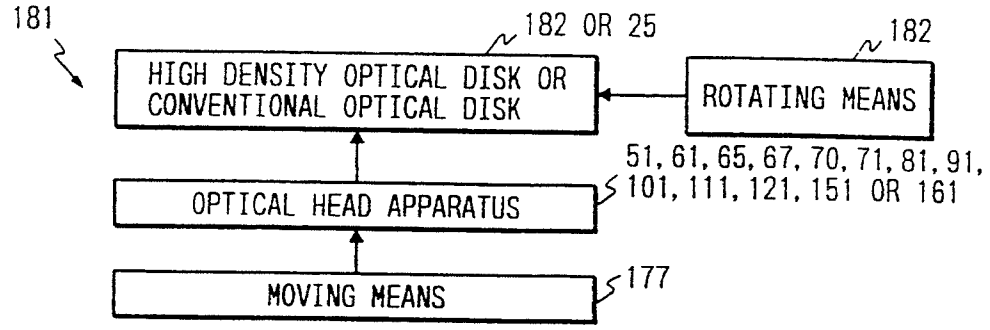

181
182 OR 25
182
HIGH DENSITY OPTICAL DISK OR CONVENTIONAL OPTICAL DISK
ROTATING MEANS
51, 61, 65, 67, 70, 71, 81, 91, 101, 111, 121, 151 OR 161
OPTICAL HEAD APPARATUS
MOVING MEANS
177

FIG. 58

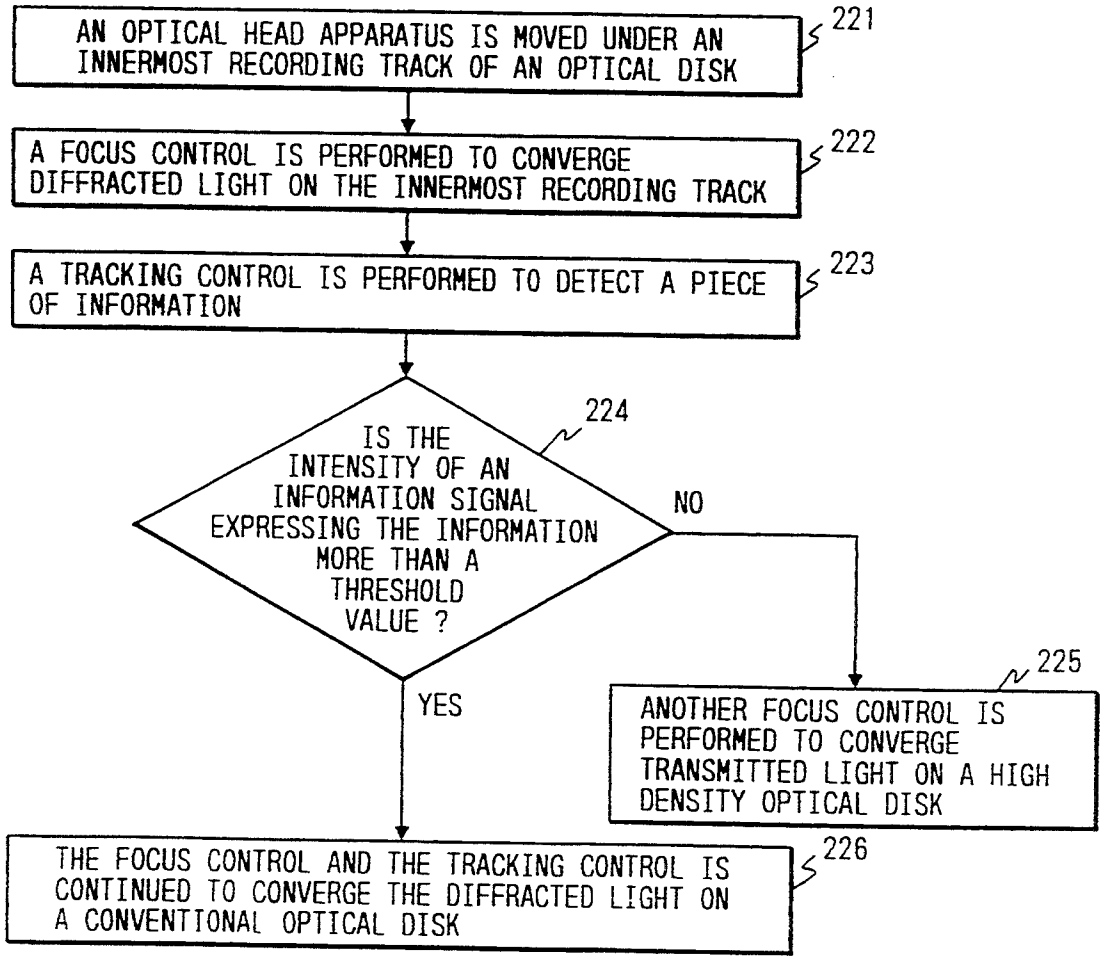

AN OPTICAL HEAD APPARATUS IS MOVED UNDER AN INNERMOST RECORDING TRACK OF AN OPTICAL DISK
221
A FOCUS CONTROL IS PERFORMED TO CONVERGE DIFFRACTED LIGHT ON THE INNERMOST RECORDING TRACK
222
A TRACKING CONTROL IS PERFORMED TO DETECT A PIECE OF INFORMATION
223
IS THE INTENSITY OF AN INFORMATION SIGNAL EXPRESSING THE INFORMATION MORE THAN A THRESHOLD VALUE ?
224
NO
YES
ANOTHER FOCUS CONTROL IS PERFORMED TO CONVERGE TRANSMITTED LIGHT ON A HIGH DENSITY OPTICAL DISK
225
THE FOCUS CONTROL AND THE TRACKING CONTROL IS CONTINUED TO CONVERGE THE DIFFRACTED LIGHT ON A CONVENTIONAL OPTICAL DISK
226

FIG. 59

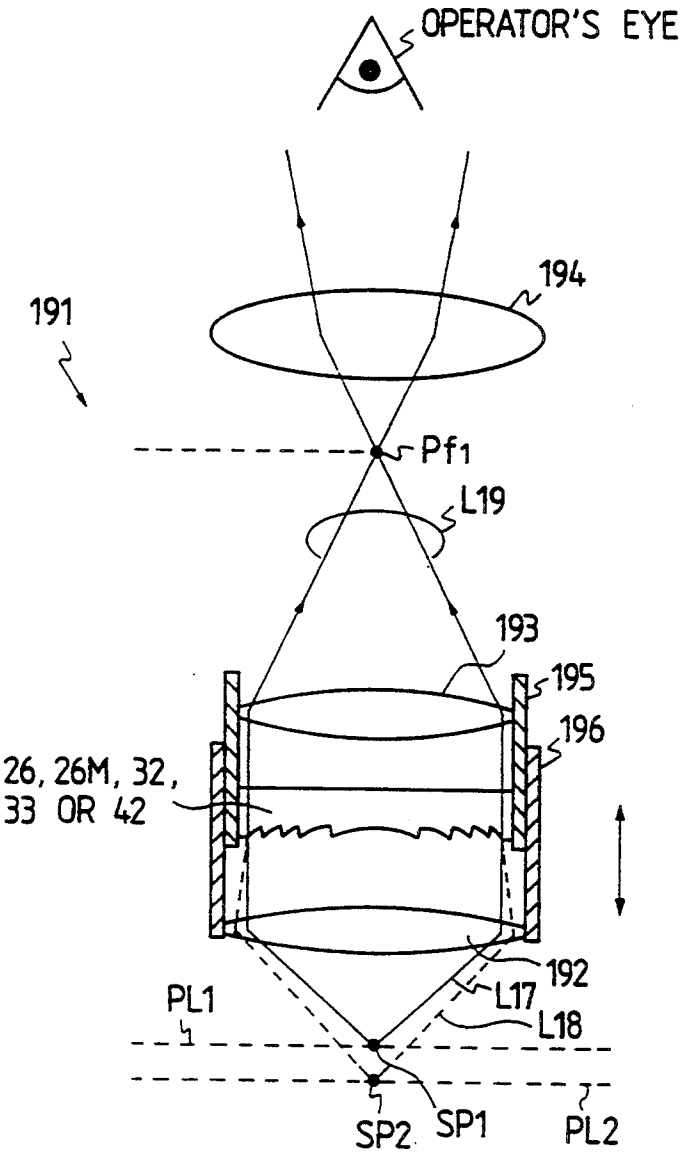

OPERATOR'S EYE
191
194
Pf1
L19
193
195
196
26, 26M, 32,
33 OR 42
192
L17
L18
PL1
SP2
SP1
PL2

FIG. 60

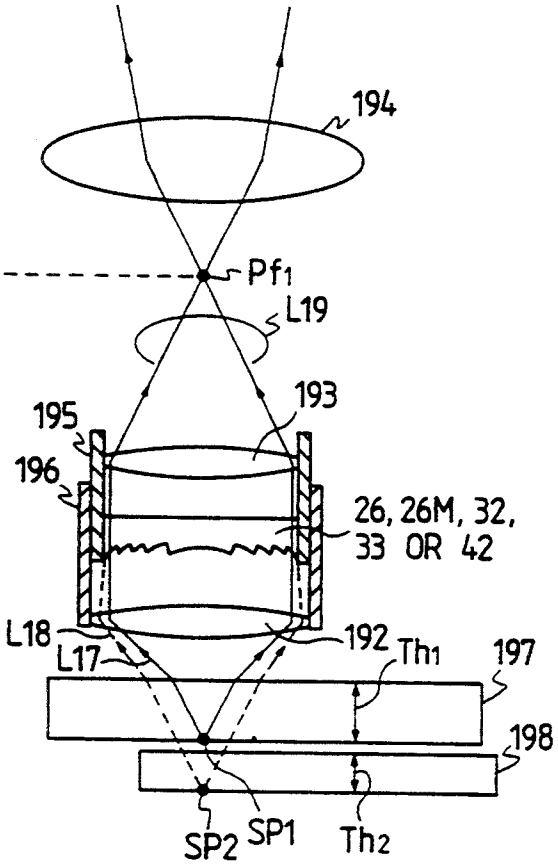

194
Pf1
L19
193
195
196
26, 26M, 32,
33 OR 42
L18
L17
192
Th1
197
198
SP2
SP1
Th2

FIG. 61

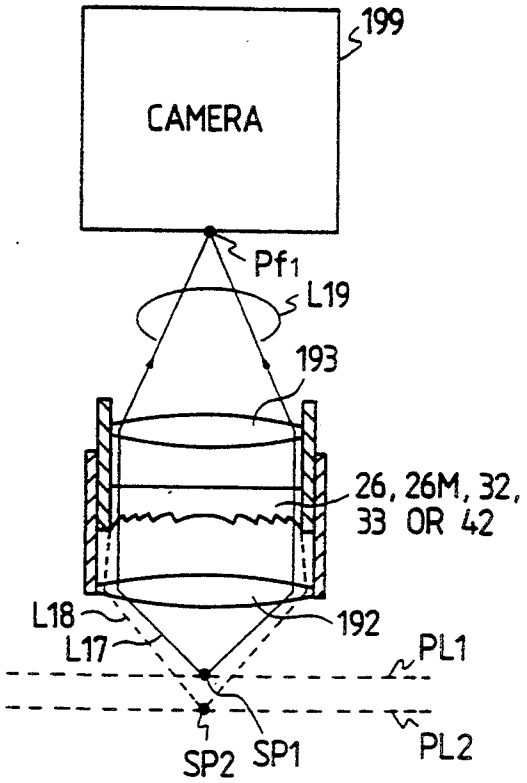
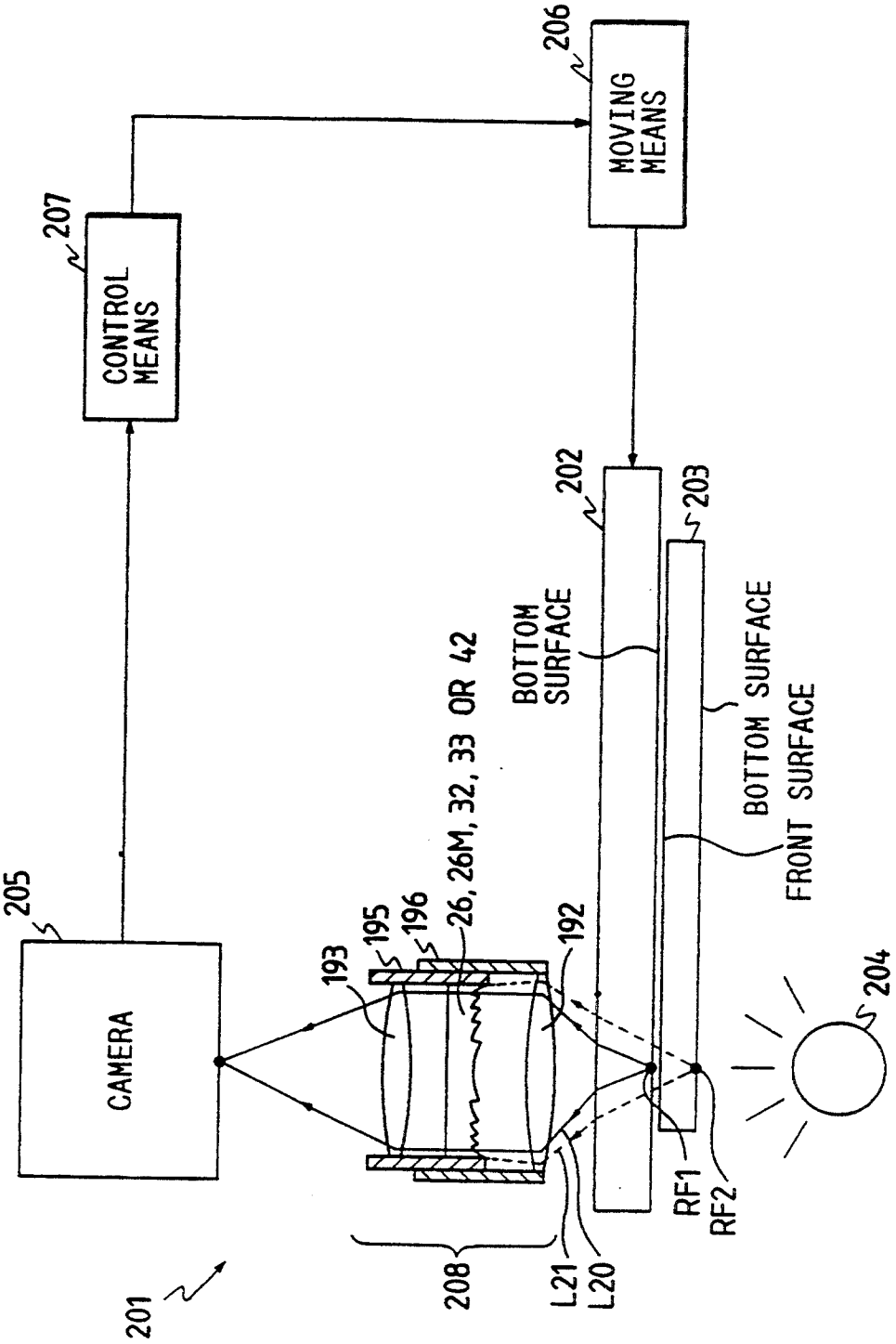

199
CAMERA
Pf1
L19
193
26, 26M, 32,
33 OR 42
L18
L17
192
PL1
PL2
SP2
SP1

FIG. 62


206
MOVING MEANS
207
CONTROL MEANS
202
203
BOTTOM SURFACE
BOTTOM SURFACE
FRONT SURFACE
205
CAMERA
193
195
196
26, 26M, 32, 33 OR 42
192
204
RF1
RF2
208
L21
L20
201

COMPOUND OBJECTIVE LENS HAVING TWO FOCAL POINTS

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a compound objective lens composed of an objective lens and a hologram lens which has two focal points, an imaging optical system for converging light on two converging spots placed at different depths of an information medium with the compound objective lens, an optical head apparatus for recording, reproducing or erasing information on or from an information medium such as an optical medium or a magneto-optical medium like an optical disk or an optical card with the imaging optical system, an optical disk in which a series of high density recording pits and a series of comparatively low density recording pits are provided, an optical disk apparatus for recording or reproducing information on or from the optical disk with the compound objective lens, a binary focus microscope having two focal points in which two types of images drawn at different depths are simultaneously observed, and an alignment apparatus for aligning two types of images drawn at different depths with the binary focus microscope.

2. Description of the Related Art

An optical memory technique has been put to practical use to manufacture an optical disk in which a pit pattern formed of a series of pits is drawn to record information. The optical disk is utilized as a high density and large capacity of information medium. For example, the optical disk is utilized for a digital audio disk, a video disk, a document file disk, and a data file disk. To record information on the optical disk and to reproduce the information from the optical disk, a light beam radiated from a light source is minutely converged in an imaging optical system, and the light beam minutely converged is radiated to the optical disk through the imaging optical system. Therefore, the light beam is required to be reliably controlled in the imaging optical system with high accuracy.

The imaging optical system is utilized for an optical head apparatus in which a detecting system is additionally provided to detect the intensity of the light beam reflected from the optical disk. Fundamental functions of the optical head apparatus are classified into a converging performance for minutely converging a light beam to form a diffraction-limited micro-spot of the light beam radiated on the optical disk, a focus control in a focus servo system, a tracking control in a tracking serve system, and the detection of pit signals (or information signals) obtained by radiating the light beam on a pit pattern of the optical disk. The fundamental function of the optical head apparatus is determined by the combination of optical sub-systems and a photoelectric transfer detecting process according to a purpose and a use. Specifically, an optical head apparatus in which a holographic optical element (or hologram) is utilized to minimize and thin the optical head apparatus has been recently proposed.

PREVIOUSLY PROPOSED ART

FIG. 1 is a constitutional view of a conventional optical head apparatus proposed in Japanese Patent Application No. 46630 of 1991 which is applied by inventors of the present invention.

As shown in FIG. 1, a conventional optical head apparatus **11** for recording or reproducing information on or from an information medium **12** such as an optical disk is provided with a light beam source **13** such as a semiconductor laser, a transmission type of blazed hologram **14** for transmitting a light beam L1 radiated from the light beam source **12** without any diffraction in an outgoing optical path and diffracting a light beam L2 reflected on the information medium **12** in a returning optical path, an objective lens **15** for converging the light beam L1 transmitting through the hologram **13** on the information medium **14** to read the information, an actuator **16** for integrally moving the objective lens **15** with the blazed hologram **13** to focus the light beam L1 on the information medium **12** with the objective lens **15**, and a photo detector **17** for detecting the intensity of the light beam L2 reflected on the information medium **12** to reproduce the information.

As shown in FIG. 2A, a relative position between the blazed hologram **14** and the objective lens **15** is fixed by a fixing means **18**. Or, as shown in FIG. 2B, a blazed pattern is formed on a side of the objective lens **15** to integrally form the blazed hologram **14** with the objective lens **15**.

In the above configuration, a light beam L1 (or a laser beam) radiated from the light beam source **13** is radiated to the blazed hologram **14**, and the light beam L1 mainly transmits through the blazed hologram **14** without any diffraction in an outgoing optical path. The light beam L1 transmitting through the blazed hologram **14** is called zero-order diffracted light. Thereafter, the zero-order diffracted light L1 is converged on the information medium **12** by the objective lens **15**. In the information medium **12**, information indicated by a series of patterned pits is recorded and read by the zero-order diffracted light L1. Thereafter, a beam light L2 having the information is reflected toward the objective lens **15** in a returning optical path and is incident to the blazed hologram **14**. In the blazed hologram **14**, the light L2 is mainly diffracted. The light L2 diffracted is called first-order diffracted light. Thereafter, the first-order diffracted light L2 is received in the photo detector **17**.

In the photo detector **17**, the intensity distribution of the first-order diffracted light L2 is detected. Therefore, a servo signal for adjusting the position of the objective lens **15** by the action of the actuator **16** is obtained. Also, the intensity of the first-order diffracted light L2 is detected in the photo detector **17**. Because the information medium **12** is rotated at high speed, the patterned pits radiated by the light **17** are changed so that the intensity of the first-order diffracted light L2 detected is changed. Therefore, an information signal indicating the information recorded in the information medium **12** is obtained by detecting the change in intensity of the first-order diffracted light L2.

In the above operation, a part of the light beam L1 is necessarily diffracted in the blazed hologram **14** when the light beam L1 is radiated to the blazed hologram **14** in the outgoing optical path. Therefore, unnecessary diffracted light such as first-order diffracted light and minus first-order diffracted light necessarily occurs. In

cases where the hologram **14** is not blazed, the unnecessary diffracted light in the outgoing optical path also reads the information recorded in the information medium **12**, and the unnecessary light is undesirably received in the photo detector **17**. To prevent the unnecessary light from transmitting to the information medium **12**, the blazed hologram **14** is manufactured to form a blazed hologram pattern on the surface thereof, so that the intensity of the unnecessary light received in the photo detector **17** is decreased.

Also, because an objective lens of a conventional microscope has only a focal point, images placed within a focal depth of the objective lens can be only observed with the conventional microscope.

Also, a minute circuit is formed on a semiconductor such as a group III–V compound semiconductor to form a microwave circuit, an opto-electronic detector or a solid state laser. In this case, a photo-sensitive material is coated on a sample made of the semiconductor. Thereafter, a relative position between the sample and a photo mask covering the sample is adjusted by utilizing an alignment apparatus, and the photo-sensitive sensitive material is exposed by a beam of exposure light through the photo mask to transfer a circuit pattern drawn on the photo mask to the photo-sensitive material in an exposure process by utilizing an exposure apparatus. For example, an alignment pattern is drawn on a reverse side of the sample, and a relative position between the sample and the photo mask is adjusted with high accuracy while simultaneously observing the alignment pattern of the sample and the circuit pattern of the photo mask with the conventional microscope. Thereafter, the circuit pattern of the photo mask is transferred to a front side of the sample.

In this case, because images placed within a focal depth of an objective lens utilized in the conventional microscope can be only observed with the conventional microscope, it is required to utilize the conventional microscope having a deep focal depth in the alignment apparatus in cases where the alignment pattern and the circuit pattern are simultaneously observed with the conventional microscope. Therefore, the magnification of the conventional microscope having a deep focal depth is lowered.

PROBLEMS TO BE SOLVED BY THE INVENTION

An optical disk having a high density memory capacity has been recently developed because of the improvement in a design technique of an optical system and the shortening of the wavelength of light radiated from a semiconductor laser. For example, a numerical aperture at an optical disk side of an imaging optical system in which a light beam converged on an optical disk is minutely narrowed in diameter is enlarged to obtain the optical disk having a high density memory capacity. In this case, the degree of aberration occurring in the imaging optical system is increased because an optical axis of the system tilts from a normal line of the optical disk. As the numerical aperture is increased, the degree of the aberration is enlarged. To prevent the increase of the numerical aperture, it is effective to thin the thickness of the optical disk. The thickness of the optical disk denotes a distance from a surface of the optical disk (or an information medium) radiated by a light beam to an information recording plane on which a series of patterned pits are formed.

FIG. **3** shows a relationship between the thickness of the optical disk and the numerical aperture on condition that the tilt of the optical axis is constant.

As shown in FIG. **3**, because the numerical aperture is 0.5 when the thickness of the optical disk is 1.2 mm, it is effective to thin the optical disk to 0.6 mm in thickness when the numerical aperture is increased to 0.6. In this case, even though the numerical aperture is increased on condition that the tilt of the optical axis is not changed, the degree of the aberration is not increased. Therefore, it is preferred that the thickness of the optical disk be thinned to obtain the optical disk having a high density memory capacity.

Accordingly, it is expected that the thickness of a prospective optical disk having a high density memory capacity becomes thinner than that of a present optical disk such as a compact disk appearing on the market now. For example, the thickness of the compact disk is about 1.2 mm, and the thickness of the prospective optical disk is expected to range from 0.4 mm to 0.8 mm. In this case, it is required to record or reproduce information on or from an optical disk with an optical head system regardless of whether the optical disk is the present optical disk or the prospective optical disk having a high density memory capacity. That is, an optical head apparatus having an imaging optical system in which a light beam is converged on an optical disk within the diffraction limit regardless of whether the optical disk is thick or thin is required.

However, in a conventional optical head apparatus, a piece of information is only recorded or reproduced on or from an optical disk having a fixed thickness. For example, in cases where the thickness of the information medium **12** is off a regular range by about ± 0.1 mm or more, an aberration such as a spherical aberration occurs when the optical head apparatus **11** is operated. Therefore, the recording or the reproduction of the information is impossible. Accordingly, there is a drawback that an optical head apparatus in which a piece of information is recorded or reproduced on or from an optical disk regardless of whether the optical disk is the present optical disk or the prospective optical disk having a high density memory capacity cannot be manufactured in a conventional technique.

Also, there is a problem in the conventional microscope. That is, because an objective lens of the conventional microscope has only a focal point and images placed within a focal depth of the objective lens can be only observed with the conventional microscope, the magnification of the conventional microscope and an observed range in an optical axis direction are in a trade-off relationship. Therefore, there is a drawback that it is impossible to observe the images over a wide observed range in the optical axis direction at high magnification

Also, there is a problem in the alignment apparatus. That is, when a circuit pattern drawn on the photo mask is transferred to the front side of the sample after an alignment pattern is drawn on the reverse side of the sample, the alignment of the photomask and the sample is performed by simultaneously observing the circuit pattern of the photo mask and the alignment pattern of the sample with the conventional microscope having a deep focal depth and a low magnification. Therefore, because the conventional microscope has a low magnification, there is a drawback that it is impossible to align the photo mask with the sample at a high accuracy ranging within 5 μm.

SUMMARY OF THE INVENTION

A first object of the present invention is to provide, with due consideration to the drawbacks of such a conventional objective lens having a focal point, a compound objective lens having two focal points.

A second object of the present invention is to provide an imaging optical system having the compound objective lens in which light transmitting through the compound objective lens is converged at a diffraction limit on two converging spots placed at different depths of an information medium.

A third object of the present invention is to provide an optical head apparatus having the imaging optical system in which information is recorded, reproduced or erased on or from one of the converging spots of the information medium at which light is converged by the action of the imaging optical system.

A fourth object of the present invention is to provide a high density optical disk in which a series of first recording pits is formed to record pieces of information at high density on a thin substrate.

A fifth object of the present invention is to provide an optical disk apparatus in which information is recorded or reproduced on or from the optical disk with the compound objective lens regardless of whether a series of recording pits expressing pieces of information is recorded or reproduced on or from the high density optical disk having a thin thickness or a conventional compact disk having an ordinary thickness.

A sixth object of the present invention is to provide a binary focus microscope having two focal points in which two types of images drawn at different depths are simultaneously observed.

A seventh object of the present invention is to provide an alignment apparatus in which two types of images drawn at different depths are aligned with the binary focus microscope.

An eighth object of the present invention is to provide a focusing method for focusing light on an information medium with the optical head apparatus.

A ninth embodiment of the present invention is to provide an information reproducing method for reproducing a piece of recording information recorded on a high density optical disk having a thin thickness.

The first object is achieved by the provision of a compound objective lens having two focal points, comprising:

hologram means for transmitting a part of incident light without any diffraction to form a beam of transmitted light and diffracting a remaining part of the incident light to form a beam of diffracted light, the hologram means functioning as a lens for the diffracted light to diverge the diffracted light from the hologram means or converge the diffracted light; and

lens means for converging the transmitted light formed in the hologram means to form a first converging spot at a first focal point and converging the diffracted light formed in the hologram means to form a second converging spot at a second focal point, the second focal point differing from the first focal point.

In the above configuration, a part of incident light transmits through the hologram means without any diffraction. Therefore, a beam of transmitted light not diverged from the hologram means or not converging is formed. Thereafter, the transmitted light is refracted and converged by the lens means, so that the transmitted light is focused on a first converging spot positioned at a first focal point.

In contrast, a remaining part of incident light is diffracted by the hologram means. Therefore, a beam of diffracted light such as a beam of first-order diffracted light which is diverged from the hologram lens or converges is formed. Thereafter, the diffracted light is refracted and converged by the lens means, so that the diffracted light is focused on a second converging spot positioned at a second focal point.

In this case, because a propagation direction of the transmitted light differs from that of the diffracted light, the first focal point of the compound objective lens for the transmitted light differs from the second focal point of the compound objective lens for the diffracted light. Therefore, the compound objective lens has two focal points, and the incident light transmitting through the compound objective lens are converged on two converging points.

Accordingly, the incident light transmitting through the compound objective lens can be reliably converged on an information medium regardless whether the information medium has a first thickness or a second thickness.

It is preferred that a grating pattern be drawn in the hologram means in a concentric circle shape, the grating pattern of the hologram means be formed in relief to concentrically form alternating rows of bottom portions and top portions, a height H of relief in the grating pattern be set to $H<\lambda/(n(\lambda)-1)$ where a symbol λ denotes a wavelength of the incident light and a symbol $n(\lambda)$ denotes a refractive index of the hologram means made of a glass material for the incident light having the wavelength λ, and a difference in phase modulation degree between the incident light transmitting through a bottom portion of the grating pattern and the incident light transmitting through a top portion of the grating pattern be lower than 2π radians to set a diffraction efficiency of the hologram means to a value lower than 100%.

In the above configuration, because the height of the relief in the grating pattern is lower than a value $\lambda/(n(\lambda)1)$, the difference in phase modulation degree is induced to be lower than 2π radians. Therefore, the diffraction efficiency of the hologram means is set to a value lower than 100% over the entire grating pattern, so that the transmitted light and the diffracted light are simultaneously formed in the hologram lens.

The first object is also achieved by the provision of a compound objective lens, comprising:

lens means for converging a beam of first incident light on a front surface of a first information medium having a first thickness T1 and converging a beam of second incident light on a front surface of a second information medium having a second thickness T2 (T2<T1), the first incident light passing through the first information medium from its rear surface, and the second incident light passing through the second information medium from its rear surface; and

aperture limiting means for selectively limiting an aperture of the lens means for the second incident light which is incident on the lens means, a second numerical aperture of the lens means for the second incident light which is incident on the lens means being lower than a first numerical aperture of the

lens means for the first incident light which is incident on the lens means.

In the above configuration, an aperture of the lens means for the second incident light is limited by the aperture limiting means, and another aperture of the lens means for the first incident light is limited. Thereafter, the first incident light is converged by the lens means on the first information medium at a high numerical aperture, and the second incident light is converged by the lens means on the second information medium at a low numerical aperture. Accordingly, the compound objective lens has two focal points. Also, the intensity of the first incident light can be larger than that of the second incident light.

The first object is also achieved by the provision of a compound objective lens, comprising:

lens means for converging a beam of first incident light on a front surface of a first information medium having a first thickness and converging a beam of second incident light on a front surface of a second information medium having a second thickness, the first incident light passing through the first information medium from its rear surface, and the second incident light passing through the second information medium from its rear surface; and

curvature changing means for changing a curvature of spherical waves of a part of incident light to form the first incident light which is incident on the lens means and not changing a curvature of spherical waves of a remaining part of incident light to form the second incident light which is incident on the lens means.

In the above configuration, a curvature of spherical waves of a part of incident light is changed by the curvature changing means to form a beam of first incident light, and a curvature of spherical waves of a remaining part of incident light is not changed to form a beam of second incident light. Thereafter, the first incident light is converged on the first information medium, and the second incident light is converged on the second information medium.

Accordingly, the compound objective lens has two focal points.

The second object is achieved by the provision of an imaging optical system, comprising:

a light source for radiating a beam of incident light of which a far field pattern is distributed to decrease intensity of the incident light toward a peripheral portion of the beam;

hologram means for transmitting a part of the incident light radiated from the light source without any diffraction to form a beam of transmitted light and diffracting a remaining part of the incident light to form a beam of diffracted light, a grating pattern being formed in relief in the hologram means to concentrically form alternating rows of bottom portions and top portions on condition that a height H of relief in the grating pattern is set to $H<\lambda/(n(\lambda)-1)$ where a symbol λ denotes a wavelength of the incident light and a symbol $n(\lambda)$ denotes a refractive index of the hologram means made of a glass material for the incident light having the wavelength λ, a difference in phase modulation degree between the incident light transmitting through the bottom portions of the grating pattern and the incident light transmitting through the top portions of the grating pattern being lower than 2π radians to set a diffraction efficiency of the hologram means to a value lower than 100%, the height H of the relief in the grating pattern being gradually lowered toward an outer direction of a pattern region in which the grating pattern is drawn, and the diffraction efficiency of the hologram means for the incident light being gradually lowered toward the outer direction of the pattern region to distribute intensity of the transmitted light in a gently-sloping shape; and

lens means for converging the transmitted light formed in the hologram means to form a first converging spot at a first focal point and converging the diffracted light formed in the hologram means to form a second converging spot at a second focal point.

In the above configuration, a beam of incident light is radiated from a light source. A far field pattern of the incident light is distributed to decrease intensity of the incident light toward a peripheral portion of the beam. For example, the light source is a semiconductor laser, the far field pattern of the incident light is distributed in the Gaussian distribution. Thereafter, the incident light transmits through the hologram means. In this case, because a grating pattern is drawn in relief in the hologram means and because the height of the relief is lower than a value $\lambda/(n(\lambda)-1)$, the difference in phase modulation degree between the incident light transmitting through a bottom portion of the grating pattern and the incident light transmitting through a top portion of the grating pattern is induced to be lower than 2π radians. Therefore, the diffraction efficiency of the hologram means for the incident light is set to a value lower than 100% over the entire grating pattern, so that the transmitted light and the diffracted light are simultaneously formed in the hologram lens. In addition, because the height H of the relief in the grating pattern is gradually lowered toward the outer direction of the pattern region, the diffraction efficiency of the hologram means for the incident light is gradually lowered toward the outer direction of the pattern region. Therefore, the incident light positioned at a center portion of its beam are mainly changed to the diffracted light, and the incident light positioned at a peripheral portion of its beam are mainly changed to the transmitted light.

Thereafter, the transmitted light is refracted and converged by the lens means, so that the transmitted light is focused on a first converging spot positioned at a first focal point. Also, the diffracted light is refracted and converged by the lens means, so that the diffracted light is focused on a second converging spot positioned at a second focal point. In this case, because a propagation direction of the transmitted light differs from that of the diffracted light, the first focal point for the transmitted light differs from the second focal point for the diffracted light.

Accordingly, even though the far field pattern of the incident light is distributed in the Gaussian distribution, the far field pattern of the transmitted light is distributed in a gently-sloping shape. Therefore, secondary maxima (or side lobes) of the transmitted light can be prevented from occurring at the first converging spot.

Also, because the height H of the relief in the grating pattern is gradually lowered over the entire pattern region, a numerical aperture of the lens means for the diffracted light can be sufficiently heightened.

The second object is also achieved by the provision of an imaging optical system, comprising:

a light source for radiating a beam of incident light of which a far field pattern is distributed to decrease intensity of the incident light toward a peripheral portion of the beam;

hologram means for transmitting a part of the incident light radiated from the light source without any diffraction to form a beam of transmitted light and diffracting a remaining part of the incident light to form a beam of diffracted light, a grating pattern being formed in relief in the hologram means to concentrically form alternating rows of bottom portions and top portions on condition that a height H of relief in the grating pattern is set to $H<\lambda/(n(\lambda)-1)$ where a symbol λ denotes a wavelength of the incident light and a symbol $n(\lambda)$ denotes a refractive index of the hologram means made of a glass material for the incident light having the wavelength λ, a difference in phase modulation degree between the incident light passing through the bottom portions of the grating pattern and the incident light passing through the top portions of the grating pattern being lower than 2π radians to set a diffraction efficiency of the hologram means to a value lower than 100%, the height H of the relief in the grating pattern being gradually lowered toward an inner direction of a pattern region in which the grating pattern is drawn, and the diffraction efficiency of the hologram means for the incident light being gradually lowered toward the inner direction of the pattern region to distribute intensity of the diffracted light in a gently-sloping shape; and

lens means for converging the transmitted light formed in the hologram means to form a first converging spot at a first focal point and converging the diffracted light formed in the hologram means to form a second converging spot at a second focal point.

In the above configuration, the transmitted light and the diffracted light are simultaneously formed in the hologram lens in the same manner. Also, because the height H of the relief in the grating pattern is gradually lowered toward the inner direction of the pattern region, the diffraction efficiency of the hologram means for the incident light is gradually lowered toward the inner direction of the pattern region. Therefore, the incident light positioned at a center portion of its beam are mainly changed to the transmitted light, and the incident light positioned at a peripheral portion of its beam are mainly changed to the diffracted light.

Accordingly, even though the far field pattern of the incident light is distributed in the Gaussian distribution, the far field pattern of the diffracted light is distributed in a gently-sloping shape. Therefore, secondary maxima (or side lobes) of the diffracted light can be prevented from occurring at the second converging spot.

Also, because the height H of the relief in the grating pattern is gradually lowered over the entire pattern region, a numerical aperture of the lens means for the transmitted light can be sufficiently heightened.

The third object is achieved by the provision of an optical head apparatus for recording or reproducing a piece of information on or from a thin type of first information medium having a first thickness or a thick type of second information medium having a second thickness larger than the first thickness, comprising:

a light source for radiating a beam of incident light;

hologram means for transmitting a part of the incident light radiated from the light source without any diffraction on an outgoing path to form a beam of transmitted light and diffracting a remaining part of the incident light radiated from the light source on the outgoing path to form a beam of diffracted light, the hologram means functioning as a lens for the diffracted light to diverge the diffracted light from the hologram means or converge the diffracted light;

lens means for converging the transmitted light formed in the hologram means at a first focal length on the outgoing path to form a first converging spot at a front surface of the first information medium or converging the diffracted light formed in the hologram means at a second focal length on the outgoing path to form a second converging spot at a front surface of the second information medium, the transmitted light being incident on a rear surface of the first information medium and being converged at the front surface of the first information medium, the transmitted light being reflected at the rear surface of the first information medium and again passing through the lens means and the hologram means on an incoming path, the diffracted light being incident on a rear surface of the second information medium and being converged at the front surface of the second information medium, and the diffracted light being reflected at the rear surface of the first information medium and again passing through the lens means and the hologram means on the incoming path;

wavefront changing means for changing a wavefront of the transmitted light or the diffracted light passing through the lens means and the hologram means on the incoming path to form one or more beams of information light; and

detecting means for detecting intensities of the information light formed by the wavefront changing means and generating an information signal according to the intensities of the information light, the information signal expressing a piece of information recorded on the first information medium or the second information medium.

In the above configuration, a beam of incident light is radiated from the light source, and a part of the incident light transmits through the hologram lens to form a beam of transmitted light. Also, a remaining part of the incident light is diffracted by the hologram lens to form a beam of diffracted light. Thereafter, the transmitted light and the diffracted light are converged by the converging means. In cases where a piece of information is recorded or reproduced on or from the first information medium, the transmitted light is incident on the rear surface of the first information medium and is converged at the front surface of the first information medium to form the first converging spot. Thereafter, the transmitted light is reflected at the rear surface of the first information medium and again passes through the lens means and the hologram means without any diffraction. In contrast, in cases where a piece of information is recorded or reproduced on or from the second information medium, the diffracted light is incident on the rear surface of the second information medium and is converged at the front surface of the second information medium to form the second converging spot. Thereafter, the diffracted light is reflected at the rear surface of the second information medium and again

passes through the lens means. Thereafter, the diffracted light is again diffracted by the hologram means.

Thereafter, a wavefront of the transmitted light or the diffracted light is changed by the wavefront changing means to form a plurality of beams of reflected light, and the intensities of the reflected light is detected by the detecting means. Therefore, an information signal expressing the information recorded on the first or second information medium is generated according to the intensities of the reflected light.

Accordingly, because the first converging spot of the transmitted light differs from the second converging spot of the diffracted light, a compound objective lens composed of the hologram lens and the lens means has two focal points. Therefore, a piece of information can be recorded or reproduced on or from an information medium regardless of whether the information medium has the first thickness or the second thickness.

The third object is also achieved by the provision of an optical head apparatus for recording or reproducing a piece of information on or from a first information medium having a first thickness T1 or a second information medium having a second thickness T2 (T1<T2), comprising:

lens means for converging a beam of first incident light on a front surface of a first information medium having a first thickness T1 or converging a beam of second incident light on a front surface of a second information medium having a second thickness T2 (T2<T1), the first incident light passing through the first information medium from its rear surface, and the second incident light passing through the second information medium from its rear surface;

aperture limiting means for selectively limiting an aperture of the lens means for the second incident light which is incident on the lens means, a second numerical aperture of the lens means for the second incident light which is incident on the lens means being lower than a first numerical aperture of the lens means for the first incident light which is incident on the lens means, the first incident light being reflected at the front surface of the first information medium and again passing through the lens means and the aperture limiting means on an incoming path, and the second incident light being reflected at the front surface of the second information medium and again passing through the lens means and the aperture limiting means on the incoming path;

a light source for radiating the first incident light and the second incident light to the aperture limiting means;

wavefront changing means for changing a wavefront of the first or second incident light passing through the lens means and the aperture limiting means on the incoming path to form one or more beams of information light; and

detecting means for detecting intensities of the information light formed by the wavefront changing means and generating an information signal according to the intensities of the information light, the information signal expressing a piece of information recorded on the first information medium or the second information medium.

In the above configuration, a compound objective lens composed of the lens means and the aperture limiting means has two focal points, and the intensity of the first incident light is larger than that of the second incident light.

Accordingly, a piece of information can be recorded or reproduced on or from an information medium regardless of whether the information medium has the first thickness or the second thickness. Also, a piece of information can be efficiently recorded on the first information medium with the first incident light having a high intensity, and a piece of information can be efficiently reproduced from the second information medium with the second incident light having a comparatively low intensity.

The third object is also achieved by the provision of an optical head apparatus for recording or reproducing a piece of information on or from a first information medium having a first thickness or a second information medium having a second thickness, comprising:

lens means for converging a beam of first incident light on a front surface of the first information medium and converging a beam of second incident light on a front surface of the second information medium, the first incident light passing through the first information medium from its rear surface, and the second incident light passing through the second information medium from its rear surface; and

curvature changing means for changing a curvature of spherical waves of a part of incident light to form the first incident light which is incident on the lens means and not changing a curvature of spherical waves of a remaining part of incident light to form the second incident light which is incident on the lens means, the first incident light being reflected at the front surface of the first information medium and again passing through the lens means and the curvature changing means on an incoming path, and the second incident light being reflected at the front surface of the second information medium and again passing through the lens means and the curvature changing means on the incoming path;

a light source for radiating the incident light to the curvature changing means;

wavefront changing means for changing a wavefront of the first or second incident light passing through the lens means and the curvature changing means on the incoming path to form one or more beams of information light; and

detecting means for detecting intensities of the information light formed by the wavefront changing means and generating an information signal according to the intensities of the information light, the information signal expressing a piece of information recorded on the first information medium or the second information medium.

In the above configuration, because a compound objective lens is composed of the lens means and the curvature changing means, the compound objective lens has two focal points. Accordingly, a piece of information can be recorded or reproduced on or from an information medium regardless of whether the information medium has the first thickness or the second thickness.

The fourth object is achieved by the provision of an optical disk, comprising:

an information recording substrate partitioned into a first region and a second region, the first region having a first thickness, and the second region

having a second thickness smaller than the first thickness;

a plurality of first recording pits placed at the first region of the information recording substrate for recording pieces of recording information at a high recording density, the first recording pits being formed at narrow intervals; and

a plurality of second recording pits placed at the second region of the information recording substrate for recording pieces of distinguishing information at an ordinary recording density of a compact disk, the distinguishing information informing that the recording information are recorded on the information recording substrate having the first thickness, and the recording density of the recording information being higher than that of the distinguishing information.

In the above configuration, a substrate of a conventional compact disk has the same second thickness as that of the second region of the information recording substrate in the optical disk according to the present invention. Therefore, in cases where a beam of reproducing light is incident on a prescribed region of an unknown disk selected from a group of the conventional compact disk and the optical disk, the reproducing light is focused on a recording pit of the conventional compact disk or one of the second recording pits of the optical disk regardless of whether the unknown disk is the conventional compact disk or the optical disk.

In cases where the unknown disk is the optical disk, a piece of distinguishing information is read by the reproducing light. Because the distinguishing information informs that pieces of recording information are recorded on the information recording substrate having the first thickness, a curvature of the reproducing light is automatically changed to focus the reproducing light on the information recording substrate having the first thickness, and the reproducing light is automatically focused on one of the first recording pits. Therefore, a piece of recording information is reproduced.

In contrast, in cases where the unknown disk is the conventional compact disk, a piece of recording information is read by the reproducing light in the same manner as in a prior art.

Accordingly, a piece of recording information formed on an information recording substrate can be reliably reproduced even though the thickness of the information recording substrate is unknown.

The fourth object is also achieved by the provision of an optical disk, comprising:

an information recording substrate having a thin thickness, the thin thickness of the information recording substrate being thinner than that of a compact disk;

a plurality of first recording pits placed at a first region of the information recording substrate for recording pieces of recording information at a high recording density, the first recording pits being formed at narrow intervals; and

a plurality of second recording pits placed at a second region of the information recording substrate for recording pieces of distinguishing information at a low recording density, the distinguishing information informing that the recording information are recorded on the information recording substrate having the thin thickness, the recording density of the recording information being higher than that of the distinguishing information, each of the second recording pits being larger than that of a recording pit in the compact disk, and a converging spot of a beam of reproducing light, which is converged to focus on an ordinary recording pit formed on a substrate having an ordinary thickness of the compact disk, being formed in one of the second recording pits to read the distinguishing information.

In the above configuration, a beam of reproducing light, of which a curvature is adjusted to focus the reproducing light on a recording pit formed on an information recording substrate of the compact disk, is incident on a prescribed region of an unknown disk selected from a group of the compact disk having an ordinary thickness and the optical disk according to the present invention, In cases where the unknown disk is the optical disk, the reproducing light is converged on one of the second recording pits in defocus because the information recording substrate of the optical disk has the thin thickness. However, because each of the second recording pits is large in size, a converging spot of the reproducing light is formed in the second recording pit. Therefore, a piece of distinguishing information is read by the reproducing light. Because the distinguishing information informs that pieces of recording information are recorded on the information recording substrate having the thin thickness, a curvature of the reproducing light is automatically changed to focus the reproducing light on the information recording substrate having the thin thickness, and the reproducing light is automatically focused on one of the first recording pits. Therefore, a piece of recording information is reproduced.

In contrast, in cases where the unknown disk is the compact disk, a piece of recording information is read by the reproducing light in the same manner as in a prior art.

Accordingly, a piece of recording information formed on an information recording substrate can be reliably reproduced even though the thickness of the information recording substrate is unknown.

The fifth object is achieved by the provision of an optical disk apparatus for recording or reproducing pieces of recording information on or from an optical disk in which the recording information are recorded or reproduced at a high density on or from a first substrate having a first thickness and a piece of distinguishing information informing that the recording information are recorded or reproduced on or from the first substrate having the first thickness is recorded at an ordinary density on a second substrate having a second thickness larger than the first thickness, comprising:

rotating means for rotating the optical disk at a regular speed;

a light source for radiating a beam of incident light;

hologram means for transmitting a part of the incident light radiated from the light source without any diffraction on an outgoing path to form a beam of transmitted light and diffracting a remaining part of the incident light radiated from the light source on the outgoing path to form a beam of diffracted light, the hologram means functioning as a lens for the diffracted light to diverge the diffracted light from the hologram means;

lens means for converging the transmitted light formed in the hologram means on the first substrate of the optical disk rotated by the rotating means to record or reproduce a piece of recording informa-

tion on or from the optical disk and converging the diffracted light formed in the hologram means on the second substrate of the optical disk rotated by the rotating means to reproduce the distinguishing information from the optical disk, the transmitted light being reflected by the first substrate of the optical disk and again passing through the lens means and the hologram means on an incoming path, and the diffracted light being reflected by the second substrate of the optical disk and again passing through the lens means and the hologram means on the incoming path;

wavefront changing means for changing a wavefront of the transmitted light passing through the lens means and the hologram means on the incoming path to form one or more beams of recording information light and changing a wavefront of the diffracted light passing through the lens means and the hologram means on the incoming path to form one or more beams of distinguishing information light;

detecting means for detecting intensities of the recording information light formed by the wavefront changing means to generate a recording information signal according to the intensities of the recording information light and detecting intensities of the distinguishing information light formed by the wavefront changing means to generate a distinguishing information signal according to the intensities of the distinguishing information light, the distinguishing information signal expressing the distinguishing information recorded on the second substrate of the optical disk, and the recording information signal expressing the recording information recorded on the first substrate of the optical disk; and

moving means for moving an optical head apparatus comprising the light source, the hologram means, the lens means and the detecting means to converge the diffracted light formed in the hologram means on the second substrate of the optical disk and moving the optical disk, in which the diffracted light formed in the hologram means is converged on the second substrate of the optical disk, to converge the transmitted light formed in the hologram means on the first substrate of the optical disk in cases where the distinguishing information is detected in the detecting means.

In the above configuration, an optical head apparatus comprising the light source, the hologram means, the lens means and the detecting means has the same configuration as that described before. Initially, the optical head apparatus is moved by the moving means to converge in focus the diffracted light formed in the hologram means on the second substrate of the optical disk rotated by the rotating means. Therefore, the distinguishing information recorded on the second substrate is reproduced in the detecting means, and it is informed that pieces of recording information are recorded or reproduced on or from the first substrate having the first thickness. Thereafter, the optical head apparatus is moved by the moving means to converge in focus the transmitted light formed in the hologram means on the first substrate of the optical disk rotated by the rotating means. Therefore, a piece of recording information is recorded or reproduced on or from the first substrate of the optical disk.

Accordingly, even though a high density type of optical disk, in which pieces of recording information is recorded or reproduced on or from the substrate having the first thickness smaller than the second thickness of a conventional optical disk, is utilized, the recording information can be reliably recorded or reproduced.

The fifth object is also achieved by the provision of an optical disk apparatus for recording or reproducing pieces of recording information on or from an optical disk in which the recording information are recorded or reproduced at a high density on or from a first substrate having a thin thickness thinner than that of a compact disk and a piece of distinguishing information informing that the recording information are recorded or reproduced on or from the first substrate having the thin thickness is recorded at a low density on a second substrate having the thin thickness, comprising:

rotating means for rotating the optical disk at a regular speed;

a light source for radiating a beam of incident light;

hologram means for transmitting a part of the incident light radiated from the light source without any diffraction on an outgoing path to form a beam of transmitted light and diffracting a remaining part of the incident light radiated from the light source on the outgoing path to form a beam of diffracted light, the hologram means functioning as a lens for the diffracted light to diverge the diffracted light from the hologram means;

lens means for converging in focus the transmitted light formed in the hologram means on the first substrate of the optical disk rotated by the rotating means to record or reproduce a piece of recording information on or from the optical disk and converging in defocus the diffracted light formed in the hologram means on the second substrate of the optical disk rotated by the rotating means to reproduce the distinguishing information from the optical disk, the transmitted light being reflected by the first substrate of the optical disk and again passing through the lens means and the hologram means on an incoming path, and the diffracted light being reflected by the second substrate of the optical disk and again passing through the lens means and the hologram means on the incoming path;

wavefront changing means for changing a wavefront of the transmitted light passing through the lens means and the hologram means on the incoming path to form one or more beams of recording information light and changing a wavefront of the diffracted light passing through the lens means and the hologram means on the incoming path to form one or more beams of distinguishing information light;

detecting means for detecting intensities of the recording information light formed by the wavefront changing means to generate a recording information signal according to the intensities of the recording information light and detecting intensities of the distinguishing information light formed by the wavefront changing means to generate a distinguishing information signal according to the intensities of the distinguishing information light, the distinguishing information signal expressing the distinguishing information recorded on the second substrate of the optical disk, and the recording information signal expressing the recording infor-

mation recorded on the first substrate of the optical disk; and

moving means for moving an optical head apparatus comprising the light source, the hologram means, the lens means and the detecting means, to converge the diffracted light formed in the hologram means in defocus on the second substrate of the optical disk and moving the optical disk, in which the diffracted light formed in the hologram means is converged on the second substrate of the optical disk in defocus, to converge the transmitted light formed in the hologram means on the first substrate of the optical disk in focus in cases where an intensity of the distinguishing information signal generated in the detecting means is larger than a threshold value.

In the above configuration, an optical head apparatus comprising the light source, the hologram means, the lens means and the detecting means has the same configuration as that described before. Initially, the optical head apparatus is moved by the moving means to converge in defocus the diffracted light formed in the hologram means on the second substrate of the optical disk rotated by the rotating means. In this case, because the distinguishing information is recorded at a low density, a plurality of recording pits expressing the distinguishing information are respectively large in size. Therefore, even though the diffracted light is converged on each of the recording pits in defocus, a converging spot of the diffracted light is formed in each of the recording pits. Therefore, the distinguishing information recorded on the second substrate is reproduced in the detecting means, and it is informed that pieces of recording information are recorded or reproduced on or from the first substrate having the thin thickness. Thereafter, the optical head apparatus is moved by the moving means to converge in focus the transmitted light formed in the hologram means on the first substrate of the optical disk rotated by the rotating means. Therefore, a piece of recording information is recorded or reproduced on or from the first substrate of the optical disk.

Accordingly, even though a high density type of optical disk, in which pieces of recording information are recorded or reproduced on or from the substrate having the thin thickness smaller than an ordinary thickness of a conventional optical disk, is utilized, the recording information can be reliably recorded or reproduced.

The sixth object is achieved by the provision of a binary focus microscope for simultaneously observing a first image put on a first image plane and a second image put on a second image plane, comprising:

an objective lens for refracting a beam of first light diverging from the first image and a beam of second light diverging from the second image, a first distance between the objective lens and the first image of the first image plane differing from a second distance between the objective lens and the second image of the second image plane;

a hologram lens for transmitting the first light refracted by the objective lens without any diffraction to form a beam of transmitted light and diffracting the second light refracted by the objective lens to form a beam of diffracted light, the hologram lens functioning as a lens for the second light to pass the diffracted light through the same optical path as the transmitted light passes through, and a beam of superposed light being formed of the transmitted light and the diffracted light;

an inner lens for converging the superposed light formed by the hologram lens at an image point of a third image plane to simultaneously form the first image and the second image enlarged on the third image plane; and

an ocular lens for converging the superposed light which is converged by the inner lens and diverges from the image point to simultaneously form the first image and the second image moreover enlarged.

In the above configuration, a beam of first light diverging from the first image and a beam of second light diverging from the second image are refracted together by the objective lens. In this case, because a first distance between the objective lens and the first image of the first image plane differs from a second distance between the objective lens and the second image of the second image plane, a curvature of the first light refracted differs from another curvature of the second light refracted. Thereafter, the first light refracted transmits through the hologram lens without any diffraction to form a beam of transmitted light, and the second light refracted is diffracted by the hologram lens to form a beam of diffracted light. In this case, because the hologram lens functions as a lens for the diffracted light, a curvature of the diffracted light agrees with that of the transmitted light. In other words, the diffracted light passes through the same optical path as the transmitted light passes through. Therefore, a beam of superposed light is formed of the transmitted light and the diffracted light. Thereafter, the superposed light is converged by the inner lens at an image point of a third image plane, so that the first image and the second image enlarged are simultaneously formed on the third image plane. Thereafter, the superposed light diverging from the image point is converged by the ocular lens, so that the first image and the second image moreover enlarged are simultaneously formed.

Accordingly, an operator can observe the first image and the second image sufficiently enlarged.

The sixth object is also achieved by the provision of a binary focus microscope for simultaneously observing a first image put on a first image plane and a second image put on a second image plane, comprising:

an objective lens for refracting a beam of first light diverging from the first image and a beam of second light diverging from the second image, a first distance between the objective lens and the first image of the first image plane differing from a second distance between the objective lens and the second image of the second image plane;

a hologram lens for transmitting the first light refracted by the objective lens without any diffraction to form a beam of transmitted light and diffracting the second light refracted by the objective lens to form a beam of diffracted light, the hologram lens functioning as a lens for the second light to pass the diffracted light through the same optical path as the transmitted light passes through, and a beam of superposed light being formed of the transmitted light and the diffracted light;

an inner lens for converging the superposed light formed by the hologram lens at an image point of a third image plane to simultaneously form the first image and the second image enlarged on the third image plane; and

photographing means for photographing a superposed image formed of the first and second images enlarged on the third image plane by converging the superposed light in the inner lens.

In the above configuration, the first image and the second image enlarged are simultaneously formed on the third image plane in the same manner. Thereafter, the first image and the second image enlarged are photographed by the photographing means as a superposed image.

Accordingly, the first image and the second image enlarged can be observed.

The seventh embodiment is achieved by the provision of an alignment apparatus for aligning a first reference image drawn on a photomask with a second reference image drawn on a sample, comprising:

a light source for radiating beams of alignment light to illuminate the first and second reference images;

an objective lens for refracting both a beam of first alignment light diverging from the first reference image and a beam of second alignment light diverging from the second reference image which are illuminated with the alignment light radiated from the light source, a first distance between the objective lens and the first reference image of the photomask differing from a second distance between the objective lens and the second reference image of the sample;

a hologram lens for transmitting the first alignment light refracted by the objective lens without any diffraction to form a beam of transmitted light and diffracting the second alignment light refracted by the objective lens to form a beam of diffracted light, the hologram lens functioning as a lens for the second alignment light to pass the diffracted light through the same optical path as the transmitted light passes through, and a beam of superposed light being formed of the transmitted light and the diffracted light;

an inner lens for converging the superposed light formed by the hologram lens at an image point of an image plane to simultaneously form the first and second reference images enlarged on the image plane, an optical axis passing through centers of the objective lens, the hologram lens and the inner lens;

photographing means for photographing a superposed image formed of the first and second images enlarged on the image plane by converging the superposed light in the inner lens; and

moving means for moving the photomask or the sample according to the superposed image photographed by the photographing means to align the first reference image with the second reference image along the optical axis.

In the above configuration, the objective lens, the hologram lens and the inner lens are the same as those in the binary focus microscope. Therefore, the first and second images enlarged on the image plane is photographed by the photographing means as a superposed image. Thereafter, the photomask or the sample is moved in a direction perpendicular to the optical axis by the moving means to align the first reference image with the second reference image along the optical axis.

Accordingly, because the superposed image formed of the first and second reference images enlarged is photographed by the photographing means, a relative position between the first and second reference images can be accurately observed. Therefore, the first reference image can be accurately aligned with the second reference image.

The eighth embodiment is achieved by the provision of a focusing method for focusing light on a first information medium having a first thickness or a second information medium having a second thickness to record or reproduce a piece of information on or from the first information medium or the second information medium, comprising the steps of:

moving an optical head apparatus in a direction to decrease or increase the distance between the optical head apparatus and the first or second information medium, the optical head apparatus comprising

a light source for radiating a beam of incident light,

hologram means for transmitting a part of the incident light radiated from the light source without any diffraction on an outgoing path to form a beam of transmitted light and diffracting a remaining part of the incident light radiated from the light source on the outgoing path to form a beam of diffracted light, the hologram means functioning as a lens for the diffracted light to diverge the diffracted light from the hologram means or converge the diffracted light,

lens means for converging the transmitted light formed in the hologram means at a first focal length on the outgoing path to form a first converging spot at a front surface of the first information medium or converging the diffracted light formed in the hologram means at a second focal length on the outgoing path to form a second converging spot at a front surface of the second information medium, the transmitted light being incident on a rear surface of the first information medium and being converged at the front surface of the first information medium, the transmitted light being reflected at the rear surface of the first information medium and again passing through the lens means and the hologram means on an incoming path, the diffracted light being incident on a rear surface of the second information medium and being converged at the front surface of the second information medium, and the diffracted light being reflected at the rear surface of the first information medium and again passing through the lens means and the hologram means on the incoming path,

wavefront changing means for changing a wavefront of the transmitted light or the diffracted light passing through the lens means and the hologram means on the incoming path to form one or more beams of information light, and

detecting means for detecting intensities of the information light formed by the wavefront changing means and generating an information signal and a focus error signal according to the intensities of the information light, the information signal expressing a piece of information recorded on the first information medium or the second information medium;

judging whether or not an intensity of the focus error signal generated in the detecting means is larger than a threshold value; and

adjusting the position of the optical head apparatus to decrease the intensity of the focus error signal to zero when the intensity of the focus error signal becomes larger than the threshold value.

In the above steps, the focusing method is performed by utilizing the optical head apparatus described above. The intensity of the focus error signal is largely increased when the distance between the lens means and the first or second information medium is near to a focal length of the lens means. Therefore, when the intensity of the focus error signal becomes larger than a threshold value, the lens means is placed near to a just-focus point in which the transmitted light or the diffracted light is converged on the first or second information medium in focus.

Accordingly, in cases where the position of the optical head apparatus is adjusted to decrease the intensity of the focus error signal to zero when the intensity of the focus error signal becomes larger than the threshold value, the transmitted light or the diffracted light can be focused on the first or second information medium.

The ninth embodiment is achieved by the provision of an information reproducing method for reproducing a piece of recording information from an optical disk in which the recording information are recorded at a high density on a first substrate having a first thickness and a piece of distinguishing information informing that the recording information are recorded on the first substrate is recorded at an ordinary density on a second substrate having a second thickness larger than the first thickness, comprising the step of:

moving an optical disk apparatus under the second substrate of the optical disk, the optical disk comprising

rotating means for rotating the optical disk at a regular speed,

a light source for radiating a beam of incident light;

hologram means for transmitting a part of the incident light radiated from the light source without any diffraction on an outgoing path to form a beam of transmitted light and diffracting a remaining part of the incident light radiated from the light source on the outgoing path to form a beam of diffracted light, the hologram means functioning as a lens for the diffracted light to diverge the diffracted light from the hologram means,

lens means for converging the transmitted light formed in the hologram means on the first substrate of the optical disk rotated by the rotating means to record or reproduce a piece of recording information on or from the optical disk and converging the diffracted light formed in the hologram means on the second substrate of the optical disk rotated by the rotating means to reproduce the distinguishing information from the optical disk, the transmitted light being reflected by the first substrate of the optical disk and again passing through the lens means and the hologram means on an incoming path, and the diffracted light being reflected by the second substrate of the optical disk and again passing through the lens means and the hologram means on the incoming path,

wavefront changing means for changing a wavefront of the transmitted light passing through the lens means and the hologram means on the incoming path to form one or more beams of recording information light and changing a wavefront of the diffracted light passing through the lens means and the hologram means on the incoming path to form one or more beams of distinguishing information light, and

detecting means for detecting intensities of the recording information light formed by the wavefront changing means to generate a recording information signal according to the intensities of the recording information light and detecting intensities of the distinguishing information light formed by the wavefront changing means to generate a distinguishing information signal according to the intensities of the distinguishing information light, the distinguishing information signal expressing the distinguishing information recorded on the second substrate of the optical disk, and the recording information signal expressing the recording information recorded on the first substrate of the optical disk; and

converging the diffracted light on the second substrate of the optical disk to reproduce the distinguishing information;

moving the optical disk apparatus to a position under the first substrate of the optical disk to converge the transmitted light on the first substrate of the optical disk when the distinguishing information is detected in the detecting means; and

reproducing the recording information by generating the recording information signal in the detecting means.

In the above steps, the information reproducing method is performed by utilizing the optical disk apparatus described above. The distinguishing information placed on the second substrate of the optical disk is reproduce with the diffracted light. In this case, because the second substrate has the second thickness, the diffracted light is just focused on the second substrate. Thereafter, when the distinguishing information is detected, the optical disk apparatus is moved to a position under the first substrate of the optical disk, and the transmitted light is converged on the first substrate of the optical disk. In this case, because the first substrate has the first thickness, the diffracted light is just focused on the first substrate.

Accordingly, the recording information can be reliably reproduced.

BRIEF DESCRIPTION OF THE DRAWINGS

The objects, features and advantages of the present invention will be apparent from the following description taken in conjunction with the accompanying drawings, in which:

FIG. **1** is a constitutional view of a conventional optical head apparatus proposed in Japanese Patent Application No. 46630 of 1991;

FIGS. **2A**, **2B** are respectively a cross sectional view of a set of an objective lens and a blazed hologram shown in FIG. **1**;

FIG. **3** shows a relationship between the thickness of an optical disk and a numerical aperture of an objective lens on condition that the tilt of the optical axis is constant;

FIG. **4A** is a constitutional view of an imaging optical system having a compound objective Lens according to a first embodiment of the present invention, a beam of transmitted light not diffracted being converged on a thin type of information medium;

FIG. **4B** is a constitutional view of the imaging optical system shown in FIG. **4A**, a beam of first-order diffracted light being converged on a thick type of information medium;

FIG. 5 is a plan view of a hologram lens shown in FIGS. 4A, 4B, a grating pattern of the hologram lens being depicted;

FIG. 6 is a cross sectional view of the hologram lens shown in FIG. 5, the grating pattern formed in relief on the hologram lens being shown;

FIG. 7 is an explanatory diagram showing an intensity distribution of transmitted light L4 converged on a converging spot S1 of a first information medium, a primary maximum and secondary maxima suppressed occurring in the converging spot S1;

FIG. 8A is a cross sectional view of the hologram lens shown in FIG. 5, the grating pattern approximating to a step-wise shape composed of four stairs being shown;

FIG. 8B is a cross sectional view of the hologram lens shown in FIG. 5, the grating pattern approximating to a step-wise shape composed of a plurality of stairs being shown;

FIG. 9A is a constitutional view of an imaging optical system having a compound objective lens according to a modification of the first embodiment, a beam of first-order diffracted light being converged on a thin type of information medium;

FIG. 9B is a constitutional view of the imaging optical system shown in FIG. 9A, a beam of transmitted light not diffracted being converged on a thick type of information medium;

FIG. 10A is a constitutional view of an imaging optical system having a compound objective lens according to a second embodiment of the present invention, a beam of transmitted light not diffracted being converged on a thin type of information medium;

FIG. 10B is a constitutional view of the imaging optical system shown in FIG. 10A, a beam of first-order diffracted light being converged on a thick type of information medium;

FIG. 11 shows a change of a diffraction efficiency of a hologram lens shown in FIGS. 10A, 10B;

FIGS. 12A to 12E are respectively a cross sectional view of the hologram lens shown in FIGS. 10A, 10B, the grating pattern of the hologram lens approximating to a step-wise shape;

FIG. 13A shows an intensity distribution of incident light utilized in the second embodiment, a far field pattern of the incident light being distributed in a Gaussian distribution;

FIG. 13B shows an intensity distribution of transmitted light transmitting through a hologram lens shown in FIGS. 10A, 10B, a far field pattern of the incident light being distributed in a gently-sloping shape;

FIGS. 14A to 14C show intensity distributions of transmitted light and diffracted light transmitting through a hologram lens shown in FIGS. 10A, 10B;

FIG. 15A is a plan view of a hologram lens according to a modification of the second embodiment, a grating pattern of the hologram lens being depicted;

FIGS. 15B, 15C are respectively a constitutional view of an imaging optical system having a compound objective lens according to another modification of the second embodiment;

FIG. 16A is a constitutional view of an imaging optical system having a compound objective lens according to a third embodiment of the present invention, a beam of first-order diffracted light being converged on a thin type of information medium;

FIG. 16B is a constitutional view of the imaging optical system shown in FIG. 16A, a beam of transmitted light not diffracted being converged on a thick type of information medium;

FIG. 17 shows a change of a diffraction efficiency of a hologram lens shown in FIGS. 16A, 16B;

FIGS. 18A to 18C show intensity distributions of transmitted light and diffracted light transmitting through a hologram lens shown in FIGS. 16A, 16B;

FIG. 19A is a cross sectional view of a compound objective lens according to a fourth embodiment of the present invention;

FIG. 19B is a cross sectional view of a compound objective lens according to a modification of the fourth embodiment of the present invention;

FIG. 20 is a cross sectional view of a compound objective lens according to a fifth embodiment of the present invention;

FIG. 21 is a constitutional view of an optical head apparatus according to a sixth embodiment of the present invention;

FIG. 22 is a plan view of a wavefront changing device utilized in the six, ninth and twelfth embodiments, a grating pattern of a hologram lens utilized as the wavefront changing device being depicted;

FIG. 23 shows a positional relation between focal points of diffracted light occurring in the wavefront changing device shown in FIG. 22 and a photo detector;

FIG. 24 is a plan view of a photo detector utilized in the six, ninth, tenth, twelfth, thirteenth and seventeenth embodiments;

FIG. 25A and 25C respectively show a converging spot of first-order diffracted light radiated to detecting sections SE1, SE2 and SE3 of a sextant photo-detector shown in FIG. 24 and another converging spot of minus first-order diffracted light radiated to detecting sections SE4, SE5 and SE6 of the sextant photo-detector on condition that an objective lens shown in FIG. 21 is defocused on an information medium;

FIG. 25B shows a converging spot of first-order diffracted light radiated to the detecting sections SE1, SE2 and SE3 of the sextant photo-detector and another converging spot of minus first-order diffracted light radiated to the detecting sections SE4, SE5 and SE6 of the sextant photo-detector on condition that the objective lens is just focused on the information medium;

FIG. 26 shows a relationship between beams of diffracted light occurring in the wavefront changing device shown in FIG. 22 and the photo detector shown in FIG. 24;

FIG. 27 is a constitutional view of an optical head apparatus according to a seventh embodiment;

FIG. 28 is a plan view of a photo detector utilized in the seven, ninth, tenth, twelfth and thirteenth embodiments;

FIGS. 29A, 29B, 29C show various shapes of converging spots converged on the photo detector shown in FIG. 28;

FIG. 29D shows a radial direction Dr and a tangential direction Dt;

FIG. 30 is a constitutional view of an optical head apparatus according to a first modification of the seventh embodiment;

FIG. 31 is a constitutional view of an optical head apparatus according to a second modification of the seventh embodiment;

FIG. 32 is a constitutional view of an optical head apparatus according to a third modification of the seventh embodiment;

FIG. 33 is a constitutional view of an optical head apparatus according to a forth modification of the seventh embodiment;

FIG. 34 shows a beam of transmitted light not diffracted on an incoming optical path and a beam of transmitted light diffracted on the incoming optical path, the beams being utilized to detect an information signal;

FIG. 35A graphically shows a change of a focus error signal obtained by detecting the intensity of transmitted light, the strength of the focus error signal depending on a distance between an objective lens and a first information medium;

FIG. 35B graphically shows a change of a focus error signal obtained by detecting the intensity of diffracted light, the strength of the focus error signal depending on a distance between an objective lens and a second information medium.

FIG. 36A graphically shows a change of a focus error signal obtained by detecting the intensity of diffracted light, the strength of the focus error signal depending on a distance between an objective lens and a first information medium;

FIG. 36B graphically shows a change of a focus error signal obtained by detecting the intensity of transmitted light, the strength of the focus error signal depending on a distance between an objective lens and a second information medium;

FIG. 37 is a constitutional view of an optical head apparatus according to a ninth embodiment;

FIG. 38 is a constitutional view of an optical head apparatus according to a tenth embodiment;

FIG. 39 is a plan view of a beam splitter having a reflection type of hologram utilized in the optical head apparatus shown in FIG. 38;

FIGS. 40A, 40B are respectively a constitutional view of an optical head apparatus according an eleventh embodiment;

FIG. 41 is a plan view of a beam splitter having a reflection type of hologram utilized in the optical head apparatus shown in FIG. 38;

FIG. 42A and 42C respectively show a converging spot of first-order diffracted light radiated to detecting sections SE1, SE2 and SE3 of a sextant photo-detector shown in FIG. 24 and another converging spot of minus first-order diffracted light radiated to detecting sections SE4, SE5 and SE6 of the sextant photo-detector on condition that diffracted light is converged in defocus on a second information medium;

FIG. 42B shows a converging spot of first-order diffracted light radiated to the detecting sections SE1, SE2 and SE3 of a sextant photo-detector shown in FIG. 24 and another converging spot of minus first-order diffracted light radiated to the detecting sections SE4, SE5 and SE6 of the sextant photo-detector on condition that diffracted light is converged in focus on a second information medium;

FIG. 43 is a constitutional view of an optical head apparatus according to a twelfth embodiment;

FIG. 44 is a constitutional view of an optical head apparatus according to a thirteenth embodiment;

FIG. 45 is a constitutional view of an optical head apparatus according to a fourteenth embodiment;

FIG. 46 is a plan view of a hologram lens utilized in the optical head apparatus shown in FIG. 45;

FIG. 47 is a constitutional view of an optical head apparatus according to a fifteenth embodiment;

FIG. 48 is a plan view of a hologram lens utilized in the optical head apparatus shown in FIG. 47;

FIGS. 49A, 49B respectively show a positional relation between unnecessary light occurring in the hologram lens shown in FIG. 48 and a photo detector shown in FIG. 47;

FIG. 50 is a constitutional view of an optical head apparatus according to a sixteenth embodiment;

FIG. 51 is a diagonal view of a light source and photo detectors utilized in the optical head apparatus shown in FIG. 50;

FIG. 52 is a constitutional view of an optical head apparatus according to a seventeenth embodiment;

FIG. 53 is a diagonal view of a high density optical disk according to an eighteenth embodiment, a cross sectional view of the disk being partially shown;

FIG. 54 is a diagonal view of a high density optical disk according to a nineteenth embodiment, a cross sectional view of the disk being partially shown;

FIG. 55 is a block diagram of an optical disk apparatus with one of the optical head apparatuses shown in FIGS. 21, 27, 30, 31, 32, 33, 37, 38, 40A, 43, 44, 50 and 52 according to a twentieth embodiment;

FIG. 56 is a flow chart showing the operation of the optical disk apparatus shown in FIG. 55;

FIG. 57 is a block diagram of an optical disk apparatus with one of the optical head apparatuses shown in FIGS. 21, 27, 30, 31, 32, 33, 37, 38, 40A, 43, 44, 50 and 52 according to a twenty-first embodiment;

FIG. 58 is a flow chart showing the operation of the optical disk apparatus shown in FIG. 57;

FIG. 59 is a constitutional view of a binary focus microscope according to a twenty-second embodiment;

FIG. 60 is a partial view of the binary focus microscope shown in FIG. 59 in cases where first and second samples are located at bottoms of sample holders;

FIG. 61 is a constitutional view of a binary focus microscope according to a modification of the twenty-second embodiment; and

FIG. 62 is a constitutional view of an alignment apparatus according to a twenty-third embodiment.

DETAIL DESCRIPTION OF THE PREFERRED EMBODIMENTS

Preferred embodiments of a compound objective lens, an imaging optical system, an optical head apparatus, an optical disk, an optical disk apparatus, a binary focus microscope and an alignment apparatus according to the present invention are described with reference to drawings.

(First Embodiment)

FIG. 4A is a constitutional view of an imaging optical system having a compound objective lens according to a first embodiment of the present invention, a beam of transmitted light not diffracted being converged on a thin type of information medium. FIG. 4B is a constitutional view of the imaging optical system shown in FIG. 4A, a beam of first-order diffracted light being converged on a thick type of information medium. FIG. 5 is a plan view of a hologram lens shown in FIGS. 4A, 4B, a grating pattern of the hologram lens being depicted.

As shown in FIGS. 4A, 4B, an imaging optical system 21 for converging light on a first substrate 22 of a thin type of first information medium 23 (a thickness T1) or a second substrate 24 of a thick type of second information medium 25 (a thickness T2) to form a diffraction-limited converging spot comprises a blazed hologram lens 26 for transmitting a part of incident light

L3 radiated from a light source without any diffraction to form a beam of transmitted light L4 and diffracting a remaining part of the incident light L3 to form a beam of first-order diffracted light L5, and an objective lens 27 for converging the transmitted light L4 on the first information medium 23 or converging the first-order diffracted light L5 on the second information medium 25.

The first information medium 23 represents a prospective optical disk having a high density memory capacity, and the thickness T1 of the first information medium 23 ranges from 0.4 mm to 0.8 mm. The second information medium 25 represents a compact disk or a laser disk appearing on the market now, and the thickness T2 of the second information medium 25 is about 1.2 mm.

The term "convergence" denotes in this specification that divergent light or collimated light is focused to form a diffraction-limited micro spot.

In the above configuration, a part of incident light L3 collimated transmits through the hologram lens 26 without any diffraction, and a beam of transmitted light L4 (that is, a beam of zero-order diffracted light L4) is formed. Thereafter, the transmitted light L4 is converged by the objective lens 27. Also, a remaining part of the incident light L3 is diffracted and refracted by the hologram lens 26, and a beam of first-order diffracted light L5 is formed. In this case, the hologram lens 26 selectively functions as a concave lens for the first-order diffracted light L5, so that the first-order diffracted light L5 diverges from the hologram lens 26. Thereafter, the first-order diffracted light L5 is converged by the objective lens 27.

In cases where the thin type of first information medium 23 is utilized to record or reproduce pieces of information on or from a front surface of the medium 23, as shown in FIG. 4A, the transmitted light L4 is incident on a rear surface of the first information medium 23 and is focused on its front surface by the objective lens 27 to form a diffraction-limited converging spot S1 on the first information medium 23. In contrast, in cases where the thick type of second information medium 25 is utilized to record or reproduce pieces of information on or from a front surface of the medium 25, the diffracted light L5 is incident on a rear surface of the second information medium 25 and is focused on its front surface to form a diffraction-limited converging spot S2 on the second information medium 25. Because the hologram lens 26 functions as a concave lens to diverge the first-order diffracted light L5, the diffraction-limited converging spots S1, S2 are formed even though the thickness T1 of the first information medium 23 differs from the thickness T2 of the second information medium 25. Therefore, a compound objective lens 29 composed of the hologram lens 26 and the objective lens 27 has substantially two focal points.

As shown in FIG. 5, the hologram lens 26 is formed by drawing a grating pattern P1 in a pattern region 26A of a transparent substrate 28 in a concentric circle shape. The pattern region 26A is positioned in a center portion of the transparent substrate 28, and a no-pattern region 26B is positioned in a peripheral portion of the transparent substrate 28 to surround the pattern region 26A. An optical axis of the imaging optical system 21 passes through a central point of the grating pattern P1 and a central axis of the objective lens 27.

In addition, as shown in FIG. 6, the grating pattern P1 of the hologram lens 26 is formed in relief to produce a phase modulation type of hologram lens. That is, blocks which each are composed of a bottom portion and a top portion are concentrically formed in the grating pattern P1. The height H of the relief in the grating pattern P1 is set to:

$$H<\lambda/(n(\lambda)-1), \quad (1)$$

where the symbol λ denotes a wavelength of the incident light L3 and the symbol $n(\lambda)$ denotes a refractive index of the transparent substrate 28 for the incident light L3. In this case, a difference in phase modulation degree between the incident light L3 transmitting through a bottom portion of the grating pattern P1 and the incident light L3 transmitting through a top portion of the grating pattern P1 is lower than 2π radians. Therefore, a diffraction efficiency of the hologram lens 26 for the incident light L3 transmitting through the grating pattern P1 is less than 100% to generate the light L4 transmitting through the grating pattern P1. Also, the incident light L3 transmitting through the no-pattern region 26B is not diffracted. As a result, the intensity of the transmitted light L4 can be sufficient to record or reproduce pieces of information on or from the first information medium 23.

Also, because the intensity of the transmitted light L4 is sufficient over the entire surface of the hologram lens 26, secondary maxima (side lobes) of the transmitted light L4 undesirably occurring in the converging spot S1 can be suppressed. In detail, as an intensity distribution of the transmitted light L4 converged on the converging spot S1 is shown in FIG. 7, a primary maximum (a main lobe) of the transmitted light L4 positioned in a center of the converging spot S1 is utilized to record or reproduce a piece of information on or from the first information medium 23, and secondary maxima positioned around the primary maximum are unnecessary because the secondary maxima deteriorate a recording pit or a reproducing signal formed by the primary maximum.

The grating pattern P1 of hologram lens 26 formed in relief is blazed as shown in FIG. 6, so that the occurrence of minus first-order diffracted light is considerably suppressed. Therefore, the intensity sum of the transmitted light L4 and the first-order diffracted light L5 is maximized. In other words, a utilization efficiency of the incident light L3 is enhanced.

The numerical aperture NA of the objective lens 27 is equal to or more than 0.6. Also, when the transmitted light L4 is converged by the objective lens 27, the diffraction-limited converging spot S1 is formed on the first information medium 23 having a thickness T1.

A diameter of the hologram lens 26 is almost the same as an aperture of the objective lens 27, so that a diameter of the pattern region 26A is smaller than the aperture of the objective lens 27. Because the incident light L3 transmitting through the no-pattern region 26B is not diffracted, not only the light L4 transmitting through the pattern region 26A but also the light L4 transmitting through the no-pattern region 26B are converged on the first information medium 23 by the objective lens 27 having a high numerical aperture. Therefore, the intensity of the transmitted light L4 converged at the converging point S1 can be increased. In contrast to the transmitted light L4, only the incident light L3 transmitting through the pattern region 26A of the hologram lens 26 is changed to the first-order diffracted light L5, and the first-order diffracted light L5 is converged on

the second information medium **25** by the objective lens **27** having substantially a low numerical aperture.

The phase of the light **L4** transmitting through the grating pattern **P1** of the pattern region **26A** is determined by an average value of the phase modulation degrees in the light **L4** transmitting through the bottom and top portions of the grating pattern **P1**. In contrast, because the height of the no-pattern region **26B** is constant, the phase of the light **L4** transmitting through the no-pattern region **26B** is modulated at a phase modulation degree. Therefore, as shown in FIG. **6**, the height of the no-pattern region **26B** is set even with an average height of the grating pattern **P1** to enhance the convergence function of the objective lens **27**.

For example, as shown in FIG. **8A**, in cases where each block of the grating pattern **P1** in the hologram lens **26** shown in FIG. **6** approximates to a step-wise shape composed of four stairs, a first step is etched at a depth $h1+h2$ and a width **W1**, a second step is etched at a depth **h1** and a width **W2**, a third step is etched at a depth **h2** and a width **W2**, and a fourth step is etched at a width **W1**. Therefore, the grating pattern **P1** approximating to the step-wise shape is formed in the pattern region **26A**. Thereafter, a peripheral portion of the transparent substrate **28** is etched by a depth **h1** or **h2** to form the no-pattern region **26B**. Therefore, the height of the no-pattern region **26B** is almost the same as an average height of the pattern region **26A**, so that the phase of the light **L4** transmitting through the pattern region **26A** is almost the same as that of the light **L4** transmitting through the no-pattern region **26B**.

In addition, as shown in FIG. **8B**, an ideal blazed shape of the hologram lens **26** shown in FIG. **6** can approximate to a step-wise shape which is obtained by etching a center portion of the transparent substrate **28** many times. In this case, the height **H0** of the step-wise shape is set to satisfy an equation $H0<\lambda/(n(\lambda)-1)$ so that the difference in phase modulation degree is set to a value lower than 2π radians. Specifically, in cases where the step-wise shape of the hologram lens **26** is composed of a flight of N stairs having the same difference n_0 in level, the difference n_0 in level is set to satisfy an equation $n_0<\lambda/\{(n(\lambda)-1)*N\}$ to set the difference in phase modulation degree of each stairs to a value lower than $2\pi/N$ radians. A peripheral portion of the transparent substrate **28** is etched to set the thickness of the no-pattern region **26B** to a thickness of the pattern region **26A** at one of the N stairs which is not the top stair or the bottom stair. Therefore, the height of the no-pattern region **26B** is almost the same as an average height of the pattern region **26A**, so that the phase of the light **L4** transmitting through the pattern region **26A** is almost the same as that of the light **L4** transmitting through the no-pattern region **26B**.

The grating pattern **P1** of the hologram lens **26** is designed to correct any aberration occurring in the objective lens **27** and the second information medium **25**, so that the first-order diffracted light **L5** transmits through the second information medium **25** having a thickness **T2** and is converged on the medium **25** to form the diffraction-limited converging spot **S2** without any aberration. A method for designing the hologram lens **26** having an aberration correcting function is described.

After the first-order diffracted light **L5** is converged on the second information medium **25**, spherical waves diverge from the converging spot **S2** and transmit through the second substrate **24** and the objective lens **27**. Thereafter, the spherical waves transmit through the transparent substrate **28** and optically interfere with the incident light **L3**. Therefore, an interference pattern is formed by the interference between the spherical waves and the incident light **L3**. The interference pattern can be calculated by subtracting the phase of the spherical waves from an inverted phase obtained by inverting the phase of the incident light **L3**. Accordingly, the grating pattern **P1** of the hologram lens **26** which agrees with the interference pattern calculated can be easily formed according to a computer generated hologram technique.

Accordingly, because the compound objective lens **29** is composed of the objective lens **27** and the hologram lens **26** in which a part of the incident light **L3** is diffracted and refracted, a diffraction-limited converging spot can be reliably formed on an information medium regardless of whether the information medium has a thickness **T1** or a thickness **T2**. Also, two diffraction-limited converging spots can be simultaneously formed on an information medium at difference depths. In other words, the compound objective lens has substantially two focal points.

Also, because the diffraction efficiency of the hologram lens **26** is less than 100% and the intensity of the light **L4** transmitting through the hologram lens **26** is sufficient to record or reproduce information on or from the first information medium **23**, the secondary maxima of the transmitted light **L4** converged on the converging spot **S1** can be suppressed.

Also, because the hologram lens **26** is blazed, the occurrence of minus first-order diffracted light can be considerably suppressed. Therefore, the intensity sum of the transmitted light **L4** and the first-order diffracted light **L5** can be maximized, and a utilization efficiency of the incident light **L3** can be enhanced.

Also, because the hologram lens **26** functions as a lens only for the first-order diffracted light, the position of the converging point **S1** formed by the transmitted light **L4** differs from that of the converging point **S2** formed by the first-order diffracted light **L5** in an optical axis direction. Therefore, when the transmitted light **L4** is converged in focus on an information recording plane of the information medium **23** to record or read a piece of information, the first-order diffracted light **L5** converged on the information medium **23** is out of focus at the information recording plane. In the same manner, when the first-order diffracted light **L5** is converged in focus on an information recording plane of the information medium **25**, the transmitted light **L4** converged on the information medium **25** is out of focus at the information recording plane. Accordingly, when the light **L4** (or **L5**) is converged on the converging spot **S1** (or **S2**) in focus to record or read the information, the light **L5** (or **L4**) not converged on the converging spot **S1** (or **S2**) in focus does not adversely influence on the recording or reading of the information. To reliably prevent the adverse influence on the recording or reading of the information, a difference in the optical axis direction between the converging spots **S1**, **S2** is required to be equal to or more than 50 μm. That is, when the difference is equal to or more than 50 μm, the light **L5** (or **L4**) largely diverges to reduce the intensity of the light **L5** (or **L4**) at an information recording plane when the light **L4** (or **L5**) is converged on the converging spot **S1** (or **S2**) of the information recording plane at a high intensity.

Also, because the thickness T2 of the second information medium **25** representing the compact disk or the laser disk is about 1.2 mm and because the thickness T1 of the first information medium **23** representing a prospective optical disk ranges from 0.4 mm to 0.8 mm, the difference in the optical axis direction between the converging points **S1**, **S2** is required to be equal to or less than 1.0 mm by considering a moving range of an actuator with which the position of the compound objective lens **29** composed of the objective lens **27** and the hologram lens **26** is adjusted according to a focus servo signal. Because the hologram lens **26** functions as a concave lens for the first-order diffracted light, the difference between the converging points **S1**, **S2** can be increased to about 1 mm.

Accordingly, even though the transmitted light **L4** and the first-order diffracted light **L5** are simultaneously converged by the objective lens **27**, no adverse influence is exerted on the recording or reproduction of the information on condition that the difference between the converging points **S1**, **S2** ranges from 50 μm to 1 mm.

Examples of the utilization of the imaging optical system **21** for various types of optical disks are described.

In cases where the image optical system **21** is utilized for an optical disk device in which pieces of information recorded in a thin type of high density optical disk and a thick type of compact disk are exclusively reproduced, the diffraction efficiency of the hologram lens **26** for changing the incident light **L3** to the diffracted light **L5** is set in a range from about 20% to 70%. In this case, the intensity of the transmitted light **L4** converged on the high density optical disk is almost the same as that of the first-order diffracted light **L5** converged on the compact disk. Therefore, the output power of the incident light **L3** can be minimized.

Also, in cases where the image optical system **21** is utilized for an optical disk device in which pieces of information recorded in a thin type of high density optical disk are recorded or reproduced and pieces of information recorded in a thick type of optical disk are exclusively reproduced, the diffraction efficiency of the hologram lens **26** for changing the incident light **L3** to the first-order diffracted light **L5** is set to a value equal to or lower than 30%. In this case, even though a high intensity of transmitted light **L4** is required to record a piece of information on the high density optical disk, the recording of the information can be reliably performed without increasing the intensity of the incident light **L3** because a transmission efficiency of the hologram lens **26** for the incident light **L3** is high. In other words, a utilization efficiency of the incident light **L3** can be enhanced when a piece of information is recorded on the high density optical disk, so that the output power of the incident light **L3** can be minimized.

In the first embodiment, the hologram lens **26** functions as a concave lens for the first-order diffracted light LS. However, it is applicable that a hologram lens **26M** functioning as a convex lens for the first-order diffracted light **L5** be utilized in place of the hologram lens **26**. That is, as shown in FIGS. **9A**, **9B**, the diffracted light **L5** is converged on the first information medium **23** by the objective lens **27** to form the diffraction limited converging spot **S1**, and the transmitted light **L4** is converged on the second information medium **25** by the objective lens **27** to form the diffraction limited converging spot **S2**. In this case, the difference between the converging points **S1**, **S2** is required to be equal to or less than 0.5 mm by considering the moving range of the actuator. However, the occurrence of a chromatic aberration can be prevented in an imaging optical system **21M** in which the hologram lens **26M** functioning as a concave lens for the diffracted light **L5** is utilized. The achromatization function in the imaging optical system is described in detail.

When a focal length of the hologram lens **26M** for the incident light **L3** having a wavelength λ is represented by f_{H0} and another focal length of the hologram lens **26M** for the incident light **L3** having a wavelength λ_1 is represented by f_{H1}, an equation (2) is satisfied.

$$f_{H1}=f_{H0}\times\lambda_0/\lambda_1 \tag{2}$$

The focal length f_h of the hologram lens **22** is shortened as the wavelength λ of the incident light **L3** becomes longer. Also, when a refractive index of the objective lens **27** for the incident light **L3** having a wavelength λ_0 is represented by $n(\lambda_0)$ and another refractive index of the objective lens **27** for the incident light **L3** having a wavelength λ_1 is represented by $n(\lambda_1)$, a focal length $f_D(\lambda)$ of the objective lens **27** for the incident light **L3** having a wavelength λ is formulated by an equation (3).

$$f_D(\lambda_1)=f_D(\lambda_0)\times(n(\lambda_0)-1)/(n(\lambda_1)-1) \tag{3}$$

The focal length $f_D(\lambda)$ of the objective lens **27** is lengthened as the wavelength λ of the incident light **L3** becomes longer. That is, the dependence of the focal length $f_D(\lambda)$ on the wavelength λ in the objective lens **27** is opposite to that of the focal length f_H on the wavelength λ in the hologram lens **26M**. Therefore, a condition that the compound objective lens **29M** composed of the objective lens **27** and the hologram lens **26M** functions as an achromatic lens is formulated by an equation (4).

$$1/f_{HO}+1/f_D(\lambda_o)=1/f_{H1}+1/f_D(\lambda_1)= \tag{4}$$
$$1/(f_{HO}\times\lambda_o/\lambda_1)+(n(\lambda_1)-1)/\{f_D(\lambda_o)\times(n(\lambda_o)-1)\}$$

Accordingly, because the dependence of the focal length $f_D(\lambda)$ on the wavelength λ in the objective lens **27** is opposite to that in the hologram lens **22**, the compound objective lens **29M** having an achromatic function can be formed by the combination of the lenses **26M**, **27**, and the occurrence of the chromatic aberration can be prevented. Also, even though the equation (4) is not strictly satisfied, the occurrence of the chromatic aberration can be largely suppressed.

Also, a curvature of the objective lens **27** can be small because the hologram lens **26M** functions as a convex lens for the first-order diffracted light **L5**. Also, because the hologram lens **26M** is a plane type of element, a lightweight type of compound objective lens having an achromatic function can be made in large scale manufacture. A principal of the achromatization has been proposed in a first literature (D. Faklis and H. Morris, Photonics Spectra(1991), November p.205 & December p.131), a second literature (M. A. Gan et al., S.P.I.E. (1991), Vol. 1507, p.116), and a third literature (P. Twardowski and P. Meirueis, S.P.I.E. (1991), Vol. 1507, p.55).

(Second Embodiment)

FIG. **10**A is a constitutional view of an imaging optical system having a compound objective lens according to a second embodiment of the present invention, a beam of transmitted light not diffracted being converged on a thin type of information medium. FIG. **10**B is a constitutional view of the imaging optical system shown in FIG. **10**A, a beam of first-order diffracted light being converged on a thick type of information medium.

As shown in FIGS. **10**A, **10**B, an imaging optical system **31** for converging light on the first substrate **22** of the first information medium **23** (the thickness T1) or the second substrate **24** of the second information medium **25** (the thickness T2) to form a diffraction-limited converging spot, comprises a blazed hologram lens **32** for transmitting a part of incident light L3 without any diffraction to form a beam of transmitted light L4 and diffracting a remaining part of incident light L3 to form a beam of first-order diffracted light LS, and the objective lens **27** for converging the transmitted light L4 on the first information medium **23** or converging the first-order diffracted light L5 on the second information medium **25**.

The hologram lens **32** is formed by drawing a grating pattern P2 in a pattern region **32**A of the transparent substrate **28** in a concentric circle shape. The pattern region **32**A is positioned in a center portion of the transparent substrate **28**. An diameter of the grating pattern P2 is equal to or larger than an aperture of the objective lens **27**. Also, a diffraction efficiency of the hologram lens **32** for the incident light L3 transmitting through the grating pattern P2 is less than 100% in the same manner as in the first embodiment, so that the intensity of the transmitted light L4 is sufficient to record or reproduce a piece of information on or from the first information medium **23**.

In addition, as shown in FIG. **11**, the diffraction efficiency in a central portion of the pattern region **32**A is high, and the diffraction efficiency is gradually decreased toward an outer direction of the pattern region **32**A. In other words, in cases where the grating pattern P2 of the hologram lens **32** is formed in relief, the height H of the relief in the grating pattern P2 is gradually lowered toward the outer direction of the pattern region **32**A. Or, in cases where an ideal blazed shape of the hologram lens **26** approximates to a step-wise shape, each block of the grating pattern P2 positioned in the central portion of the transparent substrate **28** is formed in a step-wise shape shown in FIG. **12**A in which an inclined angle θ_1 of stairs is large and a relationship W1>W2 between a first etching width W1 and a second etching width W2 is satisfied, and the grating pattern P2 formed in the step-wise shape shown in FIG. **12**A is gradually changed by decreasing the first etching width W1 and increasing the second etching width W2 toward the outer direction of the pattern region **32**A while the height H of the grating pattern P2 is gradually decreased. Therefore, each block of the grating pattern P2 positioned in a peripheral portion of the transparent substrate **28** is formed in a step-wise shape shown in FIG. **12**B in which an inclined angle θ_2 of stairs is small and a relationship W1<W2 between the etching widths is satisfied. Also, each block of the grating pattern P2 positioned in a middle portion between the central and peripheral portions is formed in a step-wise shape shown in FIG. **12**C in which the etching widths W1, W2 is the same.

In the above configuration of the imaging optical system **31**, a part of the incident light L3 transmits through the hologram lens **32** without any diffraction to form a beam of transmitted light L4, and the transmitted light L4 is converged by the objective lens **27**. Also, a remaining part of the incident light L3 is diffracted and refracted by the hologram lens **32**. In this case, the hologram lens **32** functions as a concave lens for the incident light L3, so that a first-order diffracted light L5 diverges from the hologram lens **32**. Thereafter, the first-order diffracted light L5 is converged by the objective lens **27**.

In cases where the thin type of first information medium **23** is utilized to record or reproduce pieces of information on or from a front surface of the medium **23**, as shown in FIG. **10**A, the transmitted light L4 is incident on a rear surface of the first information medium **23** and is focused on its front surface by the objective lens **27** to form a diffraction-limited converging spot S3 on the first information medium **23**. In this case, because the diffraction efficiency in the central portion of the grating pattern P2 is high and because the diffraction efficiency is gradually decreased toward the outer direction of the grating pattern P2, a diffraction probability of the incident light L3 is lowered in the peripheral portion of the grating pattern P2. Therefore, the light L4 transmits through the objective lens **27** on condition that the numerical aperture NA of the objective lens **27** is high.

In contrast, in cases where the thick type of second information medium **25** is utilized to record or reproduce pieces of information on or from a front surface of the medium **25**, the diffracted light L5 is incident on a rear surface of the second information medium **25** and is focused on its front surface to form a diffraction-limited converging spot S5 on the second information medium **25**. In this case, because the hologram lens **32** functions as a concave lens to diverge the first-order diffracted light LS, the diffraction-limited converging spots S3, S4 are formed even though the thickness T1 of the first information medium **23** differs from the thickness T2 of the second information medium **25**. Therefore, a compound objective lens **34** composed of the hologram lens **32** and the objective lens **27** has substantially two focal points.

Accordingly, because the light L4 transmits through the objective lens **27** on condition that the numerical aperture NA of the objective lens **27** is high, the intensity of the transmitted light L4 converged on the first information medium **23** can be high.

Also, in cases where the incident light L3 is radiated from a semiconductor laser, a far field pattern of the incident light L3 is distributed in a Gaussian distribution as shown in FIG. **13**A. Therefore, because the diffraction efficiency is gradually decreased toward the outer direction of the grating pattern P2, a far field pattern of the transmitted light L4 is distributed in a gently-sloping shape as shown in FIG. **13**B. In contrast to the second embodiment, because the incident light L3 is not diffracted in the no-pattern region **26***b* of the hologram lens **26** in the first embodiment, the intensity of the transmitted light L4 is suddenly increased at the peripheral portion of the hologram lens **26**.

Accordingly, secondary maxima of the transmitted light L4 converged on the converging spot S3 can be moreover suppressed in the second embodiment as

compared with in the first embodiment. That is, the recording and reproducing of the information can be performed without any deterioration of the information by utilizing the imaging optical system **31**.

In addition, in cases where the first-order diffracted light **L5** is converged on the second information medium **25** to form the diffraction-limited converging spot **S4**, a numerical aperture of the objective lens **27** for the first-order diffracted light **L5** is low because the diffraction efficiency of the hologram lens **32** is decreased toward an outer direction of the pattern region **32A**. As a result, the intensity of the first-order diffracted light **L5** becomes lowered. In cases where the diffraction efficiency of the hologram lens **32** is heightened to increase the intensity of the first-order diffracted light LS, the intensity of the transmitted light **L4** at its inner beam portion is largely decreased, and secondary maxima (or side lobes) of the transmitted light **L4** at the converging spot **S3** is undesirably increased. Therefore, the incident light **L3** of which the far field pattern is distributed in the Gaussian distribution is radiated to the hologram lens **32** to increase the intensity of the first-order diffracted light **L5** without any increase of the second maxima. In detail, as shown in FIG. **14A**, the incident light **L3** distributed not only in a central portion of the Gaussian distribution but also in a peripheral portion of the Gaussian distribution transmits through the hologram lens **32** and is refracted by the objective lens **27** because the diameter of the grating pattern **P2** is equal to or larger than the aperture of the objective lens **27**. Therefore, a numerical aperture NA of the objective lens **27** at a light source side for the incident light **L3** becomes higher than that in the first embodiment, and the diffraction efficiency of the hologram lens **32** is heightened. As a result, the intensity of the first-order diffracted light **L5** converged on the second information medium **25** can be increased, as shown in FIG. **14B**. Also, because the intensity of the incident light **L3** at the peripheral portion of the Gaussian distribution is low and because the diffraction efficiency of the hologram lens **32** is increased toward the inner direction of the grating pattern region **32A**, intensity of the transmitted light **L4** is distributed in a gently-sloping shape as shown in FIG. **14C**. Accordingly, secondary maxima of the transmitted light **L4** at the converging spot **S3** can be suppressed.

Examples of the utilization of the imaging optical system **31** for various types of optical disks are described.

In cases where the image optical system **31** is utilized for an optical disk device in which pieces of information recorded in a thin type of high density optical disk and a thick type of compact disk are exclusively reproduced, the diffraction efficiency of the hologram lens **32** for the incident light **L3** is set in a range from about 20% to 70%. In this case, the intensity of the transmitted light **L4** converged on the high density optical disk is almost the same as that of the first-order diffracted light **L5** converged on the compact disk. Therefore, the output power of the incident light **L3** can be minimized.

Also, in cases where the image optical system **31** is utilized for an optical disk device in which pieces of information recorded in a thin type of high density optical disk are recorded or reproduced and pieces of information recorded in a thick type of optical disk are exclusively reproduced, the diffraction efficiency of the hologram lens **32** for the incident light **L3** is set to a value equal to or lower than 30%. In this case, even though a high intensity of transmitted light **L4** is required to record a piece of information on the high density optical disk, the recording of the information can be reliably performed without increasing the intensity of the incident light **L3** because a transmission efficiency of the hologram lens **32** for the incident light **L3** is high. In other words, a utilization efficiency of the incident light **L3** can be enhanced when a piece of information is recorded on the high density optical disk, so that the output power of the incident light **L3** can be minimized.

In the second embodiment, the grating pattern **P2** positioned in the central portion of the transparent substrate **28** is gradually changed toward the outer direction of the pattern region **32A** from the step-wise shape shown in FIG. **12A** to the step-wise shape shown in FIG. **12B** through the step-wise shape shown in FIG. **12C**. However, because the occurrence of unnecessary diffracted light such as minus first-order diffracted light can be effectively prevented in the middle portion of the transparent substrate **28** in which the grating pattern **P2** is formed in the step-wise shape shown in FIG. **12C**, it is preferred that the middle portion occupy a large part of the pattern region **32A** of the hologram lens **32**. In this case, the intensity sum of the transmitted light **L4** and the first-order diffracted light **L5** can be maximized, so that a utilization efficiency of the incident light **L3** can be enhanced.

Also, because the first etching width **W1** of the grating pattern **P2** is gradually decreased toward the outer direction of the pattern region **32A**, it is applicable that the grating pattern **P2** formed in the step-wise shape shown in FIG. **12B** be changed to a step-wise shape shown in FIG. **12D** when the first width **W1** is decreased to a value lower than about 1 μm. That is, a flight of four stairs shown in FIG. **12B** is changed to a flight of two stairs. In this case, the grating pattern **P2** formed in the step-wise shape shown in FIG. **12D** can be easily made. In addition, in cases where a height **H4** of the grating pattern **P2** formed in the step-wise shape shown in FIG. **12D** is moreover decreased toward the outer direction of the pattern region **32A**, it is preferred that the grating pattern **P2** be formed in a step-wise shape shown in FIG. **12E**. That is, a third etching width **W3** is gradually decreased toward the outer direction of the pattern region **32A** while decreasing a height **H5** of the grating pattern **P2**. Therefore, the diffraction efficiency of the hologram lens **32** can be gradually decreased toward the outer direction of the pattern region **32A** without any manufacturing difficulty of the grating pattern **P2**.

In addition, as shown in FIG. **15A**, it is applicable that a hologram lens **33** be formed, in place of the hologram lens **32**, by placing the grating pattern **P1** of the pattern region **32A** in a central portion of the transparent substrate **28** and placing four types of diffraction regions **33A**, **33B**, **33C** and **33D** which surround the grating pattern **P1**. A part of the incident light **L3** transmitting through each of the diffraction regions **33A** to **33D** is diffracted to control a transmission efficiency of the hologram lens **33**. In this case, the intensity of the transmitted light **L4** at its peripheral portion is decreased, so that secondary maxima occurring in the converging spot **S3** can be suppressed. Also, it is applicable that the grating pattern **P1** of the hologram be replaced with the grating pattern **P2**. Also, it is applicable that grating directions of the diffraction regions **33A** to **33D** differ from each other. In this case, even though

the first-order diffracted light L5 diffracted in the diffraction region 33A is, for example, incident on the diffraction region 33c after the diffracted light L5 is reflected by the second information medium 25, the diffracted light L5 again diffracted in the diffraction region 33c does not pass in parallel to the optical axis. Therefore, in cases where a piece of information read from the second information medium 25 is detected in a detector to reproduce the information, the first-order diffracted light L5 diffracted in the diffraction regions 33A to 33D is not detected by the detector as stray light. Accordingly, the reproduction of the information does not deteriorate.

Also, as shown in FIG. 15B, it is applicable that the hologram lens 32 function as a convex lens. In this case, the diffracted light L5 is converged on the first information medium 23, and the transmitted light L4 is converged on the second information medium 25, as shown in FIG. 15C.

(Third Embodiment)

FIG. 16A is a constitutional view of an imaging optical system having a compound objective lens according to a third embodiment of the present invention, a beam of first-order diffracted light being converged on a thin type of information medium. FIG. 16B is a constitutional view of the imaging optical system shown in FIG. 16A, a beam of transmitted light not diffracted being converged on a thick type of information medium.

As shown in FIGS. 16A, 16B, an imaging optical system 41 for converging light on the first substrate 22 of the first information medium 23 (the thickness T1) or the second substrate 24 of the second information medium 25 (the thickness T2) to form a diffraction-limited converging spot comprises a blazed hologram lens 42 for transmitting a part of incident light L3 without any diffraction to form a beam of transmitted light L4 and diffracting a remaining part of incident light L3 to form a beam of first-order diffracted light L6, and the objective lens 27 for converging the first-order diffracted light L6 on the first information medium 23 or converging the transmitted light L4 on the second information medium 25.

The hologram lens 42 is formed by drawing a grating pattern P3 in a pattern region 42A of the transparent substrate 28 in a concentric circle shape. The pattern region 42A is positioned in a center portion of the transparent substrate 28. An diameter of the grating pattern P3 is equal to or larger than an aperture of the objective lens 27. Also, a diffraction efficiency of the hologram lens 42 for the incident light L3 transmitting through the grating pattern P3 is less than 100% in the same manner as in the first embodiment, so that the intensity of the transmitted light L4 is sufficient to record or reproduce a piece of information on or from the second information medium 25.

In addition, as shown in FIG. 17, the diffraction efficiency of the hologram lens 42 is high in a peripheral portion of the pattern region 42A, and the diffraction efficiency is gradually decreased toward an inner direction of the pattern region 42A. In other words, in cases where the grating pattern P3 of the hologram lens 42 is formed in relief, the height H of the relief in the grating pattern P3 is gradually lowered toward the inner direction of the pattern region 42A. Or, in cases where an ideal blazed shape of the hologram lens 26 approximates to a step-wise shape, each pitch of the grating pattern P3 positioned in the peripheral portion of the transparent substrate 28 is formed in a step-wise shape shown in FIG. 12A in which the inclined angle θ_1 of stairs is large and the relationship W1>W2 between the first and second etching widths W1, W2 is satisfied, and the grating pattern P3 formed in the step-wise shape shown in FIG. 12A is gradually changed by decreasing the first etching width W1 and increasing the second etching width W2 toward the inner direction of the pattern region 42A while the height H of the grating pattern P3 is gradually decreased. Therefore, each pitch of the grating pattern P3 positioned in a central portion of the transparent substrate 28 is formed in a step-wise shape shown in FIG. 12B in which the inclined angle θ_2 of stairs is small and the relationship W1<W2 is satisfied. Also, each pitch of the grating pattern P3 positioned in a middle portion between the central and peripheral portions is formed in a step-wise shape shown in FIG. 12C in which the etching widths W1, W2 is the same.

In the above configuration of the imaging optical system 41, as shown in FIG. 16B, a part of the incident light L3 transmits through the hologram lens 42 without any diffraction to form a beam of transmitted light L4, and the transmitted light L4 is converged by the objective lens 27. Also, a remaining part of the incident light L3 is diffracted by the hologram lens 42 to form a beam of first-order diffracted light L6. In this case, the hologram lens 42 functions as a convex lens for the incident light L3, so that a first-order diffracted light L6 formed in the hologram lens 42 converges. Thereafter, the diffracted light L6 is converged by the objective lens 27.

In cases where the thin type of first information medium 23 is utilized to record or reproduce pieces of information on or from a front surface of the medium 23, as shown in FIG. 16A, the diffracted light L6 is incident on a rear surface of the first information medium 23 and is focused on its front surface to form a diffraction-limited converging spot S5 on the first information medium 23. In contrast, in cases where the thick type of second information medium 25 is utilized to record or reproduce pieces of information on or from a front surface of the medium 25, the transmitted light L4 is incident on a rear surface of the second information medium 25 and is focused on its front surface to form a diffraction-limited converging spot S6 on the second information medium 25.

In this case, because the hologram lens 42 functions as a convex lens to converge the diffracted light L6, the diffraction-limited converging spots S5, S6 are formed even though the thickness T1 of the first information medium 23 differs from the thickness T2 of the second information medium 25. Therefore, a compound objective lens 43 composed of the hologram lens 42 and the objective lens 27 has substantially two focal points.

Also, because the hologram lens 42 functions as a convex lens for the diffracted light L6, the diffracted light L6 transmits through the objective lens 27 on condition that the numerical aperture NA of the objective lens 27 is substantially high.

In addition, because the diffraction efficiency in the peripheral portion of the grating pattern P3 is high and because the diffraction efficiency is gradually decreased toward the inner direction of the grating pattern P3, a diffraction probability of the incident light L3 is higher in the peripheral portion of the grating pattern P3.

The grating pattern P3 of the hologram lens 42 is designed to correct any aberration occurring in the

objective lens 27 and the first information medium 23, so that the diffracted light L6 transmits through the first information medium 23 having the thickness T1 and is converged on the medium 23 to form the diffraction-limited converging spot S5 without any aberration. A method for designing the hologram lens 42 having an aberration correcting function is described.

After the diffracted light L6 is converged on the first information medium 23, spherical waves diverge from the converging spot S5 and transmit through the first substrate 22 and the objective lens 27. Thereafter, the spherical waves transmit through the transparent substrate 28 and optically interfere with the incident light L3. Therefore, an interference pattern is formed by the interference between the spherical waves and the incident light L3. The interference pattern can be calculated by adding the phase of the spherical waves to an inverted phase obtained by inverting the phase of the incident light L3. Accordingly, the grating pattern P3 of the hologram lens 42 which agrees with the interference pattern calculated can be easily formed according to a computer generated hologram technique.

Accordingly, because the hologram lens 42 functions as a convex lens for the first-order diffracted light L6, a curvature of the objective lens 27 can be lowered. Also, a glass material having a high refractive index is not required to produce the objective lens 27.

Also, because the first-order diffracted light L6 formed in the hologram lens 42 converges before the diffracted light L6 is incident on the objective lens 27, the distance in an optical axis direction between the converging spots S5, S6 can be lengthened to about 1 mm. Therefore, even though the transmitted light L4 (or the first-order diffracted light L6) is converged on the converging spot S6 (or S5) in focus to record or read a piece of information, the light L6 (or L4) is not converged on the converging spot S6 (or S5) in focus to reduce the intensity of the light L6 (or L4) at the converging spot S6 (or S5). Accordingly, no adverse influence is exerted on the recording or reproduction of the information

Also, because the hologram lens 42 functions as a convex lens for the first-order diffracted light L6, the occurrence of a chromatic aberration can be prevented in the imaging optical system 41. In detail, the focal length of the hologram lens 42 is shortened as the wavelength of the incident light L3 becomes longer. In contrast, the focal length of the objective lens 27 is lengthened as the wavelength of the incident light L3 becomes longer. That is, the dependence of the focal length on the wavelength in the objective lens 27 is opposite to that of the focal length on the wavelength in the hologram lens 42. Therefore, the compound objective lens 43 having an achromatic function can be formed by the combination of the lenses 27, 42, and the occurrence of the chromatic aberration can be prevented.

Also, because the hologram lens 42 is a plane type of element, a lightweight type of compound objective lens can be made in large scale manufacture.

Also, because the diffraction efficiency of the hologram lens 42 is gradually decreased toward an inner direction of the pattern region 42A, the numerical aperture of the objective lens 27 for the first-order diffracted light L6 becomes substantially enlarged. Therefore, the intensity of the first-order diffracted light L6 can be enlarged to record or reproduce a piece of information on or from the first information medium 23.

Also, in cases where the incident light L3 is radiated from a semiconductor laser, a far field pattern of the incident light L3 is distributed in a Gaussian distribution as shown in FIG. 13A. Therefore, because the diffraction efficiency of the hologram lens 42 is gradually decreased toward the inner direction of the grating pattern P2, a far field pattern of the first-order diffracted light L6 is distributed in a gently-sloping shape. Accordingly, secondary maxima of the first-order diffracted light L6 converged on the converging spot S5 can be moreover suppressed in the third embodiment as compared with in the first embodiment. That is, the recording and reproducing of the information can be performed without any deterioration of the information by utilizing the imaging optical system 41.

In addition, in cases where the transmitted light L4 is converged on the second information medium 25 to form the diffraction-limited converging spot S6, a numerical aperture of the objective lens 27 for the transmitted light L4 is low because the diffraction efficiency of the hologram lens 42 is increased toward an outer direction of the grating pattern 42A. As a result, the intensity of the transmitted light L4 becomes lowered. In cases where a transmission efficiency of the hologram lens 42 is heightened to increase the intensity of the transmitted light L4, the intensity of the first-order diffracted light L6 at its inner beam portion is largely decreased, and secondary maxima (or side lobes) of the first-order diffracted light L6 at the converging spot S6 is undesirably increased. Therefore, the incident light L3 of which the far field pattern is distributed in the Gaussian distribution is radiated to the hologram lens 42 to increase the intensity of the transmitted light L4 without any increase of the second maxima. In detail, as shown in FIG. 18A, the incident light L3 distributed in not only a central portion of the Gaussian distribution but also a peripheral portion of the Gaussian distribution transmits through the hologram lens 42 and is refracted by the objective lens 27 because the diameter of the grating pattern P3 is equal to or larger than the aperture of the objective lens 27. Therefore, a numerical aperture NA of the objective lens 27 at a light source side for the incident light L3 becomes higher than that in the first embodiment, and a transmission efficiency of the hologram lens 42 is heightened. As a result, the intensity of the transmitted light L4 converged on the second information medium 25 can be increased, as shown in FIG. 18B. Also, because the intensity of the incident light L3 at the peripheral portion of the Gaussian distribution is low and because the diffraction efficiency of the hologram lens 42 is decreased toward the inner direction of the grating pattern 42A, the first-order diffracted light L6 is distributed in a gently-sloping shape as shown in FIG. 18C. Accordingly, secondary maxima of the first-order diffracted light L6 at the converging spot S5 can be suppressed.

Examples of the utilization of the imaging optical system 41 for various types of optical disks are described.

In cases where the image optical system 41 is utilized for an optical disk device in which pieces of information recorded in a thin type of high density optical disk and a thick type of compact disk are exclusively reproduced, the diffraction efficiency of the hologram lens 42 for the incident light L3 is set in a range from about 20% to 70%. In this case, the intensity of the transmitted light L4 converged on the compact disk is almost the same as that of the first-order diffracted light L6

converged on the high density optical disk. Therefore, the output power of the incident light L3 can be minimized.

Also, in cases where the image optical system **41** is utilized for an optical disk device in which pieces of information recorded in a thin type of high density optical disk are recorded or reproduced and pieces of information recorded in a thick type of optical disk are exclusively reproduced, the diffraction efficiency of the hologram lens **42** for the incident light L3 is set to a value equal to or higher than 55%. In this case, even though a high intensity of the first-order diffracted light L6 is required to record a piece of information on the high density optical disk, the recording of the information can be reliably performed without increasing the intensity of the incident light L3 because the diffraction efficiency of the hologram lens **42** for changing the incident light L3 to the first-order diffracted light L6 is high. In other words, a utilization efficiency of the incident light L3 can be enhanced when a piece of information is recorded on the high density optical disk, so that the output power of the incident light L3 can be minimized. Also, because the diffraction efficiency of the hologram lens **42** is gradually decreased toward an inner direction of the pattern region **42A**, the numerical aperture of the objective lens **27** for the first-order diffracted light L6 becomes substantially enlarged. Therefore, the intensity of the first-order diffracted light L6 can be enlarged to record or reproduce a piece of information on or from the high density optical disk.

In the third embodiment, the grating pattern P3 positioned in the pattern region **42A** of the transparent substrate **28** is gradually changed toward the outer direction of the pattern region **42A** from the step-wise shape shown in FIG. **12B** to the step-wise shape shown in FIG. **12A** through the step-wise shape shown in FIG. **12C** while increasing the height H of the grating pattern P3. However, because the occurrence of unnecessary diffracted light such as minus first-order diffracted light can be effectively prevented in the middle portion of the transparent substrate **28** in which the grating pattern P3 is formed in the step-wise shape shown in FIG. **12C**, it is preferred that the middle portion occupy a large part of the pattern region **42A** of the hologram lens **42**. In this case, the intensity sum of the transmitted light L4 and the first-order diffracted light L6 can be maximized, so that a utilization efficiency of the incident light L3 can be enhanced.

Also, because the first etching width W1 of the grating pattern P3 is gradually decreased toward the inner direction of the pattern region **42A**, it is applicable that the grating pattern P3 formed in the step-wise shape shown in FIG. **12B** be changed to a step-wise shape shown in FIG. **12D** when the first width W1 is decreased to a value lower than about 1 μm. In this case, the grating pattern P3 formed in the step-wise shape shown in FIG. **12D** can be easily made. In addition, in cases where a height H4 of the grating pattern P3 formed in the step-wise shape shown in FIG. **12D** is moreover decreased toward the inner direction of the pattern region **42A**, it is preferred that the grating pattern P3 be formed in a step-wise shape shown in FIG. **12E**. In this case, a third etching width W3 is gradually decreased toward the inner direction of the pattern region **42A** while decreasing a height H5 of the grating pattern P3. Therefore, the diffraction efficiency of the hologram lens **42** can be gradually decreased toward the inner direction of the pattern region **42A** without any manufacturing difficulty of the grating pattern P3.

In the first to third embodiments of the image optical systems **21**, **31** and **41**, the grating patterns P1, P2 and P3 of the hologram lenses **26**, **32** and **42** are respectively formed on a front side of the transparent substrate **28** not facing the objective lens **27**. Therefore, a beam of light reflected at the front side of the transparent substrate **28** does not adversely influence as stray light on the recording or reproduction of the information. In detail, because the reflected light is diffracted by the hologram lens, the reflected light is scattered. Also, even though the first-order diffracted light L5 or L6 is reflected at a reverse side of the transparent substrate **28**, the diffracted light reflected is again diffracted by the hologram lens and is scattered. Therefore, the light reflected at the front or reverse side of the hologram lens does not adversely influence on the recording or reproduction of the information.

However, in cases where an anti-reflection film is coated on a front side of the hologram lens **28** at which the grating pattern is not formed, it is applicable that the grating patterns P1, P2 and P3 of the hologram lenses **26**, **32** and **42** be respectively formed on a reverse side of the transparent substrate **28** facing the objective lens **27**. In this case, because the first-order diffraction light L5, L6 is not refracted at the front side of the hologram lens **28**, the design of the image optical systems **21**, **31** and **41** can be simplified.

Also, in the first to third embodiments, the grating patterns P1, P2 and P3 of the hologram lenses **26**, **32** and **42** are respectively formed in relief to produce a phase modulation type of hologram lens. However, as is described in Provisional Publication No. 189504/86 (S61-189504) and Provisional Publication No. 241735/88 (S63-241735), the phase modulation type of hologram lens can be produced by utilizing a liquid crystal cell. Also, the phase modulation type of hologram lens can be produced by utilizing a birefringece material such as lithium niobate. For example, the phase modulation type of hologram lens can be produced by proton-exchanging a surface part of a lithium niobate substrate.

(Fourth Embodiment)

Also, in the first to third embodiments, the compound objective lens **29**, **34** or **43** having two focal points is composed of the objective lens **27** and the hologram lens **26**, **32** or **42**. However, as a compound objective lens according to a fourth embodiment is shown in FIG. **19A**, it is preferred that each of the hologram lenses **26**, **32** and **42** and the objective lens **27** be unified with a packaging means **44** to form a compound objective lens **45** in which a relative position between each of the hologram lenses **26**, **32** and **42** and the objective lens **27** is fixed. In this case, the transmitted light L4 and the first-order diffracted light LS, L6 can be easily converged on the first or second information medium **23**, **25** by adjusting the position of the packing means **44** with an actuator. Also, as another compound objective lens according to a modified fourth embodiment is shown in FIG. **19B**, it is preferred that each of the grating patterns P1, P2 and P3 be directly drawn on a curved side of the objective lens **27** facing a light source side to form a compound objective lens **46** in which each of the hologram lenses **26**, **32** and **42** is integrally formed with the objective lens **27**.

Accordingly, the central axis of the objective lens **27** can always agree with that of each of the hologram

lenses 26, 32 and 42, so that abaxial aberrations of each of the hologram lenses 26, 32 and 42 such as a coma aberration and an astigmatic aberration occurring in the first-order diffracted light can be prevented in the fourth embodiment.

(Fifth Embodiment)

Also, as a compound objective lens according to a fifth embodiment is shown in FIG. 20, it is preferred that each of the grating patterns P1, P2 and P3 be directly drawn on a side of the objective lens 27 facing the information medium 23 or 25 to form a compound objective lens 47 in which each of the hologram lenses 26, 32 and 42 is integrally formed with the objective lens 27. In this case, a curvature at the side of the objective lens 27 can be small or in a plane shape. Therefore, each of the grating patterns P1, P2 and P3 can be made at a low cost. Also, in cases where an aberration is caused by tilting the hologram lens from the optical axis, the aberration can be prevented by fixing the hologram lens and a light source of the incident light L3 on the same base.

(Sixth Embodiment)

An optical head apparatus with one of the compound objective lenses 29, 29M, 34, 43, 45, 46 and 47 shown in the first to fifth embodiments is described with reference to FIGS. 21 to 26 according to a sixth embodiment of the present invention. X, Y and Z co-ordinates shown in FIGS. 21 to 26 are utilized in common.

FIG. 21 is a constitutional view of an optical head apparatus according to a sixth embodiment.

As shown in FIG. 21, an optical head apparatus 51 for recording or reproducing pieces of information on or from the information medium 23 or 25, comprises a light source 52 such as a semiconductor laser for radiating the incident light L3, a collimator lens 53 for collimating the incident light L3, a beam splitter 54 for transmitting the incident light L3 on an outgoing optical path and reflecting a beam of transmitted light L4R formed by reflecting the transmitted light L4 on the information medium 23 or 25 or a beam of diffracted light L5R (or L6R) formed by reflecting the diffracted light L5 (or L6) on the information medium 23 or 25 on an incoming optical path, the compound objective lens 29 (or 29M, 34, 43, 45, 46 or 47) composed of the hologram lens 26 (or 26M, 32, 33 or 42) and the objective lens 27, a converging lens 55 for converging the transmitted light L4R or the diffracted light L5R reflected by the beam splitter 54, a wavefront changing device 56 such as a hologram for changing a wavefront of the transmitted light L4R or the diffracted light L5R to form a plurality of converging spots of the transmitted light L4R or the diffracted light L5R, a photo detector 57 for detecting intensities of the converging spots of the transmitted light L4R or the diffracted light L5R of which the wavefront is changed by the wavefront changing device 56 to obtain an information signal recorded on the information medium 23 or 25 and servo signals such as a focus error signal and a tracking error signal, and an actuating unit 58 for moving the compound objective lens composed of the hologram lens 26 and the objective lens 27 according to the servo signals.

In the above configuration, a beam of incident light L3 radiated from the light source 52 is collimated in the collimator lens 53 and transmits through the beam splitter 54. Thereafter, a part of the incident light L3 transmits through the compound objective lens 29 without any diffraction, and a remaining part of the incident light L3 is diffracted.

Thereafter, in cases where a piece of information is recorded or reproduced on or from the first information medium 23, the transmitted light L4 is converged on the first information medium 23 to form the first converging spot S1. That is, the transmitted light L4 is incident on a rear surface of the first information medium 23, and the first converging spot S1 is formed on a front surface of the first information medium 23. Thereafter, a beam of transmitted light L4R reflected at the front surface of the first information medium 23 passes through the same optical path in the reverse direction. That is, a part of the transmitted light L4R again transmits through the compound objective lens 29 without any diffraction and is reflected by the beam splitter 54. In this case, the transmitted light L4R is collimated. Thereafter, the transmitted light L4R is converged by the converging lens 55, and the wavefront of a large part of the transmitted light L4R is changed to form a plurality of converging spots on the photo detector 57. Thereafter, the intensities of the converging spots of the transmitted light L4R are detected in the photo detector 57. Therefore, an information signal and servo signals such as a focus error signal and a tracking error signal are obtained. The actuating unit 58 are operated according to the servo signals to move the compound objective lens 29 at high speed, so that the transmitted light L4 is converged on the first information medium 23 in focus.

Also, in cases where a piece of information is recorded or reproduced on or from the second information medium 25, the diffracted light L5 is converged on the second information medium 25 to form the second converging spot S2. That is, the diffracted light L5 is incident on a rear surface of the second information medium 25, and the second converging spot S2 is formed on a front surface of the second information medium 25. Thereafter, a beam of diffracted light L5R reflected at the front surface of the second information medium 25 passes through the same optical path in the reverse direction. That is, a part of the diffracted light L5R is again diffracted by the hologram lens 26 and is reflected by the beam splitter 54. In this case, the diffracted light L5R is collimated. Thereafter, the diffracted light L5R is converged by the converging lens 55, and the wavefront of a large part of the diffracted light L5R is changed to form a plurality of converging spots on the photo detector 57. In this case, the diffracted light L5R incident on the converging lens 55 is collimated in the same manner as the transmitted light L4R incident on the converging lens 55, the converging spots of the diffracted light L5R are formed at the same positions as those of the transmitted light L4R. Thereafter, the intensities of the converging spots of the diffracted light L5R are detected in the photo detector 57. Therefore, an information signal and servo signals such as a focus error signal and a tracking error signal are obtained. The actuating unit 58 are operated according to the servo signals to move the compound objective lens 29 at high speed, so that the diffracted light L5 is converged on the second information medium 25 in focus.

In this case, because the transmitted light L4R again transmits through the compound objective lens without any diffraction and the diffracted light L5R is again diffracted by the hologram lens 26, the outgoing optical path agrees with the incoming optical path in a range between the information medium 23 or 25 and the beam

splitter **54** even though the converging spot **S1** differs from the converging spot **S2**. Therefore, a converging spot **S7** on the photo detector **57** at which the light **L4R** or **L5R** not diffracted by the wavefront changing device **56** is converged relates to a radiation point of the light source **52** in a mirror image, so that the light **L4R** and **L5R** not diffracted by the wavefront changing device **56** are converged at the same converging point **S7**. In the same manner, the light **L4R** and **L5R** diffracted by the wavefront changing device **56** are converged at the same other converging points.

Accordingly, even though the compound objective lens has two focal points, the wavefront changing unit **56** and the photo detector **57** required to detect the intensity of the transmitted light **L4R** can be utilized to detect the intensity of the diffracted light **L5R**. Therefore, the number of parts required to manufacture the optical head apparatus **51** can be reduced, and a small sized optical head apparatus can be manufactured at a low cost and in light weight even though pieces of information are recorded or reproduced on or from an information medium by utilizing the optical head apparatus **51** regardless of whether the information medium is thick or thin.

In cases where the hologram lens **26** (or **32, 33, 42**) is integrally formed with the objective lens **27** as shown in FIG. **19A**, **19B** or **20**, each of the compound objective lenses **45, 46** and **47** can be manufactured in light weight because the hologram lens **26** (or **32, 33, 42**) is a plane type of optical device. For example, the hologram lens **26** (or **32, 33, 42**) is less than several tens mg in weight. Therefore, the hologram lens **26** integrally formed with the objective lens **27** can be easily moved by the actuating unit **58**.

Next, a detecting method of the servo signals is described. FIG. **22** is a plan view of the wavefront changing unit **56**. FIG. **23** is an enlarged view of first-order diffracted light and transmitted light detected in the photo detector **57**. As shown in FIG. **22**, the wavefront changing unit **56** is partitioned into a diffracted light generating region **56*a*** in which a grating pattern **P4** is drawn and a pair of diffracted light generating regions **56*b*, 56*c*** in which a pair of grating patterns **P5, P6** are drawn. The light **L4R** or **L5R** incident on the diffracted light generating region **56*a*** is diffracted to obtain a focus error signal. The light **L4R** or **L5R** incident on each of the diffracted light generating regions **56*b*, 56*c*** is diffracted to obtain a tracking error signal.

Initially, a spot size detection method utilized to detect a focus error signal is described as an example of a detecting method of a focus error signal. The method is proposed in Japanese Patent Application No. 185722 of 1990. In short, in cases where the method is adopted, an allowable assembly error in an optical head apparatus can be remarkably enlarged, and the servo signal such as a focus error signal can be stably obtained to adjust the position of the compound objective lens even though the wavelength of the incident light **L3** varies.

In detail, as shown in FIG. **23**, the grating pattern **P4** is designed to change the transmitted light **L4R** (or the diffracted light **L5R**) transmitting through the diffracted light generating region **56*a*** of the wavefront changing unit **56** to a beam of first-order diffracted light **L7** and a beam of minus first-order diffracted light **L8**. The diffracted light **L7, L8** are expressed by two types of spherical waves having different curvatures. That is, interference fringes are produced by actually interfering a spherical wave having a focal point **FP1** in the front of the photo detector **57** with another spherical wave diverging from the converging spot **S7** according to a two-beam interferometric process, so that the grating pattern **P4** agreeing with the interference fringes is formed. In other case, the interference fringes are calculated according to a computer generated hologram method. As a result, the transmitted light **L4R** (or the diffracted light **L5R**) transmitting through the diffracted light generating region **56*a*** of the wavefront changing unit **56** is diffracted and changed to beams of conjugate diffracted light such as a beam of first-order diffracted light **L7** and a beam of minus first-order diffracted light **L8**. The beam of first-order diffracted light **L7** has the focal point **FP1** at the front surface of the photo detector **57**, and the beam of minus first-order diffracted light **L8** has a focal point **FP2** in the rear of the photo detector **57**.

As shown in FIG. **24**, the photo detector **57** comprises a sextant photo-detector **59** (or a six-division photo detector) in which six detecting sections **SE1, SE2, SE3, SE4, SE5** and **SE6** are provided. The intensity of the first-order diffracted light **L7** is detected by each of the detecting sections **SE1, SE2** and **SE3** of the sextant photo-detector **59** and is changed to electric current signals **SC1, SC2** and **SC3**. Also, the intensity of the minus first-order diffracted light **L8** is detected by each of the detecting sections **SE4, SE5** and **SE6** of the sextant photo-detector **59** and is changed to electric current signals **SC4, SC5** and **SC6**.

FIG. **25A** and **25C** respectively show a converging spot of the first-order diffracted light **L7** radiated to the detecting sections **SE1, SE2** and **SE3** of the sextant photo-detector **59** and another converging spot of the minus first-order diffracted light **L8** radiated to the detecting sections **SE4, SE5** and **SE6** of the sextant photo-detector **59** on condition that the objective lens **27** is defocused on the information medium **23** or **25**. FIG. **25B** shows a converging spot of the first-order diffracted light **L7** radiated to the detecting sections **SE1, SE2** and **SE3** of the sextant photo-detector **59** and another converging spot of the minus first-order diffracted light **L8** radiated to the detecting sections **SE4, SE5** and **SE6** of the sextant photo-detector **59** on condition that the objective lens **27** is just focused on the information medium **23** or **25**.

As shown in FIGS. **25A** to **25C**, in cases where the transmitted light **L4** (or the diffracted light **L5**) is converged on the information medium **23** (or **25**) on condition that the objective lens **27** is defocused on the information medium **23** (or **25**), a converging spot **S8** of the diffracted light **L7** shown at the left side of FIGS. **25A, 25C** is formed on the sextant photo-detector **59**, and another converging spot **S9** of the diffracted light **L8** shown at the right side of FIG. **25A** or **25C** is formed on the sextant photo-detector **59**. In contrast, in cases where the transmitted light **L4** (or the diffracted light **L5**) is converged on the information medium **23** (or **25**) on condition that the objective lens **27** is just focused on the information medium **23** (or **25**), a converging spot **S8** of the diffracted light **L7** shown at the left side of FIG. **25B** is formed on the sextant photo-detector **59**, and another converging spot **S9** of the diffracted light **L8** shown at the right side of FIG. **25B** is formed on the sextant photo-detector **59**. The intensity of the diffracted light **L7** is detected in each of the detecting sections **SE1, SE2** and **SE3** of the sextant photo-detector **59** and is changed to electric current signals **SC1, SC2, SC3**. Also, the intensity of the diffracted light **L8**

is detected in the detecting sections SE4, SE5 and SE6 of the sextant photo-detector **59** and is changed to electric current signals SC4, SC5 and SC6. Thereafter, a focus error signal S_{fe} is obtained according to the spot size detection method by calculating an equation (5).

$$S_{fe}=(SC1+SC3-SC2)-(SC4+SC6-SC5) \quad (5)$$

Thereafter, the position of the compound objective lens is moved in a direction along an optical axis at high speed so as to minimize the absolute value of the focus error signal S_{fe}.

In the spot size detection method, the diffracted light L7, L8 are expressed by two types of spherical waves having different curvatures to detect the focus error signal S_{fe}. However, two beams of diffracted light L7, L8 radiated to the photo detector **57** are not limited to the spherical waves. That is, because the change of the diffracted light L7, L8 in a Y-direction is detected by the photo detector **57** according to the spot size detection method, it is required that a one-dimensional focal point of the diffracted light L7 is positioned in the front of the photo detector **57** and a one-dimensional focal point of the diffracted light L8 is positioned in the rear of the photo detector **57**. Therefore, it is applicable that diffracted light including astigmatic aberration be radiated to the photo detector **57**.

In addition, an information signal S_{in} is obtained by adding all of the electric current signals according to an equation (6).

$$S_{in}=SC1+SC2+SC3+SC4+SC5+SC6 \quad (6)$$

Because the information medium **23** or **25** is rotated at high speed, a patterned track pit radiated by the converging spots S8, S9 of the diffracted light L7,L8 is rapidly changed one after another, so that the intensity of the information signal S_{in} is changed. Therefore, the information stored in the information medium **23** or **25** can be reproduced according to the information signal S_{in}.

Next, the detection of a tracking error signal depending on a relative position between a converging spot and a patterned track pit on the information medium **23** or **25** is described.

The grating pattern P5 drawn in the diffracted light generating region **56***b* shown in FIG. **22** is designed to change the transmitted light L4R (or the diffracted light L5R) transmitting through the diffracted light generating region **56***b* of the wavefront changing unit **56** to a beam of first-order diffracted light **L9** and a beam of minus first-order diffracted light **L10**. Also, the grating pattern **P6** drawn in the diffracted light generating region **56***c* shown in FIG. **22** is designed to change the transmitted light L4R (or the diffracted light L5R) transmitting through the diffracted light generating region **56***c* of the wavefront changing unit **56** to a beam of first-order diffracted light **L11** and a beam of minus first-order diffracted light **L12**.

As shown in FIG. **24**, the photo detector **57** further comprises four tracking photo-detectors **60***a* to **60***d* for detecting intensities of the diffracted light L9 to L12. As shown in FIG. **26**, the intensity of the diffracted light L9 is detected by the tracking photo-detector **60***a* and is changed to an electric current signal SC7, the intensity of the diffracted light L10 is detected by the tracking photo-detector **60***d* and is changed to an electric current signal SC10, the intensity of the diffracted light L11 is detected by the tracking photo-detector **60***b* and is changed to an electric current signal SC8, and the intensity of the diffracted light L12 is detected by the tracking photo-detector **60***c* and is changed to an electric current signal SC9. A tracking error signal S_{te} is calculated according to an equation (7).

$$S_{te}=SC7-SC8-SC9+SC10 \quad (7)$$

Therefore, the asymmetry of the intensity distribution of the transmitted light L4R (or the diffracted light L5R) incident on the wavefront changing unit **56**, which changes in dependence on the positional relation between the converging spot S1 (or S2) and a patterned track pit radiated by the light L4 or L5, is expressed by the tracking error signal S_{te}.

Thereafter, the objective lens **27** is moved in a radial direction so as to reduce a tracking error indicated by the tracking error signal S_{te}. The radial direction is defined as a direction perpendicular to both the optical axis and a series of patterned track pits. Therefore, the converging spot S1 (or S2) of the transmitted light L4 (or the diffracted light L5) on the information medium **23** (or **25**) can be formed in the middle of the patterned track pit, so that the tracking error becomes zero.

Accordingly, focus and tracking servo characteristics can be stably obtained in the optical head apparatus **51**. That is, because the wavefront changing unit **56** has a wavefront changing function, a focus error signal can be easily obtained. Also, because the diffracted light generating regions **56***b*, **56***c* are provided in the wavefront changing unit **56**, a tracking error signal can be easily obtained. Therefore, the number of parts required to manufacture the optical head apparatus **51** can be reduced, and the number of manufacturing steps can be reduced. In addition, the optical head apparatus can be manufactured at a low cost and in light weight.

Also, because the compound objective lens having two focal points is utilized in the optical head apparatus **51**, pieces of information can be reliably recorded or reproduced from an information medium by utilizing the optical head apparatus **51** regardless of whether the information medium is thick or thin.

(Seventh Embodiment)

Next, an optical head apparatus in which servo signals such as a focus error signal and a tracking error signal are detected according to an astigmatic aberration method is described according to a seventh embodiment of the present invention.

FIG. **27** is a constitutional view of an optical head apparatus according to a seventh embodiment.

As shown in FIG. **27**, an optical head apparatus **61** for recording or reproducing pieces of information on or from the information medium **23** or **25**, comprises the light source **52**, the collimator lens **53**, the beam splitter **54**, the compound objective lens **29** (or **29M**, **34**, **43**, **45**, **46** or **47**) composed of the hologram lens **26** (or **26M**, **32**, **33** or **42**) and the objective lens **27**, the actuating unit **58**, the converging lens **55**, an astigmatic aberration generating unit **62** such as a plane parallel plate for generating an astigmatic aberration in the transmitted light L4R or the diffracted light L5R converged by the converging lens **55**, and a photo detector **63** for detecting the intensity of the transmitted light L4R or the diffracted light L5R in which the astigmatic aberration is generated to obtain an information signal and servo signals such as a focus error signal and a tracking error signal.

The astigmatic aberration generating unit **62** is classified into one of the wavefront changing unit **56** because

a wavefront of the transmitted light L4R or the diffracted light L5R is changed by the generating unit **62** to generate the astigmatic aberration in the light L4R or L5R. Also, a normal line of the unit **62** is tilted from an optical axis.

As shown in FIG. **28**, the photo detector **63** comprises a quadrant photo-detector **64** in which four detecting sections SE7, SES, SE9 and SE10 are provided.

In the above configuration, the transmitted light L4R (or the diffracted light L5R) reflected by the information medium **23** (or **25**) is converged by the converging lens **55** in the same manner as in the sixth embodiment. Thereafter, the transmitted light L4R (or the diffracted light L5R) transmits through the astigmatic aberration generating unit **62** and is converged on the photo detector **57** to form a converging spot **S10** on the detecting sections SE7, SE8, SE9 and SE10 of the quadrant photo-detector **64**. In this case, because the transmitted light L4R (or the diffracted light L5R) converged by the converging lens **55** is a spherical wave, an astigmatic aberration is generated in the transmitted light L4R (or the diffracted light L5R) by the astigmatic aberration generating unit **62**. Therefore, as shown in FIGS. **29A** to **29C**, the shape of the converging spot **S10** considerably changes depending on a distance between the compound objective lens **29** and the information medium **23** (or **25**).

For example, in cases where the transmitted light L4 (or the diffracted light L5) is converged on the information medium **23** (or **25**) on condition that the objective lens **27** is defocused on the information medium **23** (or **25**), the converging spot **S10** of the transmitted light L4R (or the diffracted light L5R) is formed on the quadrant photo-detector **64** as shown in FIGS. **29A**, **29C**. In contrast, in cases where the transmitted light L4 (or the diffracted light L5) is converged on the information medium **23** (or **25**) on condition that the objective lens **27** is just focused on the information medium **23** (or **25**), the converging spot **S10** of the transmitted light L4R (or the diffracted light L5R) is formed on the quadrant photo-detector **64** as shown in FIG. **25B**.

The intensity of the transmitted light L4R (or the diffracted light L5R) is detected in the detecting sections SE7, SE8, SE9 and SE10 of the quadrant photo-detector **64** and is changed to electric current signals **SC11**, **SC12**, **SC13** and **SC14**. Thereafter, a focus error signal S_{fe} is obtained according to an astigmatic aberration method by calculating an equation (8).

$$S_{fe}=(SC11+SC14)-(SC12+SC13) \quad (8)$$

Thereafter, the position of the compound objective lens **29** is moved in a direction parallel to an optical axis at high speed so as to minimize the absolute value of the focus error signal S_{fe}.

Also, a tangential direction Dt agreeing with an extending direction of patterned recording pits and a radial direction Dr perpendicular to both the optical axis and the patterned recording pits are defined as shown in FIG. **29D**. In this case, when the quadrant photo-detector **64** is directed as shown in FIGS. **29A** to **29C**, a tracking error signal S_{te} is calculated according to an equation (9) by utilizing an intensity distribution change of the transmitted light L4R (or the diffracted light L5R) which depends on a positional relation between the converging spot **S10** and a recording pit radiated by the light L4 or L5.

$$S_{te}=SC11+SC13-(SC12+SC14) \quad (9)$$

Thereafter, the objective lens **27** is moved in the radial direction so as to reduce a tracking error indicated by the tracking error signal S_te. Therefore, the converging spot S1, (or S2) of the transmitted light L4 (or the diffracted light L5) on the information medium **23** (or **25**) can be formed in the middle of the recording pit, so that the tracking error becomes zero.

In other case, the tracking error signal S_{te} is obtained according to a phase difference method by utilizing the result calculated in the equation (8).

In addition, an information signal S_{in} is obtained by adding all of the electric current signals according to an equation (10).

$$S_{in}=SC11+SC12+SC13+SC14 \quad (10)$$

Accordingly, focus and tracking servo characteristics can be stably obtained in the optical head apparatus **61**. That is, because an astigmatic aberration is generated in the transmitted light L4R (or the diffracted light L5R) by the astigmatic aberration generating unit **62** made of a plane parallel plate, the servo signals such as a focus error signal and a tracking error signal can be easily obtained. Therefore, the number of parts required to manufacture the optical head apparatus **61** can be reduced, and the number of manufacturing steps can be reduced. In addition, the optical head apparatus **61** can be manufactured at a low cost and in light weight.

Also, because the compound objective lens having two focal points is utilized in the optical head apparatus **61**, pieces of information can be reliably recorded or reproduced from an information medium by utilizing the optical head apparatus **61** regardless of whether the information medium is thick or thin.

In the seventh embodiment, the astigmatic aberration generating unit **62** formed out of the plane parallel plate is arranged between the converging lens **55** and the photo detector **63**. However, as an optical head apparatus **65** is shown in FIG. **30**, it is applicable that a cylindrical lens **66** integrally formed with the converging lens **55** be arranged in place of the plane parallel plate to generate an astigmatic aberration in the transmitted light L4R (or the diffracted light L5R). In this case, because the cylindrical lens **66** is integrally formed with the converging lens **55**, the optical head apparatus can be moreover manufactured at low cost. In addition, as shown in FIG. **30**, it is applicable that a normal line of the hologram lens **26** (or **32**, **33**, **42**) be tilted from an optical axis passing through the center of the objective lens **27** by about one degree to prevent stray light reflected in a surface of the hologram lens **26** from being incident on the photo detector **57** or **63**. Also, it is applicable that the hologram lens **26** (or **32**, **33**, **42**) be coated with an anti-reflection coating to prevent the occurrence of stray light.

Also, as an optical head apparatus **67** is shown in FIG. **31**, it is applicable that a polarized beam splitter **68** be arranged in place of the beam splitter **54** to perfectly transmit the incident light L3 and a $\frac{1}{4}$-λ plate **69** be additionally placed between the hologram lens **26** (or **32**, **33**, **42**) and the polarized beam splitter **68**. In this case, because the incident light L3 transmits through the $\frac{1}{4}$-λ plate **69** in an outgoing optical path and because the transmitted light L4R (or the diffracted light L5R) again transmits through the $\frac{1}{4}$-λ plate **69** in an incoming optical path, the transmitted light L4R (or the diffracted light L5R) is perfectly reflected by the polarized

beam splitter **68**. Accordingly, a utilization efficiency of the incident light L3 can be enhanced. Also, a signal-noise ratio of each of the servo signals and the information signal can be enhanced.

Also, as an optical head apparatus **70** is shown in FIG. **32**, it is applicable that the polarized beam splitter **68** be arranged in place of the beam splitter **54** to perfectly transmit the incident light L3 and the $\frac{1}{4}$-λ plate **69** be additionally placed between the hologram lens **26** (or **32, 33, 42**) and the objective lens **27**. In this case, the transmitted light L4R (or the diffracted light L5R) is perfectly reflected by the polarized beam splitter **68** in the same manner as the optical head apparatus shown in FIG. **31**. In addition, because stray light reflected from the hologram lens **26** (or **32, 33, 42**) transmits through the polarized beam splitter **68**, the stray light is not incident on the photo detector **63**. Accordingly, a signal-noise ratio of each of the servo signals and the information signal can be moreover enhanced.

Also, as an optical head apparatus **71** is shown in FIG. **33**, it is applicable that a wedge-like prism **72** for reshaping the incident light L3 radiated from the light source **52** be additionally placed between the collimator lens **53** and the polarized beam splitter **68**. In this case, an elliptic wavefront of the incident light L3 is reshaped to a circular wavefront by the wedge-like prism **72**. Accordingly, a utilization efficiency of the incident light L3 can be enhanced.

In the sixth and seventh embodiments, when the transmitted light L4 (that is, zero-order diffracted light L4) converged on the first information medium **23** is reflected toward the compound objective lens to reproduce a piece of information recorded on the first information medium **23**, a part of the transmitted light L4R is diffracted in the hologram lens **26** (or **32, 33, 42**) on the incoming optical path, so that the part of the transmitted light L4R is changed to a beam of first-order diffracted light L13. Therefore, the first-order diffracted light L13 diverges from the hologram lens **26**, and a converging spot S11 of the diffracted light L13 is formed on the photo detector **57** or **63** in a relatively large size, as shown in FIG. **34**. The size of the converging spot S11 is larger than those of the sextant photo-detector **59** and the quadrant photo-detector **64**. Therefore, there is a drawback that a signal-noise ratio in the information signal deteriorates.

To solve the drawback, it is preferred that the photo detector **57** (or **63**) further comprise an information photo-detector **73** surrounding the sextant photo-detector **59** (or the quadrant photo-detector **64**). The size of the information photo-detector **73** is equal to or larger than a 1 mm square. Therefore, in cases where the information signal is determined by the sum of the intensity of the transmitted light L4 detected in the sextant photo-detector **59** (or the quadrant photo-detector **64**) and the intensity of the diffracted light L13 detected in the information photo-detector **73**, the signal-noise ratio in the information signal can be enhanced, and frequency characteristics of the information signal can be enhanced.

(Eighth Embodiment)

Next, a method of focusing performed in the optical head apparatuses **51, 61, 65, 67, 70** and **71** is described according to an eighth embodiment of the present invention.

FIG. **35A** graphically shows a change of the focus error signal obtained by detecting the intensity of the transmitted light L4 formed in the hologram lens **26, 32** or **33**, the strength of the focus error signal depending on a distance between the objective lens **27** and the first information medium **23**. FIG. **35B** graphically shows a change of the focus error signal obtained by detecting the intensity of the diffracted light L5 formed in the hologram lens **26, 32** or **33**, the strength of the focus error signal depending on a distance between the objective lens **27** and the second information medium **25**.

The intensity of the transmitted light L4 is high because the numerical aperture of the objective lens **27** for the transmitted light L4 is large. Therefore, as shown in FIG. **35A**, a change of a focus error signal FE1 obtained in cases where the objective lens **27** is almost focused on the first information medium **23** is considerably large as compared with a change of an unnecessary focus error signal FE2 obtained in cases where the objective lens **27** is defocused on the first information medium **23**. In addition, in cases where the hologram lens **26, 32** or **33** is utilized in each of the optical head apparatuses **51, 61, 65, 67, 70** and **71**, the unnecessary focus error signal FE2 is generated when the distance between the objective lens **27** and the first information medium **23** is larger than the focal length of the objective lens **27** for the transmitted light L4.

In contrast, the intensity of the diffracted light L5 is comparatively low because the numerical aperture of the objective lens **27** for the diffracted light L5 is comparatively small. Therefore, as shown in FIG. **35B**, a change of a focus error signal FE3 obtained in cases where the objective lens **27** is almost focused on the second information medium **25** is almost the same as that of an unnecessary focus error signal FE4 obtained in cases where the objective lens **27** is defocused on the second information medium **25**. In addition, in cases where the hologram lens **26, 32** or **33** is utilized in each of the optical head apparatuses **51, 61, 65, 67, 70** and **71**, the unnecessary focus error signal FE4 is generated when the distance between the objective lens **27** and the second information medium **25** is smaller than the focal length of the objective lens **27** for the diffracted light L5.

Therefore, in cases where the focusing of the transmitted light L4 on the first information medium **23** is performed, the objective lens **27** placed far from the first information medium **23** is gradually brought near to the first information medium **23**. Thereafter, when the strength of the focus error signal reaches a threshold value, a focus servo loop provided in the photo detector **57** or **63** is set to an operation condition, so that the objective lens **27** is set to be focused on the first information medium **23**. Also, in cases where the focusing of the diffracted light L5 on the second information medium **25** is performed, the objective lens **27** placed far from the second information medium **25** is gradually brought near to the second information medium **25** in the same manner. Thereafter, when the strength of the focus error signal reaches a threshold value, a focus servo loop provided in the photo detector **57** or **63** is set to an operation condition, so that the objective lens **27** is set to be focused on the second information medium **25**.

Accordingly, the inverse influence of the unnecessary focus error signal FE4 on the focusing of the diffracted light L5 can be prevented. Also, because the objective lens **27** placed far from the information medium **23** or **25** is gradually brought near to the information medium **23** or **25** regardless of whether the information medium is T1 or T2 in thickness, a focusing

operation in each of the optical head apparatuses **51**, **61**, **65**, **67**, **70** and **71** with the hologram lens **26**, **32** or **33** can be performed according to a common procedure by changing the threshold value or performing an auto gain control in which the focus error signal is normalized by detecting the total intensity of the transmitted light L4R or the diffracted light L5R. Therefore, a control circuit required to perform the focusing operation can be made at a low cost.

FIG. **36**A graphically shows a change of the focus error signal obtained by detecting the intensity of the diffracted light L6 formed in the hologram lens **42**, the strength of the focus error signal depending on a distance between the objective lens **27** and the first information medium **23**. FIG. **36**B graphically shows a change of the focus error signal obtained by detecting the intensity of the transmitted light L4 formed in the hologram lens **42**, the strength of the focus error signal depending on a distance between the objective lens **27** and the second information medium **25**.

As shown in FIG. **36**A, a change of a focus error signal FE5 obtained in cases where the objective lens **27** is almost focused on the first information medium **23** is considerably large as compared with a change of an unnecessary focus error signal FE6 obtained in cases where the objective lens **27** is defocused on the first information medium **23**. In addition, in cases where the hologram lens **42** is utilized in each of the optical head apparatuses **51**, **61**, **65**, **67**, **70** and **71**, the unnecessary focus error signal FE6 is generated when the distance between the objective lens **27** and the first information medium **23** is smaller than the focal length of the objective lens **27** for the diffracted light L6.

In contrast, as shown in FIG. **36**B, a change of a focus error signal FE7 obtained in cases where the objective lens **27** is almost focused on the second information medium **25** is almost the same as that of an unnecessary focus error signal FE8 obtained in cases where the objective lens **27** is defocused on the second information medium **25**. In addition, in cases where the hologram lens **42** is utilized in each of the optical head apparatuses **51**, **61**, **65**, **67**, **70** and **71**, the unnecessary focus error signal FE8 is generated when the distance between the objective lens **27** and the second information medium **25** is larger than the focal length of the objective lens **27** for the transmitted light L4.

Therefore, in cases where the focusing of the diffracted light L6 on the first information medium **23** is performed, the objective lens **27** placed near to the first information medium **23** is gradually moved away from the first information medium **23**. Thereafter, when the strength of the focus error signal reaches a threshold value, a focus servo loop provided in the photo detector **57** or **63** is set to an operation condition, so that the objective lens **27** is set to be focused on the first information medium **23**. Also, in cases where the focusing of the transmitted light L4 on the second information medium **25** is performed, the objective lens **27** placed near to the second information medium **25** is gradually moved away from the second information medium **25** in the same manner. Thereafter, when the strength of the focus error signal reaches a threshold value, a focus servo loop provided in the photo detector **57** or **63** is set to an operation condition, so that the objective lens **27** is set to be focused on the second information medium **25**.

Accordingly, the inverse influence of the unnecessary focus error signal FEB on the focusing of the transmitted light L4 can be prevented. Also, because the objective lens **27** placed near to the information medium **23** or **25** is gradually moved away from the information medium **23** or **25** regardless of whether the information medium is T1 or T2 in thickness, a focusing operation in each of the optical head apparatuses **51**, **61**, **65**, **67**, **70** and **71** with the hologram lens **42** can be performed according to a common procedure by changing the threshold value or performing the auto gain control. Therefore, a control circuit required to perform the focusing operation can be made at a low cost.

(Ninth Embodiment)

An optical head apparatus with the compound objective lens **29**, **34**, **45**, **46** or **47** in which the incident light L3 is efficiently utilized to obtain an information signal and servo signals is described with reference to FIGS. **29**, **37** according to a ninth embodiment of the present invention.

FIG. **37** is a constitutional view of an optical head apparatus according to a ninth embodiment.

As shown in FIG. **37**, an optical head apparatus **81** for recording or reproducing pieces of information on or from the information medium **23** or **25**, comprises the light source **52**, the collimator lens **53**, the beam splitter **54**, the compound objective lens the compound objective lens **29** (**34**, **45**, **46** or **47**) composed of the hologram lens **26** (or **32** or **33**) and the objective lens **27**, the actuating unit **58**, the converging lens **55**, a beam splitter **82** for transmitting a beam of diffracted light L5R or reflecting a beam of transmitted light L4R, the photo detector **63** for detecting the intensity of the diffracted light L5R transmitting through the beam splitter **82** to obtain servo signals and an information signal recorded on the second information medium **25**, the wavefront changing device **56** such as a hologram for changing a wavefront of the transmitted light L4R reflected by the beam splitter **82**, and the photo detector **57** for detecting the intensity of the transmitted light L4R to obtain servo signals and an information signal recorded on the first information medium **23**. The beam splitter **82** is made of a plane parallel plate of which a normal line is tilted from an optical path, so that an astigmatic aberration is generated in the diffracted light L5R passing through the beam splitter **82**. Also, a coating is applied on a surface of the plane parallel plate.

In the above configuration, the transmitted light L4 (or the diffracted light L5) are converged by the converging lens **27** in the same manner as in the sixth embodiment. Thereafter, in cases where a piece of information is recorded or reproduced on or from the first information medium **23**, the transmitted light L4 is converged on the first information medium **23** to form the first converging spot S1. Thereafter, a beam of transmitted light L4R reflected by the first information medium **23** passes through the same optical path in the reverse direction. That is, a great part of the transmitted light L4R again transmits through the compound objective lens without any diffraction and is reflected by the beam splitter **54**. Thereafter, the transmitted light L4R is converged by the converging lens **55**, and a part of the transmitted light L4R is reflected by the beam splitter **82**. Thereafter, the wavefront of a great part of the transmitted light L4R is changed by the wavefront changing unit **56**, and the great part of the transmitted light L4R is converged on the photo detector **57** to form the converging spots S8, S9. Therefore, an information signal and servo signals such as a focus error

signal and a tracking error signal are obtained in the same manner as in the sixth embodiment. Also, a remaining part of the transmitted light L4R not changed its wavefront is converged on the photo detector 57 to form the converging spot S7.

In contrast, in cases where a piece of information is recorded or reproduced on or from the second information medium 25, the diffracted light L5 is converged on the second information medium 25 to form the second converging spot S2. Thereafter, a beam of diffracted light L5R reflected by the second information medium 25 passes through the same optical path in the reverse direction, and a great part of the diffracted light L5R transmits through the hologram lens 26 without any diffraction. Therefore, the diffracted light L5R passes through the incoming optical path differing from the outgoing optical path. Thereafter, the diffracted light L5R is reflected by the beam splitter 54 and is converged by the converging lens 55. Thereafter, a part of the diffracted light L5R transmits through the beam splitter 82. In this case, an astigmatic aberration is generated in the diffracted light L5R. Thereafter, the diffracted light L5R is converged on the photo detector 63 to form a converging spot S12 of which the shape is the same as the converging spot S10 shown in FIGS. 29A to 29C, and the intensity of the diffracted light L5R is detected in the photo detector 63. Therefore, an information signal and servo signals such as a focus error signal and a tracking error signal are obtained in the same manner as in the seventh embodiment.

In this case, though a remaining part of the transmitted light L4R transmits through the beam splitter 82, the remaining part of the transmitted light L4R is not converged at the converging spot S12 because the transmitted light L4R passes through the same optical path. Also, though a remaining part of the diffracted light L5R is reflected the beam splitter 82, the remaining part of the diffracted light L5R is not converged at the converging spot S7, S8 or S9 because the diffracted light L5R passes through the incoming optical path differing from the outgoing optical path.

In the ninth embodiment, because the diffracted light L5R transmits through the hologram lens 26 without any diffraction, the converging spot S12 formed on the photo detector 63 does not relate to a radiating point of the light source 52 in a mirror image, while the converging spot S7 formed on the photo detector 57 relates to the radiating point of the light source 52 in the mirror image. In other words, a focal point of the diffracted light L5R converged by the converging lens 55 differs from that of the transmitted light L4R converged by the converging lens 55. Therefore, the photo detector 57 for detecting the intensity of the transmitted light L4R and the photo detector 63 for detecting the intensity of the diffracted light L5R are required.

Accordingly, because the compound objective lens having two focal points is utilized in the optical head apparatus 81, pieces of information can be reliably recorded or reproduced on or from an information medium regardless of whether the information medium is thick or thin.

An example of the utilization of the optical head apparatus 81 for various types of optical disks is described.

In cases where the optical head apparatus 81 is utilized for an optical disk device in which pieces of information recorded in a thin type of high density optical disk 23 are recorded or reproduced and pieces of information recorded in a thick type of optical disk 25 are exclusively reproduced, the diffraction efficiency of the hologram lens 26, 32 or 33 in the compound objective lens 29, 34, 45, 46 or 47 for changing a beam of light to a beam of first-order diffracted light is set to a value equal to or lower than 30%. Therefore, in cases where a piece of information recorded on the thick type of optical disk 25 is reproduced in the photo detector 63, a signal-noise ratio of each of the servo signals and the information signal obtained in the photo detector 63 can be enhanced because the diffracted light L5R transmitting through the hologram lens 26, 32 or 33 at a high transmission efficiency is utilized to obtain the servo signals and the information signal. In other words, a utilization efficiency of the incident light L3 can be enhanced when a piece of information recorded on the thick type of optical disk 25 is reproduced, so that the output power of the incident light L3 can be minimized. Also, even though a high intensity of the transmitted light L4 is required to record a piece of information on the high density optical disk 23, the recording of the information can be reliably performed without increasing the intensity of the incident light L3 because a transmission efficiency of the hologram lens 26, 32 or 33 for the incident light L3 is high. Also, in cases where a piece of information recorded on the high density optical disk 23 is reproduced in the photo detector 57, a signal-noise ratio of each signal obtained in the photo detector 57 can be enhanced because the transmission efficiency of the hologram lens 32 or 33 for the light L3, L4R is high.

(Tenth Embodiment)

An optical head apparatus with the compound objective lens 29, 34, 45, 46 or 47 in which the incident light L3 is efficiently utilized to obtain an information signal and servo signals is described with reference to FIGS. 38, 39 according to a tenth embodiment of the present invention. X1 and Y1 coordinates shown in FIGS. 38, 39 are utilized in common.

FIG. 38 is a constitutional view of an optical head apparatus according to a tenth embodiment. FIG. 39 is a plan view of a beam splitter having a reflection type of hologram utilized in the optical head apparatus shown in FIG. 38.

As shown in FIG. 38, an optical head apparatus 91 for recording or reproducing pieces of information on or from the information medium 23 or 25, comprises the light source 52, the collimator lens 53, the beam splitter 54, the compound objective lens 29 (or 34, 45, 46 or 47) composed of the hologram lens 26 (or 32 or 33) and the objective lens 27, the actuating unit 58, the converging lens 55, a beam splitter 92 having a reflection type of hologram 93 for transmitting a large part of the transmitted light L4R or reflecting all of the diffracted light L5R incident on the hologram 93, the photo detector 63 for detecting the intensity of the transmitted light L4R transmitting through the beam splitter 92 to obtain servo signals and an information signal recorded in the first information medium 23, and the photo detector 57 for detecting the intensity of the diffracted light L5R to obtain servo signals and an information signal recorded in the second information medium 25.

The beam splitter 92 is made of a plane parallel plate inclined to an optical path, so that an astigmatic aberration is generated in the transmitted light L4R passing through the beam splitter 92. Also, as shown in FIG. 39, the reflection type of hologram 93 is arranged at a cen-

ter portion of the beam splitter **92**, and a light transmitting region **92***a* is arranged at a peripheral portion of the beam splitter **92** to surround the hologram **93**. Light incident on the light transmitting region **92***a* transmits without any diffraction. The hologram **92** is partitioned into a diffracted light generating region **93***a* in which a grating pattern P7 is drawn and a pair of diffracted light generating regions **93***b*, **93***c* in which a pair of grating patterns P8, P9 are drawn. The diffracted light L5R incident on the diffracted light generating region **93***a* is diffracted to obtain a focus error signal in the photo detector **57**. The diffracted light L5R incident on each of the diffracted light generating regions **93***b*, **93***c* is diffracted to obtain a tracking error signal in the photo detector **57**.

In the above configuration, the transmitted light L4 and the diffracted light L5 are converged by the converging lens **27** in the same manner as in the sixth embodiment. Thereafter, in cases where a piece of information is recorded or reproduced on or from the first information medium **23**, the transmitted light L4 is converged on the first information medium **23** to form the first converging spot S1. Thereafter, a beam of transmitted light L4R reflected by the first information medium **23** passes through the same optical path in the reverse direction. That is, a large part of the transmitted light L4R again transmits through the compound objective lens **29** without any diffraction and is reflected by the beam splitter **54**. Thereafter, the transmitted light L4R is converged by the converging lens **55**, and a large part of the transmitted light L4R transmits through the beam splitter **92**. In this case, an astigmatic aberration is generated in the transmitted light L4R. Thereafter, the transmitted light L4R is converged on the photo detector **63** to form a converging spot S13 of which the shape is the same as the converging spot S10 shown in FIGS. **29**A to **29**C, and the intensity of the transmitted light L4R is detected in the photo detector **63**. Therefore, an information signal and servo signals such as a focus error signal and a tracking error signal are obtained in the same manner as in the seventh embodiment.

In contrast, in cases where a piece of information is recorded or reproduced on or from the second information medium **25**, the diffracted light L5 is converged on the second information medium **25** to form the second converging spot S2. Thereafter, a beam of diffracted light L5R reflected by the second information medium **25** passes through the same optical path in the reverse direction, and a large part of the diffracted light L5R transmits through the hologram lens **26** without any diffraction. Therefore, the diffracted light L5R transmits on the incoming optical path differing from the outgoing optical path in the same manner as in the ninth embodiment. Thereafter, the diffracted light L5R is reflected by the beam splitter **54** and is converged by the converging lens **55** on the beam splitter **92** to form a converging spot on the reflection type of hologram **93** of the beam splitter **92**. Therefore, all of the diffracted light L5R is diffracted and reflected by the hologram **93** to be converged on the photo detector **57**. That is, the diffracted light L5R diffracted and reflected in the diffracted light generating region **93***a* of the hologram **93** is splitted into two beams and is converged on the detecting sections SE1 to SE6 of the sextant photo-detector **59** in the photo detector **57** in the same manner as in the sixth embodiment. Also, the diffracted light L5R diffracted and reflected in the diffracted light generating region **93***b* of the hologram **93** is splitted into two beams, and the intensity of the diffracted light L5R is detected in the tracking photo-detectors **60***a* and **60***d*. Also, the diffracted light L5R diffracted and reflected in the diffracted light generating region **93***c* of the hologram **93** is splitted into two beams, and the intensity of the diffracted light L5R is detected in the tracking photo-detectors **60***b* and **60***c*. Therefore, an information signal and servo signals such as a focus error signal and a tracking error signal are obtained in the same manner as in the sixth embodiment.

In the tenth embodiment, because the transmitted light L4R transmits through the hologram lens **26** without any diffraction, the converging spot S13 formed on the photo detector **63** does not relate to a radiating point of the light source **52** in a mirror image. Therefore, the photo detector **57** for detecting the intensity of the diffracted light L5R and the photo detector **63** for detecting the intensity of the transmitted light L4R are required.

Accordingly, because the compound objective lens having two focal points is utilized in the optical head apparatus **91**, pieces of information can be reliably recorded or reproduced on or from an information medium regardless of whether the information medium is thick or thin.

Also, because all of the diffracted light L5R is completely diffracted and reflected by the hologram **93** of the beam splitter **92**, the diffracted light L5R can be utilized at high efficiency. Therefore, a signal-noise ratio of the signals obtained in the photo detector **57** can be enhanced.

An example of the utilization of the optical head apparatus **91** for various types of optical disks is described.

In cases where the optical head apparatus **91** is utilized for an optical disk device in which pieces of information recorded in a thin type of high density optical disk **23** are recorded or reproduced and pieces of information recorded in a thick type of optical disk **25** are exclusively reproduced, the diffraction efficiency of the hologram lens **26**, **32** or **33** in the compound objective lens **29**, **34**, **45**, **46** or **47** for changing a beam of light to a beam of first-order diffracted light is set to a value equal to or lower than 30%. Therefore, in cases where a piece of information recorded on the thick type of optical disk **25** is reproduced in the photo detector **57**, a signal-noise ratio of each of the servo signals and the information signal obtained in the photo detector **57** can be enhanced because the diffracted light L5R transmitting through the hologram lens **26**, **32** or **33** at a high transmission efficiency is utilized to obtain the servo signals and the information signal. In other words, a utilization efficiency of the incident light L3 can be enhanced when a piece of information recorded on the thick type of optical disk **25** is reproduced, so that the output power of the incident light L3 can be minimized. Also, even though a high intensity of the transmitted light L4 is required to record a piece of information on the high density optical disk **23**, the recording of the information can be reliably performed without increasing the intensity of the incident light L3 because a transmission efficiency of the hologram lens **26**, **32** or **33** for the incident light L3 is high. Also, in cases where a piece of information recorded on the high density optical disk **23** is reproduced in the photo detector **63**, a signal-noise ratio of each signal obtained in the photo detector **63** can be enhanced because the transmission

efficiency of the hologram lens **26**, **32** or **33** for the light L3, L4R is high.

(Eleventh Embodiment)

An optical head apparatus with the compound objective lens **29**, **34**, **45**, **46** or **47** in which the incident light L3 is efficiently utilized to obtain an information signal and servo signals is described with reference to FIGS. **40** to **42** according to an eleventh embodiment of the present invention. X1 and Y1 co-ordinates shown in FIGS. **40**, **41** are utilized in common, and X, Y and Z co-ordinates shown in FIGS. **40**, **42** are utilized in common.

FIGS. **40**A, **40**B are respectively a constitutional view of an optical head apparatus according an eleventh embodiment. FIG. **41** is a plan view of a beam splitter having a reflection type of hologram utilized in the optical head apparatus shown in FIG. **38**.

As shown in FIGS. **40**A, **40**B, an optical head apparatus **101** for recording or reproducing pieces of information on or from the information medium **23** or **25**, comprises the light source **52**, the collimator lens **53**, the beam splitter **54**, the compound objective lens **29** (or **34**, **45**, **46** or **47**) composed of the hologram lens **26** (or **32** or **33**) and the objective lens **27**, the actuating unit **58**, the converging lens **55**, a beam splitter **102** having a transmission type of hologram **103** for transmitting the transmitted light L4R converged on the first information medium **23** and the diffracted light L5R converged on the second information medium **25** and diffracting the transmitted light L4R which is converged on the second information medium **25** in defocus, a photo detector **104** for detecting the intensity of the transmitted light L4R converged on the first information medium **23** to obtain servo signals and an information signal recorded in the first information medium **23**, detecting in defocus the intensity of the diffracted light L5R to obtain an information signal recorded in the second information medium **25**, and detecting the intensity of the transmitted light L4R converged on the second information medium **25** in defocus to obtain a focus error signal.

The beam splitter **102** is made of a plane parallel plate inclined to an optical path, so that an astigmatic aberration is generated in the light L4R, L5R passing through the beam splitter **102**. Also, as shown in FIG. **41**, the transmission type of hologram **103** is arranged at a center portion of the beam splitter **102**, and a light transmitting region **102***a* is arranged at a peripheral portion of the beam splitter **102** to surround the hologram **103**. The transmitted light L4R incident on the light transmitting region **102***a* transmits without any diffraction. The hologram **102** is partitioned into diffracted light generating regions **103***a*, **103***b* alternately arranged to detect a focus error signal according to the spot size detection method described in the sixth embodiment. That is, a grating pattern **P10** is drawn in each of the diffracted light generating regions **103***a*, and a converging spot is formed by the transmitted light L4R diffracted in the regions **103***a*. Also, a grating pattern **P11** is drawn in each of the diffracted light generating regions **103***b*, and another converging spot is formed by the transmitted light L4R diffracted in the regions **103***b*.

The photo detector **104** comprises the sextant photodetector **59** in which the detecting sections SE1, SE2, SE3, SE4, SE5 and SE6 are provided in the same manner as the photo detector **57**.

In the above configuration, the transmitted light L4 and the diffracted light L5 are converged by the converging lens **27** in the same manner as in the sixth embodiment. Thereafter, in cases where a piece of information is recorded or reproduced on or from the first information medium **23**, as shown in FIG. **40**A, the transmitted light L4 is converged on the first information medium **23** to form the first converging spot **S1**. Thereafter, a beam of transmitted light L4R reflected by the first information medium **23** passes through the same optical path in the reverse direction. That is, the transmitted light L4R again transmits through the compound objective lens without any diffraction and is reflected by the beam splitter **54**. Thereafter, the transmitted light L4R is converged by the converging lens **55**, and a major part of the transmitted light L4R transmits through the beam splitter **103**. In this case, an astigmatic aberration is generated in the transmitted light L4R. Thereafter, the transmitted light L4R is converged on the photo detector **104** to form a converging spot **S14** of which the shape is the same as the converging spot **S10** shown in FIGS. **29**A to **29**C, and the intensity of the transmitted light L4R is detected in the photo detector **104**. Therefore, an information signal and servo signals such as a focus error signal and a tracking error signal are obtained in the same manner as in the seventh embodiment. In this case, because the position of the photo detector **104** detecting the transmitted light L4R relates to a radiation point of the light source **52** in a mirror image, the transmitted light L4R is converged on the photo detector **104** just in focus.

In contrast, in cases where a piece of information is recorded or reproduced on or from the second information medium **25**, as shown in FIG. **40**B, the diffracted light L5 is converged on the second information medium **25** to form the second converging spot **S2**. Thereafter, a beam of diffracted light L5R reflected by the second information medium **25** passes through the same optical path in the reverse direction and transmits through the hologram lens **26** without any diffraction. Therefore, the diffracted light L5R transmits on the incoming optical path differing from the outgoing optical path in the same manner as in the ninth embodiment. Thereafter, the diffracted light L5R is reflected by the beam splitter **54** and is converged by the converging lens **55**. Thereafter, a major part of the diffracted light L5R transmits through the beam splitter **102**, and the diffracted light L5R is converged on the photo detector **57**. In this case, an astigmatic aberration is generated in the diffracted light L5R. Also, because the diffracted light L5R is not diffracted by the hologram lens **26** on the incoming optical path, the position of the photo detector **104** detecting the diffracted light L5R does not relate to the radiation point of the light source **52** in the mirror image. Therefore, the diffracted light L5R is converged on the photo detector **104** in defocus. However, because the entire intensity of the diffracted light L5R converged in defocus is detected in the photo detector **104**, an information signal is obtained in the same manner as in the seventh embodiment.

Also, the transmitted light L4 is converged on the second information medium **25** in defocus as shown in FIG. **40**B. That is, the transmitted light L4 incident on the rear surface of the second information medium **25** is converged at the front surface of the second information medium **25**. Thereafter, a beam of transmitted light L4R reflected at the front surface of the second information medium **25** again transmits through the compound objective lens without any diffraction and is reflected by the beam splitter **54**. Thereafter, the trans-

mitted light L4R is converged by the converging lens **55** on the beam splitter **102** to form a converging spot on the of hologram **103** of the beam splitter **102**. Therefore, all of the transmitted light L4R is diffracted by the hologram **103** and is converged on the photo detector **104**. That is, the transmitted light L4R diffracted in the diffracted light generating regions **103***a* of the hologram **103** is changed to a first spherical wave SW1 of which a focal point is placed at the front of the photo detector **104**, and the transmitted light L4R diffracted in the diffracted light generating regions **103***b* of the hologram **103** is changed to a second spherical wave SW2 of which a focal point is placed at the rear of the photo detector **104**. Thereafter, as shown in FIGS. **42**A to **42**C, the first spherical wave SW1 is converged on the detecting sections SE1 to SE3 of the sextant photo-detector **59** in the photo detector **104** to form a converging spot S15A, and the second spherical wave SW2 is converged on the detecting sections SE4 to SE6 of the sextant photo-detector **59** to form a converging spot S15B. Because the regions **103***a*, **103***b* are divided into many pieces, the converging spots S15A, S15B are respectively divided into many pieces.

In cases where the diffracted light L5 is converged on the information medium **25** in defocus, the converging spots S15A, S15B of the transmitted light L4R shown in FIGS. **42**A, **42**C are formed on the sextant photo-detector **59**. In contrast, in cases where the diffracted light L5 is converged on the information medium **25** in focus, the converging spots S15A, S15B of the transmitted light L4R shown in FIG. **42**B are formed on the sextant photo-detector **59**. The intensity of the transmitted light L4R is detected in each of the detecting sections SE1 to SE6 of the sextant photo-detector **59** and is changed to electric current signals SC15 to SC20. Thereafter, a focus error signal S_{fe} is obtained according to the spot size detection method by calculating an equation (11).

$$S_{fe}=(SC15+SC17-SC16)-(SC18+SC20-SC19) \quad (11)$$

Thereafter, the position of the compound objective lens is moved in a direction along an optical axis at high speed so as to minimize the absolute value of the focus error signal S_{fe}. Therefore, the focus error signal is obtained in the same manner as in the sixth embodiment.

Accordingly, because the compound objective lens having two focal points is utilized in the optical head apparatus **101**, pieces of information can be reliably recorded or reproduced on or from an information medium regardless of whether the information medium is thick or thin.

Also, because all of the transmitted light L4R reflected by the second information medium **25** is completely diffracted by the hologram **103** of the beam splitter **102** to detect the focus error signal, the transmitted light L4R can be utilized at high efficiency. Therefore, a signal-noise ratio of the focus error signal obtained in the photo detector **104** can be enhanced.

Also, the information signal and the servo signals can be obtained in the photo detector **104** regardless of whether the information medium **23** or **25** is thin or thick. Therefore, the number of parts required to manufacture the optical head apparatus **101** can be reduced, and a small sized optical head apparatus can be manufactured at a low cost and in light weight even though pieces of information are recorded or reproduced on or from an information medium by utilizing the optical head apparatus **101** regardless of whether the information medium is thick or thin.

An example of the utilization of the optical head apparatus **101** for various types of optical disks is described.

In cases where the optical head apparatus **101** is utilized for an optical disk device in which pieces of information recorded in a thin type of high density optical disk **23** are recorded or reproduced and pieces of information recorded in a thick type of optical disk **25** are exclusively reproduced, the diffraction efficiency of the hologram lens **26**, **32** or **33** in the compound objective lens **29**, **34**, **45**, **46** or **47** is set to a value equal to or lower than 30%. Therefore, in cases where a piece of information recorded on the thick type of optical disk **25** is reproduced in the photo detector **104**, a signal-noise ratio of each of the servo signals and the information signal obtained in the photo detector **104** can be enhanced because the diffracted light L5R transmitting through the hologram lens **26**, **32** or **33** at a high transmission efficiency is utilized to obtain the information signal. In other words, a utilization efficiency of the incident light L3 can be enhanced when a piece of information recorded on the thick type of optical disk **25** is reproduced, so that the output power of the incident light L3 can be minimized. Also, even though a high intensity of the transmitted light L4 is required to record a piece of information on the high density optical disk **23**, the recording of the information can be reliably performed without increasing the intensity of the incident light L3 because a transmission efficiency of the hologram lens **26**, **32** or **33** for the incident light L3 is high. Also, in cases where a piece of information recorded on the high density optical disk **23** is reproduced in the photo detector **63**, a signal-noise ratio of each signal obtained in the photo detector **63** can be enhanced because the transmission efficiency of the hologram lens **26**, **32** or **33** for the light L3, L4R is high.

(Twelfth Embodiment)

An optical head apparatus with the compound objective lens **29**M, **43**, **45**, **46** or **47** in which the incident light L3 is efficiently utilized to obtain an information signal and servo signals is described with reference to FIG. **43** according to a twelfth embodiment of the present invention.

FIG. **43** is a constitutional view of an optical head apparatus according to a twelfth embodiment.

As shown in FIG. **43**, an optical head apparatus **111** for recording or reproducing pieces of information on or from the information medium **23** or **25**, comprises the light source **52**, the collimator lens **53**, the beam splitter **54**, the compound objective lens **29**M (or **43**, **45**, **46** or **47**) composed of the hologram lens **42** (or **26**M or **32**) and the objective lens **27**, the actuating unit **58**, the converging lens **55**, the beam splitter **82**, the photo detector **63**, the wavefront changing device **56**, and the photo detector **57**.

In the above configuration, a beam of incident light L3 radiated from the light source **52** is collimated in the collimator lens **53** and transmits through the beam splitter **54**. Thereafter, a part of the incident light L3 transmits through the compound objective lens **29** without any diffraction, and a remaining part of the incident light L3 is diffracted.

Thereafter, in cases where a piece of information is recorded or reproduced on or from the first information medium **23**, the diffracted light L6 is converged on the

first information medium **23** to form the converging spot **S5**. That is, the diffracted light **L6** is incident on the rear surface of the first information medium **23**, and the converging spot **S5** is formed on the front surface of the first information medium **23**. Thereafter, a beam of diffracted light **L6R** reflected at the front surface of the first information medium **23** passes through the same optical path in the reverse direction, and a great part of the diffracted light **L6R** is again diffracted by the hologram lens **42**. Therefore, the diffracted light **L6R** transmits on the incoming optical path agreeing with the outgoing optical path. Thereafter, the diffracted light **L6R** is reflected by the beam splitter **54** and is converged by the converging lens **55**. Thereafter, a part of the diffracted light **L6R** transmits through the beam splitter **82**. In this case, an astigmatic aberration is generated in the diffracted light **L6R**. Thereafter, the diffracted light **L6R** is converged on the photo detector **63** to form the converging spot **S10** of which the shape is shown in FIGS. **29A** to **29C**, and the intensity of the diffracted light **L6R** is detected in the photo detector **63**. Therefore, an information signal and servo signals such as a focus error signal and a tracking error signal are obtained in the same manner as in the seventh embodiment.

In contrast, in cases where a piece of information is recorded or reproduced on or from the second information medium **25**, the transmitted light **L4** is converged on the second information medium **25** to form the converging spot **S6**. That is, the transmitted light **L4** is incident on the rear surface of the second information medium **25**, and the converging spot **S6** is formed on the front surface of the second information medium **25**. Thereafter, a beam of transmitted light **L4R** reflected at the front surface of the second information medium **25** passes through the same optical path in the reverse direction. That is, the transmitted light **L4R** is collimated by the objective lens **27** on the incoming optical path. Thereafter, a great part of the transmitted light **L4R** is diffracted by the hologram lens **42**. Therefore, the transmitted light **L4R** transmits on the incoming optical path differing from the outgoing optical path. Thereafter, the transmitted light **L4R** is reflected by the beam splitter **54** and is converged by the converging lens **55**. Thereafter, a part of the transmitted light **L4R** is reflected by the beam splitter **82**. Thereafter, the wavefront of a great part of the transmitted light **L4R** is changed by the wavefront changing unit **56**, and the great part of the transmitted light **L4R** is converged on the photo detector **57** to form converging spots **S16**, **S17**. Therefore, an information signal and servo signals such as a focus error signal and a tracking error signal are obtained in the same manner as in the sixth embodiment. Also, a remaining part of the transmitted light **L4R** not changed its wavefront by the wavefront changing unit **56** is converged on the photo detector **57** to form the converging spot **S18**.

In the twelfth embodiment, because the transmitted light **L4R** is diffracted by the hologram lens **42** on the incoming optical path, the converging spot **S18** formed on the photo detector **57** does not relate to a radiation point of the light source **52** in a mirror image, while the converging spot **S10** formed on the photo detector **63** relates to the radiation point of the light source **52** in the mirror image. In other words, a focal point of the transmitted light **L4R** converged by the converging lens **55** differs from that of the diffracted light **L6R** converged by the converging lens **55**. Therefore, the photo detector **57** for detecting the intensity of the transmitted light **L4R** and the photo detector **63** for detecting the intensity of the diffracted light **L6R** are required.

Accordingly, even though pieces of information are recorded or reproduced on or from an information medium, the information can be reliably recorded or reproduced on or from the information medium regardless of whether the information medium is thick or thin.

Also, because the diffracted light **L6** formed in the hologram lens **42** converges before the diffracted light **L6** is incident on the objective lens **27**, the distance in an optical axis direction between the converging spots **S5**, **S6** can be lengthened to about 1 mm. Therefore, even though the transmitted light **L4** (or the diffracted light **L6**) is converged on the converging spot **S6** (or **S5**) in focus to record or read a piece of information, the light **L6** (or **L4**) is not converged on the converging spot **S6** (or **S5**) in focus to reduce the intensity of the light **L6** (or **L4**) at the converging spot **S6** (or **S5**). Accordingly, no adverse influence is exerted on the recording or reproduction of the information

Also, because the hologram lens **42** functions as a convex lens for the first-order diffracted light **L6**, the occurrence of a chromatic aberration can be prevented in the optical head apparatus **111**.

An example of the utilization of the optical head apparatus **111** for various types of optical disks is described.

In cases where the optical head apparatus **111** is utilized for an optical disk device in which pieces of information recorded in a thin type of high density optical disk **23** are recorded or reproduced and pieces of information recorded in a thick type of optical disk **25** are exclusively reproduced, the diffraction efficiency of the hologram lens **26M** or **42** in the compound objective lens **29M**, **43**, **45**, **46** or **47** for changing a beam of light to a beam of first-order diffracted light is set to a value equal to or higher than 55%. Therefore, in cases where a piece of information recorded on the thick type of optical disk **25** is reproduced in the photo detector **57**, a signal-noise ratio of each of the servo signals and the information signal obtained in the photo detector **57** can be enhanced because the transmitted light **L4R** diffracted by the hologram lens **26M** or **42** at a high diffraction efficiency is utilized to obtain the servo signals and the information signal. In other words, a utilization efficiency of the incident light **L3** can be enhanced when a piece of information recorded on the thick type of optical disk **25** is reproduced, so that the output power of the incident light **L3** can be minimized. Also, even though a high intensity of the diffracted light **L6** is required to record a piece of information on the high density optical disk **23**, the recording of the information can be reliably performed without increasing the intensity of the incident light **L3** because the diffraction efficiency of the hologram lens **26M** or **42** for the incident light **L3** and the diffracted light **L6R** is high. Also, in cases where a piece of information recorded on the high density optical disk **23** is reproduced in the photo detector **63**, a signal-noise ratio of each signal obtained in the photo detector **63** can be enhanced because the diffraction efficiency of the hologram lens **26M** or **42** for the light **L3**, **L6R** is high.

(Thirteenth Embodiment)

An optical head apparatus with the compound objective lens **29M**, **43**, **45**, **46** or **47** in which the incident light **L3** is efficiently utilized to obtain an information

signal and servo signals is described with reference to FIG. **44** according to a thirteenth embodiment of the present invention.

FIG. **44** is a constitutional view of an optical head apparatus according to a thirteenth embodiment.

As shown in FIG. **44**, an optical head apparatus **121** for recording or reproducing pieces of information on or from the information medium **23** or **25**, comprises the light source **52**, the collimator lens **53**, the beam splitter **54**, the compound objective lens **43** (or **29M**, **45**, **46** or **47**) composed of the hologram lens **42** (or **26M** or **32**) and the objective lens **27**, the actuating unit **58**, the converging lens **55**, the beam splitter **92** having the reflection type of hologram **93**, the photo-detector **63**, and the photo detector **57**.

In the above configuration, the transmitted light L4 and the diffracted light L6 are converged by the converging lens **27** in the same manner as in the twelfth embodiment. Thereafter, in cases where a piece of information is recorded or reproduced on or from the first information medium **23**, the diffracted light L6 is converged on the first information medium **23** to form the converging spot S5. Thereafter, a beam of diffracted light L6R reflected by the first information medium **23** passes through the same optical path in the reverse direction, and a large part of the diffracted light L6R is diffracted by the hologram lens **42**. Therefore, the diffracted light L6R transmits on the incoming optical path agreeing with the outgoing optical path in the same manner as in the twelfth embodiment. Thereafter, the diffracted light L6R is reflected by the beam splitter **54** and is converged by the converging lens **55** on the beam splitter **92** to form a converging spot on the reflection type of hologram **93** of the beam splitter **92**. Therefore, all of the diffracted light L6R is diffracted and reflected by the hologram **93** to be converged on the photo detector **57** in the same manner as in the tenth embodiment. Therefore, an information signal and servo signals such as a focus error signal and a tracking error signal are obtained in the same manner as in the sixth embodiment.

In contrast, in cases where a piece of information is recorded or reproduced on or from the second information medium **25**, the transmitted light L4 is converged on the second information medium **25** to form the converging spot S6. Thereafter, a beam of transmitted light L4R reflected by the second information medium **25** passes through the same optical path in the reverse direction. That is, a large part of the transmitted light L4R is collimated by the objective lens **27** on the incoming optical path. Thereafter, a great part of the transmitted light L4R is diffracted by the hologram lens **42**. Therefore, the transmitted light L4R transmits on the incoming optical path differing from the outgoing optical path in the same manner as in the twelfth embodiment. Thereafter, the transmitted light L4R is reflected by the beam splitter **54** and is converged by the converging lens **55**. Thereafter, a large part of the transmitted light L4R transmits through the beam splitter **92**. In this case, an astigmatic aberration is generated in the transmitted light L4R. Thereafter, the transmitted light L4R is converged on the photo detector **63** to form a converging spot **S19** of which the shape is the same as the converging spot **S10** shown in FIGS. **29A** to **29C**, and the intensity of the transmitted light L4R is detected in the photo detector **63**. Therefore, an information signal and servo signals such as a focus error signal and a tracking error signal are obtained in the same manner as in the seventh embodiment.

In the thirteenth embodiment, because the transmitted light L4R is diffracted by the hologram lens **42**, the converging spot **S19** formed on the photo detector **63** does not relate to a radiation point of the light source **52** in a mirror image. Therefore, the photo detector **57** for detecting the intensity of the diffracted light L6R and the photo detector **63** for detecting the intensity of the transmitted light L4R are required.

Accordingly, because the compound objective lens having two focal points is utilized in the optical head apparatus **121**, pieces of information can be reliably recorded or reproduced on or from an information medium regardless of whether the information medium is thick or thin.

Also, because the diffracted light L6 formed in the hologram lens **42** converges before the diffracted light L6 is incident on the objective lens **27**, the distance in an optical axis direction between the converging spots S5, S6 can be lengthened to about 1 mm. Therefore, even though the transmitted light L4 (or the diffracted light L6) is converged on the converging spot S6 (or S5) in focus to record or read a piece of information, the light L6 (or L4) is not converged on the converging spot S6 (or S5) in focus to reduce the intensity of the light L6 (or L4) at the converging spot S6 (or S5). Accordingly, no adverse influence is exerted on the recording or reproduction of the information

Also, because the hologram lens **42** functions as a convex lens for the first-order diffracted light L6, the occurrence of a chromatic aberration can be prevented in the optical head apparatus **121**.

An example of the utilization of the optical head apparatus **121** for various types of optical disks is described.

In cases where the optical head apparatus **121** is utilized for an optical disk device in which pieces of information recorded in a thin type of high density optical disk **23** are recorded or reproduced and pieces of information recorded in a thick type of optical disk **25** are exclusively reproduced, the diffraction efficiency of the hologram lens **26M** or **42** in the compound objective lens **29M**, **43**, **45**, **46** or **47** for changing a beam of light to a beam of first-order diffracted light is set to a value equal to or higher than 70%. Therefore, in cases where a piece of information recorded on the thick type of optical disk **25** is reproduced in the photo detector **57**, a signal-noise ratio of each of the servo signals and the information signal obtained in the photo detector **57** can be enhanced because the transmitted light L4R diffracted by the hologram lens **26M** or **42** at a high diffraction efficiency is utilized to obtain the servo signals and the information signal. In other words, a utilization efficiency of the incident light L3 can be enhanced when a piece of information recorded on the thick type of optical disk **25** is reproduced, so that the output power of the incident light L3 can be minimized. Also, even though a high intensity of the diffracted light L6 is required to record a piece of information on the high density optical disk **23**, the recording of the information can be reliably performed without increasing the intensity of the incident light L3 because the diffraction efficiency of the hologram lens **26M** or **42** for the incident light L3 and the diffracted light L6R is high. Also, in cases where a piece of information recorded on the high density optical disk **23** is reproduced in the photo detector **63**, a signal-noise ratio of each signal obtained

in the photo detector **63** can be enhanced because the diffraction efficiency of the hologram lens **26M** or **42** for the light L3, L6R is high.

(Fourteenth Embodiment)

An optical head apparatus in which noises included in an information signal are reduced is described with reference to FIGS. **45**, **46** according to a fourteenth embodiment of the present invention.

FIG. **45** is a constitutional view of an optical head apparatus according to a fourteenth embodiment. FIG. **46** is a plan view of a hologram lens utilized in the optical head apparatus shown in FIG. **45**.

As shown in FIG. **45**, an optical head apparatus **131** for recording or reproducing pieces of information on or from the information medium **23** or **25**, comprises the light source **52**, a beam splitter **132** having a polarizing separation film **133** on its surface for reflecting the incident light L3 radiated from the light source **52** on an outgoing optical path and transmitting through the light L4R or L5R reflected on the information medium **23** or **25** on an incoming optical path, a collimator lens **134** for collimating the incident light L3 on the outgoing optical path and converging the light L4R or L5R on the incoming optical path, a hologram lens **135** for transmitting a part of the incident light L3 without any diffraction and diffracting a remaining part of the incident light L3, the $\frac{1}{4}$-λ plate **69**, the objective lens **27**, the actuating unit **58**, and a photo detector **136** for detecting the light transmitting through or diffracted by the hologram lens **135** on the incoming optical path.

As shown in FIG. **46**, the hologram lens **135** is formed by drawing the grating pattern P1 in a central region **135***a* of the transparent substrate **28** and a grating pattern P12 in a peripheral region **135***b* surrounding the central region **135***a*. The grating pattern P12 is drawn in a non-concentric shape. Because the grating pattern P1 are drawn in the hologram lens **135**, a compound objective lens **137** having two focal points is composed of the hologram lens **135** and the objective lens **27**. Light passing through the peripheral region **135***b* of the hologram lens **135** is detected by the photo detector **136** to cancel noises included in an information signal. An optical axis of the optical head apparatus **131** passes through a central point of the grating pattern P1 and a central axis of the objective lens **27**.

The photo detector **136** comprises the quadrant photo-detector **64** having the detecting sections SE7 to SE10 and a noise cancelling photo detector **138** for detecting the intensity of light passing through the peripheral region **135***b* of the hologram lens **135**. Because the grating pattern P12 of the peripheral region **135***b* is drawn in the non-concentric shape, light diffracted in the peripheral region **135***b* is not converged on the detecting sections SE7 to SE10.

In the above configuration, the incident light L3 linearly polarized in a first direction is radiated from the light source **52** and is reflected by the beam splitter **132** because the polarizing separation film **133** functions as a mirror for the incident light L3 linearly polarized in the first direction. Therefore, the incident light L3 is directed in an upper direction and is collimated by the collimator lens **134**. Thereafter, a part of the incident light L3 incident on the central region **135***a* of the hologram lens **135** transmits through the central region **135***a* without any diffraction to form the transmitted light L4, and a remaining part of the incident light L3 incident on the central region **135***a* of the hologram lens **135** is diffracted in the central region **135***a* to form the diffracted light L5. Also, a part of the incident light L3 incident on the peripheral region **135***b* of the hologram lens **135** transmits through the peripheral region **135***b* without any diffraction to form a beam of noise cancelling light L14. Thereafter, the light L4, L5 and L14 pass through the $\frac{1}{4}$-λ plates so that the light L4, L5 and L14 linearly polarized in the first direction is changed to the light L4, L5 and L14 circularly polarized. Thereafter, the light L4, L5 and L14 are converged by the converging lens **27**.

Thereafter, in cases where a piece of information is recorded or reproduced on or from the first information medium **23** (or the second information medium **25**), the transmitted light L4 (or the diffracted light L5) is converged on the information medium **23** (or **25**) to form the converging spot S1 (or S2). Thereafter, a beam of transmitted light L4R (or a beam of diffracted light L5R) reflected by the information medium **23** (or **25**) passes through the same optical path in the reverse direction. That is, the transmitted light L4R (or the diffracted light L5R) is circularly polarized in reverse and again passes through the converging lens **27** and the $\frac{1}{4}$-λ plate **69**. Therefore, the light L4R (or L5R) is linearly polarized in a second direction perpendicular to the first direction. Thereafter, a part of the transmitted light L4R transmits through the central region **135***a* of the hologram lens **135** without any diffraction, or a part of the diffracted light L5R is again diffracted in the central region **135***a*. Thereafter, the transmitted light L4R (or the diffracted light L5R) is converged by the collimator lens **134** and passes through the beam splitter **132** without any reflection because the polarizing separation film **133** functions as a transparent plate for the light L4R (or L5R) linearly polarized in the second direction. In this case, an astigmatic aberration is generated in the transmitted light L4R (or the diffracted light L5R) in the same manner as in the seventh embodiment. Thereafter, the transmitted light L4R (or the diffracted light L5R) is incident on the detecting sections SE7 to SE10 of the photo detector **136** to form a converging spot S20 of which the shape is the same as the converging spot S10 shown in FIGS. **29A** to **29C**. The intensity of the transmitted light L4R (or the diffracted light L5R) is changed to electric current signals SC21 to SC24 in the detecting sections SE7 to SE10. Therefore, servo signals such as a focus error signal and a tracking error signal are obtained in the same manner as in the seventh embodiment, so that the position of the compound objective lens **137** is adjusted to converge the transmitted light L4 (or the diffracted light L5) on the information medium **23** (or **25**) in focus. Also, an information signal expressing a piece of information recorded on the information medium **23** (or **25**) is obtained according to an equation (12).

$$S_{in}=SC21+SC22+SC23+SC24 \quad (12)$$

Also, the noise cancelling light L14 is converged on the information medium **23** to form a converging spot surrounding the converging spot S1. Thereafter, a beam of noise cancelling light L14R reflected by the first information medium **23** passes through the same optical path in the reverse direction. That is, the noise cancelling light L14R again passes through the converging lens **27** and the $\frac{1}{4}$-λ plate **69**, and a part of the noise cancelling light L14R is diffracted and converged in the peripheral region **135***b* of the hologram lens **135** and is

incident on the noise cancelling photo detector **138**. In the photo detector **138**, an output signal SC25 is generated according to the intensity of the noise cancelling light L14R. Thereafter, a noise cancelled information signal S_{nc} expressing a piece of information recorded on the first information medium **23** is obtained by adding all of the signals according to an equation (13):

$$S_{nc}=(SC21+SC22+SC23+SC24)+R\times SC25 \quad (13),$$

where the symbol R is a weighting factor.

In this case, because the term R×SC25 is added to obtain the information signal S_{nc}, inverse influence of noises included in the term (SC21+SC22+SC23+SC24) on the noise cancelled information signal S_{nc} can be reduced. The reason is described.

As is well known (for example, Japanese Patent Gazette No. 22452 of 1990 laid open to public inspection on Jul. 23, 1985 under Provisional Publication No. 138748 of 1985 and Published Unexamined Patent Application No. 131245 of 1986), signals expressing pieces of information recorded on an optical disk shifts to a higher frequency as the density of the information recorded becomes high. Also, the amplitude of a signal having a high frequency becomes low as compared with that of a signal having a low frequency in cases where the signals are produced according to light passing through a central region of a hologram lens. In contrast, the amplitude of a signal having a high frequency is emphasized in cases where the signal is produced according to light passing through a peripheral region of the hologram lens. Therefore, in cases where the information signal S_{nc} is obtained according to the equation (13), high frequency components included in the information signal She is emphasized, and low frequency noise components included in the term (SC21+SC22+SC23+SC24) are comparatively reduced. As a result, a signal-noise ratio in the information signal S_{nc} can be enhanced.

Accordingly, because the compound objective lens having two focal points is utilized in the optical head apparatus **131**, pieces of information can be reliably recorded or reproduced or or from an information medium regardless of whether the information medium is thick or thin.

Also, even though pieces of information are densely recorded in a thin type of high density optical disk represented by the first information medium **23**, the information signal S_{nc} can be reliably reproduced at a high signal-noise ratio.

Also, because the intensity of the light L4R or L5R incident on the detecting sections SE7 to SE10 of the photo detector **136** is reduced by converging the noise cancelling light L14R on the photo detector **138**, a positioning accuracy of the photo detector **136** can be coarsely lowered to 1/100.

Also, in cases where the grating pattern P12 of the peripheral region **135***b* functions as a lens for the incident light L3 diffracted in the peripheral region **135***b*, unnecessary diffracted light generated in the peripheral region **135***b* on the outgoing optical path forms a comparatively large converging spot in defocus on the first information medium **23**. Therefore, pieces of information recorded on the first information medium **23** are read by the unnecessary diffracted light, and the information are treated as a piece of averaged information in the photo detector **136** even though the unnecessary diffracted light is incident on the photo detector **136**. Accordingly, the information read by the unnecessary diffracted light does not adversely influence on the information signal S_{nc} as a noise.

Also, in cases where a transmission efficiency of the peripheral region **135***b* of the hologram lens **135** is set to agree with another transmission efficiency of the central region **135***a*, secondary maxima (or side lobes) occurring around the converging spot S1 can be lowered as compared with the first embodiment. Accordingly, a signal-noise ratio in the information signal S_{nc} can be enhanced.

(Fifteenth Embodiment)

An optical head apparatus in which noises included in an information signal are reduced is described with reference to FIGS. **47** to **49** according to a fifteenth embodiment of the present invention.

FIG. **47** is a constitutional view of an optical head apparatus according to a fifteenth embodiment. FIG. **48** is a plan view of a hologram lens utilized in the optical head apparatus shown in FIG. **47**.

As shown in FIG. **47**, an optical head apparatus **141** for recording or reproducing pieces of information on or from the information medium **23** or **25**, comprises the light source **52**, the beam splitter **82**, the collimator lens **134**, a hologram lens **142** for transmitting a part of the incident light L3 without any diffraction and diffracting a remaining part of the incident light L3, the objective lens **27**, the actuating unit **58**, and a photo detector **143** for detecting the light transmitting through or diffracted by the hologram lens **142** on the incoming optical path.

As shown in FIG. **48**, the hologram lens **142** is partitioned into a central region **142***a* in which the grating pattern P1 is drawn, a pair of side peripheral regions **142***b*, **142***c* in which grating patterns P13, P14 are drawn to cancel noises included in an information signal, and a pair of no-designed regions **142***d*, **142***e* in which no grating pattern is drawn not to reduce the intensity of light. Because the grating pattern P1 are drawn in the hologram lens **135**, a compound objective lens **144** having two focal points is composed of the hologram lens **142** and the objective lens **27**. An optical axis of the optical head apparatus **141** passes through a central point of the grating pattern P1 and a central axis of the objective lens **27**.

The photo detector **143** comprises the quadrant photo-detector **64** having the detecting sections SE7 to SE10, a pair of noise cancelling photo detector **138***a*, **138***b* for detecting the intensity of light passing through the peripheral region **142***b*, **142***c* of the hologram lens **142**.

In the above configuration, the transmitted light L4 (or the diffracted light L5) generated in the central region **142**a of the hologram lens **142** is converged on the first information medium **23** (or the second information medium **25**) in an outgoing optical path to form the converging spot S1 (or S2). Thereafter, the transmitted light L4R (or the diffracted light L5R) passes through the same optical path in the reverse direction. That is, the transmitted light L4R (or the diffracted light L5R) again passes through the converging lens **27**, and a part of the transmitted light L4R transmits through the central region **142***a* of the hologram lens **142** without any diffraction or a part of the diffracted light L5R is again diffracted in the central region **142***a*. Thereafter, the transmitted light L4R (or the diffracted light L5R) is

converged by the collimator lens **134** and passes through the beam splitter **82**. In this case, an astigmatic aberration is generated in the transmitted light L4R (or the diffracted light L5R) in the same manner as in the seventh embodiment. Thereafter, the transmitted light L4R (or the diffracted light L5R) is incident on the detecting sections SE7 to SE10 of the photo detector **143** to form a converging spot S21 of which the shape is the same as the converging spot S10 shown in FIGS. **29**A to **29**C. The intensity of the transmitted light L4R (or the diffracted light L5R) is changed to electric current signals SC26 to SC29 in the detecting sections SE7 to SE10. Therefore, servo signals such as a focus error signal and a tracking error signal are obtained in the same manner as in the seventh embodiment, so that the position of the compound objective lens **144** is adjusted to converge the transmitted light L4 (or the diffracted light L5) on the information medium **23** (or **25**) in focus. Also, an information signal recorded on the second information medium **25** is obtained according to an equation (14).

$$S_{in}=SC26+SC27+SC28+SC29 \quad (14)$$

Also, a part of the incident light L3 incident on the peripheral region **142***b* of the hologram lens **142** transmits through the peripheral region **142***b* without any diffraction to form a beam of noise cancelling light L15, and a part of the incident light L3 incident on the peripheral region **142***c* of the hologram lens **142** transmits through the peripheral region **142***c* without any diffraction to form a beam of noise cancelling light L16. Thereafter, the noise cancelling light L15, L16 are converged on the information medium **23** to form a converging spot surrounding the converging spot S1. Thereafter, beams of noise cancelling light L15R, L16R reflected by the first information medium **23** passes through the same optical path in the reverse direction. That is, the noise cancelling light L15R, L16R again passes through the converging lens **27**. A part of the noise cancelling light L15R is diffracted and converged in the peripheral region **142***b* of the hologram lens **142** and is incident on the noise cancelling photo detector **138***a*, and a part of the noise cancelling light L16R is diffracted and converged in the peripheral region **142***c* of the hologram lens **142** and is incident on the noise cancelling photo detector **138***b*. In the photo detector **138***a*, an output signal SC30 is generated according to the intensity of the noise cancelling light L15R. Also, an output signal SC31 is generated according to the intensity of the noise cancelling light L16R in the photo detector **138***b*. Thereafter, a noise cancelled information signal S_{nc} expressing the information recorded on the first information medium **23** is obtained by adding all of the signals according to an equation (15):

$$S_{nc}=(SC26+SC27+SC28+SC29)+R\times(SC30+SC31) \quad (15),$$

where the symbol R is a weighting factor.

Accordingly, because the compound objective lens having two focal points is utilized in the optical head apparatus **141**, pieces of information can be reliably recorded or reproduced from an information medium regardless of whether the information medium is thick or thin.

Also, a signal-noise ratio in the information signal S_{nc} can be enhanced in the same manner as in the fourteenth embodiment.

Also, even though pieces of information are densely recorded in a thin type of high density optical disk represented by the first information medium **23**, the information signal S_{nc} can be reliably reproduced at a high signal-noise ratio.

Also, because the intensity of the light L4R or L5R incident on the detecting sections SE7 to SE10 of the photo detector **143** is reduced by converging the noise cancelling light L15R, L16R on the photo detectors **138***a*, **138***b*, a positioning accuracy of the photo detector **143** can be coarsely lowered to 1/100.

Also, in cases where the grating patterns P13, P14 of the peripheral regions **142***b*, **142***c* functions as a lens for the incident light L3 diffracted in the peripheral region **142***b*, **142***c*, unnecessary diffracted light generated by diffracting the incident light L3 in the peripheral regions **142***b*, **142***c* on the outgoing optical path forms a comparatively large converging spot in defocus on the first information medium **23**. Also, an numerical number of each of the peripheral regions **142***b*, **142***c* is lowered as compared with that of the region **135***b* in the fourteenth embodiment because the hologram lens **142** are partitioned into many fields. Therefore, the size of the converging spot of the unnecessary diffracted light formed in defocus on the first information medium **23** becomes larger than that in the fourteenth embodiment. As a result, more pieces of information recorded on the first information medium **23** are read by the unnecessary diffracted light, and the information are treated as a piece of averaged information in the photo detector **143** even though the unnecessary diffracted light is incident on the photo detector **143**. Accordingly, the information read by the unnecessary diffracted light is moreover averaged, and the averaged information does not adversely influence on the information signal S_{nc} as a noise.

Also, as shown in FIGS. **49**A, **49**B, the unnecessary diffracted light can be prevented from being incident on the photo detector **64** in which each of the detecting sections SE7 to SE10 has SL0 square in size. In detail, in cases where light generated in the peripheral region **142***c* on the outgoing optical path is again diffracted in the peripheral region **142***b* to form a beam of unnecessary diffracted light Lu_1, the light Lu_1 is converged on a first position PT1 spaced SP1 (SP1>SL0) from the center of the photo detector **64**. In cases where light generated in the peripheral region **142***b* on the outgoing optical path is again diffracted in the peripheral region **142***c* to form a beam of unnecessary diffracted light Lu_2, the light Lu_2 is converged on a second position PT2 spaced SP2 (SP2>SL0) from the center of the photo detector **64**. In cases where light generated in the peripheral regions **142***b*, **142***c* on the outgoing optical path are again diffracted in the same peripheral regions **142***b*, **142***c* to form beams of unnecessary diffracted light Lu_3, Lu_4, the light Lu_3, Lu_4 are converged on third and fourth position PT3, PT4 spaced SP3 (SP3>SL0), SP4 (SP4>SL0) from the center of the photo detector **64**. Accordingly, the adverse influence of the unnecessary diffracted light Lu_1 to Lu_4 can be prevented.

In cases where the light source **52** is formed of a semiconductor laser, a far field pattern of the incident light L3 incident on the hologram lens **142** is distributed in the Gaussian distribution as shown in FIG. **13**A, and a cross-sectional beam profile of the incident light L3

distributed in the Gaussian distribution is in an elliptic shape. That is, a beam divergent angle (or a full angle at half maximum) of the incident light L3 in a perpendicular direction is larger than that in a horizontal direction. In this embodiment, the perpendicular direction of the incident light L3 is directed in an X2 direction shown in FIG. **48**, and the horizontal direction of the incident light L3 is directed in a Y2 direction shown in FIG. **48**. In this case, because a transmission efficiency of the regions **142***b*, **142***c* for the incident light L3 is smaller than that of the regions **142***d*, **142***e*, the intensity of the incident light L3 transmitting through the hologram lens **142** without any diffraction is largely reduced in the perpendicular direction as compared with that in the horizontal direction. Therefore, the cross-sectional beam profile of the incident light L3 is corrected to a circular shape in the hologram lens **142**. That is, the converging spot S1 formed on the first information medium **23** is corrected to the circular shape. Accordingly, secondary maxima (or side lobes) occurring around the converging spot S1 can be lowered, and a signal-noise ratio of the information signal S_{nc} can be enhanced.

In the fifteenth embodiment, the noise cancelled information signal S_{nc} is obtained according to the equation (15). However, it is preferred that the noise cancelled information signal S_{nc} be obtained according to the equation (16):

$$S_{nc}=(SC26+SC27+SC28+SC29)+(R1\times SC30+-R2\times SC31) \quad (16),$$

where the symbols R1,R2 are weighting factors. In this case, the noises included in the information can be moreover reduced.

(Sixteenth Embodiment)

An optical head apparatus manufactured in a small size and stably operated is described with reference to FIGS. **50**, **51** according to a sixteenth embodiment of the present invention.

FIG. **50** is a constitutional view of an optical head apparatus according to a sixteenth embodiment. FIG. **51** is a diagonal view of a light source and photo detectors utilized in the optical head apparatus shown in FIG. **50**.

As shown in FIG. **50**, an optical head apparatus **151** for recording or reproducing pieces of information on or from the information medium **23** or **25**, comprises the light source **52** for radiating the incident light L3 linearly polarized in a non-diffracting direction parallel to an X3 axis, an holographic element **152** for transmitting through the incident light L3 without any diffraction on an outgoing optical path and diffracting the transmitted light L4R or the diffracted light L5R linearly polarized in a diffracting direction parallel to a Y3 axis on an incoming optical path, the collimator lens **53**, the $\frac{1}{4}$-λ plate **69**, the hologram lens **26** (or **26M**, **32**, **33**, **42**, **135** or **142**), the objective lens **27**, the actuating unit **58**, and a photo detector **153** for detecting the intensity of the light L4R or L5R diffracted by the holographic element **152**.

As shown in FIG. **51**, the light source **52** and the photo detector **153** are located on a substrate **154** to precisely fix a relative position between the light source **52** and the photo detector **153**. The photo detector **153** comprises the sextant photo-detector **59** having the detecting sections SE1 to SE6 and the tracking photo-detectors **60***a* to **60***d*. Also, a mirror element **155** is located on the substrate **154** to direct the incident light L3 radiated from the light source **52** in a Z3 direction.

The holographic element **152** is produced by proton-exchanging surface parts of a lithium niobate substrate or by utilizing a liquid crystal cell, as is described in Provisional Publication No. 189504/86 (S61-189504) and Provisional Publication No. 241735/88 (S63-241735). Therefore, light linearly polarized in a non-diffracting direction parallel to an X3 axis transmits through the holographic element **152** without any diffraction. In contrast, light linearly polarized in a diffracting direction parallel to a Y3 axis which is perpendicular to the X3 axis is diffracted by the holographic element **152**.

In the above configuration, the incident light L3 linearly polarized in a non-diffracting direction parallel to an X3 axis is radiated from the light source **52** and transmits through the holographic element **152** without any diffraction. Thereafter, the incident light L3 is collimated by the collimator lens **53**, and the incident light L3 linearly polarized is changed to the incident light L3 circularly polarized by the $\frac{1}{4}$-λ plate **69**. Thereafter, a part of the incident light L3 transmits through the hologram lens **26** without any diffraction to form the transmitted light L4, and a remaining part of the incident light L3 is diffracted by the hologram lens **26** to form the diffracted light L5. Thereafter, the light L4, L5 are converged by the objective lens **27**, and the converging spot S1 of the transmitted light L4 (or the converging spot S2 of the diffracted light L5) is formed on the first information medium **23** (or the second information medium **25**). When the light L4 or L5 is reflected by the information medium **23** (or **25**) and is changed to the light L4R (or L5R), a rotational direction of the circular polarization in the light L4 is reversed. Therefore, the light L4R (or L5R) having the reversed circular polarization passes through the same optical path in the opposite direction. That is, the transmitted light L4R (or the diffracted light L5R) again passes through the converging lens **27**, and a part of the transmitted light L4R transmits through the hologram lens **142** without any diffraction or a part of the diffracted light L5R is again diffracted by the hologram lens **142**. Thereafter, the transmitted light L4R (or the diffracted light L5R) circularly polarized in reverse is changed to the light L4R (or L5R) linearly polarized in a diffracting direction parallel to a Y3 axis by the $\frac{1}{4}$-λ plate **69**. Thereafter, the light L4R (or L5R) is converged by the collimator lens **53** and is diffracted by the holographic element **152** to form a plurality of converging spots on the photo detectors **153**. Therefore, an information signal expressing a piece of information recorded on the information medium **23** (or **25**) and servo signals such as a focus error signal and a tracking error signal are obtained in the photo detector **153** in the same manner as in the sixth embodiment.

Accordingly, because the compound objective lens having two focal points is utilized in the optical head apparatus **151**, pieces of information can be reliably recorded or reproduced or or from an information medium regardless of whether the information medium is thick or thin.

Also, because all of the incident light L3 transmits through the holographic element **152** on the outgoing optical path and because all of the light L4R or L5R is diffracted by the holographic element **152** on the incoming optical path, a utilization efficiency of the inci-

dent light L3 can be enhanced. Therefore, even though a radiation intensity of the incident light L3 in the light source **52** is low, the information signal and the servo signals having a high signal-noise ratio can be reliably obtained.

Also, because no beam splitter is utilized in the optical head apparatus **151**, the optical head apparatus **151** can be manufactured at a small size, in a light weight, and at a low cost.

Also, because optical parts of the optical head apparatus **151** are located along its optical axis, the optical head apparatus **151** stably operated can be obtained even though a circumstance temperature largely varies and the apparatus is operated for a long time.

Also, because the light L4R or L5R transmitting through the holographic element **152** without any diffraction on the incoming optical path is not required, it is preferred that a diffraction efficiency of the holographic element **152** be heightened to set a transmission efficiency of the holographic element **152** to almost zero. In this case, a combination of the holographic element **152** and the $\frac{1}{4}$-λ plate **69** function functions as an isolator to prevent the light L4R or L5R from returning to the light source **52**. Therefore, in cases where a semiconductor laser is utilized as the light source **52**, any light does not return to an active layer of the semiconductor laser. Accordingly, noises induced by the light returning to the semiconductor laser can be prevented.

Also, because the light source **52** and the photo detector **153** are located on the same substrate **154**, the light source **52** and the photo detector **153** can be closely arranged each other. Therefore, a relative position between the light source **52** and the photo detector **153** can be easily set at a high accuracy. For example, the relative position can be set at an accuracy within several μm. Accordingly, a manufacturing cost of the optical head apparatus **151** can be lowered, and the optical head apparatus **151** can be moreover manufactured at a small size, in a light weight, and at a low cost.

Also, the light source **52** is electrically connected with an external circuit through first wirings, and the photo detector **153** is electrically connected with another external circuit through second wirings. In this case, because the light source **52** and the photo detector **153** are located on the same substrate **154**, the first and second wirings can pass on an X3-Y3 plane in common. Therefore, the light source **52** and the photo detector **153** can be easily and automatically connected with the external circuits. In addition, because reference lines required to connect the light source **52** and the photo detector **153** with the external circuits are only drawn on the X3-Y3 plane, the relative position between the light source **52** and the photo detector **153** can be easily set at a high accuracy.

In the sixteenth embodiment, the optical head apparatus **151** with the holographic element **152** is described. However, in cases where the intensity of the incident light L3 is sufficient, it is applicable that a hologram having a small grating pitch or a blazed hologram be utilized in place of the holographic element **152**. In this case, pieces of information can be reliably recorded or reproduced on or from an information medium regardless of whether the information medium is thick or thin. Also, because no beam splitter is utilized in the optical head apparatus **151**, the optical head apparatus **151** can be manufactured at a small size, in a light weight, and at a low cost. Also, because optical parts of the optical head apparatus **151** are located along its optical axis, the optical head apparatus **151** stably operated can be obtained even though a circumstance temperature largely varies and the apparatus is operated for a long time.

(Seventeenth Embodiment)

An optical head apparatus manufactured in a small size and stably operated is described with reference to FIG. **52** according to a seventeenth embodiment of the present invention.

FIG. **52** is a constitutional view of an optical head apparatus according to a seventeenth embodiment.

As shown in FIG. **52**, an optical head apparatus **161** for recording or reproducing pieces of information on or from the information medium **23** or **25**, comprises the light source **52** for radiating the incident light L3 linearly polarized in a first direction, the collimator lens **53**, a polarizing separation film **162** formed on a front surface of a transparent substrate **162** for reflecting the incident light L3 linearly polarized in the first direction and transmitting light linearly polarized in a second direction perpendicular to the first direction, the $\frac{1}{4}$-λ plate **69**, the hologram lens **26** (or **26M**, **32**, **33**, **42**, **135** or **142**), the objective lens **27**, the actuating unit **58**, a reflection-type hologram **164** formed on a rear surface of the transparent substrate **162** for diffracting and reflecting the light L4R, L5R, and the photo detector **57**.

In the above configuration, the incident light L3 linearly polarized in a first direction is radiated from the light source **52** and is collimated by the collimator lens **53**. Thereafter, all of the incident light L3 is reflected by the polarizing separation film **162** because the incident light L3 is linearly polarized in the first direction. Therefore, the incident light L3 is directed in an upper direction. Thereafter, the linear polarization of the incident light L3 is changed to a circular polarization in the $\frac{1}{4}$-λ plate **69**, and a part of the incident light L3 transmits through the hologram lens **26** to form the transmitted light L4. Also, a remaining part of the incident light L3 is diffracted by the hologram lens **26** to form the diffracted light L5. Thereafter, the light L4, L5 are converged by the objective lens **27**, and the converging spot S1 of the transmitted light L4 (or the converging spot S2 of the diffracted light L5) is formed on the first information medium **23** (or the second information medium **25**). Thereafter, the transmitted light L4R (or the diffracted light L5R) circularly polarized in reverse again passes through the converging lens **27** in the same manner as in the sixteenth embodiment, and a part of the transmitted light L4R transmits through the hologram lens **26** without any diffraction or a part of the diffracted light L5R is again diffracted by the hologram lens **26**. Thereafter, the transmitted light L4R (or the diffracted light L5R) circularly polarized in reverse is changed to the light L4R (or L5R) linearly polarized in a second direction perpendicular to the first direction by the $\frac{1}{4}$-λ plate **69**. Thereafter, all of the light L4R (or L5R) is refracted by the polarizing separation film **162** and is diffracted and reflected by the hologram **164**. Thereafter, the light L4R (or L5R) transmits through the polarizing separation film **162** and is converged by the collimator lens **53** to form a plurality of converging spots on the photo detector **57**. Therefore, an information signal expressing a piece of information recorded on the information medium **23** (or **25**) and servo signals such as a focus error signal and a tracking error signal are obtained in the photo detector **57** in the same manner as in the sixth embodiment.

Accordingly, because the compound objective lens having two focal points is utilized in the optical head apparatus **161**, pieces of information can be reliably recorded or reproduced on or from an information medium regardless of whether the information medium is thick or thin.

Also, because the incident light L3 incident on the polarizing separation film **162** is collimated, a reflectivity for the incident light L3 is uniform over the entire film **162**. Therefore, a diffraction-limited spot of the light L4 or L5 can be easily formed on the information medium **23** or **25**. Also, because the light L4R, L5R incident on the polarizing separation film **162** are collimated, a transmissivity for the light L4R, L5R is uniform over the entire film **162**. Therefore, an offset occurring in the servo signals can be prevented.

Also, because all of the incident light L3 transmits through the hologram **164** on the outgoing optical path and because all of the light L4R or L5R is diffracted by the hologram **164** on the incoming optical path, a utilization efficiency of the incident light L3 can be enhanced. Therefore, even though a radiation intensity of the incident light L3 in the light source **52** is low, the information signal and the servo signals having a high signal-noise ratio can be reliably obtained.

Also, because a hybrid element composed of the film **162**, the substrate **163** and the hologram **164** functions as a beam splitter and a rising mirror, the optical head apparatus **161** can be manufactured at a small size, in a light weight, and at a low cost.

Also, because optical parts of the optical head apparatus **161** are located along its optical axis, the optical head apparatus **161** stably operated can be obtained even though a circumstance temperature largely varies and the apparatus is operated for a long time.

Also, a combination of the film **162** and the $\frac{1}{4}$-λ plate **69** function functions as an isolator to prevent the light L4R or L5R from returning to the light source **52**. Therefore, in cases where a semiconductor laser is utilized as the light source **52**, any light does not return to an active layer of the semiconductor laser. Accordingly, noises induced by the light returning to the semiconductor laser can be prevented.

Also, it is preferred that the hologram **164** be blazed. In this case, because the generation of unnecessary diffracted light such as minus first-order diffracted light in the hologram **164** is prevented, a diffraction efficiency of the hologram **164** for changing light to first-order diffracted light can be set to almost 100%. Therefore, the incident light L3 can be efficiently utilized to obtain the signals.

Also, because light incident on the hologram **164** is diffracted to first-order diffracted light, a chromatic aberration occurring in the light L4R, L5R can be compensated in the hologram **164**. Therefore, the servo signals can be stably obtained.

In the seventeenth embodiment, the collimator lens **53** is located between the light source **52** and the film **162**. However, the collimator lens **53** is not necessary in the optical head apparatus **161**.

Also, the optical head apparatus **161** with the film **162** and the $\frac{1}{4}$-λ plate **69** is described. However, in cases where the intensity of the incident light L3 is sufficient, it is applicable that a reflection film having a reflectivity of almost $\frac{1}{3}$ be utilized in place of the film **162** and the $\frac{1}{4}$-λ plate **69** be omitted. In this case, pieces of information can be reliably recorded or reproduced on or from an information medium regardless of whether the information medium is thick or thin. Also, because a hybrid element composed of the film **162**, the substrate **163** and the hologram **164** functions as a beam splitter and a rising mirror, the optical head apparatus **161** can be manufactured at a small size, in a light weight, and at a low cost. Also, because optical parts of the optical head apparatus **161** are located along its optical axis, the optical head apparatus **161** stably operated can be obtained even though a circumstance temperature largely varies and the apparatus is operated for a long time.

In the sixth to seventeenth embodiments, pieces of information can be reliably recorded or reproduced on or from an information medium regardless of whether the information medium represents a conventional optical disk such as a compact disk having a thickness T2 of about 1.2 mm or a prospective high density optical disk having a thickness T1 ranging from 0.4 mm to 0.8 mm. However, when the information recorded or reproduced on or from the information medium, it is required to examine the thickness of the information medium in advance. Therefore, in cases where a piece of distinguishing information is recorded on the information medium in advance to distinguish the thickness of the information medium, it is convenient for a user. Because no distinguishing information is recorded on the conventional optical disk, it is preferred that the distinguishing information be recorded on the prospective high density optical disk appearing on the market in the future. Therefore, a high density optical disk with the distinguishing information is described according to eighteenth and nineteenth embodiments.

(Eighteenth Embodiment)

FIG. **53** is a diagonal view of a high density optical disk according to an eighteenth embodiment, a cross sectional view of the disk being partially shown.

As shown in FIG. **53**, a high density optical disk **171** is partitioned into an outer region **171***a* and an inner region **171***b*. The outer region **171***a* occupies a large part of the optical disk **171**, and an information recording substrate **171***c* of the outer region **171***a* has the thickness T1, and the information recording substrate **171***c* of the inner region **171***b* has the thickness T2. A plurality of first recording pits **172** are formed on the information recording substrate **171***c* of the outer region **171***a* at narrow intervals in series to record pieces of information at a high density. Also, a plurality of second recording pits **173** are formed on the information recording substrate **171***c* of the inner region **171***b* at ordinary intervals in series to record pieces of distinguishing information at an ordinary density of a compact disk. The distinguishing information inform that the optical disk **171** has the thickness T1. The thickness T1 of the outer region **171***a*, for example, ranges from 0.4 mm to 0.8 mm, and the thickness T2 of the inner region is, for example, about 1.2 mm.

In the above configuration, the diffracted light L5 according to the first or second embodiment (or the transmitted light L4 according to the third embodiment) is initially converged on an inner region of the information medium **23**, **25** while performing a focus control corresponding to the second information medium **25** having the thickness T2. In cases where the information medium **23** or **25** is the optical disk **171**, a piece of distinguishing information informing that the optical disk **171** having the thickness T1 is converged by the light L5 (or L4) is detected. Thereafter, the transmitted light L4 (or the diffracted light L6) is auto-

matically converged on the outer region **171***a* of the optical disk **171** while performing a focus control corresponding to the first information medium **23** having the thickness T1.

In contrast, in cases where the information medium **23** or **25** is a thick type of conventional optical disk having a thickness T2, no distinguishing information is detected when the light L5 (or L4) is converged on the inner region **171***b* of the conventional optical disk. In this case, the focus control corresponding to the second information medium **25** is continued to detect an information signal expressing a piece of information recorded on the conventional optical disk.

Accordingly, in cases where one of the optical head apparatuses shown in FIGS. **21, 27, 30, 31, 32, 33, 37, 38, 40A, 43, 44, 50** and **52** is utilized, pieces of information can be automatically recorded or reproduced on or from an information medium regardless of whether the information medium is thin or thick.

Also, because only the distinguishing information is recorded in the inner region, the inner region can be small. Therefore, a memory capacity of the optical disk **171** is not lowered by the addition of the second recording pit **173**.

(Nineteenth Embodiment)

FIG. **54** is a diagonal view of a high density optical disk according to a nineteenth embodiment, a cross sectional view of the disk being partially shown.

As shown in FIG. **54**, a high density optical disk **174** is partitioned into an outer region **174***a* and an inner region **174***b*. The outer region **174***a* occupies a large part of the optical disk **174**. The optical disk **174** has a uniform thickness of T1. The first recording pits **172** are formed on an information recording substrate **174***c* of the outer region **174***a* to record pieces of information at a high density. Also, a plurality of second recording pits **175** having a large size are formed on the information recording substrate **174***c* of the inner region **174***b* at wide intervals to record pieces of distinguishing information at a lower density than the ordinary density. The distinguishing information inform that the entire optical disk **174** has the thickness T1. The thickness T1 of the optical disk **174**, for example, ranges from 0.4 mm to 0.8 mm.

In the above configuration, the diffracted light L5 according to the first or second embodiment (or the transmitted light L4 according to the third embodiment) is initially converged on an inner region of the information medium **23** or **25** while performing a focus control corresponding to the second information medium **25** having the thickness T2. In cases where the information medium **23** or **25** is the optical disk **174**, the light L5 (or L4) is converged on each of the second recording pits **175** in defocus. However, because each of the second recording pits **175** is large in size, a converging spot of the light L5 (or L4) is reliably formed in one of the second recording pits **175**. Therefore, a piece of distinguishing information, which informs that the optical disk **174** having the thickness T1 is converged by the light L5 (or L4), is detected. Thereafter, the transmitted light L4 (or the diffracted light L6) is automatically converged on the outer region **174***a* of the optical disk **174** while performing a focus control corresponding to the first information medium **23** having the thickness T1.

In contrast, in cases where the information medium **23** or **25** is a thick type of conventional optical disk having a thickness T2, no distinguishing information is detected when the light L5 (or L4) is converged on the inner region **174***b* of the conventional optical disk. In this case, the focus control corresponding to the second information medium **25** is continued to detect an information signal expressing a piece of information recorded on the conventional optical disk.

Accordingly, in cases where one of the optical head apparatuses shown in FIGS. **21, 27, 30, 31, 32, 33, 37, 38, 40A, 43, 44, 50** and **52** is utilized, pieces of information can be automatically recorded or reproduced on or from an information medium regardless of whether the information medium is thin or thick.

Also, because only the distinguishing information is recorded in the inner region of the optical disk **174**, the inner region can be small. Therefore, a memory capacity of the optical disk **174** is not lowered by the addition of the second recording pit **173**.

Also, because the thickness of the optical disk **174** is uniform, the optical disk **174** can be easily manufactured at a low cost. Also, the optical disk **174** can be thinned.

(Twentieth Embodiment)

An optical disk apparatus with one of the optical head apparatuses in which it is automatically judged whether a high density optical disk having the thickness T1 or a conventional optical disk having the thickness T2 is utilized is described.

FIG. **55** is a block diagram of an optical disk apparatus with one of the optical head apparatuses shown in FIGS. **21, 27, 30, 31, 32, 33, 37, 38, 40A, 43, 44, 50** and **52** according to a twentieth embodiment. FIG. **56** is a flow chart showing the operation of the optical disk apparatus shown in FIG. **55**.

As shown in FIG. **55**, an optical disk apparatus **176** for recording or reproducing pieces of information on or from the high density optical disk **171** (or **174**) or the conventional optical disk **25**, comprises the optical head apparatus **51** (or **61, 65, 67, 70, 71, 81, 91, 101, 111, 121, 151** or **161**), a moving means **177** such as a feed mechanism for moving the optical head apparatus **51** to a prescribed position, and a rotating means **178** such as a spindle motor for rotating the high density optical disk **171** (or **174**) or the conventional optical disk **25**.

In the above configuration, the high density optical disk **171** or the conventional optical disk **25** is set to a prescribed position of the optical disk apparatus **176**, and the optical disk **171** or **25** is rotated by the rotating means **178**. Thereafter, the optical head apparatus **51** is moved to a position just under an innermost recording track of the optical disk **171** or **25** in a step **211**, and the diffracted light L5 is converged on the innermost recording track of the optical disk **171** or **25** while performing a focus control corresponding to the conventional optical disk **25** of the thickness T2 in a step **212**. Thereafter, a tracking control is performed, and a piece of information recorded on the innermost recording track of the optical disk **171** or **25** is detected in a step **213**. Thereafter, it is judged in a step **214** whether the information agrees with a piece of distinguishing information informing that the optical disk **171** having the thickness T1 is set to the optical disk apparatus **176**.

In cases where the high density optical disk **171** is set to the optical disk apparatus **176**, the distinguishing information is detected. Thereafter, the transmitted light L4 is automatically converged on the optical disk **171** while performing a focus control corresponding to the optical disk **171** of the thickness T1 in a step **215**.

Therefore, pieces of information are recorded or reproduced on or from the optical disk **171**.

In contrast, in cases where the conventional optical head **25** is set to the optical disk apparatus **176**, the distinguishing information is not detected. In this case, the convergence of the diffracted light L5 on the conventional optical disk **25** is continued while performing the focus control and the tracking control corresponding to the conventional optical disk **25** in a step **216**. Therefore, pieces of information are recorded or reproduced on or from the conventional optical disk **25**.

Accordingly, the thickness of the optical disk set in the optical disk apparatus **176** can be rapidly judged at a high accuracy. Also, pieces of information can be stably recorded or reproduced on or from an optical disk regardless of whether the optical disk is the high density optical disk **171** (or **174**) or the conventional optical disk **25**.

(Twenty-first Embodiment)

An optical disk apparatus with one of the optical head apparatuses in which it is automatically judged whether a high density optical disk having the thickness T1 or a conventional optical disk having the thickness T2 is utilized is described.

FIG. **57** is a block diagram of an optical disk apparatus with one of the optical head apparatuses shown in FIGS. **21**, **27**, **30**, **31**, **32**, **33**, **37**, **38**, **40A**, **43**, **44**, **50** and **52** according to a twenty-first embodiment. FIG. **58** is a flow chart showing the operation of the optical disk apparatus shown in FIG. **57**.

As shown in FIG. **57**, an optical disk apparatus **176** for recording or reproducing pieces of information on or from a high density optical disk **182** or the conventional optical disk **25**, comprises the optical head apparatus **51** (or **61**, **65**, **67**, **70**, **71**, **81**, **91**,**101**, **111**, **121**, **151** or **161**), the moving means **177**, and a rotating means **182** such as a spindle motor for rotating the high density optical disk **182** or the conventional optical disk **25**. The high density optical disk **182** has no distinguishing information and has the thickness T1.

In the above configuration, the high density optical disk **182** or the conventional optical disk **25** is set to a prescribed position of the optical disk apparatus **181**, and the optical disk **182** or **25** is rotated by the rotating means **182**. Thereafter, the optical head apparatus **51** is moved to a position just under an innermost recording track of the optical disk **182** or **25** in a step **221** because a piece of information is reliably recorded on the innermost recording track, and the diffracted light L5 is converged on the innermost recording track of the optical disk **182** or **25** while performing a focus control corresponding to the conventional optical disk **25** of the thickness T2 in a step **222**. Thereafter, a tracking control is performed, and a piece of information recorded on the innermost recording track of the optical disk **182** or **25** is detected in a step **223**. Thereafter, it is judged in a step **224** whether the intensity of an information signal expressing the information detected is more than a threshold value. That is, the intensity of the information signal more than the threshold value denotes that the diffracted light L5 is converged in focus on the optical disk **182** or **25**, and the intensity of the information signal not more than the threshold value denotes that the diffracted light L5 is converged in defocus on the optical disk **182** or **25**.

In cases where the high density optical disk **182** is set to the optical disk apparatus **181**, the intensity of the information signal not more than the threshold value is detected. In this case, the transmitted light L4 is automatically converged on the optical disk **182** while performing a focus control corresponding to the high density optical disk **182** of the thickness T1 in a step **225**. Therefore, pieces of information are recorded or reproduced on or from the optical disk **182**.

In contrast, in cases where the conventional optical head **25** is set to the optical disk apparatus **181**, the intensity of the information signal more than the threshold value is detected. In this case, the convergence of the diffracted light L5 on the conventional optical disk **25** is continued while performing the focus control and the tracking control corresponding to the conventional optical disk **25** in a step **26**. Therefore, pieces of information are recorded or reproduced on or from the conventional optical disk **25**.

Accordingly, the thickness of the optical disk set in the optical disk apparatus **181** can be judged even though the optical disk **171** or **174** is not utilized. Also, pieces of information can be stably recorded or reproduced on or from an optical disk regardless of whether the optical disk is the high density optical disk **182** or the conventional optical disk **25**.

(Twenty-second Embodiment)

A binary focus microscope having two focal points in which two images formed on different planes are simultaneously observed is described according to a twenty-second embodiment.

FIG. **59** is a constitutional view of a binary focus microscope according to a twenty-second embodiment.

As shown in FIG. **59**, a binary focus microscope **191** for simultaneously observing a first image of a first sample SP1 put on a first sample plane PL1 and a second image of a second sample SP2 put on a second sample plane PL2, comprises an objective lens **192** having a first focal length F1 for refracting a beam of first light L17 diverging from the first image and refracting a beam of second light L18 diverging from the second image, the hologram lens **26** (or **26M**, **32**, **33** or **42**) for transmitting through a part of the first light L17 without any diffraction and diffracting a part of the second light L18 to pass the second light L18 through the same optical path as the first light L17 passes through, an inner lens **193** for converging a beam of superposed light L19 formed of the first and second light L17, L18 at an inner focal point Pf1, an ocular lens **194** for simultaneously forming the first and second images by converging the superposed light L19 diverging from the inner focal point Pf1, an inner lens-barrel **195** for moving a combination element of the inner lens **193** and the hologram lens **26** along an optical axis to adjust a distance between the combination element and the ocular lens **194**, and an outer lens-barrel **196** for moving the objective lens **192** along the optical axis to set the distance between the first sample plane PL1 and the objective lens **192** to the focal length F1 of the objective lens **192**.

The optical axis passes through the centers of the objective lens **192**, the hologram lens **26**, the inner lens **195** and the ocular lens **194**. The position of the first sample plane PL1 differs from that of the second sample plane PL2 along the optical axis.

In the above configuration, the position of the objective lens **192** is adjusted to set the distance between the first sample plane PL1 and the objective lens **192** to the first focal length F1 of the objective lens **192**. In this

case, the distance between the second sample plane PL2 and the objective lens **192** is set to a second focal length F2. Also, the position of the combination element is adjusted to clearly view the first and second images. That is, a beam of first light L17 diverging from the first image on the first sample plane PL1 is collimated in the objective lens **192**, and a part of the first light L17 transmits through the hologram lens **26**. Also, a beam of second light L18 diverging from the second image on the second sample plane PL2 is refracted in the objective lens **192**, and a part of the second light L18 is diffracted in the hologram lens **26** to pass the second light L18 through the same optical path as the first light L17 passes through. Therefore, a beam of superposed light L19 is formed of the first and second light L17, L18. Thereafter, the superposed light L19 is converged by the inner lens **193** at an inner focal point Pf1 to simultaneously form the first and second images enlarged on an image plane PL3, and the superposed light L19 diverging from the point Pf1 is converged by the ocular lens **194** to simultaneously form the first and second images moreover enlarged on an operator's eye.

Accordingly, because the hologram lens **26**, **26M**, **32**, **33** or **42** is utilized to form the superposed light L19, the first image of the first sample SP1 put on the first sample plane PL1 and the second image of the second sample SP2 put on the second sample plane PL2 can be simultaneously observed by simultaneously focusing the binary focus microscope **191** on the first and second samples SP1, SP2.

Also, even though the intensities of the first and second light L17, L18 are reduced when the light L17, L18 pass through the hologram lens **26**, the intensity of the superposed light L19 is sufficient to observe the first and second images because the intensity of the superposed light L19 is determined by adding the intensities of the first and second light L17, L18.

Also, because the hologram lens **26** is blazed as shown in FIG. **6**, the generation of unnecessary diffracted light such as minus first-order diffracted light is reduced when the second light L18 is diffracted in the hologram lens **26**. Therefore, the intensity of the superposed light L19 can be increased, so that first and second images observed can be moreover brightened.

Also, as shown in FIG. **60**, in cases where the first sample SP1 is placed at a bottom of a first sample holder **197** and in cases where the second sample SP2 is placed at a bottom of a second sample holder **198** located under the first sample holder **197**, aberration such as a chromatic aberration is generated in the first and second light L17, L18 incident on the objective lens **192** because an optical path length in the first sample holder **197** for the first light L17 differs from that in the first and second sample holders **197**, **198** for the second light L18. However, the aberration can disappear in the hologram lens **26** by excessively correcting the chromatic aberration in the hologram lens **26** as is described in the first embodiment.

Also, the difference between the first and second focal lengths can be changed by moving the inner and outer lensbarrels **195**, **196** because the distance between the hologram lens **26** and the objective lens **192** is changed. Therefore, even though the thickness of the second sample holder **198** is changed, the first and second images can be reliably observed.

In the twenty-second embodiment, the ocular lens **194** is utilized in the binary focus microscope **191**. However, the ocular lens **194** is not necessarily required. Also, as shown in FIG. **61**, it is applicable that a camera **199** such as a chargecoupled device (CCD) camera be placed on the image plane PL3 in place of the ocular lens **194**. In this case, a superposed image formed of the first and second images enlarged can be photographed with the CCD camera **199**, so that the first and second images can be simultaneously recorded.

(Twenty-third Embodiment)

In cases where a minute circuit is formed on a semiconductor wafer, a photosensitive material is coated on the semiconductor wafer, and the photosensitive material covering the semiconductor wafer is exposed to ultraviolet light through a photomask having a mask pattern in an exposure process. Therefore, the mask pattern of the photomask is transferred to the photosensitive material. In this case, the semiconductor wafer is required to be aligned with the photomask at a high accuracy in an alignment process performed prior to the exposure process. Therefore, a reference image drawn on the semiconductor wafer and the mask pattern drawn on the photomask are simultaneously observed with a conventional microscope having a deep focal depth. However, because the magnification of the conventional microscope having a deep focal depth is low, it is impossible to align the reference image and the mask pattern at an accuracy within 5 μm.

To solve the above drawback in the present invention, an alignment apparatus utilized in the alignment process in which the semiconductor wafer is aligned with the photomask at a high accuracy while simultaneously observing a reference image drawn on the semiconductor wafer and the mask pattern drawn on the photomask is described according to a twenty-third embodiment.

FIG. **62** is a constitutional view of an alignment apparatus according to a twenty-third embodiment.

As shown in FIG. **62**, an alignment apparatus **201** for aligning a first reference image RF1 of a mask pattern drawn on a bottom surface of a photomask **202** with a second reference image RF2 drawn on a bottom surface of a sample such as a semiconductor substrate **203**, comprises a light source **204** for radiating beams of alignment light having a particular wavelength to illuminate the first and second reference images RF1, RF2, the objective lens **192** for receiving a beam of first alignment light L20 diverging from the first reference image RF1 illuminated with the alignment light and receiving a beam of second alignment light L21 diverging from the second reference image RF2 illuminated with the alignment light, the hologram lens **26** (or **26M**, **32**, **33** or **42**) for transmitting through a part of the first alignment light L20 without any diffraction and diffracting a part of the second alignment light L21 to pass the second alignment light L21 through the same optical path as the first alignment light L20 passes through, the inner lens **193** for converging a beam of superposed alignment light L22 formed of the first and second alignment light L20, L21 at an inner focal point Pf2, a camera **205** such as a charge-coupled device (CCD) camera placed at the inner focal point Pf2 for simultaneously photographing and recording the first and second reference images RF1, RF2, the inner lens-barrel **195**, the outer lens-barrel **196**, a moving means **206** for moving the photomask **202** in a horizontal direction perpendicular to an optical axis to align the first reference image RF1 with the second reference image RF2 along the optical axis, and a control means **207** for controlling the movement of

the photomask **202** according to the first and second reference images RF1, RF2 recorded in the camera **205**.

The particular wavelength of the alignment light is determined on condition that a transmissivity of the semiconductor substrate **203** for the alignment light is sufficiently high. The optical axis passes through the centers of the objective lens **192**, the hologram lens **26** and the inner lens **193**.

A binary microscope **208** is composed of the objective lens **192**, the hologram lens **26** (or **26M**, **32**, **33** or **42**), the inner lens **193**, the inner lens-barrel **195** and the outer lens-barrel **196** in the same manner as in the twenty-second embodiment.

In the above configuration, a beam of first alignment light L20 diverging from the first reference image RF1 is collimated in the objective lens **192**, and a part of the first alignment light L20 transmits through the hologram lens **26**. Also, a beam of second alignment light L21 diverging from the second reference image RF2 is refracted in the objective lens **192**, and a part of the second alignment light L21 is diffracted by the hologram lens **26** to pass the second alignment light L21 through the same optical path as the first alignment light L20 passes through. Therefore, a beam of superposed alignment light L22 is formed of the first and second alignment light L20, L21. Thereafter, the superposed alignment light L22 is converged at an inner focal point Pf2 to simultaneously form the first and second reference images RF1, RF2 enlarged. Thereafter, the first and second reference images RF1, RF2 enlarged are photographed and recorded by the camera **205**. Thereafter, a relative position between the first and second reference images RF1, RF2 is examined in the control means **207**, and the photomask **202** is moved in a horizontal direction by the moving means **206** under control of the control means **207** to align the first reference image RF1 with the second reference image RF2.

Accordingly, because the hologram lens **26**, **26M**, **32**, **33** or **42** is utilized to form the binary microscope **208** having two focal points, the first reference image RF1 and the second reference image RF2 can be simultaneously observed even though a focal depth of the binary microscope **208** is low. Also, because the focal depth of the binary microscope **208** can be lowered, the magnification of the binary microscope **208** can be heightened. Therefore, the first reference image RF1 of the photomask **202** can be aligned with the second reference image RF2 of the semiconductor substrate **203** at a high accuracy.

Having illustrated and described the principles of our invention in a preferred embodiment thereof, it should be readily apparent to those skilled in the art that the invention can be modified in arrangement and detail without departing from such principles. We claim all modifications coming within the spirit and scope of the accompanying claims.

What is claimed is:

1. An optical head apparatus for recording or reproducing a piece of information on or from a first information medium having a first thickness or a second information medium having a second thickness, comprising:

a light source for radiating a beam of incident light;

hologram means for transmitting a part of the incident light radiated from the light source without any diffraction on an outgoing path to form a beam of transmitted light and diffracting a remaining part of the incident light radiated from the light source on the outgoing path to form a beam of diffracted light, the hologram means functioning as a lens for the diffracted light to diverge the diffracted light from the hologram means or converge the diffracted light;

lens means for converging the transmitted light formed in the hologram means at a first focal length on the outgoing path to form a first converging spot at a front surface of the first information medium or converging the diffracted light formed in the hologram means at a second focal length on the outgoing path to form a second converging spot at a front surface of the second information medium, the transmitted light passing through the first information medium from its rear surface, the transmitted light being reflected at the front surface of the first information medium and again passing through the lens means and the hologram means on an incoming path, the diffracted light passing through the second information medium from its rear surface, and the diffracted light being reflected at the front surface of the second information medium and again passing through the lens means and the hologram means on the incoming path;

wavefront changing means for changing a wavefront of the transmitted light or the diffracted light passing through the lens means and the hologram means on the incoming path to form one or more beams of information light; and

detecting means for detecting intensities of the information light formed by the wavefront changing means and generating an information signal according to the intensities of the information light, the information signal expressing a piece of information recorded on the first information medium or the second information medium.

2. An optical head apparatus according to claim **1** in which

a grating pattern is drawn in the hologram means in a concentric circle shape,

the grating pattern of the hologram means is formed in relief to concentrically form alternating rows of bottom portions and top portions,

a height H of relief in the grating pattern is set to:

$$H<\lambda/(n(\lambda)-1),$$

where a symbol λ denotes a wavelength of the incident light and a symbol $n(\lambda)$ denotes a refractive index of the hologram means made of a glass material for the incident light having the wavelength λ, and

a difference in phase modulation degree between the incident light passing through the bottom portions of the grating pattern and the incident light passing through the top portions of the grating pattern is lower than 2π radians to set a diffraction efficiency of the hologram means to a value lower than 100%.

3. An optical head apparatus according to claim **1** in which

a far field pattern of the incident light radiated from the light source is distributed to decrease intensity of the incident light toward a peripheral portion of its beam, and

a diffraction efficiency of the hologram means for the incident light is gradually lowered toward an outer direction of the hologram means to distribute intensity of the transmitted light in a gently-sloping shape.

4. An optical head apparatus according to claim 1 in which

a far field pattern of the incident light radiated from the light source is distributed to decrease intensity of the incident light toward a peripheral portion of its beam, and

a diffraction efficiency of the hologram means for the incident light is gradually lowered toward an inner direction of the hologram means to distribute intensity of the diffracted light in a gently-sloping shape.

5. An optical head apparatus according to claim 1 in which

the hologram means functions as a concave lens for the diffracted light to diverge the diffracted light from the hologram means, and

the first thickness of the first information medium is smaller than the second thickness of the second information medium.

6. An optical head apparatus according to claim 1 in which

the hologram means functions as a convex lens for the diffracted light to converge the diffracted light diffracted by the hologram means, and

the first thickness of the first information medium is larger than the second thickness of the second information medium.

7. An optical head apparatus according to claim 2 in which

the grating pattern of the hologram means is partitioned into a plurality of pattern blocks which each are composed of one of the bottom portions and one of the top portions, and

each block of the grating pattern is formed in a stepwise shape to blaze the grating pattern.

8. An optical head apparatus according to claim 1 in which

the hologram means is partitioned into a pattern region and a no-pattern region surrounding the pattern region,

a grating pattern is drawn in the pattern region of the hologram means in a concentric circle shape, and

a diameter of the grating pattern is smaller than an aperture of the lens means to transmit the incident light through the no-pattern region of the hologram means without any diffraction.

9. An optical head apparatus according to claim 8 in which

the grating pattern of the hologram means is formed in relief to concentrically form alternating rows of bottom portions and top portions in the pattern region,

a thickness of the no-pattern region in the hologram means is set to an average value of those of the pattern region, and

a phase of the incident light passing through the no-pattern region of the hologram means agrees with an average value of those of the incident light passing through the pattern region of the hologram means.

10. An optical head apparatus according to claim 2 in which the height H of the relief in the grating pattern is gradually lowered toward an outer direction of a pattern region in which the grating pattern is drawn, and

a diffraction efficiency of the hologram means for the incident light is gradually lowered toward the outer direction of the pattern region.

11. An optical head apparatus according to claim 2 in which the grating pattern of the hologram means is partitioned into a plurality of pattern blocks which each are composed of one of the bottom portions and one of the top portions,

each block of the grating pattern is formed in a stepwise shape and is composed of a flight of stairs,

an inclined angle of the stairs is gradually lowered toward an outer direction of a pattern region in which the grating pattern is drawn to gradually lower the height H of the relief in the grating pattern toward the outer direction of the pattern region, and

a diffraction efficiency of the hologram means for the incident light is gradually lowered toward the outer direction of the pattern region.

12. An optical head apparatus according to claim 2 in which the height H of the relief in the grating pattern is gradually lowered toward an inner direction of a pattern region in which the grating pattern is drawn, and

a diffraction efficiency of the hologram means for the incident light is gradually lowered toward the inner direction of the pattern region.

13. An optical head apparatus according to claim 2 in which the grating pattern of the hologram means is partitioned into a plurality of pattern blocks which each are composed of a bottom portion and a top portion,

each block of the grating pattern is formed in a stepwise shape and is composed of a flight of stairs,

an inclined angle of the stairs is gradually lowered toward an inner direction of a pattern region in which the grating pattern is drawn to gradually lower the height H of the relief in the grating pattern toward the inner direction of the pattern region, and

a diffraction efficiency of the hologram means for the incident light is gradually lowered toward the inner direction of the pattern region.

14. An optical head apparatus according to claim 1 in which

the detecting means comprises a pair of focus error detectors for detecting intensities of two beams of first information light selected among the information light to generate the information signal and a focus error signal, and four tracking error detectors for detecting intensities of four beams of second information light selected among the information light to generate a tracking error signal, a position of the lens means being adjusted according to the focus error signal and the tracking error signal to focus the transmitted light or the diffracted light on the first information medium or the second information medium.

15. An optical head apparatus according to claim 1 in which

a beam of first information light is generated in the wavefront changing means to have a first focal point in the front of the detecting means,

a beam of second information light is generated in the wavefront changing means to have a second focal point in the rear of the detecting means, and

the detecting means comprises a pair of focus error detectors for detecting an intensity of the first information light and an intensity of the second information light to generate a focus error signal, a position of the lens means being adjusted according to the focus error signal to focus the transmitted light or the diffracted light on the first information medium or the second information medium, and

the information signal being detected in the focus error detectors.

16. An optical head apparatus according to claim 1 in which

the wavefront changing means is a hologram having a plurality types of grating patterns, and

the transmitted light or the diffracted light passing through one of the grating patterns of the hologram means is changed to one of the information light.

17. An optical head apparatus according to claim 1 in which

the wavefront changing means is an astigmatic aberration generating unit for generating an astigmatic aberration in the information light, and

the detecting means comprises a quadrant photodetector having four detecting sections for detecting an intensity of the information light having the astigmatic aberration to generate the information signal and servo signals such as a focus error signal and a tracking error signal, a position of the lens means being adjusted according to the servo signals to focus the transmitted light or the diffracted light on the first information medium or the second information medium.

18. An optical head apparatus according to claim 17 in which

the astigmatic aberration generating unit is formed of a plane parallel plate of which a normal line is tilted from an optical axis.

19. An optical head apparatus according to claim 17 in which

the astigmatic aberration generating unit is formed of a cylindrical lens.

20. An optical head apparatus according to claim 1 in which

a grating pattern is drawn on a flat surface of the hologram means, and

a normal line of the flat surface of the hologram means is tilted from an optical axis of the lens means.

21. An optical head apparatus according to claim 1, additionally including:

a polarized beam splitter for totally transmitting the incident light which is radiated from the light source and is linearly polarized in a first direction and totally reflecting light linearly polarized at a second direction perpendicular to the first direction; and

a $\frac{1}{4}$-λ plate for forming the transmitted light or the diffracted light linearly polarized in the second direction by passing the incident light transmitting through the polarized beam splitter or a pair of the transmitted light and the diffracted light on the outgoing path and passing the transmitted light or the diffracted light on the incoming path, the transmitted light or the diffracted light linearly polarized in the second direction by the $\frac{1}{4}$-λ plate being reflected by the polarized beam splitter on the outgoing path and being incident on the wavefront converging means.

22. An optical head apparatus according to claim 1, additionally including a wedge-like prism for reshaping the incident light radiated from the light source, the incident light reshaped being incident on the hologram means.

23. An optical head apparatus according to claim 1 in which

the first thickness of the first information medium is smaller than the second thickness of the second information medium,

the wavefront changing means comprises a beam splitter for transmitting the diffracted light which transmits through the hologram means without any diffraction on the incoming path to form a beam of first information light having an astigmatic aberration and reflecting the transmitted light which transmits through the hologram means without any diffraction on the incoming path, and a wavefront changing unit for changing a wavefront of the transmitted light reflected by the beam splitter to form a plurality of beams of second information light, and

the detecting means comprises a quadrant photodetector having four detecting sections for detecting an intensity of the first information light transmitting through the beam splitter to generate a first information signal and servo signals such as a first focus error signal and a first tracking error signal, a pair of focus error detectors for detecting intensities of two beams of second information light formed in the wavefront changing unit to generate a second information signal and a second focus error signal, and four tracking error detectors for detecting intensities of four beams of second information light formed in the wavefront changing unit to generate a second tracking error signal, a positional relation between the lens means and the second information medium being adjusted according to the servo signals to focus the diffracted light on the second information medium, a positional relation between the lens means and the first information medium being adjusted according to the second focus error signal and the second tracking error signal to focus the transmitted light on the first information medium, the first information signal expressing the information recorded on the second information medium, and the second information signal expressing the information recorded on the first information medium.

24. An optical head apparatus according to claim 1 in which

the first thickness of the first information medium is smaller than the second thickness of the second information medium,

the wavefront changing means comprises a beam splitter having a wavefront changing unit for transmitting the transmitted light which transmits through the hologram means without any diffraction on the incoming path to form a beam of first information light having an astigmatic aberration and diffracting and reflecting the diffracted light which transmits through the hologram means without any diffraction on the incoming path and is incident on the wavefront changing unit to form a plurality of beams of second information light, and

the detecting means comprises a quadrant photodetector having four detecting sections for detecting an intensity of the first information light transmitting through the beam splitter to generate a first information signal and servo signals such as a first focus error signal and a first tracking error signal, a pair of focus error detectors for detecting intensities of two beams of second information light formed in the wavefront changing unit to generate a second information signal and a second focus

error signal, and four tracking error detectors for detecting intensities of four beams of second information light formed in the wavefront changing unit to generate a second tracking error signal, a positional relation between the lens means and the first information medium being adjusted according to the servo signals to focus the transmitted light on the first information medium, a positional relation between the lens means and the second information medium being adjusted according to the second focus error signal and the second tracking error signal to focus the diffracted light on the second information medium, the first information signal expressing the information recorded on the first information medium, and the second information signal expressing the information recorded on the second information medium.

25. An optical head apparatus according to claim **1** in which

the first thickness of the first information medium is smaller than the second thickness of the second information medium,

the transmitted light converged by the lens means on the outgoing path is also converged at the front surface of the second information medium in defocus and is reflected to again pass through the lens means and the hologram means without any diffraction on the incoming path,

the wavefront changing means comprises a beam splitter having a wavefront changing unit for transmitting the diffracted light which transmits through the hologram means without any diffraction on the incoming path to form a beam of first information light having an astigmatic aberration and diffracting the transmitted light which is converged on the second information medium in defocus and is incident on the wavefront changing unit to form a plurality of beams of second information light, and

the detecting means comprises a quadrant photodetector having four detecting sections for detecting in defocus an intensity of the first information light transmitting through the beam splitter to generate a first information signal expressing the information recorded on the second information medium and detecting in focus intensities of the second information light diffracted in the wavefront changing unit to generate a focus error signal, a positional relation between the lens means and the second information medium being adjusted according to the focus error signal to focus the diffracted light on the second information medium.

26. An optical head apparatus according to claim **1** in which

the first thickness of the first information medium is larger than the second thickness of the second information medium,

the wavefront changing means comprises a beam splitter for transmitting the diffracted light again diffracted by the hologram means on the incoming path to form a beam of first information light having an astigmatic aberration and reflecting the transmitted light diffracted by the hologram means on the incoming path, and a wavefront changing unit for changing a wavefront of the transmitted light reflected by the beam splitter to form a plurality of beams of second information light, and

the detecting means comprises a quadrant photodetector having four detecting sections for detecting an intensity of the first information light transmitting through the beam splitter to generate a first information signal and servo signals such as a first focus error signal and a first tracking error signal, a pair of focus error detectors for detecting intensities of two beams of second information light formed in the wavefront changing unit to generate a second information signal and a second focus error signal, and four tracking error detectors for detecting intensities of four beams of second information light formed in the wavefront changing unit to generate a second tracking error signal, a positional relation between the lens means and the second information medium being adjusted according to the servo signals to focus the diffracted light on the second information medium, a positional relation between the lens means and the first information medium being adjusted according to the second focus error signal and the second tracking error signal to focus the transmitted light on the first information medium, the first information signal expressing the information recorded on the second information medium, and the second information signal expressing the information recorded on the first information medium.

27. An optical head apparatus according to claim **1** in which

the first thickness of the first information medium is larger than the second thickness of the second information medium,

the wavefront changing means comprises a beam splitter having a wavefront changing unit for transmitting the transmitted light diffracted by the hologram means on the incoming path to form a beam of first information light having an astigmatic aberration and diffracting and reflecting the diffracted light which is again diffracted by the hologram means on the incoming path and is incident on the wavefront changing unit to form a plurality of beams of second information light, and

the detecting means comprises a quadrant photodetector having four detecting sections for detecting an intensity of the first information light transmitting through the beam splitter to generate a first information signal and servo signals such as a first focus error signal and a first tracking error signal, a pair of focus error detectors for detecting intensities of two beams of second information light formed in the wavefront changing unit to generate a second information signal and a second focus error signal, and four tracking error detectors for detecting intensities of four beams of second information light formed in the wavefront changing unit to generate a second tracking error signal, a positional relation between the lens means and the first information medium being adjusted according to the servo signals to focus the transmitted light on the first information medium, a positional relation between the lens means and the second information medium being adjusted according to the second focus error signal and the second tracking error signal to focus the diffracted light on the second information medium, the first information signal expressing the information recorded on the first information medium, and the second information

signal expressing the information recorded on the second information medium.

28. An optical head apparatus according to claim **1** in which

the hologram means is partitioned into a central region and a peripheral region surrounding the central region,

a first grating pattern is drawn in the central region of the hologram means in a concentric circle shape,

a second grating pattern is drawn in the peripheral region of the hologram means in a non-concentric shape,

the transmitted light transmits through the central region of the hologram means without any diffraction on the outgoing and incoming paths,

a part of the incident light radiated from the light source transmits through the peripheral region of the hologram means on the outgoing path to form a beam of noise cancelling light which is converged by the lens means to form a third converging spot surrounding the first converging spot,

the noise cancelling light forming the third converging spot passes through the lens means and is diffracted in the peripheral region of the hologram means on the incoming path,

the detecting means comprises a first photo detector for detecting an intensity of the transmitted light transmitting through the central region of the hologram means without any diffraction on the incoming path to generate a first information signal component **SC1** expressing a piece of information recorded on the first information medium, and a second photo detector for detecting an intensity of the noise cancelling light diffracted in the peripheral region of the hologram means on the incoming path to generate a second information signal component SC2 expressing the information, a noise cancelled information signal Snc being obtained by adding the first information signal component **SC1** and a multiplied second information signal component R×SC2 which is obtained by multiplying the second information signal component SC2 by a weighting factor R.

29. An optical head apparatus according to claim **28** in which

the peripheral region of the hologram means is partitioned into a first side peripheral region and a second side peripheral region facing each other with the central region between the first and second side peripheral region,

a far field pattern of the incident light radiated from the light source is distributed to decrease intensity of the incident light toward a peripheral portion of its beam,

a cross-sectional beam profile of the incident light radiated from the light source is in an elliptic shape in which a beam divergent angle of the incident light in a perpendicular direction is larger than that in a horizontal direction,

the incident light placed at one side of its beam in the perpendicular direction passes through the first side peripheral region of the hologram means to form a part of the noise cancelling light,

the incident light placed at the other side of its beam in the perpendicular direction passes through the second side peripheral region of the hologram means to form a remaining part of the noise cancelling light, and

a cross-sectional beam profile of light defined as the combination of the transmitted light and the noise cancelling light is in a circular shape.

30. An optical head apparatus according to claim **28** in which

the peripheral region of the hologram means is partitioned into a first side peripheral region and a second side peripheral region facing each other with the central region between the first and second side peripheral region,

a second photo detector of the detecting means is composed of a first noise cancelling detector for detecting an intensity of the noise cancelling light formed in the first side peripheral region of the hologram means to generate a third information signal component **SC3** expressing the information, and a second noise cancelling detector for detecting an intensity of the noise cancelling light formed in the second side peripheral region of the hologram means to generate a fourth information signal component **SC4** expressing the information, the noise cancelled information signal Snc being obtained according to an equation:

$$Snc=SC1+R1\times SC3+R2\times SC4,$$

where **R1** is a first weighting factor and **R2** is a second weighting factor.

31. An optical head apparatus according to claim **1** in which

the light source and the detecting means are placed on a substrate to fix a relative position between the light source and the detecting means, and

the light source is placed closely to the detecting means.

32. An optical head apparatus according to claim **1** in which

the incident light radiated from the light source is linearly polarized in a first direction,

the wavefront changing means comprises a transparent substrate, a polarizing separation film formed on a front surface of the transparent substrate for reflecting the incident light linearly polarized in the first direction on the outgoing path and refracting the transmitted light or the diffracted light linearly polarized in a second direction perpendicular to the first direction on the incoming path, a hologram formed on a rear surface of the transparent substrate for diffracting the transmitted light or the diffracted light refracted by the polarizing separation film to form the beams of information light, and a $\frac{1}{4}$-λ plate for forming the transmitted light or the diffracted light linearly polarized in the second direction by passing the incident light reflected by the polarizing separation film and passing the transmitted light or the diffracted light on the incoming path.

33. A focusing method for focusing light on a first information medium having a first thickness or a second information medium having a second thickness to record or reproduce a piece of information on or from the first information medium or the second information medium, comprising the steps of:

moving an optical head apparatus in a direction to decrease or increase the distance between the optical head apparatus and the first or second information medium, the optical head apparatus comprising

a light source for radiating a beam of incident light,

hologram means for transmitting a part of the incident light radiated from the light source without any diffraction on an outgoing path to form a beam of transmitted light and diffracting a remaining part of the incident light radiated from the light source on the outgoing path to form a beam of diffracted light, the hologram means functioning as a lens for the diffracted light to diverge the diffracted light from the hologram means or converge the diffracted light,

lens means for converging the transmitted light formed in the hologram means at a first focal length on the outgoing path to form a first converging spot at a front surface of the first information medium or converging the diffracted light formed in the hologram means at a second focal length on the outgoing path to form a second converging spot at a front surface of the second information medium, the transmitted light being incident on a rear surface of the first information medium and being converged at the front surface of the first information medium, the transmitted light being reflected at the rear surface of the first information medium and again passing through the lens means and the hologram means on an incoming path, the diffracted light being incident on a rear surface of the second information medium and being converged at the front surface of the second information medium, and the diffracted light being reflected at the rear surface of the first information medium and again passing through the lens means and the hologram means on the incoming path,

wavefront changing means for changing a wavefront of the transmitted light or the diffracted light passing through the lens means and the hologram means on the incoming path to form one or more beams of information light, and

detecting means for detecting intensities of the information light formed by the wavefront changing means and generating an information signal and a focus error signal according to the intensities of the information light, the information signal expressing a piece of information recorded on the first information medium or the second information medium;

judging whether or not an intensity of the focus error signal generated in the detecting means is larger than a threshold value; and

adjusting the position of the optical head apparatus to decrease the intensity of the focus error signal to zero when the intensity of the focus error signal becomes larger than the threshold value.

34. An information reproducing method for reproducing a piece of recording information from an optical disk in which the recording information are recorded at a high density on a first substrate having a first thickness and a piece of distinguishing information informing that the recording information are recorded on the first substrate is recorded at an ordinary density on a second substrate having a second thickness larger than the first thickness, comprising the step of:

moving an optical disk apparatus under the second substrate of the optical disk, the optical disk comprising

rotating means for rotating the optical disk at a regular speed,

a light source for radiating a beam of incident light;

hologram means for transmitting a part of the incident light radiated from the light source without any diffraction on an outgoing path to form a beam of transmitted light and diffracting a remaining part of the incident light radiated from the light source on the outgoing path to form a beam of diffracted light, the hologram means functioning as a lens for the diffracted light to diverge the diffracted light from the hologram means,

lens means for converging the transmitted light formed in the hologram means on the first substrate of the optical disk rotated by the rotating means to record or reproduce a piece of recording information on or from the optical disk and converging the diffracted light formed in the hologram means on the second substrate of the optical disk rotated by the rotating means to reproduce the distinguishing information from the optical disk, the transmitted light being reflected by the first substrate of the optical disk and again passing through the lens means and the hologram means on an incoming path, and the diffracted light being reflected by the second substrate of the optical disk and again passing through the lens means and the hologram means on the incoming path,

wavefront changing means for changing a wavefront of the transmitted light passing through the lens means and the hologram means on the incoming path to form one or more beams of recording information light and changing a wavefront of the diffracted light passing through the lens means and the hologram means on the incoming path to form one or more beams of distinguishing information light, and

detecting means for detecting intensities of the recording information light formed by the wavefront changing means to generate a recording information signal according to the intensities of the recording information light and detecting intensities of the distinguishing information light formed by the wavefront changing means to generate a distinguishing information signal according to the intensities of the distinguishing information light, the distinguishing information signal expressing the distinguishing information recorded on the second substrate of the optical disk, and the recording information signal expressing the recording information recorded on the first substrate of the optical disk; and

converging the diffracted light on the second substrate of the optical disk to reproduce the distinguishing information;

moving the optical disk apparatus to a position under the first substrate of the optical disk to converge the transmitted light on the first substrate of the optical disk when the distinguishing information is detected in the detecting means; and

reproducing the recording information by generating the recording information signal in the detecting means.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 5,446,565

DATED : August 29, 1995

INVENTOR(S) : Yoshiaki KOMMA et al.

It is certified that error appears in the above-indentified patent and that said Letters Patent is hereby corrected as shown below:

On the title page, item [75] should read as follows:

Inventors: **Yoshiaki Komma**, Kyoto; **Sadao Mizuno**; **Seiji Nishino**, both of Osaka, all of Japan--

Signed and Sealed this

Nineteenth Day of December, 1995

Attest:

Attesting Officer

BRUCE LEHMAN

Commissioner of Patents and Trademarks

US005396063A

United States Patent [19]

Ito et al.

[11] Patent Number: 5,396,063

[45] Date of Patent: Mar. 7, 1995

[54] **OBJECTIVE REPLACING APPARATUS HAVING OBJECTIVE POSITION, DISPLACEMENT AND ADDRESS DETECTING MEANS AND MICROSCOPE USING IT**

[75] Inventors: **Toshinobu Ito**, Fujisawa; **Jun Matsuno**, Zushi, both of Japan

[73] Assignee: **Nikon Corporation**, Tokyo, Japan

[21] Appl. No.: **264,254**

[22] Filed: **Jun. 22, 1994**

Related U.S. Application Data

[63] Continuation of Ser. No. 69,399, Jun. 1, 1993, abandoned.

[30] **Foreign Application Priority Data**

Jun. 8, 1992 [JP] Japan 4-171533
Jun. 8, 1992 [JP] Japan 4-171534

[51] **Int. Cl.**[6] **G02B 21/00**; G02B 21/06

[52] **U.S. Cl.** **250/231.18**; 250/201.3; 359/384

[58] **Field of Search** 250/231.18, 216, 201.3, 250/205; 356/246; 359/381, 384, 385

[56] **References Cited**

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Primary Examiner—David C. Nelms
Assistant Examiner—John R. Lee
Attorney, Agent, or Firm—Shapiro and Shapiro

[57] **ABSTRACT**

An apparatus for detecting a rotation operation of revolver is provided with a rotation direction detecting device for detecting a rotation direction of revolver by detecting a displacement of a position indication portion indicating a position of objective mount portion. In case that the rotation of revolver is carried out either in a manual manner or in an automatic manner, an address of mount hole in revolver which is to be next located at the predetermined position may be determined at start of rotation operation of revolver.

14 Claims, 9 Drawing Sheets

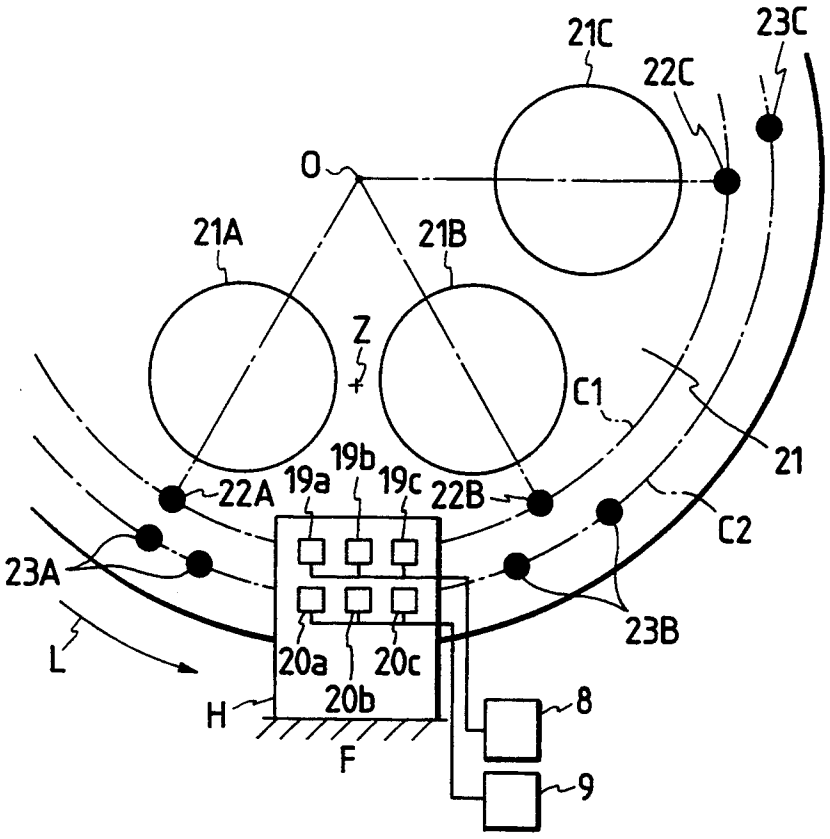


FIG. 1

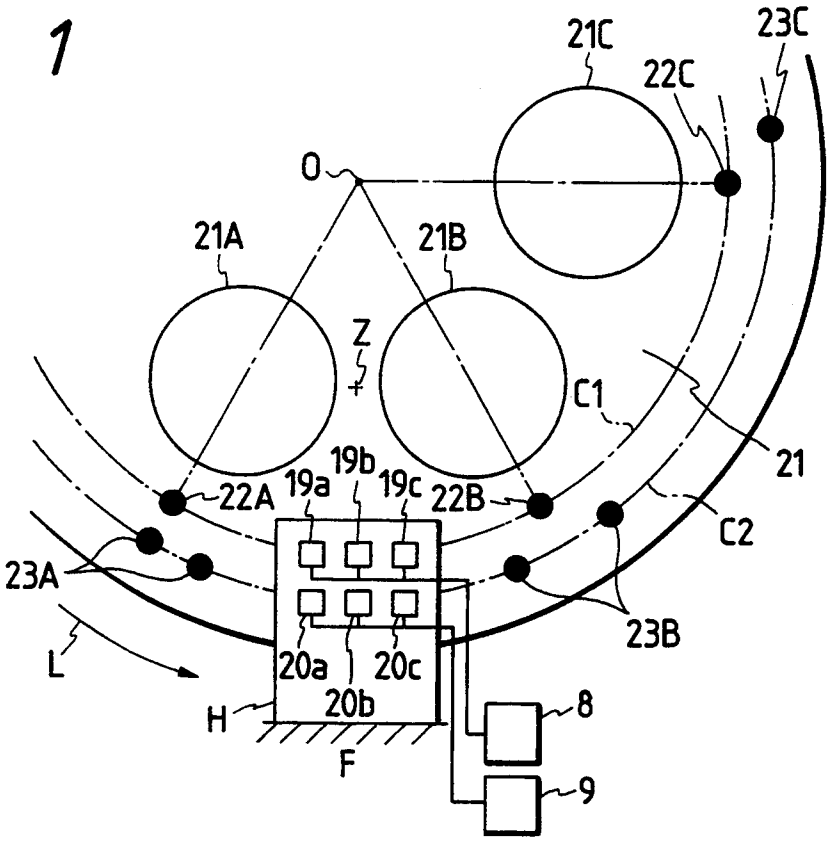
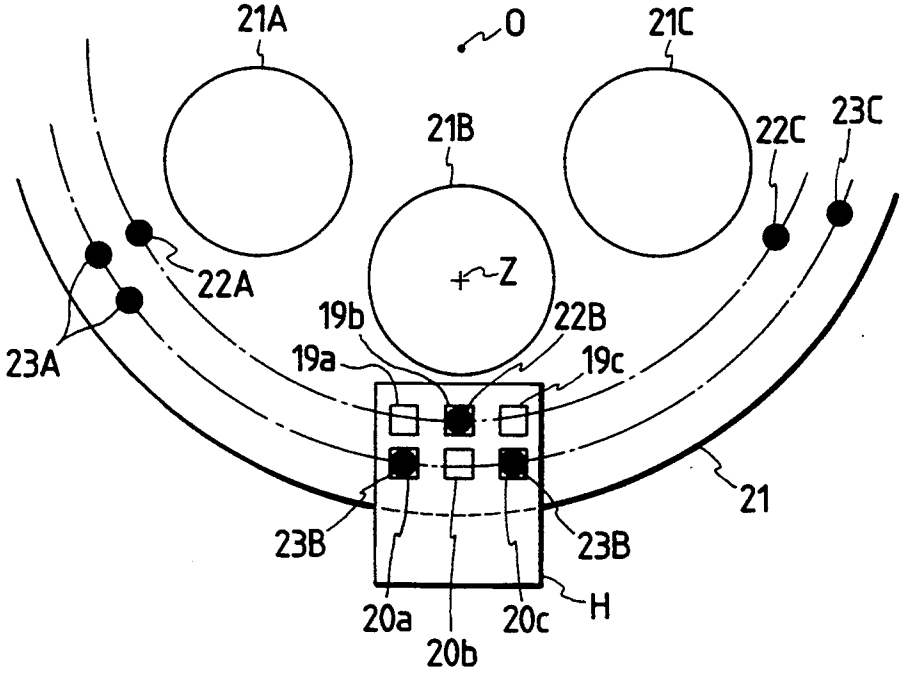

21C
23C
22C
O
21A
21B
Z
C1
21
22A
19a
19b
19c
22B
C2
23A
23B
L
20a
20c
20b
H
8
F
9

FIG. 2


21A
O
21C
21B
22C
23C
Z
22A
19b
22B
23A
19a
19c
21
23B
23B
H
20a
20c
20b

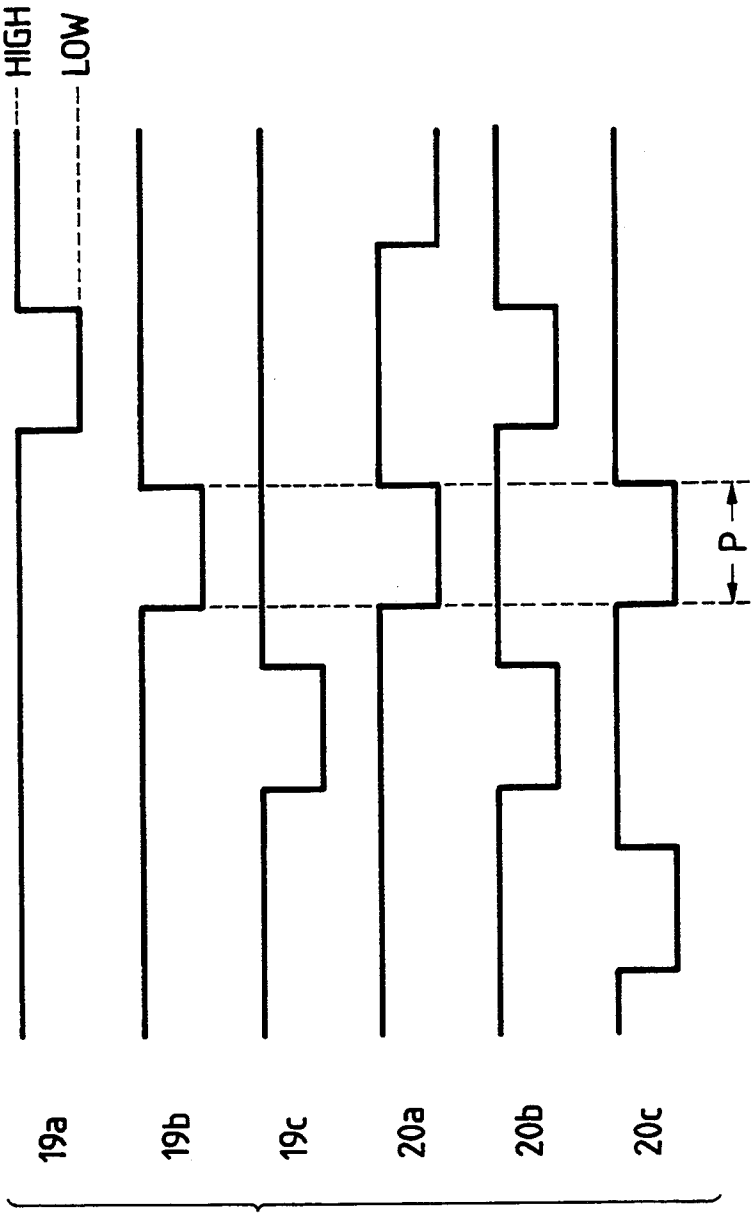


FIG. 3

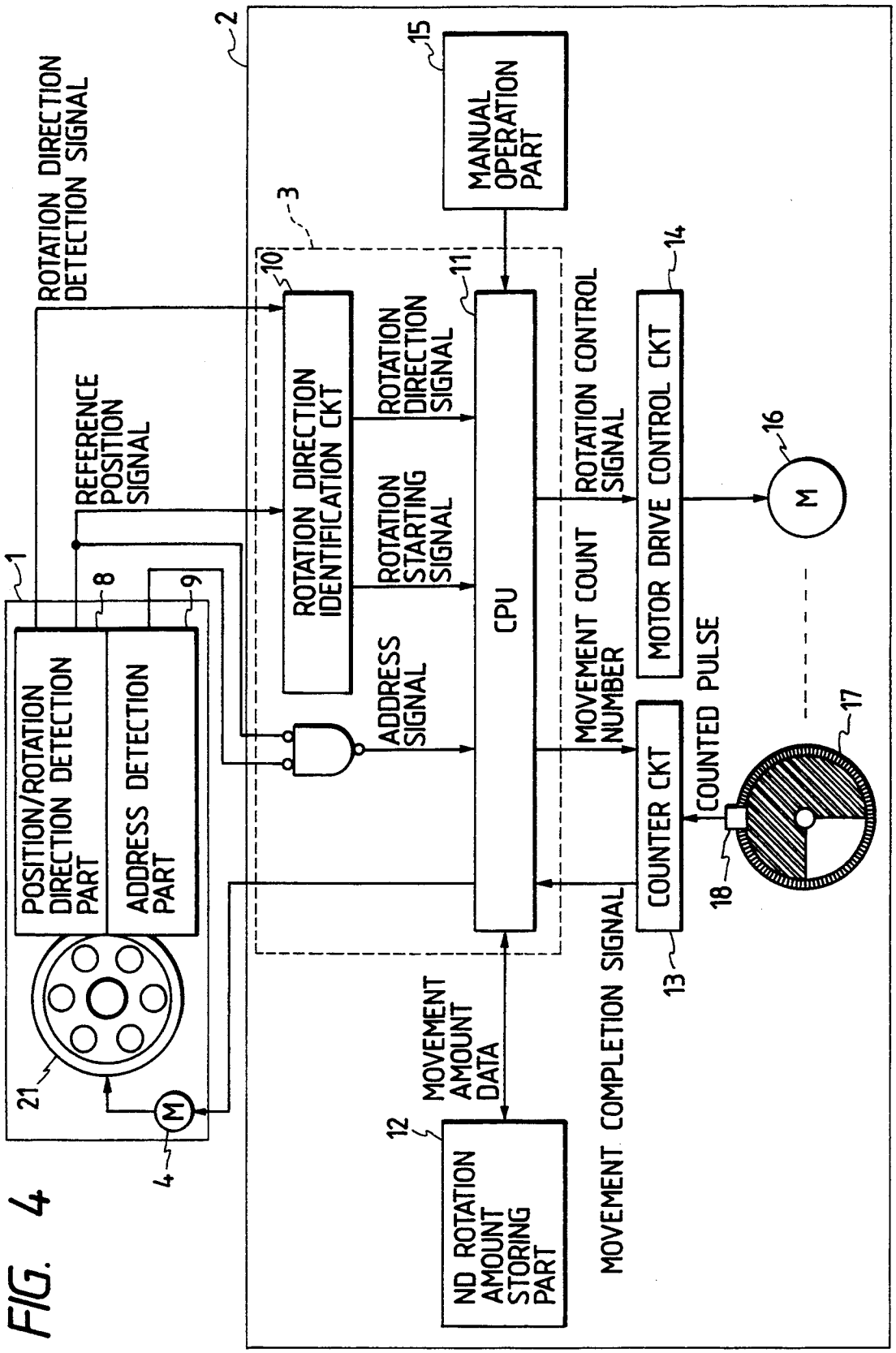

ROTATION DIRECTION DETECTION SIGNAL
REFERENCE POSITION SIGNAL
POSITION/ROTATION DIRECTION DETECTION PART
ADDRESS DETECTION PART
ROTATION DIRECTION IDENTIFICATION CKT
ROTATION DIRECTION SIGNAL
ROTATION STARTING SIGNAL
ADDRESS SIGNAL
CPU
MANUAL OPERATION PART
ROTATION CONTROL SIGNAL
MOTOR DRIVE CONTROL CKT
MOVEMENT COUNT NUMBER
COUNTER CKT
COUNTED PULSE
MOVEMENT COMPLETION SIGNAL
MOVEMENT AMOUNT DATA
ND ROTATION AMOUNT STORING PART
M
1
2
3
4
8
9
10
11
12
13
14
15
16
17
18
21

FIG. 4

FIG. 5

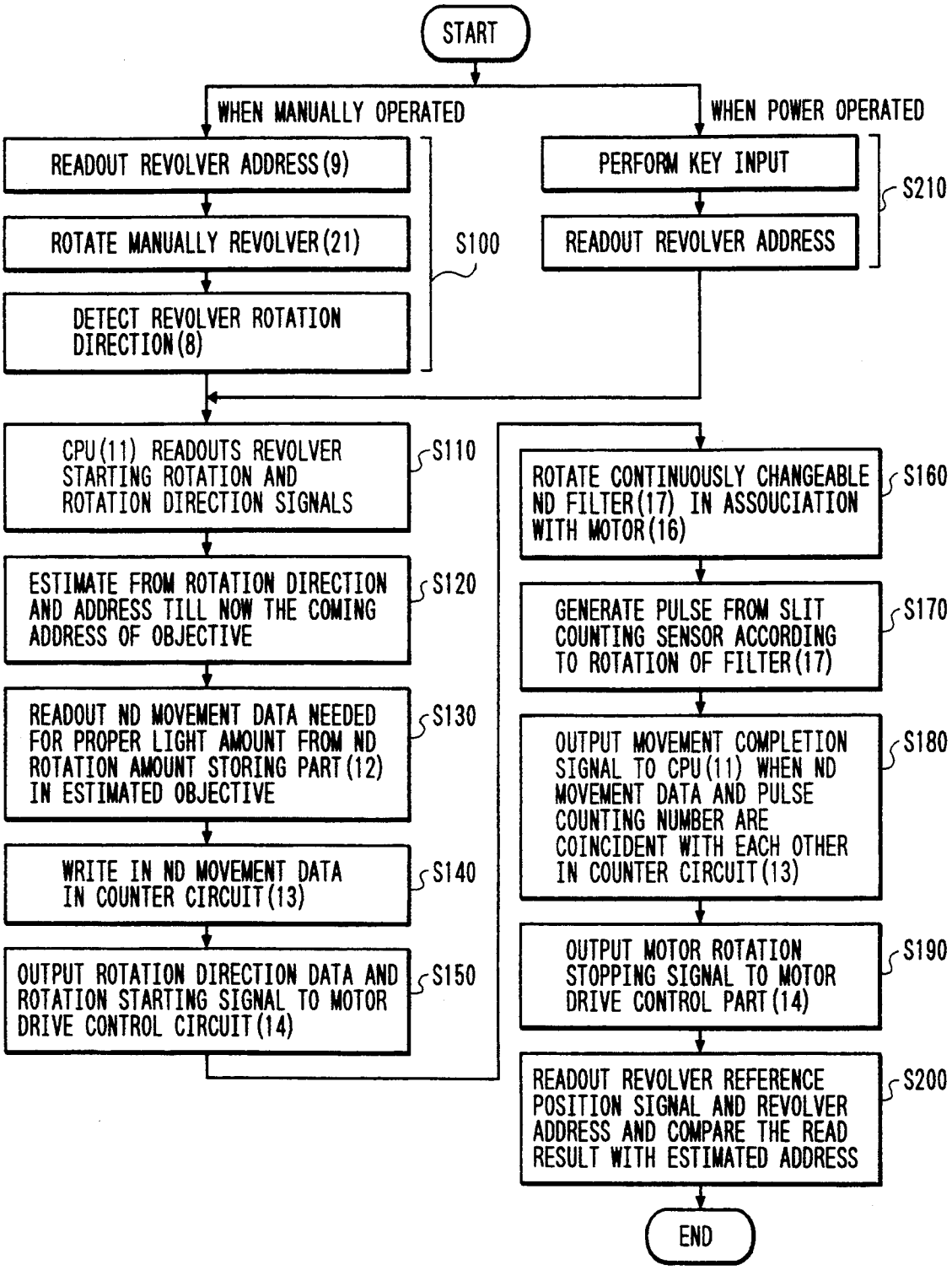
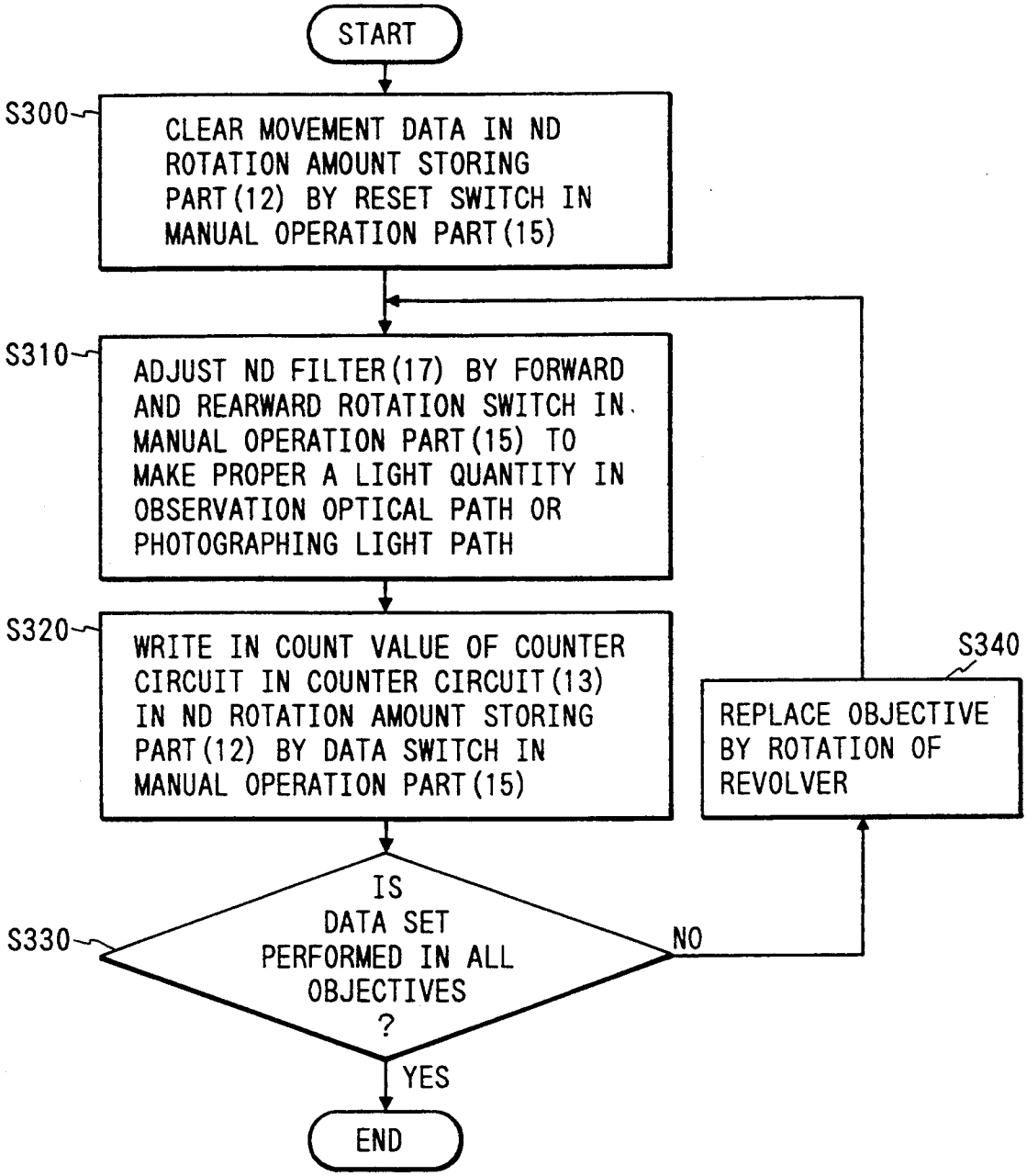

START
WHEN MANUALLY OPERATED
WHEN POWER OPERATED
READOUT REVOLVER ADDRESS (9)
ROTATE MANUALLY REVOLVER (21)
DETECT REVOLVER ROTATION DIRECTION (8)
S100
PERFORM KEY INPUT
READOUT REVOLVER ADDRESS
S210
CPU (11) READOUTS REVOLVER STARTING ROTATION AND ROTATION DIRECTION SIGNALS
S110
ESTIMATE FROM ROTATION DIRECTION AND ADDRESS TILL NOW THE COMING ADDRESS OF OBJECTIVE
S120
READOUT ND MOVEMENT DATA NEEDED FOR PROPER LIGHT AMOUNT FROM ND ROTATION AMOUNT STORING PART (12) IN ESTIMATED OBJECTIVE
S130
WRITE IN ND MOVEMENT DATA IN COUNTER CIRCUIT (13)
S140
OUTPUT ROTATION DIRECTION DATA AND ROTATION STARTING SIGNAL TO MOTOR DRIVE CONTROL CIRCUIT (14)
S150
ROTATE CONTINUOUSLY CHANGEABLE ND FILTER (17) IN ASSOUCIATION WITH MOTOR (16)
S160
GENERATE PULSE FROM SLIT COUNTING SENSOR ACCORDING TO ROTATION OF FILTER (17)
S170
OUTPUT MOVEMENT COMPLETION SIGNAL TO CPU (11) WHEN ND MOVEMENT DATA AND PULSE COUNTING NUMBER ARE COINCIDENT WITH EACH OTHER IN COUNTER CIRCUIT (13)
S180
OUTPUT MOTOR ROTATION STOPPING SIGNAL TO MOTOR DRIVE CONTROL PART (14)
S190
READOUT REVOLVER REFERENCE POSITION SIGNAL AND REVOLVER ADDRESS AND COMPARE THE READ RESULT WITH ESTIMATED ADDRESS
S200
END

FIG. 6


START
S300
CLEAR MOVEMENT DATA IN ND ROTATION AMOUNT STORING PART(12) BY RESET SWITCH IN MANUAL OPERATION PART(15)
S310
ADJUST ND FILTER(17) BY FORWARD AND REARWARD ROTATION SWITCH IN MANUAL OPERATION PART(15) TO MAKE PROPER A LIGHT QUANTITY IN OBSERVATION OPTICAL PATH OR PHOTOGRAPHING LIGHT PATH
S320
WRITE IN COUNT VALUE OF COUNTER CIRCUIT IN COUNTER CIRCUIT(13) IN ND ROTATION AMOUNT STORING PART(12) BY DATA SWITCH IN MANUAL OPERATION PART(15)
S330
IS DATA SET PERFORMED IN ALL OBJECTIVES ?
NO
S340
REPLACE OBJECTIVE BY ROTATION OF REVOLVER
YES
END

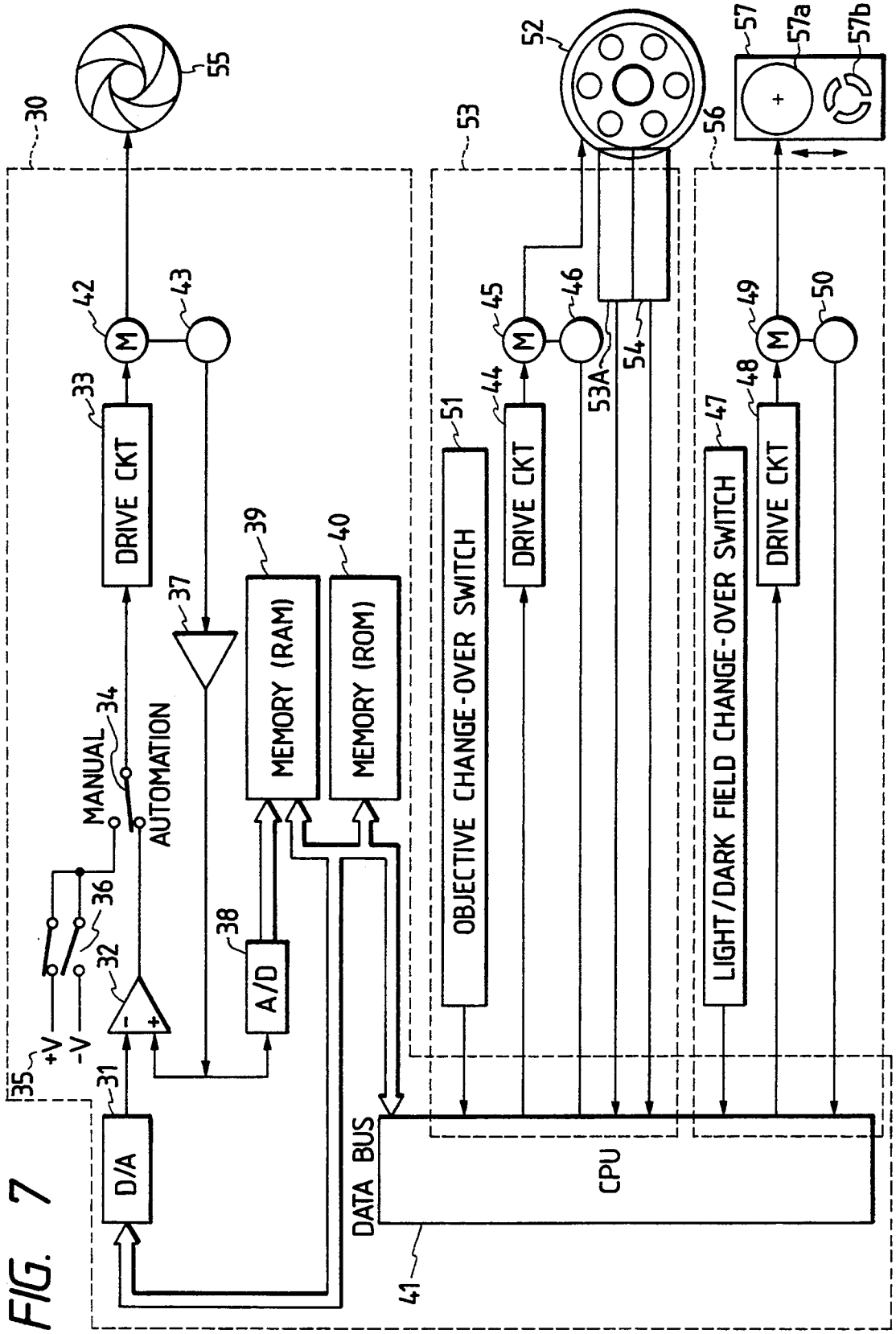

30
55
52
53
56
57
57a
57b
42
43
45
46
49
50
33
DRIVE CKT
44
DRIVE CKT
48
DRIVE CKT
51
OBJECTIVE CHANGE-OVER SWITCH
47
LIGHT/DARK FIELD CHANGE-OVER SWITCH
53A
54
37
39
MEMORY (RAM)
40
MEMORY (ROM)
MANUAL
34
AUTOMATION
36
32
38
A/D
+V
-V
35
31
D/A
DATA BUS
41
CPU

FIG. 7

FIG. 8

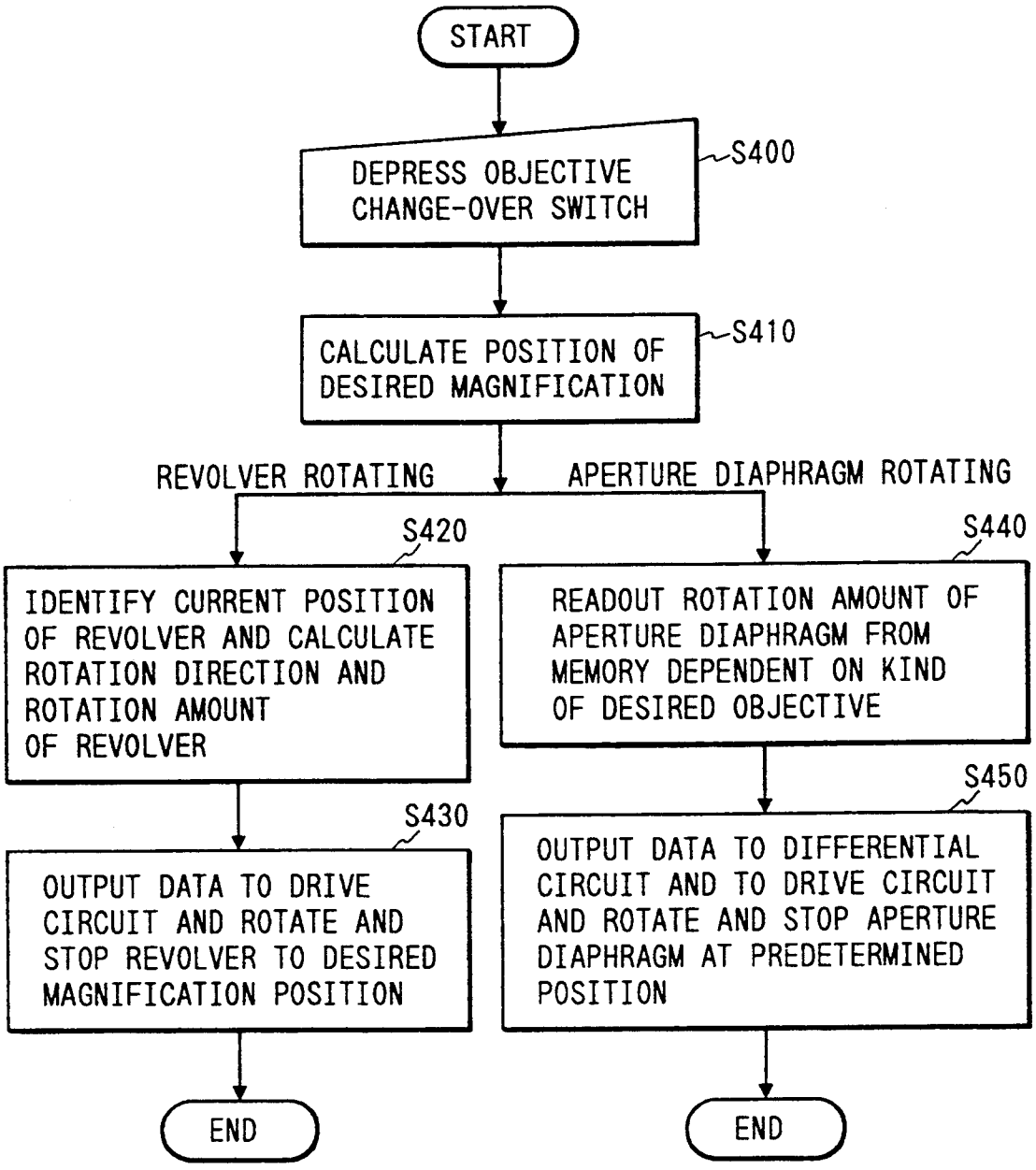

START
DEPRESS OBJECTIVE CHANGE-OVER SWITCH
S400
CALCULATE POSITION OF DESIRED MAGNIFICATION
S410
REVOLVER ROTATING
APERTURE DIAPHRAGM ROTATING
S420
IDENTIFY CURRENT POSITION OF REVOLVER AND CALCULATE ROTATION DIRECTION AND ROTATION AMOUNT OF REVOLVER
S430
OUTPUT DATA TO DRIVE CIRCUIT AND ROTATE AND STOP REVOLVER TO DESIRED MAGNIFICATION POSITION
END
S440
READOUT ROTATION AMOUNT OF APERTURE DIAPHRAGM FROM MEMORY DEPENDENT ON KIND OF DESIRED OBJECTIVE
S450
OUTPUT DATA TO DIFFERENTIAL CIRCUIT AND TO DRIVE CIRCUIT AND ROTATE AND STOP APERTURE DIAPHRAGM AT PREDETERMINED POSITION
END

FIG. 9

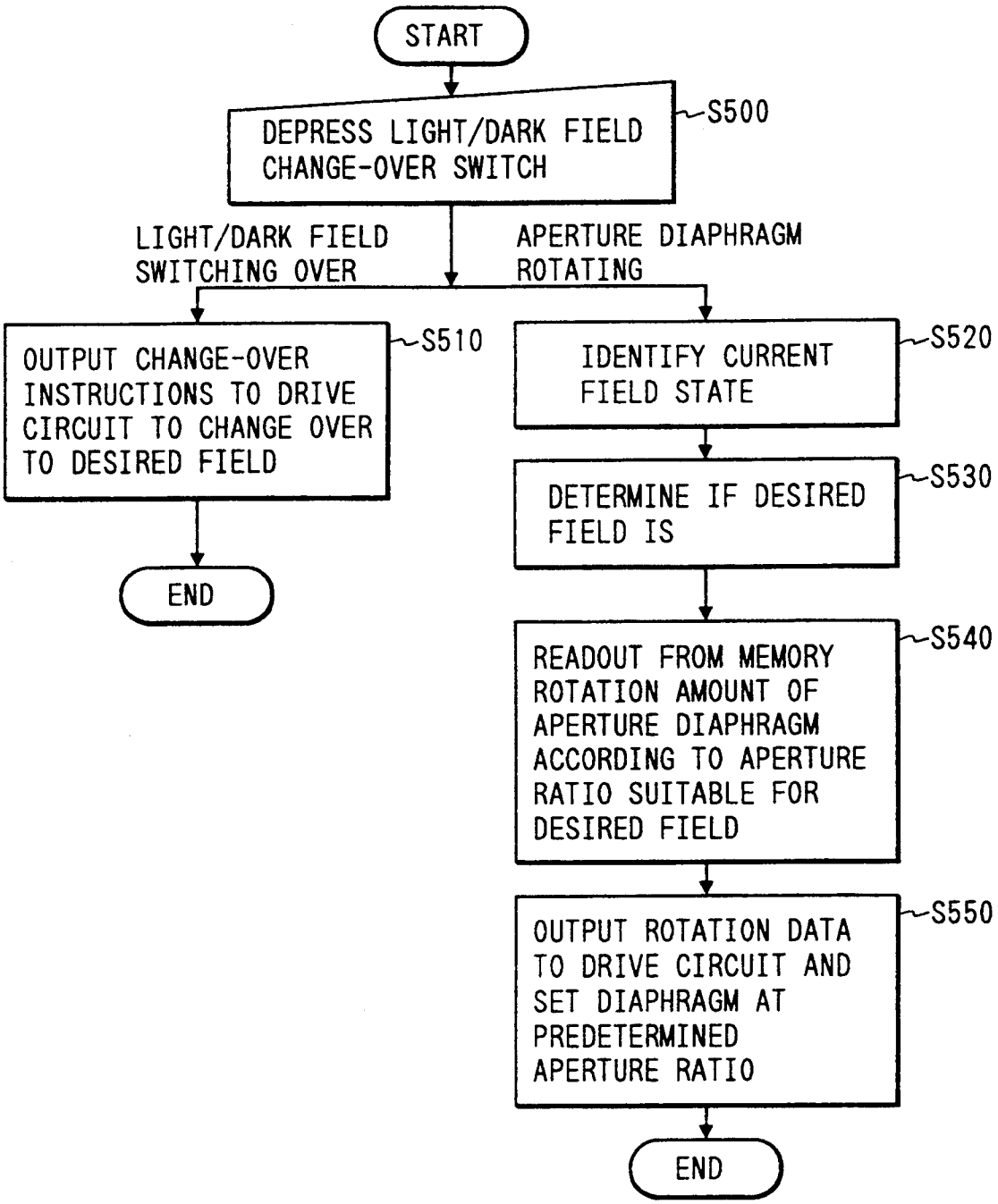
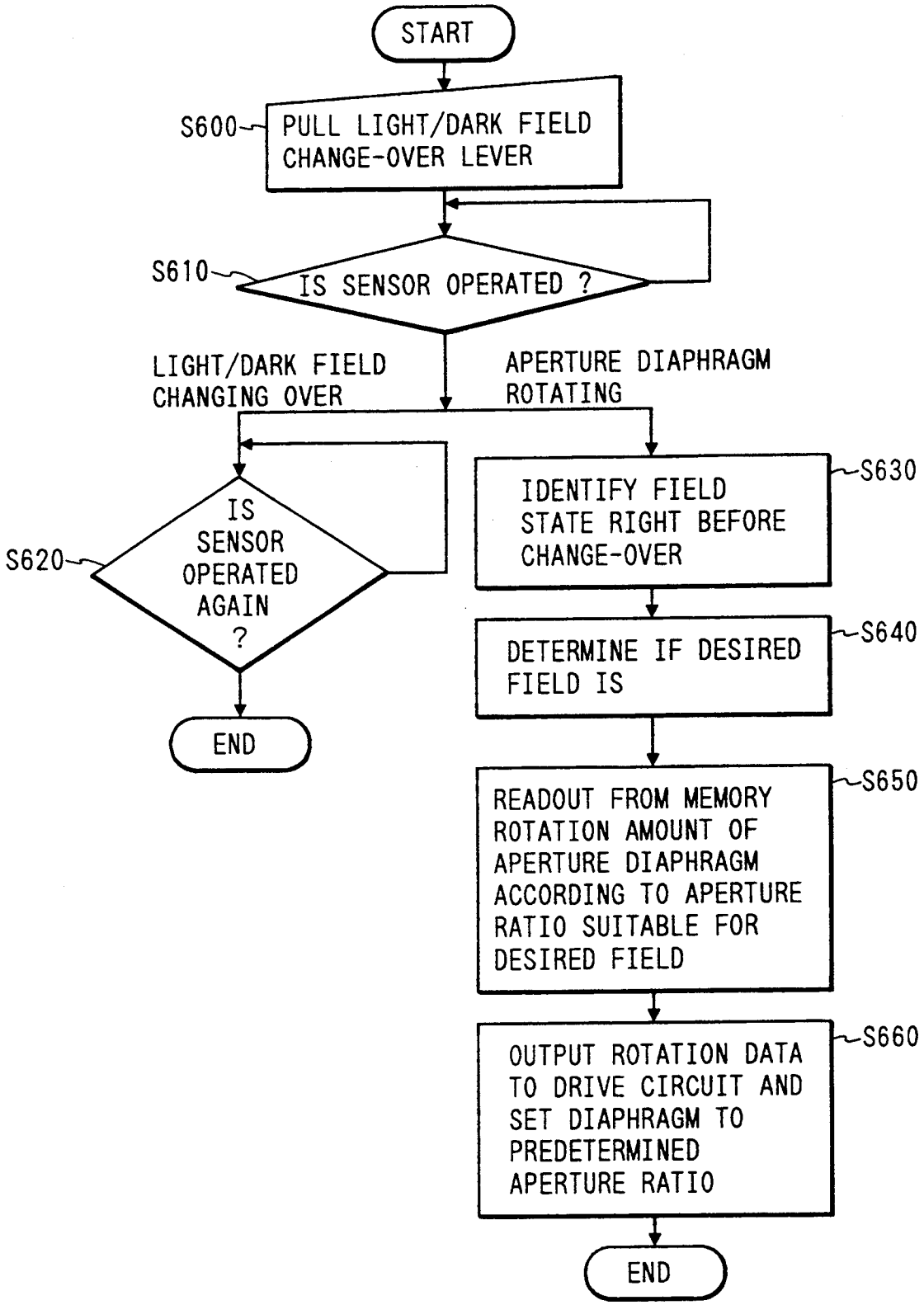

START
DEPRESS LIGHT/DARK FIELD CHANGE-OVER SWITCH
S500
LIGHT/DARK FIELD SWITCHING OVER
APERTURE DIAPHRAGM ROTATING
OUTPUT CHANGE-OVER INSTRUCTIONS TO DRIVE CIRCUIT TO CHANGE OVER TO DESIRED FIELD
S510
END
IDENTIFY CURRENT FIELD STATE
S520
DETERMINE IF DESIRED FIELD IS
S530
READOUT FROM MEMORY ROTATION AMOUNT OF APERTURE DIAPHRAGM ACCORDING TO APERTURE RATIO SUITABLE FOR DESIRED FIELD
S540
OUTPUT ROTATION DATA TO DRIVE CIRCUIT AND SET DIAPHRAGM AT PREDETERMINED APERTURE RATIO
S550
END

FIG. 10


START
S600
PULL LIGHT/DARK FIELD CHANGE-OVER LEVER
S610
IS SENSOR OPERATED ?
LIGHT/DARK FIELD CHANGING OVER
APERTURE DIAPHRAGM ROTATING
S620
IS SENSOR OPERATED AGAIN ?
END
S630
IDENTIFY FIELD STATE RIGHT BEFORE CHANGE-OVER
S640
DETERMINE IF DESIRED FIELD IS
S650
READOUT FROM MEMORY ROTATION AMOUNT OF APERTURE DIAPHRAGM ACCORDING TO APERTURE RATIO SUITABLE FOR DESIRED FIELD
S660
OUTPUT ROTATION DATA TO DRIVE CIRCUIT AND SET DIAPHRAGM TO PREDETERMINED APERTURE RATIO
END

OBJECTIVE REPLACING APPARATUS HAVING OBJECTIVE POSITION, DISPLACEMENT AND ADDRESS DETECTING MEANS AND MICROSCOPE USING IT

This is a continuation of application Ser. No. 08,069,399, filed Jun. 1, 1993, now abandoned.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to an objective replacing apparatus and a microscope using the apparatus. The objective replacing apparatus has a device for detecting an objective replacing operation. When the replacing apparatus, for example a revolver, is moved (rotated) to replace an objective with another, the detection device detects the rotation operation of revolver at rotation start. The microscope automatically controls adjustment of light quantity and adjustment of aperture diameter of aperture diaphragm with the detection device so that the illumination condition is adjusted suitable for a next coming objective being to be set in an optical path of microscope.

2. Related Background Art

There are microscopes provided with an objective replacing apparatus, a light control apparatus, and/or an aperture diaphragm apparatus, which are conventionally arranged as follows. A revolver is known as a conventional objective replacing apparatus. The revolver is held rotatable on a microscope and has a plurality of mount holes concentrically disposed around the rotation center of revolver. An objective is set in each mount hole. The revolver is rotated by an operator in a manual operation or by an automatic mechanism such as a motor, so that an arbitrary objective may be positioned in the optical path of microscope out of a plurality of objectives.

The conventional revolver had a device for detecting an address of each mount hole. There are various devices known for detecting an address of mount hole, for example as disclosed in Japanese Laid-open Utility Model Application No. 56-93713 or in Japanese Laid-open Patent Application No. 62-218915.

Such address detection devices are arranged such that when a desired mount hole is located in the optical path an address of the mount hole is then detected.

Accordingly, the conventional detection devices could not identify during movement of revolver an address of a next coming mount hole being to be set in the optical path, nor an objective set in the mount hole.

Conventional light control apparatuses are arranged such that a photo receptor is located in an observation path of microscope or in a photographic light path of TV camera or the like, that a light quantity of light from a source is detected by the photo receptor, and that the light quantity is adjusted to proper brightness by manually or automatically operating light quantity adjusting means such as a continuously variable ND filter to carry out a light control.

Such light control apparatuses, however, detect a light quantity of light emitted from the source and then passed through an objective, and then adjust the light quantity by operating the ND filter in accordance with the detected light quantity.

When the currently set objective is replaced with another objective having a different magnification by rotating the revolver, light is once shut in the field, because the objective is deviated from the optical path during rotation of revolver. The conventional light control apparatuses respond to this state with a decreased light quantity being detected by the photo receptor so that the ND filter is adjusted to become brighter.

Since brightness is detected after the next objective is located in the optical path and then the ND filter is operated in the conventional light control apparatuses, the apparatuses need a considerable time to obtain a proper light quantity, which interferes smooth observation.

In a microscope provided with such a light control apparatus, excessively bright light suddenly enters the optical path at the moment that the objective enters the optical path, which would cause eye fatigue of observer or which could deteriorate the photo receptor of TV camera. The influence appears great especially when a dark objective is replaced with a bright objective.

In addition, microscopes having an aperture diaphragm in the vicinity of condenser lens are arranged such that a resolution of image by objective, a contrast, a field of depth, and brightness may be adjusted through the aperture diaphragm. In the conventional microscopes an aperture ratio most appropriate to look could be set according to a sort of objective while an observer manually adjusts an opening diameter of aperture diaphragm. A technology was recently developed to automatically adjust the opening diameter of aperture diaphragm.

For example, often used is such an arrangement that the aperture diameter of aperture diaphragm is automatically adjusted in accordance with an objective set in a mount hole located at a stop position of revolver, using the aforementioned address detection device of mount hole in revolver.

The automatic adjusting device, however, starts the adjusting operation to optimize the opening diameter of aperture diaphragm after the revolver is stopped. Accordingly, the conventional microscopes permit no observation before the diameter of aperture diaphragm is adjusted, providing a problem of waiting time.

SUMMARY OF THE INVENTION

The first object of the present invention is to obtain an apparatus for detecting a rotation operation of revolver, which can determine a next objective being to be located at a predetermined position at an early stage of rotation of revolver. The second object of the invention is to obtain a microscope with the apparatus for detecting the rotation operation of revolver, which can start adjustment of light quantity, diameter of aperture diaphragm, or the like concomitant with replacement of objective early.

An apparatus for detecting a rotation operation of revolver according to the present invention is provided with rotation direction detecting means for detecting the rotation direction of the revolver by detecting a displacement of position indication part indicating a position of an objective mount portion.

The conventional microscopes can determine an address of next mount hole or an objective mounted in the next mount hole only either by a command signal of controller of motor-operated revolver in case that the revolver is automatically rotated or by detecting an address of mount hole after rotation in case that the revolver is manually rotated, whereas the apparatus of the present invention can determine an address of next

mount hole in revolver being to be located at a predetermined position at the start of rotation operation of revolver when the revolver is manually or automatically rotated.

A microscope of the present invention is provided with the apparatus for detecting the rotation operation of revolver as described, so that the rotation direction of revolver may be identified thereby to enable determination of next objective being to be located in the optical path of microscope, whereby various adjustments may be early conducted based on the thus determined objective.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a drawing to show a main part of apparatus for detecting a rotation operation of revolver in an embodiment;

FIG. **2** is a drawing to show a state after the revolver **21** of FIG. **1** is rotated;

FIG. **3** is a drawing to show signals of respective sensors in holder H in FIG. **1**;

FIG. **4** is a drawing to show the construction of embodiment of a light control apparatus for microscope using the apparatus of FIG. **1**;

FIG. **5** and FIG. **6** are drawings to show a flowchart for the apparatus of FIG. **4**;

FIG. **7** is a drawing to show the construction of embodiment of an aperture diaphragm apparatus for microscope using the apparatus of FIG. **1**; and

FIG. **8**, FIG. **9**, and FIG. **10** are drawings to show a flowchart for the apparatus of FIG. **7**.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

There will be described referring to FIG. **1** to FIG. **10** an apparatus for detecting the rotation operation of revolver, and a light control apparatus and an aperture diaphragm apparatus for microscope.

FIG. **1** and FIG. **2** show an embodiment of the apparatus for detecting the rotation operation of revolver.

In FIG. **1** reference numeral **21** designates a revolver, which is rotatably held on a fixed portion fixed in a microscope body. A plurality of objectives not shown are mounted at respectively predetermined positions in the revolver **21**.

FIG. **1** shows objective mount holes **21A**, **21B**, **21C** representing the predetermined positions.

Small disk permanent magnets **22A**, **22B**, **22C** are attached to the revolver **21** at peripheral positions radially outside the objective mount holes **21A**, **21B**, **21C**. These small permanent magnets **22A**, **22B**, **22C** are for identifying a reference stop position of objective mount hole **21A**, **21B**, **21C**. Each of the small permanent magnets is disposed on an intersection between an imaginary circumference **C1** with the center at the rotation center **0** of revolver **21** and a straight line passing through the center of each objective lens mount hole and the rotation center **0** of revolver.

A plurality of small disk permanent magnets **23A**, **23B**, **23C** (as will be collectively referred to as an address indication part) each for identifying an address of each mount hole **21A**, **21B**, **21C** are mounted at peripheral positions further radially outside the imaginary circle **C1**. The address indication part **23** indicates an address of each mount hole by arranging the magnets among three locations, which can indicate eight (**23**) addresses at most.

A holder H is fixed at the position F (which is a part of the fixed portion) where it is kept as not interfering with the revolver **21** upon rotation. Hall IC sensors **19*a***, **19*b***, **19*c*** (which will be collectively denoted by numeral **19**) are mounted on the holder H. The Hall IC sensors **19*a***, **19*b***, **19*c*** are located at superposing positions over the imaginary circumference **C1**, and are connected to a position/rotation direction detection part **8** for electrically converting a detection signal. The sensors **19*a*** and **19*c*** are used for rotation direction detection. The IC sensor **19*b*** is used for detecting whether the mount hole is located at the predetermined position.

Hall IC sensors **20*a***, **20*b***, **20*c*** (as will be collectively denoted by numeral **20**) are disposed outside the Hall IC sensor series **19**. The Hall IC sensors **20*a***, **20*b***, **20*c*** are superposedly arranged over an imaginary circumference **C2**. A spacing between the Hall IC sensors is equal to a mount pitch of the magnets **23A**, **23B**, **23C**. The Hall IC sensors **20*a***, **20*b***, **20*c*** are connected to the address detection circuit **9** for electrically converting a detection signal.

Next described are the address detection and the position/rotation direction detection with the Hall IC sensors **19**, **20**.

The address detection circuit **9** outputs an address signal of mount hole, based on the predetermined arrangement pattern of small permanent magnets **23A**, **23B**, **23C** detected by the Hall IC sensors **20*a***, **20*b***, **20*c***.

The position/rotation direction detection part **28** detects the position and the rotation direction by reading the position of small permanent magnet **22A**, **22B**, **22C** through the Hall IC sensors **19*a***, **19*b***, **19*c***.

The logic of revolver position detection and rotation direction detection is described referring to FIG. **2** and FIG. **3**. The detection operation of rotation direction will be described with an example in which the objective mount hole **21B** is set in the optical path, as shown in FIG. **2**.

When the Hall IC sensor **19*b*** at the objective mount hole **21B** is on (active LOW) as in the LOW part of letter P in FIG. **3**, the objective lens is in the optical path (only the optical axis Z of which is shown). Address data detected by the Hall IC sensors **20*a***, **20*b***, **20*c*** become effective only in that state. Accordingly, the Hall IC sensor. **19*b*** functions as a reference position sensor to define the stop position of revolver.

In FIG. **3**, the Hall IC sensors **20*a***, **20*b***, **20*c*** detect on, off, and on, respectively, during ON (active LOW) of the reference position sensor **19*b*** to detect the predetermined revolver address.

The Hall IC sensors **19*a***, **19*c*** are located on either side of the reference position sensor **19*b***. When the revolver **21** is rotated, the small permanent magnet **22B** is slightly deviated in the direction of rotation to enter a sensitive range of either one of the Hall IC sensors **19*a***, **19*c*** located along the rotation direction. This permits one to know in which direction the revolver **21** is rotated.

The reference position signal and the rotation direction signal detected by these detection parts **8**, **9** are output to a rotation direction identification circuit **10** provided inside the microscope, and the rotation direction identification circuit **10** outputs a revolver rotation direction signal and a revolver rotation start signal (see FIG. **4**).

The position/rotation direction identification circuit **10** determines the rotation direction by detecting which sensor **19*a*** or **19*c*** in the rotation direction becomes

LOW after the signal of the reference position sensor **19***b* is turned from LOW to HIGH as shown in FIG. **3**.

This permits one to know an address of next mount hole, or a next objective being to be next set into the optical path at the same time with the rotation of revolver **21**. Consequently, necessary data such as a light quantity suitable for the next objective may be known Substantially at the same time with the start of rotation operation of revolver.

Next described referring to FIG. **4** and FIG. **5** is a light control apparatus for performing a light control for the objective specified by the revolver rotation operation detection apparatus as described.

In FIG. **4** the above-described revolver rotation operation detection apparatus comprises the position/rotation direction detection part **8** enclosed in the revolver part **1**, the address detection circuit **9**, and the rotation direction identification circuit **10** incorporated in a control part **3** in a light control part **2**.

The light control part **2** comprises an ND filter drive part **14**, **16** for driving a continuously variable ND filter, which is variable light control means for adjusting a proper light quantity for an objective, an ND rotation amount storing part **12** storing rotation operation amounts of ND filter corresponding to respective objectives, and an ND rotation amount detection sensor part **13**, **18** for feeding back the rotation amount of ND filter.

Further connected is a manual operation part **15** for inputting initial setting or change setting of proper light quantity data or the like for objective.

An operation of the light control apparatus is now described.

First described is the change-over of objective by manually rotating the revolver.

Suppose the reference position **22**B of the current revolver is known through the sensor **19***b* and the revolver address is read by the address detection part **9**, as described with FIG. **2**. When the revolver **21** is rotated from this state in a certain direction (for example in the direction of L in FIG. **1**), the position/rotation direction detection part **8** outputs a rotation direction detection signal (an output signal of IC sensor **19**C) to the rotation direction identification circuit **10** (Step **100**). The rotation direction identification circuit determines the rotation direction with the detection signal, and outputs a rotation start signal and a rotation direction signal. A CPU **11** reads these signals and the address signal from the detection part **9** (Step **110**), and then identifies an address of next coming mount hole, that is, next objective (Step **120**).

Then, the CPU **11** reads out from the ND rotation amount storing part **12** relative movement data about rotation direction and rotation amount of the continuously variable ND filter **17** from the present position in order to equalize a light quantity through the next objective being to be set into the optical path to the light quantity through the objective set in the optical path before start of rotation (Step **130**).

The CPU **11** then writes the read relative movement data in the counter circuit **13**, and gives the motor rotation direction and a command of rotation start to the motor drive control circuit **14** (Steps **140**, **150**). A DC motor **16** starts rotating with this rotation command signal, and the continuously variable ND filter **17** attached to the rotation shaft of DC motor **16** starts rotating in the predetermined direction (Step **160**). While the continuously variable ND filter **17** is rotated, a slit counting sensor **18** detects slits formed on the peripheral edge of filter to generate count pulses (Step **170**). The count pulses are then counted by the counter circuit **13**, and a movement completion signal is output to the CPU. **11** when the movement count number and the counter pulse number set by the CPU **11** in the counter circuit **13** at Step **140** are coincident with each other (Step **180**). This signal is read by the CPU **11**, and then a motor stop signal is output to the motor drive control circuit **14** (Step **190**). Receiving this stop signal, the motor is stopped and the revolver address detection signal is simultaneously read. It is checked whether the address is coincident with the revolver position anticipated as next (Step **200**).

Next described is the change-over of objective by rotating the revolver **21** by means of motor. The revolver **21** is driven by a motor **4**. The CPU **11** controls the motor **4**, based on the operation of revolver rotation command switch provided in the manual operation part **15**. The CPU **11** outputs a drive signal to the motor **4** when either a forward/backward rotation command signal of motor-operated revolver or an objective address assignment signal is output by operating the switch of the operation part **15**. At the same time, the input signals are read to directly determine a next coming revolver address, or next objective (Step **210**). Namely, data of rotation direction and rotation start can be obtained from the command signal or the assignment signal, and a next objective can be determined simply by reading an address from the detection part **9**. Once the next objective is determined, the CPU **11** executes the light control in the same manner as in the manual rotation. The Hall IC sensor **19***b* may be omitted in case of motor-operated revolver, because it can be detected by another means whether a desired mount hole is located in the optical path.

The another means is as follows. Click grooves are formed at positions corresponding to the respective mount holes on the revolver **21**. An engagement member such as a ball urged by a spring is provided on the fixed portion of revolver, which engages with a click groove when a desired mount hole is coincident with the optical path. When the revolver is rotated, a load on the motor **4** differs depending on whether the mount portion is located in the optical path or at a position other than the optical path. Thus, the another means is one to detect whether the desired mount hole is located in the optical path by detecting the difference of load.

Also, there may be a case that a light amount Passing through the objective is desired to be changed without changing the objective. In this case, the forward rotation/backward rotation switch in the manual operation part **15** is operated to rotation-adjust the aforementioned continuously variable ND filter **17** as to secure a determined light quantity.

When the objective is replaced with another after the continuously variable ND filter **17** was adjusted by such a manual operation, the CPU **11** adjusts the continuously variable ND filter **17** by a relative movement amount corresponding to a light amount difference between proper light quantities for old and new objectives from the position set by the manual operation. In other words, the amount set by the manual operation is kept as an offset. This arrangement assures a proper light quantity for each objective before and after replacement thereof.

Next described referring to the flowchart shown in FIG. **6** is a process for storing relative movement data

of the continuously variable ND filter for objectives set in the respective mount holes in revolver.

The manual operation part **15** has an initial setting switch (for reset and data setting) and the forward-/backward rotation command switch. The storage of relative movement data is carried out with these switches.

When the reset switch of initial setting switch is turned on, the CPU **11** clears movement data stored in the ND rotation amount storing part **12** (Step **300**). Specifically, it writes initial value data in the counter circuit **13**. A desired objective is then set in the optical path of microscope, and the forward/backward rotation switch in the manual operation part **15** is operated to rotate the continuously variable ND filter **17**. By this operation, the light quantity is adjusted to be suitable for an observation optical path or a photographic optical path for example for TV camera (Step **310**). When a suitable light amount is set, the data setting switch in the manual operation part **15** is pressed to write the movement count value of counter circuit **13** at this moment in the ND rotation amount storing part **12** (Step **320**). Similarly, relative movement data for all objectives set in the revolver may be consecutively stored in the storing part **12** (Steps **330**, **340**). A difference between objectives may be calculated with absolute count value as read value to obtain the data.

There is another method for inputting the relative movement data for each objective different from the above method. The another method is as follows. Information (magnification, NA, etc.) on objectives set in the respective mount holes is input from the outside. A difference of proper light quantity is calculated between objectives, based on the Objective information. The data is converted into a corresponding rotation direction movement amount (count value) of continuously variable ND filter **17**, and stored in the ND rotation amount storing part **12**. This data input method has an advantage that there is no need to store the relative movement data, based on brightness adjustment with the continuously variable ND filter **17** for respective objectives prior to observation.

A pulse motor may be employed as the driving motor **16** in place of DC motor. Such a modification may obviate the rotation angle detection sensor such as the slit counting sensor **18**. Namely, the continuously variable ND filter may be rotation-adjusted in open-loop control by inputting pulse string for drive control directly into the counter circuit **13** and counting it.

In contrast, the aforementioned light control apparatus performs a semi-closed loop control to detect a rotation amount of continuously variable ND filter **17**. The light control apparatus of the present invention may also employ a closed-loop control to obtain the proper light quantity by detecting a light quantity of light from a source having passed through the ND filter, and feeding back the state to the set value in order to Judge if the set density of ND filter is appropriate.

Since the Hall IC sensor series **19** for detecting the position of objective mount hole, which is used in the revolver rotation operation detection apparatus as described, is for use in detection of rotation direction, it may be omitted if the revolver is manually rotated. Also, although the rotation direction is determined with the three Hall IC sensors **19***a*, **19***b*, **19***c* in the above embodiment, the rotation direction of revolver may be detected by a phase difference of generated signals. In this case, the number of sensors may be decreased. Further, although the above embodiment employs the Hall IC sensors to detect the position and the address, position detecting means such as the photoelectric transmission slit sensor or the reflection type photo interrupter may be set on the revolver.

The construction of an aperture diaphragm apparatus is next described referring to FIG. 7.

In FIG. 7 a control circuit **30** for aperture diaphragm adjustment is composed mainly of an automatic/manual change-Over switch **34**, a manual aperture diaphragm switch **36**, a D-A converter **31**, a differential amplifier **32**, a drive circuit **33**, an A-D converter **38**, a memory (RAM) **39**, a memory (ROM) **40**, and a CPU **41**. The automatic/manual change-over switch **34** is for change-over between an automatic setting mode in which the aperture diaphragm is automatically set in response to the rotation of revolver **52** and a manual setting mode in which the opening degree of aperture diaphragm may be freely set by motor drive upon setting an arbitrary aperture ratio. The manual aperture diaphragm switch **36** performs an open or close operation of diaphragm while switching an applying voltage (+V, −V) of the source **35** by change-over of switch in the manual setting mode. The D-A converter **31** converts the aperture ratio data of digital signal output through a data bus into an analog signal in the automatic setting mode. The differential amplifier **32** compares an output signal of the D-A converter **31** with a feedback voltage signal obtained by amplifying a signal from a potentiometer **43** of an aperture diaphragm motor **42** through an amplifier **37**. The drive circuit **33** drives the aperture diaphragm motor **42** with this comparison signal. The A-D converter **38** performs the analog-to-digital conversion of the value of the potentiometer **43** obtained at the time of setting of aperture ratio. The memory **39** stores the digital data after the A-D conversion. The memory **40** stores the initially set aperture rate of aperture diaphragm. The CPU **41** controls data transmission between the memories **39**, **40** through the data bus.

A motor-operated revolver drive control circuit **53** for switching objectives includes an objective change-over switch **51**, a part of CPU **41**, a drive circuit **44**, a motor **45**, and a position sensor **46**. The objective change-over switch **51** is disposed on an operation part of microscope, and an observer operates the revolver **52** through this switch **51**. The part of CPU **41** receives an operation signal from the switch **51** and outputs a control signal after a process of predetermined feedback. The drive circuit **44** controls the motor **45**, based on the control signal. The position sensor **16** feeds the position of the revolver motor **15** back to the CPU **41**. The control circuit **53** further has an address detection part **53A** of objective mount hole in revolver **52** and a position/rotation direction detection part **54**.

Moreover, a light/dark field change-over switch control circuit **56** has a light/dark field change-over switch **47**, a part of CPU **41**, a drive circuit **48**, a motor **49**, and a position sensor **50**. The switch **47** is provided on the operation part of microscope as to allow the observer to change over the observation method. The CPU **41** receives an operation signal from the light-/dark field change-over switch **47** and controls the drive circuit **48** with the predetermined feedback. The drive circuit **48** drives the motor **49** under the control of CPU **41** to effect the change-over between a light field and a dark field. The position sensor **50** feeds the position of the light/dark field change-over motor **49** back to the CPU **41**.

Operations of the circuits in the aperture diaphragm apparatus so arranged will be described referring to FIG. 7 to FIG. 10.

A standard change-over operation of objective is first explained.

After the observer sets a plurality of objectives (not shown) in the motor-operated revolver **52**, he or she conducts an operation to store a relation between the respective lenses and the revolver mount positions in the memory **40**. This operation is sequentially carried out according to an instruction on an instruction screen of display provided on a panel having the operation switch of microscope.

After that, when the observer operates the objective change-over switch **51** on the operation part to change the objective for example into one having **20** magnifications during observation (Step **400**), the CPU **41** calculates a mount hole in which the objective of **20** magnifications is set, from a signal of switch **51** and an address of address detection part **53** (Step **410**).

After that, the rotation operation of revolver **52** and the aperture diaphragm rotation operation are carried out in parallel. In the revolver rotation operation the CPU **41** first calculates a rotation direction and a rotation amount from the present position of revolver **52** to the position of mount hole for the objective of 20 magnifications (Step **420**). The CPU **41** outputs a drive signal based on the calculated value to the drive circuit **44**, and the drive circuit **44** rotates the revolver motor **45** based on the drive signal. The revolver is rotated up to a desired magnification position to set the objective of 20 magnifications while the rotation amount of motor **45** is fed back from the position sensor **46** to the CPU **41** (Step **430**).

The open-close operation of aperture diaphragm **55** is also carried out simultaneously with the above operation. The CPU **41** first reads out from the memory (ROM) **40** rotation amount data of motor **49** for obtaining an aperture diameter of aperture diaphragm corresponding to a standard aperture ratio (for example 75%) of objective of 20 magnifications (Step **440**). The data signal is subjected to the digital-to-analog conversion in the D-A converter **31** and then to a predetermined control, and the thus converted signal is output through the drive circuit **33** to the aperture diaphragm motor **42** to conduct the open/close operation of aperture diaphragm **55**. An output of the aperture diaphragm motor **42** is fed back to the potentiometer **43** connected thereto, a difference from the command value of the CPU **41** is obtained, a deviation signal is again output to the aperture diaphragm motor **42**, and the aperture diaphragm motor **42** is stopped at the position of standard aperture ratio (Step **410**). In case that the operation time of aperture diaphragm is shorter than the change-over time of objective, a waiting time of user is just the change-over time of objective. On the other hand, if the relation is reversed, the waiting time is just the operation time of aperture diaphragm.

Adjustment of aperture diaphragm in light/dark field change-over is next described with reference to FIG. 7 and FIG. **9**.

The following example illustrates a case of change-over from a light field to a dark field.

When the light/dark field change-over switch **47** is operated, a field change-over operation signal is output to the CPU **41** (Step **500**).

After that, the light/dark field change-over operation and the aperture diaphragm rotation operation are carried out in parallel. In the light/dark field change-over operation, when the CPU **41** receives a change-over command, it outputs a dark field changeover command to the drive circuit **48** and carries out the field change-over operation by the light/dark field change-over motor **49** through the drive circuit **48** (Step **510**). The field change-over operation is an exchange operation of the light field diaphragm **57***a* and a dark field diaphragm **57***b* as shown in FIG. 7.

Also simultaneously with this operation, the aperture diaphragm positioning operation similar to that as described above is carried out to set an aperture ratio of the aperture diaphragm **55** suitable for the dark field (normally full open). Namely, a present field state is first identified (Step **520**); a desired field is determined from this result (Step **530**); an operation amount of aperture diaphragm corresponding to the aperture ratio fit for the desired field is read out from the memory (ROM) **40** (Step **540**); and after conversion it is output to the drive circuit **3** to set the aperture at the desired aperture ratio (Step **550**).

In case that the operation time of aperture diaphragm is shorter than the change-over time of light/dark field, a waiting time of user is just the change-over time of light/dark-field. In case that the relation is reversed, the waiting time is just the operation time of aperture diaphragm.

Next explained with FIG. **10** is a case that the light-/dark field change-over is manually carried out.

Generally in case of manual light/dark field change-over, the field State is switched by operating a change-over lever (not shown) and moving a field diaphragm plate to a predetermined position (Step **600**). Thus, it is judged in case of manual change-over whether the change-over is carried out, using a current position sensor for detecting a current field diaphragm plate position (Step **610**). The current position sensor is for example a micro switch. The switch is so arranged that it outputs an off signal when the diaphragm **57***a* of field diaphragm plate **57** is set in the optical path and that it outputs an on signal when the diaphragm **57***b* is located in the optical path. Accordingly, a field state desired to be changed may be discriminated from that before change, using the operation state of this switch.

Also in this case, the manual light/dark field change-over operation and the aperture diaphragm open/close operation are carried out in parallel. First, in the light-/dark field change-over operation, when the field diaphragm is set in the other field state, the current position sensor is operated to identify the change-over completion (Step **620**).

Additionally, the aperture diaphragm open/close operation is carried out at the same time with this operation. The previous field state before change-over and a desired field are determined with the sensor change-over operation (Steps **630**, **640**). An operation amount of aperture diaphragm corresponding to an aperture ratio fit for the desired field is read out from the memory (ROM) **40** (Step **650**), and after conversion it is output to the drive circuit **33** to set the diaphragm at the predetermined aperture ratio (Step **660**).

Next explained with FIG. 7 is the procedure for setting an arbitrary aperture ratio and storing it in memory with necessity.

First, the automatic/manual change-over switch **34** is turned into the manual side and the manual aperture diaphragm switch **36** is operated for example to open the aperture diaphragm **55**, whereby a voltage +V is

applied from the power source **35**. The drive voltage is output through the drive circuit **33** to the aperture diaphragm motor **42** to rotate the aperture diaphragm **55** in the opening direction. When the observer Judges that the image contrast is proper for example in observation of 10 magnifications in this state, the switch **36** is made open to stop the opening operation of aperture diaphragm. An output of the potentiometer **43** at this moment is subjected to-the analog-to-digital conversion through the A-D converter **38** and the converted signal is then stored as digital data in the memory (RAM) **39**. since the standard aperture ratio preliminarily set in the apparatus is stored in the memory (ROM) **40**, the arbitrary aperture ratio will never be overwritten on the standard aperture ratio in this occasion. The arbitrary aperture ratio is thus set by the user's setting for 10 magnifications.

Since then, the CPU **41** will read the arbitrary aperture ratio stored in the memory (RAM) **39** and automatically set it as the initial value for objective of 10 magnifications. In case that the aperture ratio is temporarily changed for observation, an instruction may be given to withhold the arbitrarily set aperture ratio from being stored in the memory (RAM) **39**. In this case, the standard aperture ratio in the memory (ROM) **40** will be read out upon next revolver rotation operation or next light/dark field change-over operation.

As described, an optimum aperture ratio may be readily selected while looking at an image through the microscope, and the selected aperture ratio may be stored in the memory. Since the memory used in this operation is RAM, a very high degree of freedom is secured for erasure and rewriting of data. Also, a plurality of aperture ratio data may be stored for respective observers or for respective samples. The data representing the relation between the objectives and the aperture ratios, stored in the memory (RAM) **39** and the memory (ROM) **40** through the data of CPU **41**, may be transferred to various record media or to an external memory device through a personal computer.

For example in an application of microscope for inspection of products, the same inspection standard may be set for a plurality of inspection instruments while enjoying the advantage that a difference between the instruments may be obviated in inspection.

In the above embodiment (FIG. 7–FIG. 10), the CPU **41** read the rotation instruction of revolver through the switch **51** and preliminarily identified the next objective being to be set. However, the present embodiment includes the detection part **53, 54**, so that as in the embodiment detailed with FIGS. **4–6** the aperture diaphragm open/close operation may be carried out in parallel with the rotation operation of revolver even if the revolver is manually rotated. The detection part **53, 54** is constructed and operated in the same manner as the holder H and the detection circuits **8, 9** as described in FIGS. **1–3** and FIGS. **4–6**, and therefore is omitted to explain here.

In the above embodiment, the trigger of aperture diaphragm open/close operation was the start of objective change-over or light/dark field changeover, but the operation may be started with a command from an independent change-over switch or from an external operation device through a certain input/output interface by a software installed in a personal computer.

For example, if numerous combination data of users, samples, and objects with aperture ratios are preliminarily stored in a memory, optimum combination data may be instructed from an external computer in accordance with a user actually using the microscope or a sample to be inspected, or the data may be freely selected.

Although the embodiment is fully equipped, the switch **51**, the motor **45**, the drive circuit **44**, and the position sensor **46** may be omitted in case of manual revolver.

In the above description of the embodiments, the revolver was employed as an example of objective change-over part. In the present invention, however, the objective change-over means may be so arranged that objectives are arranged on a line, as in the field diaphragm of FIG. 7, and that the change-over means is translationally moved to replace an object with another.

Although the apparatus for detecting the rotation operation of revolver is separately described from the light control apparatus and the aperture diaphragm apparatus for easy understanding in the description of the embodiments, the microscope equipped with all apparatuses is the best.

Further, the embodiments using the apparatus for detecting the rotation operation of revolver were shown as applications for the light control apparatus and the aperture diaphragm apparatus, but it may be applied for another apparatus, for example for the field diaphragm apparatus. In addition, the light source may be controlled to increase or decrease the light quantity. Further, the stage may be controlled to move vertically to avoid the interference between the objective and the stage.

What is claimed is:

1. An objective replacing apparatus comprising:

objective replacing means having a plurality of objective mount portions and selectively positioning at a predetermined position a desired objective out of a plurality of objectives set in said mount portions;

a position indication portion for indicating respective positions of said plurality of mount portions, said position indication portion being disposed on said objective replacing means as to be formed corresponding to said respective mount portions;

an address indication portion indicating respective addresses of said plurality of mount portions, said address indication portion being disposed on said objective replacing means as to be formed corresponding to said respective mount portions;

means for detecting, when said desired objective is located at said predetermined position, an address of a mount portion in which the desired objective is set, from said address indication portion;

means for detecting a displacement of said position indication portion after said desired objective is located at said predetermined position thereby to detect a movement direction of said objective replacing means; and

means for determining an address of another desired mount portion which is to be next located at said predetermined position, based on the address of said desired mount portion from said address detecting means and on the movement direction of said objective replacing means from said movement direction detecting means.

2. An objective replacing apparatus according to claim **1**, wherein said objective replacing means further comprises means for detecting said position indication portion thereby to detect that the objective is located at said predetermined position.

3. An objective replacing apparatus according to claim 2, further comprising means for outputting, when an operator assigns another desired objective or another mount portion of said objective replacing means corresponding to said another desired objective, an assignment signal corresponding to said assigned another objective or another mount portion;

wherein said objective replacing means moves based on the assignment signal thereby to position the assigned another objective or another mount portion at said predetermined position; and

wherein said determining means determines the address of the another desired mount portion being to be next located at the predetermined position, based on the assignment signal from said assignment signal output means and the address of said desired mount portion from said address detecting means, or based on the address of said desired mount portion from said address detecting means and the movement direction of said objective replacing means from said movement direction detecting means.

4. An objective replacing apparatus according to claim 3, wherein said determining means includes memory for storing relative positions of addresses of said plurality of mount portions, and determines the address of said another desired mount portion to be next located at the predetermined position based on the assignment signal from said assignment signal output means, the address of said desired mount portion from said address detecting means and said relative positions of addresses of said plurality of mount portions from said memory, or based on the address of said desired mount portion from said address detecting means, the movement direction of said objective replacing means from said movement direction detecting means and said relative positions of addresses of said plurality of mount portions from said memory.

5. An objective replacing apparatus according to claim 1, wherein said objective replacing means is a revolver for selectively positioning the desired objective at the predetermined position by rotation.

6. An objective replacing apparatus according to claim 1, wherein said determining means includes memory for storing relative positions of addresses of said plurality of mount portions, and determines the address of said another desired mount portion to be next located at the predetermined position, based on the address of said desired mount portion from said address detecting means, the movement direction of said objective replacing means from said movement direction detecting means and said relative positions of addresses of said plurality of mount portions from said memory.

7. A microscope comprising:

objective replacing means having a plurality of objective mount portions and selectively positioning at a predetermined position a desired objective out of a plurality of objectives set in said mount portions;

a position indication portion for indicating respective positions of said plurality of mount portions, said position indication portion being disposed on said objective replacing means as to be formed corresponding to said respective mount portions;

an address indication portion indicating respective addresses of said plurality of mount portions, said address indication portion being disposed on said objective replacing means as to be formed corresponding to said respective mount portions;

means for detecting, when said desired objective is located at said predetermined position, an address of a mount portion in which the desired objective is set, from said address indication portion;

means for detecting a displacement of said position indication portion after said desired objective is located at said predetermined position thereby to detect a movement direction of said objective replacing means;

a memory for storing information of the objectives set in the respective mount portions;

means for determining an objective set in another desired mount portion which is to be next located at the predetermined position, based on the address of said desired mount portion from said address detecting means, the movement direction of said objective replacing means from said movement direction detecting means, and the information of objectives from said memory; and

means for controlling a part of the microscope other than the objectives, based on the objective determined by said determining means.

8. A microscope according to claim 7, wherein said objective replacing means further comprises means for detecting said position indication portion thereby to detect that the objective is located at said predetermined position.

9. A microscope according to claim 7, wherein said part of microscope is light control means located in an optical path of the microscope and controlling a light quantity of light from a .light source; and

wherein said control means controls said light control means as to control the light quantity as suitable for the objective determined by said determining means.

10. A microscope according to claim 7, wherein said part of microscope is means for changing an aperture diameter of an aperture diaphragm located in an optical path of the microscope; and

wherein said control means controls said aperture diameter changing means as to adjust the aperture diameter of aperture diaphragm as suitable for the objective determined by said determining means.

11. A microscope according to claim 7, further comprising means for outputting, when an operator assigns a desired objective or a mount portion of said objective replacing means corresponding to said desired objective, a signal corresponding to said assigned objective or mount portion;

wherein said determining means determines the objective set in the another desired mount portion being to be next located at the predetermined position, based on the signal from the assigning means and the information of objectives from said memory, or based on the address of said desired mount portion from said address detecting means, the movement direction of said objective replacing means from said movement direction detecting means, and the information of objectives from said memory.

12. A microscope according to claim 7, wherein said objective replacing means is a revolver for selectively positioning the desired objective at the predetermined position by rotation.

13. A microscope according to claim 7, wherein said determining means includes memory for storing relative positions of addresses of said plurality of mount portions, and determines the address of said another desired

mount portion to be next located at the predetermined position based on the address of said desired mount portion from said address detecting means, the movement direction of said objective replacing means from said movement direction detecting means and said relative positions of addresses of said plurality of mount portions from said memory.

14. A microscope according to claim **7**, further comprising means for outputting, when an operator assigns another desired objective or another desired mount portion of said objective replacing means corresponding to said another desired objective, a signal corresponding to said assigned another objective or another mount portion;

wherein said determining means includes memory for storing relative positions of addresses of said plurality of mount portions, and determines the address of said another desired mount portion to be next located at the predetermined position based on the assignment signal from said assignment signal output means, the address of said desired mount portion from said address detecting means and said relative positions of addresses of said plurality of mount portions, or based on the address of said desired mount portion from said address detecting means, the movement direction of said objective replacing means from said movement direction detecting means and said relative positions of addresses of said plurality of mount portions.

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[54] **APPARATUS FOR DETECTING THE FOCUS ADJUSTING STATE OF AN OBJECTIVE LENS BY PERFORMING FILTER PROCESSING**

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[51] **Int. Cl.**[5] **G01J 1/20**
[52] **U.S. Cl.** **250/201.8;** 354/407
[58] **Field of Search** 250/201.8, 201.2, 204; 354/406, 407, 408

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[57] **ABSTRACT**

A focus detection apparatus includes an optical system for forming first and second optical distributions associated with object images whose relative positional relationship is changed in accordance with an imaging state of an imaging optical system subjected to focus detection, a photoelectric conversion element, having a plurality of picture elements, for outputting first and second signals respectively corresponding to the first and second optical distributions, and a calculating unit for performing filter processing of the first and second signals, sequentially displacing the first and second signals relative to each other on the calculation basis, calculating an evaluation amount representing a coincidence between the first and second signals at the relatively displaced positions, obtaining positional deviations between the first and second object images on the basis of a change in evaluation amount, and detecting the imaging state of the imaging optical system on the basis of the deviations. The filter processing is performed using a filter determined by the relatively displaced positions.

15 Claims, 47 Drawing Sheets

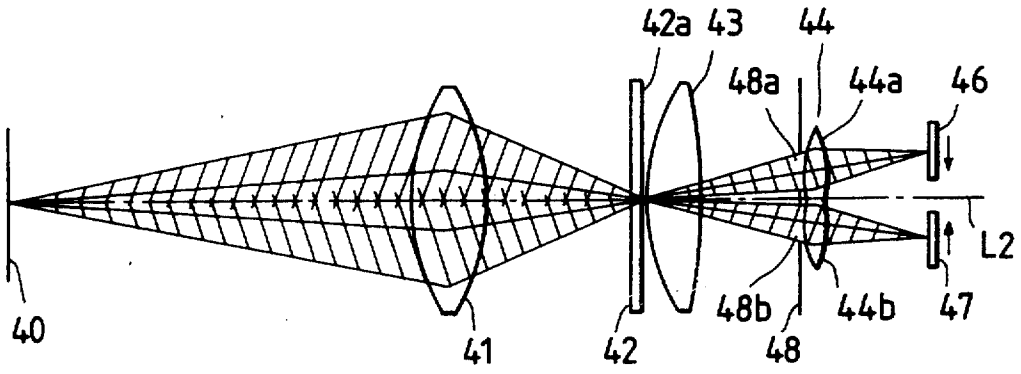


FIG. 1

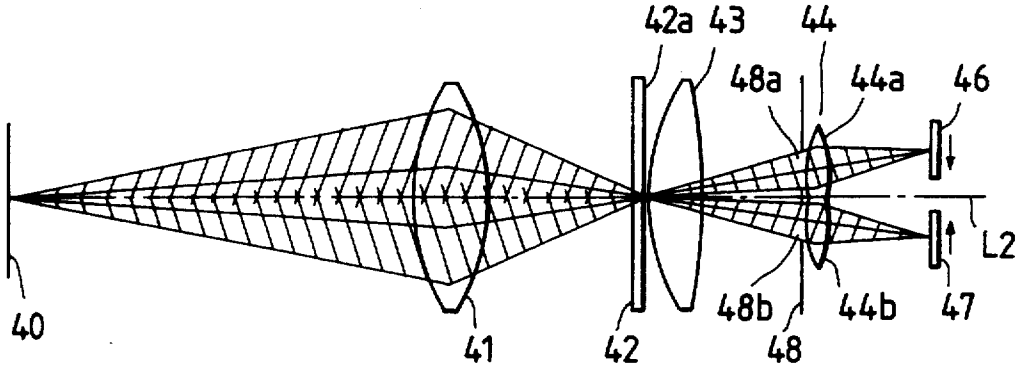


FIG. 2

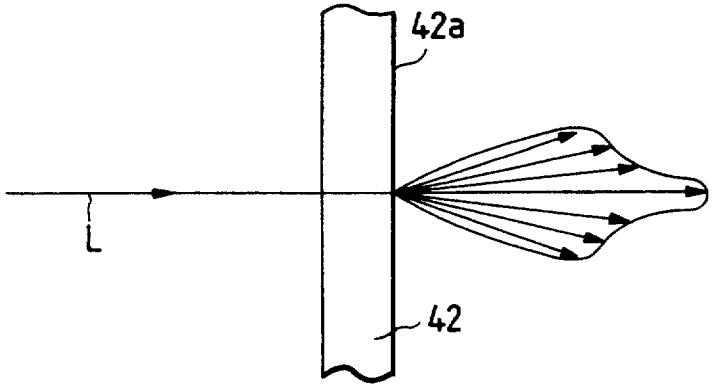


FIG. 3

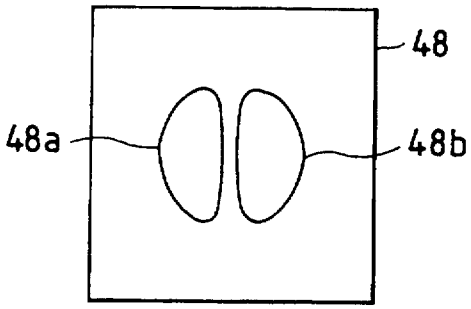


FIG. 4

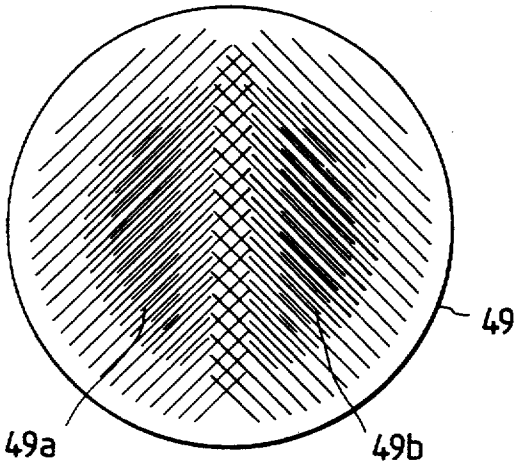


FIG. 5A

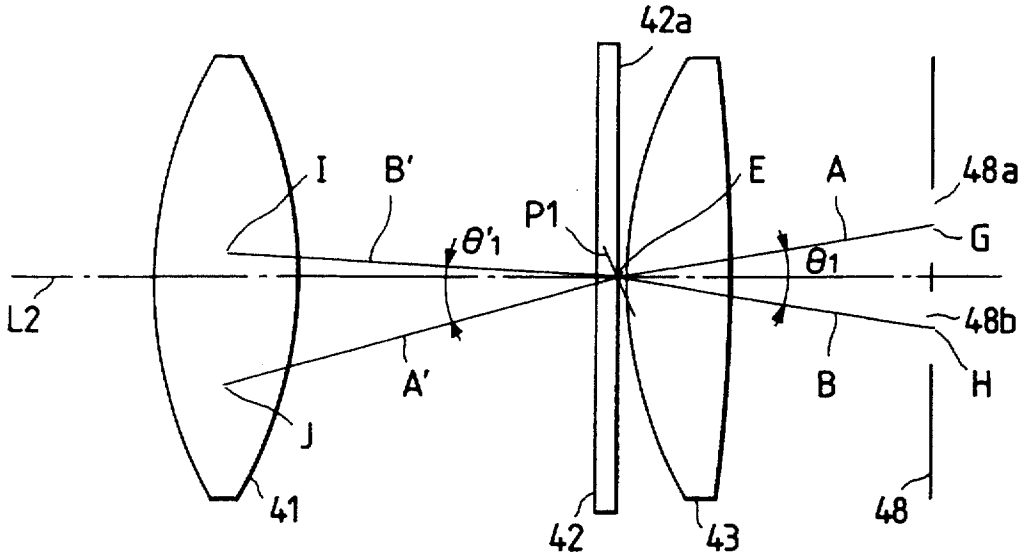

42a
I
B'
E
A
48a
P1
G
θ'1
θ1
L2
48b
A'
B
H
J
41
42
43
48

FIG. 5B

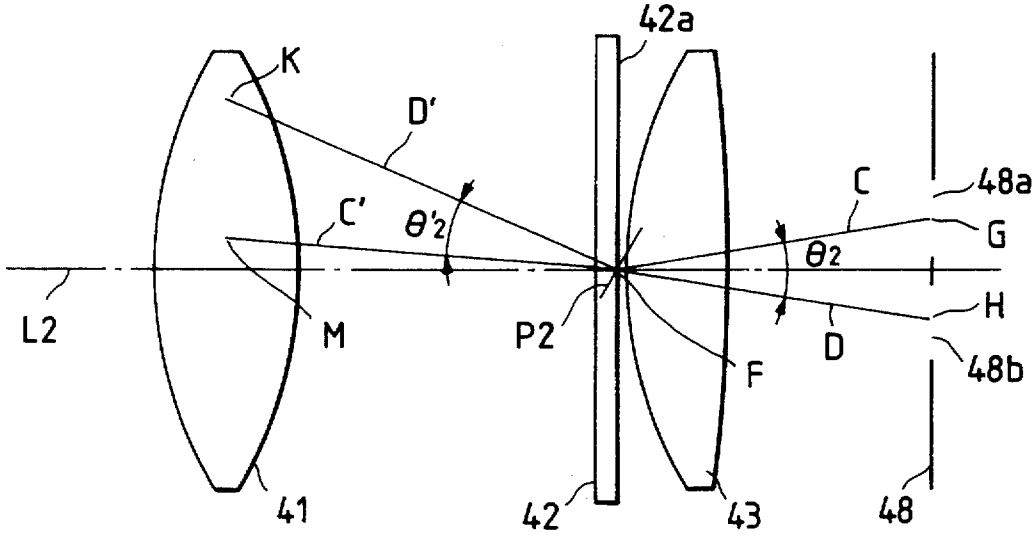

42a
K
D'
C
48a
C'
θ'2
G
θ2
L2
H
M
P2
D
48b
F
41
42
43
48

FIG. 6

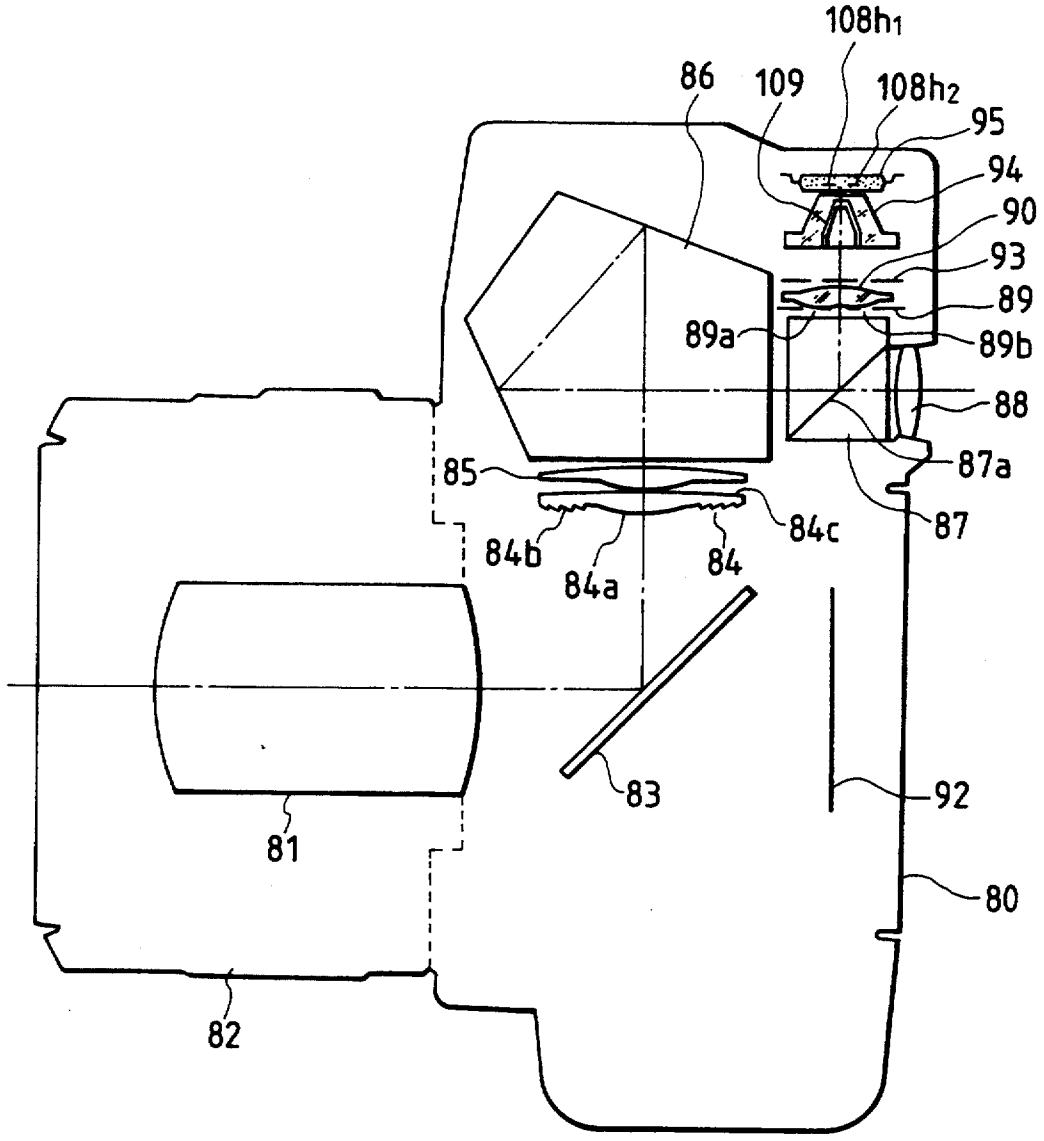

108h1
86
109
108h2
95
94
90
93
89
89a
89b
88
87a
85
87
84b
84a
84
84c
83
92
81
80
82

FIG. 7

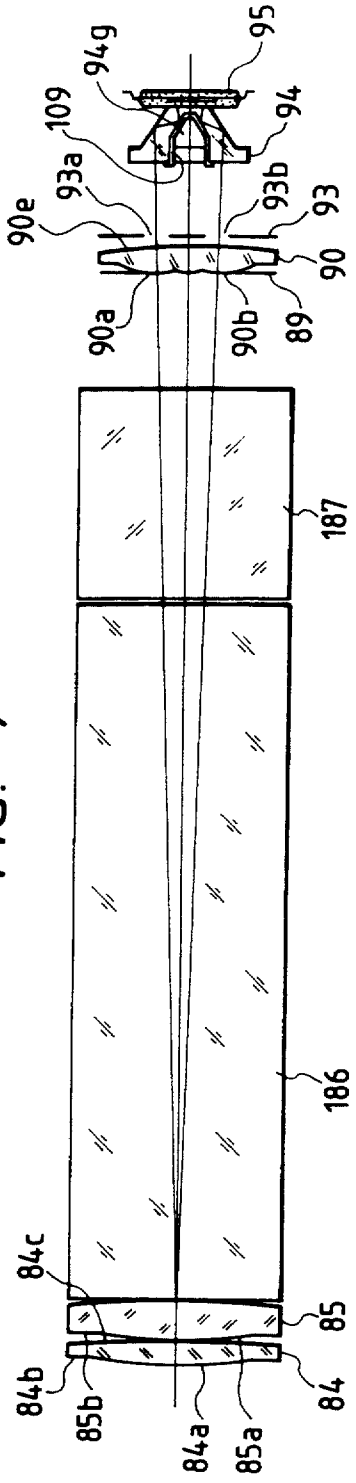

94g
95
109
94
93a
93b
93
90e
90
90a
90b
89
187
186
84c
85
84b
85b
84a
85a
84

FIG. 8

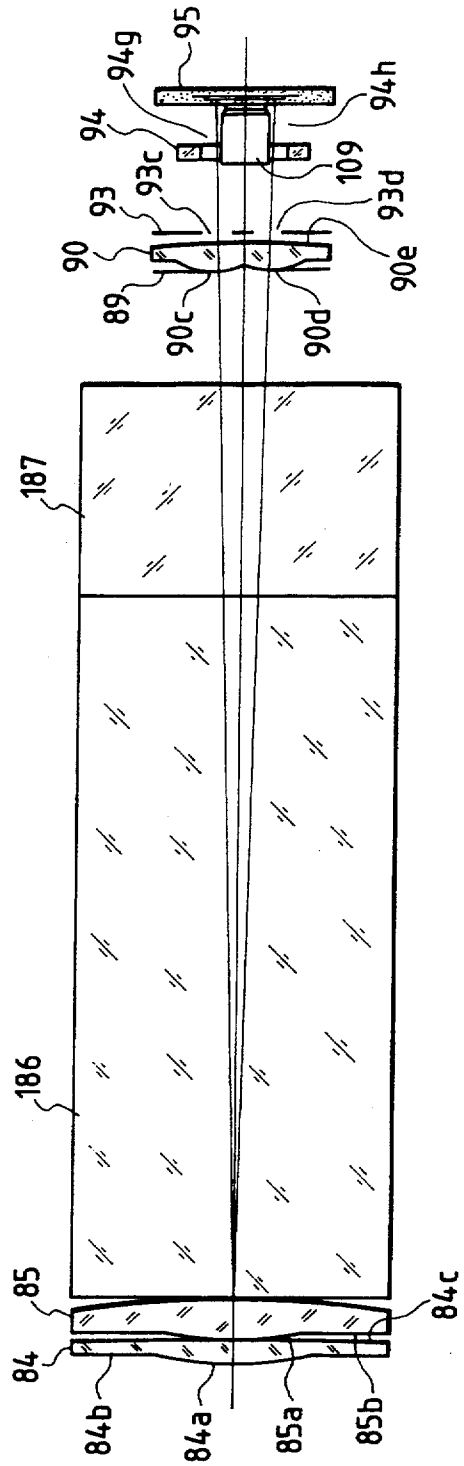

95
94g
94h
94
93c
109
93d
93
90
90e
89
90c
90d
187
186
85
84c
84
84b
84a
85a
85b

FIG. 9

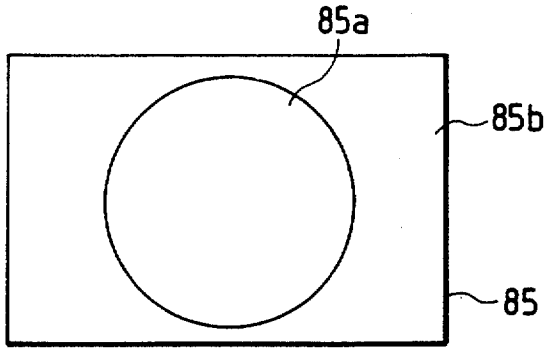


FIG. 10A

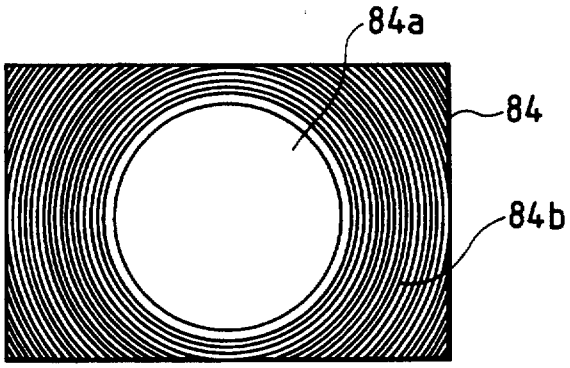


FIG. 10B

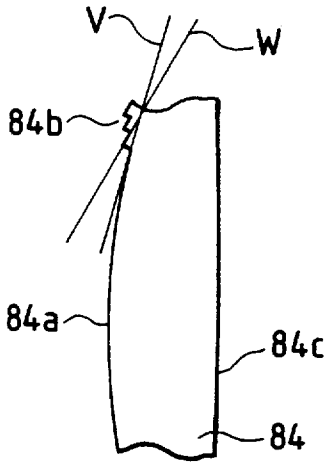


FIG. 11

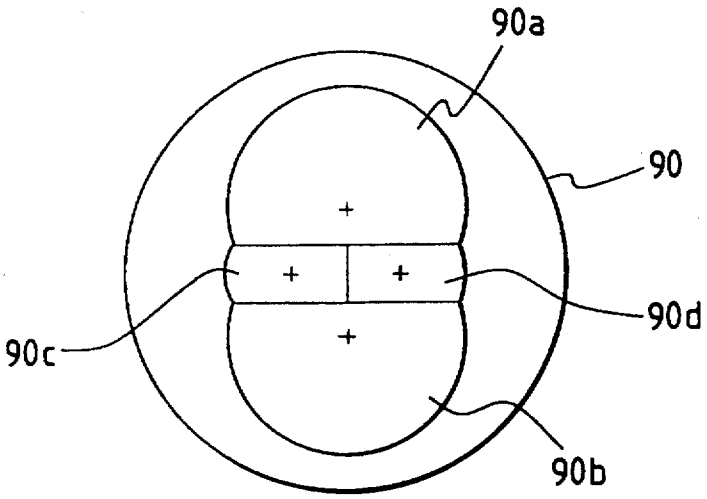


FIG. 12

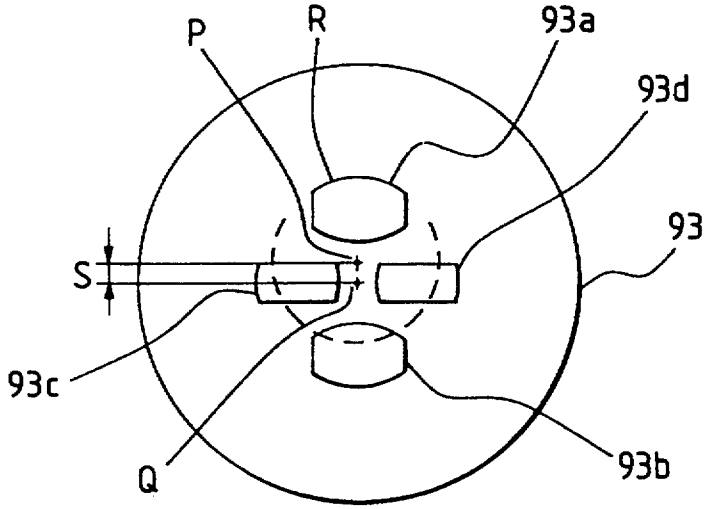


FIG. 13

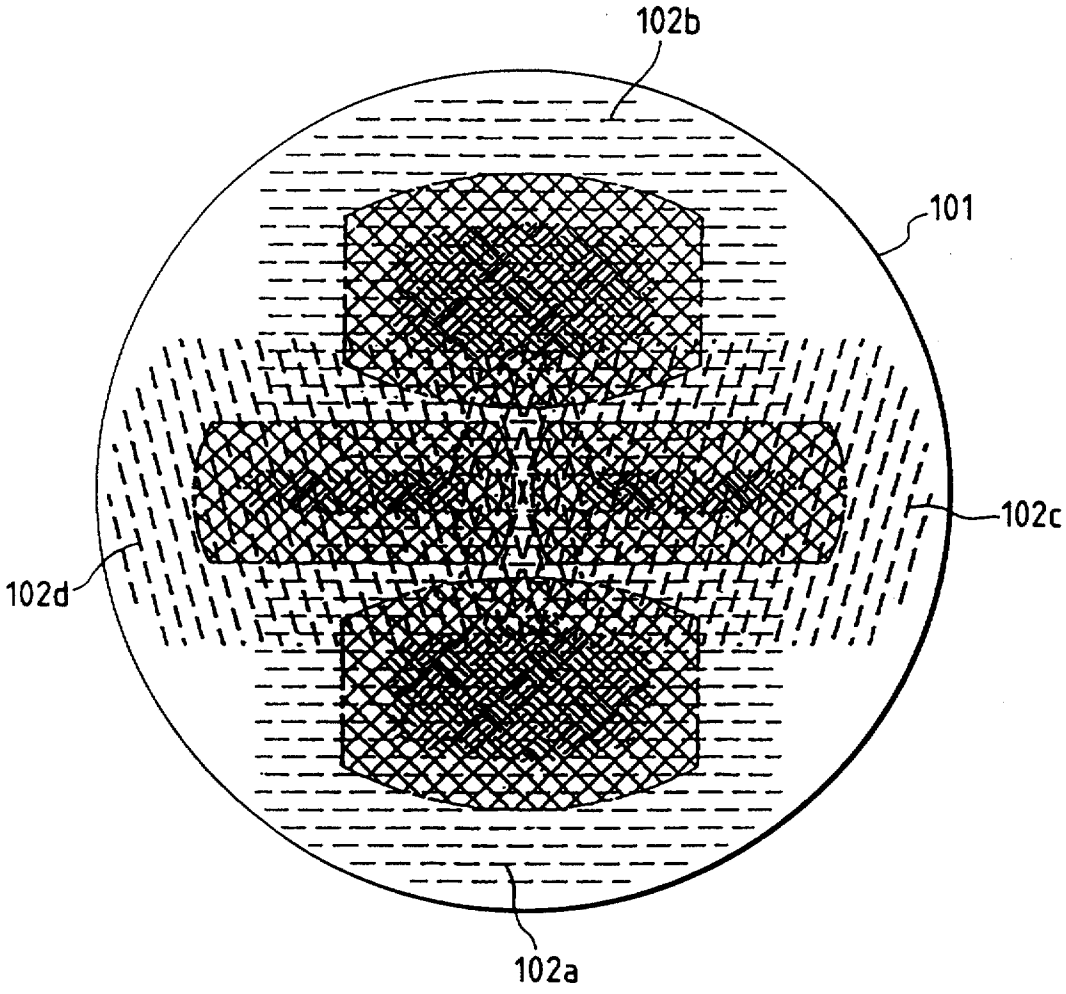


FIG. 14

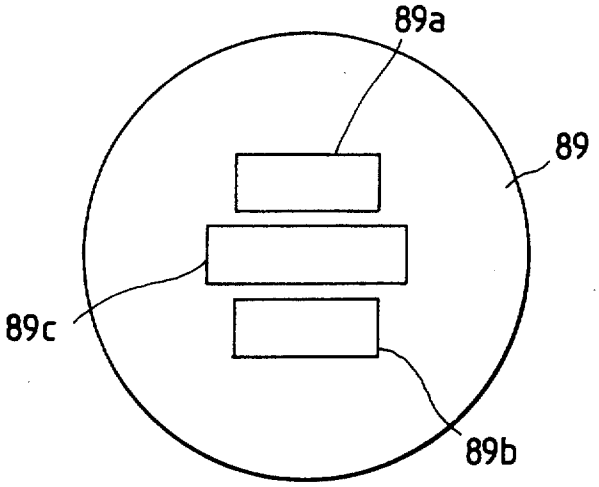


FIG. 15

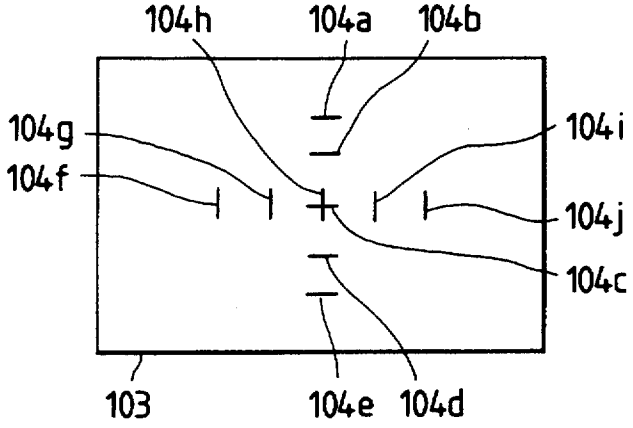


FIG. 16

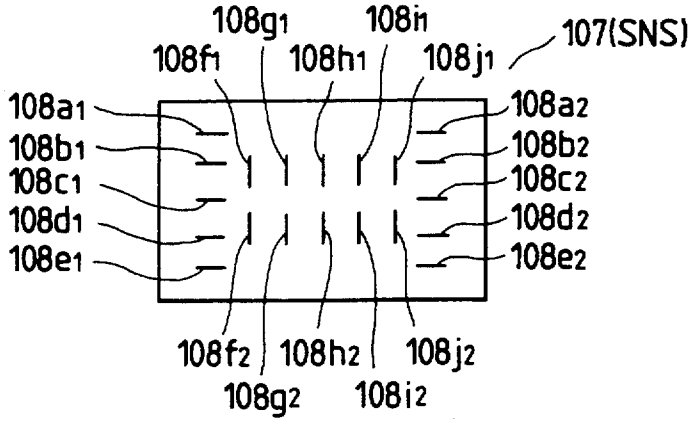


FIG. 17

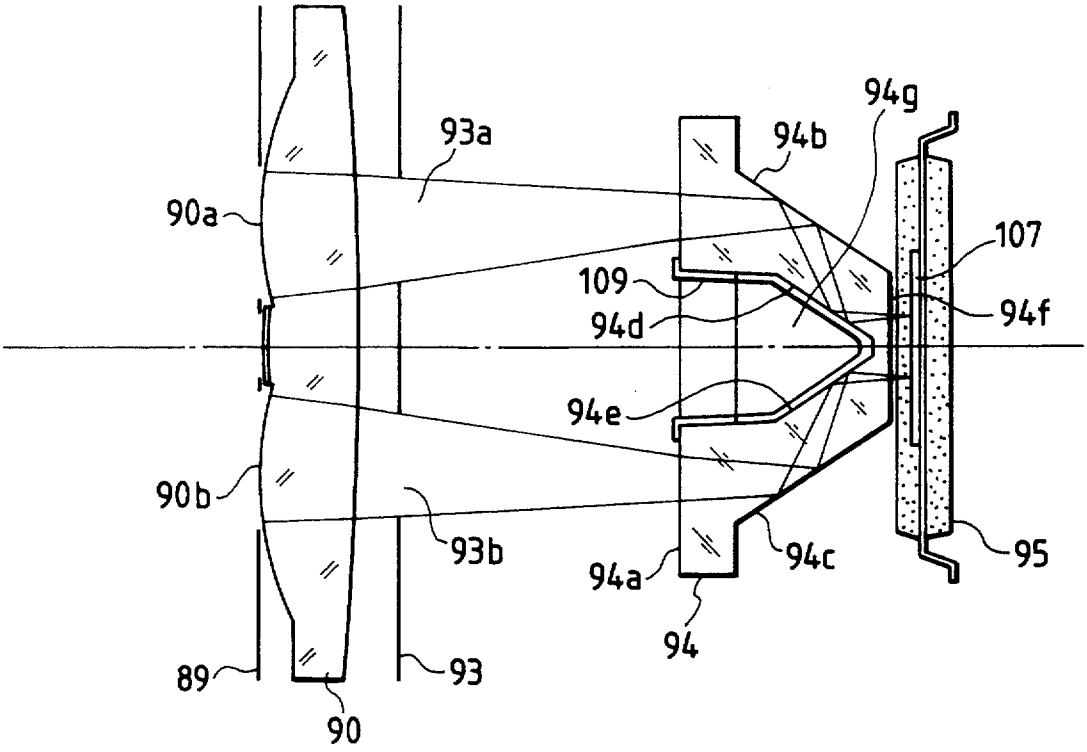
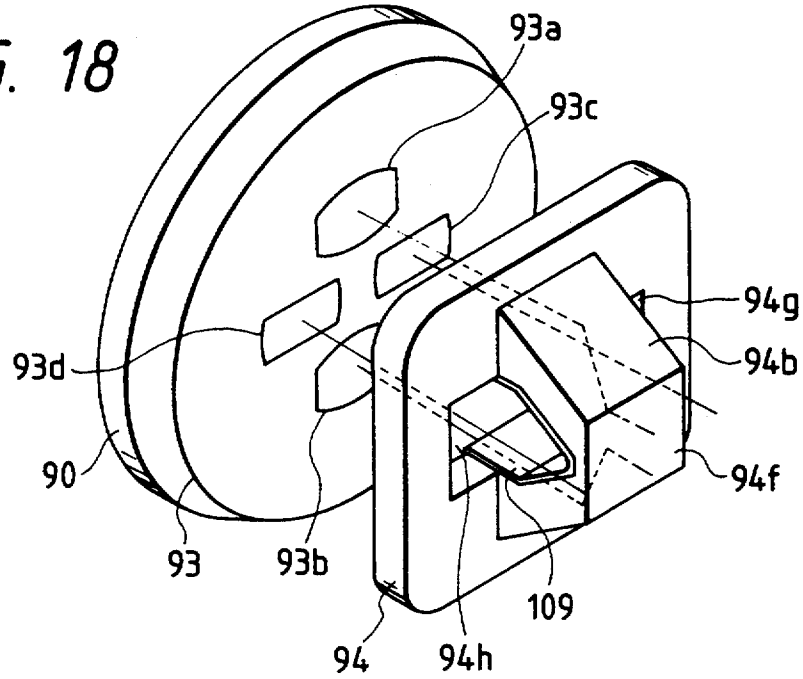

93a
94g
94b
90a
107
109
94d
94f
94e
90b
93b
94c
95
94a
94
89
93
90

FIG. 18


93a
93c
94g
93d
94b
90
94f
93
93b
109
94
94h

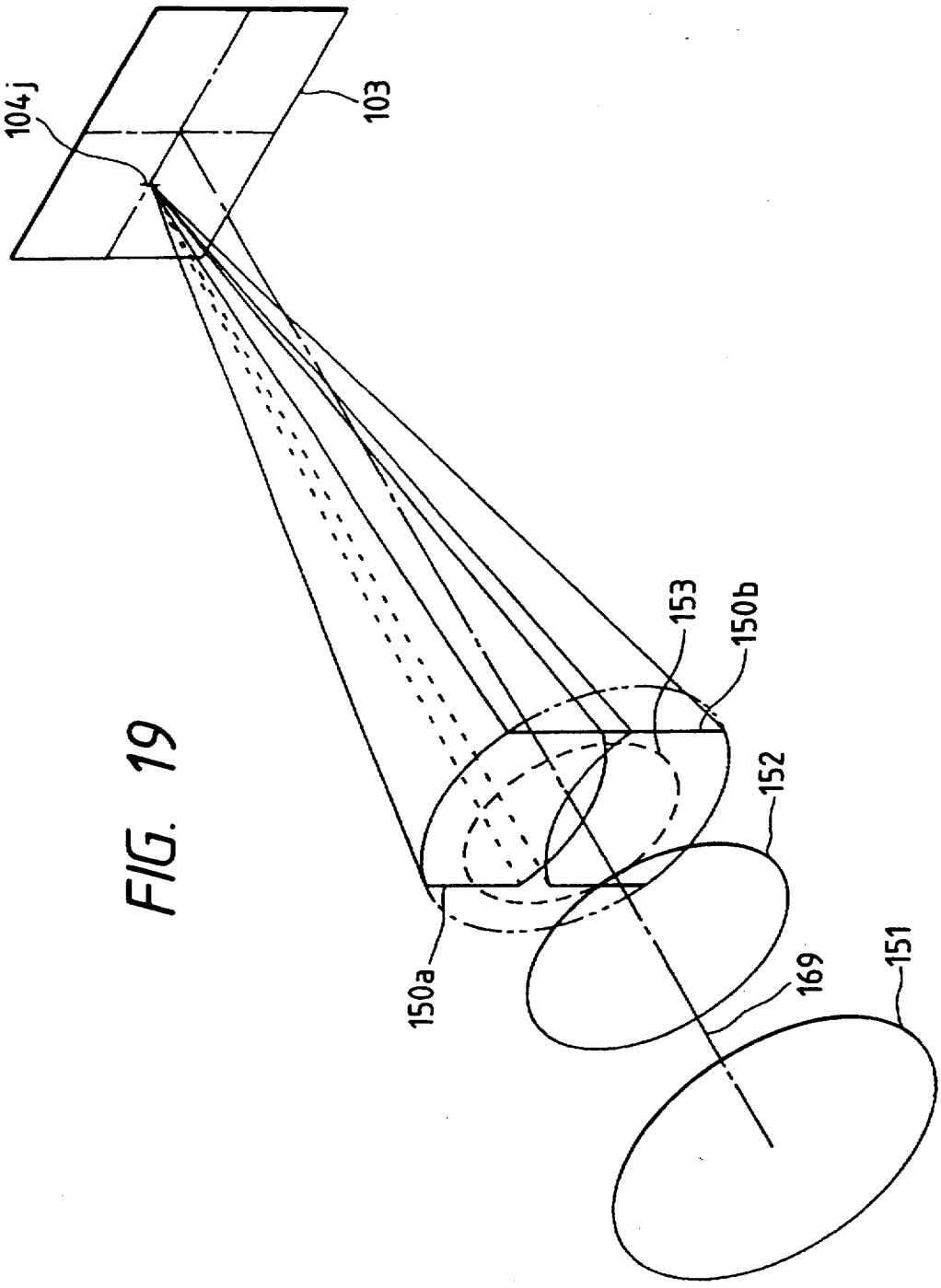


FIG. 19

FIG. 20A

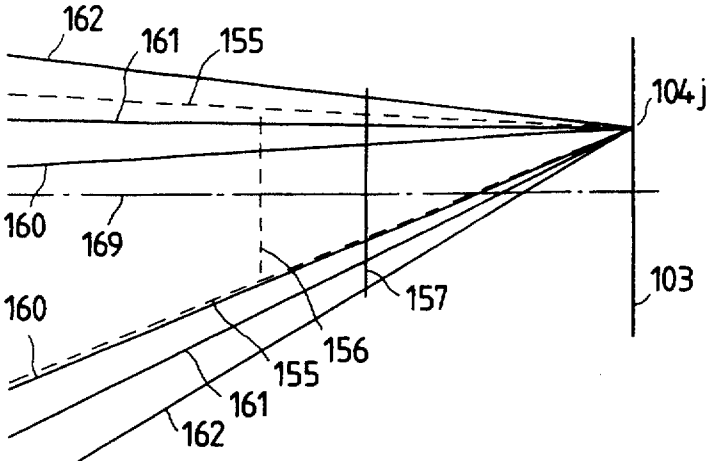


FIG. 20B

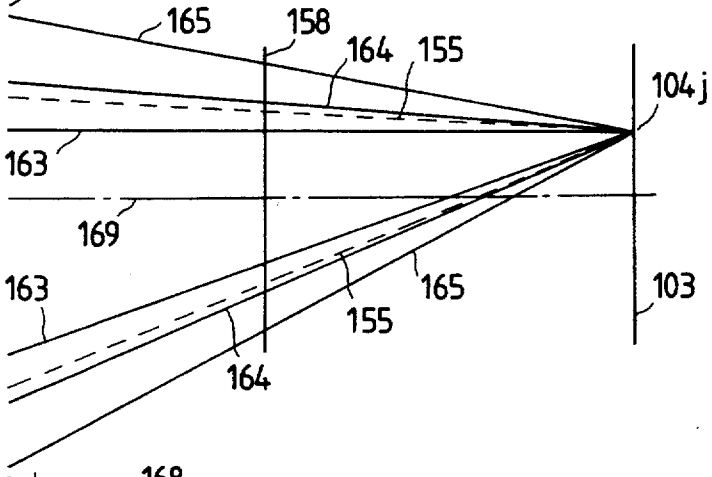
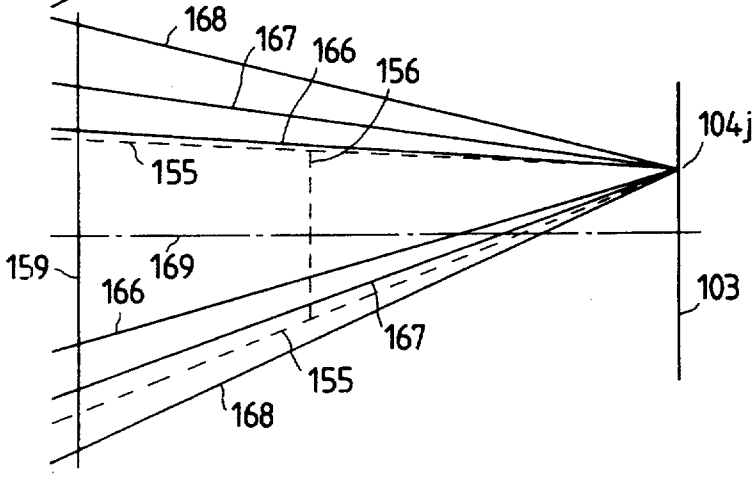


FIG. 20C



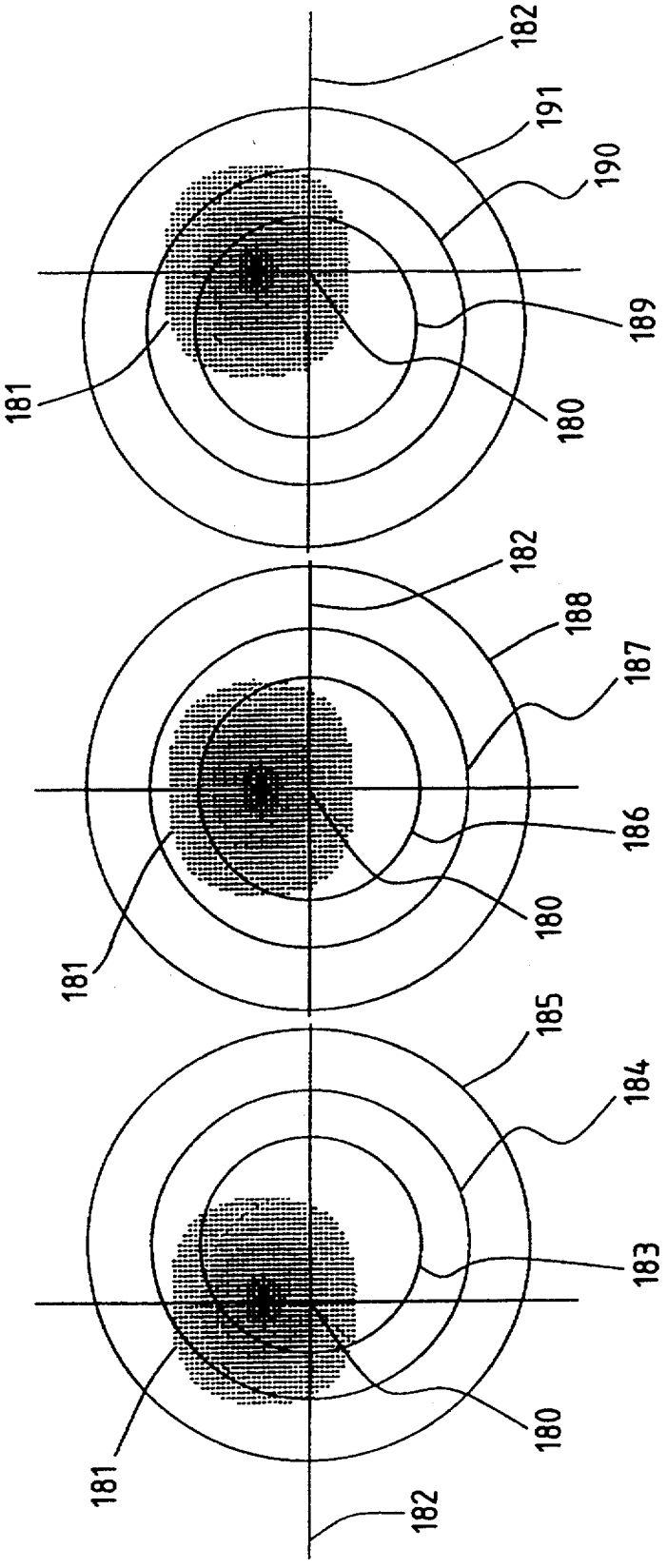


FIG. 21A FIG. 21B FIG. 21C

FIG. 22A

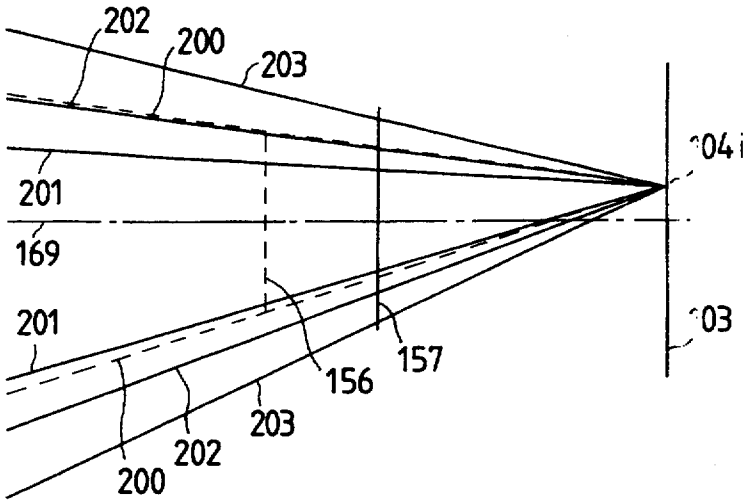


FIG. 22B

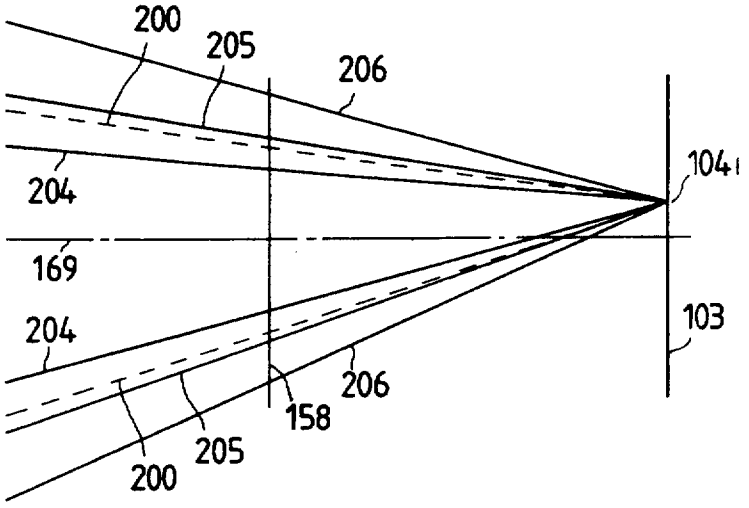


FIG. 22C

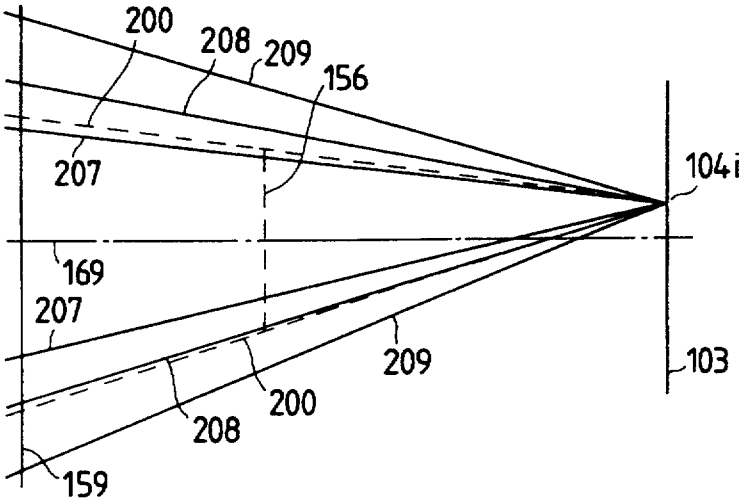


FIG. 23A

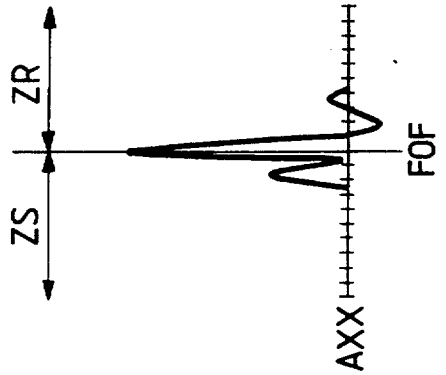


FIG. 23B

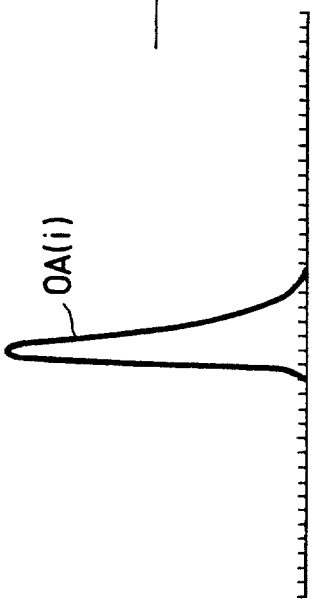


FIG. 23C

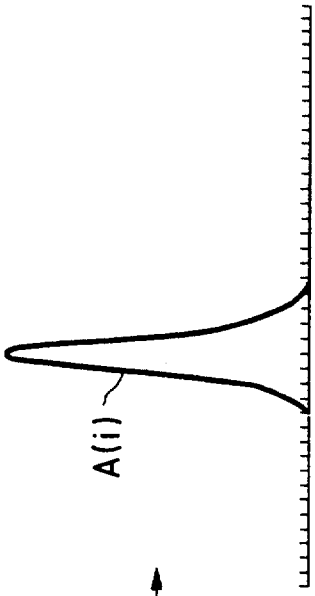


FIG. 24C

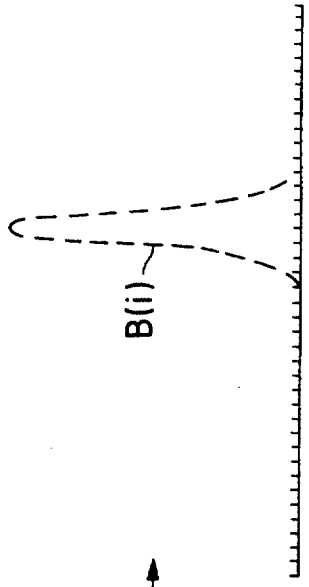


FIG. 24B

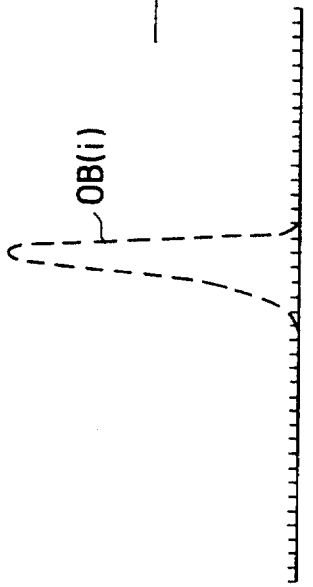


FIG. 24A

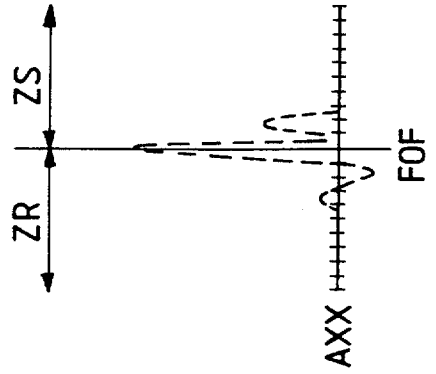


FIG. 25B

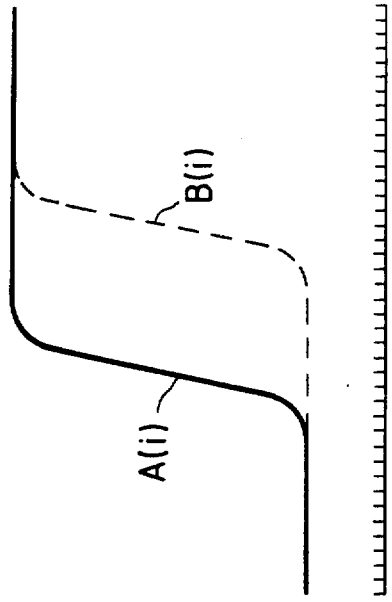


FIG. 25A

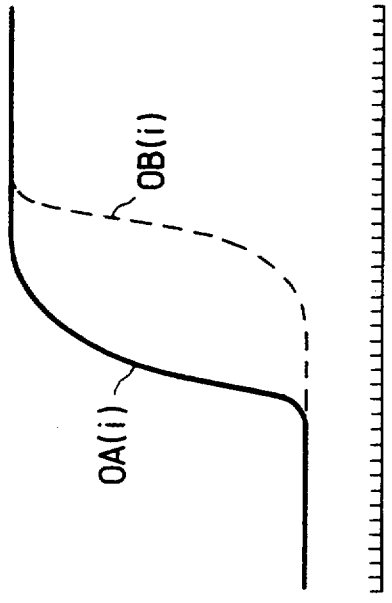


FIG. 26B

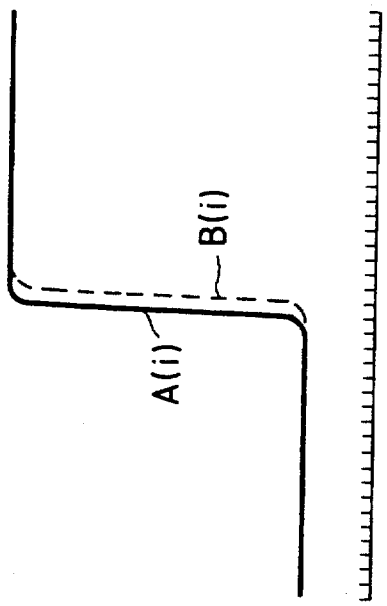


FIG. 26A

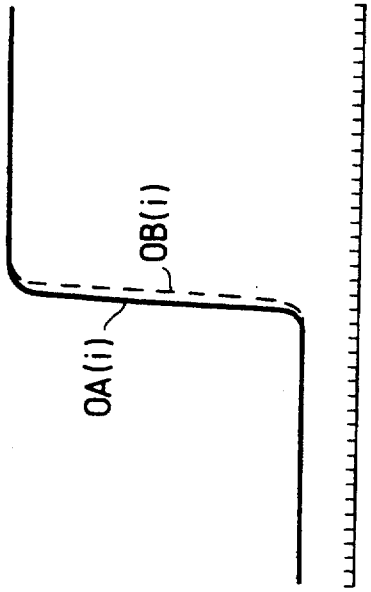


FIG. 27

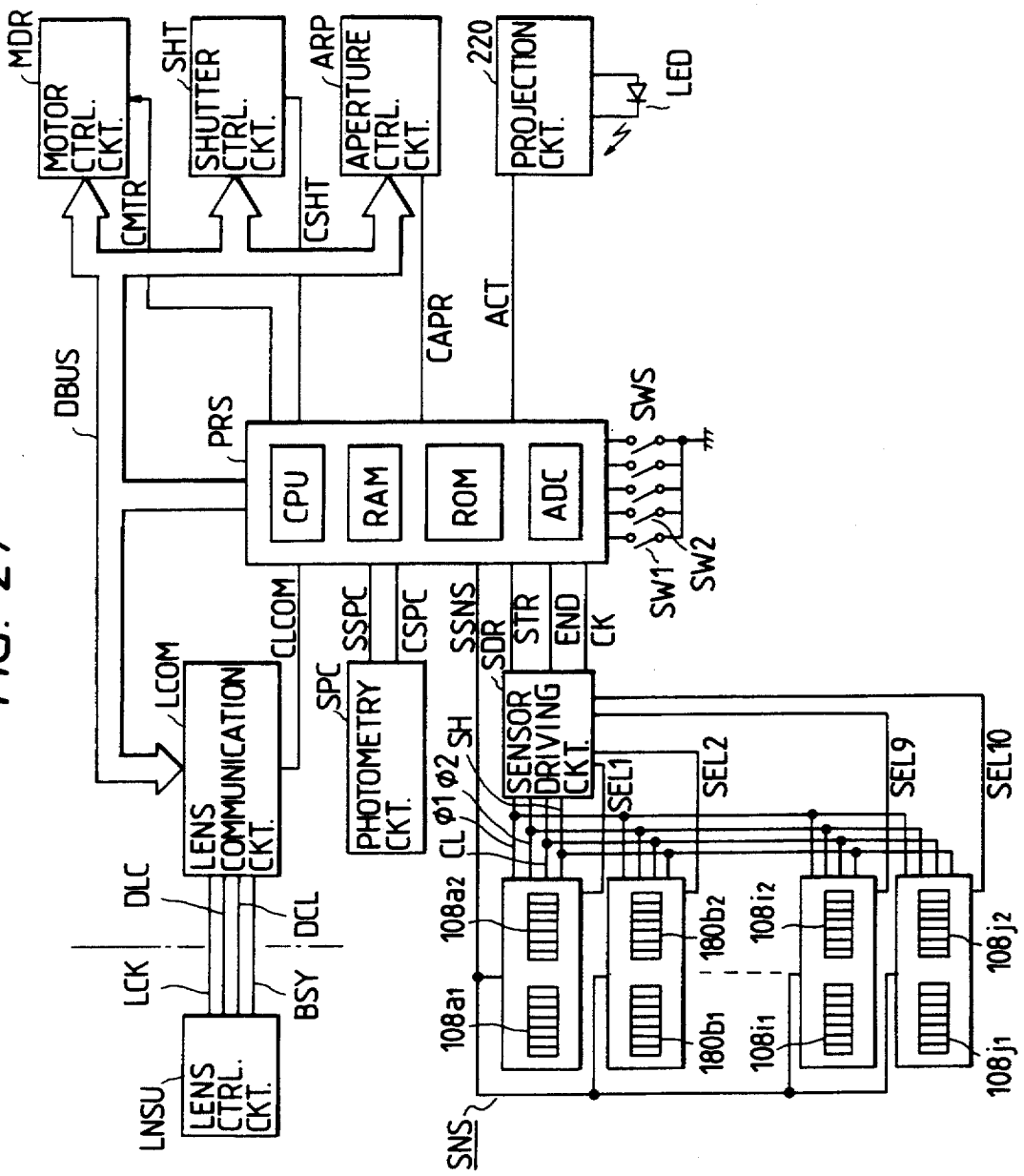

MDR
MOTOR CTRL. CKT.
SHT
SHUTTER CTRL. CKT.
ARP
APERTURE CTRL. CKT.
220
PROJECTION CKT.
LED
CMTR
CSHT
CAPR
ACT
DBUS
PRS
CPU
RAM
ROM
ADC
SWS
SW1
SW2
CLCOM
SSPC
CSPC
SSNS
SDR
STR
END
CK
LCOM
LENS COMMUNICATION CKT.
SPC
PHOTOMETRY CKT.
SENSOR DRIVING CKT.
SH
CL
φ1
φ2
SEL1
SEL2
SEL9
SEL10
DLC
DCL
LCK
BSY
LNSU
LENS CTRL. CKT.
108a2
108a1
180b2
180b1
108i2
108i1
108j2
108j1
SNS

FIG. 28

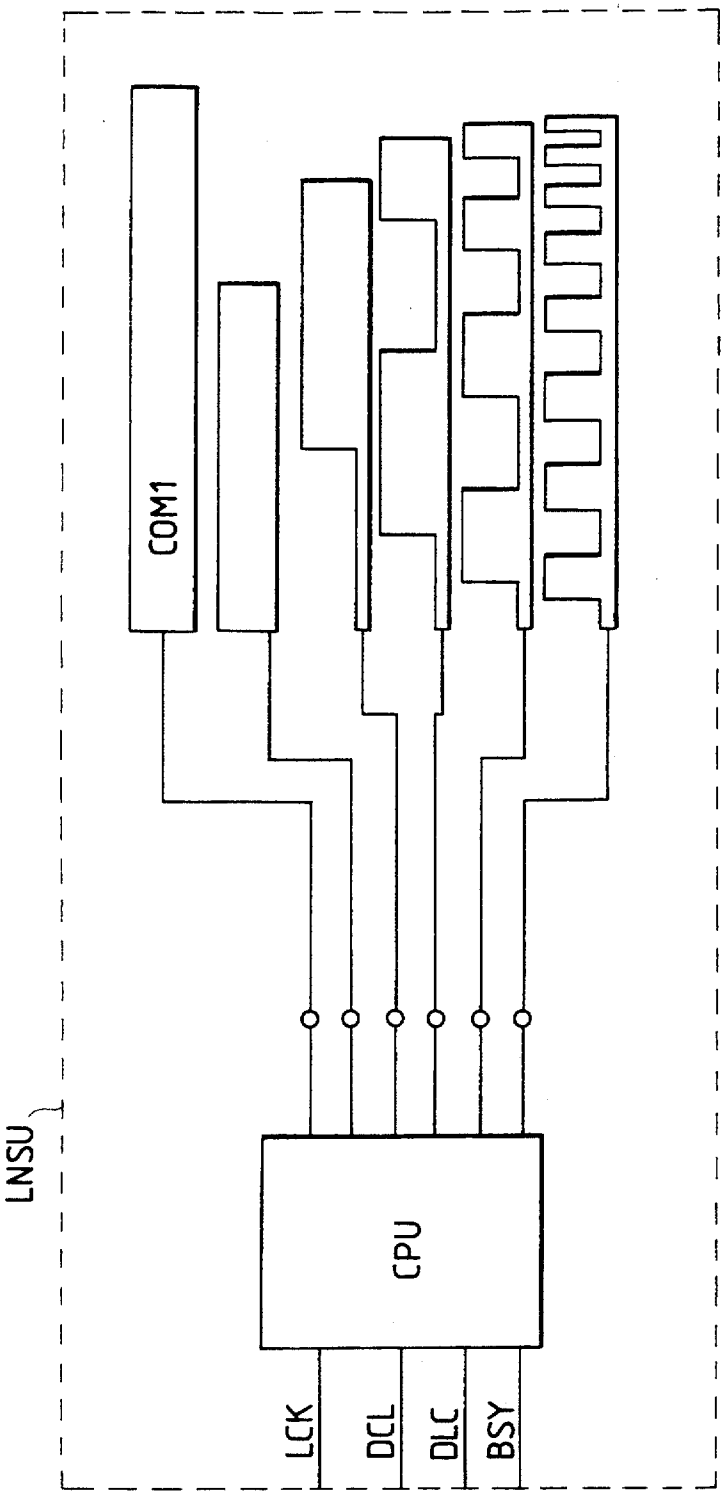


FIG. 29

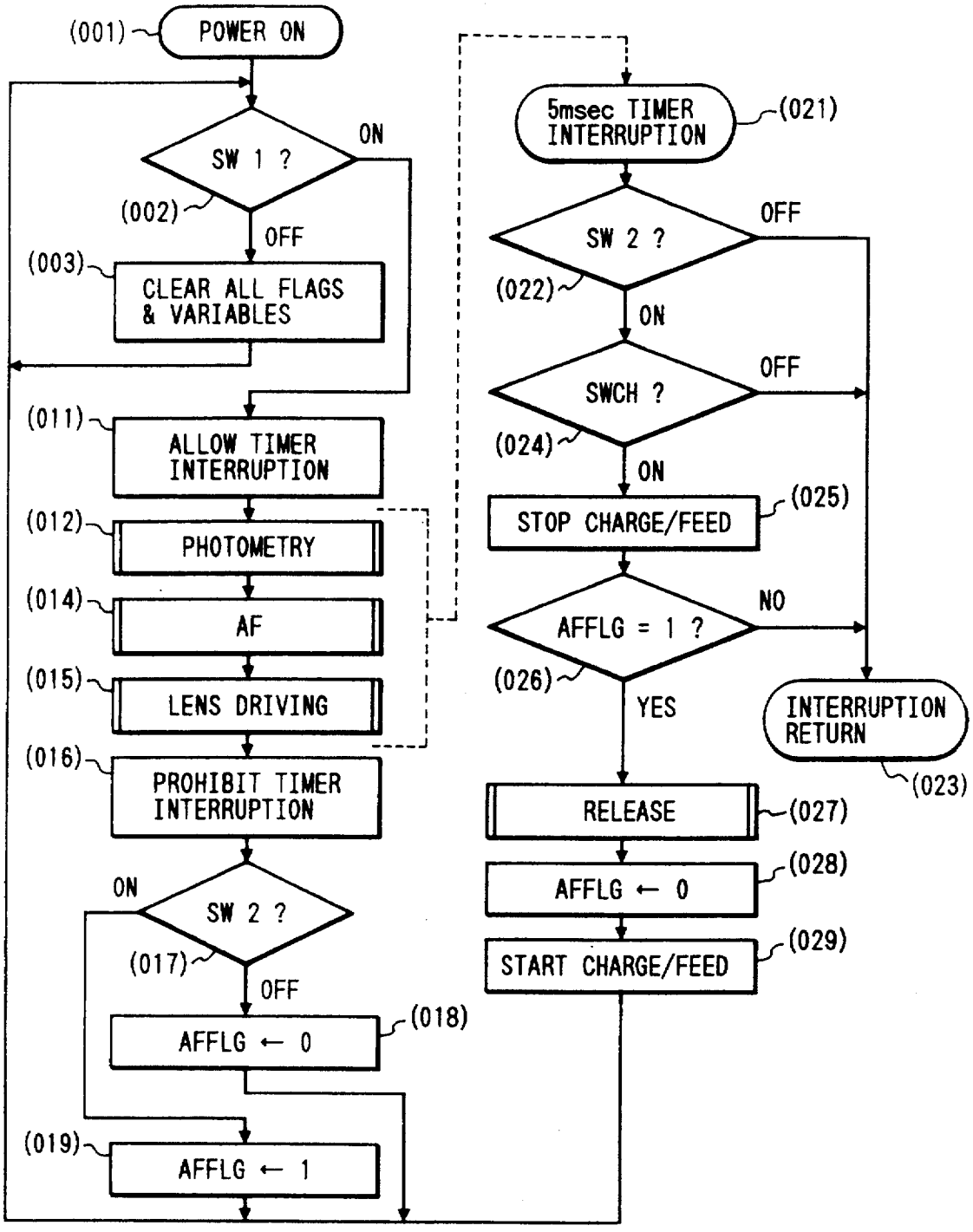

(001)
POWER ON
SW 1 ?
ON
(002)
OFF
(003)
CLEAR ALL FLAGS & VARIABLES
(011)
ALLOW TIMER INTERRUPTION
(012)
PHOTOMETRY
(014)
AF
(015)
LENS DRIVING
(016)
PROHIBIT TIMER INTERRUPTION
ON
SW 2 ?
(017)
OFF
AFFLG ← 0
(018)
(019)
AFFLG ← 1
5msec TIMER INTERRUPTION
(021)
SW 2 ?
OFF
(022)
ON
SWCH ?
OFF
(024)
ON
STOP CHARGE/FEED
(025)
AFFLG = 1 ?
NO
(026)
YES
INTERRUPTION RETURN
(023)
RELEASE
(027)
AFFLG ← 0
(028)
START CHARGE/FEED
(029)

FIG. 30

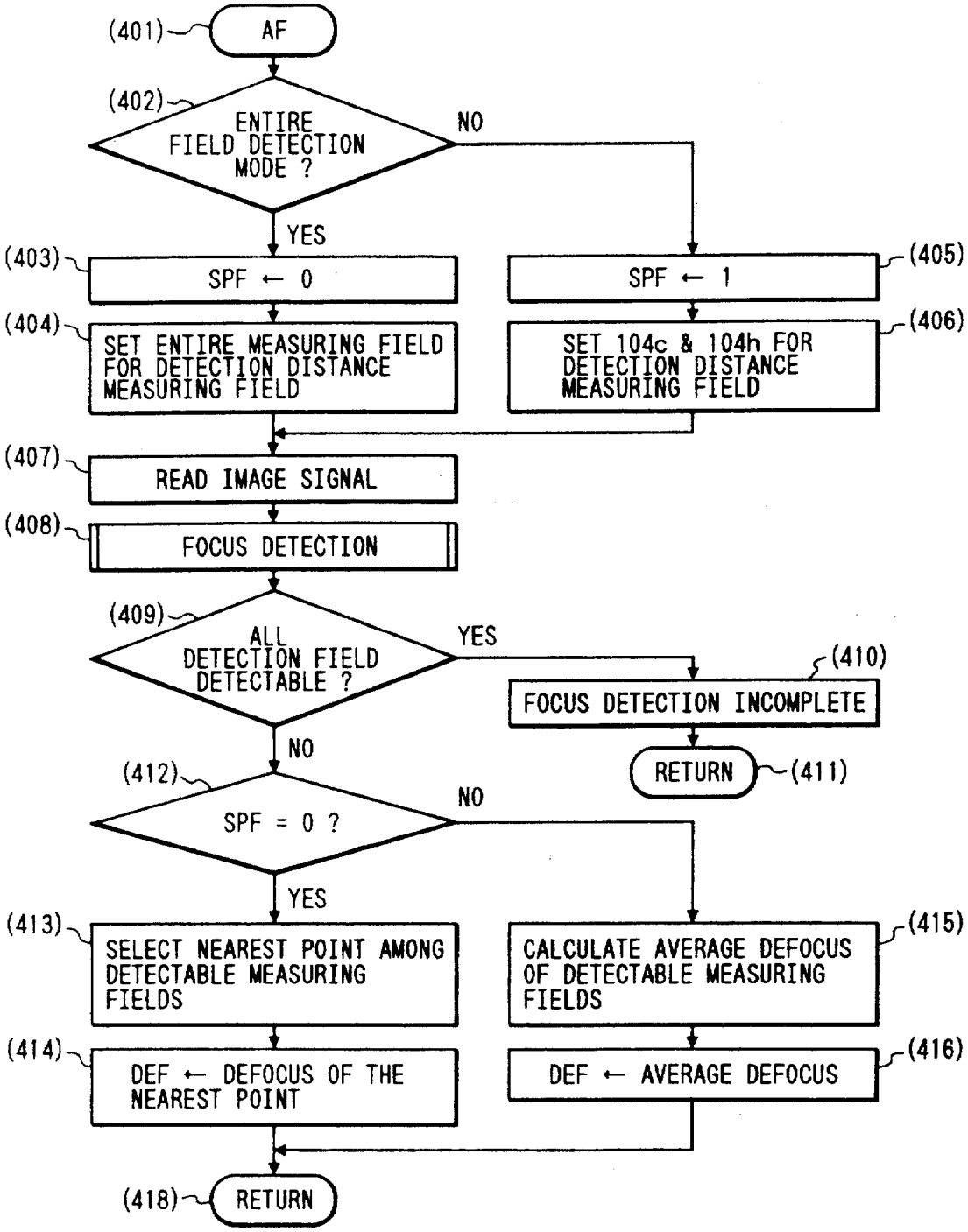

(401)
AF
(402)
ENTIRE FIELD DETECTION MODE ?
NO
YES
(403)
SPF ← 0
(405)
SPF ← 1
(404)
SET ENTIRE MEASURING FIELD FOR DETECTION DISTANCE MEASURING FIELD
(406)
SET 104c & 104h FOR DETECTION DISTANCE MEASURING FIELD
(407)
READ IMAGE SIGNAL
(408)
FOCUS DETECTION
(409)
ALL DETECTION FIELD DETECTABLE ?
YES
(410)
FOCUS DETECTION INCOMPLETE
RETURN
(411)
NO
(412)
SPF = 0 ?
NO
YES
(413)
SELECT NEAREST POINT AMONG DETECTABLE MEASURING FIELDS
(415)
CALCULATE AVERAGE DEFOCUS OF DETECTABLE MEASURING FIELDS
(414)
DEF ← DEFOCUS OF THE NEAREST POINT
(416)
DEF ← AVERAGE DEFOCUS
(418)
RETURN

FIG. 31

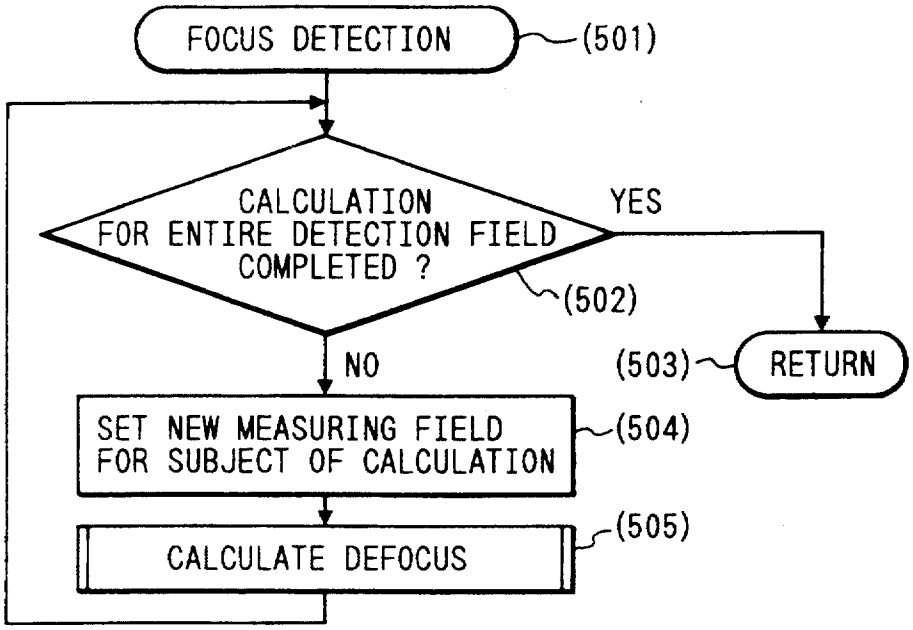

FOCUS DETECTION
(501)
CALCULATION FOR ENTIRE DETECTION FIELD COMPLETED ?
YES
(502)
NO
(503)
RETURN
SET NEW MEASURING FIELD FOR SUBJECT OF CALCULATION
(504)
CALCULATE DEFOCUS
(505)

FIG. 32

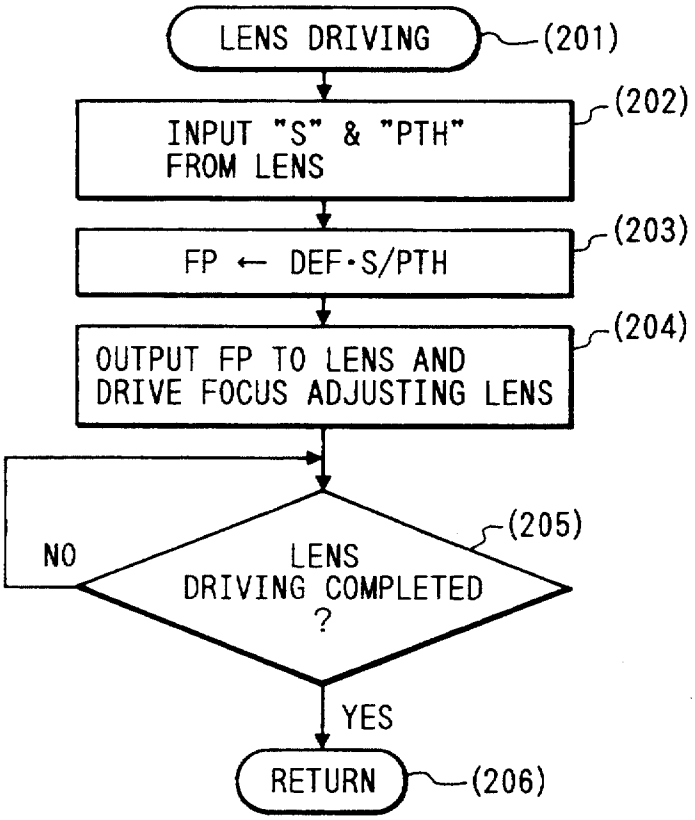

LENS DRIVING
(201)
INPUT "S" & "PTH" FROM LENS
(202)
FP ← DEF·S/PTH
(203)
OUTPUT FP TO LENS AND DRIVE FOCUS ADJUSTING LENS
(204)
NO
LENS DRIVING COMPLETED ?
(205)
YES
RETURN
(206)

FIG. 33

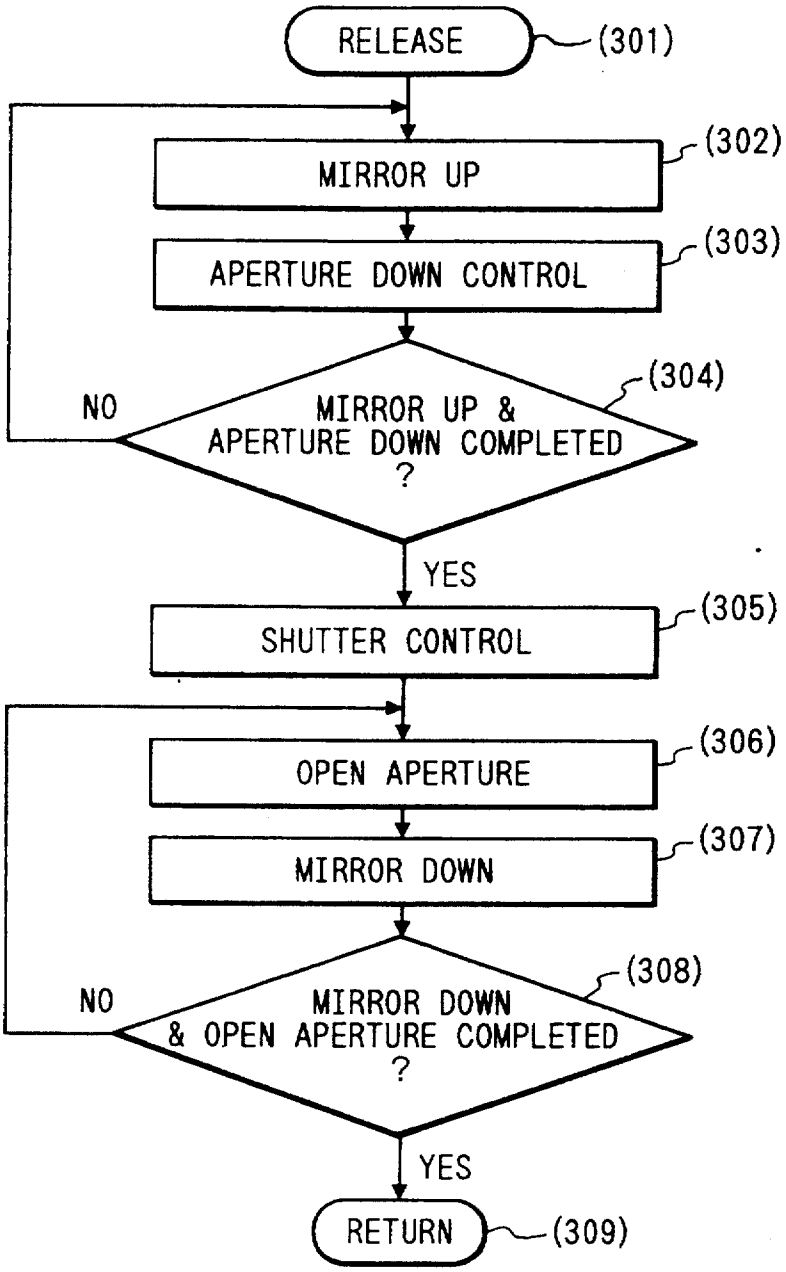

RELEASE
(301)
MIRROR UP
(302)
APERTURE DOWN CONTROL
(303)
MIRROR UP & APERTURE DOWN COMPLETED ?
(304)
NO
YES
SHUTTER CONTROL
(305)
OPEN APERTURE
(306)
MIRROR DOWN
(307)
MIRROR DOWN & OPEN APERTURE COMPLETED ?
(308)
NO
YES
RETURN
(309)

FIG. 34

FIG. 34A
FIG. 34B

FIG. 34A

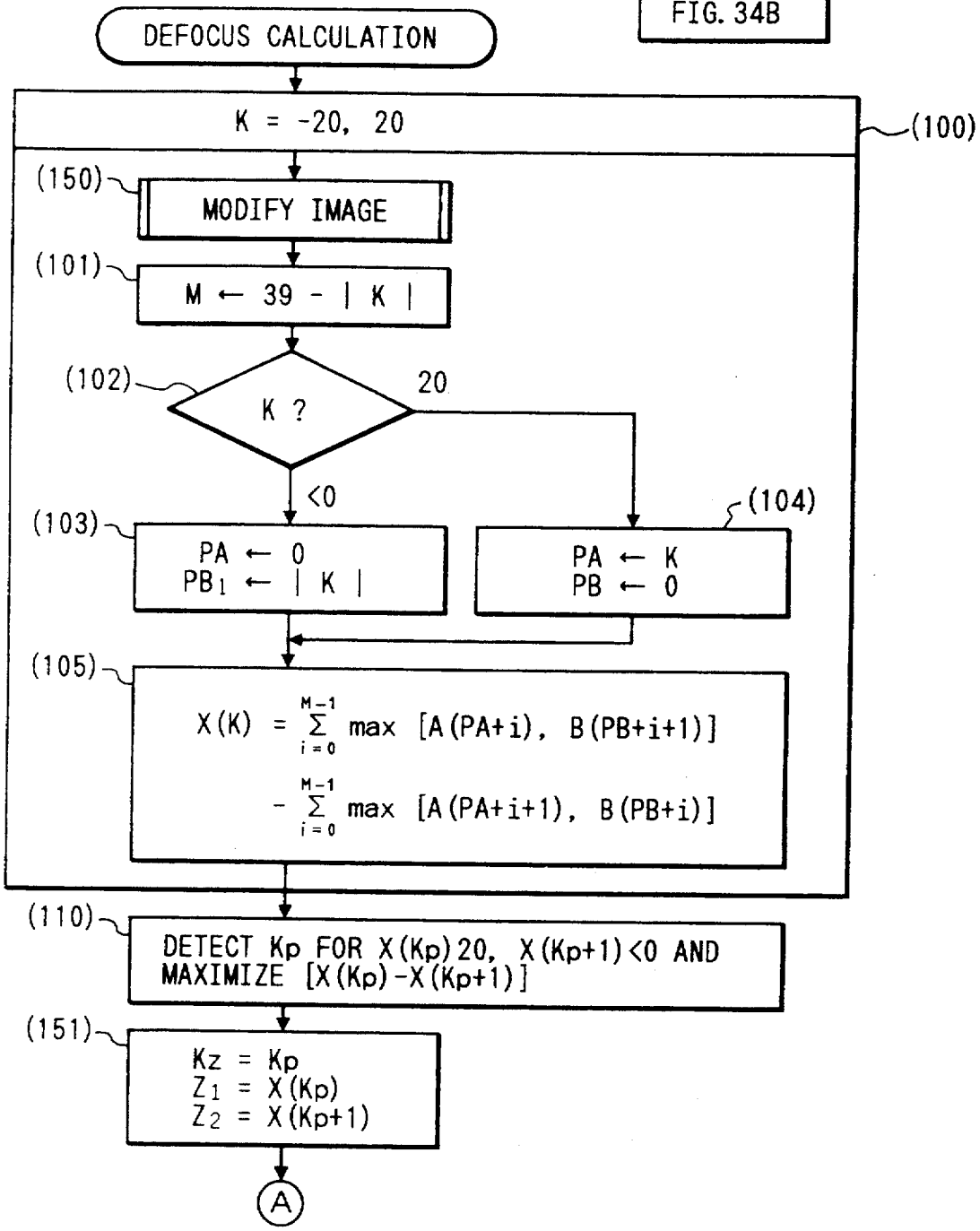


FIG. 34B

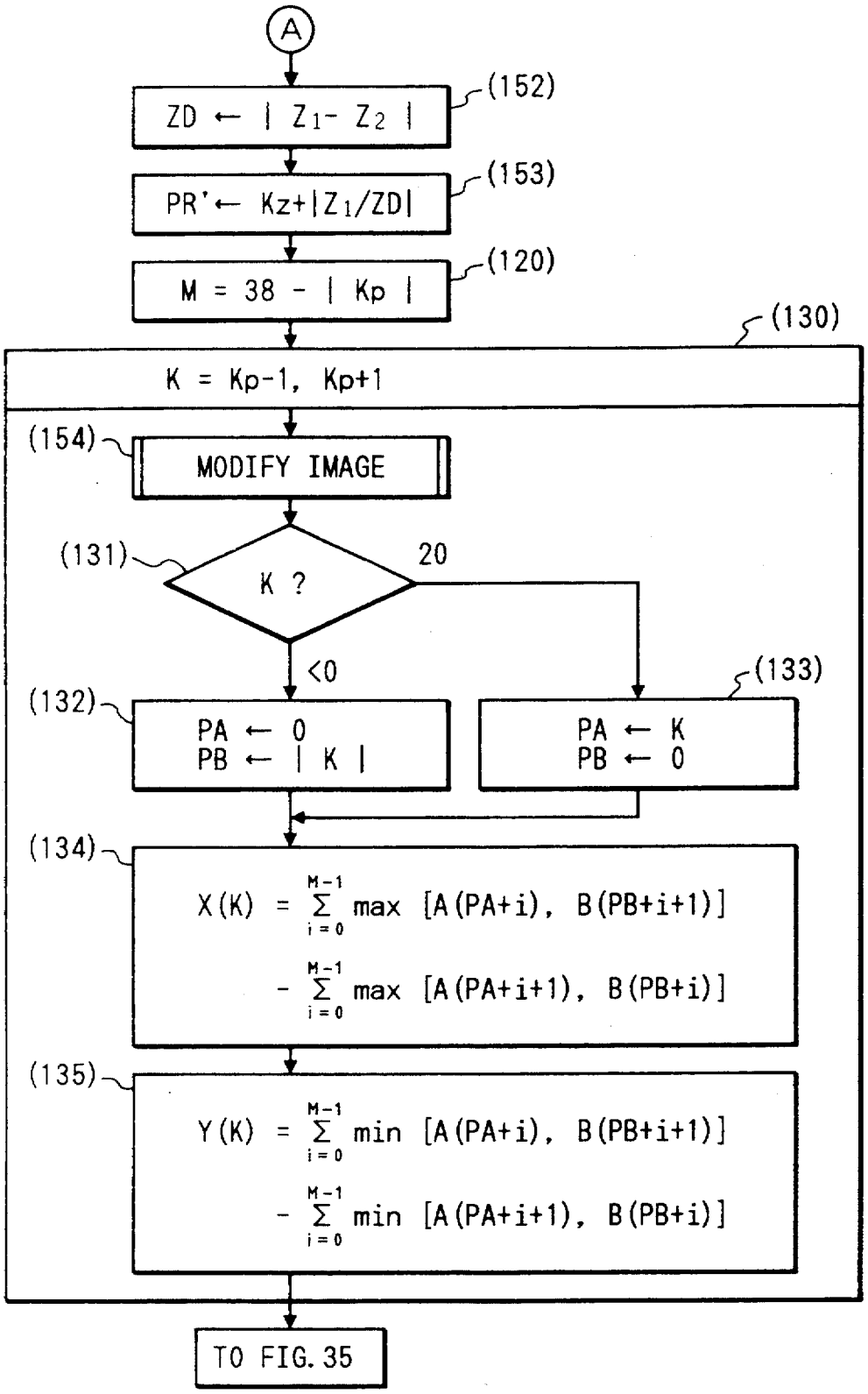

A
ZD ← | Z1- Z2 |
(152)
PR'← Kz+|Z1/ZD|
(153)
M = 38 - | Kp |
(120)
(130)
K = Kp-1, Kp+1
(154)
MODIFY IMAGE
(131)
K ?
20
<0
(132)
PA ← 0
PB ← | K |
(133)
PA ← K
PB ← 0
(134)
X(K) = Σ max [A(PA+i), B(PB+i+1)] - Σ max [A(PA+i+1), B(PB+i)]
(135)
Y(K) = Σ min [A(PA+i), B(PB+i+1)] - Σ min [A(PA+i+1), B(PB+i)]
TO FIG. 35

FIG. 35

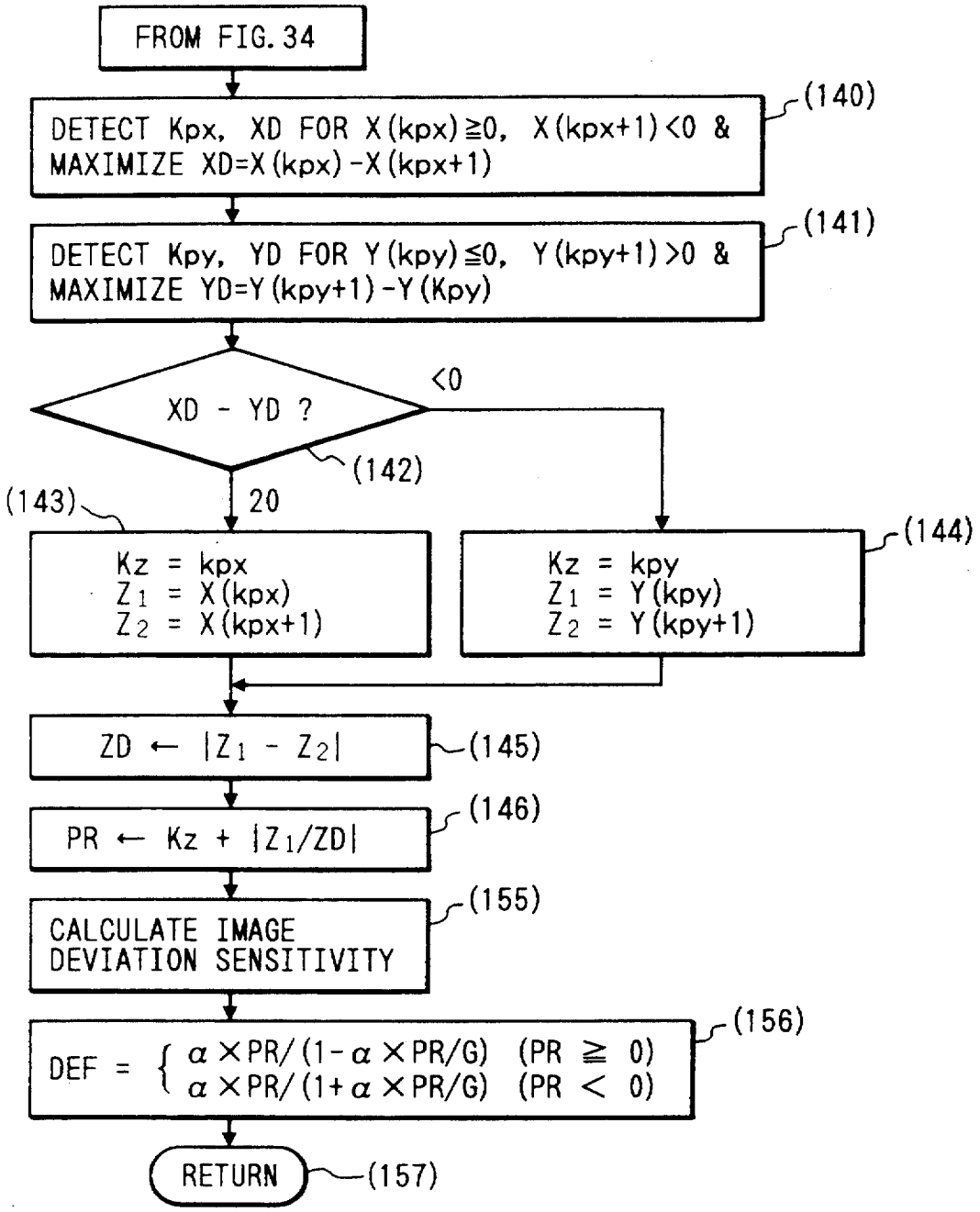

FROM FIG. 34
DETECT Kpx, XD FOR X(kpx)≧0, X(kpx+1)<0 & MAXIMIZE XD=X(kpx)-X(kpx+1)
(140)
DETECT Kpy, YD FOR Y(kpy)≦0, Y(kpy+1)>0 & MAXIMIZE YD=Y(kpy+1)-Y(Kpy)
(141)
XD - YD ?
<0
(142)
20
(143)
Kz = kpx
Z1 = X(kpx)
Z2 = X(kpx+1)
Kz = kpy
Z1 = Y(kpy)
Z2 = Y(kpy+1)
(144)
ZD ← |Z1 - Z2|
(145)
PR ← Kz + |Z1/ZD|
(146)
CALCULATE IMAGE DEVIATION SENSITIVITY
(155)
DEF = { α×PR/(1-α×PR/G) (PR ≧ 0); α×PR/(1+α×PR/G) (PR < 0) }
(156)
RETURN
(157)

FIG. 36A

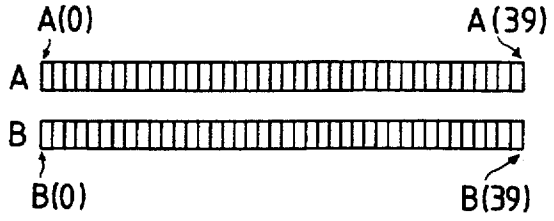


FIG. 36B

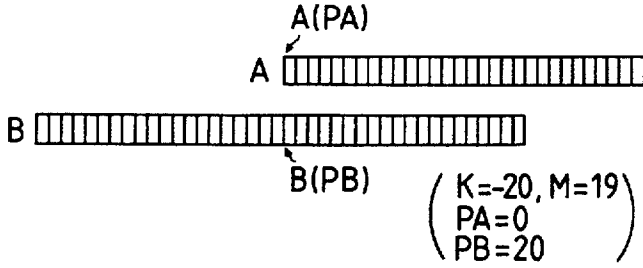


FIG. 36C

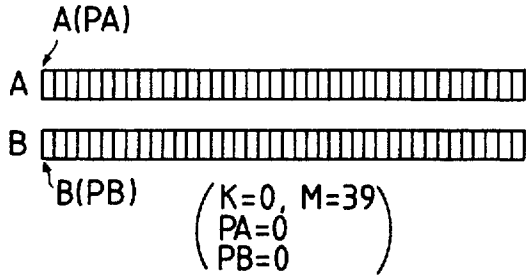


FIG. 36D

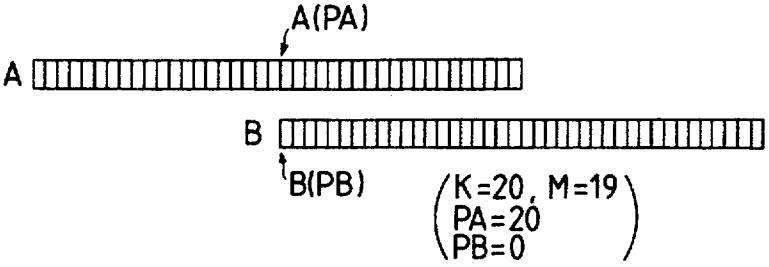


FIG. 37

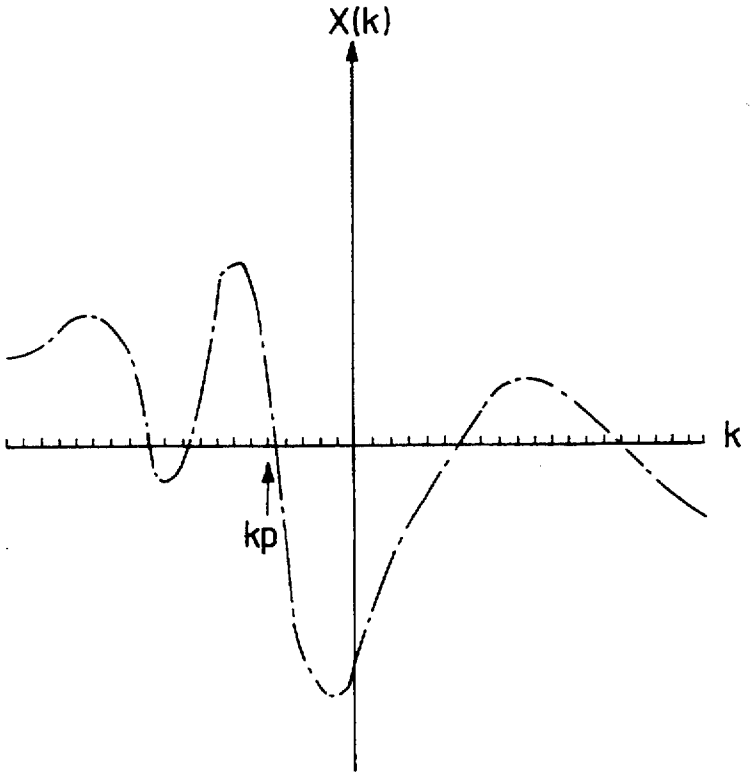


FIG. 38

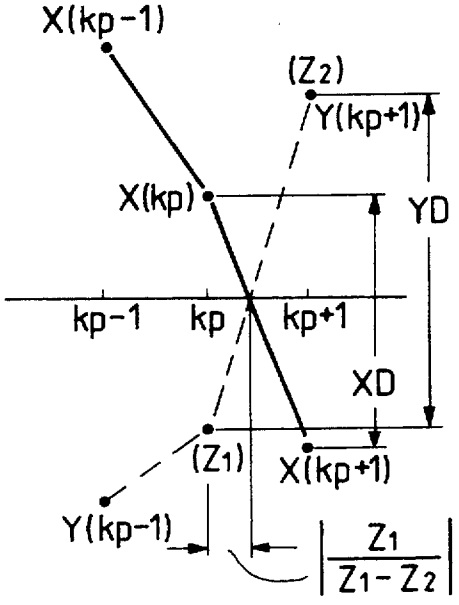


FIG. 39

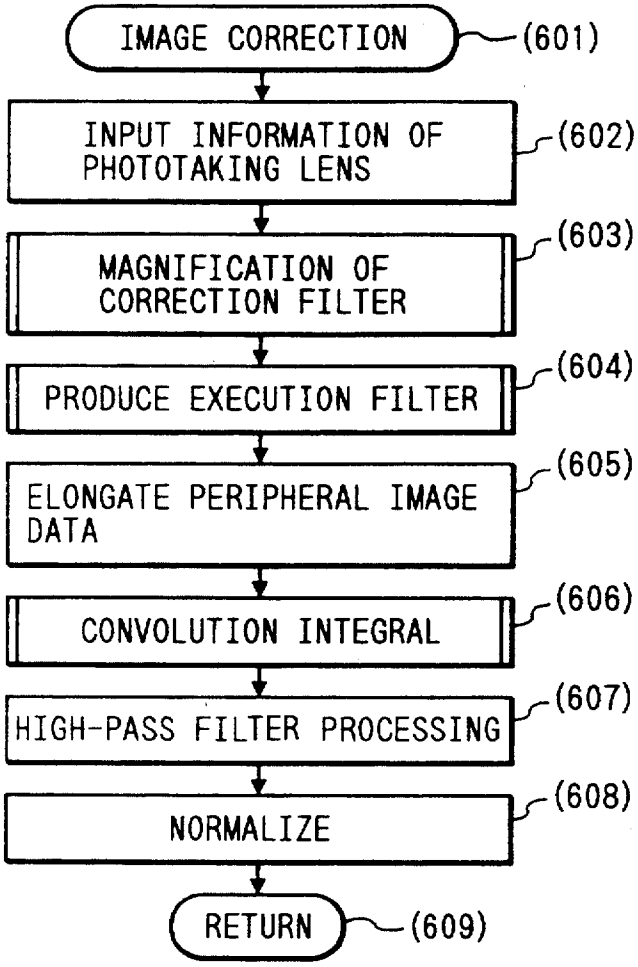


IMAGE CORRECTION
(601)
INPUT INFORMATION OF PHOTOTAKING LENS
(602)
MAGNIFICATION OF CORRECTION FILTER
(603)
PRODUCE EXECUTION FILTER
(604)
ELONGATE PERIPHERAL IMAGE DATA
(605)
CONVOLUTION INTEGRAL
(606)
HIGH-PASS FILTER PROCESSING
(607)
NORMALIZE
(608)
RETURN
(609)

FIG. 40

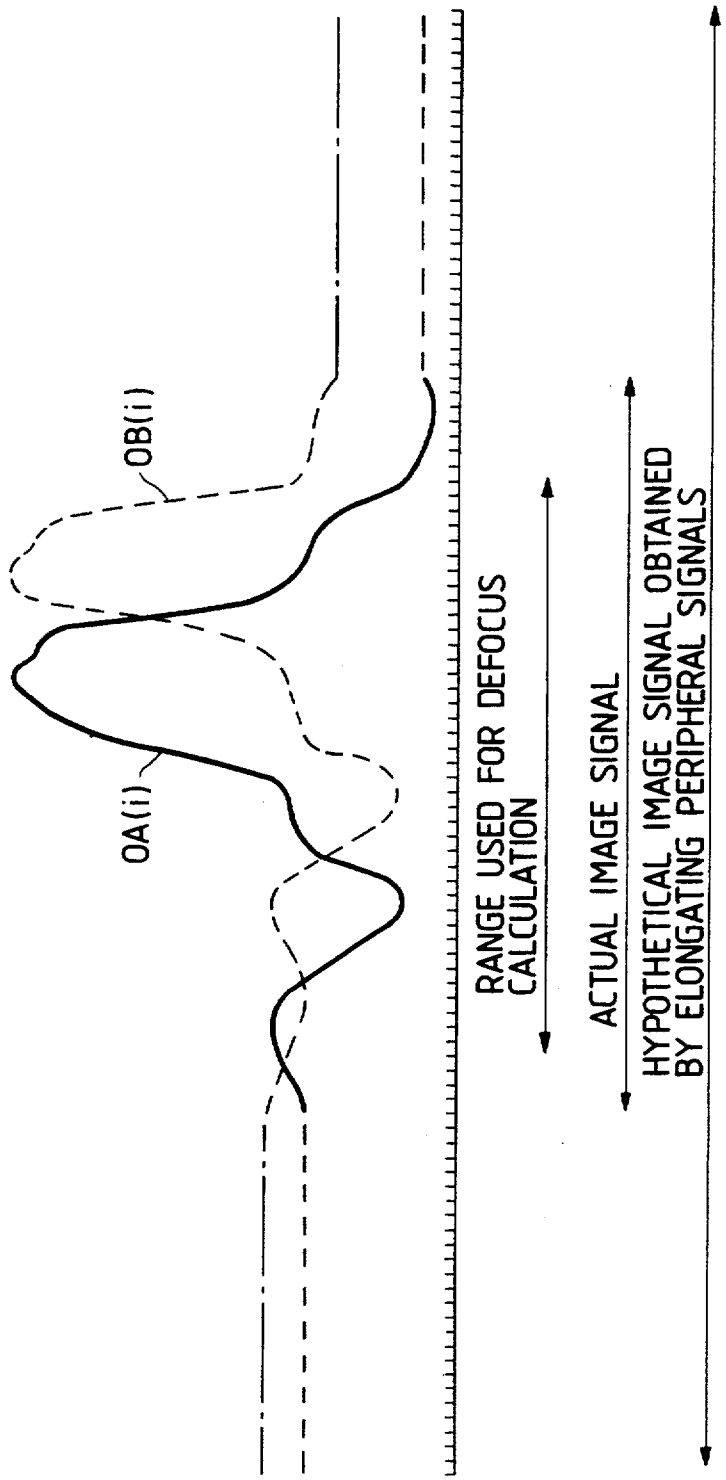

OB(i)
OA(i)
RANGE USED FOR DEFOCUS CALCULATION
ACTUAL IMAGE SIGNAL
HYPOTHETICAL IMAGE SIGNAL OBTAINED BY ELONGATING PERIPHERAL SIGNALS

FIG. 41A

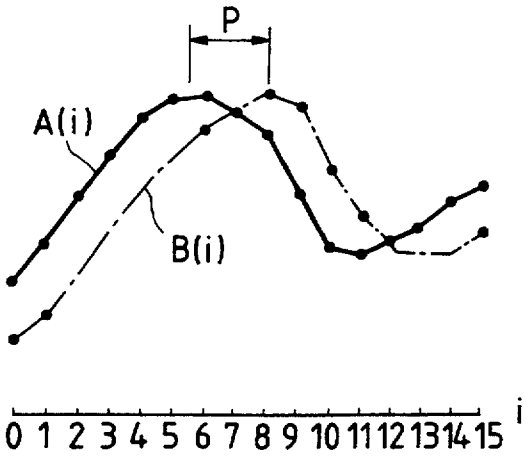


FIG. 41B

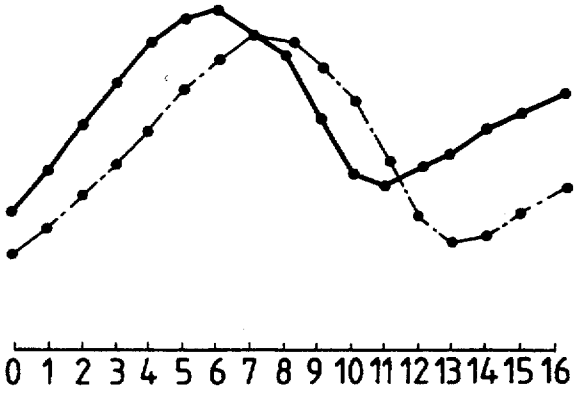


FIG. 41C

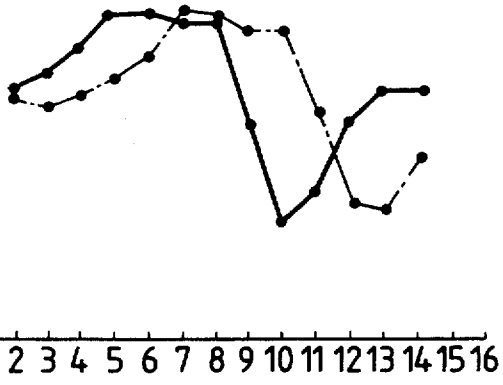


FIG. 42

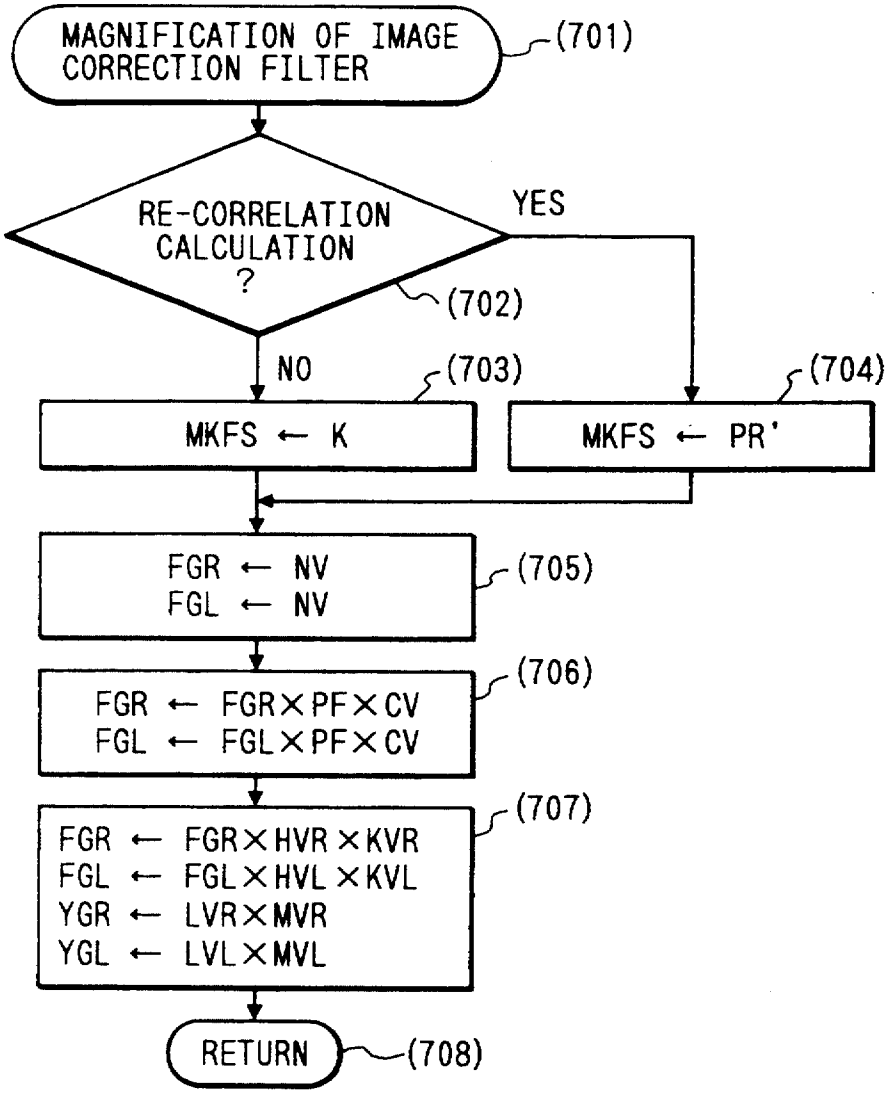

MAGNIFICATION OF IMAGE CORRECTION FILTER
(701)
RE-CORRELATION CALCULATION ?
YES
(702)
NO
(703)
(704)
MKFS ← K
MKFS ← PR'
FGR ← NV
FGL ← NV
(705)
FGR ← FGR×PF×CV
FGL ← FGL×PF×CV
(706)
FGR ← FGR×HVR×KVR
FGL ← FGL×HVL×KVL
YGR ← LVR×MVR
YGL ← LVL×MVL
(707)
RETURN
(708)

FIG. 43A

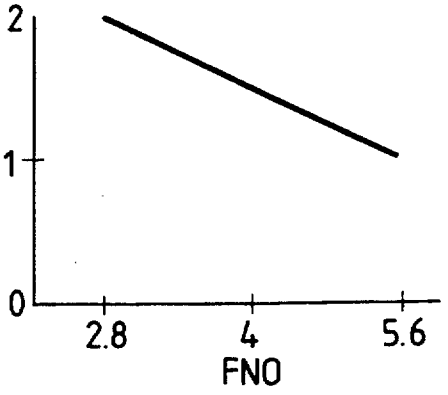


FIG. 43B

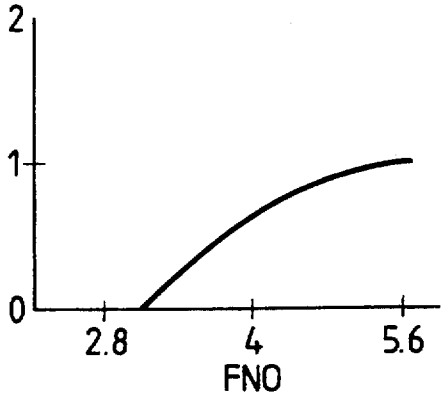


FIG. 43C

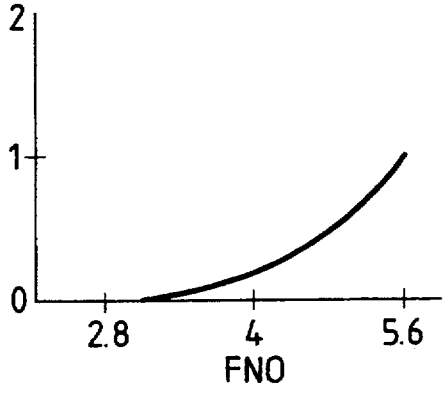


FIG. 43D

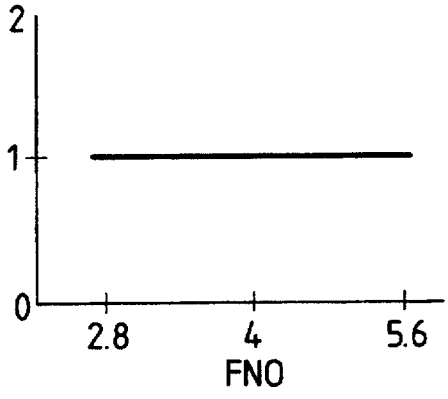


FIG. 44A

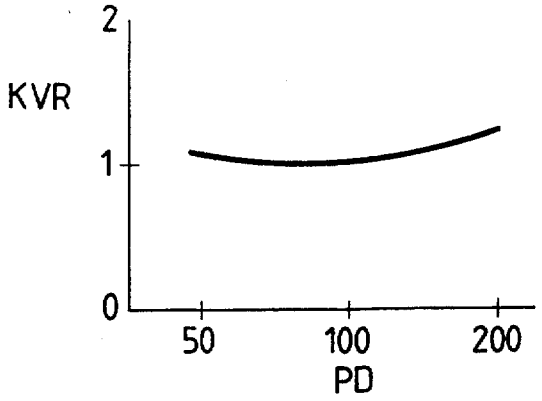


FIG. 44B

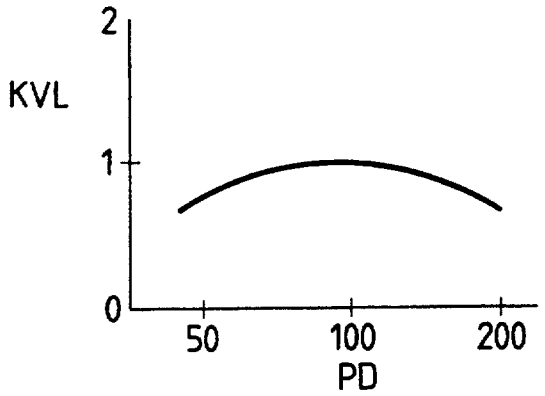


FIG. 44C

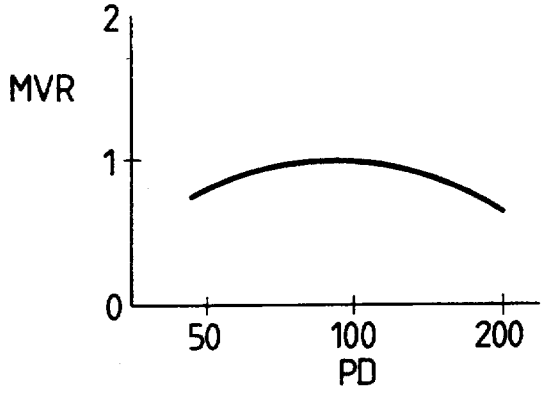


FIG. 44D

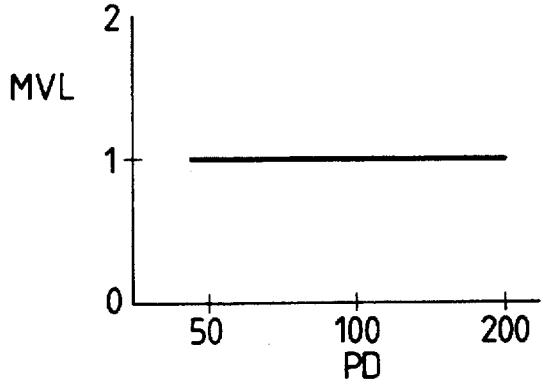


FIG. 45

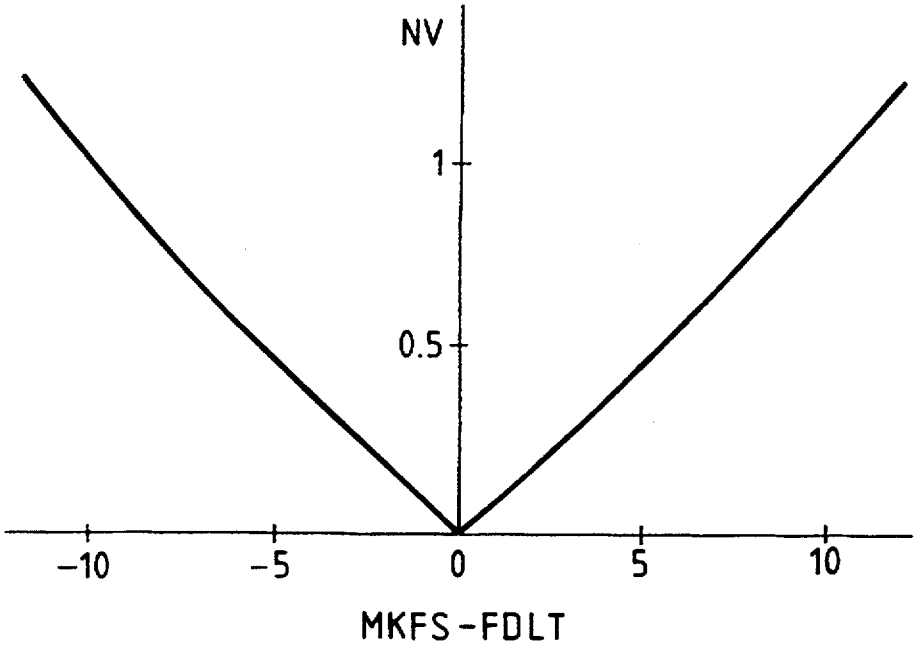
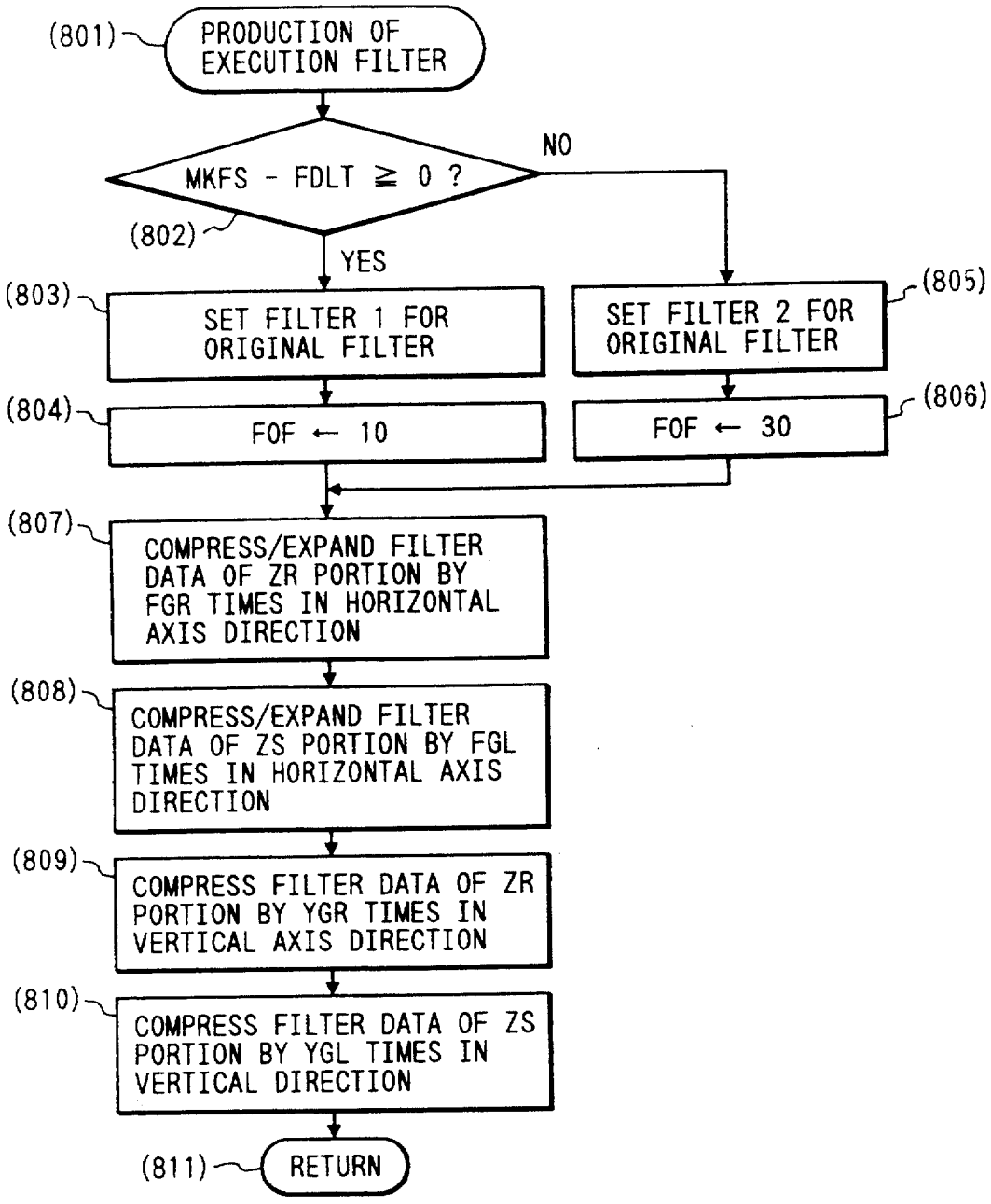

NV
1
0.5
−10
−5
0
5
10
MKFS-FDLT

FIG. 46

LINE-UP DIRECTION OF
PICTURE ELEMENTS

FIG. 47


(801)
PRODUCTION OF EXECUTION FILTER
MKFS - FDLT ≧ 0 ?
NO
(802)
YES
(803)
SET FILTER 1 FOR ORIGINAL FILTER
(805)
SET FILTER 2 FOR ORIGINAL FILTER
(804)
FOF ← 10
(806)
FOF ← 30
(807)
COMPRESS/EXPAND FILTER DATA OF ZR PORTION BY FGR TIMES IN HORIZONTAL AXIS DIRECTION
(808)
COMPRESS/EXPAND FILTER DATA OF ZS PORTION BY FGL TIMES IN HORIZONTAL AXIS DIRECTION
(809)
COMPRESS FILTER DATA OF ZR PORTION BY YGR TIMES IN VERTICAL AXIS DIRECTION
(810)
COMPRESS FILTER DATA OF ZS PORTION BY YGL TIMES IN VERTICAL DIRECTION
(811)
RETURN

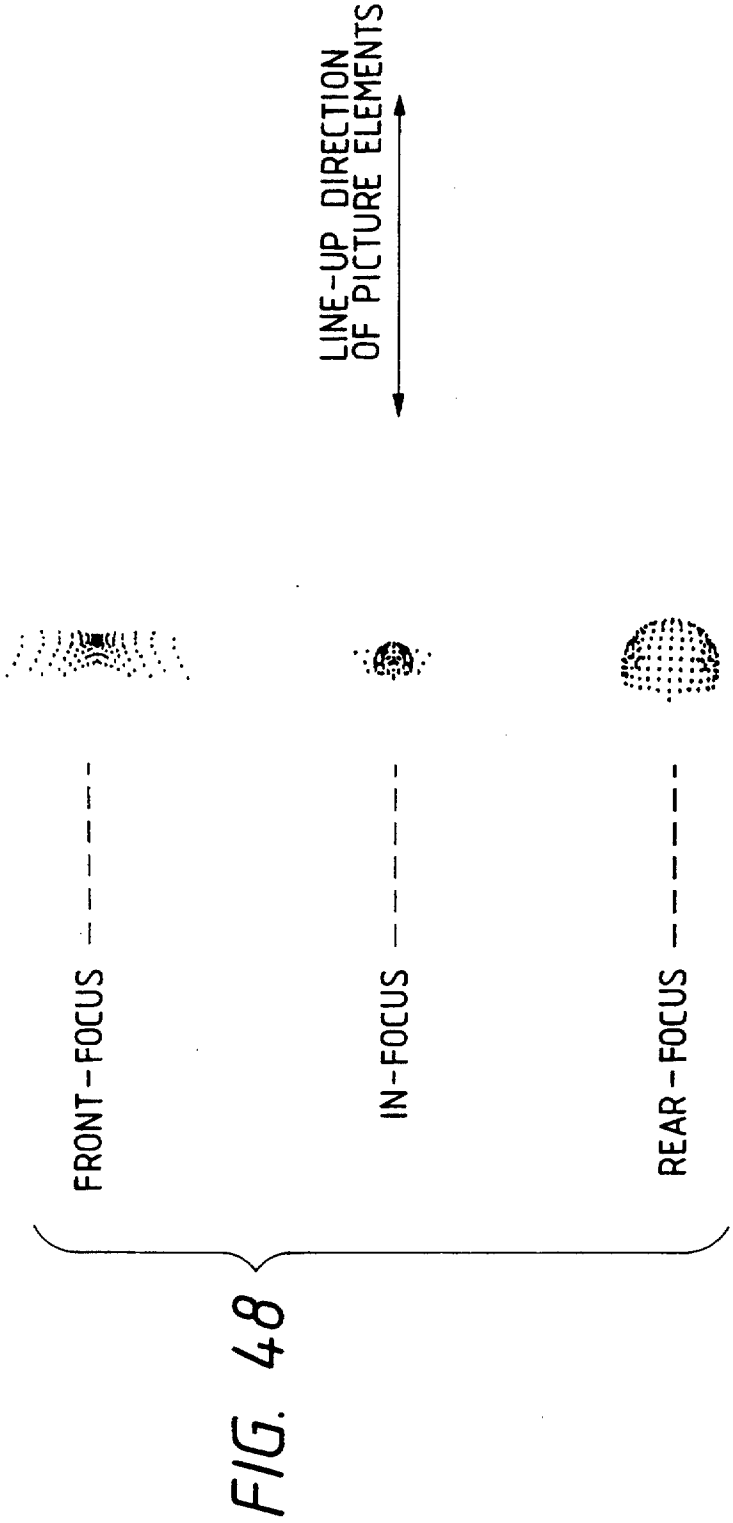

LINE-UP DIRECTION OF PICTURE ELEMENTS
FRONT-FOCUS
IN-FOCUS
REAR-FOCUS

FIG. 48

FIG. 49A

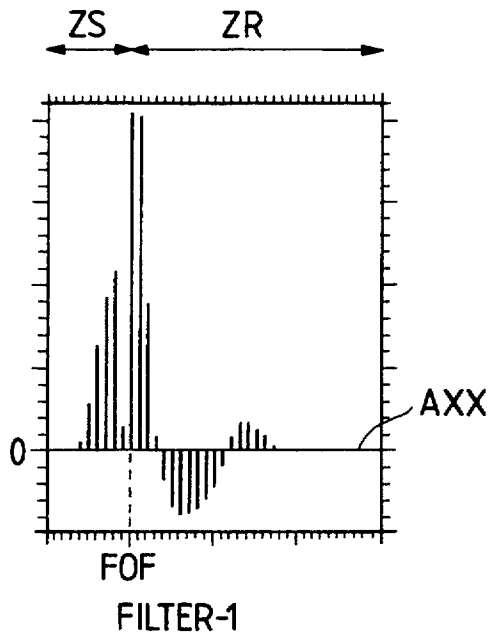


FIG. 49B

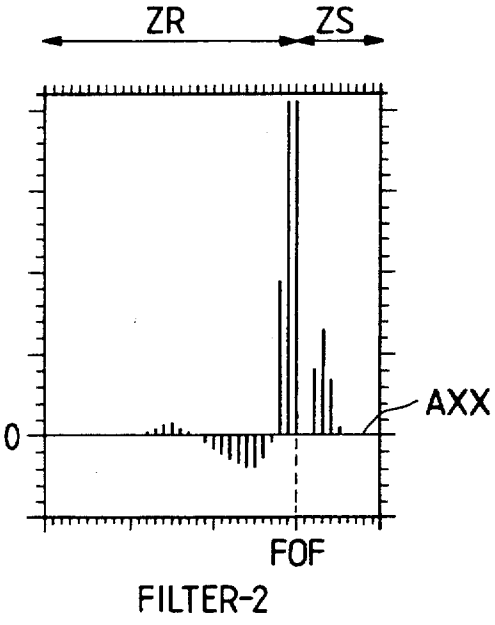


FIG. 50

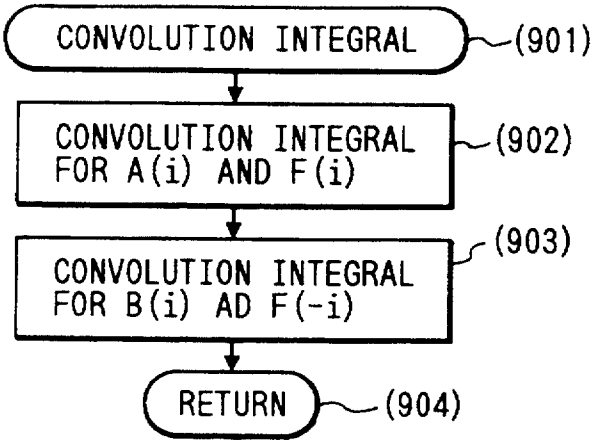

CONVOLUTION INTEGRAL
(901)
CONVOLUTION INTEGRAL FOR A(i) AND F(i)
(902)
CONVOLUTION INTEGRAL FOR B(i) AD F(-i)
(903)
RETURN
(904)

FIG. 51

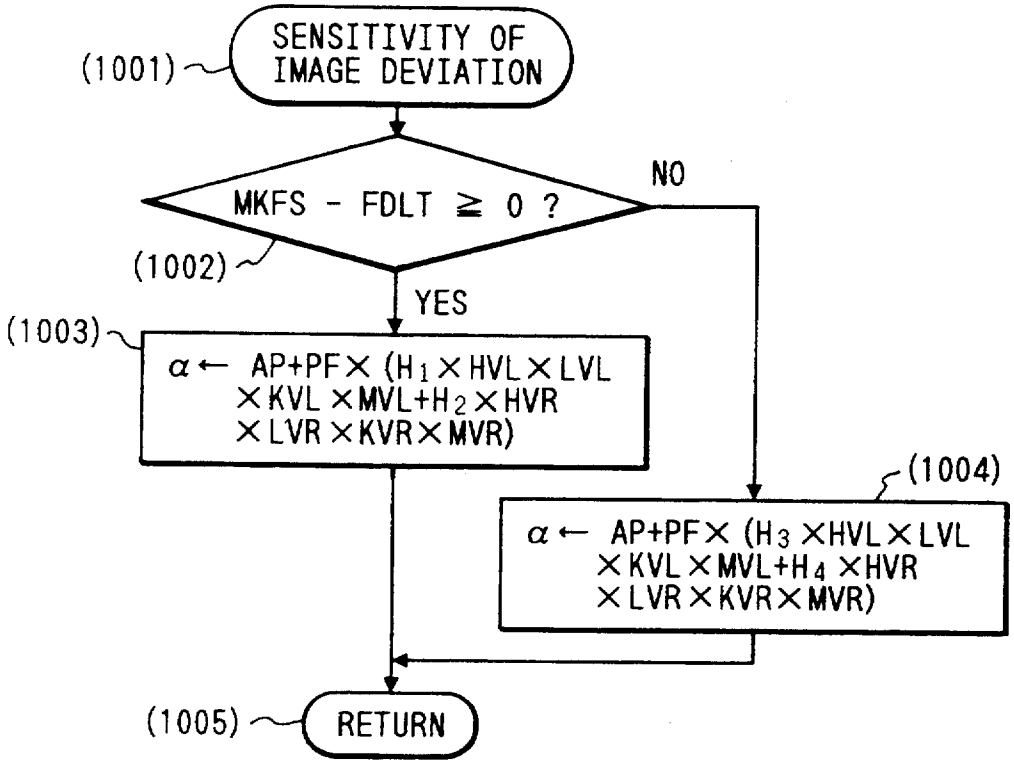

(1001)
SENSITIVITY OF IMAGE DEVIATION
MKFS - FDLT ≧ 0 ?
NO
(1002)
YES
(1003)
α ← AP+PF× (H1 ×HVL×LVL ×KVL ×MVL+H2 ×HVR ×LVR ×KVR×MVR)
(1004)
α ← AP+PF× (H3 ×HVL×LVL ×KVL ×MVL+H4 ×HVR ×LVR ×KVR×MVR)
(1005)
RETURN

FIG. 52A

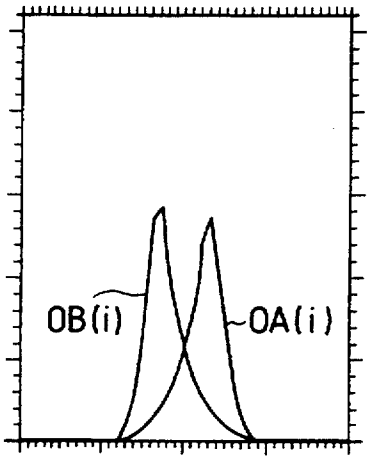


FIG. 52B

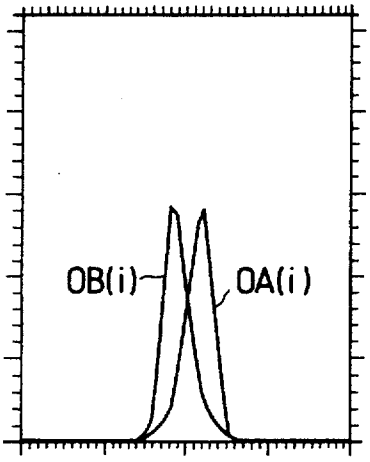


FIG. 52C

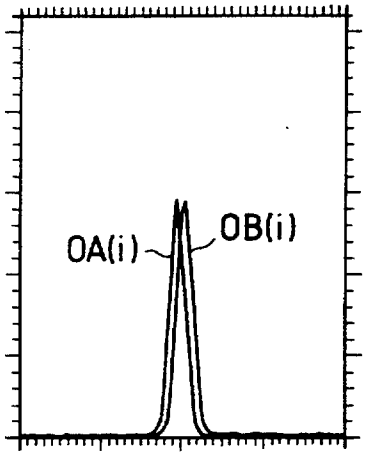


FIG. 53A

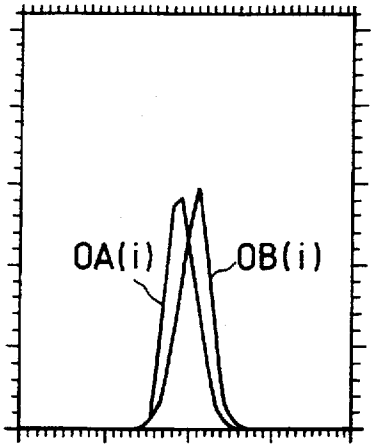


FIG. 53B

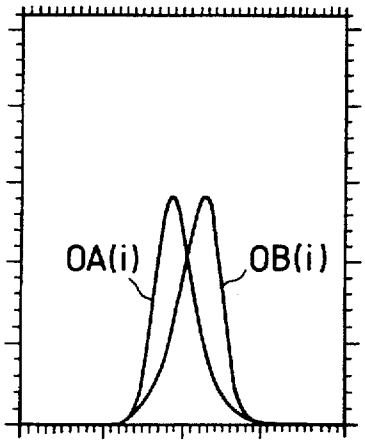


FIG. 54A

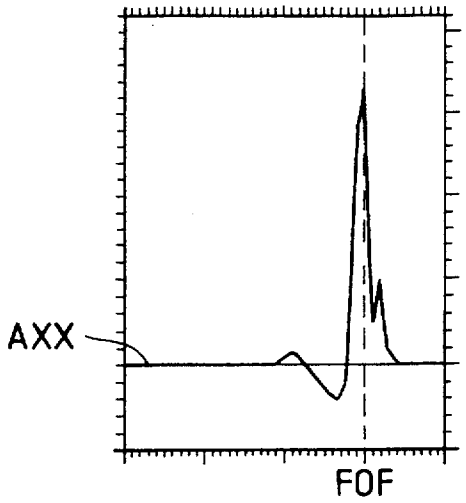


FIG. 54B

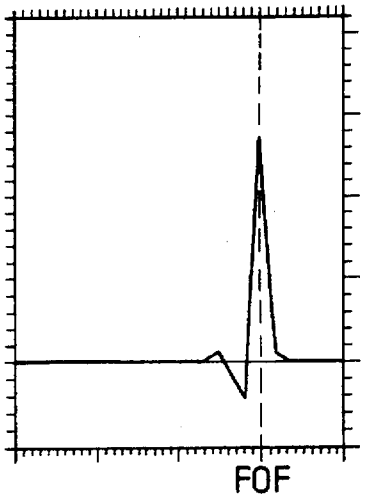


FIG. 54C

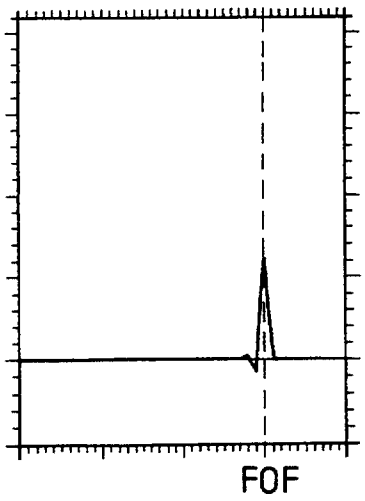


FIG. 55A

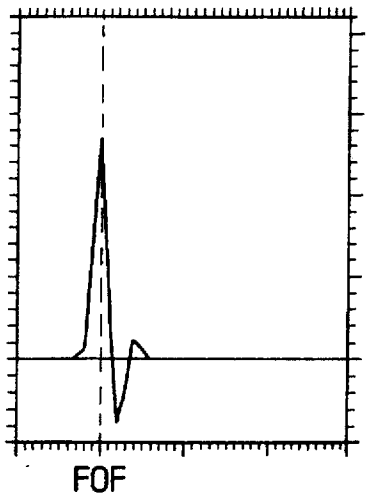


FIG. 55B

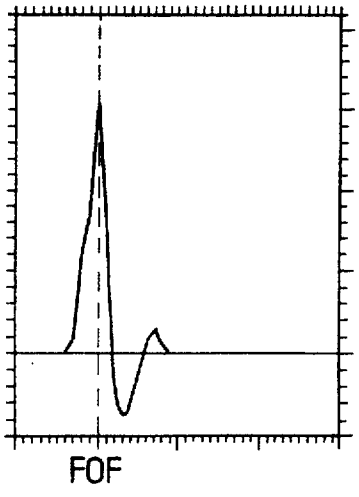


FIG. 56A

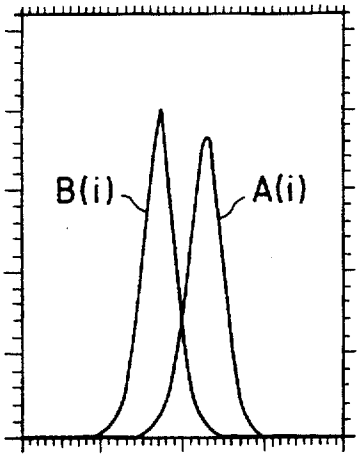


FIG. 56B

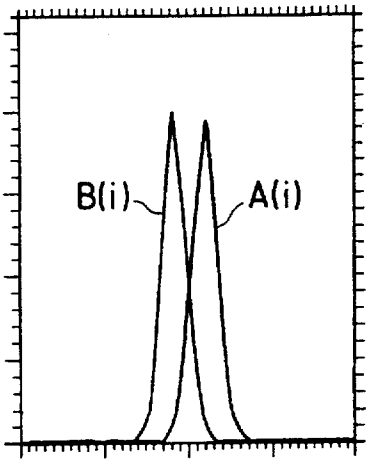


FIG. 56C

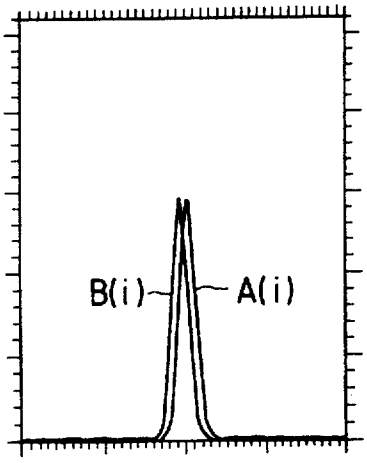


FIG. 57A

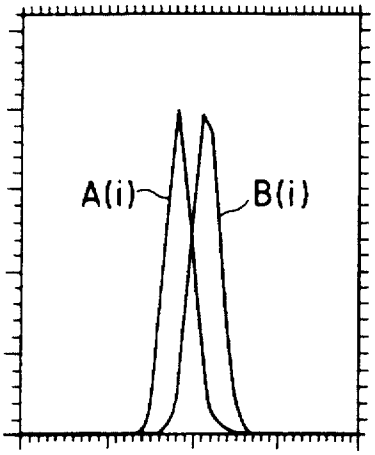


FIG. 57B

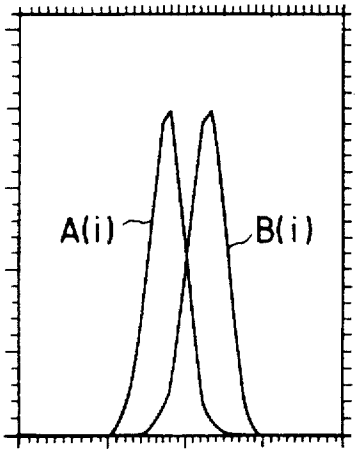


FIG. 59

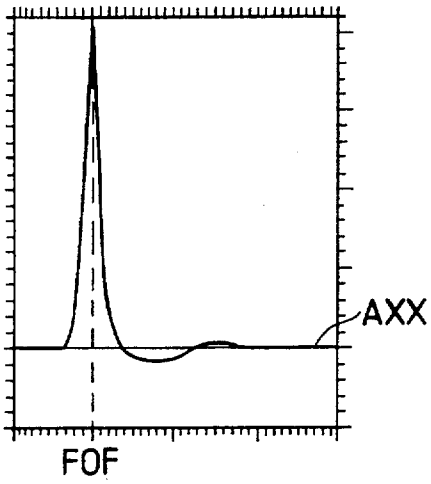


FIG. 58A

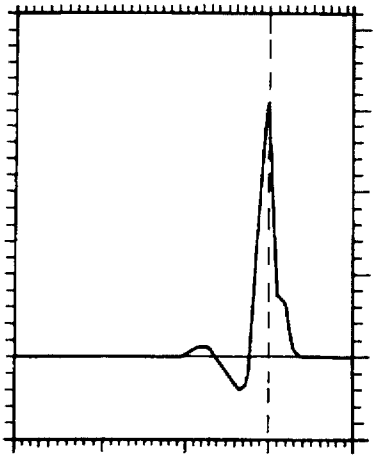


FIG. 58B

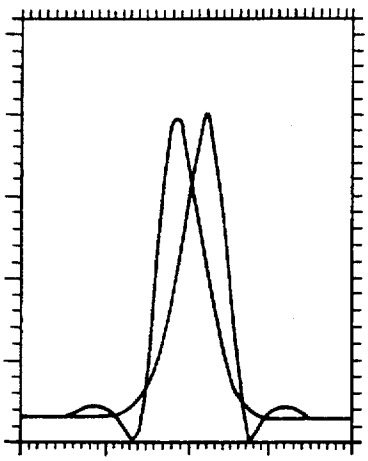


FIG. 58C

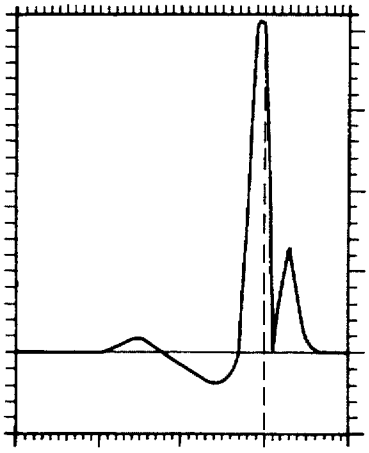
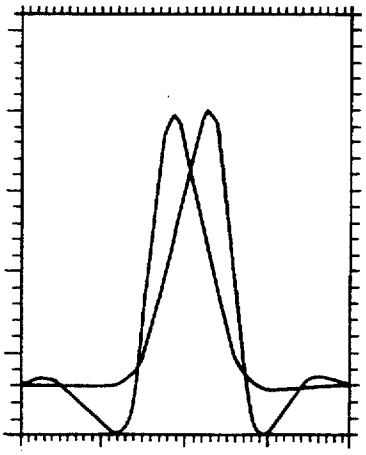


FIG. 58D



APPARATUS FOR DETECTING THE FOCUS ADJUSTING STATE OF AN OBJECTIVE LENS BY PERFORMING FILTER PROCESSING

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a focus detection apparatus and, more particularly, to an improvement in a focus detection apparatus suitable for a photographic camera, a video camera, or the like to detect the imaging state of an imaging optical system in accordance with the relative positional relationship between two object images formed by a distance measuring optical system using a beam passing through a phototaking lens (imaging optical system).

2. Related Background Art

A focus detection apparatus of a so-called image correlation scheme as a conventional method of performing focus detection in a focus detection apparatus is disclosed in U.S. Pat. Nos. 4,559,446, 4,833,313, and many other patents. This scheme has an assumption that two object images (secondary images) to be compared with each other are identical images laterally deviated from each other. For this reason, the aperture ratio of the imaging optical system or the location of the distance measuring field is limited so as not to vignette a distance measuring beam.

High-pass filter processing is known to effectively improve precision of an image signal degraded by vignetting of the distance measuring beam. However, this processing mainly aims at eliminating small adverse influences of vignetting caused by manufacturing errors. The effect of high-pass filter processing cannot perfectly eliminate the limitations of the open f-number or allow free layout of the distance measuring field.

In a camera system obtained by applying this focus detection apparatus to, e.g., a single-lens reflex camera, open f-numbers of various phototaking lenses are assumed to be generally set to fall within the range from F1.0 to F8. For this reason, when this camera system is to be arranged as an auto-focus camera system, the open f-numbers of phototaking lenses used in the auto-focus operation are limited to ones smaller than F5.6. Alternatively, the distance measuring field is located at a position near the optical axis, e.g., a position within the range of 5 mm from the optical axis so as to reduce vignetting of the distance measuring beam. It is, therefore, very difficult to realize a camera system having an auto-focus mode which can use any kind of phototaking lens and can operate (distance measurement) in any area of the finder field.

The present invention is related to an improvement of the invention of U.S. Ser. No. 723,962 filed by the present applicant.

SUMMARY OF THE INVENTION

It is an object of the present invention to allow good focus detection by an apparatus for detecting the focus adjusting state of an objective lens on the basis of a relative positional deviation between a pair of optical distributions even if a detection beam is vignetted. In the present specification, the beam represents an invisible beam as well as a visible beam.

It is another object of the present invention to reduce limitations required to reduce the f-number of the objective lens in accordance with the f-number of a beam incident on a focus detection apparatus.

It is still another object of the present invention to provide a focus detection apparatus capable of reducing the aperture ratio of an imaging optical system, eliminating the limitations of the distance measuring field location, and performing high-precision focus detection by employing a filter having an appropriate arrangement although the distance measuring beam is slightly vignetted in focus detection using an image deviation scheme.

It is still another object of the present invention to provide a focus detection apparatus comprising a reimaging optical system for forming first and second object images whose relative positional relationship is changed in accordance with an imaging state of an imaging optical system subjected to focus detection, photoelectric converting means, having a plurality of picture elements, for outputting first and second signals respectively corresponding to the first and second object images, and calculating means for performing filter processing of the first and second signals, sequentially displacing the first and second signals relative to each other on the calculation basis, calculating an evaluation amount representing a coincidence between the first and second signals at the relatively displaced positions, obtaining positional deviations between the first and second object images on the basis of a change in evaluation amount, and detecting the imaging state of the imaging optical system on the basis of the deviations, the filter processing being performed using a filter determined by the relatively displaced positions.

It is still another object of the present invention to provide a focus detection apparatus comprising a reimaging optical system for forming first and second object images whose relative positional relationship is changed in accordance with an imaging state of an objective optical system subjected to focus detection, photoelectric converting means, having a plurality of picture elements, for outputting first and second signals respectively corresponding to the first and second object images, and calculating means for, when the first and second signals are sequentially displaced relative to each other on the calculation basis and an evaluation amount representing a coincidence between the first and second signals at the relatively displaced positions is calculated, performing filter processing of the first and second signals using a filter determined by the relatively displaced positions, obtaining deviations between the first and second object images on the basis of a change in evaluation amount, and detecting the imaging state of the imaging optical system, wherein

(a) the calculating means has a first processing step of producing the filter from first original filter information and a second processing step for producing the filter from second original filter information, and further comprises selecting means for selecting one of the first and second processing steps in accordance with the relative displacement of the first and second signals,

(b) the filter corrects the first and second signals even if the relative displacement is zero,

(c) the filter has only a positive component in one direction and positive and negative components in the other direction with respect to an origin, and

(d) the photoelectric converting means has picture elements used for the filter processing outside pic-

ture elements whose outputs are used to calculate the evaluation amount.

It is still another object of the present invention to provide a focus detection apparatus comprising a reimaging optical system for forming first and second object images whose relative positional relationship is changed in accordance with an imaging state of an imaging optical system subjected to focus detection, photoelectric converting means, having a plurality of picture elements, for outputting first and second signals respectively corresponding to the first and second object images, and calculating means for, when the first and second signals are sequentially displaced relative to each other on the calculation basis and an evaluation amount representing a coincidence between the first and second signals at the relatively displaced positions is calculated, performing filter processing of the first and second signals, obtaining deviations between the first and second object images on the basis of a change in evaluation amount, and detecting the imaging state of the imaging optical system, wherein

(e) the filter processing is performed using a filter determined in accordance with an aperture ratio of the imaging optical system subjected to focus detection,

(f) the filter processing is performed using a filter determined in accordance with an exit pupil position of the imaging optical system subjected to focus detection,

(g) the calculating means has the filter processing having an (A1)th processing process performed using the filter determined by the relative displacement and an (A2)th processing step performed next to the (A1)th processing step by using a specific filter without depending on the relative displacement, the specific filter in the (A2)th processing step being determined on the basis of the deviations obtained in the (A1)th processing step,

(h) the calculating means has the filter processing having a (B1)th processing process performed using the filter determined by the relative displacement and a (B2)th processing step performed using a specific filter without depending on the relative displacement and comprises selecting means for selecting one of the (B1)th and (B2)th processing steps,

(i) the filter processing is performed using a filter determined by a distance from an optical axis of the imaging optical system subjected to focus detection to a distance measuring field determined by the photoelectric converting means, and

(j) the calculating means has a (C1)th processing step of performing filter processing of the first signal and a (C2)th processing step of performing filter processing of the second signal, the filter used in the (C2)th processing step being constituted by characteristics obtained by inverting the filter used in the (C1)th processing step.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a sectional view of a focus detection optical system according to the present invention;

FIG. **2** is a view showing diffusion characteristics of a diffusion plate **42** in FIG. **1**;

FIG. **3** is a plan view of an aperture **48** in FIG. **1**;

FIG. **4** is a view showing an aperture image on the exit pupil of a phototaking lens in FIG. **1**;

FIGS. **5**A and **5**B are views for explaining the principle of distance measurement in a focus detection apparatus;

FIG. **6** is a sectional view showing a single-lens reflex camera which incorporates the focus detection apparatus;

FIG. **7** is a sectional view showing a developed focus detection optical system in the short-side direction of the finder field;

FIG. **8** is a sectional view showing a developed focus detection optical system in the long-side direction of the finder field;

FIG. **9** is a plan view of a condenser lens **85**;

FIGS. **10**A and **10**B are views for explaining a focusing screen **84**;

FIG. **11** is a plan view showing the shape of a reimaging lens **90** when viewed from the light incident surface;

FIG. **12** is a plan view of an aperture **93**;

FIG. **13** is a view for explaining an image projected from aperture openings;

FIG. **14** is a plan view of a light-shielding mask **89**;

FIG. **15** is a view showing the positional relationship between a phototaking frame and a distance measuring field;

FIG. **16** is a view showing the picture element layout of a photoelectric conversion element;

FIG. **17** is a partially enlarged view of a light guide prism in FIG. **6**;

FIG. **18** is a perspective view of the light guide prism in FIG. **6**;

FIG. **19** is a perspective view showing a state in which a distance measuring beam is vignetted;

FIGS. **20**A to **20**C are plan views of optical paths to a position **104***j* of the distance measuring field shown in FIG. **15** when viewed from the top;

FIGS. **21**A to **21**C are views showing ranges of phototaking beams on a surface where aperture images of a distance measuring optical system are formed;

FIGS. **22**A to **22**C are plan views of optical paths to a position **104***j* of the distance measuring field shown in FIG. **15** when viewed from the top;

FIGS. **23**A to **23**C are views for explaining a defocused image and its correction filter, image data, and corrected image data;

FIGS. **24**A to **24**C are views for explaining a defocused image and its correction filter, image data, and corrected image data;

FIGS. **25**A and **25**B are views for explaining correction of a general object image;

FIGS. **26**A and **26**B are views for explaining correction of another general object image;

FIG. **27** is a block diagram showing a camera circuit according to the present invention;

FIG. **28** is a view showing an arrangement for detecting the positions of a distance ring and a zoom ring of a phototaking lens;

FIG. **29** is a flow chart for explaining a camera sequence;

FIG. **30** is a flow chart of an "AF" subroutine;

FIG. **31** is a flow chart of a "focus detection" subroutine;

FIG. **32** is a flow chart of a "lens driving" subroutine;

FIG. **33** is a flow chart of a "release" subroutine;

FIG. **34**A and **34**B are a flow chart of a "defocus calculation" subroutine;

FIG. **35** is a flow chart of the "defocus calculation" subroutine;

FIGS. **36**A to **36**D are views for explaining a correspondence between a relative displacement and calculation picture elements;

FIG. **37** is a graph showing the relationship between the relative displacement and the focus evaluation amount;

FIG. **38** is a view for explaining a method of calculating an image deviation on an order of sub-picture element;

FIG. **39** is a flow chart of an "image correction" subroutine;

FIG. **40** is a view for explaining a state in which peripheral signals of image data are elongated;

FIGS. **41**A to **41**C are charts showing an image signal free from low-frequency noise, an image signal superposed with low-frequency noise, and an image signal processed in high-pass filter processing, respectively;

FIG. **42** is a flow chart of a "magnification of image correction filter" subroutine;

FIGS. **43**A to **43**D are graphs showing f-number correction coefficients and pupil position correction coefficients;

FIGS. **44**A to **44**D are graphs showing other f-number correction coefficients and other pupil position correction coefficients;

FIG. **45** is a graph showing the relationship between MKFS-FDLT and NV;

FIG. **46** is a spot diagram of a point image;

FIG. **47** is a flow chart of a "production of execution filter" subroutine;

FIG. **48** is a spot diagram for explaining changes in a point image in different imaging states;

FIGS. **49**A and **49**B are views showing original filters, respectively;

FIG. **50** is a flow chart of a "convolution integral" subroutine;

FIG. **51** is a flow chart of a "sensitivity of image deviation" subroutine;

FIGS. **52**A to **52**C are views showing image data of line images in different imaging states of the phototaking lens, respectively;

FIGS. **53**A and **53**B are views showing image data of line images in different imaging states of the phototaking lens;

FIGS. **54**A to **54**C are views showing a defocused image correction filter;

FIGS. **55**A and **55**B are views showing another defocused image correction filter;

FIGS. **56**A to **56**C are views showing image data of corrected line images;

FIGS. **57**A and **57**B are views showing image data of other corrected line images;

FIGS. **58**A to **58**D are views showing a defocused image correction filter, and image data of corrected line images; and

FIG. **59** is a view of a correction filter corresponding to a bright phototaking lens having a small f-number when this bright phototaking lens is mounted on a camera body.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. **1** shows the basic arrangement of a focus detection system in a focus detection apparatus according to the present invention. This embodiment is characterized in that a phototaking beam is aligned with a distance measuring beam to obtain an optimal in-focus position and is also in consideration of a spatial frequency included in an object image.

The arrangement of the focus detection system will be described below. Referring to FIG. **1**, the object has an object surface **40**. A diffusion plate **42** has a mat surface **42***a* having a fine three-dimensional pattern located near a prospective imaging plane of a phototaking lens **41**. A field lens (condenser lens) **43** is located on the exit side of the diffusion plate **42**. An aperture **48** has two openings **48***a* and **48***b*. A re-imaging lens (secondary imaging lens) **44** has two lens portions **44***a* and **44***b* located symmetrically about an optical axis L2 of the phototaking lens **41**. The re-imaging lens **44** converges beams passing through the two aperture openings **48***a* and **48***b* to form secondary object images of the object on photoelectric element arrays **46** and **47** located behind the re-imaging lens **44**. Photoelectric conversion outputs from the photoelectric conversion element arrays **46** and **47** are input to a microcomputer (to be described later) and used for focus detection of the phototaking lens.

The field lens **43** has a projection function for establishing a conjugate relationship between the aperture **48** and the exit pupil of the phototaking lens **41** if diffusion in the diffusion plate **42** is neglected. The diffusion characteristics of the diffusion plate **42** and the converging characteristics of the field lens **43** determine the area of the distance measuring beam passing through the exit pupil of the phototaking lens.

FIG. **2** is a view for explaining the diffusion characteristics of the diffusion plate **42**. A beam L vertically incident from the phototaking lens **41** is diffused by the mat surface **42***a* on the re-imaging lens side. A straight incident component, which emerges at the same angle as the incident angle, is the strongest, and the intensity of light components is decreased away from the straight incident component. A beam incident from the phototaking lens side is readily understood to have a spread on the aperture **48** to some extent. A beam focused on a given point on the aperture **48** has a spread on the exit pupil to some extent in accordance with the principle of reverse light propagation.

FIGS. **3** and **4** are views for explaining the above phenomenon. FIG. **3** is a plan view of the aperture **48**, and FIG. **4** is a view showing an image of the aperture **48** on the exit pupil of the phototaking lens **41**. As shown in FIG. **3**, the two aperture openings **48***a* and **48***b* have a shape obtained by dividing one circle into halves. The images of the aperture openings **48***a* and **48***b* are formed on the exit pupil of the phototaking lens **41**. In this case, the resultant image has a blurred peripheral portion by the behavior of the diffusion plate **42**. FIG. **4** schematically illustrates the blurred state.

Two opening images **49***a* and **49***b* in FIG. **4** are represented by lines hatched from the upper right side to the lower left side and lines hatched from the upper left side to the lower right side, respectively. These opening images partially overlap each other due to blurring. These two images spread entirely within the exit pupil. As a result, the distance between the centers of gravity of the aperture opening images **49***a* and **49***b* is set relatively small, and distance measuring beams can be incident from the large area of the exit pupil.

The principle of distance measurement in the focus detection apparatus having the above arrangement will be described below.

FIGS. **5**A and **5**B are views for explaining the above principle, showing the detailed arrangement from the

phototaking lens **41** to the aperture **48**. Strictly speaking, analysis by wave optics is required for diffusion on the mat surface **42***a* of the diffusion plate **42**. However, an opto-geometric description will be made as an explanation similar to the analysis by wave optics.

Assume two beams A and B passing through optical paths connect points G and H in the aperture openings **48***a* and **48***b* and a point E on the optical axis of the mat surface **42***a* in FIG. **5**A. For descriptive convenience, assume that the condenser lens **43** is thin and is adjacent to the mat surface **42***a*. An angle defined by lines connecting the point E to the points G and H on the openings of the aperture **48** is defined as $\theta 1$. Since the mat surface **42***a* is a diffusion surface, it is a continuous, fine three-dimensional pattern. If a plane tangential to the point E of the mat surface **42***a* is defined as a plane P1, the beams A and B are refracted at the point E into beams A′ and B′. Points at which the two diffracted beams reach on the exit pupil of the phototaking lens **41** are defined as I and J, respectively.

A point F is set very close to a point E on the optical axis of the mat surface **42***a* in FIG. **5**B, and the behavior of the beam at the point F will be taken into consideration in the same manner as in FIG. **5**A. A plane tangent to the point F is defined as a plane P2, and an angle defined by lines connecting the point F to points G and H on the aperture openings is defined as $\theta 2$. Two beams C and D passing through the lines connecting the point F to the points G and H on the openings of the aperture **48** are diffracted into beams C′ and D′ in the same manner as in FIG. **5**A. Points at which the two diffracted beams reach on the exit pupil of the phototaking lens **41** are defined as K and M, respectively.

The thickness of the focusing screen **42** is neglected, and angles between the points I and J and between the points K and M on the exit pupil of the phototaking lens **41** with respect to the points E and F are respectively defined as $\theta 1'$ and $\theta 2'$ The point E is very close to the point F. If the angles $\theta 1'$ and $\theta 2'$ and the inclination angles of the tangential planes are very small, the following relation can be approximated:

$$\theta 1' \simeq \theta 2'$$

When the angle defined by the lines connecting the intersection between the optical axis and the mat surface **42***a* to the points on the two aperture openings is small, the lengths of the distance measuring base lines of the beams diffracted within a given range are identical. The diffusion characteristics (FIG. **2**) of the mat surface indicate that various planes tangent to the point E are opto-geometrically present, and the diffusion characteristics are the total characteristics obtained from the various planes. The diffusion characteristics of the mat surface fall within a given range in relation to the light amount, and explanation with reference to FIGS. **5**A and **5**B can be applied to all these tangential planes.

For the sake of descriptive simplicity, the description of FIGS. **5**A and **5**B has been made for distance measurement of a point on the optical axis. It is apparent that the same description as for FIGS. **5**A and **5**B can be applied to any point outside the optical axis. The distance measuring base line length in the focus detection apparatus of the present invention is determined by the distance between the openings of the aperture **48** and is not influenced by the characteristics of the diffusion plate.

The focus detection operation is basically identical to that of the conventional focus detection apparatus having no diffusion plate due to the above nature. For example, when the phototaking lens **41** is extended to the left in FIG. **1** to set a so-called front-focus state, the object images projected on the light-receiving surfaces of the photoelectric conversion element arrays **46** and **47** by the re-imaging lenses **44***a* and **44***b* are deviated in a direction indicated by an arrow. The front-focus state and its amount can be detected in accordance with changes in outputs from the photoelectric conversion element arrays **46** and **47**, which changes correspond to a relative deviation between the object images. In the rear-focus state, the object images are deviated in a direction opposite to that in the front-focus state. The rear-focus state and its amount can be detected in the same manner as described above.

As described above, in the focus detection apparatus, by using the diffusion plate, a distance measuring beam having an intensity corresponding to a small f-number can be received without excessively increasing the distance measuring base line length. An optimal focus position corresponding to the spatial frequency of the object image can be detected. As will be described below, the focusing screen of a single-lens reflex camera can be used as the diffusion plate.

FIG. **6** is a schematic view showing the main part of a single-lens reflex camera which employs the focus detection apparatus according to the present invention.

The camera has a single-lens reflex camera body **80**. A phototaking lens **81** is mounted to be movable in a direction of the optical axis of a lens barrel **82**. A movable mirror **83** is set in a mirror down state when the photographer observes an object. In this state, a beam from the phototaking lens **81** is deflected upward and guided to a finder and a focus detection system of the present invention. The movable mirror **83** is set in a mirror up state immediately before the start of exposure of a photographing film **92** in the phototaking mode so as not to vignet the beam from the phototaking lens. At the end of exposure, the movable mirror **83** returns to the mirror down state shown in FIG. **6**.

The finder and the focus detection system will be described below. An object image is projected from the phototaking lens **81** on a focusing screen **84**. The focusing screen **84** diffuses the distance measuring beam. The camera also includes a condenser lens (field lens) **85**, a pentagonal prism **86**, a beam splitter **87** for splitting the beam toward the focus detection system, and an eyepiece lens **88**. A spherical surface portion **84***a* is formed on the beam incident surface of the focusing screen **84** to cause the beam to impinge, at almost a right angle, on a mat surface **84***c* foraged on the light exit surface of the focusing screen **84**. A Fresnel lens **84***b* is formed in the peripheral portion serving as the range outside the distance measuring field. The mat surface **84***c* has a convex surface portion corresponding to the spherical surface portion **84***a* to correct the curvature of a prospective imaging plane. The beam diffused by the mat surface **84***c* is diffracted by the condenser lens **85** located behind the mat surface **84***c* so as to match the location of the eyepiece lens **88**. The beam passes through the pentagonal prism **86** and a half mirror surface **87***a* of the beam splitter **87** and is deflected in a direction toward the eyepiece lens **88**. The beam passing through the eyepiece lens **88** reaches eyes of the observer.

The beam splitter **87**, located in front of the eyepiece lens **88**, causes the half mirror surface **87***a* to reflect part of the beam supposed to reach the eyepiece lens **88**

upward. The reflected beam is utilized for focus detection. The components from a light-shielding mask **89** belong to the focus detection system. The focus detection system includes a secondary imaging lens (re-imaging lens) **90** comprising a transparent plastic material, an aperture **93**, a light guide prism **94**, and photoelectric conversion element (picture element) arrays **108**, **108*h*1** and **108*h*2** each made of a large number of picture elements. These picture element arrays are held by a transparent plastic package **95**. The aperture **93** is projected on the exit pupil of the phototaking lens **81** by the secondary imaging lens **90**, the condenser lens **85**, and the spherical surface portion **84*a*** of the focusing screen **84**. The secondary imaging lens **90** serves to project the mat surface **84*c*** of the focusing screen on the photoelectric transducer element arrays **108*h*1** and **108*h*2**. The projected image of the object spreads and is blurred by the diffusion behavior of the mat surface **84*c*** in the same manner as described with reference to FIG. **1**.

FIGS. **7** and **8** are developed views of the focus detection optical system having the above structure along the optical axis. FIG. **7** shows the section in the short-side direction of the finder field, whereas FIG. **8** shows the section in the long-side direction of the finder field. Equivalent flat parallel members **186** and **187** have optical path lengths equal to that obtained by developing the pentagonal prism **86** and the beam splitter **87** along the optical paths, respectively.

The condenser lens **85** has a function of brightening the entire finder field by establishing the relationship of mutual projection between the exit pupils of the eyepiece lens **88** and the phototaking lens **81** with respect to the observation system and a function of widening the distance measuring field by establishing the relationship of mutual projection between the exit pupils of the aperture **93** and the phototaking lens **81** with respect to the focus detection system. These functions can be achieved by locating the eyepiece lens **88** and the aperture **93** at almost optically equivalent positions.

Upon establishment of these two functions, in the relationship of mutual projection with respect to the focus detection system, the distortion of the detection system adversely affects detection precision. Therefore, it is difficult to limit the curvature of each of the surfaces of the condenser lens **85**. On the other hand, in the relationship of mutual projection with respect to the observation system, the curvature may be limited to some extent if a predetermined power can be obtained, thereby intentionally obtaining an arbitrary value. In order to arrange a compact camera by utilizing this characteristic, the first surface of the condenser lens **85** is constituted by two curvature portions.

FIG. **9** is a plan view showing this state when the condenser lens **85** is observed from the light incident direction. The condenser lens **85** has a spherical surface portion **85*a*** and a flat surface portion **85*b***. The diameter of the spherical surface portion **85*a*** is determined so that the distance measuring beam passes through the range defined by this diameter. The outer flat surface portion is obtained by limiting the surface in view of the observation system. When the flat surface portion is formed in the peripheral portion of the condenser lens **85** as described above, the thickness of the condenser lens can be much smaller than that of a condenser lens having a curvature on the entire light incident surface. In this case, although the boundary between the spherical surface portion **85*a*** and the flat surface portion **85*b*** becomes discontinuous, discontinuity of refracting powers is different depending on areas can be eliminated by properly selecting the shape of the focusing screen **84**. FIG. **10A** is a plan view of the focusing screen **84** when viewed from the light incident direction, and FIG. **10B** is a sectional view thereof. As shown in FIG. **10A**, the focusing screen **84** is also constituted by two areas, i.e., the spherical surface portion **84*a*** and the Fresnel lens portion **84*b***. The boundary between the two areas of the condenser lens **85** overlaps that of the focusing screen **84** when the photographer observes an image in the finder through the eyepiece lens **88** from the reference position on the optical axis.

FIG. **10B** shows the section of the focusing screen **84**, as described above. As can be apparent from two tangents V and W in FIG. **10B**, the Fresnel portion **84*b*** is added to the spherical surface portion **84*a***. For this reason, the refracting power of the Fresnel portion **84*b*** is higher than that of the spherical surface portion **84*a***. As a result, a decrease in refracting power of the flat surface portion **85*b*** of the condenser lens **85** in correspondence with the spherical surface portion **85*a*** can be compensated. That is, in order to satisfy the relationship of mutual projection in the observation system with respect to the eyepiece lens system in the entire field, a total refracting power of the spherical surface portion **84*a*** of the focusing screen **84** and the corresponding spherical surface portion **85*b*** of the condenser lens **85** is set equal to that of the Fresnel portion **84*b*** of the focusing screen **84** and the flat surface portion **85*b*** of the condenser lens **85** with respect to the exit surface of the condenser lens **85**.

The imaging relationship of the focus detection system will be supplementarily described with reference to FIGS. **7** and **8** again. The secondary imaging lens **90** is a kind of double-convex multilens obtained such that two pairs of lens portions are integrally formed to constitute a light incident surface and a light exit surface has a curved surface coaxial with the optical axis of the phototaking lens. FIG. **11** shows the shape of the secondary imaging lens **90** when viewed from the light incident direction. Upper and lower lens portions **90*a*** and **90*b*** are located to sandwich central lens portions **90*c*** and **90*d***. The lens portions **90*a*** and **90*b*** and the lens portions **90*c*** and **90*d*** are paired in the multilens to form two pairs of object images whose relative positions are changed in correspondence with an imaging state of the phototaking lens **81**. These lens portions of the multilens are entirely constituted by spherical surfaces. The center of sphere is set such that beams passing through the centers of gravity of the four openings of the aperture **93** from the optical axis position of the mat surface **84*c*** of the focusing screen **84** are incident almost perpendicularly to the lens portions respectively corresponding to the openings.

A light exit surface **90*e*** of the secondary imaging lens **90** is a spherical surface common to the lens portions **90*a*** to **90*d***. The optical axis of the light exit surface **90*e*** is common to the phototaking lens **81**. The center of sphere of the light exit surface **90*e*** is located at an optically equivalent position close to the mat surface **84*c*** of the focusing screen **84** serving as the object plane with respect to the secondary imaging lens **90**. When the optical path length between the pentagonal prism **86** and the beam splitter **87** is measured in air, the center of the mat surface **84*c*** almost coincides with the center of sphere of the light exit surface **90*e*** of the secondary imaging lens **90**. As described above, the four beams entering from the optical axis position of the mat surface

94c of the focusing screen 84 are vertically incident on the lens portions 90a to 90d even on the incident side in the secondary imaging lens 90, thereby obtaining an optical system wherein the four beams almost vertically emerge from the exit surface 90e as the main characteristic feature of this embodiment.

As described above, the secondary imaging lens 90 is arranged such that rays entering from the center of the focusing screen 84 and passing through the centers of gravity of the openings of the aperture 93, that is, rays passing through the centers of gravity of the beams passing through the lens portions 90a to 90d are guided to the photoelectric conversion element arrays 108. This indicates that the distance between two images constituting a pair can be very small even if the wavelength of light from the object is variously changed. Therefore, detection errors corresponding to the colors of the object, which are caused by influences of the chromatic aberration of the focus detection system can be almost eliminated.

When the optical system having the arrangement according to the present invention is employed, it is preferable to set an imaging magnification of the secondary imaging lens 90 within the range of about −0.2 to −0.5 so as to increase the distance measuring field while the chip area of the photoelectric conversion element arrays 108 is kept small. The arrangement shown in FIGS. 7 and 8 has an imaging magnification of about −0.2. In order to generally arrange this reduction imaging system by one convex lens, it is known that the curvature of the light incident surface is increased and the curvature of the light exit surface is decreased according to the aberration sharing rule, thereby reducing the size of a projected point image with a small aberration. As shown in FIGS. 7 and 8, the light exit surface 90e of the secondary imaging lens 90 is common to the lens portions on the incident side. In addition, since the center of sphere of the light exit surface 90e is optically very close to the mat surface 84c, the light exit surface 90e can have only a small curvature. On the other hand, the curvature of the small-diameter lens portions of the multilens is increased to compensate for a small curvature thereof on the exit side so as to maintain a given imaging magnification. In this sense, the embodiment shown in FIGS. 7 and 8 is based on the aberration sharing rule, thereby realizing a small point image. The small point image in the focus detection optical system indicates that distance measurement of a finer pattern can be performed, thereby contributing to the improvement of the detection performance.

The two pairs of positions of the light amount distributions of the object and the positions of the photoelectric conversion element (pixel element) arrays must be aligned with a precision of several μm or less so as to satisfy the distance measuring precision of the camera. The most important problem in the manufacture of a system using the secondary imaging lens integrally having the two pairs of lens portions and the photoelectric conversion element arrays arranged on a single chip is concentrated on the optical axis alignment within the secondary imaging lens. According to this embodiment, the light exit surface of the secondary imaging surface is constituted by a single spherical surface common to the two pairs of lens portions, thereby solving the above problem.

The plastic secondary imaging lens is manufactured by injection molding or compression molding. In this case, deviations between the light incident surface and the light exit surface of each secondary imaging lens element, and deviations between the secondary imaging lens elements cause a serious problem. In particular, when two pairs of second imaging lens elements are used as in the present invention, and the optical axes of the four secondary imaging lens elements are different on both the incident and exit sides, it is very difficult to achieve given alignment precision between the incident and exit sides. Components of mutual rotation of the portions constituting the light incident and exit surface portions of the molds require strict precision. If errors occur in these components, deformation of images of the secondary imaging lens elements is complicated by the aberration. As a result, point images of the secondary imaging lens elements for forming paired images cannot be similar to each other.

Upon focus detection, the object image from the phototaking lens 81 is formed as pairs of images respectively on the photoelectric conversion element arrays by the system through the secondary imaging lens 90. When the phototaking lens 81 is extended to the left in FIGS. 7 and 8 to set a front-focus state, the pair of object images formed on the light-receiving surfaces of the photoelectric conversion element arrays are deviated to come close to each other. The front-focus state and its amount are detected in accordance with changes in outputs from the photoelectric conversion element arrays in correspondence with the relative deviation between the images. In the rear-focus state, the pair of images are deviated in the direction opposite to that in the front-focus state. The rear-focus state and its amount can be detected in the same manner as in the front-focus state.

As described above, focus state detection is performed in accordance with the distance between the pair of images. This distance between the pair of images is directly represented as a distance measuring error. As in this embodiment, when the light exit surface is a spherical surface common to all the beams, mutual rotation does not adversely affect the precision, thereby facilitating its manufacture.

The beams passing through the secondary imaging lens 90 are incident on the aperture 93 located behind the secondary imaging lens 90. As shown in FIGS. 7 and 8, the aperture 93 is located to be slightly spaced apart from the secondary imaging lens 90 and has two pairs of openings corresponding to the lens portions constituting the secondary imaging lens 90. FIG. 12 is a plan view of the aperture 93, showing the shapes of the openings. Openings 93a and 93b and openings 93c and 93d of the aperture 93 are paired to respectively correspond to the secondary imaging lens portions 90a and 90b and the secondary imaging lens portions 90c and 90d. The distance between the centers of gravity of the openings corresponds to the distance measuring base line length. As is apparent from FIG. 12, the distance measuring base line length determined by the openings 93a and 93b is larger than that determined by the openings 93c and 93d according to the characteristic feature of this embodiment. By utilizing this, the chip area of the photoelectric transducer element arrays can be reduced, and the system can be made compact as a whole.

Each of the four openings 93a to 93d has a shape surrounded by two arcs. The shape of the outer arc is set such that an image thereof projected on the exit pupil of the phototaking lens 81 through the spherical surface portion 84a, the condenser lens 85, and the secondary imaging lens 90 has the shape of an arc having

its center on the optical axis of the phototaking lens **81**. The inner arc is determined by translating the outer arc of one opening of the paired openings toward the other opening of the paired openings, thereby obtaining identical shapes of the paired openings. The shapes of the effective diameters of the paired secondary imaging lens portions coincide with each other on the phototaking lens **81**. Even if the object image is defocused within the range in which the distance measuring beam is not vignetted, the similarity of the light amount distributions is not disturbed.

The shape of the outer arc of the aperture **93** should be noted. Since the secondary imaging lens **90** is a decentered system with respect to the phototaking lens **81**, the center of the outer arc of the aperture **93** is different from the point Q at which the optical axis of the phototaking lens **81** crosses the aperture **93**. Referring to FIG. **12**, the center of the outer arc R of the opening **93***a* is given as P and is deviated from the intersection Q with the optical axis of the phototaking lens **81** by a length S. The outer arc is so decentered that an image thereof projected on the exit pupil of the phototaking lens **81** through the lens portion (spherical portion) **90***a* or the like of the secondary imaging lens **90** has a shape having its center on the optical axis of the phototaking lens **81**, thereby most effectively receiving the beam. FIG. **13** is a view for explaining projected images of the aperture openings. The phototaking lens **81** has an exit pupil **101**, and projected images **102***a* to **102***d* of the aperture openings **93***a* to **93***d* are formed. The distance between the paired aperture openings corresponds to the distance measuring base line length. Since the mat surface **84***c* of the focusing screen **84** is located within the optical path, the images of the openings of the aperture **93** are blurred and spread in accordance with the diffusion characteristics shown in FIG. **2**. The hatched portions in FIG. **13** represent blurring. The aperture **93** is located behind the secondary imaging lens **90** to improve uniformity of the field angle of the point image.

FIG. **14** shows the shape of the light-shielding mask **89** located immediately before the secondary imaging lens **90**. The light-shielding mask **89** has three openings **89***a* to **89***c*, and the remaining portion of the mask **89** serves as a light-shielding portion. The light-shielding effect of the light-shielding mask **89** can prevent production of ghosts caused by the bonding portions of the lens portions **90***a* to **90***d* of the secondary imaging lens **90**.

Since the focus detection optical system described in this embodiment is arranged through the pentagonal prism **86**, the overall length of the focus detection optical system is large, as described above. On the other hand, in order to improve distance measuring precision, the distance between the centers of gravity of the openings **93***a* to **93***d* must be large. As a result, a pair of light amount distributions corresponding to an object are formed to be spaced apart from each other. FIG. **15** shows the relationship between the distance measuring field and the phototaking frame. When distance measuring fields **104***a* to **104***j* are arranged in a crossed shape in a phototaking frame **103** and are simply projected by the secondary imaging lens **90**, secondary object images are formed to be considerably spaced apart from each other, thus requiring a large space for the arrangement of picture elements.

In the embodiment shown in FIGS. **6**, **7**, and **8**, the above problem is taken into consideration to reduce the chip size of the photoelectric conversion element arrays by using the light guide prism **94**. FIGS. **17** and **18** are a partial enlarged view and a perspective view, respectively, of the light guide prism **94**. FIG. **17** shows the section corresponding to that in FIG. **7**. In this section, the light guide prism **94** made of a transparent plastic member has six optical surfaces **94***a* to **94***f*. These six optical surfaces have a function of folding the optical path in the optical axis direction of the phototaking lens **81** and a function of cutting off unnecessary light components.

The beams passing through the openings **93***a* and **93***b* in FIG. **17** are incident on the incident surface **94***a*. The beams are reflected twice by the total reflection surfaces **94***b* and **94***c* and the total reflection surfaces **94***d* and **94***e* and emerge from the light exit surface **94***f* toward a photoelectric conversion element **107**. On the other hand, as can be apparent from FIG. **18**, the beams passing through the aperture openings **93***c* and **93***d* pass through openings **94***g* and **94***h* formed in the light guide prism **94** and reach the photoelectric conversion element **107**. The optical distance between the secondary imaging lens **90** and the photoelectric conversion element **107** has a difference in accordance with whether the beam is reflected by the light guide prism **94**. Since the reflection optical path is present in the plastic component, the optical length is substantially decreased. Therefore, the optical path distance obtained with reflection by the light guide prism **94** is slightly different from that without reflection by the light guide prism **94**. In addition, since the curvature values of the two pairs of lens portions of the multilens as the secondary imaging lens **90** can be independently selected, optimal imaging for the two different optical paths can be realized.

The photoelectric conversion element **107** can be made compact by using the above light guide prism **94**. FIG. **16** shows this state of the photoelectric conversion element **107**. Picture element arrays **108***a***1** to **108***e***2** correspond to the distance measuring fields **104***a* to **104***e*, and picture element arrays **108***f***1** to **108***j***2** correspond to the distance measuring fields **104***f* to **104***j*. The suffixes indicate the correspondence of two images formed through the secondary imaging lens **90** even if the same distance measuring field is used. The picture element arrays **108***f***1** to **108***j***1** and **108***f***2** to **108***j***2**, corresponding to the distance measuring fields **104***f* to **104***j*, are located in the area defined between the picture element arrays **108***a***1** to **108***e***1** and **108***a***2** to **108***e***2** corresponding to the distance measuring fields **104***a* to **104***e*, thereby eliminating wasteful areas. The economical advantage obtained by a decrease in the photoelectric conversion element is apparent, and the camera body itself can be made compact due to the folded optical path with use of the light guide prism **94**.

In particular, since the picture element arrays of the distance measuring fields having the large distance measuring base line length are located inside, and the picture element arrays of the distance measuring fields having the short distance measuring base line length are located outside, compactness of the camera body can be further enhanced. This arrangement is advantageous not only in terms of economy but also in terms of compactness of the camera.

The focus detection apparatus described above is effective for a bright lens having a small f-number (aperture ratio), which requires strict focusing. However, in a system such as a single-lens reflex camera system using interchangeable lenses, a dark lens having a large f-number may be mounted on the camera body. The f-number

may be increased in a zoom lens upon zooming. In this case, the distance measuring beam may be vignetted by the phototaking lens. A focus detection method corresponding to various types of phototaking lenses will be described below.

FIG. **19** is a perspective view for explaining the vignetting state of the distance measuring beam. Only a distance measuring beam to be incident on the distance measuring field **104***j* of all the distance measuring fields shown in FIG. **15** is illustrated. Referring to FIG. **19**, each of the projected images **102***a* and **102***b* shown in FIG. **13** has an outermost shape **150***a*. Relatively dark phototaking lenses have exit windows **151** and **152**.

In general, a decrease in pupil area, which is called "vignetting", occurs at a portion except for the central portion of the phototaking lens. This is caused by the fact that the number of surfaces for determining the width of the beam in an open aperture state is two or more when viewed from a given point on the image plane. These surfaces are called exit windows. For example, these surfaces are the frontmost and rearmost lenses. The two exit windows **151** and **152** exemplify this case. Judging from the degree of vignetting of the distance measuring beam, these exit windows may be represented by an intermediate exit pupil (to be described later).

Assume that a beam reaches the distance measuring field **104***j* through two circles slightly spaced apart from each other in a space in FIG. **19**. In this case, the passing range of the distance measuring beam is fixed even at other distance measuring field positions, and the passing range of the phototaking beam is considered on the image formation plane of the aperture opening of the focus detection optical system. A region in which light actually pass through the above range is limited to the inside of a region **153**. The presence of the aperture opening image outside the region **153** indicates that the distance measuring beam is vignetted. FIG. **19** shows only the distance measuring beam in the distance measuring field **104***j*. When the exit pupil is projected in the same manner as described above, the vignetting degree of light for other distance measuring fields can also be determined. Therefore, the beam tends to be vignetted in the peripheral portion of the phototaking frame **103**, but not to be vignetted in the central portion thereof.

When the defocus amount of an image formed by the phototaking lens and the re-imaging lens is increased, the point image on the photoelectric conversion element has a shape close to that of the aperture. When the distance measuring beam is vignetted in this manner, the degree of blurring of the point image is asymmetrical about the vertical axis. Blurring is reversed in a pair of secondary object images, and symmetry of the two images is disturbed. As described above, the relative distance between the pair of secondary object images is obtained to calculate the defocus amount. The calculation precision of two images which are not similar to each other is low. For this reason, blurred images asymmetrical about the vertical axis are corrected for a dark phototaking lens having a large open f-number, thereby preventing degradation of image deviation calculation precision. This correction means will be described below after a description of vibrations of the light beam.

FIGS. **20**A to **20**C and **21**A to **21**C are views for explaining changes in vignetting of the distance measuring beam, depending on the characteristics of the phototaking lenses. FIGS. **20**A to **20**C are plan views illustrated when the optical path to the distance measuring field **104***j* of the distance measuring fields shown in FIG. **15** is viewed from the top. FIGS. **21**A to **21**C are views showing the range of phototaking beams passing on the aperture image formation surface of the distance measuring optical system.

Referring to FIGS. **20**A to **20**C, an alternate long and short dashed line **169** represents an optical axis of the phototaking lens. A broken line **156** represents a projection plane of the aperture opening image. A broken line **155** represents a distance measuring beam. The optical axis **169**, the projection plane **156**, and the distance measuring beam **155** are common in FIGS. **20**A to **20**C. A phototaking lens is located at positions corresponding to exit pupils **157**, **158**, and **159** in FIGS. **20**A, **20**B, and **20**C. Each exit pupil represents a middle position of the two exit windows shown in FIG. **19**. FIG. **20**A shows a state in which the exit pupil position is relatively close to the phototaking frame, FIG. **20**B shows a state in which the exit pupil coincides with the projection plane **156** of the aperture image, and FIG. **20**C shows a state in which the exit pupil position is relatively away from the phototaking frame. The beams passing through each exit pupil are represented by solid lines **160** to **168**. The innermost beam is obtained in a case for an f-number (aperture ratio) of 5.6, the middle beam is obtained in a case for an f-number of 4, and the outermost beam is obtained in a case for an f-number of 2.8. For illustrative convenience, the size in the vertical direction is increased. When a region common to the distance measuring beam **155** and the beam passing through each exit pupil on the projection plane **156** is measured, the degree of vignetting of the distance measuring beam can be detected.

As described above, since the distance measuring beam passes through the diffusion plate, its intensity distribution on the pupil plane is not uniform. In order to more accurately determine the degree of vignetting including this intensity distribution, the projection plane of the aperture opening image as in FIG. **19** is taken into consideration, and the relationship between the distance measuring beam and the phototaking beam on this plane is shown in FIGS. **21**A to **21**C. FIGS. **21**A to **21**C correspond to FIGS. **20**A to **20**C, respectively. FIG. **21**A shows a state in which the exit pupil position is relatively close to the phototaking frame, FIG. **21**B shows a state in which the exit pupil position coincides with the projection plane **156** of the aperture image, and FIG. **21**C shows a state in which the exit pupil position is relatively away from the phototaking frame.

Referring to FIGS. **21**A to **21**C, a point **180** represents a position corresponding to the optical axis **169** of the phototaking lens. For illustrative convenience, spreading of one distance measuring beam **181** of the pair of distance measuring beams is illustrated. The size of the point indicates the density of the effective beam. Circles **183** to **191** drawn on the distance measuring beam **181** indicate the exit pupils of the phototaking lens. The innermost exit pupil indicates a case for an f-number of 5.6, the middle exit pupil indicates a case for an f-number of 4, and the outermost exit pupil indicates a case for an f-number of 2.8. The actual distance measuring beam is also distributed at a position symmetrical about an axis **182**. Vignetting of the distance measuring beams occurs in a shape symmetrical about the axis **182**.

Referring to FIGS. **20**A to **20**C and **21**A to **21**C, when the brightness of the phototaking beam is increased, and the projection plane **156** of the aperture

opening image is closer to the exit pupil plane, it is understood that vignetting tends not to occur.

FIGS. **22A** to **22C** show states in which the distance measuring field is changed. The beam incident on the distance measuring field **104***i* shown in FIG. **15** will be exemplified.

Referring to FIGS. **22A** to **22C**, an alternate long and short dashed line **169** represents an optical axis of the phototaking lens, and a broken line **156** represents a projection plane of the aperture opening image as in FIGS. **20A** to **20C**. A broken line **200** represents a distance measuring beam in this distance measuring field. Beams passing through exit pupils **157**, **158**, and **159** of the phototaking lens are represented by solid lines **201** to **209**. The innermost beam indicates a case for an f-number of 5.6, the middle beam indicates a case for an f-number of 4, and the outermost beam indicates a case for an f-number of 2.8.

As is apparent from comparison between FIGS. **20A** to **20C** and FIGS. **22A** to **22C**, when the exit pupil diameter is decreased and the exit pupil position is farther away from the aperture image formation plane, the degree of vignetting of the distance measuring beam is increased regardless of the position of the distance measuring field. The degree of vignetting is small when the distance measuring field position is closer to the optical axis **169** of the phototaking lens.

As described above, since vignetting occurs in the distance measuring beam, a pair of images on the photoelectric conversion element have characteristic shapes depending on the imaging state. The shapes are defined as a function of the exit pupil diameter, the exit pupil position, the distance measuring field position, and the aberration of the re-imaging lens. The shape of the blurred image adversely affects the conventional defocus calculation. In order to maintain high detection precision, some correction means is required. Note that the aberration of the phototaking lens is not taken into consideration because the re-imaging lens is generally constituted by a single lens and the aberration of the re-imaging lens is greatly smaller than that of the phototaking lens. For this reason, the aberration of the phototaking lens can be neglected.

The method of correcting a blurred image in this embodiment will be described below. An object image by an optical system is generally given as a convolution integral between the point image determined by the characteristics of the optical system and the brightness distribution of the object. The point image corresponds to an impulse response of the optical system. An adaptive inverse filter is produced on the basis of a transfer function serving as a Fourier transfer of the impulse response and is operated for the point image, thereby restoring the point image into the original point. When the inverse filter acts on a general object image, the brightness distribution of the original object can be obtained. When this principle is applied to the focus detection optical system described herein, the object image formed on the photoelectric conversion element is given by a convolution integral between the point image of the object image and the brightness distribution of the object. In addition, the original object brightness distribution can be restored by an appropriate inverse filter.

In this case, since focus detection is performed by examining the relative distance between images, the photoelectric conversion element is a one-dimensional line sensor. Image data correction performed for the sensor outputs can be correction of a line image obtained by integrating the point image in a direction perpendicular to the picture element array. The correction of the blurred image need not "restore" the line image to a perfect line. If the line images asymmetrical about the vertical axis, which are caused by vignetting of the distance measuring beams, are restored to have at least a symmetrical shape about the vertical axis, the relative distance between the two images can be obtained with high precision.

This operation will be described in more detail with reference to FIGS. **23A** to **23C** and **24A** to **24C**. FIGS. **23A** to **23C** and **24A** to **24C** show blurred images and their correction filters. FIGS. **23A** to **23C** or **24A** to **24C** show a correction filter, image data, and corrected image data, respectively. A pair of secondary object images formed by the focus detection optical system are defined as OA(i) and OB(i), respectively, and corrected image data are represented by A(i) and B(i), respectively. Since the distance measuring beams are incident on the re-imaging optical system through the diffusion plate, vignetting occurs depending on the open f-number (aperture ratio) of the phototaking lens. As a result, line images asymmetrical about the vertical axis are formed, as shown in FIGS. **23B** and **24B**. Since the two distance measuring beams are vignetted symmetrically about the optical axis of the phototaking lens, the resultant line images are reversed to each other. The line images spread to some extent because the phototaking lens is set in a defocus state. The distance between the two images is different from that in the in-focus state. The image OA(i) in FIG. **23B** is deviated to the left and the image OB(i) in FIG. **24B** is deviated to the right due to this reason. The distance between the two images is smaller than that in a case wherein the distance measuring beams are not vignetted. This must be taken into consideration in the calculation of the sensitivity of image deviation (to be described later).

The filters for correcting these line images are shown in FIGS. **23A** and **24A**. Each correction filter has an origin FOF in the abscissa. The origin FOF is also used for inverting the correction filter (to be described later).

The algorithm performed in the calculating means has a "**C1**" processing step for performing filter processing of the first signal and a "**C2**" processing step for performing filter processing of the second signal. The filter used in the "**C2**" processing step is obtained by inverting the filter used in the "**C1**" processing step.

The filter component values are plotted with reference to an origin AXX. Since the two line images are reversed to each other, as described above, the characteristics of the filter in FIG. **23A** are reversed from the characteristics of the filter in FIG. **24A**. For this reason, one of the shapes of the filter can be stored in the camera, and original filter information (to be described later) can be efficiently utilized. The shape of the correction filter is determined to eliminate asymmetry of the line images and not to excessively restore the corrected images to the original line due to the following reason. A correction filter for faithfully restoring an image to the original line must have characteristics for greatly amplifying a high frequency. This correction filter is easily affected by random noise (particularly, a high-frequency component) caused by thermal noise of the photoelectric conversion element. When high-frequency noise superposed on the original image data is excessively amplified, the correlation between the two images is degraded to impair distance measuring preci-

sion. The shape of this filter will be described with reference to FIG. 23A. The right portion of the filter acts to shorten the bottom of the image OA(i) extending to the right, whereas the left portion of the filter acts to extend the left short bottom. In order to facilitate a subsequent description, a restoration portion is referred to as a ZR portion (e.g., the right portion in FIG. 23A with respect to the origin FOF) and the diffusion portion is referred to as a ZS portion (e.g., the left portion in FIG. 23A with respect to the origin FOF). When the ZS portion is constituted by only the positive component, and the ZR portion is constituted by positive and negative components, the image is not faithfully restored to the original line and the lengths of the right and left bottoms can be uniformed.

That is, the filter has only the positive component in one direction and both the positive and negative components in the other direction with respect to the origin.

In order to correct the images, the lines shown in FIGS. 23B and 24B are subjected to the convolution integral using the correction filters in FIGS. 23A and 24A. The results are the corrected image data in FIGS. 23C and 24C. As shown in FIGS. 23C and 24C, the corrected image data represent images symmetrical about the vertical axis. Therefore, the relative distance between the images represented in FIGS. 23C and 24C can be calculated with high precision.

The line image correction has been described above. Correction of a general object image as a result of convolution integral between line images and the object brightness distributions will be described below, as shown in FIGS. 25A and 25B. The black edge of a monochrome pattern is selected as an object and is located at the center of the distance measuring field. FIG. 25A is a view showing overlapping image data of a pair of secondary images, and FIG. 25B shows corrected image data. The image data represented by the solid line is overlapping data of the point image of FIG. 23B, and the image data represented by the broken line is overlapping data of the point image of FIG. 24B. Since the shapes of the point images are different from each other, the shapes of the two images are different from each other.

The result obtained by causing the correction filters to act on these image data is shown in FIG. 25B. The correction filter shown in FIG. 23A is used for the image data represented by the solid line, while the correction filter shown in FIG. 24A is used for the image data represented by the broken line. The corrected images have the same shape, and the distance between the images can be calculated.

When the phototaking lens has a small defocus amount, image data shown in FIGS. 26A and 26B are obtained. Since the point images have a small size, the resultant images are sharp. In addition, the relative distance between the two images is different from that in FIGS. 25A and 25B. In this case, since the size of the blurred image on the primary imaging plane of the phototaking lens changes almost in proportion to the defocus amount, the magnification of the horizontal axis or abscissa is changed in accordance with the defocus amount to perform correction in the same manner as in FIGS. 25A and 25B. More specifically, the filters shown in FIGS. 23A and 24A are used such that they are compressed in the horizontal axis direction, the corrected images shown in FIG. 26B are obtained. This will be repeatedly described in a flow chart (to be described later). Prior to this description, the control system of the camera will be described below.

FIG. 27 is a block diagram of the camera focus detection apparatus suitably embodying the present invention.

Referring to FIG. 27, a central processing circuit PRS is a one-chip microcomputer including a CPU, a RAM, a ROM, an ADC (A/D converter), and I/O ports. Software and parameters for controlling a series of camera operations including AF control are stored in the ROM. The central processing circuit PRS constitutes part of an arithmetic operating means.

The central processing circuit PRS is connected to a data bus DBUS. A shutter control circuit SHT receives data supplied through the data bus DBUS during reception of a control signal CSH from the central processing circuit PRS and controls to cause the front and rear curtains of a shutter (not shown) to run on the basis of the input data. An aperture control circuit APR receives data through the data bus DBUS during reception of a control signal CAPR and controls an aperture control mechanism (not shown) on the basis of the input data. A switch group SWS includes a release switch, a continuous photographic mode switch, various information setting switches, and a switch for selecting whether focus detection is performed in consideration of only the central portion of the frame or both the central and peripheral portions of the frame. A lens communication circuit LCOM receives data through the data bus DBUS during reception of a control signal CLCOM and performs serial communication with a lens control signal circuit LNSU on the basis of the input data. In synchronism with a clock signal LCK, the lens communication circuit LCOM supplies lens drive data DCL to a lens control circuit LNSU, and at the same time serially receives lens information DLC.

A signal BSY is used to inform the camera side that a focus adjusting lens (not shown) is being moved. During generation of this signal, the serial communication is prohibited. A photometry circuit SPC sends a photometry output SSPC to the central processing circuit PRS upon reception of a control signal CSPC from the control circuit. The photometry output SSPC is A/D-converted in an ADC in the central processing circuit PRS and is used as data for controlling the shutter control circuit SHT and the aperture control circuit APR.

A projection circuit **220** projects an auxiliary focus detection beam to drive an LED and cause the LED to emit light in accordance with a control circuit ACT and a clock signal LCK.

A distance measuring light-receiving circuit SNS has pairs of line sensors **108***a***1** and **108***a***2**, . . . **108***j***1** and **108***j***2**. The distance measuring light-receiving circuit SNS is arranged to cause the pairs of line sensors **108***a***1** and **108***a***2**, . . . , **108***j***1** and **108***j***2** to receive images at positions corresponding to the distance measuring fields **104***a* to **104***j* of the frame. A sensor driving circuit SDR controls light-receiving circuits **1** to **10** (i.e., the pairs of **108***a***1** and **108***a***2** to **108***j***1** and **108***j***2**) in accordance with a signal STR and the clock signal LCK supplied from the central processing circuit PRS. The light-receiving circuits **1** to **10** are controlled in accordance with control signals ϕ**1** and ϕ**2** and the control signals CL and SH, and one of the light-receiving circuits **1** to **10** is selected in accordance with selection signals SEL1 to SEL**10**. An image signal SSNS from the selected light-receiving circuit is transmitted from the sensor driving circuit SDR to the central processing circuit PRS.

FIG. **28** shows the operation of the lens control circuit LNSU to obtain lens focal length information and distance ring information. The distance ring position, the zoom ring position, the defocus amount vs. focus adjusting lens extension coefficients are converted into 5-bit signals by a brush. The 5-bit signals are calculated in the CPU in the lens control circuit LNSU as the lens information DLC. The lens information DLC is input to the central processing circuit PRS through the lens communication circuit LCOM. In this case, since the distance ring position information is not directly used in an in-focus operation, high precision is not required.

The operations of the camera having the above arrangement will be described with reference to a flow chart in FIG. **29**.

When a power switch (not shown) is turned on, the central processing circuit PRS is powered on to start executing a sequence program stored in the ROM.

FIG. **29** is the flow chart showing the overall flow of the program. When execution of the program is started by the above operation, the flow advances to step **002** through step **001**. In step **002**, the ON/OFF state of a switch SW1 turned on upon depression of the release button up to the first stroke is detected. If the switch SW1 is set in an OFF state, the flow advances to step **003** to clear all the control flags and variables set in the RAM in the central processing circuit PRS, thereby initializing the RAM. Steps **002** and **003** are repeated until the switch SW1 is turned on or the power switch is turned off. When the switch SW1 is turned on, the flow advances from step **002** to step **011**. In step **011**, a timer interruption operation is allowed. In this case, the timer interruption operation is periodically performed in steps from step **012** to detect various states. In step **012**, the "photometry" subroutine for exposure control is executed. The analog input terminal of the central processing circuit PRS receives the photometry output SSPC from the photometry circuit or sensor SPC. The photometry output SSPC is converted into a digital signal to calculate an optimal shutter control value and an optimal aperture control value from the digital photometry value. The calculated values are stored at predetermined addresses of the RAM. The shutter and the aperture are controlled on the basis of the stored values during a release operation.

Step **014** is a subroutine for receiving an image signal and calculating a defocus amount. After the central processing circuit PRS receives the image signal from the distance measuring light-receiving circuit SNS, the central processing circuit PRS filters this image signal and performs a predetermined calculation on the basis of the image deviation scheme, thereby calculating a defocus amount of the phototaking lens. The detailed contents of this step will be described later.

Step **015** is a subroutine for driving the lens on the basis of the detected defocus amount DEF. This subroutine will also be described in detail later.

In step **016**, the timer interruption allowed in step **011** is prohibited, and the timer interruption is kept prohibited in steps **017** to **019**. In step **017**, the ON/OFF state of a switch SW2 turned on upon depression of the release button up to the second stroke is detected. If the switch SW2 is set in an OFF state, the flow advances to step **018**. Otherwise, the flow advances to step **019**. A flag AFFLG in steps **018** and **019** defines whether AF control in steps **012** to **015** is completed in the ON state of only the switch SW1 or in the ON state of the switch SW2. The AF control is completed when the switch SW2 is OFF, i.e., only the switch SW1 is ON, the flag AFFLG is set at logic "0". If the AF control is completed when the switch SW2 is ON, the flag AFFLG is set at logic "1". In this case, since the switch SW2 is kept off, the flag AFFLG is set at logic "0".

A timer interruption operation in steps **012** to **015** executed if AF control is performed in steps **011** to **018** when only the switch SW1 is ON will be described below.

The timer interruption in step **021** has an interruption function of periodically monitoring the state of the switch SW2, the charge/feed state, and the AF history to detect whether a release operation is started. The interruption is performed every, e.g., 5 msec during execution of steps **012** to **015**.

The respective steps will be described below.

The flow advances to step **022** through step **021** to determine the state of the switch SW2. If the switch SW2 is determined to be OFF, the interruption is ended in step **023** and the flow returns to the main routine. That is, even if an interruption is performed every 5 msec during AF repetition while only the switch SW1 is kept on, the subroutine immediately returns to the main routine because the switch SW2 is kept off.

If the switch SW2 is ON in step **022**, the flow advances to step **024** to determine whether a switch SWCH is ON/OFF. If the switch SWCH is OFF, since the charge/feed operation upon completion of the release operation is still continued, the next release operation cannot be performed. Therefore, the flow returns to the main routine in step **023** to continue the AF operation. At the same time, the charge operation is also continued.

If the switch SWCH is determined to be ON in step **024**, since the charge/feed operation is completed, a charge/feed stop signal is output in step **025** to stop a motor MTR1, and the flow returns to step **026**.

In step **026**, the logic state of the flag AFFLG is determined. If AFFLG=1 in step **026**, it is determined that the AF operation is completed once upon the ON operation of the switch SW2. The flow advances to step **027** to perform a release operation. If AFFLG≠1, i.e., if the flag AFFLG is set at "0", since the AF operation is completed only one upon the ON operation of the switch SW2, the flow returns to the main routine in step **023**, and the release operation is not performed.

The flag AFFLG is set to "0" in step **028** to start the charge/feed operation in step **029** (this operation is performed by one revolution of the motor MTR1). The flow returns to step **002** while the start of the charge/-feed operation is being performed. The next focus detection operation is started from step **011**.

The flow chart of the "AF" subroutine is shown in FIG. **30**.

It is determined in step **402** whether an entire field detection mode for performing focus adjustment in accordance with distance measuring information of the entire distance measuring field or a specific field detection mode for performing focus adjustment in only a distance measuring field at the central portion of the frame is set. If the entire field detection mode is set, the flow advances to step **403**. However, if the specific field detection mode is set, the flow advances to step **405**. Note that the mode can be set by a photographer using the switch group SWS shown in FIG. **27**.

In step **403**, a flag SPF is reset. In step **404**, the entire distance measuring field is set as a detection distance measuring field. In step **405**, the flag SPF is set at "1".

In step **406**, the distance measuring fields **104***c* and **104***h* shown in FIG. **15** are set as detection distance measuring fields.

In step **407** as the step next to step **404** or **406**, the distance measuring light-receiving circuit (line sensors) SNS is driven through the sensor driving circuit SDR in FIG. **27**. Analog output signals of the detection distance measuring field are converted into digital signals, and the digital signals are stored at predetermined addresses in the RAM.

In step **408**, defocus detection is performed on the basis of the image signals stored in the RAM in the previous step. This subroutine will be described in detail later.

It is determined in step **409** whether defocus detection can be performed in the entire distance measuring field. If YES in step **409**, the flow advances to step **410** to perform focus detection incomplete processing such as a search operation and a detection incomplete display. If any one of the measuring fields can be detected, the flow advances to step **412**.

In step **412**, the state of the flag SPF set in step **403** or **405** is checked. If the logic state of the flag SPF is zero, the flow advances to step **413**. If NO in step **412**, the flow advances to step **415**.

In step **413**, the nearest point among the detectable measuring fields is selected. In step **414**, the defocus amount of the nearest point is stored in DEF. In step **415**, an average defocus of the detectable measuring fields is calculated. In step **416**, the average defocus is stored in the DEF. The subroutine returns to the main routine in step **418**.

The "focus detection" subroutine is shown in FIG. **31**.

In the defocus detection subroutine, it is determined in step **502** whether the calculation of the entire detection distance measuring field is completed. If YES in step **502**, the flow advances to step **503**, and this subroutine returns to the main routine. However, if any distance measuring field whose defocus calculation is not completed is present, the flow advances to step **504**.

In step **504**, a new measuring field for the subject of calculation is set. In step **505**, the defocus amount of the distance measuring field for the subject of calculation set in step **504** is calculated. The flow then returns to step **502**. The calculation of defocus will be described in detail later.

FIG. **32** shows a flow chart of a "lens driving" subroutine.

When this subroutine is executed, the central processing circuit PRS communicates with the lens in step **202** in FIG. **32** to receive data "S" and "PTH". The "S" is a "coefficient of the defocus amount vs. focus adjusting lens extension amount" inherent to the phototaking lens. For example, when the phototaking lens is an entire extension type single lens, since the phototaking lens as a whole is a focus adjusting lens, condition "S=1" is established. When the phototaking lens is a zoom lens, the value of "S" is changed at each zoom position. The "PTH" is a focus adjusting lens extension amount per pulse from an encoder ENCF interlocked with movement of a focus adjusting lens LNS in the optical axis direction.

A value (i.e., a lens driving amount FP) of the focus adjusting lens extension amount as an output pulse count of the encoder ENCF in accordance with the defocus amount DEF to be focus-adjusted, and the coefficient S and the amount PTH can be given as follows.

$$FP=DEF\times S/PTH$$

The operation in step **203** is a direct calculation of the above equation.

In step **204**, the amount FP obtained in step **203** is sent to a lens FLNS to command driving of the focus adjusting lens (the entire phototaking lens when the lens is the entire extension type single lens).

In step **205**, the central processing circuit PRS communicates with the lens FLNS to determine whether driving of the lens by the lens driving amount FP commanded in step **204** is completed. If YES in step **205**, the flow advances to step **206**, and the "lens driving" subroutine returns to the main routine.

FIG. **33** shows a flow chart of a "release" subroutine.

In step **302**, the quick return mirror of the camera is pivoted upward. This is performed by controlling a mirror driving motor (not shown) through the motor control circuit shown in FIG. **27**.

In step **303**, the aperture control value already stored in the "photometry" subroutine in step **012** is sent to the lens FLNS to cause the lens FLNS to perform aperture control.

It is determined in step **304** whether the mirror up operation and the aperture control in steps **302** and **303** are completed. Whether or not the mirror up operation is completed can be confirmed by a detection switch (not shown) attached to the mirror. Whether or not the aperture control is completed is confirmed in accordance with whether or not the lens FLNS is driven to the predetermined aperture value.

When either the mirror up operation or the aperture control is not completed, the central processing circuit PRS waits in step **304** and continues state detection. When both the mirror up operation and the aperture control are completed, the flow advances to step **305**. At this time, preparation for exposure is completed.

In step **305**, shutter control is performed using the shutter control value already stored in the "photometry" subroutine in step **012**, thereby exposing the film.

When the shutter control is completed, a command for obtaining an open aperture state is supplied to the lens FLNS in step **306**. A mirror down operation is performed in step **307**. The mirror down operation is performed by controlling a mirror driving motor (not shown) as in the mirror up operation.

In step **308**, the central processing circuit PRS waits for the completion of the mirror down operation and the open aperture control as in step **304**. When both the mirror down operation and the open aperture control are completed, the flow advances to step **309**, and the subroutine returns to the main routine.

The above flow will be summarized with reference to FIG. **29**.

When only the switch SW1 is ON, steps **002**, **011** to **017**, and **018** are repeated. During execution in steps **012** to **015**, an interruption from step **021** is executed every 5 msec. The switch SW2 is determined to be turned off in step **022**, and the interruption returns to the main routine.

When the switch SW2 is turned on during the above cycle, the ON operation of the switch SW2 is determined by the first timer interruption upon the ON operation of the switch SW2 in step **022**, and the flow advances to step **024**. This flow is based on an assumption

that the release operation will be performed for the first time. For this reason, the charge/feed operation has been completed. The ON state of the switch SWCH is determined in step **024**, and the flow advances to step **025**. However, execution of step **025** is meaningless, so that the flow advances to step **026**. When the flow advances to step **026** for the first time, the flag AFFLG is set at "0", and the flow returns to step **023**. When the AF operation and the timer interruption are alternately performed, and the AF operation is completed, the flow advances from step **017** to step **019**. The flag AFFLG is set at "1", and the flow returns to step **002**. In the first timer interruption upon advance from step **011** to step **012**, the flow reaches steps **022** to **026**. In step **026**, the flag AFFLG=1 is determined, and the flow is allowed to advance to step **027** to perform the release operation.

Upon completion of the release operation, the flag AFFLG is reset to "0". While the charge/feed operation is started in step **026**, the flow returns to step **023**. The flow advances from step **011** to step **012** to start the next AF operation.

In the timer interruption during the initial period of the ON state of the switch SW2, since the switch SWCH is kept off, and the flag AFFLG is set at "0", the AF operation is repeated. When the switch SWCH is turned on first, the charge/feed operation is stopped. The central processing circuit PRS waits for the flag AFFLG=1, i.e., completion of one AF cycle. When the flag AFFLG is set at "1", the release operation is performed.

On the other hand, when the flag AFFLG is set at "1" first, the AF operation is repeated, and the central processing circuit PRS waits for the ON operation of the switch SWCH. When the switch SWCH is turned on, a film feed motor (not shown) is stopped, and the release operation is started.

FIGS. **34** and **35** are flow charts of a "defocus calculation" subroutine. Correlation operations used in this subroutine and then the processing steps will be described in detail below.

Signal processing methods for detecting image deviation amounts from image signals output from arrays each consisting of a pair of sensor elements are disclosed in Japanese Laid-Open Patent Application Nos. 58-142306, 59-107313, and 60-101513. More specifically, assume that the number of picture elements constituting the sensor array is defined as N, and that image signals from the ith (i=0, . . . , N-1) sensor array are defined as A(i) and B(i), the following equation is calculated for $k_1 \leqq k \leqq k_2$:

$$\begin{aligned} X(k) &= \sum_{i=1}^{M-1} \max\{A(i),B(i+|k|+1\} - \\ &\quad \sum_{i=0}^{M-1} \max\{A(i+1),B(i+|k|)\}\ (k<0) \\ &= \sum_{i=0}^{M-1} \max\{A(i+k),B(i+1)\} - \\ &\quad \sum_{i=0}^{M-1} \max\{A(i+k+1),B(i)\}\ (k \geqq 0) \\ &= X_1(k) - X_2(k) \end{aligned} \tag{1}$$

or

$$\begin{aligned} X(k) &= \sum_{i=1}^{M-1} \min\{A(i),B(i+|k|+1\} - \\ &\quad \sum_{i=0}^{M-1} \min\{A(i+1),B(i+|k|)\}\ (k<0) \end{aligned} \tag{2}$$

-continued

$$\begin{aligned} &= \sum_{i=0}^{M-1} \min\{A(i+k),B(i+1)\} - \\ &\quad \sum_{i=0}^{M-1} \min\{A(i+k+1),B(i)\}\ (k \geqq 0) \\ &= X_1(k) - X_2(k) \end{aligned}$$

where M is the number of calculation picture elements represented by M=N−|k|−1, k is called the relative displacement amount, so that k_1 and k_2 are often defined as −N/2 and N/2, max{a,b} is an operator for extracting a larger one of a and b, and min{a,b} is an operator for extracting a smaller one of a and b. Terms $X_1(k)$, $X_2(k)$, $Y_1(k)$, and $Y_2(k)$ in equations (1) and (2) can be defined as broad correlation amounts. When equations (1) and (2) are examined in detail, $X_1(k)$ and $Y_1(k)$ represent correlation amounts by a (k−1) displacement, and $X_2(k)$ and $Y_2(k)$ represent correlation amounts by a (k+1) displacement. Therefore, an evaluation amount X(k) as a difference between the amounts $X_1(k)$ and $X_2(k)$ represents an amount of change in correlation amount of each of the image signals A(i) and B(i) by a relative displacement amount k.

As can be apparent from the above definitions, the correlation amounts $X_1(k)$ and $X_2(k)$ become minimum when the correlation between the two images is maximum. The amount of change X(k) as the correlation amount is "0" when the correlation between the two images is maximum, and has a negative slope. However, since X(k) is discrete data, actually, the peak of the correlation amount is assumed to be present in an interval [kp·kp+1] under the following conditions:

$$X(kp) \geqq 0,\ X(kp+1)<0 \tag{3}$$

and X(kp)−X(kp+1) is maximum.

For this reason, the following interpolation is performed to detect the image deviation amount PR in units of sub-picture elements:

$$PR = kp + \frac{X(kp)}{X(kp) - X(kp+1)} \tag{4}$$

On the other hand, the correlation amounts $Y_1(k)$ and $Y_2(k)$ are maximum when the correlation between the two images is maximum according to the above definitions. The amount of change Y(k) as the correlation amount is "0" when the correlation between the two images is maximum, and has a positive slope. The peak of the correlation amount is assumed to be present in an interval [kp·kp+1] under the following conditions:

$$Y(kp) \leqq 0,\ Y(kp+1)>0 \tag{6}$$

and Y(kp)−Y(kp+1) is maximum.

For this reason, the following interpolation is performed to detect the image deviation amount PR in units of sub-picture elements:

$$PR = kp + \left| \frac{Y(kp)}{Y(kp) - Y(kp+1)} \right| \tag{7}$$

The image deviation amount can be detected regardless of whether the focus evaluation amount X(k) or Y(k) is used. As can be apparent from U.S. Pat. No. 4,618,236, the focus evaluation amount X(k) is used for |X(kp)−X(kp+1)| > |Y(kp+1)−Y(kp)|, and the

focus evaluation amount Y(k) is used for $|X(kp)-X(kp+1)| > |Y(kp+1)-Y(kp)|$ to obtain the image deviation amount PR with a higher S/N ratio.

Referring back to the flow chart in FIGS. **34** and **35**, step **100** represents an "**A1**" processing step in this embodiment. In steps **100** to **105**, the focus evaluation amount X(k) is obtained when the relative displacement amount k is changed within the range of "−20 to 20". The range of the relative displacement amount k is defined to be −20 to 20 because the number of picture elements of the sensor array is assumed to be "40". The range of processing target picture elements may be set variable in accordance with the focal length of the phototaking lens.

In step **150**, image correction is performed to eliminate the influence of vignetting of the distance measuring beam. The "image correction" subroutine will be described in detail later. The image-corrected data can restore the similarity of the pair of images, and the precision of the correlation calculation is improved.

In step **101**, the calculation picture element count M is calculated by $M=39-|k|$. The calculation picture element count M is set variable in accordance with the relative displacement amount k. The count M is decreased as the absolute value of the relative displacement amount k is increased. This is because when the relative displacement amount k is increased, the outputs from the corresponding sensors are omitted from the end. The sign (positive or negative) of the relative displacement amount k is checked in step **102**. A start picture element position PA or PB for starting the calculation of the A or B image in accordance with the sign is calculated in step **103** or **104**. The focus evaluation amount X(k) is calculated in step **105**.

Processing in steps **100** to **105** will be described with reference to FIGS. **36**A to **36**D. FIG. **36**A represents the two image signals A(i) and B(i). FIG. **36**B represents a corresponding relationship of sensor arrays at k=−20. At this time, when $M=39-|20|=19$, PA is "0" and PB="20".

Since the relative displacement amount k is a negative value, the B image is relatively displaced to the left by k picture elements (−20 picture elements). The value calculated by the relationship obtained by displacing the B image by one picture element to the left from the above corresponding relationship is the first term of the equation for obtaining X(−20). The value calculated by the relationship obtained by displacing the A image by one picture element to the left from the above corresponding relationship is the first term.

Since the A and B images are displaced every picture element to the left in the first and second terms, the calculation picture element count M is not defined as $M=40-|k|$ but as $M=39-|k|$. FIG. **36**C shows a corresponding relationship at k=0. FIG. **36**D shows a corresponding relationship of the correlation calculation at k=20 and represents the A image displaced by 20 picture elements to the left, unlike the case in FIG. **36**B.

FIG. **37** is a graph obtained by plotting the focus evaluation values X(k) as described above.

Referring back to the flows in FIGS. **34** and **35**, the peak value kp of the image deviation amount between two images, the A and B images in units of picture elements is detected. In steps **120** to **146**, the image deviation amount PR in units of sub-picture elements is obtained. In steps **120** to **135**, the two focus evaluation amounts X(k) and Y(k) are calculated again in steps **120** to **135** on the basis of the peak value kp obtained in step **110**.

The above re-calculation is performed due to the following two reasons. According to one reason, in the step of calculating the peak value kp, the calculation picture element count M is set variable in accordance with the relative displacement amount k. When the focus evaluation amount X(k) calculated within the variable calculation range is interpolated to obtain the image deviation amount PR in units of sub-picture elements, an error caused by the non-coincidence of the calculation picture element count M may be included. The other reason lies in that a combination of X(k) and Y(k) is better than only the focus evaluation amount X(k) to obtain the image deviation amount PR so as to obtain a higher S/N ratio depending on the signal patterns of the object, as described in U.S. Pat. No. 4,618,236. Judging from the above, the focus evaluation amounts X(k) and Y(k) are simultaneously obtained on the basis of the peak value kp in steps **120** to **135** while the calculation picture element count M is kept constant (step **120**).

The image deviation calculation using the constant calculation picture element count M is called a re-correlation calculation.

As will be described in an "image correction" subroutine in detail, the image correction filters used in step **150** are determined as a function of the relative displacement amount k. However, since the re-correlation calculation aims at obtaining the image deviation amount in units of sub-picture elements, the image correction filter must be set more strictly. For this purpose, processing in steps **151** to **153** is performed to obtain the relative displacement amount k for producing the image correction filters at a resolution of less than the units of picture elements.

In step **151**, kz, z_1, and z_2 are set from the value kp obtained in the above step. In steps **152** and **153**, $ZD=|z_1-z_2|$ and $PR'=kz+|z_1/ZD|$ are calculated. Note that this indicates that the "**A2**" processing step is performed using the fixed filter regardless of the relative displacement amount.

In step **120**, $M=38-|kp|$ is calculated to obtain the value of the calculation picture element count M. In steps **130** to **135**, the focus evaluation amounts X(k) and Y(k) are obtained at three points, i.e., k=kp−1, kp, and kp+1 using the kp as the center in the same manner as described above. In the calculation of the calculation picture element count M, the absolute value of each of the three points k=kp−1, kp, kp+1 is fixed to the calculation picture element count M at the maximum relative displacement amount.

Step **130** corresponds to the "**A2**" processing step.

In step **154**, each image correction filter is produced using the value PR', and the corresponding image is corrected with high precision. In step **130**, the operation in step **154** is repeated three times. In this case, the image correction using the same correction filter is performed three times.

In this embodiment, the calculating means has the "**A1**" processing step performed using the filter determined in accordance with the relative displacement amount and the "**A2**" processing step performed next to the "**A1**" processing step, using the fixed filter regardless of the relative displacement amount. The filter in the "**A2**" processing step is determined on the basis of the image deviation amount obtained in the "**A1**" processing step.

The image deviation amounts kpx and kpy based on the focus evaluation amounts in units of picture elements are detected from the focus evaluation amounts X(k) and Y(k) (steps **140** and **141**). At this time, XD (XD=(X(kpx)−X(kpx+1)) and YD (YD=Y(kpx+1-)−Y(kpx)) roughly representing the contrast evaluation amounts of the focus evaluation amounts X(k) and Y(k) are also calculated due to the following reason. If a non-in-focus amount is large, the contrast evaluation amounts XD and YD obtained in consideration of the image information at the end portions are checked to obtain information as if the image signals at the end portions are checked every relative displacement. When the contrast evaluation amounts XD and YD are larger, the S/N ratio is higher. When the two contrast evaluation amounts XD and YD are compared and XD≧YD is satisfied in step **142**, the focus evaluation amount X(k) is employed (step **143**). However, if XD<YD is satisfied, the focus evaluation amount Y(k) is employed (step **144**). In steps **145** and **146**, an interpolation calculation is performed by PR=kz+|z_1/ZD| using the employed ZD(z_1-z_2) and kz, thereby obtaining the image deviation amount PR in units of sub-picture elements. This process is shown in FIG. **38**. In this case, since condition XD<YD is established, the focus evaluation amount Y(k) is employed. kz=kpy, z_1=(kP), and z_2=Y(kp+1) are used in the calculation of the image deviation amount PR in units of sub-picture elements. In step **130**, since filter processing using a predetermined correction filter is performed, the meanings of the focus evaluation amounts at kpx and kp(x+1) are identical.

When the image deviation amount in units of sub-picture elements is obtained, the defocus amount is calculated on the basis of this image deviation amount. An "image deviation sensitivity calculation" subroutine for obtaining a defocus amount conversion coefficient α from the required image deviation amount is executed in step **155**.

In step **156**, by using the defocus conversion coefficient α, the image deviation amount PR, and a constant G determined by the re-imaging optical system, the following calculations are performed to determine the DEF value as the output of this subroutine:

$$DEF = \begin{cases} \alpha \times PR/(1 - \alpha \times PR/G) & (PR \geqq 0) \\ \alpha \times PR/(1 + \alpha \times PR/G) & (PR < 0) \end{cases}$$

The subroutine returns to the main routine in step **157**.

The "image correction" subroutine will be described below. As described above, an image on the photoelectric conversion element is defined as an optical convolution integral between an object and a point image. That is, the optical impulse response is a point image, the input is the brightness distribution of the object, and the output is an image. On the other hand, when any digital filter is determined and is subjected to the convolution integral with the image signal, the shape of the blurred image can be changed by software. This digital filter is determined in accordance with the condition of the optical system, and the total result of the two convolution integral cycles is set equivalent to one transfer function symmetrical about the vertical axis. Even if line image data represents an image asymmetrical about the vertical axis due to vignetting of the distance measuring beams, the image data can be restored to represent an object shape upon filter processing.

In particular, the similarity of the image is important in the defocus calculation. A digital filter to be selected need not be an inverse filter for restoring the asymmetrical line image caused by the optical system, but can be a filter for restoring a symmetrical image with respect to the vertical axis, as previously described.

FIG. **39** shows the "image correction" subroutine. The blurred image is corrected such that a correction filter is produced in accordance with the state of the phototaking lens, the convolution integral between the image data and the correction filter is performed to correct the image, the corrected image data is filtered through a high-pass filter, and finally normalization is performed. The shape of the blurred image correction filter described with reference to FIG. **39** is changed in accordance with the state of the distance measuring optical system, the type of phototaking lens, its distance ring position, and the zoom position. For this reason, it is difficult to store all the data in the ROM. Only original data of the filter is stored in the ROM and is processed in accordance with the above conditions.

In step **601**, information such as an open f-number, the exit pupil position, and the like of the phototaking lens is fetched.

In step **603**, a "correction filter magnification" subroutine for determining parameters for producing the image correction filter is executed. The information fetched in the previous step is used in this subroutine.

In step **604**, an "execution filter production" subroutine for producing a correction filter actually used in image correction is executed in accordance with the parameters. Steps **603** and **604** will be described later.

In step **605**, in order to minimize the error caused particularly in peripheral image correction, both the peripheral image data are elongated in opposite sides to produce a hypothetical image signal. FIG. **40** is a view for explaining production of the hypothetical image signal. Signals having the same level as that of the peripheral value are added to both the sides of the actual central image signal.

As will be described later, this processing is required to perform image correction as the convolution integral with the image correction filter. That is, since a signal of a given picture element is corrected upon reception of an influence of a noncorrected signal located at a location remote by the image correction filter, the end portions of the actual image signal are not strictly corrected. If only a perfectly corrected image is used in focus detection, a considerably large number of image correction picture elements must be added in as the peripheral picture elements of the picture element used in the defocus calculation. However, when the defocus amount of the phototaking lens is considerably large, i.e., when the defocus amount is 5 mm or more, strict image correction precision need not be required. For this reason, the correction processing operation of the entire image signal can be performed. In order to minimize the image correction error, the peripheral image data are elongated, as illustrated in FIG. **40**.

On the other hand, when the defocus amount is less than several millimeters, the image signal must be strictly corrected. The number of picture elements used in the defocus calculation is set to be smaller than 5 picture elements at each peripheral portion of the actual image signal. The length of a correction filter suitable for a given defocus amount is smaller as the defocus

amount is decreased. By this characteristic, correction picture elements corresponding to the given defocus amount are arranged to cause a filter corresponding to a small defocus amount to operate without any error.

In this embodiment, the photoelectric conversion element has picture elements used for the filter processing, which elements are located outside the picture elements whose outputs are used to calculate the evaluation amounts.

Note that image data A(i) and B(i) represent data falling within the defocus calculation range, unless otherwise specified.

In step **606**, the image correction filter obtained in step **604** and the hypothetical image signal obtained in step **605** are subjected to the convolution integral. By this processing, the image signal is restored to have a shape as if the distance measuring beam is not vignetted, thereby restoring the similarity between the two images. The "convolution integral" subroutine will be described in detail later.

In step **607**, high-pass filter processing for eliminating a low-frequency component contained in the image signal is performed. When a strong beam spot is incident on the phototaking lens, a low-frequency ghost component may be contained in the image signal. For this reason, in order to improve the precision of the defocus calculation described with reference to FIGS. **34** and **35**, a low-frequency component must be cut off.

FIG. **41B** shows a state in which a low-frequency component is superposed on the image signal in FIG. **41A**. The filter processing of this image signal is performed as follows:

$$HA(i) = -A(i-2) + 2 \times A(i) - A(i+2)$$

where A(i) is the corrected image data, HA(i) is the high-pass filtered image data, and i is the sensor picture element position. If A(i) is substituted with HA(i) again, image data shown in FIG. **41C** is obtained, and an accurate image deviation amount can be detected.

In step **608**, the image data is normalized into 8-bit data, and the subroutine returns to the main routine in step **609**.

The filter processing using the filter determined in accordance with the aperture ratio of the imaging optical system subjected to focus detection and the filer determined in accordance with the exit pupil position of the imaging optical system subjected to focus detection will be described below with reference to FIGS. **42** to **44D**.

FIG. **42** shows the "correction filter magnification" subroutine. This subroutine is the preparation for producing a correction filter actually used in image correction from the original filter information of the correction filter. More specifically, a horizontal axis magnification **1FGR**, a horizontal axis magnification **2FGL**, a vertical axis magnification **1YGR**, and a vertical axis magnification **2YGL** used in the next "execution filter production" subroutine are determined. The horizontal axis magnification and the vertical axis magnification are axis magnifications for producing the correction filters by reducing or enlarging the original filter stored in the ROM.

F-number (aperture ratio) correction coefficients **1HVR** to **4HVR**, **1HVL** to **4HVL**, **1LVR** to **4LVR**, and **1LVL** to **4LVL** and pupil position correction coefficients **1KVFR** to **4KVR**, **1KV3L** to **4KVL**, **1MVR** to **4MVR**, and **1MVL** to **4MVL** used in the subsequent steps are shown in FIGS. **43A** to **43D** and FIGS. **44A** to **44D**. The f-number correction coefficients **1HVR** to **4HVR**, **1HVL** to **4HVL**, **1LVR** to **4LVR**, and **1LVL** to **4LVL** are functions of an open f-number FNO of the phototaking lens. The pupil position correction coefficients **1KVR** to **4KVR**, **1KVL** to **4KVL**, **1MVR** to **4MVR**, and **1MVL** to **4MVL** are functions of a distance PD between the exit pupil of the phototaking lens and a prospective imaging plane. These relationships are determined in accordance with the diffusion characteristics of the diffusion plate inserted in the optical path of the distance measuring optical system.

A description will be made from a re-correlation calculation in step **702** in FIG. **42**. It is determined in step **702** whether this subroutine in step **100** ("**A1**" processing step) of the "defocus calculation" subroutine shown in FIGS. **34** and **35** is called, or this subroutine is called in step **130** ("**A2**" processing step). If this subroutine is called in step **100**, the flow advances to step **703** (i.e., the "**B1**" processing step). If this subroutine is called in step **130** (i.e., the re-correlation calculation ("**A2**" processing step)), the flow advances to step **704** ("**B2**" processing step).

The calculating means of this embodiment has the "**B1**" processing step performed using the filter determined in accordance with the relative displacement amount and the "**B2**" processing step performed using the fixed filter regardless of the relative displacement amount and includes a selecting means for selecting one of the "**B1**" and "**B2**" processing steps.

In step **703**, the relative displacement amount k is stored as a parameter MKFS for determining the length of the correction filter. In the "defocus calculation" subroutine described above, the value k is changed to shift the image data because the defocus amount every k is assumed. In this case, the value k is used to set the length of the correction filter on the basis of the assumed defocus amount. On the other hand, PR' having a resolution less than the units of picture elements is stored in step **704**.

This step is executed when this subroutine is called in re-correlation. In this case, since the image deviation amount is almost known, MKFS=PR' is set to fix the correction filter for each relative displacement amount. This operation is performed to perform more accurate correction filtering and to improve linear interpolation precision in step **146** of the "defocus calculation" subroutine by determining a predetermined correlation evaluation amount regardless of the value of the relative displacement amount k when an image deviation amount which is less than the units of picture elements is calculated in step **146** of the "defocus calculation" subroutine in FIG. **35**.

In step **705**, a parameter NV determined by the defocus amount of the assumed phototaking lens is stored as the horizontal axis magnification **1FGR** and the horizontal axis magnification **2FGL**. This parameter NV is a function of MKFS-FDLT shown in FIG. **45**. FDLT is the correction term for operating the correction filter to some extent even if the image becomes asymmetrical due to the aberration of the phototaking lens and vignetting of the beam in the zero defocus state of the phototaking lens.

The filter corrects the first and second signals even if the relative displacement amount is zero.

The parameter NV generally assumes a value of 1 or less, and the original filter is enlarged to produce an execution filter, thereby preventing degradation of pre-

cision. Since the defocus amount of the phototaking lens is almost proportional to the size of the blurred image, NV has characteristics almost proportional to the absolute value of the MKFS-FDLT. Note that the parameter NV is not perfectly proportional due to the aberration of the re-imaging lens. The secondary term is added in consideration of the above aberration to determine the MKFS-FDLT in FIG. **45**.

The FDLT used herein will be described in more detail. When the distance measuring beam is vignetted in the in-focus state of the phototaking lens, a point image on the photoelectric conversion element is not symmetrical about the vertical axis, as will be described with reference to FIG. **46**. FIG. **46** shows a spot diagram on the photoelectric conversion element in the in-focus state. The direction of an arrow is the line-up direction of the picture elements. Asymmetry of the light amount distribution is found in this direction. By setting the FDLT, this asymmetry can be eliminated. A slight image noncoincidence in the in-focus state can be corrected. The FDLT value is stored in the ROM in the phototaking lens and is properly fetched in the RAM in the microcomputer through the communication between the phototaking lens and the camera body.

In step **706**, the product of the horizontal magnification 1FGR, the distance measuring field position PF, and a proportional constant CV is stored as the horizontal axis magnification 1FGR. The product of the horizontal axis magnification 2FGL, the distance measuring field position PF, and the proportional constant CV is stored as the horizontal axis magnification 2FGL. These storage operations can be performed since the degree of vignetting of the distance measuring beam is approximately proportional to the distance from the optical axis of the phototaking lens to the distance measuring field.

That is, the filter processing is performed using a filter determined by the distance from the optical axis of the imaging optical system subjected to focus detection to the distance measuring distance determined in accordance with the photoelectric converting means.

In particular, in this embodiment, when the defocus amount conversion calculation of the image deviation amount is performed to detect the imaging state of the imaging optical system, the defocus conversion calculation of the image deviation amount is set as a function of a representative distance from the optical axis of the imaging optical system subjected to focus detection to the distance measuring field determined by the photoelectric converting means comprising a plurality of picture elements.

In step **707**, the product of the horizontal axis magnification 1FGR, the f-number correction coefficient 1HVR, and the pupil position correction coefficient 1KVR is stored as the horizontal axis magnification 1FGR, and the product of the horizontal axis magnification 2FGL, the f-number correction coefficient 2HVL, and the pupil position correction coefficient 2KVL is stored as the horizontal axis magnification 2FGL.

The product of the f-number correction coefficient 3LVR and the pupil position correction coefficient 3MVR is stored as the vertical axis magnification 1YGR, and the product of the f-number correction coefficient 4LVL and the pupil position correction coefficient 4MVL is stored as the vertical axis magnification 2YGR, thereby specifying all the final correction coefficients.

The subroutine returns to the main routine in final step **708**.

FIG. **47** shows the "execution filter production" subroutine. In this subroutine, a correction filter is produced from the original filter in accordance with the axis magnifications determined in the previous "correction filter magnification" subroutine. Two different original filters are stored in the ROM and are selectively used in accordance with the positive or negative sign of the MKFS-FDLT due to the following reason. The shape of a line image is determined by mainly the re-imaging lens regardless of the type of phototaking lens. In addition, the sign of the MKFS-FDLT can be determined in accordance with the front-focus and rear-focus states. In other words, since the re-imaging lens comprises a single lens, the aberration of the single lens is considerably larger than that of the phototaking lens.

FIG. **48** is a view for explaining this, showing a spot diagram when the object distance is shifted between the front and rear sides of the in-focus position. The primary image of the object is set on three points on the optical axis of the phototaking lens. A beam reaching the photoelectric conversion element through a dark phototaking lens is traced. When the distance measuring beam is vignetted in this manner, the right side of the point image is omitted in the front-focus state. Similarly, the left side of the point image is omitted in the rear-focus state. This indicates that the direction of tailing of the point image in the front-focus state is opposite to that in the rear-focus state. In addition, since the shape of the point image in the front-focus state is entirely different from that in the rear-focus state, it is apparent that the correction filters suitable for these states are not identical even if one of the filters is reversed.

The "execution filter production" subroutine will be described with reference to FIG. **47**.

In step **802**, the sign of the MSFS-FDLT is checked. If the sign is positive or zero, the flow advances to step **803**. However, if the sign is negative, the flow advances to step **805**.

In step **803**, a "first original filter 1" shown in FIG. **49A** is selected as the original filter and stored as the correction filter in the RAM. In step **804**, **10** is stored in the FOF. In step **805**, a "second original filter 2" shown in FIG. **49B** is selected from the original filters and stored as the correction filter in the RAM. In step **806**, **30** is stored in the FOF. Note that each original filter comprises **41** 8-bit data. The FOF is a variable representing the position of origin of the original filter data. The FOF is set as a variable because the original filter is elongated in one direction with respect to the origin.

Steps **807** to **810** are executed to produce a target correction filter by compressing or expanding the original filter data stored in the RAM as the correction filter in each previous step.

More specifically, in step **807**, the ZR portion of the filter data having an effect for reducing tailing is multiplied with FGR times in the horizontal axis direction. In step **808**, the ZS portion having a function of increasing tailing is multiplied with FGL times in the horizontal axis direction.

When the filter lengths are determined, the data of the ZR portion is compressed by YGR times in the vertical axis direction in step **809**. In step **810**, the data of the ZS portion is compressed by YGL times. Note that the data of the origin FOF is not subjected to compression.

In final step **811**, this subroutine returns to the main routine.

In this embodiment, as described above, the calculating means has the first processing step of producing the filter from the first original filter information and the second processing step of producing the filter from the second original filter information and includes a selecting means for selecting one of the first and second processing steps in accordance with the relative displacement amount between the first and second signals.

The correction filter is thus produced.

In this embodiment, as described above, the first or second original filter is used in accordance with the relative displacement amount. For example, the "filter **1**" mainly corresponding to the rear-focus state and the "filter **2**" mainly corresponding to the front-focus state are used to produce an appropriate correction filter corresponding to any focus state.

As described in the "correction filter magnification" subroutine, the horizontal axis magnification **1**FGR, the horizontal axis magnification **2**FGL, the vertical axis magnification **1**YGR, and the vertical axis magnification **2**YGL are set as a function of the open f-number FNO of the phototaking lens, the distance PD between the exit pupil of the phototaking lens and the prospective imaging plane, and the distance measuring field position PF. Therefore, an appropriate correction filter can be formed for any distance measuring field regardless of the type of phototaking lens.

The shape of the correction filter is changed in accordance with changes in horizontal axis magnifications **1**FGR and **2**FGL and vertical axis magnifications **1**YGR and **2**YGL as follows. When the f-number of the phototaking lens is decreased, the f-number correction coefficient **2**LVL and the pupil position correction coefficient **1**MVL shown in FIGS. **43**B and **43**C come close to zero, and the vertical axis value of the ZR portion of the image correction filter comes close to zero. On the other hand, the image correction capacity of the ZS portion is gradually decreased as the filter length comes close to zero.

Since all the correction filters used for image correction are produced by using one of the two different original filters, the volume of information stored in the ROM can be small.

FIG. **50** shows the "convolution integral" subroutine. The convolution integral equation for discrete data is given as follows for two series D(i) and E(i):

$$S(i) = \sum_h D(h) \times E(i - h)$$

and S(i) is the output of this equation. If D(i) is defined as image data, and E(i) is a correction filter, S(i) is defined as the corrected image data. In this subroutine, a pair of secondary images are set as the image data. As previously described, since two blurred images have symmetry about the optical axis of the phototaking lens, the correction filter is reversed, and the reversed correction filter is operated for one image data, thereby obtaining corrected images.

The "convolution integral" subroutine in FIG. **50** will be described below. A pair of image data are called images OA(i) and OB(i).

In step **902**, i.e., the "**C1**" processing step, the image OA(i) and a correction filter F(i) produced in the "execution filter production" subroutine are subjected to the convolution integral as follows:

$$A(i) = \sum_h OA(h) \times F(i - h)$$

thereby obtaining a corrected image A(i).

In step **903**, i.e., the "**C2**" processing step, the image OB(i) and a correction filter F(-i) obtained by reversing the above filter about the origin FOF are subjected to the convolution integral as follows:

$$B(i) = \sum_h OB(h) \times F(-i - h)$$

thereby obtaining a corrected image B(i). In this manner, a single corrected filter is used in two ways, i.e., with and without a reverse operation. In the "execution filter production" subroutine described above, only one filter is produced. Therefore, the calculation time for producing the correction filter can be almost halved, and the volume of the original filter information stored in the ROM can also be reduced.

This subroutine returns to the main routine in step **904**.

When the imaging state of the imaging optical system is to be detected by performing a defocus amount conversion calculation of the image deviation amount, the defocus conversion calculation of the image deviation amount is a function of the aperture ratio or exit pupil position of the imaging optical system subjected to focus detection. This will be described below.

FIG. **51** shows a "sensitivity of image deviation" subroutine. This subroutine is to calculate the defocus conversion coefficient α from the image deviation amount. The shape of an appropriate correction filter is changed in accordance with not only the defocus amount of the phototaking lens but also the degree of vignetting of the distance measuring beam. The sensitivity of image deviation is also a function of the open f-number, the exit pupil position, and the distance measuring distance position.

When the defocus amount conversion calculation of the image deviation amount is to be performed to detect the imaging state of the imaging optical system, the defocus conversion calculation is a function of the aperture ratio or exit pupil position of the imaging optical system subjected to focus detection, or a representative distance from the optical axis of the imaging optical system to the distance measuring field.

In step **1001**, the sign of the MKFS-FDLT is checked. If the sign is positive or zero, the flow advances to step **1003**. However, if the sign is negative, the flow advances to step **1004**. This determination is branched in accordance with the original filter used.

In step **1003**, an image deviation sensitivity AP free from vignetting of the distance measuring beam is corrected using the f-number correction coefficients **1**HVR to **4**HVR, **1**HVL to **4**HVL, **1**LVR to **4**LVR, and **1**LVL to **4**LVL, the pupil position correction coefficients **1**KVR to **4**KVR, **1**KVL to **4**KVL, **1**MVR to **4**MVR, and **1**MVL to **4**MVL, and the distance measuring field position PF. The correction equation is given as follows:

$$a = AP + PF \times (H1 \times HVL \times LVL \times KVL \times MVL \times H2 \times HVR \times LVR \times KVR \times MVR)$$

where H1 and H2 are correction coefficients by the shape of the correction filter.

Similarly, in step **1004**, the image deviation sensitivity is determined using correction coefficients H3 and H4 as follows:

$$\alpha = AP + PF \times (H3 \times HVL \times LVL \times KVL \times MVL + H4 \times HVR \times LVR \times KVR \times MVR)$$

In final step **1005**, this subroutine returns to the main routine.

As described above, the image deviation sensitivity α of each correction filter is prepared on the basis of the corresponding equation as a function of the open f-number FNO of the phototaking lens, the distance PD between the exit pupil of the phototaking lens and the prospective imaging plane, and the distance measuring field position PF. An accurate defocus calculation of each distance measuring field can be performed regardless of the type of phototaking lens.

The above equations will be described below. According to the characteristic features of the image correction filters, the ZS portion has a function of increasing the tails of the image, and the ZR portion has a function of decreasing the tails of the image, as described previously with reference to FIGS. **23A** to **23C**. These functions will be taken into consideration in view of image movement. The ZS and ZR portions in FIG. **23A** have a function of moving the center of gravity of the line image in FIG. **23B** to the left. The ZS and ZR portions in FIG. **24A** have a function of moving the center of gravity of the line image in FIG. **24B** to the right. Therefore, it is understood that the centers of gravity of two images are separated from each other by this filter processing. In this case, since the distance measuring beam is vignetted from its peripheral portion, the distance between the images is smaller than a case in which the distance measuring beam is not vignetted. Therefore, even if the two images are separated from each other, it can be said that the state of the two images comes closer to a state free from vignetting.

Judging from the above characteristics of the filter, in order to convert an image deviation amount into a defocus amount, it is understood that this conversion function must be set as a function of the correction filter. The correction term of the filter for the image deviation sensitivity is defined as the sum of the function of the ZS portion and the function of the ZR portion in accordance with the characteristics of the ZS and ZR portions of the filter. More specifically, the image deviation sensitivity AP free from vignetting of the distance measuring beam is corrected by using the f-number correction coefficients, the pupil position correction coefficients, and the distance measuring field position for determining a correction filter required for image correction, i.e., by obtaining the sum of the product of the f-number correction coefficients 2HVL, 4HVL, 2LVL, and 4LVL and the pupil position correction coefficients 2KVL, 4KVL, 2MVL, and 4MVL and the product of the f-number correction coefficients 1HVR, 3HVR, 1LVR, and 3LVR and the pupil position correction coefficients 1KVR, 3KVR, 1MVR, and 3MVR, and multiplying the resultant sum with the distance measuring field position PF. Therefore, the image deviation sensitivity suitable for this correction filter can be obtained. By these calculations, the image deviation sensitivity can be obtained in consideration of:

(1) vignetting of the distance measuring beam occurs more easily when the position of the distance measuring field is farther away from the optical axis of the phototaking lens;

(2) vignetting of the beam occurs more easily when the aperture ratio is increased; and

(3) vignetting of the beam occurs more easily when the exit pupil position of the phototaking lens is farther away from the set pupil position of the focus detection optical system.

The description of this subroutine has thus been made. The operation of the defocus detection in FIG. **34** will be described again below.

If a diffusion plate is located on the prospective imaging plane of the phototaking lens in the optical path of the focus detection optical system, distance measuring precision is improved for a bright lens having a small f-number. When a dark phototaking lens having a large f-number is mounted on the camera incorporating this focus detection apparatus, the distance measuring beam is vignetted. For example, image data shown in FIGS. **52A** to **52C** are obtained as outputs from the photoelectric conversion element.

FIGS. **52A** to **52C** and FIGS. **53A** and **53B** show imaging states of a phototaking lens. The phototaking lens is changed in an order of a front-focus state (FIGS. **52A** and **52B**), an in-focus state (FIG. **52C**), and a rear-focus state (FIGS. **53A** and **53B**), and line images in the respective states are illustrated. Line images OA(i) and OB(i) are obtained from a pair of picture element arrays. Since the line images are impulse responses of the composite system of the phototaking lens and the distance measuring optical system and can be restored to be symmetrical about the vertical axis, the shapes of the pair of object images formed by the distance measuring optical system can be restored to have a similarity, thereby detecting a relative distance between the two images.

The pair of illustrated line images are reserved from each other, and their shapes can be classified into front- and rear-focus shapes. The degree of spreading of each line image changes in almost proportion to the image deviation amount. Front- and rear-focus blurred image correction filters shown in FIGS. **49A** and **49B** are prepared, and the filter length is appropriately adjusted in accordance with the corresponding defocus amount. Therefore, the line images can be restored to be symmetrical about the vertical axis.

A method of filtering image data through a correction filter while an image deviation amount is unknown is the "defocus calculation" subroutine shown in FIGS. **34** and **35**. In this subroutine, in step **100**, the value of the relative displacement amount k is sequentially changed, and the correlation evaluation amounts (equations (1) and (2)) of the paired images are obtained while image correction is being performed using the correction filters as a function of the amount k.

FIGS. **54A** to **54C** and FIGS. **55A** and **55B** are views showing the shapes of correction filters for various k values. FIGS. **54A** to **54C** and FIGS. **55A** and **55B** show filters for appropriately correcting the line images in FIGS. **52A** to **52C** and FIGS. **53A** and **53B**. The relative evaluation amount is obtained for one line image by causing such a filter to act on this line image. When the relative displacement amount k is different from the actual image deviation amount, image correction becomes inappropriate. However, when the relative displacement amount k is gradually changed to

come close to the actual image deviation amount, image correction comes close to an appropriate state accordingly. An optimal image correction state can be obtained when the relative displacement amount k is closest to the actual image deviation amount. Therefore, to find a relative displacement amount k corresponding to the zero relative evaluation amount is to find an optimal image correction filter. When appropriate correction filters act on line images, the line images are obtained as shown in FIGS. **56**A to **56**C and FIGS. **57**A and **57**B, thereby satisfactorily achieving symmetry of the line images about the vertical axis. As a result, each pair of images are similar to each other, and it is possible to obtain a distance between the two images with high precision. As previously described, if the line images are corrected in this manner, a general object image can also be corrected to two similar images.

On the other hand, FIGS. **58**A to **58**D show states in which inappropriate correction filters act on the line images shown in FIG. **53**B when the relative displacement amount k is sequentially changed. FIGS. **58**A and **58**C show correction filters different from that of FIG. **55**B, and FIGS. **58**B and **58**D show images corrected by these correction filters. In this manner, when the relative displacement amount k is greatly different from the deviation amounts of the two images, the corrected images have a small degree of similarity. A change in relative evaluation amount with a relative displacement of the image becomes conspicuous.

In step **130** of the "defocus calculation" subroutine in FIGS. **34** and **35**, a more accurate correction filter is produced using the relative displacement amount PR' in units of sub-picture elements obtained in interpolation, and the final image deviation amount is calculated by the most correlation calculation while the shape of the correction filter is fixed.

In order to obtain a correction filter suitable for various conditions for determining the degree of vignetting of the distance measuring beam, the horizonal and vertical axes of the original filter are enlarged or reduced ("execution filter production" subroutine) on the basis of the f-number correction coefficients **1**HVR to **4**HVR, **1**HVL to **4**HVL, **1**LVR to **4**LVR, and **1**LVL to **4**LVL and the pupil position correction coefficients **1**KVR to **4**KVR, **1**KVL to **4**KVL, **1**MVR to **4**MVR, and **1**MVL to **4**MVL which are obtained as a function of the open f-number, the exit pupil positions, and the distance measuring field position. For example, FIG. **59** shows a correction filter corresponding to a bright phototaking lens having a small f-number. In this case, slight vignetting is still present, and the relative displacement amount in FIG. **57**B is assumed. This filter is obtained such that the length of the original filter is caused to correspond to the relative displacement amount, the ZR portion is enlarged in the horizontal axis direction and reduced in the vertical axis direction, and the ZS portion is reduced in the horizontal axis direction.

The above description exemplifies the defocus detection method utilizing image correction in the distance measuring optical system having the diffusion plate in the optical path. This defocus detection method is not limited to this distance measuring optical system, but is applicable to various other distance measuring optical systems.

For example, in the conventional distance measuring optical system obtained by omitting the diffusion plate **42** from the distance measuring optical system shown in FIG. **1**, this defocus detection is effective when a considerably dark phototaking lens is mounted and the distance measuring beam is vignetted. For this reason, the following combination may be proposed. That is, a distance measuring optical system is arranged such that a distance measuring beam is not vignetted by a phototaking lens having an open f-number of 5.6 or less. The conventional distance measurement is performed for a phototaking lens having an open f-number of 5.6 or less. However, when a phototaking lens having an open f-number of more than 5.6 is mounted, the above image correction is performed to detect a defocus amount.

If this conventional distance measuring optical system has an aperture as shown in FIG. **3**, strictly speaking, the shapes of two pairs of blurred images are not symmetrical with each other due to the following reason. The shapes of the aperture openings **48***a* and **48***b* do not overlap each other when one of the openings is translated to the other. The blurred images behave as if the outer side of the rectangular opening is vignetted in an arcuated shape. Therefore, as described above, the image can be corrected later in the filter processing. Note that the correction filter is different from that described above except that the correction filter is formed not as a function of the f-number and exit pupil position of the phototaking lens, and the distance measuring field position.

According to the embodiment described above,

(a) since vignetting of the distance measuring beam is allowed, the limitations of the aperture ratio of the imaging optical system in the conventional focus detection apparatus can be relaxed, and focus detection of a dark imaging lens having a large f-number can be performed.

In particular, in a focus detection apparatus having an improved distance measuring optical system having a diffusion plate in the optical path of a distance measuring optical system, distance measuring precision as the characteristic feature of this apparatus can be achieved for a bright imaging lens. At the same time, focus detection can be performed for even a dark imaging lens in which the distance measuring beam is conventionally vignetted.

(b) Even if the distance measuring beam is vignetted, distance measurement can be performed. The distance measuring field can be located at an arbitrary position within the phototaking frame without darkening the beam incident on the focus detection optical system.

(c) Accurate image correction can be performed even if the imaging lens is set in the front- or rear-focus state. As a result, focus detection precision can be remarkably improved.

Accurate defocus detection can be performed regardless of the imaging states of the imaging optical system. The nun%bet of times of driving the lens to achieve the in-focus state can be reduced.

(d) All the correction filters can be produced in accordance with the aperture ratios of phototaking lenses on the basis of two original filters.

Accurate defocus detection can be performed regardless of the aperture ratio of the imaging optical system. The number of times of driving the lens to achieve the in-focus state can be reduced.

In addition, if the correction filter is calculated as a function of the aperture ratio, the volume of information required to be stored in the focus detection apparatus can be minimized, and a small ROM can be used,

resulting in low cost. In particular, a great effect can be obtained for industrial equipment such as cameras having restricted costs.

(e) Since all the correction filters can be produced in accordance with the exit pupil position of the phototaking lens on the basis of the two original filters, focus detection can be performed for imaging lenses having different exit pupil positions.

Accurate defocus detection can be performed regardless of the exit pupil position of the imaging optical system. The number of times of driving the lens to achieve the in-focus state can be reduced.

In addition, if the correction filter is calculated as a function of the exit pupil position, the volume of information required to be stored in the focus detection apparatus can be minimized, and a small ROM can be used, resulting in low cost. In particular, a great effect can be obtained for industrial equipment such as cameras having restricted costs.

(f) In focus detection of a dark imaging lens having a large f-number, the filter in the "A2" processing step is determined on the basis of the image deviation amount obtained in the "A1" processing step. The accurate correction filter can be produced in the "A2" processing step. The image deviation amount can be calculated with high precision. Therefore, the restrictions as to the aperture ratio of the imaging optical system can be relaxed, unlike the conventional focus detection apparatus.

(g) Even if the relative displacement amount is zero, the digital filter is arranged to correct the first and second signals. A slight image noncoincidence in the in-focus state can be corrected. In the focus detection of a dark imaging lens having a large f-number and a large vignetting amount of the distance measuring beam, the images can coincide with each other with high precision.

As a result, the restrictions as to the aperture ratio of the imaging optical system can be relaxed, unlike the conventional focus detection apparatus, and focus detection of a dark imaging lens having a large f-number can be performed.

An accurate defocus amount of the imaging optical system can be detected regardless of whether the in-focus state is obtained. The number of times of driving the lens to achieve the in-focus state can be reduced.

(h) In focus detection of a dark imaging lens having a large f-number, the filter in the "B2" processing step is determined on the basis of the image deviation amount obtained in the "B1" processing step. In addition, the correction filter is fixed in the "B2" processing step regardless of the relative displacement of the image signal. The weighting coefficients of the evaluation amounts at the respective relative displacements obtained by interpolation of the evaluation amounts representing the coincidence between the signals in units of sub-picture elements do not change, and high-precision evaluation amounts can be obtained. Therefore, the restrictions as to the aperture ratio of the imaging optical system can be relaxed, unlike the conventional focus detection apparatus, and focus detection of a dark imaging lens having a large f-number can be performed.

Accurate defocus detection can be performed regardless of the aperture ratio of the imaging optical system. The number of times of driving the lens to achieve the in-focus state can be reduced.

(i) All the correction filters can be produced in accordance with the distance measuring field positions of phototaking lenses on the basis of two original filters. Focus detection in a plurality of distance measuring fields can be performed for imaging lenses having different aperture ratios.

In addition, if the correction filter is calculated as a function of the distance measuring field position, the volume of information required to be stored in the focus detection apparatus can be minimized, and a small ROM can be used, resulting in low cost. In particular, a great effect can be obtained for industrial equipment such as cameras having restricted costs.

(j) Since the length of the correction filter adaptive to a given focus amount is decreased when the defocus amount is decreased, the number of picture elements used in the defocus calculation is smaller than that of the actual image signal by five picture elements at each end of the actual image signal. When the defocus amount is several millimeters or less, a filter corresponding to a small defocus amount can be operated without any error. Therefore, accurate defocus detection can be performed, and the number of times of driving the lens to achieve the in-focus state can be reduced.

Since vignetting of the distance measuring beam is allowed, the limitations of the aperture ratio of the imaging optical system in the conventional focus detection apparatus can be relaxed, and focus detection of a dark imaging lens having a large f-number can be performed.

(k) Since the correction filter having the above-mentioned arrangement is used, the corrected images do not excessively come close to the original line. The high-frequency component of the original image data is not excessively amplified, and the right and left tails of the image signal can be set equal to each other. Therefore, even if random noise caused by thermal noise is superposed on image data, distance measuring precision is rarely degraded.

Since vignetting of the distance measuring beam is allowed, the limitations of the aperture ratio of the imaging optical system in the conventional focus detection apparatus can be relaxed, and focus detection of a dark imaging lens having a large f-number can be performed.

(l) The calculation time for producing the correction filters can be halved as compared with a case in which correction filters for the two images are independently produced.

Since vignetting of the distance measuring beam is allowed, the limitations of the aperture ratio of the imaging optical system in the conventional focus detection apparatus can be relaxed, and focus detection of a dark imaging lens having a large f-number can be performed.

In addition, since the correction filter for one image can be produced from that for the other image, the volume of information required to be stored in the focus detection apparatus can be minimized, and a small ROM can be used, resulting in low cost. In particular, a great effect can be obtained for industrial equipment such as cameras having restricted costs.

What is claimed is:

1. A focus detection apparatus comprising an optical system for forming first and second optical distributions associated with object images whose relative positional

relationship is changed in accordance with an imaging state of an imaging optical system subjected to focus detection, photoelectric converting means, having a plurality of picture elements, for outputting first and second signals respectively corresponding to the first and second optical distributions, and calculating means for performing filter processing of the first and second signals, wherein the first and second signals are respectively processed through filters having mutually different characteristics, processed sequentially displacing the first and second signals relative to each other, calculating an evaluation amount representing a coincidence between the first and second signals at the relatively displaced positions, obtaining positional deviations between the first and second object images on the basis of a change in evaluation amount, and detecting the imaging state of the imaging optical system on the basis of the deviations, the filter processing being performed using a filter determined by the relatively displaced positions.

2. An apparatus according to claim 1, wherein said calculating means has a first processing step of producing said filter from first original filter information and a second processing step for producing said filter from second original filter information, and further comprises selecting means for selecting one of the first and second processing steps in accordance with the relative displacement of the first and second signals.

3. A focus detection apparatus comprising an optical system for forming first and second optical distributions associated with object images whose relative positional relationship is changed in accordance with an imaging state of an imaging optical system subjected to focus detection, photoelectric converting means, having a plurality of picture elements, for outputting first and second signals respectively corresponding to the first and second optical distributions, and calculating means for, when the first and second signals are sequentially displaced relative to each other, and an evaluation amount representing a coincidence between the first and second signals at the relatively displaced positions is calculated, performing filter processing of the first and second signals, obtaining deviations between the first and second object images on the basis of a change in evaluation amount, and detecting the imaging state of the imaging optical system, the filter processing, wherein the first and second signals are respectively processed through filters having mutually different characteristics, being performed using a filter determined by an aperture ratio of said imaging optical system subjected to focus detection.

4. A focus detection apparatus comprising an optical system for forming first and second optical distributions associated with object images whose relative positional relationship is changed in accordance with an imaging state of an imaging optical system subjected to focus detection, photoelectric converting means, having a plurality of picture elements, for outputting first and second signals respectively corresponding to the first and second optical distributions, and calculating means for, when the first and second signals are sequentially displaced relative to each other, and an evaluation amount representing a coincidence between the first and second signals, obtaining deviations between the first and second object images on the basis of a change in evaluation amount, and detecting the imaging state of the imaging optical system, the filter processing, wherein the first and second signals are respectively processed through filters having mutually different characteristics, being performed using a filter determined by an exit pupil position of said imaging optical system subjected to focus detection.

5. A focus detection apparatus comprising an optical system for forming first and second optical distributions associated with object images whose relative positional relationship is changed in accordance with an imaging state of an imaging optical system subjected to focus detection, photoelectric converting means, having a plurality of picture elements, for outputting first and second signals respectively corresponding to the first and second optical distributions, and calculating means for, when the first and second signals are sequentially displaced relative to each other, and an evaluation amount representing a coincidence between the first and second signals at the relatively displaced positions is calculated, performing filter processing of the first and second signals, obtaining deviations between the first and second object images on the basis of a change in evaluation amount, and detecting the imaging state of the imaging optical system, wherein said calculating means has a first processing step of performing the filter processing using a filter determined by the relative displacement and a second processing step, performed next to the first processing step, of performing the filter processing using a fixed filter regardless of the relative displacement, and said filter in the second processing step is determined on the basis of the image deviation obtained in the first processing step.

6. A focus detection apparatus comprising an optical system for forming first and second optical distributions associated with object images whose relative positional relationship is changed in accordance with an imaging state of an imaging optical system subjected to focus detection, photoelectric converting means, having a plurality of picture elements, for outputting first and second signals respectively corresponding to the first and second optical distributions, and calculating means for, when the first and second signals are sequentially displaced relative to each other, and an evaluation amount representing a coincidence between the first and second signals at the relatively displaced positions is calculated, performing filter processing of the first and second signals, Wherein the first and second signals are respectively processed through filters having mutually different characteristics, using a filter determined by the relative displacement, obtaining deviations between the first and second object images on the basis of a change in evaluation amount, and detecting the imaging state of the imaging optical system, wherein said filter corrects the first and second signals even when the relative displacement is zero.

7. A focus detection apparatus comprising an optical system for forming first and second optical distributions associated with object images whose relative positional relationship is changed in accordance with an imaging state of an imaging optical system subjected to focus detection, photoelectric converting means, having a plurality of picture elements, for outputting first and second signals respectively corresponding to the first and second optical distributions, and calculating means for, when the first and second signals are sequentially displaced relative to each other, and an evaluation amount representing a coincidence between the first and second signals at the relatively displaced positions is calculated, performing filter processing of the first and second signals, obtaining deviations between the

first and second object images on the basis of a change in evaluation amount, and detecting the imaging state of the imaging optical system, wherein said calculating means has a first processing step of performing the filter processing using a filter determined by the relative displacement and a second processing step, performed next to the first processing step, of performing the filter processing using a fixed filter regardless of the relative displacement, and further comprises selecting means for selecting one of the first and second processing steps.

8. A focus detection apparatus comprising an optical system for forming first and second optical distributions associated with object images whose relative positional relationship is changed in accordance with an imaging state of an imaging optical system subjected to focus detection, photoelectric converting means, having a plurality of picture elements, for outputting first and second signals respectively corresponding to the first and second optical distributions, and calculating means for, when the first and second signals are sequentially displaced relative to each other, and an evaluation amount representing a coincidence between the first and second signals at the relatively displaced positions is calculated, performing filter processing of the first and second signals, obtaining deviations between the first and second object images on the basis of a change in evaluation amount, and detecting the imaging state of the imaging optical system, the filter processing being performed using a filter determined by a distance from an optical axis of the imaging optical system subjected to focus detection to a distance measuring field determined by said photoelectric converting means.

9. A focus detection apparatus comprising an optical system for forming first and second optical distributions associated with object images whose relative positional relationship is changed in accordance with an imaging state of an imaging optical system subjected to focus detection, photoelectric converting means, having a plurality of picture elements, for outputting first and second signals respectively corresponding to the first and second optical distributions, and calculating means for, when the first and second signals are sequentially displaced relative to each other, and an evaluation amount representing a coincidence between the first and second signals at the relatively displaced positions is calculated, performing filter processing of the first and second signals using a filter determined by the relatively displaced positions, obtaining image deviations between the first and second object images on the basis of a change in evaluation amount, and detecting the imaging state of the imaging optical system, wherein said filter has only a positive component in one direction and positive and negative components in the other direction with respect to an origin.

10. A focus detection apparatus comprising an optical system for forming first and second optical distributions associated with object images whose relative positional relationship is changed in accordance with an imaging state of an imaging optical system subjected to focus detection, photoelectric converting means, having a plurality of picture elements, for outputting first and second signals respectively corresponding to the first and second optical distributions, and calculating means for, when the first and second signals are sequentially displaced relative to each other, and an evaluation amount representing a coincidence between the first and second signals at the relatively displaced positions is calculated, performing filter processing of the first and second signals, obtaining deviations between the first and second object images on the basis of a change in evaluation amount, and detecting the imaging state of the imaging optical system, wherein said calculating means has a first processing step of performing filter processing of the first signal and a second processing step of performing filter processing of the second signal, and a filter used in the second processing step has characteristics obtained by inverting a filter used in the first processing step.

11. A focus detection apparatus comprising an optical system for forming first and second optical distributions associated with object images whose relative positional relationship is changed in accordance with an imaging state of an imaging optical system subjected to focus detection, photoelectric converting means, having a plurality of picture elements, for outputting first and second signals respectively corresponding to the first and second optical distributions, and calculating means for, when the first and second signals are sequentially displaced relative to each other, and an evaluation amount representing a coincidence between the first and second signals the relatively displaced positions is calculated, performing filter processing of the first and second signals using a filter determined by the relatively displaced positions, obtaining image deviations between the first and second object images on the basis of a change in evaluation amount, and detecting the imaging state of the imaging optical system, wherein said photoelectric converting means has picture elements used in the filter processing, which are located outside picture elements whose outputs are used to calculate the evaluation amounts.

12. A focus detection apparatus comprising an optical system for forming first and second optical distributions associated with object images whose relative positional relationship is changed in accordance with an imaging state of an imaging optical system subjected to focus detection, photoelectric converting means, having a plurality of picture elements, for outputting first and second signals respectively corresponding to the first and second optical distributions, and calculating means for, when the first and second signals are sequentially displaced relative to each other, and an evaluation amount representing a coincidence between the first and second signals at the relatively displaced positions is calculated, performing filter processing of the first and second signals using a filter determined by the relatively displaced positions, obtaining image deviations between the first and second object images on the basis of a change in evaluation amount, and performing a defocus conversion calculation of the image deviation to form a signal representing the imaging state of the imaging optical system, wherein the defocus conversion calculation of the image deviation is a function of an aperture ratio of the imaging optical system subjected to focus detection.

13. A focus detection apparatus comprising an optical system for forming first and second optical distributions associated with object images whose relative positional relationship is changed in accordance with an imaging state of an imaging optical system subjected to focus detection, photoelectric converting means, having a plurality of picture elements, for outputting first and second signals respectively corresponding to the first and second optical distributions, and calculating means for, when the first and second signals are sequentially displaced relative to each other, and an evaluation

amount representing a coincidence between the first and second signals at the relatively displaced positions is calculated, performing filter processing of the first and second signals using a filter determined by the relatively displaced positions, obtaining image deviations between the first and second object images on the basis of a change in evaluation amount, and performing a defocus conversion calculation of the image deviation to form a signal representing the imaging state of the imaging optical system, wherein the defocus conversion calculation of the image deviation is a function of an exit pupil position of the imaging optical system subjected to focus detection.

14. A focus detection apparatus comprising an optical system for forming first and second optical distributions associated with object images whose relative positional relationship is changed in accordance with an imaging state of an imaging optical system subjected to focus detection, photoelectric converting means, having a plurality of picture elements, for outputting first and second signals respectively corresponding to the first and second optical distributions, and calculating means for, when the first and second signals are sequentially displaced relative to each other, and an evaluation amount representing a coincidence between the first and second signals at the relatively displaced positions is calculated, performing filter processing of the first and second signals using a filter determined by the relatively displaced positions, obtaining image deviations between the first and second object images on the basis of a change in evaluation amount, and performing a defocus conversion calculation of the image deviation to form a signal representing the imaging state of the imaging optical system, wherein the defocus conversion calculation of the image deviation is a function of a representative distance from an optical axis of said imaging optical system subjected to focus detection to a distance measuring field determined by said photoelectric converting means comprising the plurality of picture elements.

15. A focus detection apparatus comprising:

an optical system for forming first and second optical distributions associated with object images whose relative positional relationship is changed in accordance with an imaging state of an imaging optical system;

photoelectric converting means, having a plurality of picture elements, for outputting first and second signals respectively corresponding to the first and second optical distributions;

filter processing means for employing filter-processing wherein the first and second signals are respectively processed through filters having mutually different characteristics; and

detection means for detecting a focal point state of said imaging optical system on the basis of the first and second signals to which said filter-processing is applied.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 5,367,153
DATED : November 22, 1994
INVENTOR(S) : YASUO SUDA, ET AL.

It is certified that error appears in the above-indentified patent and that said Letters Patent is hereby corrected as shown below:

COLUMN 4

Line 65, "FIG." should read --FIGS.--.

COLUMN 8

Line 38, "vignet" should read --vignette--.

COLUMN 31

Line 66, 1KVFR" should read --1KVR--.

COLUMN 40

Line 56, "nun%bet" should read --number--.

Signed and Sealed this

Thirtieth Day of May, 1995

Attest:

BRUCE LEHMAN

Attesting Officer

Commissioner of Patents and Trademarks

US005329347A

United States Patent [19]

Wallace et al.

[11] Patent Number: 5,329,347

[45] Date of Patent: Jul. 12, 1994

[54] MULTIFUNCTION COAXIAL OBJECTIVE SYSTEM FOR A RANGEFINDER

[75] Inventors: **Robert E. Wallace**, Garland; **Wayne E. Isbell**, Dallas, both of Tex.

[73] Assignee: **Varo Inc.**, Garland, Tex.

[21] Appl. No.: **945,743**

[22] Filed: **Sep. 16, 1992**

[51] **Int. Cl.**[5] **G01C 3/08**; H01J 31/50; G02B 21/06

[52] **U.S. Cl.** **356/5**; 250/213; 359/211; 359/389; 359/425; 359/426

[58] **Field of Search** 356/5; 359/211, 389, 359/425, 426; 250/213

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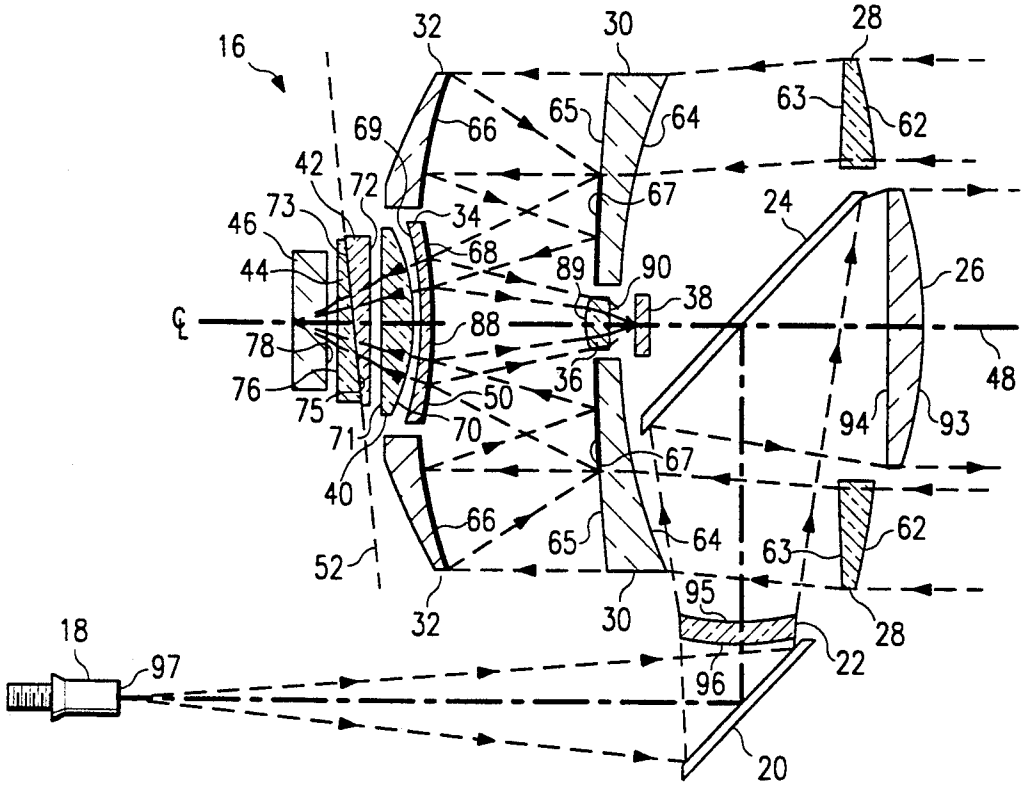
Primary Examiner—Stephen C. Buczinski
Attorney, Agent, or Firm—Baker & Botts

[57] **ABSTRACT**

There is provided a multifunction coaxial objective system (**16**) for a laser rangefinder (**10**). The transmitter, receiver, and viewing optical systems have a common, coaxial optical axis (**48**). The multifunction coaxial objective system (**16**) includes lenses (**28**), (**30**) and mirror (**32**) each having a central obscuration therein. The multifunction coaxial objective system (**16**) further includes a lens (**34**) having a dichroic coating on one surface (**50**). The dichroic coated lens (**34**) transmits visible and near infrared light and reflects light of the wavelength transmitted by a laser emitter (**18**). The viewing optical system includes a pair of focusing wedges (**42**), (**44**) for adjusting the focus of the viewing optical system. Each focusing wedge (**42**), (**44**) is a wedge-shaped optical flat. The pair of focusing wedges (**42**), (**44**) are disposed against one another along a plane inclined with respect to the coaxial optical axis (**48**) of the multifunction coaxial objective system (**16**). Focus adjustment is achieved by relative movement between the focusing wedges (**42**), (**44**) along the inclined plane. The multifunction coaxial objective system (**16**) of the present invention may alternatively be incorporated into a rangefinder and camera for example.

33 Claims, 1 Drawing Sheet



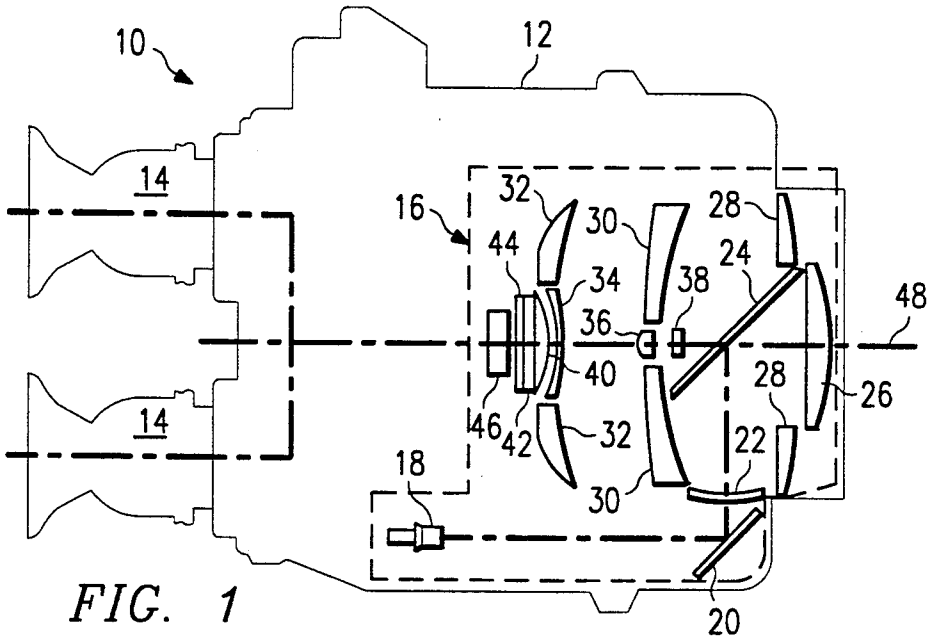

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FIG. 1

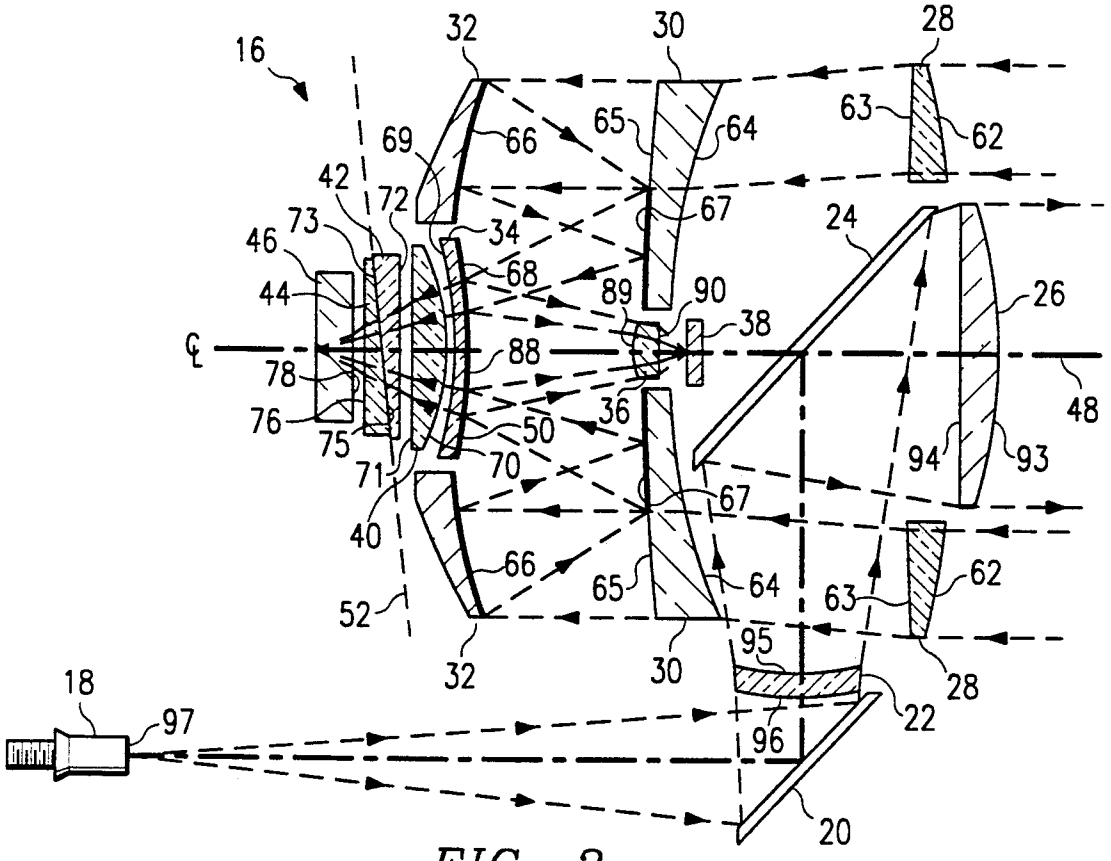
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FIG. 2

MULTIFUNCTION COAXIAL OBJECTIVE SYSTEM FOR A RANGEFINDER

TECHNICAL FIELD OF THE INVENTION

The present invention relates to optical systems and, more particularly to an improved optical system for a laser rangefinder having coaxial viewing, transmitting, and receiving channels.

BACKGROUND OF THE INVENTION

Laser rangefinders are well known in the rangefinding art. A laser rangefinder emits one or more laser pulses toward an object the range of which is to be determined. The laser pulses reflect from the object back to the rangefinder, and are detected by a laser detector. The length of time between emission of each laser pulse and its detection by the laser detector is measured by a timer clock, and the range is determined from this time period. A numerical range figure may be displayed on a suitable electronic display on the rangefinder, or may be printed on a remote paper printer, for example.

Typical laser rangefinders of the prior art have three separate optical channels: a channel for the transmitting optics, a channel for the receiving optics, and a channel for the viewing optics. Each of these optical channels typically has its own distinct optical axis. A few laser rangefinders have been designed in which the receiving and viewing channels are coaxial. However, there are no known laser rangefinders with coaxial transmitting, receiving and night viewing channels. Such a rangefinder having coaxial optics for all three functions is highly desirable for reducing size, weight, and cost of the rangefinder.

A second disadvantage with laser rangefinders of the prior art resides in the lens system for focusing the viewing optics. A typical focusing system requires relative movement between the viewing lens and the transmitter and receiver optics. This relative movement between the viewing and the rangefinder optics contributes to boresight loss, parallax, and alignment stability problems in the rangefinder.

Consequently, a need exists for a laser rangefinder with an improved optical system which uses a single optical channel for transmitting, receiving and viewing functions. Preferably, such an improved laser rangefinder will have an optical system which permits focus adjustment for the viewing system without relative movement between the viewing lens and the transmitter or receiver optics. Such an improved laser rangefinder will further preferably have night vision capability.

SUMMARY OF THE INVENTION

The present invention provides a laser rangefinder and night vision goggle having an improved optical system. The transmitter, receiver, and viewing optical systems have coaxial optical axes. The improved optical system includes at least one optical element having a central obscuration therein. The improved optical system further includes a lens having a dichroic coating on one surface for transmitting visible and near infrared light and for reflecting light of the wavelength transmitted by the laser emitter. The viewing optical system includes a pair of focusing wedges for adjusting the focus of the viewing optical system. Each focusing wedge is a wedge-shaped optical flat, the pair of focusing wedges being disposed against one another along a plane inclined with respect to the optical axis of the viewing optical system, whereby focus adjustment is achieved by relative movement between the focusing wedges along the inclined plane.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a top, cross-sectional schematic view of a laser rangefinder and night vision goggle of the present invention.

FIG. **2** is an enlarged schematic view of the improved optical system of the present invention, illustrating the path of representative rays through the optical system.

DETAILED DESCRIPTION OF THE INVENTION

The preferred embodiment of the present invention and its advantages are best understood by referring to the drawings, like numerals being used for like and corresponding parts of the various drawings.

Referring now to the drawings, and more particularly to FIG. **1**, there is shown a top, cross-sectional view of a laser rangefinder and night vision goggle, generally designated **10**, which incorporates the preferred embodiment of the present invention. Rangefinder and night vision goggle **10** comprises a housing **12** having on its rear a pair of eyepieces **14**. The front portion of housing **12** contains the improved optical system or multifunction coaxial objective system, generally designated **16**, of the present invention. Improved optical system **16** includes a transmitter optical system, a receiver optical system, and a viewing or imaging optical system.

The transmitter optical system includes laser emitter **18**, folding mirror **20**, lens **22**, folding mirror **24**, and lens **26**. Laser emitter **18** is preferably a triple emitting region, pulsed output, semiconductor laser diode. The preferred commercially available laser diode that may be used for laser emitter **18** is the EG&G Model C86091E which emits laser energy of 1.55 μm wavelength. Alternatively, the Stantel LE Series Type LE25-02 diode, having a 905 nm pulsed output, may be used for emitter **18**. Mirrors **20** and **24** are commercially available, optical grade, flat mirrors which are well known in the art. The lens prescription and mounting distance data for lenses **22** and **26** are listed in Table I. Listed in order from left to right are: (1) the lens surface number; (2) the radius of curvature of the surface (mm) (positive (+) radii for centers of curvature to right of lens surface, and negative (−) radii for centers to left of surfaces); (3) the lens axial thickness, or distance to the next surface (mm); (4) the clear aperture radius (mm); and (5) the lens material.

TABLE I

SURFACE NO.	RADIUS OF CURVATURE (mm)	THICKNESS (mm)	CLEAR APERTURE RADIUS (mm)	MATERIAL
93	70.75	5.73	22.0	BK7
94	∞	74.83	21.7	AIR
95	−41.32	3.10	9.5	SFL6
96	−68.89	110.82	9.5	AIR
97	∞	—	—	AIR

The receiver optical system includes lens **28**, lens **30**, mirror **32**, lens **34**, lens **36**, and laser detector **38**. Table II lists the preferred lens prescription and mounting distance data for the receiver optical system. Listed in

order from left to right are: (1) the lens surface number; (2) the radius of curvature of the surface (mm) (positive (+) radii for centers of curvature to right of lens surface, and negative (−) radii for centers to left of surface); (3) the lens axial thickness, or distance to the next surface (mm); (4) the lens material; (5) the clear aperture radius (mm); and (6) the central obscuration radius (mm), if any.

TABLE II

SURFACE NO.	RADIUS OF CURVATURE (mm)	THICKNESS (mm)	MATERIAL	CLEAR APERTURE RADIUS (mm)	CENTRAL OBSCURATION RADIUS (mm)
62	+192.5	7.733	FK3	42.5	24.3
63	−744.288	35.307	AIR	42.3	24.3
64	−104.902	3.801	FK3	38.5	22.8
65	−358.443	29.843	AIR	38.8	22.9
66	−136.934	−29.843	MIRROR	39.0	17.5
67	−358.443	27.024	MIRROR	22.9	6.8
88	+77.00	−25	DICHROIC MIRROR	9.4	—
89	−8.467	−3.987	SF6	4.0	—
90	∞	−4.268	AIR	3.0	—
91	∞	0	DETECTOR	—	—

The viewing optical system includes lens **28**, lens **30**, mirror **32**, lens **34**, lens **40**, focusing wedges or optical flats **42** and **44**, and image intensifier tube **46**. Table III lists the preferred lens prescription and mounting distance data for the viewing optical system. Listed in order from left to right are: (1) the lens surface number; (2) the radius of curvature of the surface (mm) (positive (+) radii for centers of curvature to right of lens Surface, and negative (−) radii for centers to left of surface); (3) the lens axial thickness, or distance to the next surface (mm); (4) the lens material; (5) the clear aperture radius (mm); and (6) the central obscuration radius (mm), if any. Image intensifier tube **46** permits night vision when the present invention is incorporated in a night vision goggle.

TABLE III

SURFACE NO.	RADIUS OF CURVATURE (mm)	THICKNESS (mm)	MATERIAL	CLEAR APERTURE RADIUS (mm)	CENTRAL OBSCURATION RADIUS (mm)
62	+192.5	7.733	FK3	42.5	24.3
63	−744.288	35.307	AIR	42.3	24.3
64	−104.902	3.801	FK3	38.5	22.8
65	−358.443	29.843	AIR	38.8	22.9
66	−136.934	−29.843	MIRROR	39.0	17.5
67	−358.443	27.024	MIRROR	22.9	6.8
68	+77.00	1.935	SFL6	15.3	—
69	+47.533	1.277	AIR	14.7	—
70	+31.893	5.054	LaKL21	14.3	—
71	−932.728	1.843	AIR	13.9	—
72	∞	2.5	FK3	12.8	—
73	∞	0.05	AIR	12.3	—
				WEDGE 3.81°	
75	∞	2.5	FK3	12.3	—
76	∞	1.88	AIR	12.5	—
				WEDGE 3.81°	
78	∞	5.46	FK5	10.4	—
79	∞	0	—	9.0	—
				IMAGE	

Referring now to FIG. **2**, there is shown an enlarged, cross-sectional view of the improved optical system **16** of the present invention. One of the important features of this invention is that the transmitter, receiver, viewing optical systems are coaxial in object space, sharing a common optical axis **48**. The innovative means by which all three of these optical systems have a common optical axis is another important feature of this invention, and is explained hereinafter.

As seen in FIG. **2**, lenses **28** and **30** and mirror **32** together comprise the major part of a catadioptric lens system. A catadioptric lens system is one in which both reflecting and refracting elements are used to form its focal power. The central portions of these lenses and mirror are not used for imaging. This unused, central area of lenses **28** and **30** and mirror **32** is referred to as the central obscuration or centrally obscured region and is used instead for portions of the transmitter and/or receiver optical systems. The use of these optical elements having central obscurations therein constitutes an important feature of this invention. As seen in FIG. **2**, laser energy transmitted by laser emitter **18** passes through the central obscuration of lens **28**. Laser energy received by lens **28** focuses to laser detector **38** situated within the central obscuration of lens **30**. Finally, the visible image produced by the viewing optical system passes through the central obscuration of mirror **32**. Thus, the central obscuration of each of lenses **28** and **30** and mirror **32** are used by a different optical system of the present invention.

As seen in FIG. **2**, lens **36** of the receiver optical system is located in the central obscuration of lens **30**. Lens **34**, used in both the viewing and receiving optical systems, and lens **40** of the viewing optical system, are located in the central obscuration of mirror **32**. Lens **26** of the transmitting optical system is located adjacent to and within the centrally obscured region of lens **28**. Laser detector **38** is located adjacent to lens **36**, and within the centrally obscured region of lens **30**.

It should be noted that the inner surface **67** of the side of lens **30** which faces lens **34** is mirror coated, whereas the outer surface **65** of this side of lens **30** is uncoated. Surface **67** of lens **30** is mirror coated to reflect light from mirror **32** to lens **34**. Surface **65** of lens **30** is uncoated to permit light to pass through lens **30** to mirror **32**.

A key aspect of this invention resides in the dichroic coating applied to side **50** of lens **34**. The dichroic coating on side **50** of lens **34** transmits visible and near infrared light produced by the viewing optical system to the image intensifier tube **46**, but reflects light or laser energy of the wavelength transmitted by the laser emitter **18** back to laser detector **38**. Dichroic coated lens **34** thus performs a dual function as a short wavelength pass filter in transmitting visible and near infrared light for the viewing optical system and in reflecting laser energy for the receiver optical system.

The wavelength transmitted by the EG&G Model C86091E laser diode, the preferred choice for laser emitter **18**, is 1.55 μm. Dichroic coatings suitable for this application are well known in the art, and are commercially available. Dichroic coated lens **34** is preferably located at least partially within the central obscuration of mirror **32**. Alternatively, dichroic coated lens **34** may be located adjacent to and near the central obscuration of mirror **32**.

FIG. **2** also illustrates another important feature of this invention: The viewing optical system includes a

pair of focusing wedges **42** and **44** for adjusting the focus of visual images transmitted to image intensifier tube **46**. Each focusing wedge **42** and **44** is a wedge-shaped optical flat. The two optical flats **42** and **44** are disposed against one another along a plane **52** which is inclined with respect to the common optical axis **48**. Focus adjustment for the viewing optical system is achieved by relative movement between focusing wedges **42** and **44** along inclined plane **52**. This relative movement changes the combined optical thickness of the pair of focusing wedges **42** and **44**, thereby adjusting the focus of the viewing optical system.

The relative movement between focusing wedge **42** and **44** may be achieved by one of several alternative means. In the preferred embodiment, focusing wedges **42** and **44** are simultaneously moved along plane **52** in opposite directions by rotating a knob (not illustrated) attached to housing **12**. The rotatable knob is attached to focusing wedges **42** and **44** through a suitable linkage (not illustrated). Alternatively, focusing wedges **42** and **44** may be moved along plane **52** in opposite directions by a pivotable lever (not illustrated) attached to housing **12**. The pivotable lever is attached to focusing wedges **42** and **44** through a suitable linkage (not illustrated). Focus adjustment may also be achieved by moving only one of focusing wedges **42** or **44** along inclined plane **52**, the other focusing wedge **42** or **44** being held stationary. For a handheld rangefinder, displacement of focusing wedge **42** or **44** by approximately $\frac{3}{4}$ inch would be sufficient to adjust the viewing system focus over the required range.

The improved optical system **16** of the present invention has been described and illustrated as it might be incorporated in a handheld laser rangefinder and night vision goggle or viewer. Although not illustrated or described in detail, an alternative embodiment of the improved optical system of the present invention might be a laser rangefinder and camera, for example. In this embodiment, a camera film plane would be substituted for the image plane of the image intensifier tube of the described embodiment. Still another embodiment of this invention might be a laser rangefinder alone. In this embodiment, only the coaxial transmitter and receiver optical systems would be included, without the viewing optical system. Such a rangefinder might be used in a motion detector for a security system, in an aircraft altitude sensor, or in a vehicle separation sensor.

The laser rangefinder multifunction coaxial objective system of the present invention, and many of its intended advantages, will be understood from the foregoing description and it will be apparent that, although the invention and its advantages have been described in detail, various changes, substitutions, and alternations may be made in the manner, procedure, and details thereof without departing from the spirit and scope of the invention, as defined by the appended claims, or sacrificing all of its material advantages. The form hereinbefore described being merely a preferred or exemplary embodiment thereof.

We claim:

1. An improved optical catadioptric lens system for a rangefinder suitable for use as part of a night vision goggles system, comprising:

a transmitter optical system having an optical axis;

a receiver optical system having an optical axis;

an image intensifier; and

a viewing optical system adapted for receiving an image from the image intensifier, the viewing optical system having an optical axis, wherein the optical axes of the transmitter optical system, the receiver optical system, and the viewing optical system are coaxial in object space.

2. The improved optical system of claim **1**, wherein the viewing optical system includes a plurality of optical elements having central obscurations therein.

3. The improved optical system of claim **2**, wherein a visible and near infrared image produced by the viewing optical system passes through the central obscuration of a first optical element of the plurality of optical elements.

4. The improved optical system of claim **2**, wherein the rangefinder includes a laser emitter and a laser detector.

5. The improved optical system of claim **4**, wherein the optical axis of the laser emitter of the rangefinder is offset with respect to the coaxial axis of the transmitter, receiver, and viewing optical system, and wherein the transmitter optical system includes at least one folding mirror for reflecting laser energy from the laser emitter into a path concentric with the coaxial axis of the transmitter, receiver, and viewing optical systems.

6. The improved optical system of claim **4**, wherein laser energy transmitted by the laser emitter passes through the central obscuration of a second optical element of the plurality optical elements.

7. The improved optical system of claim **4**, wherein laser energy received by the laser detector passes through the central obscuration of the optical element.

8. The improved optical system of claim **4**, wherein the laser detector is located in the central obscuration of the optical element.

9. The improved optical system of claim **4**, further including a lens having a dichroic coating on one surface for transmitting visible and near infrared light and for reflecting light of the wavelength transmitted by the laser emitter.

10. The improved optical system of claim **9**, wherein the dichroic coated lens is located in the central obscuration of the optical element.

11. The improved optical system of claim **1**, wherein the viewing optical system includes an image intensifier tube for permitting night vision.

12. The improved optical system of claim **1**, wherein the viewing optical system includes a pair of focusing wedges for adjusting the focus of the viewing optical system.

13. The improved optical system of claim **12**, wherein each focusing wedge is a wedge shaped optical flat, the pair of focusing wedges being disposed against one another along a plane inclined with respect to the optical axis of the viewing optical system, whereby focus adjustment is achieved by relative movement between the focusing wedges along the inclined plane.

14. The improved optical system of claim **13**, further including means for moving at least one of the focusing wedges with respect to the other focusing wedge along the inclined plane for changing the optical thickness of the pair of focusing wedges, and thereby adjusting the focus of the viewing optical system.

15. The improved optical system of claim **14**, further including a housing for supporting the improved optical system, and wherein the means for moving at least one of the focusing wedges with respect to the other focusing wedge is a rotatable knob attached to the housing.

16. The improved optical system of claim **14**, further including a housing for supporting the improved optical

system, and wherein the means for moving at least one of the focusing wedges with respect to the other focusing wedge is a pivotable lever attached to the housing.

17. An improved optical catadioptric lens system for a rangefinder suitable for use as part of a night vision goggles system, the improved system including a laser emitter and a laser detector, the improved optical system comprising:

a viewing optical system;

an image intensifier adapted for projecting an image to the viewing optical system for viewing;

a transmitter optical system having an optical axis for transmitting laser energy from the laser emitter;

a receiver optical system having an optical axis for permitting the laser detector to receive laser energy, wherein the optical axes of the transmitter optical system and the receiver optical system are coaxial in object space; and

at least one optical element having a central obscuration therein included within the receiver optical system, wherein laser energy transmitted by the laser emitter passes through the central obscuration of the optical element.

18. The improved optical system of claim 17, wherein the optical axis of the laser emitter of the rangefinder is offset with respect to the coaxial axis of the transmitter and receiver optical systems, and wherein the transmitter optical system includes at least one folding mirror for reflecting laser energy from the laser emitter into a path concentric with the axis of the transmitter and receiver optical systems.

19. The improved optical system of claim 17, wherein laser energy received by the laser detector passes through the central obscuration of the optical element.

20. The improved optical system of claim 17, wherein the laser detector is located in the central obscuration of the optical element.

21. The improved optical system of claim 17, further including a viewing optical system having an optical axis, wherein the optical axes of the transmitter optical system, the receiver optical system, and the viewing optical system are coaxial in object space.

22. The improved optical system of claim 21, wherein at least one of the viewing optical system and the receiver optical system includes a lens having a dichroic coating on one surface, for transmitting visible and near infrared light, and for reflecting light of the wavelength transmitted by the laser emitter.

23. The improved optical system of claim 21, wherein the viewing optical system includes a pair of focusing wedges for adjusting the focus of the viewing optical system.

24. The improved optical system of claim 23, wherein each focusing wedge is a wedge shaped optical flat, the pair of focusing wedges being disposed against one another along a plane inclined with respect to the optical axis of the viewing optical system, whereby focus adjustment is achieved by relative movement between the focusing wedges along the inclined plane.

25. The improved optical system of claim 24, further including means for moving at least one of the focusing wedges with respect to the other focusing wedge along the inclined plane for changing the optical thickness of the pair of focusing wedges, and thereby adjusting the focus of the viewing optical system.

26. The improved optical system of claim 25, further including a housing for supporting the improved optical system, and wherein the means for moving at least one of the focusing wedges with respect to the other focusing wedge is a rotatable knob attached to the housing.

27. The improved optical system of claim 25, further including a housing for supporting the improved optical system, and wherein the means for moving at least one of the focusing wedges with respect to the other focusing wedge is a pivotable lever attached to the housing.

28. The improved optical system of claim 21, wherein the viewing optical system includes an image intensifier tube for permitting night vision.

29. A night vision goggle and rangefinder, comprising:

a housing;

a laser emitter having an optical axis supported within the housing;

a laser detector supported within the housing;

a transmitter optical system having an optical axis supported within the housing;

a receiver optical system having an optical axis supported within the housing;

a viewing optical system having an optical axis supported within the housing, wherein the optical axes of the transmitter optical system, the receiver optical system, and the viewing optical system are coaxial in object space;

an image intensifier tube included within the viewing optical system for permitting night vision;

a first optical element supported within the housing and having a central obscuration therein, wherein a visible image produced by the viewing optical system passes through the central obscuration of the first optical element;

a second optical element supported within the housing and having a central obscuration therein, wherein laser energy received by the laser detector passes through the central obscuration of the second optical element;

a third optical element supported within the housing and having a central obscuration therein, wherein laser energy transmitted by the laser emitter passes through the central obscuration of the third optical element;

a lens having a dichroic coating on one surface in at least one of the viewing optical system and the receiver optical system, for transmitting visible and near infrared light to the image intensifier tube and for reflecting laser energy received by the receiver optical system to the laser detector; and

a pair of focusing wedges for adjusting the focus of the viewing optical system, each focusing wedge being a wedge-shaped optical flat, the pair of focusing wedges being disposed against one another along a plane inclined with respect to the coaxial axis of the transmitter, receiver, and viewing optical systems, whereby focus adjustment is achieved by relative movement between the focusing wedges along the inclined plane.

30. The night vision goggle and rangefinder of claim 29, wherein the optical axis of the laser emitter is offset with respect to the coaxial axis of the transmitter, receiver, and viewing optical systems, and wherein the transmitter optical system includes at least one folding mirror for reflecting laser energy from the laser emitter into a path concentric with the coaxial axis of the transmitter, receiver, and viewing optical systems.

31. The night vision goggle and rangefinder of claim 29, further including means for moving at least one of the focusing wedges with respect to the other focusing

wedge along the inclined plane for changing the optical thickness of the pair of focusing wedges, and thereby adjusting the focus of the viewing optical system.

32. The night vision goggle and rangefinder of claim **31**, wherein the means for moving at least one of the focusing wedges with respect to the other focusing wedge is a rotatable knob attached to the housing.

33. The night vision goggle and rangefinder of claim **31**, wherein the means for moving at least one of the focusing wedges with respect to the other focusing wedge is a pivotable lever attached to the housing.

* * * * *

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United States Patent [19]

Baker et al.

[11] Patent Number: 5,327,291

[45] Date of Patent: Jul. 5, 1994

[54] COMPACT OBJECTIVE LENS

[75] Inventors: **James G. Baker**, Bedford, N.H.; **William T. Plummer**; **Jon Van Tassell**, both of Concord, Mass.

[73] Assignee: **Polaroid Corporation**, Cambridge, Mass.

[21] Appl. No.: **860,401**

[22] Filed: **Mar. 30, 1992**

[51] **Int. Cl.**[5] **G02B 3/02**; G02B 9/04

[52] **U.S. Cl.** **359/716**; 359/717; 359/740; 359/793; 359/794

[58] **Field of Search** 359/793-794, 359/740, 716-717, 715, 771, 772, 791, 792

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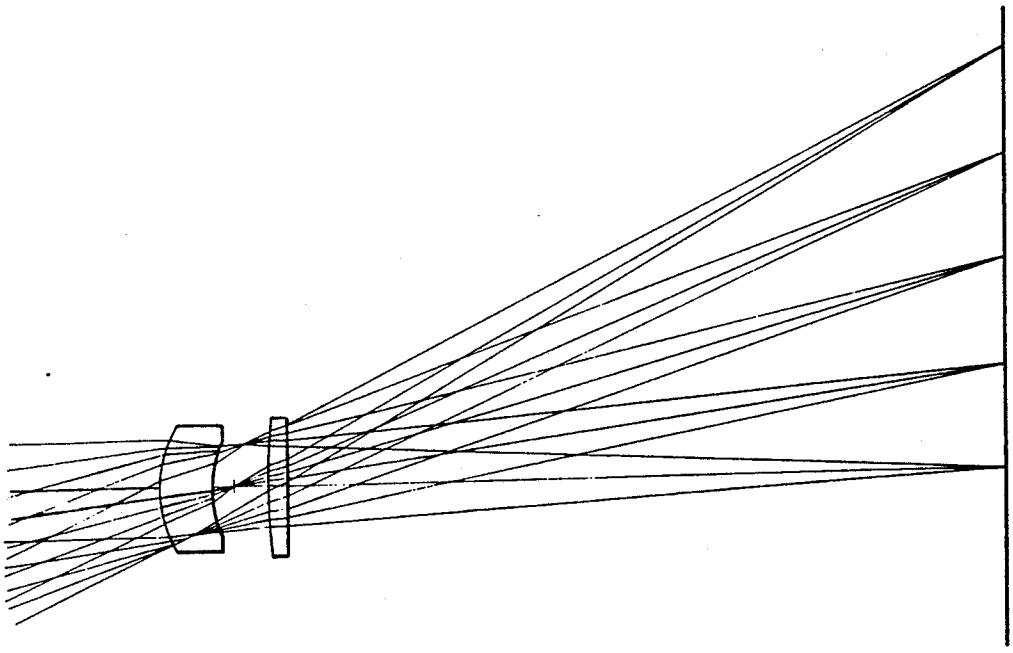
Primary Examiner—Bruce Y. Arnold
Assistant Examiner—James Phan
Attorney, Agent, or Firm—Francis J. Caufield

[57] **ABSTRACT**

A lens system for a folding reflex camera is provided. The system includes: (a) a first group on the object side of the system's stop which (i) has a positive dioptric power, (ii) includes an aspheric surface, and (iii) has a concave surface adjacent to the stop; and (b) a second group on the image side of the stop consisting of either a single positive component or the combination of a single positive component and one or more focusing elements. The system includes at least two elements made of materials differing in dispersive powers where at least one of the elements is of plastic. The system can comprise just two plastic elements and even with such a simple configuration achieves excellent optical performance including a relatively flat field, relatively low distortion, and at least partial correction for lateral chromatic aberration.

18 Claims, 43 Drawing Sheets



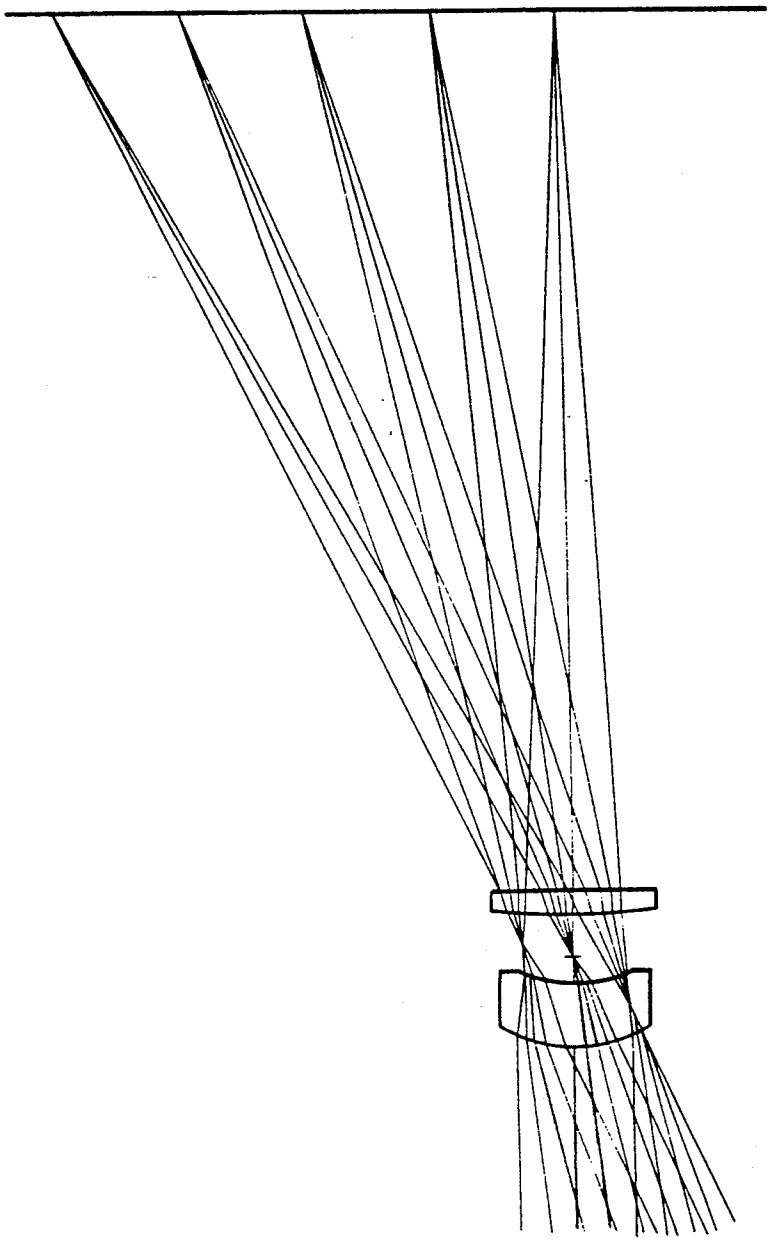


FIG. IA

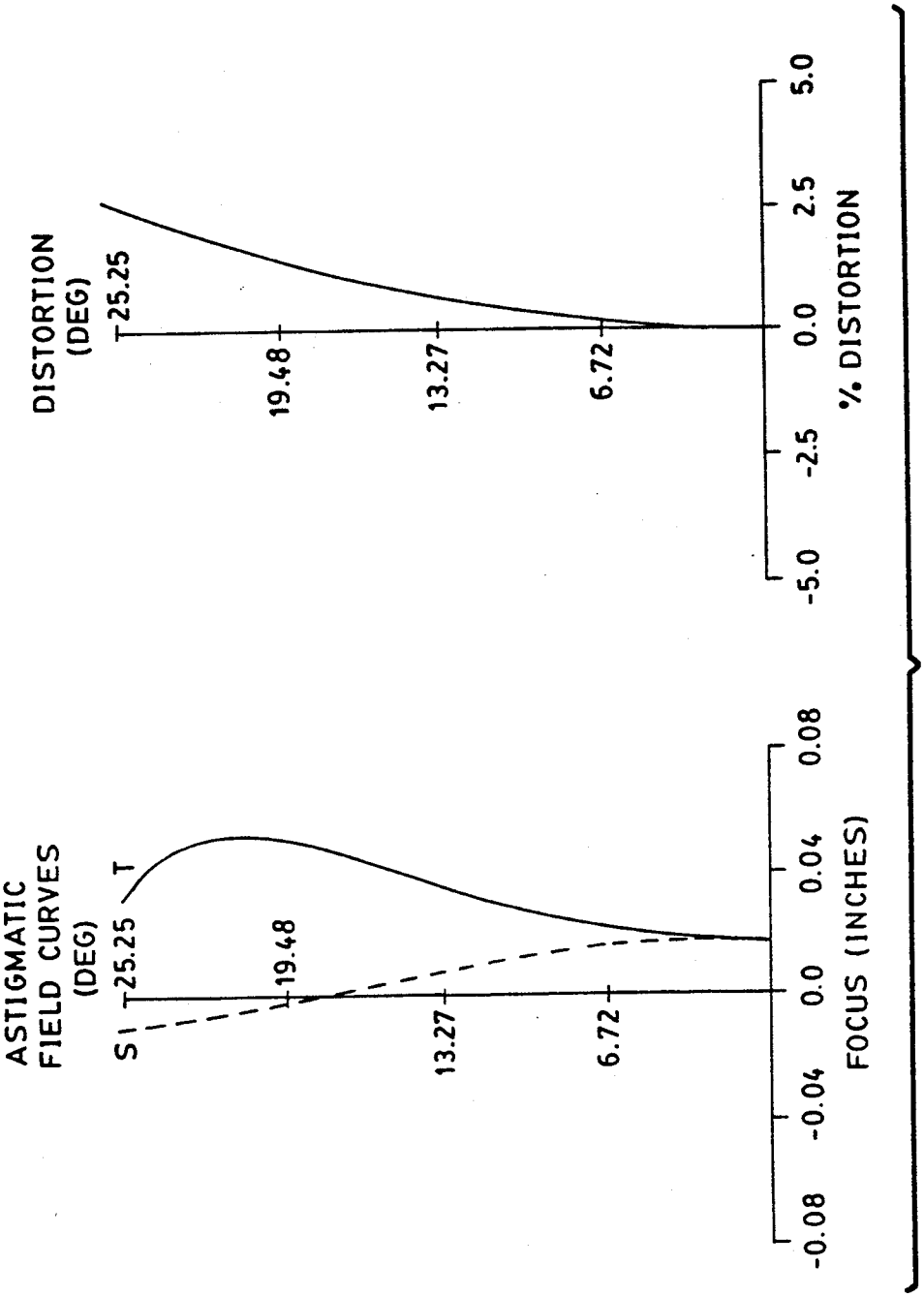

DISTORTION (DEG)
25.25
19.48
13.27
6.72
5.0
2.5
0.0
-2.5
-5.0
% DISTORTION
ASTIGMATIC FIELD CURVES (DEG)
S
T
25.25
19.48
13.27
6.72
0.08
0.04
0.0
-0.04
-0.08
FOCUS (INCHES)

FIG. 1B

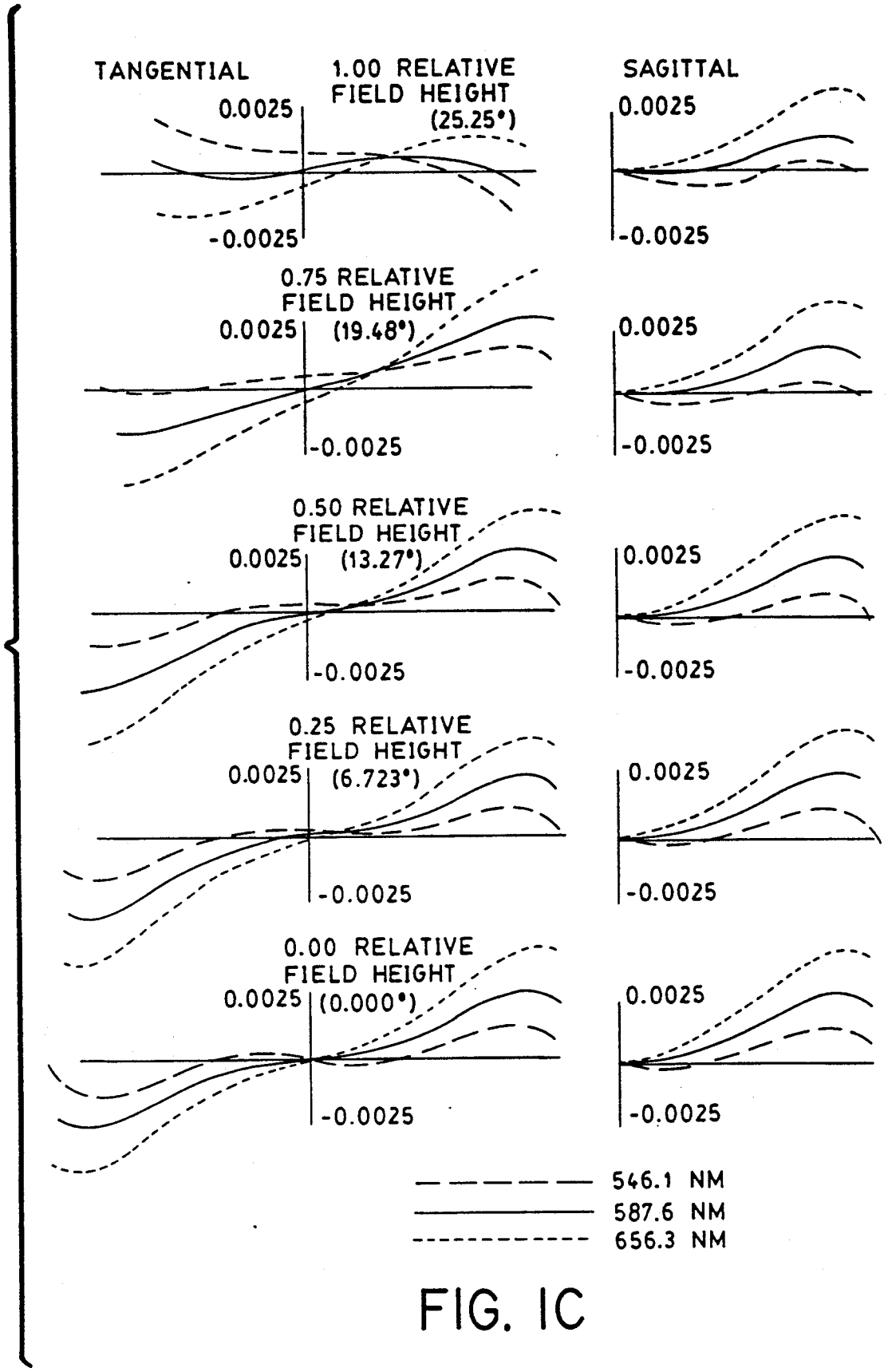

TANGENTIAL
1.00 RELATIVE FIELD HEIGHT (25.25°)
SAGITTAL
0.0025
-0.0025
0.75 RELATIVE FIELD HEIGHT (19.48°)
0.50 RELATIVE FIELD HEIGHT (13.27°)
0.25 RELATIVE FIELD HEIGHT (6.723°)
0.00 RELATIVE FIELD HEIGHT (0.000°)
546.1 NM
587.6 NM
656.3 NM

FIG. IC

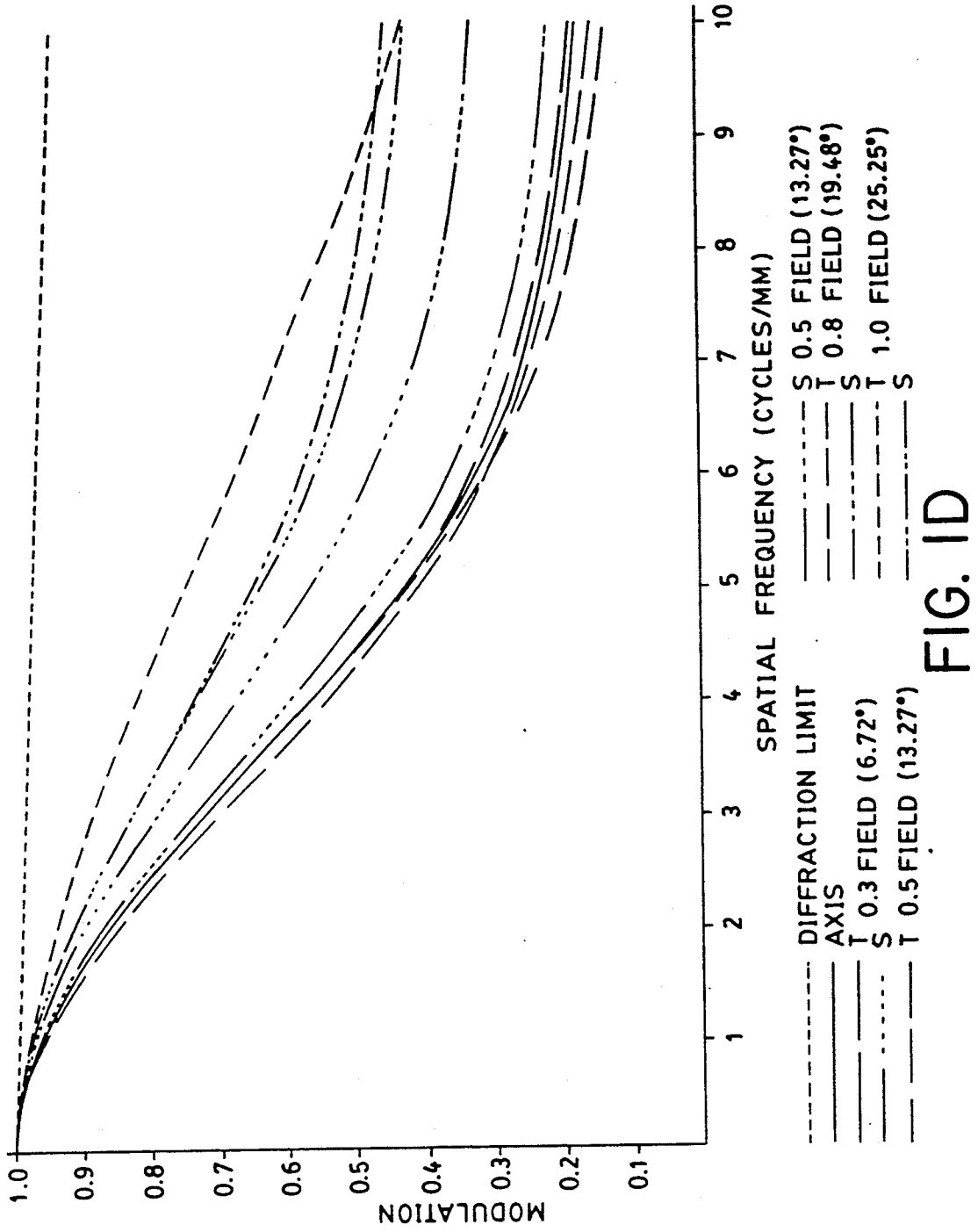

MODULATION
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
SPATIAL FREQUENCY (CYCLES/MM)
1
2
3
4
5
6
7
8
9
10
DIFFRACTION LIMIT
AXIS
T 0.3 FIELD (6.72°)
S 0.3 FIELD (6.72°)
T 0.5 FIELD (13.27°)
S 0.5 FIELD (13.27°)
T 0.8 FIELD (19.48°)
S
T 1.0 FIELD (25.25°)
S

FIG. 1D

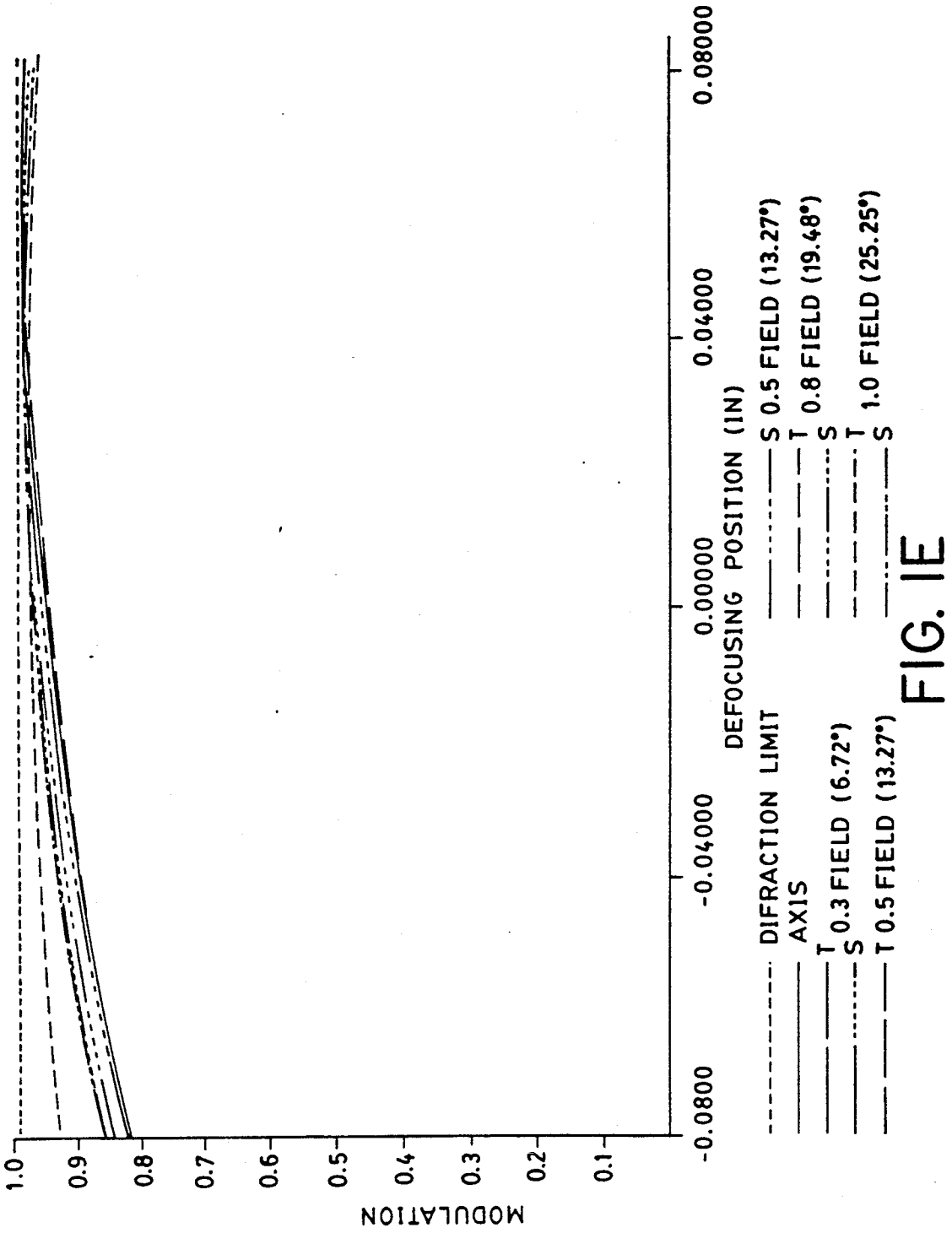

MODULATION
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
-0.0800
-0.04000
0.00000
0.04000
0.08000
DEFOCUSING POSITION (IN)
DIFRACTION LIMIT
AXIS
T 0.3 FIELD (6.72°)
S 0.3 FIELD (6.72°)
T 0.5 FIELD (13.27°)
S 0.5 FIELD (13.27°)
T 0.8 FIELD (19.48°)
S 0.8 FIELD (19.48°)
T 1.0 FIELD (25.25°)
S 1.0 FIELD (25.25°)

FIG. 1E

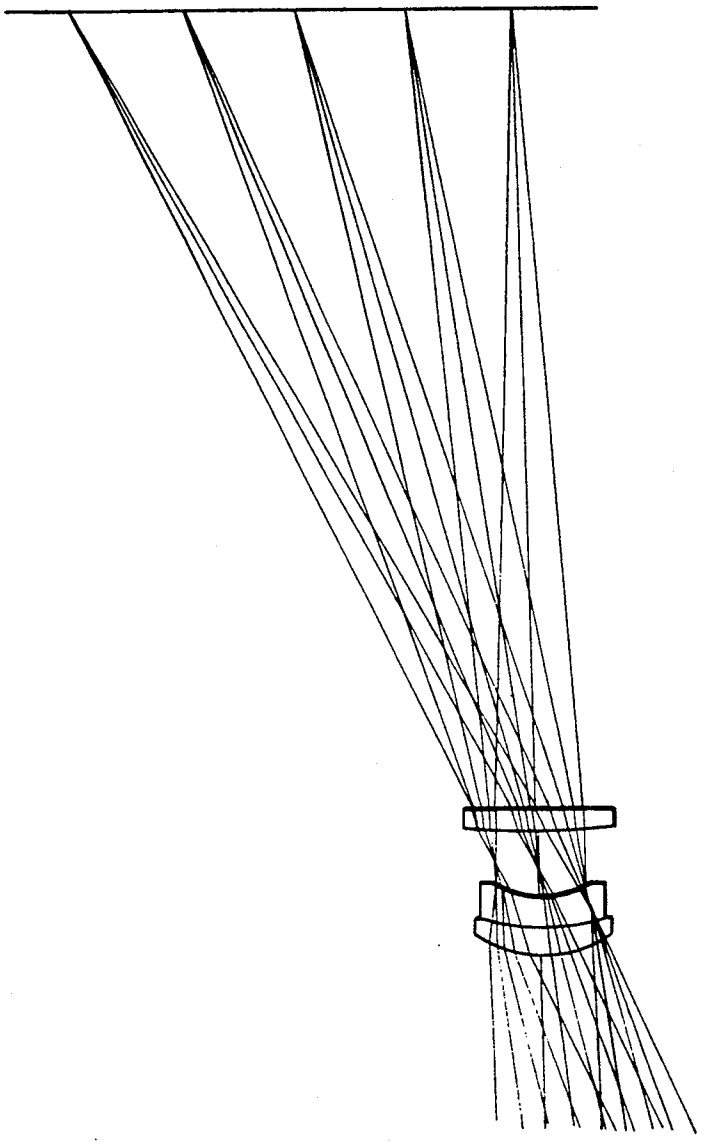


FIG. 2A

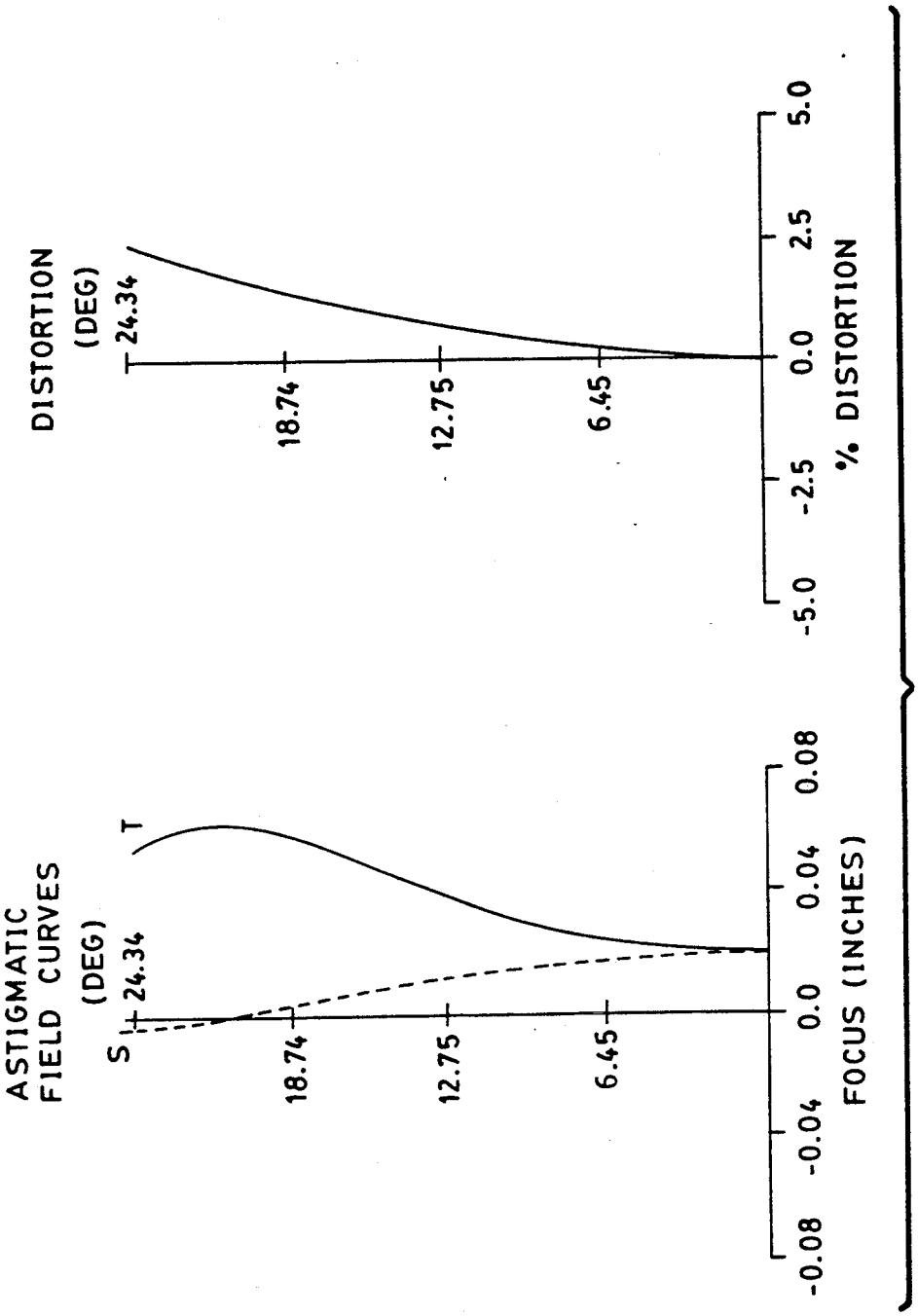

DISTORTION
(DEG)
24.34
18.74
12.75
6.45
-5.0
-2.5
0.0
2.5
5.0
% DISTORTION
ASTIGMATIC
FIELD CURVES
(DEG)
S
T
24.34
18.74
12.75
6.45
-0.08
-0.04
0.0
0.04
0.08
FOCUS (INCHES)

FIG. 2B

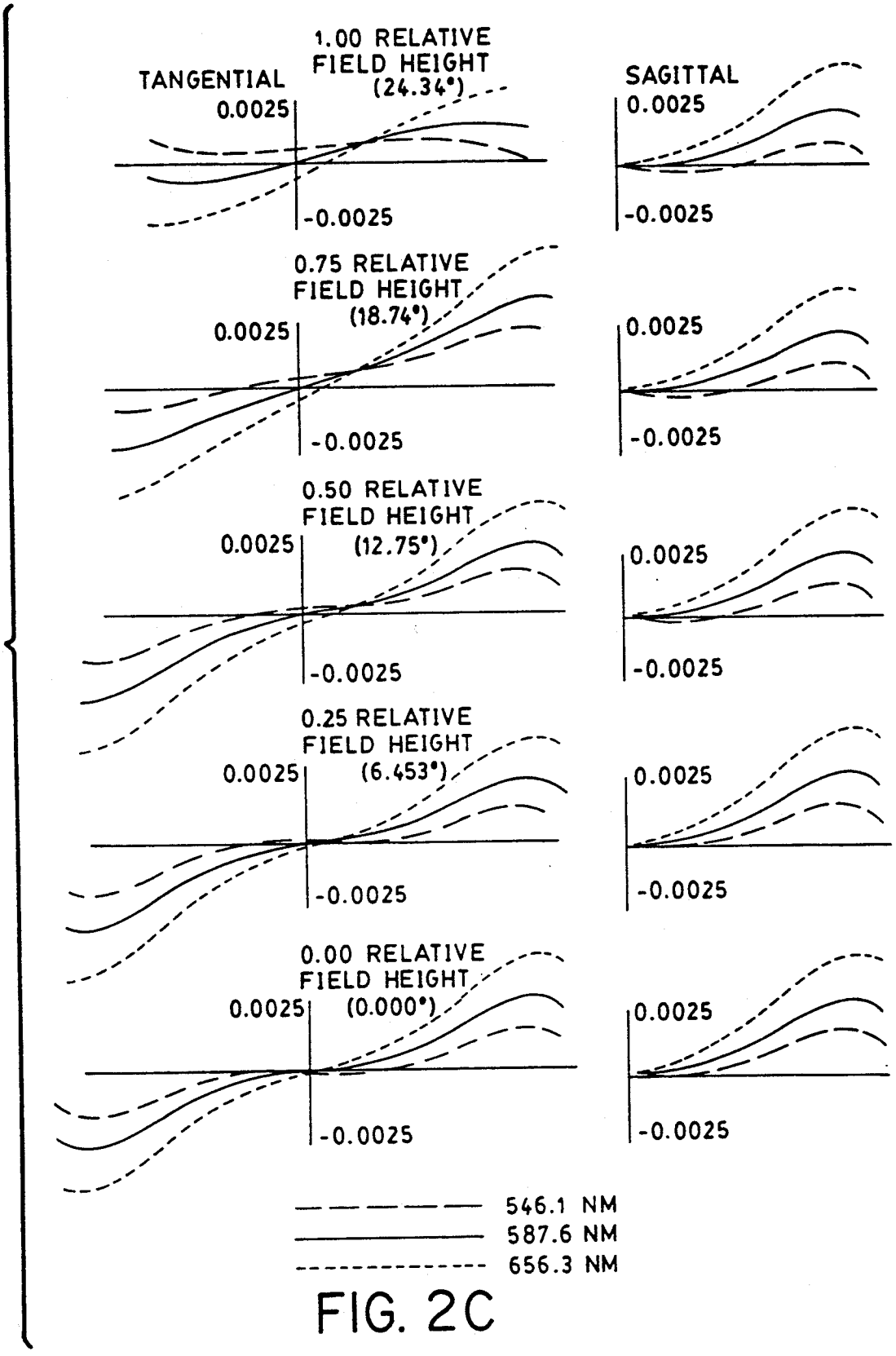

1.00 RELATIVE FIELD HEIGHT (24.34°)
TANGENTIAL
SAGITTAL
0.0025
-0.0025
0.75 RELATIVE FIELD HEIGHT (18.74°)
0.50 RELATIVE FIELD HEIGHT (12.75°)
0.25 RELATIVE FIELD HEIGHT (6.453°)
0.00 RELATIVE FIELD HEIGHT (0.000°)
546.1 NM
587.6 NM
656.3 NM

FIG. 2C

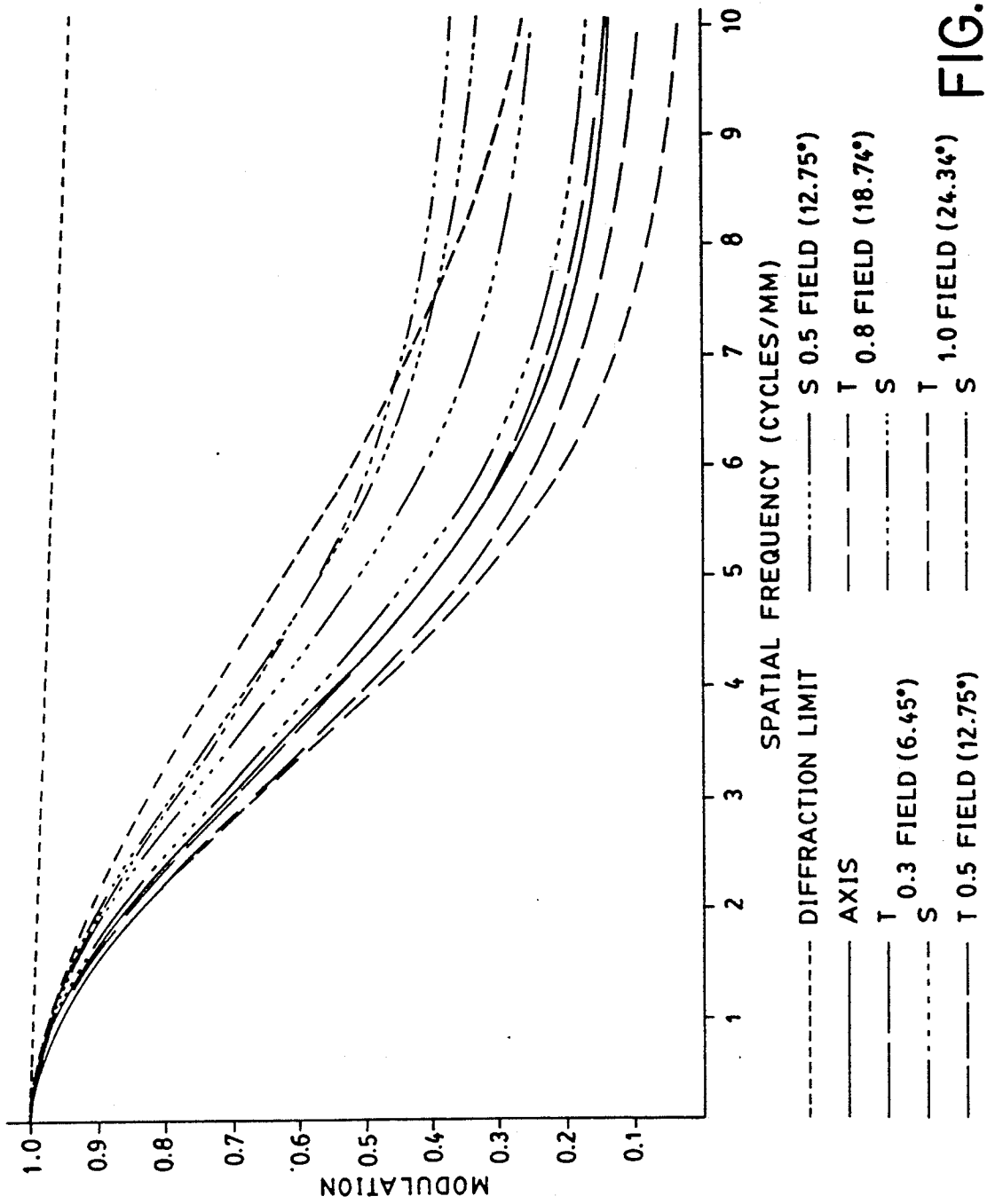

MODULATION
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
1
2
3
4
5
6
7
8
9
10
SPATIAL FREQUENCY (CYCLES/MM)
DIFFRACTION LIMIT
AXIS
T 0.3 FIELD (6.45°)
S
T 0.5 FIELD (12.75°)
S 0.5 FIELD (12.75°)
T 0.8 FIELD (18.74°)
S
T 1.0 FIELD (24.34°)
S

FIG. 2D

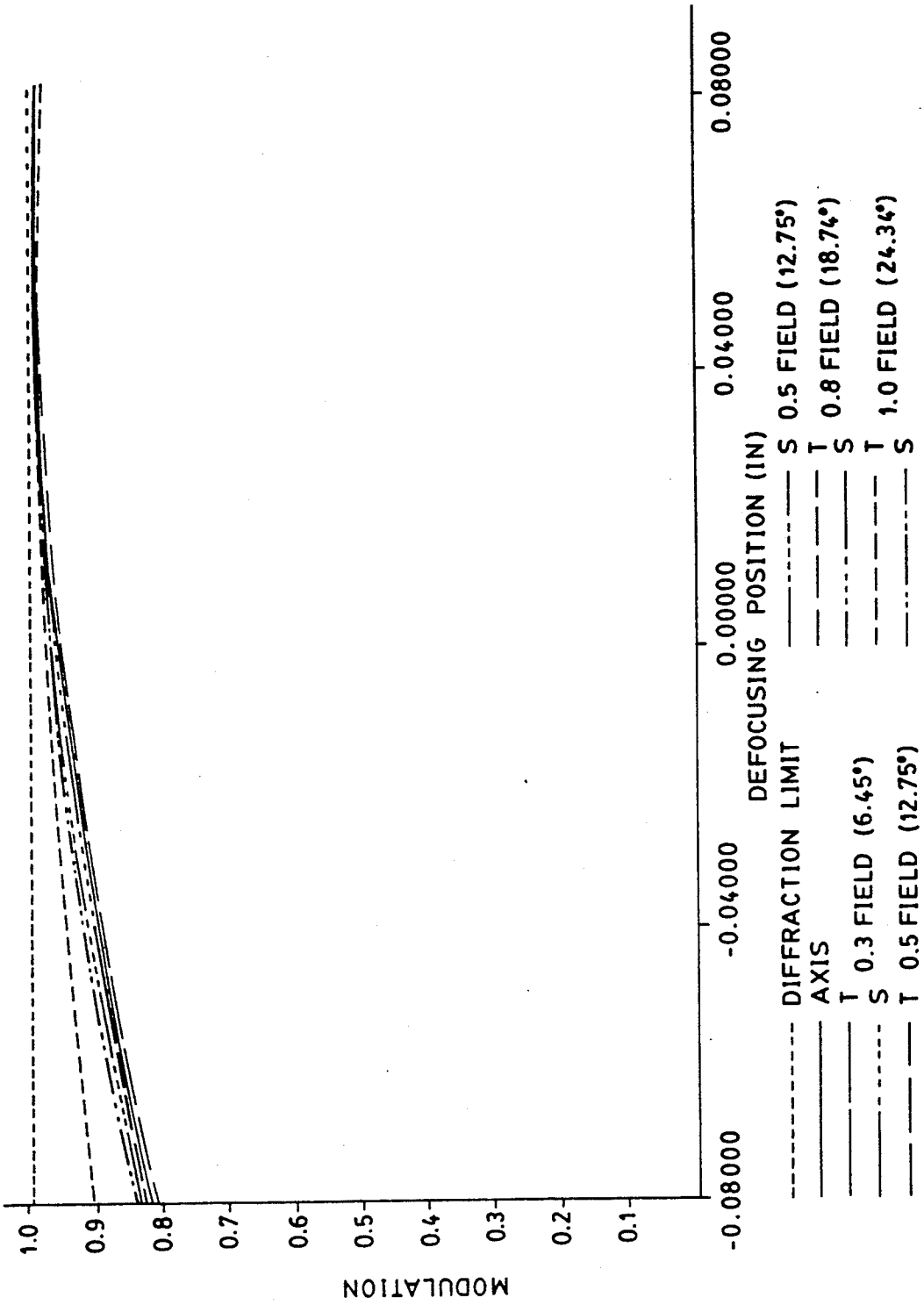

MODULATION
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
-0.08000
-0.04000
0.00000
0.04000
0.08000
DEFOCUSING POSITION (IN)
DIFFRACTION LIMIT
AXIS
T 0.3 FIELD (6.45°)
S 0.3 FIELD (6.45°)
T 0.5 FIELD (12.75°)
S 0.5 FIELD (12.75°)
T 0.8 FIELD (18.74°)
S 0.8 FIELD (18.74°)
T 1.0 FIELD (24.34°)
S 1.0 FIELD (24.34°)

FIG. 2E

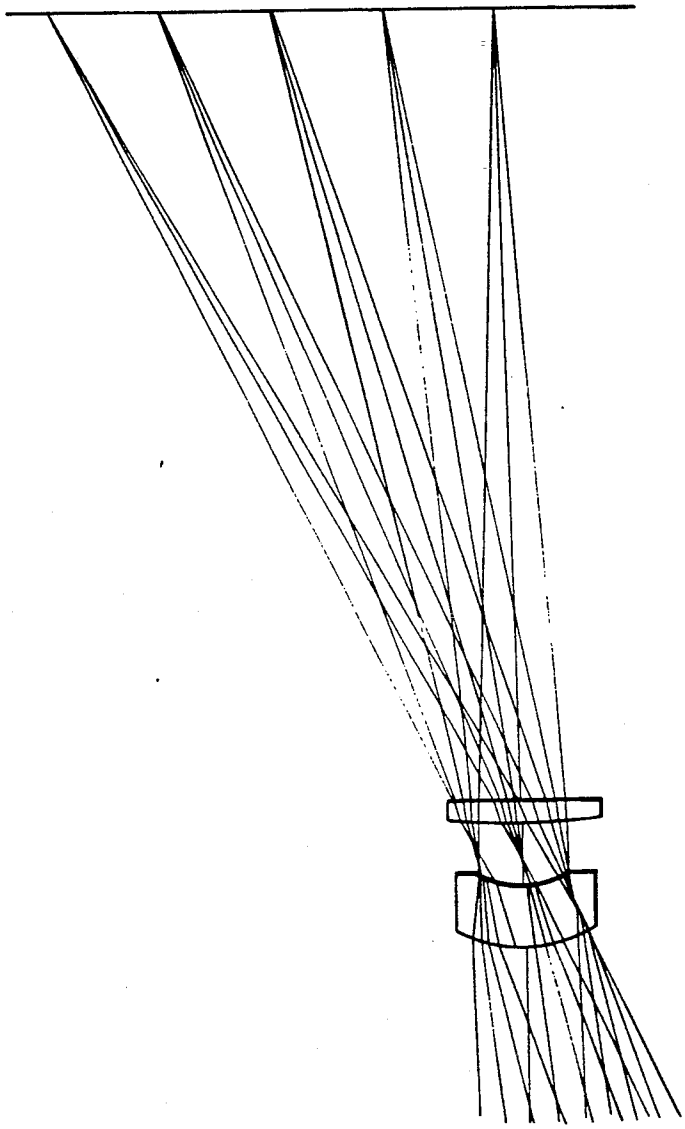


FIG. 3A

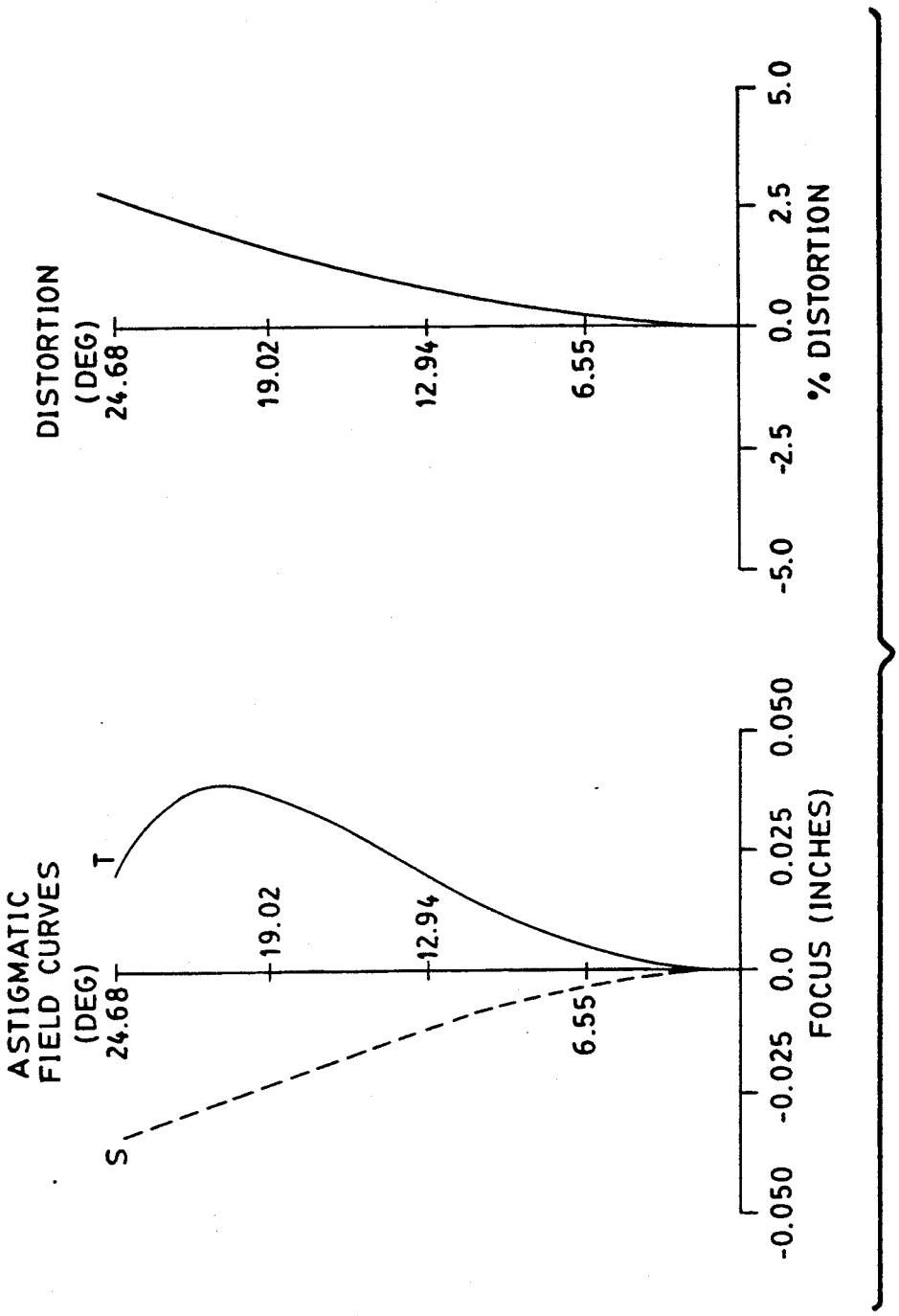

ASTIGMATIC FIELD CURVES
(DEG)
24.68
19.02
12.94
6.55
T
S
-0.050
-0.025
0.0
0.025
0.050
FOCUS (INCHES)
DISTORTION
(DEG)
24.68
19.02
12.94
6.55
-5.0
-2.5
0.0
2.5
5.0
% DISTORTION

FIG. 3B

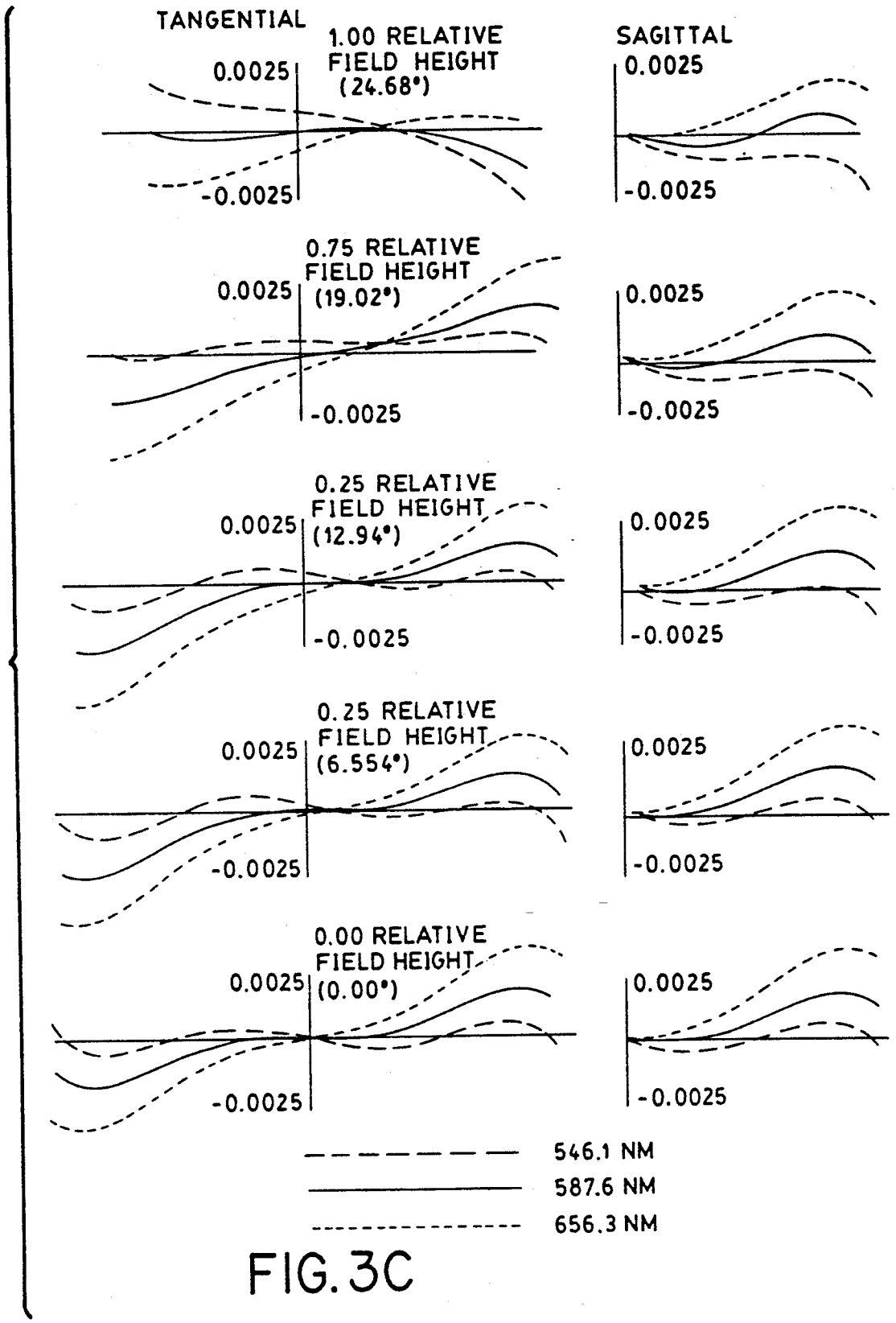

TANGENTIAL
SAGITTAL
1.00 RELATIVE FIELD HEIGHT (24.68°)
0.75 RELATIVE FIELD HEIGHT (19.02°)
0.25 RELATIVE FIELD HEIGHT (12.94°)
0.25 RELATIVE FIELD HEIGHT (6.554°)
0.00 RELATIVE FIELD HEIGHT (0.00°)
0.0025
-0.0025
546.1 NM
587.6 NM
656.3 NM

FIG. 3C

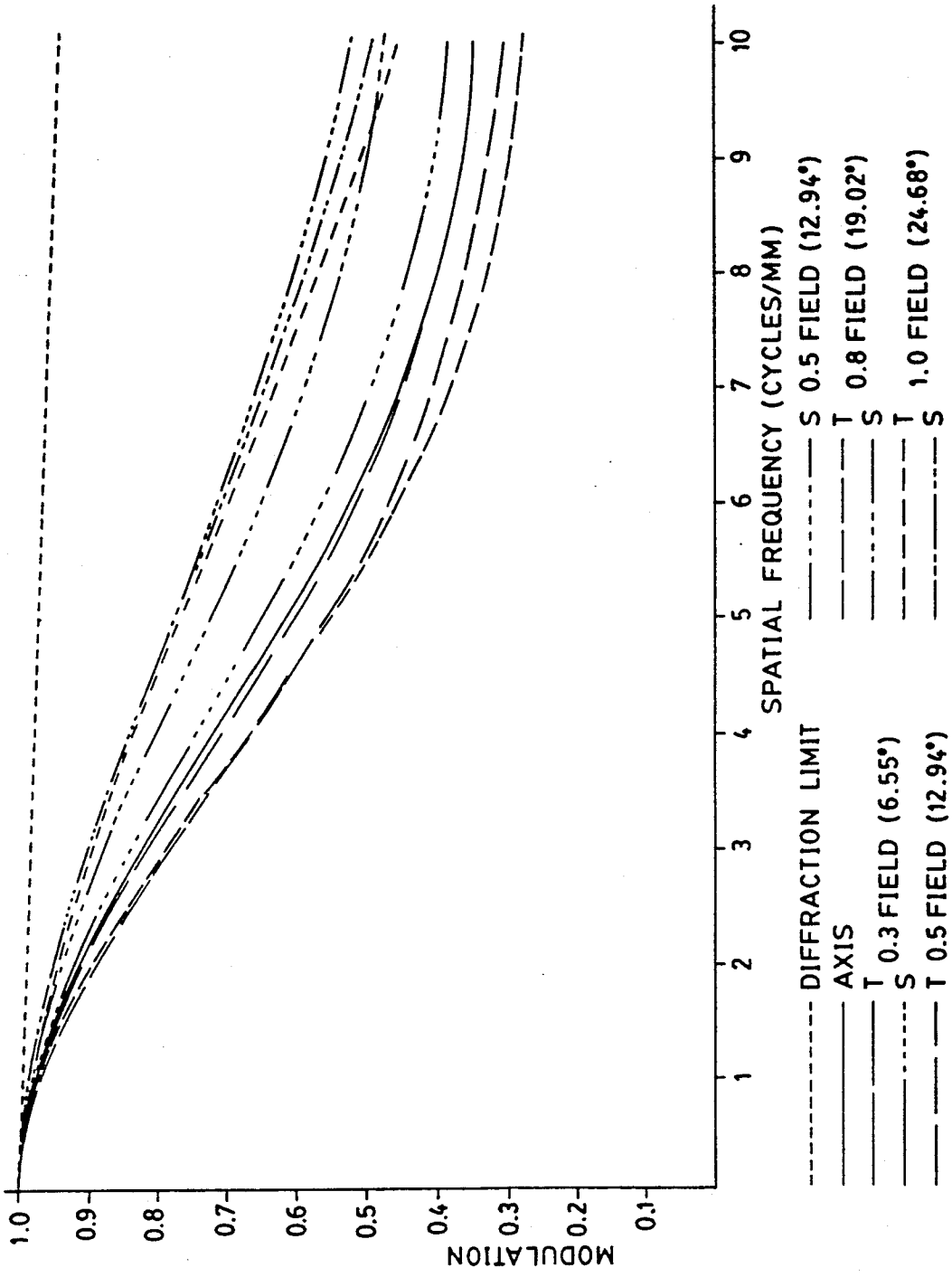

MODULATION
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
1
2
3
4
5
6
7
8
9
10
SPATIAL FREQUENCY (CYCLES/MM)
DIFFRACTION LIMIT
AXIS
T 0.3 FIELD (6.55°)
S 0.3 FIELD (6.55°)
T 0.5 FIELD (12.94°)
S 0.5 FIELD (12.94°)
T 0.8 FIELD (19.02°)
S 0.8 FIELD (19.02°)
T 1.0 FIELD (24.68°)
S 1.0 FIELD (24.68°)

FIG. 3D

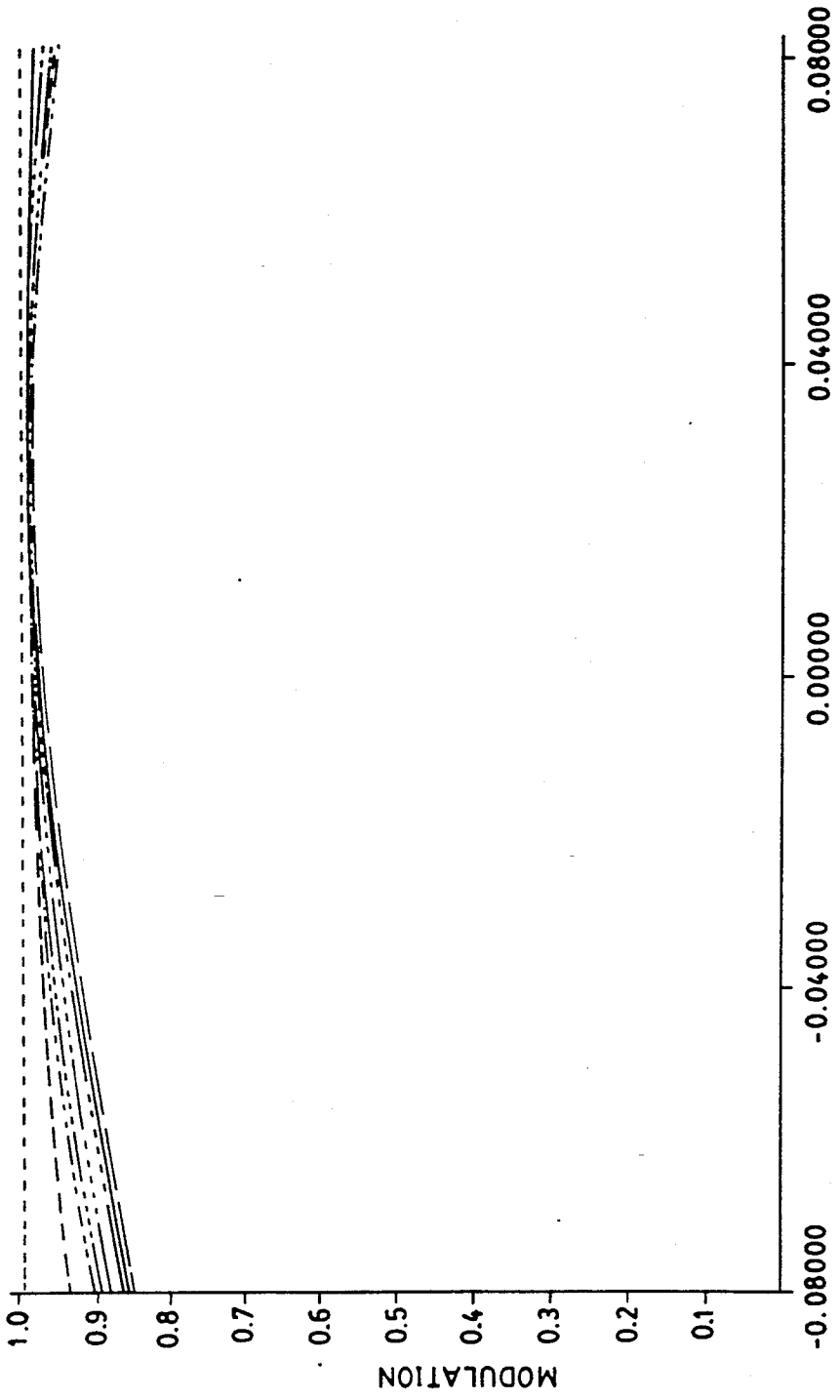

MODULATION
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
-0.08000
-0.04000
0.00000
0.04000
0.08000
DEFOCUSING POSITION (IN)
DIFFRACTION LIMIT
AXIS
T 0.3 FIELD (6.55')
S 0.3 FIELD (6.55')
T 0.5 FIELD (12.94')
S 0.5 FIELD (12.94')
T 0.8 FIELD (19.02')
S 0.8 FIELD (19.02')
T 1.0 FIELD (24.68')
S 1.0 FIELD (24.68')

FIG. 3E

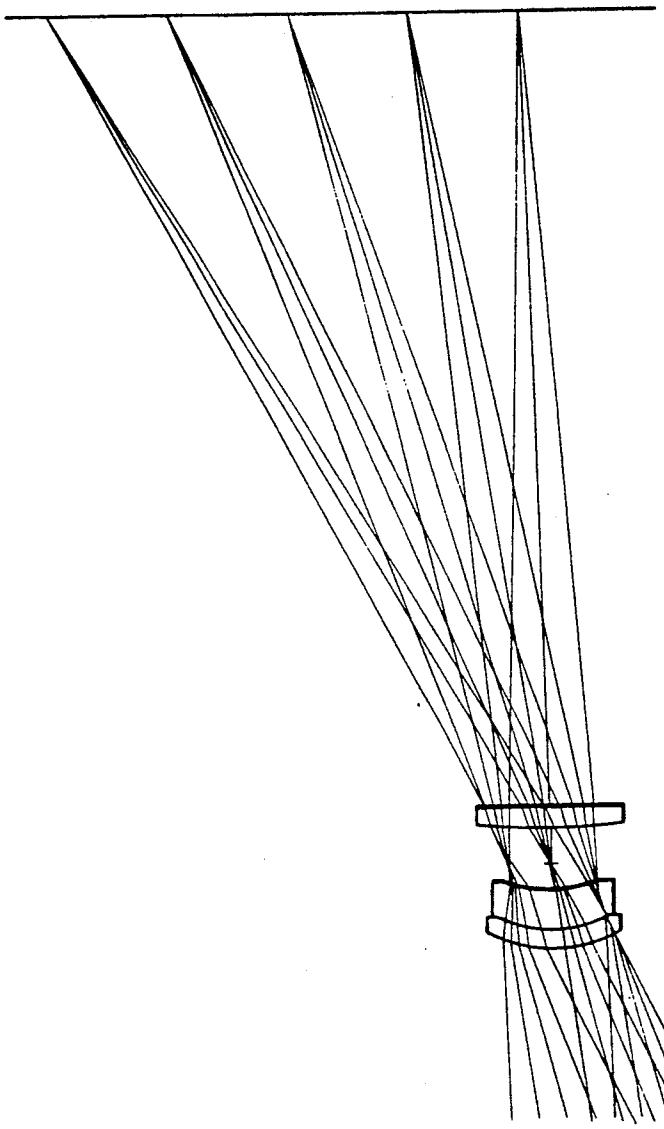


FIG.4A

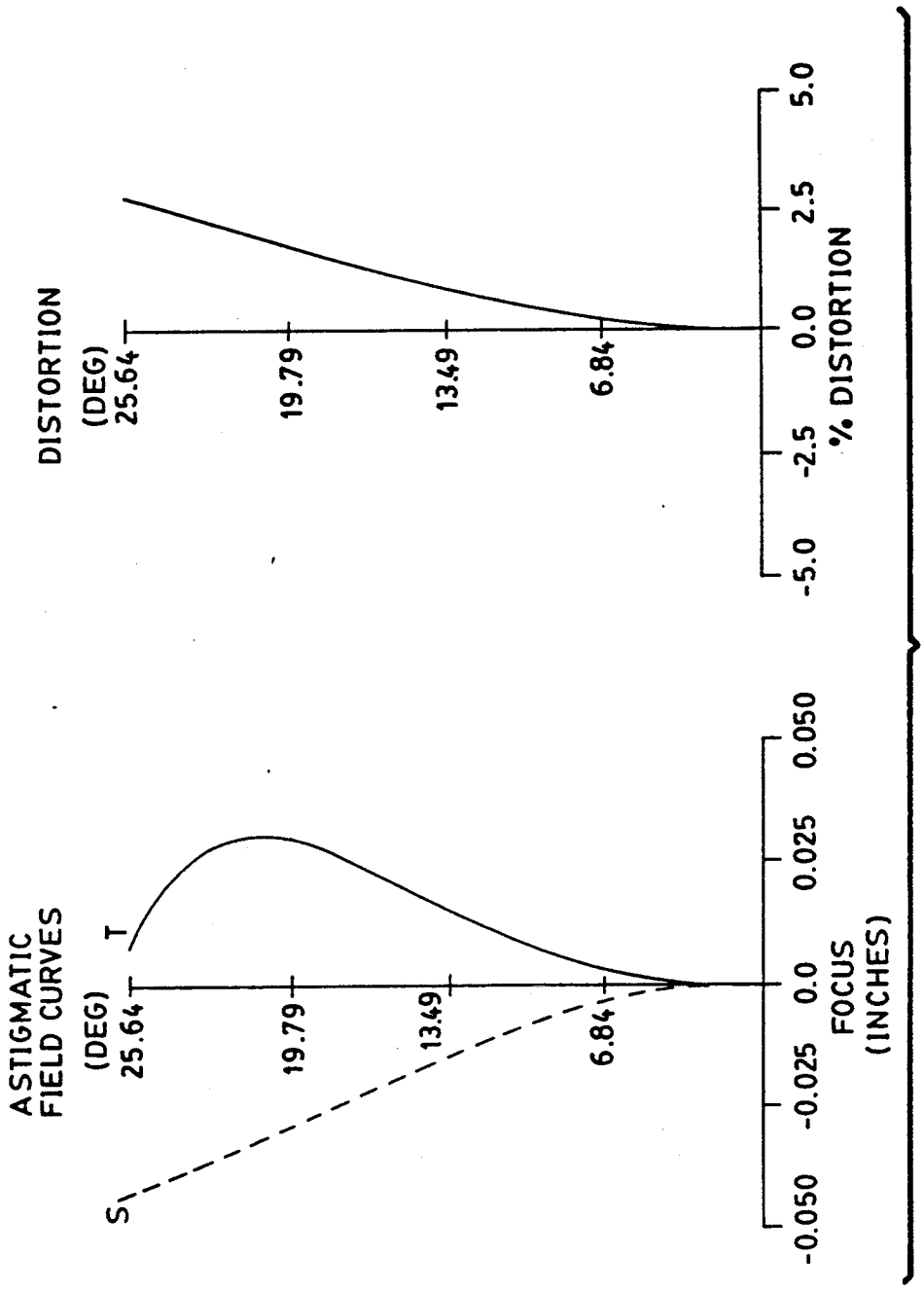

DISTORTION
(DEG)
25.64
19.79
13.49
6.84
-5.0
-2.5
0.0
2.5
5.0
% DISTORTION
ASTIGMATIC
FIELD CURVES
(DEG)
25.64
19.79
13.49
6.84
T
S
-0.050
-0.025
0.0
0.025
0.050
FOCUS
(INCHES)

FIG. 4B

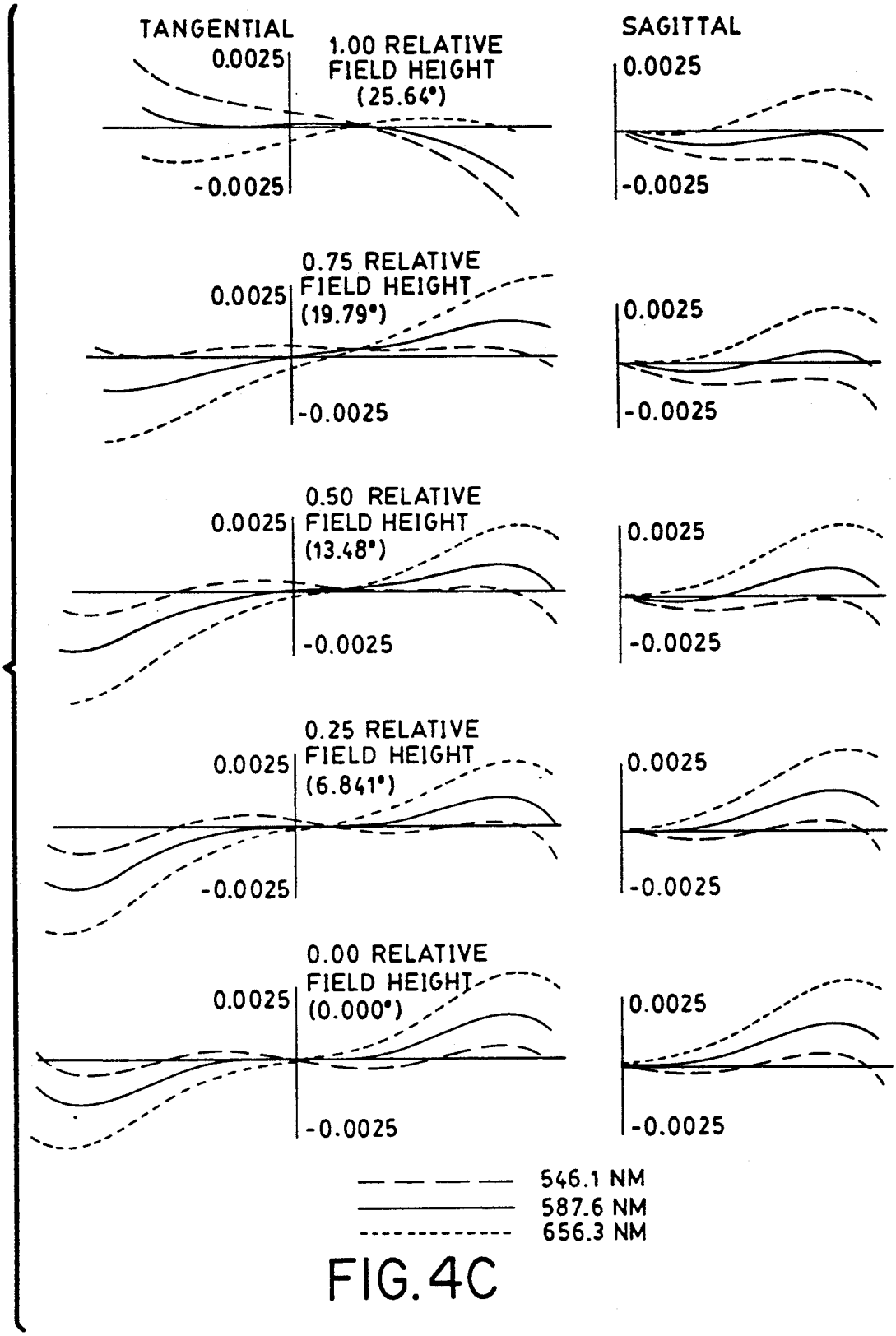

TANGENTIAL
SAGITTAL
1.00 RELATIVE FIELD HEIGHT (25.64°)
0.75 RELATIVE FIELD HEIGHT (19.79°)
0.50 RELATIVE FIELD HEIGHT (13.48°)
0.25 RELATIVE FIELD HEIGHT (6.841°)
0.00 RELATIVE FIELD HEIGHT (0.000°)
0.0025
-0.0025
546.1 NM
587.6 NM
656.3 NM

FIG. 4C

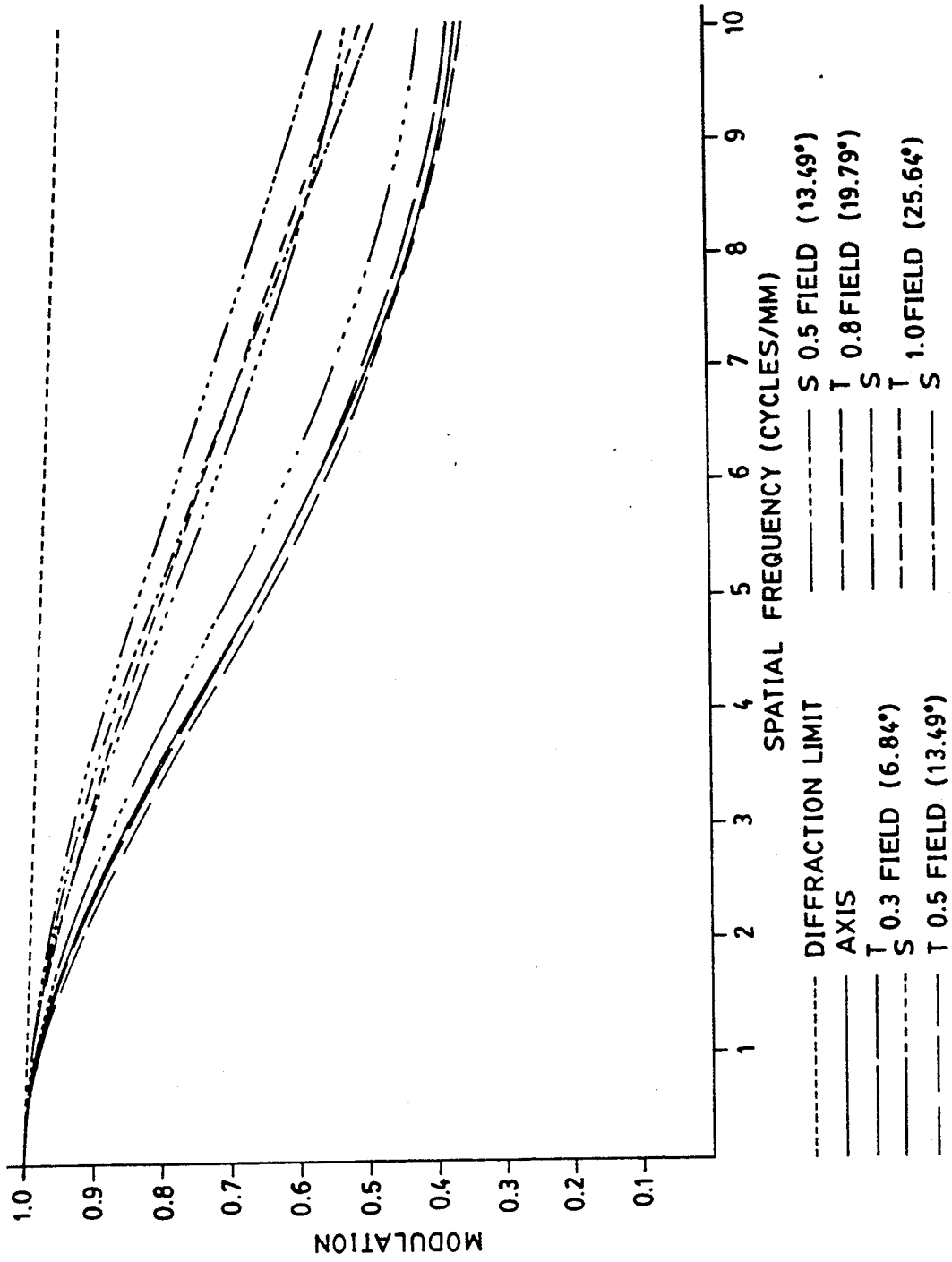

MODULATION
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
SPATIAL FREQUENCY (CYCLES/MM)
1
2
3
4
5
6
7
8
9
10
DIFFRACTION LIMIT
AXIS
T
S 0.3 FIELD (6.84°)
T 0.5 FIELD (13.49°)
S 0.5 FIELD (13.49°)
T 0.8 FIELD (19.79°)
S
T 1.0 FIELD (25.64°)
S

FIG.4D

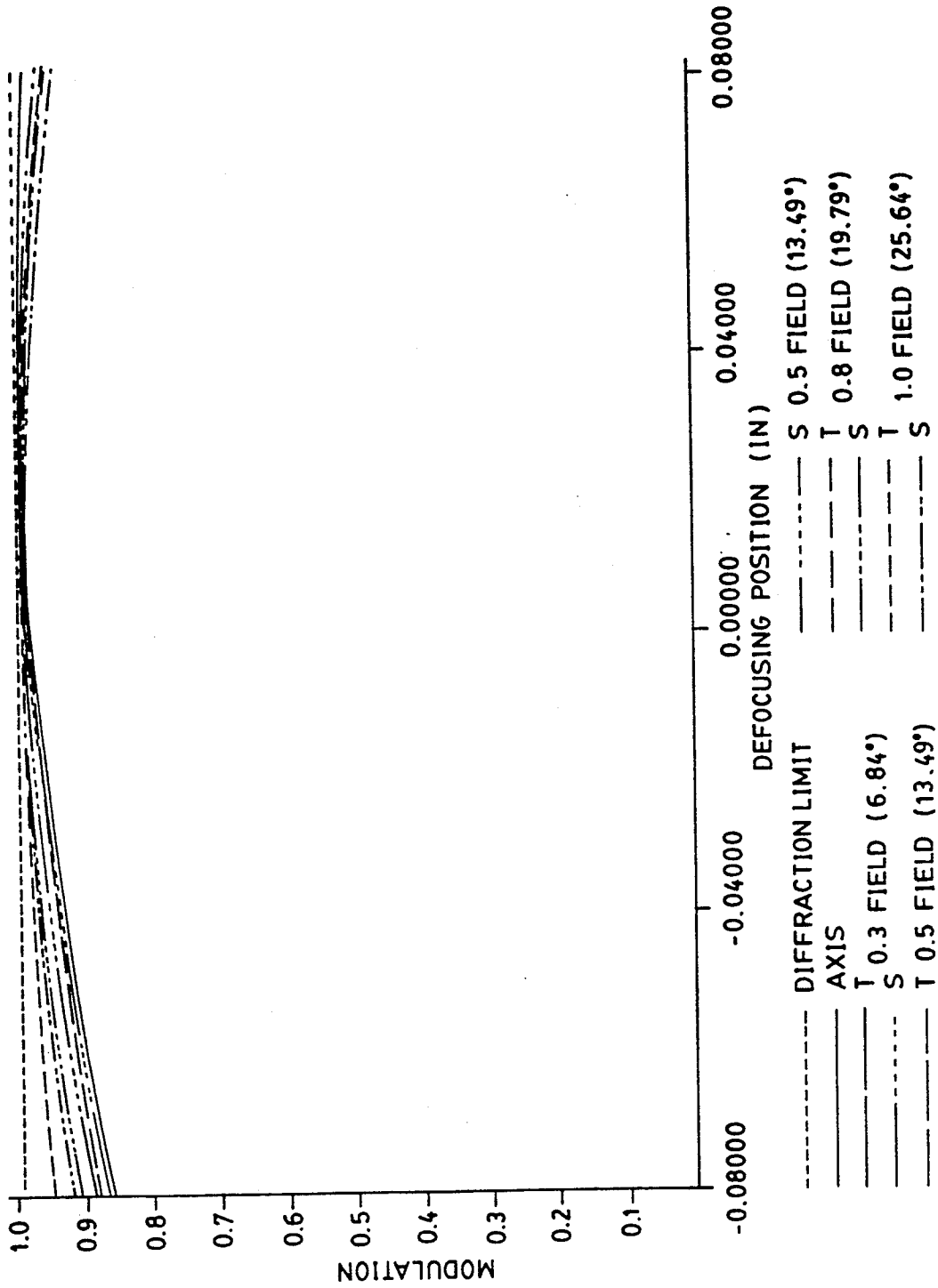

MODULATION
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
-0.08000
-0.04000
0.00000
0.04000
0.08000
DEFOCUSING POSITION (IN)
DIFFRACTION LIMIT
AXIS
T 0.3 FIELD (6.84°)
S 0.3 FIELD (6.84°)
T 0.5 FIELD (13.49°)
S 0.5 FIELD (13.49°)
T 0.8 FIELD (19.79°)
S 0.8 FIELD (19.79°)
T 1.0 FIELD (25.64°)
S 1.0 FIELD (25.64°)

FIG.4E

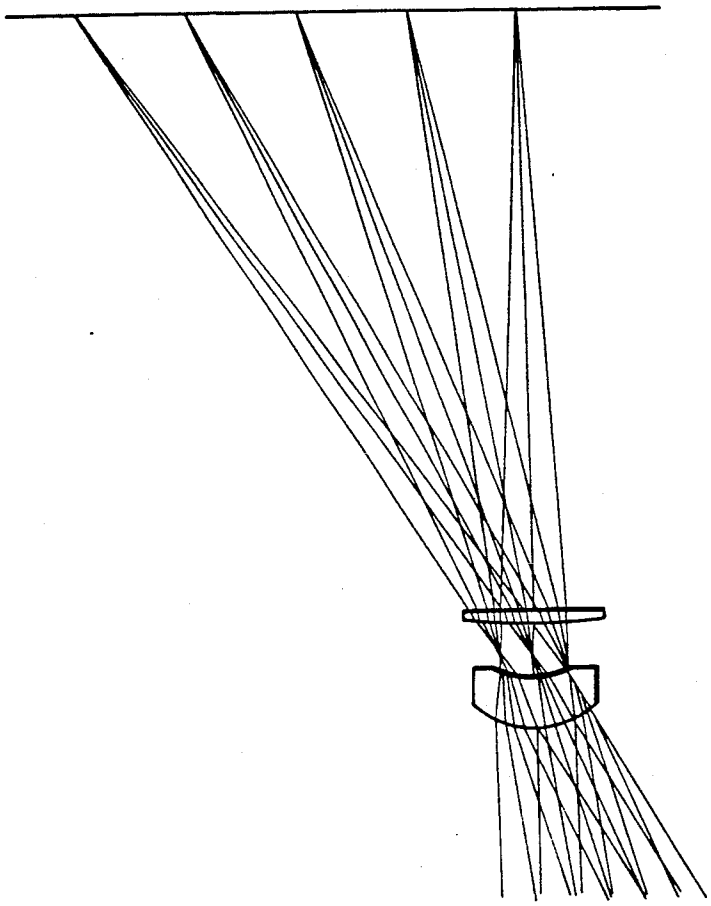


FIG.5A

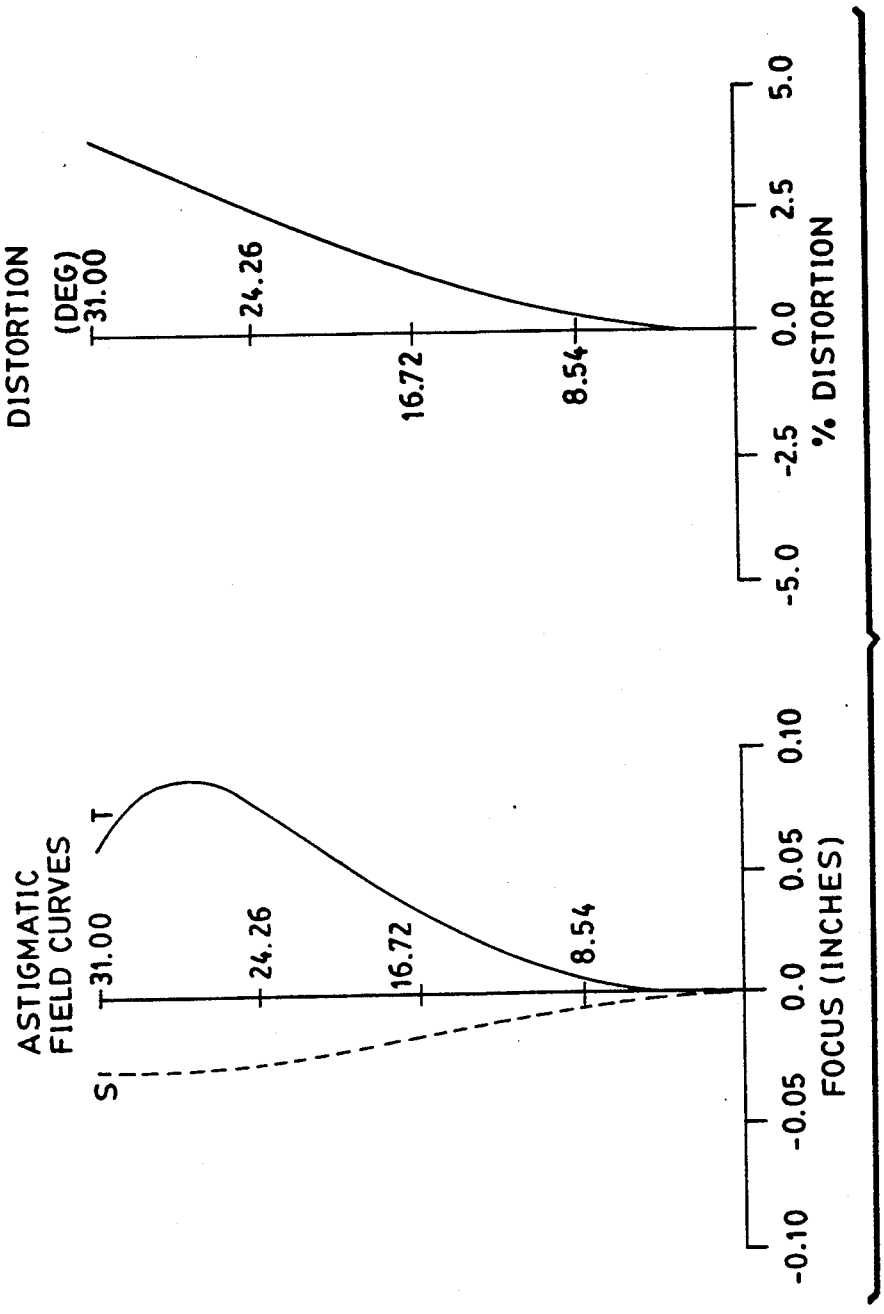

DISTORTION
(DEG)
31.00
24.26
16.72
8.54
5.0
2.5
0.0
-2.5
-5.0
% DISTORTION
ASTIGMATIC
FIELD CURVES
T
S
31.00
24.26
16.72
8.54
0.10
0.05
0.0
-0.05
-0.10
FOCUS (INCHES)

FIG. 5B

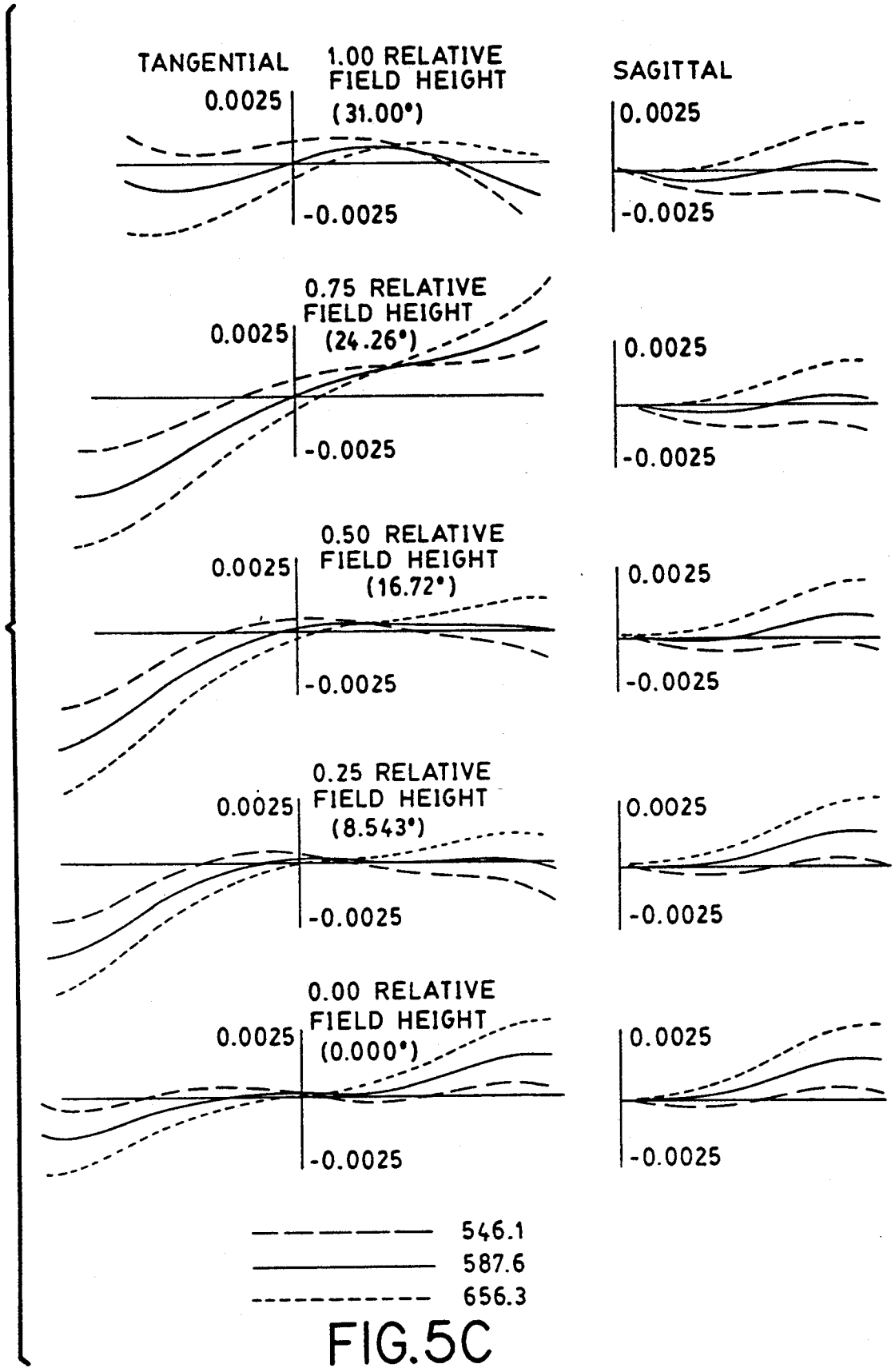

TANGENTIAL
1.00 RELATIVE FIELD HEIGHT (31.00°)
SAGITTAL
0.0025
-0.0025
0.75 RELATIVE FIELD HEIGHT (24.26°)
0.50 RELATIVE FIELD HEIGHT (16.72°)
0.25 RELATIVE FIELD HEIGHT (8.543°)
0.00 RELATIVE FIELD HEIGHT (0.000°)
546.1
587.6
656.3

FIG.5C

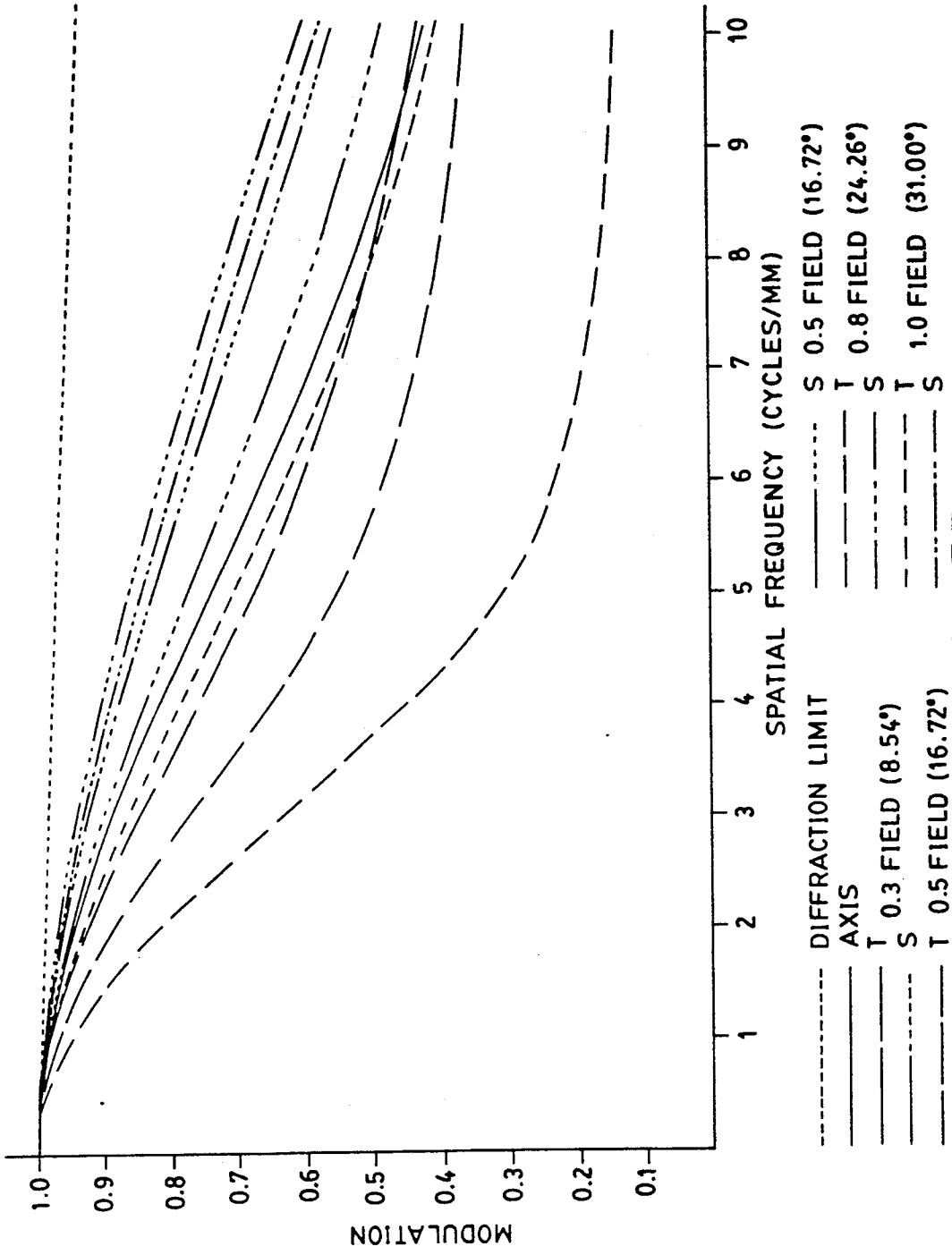

MODULATION
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
SPATIAL FREQUENCY (CYCLES/MM)
1
2
3
4
5
6
7
8
9
10
DIFFRACTION LIMIT
AXIS
T 0.3 FIELD (8.54°)
S 0.3 FIELD (8.54°)
T 0.5 FIELD (16.72°)
S 0.5 FIELD (16.72°)
T 0.8 FIELD (24.26°)
S 0.8 FIELD (24.26°)
T 1.0 FIELD (31.00°)
S 1.0 FIELD (31.00°)

FIG. 5D

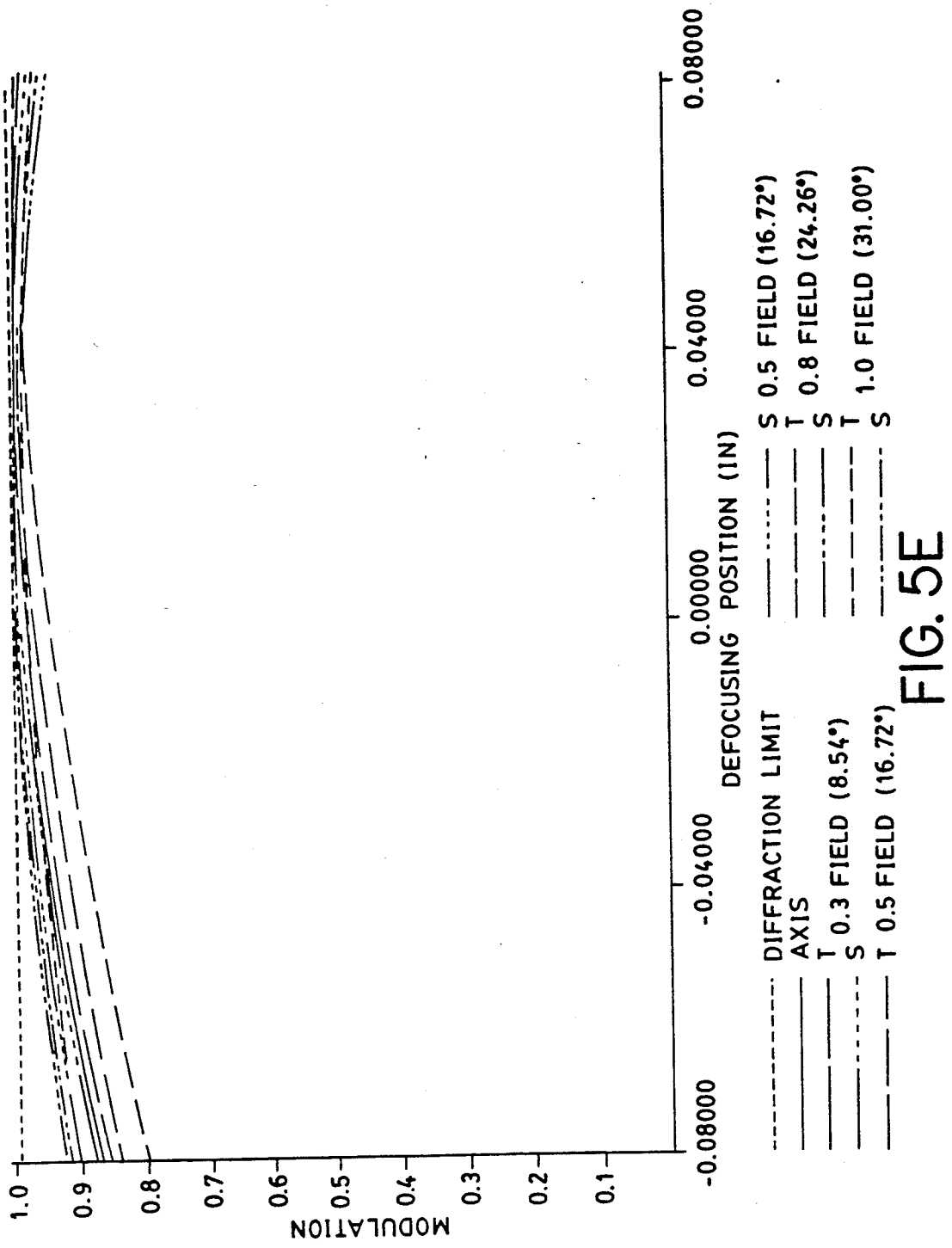

MODULATION
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
-0.08000
-0.04000
0.00000
0.04000
0.08000
DEFOCUSING POSITION (IN)
DIFFRACTION LIMIT
AXIS
T 0.3 FIELD (8.54°)
S 0.3 FIELD (8.54°)
T 0.5 FIELD (16.72°)
S 0.5 FIELD (16.72°)
T 0.8 FIELD (24.26°)
S 0.8 FIELD (24.26°)
T 1.0 FIELD (31.00°)
S 1.0 FIELD (31.00°)

FIG. 5E

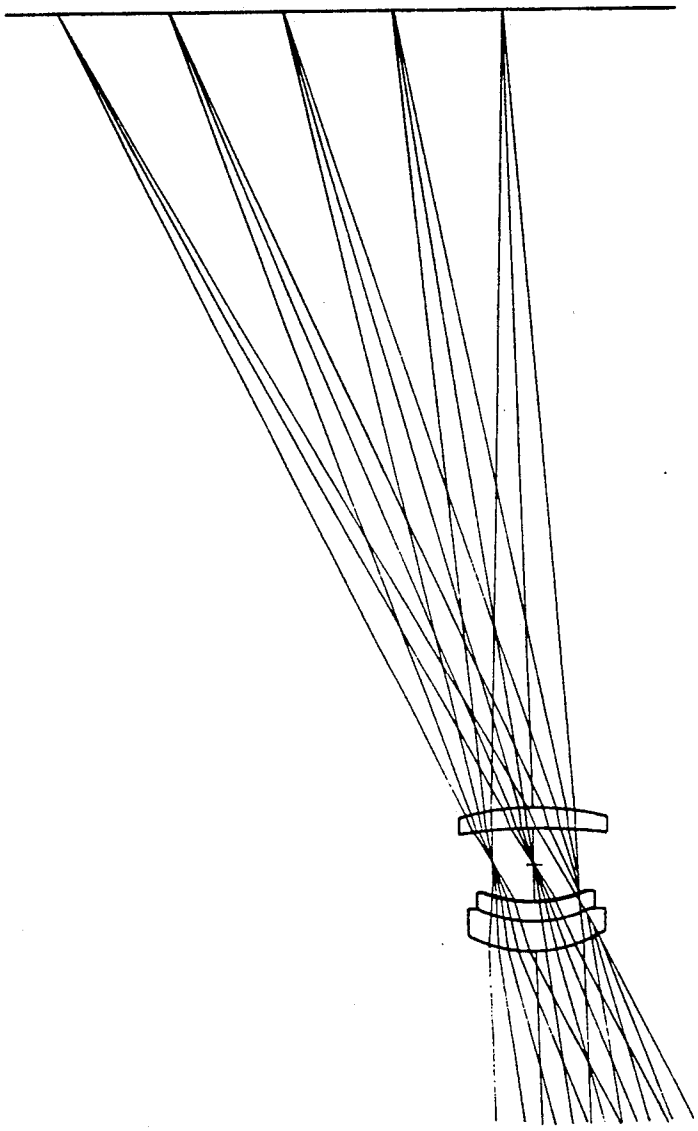


FIG. 6A

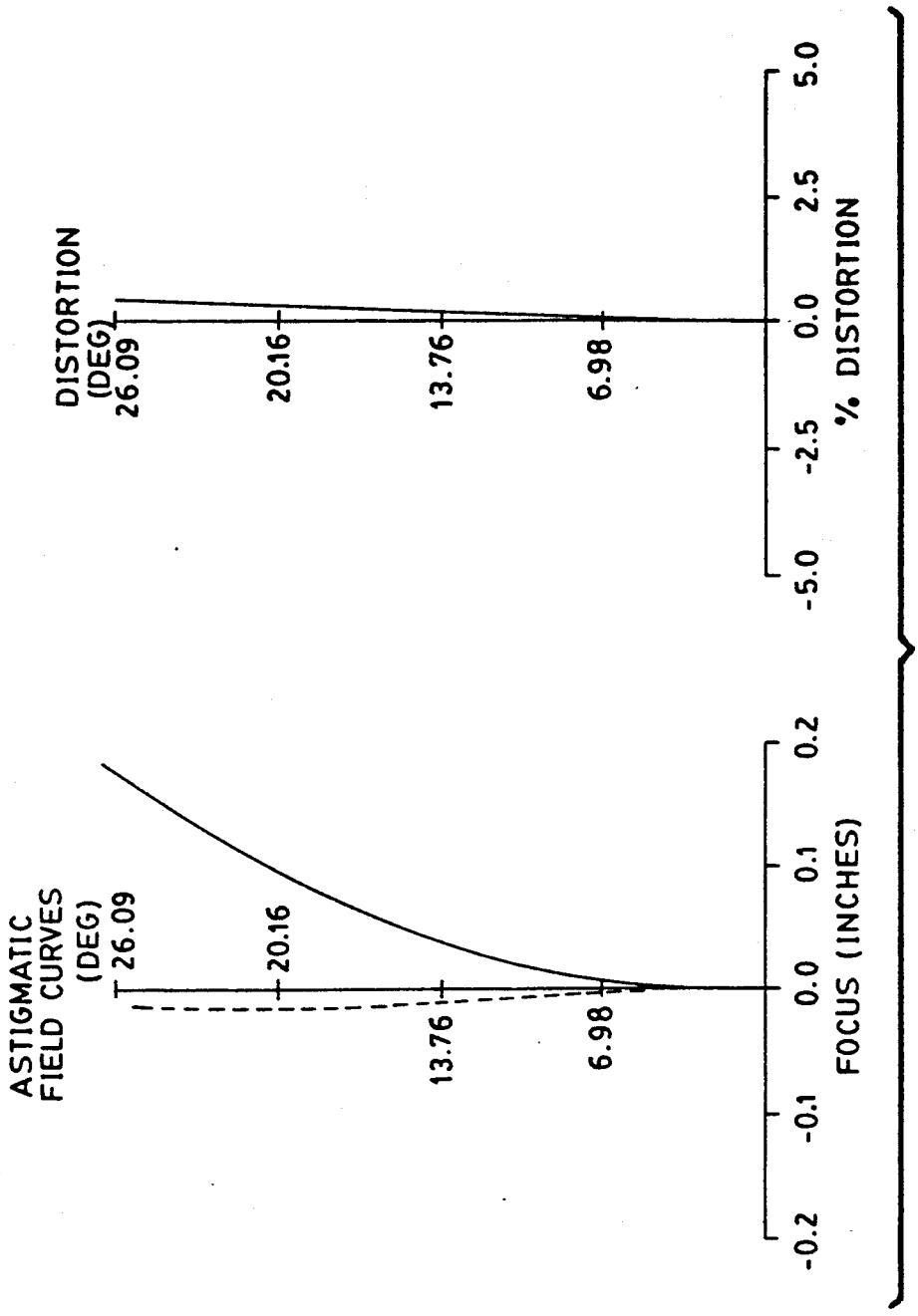

ASTIGMATIC FIELD CURVES (DEG)
26.09
20.16
13.76
6.98
-0.2
-0.1
0.0
0.1
0.2
FOCUS (INCHES)
DISTORTION (DEG)
26.09
20.16
13.76
6.98
-5.0
-2.5
0.0
2.5
5.0
% DISTORTION

FIG. 6B

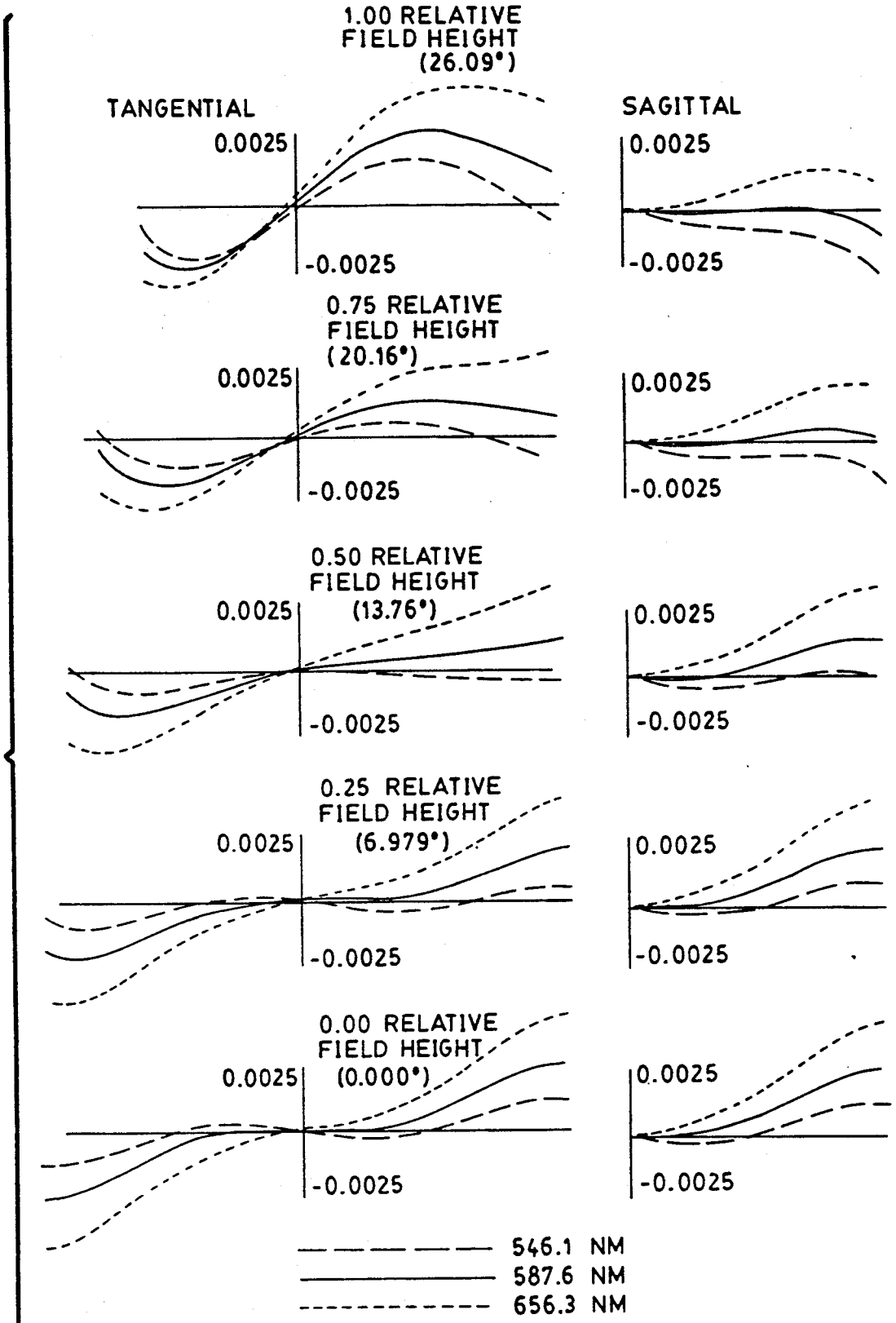

1.00 RELATIVE FIELD HEIGHT (26.09°)
TANGENTIAL
SAGITTAL
0.0025
-0.0025
0.75 RELATIVE FIELD HEIGHT (20.16°)
0.50 RELATIVE FIELD HEIGHT (13.76°)
0.25 RELATIVE FIELD HEIGHT (6.979°)
0.00 RELATIVE FIELD HEIGHT (0.000°)
546.1 NM
587.6 NM
656.3 NM

FIG. 6C

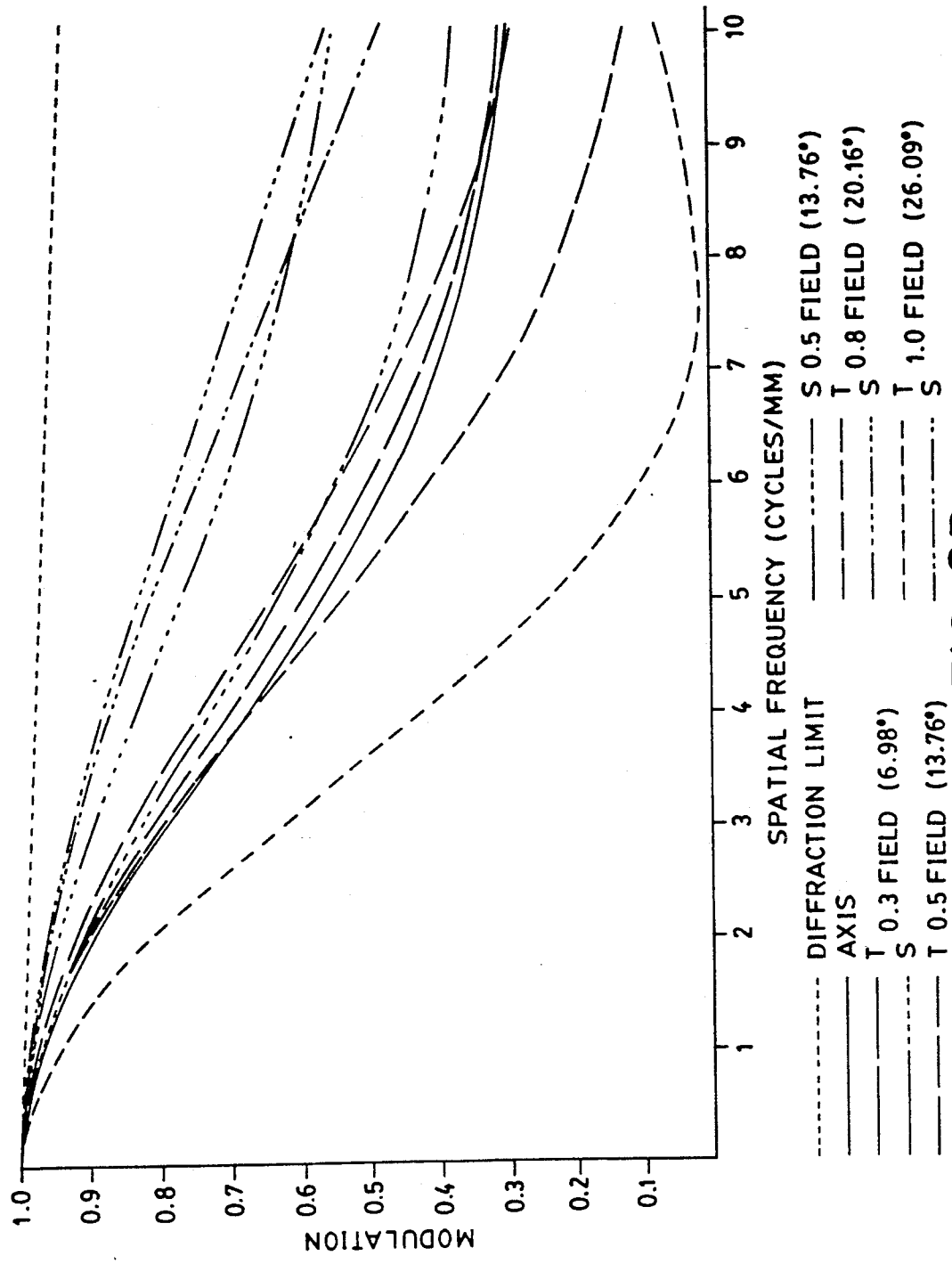

MODULATION
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
1
2
3
4
5
6
7
8
9
10
SPATIAL FREQUENCY (CYCLES/MM)
DIFFRACTION LIMIT
AXIS
T 0.3 FIELD (6.98°)
S 0.3 FIELD (6.98°)
T 0.5 FIELD (13.76°)
S 0.5 FIELD (13.76°)
T 0.8 FIELD (20.16°)
S 0.8 FIELD (20.16°)
T 1.0 FIELD (26.09°)
S 1.0 FIELD (26.09°)

FIG. 6D

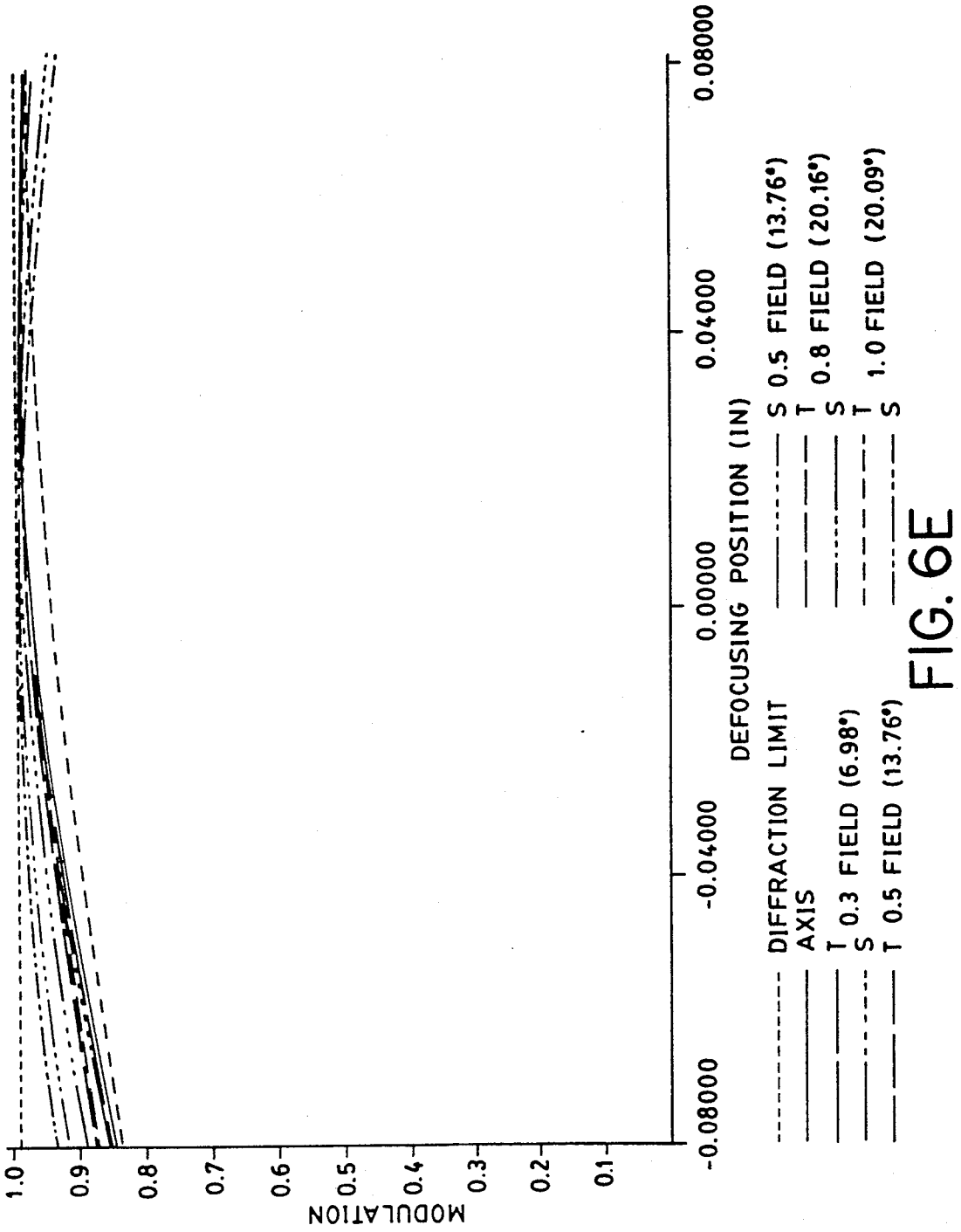

MODULATION
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
-0.08000
-0.04000
0.00000
0.04000
0.08000
DEFOCUSING POSITION (IN)
DIFFRACTION LIMIT
AXIS
T 0.3 FIELD (6.98°)
S 0.3 FIELD (6.98°)
T 0.5 FIELD (13.76°)
S 0.5 FIELD (13.76°)
T 0.8 FIELD (20.16°)
S 0.8 FIELD (20.16°)
T 1.0 FIELD (20.09°)
S 1.0 FIELD (20.09°)

FIG. 6E

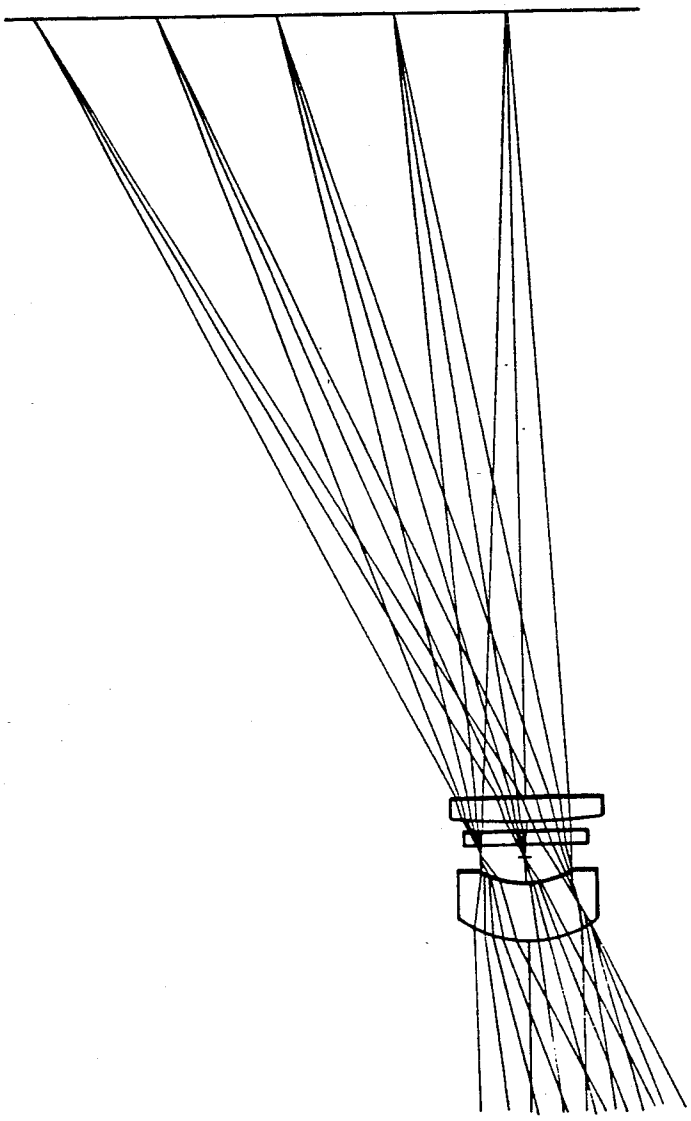


FIG. 7A

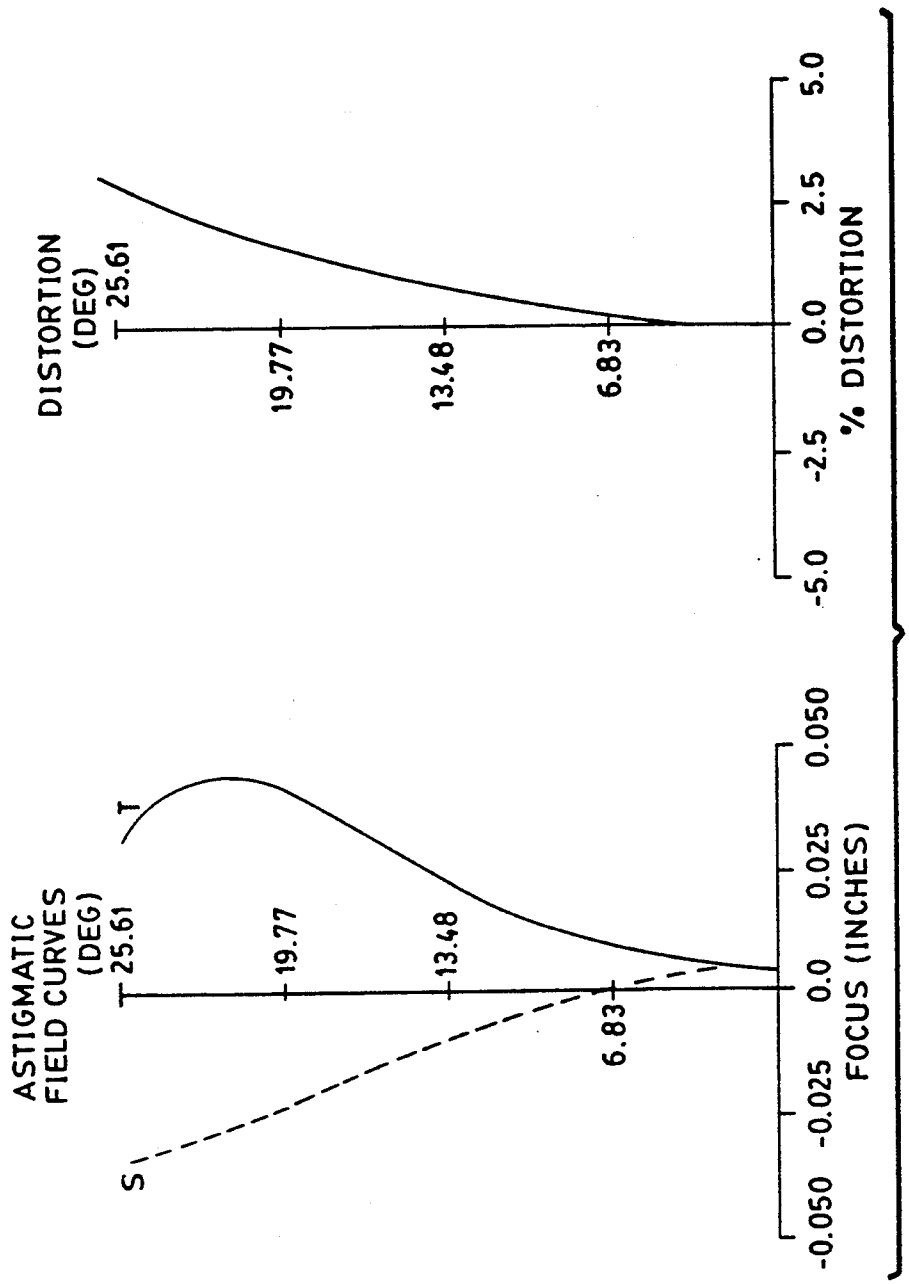

DISTORTION
(DEG)
25.61
19.77
13.48
6.83
-5.0
-2.5
0.0
2.5
5.0
% DISTORTION
ASTIGMATIC
FIELD CURVES
(DEG)
25.61
19.77
13.48
6.83
T
S
-0.050
-0.025
0.0
0.025
0.050
FOCUS (INCHES)

FIG. 7B

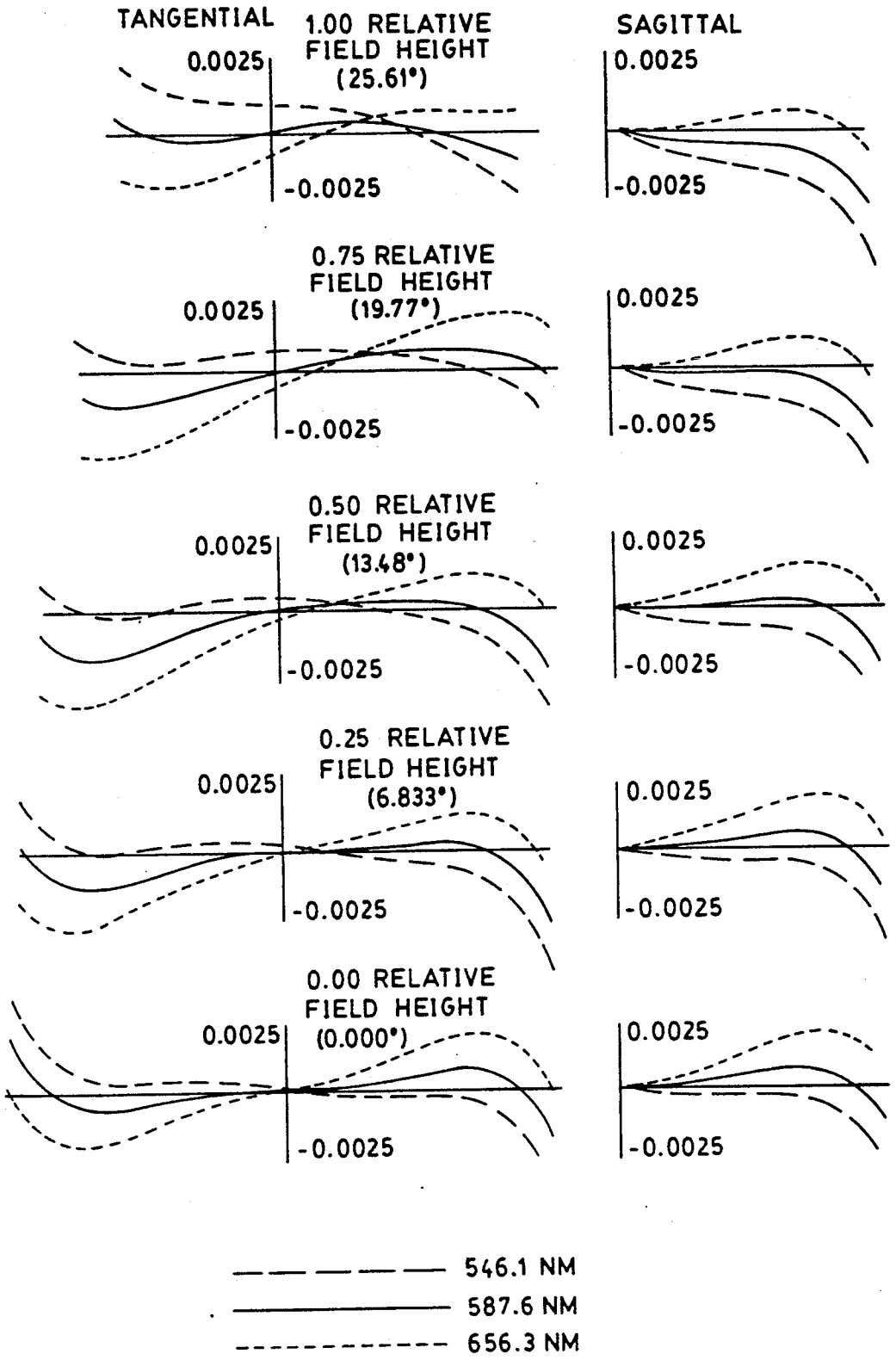

TANGENTIAL
1.00 RELATIVE FIELD HEIGHT (25.61°)
SAGITTAL
0.0025
-0.0025
0.75 RELATIVE FIELD HEIGHT (19.77°)
0.50 RELATIVE FIELD HEIGHT (13.48°)
0.25 RELATIVE FIELD HEIGHT (6.833°)
0.00 RELATIVE FIELD HEIGHT (0.000°)
546.1 NM
587.6 NM
656.3 NM

FIG. 7C

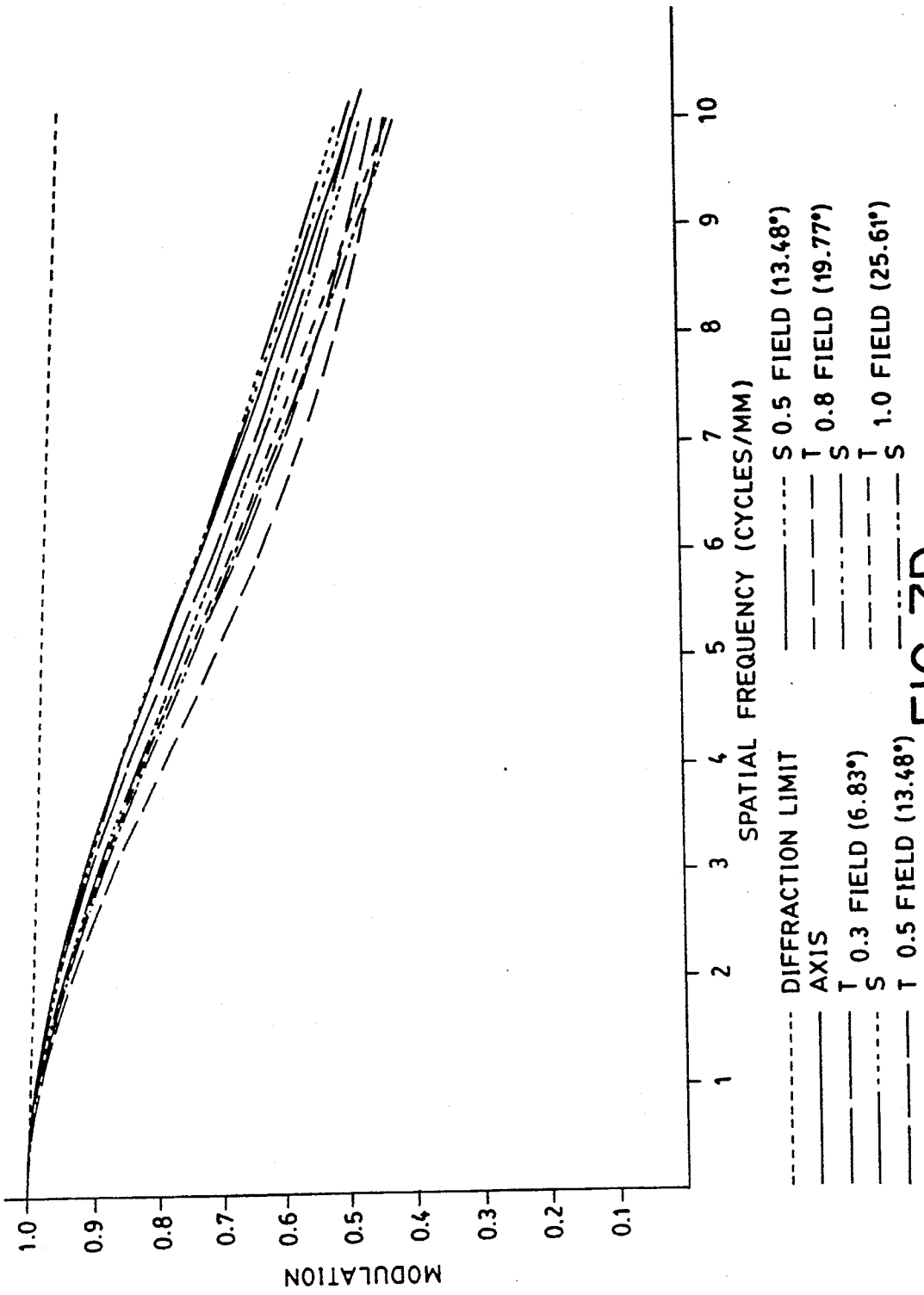

MODULATION
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
1
2
3
4
5
6
7
8
9
10
SPATIAL FREQUENCY (CYCLES/MM)
DIFFRACTION LIMIT
AXIS
T 0.3 FIELD (6.83°)
S 0.3 FIELD (6.83°)
T 0.5 FIELD (13.48°)
S 0.5 FIELD (13.48°)
T 0.8 FIELD (19.77°)
S 1.0 FIELD (25.61°)

FIG. 7D

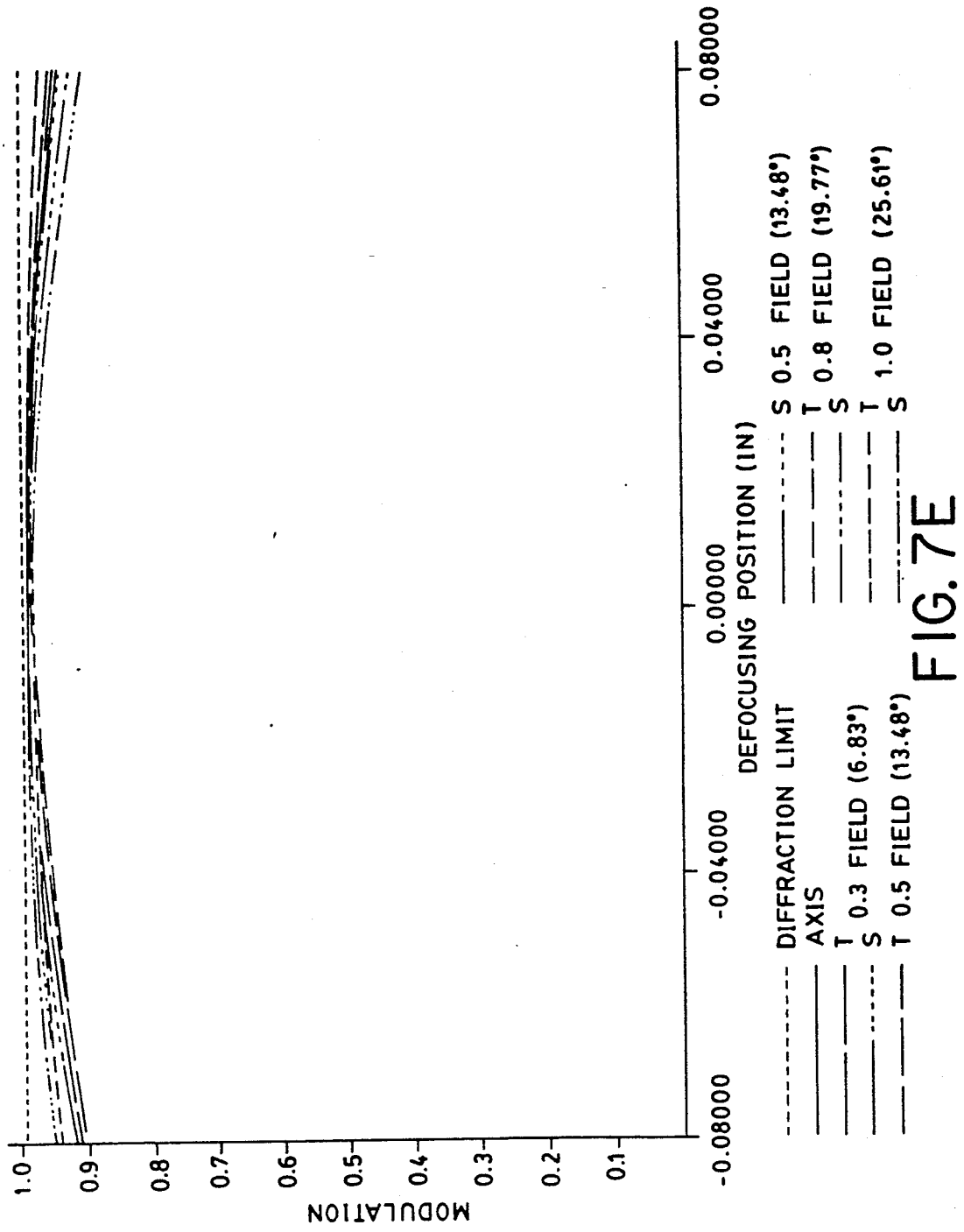

MODULATION
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
-0.08000
-0.04000
0.00000
0.04000
0.08000
DEFOCUSING POSITION (IN)
DIFFRACTION LIMIT
AXIS
T 0.3 FIELD (6.83°)
S 0.3 FIELD (6.83°)
T 0.5 FIELD (13.48°)
S 0.5 FIELD (13.48°)
T 0.8 FIELD (19.77°)
S 0.8 FIELD (19.77°)
T 1.0 FIELD (25.61°)
S 1.0 FIELD (25.61°)

FIG. 7E

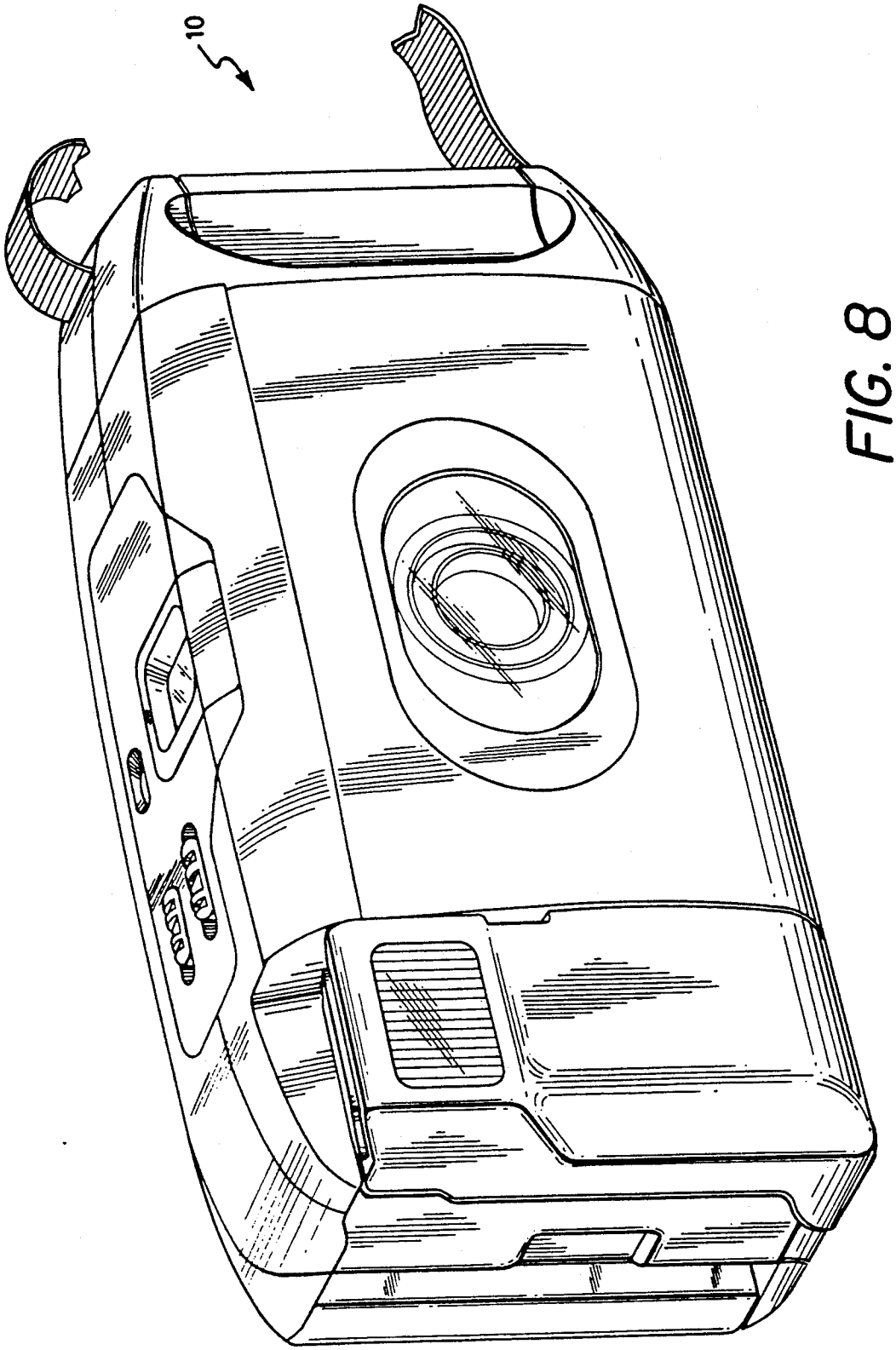


FIG. 8

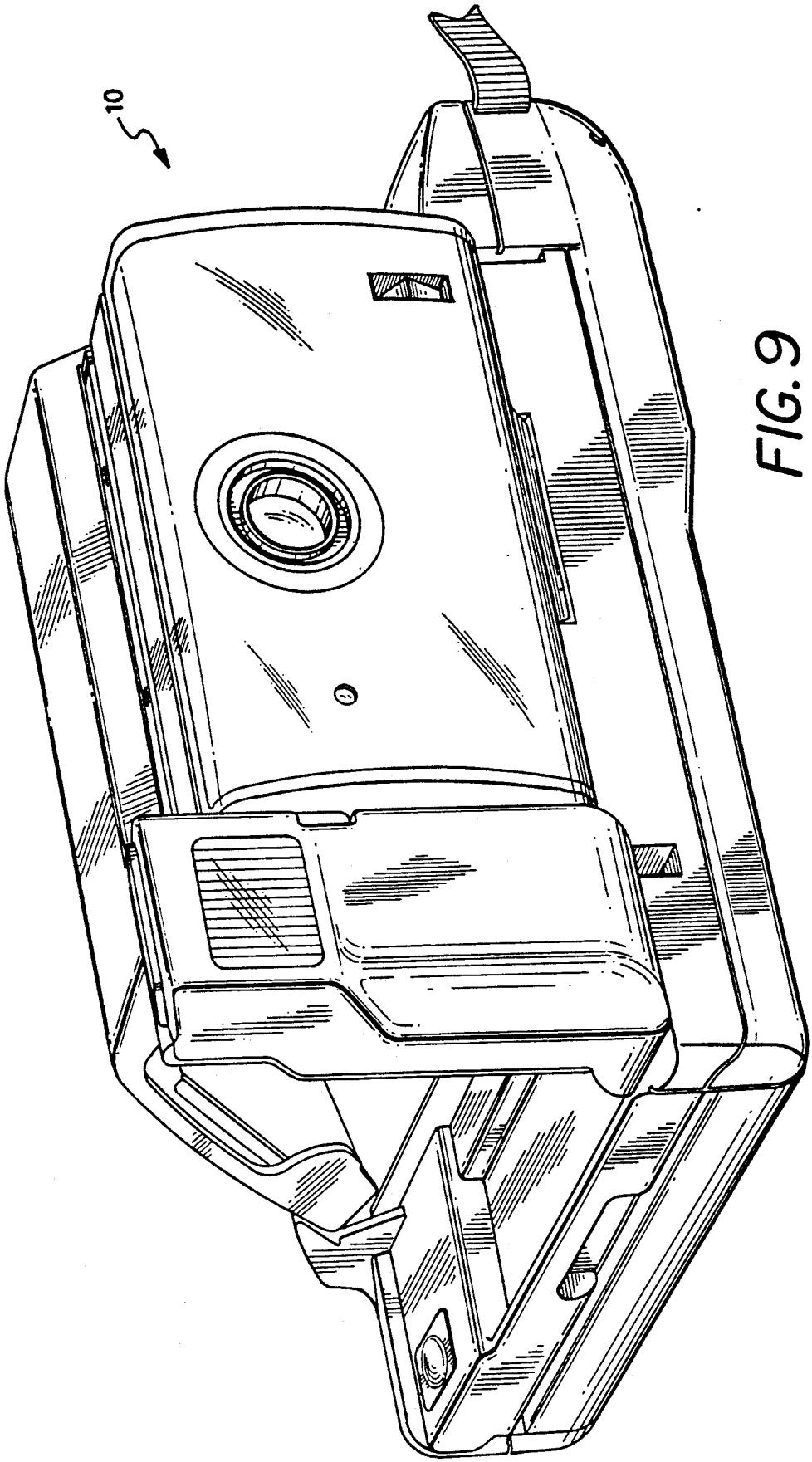


FIG. 9

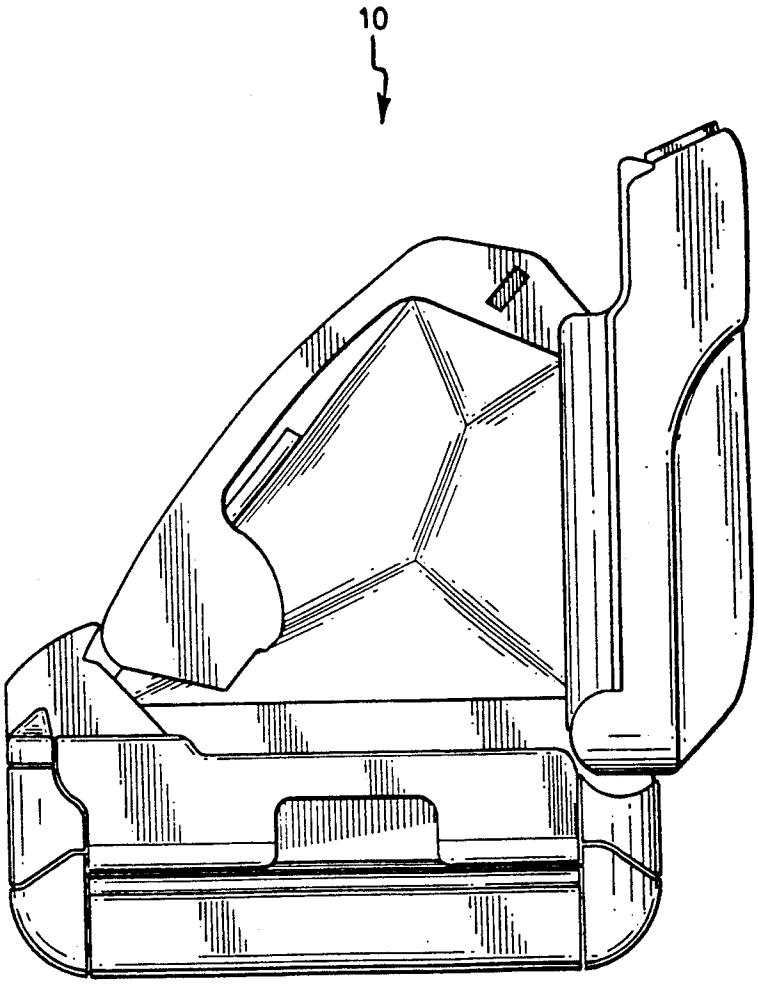


FIG. 10

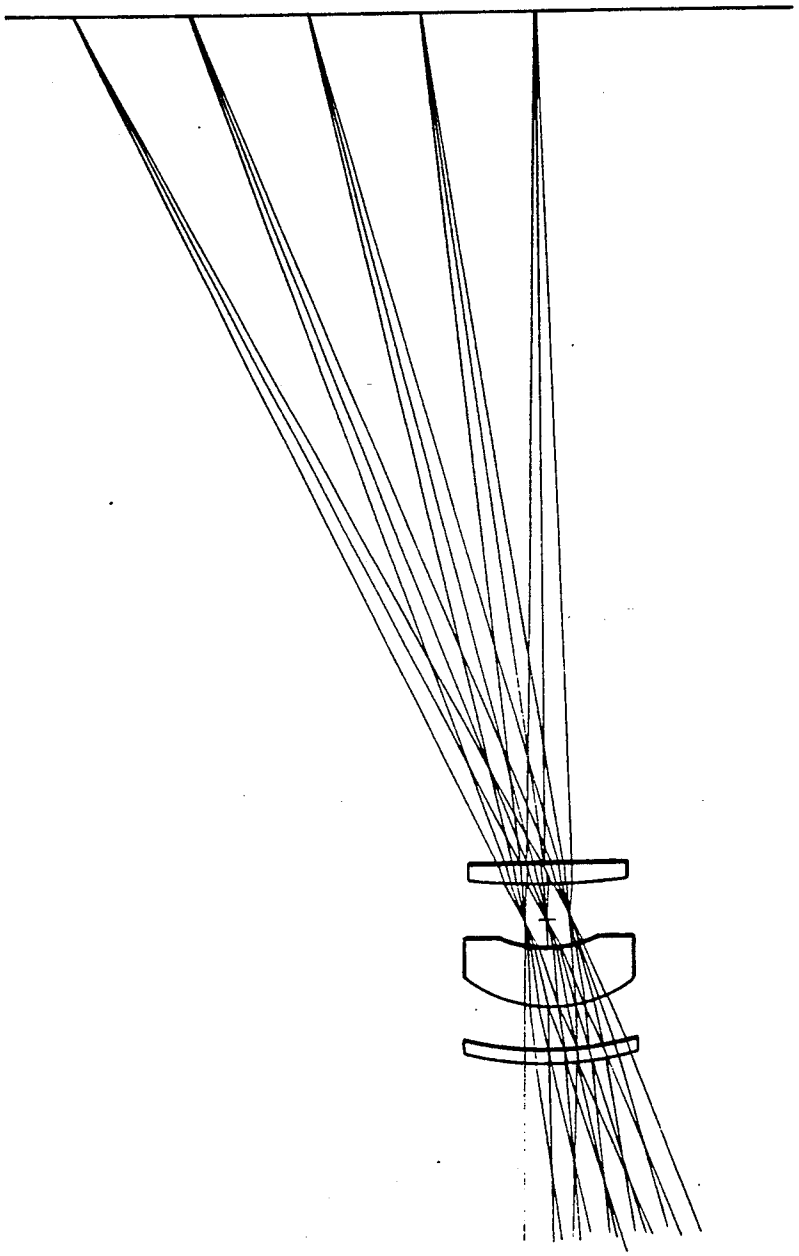


FIG. 11A

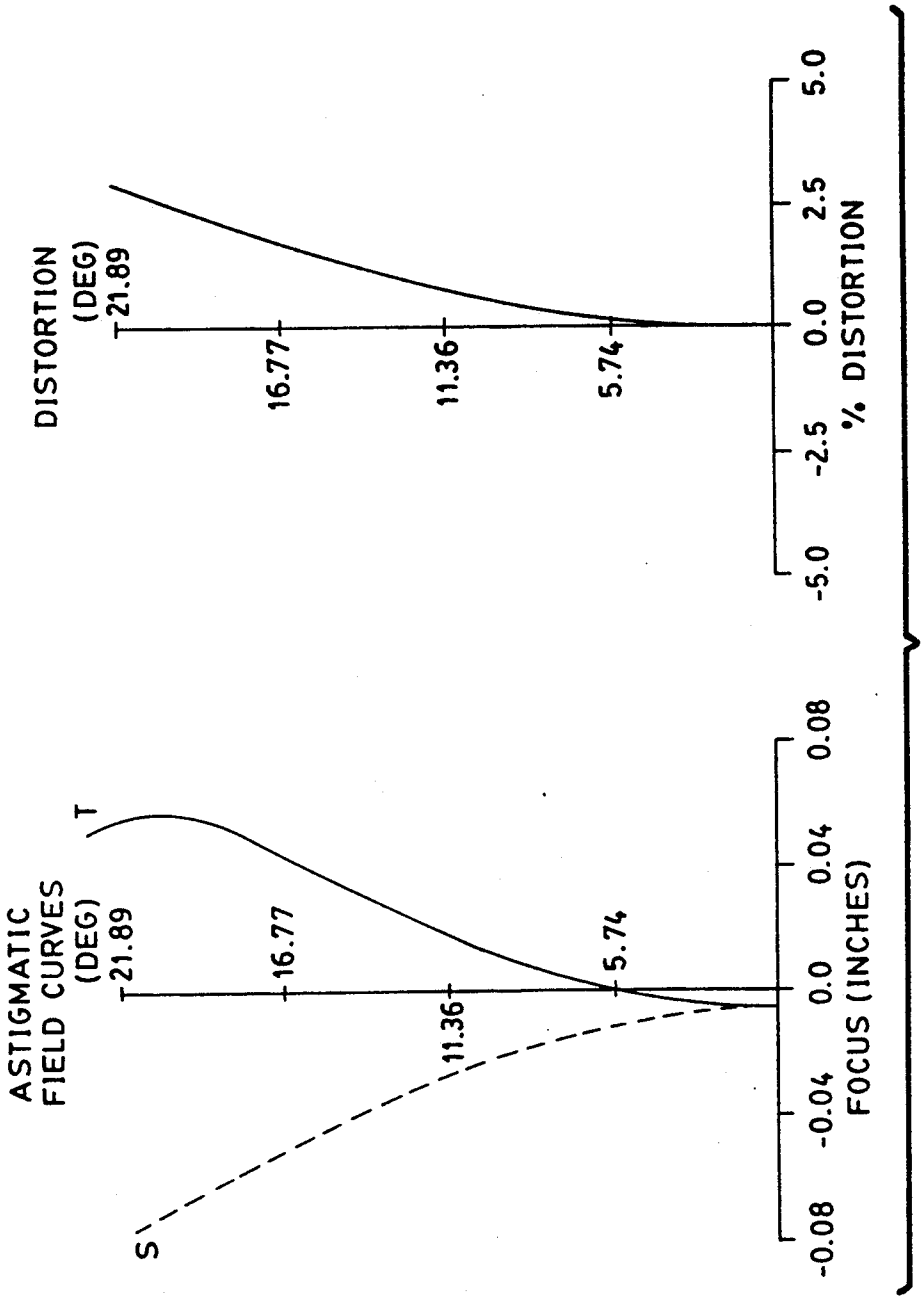

ASTIGMATIC FIELD CURVES (DEG)
21.89
16.77
11.36
5.74
T
S
-0.08
-0.04
0.0
0.04
0.08
FOCUS (INCHES)
DISTORTION (DEG)
21.89
16.77
11.36
5.74
-5.0
-2.5
0.0
2.5
5.0
% DISTORTION

FIG. 11B

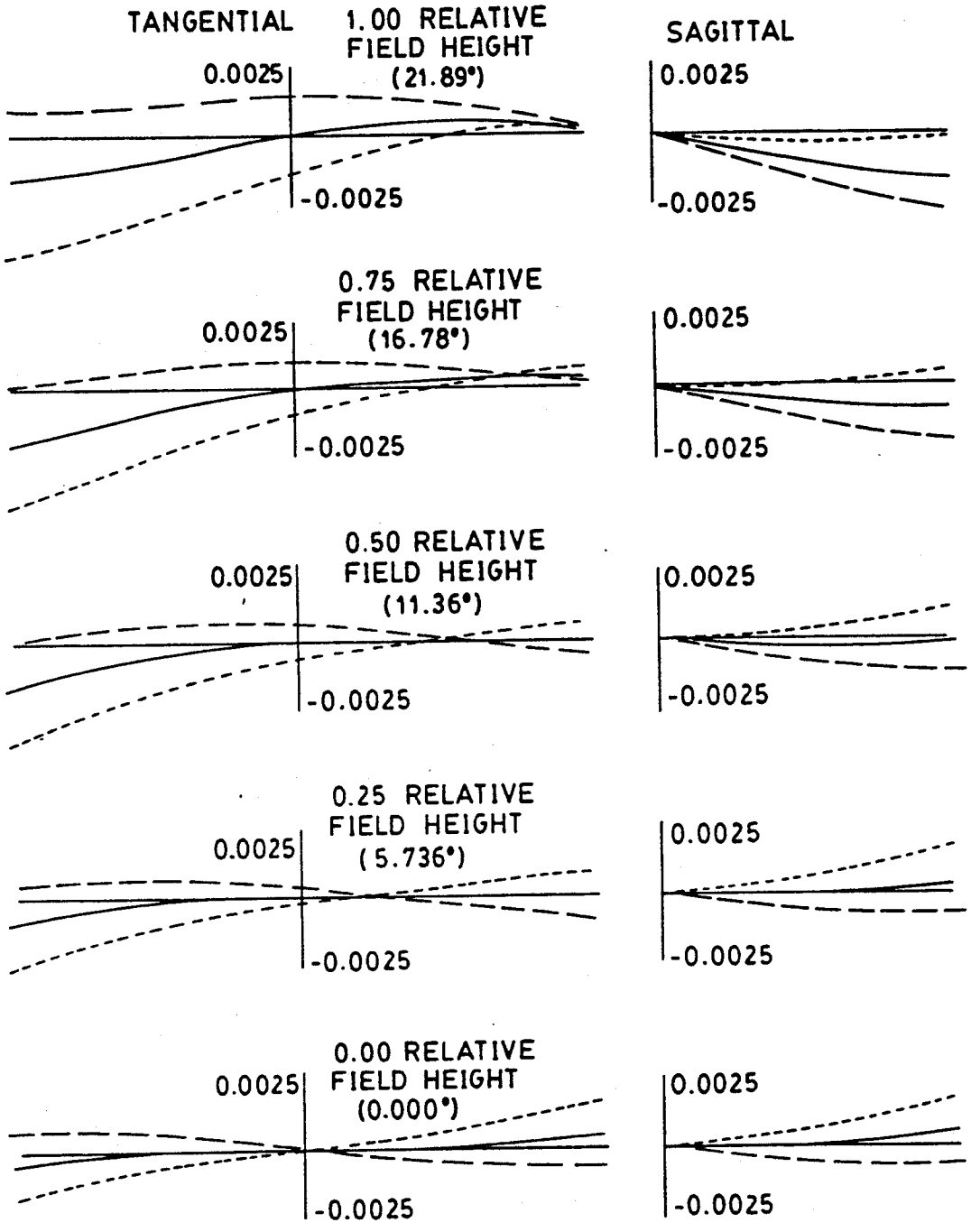

TANGENTIAL
1.00 RELATIVE FIELD HEIGHT (21.89°)
SAGITTAL
0.0025
-0.0025
0.75 RELATIVE FIELD HEIGHT (16.78°)
0.50 RELATIVE FIELD HEIGHT (11.36°)
0.25 RELATIVE FIELD HEIGHT (5.736°)
0.00 RELATIVE FIELD HEIGHT (0.000°)
546.1 NM
587.6 NM
656.3 NM

FIG. 11C

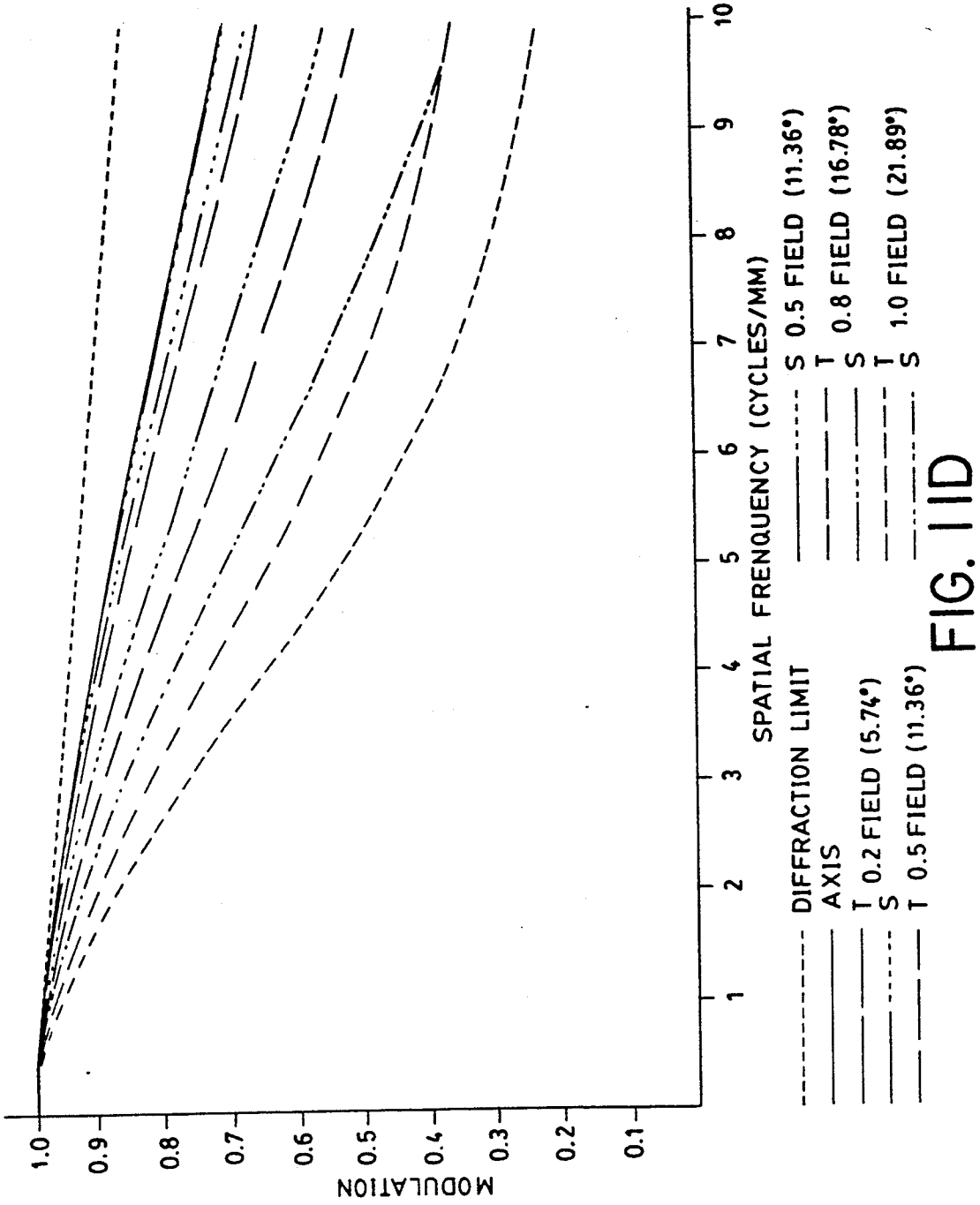

MODULATION
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
SPATIAL FRENQUENCY (CYCLES/MM)
1
2
3
4
5
6
7
8
9
10
DIFFRACTION LIMIT
AXIS
T 0.2 FIELD (5.74°)
S 0.2 FIELD (5.74°)
T 0.5 FIELD (11.36°)
S 0.5 FIELD (11.36°)
T 0.8 FIELD (16.78°)
S 0.8 FIELD (16.78°)
T 1.0 FIELD (21.89°)
S 1.0 FIELD (21.89°)

FIG. 11D

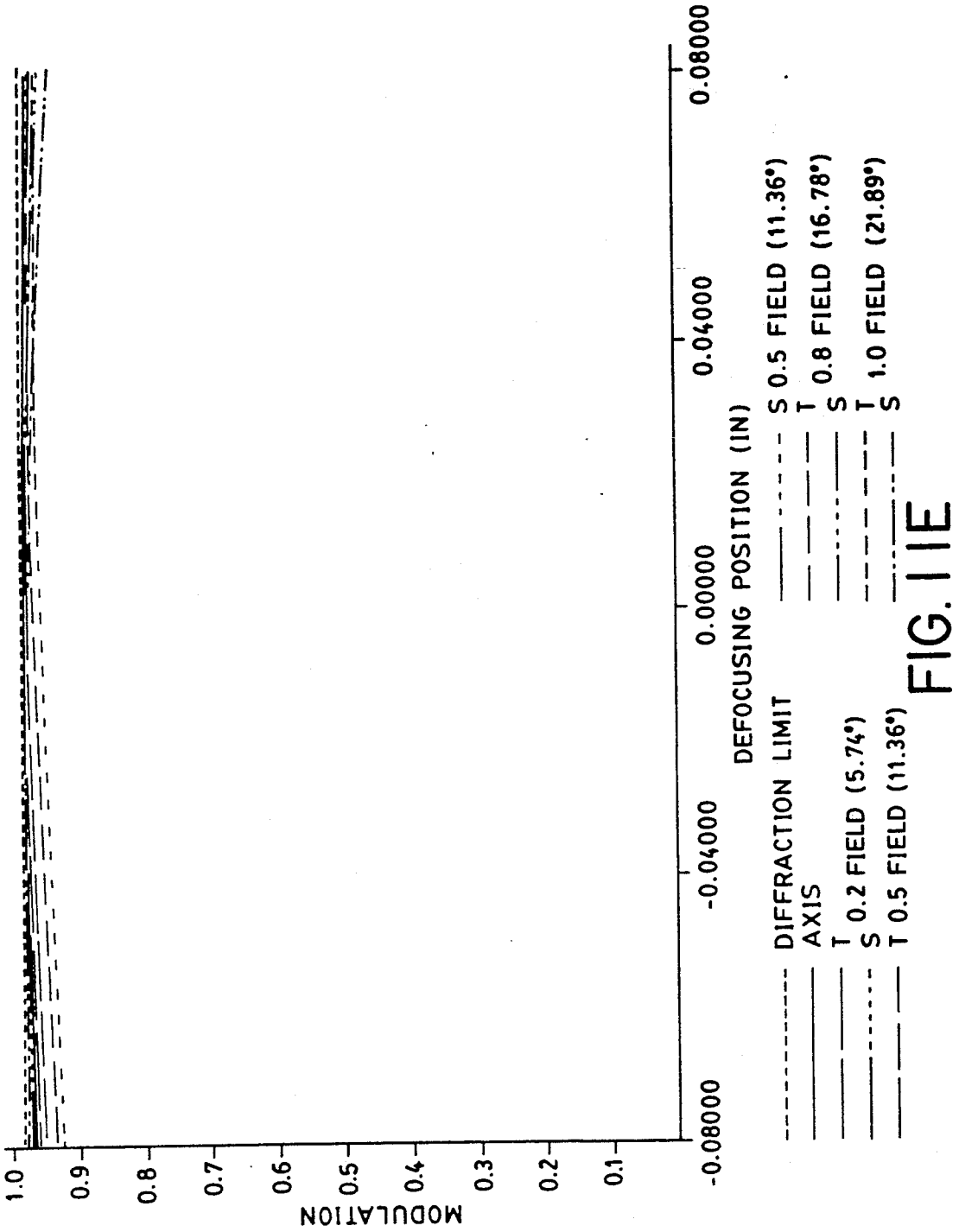

MODULATION
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
-0.08000
-0.04000
0.00000
0.04000
0.08000
DEFOCUSING POSITION (IN)
DIFFRACTION LIMIT
AXIS
T
S 0.2 FIELD (5.74°)
T 0.5 FIELD (11.36°)
S 0.5 FIELD (11.36°)
T
S 0.8 FIELD (16.78°)
T
S 1.0 FIELD (21.89°)

FIG. 11E

COMPACT OBJECTIVE LENS

FIELD OF THE INVENTION

This invention relates to objective lens systems for use in cameras and, in particular, to objective lens systems for use in folding, reflex cameras.

BACKGROUND OF THE INVENTION

1. Description of the Prior Art

Numerous objective lens systems for cameras have been proposed. Examples employing two elements include Simpson, Jr. et al., U.S. Pat. Nos. 4,932,764 and 5,000,552, and Davis, U.S. Pat. No. 2,586,418. See also Aldis, U.S. Pat. No. 682,017, discussed below. A two element lens for use in a copying machine, as opposed to a camera, is disclosed in Japanese Patent Publication No. 3-242608. Similarly, Rothe, U.S. Pat. No. 4,645,311, discloses a two element design including an aspheric surface for use in an optical scanner.

Three element designs include Bertele, U.S. Pat. No. 2,721,501, Grey, U.S. Pat. No. 3,784,287, De Jager, U.S. Pat. No. 3,967,884, and Sato, U.S. Pat. No. 4,542,961 in which an aspheric surface is used, as well as the early Cooke/Taylor triplet and variations thereof. See Kingslake, R., *A History of the Photographic Lens*, Academic Press, New York, 1989, pages 103–115.

The incorporation of a focusing element or group in an objective lens system is disclosed in the following patents: Westphalen, U.S. Pat. Nos. 3,185,061 and 3,388,650, Laurent, U.S. Pat. No. 4,174,153, Yamada, U.S. Pat. No. 4,394,071, Owen, Jr. et al., U.S. Pat. No. 4,443,067, Wakabayashi, U.S. Pat. No. 4,669,848, Nishi et al., U.S. Pat. No. 4,791,441, Nakayama et al., U.S. Pat. No. 4,830,474, Takase, U.S. Pat. No. 4,913,537, and Ogawa et al., U.S. Pat. No. 5,005,038. A construction of this general type for use in a viewfinder is disclosed in Wakamiya, U.S. Pat. No. 4,832,470. A magnifying lens employing an aspheric surface for attachment to the objective of a camera is disclosed in Baker, U.S. Pat. No. 3,604,786, and the use of an auxiliary lens for short range work is disclosed in Noguchi, U.S. Pat. No. 4,505,566.

Also of interest is U.S. Pat. No. 697,959, dated Apr. 22, 1902 to Ernst Abbe. He discusses how an aspheric surface can be used to improve far off-axis performance of a landscape type lens (cemented doublet and stop).

Notwithstanding the variety of objective lens systems which have been previously proposed, there still exists a need for lens systems of relatively simple construction which can be mass produced at low cost. In particular, such systems are needed in the field of multiple purpose hand cameras which are used by individuals and families, as well as for commercial applications, such as in the preparation of advertisements and the like, where small scale photographs of good to excellent quality can be useful and economic.

The present invention addresses this need and provides objective lens systems which 1) contain a minimum number of elements, 2) can be manufactured at low cost, and 3) have optical and physical properties suitable for use in a mass produced camera.

2. Design Principles

As is known from basic optical principles, even a simple, single lens element with spherical surfaces possesses a paraxial image position conjugate to an object distance, and an equivalent focal length, which together comprise the element's "Gaussian" optics of first order magnitude. For a rotational lens system, the usual case for practical objectives intended for mass production, there are no second order aberrations.

The chromatic variations of both image location and image size, that is to say, longitudinal and lateral chromatic aberrations, can be construed as of third order in magnitude. For the monochromatic third order of approximation and, in particular, for the development of a power series which represent the x and y intercepts on the image surface of a light ray from an object point after transit through the optical system, there will be five independent mathematical coefficients of series terms which represent the conditions to be reduced essentially to zero or at least to optimized small non-zero values. These "Seidel" coefficients in physical meaning have to do with spherical aberration, coma, astigmatism, curvature of field, and distortion.

The development of the associated power series can be carried out in explicit formulations of object distance, curvature of the object surface if any, off-axis position of the object point, intercepts of a given ray in the entrance pupil, or the equivalent in image space, and the like. Thus, the x and y intercepts of a given ray on a desired image surface can be given as a power series in 5 variables, one of which is the wavelength, or in 4 variables monochromatically, or even in 3 if rotational relationships are employed. The variables may be simple, as for example the direction of the object point as seen from the center of the entrance pupil (2 variables), and the x and y intercepts of a ray from the object point on the entrance pupil, or in terms of selected functions of the simple variables. The design task if formulated in simplest terms is to bring all rays from an object point into sharp focus at an image point. The location of the image point may not be exactly where desired but may include a displacement in x, y and z according to allowable tolerances. For example, a lateral displacement in the image surface may be permitted to some degree, in the nature of distortion, one of the Seidel conditions.

In the fifth order of approximation one encounters nine monochromatic aberrations, plus chromatic variations of the five Seidel conditions, and secondary chromatic variations of the image position in longitudinal displacement, as well as secondary chromatic variations of magnification, or of the equivalent focal length if the object plane lies at infinity. Higher orders of power series approximation have been worked out by various theorists, but the complexities of solution are such as to confine the higher order formulas generally to analysis rather than to synthesis of optical structures.

The above mentioned power series contain the basic parameters of construction of the optical system, such as the radii of curvature of the multiple surfaces, the axial spacings of the surfaces, the indices of refraction of the media used, including the wavelength dependence in some mathematical form, and if any particular surface is aspheric, that is, nonspherical, the aspheric coefficients that define the shape of the surface according to the order of approximation. The object of the invention is thus to select a set of parameters which can be used to cost-effectively to produce an objective lens system which can be successfully employed for family or general purpose applications and the like.

3. Historic Lens Designs

In the past, so-called landscape lenses have combined a single meniscus lens element with spherical surfaces with a stop at an optimum location in the lens barrel,

such that one can say that the meniscus is curved in a general sense about the stop. Even if the aperture-ratio is quite limited, as for example, f/16 or slower, such a landscape lens is afflicted with distortion. With the stop forward, the distortion is barrel in nature, and if the stop is rearward of the meniscus, the distortion is pin-cushion. If the stop is rearward, the overall length is accordingly reduced. In addition, compromises have to be made with curvature of field, chromatic aberrations, astigmatism and residual aberrations of spherical aberration and coma. Nevertheless, vast numbers of family photographs have been made by means of such simplified objectives, optimized as well as may be from the complex of considerations.

In accordance with the invention, it has been found that the optical performance can be improved even for a plastic material having a relatively low index and moderate dispersion characteristics by means of at least one surface of the meniscus becoming aspheric. Use of an aspheric of optimum shape has been found to reduce distortion and to reduce astigmatism to a level sufficient to flatten the mean image surface. By means of modern manufacturing techniques known in the art the use of at least one aspheric surface per plastic element is practical for mass production.

As discussed in detail below, the photographic objective of the present invention has two lens groups, one before a centrally located stop and one after. Thus, in general terms, it can be considered to resemble that of the Aldis lens (see Aldis, U.S. Pat. No. 682,017, issued Sep. 3, 1901).

Symmetrical or nearly symmetrical objectives of two meniscus elements enclosing a central stop are known in the art and have many uses, particularly for medium to wide angle performance where a "slow" lens may be used. The well-known "Hypergon", U.S. Pat. No. 706,650 by Carl Paul Goerz, which at a high aperture-ratio such as f/60 can cover very wide angle fields on a nearly flat image surface, uses this approach. The symmetry of the arrangement eliminates most of the coma even for an infinite object distance, although not entirely. The very restrictive central stop reduces the spherical aberration and longitudinal chromatic aberrations to manageable proportions and the rest of the residual coma as well. The effectiveness of the thin Hypergon menisci arises from the near optical cancellation of the convex and adjacent concave surfaces of the individual meniscus, the power, though low, coming partly from the separation of the convex and concave surfaces, that is, from the thickness of the individual meniscus. An optimization causes the tangential and radial image surfaces to lie close to a mean nearly flat image surface and to one another as well.

A difficulty with the more or less symmetrical double meniscus form is that the principal points and indeed the perspective center lie more or less within a rather long lens barrel. The overall length of the objective from front surface vertex to the axial point of the image surface is thereby greater than the equivalent focal length, resulting usually in a lack of compactness in the camera itself. Indeed, an important requirement of the modern hand camera is compactness. Another requirement is that the clear apertures of front and rear surfaces be relatively modest which means that the menisci cannot be very far from the central stop, front and rear, if an adequate field of view is to be covered.

Unsymmetrical objectives employing at least one strong meniscus component preceding the stop, which in some cases is only a single element, are also known in the art. This structure enhances several characteristics of the front element of the Hypergon. The inner concave surface opposed to and lying at a moderate axial distance from the stop provides to some extent for a reduced Petzval sum and reduction in astigmatism caused by the meniscus component as a whole, while at the same time a substantial thickness of the meniscus component preserves much of the net lens power needed for focusing the oncoming rays from a distance object. These historic designs, however, have not achieved the optical performance at low cost which the present invention achieves.

SUMMARY OF THE INVENTION

In accordance with certain of its aspects, the invention provides a lens system which comprises:

(a) a first group on the object side of the system's stop or aperture which (i) has a positive dioptric power, (ii) includes a concave surface preceding and adjacent to the stop or aperture, and (iii) includes at least one aspheric surface; and

(b) a second group on the image side of the stop or aperture consisting of a single component having only two air surfaces and a positive power;

the overall system

(i) having a total diagonal field of view not exceeding about 60 degrees;

(ii) having a relatively flat or weakly concave field;

(iii) having relatively low distortion;

(iv) being corrected at least partially for lateral chromatic aberration; and

(v) having at least two elements made of plastic materials differing in dispersive powers, where at least one of the elements is plastic.

In certain embodiments, the second group includes an aspheric surface. In other embodiments, the second group includes means for focusing the system over a range of object distances from infinity down to about 4.0 times the effective focal length of the system.

In its simplest form, the lens system includes just two elements. Even for this level of simplicity, the system achieves excellent performance, particularly with regard to correction of lateral color and distortion (see below). This is, in part, a consequence of the use of a thick front element, the choice of materials for their dispersion, and their sequence.

The thick front element, while appearing strongly positive, actually is not. In fact, it acts much like a Galilean telescope as evidenced by the nearly parallel bundle of rays in the intervening space between it and the second element (see, for example, FIG. 1A). Most of the power in the system is in the second element.

The shape or bending of the thick front element about the real stop, along with the inclusion of an aspheric surface aids in the control of aberrations as does the use of an aspheric surface with the second element. The entire system may be injection molded for mass production, and the placement of the rear element is relatively insensitive to tilt and decentering errors because, while more positive than the thick front element, it is less positive than the system as a whole.

In overview, the two element embodiment of the invention can be considered an asymmetric system comprising a thick front telescopic element bent about a following real stop which in turn is followed by a more dispersive more powerful positive element.

The accompanying drawings, which are incorporated in and constitute part of the specification, illustrate the preferred embodiments of the invention, and together with the description, serve to explain the principles of the invention. It is to be understood, of course, that both the drawings and the description are explanatory only and are not restrictive of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. **1A-7E** show lens systems constructed in accordance with the present invention. In each of these figures, the configuration of the system is shown in the "A" panel of the figure, the residual astigmatism and distortion as a function of field angle is shown in the "B" panel, the ray aberrations (blur) as a function of position over the field at three different wavelengths is shown in the "C" panel, the MTF versus field angle at the paraxial image surface ($r=-80$ inches) is shown in the "D" panel, and the departure in the modulation at 1 cycle/mm with changes in the position of the image surface of best focus from its nominal or paraxial position is shown in the "E" panel.

FIG. **8** is a perspective view of a folding reflex camera with which the lens systems of the present invention can be used. As shown in this figure, the camera is in its folded configuration.

FIGS. **9** and **10** are perspective and side views, respectively, of the camera of FIG. **8** in its unfolded configuration.

FIGS. **11A-11E** are similar to FIGS. **1A-7E** showing the example of FIG. **3** in conjunction with a close-up lens.

BRIEF DESCRIPTION OF THE TABLES

Tables 1-7 give prescriptions for the examples corresponding to FIGS. **1A** through 7E and Table 8 gives the prescription of the example corresponding to FIG. **11A-11E**.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

1. General Principles and Features

In general terms, the objective lens systems of the present invention have moderate speeds, e.g., f/8 or slower, and field angles no larger than 62 degrees relative to the full diagonal of the format.

As can be seen from the Figures and Tables, the systems may include two plastic elements of differing dispersions, one forward and the other to the rear of a central stop, with not more than one aspheric surface per plastic element. When desired, additional elements in glass or plastic can be included or the rear element may be glass. The lens systems are normally used with photographic film, but can be used with other types or kinds of light-sensitive recording media, such as in all-electronic cameras, infra-red detectors, and the like.

The lens systems are intended for use in imaging objects whose distance from the system is at least four equivalent focal lengths. The systems can have internally disposed focusing means immediately following the stop or objective focusing as a whole can be used. Auxiliary lenses can be added externally or within the objective structure to extend the useful range of object distances, such as for a hyperfocal object distance for scenic shots, or for close-up portrait photography, or for even closer technical or artistic applications.

In terms of overall design, the systems have a first (front) lens group forward of the central stop (to the left in the usual lens drawing) such that the surface adjacent to the stop is a concave "air" surface curved about the stop and such that the first lens group has at least some positive focusing power. The axial bundle emerging from the concave surface and about to pass through the stop thus has convergence and of itself is able to produce a real image at some location to the right in the usual convention. For example, in Example 1 discussed below, the equivalent focal length (EFL) of the first lens group (single element in this instance) is 2.556 in units of the focal length of the objective as a whole. The reciprocal gives the dioptric power, namely, 0.391 where the power of the overall system is 1.000.

If in the general case the dioptric power of the front group is made very small, the positive power of the rear group must be correspondingly large. Such a situation leads to imbalance in distortion correction, astigmatism, coma and even spherical aberration. If the power of the first group is too large, there will again be an imbalance among the various corrections. Accordingly, the range of dioptric power for the first group (K_1) should be between about 0.200 and about 0.500 of the total power of the lens system (K_0), corresponding to a range in the equivalent focal length of the front group from about 5.000 down to about 2.000 relative to the EFL of the entire lens system.

The first group with its weak net positive power can be viewed as a corrector for the rearward strongly positive group, the combination by design yielding a flat or nearly flat mean image surface, which can be optimized to conform to a known non-flat film surface such as may exist on the average when cut film is stacked sequentially in a supply pack, or when the sensitive surface is flat, or only relatively flat for any reason.

The first group includes a meniscus component which serves to reduce the diameter of the oncoming axial bundles of rays defined by the entrance pupil. This, in turn, has a telephoto effect which improves the compactness of the imaging system. Thus, if the effective cross-section of the axial bundle is reduced to, for example, 84% of the bundle in object space, the aperture stop is then small, and the optical focusing by the second group operates on a smaller bundle to produce the desired positive focal length for the system as a whole. The back focus is also reduced which provides for compactness in the camera itself.

For example, in Example 1, the overall length from front vertex to focal point for an infinite object distance is only 0.961 times the EFL of the entire lens system, which represents a great improvement in compactness over the symmetrical double meniscus form. The distance of the stop from the focal point is 0.875 times the EFL, which again accentuates the compactness resulting from the use of the compressing front meniscus component.

The front meniscus component, which is relatively thick, is used in combination with the rear positive group to minimize the aberrations of the lens system. The rear positive group of itself makes a strong positive (undercorrected) contribution to the Petzval sum. For example, in Example 1, the rear group by itself leads to a Petzval image surface of curvature -0.461, where a positive Petzval sum corresponds to a negative curvature, that is, to a concave surface curved about the exit pupil with the center of curvature to the left in the usual lens drawing where light travels from left to right. More specifically, the tangential image surface for the

second group has a curvature of −2.437, and the radial surface −1.120.

The correcting front meniscus component has strong negative (over-corrected) astigmatism and indeed a slightly negative Petzval sum contribution. In combination, the mean field is adequately coincident with a desired weakly cylindrical concave image surface (e.g., a radius of approximately −80 inches corresponding to the curvature of the average sheet in a film pack) and the performance is approximately anastigmatic.

In accordance with the invention the front lens group can take on various forms adapted for variables as the size of the format, the focal length of the lens system, the effective lens speed, the desired materials for the lens elements, the overall complexity and thus cost of the lens system, and the like. While the invention permits complexity of construction and multiple components forward of the stop, consistent with the desired weak convergence, the construction rearward of the stop is confined strictly to one component, that is with but two "air" surfaces whatever the internal construction of the component may be. (As used herein a "group" comprises one or more air-spaced "components," where a "component" has two air-contacting surfaces and is composed of one or more "elements".)

As discussed further below, a focusing means can be inserted between the stop and the rear component. Except for minor readjustments caused by interpolation of such focusing means, the rear component otherwise retains its characteristics. Except for the focusing means, the invention is therefore restricted to a single rearward component having a moderate total central thickness for purposes of improving compactness, and an "air" surface adjacent to the stop or interpolated focusing means that is generally convex or at most weakly concave, according to the field angle or other combinations of parameters.

The total thickness of the rearward component must be at least a reasonable value to allow for the curvatures of its "air" surfaces. The lower limit is small if the component lies relatively near the stop and if the aperture-ratio is moderate, such as f/10, e.g., the lower limit is on the order of 0.01 times the EFL of the entire lens system. The upper limit is on the order of 0.05 times the EFL if numerous cemented elements, which would unduly increase the cost of the lens system, are to be avoided. At this upper limit, the air surface adjacent to and opposed to the stop or to the interpolated focusing means, if any, tends toward plano and the final air surface tends to become strongly convex and curved more or less about the exit pupil. Also, at the upper limit, the overall length of the objective tends to become somewhat long for a compact construction for the camera. Accordingly, operating towards the middle to lower end of the range of thicknesses for the rearward component is normally preferred.

Similarly, to achieve compactness, the axial displacements of the last air surface of the first group and the first air surface of the rearward component with respect to the stop are relatively small, that is, the respective surfaces lie close to the stop. For the forward group, the concavity requires enough displacement axially from the stop to prevent interference of the periphery of the lens surface in its cell, if any, with the action of the shutter and stop, the latter usually comprising an iris or similar defining and variable opening. Optimum results are generally obtained if the rear surface of the forward component adjacent to the stop lies at a moderate distance from the stop, owing to the strong negative curvature of the surface, and generally curved about the stop, as is the case for the Hypergon.

Generally, the first group will include at least one plastic element having an aspheric surface. In the simplest case the aspherizing may be confined to the concave surface adjacent to and opposed to the stop, if the associated lens element is made of plastic.

Different considerations apply to the rear group than the front group. There are numerous lens designs that have complex structures following the stop, many with lead-off concave surfaces but the overall length of the objective and the clear apertures of the rearmost surfaces become much increased if wide angle performance is to be achieved. For purposes of the present invention, compactness requires that convergence after the stop be not too long delayed, either by too large an axial displacement from stop to lead-off surface of the rear component, or by use of a lead-off concave surface. The present invention is distinguished from the prior art in part from the fact that well-corrected optical performance is achieved even though the rearward component is relatively thin and relatively near the stop.

In quantitative terms, the axial clearance of the forward surface of the rear component from the stop should have a minimum value of about 0.015 times the EFL of the lens system. To achieve compactness, the upper limit is preferably set at about 0.050. For example, in Example 1, the axial separation between the stop and the front refracting surface of the rearward component is 0.038 times the lens system's EFL, which is within the 0.050 limit. While an even larger value is permissible for some applications, in general, the 0.050 value is appropriate for most applications of the present invention.

With respect to the rear component, there is also another way of looking at the limitations on total thickness and location. It is important as to the location of the convex rear air surface, if the front surface of the rear component tends toward plano. In this instance most of the converging power rests with the convex last refracting surface. The resulting strong curvature about the exit pupil is favorable for reducing the contribution of the surface to the undercorrected astigmatism of the system, particularly if the net convergence of the front component is weak. Conversely, if the element is thin, the axial separation from the stop becomes larger and indeed at or near the upper bound stated above. The refractive power of the component reacts favorably on the correction for distortion, that is, toward an inward or barrel-type refraction which offsets most if not all of the outward or pin-cushion refraction of the forward group. Correction for distortion need not be complete and thus the overall system can be held to a pin-cushion residual acceptable according to the application.

It should be noted that with respect to the off-axis refracting power of the rear component, a larger air space produces a kind of lever arm action which must not be overdone. It should also be noted that, except for wider angle systems, as the air space becomes larger and the rear component thinner, the first air surface of the rear component tends to become more and more convex and the rear surface weaker. This result holds true even if a focusing means is interpolated between the stop and the rear component.

In accordance with the invention, it is preferred to use at least one aspheric surface in the front group and not more than one in the rear component. The aspheric coefficients of power terms in a series expression for the

physical shape of the aspheric surface act as additional parameters, both for the forward group and for the rear component. Optimization procedures then produce favorable compactness, relatively short barrel lengths as an offshoot of compactness, and above all, improved correction for the many lower and higher order aberrations described above. Also, by means of these parameters, as well as the other optical parameters of the system, economy of construction, insensitivity to alignment errors, relative insensitivity to thermal changes of focus, and the like can be achieved to a greater or lesser extent depending upon the particular application.

Prior plastic systems used as camera objectives, including those having aspheric surfaces, have in many cases suffered from uncorrected longitudinal and lateral chromatic aberrations, as indeed have the landscape plastic and glass simple systems described earlier.

While the double meniscus systems with central stop generally have excellent correction for lateral chromatic aberration, that is to say, far off-axis images are more or less point-like rather than short spectra, the double meniscus forms are not short nor even compact. If the design makes use of a relatively short unsymmetrical barrel, as for the present invention, lateral chromatic aberration, if present, may indeed lead to degraded image quality at large off-axis angles. In the case of longitudinal chromatic aberration at f/10 more or less, the situation is much more forgiving. If not overdone, an improvement in depth of focus may even result.

Accordingly, in accordance with certain aspects of the invention, the lens system neglects longitudinal chromatic aberration but corrects for lateral chromatic aberrations. A short lens barrel also is helpful in this respect and may be thought of as a by-product of the designs conforming in other ways to the ranges and limitations expressed in this specification. In addition, a choice of materials front and rear is helpful.

Thus, the front group, at least for the simplest constructions, produces a net outward dispersion of the chief rays (such rays are defined as passing through the axial point of the real stop, one for each field angle), and the rear component, at least for the simplest constructions, an inward net dispersion. By arrangement of materials, lens powers and locations, a quite complete correction for lateral chromatic aberration over the field of view is achieved. A requirement, however, is that the rear component contain a material of strong dispersive power for a positive element in the rear component, which in the simplest case stands alone. This requirement is all the more important if the rear component lies near the stop. Incomplete correction, though a partial improvement, is allowable according to the image quality sought, but in any event, for purposes of this invention, at least some reduction in the lateral chromatic aberration for the system is generally required, as compared to that obtaining for a completely uncorrected system of equivalent monochromatic correction.

Thus, if a weakly dispersive material such as CHM or plexiglas ® is used for the strongest positive element in the rear component, particularly if the rear component is comprised in the simplest form of but a single positive element, the correction for lateral chromatic aberration in the case of the unsymmetrical objective forms outlined above, though partial, is generally inadequate. For purposes of the present invention one generally must resort to some more dispersive material for use as a positive element in the rear component. Viable materials are available, such as AN (acrylonitrile), styrene, or polycarbonate, where a moldable plastic is used. There will also be the cases where the rear component contains a dispersive glass element with spherical surfaces, aided by a thin contact element of plastic, including plexiglas ® or CHM, if only for the purpose of incorporating an aspheric surface on the plastic element or elements. In all these circumstances the design purpose is to achieve some marked reduction of the lateral chromatic aberration. Objectives not having such a reduction are generally not to be considered as part of the present invention.

Moreover, if the rear component is compounded of at least two materials of high and low dispersive powers, which can be called hyperchromatic for the net action resulting, it becomes possible to continue the correction or reduction in lateral chromatic aberration, even if the material of highest dispersive power for the positive element is not as dispersive as for the simpler, non-hyperchromatic combinations. This is true even if the hyperchromatic pairing lies near the stop. It is for this reason, when taken together with the stated bounds on axial location and dioptric power of the rear component that the present invention includes systems with two or more elements bonded together in optical contact to effect the correction and to simulate the action of non-existing single materials.

In summary, it is a purpose of this invention to require that a reduction in lateral chromatic aberration for the system as a whole be effected at least in part, as measured by the spectral spread in the image surface of an otherwise desired image point, according to the off-axis angle and spectral band-width, for uncorrected and totally or partially corrected systems being compared.

Thus, the inventive systems comprise a type of unsymmetrical objective which is compact, in terms of both barrel length and overall length, which provides improved performance for systems of moderate speed, such as f/8 or slower, having only a single rear component or which may incorporate a focusing means between said rear component and stop, such an objective having acceptable correction for distortion not exceeding 5%, according to aspheric powers and complexity of construction.

For practical reasons, any given plastic moldable element should either have spherical surfaces or not more than one of its two surfaces aspheric. To do otherwise, that is to say, if both surfaces were to be made aspheric, one usually will encounter serious misalignment, that is, lateral decentering of the respective aspheric zones, particularly if higher order aspheric terms of significance are present. Similarly, it is not feasible in large production runs for a design to have bonded aspheric surfaces of contact between adjacent elements of different materials. For purposes of the present invention, therefore, one can say that if more than one aspheric surface is used forward of the stop (that is to say, on the long conjugate side of the stop), there will be a corresponding number of plastic elements with any given aspheric at an air surface of the host element. In general, it is sufficient for the purposes of the present invention to limit the number of aspheric surfaces forward of the stop to not more than two. According to the application, the particular aspheric surface may lie either on the forward surface of its host element or on the rear. For the single rear component,

having therefore only two air surfaces, either one of these two surfaces may be aspheric but in general not both.

The objectives can be further modified by interpolation of some form of focusing means immediately following the stop and preceding the above discussed rear component. It is intended that the maximum axial distance between the shutter and rear surface vertex of the rear component not be increased, but that instead, enough space be left between the stop and the front surface vertex of the rear component for the aforesaid interpolation of a focusing means. Further discussion of the focusing means appears below.

Aspheric surfaces that are separated along the optical axis from front to rear of the objective not only have aspheric power zone by zone on the respective surface but also have a lever arm effect on refracted rays in interaction between one another. If the aspheric surfaces are far apart, the aspheric power zone by zone on either surface may be weak but varying in strength of the refractions in interplay over any angular field required. If the aspheric surfaces are close to one another, the respective coefficients often tend to be quite large but usually with less variation over the field. Moreover, higher order aspheric terms that are far apart tend to affect images in the tangential direction more sensitively than at right angles thereto. An image having an ambient aberrational extent in a direction radially outward, particularly if far from the center of the field, may be pulled together to an image core that improves the focusing effect for tangential lines while the skew direction of the image remains only partially improved in focusing effect for radial lines. Sometimes this azimuthal variation in correction may be useful if the uncorrected aberrations have the opposite tendencies, but more often not. If the aspheric surface lies relatively near to the stop, then even the higher order terms may be more tractable in the various azimuths of the image.

In terms of the present invention, the single aspheric of the rearward component, if any, may be on either air surface. Forward of the stop, at least one aspheric air surface preferably lies on the component nearest the stop, whether on the forward or rear surface of this component.

In the text above, the term "air surface" has been used. It is generally true that the hand camera objective is immersed in ordinary air at a density varying with elevation above or below the earth's mean surface. In space technology, however, it may prove necessary to use some other gaseous medium, such as dry nitrogen, or helium, or other gas, at a gas pressure from some maximum value down even to zero if a true vacuum is required. Clearly, the refractive actions of the surfaces of the present invention are not affected substantially thereby, except for a slight refocusing required and calibration of scale, and the governing principles within the scope of this invention remain essentially the same. The term "air" surface is accordingly used herein in a generic sense purely by way of reference, for the case of the vacuum is also included. In particular, in this specification and in the appended claims, the phrases "air surface" and "air-spaced" are to be understood to include a vacuum and media other than air when used in the practice of the invention.

One of the important features of the present invention is that the concave surface adjacent to and forward of the stop is very strongly curved. For Example 1 (FIG. 1 Series and Table 1) the axial curvature (1/R) of this surface is 7.61 in terms of the dioptric power for the system as a whole being taken as 1.000. Such a strong curvature is unusual in camera objectives except for wide angle systems of moderate aperature-ratio, such as f/5 to f/60 or so, the latter as for the Hypergon. Clearly, the front group cannot have the weak net positive power alluded to earlier unless there is at least one strongly positive compensating surface forward of the concave surface adjacent to the stop.

In quantitative terms, the concave surface adjacent to and forward of the stop should in general have a curvature in the range from about 4.0 to about 10.0 without regard to algebraic sign in terms of the dioptric power of the system as a whole being taken as 1.0. In the examples discussed below, the range for this surface is between 5.1 and 7.7. The wider recommended range allows for variations derived from wider field angles, or higher f-numbers, or for some special requirement such as clearance between lens surface and shutter action, where no change in principle occurs.

In the specific instance of Example 1 the lens group forward of the stop is comprised of but a single plastic element of plexiglas ® with the concave surface adjacent to the stop being aspheric. This is about the simplest forms of forward group lying within the scope of the present invention. The element is relatively thick in that the axial thickness is 0.060 of the equivalent focal length, and the forward surface is almost as strongly curved as the rear, the net power arising from the separation of surfaces. As noted above, the net dioptric power of this single element is 0.391 and the equivalent focal length of the element is 2.556. A real image is formed to the right if entered on the usual lens drawing.

For Example 1, the single component lying rearward of the stop is formed of but a single element of styrene and the rear surface of this element is both weakly curved and aspheric, the surface being slightly convex. If plexiglas ® were to be used for this single rear element instead of styrene, the high v-value or low dispersive power of plexiglas ® would have resulted in a marked amount of lateral chromatic aberration. Although a single rear plexiglas ® positive element does in part counteract the opposite contribution to lateral chromatic aberration of the meniscus lens element forward of the stop, the compensation is inadequate. One can take the net lateral chromatic aberration of such an all-plexiglas ® system as defining lateral chromatic aberration in a quantitative sense, e.g., as the radial extent of an image as a short spectrum instead of as the desired point image measured radially at some off-axis angle between red and blue wavelengths. Uncorrected lateral chromatic aberration is a defect for chief rays too, even though the lens aperture may be stopped down nearly to zero. When styrene is used for the rear component as in Example 1, the radial extent of the short spectrum is reduced virtually to zero.

Example 3 (FIG. 3 Series and Table 3) is closely related to Example 1 in general nature except that polycarbonate or PC has been used instead of styrene. The dispersive power of polycarbonate is approximately the same as for styrene, the respective nu-values being 29.9 (PC) and 30.8 (styrene). For comparison, the nu-value for plexiglas ® is 57.2, while that for AN is 34.9 approximately. Thus, any one of the three dispersive plastic materials styrene, PC or AN will reduce lateral chromatic aberration to acceptable residuals, as compared to use of plexiglas ® alone.

It should be noted that use of a very dispersive medium for the positive lens of the rear component, while needed for reducing or eliminating lateral chromatic aberration, increases the undercorrected longitudinal chromatic aberration of the system as a whole. It should also be noted that if elaborate compounding of elements of different dispersive power is employed within the lens group forward of the stop, or if multiple strong elements are used, as for many photographic objectives, it is feasible to reduce the longitudinal chromatic aberration to such a level that use of plexiglas ® for the rear element will lead to correction for lateral chromatic aberration. Such elaborate construction however results in extra costs and complexity, not in keeping with the needs of an economic photographic objective intended for the mass market.

Within the scope of this invention, it is intended that the longitudinal chromatic aberration of the front group is only partially corrected, if at all, and that the use of a dispersive medium for a positive element in the rear component may actually increase the longitudinal chromatic aberration for the system as a whole. The dividing line rests with the choice of dispersive medium for the rear component, where one can take an averaged value for the rear pairings, if of more than one element, or if but a single element, for the one plastic medium, as being not larger than 44.0, about the halfway point for the specific materials already mentioned. At this halfway point either the longitudinal chromatic aberration of the system as a whole, as a result of elaboration of construction and materials in the front group, is about 50% corrected with the effective elimination of lateral chromatic aberration, or else the lateral chromatic aberration is about half corrected, if the group of elements forward of the stop is not at all corrected for longitudinal chromatic aberration.

Apart from considerations of chromatic corrections there is another reason for elaboration of the structure of the front group. Plastic molded elements are economical and well suited for the mass market. However, at least to some extent, a need exists for having a lead-off element made of an optical glass and generally therefore with spherical surfaces. Hand cameras quite often receive rough treatment in the family environment in that the front surface becomes soiled, abraded, or corroded. Accordingly, for some cameras it becomes desirable to have the simple element used in Example 1 or in Example 3 protected by the addition of a front spherically surfaced glass element. For minimization of costs with respect to lens cells, and other mounting details, it is desirable that the one glass element with a single companion plastic element (with one aspheric surface) comprise a more elaborate front lens group fitting the same cell as for the simpler cases of Examples 1 or 3. Such a two-element front group fitting the same cell and mount as for the single element front component may be called a "drop-in" replacement, to be used or not used, as desired. Examples 2 and 4 (Figures and Tables) thus have glass front elements that by design and in combination with suitably shaped plexiglas ® second elements form "drop-in" equivalents of Examples 1 and 3 having glass front surfaces. The optical performances remain very nearly the same and no new principles are introduced affecting the range of parameters already discussed.

It has been mentioned above that the lens systems incorporating the several principles of this invention can be further modified by the interpolation of focusing means between the stop and the front surface of the rear component. Various forms of focusing are known in the art. One of the oldest is physical movement of the objective as a whole along the optical axis until the image conjugate to the object surface is focused as well as need be on the recording surface of the camera. This kind of focusing can be used with the lens systems of this invention to achieve focusing for object planes from 4 equivalent focal lengths of the objective at the near point through a continuous range up to an infinite object distance.

Interpolation of focusing means can be used instead of the above discussed physical movement of the objective as a whole. In particular, compactness and camera construction may preclude any marked change in position of the objective and instead, one may interpolate a much more compact focusing means. Known in the art is the direct interpolation of one or more dioptrically weak elements of glass or plastic, but only one at a time to accord with any given object distance. Such weak dioptric elements can be arranged on an eccentric wheel and if of plastic molded as a unit to accommodate several interchangeable weak elements according to the angular setting of the disc. For any given object distance the corresponding element will be centered in position on the optical axis between stop and rear component. If of plastic, weak aspherics may also be used for each of the weak elements on the disc to improve performance according to the object distance. Such aspherics are permitted and are not to be confused with the aspherics previously described on one of the air surfaces of the rear component.

Another form of focusing known in the art is the interpolation of a pair of plates, each with an external plano optical surface, in close juxtaposition on the optical axis immediately following the stop as, for example, that disclosed in U.S. Pat. No. 3,583,790 issued to James G. Baker on Jun. 8, 1971. The opposed and adjacent internal surfaces of the pair of plates can be of an aspheric shape of analytic mathematical surfaces described in detail by polynomial expressions of non-rotational terms in x and y up to some cutoff term in what may otherwise be a power series that represents the desired analytic surface mathematically to any desired precision. The polynomial terms may include the ordinary second and higher order rotational terms of any dioptric surface and aspherics normally associated with purely rotational aspheric surfaces. Focusing is accomplished by an eccentric rotation of one or both of the plates about axes displaced laterally from the optical axis generally completely outside of the interrupted lens barrel. Another means is to slide one or both of the plates laterally such that the plano surface on each remains in its own plane during the sliding. The quantitative nature of the polynomial terms are optimized throughout the focusing range according to the type of focusing motion of the plates deemed desirable for the application.

2. Specific Embodiments and Applications

FIGS. 1–7 illustrate various lens systems constructed in accordance with the invention. Corresponding prescriptions appear in Tables 1 to 7, respectively. The dimensions given in these tables have been normalized to the EFL of the lens which is nominally 100 mm. The aspheric coefficients set forth in the tables are for use in the following equation:

$$z(r) = \frac{cr^2}{1 + [1 - (1 + K)c^2r^2]^{\frac{1}{2}}} + Ar^4 + Br^6 + Cr^8 + Dr^{10}$$

where $r^2 = x^2 + y^2$, c is the curvature at the pole of the surface, K is a conic constant ($K = -e^2$), which for the lenses of Tables 1-7 is zero, and A, B, C, and D are the 4th, 6th, 8th, and 10th order deformation terms.

In overview, the examples of FIGS. **1** and **3** show the two-component form of the lens system of the invention. Example 1 uses styrene for the rear component, and Example 3 uses PC. Examples 2 and 4 illustrate the use of a "drop-in" plastic-glass combination with the front element being made of glass. Examples 5-7 show further variations embodying the principles of the invention. Example 5 increases the field to 62 degrees; Example 6 has very low distortion as well as a glass front element; and Example 7 includes a focusing means.

A preferred application of the objective lens systems of the present invention is in connection with a folding, reflex camera **10** such as the one illustrated in FIGS. **8-10**. FIG. **8** shows camera **10** in its folded condition and FIG. **9** and **10** in its fully erected, picture taking condition. If the base of camera **10** is placed on the horizontal, the objective "looks" slightly up. The camera preferably accepts instant, or self-processable, film whose format can be, for example, 2.15 by 2.87 inches with a diagonal of 3.586 inches.

Prior to taking a picture, camera **10**, upon actuation by pressing a shutter button, automatically determines which one of two zones the subject is in and then, depending on the zone, sets the objective lens system in one of two possible configurations to assure that the subject will be sharply reproduced (see below).

In both of its configurations, the lens system preferably has a maximum aperture of f/10 with a semi-field coverage of 14.25 by 18.76 degrees with a half diagonal of 23.05 degrees. The effective focal length preferably is 99.1 mm. Preferably, distortion is less than 3%, and the blur diameter due to all aberrations is less than 0.005 inches.

The lens system, here preferably example 7 of FIGS. 7A-7E and Table 7, preferably includes two plastic elements. The first element is molded of plexiglas ® and has an aspheric rear surface. Following the first element is a stop which is preferably oblong in shape being longer along the y-axis, the up and down of the camera, than in the x-axis, the horizontal azimuth of the camera.

Following the stop, adjacent and in alignment with it, are a pair of apertured reciprocating blades (not shown) that open and close to control exposure. In the x-direction, the maximum aperture is f/1 4 while in the y-direction, it is f/10 for an average overall aperture of about f/12. Hence, the f/10 designation has been adopted to go along with the maximum in the y-direction.

Following the reciprocating blades is a second positive lens made of polystyrene having a first surface which is spherical and a second surface which is aspheric.

Following the second element is a plano mirror (not shown) for folding the optical path and following that is the film surface which is slightly curved inwardly, i.e., the ends bend toward the front of the camera **10**. In particular, the film surface is curved in the x-z plane and, as such, must be included in evaluating the overall performance of the camera optical system, i.e., objective plus curved film surface, because it relaxes the demands on the objective for correcting curvature of field.

The second, longer focal length configuration of the lens system is achieved by introducing a supplemental lens in the intervening space between the two elements of the first configuration. This lens is preferably made of plexiglas ®, has a net negative power and is positioned along the optical axis following the stop and shutter blades. This element is preferably all spherical, although an aspheric surface can be included if desired. By introducing this element, the net power of the combination is reduced, nominally focusing it at 11 feet with a range of focus of 8 feet to infinity. A suitable prescription for this focusing lens, focusing to infinity for example, to an image position preset beyond a focal point for alternate usage, for use with the lens system of Table 3 is given in Table 7. The front vertex of the focusing lens is located 0.0128 behind the stop in Table 7.

As discussed above, the lens system's front plastic element can be replaced by a glass-plastic combination. The glass element can be made of BK7 glass from the OHARA glass catalog. In both the near and far configurations, the remainder of the optics following the glass-plastic pair are as before. As also discussed above, the glass-plastic pair is preferably packaged so that its outside shape and dimensions match those of the plastic front element of the all plastic version so that it can be used as a "drop-in" replacement during manufacturing. This is accomplished by encapsulating the outside exterior surfaces of the glass-plastic combination in a casing which closely matches the exterior geometry of the plastic version.

With both the all plastic and glass-plastic version, a close-up lens can be provided. The close-up lens, which is a manual, external attachment, can be made of plexiglas ® and preferably has spherical surfaces. This element is intended to be used at a aperture no larger than f/40 so its shape is not critical, just its power. It can nominally focus the camera at 12 inches and can have a range of focus which is largely dependent on exposure errors rather than optical capability. This is because exposure errors vary as the inverse of the fourth power and are large at this distance range (small changes result in large exposure errors) while focus errors are less sensitive. In other words, the exposure errors will become noticeable so quickly that they will completely overwhelm any blurriness that may be present. A suitable prescription for the close-up lens for use with the lens system of Table 3 is given in Table 8. The rear vertex of the close-up lens is forward of the front vertex of the lens system of Table 3.

Although specific embodiments of the invention have been described and illustrated, it is to be understood that a variety of modifications which do not depart from the scope and spirit of the invention will be evident to persons of ordinary skill in the art from the foregoing disclosure. For example, the front group may be made of glass and the rear moldable plastic with the difference in their Abbé v-values exceeding 10 numerically. The following claims are intended to cover the specific embodiments set forth herein as well as such modifications, variations, and equivalents.

TABLE 1

Surface No.	Radii	Separations	n(d)	nu
1	0.1369	0.0604	1.492	57.2
2	0.1314*	0.0257		
3	Stop	0.0380		
4	0.843	0.0203	1.592	30.8
5	−18.18*	0.817**		

overall length = 0.9614;
48.9°, infinite object distance
f = 1.000
*aspheric
**back focus, inf. obj. dist. (to focal point)
Aspheric Surface Data:

Surface	A	B	C	D
2	0.345×10^{2}	0.121×10^{0}	0.180×10^{-3}	$0.277 \times 10^{+1}$
5	-0.481×10^{0}	-0.108×10^{4}	-0.351×10^{-2}	-0.609×10^{-5}

TABLE 2

Surface No.	Radii	Separations	n(d)	nu
1	0.1363	0.0221	1.516	64.1
2	0.1631	0.0010		
3	0.1664	0.0374	1.492	57.2
4	0.1315*	0.0257		
5	Stop	0.0381		
6	0.8440	0.0203	1.592	30.8
7	−18.19*	0.817**		

OAL = 0.9616;
48.9°, inf. obj. distance
f = 1.000
*aspheric
**back focus, inf. obj. dist. (to focal point)
Aspheric Surface Data:

Surface	A	B	C	D
4	0.354×10^{2}	0.136×10^{0}	0.725×10^{-3}	$0.275 \times 10^{+1}$
7	-0.479×10^{0}	-0.108×10^{4}	-0.349×10^{-2}	-0.605×10^{-5}

TABLE 3

Surface No.	Radii	Separations	n(d)	nu
1	0.1351	0.0610	1.492	57.2
2	0.1297*	0.0260		
3	Stop	0.0384		
4	0.7628	0.0205	1.586	29.9
5	10.50*	0.811**		

OAL = 0.9569;
49.4°, inf. obj. distance
f = 1.000
*aspheric
**back focus, inf. obj. dist. (to focal point)
Aspheric Surface Data:

Surface	A	B	C	D
2	0.370×10^{2}	0.115×10^{0}	0.167×10^{-3}	$0.252 \times 10^{+1}$
5	-0.676×10^{0}	-0.102×10^{4}	-0.326×10^{-2}	-0.554×10^{-5}

TABLE 4

Surface No.	Radii	Separations	n(d)	nu
1	0.1378	0.0223	1.516	64.1
2	0.1650	0.0010		
3	0.1670	0.0378	1.492	57.2
4	0.1332*	0.0260		
5	Stop	0.0385		
6	0.8694	0.0205	1.586	29.9
7	−18.44*	0.814**		

OAL = 0.9601;
49.4°, inf. obj. distance
f = 1.000
*aspheric
**back focus, inf. obj. dist. (to focal point)
Aspheric Surface Data:

Surface	A	B	C	D
4	0.346×10^{2}	0.129×10^{0}	0.671×10^{-3}	$0.249 \times 10^{+1}$

TABLE 4-continued

7	-0.695×10^{0}	-0.943×10^{3}	-0.323×10^{-2}	-0.548×10^{-5}

TABLE 5

Surface No.	Radii	Separations	n(d)	nu
1	0.1442	0.0627	1.492	57.2
2	0.1448*	0.0295		
3	Stop	0.0438		
4	1.1082	0.0151	1.586	29.9
5	−7.201*	0.811**		

OAL = 0.9621;
62°, inf. obj. distance
f = 1.000
*aspheric
**back focus, inf. obj. dist. (to focal point)
Aspheric Surface Data:

Surface	A	B	C	D
2	0.323×10^{2}	0.117×10^{0}	0.167×10^{-3}	$0.253 \times 10^{+1}$
5	-0.136×10^{0}	-0.439×10^{3}	-0.327×10^{-2}	-0.556×10^{-5}

TABLE 6

Surface No.	Radii	Separations	n(d)	nu
1	0.1659	0.0339	1.621	60.3
2	0.2070	0.0011		
3	0.2092	0.0161	1.492	57.2
4	0.1511*	0.0416		
5	Stop	0.0410		
6	−0.5831	0.0218	1.586	29.9
7	−0.3173*	0.874**		

OAL = 1.0295;
52.2°, inf. obj. distance
f = 1.000
*aspheric
**back focus, inf. obj. dist. (to focal point)
Aspheric Surface Data:

Surface	A	B	C	D
4	0.281×10^{2}	0.234×10^{0}	0.453×10^{-3}	0.225×10^{-11}
7	-0.439×10^{1}	-0.877×10^{3}	-0.247×10^{-1}	-0.489×10^{-8}

TABLE 7

Surface No.	Radii	Separations	n(d)	nu
1	0.1351	0.0610	1.492	57.2
2	0.1297*	0.0260		
3	Stop	0.0128		
4	−266.1*	0.0128	1.492	57.2
5	Plano	0.0119		
6	0.7628	0.0205	1.586	29.9
7	10.50*	0.813**		

OAL = 0.9583;
49.4°, inf. obj. distance
f = 1.000
*aspheric
**back focus, inf. obj. dist. (to focal point)
Aspheric Surface Data:

Surface	A	B	C	D
2	0.370×10^{2}	0.115×10^{0}	0.167×10^{-3}	$0.252 \times 10^{+1}$
4	0.532×10^{1}	0.211×10^{0}	0.135×10^{-2}	0.148×10^{-4}
7	-0.676×10^{0}	-0.102×10^{4}	-0.326×10^{-2}	-0.554×10^{-5}

TABLE 8

Surface No.	Radii	Separations	n(d)	nu
1	0.2856	0.0171	1.492	57.2
2	0.3313	0.0453		
3	0.1351	0.0610	1.492	57.2
4	0.1297*	0.0260		
5	Stop	0.0384		
6	0.7628	0.0205	1.586	29.9
7	10.50*	0.8855**		

f = 1.000

TABLE 8-continued

*aspheric
**back focus (to image surface, close up object distance = $3.075f_0$)
Aspheric Surface Data:

Surface	A	B	C	D
4	0.370×10^{2}	0.115×10^{0}	0.167×10^{-3}	$0.252 \times 10^{+1}$
7	-0.676×10^{0}	-0.102×10^{4}	-0.326×10^{-2}	-0.554×10^{-5}

What is claimed is:

1. A lens system for use in forming an image on a flat or weakly concave recording surface which has a half-diagonal length $D_{\frac{1}{2}}$, said lens system (i) having an equivalent focal length f_0, (ii) a diotropic power K_0, and (iii) including a stop or aperture, said lens system comprising:

(a) a first group on the object side of the stop or aperture having a positive dioptric power K_1 which is in the range from about 0.2 to about 0.5 times K_0, said first group comprising a concave surface preceding and adjacent to the stop or aperture, said concave surface having a radius of curvature, if spherical, or a central radius of curvature, if aspheric, lying in the range from about 0.1 to about 0.25 times f_0, the vertex or axial point of said concave surface lying within a distance along the lens system's optical axis from the axial point of the stop or aperture not greater than about 1/20 times f_0; and

(b) a second group on the image side of the stop or aperture consisting of a single component comprising one or more lens elements, said single component having:

(i) only two air surfaces;

(ii) a positive power;

(iii) a front vertex which lies axially to the rear of the axial point of the stop or aperture at a distance not greater than about 1/20 times f_0;

(iv) an axial thickness not greater than about 1/20 times f_0; and

(v) a forward surface adjacent to the stop or aperture having a curvature, if spherical, or an axial or central curvature, if aspheric, lying in the range from about -2.0 to about $+1.5$ times K_0;

said lens system:

(i) having a total diagonal field of view not exceeding about 62 degrees;

(ii) having an average field curvature whose magnitude in any azimuth does not exceed about 0.1 times K_0;

(iii) having a distortion not exceeding about 5% of $D_{\frac{1}{2}}$;

(iv) being corrected at least partially for lateral chromatic aberration; and

(v) having at least two elements made of materials differing in dispersive powers, at least one of the two elements is plastic.

2. The lens system of claim 1 wherein:

(A) the overall axial length from the lens system's first surface vertex to the focal point in image space does not exceed about 1.030 times f_0, external attachments excluded, for an object at infinity; and

(B) the overall axial length from the lens system's first surface vertex to the conjugate focus in image space does not exceed about 1.365 times f_0, external attachments excluded, for object distances down to but not less than about 4 times f_0, object distances being measured from the axial point of the object surface along the axis to the vertex of the first lens surface on the long conjugate side of the lens system.

3. The lens system of claim 2 wherein the overall axial length from the lens system's first surface vertex to its rear surface vertex does not exceed about 0.165 f_0, external attachments excluded.

4. A lens system for use in forming an image on a flat or weakly concave recording surface which has a half-diagonal length $D_{\frac{1}{2}}$, said lens system (i) having an equivalent focal length f_0, (ii) a dioptric power K_0, and (iii) including a stop or aperture, said lens system comprising:

(a) a first group on the object side of the stop or aperture having a positive dioptric power K_1 which is in the range from about 0.2 to about 0.5 times K_0, said first group comprising:

(i) a concave surface preceding and adjacent to the stop or aperture, said concave surface having a radius of curvature, if spherical, or a central radius of curvature, if aspheric lying, in the range from about 0.1 to about 0.25 times f_0, the vertex or axial point of said concave surface lying within a distance along the lens system's optical axis from the axial point of the stop or aperture not greater than about 1/20 times f_0; and

(ii) at least one aspheric surface; and

(b) a second group on the image side of the stop or aperture consisting of two separated subgroups,

the first of said two separated subgroups comprising focusing means for focusing the lens system as a whole over a range of object distances from infinity down to about 4.0 times f_0, object distances being measured from the axial point of the object surface along the axis to the vertex of the first lens surface on the long conjugate side of the lens system, and

the second of said two separated subgroups consisting of a single component comprising one or more lens elements, said single component having:

(i) only two air surfaces;

(ii) a positive power;

(iii) a front vertex which lies axially to the rear of the axial point of the stop or aperture at a distance not greater than about 1/20 times f_0, said distance containing wholly within it said first of said two separated subgroups;

(iv) an axial thickness not greater than about 1/20 times f_0; and

(v) a forward surface having a curvature, if spherical, or an axial or central curvature, if aspheric, lying in the range from about -2.0 to about $+1.5$ times K_0;

said lens system:

(i) having a total diagonal field of view not exceeding about 62 degrees;

(ii) having an average field curvature whose magnitude

in any azimuth does not exceed about 0.1 times K_0;

(iii) having a distortion not exceeding about 5% of $D_{\frac{1}{4}}$;

(iv) being corrected at least partially for lateral chromatic aberration; and

(v) having at least two elements made of plastic materials differing in dispersive powers.

5. The lens system of claim 4 wherein:

(A) the overall axial length from the lens system's first surface vertex to the focal point in image space does not exceed about 1.030 times f_0, external attachments excluded, for an object at infinity; and

(B) the overall axial length from the lens system's first surface vertex to the conjugate focus in image space does not exceed about 1.365 times f_0, external attachments excluded, for object distances down to but not less than about 4 times f_0.

6. The lens system of claim 5 wherein the overall axial length from the lens system's first surface vertex to its rear surface vertex does not exceed about 0.165 f_0, external attachments excluded.

7. The lens system of claim 1, 2, 3, 4, 5, or 6 wherein the first group consists of a single element.

8. The lens system of claim 1, 2, 3, 4, 5, or 6 wherein the single component of the second group has an aspheric surface.

9. The lens system of claim 1, 2, 3, 4, 5, or 6 wherein the forward surface of the single component of the second group is convex in the direction of the stop or aperture.

10. The lens system of claim 1 having at least two elements made of plastic materials differing in dispersive powers.

11. The lens system of claim 1 having the following prescription:

Surface No.	Radii	Separations	n(d)	nu
1	0.1369	0.0604	1.492	57.2
2	0.1314*	0.0257		
3	Stop	0.0380		
4	0.843	0.0203	1.592	30.8
5	−18.18*	0.817**		

overall length = 0.9614;
48.9°, infinite object distance
f = 1.000
*aspheric
**back focus, inf. obj. dist. (to focal point)
Aspheric Surface Data:

Surface	A	B	C	D
2	0.345×10^{2}	0.121×10^{0}	0.180×10^{-3}	$0.277 \times 10^{+1}$
4	-0.481×10^{0}	-0.108×10^{4}	-0.351×10^{-2}	-0.609×10^{-5}

12. The lens system of claim 1 having the following prescription:

Surface No.	Radii	Separations	n(d)	nu
1	0.1363	0.0221	1.516	64.1
2	0.1631	0.0010		
3	0.1664	0.0374	1.492	57.2
4	0.1315*	0.0257		
5	Stop	0.0381		
6	0.8440	0.0203	1.592	30.8
7	−18.19*	0.817**		

OAL = 0.9616; 48.9°, inf. obj. distance
f = 1.000
*aspheric
**back focus, inf. obj. dist. (to focal point)
Aspheric Surface Data:

Surface	A	B	C	D
4	0.354×10^{2}	0.136×10^{0}	0.725×10^{-3}	$0.275 \times 10^{+1}$
7	-0.479×10^{0}	-0.108×10^{4}	-0.349×10^{-2}	-0.605×10^{-5}

13. The lens system of claim 1 having the following prescription:

Surface No.	Radii	Separations	n(d)	nu
1	0.1351	0.0610	1.492	57.2
2	0.1297*	0.0260		
3	Stop	0.0384		
4	0.7628	0.0205	1.586	29.9
5	10.50*	0.811**		

OAL = 0.9569; 49.4°, inf. obj. distance
f = 1.000
*aspheric
**back focus, inf. obj. dist. (to focal point)
Aspheric Surface Data:

Surface	A	B	C	D
2	0.370×10^{2}	0.115×10^{0}	0.167×10^{-3}	$0.252 \times 10^{+1}$

-continued

5	-0.676×10^{0}	-0.102×10^{4}	-0.326×10^{-2}	-0.554×10^{-5}

14. The lens system of claim **1** having the following prescription:

Surface No.	Radii	Separations	n(d)	nu
1	0.1378	0.0223	1.516	64.1
2	0.1650	0.0010		
3	0.1670	0.0378	1.492	57.2
4	0.1332*	0.0260		
5	Stop	0.0385		
6	0.8694	0.0205	1.586	29.9
7	−18.44*	0.814**		

OAL = 0.9601; 49.4°, inf. obj. distance
f = 1.000
*aspheric
**back focus, inf. obj. dist. (to focal point)
Aspheric Surface Data:

Surface	A	B	C	D
4	0.346×10^{2}	0.129×10^{0}	0.671×10^{-3}	$0.249 \times 10^{+1}$
7	-0.695×10^{0}	-0.943×10^{3}	-0.323×10^{-2}	-0.548×10^{-5}

15. The lens system of claim **1** having the following prescription:

Surface No.	Radii	Separations	n(d)	nu
1	0.1442	0.0627	1.492	57.2
2	0.1448*	0.0295		
3	Stop	0.0438		
4	1.1082	0.0151	1.586	29.9
5	−7.201*	0.811**		

OAL = 0.9621; 62°, inf. obj. distance
f = 1.000
*aspheric
**back focus, inf. obj. dist. (to focal point)
Aspheric Surface Data:

Surface	A	B	C	D
2	0.323×10^{2}	0.117×10^{0}	0.167×10^{-3}	$0.253 \times 10^{+1}$
5	-0.136×10^{0}	-0.439×10^{3}	-0.327×10^{-2}	-0.556×10^{-5}

16. The lens system of claim **1** having the following prescription:

Surface No.	Radii	Separations	n(d)	nu
1	0.1659	0.0339	1.621	60.3
2	0.2070	0.0011		
3	0.2092	0.0161	1.492	57.2
4	0.1511*	0.0416		
5	Stop	0.0410		
6	−0.5831	0.0218	1.586	29.9
7	−0.3173*	0.874**		

OAL = 1.0295; 52.2°, inf. obj. distance
f = 1.000
*aspheric
**back focus, inf. obj. dist. (to focal point)
Aspheric Surface Data:

Surface	A	B	C	D
4	0.281×10^{2}	0.234×10^{0}	0.453×10^{-3}	0.225×10^{-11}
7	-0.439×10^{1}	-0.877×10^{3}	-0.247×10^{-1}	-0.489×10^{-8}

17. The lens system of claim **1** having the following prescription:

Surface No.	Radii	Separations	n(d)	nu
1	0.1351	0.0610	1.492	57.2
2	0.1297*	0.0260		
3	Stop	0.0128		
4	−266.1*	0.0128	1.492	57.2
5	Plano	0.0119		
6	0.7628	0.0205	1.586	29.9
7	10.50*	0.813**		

-continued

OAL = 0.9583; 49.4°, inf. obj. distance
f = 1.000
*aspheric
**back focus, inf. obj. dist. (to focal point)
Aspheric Surface Data:

Surface	A	B	C	D
2	0.370×10^{2}	0.115×10^{0}	0.167×10^{-3}	$0.252 \times 10^{+1}$
4	0.532×10^{1}	0.211×10^{0}	0.135×10^{-2}	0.148×10^{-4}
7	-0.676×10^{0}	-0.102×10^{4}	-0.326×10^{-2}	-0.554×10^{-8}

18. The lens system of claim 1 having the following prescription:

Surface No.	Radii	Separations	n(d)	nu
1	0.2856	0.0171	1.492	57.2
2	0.3313	0.0453		
3	0.1351	0.0610	1.492	57.2
4	0.1297*	0.0260		
5	Stop	0.0384		
6	0.7628	0.0205	1.586	29.9
7	10.50*	0.8855**		

f = 1.000
*aspheric
**back focus (to image surface, close up object distance = $3.075f_0$)
Aspheric Surface Data:

Surface	A	B	C	D
4	0.370×10^{2}	0.115×10^{0}	0.167×10^{-3}	$0.252 \times 10^{+1}$
7	-0.676×10^{0}	-0.102×10^{4}	-0.326×10^{-2}	-0.554×10^{-8}

* * * * *

US005321555A

United States Patent [19]

Koelsch et al.

[11] Patent Number: 5,321,555

[45] Date of Patent: Jun. 14, 1994

[54] **COMPACT PHOTOGRAPHIC OBJECTIVE OF THE TRIPLET TYPE HAVING IMPROVED CHROMATIC AND MONOCHROMATIC CHARACTERISTICS**

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[73] Assignee: **Leica Camera GmbH**, Solms, Fed. Rep. of Germany

[21] Appl. No.: **960,108**

[22] Filed: **Oct. 13, 1992**

[30] **Foreign Application Priority Data**

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[51] **Int. Cl.**[5] **G02B 9/14**

[52] **U.S. Cl.** **359/786**; 359/785

[58] **Field of Search** 359/784–786, 359/748, 753

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Primary Examiner—Loha Ben
Assistant Examiner—James Phan
Attorney, Agent, or Firm—Foley & Lardner

[57] **ABSTRACT**

An objective for use in photographic compact cameras has a relative aperture of 3.5 and a focal length of 35 mm, and is of the triplet type. The lens element on the object side is a cemented element. In order to achieve an extremely compact structural shape and balanced monochromatic correction, as well as a reduction in the chromatic magnification difference, the color coma and the color astigmatism, four design conditions are specified.

3 Claims, 5 Drawing Sheets

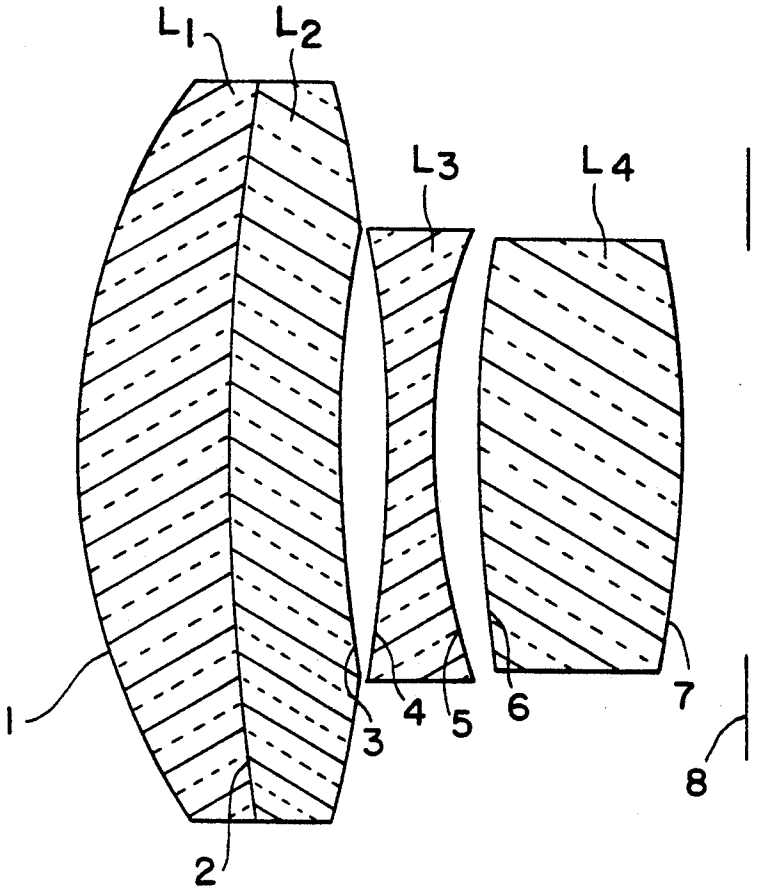


FIG. 1

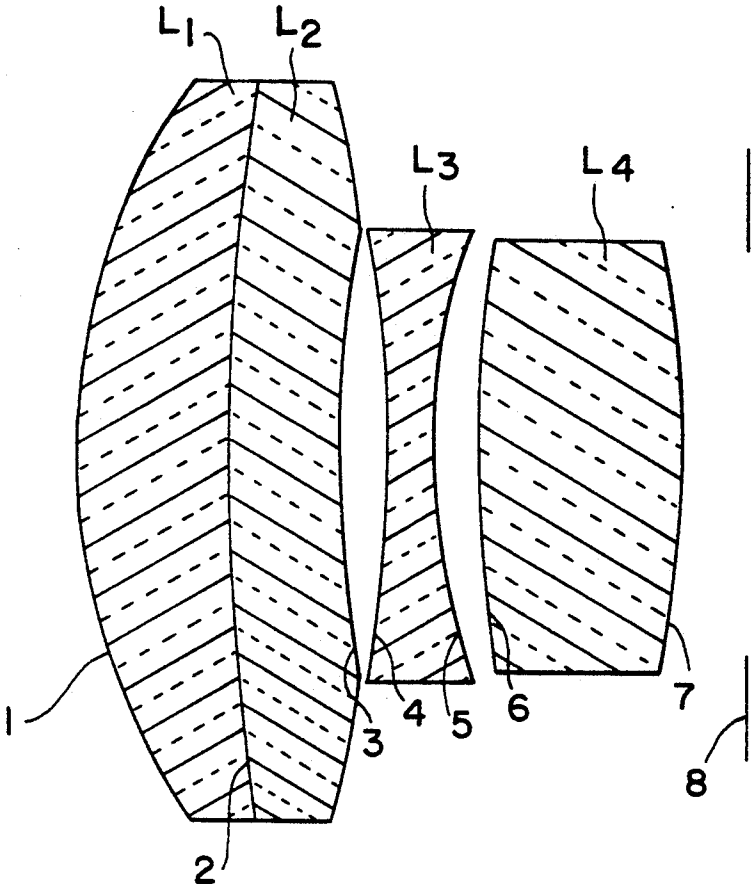


FIG. 2A

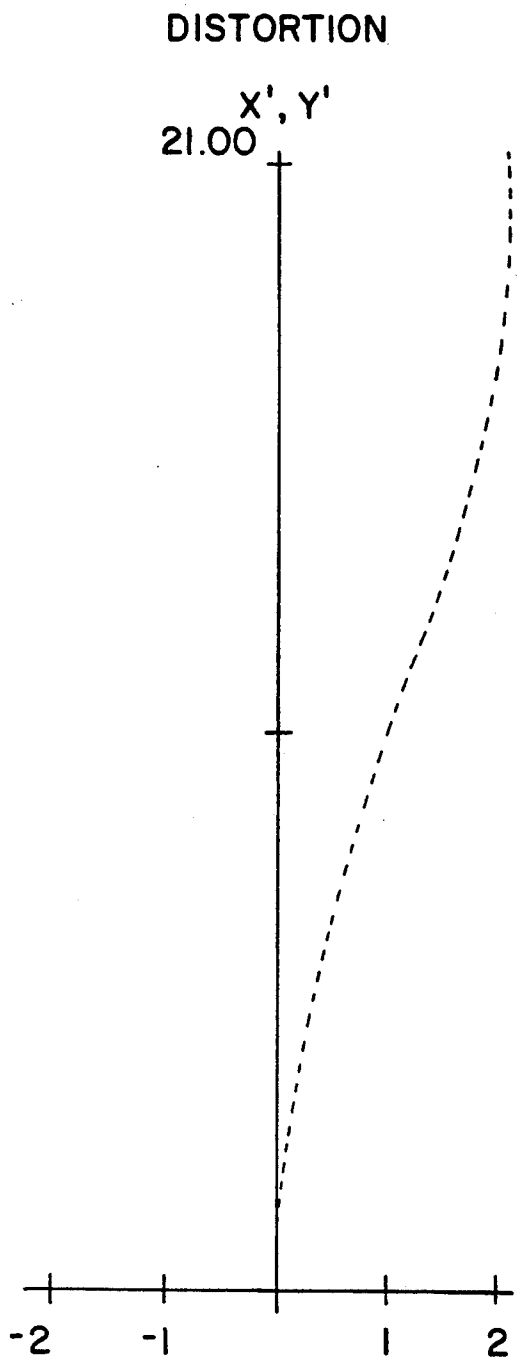
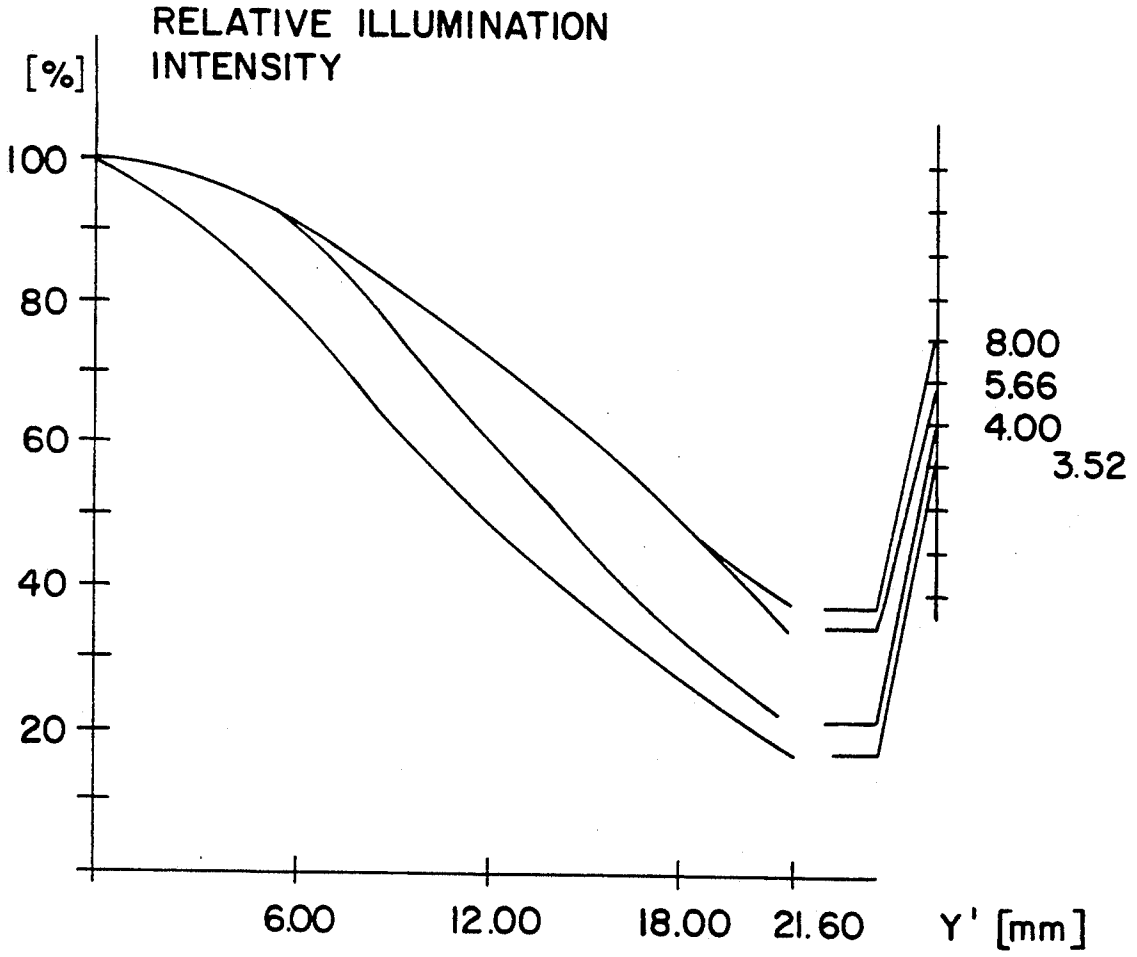


FIG. 2B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[%]
100
80
60
40
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18.00
21.60
Y' [mm]
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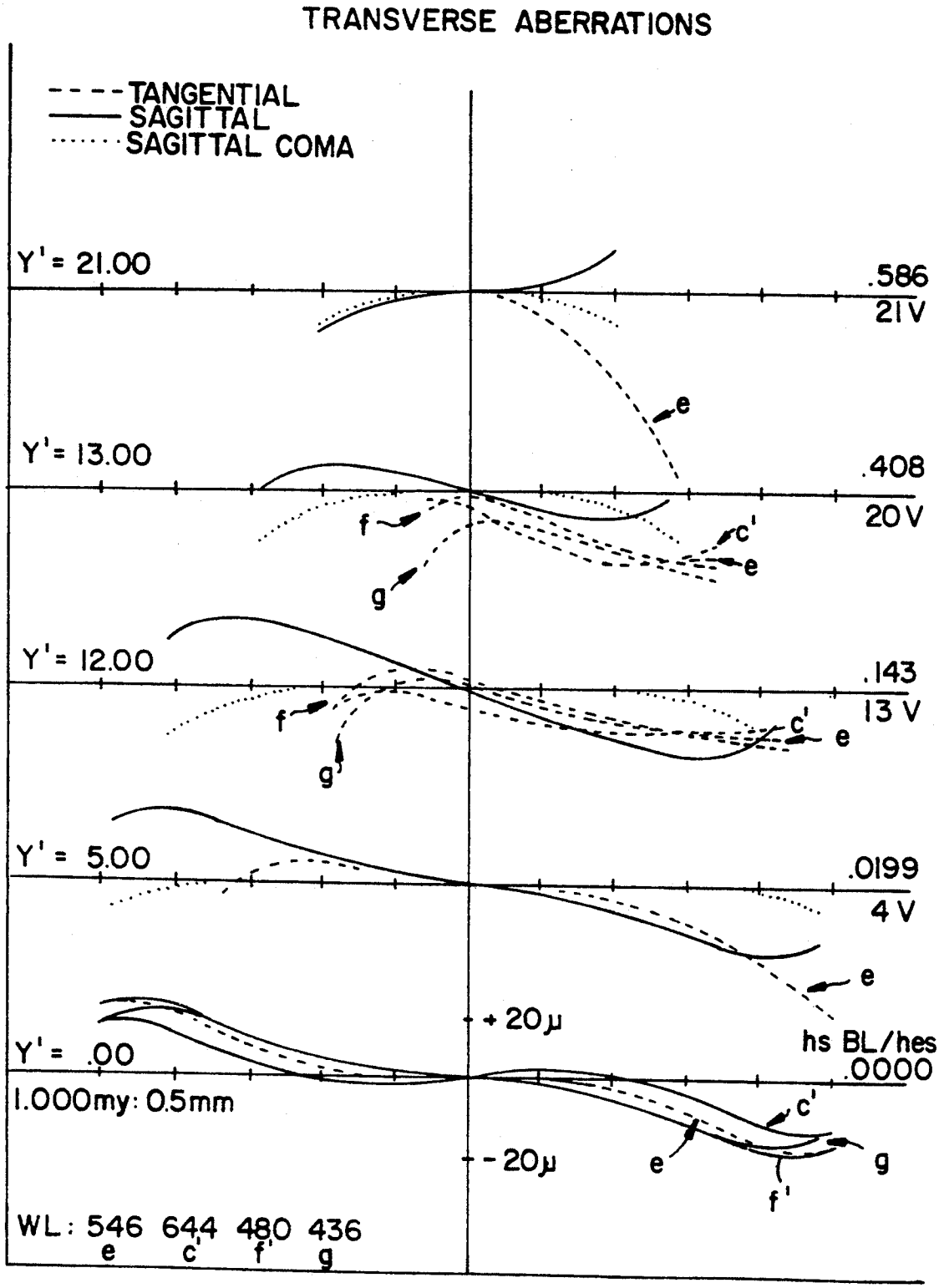
5.66
4.00
3.52

FIG.2C


TRANSVERSE ABERRATIONS
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SAGITTAL COMA
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21V
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Y' = 13.00
.408
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c'
e
g
Y' = 12.00
.143
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f
c'
e
g'
Y' = 5.00
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4 V
e
+ 20μ
hs BL/hes
Y' = .00
.0000
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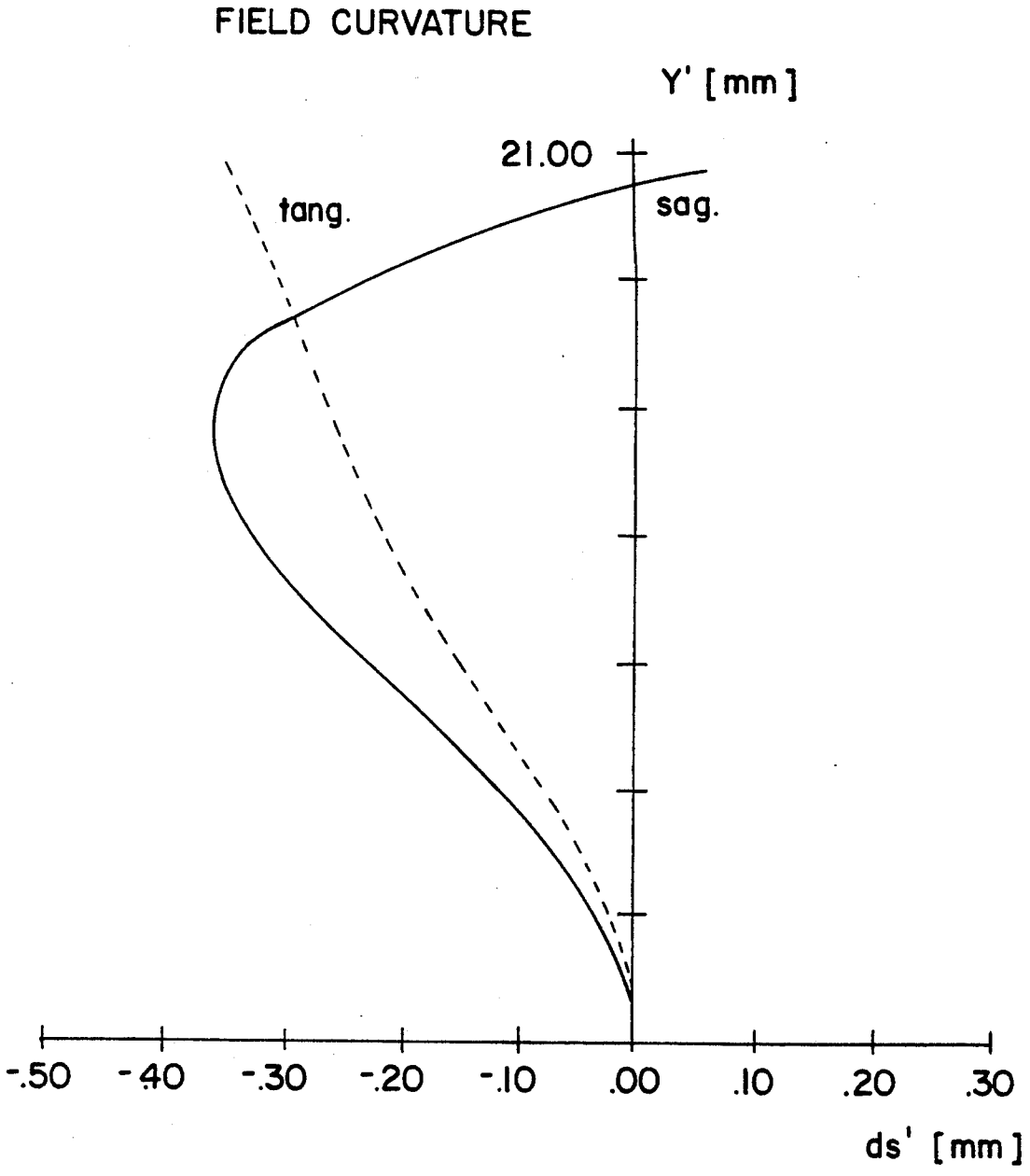
c'
- 20μ
e
g
f'
WL: 546 644 480 436
e c' f' g

FIG. 2D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ds' [mm]

COMPACT PHOTOGRAPHIC OBJECTIVE OF THE TRIPLET TYPE HAVING IMPROVED CHROMATIC AND MONOCHROMATIC CHARACTERISTICS

BACKGROUND

The invention relates to a photographic objective having a relative aperture 3.5 and a focal length 35 of the triplet type with a rear stop, which is provided especially for compact photographic cameras.

A photographic objective of the triplet type having a rear stop is disclosed in DE 24 24 343 C2, which contains three lens elements of which the front element is a positive meniscus lens which is convex on the object side, the central lens element is a hi-concave lens, and the rear lens element is a hi-concave cemented element consisting of two lenses of opposite refractive power.

DE-PS 544,329 discloses a photographic objective comprising a diverging lens and in each case one collecting lens element, arranged in front of and behind it, of which that on the object side is constructed as a cemented element with a positive overall refractive power. This known objective has a focal length of 100 mm; there are no statements on the position of the aperture stop.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide an extremely compact photographic objective of the generic type mentioned initially, having balanced monochromatic correction and a reduction in the chromatic magnification difference, the color coma and the color astigmatism. This photographic objective overall has improved imaging characteristics over known systems of this type. .

In order to achieve the above and other objects of the present invention, the photographic objective has a relative aperture of 3.5 and a focal length of 35 mm and is of the triplet type with a rear aperture stop. The objective further includes: a cemented element, including a first and a second lens element, having a positive overall refractive power on its object side; a bi-concave central lens element; and a bi-convex rear element. In order to achieve the desired objects of the invention, the objective composed of the above elements also meets four design conditions.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be described in further detail with reference to the accompanying drawings, in which:

FIG. **1** shows a sectional view of an objective system according to an embodiment of the invention, and

FIGS. **2A–D** show the correction state of the objective according to an embodiment of the invention, where FIG. **2A** is a distortion plot, FIG. **2B** is a relative illumination intensity plot, FIG. **2C** is a transverse aberrations plot, and FIG. **2D** is a field curvature plot.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The objective shown in FIG. **1** has a first lens element L_1 with surfaces 1 and 2 cemented to a second lens element L_2 with surfaces 2 and 3 as the lens group closest to the object. The objective also has a middle lens element L_3 with surfaces 4 and 5, as well as a back lens element L_5 with surfaces 6 and 7. A rear aperture stop 8 is also shown.

The compactness of the objective is described by the condition $B_L/S' < 0.6$, where $S'_{max} = 0.8 \times f'$, where B_L is the structural length of the objective, S' is the distance between the back lens and the image, and f' is the focal length of the objective. In order to correct for monochromatic aberrations, a high refractive index in the first lens group, corresponding to the condition $n_2 > 1.7$, where n_2 is the refractive index of the second lens element L_2, has been found to be favorable. In order to achieve the desired matching between the lens surfaces 2 and 7 while avoiding higher order aberrations, a large difference $\nu_1 - \nu_2 > 15$, where $\nu_{1,2}$ are the Abbe numbers of the first and second lens elements L_1, L_2, is essential. Finally, as a result of condition $0.7 \times F_2(7) < F_2(2) < 1.3 \times F_2(7)$, where $F_2(2)$ and $F_2(7)$ are the Seidel coefficients for the chromatic magnification difference of the lens elements having the lens surfaces 2 and 7, respectively, the effect of the cemented surface in the first lens group is described, the final surface 7 is compensated for the effect F_2 (chromatic magnification difference) by means of this cemented surface. In addition, relief of stress in the second lens element is thus produced such that, here, a relatively large ν value and a relatively low refractive index are adequate, which has a positive effect on the Petzval sum. In addition, a reduction in the 3rd order aberration coefficient is achieved which has a favorable effect on the higher order monochromatic and chromatic aberrations.

The photographic objective of the present invention also has the following numeric data:

	r	d	n(546)	ν
1	11.0297	2.7300	1.808109	46.34
2	39.1519	2.0219	1.812640	25.23
3	19.1519	0.7000		
4	−40.8013	1.0051	1.652230	33.57
5	10.4692	0.8000		
6	20.7116	3.5430	1.716700	42.89
7	−24.0136	1.2000		
8	Stop	24.5165		

where r(1–7) are the radii of curvature of the individual lens surfaces 1–7, d(1–6) are distances between and thicknesses of same, d(7) is the distance from the rear lens face 7 to the near aperture stop 8, d(8)is the distance from the rear aperture stop 8 to the image plane, n(1,2,4,6) are the refractive indices of the lens elements having the lens surfaces 1,2,4,6 and ν(1,2,4,6) are the corresponding Abbe numbers of these lens elements.

In addition to the numeric data mentioned above, the objective according to the invention has the following paraxial data:

$f' = 33.6323$

$S' = 26.7165$

$\beta ap' = 0.7290$

$SS' = 10.8000$

$Z' = 1.2000$

where S' is the distance between the rear lens and the image, f' is the focal length, $\beta ap'$ is the pupil magnification of the exit pupil, SS' is the structural length be-

tween the first and the last lens vertex, Z' is the distance between the rear shutter and the last lens vertex.

From the correction curves shown in FIG. 2, it is apparent that the objective according to the invention has a favorable monochromatic correction with an extremely compact construction, despite the use of a rear aperture stop. The objective especially has a major reduction in the chromatic magnification difference, the color coma and the color astigmatism.

It is self-evident that the numeric data may differ in the context of normal variations. Other designs within the spirit and scope of the invention will be apparent to those skilled in the field after receiving the above teachings. The invention, therefore, is defined with reference to the following claims.

What is claimed is:

1. A photographic objective having a relative aperture of 3.5 and a focal length of 35 mm, of the triplet type with a rear lens aperture stop, comprising:

a cemented element, including a first and a second lens element, having a positive overall refractive power on its object side;

a bi-concave central lens element; and

a bi-convex rear lens element, wherein said photographic objective satisfies the following conditions:

$$\frac{B_L}{S'} < 0.6, \text{ where } S_{max}' = 0.8 \times f \quad \text{(I)}$$

$$n_2 > 1.7 \quad \text{(II)}$$

$$\nu_1 - \nu_2 > 15 \text{ and} \quad \text{(III)}$$

$$0.7 \times F_2(7) < F_2(2) < 1.3 \times F_2(7), \quad \text{(IV)}$$

where

where

B_L is the structural length of the objective,

S' is its distance between the rear lens and an image formed by said objective,

f' is the focal length of the objective,

S'_{max} is the maximum distance between the rear lens and the image formed by said objective,

n_2 is the refractive index of the second lens element,

$\nu_{1,2}$ are the Abbe numbers of said first and second lens elements, and

$F_2(2)$ and $F_2(7)$ are the Seidel coefficients for the chromatic magnification difference of said cemented element having lens surface 2 and said bi-convex rear lens element having lens surface 7.

2. The photographic objective as claimed in claim 1, wherein said objective has the following numeric data:

	r	d	n(546)	ν
1	11.0297	2.7300	1.808109	46.34
2	39.1519	2.0219	1.812640	25.23
3	19.1519	0.7000		
4	−40.8013	1.0051	1.652230	33.57
5	10.4692	0.8000		
6	20.7116	3.5430	1.716700	42.89
7	−24.0136	1.2000		
8	Stop	24.5165		

where

r(1–7) are the radii of curvature of the individual lens surfaces 1–7,

d(1–6) are distances between the consecutive lens surfaces 1–7,

d(7) is the distance from the final lens surface 7 to said rear aperture stop,

d(8) is the distance from said rear aperture stop to said image formed by the objective,

n(1,2,4,6) are the refractive indices at 546 nm of the lens elements having front lens surfaces 1,2,4,6, and

ν(1,2,4,6) are the corresponding Abbe numbers of the lens elements having front lens surfaces 1,2,4,6.

3. The photographic objective as claimed in claim 2, wherein said objective has the following paraxial data:

$f' = 33.6323$

$S' = 26.7165$

$\beta ap' = 0.7290$

$SS' = 10.8000$

$Z' = 1.2000$

where

βap' is a pupil magnification of an exit pupil,

SS' is a structural length between a first and a last lens vertex, and

Z' is a distance between said rear aperture stop and said last lens vertex.

* * * * *

US005306892A

United States Patent [19]

Hohberg

[11] Patent Number: 5,306,892

[45] Date of Patent: Apr. 26, 1994

[54] MIRROR OBJECTIVE ARRANGEMENT

[75] Inventor: **Gerhard Hohberg**, Aalen-Dewangen, Fed. Rep. of Germany

[73] Assignee: **Carl-Zeiss-Stiftung**, Heidenheim, Fed. Rep. of Germany

[21] Appl. No.: **901,729**

[22] Filed: **Jun. 22, 1992**

[30] **Foreign Application Priority Data**

Jun. 22, 1991 [DE] Fed. Rep. of Germany 4120684

[51] **Int. Cl.**[5] **B23K 26/06**

[52] **U.S. Cl.** **219/121.67**; 359/859; 359/863; 219/121.74

[58] **Field of Search** 359/858, 859, 863; 219/121.67, 121.72, 121.73, 121.74

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Primary Examiner—Edward K. Look
Assistant Examiner—F. Daniel Lopez
Attorney, Agent, or Firm—Walter Ottesen

[57] **ABSTRACT**

The invention is directed to a pancratic mirror objective system for laser focussing and especially for laser machining apparatus. The pancratic mirror objective system preferably includes a convex paraboloid mirror and an ellipsoid mirror. The ellipsoid mirror can be approximated by a toric or spherical form. The focus F_1 of the paraboloid mirror P and the first focus of the ellipsoid mirror E are coincident. By rotating the ellipsoid mirror E about the axis parallel to the incident laser beam through the first focus F_1, the effective image side aperture (for example K=4 to K=8) and the focal length are varied. The track control compensates for the movement of the focus F_2 in laser machining apparatus.

10 Claims, 2 Drawing Sheets

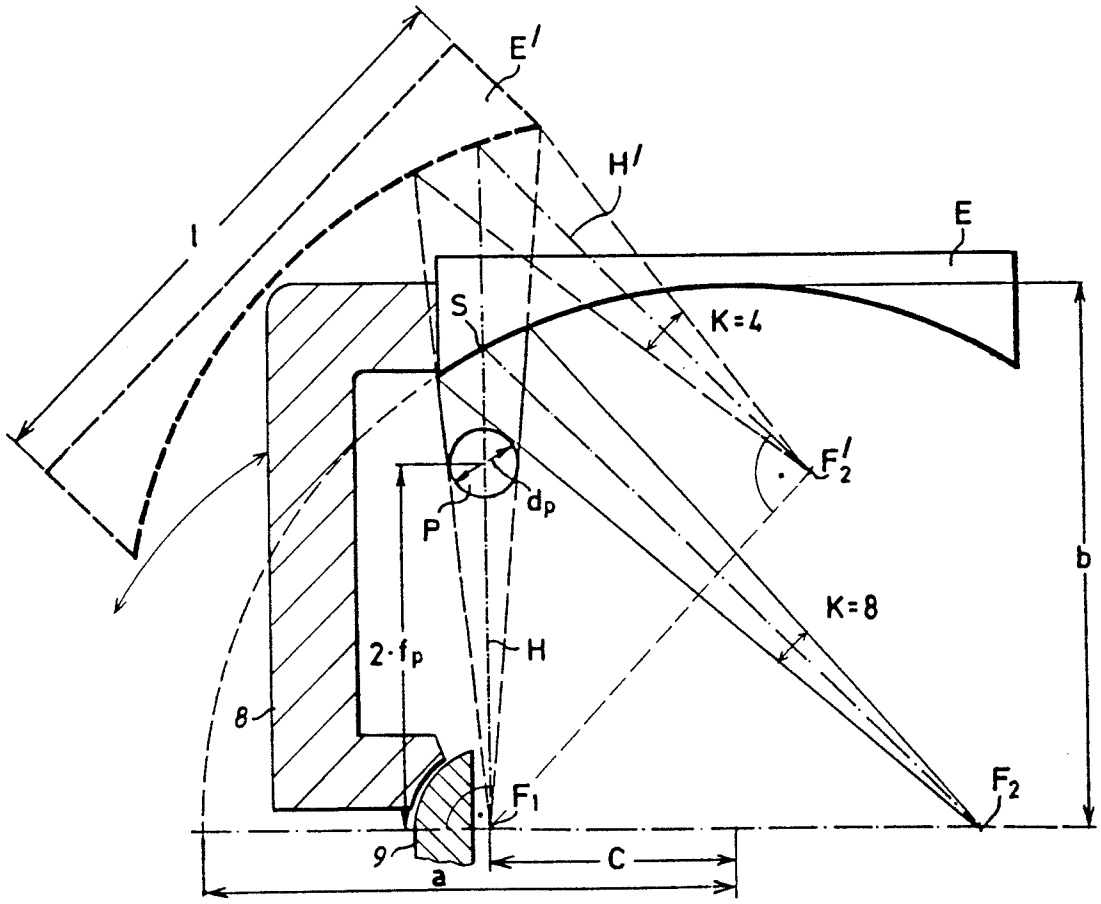


FIG.1

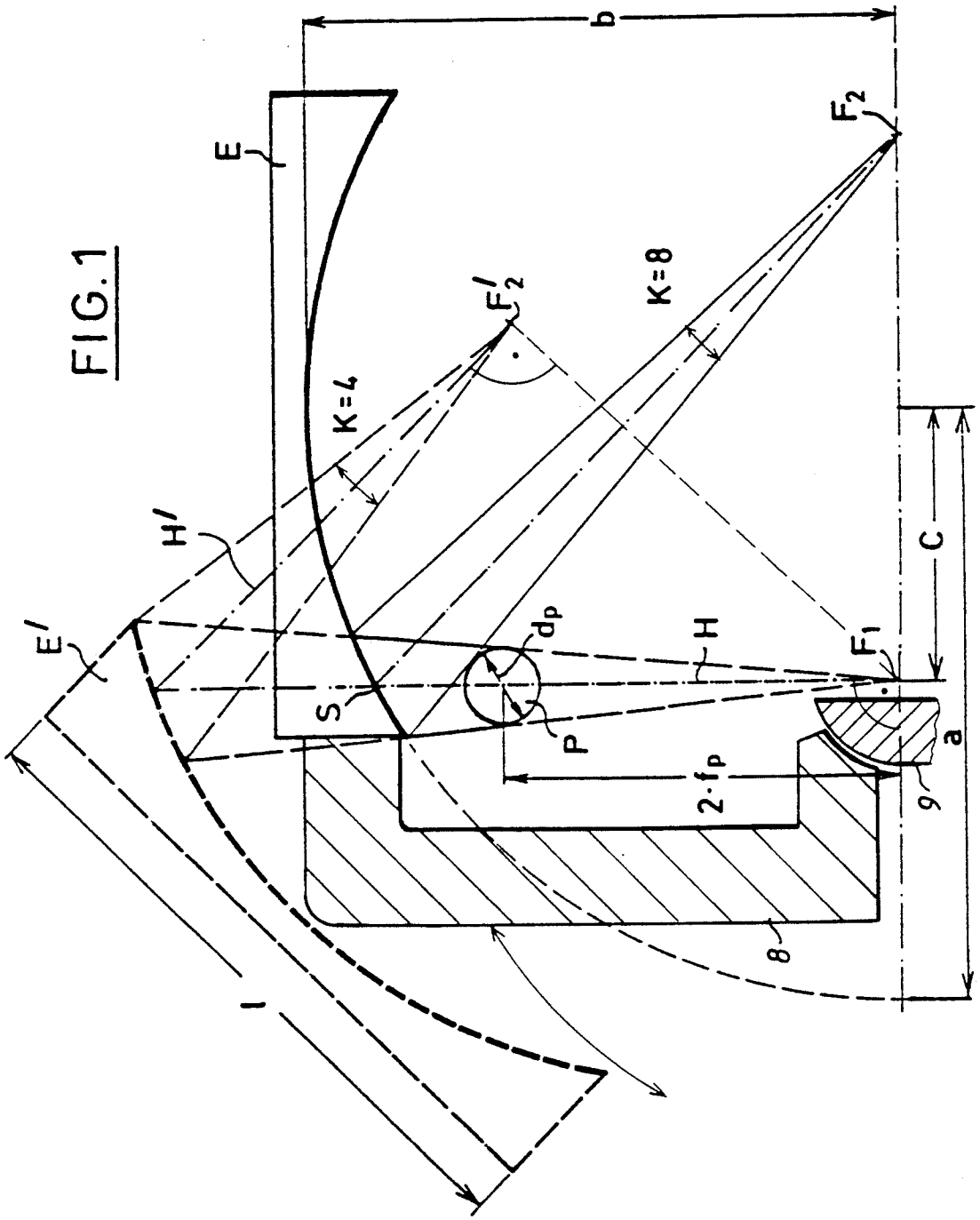


FIG. 2

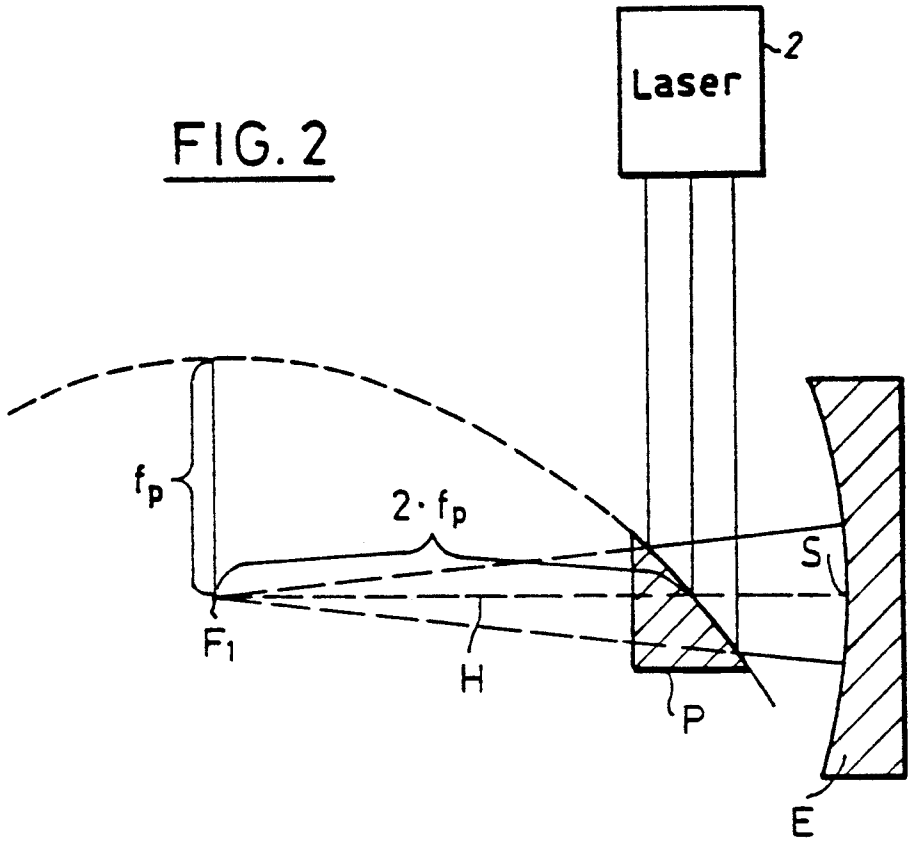
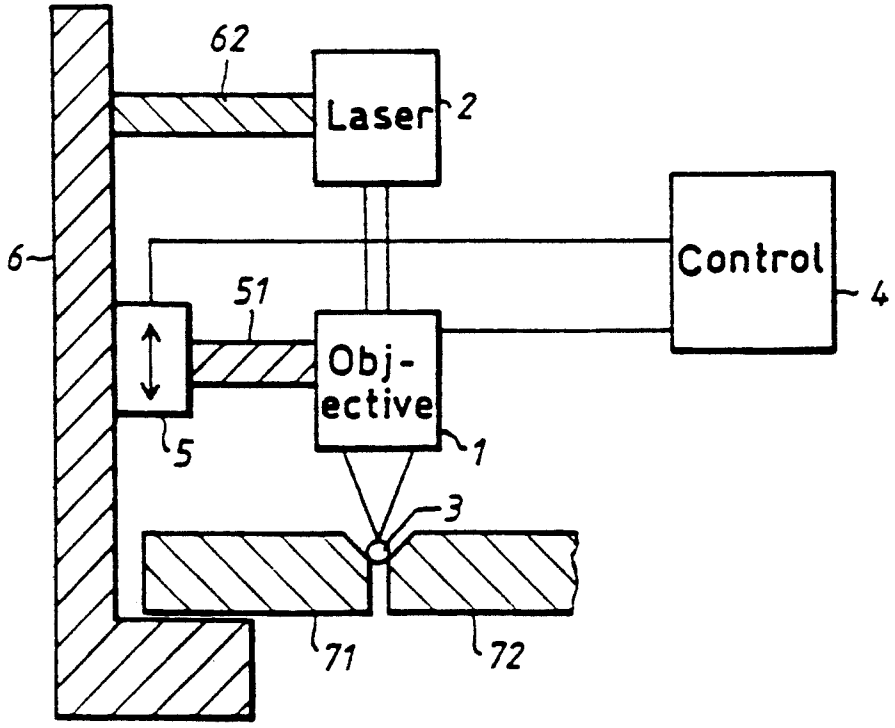

Laser
2
f_p
$2 \cdot f_p$
S
F_1
H
P
E

FIG. 3


62
Laser
2
Control
4
6
51
Obj-
ective
1
5
3
71
72

MIRROR OBJECTIVE ARRANGEMENT

FIELD OF THE INVENTION

The invention relates to a mirror objective arrangement having two mirrors. Arrangements of this kind having a fixed geometry and focal length are known in various configurations also with paraboloid and ellipsoid mirrors. The invention also relates to a laser machining apparatus incorporating the mirror objective arrangement.

BACKGROUND OF THE INVENTION

For machining materials with lasers, the machining result is very critically dependent upon the energy distribution at the focus. This applies especially to laser cutting. Here, lasers are preferably utilized which radiate in a low mode and therefore supply an approximately diffraction limited focus distribution. An adaptation of the focus distribution to the requirements (for example, determined by the type of material and the material thickness) can, in this case, be obtained practically only by means of the effective aperture and therefore the focal length of the focussing optics. For this reason, different focal lengths are used depending upon the application. When the requirements change frequently, then the need for focussing optics having a changeable aperture increases in order to reduce the change-over time.

Such systems have long been utilized when using lens optics. Here, complete pancratic focussing units or pancratic expansion or contraction systems in combination with fixed focussing optics are utilized.

Lens systems are only of use to a limited extent when utilizing lasers of high capacity. For this reason, the lens systems are increasingly replaced with mirror optics which can be loaded to a significantly greater extent. However, only embodiments having a fixed aperture are known.

SUMMARY OF THE INVENTION

In view of the foregoing, it is an object of the invention to provide a mirror objective arrangement which is configured as a pancratic system.

The mirror objective arrangement of the invention includes: a first mirror having a shape which at least approximates a paraboloid form and defining a first focus F_1; a second mirror having a shape which at least approximates an ellipsoid form; the second mirror being in a first position wherein the second mirror images the first focus F_1 at an initial second focus F_2; and, pivot means for pivoting the second mirror about a pivot axis passing through the first focus F_1 from the first position to a second position so as to cause the second mirror to image the first focus F_1 at a new second focus F_2'.

The pancratic system of the invention includes two mirrors with one of these mirrors being configured at least approximately as a paraboloid mirror and the other one being configured at least approximately as an ellipsoid mirror. The laser beam is focussed by the paraboloid mirror. This focus is positioned in the one focal point of the ellipsoid mirror and is imaged by the ellipsoid mirror into the other focal point thereof.

The change of the effective aperture does not take place in the manner conventional with lens systems by changing the spacing between the optical elements; instead, by changing the angle between the optical elements, that is, the angle between the paraboloid mirror and ellipsoid mirror.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will now be described with reference to the drawings wherein:

FIG. **1** is a schematic of the mirror objective arrangement of the invention showing the paraboloid mirror and the ellipsoid mirror thereof disposed in spaced relationship to each other and how the ellipsoid mirror is moved relative to the paraboloid mirror;

FIG. **2** is a section view taken through the axis F_1-S of FIG. **1**; and,

FIG. **3** shows a laser machining arrangement according to an embodiment of the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS OF THE INVENTION

In FIG. **1**, a laser beam impinges perpendicularly to the plane of the paper on the convex paraboloid mirror P and is reflected so that a virtual focus at F_1 is formed. The ellipsoid mirror E is first in a position having an image-side aperture $K=8$ and images F_1 at F_2.

As shown in FIG. **2**, a section of paraboloid mirror P is illuminated by the laser **2** at an elevation which corresponds to twice the vertex focal length f_p so that a mean deflection of 90° takes place.

In the embodiment shown, the ellipsoid mirror E is so dimensioned that a variation of the image side aperture by a factor of two is possible between $K=4$ and $K=8$. Preferably, the ellipsoid mirror E is so configured that the end positions (E, E') are symmetrical. Then, the incident beam (generated by paraboloid mirror P) must have an aperture of $K=5.6$ (geometric mean). Thus, for a diameter of the beam of $dp=40$ mm, an effective focal length of the paraboloid mirror P is required which is twice the vertex focal length f_p in the embodiment or $2 \cdot f_p = 225$ mm. A minimum spacing must be maintained between the two mirrors (P, E) so that the reflected beam is not shaded. The spacing F_1-S should be at least 300 mm for the dimensions given above.

The precise form of the ellipsoid mirror E is not yet determined. A further parameter can be arbitrarily selected. In FIG. **1**, the additional requirement is introduced that a primary ray H or H' should be perpendicular to the axis of the ellipsoid mirror E in the extreme positions. With these requirements, an ellipsoid mirror E is obtained having the values $a=362$ mm, $b=329$ mm for the half axes and $c=151$ mm for the half focal point spacing. The minimum length of the mirror necessary for the application is $L=366$ mm.

Changes of the arbitrary parameter have only a slight influence on the required length of the mirror. The dimensions of the arrangement can be varied widely.

If the ellipsoid mirror E is rotated about the axis through the first focus F_1 wherein the holder **8** rotates about the bearing **9**, then the second ellipsoid focus F_2 moves while at the same time the aperture of the beam focussed there changes and therefore the focal length of the entire system. The above-mentioned axis is perpendicular to the plane of the paper but parallel to the incident laser beam. The new position of the ellipsoid mirror is identified by E' and is shown in phantom outline in FIG. **1**. The ellipsoid mirror E' has an aperture $K=4$ and a focus F_2'.

While for camera-related variable-focus lenses with changing focal lengths the image must always be formed on the plane of the film, it is not a problem for

the mirror objective arrangement of the invention for the application to laser machining that the focus F_2, F_2' moves along a circular arc.

A laser machining apparatus often has a track control **4** as shown in FIG. **3** for the movement of a laser head (**1**, **2**) relative to the workpiece (**71**, **72**). The laser head (**1**, **2**) includes the laser **2** and the objective **1**. The track control **4** can be so programmed for the use of the pancratic system **1** of the invention that the position of the machining point **3**, that is the focus (F_2, F_2') is always considered relative to the laser head (**1**, **2**). The position of the machining point **3** is dependent upon the desired focal length or aperture.

The beam direction of the emitted beam is not significantly changed with the variation of the effective focal length. The use of an ellipsoid mirror for forming a finite image achieves a trouble-free joining of beams.

In some cases, slight imaging errors are accepted when in this way, a mirror can be used which is more simple to produce.

In the case of FIG. **1**, the ellipsoid mirror can be replaced, for example, by a toric surface having a primary radius of curvature in the plane of the drawing of:

$$R_1 = a^2/b = 362^2/329 = 398 \text{ mm}$$

and perpendicularly thereto,

$$R_2 = b = 329 \text{ mm}.$$

A still coarser approximation is obtained with a spherical surface. However, the imaging error is significant, especially the astigmatism.

The paraboloid mirror shown in FIG. **1** can be replaced with a surface, which is simpler to produce, when a deterioration of the focus quality is permissible.

A spherical surface would cause very considerable imaging errors in the arrangement shown, that is, with a 90° beam deflection. For this reason, a sphere having the smallest possible deflection angle would be used. The component of the astigmatism can be substantially eliminated by using a toric surface.

It is also plausible to dimension the astigmatic error components of both mirrors so that they compensate when added. However, this appears to be advantageous only in rare cases since modern manufacturing machines are available in most cases with which the ellipsoid and paraboloid surfaces can be produced with no problem and at acceptable cost.

It is understood that the foregoing description is that of the preferred embodiments of the invention and that various changes and modifications may be made thereto without departing from the spirit and scope of the invention as defined in the appended claims.

What is claimed is:

1. A mirror objective arrangement comprising:

a first mirror having a shape which at least approximates a paraboloid form and defining a first focus F_1;

a second mirror having a shape which at least approximates an ellipsoid form;

said second mirror being in a first position wherein said second mirror images said first focus F_1 at an initial second focus F_2; and,

pivot means for pivoting said second mirror about a pivot axis passing through said first focus F_1 from said first position to a second position so as to cause said second mirror to image said first focus F_1 at a new second focus F_2'.

2. The mirror objective arrangement of claim **1**, wherein the effective aperture K of light focussed at said initial second focus F_2 is varied when focussed at said new second focus F_2'.

3. The mirror objective arrangement of claim **2**, wherein the variation of said effective aperture can vary between $K=4$ and $K=8$.

4. The mirror objective arrangement of claim **1**, further comprising a laser light source for supplying a laser beam defining a beam axis parallel to said pivot axis and incident upon said first mirror for focussing at said first focus F_1.

5. The mirror objective arrangement of claim **1**, wherein said first mirror is convex.

6. The mirror objective arrangement of claim **1**, said first mirror being a precision paraboloid mirror and said second mirror being a precision ellipsoid mirror.

7. The mirror objective arrangement of claim **1**, wherein said paraboloid form of said first mirror is approximated by a toric surface and said ellipsoid form of said second mirror is approximated by a toric surface.

8. The mirror objective arrangement of claim **1**, wherein said paraboloid form of said first mirror is approximated by a toric surface.

9. The mirror objective arrangement of claim **1**, wherein said ellipsoid form of said second mirror is approximated by a toric surface.

10. A laser machining apparatus for machining a workpiece, said apparatus comprising:

a laser head including laser means for supplying a laser beam defining a beam axis; and, a mirror objective arrangement mounted on said beam axis for directing said laser beam to a machining point on the workpiece;

said mirror objective arrangement having an adjusted focal length and including: a first mirror having a shape which at least approximates a paraboloid form and defining a first focus F_1; a second mirror having a shape which at least approximates an ellipsoid form; said second mirror being in a first position wherein said second mirror images said first focus F_1 at an initial second focus F_2; and, pivot means for pivoting said second mirror about a pivot axis passing through said first focus F_1 from said first position to a second position so as to cause said second mirror to image said first focus F_1 at a new second focus F_2'; and,

track control means for controlling said laser head to change the location of said machining point relative to said laser head so as to cause said machining point to be coincident with said focus (F_2, F_2').

* * * * *

US005305035A

United States Patent [19]

Schönherr et al.

[11] Patent Number: 5,305,035

[45] Date of Patent: Apr. 19, 1994

[54] **PANORAMIC CAMERA WITH OBJECTIVE DRUM**

[75] Inventors: **Hans-Jörg Schönherr; Hans Zimmet,** both of Dresden; **Jürgen Krase; Michael Lenk,** both of Pirna; **Siegfried Hainy; Karl-Heinz Werner,** both of Dresden, all of Fed. Rep. of Germany

[73] Assignee: **Kamerawerke Noble GmbH,** Dresden, Fed. Rep. of Germany

[21] Appl. No.: **100,542**

[22] Filed: **Jul. 30, 1993**

[30] **Foreign Application Priority Data**

Aug. 8, 1992 [DE] Fed. Rep. of Germany 4226286

[51] **Int. Cl.**[5] **G03B 37/00**

[52] **U.S. Cl.** **354/96**

[58] **Field of Search** 354/94, 95, 96, 98, 354/99; 352/69, 70, 71

[56] **References Cited**

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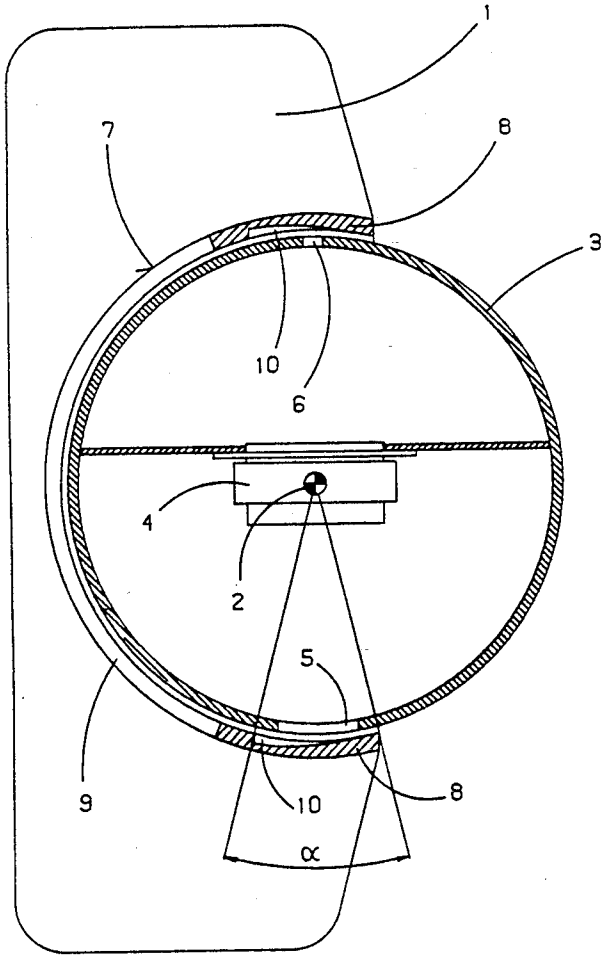
Primary Examiner—Michael L. Gellner
Assistant Examiner—Howard B. Blaneknship
Attorney, Agent, or Firm—Michael J. Striker

[57] **ABSTRACT**

A panoramic camera has a camera housing having a cylinder segment provided with an image window, an objective drum which is rotatable relative to the cylinder segment about a rotary axis, the cylinder segment having segment flanks located laterally near the image window, the segment flanks being provided with light catching grooves extending parallel to the rotary axis of the objective drum and ending at an angular distance from the outer edges of the cylinder segment, covered by a curvature of the drum.

7 Claims, 2 Drawing Sheets



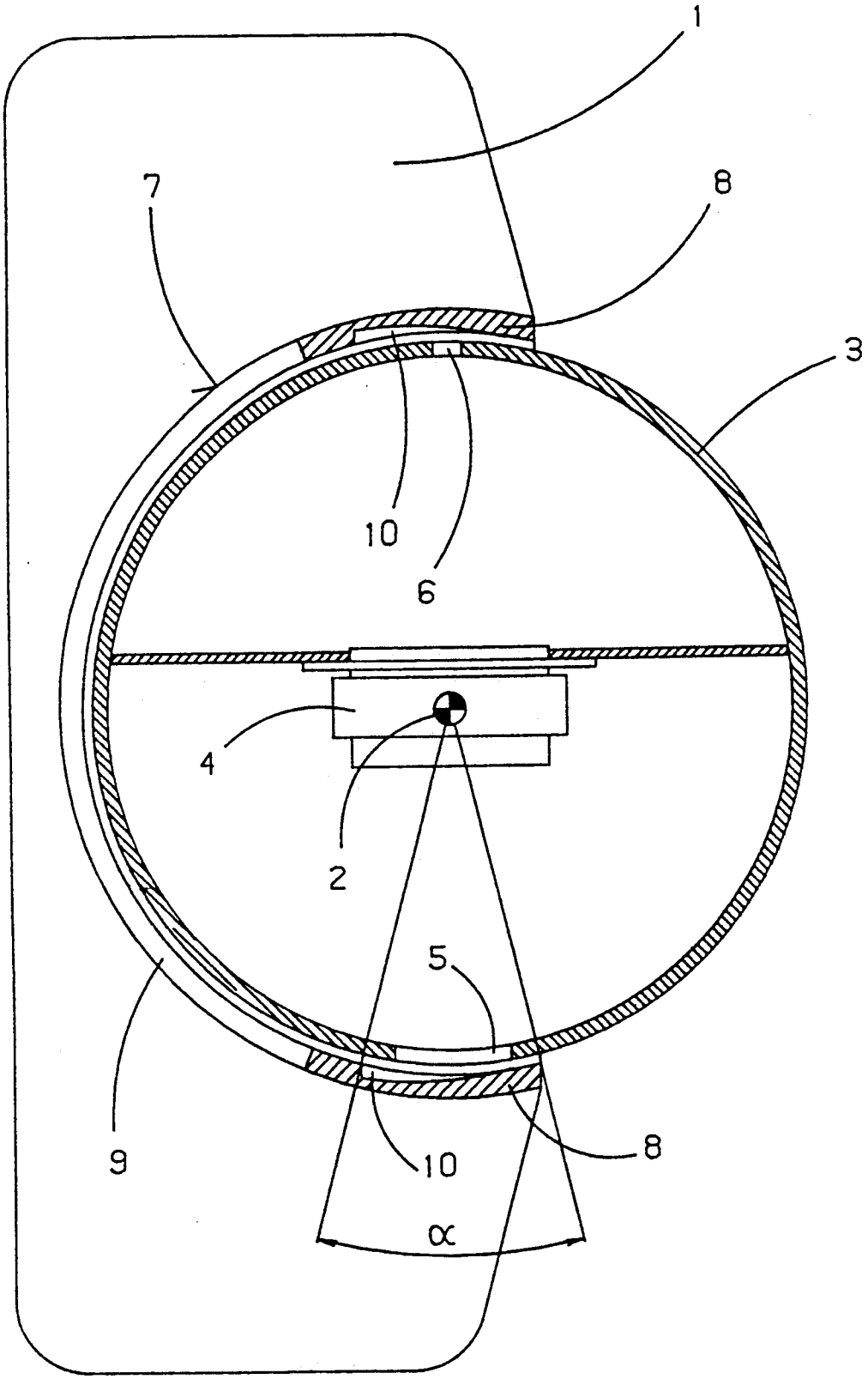


Fig. 1

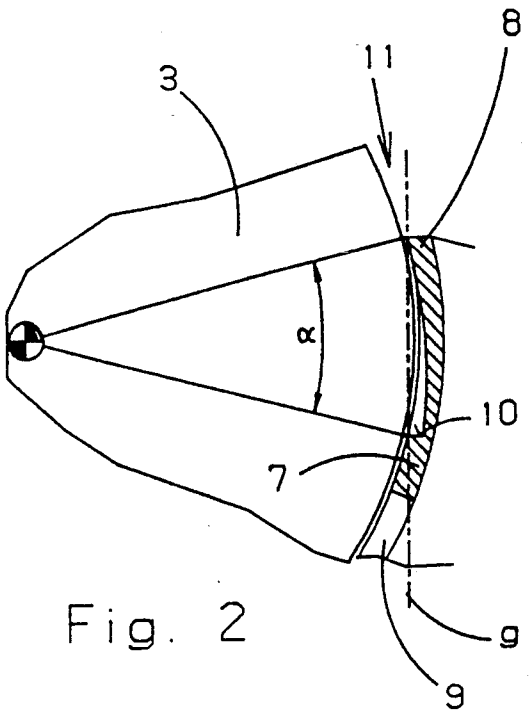


Fig. 2

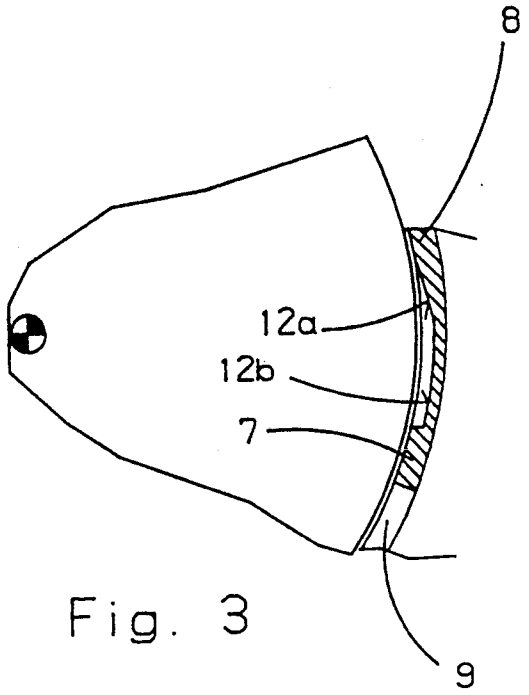


Fig. 3

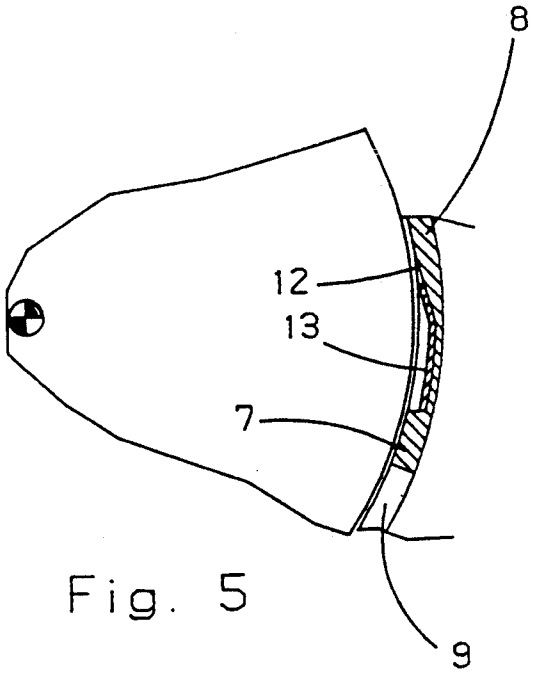


Fig. 5

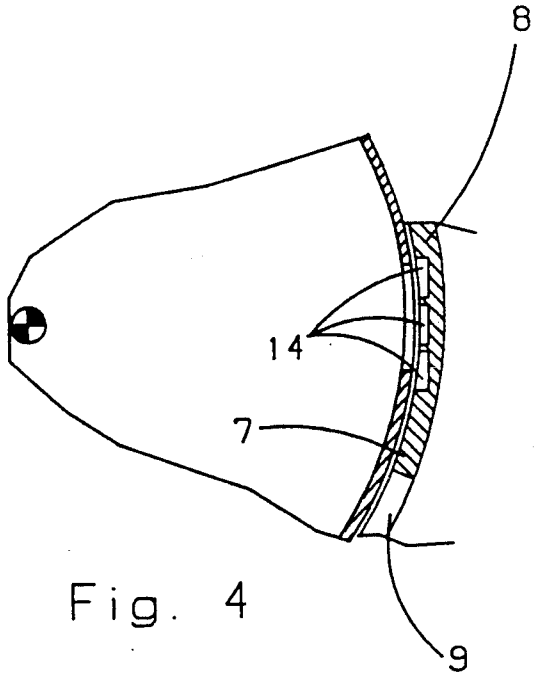


Fig. 4

PANORAMIC CAMERA WITH OBJECTIVE DRUM

BACKGROUND OF THE INVENTION

The present invention relates to a panoramic camera with an objective drum which is rotatable relative to a cylinder segment of the camera housing provided with an image window.

Panoramic cameras of the above-mentioned general type are known in the art. In a known panoramic camera which is disclosed for example in the German document DE-PS 1 173 331, felt inserts are provided for blocking undesired light impingement. The felt inserts mounted in the camera housing rub during the receipt against the casing of the drum and brake the drum turning, which must be compensated by higher force application during driving. Moreover, the felt inserts have a tendency for embedding dust particles which further increase the above-mentioned braking friction and in addition cause scratching traces on the objective drum.

SUMMARY OF THE INVENTION

Accordingly, it is an object of the present invention to provide a panoramic camera which avoids the disadvantages of the prior art.

More particularly, it is an object of the present invention to provide a panoramic camera with improved features for obtaining the required light safety.

In keeping with these objects and with others which will become apparent hereinafter, one feature of the present invention resides, briefly stated, in a panoramic camera with an objective drum in which the cylinder segment is provided laterally near the image window with segment flanks formed with light catching grooves which extend parallel to the rotary axis of the objective drum, and the light catching grooves end at a distance from the outer edges of the cylinder segment, which is covered by the curvature of the objective drum.

When the panoramic camera is designed in accordance with the present invention, it eliminates the disadvantages of the prior art and provides for the above-mentioned highly advantageous results.

In accordance with another feature of the present invention, the light catching groove has a depth which increases relative to the image window in a wedge-shaped manner.

Still a further advantageous feature of the present invention is that the light catching groove is provided with a portion which is deepened in a wedge-shaped manner relative to the image window and a cylindrical portion connected with the image window.

When in accordance with a further feature of the present invention the light catching groove has a rectangular cross-section, it provides for a technologically advantageous solution.

Finally, in accordance still another advantageous feature of the present invention, a light absorbing layer is arranged additionally in the light catching groove.

The novel features which are considered as characteristic for the invention are set forth in particular in the appended claims. The invention itself, however, both as to its construction and its method of operation, together with additional objects and advantages thereof, will be best understood from the following description of specific embodiments when read in connection with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a view showing a camera housing with an objective drum in accordance with the present invention;

FIG. **2** is a view showing a light catching groove of the inventive panoramic camera;

FIG. **3** is a view showing a further modification of the light catching groove in accordance with the invention;

FIG. **4** is a view showing a technologically favorable further embodiment of the invention; and

FIG. **5** is a view showing a light catching groove with a light absorbing layer in accordance with the invention.

DESCRIPTION OF PREFERRED EMBODIMENTS

A panoramic camera in accordance with the present invention has a camera housing which is identified as a hole with reference numeral **1**. A drum **3** is supported in the camera housing rotatably about an axis **2**, and an objective **4** is arranged in the drum **3**. The camera is provided with a light inlet opening **5** and illuminating slots **6** which extend through the casing of the drum **3** and are located opposite to one another in an objective ray path. A cylinder segment **7** is provided concentrically to the drum **3** in the camera housing **1** and has segment flanks **8** arranged so that an image window **9** is located between the flanks.

Light catching grooves **10** are provided in the segment flanks **8** and extend parallel to the rotary axis **2** of the drum **3**. The light catching grooves **10** are spaced from the outer edges of the cylinder segment **7** at such an angular distance α, that the ends of the light catching grooves **10** which face toward the image window **9** are covered relative to the outer edges of the cylinder segment **7** by the drum **3** as can be seen from FIG. **2**. An imaginary straight line "g" between the outer edge of the cylinder segment **7** and the end of the light catching groove **10** which faces the image window **9**, intersects the outer surface of the drum **3**.

The panoramic camera in accordance with the present invention operates in the following manner:

When undesired light enters through the gap **11** [see FIG. 2]between the drum **3** and the cylinder segment **7**, the light rays reach the light catching groove **10**. If the light rays are not absorbed by the matted walls of the cylinder segment **7** or the light catching groove **10** or the outer surface of the drum **3**, the light rays, directly or after multiple reflection on the outer surface of the drum and the light catching grooves, reach the end which faces the image window **9**. At this end which is located substantially radially to the drum axis **2**, these residual light rays are turned back and guided back directly or after multiple reflection through the gap **11**.

In a further embodiment shown in FIG. **3**, the segment flanks **8** are provided with a light catching groove **12** which has a portion **12*a*** with a depth increasing in a wedge-shaped manner relative to the image window **9** and a portion **12*b*** which is cylindrical and faces the image window **9**. The operation of this embodiment corresponds to the operation of the first embodiment of the invention.

FIG. **4** shows another embodiment which is favorable technologically for manufacturing purposes. In the embodiment shown in FIG. **4** the light catching groove **14** has a rectangular cross-section.

FIG. 5 shows another embodiment of the invention. Here an additional light absorbing layer 13 is inserted in the light catching groove 12. The light absorbing layer 13 can be composed of any suitable material.

In accordance with a further not-shown embodiment of the invention, a light catching groove can be provided with a plurality of saw-tooth-shaped wedge surfaces or with a plurality of rectangular grooves.

It will be understood that each of the elements described above, or two or more together, may also find a useful application in other types of constructions differing from the types described above.

While the invention has been illustrated and described as embodied in a panoramic camera with an objective drum, it is not intended to be limited to the details shown, since various modifications and structural changes may be made without departing in any way from the spirit of the present invention.

Without further analysis, the foregoing will so fully reveal the gist of the present invention that others can, by applying current knowledge, readily adapt it for various applications without omitting features that, from the standpoint of prior art, fairly constitute essential characteristics of the generic or specific aspects of this invention.

What is claimed as new and desired to be protected by Letters Patent is set forth in the appended claims.

We claim:

1. A panoramic camera, comprising a camera housing having a cylinder segment provided with an image window; an objective drum which is rotatable relative to said cylinder segment about a rotary axis, said cylinder segment having segment flanks located laterally near said image window, said segment flanks being provided with light catching grooves extending parallel to said rotary axis of said objective drum and ending at an angular distance from the outer edges of said cylinder segment, covered by a curvature of said drum.

2. A panoramic camera as defined in claim 1, wherein at least one of said light catching grooves has a depth which increases in a wedge-shaped manner relative to said image window.

3. A panoramic camera as defined in claim 1, wherein at least one of said light catching grooves has a first portion which deepens relative to said image window in a wedge shaped manner and a second cylindrical portion which follows said image window.

4. A panoramic camera as defined in claim 1, wherein at least one of said light catching grooves has a rectangular cross-section.

5. A panoramic camera as defined in claim 1; and further comprising at least one light absorbing sheet arranged in at least one of said light catching grooves.

6. A panoramic camera as defined in claim 1, wherein at least one of said light catching grooves has a plurality of partial grooves.

7. A panoramic camera as defined in claim 6, wherein said partial grooves have a rectangular cross-section.

* * * * *

US005258791A

United States Patent [19]

Penney et al.

[11] Patent Number: 5,258,791

[45] Date of Patent: Nov. 2, 1993

[54] SPATIALLY RESOLVED OBJECTIVE AUTOREFRACTOMETER

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[73] Assignee: General Electric Company, Schenectady, N.Y.

[21] Appl. No.: 557,263

[22] Filed: Jul. 24, 1990

[51] Int. Cl.[5] A61B 3/10; A61B 3/14

[52] U.S. Cl. 351/211; 351/208

[58] Field of Search 351/205, 206, 211, 221, 351/208

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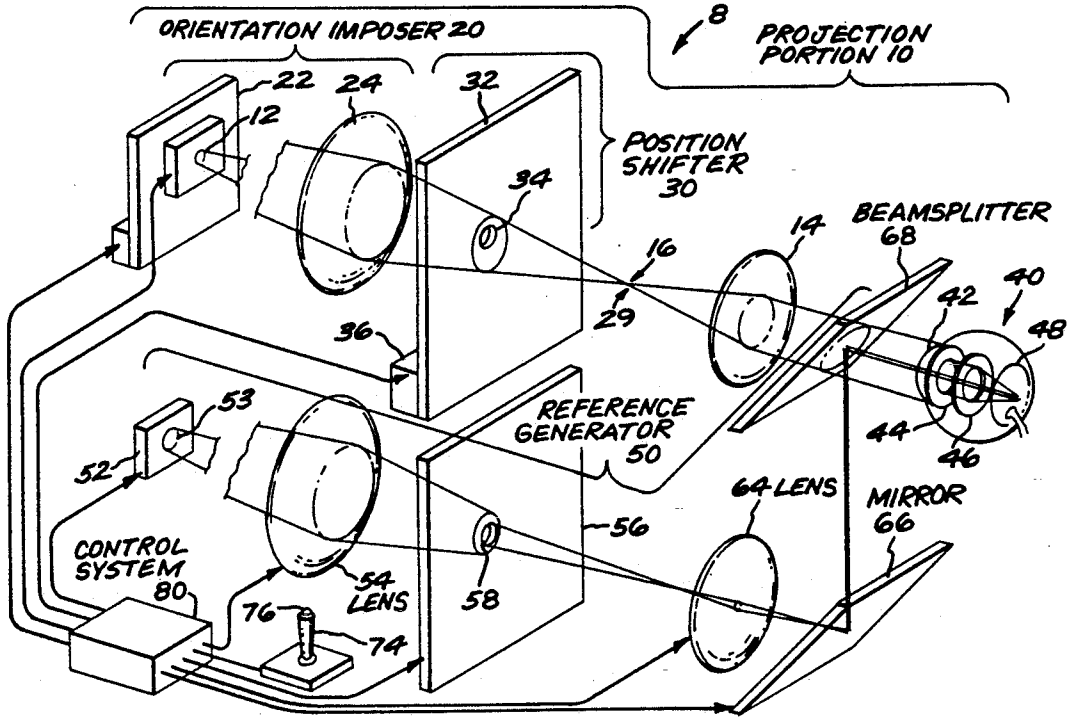
Primary Examiner—Rodney B. Bovernick

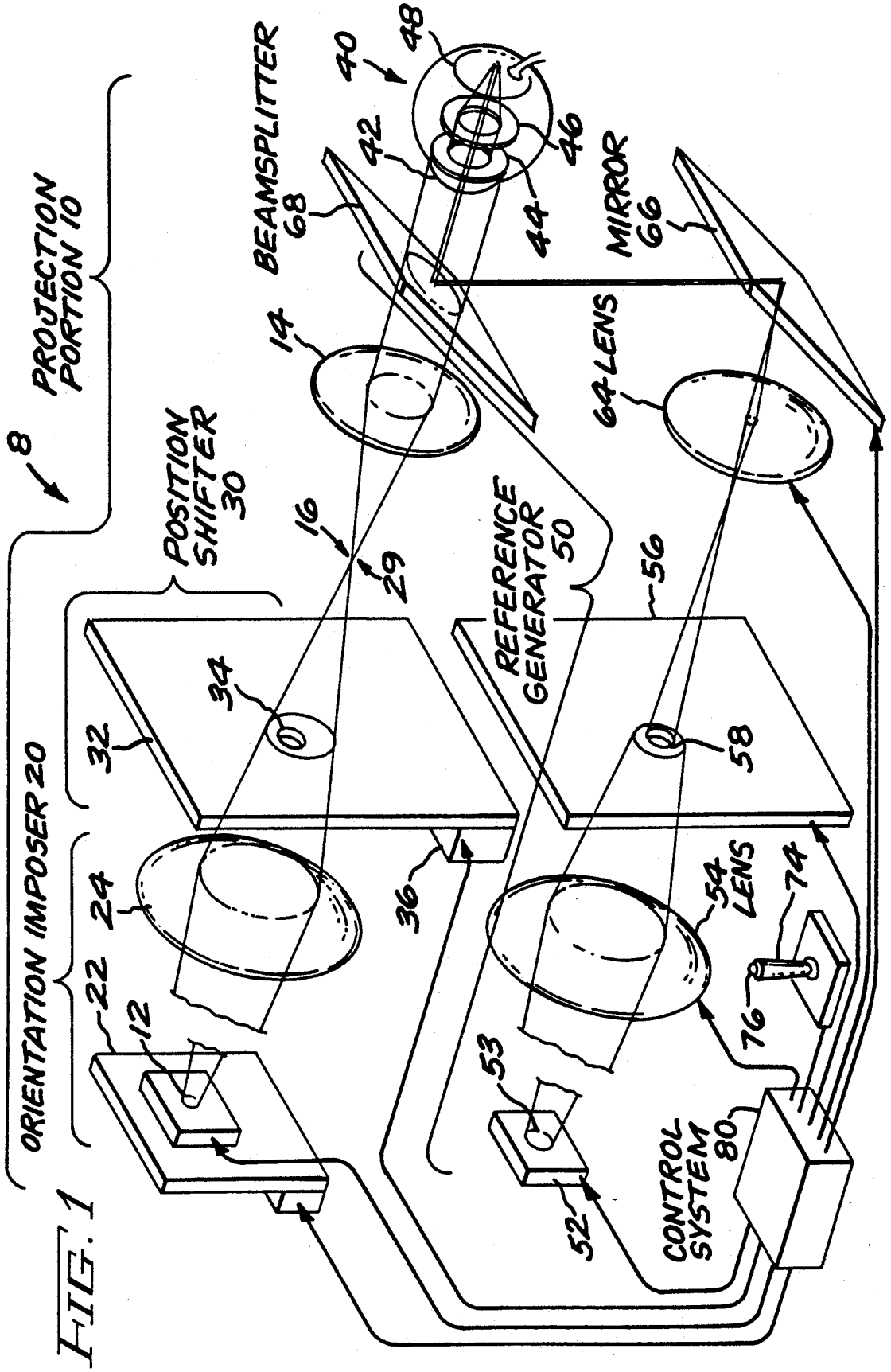
Attorney, Agent, or Firm—James R. McDaniel; Paul R. Webb, II

[57] ABSTRACT

A spatially resolved map of the eye's refractive characteristics are provided by measuring the eye's refractive characteristics on a point-by-point basis across the anterior surface of the eye. This spatially resolved refraction data may be obtained subjectively by providing a reference pattern and a measurement beam, by establishing a particular position on the cornea as the location to be measured and manipulating the orientation of the measurement beam at that measurement point to bring the measurement beam to a desired position relative to the reference image. When the patient indicates that the measurement beam is in the desired position relative to the reference pattern, the orientation of the beam is recorded as the refractive data for that measurement point and the process proceeds to another measurement point. This provides relatively rapid, physiologically accurate refractive data on a spatially resolved basis. Alternatively, this spatially resolved refraction data may be obtained objectively by independently controlling the position and orientation of a measurement beam and using a feedback null system to determine the refractive characteristics. This enables rapid, automatic non-subjective determination of the refractive characteristics of the eye and thereby provides the ability to provide improved correction of the eye. This spatially resolved refraction information enables spatially resolved correction of vision by spatially resolved shaping of the anterior surface of the eye.

36 Claims, 13 Drawing Sheets

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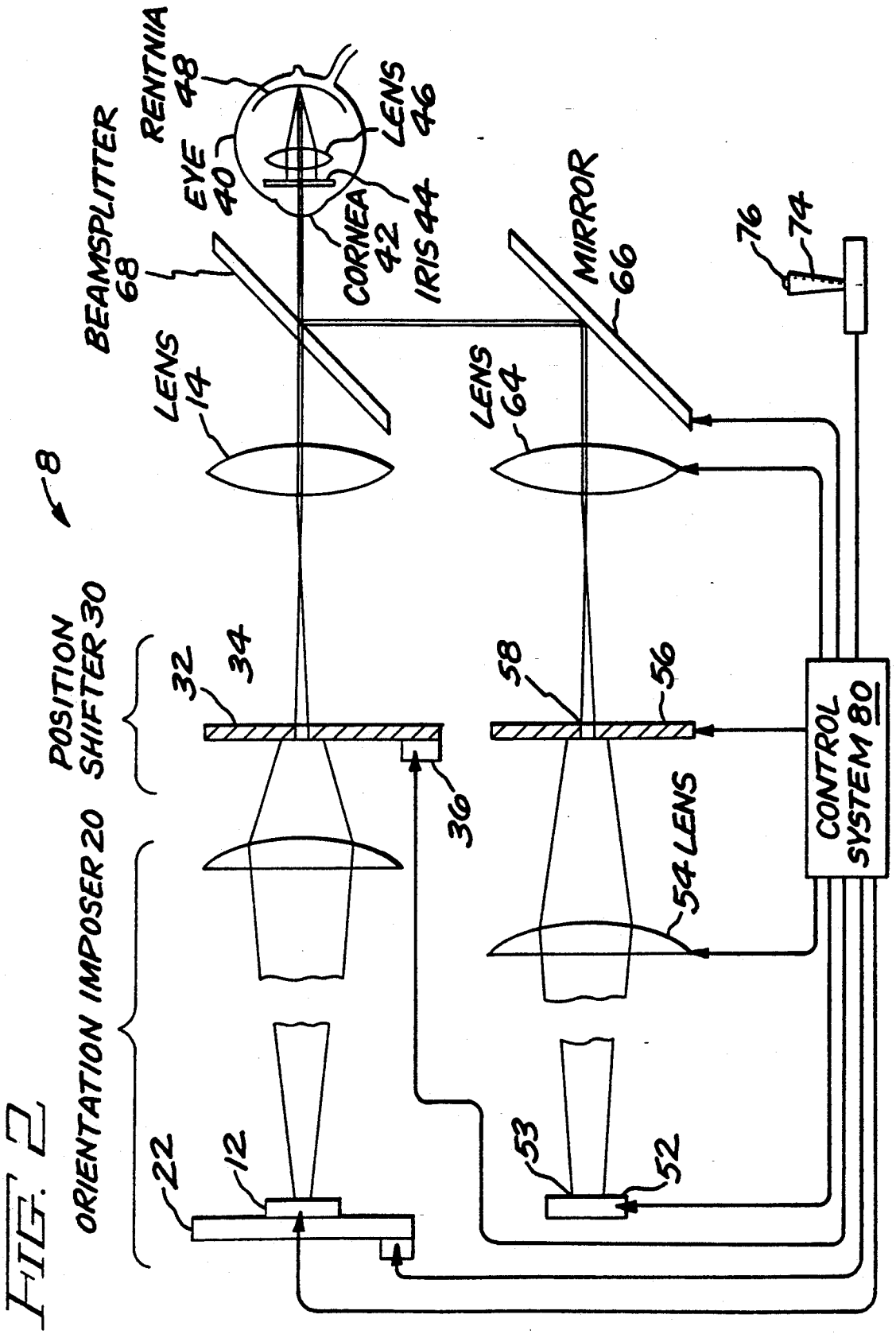
ORIENTATION IMPOSER 20
POSITION SHIFTER 30
REFERENCE GENERATOR 50
BEAMSPLITTER 68
MIRROR 66
64 LENS
54 LENS
CONTROL SYSTEM 80
40
48
42
46
44
14
16
29
56
34
32
58
24
36
22
12
53
52
74
76

FIG. 1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ORIENTATION IMPOSER 20
POSITION SHIFTER 30
BEAMSPLITTER 68
RENTNIA 48
EYE 40
LENS 46
CORNEA 42
IRIS 44
MIRROR 66
LENS 14
LENS 64
76
74
32
34
58
56
36
54 LENS
CONTROL SYSTEM 80
22
12
53
52

FIG. 2

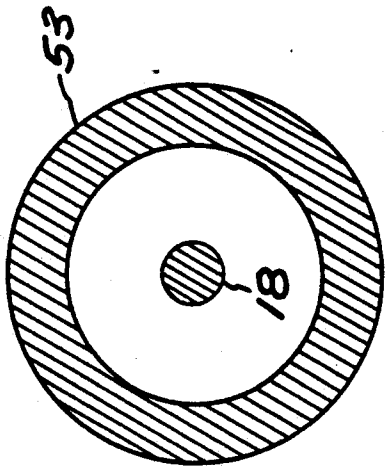


FIG. 3C

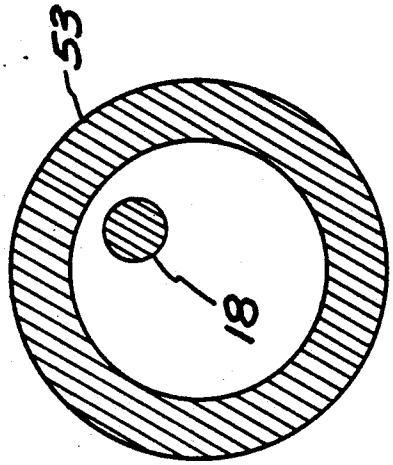


FIG. 3B

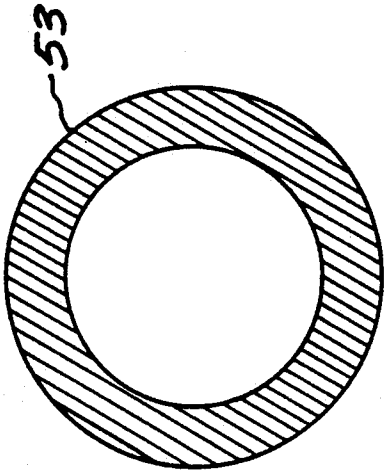
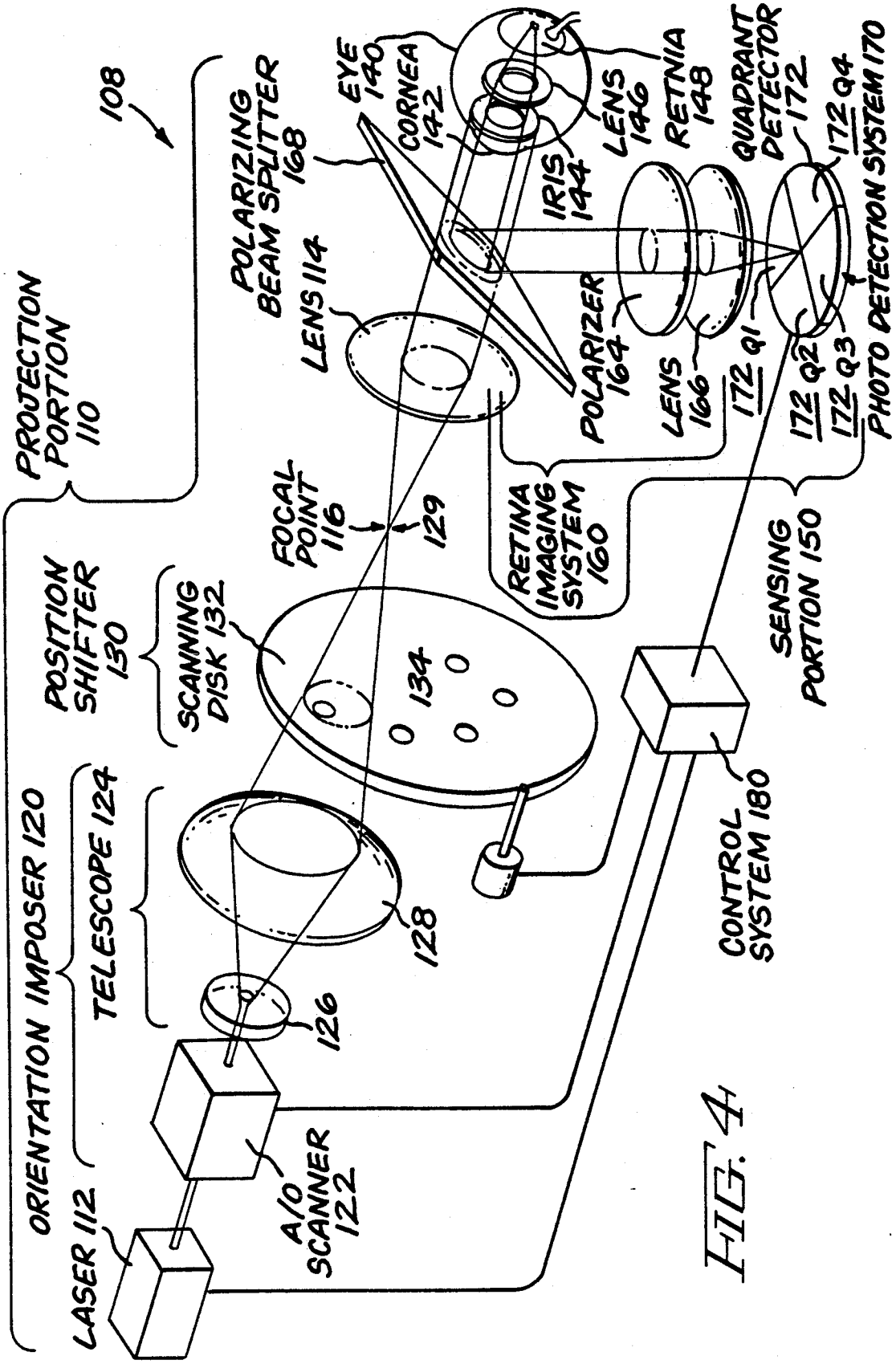


FIG. 3A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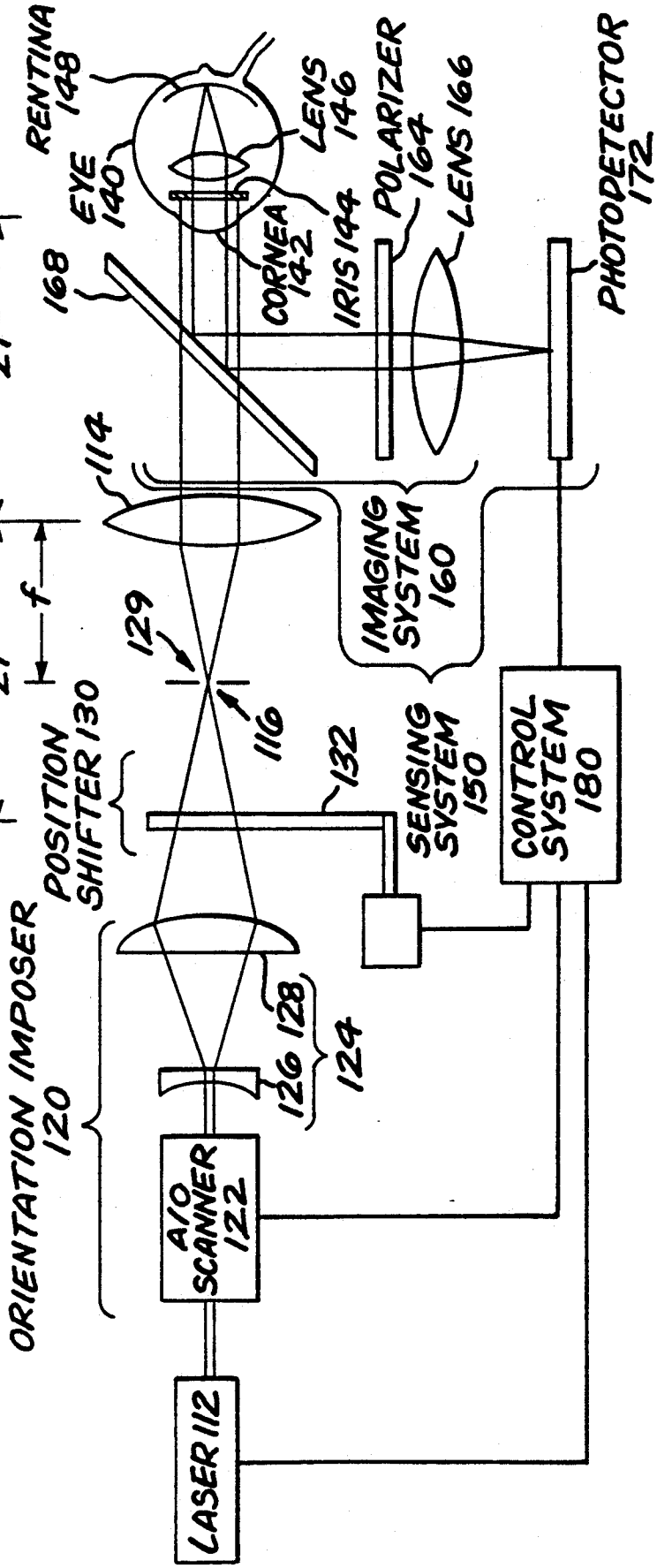
PROJECTION PORTION 110
ORIENTATION IMPOSER 120
LASER 112
A/O SCANNER 122
TELESCOPE 124
126
128
POSITION SHIFTER 130
SCANNING DISK 132
134
FOCAL POINT 116
129
LENS 114
POLARIZING BEAM SPLITTER 168
EYE 140
CORNEA 142
IRIS 144
LENS 146
RETNIA 148
QUADRANT DETECTOR 172
172 Q4
172 Q3
172 Q2
172 Q1
PHOTO DETECTION SYSTEM 170
POLARIZER 164
LENS 166
RETINA IMAGING SYSTEM 160
SENSING PORTION 150
CONTROL SYSTEM 180

FIG. 4

FIG. 5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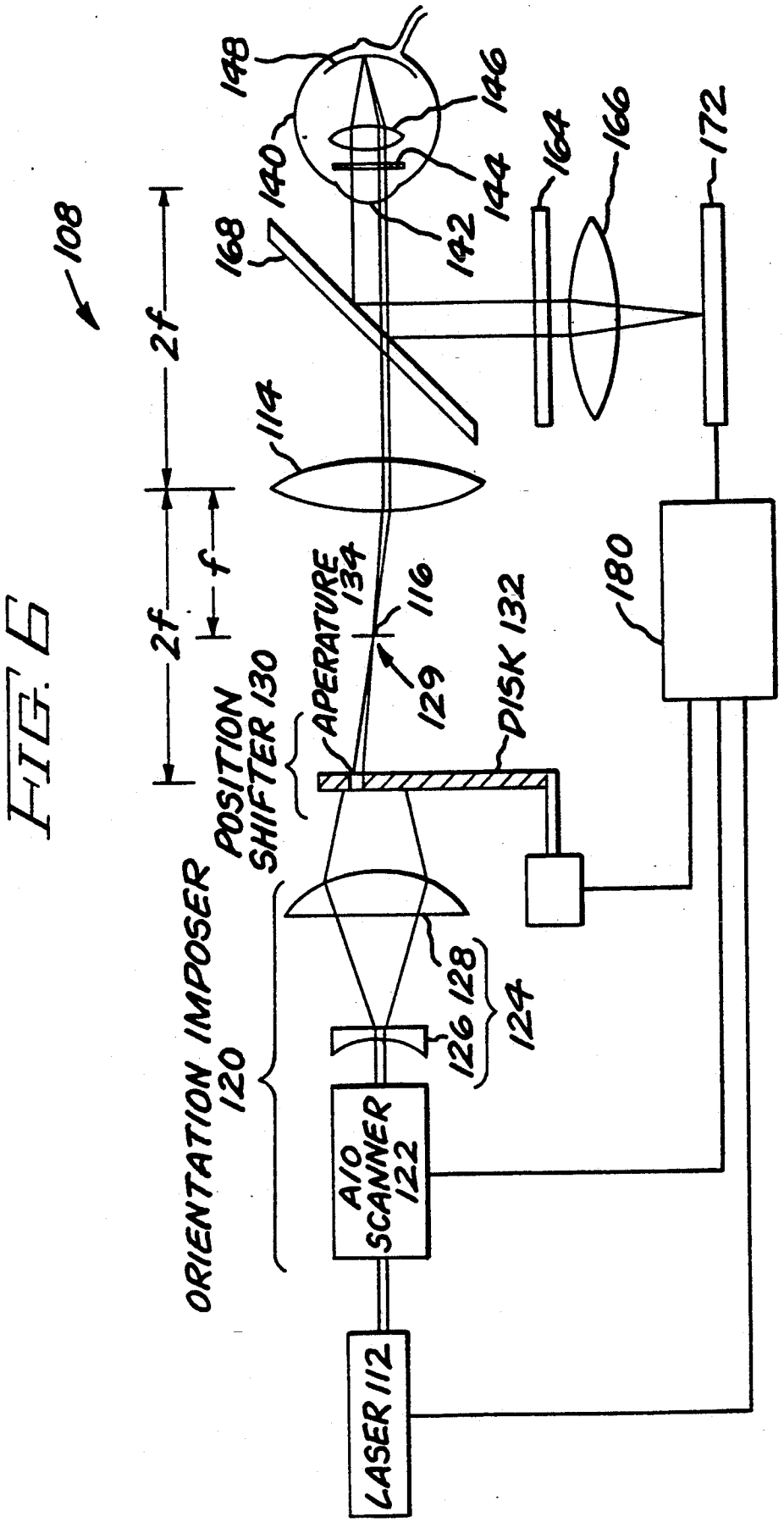
RENTINA 148
EYE 140
LENS 146
CORNEA 142
IRIS 144
POLARIZER 164
LENS 166
PHOTODETECTOR 172
168
2f
114
IMAGING SYSTEM 160
f
2f
129
116
POSITION SHIFTER 130
132
SENSING SYSTEM 150
CONTROL SYSTEM 180
ORIENTATION IMPOSER 120
128
124
126
A/O SCANNER 122
LASER 112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146
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166
172
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114
2f
f
APERATURE 134
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DISK 132
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POSITION SHIFTER 130
ORIENTATION IMPOSER 120
126 128
124
A/O SCANNER 122
LASER 112

FIG. 6

FIG. 7

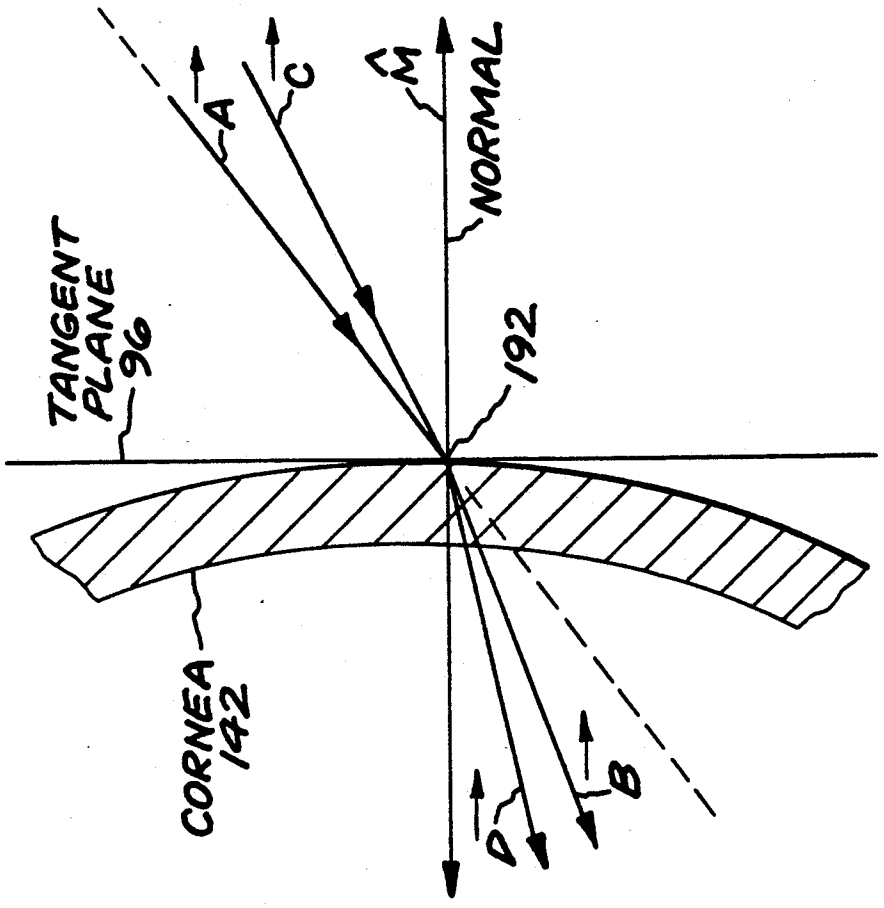
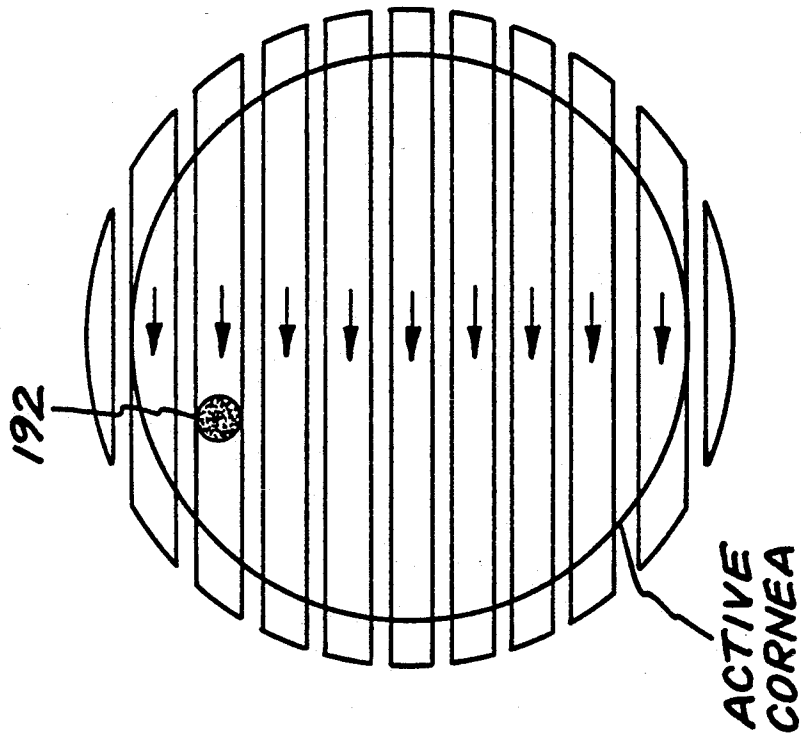


FIG. 8



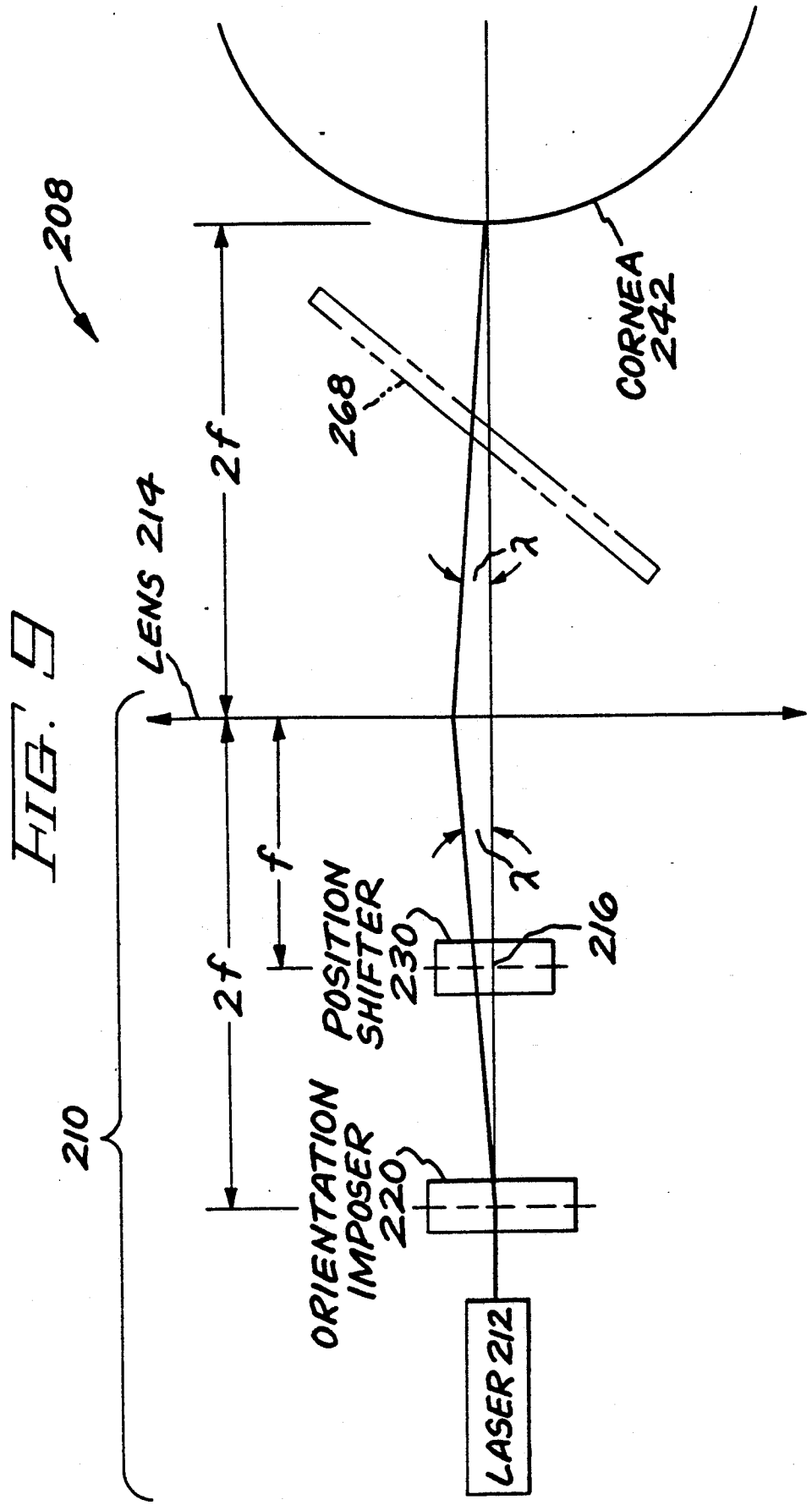
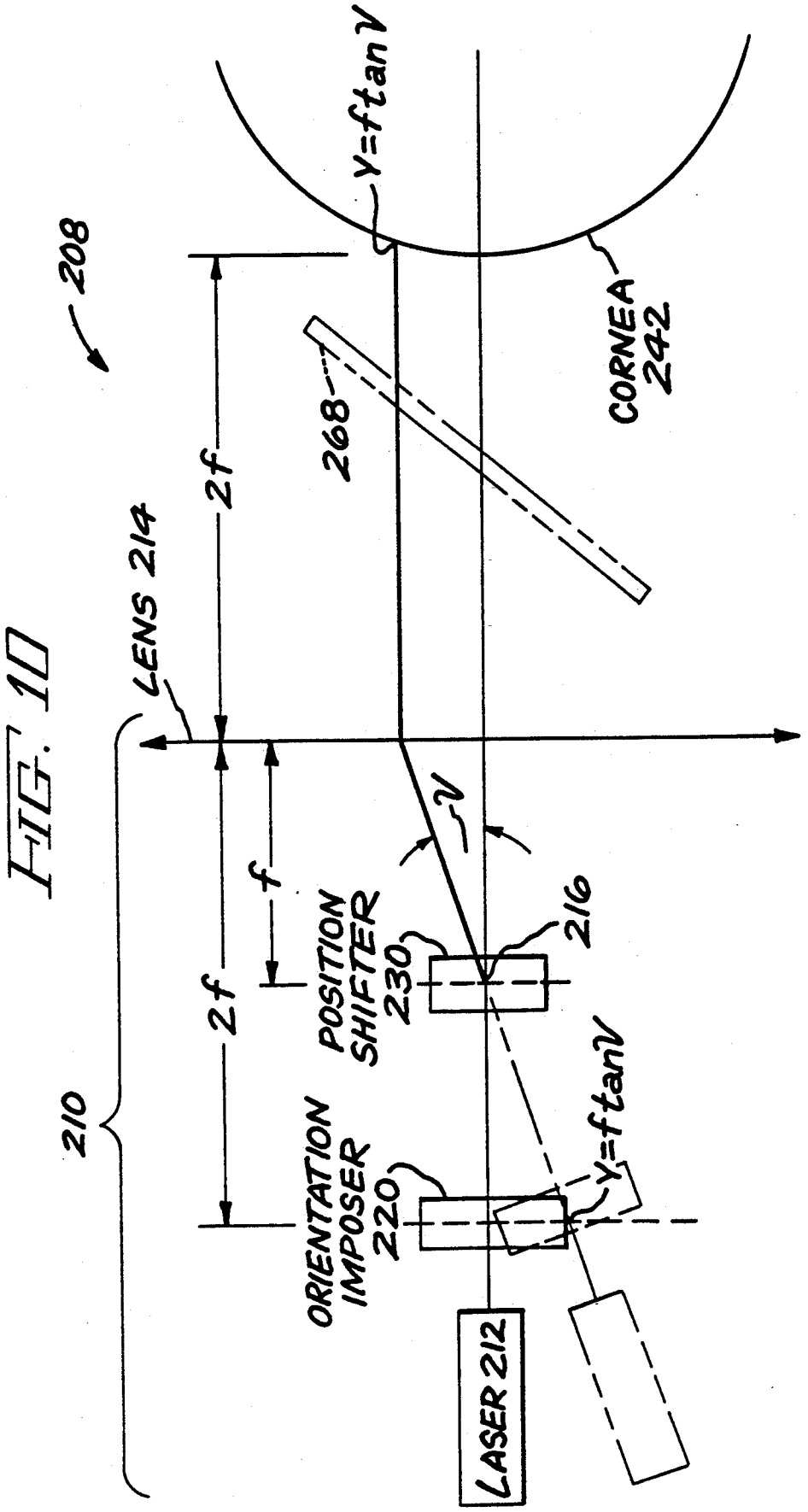
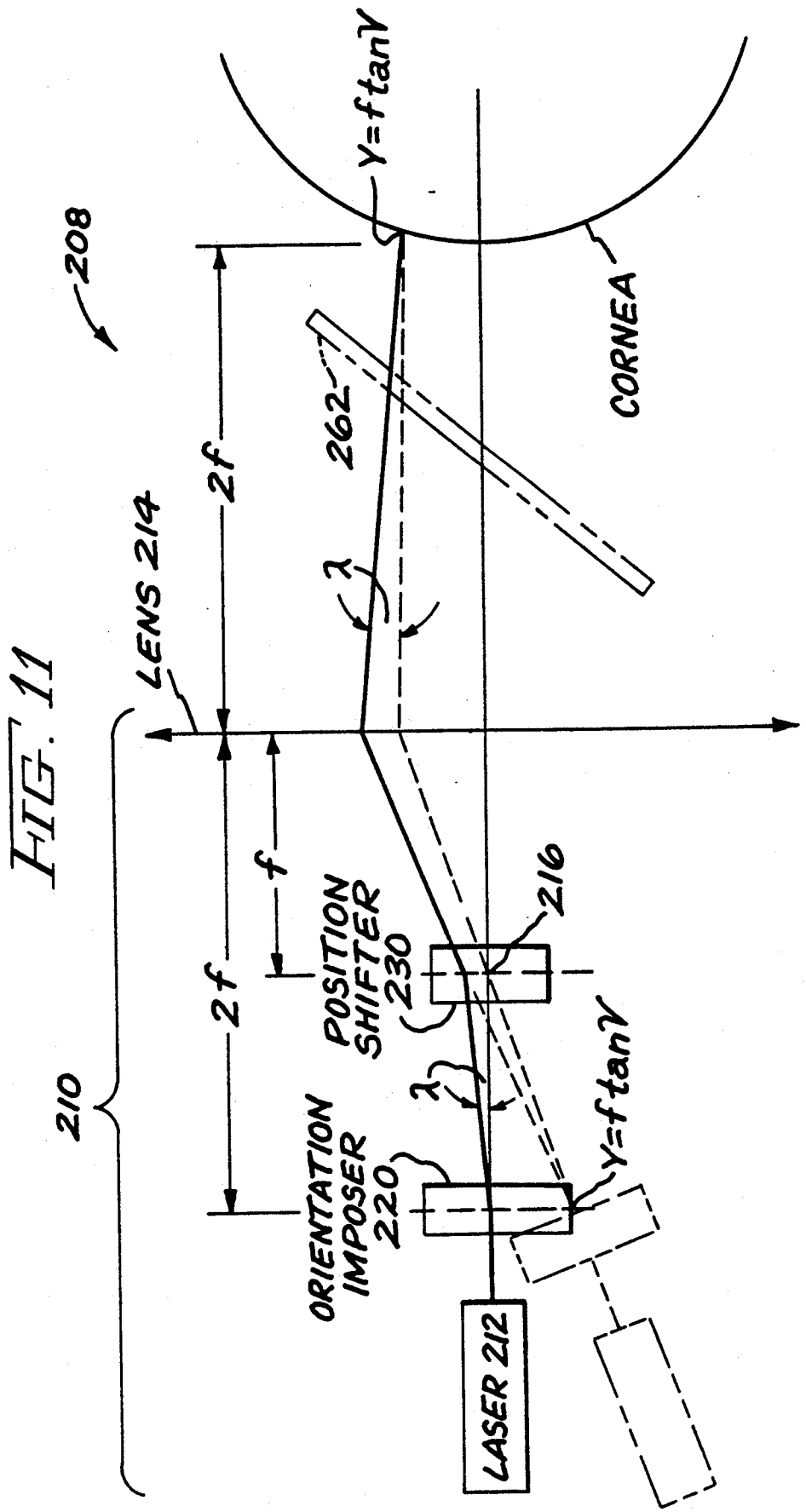

208
CORNEA
242
268
2f
LENS 214
λ
f
2f
POSITION
SHIFTER
230
216
λ
210
ORIENTATION
IMPOSER
220
LASER 212

FIG. 9

FIG. 10


208
Y=f tan V
CORNEA 242
268
2f
LENS 214
V
f
2f
POSITION SHIFTER 230
216
210
ORIENTATION IMPOSER 220
Y=f tan V
LASER 212


208
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262
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λ
LENS 214
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2f
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λ
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ORIENTATION IMPOSER 220
LASER 212

FIG. 11

FIG. 12A

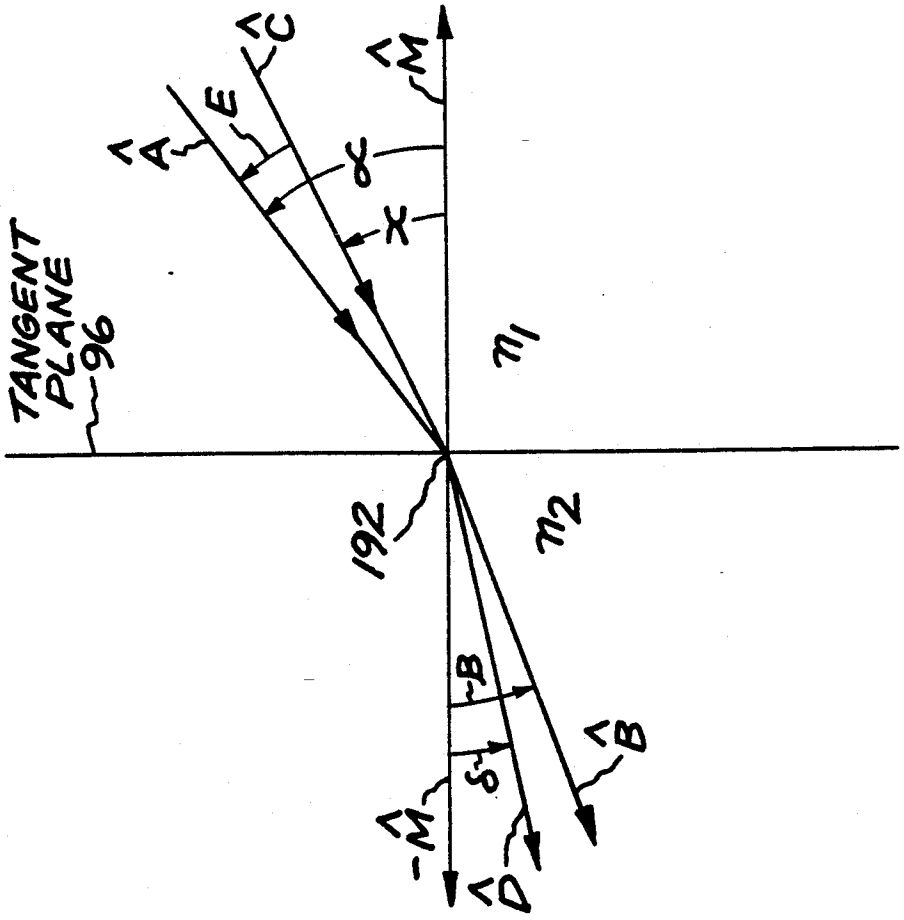
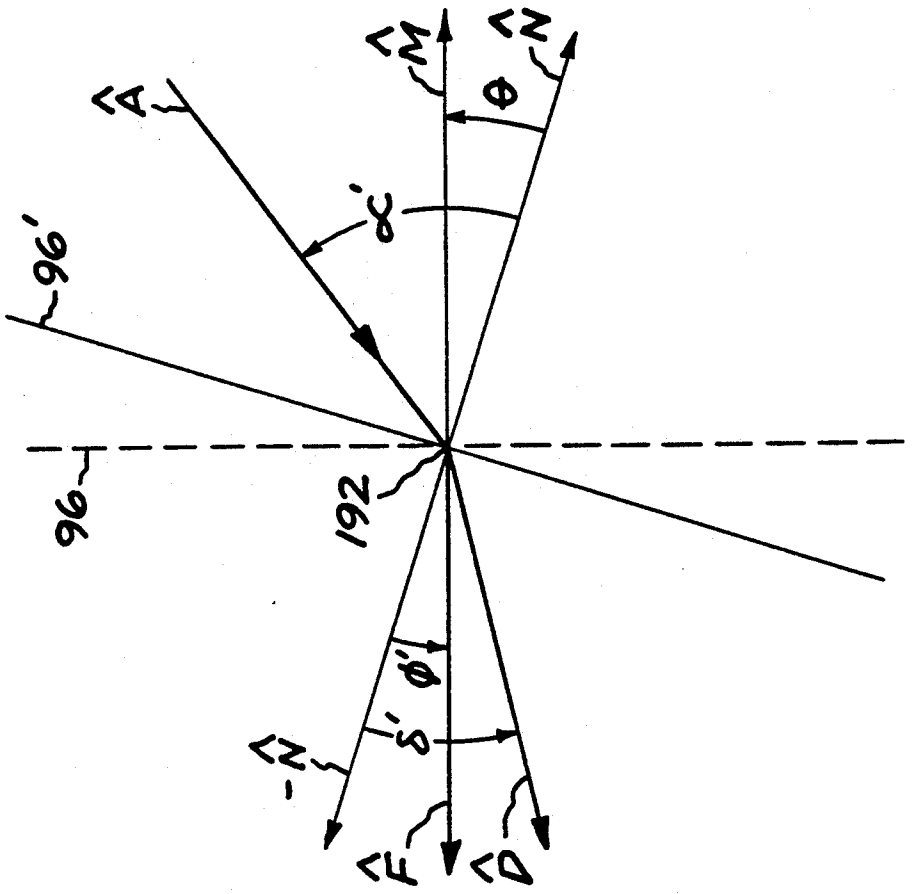

TANGENT PLANE 96
192
η_1
η_2
$\hat{A}$
$\hat{E}$
$\hat{C}$
$\hat{M}$
α
χ
$-\beta$
ρ
$\hat{B}$
$-\hat{M}$
$\hat{D}$

FIG 12B



SPATIALLY RESOLVED OBJECTIVE AUTOREFRACTOMETER

RELATED APPLICATION

This application is related to U.S. patent application Ser. No. 07/402,946, filed Sep. 5, 1989 and entitled, "Laser Shaping With an Area Patterning Mask" by R. M. Levinson et al. now abandoned, which is incorporated herein by reference in its entirety.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to the field of measurement of the refractive characteristics of an optical system, and more particularly, to automatic measurement of the refractive characteristics of the human or other animal eye and to corrections to the vision thereof.

2. Background Information

The refractive characteristics of individual components of such man-made optical systems as telescopes, microscopes, cameras and so forth are well understood and susceptible to accurate, non-subjective measurement as are the overall characteristics of such systems.

In such optical systems, prior to their assembly, each component of the optical system is individually accessible for shaping, measurement, modification, adjustment and so forth. Further, each of these components is normally extremely stable over time when disposed in a stable environment. In addition, the position and orientation of each component can be carefully selected and accurately adjusted during assembly and/or alignment of the system, if need be. As a result, the physical configuration of each component and the overall effect it produces in that optical system can be accurately controlled and adjusted to meet the system's overall specifications. Thus, the overall optical system may be accurately characterized as the sum of its parts. Further, in most such systems, both the input and the output ends are accessible with the result that accurate measurement of the complete system is possible.

In contrast with such man-made optical systems, human and animal eyes are optical systems in which the individual internal components of a given eye are not normally separately accessible for either direct measurement or adjustment, the output of the optical system is not directly accessible for analysis and the characteristics of individual components change over time with growth, aging and other factors.

The most common reason for measuring the optical characteristics of a human eye is to determine a prescription for corrective lenses to correct vision problems. Such measurements of the optical characteristics of the eye have long been made by the actual or apparent substitution of lenses with various correction factors with the patient indicating the effect of each substitution in terms of the image being clearer or fuzzier. This technique determines an overall correction for the optical characteristics of the eye.

Such determinations are subject to experimental errors and such events as accommodation of the eye to the substituted lens in a manner which gives the impression that a particular correction is desirable, when in fact that correction is not optimum.

Further, these measurement techniques determine corrections which improve overall vision, but are limited in normal practice to prism, cylindrical and spherical corrections which are low order corrections to the patient's actual, detailed vision errors which include higher order terms or characteristics which these measurement techniques cannot determine.

For the most part these prior art measurement systems are subjective and require the active participation of the patient for their success. In such cases the ophthalmologist must rely on the patient to indicate accurately which images are clearer than others as an indication of the appropriate degree of correction. This requirement for active participation of the patient is a disadvantage in a number of circumstances such as in the diagnosis of small children who have difficulty in understanding what is being asked of them and prevents its use for infants who are incapable of indicating the effect of such lens substitutions.

The requirement for the active participation of the patient in the determination of the characteristics of the eye can have unfortunate effects. Some anomalous conditions result in permanent disabilities because they are not detected during infancy because of the inability of infants to communicate with ophthalmologists. For example, if one eye is in focus and the other is severely out of focus during the time the brain is developing its ability to interpret visual signals, then a permanent disability develops in which the out-of-focus eye is never able to contribute usefully to the brain's image recognition because of a lack of proper stimulation during the period in which the brain's image interpretation functions became established. A person suffering from this condition can tell with the affected eye whether the lines in an image are sharp or fuzzy, but cannot assimilate the perceived information into an image. Present subjective refraction measurement systems are incapable of determining the development of this condition in infants because they cannot accurately diagnose the visual acuity of the eye without the active participation of the patient.

A number of objective refractometers have been developed in the hope of overcoming these problems. However, each of these has had problems or deficiencies of its own. One common deficiency is accommodation by the eye being measured. Another common problem is determining and maintaining accurate alignment of the measurement system during the measurement cycle, since any misalignment can cause inaccurate results.

In recent years, substantial interest has developed in using laser sculpturing, i.e. ultraviolet (UV) light laser ablation, to shape the anterior surface of the cornea as a means of providing corrected vision in place of the use of glasses or contact lenses. U.S. Pat. No. 4,665,913, which is incorporated herein by reference, discloses a UV laser scanning ablation technique for shaping a cornea in which a laser beam which produces a small spot is scanned across the cornea to remove a desired thickness of corneal material on each scan. The area scanned is increased or decreased on subsequent passes to scan each portion of the corneal surface a number of times which is proportional to the thickness of material to be removed at that portion of the cornea.

An alternative to the direct shaping of the corneal surface, is to essentially permanently attach a lenticule to the cornea with the lenticule being shaped to provide the desired vision correction. We say "essentially permanent" because the intention is to leave the lenticule in place permanently, unless some problem should develop which requires its removal. Such lenticules them-

selves may be reshaped or reprofiled by laser ablation at the time of installation or subsequent thereto to compensate for changes in the overall characteristics of the eye. Such techniques are disclosed in more detail in U.S. Pat. No. 4,923,467, entitled, "Apparatus and Process for Application and Adjustable Reprofiling of Synthetic Lenticules for Vision Correction" by Keith P. Thompson, which is incorporated herein by reference.

In addition to the advantages provided by eliminating the need for eye glasses or contact lenses, both of these techniques are conceptually capable of providing substantial additional advantages in that each should, under proper control and with sufficiently detailed correction instructions, be able to produce fully asymmetric reshaping of the cornea in a practical manner, rather than being limited to the sphere, cylinder and wedge approximation mentioned previously.

However, in order to provide such detailed correction, there is a need for measurement techniques which measure the shape of the cornea and the existing refraction characteristics of the eye with the same detail and precision as can be provided by the correction modality in order that the errors may be fully corrected in this manner.

U.S. Pat. No. 4,669,466, which is incorporated herein by reference, discloses a system for providing an ophthalmic surgeon with data on the shape and thickness of the cornea to aid in making surgical decisions. That system measures the contour of the anterior surface of the cornea and the thickness of the cornea in order to provide the surgeon with data as to the present configuration and thickness of the cornea. That system is neither intended for nor capable of determining the refractive correction required for that eye. Rather, the surgeon must rely on a separately determined desired correction.

A measurement system providing such a correction measurement should be fast and should measure the eye's detailed refraction characteristics referenced to the cornea as a function of position across the dilated pupil. This position-dependent measurement may be categorized as a spatially resolved refraction measurement because the refraction at each measurement region (point) is determined in that local measurement region independent of the refraction at other, non-overlapping measurement regions.

Ideally, such a spatially resolved measurement system should be operable in both an objective mode which does not require the patient to interpret the quality of images and a subjective mode in which the patient determines the quality of the image. In that way, the best features of both techniques may be employed and the refraction of both cooperative and non-cooperative patients may be measured. As a desirable alternative, separate objective and subjective embodiments may be provided.

OBJECTS OF THE INVENTION

Accordingly, a primary object of the present invention is to provide an optical measurement system suitable for measuring the refractive characteristics of an eye in a spatially resolved manner.

Another object of the present invention is to provide an optical measurement system which relies on patient responses in measuring the refractive characteristics of the eye in a spatially resolved manner with the measurements referenced to the cornea.

Another object of the present invention is to provide an optical measurement system which relies on patient responses in measuring the refractive characteristics of the eye in a manner which minimizes adverse effects which result from accommodation.

Another object of the present invention is to provide an optical measurement system which does not rely on patient responses in measuring the refractive characteristics of the eye in a spatially resolved manner with the measurements referenced to the cornea.

Another object of the present invention is to provide an automatic optical measurement system capable of fully measuring an optical system in a spatially resolved manner in only seconds, and preferably in well under one second where the optical system is an eye.

Still another object of the present invention is to provide an automatic optical measurement system which avoids fatigue, eye motion and accommodation and which permits multiple measurements to be made.

A further object of the present invention is to provide an optical measurement system which provides the capability for automatic alignment.

A still further object of the present invention is to derive spatially resolved correction data from the spatially resolved refraction data.

A still further object of the present invention is to provide spatially resolved correction of vision.

SUMMARY OF THE INVENTION

The above and other objects which will become apparent from the specification as a whole, including the drawings, are accomplished in accordance with the present invention by determining the refractive characteristics of the eye in a spatially resolved manner. In accordance with this invention, these spatially resolved refraction measurements may made by both subjective and objective refractometers.

In accordance with a subjective refractometer embodiment of the present invention, a reference image or pattern and a measurement beam of light which is essentially collimated, are projected into the eye. The reference pattern and the measurement beam are preferably directed into the eye along two initially different optical paths which are merged into a single optical path by an appropriate optical mechanism such as a beam splitter. The patient controls manipulation of the measurement beam to properly position its image with respect to the reference image or pattern. This is preferably done directly by manipulation of a joystick or another input mechanism, but may also be done by verbal instructions to the ophthalmologist. For each measurement point on the cornea, the measurement beam is preferably held stationary at that measurement point while its impingement orientation relative to the optical axis of the refractometer is manipulated until the patient is satisfied that the image of the measurement beam is disposed in the desired relationship to the reference pattern.

During measurements, the eye must be properly aligned with respect to the refractometer. A desirable alignment choice is with the visual axis of the eye aligned with the optical axis of the refraction instrument. For this purpose we define the visual axis as the path of an optical ray that passes through the centroid of the pupil and strikes the fovea centralis. This visual axis may not be a straight line within the eye because this optical ray can bend through refraction at each of the optical surfaces within the eye. The fovea centralis, as is well known in the ophthalmic art, is that portion of

the retina where the clearest image is produced and can be visually located as a substantially featureless depression in the retinal surface.

In this subjective embodiment, after correct alignment is obtained, the collimated measurement light beam projected by the refractometer is directed at a selected measurement point on the cornea. Typically, the beam diameter is chosen to be 1/5 to 1/10 of the diameter of the dilated pupil, such that measurements may be taken at between 25 and 100 separate measurement regions or "measurement points" on the cornea. At each measurement region, the beam direction is varied in response to patient inputs without changing the location at which the beam impinges on the cornea, until the patient sees the measurement beam as being properly aligned with respect to the reference pattern. The beam's angles, with respect to the instrument's optical axis in two perpendicular planes which include the instrument's optical axis describe the deviation of the beam direction from the optical axis. These angles are recorded and constitute the refraction information for that region of the cornea. The beam is then directed to another measurement point and the process of the patient aligning the measurement beam with respect to the reference pattern is repeated until measurements have been obtained at a desired set of measurement points.

A complete refraction measurement produces a record of these angle pairs for each measurement point. This record constitutes a refraction map of the eye which specifies the eye's refraction as a function of position on the cornea. For example, for an ideal or perfect eye which is perfectly aligned to the refractometer, the result for each measurement point would be 0° for each angle or an angle pair of 0,0. I.e., at each measurement point, the beam would strike the fovea centralis when it was parallel to the optical axis of the refractometer. For a real eye, most of the angles are likely to assume differing non-zero values. A conventional correction prescription in terms of prismatic, cylindrical and spherical corrections can be calculated rapidly from this information within a computer. However, considerably more information is contained within the refraction map. Thus, for example, the conventional refractive corrections can be subtracted within the computer from a full correction to indicate how well or poorly the conventional means can correct the eye. Alternatively, the full correction can be used in controlling a refractive correction technique such as a laser ablation to modify the refraction of the eye in a fully asymmetrical manner to produce a better correction than can be produced by conventional means.

In accordance with the invention, these measurements are preferably made by separately varying the location of the measurement point on the cornea and the direction of the beam at that measurement point.

In accordance with one embodiment, the actual or apparent position of the measurement beam light source controls the measurement beam impingement orientation, that is, the direction at which the measurement beam strikes the cornea relative to the optical axis of the refractometer (or the beams angles with respect to the optical axis in two preferably perpendicular planes, each of which includes the optical axis). A system for shifting the position of the light source serves as an impingement orientation imposer, i.e. controls the direction of the measurement beam with respect to the cornea. The beam is then passed through an aperture which narrows the beam and serves as a position shifter, i.e. selects the location on the cornea of the measurement point. That narrow beam is passed through a collimating lens which focuses the position shifting aperture onto the cornea. The aperture and the cornea are placed at conjugate locations with respect to the collimating lens so that the position of the scanning aperture determines the point on the cornea at which the measurement beam impinges independent of the beam orientation established by the orientation imposer. A beam splitter which combines the measurement beam and the reference pattern is preferably disposed between the collimating lens and the cornea. The reference pattern is separately provided, focused by a reference lens and reflected off the beam splitter toward the eye.

In accordance with an objective refractometer embodiment of the invention for use in measuring the eye, a measurement beam of light which is essentially collimated is projected through a measurement point on the cornea onto the retina where it forms a small illuminated spot. The retina of the eye is imaged onto a photosensitive detector which can determine when this small illuminated spot is essentially precisely centered on a target region on the retina. In response to the output of that photosensitive detector, appropriate electronics guide the movement of that illuminated spot to that target retinal region by generating electronic signals which result in the impingement orientation of the projected beam changing to one at which the illuminated spot is centered on the target region. One example of such a detector is a quadrant photodiode on which the retina is centered with its target region imaged on the origin of the quadrant photodiode. Preferably the origin of the quadrant photodiode is shifted into alignment with the image of the illuminated spot on the retina while the measurement beam of light is aimed along the optical axis of the refraction instrument and the visual axis of the eye.

During operation of this objective refractometer, the eye must be aligned and maintained in alignment for the short time (typically 10–30 milliseconds) required to take a complete set of refraction measurements. A desirable alignment choice is with the visual axis of the eye aligned with the optical axis of the refraction instrument. The eye can be aligned subjectively by the patient fixating on a target placed on the optical axis of the refractometer. Alternatively, correct alignment can be sensed objectively, as, for example, by viewing the position at which an undeflected projected beam from the refractometer passing through the pupil's centroid strikes the retina and moving the eye or the refractometer axis until this position coincides with the fovea centralis.

After correct alignment is obtained, the collimated light beam projected by the refractometer is scanned across the cornea. At each measurement region or point, the beam direction is varied without changing the point at which the beam impinges on the cornea until the position sensing detector determines that the beam is striking the fovea centralis. The beam's angles, with respect to the instrument's optical axis in two perpendicular planes constitute the refraction information for that region of the cornea. Using high speed circuit components, approximately 30 to 50 microseconds is required to complete the beam direction variation at each corneal measurement region. In this case, a complete refraction covering 100 distinct corneal regions can be completed in 3 to 5 milliseconds.

As an alternative to this measurement scheme, the beam direction may be set at a particular orientation and the beam scanned to the various measurement points and those measurement points for which the position sensing detector determines that the beam is striking the fovea centralis may be recorded as having that beam direction as their "optimum" orientation. The beam direction is then changed and the process repeated.

Since the refraction can be accomplished so quickly, the complete refraction can be repeated many times within a few seconds and the results compared to evaluate measurement quality.

In accordance with one embodiment, the measurement beam first passes through an orientation imposer which is a two dimensional beam scanner which provides an orientation-selected collimated beam. That beam is then passed through the position shifter which is a scanning aperture to provide a narrow beam. That narrow beam is passed through a collimating lens which focuses the scanning aperture onto the cornea. The scanning aperture and the cornea are placed at conjugate locations with respect to the collimating lens so that the position of the scanning aperture determines the point of impingement on the cornea independent of the beam orientation established by the orientation imposer.

In accordance with another embodiment, the orientation imposer is a first two dimensional beam deflector, the position shifter is a second two dimensional beam deflector effectively positioned at the focal point of the collimating lens. The orientation imposer and the tangent plane to the surface of the cornea are positioned at conjugate locations to the collimating lens, such as at twice the focal length (f) of the collimating lens with the cornea on the side of the collimating lens opposite the orientation imposer and the position shifter. The direction of deflection imposed by the first beam deflector controls the direction relative to the instrument's optical axis at which the measurement beam strikes the cornea. The second beam deflector determines the position (in two dimensions) at which the measurement beam strikes the cornea by displacing the measurement beam at the collimating lens a distance equal to $f\tan\nu$ from the reference position, where ν is the angle of deflection imposed on the beam by the position beam deflector as measured in the plane defined by the optical axis and the beam itself.

In either fully automatic embodiment, an image of the retina is separately formed on a photodetector for the purpose of determining the point on the retina at which the measurement beam strikes the retina. This retina imaging system may preferably comprise (1) a beam splitter (preferably polarizing) through which the measurement beam passes, preferably after passing through the collimating lens, (2) an additional polarizing filter (optional) and (3) a lens which focuses an image of the retina on the photodetector. The polarizing beam splitter and the polarizer in the retina imaging system serve to filter out light from a cross-polarized measurement beam which reflects off the surface of the cornea or the eye's lines. This minimizes the adverse impact of those corneal reflections (which may be brighter than the image of the retina) on the determination of the location of the bright spot on the retina.

The output from the photodetector is used to determine the location of the image of the beam on the retina. The measurement electronics adjust the beam orientation to move the image of the beam to a reference point such as the fovea centralis, without changing the measurement point. The photodetector may preferably be a quadrant detector or other sensor which provides an output which can be used to rapidly adjust the beam orientation to move the beam image to the reference point. Under these conditions, the system operates as a negative feedback loop to maintain the beam image in the null position (at the reference point) as the location of the measurement point is scanned across the eye. When implemented with suitable optics and high speed electronics, this overall system can obtain the data necessary for a hundred point map of the refractive characteristics of the eye in well under one second.

The spatially resolved refraction data, in combination with a measured existing surface contour of the anterior surface of the eye, enable the calculation of a detailed (spatially resolved) new contour for the anterior surface of the eye which will provide corrected vision. This new contour is provided by detailed (spatially resolved) modification of the contour of the anterior surface of the eye, as by laser ablation.

BRIEF DESCRIPTION OF THE DRAWINGS

The subject matter which is regarded as the invention is particularly pointed out and distinctly claimed in the concluding portion of the specification. The invention, however, both as to organization and method of practice, together with further objects and advantages thereof, may best be understood by reference to the following description taken in connection with the accompanying drawings in which:

FIG. **1** is a perspective, schematic illustration of one embodiment of a subjective refractometer in accordance with the present invention;

FIG. **2** is an optical diagram of the subjective refractometer of FIG. **1**;

FIGS. **3A**, **3B** and **3C** illustrate images observed by the patient during the use of the FIG. **1** refractometer;

FIG. **4** is a perspective illustration of an autorefractometer in accordance with the present invention;

FIGS. **5** and **6** comprise optical diagrams of the structure of FIG. **4** under different conditions;

FIG. **7** illustrates conditions at a measurement point;

FIG. **8** is an illustration of a measurement beam scanning pattern produced by the system of FIG. **7**;

FIGS. **9–11** are illustrations of an alternative embodiment of the projection portion of the FIG. **4** system; and

FIGS. **12A** and **12B** are diagrams of geometric relationships at a measurement point.

DETAILED DESCRIPTION

In order to determine the refractive characteristics of an eye, in accordance with the present invention, a narrow, collimated measurement light beam is directed to selected measurement points on the cornea of the eye, one measurement point at a time. While holding the measurement beam to impinging on the cornea at the selected measurement point, the direction or orientation of the measurement beam relative to the refractometer system's axis (that is, the measurement beam's impingement orientation or direction) is adjusted until the measurement beam strikes the retina in a location associated with desired or optimum performance in accordance with the criterion being employed for the refraction measurement. Once that direction or orientation has been determined for a given measurement point, a different measurement point is selected and the process is repeated.

Since vision involves both physical optics within the eye and physiological effects within the image processing portions of the mind, we consider it preferable to involve a cooperative patient in the determination of when the beam is in the position which corresponds to optimum image formation. To this end, in a first, subjective refractometer embodiment of the present invention, we include a reference image generating portion **50** for providing a reference image with respect to which the patient adjusts the measurement beam into a desired optimum relationship. In the refractometer embodiment **8** illustrated in a perspective view in FIG. **1** and as an optical diagram in FIG. **2**, a reference image generation system **50** comprises a source **52** of a reference image **53**, a shaping lens **54**, an opaque member **56** having a beam size restricting aperture **58** therein, a reference collimating lens **64**, a mirror **66** and a beam splitter **68**. The opaque member **56** serves to prevent the light which forms the reference pattern from flooding the cornea and the aperture **58** therein allows the light which forms the reference pattern to enter the eye in the vicinity of the center of the pupil. This is to minimize distortion of the reference pattern as a result of any existing refractive errors. To this end, the opaque member **56** is positioned where reference collimating lens **64** conjugates it to the cornea **42**. The lenses **54** and **64** focus the reference image **53** onto the retina of the eye and are positioned with a common focal plane disposed between them with their axial focal points which are disposed in that focal plane co-incident and respectively conjugate with respect to the image source **52** and the retina **48** whereby the image source **52** is positioned conjugate to the retina **48**. The mirror **66** bends the reference optical path toward the optical axis of the eye and the beam splitter **68** bends the reference optical path into the eye substantially concentric to the eye's optical axis while allowing the measurement beam which is separately provided by a projection portion **10** of the refractometer to pass directly through the beam splitter to reach the eye substantially parallel to the eye's optical axis. Thus, beam splitter **68** preferably merges the reference image and the measurement beam to cause them to appear to the eye as two parts of a single image. In FIG. **1** the distance between the lens **64** and the eye **40** is excessive compared to the distance between the lens **14** (to be discussed subsequently) and the eye. These two distances are preferably the same in the actual system. In the drawing the need to fit all of the elements of the Figure on the drawing sheet results in the lens-**64**-to-eye distance being exaggerated.

A vast number of reference images may be used in accordance with the particular vision characteristics of the patient and the portion of the eye to be measured. For reasons to be discussed subsequently, our preferred reference image comprises an illuminated circular annulus **53** as illustrated in FIG. **3A**. It may be considered desirable to provide a discrete fixation target such as a cross within the reference image **53** in order to aid the patient in maintaining eye fixation throughout the measurement process. However, that is generally unnecessary in this embodiment since the reference pattern itself serves as a fixation target. The pattern shown in FIG. **3A** is the image the patient sees (1) with a reference image which does not include a separate fixation target while (2) the measurement beam **18** (to be discussed subsequently) is turned off or blocked. We prefer to have the patient adjust the focus of the annulus **53** at the beginning of the measurement process so that it appears sharply defined to the patient. This adjustment of the focus of the annulus **53** is to minimize the effect of any existing refractive errors on the measurements to be taken.

This adjustment to sharp focus may be done manually by the patient adjusting the position of the collimating lens **64** or the position of the reference image source **52** with respect to the position of the collimating lens **64**. Alternatively, it may be done under electronic control by the patient manipulating a joy stick **74** which is connected to a control system **80** which then, in turn, controls the position of either the collimating lens **64** or the reference image source **52**, and/or other components of the reference portion of the system. As a further alternative, the adjustment may be done by the ophthalmologist in response to responses from the patient.

The eye is generally properly aligned with respect to the optical axis of the refractometer when the patient is "looking at" the reference pattern.

With these preliminary adjustments completed, the system is ready to perform a refraction on the patient's eye.

A projection portion **10** of the refractometer **8** comprises a point light source **12** which may preferably be a light emitting diode (either an incoherent diode or a laser diode, as may be preferred).

For this subjective refractometry system, the light source **12** provides a beam of visible light which the patient can see in order to make the decisions and/or adjustments required in the process of performing the refraction measurements.

The position of the light source **12** is controlled by an impingement orientation imposer **20** which operates under the control of the control system **80**. A light source **12** should be disposed at a distance from orientation imposer **20** which renders its light rays substantially parallel at the angle imposer. The light source **12** may be mounted on an X-Y table or stage **22** or any other mechanism which is suitable for shifting the position of the light source in the X-Y plane in the FIG. **1** and **2** illustrations. The X-Y stage **22** should be capable of providing accurate, repeatable small changes in the position of the light source **12** in a manner in which the control system **80** is accurately informed of the actual position of that light source. The light emerging from the light source **12** passes through a lens system **24** which focuses that light into a beam which is focused in the focal plane of the lens system **24**. This focus of the beam to a point in the focal plane is provided independent of the setting of the X-Y stage. As an alternative to movement of the light source itself, the position of the light source may be fixed with the light from the light source being reflected by a galvanometer mounted mirror whose orientation is controlled by control system **80** to provide an effect like that produced by moving the light source in the plane in which the X-Y stage is disposed in FIG. **1**.

After passing through the lens system **24**, the light from light source **12** passes through a position shifter **30** whose function is to control the location of the measurement point on the cornea. In the illustrated embodiment, the position shifter **30** comprises an opaque member **32** whose position in the X-Y plane is controlled by control system **80** via a position drive system **36** which may be another X-Y stage. The opaque member **32** has a single, small aperture **34** therein. In FIG. **1**, the full pattern of the measurement light beam is illustrated as though member **32** were transparent. FIG. **2** illustrates

a beam pattern present in the system during actual use, i.e. with the member **32** being treated as being opaque except for its aperture **34**. As will be observed, only a portion of the light from light source **12** passes through the aperture **34** to comprise the beam **18** (FIG. **2**) with the remainder of the light being blocked by the member **32**. In a manner to be discussed subsequently, the position of the aperture **34** controls the location of the measurement point on the cornea. The size of the aperture **34** also controls the size of the portion of the cornea which constitutes a measurement point, that is, the size of the portion of the cornea whose refractive characteristics affect the data at that measurement point. The measurement beam at the cornea is preferably small in diameter compared to the area of the dilated pupil (also referred to as the active portion of the cornea) and preferably has a diameter of about 0.5 to 1 mm or less (about 1/10 to 1/5 of the diameter of the dilated pupil). The dilation of the pupil may be as a result of dark adaptation or medication or other causes. Dilation of the pupil is not essential, but in absence of dilation, measurements are limited to that portion of the corneal surface through which light of the measurement beam can reach the active retina. Such restricted data limits the quality of the correction which can be provided.

After passing through the aperture **34**, the light passes through the focal plane of the lens system **24** at a point whose location is determined by the position of the aperture **34**. Thereafter, the light beam expands until it reaches the collimating lens **14**. The collimating lens **14** is positioned with its focal plane coincident with the focal plane of lens system **24** and with its focal point **16** coincident with the focal point **29** of the lens system **24**. Upon emerging from the collimating lens **14**, the light beam is collimated with parallel rays because the incident light beam was focused in the focal plane of the collimating lens **14**. This narrow beam **18** of parallel light rays (FIG. **2**) then passes through the beam splitter **68**. The beam splitter **68** is not a necessary part of the projection portion **10** of the refractometer, but is present to combine the measurement beam **18** and the reference image **53** into a single image as seen by the eye. The measurement beam enters the eye via the cornea **42** at the selected measurement point and is refracted by the cornea which provides much of the eye's refraction. Thereafter, the measurement light beam is further refracted by the lens **46** of the eye and finally strikes the retina **48** of the eye.

The position shifter **30** and the measurement surface (cornea **42**) of the eye **40** are positioned with respect to the collimating lens **14** so that they are at conjugate surfaces. In general, conjugate surfaces, are paired surfaces associated with a lens. A characteristic of conjugate surfaces for a lens is that any light passing through a given point in the first conjugate surface (on the first side of the lens) will pass through the corresponding or conjugate point in the second conjugate surface (on the second side of the lens). This is true independent of the light's orientation at the first conjugate surface, so long as that light passes through the lens rather than passing beyond its outer edge. Specifically, if the member **32** and the cornea of the eye are disposed on opposite sides of a collimating lens and each is positioned twice the collimating lens' focal length from the collimating lens, then the member **32** and a tangent plane to the cornea (perpendicular to the axis of the projection system) are conjugate surfaces. Consequently, any light passing through an aperture **34** in the member **32** will also pass through the corresponding measurement point on the cornea of the eye. It is in this manner that the position of the aperture **34** determines the location of the measurement point.

The direction of propagation of (also referred to as the orientation of) the measurement beam where it strikes the cornea is determined by the direction or orientation of the measurement beam at the focal plane of the collimating lens. For a properly configured refractometer, if the orientation imposer **20** is set so that the rays emerging from the lens system **24** are focused above the axial focal point **16** of collimating lens **14** (that is, angled upward), then the light rays emerging from collimating lens **14** are disposed parallel to each other, but angled downward at a corresponding angle. If the orientation imposer **20** is not imposing a deflection on the light beam, the light rays emerging from the lens system **24** are focused at the axial focal point of collimating lens **14** (that is, the light rays are parallel to the optical axis), then those light rays are disposed parallel to the axis of the optical system when they emerge from collimating lens **14**. If the orientation imposer is set so that the light rays emerging from the lens system **24** are focused below the axial focal point **16** of collimating lens **14** (that is, angled downward), then those light rays emerge from collimating lens **14** angled upwards relative to the axis of the optical system. As a result, for these three conditions, the light rays at the corresponding measurement point on the cornea are traveling, respectively, downward, parallel to and upward with respect to the optical axis. It will be understood that this type of relationship applies also to beams which are angled relative to the YZ plane, the YZ plane being the plane of the paper in the drawing. In all cases, the beams will impinge on the cornea at the same point because the collimating lens **14** conjugates points on member **32** at the cornea, i.e. it focuses an image of the member **32** onto the cornea. This ability of the imposer to control the orientation at which the light ray impinges on the cornea surface without changing the position where it meets the cornea is important in this technique for measuring the refraction of the eye as is described hereinafter. The impingement orientation or direction is set relative to the optical axis of this refraction instrument (i.e., it is *not* the angle of incidence of the beam on the cornea, that is, it is *not* measured relative to the normal to the cornea surface at the measurement point).

It will be recognized that if the aperture **34** in the member **32** were large enough, the entire active portion of the cornea would be illuminated by the measurement beam. The small size of the aperture **34** serves to block any portion of the light beam emerging from the lens system **24** which would strike the cornea outside the desired measurement point and has no effect on the orientation of the measurement beam at the cornea for a properly focused beam emerging from the lens system **24**.

At a measurement point where the eye exhibits refractive error, a narrow beam of light oriented parallel to the optical axis of the refractometer does not get refracted to the fovea centralis, but rather is refracted to some other location. However, there is another orientation for a narrow light beam at that measurement point which results in the beam being refracted to the fovea centralis. The difference in orientation of these two beams is a measure of the present refractive error at that measurement point. It will be recognized, that the orientation of that off-orientation beam is defined by its

angle with respect to the optical axis of the refractometer system in the Y-Z plane and its angle with respect to that optical axis in the X-Z plane.

For a measurement beam which is oriented parallel to the optical axis of the refraction system at a measurement point where the eye exhibits refractive error, the image seen by the patient will appear in some fashion like that illustrated in FIG. 3B in that the image of the measurement beam **18** will not be centered in the center of the blank (nonilluminated) disk in the middle of the annulus **53**. With the joystick now connected to control the position of the light source **12** by controlling the X-Y stage **22** (or mirror, if used), the patient manipulates joystick **74** to bring the image of the measurement beam **18** into the center of the annulus **53**, as illustrated in FIG. 3C. As is known from target rifle shooting, the human eye and mind together can determine when a small disk is centered within the open center of an annulus with great accuracy. It is for this reason that the annulus **53** is a preferred reference pattern for this subjective refraction measurement. When the patient concludes that the image **18** is centered in the annulus **53**, the patient presses the joystick button **76**. At that point, the control system records or stores the position of the X-Y stage **22** as the measured data for that measurement point. The recorded information may be the physical positioning of the X-Y stage (or mirror or other orientation control structure) or the beam angles in the X-Z and Y-Z planes which result from that position or any other appropriate data. Recording that data completes the process of measuring the refraction of the eye at that measurement point. The control system **80** may be considered as a means for storing data representative of the position and/or orientation of the measurement pattern when said measurement pattern is in the desired relationship centered within the annulus **53**. The control system **80** may also be considered as a means for providing data indicative of the refraction of the eye. The control system **80** then causes the position shifting drive system **36** to shift the member **32** to place the aperture **34** in a new location which corresponds to the next desired measurement point. Once again, the patient manipulates the joystick to center the image **18** in the annulus **53** and presses the joystick button when it is centered.

Use of this reference pattern measurement beam positioning technique minimizes the problem of accommodation because the bulk of the image perceived by the patient remains fixed throughout the measurement process because no lenses are substituted in front of it and only the initial position of the measurement beam changes from measurement point to measurement point.

This process is repeated at each desired measurement point on the cornea until all of the desired measurement data has been taken. This measurement process can include repeating measurements at each measurement point more than once in order to ascertain that the data is accurate, or at least repeatable. Further, substantially identically data for the same measurement point taken at different times provides assurance that the eye was still in the same location and orientation at the time of the repeated measurements as it was at the time of the original measurement. Several substantially identical measurements at each measurement point ensure that the eye has remained stationary during the measurement process and that the data is therefore valid.

One advantage with this subjective system is that the process of making the measurement can help in obtaining and retaining a child's attention by presenting it as being like a video game in which the goal is to center the measurement beam spot in the central disk of the reference pattern.

For use with a non-cooperative patient, an objective, automatic refractometer is preferred. Such an objective, automatic refractometer system **108** in accordance with the present invention is illustrated in a perspective, stylized view in FIG. **4** and in a side view as an optical diagram in FIGS. **5** and **6**. Automatic refractometer system **108** comprises a projection portion **110**, a sensing portion **150** and a control system **180**. In both FIGS. **4** and **5**, the full pattern of the light beam is illustrated as though the scanning disk **132** within the projection portion **110** were transparent. FIG. **6** illustrates a beam pattern present in the system during actual use, i.e. with the scanning disk **132** opaque except for its scanning apertures.

The autorefractometer **108** comprises a light source **112** which provides a narrow collimated beam of light having a frequency to which the components of the eye in front of the retina are transparent and to which the retina is at least partially reflective or scattering. Thus, this light source may preferably be a laser which emits visible, UV or infrared radiation. In this specific embodiment, the laser beam is preferably vertically polarized. The beam from this laser passes through beam impingement orientation imposer **120** which may be an acoustic/optical (A/O) scanner **122** in combination with a lens system **124**. In accordance with control signals applied thereto, the scanner **122** is capable of deflecting the angle of the beam in both the vertical and horizontal directions simultaneously. Other two dimensional beam deflectors such as galvanometer mounted mirrors may also be used.

The light beam emerging from (A/O) scanner **122** passes through the lens system **124** which is shown in this schematic illustration as being a telescope including lenses **126** and **128**. This beam of light, when it emerges from the lens **128**, is converging toward a point in the focal plane of the lens system **124**, independent of the selected measurement beam orientation.

A position shifter **130** comprised of a scanning disk **132** is positioned in the path of the light beam emerging from the orientation imposer for the purpose of establishing the position of the measurement point on the cornea. This is done by restricting the light beam to a small cross-section (narrow beam) (FIG. **6**) which is appropriate for making the desired measurements of the refraction of the eye. The location of the aperture which narrows the beam controls the location in which this narrow light beam strikes the cornea. This narrowed laser beam is preferably small in diameter compared to the area of the optically active portion of the cornea and preferably has a diameter of about 0.5 to 1 mm or less.

This scanning mechanism (rotating disk **132**) scans the measurement beam or measurement point along the surface of the eye in a predetermined pattern. However, we use "scan" as a general term which is free of implications as to the particular type of scan pattern employed. Depending on the scanning mechanism employed, the measurement point may be scanned in a continuous manner or in steps or jumps separated by pauses between such movements along the surface of the eye. Such pauses may be uniform or of varying length. The scan pattern may follow a predetermined path (such as a raster scan), may follow a random path or a path

which is dependent on the results of previous measurements, or any other desired path.

After passing through the scanning disk **132**, the light comes to a point in the focal plane of lens system **124**, after which the light beam expands until it reaches a collimating lens **114** having its focal plane coincident with the focal plane of lens system **124** and its focal point **116** coincident with the focal point **129** of lens system **124**. Upon emerging from the collimating lens **114**, the light beam is collimated with parallel rays because the incident light beam was focused in the focal plane of the collimating lens **114**.

This narrow beam of parallel light rays then passes through a beam splitter **168** which preferably passes vertically polarized light and reflects horizontally polarized light. Substantially all the light in the beam passes through the beam splitter, because none of the operations performed on the beam has the effect of changing its polarization. Beam splitter **168** is part of the sensing portion **150** of the system rather than the projection portion **110**. The light beam is refracted by the cornea **142** of the eye **140**, is further refracted by the eye's lens **146** and finally strikes the eye's retina **148**.

The scanning disk **132** and the measurement surface (cornea **142**) of the eye **140** are positioned with respect to the collimating lens **114** so that they are at conjugate surfaces.

The light beam in FIGS. **4** and **5** subtends, encompasses or spans the entire active part of the cornea at all useful beam impingement orientations in order to ensure than any desired beam impingement orientation (relative to the optical axis) can be provided at any given measurement point.

What is actually present at the measurement surface or cornea is an image of the scanning disk **132**. However, since only the scanning aperture **134** (about 0.5–1 mm in diameter) in the scanning disk transmits light, the rest of the scanning disk's image is dark and we observe the 0.5–1 mm diameter light beam from hole **134** as though it were the entire image.

Together, the position shifter **130** (scanning disk **132**) and the orientation imposer **120** (scanner **122** and lens system **124**), under the control of the control system **180** independently control both the position at which the beam strikes the cornea and the impingement orientation at which it strikes the cornea. This capability is of general utility and not restricted to this particular application.

The measurement region of the cornea at which the measurement beam is directed may be at any desired location on the cornea. For perfect refraction, a measurement beam which is disposed parallel to the visual axis should impinge on the retina at the fovea centralis. If the measurement beam strikes the eye in the center of the fovea centralis, then the eye's refraction at this measurement point is considered optimum.

A fraction of the light which strikes the retina is scattered by the retina. This scattered light leaves the retina in all directions. The portion of this scattered light which strikes the eye's lens **146** is refracted, continues on toward the iris **144** (which blocks any portion outside the pupil), continues on to the cornea **142** where further refraction takes place as the light emerges from the cornea into the ambient atmosphere. On emerging from the cornea, the rays of light will be parallel for an eye having optimum refraction. This emergent beam of light then enters the sensing system **150** by striking the surface of the beam splitter **168** which reflects the horizontally polarized portion of that light toward a photodetector **172**. The beam splitter **168** is preferably chosen to pass one state of polarized light and to reflect the other polarization state. The polarization of the projected laser light is chosen to be in the "pass" state (vertical in this example) so that substantially all of that projected light beam will pass through the beam splitter and strike the cornea. Light reflected off the cornea and the eye's lens back toward the beam splitter will primarily pass through the beam splitter and only be reflected weakly by the beam splitter because reflections off a smooth surface at relatively small angles with respect to the surface normal are by nature so-called Fresnel reflections in which the reflected light is strongly polarized in the same direction as the incident light. However, the light scattered off the cells of the retina is partially-to-completely depolarized and thus will be significantly reflected by the beam splitter. In this way, a clean image of the measurement beam spot on the retina can be obtained without clutter from the reflections off the cornea and lens of the eye. Any remnants of clutter from the Fresnel reflections can be further filtered by a polarization filter **164**. The remaining light is then focused on the photodetector **172** as an image of the retina by a retina imaging lens **166**.

This interaction of the measurement beam with the eye is shown schematically in the optical diagram in FIG. **6**. The incident beam is narrow and collimated because of the nature of its production. In contrast, the light pattern emerging from the eye is substantially wider than the incident beam because of the scattering at the retinal surface which produces that beam.

The position photodetector **172** is preferably composed of four separate quadrants 172_{Q1}–172_{Q4}. Such a quadrant detector provides an output signal indicating which quadrant or quadrants of the detector have the most light impinging on it or them and, therefore, in which quadrants of the detector the image of the illuminated spot on the retina is predominantly located. The control system **180** processes the output signals from the quadrant detector **172** and generates control signals for the orientation imposer **120** which set an orientation which brings the beam spot on the retina to a reference point on the retina. The origin of the quadrant detector is placed so that the image of the retina reference point is centered there. This reference point is the point at which it is desired to have parallel-to-the-axis rays focus. The reference point is normally the fovea centralis.

A reference point other than the fovea centralis may be selected. However, it is preferred in most cases to select the fovea centralis as the reference point, since that ensures that the refractive correction determined will in fact result in focusing an image disposed on the optical axis at infinite distance at the point of maximum visual acuity. During measurements on a cooperative patient, this reference point is preferably established at the fovea centralis by asking the patient to fixate on the measurement light beam when it is on axis and its set impingement orientation is zero. The quadrant detector is then shifted so that the image of the beam spot on the retina is centered at its origin so that its output indicates that the beam is centered at the reference point.

FIG. **7** is a diagram illustrating an incident ray $\vec{A}$ disposed parallel to the optic axis which is refracted by the cornea at a measurement point **192** into the beam $\vec{B}$ which strikes the retina below the fovea centralis and an incident ray of light $\vec{C}$ disposed at an angle to the optic axis which is refracted by the cornea at measurement

point **192** into the beam $\vec{D}$ which strikes the retina at the fovea centralis. $\hat{M}$ is the normal to the tangent plane **96** at the measurement point **192**. How small a cross-section the measurement beam needs to have depends in part on the desired measurement accuracy, in part on the focusing limits of light and in part on how rapidly the refractive characteristics of the eye change with position. The size of the measurement region is determined by the size of the measurement beam. For a small enough measurement beam, the measurement region may be called a measurement point. The term "measurement point" is also used as the point at which the center of the measurement beam is directed, independent of its size. For refractions which vary slowly with the position, a larger beam cross-section can provide more accurate data because the diffractive nature of light allows a larger beam to be focused into a tighter spot on the retina. Thus, reducing the measurement beam's cross-section only improves measurement accuracy up to a point. As illustrated in FIG. **7**, the angle of the ray of light $\vec{C}$ is substantially displaced from the optical axis for drawing clarity. It is this deflection (in two dimensions) of the incident beam from parallel to optical axis which provides the data which enables the refraction of the eye to be determined.

Where the visual axis is treated as the Z-axis of an XYZ coordinate system, the XY plane can be located tangent to the cornea at its intersection with the visual axis. The orientation of the measurement beam may be uniquely specified by specifying its angle in the XZ plane relative to the normal $\hat{M}$ and in the YZ plane relative to the normal $\hat{M}$.

Conceptually, a parallel-to-the-axis measurement beam is directed at each measurement point on the cornea and the general direction of the resulting bright spot's displacement from the fovea centralis is determined from the output of the quadrant detector. In response to that output signal, the control system **180** sets the orientation imposer **120**'s A/O scanner **122** to deflect the orientation of the beam to cause the bright spot to move closer to the fovea centralis. When that bright spot is centered in the fovea centralis, it is centered in the quadrant detector whose output signal then indicates that all the quadrants are receiving substantially equal illumination at which point the deflection angles (vertical=YZ-plane and horizontal=XZ-plane) imposed by the A/O scanner **122** are recorded along with the location of the measurement point on the cornea as a data point for a corneal map of the eye's refractive characteristics.

Where a quadrant detector is used to detect the location of the bright spot on the retina, the parallel-to-the-axis beam produces no quantitative data, unless the bright spot for such a beam is centered in the fovea centralis. Consequently, in the interest of system simplicity, speed and elegance, an initial beam or ray oriented parallel to the refractometer's optical axis is used only with the first data point of a scan (as a default position). Thereafter, the measurement beam deflection angle is maintained at its deflected value as the measurement point is scanned across the eye and the quadrant detector's output is used as a feedback signal to adjust the A/O scanner angle to maintain the bright spot centered in the quadrant detector as the measurement point (beam) moves. Thus, this system operates on the null principle in which feedback control signals are used to maintain the bright spot centered in the quadrant detector with the control signals themselves providing the measurement data, rather than in an open loop manner in which the position of the bright spot must be continually measured, with the measured position of the bright spot being the data. Since measuring the position of the bright spot is a time consuming process, the null system of this invention can operate much more rapidly than an open loop system. Further, it provides substantially increased measurement accuracy over that provided by an open loop system. Consequently, this system can accurately measure the refractive characteristics of the eye in almost unbelievably short times.

The scanning pattern across the eye with use of the scanning disk **132** is illustrated in FIG. **8**. In this pattern, each scan line is scanned in the same direction as successive apertures in the disk come into alignment with the laser beam. Successive scans are all in the same direction and the size of a measurement point **192** is determined by the size of the apertures **134**. Each aperture **134** in the scanning disk controls scanning across a strip of the cornea which, although actually an arc, is essentially straight because of the small portion of the scanning disk subtended by the light beam from the lens system **124**. The individual scan lines are illustrated as being spaced apart vertically for drawing clarity. It will be understood that in an actual system, they may be spaced apart, just contiguous or overlapping, depending on the positioning of the apertures **134** in the scanning disk **132**.

With a constantly rotating scanning disk **132**, the locations of measurement points along the scan line for a given hole in the disk is determined by the point in time at which the data is taken. Acoustic/optic scanners, quadrant detectors and electronic systems, are available which are fast enough to institute a change in the impingement orientation of the measurement beam and determine the effect of that change in less than 10 microseconds in this null system. This makes it possible to take measurements at a rate of one every 30 microseconds if no more than three orientation adjustments are needed per measurement point on the average. One measurement point every 30 microseconds corresponds to 100 measurement points in 0.003 second. Once a given aperture **134** in the scanning disk has scanned past the active area of a cornea, the next lower aperture in the scanning disk comes into the beam from the telescope and starts the next higher scan across the cornea. With the scanning disk rotating at 18,000 rpm, a complete revolution of the scanning disk takes 0.0033 second. Consequently, the entire scanning of the eye can be done in 0.0033 second. This total scanning time is fast enough that the eye does not accommodate (that is, refocus) in response to the stimulation provided by the measurement light beam. At a nominal disk speed of 1,800 rpm the entire scan pattern would be completed in 0.033 second. Preferably, a map having from about 25 to 100 data points is generated in order to provide detailed information on the existing refractive characteristics of the eye. More or fewer data points may be used as may be preferred. A scanning disk **132** may be used in the FIG. **1** system **8** for measurement point control, provided that the light source **12** is pulse or flashed in synchronism with the rotation of the scanning disk so that the light source is only on when the aperture **134** is positioned at the measurement point at which data is presently being taken.

For scan line sweeps of the type illustrated in FIG. **8**, the orientation which results in the bright spot being centered in the fovea centralis is expected to vary rela-

tively smoothly with position along the scan line for typical corneal configurations. Abrupt changes are expected only with a relatively rough surfaced (injured or diseased) corneas. Thus, the setting of the A/O scanner **122** deflection angle will normally vary in a smooth manner which requires only minor variations in the deflection setting to keep the bright spot centered in the fovea centralis as the measurement point moves across to the eye.

A major advantage of this null scanning technique is that the control system **180** operates essentially as a negative feedback loop which continuously adjusts the A/O scanner **122** to keep the bright spot centered in the quadrant detector (at a null). The use of the scanning disk which scans across one "strip" of the cornea at a time provides the ability to take data points as close together along that strip as may be considered desirable. It is only at the transition between different apertures in the scanning disk (which control the scanning across different strips of the cornea), where a significant abrupt change in orientation required from the orientation imposer **120** should occur. However, the orientation imposer setting for the beginning of one scan line can be expected to be similar to the orientation for the beginning of the previous scan line. Consequently, if desired, during the "dead" time between scan lines, the scanner can be switched from its end-of-the-first-scan-line value back to its beginning-of-the-first-scan-line value in anticipation of the beginning of the second scan line in order to minimize feedback loop settling time.

At the beginning of each scan line in FIG. **8**, the measurement beam is preferably positioned on the cornea in a location where it strikes the iris rather than passing through the pupil. The iris scatters this incident light in a manner quite similar to that in which the retina scatters the incident light. Consequently, even with the use of a polarized system, substantial light will reach the quadrant detector while the beam is impinging on the iris. The intensity of the light striking the quadrant detector will be substantially greater while the beam is striking the iris than it is when the beam is striking the retina. This is (1) because of the small portion of light which is scattered by the retina rather than being absorbed and (2) because of the relatively small solid angle of the light scattered by the retina which can reach the quadrant detector as compared to the solid angle for which light scattered by the iris can reach the photodetector.

While this relatively high intensity light striking the quadrant detector when the beam is on the iris might initially seem to be a problem, it is actually a benefit in that it enables automatic alignment of the system and automatic tracking of the alignment of the system. In particular, the topmost aperture in the scanning disk should result in the beam striking the iris for the full scan. The first aperture for which the measurement beam passes through the pupil will have a brief period of low intensity light impinging on the photodetector **172**. During that time, useful data will be taken. As successive apertures scan the eye, the period of low intensity light on the quadrant detector will increase until the scan which crosses the center of the eye. Thereafter, the period of low intensity light on the quadrant detector will decrease with successive scans until there is no period of low intensity. For proper alignment, the "circle" of beam position for which low intensity illumination strikes the quadrant detector should be centered in the scan pattern. We say "circle" because although the pupil is often thought of as being circular, many pupils are not perfect circles. Consequently, proper alignment of the system can be checked after the data is taken. Further, while the data is being taken, any unexpected substantial offset in the point at which the low intensity portion of the scan begins or ends is an indication that the eye has moved relative to the measurement system. Thus, proper alignment is automatically determined and checked.

Proper alignment can be checked in the initial stages of the scanning process if, instead of the aperture pattern illustrated in FIG. **4** in which successive apertures are disposed on a single inwardly curving spiral, the apertures are alternated between the outermost aperture and the innermost aperture working successively toward the middle aperture. In that way, the first aperture scans the bottom of the cornea, the second aperture scans the top of the cornea, the third aperture scans the next strip toward the center of the eye at the bottom of the cornea, the fourth aperture scans the next strip toward the center of the eye at the top of the eye and so forth. In this manner, for a properly aligned system with a circular pupil, the system is properly aligned when after the first scan in which the beam passes through the pupil, every following scan of the beam passes through the pupil. If that does not occur, then the eye is misaligned with respect to the measurement system and realignment is desirable prior to taking the measurements.

During the time the quadrant detector output is large because the measurement beam is striking the iris, the beam impingement orientation does not need to be adjusted, since the beam cannot strike the fovea centralis and thus its image cannot be centered in the quadrant detector. Pinning of the orientation adjustment portion of the electronics at a maximum deflection angle in an attempt to center this "image" is preferably avoided by including a threshold detector in the orientation adjustment portion of the control system to freeze the orientation for quadrant detector outputs in excess of the threshold value.

Control system **180** serves many functions in this system. It provides appropriate control signals to the orientation imposer and the position shifter, it receives the signals from the position sensor, establishes the locations of the measurement points, determines the impingement orientation for each measurement point, stores the measurement values for subsequent use or output and so forth. This storage is preferably in electronic form, but may also be provided in paper or other forms. The control system can also perform the data reduction which is discussed hereinafter in connection with determining appropriate corrections for the measured eye and so forth.

One disadvantage of the system **108** of FIG. **4** is the fact that it is rather inefficient in the use of laser power. In particular, the laser beam which emerges from the hole in the scanning disk is a small fraction of the overall area of the beam striking the disk. The resulting waste of laser power is of concern from an efficiency point of view. Also of possible concern is the fact that if the scanning disk were, for some reason, removed from the apparatus and the apparatus were turned on with a patient's eye in the measurement position, the full laser power would be incident on the eye. That could cause damage to the eye.

These potential disadvantages of the FIGS. **4–6** embodiment of the invention are avoided in accordance

with an alternative embodiment **208** illustrated in FIGS. **9–11**. In the system **208**, reference numerals which are higher by **100** than corresponding reference numerals in the system **108** identify portions of the system which perform substantially the same function as their corresponding system **108** components. In system **208**, the sensing portion of the system, the control system and the internal components of the eye are omitted for drawing clarity. It will be understood that in FIGS. **9–11**, they would be similar to those shown in FIGS. **4–6**. In FIG. **9**, the cornea **242** of the eye is positioned at twice the focal length f of the collimating lens **214** from the collimating lens. The beam splitter **268** serves the same purpose as the beam splitter **168** in system **108**. To the left of the collimating lens **214**, an orientation imposer **220** is positioned at twice the focal length of the collimating lens from the collimating lens and thus is conjugate to the cornea. Also on the left-hand side of the collimating lens is a position shifter **230** which is positioned at the focal plane of the collimating lens and preferably centered at the focal point of the collimating lens. The laser **212** provides the measurement light beam.

Suitable devices for use as the orientation imposer **220** are acoustic/optic scanners, galvanometer mounted mirrors or other devices. Suitable devices for use as the position shifter **230** are galvanometer mounted mirrors or other devices. Acoustic/optic scanners are not suitable at this time because of their requirement that the incident beam be disposed strictly on and parallel to their axis. It will be recognized that where galvanometer mounted mirrors are used to control the deflections which select the orientation or position, the optical axis will not be a straight line, but will be reflected at each of the mirrors. However, the effect will be similar. The orientation imposer **220** and the measurement surface (cornea) may be positioned at any conjugate locations for which the distance from the collimating lens is greater than f, so long as the angled beam emerging from orientation imposer **220** passes through the two-dimensional position shifter **230** in its active region.

FIG. **9** illustrates the system with the orientation imposer **220** set to introduce a deflection angle while the position shifter **230** is set to an on-axis setting (no deflection). It will be noted that the light beam in the deflected position still strikes the cornea at the same point as it would without the orientation imposing deflection because of the conjugate locations of the orientation imposer **220** and the cornea **242**.

In FIG. **10**, the system is illustrated with the orientation imposer **220** set to a parallel-to-the-axis setting (no deflection) and the position shifter **230** set to position the beam at a desired, off-axis, measurement point on the cornea. It will be noted that the position at which the beam strikes the cornea is displaced from the optical axis by a distance in the Y-direction of $f\tan\nu$, where ν is the angle of deflection in the YZ plane introduced by the position shifter **230**. This is simply the focal length f length of the collimating lens times the tangent of the angle of deflection set by the position shifter. This geometric formula is well known. This position offset is a result of the deflection introduced by the position shifter **230** placing its emergent beam at an orientation which causes that ray to be coincident with the direction of an undeflected ray from a point in the left-hand 2f plane which is that distance ($f\tan\nu$) below the optical axis (a point which the collimating lens conjugates to the corresponding conjugate point at the opposite 2f plane (i.e. at the cornea)). This is true for all angles ν which do not deflect the beam outside the collimating lens. While in FIG. **10** the illustration is for the YZ plane, it will be understood that for a position which is not in the YZ plane, this same diagram applies for that position's component in the YZ plane since that component is established by the Y deflection imposed by the position shifter **230**. In that situation, there would a be a similar diagram which would apply in the XZ plane for the component of the beam's position in the XZ plane which is controlled by the X-direction deflection established by the position shifter **230**.

In FIG. **11**, the system **208** is illustrated with both the orientation imposer **220** and the position shifter **230** set to provide deflections. In particular, the orientation imposer **220** is set to produce the same deflection as in FIG. **9** and the position shifter **230** is set to provide the same deflection as in FIG. **10**. It will be noted that the position at which the measurement beam strikes the cornea is unchanged by the addition of the orientation deflection and the orientation at which the measurement beam strikes the cornea relative to the optical axis of the projection portion **210** of the system (the beam's relative orientation) is unaffected by the position displacement. Consequently, the position of the measurement point and the orientation of the incident beam are independently controlled.

System **208** has the advantage that the entire laser beam is used in the measurement process. Consequently, system **208** is much more efficient in its use of laser energy than system **108** is and reduces or eliminates the risk of exposure of the eye to an unintended high intensity of light. Further unlike the system **108** which uses a scanning disk, the position setting for the system **208** may be randomly controlled in any desired manner since the position is controlled by the position shifter **230** which can be a random access device.

It will be noted that where a galvanometer mounted mirror is used to produce the deflections which establish the position of the beam, then the position deflection may be slightly displaced from the focal plane of the collimating lens for some angle deflection settings. Such variations can be compensated for by a correction table which once measured and determined, remains invariant for the corresponding orientation and position deflection settings. It will be further recognized that the significance of any offset from the focal plane depends in part on the focal length f of the collimating lens. Where the focal length of the collimating lens is relatively long, such deviations from the focal plane will have a smaller effect than where the focal length of the collimating lens is quite short. It will be recognized that other small aberrations may be present in either mirror or acoustic/optic scanner systems, but that in the detailed engineering design of such systems, those aberrations can be measured and compensated for if they have an undesired effect on the measurement accuracy.

While the system **208** is preferably operated in the same manner as has been described for the system **108**, that is by selecting a measurement point and adjusting the impingement orientation of the measurement beam to cause that beam to be refracted to the fovea centralis, it is also conceivable (in either system) to instead set an impingement orientation and then map the locus of positions for which that deflection angle results in the beam being centered in the fovea centralis. However, such a procedure is not at this time preferred, unless it is being used to check measurements of refraction errors

which have already been performed such that the expected locus of such points is already known and thus may be swept in an efficient manner. Alternatively, in a fixed orientation scan mode, the quadrant in which the bright spot is located can be determined and recorded for each measurement point as a means of expediting the process of finding the optimum orientation for each measurement point by selecting orientations for subsequent scans which should approach optimum for selected measurement points at which optimum values have not been determined.

While it is preferred to place the beam splitter between the collimating lens **114** or **214** and the eye, it should be recognized that the beam splitter can be placed in other locations (such as between the positioner and the collimating lens) as long as it still achieves its purpose of deflecting light emerging from the eye toward the position sensing photodetector.

Both subjective and objective embodiments of a refractometer in accordance with the present invention have been illustrated and described with corresponding orientation imposition and control systems and techniques. It will be recognized that these various techniques are not limited to use with the particular type of system (subjective or objective) in which they have been disclosed, but may be used in the other type as well.

While separate objective and subjective embodiments have been illustrated and described, both embodiments may be incorporated in the same refractometer by providing for substitution of a reference generator for a sensor system or vice versa. Alternative or combined projection portions may also be employed.

In order to determine how to correct the refractive errors determined during the measurement process, the existing contour of the cornea or lenticule is measured separately using an instrument such as the CMS Keratometer produced by Computed Anatomy, Inc. The angle of a normal to the corneal surface at each measurement point (perpendicular to a plane tangent to the cornea surface at that measurement point) or equivalent contour data is determined and stored in association with its measurement point. For each measurement point, the desired change in refraction obtained from the current invention and the orientation of the existing normal to the surface-to-be-shaped obtained from the keratometer may be used to determine the change in the surface configuration required to cause a light ray disposed parallel to the optical axis and striking the cornea at the measurement point to impinge on the retina in the fovea centralis.

The determination of the required surface angle change is made using Snell's law, the index of refraction (n_1) of the material on the side of the measurement surface away from the eye (typically 1.0003 for air) and the index of refraction (n_2) of the material on the side of the measurement surface toward the retina (typically 1.34 for the cornea) in combination with the measured beam impingement angle for a measurement light beam striking the fovea centralis and the angle of the normal to the existing surface at the measurement point. The relationships used in determining the angle of a normal to the surface of the cornea which provides proper refraction at a measurement point are illustrated in FIGS. **12A** and **12B**.

During the initial portions of the following discussion, the angles indicated in FIGS. **12A** and **12B** should be ignored. In FIGS. **12A** and **12B**, the surface of the cornea is omitted from the figure for drawing clarity. A plane **96** tangent to the corneal surface at a measurement point **192** has a normal $\hat{M}$. An initial trial beam arrives at the measurement point **192** along the unit vector $\hat{A}$. The unit vector $\hat{A}$ is parallel to the reference incident beam direction which will generally be parallel to the optical axis of the eye and the measurement system. In passing from the air into the cornea, the incident beam is refracted and continues on a path coincident with the unit vector $\hat{B}$, passes through the eye's lens and strikes the retina (neither shown) outside the fovea centralis. With a refractometer in accordance with this invention, an incident vector direction $\hat{C}$ is found which results in refraction of that beam along the vector $\hat{D}$ within the cornea which results in the beam striking the retina in the center of the fovea centralis. Thus, the measurement data recorded for this measurement point is the vector direction $\hat{C}$.

In order to provide corrected refraction, the angle of the corneal surface should be changed to have a tangent plane **96'** in FIG. **12B**. The new tangent plane **96'** has a normal $\hat{N}$ which is displaced from the normal $\hat{M}$ to the existing tangent plane **96**. The new tangent plane **96'** must be chosen so that a beam incident at the measurement point along the unit vector $\hat{A}$ will be refracted by the cornea along the unit vector $\hat{D}$. For derivation of the relationship between the normals $\hat{N}$ and $\hat{M}$, an additional unit vector $\hat{F}$ is shown in FIG. **12B** which represents the direction of refraction of the beam $\hat{A}$ for the general case of a changed normal. The normal $\hat{N}$ which produces proper refraction is found by setting the vector $\hat{F}$ equal to the vector $\hat{D}$.

During the analysis of the changes to be made in the corneal surface, the assumption will be made that the angle of the corneal surface is changed without changing its position. In actual practice, the position change is likely to be small enough that it can be ignored. However, those skilled in geometry will recognize that it is straightforward to include this surface position shift in the relationships developed here by adding a translation to the coordinate system transformation used hereinafter during this explanation. However, such translation is omitted here for simplicity and clarity of the discussion. For simplicity and clarity in the discussion, the relationship between the normals of the uncorrected and a corrected corneal surface will be calculated for the simplified case wherein the surface normals and all the vectors defined above lie in a single plane. This simple case is illustrated in FIGS. **12A** and **12B** when it is assumed that all vectors lie in the plane of the paper. It is also directly applicable to any cornea or portion of a cornea whose anterior surface is essentially cylindrically symmetric about the visual axis through the region of interest and the only refraction changes required preserve that symmetry. This is also a good approximation to the rigorous solution for cases involving moderately asymmetric corneas.

Those readers for whom the derivation of equation (21) below is not of interest can skip to the paragraph containing Equation (21).

Turning now to the derivation of the relationship between the normals in which all vectors and normals are in a single plane, the angle α is the angle of the unit vector $\hat{A}$ from the unit normal vector $\hat{M}$ and β is the angle of the unit vector $\hat{B}$ from the unit normal vector $-\hat{M}$. In this explanation, counterclockwise rotation is taken as positive. Thus, in the illustration both α and β are positive. The air in front of the eye has a refractive

index n_1 and the cornea itself has a refractive index n_2. The relationship between the vectors $\hat{A}$ and $\hat{B}$ are given by Snell's Law as:

$$\sin \alpha = n \sin \beta \quad (1)$$

where

$$n = n_2/n_1 \quad (2)$$

We can solve equation (1) for β in terms of α which yields:

$$\beta = \arcsin[n^{-1} \sin \alpha] \quad (3)$$

During the process of measuring the refraction at measurement point **192**, it is found that a beam in the direction of the unit vector $\hat{C}$ when incident at the point **192** is refracted to strike the retina in the fovea centralis. In passing into the cornea, the beam $\hat{C}$ is refracted into the beam $\hat{D}$. Beam $\hat{C}$ is at an angle χ to the normal $\hat{M}$ and is displaced from the beam $\hat{A}$ by a rotation through an angle ϵ. The angle χ is related to the angles α and ϵ by the following equation:

$$\alpha + \epsilon = \chi \quad (4)$$

The diffracted beam $\hat{D}$ is disposed at an angle δ relative to the normal $-\hat{M}$. In a manner similar to Equation (3), the angle δ may be expressed as:

$$\delta = \arcsin[n^{-1} \sin(\alpha + \epsilon)] \quad (5)$$

Turning now to FIG. **12B**, the angle of the initial trial beam $\hat{A}$ relative to the new surface normal $\hat{N}$ is α' where the new normal $\hat{N}$ is obtained from the old normal $\hat{M}$ by rotation through the angle θ as shown, α' may be expressed as follows:

$$\alpha' = \alpha - \theta \quad (6)$$

it being noted that θ is a rotation in the negative sense in this illustration. The light beam along the unit vector $\hat{A}$ is diffracted by its passage into the cornea along the unit vector $\hat{F}$ which is disposed at an angle ϕ' with respect to the new surface normal $-\hat{N}$. By equation (1):

$$\sin \alpha' = n \sin \phi' \quad (7)$$

substituting for α', yields:

$$\sin(\alpha - \theta) = n \sin(\phi') \quad (8)$$

which may be solved for ϕ' to obtain:

$$\phi' = \arcsin[n^{-1} \sin(\alpha - \theta)] \quad (9)$$

The angle between the desired diffracted beam direction $\hat{D}$ and the normal $-\hat{N}$ is δ' which may be expressed as:

$$\delta' = \delta - \theta \quad (10)$$

The surface normal $\hat{N}$ required to provide proper refraction for this region of the cornea is obtained when the unit vectors $\hat{D}$ and $\hat{F}$ are coincident. Thus, the desired new normal vector $\hat{N}$ is obtained by setting $\phi' = \delta'$ and solving the equations. More particularly,

$$\phi' = \delta' = \delta - \theta \quad (11)$$

or

$$\phi' = \delta - \theta \quad (12)$$

Substituting the value of ϕ' obtained in equation (9) and the value of δ obtained in equation (5) yields

$$\arcsin[n^{-1} \sin(\alpha - \theta)] = \arcsin[n^{-1} \sin(\alpha + \epsilon)] - \theta \quad (13)$$

which simplifies successively to:

$$n^{-1} \sin(\alpha - \theta) = \sin\{\arcsin[n^{-1} \sin(\alpha + \epsilon)] - \theta\} \quad (14)$$

$$\sin(\alpha - \theta) = n \sin\{\arcsin[n^{-1} \sin(\alpha + \epsilon)] - \theta\} \quad (15)$$

For any given measurement point, the values of α, ϵ and n will be known. Consequently, equation (15) can be easily solved for θ which is the desired change in surface angle by methods of graphing, computer analysis or approximation. In an actual measurement system, because of the number of data points in the measurement of a single eye, this analysis will be done by computer in a manner which is straightforward. This equation can be solved explicitly when the arguments of the sin functions are sufficiently small that the approximation:

$$\sin x = x \quad (16)$$

which also implies:

$$\arcsin x = x \quad (17)$$

is valid. It is normally considered that this approximation is valid for arguments of less than 6 degrees. Using equations (16) and (17) to simplify equation (15) leads successively to:

$$\alpha - \theta = n \arcsin[n^{-1}(\alpha + \epsilon)] - n\theta \quad (18)$$

$$(n-1)\theta = n[n^{-1}(\alpha + \epsilon)] - \alpha \quad (19)$$

$$\theta = \epsilon/(n-1) \quad (20)$$

The index of refraction for the cornea is approximately 1.33, thus, the denominator is equation (2) is equal to 0.33 and:

$$\theta = 3\epsilon \quad (21)$$

Thus, the deviation of the new $\hat{M}$ normal-to-the-surface from the old-normal-to-the surface $\hat{N}$ is three times the deviation between the vectors $\hat{A}$ and $\hat{C}$.

While the value $\theta = 3\epsilon$ is only valid for small angles, most refractive errors fall in this range. For those situations in which the refractive errors are larger, equation (15) may be easily solved by computer so long as all of the vectors are disposed in a common plane.

For those situations in which the simplifying assumption that all of the vectors are in a common plane does not hold, a derivation similar to that given above may be done for the general situation where the position of each vector must be specified by its components in two different planes. Where the Z axis of a rectangular coordinate system S is disposed coincident with the normal $\hat{M}$, the vectors are specified by their angles of deviation from the Z axis in the ZX and ZY planes. The new normal $\hat{N}$ is then coincident with the Z' axis of a transformed coordinate system S'. Such a transformation is

straightforward for one of ordinary skill in the arts of geometry including transformations of coordinate systems.

While the method for determining the new desired normal $\hat{N}$ has been derived using simplifying assumptions in order to be tractable in this patent, it will be understood that in a refractometry system employing this invention, all of the data reduction is expected to be done by computer and presumably in software. As such, the required transformations and calculations can be done very rapidly with almost any desired degree of accuracy in order to produce a map of the cornea specifying the desired new normal at each of the measurement points. Alternatively, these calculations may be done once for common values and stored as a look-up table, with resort to detached calculation being reserved for anomalous cases whose values are not in the table.

For clarity and conciseness, the exposed surface of a lenticule which is attached to the eye or the cornea of an eye which has no lenticule attached thereto is referred to as the anterior surface of the eye. It will be understood that by anterior surface of the eye, we mean the exposed surface of the cornea or the lenticule. That anterior surface may or may not have the epithelium present thereover in accordance with the condition being discussed. During measurement of the refractive characteristics of the eye, it is preferred to have the epithelium and tear film present. During shaping of the anterior surface of the eye by laser ablation, it is customary to remove the epithelium before performing the shaping.

Once the desired new normal $\hat{N}$ to the surface has been determined for each measurement point, a new surface contour which will provide those desired normals $\hat{N}$ at each data point may be determined. This may preferably be done beginning at the optical axis of the eye and working outward from there to beyond the visually active portion of the lenticule or cornea.

In determining the new surface contour, experience with the effect of minor deviations from perfect refraction should be taken in to account in determining the optimum surface in terms of vision correction versus the quantity of corneal or lenticule material which needs to be removed. Similarly, where the corneal surface has an indentation in it which is relatively small in area and which would call for removing substantial corneal material over the rest of the cornea to correct the refraction in that small depression, it may be considered desirable to leave that small depression uncorrected. It will be understood that many considerations will go into the ophthalmologist's decision as to how to correct the measured refractive errors and that it is desirable to have the measurement system provide the ophthalmologist with alternative suggestions extending from the limit of safe material removal (if the refractive errors call for such a large correction) to lesser corrections which optimize other criteria such as material removal and so forth.

It will also be recognized that the ideal or optimum correction surface may have substantial local variations with the result that the correction is much more detailed than that provided by merely prism, cylindrical and spherical corrections. Such detailed correction may preferably be provided by the mask controlled laser shaping technique disclosed in related, incorporated by reference, U.S. patent application Ser. No. 07/402,946, entitled, "Laser Shaping With an Area Patterning Mask". Other techniques may also be used. Where it is considered desirable to do so, such as in situations where the correction will be done with eyeglasses or contact lenses, the prism, cylindrical and spherical portions of this correction may be extracted from this data and a new surface contour determined which will provide that correction. Further, for eyeglasses, the measured refractive error can be directly converted to diopters of correction required without knowledge of the existing contour of the cornea. Even in those situations where the correction will be done by shaping of the cornea or a lenticule, it may be desirable to derive prism, cylindrical and spherical corrections and compare them with the more detailed corrective surfaces as part of the process of selecting the actual corrective surface to be used.

Control system **180** may include these data reduction and contour determination functions or they may be separately performed on a different computer which is provided with both the refraction map of the eye and the contour of the cornea.

While the greatest benefit is obtained from the results of using this autorefractometer system by providing spatially resolved correction of the patient's vision or adjustment of the characteristics of other optical systems, it should be understood that prior art corrections which are limited to spherical, cylindrical and astigmatism can be derived from this data and applied in the prior art manner. Such use of this invention takes advantage of its short measurement time, but fails to make use of much of the information it can provide. Nevertheless, such use of the data is within the scope of the invention. Such low order correction information can be extracted from the spatially resolved refractive data by curve fitting procedures. Curve fitting procedures can be used in two dimensions with the fitting of a curve being done simultaneously with respect to the data along a number of different meridians of the eye. Alternatively, 3D or surface fitting techniques may be used as may any other appropriate techniques.

The term measurement surface has been loosely interchanged with the surface of the cornea. This introduces a slight error if the impingement orientation imposer or the position shifter (which ever is disposed conjugate to the cornea) is a plane, whereas, the cornea is curved. However, the distance between the collimating lens **114** or **214** and the cornea **142** or **242** on one hand and between the collimating lens **114** or **214** and the conjugate selector **130** or **220** on the other can be made large enough that any resulting measurement error is insignificant. Alternatively, the conjugate selector could be moved forward and back to maintain it at the same distance from collimating lens as the measurement point on the cornea.

While the preferred retina position detector in this embodiment is the quadrant detector **172**, other detection techniques may be used. These include the use of a two dimensional array of light sensitive devices to determine the actual spot at which the bright spot is located. Other detectors, and other measurement techniques may also be employed for measuring the eye's refraction as a function of position along the surface of the cornea.

While the description of the use of the apparatus **108** of FIG. **4** and apparatus **208** of FIG. **9** has been in terms of measuring the refraction of the eye referenced to the surface of the cornea, it should be understood that the refraction measurement may be referenced to any de-

sired location. In particular, if the measurements being taken are for the design of a contact lens, then it is preferred to place the measurement surface at the location where the surface of the contact lens will be by adjusting the position of the eye to place the expected position of the contact lens' surface at the conjugate location to the orientation or position selector. In this way, the refraction required at that surface in order to refract all rays extending parallel to the optical axis to the fovea centralis is determined directly and an appropriately shaped contact lens may be fabricated to provide that change in refraction. The measurement technique is similar where rather than a contact lens, a lenticule for essentially permanent attachment to the cornea is being fabricated. The measurement surface may also be made the location in which eyeglass lenses will be positioned in order to determine the correction which is appropriate for eyeglass lenses. Thus, the term "measurement surface" is used to refer to the surface (whether a physical interface between two different materials or an "imaginary" surface located at a specific location within one material such as air) at which the refractive characteristics are determined.

The non-subjective determination of the eye's refraction provided by this invention is desirable because it enables the refraction of an eye to be measured independent of the age, present mental capacity or state of consciousness of the patient and makes such measurement feasible from the time of birth on. It also makes measurement and correction of animal vision possible.

The discussion of the measurement process has been general. Normally, these measurements will be made on an uncorrected eye. However, they can also be made on an already corrected eye on which prior art correction has already been done, whether by corneal sculpturing (reshaping), attachment of a lenticule or by the presence of a contact lens. In these situations, the low order corrections (prism, cylindrical and spherical) have already been made (unless subsequent changes have taken place) and the system will be measuring data which relates to higher order terms only or to changes in those low order corrections. Once a correction based on such measurements has been determined, it can be applied to the cornea or lenticule, and if based on measurements with a contact lens in place, should have the contact lens correction included in it unless the patient desires to continue to wear the contact lens and have only the higher order corrections sculpted on the anterior surface of the eye. One reason for using a combination of a contact lens and sculptured correction would be where the low order corrections are large enough to raise concerns with respect to excessive thinning of the cornea if provided by corneal sculpturing. The higher order terms by themselves should not run that risk. Thus, a combination of corneal sculpturing and contact lens is appropriate for some patients.

While the discussion of the illustrated embodiments has concentrated on the measurement of the refractive characteristics of an eye because this system provides so many benefits over the prior art when used to measure an eye, it should be recognized that this measurement system can be used to measure any optical system with appropriate adaptation.

In optical systems where the image surface is a separate element of the system, the system for focusing an image of the image surface on a photodetector, such as the quadrant detector **172**, may be omitted and the image detector itself may replace the image surface of the optical system during the measurement process. That is, the image surface does not have to be part of the optical system under test, but will be where the system under test is an eye. In other optical systems, the reference point from which displacement of a beam is determined or to which it is desired to deflect a beam will depend on the particular characteristics of the optical system. Thus, in some optical systems, there will be no equivalent to the fovea centralis or more than one equivalent.

While this measurement system may be used for any optical system, without restriction, it is more ideally suited to the measurement of an eye than to the measurement of a camera lens system. This is because the eye only accurately focuses the portion of the image which is within a few degrees of the optical axis and provides less accurate focus, or at least a less detailed mental image for portions of the image outside that small solid angle. Thus, the eye's refractive characteristics can be measured with sufficient accuracy by measuring them only for that small solid angle around the optic axis. In contrast, in a camera lens system, the entire image field of view is expected to be clearly focused on the film in order to provide a sharp picture of the entire field of view. Consequently, in order for this measurement system to determine the entire refractive characteristics of a camera lens system, measurements must be taken from many different positions of the measurement light source relative to the camera's lens system. While such measurements can be made to characterize such a lens system, such a lens system, unlike the eye, might be more efficiently tested by other test techniques.

The laser scanning systems of FIGS. **1**, **4** and **9** are of general utility for other uses than testing optical systems. Their ability to independently control beam position and beam orientation at a surface has utility in many areas. For example, these systems can be used for optically addressing different devices, with the beam position selecting one group of devices out of a plurality of groups and the beam orientation selecting an individual member of the selected group, where the devices are positioned relative to a conjugate surface in a manner which causes them to be illuminated one at a time as a function of the angle of incidence. For example, positioning them a distance from the conjugate plane or having fiber optic cables disposed at different orientations and other techniques may be used.

Information about the eye's refractive characteristics can also be obtained, in an objective system, by using a measurement beam which is always parallel to the optical axis in combination with a photodetector which provides output signals which facilitate determination of the location of the bright spot on the retina. The photodetector may be an X-Y array of photosensitive cells such as a charge coupled device imager. While such a technique enables the present refractive errors of the eye to be determined, at the present time it requires much more time to determine the location of the image of the beam than is required in the preferred embodiments to move the beam to the reference point. It is for this reason that such a system is not preferred. Such a system may be provided by substituting an array detector for the quadrant detector either in system **108** or system **208** and either omitting the orientation imposer or by controlling the orientation imposer in the system to retain the measurement beam parallel to the optical axis.

While determination of proper refraction for an image position at infinite distance is most easily performed, the system may also be employed to perform a refraction for an image which is substantially closer to the eye. In so doing, the fixation point is moved to the desired image distance and the refraction is performed in the same manner as has been described.

In general, the data obtained can be preserved in any of a variety of ways. These including storing it in a computer or other control system, printing it out in a permanent hardcopy form, displaying it for an operator to write down, further processing it into control data for use in generating a corrective lens or lenticule or for use in modifying the existing surface of the cornea to provide improved vision or any of a wide variety of other techniques. All such techniques fall in the general class of storing, recording or preserving the data for a sufficient period of time to enable the measured refraction data to be put to therapeutic or diagnostic use. We use the word "storing" as a general term which encompasses such preservation of the data thus obtained, no matter how that storage is performed.

While the invention has been described in detail herein in accord with certain embodiments thereof, many modifications and changes therein may be effected by those skilled in the art. Accordingly, it is intended by the appended claims to cover all such modifications and changes as fall within the true spirit and scope of the invention.

What is claimed is:

1. A refractometer comprising:

means for providing a reference pattern to be viewed by an eye whose refraction is to be measured wherein said reference pattern comprises an annulus;

means for providing a measurement pattern to the eye wherein said measurement pattern comprises a disk-like pattern, said means for providing a measurement pattern being positioned adjacent to said means for providing a reference pattern;

means, connected to said means for providing a measurement pattern, for adjusting said means for providing a measurement pattern to change a position and/or orientation of said measurement pattern in order to enable a patient to use the eye to perceive said measurement pattern in a desired relationship to said reference pattern; and

means for storing data representative of the position and/or orientation of said measurement pattern when said measurement pattern is in said desired relationship to said reference pattern, said data being indicative of refraction characteristics of the eye.

2. A method for determining the characteristics of an eye comprising:

(a) providing a reference pattern to said eye;

(b) directing a measuring beam of light into said eye, said beam passing through a measurement point on an anterior surface of said eye and being narrower in cross-section than the entrance aperture of said eye;

(c) sensing an offset between a reference point on the retina and a location at which said beam impinges on the retina;

(d) changing the orientation at which said beam impinges on said anterior surface at said measurement point to an orientation for which said beam impinges on said retina at said reference point;

(e) storing, for each measuring point, the orientation in step (d) for which said beam impinges on said retina at said reference point;

(f) storing the location of each measurement point in association with said orientation;

(g) repeating said method for at least three measurement points on said anterior surface of said eye;

(h) determining the refractive characteristics of said eye from the measured orientations for which said beam impinges on the retina at the reference point; and

(i) determining a spatially resolved refraction from said refractive characteristics.

3. The method recited in claim 2 wherein step (d) comprises:

feeding back a signal representative of the sensed direction from said reference point to the location where said beam impinges on said retina, said feedback being to a control system which controls the orientation of said beam and, said feedback signal having a polarity to drive said impingement-on-the-retina point to said reference point in a self-centering manner.

4. The method recited in claim 3 further comprising the step of:

determining the refractive characteristics of said eye at said measurement point from the measured orientation for which said beam, when disposed at said measurement point, impinges on the retina at said reference point.

5. The method recited in claim 2 wherein said step of changing said orientation comprises:

the patient whose eye is being examined controlling the orientation of said measurement beam at said measurement point to bring the image of the measurement beam into a predetermined relationship with respect to a reference pattern.

6. A method for determining vision correction parameters for an eye comprising:

(a) directing a beam of light into said eye, said beam passing through a measurement point on the anterior surface of said eye, said beam being narrower in cross-section than the entrance aperture of said eye;

(b) sensing an offset between a reference point on the retina of said eye and a location where said beam impinges on said retina;

(c) while keeping said beam directed at said measurement point, changing the orientation of said beam relative to the optical axis of said eye to an orientation which shifts the location of said beam's impingement point on said retina toward said reference point wherein said beam impinges on said retina at said reference point;

(d) storing, for each measurement point on said anterior surface, the relative orientation for which said beam impinges on said retina at said reference point, said stored relative orientation being dependent on the refractive characteristics of the eye;

(e) determining from said orientation data, a first point on said anterior surface where minimal correction is required; and

(f) determining for all other points on said anterior surface the degree of correction required relative to said first point.

7. The method recited in claim 6 further comprising the step of:

determining a detailed pattern for shaping an optical surface located substantially at said anterior surface to provide correction for said eye, said optical surface being selected from the group comprising: a surface of a cornea of said eye, a surface of a contact lens, and a surface of a lenticule.

8. The method recited in claim **6** further comprising:
extracting a spherical correction from said refractive characteristics.

9. The method recited in claim **8** further comprising:
extracting a cylindrical correction from said refractive characteristics.

10. The method recited in claim **9** further comprising:
extracting from said refractive characteristics a correction which is more detailed than cylindrical and spherical corrections.

11. The method recited in claim **6** further comprising:
extracting from said refractive characteristics a correction which is more detailed than cylindrical and spherical corrections.

12. The refractometer for measuring the deviation of the refractive characteristics of an eye having a retina and a cornea from a desired optical performance of said eye comprising:
means for providing a reference beam of light which forms a first image of a reference pattern on said retina after passing through a first point on said cornea;
means for directing a second beam of light into said eye with a separately controllable position and angular orientation at said cornea, said second beam forming a second image on said retina, said reference beam and said second beam having diameters at said cornea which are substantially smaller than a predetermined size of an entrance aperture of said eye;
means for sensing an alignment of said second image with respect to said first image;
means for altering said angular orientation of said second beam in order to produce an alignment of said second image with respect to said first image that is substantially indicative of said desired optical performance of said eye;
means for storing said indicative orientation of said second image with respect to said first image; and
means for providing a spatially resolved map of said refractive characteristics of said eye by operating said means for directing said second beam over a plurality of predetermined measurement regions on an anterior surface of said eye.

13. The refractometer, recited in claim **12**, wherein:
said means for altering said angular orientation comprises:
a control system to which said means for directing is responsive.

14. The refractometer as recited in claim **12**, wherein said sensing means is further comprised of:
an electronic image sensing means viewing said first and second images on said retina through said eye; and an image processing system which determines said alignment of said first and second images.

15. The refractometer recited in claim **12** wherein:
said means for providing a reference beam comprises;
a source of the projected second light beam;
a collimating lens disposed in the path of said second beam;
means for imposing an impingement orientation on said second beam, said means for imposing being disposed in the path of said second beam between said light source and said collimating lens;
means for positioning said second beam at selected measurement points, said means for positioning being disposed in the path of said second beam between said light source and said collimating lens; and
said sensing portion which is comprised of:
a transducer for converting sensed light to an electrical signal, and
means for imaging said retina onto said transducer.

16. The refractometer recited in claim **15** wherein:
said means for positioning is disposed between said means for imposing and said collimating lens.

17. The refractometer recited in claim **15** wherein:
said means for positioning and said collimating lens are positioned such that said means for positioning is at a conjugate position with respect to an intended position of said anterior surface of said eye during said measurement.

18. The refractometer recited in claim **15** wherein:
said means for positioning comprises:
means for scanning.

19. The refractometer recited in claim **17** wherein:
said means for positioning comprises means:
for scanning said second beam along said anterior surface of said eye in a random access manner.

20. The refractometer recited in claim **19** wherein:
said means for positioning comprises:
a scanning mirror.

21. The refractometer recited in claim **18** wherein said means for scanning comprises:
a movable opaque member having a transmissive portion.

22. The refractometer recited in claim **21** wherein said transmissive portion of said movable opaque member comprises:
an aperture in said member.

23. The refractometer recited in claim **15** wherein:
said means for imposing comprises:
a two-dimensional acoustic/optical scanner.

24. The refractometer recited in claim **15** wherein:
said means for positioning is disposed substantially at the focal plane of said collimating lens.

25. The refractometer recited in claim **24** wherein:
said means for positioning comprises:
a scanning mirror.

26. The refractometer recited in claim **25** wherein:
said means for imposing is disposed at a conjugate location to said eye with respect to said collimating lens.

27. The refractometer recited in claim **26** wherein:
said means for imposing comprises:
a two-dimensional acoustic/optical scanner.

28. The refractometer recited in claim **26** wherein said sensing portion comprises:
means for deflecting light emerging from said eye away from the optical axis of said projecting portion; and
means for focusing light, which is deflected by said means for deflecting, onto said transducer as an image of said retina.

29. The refractometer recited in claim **28** wherein:
said means for deflecting comprises:
a beam splitter which is disposed in the path of said second light beam between said source and an intended position of said eye during measurement.

30. The refractometer recited in claim **29** wherein:

said means for deflecting is disposed between said collimating lens and the position of the eye during said measurement.

31. The refractometer recited in claim **29** wherein:

said beam splitter is a polarizing beam splitter and said second beam is polarized in a pass orientation of said beam splitter.

32. The refractometer recited in claim **28** wherein:

said transducer comprises:

a quadrant detector.

33. The refractometer recited in claim **32** further comprising a control means connected to receive an output of said quadrant detector and to control said means for imposing an impingement orientation and to keep said second beam centered in said quadrant detector as the measurement point is scanned along the anterior surface of said eye.

34. The refractometer recited in claim **33** wherein:

said control means is configured to, in response to a sensed second beam location on the retina which is away from said reference point, to cause said means for imposing to impose a new impingement orientation which is changed in a direction to move the sensed location of said second beam on the retina toward the reference point.

35. The refractometer recited in claim **33** further comprising:

means for relating the impingement angles which placed the sensed position of said second beam at the reference point on the retina to change in the shape of said anterior surface which will cause the eye to exhibit more desirable refraction.

36. A refractometer comprising:

means for providing a reference pattern to be viewed by an eye whose refraction is to be measured wherein said reference pattern comprises an annulus;

means for providing a measurement pattern to the eye wherein said measurement pattern comprises a disk-like pattern, said means for providing a measurement pattern being positioned adjacent to said means for providing a reference pattern;

means, connected to said means for providing a measurement pattern, for adjusting said means for providing a measurement pattern to change a position and/or orientation of said measurement pattern in order to enable a patient to use the eye to perceive said measurement pattern in a desired relationship to said reference pattern; and

means for providing data indicative of refraction characteristics of the eye and based upon adjustments made to the means for providing a measurement pattern in order to bring said measurement pattern into said desired relationship to said reference pattern.

* * * * *

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United States Patent [19]

Cobb et al.

[11] Patent Number: 5,257,136

[45] Date of Patent: Oct. 26, 1993

[54] **REVERSE TELEPHOTO AGRON OBJECTIVE LENS**

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[73] Assignee: **International Business Machines Corporation**, Armonk, N.Y.

[21] Appl. No.: **813,243**

[22] Filed: **Dec. 23, 1991**

[51] **Int. Cl.**[5] **G02B 13/04**

[52] **U.S. Cl.** **359/753**; 359/749

[58] **Field of Search** 359/749-753, 359/740, 795, 793

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Primary Examiner—Bruce Y. Arnold

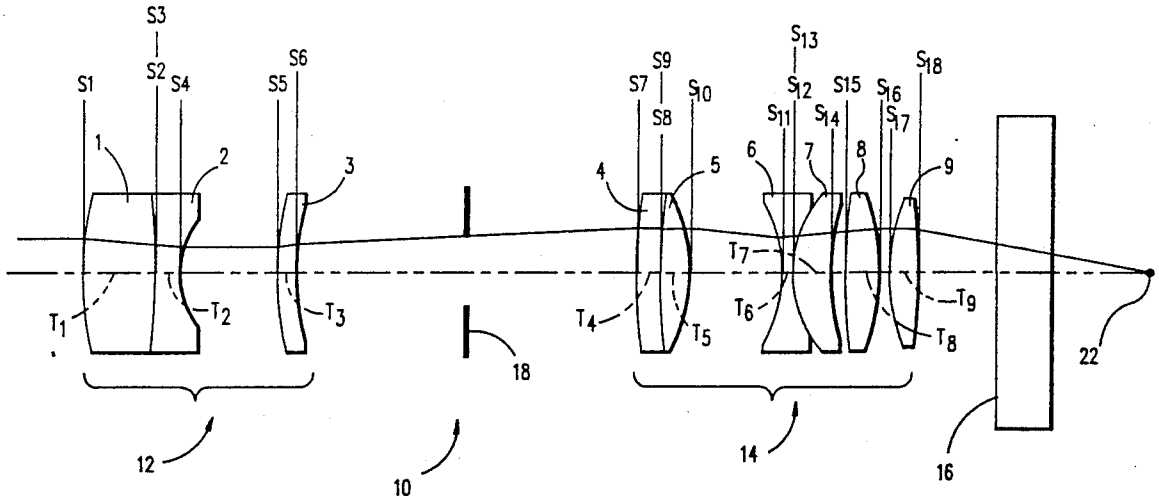
Assistant Examiner—James Phan

Attorney, Agent, or Firm—Floyd A. Gonzalez

[57] **ABSTRACT**

An air spaced reverse telephoto objective lens for use in a laser chemical vapor deposition system or the like having a quartz plate window. The objective lens includes a negative component having a first air-spaced doublet wherein each doublet element is made of crown glass and a negative meniscus crown glass element spaced from said first air-spaced doublet. The objective lens further includes an aperture stop, a positive component including second and third doublet components for effecting color correction, and a pair of bi-convex elements for effecting spherical aberration correction. The objective lens provides a common focal plane for both illuminating light and laser light passing through the objective lens and the quartz plate window.

6 Claims, 3 Drawing Sheets



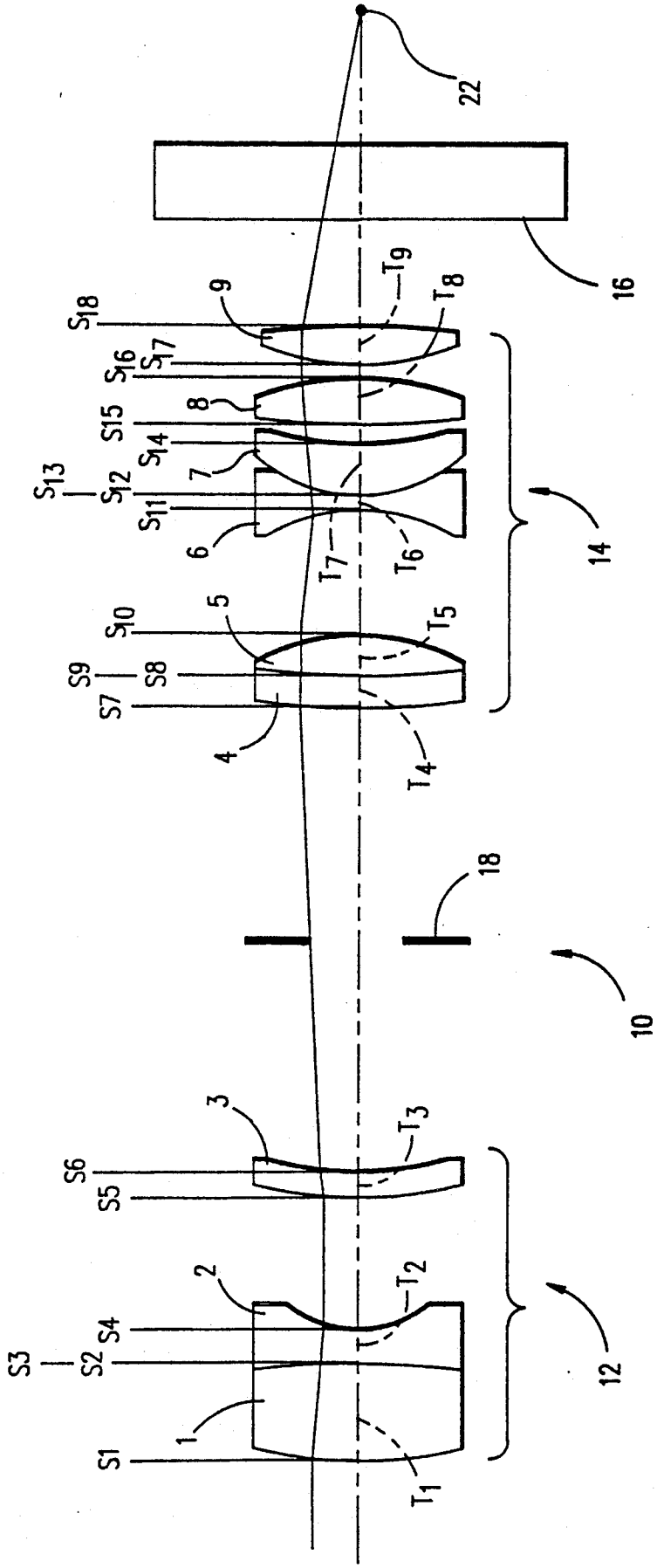

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FIG. 1

TRANSVERSE RAY ABERRATIONS

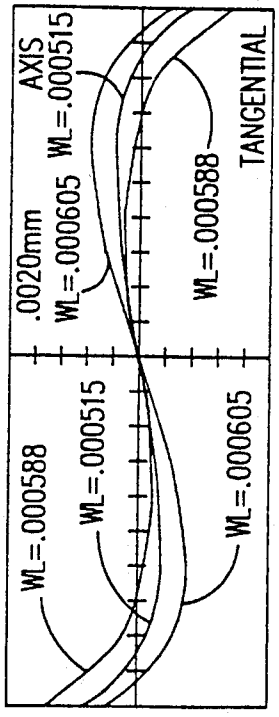


FIG. 2A

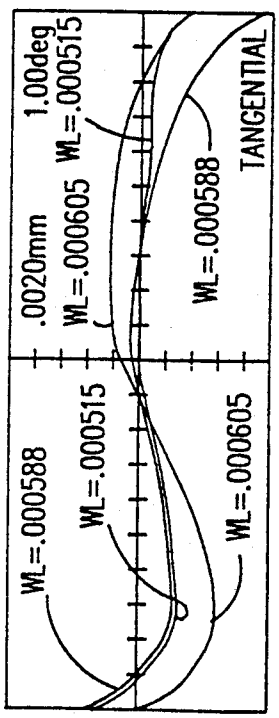


FIG. 2B

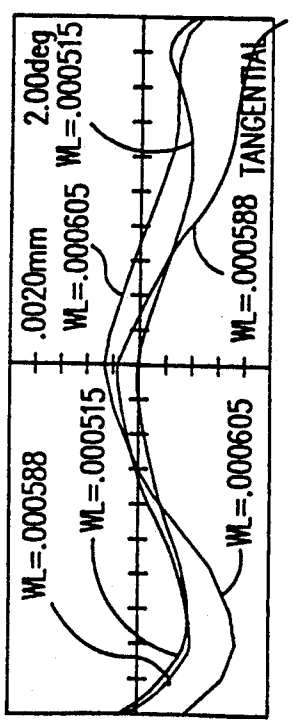


FIG. 2C

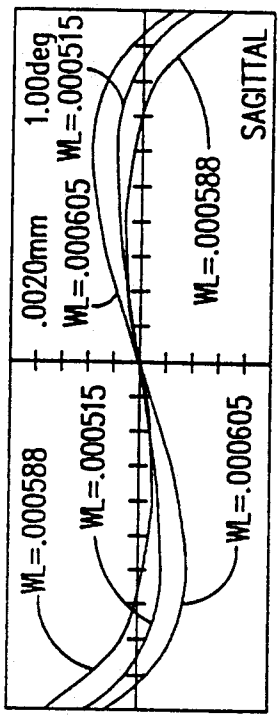


FIG. 2D

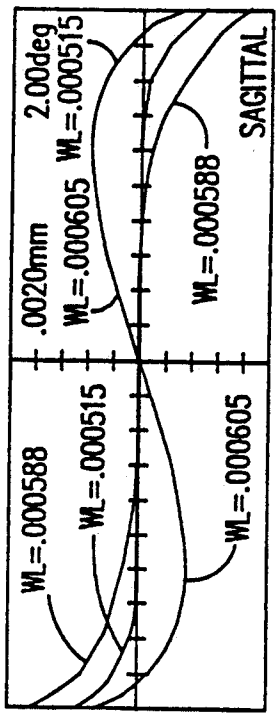
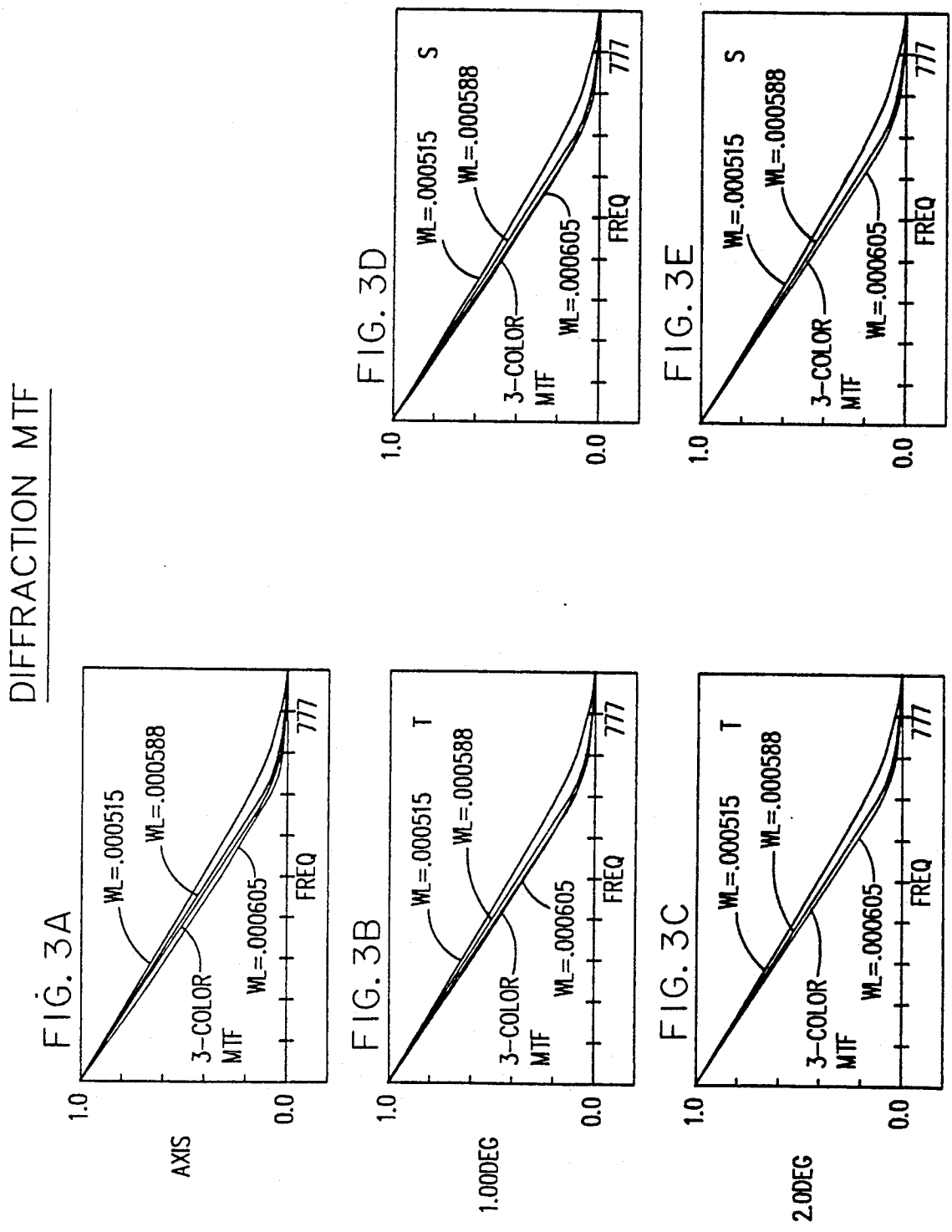


FIG. 2E


DIFFRACTION MTF
FIG. 3A
FIG. 3B
FIG. 3C
FIG. 3D
FIG. 3E
1.0
0.0
AXIS
1.00DEG
2.00DEG
WL=.000515
WL=.000588
WL=.000605
3-COLOR MTF
FREQ
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REVERSE TELEPHOTO AGRON OBJECTIVE LENS

FIELD OF THE INVENTION

This invention relates to the field of optical lenses and, more particularly, reverse telephoto objective lens with a long working distance for projecting and focusing a finely focused spot of light at a significant distance from the exit lens element.

BACKGROUND OF THE INVENTION

In manufacturing processes which use a vapor deposition technique, a vapor of a metal such as gold is created within a vacuum chamber which contains the workpiece. The workpiece is held on a movable stage such that it may be moved relative to a window which is typically a quartz plate in the wall of the vacuum chamber. In order to deposit the gold onto the substrate, a laser beam is used to locally heat a very, very small region of the silicon substrate. The heating of the substrate creates a condition and environment which permits the gold molecules to deposit out of the vapor form onto the surface of the silicon substrate.

The gold molecules, when deposited on the silicon substrate, may create electrical conductors on the insulations. In order to create extremely fine electrically conductive paths on the insulation surface of the silicon, it is necessary to very, very finely focus the laser beam while at the same time passing the focused laser beam through the quartz plate which serves as the window into the working vacuum chamber.

Since the lens elements must all remain outside the vacuum chamber, it is necessary for the lens assembly to have a sufficiently long back working distance between the exit or last element and the focal point such that the focused beam may be passed through the quartz plat and sufficiently inside the vacuum chamber to focus on the surface of the silicon slab where the gold molecules of the gold vapor are to be deposited. The reverse telephoto nature of a lens displaces the principle point outside the lens assembly providing a longer back working distance between the lens assembly and the focal point, while maintaining a relatively short focal length.

In order to project the maximum amount of illumination from the laser and the laser beam onto the focus point within the vacuum chamber of the vapor deposition device, it is necessary to expand the laser beam as received from the laser from a 1.6 millimeter diameter to approximately a 10.8 millimeter diameter where the beam enters the reverse telephoto objective lens of this invention. By expanding the beam to that diameter, the maximum beam diameter may be then introduced into the reverse telephoto lens thus causing the maximum controllable focus into an extremely fine point of approximately 3.14 microns airy disk diameter. Lenses for such expansion are known in the art.

OBJECTS OF THE INVENTION

It is an object of the invention to accurately focus a beam of coherent laser light to an extremely fine focal point, and to cause the focal point to be positioned at a substantial distance from the exit element of the lens.

It is another object of the invention to focus an expanded entering beam of coherent radiation from a laser into a finely controlled focused point of light on the opposite side of a quartz plate.

It is a further object of the invention to focus the light of an expanded coherent radiation beam within a vapor deposition vacuum chamber.

SUMMARY OF THE INVENTION

The focusing of the entering beam of coherent laser radiation into the extremely fine focus point within the vacuum chamber of a vapor deposition apparatus is accomplished by a lens having a negative component and a positive component. The negative component is comprised of a doublet component and a negative miniscus element. The positive component is comprised of two doublets and two bi-convex elements.

The entire lens apparatus is color corrected for selected light frequencies by the selection of appropriate glasses for the elements of the lens. However, each element of the lens is not an individually color corrected element.

The elements are air spaced from each other to avoid the effects caused by cementing lenses thereby avoiding the absorption of the energy by the cement of cemented lens assemblies. By avoiding the absorption of the light and energy, the cracking of the cement or lens elements due to heat build up is avoided.

Due to the color correction of the overall lens assembly, the same lens may be used not only for focusing of the laser beam at the desire point and to the desired diameter, but also may be used for visual of inspection of the work.

The objects of the invention are accomplished and the shortcomings and deficiencies of the prior art such as cemented element lenses are overcome by the selection of materials, the accurate formation of each individual lens element together with the accurate placement and spacing of the lens elements from the adjacent lens elements as will be better understood from reference to the drawing and the detailed description of the invention to follow.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** illustrates the lens elements and their spacing relative to each other and to the quartz plate which forms the window of the vapor deposition gas chamber.

FIG. **2** is formed of three color transverse ray aberration plots for the lens of FIG. **1** on axis and the tangential and sagittal plots for the off axis points at one degree and two degrees field angles, as labeled.

FIG. **3** is formed of three color diffraction MTF plots for the lens of FIG. **1** on axis and the tangential (T) and sagittal (S) plots for the off axis points at one degree and two degrees field angles, as labeled.

DETAILED DESCRIPTION OF THE INVENTION

With reference to the drawing, the nine lens elements of the reverse telephoto argon objective lens are illustrated together with other pertinent elements of the optical system.

The mounting hardware uses conventional materials and fabrication techniques to insure that the lens elements remain in their proper relative positions. Preferred materials are stainless steel to avoid thermal expansion over the long barrel length of the lens assembly.

The reverse telephoto lens **10** shown in FIG. **1** is comprised of a negative component **12** which is further comprised of lens elements **1**, **2** and **3**. Negative component **12** acts to spread the light beam that enters surface **S1** of lens element **1** so that the light beam diameter may

be controlled by aperture stop **18**. The two separate glass lens elements **1** and **2** are selected from the available glass types to help color correct the lens. Additionally, the negative component acts to move the principle point of the lens assembly and positions the principle surface outside the lens assembly and toward the focal point. This displacement of the principle surface increases the back working distance to permit the projecting of the beam of laser light well within the chamber of the vapor deposition equipment. The shifting of the principle surface also shortens the focal length of the lens assembly.

The positive component **14** of the lens assembly **10** is illustrated to the right of the aperture stop **18** and is comprised of two doublet lens elements **4** and **5** and lens elements **6** and **7** together with bi-convex elements **8** and **9**.

Again, doublets **4**, **5** and **6**, **7** further act to color correct the lens by the judicious selection of glass types. Color correction is not normally necessary for laser lenses since the laser is monochromatic. However, the color correction of the lens over a band of orange light is desirable since the lens is used in a dual purpose role with the other purpose being an objective lens of a viewing system such as a television type inspection camera. The camera provides signals to a monitor to display the work area. The orange illumination light may be focused by the lens on the work area. The reflected orange illumination provides the image for the inspection camera.

Positive components **14** take the diverged beam passing through aperture stop **18** and focuses the rays of the beam to a focal point **22**. In route from lens element **9** to focal point **22**, the focused beam passes through quartz plate **16** which is a window in the wall of the vapor deposition gas chamber with which this lens assembly is used.

Reference is made to the table which follows below which sets forth the significant parameters of the individual lens elements, together with the respective spacing between lens elements.

All dimensions are expressed in terms of millimeters. The lens element numbers correspond to the reference numerals associated with a lens element in the drawing while the surfaces are designated by an S with a numeral, the numeral corresponding to the numerical sequence of the surface starting with the entering surface and terminating with the exit surface of the lens assembly. The radius of the spherical surface of each lens element is expressed as a positive number where the center of the radius is to the right of the surface as shown in the drawing and a negative number where the center of the radius is located to the left of the surface referred to, as illustrated in the drawing.

The thickness of the lens is expressed in a linear thickness of millimeters measured at the axis of the lens.

The air spacing is designated in the form of $D_{x\text{-}y}$. The x and the y are the lens numbers immediately adjacent the air space distance. Thus, for example, the air space between lenses **4** and **5** would be $D_{4\text{-}5}$.

The column headed "Glass" utilizes the glass designations found on a Schott Glass Map published by Schott Glass Technologies. The use of a designation on the Schott glass map are as a matter of convenience. The alternative technique for disclosing the characteristics of the glass is by expressing the index of refraction and the Abbe' V number.

The columns designated Index @ λ and a number followed by the symbol for microns is the refraction index for that particular wavelength of light. Three separate wavelengths of light are illustrated for purposes of defining the refractive index of the glass. The Abbe' V number is likewise shown for each glass selection.

TABLE 1

LENS L	RADIUS OF SURFACE	THICKNESS TL	AIR-SPACE $D_{x\text{-}y}$	CLEAR APERTURE	LENS MATERIAL	INDEX@λ = 0.5146μ	INDEX@λ = 0.6050μ	INDEX@λ = 0.5876μ	ABBE V NO
1	S1 = 43.64	17.55		26.0	LAK 28	1.751023	1.743025	1.744284	50.77
	S2 = −186.85		0.025						
2	S3 = −186.85	3.51		26.0	BK 10	1.501225	1.497173	1.497820	66.95
	S4 = 17.09		10.00						
3	S5 = 99.80	3.56		26.0	LAK 9	1.696803	1.689912	1.691000	54.71
	S6 = 48.42		57.95						
4	S7 = 998.80	5.90		27.0	F 5	1.610735	1.602077	1.603417	38.03
	S8 = 112.75		0.84						
5	S9 = 62.74	6.30		27.0	LAKN 7	1.656713	1.650638	1.651598	58.52
	S10 = −35.14		9.00						
6	S11 = −25.00	2.16		26.0	SF 12	1.657149	1.646697	1.648306	33.84
	S12 = 20.93		0.025						
7	S13 = 20.93	6.50		26.0	LAK 10	1.726562	1.718770	1.719997	50.42
	S14 = 31.82		2.50						
8	S15 = 58.85	6.50		26.0	LAKN 7	1.656713	1.650638	1.651598	58.52
	S16 = −54.94		0.08						
9	S17 = 31.61	4.94		26.0	LAKN 7	1.656713	1.650638	1.651598	58.52
	S18 = −129.80								

Individual lens elements fabricated to the dimensions indicated in the above table with a thickness tolerance of plus or minus 25.0 microns, diameter tolerances of plus 0 minus 25.0 microns and the radiuses of the surfaces to less than one fringe sphericity and to less than one fringe of power. The lens elements are then positioned relative to each other and held relative to the aperture stop **18** such that an air gap to the left of the aperture stop has a 28.25 millimeter length and the air gap to the right of the aperture stop has a 29.70 millimeter length. This assembly results in an air gapped reverse telephoto lens which will focus an entering laser beam having an entrance diameter of approximately 10.8 millimeters to an extremely fine 3.14 micron Airy Disk diameter at the focal point **22** where the back working distance of this lens assembly is about 42.0 millimeters.

Since the diameter of the Airy Disk is a function of the focal length of the lens, according to the formula:

$$\phi = \frac{2.44 \lambda F}{D} \text{ where}$$

ϕ=Diameter of the Airy Disk,
λ=Wavelength of light,
F=Focal length, and
D=Diameter of entering laser beam,

it is highly desirable to have a small focal length to allow the use of a smaller diameter entering laser beam. By using a reverse telephoto lens arrangement, the focal length may be smaller than a non-reverse telephoto lens, while maintaining a larger back working distance. The need for unduly large entering laser beams complicates the design of equipment, particularly the beam spreading lens necessary to precede the reverse telephoto lens. The long back working distance affords adequate room to insert the quartz plate **16** between the exit lens element **9** and the focal point **22**.

It is preferred that all nine element **1–9** of the lens assembly **10** be coated with a broad band anti-reflection coating which is formulated to be peaked at 0.5145 micron wavelength.

Referring to FIGS. **2** and **3**, it is readily seen that a lens assembly made according to this description is not aberration limited, but is limited only by diffraction. The transverse ray aberration plots of FIG. **2** shows very little degradation due to aberrations and vary from perfect by only approximately 1.5 microns while the lens has an Airy Disk diameter of about 3.14 microns for the lens F stop of 2.5. The diffraction MTF plots, FIG. **3**, illustrates that the lens will have limitations due to diffraction.

The lens assembly is corrected for use with a 16 millimeter quartz plate **16**. The foregoing lens further has an effective focal length of 27.0 millimeters, a working numerical aperture of 0.2, lens thickness, glass only, of 137.25 millimeters and a workable field of view plus or minus 2.0 millimeters (plus or minus 4.2 degrees) with color correction corrected for a band of wavelengths between 0.5876 and 0.6328 microns in the visible spectrum and highly corrected for wavelengths of 0.5145 microns, and 0.5876 microns and 0.6050 microns.

The foregoing is a description of the invention we desire to protect by Letters Patent is defined by the claims that follow.

We claim:

1. An air spaced reverse telephoto type/objective lens for use in a laser chemical vapor deposition system having a quartz window, said objective lens comprising, from the object side to the image side:

a negative component including a first air-spaced doublet wherein each doublet element is made of crown glass having an Abbe' V number greater than 50 and a negative meniscus crown glass element spaced from said first air-spaced doublet;

an aperture stop; and

a positive component including second and third air-spaced doublet components for effecting color correction and a pair of bi-convex elements for effecting spherical aberration correction;

said objective lens providing a common focal plane for both illuminating light and laser light passing through said objective lens and said quartz plate window.

2. The lens of claim **1** wherein said lens elements conform to the radius and the materials set forth in the table following:

Lens #	Surface Radius	Material
1	S1 = 43.64	LAK 28
	S2 = −186.85	
2	S3 = −186.85	BK 10
	S4 = 17.09	
3	S5 = 99.80	LAK 9
	S6 = 48.42	
4	AS7 = 998.80	F 5
	S8 = 112.75	
5	S9 = 62.74	LAKN 7
	S10 = −35.14	
6	S11 = −25.00	SF 12
	S12 = 20.93	
7	S13 = 20.93	LAK 10
	S14 = 31.82	
8	S15 = 58.85	LAKN 7
	S6 = −54.94	
9	S17 = 31.61	LAKN 7
	S18 = −129.80	

wherein surfaces are designated from the surface laser light enters first and progresses to the surface said laser light exits with each lens element having an odd and even numbered surface in ascending order respectively.

3. The lens of claim **2** wherein the inter lens air spacing at the axis of the lens, $D_{x\text{-}y}$, with the x and y being surface numbers bounding said inner lens air spacing, in millimeters are $D_{2\text{-}3}$=0.025; $D_{4\text{-}5}$=10.00; $D_{6\text{-}7}$=57.95; $D_{8\text{-}9}$=0.84; $D_{10\text{-}11}$=9.00; $D_{12\text{-}13}$=0.025; $D_{14\text{-}15}$=2.50; and $D_{16\text{-}17}$=0.08.

4. The lens of claim **3** wherein each said lens element comprises an anti-reflective coating.

5. The lens of claim **3** wherein said aperture stop is disposed between lens surfaces **6** and **7**.

6. An air spaced reverse telephoto lens comprising a plurality of lens elements designated by lens numbers, **1–9**;

said lens elements having center lens element distances separating them designated $D_{x\text{-}y}$, where x and y are lens numbers for lenses defining said center lens distances;

said lens elements each having an entry surface and an exit surface, each said surface having a radius;

each of said lens elements further having a thickness T_L;

each of said lens elements being fabricated from a designated material;

and said lens numbers, surface numbers, radius, thickness, center lens element distance and material conforming to specifications set out in a table below:

LENS #	RADIUS OF SURFACE	THICKNESS TL	AIR-SPACE $D_{x\text{-}y}$	CLEAR APERTURE	LENS MATERIAL	INDEX@λ = 0.5146μ	INDEX@λ = 0.6050μ	INDEX@λ = 0.5876μ
1	S1 = 43.64	17.55		26.0	LAK 28	1.751023	1.743025	1.744284
	S2 = −186.85		0.025					
2	S3 = −186.85	3.51		26.0	BK 10	1.501225	1.497173	1.497820
	S4 = 17.09		10.00					

-continued

LENS #	RADIUS OF SURFACE	THICK-NESS TL	AIR-SPACE D_{X-Y}	CLEAR APER-TURE	LENS MATERIAL	INDEX@λ = 0.5146μ	INDEX@λ = 0.6050μ	INDEX@λ = 0.5876μ
3	S5 = 99.80	3.56		26.0	LAK 9	1.696803	1.689912	1.691000
	S6 = 48.42		57.95					
4	S7 = 998.80	5.90		27.0	F 5	1.610735	1.602077	1.603417
	S8 = 112.75		0.84					
5	S9 = 62.74	6.30		27.0	LAKN 7	1.656713	1.650638	1.651598
	S10 = −35.14		9.00					
6	S11 = −25.00	2.16		26.0	SF 12	1.657149	1.646697	1.648306
	S12 = 20.93		0.025					
7	S13 = 20.93	6.50		26.0	LAK 10	1.726562	1.718770	1.719997
	S14 = 31.82		2.50					
8	S15 = 58.85	6.50		26.0	LAKN 7	1.656713	1.650638	1.651598
	S16 = −54.94		0.08					
9	S17 = 31.61	4.94		26.0	LAKN 7	1.656713	1.650638	1.651598
	S18 = −129.80							

* * * * *

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United States Patent [19]

Oshima et al.

[11] Patent Number: 5,251,068

[45] Date of Patent: Oct. 5, 1993

[54] **OBJECTIVE LENS HAVING A FILTER**

[75] Inventors: **Shigeru Oshima**, Yokohama; **Yusuke Furue**, Tokyo, both of Japan

[73] Assignee: **Canon Kabushiki Kaisha**, Tokyo, Japan

[21] Appl. No.: **2,677**

[22] Filed: **Jan. 8, 1993**

Related U.S. Application Data

[63] Continuation of Ser. No. 691,422, Apr. 25, 1991, abandoned.

[30] **Foreign Application Priority Data**

Apr. 27, 1990 [JP] Japan 2-112544

[51] **Int. Cl.**[5] **G02B 5/22**; G02B 27/14; H04N 9/097

[52] **U.S. Cl.** **359/634**; 359/637; 359/723; 359/888; 359/891; 358/55

[58] **Field of Search** 350/173, 439, 438, 317, 350/316, 166; 358/55; 359/634, 637, 723, 722, 888, 891

[56] **References Cited**

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Primary Examiner—Jon W. Henry

Attorney, Agent, or Firm—Fitzpatrick, Cella, Harper & Scinto

[57] **ABSTRACT**

This specification discloses an objective lens disposed forwardly of a prism block for dividing light into a plurality of color components, the objective lens having an optical filter differing in spectral transmission factor between the central area thereof and the marginal areas thereof, this filter being given the characteristic that one of the marginal areas transmits much of magenta light therethrough and the other marginal area transmits much of green light therethrough, thereby suppressing the coloring of a blurred image based on the light incidence angle dependency of the color dividing surface of the prism block.

12 Claims, 5 Drawing Sheets

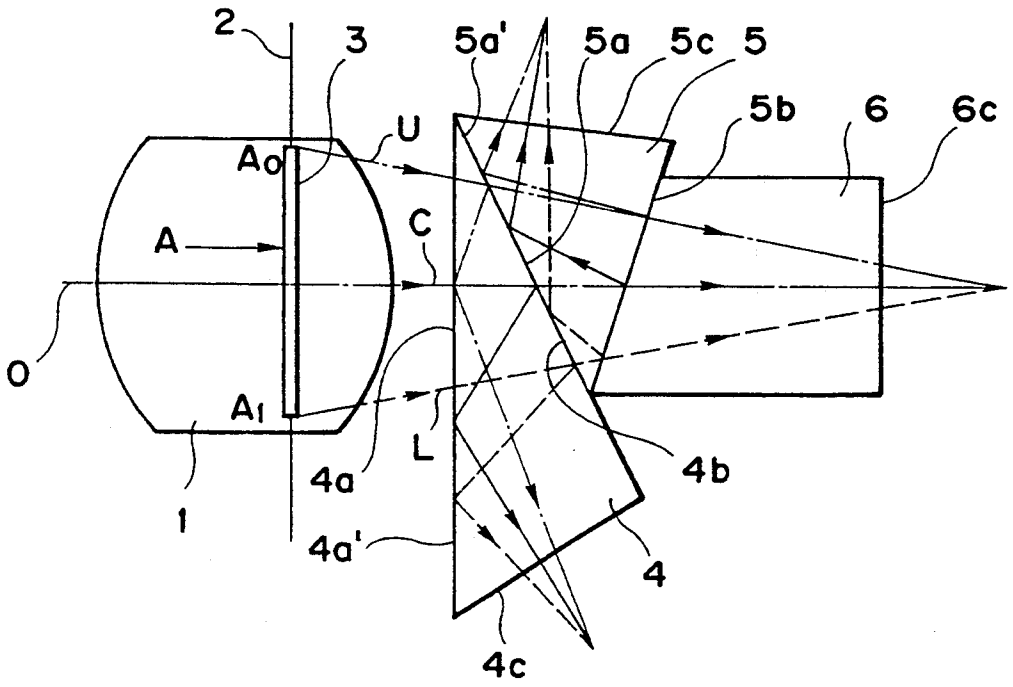


FIG. 1

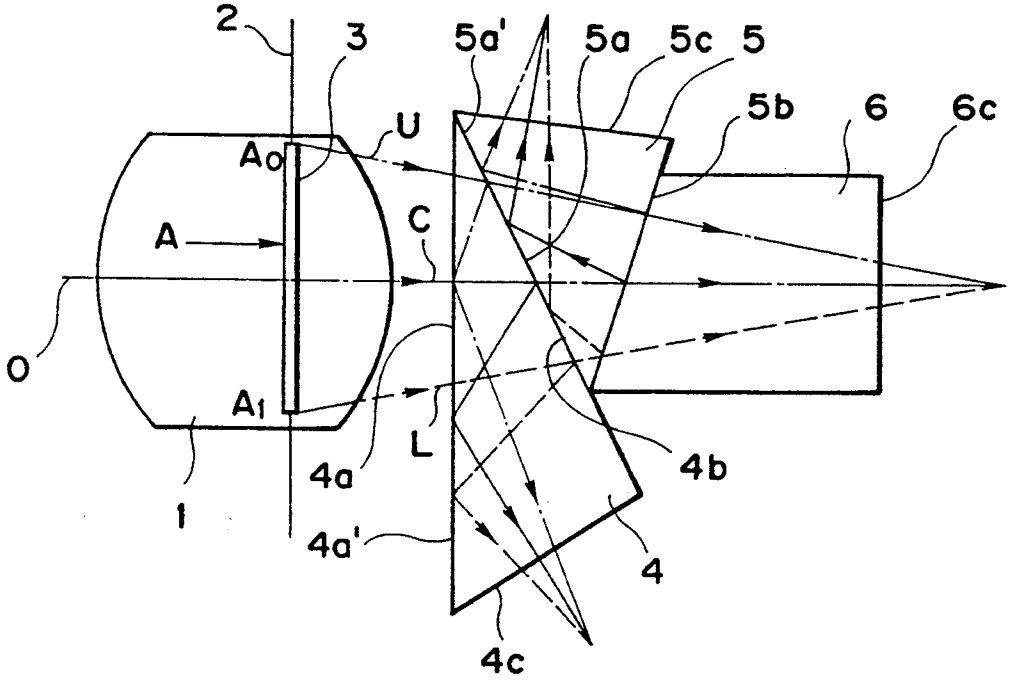


FIG. 2

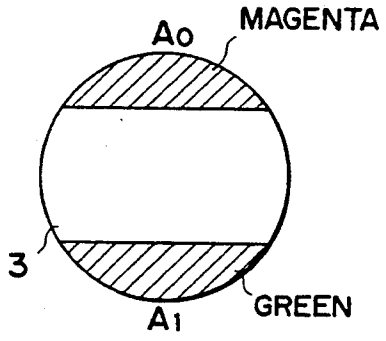


FIG. 3

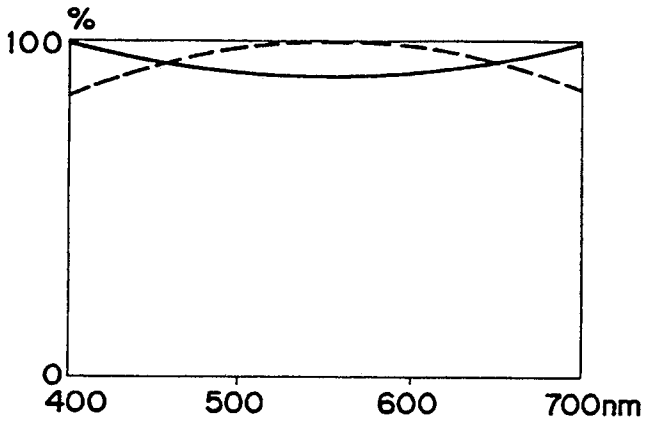


FIG. 4

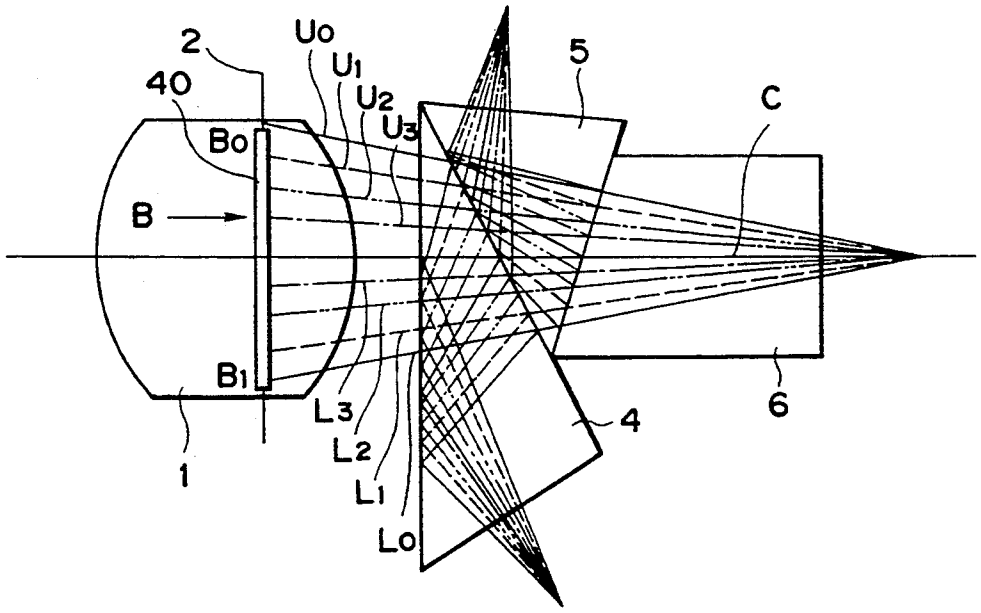


FIG. 5

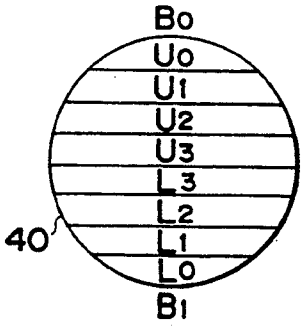


FIG. 6

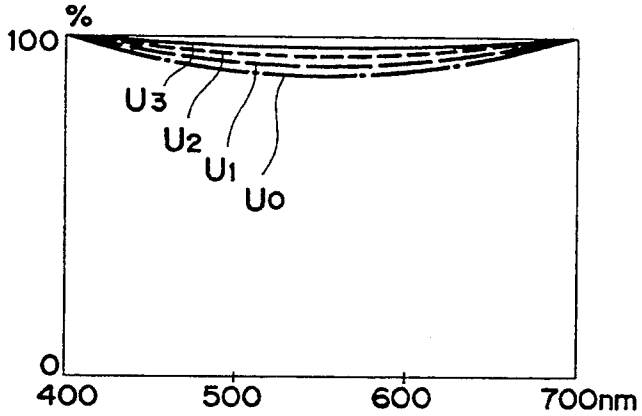


FIG. 7

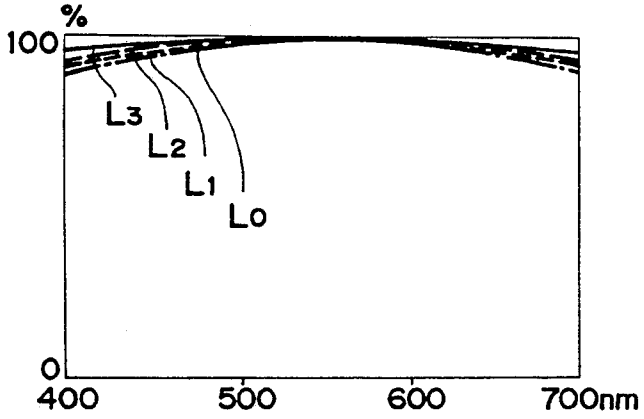


FIG. 8

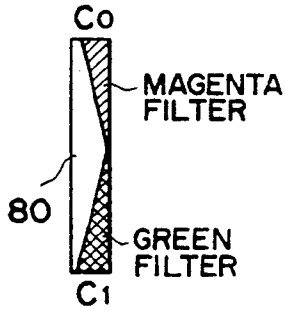


FIG. 9
PRIOR ART

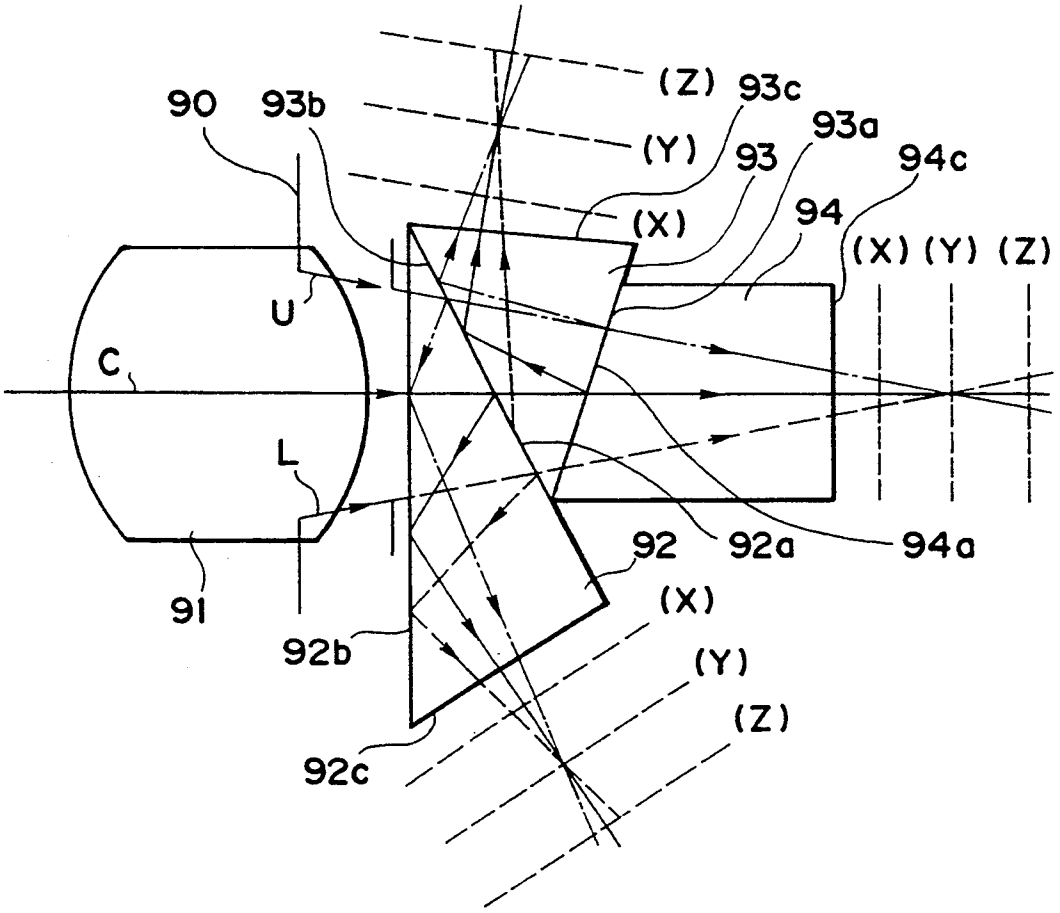


FIG. 10
PRIOR ART

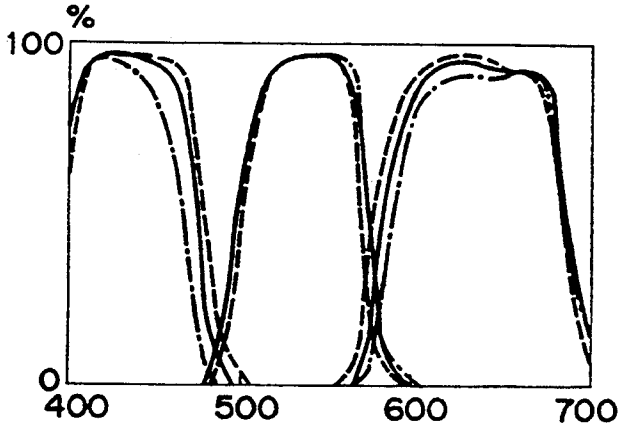


FIG. 11
PRIOR ART

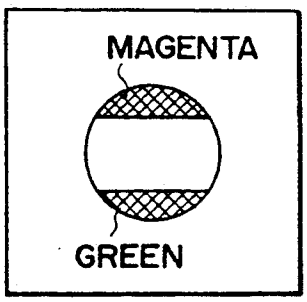
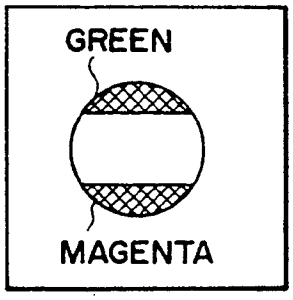


FIG. 12
PRIOR ART



OBJECTIVE LENS HAVING A FILTER

This application is a continuation of application Ser. No. 07/691,422 filed Apr. 25, 1991 now abandoned.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to an objective lens, and particularly to an objective lens suitable for use in a color video camera having a prism block having dichroic film on the image side of the objective lens and dividing a light beam into a plurality of color components.

2. Related Background Art

In a three-tube type TV camera, a three-color resolving optical system comprising a plurality of prisms, color filters or the like is provided as means for color-resolving an incident light beam into a plurality of predetermined color lights between a photo-taking lens and an image pickup plate (or an image pickup tube or a solid state image pickup element).

This three-color resolving optical system is composed chiefly of a prism block comprising three to four prisms of a predetermined shape each having multilayer film, for color resolution provided on one surface thereof and combined as a unit while having a predetermined relation therebetween. The optical system is designed to resolve a light beam incident from the photo-taking lens into color lights of plural wavelength bands through the reflecting surfaces for color resolution of the prisms and direct the color lights to respective image pickup plates.

FIG. **9** of the accompanying drawings is a schematic view of a prior-art three-color resolving optical system comprising three prisms. In FIG. **9**, the reference numeral **91** designates a photo-taking lens, the reference numeral **92** denotes a blue resolving prism, and the reference numeral **93** designates a red resolving prism having its entrance surface **93***b* disposed with a minute gap with respect to the blue resolving prism **92**. The reference numeral **94** denotes a green resolving prism having its entrance surface **94***a* adhesively secured to the reflecting surface **93***a* of the red resolving prism **93**.

In FIG. **9**, of a light beam passed through the photo-taking lens **91**, blue light B is separated by the light dividing surface **92***a* of the blue resolving prism **92**, which is coated with dichroic film, and is totally reflected by the entrance surface **92***b* of the blue resolving prism **92**, whereafter it emerges from the exit surface **92***c* of the blue resolving prism. Red color R is separated by the light dividing surface **93***a* of the red resolving prism **93**, which is coated with dichroic film, and is totally reflected by the entrance surface **93***b* of the red resolving prism, whereafter it emerges from the exit surface **93***c* of the red resolving prism. The remaining green light G, than the blue and red components passes through the green resolving prism **94** and emerges from the exit surface **94***c* of this prism. The blue light B, the red light R and the green light G, thus, total three light beams, and are directed to image pickup plates, not shown.

In the prior-art three-color resolving optical system shown in FIG. **9**, when light beams U (dot-and-dash line), C (solid line) and L (dotted line) passes through the central portion and marginal portion of the photo-taking lens as shown enter the blue dichroic film provided on the light dividing surface **92***a* of the blue resolving prism **92** and the red dichroic film provided on the light dividing surface **93***a* of the red resolving prism **93**, which prisms are positioned in the course of the arrival of the light beams at the respective image pickup plates, not shown, there are created differences among the angles of incidence of the light beams U, C and L. Therefore, the spectral transmission characteristics for the light beams U, C and L become different from one another as shown, for example, in FIG. **10** of the accompanying drawings. Respective lines in FIG. **10** correspond to respective lines in FIG. **9**. In FIG. **10**, the abscissa represents wavelength.

Therefore, when the color reproduction of a color image is effected in an in-focus state (a position Y indicated in FIG. **9**), no color misregistration occurs to the object image, but when the color reproduction of a color image is effected, for example, in a state in which the object is deep and is out of focus (positions x and z indicated in FIG. **9**), a blurred image gradually becomes colored in the vertical direction thereof.

Assuming that the image pickup surface lies at the position Y, when the coloring of the blurred image at this time is watched on a color monitor, the blurred image on the image pickup surface Y, when the position x is the image point, will appear as magenta in the upper portion thereof and as green in the lower portion thereof, as shown in FIG. **11** of the accompanying drawings. Also, the blurred image on the image pickup surface Y when the position Z is the image point will conversely appear as green in the upper portion thereof and as magenta in the lower portion thereof, as shown in FIG. **12** of the accompanying drawings. Thus, there has been problems in that the quality of the image, when a color image which is out of focus is represented, becomes greatly deteriorated.

SUMMARY OF THE INVENTION

It is a first object of the present invention to provide an optical device which can suppress the coloring of a blurred image and obtain a good quality image.

It is a second object of the present invention to provide a photo-taking lens having an optical unit of suitable spectral transmission characteristic for a TV camera, a video camera or the like.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. **1** and **4** are schematic views showing the essential portions of photo-taking lenses according to first and second embodiments, respectively, of the present invention.

FIG. **2** is a view of the color filter in FIG. **1** taken along arrow A in FIG. **1**.

FIG. **3** is a graph illustrating the spectral transmission characteristic of the color filter shown in FIG. **1**.

FIG. **5** is a view of the color filter in FIG. **4** taken along arrow B in FIG. **4**.

FIGS. **6** and **7** are graphs illustrating the spectral transmission characteristic of the color filter shown in FIG. **4**.

FIG. **8** is a view of a color filter according to a third embodiment of the present invention.

FIG. **9** is a schematic view showing the essential portions of a color resolving optical system according to the prior art.

FIG. **10** illustrates the spectral transmission characteristics of light beams which cause the coloring of a blurred image in the prior art.

FIGS. **11** and **12** illustrate blurred images on a color monitor according to the prior art.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. 1 is a schematic view showing the essential portions of an optical device having a filter having a predetermined spectral transmission factor according to a first embodiment of the present invention.

In FIG. 1, the reference numeral 1 designates an objective lens having a plurality of lenses and endowed with the zooming function. The objective lens 1 has a stop 2 at a predetermined position therein. The reference character 0 denotes the optic axis of the objective lens.

The reference numeral 3 designates a color filter according to the present invention. The color filter 3 is disposed near the position of the stop 2 (the pupil position), and partially has a spectral transmission factor to correct the coloring of a blurred image based on the incidence angle dependency of a light beam entering a prism block which will be described later.

The reference numeral 4 denotes a blue resolving prism, and the reference character 4*b* designates the light dividing surface (the reflecting or transmitting surface) thereof. The light dividing surface 4*b* is coated with blue dichroic film to effect color resolution, and separates and reflects a light beam of blue component.

The reference numeral 5 denotes a red resolving prism disposed with a slight air space with respect to the blue resolving prism. The reference character 5*b* designates the light dividing surface (the reflecting or transmitting surface) of the red resolving prism 5. The light dividing surface 5*b* is coated with red dichroic film to effect color resolution, and separates and reflects a light beam of red component.

The reference numeral 6 denotes a prism adhesively secured to the light dividing surface 5*b* of the red resolving prism 5.

FIG. 2 is a front view of the color filter 3 according to the present invention as it is seen in the direction of arrow A in FIG. 1.

The color filter 3 of the present embodiment has the characteristic that the spectral transmission factor of the AO side marginal portion (the upper hatched portion as viewed in FIG. 2) is set as indicated by a solid line in FIG. 3 to compensate for the incidence angle dependency of a light beam entering the prism block at various angles so as to transmit much of magenta light and the spectral transmission factor of the Al side marginal portion (the lower hatched portion as viewed in FIG. 2) is set as indicated by a dotted line in FIG. 3 so as to transmit much of green light.

In the present embodiment, by such a construction, the light beams from an object, not shown, are caused to enter the entrance surface 4*a* of the blue resolving prism 4 in such a manner that the A0 side of the marginal portion which is on the same side as the direction in which red light is imaged transmits much magenta light by the color filter disposed near the position of the stop 2 in the objective lens 1 and the A1 side of the marginal portion which is opposite to said direction transmits much of green light.

Of the incident light beams, the light beam of a blue wavelength band is reflected by the light dividing surface 4*b* coated with the blue dichroic film, whereafter it is totally reflected by a reflecting surface 4*a*′ on the same plane as the entrance surface 4*a* of the blue resolving prism 4 so as to emerge from the exit surface 4*c* of the prism 4, and is directed to an image pickup plate for blue, not shown.

Also, the light beams other than the light beam of blue component transmitted through the light dividing surface 4*b* of the blue resolving prism 4 enter the entrance surface 5*a* of the red resolving prism 5, and of the incident light beams, the light beam of red wavelength band is reflected by the light dividing surface 5*b* coated with the red dichroic film, whereafter it is totally reflected by a reflecting surface 5*a*′ on the same plane as the entrance surface 5*a* of the red resolving prism 5 so as to emerge from the exit surface 5*c* of the prism 5, and is directed to an image pickup plate for red, not shown.

On the other hand, the light beam of green component transmitted through the light dividing surface 5*b* of the red resolving prism 5 passes through the prism 6, emerges from the exit surface 6*c* of the prism 6 and is directed to an image pickup plate for green, not shown. The object images are formed on the surfaces of the predetermined image pickup plates so as to obtain image information, thereby representing a good color image.

Also, even in a state in which the object is deep and is out of focus at this time (the positions X and Z indicated in FIG. 9), the color filter having the spectral transmission factor shown in FIG. 3 is disposed near the position f the stop in the objective lens, whereby a good color image can be obtained without any color misregistration being created in a blurred image when the color image is color-reproduced.

If filters in the form of very thin sheets are stuck to the upper and lower portions of the vicinity of the stop, the color filter can be easily realized.

Also, the present invention is equally applicable even if a dye is thinly applied to the surface of a glass plate as another filter.

FIG. 4 is a schematic view showing the essential portions of a photo-taking lens having a filter having a predetermined spectral transmission factor according to a second embodiment of the present invention.

In FIG. 4, elements identical to those shown in FIG. 1 are given identical reference numerals. The reference numeral 40 designates a color filter. The optical density, i.e., the transmission factor, of this color filter 40 is controlled so as to be stepwisely higher, that is, higher in the transmission factor for the subject color light, from the central portion of the color filter 40 toward the marginal portion (the B0 and B1 sides) thereof.

FIG. 5 is a front view of the color filter 40 as it is seen in the direction of arrow B in FIG. 4.

The spectral transmission factors of the portions U3, U2, U1 and U0 of the color filter 40 of FIG. 5 from the central portion thereof toward the B0 side of the marginal portion are shown in FIG. 6. Also the spectral transmission factors of the portions L3, L2, L1 and L0 of the color filter 40 from the central portion thereof toward the B1 side of the marginal portion are shown in FIG. 7.

In the present embodiment, the color filter 40 thus constructed is disposed near the position of the stop 2 in the objective lens 1 as previously described, whereby the light beam from an object, not shown, has much of its magenta light stepwisely transmitted through the color filter 40 from the central portion thereof toward the B0 side of the marginal portion thereof and has much of its green light stepwisely transmitted through the color filter 40 from the central portion thereof toward the B1 side of the marginal portion thereof.

Thereby, even in an out-of-focus state, the color misregistration of a blurred image when a color image is color-reproduced can be prevented better than in the first embodiment shown in FIG. **1**, whereby a good color image is obtained.

FIG. **8** is a front view of a color filter according to a third embodiment of the present invention as it is seen in the direction B when it is disposed at the position of the stop shown in FIG. **4**.

The color filter **80** in this embodiment is of the so-called gradient type in which the spectral characteristic of the color filter **80** continuously differs among the various portions thereof.

The density of this color filter **80** is controlled so as to be continuously higher that is, higher in the transmission factor for the subject color light, from the central portion thereof toward the marginal portion thereof (the C0 and C1 sides).

The color filter **80** thus constructed is disposed near the position of the stop in the objective lens **1** as in the aforedescribed embodiments, whereby the light beam from the object is controlled so that much of magenta light may be continuously transmitted through the color filter **80** from the central portion thereof toward the C0 side of the marginal portion thereof and much of green light may be continuously transmitted through the color filter **80** from the central portion thereof toward the C1 side of the marginal portion thereof.

Thereby, when even in an out-of-focus state, a color image is color-reproduced, there can be obtained the effect that the color misregistration of a blurred image can hardly be recognized.

As a method of making the color filter of the present embodiment, for example, a glass plate, a magenta filter and a green filter are stuck to one another in a wedge-like fashion and polished and shaped into a parallel flat plate.

As described above, according to the present invention, when the light beam from the objective lens is to be resolved into a plurality of color lights of different wavelength bands through a plurality of prisms and object images are to be formed on image pickup plates for respective color resolving systems, spectral characteristic control means whose spectral transmission factor is partly controlled, for example, a color filter or the like, is disposed near the position of the stop in the objective lens, whereby there can be achieved a photo-taking lens having spectral characteristic control means suitable, for example, for a TV camera, a video camera or the like which can improve the quality of the image without creating any color misregistration when a color image is color-reproduced even in an out-of-focus state.

What is claimed is:

1. An objective lens unit disposed forwardly of a prism block for dividing light into a plurality of light components, said objective lens unit comprising:

optical conveying means for conveying light beams from an object along an optical light path; and

an optical unit disposed in the optical light path and differing in the transmission factor for a wavelength depending on the areas of said optical unit.

2. An objective lens unit according to claim **1**, further having a stop and wherein said optical unit is positioned near said stop.

3. An objective lens unit according to claim **1**, wherein said optical unit is more deeply colored in the peripheral area thereof than in the central area thereof.

4. An objective lens unit according to claim **3**, wherein said transmission factor varies by small amounts.

5. An objective lens unit according to claim **3**, wherein said optical unit has a predetermined transmission factor characteristic in an area thereof located in a predetermined direction away from the optic axis of said objective lens unit, and has another transmission factor characteristic in an area there located in the direction opposite to said predetermined direction and away from the optic axis of said objective lens unit.

6. An objective lens according to claim **5**, wherein the area located in said predetermined direction away from the optic axis of said objective lens unit has a magenta-like color, and the area far in the opposite direction has a green-like color.

7. A photographing system including:

an objective lens unit comprising both:

optical conveying means for conveying light beams from an object along an optical light path; and

an optical filter differing in the transmission factor for wavelength depending on the areas thereof and disposed in the optical light path; and

a prism block positioned adjacent to the image plane side of said objective lens unit and having dichroic film and dividing light emerging from said objective lens unit into a plurality of color components.

8. A photographing system according to claim **7**, further having a stop and wherein said optical filter is positioned near said stop.

9. A photographing system according to claim **7**, wherein said optical filter is more deeply colored in the peripheral area thereof than in the central area thereof.

10. A photographing system according to claim **9**, wherein said transmission factor varies by small amounts.

11. A photographing system according to claim **9**, wherein said optical filter has a predetermined transmission factor characteristic in an area thereof located in a predetermined direction away from the optic axis of said object lens unit, and has another transmission factor characteristic in an area thereof located in the direction opposite to said predetermined direction and away from the optic axis of said objective lens unit.

12. A photographing system according to claim **11**, wherein the area located in said predetermined direction away from the optic axis of said objective lens unit has a magenta-like color, and the area far in the opposite direction has a green-like color.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 5,251,068
DATED : October 5, 1993
INVENTOR(S) : OSHIMA, ET AL.

It is certified that error appears in the above-indentified patent and that said Letters Patent is hereby corrected as shown below:

COLUMN 2:

Line 32, "has" should read --have--.

COLUMN 3:

Line 5 , "of" should be deleted; and
Line 62, "of" should be deleted.

COLUMN 4:

Line 27, "f" should read --of--.

COLUMN 6:

Line 21, "lens" should read --lens unit--; and
Line 50, "object" should read --objective--.

Signed and Sealed this

Seventh Day of June, 1994

Attest:

BRUCE LEHMAN

Attesting Officer

Commissioner of Patents and Trademarks

US005249012A

United States Patent [19]

Taniguchi et al.

[11] Patent Number: 5,249,012

[45] Date of Patent: * Sep. 28, 1993

[54] **AUTO-FOCUSING SYSTEM FOR CAMERAS WITH IN INTERCHANGEABLE OBJECTIVE LENS**

[75] Inventors: **Nobuyuki Taniguchi**, Tondabayashi; **Takeshi Egawa**, Sennan; **Tohru Matsui**, Sakai; **Takanobu Omaki**, Sennan; **Norio Ishikawa**, Osaka; **Akiyoshi Nakamura**, Sakai; **Shuzo Matsushita**, Ikeda, all of Japan

[73] Assignee: **Minolta Camera Kabushiki Kaisha**, Osaka, Japan

[*] Notice: The portion of the term of this patent subsequent to Jul. 29, 2003 has been disclaimed.

[21] Appl. No.: **864,392**

[22] Filed: **Apr. 6, 1992**

Related U.S. Application Data

[60] Division of Ser. No. 154,540, Feb. 5, 1988, Pat. No. 5,130,734, which is a continuation of Ser. No. 828,653, Feb. 12, 1986, abandoned, which is a continuation of Ser. No. 561,972, Dec. 16, 1983, Pat. No. 4,602,861.

[30] **Foreign Application Priority Data**

Dec. 23, 1982 [JP] Japan 57-229143
Dec. 29, 1982 [JP] Japan 57-228554
Jan. 17, 1983 [JP] Japan 58-6027
Feb. 8, 1983 [JP] Japan 58-19103

[51] **Int. Cl.**[5] **G03B 13/36**
[52] **U.S. Cl.** **354/402**
[58] **Field of Search** 354/402, 403, 406, 407, 354/408, 486

[56] **References Cited**

U.S. PATENT DOCUMENTS

4,509,842 4/1985 Taniguchi et al. 354/402
4,602,861 7/1986 Taniguchi et al. 354/403

Primary Examiner—W. B. Perkey
Attorney, Agent, or Firm—Watson, Cole, Grindle & Watson

[57] **ABSTRACT**

An auto-focusing system includes a focus condition detector which detects focus condition based on the infrared light. A data producer is provided for producing a deflection signal indicating a difference between an image forming distance for the infrared light and that for the visible light, due to aberration. In accordance with the detected focus condition and deflection signal, an objective lens is shifted to a position for properly focusing an image of visible light on an image forming plane.

25 Claims, 16 Drawing Sheets

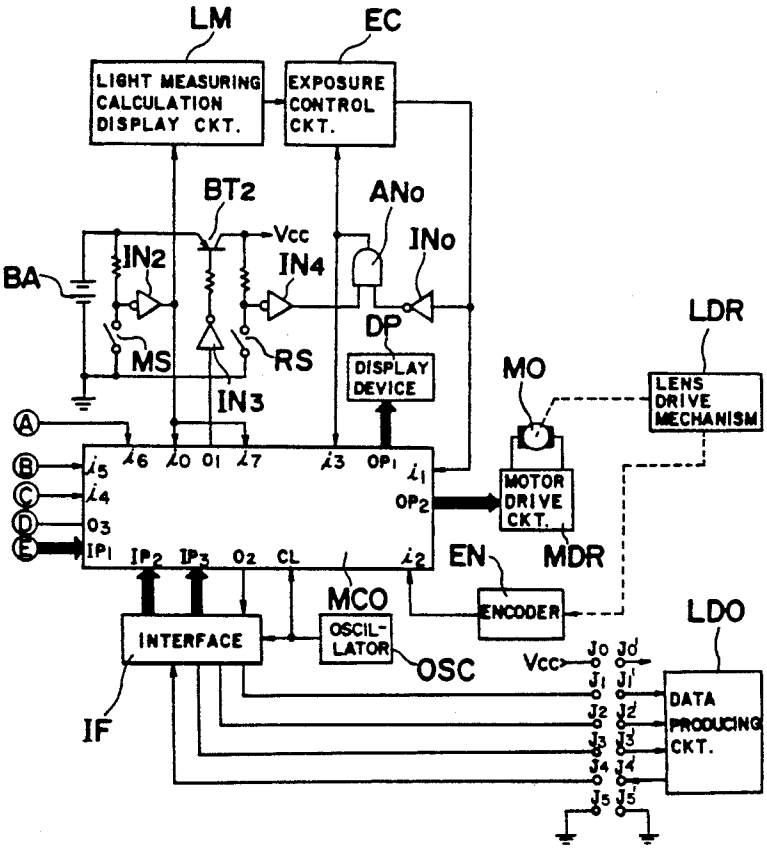
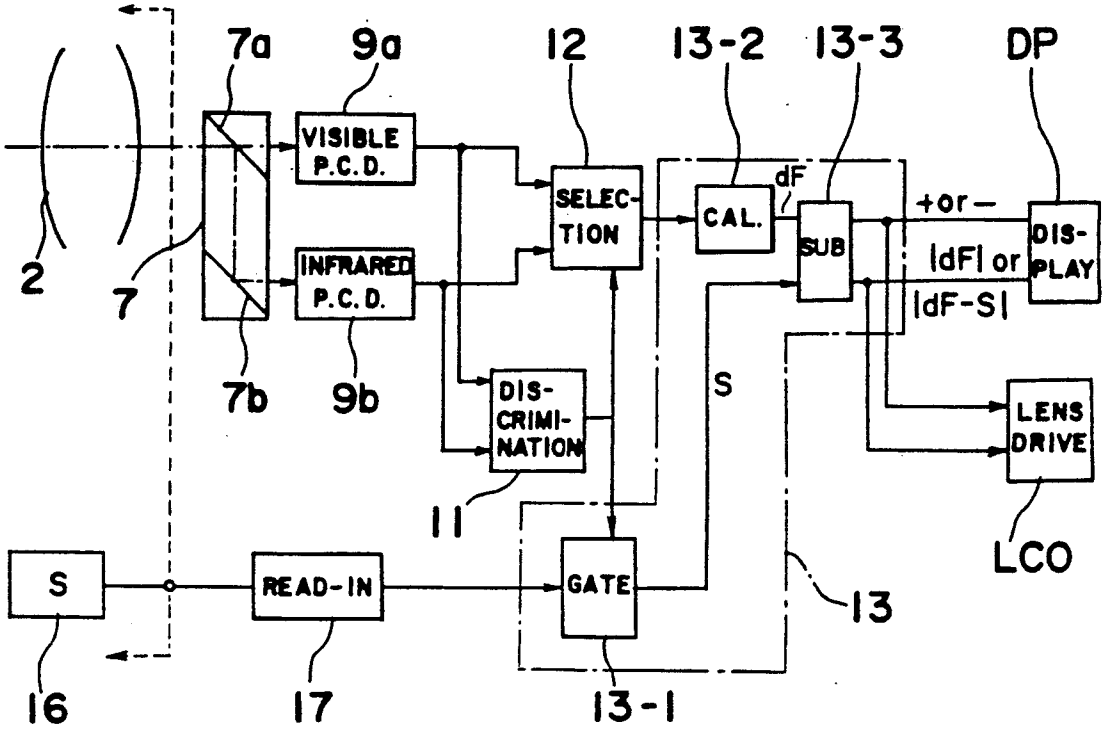


Fig. 1a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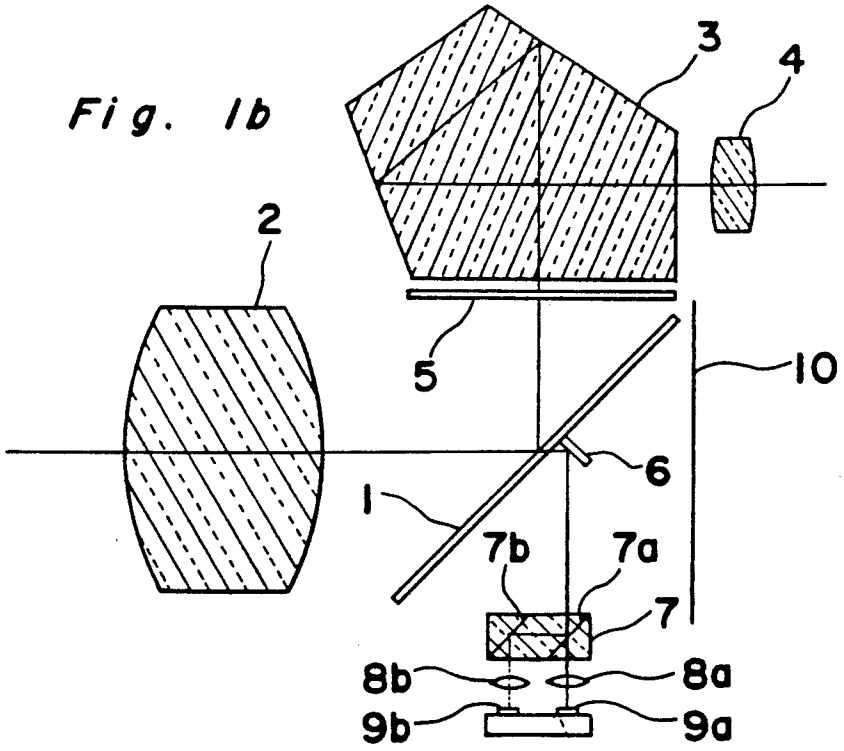
9a
12
13-2
13-3
DP
VISIBLE P.C.D.
INFRARED P.C.D.
SELEC-TION
CAL.
dF
SUB
+or−
|dF| or |dF-S|
DIS-PLAY
2
7
7b
9b
DIS-CRIMI-NATION
11
S
LENS DRIVE
LCO
S
READ-IN
GATE
13
16
17
13-1

Fig. 1b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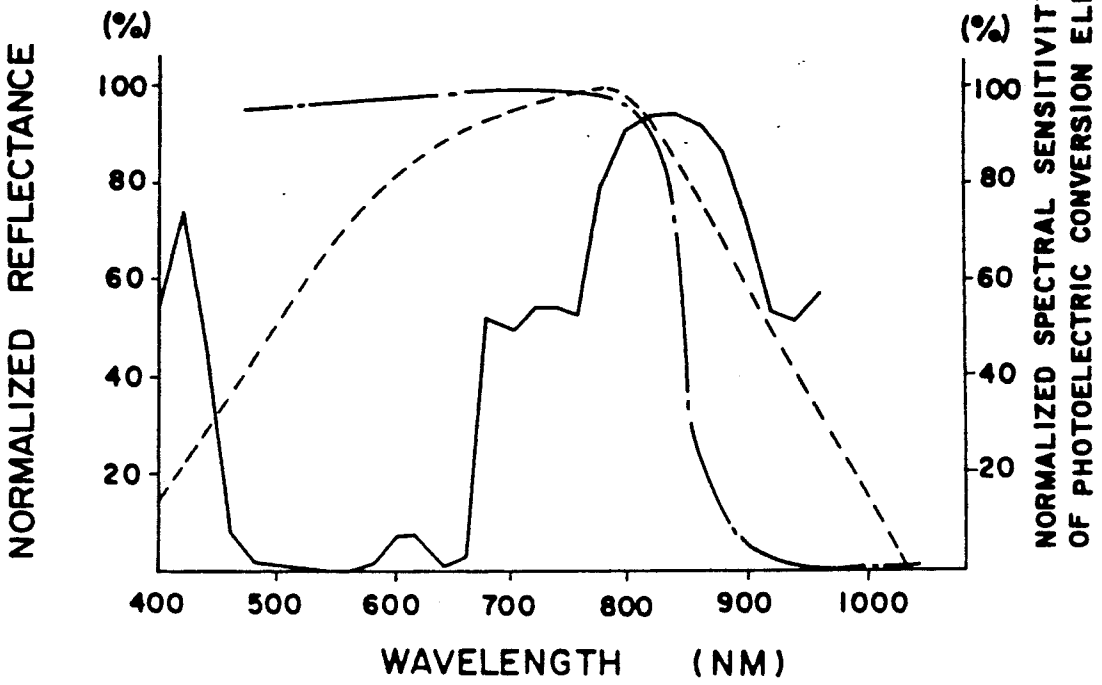
5
10
6
1
7b
7a
7
8b
8a
9b
9a

Fig. 2a


NORMALIZED REFLECTANCE
(%)
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60
40
20
400
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600
700
800
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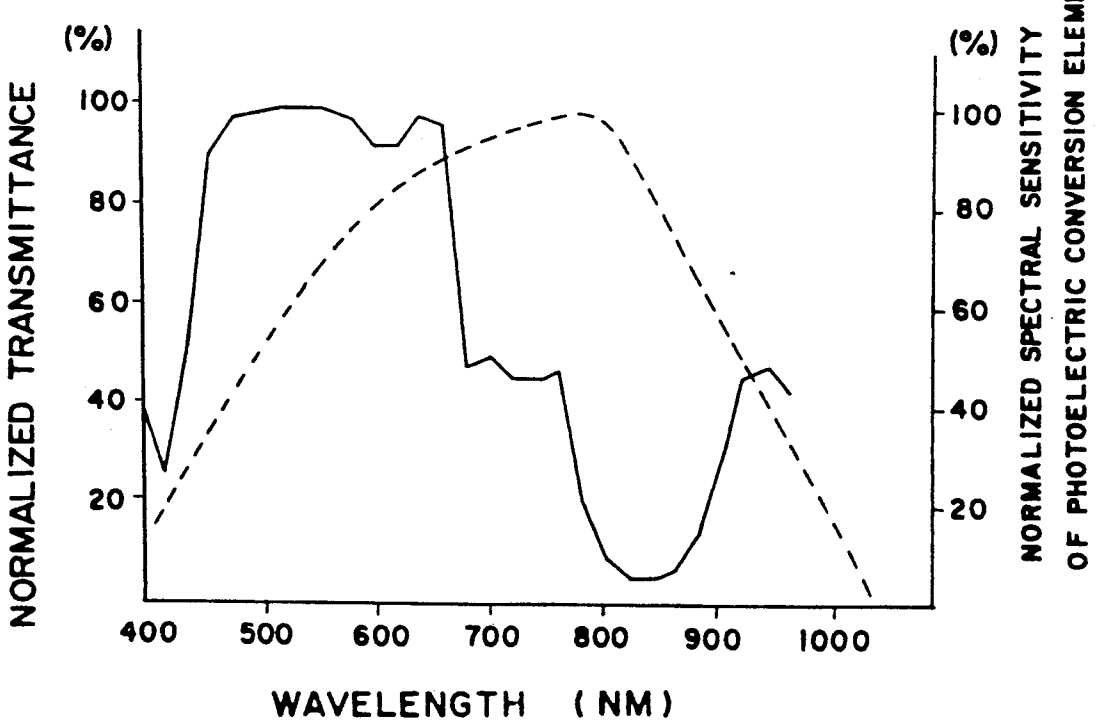
WAVELENGTH (NM)
(%)
NORMALIZED SPECTRAL SENSITIVITY OF PHOTOELECTRIC CONVERSION ELEMENT

Fig. 2b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500
600
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NORMALIZED SPECTRAL SENSITIVITY OF PHOTOELECTRIC CONVERSION ELEMENT

Fig. 3

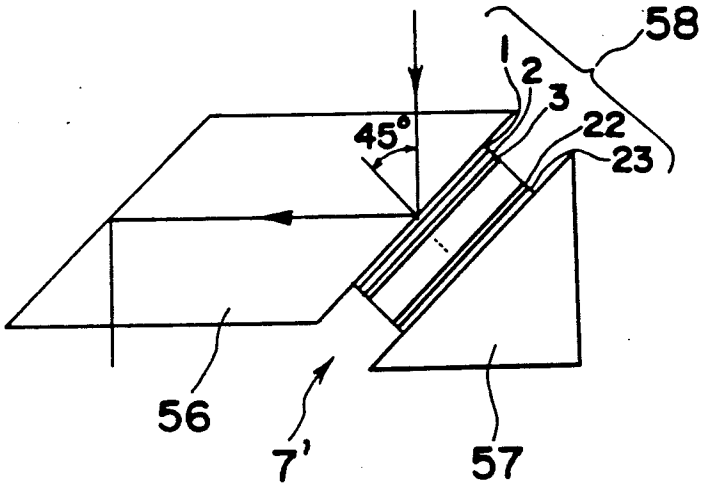
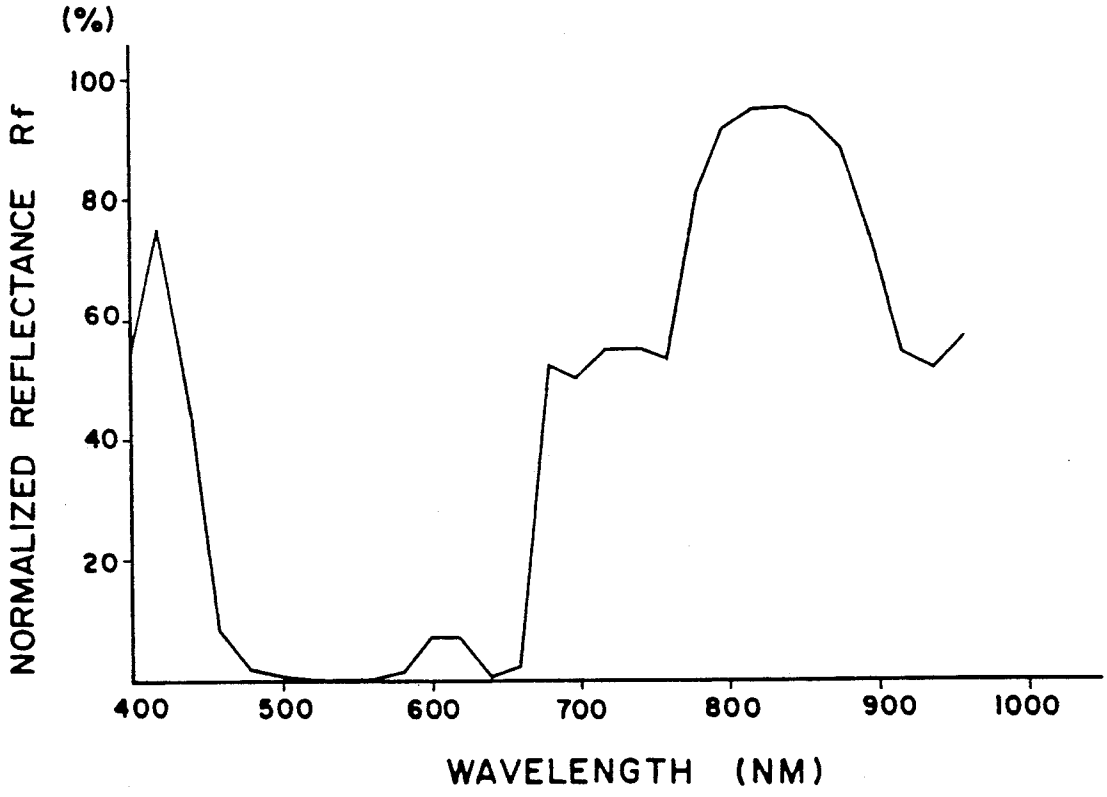

58
1
2
3
22
23
45°
56
7'
57

Fig. 4


(%)
100
80
60
40
20
NORMALIZED REFLECTANCE Rf
400
500
600
700
800
900
1000
WAVELENGTH (NM)

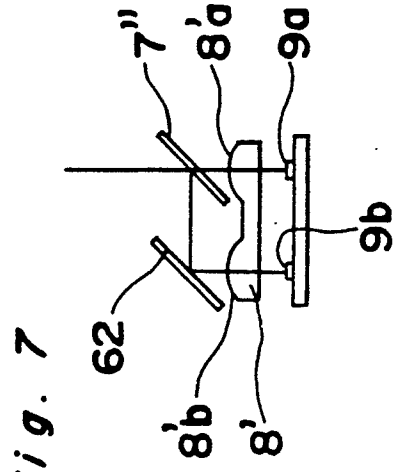


Fig. 7

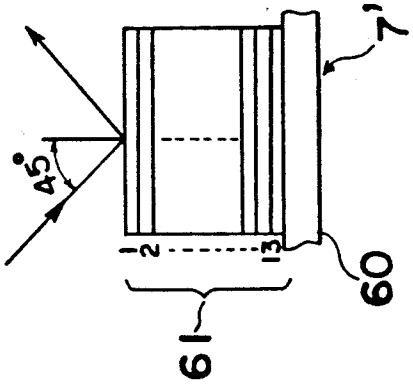


Fig. 5

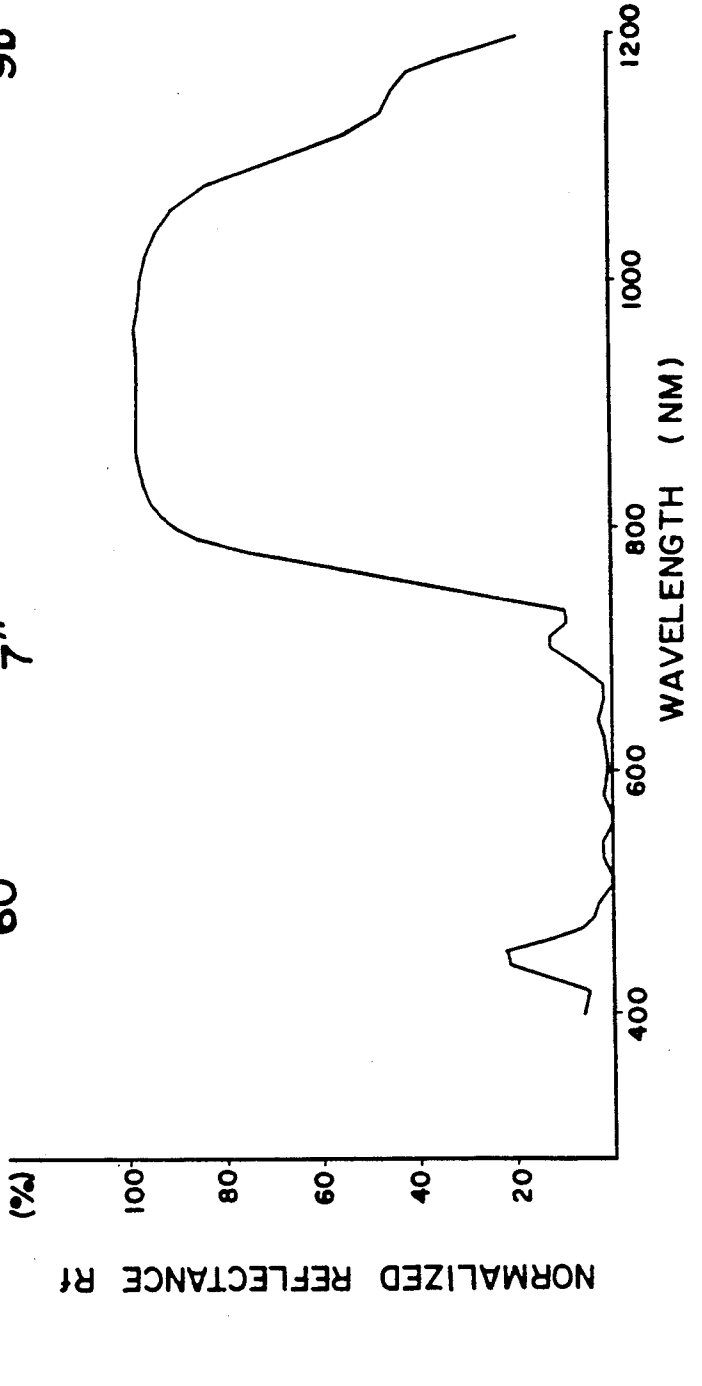
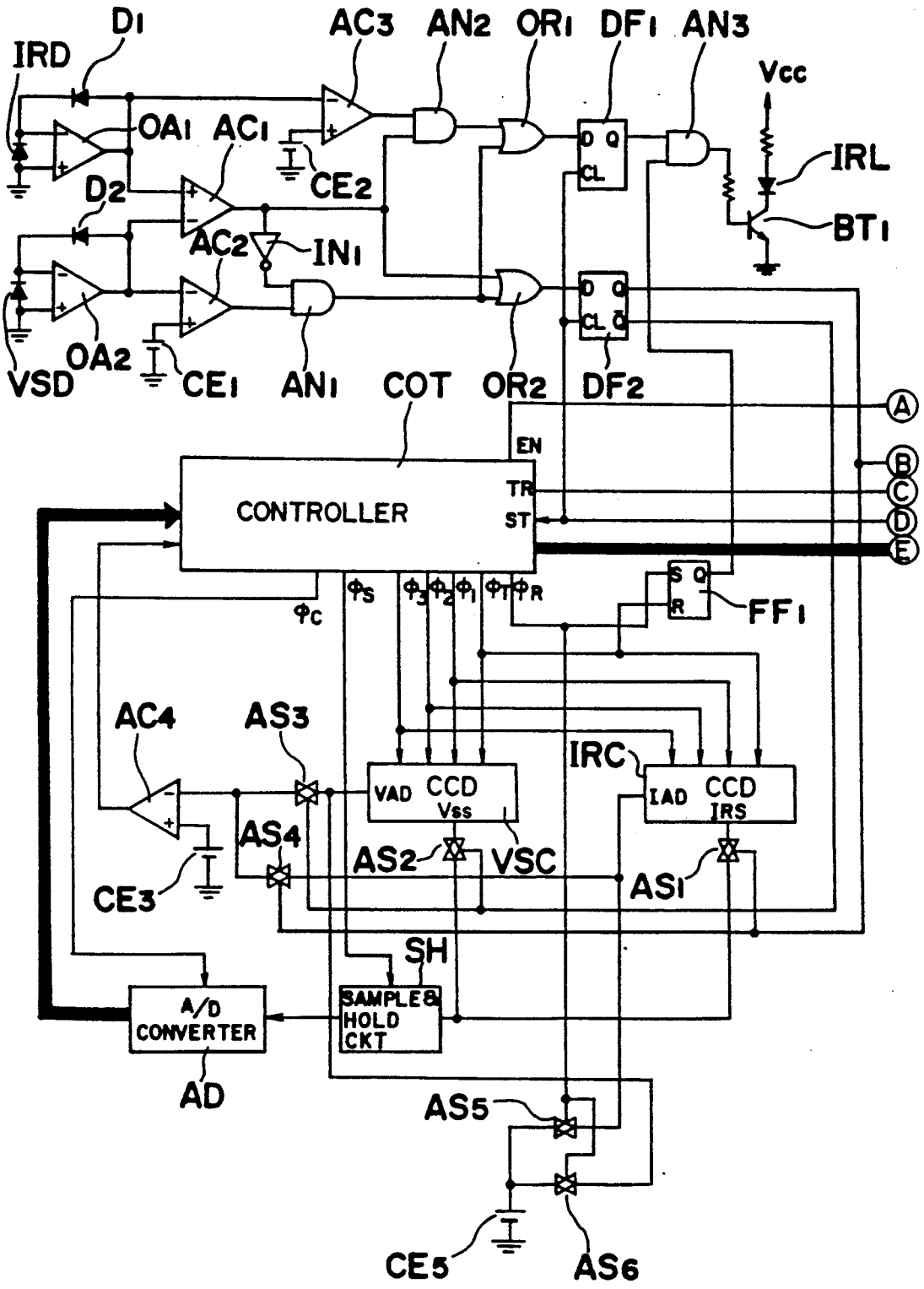


Fig. 6

Fig. 8a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IRD
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AN2
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DF1
AN3
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OA1
AC1
CE2
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D2
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OA2
VSD
CE1
AN1
COT
OR2
DF2
A
B
C
D
E
EN
CONTROLLER
TR
ST
φC
φS
φ3
φ2
φ1
φT
φR
FF1
AC4
AS3
IRC
VAD
CCD
Vss
IAD
CCD
IRS
AS4
AS2
VSC
AS1
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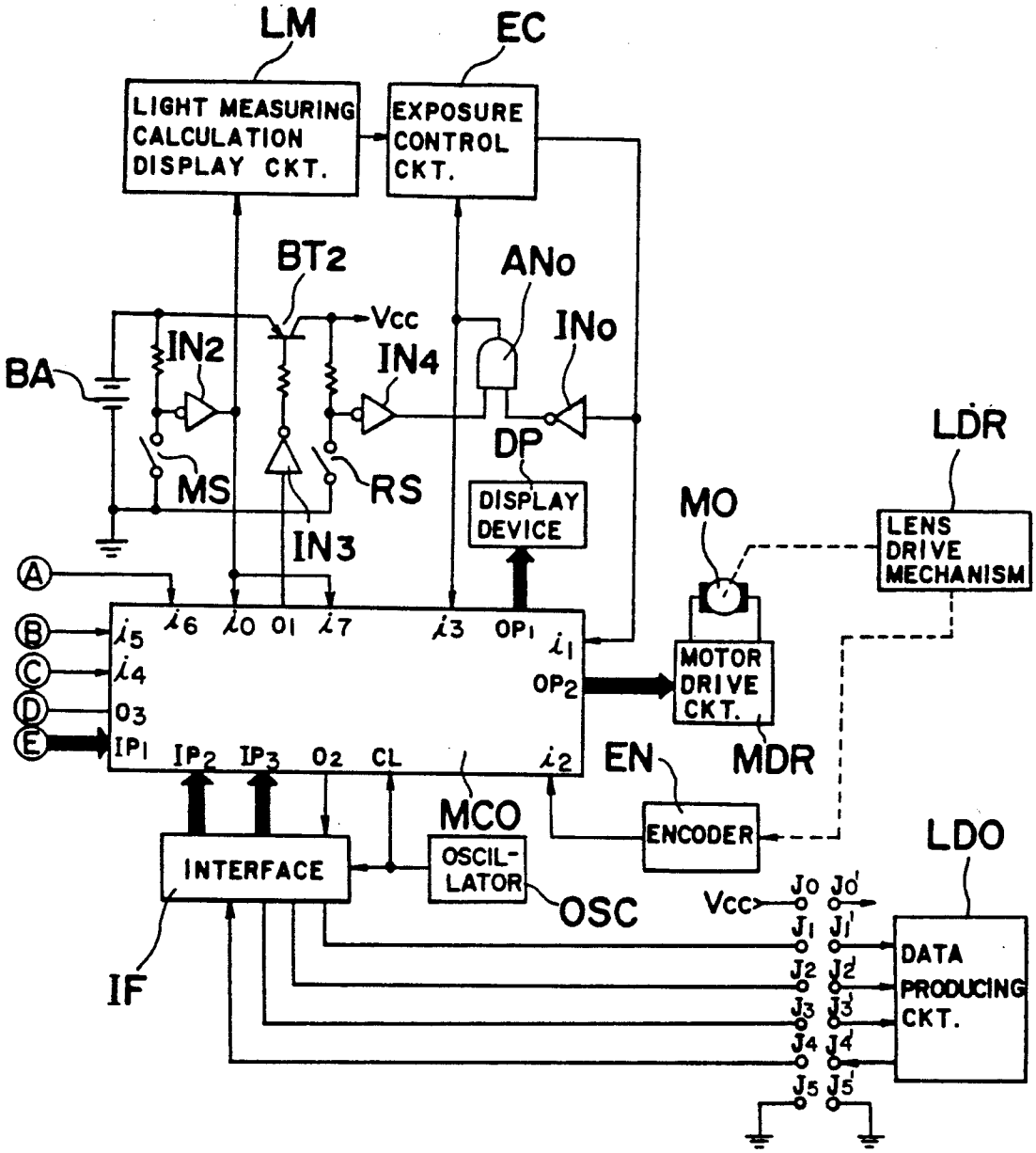
CONVERTER
SAMPLE&
HOLD
CKT
AD
AS5
CE5
AS6

Fig. 8b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EXPOSURE CONTROL CKT.
BT2
ANo
INo
Vcc
IN2
IN4
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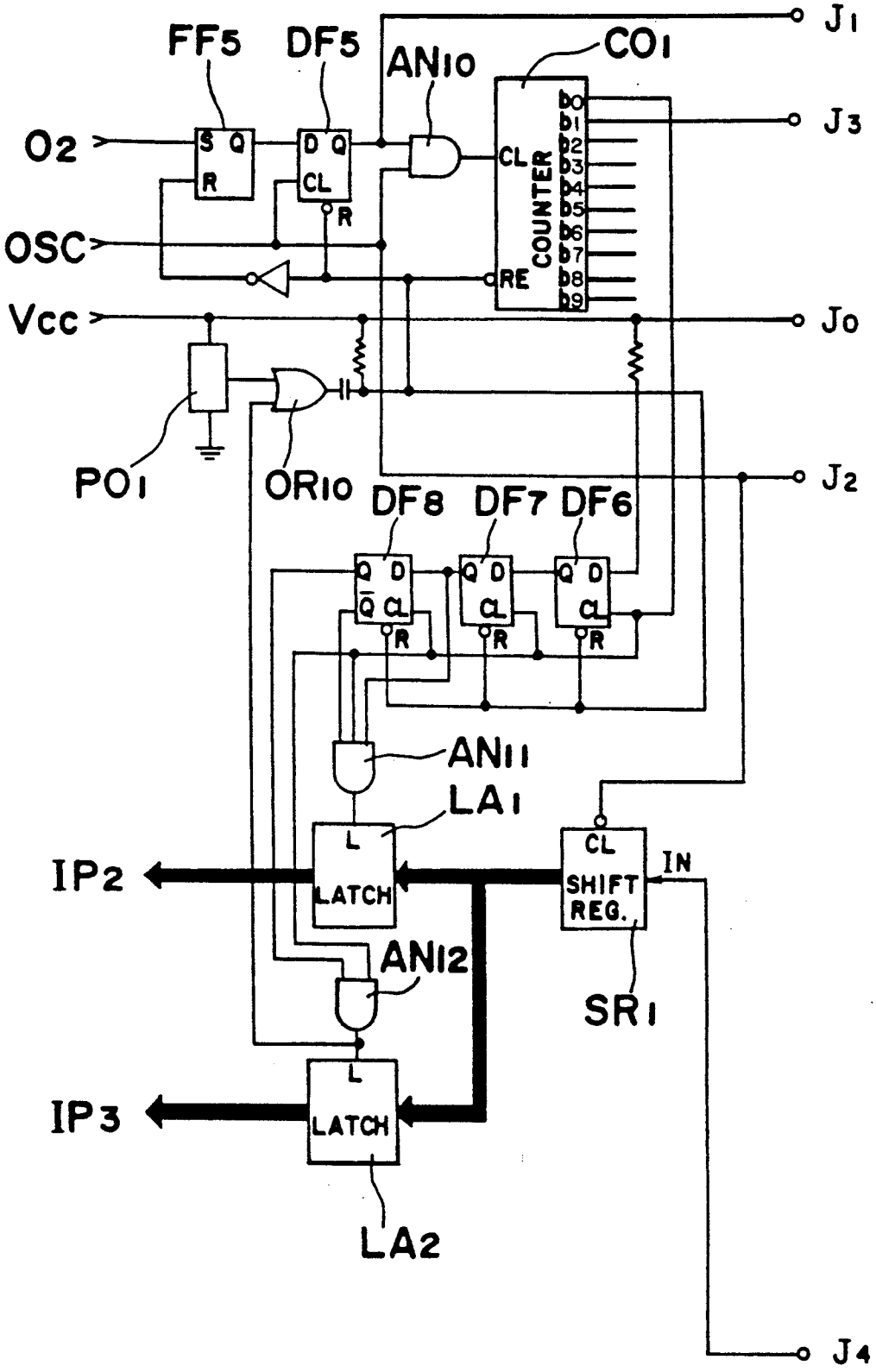
RS
IN3
DP
DISPLAY DEVICE
LDR
MO
LENS DRIVE MECHANISM
A
B
C
D
E
i5
i6
i0
01
i7
i3
OP1
i1
i4
OP2
MOTOR DRIVE CKT.
03
IP1
IP2
IP3
02
CL
i2
EN
MDR
MCO
ENCODER
LDO
INTERFACE
OSCIL-LATOR
OSC
Vcc
J0
J0'
J1
J1'
J2
J2'
J3
J3'
J4
J4'
J5
J5'
DATA PRODUCING CKT.
IF

Fig. 9a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DF5
AN10
CO1
O2
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R
D Q
CL
R
CL
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b3
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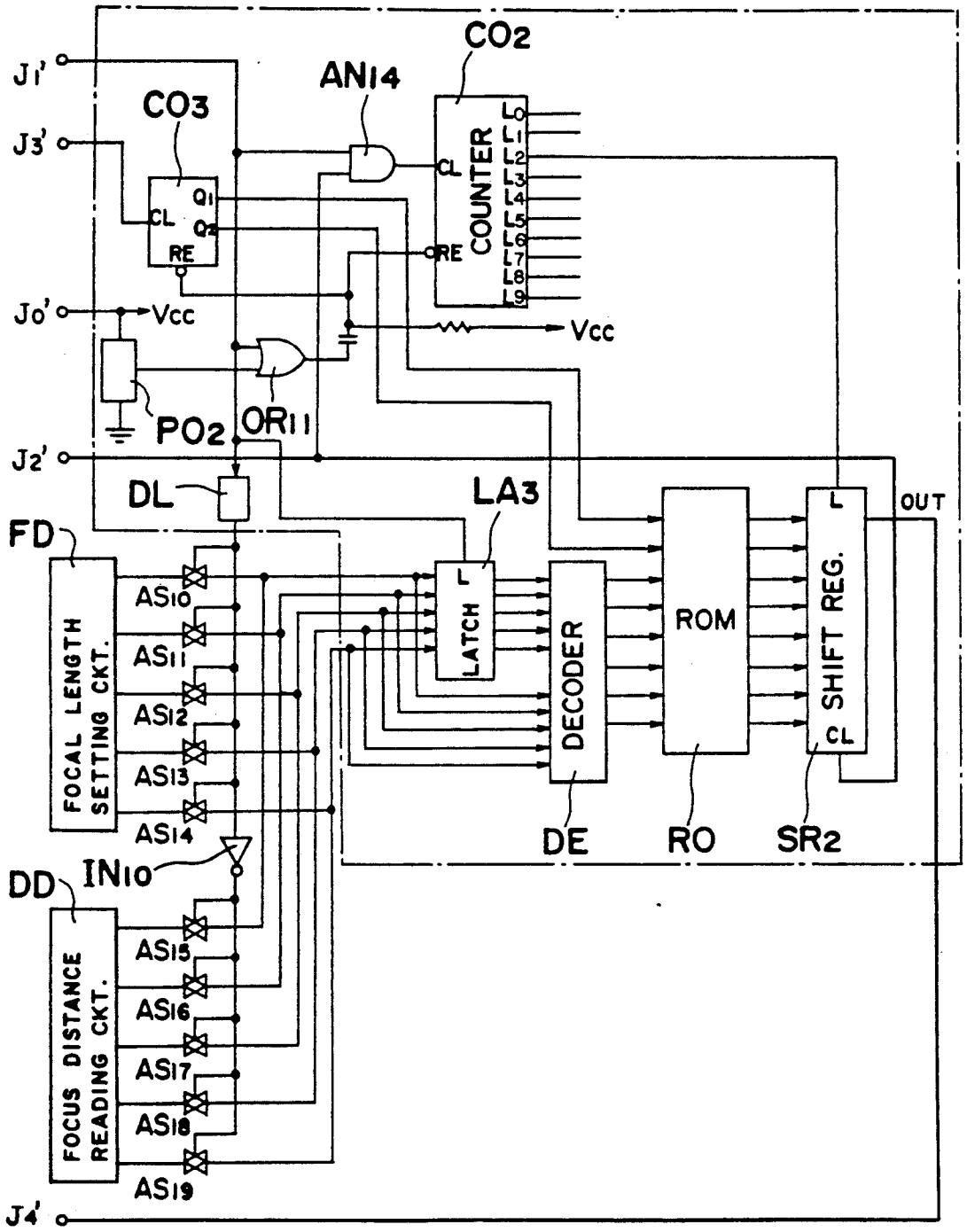
b5
b6
b7
b8
b9
J3
OSC
RE
Vcc
Jo
PO1
OR10
J2
DF8
DF7
DF6
Q D
Q CL
R
AN11
LA1
L
LATCH
IP2
CL
SHIFT REG.
IN
AN12
SR1
IP3
LA2
J4

Fig. 9b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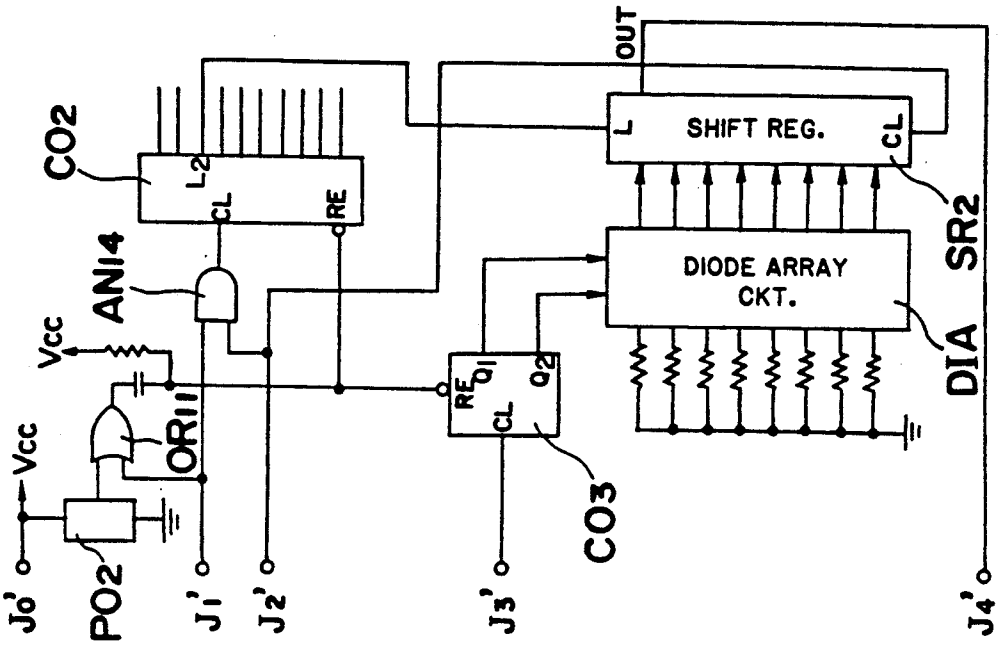
J3'
Jo'
J2'
J4'
CO2
AN14
CO3
COUNTER
CL
RE
Q1
Q2
L0
L1
L2
L3
L4
L5
L6
L7
L8
L9
Vcc
Vcc
PO2
OR11
DL
LA3
FD
FOCAL LENGTH SETTING CKT.
AS10
AS11
AS12
AS13
AS14
LATCH
DECODER
ROM
SHIFT REG.
OUT
DE
RO
SR2
DD
IN10
FOCUS DISTANCE READING CKT.
AS15
AS16
AS17
AS18
AS19

Fig. 11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L
CL
SR2
DIODE ARRAY CKT.
DIA
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L2
CL
RE
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Q1
Q2
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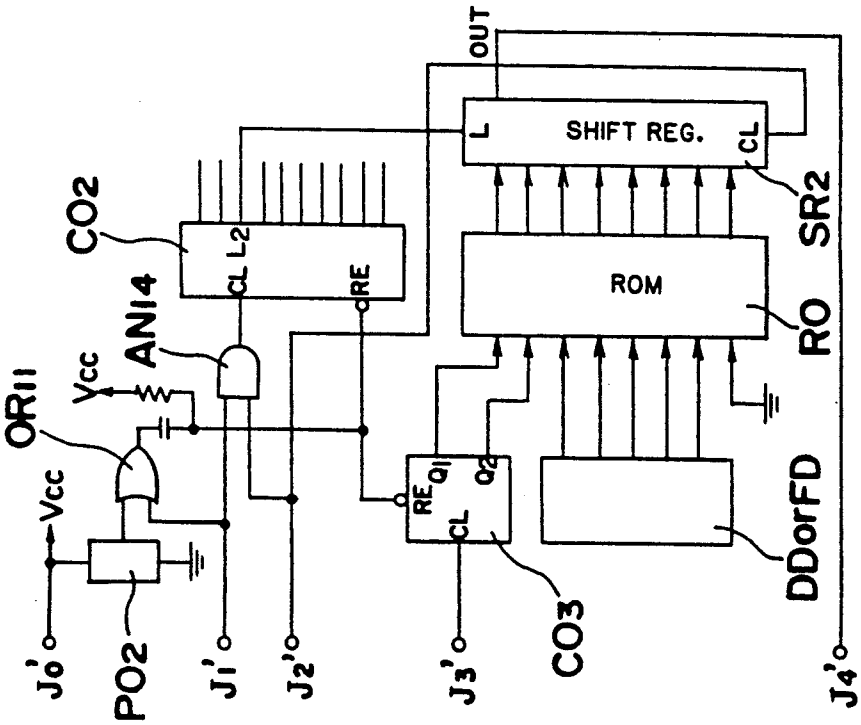
CO3
Jo'
PO2
J1'
J2'
J3'
J4'

Fig. 10


OUT
SHIFT REG.
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SR2
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CO2
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AN14
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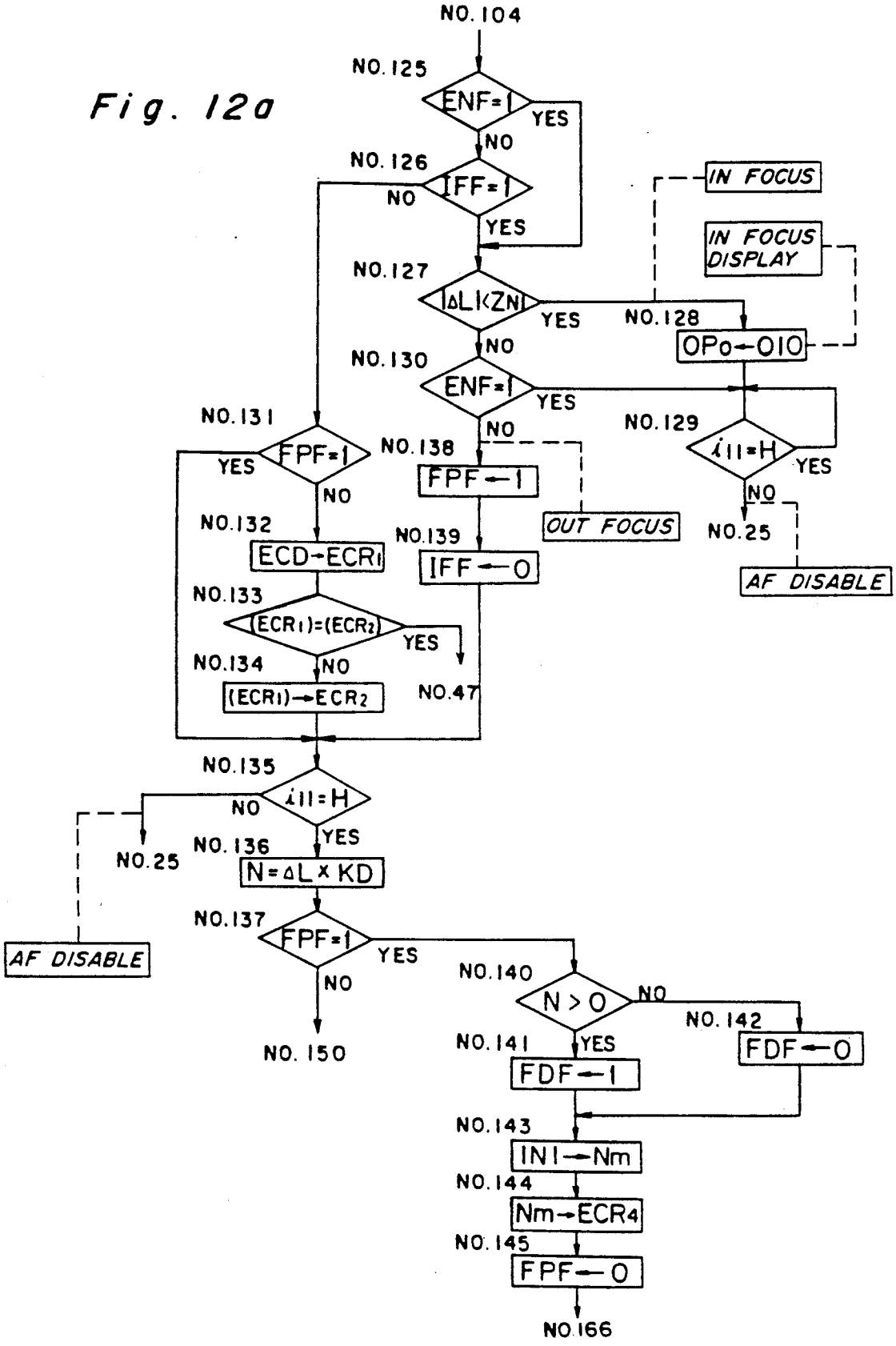
RE
Q1
Q2
CL
CO3
Jo'
PO2
J1'
J2'
J3'
J4'

Fig. 12a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NO
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IN FOCUS DISPLAY
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NO.130
ENF=1
YES
NO.131
FPF=1
YES
NO
NO.138
FPF←1
NO.129
AF=H
YES
NO
OUT FOCUS
NO.25
AF DISABLE
NO.132
ECD→ECR1
NO.139
IFF←0
NO.133
(ECR1)=(ECR2)
YES
NO.134
NO
(ECR1)→ECR2
NO.47
NO.135
AF=H
NO
YES
NO.25
NO.136
N=ΔL×KD
AF DISABLE
NO.137
FPF=1
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NO.150
NO.140
N>0
NO
NO.142
FDF←0
NO.141
YES
FDF←1
NO.143
IN1←Nm
NO.144
Nm→ECR4
NO.145
FPF←0
NO.166

Fig. 12b

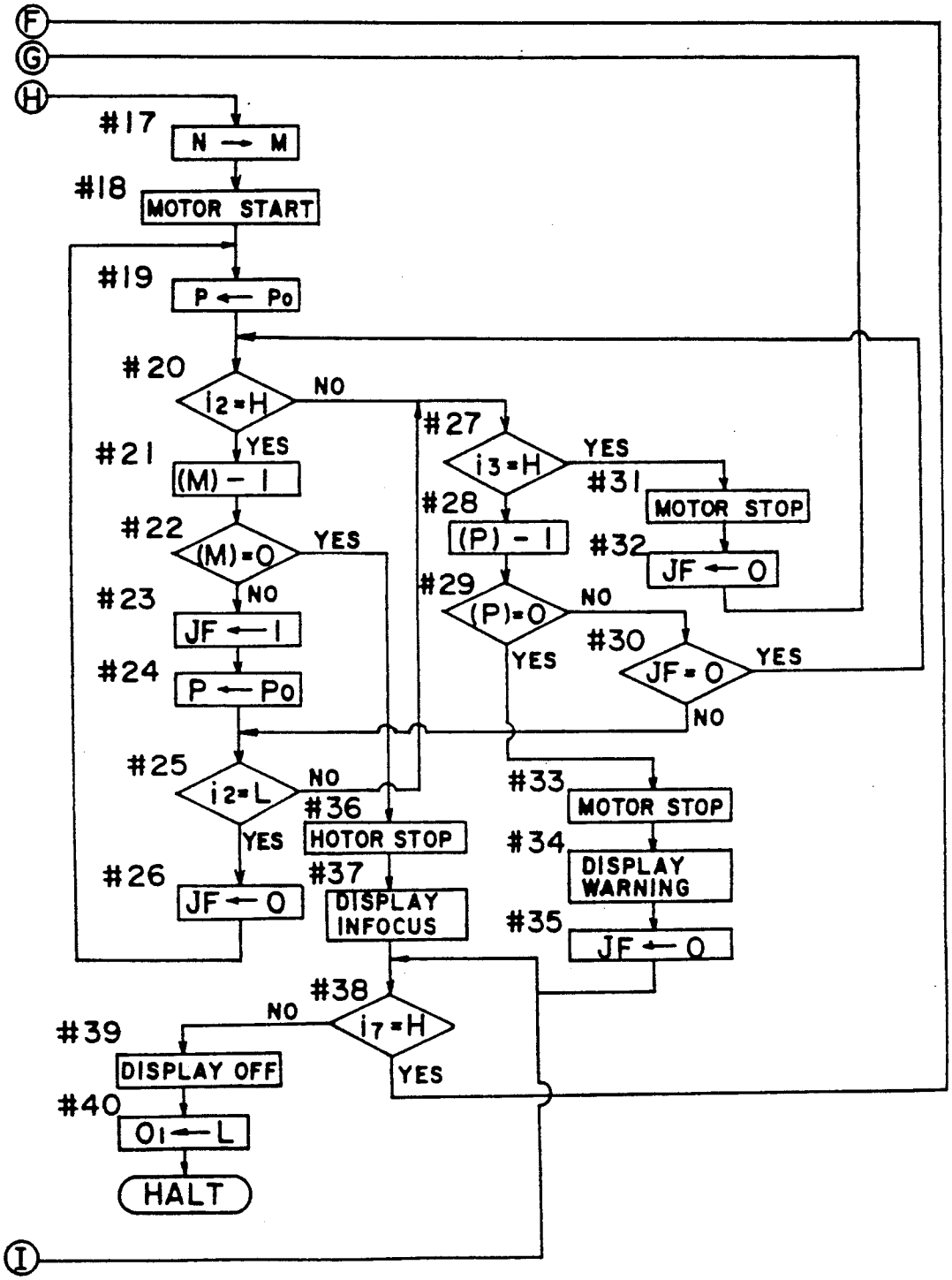

F
G
H
#17
N → M
#18
MOTOR START
#19
P ← Po
#20
i2=H
NO
YES
#21
(M) - 1
#22
(M)=0
YES
NO
#23
JF ← 1
#24
P ← Po
#25
i2=L
NO
YES
#26
JF ← 0
#27
i3=H
YES
#28
(P) - 1
#29
(P)=0
NO
YES
#30
JF=0
YES
NO
#31
MOTOR STOP
#32
JF ← 0
#33
MOTOR STOP
#34
DISPLAY WARNING
#35
JF ← 0
#36
HOTOR STOP
#37
DISPLAY INFOCUS
#38
i7=H
NO
YES
#39
DISPLAY OFF
#40
O1 ← L
HALT
I

Fig. 13

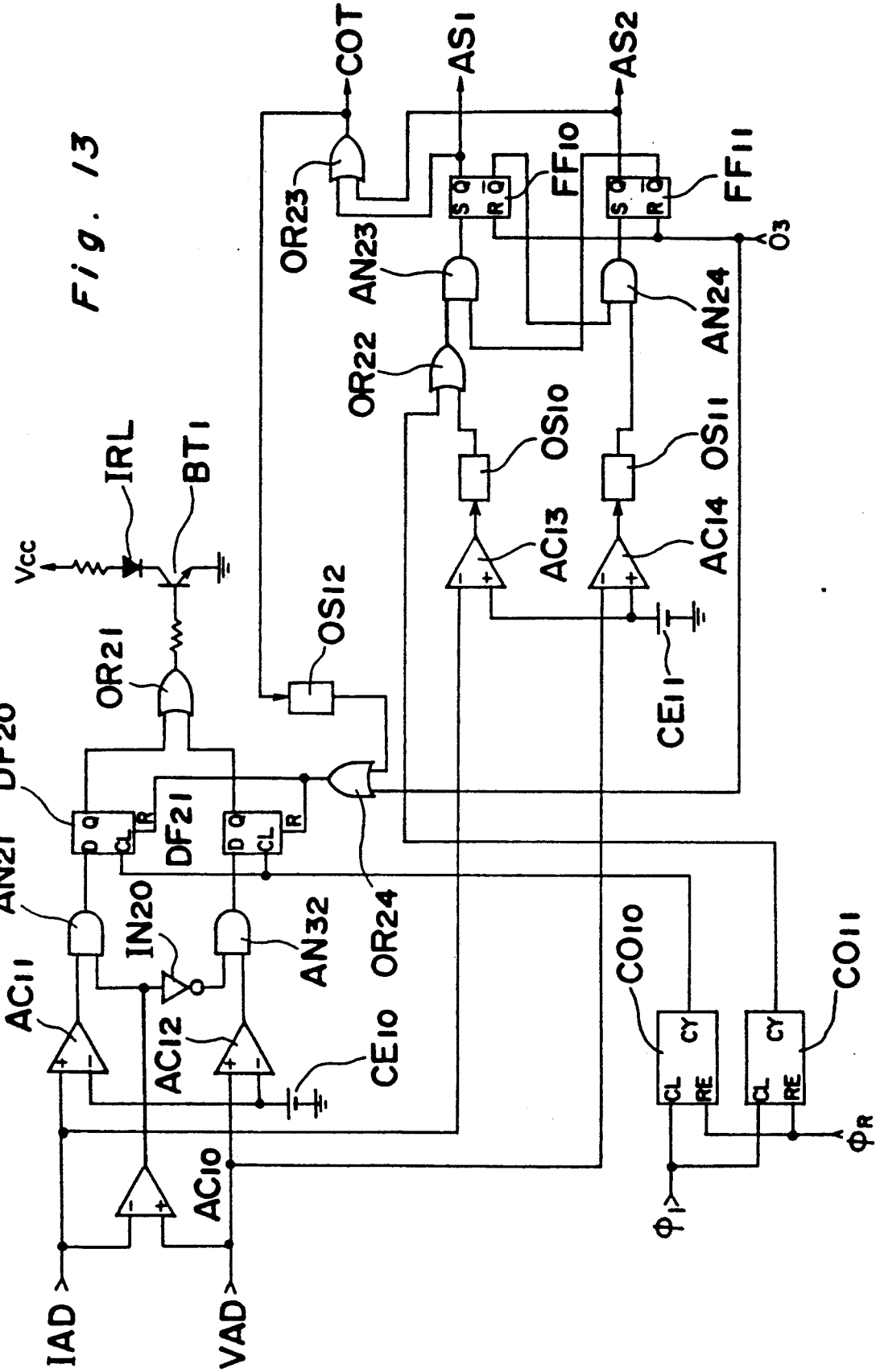

COT
AS1
AS2
OR23
FF10
FF11
AN23
AN24
O3
OR22
OS10
OS11
IRL
BT1
AC13
AC14
Vcc
OS12
CE11
OR21
DF20
DF21
AN21
IN20
AN32
OR24
AC11
AC12
CE10
CO10
CO11
AC10
IAD
VAD
CY
CL
RE
φR
φI

Fig. 14

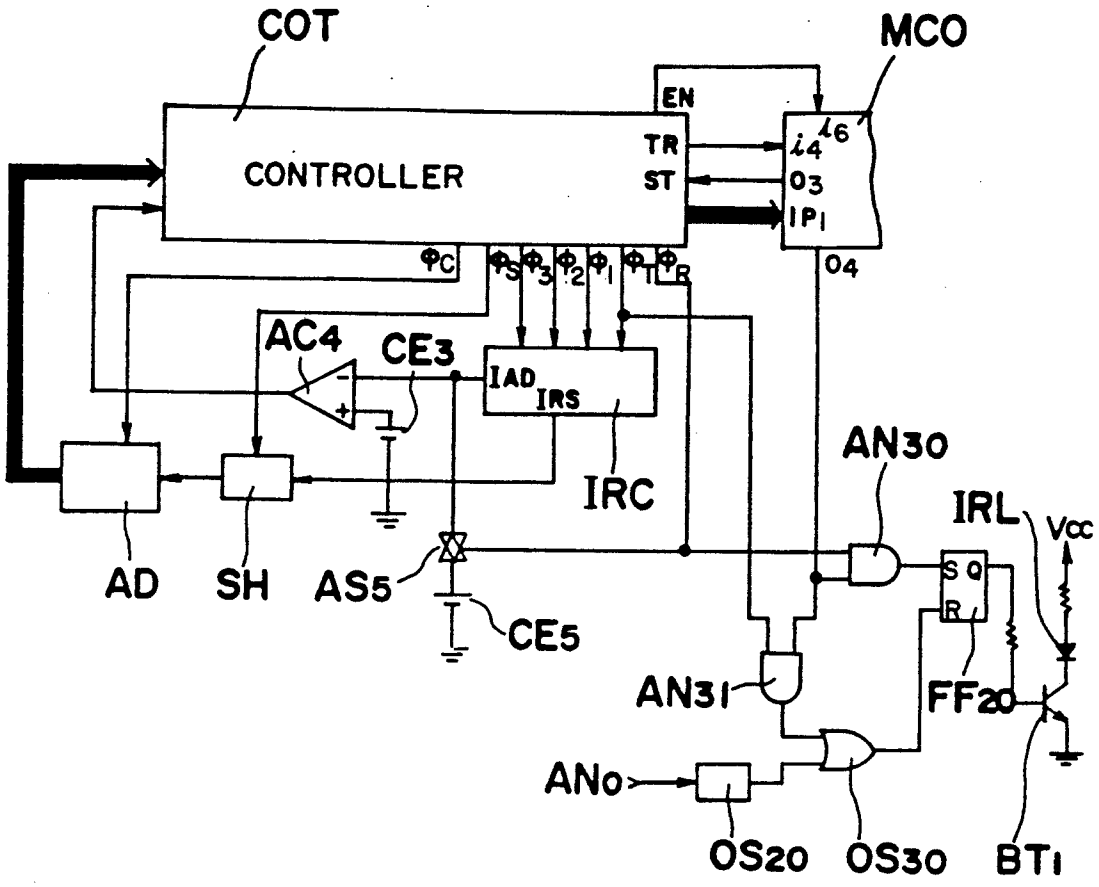

COT
MCO
EN
CONTROLLER
TR
ST
i4
i6
O3
IP1
O4
ΦC
ΦS
Φ3
Φ2
Φ1
ΦT
ΦR
AC4
CE3
IAD
IRS
IRC
AN30
IRL
Vcc
AD
SH
AS5
CE5
S
Q
R
AN31
FF20
ANo
OS20
OS30
BT1

Fig. 16

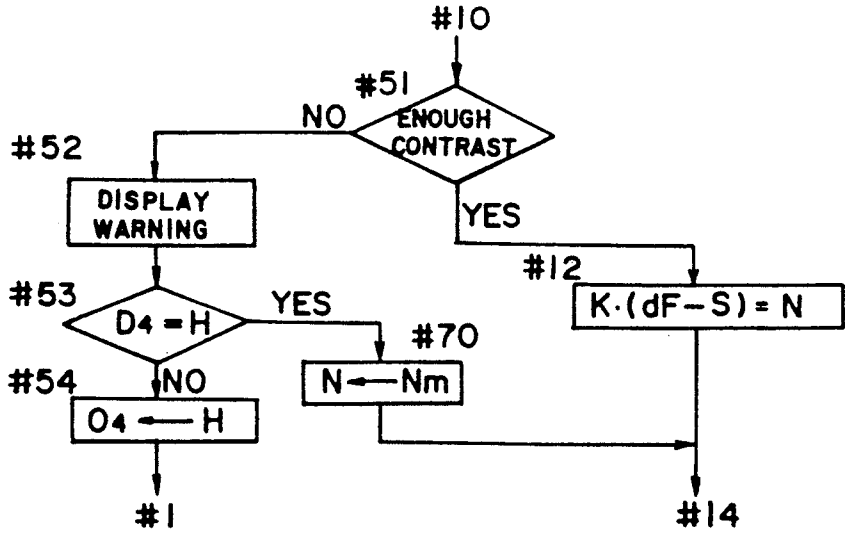

#10
#51
NO
ENOUGH CONTRAST
YES
#52
DISPLAY WARNING
#12
K·(dF−S)=N
#53
D4=H
YES
#70
N←Nm
#54
NO
O4←H
#1
#14

Fig. 15

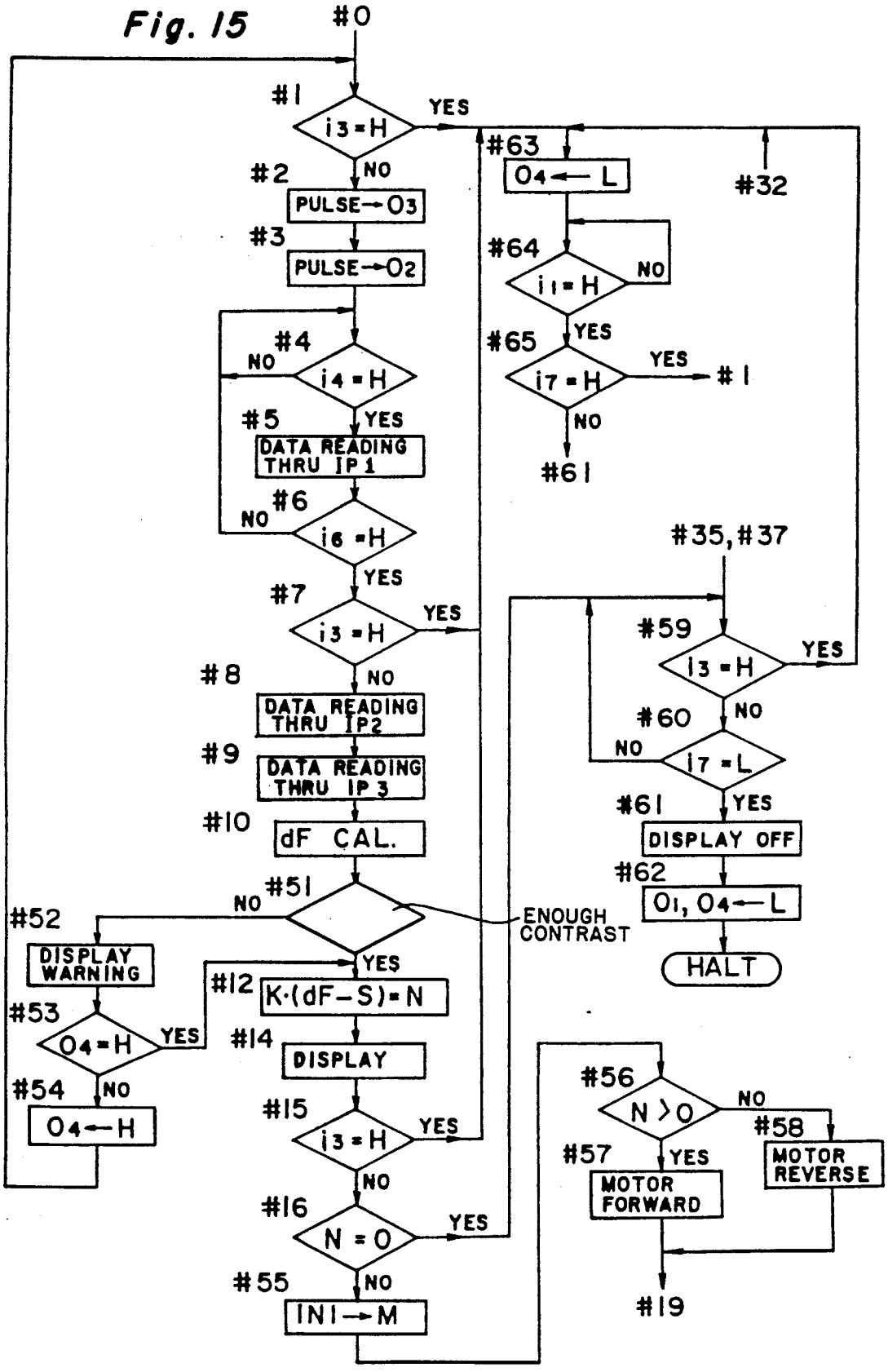

#0
#1
i3=H
YES
NO
#2
PULSE→O3
#3
PULSE→O2
#4
NO
i4=H
YES
#5
DATA READING THRU IP1
#6
NO
i6=H
YES
#7
i3=H
YES
NO
#8
DATA READING THRU IP2
#9
DATA READING THRU IP3
#10
dF CAL.
#51
NO
YES
ENOUGH CONTRAST
#52
DISPLAY WARNING
#53
O4=H
YES
NO
#54
O4←H
#12
K·(dF-S)=N
#14
DISPLAY
#15
i3=H
YES
NO
#16
N=0
YES
NO
#55
IN1→M
#63
O4←L
#64
i1=H
NO
YES
#65
i7=H
YES
#1
NO
#61
#32
#35,#37
#59
i3=H
YES
NO
#60
NO
i7=L
YES
#61
DISPLAY OFF
#62
O1, O4←L
HALT
#56
N>0
NO
YES
#57
MOTOR FORWARD
#58
MOTOR REVERSE
#19

Fig. 17

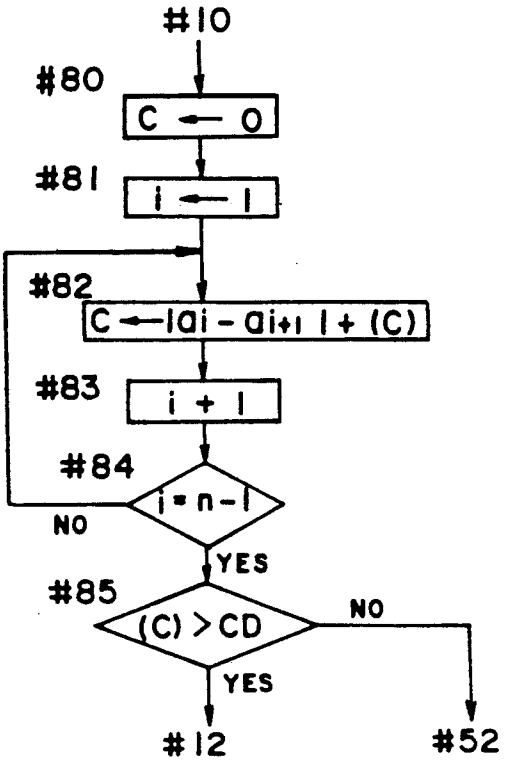


Fig. 18

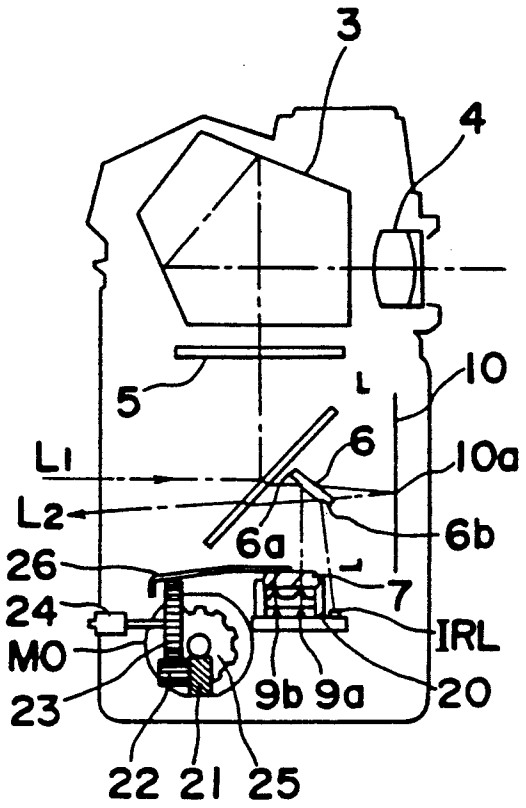


Fig. 19

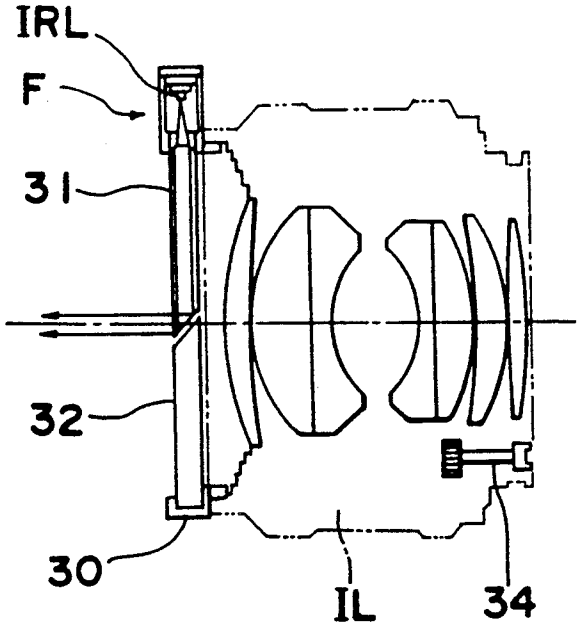


Fig. 20

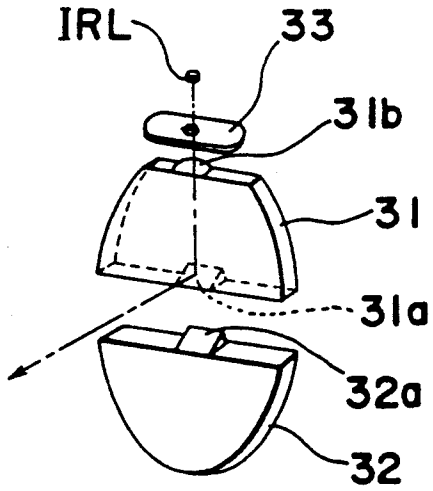
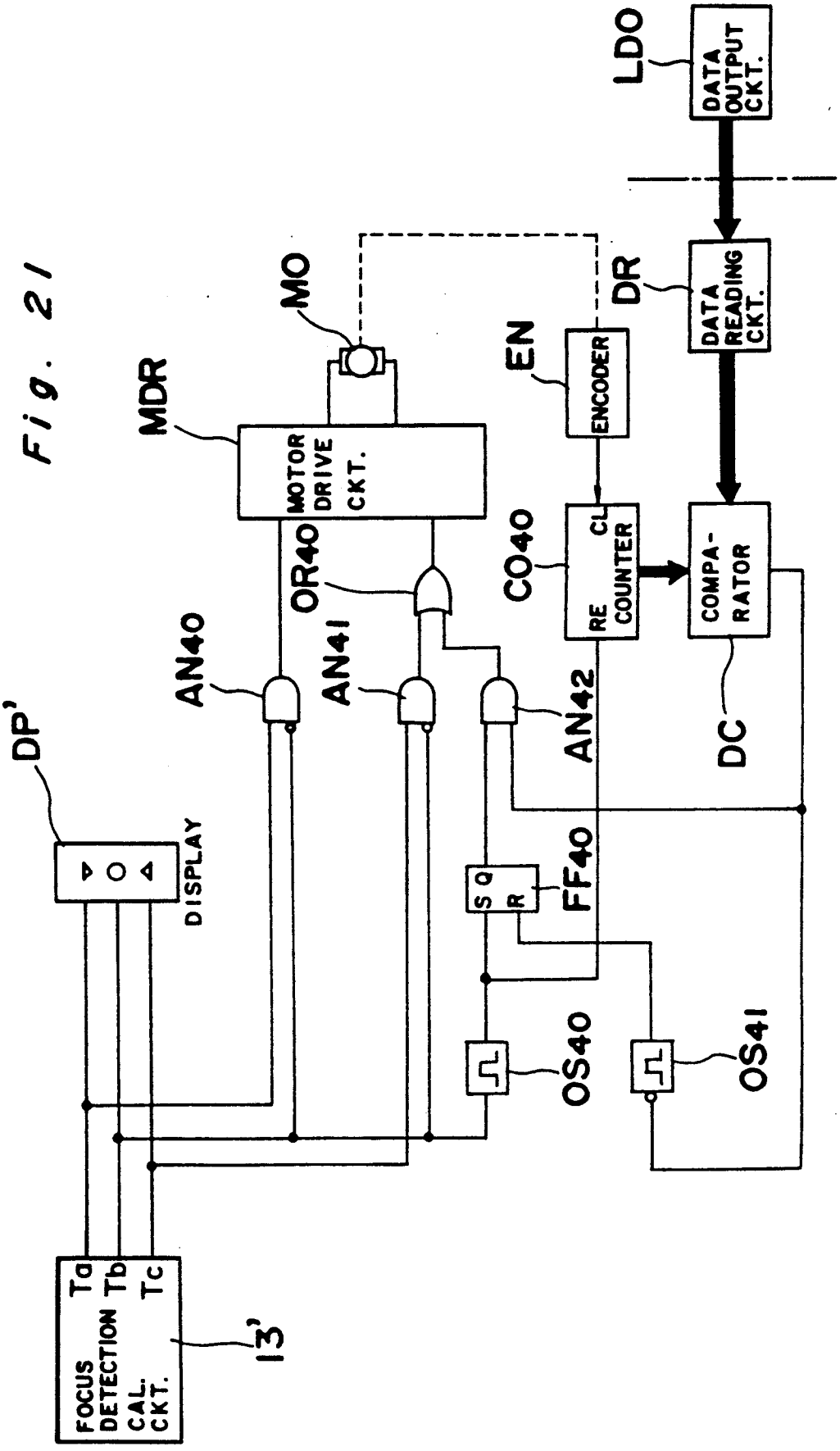


Fig. 21


LDO
DATA OUTPUT CKT.
DR
DATA READING CKT.
MO
MDR
MOTOR DRIVE CKT.
EN
ENCODER
CO40
CL
RE COUNTER
COMPA-RATOR
DC
OR40
AN40
AN41
AN42
DP'
DISPLAY
SQ
R
FF40
OS40
OS41
Ta
Tb
Tc
FOCUS DETECTION CAL. CKT.
13'

AUTO-FOCUSING SYSTEM FOR CAMERAS WITH IN INTERCHANGEABLE OBJECTIVE LENS

This application is a divisional application of application Ser. No. 154,540, filed Feb. 5, 1988, now U.S. Pat. No. 5,130,734 which is a continuation application of application Ser. No. 828,653, filed Feb. 12, 1986, and now abandoned, which is a continuation application of application Ser. No. 561,972, filed Dec. 16, 1983 and is now U.S. Pat. No. 4,602,861.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to an auto-focusing device and method of a camera of an interchangeable objective lens type and, more particularly, to an auto-focusing system wherein the reflected light from an object to be photographed passes through the objective lens of the interchangeable lens and forms an image on or near a predetermined image forming plane, which image is detected for detecting the degree of out of focus, thereby controlling the lens shift by the detected degree of out of focus. The present invention also relates to an interchangeable lens itself for use in the above described type of camera.

2. Description of the Prior Art

There have been conventionally proposed various types of the above described auto-focusing method, but most of them use visible light Therefore, when the intensity of the visible light is very weak, such as when the scenery is dark, it is very difficult to detect the focusing condition of the target object, resulting in an error control of the objective lens. Also, for detecting the image, a charge accumulating device, such as CCD, can be employed, but would result in a disadvantage that the charging period becomes long as the visible light becomes weak, resulting in long time of focus detection.

It is known in the art that the photoelectric conversion device, such as CCD or photodiode, for use in focus detection is generally more sensitive to infrared rays than the visible rays. Also, it is known in the art that the infrared rays reflect at a high rate even on a black object and also on an organic object.

From this view point, it is possible to detect, if the infrared rays are used for focus detection, the focusing condition of an object even if the object is located in a dark place, and consequently improving the focus detection ability.

But, on the other hand, if the infrared rays are used for focus detection, it takes a disadvantage that there will be a difference in focusing distance between the the infrared rays and the visible rays, due to color aberration, and such a difference varies as the type of an interchangeable lens mounted on a camera body changes. Therefore, unless a suitable correction is effected, a picture taken by an auto-focusing system using the infrared rays always results more or less in out of focus.

To remove the above disadvantage, an improved auto-focusing system is proposed in Japanese Patent Laid-open Publication (Tokkaisho) No. 57-154224, wherein a signal pin having a length corresponding to the focusing distance difference is provided to each interchangeable lens, and a focus detecting device having a means to correct the focusing distance difference by the signal pin are provided. According to the proposed device as described above, the signal pin extending from the lens must have a required strength to avoid undesirable break or bent, and also the signal pin should be positioned with a high accuracy to enable the precise correction. Also, the focus detecting device provided in the camera body will have a complicated structure, resulting in high manufacturing cost, and because of the complicated structure, it may not be able to correct the difference to the required degree due to the inaccuracy of size and positioning of each constructing part.

Furthermore, according to the auto-focusing device disclosed in Tokkaisho No. 57-154224, it is very difficult to detect the focusing when a target object is under a weak visible light and yet containing almost no infrared rays, such as under fluorescent lamp, not only when detecting the focus condition by way of visible light, but also by way of infrared rays. Moreover, if the target object has no or hardly any contrast, such as in the case of plain wall, it is very difficult to detect the focus condition even when using the infrared rays.

Another improved auto-focusing system is proposed in Japanese Patent Laid-open Publication (Tokkaisho) No. 57-150808, which is so designed that the focus condition can be detected either by the visible rays or infrared rays. The auto-focusing system according to Tokkaisho No. 57-150808 comprises two photoelectric conversion means, one for visible rays and the other for infrared rays, and a beam splitter for dividing the rays from the object in terms of amount into rays to be directed to the visible light photoelectric conversion means and to the infrared light photoelectric conversion means. An infrared cut filter is disposed between the visible light photoelectric conversion means and beam splitter for cutting the infrared rays to be directed to the visible light photoelectric conversion means. Each photoelectric conversion means is connected, through a discrimination circuit, to a selection circuit and further to a focus condition detecting circuit.

According to the auto-focusing system of Tokkaisho No. 57-150808, it is stated that when no infrared light pass filter is used to carry out photographing using visible rays, almost the same amount of light impinges on both photoelectric conversion means and, therefore, the outputs from both photoelectric conversion means have approximately the same level. Thus, the discrimination circuit discriminates that the ratio of outputs from both photoelectric conversion means is approximately equal to one, thereby actuating the selection circuit to select output from the visible light photoelectric conversion means.

It further states that when the infrared light pass filter is used to carry out photographing using infrared rays, the amount of light impinging on the infrared light photoelectric conversion means is greater than that on the visible light photoelectric conversion means. Thus, the discrimination circuit discriminates that the ratio of outputs from both photoelectric conversion means is not equal to one, thereby actuating the selection circuit to select output from the infrared light photoelectric conversion means.

The focus condition detecting circuit operates in response to the output signal selected by the selection circuit.

From a practical point of view, however, there are a variety of objects differing from one another in reflection properties. Thus, it is not always true that the ratio between outputs from the visible light photoelectric conversion means and from the infrared light photoelectric conversion means is constant with use of no

infrared light pass filter. Thus, it is practically very difficult to set a level or borderline for causing selection of an output from visible light photoelectric conversion means whenever photographs are taken using the visible light. Therefore, even when the output from the visible light photoelectric conversion means is selected, there may be a case wherein the focus detection is carried out using the infrared rays, resulting in out of focus, because there is a difference in an image forming distance of the objective lens between the visible rays and infrared rays. Moreover, when taking a photograph under the A-light source (tungsten type lamp) or under the natural light, there may be a case in which the infrared rays are stronger than the visible rays. In such a case, the photographing is carried out using the visible rays, but the focus detection is carried out using infrared rays, resulting in an error in focus adjustment.

Also, according to the prior art, it is well know to emit an auxiliary light to the object, when the object is too dark to carry out the focus detection. In this case, if the object is people, and when the auxiliary light is visible light, such an auxiliary light makes people unpleasant. In order to overcome this, an improved focus detecting device is disclosed in Japanese Patent Laid-open Publication (Tokkaisho) 55-111929, which device emits, instead of visible lights, infrared rays as the auxiliary light when the target object is very dark and has less contrast. However, Japanese Patent Laid-open Publication (Tokkaisho) 55-111929 does not take any consideration to the difference in focusing distance between the the infrared rays and the visible rays, due to color aberration of the objective lens.

SUMMARY OF THE INVENTION

The present invention has been developed with a view to substantially solving the above described disadvantages and has for its essential object to provide an improved auto-focusing system which can carry out an auto-focusing operation for the visible light using infrared rays with high accuracy, without employing any mechanical or optical correcting means.

It is also an essential object of the present invention to provide an auto-focusing system of the above described type which can carry out an auto-focusing operation quickly and accurately, with an aid of emission of infrared rays, even when the target object is dark or has a low contrast.

It is a further object of the present invention to provide an interchangeable lens suited for use with a camera employing an auto-focusing system of the above described type.

According to the auto-focusing system of the present invention, a focus condition is detected based on the infrared light. A data producer is provided for producing a deflection signal indicating a difference between an image forming distance for the infrared light and that for the visible light, due to aberration. In accordance with the detected focus condition and deflection signal, an objective lens is shifted to a position for properly focusing an image of visible light on a predetermined image forming plane.

Furthermore, according to the present invention, an auxiliary light source for emitting infrared light is provided for lighting an object, thus facilitating the focus condition detection. According to one embodiment, a dark object is brightened by the emitted infrared light to increase the detecting level, and according to another embodiment, a plain object, such as a wall, is spot-lighted by the emitted infrared light to provide a contrast.

Moreover, according to the present invention, the objective lens can be shifted in one step or in two steps to bring it to the properly focused position for the visible light. In the case of one step, an amount of lens shift is calculated using the detected focus condition based on the infrared light and deflection signal, and then, the lens is shifted in accordance with the calculated result. In the case of two steps, the lens is first shifted based on the focus detection under the infrared light, and is shifted again based on the deflection signal.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other objects and features of the present invention will become apparent from the following description taken in conjunction with preferred embodiments thereof with reference to the accompanying drawings, throughout which like parts are designated by like reference numerals, and in which:

FIG. **1***a* is a block diagram of an auto-focusing system according to the present invention;

FIG. **1***b* is a diagrammatic view showing an optical arrangement of the auto-focusing system of the present invention employed in a camera;

FIG. **2***a* is a graph showing a spectral sensitivity of a visible light photoelectric conversion means and a normalized reflectance of a first reflecting face of a beam splitter;

FIG. **2***b* is a graph similar to FIG. **2***a*, but particularly showing a spectral sensitivity of an infrared light photoelectric conversion means;

FIG. **3** is a diagrammatic view showing one example of a beam splitter employed in the auto-focusing system of FIG. **1***a*;

FIG. **4** is a graph showing a normalized reflectance of a junction face of glass blocks of defining the beam splitter of FIG. **3**;

FIG. **5** is a diagrammatic view showing another example of a beam splitter;

FIG. **6** is a graph showing a normalized reflectance of the beam splitter of FIG. **5**, particularly when the incident angle of the beam is 45°;

FIG. **7** is a diagrammatic view showing a major portion of optical arrangement employing the beam splitter of FIG. **5**;

FIGS. **8***a* and **8***b* taken together show a circuit diagram of an auto-focusing system according to one embodiment the present invention, wherein characters A–E in FIG. **8***a* are connected to corresponding characters in FIG. **8***b*;

FIG. **9***a* and **9***b* taken together show a detailed circuit diagram of interface circuit and data output circuit shown in FIG. **8***b*, wherein characters **J1–J4** in FIG. **9***a* are terminals connectable to terminals in FIG. **9***b* with corresponding characters;

FIGS. **10** and **11** are circuit diagrams showing modifications of the circuit shown in FIG. **9***b*;

FIGS. **12***a* and **12***b* taken together show a flow chart of the auto-focus detection carried out by the circuit of FIGS. **8***a* and **8***b*, wherein characters F–I in FIG. **12***a* are connected to corresponding characters in FIG. **12***b*;

FIG. **13** is a circuit diagram showing a major portion of an auto-focusing system according to another embodiment the present invention;

FIG. **14** is a circuit diagram showing a major portion of an auto-focusing system according to yet another embodiment the present invention;

FIG. 15 is a flow chart of the auto-focus detection carried out by the circuit of FIG. 14;

FIG. 16 is a flow chart similar to FIG. 15, but showing only a modified portion;

FIG. 17 is a flow chart showing a detail of a step #51 of FIG. 15 or 16 for the detection of contrast;

FIG. 18 is a diagrammatic view of a camera installed with a device for emitting infrared rays to an object to be photographed;

FIG. 19 is a diagrammatic view of an interchangeable lens installed with a device for emitting infrared rays to an object to be photographed;

FIG. 20 is a diagrammatic exploded view of a filter employed in the interchangeable lens of FIG. 19, particularly showing an arrangement for emitting infrared rays; and

FIG. 21 is a circuit diagram of an auto-focusing system according to a further embodiment the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to FIG. 1*a*, a block diagram of an auto-focusing system of the present invention is shown. A reference number 2 designates an objective lens included in an interchangeable lens; 7 designates a beam splitter defining a major portion of an optical arrangement of focus detector; and 9*a* and 9*b* designate photoelectric conversion devices for visible light and infrared light, respectively. The beam splitter 7 is provided for splitting the light from a target object and passed through the lens 2 into visible light and infrared light, and for this purpose, it has a first and second reflecting faces 7*a* and 7*b*. The first reflecting face 7*a* has a normalized reflectance (normalized in percentage of reflected light when the incident light is rendered as "1") as shown by a real line in FIG. 2*a* , and a normalized transmittance (normalized in percentage of transmitted light when the incident light is rendered as "1") as shown by a real line in FIG. 2*b*. As apparent from the graphs of FIGS. 2*a* and 2*b*, lights having wavelength of about 700 nanometers or longer, i.e., lights in infrared and/or near-infrared region, are reflected on the first reflecting face 7*a*, and lights having wavelength of less than about 700 nanometers, i.e., visible lights, are transmitted through the first reflecting face 7*a*.

A term infrared used herein includes a range in which photoelectric conversion device 9*b* for the infrared light is sensitive, such as lights having wavelength of 650–900 nanometers. Thus, a term infrared used herein includes near-infrared and partly visible lights of long wavelength.

The photoelectric conversion device 9*a* is so located as to receive the lights transmitted through the first reflecting face 7*a*. Thus it mainly receives visible lights. The photoelectric conversion device 9*b* is so located as to receive the lights reflected from the second reflecting face 7*b* which has a high reflectance at least in the infrared region. Thus, the photoelectric conversion device 9*b* mainly receives infrared lights.

Instead of the beam splitter 7 described above, a normal beam splitter which merely splits the lights in terms of amount can be employed. In this case, a filter for cutting infrared rays should be provided in front of the visible light photoelectric conversion device 9*a*, and a filter of cutting visible light should be provided in front of the infrared light photoelectric conversion device 9*b*.

Referring to FIG. 1*b*, an optical arrangement of a single-reflex interchangeable lens type camera employing the auto-focusing system of the present invention is shown. A reference number 1 designates a main mirror defined by a half-mirror plate; 6 designates a submirror supported by the main mirror 1; 8*a* and 8*b* designate relay lenses; 3 is a pentaprism; 4 is an eyepiece lens; 5 is a focus plate; and 10 is a predetermined image forming plane (film plane) for which objective lens 2 is to be adjusted to focus visual light thereon. Both main mirror 1 and submirror 6 have a uniform reflectance characteristic to all colors including visible light and infrared light. The photoelectric conversion devices 9*a* and 9*b* have a normalized spectral sensitivity (normalized in percentage when the maximum sensitivity is rendered as "1"), as shown by a dotted line in FIGS. 2*a* and 2*b*.

Because of the color aberration of the objective lens, an image forming distance for the infrared light is longer than that for the visible light by an amount dL, and such an amount dL is referred to as deflection dL. The deflection dL varies with respect to the type of interchangeable lens depending on the various factors, such as number and arrangement of lenses defining one interchangeable lens, focal length, etc. Therefore, each interchangeable lens has its own deflection dL which is different from the deflection dL of another interchangeable lens. Furthermore, the deflection dL varies relatively to the change of focus distance, or to the change of focal length if the interchangeable lens is a zoom lens.

If the lens is shifted to an in-focus position in accordance with a focus detection carried out by the infrared lights, and thereafter, if a picture is taken with visible light, the picture will result in out of focus. To obtain a properly focused picture, in this case, it is necessary to correct the deflection dL, which is intrinsic to each type of interchangeable lens.

According to the optical arrangement shown in FIG. 1*a* or 1*b*, an optical distance between the lens 2 and relay lens 8*b*, or infrared light photoelectric conversion device 9*b*, is longer than an optical distance between the lens 2 and relay lens 8*a*, or visible light photoelectric conversion device 9*a*, by an optical distance d/n, wherein d is an actual distance between the first and second reflecting faces 7*a* and 7*b*, and n is a refractive index of the beam splitter 7, provided that the photoelectric conversion devices 9*a* and 9*b* are both positioned at the same distance from the beam splitter 7. If the optical distance d/n is selected to be equal to the deflection dL for one standard lens, an image of visible light can be properly focused on the visible light conversion device 9*a* as well as on predetermined image forming plane 10 and, at the same time, an image of infrared light can be properly focused on the infrared light conversion device 9*b*, provided that said one standard lens is mounted on the camera. Thus, in this case, the lens can be properly focused for the visible light with the focus detection carried out by the infrared light.

If the lens is changed to another interchangeable lens having a deflection dL' which is greater than the deflection dL, such a deflection dL' can not be properly corrected by the optical distance d/n. To properly correct the deflection dL', the camera must be provided with a following correction data S:

$$S = dL' - d/n$$

In the foregoing description, the infrared lights having a predetermined wavelength should be used for

determining the data S, and in the case of using the beam splitter 7, such a wavelength should preferably be 830 nanometers, at which the production of normalized reflectance of the reflecting face 7*a* and normalized spectral sensitivity of the photoelectric conversion device 9*b* takes the maximum value.

Referring again to FIG. 1*a*, both outputs from the visible light photoelectric conversion device 9*a* and from the infrared light photoelectric conversion device 9*b* are applied to a discrimination circuit 11 and also to selection circuit 12. The discrimination circuit 11 discriminates which one of the two outputs from the devices 9*a* and 9*b* is greater, and produces a discrimination signal indicating the one which is greater. The discrimination signal is applied to the selection circuit 12, and also to other circuits, such as a gate circuit 13-1 provided in a focus detection calculation circuit 13. A reference number 16 designates a data output circuit installed in each interchangeable lens for producing a correction data S intrinsic to each interchangeable lens The data output circuit 16 is connectable, when the lens is mounted on the camera, to a read-out circuit 17 for supplying the correction data S to the gate circuit 13-1.

When the gate circuit 13-1 is receiving a discrimination signal indicating that the output from the infrared light photoelectric conversion device 9*b* is greater than that from the visible light photoelectric conversion device 9*a*, the gate circuit 13-1 permits to pass the correction data S from the read-out circuit 17 to a subtractor 13-3.

On the contrary, when the gate circuit 13-1 is receiving a discrimination signal indicating that the output from the visible light photoelectric conversion device 9*a* is greater than that from the infrared light photoelectric conversion device 9*b*, the gate circuit 13-1 cuts the correction data S, and instead, provides a data representing zero to the subtractor 13-3.

The selection circuit 12 operates in such a manner that it produces the output from the infrared light photoelectric conversion device 9*b* when the discrimination signal indicating that the output from the infrared light photoelectric conversion device 9*b* is greater than that from the visible light photoelectric conversion device 9*a*. Contrary, the selection circuit 12 produces the output from the visible light photoelectric conversion device 9*a* when the discrimination signal indicating that the output from the visible light photoelectric conversion device 9*a* is greater than that from the infrared light photoelectric conversion device 9*b*. The output produced from the selection circuit 12 is applied to a calculation circuit 13-2 which calculates an amount of defocus (out of focus) of the image formed by visual light on image forming plane 10 as well as on the device 9*a*, and also a direction of defocus whether it is defocused forwardly or rearwardly. After calculating, the calculation circuit 13-2 produces a defocus signal dF representing the calculated amount and direction of defocus. The defocus signal dF is applied to a subtractor 13-3 which subtracts the data S from the defocus signal dF and produces an absolute value of the subtracted result, i.e., $|dF-S|$. When the data S is equal to zero, the subtracted result is $|dF|$. The subtractor 13-3 also produces a signal representing + or − for the direction of defocus.

The outputs of the subtractor 13-3 are applied to a display device DP for displaying the amount and direction of defocus as obtained from the subtractor 13-3, and also to a lens driver LCO for driving the lens 2 based on the direction of defocus signal from the subtractor 13-3.

In the foregoing description, the amount and direction of defocus can be calculated in a manner disclosed in U.S. Pat. Nos. 4,333,007 patented Jun. 1, 1982 to Langlais et al., 4,341,953 patented Jul. 27, 1982 to Sakai et al., or in Japanese Patent Laid-open Publication (Tokkaisho) No. 57-45510.

Furthermore, when the visible light photoelectric conversion device 9*a* is selected for carrying out the focus detection with visible light, the display device DP displays information based on the signal $|dF|$, but when the infrared light photoelectric conversion device 9*b* is selected for carrying out the focus detection with infrared light, the display device DP displays information based on the signal $|dF-S|$. Therefore, in either cases, the objective lens can be so adjusted as to properly focus the image for the visible light.

According to the block diagram shown in FIG 1*a*, each interchangeable lens produces a data S (=dL-d/n) which is determined by the deflection dL and distance d/n with an assumption that the distance d/n is constant. If the distance d/n of one camera body is difference from the other camera body, and if the interchangeable lens is applicable to both camera bodies, it is necessary to change the data S with respect to the change of the distance d/n. This can be accomplished by two different ways. The first way is to store a data dL to each interchangeable lens, and store a data d/n to each camera body, and by the use of data dL from the lens and d/n from the camera body, the required data S is calculated. The second way is to store a data S to each interchangeable lens, in which S is equal to dL-d/n, wherein d/n is an optical distance for the standard camera body. The camera body other than the standard is stored with a difference dP between the optical distance d/n for the standard camera and its optical distance d/n. When the interchangeable lens is mounted on the standard camera body, the data S from the lens is used in the camera body without any change. But, when the interchangeable lens is mounted on a non-standard camera body, the data S from the lens is corrected using the difference dP.

Referring to FIG. 3, there is shown a first modification of the beam splitter 7 described above. A beam splitter 7′ shown therein includes a parallelepiped glass block 56, a triangle glass block 57, and a multi-film layer 58 sandwiched between blocks 56 and 57. The multi-film layer 58 is defined by twenty-three films deposited one over the other by a suitable depositing method. The twenty-three films have refractive index and optical thickness as given in Table 1 below.

TABLE 1

Layer No.	1	2	3	4
Refractive Index n	1.38	2.30	1.38	2.30
Optical Thickness nd	$0.32\lambda_0$	$0.25\lambda_0$	$0.25\lambda_0$	$0.25\lambda_0$
5	6	7	8	9	10
1.38	2.30	1.38	2.30	1.38	2.30
$0.25\lambda_0$	$0.25\lambda_0$	$0.25\lambda_0$	$0.25\lambda_0$	$0.25\lambda_0$	$0.25\lambda_0$
11	12	13	14	15	16
1.38	2.30	1.38	2.30	1.38	2.30
$0.25\lambda_0$	$0.25\lambda_0$	$0.25\lambda_0$	$0.25\lambda_0$	$0.25\lambda_0$	$0.25\lambda_0$
17	18	19	20	21	22
1.38	2.30	1.38	2.30	1.38	2.30
$0.25\lambda_0$	$0.25\lambda_0$	$0.25\lambda_0$	$0.25\lambda_0$	$0.25\lambda_0$	$0.25\lambda_0$
23					
1.38					

TABLE 1-continued

$0.32\lambda_0$

*Note: λ_0 = 1100 nanometers

It is to be noted that the glass blocks **56** and **57** have a refractive index of 1.5168. Of the twenty-three films in the multi-film layer **58**, the films having a refractive index of 1.38 as shown in Table 1 are made of MgF_2, and the films having a refractive index of 2.30 are made of TiO_2 or CeO_2. When light rays hit on the junction face between the glass blocks **56** and **57** with an incident angle of 45°, as illustrated in FIG. **3**, rays in infrared region reflect with a high percentages, but rays in visible light region reflect with a low percentages, as shown in a graph of FIG. **4**, wherein abscissa and ordinate represent, respectively, wavelength in nanometers and normalized reflectance Rf in percentages. More specifically, the reflectance is less than 10% within a visible light range, such as 460–660 nanometers, and is greater than 90% within an infrared light range, such as 800–870 nanometers. Since twenty-three films of the multi-film layer **58** are made of dielectric material, such as MgF_2, and TiO_2, or CeO_2, no light is absorbed in these films. Thus, the transmittance Tf of the rays through the junction can be given as:

$$Tf \div 100 - Rf\ (\%).$$

Therefore, it can be said that the transmittance is greater than 90% in a visible light range, 460–660 nanometers, and is less than 10% in an infrared light range, 800–870 nanometers. Thus, when the beam splitter 7' is used, it is possible to divide the incident light into visible light and infrared light with almost no loss of light.

Referring to FIG. **5**, there is shown a second modification of the beam splitter **7** described above. A beam splitter 7'' shown therein is a so-called half-mirror type defined by a base glass plate **60** and a multi-film layer **61** deposited on the base glass plate **60**. The multi-film layer **61** has thirteen films deposited one over the other through a suitable depositing method. The thirteen films have refractive index and optical thickness as given in Table 2 below.

TABLE 2

Layer No.	1	2	3	4	5	6	7	8	9	10
Refractive Index n	1.38	2.30	1.38	2.30	1.38	2.30	1.38	2.30	1.38	2.30
Optical Thickness nd	$0.125\lambda_0$	$0.25\lambda_0$	$0.25\lambda_0$	$0.25\lambda_0$	$0.25\lambda_0$	$0.25\lambda_0$	$0.25\lambda_0$	$0.25\lambda_0$	$0.25\lambda_0$	$0.25\lambda_0$

11	12	13
1.38	2.30	1.38
$0.25\lambda_0$	$0.25\lambda_0$	$0.32\lambda_0$

*Note: λ_0 = 1000 nanometers

It is to be noted that the base glass plate **60** has a refractive index of 1.5168. Of the thirteen films in the multi-film layer **61**, the films having a refractive index of 1.38 as shown in Table 2 are made of MgF_2, and the films having a refractive index of 2.30 are made of TiO_2 or CeO_2. When light rays hit on the beam splitter 7'' with an incident angle of 45°, as illustrated in FIG. **5**, rays in infrared region reflect with a high percentages, but rays in visible light region reflect with a low percentages, as shown in a graph of FIG. **6**, wherein abscissa and ordinate represent, respectively, wavelength in nanometers and normalized reflectance Rf in percentages. More specifically, the reflectance is very low (thus, transmittance is very high) in a visible light range, such as 400–700 nanometers, and is very high (thus, transmittance is very low) in an infrared light range, such as 800–1000 nanometers.

Referring to FIG. **7**, a major portion of the optical arrangement of the focus detecting device employing the beam splitter 7'' is shown. In FIG. **7**, **62** is a reflection mirror, **8'** is an optical element having relay lenses **8'***a* and **8'***b*.

It is to be noted that the auto-focusing system according to the present invention can be arranged in different manner than the above described arrangement.

For example, in the beam splitter **7** shown in FIGS. **1***a* and **1***b*, the second reflecting face **7***b* can be so arranged as to have reflectance and transmittance characteristic varied with respect to wavelength in a similar manner to the first reflecting face **7***a*. More specifically, the second reflecting face **7***b* can be so arranged as to have a normalized reflectance as shown by a dot-dash line in FIG. **2***a*. When this is done, the range in which the infrared light photoelectric conversion device **9***b* receives light is narrowed. Accordingly, the wavelength of light that can be detected by the infrared light photoelectric conversion device **9***b* is limited to a certain narrow range, resulting in preciseness of the deflection dL. Thus, the correction using the deflection dL (or data S) can be done with a high accuracy. Also, in a case where an auxiliary light is emitted, an infrared LED or infrared laser having intense beam with a high reflectance to the first and second reflecting faces **7***a* and **7***b* should be used, thereby improving the accuracy of the correction using deflection dL (or data S). In this case, it is preferable to provide a light absorber at left end surface, when viewed in FIG. **1***b*, of the beam splitter **7**, so that the lights which have passed through the second reflecting face **7***b* will not reflect back on such an end surface.

Also, in the above description, a beam splitter having a high transmittance of visible light and a high reflectance of infrared light is used. But instead, a beam splitter having a high reflectance of visible light and a high transmittance of infrared light can be used.

Furthermore, a beam splitter having three reflecting faces can be used. In this case, the first reflecting face reflects infrared lights and transmits visible lights. The second reflecting face receives the infrared lights reflected from the first reflecting face and reflects infrared lights having a wavelength of a first particular range, and transmits infrared lights having a wavelength of a second particular range. The third reflecting face receives and reflects the infrared lights having a wavelength of the second particular range. In this case, two infrared light photoelectric conversion devices should be provided: one for receiving the infrared lights from the second reflecting face; and the other for receiving the infrared lights from the third reflecting face.

Referring to FIGS. **8***a* and **8***b*, a circuit diagram of the auto-focusing system according to one embodiment of the present invention is shown, in which characters A–E in circle in FIG. **8***a* are connected to corresponding characters in circuit in FIG. **8***b*.

A reference character IRD at upper left corner of FIG. **8***a* is a photoelectric conversion element for monitoring infrared lights, and VSD is a photoelectric conversion element for monitoring visible lights. The photoelectric conversion element IRD is provided in the infrared light photoelectric conversion device **9***b*,

shown in FIG. 1*a* or 1*b*, and the photoelectric conversion element VSD is provided in the visible light photoelectric conversion device 9*a*. These photoelectric conversion elements IRD and VSD are coupled with operational amplifiers OA1 and OA2 and logarithmic compression diodes D1 and D2, thereby defining light measuring circuits. The outputs of the operational amplifiers OA1 and OA2 are compared with each other in a comparator AC1. When the output from the amplifier OA1 is greater than that from the amplifier OA2, i.e., when the infrared lights are stronger than the visible lights, the comparator AC1 produces HIGH, and when the output from the amplifier OA2 is greater than that from the amplifier OA1, i.e., when the visible lights are stronger than the infrared lights, the comparator AC1 produces LOW.

The output of the operational amplifier OA1 is also compared with a reference voltage from a constant voltage source CE2 by a comparator AC3. When the output from the operational amplifier OA1 representing the infrared light level is smaller than the reference voltage from the voltage source CE2, the comparator AC3 produces HIGH. But, when the output from the amplifier OA1 is greater than the reference voltage from the voltage source CE2, the comparator AC3 produces LOW.

Likewise, the output of the operational amplifier OA2 is also compared a reference voltage from a constant voltage source CE1 by a comparator AC2. When the output from the operational amplifier OA2 representing the visible light level is greater than the reference voltage from the voltage source CE1, the comparator AC2 produces HIGH. But, when the output from the amplifier OA2 is smaller than the reference voltage from the voltage source CE1, the comparator AC2 produces LOW.

A logic circuit defined by inverter IN1, AND gates AN1 and AN2 and OR gates OR1 and OR2 receives the outputs from three comparators AC1, AC2 and AC3 and selects which one of the two outputs from photoelectric conversion devices 9*a* and 9*b* should be used, and determines whether or not an infrared LED for the auxiliary light should be actuated to emit infrared light for the focus detection. A detail of operation of the logic circuit is shown below in Table 3.

TABLE 3

	Output levels of Photoelectric Conversion Elements IRD & VSD	AC1	AC2	AC3	IN1	AN1	AN2	OR1	OR2	Selected Element IRD or VSD	Infrared LED IRL ON or OFF
1	IRD > VSD + IRD > CE2	H	ϕ	L	L	L	L	L	H	IRD	OFF
2	IRD > VSD + IRD < CE2	H	ϕ	H	L	L	H	H	H	IRD	ON
3	VSD > IRD + VSD > CE1	L	L	ϕ	H	L	L	L	L	VSD	OFF
4	VSD > IRD + VSD < CE1	L	H	ϕ	H	H	L	H	H	IRD	ON

NOTE:
(1) + means "at the same time".
(2) ϕ means "either H or L".

As understood from Table 3, row 1, when the output level of photoelectric conversion element IRD is greater than that from the element VSD and, at the same time, greater than the reference voltage from the voltage source CE2, comparators AC1 and AC3 produces HIGH and LOW, respectively. Thus, the AND gate AN2 produces LOW, and the inverter IN1 produces LOW, thereby producing LOW from the AND gate AN1. Furthermore, OR gate OR1 produces LOW and OR gate OR2 produces HIGH. Thus, when a data flip-flop DF1 receives a clock pulse, its Q output produces LOW. Thus, an AND gate AN3 produces LOW to turn off transistor BT1. As a result, the infrared LED IRL is maintained OFF. Moreover, when a data flip-flop DF2 receives a clock pulse, its Q output produces HIGH, and its $\overline{Q}$ output produces LOW, thus turning an analog switches AS1 and AS4 on, permitting the transmission of signal from a CCD (charge coupled device) IRC provided in the infrared light photoelectric conversion device 9*b*, and turning an analog switches AS2 and AS3 off, cutting signal from a CCD VSC provided in the visible light photoelectric conversion device 9*a*.

The operation shown in Table 3 under other rows is similar to that described above.

As apparent from Table 3, rows 1 and 2, when ever the output level of infrared light photoelectric conversion element IRD is greater than that from the visible light photoelectric conversion element VSD, infrared light photoelectric conversion device 9*b* is selected. In this case, if the output level of infrared light photoelectric conversion element IRD is lower than a predetermined level (row 2), the infrared LED IRL is actuated to emit auxiliary light of infrared rays.

Contrary, the visible light photoelectric conversion device 9*a* is selected only when the output level of visible light photographic conversion element VSD is greater than that from the infrared light photoelectric conversion element IRD and, at the same time, greater than a predetermined level (row 3). When the output level of visible light photographic conversion element VSD is greater than that from the infrared light photoelectric conversion element IRD, but less than the predetermined level (row 4), the infrared light photoelectric conversion device 9*b* is selected and, at the same time, the infrared LED IRL is actuated to emit auxiliary light of infrared rays.

A further detail of the circuit shown in FIG. 8*a* will become apparent from the following description.

The output of the OR gate OR1 is connected to D input of data flip-flop DF1, and the output of the OR gate OR2 is connected to D input of data flip-flop DF2. Each of the data flip-flops DF1 and DF2 has a clock terminal CL which is connected to an output 03 of a microcomputer MCO (FIG. 8*b*). When the microcomputer MCO produces from its output 03 a start measuring signal for effecting the start of light measuring for the focus detection, data flip-flops DF1 and DF2 latches the data at their D input.

Still referring to FIG. 8*a*, a reference character COT designates a controller for controlling the light measuring operation for the focus detection, IRC is a CCD provided in the infrared light photoelectric conversion device 9*b*, and VSC is a CCD provided in the visible light photoelectric conversion device 9*a*. These CCDs IRC and VSC are provided for the focus detection. A

sample-and-hold circuit SH is provided for holding analog signal from either CCD IRC or VSC, and an analog-to-digital converter AD is provided for converting an output of sample-and-hold circuit SH from analog to digital form.

When the start measuring signal, which is a pulse, is applied from output **03** of microcomputer MCO to input ST of controller COT, the controller COT produces from its output ϕR a reset pulse which is applied to each of analog switches **AS5** and **AS6**, thereby turning the analog switches **AS5** and **AS6** on. By the turn on of the analog switches **AS5** and **AS6**, each of the CCDs IRC and VSC are charged through terminals IAD and VAD up to a level equal to a constant voltage source **CE5**. The output ϕR is also connected to a set terminal S of a flip-flop **FF1**. Thus, by a reset pulse produced from the output ϕR, the flip-flop **FF1** is turned to set condition, thereby producing HIGH from Q output of the flip-flop **FF1**. This HIGH is applied to AND gate **AN3**, and if the data flip-flop **DF1** is producing HIGH at this moment, the AND gate **AN3** produces HIGH, thereby conducting transistor **BT1**. Thus, the LED IRL emits infrared beams.

The CCDs IRC and VSC receive signals from their own light receiving elements, charge the signals, and produce gradually-increasing voltage signals representing the charged amount in each CCD from their outputs IAD and VAD. In this case, when the data flip-flop **DF2** is producing HIGH from its Q output (meaning that CCD IRC of infrared should be used), analog switch **AS4** conducts to transmit voltage signal from output IAD of CCD IRC to comparator **AC4**. On the other hand, when the $\overline{Q}$ output of flip-flop **DF2** is producing HIGH, analog switch **AS3** conducts to transmit voltage signal from output VAD of CCD VSC to comparator **AC4**.

The comparator **AC4** compares the gradually increasing voltage signal from output IAD or VAD with a reference voltage from a constant voltage source **CE3**, and when the voltage signal reaches the reference voltage from the voltage source **CE3**, it produces HIGH which is applied to controller COT. Thereupon, the controller COT produces a transmission pulse from its output ϕT, thereby shifting the charge stored in each CCD IRC or VSC to transmission gate. The transmission pulse is also applied to reset terminal R of flip-flop **FF1**, thereby resetting the flip-flop **FF1**. Thus, the LED IRL for the auxiliary light stops the infrared light emission. Thereafter, output terminal IRS or VSS of CCD IRC or VSC continuously produce stored charge in accordance with transmission clocks from outputs ϕ**1**, ϕ**2** and ϕ**3**. In this case, when the data flip-flop **DF2** is producing HIGH from its Q output, analog switch **AS1** conducts to transmit the signal representing the received infrared light from output IRS to sample-and-hold circuit SH. But, when the data flip-flop **DF2** is producing HIGH from its $\overline{Q}$ output, analog switch **AS2** conducts to transmit the signal representing the received visible light from output VSS to sample-and-hold circuit SH.

The controller COT produces from its terminal ϕS a pulse for effecting the sample-and-hold operation in the circuit SH and, thereafter, produces a pulse from its terminal ϕC to AD converter AD for effecting analog-to-digital conversion. Then, controller COT produces from its output TR a pulse to an input **i4** of microcomputer MCO for the indication that the data transmission will be carried out. Thereupon, the AD converted data by the AD converter AD is transmitted from controller COT to microcomputer MCO through its input port **IP1**. Thereafter, the above described series operation of producing stored charge, sample-and-hold, AD conversion; and data transmission is repeated for a number of times equal to the number of light receiving element in CCD IRC or VSC. When repeated for the required number of times, the controller COT produces from its output EN a pulse indicating the completion of transmission to an input **i6** of microcomputer MCO, thereby stopping the repetition.

According to the above description, the determination of which one of the two CCDs should be selected and the determination of whether or not to turn on the LED IRL are carried out by the use of photoelectric conversion elements IRD and VSD. But, both determinations can be done without such elements IRD and VSD. For example, before carrying out the light measuring for the focus detection, the CCDs IRC and VSC are actuated to store charges corresponding to the infrared and visible lights, respectively, and the voltage signals representing the charged amounts, as produced from the outputs IAD and VAD, can be used as output signals from the elements IRD and VSD, or from the amplifiers **OA1** and **OA2** if such voltage signals have enough high amplitude.

Referring particularly to FIG. **8***b*, the auto-focusing system further includes a battery BA for supplying D.C. power and a manually operable switch MS, such as one provided in association with a shutter release button (not shown) and closes upon depression to a half-way down. The switch MS is connected to an inverter **IN2** which, when the switch MS is turned on, produces HIGH, thereby starting the microcomputer MCO to carry out the focus condition detection and focus adjustment and, at the same time, starting a light measuring, calculation and display circuit LM. Also, in response to the closure of the switch MS, the microcomputer MCO produces HIGH from its output **01**, thereby producing LOW from an inverter **IN3** to turn a transistor **BT2** to a conductive state. Thus, D.C. power is supplied to line Vcc.

Another manually operable switch RS is provided, for example in association with a shutter release button, and closes upon depression to its full way. When the switch RS closes, an inverter **IN4** produces HIGH. In this case, if an exposure control circuit EC is in a preparatory condition and an inverter **IN0** is producing HIGH, AND gate **AN0** produces HIGH, thereby stopping the microcomputer to further carry out the focus condition detection and focus adjustment. Then, it is waited until the exposure control stops. Also, when the switch RS closes, the exposure control circuit EC carries out an exposure control operation based on exposure control values from the light-measuring, calculation and display circuit LM. When the exposure control operation completes, the exposure control circuit EC produces HIGH indicating the completion of operation, and applies it to input **i1** of the microcomputer MCO. The exposure control circuit EC produces LOW when an exposure control arrangement has completed its charge and when the preparation for the exposure control operation is completed.

A display device DP receives data from an output port **OP1** of the microcomputer MCO and displays either one of in-focus, near-focus and far-focus. A motor drive circuit MDR receives data from an output port **OP2** and drives a motor MO either in forward or

backward direction, thereby operating a lens drive mechanism LDR to shift the lens to an in-focus position. An encoder EN is coupled to lens drive mechanism LDR for producing a pulse each time the lens is shifted for a predetermined unit distance. An interface circuit IF is provided, which takes data necessary for driving the lens from a data producing circuit LDO in response to a pulse from output 02 of microcomputer MCO. The data producing circuit LDO, provided in the interchangeable lens mounted on a camera body, supplies the data S (or data dL) and data K representing the rate of lens shift with respect to a predetermined number of pulses produced from the encoder EN.

Next, a detail of the interface circuit IF and data producing circuit LDO is described with reference to FIGS. 9*a* and 9*b*, wherein terminals J1 to J4 provided in a camera body are connectable to corresponding terminals J1' to J4' provided in an interchangeable lens.

Referring particularly to FIG. 9*a*, when microcomputer MCO produces HIGH from its output 02, a flip-flop FF5 is set, thereby producing HIGH from Q output of flip-flop FF5. Then, when a clock terminal CL of data flip-flop DF5 receives a clock pulse from oscillator OSC, the data flip-flop DF5 produces HIGH from its Q output. Accordingly, an AND gate AN10 is enabled to transmit a train of clock pulses from oscillator OSC to clock terminal CL of a ring counter CO1. In response to each clock pulse, the ring counter CO1 counts up. More specifically, when the ring counter CO1 has counted one clock pulse, it produces HIGH from its output b0 and produces LOW from the rest of its outputs; when it has counted two clock pulses, it produces HIGH from its output b1 and produces LOW from the rest of its outputs; when it has counted ten clock pulses, it produces HIGH from its output b9 and produces LOW from the rest of its outputs; when it has counted eleven clock pulses, it produces HIGH from its output b0 and produces LOW from the rest of its outputs; and so on.

Referring also to FIG. 9*b*, the Q output of data flip-flop DF5 is also connected through terminals J1 and J1' to the circuit provided in the mounted interchangeable lens. More specifically, the terminal J1' is connected to a latch circuit LA3 which upon receipt of HIGH from the Q output of data flip-flop DF5, latches 5-bit data representing a distance between the object to be photographed and the camera from a focus distance reading device DD through analog switches AS15–AS19. The focus distance reading device DD reads the distance between the object to be photographed and the camera by detecting the shifted position of be objective lens. The terminal J1' is also connected to a delay circuit DL which after a predetermined period from the receipt of HIGH from the Q output of data flip-flop DF5, produces HIGH which is inverted to LOW by an inverter IN10. The HIGH from the delay circuit DL is applied to analog switches AS10–AS15 to turn on the same, and LOW from the inverter IN10 is applied to analog switches AS15–AS19 to turn off the same. Thus, when a HIGH is produced from the delay circuit DL, a decoder DE receives 10-bit signal (5-bit distance data from the latch LA3 and 5-bit focal length data from a focal length setting circuit FD) which is converted to 6-bit signal and applied to a ROM RO at its least significant six bits.

In FIG. 9*b*, the focus distance reading device DD and focal length setting device FD are each formed by a coded plate (not shown) and a portion enclosed by a dot-dash line can be formed in a single IC chip. According to the arrangement shown in FIG. 9*b*, it is possible to transmit 10-bit signal from the devices DD and DF to the IC chip through only six lines: five lines extending from the latch LA3; and one line extending from the delay circuit DL, resulting in fewer connections between the IC chip and its associated circuit. Furthermore, the circuit shown in FIG. 9*b* is particularly designed for the employment in an interchangeable lens having data S (or data dL) and data K which vary with respect to the change of focusing distance and focal length. Therefore, signals representing these two variants as produced from the devices DD and FD are converted by the decoder DE into 6-bit signal to be applied to the ROM RO at its least significant six bits.

Moreover, the Q output of data flip-flop DF5 is connected through terminals J1 and J1' to AND gate AN14. Thus, the AND gate AN14 is enabled upon receipt of HIGH from the data flip-flop DF5, thereby permitting the supply of clock pulses from the oscillator (FIG. 9*a*) through the terminal J2 and J2' to a ring counter CO2, which operates in the same manner as the above-described ring counter CO1.

When the ring counter CO1 receives second clock pulse to its clock terminal CL, it produces HIGH from its output b1 for the first time. Accordingly, a counter C03 (FIG. 9*b*) connected to the output b1 of the counter CO1 through terminals J3 and J3' counts up to one, thereby producing a 2-bit signal "01" from its outputs Q1 and Q2. These outputs Q1 and Q2 of the counter C03 are connected to two most significant bit terminals of ROM RO. Thus, in this case, the ROM RO receives an 8-bit signal "01XXXXXX" (XXXXXX is a 6-bit output from decoder DE.) which is an address for designating a location in ROM RO where data S (or dL) corresponding to the detected focus distance and set focal length is stored. Then, when output L2 of ring counter CO2 produces HIGH, the designated data S (or dL) defined by a plurality of bits, such as 8 bits, in ROM RO is transferred parallelly to a shift register SR2. Thereafter, in a synchronized relation with the clock pulses from the terminal J2', the data S (or dL) is sent out bit-by-bit in response to the positive edge of each clock pulse from a terminal OUT of the shift register SR2, and is transferred though the terminals J4' and J4 to a shift register SR1 provided in interface circuit IF in a camera body. The shift register SR1 stores the data S (or dL) bit-by-bit in response to the negative edge of each clock pulse from the oscillator OSC. Therefore, the storing of the data S (or dL) in the shift register SR1 starts in synchronized relation to the negative edge of a pulse produced from terminal b2 of the ring counter CO1 and ends in synchronized relation to the negative edge of a pulse produced from terminal b9 of the ring counter CO1.

Thereafter, when terminal b0 of the ring counter CO1 produces HIGH for the second time, a data flip-flop DF7 produces HIGH from its Q output. At this moment, a data flip-flop DF8 is producing HIGH from its $\overline{Q}$ output, an AND gate AN11 is enabled to produce HIGH from terminal b0 of ring counter CO1. And, in response to the positive edge of HIGH produced from AND gate AN11, a latch LA1 stores data S (or dL) from shift register SR1.

Then, while terminal b1 of the ring counter CO1 is producing HIGH for the second time, this HIGH is applied through terminals J3 and J3' to counter C03 which then produces "10" from its outputs Q1 and Q2. Thus, in this case, the ROM RO receives an 8-bit signal

"10XXXXXX" which is an address for designating a location in ROM RO where data K corresponding to the read focus distance and set focal length is stored. Then, in response to the positive edge of a pulse produced from output L2 of ring counter CO2, the designated data K is transferred to shift register SR2. Thereafter, in a synchronized relation with the clock pulses from the terminal J2', the data K is sent out bit-by-bit in response to the positive edge of each clock pulse from a terminal OUT of the shift register SR2, and is transferred though the terminals J4' and J4 to a shift register SR1 provided in interface circuit IF in a camera body. The shift register SR1 stores the data K bit-by-bit in response to the negative edge of each clock pulse from the oscillator OSC. Therefore, the storing of the 8-bit data K in the shift register SR1 starts in synchronized relation to the negative edge of a pulse produced from terminal b2 of the ring counter CO1 and ends in synchronized relation to the negative edge of a pulse produced from terminal b9 of the ring counter CO1.

Thereafter, when terminal b0 of the ring counter CO1 produces HIGH, a data flip-flop DF8 produces HIGH from its Q output. Therefore, an AND gate AN12 is enabled to produce HIGH from terminal b0 of ring counter CO1. And, in response to the positive edge of HIGH produced from AND gate AN12, a latch LA2 stores data K from shift register SR1. The HIGH from AND gate AN12 is also applied through an OR gate OR10 to reset terminal of each of flip-flop FF5, data flip-flops DF5, DF6, DF7 and DF8 and ring counter CO1, thereby resetting these circuits. When the data flip-flop DF5 is reset, its Q output produces LOW which is applied through terminals J1 and J1' and OR gate OR11 to reset terminal of each of counters CO2 and CO3, thereby resetting these counters.

The above described operation is carried out to provide necessary data S (or dL) and data K to the interface circuit IF of the camera body, and through input ports IP2 and IP3 to microcomputer MCO. And, whenever the condition of focus distance or focal length changes, the above described operation is repeated to renew the necessary data S (or dL) and data K.

In FIGS. 9*a* and 9*b*, reference characters PO1 and PO2 designate power-on-reset circuit, and each produces a reset signal when a power is supplied from a power supply line Vcc in response to the conduction of transistor BT2. The reset signal produced from the power-on-reset circuit PO1 is applied to OR gate OR10, and in response to the negative edge of the reset signal, each of flip-flop FF5, data flip-flop DF5, DF6, DF7 and DF8 and ring counter CO1 is reset. And, the reset signal produced from the power-on-reset circuit PO2 is applied to OR gate OR11, and in response to the negative edge of the reset signal, each of counters CO2 and CO3 is reset.

Referring to FIG. 10, a circuit which is a modification of the circuit of FIG. 9*b* is shown, and is arranged such that the data S (or dL) and data K vary with respect to the change of either one of focus distance or focal length. According to the circuit shown in FIG. 10, the ROM RO has its two most significant bits of 8-bit inputs connected to counter CO3, the least significant bit connected to ground, and the remaining five bits connected to focus distance measuring device DD or focal length setting device FD, which ever is provided in the circuit. The remaining parts and the operation of the circuit of FIG. 10 is similar to that described above in connection FIG. 9*b*.

Referring to FIG. 11, a circuit which is a further modification of the circuit of FIG. 9*b* is shown. According to this modification, a circuit DIA defined by diode arrays is provided in place of ROM RO. When output Q2 of counter CO3 produces HIGH, a diode array provided in circuit DIA and connected to the output Q2 is so actuated as to produce a signal represented data S (or dL). And, when output Q1 of counter CO3 produces HIGH, another diode array provided in circuit DIA and connected to the output Q1 is so actuated as to produce a signal representing data K. The remaining circuit of FIG. 11 is the same as that shown in FIG. 9*b*.

Next, the operation of the circuit of FIGS. 8*a* and 8*b* will be described with reference to a flow chart of FIGS. 12*a* and 12*b*. While the manual switch MS is turned off, microcomputer MCO is in a "HALT" condition consuming a very low electric power. When the switch MS is turned on, a HIGH produced from inverter IN2 is applied to an interruption terminal i0, whereby the microcomputer MCO starts to operate from step #0. At step #0, a HIGH is produced from output terminal 01, thereby producing a LOW from inverter IN3. Thus, transistor BT2 conducts to supply electric power to power supply line Vcc. Then, at step #1, it is discriminated whether or not switch RS is turned on, by the discrimination of signal at the input i3. When the switch RS is turned off, input i3 receives LOW from inverter IN4 through AND gate AN0. But if switch RS is turned on, input i3 receives HIGH from inverter IN4. When input i3 is receiving HIGH, i.e., when switch RS is on, the program advances to step #41 for the exposure control as will be described later. Contrary, when input i3 is receiving LOW, i.e., when switch RS is off, output 03 produces HIGH, at step #2 for starting the light measuring operation for the focus detection. Then, at step #3, output 02 produces HIGH to fetch data S (or dL) and data K from the mounted interchangeable lens.

Then, at step #4, it is waited until input i4 receives HIGH. When input i4 receives HIGH, data (of A-D converted value of charge in CCD VSC or IRC by one light receiving element) from controller COT is read into microcomputer MCO through input port IP1, at step #5. At step #6, it is discriminated whether input i6 is receiving HIGH. If input i6 is receiving LOW, the program returns back to step #4 for reading next data (of A-D converted value of charge in CCD VSC or IRC by another light receiving element). Contrary, if input i6 is receiving HIGH, as occurred when data of A-D converted value of charge in CCD VSC or IRC by all the light receiving elements is read in, the program advances to step #7. At step #7, it is discriminated whether or not input i3 is receiving HIGH, in the same manner as step #1. If input i3 is receiving HIGH, the program jumps to step #41. If not, then the program proceeds to step #8. At step #8, data S (or dL) is read in through input port IP2, and at step #9, data K is read in through input port IP3. Then, at step #10, an amount of defocus (out of focus) of the image formed on a CCD, and also a direction of defocus are calculated using data received through input port IP1. A manner for carrying out this calculation is disclosed, for example, in U.S. Pat. No. 4,333,007 patented Jun. 1, 1982 to Langlais et al., or in Japanese Patent Laid-open Publication (Tokkaisho) No. 57-45510.

Then, at step #11, it is discriminated whether input i5 is receiving HIGH or not. If input i5 is receiving HIGH, it is understood that the defocus signal dF (representing

the amount and direction of defocus) is calculated using output from CCD IRC provided in the infrared light photoelectric conversion device **9***b*. Therefore, microcomputer MCO carries out a calculation:

$$K\cdot(dF-dL)=N$$

using deflection data dL for correcting defocus signal dF and rate K which are obtained from ROM RO.

If input i5 is not receiving HIGH, it is understood that the defocus signal dF is calculated using output from CCD VSC provided in the visible light photoelectric conversion device **9***a*. In this case, microcomputer MCO carries out a calculation:

$$K\cdot dF=N$$

using defocus signal dF without correction and rate K.

It is to be noted that the calculated result N in the above two equations indicates a number of pulses to be produced from encoder EN to shift the mounted lens to the properly infocused position.

Then, at step **#14**, the focus condition is indicated through display device DP. And, at step **#15**, it is discriminated whether or not input i3 is receiving HIGH for discriminating whether the switch RS is turned on or not, in the same manner described above. At step **#16**, it is discriminated whether the number N is equal to zero or not. If it is zero, the program jumps to step **#38**, which will be described later. If not, the program advances to step **#17** for setting the number N in register M in microcomputer MCO. Then, at step **#18**, motor drive circuit MDR is actuated to start motor MO in forward or backward direction determined by dF, and then a data P0 is set up in a register P in microcomputer MCO, at step **#19**. Then, it is discriminated at step **#20** whether or not input i2 receives HIGH pulse from encoder EN. If input has received HIGH, the program advances to step **#21**, and if not, advances to step **#27**.

At step **#27**, it is discriminated whether or not input i3 is receiving HIGH to discriminate whether switch RS is closed or not. If input i3 is receiving HIGH, it is understood that an exposure control operation will be carried out. In this case, motor MO is stopped at step **#31**, and a flag JF in microcomputer MCO is reset, and then, the program advances to step **#41**. Contrary, if input i3 is receiving LOW, "1" is subtracted from the content of register P (step **#28**) and, thereafter, it is discriminated whether the content of register P is zero (step **#29**). If not equal to zero, the program advances to step **#30** at which it is discriminated whether flag JF is carrying zero or not. If flag JF is carrying zero, the program returns to step **#20** to repeat the discrimination whether input i2 receives HIGH pulse from encoder EN. But, if the flag JF is not carrying zero, the program advances to step **#25** at which it is discriminated whether or not input i2 is receiving LOW. If input i2 is receiving LOW, the program again goes to step **#27**. The above operation is repeatedly carried out until input i2 receives HIGH. If input i2 fails to receive HIGH before the content of the register P becomes zero, i.e., before a predetermined period of time, it is understood that the lens is unable to move any further because it is already shifted to one extreme end. In this case, motor MO is stopped at step **#33**, and a warning is displayed (step **#34**). Then, flag JF is reset at step **#35** and then program advances to step **#38**.

Returning back to step **#20**, if input i2 receives a HIGH pulse from encoder EN, the content of the register M, which is now N, is subtracted by "1" (step **#21**). Then, it is discriminated whether the content of the register is equal to zero or not (step **#22**). If not, "1" is set in flag JF (step **#23**) and a data P0 is set up in register P (step **#24**). Then, it is discriminated whether input i2 receives LOW, i.e., whether the HIGH pulse ends or not (step **#25**). If it is discriminated that the HIGH pulse has ended, the program advances to step **#26** to reset flag JF and, thereafter, it returns back to step **#19**.

In the foregoing description, the content of register M is subtracted by "1" only when it is discriminated that input i2 receives HIGH, i.e., in response to the positive edge of a pulse from encoder EN. Instead, according to one modification, the number N may be doubled and the content of register M is subtracted by "1" also when it is discriminated that input i2 receives LOW, i.e., in response not only to the positive edge, but also to the negative edge of a pulse from encoder EN. In this case, a discrimination step same as the step **#22** should be added between steps **#25** and **#26** for the discrimination whether the content of the register M is equal to zero or not. If it is equal to zero, the program advances to step **#36**, as in the case of step **#22** to end the lens adjustment, as will be described below. When this modification is employed, the lens position can be adjusted more precisely to the infocus position.

At step **#22**, if it is discriminated that the content of register M is equal to zero, it is understood that the lens is shifted to the infocus position. Therefore, at step **#36**, motor MO is stopped and, at step **#37**, it is indicated through display device DP that the lens is shifted to the infocus position.

At step **#38**, it is discriminated whether manual switch MS is on or not, by the discrimination of whether input i7 is receiving HIGH or not. If input i7 receives HIGH as occurs when manual switch MS turns on, the program returns back to step **#1** to repeat the above described operation. Contrary, if input i7 receives LOW, display device DP is turned off at step **#39** and LOW is produced from output **01** to turn transistor BT2 off, thereby cutting the supply of electric power to power supply line Vcc, and returning microcomputer MCO again to "HALT" condition. Also, if it is discriminated at step **#1** that switch RS is turned off, it is waited at step **#41** until input i1 receives HIGH. Then, after completing the exposure control operation and when input i1 receives HIGH pulse from exposure control circuit EC, the program advances to step **#38**.

Next, the description is directed to modifications of the above described embodiment.

As mentioned before, the photoelectric conversion element for the focus detection can be formed by diode arrays which respond immediately to the light, instead of an integration type which respond gradually to the light, such as ROM RO.

Also, according to the above description, the data dF is calculated using digital value, which is an A/D converted value of output signal from photoelectric conversion element. Instead, it is possible to calculate the data dF using analog value from the photoelectric conversion element, and the calculated result may be converted to digital form for the motor control and display.

Referring to FIG. **13**, another embodiment of the present invention is shown. According to this embodiment, the photoelectric conversion elements IRD and VSD are eliminated, and CCDs IRC and VSC are used for obtaining signals which determine whether to use

the auxiliary light, or not, and which determine which one of the two signals from CCDs IRC and VSC is to be used.

A counter CO10 is reset by a reset pulse ϕR, counts up by clock pulse ϕ1, and produces a pulse from its carry terminal after, e g., 40 msec. When this pulse is produced, the signals produced from outputs IAD and VAD from CCDs IRC and VSC are compared with each other in comparator AC10 and are each compared with a reference voltage from constant voltage source CE10 in comparators AC11 and AC12, and the compared signals are applied to logic circuit defined by AND gates AN21 and AN32 and inverter IN20. Furthermore, the outputs from AND gates AN21 and AN32 are stored in data flip-flops DF20 and DF21.

If the compared results are such that IAD is smaller than VAD (meaning that the infrared light is stronger than visible light) and IAD is smaller than a predetermined level CE10 (meaning that the infrared light is stronger than a predetermined level), or that IAD is equal to or greater than VAD (meaning that the infrared is not stronger than visible light) and VAD is weaker than the predetermined level CE10 (meaning that visible light is stronger than the predetermined level), both AND gates AN21 and AN22 produce LOW, thereby storing LOW in both data flip-flops DF20 and DF21. In this case, OR gate OR21 continues to produce LOW, thereby preventing LED IRL from emitting infrared light. In the above given situation, since both outputs from CCDs IRC and VSC reach the predetermined level CE10 before counter CO10 counts the time, e.g., 40 msec, the charge to CCDs can be completed within a predetermined period of time, such as 80 msec.

Contrary, if the compared results are such that IAD is smaller than VAD (meaning that the infrared light is stronger than visible light) and IAD is equal to or greater than a predetermined level CE10 (meaning that the infrared light is not stronger than a predetermined level), or that IAD is equal to or greater than VAD (meaning that the infrared is not stronger than visible light) and VAD is equal to or greater than the predetermined level CE10 (meaning that visible light is not stronger than the predetermined level), both AND gates AN21 and AN22 produce HIGH, thereby storing LOW in both data flip-flops DF20 and DF21. In this case, OR gate OR21 produces HIGH, thereby emitting infrared light from LED IRL. In the above given situation, an infrared light is emitted because, if CCD continues to charge without an auxiliary infrared light, the charging may not complete within a predetermined period of time, such as 80 msec., resulting in a long period of time for the focus detection.

When a signal level from outputs IAD or VAD reaches the reference voltage level of constant voltage source CE11, comparator AC13 or AC14 producers HIGH, thereby producing a HIGH pulse from one-shot circuit OS10 or OS11. Before producing a HIGH pulse from one-shot circuit OS10 or OS11, flip-flops FF10 and FF11 are both in reset condition. Therefore, a $\overline{Q}$ terminal of each flip-flop FF10 or FF11 is producing HIGH, thereby enabling AND gates AN24 and AN23.

When a HIGH pulse is produced from one-shot circuit OS10, it is transmitted through OR gate OR22 and AND gate AN23 to flip-flop FF10, thereby changing the flip-flop FF10 to set condition. Accordingly, flip-flop FF10 produces HIGH from its Q output which is applied to controller COT through OR gate OR23 and also to analog switch AS1, and LOW from its $\overline{Q}$ output which is applied to AND gate AN24, thereby disabling AND gate AN24 to cut any HIGH pulse from one-shot circuit OS11. Thus, flip-flop FF11 continues to produce LOW from its Q output and HIGH from its $\overline{Q}$ output. This condition is maintained until a reset pulse is produced from output 03 of microcomputer MCO.

Contrary, when a HIGH pulse is produced from one-shot circuit OS11, flip-flop FF11 is turned to set condition and flip-flop FF10 is maintained in reset condition, thereby providing HIGH to controller COT and analog switch AS2.

In the above described operation, when controller COT receives HIGH from OR gate OR23, controller COT produces a transmission pulse ϕT which is applied to CCDs VSC and IRC. Furthermore, in the above operation, when HIGH is applied to analog switch AS1, CCD IRC is selected for use in focus detection, and when HIGH is applied to analog switch AS2, CCD VSC is selected for use in focus detection. In this way, a CCD which is charged to a predetermined level first is selected to be used in focus detection.

An output of OR gate OR23 is also connected to a one-shot circuit OS12 which produces a HIGH pulse when OR gate OR23 produces HIGH. The HIGH pulse from one-shot circuit OS12 is transmitted through OR gate OR24 to a reset terminal of data flip-flops DF20 and DF21. Accordingly, if LED has been emitting infrared light, the light emission stops when data flip-flops DF20 and DF21 resets.

A counter CO11 is reset by a reset pulse ϕR from controller COT, and counts a predetermined period of time, such as 80 msec., by the count of clock pulses ϕ1 and produces a pulse from its carry terminal when counting has completed. If both comparators AC13 and AC14 are producing LOW at a moment when a pulse is produced from the counter CO11, the pulse from the counter CO11 is applied through OR gate OR22 and AND gate AN23 to set terminal of flip-flop FF10. Thus, flip-flop FF10 produces HIGH from its Q output, thereby actuating the controller COT to produce a transmission pulse ϕT and, at the same time, selecting CCD IRC provided in the infrared light photoelectric conversion device 9*b*. The above described operation is carried out when the object is relatively dark such that a CCD fails to charge up to a predetermined level within 80 msec. In this case, the charging is forcibly ended at the end of counting 80 msec. Furthermore, since LED IRL emits infrared light under this operation, it is more likely that CCD IRC for the infrared light produces a higher output level than that from CCD VSC for the visible light. Therefore, under this operation, it is so arranged that CCD IRC is selected.

Referring to FIG. 14, yet another embodiment of the present invention is shown. When compared with the first embodiment shown in FIGS. 8*a* and 8*b*, this embodiment has no photoelectric conversion elements IRD and VSD, and has only one CCD IRC, which is sensitive to infrared light. Furthermore, LED emits infrared light only when it is so determined that the data dF, calculated by the use of output from CCD IRC, is unreliable due to low contrast.

An operation of the auto-focusing system of FIG. 14 is described hereinbelow.

Referring also to FIG. 15 showing a flow chart of operation by the circuit of FIG. 14, the steps up to step #10 is the same as those shown in FIG. 12*a* and, therefore, data dF is calculated using output signal from

CCD IRC for the infrared light. Thus, the data dF is equal to amount and direction of defocus based on the infrared light. Then, at step #51, it is discriminated whether or not a data of contrast as obtained through a calculation carried out in step #10 is above a predetermined level. If the contrast data is below a predetermined level, the program advances to step #52 for producing a warning signal because the obtained data dF is unreliable. Then, at step #53, it is discriminated whether output 04 of microcomputer MCO is producing HIGH, or not. If output 04 is producing HIGH, it is understood that the data dF has been calculated with the aid of auxiliary infrared light. Therefore, in this case, there is no need to calculate the data dF again with the aid of auxiliary infrared light, because there will be hardly any difference in the newly calculated result. In this case, the program advances to step #12.

Contrary, if output 04 is not producing HIGH, HIGH is produced from output 04 and, thereafter, the program returns back to step #1 to repeat the light measurement by the CCD IRC under the auxiliary infrared light and the calculation of data dF.

While output 04 is producing HIGH to enable AND gate AN30 (FIG. 14), a reset pulse produced from output ϕR is applied to set terminal of flip-flop FF20. Thus, flip-flop FF20 produces HIGH from its Q output effecting an emission of infrared light. Thereafter, when a transmission pulse is produced from output ϕT, this pulse is applied through AND gate AN31 and OR gate OR30 to reset terminal of flip-flop FF20. Thus, flip-flop FF20 produces LOW from its Q output stopping the emission of infrared light.

Next, at step #12, amount and direction of rotation of motor MO is calculated using data dF, data S (or dL) and data K, as described earlier. Then, after carrying out steps #14–#16, which are the same as those shown in FIG. 12*a*, the program advances to step #55. A program including steps #55–#58 indicates the same operation of steps #17 and #18 shown in FIG. 12*a*, but in more details. At step #55, data |N| representing an amount of rotation of motor MO is stored in register M. At step #56, it is discriminated whether N is smaller than zero or not. If it is smaller than zero, motor MO is driven forward direction. If it is greater than zero, motor MO is driving backwardly. Thereafter, the program advances to step #19.

When the focus adjustment operation through steps #16, #35 and #37 completes, the program advances to step #59 at which it is discriminated whether switch RS is turned on or not. If switch RS is not turned on, it is further discriminated whether switch MS is turned off by the discrimination whether input i7 is receiving LOW. If input i7 is not receiving LOW, the above described operation is repeated, and when input i7 receives LOW, display device DP is disabled, and LOW is produced from each of outputs 01 and 04, thereby returning microcomputer MCO to HALT condition. Therefore, according to the flow chart shown in FIG. 15, when one cycle of focus adjustment operation completes, it is necessary to open the switch MS to start a new cycle of focus adjustment operation.

Furthermore, when it is discriminated that output i3 is producing HIGH as a result of closure of switch RS, output 04 produces LOW at step #63, and it is waited, after the completion of exposure control operation, until input i1 receives HIGH. When i1 receives HIGH, it is discriminated whether or not input i7 is receiving HIGH as a result of closure of switch MS. If input i7 is receiving HIGH, the program returns back to step #1, thereby repeating the focus adjustment operation. If input i7 is receiving LOW, the program advances to step #61 to end the operation.

It is to be noted that in FIG. 14, if switch RS closes to produce HIGH from AND gate AN0, a one-shot circuit OS20 produces a HIGH pulse which is applied through OR gate OR30 to a reset terminal of flip-flop FF20. Accordingly, a LOW is produced from Q output of flip-flop FF20 to stop the emission of infrared light.

Referring to FIG. 16, there is shown a flow chart which is a modification of the flow chart shown in FIG. 15. If it is discriminated at step #51 that the image lacks contrast, and when it is discriminated that data dF is calculated with an aid of auxiliary light at step #53, it is understood that the situation in this case is such that the object to be photographed is located very far from the camera. In this case, data Nm is set for the amount and direction of rotation of motor MO to shift the lens to the infinite focusing position. Thereafter, the program advances to step #14.

According to the modification of FIG. 14, only a CCD IRC, which is sensitive to infrared light, is necessary for the optical arrangement of focus detection. From this view point, the circuit of FIG. 1*a* can be simplified such that photoelectric conversion device 9*a* may be deleted, or beam splitter 7 can be replaced with a filter which cuts lights other than infrared light, and the transmitted infrared light is relayed through a suitable relay lens to CCD IRC.

According to the modification described above in connection with FIG. 14, infrared beam is emitted when an object has a low contrast, such as when aiming at a plain wall with a single color. In this case, the purpose for emitting infrared beam is to present a contrast around the spot receiving infrared beam. To this end, the spot on which the infrared beam impinges, or at least a border line of the lit spot should be included in an area for the focus detection. Therefore, the diameter of the infrared beam for the above described modification should be made smaller than that for the embodiments shown in FIGS. 8*a* and 8*b* and FIG. 13.

Referring to FIG. 17, a detailed flow chart of step #51 shown in FIGS. 15 and 16 for determining whether the contrast is low or not is shown. At step #80, a register C in microcomputer MCO is reset to "0", and at step #81, a register i is stored with "1". Then, at step #82, an absolute value of a difference between output ai from ith light receiving element and output ai+1 from (i+1)th light receiving element, which is substantially equal to the contrast difference between the two neighboring light receiving elements, is added with the content of register C and the sum is stored in the same register C. Thus, register C is now storing:

$$|ai-ai+1|.$$

At step #83, "1" is added to the content of register i, and at step #84, the content of the register i is compared with a number n (n is equal to the number of the total light receiving elements). If, the content of register i is smaller than n-1, the program returns back to step #82, thereby repeating the steps #82 and #82. Thus, the contrast differences between the two neighboring light receiving elements are added for n-1 times. When the content of the register i becomes equal to n-1, the program advances to step #85. At this step, the content of the register C is storing:

$$|a1-a2|+|a2-a3|+\ldots$$
$$+|an-2-an-1|+|an-1-an|,$$

which represents the contrast of the image.

At step #85, it is discriminated whether the content of the register C carrying a sum of the above formula is greater than a predetermined value CD or not. If the content of the register C is greater than the value CD, this means that the image has an enough contrast. In this case, the program advances to step #12. Contrary, if the content of the register C is not greater than the value CD, this means that the contrast is relatively low and, therefore, the program goes to step #52.

Referring to FIG. 18, an example of an optical arrangement for installing infrared LED IRL is shown. Submirror 6 has two reflection faces 6*a* and 6*b* which are slightly slanted with each other. Light ray L1 reflected from an object to be photographed and passing though the picture taking lens reflects on reflection face 6*a* and impinges on beam splitter 7. Infrared LED IRL is mounted on a base plate on which the beam splitter 7 is provided. Infrared light ray L2 emitted from LED IRL reflects on reflection face 6*b*, passes through main mirror 1 and picture taking lens, and directs to an object to be photographed.

It is to be noted that the light rays L1 and L2, when extended through submirror 6, intersect with each other at a point 10*a* on film surface 10. Accordingly, infrared LED IRL is installed as if light beam L2 is emitted from point 10*a*. Furthermore, emitted light beam L2 hits on a spot which is the same as the spot for the focus detection.

It is also to be noted that, from a practical point of view, reflection faces 6*a* and 6*b* may not be so precisely arranged as to intersect light rays L1 and L2 exactly on the point 10*a*, but should be so arranged as if light ray L2 emits not from the point 10*a* but from a point within a spot for the focus detection.

Furthermore, according to the arrangement shown in FIG. 18, a plate 20 is provided for holding beam splitter 7 and for intercepting infrared light beam from LED IRL, thereby preventing the infrared light from LED IRL from being directly impinged on the photoelectric conversion devices 9*a* and 9*b*. Reference numerals 21, 22 and 23 designate a gear arrangement for reducing the speed and transmitting the driving force of motor MO, and 24 is an actuator integrally provided to gear 23. When an interchangeable lens is mounted on a camera, actuator 24 engages a shaft 34 (FIG. 19). Thus, when actuator 24 rotates shaft 34, the focusing position of the lens is changed, thereby carrying out the focus adjustment. Furthermore, 25 designates a rotating plate defining encoder EN, and 26 designates a separation plate for separating the camera into a dark space and a lower space for intalling gears and motor MO. Separation plate 26 has an opening for the path of light beam from LED IRL and light beam into the beam splitter.

Moreover, according to the arrangement shown in FIG. 18, relay lens 8*a* and 8*b* are both integrally formed by a transparent plastic and are held by plate 20 together with beam splitter 7.

Referring to FIGS. 19 and 20, another example of an optical arrangement for installing infrared LED IRL is shown. Instead of the camera body, LED IRL is provided in a filter F, which can be detachably mounted on an interchangeable lens at its end remote from the camera-body receiving end. Filter F comprises a frame 30 having a threaded cylinder portion for engagement with the lens and a pair of filter plates 31 and 32 which are mold-formed by acrylic resin and each having a configuration of a half-circle. Filter plates 31 and 32 have, respectively, recessed face 31*a* and projecting face 32*a* which are slanted 45° to the flat face of the filter plates. Filter plates 31 and 32 are accommodated in frame 30 with faces 31*a* and 32*a* parallelly facing each other with a small air gap therebetween. Filter plate 31 has a lens 31*b* formed thereon on opposite side of recessed face 31*a*. Filter F also has an aperture plate 33 and infrared LED IRL. The infrared beam emitted from the LED IRL passes through aperture plate 33, serving as F-stop, and lens 31*b* reflects totally at face 31*a*, thereby emitting infrared beam from the center of the filter F and in alignment with the axis of the lens.

According to the arrangement shown in FIGS. 19 and 20, since there is no or very little angular difference between the projecting beam from the camera to the object and reflected beam from the object to the camera, there will be no parallax observed between the projecting and receiving beams. Furthermore, since the recess 31*a*, as well as the projection 32*a*, can be formed very small, it has little or no affect on the focus detection or on the exposure operation.

Referring now to FIG. 21, an auto-focusing system according a further embodiment of the present invention is shown. The auto-focusing, according to the auto-focusing system of FIG. 21 is done by the contrast detection, and this method is disclosed, e.g., in U.S. Pat. No. 4,341,953 patented Jul. 27, 1983 to Sakai et al, in Japanese Patent Laid-open Publication (Tokkaisho) No. 57-72110 or in Tokkaisho No. 57-88418. A focus detection calculation circuit 13' shown in FIG. 21 is provided to produce only the direction of defocus. When an image is blur because of front-focus, a terminal Ta produces HIGH, and when it is so because of rear-focus, a terminal Tc produces HIGH. And, when an image is properly focused, a terminal Tb produces HIGH. Based on these HIGH signals, a display DP' viewable through the viewfinder indicates a focused condition whether it is in front-focus, rear-focus or infocus condition. Terminals Ta and Tc are also connected to AND gates AN40 and AN41, respectively, and terminal Tb is connected to an inverting input of both AND gates AN40 and AN41. Motor drive circuit MDR is connected to an output of AND gate AN40 and also to an output of AND gate AN41 through OR gate OR40. When AND gate 40 produces HIGH from its output, motor drive circuit MDR is so actuated as to drive the motor MO in, e.g., forward direction, thereby shifting the lens to infinite focus position. Contrary, when OR gate OR40 produces HIGH from its output, motor drive circuit MDR is so actuated as to drive the motor MO in, e.g., reverse direction, thereby shifting the lens to near focus position. Furthermore, when AND gate AN40 or OR gate OR40 stops producing HIGH to supply LOW from both AND gate AN40 and OR gate OR40, motor drive circuit MDR immediately stops the motor MO, thereby stopping the lens shift.

A one-shot circuit OS40 produces a HIGH pulse in response to HIGH from terminal Tb, thereby setting flip-flop FF40. Thus, flip-flop FF40 produces HIGH from its Q output. Furthermore, the HIGH pulse from one-shot circuit OS40 is applied to counter CO40, thereby resetting the counter CO40, which is provided for counting the number of pulses from encoder EN, to zero. A digital comparator DC compared the output of

counter CO40 with data S (or dL) stored in a data reading circuit DR as obtained from data output circuit LDO provided in an interchangeable lens. When two signals match with each other, comparator DC produces LOW which is applied to AND gate AN42. An output of AND gate AN42 is connected to OR gate OR 40. Furthermore, the output of comparator DC is connected to one-shot OS41. Thus, in response to the change of output from comparator DC from HIGH to LOW, one-shot circuit OS41 produces HIGH to reset flip-flop FF40.

The auto-focusing system according to the embodiment shown in FIG. 21 operates as follows. When focus detection is started by infrared light, and when circuit 13' produces HIGH from its output terminal Ta, AND gate AN40 produces HIGH, thereby turning the motor MO forwardly to effect the lens shift toward infinite focus position. Then, when the lens is shifted to a position at which the image formed by infrared light properly focuses on a predetermined image forming plane, terminal Ta produces LOW and, at the same time, terminal Tb produces HIGH. Thus, one-shot circuit OS40 produces a HIGH pulse, thereby setting flip-flop FF40. Thus, flip-flop FF40 produces HIGH from its output Q. Thus, the motor MO is turned in the reverse direction to effect the lens shift toward near-focus position. This lens shift is detected by encoder EN and counter CO40 and, when the lens shift is effected for a required amount determined by the data S (or dL) stored in data reading circuit DR, comparator DC produces LOW, thereby producing LOW from AND gate AN42 and OR gate OR40. Since, at this moment, AND gate AN41 is producing LOW, motor drive circuit MDR receives LOW from OR gate OR40, thereby immediately stopping the motor MO.

It is to be noted that when comparator DC changes its output from HIGH to LOW, one-shot circuit OS41 produces HIGH, thereby resetting flip-flop FF40. Thus, flip-flop FF40 produces LOW from its Q output, thereby disabling AND gate AN42.

In contradistinction to the above, when focus detection is started by infrared light, and when circuit 13' produces HIGH from its output terminal Tc, both AND gate AN41 and OR gate OR40 produce HIGH, thereby turning the motor MO reversely to effect the lens shift toward near focus position. Then, when the lens is shifted to a position at which the image formed by infrared light properly focuses on the predetermined image forming plane, terminal Tc produces LOW and, at the same time, terminal Tb produces HIGH. Accordingly, AND gate AN41 produces LOW, but AND gate AN42 produces HIGH, because flip-flop FF40 produces HIGH from its Q output due to the HIGH pulse produced from one-shot circuit OS40. Thus, OR gate OR40 continues to produce HIGH. Accordingly, motor drive circuit MDR continues to drive the motor MO in the reverse direction. Thus, the lens shifts past the position for properly focusing an image by infrared light. The amount of lens shift past said position is detected by encoder EN and counter CO40 and, when the lens is shifted for a required amount determined by the data S (or dL) stored in data reading circuit DR, comparator DC produces LOW, thereby immediately stopping the lens in the same manner described above.

By the above described operation, the picture taking lens is shifted to a position at which the image formed by visible light focuses properly on the predetermined image forming plane, thereby completing the correction of the deflection dL.

In contrast to the embodiments described above in connection with FIGS. 8*a*, 8*b*, 13 and 14 offering a one-step control system, the lens, according to the embodiment described above in connection with FIG. 21, is controlled in two steps. First, the lens is shifted to a quasi-infocus position based on the focus detection carried out by the infrared light. Secondly, by the use of a signal representing the data S (or dL) as obtained from data output circuit IDO provided in the mounted interchangeable lens, the lens is further shifted to a true-infocus position for the visible light. This two-step control system can be applied to the previous embodiments of FIGS. 8*a*, 8*b*, 13 and 14, as described below.

In the embodiments described above in connection with FIGS. 8*a*, 8*b*, 13 and 14, focus detection is carried out by a so-called phase difference detecting system. When the two-step control system is employed, the lens is first shifted to a quasi-infocus position based on the defocus signal dF as obtained from focus detection calculation circuit 13 and, thereafter, the lens is further shifted in accordance to the signal S (or dL) to the true-infocus position for the visible light. More specifically, the lens is first shifted until encoder EN produces $N1=K\cdot dF$ pulses. Thereafter, the lens is further shifted until encoder EN produces $N2=K\cdot dL$ pulses. Accordingly, in total, the lens is shifted by a distance $N=N1-N2=K(dF-S)$, which is substantially equal to the distance of lens shift carried out in one-step control system.

In any one of the above described embodiments, various changes and modifications can be adapted. For example, beam splitter 7 can be eliminated when the focus condition detection is carried out based on only infrares light. In this case, an infrared light pass filter should be provided between submirror 6 and photoelectric conversion device 9*b* for transmitting only the infrared light to device 9*b*. When this arrangement is employed, it is not necessary to take the optical length d/n for the infrared light between first and second reflecting faces 7*a* and 7*b* into consideration. Therefore, data output circuit 16 needs to produce only the deflection signal dL.

Although the present invention has been fully described with reference to several preferred embodiments, many modifications and variations thereof will now be apparent to those skilled in the art, and the scope of the present invention is therefore to be limited not by the details of the preferred embodiments described above, but only by the terms of appended claims.

What is claimed is:

1. In an automatic focusing system for a camera with an interchangeable objective lens and a camera body for mounting the interchangeable lens, the improvement, comprising:

means for receiving light from the object through the objective lens to produce a signal representative of the received light;

means for processing the signal from said light receiving means to produce defocus data representative of the amount and direction of defocus of an image formed by the objective lens with respect to a predetermined focal plane;

means for providing first data and second data different from said first data, both said first and second

data being intrinsic to the interchangeable objective lens actually mounted on the camera body;

first means for determining the amount of focusing movement necessary for the objective lens to focus the object in accordance with said amount of defocus in accordance with said first and said second data;

second means for determining the direction of focusing movement necessary for the objective lens to focus the object in accordance with said direction of defocus; and

means for carrying out the focusing movement of the objective lens with the amount and direction thereof determined by said first and said second determining means.

2. The improvement according to claim 1, wherein said first data represents converting information necessary for converting said amount of defocus into said amount of focusing movement.

3. The improvement according to claim 2, wherein said providing means alters the contents of said first data in accordance with the change in the photographing distance of the interchangeable lens.

4. The improvement according to claim 1, wherein said providing means alters the contents of said first data in accordance with the change in focal length of the interchangeable objective lens.

5. The improvement according to claim 2, wherein said second data represents correcting information for correcting the influence of the aberration of the objective lens on said amount of focusing movement.

6. The improvement according to claim 1, wherein said second data represents correcting information for correcting the influence of the aberration of the objective lens on said amount of focusing movement.

7. The improvement according to claim 1, wherein said providing means further provides third data different from said first and second data, said third data being intrinsic to the interchangeable objective lens actually mounted on the camera body, and wherein said second determining means determines the direction of focusing movement in accordance with said direction of defocus and said third data.

8. The improvement according to claim 7, wherein said third data represents information to determine whether or not to reverse the relationship between said direction of focusing movement and said direction of defocus.

9. The improvement according to claim 1, wherein said providing means is located within the interchangeable objective lens, and said first data and said second data are sequentially transmitted to the camera body in which said receiving means, said processing means and said first and second determining means are located.

10. In an automatic focusing system for a camera with an interchangeable objective lens and a camera body for mounting the interchangeable lens, the improvement, comprising:

means for receiving light from the object through the objective lens to produce a signal representative of the received light;

means for processing the signal from said light receiving means to produce defocus data representative of the amount and direction of defocus of an image formed by the objective lens with respect to a predetermined focal plane;

means for providing data representative of converting information for converting said amount of defocus into the amount of focusing movement necessary for the objective lens to focus the object, the data being intrinsic to the interchangeable objective lens actually mounted on the camera body, wherein said providing means includes means for altering the contents of said data in accordance with the change in photographing distance of the interchangeable objective lens;

first means for determining said amount of focusing movement necessary for the objective lens to focus the object in accordance with said amount of defocus and said data from said providing means;

second means for determining the direction of focusing movement necessary for the objective lens to focus the object in accordance with said direction of defocus; and

means for carrying out the focusing movement of the objective lens with the amount and direction determined by said first and second determining means.

11. The improvement according to claim 10, wherein said providing means is located within the interchangeable objective lens, and data is transmitted to the camera body in which said receiving means, said processing means and said first and second determining means are located.

12. In an automatic focusing system for a camera including an interchangeable objective lens to be mounted on a camera body having means for receiving light from the object through the objective lens to produce a signal representative of the received light, means for processing the signal to produce defocus data representative of the amount and direction of defocus of an image formed by the objective lens with respect to a predetermined focal plane, and means for determining the amount and direction of focusing movement necessary for the objective lens to focus the object in accordance with the amount and direction of defocus and data intrinsic to the interchangeable objective lens actually mounted on the camera body, said interchangeable objective lens comprising:

means for providing data intrinsic to the interchangeable objective lens, said data including data representative of converting information for converting said amount of defocus into the amount of defocusing movement necessary for the objective lens to focus the object, wherein said providing means includes means for altering the contents of said data in accordance with the change in photographing distance of the interchangeable objective lens; and

means for transmitting the data to the camera body.

13. The interchangeable objective lens according to claim 12, further comprising means for generating information of photographing distance, wherein said altering means is responsive to said generating means.

14. The interchangeable objective lens according to claim 12, further comprising means for generating information representative of the current focusing position of the objective interchangeable lens, wherein said altering means is responsive to said generating means.

15. In an automatic focusing system for a camera including an interchangeable objective lens to be mounted on a camera body having means for receiving light from the object through the objective lens to produce a signal representative of the received light, means for processing the signal to produce defocus data representative of the amount and direction of defocus of an image formed by the objective lens with respect to a predetermined focal plane, and means for determining

the amount and direction of focusing movement necessary for the objective lens to focus the object in accordance with the amount and direction of defocus and data intrinsic to the interchangeable objective lens actually mounted on the camera body, said interchangeable objective lens comprising:

means for providing data intrinsic to the interchangeable objective lens, said data including first data and second data different from said first data, both of said first and second data being utilized for determining the amount of focusing movement necessary for the objective lens to focus the object; and

means for sequentially transmitting said first and second data to the camera body.

16. The interchangeable objective lens according to claim **15**, wherein said first data represents converting information necessary for converting said amount of defocus into said amount of focusing movement.

17. The interchangeable objective lens according to claim **16**, wherein said second data represents correcting information for correcting the influence of the aberration of the objective lens on said amount of focusing movement.

18. The interchangeable objective lens according to claim **15**, wherein said second data represents correcting information for correcting the influence of the aberration of the objective lens on said amount of focusing movement.

19. In an automatic focusing system for a camera with an interchangeable objective lens having means for providing data intrinsic to the objective lens and a camera body for mounting the interchangeable lens, the camera body comprising:

means for receiving light from the object through the objective lens to produce a signal representative of the received light;

means for processing the signal from said light receiving means to produce defocus data representative of the amount and direction of defocus of an image formed by the objective lens with respect to a predetermined focal plane;

means for sequentially receiving, from the interchangeable objective lens, data intrinsic to the objective lens, the data including first data and second data different from said first data;

first means for determining the amount of focusing movement necessary for the objective lens to focus the object in accordance with said amount of defocus in accordance with said first and said second data;

second means for determining the direction of focusing movement necessary for the objective lens to focus the object in accordance with said direction of defocus.

20. The camera body according to claim **19**, wherein said first data represents converting information necessary for converting said amount of defocus into said amount of focusing movement.

21. The camera body according to claim **20**, wherein said second data represents correcting information for correcting the influence of the aberration of the objective lens on said amount of focus movement.

22. The camera body according to claim **19**, wherein said second data represents correcting information for correcting the influence of the aberration of the objective lens on said amount of focusing movement.

23. An interchangeable zoom lens including an optical system adjustable for both focusing and zooming, and adapted to be detachably mounted on a camera body which is provided with focus detection means for detecting an amount of defocus of an object image formed by said optical system, and means for determining the focus adjustment of said optical system in accordance with the detected amount of defocus, said interchangeable zoom lens comprising:

a code plate for producing a plurality of digital focal length signals representing given discrete focal lengths of said optical system in accordance with the zooming adjustment of said optical system;

circuit means for outputting a predetermined one of a plurality of outputs in response to a predetermined one of a plurality of inputs, said plurality of outputs including a plurality of conversion coefficients needed for converting the detected amount of defocus into the amount of focus adjustment determined by said determining means, said conversion coefficients being intrinsic to said interchangeable lens and having values depending upon the given discrete focal lengths of said optical system represented by said digital focal length signals, respectively;

means for applying one of said digital focal length signals, being produced, to said circuit means as said predetermined input to cause said circuit means to output one of said conversion coefficients as said predetermined output, the value of which depends upon the focal length of said optical system represented by said one digital focal length signal being produced; and

transmission means for transmitting the output conversion coefficient to said camera body.

24. An interchangeable zoom lens including an optical system adjustable for focusing and adapted to be detachably mounted on a camera body which is provided with focus detection means for detecting an amount of defocus of an object image formed by said optical system, and means for determining the focus adjustment of said optical system in accordance with the detected amount of defocus, said interchangeable zoom lens comprising:

a code plate for producing a plurality of digital photographic distance signals representing given discrete photographic distances of said optical system in accordance with the adjustment of said optical system for focusing;

circuit means for storing a predetermined one of a plurality of outputs in response to a predetermined one of a plurality of inputs, said plurality of outputs including a plurality of conversion coefficients needed for converting the detected amount of defocus into the amount of focus adjustment determined by said determining means, said conversion coefficients being intrinsic to said interchangeable lens and having values depending upon the discrete photographic distances of said optical system represented by said digital photographic distance signals, respectively;

means for applying one of said digital photographic distance signals, being produced, to said circuit means as said predetermined input to cause said circuit means to output one of said conversion coefficients as said predetermined output, the value of which depends upon the photographic distance of said optical system represented by said one digital photographic distance signal being produced; and

transmission means for transmitting the output conversion coefficient to said camera body.

25. An interchangeable zoom lens including an optical system adjustable for both focusing and zooming, and adapted to be detachable mounted on a camera body which is provided with focus detection means for detecting an amount of defocus of an object image formed by said optical system, and means for determining the focus adjustment of said optical system in accordance with the detected amount of defocus, said interchangeable zoom lens comprising:

a first code plate for producing a plurality of digital focal length signals representing given discrete focal lengths of said optical system in accordance with the zooming adjustment of said optical system;

a second code plate for producing a plurality of digital photographic distance signals representing given discrete photographic distances of said optical system in accordance with the focus adjustment of said optical system;

circuit means for outputting a predetermined one of a plurality of outputs in response to a predetermined one of a plurality of inputs, said plurality of outputs including a plurality of conversion coefficients needed for converting the detected amount of defocus into the amount of focus adjustment determined by said determining means, said conversion coefficients being intrinsic to said interchangeable lens and having values depending upon the given discrete focal lengths of said optical system represented by said digital focal length signals and also upon said given photographic distances of said optical system represented by said digital photographic distance signals, respectively;

means for applying a combination of one of said digital focal length signals, being produced, to said circuit means as said predetermined input to cause said circuit means to output one of said conversion coefficients as said predetermined output, the value of which depends upon the focal length and the photographic distance of said optical system represented by said one digital focal length signal and said one digital photographic distance signal being produced; and

transmission means for transmitting the output conversion coefficient to said camera body.

* * * * *

US005243468A

United States Patent [19]

Ohtake

[11] Patent Number: 5,243,468

[45] Date of Patent: Sep. 7, 1993

[54] **WIDE ANGLE OBJECTIVE LENS**

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[73] Assignee: **Nikon Corporation**, Tokyo, Japan

[21] Appl. No.: **983,735**

[22] Filed: **Dec. 1, 1992**

[30] **Foreign Application Priority Data**

Dec. 6, 1991 [JP] Japan 3-322186

[51] **Int. Cl.**[5] **G02B 9/34**; G02B 9/62

[52] **U.S. Cl.** **359/740**; 359/747; 359/757; 359/772

[58] **Field of Search** 359/740, 757–758, 359/764, 772, 747

[56] **References Cited**

U.S. PATENT DOCUMENTS

4,235,521 11/1980 Imai 359/766
4,394,073 7/1983 Wakamiya 359/764

FOREIGN PATENT DOCUMENTS

43-30782 12/1943 Japan .
44-10831 5/1969 Japan .
1-209413 8/1989 Japan .

Primary Examiner—Bruce Y. Arnold
Assistant Examiner—James Phan
Attorney, Agent, or Firm—Shapiro and Shapiro

[57] **ABSTRACT**

A wide angle objective lens has, in succession from the object side, a first lens component which is a positive meniscus lens having its convex surface facing the object side, a second lens component which is a cemented meniscus lens comprising a negative lens and a positive lens cemented together and having its concave surface facing the object side and having positive refractive power, a third lens component which is a cemented meniscus lens comprising a negative lens and a positive lens cemented together and having its concave surface facing the object side and having positive refractive power, and a fourth lens component which is a negative meniscus lens having its concave surface facing the object side, and has a stop between the second lens component and the third lens component, and satisfies various predetermined conditions.

15 Claims, 1 Drawing Sheet

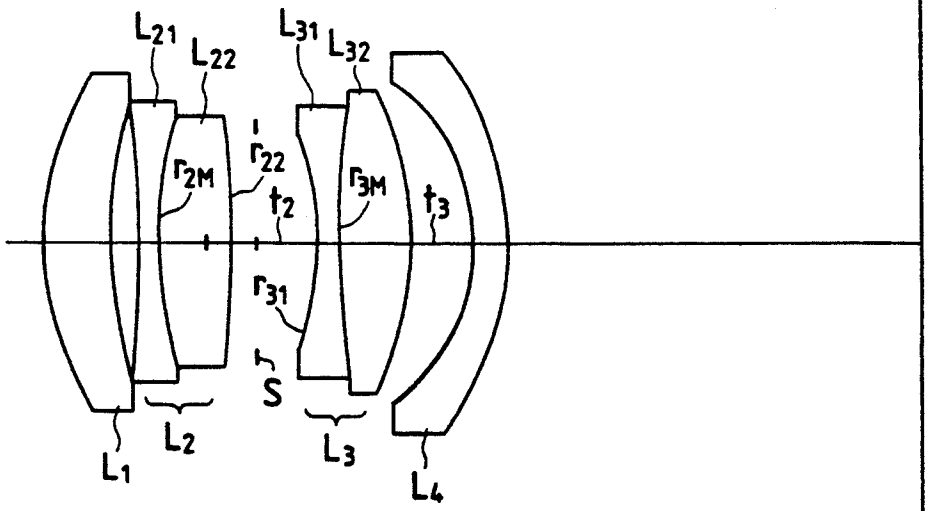
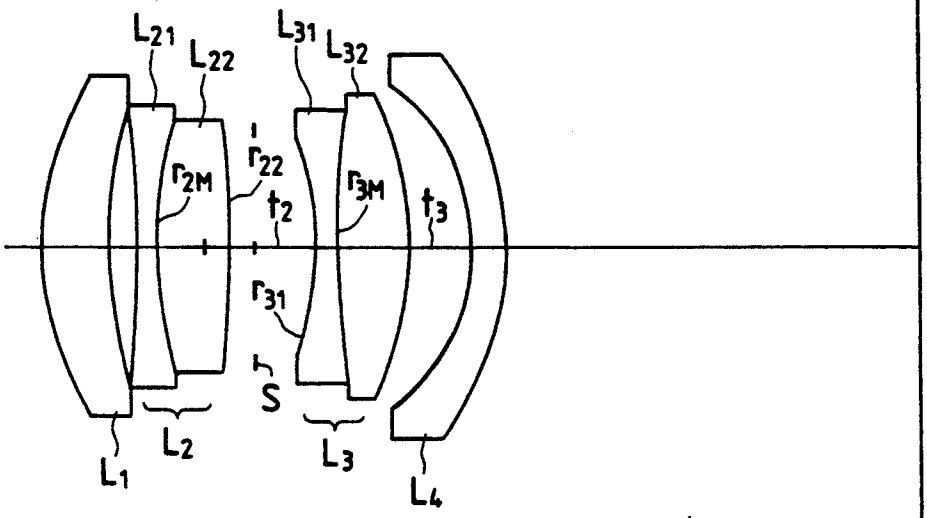


FIG. 1


L21
L22
L31
L32
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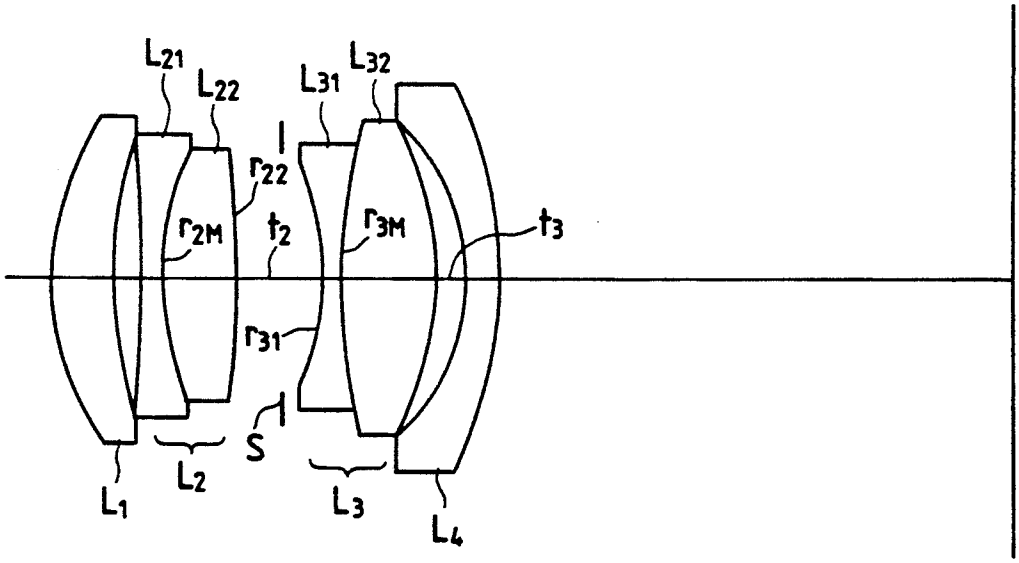
r2M
t2
r3M
t3
r31
S
L1
L2
L3
L4

FIG. 2


L21
L22
L31
L32
r22
r2M
t2
r3M
t3
r31
S
L1
L2
L3
L4

WIDE ANGLE OBJECTIVE LENS

BACKGROUND OF THE INVENTION

1.Field of the Invention

This invention relates to a wide angle objective lens, and particularly to a wide angle objective lens suitable for use with a 35 mm format lens shutter camera, a 35 mm format camera with a range finder or the like.

2. Related Background Art

An optical system of four-unit construction of the so-called telephoto type in which a posterior unit having negative refractive power is disposed rearwardly of an anterior unit of positive-negative-positive lens unit construction having positive refractive power to shorten the full length of a standard lens for a compact camera to the focal plane thereof is known as is disclosed, for example, in Japanese Patent Publication No. 44-10831.

As a wide angle objective lens of such telephoto type and having an angle of view wider than that of a standard lens, there are known an example in which as disclosed in U.S. Pat. No. 4,394,073, an anterior unit disposed forwardly of a negative posterior unit is made into a four-unit construction of positive-negative-positive-positive to thereby improve coma and the eclipse of the marginal light flux, an example in which as disclosed in U.S. Pat. No. 4,235,521, a negative posterior unit is comprised of two negative and positive meniscus lenses to thereby achieve an angle of view of 60° or greater and brightness of F-number 2.8, an example in which as disclosed in Japanese Laid-Open Patent Application No. 1-209413, a negative lens component in an anterior unit is a cemented lens comprising a negative biconcave lens and a positive meniscus lens, etc..

In these optical systems of the telephoto type, however, in order to achieve the compactness thereof, the refractive powers of the anterior unit having positive refractive power and the posterior unit having negative refractive power have been made great and moreover, the air gap between the anterior unit and the posterior unit has been made great. Therefore, the marginal light flux has been eclipsed, and this has led to the disadvantages that not only the quantity of marginal light becomes deficient, but also distortion shifts greatly to the positive and chromatic difference of magnification also is greatly fluctuated by the angle of view. Further, the refractive power of each lens component is great, and this has led to the disadvantage that curvature of image field increases.

Also, in the aforementioned U.S. Pat. No. 4,235,521, a positive lens is disposed most adjacent to the image side and this has led to the disadvantage that the effecitve diameter of this positive lens most adjacent to the image side becomes great and further, from the mutual ecccentricity or inclination or the like of the negative lens and the positive lens in the posterior unit, it has been difficult to provide a predetermined optical performance in manufacture. Also in the wide angle lens described in the aforementioned U.S. Pat. No. 4,394,073, from the mutual eccentricity or inclination or the like of a negative second lens component and a positive third lens component, it has been difficult to obtain a predetermined optical performance in manufacture.

Further, in the wide angle lens described in the aforementioned Japanese Laid-Open Patent Application No. 1-209413, the cemented surface in a negative second lens component has negative refractive power and therefore, positive spherical aberration of high order has occurred and the correction of spherical aberration could not be sufficiently accomplished.

SUMMARY OF THE INVENTION

Accordingly, it is an object of the present invention to solve the above-noted problems peculiar to the wide angle lenses according to the prior art and to provide a compact wide angle objective lens of high performance in which the fluctuation of aberrations when focusing is effected is suppressed and an improvement in the performance in a short distance in-focus state is achieved and also the deterioration of the performance by the eccentricity of each lens unit is little.

To achieve the above object, the wide angle objective lens according to the present invention includes, in succession from the object side, a positive first lens component comprising a positive meniscus lens having its convex surface facing the object side, a positive second lens component comprising a cemented meniscus lens comprising a negative lens and a positive lens cemented together and having its concave surface facing the object side, a positive third lens component comprising a cemented meniscus lens comprising a negative lens and a positive lens cemented together and having its concave surface facing the object side, and a negative fourth lens component comprising a negative meniscus lens having its concave surface facing the object side, and is constructed into a refractive power arrangement of the telephoto type as a whole. It also has a stop between the second lens component and the third lens component.

As described above, in the present invention, the three lens components in the anterior unit are comprised of only lens units having positive refractive power and therefore, if the combined refractive power of this anterior unit is the same, the refractive power of each lens component can be made smaller than in the prior-art wide angle lenses of positive-negative-positive lens unit construction and accordingly, it is possible to suppess the deterioration of the performance caused by the eccentricity of each lens component. Also, the refractive index of the positive lens in the second lens component is made higher than that of the negative lens in the same lens component to thereby suppress astigmatism and curvature of image field and further, the cemented surface thereof is endowed with positive refractive power to thereby correct spherical aberration better. Also, in order to well suppress negative astigmatism occurring when short distance focusing is effected, that surface of the second lens component which is most adjacent to the image side is designed to have its convex surface fact the image side.

Further, when the refractive index of the negative lens in the second lens component for d-line ($\lambda=597.6$ nm) is n_{21} and the refractive index of the positive lens in the same lens component for d-line ($\lambda=597.6$ nm) is n_{22} and the radius of curvature of that surface of the second lens component which is most adjacent to the image side is r_{22} and the radius of curvature of the cemented surface in the second lens component is r_{2M} and the focal length of the third lens component is f_3 and the radius of curvature of that surface of the third lens component which is most adjacent to the object side is r_{31} and the mean value of the absolute values of the refractive powers of the first to fourth lens components

is ψ_{1-4} and the refractive power of the entire optical system is ψ and the refractive power ψ_{2M} of the cemented surface in the second lens component is expressed as $\psi_{2M}=(n_{22}-n_{21})/r_{2M}$, the first to fourth lens components may preferably be designed to satisfy the following conditions:

$$-0.9 \leqq \psi_{2M} \cdot r_{22} \leqq -0.1 : r_{22} < 0$$

$$-0.6 \leqq r_{31}/f_3 \leqq -0.1 : r_{31} < 0$$

$$\psi_{104}/\psi < 0.9$$

Other objects, features and effects of the present invention will become fully apparent from the following detailed description taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows the lens construction of first to fourth embodiments of the present invention.

FIG. 2 shows the lens construction of a fifth embodiment of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Some embodiments of the present invention will hereinafter be described in detail with reference to the accompanying drawings.

FIG. 1 shows the lens construction of first to fourth embodiments of the present invention, and FIG. 2 shows the lens construction of a fifth embodiment in which the spacing between a third lens component and a fourth lens component is very short.

Any of the wide angle lenses of the present invention, as shown in FIGS. 1 and 2, includes, in succession from the object side, a first lens component L1 which is a positive meniscus lens having its convex surface facing the object side, a second lens component L2 comprising a cemented meniscus lens comprising a negative lens L21 and a positive lens L22 cemented together and having its concave surface facing the object side, and having positive refractive power, a third lens component L3 comprising a cemented meniscus lens comprising a negative lens L31 and a positive lens L32 cemented together and having its concave surface facing the object side, and having positive refractive power, and a fourth lens component L4 which is a positive meniscus lens having its convex surface facing the object side, and further has a stop S between the second lens unit L2 and the third lens unit L3.

The wide angle lens of the present invention is of a construction of so-called telephoto type refractive power arrangement as a whole, from the fact that as described above, the first lens component L1, the second lens component L2 and the third lens component L3 each have positive refractive power and the fourth lens component L4 has negative refractive power.

The prior-art wide angle lens of the telephoto type has an anterior unit having positive refractive power and comprised of three positive, negative and positive lens components or four positive, negative, positive and positive lens components, and the refractive power of each lens component is very strong and therefore, due to the eccentricity, inclination or the like of the lenses, it has been difficult to provide a predetermined optical performance in manufacture. It has also suffered from the disadvantage that chromatic difference of magnification is greatly fluctuated by the angle of view.

So, according to the present invention, the anterior unit is comprised of only three lens components each having positive refractive power, and even if the combined refractive power of the anterior unit is the same as the combined refractive power of the anterior unit of the prior-art positive-negative-positive lens construction, the refractive power of each lens component can be made small and it is possible to suppress the deterioration of performance caused by the eccentricity of each unit.

Also, by the stop S being disposed between the positive second lens component L2 and the positive third lens component L3, it is made possible to increase the quantity of marginal light and make the refractive power distributions before and behind the stop substantially approximate to a symmetrical type, thereby correcting distortion better.

Also, that surface of the second lens component L2 which is most adjacent to the image side has its convex surface face the image side to well suppress negative astigmatism occurring when the short distance focusing by the totally axially moving system is effected.

In the lens system of the conventional telephoto type, the correction of spherical aberration has heretofore been effected chiefly by that surface of the negative second lens unit which is most adjacent to the object side, while in the present invention, the refractive index of the positive lens in the second lens component L2 is made higher than that of the negative lens in the same lens component to decrease Petzval sum and suppress astigmatism and curvature of image field and further, the cemented surface thereof is endowed with positive refractive power to thereby cause negative spherical aberration of high order to occur, and correct spherical aberration better.

Further, the third lens component L3 is designed such that the surface thereof which is most adjacent to the object side has its concave surface face the stop S, and this surface shares the correction of spherical aberration with the cemented surface in the second lens component L2. Also, since said surface which is most adjacent to the object side has its concave surface face the stop S, aberrations to off-axis rays are not liable to occur and it becomes possible to obtain a good image plane performance.

The fourth lens component L4 is a negative meniscus lens having its concave surface facing the stop S in order to correct curvature of image field and astigmatism sufficiently.

The wide angle lens of the present invention is constructed as described above, and it is desirable that the wide angle lens of the present invention be further designed to satisfy the following conditions:

$$-0.9 \leqq \psi_{2M} \cdot r_{22} \leqq -0.1 : r_{22} < 0 \quad (1)$$

$$-0.6 \leqq r_{31}/f_3 \leqq -0.1 : r_{31} < 0 \quad (2)$$

$$\psi_{104}/\psi < 0.9 \quad (3)$$

where

ψ_{2M}: the refractive power of the cemented surface in the second lens component L2 expressed by the following equation:

$$\psi_{2M}=(n_{22}-n_{21})/r_{2M}$$

r_{22}: the radius of curvature of that surface of the second lens component L2 which is most adjacent to the image side;

n_{21}: the refractive index of the negative lens L21 in the second lens component L2 for d-line (λ=587.6 nm);

n_{22}: the refractive index of the positive lens L22 in the second lens component L2 for d-line (λ=587.6 nm);

r_{2M}: the radius of curvature of the cemented surface in the second lens component L2;

r_{31}: the radius of curvature of that surface of the third lens component L3 which is most adjacent to the object side;

f_3: the focal length of the third lens component L3;

ψ_{1-4}: the mean value of the absolute values of the refractive powers of the first to fourth lens components L1 to L4;

ψ: the refractive power of the entire optical system.

Further, with regard to the third lens component L3 and the fourth lens component L4, it is desirable that the wide angle lens of the present invention be designed to satisfy the following conditions:

$$0<\psi_{3M}/\psi<0.5:\ r_{3M}>0 \quad (4)$$

$$0.2\leqq t_3/t_2\leqq 1.0, \quad (5)$$

where

ψ_{3M}: the refractive power of the cemented surface in the third lens component L3 expressed by the following equation:

$$\psi_{3M}=(n_{32}-n_{31})/r_{3M}$$

ψ: the refractive power of the entire optical system;

r_{3M}: the radius of curvature of the cemented surface in the third lens component L3;

n_{31}: the refractive index of the negative lens L31 in the third lens component L3 for d-line (λ=587.6 nm);

n_{32}: the refractive index of the positive lens L32 in the third lens component L3 for d-line (λ=587.6 nm);

t_2: the air gap on the optical axis from that surface of the second lens component L2 which is most adjacent to the image side to that surface of the third lens component L3 which is most adjacent to the object side;

t_3: the air gap on the optical axis from that surface of the third lens component L3 which is most adjacent to the image side to that surface of the fourth lens component L4 which is most adjacent to the object side.

Furthermore, when the mean value of the refractive indices of the positive lenses L1, L22 and L32 in the entire optical system for d-line (587.6 nm) is Np and the mean value of the refractive indices of the negative lenses L21, L31 and L4 for d-line (λ=587.6 nm) is Nn, it is desirable that the wide angle lens of the present invention be designed to satisfy the following conditions:

$$Np>1.70 \quad (6)$$

$$Nn>1.70 \quad (7)$$

The above-mentioned conditional expressions in the present invention will hereinafter be described in detail.

Conditional expression (1) is a condition for contriving the balance with spherical aberration and curvature of image field and further, the amount of fluctuation of astigmatism during the short distance focusing by the totally axially moving system.

When the lower limit of conditional expression (1) is exceeded, the following cases ① and ② are conceivable:

① A case where the refractive power ψ_{2M} of the cemented surface in the second lens component L2 is great; and

② A case where the radius of curvature r_{22} of that surface of the second lens component L2 which is most adjacent to the image side is negative and great.

In case ①, curvature of image field decreases, but positive distortion increases and negative spherical aberration become uncorrectable. In case ②, astigmatic difference becomes small and spherical aberration can be corrected well, but curvature of image field increases. Also, during short distance focusing, negative astigmatism occurs greatly, and this is not preferable.

When the upper limit of conditional expression (1) is exceeded, the following cases ③ and ④ are conceivable:

③ A case where the refractive power ψ_{2M} of the cemented surface in the second lens component L2 is small; and

④ A case where the radius of curvature r_{22} of that surface of the second lens component L2 which is most adjacent to the image side is negative and small.

In case ③, spherical aberration can be corrected well, but curvatrue of image field increases, and this is not preferable. In case ④, curvatrue of image field decreases and negative astigmatism occurring during short distance focusing can be suppressed to a small level, but astigmatic difference becomes great and negative spherical aberration become uncorrectable.

Conditional expression (2) is a condition for contriving the balance between on-axis aberrations and off-axis aberrations.

When the lower limit of conditional expression (2) is exceeded, the following cases ⑤ and ⑥ are conceivable:

⑤ A case where the radius of curvature r_{31} of that surface of the third lens component L3 which is most adjacent to the object side is negative and great; and

⑥ A case where the focal length f_2 of the second lens component L2 is small.

In case ⑤, curvature of image field decreases and astigmatic difference also becomes small, but positive distortion increases and spherical aberration becomes uncorrectable. In case ⑥, spherical aberration can be corrected well, but Petzval sum increases greatly to the positive and curvature of image field increases and thus, a good image plane performance becomes unobtainable.

When the upper limit of conditional expression (2) is exceeded, the following cases ⑦ and ⑧ are conceivable:

⑦ A case where the radius of curvature r_{31} of that surface of the third lens component L3 which is most adjacent to the object side is small; and

⑧ A case where the focal length f_2 of the second lens component L2 is great.

In case ⑦, spherical aberration can be corrected well, but curvature of image field increases and astigmatic difference becomes great. In case ⑧, curvature of

image field decreases and a good image plane performance is obtained, but spherical aberration becomes uncorrectable.

Conditional expression (3) is a condition for prescribing the deterioration of performance caused by the mutual eccentricity, inclination, etc. of the lens components.

If the upper limit of this conditional expression is exceeded, the refractive power of each lens component will become strong and therefore, the deterioration of performance by the mutual eccentricity of the lens components will become great, and this is not preferable. Also, curvature of image field will increase and the quantity of marginal light will be remarkably reduced, and this is not preferable.

Conditional expressions (4) and (5) will now be described in detail.

Conditional expression (4) is a condition for prescribing the refractive power of the cemented surface in the third lens component L3.

If the upper limit of conditional expression (4) is exceeded, negative spherical aberration of high order will occur and the correction of spherical aberration will become possible, but astigmatic difference will increase in a portion having a great angle of view and therefore, a good image plane performance will become unobtainable. If conversely, the lower limit of conditional expression (4) is exceeded, positive distortion will occur greatly and the correction of spherical aberration will be deficient.

Conditional expression (5) is a condition for contriving the balance between on-axis aberrations and off-axis aberrations.

When the lower limit of this conditional expression (5) is exceeded, the following cases (9) and (10) are conceivable:

(9) A case where t_3 is small; and

(10) A case where t_2 is great.

In case (9), the difference between the heights of the on-axis ray and the off-axis ray becomes small in the fourth lens component L4 and therefore, the degree of freedom of aberration correction is deficient and on-axis aberrations and off-axis aberrations cannot be corrected independently of each other. Also, to render the focal length of the optical system into a predetermined value, the refractive power of the fourth lens component L4 becomes great and therefore, curvature of image field increases, and this is not desirable. In case (10), on-axis aberrations and off-axis aberrations can be corrected independently of each other, but if an increase in the quantity of marginal light is contrived, the effective diameter of the lens will become large, and this is not preferable.

Also, when the upper limit of conditional expression (5) is exceeded, the following cases (11) and (12) are conceivable:

A case where t_3 is great; and

A case where t_2 is small.

In case (11), conversely to the aforedescribed case (9), on-axis aberrations and off-axis aberrations can be corrected independently of each other and a better image plane performance can be obtained. However, the effective diameter of the lens becomes large, and this is not preferable. In case (12), the difference between the heights of the on-axis ray and the off-axis ray becomes small in the lenses far from the stop S and therefore, the degree of freedom of aberration correction is deficient and on-axis aberrations and off-axis aberrations cannot be corrected independently of each other. It also becomes impossible to dispose the stop and a shutter mechanism, and this is not preferable.

Conditional expressions (6) and (7) are conditions regarding the distribution of the refractive index in the optical system.

If the lower limit of conditional expression (6) is exceeded or if the upper limit of conditional expression (7) is exceeded, Petzval sum will exhibit a great positive value and thus, curvature of image field and negative astigmatism will become uncorrectable, and this is not preferable.

The constructions of the embodiments of the present invention will now be described in greater detail.

In any of the first to fourth embodiments, as shown in FIG. 1, the first lens component L1 comprises a positive meniscus lens having its convex surface facing the object side, and the second lens component L2 is comprised of a positive cemented meniscus lens comprising a biconcave lens L21 and a biconvex lens L22 having a refractive index higher than that of the biconcave lens L21, the lenses L21 and L22 being cemented together, the positive cemented meniscus lens having its concave surface facing the object side. The third lens component L3, like the second lens component L2, comprises a positive cemented meniscus lens comprising a biconcave lens L31 and a bicovex lens L32 having a refractive index higher than that of the biconcave Lens L31, the lenses L31 and L32 being cemented together, the positive cemented meniscus lens having its concave surface facing the object side, and the fourth lens component L4 comprises a negative meniscus lens having its concave surface facing the object side, and the entire lens system is comprised of four units six lenses. The stop S is provided between the second lens component L2 and the third lens component L3.

The fifth embodiment assumes a construction substantially similar to the constructions of the first to fourth embodiments, with the exception that as shown in FIG. 2, the lens thickness of the biconvex lens L32 in the third lens component L3 is relatively great and the on-axis air gap between this biconvex lens L32 and the fourth lens component L4 is very short.

In any of the above-described embodiments, focusing is effected from infinity to a close distance by the totally axially moving system.

The numerical data of the respective embodiments of the present invention will be shown in Tables 1 to 5 below. In these tables, the numbers at the left end represent the order from the object side, r represents the radius of curvature of each lens surface, d represents the spacing between adjacent lens surfaces, and the refractive index n and Abbe number ν are values for d-line (λ=587.6 nm). FN represents F-number, and 2ω indicates the angle of view.

TABLE 1

(First Embodiment)

f = 100.0
FN = 2.88
2ω = 63.6

	r	d	ν	n
1	39.671	9.14	41.0	1.80500
2	57.105	4.00		
3	−130.700	2.86	27.8	1.69911
4	57.143	10.00	43.3	1.84042
5	−133.667	12.00		
6	−39.290	2.86	35.5	1.59507
7	114.917	10.14	44.7	1.80218
8	−42.384	8.57		

TABLE 1-continued

(First Embodiment)

f = 100.0
FN = 2.88
2ω = 63.6

	r	d	ν	n
9	−25.630	4.57	64.1	1.51680
10	−39.674	57.48		

The condition-corresponding values of the first embodiment are as follows:

(1)	$\psi_{2M} \cdot r_{22}$	= −0.331
(2)	r_{31}/f_3	= −0.295
(3)	ψ_{1-4}/ψ	= 0.628
(4)	ψ_{3M}/ψ	= 0.180
(5)	t_3/t_2	= 0.714
(6)	Np	= 1.816
(7)	Nn	= 1.604

TABLE 2

(Second Embodiment)

f = 100.0
FN = 2.88
2ω = 63.4

	r	d	ν	n
1	40.936	9.14	44.7	1.80218
2	57.301	4.00		
3	−149.580	2.86	32.2	1.67270
4	34.286	10.00	44.7	1.80218
5	−171.428	12.00		
6	−39.393	2.86	35.5	1.59507
7	112.625	10.14	44.7	1.80218
8	−42.850	8.57		
9	−24.728	4.57	64.1	1.51680
10	−36.548	57.99		

The condition-corresponding values of the second embodiment are as follows:

(1)	$\psi_{2M} \cdot r_{22}$	= −0.647
(2)	r_{31}/f_3	= −0.292
(3)	ψ_{1-4}/ψ	= 0.608
(4)	ψ_{3M}/ψ	= 0.184
(5)	t_3/t_2	= 0.714
(6)	Np	= 1.802
(7)	Nn	= 1.595

TABLE 3

(Third Embodiment)

f = 100.0
FN = 2.88
2ω = 63.6

	r	d	ν	n
1	36.795	8.57	46.4	1.80411
2	49.451	4.29		
3	−134.095	2.86	32.2	1.67270
4	40.561	7.43	46.4	1.80411
5	−142.607	11.43		
6	−40.525	2.93	37.0	1.61293
7	97.639	9.76	44.7	1.80218
8	−44.255	8.65		
9	−23.831	4.40	60.0	1.64000
10	−31.870	59.74		

The condition-corresponding values of the third embodiment are as follows:

(1)	$\psi_{2M} \cdot r_{22}$	= −0.462
(2)	r_{31}/f_3	= −0.275
(3)	ψ_{1-4}/ψ	= 0.584
(4)	ψ_{3M}/ψ	= 0.296
(5)	t_3/t_2	= 0.757
(6)	Np	= 1.803
(7)	Nn	= 1.642

TABLE 4

(Fourth Embodiment)

f = 100.0
FN = 2.88
2ω = 63.4

	r	d	ν	n
1	39.987	9.71	52.3	1.74810
2	56.507	4.00		
3	−125.799	2.86	32.2	1.67270
4	43.591	9.43	43.3	1.84042
5	−140.097	10.86		
6	−38.347	2.86	35.5	1.59507
7	166.228	10.14	44.7	1.80218
8	−42.415	9.71		
9	−24.851	4.57	53.6	1.54739
10	−35.397	58.40		

The condition-corresponding values of the fourth embodiment are as follows:

(1)	$\psi_{2M} \cdot r_{22}$	= −0.539
(2)	r_{31}/f_3	= −0.258
(3)	ψ_{1-4}/ψ	= 0.594
(4)	ψ_{3M}/ψ	= 0.125
(5)	t_3/t_2	= 0.895
(6)	Np	= 1.797
(7)	Nn	= 1.605

TABLE 5

(Fifth Embodiment)

f = 100.0
FN = 2.88
2ω = 62.9

	r	d	ν	n
1	37.198	8.58	55.6	1.69680
2	57.533	4.01		
3	−151.349	2.86	35.5	1.59507
4	39.481	9.87	49.5	1.74443
5	−172.004	11.44		
6	−44.035	2.86	33.8	1.64831
7	89.874	12.59	43.3	1.84042
8	−37.774	3.72		
9	−26.149	4.72	56.0	1.56883
10	−58.521	69.40		

The condition-corresponding values of the fifth embodiment are as follows:

(1)	$\psi_{2M} \cdot r_{22}$	= −0.651
(2)	r_{31}/f_3	= −0.537
(3)	ψ_{1-4}/ψ	= 0.891
(4)	ψ_{3M}/ψ	= 0.214
(5)	t_3/t_2	= 0.325
(6)	Np	= 1.761
(7)	Nn	= 1.604

In any of the above-described embodiments of the present invention, various aberrations are corrected well and the fluctuations of the various aberrations are suppressed particularly from during infinity focusing to during short distance focusing, and there is maintained

a good optical performance even during short distance focusing.

By introducing an aspherical surface into the first lens component L1 or the fourth lens component L4 of the present invention, it is possible to correct astigmatism and curvature of image field better and achieve a wide angle. Also, it is a matter of course from the way of using popular aspherical lenses that by introducing an aspherical surface into the second lens component L2 or the third lens component L3, it is possible to correct spherical aberration better and achieve a great aperture.

According to the present invention, a wide angle lens which is as bright as the order of F2.8 and has little distortion can be realized by a relatively simple lens construction. The present invention can be used as a lens not only for 35 mm format cameras, but also for large format cameras.

What is claimed is:

1. A wide angle objective lens including in succession from the object side:

a first lens component comprising a positive meniscus lens having its convex surface facing the object side;

a second lens component comprising a cemented meniscus lens comprising a negative lens and a positive lens cemented together and having its concave surface facing the object side and having positive refractive power;

a third lens component comprising a cemented meniscus lens comprising a negative lens and a positive lens cemented together and having its concave surface facing the object side and having positive refractive power; and

a fourth lens component comprising a negative meniscus lens having its concave surface facing the object side; and

further having a stop between said second lens component and said third lens component;

said wide angle objective lens being designed to satisfy the following conditions when the refractive power ψ_{2M} of the cemented surface in said second lens component is expressed as $\psi_{2M}=(n_{22}-n_{21})/r_{2M}$ and the mean value of the absolute values of the refractive powers of said first to fourth lens components is ψ_{1-4} and the refractive power of the entire optical system is ψ:

$$-0.9 \leqq \psi_{2M} \cdot r_{22} \leqq -0.1;\ r_{22}<0$$

$$-0.6 \leqq r_{31} \cdot f_3 \leqq -0.1;\ r_{31}<0$$

$$\psi_{1-4}/\psi<0.9,$$

n_{21}: the refractive index of the negative lens in the second lens component for d-line ($\lambda=587.6$ nm);

n_{22}: the refractive index of the positive lens in the second lens component for d-line ($\lambda=587.6$ nm);

r_{2M}: the radius of curvature of the cemented surface in the second lens compartment;

r_{22}: the radius of curvature of that surface of the second lens component which is most adjacent to the image side;

r_{31}: the radius of curvature of that surface of the third lens component which is most adjacent to the object side;

f_3: the focal length of the third lens component.

2. A wide angle objective lens according to claim 1, wherein when the refractive power ψ_{3M} of the cemented surface in said third lens component is expressed as $\psi_{3M}=(n_{32}-n_{31})/r_{3M}$, said third lens component is designed to satisfy the following condition:

$$0<\psi_{3M}/\psi<0.5;\ r_{3M}>0,$$

where

n_{31}: the refractive index of the negative lens in the third lens component for d-line ($\lambda=587.6$ nm);

n_{32}: the refractive index of the positive lens in the third lens component for d-line ($\lambda=587.6$ nm);

r_{3M}: the radius of curvature of the cemented surface in the third lens component;

ψ: the refractive power of the entire optical system.

3. A wide angle objective lens according to claim 1, wherein when the air gap on the optical axis from that surface of said second lens component which is most adjacent to the image side to that surface of said third lens component which is most adjacent to the object side is t_2 and the air gap on the optical axis from that surface of said third lens component which is most adjacent to the image side to that surface of said fourth lens component which is most adjacent to the object side is t_3, said second to fourth lens components are disposed so as to satisfy the following condition:

$$0.2 \leqq t_3/t_2 \leqq 1.0$$

4. A wide angle objective lens according to claim 1, wherein when the mean value of the refractive indices of the positive meniscus lens in said first lens component, the positive lens in said second lens component and the positive lens in said third lens component for d-line ($\lambda=587.6$ nm) is Np and the mean value of the refractive indices of the negative lens in said second lens component, the negative lens in said third lens component and said third lens component for d-line ($\lambda=587.6$ nm) is Nn, said wide angle objective lens is designed to further satisfy the following conditions:

$$Np>1.70,\ Nn<1.70$$

5. A wide angle objective lens according to claim 1, deisgned in accordance with the following data:

f = 100.0
FN = 2.88
2ω = 63.6

	r	d	ν	n
1	39.671	9.14	41.0	1.80500
2	57.105	4.00		
3	−130.700	2.86	27.8	1.69911
4	57.143	10.00	43.3	1.84042
5	−133.667	12.00		
6	−39.290	2.86	35.5	1.59507
7	114.917	10.14	44.7	1.80218
8	−42.384	8.57		
9	−25.630	4.57	64.1	1.51680
10	−39.674	57.48		

(1)	$\psi_{2M} \cdot r_{22}$	= −0.331
(2)	r_{31}/f_3	= −0.295
(3)	ψ_{1-4}/ψ	= 0.628
(4)	ψ_{3M}/ψ	= 0.180
(5)	t_3/t_2	= 0.714
(6)	Np	= 1.816
(7)	Nn	= 1.604

where the numbers at the left end represent the order from the object side, r represents the radius of curvature of each lens surface, d represents the spacing between

adjacent lens surfaces, the refractive index n and Abbe number ν indicate values for d-line (λ=587.6 nm), FN indicates F-number, and 2ω indicates the angle of view;

t_2: the air gap on the optical axis from that surface of the second lens component which is most adjacent to the image side to that surface of the third lens component which is most adjacent to the object side;

t_3: the air gap on the optical axis from that surface of the third lens component which is most adjacent to the image side to that surface of the fourth lens component which is most adjacent to the object side;

Np: the mean value of the refractive indices of the positive meniscus lens of the first lens component, the positive lens in the second lens component and the positive lens in the third lens component for d-line (λ=587.6 nm);

Nn: the mean value of the refractive indices of the negative lens in the second lens component, the negative lens in the third lens component and the third lens component for d-line (λ=587.6 nm);

ψ_{3M}: the refractive power of the cemented surface in the third lens component expressed by the following equation: $\psi_{3M}=(n_{32}-n_{31})/r_{3M}$ (n_{31}: the refractive index of the negative lens in the third lens component for d-line (λ=587.6 nm), n_{32}: the refractive index of the positive lens in the third lens component for d-line (λ=587.6 nm), r_{3M}: the radius of curvature of the cemented surface in the third lens component).

6. A wide angle objective lens according to claim 1, designed in accordance with the following data:

f = 100.0
FN = 2.88
2ω = 63.4

	r	d	ν	n
1	40.936	9.14	44.7	1.80218
2	57.301	4.00		
3	−149.580	2.86	32.2	1.67270
4	34.286	10.00	44.7	1.80218
5	−171.428	12.00		
6	−39.393	2.86	35.5	1.59507
7	112.625	10.14	44.7	1.80218
8	−42.850	8.57		
9	−24.728	4.57	64.1	1.51680
10	−36.548	57.99		

(1) $\psi_{2M} \cdot r_{22}$ = −0.647
(2) r_{31}/f_3 = −0.292
(3) ψ_{1-4}/ψ = 0.608
(4) ψ_{3M}/ψ = 0.184
(5) t_3/t_2 = 0.714
(6) Np = 1.802
(7) Nn = 1.595

where the numbers at the left end represents the order from the object side, r represents the radius of curvature of each lens surface, d represents the spacing between adjacent lens surfaces, the refractive index n and Abbe number ν indicate values for d-line (λ=587.6 nm), FN indicates F-number, and 2ω indicates the angle of view;

t_2: the air gap on the optical axis from that surface of the second lens component which is most adjacent to the image side to that surface of the third lens component which is most adjacent to the object side;

t_3: the air gap on the optical axis from that surface of the third lens component which is most adjacent to the image side to that surface of the fourth lens component which is most adjacent to the object side;

Np: the mean value of the refractive indices of the positive meniscus lens of the first lens component, the positive lens in the second lens component and the positive lens in the third lens component for d-line (λ=587.6 nm);

Nn: the mean value of the refractive indices of the negative lens in the second lens component, the negative lens in the third lens component and the third lens component for d-line (λ=587.6 nm);

ψ_{3M}: the refractive power of the cemented surface in the third lens component expressed by the following equation: $\psi_{3M}=(n_{32}-n_{31})/r_{3M}$ (n_{31}: the refractive index of the negative lens in the third lens component for d-line (λ=587.6 nm), n_{32}: the refractive index of the positive lens in the third lens component for d-line (λ=j587.6 nm), r_{3M}: the radius of curvature of the cemented surface in the third lens component).

7. A wide angle objective lens according to claim 1, designed in accordance with the following data:

f = 100.0
FN = 2.88
2ω = 63.6

	r	d	ν	n
1	36.795	8.57	46.4	1.80411
2	49.451	4.29		
3	−134.095	2.86	32.2	1.67270
4	40.561	7.43	46.4	1.80411
5	−142.607	11.43		
6	−40.525	2.93	37.0	1.61293
7	97.639	9.76	44.7	1.80218
8	−44.255	8.65		
9	−23.831	4.40	60.0	1.64000
10	−31.870	59.74		

(1) $\psi_{2M} \cdot r_{22}$ = −0.462
(2) r_{31}/f_3 = −0.275
(3) ψ_{1-4}/ψ = 0.584
(4) ψ_{3M}/ψ = 0.296
(5) t_3/t_2 = 0.757
(6) Np = 1.803
(7) Nn = 1.642

where the numbers at the left end represents the order from the object side, r represents the radius of curvature of each lens surface, d represents the spacing between adjacent lens surfaces, the refractive index n and Abbe number ν indicate values for d-line (λ=587.6 nm), FN indicates F-number, and 2ω indicates the angle of view;

t_2: the air gap on the optical axis from that surface of the second lens component which is most adjacent to the image side to that surface of the third lens component which is most adjacent to the object side;

t_3 the air gap on the optical axis from that surface of the third lens component which is most adjacent to the image side to that surface of the fourth lens component which is most adjacent to the object side;

Np: the mean value of the refractive indices of the positive meniscus lens of the first lens component, the positive lens in the second lens component and the positive lens in the third lens component for d-line (λ=587.6 nm);

Nn: the mean value of the refractive indices of the negative lens in the second lens component, the negative lens in the third lens component and the third lens component for d-line (λ=587.6 nm);

ψ_{3M}: the refractive power of the cemented surface in the third lens component expressed by the following equation: $\psi_{3M}=(n_{32}-n_{31})/r_{3M}$ (n_{31}: the refractive index of the negative lens in the third lens component for d-line ($\lambda=587.6$ nm),

n_{32}: the refractive index of the positive lens in the third lens component for d-line ($\lambda=587.6$ nm), r_{3M}: the radius of curvature of the cemented surface in the third lens component).

8. A wide angle objective lens according to claim **1**, designed in accordance with the following data:

f = 100.0				
FN = 2.88				
2ω = 63.4				
	r	d	ν	n
1	39.987	9.71	52.3	1.74810
2	56.507	4.00		
3	−125.799	2.86	32.2	1.67270
4	43.591	9.43	43.3	1.84042
5	−140.097	10.86		
6	−38.347	2.86	35.5	1.59507
7	166.228	10.14	44.7	1.80218
8	−42.415	9.71		
9	−24.851	4.57	53.6	1.54739
10	−35.397	58.40		

(1)	$\psi_{2M}\cdot r_{22}$	= −0.539
(2)	r_{31}/f_3	= −0.258
(3)	ψ_{1-4}/ψ	= 0.594
(4)	ψ_{3M}/ψ	= 0.125
(5)	t_3/t_2	= 0.895
(6)	Np	= 1.797
(7)	Nn	= 1.605

where the numbers at the left end represent the order from the object side, r represents the radius of curvature of each lens surface, d represents the spacing between adjacent lens surfaces, the refractive index n and Abbe number ν indicate values for d-line ($\lambda=587.6$ nm), FN indicates F-number, and 2ω indicates the angle of view;

t_2: the air gap on the optical axis from that surface of the second lens component which is most adjacent to the image side to that surface of the third lens component which is most adjacent to the object side;

t_3: the air gap on the optical axis from that surface of the third lens component which is most adjacent to the image side to that surface of the fourth lens component which is most adjacent to the object side;

Np: the mean value of the refractive indices of the positive meniscus lens of the first lens component, the positive lens in the second lens component and the positive lens in the third lens component for d-line ($\lambda=587.6$ nm);

Nn: the mean value of the refractive indices of the negative lens in the second lens component, the negative lens in the third lens component and the third lens component for d-line ($\lambda=587.6$ nm);

ψ_{3M}: the refractive power of the cemented surface in the third lens component expressed by the following equation: $\psi_{3M}=(n_{32}-n_{31})/r_{3M}$ (n_{31}: the refractive index of the negative lens in the third lens component for d-line ($\lambda=587.6$ nm), n_{32}: the refractive index of the positive lens in the third lens component for d-line ($\lambda=587.6$ nm), r_{3M}: the radius of curvature of the cemented surface in the third lens component).

9. A wide angle objective lens according to claim **1**, designed in accordance with the following data:

f = 100.0				
FN = 2.88				
2ω = 62.9				
	r	d	ν	n
1	37.198	8.58	55.6	1.69680
2	57.33	4.01		
3	−151.349	2.86	35.5	1.59507
4	39.481	9.87	49.5	1.74443
5	−172.004	11.44		
6	−44.035	2.86	33.8	1.64831
7	89.874	12.59	43.3	1.84042
8	−37.774	3.72		
9	−26.149	4.72	56.0	1.56883
10	−58.521	69.40		

(1)	$\psi_{2M}\cdot r_{22}$	= −0.651
(2)	r_{31}/f_3	= −0.537
(3)	ψ_{1-4}/ψ	= 0.891
(4)	ψ_{3M}/ψ	= 0.214
(5)	t_3/t_2	= 0.325
(6)	Np	= 1.761
(7)	Nn	= 1.604

where the numbers at the left end represent the order from the object side, r represents the radius of curvature of each lens surface, d represents the spacing between adjacent lens surfaces, the refractive index n and Abbe number ν indicate values for d-line ($\lambda=587.6$ nm), FN indicates F-number, and 2ω indicates the angle of view;

t_2: the air gap on the optical axis from that surface of the second lens component which is most adjacent to the image side to that surface of the third lens component which is most adjacent to the object side;

t_3: the air gap on the optical axis from that surface of the third lens component which is most adjacent to the image side to that surface of the fourth lens component which is most adjacent to the object side;

Np: the mean value of the refractive indices of the positive meniscus lens of the first lens component, the positive lens in the second lens component and the positive lens in the third lens component for d-line ($\lambda=587.6$ nm);

Nn: the mean value of the refractive indices of the negative lens in the second lens component, the negative lens in the third lens component and the third lens component for d-line ($\lambda=587.6$ nm);

ψ_{3M}: the refractive power of the cemented surface in the third lens component expressed by the following equation: $\psi_{3M}=(n_{32}-n_{31})/r_{3M}$ (n_{31}: the refractive index of the negative lens in the third lens component for d-line ($\lambda=587.6$ nm), n_{32}: the refractive index of the positive lens in the third lens component for d-line ($\lambda=587.6$ nm), r_{3M}: the radius of curvature of the cemented surface in the third lens component).

10. A wide angle objective lens including in succession from the object side:

a first lens component comprising a positive meniscus lens having its convex surface facing the object side;

a second lens component comprising a cemented meniscus lens comprising a negative biconcave lens and a positive biconvex lens cemented together and having its concave surface facing the object side and having positive refractive power;

a third lens component comprising a cemented meniscus lens comprising a negative biconcave lens and a positive biconvex lens cemented together and

having its concave surface facing the object side and having positive refractive power; and

a fourth lens component comprising a negative meniscus lens having its concave surface facing the object side; and

further having a stop between said second lens component and said third lens component.

11. A wide angle objective lens according to claim **10**, wherein when the refractive index of said biconcave lens in said second lens component for d-line ($\lambda=587.6$ nm) is n_{21} and the refractive index of said biconvex lens for d-line ($\lambda=587.6$ nm) is n_{22} and the radius of curvature of the cemented surface of said biconcave lens and said biconvex lens is r_{2M} and the radius of curvature of that surface of said second lens component which is most adjacent to the image side is r_{22} and the refractive power ψ_{2M} of the cemented surface of said biconcave lens and said biconvex lens is expressed as $\psi_{2M}=(n_{22}-n_{21})/r_{2M}$, said second lens component is designed to satisfy the following condition:

$$-0.9 \leqq \psi_{2M} \cdot r_{22} \leqq -0.1;\ r_{22}<0$$

12. A wide angle objective lens according to claim **10**, wherein when the radius of curvature of that surface of said third lens component which is most adjacent to the object side is r_{31} and the focal length of said third lens component is f_3 and the refractive index of said concave lens in said third lens component for d-line ($\lambda=587.6$ nm) is n_{31} and the refractive index of said biconvex lens for d-line ($\lambda=587.6$ nm) is n_{32} and the radius of curvature of the cemented surface of said biconcave lens and said biconvex lens is r_{3M} and the refractive power of the entire optical system is ψ and the refractive power ψ_{3M} of the cemented surface of said bocincave lens and said biconvex lens is expressed as $\psi_{3M}=(n_{32}-n_{31})/r_{3M}$, said third lens component is designed to satisfy the following conditions:

$$-0.6 \leqq r_{31} \cdot f_3 \leqq -0.1;\ r_{31}<0$$

$$0<\psi_{3M}/\psi<0.5;\ r_{3M}>0$$

13. A wide angle objective lens according to claim **10**, wherein when the mean value of the absolute values of the refractive powers of said first to fourth lens components is $\psi_{1\text{-}4}$ and the refractive power of the entire optical system is ψ, said lens components are designed to further satisfy the following condition:

$$\psi_{1\text{-}4}/\psi<0.9$$

14. A wide angle objective lens according to claim **10**, wherein when the air gap on the optical axis from that surface of said second lens component which is most adjacent to the image side to that surface of said third lens component which is most adjacent to the object side is t_2 and the air gap on the optical axis from that surface of said third lens component which is most adjacent to the image side to that surface of said fourth lens component which is most adjacent to the object side is t_3, said second to fourth lens components are designed to satisfy the following condition:

$$0.2 \leqq t_3/t_2 \leqq 1.0$$

15. A wide angle objective lens according to claim **10**, wherein when the mean value of the refractive indices of the positive meniscus lens in said first lens component, the positive biconvex lens in said second lens component and the positive biconvex lens in said third lens component for d-line ($\lambda=587.6$ nm) is Np and the mean value of the refractive indices of the negative biconcave lens in said second lens component, the negative biconcave lens in said third lens component and the negative meniscus lens of said fourth lens component for d-line ($\lambda=587.6$ nm) is Nn, said wide angle objective lens is designed to further satisfy the following conditions:

$$Np>1.70,\ Nn<1.70.$$

* * * * *

US005218445A

United States Patent [19]

van Roessel

[11] Patent Number: 5,218,445

[45] Date of Patent: Jun. 8, 1993

[54] **SYSTEM FOR FOCUSING A TELEVISION CAMERA OBJECTIVE LENS**

[75] Inventor: **Frederik J. van Roessel**, Upper Saddle River, N.J.

[73] Assignee: **BTS Broadcast Television Systems GmbH**, Darmstadt, Fed. Rep. of Germany

[21] Appl. No.: **604,972**

[22] Filed: **Oct. 26, 1990**

[30] **Foreign Application Priority Data**

Nov. 21, 1989 [DE] Fed. Rep. of Germany 3938522

[51] **Int. Cl.**[5] **H04N 5/232**

[52] **U.S. Cl.** **358/227**; 354/402

[58] **Field of Search** 358/227, 228; 354/402, 354/400, 403, 406

[56] **References Cited**

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"The Computer as a Camera-Operation and Image--Quality Manager", by Frederik J. van Roessel and Engbert Tienkamp, pp. 1079-1086.

Primary Examiner—James J. Groody
Assistant Examiner—Glenton B. Burgess
Attorney, Agent, or Firm—Frishauf, Holtz, Goodman & Woodward

[57] **ABSTRACT**

A system for focusing a zoom lens objective of a color television camera. A luminance or green video signal derived from a portion of the picture is full-wave rectified and then averaged. The sharpest focus corresponds to the highest value of that average. The signal is converted to digital form and processed by a microcomputer for automatic focusing control by finding the signal maximum with shifting of the lens focus setting. The video signal is stripped of its d.c. component before rectification, but is used with its full bandwidth.

5 Claims, 2 Drawing Sheets

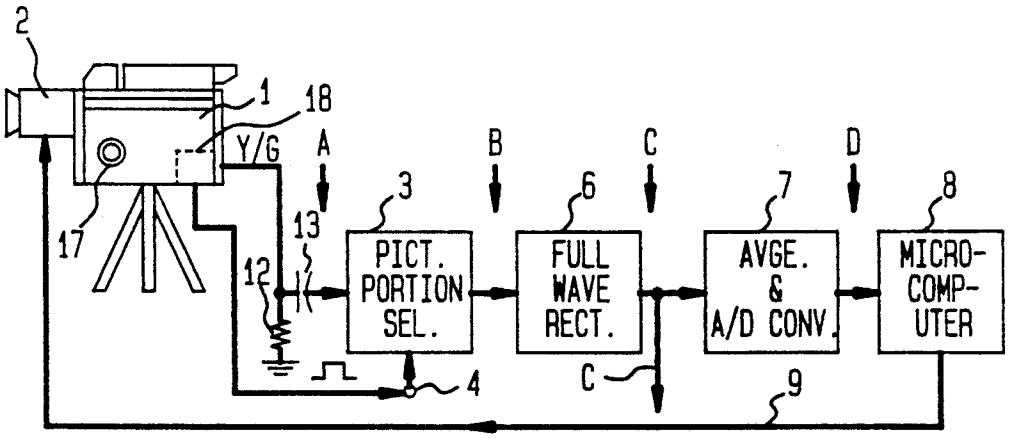


FIG. 1

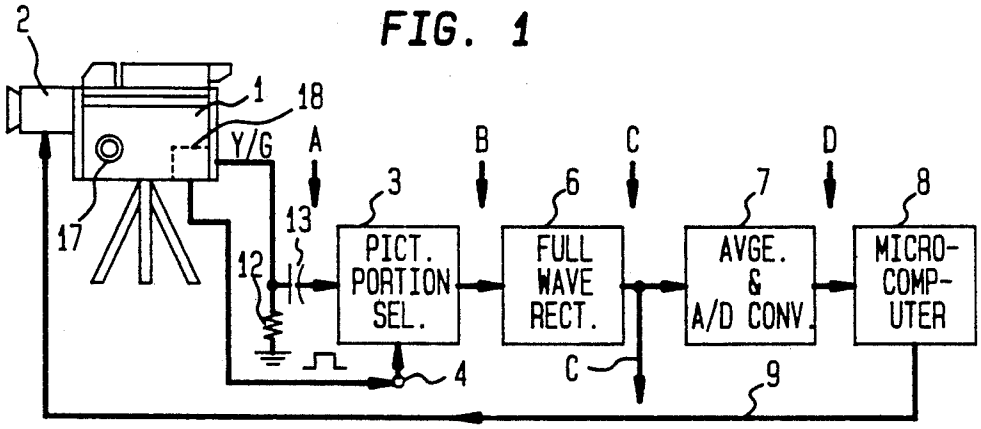


FIG. 2B

FIG. 2C

FIG. 2A

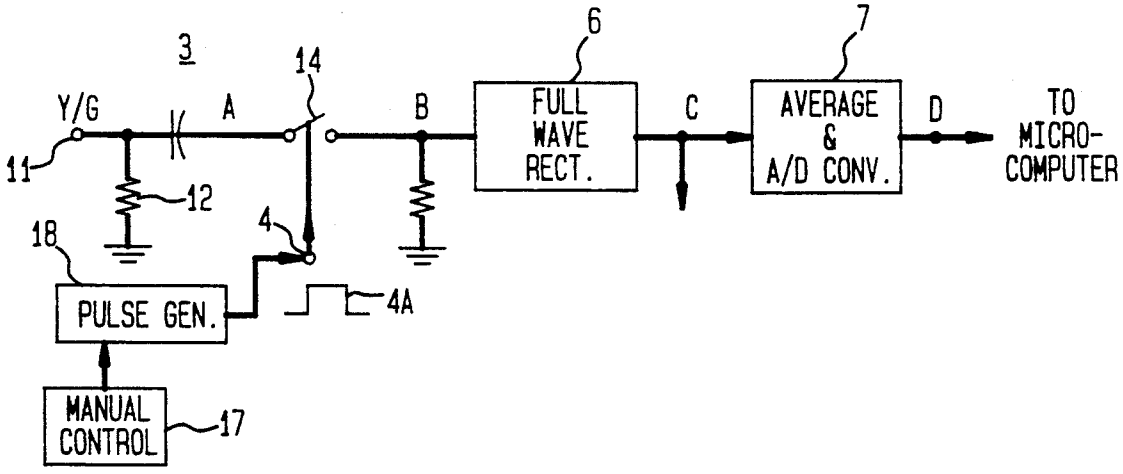


FIG. 3A

FIG. 3B

FIG. 4

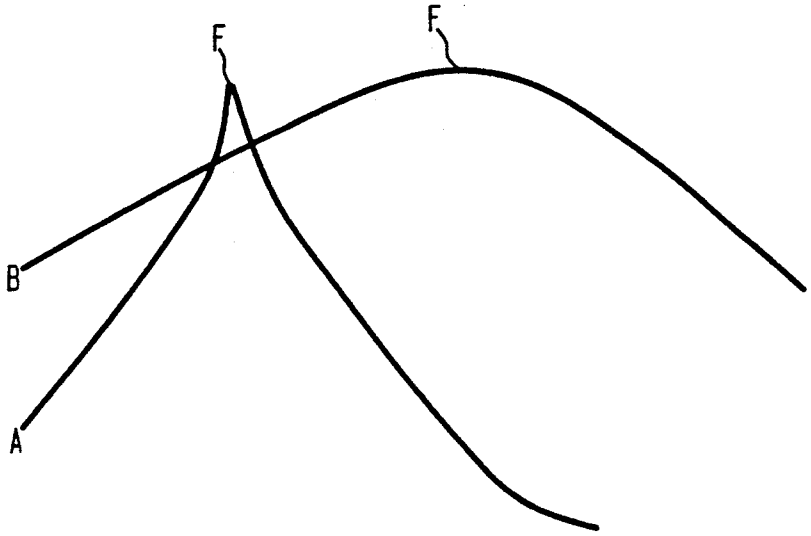
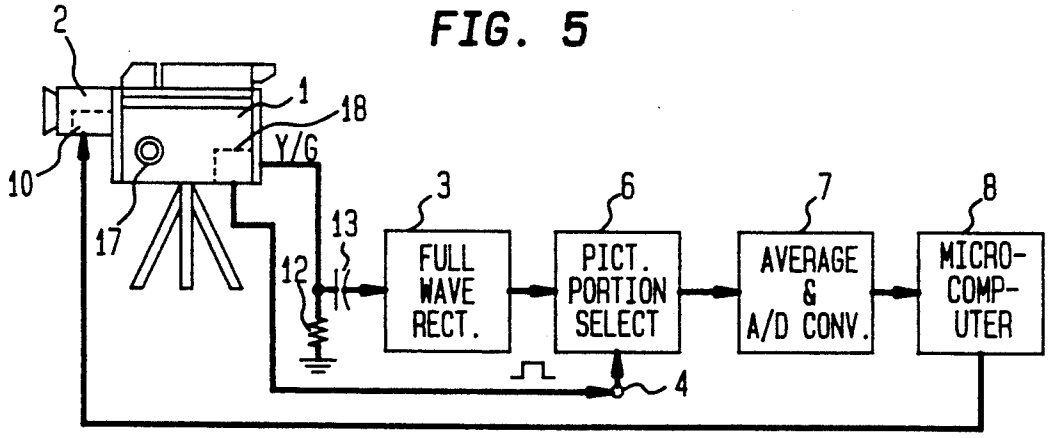

F
F
B
A

FIG. 5


2
1
18
Y/G
10
17
12
13
3
FULL WAVE RECT.
6
PICT. PORTION SELECT
7
AVERAGE & A/D CONV.
8
MICRO-COMP-UTER
4

SYSTEM FOR FOCUSING A TELEVISION CAMERA OBJECTIVE LENS

This invention concerns the focusing of a television camera objective, which is typically a zoom lens equipped with lens shifting means for focus, by a system in which a focus signal derived from a video signal is generated by rectification or absolute value formation followed by averaging of a video signal relating to a region of a television picture. The focus signal so derived is digitalized and processed in a microcomputer programmed for shifting the lens, comparing focus status values and deriving control signals for optimizing the focus status.

Such an automatic focusing circuit for a television camera is disclosed in U.S. Pat. No. 4,638,364. In this case the luminance component of the video signal is passed through a high-pass filter for deriving the focus signal, so that only the high-frequeny components of the luminance signal contribute to the generation of the focus signal.

A similar provision for carrying out focus correction is known from the adjustment system of a television camera disclosed in European Patent 0 084 908 B1. Here also only the higher frequency components of the video signal are measured and are set at a maximum value for seeking the best focus.

If only the higher frequency components of this video signal are used for measuring the sharpness of the picture, however, the objective positioning may indeed lie close to the actual focus position, but this point of actual focus cannot be readily found by the automatic means described in the above references. There is a further disadvantage in those systems that the objective cannot be focused with reference to horizontal lines, because these vertical transitions have no high frequency components of the video signal in the neighborhood of the actually focussed condition.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide automatic focusing of a television camera in which, for practically every possible setting, of, a zoom lens objective an optimal focusing can be obtained in the shortest time.

Briefly, the video signal from which the focus signal is derived is the d.c.-free luminance or green signal of the camera and it is utilized with full bandwidth. The system of the invention has the advantage that even video signals generated far from the actual focussed point can be used to derive information signals for automatic focussing of the objective. There is a further advantage that the objective can also be focussed with reference to horizontal lines, i.e. vertical transitions.

The portion of the picture in which the video signal used for focusing is derived can be made manually selectable and for this purpose the selection of the picture portion for generating the focus signal can utilize a gate that is open during the time the video signal relates to that picture portion.

The above-mentioned gate can be located in circuit just before or just after the rectifying circuit of the video signal processing.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention is further described by way of illustrative example with reference to the annexed drawings, in which:

FIG. **1** is a circuit block diagram of a system of the invention;

FIG. **2A** is a somewhat more detailed circuit block diagram of the mid-portion of the diagram of FIG. **1**.

FIG. **2B** is a graphical representation of a signal at poing B of FIG. **2A**;

FIG. **2C** is a graphical representation of a signal at point C of FIG. **2A**;

FIG. **3A** is a time-amplitude diagram of output signals of the full wave rectifier of FIG. **2** before the focusing adjustment has been found;

FIG. **3B** is a time-amplitude diagram of the output signal of the full wave rectifier of FIG. **2** after the focus adjustment has been found;

FIG. **4** are two typical sharpness curves of a zoom lens television camera objective, with axial position of the objective as the horizontal variable; and

FIG. **5** is a diagram showing another embodiment of the invention differing from the embodiment of FIG. **1**.

DESCRIPTION OF THE ILLUSTRATED EMBODIMENT

In the circuit block diagram of FIG. **1** the luminance signal Y or the green signal G of a video signal is obtained from the television camera **1** having a zoom-lens **2**, and is supplied to a region selecting circuit **3** through a filter **12**, **13**, which converts the Y or G video signal into a d.c.-free video signal without appreciably limiting its bandwidth.

A so-called cursor pulse signal is supplied at the terminal **4** of the selection circuit **3**. The cursor pulse signal defines a manually selected portion of the picture in which the picture sharpness is to be measured. It operates a switch **14** as shown in FIG. **2A** for time-wise limiting of the signal passing through the switch so that only that part of the signal relating to the selected picture region will be passed on. The size and position of this picture region can be selected, for example, by the camera operator, by a manual control **17** and a time gate signal generator **18**. Manually controlled cursor signals for selecting picture areas are well known and do not need to be further described here.

The video signal of the selected picture portion is then supplied to a full wave rectifier circuit **6** at the output of which the rectified video signal is made available during the intervals in which the selected picture portion is being scanned by the camera. This signal is then supplied to a measurement circuit **7** in which the amplitude of the average value of the rectified video signal is produced and converted into a digital signal, for example a 12-bit signal.

The measurement result is then utilized to determine the picture sharpness for the focus adjustment. For that purpose the digital signal is supplied to a microcomputer **8**. The microcomputer **8** is programmed to provide a focus adjustment signal for the zoom lens **2** over the line or cable **9** for setting the optimal picture sharpness by control of the lens shifting device **10** with which the zoom lens **2** is equipped. The lens shifting device **10** is only symbolically shown in FIG. **1** because electronically controlled lens shifting devices for suitable for various kinds of automatic focus are well known. A common way of axially shifting an objective lens is by a

screw or micrometer drive. The connection **9** may include a conductor for reporting the position of the objective lens to the microcomputer **8**.

The processing of the digital measurement signal for generating the focus signal in the microcomputer **8** is of the kind disclosed in the above-mentioned European patent document Ep 0 084 908 B1 or of the kind disclosed in the article "The Computer as a Camera-Operation and Image-Quality Manager" by F. J. van Roessel and E. Tienkamp in SMPTE Journal, November, 1987, page 1079ff. These publications describe such programming in so great detail that it is not necessary to describe that subject matter further here.

In FIG. **2A** a portion of the system of FIG. **1** according to the invention is shown in somewhat more detail, and the same parts that appear in FIGS. **1** and **2A** are designated with the same reference numerals. In FIG. **2A** the video signal Y or G is present at the terminal **11** and is supplied through a resistance-capacitance network **12**, **13** to a switch **14**. The numeral **3** in FIG. **2A** identifies a switch **14** and the resistor **15** as the picture region selection circuit **3** of FIG. **1**. The capacitor **13** eliminates the d.c. component of the video signal The cursor pulse signal supplied to the switch **14** from the terminal **4** closes the switch **14**, when it has positive amplitude and thereby allows the further conduction of the video signal, now stripped of its d.c. component, past the circuit point B to the full wave rectifier **6**. In the absence of the positive cursor pulse the switch **14** is open and a d.c. voltage of 0 volt is present at the input of the full wave rectifier, as assured by the input resistance **15** connected to ground. The cursor pulse is symbolized by the wave shape **4A** below the terminal **4** in FIG. **2A**. It operates a switch **14** and thus defines a time-wise limiting of the Y or G video signal supplied to the circuit point B and shown in FIG. **2B**. By so doing it likewise provides a time-wise limiting of the signal produced by the full wave rectifier **6**, as shown in FIG. **2C** which is supplied to the averaging and digitizing unit **7**. FIG. **2B** shows a voltage-time graph of a typical signal at point B of FIG. **2A**. In FIG. **2B** a horizontal line during the open period of the switch **14** is labelled 0V to designate the 0 voltage level. The signal at C at the output of the full wave rectifier **6** can be used to highlight the selected picture portion on a local monitor or in the camera's electronic finder. This is indicated by the branching connection **16** in FIG. **2C**.

After full-wave rectification of this signal present at point B there is produced at the circuit point C at the output of the full wave rectifier **6** a video signal having the signal course illustrated in FIG. **2C**. The average value of this signal at circuit point C is a measure for the picture sharpness set by the position of the shifting device of the lens **2**. The video signal at point C, as mentioned above, is converted from analog to digital form for a very large dynamic range in the measurement circuit **7**. The resulting **12** bit measurement output signal is then supplied to the microcomputer **8** and there further processed. Details of this video signal processing can, as mentioned above, be found in the above-mentioned article by van Roessel and Tienkamp.

It will now be explained, by reference to FIGS. **3A** and **3B**, how the signal average value produced in the measurement circuit **7** before analog to digital conversion provides a measure for the picture sharpness. Both FIGS. **3A** and **3B** show the course of a full-wave rectified video signal at point C that is produced by scanning an alternating succession of black and white areas. The signal of FIG. **3A** has rounded edges and oblique flanks, because the lens was not focussed on the test pattern. In contrast thereto the signal of FIG. **3B** resulting from optimal focusing on the test picture has steep flanks and unrounded corners. It is thus easily visible that the average value of the signal of FIG. **3B** is greater than that of the signal of FIG. **3A**. The principle of this measurement system, however, is not limited to the use of any particular kind of test picture. It can also be used, advantageously, for focusing on a picture of normal picture content.

FIG. **4** shows two typical curves of the degree of sharpness as a function of the focus position of the objective lens. Curve A illustrates camera exposure to a scene with a telephoto setting (small picture angle) of a zoom lens and the curve B is generated with a wide angle setting of the zoom lens **2**. In both cases the focus point F of the zoom lens **2** is readily recognizable.

FIG. **5** is a diagram of a modification of FIG. **1** that has been mentioned already at the end of the Summary of the Invention. In FIG. **5** the gate **3** for time-wise allowing passage only of a video signal relating to the portion of the field of view that has been selected for focusing is located after the full wave rectifier **6** instead of before it, as shown in FIG. **1**. It still precedes the averaging means **7**.

The system of the invention can be used with particular advantage for high definition television (HDTV) cameras. With such cameras it is often difficult for the camera operator to focus a zoom lens objective optimally, because the picture reproduction on the picture screen of the electronic finder is not sharp enough. With use of the invention this disadvantage can be avoided if the rectified video signal at point C is supplied either to a monitor or to the electronic finder of the television camera **1** for manual focusing or, by pressing a button, supplied instead through the measurement circuit **7** to the microcomputer **8** for automatic focusing. Of course the system of the invention can also be used in conventional television cameras, whether in automatized studio operation or by retrofit into existing equipment to simplify the operation for the cameramen.

Although the invention has been described with reference to a particular illustrative example, it will be understood that variations and modifications are possible within the inventive concept.

I claim:

1. Apparatus for focusing a zoom-lens objective of a television camera having means for axially shifting said objective over a focusing position range, said shifting means having a control input for an electrical control signal, comprising:

electrical filter means, connected to a source of a luminance or green component of a video signal produced by said camera, for eliminating a d.c. component of said luminance or green component of said video signal and providing, at an output of said electrical filter means, the remainder of said luminance or green component of said video signal at its full bandwidth;

means, connected to said output of said d.c. component eliminating means, for full wave rectification of said full-bandwidth remainder of said luminance or green component of said video signal and for providing a rectified video signal at an output of aid rectification means;

means for averaging said rectified video signal component and means for converting successive aver-

age values thereof to digital signal values provided at an output of said averaging and converting means;

means for time-wise limiting the input to said means for averaging said rectified video signal to the rectification product of time-segments of said component remainder of said video signal which relate to a portion of a total field of view of said camera, said time-wise limiting means being interposed between said source of a luminance or green component of a video signal and said means for averaging said rectified video signal. and

signal processing means connected to said output of said averaging and converting means and to said control input of said zoom-lens objective sifting means for producing said electrical control signal in response to said digital signal values so as to position said shifting means at a position at which said digital signal values show a maximum for said focusing position range.

2. The apparatus of claim 1, wherein said means for time-wise limiting the input to said averaging and converting means includes means for manually selecting a portion of a total field of view of said camera.

3. The apparatus of claim 2, wherein sad means for selecting said portion of a total field of view of said camera comprises means for generating cursor pulses defining the time intervals during which said portion of a total field of view of said camera is being scanned by said camera and wherein said means (14) for time-wise limiting the input to said averaging means is responsive to said cursor pulses for allowing passage through said time-wise limiting means of a video signal relating only to said portion of a total field of view of said camera.

4. The apparatus of claim 3, wherein said time-wise limiting means is interposed between an output of said means for eliminating any d.c. component of said luminance or green component of said video signal and an input of said means for full-wave rectification of said component of said video signal.

5. The apparatus of claim 3, wherein said time-wise limiting means is interposed between said output of said rectification means and an input of said averaging and converting means.

* * * * *

US005214455A

United States Patent [19]

Penney et al.

[11] Patent Number: 5,214,455

[45] Date of Patent: May 25, 1993

[54] OBJECTIVE EYE ALIGNMENT MEASUREMENT METHOD AND SYSTEM

[75] Inventors: Carl M. Penney, Saratoga Springs, N.Y.; Keith P. Thompson, Atlanta, Ga.; Robert H. Webb, Lincoln, Mass.

[73] Assignee: General Electric Company, Schenectady, N.Y.

[21] Appl. No.: 677,902

[22] Filed: Apr. 1, 1991

[51] Int. Cl.[5] A61B 3/14

[52] U.S. Cl. 351/210; 351/208; 351/246; 356/153

[58] Field of Search 351/210, 208, 206, 246; 356/153

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4,253,743	3/1981	Matsumura	351/206
4,867,554	9/1989	Matsumura	351/206

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Assistant Examiner—Hung Xuan Dang
Attorney, Agent, or Firm—Paul R. Webb, II

[57] ABSTRACT

Eye alignment is determined by producing a combined iris/retinal image by use of an imaging system. The relative position of the centroid of the pupil and various structures on the retina is indicative of the eye alignment. The eye alignment may be determined by comparing a combined iris/retinal image at the present time with a stored iris/retinal image at a past time. The imaging system may be a laser scanning ophthalmoscope.

22 Claims, 5 Drawing Sheets

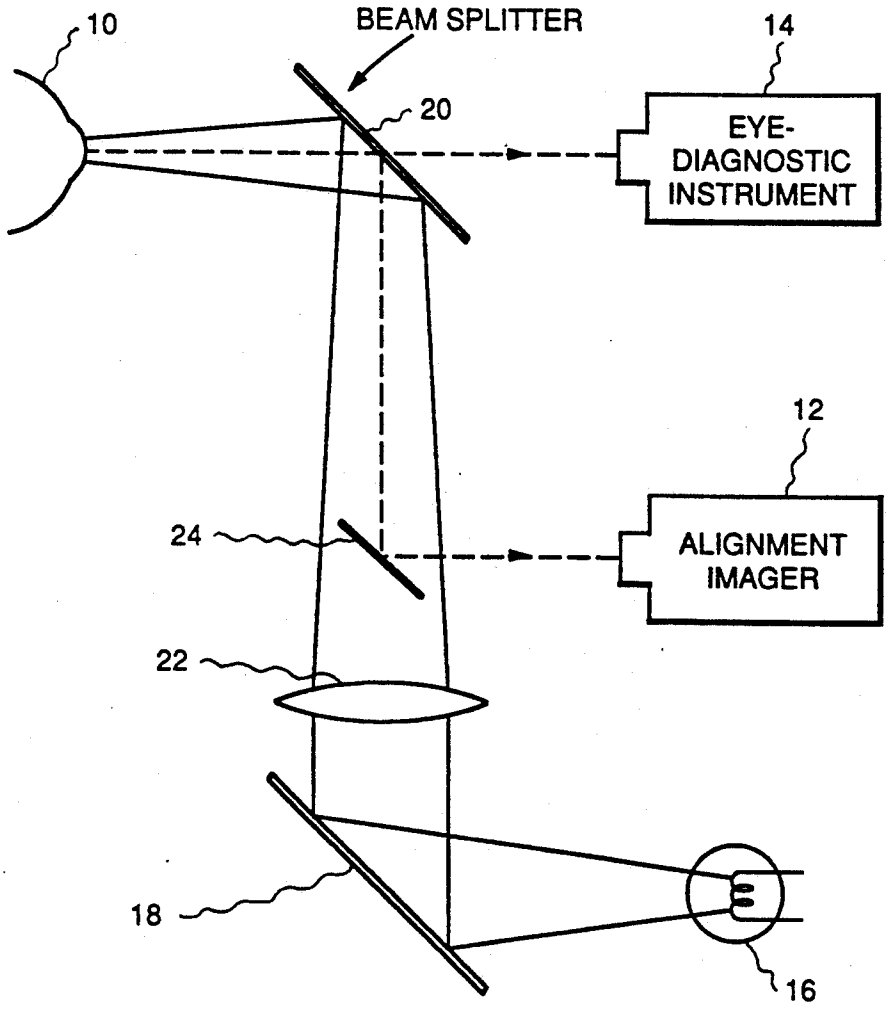
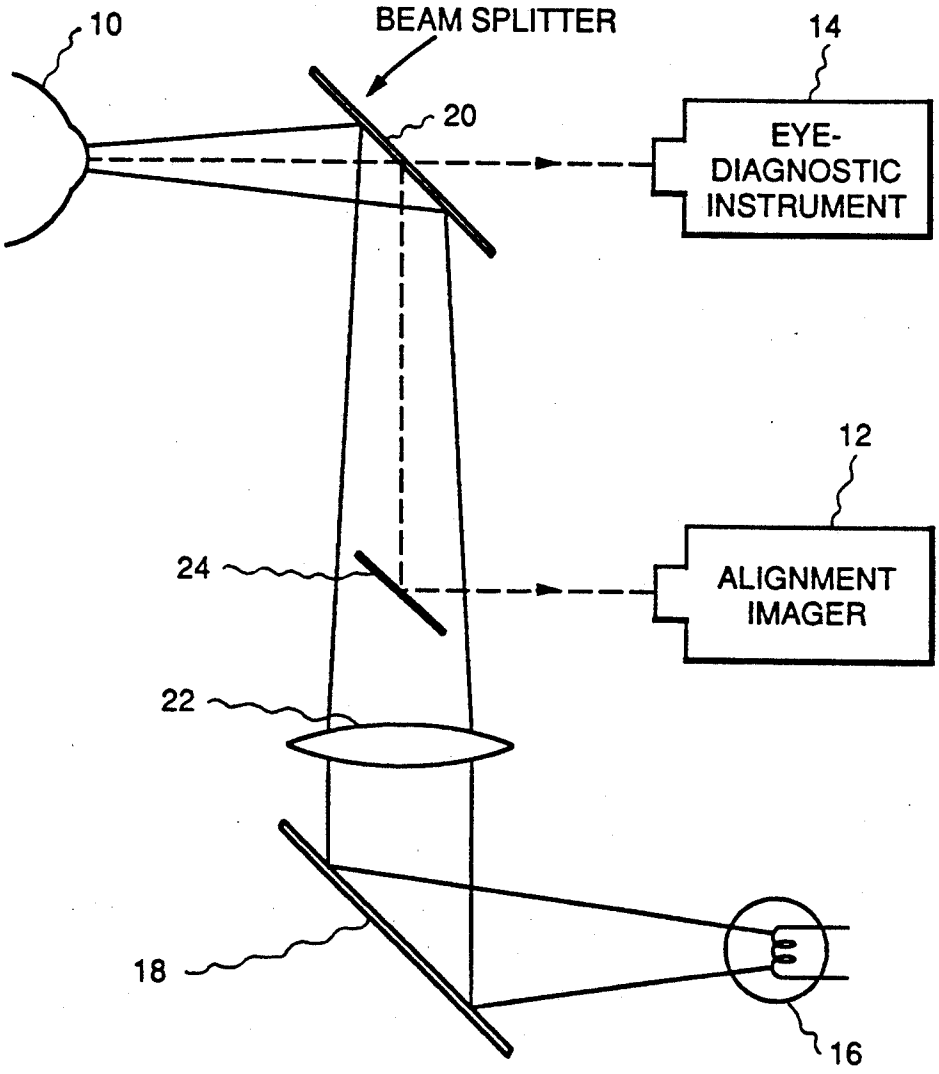


FIG. 1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BEAM SPLITTER
14
20
EYE-
DIAGNOSTIC
INSTRUMENT
12
24
ALIGNMENT
IMAGER
22
18
16

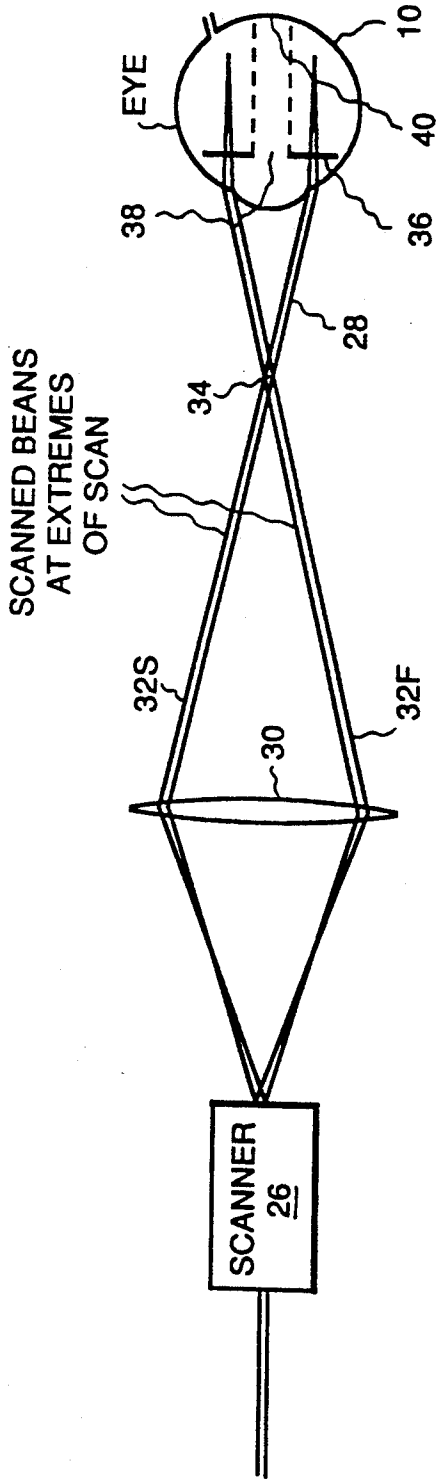

EYE
10
40
38
36
28
34
SCANNED BEANS
AT EXTREMES
OF SCAN
32S
32F
30
SCANNER
26

FIG. 2

FIG. 3A

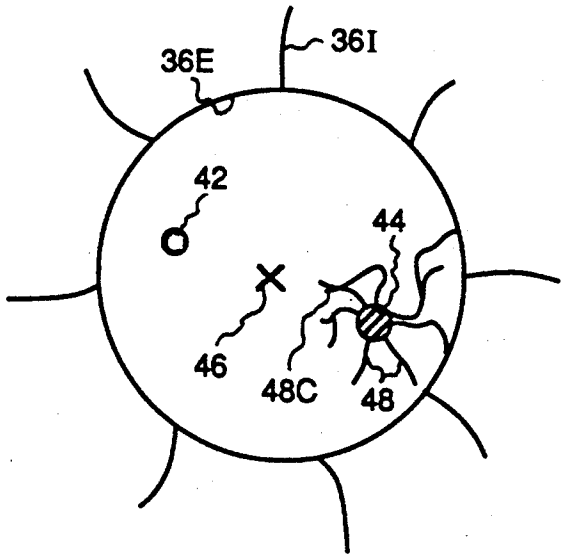


FIG. 3B

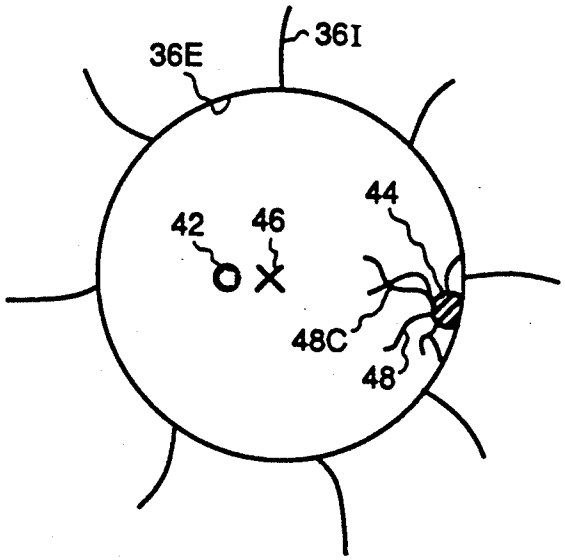


FIG. 3C

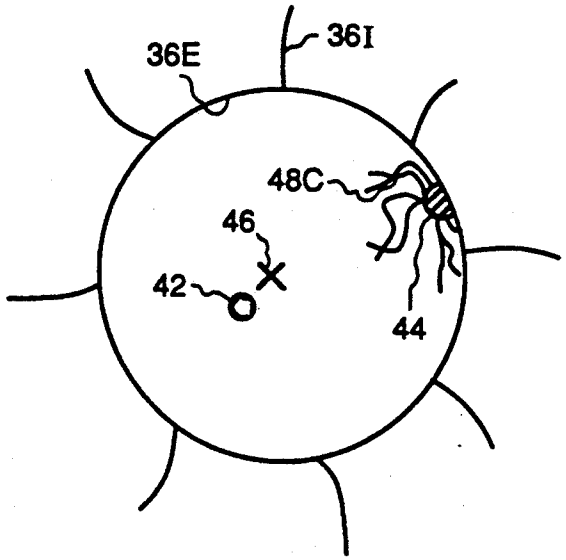


FIG. 4

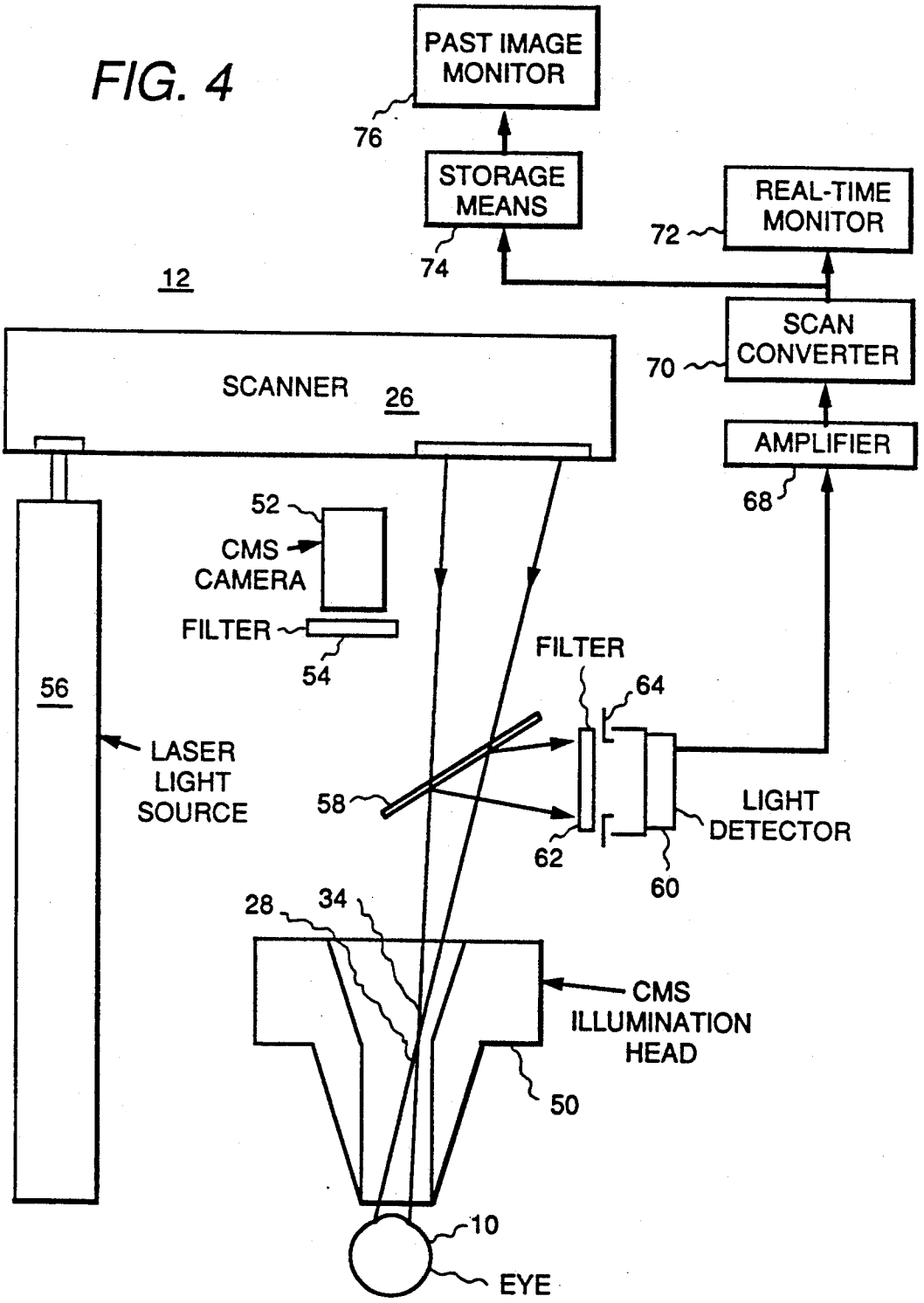
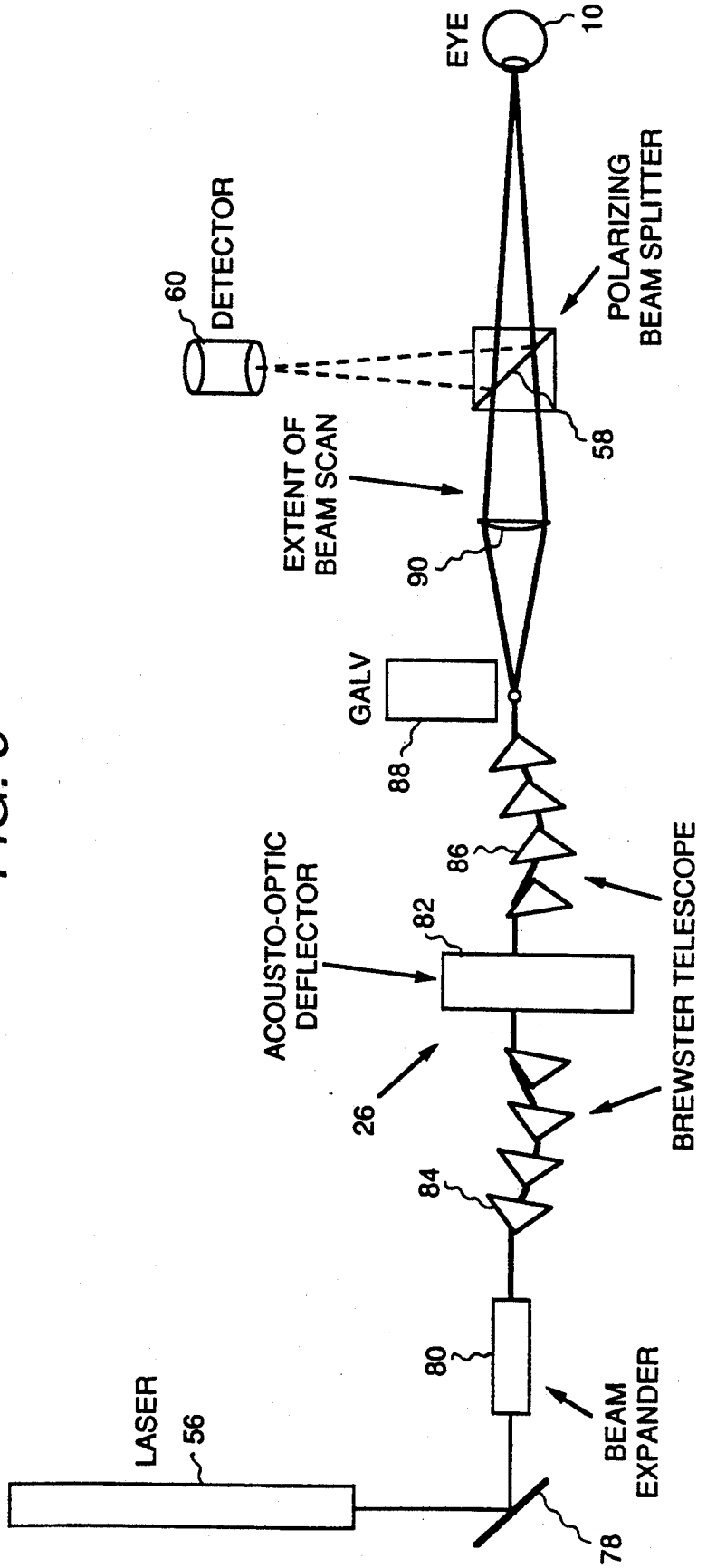

PAST IMAGE MONITOR
76
STORAGE MEANS
74
REAL-TIME MONITOR
72
12
SCAN CONVERTER
70
SCANNER 26
AMPLIFIER
68
52
CMS CAMERA
FILTER
54
56
FILTER
64
LASER LIGHT SOURCE
58
LIGHT DETECTOR
62
60
28
34
CMS ILLUMINATION HEAD
50
10
EYE

FIG. 5


EYE
10
DETECTOR
60
POLARIZING
BEAM SPLITTER
58
EXTENT OF
BEAM SCAN
90
GALV
88
86
ACOUSTO-OPTIC
DEFLECTOR
82
BREWSTER TELESCOPE
26
84
80
LASER
56
BEAM
EXPANDER
78

OBJECTIVE EYE ALIGNMENT MEASUREMENT METHOD AND SYSTEM

CROSS REFERENCE TO RELATED APPLICATION

This application relates to copending application Ser. No. 557,263, filed Jul. 24, 1990, assigned to the same assignee as the present invention.

BACKGROUND OF THE INVENTION

This invention relates to a system and method for aligning the eyes of a subject.

There are a number of situations where the alignment of a subject's eyes are important. The subject may be human or may be a research animal.

When taking certain types of eye measurements, one may need to know that the eye alignment is in a particular reference position. For example, if one measures the cornea of a person's eye before some type of treatment and one wishes to repeat those measurements after the treatment to determine how much, if any, the treatment has affected the measurements, one must ensure that the eye alignment is in the same position each time the particular measurements are made. Otherwise, the difference in data from before and after the treatment might be due to a change in eye alignment rather than the treatment.

In addition to those situations where one needs to ensure that eye alignment is in the same position for two or more different measurements, there are situations where eye alignment is desirable for diagnostic measurements of eye performance. There are situations when a human subject can simply be requested to fixate on a particular object. Thus, the human may state that he is currently looking at a light source, thereby providing "subjective" eye alignment information. However, there are situations where a doctor or researcher would like "objective" eye alignment information indicating the orientation of the eye and, to the extent possible, indicating what the eye is viewing. For example, very young children cannot be relied upon to fixate on such an object for measurements, such as refraction measurements which are very desirable to ensure that "in focus" images are being received when the child's brain is learning to interpret images. Likewise, adults subjected to extended eye examinations may become tired or subject to other duress and fail to maintain reliable fixation. A patient who is subjected to a therapeutic process such as laser ablation eye surgery may not be able to maintain desired eye orientation over an extended treatment time because of applied anesthesia, fatigue, or distraction by the procedure. Further, a research animal usually cannot be trained to fixate during eye measurements.

In each of the above cases, the failure or inability of the subject to maintain eye fixation upon an object can produce eye measurements or treatments that are seriously in error.

Therefore, there are situations where absolute eye alignment data is needed (i.e., the eye is aligned in a certain manner) and situations where comparative eye alignment data (i.e., the eye is in the same alignment as when earlier measurements were taken) are needed and one cannot rely upon a subject maintaining the alignment.

The use of various optical/electronic systems for making eye measurements has become more common in recent years. One example of such a system is shown in U.S. Pat. No. 4,213,678 to Pomerantzeff and Webb issued on Jul. 22, 1980. That patent discloses a scanning laser ophthalmoscope (SLO) for scanning a portion of the eye fundus. That patent, coinvented by one of the present inventors, is hereby incorporated by reference.

OBJECTS AND SUMMARY OF THE INVENTION

Accordingly, a primary object of the present invention is to provide a new and improved method and system for determining objective eye alignment.

A more specific object of the present invention is to provide objective eye alignment information which may provide the eye alignment relative to some external point or line, such as an instrument axis, or to provide eye alignment information by indicating when the present eye alignment is the same as an earlier eye alignment.

A further object of the present invention is to provide eye alignment data which can be used in combination with other diagnostic and therapeutic instruments. In other words, an object is to allow eye alignment data to be provided without requiring instrumentation which would block or prevent use of diagnostic and/or therapeutic devices which may advantageously use eye alignment information for improving their diagnostic and/or therapeutic operations.

Yet another object of the present invention is to allow one to bring the eye of a subject to a particular desired alignment, while the subject is under general anesthesia or is otherwise unable to cooperate in bringing his eye to a particular alignment.

A still further object of the present invention is to provide eye alignment information in a reliable and convenient fashion.

A more specific object of the present invention is to provide an imaging system and a method of use of an imaging system for determining objective eye alignment.

The above and other objects of the present invention, which will become more apparent as the following detailed description is considered, are realized by a method of determining objective eye alignment. A subject's eye is positioned relative to an imaging system to allow imaging of the eye. The imaging system provides an iris image of an iris portion of the subject's eye and a retinal image of a retinal portion of the subject's eye. The iris image and the retinal image are used to determine objective eye alignment. Preferably, the imaging system obtains the iris image and the retinal image within a time no greater than 50 milliseconds. To minimize intervening eye movements the time of obtaining the images would preferably be substantially less than that. The iris image and the retinal image are simultaneously displayed on a first monitor of the imaging system. (As used herein, "simultaneous display" means that the images appear simultaneous to a human eye.)

The eye alignment may be determined in two different manners. A first way of determining the eye alignment includes the step of comparing the iris image and the retinal image with a stored image of the iris portion and the retinal portion, the stored image corresponding to eye alignment at a previous time. More specifically, this first manner involves finding an eye position at which the iris image and the retinal image are substantially identical to the stored image. A second manner of

determining eye alignment involves finding a relationship between an instrument axis of the imaging system and an axis of the subject's eye. More specifically, the axis of the subject's eye may be the pupillary axis.

The iris image and the retinal image are provided by the imaging system scanning a beam across the eye and detecting scatter from the application of the beam to the eye. The beam is preferably a beam of electromagnetic radiation in the infra-red, visible or ultraviolet portions of the spectrum..

The method of the present invention may alternately be described as a method of determining objective eye alignment including a step of scanning a light beam from an imaging system across a subject's eyes such that the light beam strikes an iris portion adjacent a pupil and strikes a retinal portion. Scattered light from the application of the light beam to the iris portion and the retinal portion is then detected by operation of the imaging system. Nearly simultaneous (meaning simultaneous or within 50 milliseconds thereof) views of the iris portion and the retinal portion are generated by operation of the imaging system. The nearly simultaneous views are then used to determine objective eye alignment. The light beam is scanned between extremes of scan which cross in front of the object's eye. More specifically, the extremes of scan preferably cross at least three centimeters in front of the subject's eye (i.e., the closest point on the subject's eye to the scan crossing point is 3 centimeters or greater). The light beam applied to the subject's eye has a diameter of no more than 1 millimeter at the iris.

The system of the present invention is a system for measuring objective eye alignment including a scanner for scanning a beam across a subject's eye such that the beam strikes an iris portion adjacent a pupil and strikes a retinal portion. A detector for detecting scatter from the application of the beam to the iris portion and the retinal portion is operatively connected to a first monitor for showing simultaneous views (i.e., they appear simultaneous to a human eye) of the iris portion and the retinal portion based upon the scatter detected by the detector. The simultaneous views provide objective eye alignment information. More specifically, the scanner scans a light beam. The system may further include a second monitor and storage means to supply the second monitor with a stored image of the iris portion and the retinal portion at a previous time.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and other features of the present invention will be more readily understood when the following detailed description is considered in conjunction with the accompanying drawings wherein like characters represent like parts throughout the several views and in which:

FIG. 1 shows a general schematic diagram illustrating how the present eye alignment system may be used in conjunction with another eye diagnostic instrument;

FIG. 2 shows a simplified view illustrating how the present alignment system may apply beams to the eye of a subject;

FIG. 3A, 3B, and 3C show separate images which the present system may provide for purposes of determining eye alignment information;

FIG. 4 shows an arrangement wherein the present eye alignment system is operating in conjunction with a known instrument which provides measurements of a cornea of the subject's eye; and

FIG. 5 shows a detailed view of an arrangement which may be used to provide the scanning.

DETAILED DESCRIPTION

With reference now to FIG. 1, there is shown a simplified view of part of a subject's eye 10 with an alignment imaging system 12 positioned to allow determination of the eye 10. The alignment imaging system or imager 12 according to the present invention is used to provide eye alignment information in a manner discussed in more detail below. For purposes of an initial general explanation, the arrangement of FIG. 1 shows how this alignment imaging system 12 may be used in combination with some other previously known eye diagnostic instrument 14. In particular, the instrument 14 might be some instrument which may diagnose conditions in the eye 10. The instrument 14 may alternately be some sort of therapeutic instrument (not separately indicated in the diagram) which may be used at the same time as the eye alignment imaging system 12. At any rate, the instrument 14 might be useful independently of any alignment information provided by the alignment system 12 or, more likely, the instrument 14 may use the alignment information from alignment system 12 for more accurately diagnosing and/or applying treatment to the eye 10.

As shown in FIG. 1, a light source 16 may supply light to a reflector 18 which in turn supplies the light to a beam splitter 20 by way of a lens 22. The light from source 16 is applied to the eye 10 and reflects back through the beam splitter 20 to the instrument 14. The eye diagnostic instrument 14 may produce data about the eye 10 depending upon the light reaching the diagnostic instrument 14.

At the same time as the instrument 14 is operating to provide the diagnostic information, the alignment imager 12 uses a reflector 24 and the beam splitter 20 to obtain alignment data about the eye. A manner in which the alignment imager 12 and eye diagnostic instrument 14 may be operated at the same time without one instrument blocking the other is shown in FIG. 1, it being readily appreciated that various other optical configurations could be used. A technique by which light from the alignment imager 12 and light from source 16 used with the instrument 14 can be used at the same time without interfering with each other will be discussed in more detail below, it simply being noted at present that these lights may be at different wavelengths (i.e., different colors) to avoid such interference. It should also be noted that, although the preferred embodiment of the present invention does use an alignment imaging system having a scanned light beam, other imaging systems might possibly be used. Further, the instrument 14 does not necessarily have to be an eye diagnostic instrument using a light source such as source 16. Finally, although FIG. 1 shows the alignment imaging system 12 being used in conjunction with the instrument 14, the alignment imaging system 12 may be used without regard to any other instrument such as instrument 14.

The manner in which the alignment imager 12 functions to determine the alignment of the eye will be explained by reference to the simplified concept drawing of FIG. 2. As shown in FIG. 2, a scanner 26 scans a beam of light 28 across the eye 10, the beam of light 28 passing through lens 30 prior to its application to the eye 10. As shown, the beam 28 has first and second scan extremes 32F and 32S respectively, which cross at point 34, which point is in front of the subject's eye 10. By

crossing in front of the subject's eye, the extremes of scan of beam **28** will allow it to fall upon the edges of iris **36** and, where the beam passes through the pupil **38** within the iris **36**, a retinal portion **40** at the back of eye **10**. By having the light beam **28** scan across the eye **10** and by using a detector (not shown in FIG. **2**, will be discussed in more detail below), the general principle of FIG. **2** may be used to provide a flying spot camera. In order to allow one to have a flying spot camera from the arrangement of FIG. **2** wherein one is able to provide an iris image corresponding to that portion of iris **36** upon which the beam **28** hits and a retinal image corresponding to retinal portion **40**, the point **34** at which the extremes of scan cross is typically about 3 centimeters in front of the subject's eye **10** (i.e., the point **34** is about 3 centimeters from the closest point on the eye **10**). Additionally, and in order to provide a relatively good focus on the iris portion, the beam **28** will have a beam diameter of no more than 1 millimeter and preferably 0.5 millimeters or slightly above that. In other words, the beam diameter will be at or between 1.0 millimeters and 0.5 millimeters. Note that use of too small a beam diameter would degrade the resolution at the retina **40**, whereas use of too large a beam diameter would interfere with the ability of the system to get a good focus on the portions of iris **36** which are around the pupil **38**.

In order to fully define the orientation of a generally spherical object such as an eye, certain information is required. If one is using alignment to simply mean the direction of a particular axis of the eye, simply identifying the location of two points along such an axis would indicate the alignment of the eye. However, as used herein, "alignment" will be interpreted as also including information about rotation of the eye about such an axis. Thus, if the particular axis within the eye corresponds to the look direction, rotating the eye about such a look direction axis may maintain the same object in view, even though the orientation of the eye relative to that object has changed. (In practice, the axis within the eye which is used for reference purposes may or may not correspond to the look direction, but this will be discussed in more detail below.) If one wants alignment information to include not only the direction and position of an eye axis but also the rotational position of the eye relative to that axis, this information can be determined by using at least three well-separated points lying in two nearly perpendicular planes. For such a measurement, two of these three points are used to determine the direction and position of the axis, whereas the third point is within a plane normal to the axis, which plane also includes one of the other two points.

The above discussion of eye alignment information will be more readily understood by reference to FIGS. **3A**, **3B**, and **3C** which show images corresponding to the operation of the present invention. In particular, FIG. **3A** shows an iris image **36I** having an edge **36E** which defines the outside boundaries of the pupil (not separately labeled in these figures). For ease of illustration, the image **36I** of the figures is simplified and does not include the large number of irregularities which would be disposed at the image of iris edge **36E**. Within the closed loop of edge **36E** is the image of the retinal portion corresponding to retinal portion **40** of FIG. **2**. In particular, and as shown in FIGS. **3A**, **3B**, and **3C**, this retinal image part of the combined iris portion/retinal portion image includes the fovea **42** and the optical disc **44**, both of which are disposed at the retina of the subject's eye.

Although various axes or lines might be used within a subject's eye for defining the alignment of the eye, the discussion which follows makes reference to the pupillary axis, which may be defined as a line between the centroid **46** of the pupil (area within edge **36E** in the image figures) and the fovea **42** (more specifically, the center of the foveola). In FIGS. **3A**, **3B** and **3C**, the centroid of the pupil is shown as an "X" **46**.

In the view of FIG. **3A**, the dextral eye shown therein with the centroid **46** of the pupil disposed at about the mid point between the fovea **42** and the center of optical disc **44**. Since the fovea and disc are separated by about 15° in the vision field, the pupillary axis between the centroid and the fovea **42** (more specifically, the center of the foveola, not separately shown) is directed about 7.5° to the right of the alignment instrument axis. The alignment instrument axis (not separately shown in these figures) has an axis normal to the plane of view of FIGS. **3A**, **3B**, and **3C**. This instrument axis will be considered to extend through the centroid **46** in order to clarify the discussion which follows. Relative positioning between the subject's eye and the eye alignment imaging system or other techniques may be used to provide that the alignment instrument axis extends through the centroid, although it is not essential that a uniquely defined alignment instrument axis extend through the centroid **46**. Instead, one might simply define an instrument point of view axis corresponding to the direction of "view" of the instrument and which passes through the centroid **46**.

Although the pupillary axis would be directed about 7.5° to the right of the alignment instrument axis (or alignment point of view axis) in the position of FIG. **3A**, one can say that the eye is looking about 7.5° to the right of the instrument axis only to the extent that one is certain that the subject's visual axis necessarily extends between the centroid **46** and the fovea **42** (more specifically, center of foveola). For certain purposes, it may be reasonable or necessary to assume that the visual axis of the subject's eye is the same as the pupillary axis. However, the use of the present method does not require that this assumption be made.

In the view of FIG. **3B**, the eye orientation has changed so that the pupillary axis is now only a few degrees to the right of the instrument axis. If the fovea **42** were moved slightly to the left in the view of FIG. **3B** such that it was centered beneath the centroid **46**, then the pupillary axis would be directly in line with the alignment instrument axis (or instrument point of view axis).

In the view of FIG. **3C**, the eye has rotated about an axis extending through centroid **46**, but the separation between centroid **46** and fovea **42** (i.e., the separation distance as viewed) has remained constant. As shown in the views of FIGS. **3A**, **3B**, and **3C**, the optical disc **44** may have a number of visible fine blood vessels **48** extending near it. The vessels may include crossing points **48C** (only one shown for simplicity). By noting that the crossing point **48C** has moved counter-clockwise about 30° between the positions of FIGS. **3B** and **3C**, this indicates that the eye has rotated about 30° counter-clockwise. The centroid **46** may be used as the origin for defining angles of rotation.

The alignment of the eye can thus be established by knowing the relationship between the centroid **46** and the fovea **42**. This relationship can establish the angle

between the pupillary axis and the instrument axis. However, if the fovea **42** and centroid **46** are both in line with the instrument axis, the position of an additional point must be used in order to determine uniquely or establish alignment of the eye provided that we use the term "alignment" to include rotation about the pupillary axis. Accordingly, use of the image of the optical disc **44** and, especially, the crossings of visible fine blood vessels such as crossing **44C** will allow us to uniquely establish the alignment of the eye.

The image of the retina portion as appearing within the iris edge **36E** would usually appear as a dark hole in a bright surrounding image because the reflectivity of the iris is much greater than that of the retina in most cases. The substantial detail within the darker retinal image, especially the visible fine blood vessels near the optical disc are quite suitable for computer vision processing. For example, processing can be used to locate and indicate the pupil centroid **46**. Various known pattern recognition techniques may be used to compare retinal detail to a reference image of the same eye.

The imaging system **12** used for eye alignment must meet relatively demanding performance requirements to accomplish its full purpose. The eye alignment information must be obtained and indicated in a time that is short compared to the time during which the eye normally changes its alignment significantly. A typical acceptable time is believed to be about 30 to 50 milliseconds. Within a fraction of this time, the imaging system **12** must form an image with sufficient resolution and depth of focus to provide accurate measurement of the pupil centroid and the retinal detail. Typically, the relatively low reflectivity of the retina means that it must be illuminated artificially to satisfy these requirements, but injurious light levels must be avoided. Further, it is best to avoid uncomfortable light levels because eye responses such as accommodation, aversion or blinking may result and may invalidate a diagnostic measurement. The imaging system should also provide frequent images in order to follow eye motion to guide the approach to proper alignment.

By using the general principles of operation of the scanning laser ophthalmoscope (SLO) co-invented by one of the present inventors and described in more detail in the incorporated by reference U.S. Pat. No. 4,213,678, one can provide an imaging system which will meet the criteria specified above. The SLO has two major advantages for providing alignment information based upon the showing of a dual iris image and retinal image. In particular, the SLO provides retinal images at TV rates with relatively low levels of retinal illumination. Further, the SLO, as modified for the present purposes, may provide high resolution with the large depth of focus required to image both the pupil and the retina.

FIG. **4** shows the eye alignment imaging system **12** in position for measuring a subject's eye **10**, while the eye **10** is, at the same time subject to measurement by a Computer Modeling System (CMS) keratograph having an illumination head **50** and a camera **42**. The illumination head **50** and the camera **52** are part of the CMS manufactured by Computed Anatomy, Inc. and designed to provide topographic measurements of a cornea. The CMS head **50** and camera **52** are simply shown in FIG. **4** to illustrate how the present invention may be used in combination with a particular known diagnostic instrument. Additionally, the head **50** and camera **52** are included in FIG. **4** to show a specific manner in which the present imaging system **12** may be used without interference between it and another eye diagnostic instrument. Specifically, the illumination head **50** may use red light and a filter **54** may only allow red light to pass through to the camera **52**. In that fashion, the camera **52** will avoid errors which might otherwise be caused by light from the imaging system **12** since the imaging system **12** may use green light from laser source **56**.

The green light from laser light source **56** is supplied to a scanner **26** which may scan the beam **28** in a pattern in order to image a retinal portion and an iris portion of the eye **10** as discussed in detail previously. Numerous scanning patterns could be used, but the preferred scanning pattern resembles a conventional interlaced television scanning pattern except that image scanning is continued during the backward sweep, this pattern being discussed in more detail in the incorporated by reference Pomerantzeff patent. The scanner **26** may include various optical elements as will be discussed in detail below. The light from the scanner **26** will pass through the beam splitter **58** on its way to the eye **10**. The beam splitter **58** is preferably a polarizing beam splitter. Since the scanner **26** may supply polarized light (by use of a polarized laser **56**) and the polarized light is about 98% transmitted through the polarizing beam splitter **58**, most of the beam energy from scanner **26** will pass through to the eye **10**. Additionally, the reflections from the cornea and lens of the eye **10**, which are interfering signals for present purposes, will generally still be polarized such that these reflections will pass through the polarizing beam splitter **58** and will not be directed towards a light detector **60**. However, unlike the reflections from the cornea and lens, the scatter returning from the iris and retina are substantially depolarized such that about 50% of the light returning from the surface of interest will be deflected towards the light detector **60**. Thus, use of a polarizing laser **56** and a polarized beam splitter **58** allows one to substantially increase the strength of light returning from the surfaces of interest relative to reflections from surfaces which are not of interest for alignment purposes. The reflected light supplied to light detector **60** goes through filter **62** which would be a green filter corresponding to the green light from laser **56**. The filter **62** will minimize the response of the light detector **60** to reflections from the red light used by the illumination head **50**.

In addition to having the scan crossing point **34** disposed in front of the eye as shown, note that the system does not include any optical elements between that crossing point **34** and the eye **10**. Among other modifications to the SLO disclosed by the Pomerantzeff incorporated by reference patent, the diameter of beam **28** would generally be significantly smaller than the diameter used for high resolution at the retina when the SLO is used as a fundus camera in accord with the Pomerantzeff patent. By use of a smaller beam than in the fundus camera application of the SLO, one can get a good focus on the pupil, while at the same time having a sufficient depth of focus that the retina features can be used for alignment purposes. It should briefly be noted that the SLO fundus camera as described in the incorporated by reference Pomerantzeff patent uses a stop **88** in FIG. **1** of that patent having an aperture therein which corresponds to the size of the pupil, thereby preventing the detector from detecting light reflected from the iris. Although the present system **12** may include a stop **64**, the stop will have an aperture which is sufficiently wide

to allow light from the iris to pass there through. In other words, the light detector **60** will be able to receive reflected light from the iris as well as the retina. The stop **64** may avoid reflections or stray light from outside the area upon which the light beam **28** is applied.

The light detector **60** is connected to an amplifier **68** which provides an output to a scan converter **70**. The scan converter **70** in turn supplies an output to a real-time monitor **72**. Additionally, the scan converter **70** might be connected to a print-out device (not shown). Generally, the operation of the amplifier **68**, scan converter **70**, and monitor **72** will be the same as the corresponding components in FIG. **2** of the Pomerantzeff patent. It should also be noted that, for ease of illustration, the timing and synchronization, scan amplitude and centering, X driver and Y driver blocks have not been shown in FIG. **4**, it being readily understood that these may operate in the same manner as shown and discussed relative to FIG. **2** of the Pomerantzeff patent.

As shown in FIG. **4**, the arrangement may also include a storage means **74** which may store the image of a particular eye alignment (i.e., a combined iris image and retinal image which reveals eye alignment information). The storage means **74** may be a digital memory or any of various known types. Alternately, one could use a videotape recorder (not shown) to store past alignment data, in which case the video tape recorder might be connected directly to the output of amplifier **68**.

Regardless of the type of storage means **74** which is used, it may supply a signal to a past image monitor **76**. The monitor **76** will show a previous eye alignment in accord with the digital memory, video tape, or other type of storage means **74**. Although FIG. **4** shows two separate monitors **72** and **76**, these monitors might simply be separate halves of a cathode ray tube (not separately shown) by use of known splitscreen techniques. In that case, one half of the screen would show the past combined iris/retinal image, whereas the other half of the screen would show the real-time combined iris/retinal image. The two separate monitors **72** and **76** may collectively be considered as a monitor means.

By use of the storage means **74**, one can use the system **12** to determine that the eye **10** is back into a previous orientation. For example, the eye **10** may be in a relatively arbitrary position when the CMS keratograph is first used. When the keratograph is used, one would also use the imaging system **12** to provide a combined iris/retinal image which would be stored within the storage means **74**. A doctor or other person may then perform some therapeutic procedure upon the eye **10**. In order to determine what effect, if any, the therapeutic procedure has had upon the topography of the cornea, one would like to remeasure the cornea. However, in order to have meaningful data, the eye **10** must be oriented the same way it was when the cornea measurements were first made.

Ensuring that the post-therapeutic cornea measurements are made with the eye in the same orientation as the pre-therapeutic measurements, one would first position the eye **10** relative to the imaging system **12** to allow it to image the eye. The imaging system **12** would then provide an iris image of the iris portion of the subject's eye and a retinal image of a retinal portion of the eye. This post-therapeutic combined image is then used to determine objective eye alignment. More specifically, the doctor or other medical professional could move the subject's head, or, more directly, his eye until the real-time monitor **72** shows a combined image which is substantially identical to the combined image of the pre-therapeutic combined image which may be on display in the past image monitor **76**. In order to return the eye **10** to its same alignment as in the past-therapeutic combined image, the person manipulating the eye would ensure that the relative positions of the pupil centroid **46**, fovea **42**, and optical disc **44** (refer back momentarily to FIGS. **3A**, **3B**, and **3C**) are the same as in the pre-therapeutic combined image. To that end, the positioning of the crossings of blood vessels **48C** (again referring to FIGS. **3A**, **3B**, and **3C**) and the blood vessels themselves may be especially helpful in establishing that eye alignment is the same for the post-therapeutic measurement as it was for the pre-therapeutic measurement. Indeed, one might use several features of the blood vessels around the optical disc to return to a previous alignment without necessarily specifically considering the position of the fovea.

In addition to using various known computer vision processing techniques to automatically supply the centroid **46** (FIGS. **3A**, **3B**, and **3C**), one could alternately simply insert the centroid in the image by the operator locating the centroid and inserting it using known technology to insert points or marks on an image.

Upon the past image monitor **76** and the real-time monitor **72** showing that the post-therapeutic eye alignment is the same as the pre-therapeutic eye alignment, one may then turn on the CMS keratograph to provide the cornea measurements. Since the alignment of the eye **10** is the same as it was when the original cornea measurements were made, differences between the cornea measurements before and after the therapeutic procedure can reasonably be said to result from the therapeutic procedure.

As an alternative to having the operator bring the eye **10** into the same alignment for the post-therapeutic measurement as the alignment in the pre-therapeutic measurement, the past combined iris/retinal image may be compared to the real-time combined image and the difference in orientation could be calculated. In that case, the cornea measurements may be made in a post-therapeutic alignment which is different than the pre-therapeutic alignment, but computer software could be used to provide a transformation to convert the post-therapeutic cornea values into corresponding pre-therapeutic values. To take a simple example, if the pre-therapeutic measurement was made with the pupillary axis in line with the instrument axis, and the eye alignment imaging system **12** shows that the post-therapeutic cornea measurements are being made with the pupillary axis still in line with the instrument axis, but with the eye rotated 30° counter-clockwise about the pupillary axis, the post-therapeutic cornea measurements would be transformed by, in effect, rotating the cornea measurements 30° counter-clockwise about the pupillary axis.

In addition to allowing one to determine eye alignment information by comparison of before and after combined iris/retinal images, a single combined iris/-retinal image might be used to determine objective eye alignment in the same fashion as discussed above during the initial explanation of FIG. **3A**. In other words, the relative positioning of the fovea **42**, optical disc **44** and centroid **46** in FIG. **3A** was indicative of the pupillary axis being directed about 7.5° to the left of the alignment instrument axis. Depending upon the degree of accuracy which is required in a particular application, one might assume that the pupillary axis corresponds to the

visual axis such that information about the direction of the pupillary axis could be used to infer what the subject (such as a test animal) was viewing. Since the visual axis does not pass through the centroid of the pupil for all subjects, this assumption that the pupillary axis and visual axis coincide would be an inappropriate assumption under other circumstances.

Upon determining the eye alignment by the relationship between the pupillary axis and the instrument axis (and preferably also including some indication about the rotation of the eye), one could continue to track this eye alignment data with the alignment imaging system **12** of the present invention during a therapeutic procedure upon the eye **10**. Alternately, one could obtain this alignment data and, in effect, transfer the alignment data to an eye tracker. The eye tracker is a known instrument which is simpler than the present invention, but normally yields incomplete or inaccurate alignment data. By using one of several known types of eye trackers to which the alignment data from system **12** has been transferred, the system **12** may be removed from its position whereas it images eye **10** such that the system **12** will be out of the way of any therapeutic instruments which might be used on the person's eye. The eye tracker will provide information based upon a starting point supplied by the system **12**.

The scanner **26** of FIG. **4** may be constructed in any of various generally known ways to provide the desired scan pattern as discussed above. However, with reference now to FIG. **5**, an especially advantageous manner of constructing the scanner **26** will be discussed. The laser light source **56** supplies light to a reflector **78** which reflects the light to a beam expander **80**. An acousto-optic deflector **82** may be used to provide TV rate deflection without moving parts or excessive sound. However, the acousto-optic deflector has a large aperture. As the deflector **82** is a diffraction limited device, the number of resolvable positions is proportional to the aperture in the direction of scan. In order to supply a sufficiently large number of resolvable positions, acousto-optic deflectors have large apertures only in the necessary direction. Accordingly, they require a light beam which is much wider than it is high. Although the necessary beam may be provided with cylindrical mirrors and off-axis parabaloids (not shown) or various other anamorphic schemes, the arrangement of FIG. **5** uses a Brewster telescope having prism chains **84** and **86** which are relatively easy to align and more compact than various other anamorphic schemes. The portion **84** of the Brewster telescope in front of the acousto-optic deflector **82** increases one dimension of the beam from expander **80** by four times, whereas the portion **86** of the Brewster telescope after the deflector **82** returns the beam to the same dimensions as it had when entering the first part of the Brewster telescope. Portion **86** of the Brewster telescope also multiplies the scan angle by four. A moving-mirror galvanometer **88** is used to provide vertical deflection, the mirror being shown just above its actual working position for ease of illustration. The light from the reflector **88** would go to a relay lens **90** and on to the polarizing beam splitter **58**. (Although the relay lens **90** was not shown in FIG. **4**, such a lens would preferably be used between the scanner **26** and polarizing beam splitter **58** of FIG. **4**.)

Although various specific constructions have been included herein, it is to be understood that these are for illustrative purposes only. Various modifications and adaptations will be apparent to those of skill in the art. Accordingly, the scope of the present invention should be determined by reference to the claims appended hereto.

What is claimed is:

1. A method of determining objective eye alignment comprising the steps of:

positioning a subject's eye relative to an imaging system to allow imaging of the subject's eye;

applying a beam to the subject's eye;

using the imaging system to detect a portion of the beam returned after striking the subject's eye and to generate, based on the detected portion of the beam, an iris image of an iris portion of the subject's eye and a retinal image of a retinal portion of the subject's eye; and

observing positions of said iris image and said retinal image to determine objective eye alignment.

2. The method of claim **1** wherein the imaging system obtains the iris image and the retinal image within a time no greater than 50 milliseconds.

3. The method of claim **2** further comprising simultaneously displaying the iris image and the retinal image on a first monitor of the imaging system.

4. The method of claim **1** wherein the eye alignment is determined by comparing the iris image and the retinal image with a stored image of an iris portion and a retinal portion corresponding to eye alignment at a previous time.

5. The method of claim **4** wherein the eye alignment is determined by finding an eye position at which the iris image and the retinal image are substantially identical to the stored image.

6. The method of claim **1** wherein the eye alignment is determined by finding a relationship between an instrument axis of the imaging system and an axis of the patient's eye.

7. The method of claim **6** wherein the axis of the subject's eye is a pupillary axis.

8. The method of claim **1** further comprising the step of simultaneously displaying the iris image and the retinal image, and wherein the imaging system develops the iris image and the retinal image by scanning the beam across the eye and detecting scatter from the application of the beam to the eye.

9. The method of claim **8** wherein the beam is a light beam.

10. A method of determining objective eye alignment comprising the steps of:

scanning a light beam from an imaging system across a subject's eye such that the light beam strikes an iris portion adjacent a pupil and strikes a retinal portion;

detecting, by operation of the imaging system, scattered light from the application of the light beam to the iris portion and the retinal portion;

generating nearly simultaneous views of the iris portion and the retinal portion by operation of the imaging system; and

using said nearly simultaneous views to determine objective eye alignment.

11. The method of claim **10** wherein the light beam is scanned between extremes of scan which cross in front of the subject's eye.

12. The method of claim **11** wherein said extremes of scan cross at least 3 centimeters in front of the subject's eye.

13. The method of claim **10** wherein the light beam has a diameter of no more than 1 millimeter.

14. The method of claim 10 wherein the eye alignment is determined by comparing a real-time image to a stored image representative of eye alignment at a previous time.

15. The method of claim 14 wherein the eye alignment is determined by finding an eye position at which the real-time image is substantially identical to the stored image.

16. The method of claim 10 wherein the eye alignment is determined by finding a relationship between an instrument axis of the imaging system and an axis of the subject's eye.

17. The method of claim 16 wherein the axis of the subject's eye is a pupillary axis.

18. A system for measuring objective eye alignment comprising:

a scanner for scanning a beam across a subject's eye such that the beam strikes an iris portion adjacent a pupil and strikes a retinal portion;

a detector for detecting scatter from the application of the beam to the iris portion and the retinal portion;

a stop having an aperture through which scatter from the application of the beam to the iris portion and the retinal portion passes on its way to said detector; and

a first monitor operatively connected to said detector for showing simultaneous views of the iris portion and the retinal portion based upon the scatter detected by the detector, the simultaneous views providing objective eye alignment information.

19. The system of claim 18 wherein said scanner scans a light beam.

20. The system of claim 18 wherein said scanner scans the beam between extremes of scan which cross in front of the subject's eye.

21. A system for measuring objective eye alignment comprising:

a scanner for scanning a beam across a subject's eye such that the beam strikes an iris portion adjacent a pupil and strikes a retinal portion;

a detector for detecting scatter from the application of the beam to the iris portion and the retinal portion;

a first monitor operatively connected to said detector for showing simultaneous views of the iris portion and the retinal portion based upon the scatter detected by the detector, the simultaneous views providing objective eye alignment information; and a second monitor and storage means to supply the second monitor with a stored image of the iris portion and the retinal portion at a previous time.

22. A system for measuring objective eye alignment comprising:

a scanner for scanning a beam across a subject's eye such that the beam strikes an iris portion adjacent a pupil and strikes a retinal portion;

a detector for detecting scatter from the application of the beam to the iris portion and the retinal portion;

monitor means operatively connected to said detector for showing simultaneous views of the iris portion and the retinal portion based upon the scatter detected by the detector, the simultaneous views providing objective eye alignment information; and

storage means connected to the monitor means for supplying the monitor means with a stored image of the iris portion and the retinal portion at a previous time.

* * * * *

US005191203A

United States Patent [19]

McKinley

[11] Patent Number: 5,191,203

[45] Date of Patent: Mar. 2, 1993

[54] **STEREO VIDEO ENDOSCOPE OBJECTIVE LENS SYSTEM**

[75] Inventor: **Harry P. McKinley**, Southampton, Mass.

[73] Assignee: **McKinley Optics, Inc.**, Southampton, Mass.

[21] Appl. No.: **868,706**

[22] Filed: **Apr. 15, 1992**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 687,330, Apr. 18, 1991, Pat. No. 5,122,650.

[51] **Int. Cl.**[5] **H01J 40/14**

[52] **U.S. Cl.** **250/208.1**; 359/480; 359/652

[58] **Field of Search** 250/208.1, 558; 128/4-7; 358/98; 359/377, 641, 652-654, 480, 481

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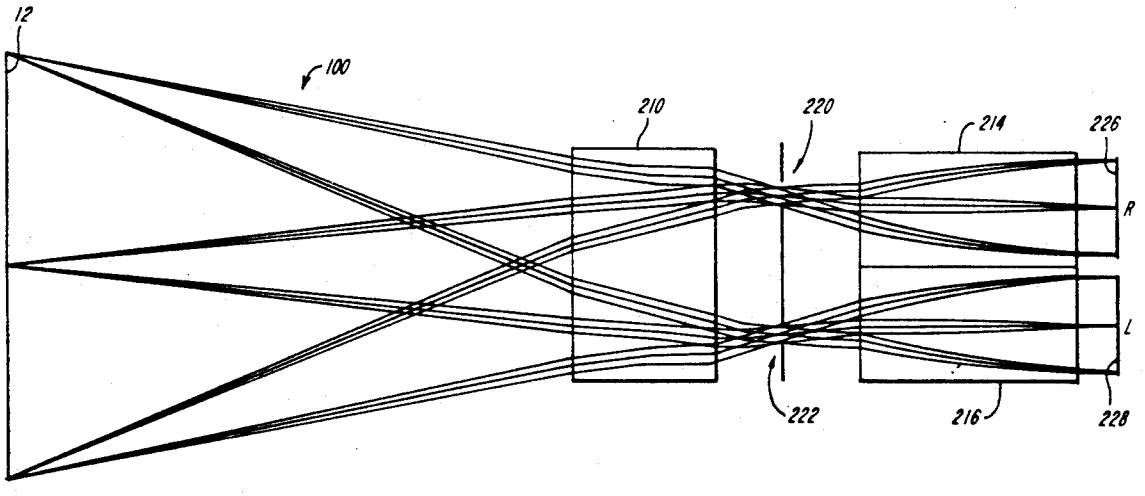
0211783 7/1986 European Pat. Off. .

Primary Examiner—David C. Nelms
Assistant Examiner—Stephone B. Allen
Attorney, Agent, or Firm—Lahive & Cockfield

[57] **ABSTRACT**

A stereoscopic objective lens system for video endoscopes and borescopes includes a full diameter collimator lens systems and a pair of half-diameter stereo lens systems. The lens systems can be formed of doublet lenses or a combination of singlet and doublet lenses, or of gradient index lenses, or of a mixture of such lenses. The full-diameter lens system collimates object points, imaging object points to infinity to present equal-angle pairs from symmetrically disposed object points to the small stereo pair. This equal-angle property enables accurate object/image mapping onto the final stereo image pair, such that all parts of each left/right image can be mapped to within a fraction of a video pixel to each other.

17 Claims, 7 Drawing Sheets



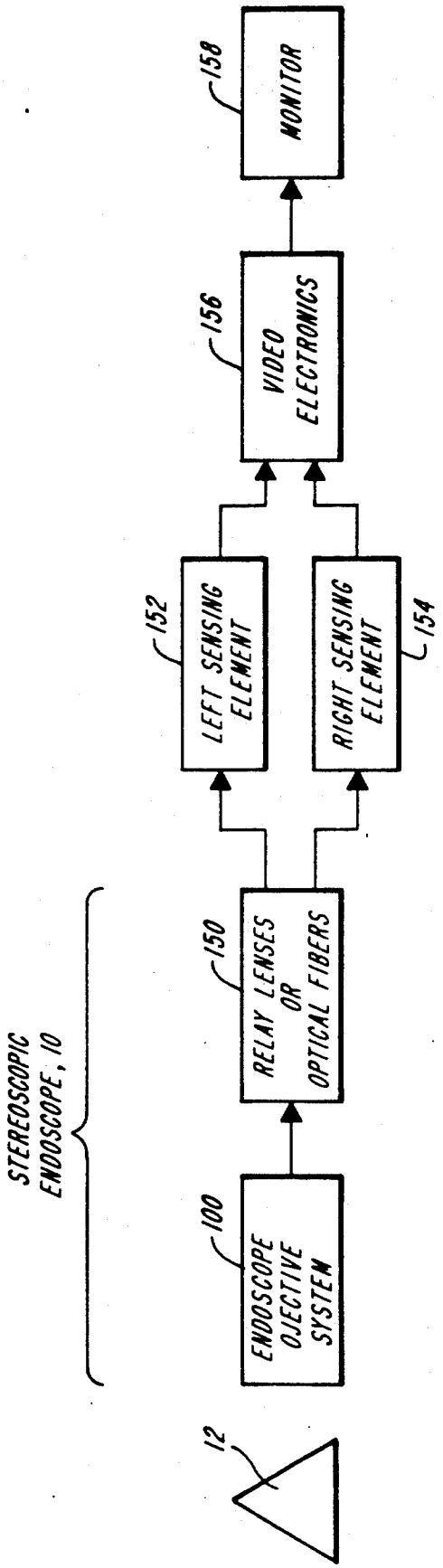

1
12
STEREOSCOPIC ENDOSCOPE, 10
100
ENDOSCOPE OJECTIVE SYSTEM
150
RELAY LENSES OR OPTICAL FIBERS
152
LEFT SENSING ELEMENT
154
RIGHT SENSING ELEMENT
156
VIDEO ELECTRONICS
158
MONITOR

FIG. 1

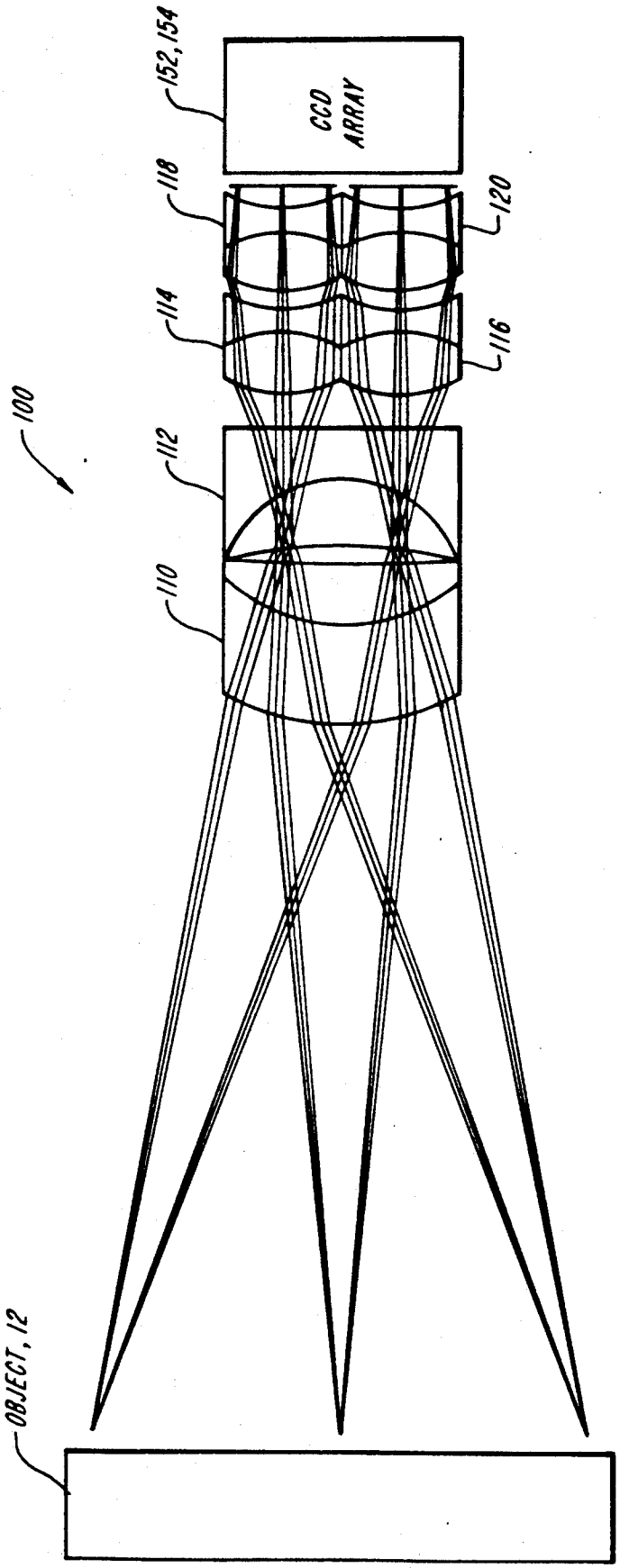


FIG. 2

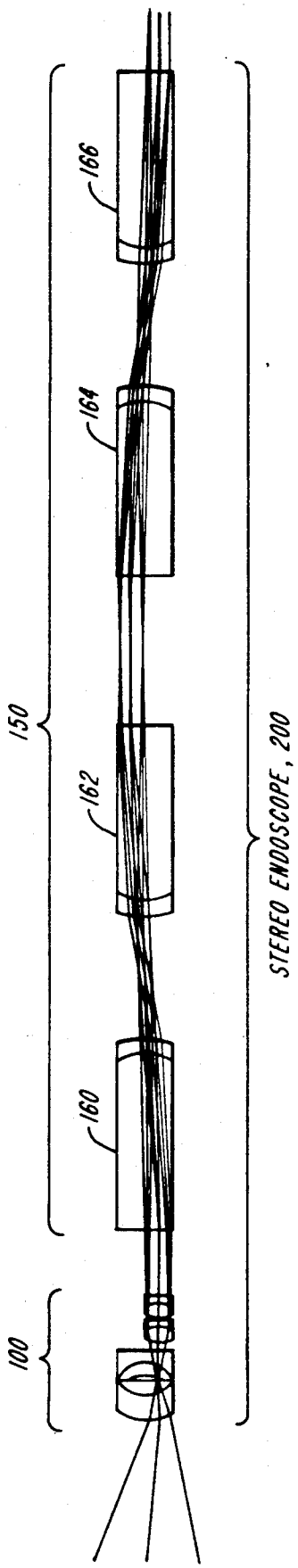


FIG. 3

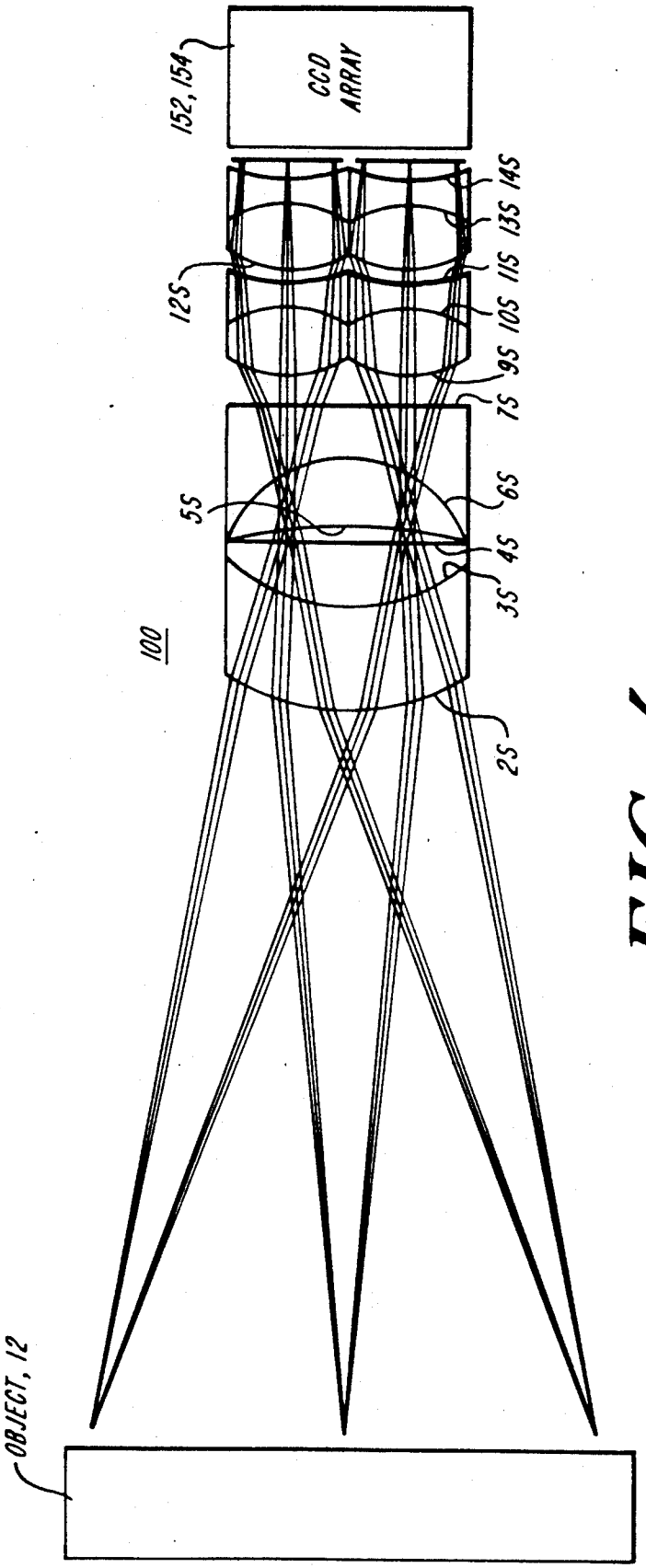

152, 154
CCD ARRAY
14S
13S
11S
10S
9S
7S
6S
5S
4S
3S
2S
12S
100
OBJECT, 12

FIG. 4

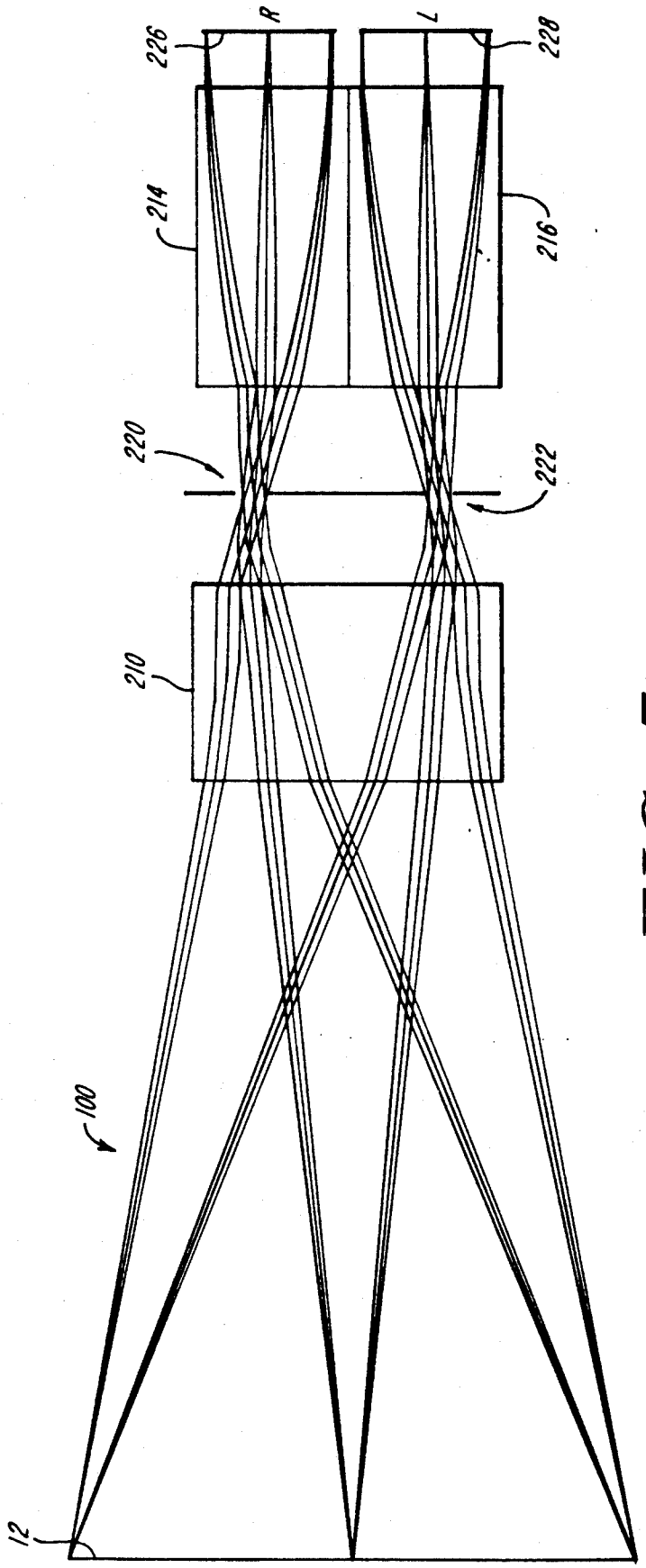


FIG. 5

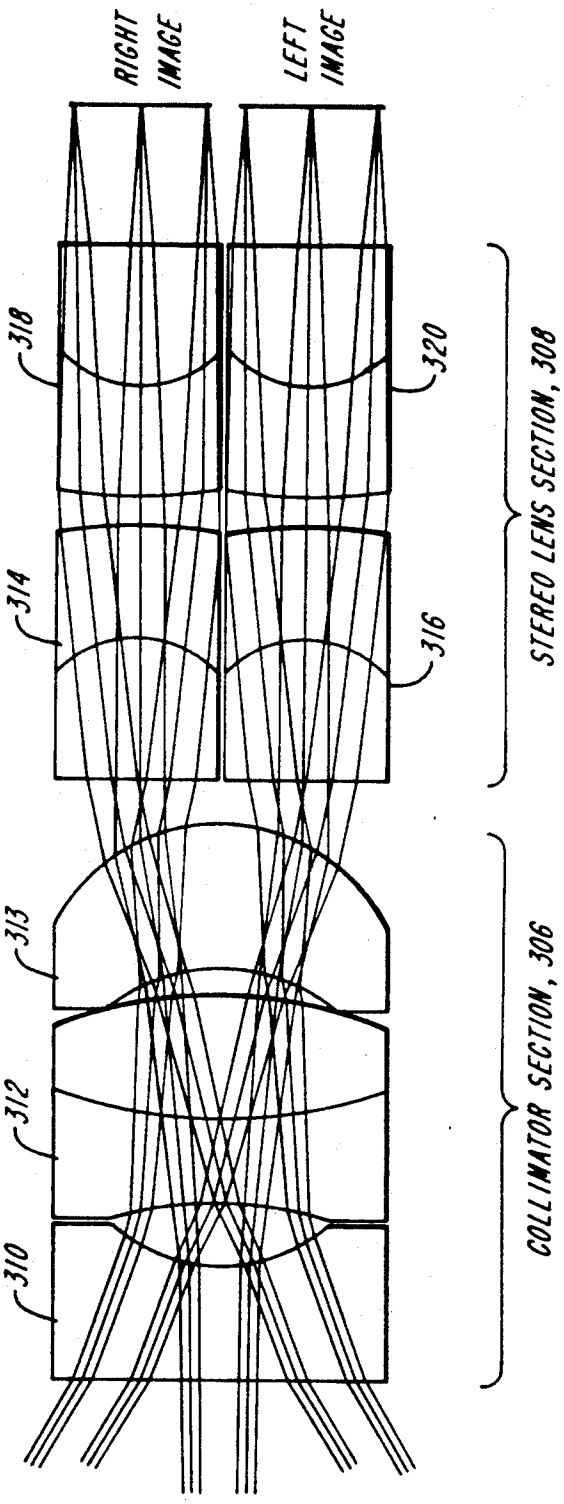

RIGHT IMAGE
LEFT IMAGE
318
320
314
316
313
312
310
STEREO LENS SECTION, 308
COLLIMATOR SECTION, 306

FIG. 6

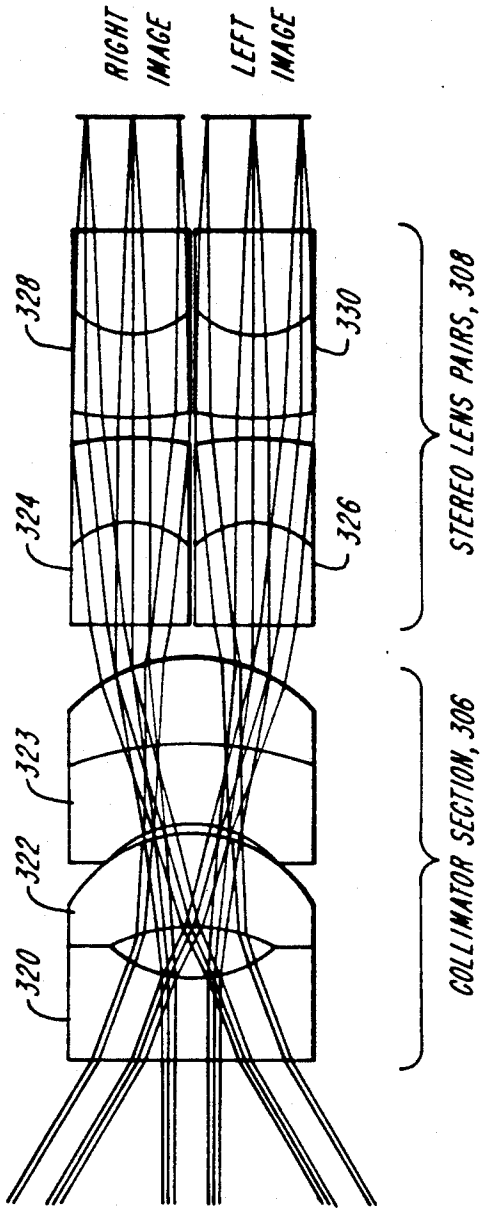

RIGHT IMAGE
LEFT IMAGE
328
330
324
326
323
322
320
STEREO LENS PAIRS, 308
COLLIMATOR SECTION, 306

FIG. 7

STEREO VIDEO ENDOSCOPE OBJECTIVE LENS SYSTEM

BACKGROUND OF THE INVENTION

This application is a Continuation-In-Part of U.S. patent application Ser. No. 687,330 filed Apr. 18, 1991, now U.S. Pat. No. 5,122,650.

This invention relates generally to optical lens systems, and, more particularly, relates to stereoscopic objective lens designs adapted for use in stereo video endoscopes.

Medical endoscopes are widely utilized to view internal regions of the human body during diagnostic, surgical, and other medical procedures. Endoscopes typically include a long, thin, rigid or semi-rigid optical cylinder affixed to a viewing mechanism. The cylinder is sufficiently narrow to be inserted through a small opening in the body, which may be natural or surgical. When the endoscope is inserted and positioned for use, an image of the object being viewed is formed at an inserted end of the endoscope by an objective lens. The image passes through a series of relay lenses down the cylinder to an eye lens or video camera at a viewing end of the endoscope.

In recent years, researchers have attempted to improve the imaging available through endoscopic devices by developing stereoscopic video endoscopes. These endoscopes present an apparently three-dimensional image on a video monitor. The stereoscopic effect is created by producing two optical images—a left image and a right image—through the endoscope. The left and right optical images are presented by the endoscope to left and right image sensors, which may be charge-coupled device (CCD) cameras or other image sensing devices. The sensing devices convert the left and right optical images into left and right video images which are then presented as alternating left-right images on a monitor, at a switching rate higher than the flicker-sensing limit of the human eye, so that observed images appear flicker-free.

The images are alternately switched from a left-hand polarization mode to a right-hand polarization mode, such that, for example, the left image has a left-hand polarization and the right image has a right-hand polarization. In accord with his example, the observer wears polarized glasses in which the left lens has the left-hand polarization and the right lens has the right-hand polarization. Thus, the left eye sees only images from the left channel of the endoscope system and the right eye sees only images from the right channel, resulting in stereoscopic viewing.

The following U.S. and foreign patents disclose examples of stereo endoscopes, some of which utilize video imaging and display elements:

U.S.	4,061,135
U.S.	4,615,332
U.S.	4,651,201
U.S.	4,862,873
U.S.	4,873,572
U.S.	4,895,431
EP	211,783

In particular, U.S. Pat. No. 4,061,135 discloses a binocular endoscope in which images are transmitted from the viewed object to the viewing station through an optical system utilizing a dove prism and mechanical linkage to compensate for rotation effects.

U.S. Pat. No. 4,615,332 discloses a binocular endoscope having flexible light guides and binocular eyepieces.

U.S. Pat. No. 4,651,201 discloses a stereoscopic video endoscope including two image guides and an illumination light guide. The image guides are optically coupled to a stereoscopic viewer for three dimensional viewing. The viewer includes couplings for attaching miniature video cameras that can be connected to a head-mounted stereoscopic video display.

U.S. Pat. No. 4,862,873 discloses a stereo endoscope having two light guides for carrying images of an object to an electro-optical imaging assembly. A lens system directs light from the object to the objective end of the light guides. Illuminating light is transmitted to the object from the opposite end of one light guide, thereby illuminating the object. Simultaneously, the image transmitted through the other optical guide is conducted to the imaging assembly.

U.S. Pat. No. 4,873,572 discloses a stereo endoscope having a CCD camera module and two image-forming lens systems that form two object images. The object images are integrated and directed to the CCD camera to provide a stereoscopic output. The lens systems include red, green, and blue color filters disposed at the camera imaging surface.

U.S. Pat. No. 4,895,431 discloses an endoscope apparatus that generates a three-dimensional image of an object from overlapping images recorded by a camera. The endoscope includes an insertion module and a movable end section capable of being deflected through an angle. A first image is recorded with the end section positioned at a first angle. A second image, partially overlapping the first image, is recorded after moving the end section to a second angle. The relative position of the movable end section is detected by an encoder that generates position signals for input to a microprocessor, which utilizes the position signals to generate a three-dimensional image of the object.

European Patent No. 211,783 discloses a stereo video endoscope in which two light pipes deliver two images of the same object. These images are presented by a binocular device to the user's eyes to show a three dimensional image of the target. The apparatus includes two television cameras and video recorders for recording the images. The recorded images can be displayed on separate screens and viewed by a binocular viewing system.

Most conventional stereo endoscopes, however, share a number of deficiencies associated with their objective lens systems. These problems include a bulky and unwieldy configuration; high cost and complexity of fabricating the objective lens system; and the mediocre optical performance afforded by conventional objective lens systems.

An additional problem associated with conventional stereo video endoscope objectives involves the requirement that all portions of each left/right image be mapped to within a fraction of a video pixel to each other. This pixel mapping condition is a significant optical design constraint, because the object-to-image ray paths through the lens system are quite different for the left and right image points associated with a common object point.

Accordingly, it is a general object of the present invention to provide improved stereo endoscope objec-

tive lens systems that overcome the problems associated with conventional designs.

A more specific object is to provide an improved stereo endoscope objective lens system having optical elements that facilitate assembly of the system.

It is another object of the invention to provide an improved stereo endoscope objective lens system having elements that are substantially less expensive to manufacture than the elements of conventional systems.

A further object is to provide an improved stereo endoscope objective lens system having optical performance characteristics that are substantially superior to the performance characteristics of conventional systems.

Another object of the invention is to provide a stereo objective lens system affording a pixel mapped image.

The above and other objects and advantages of this invention will become more readily apparent when the following description is read in conjunction with the accompanying drawings.

SUMMARY OF THE INVENTION

The foregoing objects are attained by the invention, which provides an improved stereo endoscope objective lens system for video imaging in medical endoscopes and industrial borescopes.

One aspect of the invention includes two full-diameter doublets and a double set of two half-diameter identical doublets. The full-diameter doublets substantially collimate object points, i.e., image them substantially to infinity.

In accord with this aspect of the invention, most of the optical power necessary to accomplish this collimation is provided by in the first or outer doublet, while the second collimator doublet is of low power.

In a further aspect of the invention, the smaller doublets are identical, so that they can be most economically fabricated in production quantities. This is advantageous because these small lenses are inherently difficult to manufacture.

In another aspect of the invention, the large collimator lens system presents equal-angle pairs from symmetrically disposed object points to the small stereo lens systems. This equal-angle solution provides accurate object/image mapping onto the final stereo image pair. In this design, the larger, and hence easier to fabricate, collimator lens system carries the corrective burden, so that the smaller, more difficult to manufacture lenses can be made as simple as possible.

In still another aspect of the invention the collimator lens system may be formed of a combination of singlet and doublet lenses.

In another embodiment gradient index (GRIN) lenses can be substituted for either the collimator doublets or the stereo doublet pairs or both. These lenses are more economical to fabricate and can be constructed to produce the same ray bending and hence the same optical output as the doublet lenses.

The invention will next be described in connection with certain illustrated embodiments; however, it should be clear to those skilled in the art that various modifications, additions and subtractions can be made without departing from the spirit or scope of the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

For a fuller understanding of the nature and objects of the invention, reference should be made to the following detailed description and the accompanying drawings, in which:

FIG. **1** is a schematic diagram depicting a stereo video endoscope utilizing an objective lens system constructed in accordance with the invention;

FIG. **2** is an optical schematic diagram depicting an objective lens system constructed in accordance with the invention, showing light rays transmitted through the system;

FIG. **3** is an optical schematic diagram depicting the objective lens system of FIG. **2** in combination with relay lenses for transmitting the optical images;

FIG. **4** is an optical schematic diagram of the objective lens system of FIG. **2** illustrating the location of the surfaces specified in Table A; and

FIG. **5** is a optical diagram of the objective lens system of FIG. **2** incorporating gradient index lenses in place of the doublet lenses.

FIG. **6** and **7** are optical schematic diagrams depicting an objective lens system constructed in accordance with the invention wherein the collimating lens system is formed of a combination of singlet and doublet lenses.

DESCRIPTION OF ILLUSTRATED EMBODIMENTS

FIG. **1** depicts the invention, an endoscope objective system **100**, utilized in a stereo video endoscopy system **1** for generating stereoscopic images of an object **12**. The system **1** includes a stereoscopic endoscope **10** containing objective system **100**; sensing modules **152**, **154**; switching module **156**; and a monitor **158**. In addition to objective lens system **100**, the endoscope **10** includes conventional relay lenses or optical fibers **150** for transmitting light collected by the endoscope objective system **100** to light sensing modules **152**, **154**.

The endoscope objective system **100** generates left and right optical images of the object **12** that are processed by sensing elements **152**, **154** and video switching module **156** in a known manner to display an apparently three-dimensional image of the object **12** on video monitor **158**.

The stereoscopic effect is created by producing two optical images—a left image and a right image—through the endoscope objective system **100**. The left and right optical images generated by the objective system **100** are presented by the relay lens or optical fiber system **150** to left and right image sensors **152**, **154**, which can be conventional charge-coupled device (CCD) cameras or other image sensing devices. The CCD elements operate in a known manner to convert the light collected by the objective system **100**, and transmitted by the relay lenses or optical fibers **150**, into electrical signals representative of the left and right optical images of the object **12**.

Conventional video switching circuitry **156** transmits the electronic signals representative of left and right video images as alternating left-right images on the monitor **158**. In accord with known video practice, these alternating images are presented at a switching rate higher than the flicker-sensing limit of the human eye, so that observed images appear flicker-free.

Moreover, the images can be alternately switched from a left-hand polarization mode to a right-hand polarization mode, such that, for example, the left image has a left-hand polarization and the right image has a right-hand polarization. The observer wears polarized glasses in which the left lens has the left-hand polarization and the right lens has the right-hand polarization.

Thus, when the observer views the monitor **158**, the left eye sees only images from the left channel of the endoscope system and the right eye sees only images from the right channel, resulting in stereoscopic viewing. Video switching and display equipment of this type is commercially available from Stereographics, Inc. of San Rafael, Calif.; and from Tektronix Corp., of Beaverton, Oreg.

The accuracy and quality of the image displayed on monitor **158** is controlled by the performance of the endoscope objective system **100**, which is the subject of the present invention. FIGS. **2** and **3** depict an objective lens system **100** constructed in accordance with the invention, showing light rays transmitted through the system. FIGS. **2** and **3** depict the same system, with two elements being omitted from FIG. **3** for purposes of clarity.

As indicated in FIG. **2**, one embodiment of the objective system **100** includes two full-diameter doublets **110**, **112** and a double set of two half-diameter identical doublets **114**, **116**, **118**, **120**. The full-diameter doublets collimate object points, i.e., image them to infinity. In accordance with the invention, most of the optical power required to accomplish this collimation is provided by the first collimator doublet **110** closest to the object **12**, while the second collimator doublet **112** can have a very low optical power.

Those skilled in the art will appreciate that the lenses of the objective system **100** depicted in FIG. **2** define a sequence of sixteen optical surfaces. A working example of a set of lenses for objective system **100** is set forth below in Table A.

TABLE A

SURFACE	RADIUS	THICKNESS	APERTURE	GLASS
1	—	−4.002608	0.225000	AIR
2	6.211875	2.500000	3.000000	SK5
3	4.462623	1.500000	3.000000	SF8
4	53.596342	0.400000	3.000000	AIR
5	−11.075366	1.600000	2.500000	SK5
6	−3.318618	1.500000	3.000000	SF8
7	−31.896589	−1.200000	2.500000	AIR
8	—	1.900000	0.464074	AIR
9	2.747539	1.600000	1.500000	SSKN8
10	−3.153676	0.700000	1.500000	SF1
11	4.815753	0.250000	1.500000	AIR
12	2.747539	1.600000	1.500000	SF1
13	−3.153676	0.700000	1.500000	SSKN8
14	4.815753	0.400000	1.500000	AIR
15	—	0.001000	1.400000	BK7
16	—	—	1.400000	AIR

In Table A, the numerical value in the "RADIUS" and "THICKNESS" columns are set forth in millimeters. The "GLASS" descriptions are standard optical glass characterizations as found in the product catalog of the Schott Glass Company of the Federal Republic of Germany. The "THICKNESS" column refers to the distance to the next optical surface. For example, in connection with surface **3**, the number 1.5000 signifies 1.5 millimeters to surface **4**. The column "RADIUS" refers to the radii of curvature of the respective curved surfaces. In this working example, the lens diameters are 6 millimeters for the large doublets and 3 millimeters for the small doublets. The 14 overall object-to-image distance is 28.3 millimeters. The image diameter is 2.5 millimeters.

In Table A, the surfaces correspond to the labeled surfaces in FIG. **4**. The surfaces in the table identified as **1**, **8**, **15** and **16** do not correspond to actual surfaces, but are artifacts introduced by the specific program employed to generate this table. For clarity the numbered surfaces from table A are designated with an S following the numeral, for example, the surface designated 2S in FIG. **4** corresponds to the surface **2** in table A.

The system **100** is designed so that all parts of each left/right image are mapped to within a selected distance of each other such that stereoscopic image quality is maintained. For video applications, this selected distance is typically a fraction of a video pixel. This is a difficult condition to satisfy, because the object-to-image ray paths through the lens system are quite different for the left and right image points of a common object point. FIG. **2** clearly illustrates this path difference. The ray paths shown in FIG. **2** demonstrate how differently an object point is imaged through the lens elements for the left and right images.

The objective system **100** depicted in FIG. **2** is able to map all parts of each left/right image to within a fraction of a video pixel to each other, because the large collimator doublets present equal-angle pairs from symmetrically disposed object points to the small stereo doublet pairs.

This exact equal-angle solution results in an accurate object/image mapping onto the final stereo image pair. Accuracy is also enhanced by the combination of a first high power collimator doublet **110** and a second, lower power collimator doublet **112**. This second doublet **112** strongly influences the optical solution to the image-mapping problem.

A further advantage is provided in that the smaller doublets **114**, **116**, **118**, and **120** are identical, so that they can be most economically fabricated in production quantities. This characteristic tends to offset the inherent difficulty of manufacturing small lenses. The larger, and hence easier to fabricate, doublets carry the corrective burden, so that the smaller, more difficult to manufacture lenses can be as simple as possible.

FIG. **5** illustrates an objective system **100** where the lens systems are formed of gradient index lenses (GRINS) in place of the doublet lenses. These lenses can be manufactured to duplicate the optical performance of the doublet lenses. In FIG. **5** a full diameter GRIN collimator lens **210** performs the collimator function and a matched pair of GRIN one half diameter stereo lenses **214** an **216** complete the objective lens assembly. The pair of stereo lenses produce left and right images **226** and **228** on the image plane. (A pair of aperture stops **220** and **222** may be employed to define the pupils.)

Of course aperture stops may be placed at other locations in the objective lens system according to the purposes of the designer.

FIGS. **6** and **7** illustrate objective lens systems in which the collimator lens system is formed of a combination of singlet and doublet lenses. The embodiment of the objective system **100** illustrated in FIG. **6** includes in the collimator lens system **306** a singlet lens **310** coupled to a doublet lens **312**, coupled to another singlet lens **313**. The stereo lens pair system **308** is formed as in FIG. **2** by a pair of doublet lenses **314** ad **316** coupled to a second pair of doublet lenses **316** and **320**. The full diameter lens system collimates object points. The critical requirement is that the collimator system present equal angle pairs from symmetrically disposed object points to the small stereo lens pairs. This can be accomplished with a doublet lens system as illustrated in FIG. **2**, a GRIN lens system as illustrated in FIG. **5**, combina-

tions of singlets and doublets as illustrated in FIGS. **6** or **7**, triplet lenses or combinations of the above. Of course, the stereo lens system can be formed of GRIN lenses also, as well as combinations of singlets, doublets, and triplets as above.

A working example of a set of lenses for implementation of the objective lens system **100** illustrated in FIG. **6** is set forth in Table B. As in Table A, the numerical value in the radius and thickness columns are in millimeters. The "GLASS" descriptions are standard optical glass characterizations as found in the product catalog of the Schott Glass Company of the Federal Republic of Germany. The "THICKNESS" column refers to the distance to the next optical surface. For example, in connection with surface **3**, the number 1.5000 signifies 1.5 millimeters to surface **4**. The column "RADIUS" refers to the radii of curvature of the respective curved surfaces.

In Table B lens surfaces **1**, **2**, **9**, **16** and **17** do not correspond to actual lens surfaces.

TABLE B

STEREO OBJECTIVE, TYPE 3

SRF	RADIUS	THICK-NESS	APERTURE	GLASS	SPE
1	—	−3.222728	0.180000A	AIR	
2	—	2.000000	3.000000	SIO2	C
3	3.000000	1.130000	2.000000	AIR	
4	−6.917339	1.500000	2.000000	SF1	
5	9.000000	2.200000	3.000000	LAKN12	
6	−8.000000	0.505000	3.000000	AIR	
7	−3.200000	2.500000	2.100000	F4	
8	−3.422239	−1.400000	3.000000	AIR	
9	—	2.200000	1.000000	AIR	
10	44.701000	2.500000	1.500000	LAK8	
11	−2.100000	2.000000	1.500000	SF1	
12	−8.920000	0.500000	1.500000	AIR	
13	8.920000	2.000000	1.500000	SF1	
14	2.100000	2.500000	1.500000	LAK8	
15	−44.701000	2.395144	1.500000	AIR	
16	—	0.001000	1.250000	BK7	
17	—	—	1.250000	AIR	

FIG. **7** illustrates another collimator lens combination **306**, employing a sequence of two singlet lenses **320** and **322** followed by doublet lenses **323**. The physical characteristics for this sequence are set forth in Table C.

Table C is a working example of the objective lens system illustrated in FIG. **7**.

In Table C lens surfaces **1**, **2**, **9**, **16** and **17** do not correspond to physical lens surfaces.

TABLE C

STEREO VIDEO SYSTEM

SRF	RADIUS	THICK-NESS	APERTURE	GLASS	SPE
1	—	−3.095070	0.160000A	AIR	
2	—	2.000000	3.000000	SIO2	C
3	3.000000	1.245000	2.000000	AIR	
4	−4.400000	2.200000	2.000000	F4	
5	−3.522702	0.244000	3.000000	AIR	
6	−2.856443	2.000000	2.100000	LAKN12	
7	−9.000000	2.000000	3.000000	SF1	
8	−4.387343	−1.400000	3.000000	AIR	
9	—	2.200000	1.000000	AIR	
10	44.701000	2.500000	1.500000	LAK8	
11	−2.100000	2.000000	1.500000	SF1	
12	−8.920000	0.500000	1.500000	AIR	
13	8.920000	2.000000	1.500000	SF1	
14	2.100000	2.500000	1.500000	LAK8	
15	−44.701000	2.669074	1.500000	AIR	
16	—	0.001000	1.250000	BK7	
17	—	—	1.250000	AIR	

As indicated in FIG. **1**, the endoscope objective system **100** can be utilized in connection with optical fiber elements or a set of relay lenses **150** to conduct light from the objective system to the sensing element **152**, **154**. An example of the relay lens system **150** that can be employed with the objective system **100** is depicted in FIG. **3**.

The relay lens system of FIG. **3** includes a plurality of rod relays **160**, **162**, **164** utilized in combination with objective system **100**. Those skilled in the art will recognize that a wide range of relay lens systems can be employed with an objective system constructed in accordance with the invention.

Alternatively, an endoscope constructed in accordance with the invention can employ a conventional CCD array mounted within the same housing as the objective system. As indicated in FIG. **2**, the CCD array can include left and right sensing elements **152**, **154**, disposed to receive the optical images generated at the output of doublets **118** and **120**. The design and construction of CCD elements having more than one photosensitive region in a monolithic package is well known in the art. The electrical signals generated by the CCD array can be conducted from the housing by a conventional conduit. This configuration eliminates the requirement for a relay lens system or optical fibers.

The system **100** depicted in FIGS. **2** and **3** offers advantages for use in medical endoscopes and industrial borescopes. The configuration offers the advantage of being adaptable to fit into a small tube diameter, as small as 3 millimeters. The design also affords high resolution and low distortion for diagnostic and surgical use, and for high-accuracy industrial measurement applications.

It will thus be seen that the invention efficiently attains the objects set forth above, among those made apparent from the preceding description.

It will be understood that changes may be made in the above construction and in the foregoing sequences of operation without departing from the scope of the invention. It is accordingly intended that all matter contained in the above description or shown in the accompanying drawings be interpreted as illustrative rather than in a limiting sense.

It is also to be understood that the following claims are intended to cover all of the generic and specific features of the invention as described herein, and all statements of the scope of the invention which, as a matter of language, might be said to fall therebetween.

Having described the invention, what is claimed as new and secured by Letters Patent is:

1. A stereoscopic objective lens system for a stereo video endoscope, the objective lens system converting optical images of an object generated at an objective end of the objective system to pixel-mapped left and right optical images at an image plane end of the objective system, the objective lens system comprising,

A. a gradient index collimator lens element proximate the objective end for collecting light from points on the object,

said gradient index lens having a first optical axis, a selected diameter and a selected optical power,

wherein said gradient index lens images the object points substantially to infinity so that light transmitted by the gradient index lens from the object points is substantially collimated,

B. a right/left pair of stereo gradient index lenses situated adjacent said gradient index collimator

lens for collecting light from said gradient index collimator lens,

said first right/left pair of stereo gradient index lenses including,

a right gradient lens and

a left gradient lens,

the optical axis of said right stereo lens and the optical axis of said left stereo lens being substantially parallel to the optical axis of collimator lens,

wherein said collimator lens and said right/left pair of stereo lenses cooperate so that the collimator lens presents equal-angle light ray pairs from symmetrically disposed object points to the right/left pair of stereo lenses, and

said right stereo lens collects light from said collimator lens to generate a right image at the image plane,

said left stereo lens collects light from said collimator lens to generate a left image at the image plane, such that corresponding portions of each left/right image are mapped to within a selected distance of each other.

2. A lens system according to claim 1, wherein said right stereo lens and said left stereo lens, are substantially identical.

3. A lens system according to claim 1 wherein the diameter of said right stereo lens and said left stereo lens, are approximately one-half the diameter of said collimator lens.

4. Stereoscopic endoscope apparatus for displaying stereoscopic images of an object, the apparatus comprising

A. a stereoscopic objective lens system,

the objective lens system converting optical images of the object generated at an objective end of the objective system to pixel-mapped left and right optical images at an image plane end of the objective system,

the objective lens system including,

(i) a collimator lens system proximate the objective end for collecting light from points on the object,

said collimator lens system having a defined optical axis, a selected diameter and a selected optical power, such that said collimator lens system images the object points substantially to infinity so that light transmitted by said collimator lens system from the object points is substantially collimated,

(ii) a right/left pair of stereo lens systems situated adjacent said collimator lens system for collecting light from said collimator lens system, said right-/left pair of stereo lens systems including,

a right stereo lens system having a defined optical axis and a selected diameter,

a left stereo lens system having a defined optical axis and a selected diameter equal to the diameter of said right stereo lens system,

the optical axis of said right lens system and the optical axis of said left lens system being substantially parallel to the defined optical axis of said collimator lens system,

wherein said collimator lens system and said right-/left pair of stereo lens systems cooperate so that the collimator lens system presents equal-angle light ray pairs from symmetrically disposed object points to said right/left pair of stereo lens systems.

5. An apparatus in accordance with claim 4 wherein at least one of said collimator lens systems or said right-/left pair of stereo lens systems are formed of gradient index lenses and corresponding portions of each left/-right image are mapped to within a selected distance of each other, and wherein at least one of said collimator lens systems or said right/left pair of stereo lens systems are formed of gradient index lenses.

6. An apparatus in accordance with either of claims 4 or 5 wherein the diameter of each of said left and right stereo lens systems is substantially one half the diameter of said collimator lens system.

7. An apparatus in accordance with claim 4 and further including right and left optical sensing means, situated at right and left regions of the image plane, respectively, for converting said right and left optical images to electrical signals representative of right and left video signals in response to said right and left optical images, respectively.

8. An apparatus in accordance with claim 5 and further including right and left optical sensing means, situated at right and left regions of the image plane, respectively, for converting said right and left optical images to electrical signals representative of right and left video signals in response to said right and left optical images, respectively.

9. Apparatus in accordance with either of claims 4 or 5 having aperture stops between said collimator and said right/left pair of stereo lens systems.

10. Apparatus according to either of claims 7 or 8, further comprising video monitor means, in electrical communication with said first and second optical sensing means, for displaying right and left video images in response to said electrical signals generated by the first and second optical sensing means.

11. Apparatus according to claim 7 wherein said right and left optical sensing means include at least one CCD element.

12. Apparatus according to claim 8 wherein said right and left optical sensing means include at least one CCD element.

13. Apparatus according to claim 11 wherein said objective lens system is contained within a housing, and said at least one CCD element is disposed within said housing in proximity to said objective lens system so that optical images generated by said objective lens system are transmitted to said at least one CCD element.

14. A stereoscopic endoscope apparatus in accordance with claim 4 wherein said collimator lens system comprises

A. a first collimator doublet lens element proximate the objective end for collecting light from points on the object,

said first doublet lens having a first optical axis, a selected diameter and a selected optical power,

B. A second collimator doublet lens for collecting light from said first collimator doublet lens,

said second collimator doublet lens being situated adjacent said first collimator doublet lens, so that the optical axis of said second collimator doublet lens is substantially collinear with the optical axis of the first collimator double lens,

said second collimator doublet lens having a selected diameter and a selected optical power,

wherein said first and second collimator doublet lenses cooperate to image the object points substantially to infinity so that light transmitted by the second collimator doublet lens from the object points is substantially collimated.

15. A stereoscopic apparatus in accordance with claim 4, wherein said collimator lens system comprises a gradient index lens providing substantially the same optical output as a doublet lens in imaging the object points substantially to infinity.

16. A stereoscopic apparatus in accordance with claim 4 wherein said collimator lens system comprises,

a first collimator singlet lens proximate the objective end for collecting light from points on the object,

a first collimator doublet lens for collecting light from said first collimator singlet lens, and

a second collimator singlet lens proximate to said first collimator doublet lens for collecting light from said first collimator doublet lens,

said collimator singlet lenses and said collimator doublet lens all having colinear optical axes and wherein said first and second collimator singlet lenses and said first collimator doublet lens cooperate to image the object points substantially to infinity.

17. A stereoscopic apparatus in accordance with claim 4 wherein said collimator lens system comprises,

a first collimator singlet lens proximate the objective end for collecting light from points on the objective,

a second collimator singlet lens for collecting light from said first collimator singlet lens, and

a first collimator doublet lens proximate said second collimator singlet lens for collecting light from said second collimator singlet lens, wherein said first and second collimator singlet lenses and said first collimator doublet lens cooperate to image the object points substantially to infinity.

* * * * *

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United States Patent [19]

Takayama et al.

[11] Patent Number: 5,175,650

[45] Date of Patent: Dec. 29, 1992

[54] **OBJECTIVE LENS SYSTEM FOR ENDOSCOPES**

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[73] Assignee: **Olympus Optical Co., Ltd.,** Tokyo, Japan

[21] Appl. No.: **520,501**

[22] Filed: **May 8, 1990**

[30] **Foreign Application Priority Data**

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Feb. 2, 1990 [JP] Japan 2-22222

[51] **Int. Cl.**[5] **G02B 13/18;** G02B 5/20
[52] **U.S. Cl.** **359/716;** 359/644; 359/645; 359/663; 359/714; 359/715; 359/723
[58] **Field of Search** 350/432, 410, 450, 415, 350/439; 359/716, 644, 715, 663, 645, 723, 714

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Primary Examiner—Scott J. Sugarman
Attorney, Agent, or Firm—Cushman, Darby & Cushman

[57] **ABSTRACT**

An objective optical system for endoscopes comprising, in the order from the object side, a front negative lens unit, an aperture stop, a positive lens unit comprising at least one positive lens component, and an infrared cut filter arranged immediately before said aperture stop, said objective optical system being adapted so as to allow rays to be incident on said filter at heights lower than the outside circumference of said filter.

13 Claims, 19 Drawing Sheets

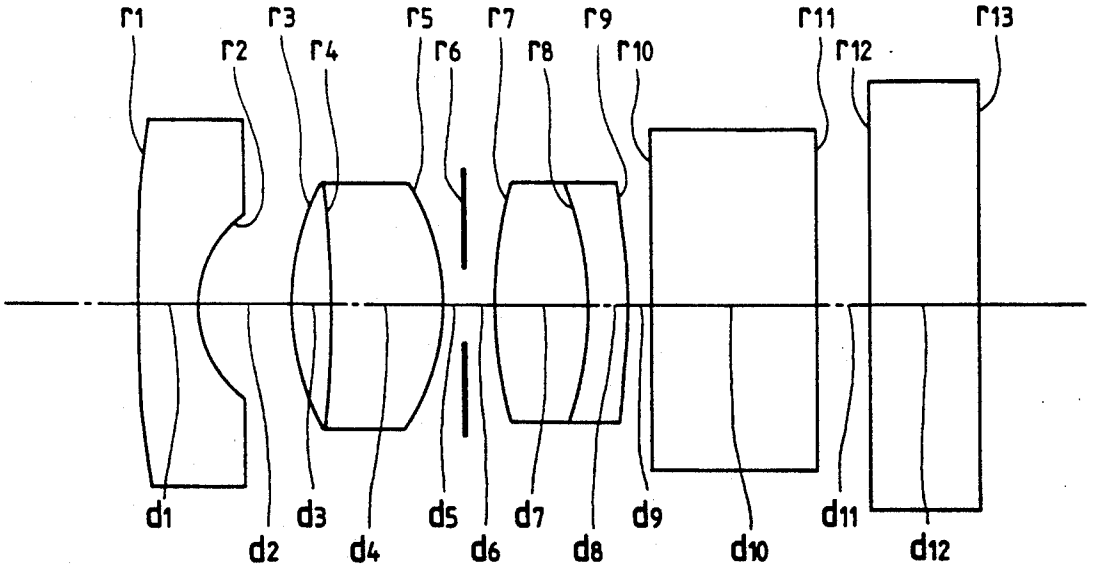


FIG. 1
PRIOR ART

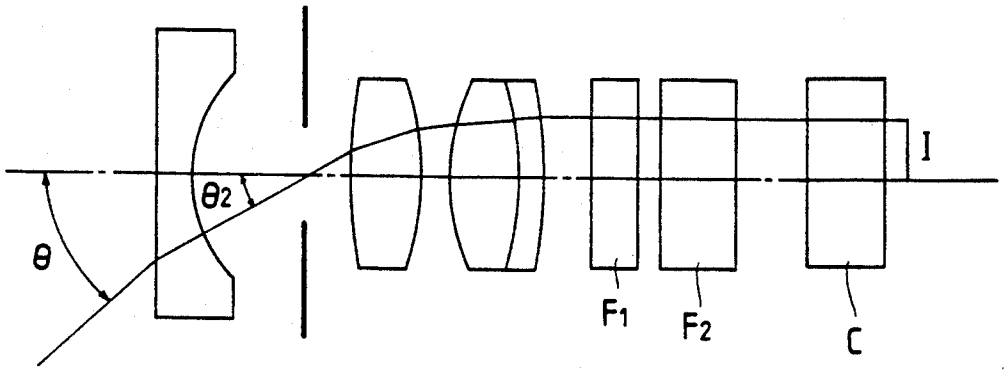


FIG. 2

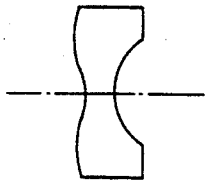


FIG. 3

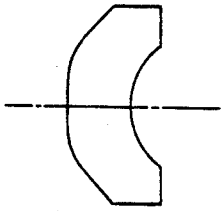


FIG. 4

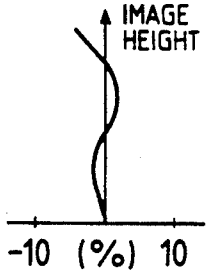


FIG. 5

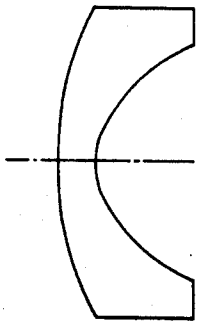


FIG. 6

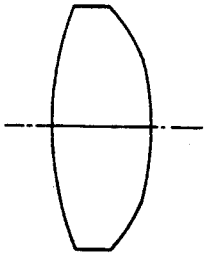


FIG. 7

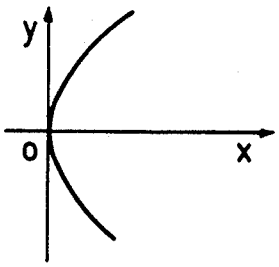


FIG. 8

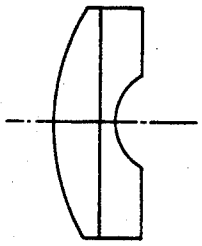


FIG. 9

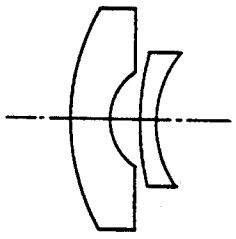


FIG. 10

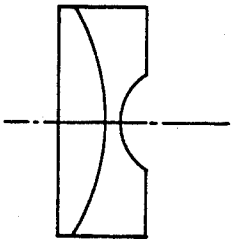
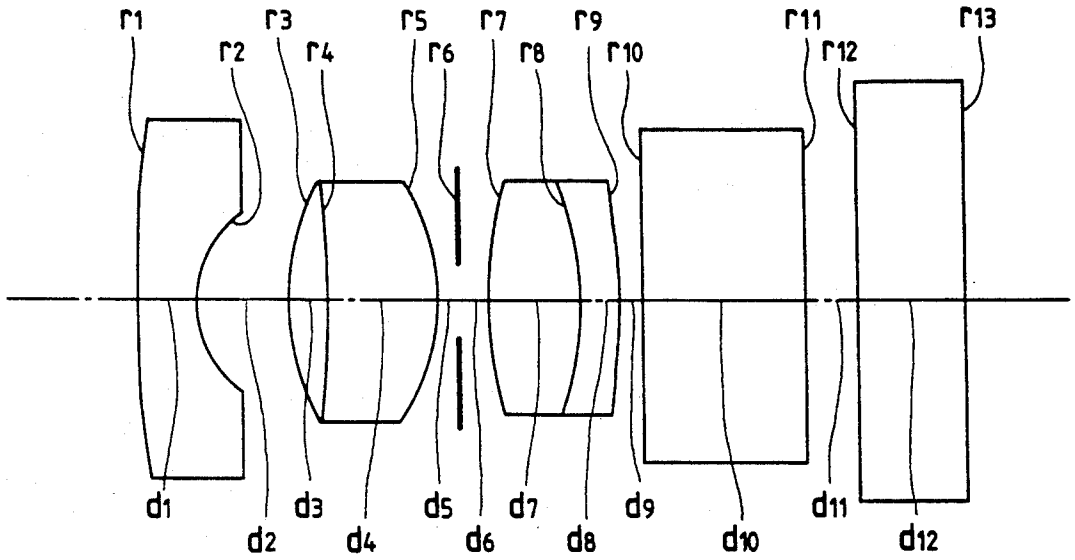


FIG. 11


r1
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r12
r13
d1
d2
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d4
d5
d6
d7
d8
d9
d10
d11
d12

FIG. 12

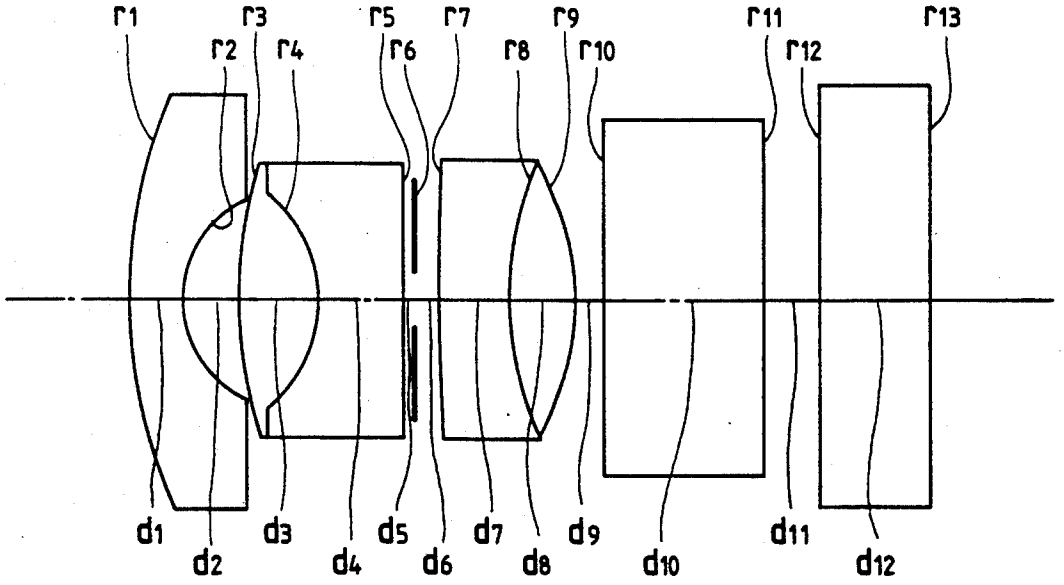

r1
r2
r3
r4
r5
r6
r7
r8
r9
r10
r11
r12
r13
d1
d2
d3
d4
d5
d6
d7
d8
d9
d10
d11
d12

FIG. 13

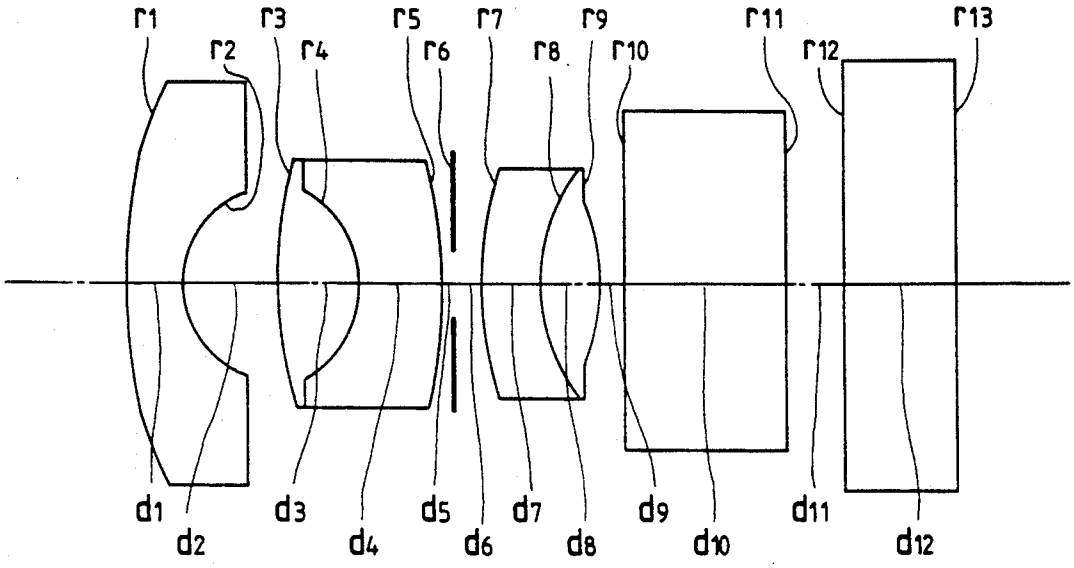

r1
r2
r3
r4
r5
r6
r7
r8
r9
r10
r11
r12
r13
d1
d2
d3
d4
d5
d6
d7
d8
d9
d10
d11
d12

FIG. 14

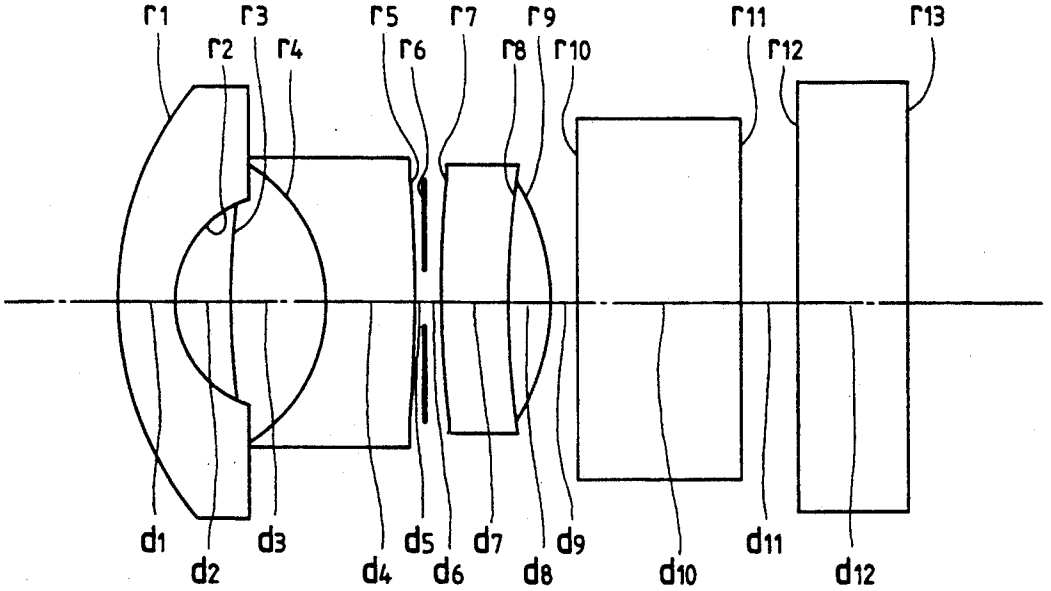

r1
r2
r3
r4
r5
r6
r7
r8
r9
r10
r11
r12
r13
d1
d2
d3
d4
d5
d6
d7
d8
d9
d10
d11
d12

FIG. 15

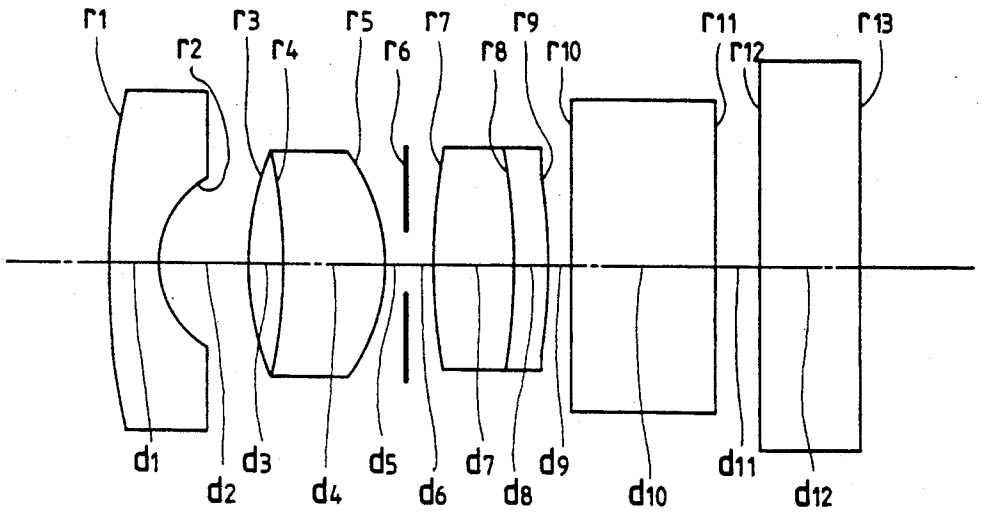

r1
r2
r3
r4
r5
r6
r7
r8
r9
r10
r11
r12
r13
d1
d2
d3
d4
d5
d6
d7
d8
d9
d10
d11
d12

FIG. 16

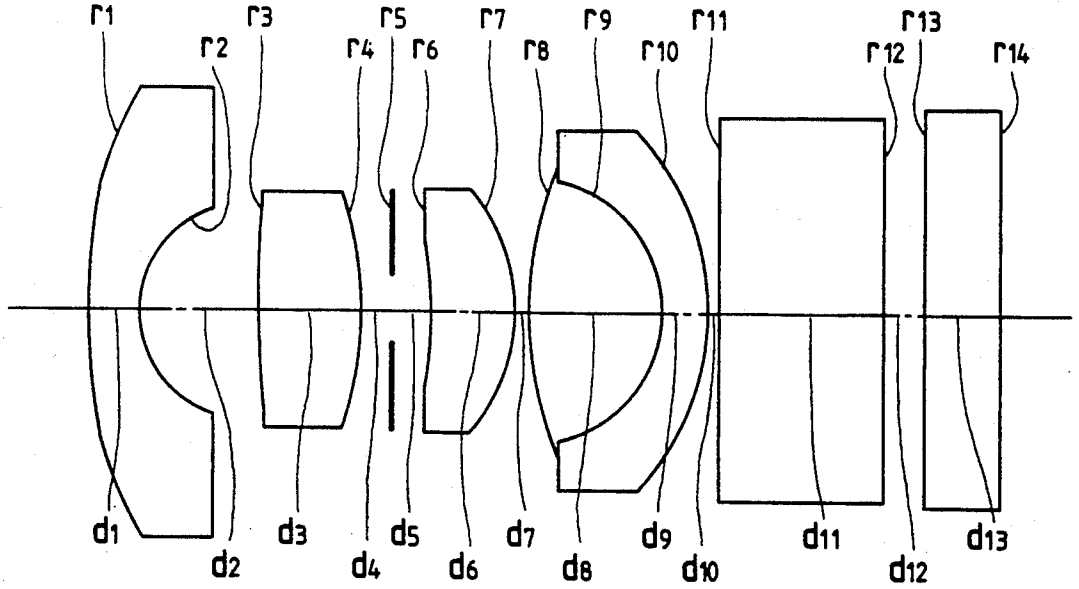

r1
r2
r3
r4
r5
r6
r7
r8
r9
r10
r11
r12
r13
r14
d1
d2
d3
d4
d5
d6
d7
d8
d9
d10
d11
d12
d13

FIG. 17

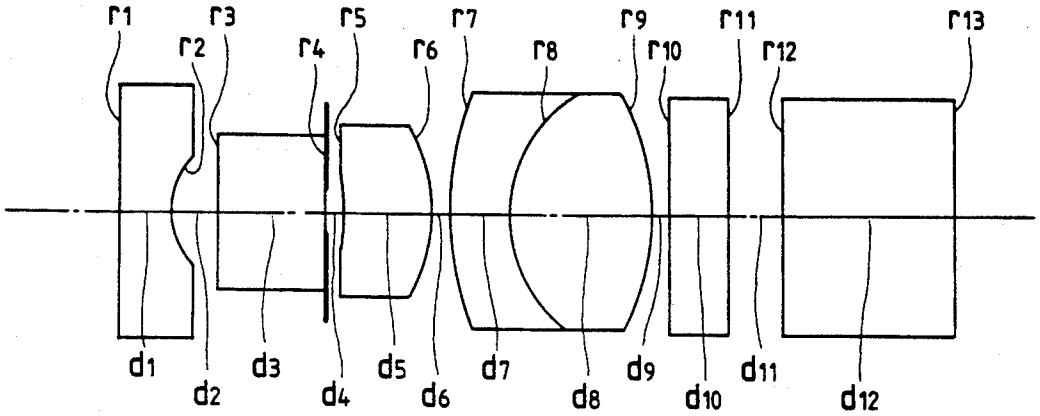

r1
r2
r3
r4
r5
r6
r7
r8
r9
r10
r11
r12
r13
d1
d2
d3
d4
d5
d6
d7
d8
d9
d10
d11
d12

FIG. 18

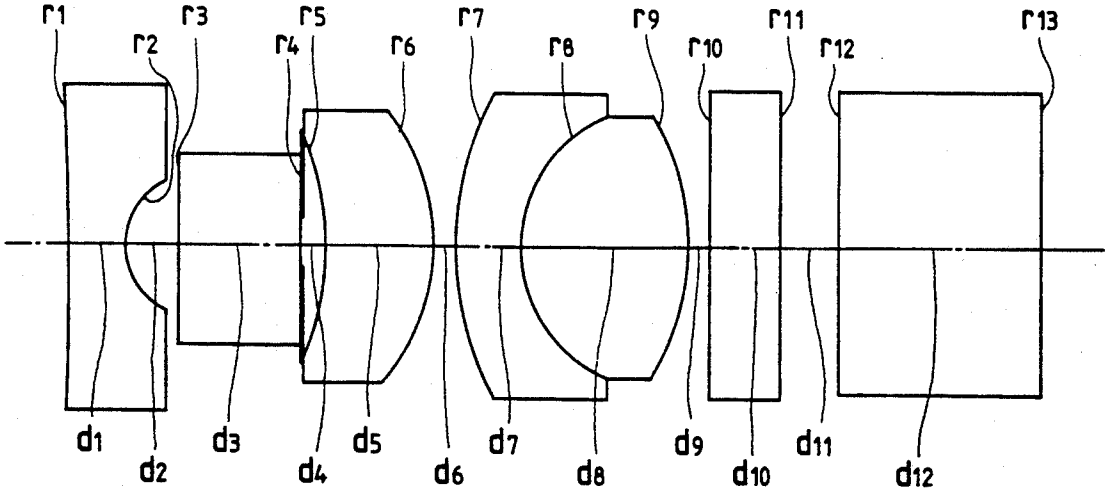

r1
r2
r3
r4
r5
r6
r7
r8
r9
r10
r11
r12
r13
d1
d2
d3
d4
d5
d6
d7
d8
d9
d10
d11
d12

FIG. 19

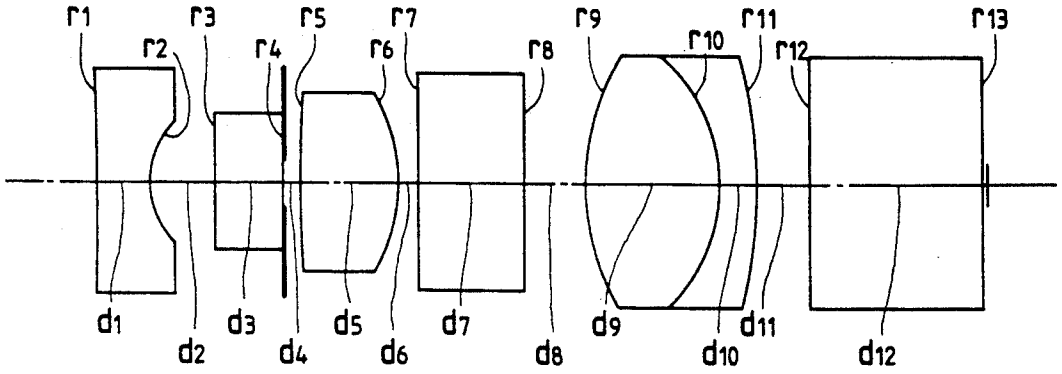

r1
r2
r3
r4
r5
r6
r7
r8
r9
r10
r11
r12
r13
d1
d2
d3
d4
d5
d6
d7
d8
d9
d10
d11
d12

FIG. 20

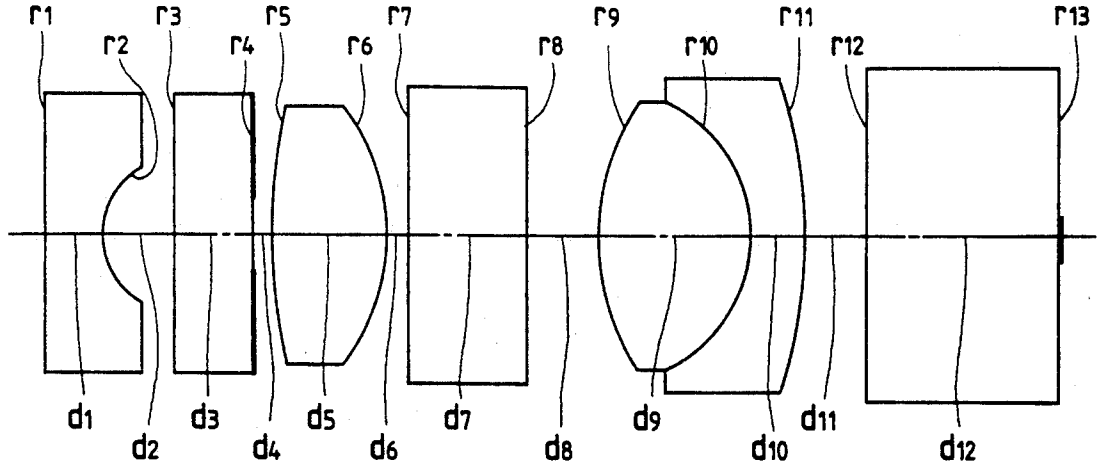

r1
r2
r3
r4
r5
r6
r7
r8
r9
r10
r11
r12
r13
d1
d2
d3
d4
d5
d6
d7
d8
d9
d10
d11
d12

FIG. 21

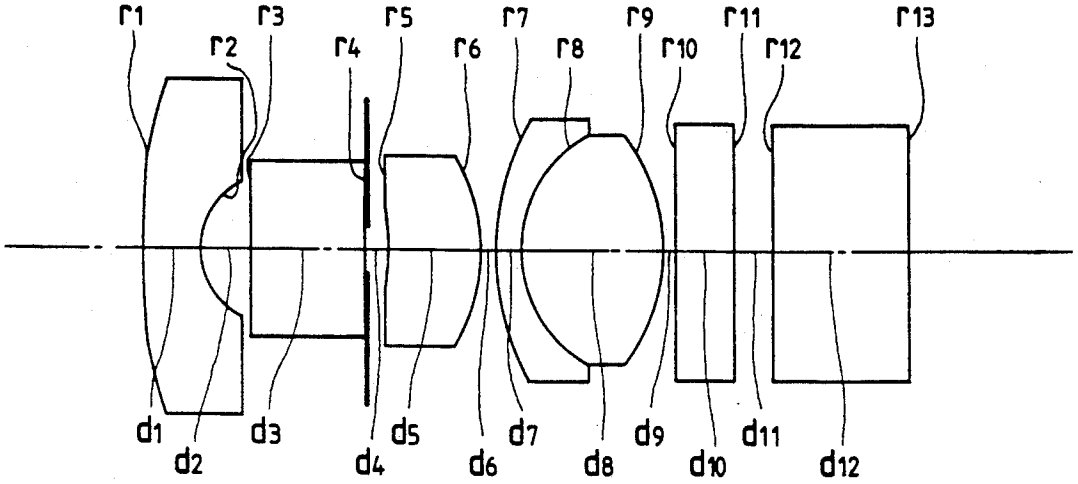

r1
r2
r3
r4
r5
r6
r7
r8
r9
r10
r11
r12
r13
d1
d2
d3
d4
d5
d6
d7
d8
d9
d10
d11
d12

FIG. 22

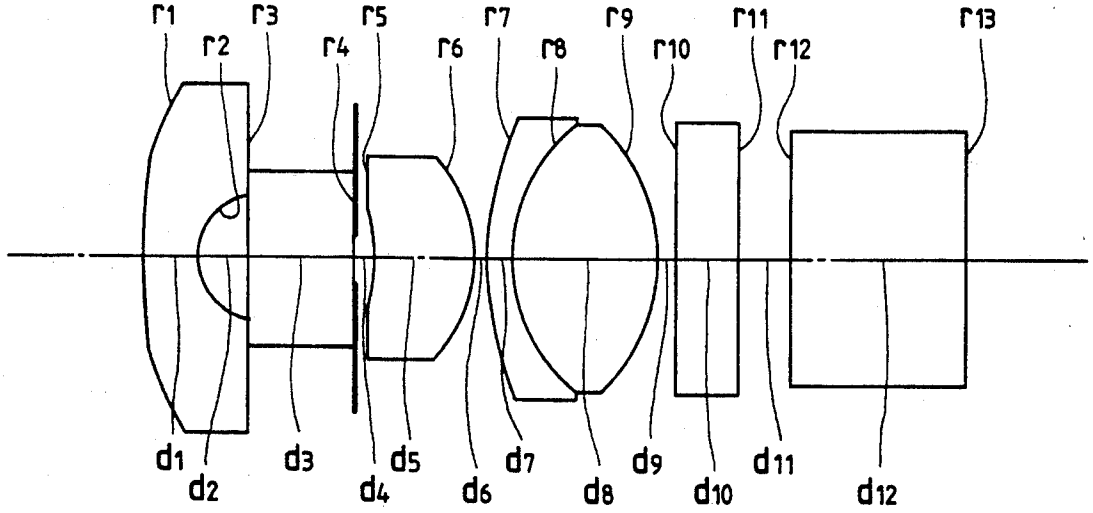

r1
r2
r3
r4
r5
r6
r7
r8
r9
r10
r11
r12
r13
d1
d2
d3
d4
d5
d6
d7
d8
d9
d10
d11
d12

FIG. 23

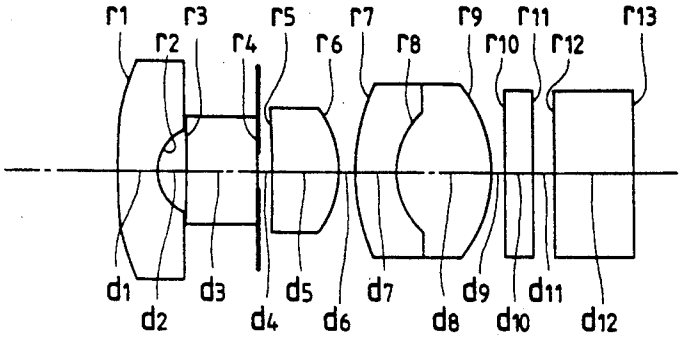

r1
r2
r3
r4
r5
r6
r7
r8
r9
r10
r11
r12
r13
d1
d2
d3
d4
d5
d6
d7
d8
d9
d10
d11
d12

FIG. 24

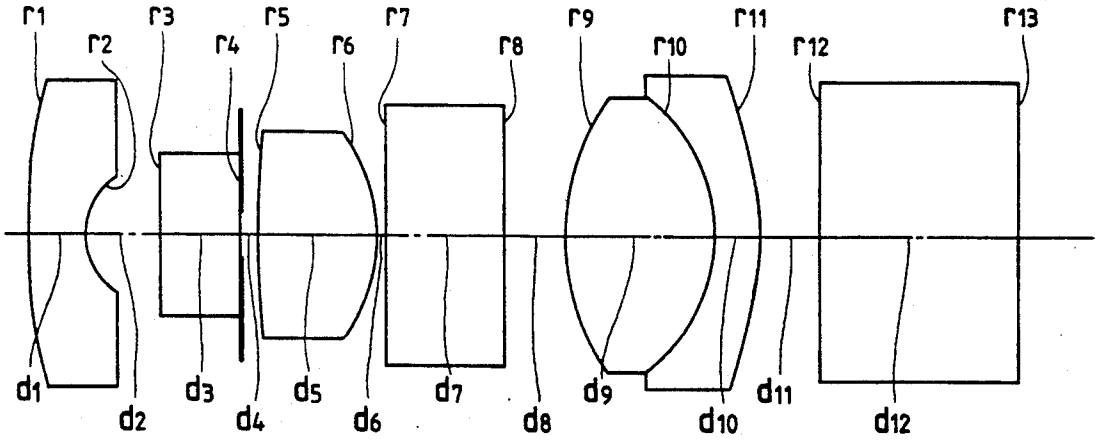

r1
r2
r3
r4
r5
r6
r7
r8
r9
r10
r11
r12
r13
d1
d2
d3
d4
d5
d6
d7
d8
d9
d10
d11
d12

FIG. 25

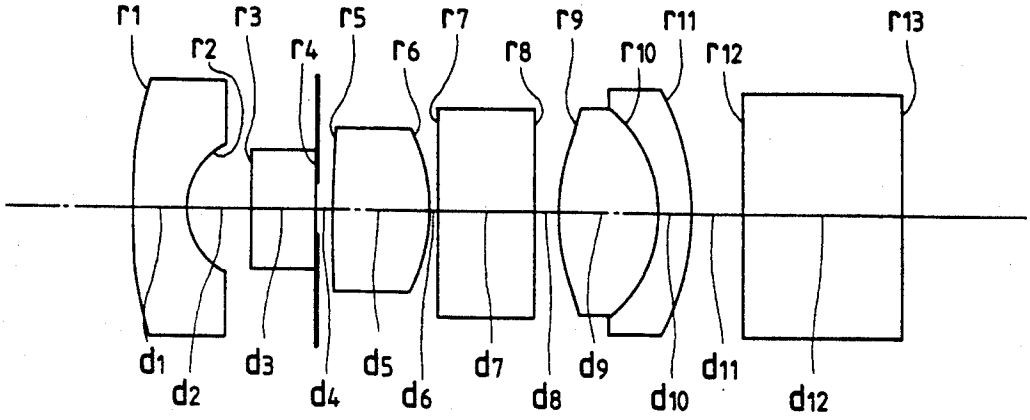

r1
r2
r3
r4
r5
r6
r7
r8
r9
r10
r11
r12
r13
d1
d2
d3
d4
d5
d6
d7
d8
d9
d10
d11
d12

FIG. 26

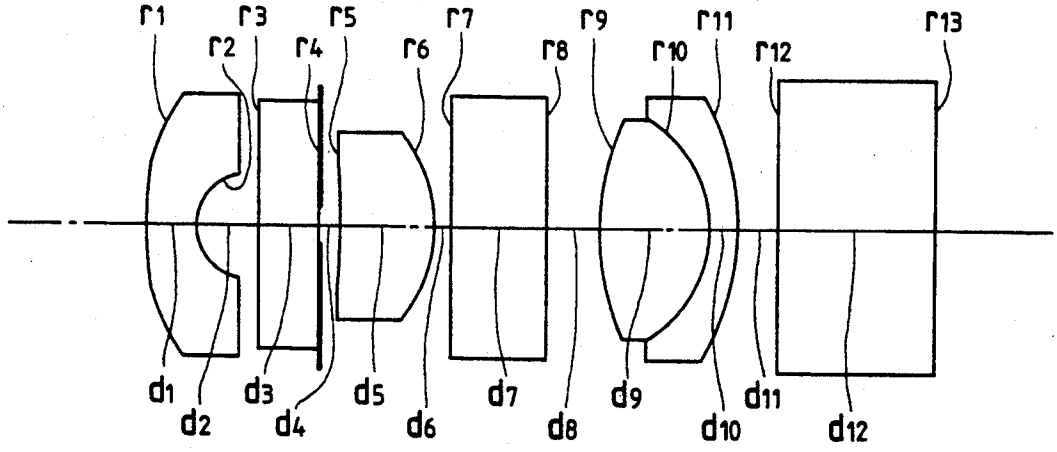

r1
r2
r3
r4
r5
r6
r7
r8
r9
r10
r11
r12
r13
d1
d2
d3
d4
d5
d6
d7
d8
d9
d10
d11
d12

FIG. 27

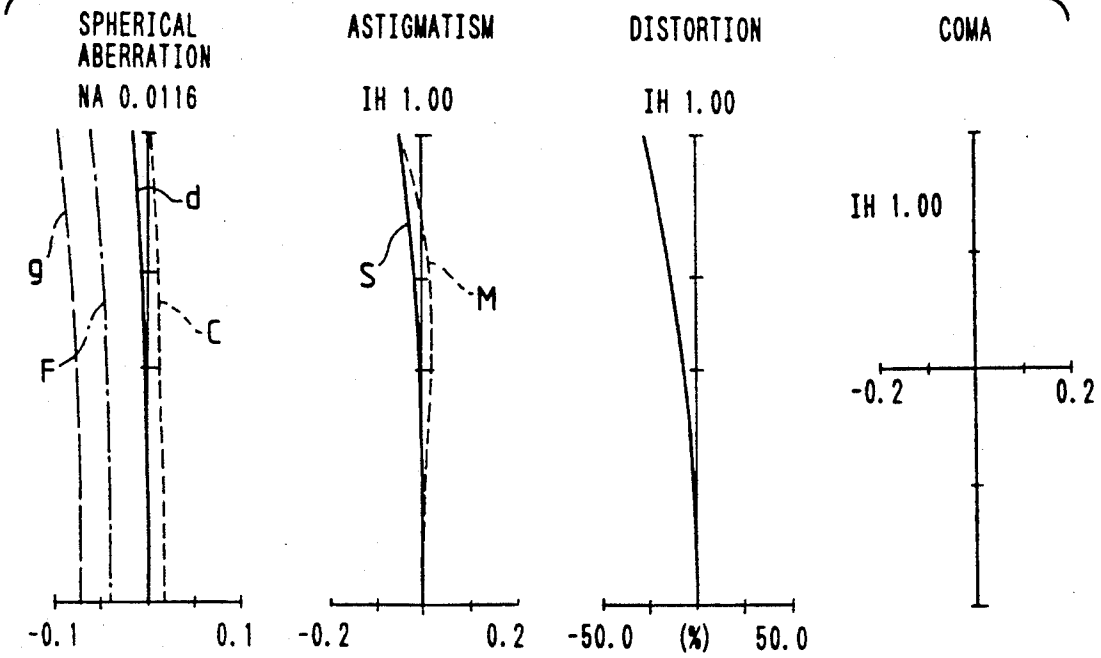

SPHERICAL ABERRATION
NA 0.0116
ASTIGMATISM
IH 1.00
DISTORTION
IH 1.00
COMA
IH 1.00
g
d
C
F
S
M
-0.1
0.1
-0.2
0.2
-50.0
(%)
50.0
-0.2
0.2

FIG. 28

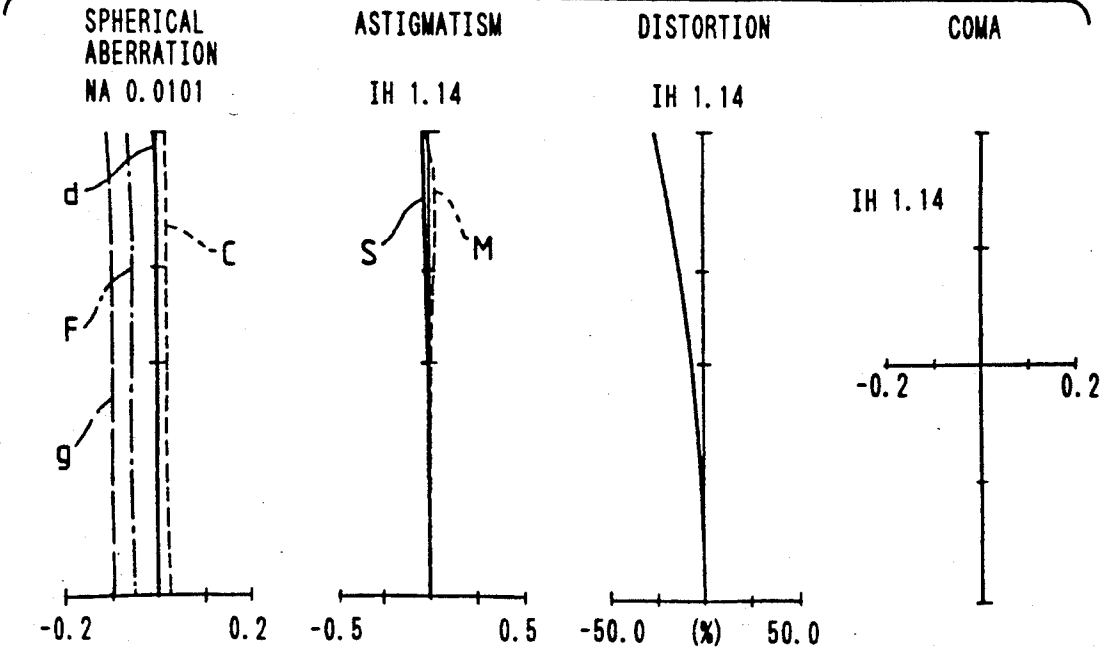

SPHERICAL ABERRATION
NA 0.0101
ASTIGMATISM
IH 1.14
DISTORTION
IH 1.14
COMA
IH 1.14
d
C
F
g
S
M
-0.2
0.2
-0.5
0.5
-50.0
(%)
50.0
-0.2
0.2

FIG. 29

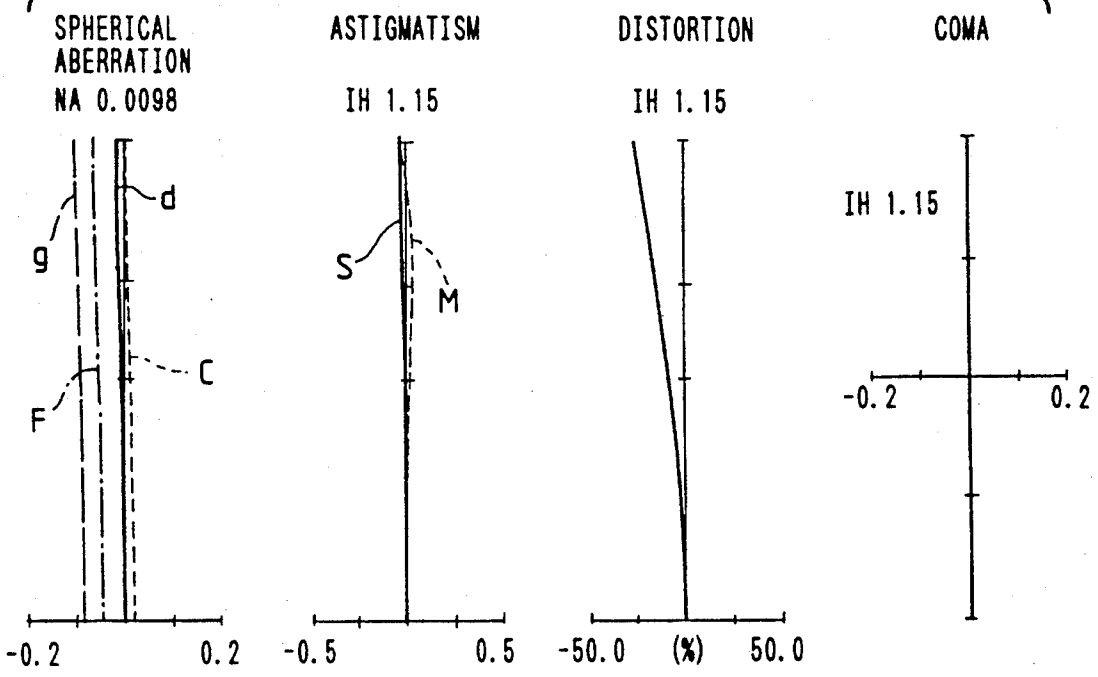

SPHERICAL ABERRATION
NA 0.0098
ASTIGMATISM
IH 1.15
DISTORTION
IH 1.15
COMA
IH 1.15
g
d
C
F
S
M
-0.2
0.2
-0.5
0.5
-50.0
(%)
50.0
-0.2
0.2

FIG. 30

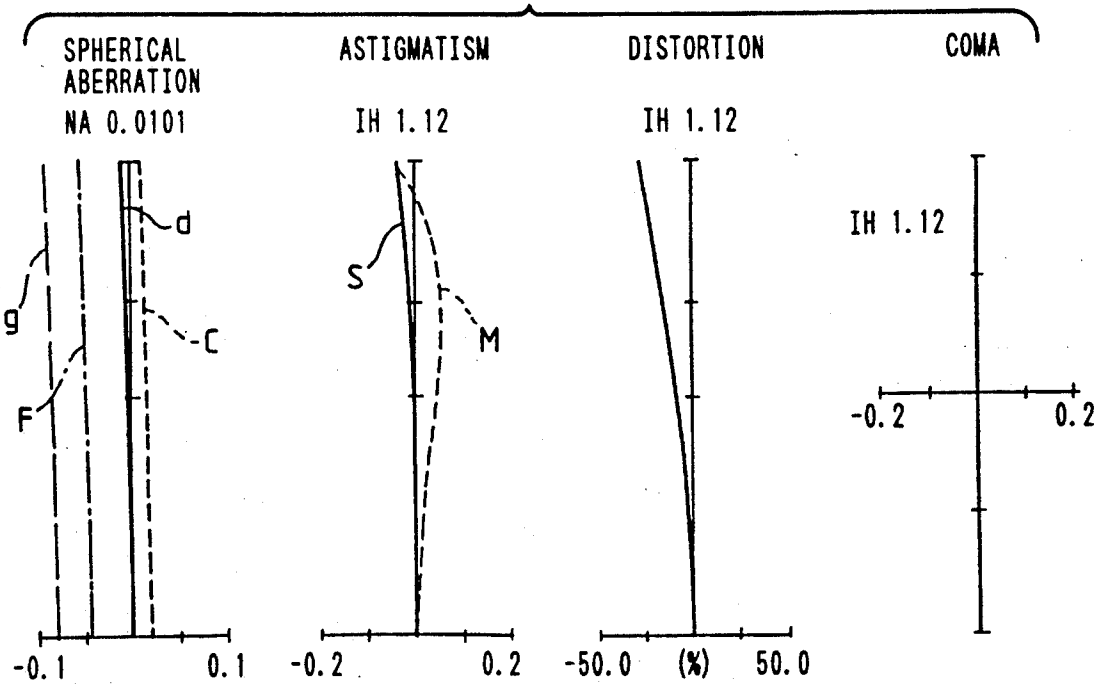

SPHERICAL ABERRATION
NA 0.0101
ASTIGMATISM
IH 1.12
DISTORTION
IH 1.12
COMA
IH 1.12
g
d
C
F
S
M
-0.1
0.1
-0.2
0.2
-50.0
(%)
50.0
-0.2
0.2

FIG. 31

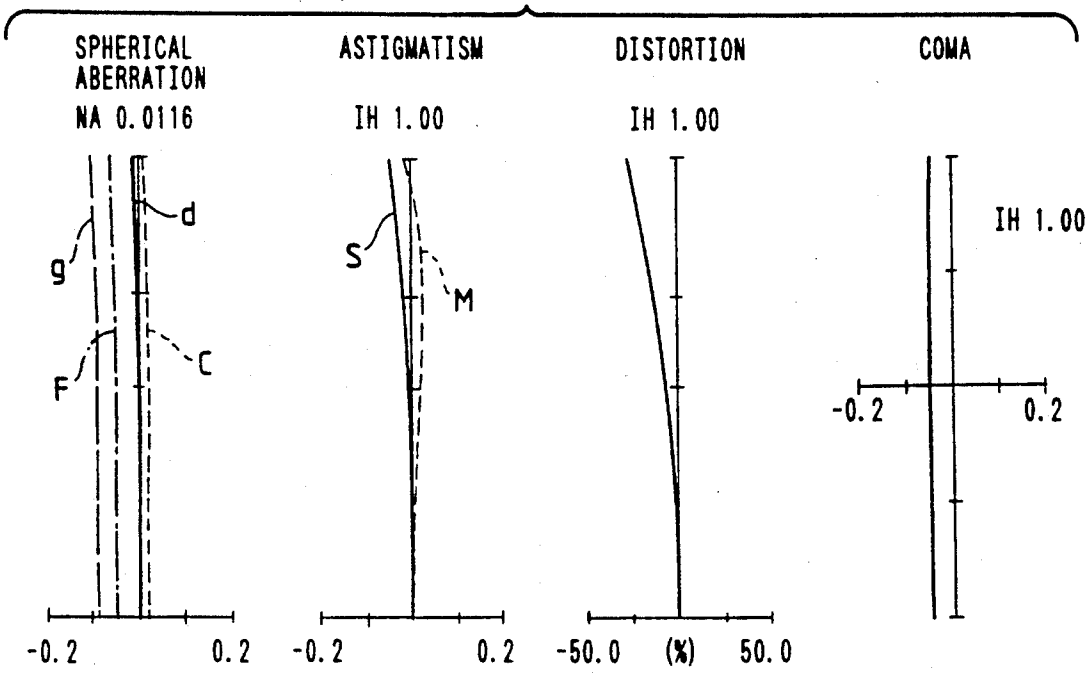

SPHERICAL ABERRATION
NA 0.0116
ASTIGMATISM
IH 1.00
DISTORTION
IH 1.00
COMA
IH 1.00
d
g
F
C
S
M
-0.2
0.2
-0.2
0.2
-50.0
(%)
50.0
-0.2
0.2

FIG. 32

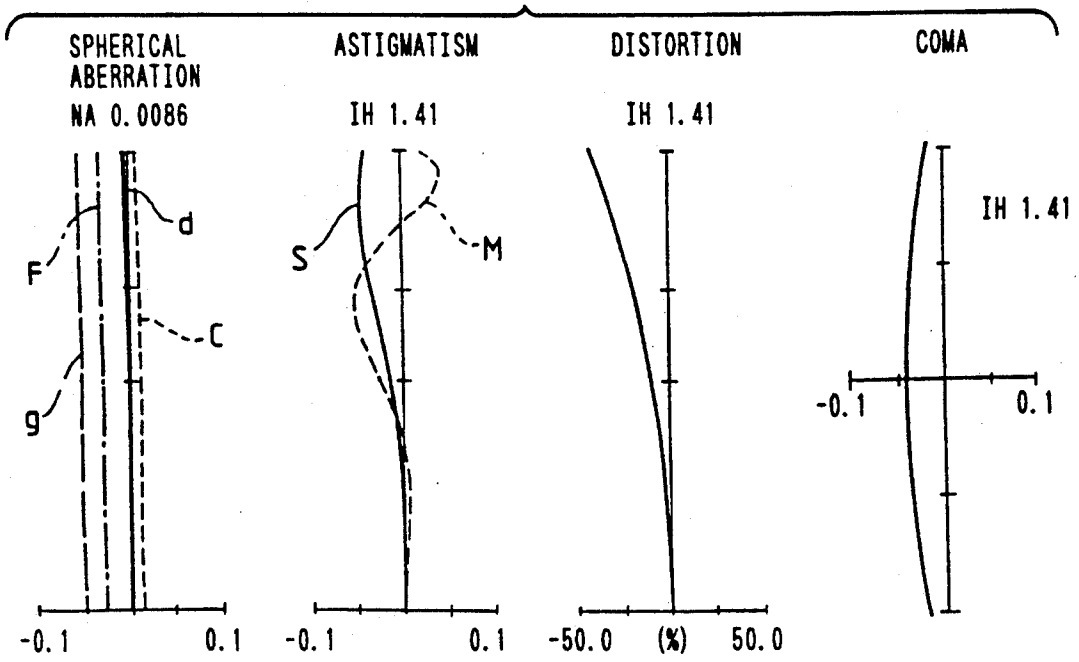

SPHERICAL ABERRATION
NA 0.0086
ASTIGMATISM
IH 1.41
DISTORTION
IH 1.41
COMA
IH 1.41
d
F
C
g
S
M
-0.1
0.1
-0.1
0.1
-50.0
(%)
50.0
-0.1
0.1

FIG. 33

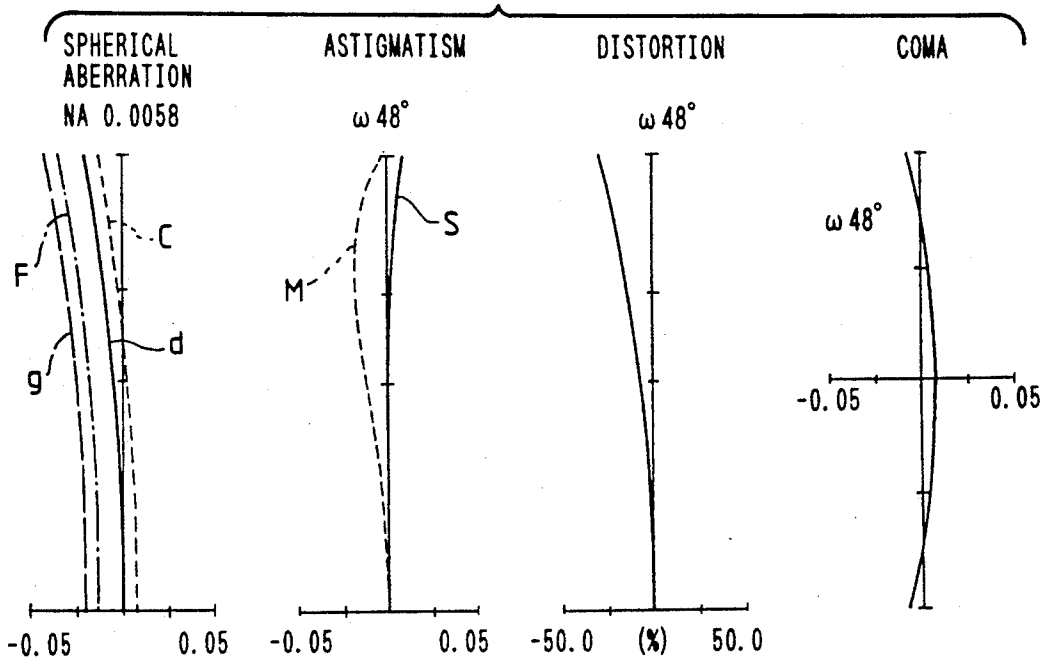

SPHERICAL ABERRATION
NA 0.0058
ASTIGMATISM
ω 48°
DISTORTION
ω 48°
COMA
ω 48°
C
F
g
d
M
S
-0.05
0.05
-0.05
0.05
-50.0
(%)
50.0
-0.05
0.05

FIG. 34

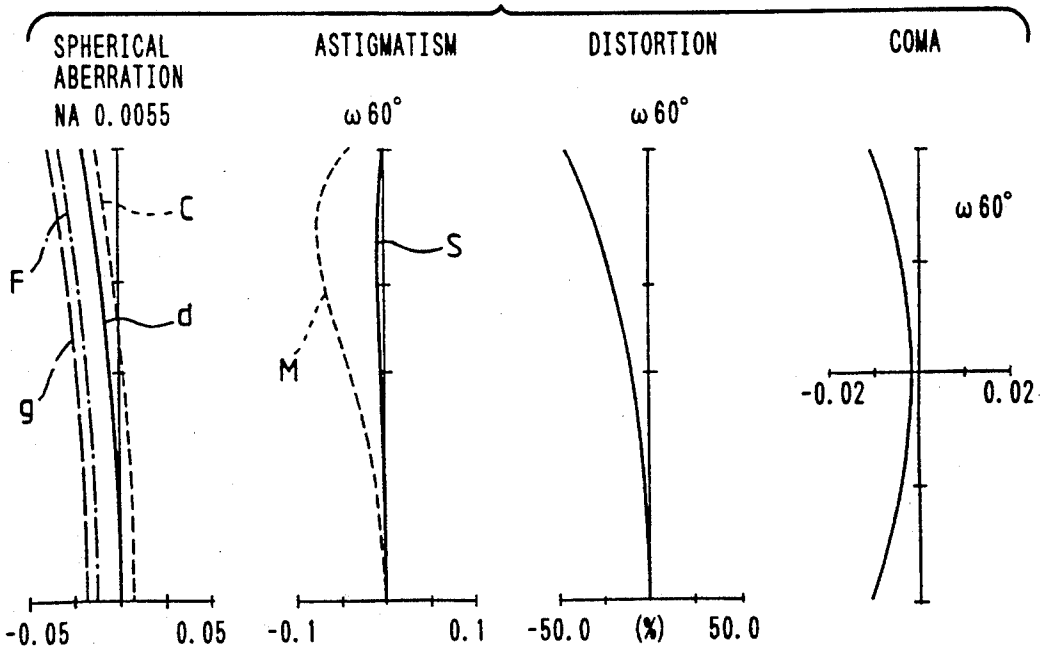

SPHERICAL ABERRATION
NA 0.0055
ASTIGMATISM
ω 60°
DISTORTION
ω 60°
COMA
ω 60°
C
F
g
d
M
S
-0.05
0.05
-0.1
0.1
-50.0
(%)
50.0
-0.02
0.02

FIG. 35

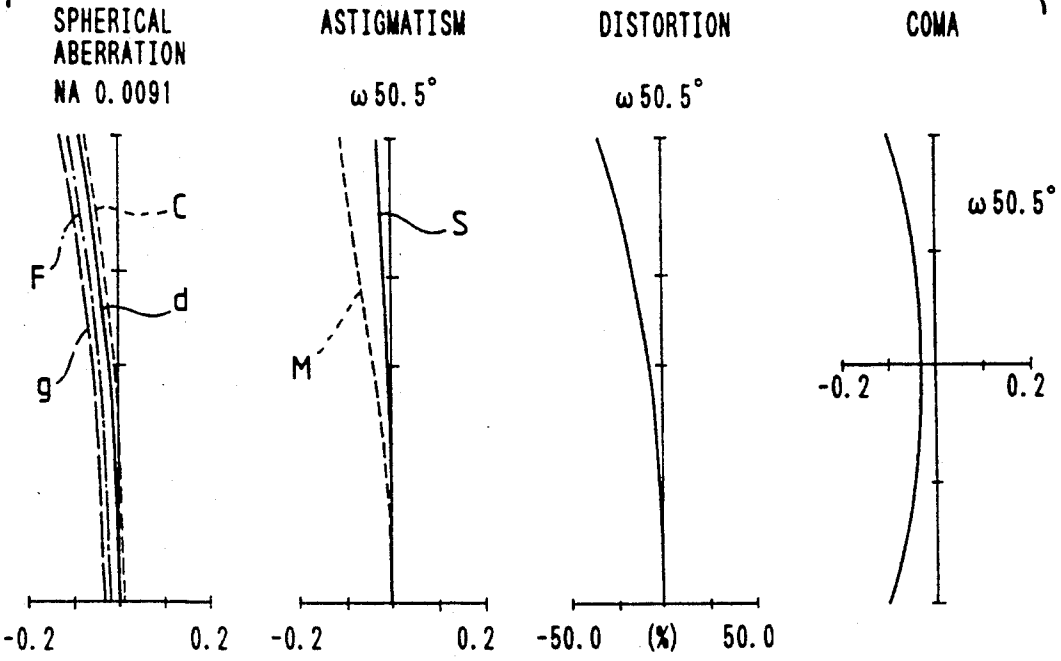

SPHERICAL ABERRATION
NA 0.0091
ASTIGMATISM
ω 50.5°
DISTORTION
ω 50.5°
COMA
ω 50.5°
C
F
d
g
S
M
-0.2
0.2
-0.2
0.2
-50.0
(%)
50.0
-0.2
0.2

FIG. 36

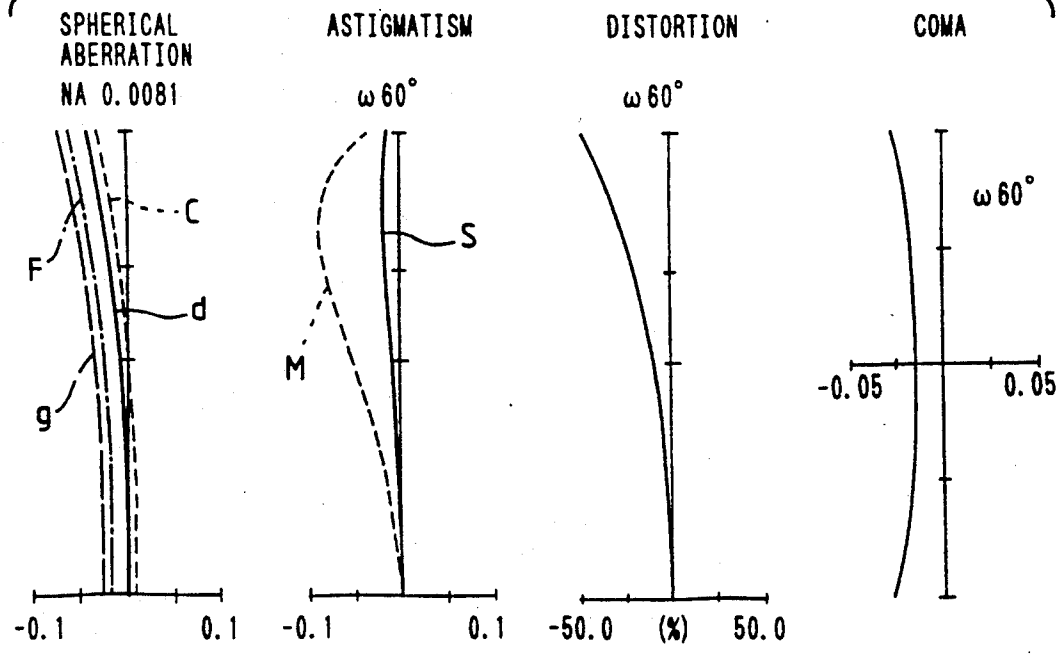

SPHERICAL ABERRATION
NA 0.0081
ASTIGMATISM
ω 60°
DISTORTION
ω 60°
COMA
ω 60°
C
F
d
g
S
M
-0.1
0.1
-0.1
0.1
-50.0
(%)
50.0
-0.05
0.05

FIG. 37

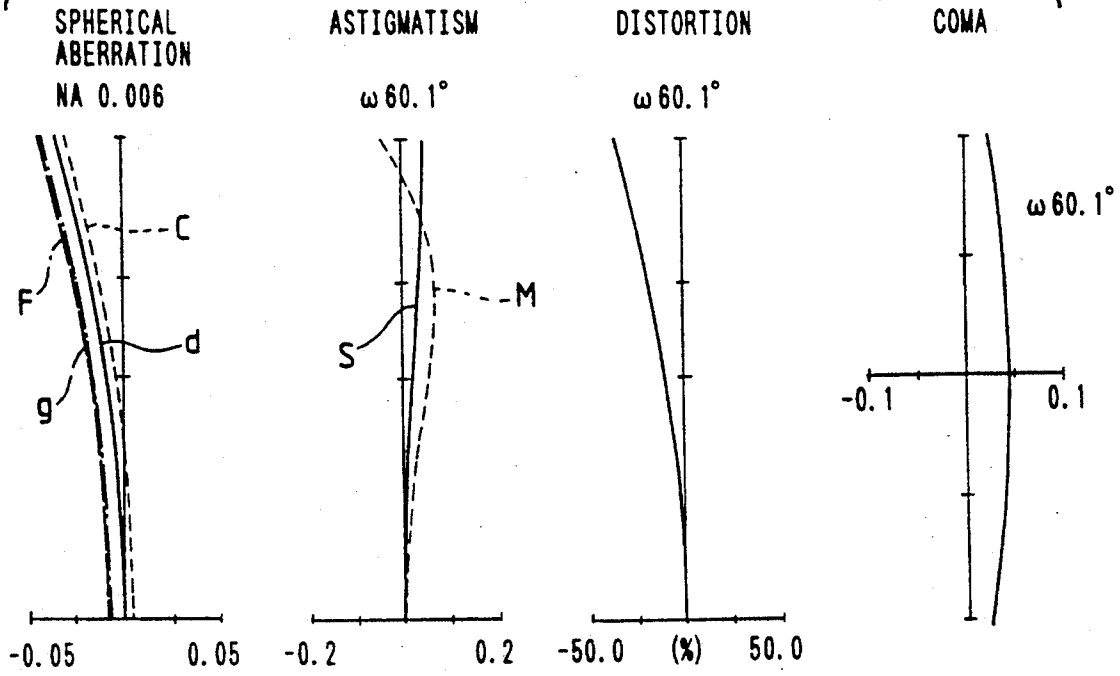

SPHERICAL ABERRATION
NA 0.006
ASTIGMATISM
ω 60.1°
DISTORTION
ω 60.1°
COMA
ω 60.1°
C
F
d
g
M
S
-0.05
0.05
-0.2
0.2
-50.0
(%)
50.0
-0.1
0.1

FIG. 38

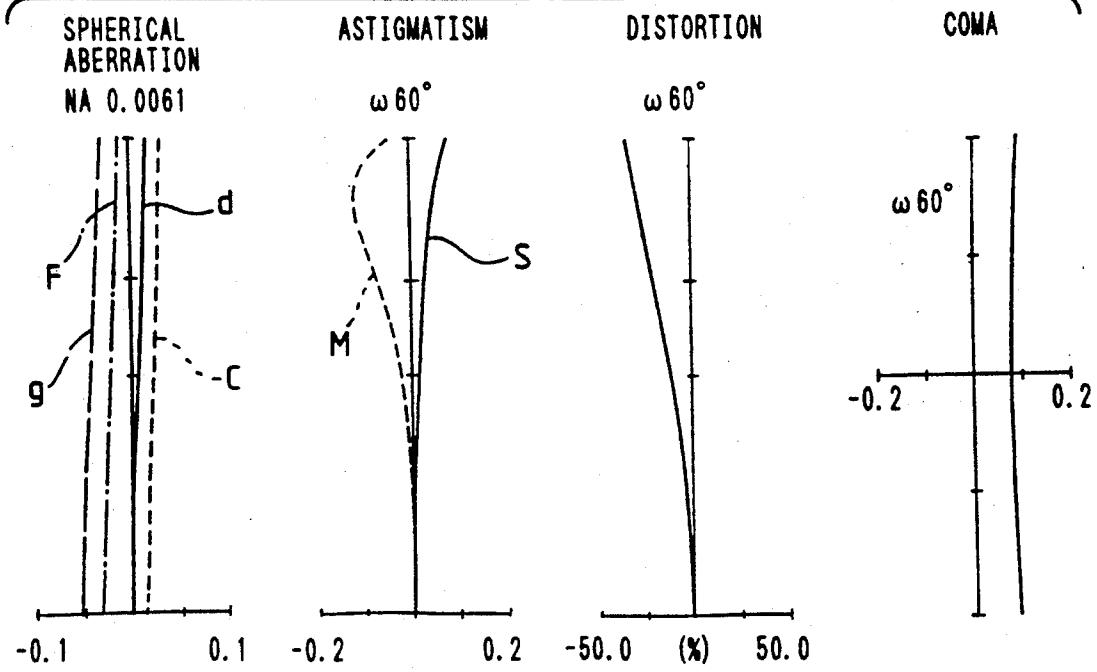

SPHERICAL ABERRATION
NA 0.0061
ASTIGMATISM
ω 60°
DISTORTION
ω 60°
COMA
ω 60°
d
F
g
C
S
M
-0.1
0.1
-0.2
0.2
-50.0
(%)
50.0
-0.2
0.2

FIG. 39

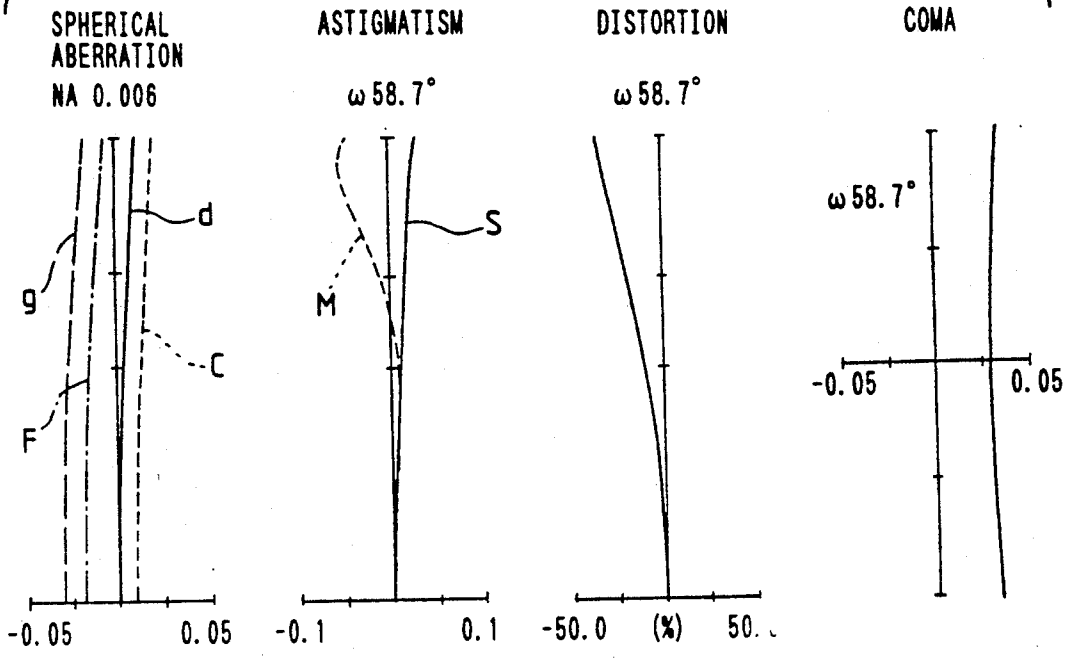

SPHERICAL ABERRATION
NA 0.006
ASTIGMATISM
ω 58.7°
DISTORTION
ω 58.7°
COMA
ω 58.7°
d
g
C
F
S
M
-0.05
0.05
-0.1
0.1
-50.0
(%)
50.
-0.05
0.05

FIG. 40

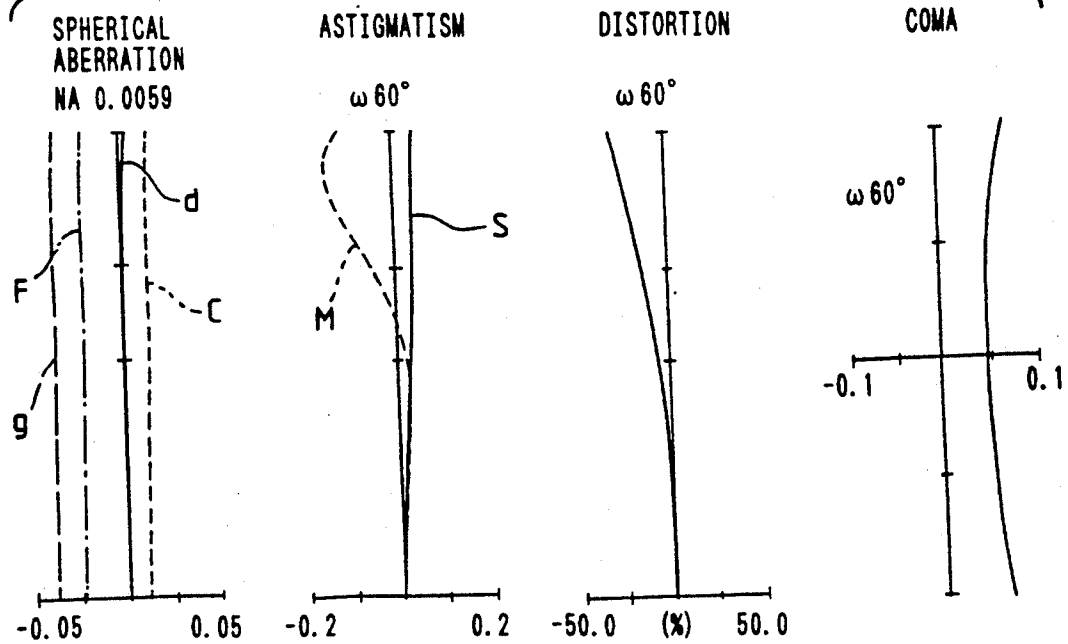

SPHERICAL ABERRATION
NA 0.0059
ASTIGMATISM
ω 60°
DISTORTION
ω 60°
COMA
ω 60°
d
F
C
g
S
M
-0.05
0.05
-0.2
0.2
-50.0
(%)
50.0
-0.1
0.1

FIG. 41

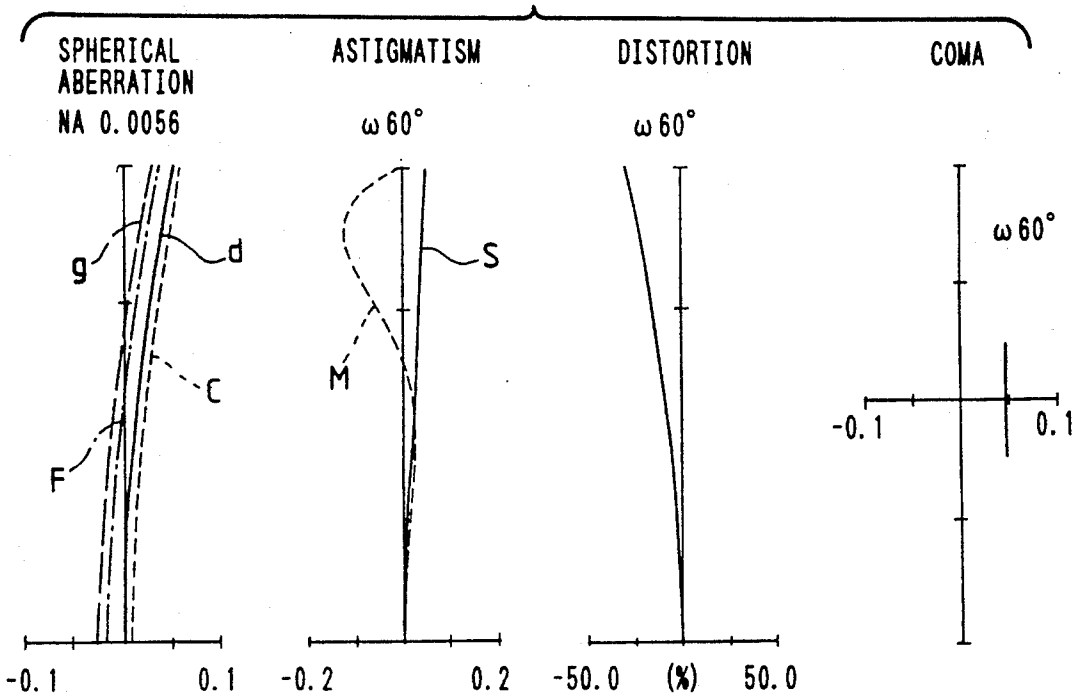

SPHERICAL ABERRATION
NA 0.0056
ASTIGMATISM
ω 60°
DISTORTION
ω 60°
COMA
ω 60°
g
d
C
F
M
S
-0.1
0.1
-0.2
0.2
-50.0
(%)
50.0
-0.1
0.1

FIG. 42

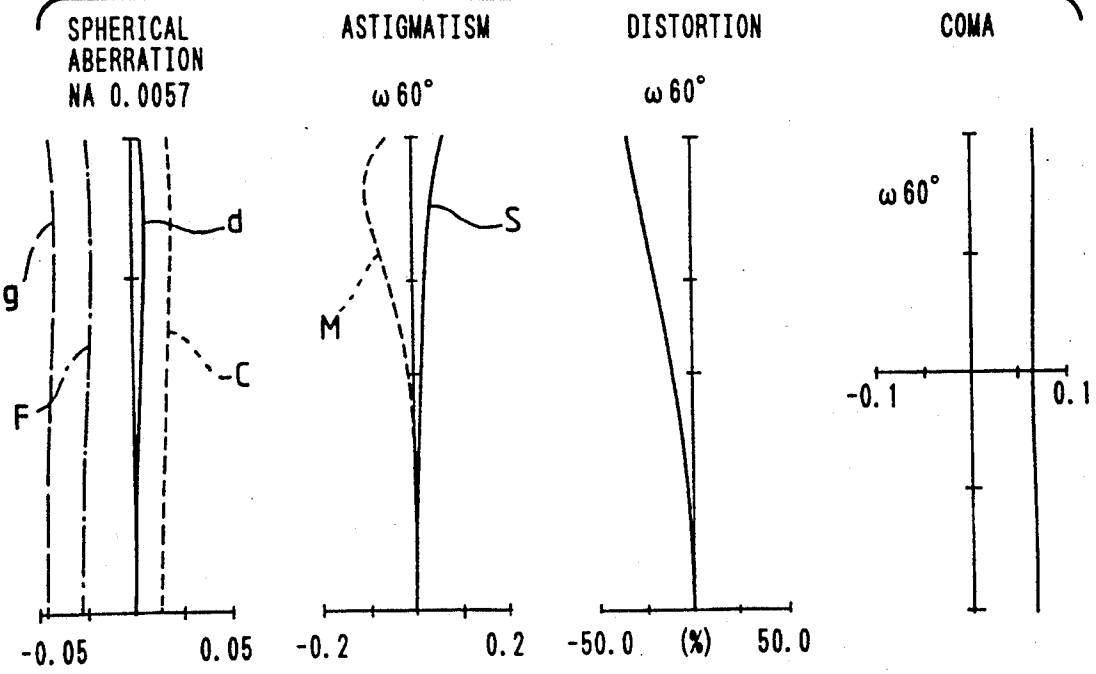

SPHERICAL ABERRATION
NA 0.0057
ASTIGMATISM
ω 60°
DISTORTION
ω 60°
COMA
ω 60°
g
d
C
F
M
S
-0.05
0.05
-0.2
0.2
-50.0
(%)
50.0
-0.1
0.1

FIG. 43

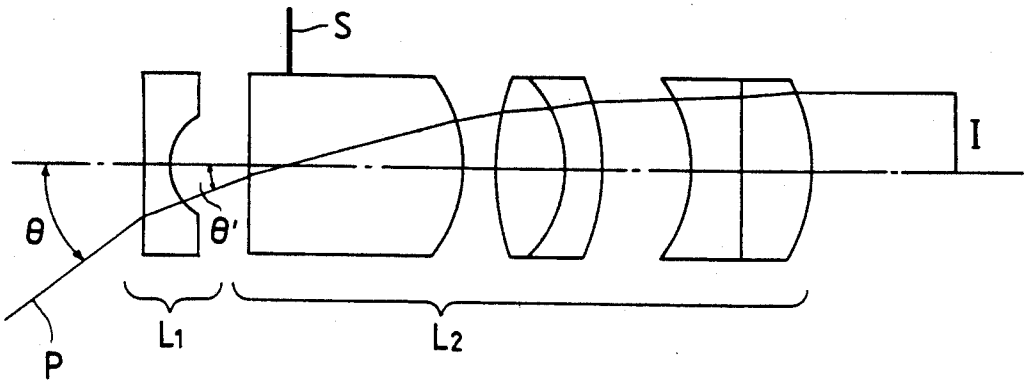

S
I
θ
θ'
P
L1
L2

FIG. 44

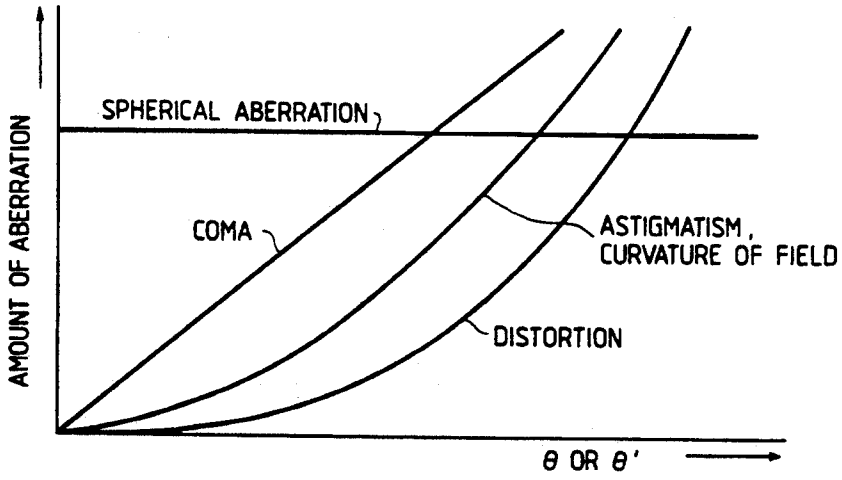

AMOUNT OF ABERRATION
SPHERICAL ABERRATION
COMA
ASTIGMATISM,
CURVATURE OF FIELD
DISTORTION
θ OR θ'

FIG. 45

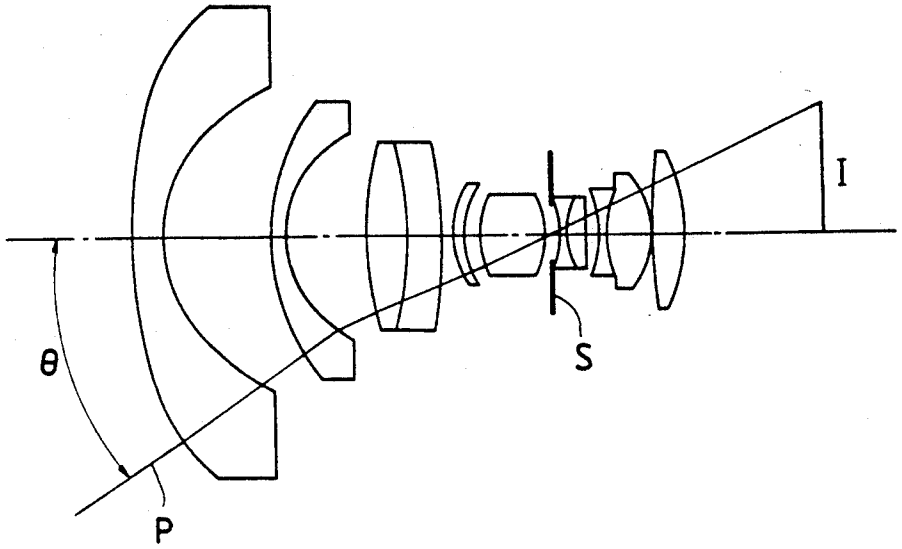
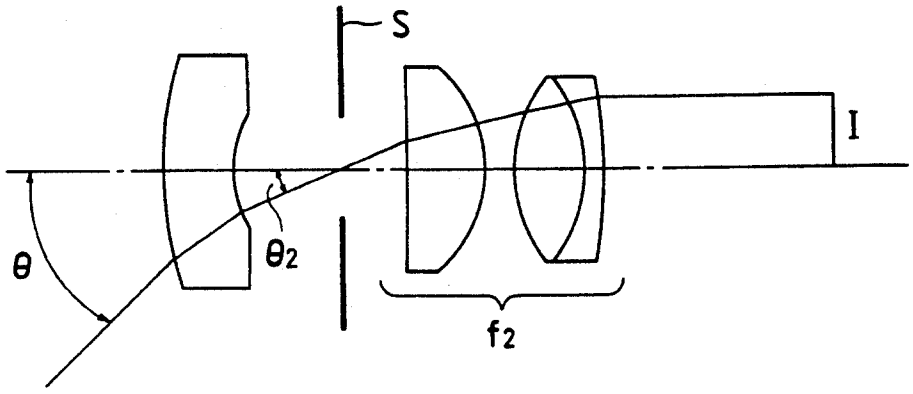


FIG. 46



OBJECTIVE LENS SYSTEM FOR ENDOSCOPES

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to an objective lens system for endoscopes.

2. Description of the Prior Art

As an objective lens system for endoscopes, there is known the lens system disclosed by Japanese Patent Kokai Publication No. Sho 62-173415. This objective lens system has defects that the lens system has a long total length, that the outside diameter of the lens system is large as compared with the diameter of an image formed thereby, and so on.

Further, as another conventional example of objective lens systems, there is also known the lens system disclosed by Japanese Patent Kokai Publication No. Sho 63-26123. This objective lens system has defects that the lens system has a narrow field angle and that the lens system produces remarkable distortion which deforms the marginal portion of an image formed thereby.

Furthermore, used as endoscopes are fiber scopes which use image guides and, in addition, video scopes which use solid-state image pickup devices such as CCD's in the distal ends thereof.

In the recent years where video scopes have smaller outside diameters owing to compacter designs of image pickup devices, there are developed video scopes for observing interiors of bronchial tubes and urinary organs.

Video scopes do not permit reproducing colors or images formed on the monitors therefor since the solid-state image pickup devices have sensitivity not only to visible rays but also to infrared rays. It is therefore necessary to arrange filters for shielding the infrared rays in the optical systems of video scopes. Further, when a laser ranging from near infared to far infrared regions is used for medical treatment through video scopes, the laser saturates the CCD's, thereby hindering observation of locations to be treated due to smear and blooming. It is therefore necessary to arrange filters for cutting off wavelengths of the laser in the objective optical systems.

Thickness of the infrared cut filters, CCD cover glass, laser shielding filters, etc. remains unchanged even after the image pickup devices have compacter designs and the optical systems have shorter focal lengths. Accordingly, the optical path lengths as measured in the direction of the thickness of the filters are long relative to the focal lengths.

As an objective lens system for endoscopes comprising filters in the optical system thereof, there is known the lens system which has the composition illustrated in FIG. 1. This optical system is usually of the retrofocus type and satisfies the following relationship.

$$I=f\sin\theta$$

wherein the reference symbol I represents the image height, the reference symbol f designates the focal length of the optical system and the reference symbol θ denotes the half field angle of the optical system.

In order to arrange filters, F_1, F_2 and a cover glass C which have long optical path lengths as compared with the focal length f in this type of lens system, it is necessary to select a high retro ratio (a value obtained by dividing the distance as measured from the final surface to the image surface of a lens system by the focal length thereof). When a high retro ratio is selected, without prolonging total length, for a lens system which has a short total length, each of the lens components has strengthened power, thereby making it difficult to correct aberrations. Since focal length of the lens system is further shortened especially by widening field angle thereof, it is impossible to widen the field angle of the lens system.

When an attempt is made to correct aberrations favorably in this type of lens system, the lens system comprises a larger number of lens components, a longer total length accordingly and becomes unsuited for use with endoscopes for observing interiors of thin tubes.

The absorption type of infrared cut filters are usually made of phosphate glass materials. Since the phosphate glass materials have low resistance to humidity, these materials must always be coated so as to prevent contact with ambient air. The coated filters may be injured on the circumferences thereof or the coating may peel off and, in such a condition, the injured portion is exposed to ambient air and may allow the filters to become whitely turbid from the marginal portions thereof. It is necessary to design the filters in such a manner that rays are incident on the filters at the portions rather lower than the outside diameters of the filters. However, in the above-described type of lens system wherein the two filters F_1 and F_2 are arranged before the CCD cover glass C, rays are incident on the filters at heights which are nearly the same as the image height or higher than the image height, and since the filters are arranged at locations where rays are highest in the lens system, it is impossible to set the heights of rays at levels sufficiently lower than the diameters of the filters.

SUMMARY OF THE INVENTION

A primary object of the present invention is to provide an objective optical system for endoscopes which has a short total length, a small outside diameter, a wide field angle and favorably corrected distortion.

Another object of the present invention is to provide an objective optical system for endoscopes having a short total length and comprising filters on which rays are incident at low portions thereof.

A further object of the present invention is to provide a video endoscope equipped with the objective optical system described above in the distal end thereof.

The objective optical system for endoscopes according to the present invention consists of a front lens unit comprising a lens component having negative refractive power and a rear lens unit comprising a positive lens element which are arranged with an aperture stop interposed therebetween, each of said front lens unit and said rear lens unit comprising at least one aspherical surface, said front lens unit satisfying either of the following conditions (A) and (B), said rear lens unit satisfying either of the following conditions (C) and (D), and said objective optical system satisfying the following condition (E):

(A) The aspherical surface which has a shape including portions having curvature progressively enhanced as the portions are farther from the optical axis is arranged as an object side surface in said front lens unit.

(B) The aspherical surface which has a shape including portions having curvature is progressively lowered

as the portions are farther from the optical axis is arranged as an image side surface in said front lens unit.

(C) The aspherical surface which has a shape having curvature is progressively lowered as the portions are farther from the optical axis is arranged as an object side surface in said rear lens unit.

(D) The aspherical surface which has a shape including portions having curvature progressively enhanced as the portions are farther from the optical axis is arranged as an image side surface in said rear lens unit.

(E) $0.2f<D_A<8f$ wherein the reference symbol D_A represents the optical path length as measured from the aperture stop to the aspherical surface arranged in the rear lens unit.

Description will be made below on the reason why both distortion and curvature of field are corrected sufficiently favorably in the objective optical system for endoscopes using the aspherical surfaces as explained above.

The conventional objective optical system, for endoscopes having the composition illustrated in FIG. **1** produces strongly negative distortion because the principal ray is refracted, as image height increases, by the front lens unit and the rear lens unit in the direction to widen the field angle when the principal ray is traced inversely from the image side. It is therefore possible to correct the strongly negative distortion by arranging an aspherical surface which weakens refractive power for the principal ray as the surface portions are farther from the optical axis.

For this purpose, it is sufficient to design an object side surface on a lens component arranged in the front lens unit so as to include portions whose curvature is enhanced as the portions are farther from the optical axis, to design an image side surface of a lens component arranged in the front lens unit so as to include portions whose curvature is lowered as the portions are farther from the optical axis, to design an object side surface of a lens component arranged in the rear lens unit so as to include portions whose curvature is lowered as the portions are farther from the optical axis or to design an image side surface of a lens component arranged in the rear lens unit so as to include portions whose curvature is enhanced as the portions are farther from the optical axis.

The surfaces illustrated in FIG. **2** and FIG. **3** are also included among the surfaces whose curvature is progressively enhanced as the surface portions are farther from the optical axes. Sign of curvature is considered as positive when the center of the spherical surface in contact with the aspherical surface of interest at a certain point is located on the object side of the aspherical surface or as negative when the center of the spherical surface in contact with the aspherical surface at a certain point is located on the image side of the aspherical surface. Therefore, FIG. **2** shows an example of aspherical surface whose curvature is progressively enhanced as the surface portions are farther from the optical axis (when the signs of curvature are taken into consideration, the negative curvature of a surface concave on the object side is enhanced to the positive curvature of a surface convex on the object side). In the example shown in FIG. **3**, curvature is once enhanced and then is lowered. The aspherical surface shown in FIG. **3** is usable for correcting distortion since undulation of a distortion curve as shown in FIG. **4** is practially allowable, and the marginal portion of the aspherical surface through which the lower ray passes but the principal ray does not pass has no relation to the correction of distortion.

FIG. **5** and FIG. **6** exemplify surfaces whose curvature is progressively lowered as the surface portions are farther from the optical axis.

As is understood from the foregoing description, the aspherical surface to be arranged in the front lens unit of the objective optical system for endoscopes according to the present invention is a surface, which may be such an aspherical surface as that shown in FIG. **2** or FIG. **3**, including at least portions whose curvature is progressively enhanced as the portions are farther from the optical axis when the aspherical surface is designed as an object side surface of a lens element, or a surface, which may be such a surface as that shown in FIG. **5** or FIG. **6**, including at least portions whose curvature is progressively lowered as the portions are farther from the optical axis when it is designed as an image side surface of a lens element. The objective lens system comprising at least one aspherical surface such as that described above is capable of favorably correcting distortion.

Shape of an aspherical surface can generally be expressed by the following formula (i):

$$x = \frac{Cy^2}{1+\sqrt{1-pC^2y^2}} + By^2 + Ey^4 + Fy^6 + Gy^8 + \ldots$$

wherein the reference symbols x and y represent coordinates values when the optical axis is taken as the abscissa, the direction toward the image is taken as positive, the intersection between the optical axis and the aspherical surface is taken as the origin, and the direction perpendicular to the abscissa is taken as the ordinate as shown in FIG. **7**, the reference symbol C designates the inverse number of the radius of curvature of the circle in contact with the aspherical surface in the vicinity of the optical axis, the reference symbol p denotes the conical constant, and the reference symbols B, E, F, G, . . . represent the aspherical surface coefficients of the second order, fourth order, sixth order and eighth order respectively.

In the objective optical system for endoscopes according to the present invention, it is desirable that departure between the plane surface and the aspherical surface used as the extremely object side surface of the front lens unit, i.e., values of the aspherical surface coefficient of the fourth order E and the aspherical surface coefficient of the sixth order F satisfy at least either of the following conditions (5) and (6):

$$0.0006/f^3<E<0.6/f^3 \quad (5)$$

$$0.0001/f^5<F<0.1/f^5 \quad (6)$$

In order to correct distortion sufficiently favorably by the aspherical surface used in the front lens unit, $0.0006/f^3$ must be smaller than the value of E. That is to say, distortion cannot be corrected sufficiently favorably when the lower limit of the condition (5) is exceeded. If the upper limit of the condition (5) is exceeded, in contrast, it will be impossible to correct astigmatism and the lens element can be difficultly manufactured.

Further, it is possible to correct distortion by selecting a value of F so as to satisfy the condition (6). If the lower limit of the condition (6) is exceeded, distortion

will be corrected insufficiently. If the upper limit of the condition (6) is exceeded, in contrast, it will be impossible to correct astigmatism sufficiently and the lens element can hardly be manufactured.

When only distortion is to be corrected in a lens system such as the objective optical system for endoscopes according to the present invention, it is sufficient to arrange the above-described aspherical surface only on either side of the aperture stop. In such a case, however, the meridional curvature of field will be largely swollen at the intermediate image height and image quality will be remarkably degraded. When an aspherical surface is arranged in each of the front lens unit and the rear lens unit, the meridional curvature of field due to the aspherical surface arranged in the front lens unit and the meridional curvature of field due to the aspherical surface arranged in the rear lens unit are swollen in the direction reverse to each other and cancelled with each other, thereby effacing the swelling in the optical system as a whole.

In the objective optical system for endoscopes according to the present invention, it is desirable that the aspherical surface arranged in the rear lens unit satisfies the following condition (7):

$$0.2f < D_A < 8f \tag{7}$$

wherein the reference symbol D_A represents the optical path length as measured from the aperture stop to the aspherical surface, said optical path length including, when a lens is interposed in the section, a value obtained by dividing thickness on the optical axis by the refractive index thereof.

By arranging the aspherical surface in the rear lens unit at a location rather close to the aperture stop, it is possible to reserve a large difference between the heights of the upper ray and the lower ray passing through the aspherical surface and accordingly to obtain an advantage for correction of coma. If the aspherical surface is too close to the aperture stop, however, correction of astigmatism will undesirably become difficult.

Let us now define Seidel's aberrations as expressed by the formulae (ii) and (iii) to be described later. These definitions are the same as those adopted for the universal lens design program ACCOS-V. When the object distance is represented by OB, the numerical aperture of the marginal ray is designated by NA and the refractive index of the medium located on the object side of the first lens surface is denoted by n_0, ACCOS-V determines the height of ray on the first surface by the following formula:

$$H_0 = OB \times \tan\{\sin^{-1}(NA/n_0)\}$$

In contrast, the present invention determines the height of ray H: by the following formula:

$$H_0 = OB \times (NA/n_0)$$

Accordingly, each of the aberration coefficients is determined in the present invention by performing the paraxial tracing on the basis of H_0 calculated as $H_0 = OB \times (NA/n_0)$. NA is taken as $\frac{1}{2}$FNO.

Speaking more concretely, the aberration coefficient for the meridional ray ($\overline{X}=0$) is calculated by the formula (ii), whereas the aberration coefficient for the sagital ray ($\overline{Y}=0$) is calculated by the formula (iii):

$$\Delta Y = (SA3)\overline{Y}^3 + (CMA3)\overline{Y}^2\overline{H} + \{3(AST3) + (PTZ3)\}\overline{Y}\overline{H}^2 + (DIS3)\overline{H}^3 + (SA5)\overline{Y}^5 + (CMA5)\overline{Y}^4\overline{H} + (TOBSA)\overline{Y}^3\overline{H}^2 + (ELCMA)\overline{Y}^2\overline{H}^3 + \{5(AST5) + (PTZ5)\}\overline{Y}\overline{H}^4 + (DIS5)\overline{H}^5 + (SA7)\overline{Y}^7 \tag{ii}$$

$$\Delta X = (SA3)\overline{X}^3 + \{(AST3) + (PTZ3)\}\overline{X}\overline{H}^2 + (SA5)\overline{X}^5 + (SOBSA)\overline{X}^3\overline{H}^2 + \{(AST5) + (PTZ5)\}\overline{X}\overline{H}^4 + (SA7)\overline{X}^7 \tag{iii}$$

In the above-mentioned formula (ii), the reference symbol ΔY represents deviation between the paraxial image point (the image point in the aplanatic condition) and the actual image point, the reference symbol $\overline{Y}$ designates the position of incidence of the paraxial principal ray on the image surface normalized to the maximum image height and the reference symbol F denotes the position of incidence of the marginal ray on the pupil surface normalized to the pupil diameter. Further, the reference symbols SA3, SA5 and SA7 represent spherical aberrations of the third order, fifth order and seventh order respectively, the reference symbols CMA3 and CMA5 designate the tangential comas of the third order and fifth order respectively, the reference symbols AST3 and AST5 denote astigmatisms of the third order and fifth order respectively the reference symbols PTZ3 and PTZ5 represent Petzval's sums of the third order and fifth order respectively, the reference symbols DIS3 and DIS5 designate distortion of the third order and fifth order respectively, the reference symbol TOBSA denotes tangential oblique spherical aberration of the fifth order, the reference symbol ELCMA represents elliptic coma of the fifth order, and the reference symbol SOBSA designates sagital oblique spherical aberration of the fifth order.

When the i'th surface in the rear lens unit is designed as an aspherical surface, it can be considered that the i'th surface is obtained by deviating the spherical surface (the reference sphere) for a predetermined distance. Let us represent the coma of the third order produced by the reference sphere by Si, designate the coma of the third order produced by the deviation from the reference sphere by Ai, and denote the values obtained by normalizing Si and Ai to F number by ARi and SRi respectively.

When a plural number of aspherical surfaces are arranged in the rear lens unit, the coma coefficients are expressed as follows:

$$A_R = \Sigma ARi$$

$$S_R = \Sigma SRi$$

When a total of the coefficients of coma of the third order produced by surfaces having negative refractive power in the front lens unit is represented by A_2, it is desirable that the front lens unit satisfies the following conditions (8) and (9):

$$-13 < A_2/(A_R + S_R) < -0.03 \tag{8}$$

$$-0.2 < A_R < 0.2 \tag{9}$$

Since an objective lens system for endoscopes generally comprises surfaces having strongly negative refractive powers in the front lens unit for obtaining a wide field angle, remarkable coma is produced by these sur-

faces. It is therefore necessary to cancel this coma with the aberration produced in the rear lens unit so that coma is corrected favorably in the objective lens system as a whole. In addition, when the first lens component consists of a plural number of lens elements as illustrated in FIG. **8** through FIG. **10**, the air-contact surface located on the image side has strongly negative refractive power in the case shown in FIG. **8** or FIG. **10** wherein the lens component consists of lens elements cemented to each other, whereas the image side surface of the lens element arranged on the object side has the strongly negative refractive power in the case shown in FIG. **9** wherein the elements of the first lens component are separated from each other. It is necessary to cancel the negative coma produced by these surfaces with the aberration produced in the rear lens unit. It is therefore desirable that A_2 and (A_R+S_R) are equal to each other in the absolute values thereof and have signs which are reverse to each other. From the viewpoint of practical use, however, it is sufficient that $A_2/(A_R+S_R)$ is within the range defined by the condition (8).

Further, if A_R has too large a value, the other aberrations will be aggravated and can hardly be corrected. If A_R has too small a value, in contrast, it will be impossible to correct the coma produced by the front lens unit. It is therefore desirable that A_R has a value within the range defined by the condition (9).

Now description will be made on an objective optical system according to the present invention which is characterized in location of a filter. Speaking concretely, the optical system consists, in the order from the object side, of a front lens unit having negative refractive power, an aperture stop and a rear lens unit which has positive refractive power and comprises at least one positive lens component, and comprises either an infrared cut filter or a filter for shielding laser arranged immediately before the aperture stop.

By composing the objective optical system as described above, the present invention has succeeded in shortening total length of the optical system and lowering height of the ray incident on said filter, thereby obtaining high resolution.

In order to reserve a space for arranging the filter immediately before the aperture stop, it is necessary to design the front lens unit so as to satisfy the following condition (10):

$$0.3<|f_1/f|<4.0 \quad (10)$$

wherein the reference symbol f_1 represents the focal length of the front lens unit and the reference symbol f designates the focal length of the objective optical system as a whole.

If the lower limit of the condition (10) is exceeded, the airspace reserved between the rear lens unit and the front lens unit will be narrowed, thereby making it difficult to arrange the filter immediately before the aperture stop. If the upper limit of the condition (10) is exceeded, the airspace reserved between the rear lens unit and the front lens unit will be too wide, thereby undesirably prolonging the total length of the objective optical system.

Further, it is desirable that the rear lens unit satisfies the following condition (11):

$$I/f_2<0.64 \quad (11)$$

wherein the reference symbol f_2 represents the focal length of the rear lens unit and the reference symbol I designates the maximum image height.

The condition (11) is required for limiting the angle of incidence of the offaxial ray on the filter arranged immediately before the filter.

When the angle of incidence exceeds 40°, transmittance of an interference filter, which is to be used as said infrared cut filter, is abruptly enhanced for the rays in the infrared region and the filter cannot cut off these rays. Further, when an absorption filter is to be used as the infrared cut filter, optical path length in terms of glass thereof is largely different dependently on image heights, thereby producing color ununiformity on the image. Therefore, it is necessary to select a small angle of incidence on the infrared cut filter which may be either an interference filter or an absorption filter.

If the upper limit of the condition (11) is exceeded, the principal ray will have an undesirably large angle of incidence on the filter.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** shows a sectional view illustrating the conventional objective optical system for endoscopes;

FIG. **2** and FIG. **3** show sectional views illustrating examples of aspherical lens elements having aspherical surfaces on the object side;

FIG. **4** shows a curve illustrating an example of distortion;

FIG. **5** and FIG. **6** show sectional views illustrating examples of aspherical lens elements having aspherical surfaces on the image side;

FIG. **7** shows a diagram illustrating the coordinates system for the formula of aspherical surface;

FIG. **8** through FIG. **10** show sectional views illustrating examples of the front lens unit of the objective optical system according to the present invention;

FIG. **11** through FIG. **26** show sectional views illustrating Embodiments 1 through 16 of the objective optical system for endoscopes according to the present invention;

FIG. **27** through FIG. **42** show curves illustrating aberration characteristics of the Embodiments 1 through 16 of the present invention;

FIG. **43** shows a sectional view illustrating refracted condition of a ray in the objective optical system for endoscopes according to the present invention;

FIG. **44** shows curves illustrating relationship between inclination angle of the principal ray and amounts of aberrations;

FIG. **45** shows a sectional view illustrating an example of wide-angle camera lens system; and

FIG. **46** shows a sectional view illustrating refracted condition of the principal ray in the optical systems preferred as the Embodiments 5 through 10 of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Now, the present invention will be described more detailedly below with reference to the preferred embodiments shown in the accompanying drawings and given in the form of the following numerical data:

Embodiment 1

f = 1.000, F/4.7, 2ω = 106°
IH = 1.00

-continued

$r_1 = \infty$ (Aspherical surface)
$d_1 = 0.3026$ $n_1 = 1.80610$ $\nu_1 = 40.95$
$r_2 = 0.6320$
$d_2 = 0.5326$
$r_3 = 1.4455$
$d_3 = 0.2291$ $n_2 = 1.75520$ $\nu_2 = 27.51$
$r_4 = -6.7934$
$d_4 = 0.6325$ $n_3 = 1.56883$ $\nu_3 = 56.34$
$r_5 = -1.2679$
$d_5 = 0.1332$
$r_6 = \infty$ (Stop)
$d_6 = 0.1724$
$r_7 = 2.4437$
$d_7 = 0.5403$ $n_4 = 1.51633$ $\nu_4 = 64.15$
$r_8 = -1.8760$
$d_8 = 0.2195$ $n_5 = 1.84666$ $\nu_5 = 23.78$
$r_9 = -2.8190$ (Aspherical surface)
$d_9 = 0.1332$
$r_{10} = \infty$
$d_{10} = 0.9079$ $n_6 = 1.52000$ $\nu_6 = 74.00$
$r_{11} = \infty$
$d_{11} = 0.2766$
$r_{12} = \infty$
$d_{12} = 0.6053$ $n_7 = 1.51633$ $\nu_7 = 64.15$
$r_{13} = \infty$
Aspherical coefficient
(1st surface)
P = 1.0000, B = 0.23263×10^{-1}
E = 0.34082×10^{-1}, F = -0.48683×10^{-2}
(9th surface)
P = −6.7002, B = 0
E = 0.17408, F = -0.69257×10^{-1}
D_A = 0.6475, A_R = 0.00526,
$A_2/(A_R - S_R) = -0.996$

Embodiment 2

f = 1.000, F/4.5, 2ω = 113.0°
IH = 1.14

$r_1 = \infty$ (Aspherical surface)
$d_1 = 0.3459$ $n_1 = 1.80610$ $\nu_1 = 40.95$
$r_2 = 0.7439$
$d_2 = 0.3459$
$r_3 = 2.6052$
$d_3 = 0.5328$ $n_2 = 1.72825$ $\nu_2 = 28.46$
$r_4 = -0.8588$
$d_4 = 0.5535$ $n_3 = 1.58913$ $\nu_3 = 60.97$
$r_5 = 266.4111$
$d_5 = 0.0692$
$r_6 = \infty$ (Stop)
$d_6 = 0.1683$
$r_7 = 24.8283$
$d_7 = 0.4559$ $n_4 = 1.53172$ $\nu_4 = 48.90$
$r_8 = 2.0198$
$d_8 = 0.4690$ $n_5 = 1.84100$ $\nu_5 = 43.23$
$r_9 = -1.3623$ (Aspherical surface)
$d_9 = 0.1730$
$r_{10} = \infty$
$d_{10} = 1.0378$ $n_6 = 1.52000$ $\nu_6 = 74.00$
$r_{11} = \infty$
$d_{11} = 0.3407$
$r_{12} = \infty$
$d_{12} = 0.6919$ $n_7 = 1.51633$ $\nu_7 = 64.15$
$r_{13} = \infty$
Aspherical coefficient
(1st surface)
P = 1.000, B = 0.14569
E = 0.29823×10^{-1}, F = -0.13020×10^{-1}
(9th surface)
P = 1.7759, B = 0
E = 0.14285, F = 0.10574
D_A = 0.7207, A_R = 0.0025
$A_2/(A_R + S_R) = -0.596$

Embodiment 3

f = 1.000, F/4.7, 2ω = 113.0°
IH = 1.15

$r_1 = \infty$ (Aspherical surface)
$d_1 = 0.3480$ $n_1 = 1.80610$ $\nu_1 = 40.95$
$r_2 = 0.6177$
$d_2 = 0.5740$
$r_3 = 2.4828$
$d_3 = 0.5111$ $n_2 = 1.72825$ $\nu_2 = 28.46$

-continued

$r_4 = -0.6841$
$d_4 = 0.5569$ $n_3 = 1.58921$ $\nu_3 = 41.08$
$r_5 = -3.2002$
$d_5 = 0.0696$
$r_6 = \infty$ (Stop)
$d_6 = 0.1798$
$r_7 = 2.2304$
$d_7 = 0.3829$ $n_4 = 1.84666$ $\nu_4 = 23.78$
$r_8 = 1.1621$
$d_8 = 0.3921$ $n_5 = 1.51633$ $\nu_5 = 64.15$
$r_9 = -1.1830$ (Aspherical surface)
$d_9 = 0.1740$
$r_{10} = \infty$
$d_{10} = 1.0441$ $n_6 = 1.52000$ $\nu_6 = 74.00$
$r_{11} = \infty$
$d_{11} = 0.3554$
$r_{12} = \infty$
$d_{12} = 0.6961$ $n_7 = 1.51633$ $\nu_7 = 64.15$
$r_{13} = \infty$
Aspherical coefficient
(1st surface)
P = 1.0000, B = 0.11531
E = 0.26826×10^{-1}, F = 0.98377×10^{-3}
(9th surface)
P = 2.8824, B = 0, E = 0.24847
F = 0.77271, G = -0.48669×10^{-1}
D_A = 0.6457, A_R = 0.00135,
$A_2/(A_R + S_R) = -1.328$

Embodiment 4

f = 1.000, F/4.6, 2ω = 112.4°
IH = 1.12

$r_1 = \infty$ (Aspherical surface)
$d_1 = 0.3382$ $n_1 = 1.80610$ $\nu_1 = 40.95$
$r_2 = 0.7123$
$d_2 = 0.3382$
$r_3 = 4.2817$
$d_3 = 0.6242$ $n_2 = 1.72825$ $\nu_2 = 28.46$
$r_4 = -1.0308$
$d_4 = 0.5411$ $n_3 = 1.58913$ $\nu_3 = 60.97$
$r_5 = -14.9956$
$d_5 = 0.0676$
$r_6 = \infty$ (Stop)
$d_6 = 0.1112$
$r_7 = 10.0801$
$d_7 = 0.4259$ $n_4 = 1.53172$ $\nu_4 = 48.90$
$r_8 = 5.8518$
$d_8 = 0.2662$ $n_5 = 1.84100$ $\nu_5 = 43.23$
$r_9 = -1.1895$ (Aspherical surface)
$d_9 = 0.1691$
$r_{10} = \infty$
$d_{10} = 1.0146$ $n_6 = 1.52000$ $\nu_6 = 74.00$
$r_{11} = \infty$
$d_{11} = 0.3466$
$r_{12} = \infty$
$d_{12} = 0.6765$ $n_7 = 1.51633$ $\nu_7 = 64.15$
$r_{13} = \infty$
Aspherical coefficient
(1st surface)
P = 1.000, B = 0.23401
E = 0, F = 0.93316×10^{-2}
(9th surface)
P = −0.306, B = 0
E = 0.33663×10^{-1}, F = 0.51107×10^{-1}
D_A = 0.5338, A_R = −0.0108
$A_2/(A_R + S_R) = -0.502$

Embodiment 5

f = 1.000, F/4.6, 2ω = 106°
IH = 1.00

$r_1 = \infty$ (Aspherical surface)
$d_1 = 0.3026$ $n_1 = 1.80610$ $\nu_1 = 40.95$
$r_2 = 0.6333$
$d_2 = 0.5326$
$r_3 = 1.7941$
$d_3 = 0.2287$ $n_2 = 1.75520$ $\nu_2 = 27.51$
$r_4 = -2.6805$
$d_4 = 0.6325$ $n_3 = 1.56883$ $\nu_3 = 56.34$
$r_5 = -1.1728$
$d_5 = 0.1332$
$r_6 = \infty$ (Stop)
$d_6 = 0.1721$

-continued

$r_7 = 4.7481$

$d_7 = 0.5368$ $n_4 = 1.51633$ $\nu_4 = 64.15$

$r_8 = -3.0936$

$d_8 = 0.2169$ $n_5 = 1.84666$ $\nu_5 = 23.78$

$r_9 = -2.4248$ (Aspherical surface)

$d_9 = 0.1332$

$r_{10} = \infty$

$d_{10} = 0.9079$ $n_6 = 1.52000$ $\nu_6 = 74.00$

$r_{11} = \infty$

$d_{11} = 0.2713$

$r_{12} = \infty$

$d_{12} = 0.6053$ $n_7 = 1.51633$ $\nu_7 = 64.15$

$r_{13} = \infty$

Aspherical coefficient

(1st surface)

$P = 1.000.$ $B = 0.83810 \times 10^{-1}$

$E = 0.$ $F = 0.75968 \times 10^{-2}$

(9th surface)

$P = 0.3802.$ $B = 0$

$E = 0.14794.$ $F = 0.21801 \times 10^{-1}$

$D_A = 0.6436.$ $A_R = 0.00353$

$A_2/(A_R + S_R) = 1.334$

Embodiment 6

$f = 1.000.$ $F/3.7.$ $2\omega = 135.9°$

$IH = 1.41$

$r_1 = \infty$ (Aspherical surface)

$d_1 = 0.4132$ $n_1 = 1.88300$ $\nu_1 = 40.78$

$r_2 = 0.9706$

$d_2 = 0.9885$

$r_3 = 10.5419$

$d_3 = 0.8724$ $n_2 = 1.84666$ $\nu_2 = 23.78$

$r_4 = -3.2037$

$d_4 = 0.2755$

$r_5 = \infty$ (Stop)

$d_5 = 0.3449$

$r_6 = -3.5233$

$d_6 = 0.7526$ $n_3 = 1.51633$ $\nu_3 = 64.15$

$r_7 = -1.6611$

$d_7 = 0.1412$

$r_8 = 3.2843$

$d_8 = 1.1786$ $n_4 = 1.58913$ $\nu_4 = 60.97$

$r_9 = -1.2919$ (Aspherical surface)

$d_9 = 0.3673$ $n_5 = 1.84666$ $\nu_5 = 23.78$

$r_{10} = -2.2845$

$d_{10} = 0.0918$

$r_{11} = \infty$

$d_{11} = 1.3774$ $n_6 = 1.51633$ $\nu_6 = 64.15$

$r_{12} = \infty$

$d_{12} = 0.3398$

$r_{13} = \infty$

$d_{13} = 0.6428$ $n_7 = 1.51633$ $\nu_7 = 64.15$

$r_{14} = \infty$

Aspherical coefficient

(1st surface)

$P = 1.000.$ $B = 0.53237 \times 10^{-1}$

$E = 0.37136 \times 10^{-1}.$ $F = -0.10040 \times 10^{-1}$

$G = 0.13094 \times 10^{-2}$

(9th surface)

$P = 0.8681.$ $B = 0$

$E = -0.14223.$ $F = 0.39404 \times 10^{-1}$

$G = -0.62118 \times 10^{-1}$

$D_A = 1.724.$ $A_R = 0.0108$

$A_2/(A_R + S_R) = -0.605$

Embodiment 7

$f = 1.$ $F/6.065.$ $2\omega = 96°$

$r_1 = \infty$

$d_1 = 0.4484$ $n_1 = 1.51633$ $\nu_1 = 64.15$

$r_2 = 0.6543$

$d_2 = 0.3906$

$r_3 = \infty$

$d_3 = 0.9268$ $n_2 = 1.51633$ $\nu_2 = 64.15$

$r_4 = \infty$ (Stop)

$d_4 = 0.1504$

$r_5 = -2.5940$

$d_5 = 0.7961$ $n_3 = 1.88300$ $\nu_3 = 40.78$

$r_6 = -1.3698$

$d_6 = 0.1495$

$r_7 = 2.8985$

$d_7 = 0.5105$ $n_4 = 1.84666$ $\nu_4 = 23.78$

$r_8 = 1.2075$

-continued

$d_8 = 1.3163$ $n_5 = 1.58913$ $\nu_5 = 60.97$

$r_9 = -1.9538$

$d_9 = 0.1495$

$r_{10} = \infty$

$d_{10} = 0.5232$ $n_6 = 1.51633$ $\nu_6 = 64.15$

$r_{11} = \infty$

$d_{11} = 0.4683$

$r_{12} = \infty$

$d_{12} = 1.4948$ $n_7 = 1.51633$ $\nu_7 = 64.15$

$r_{13} = \infty$

$|f_1/f| = 1.267.$ $I/f_2 = 0.516.$ $D/f = 1.949$

Incidence angle in 1st filter 25.3°

Embodiment 8

$f = 1.$ $F/5.526.$ $2\omega = 120°$

$r_1 = \infty$

$d_1 = 0.5223$ $n_1 = 1.51633$ $\nu_1 = 64.15$

$r_2 = 0.6521$

$d_2 = 0.4311$

$r_3 = \infty$

$d_3 = 1.0793$ $n_2 = 1.51633$ $\nu_2 = 64.15$

$r_4 = \infty$ (Stop)

$d_4 = 0.1871$

$r_5 = -2.8407$

$d_5 = 0.9761$ $n_3 = 1.88300$ $\nu_3 = 40.78$

$r_6 = -1.7120$

$d_6 = 0.1742$

$r_7 = 2.7683$

$d_7 = 0.5818$ $n_4 = 1.84666$ $\nu_4 = 23.78$

$r_8 = 1.2503$

$d_8 = 1.5320$ $n_5 = 1.58913$ $\nu_5 = 60.97$

$r_9 = -1.9698$

$d_9 = 0.1741$

$r_{10} = \infty$

$d_{10} = 0.6093$ $n_6 = 1.51633$ $\nu_6 = 64.15$

$r_{11} = \infty$

$d_{11} = 0.5223$

$r_{12} = \infty$

$d_{12} = 1.7409$ $n_7 = 1.51633$ $\nu_7 = 64.15$

$r_{13} = \infty$

$|f_1/f| = 1.263.$ $I/f_2 = 0.533.$ $D/f = 2.246$

Incidence angle in 1st filter 28.4°

Embodiment 9

$f = 1.$ $F/3.899.$ $2\omega = 101°$

$r_1 = \infty$

$d_1 = 0.4664$ $n_1 = 1.88300$ $\nu_1 = 40.78$

$r_2 = 0.7372$

$d_2 = 0.5416$

$r_3 = \infty$

$d_3 = 0.6018$ $n_2 = 1.52287$ $\nu_2 = 59.89$

$r_4 = \infty$ (Stop)

$d_4 = 0.1505$

$r_5 = 16.9033$

$d_5 = 0.8726$ $n_3 = 1.72916$ $\nu_3 = 54.68$

$r_6 = -1.3616$

$d_6 = 0.1505$

$r_7 = \infty$

$d_7 = 0.9328$ $n_4 = 1.52000$ $\nu_4 = 74.00$

$r_8 = \infty$

$d_8 = 0.5567$

$r_9 = 2.3531$

$d_9 = 1.1886$ $n_5 = 1.60311$ $\nu_5 = 60.70$

$r_{10} = -1.4142$

$d_{10} = 0.3159$ $n_6 = 1.84666$ $\nu_6 = 23.78$

$r_{11} = -4.8145$

$d_{11} = 0.4514$

$r_{12} = \infty$

$d_{12} = 1.5045$ $n_7 = 1.51633$ $\nu_7 = 64.15$

$r_{13} = \infty$

$|f_1/f| = 0.835,$ $I/f_2 = 0.475$

$f_{21}/f_2 = 1.067,$ $f_{22}/f_2 = 2.365$

Incidence angle in 1st filter 21.7°

Embodiment 10

$f = 1.$ $F/3.870.$ $2\omega = 120°$

$r_1 = \infty$

$d_1 = 0.5072$ $n_1 = 1.88300$ $\nu_1 = 40.78$

$r_2 = 0.6938$

$d_2 = 0.6135$

$r_3 = \infty$

-continued

$d_3 = 0.6763$ $n_2 = 1.52287$ $\nu_2 = 59.89$

$r_4 = \infty$ (Stop)

$d_4 = 0.1655$

$r_5 = 5.1647$

$d_5 = 0.9875$ $n_3 = 1.72916$ $\nu_3 = 54.68$

$r_6 = -1.8356$

$d_6 = 0.1836$

$r_7 = \infty$

$d_7 = 1.0482$ $n_4 = 1.52000$ $\nu_4 = 74.00$

$r_8 = \infty$

$d_8 = 0.6401$

$r_9 = 2.2962$

$d_9 = 1.3483$ $n_5 = 1.60311$ $\nu_5 = 60.70$

$r_{10} = -1.3264$

$d_{10} = 0.4923$ $n_6 = 1.84666$ $\nu_6 = 23.78$

$r_{11} = -4.0870$

$d_{11} = 0.5072$

$r_{12} = \infty$

$d_{12} = 1.6907$ $n_7 = 1.51633$ $\nu_7 = 64.15$

$r_{13} = \infty$

$|f_1/f| = 0.786$, $I/f_2 = 0.447$

$f_{21}/f_2 = 0.999$, $f_{22}/f_2 = 1.844$

Incidence angle in 1st filter 22.3°

Embodiment 11

f = 1, F/4.067, $2\omega = 120.2°$

$r_1 = 16.8803$ (Aspherical surface)

$d_1 = 0.6472$ $n_1 = 1.51633$ $\nu_1 = 64.15$

$r_2 = 0.8621$

$d_2 = 0.5965$

$r_3 = \infty$

$d_3 = 1.4574$ $n_2 = 1.51633$ $\nu_2 = 64.15$

$r_4 = \infty$ (Stop)

$d_4 = 0.2687$

$r_5 = -3.9741$

$d_5 = 1.1815$ $n_3 = 1.88300$ $\nu_3 = 40.78$

$r_6 = -2.0865$

$d_6 = 0.2127$

$r_7 = 3.6172$

$d_7 = 0.2687$ $n_4 = 1.84666$ $\nu_4 = 23.78$

$r_8 = 1.5713$

$d_8 = 1.7548$ $n_5 = 1.58913$ $\nu_5 = 60.97$

$r_9 = -1.8576$ (Aspherical surface)

$d_9 = 0.1221$

$r_{10} = \infty$

$d_{10} = 0.7327$ $n_6 = 1.51633$ $\nu_6 = 64.15$

$r_{11} = \infty$

$d_{11} = 0.5129$

$r_{12} = \infty$

$d_{12} = 1.6486$ $n_7 = 1.51633$ $\nu_7 = 64.15$

$r_{13} = 28$

Aspherical coefficient

(1st surface)

$P = 1.0000$, $B = 0$, $E = 0.88523 \times 10^{-2}$

$F = 0.92065 \times 10^{-4}$

(9th surface)

$P = 1.0000$, $B = 0$, $E = 0.28532 \times 10^{-1}$

$F = -0.12887 \times 10^{-2}$

$|f_1/f| = 1.784$, $I/f_2 = 0.606$, $D/f = 2.205$

$f_2/f = 1.830$, $\theta/0.64$ (rad) = 1.636, $D_A = 2.359$

Incidence angle in 1st filter 33.8°

Embodiment 12

f = 1, F/3.890, $2\omega = 120°$

$r_1 = 21.4252$ (Aspherical surface)

$d_1 = 0.6582$ $n_1 = 1.51633$ $\nu_1 = 64.15$

$r_2 = 0.7634$

$d_2 = 0.5806$

$r_3 = \infty$

$d_3 = 1.3603$ $n_2 = 1.51633$ $\nu_2 = 64.15$

$r_4 = \infty$ (Stop)

$d_4 = 0.2327$

$r_5 = -1.8851$

$d_5 = 1.2486$ $n_3 = 1.88300$ $\nu_3 = 40.78$

$r_6 = -1.9074$

$d_6 = 0.1586$

$r_7 = 3.3202$ (Aspherical surface)

$d_7 = 0.3151$ $n_4 = 1.84666$ $\nu_4 = 23.78$

$r_8 = 2.0796$

$d_8 = 1.7611$ $n_5 = 1.58913$ $\nu_5 = 60.97$

$r_9 = -2.2592$

$d_9 = 0.2194$

-continued

$r_{10} = \infty$

$d_{10} = 0.7679$ $n_6 = 1.51633$ $\nu_6 = 64.15$

$r_{11} = \infty$

$d_{11} = 0.6582$

$r_{12} = \infty$

$d_{12} = 2.1426$ $n_7 = 1.51633$ $\nu_7 = 64.15$

$r_{13} = \infty$

Aspherical coefficient

(1st surface)

$P = 1.0000$, $B = 0$, $E = 0.22760 \times 10^{-1}$

$F = -0.71077 \times 10^{-3}$

(7th surface)

$P = 1.0000$, $B = 0$, $E = -0.20373 \times 10^{-1}$

$F = 0.15996 \times 10^{-2}$

$|f_1/f| = 1.55$, $I/f_2 = 0.619$, $D/f = 2.797$

$f_2/f = 1.849$, $\theta/0.64$ (rad) = 1.636, $D_A = 1.054$

Incidence angle in 1st filter 36.1°

Embodiment 13

f = 1, F/4.186, $2\omega = 117.40°$

$r_1 = 12.9649$ (Aspherical surface)

$d_1 = 0.6251$ $n_1 = 1.51633$ $\nu_1 = 64.15$

$r_2 = 0.7064$

$d_2 = 0.5202$

$r_3 = \infty$

$d_3 = 1.3014$ $n_2 = 1.51633$ $\nu_2 = 64.15$

$r_4 = \infty$ (Stop)

$d_4 = 0.2287$

$r_5 = -4.1941$

$d_5 = 1.1762$ $n_3 = 1.88300$ $\nu_3 = 40.78$

$r_6 = -1.8012$ (Aspherical surface)

$d_6 = 0.2733$

$r_7 = 3.3810$

$d_7 = 0.662$ $n_4 = 1.84666$ $\nu_4 = 23.78$

$r_8 = 1.4568$

$d_8 = 1.7429$ $n_5 = 1.58913$ $\nu_5 = 60.97$

$r_9 = -2.1536$

$d_9 = 0.2084$

$r_{10} = \infty$

$d_{10} = 0.5000$ $n_6 = 1.51633$ $\nu_6 = 64.15$

$r_{11} = \infty$

$d_{11} = 0.4000$

$r_{12} = \infty$

$d_{12} = 1.4000$ $n_7 = 1.51633$ $\nu_7 = 64.15$

$r_{13} = \infty$

Aspherical coefficient

(1st surface)

$P = 1.0000$, $B = 0$, $E = 0.16198 \times 10^{-1}$

$F = -0.13555 \times 10^{-3}$

(6th surface)

$P = 1.0000$, $B = 0$, $E = 0.18395 \times 10^{-1}$

$F = -0.51972 \times 10^{-2}$

$|f_1/f| = 1.472$, $I/f_2 = 0.574$, $D/f = 1.861$

$f_2/f = 1.833$, $\theta/0.64$ (rad) = 1.601, $D_A = 0.8533$

Incidence angle in 1st filter 32.7°

Embodiment 14

f = 1, F/3.946, $2\omega = 120°$

$r_1 = 21.7083$ (Aspherical surface)

$d_1 = 0.6811$ $n_1 = 1.88300$ $\nu_1 = 40.78$

$r_2 = 0.8528$

$d_2 = 0.8649$

$r_3 = \infty$

$d_3 = 0.9082$ $n_2 = 1.52287$ $\nu_2 = 59.89$

$r_4 = \infty$ (Stop)

$d_4 = 0.1864$

$r_5 = 13.6166$

$d_5 = 1.3061$ $n_3 = 1.72916$ $\nu_3 = 54.68$

$r_6 = -2.5071$

$d_6 = 0.1074$

$r_7 = \infty$

$d_7 = 1.4076$ $n_4 = 1.52000$ $\nu_4 = 74.00$

$r_8 = \infty$

$d_8 = 0.6826$

$r_9 = 2.8757$

$d_9 = 1.7932$ $n_5 = 1.60311$ $\nu_5 = 60.70$

$r_{10} = -1.9781$

$d_{10} = 0.5167$ $n_6 = 1.84666$ $\nu_6 = 23.78$

$r_{11} = -3.3410$ (Aspherical surface)

$d_{11} = 0.6811$

$r_{12} = \infty$

$d_{12} = 2.2705$ $n_7 = 1.51633$ $\nu_7 = 64.15$

-continued

$r_{13} = \infty$
Aspherical coefficient
(1st surface)
P = 1.0000, B = 0, E = 0.32789×10^{-1}
F = -0.49161×10^{-2}
(11th surface)
P = 1.000, B = 0, E = 0.22862×10^{-1}
F = -0.22050×10^{-2}
$|f_1/f| = 0.980$, $I/f_2 = 0.444$
$f_{21}/f_2 = 1.125$, $f_{22}/f_2 = 1.243$
$f_2/f = 2.671$, $\theta/0.64$ (rad) = 1.636, $D_A = 4.056$
Incidence angle in 1st filter 26.6°

Embodiment 15

f = 1, F/4.042, $2\omega = 120°$

$r_1 = 60.9504$ (Aspherical surface)			
	$d_1 = 0.7005$	$n_1 = 1.88300$	$\nu_1 = 40.78$
$r_2 = 0.9640$			
	$d_2 = 0.8875$		
$r_3 = \infty$			
	$d_3 = 0.8929$	$n_2 = 1.52287$	$\nu_2 = 59.89$
$r_4 = \infty$ (Stop)			
	$d_4 = 0.2273$		
$r_5 = 19.0928$			
	$d_5 = 1.3545$	$n_3 = 1.72916$	$\nu_3 = 54.68$
$r_6 = -2.4303$			
	$d_6 = 0.0962$		
$r_7 = \infty$			
	$d_7 = 1.3736$	$n_4 = 1.52000$	$\nu_4 = 74.00$
$r_8 = \infty$			
	$d_8 = 0.3336$		
$r_9 = 2.8398$ (Aspherical surface)			
	$d_9 = 1.5085$	$n_5 = 1.60311$	$\nu_5 = 60.70$
$r_{10} = -1.6896$			
	$d_{10} = 0.4377$	$n_6 = 1.84666$	$\nu_6 = 23.78$
$r_{11} = -3.2673$			
	$d_{11} = 0.7074$		
$r_{12} = \infty$			
	$d_{12} = 2.2115$	$n_7 = 1.51633$	$\nu_7 = 64.15$

$r_{13} = \infty$
Aspherical coefficient
(1st surface)
P = 1.0000, B = 0, E = 0.39178×10^{-1}
F = -0.57259×10^{-2}
(9th surface)
P = 1.0000, B = 0, E = -0.25386×10^{-1}
F = 0.42102×10^{-2}
$|f_1/f| = 1.115$, $I/f_2 = 0.520$
$f_{21}/f_2 = 1.303$, $f_{22}/f_2 = 1.503$
$f_2/f = 2.230$, $\theta/0.64$ (rad) = 1.636, $D_A = 2.344$
Incidence angle in 1st filter 29.5°

Embodiment 16

f = 1, F/4.251, $2\omega = 120°$

$r_1 = 7.0860$ (Aspherical surface)			
	$d_1 = 0.6742$	$n_1 = 1.88300$	$\nu_1 = 40.78$
$r_2 = 0.7395$			
	$d_2 = 0.8285$		
$r_3 = \infty$			
	$d_3 = 0.8699$	$n_2 = 1.52287$	$\nu_2 = 59.89$
$r_4 = \infty$ (Stop)			
	$d_4 = 0.2611$		
$r_5 = -29.5060$			
	$d_5 = 1.3439$	$n_3 = 1.72916$	$\nu_3 = 54.68$
$r_6 = -1.7847$ (Aspherical surface)			
	$d_6 = 0.1810$		
$r_7 = \infty$			
	$d_7 = 1.3484$	$n_4 = 1.52000$	$\nu_4 = 74.00$
$r_8 = \infty$			
	$d_8 = 0.7682$		
$r_9 = 3.8053$			
	$d_9 = 1.6352$	$n_5 = 1.60311$	$\nu_5 = 60.70$
$r_{10} = -1.6747$			
	$d_{10} = 0.3262$	$n_6 = 1.84666$	$\nu_6 = 23.78$
$r_{11} = -3.2953$			
	$d_{11} = 0.5655$		
$r_{12} = \infty$			
	$d_{12} = 2.1748$	$n_7 = 1.51633$	$\nu_7 = 64.15$

$r_{13} = \infty$
Aspherical coefficient
(1st surface)
P = 1.0000, B = 0, E = 0.24264×10^{-1}
F = -0.83617×10^{-3}
(6th surface)
P = 1.0000, B = 0, E = 0.14631×10^{-1}
F = -0.72865×10^{-2}
$|f_1/f| = 0.984$, $I/f_2 = 0.456$
$f_{21}/f_2 = 1.026$, $f_{22}/f_2 = 1.605$
$f_2/f = 2.489$, $\theta/0.64$ (rad) = 1.636, $D_A = 1.038$
Incidence angle in 1st filter 28.2°

wherein the reference symbol r_1, r_2, . . . represent radii of curvature on the surfaces of the respective lens elements, the reference symbols d_1, d_2, . . . designate thicknesses of the respective lens elements and the airspaces reserved therebetween, the reference symbols n_1, n_2, . . . denote refractive indices of the respective lens elements, and the reference symbols ν_1, ν_2, . . . represent Abbe's numbers of the respective lens elements.

The Embodiments 1 through 6 have the compositions illustrated in FIG. **11** through FIG. **16** respectively.

Out of these embodiments, each of the Embodiments 1 through 5 comprises a positive lens component which is arranged in the front lens unit before the aperture stop and designed as a cemented doublet satisfying the condition (3).

The Embodiments 7 and 8 have the compositions illustrated in FIG. **17** and FIG. **18** respectively wherein an absorption filter for cutting off the infrared rays is arranged immediately before the aperture stop and an interference filter for cutting off laser is arranged after the cemented doublet. The Embodiment 7 and 8 satisfy the following condition (12) in addition to the conditions (10) and (11):

$$1.0 < D/f < 5.0 \quad (12)$$

wherein the reference symbol D represents the optical path length as measured from the image side surface of the cemented doublet to a solid-state image pickup device.

The condition (12) defines the airspace required for arranging the filter arranged after the cemented doublet. If the lower limit of the condition (12) is exceeded while maintaining a short total length of the objective optical system, it will be impossible to reserve the airspace for arranging the filter and each lens surface will have strengthened power, thereby making it difficult to correct aberrations. If the upper limit of the condition (12) is exceeded, the airspace reserved between the optical system and the solid-state image pickup device will be too wide and the total length of the optical system will be prolonged.

The Embodiments 7 and 8 satisfy the conditions (10) through (12). Further, in the Embodiment 7, the offaxial principal ray has an angle of incidence of 25.3° on the front filter and an angle of incidence of 5.6° on the rear filter. Furthermore, when image height on the solid-state image pickup device is taken as 1, height of the offaxial principal ray on the absorption filter used as the infrared cut filter is approximately 0.35. In the Embodiment 8, the offaxial principal ray has an angle of incidence of 28.4° on the front filter and an angle of incidence of 2.5° on the rear filter, and height of the offaxial principal ray on the infrared cut filter is approximately 0.4 when the image height on the solid-state image pickup device is taken as 1.

The Embodiments 7 and 8 are designed so as to satisfy the conditions (10) through (12), and have short

total lengths, small angles of incidence on the filters or low heights of rays, and favorably corrected aberrations.

The Embodiments 9 and 10 have the compositions illustrated in FIG. **19** and FIG. **20** respectively, in each of which an interference filter for cutting off laser is arranged immediately before the aperture stop, and an absorption filter for cutting off the infrared rays is arranged between the positive lens component and the cemented doublet.

The Embodiments 9 and 10 satisfy the following conditions (13) and (14) in addition to the conditions (10) and (11):

$$0.5<f_{21}/f_2<3.0 \quad (13)$$

$$0.5<f_{22}/f_2<5.0 \quad (14)$$

wherein the reference symbol f_{21} represents the focal length of the positive lens component arranged immediately after the aperture stop and the reference symbol f_{22} designates the focal length of the cemented doublet.

The condition (13) is required for lowering the heights of the rays incident on the filter arranged after the aperture stop and the cemented doublet. The airspace reserved between the positive lens component arranged immediately after the aperture stop and the cemented doublet is defined by satisfying the conditions (13) and (14).

If the upper limit of the condition (13) is exceeded, the rays incident on the filter arranged after the aperture stop and the cemented doublet are enhanced, thereby making it necessary to enlarge the diameter of the lens system and making the lens system unsuited for use as an objective lens system for endoscopes. Further, ray incident on the cemented doublet is enhanced, thereby making it difficult to correct coma.

If the lower limit of the condition (14) is exceeded, the positive lens component arranged immediately after the aperture stop will have too strong power and produce spherical aberration.

In order to lower the height of the rays incident on the filter arranged after the aperture stop and the cemented doublet, and to make the optical system compact, it is desirable to design the objective optical system so as to satisfy the conditions (13) and (14).

In the Embodiment 9, the offaxial principal ray has an angle of incidence of 21.7° on the filter arranged before the aperture stop and an angle of incidence of 13.7° on the filter arranged after the aperture stop, and the image height on the infrared cut filter is approximately 0.55 when the image height on the solid-state image pickup device is taken as 1.

In the Embodiment 10, the offaxial principal ray has an angle of incidence of 22.3° on the front filter and an angle of incidence of 14.9° on the rear filter, and height of the offaxial principal ray on the infrared cut filter is approximately 0.6 when the height of the offaxial ray on the solid-state image pickup device is taken as 1.

As is understood from the foregoing description, the Embodiments 9 and 10 which are designed so as to satisfy the conditions (10), (11), (13) and (14) are optical systems having short total lengths, small angles of incidence on the filters or low heights of rays, and favorably corrected aberrations.

The Embodiments 11, 12 and 13 have the compositions illustrated in FIG. **21** through FIG. **23**, are of the type similar to the Embodiments 9 and 10, and use two aspherical surfaces respectively.

The Embodiments 7 through 10 are of the type consisting only of spherical lens elements. In the objective optical system of this type or the optical system shown in FIG. **43**, comparison between inclination angle θ relative to the optical axis of the principal ray P which is incident on the lens component L_1 arranged on the object side of the aperture stop and inclination angle θ' relative to the optical axis of the principal ray P which emerges from the lens component L_1 and is incident on the lens unit L_2 (comprising at least one positive lens component) located on the image side of the aperture stop, will clarify that θ' is prettily smaller than θ. This is apparent also from the fact that the lens component L_1 has a negative function for widening the field angle.

In the optical system having the above-described characteristic, it is known that there establishes between θ' and aberrations the relationship described below. When θ' is small, curvature of field, astigmatism and distortion are produced in small amounts, whereas spherical aberration is produced in a relatively large amount. FIG. **44** illustrates this relationship. Accordingly, it is sufficient that spherical aberration and coma are corrected when the pupil located between the lens unit L_2 having positive refractive power and the lens component L_1 having positive refractive power is considered as an object, and that the sine condition is satisfied.

The sine condition is described as follows:

When image height is represented by I, the focal length of the lens unit L_2 is designated by f_2 and the inclination angle of the principal ray P incident on the lens unit L_2 relative to the optical axis is denoted by θ', the following formula establishes in a telecentric optical system wherein the principal ray P is incident perpendicularly on the image surface I:

$$I=f_2\sin\theta'$$

When the lens component L_1 consists only of spherical lens elements as shown in FIG. **43**, departure from the sine condition is little even before the aperture stop S. Accordingly, the following formula of the sine condition establishes:

$$I=f\sin\theta$$

wherein the reference symbol f represents the focal length of the objective optical system as a whole and the reference symbol θ designates the inclination angle of the principal ray P incident on the lens component L_1 relative to the optical axis.

Under the restrictions imposed on outside diameters of lens systems and numbers of lens elements, the sine condition is nearly satisfied by almost all of the objective optical systems for endoscopes which are used currently.

In the optical systems satisfying the sine condition, distortion increases abruptly as θ is widened as illustrated in FIG. **44**. Relationship between distortion and θ can be expressed by the following formula:

$$DT(\theta)=\cos\theta-1$$

wherein the reference symbol DT represents a value given by the following formula:

$DT=(y-y_0)/y_0\times 100\ (\%)$

wherein the reference symbol y represents size of an image deformed due to distortion and the reference symbol y_0 designates size of an ideal image calculated by the paraxial theory.

In an ordinary objective optical system for endoscopes to which the formula of the sine condition and formula of distortion DT(θ) apply, negative distortion (barrel-type distortion) increases abruptly as θ is enlarged.

Values of DT(θ) corresponding to various field angles 2θ in an objective optical system satisfying $I=f\sin\theta$ are tabulated below:

Field angle 2θ	80°	100°	120°	140°
Distortion DT(θ)	−23	−36	−50	−66 (%)

As is understood from the foregoing description, the conventional objective optical systems produce remarkable negative distortion though the optical systems satisfy the sine condition for meeting the essential requirements for objective optical systems for endoscopes, or the optical systems have wide field angles, telecentric compositions, favorably corrected aberrations and compact designs.

When an object is observed through the objective optical systems for endoscopes which produce distortion as described above, the marginal portions of images are distorted and smaller than the central portions. Accordingly, such optical systems do not permit accurate measurements or analyses of forms of industrial products when the optical systems are applied to industrial inspections. Further such objective optical system may be causes of erroneous diagnoses when applied in the medical field.

Furthermore, the following formula establishes for the optical systems which produce little distortion, for example, the wide-angle photographic camera lens system illustrated in FIG. **45**:

$$I=f\tan\theta$$

In an optical system for which the above-mentioned formula establishes, light amount on the image surface is reduced at a rate of $\cos^4\theta$ as value of θ increases. In case of the conventional objective optical system for endoscopes which produces the negative distortion, however, image size is reduced from the central portion toward the marginal portion, thereby cancelling the reduction of light amount at the rate of $\cos^4\theta$. Accordingly, brightness is kept constant regardless of enlargement of θ in the optical system satisfying $I=f\sin\theta$.

The objective optical system for endoscopes satisfying the sine condition has a characteristic that brightness is constant over the entire range of an image from the center to the marginal portion thereof. However, this optical system is undesirable in that it has distortion. In the optical system satisfying $I=f\sin\theta$, it is therefore necessary to correct the distortion to the level similar to that produced in an optical system satisfying the relationship of $I=f\theta$.

Distortion DT(θ) corresponding to various values of 2θ of the optical system satisfying $I=f\theta$ are tabulated below:

Field angle 2θ	80°	100°	120°	140°
Distortion DT(θ)	−17	−27	−39.5	−55.5 (%)

The Embodiments 11 through 16 are objective optical systems for endoscopes which are designed so as to have distortion corrected to levels sufficient for practical use regardless of large field angles, in addition to the merits of the Embodiments 7 through 10, and obtain image brightness substantially constant from the center to the marginal portion of images. The Embodiments 11 through 16 use aspherical surfaces for obtaining the above-described merits. Speaking concretely, the Embodiments 11 through 16 use the aspherical surfaces in the optical system shown in FIG. **46** so as to satisfy the following formulae (iv) and (v):

$$I=f_2\sin\theta_2 \tag{iv}$$

$$I=f\theta_2 \tag{v}$$

The formula (iv) is a condition required for correcting spherical aberration, coma, etc., and applies to the rear lens unit arranged after the aperture stop.

Accordingly, distortion is produced in the rear lens units of the Embodiments 11 through 16 as θ_2 is enlarged, but the distortion is not produced so remarkably since θ_2 has small values. Further, the optical system satisfying the formula (iv) provides brightness which is constant from the center of an image to the marginal portion thereof regardless of enlargement of θ_2.

The formula (v) applies to an optical system which satisfies $I=f\theta$ and produces little distortion.

The objective optical systems preferred as the Embodiments 11 through 16 are adapted so as to correct distortion to a level sufficient for practical use and provide images having constant brightness from the center to the marginal portion thereof by designing an optical system having a front negative lens unit which is arranged after the pupil position S and satisfies $I=f\sin\theta_1$ so as to satisfy $I=f\theta$ through use of aspherical surfaces without departing from the sine condition $I=f_2\sin\theta_2$.

In addition, the aspherical surfaces have shapes which are expressed by the above-mentioned formula (i).

The Embodiments 11 through 16 satisfy the following conditions (15) in addition to the conditions (10) and (11):

$$f_2/f>\theta(rad)/0.64 \tag{15}$$

wherein the reference symbol θ represents the half field angles of the objective optical systems for endoscopes.

The condition (15) defines the angle of the ray incident on the filter arranged immediately before the aperture stop when the aspherical surfaces are arranged in the objective optical systems for correction of distortion.

If f_2/f is smaller than θ(rad)/0.64 in the condition (15), the ray incident on said filter will undesirably have a large angle of incidence.

The Embodiments 11 through 13 satisfy the conditions (10), (11), (12) and (15), whereas the Embodiments 14 through 16 satisfy the conditions (10), (11), (13) and (14). All of these embodiments have short total lengths, small angles of incidence on the filters, distortion corrected to levels sufficient for practical use and provide

brightness constant from the centers to the marginal portions of images.

The present invention has succeeded in providing an objective optical system for endoscopes which has a compact size, a wide field angle and favorably corrected distortion by adequately arranging aspherical surfaces. Further, the present invention makes it possible to lower height of the ray incident on the filter relative to the outside diameter of the filter, thereby providing an objective optical system for endoscopes having high resolution.

The objective optical system according to the present invention is designed for use in distal ends of endoscopes, and owing to the characteristics described above, contributes to more compact designs of distal ends of endoscopes and improvement of qualities of images formed by optical systems for endoscopes.

We claim:

1. An imaging optical system for endoscopes comprising:

an objective lens system comprising a front lens unit consisting of a lens component having negative refractive power and a cemented lens component having positive refractive power, an aperture stop and a rear lens unit including only one lens component, said one lens component being a cemented lens component having a positive refractive power,

an electronic image pickup means for receiving images formed by said objective lens system, and

a filter for eliminating infrared light and a properly limiting spectral sensitivity of said electronic image pickup means,

wherein each of said front unit and said rear lens unit including at least one aspherical surface, said front lens unit satisfying one of the following conditions (A) and (B), said rear lens unit satisfying one of the following conditions (C) and (D), and said objective lens system satisfying the following condition (E):

(A) the front lens unit includes, as an object side surface, an aspherical surface which has a shape including portions having curvature that is progressively enhanced as the portions are farther from the optical axis of said objective lens system;

(B) the front lens unit includes, as an image side surface, an aspherical surface which has a shape including portions having curvature that is progressively lowered as the portions are farther from the optical axis of said objective lens system;

(C) the rear lens unit includes, as an object side surface, an aspherical surface which has a shape including portions having curvature that is progressively lowered as the portions are farther from the optical axis of said objective lens system;

(D) the rear lens unit includes, as an image side surface, an aspherical surface which has a shape including portions having curvature that is progressively enhanced as the portions are farther away from the optical axis of the objective lens system; and

(E) $0.2f < D_A < 8f$

wherein the reference symbol D_A represents an optical path length as measured from the aperture stop to the aspherical surface disposed in said rear lens unit.

2. An objective optical system for endoscopes according to claim **1** which said aspherical surface is expressed by the formula given below and satisfies the following conditions:

$$x = \frac{C_1^2}{1 + \sqrt{1 - pC^2y^2}} + By^2 + Ey^4 + Fy^6 + Gy^8 + \ldots$$

$$0.0006/f^3 < E < 0.6/f^3$$
$$0.0001/f^5 < F < 0.1/f^5$$

wherein the reference symbols x and y represent coordinates values when the optical axis is taken as the abscissa, the direction toward the image is taken as positive, the intersection between the optical axis and the aspherical surface is taken as the origin, and the direction perpendicular to the abscissa is taken as the ordinate, the reference symbol C designates the inverse number of the radius of curvature of the circle in contact with the aspherical surface in the vicinity of the optical axis, the reference symbol p denotes the conical constant, and the reference symbols B, E, F, G, . . . represent the aspherical surface coefficients of the second order, fourth order, sixth order and eighth order respectively.

3. An objective optical system for endoscopes according to claim **1** wherein said aspherical surfaces arranged in the front lens unit satisfies the following conditions:

$$-13 < A_2/(A_R + S_R) < -0.03$$

$$-0.2 < A_R < 0.2$$

wherein the reference symbol S_R represents the total sum of the coefficients of coma of the third order to be produced by the reference spheres for the aspherical surfaces, the reference symbol A_R designates the total sum of the coefficients of coma to be produced due to the departure of the aspherical surfaces from the reference spheres therefor and the reference symbol A_2 denotes the total sum of the coefficients of coma of the third order to be produced by the surfaces having negative refractive powers in the front lens unit.

4. An endoscope equipped with an objective optical system in the distal end thereof, said objective optical system consisting of, in the order from the object side,

a negative lens component,

an infrared light cut filter,

an aperture stop, and

a positive lens unit comprising at least one positive lens component.

5. An endoscope according to claim **4** satisfying the following condition (10):

$$0.3 < |f_1/f| < 4.0 \quad (10)$$

wherein the reference symbol f_1 represents the focal length of said negative lens unit and the reference symbol f designates the focal length of said optical system as a whole.

6. An endoscope according to claim **4** or **5** wherein another filter is arranged on the image side of the lens component arranged in said positive lens unit at a location nearest said aperture stop.

7. An endoscope according to claim **6** satisfying the following condition (11):

$I/f_2 < 0.64$ (11)

wherein the reference symbol f_2 represents the focal length of the rear lens unit and the reference symbol I designates the maximum image height.

8. An endoscope according to claim 7 comprising a solid-state image pickup device on the exit side of said objective optical system and satisfying the following condition (12):

$$1.0 < D/f < 5.0 \quad (12)$$

wherein the reference symbol D represents the optical path length as measured from the extremely image side surface of the objective optical system to the solid-state image pickup device.

9. An endoscope according to claim 7 wherein said objective optical system satisfies the following conditions (13) and (14):

$$0.5 < f_{21}/f_2 < 3.0 \quad (13)$$

$$0.5 < f_{22}/f_2 < 5.0 \quad (14)$$

wherein the reference symbol f_{21} represents the focal length of the lens element arranged on the extremely object side in said positive lens unit and the reference symbol f_{22} designates the total focal length of the lens components arranged on the image side of said another filter.

10. An endoscope according to claim 7 comprising at least one aspherical surface in said objective optical system satisfying the following condition (15):

$$f_2/f < \theta/0.64 \quad (15)$$

wherein reference symbol f represents the focal length of the objective optical system as a whole, reference symbol f_2 designates the focal length of the rear lens unit and reference symbol θ denotes the half field angle of the objective optical system.

11. An endoscope according to claim 8 comprising at least one aspherical surface in said objective optical system satisfying the following condition (15):

$$f_2/f < \theta/0.64 \quad (15)$$

wherein reference symbol f represents the focal length of the objective optical system as a whole, reference symbol f_2 designates the focal length of the rear lens unit and reference symbol θ denotes the half field angle of the objective optical system.

12. An endoscope according to claim 9 comprising at least one aspherical surface in said objective optical system satisfying the following condition (15):

$$f_2/f < \theta/0.64 \quad (15)$$

wherein reference symbol f represents the focal length of the objective optical system as a whole, reference symbol f_2 designates the focal length of the rear lens unit and reference symbol θ denotes the half field angle of the objective optical system.

13. An imaging optical system for endoscopes comprising:

an objective lens system comprising a front lens unit consisting of a lens component having negative refractive power and a lens component having positive refractive power, an aperture stop and a rear lens unit consisting of a lens component having positive refractive power and a cemented lens component having a positive refractive power,

an electronic image pickup means for receiving images formed by said objective lens system, and

a filter for eliminating infrared light and properly limiting spectral sensitivity of said electronic image pickup means,

wherein each of said front lens unit and said rear lens unit includes at least one aspherical surface, said front lens unit satisfying one of the following conditions (A) and (B), said rear lens unit satisfying one of the following conditions (C) and (D), and said objective lens system satisfying the following condition (E):

(A) the front lens unit includes, as an object side surface, an aspherical surface which has a shape including portions having curvature that is progressively enhanced as the portions are farther from the optical axis of said objective lens system;

(B) the front lens unit includes, as an image side surface, an aspherical surface which has a shape including portions having curvature that is progressively lowered as the portions are farther from the optical axis of said objective lens system;

(C) the rear lens unit includes, as an object side surface, an aspherical surface which has a shape including portions having curvature that is progressively lowered as the portions are farther from the optical axis of said objective lens system;

(D) the rear lens unit includes, as an image side surface, an aspherical surface which has a shape including portions having curvature that is progressively enhanced as the portions are farther away from the optical axis of the objective lens system; and

(E) $0.2f < D_A < 8f$

wherein the reference symbol D_A represents an optical path length as measured from the aperture stop to the aspherical surface disposed in said rear lens unit.

* * * * *

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United States Patent [19]

Humphrey

[11] Patent Number: 5,157,427

[45] Date of Patent: Oct. 20, 1992

[54] **OBJECTIVE REFRACTOR**

[75] Inventor: **William E. Humphrey**, Oakland, Calif.

[73] Assignee: **Allergan Humphrey**, San Leandro, Calif.

[21] Appl. No.: **510,348**

[22] Filed: **Apr. 16, 1990**

[51] **Int. Cl.**[5] **A61B 3/10**

[52] **U.S. Cl.** **351/205**; 351/211

[58] **Field of Search** 351/205, 206, 211, 212, 351/221, 234

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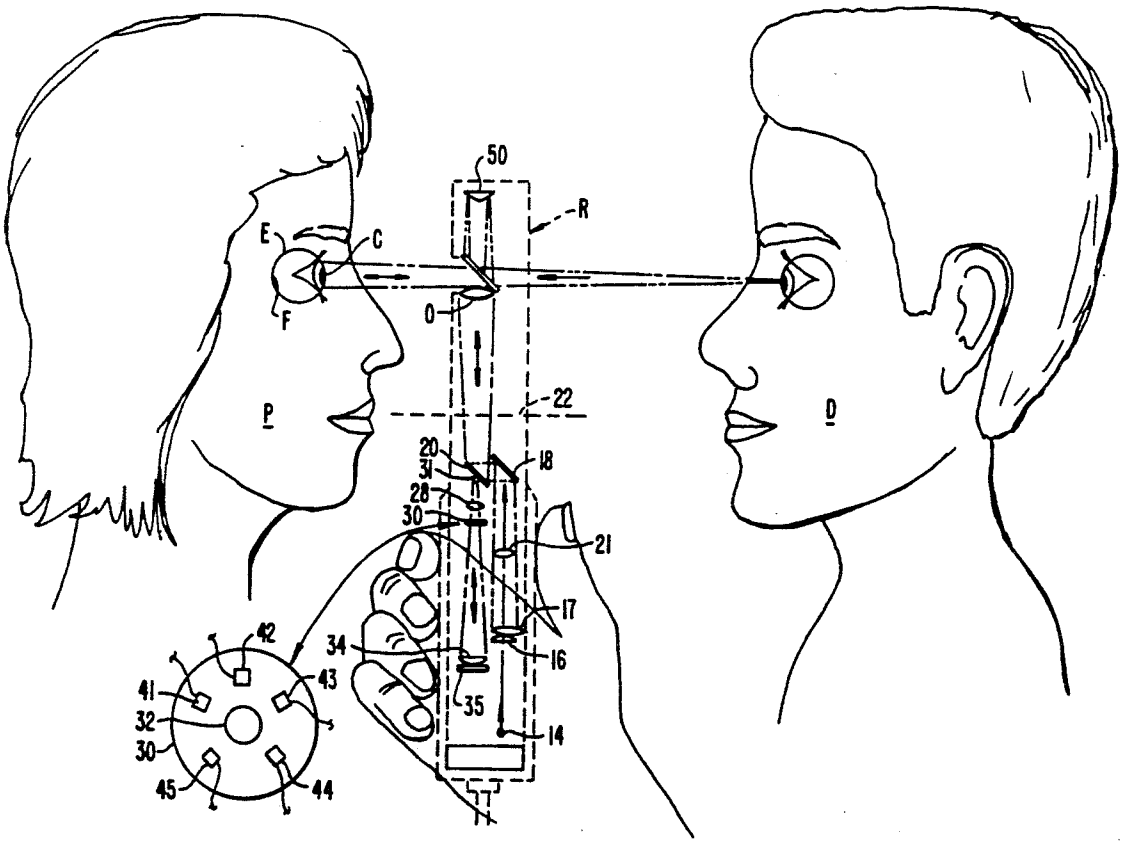
Primary Examiner—Paul M. Dzierzynski

Attorney, Agent, or Firm—Townsend and Townsend

[57] **ABSTRACT**

An objective refractor having no moving parts is disclosed. The refractor, which can be either a hand held or table mounted instrument, includes a reference array and an interrogating array projected onto the eye fundus. The reference array is projected from light sources and the interrogating array is projected to light detectors. Both the reference array and the interrogating array are projected onto the fundus of the eye through preselected spaced apart regions of the eye lens. The movement of the reference array with respect to the interrogating array is observed. By the expedient of making at least two sequential observations utilizing at least three separate regions of the eye lens, the amount of relative pattern displacements can be reduced to a requisite optical prescription for the eye.

29 Claims, 15 Drawing Sheets



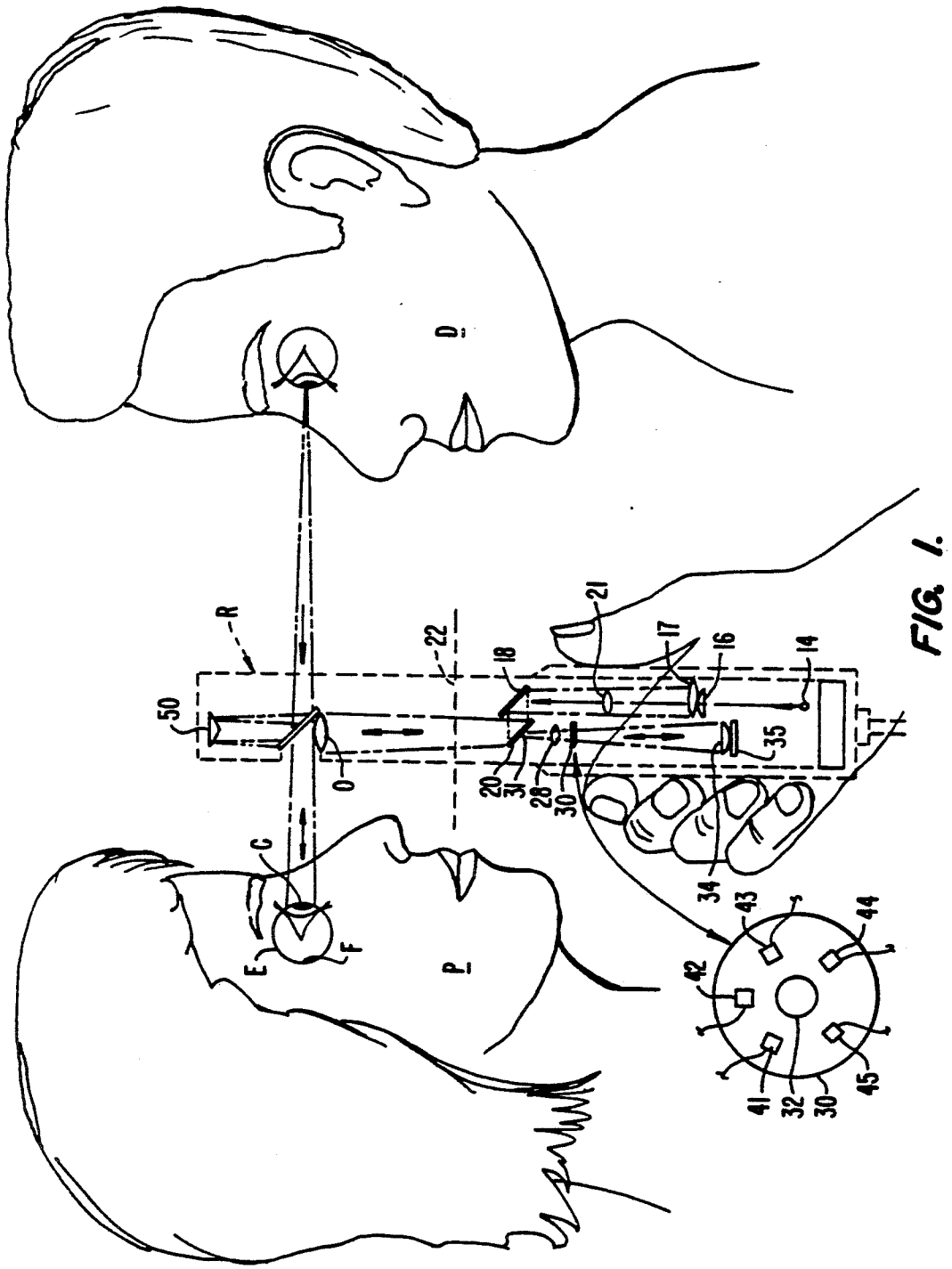


FIG. 1.

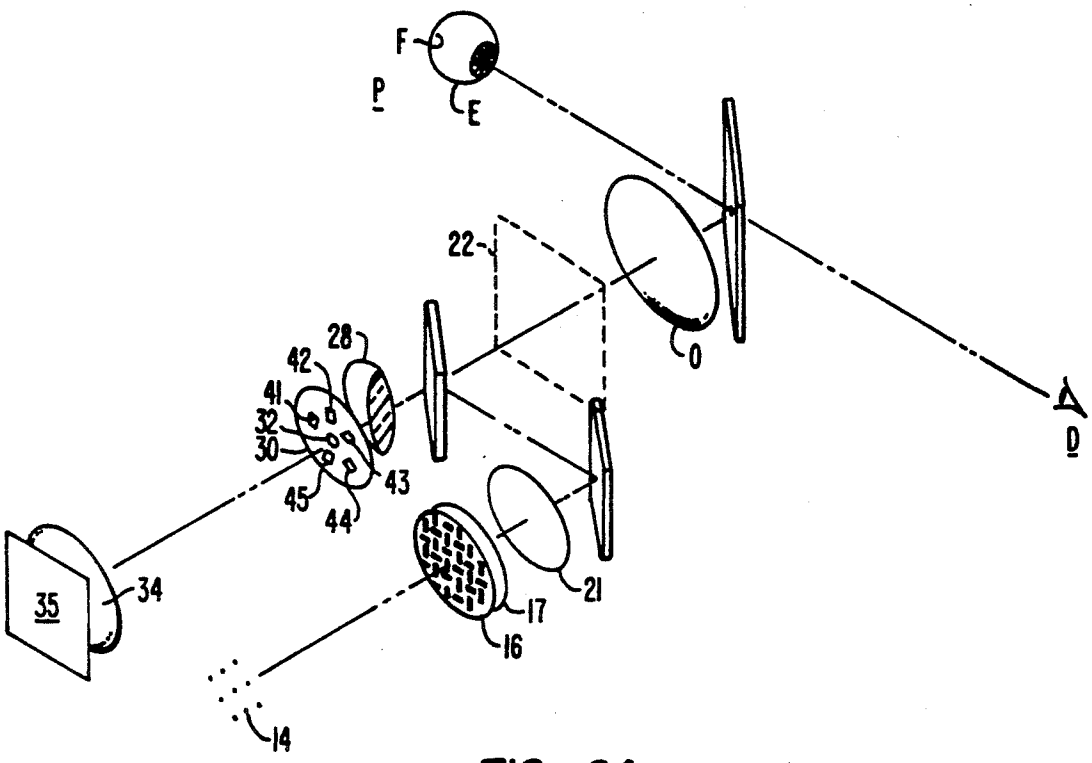


FIG. 2A.

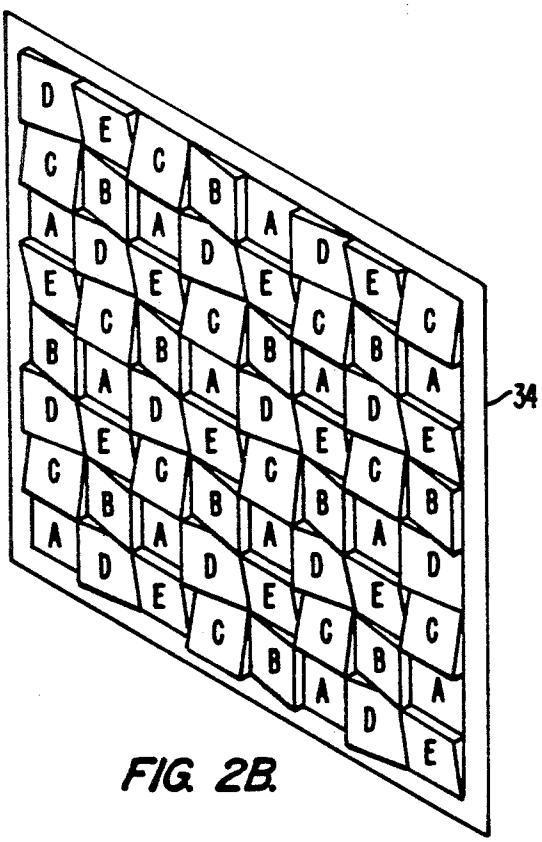


FIG. 2B.

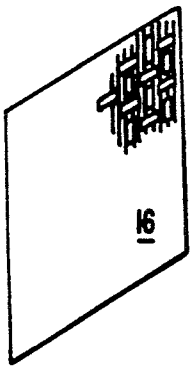


FIG. 2C.

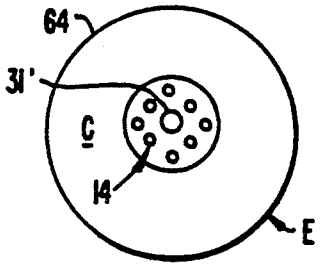


FIG. 2D.

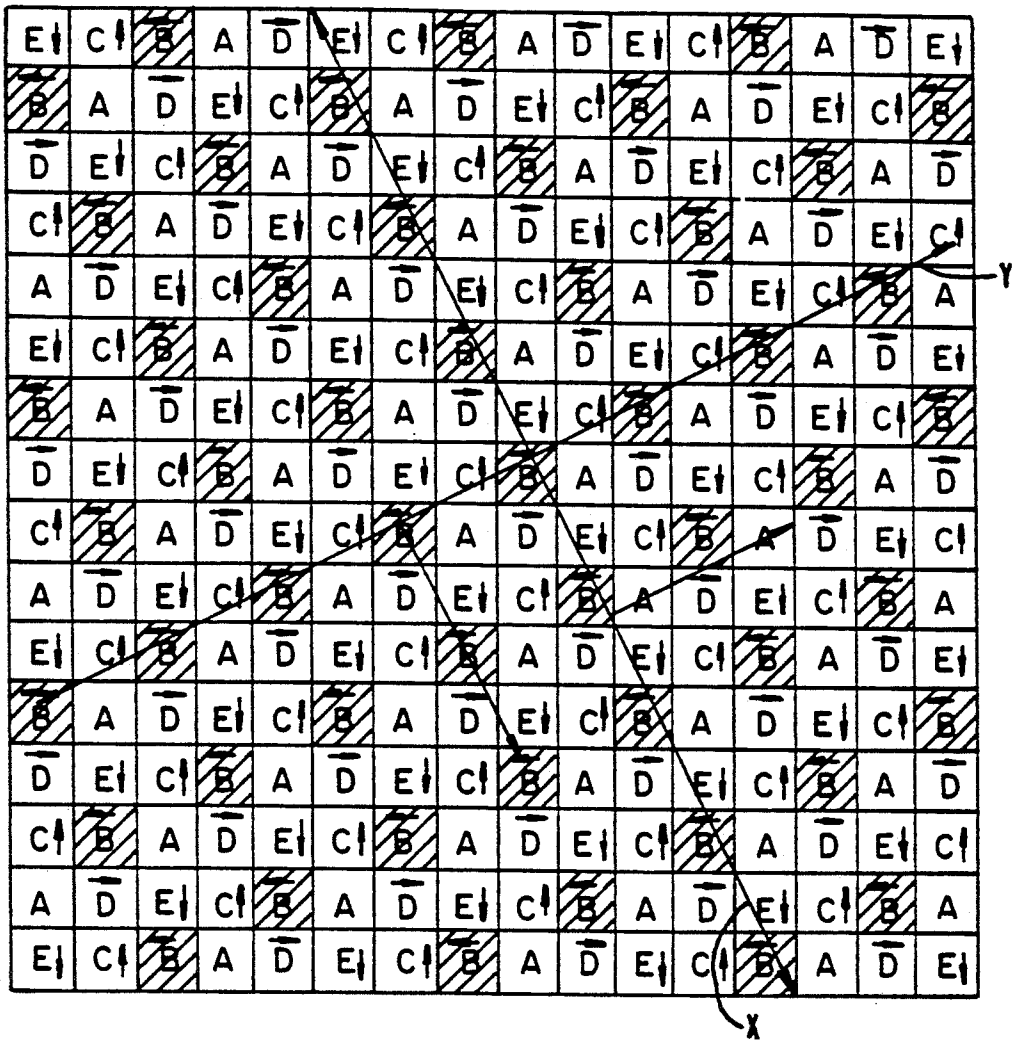


FIG. 4.

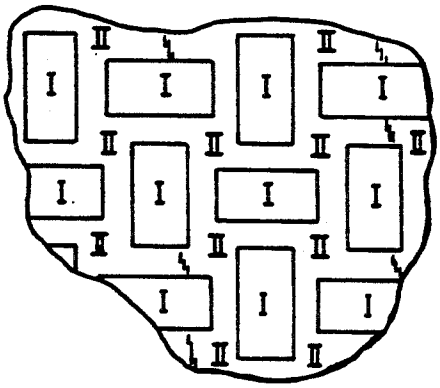


FIG. 3.

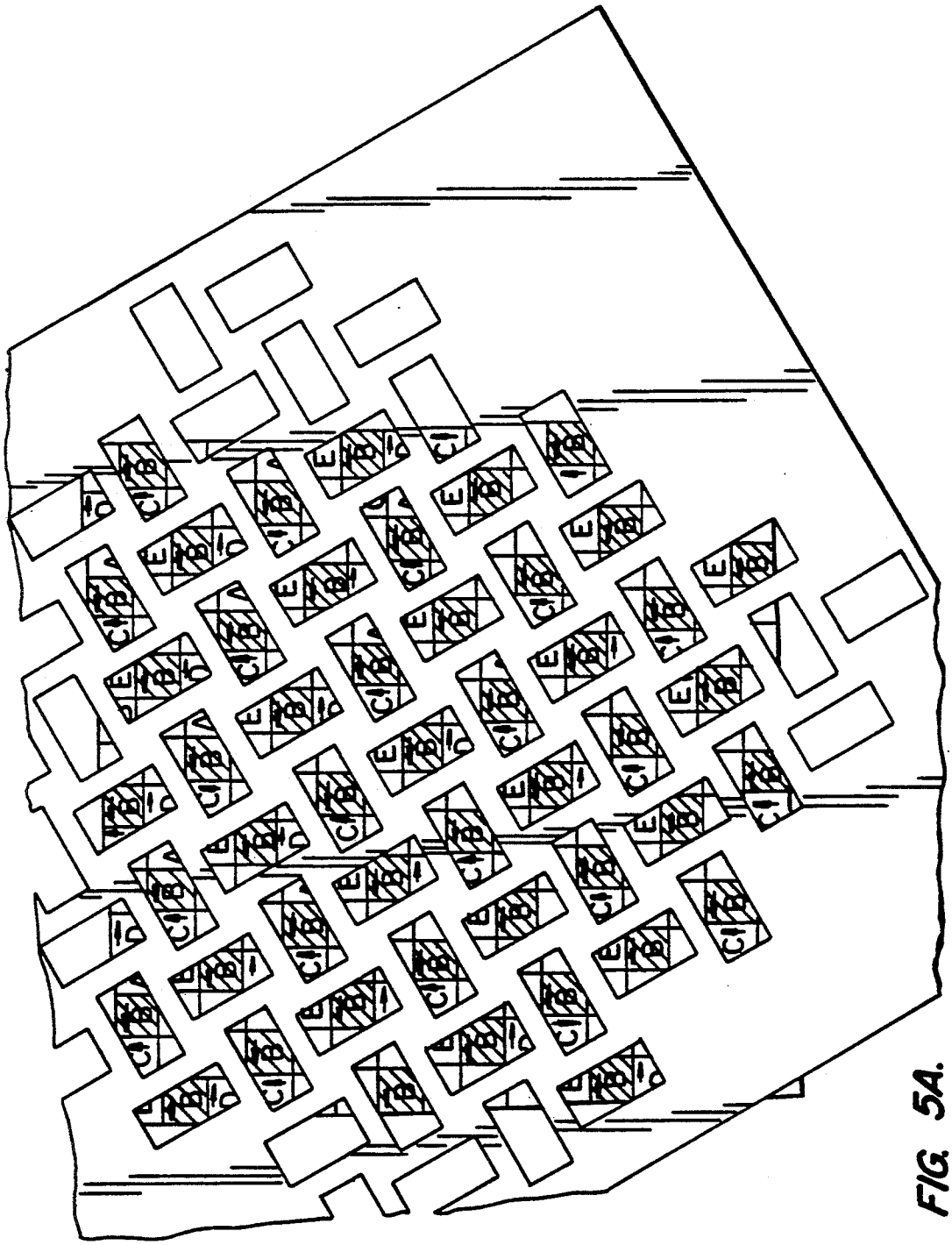


FIG. 5A.

FIG. 5B.

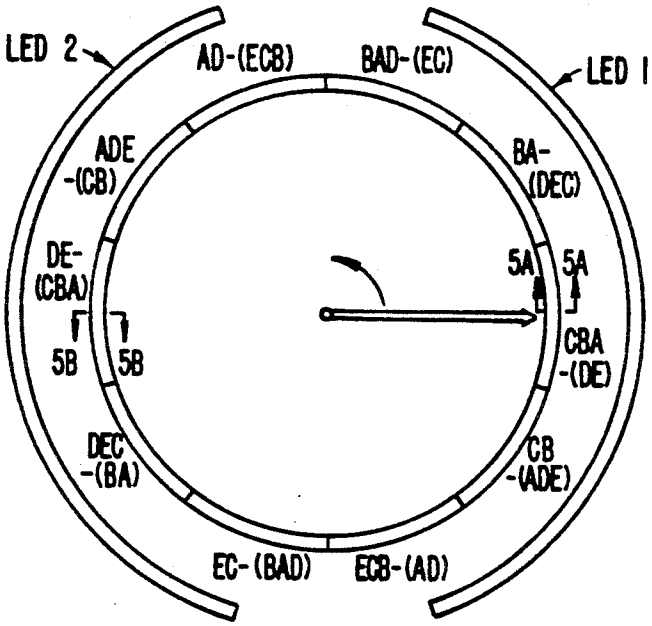

LED 2
AD-(ECB)
BAD-(EC)
LED 1
ADE -(CB)
BA- (DEC)
DE- (CBA)
5A
5A
5B
5B
CBA -(DE)
DEC -(BA)
CB -(ADE)
EC-(BAD)
ECB-(AD)

FIG. 5C.

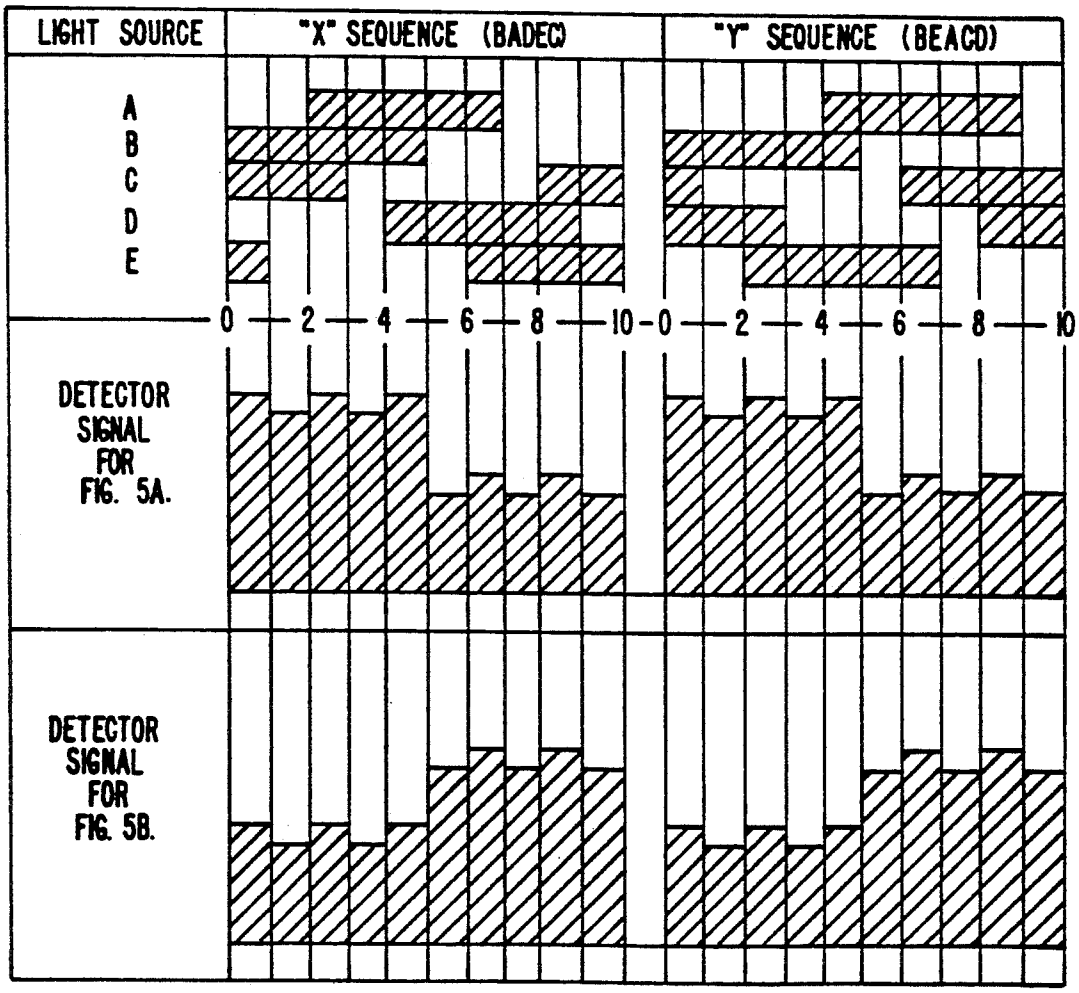

LIGHT SOURCE
"X" SEQUENCE (BADEC)
"Y" SEQUENCE (BEACD)
A
B
C
D
E
0 2 4 6 8 10 0 2 4 6 8 10
DETECTOR SIGNAL FOR FIG. 5A.
DETECTOR SIGNAL FOR FIG. 5B.

FIG. 6.

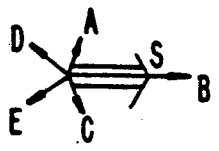
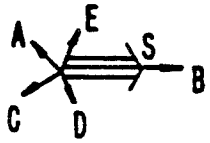
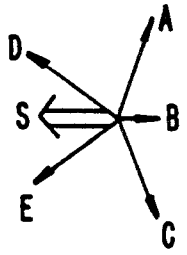
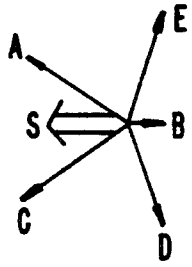
	"X" VECTOR SUM (S)	"Y" VECTOR SUM (S)
DETECTOR SIGNALS FOR FIG. 5A		
DETECTOR SIGNALS FOR FIG. 5B		

FIG. 7A.

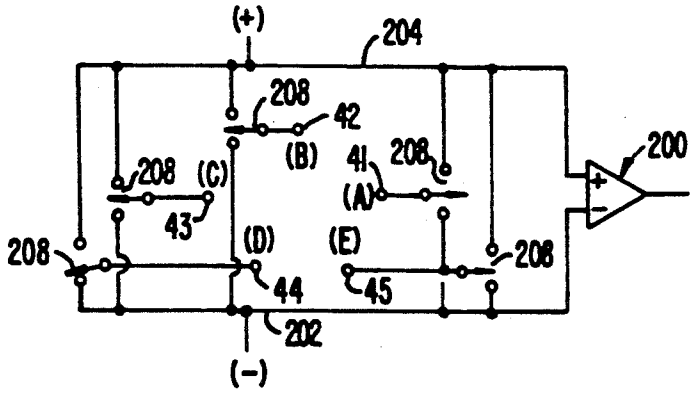


FIG. 8.

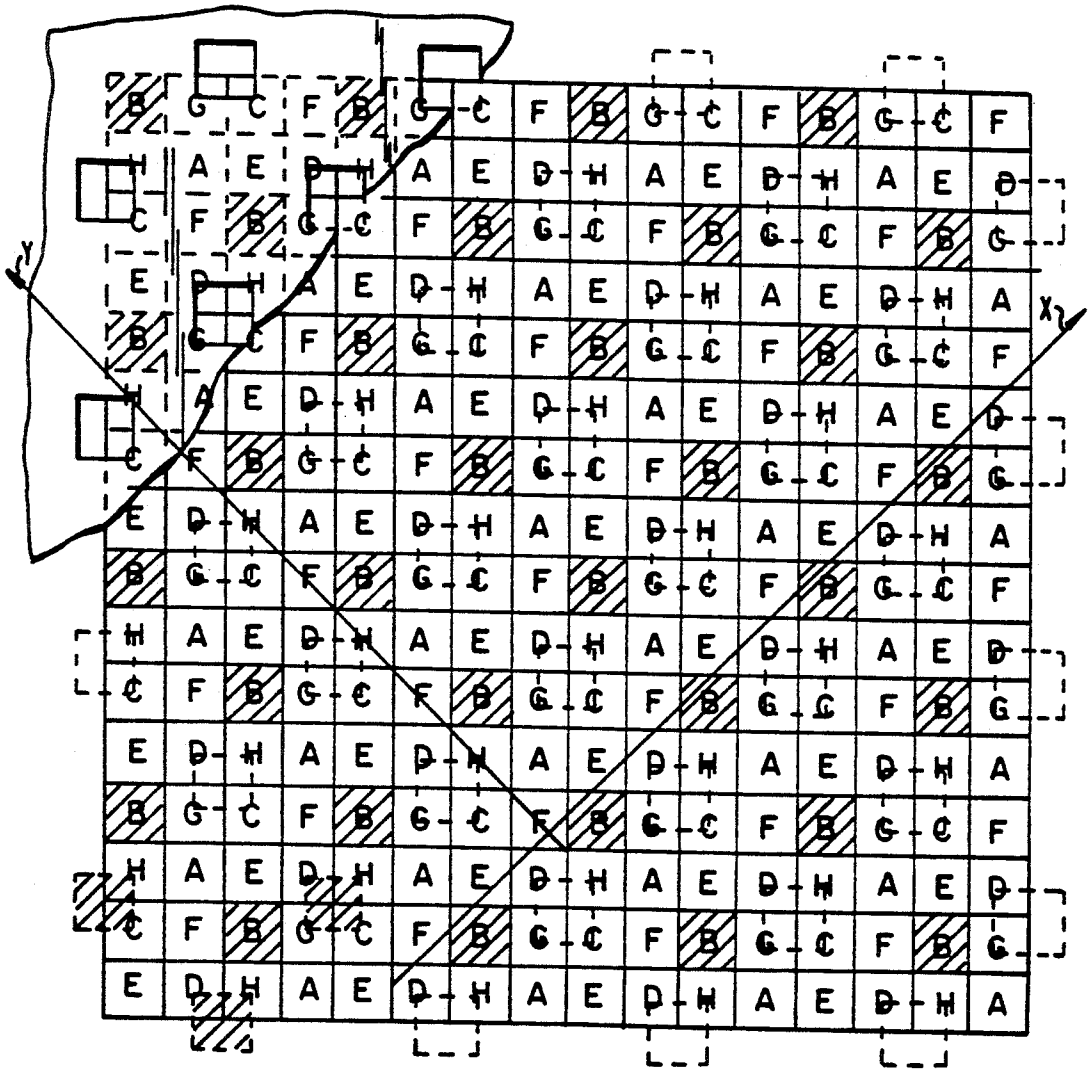


FIG. 7B.

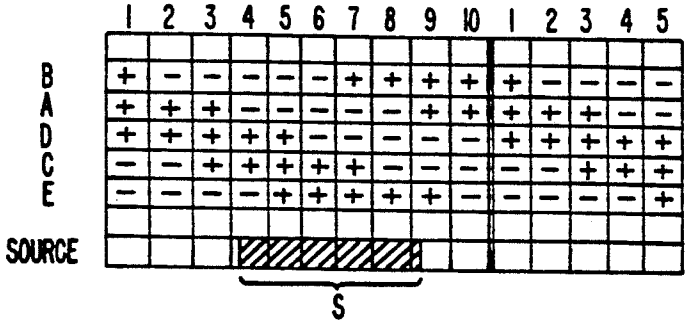


FIG. 9A.

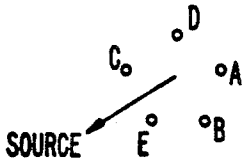


FIG. 9B.

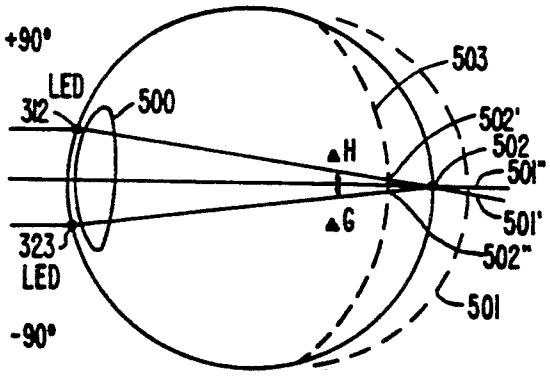


FIG. 10.

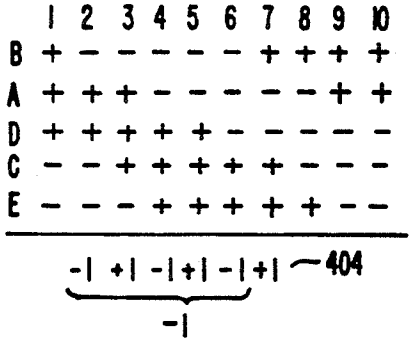


FIG. 11A.

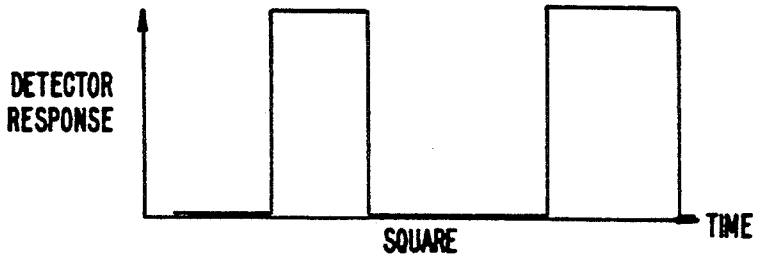


FIG. 11B.

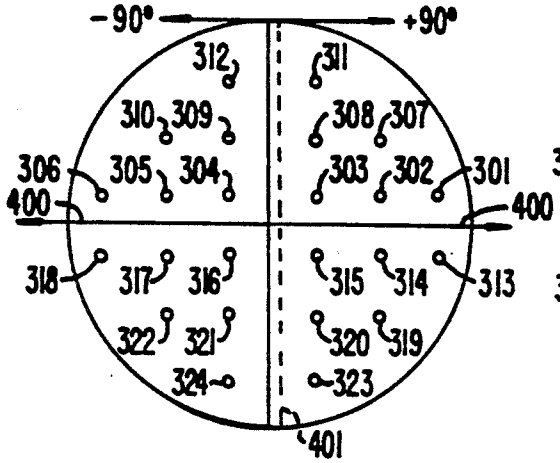


FIG. 12A.

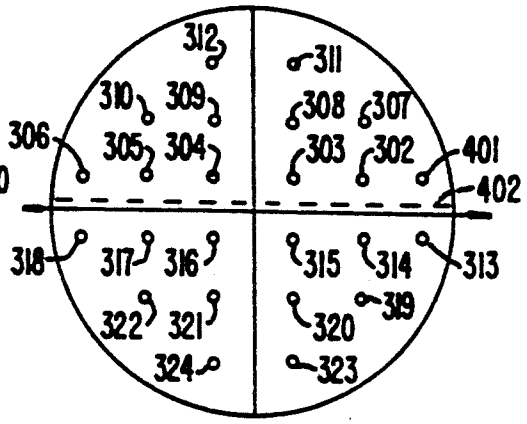


FIG. 12B.

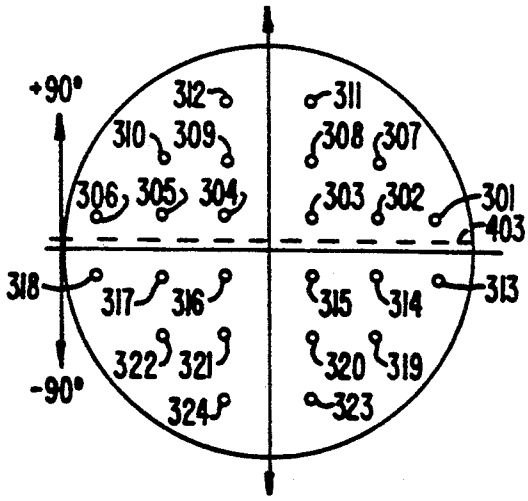


FIG. 12C.

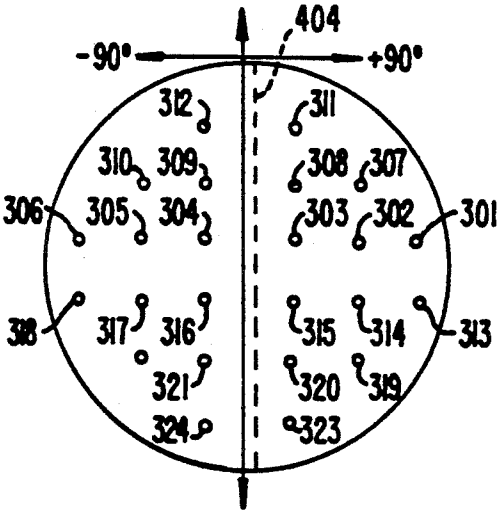


FIG. 12D.

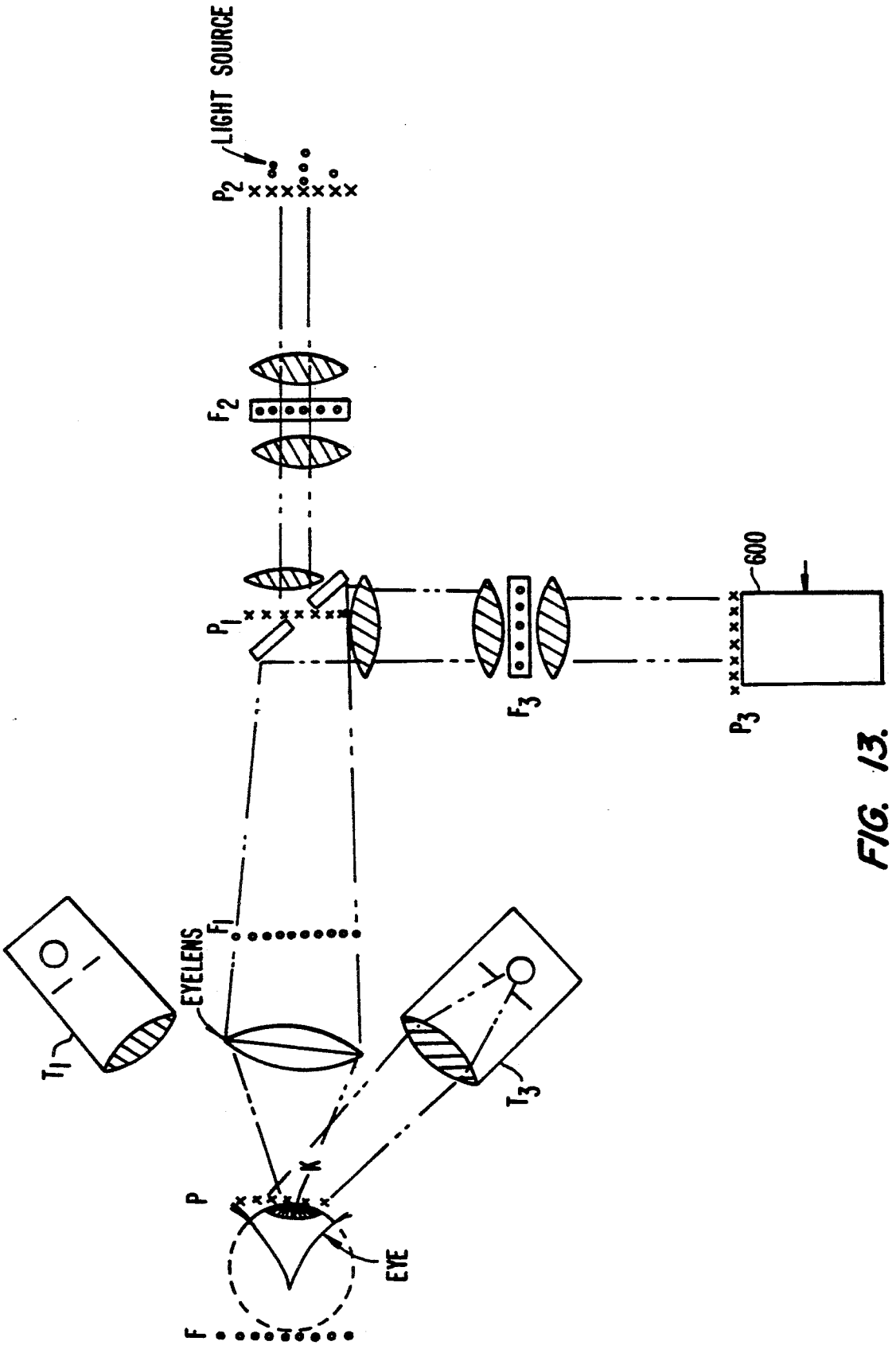


FIG. 13.

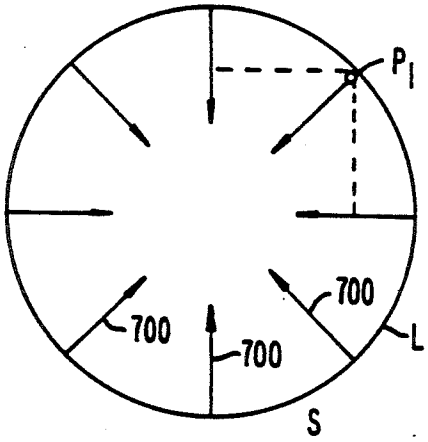


FIG. 14A.

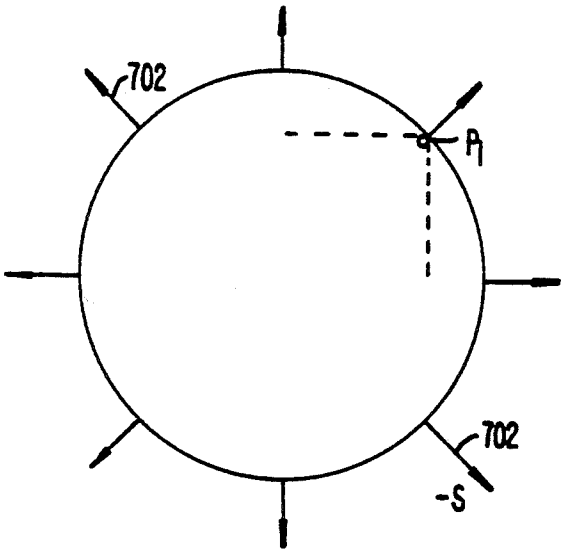


FIG. 14B.

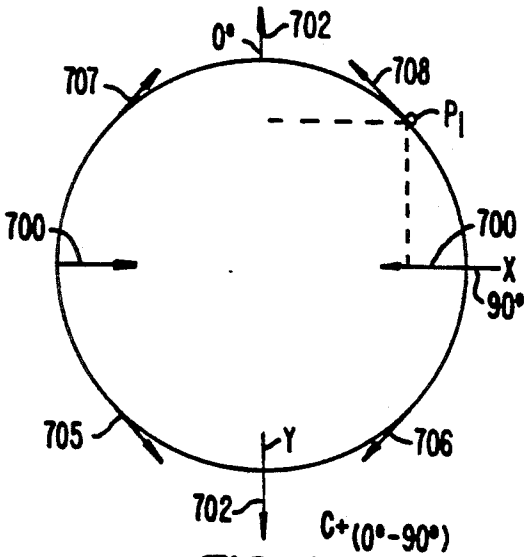


FIG. 14C.

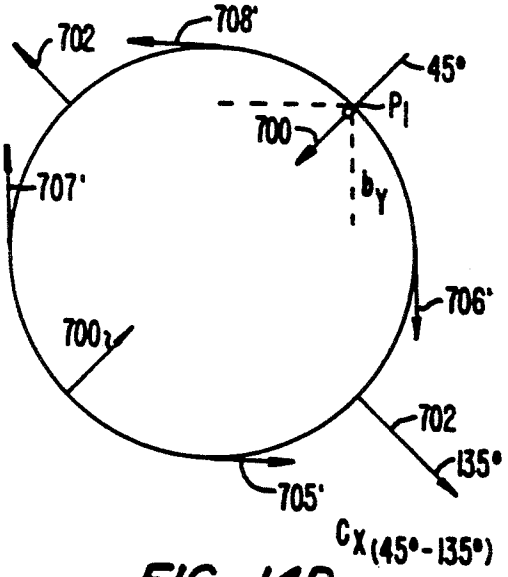


FIG. 14D.

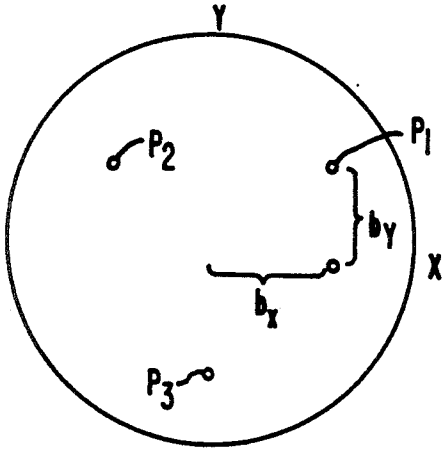


FIG. 14E.

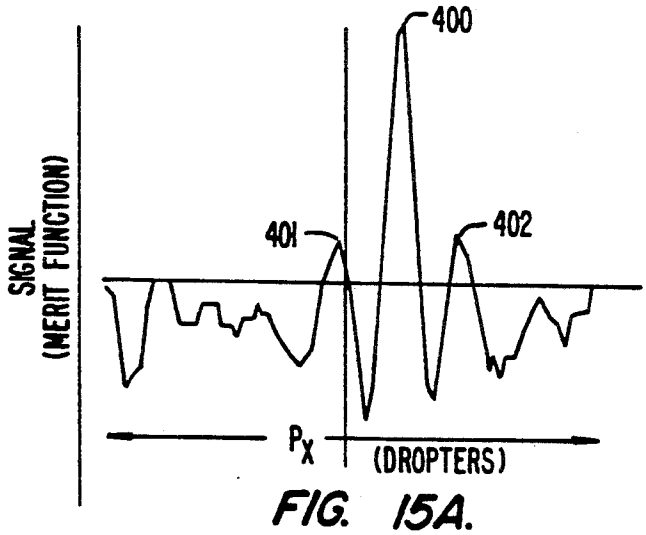


FIG. 15A.

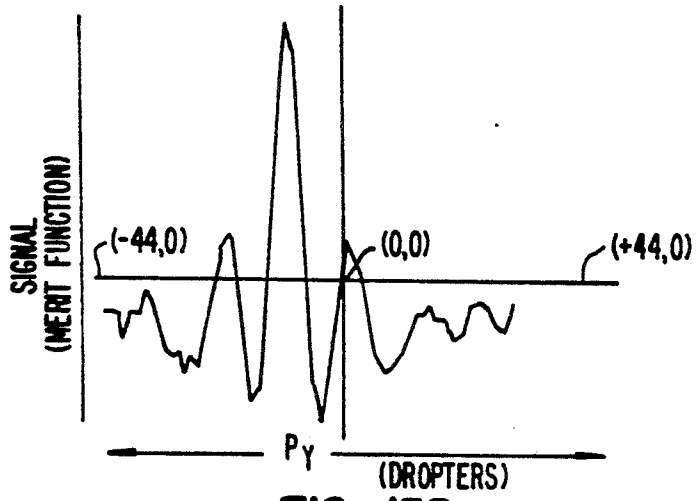


FIG. 15B.

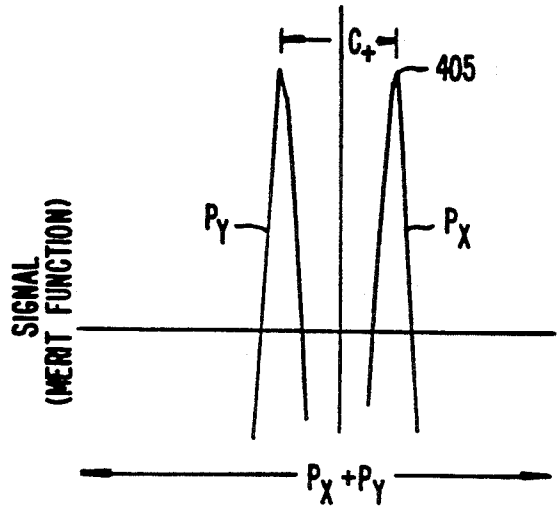


FIG. 15C.

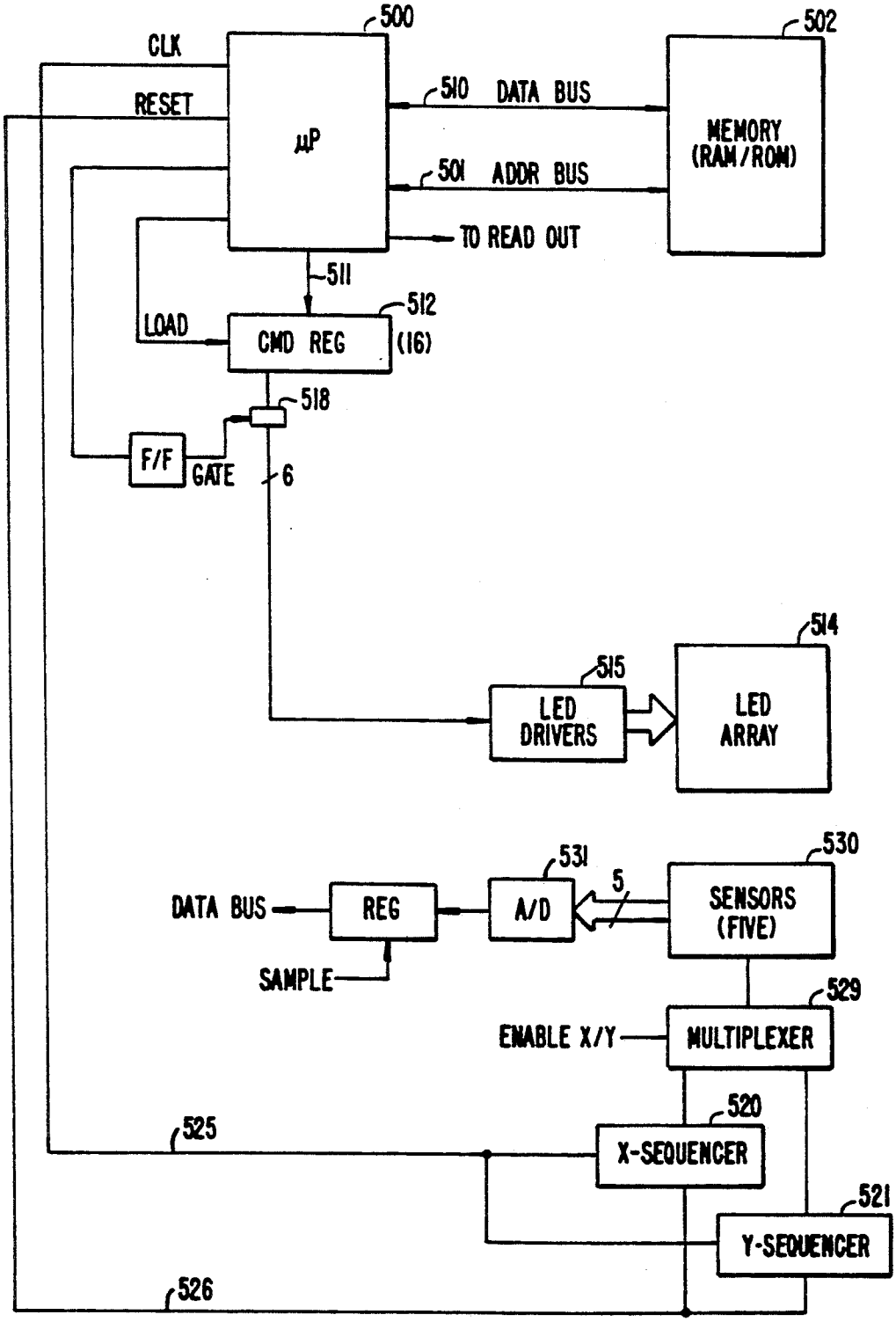

500
502
CLK
RESET
μP
510 DATA BUS
501 ADDR BUS
TO READ OUT
MEMORY (RAM/ROM)
511
512
LOAD
CMD REG
(16)
518
F/F
GATE
6
514
515
LED DRIVERS
LED ARRAY
530
531
DATA BUS
REG
A/D
5
SENSORS (FIVE)
SAMPLE
529
ENABLE X/Y
MULTIPLEXER
520
525
X-SEQUENCER
521
Y-SEQUENCER
526

FIG. 16A.

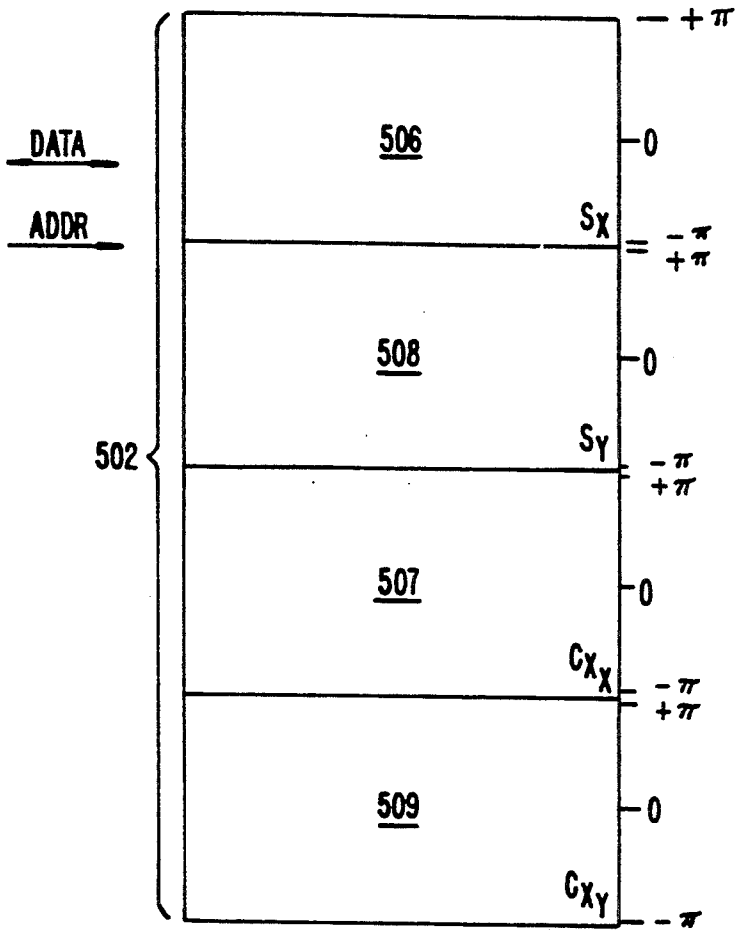


FIG. 16B.

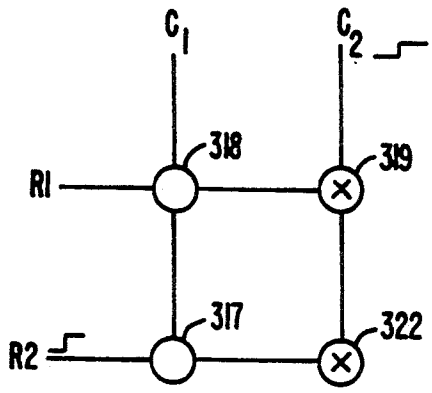


FIG. 16C.

OBJECTIVE REFRACTOR

BACKGROUND OF THE INVENTION

This invention relates to refractors and specifically to an objective refractor having reduced sensitivity to ambient light and improved reliability coupled with lower cost of production.

SUMMARY OF THE PRIOR ART

The cornea of the eye refracts light observed onto a photosensitive image surface, the fundus of the eye. Objective refraction has heretofore consisted of observing from the outside of the eye, image patterns projected to the inside of the eye on the fundus. When these image patterns are optimally recognized, the objective refraction prescription is generated.

Because the fundus of eye is a photosensitive surface, the intensity of light used to interrogate the eye must be at a level where impairment of its photosensitive function does not occur. Consequently it is desired to maintain this interrogating light to a low level or to a spectral band having little photosensitive effect.

Objective refractors have heretofore required relatively moving parts such as lenses placed in the front of the eye for the generation of a corrective eye prescription. These lenses are changed or moved to optimize the view of an image on the fundus of the eye. These lens in front of the eye complicate the objective refraction by adding relatively expensive moving parts and adding refractive interfaces. Very little light incident on the retinal image ever leaves the eye and the addition of refractive interfaces and moving lens members makes the low level light image harder to observe.

In some cases, it is desirable to produce an objective refraction in the presence of intense light sources associated with surgical illumination or diagnostic instruments such as slit lamp systems. These severe ambient light conditions generally render such objective refraction nonoperational.

Accordingly, there is a need for an objective refractor operable with low levels of interrogating light useful in objective refraction of the eye even in the presence of strong ambient light. Further, there is a need to limit relatively moving parts to improve reliability and reduce cost.

SUMMARY OF THE INVENTION

An objective refractor having no relatively moving parts such as lenses for generating corrective prescriptions and a minimum of refractive optical interfaces is disclosed. The refractor, which can be either a hand held or table mounted instrument includes a reference array and an interrogating array projected onto the fundus of the eye. The reference array is the real image at the eye projected from light detectors; the interrogating array is the real image at the eye projected from light sources. Both the reference array and the interrogating array are projected from disclosed patterns where the arrays are interchangeable one with another. Both the reference array and the interrogating array are projected onto the fundus of the eye through spaced apart regions of the eye lens. The movement of the reference array relative to the interrogating array for each region of the eye lens is observed. By the expedient of utilizing at least three separate regions of the eye lens, the amounts of relative pattern displacement can be reduced to a requisite optical prescription of sphere, cylinder and axis for the eye. Preferred patterns of interrogation together with a microprocessor driven embodiment are disclosed.

The preferred interrogating arrays are generated through a "basket weave" or "brick" pattern in which rectangles having a ratio of being twice as long as they are wide are utilized. The rectangles alternate in axial alignment with the major axis and minor axes of adjacent rectangles being alternately disposed at 90° angles. These rectangles with their alternating alignments are separated one from another by a spatial separation of at least one half the minor width of the rectangles. This separation disposes the rectangles in a "basket weave" pattern. This basket weave pattern delimits the boundaries of LED illumination projected through the pattern of rectangles onto the fundus. The interrogating pattern is pupiled at points on the eye lens and expanded to present the interrogating pattern on the fundus.

The LEDs, disposed in an eye lens sampling array are preferably sequentially illuminated. These point sources of light are projected through the basket weave pattern, and have real images of the point sources of light projected to the lens of the eye. The projection of the real images of the LEDs to the eye in effect pupils the light sources at the eye lens on precisely controlled locations. Deflection of the interrogating pattern for each eye lens sample location relative to a reference pattern can be measured to determine prescription. Preferably, the LEDs are duty cycled on the basis of a predicted prescription. Hence each LED effects a sample of the eye lens at precise eye lens locations for each predicted prescription.

The reference array is projected centrally of the eye and overlies the interrogating arrays as the interrogating arrays are projected by each of the LEDs. The reference array is preferably formed out of five discrete aperture types. These five discrete aperture types have their real image projected centrally through the eye in a repeating pattern of the five detectors. The pattern is selected such that the displacement of the interrogating array relative to the reference array can be identified either by the direction of a vector produced from vector addition or alternately the phase of a temporal scan when the interrogating arrays and the reference array are duty cycled, one with respect to the other.

The displacement measurement between interrogating and reference arrays is insensitive to background illumination and consequently provides for rejection of ambient light. Once the deflection of the interrogating arrays relative to the reference array is measured utilizing at least three separate regions of the eye lens, an optical prescription for the eye can be generated in sphere, cylinder and axis.

A microprocessor driven embodiment of the invention is disclosed. The microprocessor accesses in look up table memory values of interrogating LED duty cycles for refractive power in the x meridian, refractive power in the Y direction, and two values of cross cylinder (one for the X direction and one for the Y direction). The eye is electronically interrogated for a peak signal as LED duty cycle entries from each table are sequentially swept through the possible range of prescriptions. Values of power in the X meridian and values of power in the Y meridian are preferably swept first. Maximum signal from both sphere values enable one component of cross cylinder to be computed. Assuming the determined values of sphere, the eye is then

swept in the remaining component of cylinder to determine objective prescription. A sequence of rapidly determining patient prescription in a automated mode is disclosed.

Other Objects, Features and Advantages

Because of the relative theoretical complexity of this instrument, the invention will be discretely analyzed. First, the configuration of the optical instrument will be discussed. Secondly, the configuration of the interrogating and referencing patterns will be set forth. The relative movement of these patterns will be disclosed as enabling optical prescription. Finally, and taking the case of one interrogating light emitting diode (LED), the duty cycle of the LED relative to the separate duty cycle of the detectors will be set forth.

Thereafter, I disclose the preferred method relating to the operation of the objective refractor. This method includes supplying a cluster of light emitting diodes, and adjusting the phase of the diodes to emulate the prescription of a patient. Methods for estimating the prescription of the patient, and generating the final prescription of the patient are discussed. A microprocessor driven embodiment is disclosed.

As part of the above disclosure, methods are discussed for eliminating ripple that may be generated by the disclosed phasing of the light sources and detectors. Reference is also made to an accompanying use of light sources in conjunction with a CCD camera to generate prescription, this latter system not now being preferred.

Configuration of the Instrument

An object of this invention is to set forth the configuration of an objective refractor for examining the human eye. The instrument includes an objective lens for producing a conjugate image plane of the fundus of the eye being examined. Interrogating and reference arrays are first projected to the fundus conjugate plane and thereafter relayed to and from the fundus of the eye by the objective lens to determine optical prescription.

The interrogating array comprises an array of light emitting diodes projected through a pattern. Each light emitting diode is focused or pupiled to precise points on an eye lens and thus interrogates different regions of the eye lens being examined. Likewise, the reference array is focused to or pupiled at the central portion of the eye lens being examined. Both the interrogating array and the reference array are relayed between the conjugate image plane of the eye and the fundus of the eye. At this point it should be made clear that although the interrogating array and reference array may be conjugate to the fundus plane for an emmetropic eye, this is not strictly the condition for eyes having other refractive states.

Each LED projects its own separate array of interrogating rectangles. Moreover, the LEDs are each given discrete cycle timing with respect to their position on the eye and the predicted prescription for the eye. These LEDs together produce cumulatively a maximum signal when the selected eye prescription duty cycle timing is appropriate to the actual eye prescription.

The reference array is typically an array of preferably five types of optical elements, each directing light to a corresponding detector element. This reference array is similarly projected to a plane near the conjugate plane of the fundus. Preferably a single reference array is relayed from the fundus conjugate through an aperture which localizes the light rays to a small central region of the eye lens. In this manner, the reference array is relayed to a position of overlap on the various interrogating arrays at the fundus.

The reference array reads the displacement of the interrogating arrays. The detector elements of the reference array are actuated to receive light with each detector element having its own sequential duty cycle with respect to the other detector elements to provide a sequence of interrogation. By establishing proper timing and duty cycle of the LEDs of the interrogating array with respect to the duty cycle of the detectors of the reference array, the prescription of the eye can be determined.

An advantage of the disclosed instrument is that it is capable of being configured in a small package. Consequently, the disclosed instrument can be conveniently "tree" mounted to the instrument pole in an eye examination office or alternatively hand held, or incorporated in a table mounted instrument.

A further advantage of the light emitting diode array is that the size of the pupil can be measured by the device. This pupil size measurement is a useful aside of the instrument herein disclosed.

A further object of the disclosed instrument is that the optical train can be readily altered to that of a keratometer. Accordingly, when the disclosed instrument operates as a keratometer, the objective lens is configured so as to relay the keratometer target images to a common image plane after reflection from the cornea.

A further advantage of the disclosed invention is that the examination of the eye at a matrix of sample points is possible. By the using of a multiplicity of such sample points, the entirety of a fully open pupil can be refracted. While it will be normal to refract the center of the eye lens and ignore the periphery, it should be understood that it is possible to determine the full optical effect of the eye lens, including the periphery, to monitor disease, such as keratoconus of the cornea or to establish the size of regional departures from the nominal refractive state of the eye.

Yet another advantage of this instrument is that the LEDs are duty cycled in their interrogation. Pulsing of the LEDs to short high intensity pulses is possible. Consequently, the LEDs can produce on the fundus light differentials that can be easily detected and seen over ambient light.

Yet another advantage of this invention is that the LEDs can be both cycled in their relative phase with respect to one another and with respect to the detector elements to generate a prescription sensitive signal having significant magnitude over background illumination. At the same time, the LEDs can be duty cycled for high common mode rejection of extraneous signals, especially so-called harmonics.

Configuration of Interrogating and Reference Patterns

A further object of this invention is to describe reference and interrogating patterns. These patterns, when projected to the fundus of the eye, deliver telltale displacement readings of the patterns one to another and enable accurate determination of eye refractive error.

Two distinct patterns are utilized, a reference pattern and an interrogating pattern. Either pattern may be configured to be a light source, and the other is used as a detector pattern for corresponding photosensitive elements. In a preferred embodiment the pattern comprises optical aperture patterns through which are pro-

jected light sources onto the eye lens. The reference pattern comprises a second optical aperture pattern which directs light returning from a region of the eye lens onto a set of light detectors. Since the first and second patterns are interchangeable, they will be discussed in this section without regard to the fact that they can be interrogating or detecting in character.

In the preferred embodiment, one pattern has elements in a matrix of two apertures. The pattern of the two apertures are essentially "stackable" or infinitely repeatable into a repeating array. These two apertures from which the large array of any desired size are constructed each comprise rectangles. The rectangle of one aperture has its major axis orthogonally aligned with respect to the rectangle of the other aperture. Half the area of the pattern is made up of these rectangular apertures in the preferred embodiment. The remaining area constitutes a boarder. Each aperture of each rectangle is preferably twice as long as it is wide and has an area that is 5/2nds of the area of elements of the remaining pattern. The rectangles are separated one from another by a boarder having one half the thickness of the minor axes of the rectangles.

Regarding the sensitivity of the so-called brick pattern, either each of the bricks may be provided with discrete sensitivity or the areas of the bricks can be given one sensitivity and the area of the boarders may be provided with a second and different sensitivity. Required sensitivity can be imparted by discrete optoelectric elements, color filters, or preferably by aperture elements capable of deflecting light rays such as arrays of refractive or reflective prisms.

The remaining pattern is composed of five discrete optical aperture types, each preferably with a square configuration. Each of the five aperture types is distinct from the remaining four. Such distinct qualities can be imparted by discrete optoelectric elements, color filters, or preferably by aperture elements capable at deflecting light rays such as an array of reflective or refractive prismatic components.

Each square area is preferably 2/5ths the area of a typical rectangle of the previous pattern. The discrete elements of the five element array are generated in a so-called "knights move" pattern; elements repeat in a "two forward, one to the side" pattern. In fact, the generated displacement pattern represents discrete square roots of a sum of squares equal to the total number of discrete elements used in the reference pattern.

The elements of the reference pattern are selected in such a way that each element of the five elements used has distinctly different neighbors bounding that element on each side. Furthermore, the array of the five apertures are essentially "stackable" or infinitely repeatable into a repeating array of any desired size.

Each element of the five element array when sequentially emphasized, as for example by being sequentially illuminated, causes advancing borders or "fronts" to move across the array. There is a first sequence of emphasis for X-axis sensitivity; there is a second sequence of emphasis for Y axis sensitivity. In the preferred five element array here shown, two sequences of illumination each produce substantially uniform fronts moving through the total array; one front for one sequence moving at right angles to the remaining front for the remaining sequence. It is the detection of these two discrete fronts by their varying degrees of overlap between the reference and interrogation patterns that enables the displacement between the two patterns to be detected.

Relative alignment of the arrays one to another is disclosed. The two element array has the major axis of the rectangle parallel or orthogonal to the progressively moving array fronts. Consequently, overlap of the two arrays results in temporally phased signals or vector directions which are highly sensitive to relatively small movements between the arrays. Consequently, relative motion between the arrays and hence prescription of the eye can be rapidly determined.

An object of this invention is to disclose a sequence of array activation of the preferred five element array. According to this aspect, the array is assigned five arbitrary letter designations, these designations constituting the letters A through E and being illustrated in FIG. 4. A pattern is activated or interrogated in the order AEDBC for sensitivity in one orthogonal direction and in the order ADCEB for sensitivity in the remaining orthogonal direction. (See FIG. 4)

Rules for the expansion of the squares of a matrix are set forth for determining arrays of varying numbers of apertures which are the sum of two squares, this sum not including any number less than five but including 5, 8, 9, 10, 13, 16, etc. A specific example of a matrix having 8 elements is illustrated, it being left to the reader to generate additional matrices in accordance with the teachings of this invention.

An advantage of the patterns is that they are readily interchangeable as either interrogating or reference patterns. For example, I prefer that the five element pattern be the light detecting, reference pattern. However, this pattern can also function as the illuminating or interrogating pattern, the only limitation being that one array illuminate or interrogate and the other detect or form the reference.

A further object of this invention is to disclose two modes of analyzing the relative overlap of the patterns. According to a first embodiment of this invention, one pattern is sequentially illuminated in a timed cycle. In such sequential illumination, the squares of the preferred embodiment are illuminated either singly or in adjacent sets. Responsive to this cyclical illumination, advancing fronts of light sweep across the array pattern in the disclosed orthogonal patterns. These advancing fronts of light having their orthogonal patterns are observed through apertures of the complementary array. Each displaced orthogonal pattern is discretely observed. The resultant phase angle only—and not the magnitude—of produced light modulation contain the requisite displacement information.

According to a second and preferred embodiment of analysis of overlap, the reference and interrogating arrays are duty cycled, one with respect to another, dependent upon the predicted prescription of the patient. The respective observation of overlap between the reference pattern and many interrogating patterns is simultaneously collected, as by prisms deflecting rays from the discrete areas to respective detectors. These respective detectors resolve the light received from the overlapping reference and interrogating patterns in a vector format. The resultant angle (and not the magnitude) of the resultant vector determines the relative pattern displacement.

An advantage of both embodiments of measuring relative pattern movement is that these techniques are not sensitive to amplitude and only sensitive to temporal phase or vector direction. Consequently, the pattern

displacement technique assists in rejection of ambient light.

An advantage of this interrogation is that phase or vector determination may be repeated more than once over the expected total deflections encountered for the refraction of the human eye. For example, over a 15 diopter range, three 360° rotations of phase or vector angle might be utilized. There results an expanding scale having greater accuracy.

A further advantage of this aspect is that by assuming spherical and cylindrical aberrations of the eye, it is possible to calculate expected phase angles corresponding to those observed for each interrogating pattern corresponding to various pupil positions. The sphere-cylinder combination which most closely simulates the observed vector phase angles for the various spared apart points in the pupil area represents the preferred refractive finding for the eye.

Yet another advantage of the disclosed technique of pattern overlap is that irregularities on the fundus are in effect averaged over a substantial area of the retina. For example, the structure of the macula lueta of the retina will not appreciably interfere with pattern displacement as its irregularity will be averaged over its surroundings.

A further object of this invention is to disclose a detector configuration that is relatively insensitive to high levels of ambient light. Accordingly, five photosensitive elements in the preferred configuration are each given distinct emphasis by corresponding subsets of directional prisms which make up the interrogating array. The photosensitive elements are synchronous rectifiers, these rectifiers being given polarity and sequence for optimum detection along displacement directions shown in orthogonal axes on the eye.

An advantage of the disclosed synchronous rectifier circuit is that by the expedient of varying the exciting LED duty cycle according to estimated prescription read out, cumulative detector sensitivity results. Assuming 24 interrogating LEDs, a correct prescription will generate 24 times the signal of a random and incorrect interrogation. Over conventional methods, the disclosed timing protocol achieves a sensitivity that utilizing a single interrogating LED would require an increase in sample time in the order of 500 times.

Yet another advantage of the disclosed strength of signal from the detectors is that background lighting is easily discriminated from the phase relation indicating the correct generation of prescription. Consequently, the instrument can be used in high levels of background illumination.

A further advantage of the preferred detector array is that filtering of the received signals to preselect precise frequencies is not required. The disclosed detector resolves vectors from the difference of received signals. The detector is not subject to variations of phase shift in the filters necessary for the resolution of phase in temporal detection formats.

Objective Refractor Operation

Regarding the cycle of the LEDs in their phase relative to one another, the eye is first grossly swept, preferably in sphere, to determine a gross eye prescription. A first sweep is made in meridional power in a first (say x) orthogonal direction; a second sweep in meridional power is made in the second and remaining orthogonal direction. Combining the results of these two sweeps, and resolving one component of cross-cylinder, a best predicted gross prescription is selected.

The LEDs are thereafter given cycle timing relative to the detector array dependent upon their point projection position on the pupil of the eye and the deflection to be expected at that portion of the eye for the gross predicted prescription. This cycle timing is imparted so as to give detectors coupled to the reference array a maximum signal when the prescription is correct. With these cycle timings, it is possible for many interrogating arrays to impact the reference array and its detector with a cumulative signal indicating the determination of the correct prescription. A highly sensitive protocol results which readily signals generation of the correct prescription and incorporates common mode rejection.

A further object of this invention is to disclose a sequence for determining from an estimated prescription the more exact and finally correct prescription. According to this aspect of the invention, the field of LEDs has its interrogating cycle timing shifted by 90° along a field dividing line. LEDs on a first side of the dividing line are shifted by a 90° phase in a first direction; LEDs on a second and opposite side of the dividing line are shifted by a 90° phase in a second direction. Comparison examination of the resulting signal after the phase shifts generates a so-called "discrimination function." This discrimination function indicates both the direction and approximate amount of correction required for determination of a final and correct prescription.

Yet another object of this invention is to disclose an interrogation sequence relative to the respective dividing lines utilized to generate the correct prescription. According to this aspect of the invention, detector array interrogation is made sensitive to displacement between the interrogating array and the detecting array along a first direction. Phase shifting for the determination of the successive merit functions is made as a function of LED position normal to and parallel to the chosen direction of detecting array sensitivity. Thereafter, detector array interrogation is made sensitive to displacement between the interrogating array and the detecting array along a second direction. Phase shifting for the determination of the successive merit functions is again made as a function of LED position normal to and parallel to the second chosen direction of sensitivity. Utilizing the disclosed interrogation sequence, final correct prescription of the eye can be objectively determined.

Regarding the duty cycling of the LEDs, a duty cycle scenario is set forth in which harmonics of significant and interfering proportion are eliminated. Specifically, a duty cycle is disclosed which rejects major contributing harmonics, these harmonics including for the major portion the third and fifth Fourier cosine components.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a side elevation schematic illustrating an examiner hand holding an instrument objectively refracting the eye of a patient, the instrument here being shown in outline form broken away so that the inner optical paths may be understood and described;

FIG. 2A is an optical schematic of the layout of FIG. 1 utilized for an explanation of FIG. 1;

FIG. 2B is an expanded perspective view of five element prism array used in the so-called reference capacity for causing the relay of images from each of

the detecting patterns to discrete detectors, this prism array producing the optical pattern that is illustrated in FIG. 4;

FIG. 2C is a perspective view of the two element interrogating array this two element array producing the optical pattern that is illustrated in FIG. 3;

FIG. 2D is perspective view of the cornea of a human eye with the projection of the point sources of the light emitting diodes imaged near the surface of the cornea, it being remembered that the respective patterns of FIGS. 4, 5A and 5B only become visible after the patterns are projected to the fundus of the eye;

FIG. 3 is a plan view of the interrogating pattern of the preferred embodiment of this invention, this pattern being projected from the pupil represented by each light source image on FIG. 2D to the fundus of the eye;

FIG. 4 is a plan view of the reference pattern of this invention, the illustrated plan view having superimposed thereon directions of displacement labeled "X" and "Y", this pattern being the pattern of detectors that are projected through the central portion of the eye shown in FIG. 2D to the fundus of the eye;

FIG. 5A is an overlay of the interrogating pattern on the reference pattern illustrating the predominance of the "B" elements for the particular displacement illustrated, this pattern being representative of one light emitting diode only;

FIG. 5B is an overlay of the interrogating pattern on the reference pattern illustrating the viewing by the patterns of a 180° phase shift from the element "B", this pattern being representative of an alternate light emitting diode but having a differing displacement because of a different point of incidence on the eye of FIG. 2D;

FIG. 5C is a phase timing diagram useful for understanding the sequence of interrogation of the interrogating array of FIG. 3 with the reference array of FIG. 4;

FIG. 6 is a set of temporal plots of the displacements illustrated in FIGS. 5A and 5B;

FIG. 7A is a set of vector plots of the displacements illustrated in FIGS. 5A and 5B;

FIG. 7B is an overlay in a manner similar to that illustrated in FIGS. 5A and 5B disclosing the use of an eight element reference array with an overlying interrogating array;

FIG. 8 is an electrical schematic of a detector system for determining the merit function or discriminator function, the detector here illustrated utilizing synchronous light sensitive detectors switched by computer driven analog switches for reading the reference array, the duty cycle of interrogation being taken from the phasing timing diagram of FIG. 5C;

FIG. 9A is a temporal plot illustrating the desired polarity of the light sensitive synchronous rectifiers for the signal to be read from a typical LED of a particular phase being illustrated below the temporal plot as a schematic temporal band of lights;

FIG. 9B is a vector plot of the phase of the typical LED as imparted through the synchronous rectifier network of FIG. 9A;

FIG. 10 is an optical schematic of an emmetropic eye with interrogating bands of light focusing at the retina, the figure showing in broken lines a so-called "far sighted" and "near sighted" configuration of the retina for explaining the need to produce phase shifts for interrogation of the eye;

FIG. 11A is a table figure identifying the so-called 5 omega Fourier component;

FIG. 11B is a graphical representation of the source of the so-called 3 omega Fourier component which constitutes a portion of the square wave, it being noted that both the component of FIG. 11A and 11B can be removed by appropriate phase or duty cycle shifting of the interrogating LEDs;

FIG. 12A is a schematic showing an LED field with a vertical dividing line normal to the horizontal direction of displacement sensitivity illustrating the shifting of the phase of the field on either side of the dividing line by opposite increments of 90° to obtain a so-called discriminator function for one component of meridional refractive correction;

FIG. 12B is a schematic showing the LED field of FIG. 12A with a horizontal dividing line parallel to the direction of displacement sensitivity illustrating the shifting of the phase of the field on either side of the dividing line by opposite increments of 90° to obtain a so-called discriminator function for the 45–135 so-called "oblique" component of eye correction;

FIG. 12C is a schematic showing the LED field of FIG. 12A with horizontal dividing line normal to the vertical direction of displacement sensitivity illustrating the shifting of the phase of the field on either side of the dividing line by opposite increments of 90° to obtain the second and final component of meridional power correction, it being noted that the scans illustrated in FIGS. 12A, 12B and 12C are sufficient in their total for the generation of a prescription;

FIG. 12D is a schematic similar to FIG. 12B showing the LED field of FIG. 11C with a vertical dividing line parallel to the direction of displacement sensitivity illustrating the shifting of the phase of the field on either side of the dividing line by opposite increments of 90° to obtain a so-called merit function for the 45°–135° so-called "oblique" component of eye correction, the information obtained being redundant to the information obtained in FIG. 12B; and,

FIG. 13 is a schematic of the objective refractor of this invention with attachments for keratometry attached so that the instrument has both objective refraction capabilities and keratometry capabilities.

FIG. 14A is a schematic diagram of the eye lens having a positive spherical correction;

FIG. 14B is a schematic diagram of the eye lens having negative spherical correction;

FIG. 14C is a schematic diagram of the eye lens having so-called 0°–90° cylinder;

FIG. 14D is a schematic diagram of an eye lens having so-called 45°–135° cylinder; and,

FIG. 14E is a schematic of an eye having unknown optical characteristics with the minimum of three points being illustrated on the eye for determination of the traditional measurements of sphere, cylinder and axis with one of the three illustrated points being delineated in X and Y values for determining applicable equations for the computation of sphere, cylinder and axis.

FIG. 15A is a diagram of meridian sphere power plotted against intensity, the diagram illustrating how peaking of the intensity of the received signal occurs when sweep of a value approximating that of the correct prescription along the X axis of eye interrogation occurs;

FIG. 15B is a diagram of meridional power plotted against intensity, the diagram illustrating how peaking of the intensity of the received signal occurs when sweep of a different value approximating that of the

correct prescription along the Y axis of eye interrogation occurs;

FIG. 15C is a diagram of the peaks illustrated in FIGS. 15A and 15B plotted on the same axis for meridional power with the difference in the peaks plotting as 0°-90° cross cylinder (presuming instrument alignment with the horizontal and vertical);

FIG. 16A is a microprocessor schematic illustrating microprocessor hardware for effecting the scanning sequence necessary to generate a prescription with the apparatus of this invention;

FIG. 16B is a memory schematic for use with the microprocessor of FIG. 16A illustrating of the necessary look-up tables for the determination of a prescription utilizing the apparatus and process herein disclosed; and,

FIG. 16C is a schematic of a circuit for effecting illumination of the interrogating LEDs utilized with this invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

With respect to FIG. 1, a doctor D is shown examining the eye E of a patient P with the hand held objective refractor R. Specifically, interrogating LEDs 14 (only one LED here being shown) project their light through a two element optical brick pattern 16 having the interrogating pattern illustrated in FIG. 3. Light from the LEDs proceeds and is deflected at mirror 18 onto an apertured beam splitter 20. Brick pattern 16 is imaged at a fundus plane conjugate 22 through the action of lens 21. Plane 22 is conjugate through objective lens 0 to the fundus F of eye E. Consequently, an image of optical brick 16 will appear on fundus F of the eye E of patient P. The reader will understand that more than one light source is utilized; consequently, there will be more than one image of the brick pattern on the eye fundus.

Light emitting diodes 14 are projected through lens 17. Lens 17, lens 21 and lens 0 relay an image of the diodes to the cornea C of the patient. Consequently, the image of brick pattern 16 is pupiled at cornea C. This pupil at cornea C enables the light to be incident upon the cornea C at precisely controlled points. Refraction of the light entering through different locations on the cornea causes the brick pattern 16 to appear at corresponding locations on the fundus, depending on the refractive error of the eye.

Having set forth the projection of the image, the receiving path for light returning from the fundus can now be set forth. Specifically, beam splitter 20 has central aperture and a lens 28 which is preferably chosen to relay to the fundus of a normal eye a prism array. As will hereinafter be more fully set forth, the prism array assigns to the discrete detectors the pattern illustrated in FIG. 4.

A detector plate 30 is mounted immediately behind beam splitter 20. Plate 30 includes an aperture 32 through which central rays pass. These central rays are incident at a prism array 34 backed by a mirror 35. (The reader will understand that either the prism array 34 or the mirror 35 may include refractive power.)

The prism array 34 and mirror 35 retroreflect and deflect portions of images from the conjugate plane 22 to the discrete detectors. This image is relayed from the fundus F of eye E of patient P.

The respective images are reflected and deflected to the discrete photodetector array at individual elements 41, 42, 43, 44, 45 on the back side of detector plate 30. It is the difference in signal received at respective photodetectors 41-45 which enables the displacement of the light pattern to be determined for each interrogating LED.

It will be noted that the apparatus is provided with a data display 50 for directly reading out to the eye examiner the observed prescription. This much will be set forth with respect to FIGS. 16A-16C illustrating the microprocessor circuitry utilized with this invention.

Having set forth the preferred instrument, the theory behind the operation of this invention can be further discussed with respect to the schematic illustrated in FIG. 2A-2D.

Referring to FIG. 2A, fundus F from eye E has objective 0 relay an image of the fundus to the conjugate image plane 22. As in FIG. 1, a lens 21 relays a conjugate image of the first array 16 to fundus conjugate 22. Further, a second lens 28 relays a conjugate image of prism array 34 to fundus plane 22. First array 16 is illustrated separately in an expanded view in FIG. 2C. Prism array 34 is likewise illustrated in an expanded view of FIG. 2B. A cornea is illustrated in FIG. 2D.

Prism array 34 is facetted to deflect light to the respective detectors 41, 42, 43, 44 and 45. This array will be more fully set forth with respect to FIG. 2*b* and FIG. 4.

It will be seen that LEDs include respective array 14. This array can be passed in the entirety through all of the apertures zones of FIG. 3. Array 14 can be passed through the rectangular zones (see I). Alternately, array 14 can be passed through the zones surrounding the rectangular zones. (See II)

The LEDs 14 are in turn relayed to the lens of the eye in pattern 64 by lens 17, 21 and 0. This relay images the LEDs as point sources of light near the plane of the cornea. Thus, the brick pattern 16 is pupiled to point sources of light on the surface of the eye E (see FIG. 2D).

The effect of this pupiling can be readily understood. Specifically, refraction by the eye lens and cornea C will cause light of the array to be deflected. This deflection will be a function of the pupil deflection occurring purely locally at the image points of the LEDs. Thus, the deflection of the rays forming the interrogation pattern will be a function of the local qualities of the lens of the eye at the image point for a particular LED element on the eye lens.

I have shown here the LEDs to be an array of six evenly spaced light emitting diodes, 14A, 14B, 14C, 14D, 14E and 14F. The reader will understand that a greater number of LEDs will be used; it is not possible with the limited space of the drawing of FIG. 2A and FIG. 2D to illustrate such an exemplary spacing. Representative spacings are shown in FIGS. 12A-12D.

Referring both the schematic of FIG. 2A and the expanded view of the eye shown in FIG. 2D, the reader will note that I have not shown an LED registered to the exact center of the cornea C. This reason is that at this exact center location, the reference array 15 is pupiled. This reference array measures the displacement of the various arrays 14A, 14B, 14C, 14D, 14E and 14F. Having a LED project an interrogating array from a light emitting diode through the same aperture as the reference array does not yield useful information as both deflections should theoretically be the same.

Arrays having numerous LEDs have an additional advantage. The total field of such arrays will be obscured at the edges by a partially dilated eye. By having

such obscured LED images, the diameter of the pupil, a useful piece of medical information, can be determined responsive to objective refraction in ambient light.

Having set forth the operative portions of the instrument, attention may now be directed to the preferred embodiments of the patterns of elements here utilized.

First, and referring to FIGS. 3 and 4, two interchangeable patterns of elements are disclosed. As will hereinafter become more fully apparent, in the preferred embodiment I utilize the pattern of elements shown in FIG. 3 as an interrogating pattern. This pattern of elements constitutes a grid through which the light emitting diodes are pupiled at the lens of the eye. This pattern appears on the retina, deflected from the pupiled position on the cornea responsive to the power of the eye lens.

Referring to FIG. 4, this pattern of elements is preferably used as the reference array. That is to say, it is a pattern of distinct light sensitive areas which serve to define a reference position at the retina of the eye. Each element of the array is made distinct by its own prism facet. Each prism facet—overlying a specific set of areas of the interrogating array at the fundus plane of the eye—causes the returning retinal reflex light to be directed into a set of discrete photodetectors.

The reader should understand that the composite instrument includes one reference array for reading many interrogating arrays corresponding to each interrogating LED.

Referring to FIG. 2B, a prism array has been illustrated. This prism array has discrete prism facets, labeled respectively A, B, C, D, and E. Prism facets A–E cooperate with the discrete light sensitive elements 41–45. Specifically, each discrete facet is aligned to produce a pattern on the fundus of the eye identical to the pattern illustrated at FIG. 4. That is to say, all of the prism elements A of the prism pattern project an image of detector 41 to the elements A shown in FIG. 4. Likewise, all of the prism elements B of the prism pattern project an image of detector 42 to the elements B shown in FIG. 4. Similarly, all of the prism elements C of the prism pattern project an image of detector 43 to the elements C shown in FIG. 4. Additionally, all of the prism elements D of the prism pattern project an image of detector 44 to the elements D shown in FIG. 4. Finally, all of the prism elements E of the prism pattern project an image of detector 45 to the elements E shown in FIG. 4.

The array of FIG. 4 will appear at two discrete places. First, the array will appear at the fundus conjugate at plane 22. Second, the array will be pupiled at the eye E and thereafter appear on the fundus F of the eye.

It will be understood that the projection of prism elements and the photosensitive elements through the fundus of the eye occurs at a conjugate of aperture 31 relayed to cornea C of eye E. (See FIG. 2D at 31') It is sufficient to say that in appearance at the eye E, the reference array also acts through a small pupiled area—see 31' in FIG. 2D. It is only when the light expands to the pattern of FIG. 4 at the fundus of the eye that the useful expanded pattern of FIG. 4 is ready to interrogate the eye.

Referring to FIG. 4, it will be seen that the areas of the reference array are lettered A, B, C, D, E. Each reference area comprises squares. The elements B, C, D and E are provided with arrows. These arrows here indicate the direction of prism displacement. Element A is without an arrow. This is because in this example, element A passes light through the prism array without appreciable deflection.

Returning to FIG. 3, the rectangles having their major axis disposed vertically or horizontally. In this example, the rectangular areas (I) pass light. The surrounding area is labeled II and does not pass light.

The reader will understand that the following example employs the easier to understand case of the rectangular areas I of FIG. 3 occluding the five element array of FIG. 4. It will be understood that the boarders II about the rectangles could as well be used for the desired occlusion. Further, both of these areas could be utilized, each area being separately utilized from the remaining area.

There is a preferred relationship between the areas of the elements of FIG. 3 and the square areas of the elements of FIG. 4. Specifically, the rectangles are 5/2nds the area of each of the squares. Conversely, each of the squares is 2/5ths the area of the respective rectangles. Further, it will be noticed that each rectangular area is separated from its adjacent rectangular area by an interval equal to one half the width (narrow dimension) of the minor axis of the rectangle.

These dimensions are important. They have been empirically determined with respect to the two element array of FIG. 3 and the five element array of FIG. 4. I have found that this is the combination of arrays having the least respective number of elements. While these particular relative dimensions are important for the array here illustrated, the reader will understand that using techniques similar to those illustrated in FIGS. 5A and 5B, the determination of these dimensions can relatively easily be made once the principles of the illustrated pattern displacement is understood.

Referring to FIG. 3, the elements of the pattern are rectangles and are separated one from another in what appears to be a "basket weave" pattern. Specifically, rectangles with their major axis vertically disposed are centered with respect to the rectangles having their major axis orthogonally and horizontally disposed. The separation between the ends of the vertically disposed rectangles and the sides of the horizontally disposed rectangle is half the width of the minor dimension of the rectangles. Similarly, the separation between the ends of the horizontally disposed rectangles and the sides of the minor dimension vertically disposed rectangle is again half the width of the vertically disposed rectangles. There appears to be a "basket weave" orientation although some prefer the label "brick orientation".

It will be understood that the illustrated dimensions will admit of minor variations. For example, the dimensions of the rectangles of FIG. 3 and the squares of FIG. 4 can be slightly varied. It will be understood however, such variations will detract from the sensitivity for the relative displacements which occur during determining the prescriptive correction for the eye E.

It has been found that the disclosed apertures are ideal for overlay on the apertures of FIG. 4.

Having set forth the simple pattern of FIG. 3, the more complex pattern of FIG. 4 may now be more completely analyzed.

It can be seen that FIG. 4 consists of an array of 5 elements. The elements horizontally are aligned in the order A, D, E, C, B. The elements are each square and hence can form an infinitely repeating pattern if allowed to infinitely extend.

The elements repeat in what might be referred to as a "knight's move" pattern after the well known game of

Chess. That is to say, by moving two forward and one to the side, elements repeat.

This repeating pattern is derived from the total number of elements used and a sum of squares which equals this total number of elements used. Here, the total number of different elements used is five: A, B, C, D, and E. The two steps forward constitute the square root of four (4) or a total of two (2). The one step to the side constitutes the square root of 1 or one. It can be seen that the sum of these two squares (i.e., 4+1) is the same as five, the total number of elements used.

FIG. 4 has all "B" elements shaded. These shaded B elements cause a linear front of the elements B to appear. One element front is labeled X, the other perpendicular element front is labeled Y. It is by alignment of the major axes of rectangles I in FIG. 3 to these respective "fronts" that interrogation occurs.

It is with the respective X and Y axes that movement of one array with respect to the other array is described. In the array here shown having five such squares, the lowest number of elements is illustrated which permits unambiguous detection of movement in both the X and Y directions.

Presuming that the X axis advances upwardly and to the right in the Y axis direction, the order of element interrogation can be determined. Starting with the element A, the order is A, C, D, B, E, A, etc. This order can be determined by the reader in observing those elements which an advancing X axis sequentially contacts.

Assuming that the Y axis advances downward and to the right in the X axis direction, the order of interrogation is A, D, E, C, B, A, etc. As will hereinafter be pointed out, by either observing the direction of vectors or alternatively the phase of temporally produced cycles, the relative translation of the elements in both the X and Y directions can be determined.

Observing the diagram of FIG. 4, it will be observed that each square has a four distinctly different element neighbors. Take for example a square B. Nowhere in the disclosed pattern is one square B bounded on any of its four sides by an adjacent square B, or more than one square of the same type.

Further, it can be seen that if the squares are illuminated in the orders specified, advancing wavefronts of light will sweep across the elemental array. Such an order is either A, C, D, B, E (X direction) or A, D, E, C, B (Y direction) or the reverse of either order.

Alignment of the reference array to the interrogating array occurs along the X and Y axis as it is disposed in FIG. 4. The results of such alignment can be best seen in FIG. 5A and FIG. 5B.

Before analysis of the overlap produced at FIGS. 5A and 5B, at least two important points must be called to the attention of the reader.

First, the functionality here provided is the result of the vector sum of all of the light received from all of the elemental arrays. Only the direction or phase of the sum is important; the disclosed patterns are relatively insensitive to the resultant amplitude.

Secondly, although the examples of FIGS. 5A and 5B illustrate in the case of FIG. 5A, maximum visibility of element B and in the case of FIG. 5B minimum visibility of element B, it is misleading to consider the viewed portion or occluded portion of any single element alone. The device requires for its operation the sum of all elements, the minimum total being 5.

To assist the reader in further understanding, the plots of FIGS. 6 and 7 are provided. These respective plots assume temporal phasing of the five discrete light sources A-E. The reader will remember that the arrays can be either light sources or detectors. Accordingly, this description will be generically directed to either in the section of this description immediately following.

At this point in the description for ease of understanding of the invention, a 50% duty cycle will be assumed for all light sources, even though this is not preferred Later, the preferred 40% duty cycle will be introduced, it being pointed out that this duty cycle reduces certain harmonic inputs into the resulting output. As the understanding of these harmonic outputs requires understanding of system operation, explanation begins with the 50% duty cycle.

It is previously been mentioned that fronts of light will sweep across the five element display. Such sweeping will occur in either the X and Y direction as indicated on FIG. 4. This will be ACDBE for the advancement of the X axis and ADECB for the advancement of the Y axis. The reader must therefore keep in mind for the following descriptions that sensitivity of the arrays must be discretely activated for the X direction and thereafter discretely activated for the Y direction. Examples of this discrete activation follow.

Turning to FIG. 6, it will be seen that each of the detectors or lights are actuated on a 50% duty cycle. Each cycle has a total of 10 clock counts. Therefore for each detector or light to be on a 50% duty cycle, the device must be on for 5 clock counts and off for the remaining 5 clock counts. This actuation occurs here in the sequence B, A, D, E, C for interrogation in the X direction. The reader will see that with five elements to be evenly timed with respect to one another, each element must be time spaced from other elements by increments of two time counts. (See FIG. 6)

Starting with detectors or lights B, actuation from time period 0 through time period 5 will occur. Detectors or lights A actuate from time period 2 through time period 7, D from time period 4 through time period 9, E from time period 6 through time period 1 and finally C from time period 8 through time period 3.

Referring to FIG. 6, and remembering the displacement directions illustrated in FIG. 4, detector signals for X displacement equal to that shown in FIG. 5A are set forth. Similarly, and with reference to FIG. 5B, detector signals for the same X displacement are set forth immediately below. It can be seen that the two displacements produce two distinctly different temporal images.

The case of Y displacement is also illustrated in FIG. 6. Again commencing with light or detector B and commencing at time period 0, and ending at time period 5, the illumination sequence can likewise be understood. E commences at time period 2 and ends at time period 7. A commences at time period 4 and ceases at time period 9. C commences at time period 6 and ends at time period 1. Finally, D commences at time period 8 and ends at time period 3.

For the displacement given in FIG. 4 in the "Y" direction, a detection pattern for each of the time periods through the pattern illustrated for FIG. 5A is given in FIG. 6. Likewise, the detection is illustrated for the displacement in the "Y" direction in the amount illustrated in FIG. 5B is shown.

It will be understood that reception to or from each of the elements A, B, C, D, E can be indicated in a polar

coordinate format. In this polar coordinate format, the respective elements A-E are arrayed circularly in the order of the respective "X" and "Y" displacements. Such a polar coordinate format is set forth with respect to FIG. 7A.

Referring to FIG. 7A and remembering the displacement illustrated in FIG. 5A with the detector signal detected for FIG. 5A in the X direction, a vector diagram has been constructed. In this vector diagram for displacement in the X direction, the vector aligns with B. Similarly, and for displacement in the Y direction, again the vector aligns with B.

As translations gradually occurs from the alignment illustrated in FIG. 5A to the alignment illustrated in FIG. 5B, the vector sum of the elements will rotate. Rotation will occur counterclockwise presuming relative displacement of the pattern in one direction; displacement in the opposite direction will include opposite vector clockwise rotation. In the lower left portion of FIG. 7A, translation has occurred until the vector sum of the discrete elements has been transferred to an intermediate point between the vectors D and E for translation in the "X" direction.

Similarly, in the lower right portion of FIG. 7A, translation has occurred until the vector sum of the discrete elements has been transferred to an intermediate point between the vectors A and C for translation in the "Y" direction. It is to be understood that the vector format for each of the two directions "X" and "Y" is distinct and in the order that each of the elements would be interrogated by translation such as that shown in FIGS. 5A and 5B.

In the 5 position rotational pattern illustrated in FIG. 7A, each of the discrete vectors, D, A, B, E, C, for translation in the X direction and B, E, A, C, D for translation in the Y direction have been illustrated. The vectors have been added to yield a resultant vector direction. It can be seen that the vector direction is produced as the outcome of the respective translation. It is only the vector direction which yields a useful result. Vector magnitude is ignored.

I have previously mentioned that other arrays can possibly be utilized other than the five element array that I preferred. I illustrate such an alternate array in FIG. 7B.

Referring to FIG. 7B, an eight element array is shown. It includes the eight reference elements A, B, C, D, E, F, G, and H. Interrogating elements I are illustrated. The interrogating elements are also squares. These interrogating squares are shown having the same individual areas as the reference squares.

In the embodiment here shown, I have empirically determined that the interrogating squares can be the same size as the squares on the pattern referenced. While other sizes of squares or rectangles can be used, the same size of square here gives a simple output which directly indicates displacement. The reader will likewise understand that the boarders around the interrogating squares could as well be used for interrogation. In this latter case, the interrogating squares themselves would be opaque.

Just as the pattern of squares repeats, so does the interrogating pattern of squares. For example, the interrogating squares I are shown straddling each intersection of the adjacent elements DHGC in the example set forth in FIG. 7B.

The interrogating squares I are shown here straddling the adjacent elements DHGC. This is an exemplary displacement. As further translation occurs, other displacements will be generated.

Referring to the elements ABCDEFGH, these elements repeat in a two forward, two to the side arrayed infinitely stackable pattern. Following the rules set forth with respect to the pattern of FIG. 4, this repeating pattern is derived from a sum of the total number of squares. Here, the total number of elements is eight. The two steps forward constitute the square root of four. The two steps to the side constitute the square root of four. It can be seen that the sum of these two squares is eight, the total number of individual elements used.

All of the elements B are shaded. It can be seen that this shading give two directions of investigation. These directions of investigation are labeled "X" and "Y".

It will be understood that this is the second lowest number of squares that can detect relative displacement between the patterns in both the X and Y directions.

Presuming that interrogation of the advancing wave front parallel to the Y axis in the direction of the X axis is to occur, actuation of detector elements or illuminating elements as the case may be can include sequentially activating elements pairs G—E, C—D, H—F, and A—B (or the reverse of this order).

Likewise, presuming that interrogation of an advancing wave front parallel to the X axis in the direction of the Y axis is to occur, actuation of detector elements or illuminating elements as the case may be can include sequentially activating element pairs E—F, A—C, G—H, and B—D (or the reverse of this order).

The reader will understand that vector and temporal plots can be discretely developed for the illustrated array. By observing the discrete phase of the vector or the phase of the temporal cycles, the relative displacements between the patterns can be precisely determined.

I will hereafter set forth apparatus for the automated observation of the relative displacements between the patterns illustrated in FIGS. 3 and 4. This apparatus will be useful for the five element reference pattern of FIG. 4 and the two element interrogating pattern of FIG. 3. The reader will understand that through simple modification of the disclosed apparatus as to the interrogating pattern projected through element 16 of FIG. 2C and element 34 of FIG. 2B, techniques similar to those disclose hereafter can be used for the generation of a useful result from the pattern of FIG. 7B.

As is similar to the array of FIG. 4, the array of FIG. 7B has been discrete elements with all adjoining elements being distinctly different neighbors. Take any square B for example. Nowhere in the disclosed pattern are the sides of one square B bounded by another square B, or more than one other square of the same type.

Further, it can be seen that if the squares are illuminated in the specified order, advancing wavefronts of light will pass across the elemental array. This order is specified in element pairs immediately above.

The same caveats apply to this array. Directionality and displacement is only supplied by the vector sum of the array. Further, maximum or minimum visibility of any given element is misleading; summation of all elements is required.

It can be seen that the pattern for description of the embodiment herein is precisely equivalent to that pattern used for the disclosure of the five element array. It will be understood that this array is not preferred; it must contain at least three more individual elements than the preferred array of FIGS. 3 and 4.

Regarding the total number of elements utilized in the so-called reference pattern, the reader will recall that I require that the total number of elements used follow a "sum of squares" rule. Utilizing the sum of the squares of one and two, I have developed my preferred five element array illustrated in FIGS. 3, 4, 5A and 5B. Utilizing the sum of the squares of two and two, I have developed the eight element array illustrated in FIGS. 7B. Utilizing the sum of the squares one and three, the reader can develop an array utilizing 10 elements. Other arrays with more numerous elements are all possible. As the arrays increase, so does the difficulty of precisely directing the light sources and detectors to realize the utility of the patterns here disclosed such as FIGS. 4 and 7B.

I therefore prefer to utilize the five element pattern illustrated in FIG. 7A as a detector array.

Referring to FIG. 8 the electronics of an appropriate detector scheme for the five element array of my invention is illustrated. In the embodiment of FIG. 8, discrete detectors are switched on and off in a temporal pattern indicated in FIG. 9A. The device utilizes synchronous switches for detecting signals from the various light detectors.

I will hereafter set forth a microprocessor circuit with respect to FIG. 16A. This circuit will disclose the use of two sequencers and a multiplexer to choose between the two for sequencing the synchronous switches for the various light detectors utilized. One sequencer will sequence the switches for sensitivity in the X direction. The other sequencer will sequence the switches for sensitivity in the Y direction. For the present, it will suffice that the reader understand that by using a microprocessor clock signal and paired sequencers, the respective synchronous switches can each be activated to observe the presence of light.

The construction of the circuitry of FIG. 8 is easy to understand. Referring to FIG. 8, a differential amplifier 200 has a negative leg 202 for observing the absence of light and a positive leg 204 for observing the presence of light. Each light detectors A, B, C, D, and E is connected to a respective switch 208. Each of the switches acts under microprocessor controls and switches in a temporal pattern between a positive state and a negative state. The temporal pattern can best be seen with respect to FIG. 9A.

It will be remembered that for purposes of simplicity, we here are utilizing a 50% duty cycle of each of the light detectors 41, 42, 43, 44 and 45. That is to say for half of the respective time period each light detector will look for the presence of light. Signals indicating the presence of light will be output on line 204 and pass through the positive leg of amplifier 200. For the remaining half of the respective time period each light detector will look for the absence of light. Signals indicating the absence of light will be output on line 202 and pass through the negative leg of amplifier 200. Amplifier 200 will emit a signal that is additive of all of the outputs of all of the detectors.

As will hereinafter be set forth, the output of amplifier 200 is important. By the expedient of examining the total intensity of the signal output from amplifier 200, it is possible to ascertain when the apparatus of this invention determines a possible prescription component for a patient being examined.

Referring to FIG. 9A a group of ten time periods is illustrated. It can be seen that the switching here illustrated occurs in the direction of "X" sensitivity. That is to say in the order B, A, D, C, E. Switching for sensitivity in the "Y" direction in the order B, E, A, C, D could likewise occur.

It is required that the respective detectors 41–45 each sample for the presence and the absence of light at evenly spaced intervals throughout the ten (10) period time cycle here illustrated. For the exemplary 50% duty cycle here used, this imparts to each light detector a time period of 5 clock counts where the detector looks for the presence of light and a time period of 5 clock counts where the detector looks for the absence of light. In order for this spreading of the duty cycle to occur over the ten (10) period time cycle here illustrated, it is required that the duty cycle of each detector be offset by two of the time periods from any adjacently cycled detector.

In the example of FIG. 9A, detector B is in the negative state from time period 2 through time period 6; it is in the positive state from time period 7 through time period 1. Detector A is in the negative state from time period 4 through time period 8; it is in the positive state from time period 9 through time period 3.

Detector D is in the negative state from time period 6 through time period 10; it is in the positive state from tim period 1 through time period 5. Detector C is in the negative state from time period 8 through time period 2; it is in the positive state during time period 3 through time period 7. Finally, detector E is in the negative state from time period 10 through time period 4; it is in the positive state from tim period 5 through time period 9.

Assume that a single light emitting diode is given an arbitrary timing. The diode as illustrated in the bottom portion of FIG. 9A switches on at time period 4.3 and switches off at time period 9.2 for an approximate 50% duty cycle. Such a light source timing would be appropriate to an X pattern displacement corresponding to rotation of the vector as illustrated in FIG. 9B.

For example, suppose the relative displacement of a particular LED pupiled to the eye at one location gives the displacement pattern of FIG. 5A. Suppose the relative displacement of a particular LED pupiled to the eye at an adjacent location gives the displacement pattern of FIG. 5B. If the two LEDs are given the same duty cycles, differing detected voltages will emanate from amplifier 200 of FIG. 8 because of the differing overlap between the interrogating patterns and the reference pattern.

Referring to FIGS. 1, 2A, 2B and 2C, it will be remembered that detector element 41 is optically communicated to all the elements A, detector element 42 to optical elements B, detector element 43 to optical element C, detector element 44 to optical elements D and detector element 45 to optical elements E. Such alignments occur by appropriately adjusting the discrete prism facets of the prism array 34 (see FIG. 2B).

I naturally desire to read the individual patterns of my invention with a high signal to noise ratio. I therefore shift the phase of each discrete light emitting diode 14 at each location on the eye E so that for the sensed prescription, each detector element 41–45 receives separately the cumulative light from all of the LEDs. The cumulative reception of light enables my objective refractor to be operable in relatively high levels of background illumination.

Shift of the duty cycles of the LEDs 14 will be set forth hereinafter. Specifically, I will hereafter disclose formulas that can be applied to the specific locations interrogated by the LEDs. These formulas allow any-

one having skill in the art to predict the relative displacement between the pattern of FIG. 3 and FIG. 4 for any given prescription of the eye. From these relative predicted duty cycles, the duty cycles of the LEDs 14 interrogating the eye are varied. These variations occur so as to "sweep" the eye for the various prescriptive components in sphere and cylinder. When the eye is swept through a component which is closest to the actual eye prescription, the sequenced detectors 41–45 all receive the strongest possible signal. This strong signal indicates the presence of a prescriptive component in sphere or cylinder that is close to the actual value required for correction of the objective refraction of the eye.

The reader will understand that the prescription of the human eye expressed in terms of sphere, cylinder and axis is complex. Specifically, it is well known that sphere, cylinder and axis are all related one to another utilizing certain well known relationships (formulas) well known in the prior art. I therefore will disclose in summary format a sequence of sweeping the eye—and varying the duty cycle—for the various components of optical prescription. When this sequence is followed, it will be seen that the apparatus and process of this invention is quite capable of making an objective refraction for any normally encountered optical prescription.

Brief reference can be made to the diagram of the emmetropic eye illustrated in FIG. 10. It will be remembered from the description of FIG. 2A that each LED is imaged so a point source of light upon cornea C. Assuming that respective images of LEDs are incident upon the retina of an emmetropic eye at locations 312' and 323', this person enjoying hypothetical "perfect" vision. Assume further that both diodes 312 and 323 are given the time period illustrated in FIG. 9A. Presuming illumination of the "basket weave" pattern of FIG. 3, the patterns of LED 312 and 323 will identically overlap. For example, each of these LEDs may overlap rectangles as shown in FIG. 5B. Since neither LED 312 or LED 323 is relatively deflected upon reaching the retina, both arrays of rectangles will overlap one another.

I have previously illustrated with respect to FIG. 7A the phenomena of the relative displacements of the patterns with respect to one another. Specifically, I have demonstrated that as displacement occurs between the respective patterns, a vector which is the sum of the displacement can be generated. Just as the vector was generated in the case of FIG. 7A for the displacements of FIGS. 5A and 5B, a vector can be generated here for the relative displacement of FIG. 9A. This vector is plotted in FIG. 9B.

It now remains for this pattern of overlap at the eye to be read. This reading must occur through the projection of the images of the detectors 41–45 onto the pattern of the elements A–E shown in FIG. 5B.

Projection of the detector images has been previously set forth. Specifically, detector elements 41–45 will each be projected through prism array 34, with each element being projected in the repetitive pattern illustrated for the elements A–E of FIG. 5A. Presuming that the timing of the illumination of each diode and the timing of the enabling of each detector is the same, the reading of the overlap will be the same for LED 312 and 323.

Now let us presume that the hypothetical eye illustrated in FIG. 10 is hyperopic or "farsighted". Such a condition has been illustrated on the eye of FIG. 10 by shortening the distance between the eye lens and the fundus 503. It can be seen that the central ray of light from LED 312 strikes the upper portion of fundus 503 at point 502'. The central ray of light from LED 323 strikes the lower portion of fundus 503 at point 502".

Remembering that light from each of the LEDs 312 and 323 is projected through the "basket weave" pattern of FIG. 3, it can be seen from the lack of convergence between the two central rays from the respective LEDs that relative displacement will exist between the two patterns. I will suppose for the purpose of the present discussion that the projected "basket weave" pattern of FIG. 5A results from LED 312; similarly I will suppose for the purpose of the present discussion that the projected "basket weave" pattern of FIG. 5B results from LED 323. These differing displacements will result from the refractive power of the eye deflecting the pupiled image of each LED at the eye lens 500 to differing locations 502' and 502" on the fundus 503 of the eye.

Projection of the detector images will be precisely as before. Images of detector elements 41–45 will be projected centrally to the fundus by the prism array in the pattern of elements A–E. This projection will occur through a pupil in the central part of the eye lens and produce the pattern illustrated in FIG. 4. This FIG. 4 pattern will be in the same location on the eye fundus for both illustrated displacements of FIG. 5A and FIG. 5B.

In the above example for the "far sighted" eye, this detector has the characteristic that for an array of light emitting diodes all having the same 50% duty cycle, the detector segments will receive light signals in accordance with FIG. 5A which represents the relative displacement of LED 312 and FIG. 5B which represents the displacement of LED 323.

Let us suppose that the hypothetical eye illustrated in FIG. 10 is myopic or "near sighted". Such a condition has been illustrated on the eye of FIG. 10 by lengthening the distance between the eye lens 500 and the fundus 501. It can be seen that the central ray of light from LED 312 strikes the lower portion of fundus 501 at point 501'. The central ray of light from LED 323 strikes the upper portion of fundus 501 at point 501".

Remembering that each of the LEDs 312 and 323 is projected through the "basket weave" pattern of FIG. 3, it can be seen from the impingement upon the fundus beyond the point of convergence between the two central rays from the respective LEDs that relative displacement will exist between the two patterns, this relative displacement being the opposite of that previously illustrated. I will suppose for the purpose of the present discussion that the projected "basket weave" pattern of FIG. 5B results from LED 312; similarly I will suppose for the purpose of the present discussion that the projected "basket weave" pattern of FIG. 5A results from LED 323. These differing displacements will result from the refractive power of the eye lens deflecting the pupiled image of each LED at the eye lens 500 to the differing locations on fundus 501 of the eye.

The reader will realize that the displacements of FIGS. 5A and 5B illustrate an oversimplification of the various displacements that an eye having other than perfect refractive characteristics will generate. For each individual LED in an array of LEDs, differing displacements will result. Consequently, and in the absence of some adjustment, there will be no predictability at any of the elements 41–45 as to when signal will be received and from what discrete diode signal will be

received. Realizing this detection problem, attention will now be devoted to the diagram of FIG. 5C.

In the review of FIG. 5C, three separate principles will be addressed. First, an order of detector sequencing will be disclosed. This order will be illustrated for movement of the patterns relative to one another in the X direction. The case of the displacement in the Y direction will not be considered completely as it is precisely analogous to the X direction.

Second, the duty cycle of the LED 312 and 323 will be considered. It will be seen that each of the LEDs can be adjusted in duty cycle relative to the displacements of FIGS. 5A and 5B to obtain a maximum signal and a minimum signal. For the purposes of this demonstration, the preferred 40% duty cycle will be used.

Finally, it will be proposed to vary duty cycle of LEDs in an array in accordance with a predicted prescription. Such a variation will be seen to give at the detectors cumulatively the strongest signal. The received signal will be seen to have a highly desirable signal to noise ratio.

Referring to FIG. 5C, a detector timing diagram is shown. The timing diagram includes a circle 600 with ten equally divided arc segments. These arc segments are ordered in the counterclockwise direction.

The vector diagram of FIG. 5C assumes a continuing displacement of the rectangles of FIG. 3 in the X direction of FIG. 4. The displacement occurs from the relative displacements illustrated in FIG. 5A to the relative displacements in FIG. 5B and returning to the displacements of FIG. 5A. In other words, a full "revolution" of displacement is illustrated in the vector diagram of FIG. 5C.

The vector diagram is sequentially labeled. It includes the section 5A—5A for the detection of the displacement of FIG. 5A and section 5B—5B for the detection of the displacement of FIG. 5B. Assuming X axis displacement upwardly and to the right of that illustrated in FIG. 4, counterclockwise vector rotation will result.

For the displacements given, there will be two classes of detector elements. There will be a first class of detector elements illuminated. These are shown at each circle segment representing one tenth of the overall detector duty cycle. At 5A—5A the sequence CBA appears. This means that when displacement of the patterns to the relative position of FIG. 5A occurs, elements C, B, and A are illuminated. Similarly at 5B—5B, the sequence DE appears. This means that when displacement of the patterns to the relative position of FIG. 5B occurs, elements D and E are most likely to be illuminated.

In each position of rotation, some elements are most likely to be vignetted or obscured from illumination. At 5A—5A these elements are elements DE. These elements are shown in brackets (DE). Likewise, at 5B—5B elements CBA are vignetted obscured from illumination. These elements are shown in brackets (CBA).

I have found that it is preferable to actuate the optical segments in the order illustrated by the counterclockwise rotating vector of FIG. 5C. This sequence establishes the desired X axis sensitivity to displacement and enables activation of all communicated light detectors.

It will be remembered that I utilize synchronous light sensitive rectifiers. These elements can be activated in the positive (light receiving) and the negative (nonlight receiving) modes. Accordingly, it will be understood that in any position of vector rotation, all elements 41–45 will be activated—some will be present for the reception of light and will emit signal as light is received; other will be preset for the absence of light and will emit a negative signal when light is received. This much has been previously set forth in the circuitry of FIG. 8.

The next consideration is LED duty cycle timing relative to the established detector cycle. Using the preferred 40% duty cycle, the question becomes for the displacement illustrated in FIG. 5A, what duty cycle illumination of an LED will produce that maximum signal and what LED illumination will produce the minimum signal? These respective LED duty cycles are illustrated. The duty cycle of LED 1 will produce maximum signal; the duty cycle of LED 2 will produce minimum (i.e., negative) signal.

For the displacement illustrated in FIG. 5B, the opposite is true. LED 2 will produce maximum signal and LED 1 will produce minimum signal.

The reader will realize that as the duty cycle of the LEDs is shifted relative to the sequence of interrogation illustrated in the timing diagram of FIG. 5C, signal will decrease. For example, shifting each of the LED duty cycles by one quarter of a full detector cycle will produce an intermediate result in particular, nearly a zero signal.

It will therefore be understood that for each particular displacement along the X direction of FIG. 4 of the pattern of FIG. 3 there will be an LED duty cycle that will result in both a maximum signal being received and another LED cycle that will result in a minimum signal being received.

Realizing that by the shifting of the duty cycle of each of the interrogating LEDs 14 to a duty cycle required by a particular prescription, it will be understood that duty cycles for an array of LEDs can be varied for the determination of prescriptions. As will hereinafter be set forth, these respective various timings for various prescriptions are set forth in a look up table. A microprocessor accesses the look up table. When the correct prescription is interrogated in the look up table, a very strong cumulative signal appears from detectors 41–45. This strong signal enables the correct prescription component to be flagged.

Realizing this much, the case of an LED array can be considered. If an array of LEDs are all given discrete phases which anticipate a predicted prescription, an extremely strong signal will result. The reader will recognize that this "tuning" of the duty cycle is an extremely powerful technique for achieving high signal to noise ratio. By way of example, using an array of 24 LEDs and effecting timing of the LEDs to predict a realized prescription, a signal 24 times that for a single LED will be realized while the detector noise is little changed: more than 500 single LED determinations would be required to achieve this result from 24 cooperating LED sources

Having set forth the relative displacement of the patterns upon incidence to the fundus, the use of an entire array of interrogating light sources can now be understood.

First, reference will be made to such an array as illustrated in FIG. 12A. Thereafter, and with reference to the timing diagrams illustrated in FIGS. 9A and 9B, I will set forth how the duty cycle of each interrogating LED can be temporally shifted for given optical conditions of the eye that are not emmetropic. This temporal shift will enable the detector array of FIG. 8 to receive

an additive signal from an entire array of LEDs to indicate generation of a correct prescription by the apparatus disclosed herein.

Referring to FIG. **12A** an array of **24** light emitting diodes is illustrated. This array includes diodes **301–306**, **307–310** and **311–312** on the upper portion of dividing line **400** and light emitting diodes **313–318**, **319–322** and **323–324** on the bottom of the dividing line **400**.

For a given predicted prescription of sphere and cylinder for each of the light emitting diodes **301–324** a specific displacement can well occur. This displacement will be associated with a temporal shift of the light emitting diode duty cycle which will be shifted to a particular interval of the synchronous sampling of the detector array as illustrated in FIGS. **9A** and **9B**. It can be seen that assuming the temporal duty cycle of each light emitting diode is individually varied, a maximum sensitivity for the incidence together of all light emitting diodes **301–324** on a detector operating in the temporal pattern of FIG. **9A** can be attained. Specifically, and by the expedient of predicting displacement for a suspected prescription and varying the duty cycle as shown in FIG. **9A** discretely for each of the 24 light emitting diodes **301–324**, all detectors in the array illustrated in FIG. **8** can receive an optimal signal with simultaneity.

I prefer for each prescription component I detect to utilize look-up tables in a microprocessor. These prescriptive components can usually signal the start of the temporal phase of each LED in accordance with suspected prescription.

Thus, by the simple expedient of varying the time period of the 40% duty cycle of each of the light emitting diodes, a reinforced signal simultaneously received from all 24 light emitting diodes can signal correct prescription. It will be understood that the 24 light emitting diodes reinforce one another. In such reinforcement, a signal of unique strength indicating the presence of a correct prescription is attained.

Having set forth the possibility of an LED array being phased for reception of a tuned signal, a digression will be made. Specifically, the digression will refer to FIGS. **14A–14E**. A set of equations will be derived to describe standard eye prescription in terms of sphere 0°–90° cross cylinder and 45°–135° cross cylinder. These equations will relate the power of the eye at any particular point to values of sphere and cross cylinder.

Once this determination is made it will be emphasized that to determine sphere, cylinder and axis, measurement of at least three points on the surface of the eye is required. Thereafter, three discrete methods of measuring the power of correction necessary for an eye will be disclosed.

A first method will constitute scanning a group of light emitting diodes with duty cycles anticipating displacement. It will be shown that by scanning in meridional power for both the X and Y directions, sphere and 0°–90° cylinder may be measured.

Second, the use of a charge coupled device will be briefly considered. It will be shown that by using the derived equations, computation of optical prescription is possible. Specifically, by illuminating the eye sequentially through each of the "detector" elements and storing each corresponding video image, computations can be made resulting in the determination of a prescription.

Finally, an additional technique including scanning for error will be disclosed. This technique will be shown to give an indication of error both in sense and magnitude which enables rapid determination of the correct optical prescription.

Referring to FIG. **14A** an optical schematic is disclosed. An eye lens L is shown which lens L is subject to spherical correction. The correction here is positive sphere. This positive sphere is represented by a series of vectors which include a series of inwardly directed radial vectors **700**.

Referring to FIG. **14B**, an eye lens is schematically illustrated having required negative spherical correction. Accordingly a vector format of outwardly directed radial arrows **702** is illustrated for the negative spherical correction.

Referring to FIG. **14C**, a cross cylinder is illustrated. The cross cylinder has positive power along the X axis and negative power along the Y axis. Accordingly, it includes inwardly directed spherical vectors **700** aligned to the X axis and negatively directed vectors **702** aligned to the Y axis. Vectors in each of the respective quadrants of the graphical representation are shown. These vectors are a resolution of the vector deflections in the respective quadrants. Accordingly, vectors **705** and **706** respectively resolve the vectors of the respective lower left and lower right quadrants. Similarly vectors **707**, **708** respectively resolve the vectors of the respective upper right and upper left quadrants.

Referring to FIG. **14B**, a second cross cylinder is shown. This cross cylinder has positive cylindrical power on the 45° axis and negative cylindrical power on the 135° axis. Accordingly, a positive radial vector **700** can be seen on the 45° axis and a negative vector **702** on the 135° axis.

Each of the quadrants are here shown with vector resolution. These quadrants, however, appear on 0°, 90°, 180°, and 270° axis. Specifically, vectors **705'**, **706'**, **707'**, and **708'** resolve the vector powers in each of their respective quadrants of the **45**, **135** cross cylinder power here shown.

It is known to those skilled in the art that by varying cross cylinder powers as shown in FIGS. **14C** and **14D**, an overall cylinder of any power and any axis can be generated. I have discussed such a technique in my U.S. Pat. No. 3,822,932 entitled "Optometric Apparatus and Process Having Independent Astigmatic and Spherical Inputs" issued Jul. 9, 1974. Incorporation of that patent is herein made by reference.

I further wish to adopt a convention that will render more clear the terminology which I hereafter adopt. Specifically, for cylinder which is aligned on the 0°–90° axis, I will adopt the symbol C_+. For cylinder which is aligned to the 45°–135° axis, I will adopt the symbol C_x. It can thus be seen that the C standing for cylinder and the subscript + for 0°–90° and the subscript x for 45°–135° render the disclosed symbols quite understandable.

I now turn to the illustration of a hypothetical eye at FIG. **14E**. The eye is shown with three respective points, P_1, P_2, and P_3. For a power of sphere, cylinder and axis (or sphere and pair of cross cylinders) to be determined, at least measurement in three such points must occur.

In order to set forth equations by which such a three part solution can be rendered, it is necessary to establish the variables for any given point. Taking the point P_1 and referring to the above diagrams **14A–14D** can be instructive.

It will be remembered that my measurement technique is sensitive to X direction displacement only and Y direction displacement only. Therefore it is necessary for any point P_1 to write an equation which will measure the X axis displacement between the interrogating and reference patterns and the Y axis displacement between the interrogating and reference patterns.

Taking the case of a point P_1 and worrying only about the X axis displacement, it can be seen that for the X displacement of P_i the X axis displacement will be generated by any spherical power present such as illustrated in FIG. **14A** combined with any C_+ power present as illustrated in FIG. **14C**. In actual observation, when these two powers combine, they will not be distinguishable. I therefore choose to call these powers meridian power S_{bx} denoting that they are power resulting in pattern displacement in the x direction due to an aperture displacement of "base leg" b.

Referring to FIG. **14D**, it can further be seen that as a function of the point P_1 in distance above the b axis by a distance b_y another contribution to x axis displacement will occur. This x axis displacement is described by the term

$$\left(\frac{C_x}{2}\right)b_y$$

Thus, the equation for displacement in the x axis direction is as follows:

$$\phi_x = S_{bx}b_x + \left(\frac{C_x}{2}\right)b_y \quad [1]$$

Following exactly similar logic the equation for displacement in the Y axis direction due to the location of the point P_1 is defined by the equation

$$\phi_y = S_{by}b_y + \left(\frac{C_x}{2}\right)b_x \quad [2]$$

I have previously demonstrated that the terms S_{bx} (x axis meridian power) and S_{by} (y axis meridian power) are a combination of sphere and 0°–90° cylinder (see subscript +). The correct equations for these displacements are

$$S_{bx} = S + \frac{C_+}{2} \quad [3]$$

$$S_{by} = S - \frac{C_+}{2} \quad [4]$$

Having these equations, three discrete methods of determining prescription for the eye can now be determined.

First, and by the utilization of the foregoing equations, it is a matter for the reader to determine the expected displacement at any of the points P_1, P_2 or P_3. Indeed, I prefer to compute displacement for a matrix of such points. The matrix having the number of light emitting diodes illustrated in FIGS. **12A–12D**. It has been found that by varying the temporal relationship of the diode duty cycle with respect to the detector duty cycle (see FIG. **5C**) first for x sensitive sequencing and thereafter for y sensitive sequencing, a scanning mode results in a peak signal being determined for the values of ϕ_x and ϕ_6 corresponding to the correct refractive correction. This peak signal plots out with a well defined maxima at the point where meridional power is correctly chosen. Thus, and assuming a first X sensitive sweep for meridional power and a second y sensitive sweep for meridional power, two points of strongest signal will be received.

Referring to FIG. **15A** I include herewith an actual plot of signal produced by scanning in so-called meridian power. The meridian power was varied by varying the duty cycle of light emitting diodes. The diodes were varied to emulate a spherical prescription ranging from +44 dropters to −44 dropters.

Observing FIG. **15A**, it can be seen that there is present a peak **400**. This peak coincides to that portion of the scan that is closest to the required correction for a patient. Adjacent peaks **401** and **402** may also be observed. These respective adjacent peaks are false maxima. It is because of these false maxima I prefer to conduct (at least initially) a full scan of the possible ranges of sphere and cylinder. This full scan prevents the apparatus from determining a prescriptive component has been reached at peaks **401**, **402**.

It can be seen that the graph of FIG. **15A** is obtained by having the detectors interrogate the respective pattern of FIG. **4** using the X direction sensitivity. It will be remembered that X direction sensitivity is obtained by scanning the photosensitive elements **41–45** as communicated through the prism element **34** of FIG. **2B** to the pattern of FIG. **4** in the order A, C, D. B, E, A, etc.

As similar graph is obtained for Y direction sensitivity, it will be remembered that Y direction sensitivity is obtained by scanning the photosensitive elements **41–45** as communicated through the prism element **34** of FIG. **2B** to the pattern of FIG. **4** in the order A, D, E. C, B, A, etc.

We now make the assumption that there is no cross cylinder C_x. It can be seen from equations **3** and **4** above that if the curves are coincident, the term for 0°–90° cylinder C_+ will be 0. If the maxima of the spherical sweep curves are separated one from another by a distance, it has been found that distance is an approximation to the cylinder component C_+.

Referring to FIG. **15C**, I illustrate a plot having the intensity of the X interrogation plotted with respect to the intensity of the Y interrogation. It can be seen that two peaks appear; one peak **405** appears for the X direction interrogation and one peak **406** appears for the Y direction interrogation. It further can be seen that these respective peaks are separated one from another by a distance. This distance has been found to be magnitude directly proportional to the value of 0°–90° cylinder C_+.

It may be further seen that using equations [4] and [5] we may determine a value for sphere. At this juncture, values will be known for sphere S, and for the 0°–90° cylinder C_+. By the simple expedient of maintaining the two known maxima for Sx and Sy, a sweep for so-called 45°–135° cylinder can be made. Specifically, one sweep for Cx will be made for the X direction of interrogation and one scan for Cx will be made for the Y direction of interrogation. When the maximum function is found, very close estimates for sphere S, and cylinders C_+ and C_x will be present. By the simple expedient of iteration, the true prescription may be generated.

With respect to FIG. **16**A, a microprocessor embodiment of this invention is disclosed. In this microprocessor embodiment I disclose the use of four look up tables for scanning the eye to determine eye prescription. These look up tables are set forth with respect to FIG. **16**B and include spherical power in the X direction, spherical power in the Y direction. Cx in the X direction and Cx in the Y direction. From the foregoing explanation, the reader will understand that these look up tables will be all that is required to determine the prescriptive power of the eye in sphere S and cross cylinder C+ and Cx.

The reader can understand that the disclosed computations could as well be made by a charged coupled device (CCD) receiving the images from the eye. Specifically, in such a protocol, each discrete light emitting diode would be cycled in turn. The CCD would view the intensity variations in the pupil plane resulting from retinal pattern taking each element of the CCD image as an aperture at the pupil of the eye, the image intensities for a series of 5 image exposures provides sufficient information to define the phases ϕ_x and ϕ_y displacements from each diode. The CCD element position and its estimated values for ϕ_x and ϕ_y allow equations 1–4 will be solved. The solution, a function of numeric processing, will yield the correct sphere, cylinder and axis for the eye.

I at present do not prefer the use of the charge coupled device to the assignment of the discrete duty cycles to the LEDs. This being the case, I include the foregoing summary only for completeness of the disclosure and to note that the use of a charge coupled device is possible.

I further have made it clear that an array of light emitting diodes is preferred. Such an array can be patterned after those arrays illustrated in FIGS. **12**A through **12**B. In such arrays 24 light emitting diodes are utilized. These diodes are labeled **301–324**. The reader will understand that in a look up table, the discrete timing of the duty cycles for all of the LEDs can be set forth for the full range of each of the prescription components to be scanned.

Having set forth the usefulness of using 24 discrete light emitting diodes, all with varying timing to give unique reinforcing signals in both X and Y sensitive modes, two useful characteristics of the disclosed displacement interrogation will be set forth.

First, and with respect to FIGS. **11**A and **11**B, the problem of harmonics will be addressed. Thereafter, and with attention first to FIG. **10** and thereafter to the diagrams of FIGS. **12**A–**12**D an interrogating sequence will be set forth.

Referring to FIG. **11**A, a "ripple" effect of the utilization of five time periods is illustrated. In FIG. **11**A, it is presumed that each of the detectors B, A, D, C, E has a 50% positive duty cycle and a 50% negative duty cycle. As before, these respective duty cycles are averaged over a time period of 10 units for half or 5 of the ten units of time. The detectors are in the positive state half the time. For the remaining 50% of the 100% duty cycle, the synchronous rectifiers are in the negative state.

As before, the temporal phasing of the detectors is illustrated for sensitivity in the X direction. Displacement is one time unit out of a total of 10 time units between the leading edge of the successive sensitivity of each of the detector units B, A, D, C, and E. Here detector B is negative for time period 2 through time period and positive from time period 7 through time period **1**. The sequence continues with respective two unit displacements for the detector sequence B, A, D, C, E.

Assuming that a light source is given a 50% duty cycle and is illuminated from time period **2** through time period **6** for five discrete units, addition of the state of each of the total of five detectors is instructive. Specifically, during time period **2** one excessive negative state will be present. During time period **3** one excessive positive state will be present. During time period **4** one excessive negative state will be present. During time period **5** one excessive positive state will be present and finally at time period **6** one excessive negative state will be present.

For the entire time periods **2** through **6**, it can be seen that this is a total of three negative states and two positive states. Thus, the negative states will for the light source illustrated at **404** predominate by one negative state. (See FIG. **11**A)

Assume an elemental shift of the time period and illumination of a light source in a 50% duty cycle commencing at time period **3** and ending at time period **7**, it can be seen that there will be an excessive positive state by the addition process just illustrated. The negative state of time period **2** will be eliminated. The positive state of time period **7** will be added. Positive states from time periods **3**, **5**, **7** will exceed by one negative states from time periods **4** and **6**.

Referring to the lower portion of FIG. **11**A it can be seen that as displacement occurs, oscillation will occur from a negative state to a positive state at a frequency of approximately five times the total time required for one-half of a complete detector cycle.

I have dubbed this phenomena a "five omega ripple"; two solutions suggest themselves.

First, by the simple expedient of adapting a 40% duty cycle, this ripple can be eliminated. This is preferred and is illustrated in FIG. **5**C.

Second, successive duty cycles of each LED can be displaced by 1/20th of a cycle. Displacement in one direction (for example forward in time) by 1/20th of a cycle followed by displacement in an opposite direction (for example, retardation in time) by 1/20th of a cycle in the opposite direction will eliminate this "five omega" ripple phenomena when the results are combined.

Referring to FIG. **11**B, an additional ripple phenomena is therein illustrated. Referring to FIG. **11**B, I have discovered that a second so-called "three omega ripple" is present. Simply stated, the Fourier series includes a harmonic contributor of three omega. Again, two solutions are present. The first solution is to alter successive interrogating time periods by 1/12th, commencing one lighting state at a positive 1/12th time period and the remaining state at a negative 1/12th time period.

I have discovered that a timing count which is a multiple of **2**, **3**, and **5** is to be preferred. For example, instead of using the normal binary count of 256 I prefer to utilize a timing count of 240. Taking a 40% duty cycle, it can be seen that 96 counts comprise precisely 40% of a 240 time period cycle. Likewise by advancing or retarding an illuminating diode in the order of 20 of the total of 240 time units, the "three omega" ripple phenomena just discussed can likewise be eliminated.

An additional method of generating eye prescription once the gross prescription is estimated involves dividing the field of interrogating light emitting diodes into sectors, the sectors can be shifted in phase to produce an

error function or discriminator function. This error function can be understood by first utilizing and understanding the diagrams of FIGS. **12A** through **12D**.

Referring to FIG. **12A**, an array of **24** LEDs **301–324** is set forth. These LEDs include LEDs **301–312** above horizontal dividing line **400** and LEDs **313–324** below horizontal dividing line **400**. The reader will remember that by setting the discrete timing of each of the LEDs **301–324**, a vector signal of relatively great magnitude over the background illumination would be simultaneously received at each of the individual detectors A–E in the array of FIG. **8**.

Two phenomena rise from the division concept illustrated in FIGS. **12A–12D**. It will be first demonstrated that assuming optimum signal has been received and the prescription detected by the instrument is correct, by shifting the phase on one side of the dividing line **400** by plus 90° and simultaneously shifting the phase on the opposite side of the dividing line **400** by −90°, the signal at the detector apparatus of FIG. **8** will disappear for original phases appropriate to the refractive error.

Second, and assuming the same kind of phase shift but further assuming that the prescription is not correct, a vector function which I call a "discrimination" function will be generated. This "discrimination" function will have a magnitude and sign indicating the required sense and approximate magnitude required for correction of an estimated prescription to a correct prescription.

Referring to FIGS. **9A**, **9B** and **12A**, and assuming the emmetropic eye of FIG. **10** at fundus **501**, the reader will remember that there is no relative displacement from the vector configuration of FIG. **9B** for each of the LEDs **301–324**. That is to say, all of the LEDs can be timed to give the vector addition seen in FIG. **9B**, which vector will have relatively great strength over ambient background illumination.

It will be seen with respect to FIG. **12A**, sensitivity is in the "X" direction. It can further be seen that phase dividing line **401** for the phase shift is normal to the direction of shift sensitivity.

Now assume that LEDs **301**, **302**, **303**, **307**, **308**, **311**, **313**, **314**, **315**, **319**, **320**, **323** are each shifted positively 90° in phase. Assume that the remaining LEDs are each shifted negatively 90° in phase. As these groups of LEDs are on opposite sides of the dividing line **401**, the equal and opposite shift in phase in the amount of 90° will cause the detector array of FIG. **8** to go from a maximum signal to no signal at all for either of the two groups of LEDs. A zero signal will indicate by its null signal that the test prescription of the moment is correct. If the estimated retractive error was incorrect, the signal will be non-zero, and increase in strength in proportion to the size of the misestimate.

I have assumed in the description generated thus far that the meridional component measured by the light array divided on dividing line **401** and phase shifted in opposite 90° components to left and right of dividing line **401** was correct for the prescription being measured. It is a surprising result of my invention that if the component is other than correct, by the phase shifting process described with respect to FIG. **12A**, a signal indicating the component error will originate. This signal will indicate in both sign and magnitude the sense and magnitude required for correction of the particular component being measured.

It will be understood that the phase shifting process of FIG. **12A** must be repeated for each of the suspected components being tested. Specifically, and for each component of prescription measured, shifting will occur on opposite sides of a dividing line to opposite 90° phase differentials.

Shifting as indicated in FIG. **12B** along a dividing line **402** parallel to the direction of X sensitivity will give a sensitivity to 45°–135° components—useful in the determination of astigmatism.

Shifting as indicated in FIG. **12C** along a dividing line **403** normal to the direction of Y shift sensitivity will give the second and remaining meridional component of prescription.

Finally, shifting as indicated in FIG. **12D** along dividing line **404** parallel to the direction of Y shift sensitivity will give a second and redundant 45°–135° component of sensitivity.

In each case, should an error be present in the particular component being detected, a signal indicating both the sense and magnitude of the required correction will be generated. By the expedient of applying this vector indicated correction to the next iteration for the indicated component of prescription, the total prescription for the eye can be rapidly generated.

Referring to FIG. **13**, it can be seen that the optical arrangement of the instrument particularly lends itself to the addition of targets T useful in keratometry. Referring to FIG. **13**, two targets T1 and T3 of four preferred keratometry targets T1 through T4 are illustrated. These keratometry targets are measured in their apparent separation in reflection from the patient's cornea K by a video imaging device such as charge coupled device **600**. By the expedient of having the charged coupled device read out the apparent separation of the targets T1–T4, the curvature of the cornea K in sphere, cylinder and axis can be readily determined.

Referring to FIG. **16A**, a microprocessor embodiment of this invention is disclosed. The microprocessor includes three main operative functions for the practice of this invention. These functions are a look up table for communicating to the LED array the various duty cycles for sweeping the eye in prescription. Secondly, two sequencers which control two multiplexers. These respective multiplexers initiate interrogation in the X direction and the Y direction by the respective photosensitive elements. Finally, the microprocessor recognizes the various signal peaks when they are encountered. From the recognition of the signal peaks, eye prescription in sphere and cylinder can be computed.

Regarding the duty cycle communicated to each of the light emitting diodes, microprocessor **500** addresses through address bus **501** a look up table **502**. Look up table **502** is divided into four sections, these sections having been previously described with respect to the preferred protocol for locating the prescription of the eye. These sections of the look up table are schematically illustrated in FIG. **16B**.

Referring to FIG. **16B**, it can be seen that a first portion of the look up table **506** includes information corresponding to values of sphere dependent upon variations of LED position with respect to X displacement. These values are computed using the relationships of equation [1].

A second portion **507** of the look up table includes information corresponding to values of Cx for displacement in the X direction. These values will be computed utilizing the relationships of equation [1].

A third portion **508** of the look up table includes information corresponding to values of sphere dependent upon variations of the LED position with respect

to Y displacement. These values can be computed utilizing the relationships of equation [2].

Finally, a fourth portion **509** of the look up table includes information corresponding to values of cross cylinder Cx with respect to variations of the LED position with respect to Y displacement. These values can be computed utilizing the relationship of equation [2].

Each of the tables preferably contains information corresponding to ranges of sphere and cylinder which encompass the vast majority of possible refractive errors likely to be encountered.

Having set forth the layout of the look up table **502**, the sequence of examination can now be set forth. For the determination of prescription, the eye will typically be swept in one component of sphere power. This component of sphere power can include Sx for meridional power sensitivity related to displacement in the X direction.

Typically microprocessor **500** will address memory **502** at portion **506** on a block by block basis, each block corresponding to a value of sphere. I will assume that a full duty cycle will comprise a count of 240. For the preferred 40% duty cycle, the ON-time of each diode will be 96 counts long. Further, a separate starting count for each LED will be required. It will thus be understood that each block of memory will contain at least information indicating the count corresponding to the start of the ON-time for each of the separate LEDs **301–324**.

The value of the starting count of the microprocessor clock for each of the LEDs will be output on the data bus **510**. The microprocessor **500** will add 96 to the value of the starting count to determine the value of the stop count. Thereafter the clock count will be compared with these values. The result will be output to the LED register **512**. This command register will reflect whether a discrete LED is to be in the ON or OFF state.

LED register **512** will receive from the microprocessor **500** in a bit-mapped form. Each bit in the register will address an discrete LED. One bit in this register will be a gate enable signal for the LED gates. When this bit is set, LED illumination information will be gated from LED register **512**, by LED gates **518**, to LED drivers **515**. There is a LED driver for each discrete LED. Each driver furnishes the power to illuminate its associated LED when the corresponding bit in the LED register is set and the LED gates are enabled.

In use, and for each scan of a selected prescription to be scanned, the LED register will be loaded with ON or OFF data for each of the LEDs. Assuming the preferred complete cycle of 240 counts, each scan at a particular prescription will consume at least a full 240 counts. Scan will occur on a block by block basis through the look up table **502** at portion **506**.

Having set forth the cycling of the individual LEDs, the simpler case of the cycling of the detectors can now be set forth.

For the cycling of the detectors, sequencers **520** and **521** will be utilized. Sequence **520** will cycle detectors **41–45** (see FIG. 2A) for detection in the X direction. Sequencer **521** will cycle detectors **41–45** for detection in the Y direction.

Each of the sequencers **520** and **521** will be selected on an alternate basis by the multiplexer **529** under control of the microprocessor **500**. For sweep of Sx and for Cx related to displacement in the X direction, sequencer **520** will command the sequence of interrogation. For sweep of Sy and for Cx relating to displacement in the Y direction, sequencer **521** will command the sequence of interrogation. Control will occur through clock signal at line **525** and be initialized by a reset **526**.

As set forth in FIG. **8**, the cumulative output of the detectors will be utilized. Specifically, the detector array will output through an analog to digital converter **531**. An output for each value swept from the table **502** will occur.

Once sweeping of a portion of look up table **502**—say a portion **506** occurs, the values of signal output from the detectors **41–45** are compared for each prescription value swept. As the reader will undoubtedly recognize, the peak illustrated in FIG. **15A** can be easily identified and recorded to appropriate memory.

This process will be repeated for each portion of the memory **502** in the order **507**, **508** and **509**. Respective maxima for each of the values swept will be recorded.

The sequence of the microprocessor interrogation and computation has been previously set forth. It will be repeated only in summary format herein.

Specifically, Sx will be swept and the maximum recorded. Thereafter Sy will be swept and its maxima recorded. The two values Sx and Sy will most likely occur at differing values. The difference between these values will directly relate to cylinder C+. From C+, the actual values of sphere S can be computed using the relationship of equations [3] and [4].

Thereafter, as assuming a value for sphere S and C+, cross cylinder Cx will be swept. This cross cylinder will first be swept as it relates to X displacement and second will be swept as it relates to Y displacement. From these two sweeps, a value of Cx will be determined.

At this juncture, the reader will understand that tentative values for S, C+ and Cx will be present. Naturally, by assuming these values and iterating the process through sweeps reduced in scope based to the determined values, more accurate prescriptive data can be generated.

What is claimed is:

1. An optical instrument for objectively refracting the eye on the eye fundus, said instrument comprising:

an interrogating pattern of elements configured for projection to the eye fundus;

a reference pattern of elements configured for projection to the eye fundus for overlying said interrogating pattern for determining displacement of said interrogating pattern with respect to said reference pattern;

one of said patterns including a first array of elements including at least five distinct and repeating elements, said elements distinct in being distinguishable one from another, said elements being repeating in that the same distinguishable element appears more than once in each said array;

the other of said patterns including a second array of elements including at least two repeating elements, said elements being repeating in that the same element appears more than once in each said array;

optics for relaying respective images of said interrogating pattern along a first optical path through the lens of said eye and onto said eye fundus and relaying the respective images of said reference pattern along a second optical path through a different portion of the lens of said eye and onto the fundus of said eye;

at least one light source for illuminating one of said respective first or second arrays for projection as

said interrogating pattern onto fundus of the eye and at least two photosensitive elements optically communicated to the other of said respective second or first patterns for reading light as said reference pattern from the fundus of said eye; and,

means for detecting the signal at said photosensitive elements to determine the relative displacement of said patterns on the fundus of the eye.

2. The invention of claim **1** and wherein said photosensitive elements are five in number and communicated directly to at least five distinct and repeating elements.

3. The invention of claim **1** and including means for synchronously switching said photosensitive elements.

4. The invention of claim **1** and including a light source having a plurality of light emitting diodes for illuminating one of said patterns on said eye, said light emitting diodes arrayed for projection at spaced apart locations across the lens of said eye.

5. The invention of claim **4** and wherein said light emitting diodes are temporally phased to produce at said detector an additive signal.

6. The invention of claim **1** and wherein said first array of elements includes at least five distinct and repeating elements of square area with each distinct element bordered on every side by differently distinct elements and said second array includes at least first and second rectangles, said rectangles having an area equal to 5/2nds of the area of the squares of said first array and having a length equal to twice the width elongate dimension of said first rectangle at 90° to the elongate dimension of said second rectangle.

7. The invention of claim **1** and wherein said optics pupil respective images of said interrogating pattern and said reference pattern at said eye lens with said interrogating pattern being projected through at least three points on said eye lens and said reference pattern being projected through one point on said eye lens.

8. The invention of claim **1** and including means for providing a keratometry target projected adjacent said eye, said keratometry target positioned for reflection from a cornea of said eye along the center optical path of said instrument; and

means for measuring the dimension of said keratometry target attached to said instrument whereby at least the curvature in sphere, cylinder and axis of said eye may be measured.

9. The invention of claim **1** and including the prism array, said prism array disposed in the array of one of said pattern of elements.

10. The optical instrument of claim **1** and wherein:

said photosensitive elements include a charge coupled device.

11. A process for objectively refracting the eye, said process comprising:

providing an interrogating pattern of elements configured for projection to the eye;

providing a reference pattern of elements configured for projection to the eye, said reference pattern for overlying said interrogating pattern for determining the displacement of said interrogating pattern with respect to said reference pattern;

providing to said respective patterns a first array of at least five distinct and repeating elements, said elements distinct in being distinguishable one from another, said elements repeating in that the same distinguishable element appears more than once in said array;

providing to said respective patterns a second array having at least two repeating elements, said elements repeating in that the same element appears more than once in said pattern;

providing relay optics for relaying respective images of said interrogating pattern and said reference pattern to and from the eye;

projecting said interrogating and reference patterns to the eye through said relay optics;

providing a light source;

illuminating said interrogating patterns with said light source along a path for projection of either said respective first or second arrays through said optics to the eye and onto the fundus of the eye;

providing photosensitive elements,

projecting said reference pattern with said photosensitive elements optically communicated to the other of said respective second or first arrays along a path for projection through said optics from the eye and onto said photosensitive elements; and,

measuring the difference of signal between said respective photosensitive elements to determine the relative displacement of said interrogating pattern relative to said reference pattern whereby varying displacements of said image on the fundus of said eye may be measured for determining the prescription of the eye.

12. The invention of claim **11** and wherein said provided photosensitive elements are provided synchronous switches; and

switching said provided synchronous switches between positive polarity and negative polarity for detecting the presence and absence of light.

13. The process of claim **11** and wherein said provided light source includes a plurality of light emitting diodes, said diodes having a duty cycle in the range of 20% to 50%.

14. The process of claim **13** and including the step of varying the duty cycle of said diodes temporally one with respect to another to provide at said detectors additive signals.

15. The process of claim **11** and wherein the first of said provided arrays includes five distinctly different elements, each said element being square in shape and having an infinitely stackable array wherein each one of said distinct elements is surrounded by differing ones of said distinct elements on said four sides of said square and providing to said other array first and second rectangles, the major axis of said first rectangle aligned at 90° to the major axis of said second rectangles.

16. The process of claim **11** and including the step of projecting said reference or interrogating pattern through at least at one point on the eye lens, and

projecting said interrogating or reference pattern through at least three points on said eye lens, pupiled at each point of incidence on said eye lens.

17. The process of claim **11** and including providing a keratometry target surrounding said eye; and

projecting an image of said keratometry target to means for measuring the dimension of said keratometry target whereby the curvature of said eye may be detected.

18. The process of claim **11** and wherein the step of providing a light source includes the step of providing an array of light emitting diodes, said provided array of light emitting diodes for projecting through an area exceeding the dimension of the iris of said eye whereby

vignetting of said light emitting diodes by the iris of said eye indicates the dimension of said iris of said eye.

19. The process of claim **11** and wherein said step of providing a light source includes the step of providing a plurality of light sources selected to overlie a preselected portion of the optic being examined, said preselected portion being less than the total expanse of said optic.

20. The process of claim **11** and wherein said providing photosensitive elements step includes the step of:

providing a charge coupled device.

21. A process for objectively refracting the eye through projection optics, said process comprising the steps of:

providing an interrogating pattern of elements for projection to the eye;

providing a reference pattern of elements configured for projection to the eye for overlying said interrogating pattern to determine displacement of said interrogating pattern with respect to said reference pattern;

projecting both said patterns to the eye with a pupil of said projected patterns passing through the lens of said eye at distinctly different points;

providing to one of said patterns an array of five distinct and repeating elements, said elements being distinct in being distinguishable one from another, said elements repeating in that the same distinguishable element appears more than once in each pattern;

providing to the other of said patterns an array of at least two repeating elements, said elements repeating in that the same element appears more than once in each said pattern;

providing a plurality of light sources;

providing a plurality of photosensitive elements;

illuminating said respective first or second array by said plurality of light sources;

optically communicating said respective second or first array to said photosensitive elements; and,

timing the duty cycle of said light emitting sources to provide at said photodetectors an additive signal upon displacement of said patterns on the fundus of said eye.

22. The invention of claim **21** and including dividing said light emitting sources into first and second groups;

shifting the temporal illumination of said first group by 90° in a first and positive direction; and,

shifting the temporal illumination of said phase of the remaining half of said light sources in the opposite direction;

measuring the sensitivity at said detectors to determine the magnitude and sense of the resultant received signal.

23. The process of claim **21** and including the step of utilizing five photosensitive elements to said five distinct and repeating elements of said first pattern;

illuminating light sources on a 40% duty cycle said distinct and repeating elements of said second pattern.

24. The process of claim **21** and including successively advancing and retarding alternate duty cycle duration on each said light source.

25. The process of claim **24** and wherein said advance and said retard of said duty cycle moves advancing said duty cycle by 5% and retarding said cycle by 5% in sequential illumination of each said light source.

26. The process of claim **21** and wherein said providing photosensitive elements step includes the step of:

providing a charge coupled device.

27. A process for objective refracting a human eye, said process comprising the steps of:

providing an interrogating pattern of elements configured for projection through said eye;

providing a reference pattern of elements configured for projection overlying said interrogating pattern through said eye, said projection pattern and said interrogating pattern having relative sensitivity one to another upon relative displacement one to another;

providing one of said patterns with a first array of elements with at least five distinct and repeating elements, said elements distinct in being distinguishable from one another, said elements repeating in that the same element appears more than once in each pattern;

providing the other of said patterns with a second array of elements of at least two repeating elements, said elements repeating in that the same element appears more than once in each said array;

projecting a plurality of light sources through one said array through said eye to pupil said sources at said eye and to project said resultant pattern beyond said eye to an imaging surface on the regina;

projecting a second of said arrays to photosensitive elements, each element of said array communicated to one of said photosensitive elements;

interrogating said eye with an estimated prescription including a component of corrective cylindrical lens power provided by providing differing timing to differing ones of said plurality of light sources;

shifting the phase f half said light sources on one side of said array of said light sources 90° in duty cycle in a first temporal direction;

shifting the phase of the other half of said light sources in said array of said light sources in duty cycle 90° in the opposite temporal direction;

receiving at said photosensor said shifted phase to determine the sense and magnitude of optical change required for said estimated corrective prescription in an iterative procedure.

28. The process of claim **27** and including the step of sequencing the detectors in a first sequence to sensitize said detectors to displacement along a first axis across the imaging surface; and

sequencing said detectors to a second sequence, said second sequence for sensitizing said detectors for displacement of said pattern along and towards a direction normal to said first axis across said imaging surface.

29. The process of claim **27** and wherein said projecting the second of said arrays to photosensitive elements includes the step of projecting the second of said arrays to charge coupled devices.

* * * * *

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United States Patent [19]

Nagano et al.

[11] Patent Number: 5,138,359

[45] Date of Patent: Aug. 11, 1992

[54] **FOCUS DETECTING APPARATUS IN WHICH MATCHING WITH THE IMAGE PERFORMANCE OF AN OBJECTIVE LENS IS ACHIEVED**

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[21] Appl. No.: **718,907**

[22] Filed: **Jun. 24, 1991**

Related U.S. Application Data

[63] Continuation of Ser. No. 281,326, Dec. 8, 1988, abandoned.

[30] **Foreign Application Priority Data**

Dec. 10, 1987 [JP] Japan 62-313179

[51] **Int. Cl.**[5] **G03B 13/36**; G02B 7/34

[52] **U.S. Cl.** **354/406**; 250/201.18

[58] **Field of Search** 354/402, 406, 407, 408; 250/201.2, 201.8

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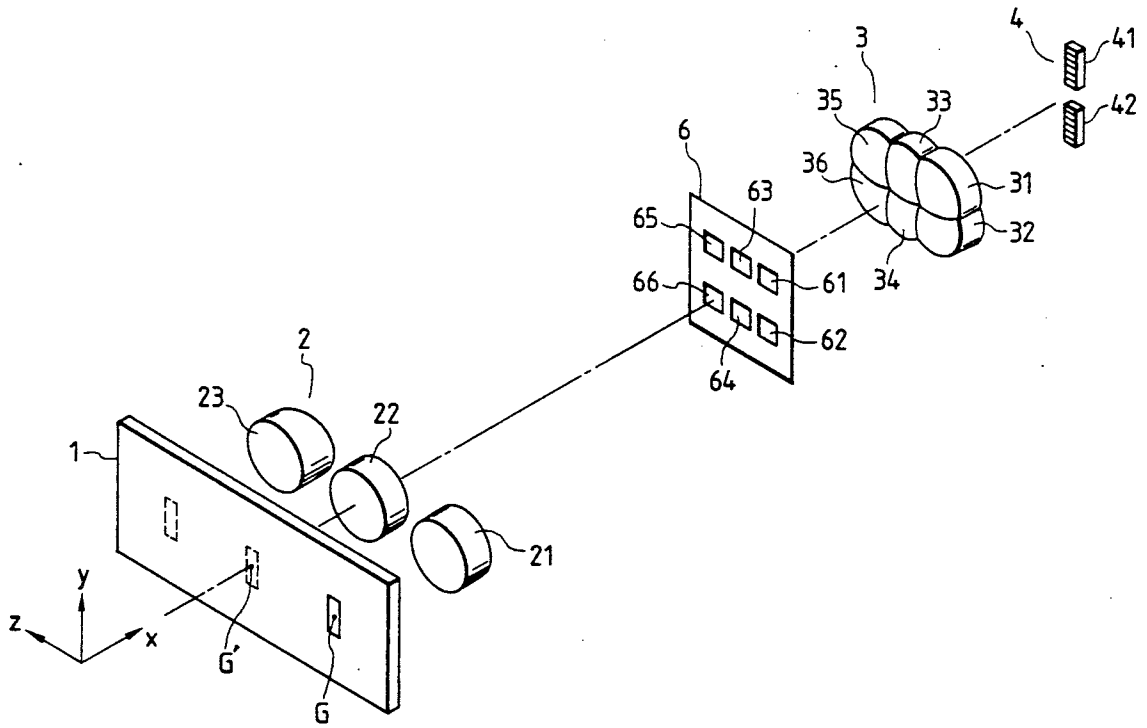
Primary Examiner—W. B. Perkey

Attorney, Agent, or Firm—Fitzpatrick, Cella, Harper & Scinto

[57] **ABSTRACT**

In an apparatus for detecting the relative positional relation between light intensity distributions relating to an object image and detecting the focus-adjusted state of an objective lens, a pair of stop openings for limiting an off-axis light flux forming light intensity distributions entering a pair of secondary imaging lenses are provided so as to be symmetrical with respect to a meridian centered at the optic axis of the objective lens so that the influence of the residual aberrations of the objective lens becomes uniform.

4 Claims, 7 Drawing Sheets



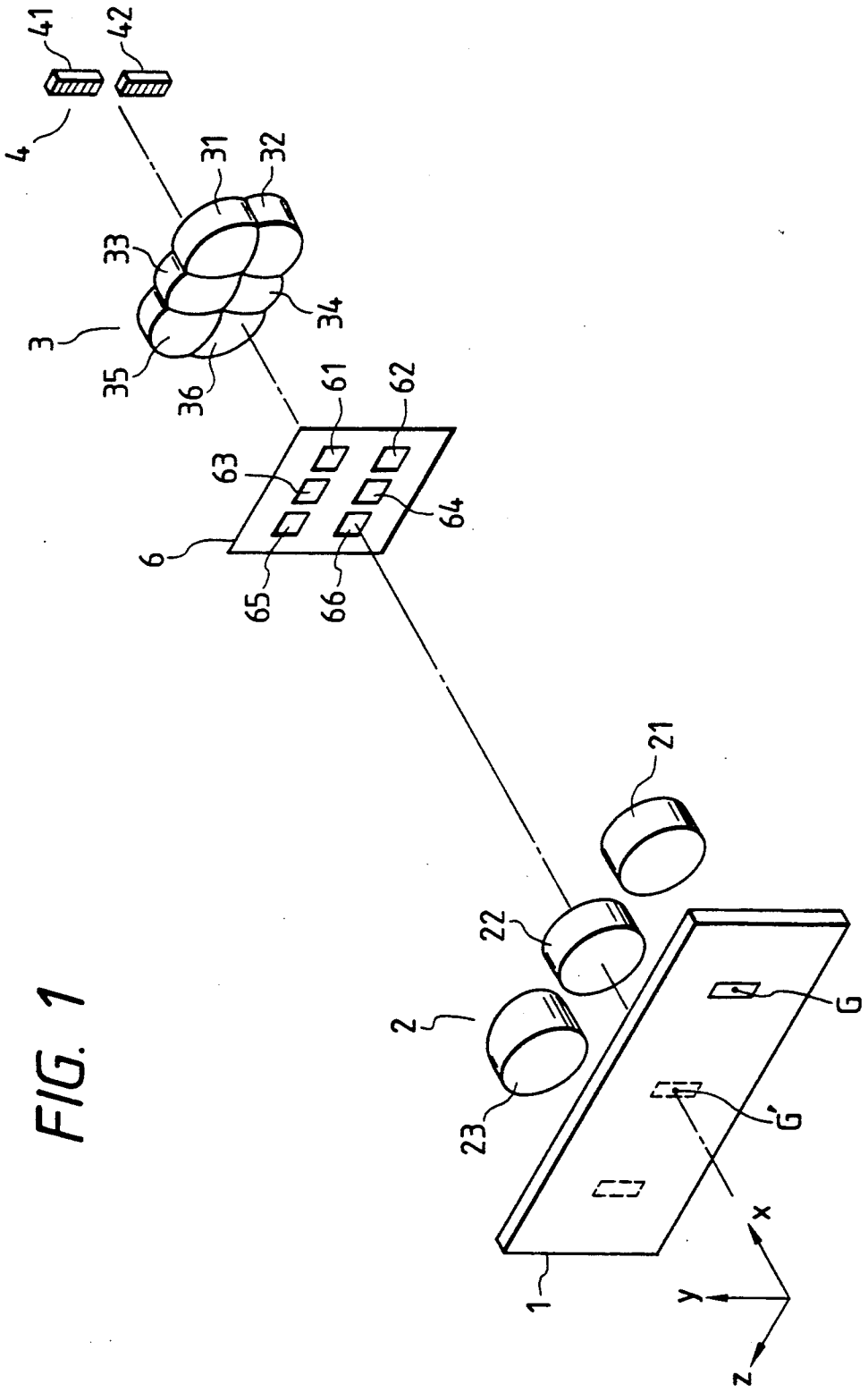
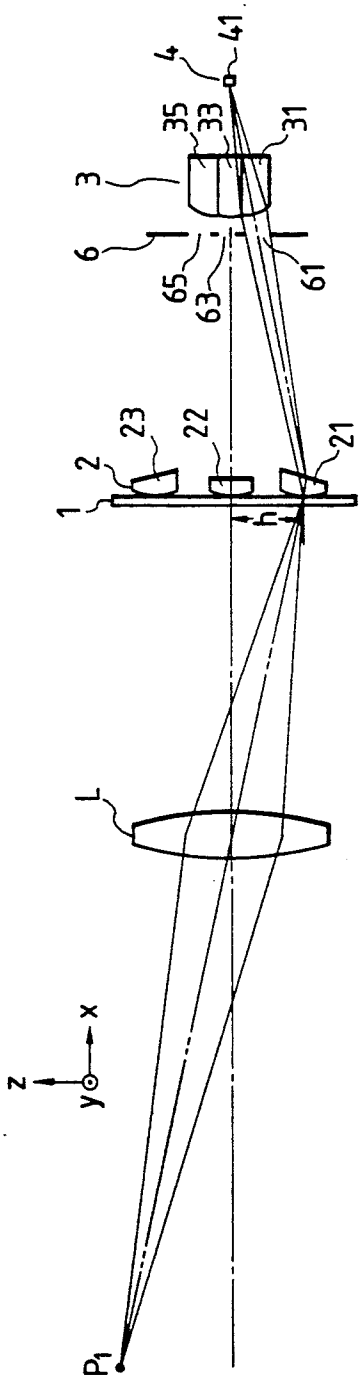


FIG. 1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y
P1

FIG. 2A

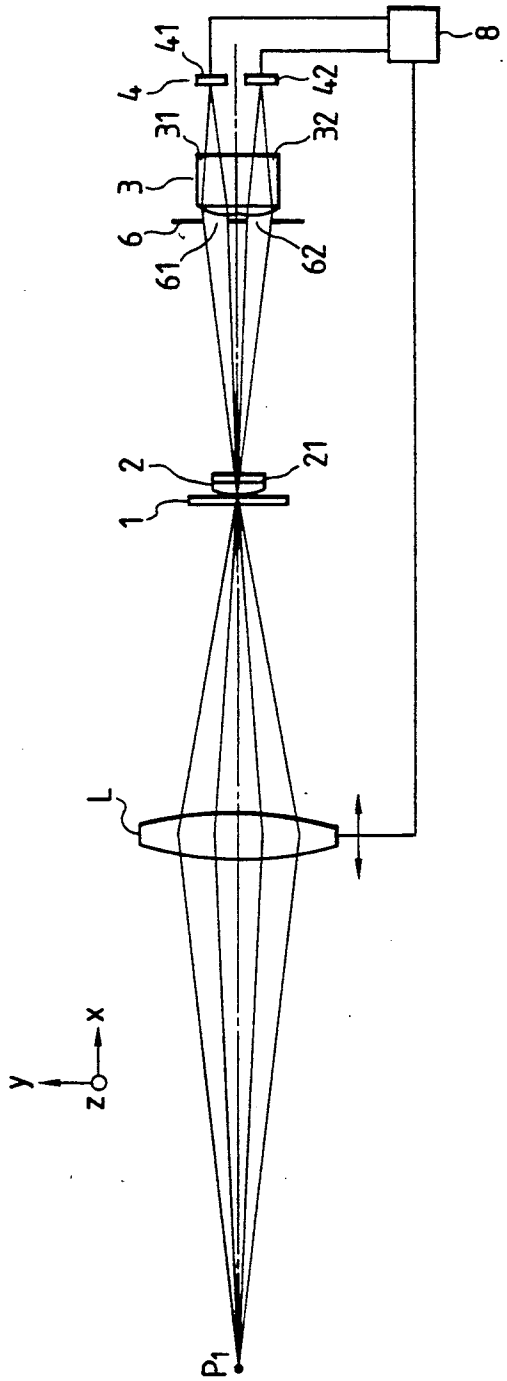

8
41
4
42
31
32
3
6
61
62
2
21
1
L
x
y
z
P1

FIG. 2B

FIG. 3

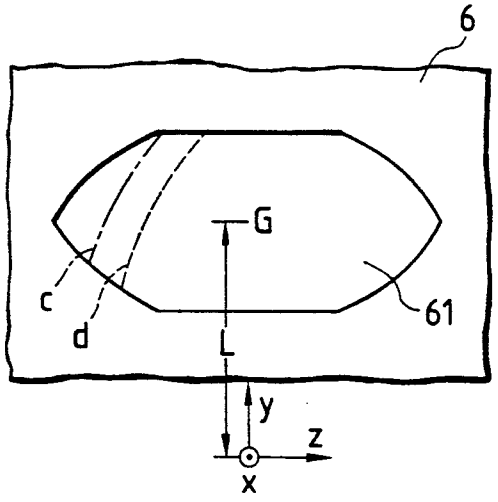
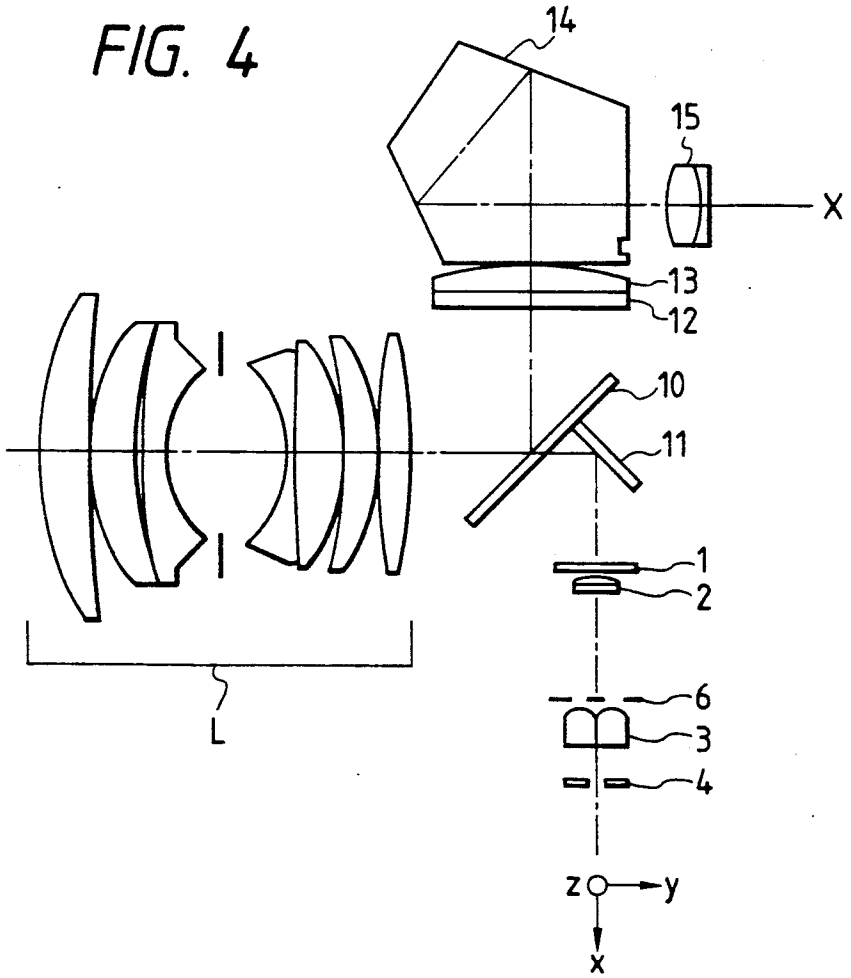


FIG. 4



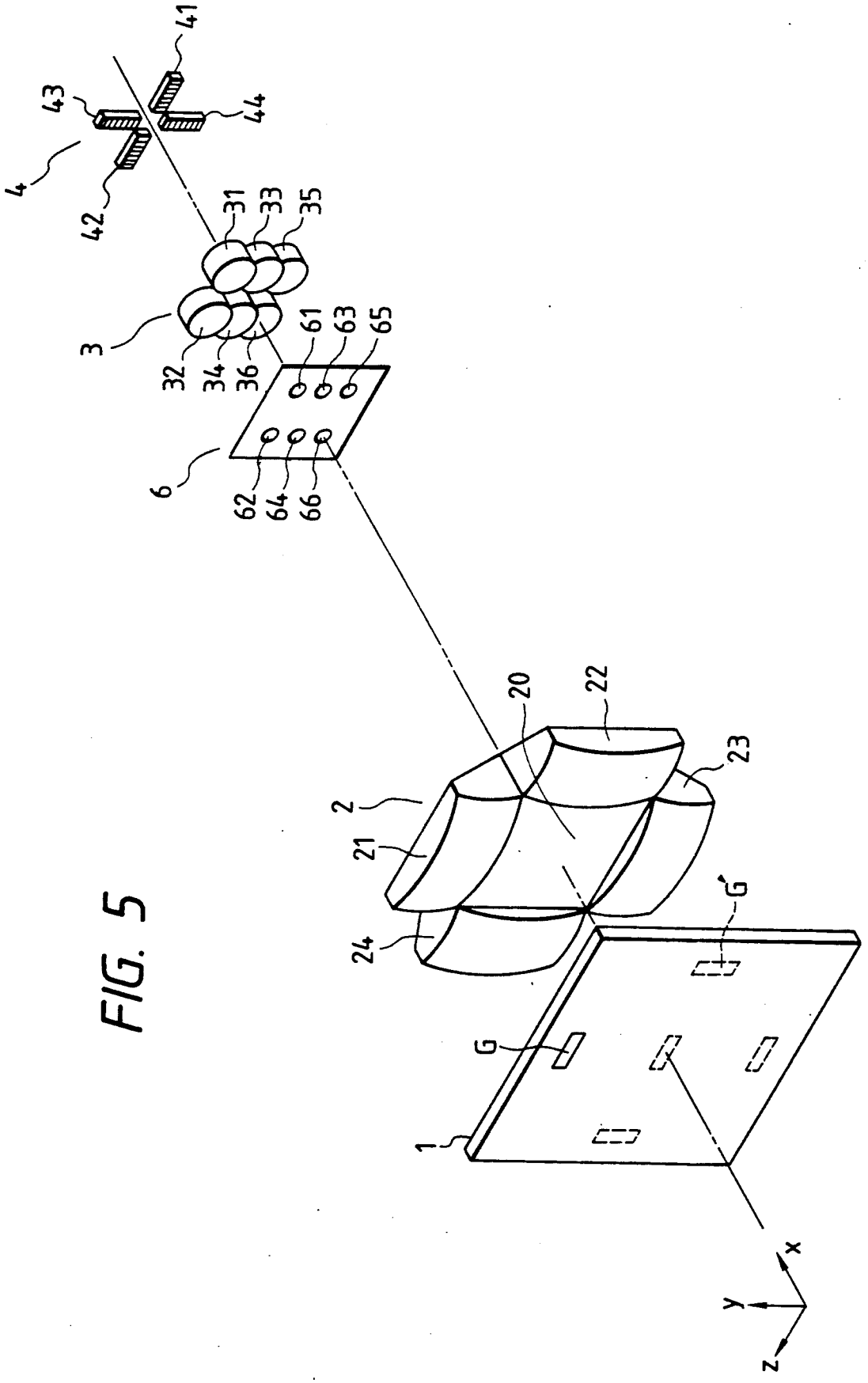

41
43
44
4
42
31
33
35
3
61
63
65
32
34
36
6
62
64
66
20
22
23
2
21
G'
24
G
1
x
y
z

FIG. 5

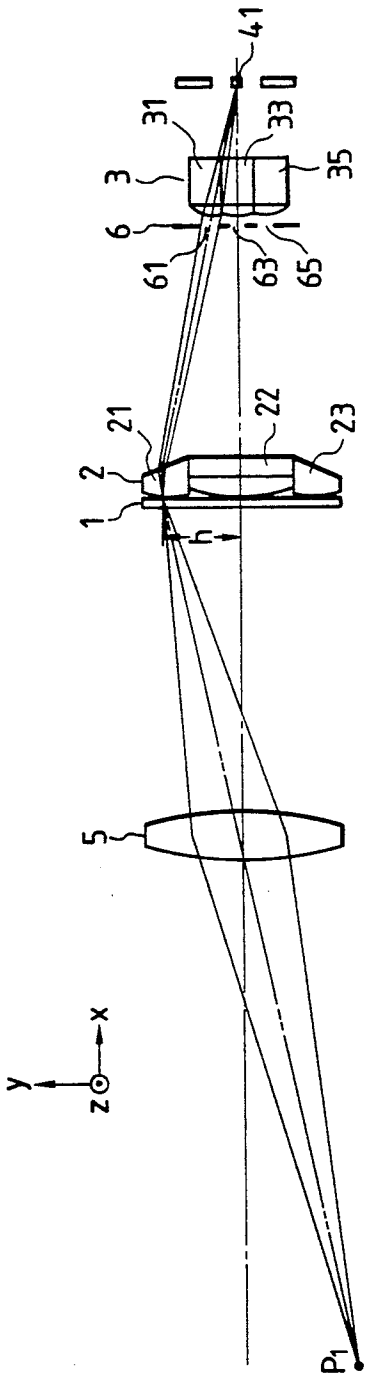

41
31
33
3
35
6
61
63
65
21
22
23
2
1
h
5
y
x
z
P1

FIG. 6A

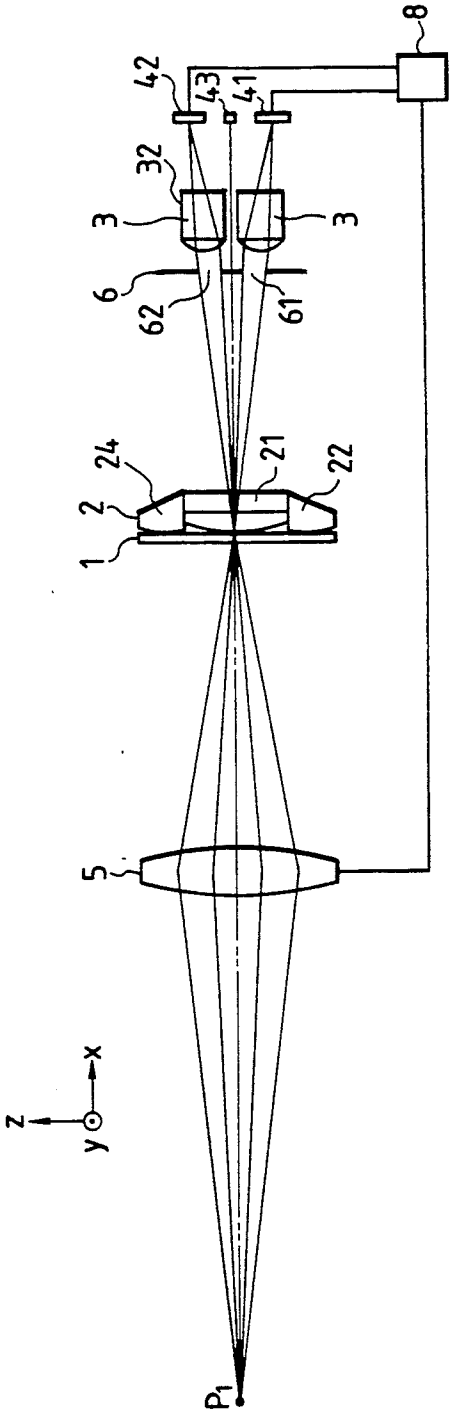

8
42
43
41
32
3
3
6
62
61
24
21
22
2
1
5
z
x
y
P1

FIG. 6B

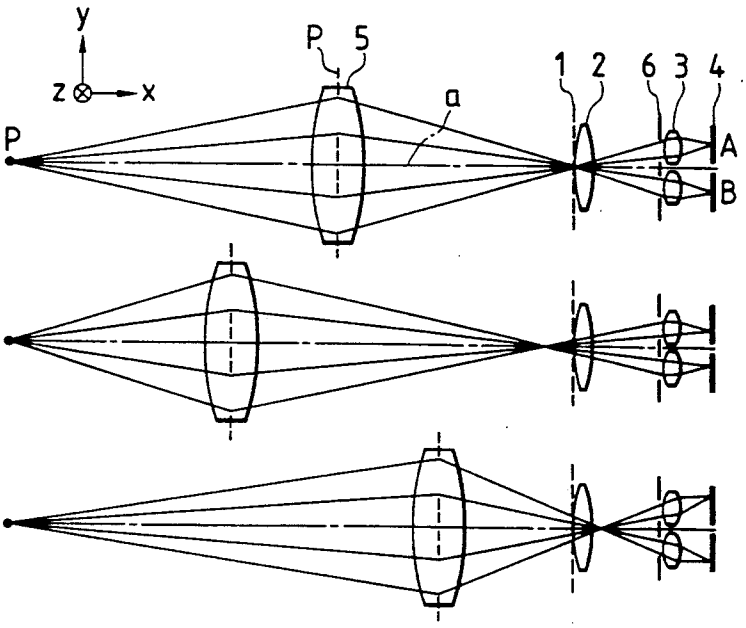


FIG. 7A
PRIOR ART

FIG. 7B
PRIOR ART

FIG. 7C
PRIOR ART

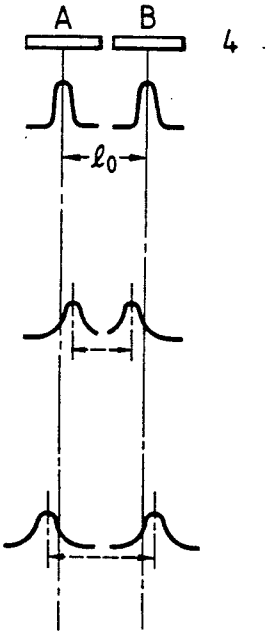


FIG. 8A
PRIOR ART

FIG. 8B
PRIOR ART

FIG. 8C
PRIOR ART

FIG. 9

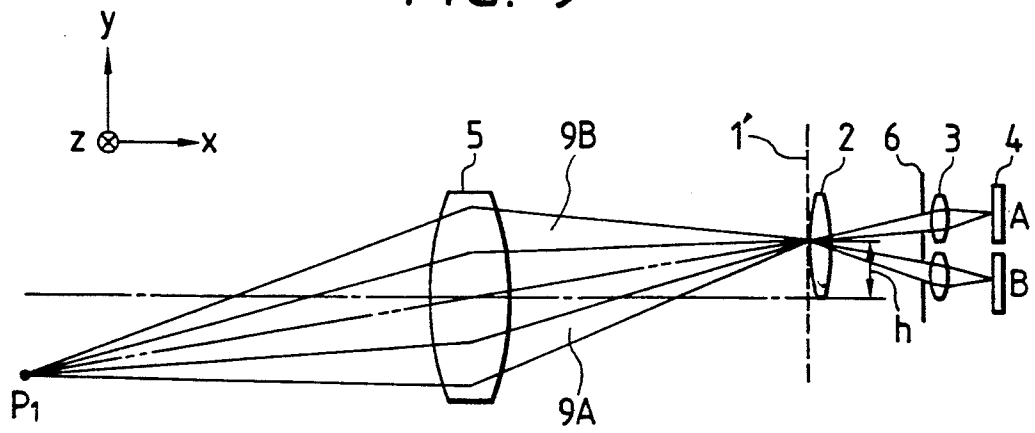


FIG. 10

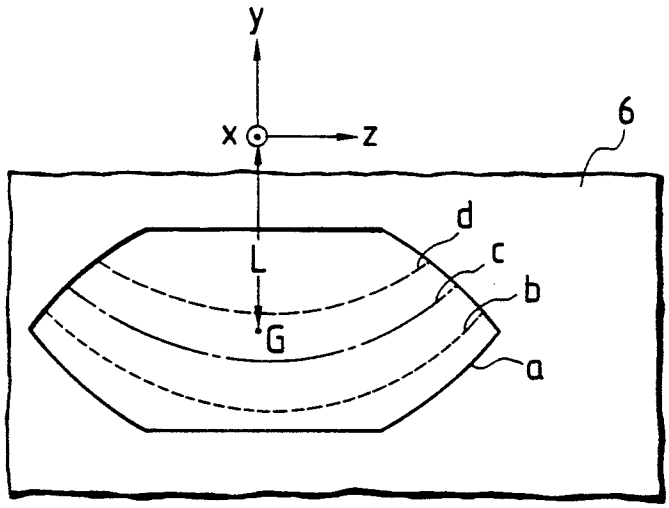
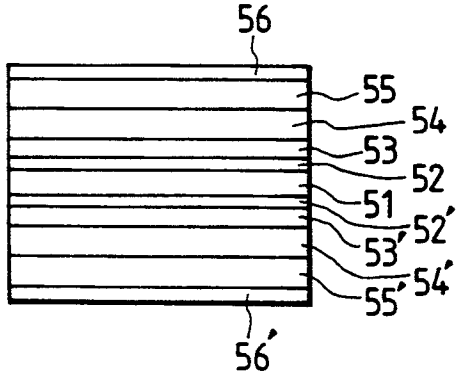


FIG. 11



FOCUS DETECTING APPARATUS IN WHICH MATCHING WITH THE IMAGE PERFORMANCE OF AN OBJECTIVE LENS IS ACHIEVED

This application is a continuation of application Ser. No. 281,326 filed Dec. 8, 1988, now abandoned.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to a focus detecting apparatus suitable for a single-lens reflex camera.

2. Description of the Related Background Art

As one of the focus detecting systems for single-lens reflex cameras, there is known the image correlation system. FIGS. 7 and 8 of the accompanying drawings illustrate focus detection by the image correlation system, FIG. 7 showing the optical path of a focus detecting optical system, and FIG. 8 showing the light amount distribution on a light detecting element (hereinafter referred to as a sensor) in which photo-electric elements are arranged in the form of a line. In these figures, the reference numeral **1** designates a film-equivalent surface, the reference numeral **2** denotes a field lens, the reference numeral **3** designates secondary imaging lenses, the reference numeral **4** denotes sensors, and the reference numeral **5** designates a photo-taking lens.

An on-axial light beam emitted from a point source of light P on the optic axis a (in the figure, parallel to the x-axis) of the photo-taking lens **5** is imaged near the film-equivalent surface **1** through the photo-taking lens **5**. The object light is transmitted through the field lens **2**, is converged by the secondary imaging lenses **3** and is projected onto the sensors **4**. Here, the secondary imaging lenses **3** have their focal length and arrangement set so that the image on the film-equivalent surface **1** is imaged on the sensor **4** at a predetermined magnification. Also, the secondary imaging lenses **3** are disposed as one set of two at locations symmetrical with respect to the optic axis of the photo-taking lens **5**, and cause part of the object light to be imaged on the one set of two sensors **4**. The sensors may be a row of sensors divided into two areas.

FIG. 7A shows a state in which the positional relation between the object P (which is the point source of light) and the photo-taking lens **5** and the film-equivalent surface is in the in-focus state. FIG. **8A** shows the light amount distributions on the sensors **4** at this time, and a light amount distribution having a sharp peak substantially at the central position of each sensor A, B is created, and the interval between the peak positions is l_0. l_0 is an independent value determined by the construction of the focus detecting optical system.

FIG. 7B shows the optical path in the forward focus state in which the photo-taking lens **5** has been moved to the object side, and the light amount distributions on the sensors **4** present distributions low in the degree of sharpness, as shown in FIG. **8B**, and the internal l between the peak positions of the light amount distributions on the sensors is narrower than the interval l_0 in the in-focus state. The difference $\Delta l(=l-l_0)$ between these peak-position intervals corresponds to the defocus amount and therefore, focus detection is accomplished using this amount Δl.

FIG. 7C shows the optical path in the rearward focus state after the photo-taking lens **5** has been moved to the film surface side, and the light amount distributions on the sensors **4** present distributions low in the degree of sharpness, as shown in FIG. **8C**, and the interval l between the peak positions on the sensors is wider than the interval l_0 in the in-focus state. The difference Δl $(=l-l_0)$ between these intervals corresponds to the defocus amount and therefore, focus detection is accomplished using this amount Δl. Also in the case of an ordinary object having a brightness distribution, the correlation between the object images on the sensors is taken and focus detection is accomplished from the amount of deviation l between the two images. Also, the field lens **2** is disposed near the film-equivalent surface (including the film-equivalent surface), and is set to such a focal length that the positional relation between the exit pupil P of the photo-taking lens **5** and the entrance pupils of the secondary imaging lenses **3** satisfies the imaging relation. Also, a stop **6** usually having two openings is disposed near the pupil positions of the secondary imaging lenses **3**, and this stop is set to such a size that two light fluxes transmitted through the openings thereof are separated and not eclipsed in the photo-taking lens **5**.

However, in the above-described focus detecting system, when an attempt is made to effect focus detection of an object lying at a location in the photo-taking picture plane which is off the optic axis of the lens, if the disposition of the sensors is done arbitrarily, the openings of the stop at the focus detecting position must be made small and the interval between the openings of the stop must be made narrow so that the focus detecting light flux entering the sensors may not have its focus detecting performance deteriorated under the influence of the residual aberrations of the photo-taking lens or the focus detecting light flux may not be eclipsed in the photo-taking lens, and this has led to the disadvantage that the focus detecting performance is deteriorated.

FIG. **9** of the accompanying drawings illustrates how the focus detecting light flux is influenced by the aberrations of the photo-taking lens, and shows the optical path of the focus detecting optical system. The reference numeral **1'** designates the film-equivalent surface, the reference numeral **2** denotes the field lens, the reference numeral **3** designates the secondary imaging lenses, the reference numeral **4** denotes the sensors, the reference numeral **5** designates the photo-taking lens, the reference numeral **6** denotes the stop, and the reference characters **9A** and **9B** designate focus detecting off-axial light fluxes.

An object P_1 is in the direction $-y$ relative to the optic axis of the photo-taking lens **5** in a plane x-y containing the optic axis, and the object light is transmitted through the photo-taking lens **5**, whereafter it is imaged at a position of height h in the direction of the y-axis on the film-equivalent surface **1'**. The stop **6** and the secondary imaging lenses **3** divide the object light into two and direct the divided light fluxes onto the two sensors **4**, and the direction of division of the light fluxes is the direction of the y-axis and is coincident with the direction of deviation of the object image from the optic axis. At this time, the two divided focus detecting light fluxes **9A** and **9B** are asymmetrical with respect to the optic axis of the photo-taking lens **5** and therefore, aberrations having asymmetry are created in the respective object images on A and B of the sensors **4**. As a result, in an apparatus wherein the correlation between the images on A and B of the sensors **4** is taken to thereby accomplish focus detection, it becomes difficult to take the

correlation between the two images and the focus detecting performance is deteriorated.

FIG. **10** of the accompanying drawings shows the vignetting in the opening of the stop **6** which corresponds to the focus detecting light flux **9B**. The solid line indicates the opening of the stop **6**, and it is set to a shape in which no vignetting occurs when the image height h=0 [mm] (which corresponds to a in FIG. **10**). As the image height h becomes higher to 6 [mm] (the dotted line b in the figure), 9 [mm] (the dot-and-dash line c in the figure) and 12 [mm] (the broken line d in the figure), eclipse of the light flux occures from the direction −y in the figure. Here, the area in the direction +y of the areas demarcated by the respective lines is an effective light flux area, and as the image height becomes higher, the light fluxes entering the sensors become less and the performance of the brightness of the focus detecting apparatus is reduced Also, as the image height becomes higher, the position G of the center of gravity of the light flux comes near to the optic axis of the photo-taking lens (the x-axis in the figure) and the distance L between the position G of the center of gravity of the light flux and the optic axis of the photo-taking lens becomes smaller. Here, the value of 2*L is a value corresponding to the length of the base line in triangulation, and if L becomes smaller, there arises the difficulty that the focus detecting performance is reduced.

On the other hand, an apparatus designed to effect focus detection for an object lying at an off-axis position off the optic axis of the photo-taking lens is known from Japanese Laid-Open Patent Application No. 62-47612 and Japanese Laid-Open Patent Application No. 62-189415. Particularly, one of the examples of the arrangement of sensor arrays disclosed in Japanese Laid-Open Patent Application No. 62-189415 is such that respective sensor arrays disposed off the axis are provided so as to be symmetrical with respect to a meridian centered at the optic axis. However, the other examples of the arrangement are such that the off-axis sensor arrays are not symmetrical with respect to the radius, and it is apparent that these examples do not take into account the aberrations caused in the imaging light flux by the objective lens.

SUMMARY OF THE INVENTION

It is a first object of the present invention to mitigate the reduction in detection accuracy caused by the residual aberrations of an objective lens when detecting the focus-adjusted state of the objective lens for an object lying off the central position in the field of view.

It is a second object of the present invention to mitigate the reduction in detection accuracy caused by the vignetting of an objective lens.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a perspective view showing an embodiment of the present invention.

FIGS. **2A** and **2B** are optical cross-sectional views for illustrating the optical action of the embodiment.

FIG. **3** is a plan view for illustrating the optical action.

FIG. **4** is a cross-sectional view showing the present invention as it is applied to a single-lens reflex camera.

FIG. **5** is a perspective view showing another embodiment of the present invention.

FIGS. **6A** and **6B** are optical cross-sectional views for illustrating the optical action of the FIG. **5** embodiment.

FIGS. **7A**, **7B** and **7C** are optical cross-sectional views showing an example of the prior art.

FIGS. **8A** to **8C** illustrate the optical actions.

FIG. **9** is an optical cross-sectional view for illustrating problems peculiar to the prior art.

FIG. **10** is a plan view for illustrating the optical action.

FIG. **11** illustrates the action of a constituent member.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIGS. **1** to **4** show a first embodiment of the present invention, FIG. **1** being a perspective view of a focus detecting optical system. The x-axis in the figures is coincident with the optic axis of a photo-taking lens, not shown. The reference numerals **21–23** designate field lenses, the reference numerals **31–36** denote secondary imaging lenses, the reference numerals **41** and **42** designate line sensors, the reference numeral **6** denotes a stop, the reference numerals **61–66** designate the openings of the stop, and the reference numeral **1** denotes a field mask comprised of a liquid crystal element or the like. The regions of the field mask which are indicated by rectangles can be made transparent and the remaining portion thereof is opague. The field mask **1** is disposed near the film-equivalent surface of the photo-taking lens and is capable of arbitrarily selecting a field of view for effecting focus detection by a driving device, not shown. That is, that portion of the field mask **1** which is indicated by a solid-line rectangle is the off-axis opening, and the center thereof is G. The field lens group **2** is disposed immediately rearwardly of the field mask **1** in the direction +x and one-dimensionally in the direction of the z-axis. The secondary imaging lens group **3** is set so that the film-equivalent surface of the photo-taking lens, not shown, and the line sensor group **4** satisfy the imaging relation. The stop **6** is disposed near the secondary imaging lens groups **3** and toward the field lens group **2**, and the stop openings **61** and **63**, **63** and **64**, and **65** and **66** substantially satisfy the imaging relation with the exit pupil of the photo-taking lens by the field lenses **21**, **22** and **23**. However, the off-axis field lenses **21** and **23** are of a shape suitable for inwardly refracting light. The stop openings **61**, **62**, the secondary imaging lenses **31**, **32** and the line sensors **41**, **42** form pairs, respectively, and effect the focus detection of a light flux forming an image near the location at which the field lens **21** off the optic axis of the photo-taking lens, not shown, is disposed, while the stop openings **61** and **62** which are in a conjugate relation with the exit pupil of the photo-taking lens are disposed symmetrically with respect to a plane passing through the center G of the opening of the field mask and containing the optic axis of the photo-taking lens (in the figure, the plane z-x). A system for forming an image near the position of the field lens **23** is similar to what has been described above. Also in a light flux which forms an image near the location at which the field lens **22** is disposed, the stop openings **63**, **64**, the secondary imaging lenses **33**, **34** and the line sensors **41**, **42** form pairs, respectively, and the stop openings **63** and **64** are disposed symmetrically with respect to a plane passing through the center G' of the on-axis opening of the field mask **1** which is

indicated by dotted line and containing the optic axis of the photo-taking lens (in the figure, the plane z-x).

The optical action will hereinafter be described.

FIG. 2 shows the optical path of the focus detecting optical system, FIG. 2A being a top plan view, and FIG. 2B being a side view. In FIG. 2, the letter L designates a photo-taking lens, the reference numeral 1 denotes the field mask comprised of a liquid crystal element or the like, the reference numeral 2 designates the field lens group, the reference numeral 3 denotes the secondary imaging lens group, the reference numeral 4 designates the line sensor group, the reference numeral 6 denotes the stop, and the reference numeral 8 designates an operation processing circuit, although it is not shown in FIG. 2A. The origin of the axis of the coordinates x-y-z is an arbitrary point on the optic axis of the photo-taking lens L.

In FIG. 2, the light flux from an object P, lying in the direction +Z off the optic axis of the photo-taking lens L is transmitted through the photo-taking lens L, whereafter it is imaged at a position of h on the field mask 1 in the direction −z relative to the optic axis of the photo-taking lens L. At this time, only the portion of the field mask 1 comprised of a liquid crystal element which is near the image point of the object P_1 is in a transmitting state. Part of the object light is transmitted through the field lens 21, and is thereafter limited by the stop openings 61 and 62 and is re-imaged on the line sensors 41 and 42 by the secondary imaging lenses 31 and 32. In the operation processing circuit 8, the correlation between the object images on the line sensors 41 and 42 is taken to thereby effect focus detection, and the resulting signal is supplied to the photo-taking lens L, whereby focus adjustment is effected. Now, the object light of the object P_1 lying in the direction +z relative to the optic axis of the photo-taking lens L is transmitted through the field lens 21, whereafter it is divided in the direction of the y-axis orthogonal to the z-axis by the stop openings 61 and 62, and light fluxes concerned in focus detection are symmetrical in the photo-taking lens L with respect to a plane passing through the center G of the opening of the field mask 1 and perpendicular to the direction of division (the direction of the y-axis) of the stop openings 61 and 62 including the optic axis of the photo-taking lens L (or a meridian about the optic axis) and therefore, no asymmetrical aberration occurs between the object images re-imaged on the line sensor 41 and the line sensor 42. This also holds true for the object light transmitted through the area corresponding to the field lens 23.

FIG. 3 shows the vignetting in the stop opening 61 when, in FIG. 2A, the image height h of the object image has varied. The solid line in FIG. 3 indicates the stop opening when the object is on the optic axis. The dot-and-dash line c indicates the boundary of the vignetting when the image height h=9 [mm], and the broken line d indicates the boundary of the vignetting when the image height h=12 [mm], and the eclipse of the light flux is small. Also, the eclipse of the light flux occurs from the direction −z in FIG. 3, and since the direction of travel thereof is substantially orthogonal to the direction of a base line (parallel to the y-axis), setting of the stop opening is possible without, reducing the value 2*L relative to the length of the base line in triangulation.

FIG. 4 shows the arrangement of a focus detecting apparatus in a single-lens reflex camera. In the figure, the letter L designates the photo-taking lens, the reference numeral 1 denotes the field mask, the reference numeral 2 designates the field lens group, the reference numeral 3 denotes the secondary imaging lens group, the reference numeral 4 designates the line sensor group, and the reference numeral 6 denotes the stop. The reference numeral 10 designates a movable mirror having a light-transmitting portion, the reference numeral 11 denotes a sub-mirror, the reference numeral 12 designates a focusing screen, the reference numeral 13 denotes a condenser lens, the reference numeral 14 designates a pentadach prism, the reference numeral 15 denotes an eyepiece, and the operation processing circuit is not shown.

The focus detecting optical system is disposed at the bottom of the camera body, and the center axis x of the focus detecting optical system is coincident with the optic axis of the photo-taking lens L through the half-mirror 10 and the sub-mirror 11.

In the present embodiment, the field lenses 21 and 22 have been shown as plano-convex lenses, but alternatively may be biconvex lenses.

FIGS. 5 to 6 show a second embodiment of the present invention, FIG. 5 being a perspective view of a focus detecting optical system. In FIG. 5, the reference numerals 20 and 21–24 designate field lenses, the reference numerals 31–36 denote secondary imaging lenses, and the reference numerals 41–44 designate line sensors. The reference numeral 6 denotes a stop, the reference numerals 61–66 designate the openings of the stop, and the reference numeral 1 denotes a field mask comprised of a liquid crystal element. The x-axis in these figures is coincident with the optic axis of a photo-taking lens, not shown. The field mask 1 is disposed near the film-equivalent surface of the photo-taking lens, and is capable of arbitrarily selecting a field of view for focus detection by a driving device, not shown. The portion of the field mask 1 which is indicated by a rectangle is an opening, and the center thereof is G. The field lens group 2 is disposed immediately rearwardly of the field mask 1 in the direction +x. The secondary imaging lens group 3 is set so that the film-equivalent surface of the photo-taking lens, not shown, and the line sensor group 4 satisfy the imaging relation. The stop 6 is disposed near the secondary imaging lens group 3 and toward the field lens group 2, and the sets of stop openings 61 and 62, 63 and 64, 65 and 66, 61 and 65, 62 and 66 substantially satisfy the imaging relation with the exit pupil of the photo-taking lens by the field lenses 21, 20, 23, 22 and 24, respectively.

Table 1 below shows the relations of correspondence between the members constituting the focus detecting optical system.

TABLE 1

No.			(1)		(2)		(3)		(4)	
Field lens	20		21		22		23		24	
Stop opening	63	64	61	62	61	65	65	66	62	66
Secondary imaging lens	33	34	31	32	31	35	35	36	32	36
Line sensor	41	42	41	42	43	44	41	42	43	44

In the combination represented by No. (1), the stop openings 61 and 62 are disposed symmetrically with respect to a plane passing through the center G of the opening of the field mask 1 and containing the optic axis of the photo-taking lens (in the figure, the plane x-y). In the combinations represented by Nos. (2), (3) and (4), this relation holds true.

The optical action will now be described.

FIG. **6** shows the optical path of the focus detecting optical system, FIG. **6A** being a side view, and FIG. **6B** being a top plan view. In FIG. **6**, the letter L designates the photo-taking lens, the reference numeral **1** denotes the field mask, the reference numeral **2** designates the field lens group, the reference numeral **3** denotes the secondary imaging lens group, the reference numeral **4** designates the line sensor group, the reference numeral **6** denotes the stop, and the reference numeral **8** designates an operation processing circuit, although it is not shown in FIG. **6A**. In FIG. **6**, the origin of the axis of the coordinates x-y-z is an arbitrary point on the optic axis of the photo-taking lens L.

In FIG. **6**, a description will be given with respect to an object P_1 lying in the direction $-y$ off the optic axis of the photo-taking lens L taken as an example. The object light is transmitted through the photo-taking lens L, whereafter it is imaged at a position of h on the field mask **1** in the direction $+y$ relative to the optic axis of the photo-taking lens L. At this time, only the portion of the field mask **1** comprised of a liquid crystal element which is near the image point of the object P_1 is in a transmitting state. Part of the object light is transmitted through the field lens **21**, and is thereafter limited by the stop openings **61** and **62** and is re-imaged on the line sensors **41** and **42** by the secondary imaging lenses **31** and **32**. In the operation processing circuit **8**, the correlation between, the object images on the line sensors **41** and **42** is determined to thereby effect focus detection, and the resulting signal is supplied to the photo-taking lens L, whereby focus adjustment is effected. Now, the object light of the object P_1 lying in the direction-y relative to the optic axis of the photo-taking lens L is transmitted through the field lens **21**, whereafter it is divided in the direction of the z-axis orthogonal to the y-axis by the stop openings **61** and **62**, and light fluxes concerned in focus detection are symmetrical in the photo-taking lens L with respect to a plane passing through the center G of the opening of the field mask **1** and perpendicular to the direction of division (the direction of the z-axis) of the stop openings **61** and **62** including the optic axis of the photo-taking lens L and therefore, no asymmetrical aberration occurs between the object images re-imaged on the line sensor **41** and the line sensor **42**.

In FIG. **6**, the example in the combination of No. (1) in Table 1 has been shown, and this also holds true of the combinations of Nos. (2) to (4). Also, the field mask **1** has been shown as being comprised of a liquid crystal element whose transmitting and light-intercepting areas are controllable, but it may be an electrochromic element whose action will be described later, and a stop plate having an opening can also be mechanically moved. Also, the field lenses **21**, **22**, **23** and **24** have been shown as plano-convex lenses each having one surface thereof made into the form of a prism, but alternatively, they may be biconvex lenses.

FIG. **11** illustrates the passage and interception of light by an electrochromic element.

The electrochromic element comprises a transparent substrate **51**, and first electrodes **52** and **52'** formed of a transparent conductive film, first electrochromic layers **53** and **53'** which are oxidation reaction color forming layers, intermediate insulating layers **54** and **54'** formed of a dielectric film, second electrochromic layers **55** and **55'** which are reduction reaction (non-color forming) layers, and second electrodes **56** and **56'** formed of a conductive film, all successively layered on the front and back surfaces of the substrate **51**.

In the above-described construction, the substrate **51** is generally formed of a glass plate, whereas this is not restrictive, but the substrate may be a plastic plate or a transparent substrate of synthetic resin such as polyimide. The intermediate insulating layers **54** and **54'** need not always be formed of a dielectric material, but may also be a solid electrolyte.

The transparent conductive film may be tin oxide SnO_2 doped in ITO film (indium oxide In_2O_3), Nesa film (SnO_2) or the like.

The first electrochromic layer **53** which is an oxidation reaction color forming layer is formed of iridium oxide (IrOx), nickel hydroxide ($Ni(OH)_2$) or the like. The intermediate insulating layer **54** is formed by the use of an oxide represented by tantalum pentoxide (Ta_2O_5), zirconium dioxide (ZrO_2) or the like, or a fluoride represented by lithium fluoride (LiF), magnesium fluoride (MgF_2) or the like. Also, as the second electrochromic layers **55** and **55'** which are reduction reaction (non-color forming) layers, use is made of polycrystalized porous tungsten trioxide (WO_3).

The total solid electrochromic element having such structure has an electro-chemical reaction induced by a voltage being applied between the first electrodes **52**, **52'** and the second electrodes **56**, **56'** and effects coloring and discharge.

Assuming that the IrOx side is plus (+) and the WO_3 side is minus (−), on the IrOx side, a reaction

$$IrOx + yH_2Oad \rightarrow IrOx(OH)y + yH^+ + ye^- \quad (1)$$

where H_2Oad is adsorbed H_2O contained in cells, progresses, and on the WO_3 side, a reaction

$$WO_3 + yH^+ + ye^- \rightarrow HyWO_3 \quad (2)$$

(non-color forming)

progresses, and coloring stuff IrOx(OH)y is considered to be formed, and neutral light absorption is exhibited in the visible range. Also, by reversing the electric field, reverse reactions of (1) and (2) are induced and color is discharged. These reactions progress by water content (indicated as H_2Oad) contained in the cells.

According to the present invention described above, even when focus detection of an object off the optic axis is effected, the influence of the aberrations of the objective lens can be eliminated and vignetting can be mitigated and therefore, the focus detecting performance is improved and particularly, even where the present invention is adopted in a single-lens reflex camera, a performance which can be practically used can be achieved.

What is claimed is:

1. An apparatus for detecting the focus-adjusted state of an objective lens, comprising:

field lens means, having a plurality of field lenses, disposed near a predetermined imaging plane of the objective lens;

a plurality of light intensity distribution forming means for forming light intensity distributions relating to an object from a light flux passed through said objective lens and said field lens means, said light intensity distributions moving relative to each other;

light receiving means for receiving said light intensity distributions and forming a signal indicative of the

focus-adjusted state of said objective lens based on the relative positional relation between said light intensity distributions; and

masking means disposed near said predetermined imaging plane for selectively forming an opening at any one of a plurality of different locations in said masking means.

2. An apparatus according to claim 1, wherein said masking means is made of an element having a property of matter which takes the selected opening light-transmissive.

3. An apparatus for detecting a focus-adjusted state of an objective lens having an optic axis, comprising:

field lens means disposed near a predetermined imaging plane of the objective lens;

a plurality of light intensity distribution forming means for forming light intensity distributions relating to an object from a light flux passed through said objective lens and said field lens means, said light intensity distributions moving relative to each other;

light receiving means for receiving said light intensity distributions and forming a signal indicative of the focus-adjusted state of said objective lens based on the relative positional relation between said light intensity distributions;

masking means disposed near said predetermined imaging plane for masking said light receiving means except for the light receiving areas thereof and having openings at a plurality of different locations therein; and

stop means provided with a plurality of sets of stop openings for separating a light flux entering said tight intensity distribution forming means at the pupil position of said objective lens and disposed between said field lens means and said light receiving means; and

the stop openings which form the set for receiving the light flux passed through an off-axis opening of said masking means being all determined so as to be symmetrical with respect to an imaginary plane passing through the center of the off-axis opening of said masking means and containing the optic axis of said objective lens so that the influence of the abberations of said objective lens becomes uniform, said plurality of sets of stop openings including an on-axis set of stop openings disposed parallel to an off-axis set of stop openings wherein said light receiving means comprises at least one pair of line sensors, and wherein said light receiving means comprises at least one pair of line sensors, and wherein said intensity distribution forming means comprises a number of pairs of lenses, the number of pairs of said light intensity distribution forming means being greater than the number of pairs of said line sensors.

4. An apparatus for detecting the focus-adjusted state of an objective lens, comprising:

field lens means disposed near a predetermined imaging plane of the objective lens;

a plurality of light intensity distribution forming means for forming light intensity distributions relating to an object from a light flux passing through the objective lens and said field lens means, the light intensity distributions moving relative to each other;

a plurality of pairs of line sensors for receiving the light intensity distributions, each pair of said line sensors forming a signal indicative of the focus-adjusting state of the objective lens based on the relative positional relation between the light intensity distributions; and

masking means disposed near the predetermined imaging plane for selectively forming an opening at a predetermined location in said masking means.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 5,138,359

DATED : August 11, 1992

INVENTOR(S) : NAGANO ET AL.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

COLUMN 1

Line 59, "internal" should read --interval--.

COLUMN 3

Line 12, "occures" should read --occurs--.
Line 18, "reduced" should read --reduced.--.

COLUMN 4

Line 29, "opague." should read --opaque.--.
Line 43, "groups 3" should read --group 3--.

COLUMN 5

Line 63, "without," should read --without--.

COLUMN 7

Line 29, "between," should read --between--.

COLUMN 8

Line 23, "crystalized" should read --crystallized--.
Line 37, "$WO_3+yH^++ye^{-}\rightarrow HyWO_3$" should read --$WO_3+yH^++ye^{-}\rightarrow HyWO_3$--.

UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 5,138,359 Page 2 of 2

DATED : August 11, 1992

INVENTOR(S) : NAGANO ET AL.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

COLUMN 9

Line 10, "takes" should read --makes--.
Line 35, "tight" should read --light--.

COLUMN 10

Line 8, "abberations" should read --aberrations--.

Signed and Sealed this

Nineteenth Day of October, 1993

Attest:

BRUCE LEHMAN

Attesting Officer

Commissioner of Patents and Trademarks

US005122650A

United States Patent [19]

McKinley

[11] Patent Number: 5,122,650

[45] Date of Patent: Jun. 16, 1992

[54] **STEREO VIDEO ENDOSCOPE OBJECTIVE LENS SYSTEM**

[75] Inventor: **Harry R. McKinley**, Southampton, Mass.

[73] Assignee: **McKinley Optics, Inc.**, Southampton, Mass.

[21] Appl. No.: **687,330**

[22] Filed: **Apr. 18, 1991**

[51] **Int. Cl.**[5] **H01J 40/14**

[52] **U.S. Cl.** **250/208.1**; 359/362

[58] **Field of Search** 250/208.1; 128/4-7; 358/98; 359/362, 377, 462, 618, 619

[56] **References Cited**

U.S. PATENT DOCUMENTS

4,061,135	12/1977	Widran et al.	128/6
4,448,498	5/1984	Muller et al.	359/377
4,615,332	10/1986	Buess et al.	128/6
4,651,201	3/1987	Schoolman	358/98
4,787,734	11/1988	Matsumura	359/377
4,824,228	4/1989	Wickholm et al.	359/462
4,862,873	9/1989	Yajima et al.	128/6
4,873,572	10/1989	Miyanaki et al.	358/98
4,895,431	1/1990	Tsujiuchi et al.	350/320
4,926,257	5/1990	Miyazaki	359/377

FOREIGN PATENT DOCUMENTS

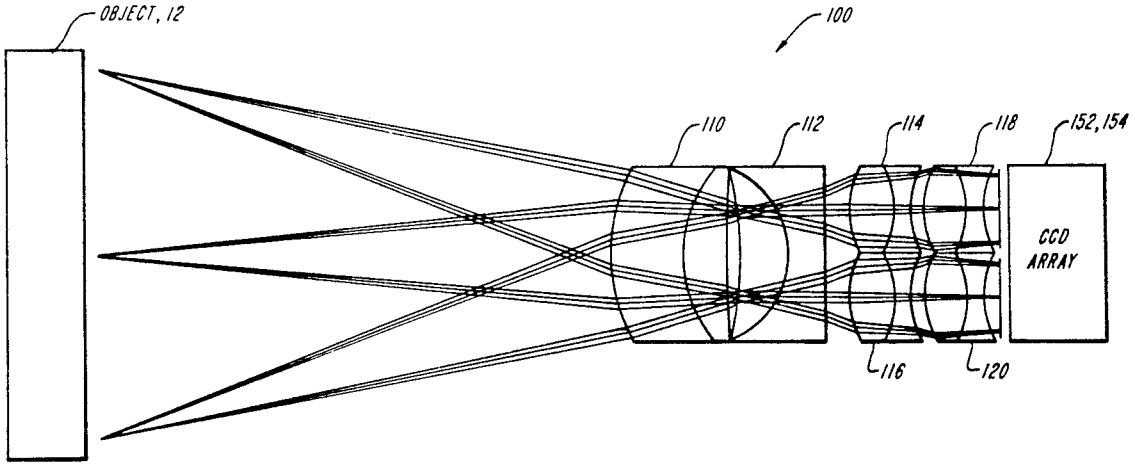
0211783	7/1986	European Pat. Off.	.

Primary Examiner—David C. Nelms
Assistant Examiner—S. Allan
Attorney, Agent, or Firm—Lahive & Cockfield

[57] **ABSTRACT**

A stereoscopic objective lens system for video endoscopes and borescopes includes two full-diameter doublets and a double set of two half-diameter identical doublets. The full-diameter doublets collimate object points, imaging object points to infinity. The large collimator doublets present equal-angle pairs from symmetrically disposed object points to the small stereo doublet pairs. This equal-angle property enables accurate object/image mapping onto the final stereo image pair, such that all parts of each left/right image can be mapped to within a fraction of a video pixel to each other.

9 Claims, 3 Drawing Sheets



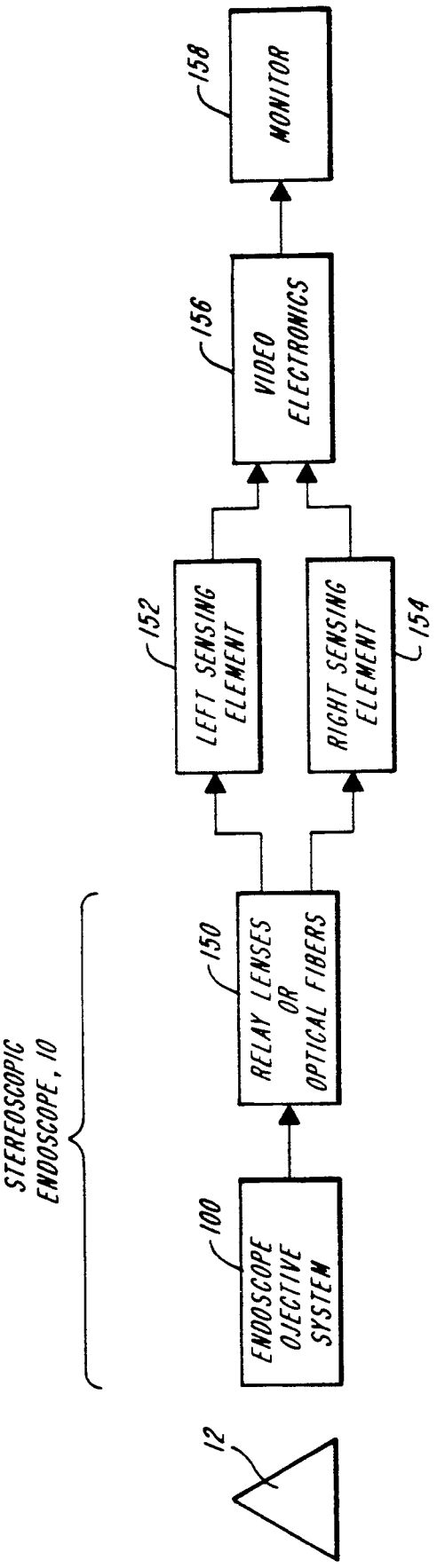

1
STEREOSCOPIC ENDOSCOPE, 10
12
100
ENDOSCOPE OJECTIVE SYSTEM
150
RELAY LENSES OR OPTICAL FIBERS
152
LEFT SENSING ELEMENT
154
RIGHT SENSING ELEMENT
156
VIDEO ELECTRONICS
158
MONITOR

FIG. 1

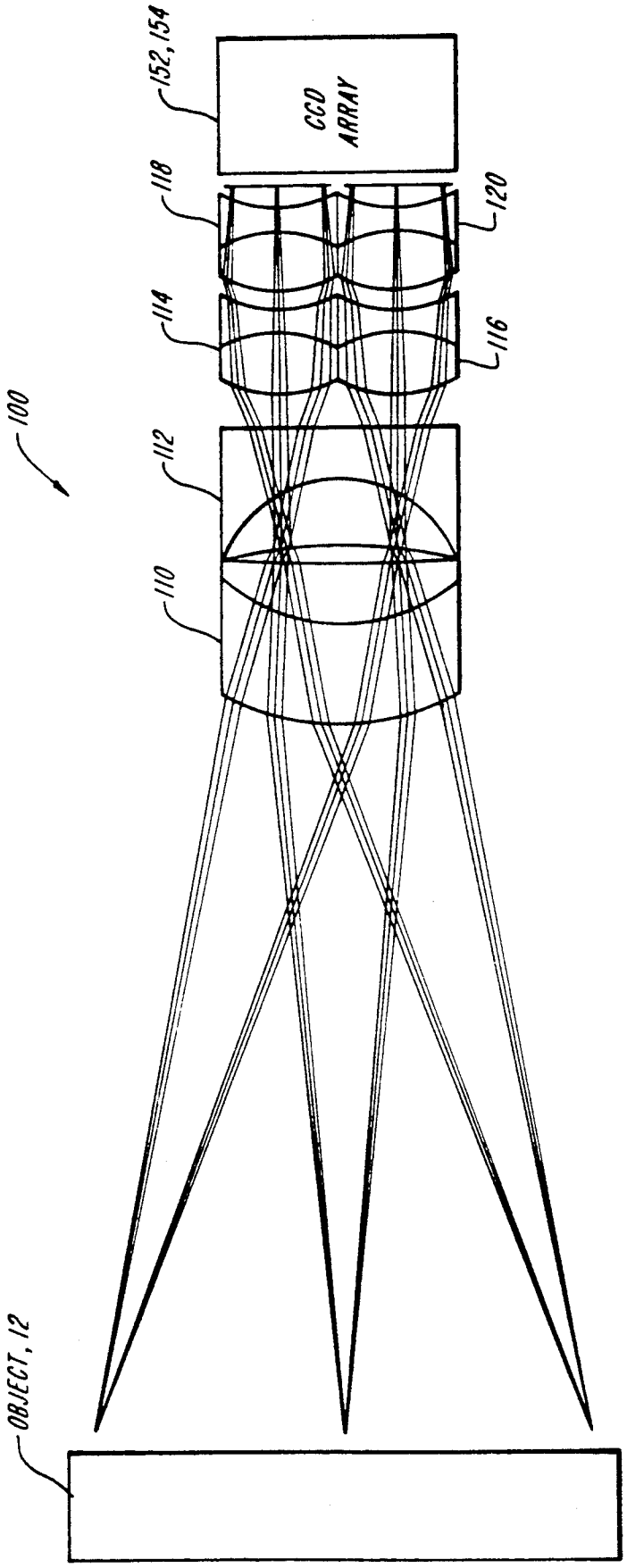


FIG. 2

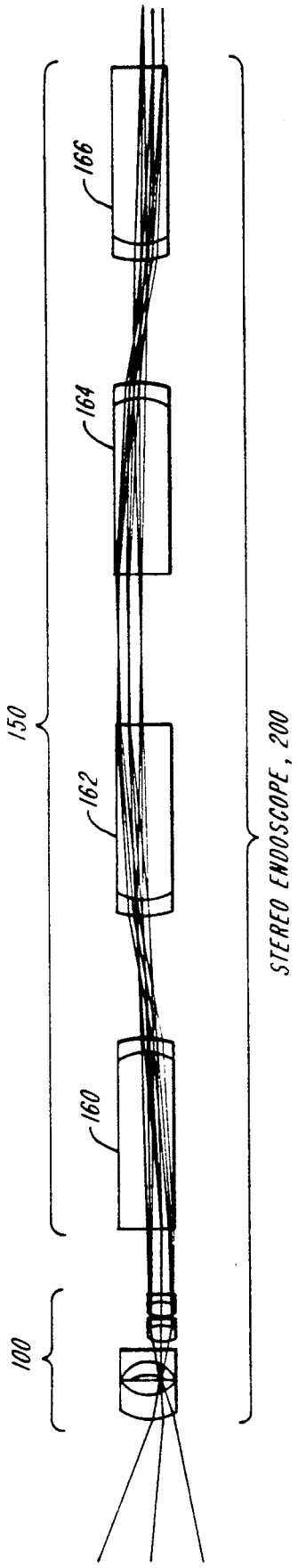


FIG. 3

STEREO VIDEO ENDOSCOPE OBJECTIVE LENS SYSTEM

BACKGROUND OF THE INVENTION

This invention relates generally to optical lens systems, and, more particularly, relates to stereoscopic objective lens designs adapted for use in stereo video endoscopes.

Medical endoscopes are widely utilized to view internal regions of the human body during diagnostic, surgical, and other medical procedures. Endoscopes typically include a long, thin, rigid or semi-rigid optical cylinder affixed to a viewing mechanism. The cylinder is sufficiently narrow to be inserted through a small opening in the body, which may be natural or surgical. When the endoscope is inserted and positioned for use, an image of the object being viewed is formed at an inserted end of the endoscope by an objective lens. The image passes through a series of relay lenses down the cylinder to an eye lens or video camera at a viewing end of the endoscope.

In recent years, researchers have attempted to improve the imaging available through endoscopic devices by developing stereoscopic video endoscopes. These endoscopes present an apparently three-dimensional image on a video monitor The stereoscopic effect is created by producing two optical images—a left image and a right image—through the endoscope. The left and right optical images are presented by the endoscope to left and right image sensors, which may be charge-coupled device (CCD) cameras or other image sensing devices. The sensing devices convert the left and right optical images into left and right video images which are then presented as alternating left-right images on a monitor, at a switching rate higher than the flicker-sensing limit of the human eye, so that observed images appear flicker-free.

The images are alternately switched from a left-hand polarization mode to a right-hand polarization mode, such that. for example, the left image has a left-hand polarization and the right image has a right-hand polarization. In accord with this example, the observer wears polarized glasses in which the left lens has the left-hand polarization and the right lens has the right-hand polarization. Thus, the left eye sees only images from the left channel of the endoscope system and the right eye sees only images from the right channel, resulting in stereoscopic viewing.

The following U.S. and foreign patents disclose examples of stereo endoscopes, some of which utilize video imaging and display elements:

U.S. Pat. No. 4,061,135
U.S. Pat. No. 4,615,332
U.S. Pat. No. 4,651,201
U.S. Pat. No. 4,862,873
U.S. Pat. No. 4,873,572
U.S. Pat. No. 4,895,431
EP 211,783

In particular, U.S. Pat, No. 4,061,135 discloses a binocular endoscope in which images are transmitted from the viewed object to the viewing station through an optical system utilizing a dove prism and mechanical linkage to compensate for rotation effects.

U.S. Pat. No. 4,615,332 discloses a binocular endoscope having flexible light guides and binocular eyepieces.

U.S. Pat. No. 4,651,201 discloses a stereoscopic video endoscope including two image guides and an illumination light guide. The image guides are optically coupled to a stereoscopic viewer for three dimensional viewing. The viewer includes couplings for attaching miniature video cameras that can be connected to a head-mounted stereoscopic video display.

U.S. Pat. No. 4,862,873 discloses a stereo endoscope having two light guides for carrying images of an object to an electro-optical imaging assembly. A lens system directs light from the object to the objective end of the light guides. Illuminating light is transmitted to the object from the opposite end of one light guide, thereby illuminating the object. Simultaneously, the image transmitted through the other optical guide is conducted to the imaging assembly.

U.S. Pat. No. 4,873,572 discloses a stereo endoscope having a CCD camera module and two image-forming lens systems that form two object images. The object images are integrated and directed to the CCD camera to provide a stereoscopic output. The lens systems include red, green, and blue color filters disposed at the camera imaging surface.

U.S. Pat. No. 4,895,431 discloses an endoscope apparatus that generates a three-dimensional image of an object from overlapping images recorded by a camera. The endoscope includes an insertion module and a movable end section capable of being deflected through an angle. A first image is recorded with the end section positioned at a first angle. A second image, partially overlapping the first image, is recorded after moving the end section to a second angle. The relative position of the movable end section is detected by an encoder that generates position signals for input to a microprocessor, which utilizes the position signals to generate a three-dimensional image of the object.

European Patent No. 211,783 discloses a stereo video endoscope in which two light pipes deliver two images of the same object. These images are presented by a binocular device to the user's eyes to show a three dimensional image of the target. The apparatus includes two television cameras and video recorders for recording the images. The recorded images can be displayed on separate screens and viewed by a binocular viewing system.

Most conventional stereo endoscopes, however, share a number of deficiencies associated with their objective lens systems. These problems include a bulky and unwieldy configuration; high cost and complexity of fabricating the objective lens system; and the mediocre optical performance afforded by conventional objective lens systems.

An additional problem associated with conventional stereo video endoscope objectives involves the requirement that all portions of each left/right image be mapped to within a fraction of a video pixel to each other. This pixel mapping condition is a significant optical design constraint, because the object-to-image ray paths through the lens system are quite different for the left and right image points associated with a common object point.

Accordingly, it is a general object of the present invention to provide improved stereo endoscope objective lens systems that overcome the problems associated with conventional designs.

A more specific object is to provide an improved stereo endoscope objective lens system having optical elements that facilitate assembly of the system.

It is another object of the invention to provide an improved stereo endoscope objective lens system having elements that are substantially less expensive to manufacture than the elements of conventional systems.

A further object is to provide an improved stereo endoscope objective lens system having optical performance characteristics that are substantially superior to the performance characteristics of conventional systems.

Another object of the invention is to provide a stereo objective lens system affording a pixel mapped image.

The above and other objects and advantages of this invention will become more readily apparent when the following description is read in conjunction with the accompanying drawings.

SUMMARY OF THE INVENTION

The foregoing objects are attained by the invention, which provides an improved stereo endoscope objective lens system for video imaging in medical endoscopes and industrial borescopes.

One aspect of the invention includes two full-diameter doublets and a double set of two half-diameter identical doublets. The full-diameter doublets substantially collimate object points, i.e., image them substantially to infinity.

In accord with this aspect of the invention, most of the optical power necessary to accomplish this collimation is provided by in the first or outer doublet, while the second collimator doublet is of low power.

In a further aspect of the invention, the smaller doublets are identical, so that they can be most economically fabricated in production quantities. This is advantageous because these small lenses are inherently difficult to manufacture.

In another aspect of the invention, the large collimator doublets present equal-angle pairs from symmetrically disposed object points to the small stereo doublet pairs. This equal-angle solution provides accurate object/image mapping onto the final stereo image pair. In this design, the larger, and hence easier to fabricate, doublets carry the corrective burden, so that the smaller, more difficult to manufacture lenses can be made as simple as possible.

The invention will next be described in connection with certain illustrated embodiments; however, it should be clear to those skilled in the art that various modifications, additions and subtractions can be made without departing from the spirit or scope of the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

For a fuller understanding of the nature and objects of the invention, reference should be made to the following detailed description and the accompanying drawings, in which:

FIG. **1** is a schematic diagram depicting a stereo video endoscope utilizing an objective lens system constructed in accordance with the invention;

FIG. **2** is an optical schematic diagram depicting an objective lens system constructed in accordance with the invention, showing light rays transmitted through the system; and

FIG. **3** is an optical schematic diagram depicting the objective lens system of FIG. **2** in combination with relay lenses for transmitting the optical images.

DESCRIPTION OF ILLUSTRATED EMBODIMENTS

FIG. **1** depicts the invention, an endoscope objective system **100**, utilized in a stereo video endoscopy system **1** for generating stereoscopic images of an object **12**. The system **1** includes a stereoscopic endoscope **10** containing objective system **100**; sensing modules **152, 154**; switching module **156**; and a monitor **158**. In addition to objective lens system **100**, the endoscope **10** includes conventional relay lenses or optical fibers **150** for transmitting light collected by the endoscope objective system **100** to light sensing modules **152, 154**.

The endoscope objective system **100** generates left and right optical images of the object **12** that are processed by sensing elements **152, 154** and video switching module **156** in a known manner to display an apparently three-dimensional image of the object **12** on video monitor **158**.

The stereoscopic effect is created by producing two optical images—a left image and a right image—through the endoscope objective system **100**. The left and right optical images generated by the objective system **100** are presented by the relay lens or optical fiber system **150** to left and right image sensors **152, 154**, which can be conventional charge-coupled device (CCD) cameras or other image sensing devices. The CCD elements operate in a known manner to convert the light collected by the objective system **100**, and transmitted by the relay lenses or optical fibers **150**, into electrical signals representative of the left and right optical images of the object **12**.

Conventional video switching circuitry **156** transmits the electronic signals representative of left and right video images as alternating left-right images on the monitor **158**. In accord with known video practice, these alternating images are presented at a switching rate higher than the flicker-sensing limit of the human eye, so that observed images appear flicker-free.

Moreover, the images can be alternately switched from a left-hand polarization mode to a right-hand polarization mode, such that, for example, the left image has a left-hand polarization and the right image has a right-hand polarization. The observer wears polarized glasses in which the left lens has the left-hand polarization and the right lens has the right-hand polarization. Thus, when the observer views the monitor **158**, the left eye sees only images from the left channel of the endoscope system and the right eye sees only images from the right channel, resulting in stereoscopic viewing. Video switching and display equipment of this type is commercially available from Stereographics, Inc. of San Rafael, Calif.; and from Tektronix Corp., of Beaverton, Oreg.

The accuracy and quality of the image displayed on monitor **158** is controlled by the performance of the endoscope objective system **100**, which is the subject of the present invention. FIGS. **2** and **3** depict an objective lens system **100** constructed in accordance with the invention, showing light rays transmitted through the system. FIGS. **2** and **3** depict the same system, with two elements being omitted from FIG. **3** for purposes of clarity.

As indicated in FIG. **2**, one embodiment of the objective system **100** includes two full-diameter doublets **110, 112** and a double set of two half-diameter identical doublets **114, 116, 118, 120**. The full-diameter doublets collimate object points, i.e., image them to infinity. In

accordance with the invention, most of the optical power required to accomplish this collimation is provided by the first collimator doublet **110** closest to the object **12**, while the second collimator doublet **112** can have a very low optical power.

Those skilled in the art will appreciate that the lenses of the objective system **100** depicted in FIG. **2** define a sequence of sixteen optical surfaces. A working example of a set of lenses for objective system **100** is set forth below in Table A.

TABLE A

SURFACE	RADIUS	THICKNESS	APERTURE	GLASS
1	—	−4.002608	0.225000	AIR
2	6.211875	2.500000	3.000000	SK5
3	4.462623	1.500000	3.000000	SF8
4	53.596342	0.400000	3.000000	AIR
5	−11.075366	1.600000	2.500000	SK5
6	−3.318618	1.500000	3.000000	SF8
7	−31.896589	−1.200000	2.500000	AIR
8	—	1.900000	0.464074	AIR
9	2.747539	1.600000	1.500000	SSKN8
10	−3.153676	0.700000	1.500000	SF1
11	4.815753	0.250000	1.500000	AIR
12	2.747539	1.600000	1.500000	SF1
13	−3.153676	0.700000	1.500000	SSKN8
14	4.815753	0.400000	1.500000	AIR
15	—	0.001000	1.400000	BK7
16	—	—	1.400000	AIR

In Table A, the numerical value in the "RADIUS" and "THICKNESS" columns are set forth in millimeters. The "GLASS" descriptions are standard optical glass characterizations as found in the product catalog of the Schott Glass Company of the Federal Republic of Germany. The "THICKNESS" column refers to the distance to the next optical surface. For example, in connection with surface **3**, the number 1.5000 signifies 1.5 millimeters to surface **4**. The column "RADIUS" refers to the radii of curvature of the respective curved surfaces. In this working example, the lens diameters are 6 millimeters for the large doublets and 3 millimeters for the small doublets. The overall object-to-image distance is 28.3 millimeters. The image diameter is 2.5 millimeters.

The system **100** is designed so that all parts of each left/right image are mapped to within a selected distance of each other such that stereoscopic image quality is maintained. For video applications, this selected distance is typically a fraction of a video pixel. This is a difficult condition to satisfy, because the object-to-image ray paths through the lens system are quite different for the left and right image points of a common object point. FIG. **2** clearly illustrates this path difference. The ray paths shown in FIG. **2** demonstrate how differently an object point is imaged through the lens elements for the left and right images.

The objective system **100** depicted in FIG. **2** is able to map all parts of each left/right image to within a fraction of a video pixel to each other, because the large collimator doublets present equal-angle pairs from symmetrically disposed object points to the small stereo doublet pairs.

This exact equal-angle solution results in an accurate object/image mapping onto the final stereo image pair. Accuracy is also enhanced by the combination of a first high power collimator doublet **110** and a second, lower power collimator doublet **112**. This second doublet **112** strongly influences the optical solution to the image-mapping problem.

A further advantage is provided in that the smaller doublets **114**, **116**, **118**, and **120** are identical, so that they can be most economically fabricated in production quantities. This characteristic tends to offset the inherent difficulty of manufacturing small lenses. The larger, and hence easier to fabricate, doublets carry the corrective burden, so that the smaller, more difficult to manufacture lenses can be as simple as possible.

As indicated in FIG. **1**, the endoscope objective system **100** can be utilized in connection with optical fiber elements or a set of relay lenses **150** to conduct light from the objective system to the sensing elements **152**, **154**. An example of a relay lens system **150** that can be employed with the objective system **100** is depicted in FIG. **3**.

The relay lens system of FIG. **3** includes a plurality of rod relays **160**, **162**, **164** utilized in combination with objective system **100**. Those skilled in the art will recognize that a wide range of relay lens systems can be employed with an objective system constructed in accordance with the invention.

Alternatively, an endoscope constructed in accordance with the invention can employ a conventional CCD array mounted within the same housing as the objective system. As indicated in FIG. **2**, the CCD array can include left and right sensing elements **152**, **154**, disposed to receive the optical images generated at the output of doublets **118** and **120**. The design and construction of CCD elements having more than one photosensitive region in a monolithic package is well known in the art. The electrical signals generated by the CCD array can be conducted from the housing by a conventional conduit. This configuration eliminates the requirement for a relay lens system or optical fibers.

The system **100** depicted in FIGS. **2** and **3** offers advantages for use in medical endoscopes and industrial borescopes. The configuration offers the advantage of being adaptable to fit into a small tube diameter, as small as **3** millimeters. The design also affords high resolution and low distortion for diagnostic and surgical use, and for high-accuracy industrial measurement applications.

It will thus be seen that the invention efficiently attains the objects set forth above, among those made apparent from the preceding description.

It will be understood that changes may be made in the above construction and in the foregoing sequences of operation without departing from the scope of the invention. It is accordingly intended that all matter contained in the above description or shown in the accompanying drawings be interpreted as illustrative rather than in a limiting sense.

It is also to be understood that the following claims are intended to cover all of the generic and specific features of the invention as described herein, and all statements of the scope of the invention which, as a matter of language, might be said to fall therebetween.

Having described the invention, what is claimed as new and secured by Letters Patent is:

1. A stereoscopic objective lens system for a stereo video endoscope, the objective lens system converting optical images of an object generated at an objective end of the objective system to pixel-mapped left and right optical images at an image plane end of the objective system, the objective lens system comprising

A. a first collimator doublet lens element proximate the objective end for collecting light from points on the object, said first doublet lens having a first

optical axis, a selected diameter and a selected optical power,

B. a second collimator doublet lens for collecting light from said first collimator doublet lens,

said second collimator doublet lens being situated adjacent said first collimator doublet lens

so that the optical axis of said second collimator doublet lens is substantially collinear with the optical axis of the first collimator doublet lens,

said second collimator doublet lens having a selected diameter and a selected optical power,

wherein said first and second collimator doublet lenses cooperate to image the object points substantially to infinity so that light transmitted by the second collimator doublet lens from the object points is substantially collimated,

C. a first right/left pair of stereo doublet lenses

situated adjacent said second collimator doublet lens for collecting light from said second collimator doublet lens,

said first right/left pair of stereo doublet lenses including

a first right doublet lens and

a first left doublet lens,

the optical axis of said first right doublet lens and the optical axis of said first left doublet lens being substantially parallel to the optical axis of the second collimator doublet lens,

wherein said first and second collimator doublet lenses and said first right/left pair of stereo doublet lenses cooperate so that the first and second collimator doublet lenses present equal-angle light ray pairs from symmetrically disposed object points to the first right/left pair of stereo doublet lenses, and

D. a second right/left pair of stereo doublet lenses,

said second pair of stereo doublet lenses being situated adjacent said first right/left pair of stereo objective system

so that the optical axis of said second right doublet lens is substantially collinear with the optical axis of said first right doublet lens and

the optical axis of said second left doublet lens is substantially collinear with the optical axis of said first left doublet lens,

said second right doublet lens collecting light from said first right doublet lens to generate a right image at the image plane,

said second left doublet lens collecting light from said first left doublet lens to generate a left image at the image plane, such that corresponding portions of each left/right image are mapped to within a selected distance of each other.

2. A lens system according to claim 1 wherein the diameter of said second collimator doublet lens is approximately equal to the diameter of said first collimator doublet lens.

3. A lens system according to claim 2, wherein said first right doublet lens, said first left doublet lens, said second right doublet lens, and said second left doublet lens are substantially identical.

4. A lens system according to claim 3 wherein the diameter of said first right doublet lens, said first left doublet lens, said second right doublet lens, and said second left doublet lens are approximately one-half the diameter of said first collimator doublet lens.

5. A lens system according to claim 4 wherein said first collimator doublet lens has a higher optical power than said second collimator doublet lens.

6. Stereoscopic video endoscope apparatus for displaying stereoscopic video images of an object, the apparatus comprising

A. a stereoscopic objective lens system,

the objective lens system converting optical images of the object generated at an objective end of the objective system to pixel-mapped left and right optical images at an image plane end of the objective system, the objective lens system including

(i) a first collimator doublet lens element proximate the objective end for collecting light from points on the object,

said first doublet lens having a first optical axis, a selected diameter and a selected optical power,

(ii) a second collimator doublet lens for collecting light from said first collimator doublet lens,

said second collimator doublet lens being situated adjacent said first collimator doublet lens so that the optical axis of said second collimator doublet lens is substantially collinear with the optical axis of the first collimator doublet lens,

said second collimator doublet lens having a selected diameter and a selected optical power,

wherein said first and second collimator doublet lenses cooperate to image the object points substantially to infinity so that light transmitted by the second collimator doublet lens from the object points is substantially collimated,

(iii) a first right/left pair of stereo doublet lenses situated adjacent said second collimator doublet lens for collecting light from said second collimator doublet lens, said first right/left pair of stereo doublet lenses including

a first right doublet lens and

a first left doublet lens,

the optical axis of said first right doublet lens and the optical axis of said first left doublet lens being substantially parallel to the optical axis of the second collimator doublet lens,

wherein said first and second collimator doublet lenses and said first right/left pair of stereo doublet lenses cooperate so that the first and second collimator doublet lenses present equal-angle light ray pairs from symmetrically disposed object points to the first right/left pair of stereo doublet lenses, and

(iv) a second right/left pair of stereo doublet lenses, said second pair of stereo doublet lenses being situated adjacent said first right/left pair of stereo doublet lenses and proximate the image plane end of the objective system

so that the optical axis of said second right doublet lens is substantially collinear with the optical axis of said first right doublet lens and

the optical axis of said second left doublet lens is substantially collinear with the optical axis of said first left doublet lens,

said second right doublet lens collecting light from said first right doublet lens to generate a right image at the image plane,

said second left doublet lens collecting light from said first left doublet lens to generate a left

image at the image plane, such that corresponding portions of each left/right image are mapped to within a selected distance of each other, and

B. right and left optical sensing means, situated at right and left regions of the image plane, respectively, for converting said right and left optical images to electrical signals representative of right and left video signals in response to said right and left optical images, respectively.

7. Apparatus according to claim **6**, further comprising video monitor means, in electrical communication with said first and second optical sensing means, for displaying right and left video images in response to said electrical signals generated by the first and second optical sensing means.

8. Apparatus according to claim **6** wherein said right and left optical sensing means include at least on CCD element.

9. Apparatus according to claim **8** wherein

said objective lens system is contained within a housing, and

said at least one CCD element is disposed within said housing in proximity to said objective lens system so that optical images generated by said objective lens system are transmitted to said at least one CCD element.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. 5,122,650

DATED June 16, 1992

INVENTOR(S) Harry R. McKinley

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Please amend the patent as follows.

Column 1, line 28, after "video monitor" insert --.--

Column 1, line 61, after "U.S." delete --Pat, No.--

Column 7, line 40, before "objective system" insert --

doublet lenses and proximate the image plane of the--

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 5,122,650

DATED : June 16, 1992

INVENTOR(S) : Harry R. McKinley

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 10, line 4, change "on" to --one--.

Signed and Sealed this

Twenty-first Day of September, 1993

Bruce Lehman

Attest:

BRUCE LEHMAN

Attesting Officer

Commissioner of Patents and Trademarks

United States Patent [19]

Rieche et al.

[11] **Patent Number: 5,056,901**

[45] **Date of Patent: Oct. 15, 1991**

[54] **WIDE-ANGLE OBJECTIVE**

[75] Inventors: **Gerd Rieche**, Jena; **Gerhard Risch**, Weimar, both of German Democratic Rep.

[73] Assignee: **Jenoptik Jena G.m.b.H.**, Jena, Fed. Rep. of Germany

[21] Appl. No.: **479,324**

[22] Filed: **Feb. 13, 1990**

[30] **Foreign Application Priority Data**

Apr. 3, 1989 [DD] German Democratic Rep. 3272015

[51] **Int. Cl.**[5] **G02B 11/34**

[52] **U.S. Cl.** **359/737**; 359/754

[58] **Field of Search** 350/432, 447, 463, 442–443, 350/449–450, 464–465; 501/44

[56] **References Cited**

U.S. PATENT DOCUMENTS

4,013,349	3/1977	Bertele	350/463
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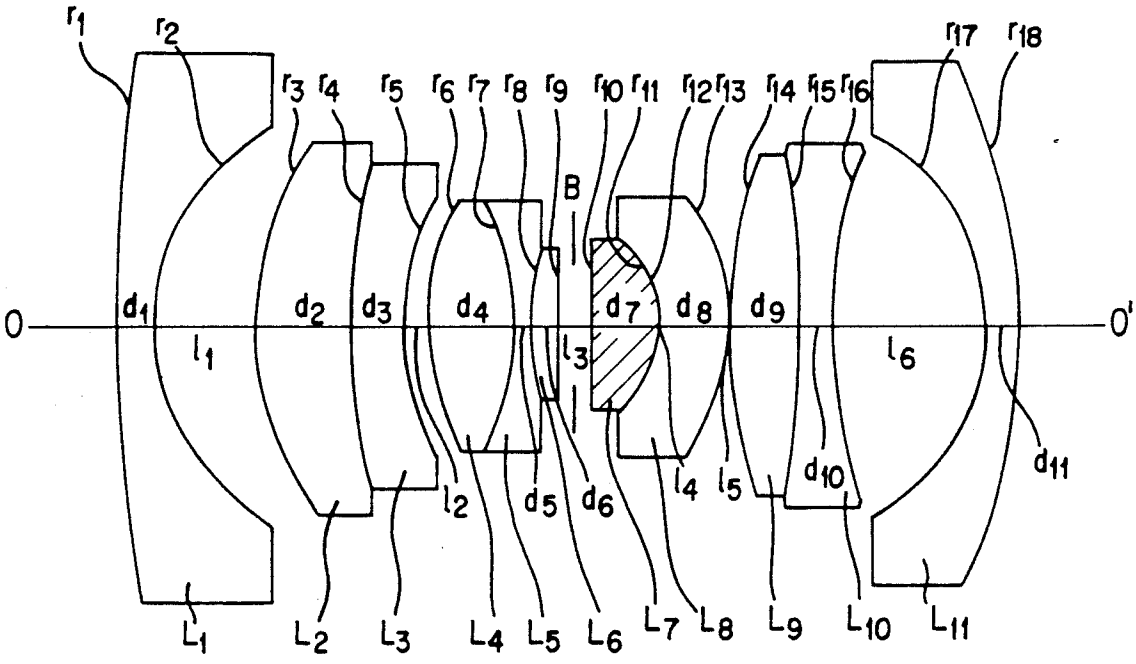
Primary Examiner—Bruce Y. Arnold
Assistant Examiner—James Phan
Attorney, Agent, or Firm—Jordan and Hamburg

[57] **ABSTRACT**

A wide-angle objective for a picture-taking lens of an aerial mapping camera, consisting of 11 lenses and 14 glass-air surfaces, the first optical element of which after the center aperture on the picture side is a converging fluorspar or fluorspar-like lens. Due to the large refractive index difference between this lens and the following meniscus lens and due to the provision of a triple group of high refractive index on the object side before the center aperture, a high resolution, low residual distortion and minimal lateral chromatic aberration are achieved.

1 Claim, 2 Drawing Sheets



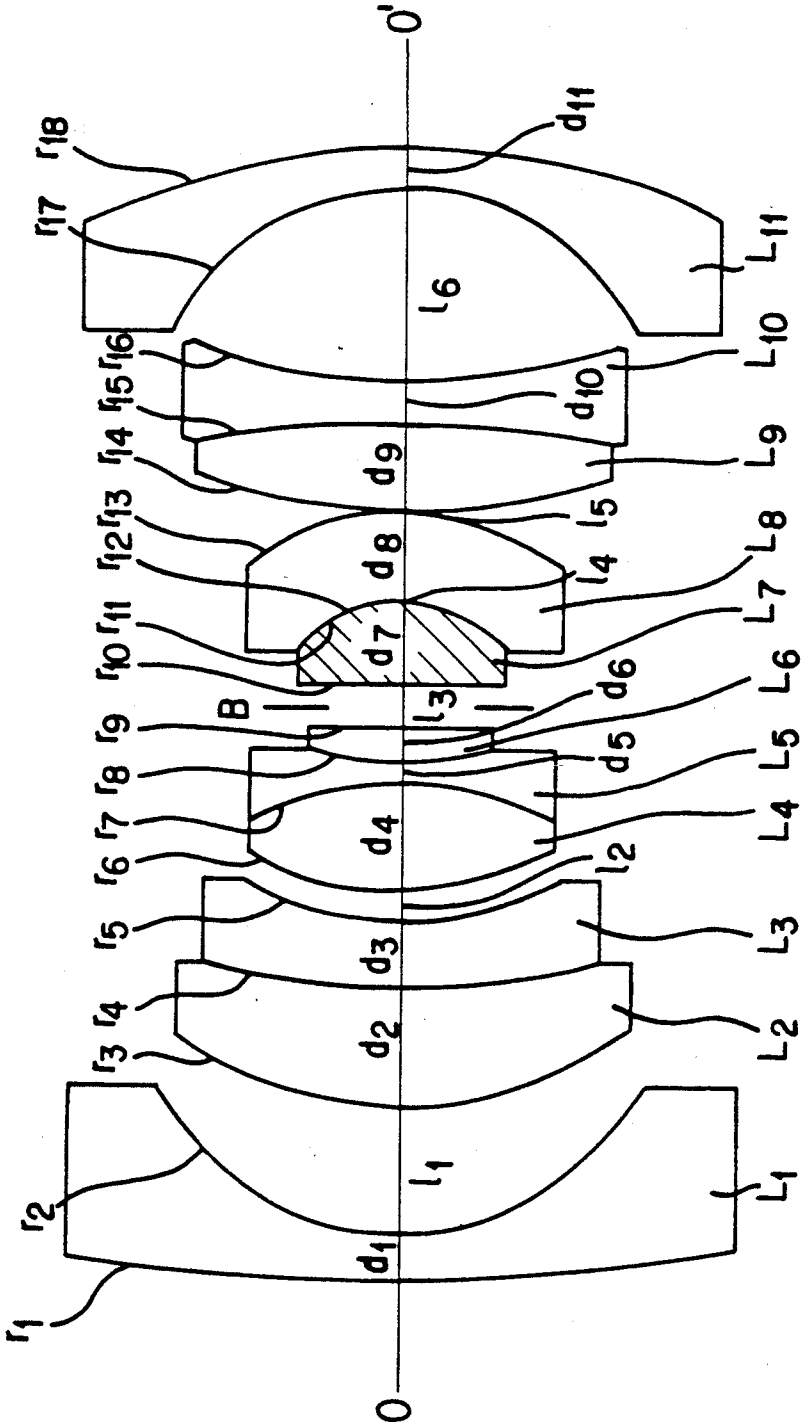

O'
O
r18
r17
r16
r15
r14
r13
r12
r11
r10
r9
r8
r7
r6
r5
r4
r3
r2
r1
d11
d10
d9
d8
d7
d6
d5
d4
d3
d2
d1
B
L11
L10
L9
L8
L7
L6
L5
L4
L3
L2
L1
l6
l5
l4
l3
l2
l1

FIG. 1

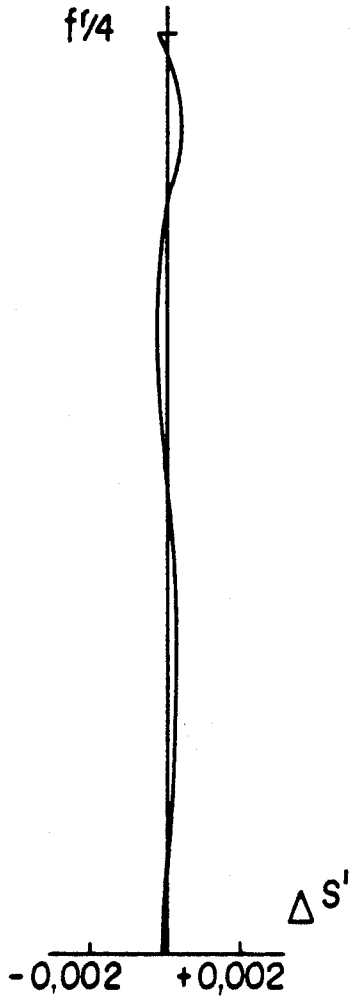


FIG. 2

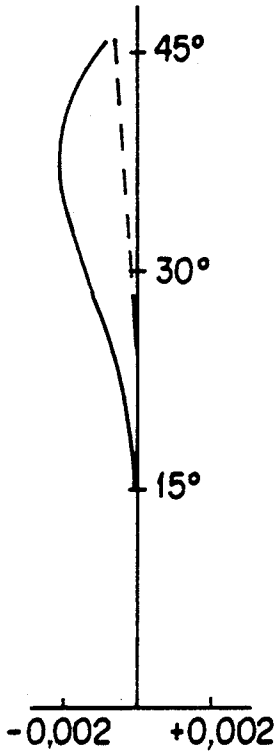


FIG. 3

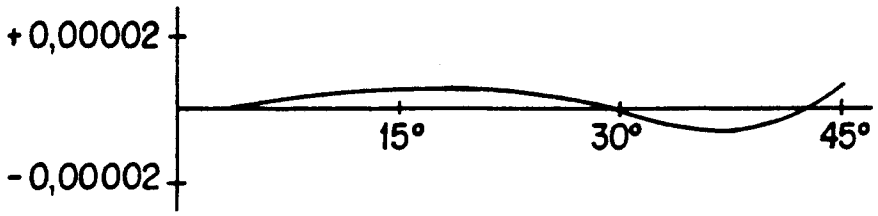


FIG. 4

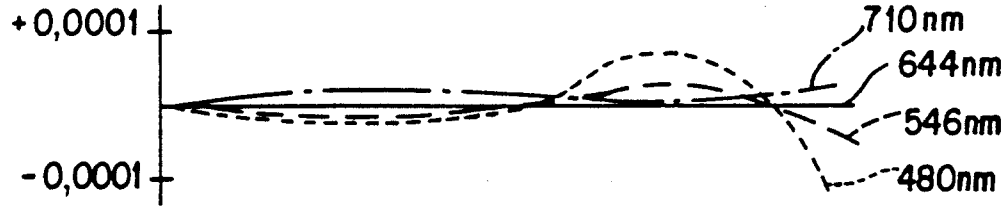


FIG. 5

WIDE-ANGLE OBJECTIVE

BACKGROUND OF THE INVENTION

The invention relates to a picture-taking lens for an aerial mapping camera.

In objectives for aerial photographic technology, the surface weighted resolution capability (AWAR), the resolution at the worst picture site, distortion and lateral chromatic aberrations are the main characteristic performance data that are used to describe the optical imaging performance. They must be considered in relation to the technological degree of difficulty of making the lens, to the material used and to the mass and dimensions of the objective. At the present time, there are three picture-taking lenses of comparable quality for aerial mapping cameras:

The universal Aviogon 15/4 UAg (f:4), with an AWAR of 75 L/mm, a resolution of 40 L/mm at the worst picture site and a distortion of ±3 microns measured at the overall length of 372 mm and the maximum lens diameter of about 234 mm. The lens has a 13-lens objective construction with a 3-fold and a 4-fold wring group, and relatively low performance data. This characteristic performance data for the AWAR and the resolution of the worst site of the picture, moreover are not attained for the full opening of k=4, but only when the aperture is stopped down to 5.6. As a result the maximum opening is practically not usable if the highest possible resolution is required. For this objective, approximately 550 nm has been selected as the achromatization wavelength. As a result, the lateral chromatic aberration in the short wave region for 480 nm is less than 20 microns. In the longwave range of the spectrum, lateral chromatic aberrations of up to 20 microns occur at 650 nm because of the relatively large secondary spectrum.

The Pleogon A 4/150 has an AWAR of 80 L/mm, a resolution of 67 L/mm at the worst site of the picture and a distortion of ±5 microns. Moreover, it is known that the best examples of this type achieve an AWAR of up to 96 L/mm and a distortion of ±1 micron. For the achromitization of the lateral chromatic aberration, a wavelength of 610 nm was selected. Because of the relatively large secondary spectrum, a lateral chromatic aberration of about 60 microns remains for a wave length of 480 nm and a lateral chromatic aberration of about 5 microns remains for a wave length of 650 nm. Nothing is known of the mass and dimensions of the objective. The material outlay with 9 lenses is relative low. However, the lenses of the objective have an extreme shape, with an center thickness ratio of about 30:1 and extreme deflections. The objective is therefore difficult technologically to produce.

The Lamegon 4.5/150 DM has an AWAR of 90 L/mm, a resolution of 70 L mm at the worst site of the picture and a distortion of ±1 microns. With this objective, however, the lateral chromatic aberration limits the performance in optical representation. For 470 nm, based on the wavelength of 640 nm at which the achromatization lies, it amounts to 30 microns. In the longwave region of the spectrum of 768 nm the lateral chromatic aberration is 30 microns. The relative large secondary spectrum of all known technical solutions does not ensure that the distortion is independent of the spectral sensitivity of the film. In color photographs, it necessarily leads to clearly identifiable color fringes and disadvantageously affects the resolution capability of broad-band sensitized black-and-white films. The AWAR achieved and the resolution capability at the worst site of the picture do not satisfy the highest requirements of photogrammetric recording techniques.

SUMMARY OF THE INVENTION

It is an object of the invention to provide a wide-angle objective as a picture-taking lens for aerial mapping cameras with demanding characteristic performance data and advantageous manufacturing parameters, while avoiding the disadvantages of the state of the art.

The invention is directed to the provision of a high resolution wide-angle lens with a picture angle $2\delta=90°$, a relative aperture of k=4 and a focal length of 150 mm, which has an AWAR of 115 L/mm on internationally customary high-resolution aerial photography films a resolution at the worst picture site of 80 L/mm and a residual distortion of less than ±1 micron. The maximum resolution capability is to be attained for a relative aperture of k=4.5 and the decrease in performance is to be small for a full aperture. Moreover, the lateral chromatic aberration in the broad-band spectral range of 480 nm to 770 nm in the picture field is to be less than 10 microns and the maximum lens diameter is to be smaller than $\frac{2}{3}$ of the picture diagonal and the overall length is not to be larger than the picture diagonal.

Pursuant to the invention, this object is accomplished by providing a wide-angle objective with a high resolution and a low residual distortion, comprised of 11 lenses and 14 glass-air interfaces. 6 lenses are disposed before a center aperture in the direction of the light and centrically to the optical axis, including diverging meniscus lens, a diverging double composite group and a converging composite groups 5 lenses are disposed after the center aperture, including a converging group, a converging double composite group and finally a diverging meniscus lens, one of the lenses after the center aperture being formed of a fluorspar or a fluorspar-like. The converging before the aperture is comprised of composite group a conlverging lens of high refractive index, a diverging lens and a further converging lens. The converging group after the center aperture includes the converging fluorspar or fluorspar-like lens and a diverging meniscus lens, which are separated from one another by a small thickness of air.

The use of a strongly converging lens of extremely low dispersion and high relative partial dispersion such as fluorspar or fluorsparlike glass in the immediate vicinity of the aperture makes is possible to realize, at the same time, a slight secondary spectrum for the longitudinal and lateral chromatic aberrations without interfering zones of the lateral chromatic aberration. The very large refractive index difference between the fluorspar lens and the subsequent meniscus lens in conjunction with very narrow air gap that is present between the two lenses satisfies the prerequisite of very good correction of the apertural error for the large relative aperture. The disadvanatageous effect of the low reflecting flurospar lens on the coma is compensated for by the high refracting converging lens of the triple group on the aperture space side.

The lenses selected have a maximum center thickness ratio of 1:10 and are therefore easily produced.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention is explained in greater detail by means of the accompanying the following description of an drawings and of the operation.

In the drawings:

FIG. 1 is a sectional representation of the lenses of an objective in accordance with the invention.

FIG. 2 shows the sperical aberration as a function of the opening and of the distance between the back lens and the image $\Delta s'$.

FIG. 3 shows the meridianal (broken line curve) and sagittal (solid line curve) curvature of the image as a function of the angle of the image.

FIG. 4 shows the distortion as a function of the angle of the image.

FIG. 5 shows the chromatic distortion, the lateral chromatic aberration, as a function of the angle of the image for 4 different wavelengths.

DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT OF THE INVENTION

In FIG. 1, lenses L1 to L11 are disposed in the following manner along the optical axis 0—0' in the direction of the light:

Before a center aperture B, a diverging meniscus lens L1, a diverging double composite group L2, L3 and a converging triple composite group L4, L5, L6 and, after the aperture B

a converging group including a converging lens L7 and a diverging menicus lens L8, which are separated by a small thickness of air, and a converging composite group L9, L10 and finally a diverging meniscus lens L11.

The lenses L1 to L11 are labeled by the radii of curvature r1 to r18 of their lens surfaces by numbering them continuously in the direction of the light. The lens thicknesses d1 to d11, measured along the optical axis, and the thicknesses of air 11 to 16 between the axial apexes of the lenses are labeled with the same numbering system.

The refractive indexes of the glasses used are likewise marked in a known manner n1 to n11, and the Abbe numbers are marked V1 to V11, these numbers being related to the e line, that is, to the wavelength of 546.0740 nm.

The following data Table contains the construction data wide-angle objective in accordance with the invention the length data being normalized for a focal length of 1.

FIGS. 2 and 3 show the good geometrical and optical correction of the lens that are prerequisite for a good resolution. The distortion of the objective is shown in FIG. 4 and the lateral chromatic aberration of the objective is shown in FIG. 5.

Lens	Radii	Thickness/ Thickness of Air	Refractive Indexes	Abbe Numbers
	r1 = +4.2149			
L1		d 1 = 0.0722	n 1 = 1.51985	V 1 = 60.80
	r2 = +0.4770			
		l 1 = 0.2196		
	r3 = +0.6420			
L2		d 2 = 0.2297	n 2 = 1.70065	V 2 = 46.67
	r4 = +1.9039			
L3		d 3 = 0.0984	n 3 = 1.52294	V 3 = 59.90
	r5 = +0.7094			
		l 2 = 0.0345		
	r6 = +0.6349			
L4		d 4 = 0.1967	n 4 = 1.69649	V 4 = 53.29
	r7 = −0.6241			
L5		d 5 = 0.0394	n 5 = 1.55156	V 5 = 45.13
	r8 = +0.7164			
L6		d 6 = 0.0623	n 6 = 1.69649	V 6 = 53.29
	r9 = +1.6418			
		l 3 = 0.0842		
	r10 = −6.4468			
L7		d 7 = 0.1280	n 7 = 1.43495	V 7 = 94.74
	r11 = −0.2319			
		l 4 = 0.0017		
	r12 = −0.2333			
L8		d 8 = 0.1588	n 8 = 1.73430	V 8 = 28.12
	r13 = −0.4537			
		l 5 = 0.0013		
	r14 = +1.4434			
L9		d 9 = 0.1645	n 9 = 1.72794	V 9 = 37.73
	r15 = −3.0995			
L10		d 10 = 0.0722	n 10 = 1.57126	V 10 = 55.73
	r16 = +1.3011			
		l 6 = 0.3330		
	r17 = −0.4671			
L11		d 11 = 0.0722	n 11 = 1.51859	V 11 = 63.86
	r18 = −1.2586			

We claim:

1. A wide-angle objective with a high resolution and low residual distortion, comprising 11 lenses and 14 glass-air interfaces, wherein, in the direction of light and centrically to the optical axis, 6 lenses are positioned before a center aperture, including a diverging meniscus lens, a converging double composite group and a first converging composite group, in that order, and 5 lenses are positioned after the center aperture, including a second converging group, a converging double composite group and finally a diverging meniscus lens, in that order, said first converging composite group comprising a converging lens of high refractive index, a diverging lens and a further converging lens, the second converging group, after the center aperture including a converging lens consisting of fluorspar or of a material of optical properties like those of flurospar and a diverging meniscus lens separated from one another by a small air gap.

* * * * *

United States Patent [19]

Tsuji

[11] **Patent Number: 5,051,833**

[45] **Date of Patent: Sep. 24, 1991**

[54] **CAMERA APPARATUS CAPABLE OF FREELY SETTING OBJECTIVE AREA WITHIN VIEWED SUBJECT**

[75] Inventor: **Akio Tsuji**, Akishima, Japan

[73] Assignee: **Casio Computer Co., Ltd.**, Tokyo, Japan

[21] Appl. No.: **510,962**

[22] Filed: **Apr. 19, 1990**

[30] **Foreign Application Priority Data**

Apr. 28, 1989 [JP] Japan 1-110111
May 9, 1989 [JP] Japan 1-115484

[51] **Int. Cl.**[5] **H04N 5/232**

[52] **U.S. Cl.** **358/227**; 358/228; 358/209; 358/213.19; 358/213.13

[58] **Field of Search** 358/227, 228, 209, 55, 358/224, 213.19, 213.13

[56] **References Cited**

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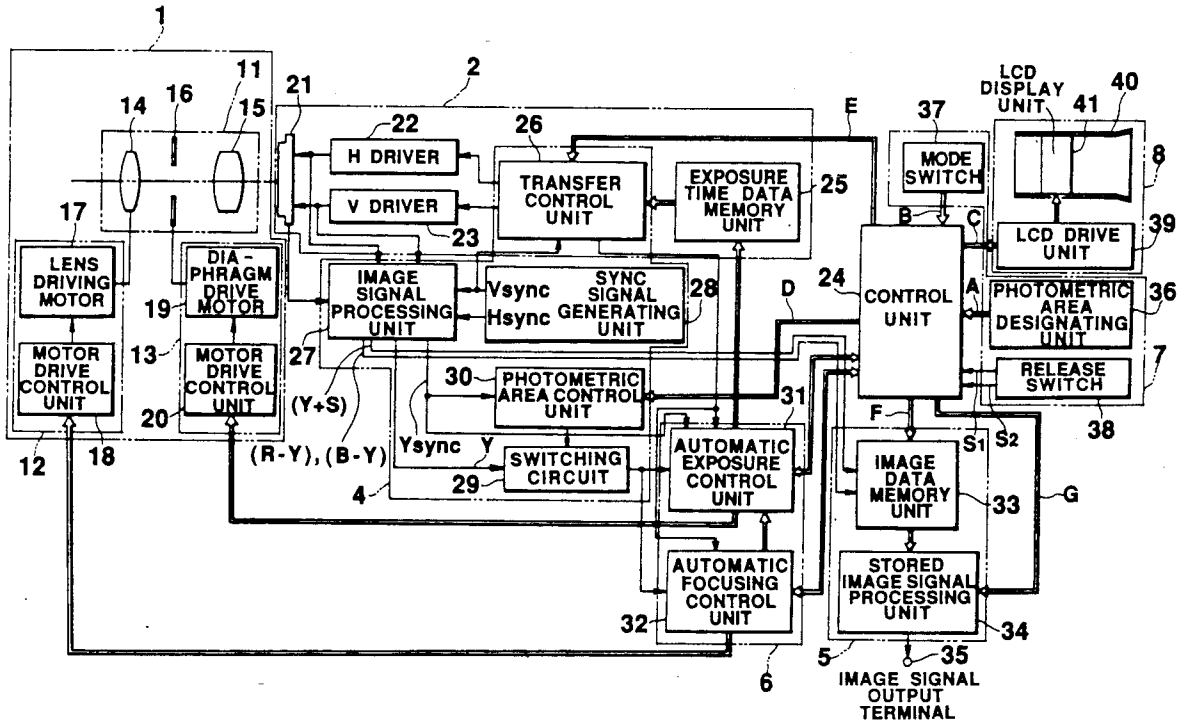
Primary Examiner—James J. Groody
Assistant Examiner—Tuan V. Ho
Attorney, Agent, or Firm—Frishauf, Holtz, Goodman & Woodward

[57] **ABSTRACT**

In an electronic still camera employing a CCD, an automatic exposure control and an automatic focusing control are carried out by utilizing an image signal derived from CCD to photograph a subject. A liquid crystal display unit is provided within a viewfinder. A designation is performed on a subject image to be automatically controlled for the exposure and focusing operations by utilizing a frame displayed on the liquid crystal display unit. The automatic exposure control and automatic focusing control are executed with respect to the subject positioned within the frame displayed on the liquid crystal display unit.

13 Claims, 10 Drawing Sheets



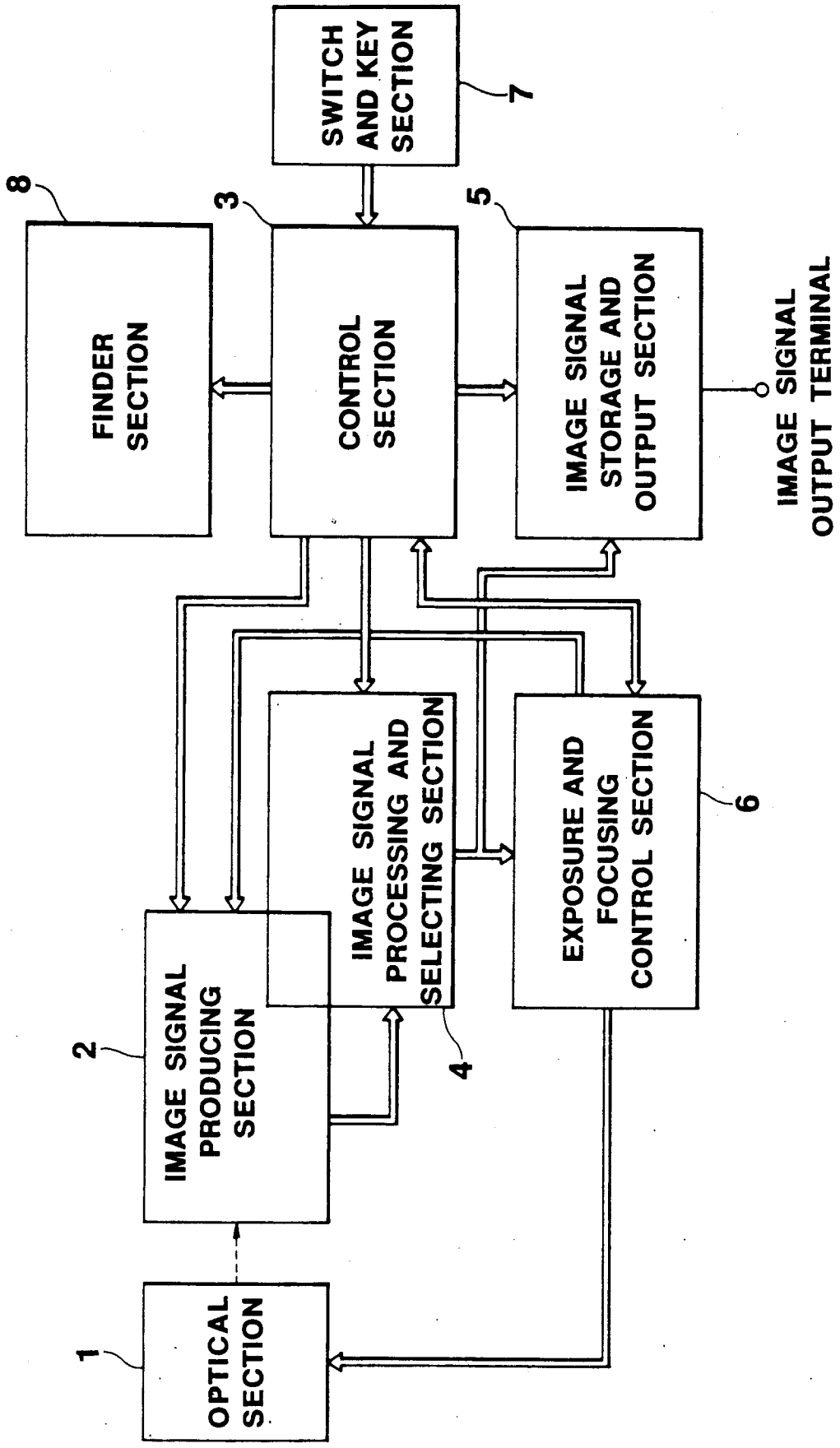

SWITCH AND KEY SECTION
7
8
3
5
FINDER SECTION
CONTROL SECTION
IMAGE SIGNAL STORAGE AND OUTPUT SECTION
IMAGE SIGNAL OUTPUT TERMINAL
IMAGE SIGNAL PROCESSING AND SELECTING SECTION
EXPOSURE AND FOCUSING CONTROL SECTION
6
2
IMAGE SIGNAL PRODUCING SECTION
4
1
OPTICAL SECTION

FIG. 1

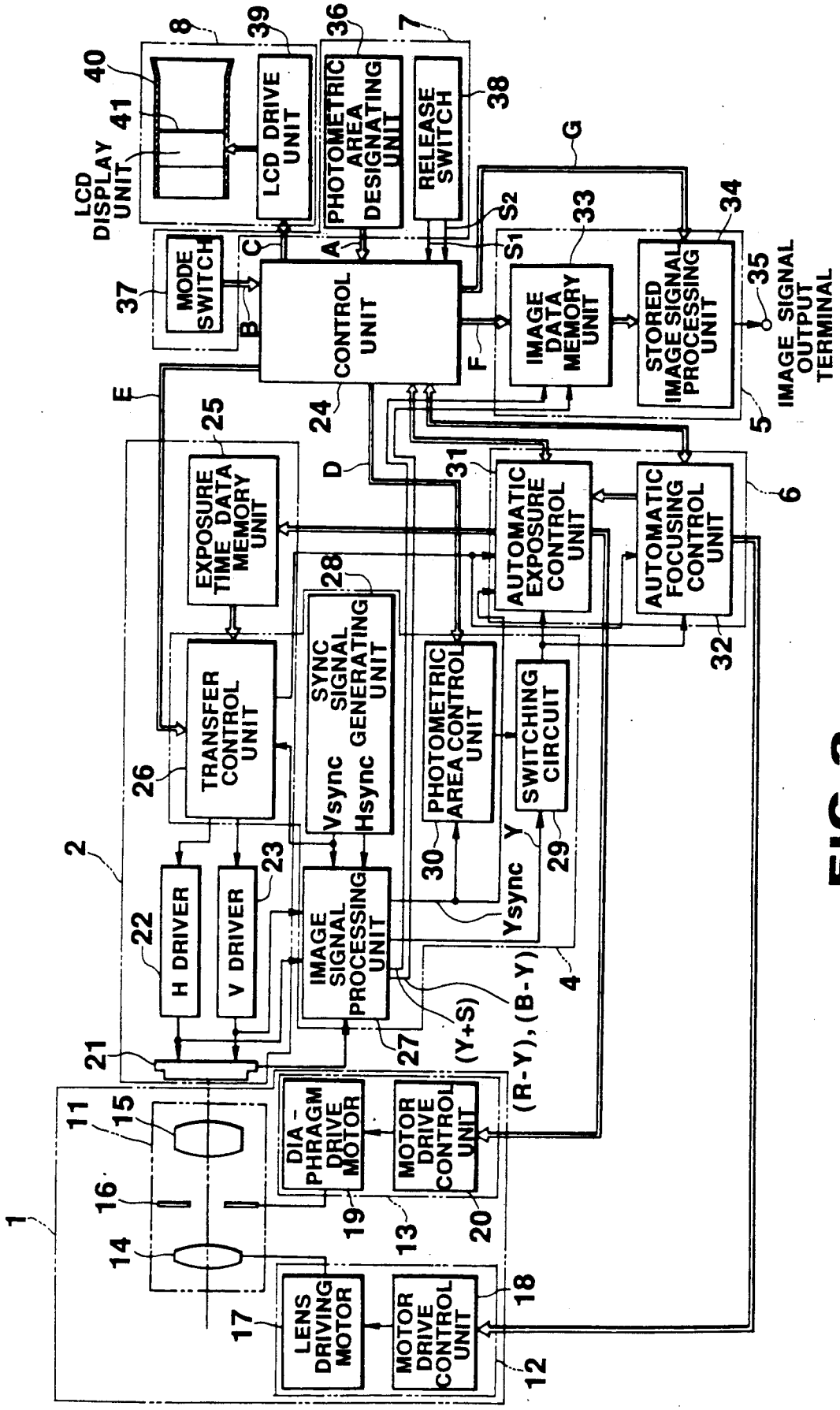

LCD DISPLAY UNIT
LCD DRIVE UNIT
PHOTOMETRIC AREA DESIGNATING UNIT
RELEASE SWITCH
MODE SWITCH
CONTROL UNIT
IMAGE DATA MEMORY UNIT
STORED IMAGE SIGNAL PROCESSING UNIT
IMAGE SIGNAL OUTPUT TERMINAL
EXPOSURE TIME DATA MEMORY UNIT
AUTOMATIC EXPOSURE CONTROL UNIT
AUTOMATIC FOCUSING CONTROL UNIT
TRANSFER CONTROL UNIT
SYNC SIGNAL GENERATING UNIT
Vsync
Hsync
PHOTOMETRIC AREA CONTROL UNIT
SWITCHING CIRCUIT
H DRIVER
V DRIVER
IMAGE SIGNAL PROCESSING UNIT
Ysync
Y
(Y+S)
(R-Y), (B-Y)
DIA-PHRAGM DRIVE MOTOR
MOTOR DRIVE CONTROL UNIT
LENS DRIVING MOTOR
MOTOR DRIVE CONTROL UNIT

FIG.2

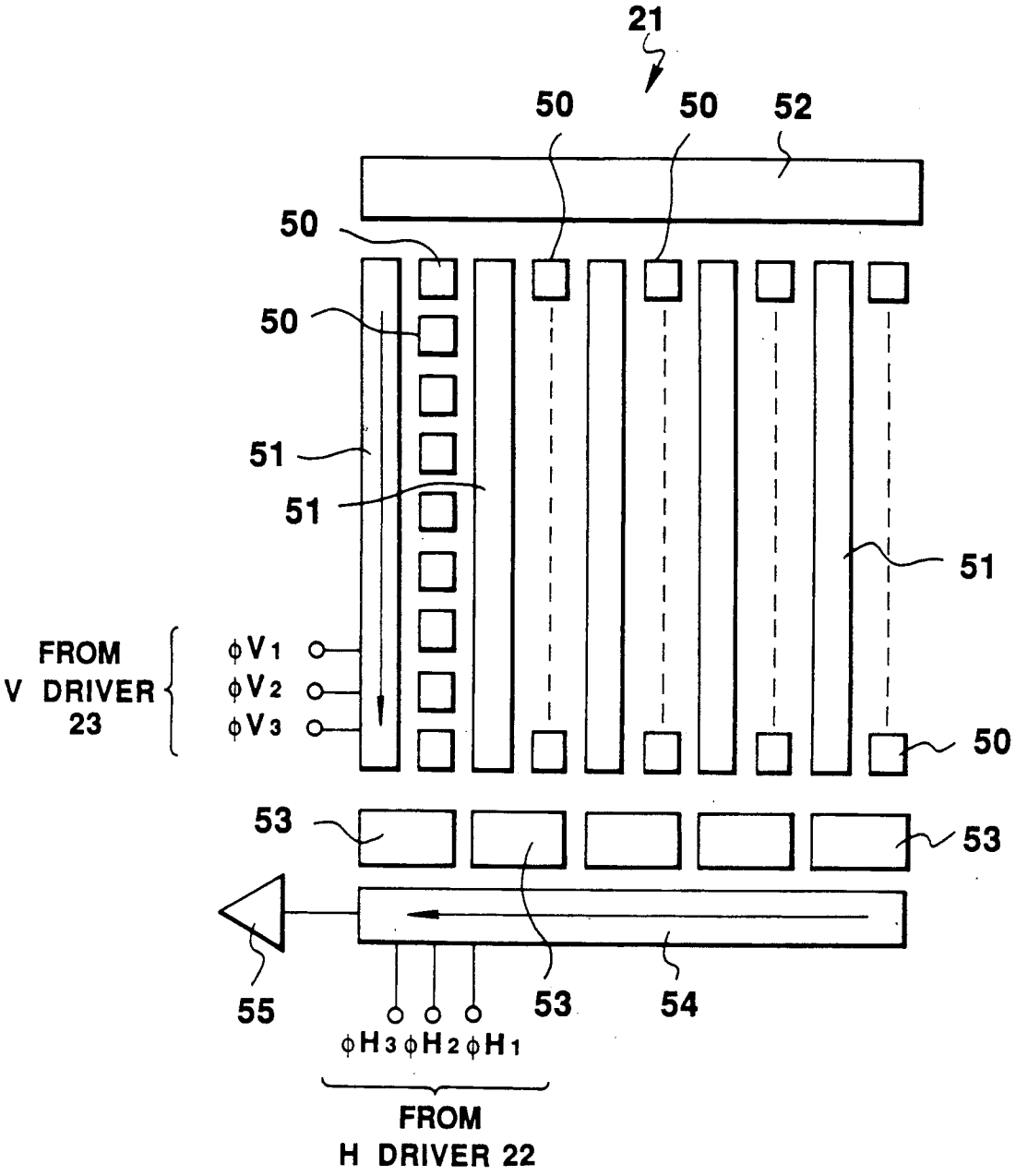

21
50
50
52
50
50
51
51
51
50
FROM
V DRIVER
23
φV1
φV2
φV3
53
53
55
53
54
φH3 φH2 φH1
FROM
H DRIVER 22

FIG. 3

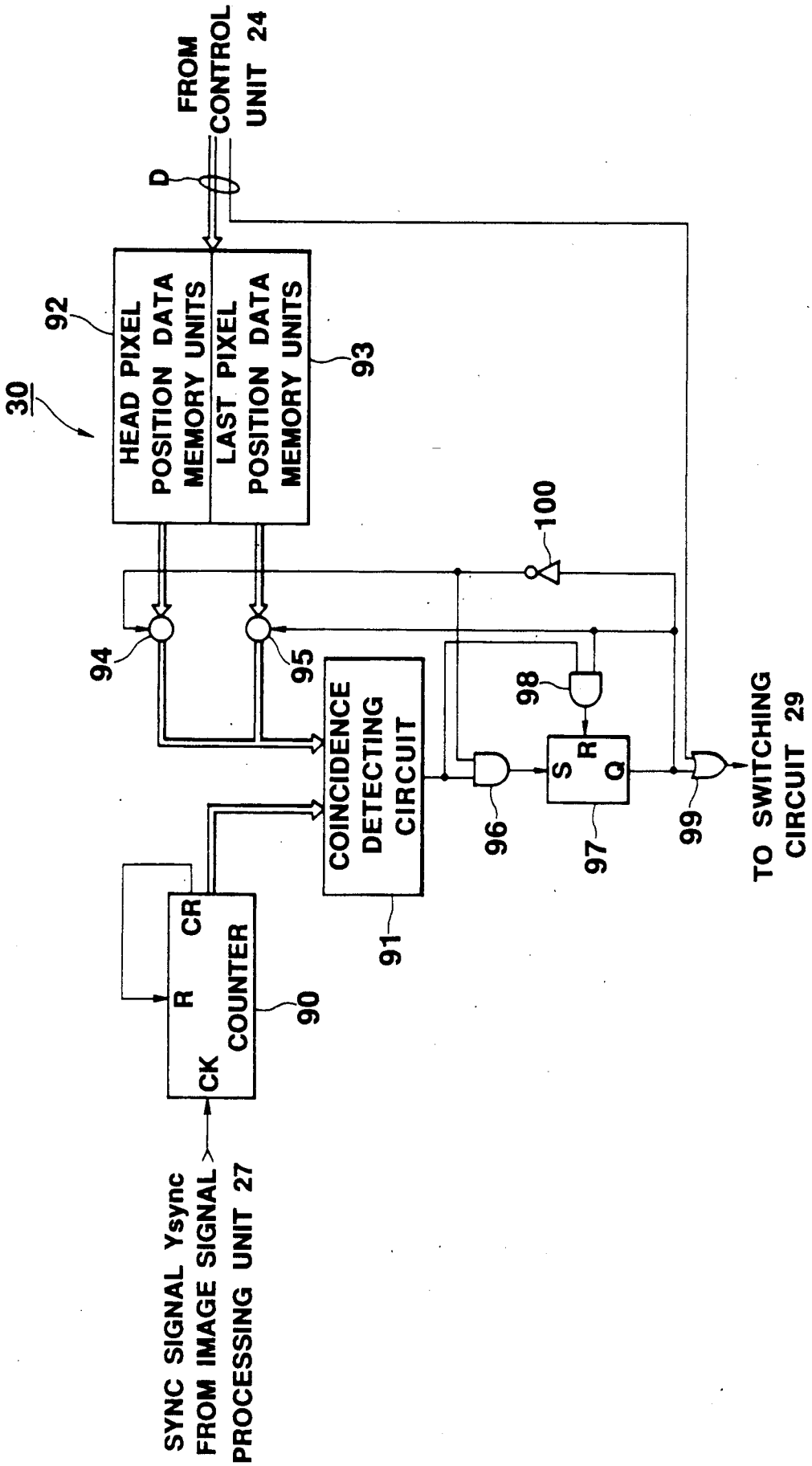

FROM CONTROL UNIT 24
D
30
92
HEAD PIXEL POSITION DATA MEMORY UNITS
LAST PIXEL POSITION DATA MEMORY UNITS
93
100
94
95
98
COINCIDENCE DETECTING CIRCUIT
S
R
Q
96
97
99
TO SWITCHING CIRCUIT 29
91
CR
R
CK
COUNTER
90
SYNC SIGNAL Ysync FROM IMAGE SIGNAL PROCESSING UNIT 27

FIG. 4

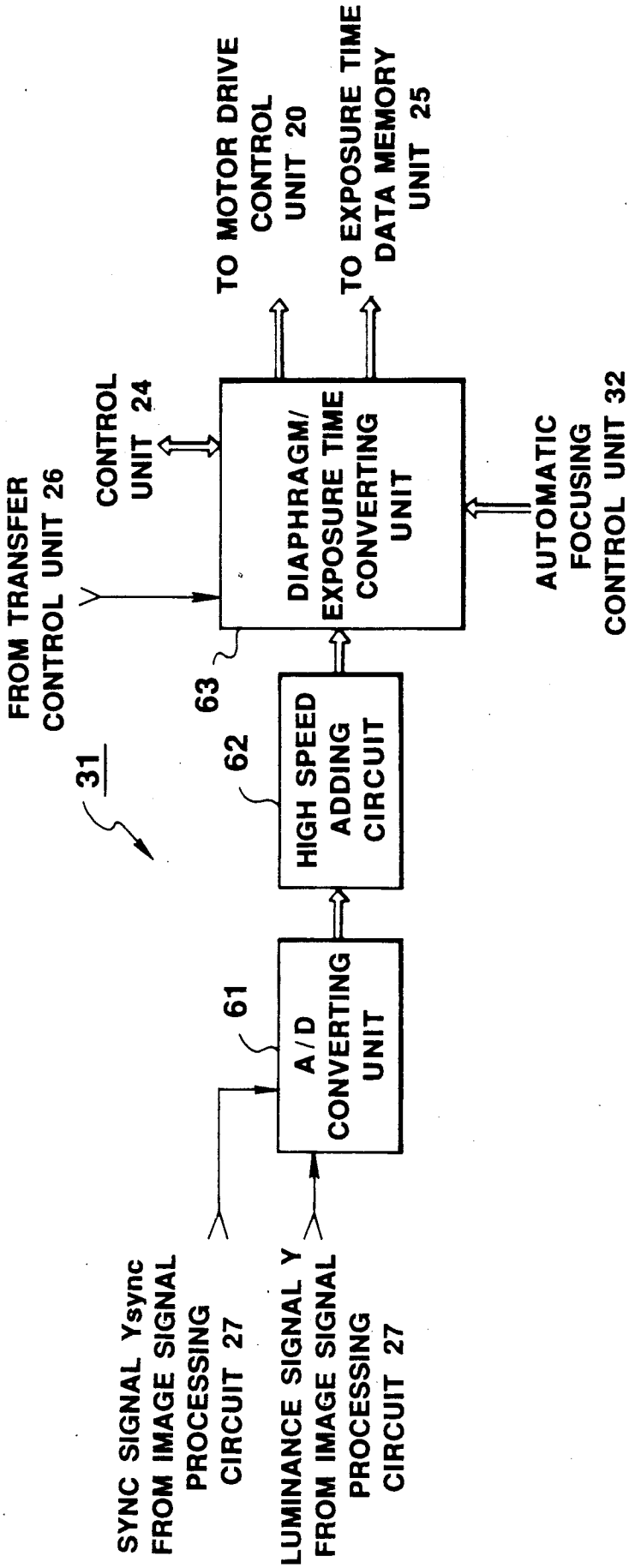

SYNC SIGNAL Ysync FROM IMAGE SIGNAL PROCESSING CIRCUIT 27
LUMINANCE SIGNAL Y FROM IMAGE SIGNAL PROCESSING CIRCUIT 27
61
A/D CONVERTING UNIT
62
HIGH SPEED ADDING CIRCUIT
63
DIAPHRAGM/ EXPOSURE TIME CONVERTING UNIT
AUTOMATIC FOCUSING CONTROL UNIT 32
TO MOTOR DRIVE CONTROL UNIT 20
TO EXPOSURE TIME DATA MEMORY UNIT 25
CONTROL UNIT 24
FROM TRANSFER CONTROL UNIT 26
31

FIG. 5

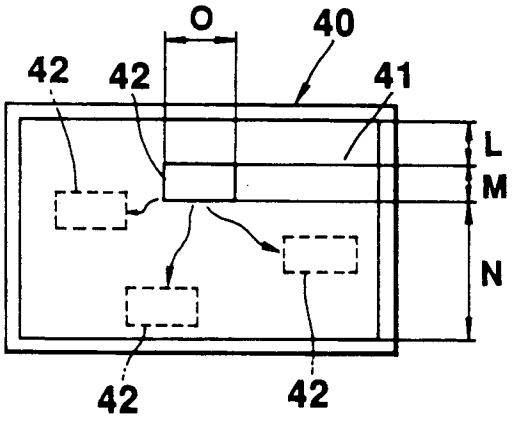

O
40
42
42
41
L
M
N
42
42

FIG. 6

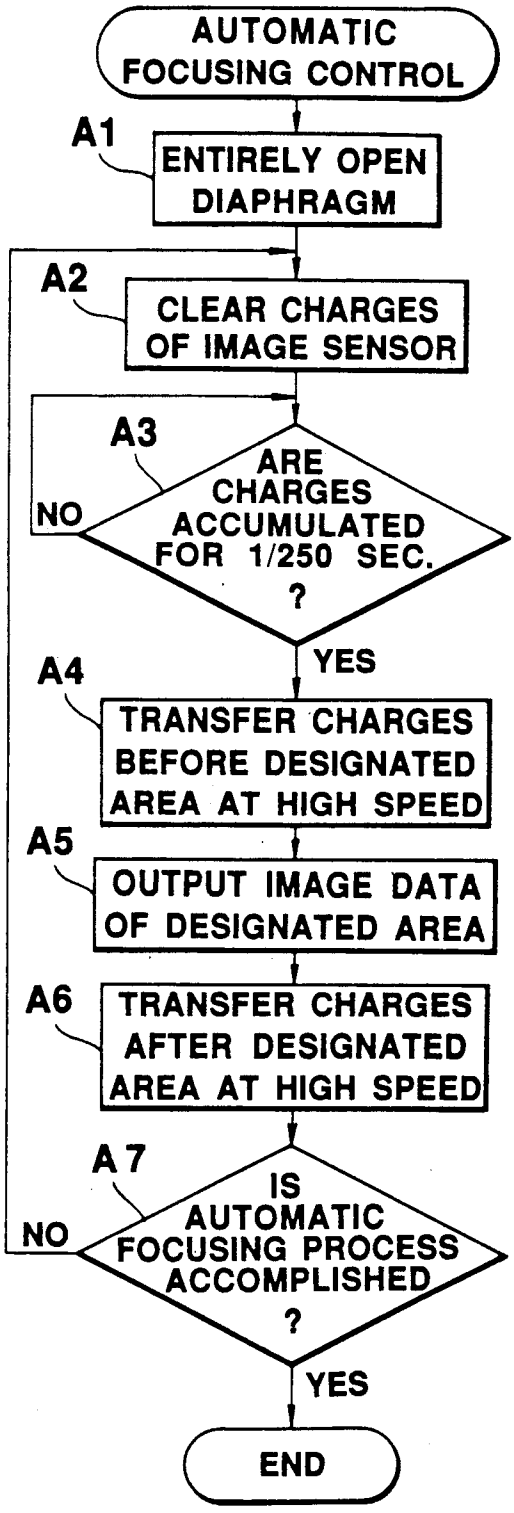

AUTOMATIC FOCUSING CONTROL
A1
ENTIRELY OPEN DIAPHRAGM
A2
CLEAR CHARGES OF IMAGE SENSOR
A3
ARE CHARGES ACCUMULATED FOR 1/250 SEC. ?
NO
YES
A4
TRANSFER CHARGES BEFORE DESIGNATED AREA AT HIGH SPEED
A5
OUTPUT IMAGE DATA OF DESIGNATED AREA
A6
TRANSFER CHARGES AFTER DESIGNATED AREA AT HIGH SPEED
A7
IS AUTOMATIC FOCUSING PROCESS ACCOMPLISHED ?
NO
YES
END

FIG. 7

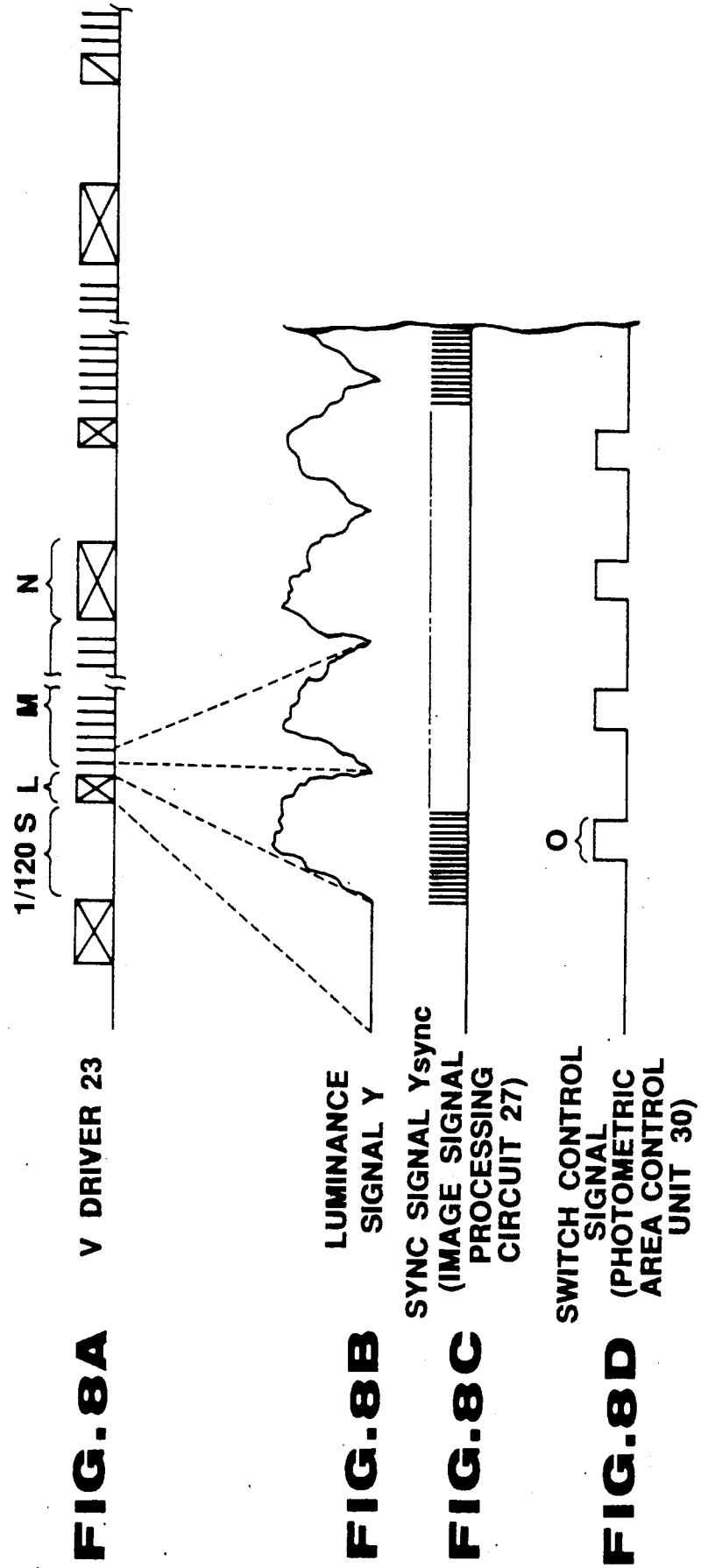


FIG.8A FIG.8B FIG.8C FIG.8D

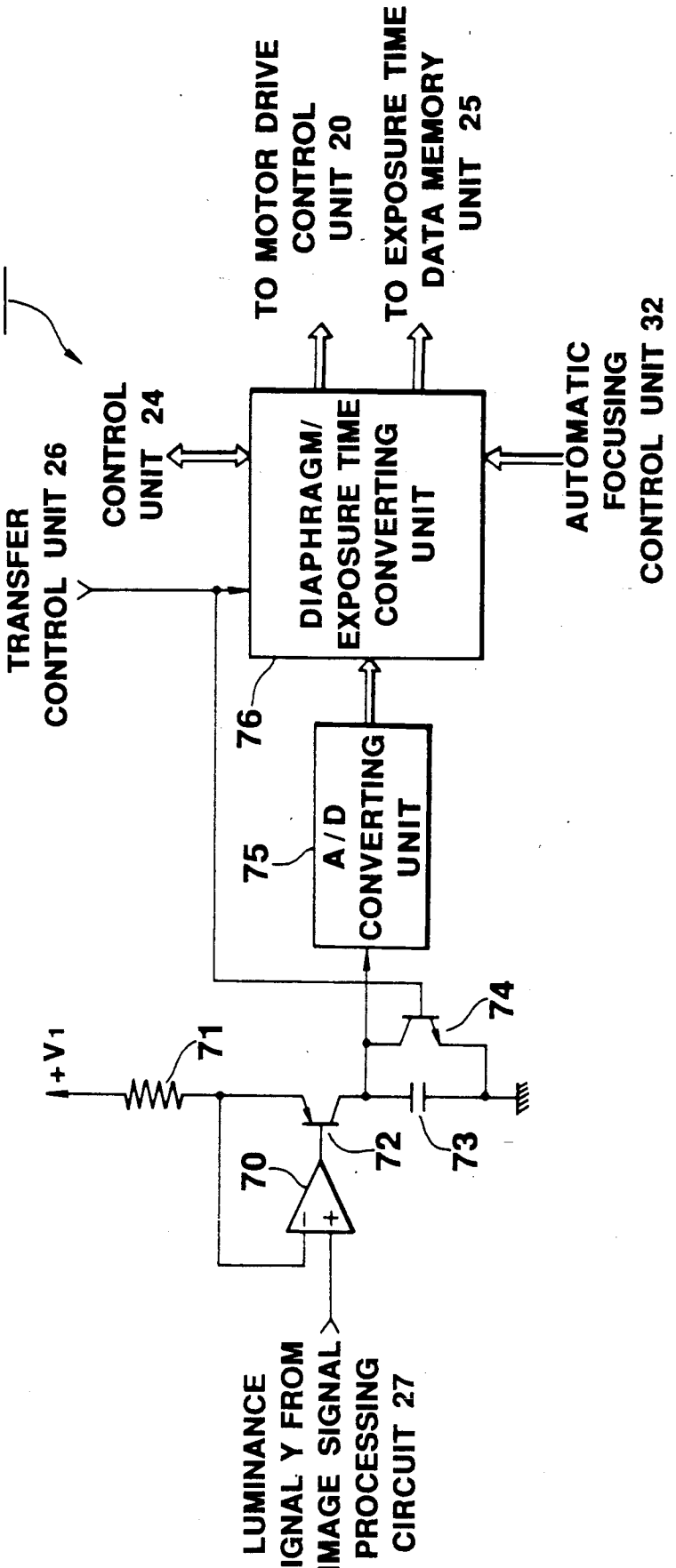

110
TO MOTOR DRIVE CONTROL UNIT 20
TO EXPOSURE TIME DATA MEMORY UNIT 25
TRANSFER CONTROL UNIT 26
CONTROL UNIT 24
DIAPHRAGM/ EXPOSURE TIME CONVERTING UNIT
AUTOMATIC FOCUSING CONTROL UNIT 32
76
75
A/D CONVERTING UNIT
+V1
71
74
70
72
73
LUMINANCE SIGNAL Y FROM IMAGE SIGNAL PROCESSING CIRCUIT 27

FIG. 9

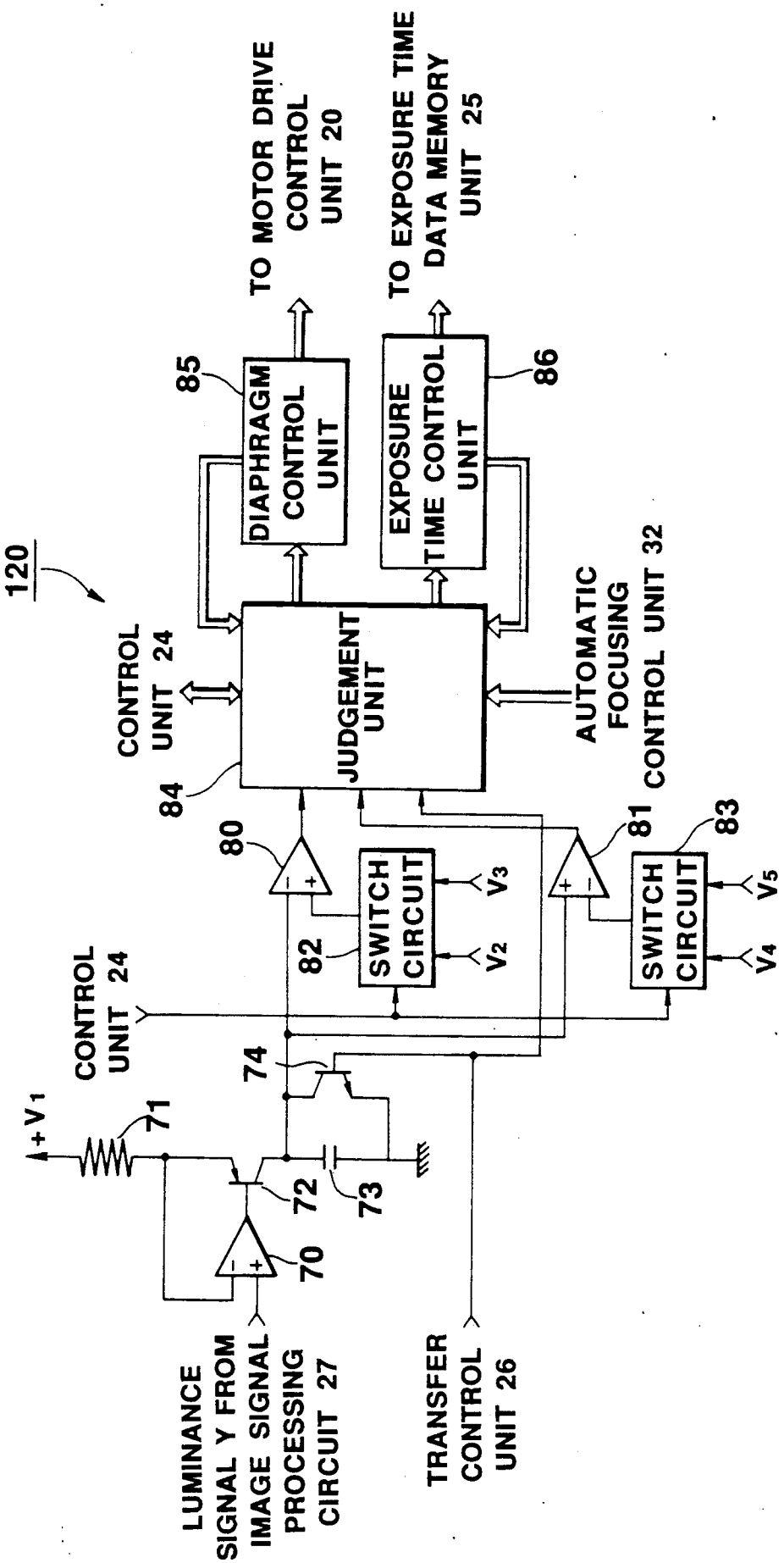

120
TO MOTOR DRIVE CONTROL UNIT 20
TO EXPOSURE TIME DATA MEMORY UNIT 25
85
DIAPHRAGM CONTROL UNIT
EXPOSURE TIME CONTROL UNIT
86
CONTROL UNIT 24
JUDGEMENT UNIT
AUTOMATIC FOCUSING CONTROL UNIT 32
84
80
81
83
SWITCH CIRCUIT
82
V3
V2
V5
V4
CONTROL UNIT 24
74
+V1
71
72
73
70
LUMINANCE SIGNAL Y FROM IMAGE SIGNAL PROCESSING CIRCUIT 27
TRANSFER CONTROL UNIT 26

FIG.10

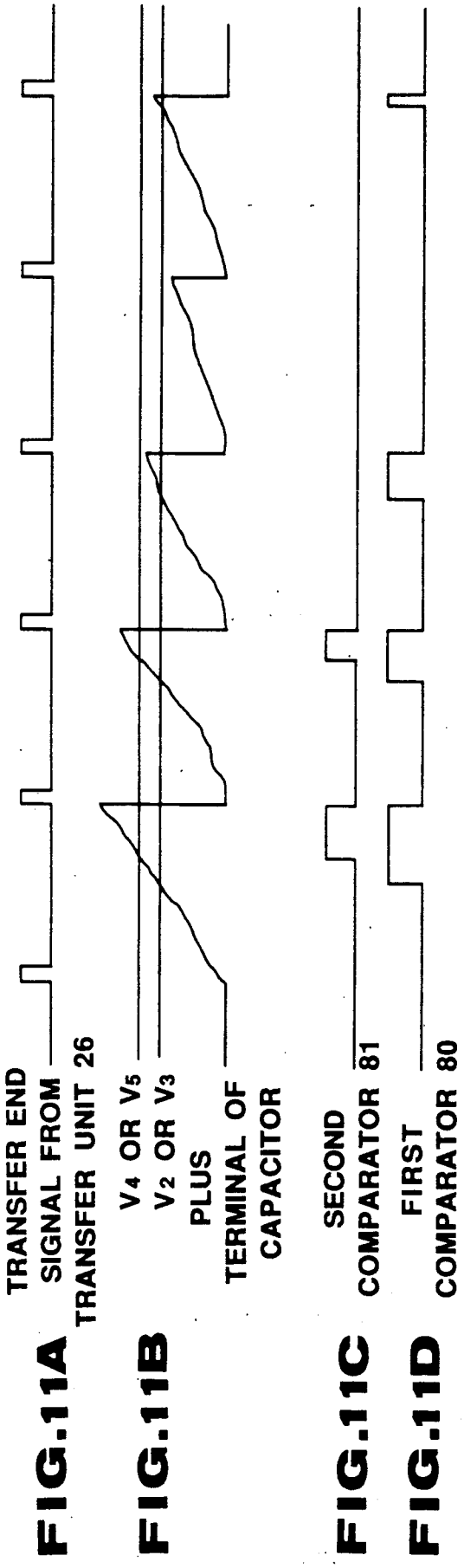


FIG.11A

FIG.11B

FIG.11C

FIG.11D

CAMERA APPARATUS CAPABLE OF FREELY SETTING OBJECTIVE AREA WITHIN VIEWED SUBJECT

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a camera apparatus equipped with an automatic focusing control function, and/or an automatic exposure control function.

2. Description of the Related Art

Recently, most of the camera apparatuses are equipped with either an automatic focusing control function, or an automatic exposure control function, or with both functions.

In such an automatic focusing control function, a focusing area is defined at a central part within a viewfinder, and then a focusing control is performed with respect to a viewed subject within this focusing area.

Furthermore, a so-called "focusing lock function" is provided with the automatic focusing control function. In accordance with the focusing lock function, a photograph focused on a subject which should be focused can be obtained even if this subject is not positioned within the focusing area while viewing the image through the viewfinder.

That is, this focusing lock function is performed as follows. Even when a change occurs in the once focused subject positioned within the focusing area, the lens position set to obtain the focused subject is locked without performing a further focusing function. In general, the focusing lock function is operable when the release switch is held under such a condition that this switch is depressed over a half travel length thereof, or the focusing lock switch is depressed.

In, on the other hand, the automatic exposure control function, the light quantity of the entire subject is generally measured so as to perform the exposure control.

When the focusing lock function is not equipped with the camera apparatus, the subject to be focused must be continuously positioned on the center of the viewfinder in order to perform the above-described automatic focusing control function, since the focusing area is fixed. Accordingly, such a camera apparatus has a drawback that a freedom on designation of an image is restricted. Furthermore, even if the automatic focusing control function is performed in conjunction with the focusing lock function, cumbersome operations are required, resulting in the incorrect operation of the camera apparatus. Also, in a still camera, there is another drawback that a lengthy photographing operation is required.

Furthermore, the above-described conventional automatic exposure control function has the following drawbacks. That is, in case that a dark portion and a light portion, the luminance of which is extremely different from that of the dark portion, are present within an overall subject to be photographed, the exposure control is executed based upon an average value of the respective luminance. As a consequence, the resultant image has different luminance from the respective luminance of both the dark and light portions. In particular, the above-described problem is emphasized when an image requiring the optimum luminance is positioned at either the dark portion, or the light portion.

SUMMARY OF THE INVENTION

The present invention has been made in an attempt to solve the above-described problems of the conventional camera apparatuses equipped with the automatic focusing function and/or automatic exposure function, and therefore, has an object to provide a camera apparatus capable of obtaining a subject image to be focused, or exposure-measured, from an arbitrary portion within the subject which is being observed through a viewfinder, while performing, for instance, the automatic focusing control function, or the automatic exposure control function.

To achieve the above-described object, a camera apparatus according to the present invention comprises:

optical image forming means for forming an optical image:

image sensing means having a photoelectric converting area comprised of a plurality of frame areas, for producing electric signals in response to said optical image formed by said optical image forming means;

area designating means for designating a desired frame area from said plurality of frame areas;

selecting means for selecting from the electric signals produced by the whole electric converting area, electric signals produced by said desired frame area designated by said area designated means; and,

producing means for producing a video signal based on said electric signals produced by said image sensing means and said selecting means.

In accordance with the camera apparatus of the present invention with the above-described arrangements, the operational capabilities for performing automatic focusing control and also automatic exposure control can be improved, and furthermore the desirable images can be acquired irrespective of the designation of the subject, and the conditions of the luminance of the subject.

BRIEF DESCRIPTION OF THE DRAWINGS

The above-described aspects and other features of the present invention are explained in the following description, taken in connection with the accompanying drawings, in which:

FIG. **1** is a schematic block diagram of a general arrangement of an electronic still camera according to a first preferred embodiment of the invention;

FIG. **2** is a schematic block diagram of a detailed arrangement of the electronic still camera shown in FIG. **1**;

FIG. **3** is a schematic diagram of a detailed arrangement of an image sensor shown in FIG. **2**;

FIG. **4** is a schematic block diagram of a detailed arrangement of a photometric area control unit represented in FIG. **2**;

FIG. **5** is a schematic block diagram of a detailed arrangement of an automatic exposure control unit represented in FIG. **2**;

FIG. **6** represents display conditions of a liquid crystal display unit employed within the viewfinder shown in FIG. **2**;

FIG. **7** is a flowchart for explaining operations of the automatic focusing control in the electronic still camera shown in FIG. **2**;

FIGS. **8A** to **8D** are timing charts for representing output conditions of signals derived from the major circuit portions of the electronic still camera while obtaining the luminance signal of the designated exposure-measuring area;

FIG. 9 is a schematic block diagram of an automatic exposure control unit shown in FIG. 2 according to a second preferred embodiment of the present invention;

FIG. 10 is a schematic block diagram of an automatic exposure control unit shown in FIG. 2 according to a third preferred embodiment of the present invention; and,

FIGS. 11A to 11D are timing charts for representing output conditions of signals derived from the major circuit portions of the electronic still camera while performing the exposure control in the automatic exposure control unit shown in FIG. 10.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

GENERAL ARRANGEMENT OF ELECTRONIC STILL CAMERA

Referring now to FIG. 1, an overall arrangement of an electronic still camera according to a first preferred embodiment of the present invention will be described in detail.

In the first electronic still camera shown in FIG. 1, an optical section 1 is employed so as to focus an image of an object (not shown in detail) being photograph with a desirable light level onto a predetermined plane of an image signal producing section 2. Under the control of a control section 3, the image signal producing section 2 produces an electronic still image signal in response to the object image focused by the optical section 1. Then, the electronic still image signal produced by the image signal producing section 2 is supplied to an image signal processing and selecting section 4.

The function of the image signal producing and selecting section 4 is to produce both a luminance signal and a color difference signal based on the electronic still image signal derived from the image signal producing section 2. Furthermore, the luminance signal is supplied from this image signal processing and selecting section 4 to both an image signal storage and output section 5, and an exposure and focusing control section 6, whereas the color difference signal is furnished therefrom to the image signal storage and output section 5. The image signal processing and selecting section 4 selects the luminance signal to be supplied to the exposure and focusing control section 6 in conjunction with the image signal producing section 2. That is, both the image signal processing and selecting section 4 and image signal producing section 2 produce a luminance signal with respect to an electronic image signal constituting a portion within a photographing range which is designated by a switch and key section 7, under the control of the control section 3, and thereafter supplies this selected luminance signal to the exposure and focusing control section 6.

The function of the above-described image signal storage and output section 5 is to store therein both the luminance signal and color difference signal supplied from the image signal processing and selecting section, and also to produce a color television signal, for instance, the NTSC (National Television System Committe) color TV signal in response to these luminance and color difference signals, which will be then furnished to an image signal output terminal.

Furthermore, the function of the exposure and focusing control section 6 is to detect an on-focusing condition of the object image focused by the optical section 1 based upon the luminance signal supplied from the image signal processing and selecting section 4, and to control the optical section 1 in such a manner that the above-described on-focusing condition of the object under imaging can be achieved. Moreover, this exposure and focusing control section 6 senses the light quantity of the object via the optical section 1, and controls both the optical section 1 and image signal producing section 2 in response to the sensed light quantity in such a way that the object image is converted into the electronic still image signal with a proper exposure level.

The switch and key section 7 outputs to the control section 3, an instruction signal for instructing a commencement of a photographing/recording process, instruction signals for instructing commencement of an exposure control process and a focusing control process, and an instruction signal for instructing an output of the recorded image signal. This switch and key section 7 further outputs a switching signal for switching an entire photometric mode and a spot photometric mode in connection with an exposure/focusing control during the photographing mode, and also a designation signal for designating a photometric region during the spot photometric mode.

In the arrangement of the electronic still camera shown in FIG. 1, a finder section 8 is provided, which is so constructed that the image of the object under photograph within the range focused by the optical section 1 can be observed, and also a photometric region designated by the switch and key section 7 can be indicated.

PARTICULAR ARRANGEMENT OF ELECTRONIC STILL CAMERA

A detailed arrangement of the respective sections shown in FIG. 1 will now be described with reference to FIG. 2.

First, the optical section 1 is constructed of an optical block 11, a lens driving block 12 and a diaphragm drive block 13.

The optical block 11 is provided to obtain the optical image of the object being photographed, and is arranged by lenses 14 and 15 and a diaphragm 16.

Then, the lens driving block 12 is constructed of a lens driving motor 17 and a motor drive control unit 18. The lens driving block 12 drives the lens 14 of the optical block 11 under the control of the exposure and focusing control unit 6.

The diaphragm drive block 13 is constituted by a diaphragm drive motor 19 and a motor drive control unit 20, and opens/closes the diaphragm 16 employed in the optical block 11 under the control of the exposure and focusing control unit 6. The optical image of the subject is focused by the optical block 11 on a predetermined position of the image signal producing section 2 at which an image sensor 21 constructed of a solid-state imaging element (CCD and the like) is provided. The image sensor 21 is, for instance, an area sensor having 380,000 picture elements (pixels). Color filters (not shown in detail) are provided on the light receiving plane of this area sensor from which an electric color image signal can be obtained. Then, the above-described image sensor 21 outputs an electric image signal corresponding to an optical image of the subject which has been formed by the optical block 11 under the control of an H driver 22 and a V driver 23.

Both the H driver 22 and V driver 23 control the operations of the sensor 21 based on the exposure time

data stored in the exposure time data memory unit **25** under the control of the control unit **24** (control section **2**). It should be noted that the above-described sensor **21**, H driver **22**, V driver **23**, transfer control unit **26** and exposure time data memory unit **25** constitute the image signal producing section **2** shown in FIG. **1**.

DETAILED ARRANGEMENT OF IMAGE SENSOR

In FIG. **3**, there is shown a detailed arrangement of the above-described image sensor **21**.

In this image sensor **21**, a plurality of photoelectric converting units (i.e., pixels) **50** are arranged along both a vertical direction and a horizontal direction. Vertical transfer units **51** are provided with each row of the vertical photoelectric converting unit **50**. Vertical transfer clocks ϕ_{V1}, ϕ_{V2}, and ϕ_{V3} are supplied from the V driver **23** to the vertical transfer unit **51** so that charges produced by the photoelectric converting unit **50** are transferred in response to these vertical transfer clocks ϕ_{V1}, ϕ_{V2}, and ϕ_{V3}. It should be noted that in this vertical transfer unit **51**, the transfer directions of the charges obtained by the photoelectric converting unit **50** are changed in accordance with the output sequence of the vertical transfer clocks ϕ_{V1}, ϕ_{V2}, and ϕ_{V3}.

A drain **52** is provided above the vertical transfer unit **51**. The drain **52** drains out the charges transferred from the vertical transfer unit **51**.

Under the vertical transfer unit **51**, an accumulating unit **53** is formed. The function of this accumulating unit **53** is to temporarily store the charges transferred from the vertical transfer unit **51**.

A horizontal transfer unit **54** is provided under this accumulating unit **53**. Horizontal transfer clocks ϕ_{H1}, ϕ_{H2}, and ϕ_{H3} are supplied from the H driver **22** to the horizontal transfer unit **54**. In response to the horizontal transfer clocks ϕ_{H1}, ϕ_{H2}, and ϕ_{H3}, this horizontal transfer unit **54** transfers the charges which are supplied from the vertical transfer unit **51** via the accumulating unit **53**.

Then, the charges transferred from the horizontal transfer unit **54** are output via an amplifier **55** to an external circuit.

When the image signal is acquired, the image sensor **15** with the above-described arrangements performs an interline transfer in response to the transfer clocks ϕ_{V1}, ϕ_{V2}, ϕ_{V3}, ϕ_{H1}, ϕ_{H2}, and ϕ_{H3} which are supplied from the V driver **17** and H driver **16**, respectively, and on the other hand, drains out the charges obtained by the photoelectric converting unit **50** to the drain **53** when the vertical transfer clocks ϕ_{V1}, ϕ_{V2}, and ϕ_{V3} are supplied in accordance with a supply sequence opposite to that of the above operation.

It should be noted that the above-described image sensor **21** or an equivalent element may be constructed by employing, for instance, the charge-coupled device type TC-245 of Texas Instruments Inc.

The image signal output from the image sensor **21** is supplied to an image signal process circuit **27** of the image signal processing and selecting section **4**, as represented in FIG. **2**.

The above-described image signal processing and selecting section **4** includes a sync signal generating unit **28**, a switching circuit **29**, and a photometric area control unit **30** in addition of the above-mentioned image signal process circuit **27**, and further includes the transfer control unit **26**. To the image signal process circuit **27**, the above-described transfer clocks from the H driver **22** and V driver **23**, and also a vertical sync signal Vsync and a horizontal sync signal Hsync from the sync signal generating unit **28** are supplied. The image signal processing unit **27** fetches the image signal supplied from the image sensor **21** in synchronism with the transfer clocks from the H driver **22** and V driver **23**, and produces a luminance signal Y from the image signal and also a luminance/sync signal (Y+S) and color difference signals (R−Y), (B−Y) by adding the vertical sync signal Vsync and horizontal sync signal Hsync to this luminance signal Y. The image signal processing circuit **27** outputs the luminance signal Y via the switching circuit **29** to an automatic exposure control unit **31** and an automatic focusing control unit **32** of the exposure and focusing control section **6**, and further outputs both the luminance/sync signal (Y+S), and color difference signals (R−Y), (B−Y) to an image data memory unit **33** of the image signal storage and output section **5**. In addition, the above-described image signal processing unit **27** supplies the sync signal Ysync corresponding to the output of the luminance signal Y to the photometric area control unit **30** and the automatic exposure control unit **31**.

The photometric area control unit **30** controls the switching operation of the switch circuit **39** under the control of the control unit **24**, and is so arranged as shown in FIG. **4**.

In FIG. **4**, a counter **90** is employed to perform a counting operation in response to the sync signal Ysync of the luminance signal Y outputted from the image signal processing unit **27**. When the counter **90** counts a quantity of sync signal Ysync outputted from the image signal processing unit **27** until all of the luminance signals Y corresponding to the pixels along **1** horizontal scanning period of the image sensor **1** have been outputted therefrom, a carry signal is outputted and is supplied to the counter **90** for reset operations. Then, the count value of this counter **90** is supplied to a coincidence detecting circuit **91**.

Furthermore, there are provided a head pixel position data memory unit **92** and a last pixel position data memory unit **93**. The head pixel position data memory unit **92** stores data on a head pixel position of a photometric area in the horizontal scanning direction which is outputted from the control unit **24** in accordance with the photometric area designated by the switch and key section **7**, whereas the last pixel position data memory unit **93** stores therein data on a last pixel position of the above-described photometric area. The memory data stored in the pixel position data memory units **92** and **93** are supplied via corresponding gate circuits **94** and **95** to the coincidence detecting circuit **91**.

On the other hand, when there is a coincidence between the count value derived from the counter **90** and the pixel position data read out from either the head pixel position data memory unit **92**, or the last pixel position data memory unit **93**, the coincidence detecting circuit **91** outputs a coincidence detecting signal. The coincidence detecting signal outputted from the coincidence detecting circuit **91** is supplied via either a set terminal S of a flip-flop **97**, or an AND gate **98** to a reset terminal R of the flip-flop **97**. Then, a set output Q of the flip-flop **97** is furnished via an OR gate **99** to a switching circuit **29**, and to an AND gate **98** and also a gate circuit **95**. Further, this set output Q is supplied via an inverter **100** to the AND gate **96** and gate circuit **94**. To this OR gate **99**, the overall photometric mode signal designated by the switch and key section **7** in the

overall photometric mode is supplied from the control unit **24**.

In the photometric area control unit **30** with the above-described circuit arrangement, first, both the count value of the counter **90** and the pixel position data of the head pixel position memory unit **92** are supplied to the coincidence detecting circuit **91**. When there exists a coincidence between the count value and pixel position data, the flip-flop **97** is set to close the switching circuit **29**. At the same time, in response to the set output Q from the flip-flop **97**, the gate circuit **95** is closed and the pixel position data from the last pixel position data memory unit **93** is supplied to the coincidence circuit **91**. Then, when the coincidence is again detected in the coincidence detecting circuit **91**, the flip-flop **97** is caused to be reset so that the switching circuit **29** is closed.

Now, the operations of the exposure and focusing control section **6** will be described.

The exposure and focusing control section **6** is constructed of an automatic exposure control unit **31** and an automatic focusing control unit **32**.

The functions of the automatic exposure control unit **31** are to obtain exposure time data, an open degree of the diaphragm **16**, and open degree control data for controlling this open degree in response to the luminance signal Y which has been supplied via the switching circuit **29** under the control of a control unit **24**.

AUTOMATIC EXPOSURE CONTROL UNIT

FIG. **5** represents a detailed arrangement of the above-described automatic exposure control unit **31**. This automatic exposure control unit **31** is constructed of an A/D converting unit **61**, a high speed adding circuit **62**, and a diaphragm/time converting circuit **63**.

The A/D converting circuit **61** has such a function that the luminance signal Y supplied via the switching circuit **29** from the image signal processing circuit **27** is sequentially converted into digital data corresponding to the value of this luminance signal Y in synchronism with the sync signal supplied from the image signal processing circuit **27**. Thus, the digital data obtained from the A/D converting unit **61** is sequentially supplied to the high speed adding circuit **62** so as to be added to each other. Furthermore, the addition data obtained from the high speed adding circuit **62** is fetched into the diaphragm/exposure time converting circuit **63** in synchronism with a transfer end signal output from a transfer control unit **26**.

The diaphragm/exposure time converting unit **63** includes a table (not shown) from which a proper open degree of the diaphragm **16** and a proper exposure time based upon the addition data of the high speed adding circuit **62** which are obtained by adding all of the luminance signals supplied via the switching circuit **29** thereto, and data on the distance between the subject and the electronic still camera, which are supplied from the automatic focusing control unit **32**.

Then, the diaphragm/exposure time converting unit **63** supplies the exposure time data to the exposure time data memory unit **25**, and also furnishes the diaphragm open degree control data to the motor drive control unit **20** for controlling a diaphragm drive motor **19** to vary the open degree of the diaphragm **16**, based upon either the data obtained from the table, or the control data supplied from the control unit **24**.

Referring again back to the automatic focusing control unit **32** shown in FIG. **2** detects an on-focusing condition of an image of a subject in response to the luminance signal Y supplied via the switching circuit **29** from the image signal processing circuit **27** so as to supply a control signal to the motor control unit **18** for controlling the lens drive motor **17** by which the positions of the lens **14** is varied. It should be noted that the above-described automatic focusing control unit **32** commences the detecting operation of the on-focusing condition in synchronism with a transfer control unit **26**. For instance, the automatic focusing control unit **32** detects the differences in the luminance between the respective pixels based upon the luminance signals in order to detect the on-focusing condition of the subject. The automatic focusing control unit **32** acquires data on the distance between the subject and camera based upon the position of the lens **14** when the on-focusing condition of the subject is just detected, and thereafter furnishes this data to the automatic exposure control unit **31**.

Then, the above-described image signal storage and output section **5** will now be described as follows. This image signal storage and output section **5** is arranged by the above-mentioned data memory unit **33** and stored image signal processing unit **34**.

The function of the image data memory unit **33** is to perform a predetermined process to both the luminance/sync signal (Y+S) and the color difference signals (R−Y), (B−Y) supplied from the image signal processing circuit **27**, and thereafter to store the processed signals into a preselected memory medium. In case that, for instance, the luminance/sync signal (Y+S) and color difference signals (R−Y), (B−Y) are recorded on a video floppy disk, the luminance/sync signal (Y+S) is sequentially superimposed with the color difference signals (R−Y), (B−Y), whereby the recording process is performed.

The image data memory unit **33** supplies both the luminance/sync signal (Y+S) and color difference signals (R−Y), (B−Y) which have been stored in the recording medium to the stored image signal processing unit **34**.

Then, this stored image signal processing unit **34** produces, for instance, an NTSC (National Television System Committee) color signal based on the luminance/sync signal (Y+S) and color difference signals (R−Y), (B−Y) supplied from the image data memory unit **23**, and thereafter outputs the color signal to an image signal output terminal **35**.

To the control unit **24**, predetermined signals A, B, S_1 and S_2 are supplied from the switch and key section **7** which provide a photometric area designation unit **36**, mode switch **37**, and release switch **38**.

The photometric area designation unit **36** is constructed of, for example, keys for designating upper, lower, right, and left directions, and supplies signals in response to the key operations to the control unit **24**.

The control unit **24** outputs display control signal C to an LCD (liquid crystal diode) drive unit **35** based upon the signal A supplied from the photometric area designation unit **36**.

As illustrated in FIG. **6**, the LCD drive unit **39** displays a designation frame **42** at a position in the LCD display unit **41** provided within a viewfinder **40**. This position corresponds to the operation of the photometric area designation unit **36**. The portion of the LCD display unit **41** except for the portion displayed by the designation frame **42** is transparent, through which the subject can be observed.

In response to the operation conditions of the mode switch **37** and release switch **38** (will be described later), the control unit **24** supplies to both the photometric are control unit **30** and transfer control unit **26**, pixel position data and mode signals D and E corresponding to the display positions of the designation frame **42** on the LCD display unit **41** which are designated by the photometric area designation unit **36**.

Then, in accordance with the pixel position data E, the transfer control unit **26** outputs only the image signal containing the subject existing in the designation frame **42** within **1** horizontal scanning period, and controls the H driver **22** and V driver **23** so as to feed out other image signals.

On the other hand, the photometric area control unit **30** controls the switching circuit **29** based upon the pixel position data D supplied from the control unit **24** and the sync signal Ysync of the luminance signal Y supplied from the image signal processing unit **27** in such a manner that only the luminance signal "Y" output from the image processing circuit **27**, which contains the subject present in the designation frame **42**, is supplied to the automatic exposure control unit **31** and automatic focusing control unit **32**.

The functions of the mode switch **37** are to switch a recording mode and an output mode, and also charge a spot photometric mode during the automatic exposure control and an entire photometric mode, and furthermore set a manual mode and also an automatic mode of a focusing control/an exposure control.

The release switch **38** outputs a first release signal "S_1" when being depressed along a half traveling path thereof, and also output a second release signal "S_2" when being depressed over a full traveling path thereof.

Under the conditions that the recording mode is set by the mode switch **37** and further the exposure/focusing control is set to the automatic mode, the control unit **24** outputs either the control signal or control data to the automatic exposure control unit **31**, automatic focusing control unit **32**, photometric area control unit **30** and transfer control unit **26** in order to perform the automatic exposure/focusing control when the first release signal S_1 is output from the release switch **38**.

That is, when the entire photometric mode is designated by the mode switch **37**, the control unit **24** supplies the pixel position data D and E corresponding to the designation made by the photometric area designation unit **36** to the photometric area control unit **30** and transfer control unit **26** only when the automatic focusing control is carried out. When the automatic exposure control is carried out, the control unit **24** supplies the pixel position data D and E to the photometric area control unit **30** and transfer control unit **26** in such a way that the luminance signals Y with respect to all of the image signals obtained by the image sensor **21** are supplied to the automatic exposure control unit **31**.

When the second release signal S_2 is output from the release switch **38** during the recording mode, the control unit **24** outputs the storing control signal F to the image data memory unit **33** so as to perform the storage process, and also outputs the transferring control signal E to the transfer control unit **26** in such a manner that the image sensor **21** produces the output signal in response to the data stored in the exposure time data memory unit **25**.

In addition, when the second release signal S_2 is output during the output mode, the control unit **24** outputs the output control signals F and G to the image data memory unit **33** and the stored image signal processing unit **34**, and outputs the image data which has been stored in the image data memory unit **33**, to the image signal output terminal **35**.

OPERATIONS OF ELECTRONIC STILL CAMERA

The electronic still camera with the above-described arrangements will now be described.

When the image data is recorded, the recording mode is set by operating the mode switch **37**.

Furthermore, a selection is made whether or not the exposure/focusing control is set to the manual mode or automatic mode by way of the mode switch **37**. In case that the automatic exposure mode is selected, another selection is made that the spot photometric mode, or entire photometric mode is chosen.

AUTOMATIC EXPOSURE CONTROL/AUTOMATIC FOCUSING CONTROL MODES

A description will now be made to such a case that the automatic exposure control/automatic focusing control modes are selected.

The designation frame **42** which is being displayed on the liquid crystal display unit **41** within the viewfinder **40**, is moved to a major portion of a subject (e.g., a person who is wanted to be photographed) by the photometric area designation unit **36**.

When the release switch **38** is operated so as to output the first release signal S_1, the automatic focusing control is first performed.

Then, the control unit **24** outputs the pixel position data D, E corresponding to the display position of the designation frame **42** which is being displayed on the liquid crystal display unit **41**, to both the photometric area control unit **30** and transfer control unit **26**. Thereafter, the control unit **24** outputs the control signal to the automatic exposure control unit **31**.

As represented in a flowchart of FIG. **7**, to entirely open the diaphragm **16**, the automatic exposure control unit **31** outputs the control signal to the motor drive control unit **20** (step A_1), and also outputs predetermined exposure time data (i.e., 1/250 sec in the preferred embodiment) to the exposure time data memory unit **25**.

On the other hand, the transfer control unit **26** controls the V driver **23** so as to drain out the charges accumulated in the image sensor **21** in response to the automatic exposure control starting signal E supplied from the control unit **24** (step A2). That is to say, the transfer control unit **26** control the V driver **23** in order to output the vertical transfer clocks ϕV_1, ϕV_2, and ϕV_3 having a frequency higher than the normal frequency at a timing reverse to the normal timing, and causes the charges obtained by the photoelectric converting unit **50** to be drained out via the vertical transfer unit **51** to the drain **52** (see FIG. **2**).

Thereafter, the charges are accumulated in the image sensor **21** for 1/250 seconds (step A3). In this step, the transfer control unit **26** counts the exposure time based upon the data which has been stored in the exposure time data memory unit **25**, and starts to control both the H driver **22** and V driver **23** after this exposure time has passed in order that the image signal is output from the image sensor **21**.

It should be noted that the transfer control unit **26** controls both the H driver **22** and V driver **23** in accordance with the control data which has been previously supplied from the control unit **24** and corresponds to the display position of the designation frame **42**. This designation frame **42** is being displayed on the liquid crystal display unit **41**.

For instance, in case that the designation frame **42** is being displayed at the position indicated by a solid line shown in FIG. **6**, the charges of the photoelectric converting unit **50** corresponding to the portion of the photographing area "L" represented in FIG. **6** are drained out at a high speed (step A4).

The transfer control unit **26** controls the charges of the photoelectric converting unit **50** corresponding to the portion of the photographing area "M" which contains the portion corresponding to the subject designated by the designation frame **42** in such a manner that the V driver **23** and H driver **22** perform the normal drive operation, whereby these charges are output to the image signal processing unit **27** (step A5). In addition, the transfer control unit **26** sweeps out the charges of the photoelectric converting unit **50** corresponding to the remaining photographing region "N" to the drain **52** in the similar manner (step A6).

It should be noted that the time chart of the V driver **23** is represented in FIG. **8**A.

As previously described, only the image signal corresponding to the photographing region "B" is output to the image signal processing circuit **27**.

Then, in this image signal processing circuit **27**, the luminance signal "Y" is produced from the image signal and supplied to the switching circuit **29**. The sync signal Ysync corresponding to the output of this luminance signal "Y" is furnished to the photometric area control unit **30** (see FIGS. **8**B and **8**C).

It should be understood that the sync signal Ysync supplied from the image signal processing unit **27** to the photometric area control unit **30** is a signal formed in response to the clock output from the H driver **22**.

It should be noted that although the clock output from the V driver **23** is completely synchronized with the output of the luminance signal Y in the time charts shown in FIGS. **8**A and **8**B, for the sake of simplicity, such a synchronization between the luminance signal and the clock signal does not occur in the actual case because there is a time shift in order to employ the image signal which has been delayed for 1 horizontal scanning period while producing the luminance signal Y.

On the other hand, when the first release signal **S1** is outputted from the release switch **38**, the photometric area control unit **30** causes the pixel position data memory units **92** and **93** to store the head pixel position data and last pixel position data supplied from the control unit **24**, respectively (see FIG. **4**). It should be noted that the above-described head pixel position data and last pixel position data represent positions of the pixels corresponding to both end portions of the designation frame **42** in the horizontal direction. Then, the pixel position data which have been stored in the head pixel position data memory unit **92** are supplied via the gate circuit **94** to the coincidence detecting circuit **91**. The sync signal Ysync outputted from the image signal processing unit **27** is supplied to the counter **90** for the counting purpose. The count value of this counter **90** is continuously supplied to the coincidence detecting circuit **91**. The coincidence detecting circuit **91** judges a coincidence between the pixel position data supplied from the head pixel position data memory unit **92** and the count value from the counter **90**, and supplies a coincidence signal when the coincidence is established therebetween. The coincidence signal outputted from the coincidence circuit **91** sets the flip-flop **97** via the AND gate **96**, so that the switching circuit **27** is brought into the ON-state and also the gate circuit **94** is turned OFF as well as the gate circuit **95** is turned ON.

Then, the pixel position data which have been stored in the last pixel position data memory unit **93** is supplied to the coincidence circuit **91**, and the above-described coincidence comparison process of the count value of the counter **90** is carried out therein.

Thereafter, when the count value of the counter **90** is coincident with the pixel position data which has been stored in the last pixel position data memory unit **93**, which is detected by the coincidence detecting circuit **91**, the coincidence detecting circuit **91** again outputs the coincidence signal. The coincidence signal outputted from the coincidence detecting circuit **91** causes the flip-flop **97** via the AND gate **98** to be reset, the switch circuit **29** to be turned OFF, and the AND gate **95** to be turned OFF, and also the AND gate **94** to be turned ON. Then, the pixel position data which have been stored in the head pixel position data memory unit **92** is again supplied to the coincidence detecting circuit **91**. When all of the sync signals Ysync during 1 horizontal scanning period have been outputted, the counter **90** outputs the carry signal, whereby the counted value is reset in response to this carry signal.

As previously described, the photometric area control unit **30** causes the switching circuit **29** to be in the ON-state in response to the pixel position data D which has been previously supplied from the control unit **24**, and also the sync signal Ysync furnished from the image signal processing circuit **27** at a timing when the luminance signal Y corresponding to a photographing area "0" shown in FIG. **6** is output from the image signal processing circuit **27** (see FIG. **8**D).

As previously explained, only the luminance signal "Y" corresponding to the subject which has been designated via the switching circuit **29** by the designation frame **42**, is supplied to the automatic focusing control unit **32**.

The automatic focusing control unit **32** commences the on-focusing condition detecting operation in response to the luminance signal Y in synchronism with the transfer end signal supplied from the transfer control unit **26**. When the off-focusing condition is detected, the automatic focusing control unit **32** outputs the control signal to the motor control unit **18** so as to move the lens **14** along the proper direction. In this case, the transfer control unit **26** repeates the processes defined at the steps A2 to A7.

When, on the other hand, the on-focusing condition is detected by the automatic focusing control unit **32**, an automatic focusing control end signal is output to the control unit **24** by the automatic focusing control unit **32**.

Thereafter, once this automatic focusing control end signal is supplied to the control unit **24**, the automatic exposure control process is commenced.

When the spot photometric mode is designated by operating the mode switch **37**, the luminance signal Y is supplied to the automatic exposure control unit **31** under the control similar to that of the above-described automatic focusing control process.

To the contrary, when the entire photometric mode is designated by operating the mode switch **37**, the control unit **24** furnishes new control data to both the photometric area control unit **30** and transfer control unit **26** in order that the luminance signal Y corresponding to all of the image signals obtained from the image sensor **21** is supplied to the automatic exposure control unit **31**.

Then, the luminance signal Y supplied to the automatic exposure control unit **31** under the either control is furnished to the A/D converting unit **61** of this automatic exposure control unit **31**.

In the A/D converting unit **61**, the above-described luminance signal "Y" is sampled based upon the sync signal Ysync supplied from the image signal processing circuit **27** so as to obtain digital data. This digital data is output from this A/D converting unit **61** to the high speed adding circuit **62**.

The added data obtained from the high speed adding circuit **62** is fetched by the diaphragm/exposure time converting unit **63** in synchronism with the transfer end signal output from the transfer control unit **26**.

It should be noted that the control data corresponding to the designated entire photometric mode or spot photometric mode is supplied from the control unit **24** to the diaphragm/exposure time converting unit **63**.

In the diaphragm/exposure time converting unit **63**, both proper exposure time data and proper diaphragm open degree data are obtained based upon the above-described added data, control data, and furthermore distance data output from the automatic focusing control unit **32**, and are supplied to the exposure time data memory unit **25** and motor control unit **20**, respectively.

The motor control unit **20** drives the diaphragm drive motor **19** in response to the diaphragm open degree data so as to set the proper open degree of the diaphragm **16**.

When the above-described automatic exposure control process is accomplished, the automatic exposure control unit **31** outputs the automatic exposure control end signal to the control unit **24**.

When the second release signal S_2 is output from the release switch **38** after the above-described exposure control process is completed (in case that the second release signal S_2 has been output, at the same time when the exposure control process is completed), the control unit **24** outputs such a control signal that the normal image signal is obtained at the transfer control unit **26**, and also outputs to the image data memory unit **33** another control data F for designating the memory operation. In other words, after the transfer control unit **26** clears the charges of the image sensor **21**, this control unit **26** counts the time based upon the exposure time data which has been stored in the exposure time data memory unit **25**. Then, the transfer control unit **26** sequentially outputs the charges accumulated in the image sensor **21** after the time determined by the above-described exposure time data has passed.

Subsequently, the image signal output from the image sensor **21** is supplied to the image signal processing circuit **27** so as to be converted into the luminance/sync signal (Y+S) and color difference signals (R−Y), (B−Y).

The luminance/sync signal (Y+S) and color difference signals (R−Y) and (B−Y) are then supplied to the image data memory unit **33** and recorded as single still image data in the image data memory unit **33**.

When the image data recorded in the image data memory unit **33** is reproduced, the output mode is set by the mode switch **37** and the release switch **38** is operated.

Once the second release signal S_2 is output from the release switch **38**, the control unit **24** outputs the control data F and G to both the image data memory unit **33** and stored image signal processing unit **34**.

Then, the image data memory unit **33** repeatedly supplies the image data corresponding to a single still image which has been recorded in the image data memory unit **33**, to the stored image signal processing unit **34**. The function of this stored image signal processing unit **34** is to produce an NTSC color TV signal from the image data supplied from the image data memory unit **33**, and delivers the NTSC color TV signal to the image signal output terminal **35**.

Furthermore, when the release switch **38** is operated, the control unit **24** instructs the image data memory unit **33** such that image data with respect to a next still image is output. As stated above, the control unit **24** sequentially updates the output still image every time the release switch **38** is operated.

SECOND AUTOMATIC EXPOSURE CONTROL UNIT

Referring to FIG. **9**, an automatic exposure control unit according to a second preferred embodiment will now be described.

First, the luminance signal Y which is derived from the image signal processing circuit **27** via the switching circuit **29** to the second automatic exposure control unit **110**, is input into an operational amplifier **70**. A voltage V_1 is applied via a resistor **71** to one terminal (i.e., minus terminal) of the operational amplifier **70**. An output from the operational amplifier **70** is input to a base electrode a PNP transistor **72**. The voltage V_1 is applied via the resistor **71** to an emitter of this PNP transistor **72**. A collector of the transistor **72** is connected to a capacitor **73**. Both terminals of this capacitor **72** are connected between an emitter and a collector of an NPN transistor **74**. One junction between one terminal of the capacitor **73** and the emitter of the NPN transistor **74** is grounded, whereas the other junction between the other terminal of the capacitor **73** and the collector thereof is connected to an A/D converting unit **75**. A transfer end signal output from the transfer control unit **26** is supplied to a base electrode of this NPN transistor **74**.

The above-described operational amplifier **70**, resistor **71**, PNP transistor **72**, capacitor **73** and NPN transistor **74** charge the charges corresponding to the luminance signal Y which has been supplied via the switching circuit **29** into the capacitor **73**, and discharge the charges from the capacitor **73** when the transfer end signal is output from the transfer control unit **26**.

That is, at the plus terminal of this capacitor **73**, a voltage is produced which is proportional to a sum of the charges accumulated in the respective photoelectric converting units **50** of the image sensor **21** corresponding to the range designated by the photometric area designation unit **36**.

The function of the A/D converting unit **75** is to obtain digital data corresponding to the voltage value appearing at the plus terminal of the capacitor **73**. This digital data is supplied to a diaphragm/exposure time converting unit **76**.

It should be noted that since the arrangement of this diaphragm/exposure time converting unit **76** is substantially identical to that of the above-described diaphragm/exposure time converting unit **76** represented

in FIG. 3, no further explanation thereof is made in the specification.

In accordance with the second automatic exposure control unit **110** with the above-described arrangement, in response to the luminance signal Y output from the image signal processing circuit **27** via the switching circuit **29**, the voltage proportional to the sum of the luminance of the pixels which have been designated by the photometric area designation unit **36** is produced at the plus terminal of the capacitor **73**. Then, the produced voltage is A/D-converted by the A/D converting unit **75** into the corresponding digital data, both the proper exposure time and proper diaphragm open degree are obtained.

THIRD AUTOMATIC EXPOSURE CONTROL UNIT

In FIG. **10**, there is shown another arrangement of an automatic exposure control unit according to a third preferred embodiment of the invention.

It should be noted that the same reference numerals shown in FIG. **9** will be employed for indicating the same or similar circuit elements shown in FIG. **10**, and no further explanation thereof is made.

Similar to the above-described second automatic exposure control unit **110**, a operational amplifier **70**, a resistor **71**, a PNP transistor **72**, a capacitor **73** and an NPN transistor **74** constitute such an arrangement that charges proportional to luminance of the respective pixels in an image which has been designated by the photometric area designation unit **36**, are charged into the capacitor **73**.

A plus terminal of the capacitor **73** is connected to a minus terminal of a first comparator **80** and also a plus terminal of a second comparator **81**.

On the other hand, to a plus terminal of this first comparator **80**, either a voltage V_2, or V_3 is applied via a switch circuit **82**.

The function of the switch circuit **82** is to select the voltage V_2, or V_3 in response to the designated photometric mode (i.e., spot photometric mode, entire photometric mode) based upon the control signal output from the control unit **24**. That is, the voltage V_2 is set to be greater than V_3, and a selection is made that the voltage V_3 is set when the spot photometric mode is designated, and the voltage V_2 is set when the entire photometric mode is designated.

Either a voltage V_4, or V_5 is applied via a switch circuit **83** to a minus terminal of the second comparator **81**.

The function of this switch circuit **83** is similar to that of the switch circuit **82**. That is, when the proper photometric mode is designated, the voltage V_4 or V_5 is selected in response to the control signal output from the control unit **24**. In other words, the voltage V_4 is set to be greater than the voltage V_5. The first voltage V_4 is selected when the spot photometric mode is designated, whereas the second voltage V_5 is selected when the entire photometric mode is selected.

Also, the voltage V_4 is selected to be larger than the voltage V_2, whereas the voltage V_5 is selected to be greater than the voltage V_3.

The outputs from the first and second comparators **80** and **81** are supplied to a judgment unit **84**. This judgment unit **84** is to output control signals to a diaphragm control unit **85** and an exposure time control unit **86** in response to the outputs derived from the first and second comparators **80** and **81**, control unit **24**, and automatic focusing control unit **22**.

In other words, when the first and second comparators **80** and **81** output both "High" signals, the judgment unit **84** judges that the measured exposure is over the proper value. To the contrary, when "Low" signals are output from the first and second comparators **80** and **81**, the judgment unit **84** judges that the measured exposure is under the proper value.

Based upon the judgment results (i.e., under exposure and over exposure), the judgment unit **84** outputs the control signals to the diaphragm control unit **85** and exposure time control unit **86**. At this time, the judgment unit **84** obtains both diagram open degree information and exposure time information which have been set by the exposure control unit **85** and exposure time control unit **86**, and also obtains information on a distance from the camera to the subject from the automatic focusing control unit **32**. As a result, the judgment unit **84** outputs the control signals to the diaphragm control unit **85** and exposure time control unit **86** in such a manner that the proper open degree is combined with the proper exposure time.

Then, the diaphragm control unit **85** outputs the control signal to the motor control unit **20** in response to the control signal supplied from the judgment unit **84**.

On the other hand, the exposure time control unit **86** obtains the exposure time data based upon the control signal supplied from the judgment unit **84**, and supplies this data to the exposure time data memory unit **25**.

AUTOMATIC EXPOSURE CONTROL

Automatic exposure control operations of the automatic exposure control unit **120** with the above-described arrangements will now be described.

In FIGS. **11A** to **11D**, there are shown time charts for representing output conditions of this automatic exposure control unit **120**.

First, the luminance signal Y which has been supplied via the switch circuit **29** from the image signal processing unit **27**, is furnished via the operational amplifier **70** to the PNP transistor **72**, so that the charges corresponding to the voltage value of this luminance signal "Y" are charged into the capacitor **73**, and therefore the voltage corresponding to the charges appears at the plus terminal of the capacitor **73** (see FIG. **9B**).

On the other hand, both the first and second comparators **80** and **81** output the signal corresponding to the voltage value appearing at the plus terminal of the capacitor **73**, to the judgment unit **84**.

In other words, the first comparator **80** outputs the "High" level signal when the voltage appearing at the plus terminal of the capacitor **73** exceeds the voltage V_2 or V_3 (see FIG. **11D**). The second comparator **81** outputs the "High" level signal when the voltage appearing at the plus terminal of the capacitor **73** exceeds the voltage V_4 or V_5 (see FIG. **11C**).

When both the outputs from the first and second comparators **80** and **81** become high levels, the judgment unit **84** judges that the measured exposure is over the proper exposure value so that the diaphragm **16** is closed, or the exposure time is shortened, or both controls are carried out. These controls are performed by sending the control signal to either the exposure control unit **81**, or exposure time control unit **86**, otherwise both control units **85** and **86**.

To the contrary, when both the outputs from the first and second comparators **80** and **81** become low levels,

the judgment unit **84** judges that the measure exposure is under the proper exposure value. Under this judgment, the judgment unit **84** transfers the control signal to either the diaphragm control unit **85**, or the exposure time control unit **86**, otherwise both control units **85** and **86**, whereby either the diaphragm is opened, or the exposure time is prolonged.

Furthermore, when the high level signal is derived from only the first comparator **80**, the judgment unit **84** judges that the measured exposure is proper, and then outputs the automatic exposure process end signal to the control unit **24**.

What is claimed is

1. A camera apparatus comprising:

optical image forming means for forming an optical image;

image sensing means having a photoelectric converting area comprised of a plurality of frame areas, for producing electric signals in response to said optical image formed by said optical image forming means;

area designating means for designating a desired frame area from said plurality of frame area;

selecting means for selecting from the electric signals produced by the whole electric converting area, electric signals produced by said desired frame area designated by said area designated means; and,

producing means for producing a video signal based on said electric signals produced by said image sensing means and said selecting means.

2. The camera apparatus of claim **1**, further comprising:

on-focusing detecting means for detecting whether or not said optical image formed by said optical image forming means is just focused on said image sensing means, based on said electric signals selected by said selecting means; and,

focusing control means for controlling said optical image forming means based on an on-focusing detecting signal obtained by said on-focusing detecting means, so as to focus said optical image formed by said optical image forming means just on said image sensing means.

3. The camera apparatus of claim **1**, further comprising:

luminous energy determining means for determining a level of a luminous energy of said optical image formed by said optical image forming means, in response to said selected electric signals selected by said selecting means; and,

luminous energy control means for controlling the level of the luminous energy of said optical image formed by said optical image forming means, based on a luminous energy determining signal obtained by said luminous energy determining means, so as to set a predetermined exposure condition.

4. The camera apparatus of claim **3**, further comprising:

diaphragm means for controlling the level of the luminous energy of said optical image; and,

diaphragm control means for controlling said diaphragm means based on said luminous energy determining signal obtained by said luminous energy determining means, so as to set the predetermined exposure condition..

5. The camera apparatus of claim **4**, further comprising:

exposure means for exposing the optical image incident upon said image sensing means for enabling said image sensing means to produce said electric signals; and,

exposure control means for controlling said exposure means, based on said luminous energy determining signal obtained by said luminous energy determining means.

6. The camera apparatus of claim **1**, further comprising:

on-focusing detecting means for detecting whether or not said optical image formed by said optical image forming means is just focused on said image sensing means, based on said electric signals selected by said selecting means;

focusing control means for controlling said optical image forming means based on an on-focusing detecting means obtained by said on-focus detecting means, so as to focus said optical image formed by said optical image forming means just on said image sensing means;

luminous energy determining means for determining a level of a luminous energy of said optical image formed by said optical image forming means, in response to said selected electric signals selected by said selecting means; and,

luminous energy control means for controlling the level of said luminous energy of said optical image formed by said optical image forming means, in response to a determining signal obtained by said determining means, so as to set a predetermined exposure condition.

7. The camera apparatus of claim **1**, further comprising:

viewfinder means for displaying a subject to be formed into said optical image by said optical image forming means and for indicating a part of said subject to be formed into said optical image corresponding to said photoelectric converting area designated by said area designating means.

8. The camera apparatus of claim **7**, wherein said viewfinder means includes display means for indicating said part of said subject to be formed into said optical image corresponding to said photoelectric converting area designated by said area designating means.

9. The camera apparatus of claim **8**, wherein said display means includes a liquid-crystal display device.

10. A method of operating a camera apparatus constructed of image sensing means having a photoelectric converting area comprised of a plurality of frame area, the method comprising the steps of:

forming an optical image;

producing first electric signals in response to said optical image;

designating a desired frame area from said plurality of frame area;

selecting second electric signals produced from said designated desired frame area from the first electric signals;

producing a video signal based on said second electric signals produced by said image sensing means.

11. The method of claim **10**, further comprising the steps of:

detecting whether or not said optical image is just focused on said image sensing means, based on said selected second electric signals; and,

controlling said optical image based on an on-focusing detecting signal obtained by said detecting step,

so as to focus said optical image just on said image sensing means.

12. The method of claim 10, further comprising the steps of:

determining a level of a luminous energy of said optical image, based on said selected second electric signals; and,

controlling said optical image based on a luminous energy level determining signal obtained by said determining step, so as to set a predetermined exposure condition.

13. The method of claim 10, further comprising the steps of:

focus-detecting whether or not said optical image is just focused on said image sensing means, based on said selected second electric signal;

controlling said optical image based on an on-focusing detecting signal obtained by said focus-detecting step, so as to focus said optical image just on said image sensing means;

luminous-determining a level of a luminous energy of said optical image, based on said selected second electric signals; and,

controlling said optical image based on a luminous energy detecting signal obtained by said luminous-detecting step, so as to set a predetermined exposure condition.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 5,051,833

DATED : September 24, 1991

INVENTOR(S) : A. TSUJI

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby **corrected as shown below**:

Column 18, line 30 (claim 6), before "determining",

insert --luminous energy--.

Column 18, line 31 (claim 6), before "determining",

insert --luminous energy--.

Signed and Sealed this

Twenty-seventh Day of April, 1993

Attest:

MICHAEL K. KIRK

Attesting Officer

Acting Commissioner of Patents and Trademarks

United States Patent [19]

Terunuma et al.

[11] **Patent Number: 5,018,832**

[45] **Date of Patent: May 28, 1991**

[54] **DEVICE FOR PREVENTING GENERATION OF HARMFUL LIGHT IN OBJECTIVE LENS ASSEMBLY**

[75] Inventors: **Hiroshi Terunuma**, Ichikawa; **Daiki Tsukahara**, Kawasaki; **Akira Katayama**, Koganei, all of Japan

[73] Assignee: **Nikon Corporation**, Tokyo, Japan

[21] Appl. No.: **429,637**

[22] Filed: **Oct. 31, 1989**

[30] **Foreign Application Priority Data**

Nov. 10, 1988 [JP] Japan ..... 63-146880[U]

[51] **Int. Cl.**[5] **G02B 7/04**; G02B 27/00

[52] **U.S. Cl.** ..... **350/276 SL**; 350/429

[58] **Field of Search** ..... 350/276 R, 276 SL, 167, 350/429, 451

[56] **References Cited**

U.S. PATENT DOCUMENTS

4,885,600 12/1989 Iwasa et al. 350/429

Primary Examiner—Bruce Y. Arnold
Assistant Examiner—Rebecca D. Gass
Attorney, Agent, or Firm—Shapiro and Shapiro

[57] **ABSTRACT**

In an objective lens assembly for an optical instrument comprising inner and outer tube members with outer and inner engaged helicoidal screws, respectively, the normal trapezoidal-section main ridge of the helicoidal screw of the outer tube member is modified to provide one or more wall surfaces that reflect stray light from the object side of the objective lens assembly to prevent such light from reaching the image side of the assembly. The wall surface or surfaces are provided by one or more sub-ridges or grooves at the top of the trapezoidal-section main ridge. Bottom portions between successive elements of the main ridge may be angulated to prevent stray light reflected therefrom from reaching the image end of the assembly.

14 Claims, 4 Drawing Sheets

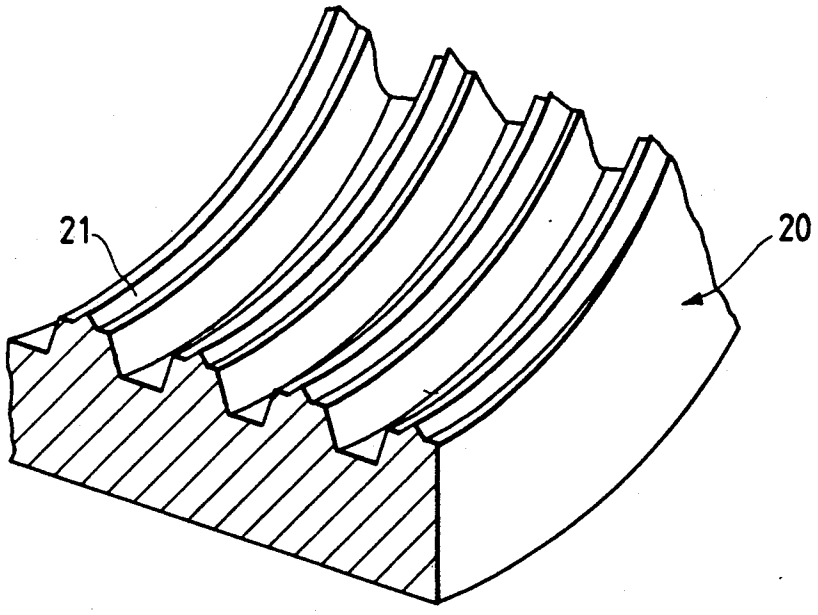


FIG. 1 PRIOR ART

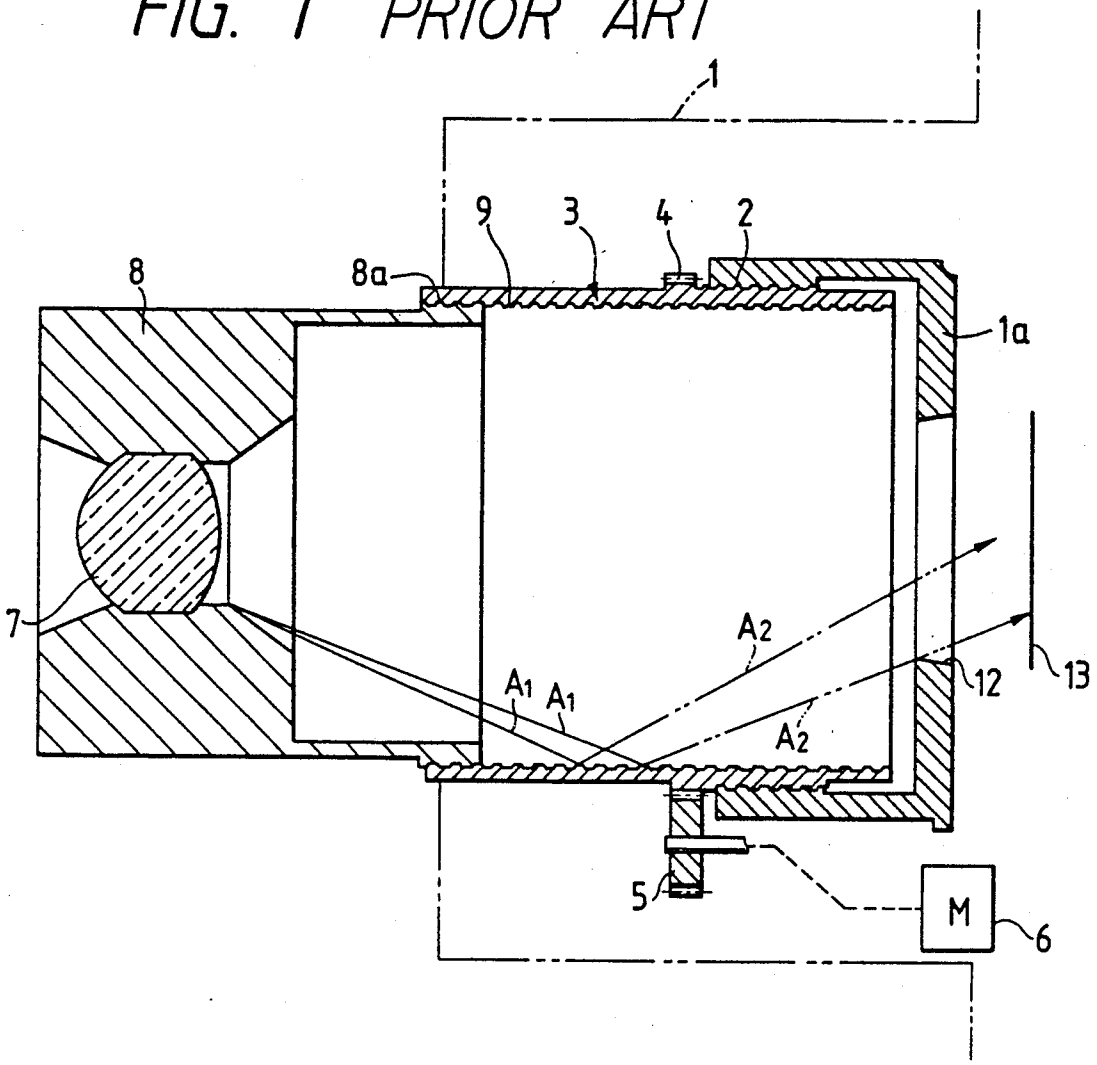


FIG. 2 PRIOR ART

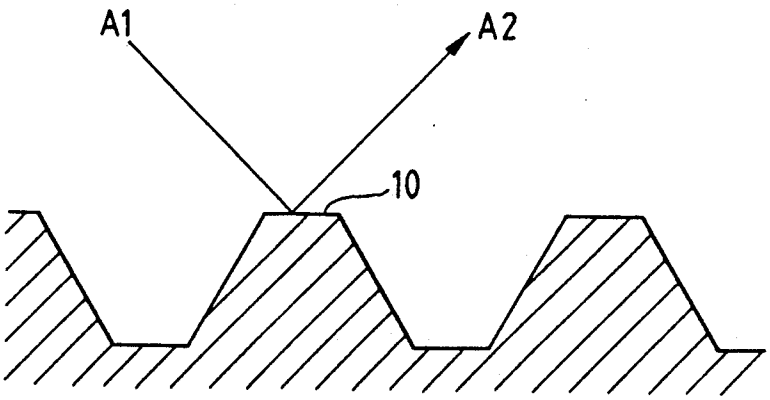


FIG. 3

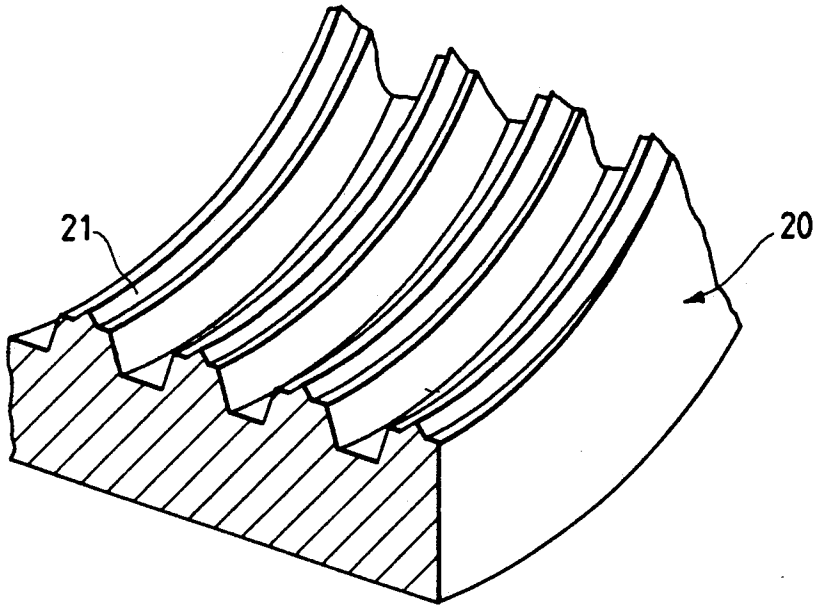


FIG. 4

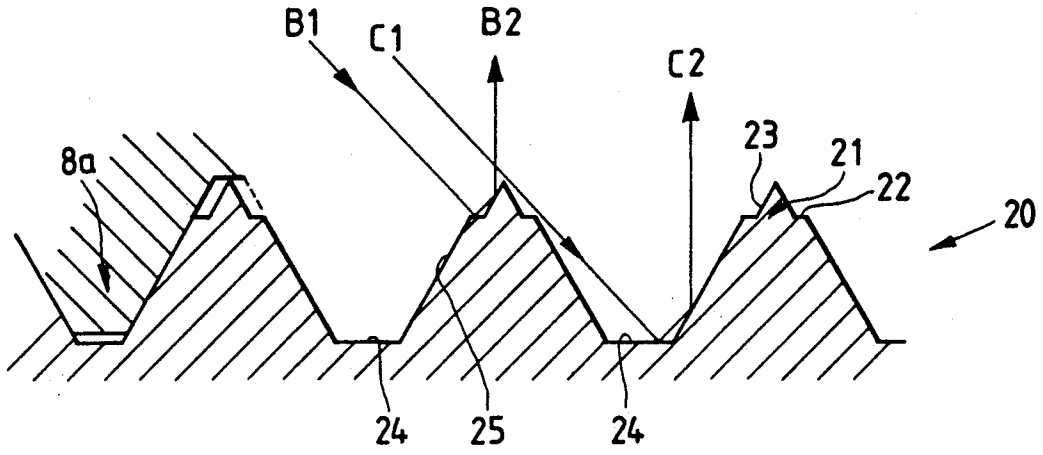


FIG. 5

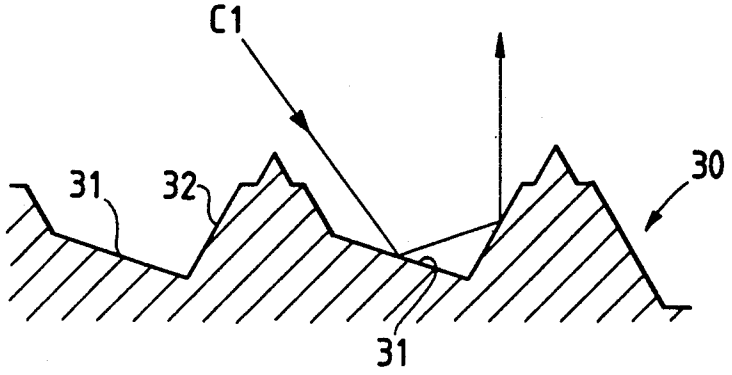


FIG. 6

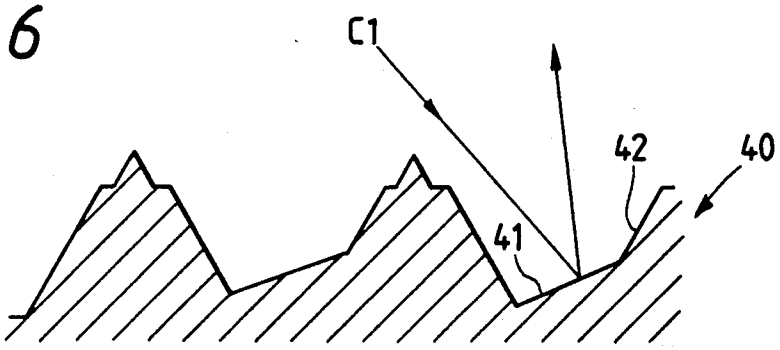


FIG. 7

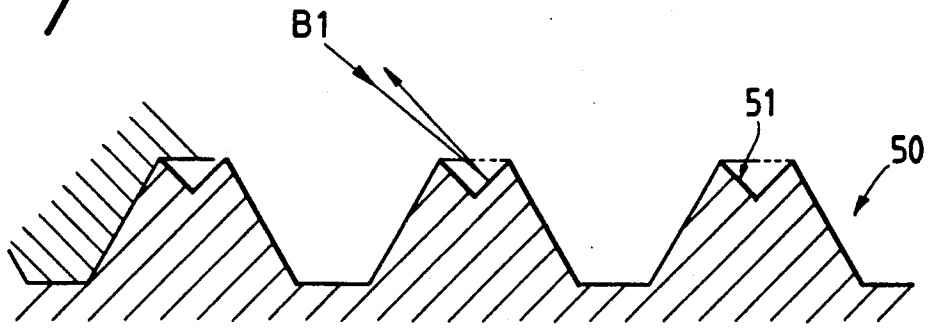


FIG. 8

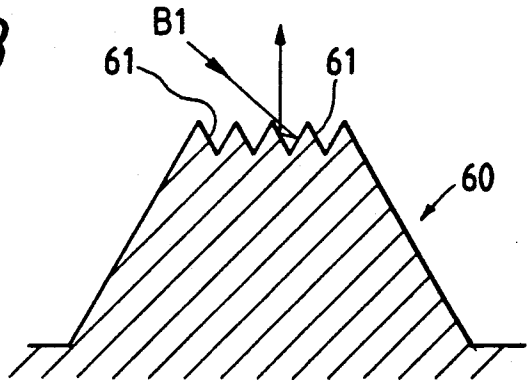


FIG. 9

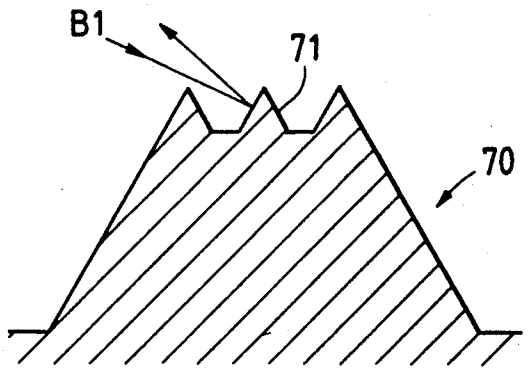


FIG. 10

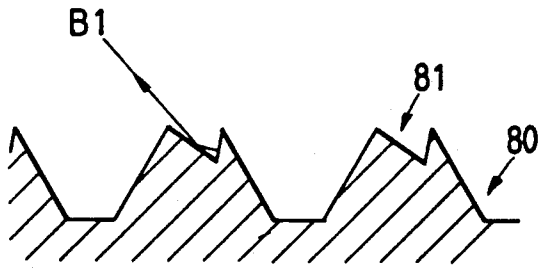
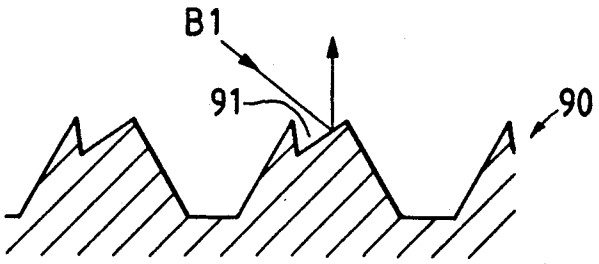


FIG. 11



DEVICE FOR PREVENTING GENERATION OF HARMFUL LIGHT IN OBJECTIVE LENS ASSEMBLY

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a lens assembly for an optical instrument such as a camera. More specifically, the present invention is directed to an improvement in the structure of a helicoidal screw adapted for driving an objective lens in the direction of an optical axis.

2. Related Background Art

In an optical instrument with an objective lens assembly there is often produced the problem of harmful stray light. The stray light generated within the lens tube has various undesirable effects on the performance of the optical instrument.

A typical solution to the problem is to prevent the reflection of light on the inside circumferential surface of the lens tube. For example, in the case of a conventional picture-taking lens assembly comprising a plural lens groups designed for a camera, the inside circumferential surface of the lens tube is usually coated with a light-absorbing black paint. This black coating serves to prevent any scattered stray light from entering the film plane of the camera.

As well-known to those skilled in the art, a lens tube of a conventional camera lens assembly is usually composed of two tubes, namely an inner tube and an outer tube. Lenses are held in the inner tube and moved in a direction along the optical axis for focusing or zooming. To this end, the inner tube is provided with a male helicoidal screw formed on the outside circumferential surface. The male helicoidal screw is in mesh with a female helicoidal screw formed on the inside circumferential surface of the outer tube.

FIG. **1** shows an example of such a structure in a lens assembly for a camera.

Referring to FIG. **1**, a lens tube is composed of an inner tube **8** and an outer tube **3**. The inner tube **8** holds a lens **7** and has a helicoidal screw **8***a* formed on its outside circumferential surface. The outer tube **3** has a helicoidal screw **9** formed on its inside circumferential surface. The helicoidal screws **8***a* and **9** are in mesh with each other to couple the inner tube **8** with the outer tube **3**.

The inner tube **8** is allowed to move in an axial direction only and its rotation relative to the camera body **1** is inhibited by stop means not shown.

The outer tube **3** is engaged in a stationary portion **1***a* of the camera body **1** through a screw **2**. The outer tube **3** has also a gear **4** formed on the outside surface of the tube. The gear **4** is rotationally driven by a driving gear **5** which is in turn driven by a motor **6**.

When the driving gear **5** is driven into rotation by the motor **6**, the outer tube **3** is also rotated through the gear **4**. While rotating, the outer tube **3** moves axially in accordance with the pitch of the screw **2**. As the result, the inner tube **8** is moved together with the lens **7** linearly along the optical axis to attain focusing.

In the above-shown lens assembly, the problem of harmful stray light arises from the fact that the helicoidal screw **9** formed on the inside surface of the outer tube **3** is exposed to a beam of photo-taking light from the lens **7**. As seen in FIG. **1**, a portion of the photo-taking light from the lens **7** runs in a direction away from the optical path of the photo-taking light as represented by a beam A_1. The off-optical path beam A_1 falls on the helicoidal screw **9** and is reflected by it toward a film plane **13**. As stray light, the reflected beam A_2 enters the film and has an undesirable effect.

The effect of the harmful stray light is larger and more significant when the inner tube **8** is moved out toward the object side. This is because the number of exposed ridges of the helicoidal screw **9** is increased when the inner tube **8** is moved out.

FIG. **2** is a section view of a prior art helicoidal screw showing the conventional form of the screw.

As seen from the figure, the sectional form of the prior art helicoidal screw is trapezoidal. The ridge of the screw has a flattened apex **10**. The flat portion **10** tends to reflect the off-optical path beam A_1. The reflected light A_2 passes through an aperture **12** (FIG. **1**) and reaches the image-forming plane or film plane **13**. Thus, the reflected light A_2 constitutes harmful stray light which degrades the image-forming performance of the lens.

SUMMARY OF THE INVENTION

Accordingly, it is an object of the present invention to provide an objective lens assembly provided with means for preventing the generation of harmful light therein.

It is another object of the present invention to provide an improved structure of helicoidal screw which does not reflect off-optical path rays to the image-forming plane side or to the eye side when the screw is exposed to the optical path.

It is a further object of the present invention to provide a camera in which the generation of harmful light is prevented by employing the above-mentioned structure of a helicoidal screw.

These and other objects, features and advantages of the invention will become more apparent from reading the following description.

According to the present invention, in order to prevent the harmful light, a shading wall surface is provided on the top of the main ridge of the helicoidal screw opposed to the optical path of the photo-taking light. The shading wall surface is formed substantially continuously along the spiral of the screw and is disposed facing the object side of the lens.

The wall surface is inclined to reflect stray light coming from the object side of the lens. The inclination angle of the shading wall surface is so determined that the stray light incident on the wall surface may be reflected in a direction substantially orthogonal to the optical axis or in direction somewhat turned toward the object side.

In an embodiment of the present invention, the shading inclined surface is provided by additionally forming a sub-ridge portion on the top of the main ridge of the helicoidal screw. The sub-ridge portion has a triangular section and is formed along the spiral of the helicoidal screw.

In another embodiment of the invention, the shading inclined surface is provided by engraving a groove in the flat top of the conventional helicoidal screw. The groove is formed substantially continuously along the spiral of the screw and in such manner that no flat portion remains on the top of the screw after engraving.

In a further preferred embodiment, the bottom of the helicoidal screw is inclined relative to the inside circumference parallel to the optical axis and is formed as a

conical surface facing the object side and centered on the optical axis or image side.

In the lens tube according to the present invention, it is preferable to form the above-mentioned slant face over all the length of the helicoidal screw. However, it is to be understood that the object of the present invention may be attained, to some extent, by forming such slant face at only a portion of the screw where the harmful stray light is apt to be generated most frequently.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a sectional view of a prior art lens assembly for a picture taking camera;

FIG. **2** is an enlarged sectional view of a portion of a prior art helicoidal screw;

FIG. **3** is an enlarged perspective view of a portion of a helicoidal screw showing a first embodiment of the present invention;

FIG. **4** is an enlarged sectional view of the first embodiment;

FIGS. **5** and **6** are enlarged fragmentary sectional views showing modifications of the first embodiment;

FIG. **7** is an enlarged sectional view of a portion of a helicoidal screw showing a second embodiment of the invention; and

FIGS. **8** to **11** are enlarged fragmentary sectional views showing modified forms of the second embodiment.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

A first embodiment of the present invention is shown in FIGS. **3** and **4** as fragmentary enlarged views of a helicoidal screw of a lens tube.

A helicoidal screw is formed on the inside circumferential surface of the lens tube **2**. The main ridge of the helicoidal screw has a sub-ridge portion **21** formed on the top of the main ridge along the spiral of the screw. The sub-ridge portion **21** has a triangular form in section. The top of the sub-ridge portion is shaped into a sharp edge.

The function of the sub-ridge portion will be seen best from FIG. **4**. A light beam B_1 coming from a lens **7** (FIG. **1**) and running away from the optical path of the lens impinges on the flat top **22** of the main ridge and is reflected by the latter. The reflected light runs first toward the film plane. But, it is then reflected by a slant face **23** of the sub-ridge portion **21**. This reflected light beam B_2 runs upwardly in the plane of the drawing and does not enter the film plane.

Another off-optical path light beam C_1 falls upon the bottom **24** of the screw and is reflected by it. The reflected light is again reflected by a slant face **25** of the main ridge and then runs upwardly as the reflected beam C_2 in the plane of the drawing.

It is most desirable to make the reflected light beams B_2 and C_2 run in a direction normal to the optical axis or in a direction rather inclined toward a object side from the plane normal to the optical axis. However, such direction of reflection is not always necessary for the construction of the present invention. Since, as previously mentioned, the surface of the helicoidal screw is coated with light-absorbing black paint, almost all of the reflected rays B_2 and C_2 may be absorbed after several reflections within the lens tube. Therefore, the inclination angle of the slant faces **23** and **25** is not critical. The slant faces may also have an inclination angle by which the reflected rays B_2 and C_2 run in a direction somewhat inclined toward the image side providing that the reflected rays B_2 and C_2 never run into the film plane directly.

In the shown embodiment, the top end of the sub-ridge portion **21** is shaped into a sharp triangular edge. Though such sharp edge is preferable, the shape of the top end of the sub-ridge portion **21** is not limited to triangular form only. Another form such as semicircular also may be selected for the top end of the sub-ridge portion without reducing the effect for the prevention of harmful light too much.

Referring to FIG. **4**, the male helicoidal screw **8***a* of the inner tube **8** is engaged with the female helicoidal screw of the lens tube **20**. The bottom of the male screw **8***a* is not required to have a particular shape. It may have any conventional form. The thing required for the bottom of the male helicoidal screw **8***a* is only that it should have a sufficient depth so as not to be touched by the sub-ridge portion **21**.

In view of the need to reflect the incident light C_1 as described above, the ridge of the screw should be as high as possible. However, in practice, we must take into consideration a case where the height of the ridge of the screw is small for the pitch of the screw.

In this case, it is advisable to dispose the bottom of the screw inclined relative to the optical axis as shown in FIGS. **5** and **6**.

In a lens tube **30** shown in FIG. **5**, which is a modification of the first embodiment, the bottom of the helicoidal screw is formed by an inclined surface facing the image side or view-finder side. The beam C_1 falling on the bottom **31** is reflected in a direction of a relatively obtuse angle and impinges upon a slant face **32** of the main ridge. Again, the slant face **32** reflects the beam C_1 upwardly in the plane of the drawing.

In a lens tube **40** shown in FIG. **6**, which is a second modification of the first embodiment, the bottom **41** of the screw is formed by an inclined surface facing the object side in contrast with the first modification shown in FIG. **5**. In this second modification, the incident light C_1 is reflected by the bottom **41** not in a direction toward the slant face **42** but in a direction somewhat toward the object side or upwardly in the plane of the drawing.

The first embodiment described above is featured by the sub-ridge portion additionally formed on the flat top of the original ridge of a helicoidal screw.

A second embodiment of the invention shown in FIG. **7** is featured by a groove formed on the flat top of the original ridge of a helicoidal screw. The groove is formed by cutting out the flat top along the spiral of the screw in such manner that no flat portion is left after engraving.

More specifically, in the lens tube **50** shown in FIG. **7**, the helicoidal screw has a groove **51**. The groove has a V-shaped cross section. It is formed by cutting out the original flat portion at the top of the ridge of the screw. After engraving the V-shaped groove **51**, no original flat portion is left as such.

In this embodiment, the beam of light B_1 incident upon the top of the ridge is reflected back by a slant face of the V-shaped groove **51**. The direction of reflection can be controlled by suitably selecting the depth of the V-shaped groove **51**. Therefore, it is possible to reflect the incident beam B_1 in a direction much more deflected toward the object side.

The second embodiment has a particular advantage in that the height of the ridge of the helicoidal screw can be reduced as compared with the first embodiment in which a sub-ridge portion has been formed additionally on the top of the original ridge (main ridge). According to the second embodiment, therefore, one can reduce the size of the total structure of the helicoidal screw without substantially reducing the effect of the present invention for preventing harmful light. Further, this enables to realization a smaller lens tube than the prior art.

FIGS. **8** to **11** illustrate various modifications of the second embodiment.

In the modification shown in FIG. **8**, the helicoidal screw in a lens tube **60** has a plurality of V-shaped grooves **61** formed on the top of the ridge. A beam of incident light B_1 is reflected first by a slant face of one of the V-shaped grooves **61** and then reflected by an opposite slant face of the groove. Finally, the beam runs upwardly in the plane of the drawing.

In the second modification shown in FIG. **9**, the helicoidal screw in a lens tube **70** also has V-shaped grooves **71**. But, the distance between the grooves is longer than that in the first modification. In this second modification, therefore, because of the longer distance between the V-shaped grooves **71**, the beam B_1 is reflected in the direction toward the object side directly by a slant face of the first groove without being directed to an opposite face of the groove.

In further modifications shown in FIGS. **10** and **11**, each the V-shaped is formed by two slopes having different inclination angles.

More specifically, referring to FIG. **10**, each of the V-shaped grooves **81** in the lens tube **80** is formed by two slant faces having different inclinations. The inclination of the slant face on the image side is far sharper than that on the object side. In this modification, the incident beam B_1 is reflected three times between the two slant surfaces of the V-shaped groove **81**. Finally, the beam B_1 runs back toward the object side along approximately the same optical path as the incident beam. During the repeated reflections in the V-shaped groove **81**, the incident light B_1 is markedly attenuated. Thus, the effect for eliminating harmful light can be further increased by employing this modification.

Referring to FIG. **11**, the V-shaped groove **91** in the lens tube **90** also has two differently inclined slopes. But, in this embodiment, the slant face on the image side is more gently sloped than that on the object side so that the incident beam B_1 may be reflected upwardly in the plane of the drawing.

In the second embodiment where a plural number of grooves are engraved in the top of the ridge of a helicoidal screw, it is not always necessary to arrange the grooves at a constant pitch along the optical axis. In addition, the grooves may have different sectional shapes from each other. The grooves can be formed in a very simple manner.

For example, man can form such grooves by rotating a lens tube with a helicoidal screw preformed in a conventional shape as shown in FIG. **2** about the optical axis and scratching the flat top surface of the ridge with a rough sand-paper or the like thereby forming a plurality of scratched lines along the spiral of the ridge of the helicoidal screw.

We claim:

1. An objective lines assembly for an optical instrument, comprising:

an inner tube member surrounding an optical axis;

an outer tube member surrounding said inner tube member;

a helicoidal screw formed on the outside circumferential surface of said inner tube member;

a helicoidal screw formed on the inside circumferential surface of said outer tube member and engaged with the helicoidal screw on the inner tube member;

said helicoidal screws of said inner tube member and said outer tube member having each a main ridge of a trapezoidal form in section, respectively; and

means for forming a wall surface facing an object side of said objective lens assembly, said wall surface being formed at the top of the trapezoidal-section main ridge of the outer tube member and along the spiral of said screw, said wall surface being angulated relative to said optical axis so as substantially to prevent light incident on said wall surface from said object side of said objective lens assembly from reaching an image side of said objective lens assembly.

2. An objective lens assembly according to claim **1**, wherein said wall surface is provided continuously substantially the length of the spiral of said screw.

3. An objective lens assembly according to claim **1**, wherein said means for forming a wall surface comprises a sub-ridge portion formed along the spiral of said screw and on the top of the main ridge of the helicoidal screw on said outer tube member, and a side surface of said sub-ridge portion constitutes the wall surface.

4. An objective lens assembly according to claim **3**, wherein said sub-ridge portion has a triangular form in section and has a ridge-line along the spiral of said screw.

5. An objective lens assembly according to claim **1**, wherein said means for forming a wall surface comprises a plurality of sub-ridge portions formed in parallel with each other along the spiral of said screw and on the top of the main ridge of the helicoidal screw on said outer tube member, and side surfaces of the respective sub-ridge portions constitute the wall surface.

6. An objective lens assembly according to claim **1**, wherein a bottom portion of the helicoidal screw on said outer tube member is formed by a conical surface centered on the optical axis.

7. An objective lens assembly according to claim **1**, wherein said means for forming a wall surface comprises at least one groove formed in the top of the main ridge of the helicoidal screw of said outer tube member and along a spiral of said screw, and the side surface of the groove constitutes the wall surface.

8. An objective lens assembly according to claim **7**, wherein said at least one groove is formed by cutting out a flat top of the main ridge of said helicoidal screw in such manner that no flat portion remains on the top of the main ridge.

9. An objective lens assembly according to claim **7**, wherein said at least one groove has a substantially V-shaped sectional form.

10. An objective lens assembly according to claim **1**, wherein said means for forming a wall surface comprises a plurality of grooves formed in the top of the main ridge of the helicoidal screw of said outer tube member and along the spiral of said screw, and side surfaces of the grooves constitute the wall surfaces respectively.

11. A lens assembly for a camera with a picture-taking lens system for forming an image of an object on an image-forming plane comprising:

an inner tube member surrounding an optical axis;

an outer tube member surrounding said inner tube member;

a helicoidal screw formed on the outside circumferential surface of said inner tube member;

a helicoidal screw formed on the inside circumferential surface of said outer tube member and engaged with the helicoidal screw on the inner tube member, said helicoidal screws of the outer tube member being partly exposed to a picture-taking optical path extending between the picture-taking lens system and the image-forming plane when the inner tube member is moved relatively to the outer tube member, and each of said helicoidal screws of the inner and outer tube members has a main ridge which is approximately trapezoidal in section; and

shade means providing a wall surface at the top of the approximately trapezoidal-section main ridge of the helicoidal screw of the outer tube member, said wall surface being angulated relative to the optical axis so as substantially to prevent light incident thereon from the picture-taking lens system from reaching the image-forming plane.

12. A lens assembly according to claim 11, wherein said wall surface is formed continuously and over substantially the length of the spiral of said screw.

13. A lens assembly according to claim 11, wherein said wall surface is a surface of a sub-ridge portion on top of said main ridge.

14. A lens assembly according to claim 11, wherein said wall surface is a surface of a groove in the top of said main ridge.

* * * * *

United States Patent [19]

Matsuda et al.

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[45] **Date of Patent: Sep. 25, 1990**

[54] **CONTROL DEVICE FOR USE IN A CAMERA HAVING AN OBJECTIVE LENS**

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[73] Assignee: **Minolta Camera Kabushiki Kaisha,** Osaka, Japan

[21] Appl. No.: **443,841**

[22] Filed: **Dec. 4, 1989**

Related U.S. Application Data

[60] Continuation of Ser. No. 267,550, Nov. 7, 1988, abandoned, which is a division of Ser. No. 43,616, Apr. 28, 1987, Pat. No. 4,800,409.

[30] **Foreign Application Priority Data**

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Jul. 16, 1986	[JP]	Japan	61-167466
Jul. 16, 1986	[JP]	Japan	61-167467
Jul. 16, 1986	[JP]	Japan	61-167468
Jul. 16, 1986	[JP]	Japan	61-167470

[51] **Int. Cl.**[5] **G03B 3/00;** G03B 7/095; G03B 7/16; G03B 15/03

[52] **U.S. Cl.** **354/400;** 354/421; 354/423; 354/432; 354/414

[58] **Field of Search** 354/414, 419–423, 354/429–433, 400, 402, 137

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Primary Examiner—W. B. Perkey

Attorney, Agent, or Firm—Burns, Doane, Swecker & Mathis

[57] **ABSTRACT**

The present invention can be applied to a control device wherein the probability of giving the proper exposure to the primary object photographed is high even when the regions to be found in range within the photographing distance are plural, thereby to being capable of more positively judging the backlight condition, an automatic focus adjusting apparatus capable of more reflecting the photographing intention of the photographer, an exposure control apparatus capable of normally providing the proper exposure amount with respect to the photographed object independently of the distance to the object photographed even when the daylight synchronized flash photographing operation is performed, and a control device which does not need a switching circuit and the switching operation by it.

3 Claims, 17 Drawing Sheets

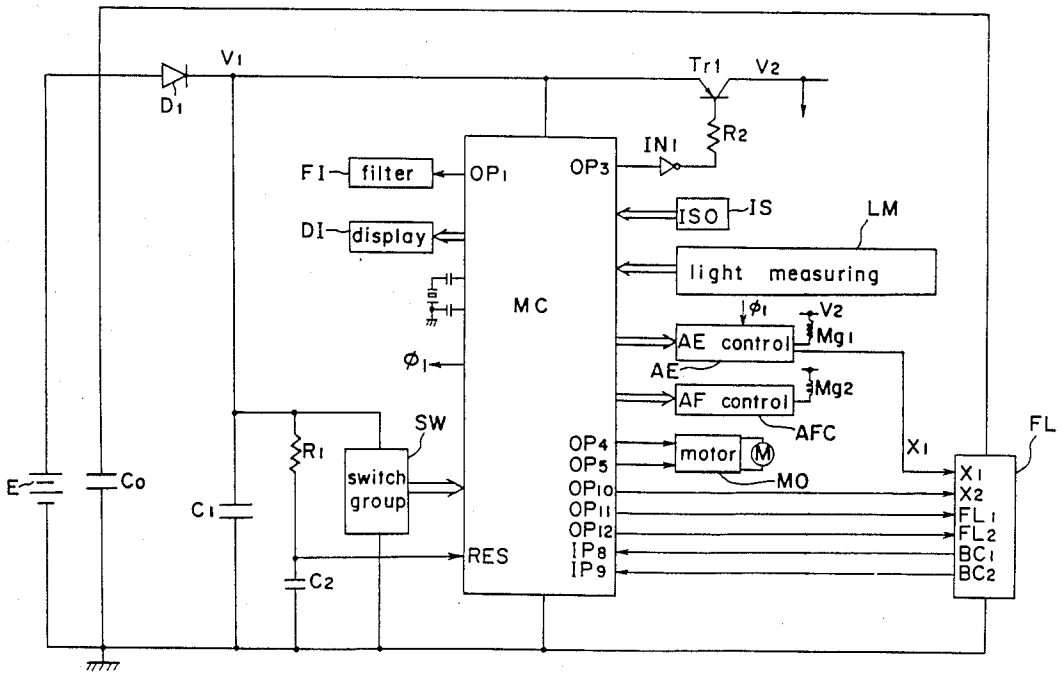

Fig. 1

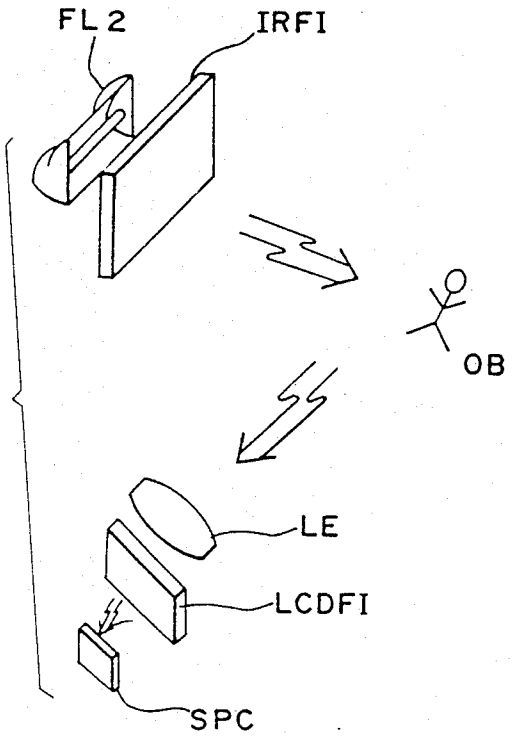

Fig. 3

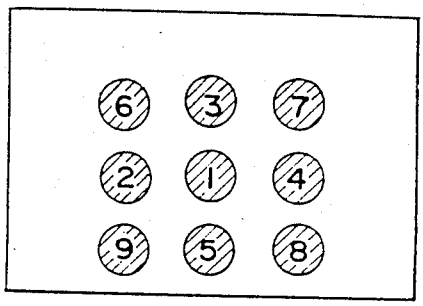

Fig. 2

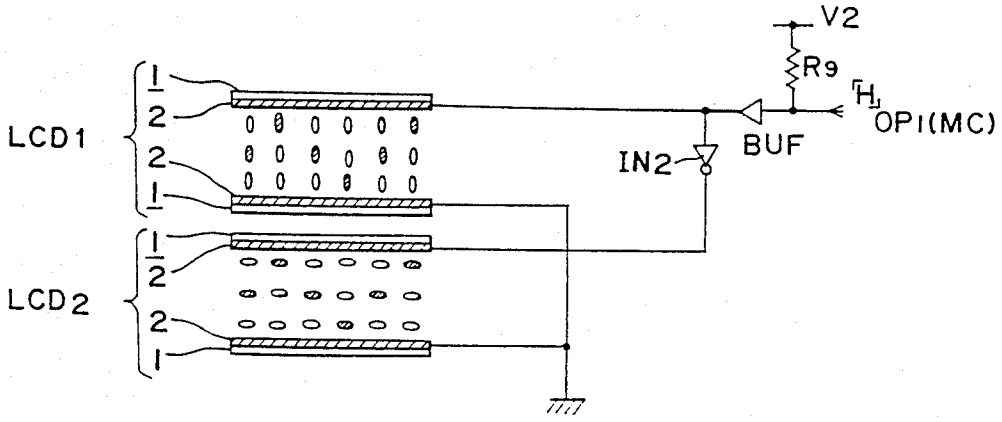

Fig. 4

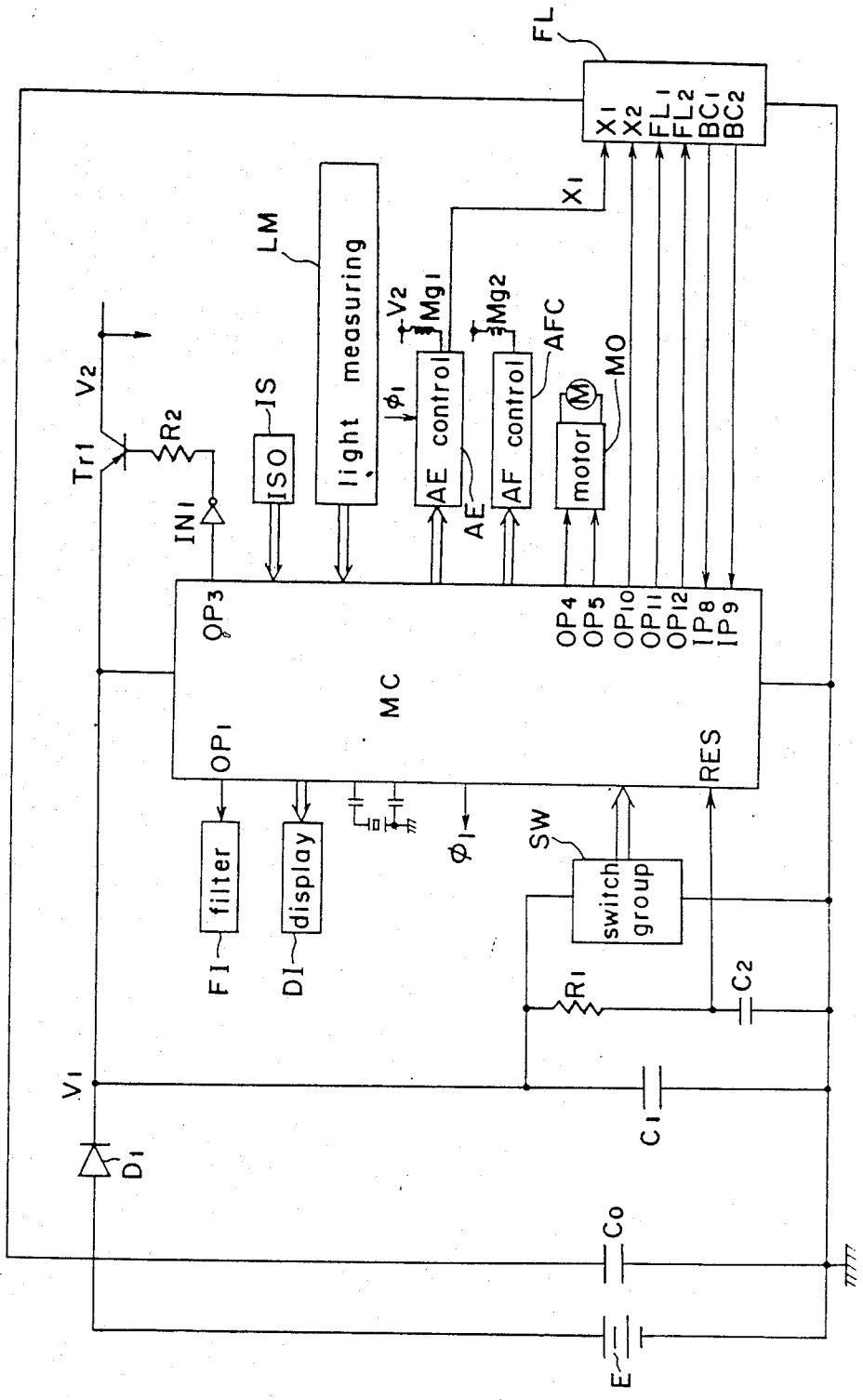
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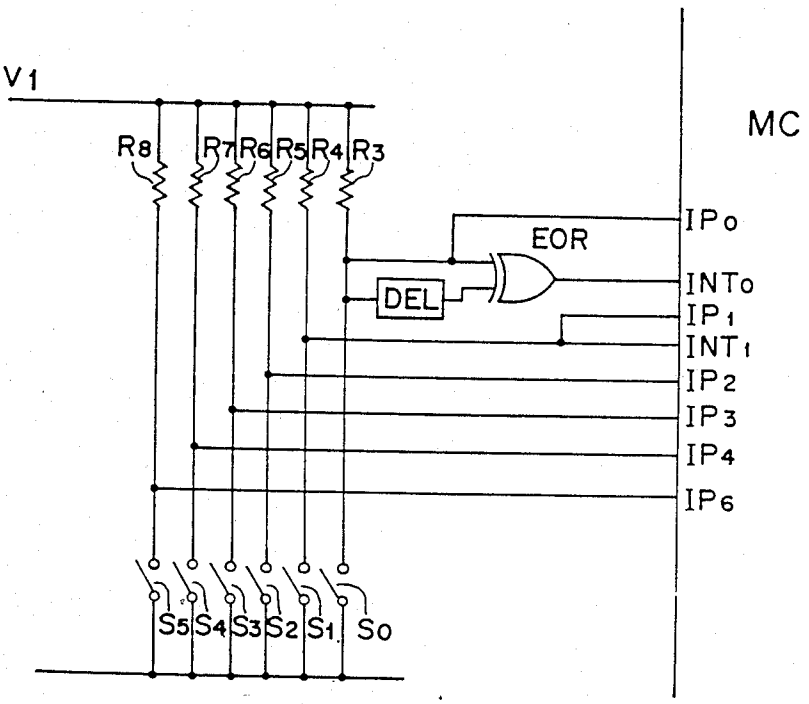
Fig. 5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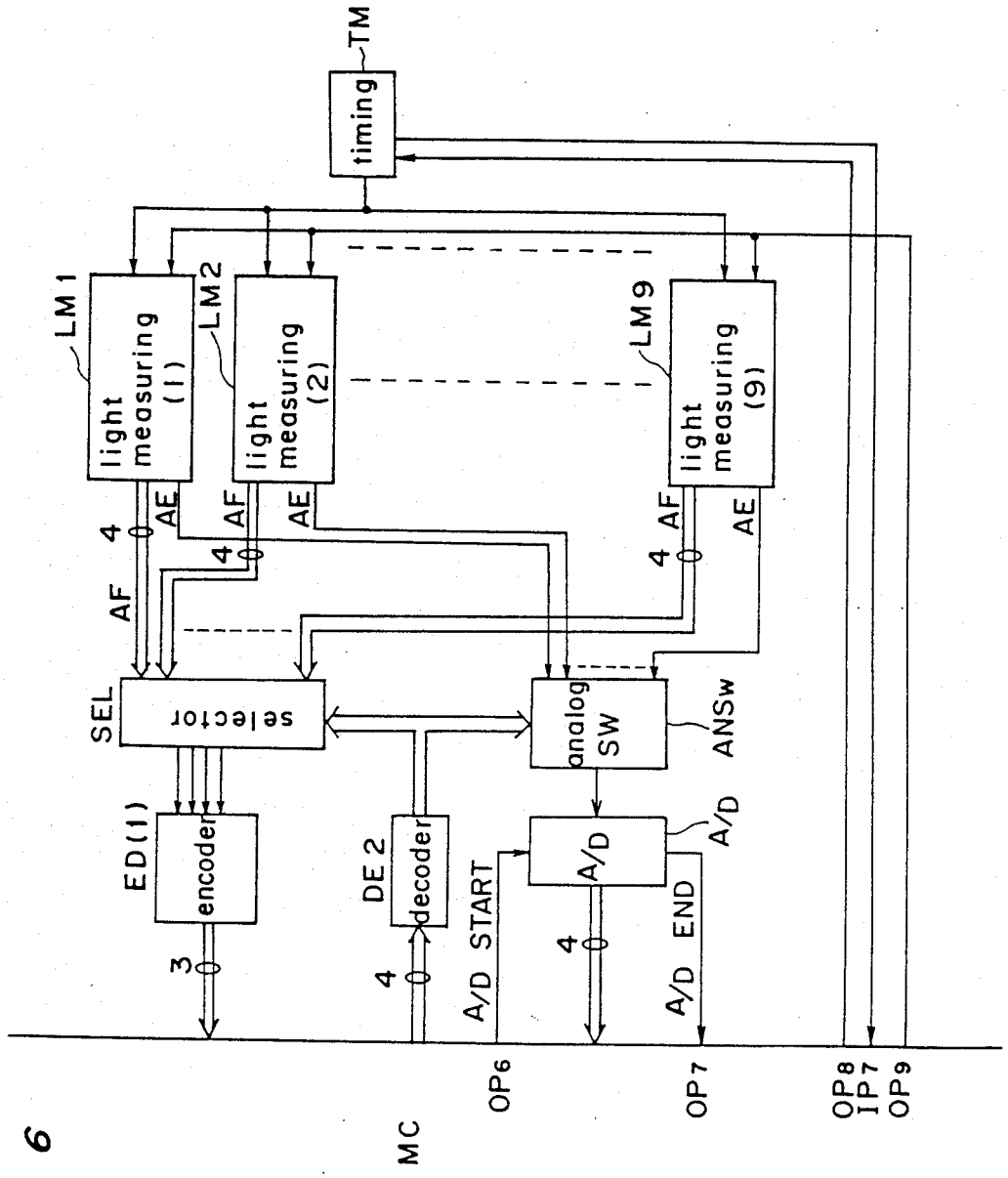
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LM2
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LM 9
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ANSw
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4
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OP7
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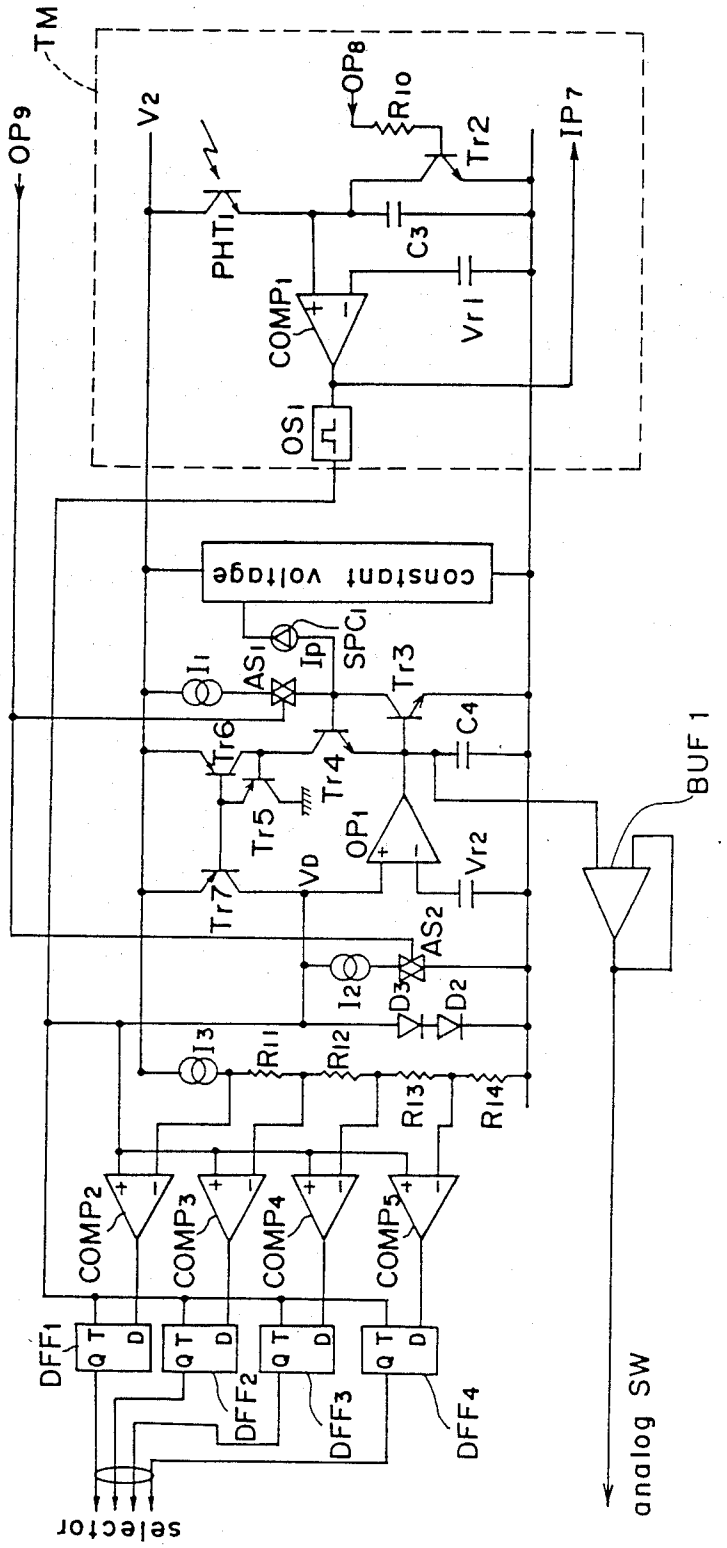
OP9

Fig. 6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Tr4
Tr5
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D3
D2
I3
R11
R12
R13
R14
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COMP3
COMP4
COMP5
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DFF2
DFF3
DFF4
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analog SW

Fig. 7

Fig. 8

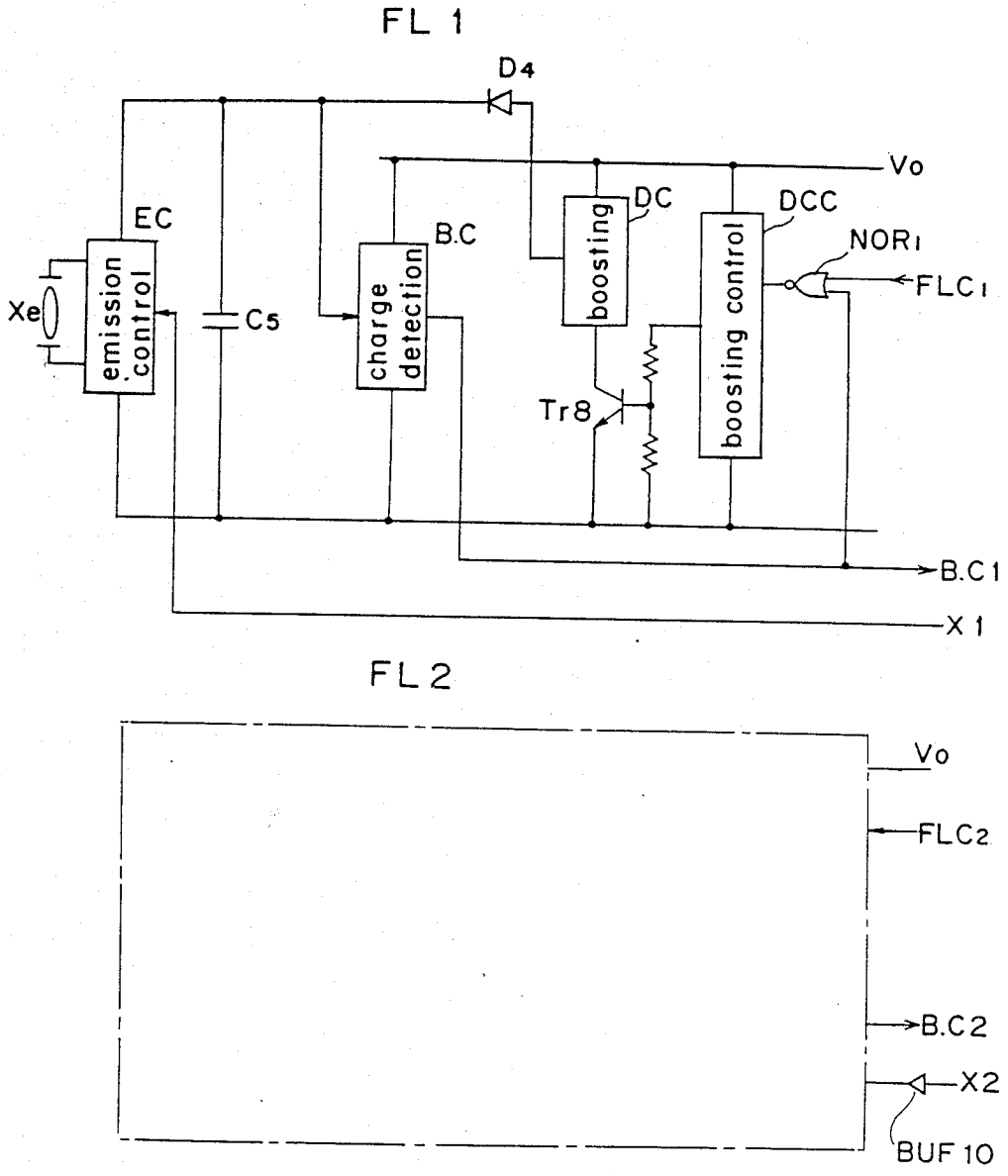
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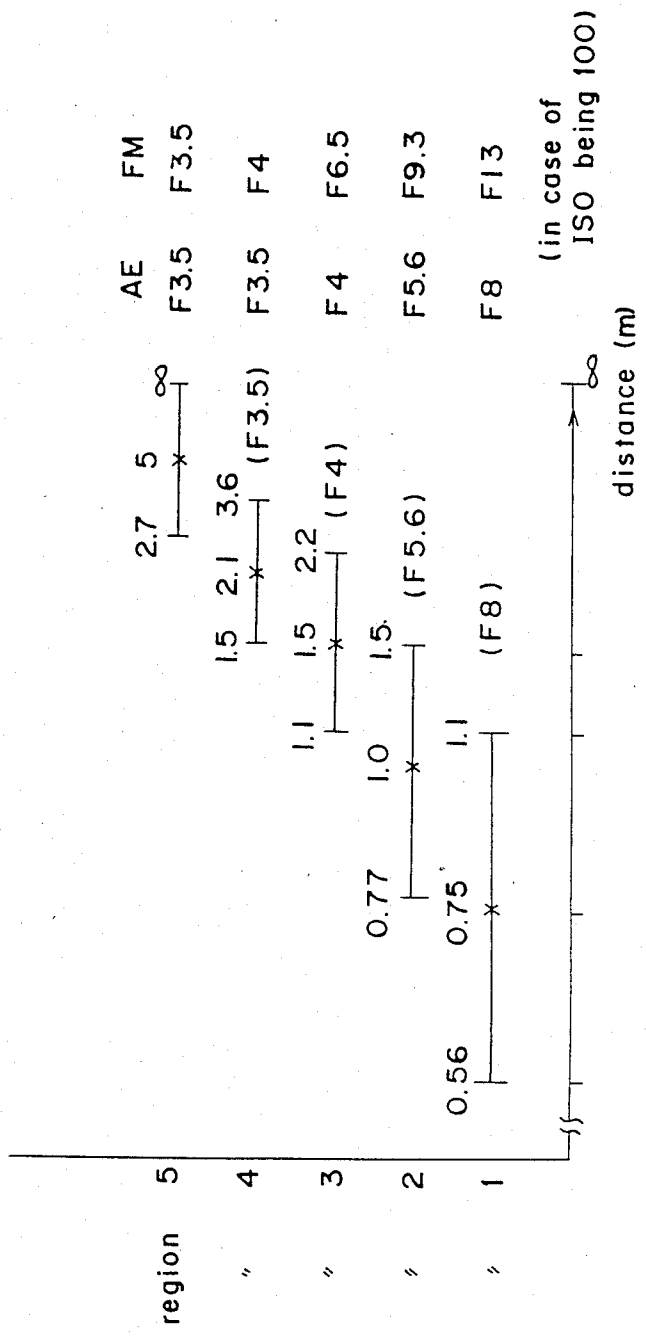
Fig. 9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3
2
1
2.7 5
1.5 2.1 3.6
1.1 1.5 2.2
0.77 1.0 1.5
0.56 0.75 1.1
(F3.5)
(F4)
(F5.6)
(F8)

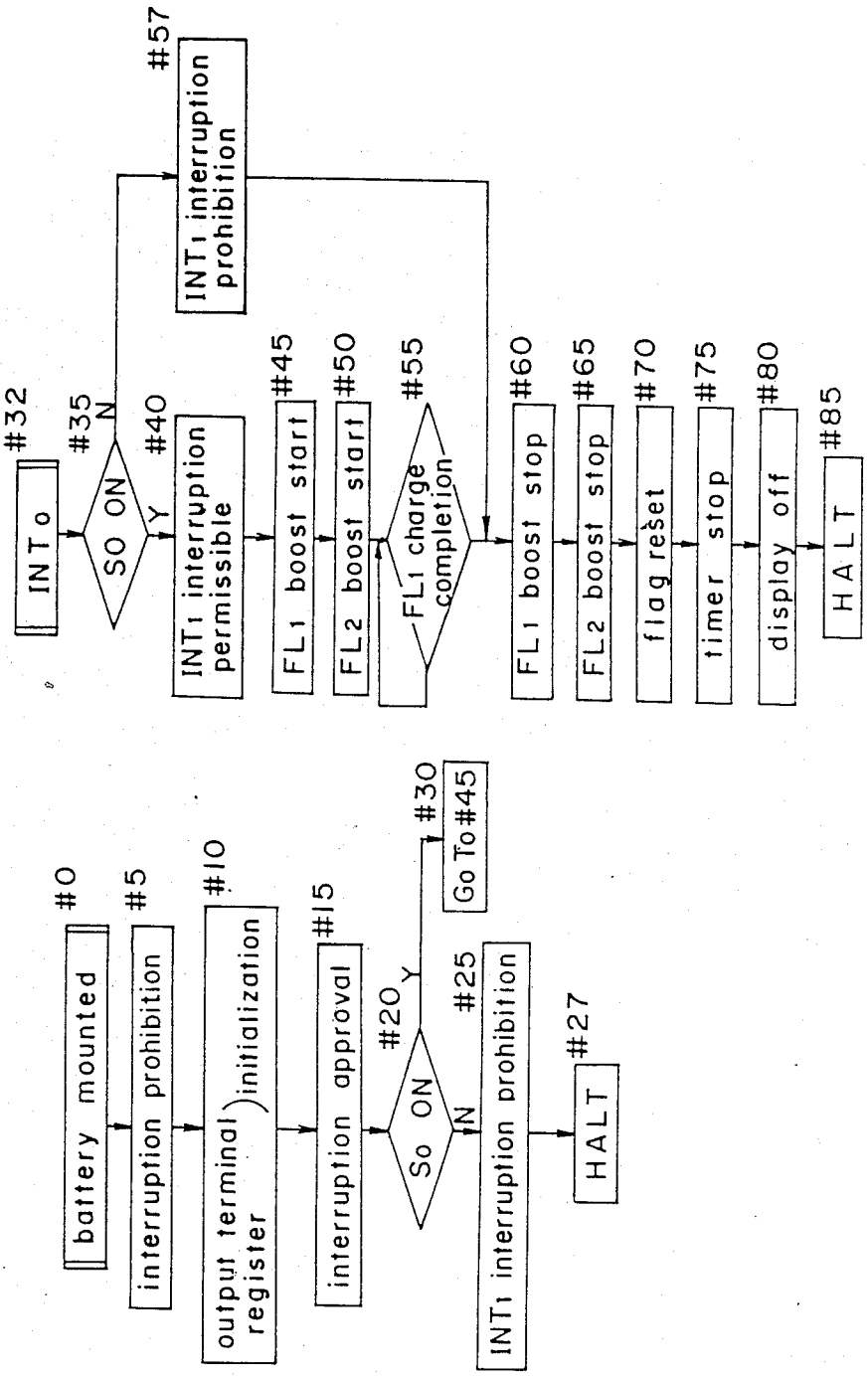

#0
battery mounted
#5
interruption prohibition
#10
output terminal register initialization
#15
interruption approval
#20
So ON
Y
#30
Go To #45
N
#25
INT1 interruption prohibition
#27
HALT
#32
INT0
#35
SO ON
N
#57
INT1 interruption prohibition
Y
#40
INT1 interruption permissible
#45
FL1 boost start
#50
FL2 boost start
#55
FL1 charge completion
#60
FL1 boost stop
#65
FL2 boost stop
#70
flag reset
#75
timer stop
#80
display off
#85
HALT

Fig. 10

Fig. 11(a)

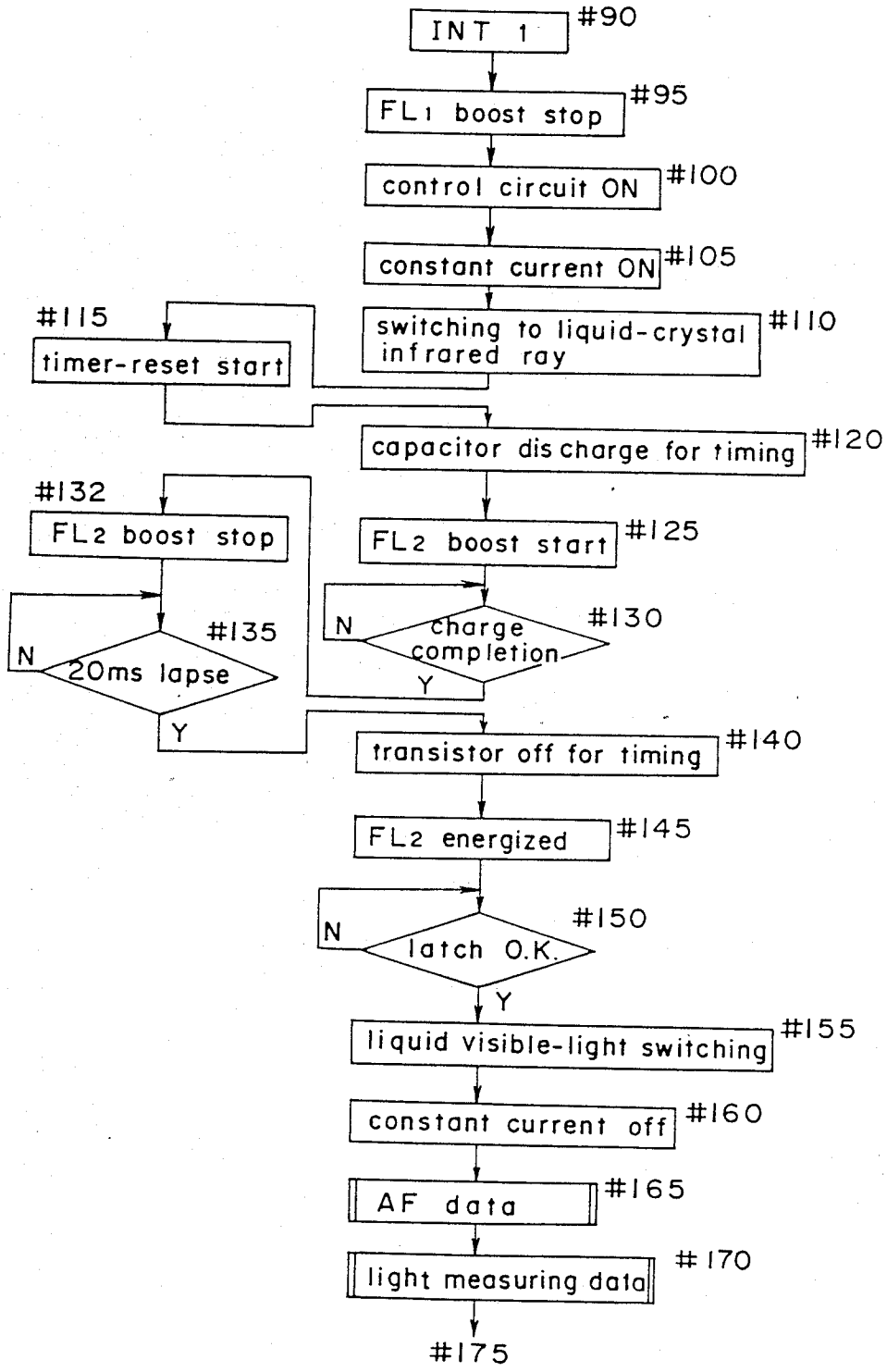

INT 1
#90
FL1 boost stop
#95
control circuit ON
#100
constant current ON
#105
switching to liquid-crystal infrared ray
#110
#115
timer-reset start
capacitor discharge for timing
#120
#132
FL2 boost stop
FL2 boost start
#125
N
charge completion
#130
Y
#135
N
20ms lapse
Y
transistor off for timing
#140
FL2 energized
#145
N
latch O.K.
#150
Y
liquid visible-light switching
#155
constant current off
#160
AF data
#165
light measuring data
#170
#175

Fig. 11(b)

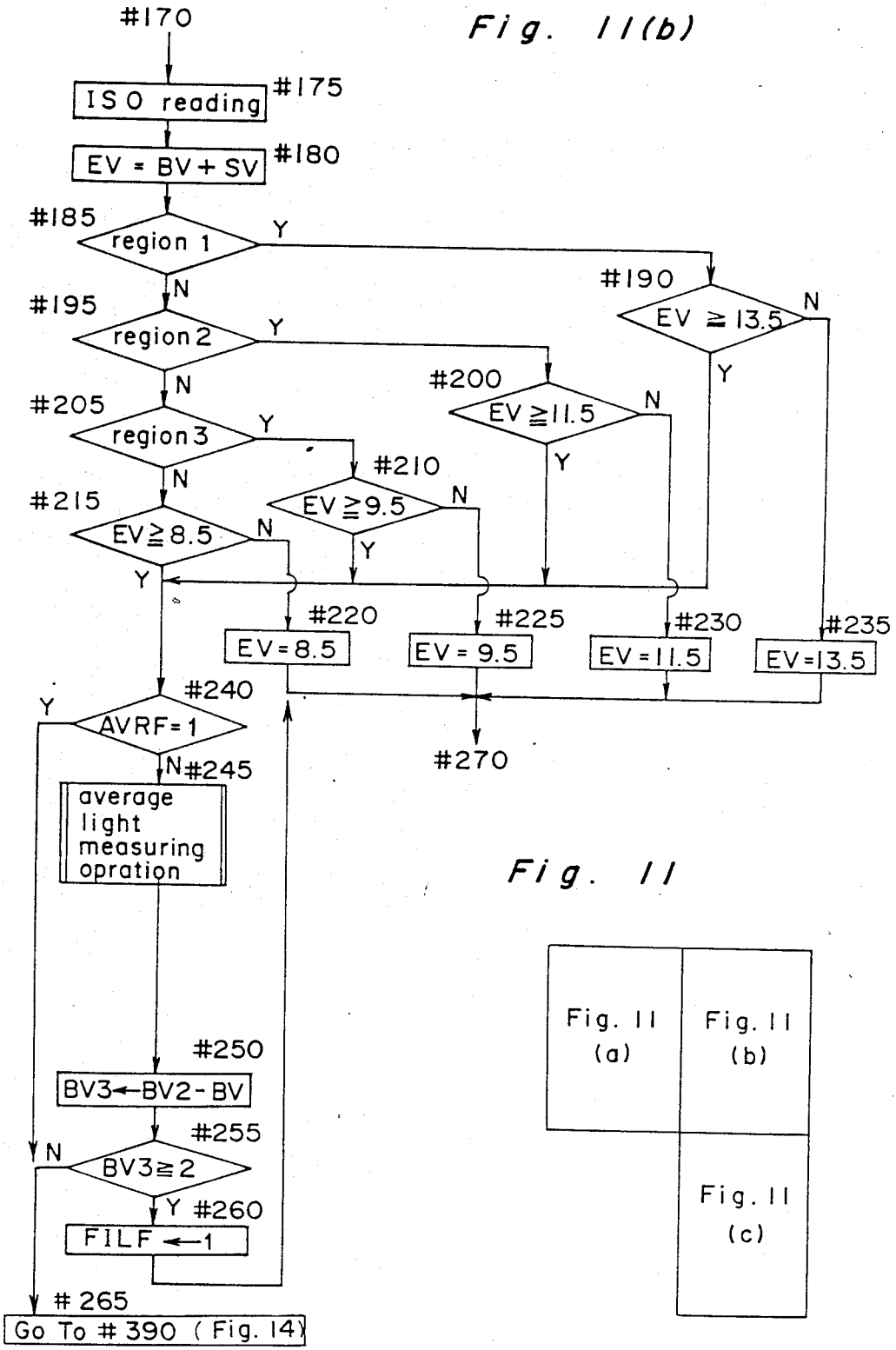


Fig. 11

Fig. 11(c)

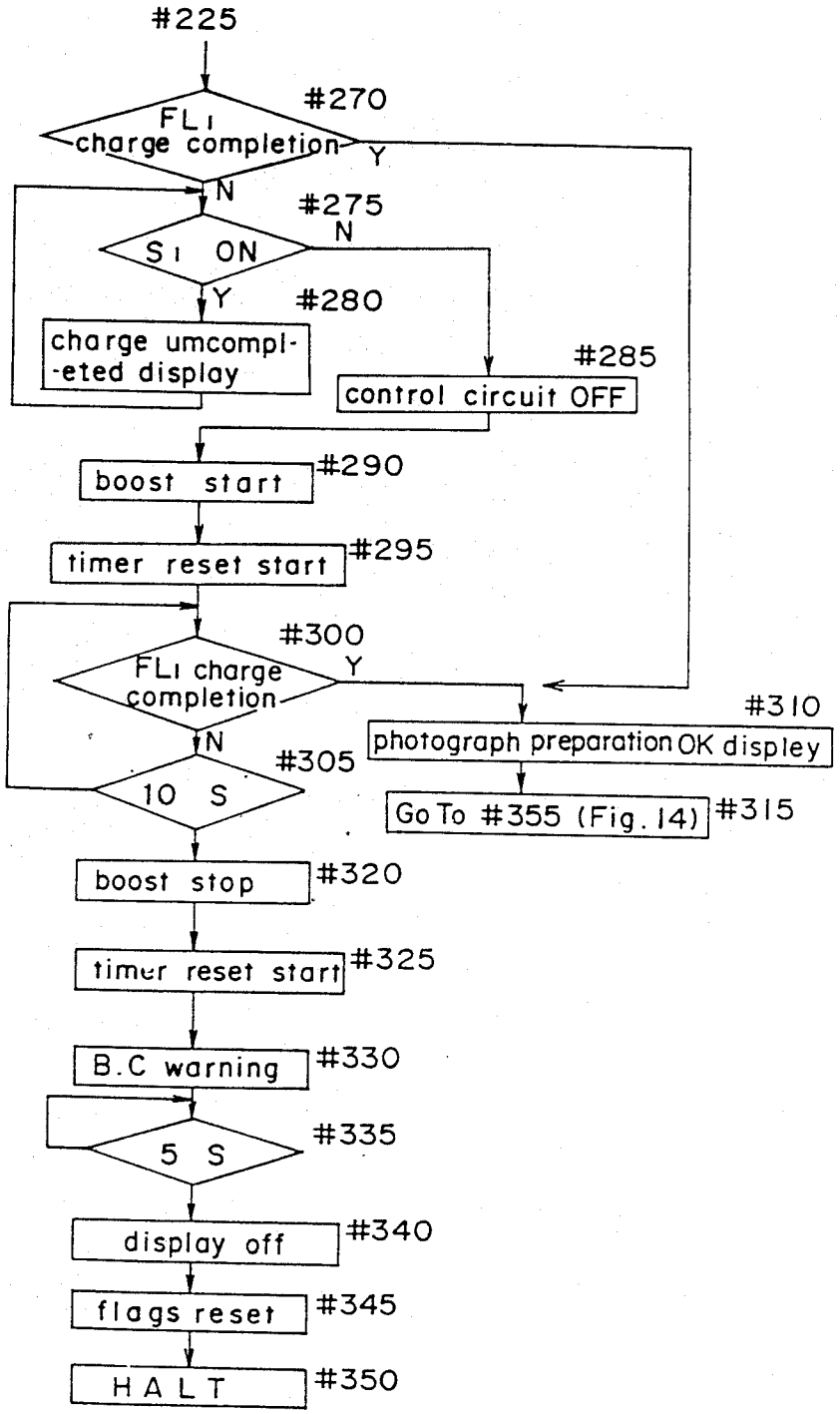

#225
#270
FL1 charge completion
Y
N
#275
S1 ON
N
Y
#280
charge umcompl--eted display
#285
control circuit OFF
boost start
#290
timer reset start
#295
#300
FL1 charge completion
Y
N
#305
10 S
#310
photograph preparation OK displey
Go To #355 (Fig. 14)
#315
boost stop
#320
timer reset start
#325
B.C warning
#330
5 S
#335
display off
#340
flags reset
#345
HALT
#350

Fig. 12(b)

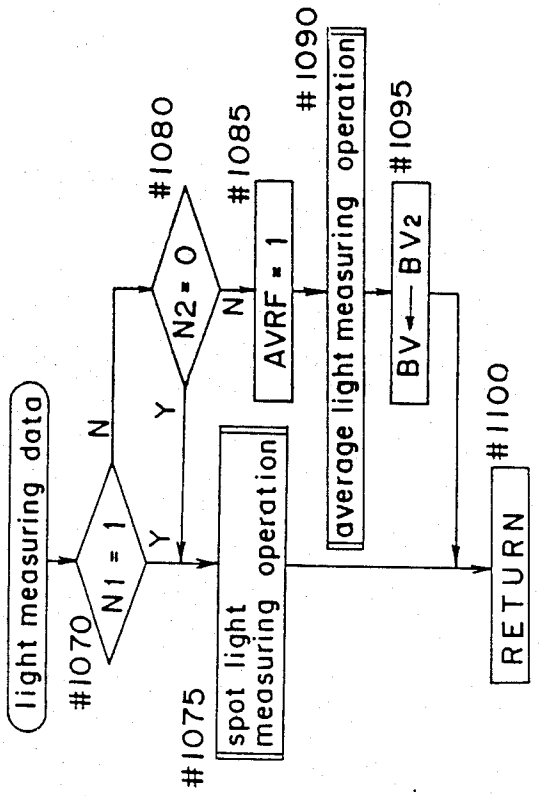


Fig. 12(a)

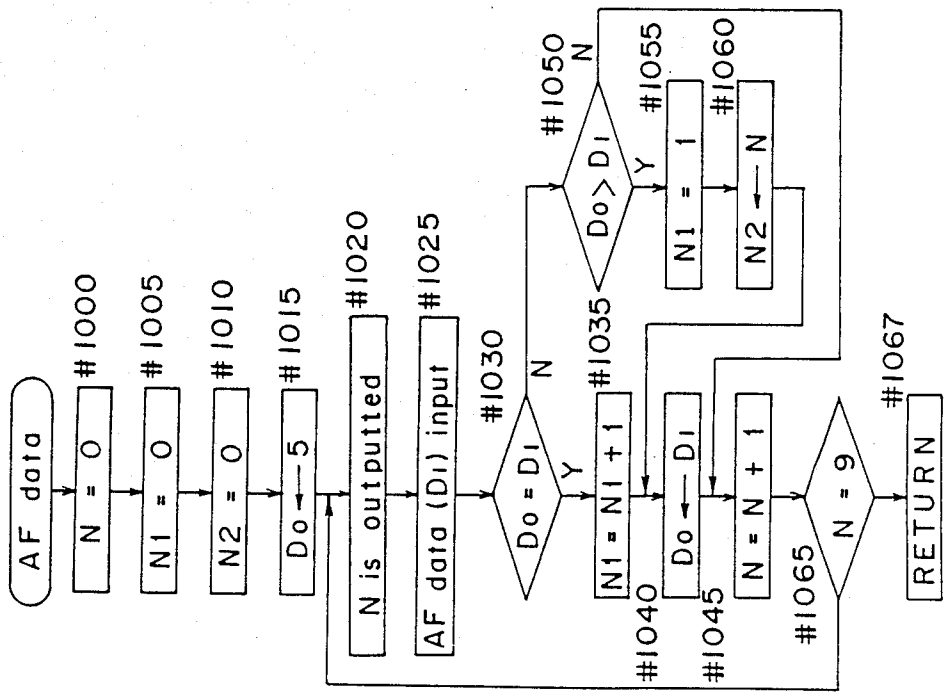


Fig. 13 (b)

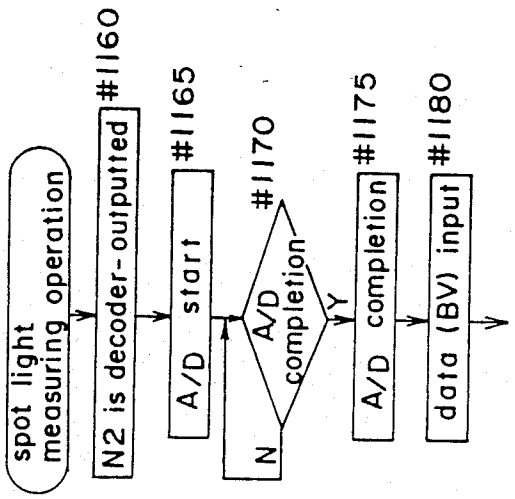


Fig. 13 (a)

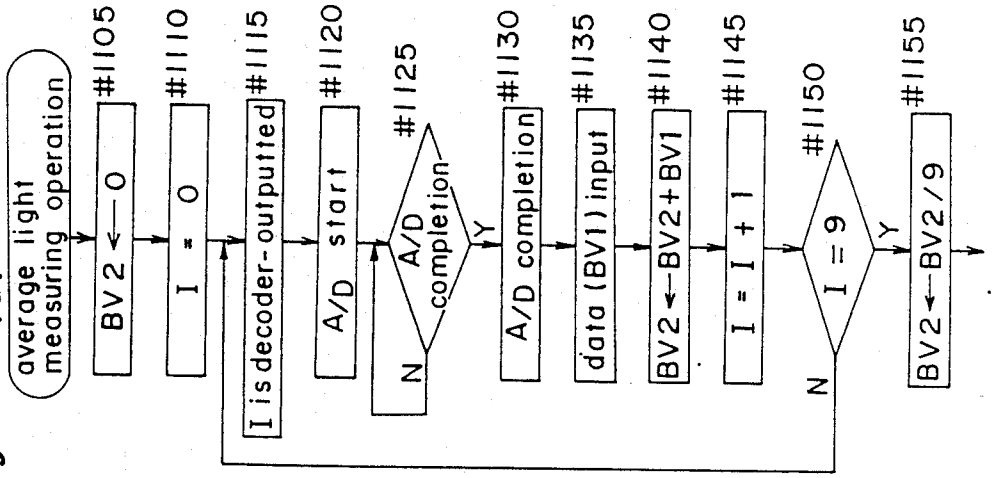


Fig. 14(a)

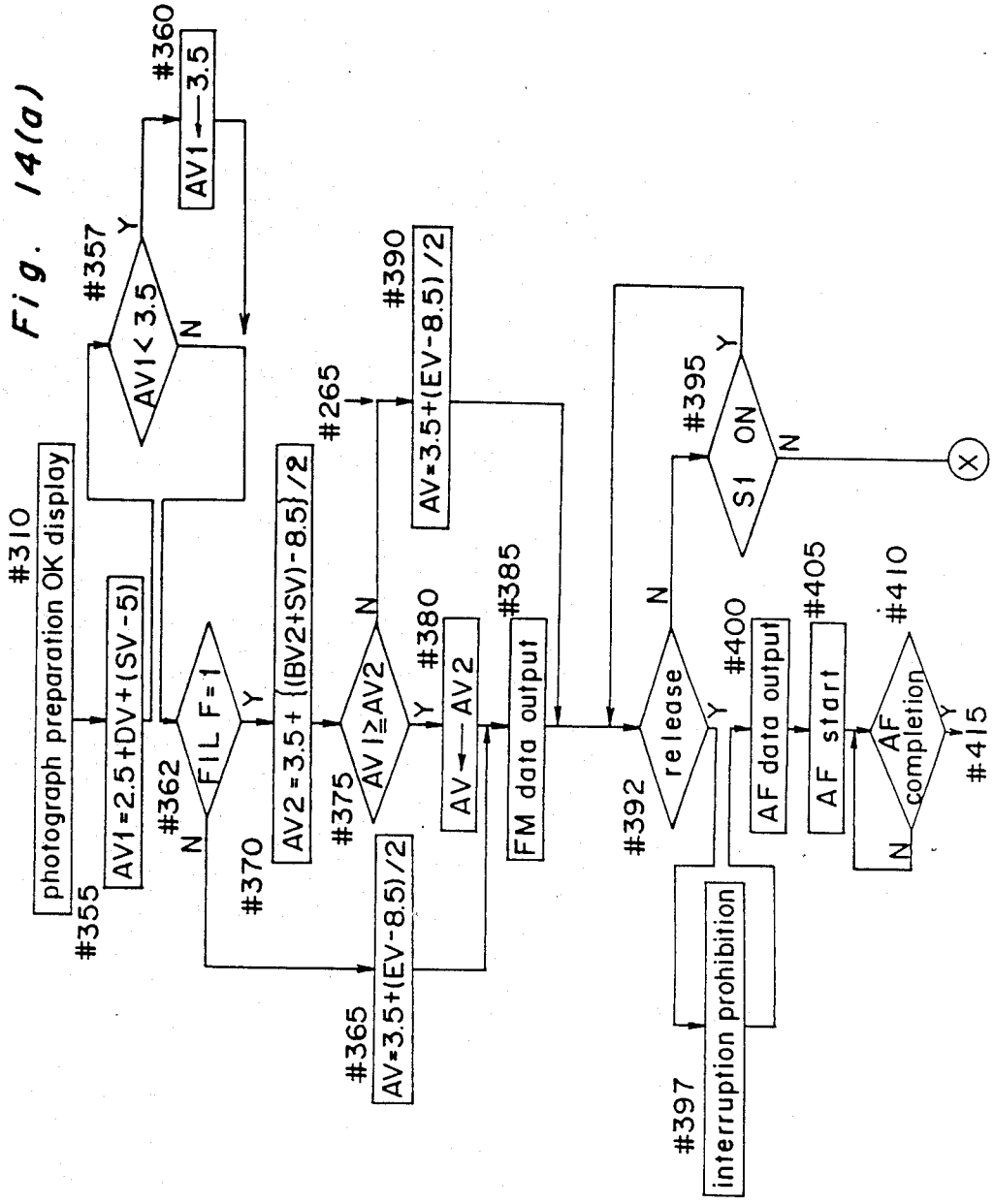


Fig. 14

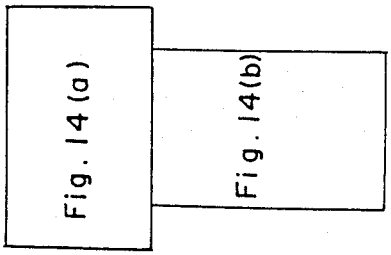


Fig. 14(b)

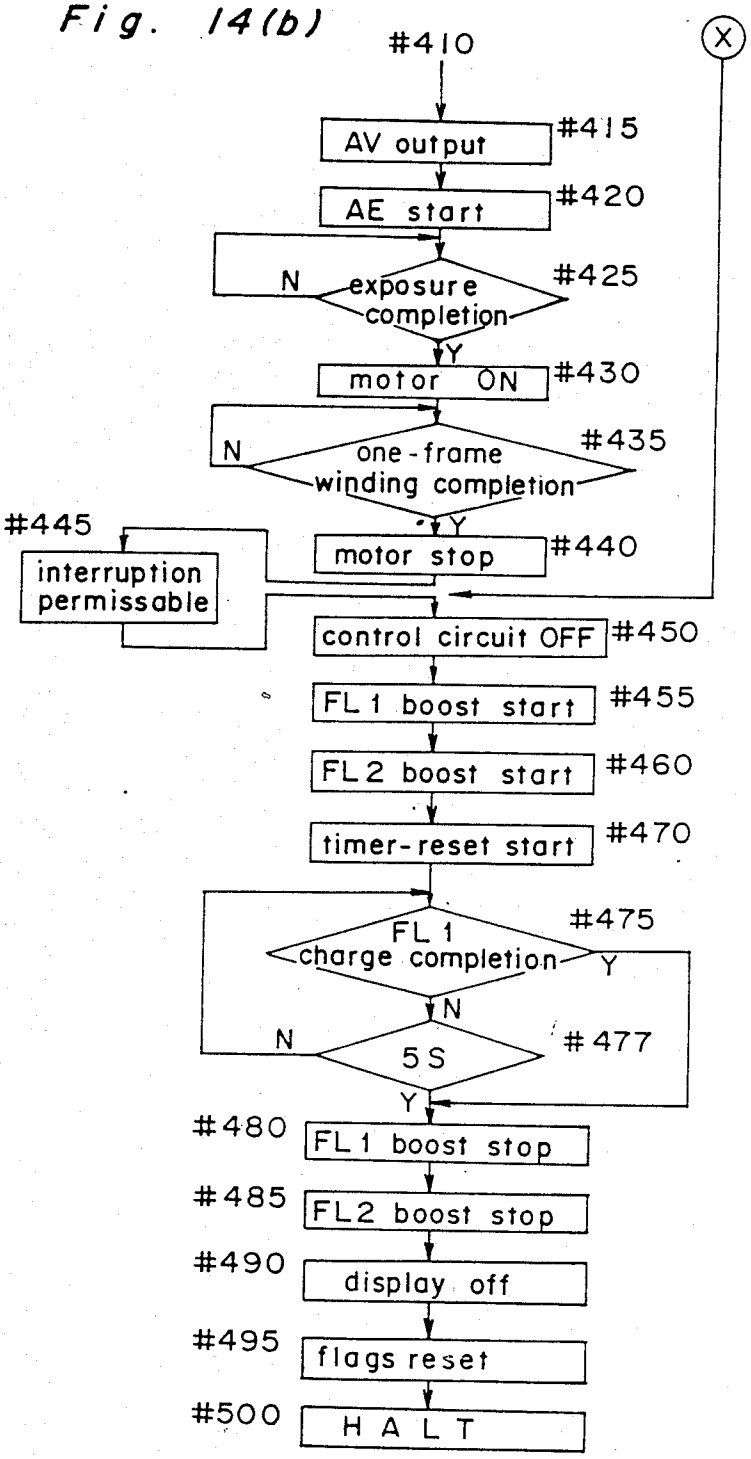
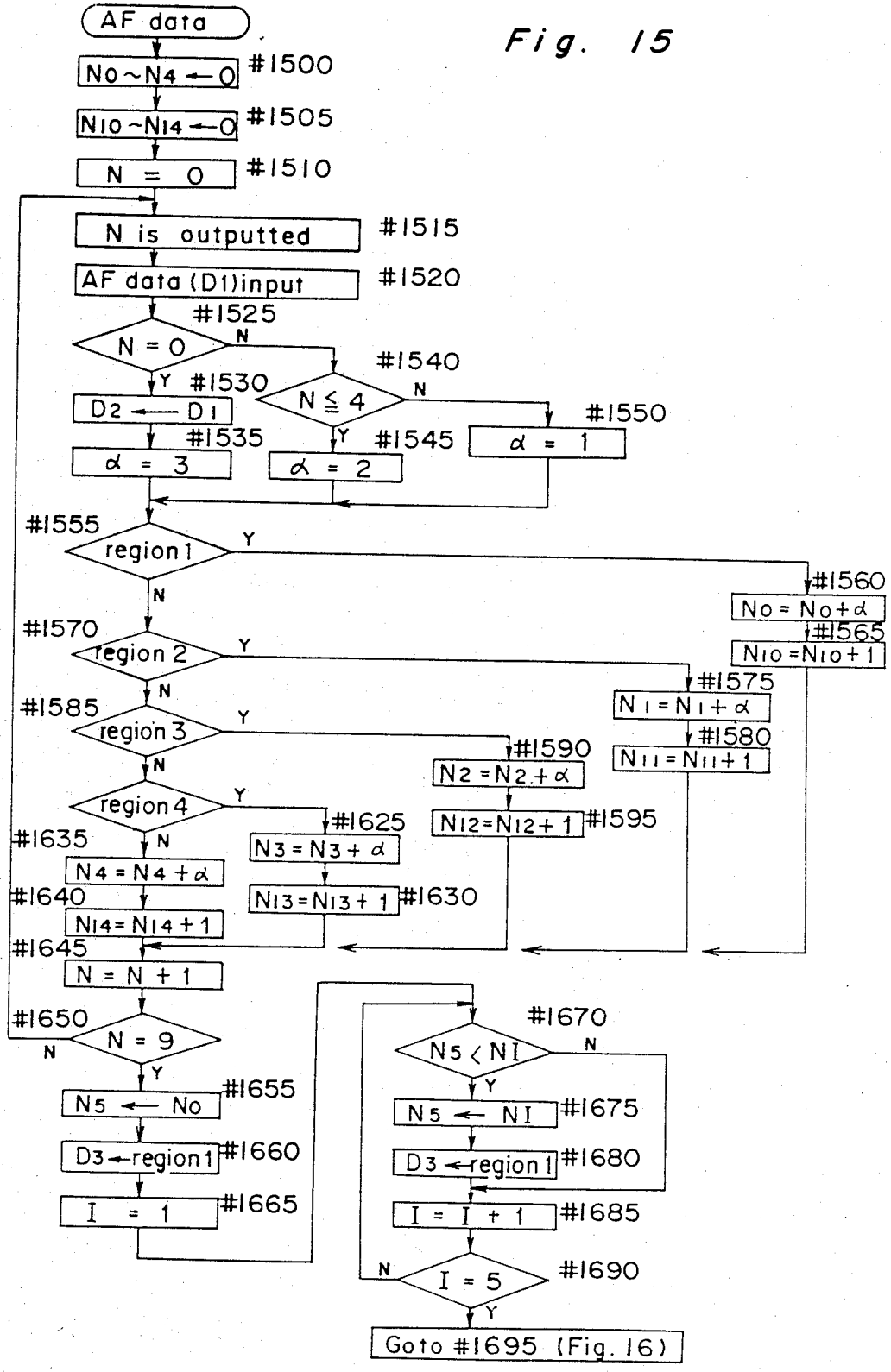

#410
X
AV output
#415
AE start
#420
N
exposure completion
#425
Y
motor ON
#430
N
one-frame winding completion
#435
Y
#445
interruption permissable
motor stop
#440
control circuit OFF
#450
FL1 boost start
#455
FL2 boost start
#460
timer-reset start
#470
FL1 charge completion
#475
Y
N
N
5S
#477
Y
#480
FL1 boost stop
#485
FL2 boost stop
#490
display off
#495
flags reset
#500
H A L T

Fig. 15


AF data
N0~N4 ← 0
#1500
N10~N14 ← 0
#1505
N = 0
#1510
N is outputted
#1515
AF data (D1)input
#1520
#1525
N = 0
N
Y
#1530
D2 ← D1
#1535
α = 3
#1540
N ≦ 4
N
Y
#1545
α = 2
#1550
α = 1
#1555
region 1
Y
N
#1560
N0 = N0 + α
#1565
N10 = N10 + 1
#1570
region 2
Y
N
#1575
N1 = N1 + α
#1580
N11 = N11 + 1
#1585
region 3
Y
N
#1590
N2 = N2 + α
#1595
N12 = N12 + 1
region 4
Y
N
#1625
N3 = N3 + α
#1630
N13 = N13 + 1
#1635
N4 = N4 + α
#1640
N14 = N14 + 1
#1645
N = N + 1
#1650
N = 9
N
Y
#1655
N5 ← N0
#1660
D3 ← region 1
#1665
I = 1
#1670
N5 < NI
N
Y
#1675
N5 ← NI
#1680
D3 ← region 1
#1685
I = I + 1
#1690
I = 5
N
Y
Goto #1695 (Fig. 16)

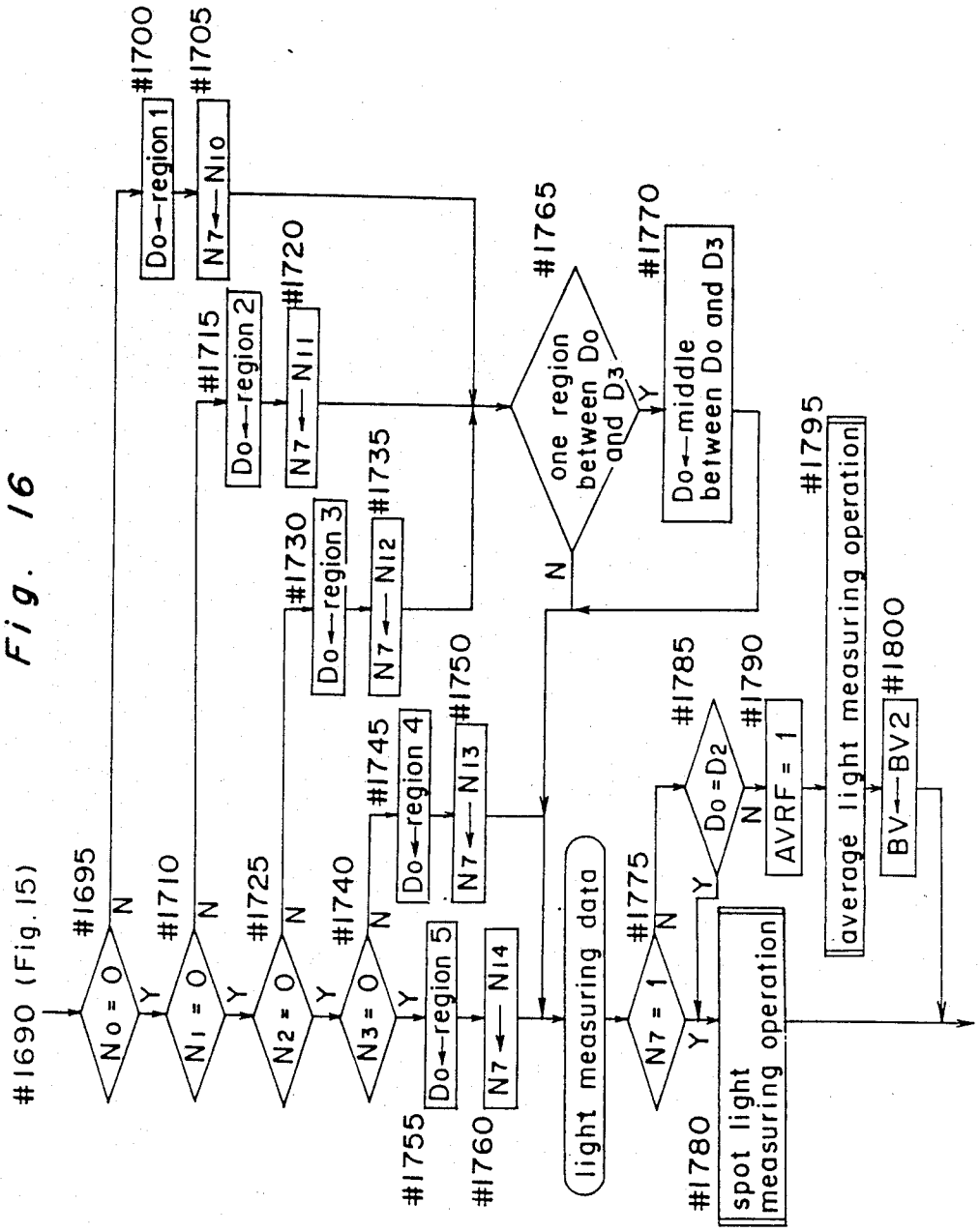

#1690 (Fig. 15)
#1695
No = 0
N
Y
#1700
Do←region 1
#1705
N7←N10
#1710
N1 = 0
N
Y
#1715
Do←region 2
#1720
N7←N11
#1725
N2 = 0
N
Y
#1730
Do←region 3
#1735
N7←N12
#1740
N3 = 0
N
Y
#1745
Do←region 4
#1750
N7←N13
#1755
Do←region 5
#1760
N7←N14
light measuring data
#1765
one region between Do and D3
N
Y
#1770
Do←middle between Do and D3
#1775
N7 = 1
N
Y
#1780
spot light measuring operation
#1785
Do = D2
N
Y
#1790
AVRF = 1
#1795
average light measuring operation
#1800
BV←BV2

Fig. 16

CONTROL DEVICE FOR USE IN A CAMERA HAVING AN OBJECTIVE LENS

This application is a continuation of application Ser. No. 267,550, filed Nov. 7, 1988, now abandoned, which is a divisional of application Ser. No. 043,616, filed on Apr. 28, 1987, now U.S. Pat. No. 4,800,409.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a control device for use in a camera, and more particularly to a control device which controls both the focusing operation of objective lens of the camera and exposure operation of the camera.

2. Description of the Prior Art

There has been proposed, in U.S. Pat. No. 4,423,936, a control device in which distance detection for the focusing operation and a light measuring for the exposure operation are performed with respect to a plurality of regions in an object area to be photographed, and a distance is selected among the detected distances for the focusing operation. If the selected distance is detected with respect to a single region, a light measurement value measured with respect to the single region is used for exposure operation to control exposure value. On the other hand, if the selected distance is detected with respect to plural regions, plural light measurement values measured with respect to the detected plural regions are averaged to be used for the exposure operation to control exposure value.

However, in the conventional device as described above, since a primary object to be focused is not always positioned at the detected plural regions, the possibility for obtaining proper exposure for the primary object is relatively low.

Furthermore, in the conventional device, backlight condition is detected in the case that, difference between a first light measurement value measured with respect to the region in which the selected distance is detected and a second light measurement value calculated by averaging all of other light measurement values, is over a predetermined value. Here, if the selected distance is detected with respect to plural regions, the first light measurement value is calculated by averaging plural light measurement values of the plural regions. However, the difference is not always indicating whether the backlight condition or not in the latter case. For example, if the selected distance is detected in two regions arranged symmetrically with an optical axis of the objective lens, it is impossible to judge at which region a primary object is positioned in the device. In such case, it would be improper to detect the backlight condition.

There has been proposed, in Japanese Laid-Open Patent Application No. 60-129732, another control device in which a common light receiving device is used for the light measuring and for the distance detection. In the device, one calculating circuit for distance detection and the other calculating circuit for light measuring are provided, and the output of the common light receiving device is sent to the two calculating circuits in time-sharing manner or in time-dividing manner. The distance detection calculation and exposure calculation are performed in respective circuits. However, such device has disadvantages that the construction thereof becomes complex since two calculating circuits and a switching circuit for selectively transmitting the output of the light receiving device to the two calculating circuits are necessary, and that the operation of the entire device becomes complex since switching operation of the switching means is necessary.

SUMMARY OF THE INVENTION

Accordingly, an object of the present invention is to provide a control device for use in a camera having an objective lens wherein the probability of giving the proper exposure to the primary object photographed is high even when the selected distance is detected with respect to plural regions.

Also, another object of the invention is to provide a control device for use in a camera having an objective lens which is capable of more positively judging the backlight condition.

An additional object is to provide a control device for use in a camera having an objective lens which does not need a switching circuit for finding a range even when regions to be found in the range within the photographing distance are plural.

In accomplishing these and other objects, according to the present invention, there is provided a control device for use in a camera having an objective lens, comprising means for producing a plurality of distance signals necessary for focusing the objective lens on a plurality of first regions of an object area to be photographed; means for determining a distance on the basis of the plurality of distance signals to produce a determined distance signal for focusing the objective lens; means for driving the objective lens in accordance with the determined distance signal; means for measuring a plurality of brightnesses of second regions of the object area to produce a plurality of brightness signals each corresponding to the measured brightnesses respectively, each of the second regions being substantially similar to each of the first regions, respectively; means for counting the number of the distance signals used in the distance determining means for determining the distance; means for discriminating whether the number counted by the counting means is single or plural; means for determining a light measuring value by a first calculation when the discriminated number is single, while determining the light measuring value by a second calculation which is different from the first calculation and which is independent of the discriminated number when the discriminated number is plural; and means for calculating exposure value of the camera in accordance with the light measuring value, so that satisfactory exposure may be provided, judging from the experiences even when the selected distance is detected with respect to plural regions.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other objects and features of the present invention will become apparent from the following description taken in conjunction with the preferred embodiments thereof with reference to the accompanying drawings, in which:

FIG. 1 is an illustrating view showing one arrangement of a light measuring optical system to be used in a first embodiment of the present invention;

FIG. 2 is an illustrating view showing the construction of a liquid-crystal filter of transmission wavelength switch type;

FIG. 3 is an illustrating view showing the light measuring range;

FIG. 4 is a block diagram showing a light measuring circuit employed in the first embodiment of the present invention;

FIG. 5 is a circuit diagram showing the switch groups in FIG. 4;

FIG. 6 is a further detailed block diagram of the light measuring circuit in FIG. 4;

FIG. 7 is a circuit diagram showing the construction of the light measuring circuit and the timing circuit thereof;

FIG. 8 is a block diagram showing the circuit construction of an electronic flashing apparatus in the first embodiment of the present invention;

FIG. 9 is a graph showing the relationship among the distance region of the photographed object, the focusing range and the aperture value (so-called lens opening);

FIGS. 10, 11, 11*a*, 11*b*, 11*c*, 12*a*, 12*b*, 13*a*, 13*b*, 14, 14*a*, and 14*b* and are flow charts showing the operation of the microcomputer of FIG. 4; and

FIGS. 15 and 16 are flow charts showing about the decision of the distance region for the photographing operation in the second embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

Before the description of the present invention proceeds, it is to be noted that like parts are designated by like reference numerals throughout the accompanying drawings.

The embodiment wherein the present invention has been applied upon the lens shutter camera will be described with reference to the accompanying drawings. First, the distance detection and the light measurement to be used in the embodiment will be described in principle. The distance detecting apparatus is composed of a projecting means for projecting the light onto the entire region of the photographed field to be detected in distance, a light-receiving means for receiving the light to be reflected from the object, and a circuit for processing the signals from the light-receiving means to detect the distance.

The light-receiving means is composed of a plurality of light-receiving elements, by which the photographed field is divided into a plurality of regions to detect the respective distances. And one of the distances is selected as a distance where the photographing lens is focused, thereby the brightness of the selected region is detected as supposing that a primary object is positioned in the selected distance. In the present embodiment, the common light-receiving elements are used for both the distance detection and the brightness detection.

Referring now to FIG. 1, there is shown a concrete example of the optical system with the light-receiving element being provided for common use. An electronic flashing apparatus FL2 is the projecting means which projects the light on the entire region of the photographed field through the filter IRF1 provided on the front face, through which the infrared light of particular wavelength or wavelength range is transmitted. The light-quantity emitted by the electronic flashing apparatus FL2 is by far less than the light-quantity emitted by the electronic flashing apparatus for object illumination use to be employed in the photographing operation. A condenser lens LE collects the light reflected from the object OB to guide into the light receiving element SPC. A filter LCDF1 which is adapted to be capable of switching to a filter for transmitting the infrared light of particular wavelength or wavelength range through it, and a filter having the characteristics of visual sensitivity is provided between the condenser lens LE and the light-receiving element SPC.

This filter is constructed as shown in FIG. 2. Namely, the filter LCDF1 is composed of ,a guest-host type liquid crystal devices LCD1 and LCD2. When the signal of the "High" level (hereinafter referred to as "H") is outputted from a terminal OP1 of a microcomputer MC shown in FIG. 4, a predetermined voltage V2 is applied upon a first liquid crystal device LCD1 through a buffer BUF, and the first liquid crystal device LCD1 comes to let the infrared light of the particular wavelength or wavelength range pass through it. On the other hand, when the signal of the "Low" level (hereinafter referred to as "L") is outputted from the output terminal OP1 of the microcomputer MC, the predetermined voltage V2 is applied upon a second liquid crystal device LCD2 through a buffer BUF and an inverter IN2, so that the second liquid crystal device LCD2 comes to operate as a visible-sensitivity filter through which the light of the visible sensitivity range may pass. The buffer BUF and the inverter IN2 are adapted to be fed by the power voltage to be described later. Accordingly, when the release button (not shown) is not depressed, both the liquid crystal devices remain colorless in light transmission condition without application of the voltage.

The light-receiving element SPC shown in FIG. 1 is composed of a plurality of elements as described hereinabove and is adapted to measure each of a plurality of regions ① through ⑨ of the object field shown by a rectangular frame in FIG. 3. A plurality of the light-receiving elements are arranged to measure the region which is deviated a little downwardly of the object field as a whole, and are composed of nine elements in total arranged symmetrically, in the horizontal, vertical relation with the No. 1 light-receiving element as a center being provided to measure the region a little lower than the center of the object field. They are adapted to detect the distance and brightness of the regions ① through ⑨ shown in the oblique-line portions. The reason where they are arranged somewhat downwardly with respect to the field to be photographed is that the object or the person regarded as the primary object is often provided in the lower portion, but in the upper portion with the lens shutter camera having a comparatively wide-angle lens.

The camera system which performs the above-described distance detection and brightness detection will be described hereinafter. In the block diagram of FIG. 4 showing the circuit construction of the entire camera, a power battery E consists of direct connection of two lithium cells each producing 3V. A diode D1 is provided for preventing the voltage applied to the microcomputer MC from becoming lowered during the operation of the boosting circuit in the electronic flashing apparatus FL. A capacitor C0 is provided to prevent the noises and to hasten the charging operation to the main capacitor in the electronic flashing apparatus FL. A capacitor C1 has comparatively large in capacity for the back-up operation of the microcomputer MC. A resistor R1 and a capacitor C2 for resetting use are adapted to reset the microcomputer MC when the power battery E is mounted. A group of switches SW have a plurality of switches which are required for the

operation of the apparatus of the present embodiment. The group of switches will be described in detail with reference to FIG. 5.

A display circuit DI displays the photographing information. A liquid-crystal filter FI, which is shown in FIG. 2, becomes an infrared filter or a visible-light filter. The microcomputer MC is provided to control the entire circuit. A film sensitivity setting circuit IS converts the film sensitivity, which is read from the code pattern provided on the film container or is manually set, into the film sensitivity value represented by an A.P.E.X. system to output it into the microcomputer MC. A light measuring circuit LM is composed of a distance detection circuit for receiving the light, which is emitted from the electronic flashing apparatus FL for distance detection to be described later and are reflected from the object to detect the distance of the object, and a light measuring circuit for measuring the brightness BV of the object. An exposure control circuit AE for controlling the exposure in accordance with the exposure value EV to be outputted from the microcomputer MC outputs the flash starting signal X1 to the electronic flashing apparatus FL at a given timing. An AF controlling circuit AFC drives the objective lens to an in-focus position in accordance with the AF data to be outputted from the microcomputer MC. A motor controlling circuit MO controls the motor M for the winding operation of the film. The electronic flashing apparatus FL is composed of the electronic flashing apparatus FL2 for distance detection use and the electronic flashing apparatus FL1 for object illumination use during the exposure. A transistor Tr1 feeds the power voltage to the filter FI, the film sensitivity setting circuit IS, the light measuring circuit LM, the exposure controlling circuit AE, the AF control circuit AFC, and the motor control circuit MO in accordance with a signal from the microcomputer MC.

FIG. 5 shows the concrete example of a group of switches SW in FIG. 4. A lens cover switch S0 turns on and off through the operative cooperation of the opening, closing operations of a lens cover (not shown). The pulse signal is outputted into the interruption terminal INT0 of the microcomputer MC through a circuit composed of a delay circuit DEL and an exclusive OR circuit EOR by turning on and off of the switch SO. When it is inputted into the microcomputer MC, the microcomputer executes a given interruption routine INTO. A photograph preparing switch S1 turns on when the release button (not shown) is depressed as far as the first stroke. If the switch S1 is turned on when the lens cover is open, the interruption routine INT1 is executed. A release switch S2 turns on when the release button is depressed as far as a second stroke provided deeper than the first stroke. An exposure completion switch S3 turns off at the charging completion of the shutter charging member (not shown) and turns on at the exposure completion.

A one frame winding switch S4 turns off at the exposure completion and turns on at the completion of one frame winding completion. A switch S5 turns on when the objective lens is driven to the given position corresponding to the control signal and turns off at the charge completion of the shutter charging member.

The details of the light measuring circuit LM of the distance detection and the brightness detection to be used in the present embodiment will be described hereinafter with reference to the block diagram of FIG. 6.

The light measuring circuits LM1 through LM9 perform the distance detection and the brightness detection of the regions ① through ⑨ shown in FIG. 3, respectively. Each of the circuits for the distance detection latches the signals from the light-receiving element, i.e., the distance signal in response to a signal of the timing, circuit TM, so that the signals from the light-receiving elements are latched at the timing when the intensity of the light projected from the electronic flashing apparatus FL2 becomes maximum in the variation thereof, thereby to output the signal to the selector SEL. The selector SEL selects the signals from the light measuring circuits LM1 through LM9 by the signal from a decoder DE2, which is adapted to decode the signal from the microcomputer MC to output the selected signals to the encoder ED. The encoder ED converts the inputted signals into given forms to output them into the microcomputer MC. The distance signals of the light measuring circuits LM1 through LM9 are outputted to the microcomputer, by the signal from the microcomputer MC, sequentially through the selector SEL and the encoder ED1.

On the other hand, signals of the detected brightnesses are outputted as analog signals to the analog switch ANSW. The analog switch ANSW is composed of nine FETs, which are connected with the light measuring circuits LM1 through LM9 respectively, so that the respective brightness signals may be inputted, all the outputs being integrated into one, and are connected with the A/D converting circuit A/D. The selection of the analog switch ANSW is performed by the signal of the decoder DE2, which is adapted to decode the signal from the microcomputer MC as in the distance signal, and is sequentially performed from the light measuring circuits LM1 through LM9. The brightness signal which has been outputted to the A/D converting circuit A/D through the analog switch ANSW is converted into digital forms and is outputted into the microcomputer MC.

The details of the light measuring circuit LM1 and the timing circuit TM1 in the above-described diagram will be described in FIG. 7. The portion surrounded by the dotted lines in the drawing shows the timing circuit, and the portion except for it shows the light measuring circuit.

First, the timing circuit TM1 will be described. When the release button is depressed, the signal of "H" is outputted from the terminal OP8 of the microcomputer MC before the electronic flashing apparatus FL2 starts to emit the light, and the transistor Tr2 turns on to discharge the, capacitor C3. The transistor Tr2 is turned off immediately before the light emission to wait therefor. A phototransistor PHT1 which charges the capacitor C3 is disposed near the light emitting portion of the electronic flash apparatus FL2 and is adapted to directly receive the emitted light. When the electronic flashing apparatus FL2 emits the light in this condition, the current corresponding to the intensity of the light received by the phototransistor PHT1 is charged into the timing capacitor C3 through the phototransistor PHT1. When the voltage of the capacitor C3 exceeds a reference voltage Vr1, the comparator COMP1 is reversed to output the signal of the "H". The signal of the "H" is pulsed by the one-shot circuit OS1 and is outputted into the terminals T of the D flip-flops, to be described later, to latch the amplification signal from the light-receiving element SPC1. The reference voltage Vr1 is adapted to reverse the comparator COMP1 at the

time point when the intensity of light emitted by the electronic flashing apparatus FL2 is slightly lower from the maximum intensity.

The light measuring circuit LM1 will be described hereinafter. The voltage is applied through the power supply line V2 by the depression of the first stroke of the release button to feed the power to each circuit. At once, the signal of the "H" is outputted from the terminal OP9 of the microcomputer MC to turn on the analog switches AS1, AS2 so that constant current circuits I1, I2 start to flow constant currents, respectively. After the lapse of a predetermined time (as the lowest 20 msec is assigned to that time in the present embodiment), the light measuring circuit LM1 remains stable.

The circuit operation before the stability of the circuit LM1 will be briefly described. As the voltage of the capacitor C4 is extremely low when the constant current circuits I1, I2 start to flow constant currents, the transistor Tr3 does not turn on. Constant current I1 flown by the constant current circuit I1 and the photocurrent IP which corresponds to the brightness of the particular wavelength light passing through the filter flow to the base of the transistor Tr4 to be amplified there. The amplified current flows through the transistor Tr6, and the equivalent current flows through the transistor Tr7 which constitutes a known current mirror circuit with the transistor 6. One part of the current becomes current of the constant current circuit I2 and the remaining current flows through the diodes D2, D3 to cause the voltage VD corresponding to two steps of the diode. The operation amplification OP1 has a reference voltage Vref inputted into the inversion input terminal, and has the voltage VD inputted into the non-inversion input terminal, and the negative feedback is applied upon the transistor Tr3 so that the voltage VD may become always constant.

As the current flowing through the transistor Tr7 corresponds to the current which has amplified most of all the photocurrent IP and the constant current I1, the voltage VD to be caused by this current becomes higher than the reference voltage Vref. Accordingly, the operation amplifier OP1 charges the capacitor C4 to boost the base voltage of the transistor Tr3. This capacitor C4 is charged through the transistor Tr4. When the voltage of the capacitor C4 is boosted to turn on the transistor Tr3, the constant current I1 and the photocurrent IP flow through the collector of the transistor Tr3 to reduce the current flowing through the base of the transistor Tr4. Thus, the current flowing through the transistor Tr6 and Tr7 is reduced to lower the voltage VD, so that the above-described operation is performed until the voltage VD becomes equal to the reference voltage Vref. During this operation, the voltage VD may become lower than the reference voltage Vref. At this time, the operation amplifier OP1 operates for discharging the charge of the capacitor C4 to reduce the voltage thereof, which reduces the current through the transistor Tr3 within the constant current I1 and the photocurrent IP so as to increase the base current of the transistor Tr4. Accordingly, the current which flows through the transistors Tr6 and Tr7 increases to boost the voltage VD.

This circuit is stabilized by the above-described operation to flow the current almost equal to the total of the constant current I1 and the photocurrent IP through the transistor Tr3, so that the voltage of the capacitor C4 for becomes equal to the base voltage corresponding to the current.

When the electronic flashing apparatus FL2 emits the light, the light reflected from the object is received by the light-receiving element SPC1 to cause the photocurrent IP' (which is referred to as IP' hereinafter to distinguish it from the above-described ambient photocurrent IP) corresponding to the light including a reflected light component reflected by the object and the ambient light component. The current IP of the ambient light component within the photocurrent flows through the collector of the transistor Tr3, and the current IP'-IP corresponding to the reflected light component flow as the base current of the transistor Tr4. At this time, the capacitor C4 has the capacity, in which the transistor Tr4 does not respond by the current while the reflected light is received by the light receiving element. And the current IP-IP' is amplified by the transistor Tr4 to flow the diodes D2, D3 through the transistors Tr6, Tr7. Thus, the voltage VD is increased to compare the voltage VD with the reference voltage determined by the constant current circuit I3 and the resistors R11 through R14, so that the distance signal is represented as the outputs of the comparators COMP2 through COMP5. The output signals of the comparators COMP2 through COMP5 are latched into the D flip-flops DFF1 through DFF4 by the signal from the timing circuit TM to output the latch signal to the selector SEL.

After the distance detection has been performed in the above-described way, the filter arranged in front of the light-receiving element SPC1 is changed from a characteristic for permitting that the infrared light having the particular wavelength pass therethrough to the other characteristic for permitting that the visual light pass therethrough. Furthermore, the constant current circuit I1 is switched off to remove the voltage of the constant current I1 with respect to the charging voltage of the capacitor C4. The constant current circuit I2 is also turned off to cut off the route of the feedback of the transistor Tr3 through this constant current I2 so that the voltage of the capacitor C4 may become only the voltage which depends upon only the intensity of the ambient light component received by the light-receiving element SPC1. The voltage is outputted into the analog-switch ANSW through the buffer BUF1.

The other light measuring circuits LM2 through LM9 shown in FIG. 6 are also completely the same in construction as in FIG. 7.

The electronic flashing apparatus FL1 for photograph use and the electronic flashing apparatus FL2 for distance detection use to be used in the embodiment will be described hereinafter with reference to FIG. 8. Except for the point that the electronic flashing apparatus FL2 for distance detection use is much smaller (approximately 1/25 in the maximum light emitting amount) than the electronic flashing apparatus FL1 for photographing use, the former is completely the same in the circuit construction as the latter FL1, thus removing the illustration of the concrete construction of the former with the circuit being shown simply in block.

In the circuit of the electronic flashing apparatus FL1 for photographing use, a boost controlling circuit DCC receives the boost controlling signal FLC1 from the microcomputer MC and produces the changing completion signal B.C1 to be described later to control the transistor Tr8 for boosting circuit DC. The rectification diode is represented by D4. A charge detecting circuit B.C detects the charging condition of a main capacitor C5. An emission control circuit EC energizes a xenon

tube Xe in accordance with the emission signal X1 from the exposure control circuit AE to illuminate the object area. The emission signal X2 of the electronic flashing apparatus FL2 for distance detection use is fed through the buffer BUF10 from the microcomputer MC.

The operation of the electronic flashing apparatus FL1 for photographing use will be described. When the, charging operation to the main capacitor C5 has not been completed, the charge completion signal B.C1 is in the "L" level. When the boosting control signal FLC1 of the "L" showing the boosting start is sent from the microcomputer MC, the NOR circuit NOR1 outputs the signal of "H", and the boost controlling circuit DCC receives it to control the transistor Tr8 to turn it on and starts the boosting operation. When the charging completion signal B.C1 becomes "H" level by the completion of the charging operation to the main capacitor C5 or the boosting control signal FLC1 from the microcomputer MC becomes "H" level, the NOR circuit NOR1 outputs "L" level, so that the boost controlling circuit DCC turns off the transistor Tr8 to stop the boosting operation of the boosting circuit DC. It is to be noted that a neon tube showing this condition lights on independently of the control circuit and the microcomputer MC when the charging operation of the main capacitor C5 is completed.

The entire operation of the camera in the embodiment will be described hereinafter. Before it, the number of the distance zones detected by the distance detection, the in-focus range in each region, and how to determine it will be described.

The distances to the objects located at each of the regions are detected in accordance with the absolute amounts of the light reflected by the objects as described hereinabove. However, as each of the objects has a reflectance different from that of the other objects, the distance detected by the detection apparatus is not always equal to the distance to the object. In the present embodiment, the in-focus range of each region is provided wider or the range is provided across two regions so that the focusing operation may be performed without fail on the object. However, if the distance range from the nearest focusing distance such as 0.6 m to the infinity distance is divided into five ranges, it is impossible to achieve the in-focus condition of the objective lens with respect to any object located within the distance range in the condition in which the aperture of the objective lens is fully opened, due to the focusing performance of the objective lens. Thus, in the embodiment the maximum aperture value is decreased in accordance with the decrease of the distance. Therefore, an in-focus range of particular distance zone can be extended to achieve the in-focus condition with respect to any object within the distance range, by dividing the latter into five ranges.

Here, since the embodiment uses a shutter serving as an aperture diaphragm, the reduction of the aperture value causes the shutter speed to shorten. Therefore, the brightness range in which the natural light photographing may be performed becomes narrower, the underexposure is likely to be caused. In this case, the flash photographing operation is performed to compensate for it. The shutter, also serving as an aperture diaphragm, which is used in the present embodiment, is a type showing the triangular waveform in time-variation characteristics of the opening degree. The shutter gradually opens to reach the given aperture value, and is adapted to move to the closed operation.

Five ranges determined in accordance with the above-described idea and their in-focus ranges, the maximum aperture value of the use limit at this time, and the aperture value at the flash photographing operation will be described in FIG. 9.

In the drawing, the axis of ordinates shows the regions 1, 2, 3, 4, 5 arranged in order from the near distance side. The axis of abscissa shows the distance as far as 0.6 m through ∞. The focusing range of each region will be described. As shown in FIG. 9, in the region 1, the open aperture value is limited to F/8, and the object distance of the objective lens is set to 0.75 m. Thus, the object positioned within a distance range from 0.56 m to 1.1 m can be in in-focus condition on the predetermined focal plane by the objective lens. In the region 2, the open aperture value is limited to F/5.6, and the object distance is set to 1.0 m, thereby the objective lens is set to be in in-focus condition with respect to an object positioned within a distance range from 0.77 m to 1.5 m. In the region 3, the open aperture value is limited to F/4, and the object distance is set to 1.5 m, thereby the objective lens is set to be in in-focus condition with respect to an object positioned within a range from 1.1 m to 2.2 m. In the region 4, the open aperture value is limited to F/3.5, and the object distance is set to 2.1 m, thereby the objective lens is set to be in in-focus condition with respect to an object positioned within a distance range from 1.5 m to 3.6 m. In the region 5, the open aperture value is limited to F/3.5 and the object distance is set to 5 m, thereby the objective lens is set to be in in-focus condition with respect to an object positioned within a distance range from 2.7 m to ∞.

The aperture value used in flash photographing operation is determined as shown in "FM" in FIG. 9. The guide number of the flashing apparatus is determined to be 10 with respect to a film sensitivity of ISO=100. In the region 1, the aperture value in flash photographing operation is set to F/13, so that under- or over-exposure is provided by 1 step with respect to the object located at the nearest or farthest distance within the distance range of region 1. Only the same exposure amount is designed to become over or under with respect to both the ends. In the region 5, the flash photographing operation is adapted to be performed as far as possible with F/3.5 in the open aperture value.

FIGS. 10 through 14 show the flow charts of the microcomputer MC. The controlling operation of the camera will be described with reference to the flow charts.

The operation with the battery E being mounted on the camera will be described with reference to FIG. 10. When the battery E is mounted thereon, the signal which changes from "L" to "H" is inputted into the reset terminal RES, the microcomputer MC executes the flow to prohibit the interruption (#5) and to initially set (#10) the output terminals, the registers. Then, the signal of the terminal IP6 shown in FIG. 5 is inputted and the microcomputer MC allows the interruption to decide whether or not the lens cover is open. When it is closed, the interruption to the interruption terminal INT1 to be described later is prohibited to come to a stop (#25 through #27). On the other hand, the program proceeds to step #45 to be described later when the lens cover is open.

The interruption INT0 which is executed through the opening and closing operation of the lens cover will be described hereinafter. If the lens cover is opened or closed in the condition where the interruption to the

flow is allowed, the pulse is inputted into the terminal INT0, so that the microcomputer MC executes the interruption INT0 operation from the step #32. At first, the decision is made as to whether the lens cover has been opened or closed (#35). When the lens cover has been closed, the interruption to the flow of the interruptions INT1 to be described later is prohibited (#57) to proceed to the step #60 (#35, 37). When the lens cover has been opened, the interruption to the terminal INT1 is allowed (#40), the signals of "H" to the output terminals FLC1, FLC2 are outputted (#40 through 50) to start the boosting operation of the electronic flashing apparatuses FL1, FL2 for photographing use and distance detecting use so as to decide whether the charging operation of the main capacitor of the electronic flashing apparatus FL1 for photographing use has been completed through the output signal BC1 (#55). Even when the lens cover is open with the battery being mounted on, the program proceeds to the step #45. When the charging completion of the main capacitor is decided at the step #55, the signals of "L"are outputted to the terminals FLC1, FLC2 (#60, 65) to stop the boosting operation of both the electronic flashing apparatuses FL1, FL2 for photographing use and distance detection use. And all the flags are reset at the step #70. The counting timer started in the interruption flow of the INT1 shown in FIG. 11 is stopped to turn off the display, and the microcomputer MC becomes halt condition (#70 through 85).

Then, in FIG. 11, when the release button is depressed to the first stroke with the lens cover being opened, the signal which changes from "H" to "L" is inputted to the terminal INT1 and the microcomputer MC executes the flow of the interruption INT1 from the step #90.

In order to perform the distance detection and the brightness detection, the boosting operation of the electronic flashing apparatus FL1 for photographing use is stopped in this flow to prevent the noise caused by the boosting operation and the decrease in the battery voltage (#95). Then, the transistor Tr1 is turned on to supply the power supply to each control circuits (#100). The analog switches AS1, AS2 are turned on to flow the constant current for distance detection use (#105), and the output of the terminal OP1 is turned into "H" so that the filter is switched for infrared ray use to detect the distance (#110). The timer for counting the time required for the circuit stability is reset and started (#115), and the transistor Tr2 or timing use is turned on (#120) to discharge the timing capacitor C3 for the determination of the timing to latch the output of the distance detecting circuit. Then, the controlling operation is performed to start the boosting operation of the electronic flashing apparatus FL2 for distance detection use to wait for the completion of the charging operation of the capacitor C5 (#125, 130). After the charging operation of the capacitor C5 completes, the boosting operation is stopped (#132). And the decision is made whether or not 20 msec have passed from the timer start of the step #115. If they have not passed, the lapse is waited for. If they have passed, the transistor Tr2 for timing use is turned off (#135, 140). The signal of "H" is outputted into the terminal X2 to detect the distance and thereby the flashing apparatus FL2 for distance detection use is energized (#145). The signal from the timing circuit is inputted to detect whether or not the data of the result of the distance detection has been latched to wait for the data to be latched (#150). When the detection is performed that the data has been latched, the terminal OP1 is turned into "L" to detect the brightness to put the filter into the visible sensitivity use (#155). The analog switches AS1, AS2 are turned off (#160), and the subroutine for taking in the data for the latched distance detection use comes in preparation for the following brightness detection.

The subroutine will be described with reference to FIG. 12. The microcomputer MC sets variables N, N1, N2 into 0, and D0 into 5 (#1000 through 1015). This variable N is outputted into the decoder DE2 shown in FIG. 6 (#1020). The distance data detected by the light measuring circuit selected by the selector SEL which receives the output of the decoder DE2 are converted into a given coded data D1 by the encoder ED, and the coded data are inputted into the microcomputer MC at the step #1025. This data D1 corresponds to the detected distance region, that is either of the regions 1 through 5. For example, the coded data D1 shows 1 if the detected distance region is the region 1, while the data D1 shows 5 if the detected distance region is the region 5.

The nearest distance region among the distance regions detected by each of the light receiving circuits LM1 through LM5 is selected in accordance with the data D1. First, a decision is made as to whether or not the data D0, wherein the data corresponding to the distance region 5 is set, are equal to the input data D1. If they are equal to each other, 1 is added to the variable N1 (#1030, 1035). This variable N1 is provided for deciding if the number of the light measuring circuits which detect if the nearest distance region is single or plural. The data D0 are set in D1 to add 1 to the variable N (#1045, 1065). On the other hand, in the step #1030, the program proceeds to the step #1050 when the set data D0 are not equal to the input data D1 to decide whether not the input data D1 is in the distance region nearer than the set data D0. The program proceeds to the step #1045 when it is not in the nearer distance region. When it is in the nearer distance region, the variable N1 is set in 1, and the variable N2 is set to the variable N to proceed to #1040 (#1055, 1060). This variable N2 shows either of the light receiving regions ① through ⑨ shown in FIG. 3. In the step #1065, the decision is made whether or not the variable N is 9, i.e., whether or not the distance data of the light-receiving regions 1 through 9 have been inputted after the addition of 1 to the variable N at the step #1045. If the inputting operation of the distance data has not been finished, the step returns to the step #1020 to repeat the loop. If the inputting operation of the distance data has been finished, the program returns to the original flow of FIG. 11 at the step #1067 to proceed to the next light measuring data subroutine of the step #1070.

The subroutine is shown from the step #1070 of FIG. 12(*b*). In the step #1070, the decision is made as to whether or not the variable N1 is 1, i.e., the number of the light receiving regions in which the nearest distance region is detected is single. If it is single (N1=1), the program proceeds to the spot light measurement subroutine of the step #1075. When the number of the light receiving regions in which the nearest distance region is detected is plural, the proceeds to the step #1080 decide whether or not the light receiving region ① of the central portion is included in the plurality of regions in which the nearest distance region is detected. Even when it is included, the program proceeds to the step #1075. When the light receiving region of the central

portion is not included at the step #1080, the average light measurement flag AVRE is set at the step #1085. The program proceeds to the average light measurement subroutine, and returns to the original flow with BV2 (average light measurement value) as the light measurement data BV.

The spot light measurement and average light measurement subroutine among the light measuring data subroutine will be described with reference to FIG. 13. First, in the spot light measurement subroutine shown in FIG. 13(*b*), the microcomputer MC outputs the variable N2, showing the number of the light receiving regions, to the decoder DE2 (#1160). The decoder DE2 decodes the inputted variable N2, and controls to turn on one of the analog switches ANSW in order to output the analog light measuring signal which corresponds to the brightness of the region related to the variable N2, to the A/D converting circuit A/D. The microcomputer MC outputs the A/D conversion start signal from the terminal OP6 to convert the light measuring signal of this analog form into the digital form at the step #1165, and decides with the signal of the terminal OP7 whether or not this A/D conversion has been completed at the step #1170. After the completion of the A/D conversion, the A/D completion signal is outputted from the terminal OP6 at the step #1175 and the digital-converted light measuring data are inputted to the microcomputer MC as the brightness value BV.

The average light measurement subroutine shown in FIG. 13(a) will be described hereinafter. The variables BV2 and I are set to 0 (#1105, 1110) and this variable I is outputted to the decoder DE2. As in the case of the above-described spot light measurement operation, the light measuring output of the analog form showing the brightness of the light receiving region corresponding to this variable I is converted in digital form by the A/D converter A/D to input the light measuring data as BV1 (#1120 through 1135). The data BV1 are added to the data BV2 at the step #1180 and 1 is added to the variable I at the step #1145. And it is decided whether or not the variable I has reached 9 (#1150). If it reaches 9, it is assumed that the light measuring data showing the brightness has been inputted from all the light-receiving regions ① through ⑨, and the program goes to the next step. If it is not 9, the program returns to the step #1115 to repeat this loop to perform the data inputting operation. After the inputting operation of all the data is over, the microcomputer MC divides the data BV2, i.e.,. the light measuring data of all of the respective light-receiving regions, by 9 to obtain the average brightness data at the step #1155. It may be modified to obtain the average brightness data by averaging all of the light measuring data, even if a plurality of light receiving regions detect the nearest distance region. The step #1080 should be omitted for this modification.

Returning to the flow of FIG. 11, the film-sensitivity data SV from the film sensitivity setting circuit IS are read in A.P.E.X. system at the step #175 to add the brightness data BV to this value SV to obtain the exposure value EV (#180). The limited exposure value (EV) for switching from the natural light photographing mode to the flash photographing mode will be explained. The limited exposure value (EV) is changed in accordance with the detected distance region. In the step #185, the decision is made as to whether or not the distance region is region 1. If it is 1, the program goes to the step #190 to decide whether or not the exposure value EV is 13.5 or more. If the exposure value EV is less than 13.5, the exposure value EV is fixed to 13.5 (#235) to go to the step #270. If the distance region is region 2, the exposure value is secured to 11.5 when the exposure value EV is less than 11.5 at the step #230. If the distance region is region 3, the exposure value EV is secured to 9.5 when the exposure value EV is less than 9.5 at the step #225. If the distance region is region 4 or 5, the exposure value EV is fixed to 8.5 when the exposure value EV is less than 8.5 at the step #230. The program moves to the step #270 respectively to enter into the flash photographing mode (#195 through 235).

If the exposure value EV is 13.5 or more when the distance region is region 1, if the exposure value is 11.5 or more when the distance region is region 2, if the exposure value EV is 9.5 or more when the distance region is region 3, and if the exposure value EV is 8.5 or more when the distance region is region 4 or 5, the program moves to the step #240 to decide whether or not the average light measurement flag AVRF is set. When this flag AVRF is not set, the program goes to the step #245 to execute the average light measurement subroutine to obtain the average brightness data BV2 for getting the difference between the obtained spot brightness data BV and it so as to decide whether or not the difference is 2EV or more at the step #255. If this difference is 2EV or more, the daylight synchronous flag FILF is set because a primary object is in backlight condition. The program moves to the step #270 to enter the flash photographing mode (#250 through 260).

When the average light measurement flag AVRF is set in the step #240, or when the difference between the average brightness data and the spot brightness data value is less than 2EV, the program moves to the step #265, and moves to the step #390 to be described later to calculate the aperture value AV to move to the flow of the shutter release operation.

The flash photography mode from the step #270 will be described hereinafter. The decision is made as to whether or not the charging operation of the main capacitor of the electronic flashing apparatus FL1 for photographing use has been completed at the step #270. If it has been completed, the program moves to the step #310 to display the completion of the photograph preparation. If the charging operation has not been completed, the decision is made as to whether or not the release button is depressed to the first stroke. When the release button is depressed to the first stroke, it is displayed that the charging operation of the electronic flashing apparatus FL1 is not completed. Then, the removal of the depression of the release button is waited for (#275, 280). After the depression of the release button is removed, the microcomputer MC turns off the transistor Tr1 to cut out the power supply to the control circuit to start the boosting operation of the electronic flashing apparatus FL1 for photographing use (#285, 290). And the timer for battery check use is reset and is started to decide whether or not the charging operation has been completed within ten seconds. When the charging operation has not been completed within ten seconds, the boosting operation is stopped at the step #320, the timer for warning display use is reset and is started at the step #325, the battery check warning is performed for five minutes at the steps #330 and 335. Then, all of the displays are turned off at the step #340, and the flags are reset at the step #345. Thereafter, the microcomputer MC becomes in halt condition at the step #350. If the charging operation is completed

within ten seconds, the program moves to the step #310 to display the completion of the photographing preparation, and moves to the step #355.

In the step #355, the aperture value AV1 used in the flash photographing mode is calculated. The distance value DV in the step #355 is the value which becomes 5, 4, . . . 1 in response to the distance regions 1, 2, . . . 5. For example, supposing that the guide number of the electronic flashing apparatus FLI is 10 with respect to the film sensitivity of ISO 100, and that the distance region detected is the region 2, the distance value DV is 4 and the film sensitivity SV is 5, respectively, if the amount of light emitted by the flashing apparatus FL1. In the case, the calculated aperture value AV1 is 6.5, that is, the F-number of F/9.3. Then, the decision is made as to whether or not this calculated aperture value AV1 is less than 3.5 at the step #357. When it is less than 3.5, it is secured to 3.5 at the step #360 and the program goes to step #362. And the decision is made as to whether or not the daylight synchronous flag FILF is set. When the flag FILF is not set, the aperture value for exposure use is calculated from the exposure value EV fixed by each region to output the data of aperture value AV1 showing the light emitting timing of the flash photographing operation (#385). When the flag FILF is set, the aperture value AV2 based on the average brightness data BV2 is obtained at the step #370 to compare it with the aperture value AV1 of the flash photographing operation (#375). Here, the decision is made whether or not the exposure amount of the primary object becomes proper in the daylight synchronized flash mode.

Generally, the exposure amount of the primary object becomes proper by the flash light while the background thereof becomes in proper exposure by the natural light, in the daylight synchronized flash mode. In the case where the aperture value is determined for the natural light photographing condition, the aperture value AV1 for flash photographing should be compared with the aperture value AV for discriminating whether the primary object located at the detected distance region becomes in proper exposure by the flash light whose intensity is constant. Since the shutter serving also as an aperture diaphragm is gradually opening, the start of flash light emission can be performed at any timing during the opening. Therefore, if the aperture value AV1 is equal to or greater than the aperture value AV, proper exposure can be reproduced with respect to the primary object. Namely, when the aperture value AV1 for the flash photographing operation is equal to or greater than the aperture value AV for the natural-light photographing opera ron, the proper daylight synchronized flash photographing is performed. In the daylight synchronized flash mode, the microcomputer MC outputs the data of the aperture value AV1 as the light emitting timing data of the flash apparatus at the step #385 with the aperture value AV2 of the average light measurement as the control aperture value AV at the step #380. When the primary object is not exposed to the proper exposure by the flash photographing operation even in the backlight condition, the control aperture value AV is obtained in accordance with the brightness value in the spot light measurement to perform the natural-light photographing operation only (#390).

At this time, the microcomputer MC decides whether or not the release operation, i.e., the depression of the release button as far as the second stroke is effected at the step #392. When the release operation is not effected, the program moves to the step #395 to decide whether or not the release button is depressed as far as the first stroke. When the release button is in its depressed position, it returns to the step #390 to wait for the release operation. When the release button is not depressed as far as the first stroke, the program moves to the step #450 to be described later.

When the computer decides, at the step #392, that the release operation is affected, the program enters the release control operation to, first, prohibit the interruption to this flow at the step #397, and the microcomputer MC outputs the distance region data to the AF control circuit AFC at the step #400. Then, the microcomputer MC outputs the start signal to start the driving operation of the objective lens. When the objective lens is driven to the given position in accordance with the data, the switch (S5) showing the AF control completion is turned on, so that the microcomputer MC detects the AF control completion (#410). Then, the date of the control aperture value AV is outputted to the AE control circuit AE, and the AE control start signal is outputted (#415, #420) to the AE control circuit AE. When the light emitting timing data of the flash during the flash photographing operation is sent from the microcomputer MC in the AE control circuit AE, a flash signal is outputted to the electronic flashing apparatus FL1 for photographing use at the given timing in accordance with the data.

When the exposure control is performed in the AE control circuit and the switch S3 showing the exposure completion is turned on, the motor is driven to wind up one frame of the film. When the film is wound up by one frame, the motor is stopped (#425 through 440). The microcomputer MC permits the interruption to this flow at the step #445, and turns off the control circuit at the step #450. Then, the microcomputer MC starts the boosting operation of the electronic flashing apparatuses FL1, FL2 in preparation for the next photographing operation, and the timer for the boosting control use is reset and started at the step #470. The respective boosting operations are stopped when the charging operation is completed in five seconds or five seconds pass, and the display is turned off thereafter. Then, all the flags are reset and the microcomputer MC is in halt condition.

Though the first embodiment of the present invention is described hereinabove in such a manner that, the nearest distance region among the plurality of detected distance regions is provided as the distance region for the focusing operation, in the second embodiment described hereinafter, each light-receiving region is weighted when the distance region is obtained, and the weighted value is added for each distance region to detect which distance region is the most frequent. And the interval between the most frequent distance region and the nearest distance region, for example, in the case of the distance region 1 and the distance region 3 the intermediate distance region, that is, the distance region 2 in the above-described example, is applied as the distance for focusing operation. In the intervals except for it, the nearest distance is provided as the distance for the focusing operation. The brightness detection and the backlight detection are performed as in the first embodiment.

The flow chart for the operation of the microcomputer MC which executes the second embodiment is shown in FIG. 15, FIG. 16. This flow chart shows the

modified example of the AF data subroutine shown in FIG. 12(*a*), and the light measurement data subroutine shown in FIG. 12(*b*) with the entire flow being completely the same as FIG. 11, FIG. 13 and FIG. 14.

The flow chart will be described hereinafter. First, the microcomputer MC sets variables N0 through N4, N10 through N14, and N to 0 at all (#1500 through 1510). The variable N is outputted to the decoder DE2, and the data D1 of the distance region coming from the given light receiving region is inputted (#1515, 1520). Then" the microcomputer MC operates the weighting operation of 3, 2, 1 respectively to the light receiving regions 1, 2 through 5, 6 through 9 with respect to each light-receiving region. When the light-receiving region is 1 (N=0), the α as the weighting data is assumed as 3 (#1535) with this input data D1 being as the data D2 (#1530). If the light-receiving region is 2 through 5 likewise, the α is set to 2. If the light-receiving region is 6 through 9, the α is set to 1 (#1540 through 1550).

Then, the microcomputer MC adds the sum of the number of light receiving regions belonging to each distance region and the weighting data. When the distance region of the light receiving region is 1, 2, ... 5, the weighting data are added respectively to N0, N1, . . . N4, and the number of the light-receiving regions are added to N10, N11 . . . . N14 (#1555 through 1640). The decision is made as to whether or not N has become 9 through addition of 1 to the N. If the N has not become 9, the program returns to the step #1515 to repeat this loop until the N becomes 9. If the N is 9, the program moves to the step #1655 (#1645, #1650), considering that all the distance data have been inputted, and the microcomputer MC obtains the distance region including the light receiving region of the most frequent. In the step #1655, the value of the N0 showing the addition value of the weighted data of the distance region 1 is shifted to the N5, then the data showing that the distance region is 1 is inputted into the variable D3 and the variable I is set to 1 (#1660, 1665). Then, the weighted data N5 established is compared with the NI (I is the established value), for example, the addition value of the weighted value corresponding to the distance region 2 if I=1. If the NI is larger, the value of the N5 is changed to the value NI and the distance region at this time is inputted into D3 (#1670 through 1680).

Even when the NI is equal to or less than N5, the program goes to the next step #1685 to add 1 to the I. And the decision is made whether or not the I has become 5. If the I has not become 5, the program returns to the step #1670. If the I becomes 5, the -microcomputer MC obtains the nearest distance region and the distance between this region and the distance region of the most frequent value to obtain the distance region for the focusing operation. The microcomputer MC obtains the distance region where the value of the weighted data is not 0 in order from the distance region 1 to the distance region 4. The data showing this distance region at a time when the value of the weighted data not been 0 is inputted into D0 to input the number of the light receiving regions in that region into N7 (#1695 through 1760).

When the nearest distance region is one of the regions 1 through 3, the decision is made whether or not the distance between the nearest distance region and the distance region of the most frequent value is only one region. When the distance is one region, the data in the middle region is inputted into the D0 (#1765, #1770), and the program proceeds to the step #1775 of the light measurement data subroutine. When the nearest distance region is the region 4 or 5, the distance between the nearest distance region and the distance region of the the most frequent value does not become 1, the program moves to the step #1775 as soon as the inputting operation to D0, N7 is completed. In the light measurement data subroutine as compared with FIG. 12, the processed content of the microcomputer MC is completely the same except for the N1 being changed into N7.

The present invention is not restricted to this embodiment described hereinabove. The following modified embodiments may be applied.

(1) In the first and second embodiments, the brightness data obtained by the average light measurement of all regions are used for controlling the exposure amount, when the number of light receiving regions in which the nearest distance region is detected or when the central region is not included for detecting the distance region for the focusing operation. However, the exposure amount may be controlled in accordance with the average of the brightness data in all the light receiving regions showing the nearest distance region may be used. Thus, the number of the light receiving region in which the nearest distance region is detected is required to be memorized. The brightness data of the light receiving region are required to be inputted in accordance with this number to provided this average. Also, when the number of the light receiving regions in which the nearest distance region is detected are plural, the average light measurement value of all the regions may be used.

(2) Though the electronic flashing apparatus which is disposed separately from the electronic flashing apparatus for the photographing use is provided as the light emitting means for the distance detection means of the present embodiment, this may use the electronic flashing apparatus for photographing use in common. In the case of the distance detection, the infrared transmission filter of the particular wavelength is required to be provided on the entire face of the light emitting portion. In the case of the photographing operation, such mechanical construction as to remove this filter is required to be provided. Also, the light emitting means may be such a plurality of LEDs as shown in Japanese Patent Application Laid-open Publication Tokkaisho No. 59-146032. Also, one LED may be required with being sequentially scanned.

(3) If the primary object does not become proper with the flashing photographing operation only in the embodiment when the backlight light condition is detected, the photographing operation is switched from the flash photographing mode to the natural-light photographing mode. In addition, in the natural-light photographing operation, the light measuring operation is switched from the average light measurement to the spot one. However, since the film has a latitude, there is no necessity to provide the most proper exposure amount to the primary object. Concretely, if the exposure amount of the primary object is low by 1.5 steps than the most proper exposure amount, the image of the primary object can be reproduced sufficiently by the latitude of the film. Thus, it may be permitted that the exposure amount of the primary object by the flash light is lower by 1.5 steps than the calculated proper exposure amount in daylight synchronized flash photographing.

(4) In addition, the (1) through (3) of the above-described examples may be properly combined with the first, and second embodiments.

(5) Though the distance from the camera to the object is detected with a plurality of regions in the object area to be photographed in the embodiments, the defocus amount of the objective lens may be detected with the plurality of regions.

(6) Since the distance detection and the brightness detection use the common light measuring circuits LM1 through LM9 in the embodiments, the distance detection regions are completely similar to the brightness detection regions, respectively. However, both of the regions may.,be deviated from each other, or the size of both regions may be different from each other.

Although the present invention has been fully described by way of example with reference to the accompanying drawings, it is to be noted here that various changes and modifications will be apparent to those skilled in the art. Therefore, unless otherwise such changes and modifications depart from the scope of the present invention, they should be constructed as included therein.

What is claimed is:

1. Control device for use in a camera having an objective lens, comprising:

means for detecting a distance from the camera to an object to be photographed to produce a distance signal indicative of the detected distance;

means for driving the objective lens in accordance with the distance signal;

means for receiving light coming from a first; region which is a relatively small area in an object area to be photographed to produce a first light receiving signal indicative of the measured amount of light;

means for receiving light coming from a second region which is wider than the first region to produce a second light receiving signal indicative of the measured amount of light;

means for detecting whether a primary object to be photographed is in backlight condition or not, in accordance with the first and second light receiving signals;

means for illuminating the object area;

means for calculating a first aperture value on the basis of the second light receiving signal;

means for calculating a second aperture value on the basis of the distance signal;

means for calculating a third aperture value on the basis of the first light receiving signal;

means for comparing the first aperture value with the second aperture value; and

means for controlling exposure operation of the camera, if the backlight condition is detected, on the basis of the second light receiving signal with energizing the illuminating means when the first aperture value is smaller than the second aperture value, while controlling the exposure operation on the basis of the third aperture value when the first aperture value is equal to or larger than the second aperture value.

2. Control device for use in a camera having an objective lens, comprising:

means for receiving light coming from a first region which is a relatively small area in an object area to be photographed and for producing a first light receiving signal indicative of the measured amount of light;

means for receiving light coming from a second region which is wider than the first region and for producing a second light receiving signal indicative of the measured amount of light;

means for detecting whether or not a primary object to be photographed is in backlight condition on the basis of the first and second light receiving signals;

means for detecting a distance from the camera to an object to be photographed to produce a distance signal indicative of the detected distance;

means for determining an aperture value on the basis of the second light receiving signal and for producing an aperture value signal indicative of the determined aperture value;

means for illuminating the object area;

means for controlling exposure of the camera;

means, if the backlight condition is detected, for discriminating whether or not the primary object will be photographed in under-exposure condition in a flash photograph condition in which the photographing operation is performed by using the illuminating means, on the basis of the distance signal and the aperture value signal; and

means for controlling the illuminating means and the exposure controlling means so that the exposure amount of the camera is determined in accordance with the aperture value signal by energizing the illuminating means if the discriminating means discriminates that the primary object will not be photographed in under-exposure condition, and that the exposure amount of the camera is determined in accordance with the first light receiving signal if the discriminating means discriminates that the primary object will be photographed in under-exposure condition.

3. Control device as claimed in claim 2, wherein the controlling means includes means for prohibiting the operation of the illuminating means if the discriminating means discriminates that the primary object will be photographed in under-exposure condition.

* * * * *

United States Patent [19]

Breitmeier

[11] **Patent Number: 4,948,984**

[45] **Date of Patent: Aug. 14, 1990**

[54] **OPTICAL SCANNING HEAD WITH OBJECTIVE POSITION MEASURING AND MIRRORS**

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[73] Assignee: **Focus MeBtechnik GmbH & Co KG**, Stuttgart, Fed. Rep. of Germany

[21] Appl. No.: **328,587**

[22] PCT Filed: **Jul. 14, 1988**

[86] PCT No.: **PCT/EP88/00527**

§ 371 Date: **Feb. 14, 1989**

§ 102(e) Date: **Feb. 14, 1989**

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PCT Pub. Date: **Dec. 29, 1988**

[30] **Foreign Application Priority Data**

Jun. 16, 1987 [DE] Fed. Rep. of Germany 3720079

[51] **Int. Cl.**[5] **G01N 21/86**; G01J 1/20; H01J 3/14

[52] **U.S. Cl.** **250/560**; 250/201.4; 250/216

[58] **Field of Search** 250/226, 201, 560, 561, 250/227, 216, 201.4, 201.5, 201.3; 369/44, 45, 46; 356/375, 376, 5

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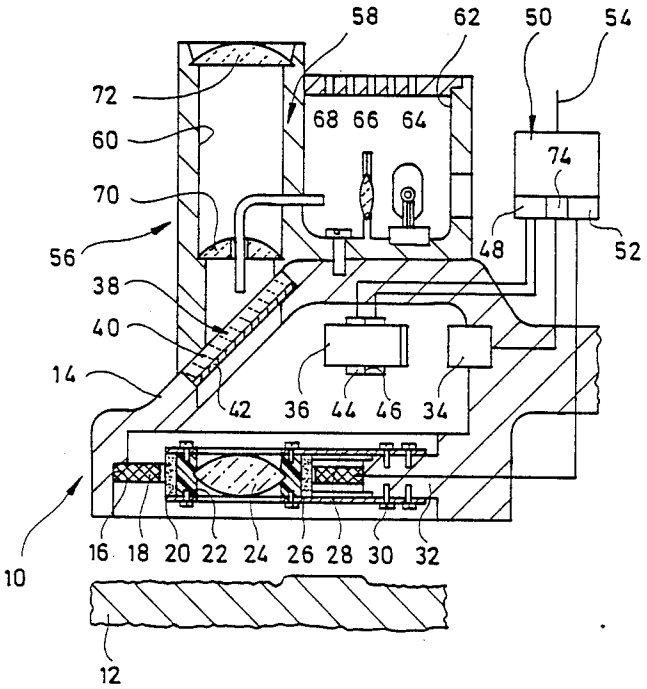
Primary Examiner—David C. Nelms
Assistant Examiner—Michael Messinger
Attorney, Agent, or Firm—Fred Philpitt

[57] **ABSTRACT**

An optical scanning head (**10**) for measuring the surface of a work-piece (**12**) contains an integrated microscope. For this purpose, a deflecting mirror (**38**) located in the wall of the housing (**14**) of the scanning head is constructed as a dielectric mirror, which is impermeable for measured light, on the other hand is permeable for observation light and is also machined to optical quality on its rear side. Seated behind this deflecting mirror (**38**) are a tube lens (**70**) and an ocular lens (**72**), which together with the objective (**24**) of the scanning head (**10**) form a microscope.

9 Claims, 2 Drawing Sheets



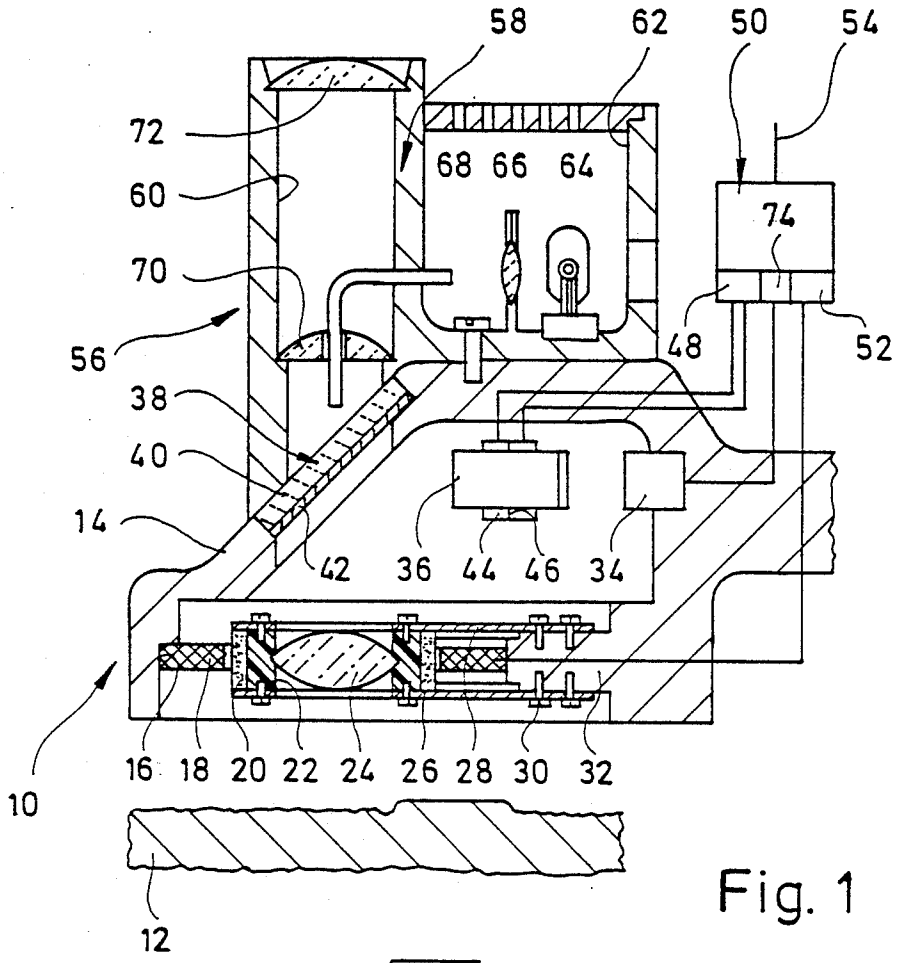

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Fig. 1

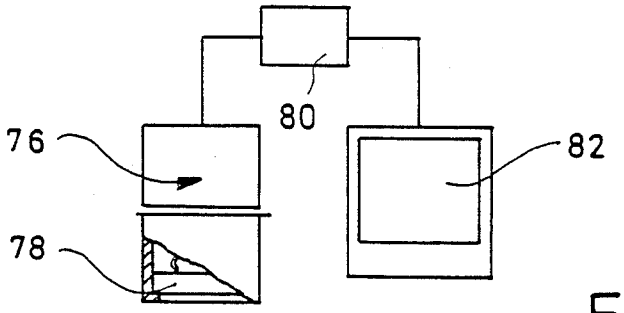
80
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Fig.2

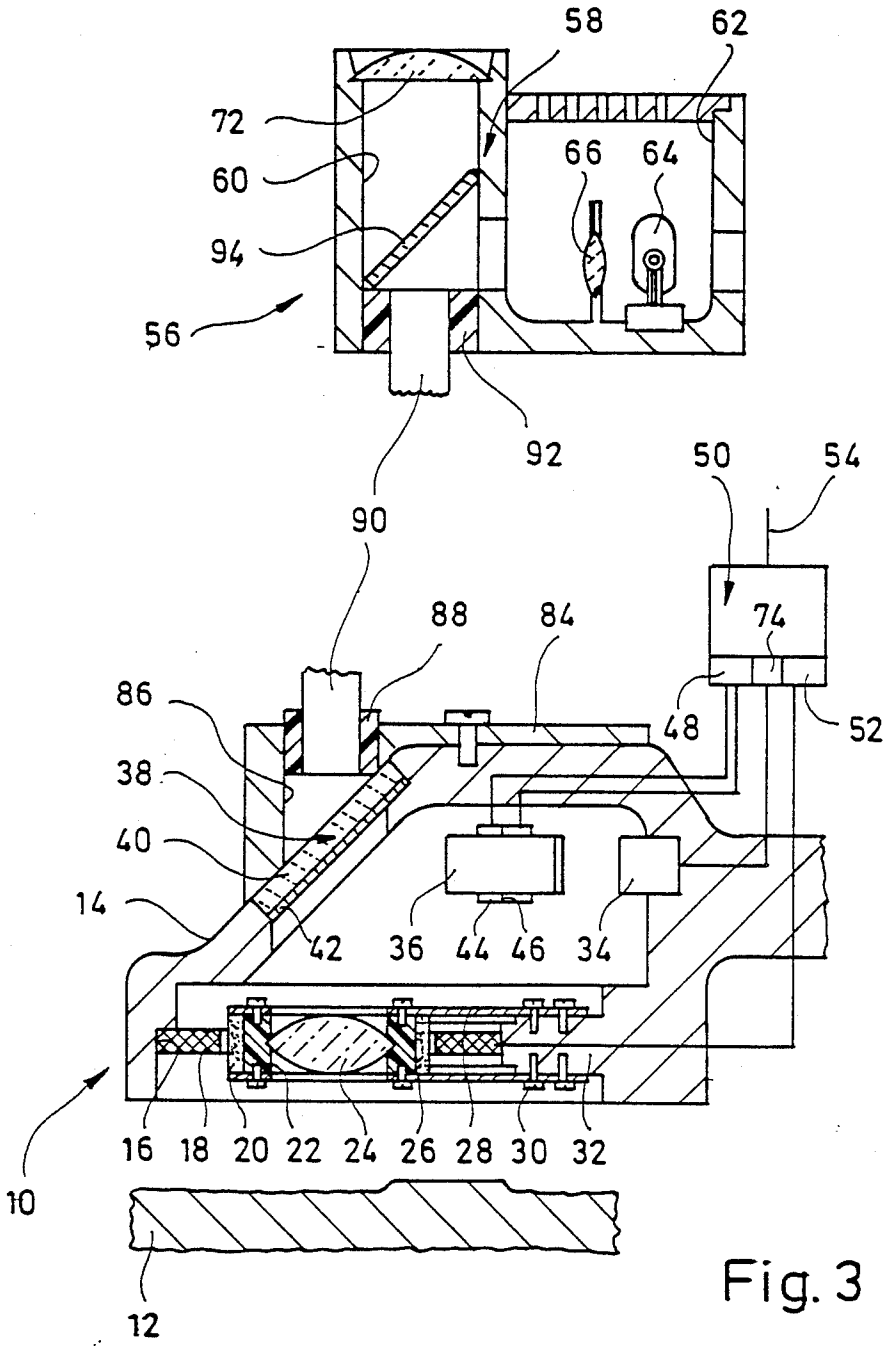
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Fig. 3

OPTICAL SCANNING HEAD WITH OBJECTIVE POSITION MEASURING AND MIRRORS

Optical scanning heads according to this invention are intended for incorporation in CD-players and serve for reading the optical information stored on the CD (compact disc). Due to the fact that the measuring light source is not located on the objective axis, on the contrary on an axis at right angles thereto and the measuring light is focussed by way of a deflecting mirror from the measuring light source by way of the objective on the surface to be scanned, one obtains a particularly low overall height of the scanning head, which makes it possible to produce CD-players with such a low overall height that they correspond to the standard dimensions of car radios.

This type of construction of the scanning head has the further advantage, which is not relevant for use in motor vehicle CD-players, that the path of rays between the measuring light source and objective is accessible for manipulations, since the deflecting mirror is inserted in an opening in the housing of the scanning head.

It was already proposed (DE-OS 35 36 700), to use such scanning heads of CD-players also for the high resolution measurement of the profiling and of the surface roughness of work-piece surfaces. In this case it would occasionally be advantageous if one could also visually inspect the surface section just measured.

It was then recognised that by slightly varying the deflection mirror on an optical scanning head, such as is used in motor vehicle CD-players at very low costs one could provide the additional possibility of direct observation of the point of the work-piece surface just measured.

For this purpose, it is proposed according to the invention to use a deflection mirror, which is indeed impermeable to the measured light, but is permeable for at least one wavelength in the visible region of the spectrum and has optical quality not solely on the reflecting front side, but also on its rear side. One can then position an observation device directly behind this deflecting mirror. Since the deflecting mirror is frequently originally a dielectric mirror, thus comprises a basic member (generally of glass) permeable to visible light, in many cases it is sufficient to remove the easily accessible deflecting mirror, already located on the scanning head intended for CD-players, to additionally polish it to optical quality on its rear side and then to re-install it. The observation optical system may be a commercially available microscope-eye-piece.

The modification according to the invention of the optical scanning head thus allows a visual observation of the respectively measured point of the work-piece surface, with very low additional costs. The additionally provided optical parts do not need to be manufactured specially, they do not require a great deal of space and do not considerably increase the weight of the scanning head.

Since the objectives used in CD-scanning heads have a very short focal length (in practice 4.5 mm) and also have a small diameter (in practice 6–8 mm), these objectives correspond very closely to microscope objectives. Thus, together with a commercially available microscope-eye-piece, according to the invention one obtains a microscope integrated in the scanning head.

With the development another embodiment of the invention a visual inspection of the measuring point is then possible even if the ambient light is very poor and the scanning head casts shadows. The observation device containing the scanning head and illumination device forms a compact, smooth-surfaced unit. Furthermore, the observation light falls exactly onto the measuring point, so that the illumination device requires only low power.

The development of the invention according to another embodiment is an advantage with regard to a solely low overall height even of the modified scanning head.

The development of the invention according to another embodiment ensures that one can carry out the visual observation of a point of the work-piece surface and the measurement of this point simultaneously, without the measurement result being adulterated and indeed even if the photoelectric transducer arrangement is sensitive per se to visible light, as is generally the case.

It is frequently necessary to measure work-piece surfaces at points which are not easily accessible and in this case the development of the invention according to another embodiment facilitates the visual inspection with the microscope integrated in the scanning head in a manner which is not tiring for the operator. Very compact solid state image converters with extremely good resolution can be obtained at relatively low prices as a vidicon replacement in television cameras. They can be connected simply to a monitor by way of the electronics developed for this camera.

The development of the invention according to another embodiment is an advantage with regard to the simple equipping of such scanning heads, which originally offer no possibility for direct observation of the measuring point.

The development of the invention according to another embodiment facilitates convenient observation of the measuring point from a distance.

With the development according to another embodiment it is ensured that the observation light source can be separated spatially from the scanning head, which is an advantage with regard to protection from heat, without additional measures as regards apparatus having to be taken for guiding the observation light to the measuring point.

The invention is described in detail hereafter by means of two embodiments, referring to the drawings, in which:

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a diagrammatic, vertical section through an optical scanning head for the high-resolution measuring of a work-piece surface;

FIG. **2** is a diagrammatic view of a modified ocular insert with integrated image converter and a monitor connected thereto, for use with the scanning head according to FIG. **1**; and

FIG. **3** is a similar sectional view to FIG. **1** through a modified scanning head.

DESCRIPTION OF PREFERRED EMBODIMENTS

In FIG. **1**, a scanning head is designated generally by the reference numeral **10**, which serves for the high accuracy measurement of surface roughnesses and surface structures on the surface of a work-piece **12**.

The scanning head **10** has a housing **14**, which is substantially cup-shaped. Securely inserted in a lower opening **16** in the housing **14** is a toroidal coil **18**, which produces an axial magnetic field. The toroidal coil **18** co-operates with an annular permanent magnet **20**, which is stuck to the outside of an objective ring **22**. The objective ring **22** retains an objective **24**. The unit formed by the permanent magnet **20**, the objective ring **22** and the objective **24** penetrates the toroidal coil **18** with radial clearance and is supported by two leaf springs **26, 28** extending parallel to each other, the section of which located on the left in FIG. **1** is constructed in the form of spectacles, so that the objective **24** remains free, whereas the section located on the right-hand side is in the form of a strip and is fixed at its outermost end by screws **30** to a cross-piece **32** of the housing **14**. The leaf springs **26, 28** thus form a resilient parallelogram suspension for the objective **24**.

Fixed in the section of the peripheral wall of the housing **14** located on the right in FIG. **1** is a semi-conductor laser **34** operating in the red. The laser beam emitted by the latter penetrates a semi-permeable measuring mirror **36** and reaches a deflecting mirror **38**. The latter consists of a glass backing member **40** and a dielectric layer **42** applied to its under side, which is chosen so that the deflecting mirror **38** reflects the laser beam. The latter then passes through the objective **24** and is focussed by the latter on the surface of the work-piece **12**.

The laser light reflected by the work-piece surface is focussed by the objective **24** and passes by way of the deflecting mirror **38** back to the measuring mirror **36**. The latter separates part of the reflected measuring light and directs it to a photoelectric transducer arrangement **44**, the centre of which is indicated at **46**. The photoelectric transducer arrangement **44** produces an output signal, which depends on the position of the incident light with regard to the centre line **46**. This output signal passes to an input amplifier **48** of an operating circuit associated with the scanning head **10** and designated generally by the reference numeral **50**.

The operating circuit **50** contains switching circuits not shown in detail, which ascertain the deviation of the instantaneously obtained output signal of the transducer arrangement **44** from that signal which is obtained at the time of incidence of the measuring light upon the centre line **46**. Corresponding to the difference between these two signals, the operating circuit **50** produces a fault signal for a power amplifier **52**, which supplies the toroidal coil **18**. The feed current for the toroidal coil **18** is increased or reduced until the measuring light spot on the transducer arrangement **44** again lies on the centre line **46**. This is the case when the distance between the objective **24** and the illuminated point of the surface of the workpiece **12** corresponds exactly to the objective focal length.

From the description given so far, it can be seen that when the scanning head **10** moves over the surface of the workpiece **12**, the objective **24** travels axially as this corresponds to the surface profile of the work-piece **12**. Due to position-measuring means co-operating with the objective ring **22** or by measuring the feed current for the toroidal coil **18** necessary for balancing, an electrical signal changing with the surface profile is thus produced. For the purposes of the present description it is assumed that this signal (possibly after correction for non-linearities in the drive system formed by the toroidal coil **18**, the permanent magnet **20** and the leaf springs **26, 28**) is derived from the magnitude of the toroidal coil feed current. This measuring signal is made available on a lead **54**.

The scanning head described so far corresponds in its construction to scanning heads as they are used in CD-players for motor vehicles.

However, in the scanning head illustrated in FIG. **1**, a device for the visual observation of the point of the work-piece surface measured is also provided by way of addition. For this purpose, the rear side of the glass backing member **40** is polished to optical quality. This can take place simply due to the fact that the deflecting mirror present in the commercially available CD-scanning head is removed from the housing **14** and is polished to optical quality on its rear side, whereupon the deflecting mirror **38** is then re-introduced into the housing **14**.

The observation device designated generally by the reference numeral **56** has a housing **58**, which defines a tube **60** and a lamp chamber **62**. Located in the lamp chamber **62** is a halogen lamp **64**, the coiled filament of which is focussed by way of a lens **66** on the end of a bent light guide **68**. The latter penetrates the tube **60** and lies with its light guide section extending vertically downwards on the axis of the objective, thus also on the axis of the tube **60**.

Inserted in the tube **60** is a tube lens **70**, which may be a plastic lens. In order to achieve the lowest possible overall height of the total arrangement, the tube lens **70** may be drilled in the centre and the lower end of the light guide **68** may be guided therethrough, as shown in the drawing. An ocular lens **72** is inserted in the upper end of the tube **60**.

The light emitted by the halogen lamp **64** passes by way of the light guide **68**, through the deflecting mirror **38** and by way of the objective **24** to the work-piece surface, where it is focussed. The observation light reflected by the work-piece surface passes partly through the deflecting mirror **38** again and passes through the tube lens **70** and the ocular lens **72** into the eye of an observer. For this, the objective **24**, the tube lens **70** and the ocular lens **72** form a microscope, through which details of the work-piece surface can be observed with magnification. The point of the work-piece surface observed in this way is exactly that which is also measured using the laser light.

Part of the observation light reflected by the work-piece surface also passes by way of the deflecting mirror **38** and the measuring mirror **36** to the transducer arrangement **44**. This light could disturb the subsequent guidance of the objective **24** and thus the measurement of the work-piece surface, if the visual observation and the measurement take place simultaneously. In order to prevent this, the semi-conductor laser **34** is excited in pulses by an associated feed circuit **74** of the operating circuit **50** and the input amplifier **48** is constructed as a phase-sensitive rectifier, so that non-modulated portions of light, which likewise fall onto the transducer arrangement **44**, do not impair subsequent adjustment of the objective position.

FIG. **2** shows an ocular member **76**, which can be inserted in the upper end of the tube **60** in place of the ocular lens **72**. The ocular member **76** contains a solid state image converter **78** in such an axial position, as it is used in television cameras, that the real image of the work-piece surface produced by the tube lens **70** lies on the light-sensitive surface of the image converter **78**. The image converter **78** is connected by way of camera

electronics **80**, which may correspond completely to the commercially available electronics of portable television cameras, to a monitor **82**. On this monitor, the microscope image of the region of the work-piece surface just measured may thus be observed at the same time as measuring of the work-piece surface. This observation is thus conveniently possible, without there being any risk that when looking into the ocular, the observer accidentally comes into contact with the scanning head **10** and thus mechanically influences the very precisely predetermined path along which the scanning head is drawn over the work-piece surface. Furthermore, in this way, a convenient visual inspection of the work-piece surface is also possible if the scanning head operates in poorly accessible places, for example measures cylinder bores or the like.

In the embodiment according to FIG. **3**, parts which have already been described above, are given the same reference numerals; they are not described in detail hereafter.

The housing **58** is separated from the housing **14** and in its place an adaptor plate **84** is screwed on, which defines a tube **86**. Fixed in the latter by means of a resilient clamping sleeve **88** is one end of a flexible, coherent fiber cable **90**. The latter comprises a plurality of glass or synthetic fibers bunched in an orderly manner and can thus transmit an image. The other end of the fiber cable **90** is fixed by a resilient clamping sleeve **92** in the lower end of the tube **60** of the housing **58**.

Also inserted in the tube **60** is a mirror **94** which is semipermeable to the observation light, which mirror deflects the observation light produced by the halogen lamp **64** and converted by the lens **66** into a beam of parallel rays, into the fiber cable **90** and allows the light reflected back by the work-piece surface to travel to the ocular lens **72**.

What is claimed is:

1. An optical surface scanning head which includes a measuring light source defining a light source axis, preferably a solid state laser, with an objective for focusing the measuring light source on a work-piece surface and having an objective axis which is inclined with respect to said light source axis and preferably intersects the latter at right angles, a deflecting mirror which is impermeable for the measuring light which is located at the intersection point of the objective axis and light source axis and has a light receiving front side and an opposing rear side, a measuring mirror which is semi-permeable for the measuring light and which is located between the measuring light source and the objective, preferably between the measuring light source and the deflecting mirror, a photoelectric transducer arrangement which is acted upon by the measuring light deflected by the measuring mirror returning from the work-piece surface and produces an output signal dependent on the incidence point of this measuring light, an adjusting device for axially moving the objective, a control circuit by which the adjusting device is actuated depending on the output signal of the transducer arrangement so that the output signal of the transducer arrangement assumes a given value, and means for producing a measuring signal corresponding to the objective position characterized in that the deflecting mirror (**38**) is permeable for at least one light wave length not contained in the measuring light spectrum and also has optical quality on its rear side, and in that an observation optical system (**70, 72**) is located behind the deflecting mirror (**38**).

2. A scanning surface head according to claim **1** characterized in that an illuminating device (**64–78**) makes available observation light with at least one wavelength not contained in the measuring light spectrum, on the axis of the objective (**24**).

3. A scanning surface head according to claim **2** characterized in that the illuminating device comprises an illuminating light source (**64**) located laterally beside the objective axis and means (**68**) for deflecting the observation light onto the objective axis, in particular a curved light guide (**68**).

4. A scanning head according to claim **1** characterized in that the measuring light source (**34**) produces modulated measuring light and the output signal of the transducer arrangement (**44**) is processed by a phase-sensitive rectifier (**48**).

5. A scanning head according to claim **1** characterized in that the observation optical system comprises a tube lens (**70**) and an ocular lens (**72**).

6. A scanning head according to claim **1** characterized in that the observation optical system comprises a tube lens (**70**) and a solid state image converter (**78**).

7. A scanning head according to claim **2** characterized in that the observation optical system (**70, 72, 78**) and optionally the illuminating device (**64–78**) are located in an additional housing (**58**) attached to the housing (**14**) of the scanning head.

8. A scanning head according to claim **1** characterized in that the observation optical system comprises a coherent fiber cable (**90**).

9. A scanning head according to claim **8** characterized by means (**94**) for introducing observation light (**64**) into the fiber cable (**90**).

* * * * *

United States Patent [19]

Kino et al.

[11] **Patent Number: 4,927,254**

[45] **Date of Patent: May 22, 1990**

[54] **SCANNING CONFOCAL OPTICAL MICROSCOPE INCLUDING AN ANGLED APERTURED ROTATING DISC PLACED BETWEEN A PINHOLE AND AN OBJECTIVE LENS**

[75] Inventors: **Gordon S. Kino**; **Guoqing Xiao**, both of Stanford, Calif.

[73] Assignee: **The Board of Trustees of the Leland Stanford Junior University**, Stanford, Calif.

[21] Appl. No.: **226,044**

[22] Filed: **Jul. 29, 1988**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 31,516, Mar. 27, 1987, abandoned.

[51] **Int. Cl.**[5] **G02B 21/06**

[52] **U.S. Cl.** ..... **350/507**; 350/527; 350/508; 350/399; 350/274; 350/276 SL

[58] **Field of Search** ..... 350/507, 508, 274, 273, 350/272, 527, 526, 1.2, 525, 524, 399, 276 SL; 250/234, 225, 235, 236

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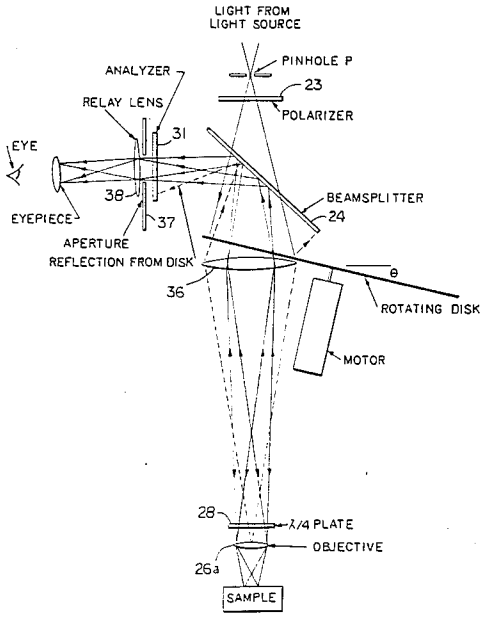
Primary Examiner—Jon W. Henry

Attorney, Agent, or Firm—Flehr, Hohbach, Test, Albritton & Herbert

[57] **ABSTRACT**

A scanning confocal optical microscope using a Nipkow disc having a plurality of pinholes to project light and an objective lens to receive the light and illuminate points on an object to be viewed. Rotation of the disc scans the points across the object. The object is viewed by viewing the reflected light focused on the pinholes by the ojective lens.

13 Claims, 10 Drawing Sheets



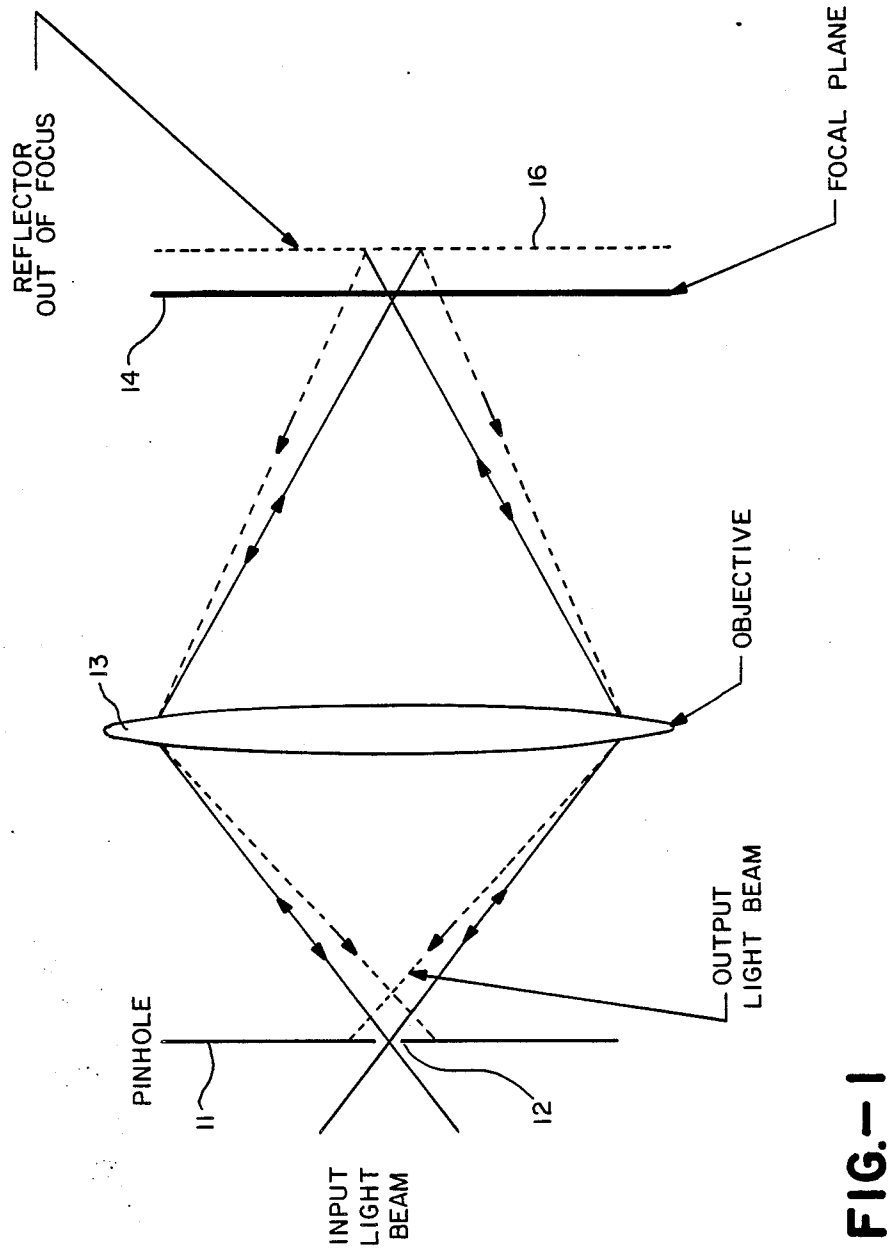

REFLECTOR OUT OF FOCUS
16
FOCAL PLANE
14
OBJECTIVE
13
OUTPUT LIGHT BEAM
PINHOLE
11
12
INPUT LIGHT BEAM

FIG.—1

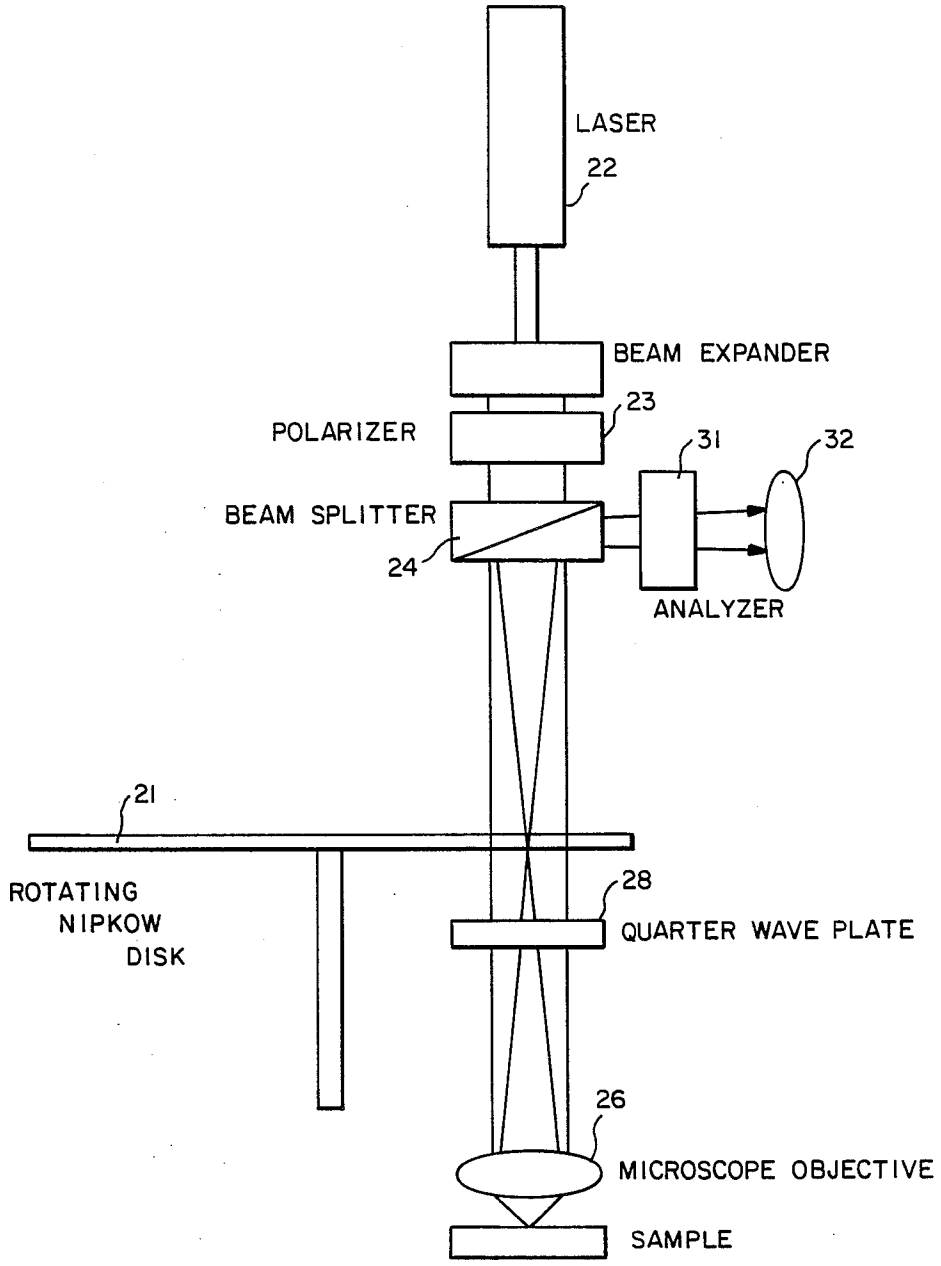

LASER
22
BEAM EXPANDER
23
POLARIZER
31
32
BEAM SPLITTER
24
ANALYZER
21
ROTATING
NIPKOW
DISK
28
QUARTER WAVE PLATE
26
MICROSCOPE OBJECTIVE
SAMPLE

FIG. —2

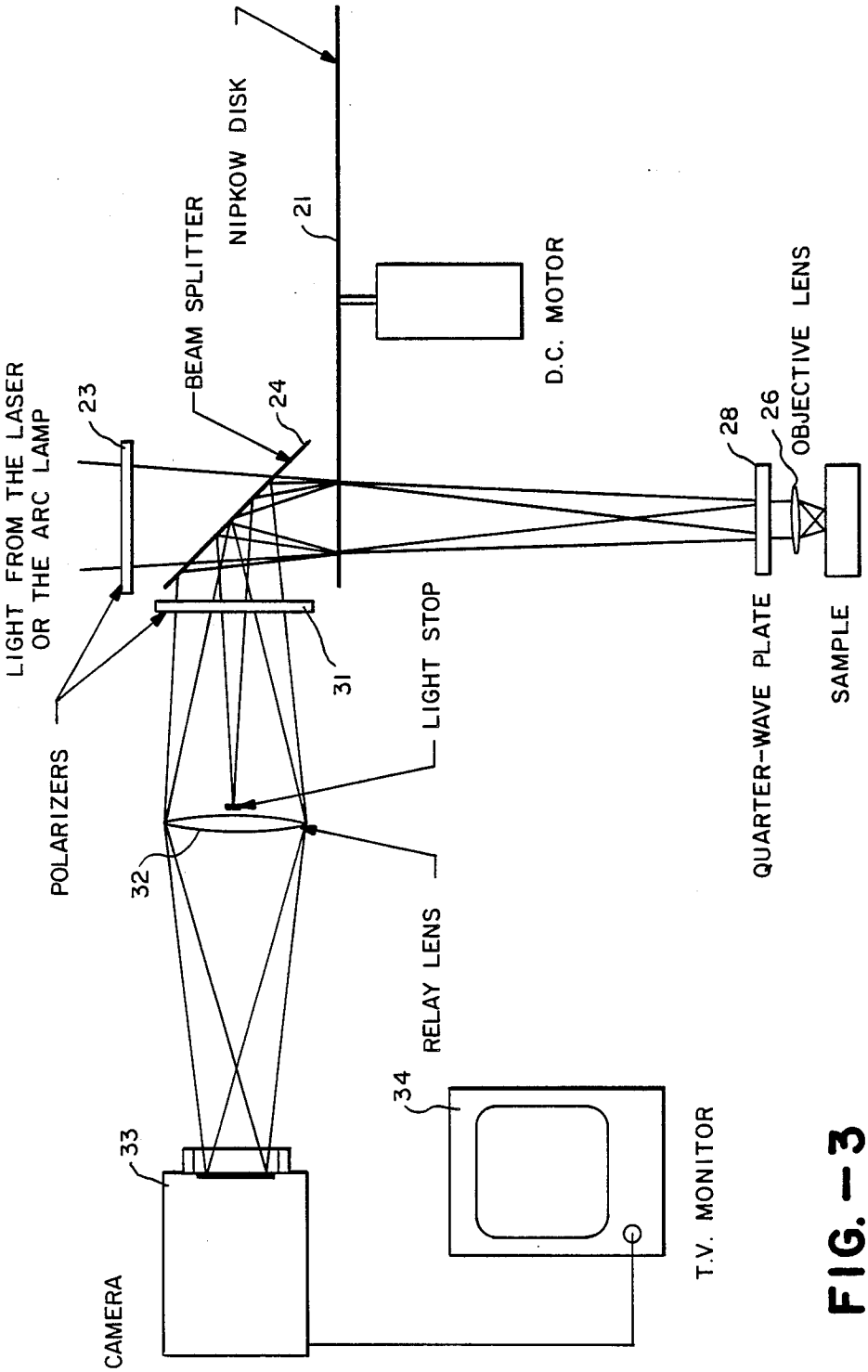

LIGHT FROM THE LASER OR THE ARC LAMP
23
BEAM SPLITTER
NIPKOW DISK
21
24
D.C. MOTOR
28
26
OBJECTIVE LENS
POLARIZERS
31
LIGHT STOP
QUARTER-WAVE PLATE
SAMPLE
32
RELAY LENS
34
33
CAMERA
T.V. MONITOR

FIG. -3

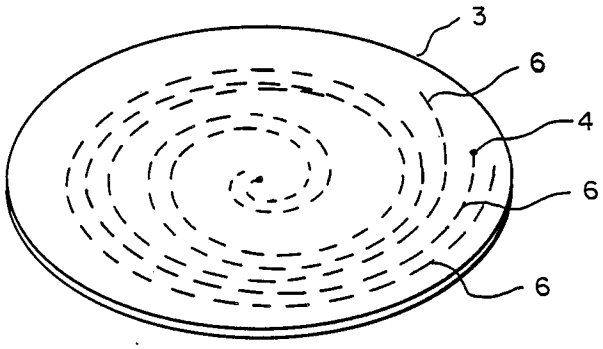


FIG. – 4

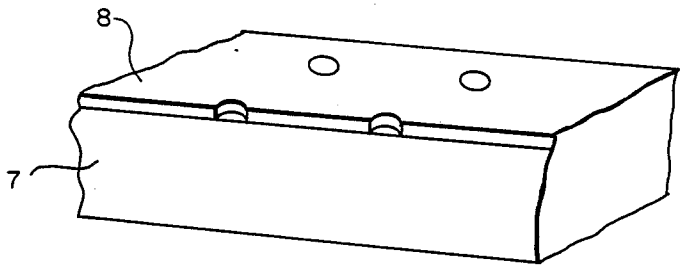


FIG. – 5

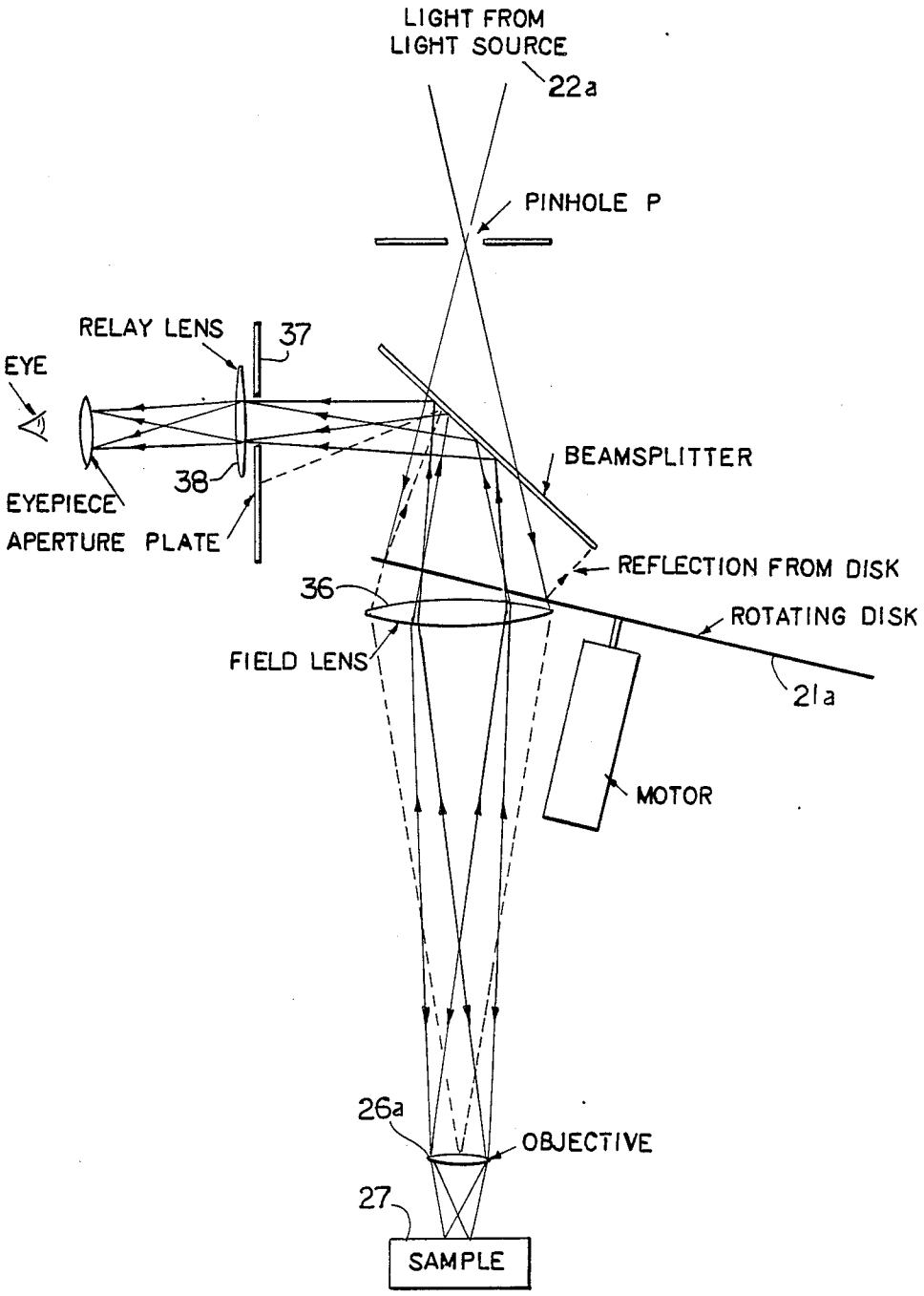

LIGHT FROM
LIGHT SOURCE
22a
PINHOLE P
RELAY LENS
37
EYE
BEAMSPLITTER
38
EYEPIECE
APERTURE PLATE
REFLECTION FROM DISK
36
ROTATING DISK
FIELD LENS
21a
MOTOR
26a
OBJECTIVE
27
SAMPLE

FIG.-6

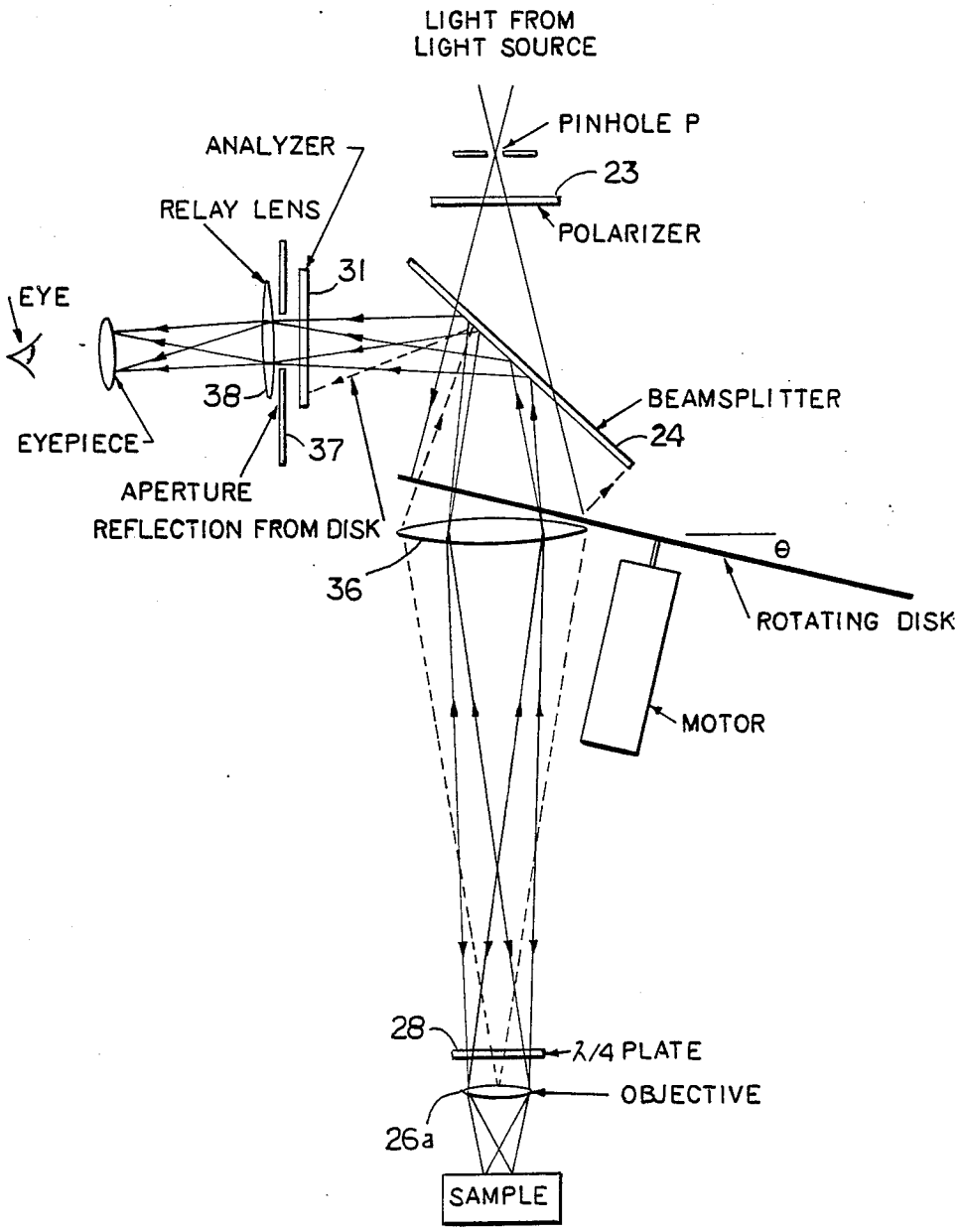

LIGHT FROM
LIGHT SOURCE
PINHOLE P
23
POLARIZER
ANALYZER
RELAY LENS
31
EYE
38
EYEPIECE
37
APERTURE
REFLECTION FROM DISK
BEAMSPLITTER
24
θ
36
ROTATING DISK
MOTOR
28
λ/4 PLATE
OBJECTIVE
26a
SAMPLE

FIG.—7

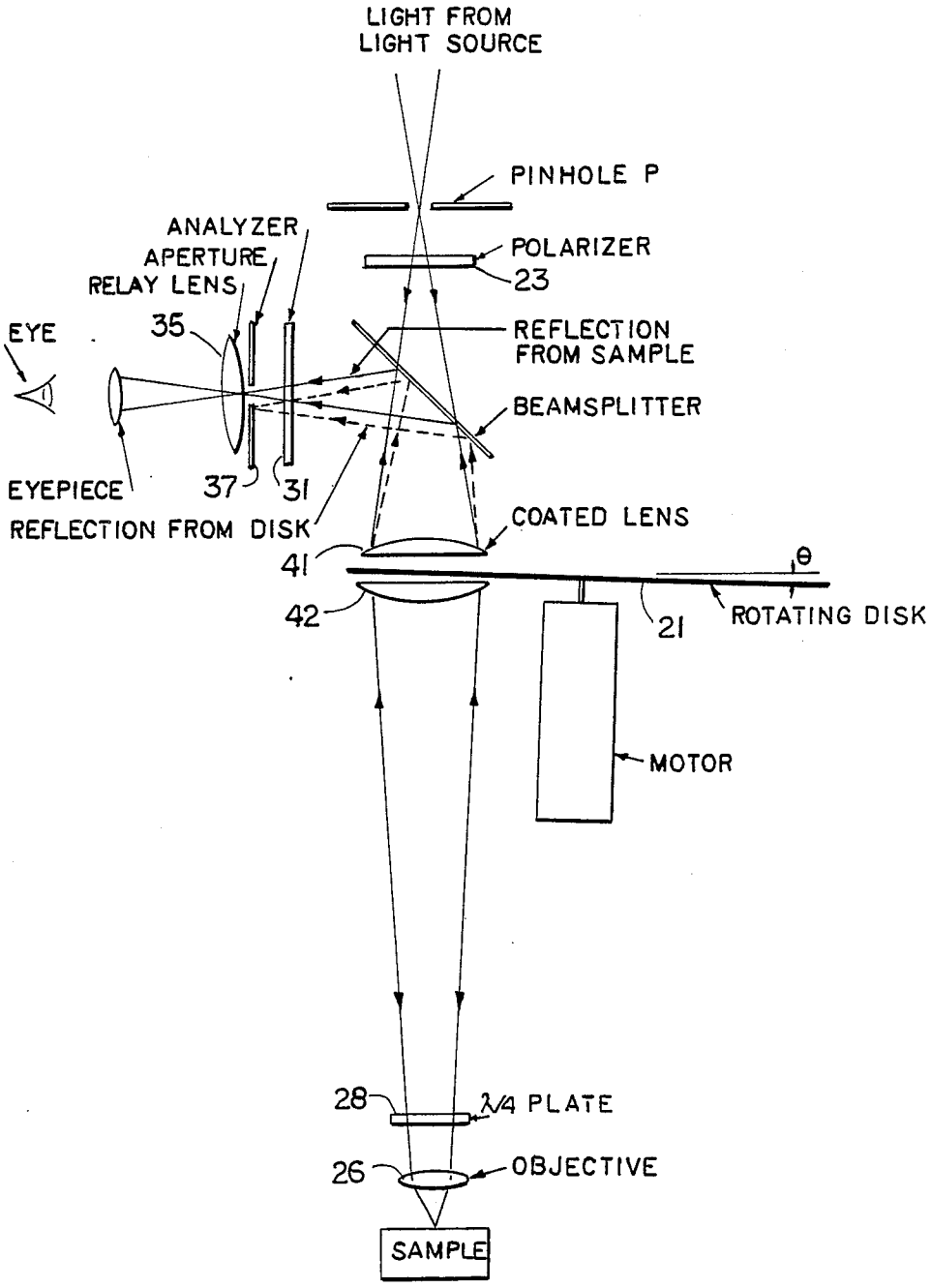

LIGHT FROM
LIGHT SOURCE
PINHOLE P
ANALYZER
APERTURE
RELAY LENS
POLARIZER
23
EYE
35
REFLECTION
FROM SAMPLE
BEAMSPLITTER
EYEPIECE
37
31
REFLECTION FROM DISK
COATED LENS
41
θ
42
21
ROTATING DISK
MOTOR
28
λ/4 PLATE
26
OBJECTIVE
SAMPLE

FIG.-8

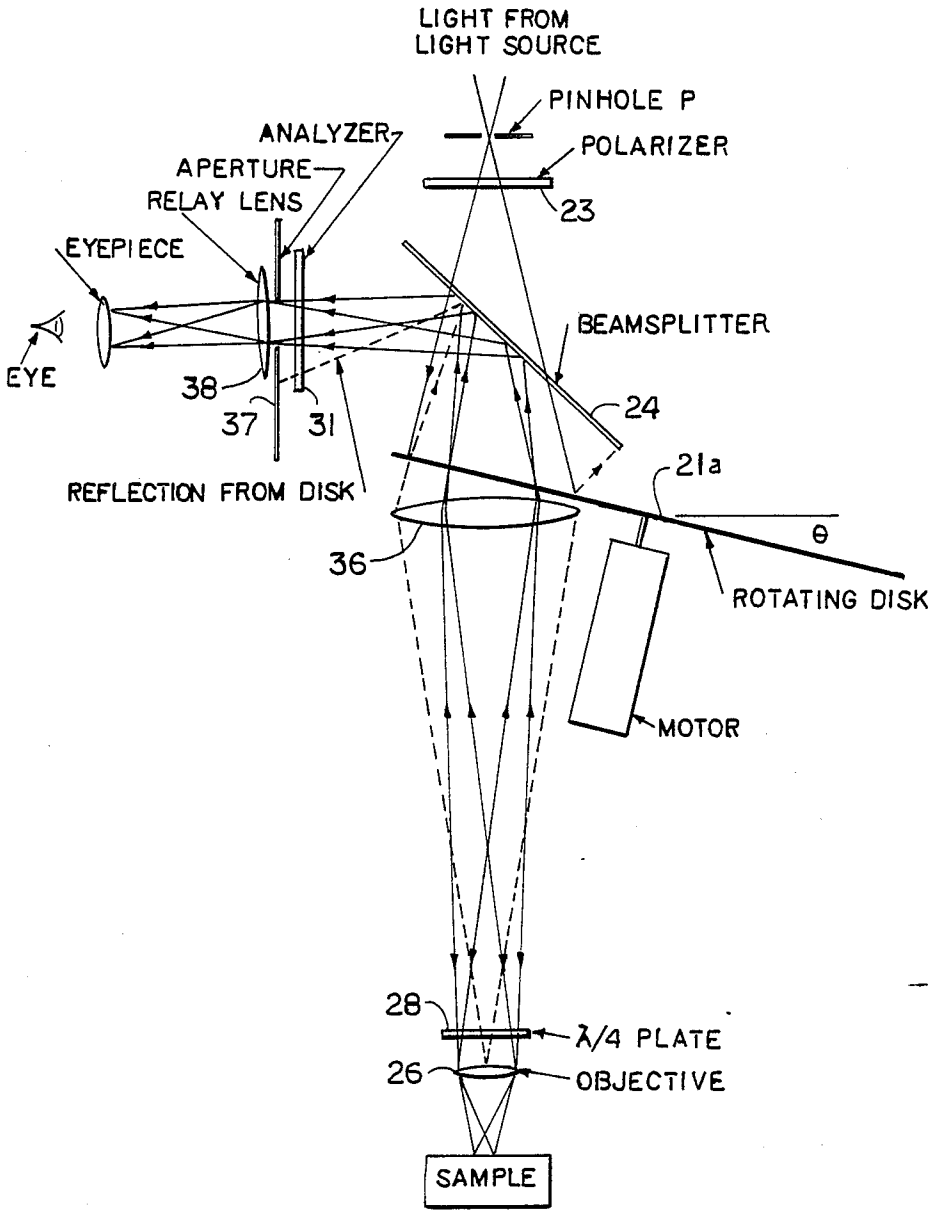

LIGHT FROM
LIGHT SOURCE
PINHOLE P
POLARIZER
23
ANALYZER
APERTURE
RELAY LENS
EYEPIECE
EYE
BEAMSPLITTER
38
37
31
24
21a
REFLECTION FROM DISK
θ
36
ROTATING DISK
MOTOR
28
λ/4 PLATE
26
OBJECTIVE
SAMPLE

FIG.-9

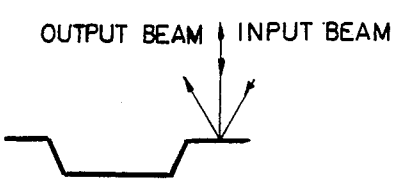


FIG.-10A

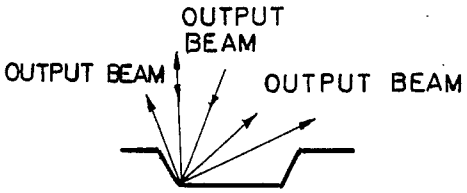


FIG.-10B

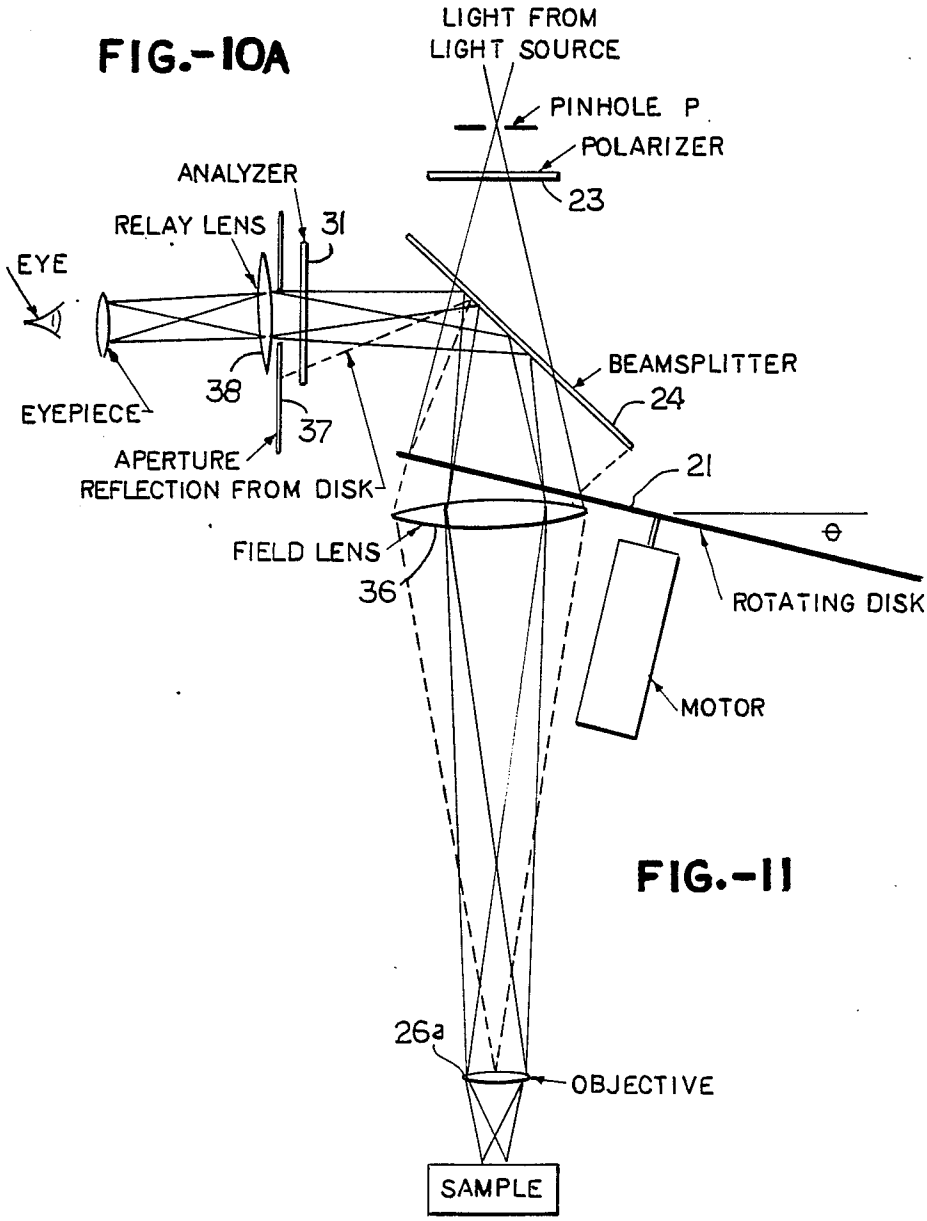


FIG.-11

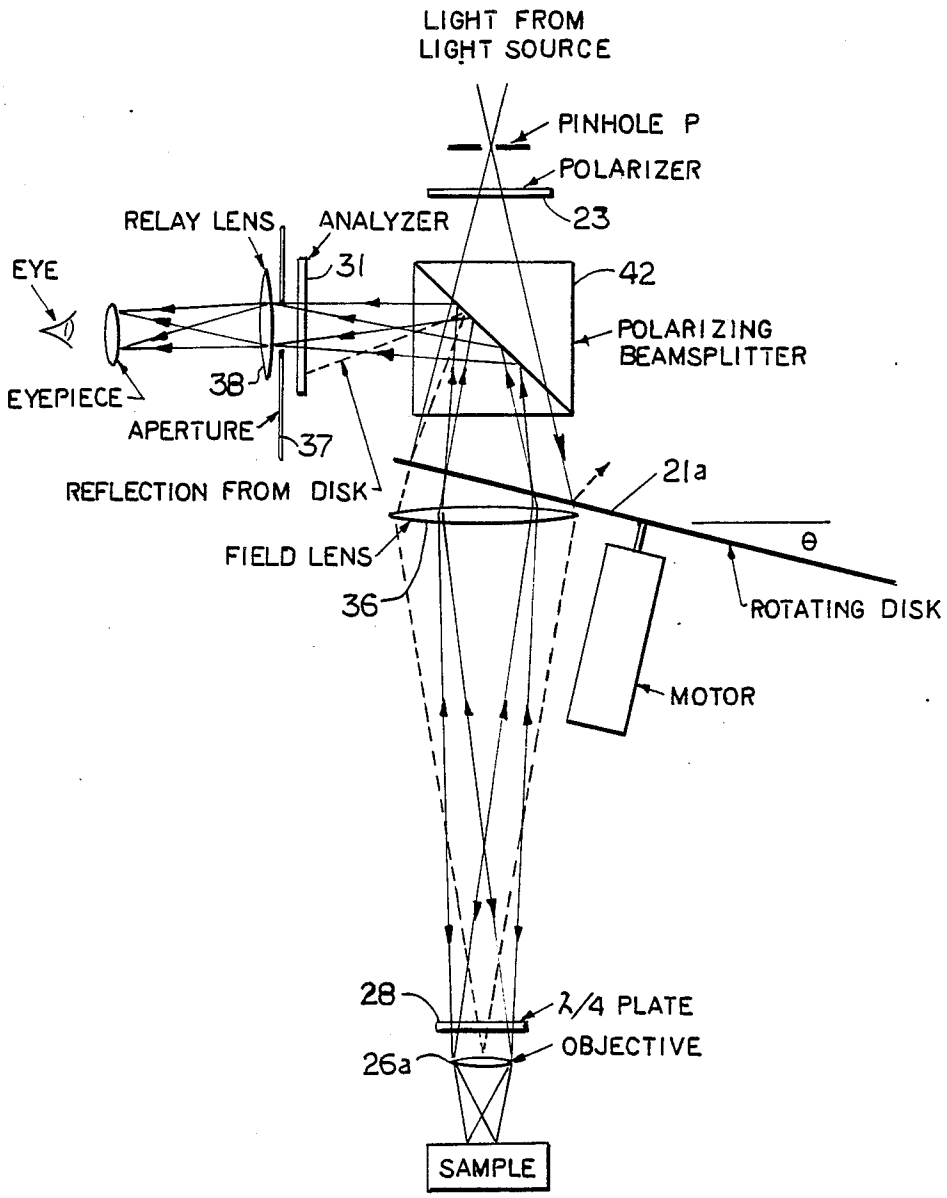

LIGHT FROM
LIGHT SOURCE
PINHOLE P
POLARIZER
23
RELAY LENS
ANALYZER
31
42
EYE
POLARIZING
BEAMSPLITTER
EYEPIECE
38
APERTURE
37
REFLECTION FROM DISK
21a
θ
FIELD LENS
36
ROTATING DISK
MOTOR
28
λ/4 PLATE
OBJECTIVE
26a
SAMPLE

FIG.-12

SCANNING CONFOCAL OPTICAL MICROSCOPE INCLUDING AN ANGLED APERTURED ROTATING DISC PLACED BETWEEN A PINHOLE AND AN OBJECTIVE LENS

This application is a continuation-in-part of copending application Ser. No. 031,516 Filed Mar. 27, 1987 now abandoned.

FIELD OF THE INVENTION

This invention relates generally to confocal optical microscopes and more particularly to a scanning confocal optical microscope.

BACKGROUND OF THE INVENTION

Conventional confocal optical microscopes are known for their extremely short depth of focus and improved transverse resolution. The main drawback with conventional confocal scanning optical microscopes is that they illuminate only one point on the object at a time. To scan the object either the sample or beam must be mechanically moved to form a raster image of the object. Mechanical scanning is time consuming.

In a paper appearing in The Journal of the Optical Society of America, Vol.58, No.5, May 1968, there is described a tandem-scanning reflected-light microscope. In the described microscope both the object plane and the image plane are scanned in tandem so that only light reflected from the object plane is included in the image. The object to be viewed is illuminated with light passing through plurality of holes in a rotating disc which are focused onto the object by an objective lens. Thus, a large number of points on the object, corresponding to the holes which are illuminated, are illuminated at one time. The holes themselves are located along spiral paths. By rotating the disc a raster scan of the object is obtained. Reflected light from the illuminated spots is directed to the opposite side of the same apertured disc and passes through optically congruent holes on diametrically opposite sides of the rotating disc. The image obtained had better contrast and sharpness than possible with the usual reflected-light microscope. This is due to the fact that reflected light from within the microscope and other stray light coming from other points is intercepted by the opaque portions of the disc and the image only comprised reflection from the illuminated spots. The system of the prior art is extremely complex and difficult to align because of the necessity of assuring that the light reflected from the illuminated spots must pass through congruent holes on the opposite side of the rotating disc.

The present invention employs the principals of a confocal optical microscope such as illustrated schematically in FIG. **1**. Light input from a laser, arc lamp or other light source impinges upon a plate **11** which includes a pinhole **12**. The light travels through the pinhole to the objective lens **13** and is focused on the object plane **14**. Light reflected from the object plane travels back through the pinhole as shown and can be viewed. Reflection from out of focus planes such as plane **16** does not converge at the pinhole and is therefore blocked by the plate **11**. In operation the reflected light passing through the pinhole impinges upon an associated detector. The detector output is maximum when the object is located at the focus of the lens, otherwise the light received at the pinhole is defocused and the amplitude of the signal falls off rapidly as the position of the object is changed on either side of the object plane. The system has a very short depth of focus in addition to excellent transverse definition.

As previously described, such a microscope can be mechanically scanned to form a raster image by moving the object or pinhole in a raster pattern.

OBJECTS AND SUMMARY OF THE INVENTION

It is a general object of the present invention to provide a scanning confocal microscope which overcomes the mechanical alignment problems of the prior art Tandem Scanning Microscope and which presents a total image of the object without the necessity of mechanical scanning of the light beam or object.

It is another object of the present invention to provide a confocal microscope employing a rotating apertured scanning disc in which reflections from the disc and other stray light is eliminated from the image making it possible to observe weakly reflecting objects.

In accordance with the invention there is provided a scanning microscope for viewing an object which comprises a scanning disc with a plurality of holes arranged in a predetermined pattern and a light source for illuminating a portion of said disc. A polarizer receives the light from the source and polarizes the light prior to the light illuminating the disc. A lens focuses light diffracted through said plurality of illuminated holes onto an objective lens which focuses a plurality of spots on the object. The objective lens receives light reflected from the object spots and focuses the light on the corresponding pin hole. A quarter wave plate is interposed between the objective lens and the disc.

A beam splitter receives the reflected light traveling through the holes and directs the light to a polarizer. Means are provided for rotating the disc to scan the spots across the object in a raster scan to provide an image of the region of the object illuminated by the spots.

In other embodiments the disc is tilted to deflect reflections from the rotating disc so that they do not impinge on the image of the object.

BRIEF DESCRIPTION OF THE DRAWING

The foregoing and other objects of the invention will be more clearly understood from the following description taken in connection with the drawings of which:

FIG. **1** shows a prior art confocal optical microscope.

FIG. **2** shows a scanning confocal optical microscope in accordance with the present invention.

FIG. **3** shows another embodiment of the scanning confocal microscope in accordance with the invention.

FIG. **4** is a perspective view of a Nipkow disc used in the present invention.

FIG. **5** is an enlarged view of a section of the disc of FIG. **1** showing its construction.

FIG. **6** shows an embodiment of the invention with tilted disc.

FIG. **7** shows an embodiment similar to that of FIG. **6** with analyzer, polarizer and quarterwave plate.

FIG. **8** shows an embodiment similar to that of FIG. **7** with a split field lens.

FIG. **9** shows an embodiment of the invention with dark field imaging.

FIGS. **1O***a* and **10***b* illustrate how the dark field stop of FIG. **9** operates.

FIG. 11 shows another embodiment of the present invention.

FIG. 12 shows an embodiment of the invention using a polarizing beam splitter.

DESCRIPTION OF THE PREFERRED EMBODIMENT(S)

Referring to FIG. 2, the microscope includes a circular disc 21, known as a Nipkow disc, which has holes 4 disposed in a pattern of several interleaved spirals 6 of several turns each, FIGS. 4 and 5. The holes are spaced approximately ten hole diameters apart. In one example the average radius of the spiral was five centimeters and the spiral extended over a radial distance of 1.8 centimeters with a total of 200,000 holes of 20 micrometer diameter formed in the periphery of the disc. Preferably the disc is of transparent material 7 with a layer 8 of black emulsion or black chrome in which the holes 4 are formed by photo masking techniques.

A suitable light source, for example, either a mercury arc lamp or a laser 22, is used to illuminate an area of 1.8 centimeters by 1.8 centimeters containing about 4,000 holes. The light from the light source is polarized by a polarizer 23 and passes through a beam splitter 24 before striking the disc 21. The holes diffract the impinging light and the incident beam converges on objective lens 26. For example, the incident beam converges to a five millimeter diameter on the back of the objective lens 26 so that 4,000 points on the object 27 are simultaneously illuminated. Because of the spacing of the image points there is negligible interference between the different illuminated points.

The disc is rotated, for instance, at 2,000 rpm and since the holes are arranged along the spiral path the rotation of the disc forms a raster scan across the object, thus forming 7,000 lines 500 frames per second.

The light focused on the object is reflected and focused at the same pinholes by the objective lens after traveling through a quarter wave plate 28. The light passing through the holes strikes a beam splitter 24 and is directed at right angles there from to an analyzer 31 and thence can be viewed by the naked eye through a transfer lens 32 which focuses on the pinholes.

In the embodiment of FIG. 3, where like reference numerals are applied to like parts, the image travels through a relay lens to a camera 33 and to a TV monitor 34 which provides a display. Alternately the camera may be a photographic camera which takes a picture of the object. It is to be noted that no precise alignment is needed. The same holes are used for transmission and reception of the light making it relatively simple to align the microscope. The eyepiece, or camera, is focused on the pinholes illuminated by reflected light from behind the pinholes. Centering of the spiral is not critical. Vibration is not a severe problem provided that disc vibration has an amplitude much less than the depth of focus of the lenses at the pinholes, typically a distance greater than 1 millimeter.

The use of the polarizer, analyzer and a quarterwave plate reduces interference from reflections from the disc as well as the surfaces of the microscope elements by a factor of the order of 10^{-4} intensity and provide a clear visual image.

With reference to FIG. 3 the apparatus also includes a light stop which is located at the focal point of the incident light reflected from the surface of the Nipkow disc.

The purpose of this stop is to completely remove all remaining reflected light from the disc When a laser source is employed, the stop is placed at the focus of the reflected converging beam. With a lamp source, an image of the source is focused on the stop. With an incoherent light source of finite diameter, the stop must be larger than it would need to be with a coherent light source. Nevertheless the stop would only intercept a very small fraction of the area of the beam passing through the pinholes to the observer. The microscope can be constructed with solely a light stop, and this may be disadvantageous when an object having a low reflectivity is being viewed.

The object or the objective lens can be moved up or down in order to focus on various planes in a translucent object such as a biological material like bone, or at various levels of a sample such as an integrated circuit. A very similar system can be used as a range sensor in robotic applications.

In the robotic application the Nipkow disc is illuminated by a collimated laser beam with, perhaps, as much as several watts in the beam. The pinholes in the disc are viewed as described in FIG. 3. Images of the pinhole are focused on a distant plane by a camera lens. The beam, after leaving the pinhole, may be expanded by a telescope to give a larger beam at the lens pupil. This is to make it possible to use a lens of larger aperture so as to obtain the optimum transverse and range definitions.

When the Nipkow disc is rotated a region at the focal plane of the lens is imaged. Thus a direct real time image of a plane at a fixed distance from the lens is obtained in real time. Images of other cross sections are easily obtained by moving the lens back and forth. This can be used to control a robot.

In the embodiments to be described, the rotating disc is tilted to eliminate reflections from the rotating disc making it possible to observe weakly-reflecting objects.

Referring to FIG. 6, light from a light source 22*a*, such as a mercury arc lamp, a filament lamp or a laser, is focused onto a pinhole P whose diameter is made small enough to get a fairly good point source consistent with providing sufficient illumination of the sample. The diameter of the pinhole is typically in the range from 100 μm to 1 mm. The light emerging from the pinhole passes through a beamsplitter 24 and through the pinholes in the rotating disc 21*a*. It then proceeds through a field lens 36 and through the objective lens 26*a* and strikes the sample. In FIG. 6, the dashed lines indicate the ray paths if the disc were not present, similar to a standard microscope; without the disc, the pinhole would be imaged onto the center of the objective lens. When the rotating disc is present, the light passes through the pinholes in the disc. The light from an individual pinhole in the disc is diffracted into an Airy pattern at the pupil of the objective lens. The center of this Airy pattern is always located at the center of the objective lens, due to the focusing of the image of the pinhole P by the field lens onto the objective, as already described. Thus, the shape and intensity of the illumination at the objective lens does not vary very much from one pinhole to another. Therefore, the definition and the intensity of the illumination of the sample is approximately uniform over the field of view.

The spacing of the rotating disc from the objective is typically of the order of 200 mm and the diameter of the pinhole is chosen so that the illumination of the objective by one pinhole in the disc is fairly uniform. This implies that the pinhole diameter should be small

enough so that the pupil of the objective lens is smaller than the diameter of the zeroth order lobe of the pinhole at the pupil. In turn, this implies that light passing through the pinhole, reflected from the sample through the objective lens, is focused to a spot at the pinhole which is larger than the diameter of the pinhole. Typically, this spot also has the form of an Airy pattern. Thus, this pinhole also acts like a spatial filter to the reflected light. If h is the distance from the objective to the rotating disc, a is the radius of the pinhole, and b is the radius of the pupil of the objective lens, then, without the field lens present, the ratio of the amplitude of the field at the edge of the pinhole to that at its center is $J_1(2\pi ab/h\lambda)/(2\pi ab/\lambda h)$ where $\lambda$is the wavelength and J_1 is a first order Bessel function. For best definition, the pinhole should be infinitesimal in diameter. However, to pass enough light through the pinhole, the pinhole size must be finite, and for optimum performance, $ab/h\lambda < 0.61$ and preferably $ab/h\lambda$ is of the order of 0.25.

With the spacings used, this implies that the pinhole diameter is typically in the range of 10–20 μm. When the pinhole diameter is infinitesimal, the beam passing through the pinhole is diffracted into a 2 λ solid angle. In this case, the objective lens is illuminated uniformly by the diffracted beam from the pinhole. As the pinhole diameter is made larger, the diffraction angle of the beam passing through the pinhole becomes smaller and the objective lens is nonuniformly illuminated. With too large a pinhole diameter, the intensity of illumination at the pupil of the objective lens is largest at its center, falls off towards its edges, and includes higher order sidelobes so that the effective aperture of the objective lens is reduced from its value with uniform illumination. Therefore, the definition of the microscope image is deteriorated when the pinhole size is too large. A further major disadvantage of using too large a pinhole is that the variation of the intensity of the output, when there is a plane reflecting sample present, is not as rapid with distance from the focus as it is with an infinitesimal pinhole. Put another way, if the pinhole diameter is made too large, then the short depth-of-focus dictated by the principle of the confocal microscope is no longer obtained and the device behaves more like a standard microscope.

It should be noted that it is not advisable to make the pinhole diameter too small, for then not enough light passes through the pinhole. In order to eliminate interactions between the light passing through individual pinholes, particularly when using a laser source, it is necessary to have the pinhole spacing on the disc of the order of ten pinhole diameters apart. Thus, less than one percent of the light reaching the disc passes through the pinholes. Therefore, it is vitally necessary to eliminate the reflected light from the disc itself.

One technique for doing this was described above with reference to FIGS. **2** and **3**. A preferred technique is shown in FIG. **6**. The disc is tilted sufficiently far so that the light reflected from the disc hits an aperture plate **37** in front of the relay lens **38** and is eliminated. This is schematically illustrated by the dotted area showing the reflections from the disc. The plane of this aperture plate is placed at the mirror image position of the plane of the pinhole P with respect to the beamsplitter. The image of a pinhole on the disc is focused on the eyepiece **39**, which in turn implies than an image of the sample can be seen at the eyepiece. The tilt angle of the disc θ can be compensated by tilting the sample by an angle θ/M, where M is the magnification of the objective lens **26***a*.

In the embodiment of FIG. **7**, polarizer **23**, analyzer **31**, and $\lambda/4$ plate **28** as in the embodiments of FIGS. **2** and **3** are added. Light from the light source is polarized, and when reflected from the disc and the beamsplitter, passes through an analyzer rotated at 90 degrees to eliminate the polarized light reflected from the disc. The polarization of the beam passing through the objective lens through the $\lambda/4$ plate and reflected back through it again is rotated by 90 degrees, and hence passes through the analyzer. Hence, the image of the sample can be observed, but the light from the disc is eliminated by two strategems, tilt and polarization.

A further improvement on this system is to split the field lens into two parts, **41** and **42**, one between the disc **21** and the sample and the other on the top side of the disc **21**, as shown in FIG. **8**. The upper lens **41** collimates the beam from the pinhole P to produce a parallel beam at the disc. Without the disc present, the lower lens focuses the collimated beam to a point on the pupil plane of the objective lens. The beam reflected from the disc is now focused by the upper field lens **41** to a point on the aperture **37** in front of the relay lens **38**. This aperture is placed in a plane which is the mirror image in the beam splitter of the plane of the pinhole P. The reflected light passing through the pinhole of radius a is diffracted so that the first zero of the Airy pattern of the diffracted beam from the pinhole is of radius $R=0.61\ \lambda L/a$, where L is the distance of the pinhole P from the upper field lens. Typically L is 75 mm, a=10 micrometers and R=2.5 mm. with λ=0.54 mm. This implies that the focused spot corresponding to the reflection from the disc should be placed a distance slightly greater than R from the center of the aperture pinhole. Thus the tilt angle of the disc need only be of the order of $\theta=R/2L$ or 1 degree.

This makes it still easier to eliminate the reflected light, in particular to eliminate any stray light due to diffraction of the light beam and the granularity of the film on the rotating disc. By this means, it is only necessary to tilt the rotating disc by one or two degrees instead of the order of five degrees, as in FIGS. **6** and **7**, since the diameter of the beam that must be eliminated at the aperture in front of the relay lens is relatively small. This has the further advantage that with a small tilt, the depth of focus is much larger than the change in height of the disc from one side of the beam to the other.

In the embodiments shown in FIGS. **6** and **7**, the quality of the image tends to deteriorate at the edges of the field because of the large tilt of the rotating disc that is required. The polarizer and analyzer, along with the $\lambda/4$ plate, are still used to improve the signal-to-noise ratio of the wanted signal to the reflected light from the disc still further. With this system, reflected light from the disc is below the level of all other sources of light in the defocused beam. For example, when the beam is badly defocused as the sample is moved out of the focal plane of the objective lens, it might be expected that approximately one percent of the reflected light from the sample would still pass through pinholes (their total area being assumed to be 1% of the illuminated area of the disc), and would give rise to background light, which is difficult to eliminate. This phenomenon dictates the lower level of the dynamic range of the system.

Another embodiment of this microscope which is useful for certain purposes is that of dark field imaging.

In FIG. **9** a stop is placed over half of the back of the objective. The presence of this stop eliminates light directly reflected from a specular reflector. For example, as shown in FIG. **10***a*, a ray A impinging on the objective lens of sample returns along a path like ray B. However, with the stop in place, no light returns along path B and hence a specular reflector cannot, in principle, be seen. However, light from a corner or a sharp edge scatters in all directions and some will go through the lens to regions where the stop is not present, as shown in FIG. **10***b*. Therefore, the system forms a dark field imaging system with the short depth-of-focus of the real-time scanning optical microscope. Such a system is particularly good for looking at holes in photoresist and other materials where the beam can enter through the region of the hole and not through the photoresist itself. In this case there is no aberration of the beam by the photoresist and the light reflected from the top and bottom corners of the hole makes it possible to make measurements of the depth and slope of the hole. In general, dark field imaging can be obtained if the shape of the stop is chosen so as to eliminate light directly reflected from a specular reflector.

A problem, and sometimes an advantage, of this type of microscope is the chromatic aberration of the objective lens. The depth-of-focus of this microscope can be of the order of 0.5 micrometers or less with a 0.9 aperture lens. When a white light source is used, however, different colors tend to be focused at different depths due to the chromatic aberration of the lens and the chromatic aberration in the focal plane can be as much as several micrometers with a white light source. This has the advantage that the microscope can be useful for inspection because different depths appear in different colors. On the other hand, for quantitative measurements, it is better to observe a beam focused on a given surface by determining when the intensity is maximum. This is best done by placing an optical filter in front of the pinhole or in front of the relay lens so that a relatively narrow band of light reaches the eye or the TV camera.

A further version of this microscope is suitable for polarization imaging. In this case, shown in FIG. **11**, the polarizer **23** and analyzer **31** are used with the analyzer rotated so that its plane of polarization is at 90 degrees to the polarizer. However, the $\lambda/4$ plate shown in FIGS. **2**, **3**, **7**, **8** and **9** is omitted. Therefore, a dark field image is obtained from a reflector which does not rotate the plane or polarization. Edges and dielectric materials rotate the plane or polarization of the beam upon reflection and therefore show up in polarization image. The system is also useful for observing reflections from magnetic materials such as a magnetic disc of the type used for computer storage. It is also apparent that the system will have the same depth-of-field as the standard confocal microscope.

Another embodiment of the microscope which can provide the advantage of less light loss than with the use of a plate beamsplitter, is to employ a polarizing beamsplitter **42**, as illustrated in FIG. **12**. Light from a laser source, mercury arc lamp or filament lamp is first linearly polarized by the polarizing beamsplitter **42** then passes through the apertures, field lens **36** and quarterwave plate **28** to the objective lens **26**. The light returning from the object has it polarization rotated by 90 degrees after passing back through the quarterwave plate and therefore is reflected by the beamsplitter **42** to the relay lens and then to the eyepiece, while the light reflected from the disc passes back to the illuminator, since its plane of polarization has not been rotated. In order to further suppress the background reflection from the disc and from the surfaces of the beamsplitter, a polarizer **23** and an analyzer **31** is used in this embodiment. The advantage of the beamsplitter is that very little light is lost in passing through it. In a normal beamsplitter, half the power is wasted on each transit through it. Furthermore, the polarizing beamsplitter also acts as a polarizer and an analyzer itself, so the overall background reflections can be lower compared to the other embodiments.

We claim:

1. A scanning microscope for viewing an object comprising:

a light source;

a pinhole for receiving light from said light source;

an objective lens disposed to focus light from said pinhole onto said sample surface area;

an apertured rotating disc placed between said pinhole and said objective lens with the axis of rotation of said disc at an angle with respect to the axis of the light from said pinhole passing through apertures in said apertured rotating disc to said objective lens and sample, said objective lens serving to focus light reflected at said sample surface onto said rotating disc whereby light reflected from said surface is transmitted through said apertures; and

means for directing said transmitted light onto an image plane and for eliminating from said image plane light from the pinhole reflected by said rotating disc.

2. A scanning microscope as in claim **1** wherein said means for eliminating from said image plane light reflected by the rotating disc comprises an apertured member which interrupts the reflected light and passes transmitted light through the aperture.

3. A scanning microscope as in claim **2** wherein said means for eliminating light reflected from said rotating disc from the image plane includes additionally a polarizer for polarizing light from said pinhole;

a quarterwave plate for receiving the light from said pinhole and the light reflected by the sample surface and an analyzer for receiving the transmitted light.

4. A scanning microscope as in claims **1**, **2** or **3** including a stop adjacent to and between said objective lens and the object being viewed to stop light specularly reflected at said sample surface.

5. A scanning microscope as in claims **1**, **2** or **3** including a beam splitter for passing light from said pinhole to the objective lens and for reflecting and directing the transmitted light.

6. A scanning microscope as in claim **5** in which said beam splitter is a polarizing beam splitter.

7. A scanning microscope as in claims **1**, **2** or **3** including a field lens for receiving light from said pinhole and focusing it onto said objective lens.

8. A scanning microscope as in claim **7** in which said field lens is a split lens with one half on each side of said rotating disc to pass collimated light through said apertures.

9. A scanning microscope for viewing an object comprising a scanning disc with a plurality of pinholes arranged in a predetermined pattern;

a light source on one side of said disc for illuminating an area of said disc;

a first polarizer for polarizing the light which illuminates the disc;

an objective lens on the opposite side of said disc for focusing light diffracted by said pinholes onto the object to illuminate a plurality of points on said object;

means for mounting said disc with its rotational axis at an angle with respect to the axis of light from said source to said objective lens;

means for rotating said disc to scan the points across the object;

said objective lens serving to receive light reflected from the object and focus the light on corresponding pinholes;

a quarterwave plate interposed between said objective lens and disc to intercept the light traveling to and reflected from said object;

a beam splitter on said one side of said disc between said first polarizer and said quarterwave plate for receiving reflected light traveling through said quarterwave plate and said pinholes and directing it; and

a polarizer for receiving the directed light.

10. A scanning microscope as in claim **9** including a light stop disposed to stop light reflected from the disc.

11. A scanning microscope as in claim **9** in which the holes are disposed in a pattern of several interleaved spirals of several turns each.

12. A scanning microscope as in claim **9** in which the disc includes an apertured dark layer on the surface of a transparent disc.

13. A scanning microscope as in claim **9** wherein said means for eliminating from said image plane light reflected by the rotating disc comprises an apertured member which interrupts the reflected light and passes transmitted light through the aperture.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 4,927,254

DATED : May 22, 1990

INVENTOR(S) : Gordon S. Kino, et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

At column 1, line 4, insert --This invention was made with Government support under Contract No. N00014-84-K-0327 awarded by the Department of the Navy. The Government has certain rights in this invention.--

Signed and Sealed this

Eleventh Day of April, 1995

Attest:

BRUCE LEHMAN

Attesting Officer

Commissioner of Patents and Trademarks

United States Patent [19]

Akada et al.

[11] **Patent Number: 4,923,848**

[45] **Date of Patent: May 8, 1990**

[54] **IMAGE FORMATION ON OBJECTIVE BODIES**

[75] Inventors: **Masanori Akada; Yoshikazu Ito; Jumpei Kanto,** all of Tokyo; **Mitsuru Takeda,** Yokohama; **Masaki Kutsukake,** Tokyo; **Noritaka Egashira,** Ichikawa; **Shunsuke Mukasa,** Tokyo; **Takao Suzuki,** Kawagoe; **Hideo Hosoi,** Tokyo; **Yasuo Otatsume,** Chiba, all of Japan

[73] Assignee: **Dai Nippon Insatsu Kabushiki Kaisha,** Japan

[21] Appl. No.: **138,384**

[22] PCT Filed: **Apr. 10, 1987**

[86] PCT No.: **PCT/JP87/00228**

§ 371 Date: **Dec. 8, 1987**

§ 102(e) Date: **Dec. 8, 1987**

[87] PCT Pub. No.: **WO87/06195**

PCT Pub. Date: **Oct. 22, 1987**

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Apr. 11, 1986	[JP]	Japan	61-81989
Sep. 24, 1986	[JP]	Japan	61-223896
Sep. 24, 1986	[JP]	Japan	61-225473
Oct. 1, 1986	[JP]	Japan	61-231224
Jan. 14, 1987	[JP]	Japan	62-5066

[51] **Int. Cl.**[5] **B41M 5/035;** B41M 5/26

[52] **U.S. Cl.** **503/227;** 8/471; 156/235; 427/256; 427/331; 427/372.2; 428/195; 428/913; 428/914

[58] **Field of Search** 8/471; 428/195, 913, 428/914; 503/201, 227; 427/256, 261, 331, 372.2; 156/235

[56] **References Cited**

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4,645,705	2/1987	Abbott	156/235

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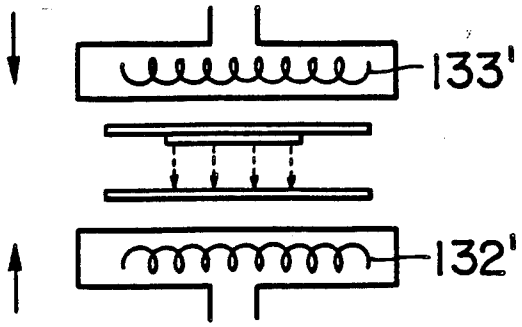
Primary Examiner—Bruce H. Hess
Attorney, Agent, or Firm—Arnold, White & Durkee

[57] **ABSTRACT**

The present invention relates to image-formation on any selected kind of objective body. The characterizing features reside in such that, based upon fed image data, required images are formed on an image-transferable sheet acting for imaging carry-over service and in reliance on sublimation image transfer technique, and then, by the use of said sheet with said images thus formed thereon, the formed images thereon are transferringly applied on the objective body. By adopting the above measures, the objective body can be formed sharply and clearly with any desired images, irrespective of kind and configuration thereof, with such superior results of highly improved unity and solidability between the formed images and the objective body to be decorated with.

11 Claims, 16 Drawing Sheets



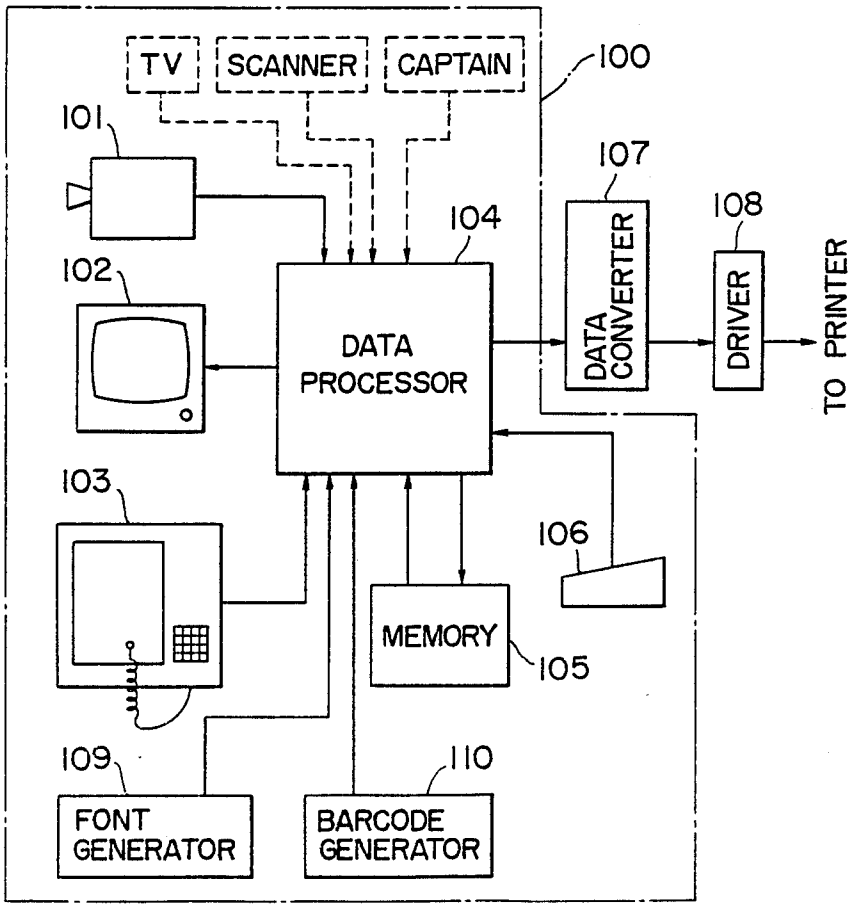

TV
SCANNER
CAPTAIN
100
101
107
108
104
102
DATA PROCESSOR
DATA CONVERTER
DRIVER
TO PRINTER
103
106
MEMORY
105
109
110
FONT GENERATOR
BARCODE GENERATOR

FIG. 1A

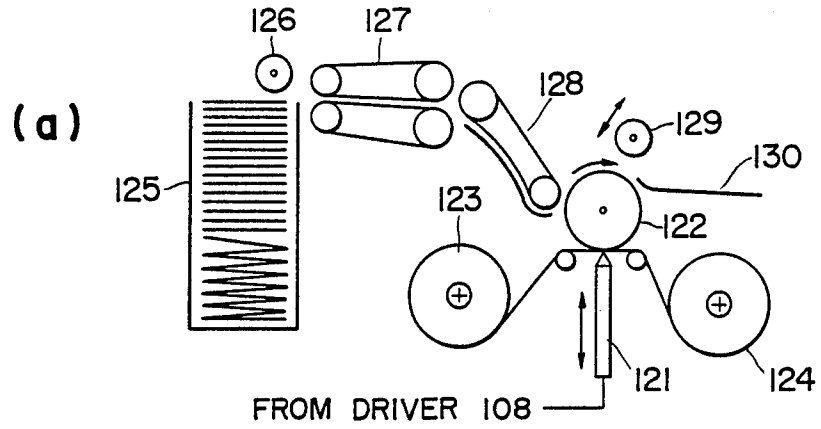

(a)
126
127
128
129
130
125
123
122
121
124
FROM DRIVER 108
(b)
131
134
122
133
123
200
121
124
132
FROM DRIVER
(c)
133'
132'

FIG. 1B

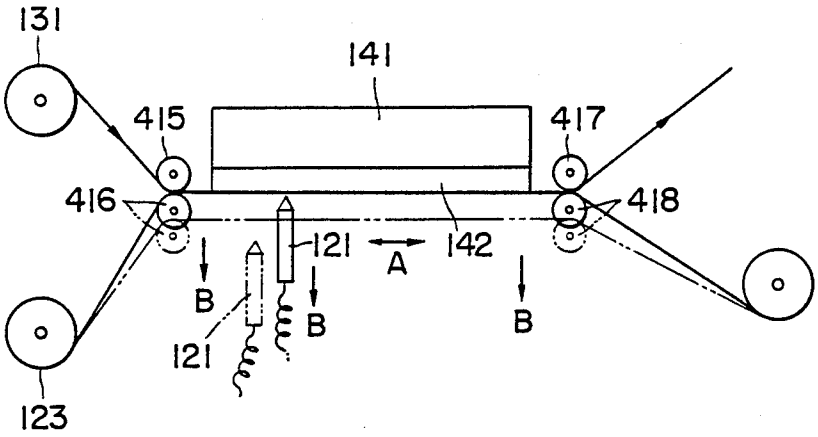


FIG. 1C

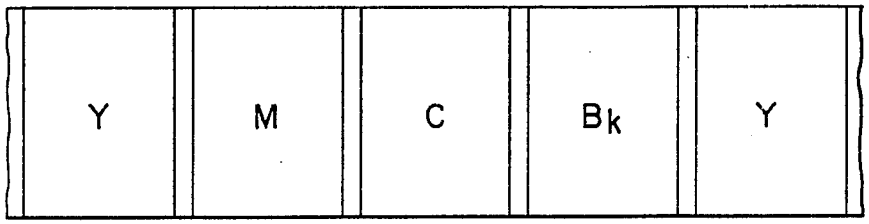


FIG. 1D

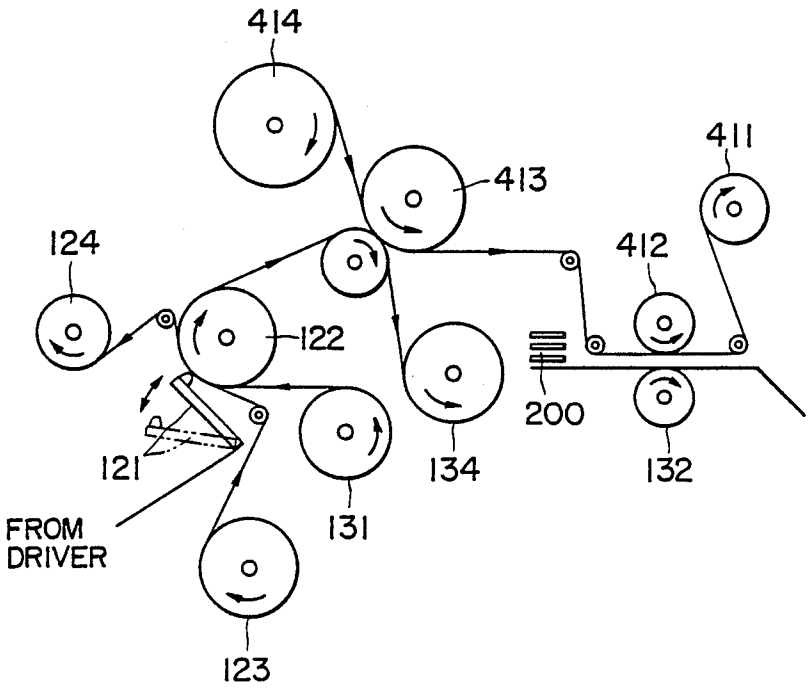


FIG. 1E

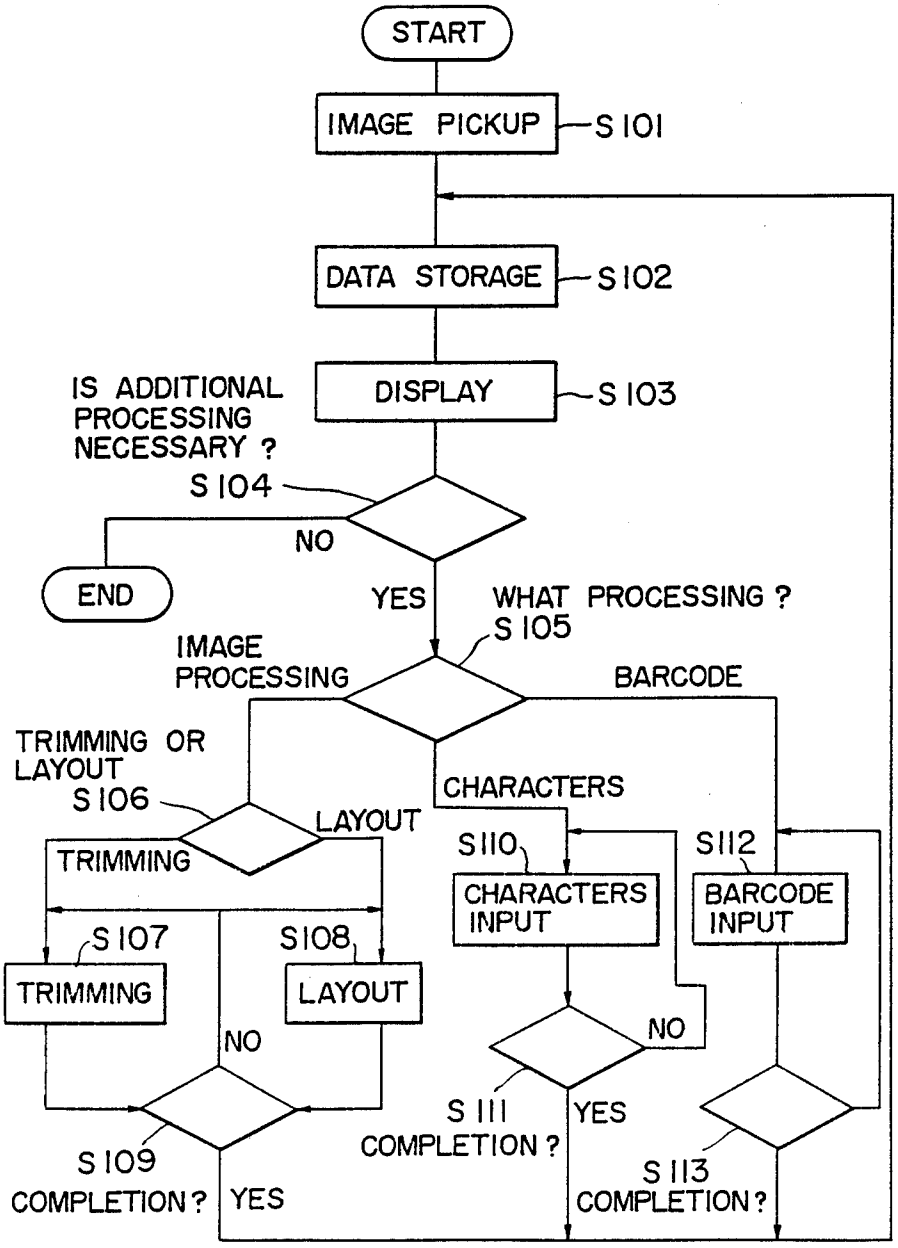

START
IMAGE PICKUP
S101
DATA STORAGE
S102
DISPLAY
S103
IS ADDITIONAL PROCESSING NECESSARY ?
S104
NO
END
YES
WHAT PROCESSING ?
S105
IMAGE PROCESSING
BARCODE
CHARACTERS
TRIMMING OR LAYOUT
S106
LAYOUT
TRIMMING
S110
S112
CHARACTERS INPUT
BARCODE INPUT
S107
S108
TRIMMING
LAYOUT
NO
NO
S111
COMPLETION ?
YES
S109
COMPLETION ?
YES
S113
COMPLETION ?

FIG. 2

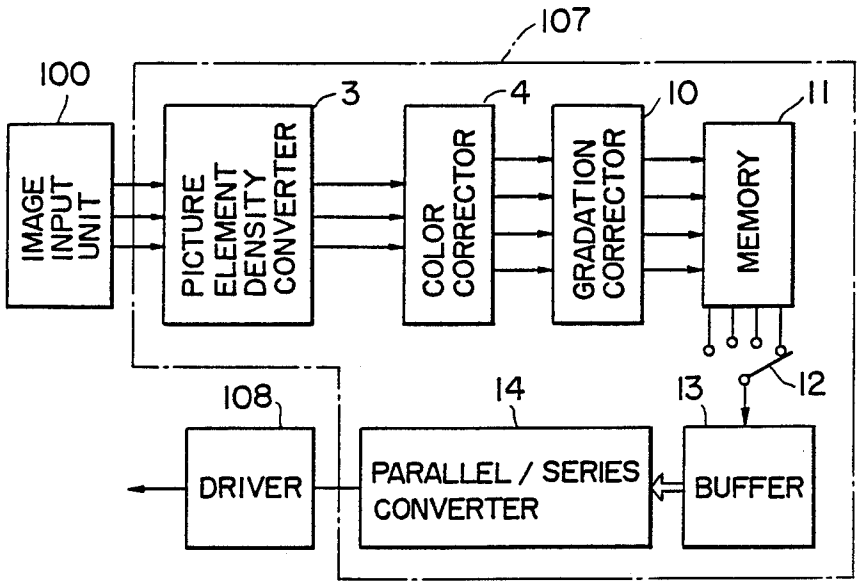

107
100
3
4
10
11
IMAGE INPUT UNIT
PICTURE ELEMENT DENSITY CONVERTER
COLOR CORRECTOR
GRADATION CORRECTOR
MEMORY
12
13
14
108
DRIVER
PARALLEL / SERIES CONVERTER
BUFFER

FIG. 3A

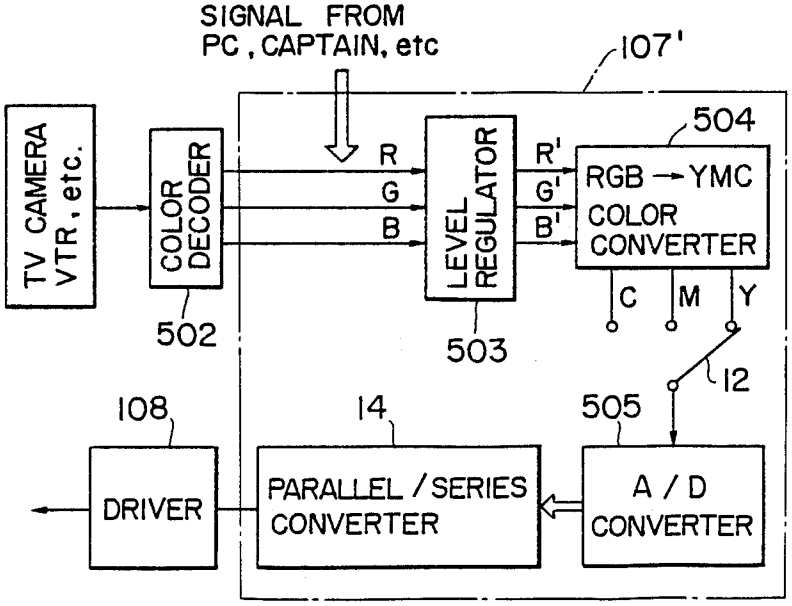

SIGNAL FROM PC, CAPTAIN, etc
107'
504
TV CAMERA VTR, etc.
COLOR DECODER
502
R
G
B
LEVEL REGULATOR
503
R'
G'
B'
RGB → YMC COLOR CONVERTER
C
M
Y
12
108
14
505
DRIVER
PARALLEL / SERIES CONVERTER
A / D CONVERTER

FIG. 3B

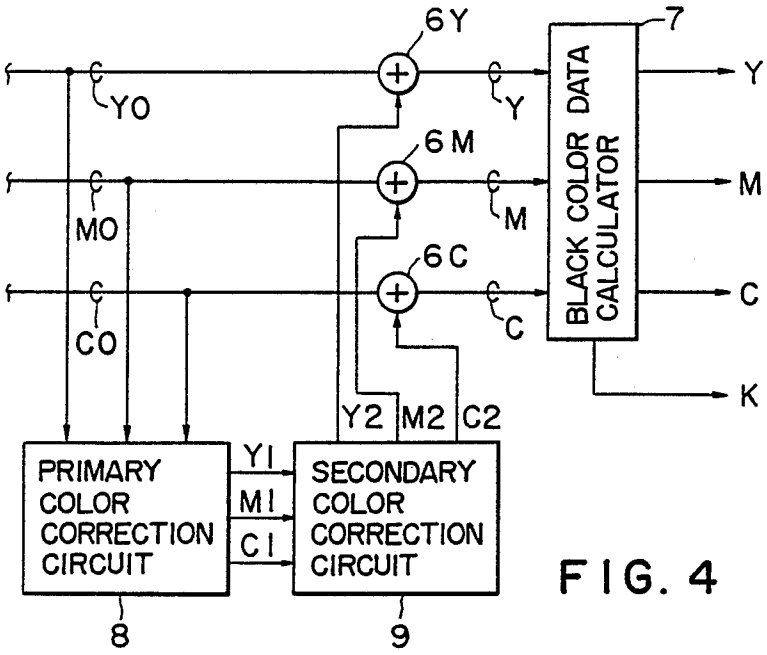

6Y
7
Y0
Y
Y
6M
M0
M
M
6C
C0
C
C
BLACK COLOR DATA CALCULATOR
K
Y2
M2
C2
PRIMARY COLOR CORRECTION CIRCUIT
Y1
M1
C1
SECONDARY COLOR CORRECTION CIRCUIT
8
9

FIG. 4

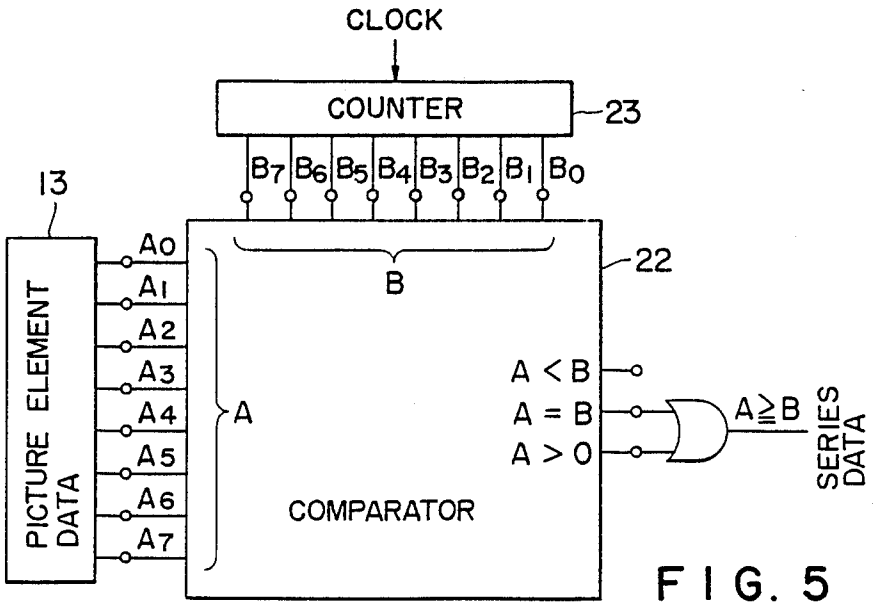

CLOCK
COUNTER
23
B7 B6 B5 B4 B3 B2 B1 B0
13
A0
A1
A2
A3
A4
A5
A6
A7
PICTURE ELEMENT DATA
B
22
A
A < B
A = B
A > 0
A≧B
SERIES DATA
COMPARATOR

FIG. 5

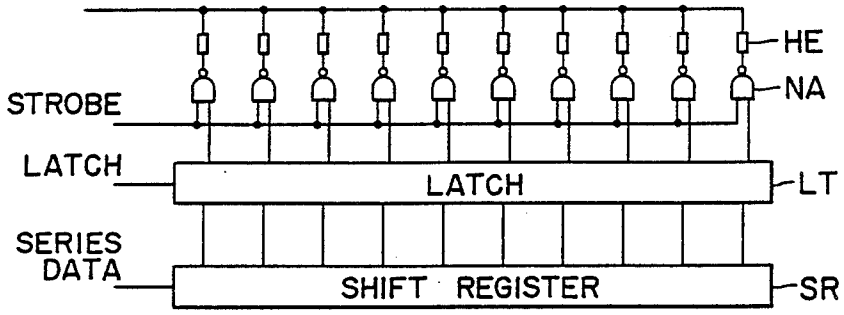

HE
NA
STROBE
LATCH
LATCH
LT
SERIES DATA
SHIFT REGISTER
SR

FIG. 6

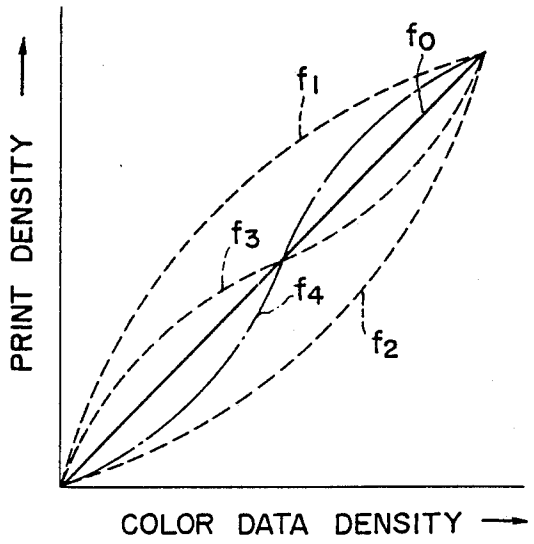

f0
f1
f3
f4
f2
PRINT DENSITY
COLOR DATA DENSITY

FIG. 7

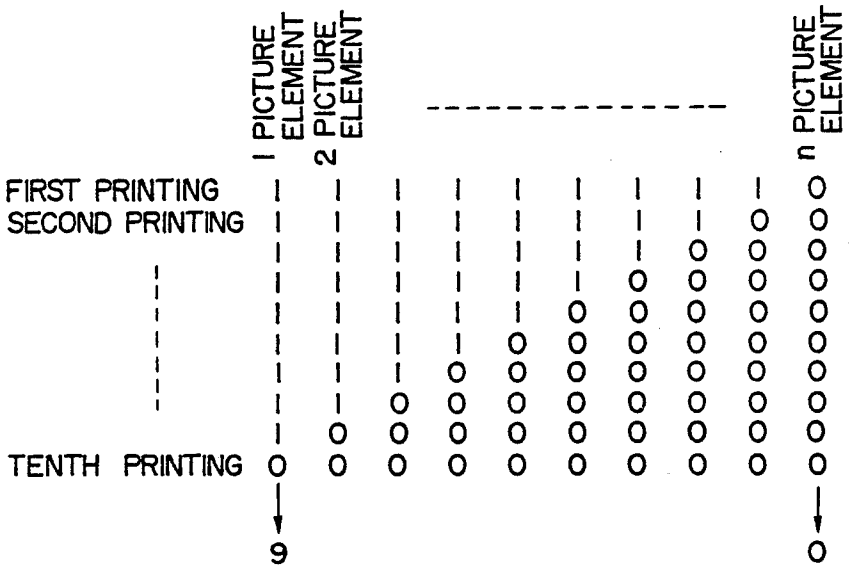

1 PICTURE ELEMENT
2 PICTURE ELEMENT
n PICTURE ELEMENT
FIRST PRINTING
SECOND PRINTING
TENTH PRINTING
9
0

FIG. 8

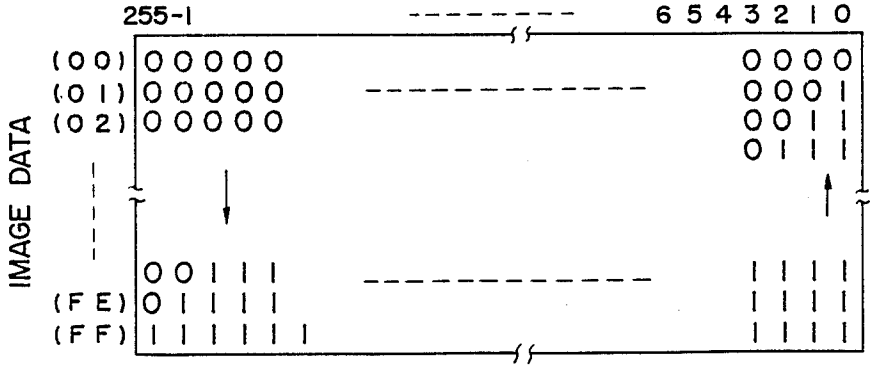

255-1
6 5 4 3 2 1 0
IMAGE DATA
(00)
(01)
(02)
(FE)
(FF)

FIG. 9

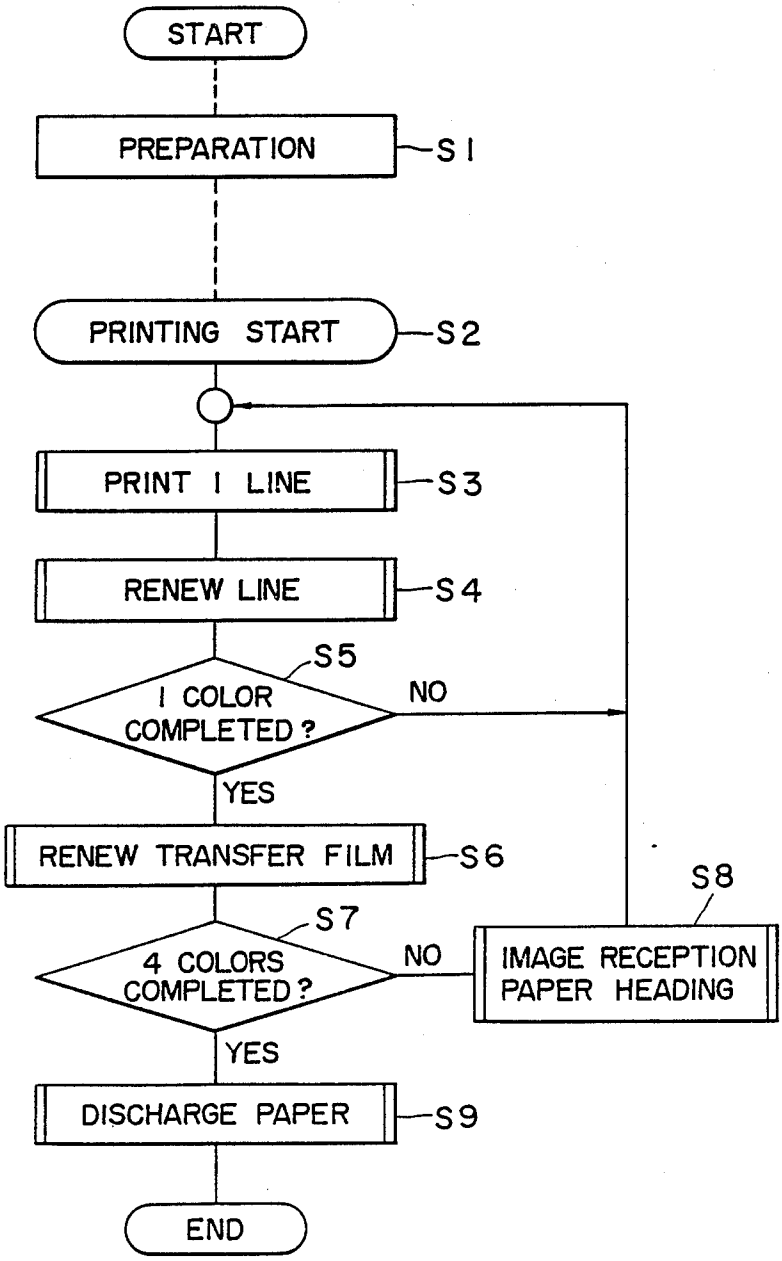

START
PREPARATION
S1
PRINTING START
S2
PRINT 1 LINE
S3
RENEW LINE
S4
S5
1 COLOR COMPLETED ?
NO
YES
RENEW TRANSFER FILM
S6
S7
4 COLORS COMPLETED ?
NO
S8
IMAGE RECEPTION PAPER HEADING
YES
DISCHARGE PAPER
S9
END

FIG. 10

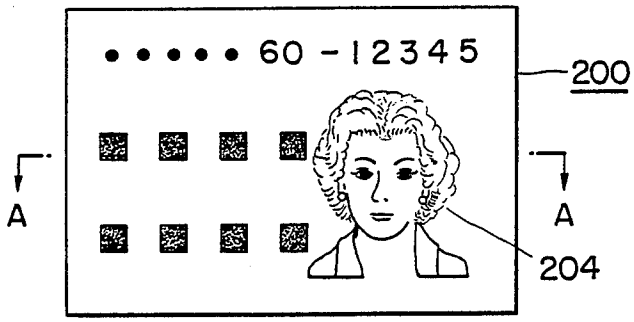


FIG. 11

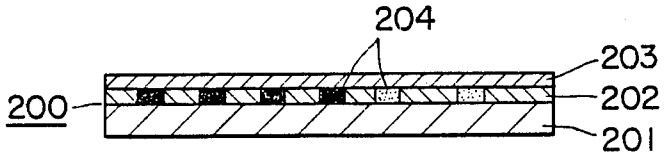


FIG. 12

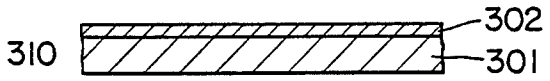


FIG. 13

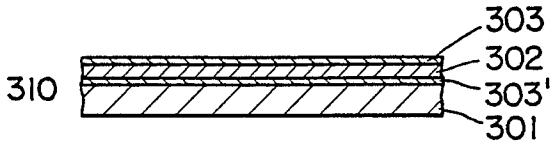


FIG. 14

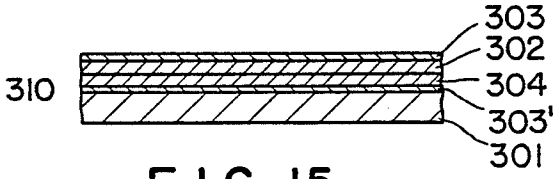


FIG. 15

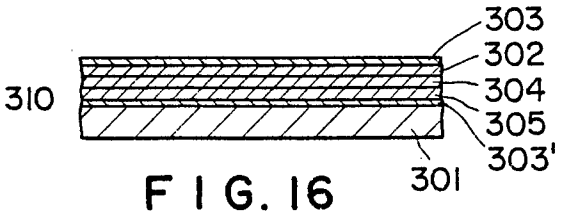


FIG. 16

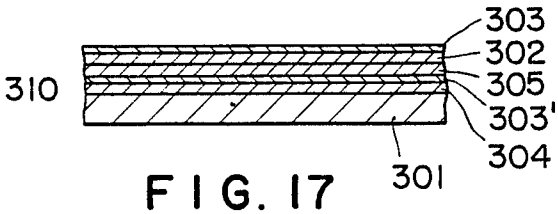


FIG. 17

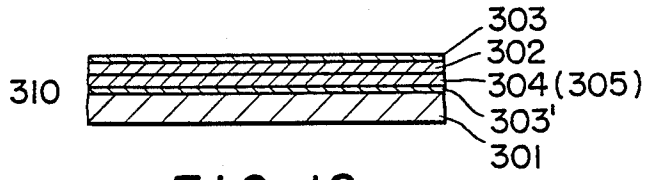


FIG. 18

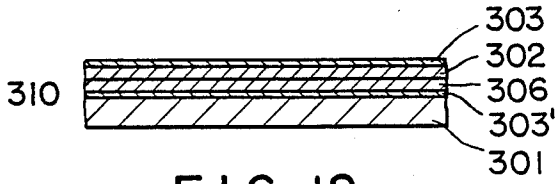


FIG. 19

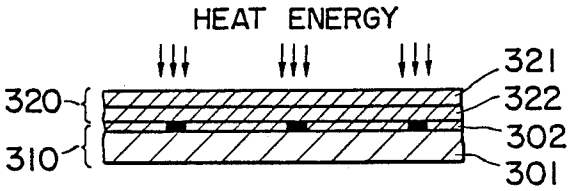


FIG. 20

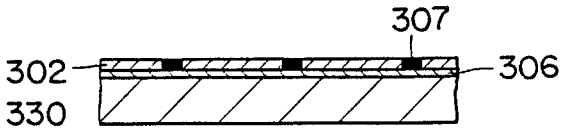


FIG. 21

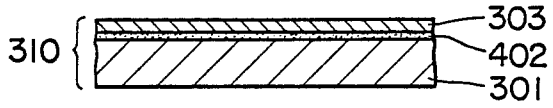


FIG. 22

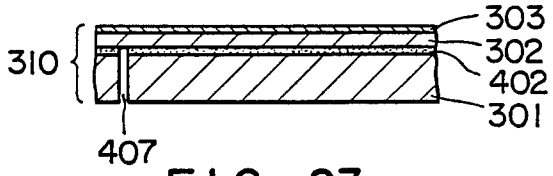


FIG. 23

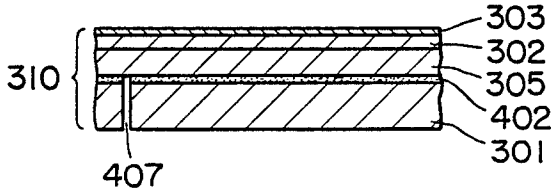


FIG. 24

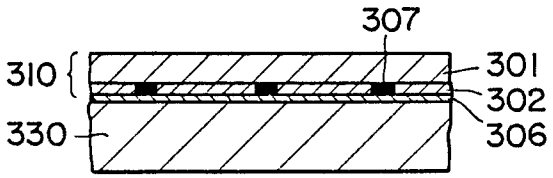


FIG. 25

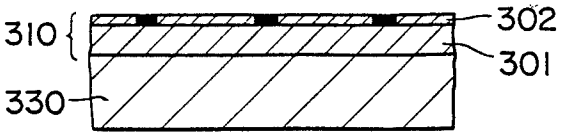


FIG. 26

FIG. 27

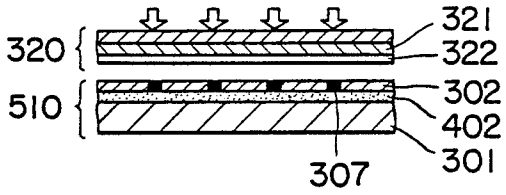


FIG. 28

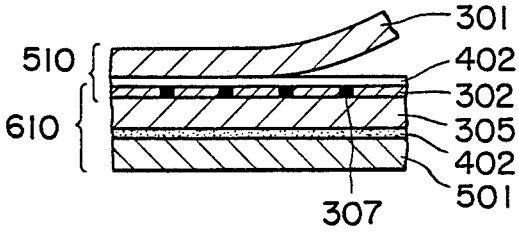


FIG. 29

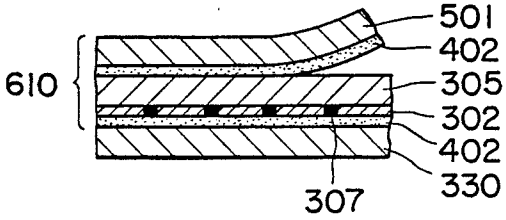


FIG. 30

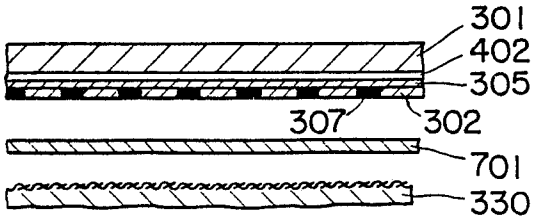
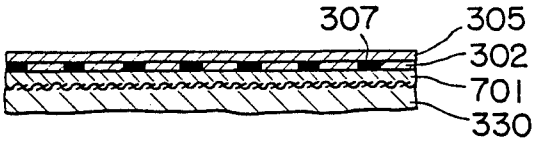


FIG. 31



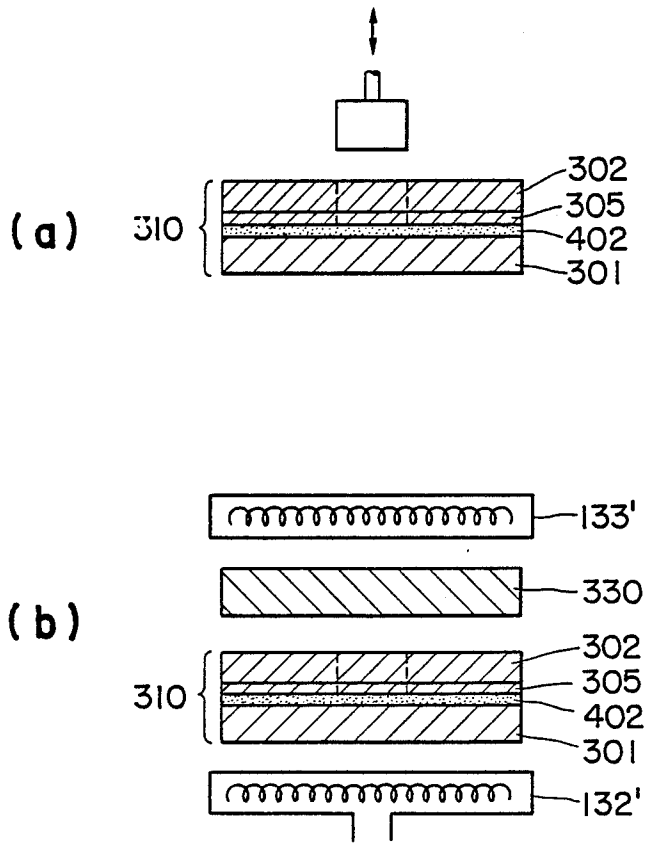

(a)
310
302
305
402
301
(b)
133'
330
310
302
305
402
301
132'
(c)
330
302
305

FIG. 32

IMAGE FORMATION ON OBJECTIVE BODIES

TECHNICAL FIELD

This invention relates to methods and apparatus for the formation of images as prints on objective bodies through transfer of images preformed by the sublimation transfer technique, and more specifically it relates to such systems as adapted for the formation of images on any selected objective body, such as cards, clothes, papers, and transparent sheets, although these are not limitative to the present invention.

BACKGROUND ART

Reliance is made generally upon the normal printing technique for formation of images on objective bodies. For the execution of the printing technique, provision and use of printing plates (forms or blocks) are requisite. No matter how simple the image-printing is, the plate-making is a very time-consuming the laborious procedure This is much more so in the printing of various and complexed image combinations, such as those of graphic or portrait images combined with characters, letters or bar codes, as an example, representing extremely complicated and troublesome work.

Further, in the normal printing operation, various operating conditions, including ink selection and the like, must be carefully considered, depending upon the kind and nature of the printing object, thus the best selection thereof is highly delicate and not as simple as expected.

The present invention is proposed upon careful consideration of the foregoing facts, and an object of the invention is to provide a unique process for the formation of sharp and clear images regardless of the kind and nature of the object to be printed upon, and usable and effective materials and apparatuses for carrying out this unique process.

The method of thermal image transfer (sublimation image transfer) on clothes or fabrics with the use of thermal transfer dyestuffs has been practiced for a long time. In this conventional process, a dyestuff picture layer carrying thermal transfer dyestuff is formed on a substrate sheet which is then subjected to heat in an overlapped state on a cloth or fabric, the dyestuff thereby being transferred thermally onto the latter for forming the desired images thereon. By utilizing this technique, and with recent development of the image forming technology concerning fine thermal printers and the like, various fine image forming processes have been proposed to provide fine images which are comparable to photographic images and are transferred onto plastic films from thermal transfer sheets carrying thermal transfer dyestuffs.

According to these recently proposed processes, various images of cameras, or TVs, graphic images of personal computers and the like can be reproduced easily in the form of hard copies on the surface of a transferred material such as a paper or the like sheet carrying thereon a fixedly attached layer of polyester resin, as an example. These images thus reproduced represent an amply high level comparable to those obtained by photography or fine printing arts.

The thermal transfer process so far set forth has an advantage in that it can form any image in a convenient manner yet entails a problem in that it is limited to image-transferred products preferably of polyester and the like materials which must be dyed with thermal transfer dyes. On the other hand, the image-transferred products must be limited to specifically selected shapes, preferably film, sheet or the like configuration, and thus, such materials as wood, metal, glass or ceramics cannot be formed with images in this way. Further, even if the material is plastics such as polyester or the like, and when the image-forming surface is curved or undulated, or physical body other than sheet, even if it represents a plane surface, it is almost impossible to reproduce images precisely thereon, which naturally constitutes a grave problem in the art.

With recent development and enlargement of utilizing fields of various card-style products, such as cash cards, telephone-cards, prepayment cards; and ID-cards, there are increasing demands for providing these cards with images, symbols and codes, so as to give various other functional and/or decorative effects. Most of these cards are of planar form, but they are frequently not pliable and/or have uneven rough portions due to provision of characters and symbols, resulting in great difficulty in the scheduled image formation relying upon the thermal image transfer process.

There is therefore an urgent demand among those skilled in the art for the provision of a unique technique capable of forming sharp and clear images of desired patterns on the surface of an objective body of any preferred kind of material and having any shape and configuration and surface condition of any kind, and indeed, for combining and unifying image- and decoration effects.

DISCLOSURE OF THE INVENTION

The present invention is basically based on such a principle that a first image transfer pattern is formed on an image transfer material, preferably an image transfer sheet, and in the form of dyestuff images through the sublimation image transfer process executed by first image transfer means, depending upon given image data, preferably including those of letters, characters, symbols, line images, graduated graphic representations, and then the first transfer pattern is transferred to second transfer means for retransferring the images onto an objective body so as to provide a final product.

Based upon the image data fed from various image data input means and at the first image-transfer means, a thermal head is actuated to execute printing operation through a dyestuff film (thermal image-transfer sheet) on an image-transfer material (or more specifically on an image-transferable material which means an image-transferable sheet. This image-printing is carried out according to the sublimation or sublimative image transfer technique. Thus, in this case, the dyestuff on the dyestuff film is transferred or shifted under the influence of heat energy from the thermal head onto the image-transfer material through sublimation, thus providing the first image-transferred means. Since this first image-transferred means has been thus formed with the images by the sublimated dyestuff, they are, then, transferred onto the second image-transferable means which will be brought into tight contact with the object to be decorated and subjected to heat and pressure for execution of further image-transfer operation to provide the final desired product.

In the present invention, the image-transfer material (image-transferable sheet) is, as above referred to, formed with images by the sublimative image transfer technique for providing first image-transfer means

which has highly sharp and clear images a the operation and results of the characterizing feature of the sublimation image-transfer technique. Therefore, because of the transfer of such sharp and clear images onto the object, it becomes possible to form the images thereon, and indeed, practically irrespective of the kind and nature of the object. In this way, thus, fine image-formation is assured onto practically any objective substance.

And further, by execution of control of the thermal energy applied during the sublimative image-transfer step, the resulting color effect is superior and the image quality is good.

The images sublimatingly applied and formed in the foregoing way are subjected to a further transfer, and onto a substrate product, for providing a final decorative product as desired. In this final product, it should be noted that the underlying layer underneath the images during the sublimative image-transfer stage appears now at the top, acting thus as a kind of protecting layer upon up-and-down positional conversion during execution of the second and final image transfer stage, resulting in realization of various and numerous effects. As an example, attainment of substantial reduction of contamination, improvement of light resistance, weather resistance and chemical resistance; substantial reduction of color fading; provision of glazing effect; easier and simpler introduction of granular and/or undulated image appearance.

The inventive process is carried into effect basically in such a manner that an image-reception layer provided on one surface of an image-transferable sheet is subjected to an image-forming step with the use of dyestuff capable of depositing therein depending upon the fed image data, so as to form the required images, and then, the image-reception layer of the image transferable sheet, having been image-fixed and thus now image-carrying, is stuck onto the surface of the object to be decorated upon.

As for the image-transferable sheet adapted for use in the image-transfer during execution of the inventive process, it consists basically of a sheet-like substrate and a reception layer attached, however, in a separable manner, onto one surface thereof. As a modification of the inventive process from the basic mode set forth above, the sheet-like substrate is caused to remain, even after completion of the image-transfer step, as may be occasionally required. In this modified case, it is unnecessary to make the image-reception layer of the image transfer sheet separable.

Under occasion, the inventive process may be brought into effect in such a wa that the image-reception layer of the image-transfer sheet is transferred upon execution of the image-forming step, and indeed, once onto an intermediate image-transfer substrate which is then retransferred, together with the once transferred image-reception layer, onto the surface of an object to be decorated on, and thus, in a retransferring manner.

BRIEF DESCRIPTION OF THE DRAWINGS

In the accompanying drawings:

FIG. **1A** is a block diagram, showing a preferred embodiment of the apparatus according to the present invention;

FIG. **1B** is a schematic view illustrating at (a), (b) and (c), several image-transfer steps for the execution of a process according to the invention;

FIG. **1C** is a schematic view of an image-transfer step, using a platen roll;

FIG. **1D** is a plan view of part of a multi-color dyestuff film adapted for use in an image-forming step;

FIG. **1E** is a schematic view for the illustration of several image-transfer steps;

FIG. **2** is a flow chart of successive operation steps with use of a data-processor, shown in FIG. **1**, functioning as an operating center;

FIG. **3A** is a schematic block diagram, showing a data-processor for the printer;

FIG. **3B** is a block diagram of a sublimative image-transferring printer adopted in the present invention, as a preferred embodiment thereof;

FIG. **4** is a schematic block diagram, showing a color correction unit shown in FIG. **3A**, and several related parts cooperating therewith;

FIG. **5** is a schematic block diagram of a comparator and several related parts cooperating therewith;

FIG. **6** is a circuit block diagram of an image-transfer head shown in FIG. **1B**;

FIG. **7** is a graph showing operational characteristics of a color tone or -gradation corrector unit shown in FIG. **3A**;

FIG. **8** is a table for the illustration, as an example, of picture- or image-elements, as expressed in binary signals;

FIG. **9** is a table showing a conversion operation, as an example, of a parallel/series converter shown in FIG. **3A**;

FIG. **10** is a flow chart, illustrating the operation of the sublimative image transfer printer;

FIG. **11** is a plan view of a final decorative product prepared according to the inventive technique;

FIG. **12** is a sectional view of the product card shown in FIG. **11**, and taken along a section line A—A shown therein;

FIGS. **13** through **31** are a series of sectional views, respectively illustrating several structural examples of image-transferable sheets, suitable for use in the invention; and

FIGS. **32** (*a*), (*b*), and (*c*) are sectional views, indicating final transfer steps.

BEST MODES FOR CARRYING OUT THE INVENTION

Referring now to FIG. **1A** and FIG. **1B**, (a), (b) and (c), a basic scheme of the inventive image data processing and image formation will be illustrated. First, in FIG. **1A**, numeral **101** represents an image input means which is adapted for forming image data based upon optical and the like inputs delivered from a TV-camera, line sensor or the like. Other than those above enlisted only by way of example, video; CD; TV; scanner; personal computer, captain system, capable of providing R.G.B.- and picture image and the like signals may also be utilized in a similar way. The image signal data delivered from the image input means are fed through a data processor **104** to a memory **105** for being stored therein. These stored data can be taken out from the memory and fed through data processor **104** to display means **102** for being displayed thereat.

To the data processer **104**, a mouth/tablet digitizer and/or the like position data processer **103** is electrically connected for introducing position data concerning displayed images appearing at the display **102**. In addition, key board and the like character data input means **106** and font generator **109** are provided for introducing character data. Still further, a barcode generator **110** is provided for introducing barcode when

necessary. By the use of these means and units, various additional processing modes can be executed.

The thus processed data are subjected to conversion at a data converter **107** into proper data adapted for operating a sublimation transfer printer and fed forward through a driver **108** to the thermal head.

In this case, by controlling the current duration period to the thermal element of the thermal head, the transfer quantity from the dyestuff film (thermal transfer sheet) is controlled depending upon the thermal energy of the element for realization of the desired gradation degree of concentration on the transfer sheet. There are two different modes of such control of current duration period as follows:

(a) A method for controlling the pulse length corresponding to the picture element in the impressed data to the thermal element of the thermal head or, more specifically, a series data introduced as input to the shift register shown in FIG. **6** and to be described more specifically hereinafter.

(b) A method for controlling the number of pulses of the pulse series corresponding to the picture elements of the data impressed upon the thermal element in the thermal head (in this case, the pulse length being constant).

The degree of gradation of the transfer image can be controlled in the above mentioned way by the regulation of the current-conducting period depending upon the desired gradation degree. On the other hand, the image concentration can be controlled by adjusting the pulse length or the number of pulses contained in the pulse series in correspondence to the picture elements contained in the data as introduced in the shift register and depending upon the driving mode of the thermal head. Further in this case, if the number of gradation of introduced image data is larger than that which can be expressed by the printer unit, a proper conversion operation can be performed by the known strobe control method As an example, in such case, the conversion of gradation number **256** to **64** may be executed by a ROM, and the thus reduced gradation number can be used as output.

Next, referring to FIG. **1B** at (a) and (b), reference numeral **121** represents a thermal head which receives signals from the driver **108** shown in FIG. **1A**. This thermal head **121** is arranged in opposition to platen roll **122**, forming the printing position therebetween. The dyestuff film (thermal transfer sheet) is fed from a delivery roll **123** to a winding roll **124** through this printing position, these structural and functional features being commonly employed in both the arrangements shown in FIG. **1B** at (a) and (b).

In the case of FIG. **1B**, (a), the mechanism is so arranged that card or sheet style transfer sheets are printed with dyestuff images.

On the other hand, in the case of FIG. **1B**, (b), the mechanism is so arranged that cards are continuously produced with the use of a film style transfer sheet and a dyestuff film in combination.

Now turning back to FIG. **1B**, (a), a number of transfer sheets (cards, sheets or the like) have been stacked and stored within a storage casing **125** and ar being thrust upward from below by a spring so that the uppermost sheet is kept in pressure contact with a take-out roll **126**. With the rotation of the roll **126**, the sheets are successively delivered from the casing **125** by conveyer belts **127**, **128** onto a platen roll **122**. Each one of the sheets is fixed on the peripheral surface of the platen roll, now positionally indexed, by means of a gripper or the like mechanical attaching and separating means, static attracting means, or electromagnetic attaching means. Then, the roll **122** is so rotated that the transfer sheet is positioned at the ready-for-printing-position.

Next, the thermal head **121** is brought into pressure contact with the transfer sheet through the intermediary of the dyestuff film, and then the thermal head **121** is energized with electric current while the dyestuff film and platen roll **122** are moved in synchronism for the execution of image transfer (first image transfer).

Upon execution of the image transfer, the platen roll **122** is rotated, the gripper is released and the take-out roll **129** is rotated and brought into pressure contact for taking out the image transfer sheet onto a tray **130**.

The thus taken out sheet is brought into overlapped state with a new image transfer sheet, not shown, and then, both the sheets are fusingly united together by pressure application of a heated roll, not shown, for execution of a second transfer step job. The whole operation has thus been completed. Before the fusion process, the sheets may be subjected to punching, trimming and/or the like processing, if necessary.

By execution of the foregoing operational steps, a monocolor printing operation has been completed. However, in the case of multicolor printing, use is made of tricolored or quadruple colored dyestuff film and the corresponding printing operations must be repeated. In this case, upon completion of a single monocolor printing procedure, the platen roll is rotated without contact of the take-out roll **129**, until it arrives again at the printing-initiation position, and so on.

In the following, a tricolor printing job will be illustrated with reference to FIG. **1B**, (b), and with use of three different series color zones, of cyan, magenta and yellow.

First, a platen roll **122** is positionally indexed, and an image transfer sheet taken out from the roll **131** and a dyestuff film taken out from the roll **123** are brought into pressure contact in an overlapped state. Then a thermal head **121** is pressed against the platen roll **122** through the intermediary of the overlapped sheets. At this stage, the platen roll **122** is rotated counterclockwise while synchronism is kept between the platen roll **122** and the dyestuff film, and the thermal head **121** is kept electrically energized. In this way, the first color printing is executed.

Further, the dyestuff film is fed to the second color zone position, and then, the platen roll **122**, the dyestuff film and the image transfer sheet are fed forward clockwise around the center roll **122**. Thus a second color printing step is executed.

Further, the print-serviced two color sections of the film is fed back counter clockwise around the center of the platen roll **122** for the execution of a third color printing step. Then, each card sheet is taken out from the stack **200** under the action of take-out rolls or the like, not shown, towards and between a pair of thermal transfer rolls **132**, **133**, brought into overlapping state with the image transfer sheet positionally indexed and already subjected to image transfer steps as was described above, and finally subjected to a picture printing operation by pressurizing application of the thermal image transfer rolls **132**, **133** from both sides of each taken-out card, and so on.

The color-printing step with the use of the thermal head is carried into effect in the following manner, as an example.

(First color printing)

Platen roll, image transfer sheet and dyestuff film perform the printing while they are moved in the counterclockwise direction.

(Second color printing)

Platen roll and image transfer sheet are moved in the clockwise direction while the dyestuff film is moved at the same speed and in the counterclockwise direction for performing the color printing under consideration.

(Third color printing)

Platen roll, image transfer sheet and dyestuff film are moved in the counterclockwise direction for execution of the color printing under consideration.

In the modified arrangement shown in FIG. **1B**, (c), thermal image transfer rolls **132, 133** have been replaced by a flat press type image transfer head having up-and-down movable flat printer elements **132'**, **133'**.

It should be noted that in the course of the foregoing first and second image transfer steps, image reversal phenomenon is necessarily brought about upon execution of each image transfer step. In other words and more specifically, when two successive image transfer steps in the foregoing sense are executed, reverse images which have once appeared will return to the original normal images. Therefore, when the printed-out products are to be provided upon execution of the first image transfer step, it is necessary to provide reversed image data in the signal processing system. For this purpose, it is only necessary to reverse the addressing order at the data introduction or readout stage into or from the memory.

In the modified arrangement shown in FIG. **1C**, the foregoing platen roll means has been replaced by a metal block **141** lined with a rubber plate **142** in an overlapped manner. The image transfer sheet and dyestuff film are fed out from respective rolls **131** and **123**. With the use of this modified arrangement, the dyestuff surface layer of the dyestuff film can be brought into tight contact with the image-receiving surface layer of the image transfer sheet, and thermal energy will be transferred evenly form the thermal head **121** to the dyestuff, film.

In this case, the image transfer sheet is delivered from the roll **131**, and the desired zone or region of the sheet is set underneath the rubber plate **142** (step **1**).

At the same time, the dyestuff film shown in FIG. **1D** on an enlarged scale is delivered from the roll **123** and a selected one of the different color regions is set underneath the rubber plate **142** (step **2**).

Next, the thermal head **121** is brought into the rear surface of the dyestuff film which is the opposite surface to the dyestuff-coated front layer, and the head **121** is driven while it is being translated in the direction shown by an arrow A, images thereby being formed at the specifically allocated zone(s) or region(s) of the image transfer sheet (step **3**).

Further, the thermal head **121** and rolls **416** and **418** are shifted downwards as shown by arrows B, so as to form an idle gap between the image transfer sheet and the dyestuff film for allowing the latter to shift towards the next following color region (step **4**).

Further, the thermal head **121** and rolls **416** and **418** are returned to their original positions, whereupon the third and further succeeding steps are repeatedly executed until a certain predesired number of color printings are completed.

As shown in FIG. **1D**, the dyestuff film is colored to have several different color regions denoted by Y (yellow), M (magenta), C (cyan) and Bk (black). However, the arrangement order is not limited to that shown: Y; M; C and Bk. In addition, as occasionally required, the Bk-region may be dispensed with. Further, as the color elements to be adopted in the Y, M, C-system may not be limited to the three primary colors provided by the subtractive color mixture. On occasion, a characterizing color which means such a color as preadjusted to provide an objective specifically selected one may be used to form the images concerned. As a further modification, the arrangement shown in FIG. **1C** may be so modified that the traveling direction of the image transfer sheet is selected to be perpendicular to that of the dyestuff film.

FIG. **2** is an operation flow chart for showing schematically operational modes taking the data processor **104** adopted in the embodiment shown in FIG. **1** as the centrum of description. The operational contents of several working parts downstream of the data converter **107** will be set forth separately hereinbelow. Now referring to FIG. **2**, in combination with FIG. **1** and at the step of **S101**, image pickup operation is carried out by means of the image pickup means **101**. For execution of this step, it may be better to pick up the face of a person per se which is to be represented on the card, or alternatively, a photograph, portrait or imagery product thereof will do. Depending upon the nature of the object, a TV camera, line sensor or the like instrument may naturally be selectively utilized.

The data taken by the image pickup means **101** are stored through the data processor **104** at a memory **105** (**S102**). By the use of these stored data, image or images is/are displayed at the display **102** (**S103**). Since this display image is not yet subjected to any processing, it is generally unsuitable for representing on the card. However, under certain circumstances, it may be represented thereon as it is.

Then, the operator observed the displayed image or images on the display unit **102** and adjudges whether additional processing is necessary or not (**S104**). If it is not necessary, he will manipulate the key board **106** to make a certain operation, resulting in the termination of processing at the data processing unit **104**, data being fed out therefrom to the succeeding data converter **107**.

On the contrary, when additional processing is necessary, the operator observes carefully the displayed image or images on the unit **102** and adjudges whether the picture image data, or character data or barcode data should be processed. If the picture image data should be processed, such an operation is made for selecting the proper mass of trimming or layout within the menu range of position-data input means **103**. By the execution of this operation, functions and operations at steps **S105** and **S106** can be executed at one stroke. If trimming is taken as an example, the next step is executed in such a way that position data are fed from the position input means **103** to the data-processer **104** with the use of a carsor. When a tablet digitizer is used as the position data input means, the carsor image displayed in an overlapped manner on the displayed picture image appearing at the display unit **102** by carsor manipulation is positionally specified beforehand in registration with the specified position on the card, for determining the trimming range. Then the operation is carried out in

such a way that the picture image data outside the specified trimming range are canceled. By completing these operations, data processing operations relating to step **107** are executed, and, then, the mass for completion of the menu range is selected out. By these measures, steps progress through **S109** to **S102**, and data storing is executed, and further, display representation is brought about through step **S103**. If there is no need for additional processing, an operation termination manipulation is carried out as before at key board **106**, and further operations will be made through data converter **107**.

As for the layout, the operation is carried out with the position data input means **103**, similarly as in the foregoing trimming operation. More specifically, layout is selected out in the menu range of position data input means **103**, and the overall configuration of the card and the display position of picture image are shown at display unit **102**. Then, image inclination correcting operation and the like are carried out so as to realize correspondence thereof with the displayed positional information, the processing operations relating to step **S108** thereby being brought about. After completion of these operations, the mass for the ending in the menu range is selected.

In this way, when selection is made from the menu range by reliance on the position data input means **103**, trimming or layout operation can be brought about. At this stage, when manual operation is carried out at the key board **106**, introduction of character data is executed (**S110**). As the character data in this sense, in the case of ID card, as an example, the name and/or birthday, month and year of the owner may be used. The data introduced from the key board **106** in accordance with the output character style from the font generator **109** are shown at the display unit **102** in the specified positions on the displaying surface and respectively arranged in accordance with display items. The operator acknowledges these items and detailed displays of the represented images. When he acknowledges them as being true, he will operate the key board **106** for showing the operation ending (**S111**).

Upon ending the operations as described above, the data are stored in memory **105** (**S102**) and represented at the display **102**. The operator will acknowledge again this fact, and upon the execution of this, the operations are terminated.

As for the barcode introduction, the data are subjected to inputing at steps **S112** and **S113**, as in a manner similar to the character data introduction as set forth above. The barcodes and the like data may be introduced separately through printing or other mechanical method.

In FIG. **3A**, a data processing circuitry usable in the sublimation image transfer printing method is shown only schematically. As shown, the circuitry **107** comprises a picture element density converter **3**; a color corrector **4**; a gradation corrector **10**; a memory **11**; a switch **12**; a buffer **13** and parallel/series converter **14**. The picture element density converter **3** is connected to a picture image input unit **100**.

The unit **100** serves for generation of three primary color data of R.G.B.- or Y.M.C.-mode from original picture images and is connected through the picture element density converter **3** to the color corrector **4**. The converter **3** converts the picture element density of the image data fed from the unit **100** to the desired one, by subtracting or supplementing, as the case may be, image data for each color element. It should be mentioned that for attaining high quality hard copies, conversion of the picture element density to at least **10** lines/mm or so is preferable.

Color corrector **4** consists preferably of a color decoder, level adjuster or color converter, and serves to correct three primary color data converted to those of a predetermined density of picture elements in consideration of characteristics of the image transfer ink in the image transfer sheet and in addition to provide black color data.

The data processing circuitry **107** is connected through a driver **108** to the sublimation image transfer printer.

In FIG. **4**, an example of the color corrector **4** is shown schematically in structure. As shown, it comprises adders **6Y**; **6M** and **6C**, a black color data calculator **7**, and primary and secondary color correction circuits **8** and **9**. Primary color correction circuit **8** serves for making correction of turbidity of the image transfer ink, while secondary color correction circuit **9** provides a capability of arbitrary and selective correction control relative to specifically selected color hue.

The gradation corrector **10** is so arranged as to make correction of the gradation of the data for each color Y, M, C or K (representing black color) fed from the foregoing color corrector **4** when necessary. For this purpose, the corrector **10** includes a gradation circuit (not shown) and the like, whereby a certain mode of highlight stressing or shadow stressing is introduced and realized.

The memory **11** functions to preserve temporarily the data of each color delivered from the gradation corrector **10**, a selection switch **12** being provided at the output side of the memory for selective writing-in of the data of each color to the buffer **13**. The buffer **13** is capable of writing-in the data of one line of the image transfer head **16** and kept in connection with the parallel/series converter **14** adapted for converting parallel data into series data. Additionally, in the simplified machine, black color data series is dispensed with in some instances.

In FIG. **5**, a schematic construction of the parallel/series converter **14** is shown. As shown, parallel data delivered from the buffer **13** are fed to an input side of a comparator **22**, while outputs from a counter **23** are fed to another input side of the comparator **22** which delivers the converted series data to the driver **15** for driving a thermal head **121**.

If necessary, however, the comparator **22** may be replaced by a converter table, not shown, utilizing a parallel/series converting ROM.

In FIG. **6**, a detailed circuit scheme of the thermal head **121** is shown. As shown, series data delivered from the comparator **22** are fed into a shift register SR and thence, after being subjected to latching at a latch circuit LT, fed to thermal elements HE through NAND gates NA which are fed at respective one side inlets with strobe signals.

Next, referring to FIG. **3A**, the operation of the data processing circuitry **107** will be described more specifically.

First, when three primary color image data are fed from the picture image inlet circuit **100** to the picture element density converter **3**, the latter converts these three primary color data to those which represent a predetermined picture element density and then are fed to the color correction unit **4**. In this case, it is assumed

that the unit **4** is fed with three primary color data expressed in respective concentration signals, which are of yellow: **Y0**; of magenta: **M0** and of cyan: **C0**, respectively, in the present example.

These data: **Y0**; **M0** and **C0** are, as shown in FIG. **4**, fed through respective adders **6Y**; **6M** and **6C** to the black color data calculator **7**, to provide a K-output as expressed mathematically by the following formula:

$$K=\min(Y, M, C)$$

wherein, "min" represents a function which provides a possible minimum value.

These data: **Y0**, **M0** and **C0** are fed from the converter **3** to the primary color correction circuit **8** to provide primarily corrected data **Y1**, **M1** and **C1** which are thence fed to the secondary color correction circuit **9** to provide, through calculation, secondarily corrected data: **Y2**, **M2** and **C2**, respectively. These are then fed to respective adders **6Y**, **6M** and **6C**, which add them to respective data **Y0**, **M0** and **C0**, to provide respectively added output data Y, M, and C to be fed to the gradation correcter circuit **10**, respectively, after being utilized for calculation of the K-output signal value.

The primary color correction circuit **8** serves to calculate primarily corrected data: **Y1**, **M1** and **C1** which are necessarily utilized for correct-out of transfer ink turbit. In this case, the original data: **Y0**, **M0** and **C0** are subjected to matrix calculation to provide the primarily corrected data **Y1**, **M1** and **C1**, as follows:

$$Y1=k_{11}.C0-k_{12}.M0+k_{13}.Y0$$

$$M1=k_{21}.C0+k_{22}.M0-k_{23}.Y0$$

$$C1=k_{31}.C0+k_{32}.M0-k_{33}.Y0$$

Where, k_{ij} represents weight coefficients:

$i=1-3$; and

$j=1-3$.

The secondary color correction circuit **9** serves to calculate secondary color correction data **Y2**, **M2** and **C2** from primary color correction data **Y1**, **M1** and **C1** by modifying the latter to make certain thereto by performing matrix calculations so as to provide a capability for making an arbitral and selective color control at a certain specifically selected-out color hue, in the following manner:

$$Y2 = Y1 + l_{11} \cdot \Delta B + l_{12} \cdot \Delta C + l_{13} \cdot \Delta G + l_{14} \cdot \Delta Y + l_{15} \cdot \Delta R + l_{16} \cdot \Delta M$$

$$M2 = M1 + l_{21} \cdot \Delta B + l_{22} \cdot \Delta C + l_{23} \cdot \Delta G + l_{24} \cdot \Delta Y + l_{25} \cdot \Delta R + l_{26} \cdot \Delta M,$$

and

$$C2 = C1 + l_{31} \cdot \Delta B + l_{32} \cdot \Delta C + l_{33} \cdot \Delta G + l_{34} \cdot \Delta Y + l_{35} \cdot \Delta R + l_{36} \cdot \Delta M$$

wherein, l_{ij} represents weight coefficients:

$i=1-3$;

$j=1-6$;

ΔB, ΔC, ΔG, ΔY, ΔR, ΔM:

characterizing color data.

Thus, when these secondary correction data **Y2**, **M2** and **C2** are added to the corresponding original data **Y0**, **M0** and **C0** by means of respective adders **6Y**, **6M** and **6C** and under proper selection of weight coefficients k_{ij} for primary color correction circuit **8**, any color discrepancy of the ideal color of the ink appearing on the printed picture images under the action of the sublimation transfer printer can be arbitrarily ammended. In this case, when the weight coefficients l_{ij} for the secondary correction circuit **9** are selected out properly, the color tone of the printing picture images can be modified to an arbitrary degree.

Further, as for the black color data K, correction data **K2** can be calculated by the following formula. With use of these correction data **K2**, which are added to the original black color data K, the desired correction can be executed in a similar manner.

$$K2=K+m1.\Delta B+m2.\Delta C+m3.\Delta G+m4.\Delta Y+m5.\Delta R+m6.\Delta M$$

wherein, Mi represents weight coefficients:

$i=1-6$.

In this way, output data: Y, M, C and K delivered from the color correction circuit **4** are introduced into the gradation corrector **10** as inputs thereof, and each constituent of these data can be subjected to correction as desired.

FIG. **7** shows several characteristic curves illustrating corrections by means of the gradation corrector **10**. More specifically, **f0** represents a standard characteristic curve; **f1** a highlight stressing operation curve; **f2** a shadow-stressing operation curve; **f3** a highlight-and-shadow stressing operation curve; and **f4** a medium tone stressing operation curve.

As indicated in FIG. **7**, by presetting, as necessary, the tone-reproducing characteristics, which determine the relationship between that concentration of color data and that of the prints printed by means of a sublimation image transferring printer, a color tone similar to that possessed by the original image can be reproduced. More specifically, when no correction is adopted, the curve **f0** is used, while in the case of correction, any selected one of these curves **f1** to **f4** may be utilized depending upon the part of gradation to be stressed. Further, it should be noted that the tone reproducing characteristic curves are not exclusively limited to those which have been specifically shown and described above. As an example, the control of gradation correction by color tone reproducing characteristic mentioned above is executed by a gradation circuit, not shown, and the setting of the color tone reproducing characteristic is brought about by manipulation of any selected one of the control knobs, not shown, which are provided separately for "highlight"; "medium tone" and "shadow".

Y.M C K. data subjected to correction by the gradation corrector **10** are once stored in the memory unit **11**. The thus stored data may be read out from the memory for each color by manipulation of the selection switch **12** and, after provisional storing, per one line of transfer head **16**, at the buffer **13**, introduced into the parallel/s-

eries converter **14** for conversion thereby into corresponding series data.

Another example of the data processing circuit for the sublimation transfer printer is shown only schematically in FIG. **3B**. As shown, the processing circuit in **107'** comprises a level regulator **503**; a color converter **504**; an A/D converter **505** and a parallel/series converter **14**.

As the image data introduced into the processing circuit **107'**, those which have been subjected to conversion into R.G.B.-signals in the color decoder **502** from composite video signals delivered from a T.V. camera, VTR or the like are used. On the other hand, R.G.B.-signals delivered from a personal computer, captain system or the like means are introduced as input into the level adjuster **503**.

As the color correction method with the use of the foregoing arrangements, it is possible, more specifically, to adjust the hue saturation and/or brightness in the color decoder **502**, or to adjust the signal level of each color light of R.G.B.-system in the level regulator **503**.

As an example, the color conversion from R.G.B.- to Y.M.C.-system can be executed in the color converter **504**. The simplest possible method in this color conversion is to procure the opposite color to each of the normal colors.

The thus produced color signals of Y.M.C.-system is subjected to A/D conversion and then fed successively through the parallel/series converter **14** and the driver **108** to the thermal head, not shown, to carry out printing in the sublimation transfer principle.

Additionally, in normal cases, with the use of the foregoing system composition, input image data must be of static mode. However, by provision of memory means in front of the color decoder or at an intermediate position between the A/D converter and parallel/series converter, animating images can be processed.

The series data converted in the foregoing manner in the data converter **107** or **107'** are fed to the shift register SR shown in FIG. **6** by n-image elements and then, upon being subjected to latching in the latch circuit LT are further delivered to NAND gate NA as its inputs. When a strobe signal ST is fed as input to the NAND gate NA, the foregoing n-image element data is fed to the thermal element HE.

FIG. **8** is a schematic diagram, showing signals for respective image elements. The gradation has been so selected that the first image element is at the highest gradation level, while the n-th image element corresponds to the lowest gradation level, and that the second to (n−1)th image elements vary linearly in gradation levels, so as to provide representatively a better understandable example of the invention.

Next, the operation of the parallel/series converter **14** will be described.

First, as shown in FIG. **5**, image elements data A, consisting of parallel data, more specifically, comprising parallel eight bit data **A0–A7**, are fed to one-side inputs of comparator **22**, while another side inputs thereof are fed with outputs B, comprising eight bit increment outputs **B0–B7**, of counter **23**. The counter **23** counts clock signals in increments, the outputs **B0–B7** being successively varied.

The comparator **22** performs comparison between the two inputs A and B, so as to deliver successively outputs of binary "1" until the increment output B is brought into coincidence with image elements data A, or more specifically, under the condition of A>B and A=B, while, thereafter, binary "0"-outputs are delivered therefrom. More specifically, comparator **22** will continue to deliver binary "1" until an increment value which corresponds to the weight of concentration of image element data A is given thereto. As an example, if the image element data A has a concentration of gradation 128 of a total 256, output "1" will be repeated to deliver 128 times first and then, output "0" will follow after again 128 times, so as to provide in total a specific series data peculiarly in this case.

These series data are taken out from the comparator **22** in the form of A>B- and A≧B-outputs and of A=B-outputs through an attributed OR-gate **24**, and in the present example, the gradation consists of 256 steps or increments. However, in practice, the gradation may represent a smaller number of steps. As an example, if the incrementing bit is **B1** instead of hitherto employed **B0**, the gradation will have 128 steps; and if **B2** is employed, it will have only 64 steps. In this way, the gradation setting may be varied in a simple manner.

When in the foregoing way, the output B from the counter **23** is stepwise incremented, such series data consisting of a first series of "1" will be delivered until the relationship between the image elements data A and the output B from counter **23** becomes A=B, and of a second series of "0" issued thereafter, as shown in FIG. **8**.

In FIG. **9**, a conversion mode at the parallel/series converter **14**, which, however, is different from that shown in FIG. **8**, as an example, is shown again in the form of a matrix. As shown, when the image data are of 8-bit parallel kind, as an example, the gradation data are ranged from 0 to 255, providing, therefore, binary series data from "00 . . . 00" to "11 . . . 11".

In this way, the data, per line in the transfer head **16**, kept preserved in the buffer **13** are fed to the parallel/series converter **14** for providing as outputs therefrom into corresponding series data which are then delivered through the driver **15** to the transfer head **16** and thus recorded on a print paper P supported on the transfer drum **17**.

FIG. **10** represents a flow chart illustrating the operation of the sublimate printer as employed in the present invention.

At the first step **S1**, print papers are set in position and the printing ribbon is also set in position ready for performing the required procedure.

At the second step **S2**, printing operation is initiated, and line printings are executed, line by line, accompanying necessary intermittent line shifts, with relation to any selected one of four colors: C (cyan); M (magenta); Y (yellow) and K (black) being carried out. Refer to **S3** and **S4**. When line printings with the selected-out single color have been completed (**S5**), the image transfer sheet is replaced by another color sheet (**S6**) and so on. In this way, line printings are completed in all four colors. In this case it is naturally most preferable to use a long extended single transfer sheet on which four color ink regions are repeatedly printed in a certain predetermined pattern. The image reception paper is initiated to make print from a certain prescribed position for each of these colors (**S8**). When all of the printing steps have been completed with the four colors, the paper is discharged from position (**S9**) and the printing operation is terminated to be repeated.

In FIG. **11**, a card style sample of the final products according to this invention is shown in front view at **200**. FIG. **12** is a sectional view thereof. Numeral **201**

represents the substrate material of the card; **202** a display layer; **203** a surface protecting layer; and **204** a display image as an example. Depending upon the kind of usage and when necessary, the protecting layer **203** may be dispensed with. It should be noted that the display image **204** on the display layer **202** is represented by a sublimative dyestuff, as a characterizing feature of the present invention.

As the main and substantial material of the image transfer sheet, various plain papers, converted papers, plastic resin sheets or the like may be used per se or in combination. When a plastic resin sheet which can be colored directly with a sublimative dye or dyes is used, these image transfer substrates (articles or objects) as at **201** can be united each with the display layer **202**. Each of these substrate materials, when it is of the card style, may have generally such dimensions: thickness of 0.68 to 0.80 mm and size: 11 to 8×8 to 5 cm.

As the material of the display layer **202**, various known materials which may be colored with sublimative dyestuffs, such as polyethylene, polypropylene, polyester, ABS, AS, polyvinylchloride, polyvinyl/vinyl acetate copolymer, polystyrene, polyacrylate, polyester, polyamide, polyurethane and the like plastic material, may be advantageously utilized. As will be more specifically described hereinafter, this material layer can be united with the substrate material layer **201**. In the case of such unified structure with substrate layer **201**, the thickness and size dimensions may be substantially as the same as before. However, when normal and/or converted papers or metals, which are practically impossible to color with sublimative dyestuffs, are used as the substrate layer **201**, various methods can be utilized for desired coloring. As an example, a solution including at least any selected one of plastic resin materials capable of coloring with sublimative dyestuffs may be coated on the substrate surface, or alternatively used in the form of a film which is laminated thereon. This kind of film preferably has a thickness of about 3 to 50 μm or so. One of main characterizing features represented in and by the final products **200** is that the appearing display image or images as at **204** is/are formed at least partially or wholly with a sublimative dyestuff or dyestuffs. Additionally, the process for formation of such images can be executed in the conventional art.

As an example, the processing method may be executed conventionally as follows.

As an example, a sublimative image transferable sheet, such as a paper sheet, plastic resin film or sheet capable of acting as the carrier is coated on its surface with any suitable binder resin carrier carrying sublimative a dyestuff or dyestuffs under heat, is overlapped on the display layer **202** and then subjected to heat from behind the heat-transferable sheet, preferably in the pattern mode, so as to transfer the dyestuff or dyestuffs into the display layer **202**. It is proper to select the molecular weight of 250 or larger of the dyestuff, for improving the fastness thereof. However, a molecular weight higher than 370 is more favorable. In the case of provision of the surface protecting layer, there is practically no limitation to the selectability of the dyestuff molecular weight.

The sublimative image transfer may be executed directly on the surface of substrate **201** provided with the display layer **202**. Or alternatively, a carrying, image transferable sheet is prepared separately and, after formation of the image **204** thereon, may be stuck onto or laminated on the substrate **201**.

Image-carrying and imaqe-transferable sheet

In the following, structure, material, usage and application purpose of the image transferable sheet to be employed in the present invention will be described in detail:

FIG. **13** illustrates only basically and in schematic sectional view the image-transferable sheet adopted in the present invention, while FIGS. **14** through **19** and **22** through **24** illustrate preferable embodiments thereof.

The basic structure of the image transferable sheet **310** is characterized in that, as shown in FIG. **13**, a sheet-like substrate **301** is provided at its one surface with an image-reception layer **302** capable of peel-off from the substrate. By adopting such a structural configuration of the image-transferable sheet, the image-reception layer **302** can be formed with the required image or images with the use of an image transferable sheet having thermally shiftable dyestuff, and then, the image-formed, image-reception layer **302** is peeled off from substrate **301** and attached firmly, preferably as by sticking, on the surface of any selected object or article with use of any suitable means. In this way, various conventional drawbacks inherent in the comparative conventional technique can be basically overcome.

More specifically, as the material of the aforementioned image reception layer **302**, limitation must be imposed to those which can be colored with thermally shiftable or transferable dyestuff. However, upon formation of necessary images and upon peel-off from the sheet like substrate **301**, the image reception layer **302** may be attached fixedly onto the surface of glass-made, metal-made or wooden-made products or plastic-resin made ones which are very difficult to color with thermally shiftable and transferable dyestuffs, indeed, by reliance on conventional sticking techniques as properly adopted in consideration of the specific nature and kind of the material of decorative products to be ornamented. Further, the image-formed and peeled-off, image-reception layer **302** from the sheet substrate **301**, is highly thin and thus sufficiently pliable so that it may be applied even onto any uneven and complicated surface of a product to be decorated or ornamented, having undulations, convexities, concavities, recesses and projections. Therefore, a maximum possible better fitness of the image-reception layer to be ornamented is attained and guaranteed by the present invention. Thus, practically no limitation in the attaching use thereof may be encountered. Further, in sharp contrast to conventional sealing seals and the like, the very thin image-reception layer bearing necessary images can be applied easily to the product per se in a very uniform manner, thus providing no raised and thickened feeling, and giving rise to no foreign feeling upon attachment.

FIG. **14** shows a further example of the image transferable sheet **310**. In this case, there is provided a parting agent layer **303** on the surface of image-reception layer **302**. Between the latter and the sheet substrate **301**, there is provided a parting agent layer **303'**. If necessary, however, any one of the two layers **303**; **303'** may be dispensed with.

The first parting agent layer **303** is provided for prevention of thermal fusion between the image-reception layer **302** and an image transferable sheet, not shown, as may occur during image transfer and formation on the first layer **302** through transfer of thermally transferable dyestuff from the said transferable sheet to the first

layer. If there is no risk of such thermal fusion of the above nature, or when the image-transferable sheet has been already provided with such a parting agent layer, the present provision thereof may be unnecessary. As for another parting agent layer **303'**, it is for the purpose of making the latter peel-off operation, to be executed after image-forming step, easier. When the sheet-like substrate **301** is made of polyester or the like material which has, as it is, sufficient separability from image-reception layer **302**, provision of parting agent layer may naturally be dispensed with.

FIG. **15** illustrates a still further example of image transferable sheet **310**. In this case, between the image-reception **302** and the sheet-like substrate **301**, an intermediate layer **304** and/or parting agent layer **303'** is/are provided. The laminating order is optional and thus not binding. The intermediate layer **304** will serve to assist the image formation to be rather firm and beautiful, the image formation being carried out by transferring the thermally shifting and transferring dyestuff from the image transferable sheet to the image-reception layer **302**. For this purpose, the intermediate layer **304** may take, for example, the form of a cushioning layer or heat insulating layer. When a cushioning layer is provided as the intermediate layer **304**, the cohesion between the image transferable sheet and th image reception layer **302** is greatly improved and the thermal shift and transfer of the dyestuff during image formation with the use of a thermal head is evenly executed, the image formation thereby being carried out amply in correspondence with the supplied image signals. Further, when a heat insulating layer consisting of a highly heat-insulative material is used as the intermediate layer **304**, ineffective release of the heat applied during shift and transfer of the dyestuff from the image transferable sheet to the image-reception layer **302** can be reduced to a minimum possible, the effective thermal efficiency thereby being correspondingly improved and ample image formation being accelerated. If necessary, however, these cushioning layer and heat-insulating layer can be prepared independently and arranged concurrently in any arranging order.

Additionally, when the intermediate layer **304** is arranged at a higher level than the parting agent layer **303'**, the intermediate layer **304** will be conjointedly peeled off in the case of peel-off of the image reception layer **302**. On the contrary, when the intermediate layer **304** is arranged at a lower level than the parting agent layer **303'**, the intermediate layer will remain on the sheet-like substrate **301** after execution of the separation of image-reception layer **302**. In this case, therefore, the intermediate layer **304** may be made preferably and at least substantially transparent, when the peeled-off image-reception layer **302** is stuck on a decorative product, while directing the surface of parting agent layer **303** towards the latter.

In the modifications shown in FIGS. **16**, **17**, and **18**, modified from the foregoing embodiment shown in FIG. **15**, a further protecting layer **305** is provided between the image-reception layer **302** and the sheet-like substrate **301**. This protecting layer **305** serves to prevent deterioration of the formed images in the image-reception layer **302** when the latter is stuck on the decorating product while directing the surface (more specifically the image-formed surface) towards the product. For example, this protecting layer **305** is prepared from a superior material which exhibits at least one of desirous properties such as antiwearing, light-fast, weather proofing and anti-chemical qualities. With the use of the protecting layer **305** having these superior qualities, the images can represent improved fastness in the above various aspects, even after execution of the foregoing sticking procedure.

In the modification shown in FIG. **16**, the protecting layer **305** is arranged between the intermediate layer **304** and the parting agent layer **303'**.

In the further modification shown in FIG. **17**, the protecting layer **305** is arranged between the image-reception layer **302** and the parting agent layer **303'**.

In still another modification shown in FIG. **18**, the intermediate layer **304** takes the role of the protecting layer **305**.

In each of these modifications, the protecting layer **305** is arranged in neighboring relationship with the partition agent layer **303'**, whereby the image-formed and remotely arranged, image-reception layer **302**, kept in its up-and-down reversed state, is capable of adhering securely to the decorative product, so as to be positioned as an uppermost layer, as may be required. In a still further modification shown in FIG. **19**, derived from that shown in FIG. **14**, a sticking layer **306** is further provided between the image-reception layer **302** and the partition agent layer **303**. It should be noted, however, that such a sticking layer as at **306** may be provided in any one of other foregoing examples and modifications, if necessary, in neighboring relationship with the parting agent layer **303'**.

The provision of such a sticking layer as at **306** is highly valuable when the image-formed and peeled off image-reception layer is adhering without position reversal onto the decorative product. With this arrangement mode, the protecting layer **305** shown in FIGS. **16**, **17**, and **18** may be dispensed with. If, however, the protecting layer **305** is composed of a material in the form of a sheet-like substrate, the part to be peeled off is thereby strengthened, the peel-off procedure thus being greatly facilitated.

By previous provision of the sticking layer **306**, the image-formed and peeled-off, image-reception sheet **302** can be caused to adhere as it is onto the decorative product without use of a separate sticking agent. As the sticking layer **306**, an ordinary sticking agent which is active at room temperature can be used. Or alternatively, a heat-sensible or light-sensitive sticking agent may be used, if necessary.

In the foregoing, the main structure of the image transferable sheet employed in the present invention has been described in detail. However, other structural modes than those set forth hereinbefore which occur easily to those skilled in the art may be employable in the invention, and thus they may be included within the scope of the invention without departing from the appended claims.

It should be further noted that, in the present invention, the sheet-like substrate may be provided on its one surface with an image transferable layer capable of peeling off through the intermediary of only one weakly sticking layer.

FIG. **22** shows only schematically in a sectional view a preferred embodiment of such an image-transferable sheet, denoted with same reference numeral **310**.

As shown in FIG. **22**, the image-transferable sheet **310** represents a basic structural characteristic such that any suitable sheet-like substrate **301** is provided on one of the surfaces with an image-reception layer **302** through an only weakly sticking intermediate layer **402**,

the layer **302** thus being easily peeled-off when desired. By providing the image-transferable sheet with such a structural characteristic as set forth above, desired positive or negative images are formed by transferring thermally shiftable and transferable dyestuff from the image heat transferable sheet to the image-reception layer **302**, and the thus image-formed layer is peeled off from the sheet-like substrate **301** and then attached onto any suitably selected product with the use of proper means or attached per se thereon without the peeling-off operation, the substrate then being peeled off, whereby an image-formed final product can be obtained.

In the foregoing example, it should be noted that the image reception sheet **302** per se has only a thin thickness and thus represents only poor feedability during the sheet-feeding period within the printer at the time of image formation, insufficient cushioning effect and only insufficient thermal efficiency during the printing operation, and further, it is very difficult to treat in advance of as well as after execution of the image formation. Therefore, the coexistence of the image-reception layer **302** and the sheet-like substrate **301** is absolutely necessary. In addition, it is a requisite requirement that the image reception layer **302** be easily peeled off from the sheet-like substrate **301** upon execution of the image forming operation, and thus, the layer **302** and the sheet **301** should not be stuck too strongly together. In order to satisfy this requirement, provision is made of weakly stuck layer **402** therebetween. Thus, it should be noted that the term "weakly stuck" employed in this specification and appended claims may be defined as "to be separable by finger's end and the like means from each other without entailing destruction or breakage of the parts originally stuck together". It is worthwhile to say, in considering the relative relationship between the image-reception layer **302** and the sheet-like substrate **301**, there is no necessity to provide the weakly-stuck layer **402** if the aforementioned peeling off is very easy to bring about.

FIG. **23** illustrates still another modification of the image-transferable sheet **310** denoted by the same reference numeral **310** only for simplicity and convenience, wherein a further parting agent layer **303** is provided on the surface of image-reception layer **302**.

This layer **302** is provided for occasional thermal sticking between the thermal image transferable sheet, not shown, and the image reception layer **302** in the progress of thermal shift and transfer of the dyestuff from the sheet to the layer **302**. This provision of the parting agent layer **303** may be dispensed with if there is no risk of occurrence of such disadvantageous sticking attachment or the sheet under consideration has already been fitted with such a parting agent layer.

A modification shown in FIG. **24** from that shown in FIG. **23** has such a modified structure that a protecting layer **305** is provided between the image-reception layer **302** and the weakly stuck layer **305**. This layer **305** serves to prevent otherwise occurring deterioration of the images at the image-reception layer **302** which has been formed with preferably reversed images and subjected to peeling-off, together with protecting layer **305**, preferably a plastic sheet layer, from the sheet-like substrate **301** and finally stuck onto the decorative product, while directing the image-formed surface of the image-reception layer towards the product. The protecting layer **305** is made of a material having various excellent physical properties, such as anti-wearing-, light-fastness and antichemical characteristics. Provision of such a protecting layer improves various fastness performances of the formed images after sticking attachment of the image-reception layer **302**.

When necessary, a separate parting agent layer, not shown, may be provided between the protecting layer **305** and the weakly stuck layer **402** for providing easy peel-off capability between these two layers **305** and **402**, as being applicable to the example shown in FIG. **24**. If the surface of the protecting layer **305** should have sufficient peel-off capability, it is natural to provide such an intermediate parting agent layer as above.

Further, in the case of the image-transferable sheet **310**, it is naturally easy to separate from each other through a peel-off operation, upon the formation of necessary images thereon and before practical use thereof as the image-transfer sheet, and a cut-out slit as at **407** in the sheet-like substrate **301** may be provided for attaining such an easy separation as stated above at a portion of the sheet **310** in proximity to one end thereof. Upon the provision of such a cut-out slit as at **407**, the thus formed flap-like portion can be easily folded out by the operator's finger-tip, thereby affording convenience in a peel-off operation.

The usable materials and composing methods of the foregoing image transferable sheets will now be described.

As a material usable for the sheet-like substrate may be any one or any combination of the following categories:

(1) synthetic paper (polyolefin series; polystyrene series and the like);

(2) fine quality paper; art paper; coated paper; cast-coated paper, wall paper; back-up paper; backing paper; resin-, emulsion- or synthetic rubber-impregnated impregnated paper; resin admixed paper; paper board; cellulose fiber paper;

(3) polyolefin-, polyvinyl chloride-, polyethylene terephthalate; polystyrene; polymethacrylate; polycarbonate and the like plastic film or sheet.

Use of the synthetic paper belonging to the foregoing category (1) is highly suitable for the purpose of the present invention since the surface thereof generally represents a microvoid layer which provides a low heat conductivity and thus a high heat-insulating performance. A laminated material representing any combination of the foregoing categories (1), (2) and (3) can be used in the present invention. A representative and recommendable example of such a laminate is that of cellulose fiber paper and synthetic paper or that of cellulose fiber paper and plastic resin film or sheet. Among others, use of the first mentioned kind of laminate will provide an advantage in that the thermal instability such as thermal elongation or shrinkage possessed by the synthetic paper component is compensated for by the cellulose fiber paper, whereby a high thermal sensibility is demonstrated during the printing step due to low thermal conductivity of the synthetic paper component. Further, in the case of the present paper combination, however, a further modified combination of a three-layer laminate: synthetic paper-cellulose fiber paper-synthetic paper may be more advantageously employed for making the frequently appearing lesser by providing a well-balanced structure between both the surfaces of the final laminate.

As the synthetic paper mentioned above, any suitable one usable as a synthetic paper substrate used as a component of the image-transferable sheet layer may be used. As a recommendable example thereof, having a

fine porous fine paper structure layer, the synthetic paper called "YUPO", manufactured and sold by Oji Yuka Goseishi Kabushiki Kaisha, Tokyo, may be mentioned. This paper layer having a fine pore structure may be prepared in such a way that a suitable plastic resin material containing a filler of finely divided state is subjected to a mechanical elongation step. When the image-transferable sheet composed of the synthetic paper sheet containing finely divided air as above mentioned is formed with images through a thermal image transfer setup, the concentration of the thus formed images is surprisingly high and no fluctuation of image configuration and concentration is encountered, thanks to the heat insulation effect provided by the very existence of fine air pores, in addition to the improved thermal energy efficiency. Especially, due to the advantageous cushioning effect provided by the air-filled fine pores, the image-receiving layer is supposed to be rather advantageously affected during the image formation step. As an alternative measure, the paper-like layer containing the above-mentioned fine air pores may be, if desired, provided directly with the core material consisting of the cellulose fiber paper or the like.

It is further possible to use plastic film in addition to the cellulose fiber paper in the laminate described above. Still further, a laminate of said cellulose fiber paper and plastic film composed together can be used.

As the method for co-sticking of synthetic paper and cellulose fiber paper, use of a known adhesive agent is naturally adopted, as an example. Or alternatively, the extrusion-laminating, heat-adhesion, or the like process may be relied upon, as the case may be. On the other hand, as the sticking-process between the synthetic paper and the plastic film, the lamination process to be carried out simultaneously with the formation of the film may be adopted. Calendering or the like method may be utilized for the same purpose. Selection of any suitable one of the several foregoing sticking processes depends upon the kind of material or the like condition of the partner member to be stuck together with the synthetic paper. As for the adhesive agent mentioned above, emulsion adhesive such as ethylene-vinyl acetate copolymer, polyvinyl acetate or the like, aqueous solution type adhesive polyester containing carboxyl radicals; or the like may be mentioned. On the other hand, as the laminating use adhesive, organic solvent solution type one such as polyurethane-, acrylic- or the like, may be mentioned.

The material for the image reception layer must be suitable for reception of heat-transfer dyestuff, such as sublimative disperse dye from the image transfer sheet and holding and maintaining the thus formed images thereon. From the view point of image-holding and blocking prevention, use of such synthetic resin as having glass transition temperature higher than 40° C. may be advantageous. For example, the synthetic resins set forth in the following items (a) through (e) may be used separately or in combination.

(a) Ester bond-bearing resins:
Polyester resin; polyacrylic ester resin; polycarbonate resin; polyvinyl acetate resin; styrene acrylate resin; vinyltoluene acrylate resin and the like.
(b) Urethane bond bearing resins:
Polyurethane resin and the like.
(c) Amide-bond carrying resins:
Polyamide resins (nylons).
(d) Urea-bond carrying resins:
Urea resins and the like.
(e) Other high polar-bond carrying substances:
Polycaprolacton resin; polystyrene resin; polyvinylchloride resin; polyacrylonitrile resin and the like.

The image-reception layer may be prepared from a resin mixture of saturated polyester and vinylchloridevinyl acetate copolymer. As the saturated polyester, such commercialized products: "Vylon 200"; "Vylon 290"; "Vylon 600"; "Vylon 103" and the like, manufactured and sold by Toyoboseki K.K., Osaka, Japan; "KA-1038C" (manufactured and sold by Arakawa Kagaku K.K., Osaka, Japan; "TP 220"; "TP 235", manufactured and sold by Nippon Gosei K.K., Osaka, Japan; may be advantageously used. The vinyl chloride-vinyl acetate copolymer may have preferably 85–97 wt. % of vinyl chloride component, the polymerization degree being between about 200 and 800. The vinyl chloride-vinyl acetate copolymer may further contain a vinyl alcohol component, maleic acid component within the purpose of the invention in addition to the main components. According to our experiments, it has been found that these modified copolymers should have rather superior compatibility with polyester resin. The image-reception layer may be, if necessary, composed of polystyrene resin, for example, in this case, styrene monomer, preferably styrene, α-methyl styrene, and vinyl toluene may be used separately or in the form of copolymer or saying in general sense polystyrene resin. Further, such styrene copolymer resin may be used as specifically recommendable material in the above sense, comprising said styrene monomer(s) with other monomer, preferably for example, acrylic acid ester, methacrylic acid ester, acrylonitrile, methacrylonitrile and the acrylic or methacrylic monomer, or further styrene copolymer resin comprising maleic acid anhydride.

It should be noted, however, that among others, polyester series resin is especially superior for the purpose of the present invention.

In any of the foregoing embodiments, however, white pigment is preferably admixed with the material of the image-reception layer for improving the whiteness thereof and further accentuating the sharpness and fineness of the images when transferred thereto and to provide a manually writing-on performance. As the white pigment for this purpose, the following materials may be used separately or in any combination: titanium oxide; zinc oxide; china clay calcium carbonate; finely divided silica and the like.

For further improving the whiteness fluorescent whiteness-increasing agent or -bleaching agent may be added to. Further, for improving the light fastness of transferred images, ultraviolet absorption agent and/or photostabilizing agent may be added to, preferably in a quantity of 0.05 to 10 and 0.5 to 3 weight parts per 100 weight parts of the material resin composing the image-reception layer.

The image-transferable sheet used in the present invention is preferably constituted for improving the separability from the image-transfer sheet in such a way that the surface of the image-reception layer is formed with a partition agent layer, or instead, such agent is admixed to the image-reception layer. As for the partition agent to be used for this purpose, polyethylene wax; Amido Wax, Teflon Powder or the like solid wax; surface active agents such as fluorine contained agent or phosphoric acid ester series surfactant; silicone oil or the like may be selectively used. Among others, silicone oil may be advantageously utilized.

The silicone oil may be used in oily state, but a hardenable type thereof may be rather advantageous. As the hardenable silicone oil, reaction hardening one, photohardening one, catalytically hardening or the like one may be used selectively according to necessity. However, use of the reaction-hardenable one is most highly recommendable. Silicone oil of this type may be obtained, as example, by reacting amino-modified silicone oil with epoxy-modified silicone oil to obtain a reaction-hardened product. As for the amino-modified silicone oil, "KF-394", "KF 857", "KF-858"; and "X-22-3680"; "X-22-3801C" (manufactured and sold by Shinetsu Kagaku Kogyo K.K., (Tokyo, Japan)) and equivalents thereof may be used. As for the epoxy-modified silicone oil, "KF-100T"; "KF-101"; "KF-60-164"; and "KF-103" (manufactured by Shinetsu, above mentioned) and equivalents thereof may be used. Further, as the catalytically hardenable and photohardenable silicone oils in the above sense, "KS-705F"; "KS-770" of the catalytic hardenable or hardened silicone oils, manufactured by Shinetsu; and "KS-720" and "KS-774" of the photohardenable or hardened silicone oils (manufactured equally by Shinetsu) and equivalents thereof may be used. The adding quantity of each of these hardenable or hardened silicone oils may advantageously range from 0.5 to 30 wt. % depending on the material of the resin composing the image-reception layer.

At least a part of the image-reception layer is coated with a solution or dispersion of any of the foregoing partition agents in a suitable solvent and dried and further treated, a suitable parting layer being provided thereon. A particularly suitable partition agent for the formation of this kind of partition layer is the aforementioned reaction type hardenable one obtainable by reaction of an amine-modified silicone oil with an epoxy-modified one. The thickness of the partition layer is 0.01–5 μ, preferably 0.05–2 μ.

It should be noted that when silicone oil is admixed during formation of the image-reception layer, the silicone oil will bleed out after coating and the parting agent layer can be formed by the hardening even after such bleeding. In order to improve the parting ability between the image transferable layer and sheet-like substrate, it is possible to provide a parting layer consisting of a heat-hardenable resin, preferably of the melamine series, and having better affinity for the image transferable layer compositions. For the same purpose as above, however, without special provision of the parting layer, a protecting layer consisting of polymethyl methacrylate resin or cellulose acetate propionate can be provided.

For the formation of the image transferable layer, a solution or dispersion of a material composition suitable for the purpose is applied on the sheet-like substrate through conventional coating or printing. As an alternative way, a separate film or sheet for the image transferable layer **302** is formed preparatorily on a provisional carrier sheet or film and then, as a succeeding step, subjected to an image-transfer onto the substrate.

The intermediate layer is made of either a cushioning or a porous material. In some cases, the intermediate layer may additionally function as the adhesive layer.

The cushioning layer is mainly composed of such a resin which has a value of 100%-modulus as defined at JIS-K-6031 (Japanese Industrial Standard) of less than 100 kg/cm^2. If this value should exceed the above prescribed value, the rigidity will become much higher than that recommended for the intermediate layer. When the layer is formed with such disadvantageous material resin, sufficient adhesion between the heat image-transfer sheet and the image-reception layer cannot be maintained during the printing step. The lower limit of the prescribed 100%-modulus is of the order of 0.5 kg/cm^2 in actual practice.

Preferable kinds of resin to be used for the above purpose, may be enlisted as follows:

polyurethane resin; polyester resin; polybutadine resin; polyacrylic acid ester resin; epoxy resin; polyamide resin rosin-modified phenol resin; terpene phenol resin; ethylene/vinylacetate copolymer resin; and the like.

These resins can be used independently or in combination of two or more kinds. Since these resins are rather viscous and tend to give rise to manufacturing troubles inorganic additives may be admixed, such as, for example, silica; alumina; clay; calcium carbonate; amide series substance such as amide stearate; and/or the like.

The cushioning layer is preferably formed with the use of one or more of the above specified resins, occasionally with the addition of suitable additive(s); solvent or diluent, prepared into a coating agent or printing ink which is then applied on, according to a known coating or printing process and then subjected to drying to provide a coating. The thickness of the coating should be between 0.5–50 μm, preferably 2–20 μm or so. With a thickness less than 0.5 μm, the coating will not be able to compensate for the surface irregularities on the substrate, thus being ineffective for the desired purpose. On the other hand, when the thickness exceeds the above specified maximum value or more specifically 50 μm, the overall thickness of the image-transferable layer becomes much too large, so that handling troubles may be encountered during wind-up and overlapping procedures, without attaining further effect as desired. In addition, in this case, a loss of production economy will be inevitably introduced.

The thus obtainable improvement of intimate adhesion between the heat image transfer sheet and the thermally image-transferable sheet by the provision of the above intermediate layer may be conceivably attributed to the lower rigidity of the intermediate layer per se, whereby it is liably to be deformed under the influence of the printing pressure, and further to the generally relatively low glass transition temperature and softening temperature of the aforementioned kinds of resin resulting in further lowering of rigidity and tendency to deform than at room temperatures upon reception of heat energy during the image printing step.

The porous layer may be formed generally in the following four ways: (1) through (4).

(1) Emulsion of polyurethane or the like resin, methylmethacrylate-butadiene series synthetic rubber latex is foamed by mechanical agitation, coated, and dried on the sheet substrate into a layer.

(2) The synthetic resin emulsion or synthetic rubber latex is admixed with a foaming agent and the liquid mixture is coated and dried on the substrate into a layer.

(3) Vinyl chloride plastisol, polyurethane or the like synthetic resin or styrene-butadiene series or the like synthetic rubber is added with a foaming agent and the liquid mixture is coated on the substrate and subjected to heating to provide a foamed layer formed thereon.

(4) A thermoplastic resin or synthetic rubber is dissolved in an organic solvent to provide a solution, and a non-solvent (including that containing aqueous main component), and the latter solution are mixed together to provide a liquid mixture, said nonsolvent being less volatile than the organic solvent and having a considerable mutual solubility with the solvent, and showing, however, non-solubility with the thermoplastic resin or synthetic rubber. The thus prepared liquid mixture is then coated on the sheet-like substrate and dried, to provide a porous membrane upon micro-coagulation of the constituents. The resulting microporous layer can be utilized for the above purpose.

It should be noted that the layers produced by any of the foregoing three processes (1) to (3) have rather large foams contained therein, and thus when the foaming solution for the image-transferable layer is applied thereon and dried, the latter may exhibit excessively coarse surface conditions. Therefore, in order to obtain an optimumly image-transferable smooth surface capable of providing transferred images of high uniformity, provision of the micro-porous layer prepared by the process as set forth in the forgoing item (4) is highly recommendable.

As the thermoplastic resin suitable for the formation of the above porous layer, saturated polyester; polyurethane; vinylchloride-vinylacetate copolymer; cellulose acetopropionate and the like can be used. Further, as the synthetic rubber usable for the same purpose, those of styrene-butadiene series, isoprene series, urethane and the like series may be used. Still further, as the organic solvent and non-solvent liquid used for the formation of the microporous layer, various known substances may be used. Generally speaking, however, methyl ethyl ketone; alcohol and the like are representatively used. On the other hand, as the non-solvent, water is mostly used.

The thickness of the porous layer usable in the present invention is preferably greater than 3 μm, especially preferably in the range of 5 to 20 μm. With the use of a porous layer having a thickness of less than 3 μm, the desired cushioning and heat-insulating effects cannot be attained.

As was referred to hereinbefore in the description stage for the formation of the image-transferable layer, the intermediate layer may act simultaneously as the sticking layer in some cases.

This kind of intermediate layer(s) may be provided on one or both of the surfaces of the thermally image-transferable sheet.

In practice, however, an electrostatic charge may accumulate in the material of the thermally image-transferable sheet during its processing step or during running through the printer. As a countermeasure, a proper antistatic agent may be applied on one surface of the image-transferable layer or on the bottom surface of the thermally image-transferable sheet or it can be included in the material of the image-transferable layer. As the antistatic agent in this sense, a surfactant such as a cation-exchange agent (for example, a quaternary ammonium salt, polyamide derivatives and the like) may be advantageously used. Further, an anion exchange type surfactant, such as alkyl sulfonate may be used. Otherwise, amphoteric ion type surfactants or even, non-ionic surfactants may be used for the same purpose.

On the other hand, the antistatic agents may be coated on the surface of image-reception layer by gravure-coating, bar-coating or the like process or alternatively, these agents may be kneaded with the material resin and then subjected to transfer towards the surface during the coating formation and drying step for preparing and providing the image-transferable layer. As the antistatic agents to be admixed with the image-transferable layer material resin, cation-type acrylic polymers may be employed.

The protecting layer is peeled off together with the image-transferred layer, from the sheet-like substrate, and then stuck, in inverted reversed state, onto any desired decorative object, the protecting layer thereby being positioned at the uppermost position, for improving the anti-wearing-light-proofing and anti-chemical performances of the image-bearing layer. As the material adapted for the formation of the protecting layer, for example, alkyd resin; phenol-modified alkyd resin; aminoalkyd resin; phenol resin; urea resin, melamine resin; silicone resin, thermosetting acryl resin, thermosetting polyurethane resin and the like thermosetting resin or normal temperature setting resin; further, ultraviolet hardenable resin; electron ray hardenable and the like activating energy flux hardenable resins or thermoplastic resins such as polyester-; polyurethane-; polyvinyl acetate resin; vinyl chloride-vinyl acetate copolymer resin; polyolefin resin, acryl resin and the like, can be used.

Preparation and use of a protecting layer comprising one or more of the above-mentioned resins are made in such a way that the material resin is dissolved in a properly selected solvent according to the necessity, so as to provide a coating liquid or ink, as the case may be, which is provided between the parting layer and the image transferable layer. The thickness thereof is generally 0.5 to 20 μm. It is also possible to form the protecting layer with the use of a resin film which consists of polyester-; acryl-; acrylpolyol-; polyvinyl chloride-; olefin resin or the like resin. It is further possible advantageously to admix an ultraviolet ray absorbing agent and/or photostabilizer to the material of the protecting layer.

The protecting layers prepared and formed in the foregoing way are thus not made integral with the sheet-like substrate or parting layer and, therefore, the peel-off operation of the sheet-like substrate upon execution of the image transfer is very simple and easy.

It is further recommendable, if necessary, to provide a slip-promoting layer on the bottom surface of the sheet-like substrate, which surface is naturally the one opposite to the image-transferable layer side, so as to properly adjust the friction between the image-transferable sheet and feed roll paper or carrier belt acting during passage through the printer and to improve the running performance of the thermally image-transferable sheet in the printer.

The slip-promoting layer can be formed by adding an organic powder such as polyethylene wax fluorine resin powder or an inorganic powder such as talc, according to necessity, to a resin such as polymethyl methacrylate resin; vinyl chloride-vinylacetate copolymer; vinyl chloride copolymer; cellulose acetate butylate; cellulose acetate propionate; styrene-acryl series or the like resin and kneading the resulting mixture to prepare a composition, applying this composition as a coating on the sheet substrate either directly or after application of a suitable primer treatment, and drying the coating thus applied. A suitable quantity of the slip promoting layer is 0.5 to 5 g/m^2 after drying.

In the embodiments shown in FIGS. **22**, **23**, and **24**, as the adhesive agent to be used in the slightly weak or weak adhesive layer, it should be noted that those conventionally used adhesives for adhesive tapes and seals can all be used. Preferred examples are polyisoprene rubber; polyisobutyl rubber; styrene butadiene rubber; butadiene acrylonitrile rubber and the like rubber-series resins (meth)acrylic acid ester-series resins; polyvinyl ether-series resins; polyvinyl acetate-series resins; vinyl-chloride-acetate copolymer series resins; polystyrene-series resins; polyester-series resins; polyamide-series resins; polychlorinated olefin-series resins; and polyvinyl butyrol series resins. To the suitably selected adherent may be added a proper quantity of a stickness improver, such as rosin; dammar; polymerized rosin; partially hydrogenated rosin; ester rosin; polyterpene-series resins, terpene-modified substances; petroleum-originated resins; cycropentadiene-series resins; phenol resins; styrene resins; xylene resins; and coumarone-indene resin. Further, when necessary, to the mixture may be added a softening agent, filler; antiaging substance or the like conventional agent(s). As the material for the formation of slightly or weak adherent layer said above, emulsion type adhesive, preferably of acryl acid ester series can be used. As for the parting function after a long time of preservation, emulsion type adhesives are highly recommendable. These adhesive agents are easily procurable from market.

When necessary, these adhesives are added with proper organic solvent(s) for the adjustment of the viscosity, and then applied by roll coating, die-coating, knife coating, gravure coating or the like conventional technique on the surface of the sheet-like substrate, image reception layer or protecting layer, so as to provide an adhesive agent layer. The thus formed adhesive layer is preferably of a thickness of 1–50 μm, although this is not limitative.

Formation of Images

In the following, the decorating process according to this invention will be set forth in detail. Utilization of the image-transferable sheet according to this invention constitutes an important main feature thereof.

In FIGS. **20** and **21**, basic practising processes will be described first.

The embodiment shown in FIG. **20** is a result of the use of the transferable sheet shown in FIG. **13**. First, a known transfer sheet **320** is applied onto the image-transferable sheet **310** in an overlapped manner such that the dye-carrying layer **321** is kept in opposition to the image-reception layer **302** of image-transfer sheet **320**, and heat energy is applied, as schematically shown by a plurality of arrows, in accordance with image signals fed at a thermal head, not shown, from the side of image-transferable sheet **310**, or preferably, from the side of the image-transfer sheet **320**, thereby forming the desired images as at **307** in the image-reception layer **302**. Next, the image-reception layer **302** formed therein with the desired images **307** is peeled off from sheet-like substrate **301** and stuck onto the decorative product **306**. Or alternatively, both the sheets **302**; **301** are stuck onto the product **306** without preparatory peeling-off. In the latter case, the peel-off step may be executed after execution of the stickingly attaching step. In the above former case, and in such a case where an adhesive agent layer **306** has preparatorily provided between image-reception layer **302** and sheet-like substrate **301** as was set forth hereinbefore, the sticking attachment is carried into effect in such a way that the adhesive layer **306** is kept in opposing contact with the product **330**, and then the sticking operation is brought about by application of heat and pressure or light and pressure, depending upon the nature and structure of the layer **306**. In this way, the decoration according to the present invention is completed as a preferred one mode thereof.

On the other hand, if there is no preparatory provision of the adhesive layer, either the surface of product **330** or of the peeled-off image reception layer **302**, may be coated with the adhesive agent, and the latter layer **302** per s or otherwise in the up-and-down reversed state may be stickingly attached onto the product **330** (refer to FIG. **21**).

Since the image-reception layer **302** is composed generally of such thermoplastic resin material as is liable to be colored with thermally transferable dyestuff, it can be thermally and fusingly attached to plastic resin-made formlings, clothes or metals even with provision of an adhesive layer, if necessary.

In this case, the image bearing layer **302**, the image thereof having been formed in the aforementioned way, is stuck on, through the intermediary of the adhesive agent layer **306** as shown in FIG. **25**, while retaining the sheet-like substrate **301** on the surface of the image-reception layer **302**.

A modification of the last-mentioned mode is shown in FIG. **26**. In this case, sheet-like substrate **301** is formed on the surface of the product **330** and the image-reception layer **302** is formed as the outermost layer. Further, in this case, sheet-like substrate **301** and product **330** may be stuck together, and, through the intermediary of a suitable adhesive layer, sticking layer or heat sealable sheet or the like.

As for the transparent film usable as the said sheet-like substrate, it must be transparent to such a degree as not to conceal the images formed in the image-reception layer, and, in addition, it must have superior surface properties such as, for instance, antiwearing characteristics. As an example, polyolefine; polyvinyl chloride; polyethylene terephthalate; polystyrene; polymethacrylate; polycarbonate and the like plastic resin-made films may be used upon variously surface conditioning. If these transparent films should be too thick, the images will be raised, and the unitary feelings may be lost when these are stuck on respective products to be decorated. Therefore, the film thickness is preferably of the order of 0.5 to 50 μm.

In the case of a further embodiment of the present invention, the image reception layer of image transferable sheet which has been, however, formed with necessary images is subjected to image transfer treatment onto an intermediate image transferable substrate, the latter is then subjected to an image-retransfer with the images, and the thus retransferred images are again transferred onto the surface of the product to be decorated. In the following, this image transfer mode will be set forth in detail.

Embodiments shown in FIGS. **27**, **28** and **29** represent such a process for execution of image transfer operation as by the intermediary of intermediate image transfer sheet **510**. First, as shown in FIG. **27**, a thermally image-transfer sheet **320** having a thermal transferable dyestuff layer **321** is overlapped to image-transfer sheet **510** which is, at this stage, not formed with images **307** and thus consists of a thermal image-transferable sheet, in such a way that the dyestuff layer **321** or more specifically the parting layer **322** is in opposi-

tion to the image-reception layer **302** of the foregoing sheet **510**. In such a case, however, that heat energy is supplied in accordance with image-forming signals delivered from the thermal head, not shown, and, indeed, preferably from the side of the sheet **320** as hinted by a plurality of double-line arrows for thermal formation of desired images (positive images) as at **307** in the image-reception layer **302**, it is highly recommendable to provide an adhesive layer **402** between the layer **302** and sheet-like substrate **301**.

Then, with the use of the image transfer sheet **510** formed with positive images **307**, the images of layer **302** are transferred, as shown in FIG. **28**, to a separate intermediate substrate **501**, which is, however, fitted with a protecting film layer **305**, thus, the transfer being carried out, in fact, onto the latter, and indeed, with the correspondingly inverted images, attached with same reference numeral only for convenience, from the foregoing layer **302**. In this case, it is preferable to subject the adhesive layer **402** of the image-transfer sheet **510** to the image-transfer operation, together with the image-reception layer **302**. Further, as for the intermediate image-transfer substrate **501**, it is recommendable to provide the protecting film layer **305** through the intermediary of a weak-adhesive layer **402'** as shown. The thus provided intermediate image-transfer. sheet **610** represents generally the image-transferable sheet. FIG. **29** illustrates the step for transfer of the image-reception layer **302** now carrying positive images onto the object **330** to be decorated and under utilization of the previously described intermediate image-transfer sheet **610**.

More specifically, the intermediate image-transfer sheet **610** is overlapped onto the said object **330** in such a way that the adhesive layer **402** of the former in opposition to the, surface of the object **330** and pressurized together. Then, the intermediate transfer substrate **501** together with the weak-adhesive layer **402'** is peeled off from the remainder of the thus-pressurized assembly, the now image-carrying layer **302** formed with positive images **307** covered with protecting the film layer **305** thereby remaining in the transferred state on the product **330**. In the case of no provision of the protecting film layer **305** on the intermediate image-transferable sheet **610**, the layer **302** remains in an exposed state. Therefore, an overcoat layer, if necessary, can be provided on the now image-carrying layer **302**.

The previously set forth process carried out by the use of said intermediate image-transferable sheet can be executed by means of the apparatus which is shown schematically in FIG. **1E**.

In this apparatus, more specifically, there is provided a carrier system comprising a series of rolls **11, 412, 413** and **414** for conveying the intermediate transfer substrate (sheet), arranged in addition to the apparatus shown in FIG. **1B**. More specifically, the substrate is drawn out from feed roll **414**, conveyed through successive rolls **413**; **412** and retransferred onto one of the products **200**. Other operations are same as set forth hereinbefore with reference to FIG. **1B**. Further, in the case of FIG. **1E**, the final product may take the form of a roll-like substrate which is subjected to an image transfer operation through the intermediate substrate, by transferring its image-carrying, image-transferable layer, for later being punched out properly. Alternatively, under occasion, it may be subjected to half-cut operations downstream of roll **122**.

As was set forth herein above, the preferable method for the formation of desired images on the image-transferable sheet is carried out by use of a heat image-transfer sheet comprising a sheet like substrate having a layer including a thermally transferable dye (evaporative dye). The heat image-transfer sheet which can be utilized in this method is known per se. And almost every kind of these known sheets can be useful in the practice of the present invention. It should be noted that by employing the foregoing image-transfer method, monocolor or full-color images can be easily formed as occasion may desire.

It should be further noted that details of such heat image-transferable sheet can be easily understood with reference to our U.S. patent application Ser. No. 833,039. As for the heat image transferable sheet usable in the present invention, the coating layer of the sheet (coating film) may include a parting agent. By adopting this measure, the image-reception layer of the image-transferable sheet or the surface thereof, to be subjected to sublimative image-transfer, must not have a separate parting agent layer, the adhesive ability between the image reception and the surface of object to be decorated can be still further improved upon execution of the sublimative image-transfer and image-formation at the image-reception layer and adherent attachment thereof to the object. As the parting agent to be included in the coating layer of the thermally image-transferable sheet (coating film), silicone oil; silicone resin; phosphoric ester or the like surfactant; and/or chelate- and the like agents, may be selectively utilized. These agents, upon mixed, will ooze out from inside to the outer surface of the coating layer, resulting in providing a better parting quality. However, it is preferable to properly select the kind and nature of the parting agent to be used for this purpose, being such that the agent cannot transfer to the image-reception layer of the image transferable sheet during the sublimating image transfer stage. The adding quantity of the parting agent may preferably be 3–25 wt. parts based upon the total amount of resin and coating composing the layer taken as 100 wt. %.

In practice, any kind of conventionally known heat transfer sheets is overlapped on the thermally image-transfer sheet employed in the present invention, and then necessary heat energy of 5–100 mJ/mm^2 is applied by use of a conventionally known heat transfer unit, for instance, "Video-printer: VY 100" manufactured and sold by Hitachi Seisakusho, Tokyo, or its equivalent machine, for the formation of necessary images on the image-reception layer of the image-transfer sheet as set forth hereinbefore.

Peel-off operation for removal of the image-reception layer formed with necessary images in the above manner may be carried into effect in a very easy manner, so as to provide it in a thin film carrying the images thereon. In case where the thus-peeled off film carrying the images is provided beforehand with an adhesive layer, composed of a suitable adhesive agent as was referred to, at the opposite surface to the image-carrying one, the peeled-off film can be, as it is, stuck on the object to be decorated. It is natural that this adhesive attachment procedure can be performed only partially and locally on selected part of the whole surface of the object, or totally thereon, as the case may be. On the contrary, if the peel-off film is provided beforehand with no adhesive layer, the film can be subjected occasionally to a heat fusion onto the surface of the object, if the physical properties or material kind thereof is suitable for such kind of thermal fusion. Or alterna-

tively, a properly selected adhesive agent can be preparatorily applied onto the surface of the film or object, and then, the stick-on job can be executed.

If the image-reception layer is provided preparatorily with a parting layer thereon, as was referred to, the latter layer can be removed off partially or wholly, by grinding or rubbing operation after execution of the sublimating image transfer job, for avoiding otherwise occurrence of ill effect by the very presence of parting layer in the adhesive attachment of the image-carrying layer film onto the decorative object.

In case of that where the image-transferable sheet is provided with a protecting layer and the latter is composed of a plastic resin film, this film may preferably be cut into pieces or subjected to punch-cuttings.

FIG. **32** illustrates successive die-cutting steps in sectional views, serving for the above purpose. In this case, as shown in FIG. **32** at (a), only image-reception layer **305** of the image-transferable sheet **310**, which has been image-formed through the way of the foregoing image-transfer step, are die-cut by operation of a cutter **801**. Next, as shown in FIG. **32** at (b), a pair of hot stamps **132'**; **133'** are used to execute a pressurizing job under heat from opposite sides, thereby the decorative product **330** being processed into a final product provided tightly with an image-reception layer and a protecting layer, as shown in FIG. **32** at (c).

Further, when occasion desires, the image-carrying film is reversed up and-down in position after execution of the peel-off job, and, the film is stuck onto the product to be decorated in such a state that the image-carrying surface of the film is kept in direct opposition to the product's decorating surface. In this case, however, it would be rather preferable that in advance of preparatory peel off of the image-reception layer, the image carrying transferable sheet is stuck onto the surface of the product to be decorated, and indeed, preferably with use of an adhesive agent, in such a way that the image-carrying layer is kept in direct opposition to the product surface and finally, the sheet-like substrate is peeled off, so as to leave the image-carrying surface on the product's surface.

As in the foregoing, when the images are once reversed and then stuck onto the object to be decorated, the forming images are preferable to reverse in mode (mirror-like relationship) the original to those of reversed mode.

It is further possible that the transfer or sticking-on of the image-carrying layer is carried out through the intermediary of a separate fusing sheet.

In FIG. **30**, use of such fusing sheet **701** for reimage-transfer operation of image-carrying layer **2** already formed with necessary images **307**, however, of reversed mode, and onto the surface of a product.

More specifically, the image-transferable sheet **310** is overlapped onto the product **330** to be decorated in such a way that the image-reception layer **302** carrying the necessary images **307** is kept in opposition to the surface of the product, and indeed, through the intermediary of a fusing seat **701** and then these three components are pressurized together. Further, sheet-like substrate **301**, together with parting layer **303'**, is peeled off, thereby the image-reception layer **302**, now having positive images **307** formed thereon, and protecting the latter, being transferred onto the product **330**. It will be seen in this case, that there is no need for this transfer job, to provide in advance on adhesive layer on the surface of image-reception layer **302** and/or on the surface of the product **330**, and further that a direct heat fusion onto the surface of the product **330** which may be composed of plastic resin, textile fabric, metal or the like common material, however, through the intermediary of a heat-fusible or heat-sealable sheet.

In case where the protecting layer **305** is of plastic resin, similar composing technique as mentioned above may be employed by substituting a weak-sticking layer **402'** for parting layer **303'**.

As the heat-fusible or heat-sealable sheet as at **701** employable in the present invention, it may be composed of one or other material capable of adhering under heat, pressure or both, especially suitable one of those which become soft to be adhesive upon heating. These heat adhering materials in the form of sheets will be, upon softening, charge the pores, meshes or stitches of the product material composed preferably of textiles, woven or non-woven; knits, rough-surface papers or meshed materials, thereby the surface of the product becoming highly smooth for well receiving the image-reception layer **302** for desired image-retransfer with trouble, which effect is superior in the art.

On the contrary, when such heat-fusible or heat adhesive sheet materials which may be called "heat bond sheets" as at **701** are not utilized, it is highly difficult to realize the image-retransfer operation onto certain kind of objects such as rough-surfaced or rough-meshed fabric or the like. Even if the retransfer job could be executed, the obtained images may be blurred and the adhesive may be insufficient, on account of the very thin thickness of the image-reception layer **302**, thus giving rise to technical and commercial troubles.

As for the heat fusible sheet **701** to be used in the foregoing manner, ethylene/vinyl acetate copolymer, nylon copolymer; epoxy/phenol copolymer; epoxy/vinyl copolymer; acrylic resin; polyester resin; or polyolefin resin and the like thermoplastic resins (heat sensible adhesive agents) which are formed into sheets or films may be used. These materials must be softened at 100°–250° C. or so to represent viscous adhesive characteristics. These materials are, when used, capable of being stuck to both the image-transferred product **330** and the image-carrying layer **302**.

These heat bond sheets **701** have generally thickness of 1–200 μm. When the surface of the product **330** to be decorated is relatively smooth, the sheet selected out may be of relatively thin thickness, while, on the contrary, when the surface of the decorative product **330** is relatively rough, as in the case of textile fabrics, unwoven fabrics, meshed fabrics or the like, use of thicker heat bond sheets is rather recommendable.

As set forth above, the use of heat bond sheets is highly recommendable in the decorative image-transfer onto rough surface products, such as those of rough fabrics, woven or non-woven, knitted clothes, meshed one or the like, thereby a better quality image-transfer being executed, in spite of the meshed or highly undulating surface conditions of the objects to be decorated.

Further in the present invention, during the adhering attachment of the image-reception layer already formed with necessary images onto the object or product, an additional processing step is preferably introduced for prevention of occasional interference in the foregoing adhering attachment step, by rubbing-off or grinding-off part or whole of the parting layer, provided on the surface of the now image-carrying layer, upon completion of the sublimating image-transfer step.

Still further, in such a case that the image-transferable sheet is fitted with a protecting layer which is composed of a plastic resin film, the latter must in advance be subjected to punching or the like cutting step for cutting the film into desirously sized pieces.

FIG. **32** represents such a die-cut (half-cut) process in sectional schema. In this case, at first, as shown at (a) of FIG. **32**, the image-reception layer **302** of an image-transferable sheet **310**, now formed with necessary images through a sublimative image-transfer step, and the protecting layer **305**, are subjected to a die-cutting process by means of a cutter **801** to shape a desired shape. And then, as shown at (b) in FIG. **32**, the cut-out piece is subjected to a pressurizing step under heat by means of a pair of hot stamps **132'**; **133'** to provide a final decorative object, as shown at (c) in FIG. **32**, which is composed of a product **330** to be decorated, however, now attached integrally and jointly with image-carrying layer **302** and protecting layer **305**.

Applied Products

The products applicable with the inventive process for decorating purposes are not limited to occasionally employed kind, shape and nature of the materials. Preferred examples of the usable product may be: cartons; vessels or packages; bags; cassette cases; cassette halves; floppy cases; paper packages and envelopes; stock certificates; personal and bank cheques; bills; bonds; certificates; notifications; car tickets; travel tickets; betting tickets; tax stamps; postage stamps; entrance tickets, money-exchangeable papers and documents; cash-cards, credit cards, orange cards, telephone cards; member's cards; greeting cards; postcards, name cards; driver's certificates; IC-cards; optical cards and the like various cards; accounting cards and documents-envelopes; tags; OHP sheets; slide films; bookmark slips; calendars; posters; pamphlets; menus; passports; POP-goods and articles; coasters; displays; nameplates; keyboards; cosmetics personal ornaments (watches; cigarette lighters); stationaries; construction materials; radio receiving sets; T.V.-sets; speakers; table calculators; automotive gauge boards; emblems., keys; clothes; wearing commodities; footwears; appliances; OA-instruments; sample books; tickets in general; albums; computer graphic and/or medicare graphic image printouts; and the like, where the material kinds, sizes and configurations are regardless for purposes of the invention.

The aforementioned goods and instruments may have printed or the like other images in advance of execution of the process of the invention. Or conversely, the goods and instruments can be formed with necessary images in accordance with the present process, and then, additional images may be formed in conventional printing or the like process.

As an example, when the invention is applied to a card style intermediate product, it is possible to combine image-forming means of the present invention with conventional recording means. As the latter, magnetic recording by use of a magnetic material layer; optical recording by use of an optical recording layer; preferably composed of a membrane having low melting point metal; application of hologram; embossing formation of characters and numerals; application of personal face photograph; engraved formation of personal face or the like; human signatures; recorded information with use of IC-memory; mechanical printing; formation of bar codes; formation of characters and patterns by use of printer, typewriter or pen plotter may be used independently or in any combination.

In the following, the present invention will be more fully described by way of preferred embodiments. In these embodiments, parts or % will be given by weight, not otherwise specifically referred to.

As the image transfer film (dye film) used for sublimating transfer onto the image-transferable sheets, a polyester film, 6 μm thick, subjected to a heat-resisting treatment on one surface thereof only, and bearing color ink composition areas of yellow, magenta and cyan, respectively, was used. The coating rate of the color ink composition was 1.0 g/m^2 when measuring at the dry state.

These color ink compositions were as follows.

These color ink compositions were as follows.

Yellow ink composition	
polyvinyl butyral resin ("Eslek-BX-1", manufactured and sold by Sekisui Kagaku K.K., Tokyo)	4.80 parts
dispersion dye ("PTY-52, Disperse Yellow-141", manufactured and sold by Mitsubishi Kasei Kogyo Co., Ltd., Tokyo)	5.50 parts;
methyl ethyl ketone	55.00 parts;
toluene	34.70 parts;
(parting agent)	1.03 parts
Magenta ink composition	
polyvinyl butyral resin (same as above in the case of yellow color ink)	3.92 parts;
dispersion dye ("MS Red G, disperse red 60", manufactured and sold by Mitsui Toatsu K.K.)	2.60 parts;
dispersion dye ("Macrolex Red Violet R, Disperse Violet 26", manufactured and sold by Beyer A.G., West Germany)	1.40 parts;
methyl ethyl ketone	43.34 parts;
toluene	43.34 parts;
(parting agent)	0.40 part
Cyan color ink composition	
polyvinyl butyral resin (same as in said yellow color ink composition)	3.92 parts;
dispersion dye ("Kayaset Blue-714, solvent blue-63", manufactured and sold by Nippon Kayaku K.K., Tokyo)	5.50 parts;
methyl ethyl ketone	68.18 parts;
(parting agent)	0.94 parts

Each of the foregoing color ink compositions was prepared with and without addition of parting agent.

As the parting agent occasionally used in each of the foregoing color ink compositions, any of the following specific agents may be employed:

(a) silicone alkyd parting agent, "KR-5206", manufactured and sold by Shinetsu Kagaku Kogyo K.K., Tokyo;

(b) graft polymer of silicone and acryl, "GS-30", manufactured and sold by Toa Gosei Kagaku K.K.;

(c) silicone graft polymer, "US-3000", manufactured and sold by the above company;

(d) phosphoric acid ester, natrium salt, "RE-410", manufactured and sold by Toho Kagaku Kogyo K.K.;

(e) natural phosphoric acid ester, "Lecytin", manufactured and sold by Ajinomoto Co., Ltd., Tokyo;

(f) silicone oil, "KF 412", manufactured and sold by Shinetsu Kagaku Kogyo K.K., Tokyo;
(g) aluminum chelate agent, "ALM", manufactured and sold by Ajinomoto; and
(h) titanium chelate agent, "TTS", manufactured and sold by Nippon Soda K.K., Tokyo.

EXAMPLE A-1

As the substrate, a laminate of a synthetic paper, "Yupo FPG 150 μm thick" manufactured and sold by Oji Yuka Co., Ltd., Tokyo, and a polyester film, 6 μm thick, was prepared and coated on the polyester film side surface by a wire bar with a mixture of pull-separating varnish, "Hakurinisu 45" manufactured and sold by Showa Ink Co., Ltd., Tokyo, with an ultra-violet absorbing agent, or more specifically, 2.5-bis(5'-tert-butylbenzoxazolyl (2))-thiofin, 0.5% based on the resin content of the varnish, and dried up to provide a protecting layer of 1 g/m^2, when weighed upon drying.

Then, on the surface of the foregoing protecting layer, an ink composition adapted for the formation of an image-reception layer was coatingly applied and dried up. The applied quantity amounted to 7 g/m^2 when measured upon drying.

Ink composition for the formation of image-reception layer	
polyester resin (manufactured and sold by Toyobo K.K.)	100 parts;
amino-modified silicone ("KF-393", manufactured and sold by Shinetsu Kagaku Kogyo K.K., Tokyo)	5 parts;
epoxy-modified silicone ("X-22-343", manufactured and sold by Shinetsu Kagaku Kogyo)	5 parts;
solvent (methyl ethyl ketone/toluene/cyclohexanon 4/2/2)	900 parts.

The ink composition was coated, dried up and cured one day under normal temperature. Then, the layer was kept at 100° C. for 30 minutes under heat, for letting the silicone to bleed up to the surface, to provide an image-transferable layer formed on its surface with a hardened silicone layer.

On the thus-provided image-reception layer, a sublimating image transfer film was overlapped which is composed of cyan color sublimative dye (molecular weight being higher than 250) carried by a proper binder resin and thermal energy is fed thereon from a thermal head adapted for receiving electric signals representing cyan color components obtained by a color analysis of a portrait photograph, as an example, for providing portrait images corresponding thereto. Then, two successive sublimative image-transfer jobs were executed with use of respective sublimating image-transfer films carrying sublimative magenta and yellow color dyes, each molecular weight being higher than 250, and substantially in the manner set forth above. In this way, after all, an overall combined display image composed of a full color portrait, in combination with several characters and graphics, was provided.

The image-reception layer of the sheet, now carrying these display images, was overlapped on the card substrate composed of a polyester resin sheet, 100 μm thick, which had been primed to white opaque state, and pressurized together at 160° C. by means of heated pressure rolls. Then, the polyester film was peeled off at the interface with the protecting layer, thereby providing a final product card transferrd with image-reception layer now carrying the desired image display.

It was found that the overall surface of the product card was generally smooth and showing no raised feeling of the thus-formed and displaying images. Even upon an accelerated testing of the product card for three months held in an atmosphere of 40° C., the images showed no blurrings as well as no interlayer separation. Further, according to an accelerated light-proof test carried out as prescribed in JIS-Standard with use of a carbon arc lamp, the results showed to be classified to JIS-4 or -5 corresponding to an acceptable superior performance. Additionally, a surface scratch test and the like showed also superior durability.

EXAMPLE A-2

The foregoing image-transferable sheet, now image-carrying, as processed in Example A-1, is then subjected to a peel-off operation for separating the image-carrying layer from the sheet. Then, an adhesive agent of polyester series was coated on the exposed surface of the peeled-off film, and stuck under pressure on a curved surface part of a telephone set. The images could follow up to the stuck curvature into a unitary solid mass, and indeed, without inviting any stuck-on feeling, contrary to the case when a sticky loose-leaf stamp should have been stuck on. In this way, miracle viewing feelings as obtainable with direct-printing operation only, were created and maintained.

EXAMPLE A-3

A white polyester film, baked on one surface thereof with melamine coating, "E 20", 100 μm thick, manufactured and sold by Toray Co., Ltd. Tokyo, is formed on the opposite surface with a slipping layer, same as in the following Example C-2, through application of polyurethane primer. And an identification mark was provided thereon through the way of regular printing technique. On the melamine resin-baked surface of the white polyester resin film, a layer of peeling varnish (of polymethyl methacrylate-series), manufactured and sold by Showa Inku. Co., Ltd., Tokyo) was applied in dry quantity of 2 g/m^2 and dried up to provide a definite layer.

On the thus-formed protecting layer, the following image-reception layer-forming composition was coated and dried up, so as to form an image-heat transferable sheet. The coated composition was in quantity of 6 g/m^2 by dry weight.

Image-reception layer-forming composition	
polyester resin ("Vylon 600", Tg: 47° C., manufactured and sold by Toyobo, Osaka	80 parts;
polyester resin ("Vylon 290", Tg: 77° C., manufactured and sold by Toyobo)	20 parts;
amino-modified silicone ("KF-393", manufactured and sold by Shinetsu Kagaku Kogyo)	7 parts;
epoxy-modified silicone ("X-22-343", manufactured and sold by Shinetsu Kagaku Kogyo)	7 parts;
solvent (methyl ethyl ketone/toluene = 1/1)	800 parts.

On the image-reception layer of the foregoing heat image-transferable sheet, reversed images composed of full color portrait images together with characters and graphics by use of a thermal head, as in the same way with Example A-1, were formed. Next, the image-reception layer, however, now carrying the reversed images formed in the foregoing manner was brought into contacting and overlapping state with the image displayable surface on a card style substrate made of white color polyester resin, 125 μm thick, preparatorily primer treated as before, and pressurized together under the action of thermal rolls, and the white polyester film, 100 μm, was peeled off between the protecting layer and the melamine-baked layer, thus providing a final card-style product transferred with the image-reception layer now carrying the necessary images.

The surface of the final card style product represented a smooth and slippery, without fear of interlayer separation and with superior light resistant power.

EXAMPLE A-4

A white foam polyester resin film, "Merinex", 125 μm thick, manufactured and sold by ICI, was provided with an identification mark on one surface thereof, with regular printing technique.

Then, on the opposite surface of the white foam polyester resin film to the foregoing surface formed with the identification mark, a coating of a polyurethane-series primer was applied and dried up. Further, the following protecting layer-forming composition was applied in dry quantity of 3 g/m^2 and dried up to form a protecting layer.

Protecting layer-forming composition	
acrylic polyole ("Acrit 6416MA", manufactured and sold by Taisei Kako K.K.)	41 parts;
toluene	36 parts;
methyl ethyl ketone	27 parts;
diisocyanate ("Colonate", manufactured and sold by Nippon Polyurethane K.K.)	6 parts.

On the above protecting layer, the following composition was applied in dry quantity of 3 g/m^2 and dried up, to provide an intermediate layer.

Intermediate layer-forming composition	
polyester resin ("Vylon 290", manufactured and sold by Toyo Boseki (Toyobo) K.K., Osaka)	15 parts;
toluene/methyl ethyl ketone = 1/1	85 parts.

On the thus-formed intermediate layer, an image-reception layer which is substantially same with that in the foregoing Example A-3 was provided, so as to form an image-transferable sheet. Then, as same in the foregoing Example A-3, correspondingly inverted images were formed on the image-reception layer and further then, subjected to transfer onto the card substrate by use of thermal rollers. In this way, a final product card, having an image transferable, yet now image formed layer, was provided.

This card showed favorable results of light-resisting test. Further, it showed a better scratch test result than the foregoing card obtained in Example A-3.

EXAMPLE A-5

Substrate

A white polyester film, "E-20", 100 μm thick, manufactured and sold by Toray Co., Ltd., Tokyo, was used.

Intermediate layer-forming composition	
Polyester resin ("Vylon 600", manufactured and sold by Toyo Boseki K.K., Osaka)	15 parts;
toluene/methyl ethyl ketone = 1/1 (dry weight: 5 g/m^2)	85 parts.
Protecting layer-forming composition	
"Hakuri-Nisu" (acrylic resin varnish, manufactured and sold by Showa Ink K.K.) (dry weight)	2 g/m^2
Image-reception layer-forming composition	
polyester resin ("Vylon 600", manufactured and sold by Toyo Boseki K.K., Osaka)	10 parts;
polyester resin ("Vylon 200", supplied by Toyo Boseki K.K.)	5 parts;
toluene/methyl ethyl ketone = 1/1	85 parts;
amino-modified silicone ("KF-393", manufactured and sold by Shinetsu Kagaku Kogyo)	1 part;
epoxy-modified silicone ("X-22-343", supplied by Shinetsu Kagaku Kogyo) (coated quantity (dry) 5 g/m^2)	1 part.

With use of the foregoing composition and processed in similar was as in Example A-3, to provide a final card product, having an image-reception layer transferred with necessary images.

EXAMPLE A-6

Substrate

White polyester resin film, "E-20", 100 μm thick, manufactured and sold by Toray was coated with polyurethane-series primer and dried up.

Parting layer-forming composition	
melamine resin ("Meran 45", manufactured and sold by Hitachi Kasei)	100 parts;
hardener (para-toluenesulfonic acid) (coating quantity (dry), 2 g/m^2)	20 parts;
Protecting layer-forming composition	
vinylchloride-vinylacetate ("Vinylite VYHH", manufactured and sold by Union Carbide Corp.)	15 parts;
methyl ethyl ketone = 2/1 (coating quantity (dry): 2 g/m^2)	85 parts;
Intermediate layer-forming composition	
polyurethane resin ("Takelac T-3350", manufactured and sold by Takeda Pharmaceutical Company, Osaka, of 23%-concentration)	50 parts;
isopropyl alcohol	15 parts;
toluene	25 parts;
methyl ethyl ketone (coating quantity (dry) 5 g/m^2)	10 parts.
Image-reception layer composition	
polystyrene resin ("Picolastic D125" (Tg = 53° C.), manufactured and sold by Hercules	15 parts;
toluene/methyl ethyl ketone = 1/1	85 parts;
amino-modified silicone ("KF-393", manufactured and	1 part;

-continued

sold by Shinetsu Kagaku)	
epoxy-modified silicone ("X-22-343", manufactured and sold by Shinetsu Kagaku) (coating quantity (dry): 6 g/m^2)	1 part.

The foregoing composition was prepared and used as in the same manner with Example A-3, to provide a card with the image-reception layer subjected to image-transfer as desired.

EXAMPLE B-1

As the substrate, a polyester resin film, 6 μm thick, was used and a polyester resin-series primer was coated on one surface thereof and dried up. Further, the following ink composition was applied and dried up. The coating quantity of the composition was set to about 7 g/m^2.

Image-reception layer-forming composition	
polyester resin ("Vylon 200", manufactured and sold by Toyo Boseki K.K.)	100 parts;
amino-modified silicone ("KF-393", manufactured and sold by Shinetsu Kagaku)	5 parts;
epoxy-modified silicone ("X-22-343", manufactured and sold by Shinetsu Kagaku)	5 parts;
solvent (methyl ethyl ketone/toluene/ cyclohexanone = 4/2/2)	900 parts.

The ink composition was coated, dried up and left standing for a full day, and then subjected to heat treatment at 100° C. for 30 minutes, so as to bleed the silicone towards the film surface for providing thereon an acceptable image-reception layer composing the active surface.

Then, a sublimative image-transferable film, composed of a resin binder evenly mixed with a proper amount of sublimative cyanic dye, the molecular weight being higher than 250, was overlapped on the above image-reception layer and applied with heat energy by means of a thermal head supplied with electric signals corresponding to cyanic color components of a portrait full color photograph as determined by regular color analysis, thus providing cyanic color component images.

Next, as for magenta and yellow color components, similar respective processings were executed and finally, full color display portrait images could be formed.

Then, the exposed surface of image reception layer of the thus display image-formed film was overlapped on a card substrate composed of a white opaque, hard vinyl chloride resin sheet, 100 μm thick and pretreated with a conventional primer, and then this assembly was subjected to heat and pressure by means of a pair of heated rolls. In this way, a card product stuck with an image-transferable and now carrying layer was provided.

The surface of this card was generally smooth and slippy, the thus-formed images thereon providing no raised feelings. In an accelerated test of these formed images in hot atmosphere of 40° C. for a continuous period of three months, there were no appreciable image blurring and interlayer separation. Upon execution of a light exposure test in accordance with prescribed conditions in JIS with use of an arc lamp, the results were classified to JIS-4 to 5 Classes which means as acceptable and better image quality. Scratch test results were also superior.

EXAMPLE B-3

A sticking layer, 1 μm thick, was formed with a polyamide resin sticking agent on the image-carrying surface of the image-transferable sheet, image-formed in the manner as described in foregoing Example B-1, and the thus provided sheet was stuck on the curved surface of a glass tumbler. These images express practically no stuck-on feelings, rather providing such a touch and viewing feeling as if they had been formed by the regular and direct printing technique.

EXAMPLE C-1

With use of the image-transferable sheet prepared in the foregoing Example A-1, images were formed substantially in accordance with procedures mentioned therein, however, with exception of the formation of reversed images, and then, the image-carrying layer was, without execution of the foregoing peel-off operation, stuck on a portion of curved outer surface of a glass tumbler, whereupon the sheet-like substrate was peeled off, together with the weak-sticking layer. The thus-applied images represent almost no sticking-on grip and viewing feeling, as if they should have been applied through regular and direct-printing technique.

EXAMPLE C-2

On the surface of a transparent polyester film, 12 μm thick, employed as a protecting film, the following image-reception layer forming composition was applied to form a coated layer (in quantity of 6 g/m^2 when measuring upon drying), dried up and left as it was for full one day. Then, it was held at 100° C. for 30 minutes, to form an image-reception layer. On the surface thereof, a parting surface layer was found to exist, which was composed of a combined hardened product of amino-modified silicone resin and epoxy-modified silicone resin.

Image-reception layer-forming composition	
polyester resin ("Vylon 600", manufactured and sold by Toyo Boseki)	100 parts
amino-modified silicone resin ("KF-393", manufactured and sold by Shinetsu)	7 parts;
epoxy-modified silicone resin ("X-22-343", manufactured and sold by Shinetsu)	5 parts;
solvent (methyl ethyl ketone/toluene = 1/1)	800 parts.

As the substrate, on the other hand, white polyester resin film, "E-20", 75 μm, manufactured and sold by Toray, was used and coated on one surface thereof with a polyurethane-series primer and dried up. Then, the following composition (in the dried quantity of 1 g/m^2) and dried up, so as to provide a smooth and stick layer.

Smooth layer-forming composition	
polymethyl methacrylate resin ("Dianal BR-85", manufactured and	12 parts;

-continued

Smooth layer-forming composition	
sold by Mitsubishi Rayon Co., Ltd., Tokyo)	
polyethylene wax ("MF8F", manufactured and sold by Dulacon Co.)	0.5 part;
toluene/methyl ethyl ketone = 1/1	85 parts.

On the opposite surface of the white-polyester resin sheet to the smoothed surface there, a primer coating of polyurethane-series is applied and dried up, and further coated thereon with the following composition, in quantity of 3 g/m^2, so as to provide a weak-sticky layer.

Weak-sticky layer-forming composition	
weak-sticky adhering agent ("Esdyme AE-206", manufactured and sold by Sekisui Kagaku Kogyo K.K., Tokyo)	50 parts;
water	50 parts.

The weak-sticky adhering layer is brought into contact with the protecting film consisting of a polyester film, 12 μm thick, at the opposite surface to the image-reception layer, and then subjected to heat and pressure, to provide an image-transferable sheet. Upon bringing the image-reception layer of the image-transferable sheet and the dyestuff layer of the heat-image transfer sheet into contact with each other, heat energy was applied from a thermal head, as in the similar manner mentioned in the foregoing Example A-1, and thus heat image-transfer job was executed, so as to provide reversed mode images for expressing a full color portrait as well as characters and graphics.

Next, the image-reception layer formed with the reversed images thereon was overlapped onto the image-displayable surface of a card style substrate, 100 μm thick, made of a white color polyester resin material preparatorily applied with a primer layer by coating a composition, consisting of "Vylon **200**", 100 μm thick, manufactured and sold by Toyo Boseki K.K., and then subjected together to heat and pressure by means of at least a heated roll at 160° C. Then, the white polyester film, 75 μm thick, and the weak-sticky adhesive layer were peeled off in unison, for providing a final decorative product card having the image-reception layer transferred with images and carrying display images.

This card had a highly smooth surface and was not liable to invite any interlayer separation and showed superior light fastness.

In place of white color polyester-made card substrate preparatorily formed with a primer layer, such a modification was prepared and experimented that the white polyester sheet was formed on its rear surface with a magnetic layer, while, on its front surface there is formed with a write-on layer which consists of proper filler and resin as conventionally, so as to provide a telephone card. This processed telephone card had the write-on layer provided with display images formed by image-transfer.

EXAMPLE C-3

On the surface of a transparent polyester film, 9 μm thick, used as the protecting layer, an intermediate layer was provided by coating. The coated amount was 5 g/m^2 as measured upon being dried up.

Intermediate layer-forming composition	
polyurethane resin ("Takelack T-3350", solid content 23%, manufactured and sold by Takeda Pharmaceutical Co., Ltd., Osaka)	50 parts;
isopropyl alcohol	15 parts;
toluene	25 parts;
methyl ethyl ketone	10 parts.

Onto the intermediate layer, the following composition was applied for the formation of an image-reception layer. The coated quantity was 5 g/m^2 as measured upon being dried up.

Image-reception layer-forming composition	
polyester resin ("Vylon 600", manufactured and sold by Toyo Boseki)	10 parts;
polyester resin ("Vylon 200", manufactured and sold by Toyo Boseki)	5 parts;
amino-modified silicone ("KF-393", manufactured and sold by Shinetsu)	1 part;
epoxy-modified silicone ("X-22-343", manufactured and sold by Shinetsu)	1 part;
solvent (methyl ethyl ketone/ toluene = 1/1)	85 parts.

On the other hand, a white color polyester film, which was similar to that employed in the foregoing Example C-2 was formed with a slidingly smooth layer, as well as a weak-sticking adhesive layer, the latter being brought into intimate contact with a transparent polyester film, 9 μm thick, at the opposite surface to the image-reception layer and then, subjected to heat and pressure, for providing a heat image-transferable sheet. As further processed in the similar manner in the foregoing Example C-2, full color photographic images (reversed images) were thus formed on the image-reception surface. In this way, a final product card, having its image-reception layer transferringly formed with display images.

EXAMPLE C-4

Substrate

White color polyester sheet, "E-20", 100 μm thick, manufactured and sold by Toray was formed thereon with a polyurethane-series primer coating. Then, a weak-sticking layer was applied thereon with use of the following composition.

Weak sticking layer-forming composition	
weak-sticking agent ("Esdyne AE-206", manufactured and sold by Sekisui Kagaku Kogyo K.K., Tokyo)	50 parts;
water	50 parts.
Protecting layer-forming composition	
polyester resin ("Vylon-200", manufactured and sold by Toyo Boseki)	15 parts;
diisocyanate ("Colonate L", manufactured and sold by Nippon Polyurethane Co., Ltd.)	1 part;

-continued

toluene/methyl ethyl ketone = 1/1	84 parts.
Image-reception layer-forming composition	
polyester resin ("Vylon 600", manufactured and sold by Toyo Boseki K.K.)	10 parts;
vinyl chloride-vinyl acetate copolymer resin ("Vinylite VAGH" (Tg = 79° C.), manufactured and sold by Union Carbide Corp)	5 parts;
toluene/methyl ethyl ketone = 1/1	85 parts;
amino-modified silicone ("KF-393", manufactured and sold by Shinetsu)	1 part;
epoxy-modified silicone ("X-22-343", manufactured and sold by Shinetsu)	1 part.

With use of the above composition and processed substantially same as in the foregoing Example C-2, a final card product was obtained.

EXAMPLE D-1

An image-transferable sheet was prepared as in the foregoing Example A-1 and thermally image-transferred with reversed mode images of a full color portrait photograph, to provide an intermediate image-transfer medium. The latter is overlapped by its image-reception layer onto the surface of a sheet of rough-textured cotton cloth, however, through the intermediary of an acrylic acid ester vinyl acetate copolymer sheet, 100 μm thick. Then, the assembly was subjected to heat and pressure. Then, the substrate sheet and weak-sticky adhesive layer, together, were peeled off. The thus transfered images have sufficient surface smoothness, showing superior surface conditions.

Without use of the bond-attaching sheet in the above process and when similar image-transfer job as above was performed, the resulted images followed the surface undulations appearing disadvantageously on the material product of the rough fabrics and thus were highly uneven, and further, on account of insufficient adhering performance acting between the image-receiving layer and the woven fabrics serving as product material, easy and frequent separations took place therebetween.

EXAMPLE D-2

In the similar way as was disclosed in the foregoing Example D-1, an intermediate image transfer medium carrying reversed images was prepared and overlapped on a polymethacrylate board preparatorily subjected to surface-roughening operation through a conventional sand-blasting step, and through the intermediary of a bond-adhering sheet pressurized together under heat, as was employed in Example D-1. Then, the sheet-like substrate was peeled off, together with the weak adhesive layer. The thus-provided images were highly smooth and even in spite of the highly rough and undulating conditions at the surface to be image-transferred. In addition, the image-carrying surface showed superior results in various resisting tests.

Without use of the foregoing bond-sticking layer, the similarly transferred images showed considerable undulations and distortions. Further, on account of insufficient adhering performance, easy and frequent peel offs of applied images were feared.

EXAMPLE D-3

On the surface of a polyester resin film, 25 μm thick, the following composition adapted for the formation of bond-sticking layer was coated and dried up, in dried quantity of 5 g/m^2, to provide a film formed thereon a bond sticking sheet.

Bond-sticking sheet-forming composition	
polyester resin ("Vylon 600", manufactured and sold by Toyo Boseki)	15 parts;
methyl ethyl ketone/toluene = 1/1	84 parts.

The bond-sticking sheet surface, together the polyester resin film proper, was brought into contact with the image-representing surface of a white color polyester made-card substrate, 25 μm thick, and then, subjected to heat and pressure by means of at least a heat roll kept at 200° C., arranged to supply heat energy from the side of the polyester resin surface, thereby heat bonding the bond-sticking sheet onto the card surface, whereupon the polyester resin film being forcedly peeled off.

Further then, as in the similar way as adopted in foregoing Examples C-2; A-3; A-4 and C-3, use is made of the image reception layers representing reversed images thereon, the respective image-reception layers were whereupon brought into contact with the card's bond-sticking surface of the card and subjected to heat and pressure by use of at least a heat roll kept at 200° C. Then, the white color polyester resin substrate was peeled off, together with the weak-sticky adhering layer. In this way, a final product card displaying the portrait photograph was obtained.

EXAMPLE D-4

Substrate

A white color polyester resin sheet, "E-20", 100 μm thick, manufactured and sold by Toray Co. Ltd., was coated with a polyurethane-series primer. On the surface of the thus precoated sheet, the following composition was coated to form a weak-sticking adhesive layer.

Weak-sticking adhesive component	
weak sticking adhesive agent, ("Esdyne AE-206", manufactured and sold by Sekisui Kagaku)	50 parts.
Image-reception layer-forming composition	
polyester resin ("Vylon 200", manufactured and sold by Toyo Boseki)	7.5 parts;
polyester resin ("Vylon 290", manufactured and sold by Toyo Boseki)	7.5 parts;
toluene/methyl ketone = 1/1	85 parts;
amino-modified silicone ("KF-393", manufactured and sold by Shinetsu)	1 part;
epoxy-modified silicone ("X-22-343", manufactured and sold by Shinetsu)	1 part.

The foregoing compositions were prepared. On the other hand, a polyester resin film, 25 μm thick, was coated on one surface thereof with a 15%-solution of polyester resin, "Vylon 200", manufactured and sold by Toyo Boseki, in toluene/methyl ethyl ketone=1/1 and dried up. The coating quantity was adjusted to 5 g/m^2

when measuring in dried state. In this way, a bond-sticking sheet was provided.

Then, the coated surface of the thus prepared bond-sticking sheet was brought into contact with the image display surface of a card style substrate of white color hard vinyl chloride or the like resin material preparatorily subjected to a primer coating treatment in overlapping state and then, the whole assembly was subjected to heat and pressure with use of at least a heated roll to 130° C., thus the bond-sticking layer being stuck on the card surface. Under this condition, the polyester resin film, 25 μm thick, was peeled off.

Then, the image-reception layer, now carrying thereon reversed images, was brought into contact with the bond-sticking sheet and the resulted whole was subjected to heat and pressure by use of at least a heated roll and the white color polyester resin substrate, together with the weak-sticking adhesive layer, was peeled off. In this way, the card, now displaying the portrait images, was provided.

EXAMPLE D-5

Substrate

Same as in the foregoing Example D-4.

Weak-sticking adhesive layer

Same as in the foregoing Example D-4.

Protecting layer-forming composition	
polyester resin ("Vylon 200", manufactured and sold by Toyo Boseki)	15 parts;
diisocyanate ("Colonate L", manufactured and sold by Nippon Polyurethane)	1 part;
toluene/methyl ethyl ketone = 1/1	84 parts.
Image-reception layer-forming composition	
polyester resin ("Vylon 600", manufactured and sold by Toyo Boseki)	10 parts;
toluene/methyl ethyl ketone = 1/1	85 parts;
amino-modified silicone ("KF-393", manufactured and sold by Shinetsu)	1 part;
epoxy-modified silicone ("X-22-343", manufactured and sold by Shinetsu)	1 part.

With use of the foregoing materials and compositions, the processings were carried out as in the foregoing Example D-4, to provide a final product card displaying portrait images as was desired.

EXAMPLE D-6

Substrate

Same as in the foregoing Example D-4.

Weak-stickinq adhesive layer

Same as in the foregoing Example D-4.

Image-reception layer-forming composition	
polyester resin ("Vylon 600", manufactured and sold by Toyo Boseki)	10 parts;
vinyl chloride-vinyl acetate copolymer resin ("Vinylite VAGH", manufactured and sold by Union Carbide Corp.)	5 parts;
toluene/methyl ethyl ketone = 1/1	85 parts.

The foregoing materials and compositions were and processed in the similar way as in the foregoing Example D-4, to provide a final product card, displaying the desired portrait images as were desired.

EXAMPLE E-1

On a polyethylene terephthalate film, 9 μm thick, a solution of saturated polyester resin, "Vylon 600", manufactured and sold by Toyo Boseki, in toluene/methyl ethyl ketone = 1/1, was coated by reliance of the known reverse roll-coating process, and dried up. The coated quantity was 7 g/m^2 when measuring in dry condition. In this way, a weak-sticking adhesive layer could be formed. On the weak-sticking adhesive layer, the following composition, 3 g/m^2 (dry), was coated by means of an oblique-lined gravure roll for solid and full printing use and in the reverse roll-coating process, and then dried up, to provide an image-reception layer.

Image reception layer-forming composition	
polyester resin ("Vylon 200", manufactured and sold by Toyo Boseki)	70 parts;
polyester resin, ("Vylon 290", manufactured and sold by Toyo Boseki)	30 parts;
amino-modified silicone ("KF-393", manufactured and sold by Shinetsu)	5 parts;
epoxy-modified silicone ("X-22-343", manufactured and sold by Shinetsu)	5 parts;
methyl ethyl ketone (wt. ratio 1/1)	700 parts.

On the opposite surface to the image-reception layer of the thus-prepared image-transferable sheet, a synthetic paper substrate, "Yupo FPG 110", 110 μm thick, manufactured and sold by Oji Yuka K.K, coated with "Vylon 600" as the adhesive agent in quantity of 10 g/m^2 (dry) was stuck intimately together.

On the other hand, a polyethylene terephthalate film substrate, 6 μm thick, preparatorily provided on one surface thereof with a heat-resisting layer was used and the following composition was applied on the opposite surface of the substrate with use of a wire bar and dried up, in the quantity of 1 g/m^2 (dry), so as to provide a dyestuff layer. In this way, a heat image-transferable **10** sheet was prepared and provided.

Dyestuff layer-forming composition	
dispersion dye ("Kayaseo Blue-136", manufactured and sold by Nippon Kayaku K.K.)	4 parts;
ethylhydroxyethyl cellulose	6 parts;
methylethylketone/toluene (wt. ratio: 1/1)	90 parts.

The dyestuff layer of the foregoing heat image-transfer sheet was brought into contact with the image-reception layer of the image-transferable sheet in overlapping manner, then, heat energy was applied from a thermal head from the side of heat-resisting layer of the heat image transfer sheet, thereby dyestuff being transferred to the image-reception layer of image-transferable sheet, and indeed, for the formation of positive images.

Then, the image transferable sheet, now carrying the required positive images was stuck together under heat

and pressure at 140° C. for 5 seconds on the intermediate image transfer substrate prepared in the following manner, in mutually opposed manner. Then, the synthetic paper "Yupo" was peeled off at the intersurface between the polyester resin film and the "Vylon 600" layer. In thus way, the inventive image-transfer sheet (intermediate image-transfer medium) carrying the corresponding reverse images was provided.

Method for the preparation of intermediate image-transfer substrate

A sheet of fine quality or stick paper, unit weight: 82 g/m^2 was applied with a coating, about 20 μm thick, of polyethylene resin through conventional extrusion coating process. Thereon, further, a catalyst-added toluene solution of a parting agent silicone, "KS-707", manufactured and sold by Shinetsu was applied and dried up in quantity of about 2 g/m^2 (dry), for the purpose of curing. Thereon, still further, the following coating liquid composition was applied by means of a conventional coating bar and dried up, to provide an intermediate image transfer substrate. The thus coated and dried resin quantity was measured to 7 g/m^2.

Coating liquid composition	
polyester resin ("Vylon 200", manufactured and sold by Toyo Boseki)	100 parts;
methyl ethyl ketone/toluene (mixing ratio by weight: 1/1)	700 parts.

A sheet of coated paper, pretreated for pore-filling, was coated, in the similar manner as above, with the foregoing liquid composition, to provide an image-transferable medium. On and with the presently coated surface, the image carrying surface of the foregoing intermediate image-transfer medium is brought into opposing contact and stuck together under heat and pressure at 140° C. for 7 seconds. Finally, the laminate of fine quality paper and polyethylene was peeled off, to provide a final decorative .product now displaying the positive images as required.

It will thus be seen that by adopting the above processing steps, the positive images formed under the action of the thermal head are transferred, through the intermediary of intermediate image transfer medium, onto the final object to be decorated, and indeed, in the form of positive mode. It will be further seen that, since the dyestuff is well distributed within the image-reception layer, the transferred positive images are highly sharp and fresh, in addition to much profundities.

Since a resin layer was overlappingly applied on the thus-formed images, weather fastness, frictional durability and light-fastness of the finally formed images could be highly and amazingly improved. When suitable ultraviolet absorbing agent, antioxydant, quenching agent and/or radical scavenger is added to, further improvement of the light-fastness can be attained.

EXAMPLE E-2

The substrate of image-transferable medium adopted in the foregoing Example E-1 was replaced by a hard polyvinyl chloride card, 100 μm thick, and other processing modes were same as in Example E-1. In this way, a high quality, positive-image transferred, decorative final product was successfully provided. When the image include human portrait photograph, the final product was highly useful for ID-card.

EXAMPLE E-3

The substrate of image-transferable medium adopted in the foregoing Example E-1 was replaced by a transparent polyester film, and other processing modes were same as employed therein. In this way, a transparent film formed with the wanted positive images of better quality as before was obtained. This film was highly useful in OHP-services.

EXAMPLE E-4

A sheet of high quality paper, unit weight: 104 g/m^2, was coated with a layer of polypropylene resin, thickness: about 20 μm, through the way of conventional extrusion coating technique, then the coating was further coated with a silicone solution for use in parting service and hardenable under electron rays and dried up. The quantity of the coating silicone was about 1 g/m^2 upon drying. In this way, an electron hardened, provisional substrate was provided. On this substrate, the following, image-reception layer-forming composition was applied as a layer by use of a coating bar, and then dried up, for providing an image-reception layer. The coated resin quantity in the above last step amounted about 5 g/m^2.

Image-reception layer-forming composition	
polystyrene ("Picolastic D 150" (Tg = 69° C.), manufactured and sold by Rika-Hercules Co., Ltd.	100 parts;
amino-modified silicone ("KF-393", manufactured and sold by Shinetsu)	7 parts;
epoxy-modified silicone ("X-22-343", manufactured and sold by Shinetsu)	7 parts.

Further processing was carried out as was set forth in the foregoing Example E-2, for providing a final product card, carrying thereon the wanted positive images of same superior quality, as was in Example E-2.

EXAMPLE E-5

On the image transferable medium used in the foregoing Example E-4, however, in the present Example, a thermoplastic resin, adhesive, polyolefine series film, "Adwin 500", manufactured and sold by Showa Denko K.K., Tokyo, was applied as a layer. Other materials were used and processed as set forth therein. In this way, a decorative final product formed with necessary positive was obtained with superior results.

Industrial Availabilities

As will be well understood from the foregoing detailed description of the invention, it is possible according to the present inventive system, to form highly easily and evenly the desired images sharply and attractingly on any product and object to be decorated or graphically ornamented, substantially irrespective of material kind and configuration thereof, and indeed, with a surprising unitary touch and feeling with the substrate. Therefore, the invention can be utilized broadly and conveniently in such various industrial fields, where unitary formation of various images, characters, symbols, numerals and graphics, on and to the

articles, objects and substrate products to a sufficiently miracle and attracting degree.

We claim:

1. A process for forming sublimation transfer images on an objective body, said process comprising:

a first transferring step for sublimation transferring images on an image-transferable sheet comprising a sheet-like substrate and an image-reception layer provided on one surface of said sheet-like substrate, said sublimation transferring being carried out by means of a thermal printer on the basis of image data formulated by an image data processor; and

a second transferring step for transferring the images formed on the image-transferable sheet from the image-transferable sheet to the objective body.

2. The process of claim 1, wherein the images are formed on an image surface of said image-reception layer by the use of a dyestuff which is capable of depositing in or on said image-transferable sheet, and then during said second transferring step, said image-reception layer of said image-tranferable sheet is caused to adhere to said objective body.

3. The process of claim 2, wherein said sheet-like substrate is a transparent film, the image surface of said image-reception layer is caused to face the body, and the image-reception layer, accompanied by the transparent film, is caused to adhere to the objective body.

4. The process of claim 2, wherein after the images are formed on the image-reception layer, the image-reception layer being separable from the sheet-like substrate, said image-reception layer is separated from said sheet-like substrate and caused to adhere to said objective body.

5. The process of claim 4, wherein the image-reception layer which has already been formed with the images is subjected provisionally to an image-transfer procedure on an intermediate transfer substrate and then, the once transferred image-reception layer is re-transferred onto the objective body.

6. The method of claims 2, or wherein the step of causing the image-reception layer to adhere to said body is carried out with the use of an adhesive agent or sticking agent.

7. The process of claims 2, or wherein the step of causing the image reception layer to adhere to said body is carried out with the use of a heat bond sheet.

8. The process of claim 2, wherein the image-reception layer of the image-transfer sheet is formed with the images in positive or regular mode when viewed from the image surface of the image-reception layer.

9. The process of claim 2, wherein the image-reception layer of the image transfer sheet is formed with the images in reversed or negative mode when viewed from the image surface of said layer.

10. The process of claim 2, wherein the image-transferable sheet further comprises a protecting layer provided on one surface thereof such that said image-reception layer is separable between said protecting layer and said substrate, and said image-reception layer is subjected, together with said protecting layer, to said second transferring step.

11. The process of claim 10, wherein said protecting layer comprises a plastic film.

* * * * *

United States Patent [19]

Nakai et al.

[11] **Patent Number: 4,912,498**

[45] **Date of Patent: Mar. 27, 1990**

[54] **CAMERA SYSTEM CAPABLE OF INTERCHANGING ITS OBJECTIVE LENS**

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[73] Assignee: **Minolta Camera Kabushiki Kaisha**, Osaka, Japan

[21] Appl. No.: **248,306**

[22] Filed: **Sep. 21, 1988**

Related U.S. Application Data

[60] Continuation of Ser. No. 138,841, Dec. 23, 1987, abandoned, which is a continuation of Ser. No. 198, Jan. 2, 1987, abandoned, which is a division of Ser. No. 632,405, Jul. 19, 1984, Pat. No. 4,639,112, which is a continuation-in-part of Ser. No. 478,910, Mar. 25, 1983, Pat. No. 4,560,267.

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Apr. 1, 1982	[JP]	Japan	57-55187
Nov. 5, 1982	[JP]	Japan	57-194968
Apr. 26, 1984	[JP]	Japan	59-85599

[51] **Int. Cl.**[4] **G03B 7/20**

[52] **U.S. Cl.** **354/442**

[58] **Field of Search** 354/441-443, 354/455, 286, 289.12

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Primary Examiner—W. B. Perkey

Attorney, Agent, or Firm—Price, Gess & Ubell

[57] **ABSTRACT**

A camera system comprising a camera body and an interchangeable lens assembly adapted to be coupled to the camera body. The interchangeable lens assembly has no manipulatable aperture adjusting ring, but has an aperture mechanism and a read-only memory both built therein. The read-only memory stores therein various data peculiar to such lens assembly. The camera body communicates with and power the lens assembly through a set of terminals connectable with associated terminals provided in the lens assembly. The terminals in each of the camera body and lens assembly are arranged in a generally arcuate row with the data transmitting terminal located at one extremity of the arcuate row on the leading side with respect to the direction of turn of the lens assembly which is effected when the lens assembly is to be completely coupled to the camera body.

11 Claims, 8 Drawing Sheets

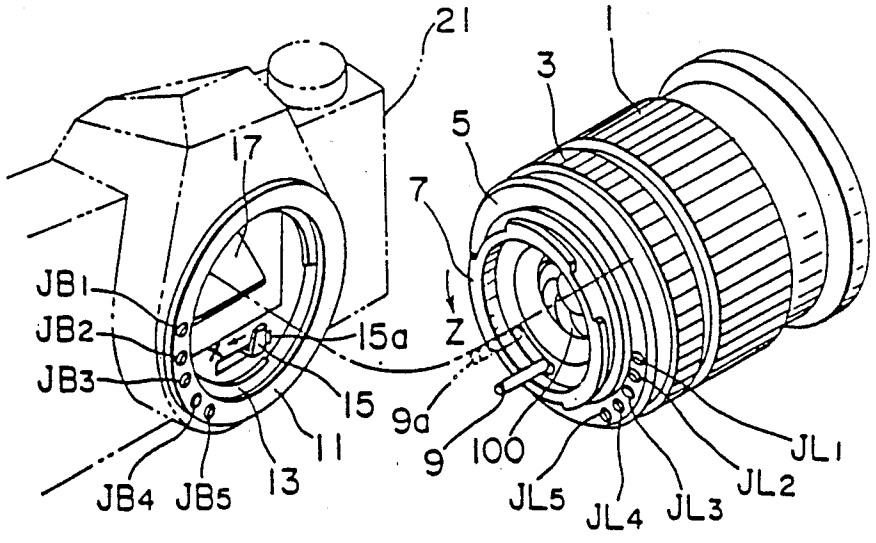

Fig. 1

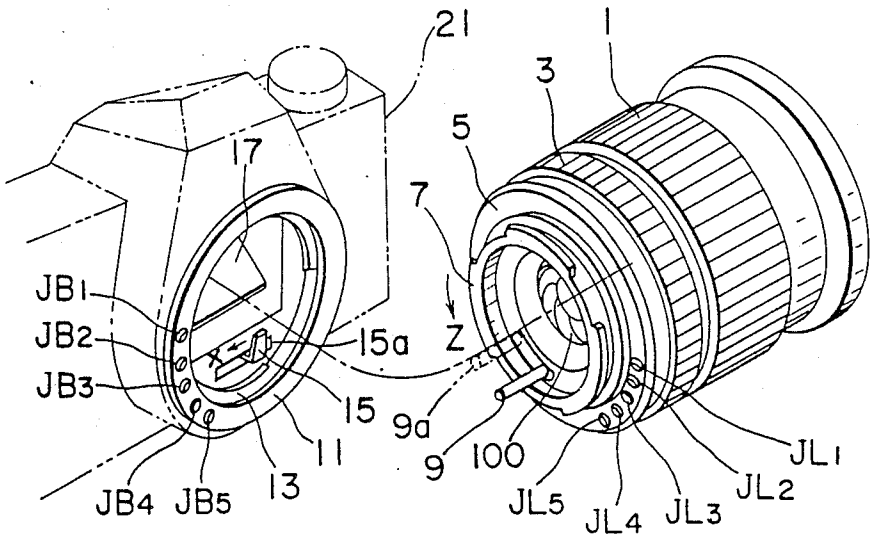
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Fig. 2

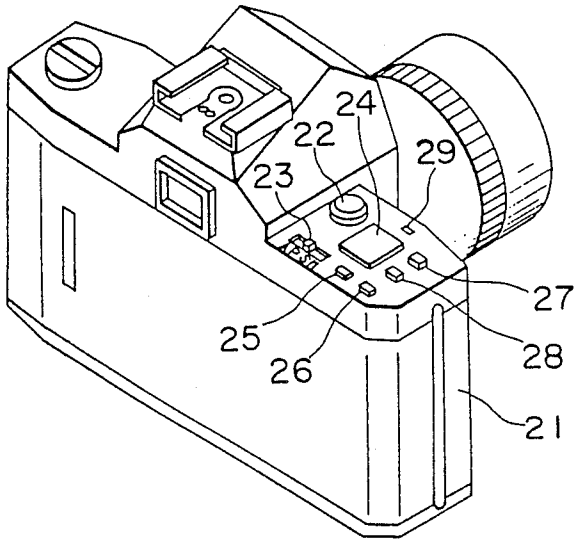
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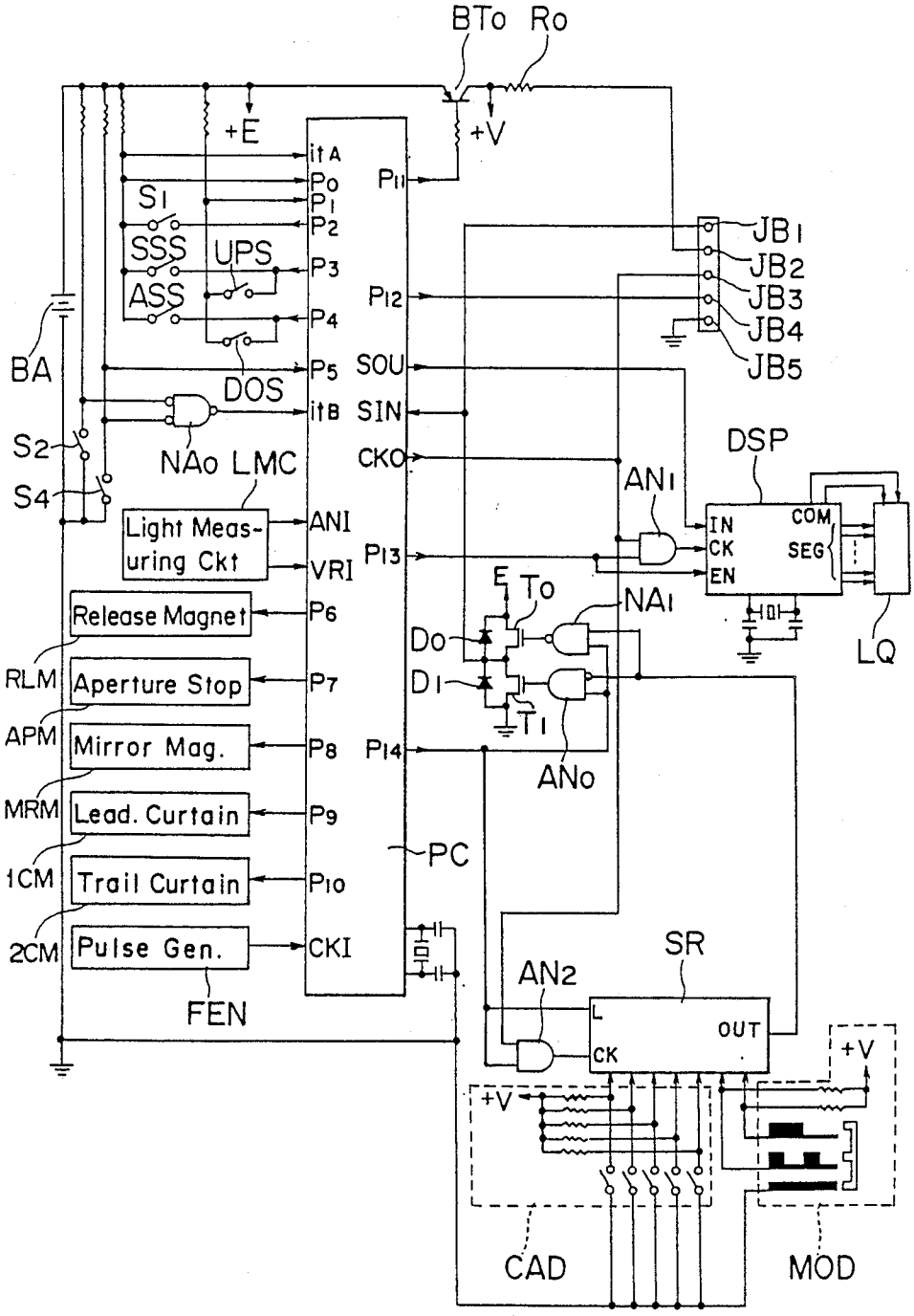
Fig. 3(a)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P10
CKI
S1
SSS
UPS
ASS
DOS
BA
S2
S4
NAo
LMC
Light Measuring Ckt
Release Magnet
Aperture Stop
Mirror Mag.
Lead. Curtain
Trail Curtain
Pulse Gen.
FEN
RLM
APM
MRM
1CM
2CM
JB1
JB2
JB3
JB4
JB5
DSP
IN
CK
EN
COM
SEG
LQ
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+V
CAD
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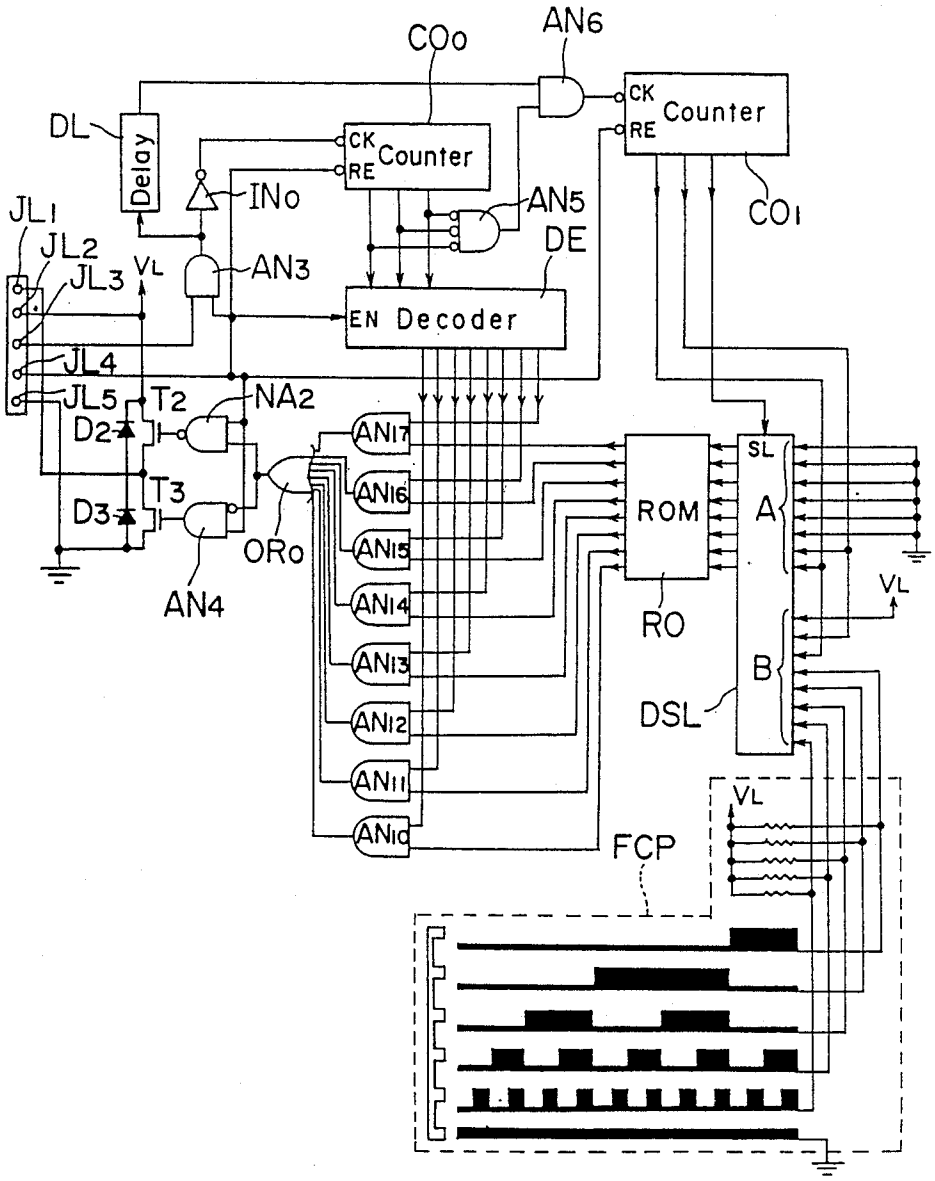
Fig. 3(b)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B
RO
DSL
VL
VL
FCP

Fig. 4

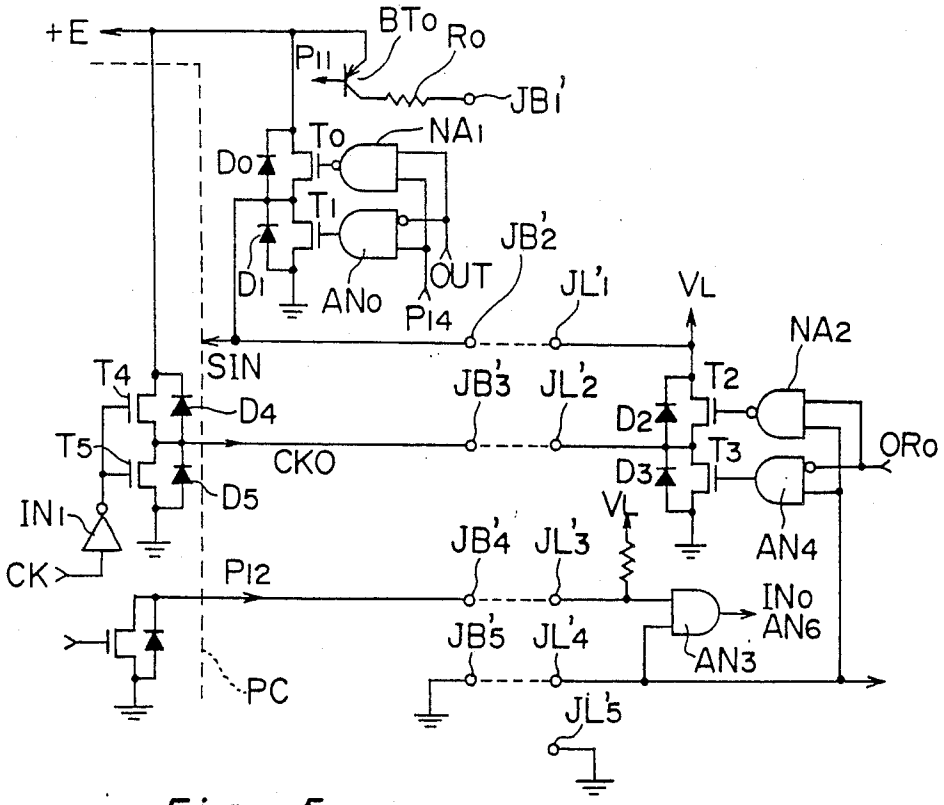
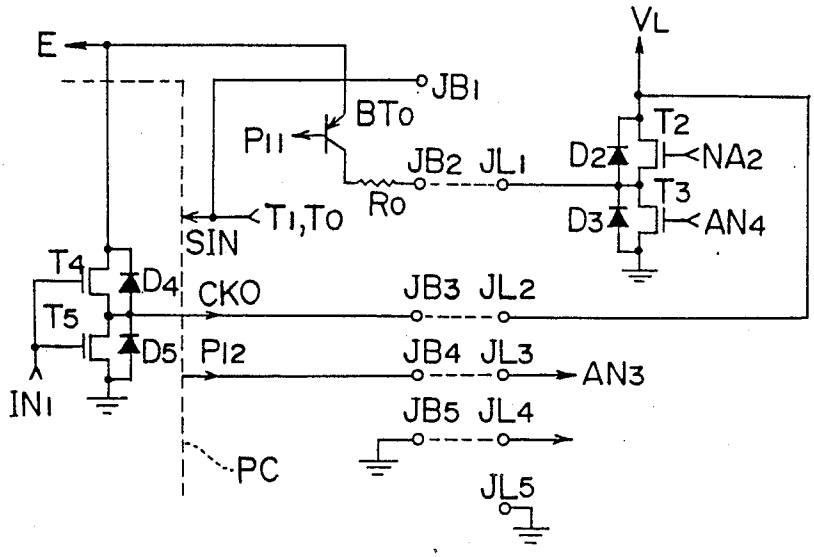

+E
BTo
Ro
P11
JB1'
To
NA1
Do
T1
JB2'
D1
ANo
OUT
P14
JL'1
VL
NA2
SIN
T4
JB'3
JL'2
T2
D4
D2
T5
CKO
T3
ORo
D5
D3
IN1
VL
JB'4
JL'3
AN4
CK
P12
INo
AN6
JB'5
JL'4
AN3
PC
JL'5

Fig. 5


E
VL
JB1
BTo
T2
P11
JB2
JL1
D2
NA2
Ro
T3
T1,To
D3
AN4
SIN
T4
D4
CKO
JB3
JL2
T5
D5
P12
JB4
JL3
AN3
IN1
JB5
JL4
PC
JL5

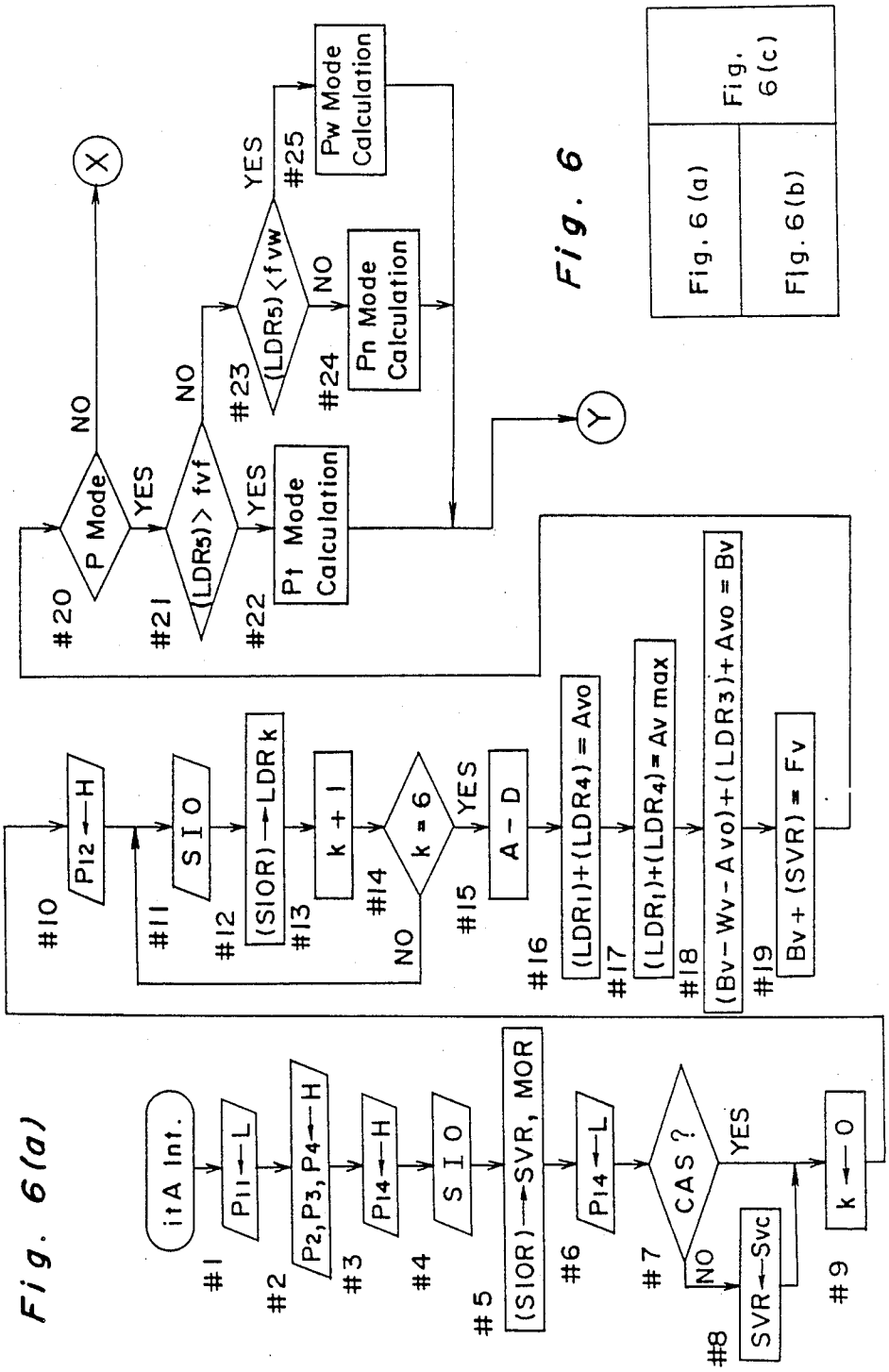

itA Int.
#1
P11←L
#2
P2, P3, P4←H
#3
P14←H
#4
S I O
#5
(SIOR)→SVR, MOR
#6
P14←L
#7
CAS ?
NO
#8
SVR←Svc
YES
#9
k←0
#10
P12←H
#11
S I O
#12
(SIOR)→LDR k
#13
k + 1
#14
k = 6
NO
YES
#15
A - D
#16
(LDR1)+(LDR4) = Avo
#17
(LDR1)+(LDR4) = Av max
#18
(Bv-Wv-Avo)+(LDR3)+Avo = Bv
#19
Bv+(SVR) = Fv
#20
P Mode
NO
YES
X
#21
(LDR5) > fvf
NO
YES
#22
Pt Mode Calculation
#23
(LDR5) < fvw
NO
YES
#24
Pn Mode Calculation
#25
Pw Mode Calculation
Y

Fig. 6(a)

Fig. 6

Fig. 6(a)
Fig. 6(b)
Fig. 6(c)

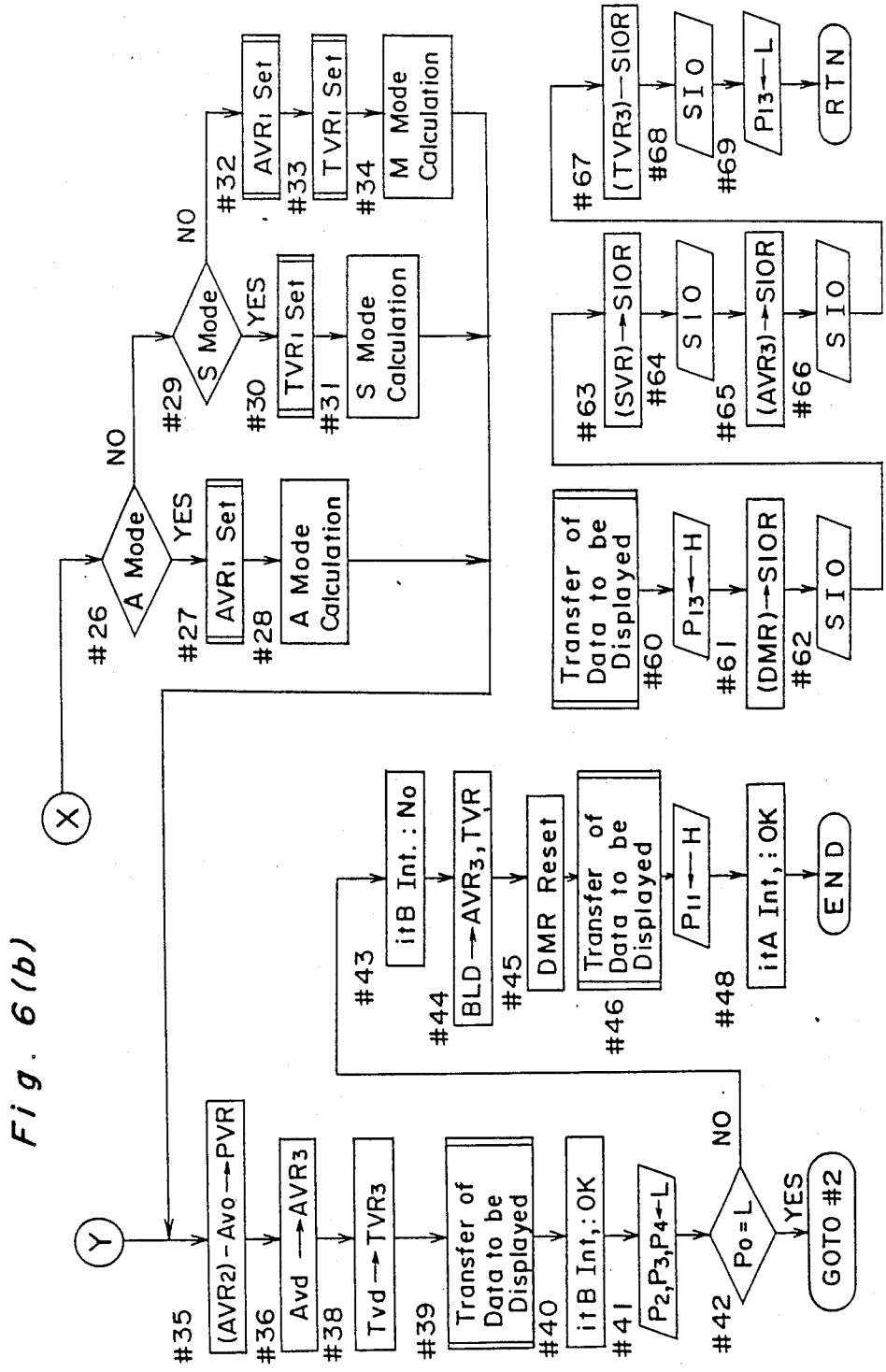

X
Y
#26
A Mode
NO
YES
#27
AVR1 Set
#28
A Mode Calculation
#29
S Mode
NO
YES
#30
TVR1 Set
#31
S Mode Calculation
#32
AVR1 Set
#33
TVR1 Set
#34
M Mode Calculation
#35
(AVR2)-Avo→PVR
#36
Avd →AVR3
#38
Tvd→TVR3
#39
Transfer of Data to be Displayed
#40
itB Int.: OK
#41
P2,P3,P4←L
#42
Po=L
NO
YES
GOTO #2
#43
itB Int.: No
#44
BLD→AVR3,TVR
#45
DMR Reset
#46
Transfer of Data to be Displayed
P11←H
#48
itA Int.: OK
END
#60
Transfer of Data to be Displayed
P13←H
#61
(DMR)→SIOR
#62
SIO
#63
(SVR)→SIOR
#64
SIO
#65
(AVR3)→SIOR
#66
SIO
#67
(TVR3)→SIOR
#68
SIO
#69
P13←L
RTN

Fig. 6(b)

Fig. 6(c)

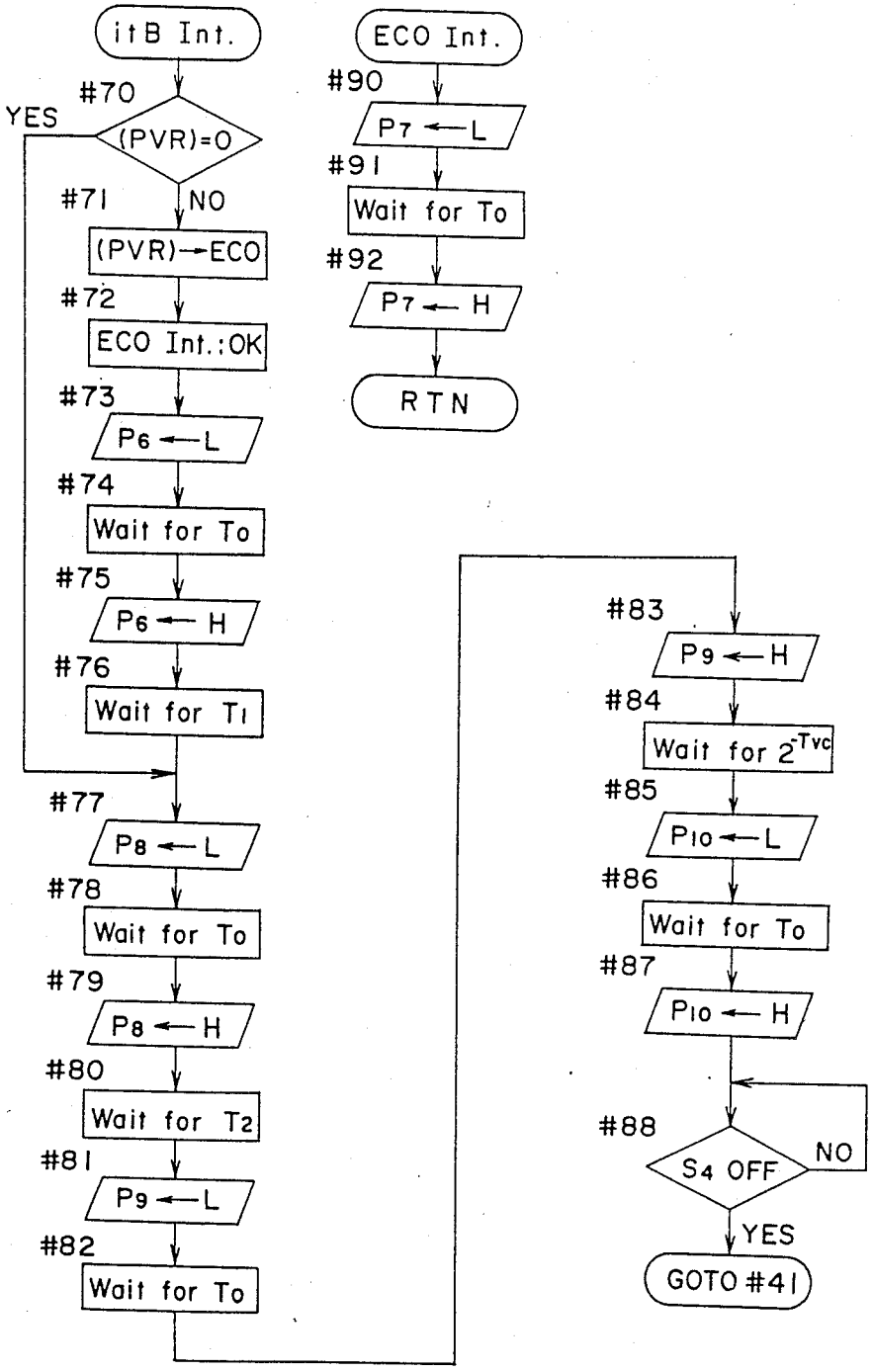
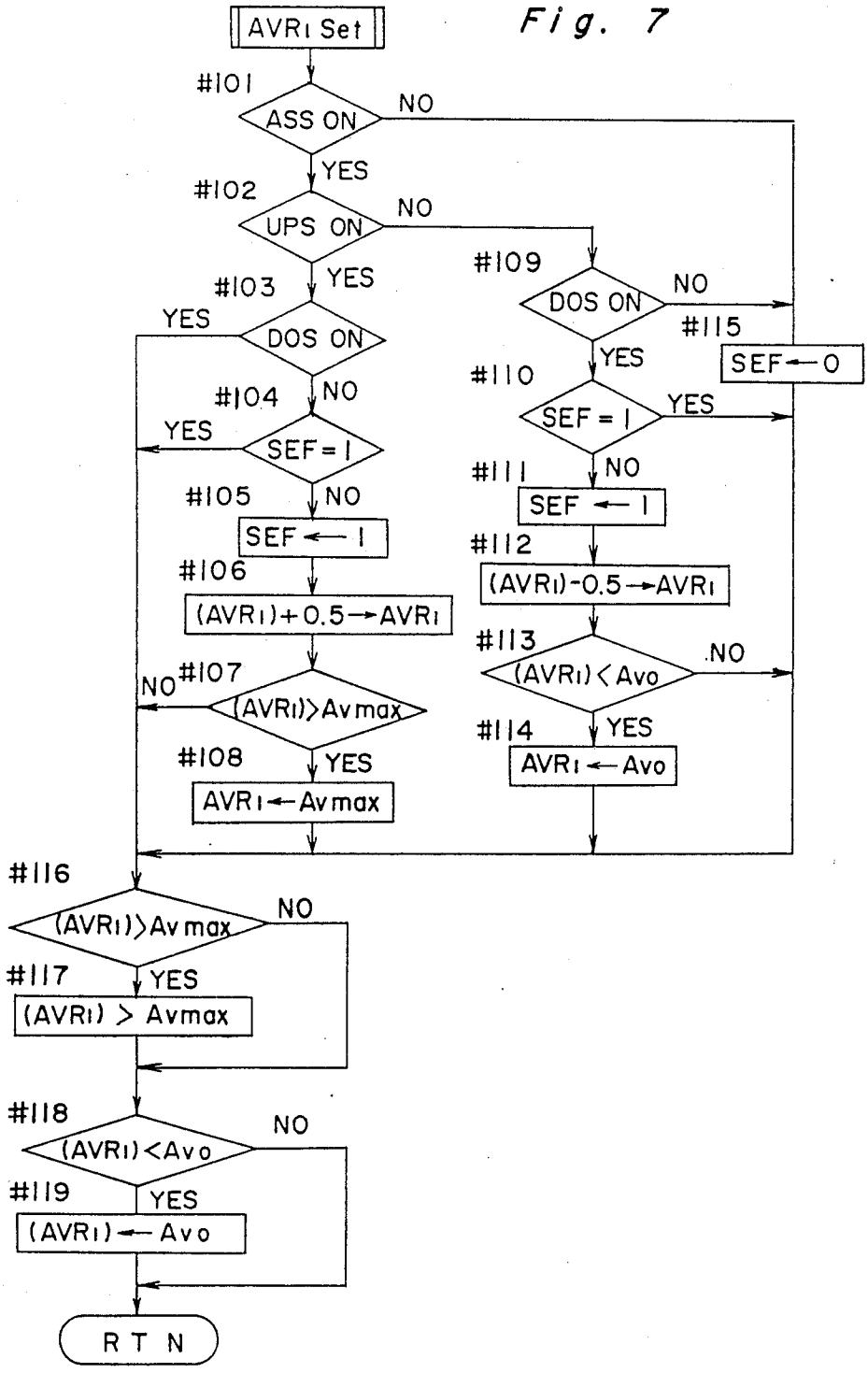

itB Int.
#70
YES
(PVR)=0
#71
NO
(PVR)←ECO
#72
ECO Int.:OK
#73
P6 ← L
#74
Wait for To
#75
P6 ← H
#76
Wait for T1
#77
P8 ← L
#78
Wait for To
#79
P8 ← H
#80
Wait for T2
#81
P9 ← L
#82
Wait for To
ECO Int.
#90
P7 ← L
#91
Wait for To
#92
P7 ← H
RTN
#83
P9 ← H
#84
Wait for 2^-Tvc
#85
P10 ← L
#86
Wait for To
#87
P10 ← H
#88
S4 OFF
NO
YES
GOTO #41

Fig. 7


AVR1 Set
#101
ASS ON
NO
YES
#102
UPS ON
NO
YES
#103
DOS ON
YES
NO
#104
SEF=1
YES
NO
#105
SEF ← 1
#106
(AVR1)+0.5→AVR1
#107
(AVR1)>Avmax
NO
YES
#108
AVR1←Avmax
#109
DOS ON
NO
YES
#110
SEF=1
YES
NO
#111
SEF ← 1
#112
(AVR1)-0.5→AVR1
#113
(AVR1)<Avo
NO
YES
#114
AVR1←Avo
#115
SEF←0
#116
(AVR1)>Avmax
NO
YES
#117
(AVR1) > Avmax
#118
(AVR1)<Avo
NO
YES
#119
(AVR1)←Avo
RTN

CAMERA SYSTEM CAPABLE OF INTERCHANGING ITS OBJECTIVE LENS

This is a continuation of application Ser. No. 138,841, filed Dec. 23, 1987, now abandoned which is a divisional application of abandoned Ser. No. 000,198, filed Jan. 2, 1987, which is a divisional application of Ser. No. 632,405, filed on July 19, 1984, now U.S. Pat. No. 4,639,112 which is a continuation in part application of Ser. No. 478,910, filed on Mar. 25, 1983 (issued as U.S. Pat. No. 4,560,267, on Dec. 24, 1985).

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention generally relates to a photographic camera system utilizing interchangeable objective lens assemblies one at a time and, more particularly, to an improvement in coordination between the camera body and the interchangeable objective lens assembly then coupled thereto.

2. Description of the Prior Art

In a photographic camera system utilizable with interchangeable objective lens assemblies one at a time, one of the most important coordinations between the camera body and the lens assembly then coupled thereto lies in the manual aperture setting required to be performed at the time of manual exposure control, automatic exposure control under the aperture-priority mode, or the like. As is well known to those skilled in the art, interchangeable lens assemblies generally have a manipulatable aperture adjustment such as an aperture setting ring mounted exteriorly on the lens barrel for the access to a photographer.

On the other hand, there is also known a photographic camera system wherein the aperture adjustment is not provided on an interchangeable lens assembly, but on the body of a photographic camera so that the setting of the aperture adjustment can be transmitted to the lens assembly to control the aperture in such lens assembly. In this camera system, since the available aperture range, i.e., the available range from the maximum settable aperture (the smallest available f-stop number) to the minimum settable aperture (the largest available f-stop number), varies from one interchangeable lens assembly to another, a mechanism comprising a mechanical signaling element, provided in any one of the interchangeable lens assemblies and indicating the aperture range available in the respective lens assembly, and an engagement element provided in the camera body for engagement with the signaling element is employed to inhibit the aperture adjustment in the camera body to set the aperture of a value outside the available aperture range.

In either of the above described camera systems, there are many limitations and/or requirements imposed on the manufacture of the interchangeable lens assemblies such as, for example, a space for accommodating an arrangement necessary to permit the aperture setting ring to rotate, a precise arrangement of both the signaling element and the engagement element, the precise machining of the associated component parts and so on. These limitations and/or requirements often render the camera system as a whole to be complicated and expensive.

Another one of the most important coordinations between the camera body and the lens assembly lies in the transmission of various electric signals therebetween. Numerous techniques and arrangements have

hitherto been utilized for transmitting electric signals through terminals between the camera body and the lens assembly. As is well known to those skilled in the art, the utmost care is required to permit the electric signals to be correctly transmitted between the camera body and the lens assembly and, therefore, an improvement has long been desired to avoid any possible inadvertent transmission of one or more of the electric signals from the camera body to the lens assembly or from the lens assembly to the camera body which would result in the erroneous operation of the camera.

SUMMARY OF THE INVENTION

An essential object of the present invention is to improve the conventional camera utilizing an interchangeable lens assembly to permit the camera system as a whole to be reasonably constructed and also to simplify the interchangeable lens assembly.

Another important object of the present invention is to provide an improved camera system wherein the manipulatable aperture adjustment is not provided on the interchangeable lens assembly, but on the body of a camera to permit the setting of the aperture of the lens assembly to be carried out on the side of the camera body.

A further object of the present invention is to provide an improved interchangeable lens assembly having its utility in the camera system of the type referred to above.

A still further object of the present invention is to improve the system so as to avoid the possibility that the camera body may process erroneous information in the event of the incorrect mounting of the lens assembly to the camera body.

A yet further object of the present invention is to provide an improved interchangeable lens assembly having its utility in the system of the type referred to in the preceding paragraph.

The present invention provides a camera system that includes a compatible camera body and interchangeable lens assembly particularly adaptable for automatic focusing. The camera body has a series of terminals for providing electrical power, enabling signals and clock signals plus the ability to receive information from the interchangeable lens assembly. The interchangeable lens assembly has complementary terminals and can have the ability to store various data peculiar to the specific lens assembly such as aperture size.

BRIEF DESCRIPTION OF DRAWINGS

These and other objects and features of the present invention will be readily understood by those skilled in the art upon the reading of the following description taken in conjunction with a preferred embodiment with reference to the accompanying drawings, in which:

FIG. **1** is a perspective view showing an essential portion of the camera with an interchangeable lens assembly shown as separated therefrom;

FIG. **2** is a perspective view of the camera of FIG. **1** as viewed from a different direction;

FIG. **3**(*a*) is a circuit diagram showing an electric circuit incorporated in the camera body according to the present invention;

FIG. **3**(*b*) is a circuit diagram showing an electric circuit incorporated in the lens assembly according to the present invention;

FIG. **4** is a circuit diagram showing an essential portion of a circuit shown for the purpose of comparison

with the operation of the embodiment in FIGS. 3(*a*) and 3(*b*) according to the present invention;

FIG. 5 is a circuit diagram showing an essential portion of the embodiment in FIGS. 3(*a*) and 3(*b*) according to the present invention, shown for the purpose of comparison with the circuit of FIG. 4;

FIG. 6 comprises FIGS. 6(*a*) to 6(*c*) and altogether shows a flow chart of the sequence of operation of the camera system according to the present invention; and

FIG. 7 is a flow chart showing a subroutine executed during the process flow of FIG. 6.

DETAILED DESCRIPTION OF THE EMBODIMENT

Before the description of the present invention proceeds, it is to be noted that like parts are designated by like reference numerals throughout the accompanying drawings.

Referring first to FIG. 1 showing a combination of an interchangeable zoom lens assembly and the body of a photographic camera utilizable with the zoom lens assembly, the zoom lens assembly includes a distance setting ring 1 for setting the camera-to-object distance, and a zooming ring 3 for the adjustment of the focal length of the zoom lens assembly. When the zooming ring 3 is rotated, the focal length of the zoom lens assembly can be adjusted and, at the same time, a slide member provided in a focal length code plate FCP as shown in FIG. 3(*b*) slides a coded pattern in contact therewith to enable the code plate FCP to generate an output data indicative of the focal length to which the lens assembly has been set by the rotation of the zooming ring 3. The lens assembly has a rear end provided with a ring-shaped abutment plate 5 fixed coaxially thereto and carrying five electric terminals JL1 to JL5, said electric terminals JL1 to JL5 being arranged in a circle coaxial with the abutment plate 5 about the optical axis of the lens assembly. Rigidly mounted on the rear end of the lens assembly adjacent the abutment plate 5 is a coupling ring having a plurality of, for example, three, radially outwardly flanged bayonet pawls 7, the function of which will be described later. The lens assembly also has a stop-down pin 9 protruding axially outwardly from the rear end of the lens assembly and normally angularly biased by a spring in a direction shown by the arrow Z, said stop-down pin 9 being so operatively associated with an aperture control mechanism 100 built in the lens assembly that the aperture of the lens assembly can be adjusted to the minimum aperture size (the largest f-stop number) with the pin 9 located at the position shown by solid line and the full open aperture size (the smallest f-stop number) when the stop-down pin 9 is angularly moved to a position 9*a* shown by the broken line in a direction counter to the biasing direction Z.

The camera body 21 has a ring-shaped abutment plate 11 rigidly secured thereto for engagement with the abutment plate 5 fast with the lens assembly and carrying an equal number of electric terminals JB1 to JB5, said electric terminals JB1 to JB5 being so positioned and so arranged that, when and after the lens assembly has been completely coupled to the camera body 21 with the abutment plate 5 held in contact with the abutment plate 11, the terminals JB1 to JB5 on the camera body 21 can be electrically connected with the associated terminals JL1 to JL5 on the lens assembly, respectively. The camera abutment plate 11 has an equal number of bayonet flanges 13 extending radially inwardly therefrom and engageable with the lens bayonet pawls 7 when the lens assembly is mounted onto the camera body and subsequently turned in the direction Z so as to assume a locked position. It is to be noted that the complete coupling of the lens assembly to the camera body 21 is intended to mean that the lens assembly mounted onto the camera body 21 and then turned so as to assume the locked position is held in such locked position and that, although not shown because of the well known expedient in the related art, the camera body 21 is to be understood as provided with a releasable locking member for holding the lens assembly in the locked position. The camera body 21 also has an aperture stop-down control lever 15 having a side edge 15*a* engageable with the stop-down pin 9 when and after the lens assembly has been completely coupled. Accordingly, the aperture of the lens assembly depends on the position of the aperture stop-down control lever 15. Although in practice the aperture stop-down control lever 15 is spring-loaded so as to move in a direction shown by the arrow X, it is held in a position shown by the solid line during a period other than during the exposure control operation and, therefore, the aperture of the lens assembly is set to the maximum aperture size, i.e., the full open aperture size. When the exposure control operation takes place, the control lever 15 is disengaged from the solid line position to move in the direction X accompanied by the angular movement of the stop-down pin 9 in the direction Z with the aperture of the lens assembly consequently stopped down. After the control lever 15 has been moved in the direction X by a predetermined distance corresponding to the stopping-down degree to attain a required aperture size, the control lever 15 is brought to a halt and, at the same time, the stop-down pin 9 having been following to the control lever 15 is brought to a halt with the aperture of the lens assembly consequently set to the predetermined value. The camera body 21 also has a reflective mirror 17 supported for pivotal movement between an up position, at which the incoming light passing through the lens assembly is allowed to reach a photosensitive film, and a down position as shown and at which the incoming light is reflected towards a viewfinder of the camera.

To mount onto the camera body 21, the lens assembly is first inserted into the camera body 21 until the lens abutment plate 5 contacts the camera abutment plate 11 and then is turned in the direction Z to allow it to be held in the locked position. When the lens assembly is so locked, the bayonet pawls 7 are held in position between the bayonet flanges 13 and spring members (not shown) provided in the camera body 21 and positioned on one side of the bayonet pawls 7 opposite to the associated bayonet flanges 13 and, at the same time, the lens terminals JL1 to JL5 are aligned and electrically connected with the camera terminals JB1 to JB5, respectively. The paired terminals JB1 and JL1 are utilized to transmit data from the lens assembly onto the camera body; the paired terminals JB2 and JL2 are utilized to supply an electric power from the camera body onto the lens assembly; the paired terminals JB3 and JL3 are utilized to supply synchronizing clock pulses from the camera body onto the lens assembly; the paired terminals JB4 and JL4 are utilized to supply from the camera body onto the lens assembly a chip select signal necessary to activate a circuit built in the lens assembly; and the paired terminals JB5 and JL5 are utilized to make

the ground common to both the camera body and the lens assembly.

As can readily be understood from FIG. **1**, it is clear that, except for a mechanical linkage associated with the control of the lens aperture, no other mechanical linkage intended for the transmission of pieces of information is employed between the camera body and the lens assembly. Accordingly, not only can the lens assembly have enough space to spare, but also no substantial care is required in designing and machining component parts of the mechanical linkage necessitated to transmit a physical information concerned of the lens aperture.

In addition, since the paired terminals for the transmission of the electric signals are arranged in the manner as hereinabove described, the data transfer terminal JB1 on the camera body **21** contacts none of the lens terminals JL1 to JL5 during the mounting of the lens assembly and prior to the complete coupling of the lens assembly to the camera body, but contacts the associated lens terminal JL1 only when the lens assembly has been completely coupled to the camera body having been held in the locked position. Accordingly, as will be described later, even when the lens assembly is incompletely coupled to the camera body, there is no possibility that electric current may flow from any of the other terminals to this data transfer terminal through the circuit built in the lens assembly. This is advantageous in that the possibility is eliminated that the data may be destroyed by the current flowing from any of the other terminals while a microcomputer is in operation to transact the data with blocks other than the lens assembly, thereby permitting the data to be correctly read.

FIG. **2** illustrates the appearance of the camera body viewed from the rear. As shown, the camera body has a shutter release button **22**, a mode selector slide **23**, a liquid crystal display unit **24**, an aperture setting button **25**, an exposure time setting button **26**, an up-shift button **27**, a down-shift button **28** and a frame counter window **29** all arranged at convenient places readily accessible to and noticeable by the photographer. The shutter release button **22** when depressed is moveable in two stages between inoperative and operated positions past an intermediate position, and the first stage of movement from the inoperative position to the intermediate position results in the closure of a light measuring switch S1, shown in FIG. **3**(*a*), to initiate the light measurement, the calculation and the display operation, but the subsequent second stage of movement from the intermediate position to the operated position results in the closure of a release switch S2, shown in FIG. **3**(a), to initiate the exposure control if an exposure control mechanism has already been charged. The mode selector slide **23** is selectively movable to any one of the four click positions marked "A", "P", "S" and "M", respectively. When this mode selector slide **23** is in the A position, the camera is brought in position to operate under an aperture priority mode (hereinafter referred to as A mode) at which the exposure time is automatically controlled in reference to the preset aperture, but when the slide **23** is moved to the P position, the camera is brought in position to operate under a programmed mode (hereinafter referred to as P mode) at which a combination of the exposure time and the aperture are automatically controlled in dependence on the amount of light. It is to be noted that, during the P mode of operation, the program line varies dependent on the data fv fed from the lens assembly indicating the focal length, to which the zooming ring **3** has been adjusted, in such a way that, when fv>fvt, wherein fvt represents the data indicative of the focal length of, for example, 80 mm, a Pt mode is established in which a priority is given to the high shutter speed in determining the combination of aperture and exposure time, but when fvw>fv, wherein fvw represents the data indicative of the focal length of, for example, 35 mm, a Pw mode is established in which a priority is given to the small aperture in determining the combination of exposure time and aperture. However, when and so long as fvt>fv>fvw, a normal Pn mode is established. When the mode selector slide **23** is set at the S position, the camera is brought in position to operate under an exposure time priority mode at which the aperture is automatically controlled in reference to the preset exposure time, which mode is hereinafter referred to as S mode. On the other hand, when the slide **23** is in the M position, the camera is brought in position to operate under a manual mode at which both the exposure time and the aperture can be manually set according to the photographer's desire, which mode is hereinafter referred to as M mode.

The aperture setting button **25** is adapted to be depressed at the time of setting of the aperture, and the depression of this button **25** results in the closure of a switch ASS, shown in FIG. **3**(*a*), to initiate the light measurement, the calculation and the display operation and also to modify the aperture in dependence on the state of any one of the upshift and down-shift buttons **27** and **28**. The exposure time setting button **26** is adapted to be depressed at the time of setting of the exposure time, and when this button **26** is depressed, a switch SSS shown in FIG. **3**(*a*) is closed to initiate the light measurement, the calculation and the display operation and also to modify the aperture in dependence on the state of any one of the upshift and down-shift buttons **27** and **28**. When the up-shift button **27** is depressed, a switch UPS shown in FIG. **3**(*a*) is closed. When at this time the aperture setting button **25** is depressed while the camera is operable under any one of the A and M mode, the aperture size once set changes to a size smaller than it by 0.5 Ev. However, when at this time the exposure time setting button **26** is depressed while the camera is operable under any one of the S and M modes, the exposure time once set changes to a value shorter than it by 0.5 Ev. The repression of the down-shift button **28** results in the closure of a switch DOS shown in FIG. **3**(*a*). When at this time the aperture setting button **25** is depressed while the camera is operable under any one of the A and M modes, the aperture size once set changes to a size larger than it by 0.5 Ev, but when at this time the exposure time setting button **26** is depressed while the camera is operable under any one of the S and M modes, the exposure time once set changes to a value longer than it by 0.5 Ev. The liquid crystal display unit **24** is used to display various pieces of information such as, for example, the ISO value, the combination of the exposure time and the aperture both used for the control, a camera wobbling warning, and the out-of coupling range warning. The frame counter window **24** is used to display the count of film frames exposed.

FIGS. **3**(*a*) and **3**(*b*) altogether illustrate an electric circuit of the camera system as a whole embodying the present invention, wherein FIG. **3**(*a*) shows the circuit incorporated in the camera body while FIG. **3**(*b*) shows the circuit incorporated in the lens assembly. The circuit incorporated in the camera body, which is hereinaf-

ter referred to as camera circuit in contrast to a lens circuit which is the circuit shown in FIG. 3(*b*) and incorporated in the interchangeable lens assembly, includes a source BA of electric power which may be constituted by one or more batteries. This power source BA feeds, through a power supply line +E, a microcomputer, a display circuit DSP, a shift register SR, AND gates AN0, ANI, AN2, and NAND gates NA0 and NA1. The camera circuit also includes the switch S1, which is a light measuring switch adapted to be closed upon the first stage of depression of the release button 22; the switch SSS which is a Tv switch adapted to be closed when the exposure time setting button 26 is depressed, the switch ASS which is an Av switch adapted to be closed when the aperture setting button 25 is depressed; the switch UPS which is an up-shift switch adapted to be closed when the up-shift button 27 is depressed; and the switch DOS which is a down-shift switch adapted to be closed when the down-shift button 28 is depressed.

A transistor BTo acts as a power supply transistor and is adapted to conduct, when the microcomputer PC initiates its operation, to supply an electric power from the power supply line +V to a light measuring circuit LMC, a release magnet circuit RLM, an aperture stop magnet circuit APM, a mirror magnet circuit MRM, a leading curtain magnet circuit 1CM, a trailing curtain magnet circuit 2CM, an aperture stop-down pulse generator FEN, an ISO data detecting circuit CAD, and an exposure control mode data generator MOD. Moreover, when and so long as the transistor BTo is in conduction, an electric power is supplied to the camera terminal JB2 through a protecting resistor Ro and then to a power line vL of the lens circuit of FIG. 3(*b*) through the lens terminal JL2 then connected with the camera terminal JB2. The protecting resistor Ro is used to avoid any possible shortcircuiting which may happen to occur between the power supply line +V and the ground when, for example, forceps touch the camera terminal JB2. It is to be noted that, except for the circuits LMC, RLM, APM, MRM, 1CM, 2CM and FEN, the camera circuit is fabricated in C-MOS.

The operation of the camera system as a whole will now be described with reference to the flow charts of FIG. 6 and 7 showing the sequence of operation of the microcomputer PC. Assuming that the microcomputer PC is in the inoperative position, terminals P2, P3 and P4 are all in a low level state. When any one of the light measuring switch S1, the Tv switch SSS and the Av switch ASS is subsequently closed, an input to an interruption terminal itA sets down to a low level state and the microcomputer PC consequently starts its operation from the initial step #1. At step #1, a terminal P11 is rendered in a low level state wherefor the transistor BTo is caused to conduct to initiate the electric power supply from the power supply line +V and also the electric power supply through the resistor Ro. By rendering the terminals P2, P3 and P4 in a high level state, a terminal P14 is rendered in a high level state. When the terminal P14 is rendered in the high level state, ISO data and mode data are latched in the shift register SR in response to the positive edge of the high level signal emerging from the terminal P14. An ISO data output circuit CAD is a circuit operable to read a coded pattern indicative of the ISO data, which coded pattern is provided on a film container as is well known to those skilled in the art, whereas the mode data generator MOD is operable to generate the mode data from a coded pattern depending on the position of a slide member movable together with the mode selector slide 23 shown in FIG. 3(*a*). In addition, at the same time as the terminal P14 is rendered in the high level state, the NAND gate NA1 and the AND gates AN0 and AN2 are brought in position ready to be enabled. At step #4, the microcomputer PC undergoes a serial input and output operation with the consequence that eight clock pulses are output from a terminal CKO on the one hand and data fed to a data input terminal SIN are taken in a serial input/output register SIOR, provided internally of the microcomputer PC, in response to the negative edge of each positive edge of the eight clock pulses on the other hand. Substantially at the same time, the shift register SR sequentially outputs the data, which have been latched therein, on the basis of the eight clock pulses successively fed to the AND gates AN2. When the data so output are in the high level state, and output from both of the gates AN0 and NAl is in a low level state and, accordingly, a field-effect transistor To is brought in a conductive state thereby permitting a high level signal to be fed to the data input terminal SIN. On the other hand, when the data outputed from the shift register SR are in the low level state, an output from both of the gates AN0 and NAl is in a high level state and, accordingly, a field-effect transistor T1 is brought in a conductive state thereby permitting a low level signal to be fed to the data input terminal SIN. It is to be noted that, when and so long as the terminal P14 of the microcomputer PC is in a low level state, the NAND gate NAl and the AND gate AN0 generate high and low level signals, respectively, and therefore both of the field-effect transistors T0 and T1 are held in a non-conducting state, thereby avoiding any possible adverse influence which would otherwise occur when data taken from the lens circuit of FIG. 3(*b*) are fed to the data input terminal SIN. Upon termination of step #4, of the data taken in the serial input/output register SIOR, the mode data are set in a register MOR, and the ISO data are, after having converted the data taken in into data for the calculation, set in a register SVR. Then, the microcomputer PC renders the terminal P14 in a lower level state and proceeds to step #7.

At step #7, a decision is made as to whether or not data appropriate to the law of the coded pattern on the film container have been read out from the ISO data taken in the serial input/output register SIOR. If it proves that the data appropriate to the law of the coded pattern have been read out, the contents of the register SVR remain unchanged, but if it proves to the contrary, it can note that the film container having no coded pattern is loaded or any film container is not loaded and, in such case, data representative of the ISO sensitivity which is most often utilized, for example, ISO 100, can be set in the register SVR.

Subsequently, the microcomputer PC proceeds to the reading of data out from the lens circuit shown in FIG. 3(*b*). In the first place, the content of a register k is rendered "0" and a terminal P12 is rendered in a high level state. The register k serves to select one of the data setting registers LDR0 to LDR5 according to the content stored therein More specifically, when the content of the register k is "0", "1", "2", "3", "4" or "5", the register LDR0, LDR1, LDR2, LDR3, LDR4 or LDR5, can be selected, respectively. When the terminal P12 is rendered in the high level state as hereinabove described, this high level signal is fed to the lens circuit through the terminal JB4 and then the terminal JL4. By

this high level signal, all of the AND gates AN3 and AN4, the NAND gate NA2 and a decoder DE are brought in position ready to be enabled and, on the other hand, counters C00 and C01 are released from their reset states. Then, the microcomputer undergoes the serial input and output operation to sequentially read in the data, which are fed to the data input terminal SIN from the lens circuit through the coupled terminals JL1 and JB1, in response to the negative edge of the same clock signal as the clock signal outputed from the clock output terminal CKO, the data so read in being subsequently set in a register LDRK to add "1" to the register k. Then, a decision is made as to whether or not the content of the register k has become "6". If the content of the register k is determined "6", the process flow proceeds to step #15, but if it is not, the process flow proceeds to step #11 to read in the next succeeding data fed from the lens circuit. By repeating the above described process flow, six types of data can be read in the microcomputer PC and set in the register LDR0 to LDR5, respectively.

Referring to FIG. 3(*b*) showing the lens circuit, that is, the circuit built in the interchangeable lens assembly, a counter C00 is a 3-bit counter operable to count the number of negative edges of the respective clock pulses which have been fed from the clock output terminal through the coupled terminals JB3 and JL3 and then the AND gate AN3 and subsequently inverted by an inverter IN0, that is, the number of positive edges of the respective clock pulses outputed from the clock output terminal CKO. The decoder DE sequentially generates a high level signal from its left-hand terminal to its right-hand terminal in correspondence with an output from the counter C00, thereby bringing AND gates AN10 to AN17 in position ready to be enabled. Accordingly, each of the AND gates is held in position ready to be enabled during a period from the positive edge of one clock pulse to the positive edge of the next succeeding clock pulse, thereby generating one-bit data. On the other hand, when the outputs from the counter C00 are all rendered in a low level state upon completion of its counting operation up to eight clock pulses and an AND data AN5, therefore generates a high level output, a counter C01 receives the clock pulses, which have been outputed from an AND gate AN3 and subsequently delayed by a delay circuit DL, and counts the number of negative edges of the clock pulses so received thereby. The delay circuit DL is utilized to inhibit the AND gate AN6 from outputing a pulse in response to the positive edge of the first clock pulse. Accordingly, each time the eight clock pulses are fed thereto, one clock pulse is counted. Reference character DSL represents a data selector adapted to output the input data, which have been fed to an input section A, when and so long as the most significant bit of the counter C01 is in a low level state, but to output the input data, which have been fed to an input section B, when and so long as it is in a high level state. And, RO fixedly stores various data of the interchangeable lens assembly at respective addresses. When one of the addresses is specified by address data fed from the data selector, the data stored and fixed at such specified address are outputed and are then output through the AND gates AN10 to AN17 bit to bit from the least significant bit. The data output from the AND gates AN10 to AN17 emerges from an OR gate OR0 and, when and so long as the output from the OR gate OR0 is in a high level state, a field-effect transistor T2 is rendered conductive with the high level signal consequently fed to the data input terminal SIN through the coupled terminals JL1 and JB1. However, when and so long as the output from the OR gate OR0 is in a low level state, a field-effect transistor T3 is rendered conductive with the low level signal consequently fed to the data input terminal SIN through the coupled terminals JL1 and JB1.

Hereinafter, the reason will be discussed that, even if the lens assembly is incompletely coupled to the camera body, the transmission of various data between the lens assembly and the camera body will not be adversely affected. For this purpose, reference will now be made to FIGS. 4 and 5. It is to be noted that FIG. 4 illustrates the case employed only for the purpose of comparison, in which the power terminal on each of the camera body and the interchangeable lens assembly is positioned at one extremity of the arcuate row of the terminals and the lens assembly is incompletely coupled to the camera body. FIG. 5 illustrates the case in which the lens assembly incorporating the lens circuit of FIG. 3(*b*) is incompletely coupled to the camera body incorporating the camera circuit of FIG. 3(*a*).

Referring first to FIG. 4, the lens assembly is incorrectly coupled to the camera body such that a data terminal JB2' and a clock terminal JB3', both on the camera body, are electrically connected with a power terminal JL1' and a data terminal JL2' both on the lens assembly, respectively. At the outset, a discussion will be made as to what will happen when, in the incomplete condition, the clock pulses are generated from the clock terminal CKO to permit data from other data output sections, that is, the shift register SR, provided internally of the camera body, to be read in the data input terminal SIN. A high level signal of the clock is generated upon the conduction of a field-effect transistor T4. Then, a voltage from the power supply line +V is supplied through the field-effect transistor T4 and the coupled terminals JB3' and JL2' to the lens assembly and then to a power supply line VL in the lens assembly through a diode D2 which is essentially formed by a CMOS circuit. This signal is in turn fed to the data input terminal SIN in the camera body through the coupled terminals JL1' and JB2'. At this time, it is assumed that the data from the shift register SR in the camera body are in the low level state, an N-channel field-effect transistor T1 is conducting and the low level signal is to be read in the data input terminal SIN. However, when and so long as the field-effect transistor T1 is conducting, the potential at the data input terminal SIN is equal to the potential of the electric power +E divided by the on-resistance of a field-effect transistor T4, and the on-resistance of both the diode D2 and the field-effect transistor T1 and is not clear as to whether it becomes a high level state or whether it becomes a low level state. Accordingly, there is a possibility that incorrect data will be read in the data input terminal SIN. (It may be contemplated to employ a resistor of relatively high resistance between the terminal JB2' and the data input terminal SIN or between the clock output terminal CKO and the terminal JB3' to avoid the reading of the incorrect data. However, where such a resistor is employed, it may happen that a low-pass filter having a large time constant will be formed by the above described resistor and the parasitic capacitance of the data transfer line or the clock transfer line, in which case a high speed data transmission will be hampered.) On the contrary thereto, in the embodiment according to the

present invention, since the data terminal JL1 for transmitting the data from the lens assembly to the camera body is positioned on the leading extremity of the row of the lens terminals with respect to the direction of turn of the lens assembly which is effected when the lens assembly is coupled to the camera body, even if any erroneous connection between the terminals such as corresponding to that described with reference to and shown in FIG. 4, no voltage will be imposed on the data terminal JB1 on the camera body as shown in FIG. 5 and, therefore, no adverse effect will occur when the data input terminal SIN in the camera body reads in the output from the shift register SR. In general, in the case of the embodiment according to the present invention, the terminal JB1 for receiving the data of the camera is electrically connected with the terminal JL1 only when and after the interchangeable lens assembly has been completely coupled to the camera body and hence held in the locked position, and will not be connected to any one of the other terminals JL2 to JL5 during the mounting of the lens assembly. Accordingly, even if while the lens assembly is incompletely coupled to the camera body the ISO data are read in through the data input terminal SIN, there is no factor that adversely affect the data and the ISO data are, therefore, correctly read in by the microcomputer PC. It is to be noted that, in the case of the embodiment according to the present invention, although a current tends to flow in through the transistor BTo, the resistor Ro, the coupled terminals JB2 and JL1, the diode D2, a power source VL and the coupled terminals JL2 and JB3, the waveform of the clock signal will not be adversely affected because the impedance is increased by the protecting resistor Ro.

The relationship between the data stored and fixed in a read-only memory RO and the addresses of the read-only memory RO as well as the operation necessary to specify the addresses will now be described.

TABLE 1

Counter (CO1)	Addresses	Data	Registers
000	000 00000	Check data	LDR0
001	000 00001	AVo: Full Open Aperture Size	LDR1
010	000 00010	Avmax: Minimum Aperture Size (maximum F-number)	LDR2
011	000 00011	Wv: Error in Full Open Aperture Metering	LDR3
100	100 *****	Avz: Deviation in Effective Aperture Size from A Standard	LDR4
101	101 *****	fv: Focal Length	LDR5

Table 1 illustrates the relationship among the output from the counter C01, the address of the read-only memory RO to be specified, the data stored at the specified address, and the register to which the data are set within the microcomputer PC. Each time the eight clock pulses are fed to the counter C01, the latter increases its count by one increment. Accordingly, at the outset, the output from the counter C01 is "000". As a result, the data, "000 00000", from an input section A are outputed from the data selector DSL to the read-only memory RO. Subsequently, check data (for example, "10101010") common to all of the available interchangeable lens assemblies is transferred from the read only memory RO to the camera body. When the output from the counter C01 subsequently become "001", an address data "000 00001" from the input section A is outputed from the data selector DSL and a data Avo representative of the full open aperture size is outputed from the read-only memory RO. In the case of the zoom lens assembly having its effective aperture variable with change in focal length, a data representative of the full open aperture size at the shortest focal length, that is, the greatest aperture size available in the lens system, is outputed. When the output from the counter C01 becomes "010", an address data "000000010" from the input section A is output from the data selector DSL and a data Avmax representative of the minimum aperture size (the maximum f-stop number) is output from the read-only memory RO. Also, as for this minimum aperture size, in the case of the zoom lens assembly having its effective aperture variable with change in focal length, a data representative of the minimum aperture size at the shortest focal length is outputed. When the output from the counter C01 becomes "011", an address data "00000011" is output from the data selector DSL and a data Wv representative of an error in full open aperture metering is output. When the output from the counter C01 becomes "100", an address data "100*****" from the input section B is output from the data selector DSL. The five-bit data represented by "*****" is a data output from the focal length code plate FCP in correspondence with the focal length set by the zooming ring 1. At this address, a data representative of the deviation in effective aperture size from that at the shortest focal length is fixedly stored. It is, however, to be noted that, in the case of a zoom lens assembly having its effective aperture not variable with change in focal length, a data "00000000" is fixedly stored. In addition, in the case of a lens assembly of a fixed focal length, no focal length code plate is employed and, at the same time, no data selector DSL is employed, and the address in the read-only memory RO is specified "00000100" and, therefore, a data "00000000" is output from the read-only memory RO. When the output from the counter C01 become "101" a data "101*****" from the input section B is output from the data selector DSL and a data fv corresponding to the focal length set by the zooming ring 1 is output. In the case of the lens assembly of a fixed focal length, the address of "00000101" is specified and a data fv representative of the fixed focal length is output.

Referring to the flow chart of FIG. 6, the operation of the microcomputer PC will now be described. After the data has been taken in from the lens circuit, the analog-to-digital conversion of an output from the light measuring circuit LMC is carried out at step #15. The output from the light measuring circuit LMC is fed to an analog input terminal ANI so that a reference voltage created within the light measuring circuit LMC can be utilized as a reference voltage for a digital-to-analog converter built in the microcomputer PC for the analog-to-digital conversion and the output from the light measuring circuit LMC is subjected to the analog-to-digital conversion on the basis of this reference voltage. Subsequently, at steps #16 and #17, both the full open aperture size and the minimum aperture size at the focal length once set are calculated, the resultant data being designated by Avo and Avmax, respectively. Then, at step #18, the error Wv, included in the data of the output from the light measuring circuit LMC which has been subjected to the analog-to-digital conversion, and a factor of the full open aperture size Avo are subtracted on the basis of the data read out from the lens assembly to calculate Bv to which the film sensitivity

data set in a register SVR is added to calculate an exposure value EV.

Upon the completion of the above described operation, an exposure calculation operation starting from step #20 starts. At step #20, based on the data taken in a register MOR, a decision is made as to whether or not it is the P mode. If it is the P mode, the program flow proceeds to step #21 at which a decision is made as to whether or not the focal length data fv from the lens assembly is greater than fvt. If fv>fvt, the programmed calculation for the high speed shutter priority is performed at step #21 which is followed by step #35. However, if the determination at step #21 shows fv≦fvt, a decision is made at step #23 to find if fv<fvw. If fv≦fvw, the program flow proceeds to step #25 at which the programmed calculation for the small aperture priority is performed, which step #25 is subsequently followed by step #35. When the determination at step #23 shows fv≧fvw, the normal programmed calculation is performed at step #24 which is followed by step #35. On the other hand, if the determination at step #20 is such that it is not the P mode, a decision is made at step #26 to find if it is the A mode. If it is the A mode, the aperture is set in a register AVR1 depending on the states of the respective buttons 25, 27 and 28, and at subsequent step #26, the calculation for the A mode is performed, followed by step #35. If it is not the A mode as determined at step #26, a decision is performed at step #29 to determine if it is the S mode. If it is the S mode, an exposure time is set in a register TVR1 at step #30 in dependence on the states of the respective buttons 26, 27 and 28 and, after the calculation for the S mode has been performed at step #31, the program flow proceeds to step #35. If it is not the S mode as determined at step #29, this means the M mode and, therefore, at step #32, the aperture determined in dependence on the states of the respective buttons 25, 27 and 28, and the exposure time determined in dependence on the states of the respective buttons 26, 27 and 28 are set in registers AVR1 and TVR1, respectively, at step #32 which is followed by step #34 at which the calculation for the M mode is performed, the program flow thereafter proceeding to step #35.

The aperture for the control obtained from one of the above described calculations for the respective modes is set in a register AVR2 while the exposure time for the control obtained from one of the above described calculations for the respective modes is set in a register TVR2. Moreover, an over exposure warning, an under exposure warning, a camera wobbling warning and the data of the displacement from a proper exposure during the M mode are all set in a register DMR. The preset aperture and exposure time are set in the registers AVR1 and TVR1. If during the calculation for the S mode the calculated aperture AV is such that Av°Av-max, Avmax and the data on the preset exposure time are set in the registers AVR2 and TVR2, respectively, with the over exposure warning effected. On the other hand, if Av°Avo, Avo and the data on the preset exposure time are set in the registers AVR2 and TVR2, respectively, with the under exposure warning effected. During the P mode, if Avmax+Tvmax°Ev, Avmax and Tvmax are set in the registers AVR2 and TVR2, respectively, with the over exposure warning effected. Moreover, if the calculated Av is smaller than Avo, Avo is set in the register AVR2 and, if Tv which is obtained by Ev-Avo=Tv is higher than Tvmin, the Tv so obtained is set in the register TVR2, but if Tv<Tvmin, Tvmin is set in the register TVR2 with the under exposure warning effected. At step #35, the number of steps to be stopped-down is calculated from both the data on the aperture size for the control and the data on the full open aperture size, the calculated data beings et in a register PVR. At the subsequent step #36, data Avd on the aperture for the display, of which minimum unit is 0.5 Ev, is calculated from the data on the aperture for the control and is then set in a register AVR3. At step #38, data Tvd on the exposure time for the display, of which minimum unit is 0.5 Ev, is calculated from the data on the exposure time for the control and is then set in a register TVR3. After the above described operation has been completed, the program flow proceeds to step #39 at which a subroutine for the transfer of the data to be displayed is executed.

The subroutine for the transfer of the data to be displayed will now be described. At step #60, a terminal P13 is rendered in a high level state, the AND gate AN1 is brought in position ready to be enabled, and the display circuit DSP is set in position ready to receive inputs. The content of the register DMR is set in a serial input/output register SIOR and the serial input and output operation is performed. Thereby, the content of the register DMR is taken in the display circuit DSP. Subsequently, the content (ISO data) of the register SVR is set in the register SIOR and the serial input and output operation is performed. After the data in the register AVR3 on the aperture for the display and the data in the register TVR3 on the exposure time for the display have been fed to the display circuit DSP, the terminal P13 is rendered in a low level state, followed by the return to the main routine. Then, the display circuit DSP outputs a signal, corresponding to the data so read out, to a segment terminal SEG and a display corresponding to the data fed together with a signal from a common terminal COM is carried out by means of a liquid crystal display unit LQ.

After the completion of the transfer of the data to be displayed, and at step #40, interruption to a terminal itB is enabled. This is such that, if the release switch S2 shown in FIG. 3 is closed and, at the same time, the exposure control mechanism has been charged with the switch S4 consequently closed, the output from the NAND gate NA0 changes to a low level state with an interruption signal consequently fed to the terminal itB, and the microcomputer performs an exposure control operation from step #70 if the interruption to the terminal itB is in condition ready to be enabled, no matter what operation it has performed. When the interruption to the terminal itB is enabled, the terminals P2, P3 and P4 are rendered in a low level state and a decision is made as to whether or not an input terminal P0 is rendered in a low level state as a result of at least one of the switches S1, SSS and ASS having been closed. If the terminal P0 is rendered in the low level state, the program flow returns to step #2, thereby repeating the above described operation. On the other hand, if the terminal P0 is in the high level state, the program flow proceeds to step #43 at which the interruption to the terminal itB is disabled and a blank data BLD for turning off the display is set in the registers AVR3 and TVR3 and, further, the register DMR in which display data such as for warning is set is reset, followed by the subroutine for the transfer of the data to be displayed. After the completion of the data transfer starting from step #60 in the manner as hereinbefore described, the terminal PII is rendered in a high level state to interrupt

the power supply by means of the transistor BTo while the interruption to a terminal itA is enabled to interrupt the operation of the microcomputer PC. Accordingly, at the time of interruption of the operation of the microcomputer, the display unit LQ merely displays only the ISO data.

Hereinafter, a subroutine for the aperture setting will be described with reference to FIG. 7. At step #101, a decision is made to find if the switch ASS is closed. This is to determine if, while a terminal P4 is rendered in a low level state, the terminal P0 is rendered in a low level state and to render the terminal P4 in a high level state. If the switch ASS is not closed, a flag SEF is set to "0" at step #115 followed by step #116. On the other hand, if the switch ASS is closed, a decision is made at step #102 as to whether or not the switch UPS is closed. This operation is to determine if, while the terminal P3 is rendered in a low level state, the terminal Pl is rendered in a low level state and to render the terminal P3 in a high level state. If the switch UPS is closed, a decision is made at step #103 as to whether or not the down-shift switch DOS is closed. This operation is to determine if, while the terminal P4 is rendered in a low level state, the terminal Pl is in a low level state and to render the terminal P4 in a high level state. If the down-switch DOS is, too, closed, it means that the up shift button 27 and the down-shift button 28 are simultaneously depressed and, therefore, the program flow proceeds to step #116 with no set value altered. If it proves at step #103 that the switch DOS is not closed, a decision is made at step #104 to find if the flag SEF is "1". If the flag SEF has been found to be "1", this means that the up-shift button 27 is kept depressed and, therefore, the program flow proceeds to step #116. On the other hand, if the flag SEF has been found to be "0", this means that the up-shift button 27 is first depressed and, therefore, the flag SEF is set to "1" at the subsequent step #105 followed by step #106 at which 0.5 is added to the content of the register AVR1. At step #107, the minimum aperture size Avmax obtained at step #17 is compared with the content of the register AVRl. If (AVRl)° Avmax, Avmax is set in the register AVRl at step #108 followed by step #116. On the other hand, if (AVRl)≦Avmax, the data of the register AVRl remains unchanged and the program flow proceeds to step #116.

If the determination at step #102 is such that the switch UPS is not closed, step #102 is followed by step #109 at which a decision is made to find if the switch DOS is closed. If the switch DOS is not closed, too, the flag SEF is set to "0" at step #115 followed by step #116. On the other hand, if the switch DOS is closed, a decision is made at step #110 to find if the flag SEF is set to "1". If the result at step #110 indicates that the flag SEF is "1⇌, this means that the down-shift button 28 is kept depressed and, therefore, the program flow proceeds to step #116 without the data being altered. On the other hand, if the result at step #110 indicates that the flag SEF is "0", this means that the down-shift button 28 is first depressed and, at this time, the flag SEF is set to "1" at step #111 followed by step #112 at which 0.5 is subtracted from the content of the register AVRl. If the result of comparison carried out at the step between the content of the register AVRl and the data Avo of the full open aperture size obtained at step #16 shows (AVRl)≧Avo, the content of the register AVRl remains unchanged and the program flow proceeds to step #116. On the other hand, if it shows (AVRl)<Avo, the full open aperture size Avo is set in the register AVRl at step #114, followed by step #116.

At step #116, a decision is made as to whether or not the content of the register AVRl is greater than the value representative of the minimum aperture size Avmax, and if it not greater than Avmax, the content of the register AVRl remains unchanged, but if it is greater than Avmax, the minimum aperture size Avmax is set in the register AVRl at step #117 in place of the original content in the register AVRl. At step #118, a decision is made as to whether the content of the register AVRl is smaller than the value representative of fuller open aperture size Avo determined at step #16. If the result of comparison at step #118 indicates that the content of the register AVR1 is smaller than Avo, Avo is set in the register AVRl at step #119 in place of the original contents in the register AVRl, but if it shows the content of the register AVRl not smaller than Avo, the content of the register AVRl remains unchanged and the program flow subsequently returns to the main routine. The program flow from step #116 to step #119 is provided for the purpose of avoiding any possible departure of the data, set in the register AVRl prior to the lens assembly being interchanged, from a controllable range when the lens assembly is interchanged. In addition, as shown in the subroutine, a single depression of any one of the up-shift and down-shift buttons results in the change of the set value by 0.5 Ev.

The subroutine for the determination of the exposure time is similar to the subroutine shown in FIG. 7 except that step #101 is substituted by a decision step to determined if the switch SSS is closed; the register AVRl at each of the steps #106, 107, 108, 112, 113 and 114 is substituted by the register TVR1; Avmax is substituted by the data Tvmax on the shortest exposure time; Avo is substituted by the data Tvmin on the longest exposure time; and steps #116 to #119 are omitted because of no change occurring in any one of the shortest and longest exposure times.

Referring to FIG. 6, particularly to FIG. 6(*c*), the operation which takes place when an interruption signal is fed to the interruption terminal itB will now be described. At step #60, a decision is made as to whether or not the data of a register PVR associated with the number of f-stop steps to be stopped down is "0". If it is not "0", the content of the register PVR is set in an event counter ECO to enable the interruption by the event counter ECO. And, a low level pulse of a duration To is generated from a terminal P6 to activate the release magnet circuit RLM. Then, the engagement of the control lever 15 shown in FIG. 1 is released and the control lever 15 starts its movement in the direction X to initiate the aperture stop-down operation. In addition, in response to the movement of the control lever 15, the pulse generator FEN generates a pulse which is in turn fed to a clock input terminal of the microcomputer PC at which, in response to each pulse, the data of the number of f-stop steps to be stopped down, which is preset in the event counter ECO, is subtracted. The microcomputer, after the lapse of a time T1 subsequent to the generation of a low level pulse from the terminal P6, generates from a terminal P8 a pulse of a duration To necessary to activate the mirror magnet circuit MRM. When the mirror magnet circuit MRM is so activated, the engagement of the reflective mirror 17 shown in FIG. 1 is released and the reflective mirror 17 is therefore is pivoted upwards. After the lapse of a time T2 subsequent to the generation of the low level pulse

from the terminal P8, the program flow proceeds to step #81 at which a low level pulse of a duration To is generated from a terminal P9. During a period from the generation of the low level pulse from the terminal to step #81, the aperture spends time enough to allow it to be stopped down from the full open aperture size to the minimum aperture size regardless of the type of an interchangeable lens assembly, and during this time pulses equal in number to the number of f-stop steps to be stopped down are generated from the encoder FEN and the content of the event counter ECO is zeroed. By this operation, the interruption by the event counter ECO is effected and the operation starting from step #90 is initiated. In this program flow, a low level pulse of a duration To is generated from a terminal P7, thereby returning to the main routine. In this way, the aperture stop magnet circuit APM is activated to stop the movement of the control lever 15 so that the aperture can be controlled to a preset aperture. When a time T2 elapses subsequent to the generation of the low level pulse from the terminal P8, the upward pivotal movement of the mirror 17 has completed, and a low level pulse is generated from the terminal P9 to initiate the travel of the leading curtain.

Upon the initiation of the travel of the leading curtain incident to the generation of the low level pulse from the terminal P9, a time 2—Tvc based on the data Tvc of the exposure time for the control, set in a register TvR2, is counted, and upon the completion of the counting of this time, a low level pulse is generated from a terminal P10 to activate the trailing curtain magnet circuit 2CM so that the travel of the trailing curtain can be initiated. After the completion of the travel of the trailing curtain, and the subsequent closure of a switch S4, the program flow proceeds to step #41 with the subsequent operation taking place in a manner similar to that hereinbefore described.

As hereinbefore fully described, according to the present invention, except for the aperture stop-down quantity transmission means essentially required to control the aperture mechanism of the interchangeable lens assembly from the side of the camera body, neither the aperture adjusting ring in the interchangeable lens assembly nor mechanical component parts such as mechanical linkage members associated with the aperture between the interchangeable lens assembly and the camera body are employed. Therefore, not only can the number of component parts of one or both of the lens assembly and the camera body be minimized, but also they can have enough space to spare. In addition, in these component parts, neither the machining precision nor the accurate positioning, which have hitherto been considered important problems, need be required to be taken into consideration. Furthermore, although information to be transmitted between the interchangeable lens assembly and the camera body includes information in the error in full aperture metering, and, in the case of the zoom lens assembly, the focal length, changes in aperture resulting from the zooming as the case may be, and the like, if these pieces of information are stored in the read-only memory in a manner similar to information of the full open aperture size and the minimum aperture size, the construction of the present invention can be concurrently utilized to transmit these pieces of information between the lens assembly and the camera body. Yet, while in the case of the customary interchangeable lens assembly having an aperture adjusting ring and an aperture mechanism mechanically associated therewith, a manipulation to set the aperture adjusting ring to a particular position to prevent a mechanical control by the aperture adjusting ring from interfering with this is required even though the aperture is set on the side of the camera body, such complicated procedures are not required according to the present invention. What is more, according to the present invention, any possible confusion which would occur in transmitting electric signals between the lens assembly and the camera body in the event of the incorrect coupling therebetween can advantageously be eliminated.

Although the present invention has fully been described in connection with the preferred embodiment thereof with reference to the accompanying drawings, it is to be noted that various changes and modifications are apparent to those skilled in the art. Such changes and modifications are to be understood as included within the true scope of the present invention as defined by the appended claims unless they depart therefrom.

We claim:

1. In a camera system capable of selectively functioning in a manual exposure control mode or an automatic exposure control mode having a camera body and an interchangeable objective lens removably coupled with the camera body, the improvement which comprises:

means, located in the interchangeable objective lens, for adjusting the aperture size of the lens without any source of manually controlling the adjusting means within the interchangeable objective lens;

a common electric terminal for data transmission from the interchangeable objective lens to the camera body;

means, located in the interchangeable objective lens, for transmitting a first electric data representative of the fully open aperture size and a second electric data representative of the minimum available aperture size peculiar to the objective lens, through said common electric terminal to the camera body;

means, located in the camera body, for manually setting exposure time including means for retaining the manually set exposure time regardless of a selection between the manual and automatic exposure control modes;

means, located in the camera body, for manually setting aperture including means for retaining the manually set aperture regardless of a selection between the manual and automatic exposure control modes;

means, located in the camera body, for restricting the manual aperture value setting within an aperture value range defined between the first and second electric data transmitted from the interchangeable objective lens;

means, located in the camera body, for performing a calculation for the manual exposure control mode in response to said manual exposure time setting means and said manual aperture value setting means;

a shutter means located in the camera body;

first means, located in the camera body, for controlling said shutter means in response to said manual exposure time setting means in the manual exposure control mode, and

second means, located in the camera body, for controlling said adjusting means in response to said manual aperture setting means in the manual exposure control mode.

2. The improvement according to claim 1, wherein said second controlling means includes means for calculating an aperture stop-down degree from the fully open

aperture size in response to said manual aperture value setting means and said first electric data received from the interchangeable objective lens.

3. The improvement according to claim 1, further comprising means for measuring light through the interchangeable objective lens with its aperture kept fully open.

4. The improvement according to claim 3, further comprising means for selecting between the manual exposure control mode and a program exposure control mode in which both exposure time and the aperture size are automatically controlled, means for calculating both the exposure time and aperture value in the program exposure control mode in response to said measuring means and said first and second electric data so that the calculated aperture value is restricted within the aperture value range defined between the first and second electric data, wherein said first controlling means is further responsive to the calculated exposure time in place of the manually set exposure time with the program exposure control mode selected, and said second controlling means is further responsive to the calculated aperture value in place of the manually set aperture value with the program exposure control mode selected.

5. The improvement according to claim 4, further comprising means, located in the interchangeable objective lens, for transmitting a third electric data representative of the focal length of the interchangeable objective lens through said common electric terminal to the camera body, wherein said exposure time and aperture value calculating means includes a plurality of exposure programs and means for adopting one of the programs in response to the third electric data, the first and second electric data being effective to restrict the calculated aperture value regardless of the selection of the program.

6. The improvement according to claim 4, wherein said mode selecting means is adapted to be capable of further selecting a shutter priority mode or an aperture priority mode, and further comprising means for calculating an aperture value in the shutter priority mode in response to said measuring means, said manually set exposure time and said first and second electric data so that the calculated aperture value is restricted within the aperture value range defined between the first and second electric data, and means for calculating an exposure time in the aperture priority mode in response to said measuring means, said manually set aperture value and said first electric data, wherein said first controlling means is responsive to the manually set exposure time in the shutter priority mode and responsive to the calculated exposure time in the aperture priority mode, and said second controlling means is responsive to the manually set aperture value in the aperture priority mode and responsive to the calculated aperture value in the shutter priority mode.

7. In a camera system having a camera body and an interchangeable objective lens removably coupled with the camera body, the improvement which comprises:

means, located in the camera body, for manually setting exposure time;

means, located in the camera body, for manually setting aperture value;

means, located in the camera body, for restricting the manual aperture value setting within an aperture value range;

means, located in the camera body, for measuring light through the interchangeable objective lens with its aperture fully open;

means, located in the camera body, for selecting one of manual, shutter priority, aperture priority and program exposure modes;

means for retaining the manually set exposure time and the manually set aperture value regardless of a selection among the manual, shutter priority, aperture priority and program exposure modes;

means, located in the camera body, for practicing an automatic exposure control calculation in one of the shutter priority, aperture priority and program exposure modes in response to at lest necessary one of the measuring means, the manually set exposure time and the manually set aperture value so that the calculated aperture value is restricted within the aperture value range;

first means located in the camera body, for controlling the shutter speed in response to the manually set or calculated exposure time;

second means, located in the camera body, for controlling the aperture size in response to the manually set or calculated aperture value;

a common electric terminal located in the interchangeable lens;

means, located in the interchangeable objective lens, for transmitting a first electric data representative of the fully open aperture size and a second electric data representative of the minimum available aperture size peculiar to the objective lens, through said common electric terminal to the camera body for the use in the restriction of manual aperture value setting in the camera body and for the use in the automatic exposure control calculation, and

means, located in the interchangeable objective lens, for adjusting the aperture size always in response to the second controlling means in any one of the manual, shutter priority, aperture priority and program exposure modes without any source of manually controlling the adjusting means within the interchangeable objective lens.

8. In a camera system capable of a manual and an automatic exposure control having a camera body and an interchangeable objective lens removably coupled with the camera body, the interchangeable objective lens comprising:

a camera electric terminal;

means for transmitting a first electric data representative of the fully open aperture size and a second electric data representative of the minimum available aperture size peculiar to the objective lens, through said common electric terminal to the camera body for the use in a restriction of manual aperture value setting in the camera body within an aperture value range defined between the first and second electric data and for use in an automatic exposure control calculation in the camera body;

means for transmitting a third electric data representative of the focal length of the interchangeable objective lens, through said common terminal to the camera body;

means for transmitting a fourth electric data representative of an error in fully open aperture metering which is to be caused by using the interchangeable objective lens, through said common terminal, and

means for adjusting the aperture size always under the control of the camera body in any one of the

manual and automatic exposure control mode without any source of manually controlling the adjusting means within the interchangeable objective lens.

9. In a camera system capable of a manual and automatic exposure control having a camera body and an interchangeable objective lens removably coupled with the camera body, the interchangeable objective lens comprising:

a common electric terminal;

means for transmitting a first electric data representative of the fully open aperture size and a second electric data representative of the minimum available aperture size peculiar to the objective lens, through said common electric terminal to the camera body for use in a restriction of manual aperture value setting in the camera body within an aperture value range defined between the first and second electric data and for use in an automatic exposure control calculation in the camera body;

means for transmitting a third electric data representative of the focal length of the interchangeable objective lens, through said common electric terminal to the camera body;

means for transmitting a predetermined data common to all of the available interchangeable objective lenses in the system, through said common terminal to the camera body, and

means for adjusting the aperture size always under the control of the camera body in any one of the manual and automatic exposure control modes without any source of manually controlling the adjusting means within the interchangeable objective lens.

10. In a camera system capable of a manual and automatic exposure having a camera body and an interchangeable objective lens removably coupled with the camera body, the improvement comprising:

means, located in the interchangeable objective lens, for adjusting the aperture size of the lens without any source of manually controlling the adjusting means within the interchangeable objective lens;

a common electric terminal for data transmission for the interchangeable objective lens to the camera body;

means, located in the interchangeable objective lens, for transmitting a first electric data representative of the fully open aperture size and a second data representative of the minimum available aperture size peculiar to the objective lens, through said common electric terminal to the camera body;

means, located in the interchangeable objective lens, for transmitting a third electric data representative of the focal length of the interchangeable objective lens through said common electric terminal to the camera body;

means, located in the camera body, for measuring light through the interchangeable objective lens with its aperture kept fully open;

means, located in the interchangeable objective lens, for transmitting a fourth electric data representative of an error in the fully open aperture light measurement which is inevitable depending on the interchangeable objective lens coupled with the camera body;

means, located in the camera body, for selecting between the manual exposure control mode and a program exposure control mode in which both exposure time and the aperture size are automatically controlled;

means, located in the camera body, for manually setting exposure time;

means, located in the camera body, for manually setting aperture value;

means, located in the camera body, for restricting the manual aperture value setting within an aperture value range defined between the first and second electrical data transmitted from the interchangeable objective lens;

means, located in the camera body, for calculating both the exposure time and aperture value free from the fully open aperture light measurement error in the program exposure control mode in response to said measuring means and said first, second and fourth data so that the calculated aperture value is restricted within the aperture value range defined between the first and second electric data, said calculating means including a plurality of exposure programs and means for adopting one of the programs in response to said third electric data, the first and second electric data being effective to restrict the calculated aperture value regardless of the selection of the program;

means, located in the camera body, for performing a calculation for the manual exposure control mode in response to said manual exposure time setting means and said manual aperture value setting means;

a shutter means located in the camera body;

first means, located in the camera body, for controlling said shutter means in response to the manually set or automatically calculated exposure time, and

second means, located in the camera body, for controlling said adjusting means in response to the manually set or automatically calculated aperture value.

11. The improvement according to claim **10**, further comprising means for retaining the manually set exposure time and the manually set aperture value against the selection between the manual and automatic exposure control modes.

* * * * *

United States Patent [19]

Kitagishi et al.

[11] Patent Number: 4,907,866

[45] Date of Patent: Mar. 13, 1990

[54] OBJECTIVE OF VARIABLE FOCAL LENGTH

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[73] Assignee: **Canon Kabushiki Kaisha**, Tokyo, Japan

[21] Appl. No.: **847,236**

[22] Filed: **Apr. 2, 1986**

[30] **Foreign Application Priority Data**

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Apr. 25, 1985 [JP] Japan 60-089193
Apr. 26, 1985 [JP] Japan 60-090127

[51] **Int. Cl.**[4] **G02B 15/177**
[52] **U.S. Cl.** **350/426**; 350/413
[58] **Field of Search** 350/426, 413, 96.31

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Primary Examiner—Bruce Y. Arnold
Assistant Examiner—Terry S. Callaghan
Attorney, Agent, or Firm—Fitzpatrick, Cella, Harper & Scinto

[57] **ABSTRACT**

An objective of variable focal length includes a plurality of lens units of which the first, counting from front, is of negative power and the second is of positive power. At least the first and second lens units are moved with variation of the air separation therebetween to vary the focal length of the entire system. The objective is characterized in that at least one of the lens units is included with at least one refractive index distribution type lens arranged on the common optical axis of the other lenses.

18 Claims, 12 Drawing Sheets

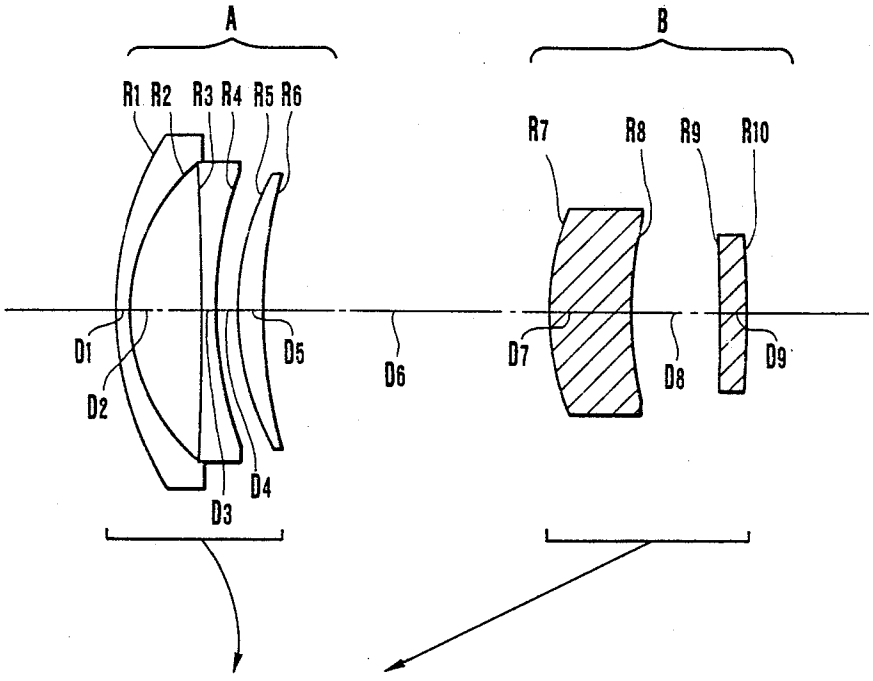


FIG. 1

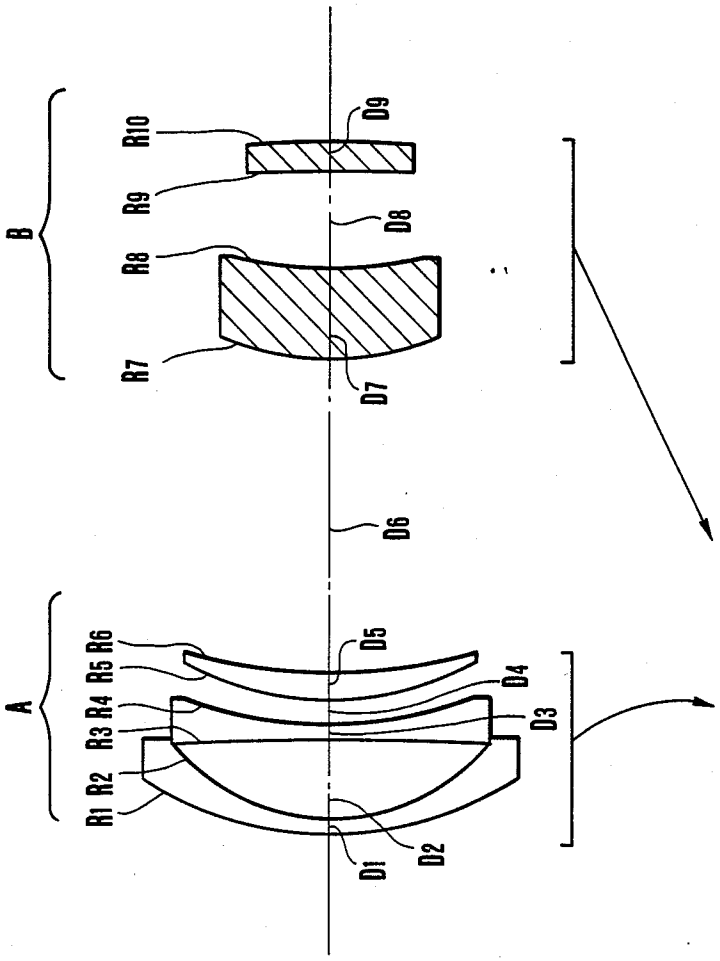
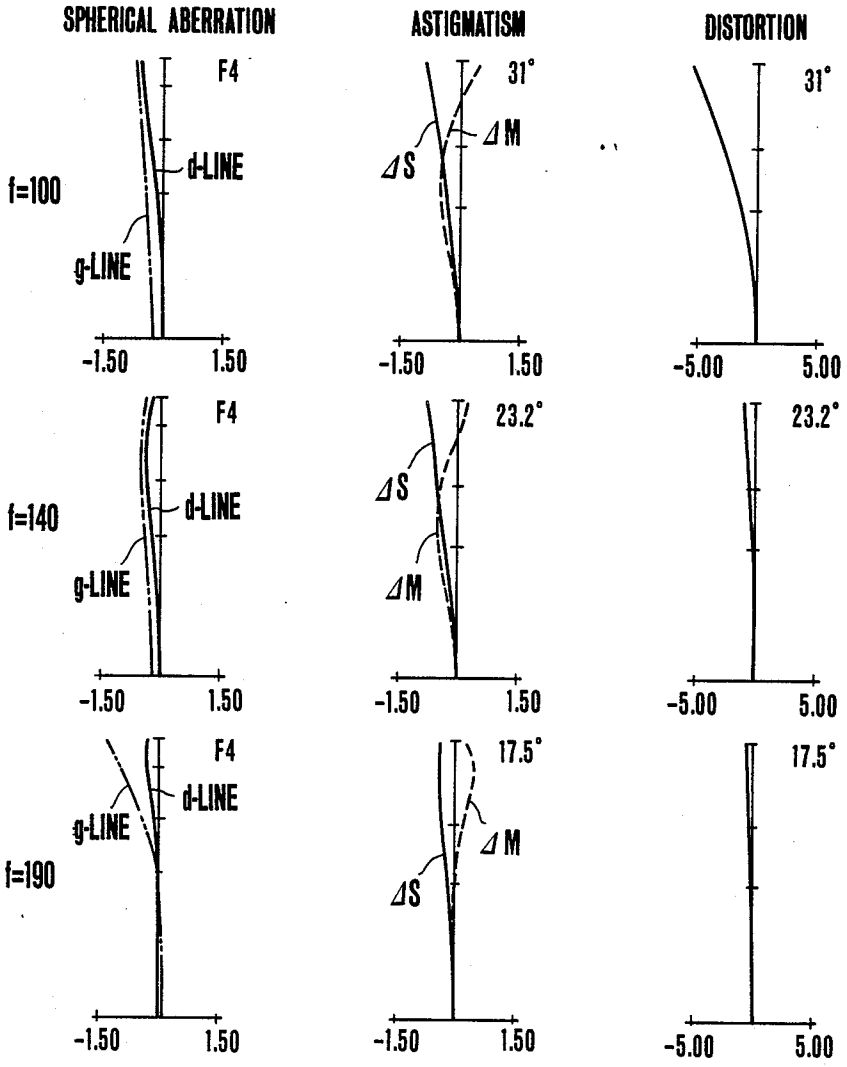


FIG.2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ΔM
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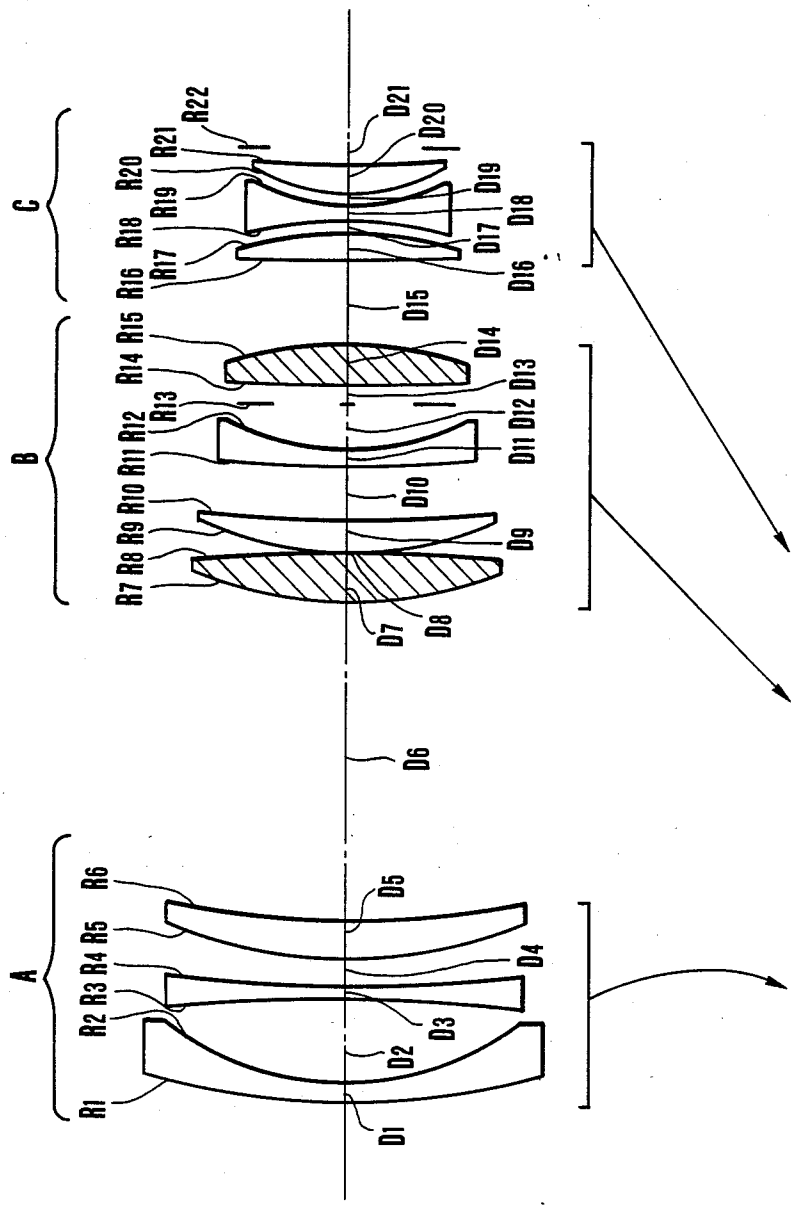
5.00

FIG.3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R3
R4
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R15
R16
R17
R18
R19
R20
R21
R22
D1
D2
D3
D4
D5
D6
D7
D8
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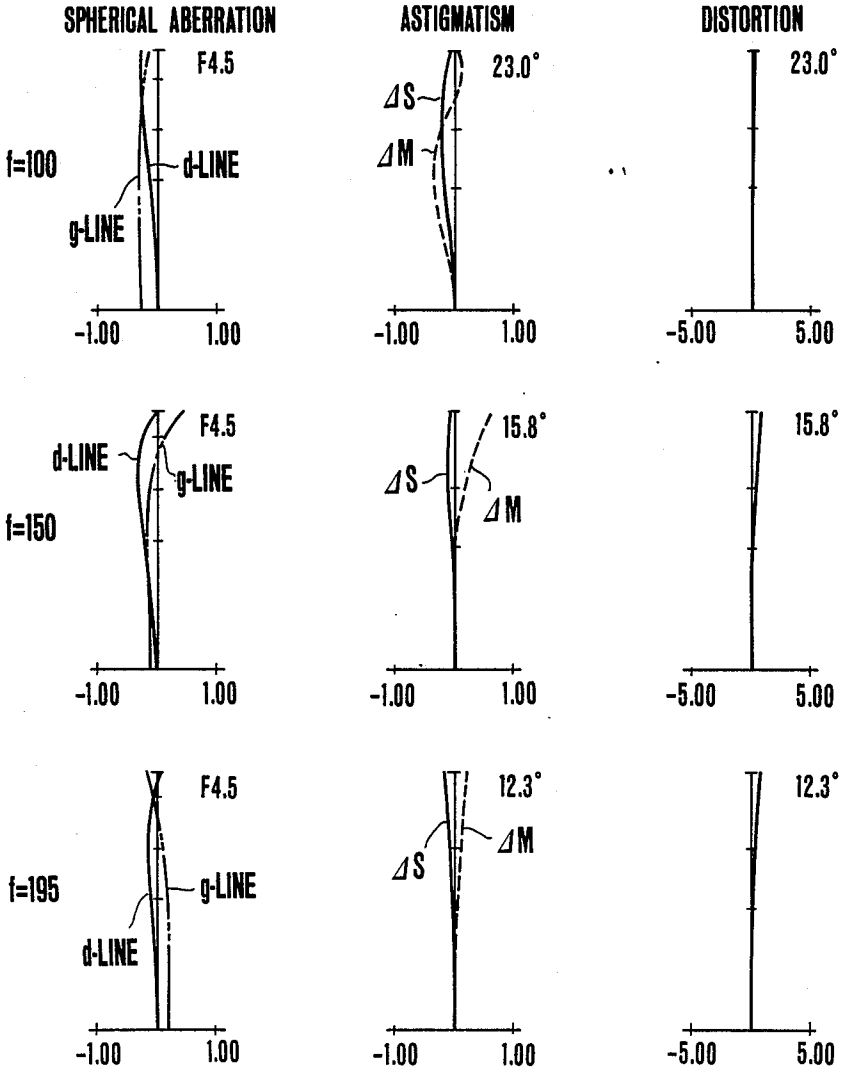
D20
D21

FIG.4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1.00
-5.00
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15.8°
d-LINE
g-LINE
f=150
ΔS
ΔM
-1.00
1.00
-1.00
1.00
-5.00
5.00
F4.5
12.3°
12.3°
f=195
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ΔM
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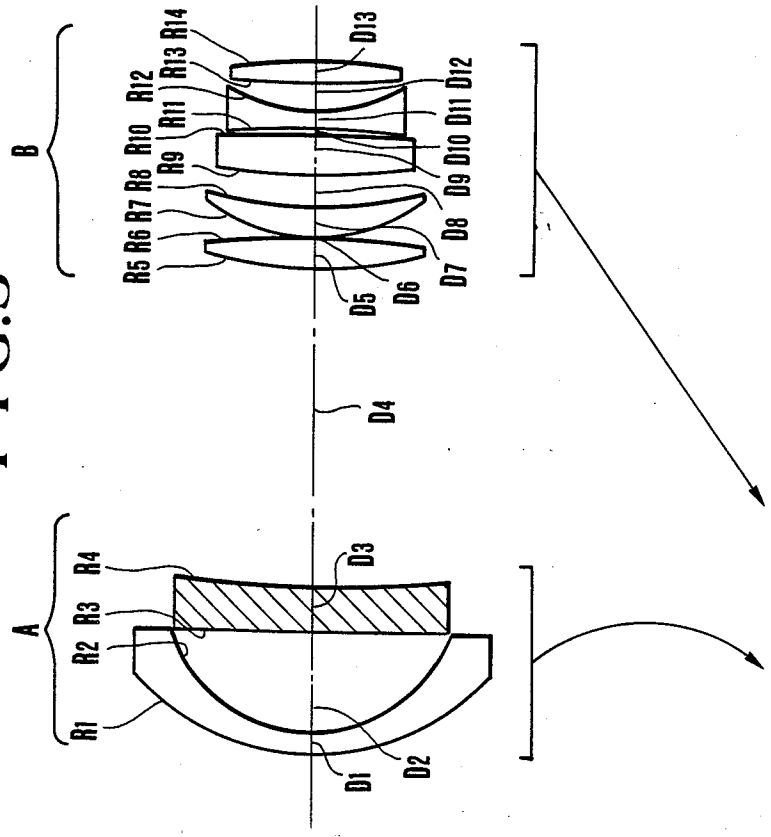
1.00
-1.00
1.00
-5.00
5.00

FIG.5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R7
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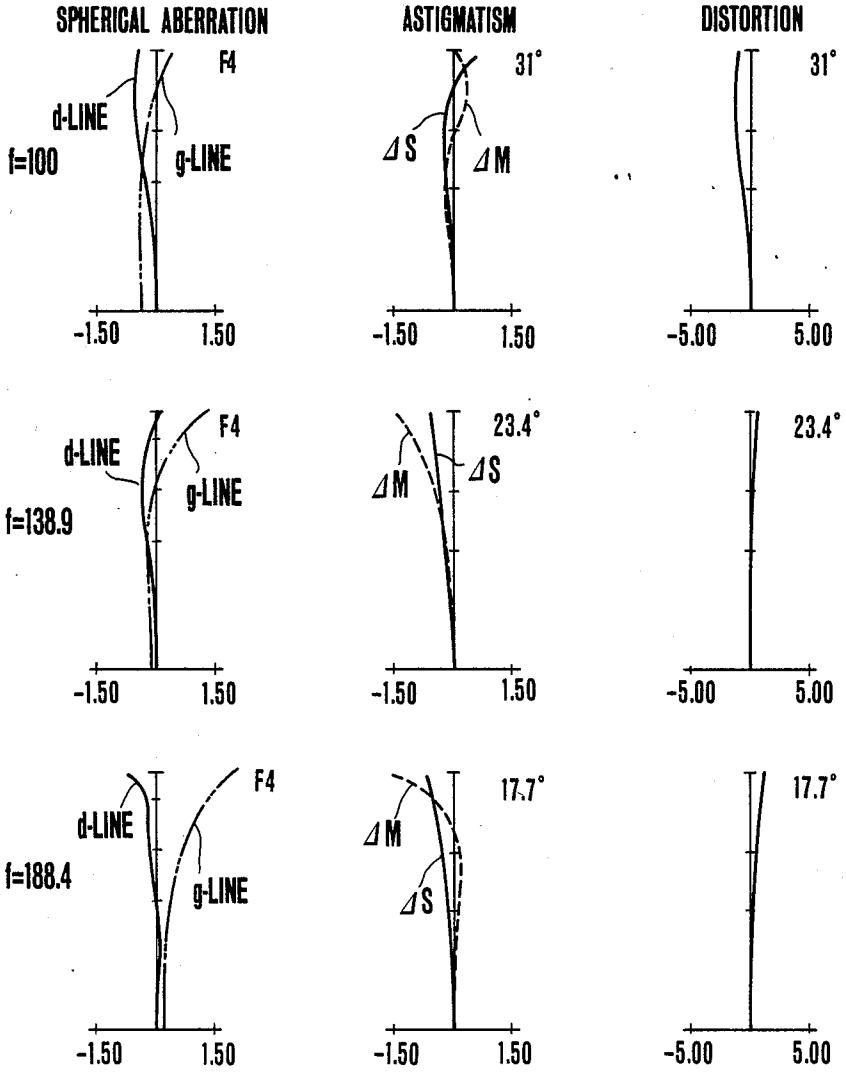
D13

FIG.6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ΔM
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17.7°

FIG. 7

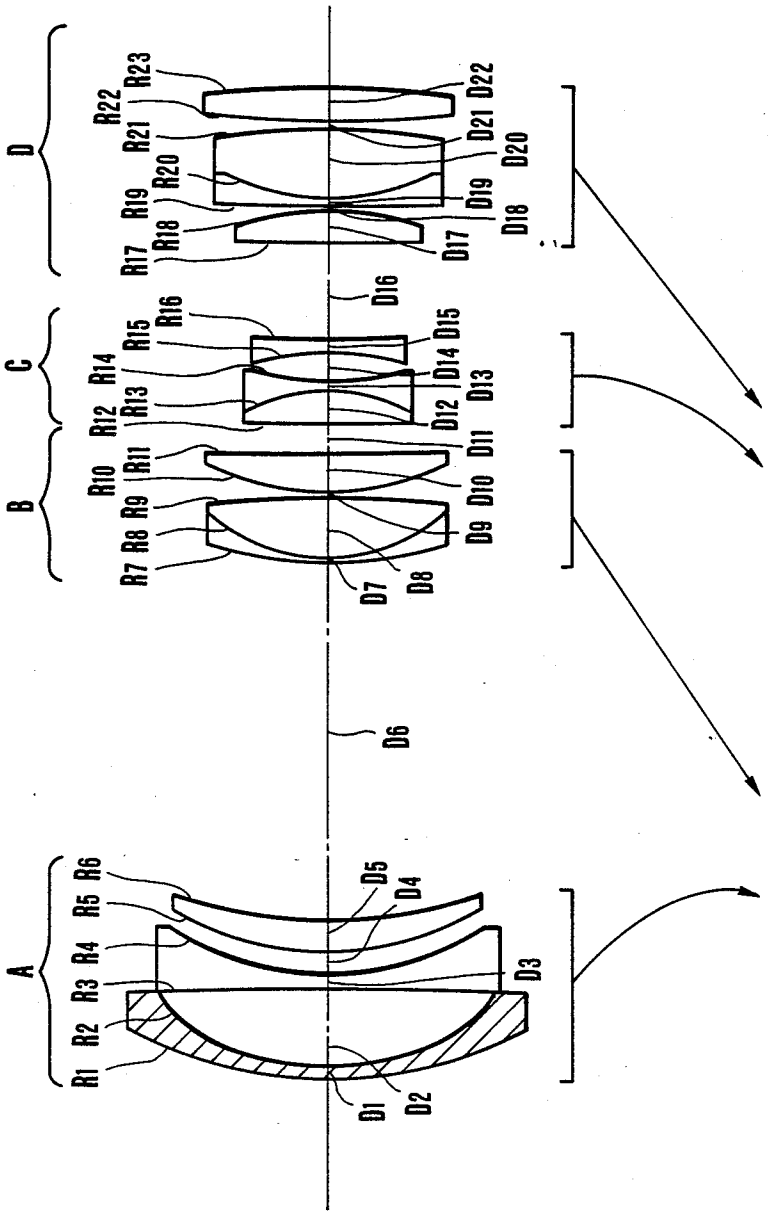
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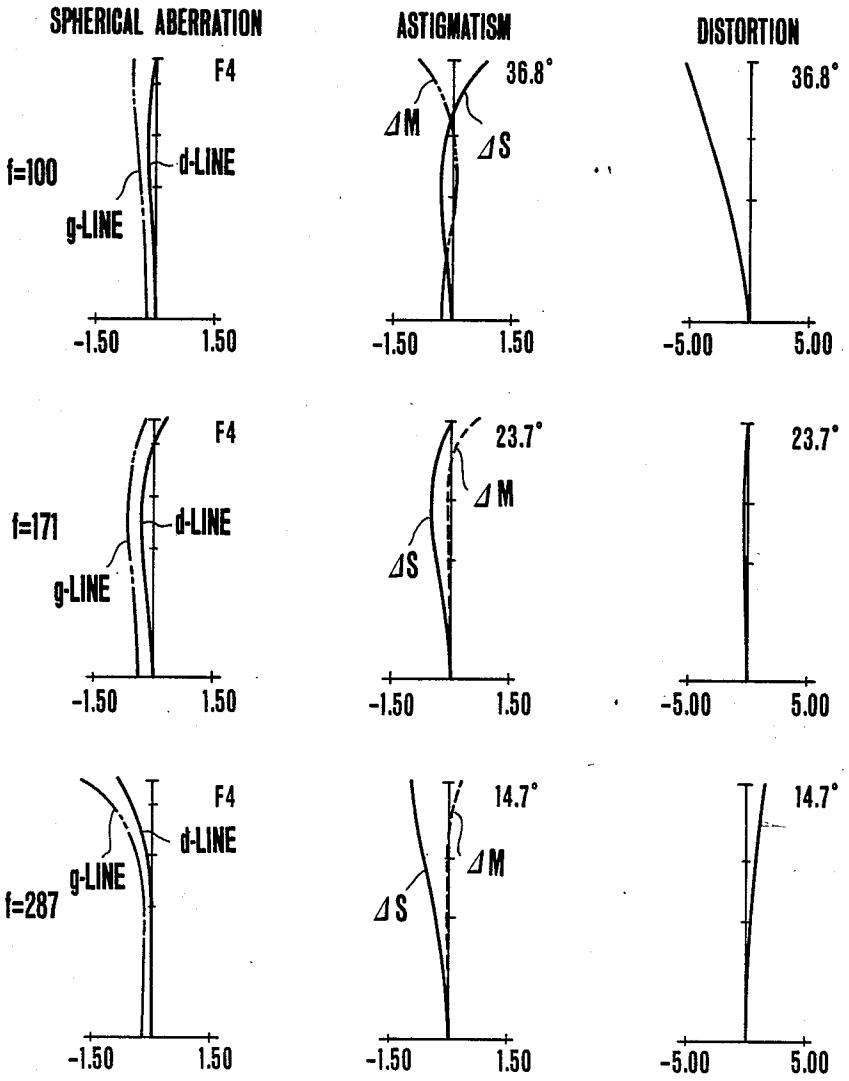
FIG.8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g-LINE
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1.50
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ΔM
ΔS
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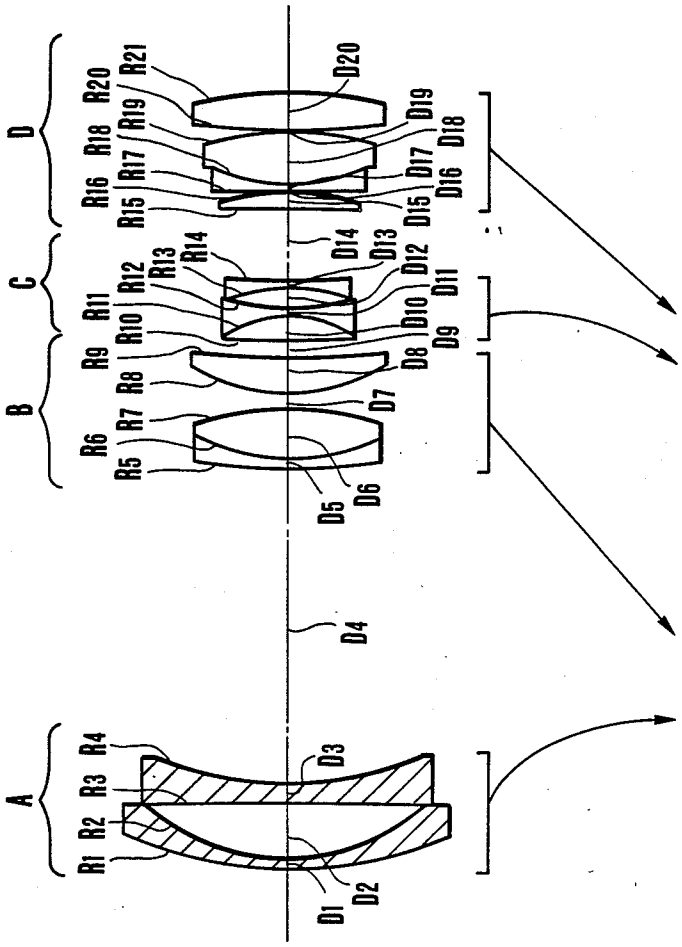
f=171
23.7°
f=287
14.7°

FIG.9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R1
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R5
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R7
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R10
R11
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R14
R15
R16
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R18
R19
R20
R21
D1
D2
D3
D4
D5
D6
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D17
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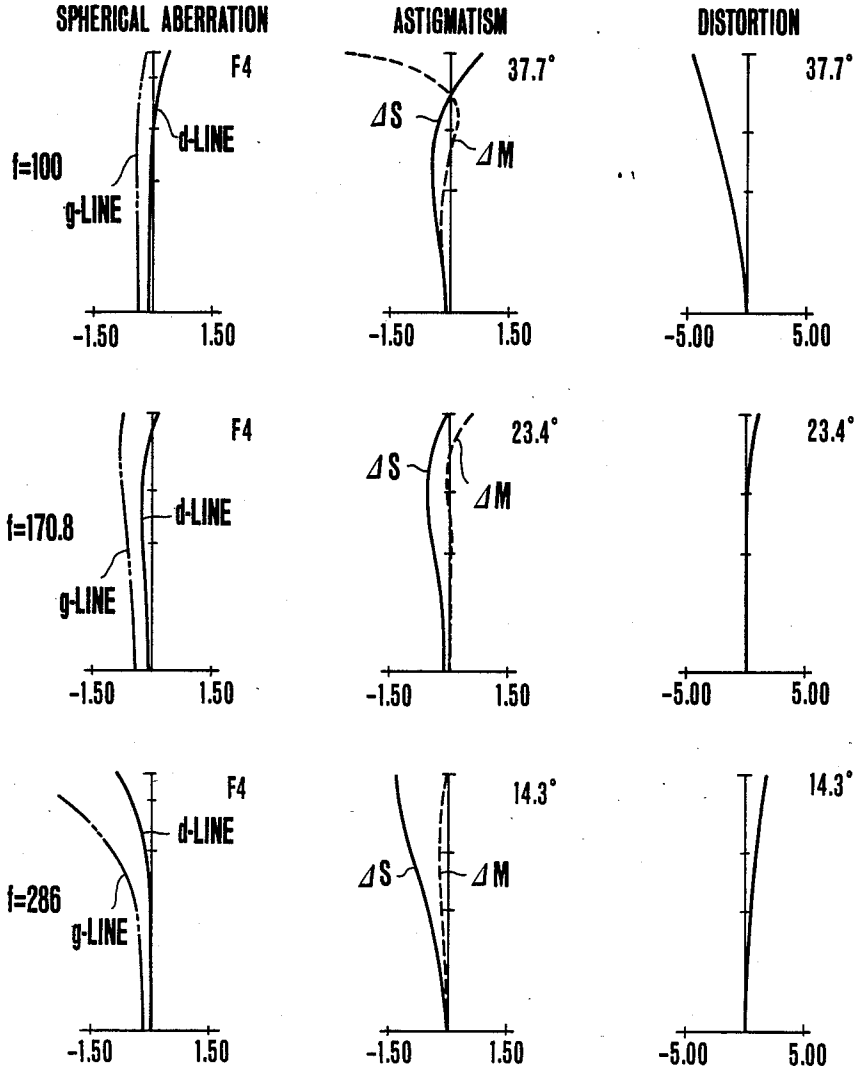
FIG.10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1.50
37.7°
ΔS
ΔM
-5.00
5.00
F4
d-LINE
f=170.8
g-LINE
-1.50
1.50
23.4°
ΔS
ΔM
-5.00
5.00
F4
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g-LINE
-1.50
1.50
14.3°
ΔS
ΔM
-5.00
5.00

FIG.11

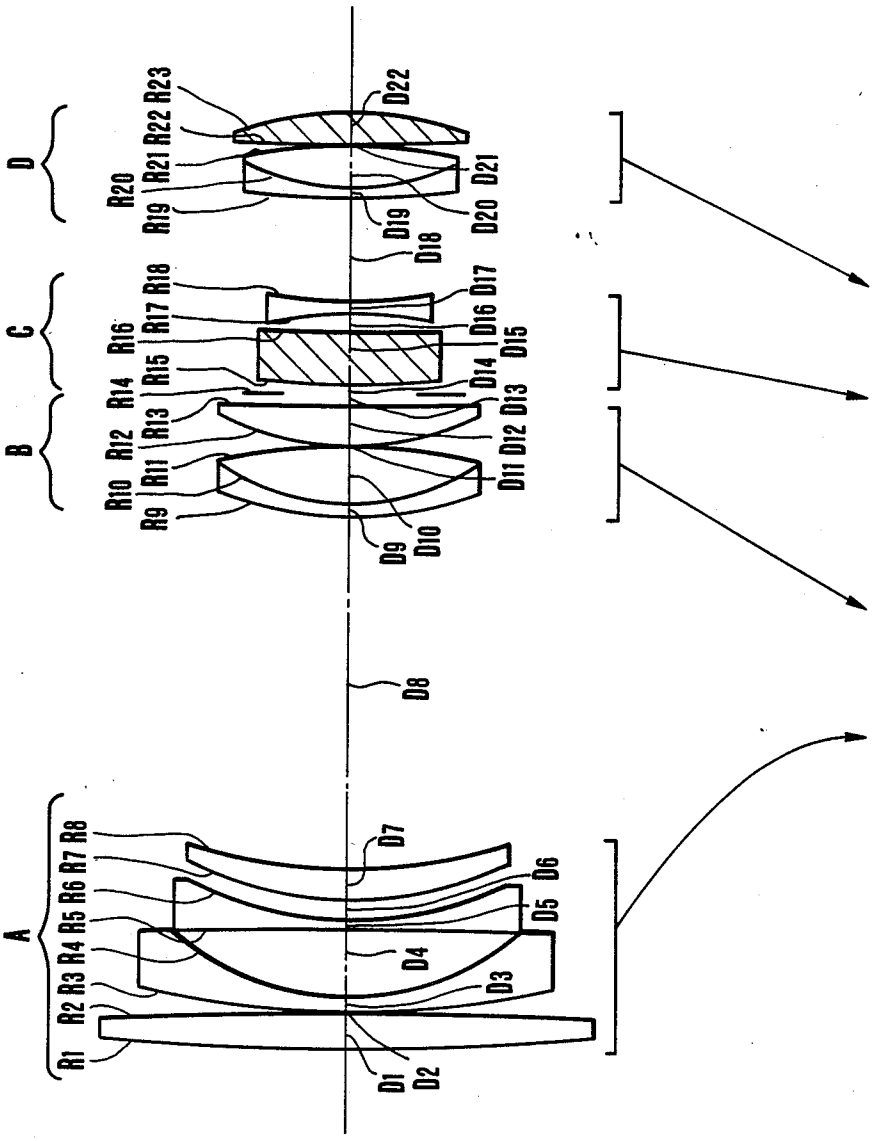
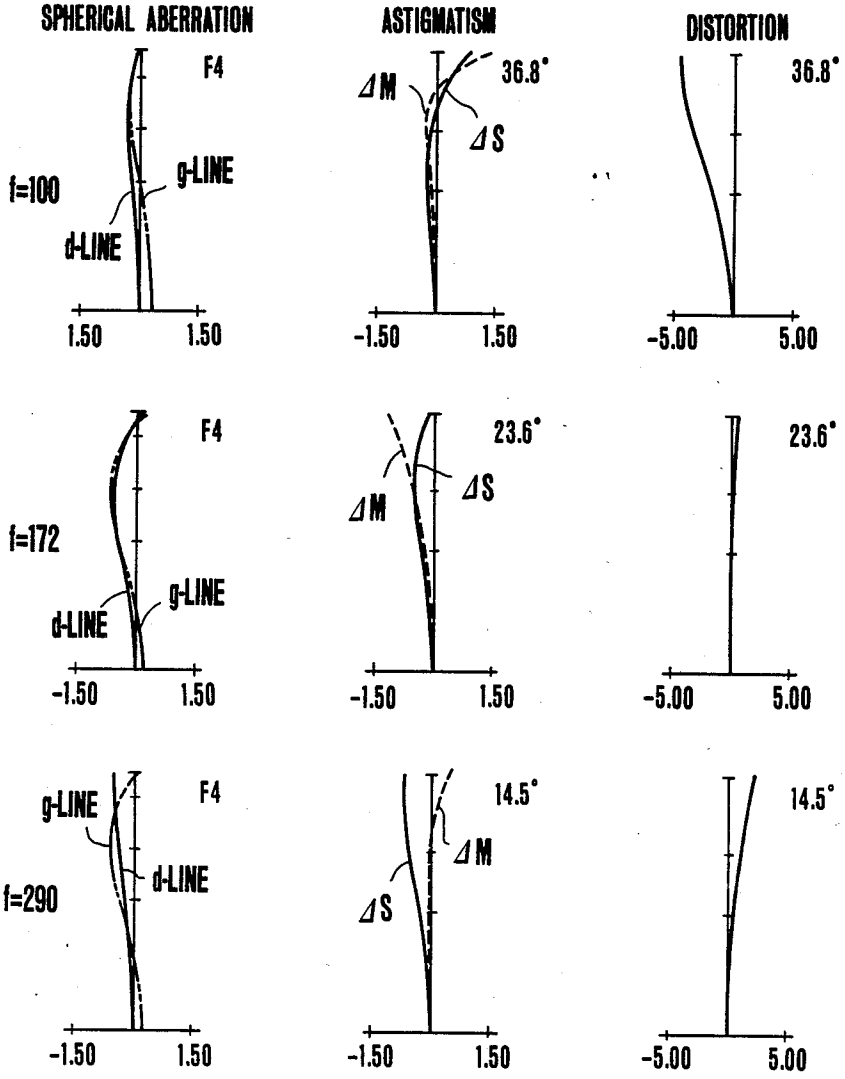

A
B
C
D
R1
R2
R3
R4
R5
R6
R7
R8
R9
R10
R11
R12
R13
R14
R15
R16
R17
R18
R19
R20
R21
R22
R23
D1
D2
D3
D4
D5
D6
D7
D8
D9
D10
D11
D12
D13
D14
D15
D16
D17
D18
D19
D20
D21
D22

FIG.12


SPHERICAL ABERRATION
ASTIGMATISM
DISTORTION
F4
f=100
g-LINE
d-LINE
1.50
1.50
ΔM
ΔS
36.8°
-1.50
1.50
36.8°
-5.00
5.00
F4
f=172
d-LINE
g-LINE
-1.50
1.50
23.6°
ΔM
ΔS
-1.50
1.50
23.6°
-5.00
5.00
g-LINE
F4
f=290
d-LINE
-1.50
1.50
14.5°
ΔM
ΔS
-1.50
1.50
14.5°
-5.00
5.00

OBJECTIVE OF VARIABLE FOCAL LENGTH

BACKGROUND OF THE INVENTION

1. Field of the Invention:

This invention relates to objectives of variable focal length, and more particularly to such an objective comprising a plurality of lens units of which the first and second counting from the front, i.e. objective side, are of negative and positive powers respectively, and are moved with variation of the amount of air separation therebetween to vary the focal length of the complete objective.

2. Description of the Prior Art:

In the objectives of variable focal length, besides the achievement of good correction of aberrations at a standard setting, it is generally required that the good correction of aberrations be maintained as stable as possible throughout entire range of variation of the focal length. To this end, all the movable lens units must be individually well corrected for spherical aberration, coma and astigmatism. So, each of such lens units is usually constructed with several lens elements.

Recently there have been an increasing demand for reducing the bulk and size of the varifocal objective and extending the range of the focal length. With respect to the former, in the type of varifocal objective comprising two or more lens units of which the first and second counting from the front are respectively negative and positive in the refractive power. The lens units are moved axially in differential relation to each other to vary the focal length of the complete objectives, so far as the paraxial region is concerned, either the power of each lens unit may be strengthened, or the interval between the principal points of the successive two of the lens units may be shortened. With respect to extending the range of variation of the focal length, so far as the paraxial region is concerned, either the power of each lens unit may be strengthened, or the total movement of the zoom lens unit may be elongated. For the paraxial region alone, a common means for achieving both a reduction in the size and an increase in the zoom ratio is found to strengthen the power of each zoom lens unit. For the intermediate and marginal zones, good stability of aberration correction is realized when the number of constituent lenses in each unit is increased in order to strengthen the power of the unit. Another method of strengthening the power of each unit is to increase the surface curvatures of each constituent lens. For this purpose, the minimum acceptable center thickness of the convex lens, or the minimum acceptable air separation of the concave lens surface must be increased. In either case, the overall thickness of each lens unit has to be increased, with the result that it becomes difficult to achieve a much-desired reduction of the physical length of the complete objective. Also, for a given value of the physical length, the longer the overall thickness of each lens unit, the shorter the total movement of the zoom lens unit. A much-desired increase in the zoom ratio becomes difficult to achieve.

In this connection, it should be pointed out that in the above-identified zoom lens unit, positive second lens unit often has the strongest power among all the lens units, thus contributing to a large proportion of the zoom ratio. If a reduction in size is attempted by further strengthening the power of the second lens unit, the necessary number of its constituent lenses increases. Concomitantly, its over all thickness tends to increase objectionably.

The thickness of last lens unit which increases due to the increase in the number of lenses also gives rise to a problem, i.e. if a flippable mirror or a beam splitter is positioned in a space between the rear vertex of the last lens unit and an image plane, a sufficiently large space cannot often be created. Such a vicious circle has placed a limitation on the reduction of the size and the increase of the range of variation of the focal length insofar as any usual homogenous medium lens system is adopted.

As a specific example, suppose a two-unit objective of variable focal length whose negative first and positive second units are moved with decreasing air separations therebetween as when zooming from the wide angle to the telephoto side is designed with an aim to reduce the total length of the entire system from the front vertex to the image plane. Such a design may be achieved by relying on the method of strengthening the power of the second lens unit in combination with shortening of the interval between the principal points of the first and second units. Then, increase of the power of the positive second unit calls for an increase in the necessary number of its constituent lenses to properly correct all aberrations therein itself. This involves an increase of the overall thickness of the second lens unit. Therefore, the principal point interval has to be increased. For this reason, this militates against a decrease in the total length of the entire system.

Such an increase of the overall thickness of the second lens unit has produced another problem. Since it is the last lens unit, for, as a flippable mirror or a prism occupies a space between the rear vertex of the second or last lens unit and the image plane, a somewhat long lens back is required. It is impossible to keep it at the minimum acceptable value.

Meanwhile, using the method of strengthening the power of each lens unit in shortening the total length of the complete objective of variable focal length makes correction of the Petzval sum difficult.

Taking an example of the two-unit objective whose first and second lens units counting from the front are negative and positive in power respectively. The focal length f of the entire system can be expressed by $f=f_1\times\beta_2$ where f_1 is the focal length of the negative first lens unit, and β_2 is the image magnification. Therefore, even for the same value of image magnification, whichever focal length of the positive second lens unit is shorter, the total length of the entire system can be shortened even more. To use this rule without sacrificing the preservation of the total zooming movements of the positive first and negative second lens units, the second lens unit has to be constructed in the telephoto form with such a power distribution that the principal point is brought farther ahead by increasing the tendency to the second lens unit to be of the telephoto type. So, an attempt to shorten the total length by this method results in a large negative value of the Petzval sum. This implies that the curvature of field is over-corrected.

Further, if the Petzval sum is corrected by lowering the refractive index of the convex lens, or by combining positive and negative lenses of strong power, the spherical aberration is increased very much and very large higher order aberrations are produced. Thus it becomes impossible to achieve good stability of aberration correction throughout the entire range of variation of the

focal length. It should be recognized that the reduction of the bulk and size of the objective of variable focal length and the good correction of the Petzval sum are contradictorily related to each other.

SUMMARY OF THE INVENTION

An object of the present invention is to eliminate the above-described drawbacks of the prior art, and to provide an objective of variable focal length which enables its bulk and size to be reduced with an increase in the range of variation of the focal length, while still permitting good stability of aberration correction to be achieved throughout the extended range of variation of the focal length.

Another object is to provide an objective of variable focal length which is amenable to easy assembling and adjusting techniques.

To achieve these objects, according to the present invention applied to the objective of variable focal length comprising a plurality of lens units of which the first counting from front, i.e. objective side, is of negative power and the second is of positive power, the first and second lens units being moved with varying air separations therebetween to vary the focal length of the entire system, at least one of the lens units is included with at least one refractive index distribution type lens.

The above-stated refractive index distribution type lens has a refractive index pattern along either the radius or the optical axis thereof (hereinafter referred to as "radial" or "axial" type, respectively). Both patterns of the radial and axial types can also take place in a single lens. Further, the radial type pattern has two directional aspects, one of which is to decrease the refractive index as the height from the optical axis increases, (hereinafter referred to as "positive gradient" power), and the other of which is to increase as the height increases (hereinafter referred to as "negative gradient" power).

As has been described above, the objective constituting the present invention has a feature that at least the second lens unit is made up by using at least one refractive index distribution type lens. Accordingly, it is possible possible to properly correct aberrations without involving any increase in the number of constituent lenses. Thus, a great reduction of the bulk and size and weight can be achieved. Further improved results can be attained when one or more of the lens units other than the second one is designed with the use of one or more of the refractive index distribution type lens. Again, the refractive index distribution type lens can take any form. So, when its surface curvature, focal length and refractive index gradient are controlled, the lens can embody a wide variety of capabilities. By selecting one or more of the lens units for employing such a lens and by arranging it in a desired position, a wide variety of forms of the lens system can be obtained.

BRIEF DESCRIPTION OF THE DRAWINGS

Odd-numbered FIGS. **1** to **11** are longitudinal section views of Examples 1 to 6 of specific objectives of the invention.

Even-numbered FIGS. **2** to **12** are graphic representations constituting the aberrations of the lenses of the present odd-numbered FIGS. **1** to **11** in three different focal length positions.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIGS. **1** and **2** illustrates an example of a specific objective constituting the present invention. In FIG. **1**, Ri(i=1, 2, 3, . . .) represents the i-th surface counting from front, Di(i=1, 2, 3, . . .) represents the axial thickness or air separation between the i-th and (i+1)th surfaces counting from front, and A and B represent the first and second lens units respectively, whose motions during zooming are roughly depicted by respective arrow-headed curves.

The aberration curves represent the spherical aberration, astigmatism and distortion when the focal length is f=100 mm, 138.9 mm, or 188.4 mm. The spherical aberration for spectral g-line or d-line is labelled g or d respectively, and S and M indicate the astigmatisms in the sagittal and meridional planes respectively.

The numerical data in accordance with which the objective of FIG. **1** can be constructed are listed in the following Tables 1-1 and 1-2, and the values of the coefficients of the terms of a refractive index distribution function for the used refractive index distribution type lens are listed in the following Table 1-3. In Table 1-1, f is the focal length, FNO is the F≠number, 2 w is the total image angle, Ri(i=1, 2, 3, . . .) is the radius of curvature of the i-th surface counting from front with the convex curvature toward the front being taken as positive, and the concave curvature as negative. Also, Di(i=1, 2, 3, . . .) is the axial thickness or air separation between the i-th and (i+1)th surfaces counting from front. Ni and Vi(i=1, 2, 3, . . .) are refractive index and Abbe number of the i-th lens counting from front respectively. Further, a refractive index distribution function for the radial type lens at the i-th place counting from front in terms of the height h from the optical axis can be expressed by the following formula:

$$Ni(h)=N_0+N_1h^2+N_2h^4+N_3h^6+N_4h^8+N_5h^{10}+\ldots \quad (1)$$

where N_O represents the value of refractive index on the axis, and N_1, N_2, N_3 . . . are the coefficients. The values for the g-line and d-line of the N_O and the coefficients are listed in Table 1-3. Table 1-2 shows the axial air separations between the lens units A and B during varying the focal length.

The objective of FIG. **1** has features which are described in detail below. This objective is constructed with, from front to rear, a negative first lens unit A and positive second lens unit B. As the focal length varies from the shortest or wide angle to the longest or telephoto side, the lens units A and B are moved axially while their air separation is shortened. The second lens unit B is constructed with, from front to rear, a positive radial gradient type lens defined by surfaces R7 and R8, and a negative radial gradient type lens defined by surfaces R9 and R10.

As the front lens R7, R8 in the positive second lens unit B has such a refractive index pattern that the refractive index becomes progressively lower as the distance in a perpendicular direction to the optical axis increases from the optical axis to the margin, the refractive index distribution coefficients N_1 and N_2 have negative values, or $N_1<0$, $N_2<0$. Such a refractive index distribution is used for correcting the spherical aberration of the positive lens R7, R8, since this lens, if of a homogeneous medium, would produce large residual

spherical aberration. That is, when the conditions or features $N_1<0$ and $N_2<0$ are satisfied, the refractive index pattern on the front or convex surface R7 of that positive lens can be made progressively lower from the optical axis to the marginal zone. Consequently that the spherical aberration which would otherwise be under-corrected as usual can be corrected toward the opposite direction. Because $N_2<0$, the third-order spherical aberration due to the positive gradient of refractive index in the medium of the lens is increased in a direction to be under-corrected. When this aberration is balanced with the aforesaid one of the front surface, good correction of spherical aberration and coma can be achieved.

Another advantage arising from $N_1<0$ is that because the medium of the lens gets a positive power $\phi(=-2NID)$, it shares the required power for the positive lens with its surface curvatures R7 and R8. This permits these curvatures to be weakened with a reduction of aberrations. Further, because the power of the positive or front lens can be strengthened, it is possible to increase the tendency of the second lens unit to be of the telephoto type.

With respect to the rear lens R9, R10 in the second lens unit B though of the convex form, because of its refractive index pattern, its refractive index becomes progressively higher with an increase in the height from the optical axis, and gets a negative power. When features $N_1<0$ and $N_2>0$ are satisfied, distortion in the wide angle side, and astigmatism in the wide angle and telephoto sides are well corrected. Further, the feature or $N_1>0$ implies that the negative power of the rear part of the second lens unit B is strengthened. This contributes to an increase in the tendency to the telephoto type. Another advantage is that as rays of light pass through the interior of the rear lens, over-corrected spherical aberration is produced particularly on the telephoto side, cancelling the residual under-corrected spherical aberration of the front lens R7, R8.

The use of such refractive index distribution type lenses in the objective of the invention produce additional advantages which are explained below.

Compared with the conventional second lens unit which usually requires five or more lenses provided that the conventional objective is of the same type as that of the objective of the invention, the positive second lens unit of the invention is constructed with only two lenses. Therefore, a great reduction of the weight and size has been achieved. Also, because the necessary number of lenses is greatly reduced, despite the fact that it is customary to assign very severe tolerances of the air separations and decentering to the second lens unit, the assembling and adjusting operations are facilitated. Also, the second lens unit B is used for correcting spherical aberrations in the telephoto positions, distortion in the wide angle positions, and astigmatism over the entire range of focal length.

The front and rear parts of the positive second lens unit B are both provided with the positive and negative gradient powers in the media thereof respectively. Consequently, the positive power of the front part of the positive second lens unit B and the negative power of the rear part can both be strengthened. Therefore, the tendency to the telephoto nature of the positive second lens unit B can be strengthened to bring the principal point farther ahead. Because the interval between the principal points of the negative first lens unit A and the positive second lens unit B can be shortened, and further the focal length of the positive second lens unit can be decreased, it made possible to achieve a great reduction of the total length of the entire system. Also, because the number of constituent lenses is so much reduced that the overall thickness of the second lens unit B can be held to a minimum, a sufficiently large lens back on the wide angle side can be preserved.

While the use of the method of strengthening the negative power of the rear part of the positive second lens unit to reduce the size of such an objective of variable focal length, as in the present invention, usually results in extreme over-correction of curvature of field, it is possible to avoid the fall of the curvature of field to over-correction by using the refractive index distribution type lens.

TABLE 1-1

f = 100–190 mm FNO = 4 2ω = 62°–35.1°

Radius of Curvature	Axial Thickness or Air Separation	Refractive Index	Abbe Number
R1 = 88.072	D1 = 5.28	N1 = 1.65844	ν1 = 50.9
R2 = 54.302	D2 = 25.83		
R3 = −640.871	D3 = 4.72	N2 = 1.65844	ν2 = 50.9
R4 = 124.363	D4 = 7.46		
R5 = 87.335	D5 = 8.56	N3 = 1.72825	ν3 = 28.5
R6 = 181.835	D6 = variable		
R7 = 81.535	D7 = 27.15	N4 = N4 (h)	
R8 = 150.326	D8 = 28.76		
R9 = −2292.783	D9 = 9.29	N5 = N5 (h)	
R10 = −275.983			

TABLE 1-2

	f		
Di	100	140	190
D6	95.8284	45.6001	12.5552

TABLE 1-3

Ni ( )	λ	N_0	N_1	N_2	N_3
N4 (h)	d	1.60311	-1.08471×10^{-4}	-1.92180×10^{-8}	-5.90890×10^{-12}
	g	1.61539	-1.07847×10^{-4}	-1.89218×10^{-8}	-5.81400×10^{-12}
N5 (h)	d	1.59270	1.29581×10^{-4}	1.05090×10^{-7}	6.49298×10^{-11}
	g	1.61455	1.37053×10^{-4}	1.07045×10^{-7}	6.54842×10^{-11}

FIG. 3 illustrates another example of the objective of variable focal length according to the invention whose aberrations in the focal length positions of f=100 mm, 150 mm and 195 mm are shown in FIG. 4. This objective can be constructed in accordance with the numerical data given in Tables 2-1 to 2-3 where an equation for the refractive index distribution Ni(x) of the i-th lens which is of the axial type in terms of the axial distance, x, measured from the front vertex can be expressed by the following formula:

$$Ni(x)=N_0+N_1x+N_2x^2+N_3x^3+N_4x^4+\ldots \quad (2)$$

where N_0 is the refractive index at the front vertex, and N_1, N_2, N_3, . . . are refractive index distribution coefficients.

The objective of FIG. 3 comprises, from front to rear, a negative first lens unit A, a positive second lens unit B and positive third lens unit C. All three units being axially moved with the air separations between the units A and B and between the units B and C both being decreased as the focal length of the entire system is increased from the wide angle to the telephoto side.

The positive second lens unit B is included with a frontmost lens defined by surfaces R7 and R8 and a rearmost lens defined by surfaces R14 and R15. Both lenses are of the axial type and have such a pattern that the refractive index becomes progressively lower as the distance from the front to rear increases.

The frontmost lens R7, R8 has a positive power, and, because of its lowering refractive indices from the front surface to the rear surface, affects that spherical aberration which would otherwise usually result in large under-correction from the front surface of the unit B tends toward over-correction. Also, the astigmatism which would otherwise result in under-correction when in the wide angle and telephoto positions tends toward over-correction.

The rearmost lens R14. R15 has a positive power. Because of its lowering refractive indices from the front to the rear surface, it is able to correct the higher order spherical aberrations which have been too over-corrected by the positive frontmost lens R7, R8.

TABLE 2-1

f = 100–195.0 mm FNO = 4.5 2ω = 46°–24.6°

Radius of Curvature	Axial Thickness or Air Separation	Refractive Index	Abbe Number
R1 = 131.851	D1 = 4.31	N1 = 1.83400	ν1 = 37.2
R2 = 53.473	D2 = 15.72		
R3 = −346.320	D3 = 2.94	N2 = 1.62280	ν2 = 57.0
R4 = 352.665	D4 = 4.55		
R5 = 83.175	D5 = 6.86	N3 = 1.80518	ν3 = 25.4
R6 = 181.040	D6 = variable		
R7 = 72.542	D7 = 9.39	N4 = N4 (x)	
R8 = −356.984	D8 = 0.20		
R9 = 76.167	D9 = 5.88	N5 = 1.49831	ν5 = 65.0
R10 = 273.898	D10 = 9.71		
R11 = 190.622	D11 = 3.73	N6 = 1.84666	ν6 = 23.9
R12 = 46.571	D12 = 8.24		
R13 = diaphragm	D13 = 3.53		
R14 = 417.367	D14 = 7.84	N7 = N7 (x)	
R15 = −81.444	D15 = variable		
R16 = −3493.888	D16 = 4.71	N8 = 1.60562	ν8 = 43.7
R17 = −73.601	D17 = 2.53		
R18 = −80.767	D18 = 2.75	N9 = 1.62041	ν9 = 60.3
R19 = 36.911	D19 = 2.33		
R20 = 42.473	D20 = 4.71	N10 = 1.67000	ν10 = 57.4
R21 = 148.808	D21 = variable		
R22 = movable stopper			

TABLE 2-2

Di	f = 100	f = 150	f = 195
D6	61.515	21.617	2.328
D15	15.097	8.218	4.888
D21	3.628	18.827	31.373

TABLE 2-3

Ni ( )	λ	N_0	N_1	N_2
N4 (x)	d	1.75500	-2.18362×10^{-2}	-5.31731×10^{-15}
	g	1.77296	-2.27914×10^{-2}	-3.44476×10^{-5}
N7 (x)	d	1.67000	-1.05404×10^{-2}	-3.12351×10^{-5}
	g	1.68449	-1.09583×10^{-2}	-1.36816×10^{-5}

FIG. 5 illustrates a third specific example of the objective whose spherical aberrations for the spectral g- and d-lines, astigmatisms in the sagittal and meridonal planes S and M and distortion in the focal length positions of f=100 mm, 138.9 mm and 188.4 mm are shown in FIG. 6. The objective can be constructed in accordance with the numerical data given in Tables 3–1 to 3–3 for the radii of curvature, R, the axial thicknesses or air separations, D, and the refractive indices N and Abbe numbers V of the various lens elements. The subscripts are subscripts numbered consecutively from front to rear, and the plus and minus values of R indicate convex and concave surfaces relative to the front respectively. The refractive index distribution in the i-th lens counting from the front which is of the radial type can be expressed by the equation (1).

The objective of FIG. 5 comprises, from front to rear, a negative first lens unit A and a positive second lens unit B. Both lens units are axially moved with the air separation therebetween being decreased as the focal length of the entire system is varied from the shortest to the longest value. The front unit A consists of, from front to rear, a negative meniscus lens of forward convexity defined by surfaces R1 and R2 and a positive radial gradient type lens defined by surfaces R3 and R4. The rear unit B has its constituent lenses all made of homogeneous media.

The refractive index distribution type lens R3, R4 has such a pattern that the refractive index varies at a small rate in the paraxial region and drops steeply in the marginal zone. As the coefficient N_2 of the equation N(h) is $N_2<0$, it is able to correct barrel type distortion in the wide angle positions to a minimum.

Also in the telephoto positions, the spherical aberration produced from the second surface R2 of the frontmost or negative meniscus lens of the front unit A, as is largely over-corrected, is corrected to the opposite direction, when rays of light pass through the interior of the refractive index distribution type lens. Further, the coma in the telephoto positions is affected toward over-correction when the rays of light pass through the interior of that lens.

For this reason, the negative first lens unit which was heretofore constructed with three or four lenses can be constructed with only two lenses. A good stability of correction of the various aberration throughout the entire range is still achieved.

The use of the refractive index distribution type lens in the objective gives additional advantages which are explained below.

Because the negative first lens unit A, which is bulky and heavy as a rule, can be constructed with a greatly reduced number of constituent lenses, a great reduction in the weight and a great advance in compactness have been achieved. Moreover, this is accompanied with a possibility of shortening the total length of the entire system. Also, the effective diameter of the front unit necessary to the off-axis light pencil can be minimized. Further, concerning the aberration correction, barrel type distortion in the wide angle positions and spherical aberration and coma in the telephoto positions can be held to a minimum.

TABLE 3-1

f = 100–188.4 mm FNO = 4 2ω = 62°–35.4°

Radius of Curvature	Axial Thickness or Air Separation	Refractive Index	Abbe Number
R1 = 74.159	D1 = 5.28	N1 = 1.65160	ν1 = 58.6
R2 = 43.253	D2 = 36.49		
R3 = 828.363	D3 = 17.14	N2 = N2 (h)	
R4 = 297.760	D4 = variable		
R5 = 145.269	D5 = 8.00	N3 = 1.62230	ν3 = 53.2
R6 = −420.377	D6 = 0.28		
R7 = 53.378	D7 = 8.08	N4 = 1.60311	ν4 = 60.7
R8 = 136.821	D8 = 7.64		
R9 = 177.608	D9 = 11.44	N5 = 1.60311	ν5 = 60.7
R10 = 644.746	D10 = 2.09		
R11 = −262.999	D11 = 5.31	N6 = 1.80518	ν6 = 25.4
R12 = 52.185	D12 = 6.96		
R13 = 186.667	D13 = 7.75	N7 = 1.67270	ν7 = 32.1
R14 = −104.910			

TABLE 3-2

	f		
Di	100.0	138.9	188.4
D4	90.4271	41.1932	7.9396

TABLE 3-3

Ni ( )	λ	N_0	N_1	N_2
N2 (h)	d	1.64769	-3.379851×10^{-5}	-1.772131×10^{-8}
	g	1.67252	-3.731571×10^{-5}	-1.576371×10^{-8}

N_3	N_4	N_5
$-7.347091 \times 10^{-12}$	3.960301×10^{-15}	$-3.032661 \times 10^{-18}$
$-1.051681 \times 10^{-11}$	5.477601×10^{-15}	$-3.078831 \times 10^{-18}$

FIG. 7 illustrates a fourth specific example of the objective according to the invention whose aberrations in the focal length positions of f=100 mm, 171 mm and 287 mm are shown in FIG. 8. This objective can be constructed in accordance with the numerical data given in Tables 4–1 to 4–3, where the refractive index distribution is expressed by the equation (1).

The objective of FIG. 7 comprises, from front to rear, a negative first lens unit A, a positive second lens unit B, a negative third lens unit C and a positive fourth lens unit D. All of the lens units are axially moved with the air separations between the units A and B and between the units C and D being decreased, and the air separation between the units B and C being increased, as the focal length of the entire system is increased from the shortest to the longest value. The negative first lens unit A is provided with a positive radial gradient type meniscus lens defined by surfaces R1 and R2 at the frontmost position.

With the first lens unit of negative power, when the angular field is so widened as in the objective of the invention, the negative first lens unit produces large barrel type distortion in the wide angle positions. This has constituted an obstacle to aberration correction. In the objective of the invention, however, as the frontmost or negative meniscus lens of the negative first lens unit A, use is made of a positive radial gradient type lens having such a pattern that the refractive index in the marginal zone is smaller than that in the paraxial region. Accordingly, barrel type distortion produced from the first lens unit A in the wide angle positions is reduced.

Meanwhile, the second surface R2 of the negative meniscus lens of the negative first lens unit A usually produces large over-corrected spherical aberration. The impartment of such a refractive index pattern thereto reduces the tendency of the spherical aberration to be over-corrected, since the refractive index on the concave rear surface R2 of the negative meniscus lens becomes progressively smaller as the height from the optical axis increases.

The impartment of such a refractive index distribution also causes the rays of light in passing through the interior of the negative meniscus lens to produce spherical aberration and coma in the opposite direction to that in which they are produced from the second surface of the negative meniscus lens. Alternatively, it produces under-corrected spherical aberration and coma, thus producing an aberration correcting effect.

Therefore, it is possible to achieve an objective corrected for good stability of the various aberrations throughout the entire range of variation of the focal length.

The use of the refractive index distribution type lens in the objective provides additional advantages. The number of constituent lenses for the negative first lens unit of the objective of the type described above, which was heretofore usually four or more, is reduced to as few as three. This leads to a reduction of the weight and a decrease of the overall thickness of the negative first lens unit. Therefore, it is possible to shorten the total length of the entire system.

Also, barrel type distortion in the wide angle positions is held to a minimum, and the spherical aberration and coma in the telephoto positions can be properly corrected.

The above-described improved results can be attained particularly when the condition that $N_2<0$ where N_2 is the coefficient in the equation for the refractive index distribution N(h) is satisfied.

TABLE 4-1

f = 100–287 mm F.NO. = 4.0 2ω = 73.6°–29.3°

Radius of Curvature	Axial Thickness or Air Separation	Refractive Index	Abbe Number
R1 = 177.986	D1 = 4.71	N1 = N1 (h)	
R2 = 99.569	D2 = 30.58		
R3 = −1404.275	D3 = 5.16	N2 = 1.71300	ν2 = 53.8
R4 = 117.710	D4 = 9.34		
R5 = 122.243	D5 = 12.28	N3 = 1.80518	ν3 = 25.4
R6 = 195.281	D6 = variable		
R7 = 154.012	D7 = 3.53	N4 = 1.80518	ν4 = 25.4
R8 = 79.887	D8 = 22.54	N5 = 1.62299	ν5 = 58.2
R9 = −309.070	D9 = 1.60		
R10 = 117.912	D10 = 13.58	N6 = 1.62299	ν6 = 58.2
R11 = 1976.958	D11 = variable		
R12 = 493.901	D12 = 13.83	N7 = 1.74077	ν7 = 27.8
R13 = −67.733	D13 = 3.47	N8 = 1.77250	ν8 = 49.6
R14 = 130.479	D14 = 10.44		
R15 = −115.002	D15 = 4.09	N9 = 1.62299	ν9 = 58.2
R16 = 482.241	D16 = variable		
R17 = −3571.624	D17 = 11.95	N10 = 1.71300	ν10 = 53.8
R18 = −129.192	D18 = 1.84		
R19 = −2335.447	D19 = 3.25	N11 = 1.80518	ν11 = 25.4
R20 = 104.135	D20 = 25.87	N12 = 1.51633	ν12 = 64.1
R21 = −267.983	D21 = 1.64		
R22 = 268.367	D22 = 14.26	N13 = 1.62299	ν13 = 58.2
R23 = −399.312			

TABLE 4-2

	f		
Di	100	171	287
D6	139.78	54.43	10.50
D11	10.89	32.06	58.73
D16	37.27	21.94	2.50

TABLE 4-3

Ni ( )	λ	N_0	N_1	N_2
Ni (h)	d	1.60311	-4.27443×10^{-6}	-1.46649×10^{-9}
	g	1.61539	-2.78146×10^{-6}	-1.86272×10^{-9}
			N_3	N_4
			1.94216×10^{-13}	-1.74743×10^{-17}
			2.20268×10^{-13}	-1.64317×10^{-17}

FIG. 9 illustrates a fifth specific example of the objective of variable focal length according to the invention whose aberrations in the focal length positions of f = 100 mm, 170.8 mm and 286 mm are shown in FIG. 10. This objective can be constructed in accordance with the numerical data given in Tables 5-1 to 5-3 where the refractive index distribution of the axial type lens is expressed by the equation (2).

The objective of FIG. 9 comprises, from front to rear, a negative first lens unit A, a positive second lens unit B, a negative third lens unit C and a positive fourth lens unit D. All of the lens units are axially moved with the air separations between the units A and B and between the units C and D being decreased, and the air separation between the units B and C being increased, as the focal length of the entire system is increased from the shortest to the longest value. The negative first lens unit A is provided with a positive radial gradient type lens defined by surfaces R1 and R2 at the frontmost position and an axial type lens having increasing refractive indices from the front surface R3 to the rear surface R4 and positioned on the image side of the radial type lens.

In the known wide angle objective having a configuration similar to that of the objective of the invention in that the first lens unit is of negative power, much barrel type distortion is produced in the wide angle positions. Thus, the negative first lens unit has been considered as an obstacle to improve aberration correction. According to the present invention, the frontmost or negative meniscus lens in the negative first lens unit A is imparted with such a refractive index distribution that the refractive index in the marginal zone is smaller than that in the paraxial zone. The frontmost lens use has a positive radial gradient type lens so that the barrel type distortion, produced from the negative first lens unit A in the wide angle positions, is minimized.

Meanwhile, the second surface R2 of the frontmost or negative meniscus lens in the first lens unit A produces spherical aberration in a direction to be largely over-corrected. The co-existance of the above-stated refractive index distribution reduces the tendency of spherical aberration to be over-corrected, because the refractive index in the concave surface R2 of the negative meniscus lens decreases with increases in the height from the optical axis.

The impartment of such a refractive index distribution to the negative meniscus lens also causes the rays of light passing in the interior thereof to produce spherical aberration and coma in the opposite direction to that in which the second surface R2 of the negative meniscus lens produces them, or under-corrected ones, thus producing a correcting effect. It should be recognized that the above-described improvement in aberration correction are attained particularly when the condition of $N_2 < 0$ is satisfied where N_2 is the coefficient of the equation (1) for the refractive index distribution N(h).

The other or rearmost lens, defined by surfaces R3 and R4 in the negative first lens unit A, has such a refractive index distribution that the refractive index becomes progressively higher as the distance from the front surface to the rear surface increases. This affects the spherical aberration which has been too under-corrected by the frontmost or negative meniscus lens toward the direction of being over-corrected.

Therefore, it is possible to achieve an objective of variable focal length corrected for good stability of aberrations over the extended range of variation of the focal length.

TABLE 5-1

f = 100–286 mm FNO = 4 2ω = 75.4°–28.6°

Radius of Curvature	Axial Thickness or Air Separation	Refractive Index	Abbe Number
R1 = 208.122	D1 = 6.65	N1 = N1 (h)	
R2 = 119.274	D2 = 26.55		
R3 = −1601.647	D3 = 9.04	N2 = N2 (x)	
R4 = 193.189	D4 = variable		
R5 = 238.052	D5 = 4.24	N3 = 1.80518	ν3 = 25.4
R6 = 111.949	D6 = 22.27	N4 = 1.62299	ν4 = 58.2
R7 = −207.988	D7 = 10.15		
R8 = 94.430	D8 = 15.50	N5 = 1.62299	ν5 = 58.2
R9 = 440.545	D9 = variable		
R10 = 520.349	D10 = 11.96	N6 = 1.74077	ν6 = 27.8
R11 = −72.653	D11 = 3.44	N7 = 1.77250	ν7 = 49.6
R12 = 127.096	D12 = 9.59		
R13 = −100.777	D13 = 3.13	N8 = 1.62299	ν8 = 58.2
R14 = 1811.221	D14 = variable		
R15 = −606.224	D15 = 6.30	N9 = 1.71300	ν9 = 53.8
R16 = −134.670	D16 = 1.31		
R17 = −2417.433	D17 = 3.10	N10 = 1.80518	ν10 = 25.4
R18 = 103.456	D18 = 23.56	N11 = 1.51633	ν11 = 64.1
R19 = −199.361	D19 = 1.61		
R20 = 419.198	D20 = 17.53	N12 = 1.60300	ν12 = 65.5
R21 = −206.990			

TABLE 5-2

	f		
Di	100	170	286
D4	151.97	66.61	22.68
D9	8.9	30.05	56.72
D14	36.9	21.59	2.15

TABLE 5-3

Ni ( )	λ	N_0	N_1	N_2
N1 (h)	d	1.60311	3.21212×10^{-6}	-3.17685×10^{-9}
	g	1.61539	1.20257×10^{-6}	-2.07249×10^{-9}
N2 (x)	d	1.76200	8.48492×10^{-5}	1.98427×10^{-7}
	g	1.78633	-1.18722×10^{-3}	-1.10890×10^{-6}
			N_3	N_4
			3.91890×10^{-13}	-2.59985×10^{-17}
			8.60312×10^{-14}	2.56331×10^{-18}
			5.47972×10^{-10}	4.88103×10^{-12}
			-6.26883×10^{-9}	8.38526×10^{-12}

FIGS. 11 and 12 illustrate a sixth example of the objective of the invention comprising, from front to rear, a negative first lens unit A, a positive second lens unit B, a negative third lens unit C, and a positive fourth lens unit D. The first to fourth lens units A to D are moved axially with the air separations between the units A and B and between the units C and D being decreased. The air separation between the units B and C being increased as the focal length is increased from the shortest to the longest valve. As a result, the third and fourth lens units C and D each are included with a refractive index distribution type lens.

TABLE 6-1

(FIGS. 11 and 12)
F = 100-290 FNO. = 1:4.0 2ω = 73.7°-29°

R1 = 1189.52	D1 = 14.55	N1 = 1.51112	ν1 = 60.5
R2 = −1836.55	D2 = 0.69		
R3 = 371.24	D3 = 5.54	N2 = 1.71300	ν2 = 53.8
R4 = 98.64	D4 = 25.98		
R5 = 30639.98	D5 = 4.50	N3 = 1.71300	ν3 = 53.8
R6 = 151.14	D6 = 6.93		
R7 = 129.17	D7 = 12.82	N4 = 1.80518	ν4 = 25.4
R8 = 217.96	D8 = variable		
R9 = 155.05	D9 = 4.16	N5 = 1.80518	ν5 = 25.4
R10 = 81.38	D10 = 22.51	N6 = 1.62299	ν6 = 58.2
R11 = −296.65	D11 = 0.69		
R12 = 120.67	D12 = 13.85	N7 = 1.62299	ν7 = 58.2
R13 = 2012.36	D13 = variable		
R14 = diaphragm	D14 = 3.46		
R15 = ∞	D15 = 16.03	N8 (h)	
R16 = ∞	D16 = 10.26		
R17 = −102.15	D17 = 3.46	N9 = 1.61800	ν9 = 63.4
R18 = 143.62	D18 = variable		
R19 = 417.39	D19 = 4.16	N10 = 1.80518	ν10 = 25.4
R20 = 92.33	D20 = 15.59	N11 = 1.51633	ν11 = 64.1
R21 = −207.27	D21 = 0.69		
R22 = 767.88	D22 = 12.12	N12 (x)	
R23 = −135.71			

TABLE 6-2

f	100	172	290
D8	137.43	52.11	8.27
D13	5.36	27.15	53.84
D18	40.61	25.28	5.81

TABLE 6-3

$N8(h) = N_0 + N_1h^2 + N_2h^4 + N_3h^6$
$N12(x) = N_0 + N_1x + N_2x^2$

		N_0	N_1	N_2	N_3
N8 (h)	d	1.62	3.64450×10^{-5}	-7.43660×10^{-9}	3.68304×10^{-13}
	g	1.64209	3.25036×10^{-5}	-9.37109×10^{-9}	6.67792×10^{-13}
		N_0	N_1	N_2	
N12 (x)	d	1.81554	-1.38490×10^{-2}	5.39781×10^{-4}	
	g	1.83867	-1.54723×10^{-2}	6.18003×10^{-4}	

The advantages of the invention may be summarized as follows:

The number of constituent lenses for each of the lens units can be significantly reduced, enabling a great reduction of the weight and size to be achieved. The reduction of the number of constituent lenses of the positive second lens unit results in a reduction in its overall thickness. This leads to either or both of an increase of the total zooming movement of itself or any of the adjacent units and a reduction of the air separations between the second lens unit and any of the adjacent lens units. Therefore, it is very easy to achieve either or both of a great increase in the range of variation of the focal length and a great reduction of the total length of the entire system.

The use of at least one refractive index distribution type lens in either of the first and second lens units enables the interval between the principal points of the first and second lens units to be reduced. This leads to a decrease in the diameter of the first lens unit that admits of the off-axis light pencil. Therefore, the diameter of the outer lens barrel can be reduced. So, filters of smaller diameter become usable with the objective of the invention.

As for the aberrational problems, because each lens unit can be better corrected in itself than was heretofore possible, all the aberrations of the objective can be maintained more stable throughout the entire range of variation of the focal length. Because there is no necessity of using a compound-eye optical system, good image quality is preserved.

The reduction of the Petzval sum allows for an increase in the power of the positive second lens group. So, it becomes possible to shorten the physical length. Because the reduced Petzval sum is corrected by smaller surface curvatures or a gentler power arrangement than was heretofore required, the higher order aberrations can be reduced.

Ghosts which are very difficult to remove in the conventional objective can be significantly minimized due to the great reduction of the total number of lenses of the objective. From the same reason, as the light loss due to the surface reflection and internal absorption is reduced, the T-number can be made faster than was heretofore possible. The rapid reduction of the total number of lens surfaces implies that the cost of the multi-layer anti-reflection coatings is largely reduced. (The transmittance of the ordinary zoom lenses is not more than 90%, and, in the case of larger numbers of constituent lenses, it sometimes falls below 80%).

The assembling and adjusting operations are facilitated when the number of constituent lenses in each lens unit is reduced. In the past, it was impossible to build the zoom lens in ultra-small sized optical instruments such as sub-miniature cameras and gastrocameras, although there were urgent demands for it, since the total number of lenses of the complete zoom lens was very large, and the individual elements are very small in size. The use of the refractive index distribution type lens enables each lens unit to be constructed with only one or two lenses. So, the machining and assembling operations become far easier. Therely, it will be possible to install the zoom lens in the ultra-small sized optical instrument.

As has been described above, according to the present invention as applied to the two-unit objective of variable focal length whose first and second units are of negative and positive powers respectively, use is made of a refractive index distribution type lens made of a homogeneous medium in at least one of the two lens units. A great advance in the imaging performance, the reduction of the weight, the compactness, and further the zoom ratio have been achieved. This makes it possible to significantly reduce the complexity of structure of the operating mechanism for such a type of objective.

What is claimed is:

1. An objective of variable focal length comprising a plurality of lens units, of which the first lens unit, counting from an object side, has a negative refractive power and a second unit has a positive refractive power, at least said first and said second lens units being moved axially with their air separation being varied to vary the focal length of the entire system, whereby at least one of said lens units includes at least one refractive index distribution type lens varying in refractive index that is arranged on a common optical axis with said plurality of lens units, wherein said refractive index distribution type lens comprises a distribution of refractive indexes so that a change in aberrations due to a variation of the objective focal length is restricted.

2. An objective according to claim 1, wherein said refractive index distribution type lens is positioned in said first lens unit.

3. An objective according to claim 2, wherein said refractive index distribution type lens in said first lens unit has such a refractive index distribution that the refractive index becomes progressively lower as the height from the optical axis increases.

4. An objective according to claim 3, satisfying the following condition that, as the refractive index distribution in said refractive index distribution type lens is expressed by $N(h)=N_0+N_1h^2+N_2h^4+N_3h^6...$ where h is the height from the optical axis, N_0 is the refractive index on the optical axis, and N_1, N_2, N_3, . . . are the coefficients, $N_1<0$.

5. An objective according to claim 4, which satisfies the condition $N_2<0$.

6. An objective according to claim 5, wherein said refractive index distribution type lens is a negative lens having a concave surface on the image side.

7. An objective according to claim 6, wherein said negative lens is of a meniscus shape.

8. An objective according to claim 2, wherein said refractive index distribution type lens in said first lens unit has such a refractive index distribution that the refractive index becomes progressively higher as the axial distance from the front surface thereof increases.

9. An objective according to claim 1, wherein said refractive index distribution type lens is positioned in said second lens unit.

10. An objective according to claim 9, wherein said second lens unit includes a frontmost portion with a refractive index distribution type lens having a front convex surface in which the refractive index becomes progressively lower as the height from the optical axis increases.

11. An objective according to claim 10, wherein said refractive index distribution type lens has a refractive index that is variable in the optical axis direction.

12. An objective according to claim 10, satisfying the condition that as the refractive index distribution in said refractive index distribution type lens is expressed by $N(h)=N_0+N_1h^2+N_2h^4+N_3h^6+...$ where h is the height from the optical axis, N_0 is the refractive index in the paraxial region, and N_1, N_2, N_3, . . . are the coefficients, $N_1<0$ and $N_2<0$.

13. An objective according to claim 9, wherein said second lens unit includes a rearmost portion with a refractive index distribution type lens in which the refractive index becomes progressively higher as the height from the optical axis increases.

14. An objective according to claim 13, satisfying the condition that as the refractive index distribution in said refractive index distribution type lens is expressed by $N(h)=N_0+N_1h^2+N_2h^4+N_3h^6+...$ where h is the height from the optical axis, N_0 is the refractive index in the paraxial region, and N_1, N_2, N_3, . . . are the coefficients, and $N_1>0$.

15. An objective according to claim 14, which satisfies the condition $N_2>0$.

16. An objective according to claim 15, wherein said refractive index distribution type lens has a negative power.

17. An objective according to claim 1, further comprising a third lens unit which comprises another refractive index distribution type lens and has a negative refractive power.

18. An objective according to claim 1, further comprising a third lens unit which has a negative refractive power and a fourth lens unit which comprises another refractive index distribution type lens and has a positive refractive power.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 4,907,866 Page 1 of 3

DATED : March 13, 1990

INVENTOR(S) : NOZOMU KITAGISHI, ET AL.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 1

Line 17, "the" should read --a--.

Line 19, before "entire", insert --the--.

Line 24, "have" should read --has--.

Line 32, "objectives, so" should read --objectives. So--.

Column 2

Line 1, "over all" should read --overall--.

Line 23, "increase" should read --an increase--.

Line 42, Q: "Taking an example of the" should read --consider for example a--.

Column 3:

Line 45, "possible" should be deleted.

Line 51, "lens." should read --lenses.--

Line 63, "of the" should read --constituting the present--.

Line 66, "constituting" should read --of--.

Line 67, "present" should be deleted.

Column 4

Line 25, "F≠ number," should read --F number,--.

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 4,907,866
DATED : March 13, 1990
INVENTOR(S) : NOZOMU KITAGISHI, ET AL.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 5

Line 29, "$N_1 < 0$" should read --$N_1 > 0$--.

Column 7

Line 14, "frontmost" should read --front--.

Column 8

Line 50, "aberration" should read --aberrations--.

Column 11

Line 43, "use" should read --used--.

Line 63, "improvement" should read --improvements--.

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 4,907,866

DATED : March 13, 1990

INVENTOR(S) : NOZOMU KITAGISHI, ET AL.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 12

Line 65, "being" should read --is--.

Line 66, "valve." should read --value--.

Column 14

Line 20, "From" should read --For--.

Line 40, "Therely," should read --Thereby,--.

Signed and Sealed this

Third Day of November, 1992

Attest:

DOUGLAS B. COMER

Attesting Officer

Acting Commissioner of Patents and Trademarks

United States Patent [19]

Kudo et al.

[11] **Patent Number: 4,892,398**

[45] **Date of Patent: Jan. 9, 1990**

[54] **TRIPLET TYPE OBJECTIVE WITH A DIAPHRAGM ARRANGED BEHIND THE LENS SYSTEM**

[75] Inventors: **Yoshinobu Kudo; Akira Fukushima; Kazuo Kimura; Mitsuko Date,** all of Osaka, Japan

[73] Assignee: **Minolta Camera Kabushiki Kaisha,** Osaka, Japan

[21] Appl. No.: **272,759**

[22] Filed: **Nov. 17, 1988**

[30] **Foreign Application Priority Data**

Nov. 18, 1987 [JP] Japan 62-291479

[51] **Int. Cl.**[4] **G02B 9/14**

[52] **U.S. Cl.** **350/475;** 350/449; 350/432

[58] **Field of Search** 350/474, 475, 449, 432

[56] **References Cited**

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Primary Examiner—P. M. Dzierzynski

Attorney, Agent, or Firm—Price, Gess & Ubell

[57] **ABSTRACT**

In a triplet type objective for a compact lens shutter camera with a diaphragm arranged behind the lens system, the first and the second lens elements are formed of plastic and the third lens element is formed of glass, so that it is advantageous in manufacturing cost and weight. Therefore, an F No. of the objective is small and aberrations, for example astigmatic difference, are corrected well.

3 Claims, 3 Drawing Sheets

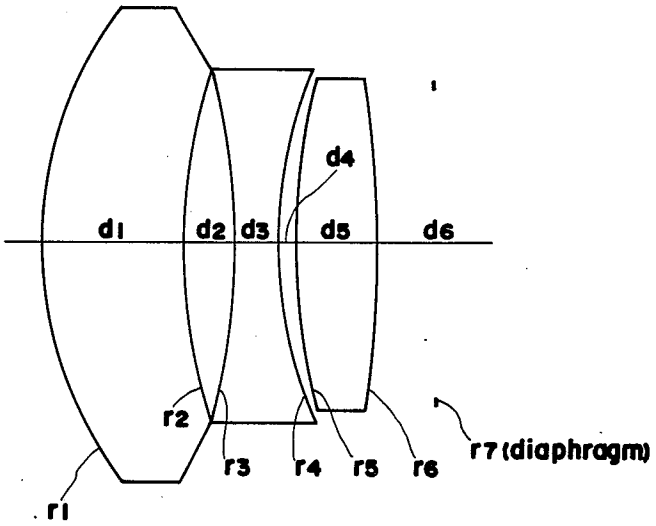


FIG. 1

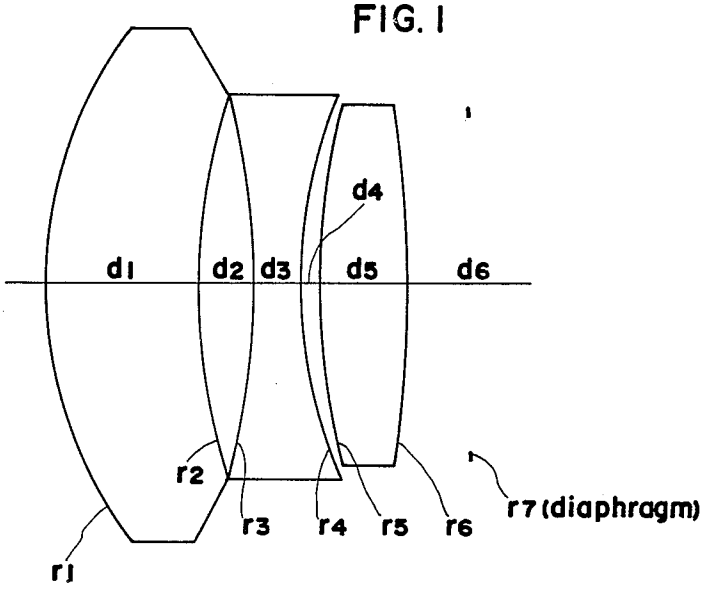


FIG.2A

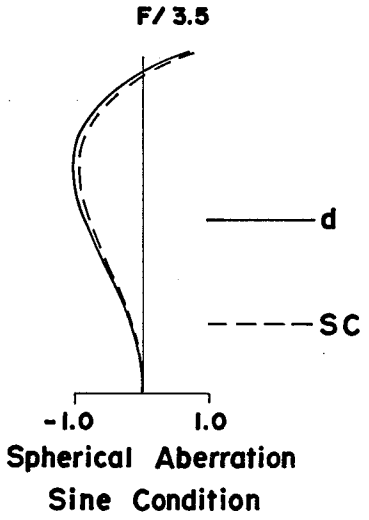


FIG.2B

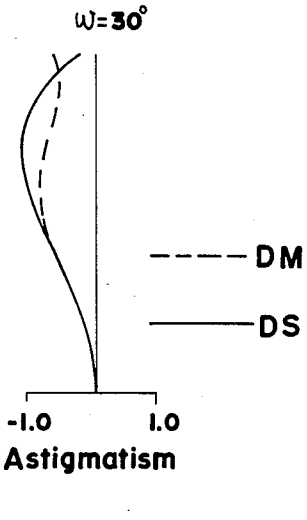


FIG.2C

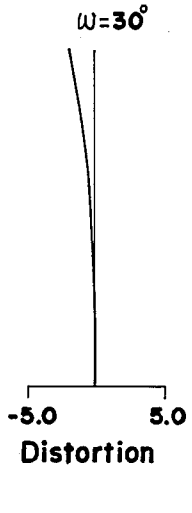
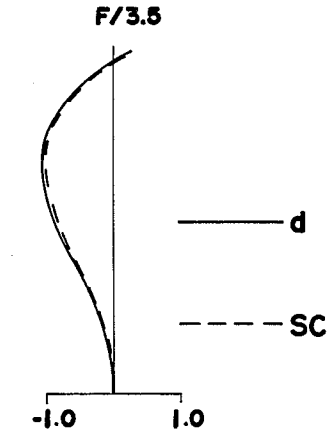
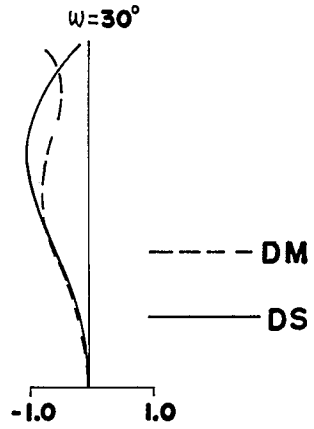


FIG.3A



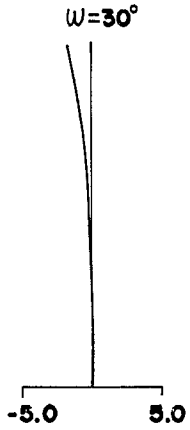
Spherical Aberration
Sine Condition

FIG.3B



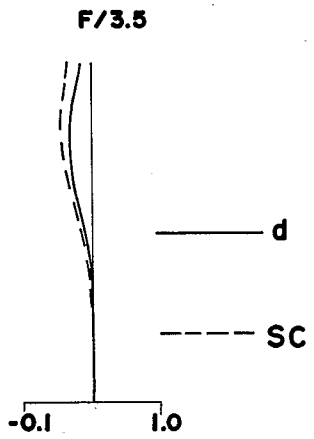
Astigmatism

FIG.3C



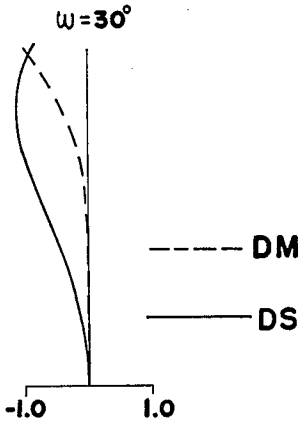
Distortion

FIG.4A



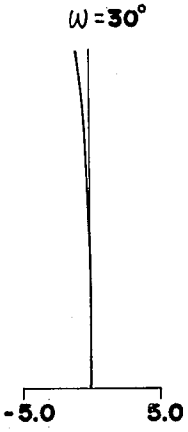
Spherical Aberration
Sine Condition

FIG.4B



Astigmatism

FIG.4C



Distortion

FIG.5A

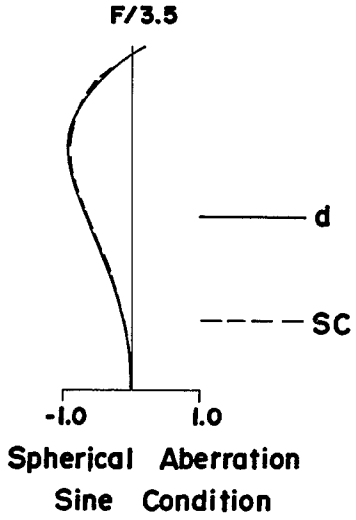


FIG.5B

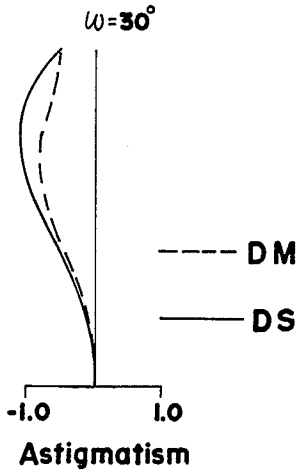
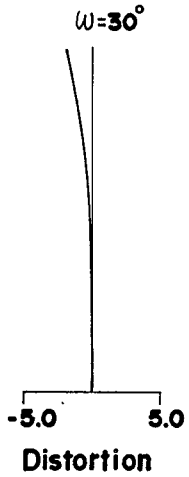


FIG.5C



TRIPLET TYPE OBJECTIVE WITH A DIAPHRAGM ARRANGED BEHIND THE LENS SYSTEM

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to an objective for compact lens-shutter cameras whose diaphragm is arranged behind the whole optical system, and more particularly to a compact wide angle objective with a simple construction for cameras for a spread use.

2. Description of the Prior Art

With a compact lens-shutter camera for cameras for a spread use, a wide angle objective with a diaphragm arranged behind the whole lens system is advantageous for accommodation in the camera, for compactization of the camera or the objective itself and for realization of precise focusing. As this kind of objective, triplet type objectives with F No. 4~2.8 and a total angular field coverage of 60°~64° have been proposed. With a wide angle triplet type objective, since a astigmatic difference tends to become large at a marginal angular field, it was conventional to construct this type of objective by using lens elements formed of glass with a high refractive index. For example, in Japanese patent application laid-open number Sho. 59-34510, all lens elements, one or two of which have an aspherical surface, are formed of glass with a high refractive index to construct an objective with a total angular field coverage of 64°, and F No. 3.5. In Japanese patent application laid-open number Sho. 57-2012, an objective with F No. 4 and a total angular field coverage of 64° has been realized by using glass with a high refractive index. But forming a lens element of glass of a high refractive index incurs an increase in the manufacturing cost.

On the other hand, in U.S. Pat. No. 3,784,287 or in Japanese patent application laid-open number Sho. 61-272710, a wide angle triplet type objective without using glass of a high refractive index have been proposed, but the objective in the former prior art is of F No. 5.6 and the objective in the latter prior art is of F No. 8.0 which are relatively small.

Further, in Japanese patent application laid-open number Sho. 62-183420, a wide angle triplet type objective with a diaphragm arranged behind the lens system comprising from the object side, a first positive lens formed of glass with a high refractive index, a second negative lens formed of plastic, a third positive lens formed of plastic. In the objective, the second and the third lenses are formed of plastic, so that manufacturing cost is low as well as the change in the back focus depending on the temperature is cancelled. And the first lens is formed of glass with a high refractive index, so that aberrations are corrected well. However, for securing sufficient marginal light rays, it is necessary to construct a diameter of the first lens so large that manufacturing cost tends to become high. Because, glass material, which is much expensive than plastic, is employed of the largest volume lens in the whole lens system.

SUMMARY OF THE INVENTION

An object of the present invention is to provide a triplet type wide angle objective with a compact size, a small F No. and light weight, whose manfuacturing cost is low, whose construction is advantageous in manufacturing of lens elements and whose aberrations are corrected well.

According to the present invention, the lens system comprises, from the object side, a first positive meniscus lens element having an object side surface convex to the object side, a second biconcave lens element, a third biconvex lens element and a diaphragm. The first and second lens elements are formed of plastic and the third lens element is formed of glass. Further the lens system fulfills the following conditions:

$$0.15<N_3-N_1<0.45$$

$$0.75<N_2/N_3<0.90$$

wherein, N_1 represents the refractive index of the first lens element, N_2 represents the refractive index of the second lens element, and N_3 represents the refractive index of the third lens element.

The features of the present invention, which are believed to be novel, are set forth with particularly in the appended claims. The present invention, both as to its organization and manner of operation, together with further objects and advantages thereof, may be best understood by reference to the following description, taken in conjunction with the accompanying drawing.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a cross sectional view of an objective according to the respective embodiments of the present invention.

FIGS. 2A to 2C represent the aberration curves of the embodiment 1 respectively;

FIGS. 3A to 3C represent the aberration curves of the embodiment 2 respectively;

FIGS. 4A to 4C represent the aberration curves of the embodiment 3 respectively;

FIGS. 5A to 5C represent the aberration curves of the embodiment 4 respectively;

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The following description is provided to enable any person skilled in the optical and camera field to make and use the invention and sets forth the best modes contemplated by the inventors for carrying out our invention. Various modifications, however, will remain readily apparent to those skilled in the art, since the generic principles of the present invention have been defined herein specifically to provide a relatively economical and easily manufactured triplet type objective. The derivation of the formulas and the relation of the powers set forth herein can be accomplished with the assistance of a computer. The present invention represents the parameters of a compromise balance of acceptable aberrrations which can be relatively easily manufactured to provide a low cost lens system for utilization with a compact lens shutter camera.

In the drawings, FIG. 1 shows the position of the lens elements. Values of radii of curvature and axial distances for each lens element and air spaces in the respective embodiments are provided in the accompanying tables set forth herein, and the schematic cross sectional view of FIG. 1 follows the normal conventions of an object at the left-hand side of the drawing and the image plane at the right-hand side.

As shown in FIG. 1, the present invention provides a lens system comprising, from the object side, a first

positive meniscus lens element (L_1) having an object side surface convex to the object side surface, a second biconvex lens element (L_2), a third biconvex lens element (L_3), and a diaphragm (S). The first (L_1) and second (L_2) lens elements are formed of plastic and the third lens elements (L3) is formed of glass. Further the lens system fulfills the following conditions:

$$0.15<N_3-N_1<0.45 \quad (1)$$

$$0.75<N_2/N_3<0.90 \quad (2)$$

wherein, N_1 represents the refractive index of the first lens element (L_1), N_2 represents the refractive index of the second lens element (L_2), and N_3 represents the refractive index of the third lens element (L_3).

According to the present invention, the first positive lens element (L_1) and the second negative lens element (L_2) are made of plastic, so that the change in back focus caused by change of the temperature is cancelled. Although the first plastic lens element (L_1) has a low refractive index, the third lens element (L_3) formed of glass with a high refractive index prevents the petzval sum from becoming great. Further, because the radius of curvature of the third lens element (L_3) is larger than that of the first lens element (L_1) and the volume of the third lens element (L_3) is smaller than that of the first lens element (L_1), the weight of the lens system and the cost for manufacturing of the lens elements can decrease in comparison with a triplet type objective having a first lens element (L_1) formed of glass with a high refractive index.

Thus, the present invention is characterized in that the refractive index of the third lens element (L_3) is much greater than that of the first lens element (L_1) as represented by the condition (1). When the condition (1) is satisfied, image field of the objective can be kept substantially flat over angular field of 65° and the petzval sum can be kept substantially small. If the lower limit of the condition (1) is violated, the petzval sum cannot be kept small and the astigmatic difference at the great angular field becomes great. On the other hand, the upper limit of the condition (1) shows the highest limit of the refractive index of the glass which is normally available as the third lens element (L_3).

Condition (2) is for a ratio of the refractive index of the second lens element (L_2) to that of the third lens element (L_3). The refractive index of the second lens element (L_2) is about constant because the second lens element (L_2) is formed of plastic which is normally available for photographic lens. Therefore, if the upper limit of the condition (2) is violted, the refractive index of the third lens element (L_3) becomes so small that the third lens element (L_3) cannot be formed of glass with a high refractive index, and the petzval sum increases so much that it becomes difficult to correct the astigmatic difference and a field curvature well. On the other hand, the upper limit of the condition (2), as same as in the condition (1), shows the highest limit of the refractive index of glass which is normally available as the third lens element (L_3).

Furthermore, according to the present invention, it is desirable to fulfill the following conditions.

$$2.5<d_2/d_4<4.0 \quad (3)$$

$$0.55<|f_{12}|/f<0.8 \quad (4)$$

$$0.3<f_3/f<0.6 \quad (5)$$

wherein, d_2 represents the axial distance between the first lens element (L_1) and the second lens element (L_2), d_4 represents the axial distance between the second lens element (L_2) and the third lens element (L_3), f_{12} represents the compound focal length of the first (L_1) and the second (L_2) lens elements, f_3 represents the focal length of the third lens element (L_3), and f represents the focal length of the lens system.

Condition (3) is for correcting the field curvature well. If the upper limit of the condition (3) is violated, the petzval sum increases so much that it becomes difficult to correct the field curvature, and the diameter of the first lens element (L_1) must be constructed large for securing sufficient amount of marginal light rays. In contrast thereto, if the lower limit of the condition (3) is violated, a spherical aberration is in undercorrection state and it becomes difficult to correct a distortion, a astigmatism and a chromatic aberration, while the petzval sum decreases.

Condition (4) is desirable for compactization of the objective and for keeping a vignetting small. If the upper limit of the condition (4) is violated, the vignetting and the field curvature increase. In contrast thereto, if the lower limit of the condition (4) is violated, the total length of the lens system including the back focal distance increases so long that it is difficult to construct the lens system with compact in size, while the vignetting becomes small.

Condition (5) is desirable for decreasing the change of aberrations depending on the decentering of the third lens element (L_3) from the optical axis defined by the first (L_1) and second (L_2) lens elements. If the upper limit of condition (5) is violated, the vignetting at a large angular portion of the field increases and it becomes difficult to correct the field curvature well. On the other hand, if the lower limit of condition (5), the focal length of the third lens element (L_3) becomes so short that the change of aberrations depending on the decentering of the third lens element (L_2) increases.

Furthermore, for correcting aberrations more satisfactory, the lens system is recommended to fulfill the following condition instead of the condition (5).

$$0.32<f_3/f<0.5 \quad (6)$$

According to this invention, the first (L_1) and second (L_2) lens elements are formed of plastic, so that it becomes easier to employ an aspherical surface. Especially, when the aspherical surface is employed for at least one surface of the first lens element (L_1), the spherical aberration, the distortion, the field curvature and the coma which are not so satisfactory corrected in case of an object consisting of only spherical lens elements can be corrected almost completely.

The following tables 1 to 4 disclose, respectively design parameters of embodiments 1 to 4 of the present invention. In the embodiments r_1, r_2, r_3 . . . is respectively the radius of curvature from the object side, and the d_1, d_2, d_3 . . . is respectively the axial thickness including both air spaces and the actual thickness of a lens element. Nd_1, Nd_2, Nd_3 is respectively the refractive index of the first through third lens element and νd_1, νd_2, νd_3 is respectively the abbe number of the first (L_1) through third lens element (L_3). A surface with the mark * represents an aspherical surface, whose configuration is defined as follows:

$$X = \frac{Y^2}{ri + ri\sqrt{1 - \left(\frac{Y}{ri}\right)^2}} + AY^2 + BY^4 + CY^6 + DY^8 + EY^{10} + FY^{12} + \ldots$$

wherein, X represents the coordinate along the optical axix measured from an imaginary plane tangent to the aspherical surface perpendicularly to the optical axis, Y represents the coordinate perpendicular to the optical axis from the optical axis, ri represents a paraxial radius of curvature, and A, B, C, D, . . . is aspherical coefficient.

TABLE 1

Embodiment 1
f = 100 $F_{No.}$ = 3.5 2w = 60°

		radius of curvature	axial distance		refractive index		Abbe number
L_1	r_1*	28.581	d_1	11.403	N_1	1.49140	ν_1 57.82
	r_2	43.298					
			d_2	4.191			
L_2	r_3	−46.546	d_3	3.400	N_2	1.58400	ν_2 31.00
	r_4	33.494					
			d_4	1.300			
L_3	r_5	50.000	d_5	6.822	N_3	1.80500	ν_3 40.97
	r_6	−51.016					
			d_6	4.737			
S	r_7	∞					

aspheric surface coefficients		parameters	
A	= 0.0	N_3–N_1	= 0.314
B	= −0.58716 × 10^{-7}	N_2/N_3	= 0.878
C	= 0.14066 × 10^{-8}	d_2/d_4	= 3.224
D	= −0.32495 × 10^{-10}	$\|f_{12}\|/f$	= 0.559
E	= 0.14141 × 10^{-12}	f_3/f	= 0.3223
F	= −0.17872 × 10^{-15}		

TABLE 2

Embodiment 2
f = 100 $F_{No.}$ = 3.5 2w = 60°

		radius of curvature	axial distance		refractive index		Abbe number
L_1	r_1*	28.405	d_1	11.402	N_1	1.49140	ν_1 57.82
	r_2	42.904					
			d_2	4.183			
L_2	r_3	−46.694	d_3	3.400	N_2	1.58400	ν_2 31.00
	r_4	33.804					
			d_4	1.300			
L_3	r_5	51.000	d_5	6.671	N_3	1.82050	ν_3 43.00
	r_6	−52.571					
			d_6	4.737			
S	r_7	∞					

aspheric surface coefficients		parameters	
A	= 0.0	N_3–N_1	= 0.329
B	= 0.34706 × 10^{-7}	N_2/N_3	= 0.870
C	= 0.37596 × 10^{-9}	d_2/d_4	= 3.218
D	= −0.29099 × 10^{-10}	$\|f_{12}\|/f$	= 0.566
E	= 0.14248 × 10^{-12}	f_3/f	= 0.325
F	= −0.18383 × 10^{-15}		

TABLE 3

Embodiment 3
f = 100 $F_{No.}$ = 3.5 2w = 60°

		radius of curvature	axial distance		refractive index		Abbe number
L_1	r_1*	29.764	d_1	11.403	N_1	1.49140	ν_1 57.82
	r_2	46.420					
			d_2	4.206			
L_2	r_3	−60.616	d_3	3.200	N_2	1.58400	ν_2 31.00
	r_4	34.522					
			d_4	1.500			
L_3	r_5	54.400	d_5	7.386	N_3	1.80500	ν_3 40.97
	r_6	−61.975					
			d_6	4.737			
S	r_7	∞					

aspheric surface coefficients		parameters	
A	= 0.0	N_3–N_1	= 0.314
B	= 0.28547 × 10^{-5}	N_2/N_3	= 0.878
C	= −0.16114 × 10^{-7}	d_2/d_4	= 2.804
D	= 0.13227 × 10^{-9}	$\|f_{12}\|/f$	= 0.732
E	= −0.46555 × 10^{-12}	f_3/f	= 0.370
F	= 0.49329 × 10^{-15}		

TABLE 4

Embodiment 4
f = 100 $F_{No.}$ = 3.5 2w = 60°

		radius of curvature	axial distance		refractive index		Abbe number
L_1	r_1*	29.764	d_1	11.403	N_1	1.49140	ν_1 57.82
	r_2	46.420					
			d_2	4.191			
L_2	r_3	−46.621	d_3	3.400	N_2	1.58400	ν_2 31.00
	r_4	36.165					
			d_4	1.300			
L_3	r_5	54.768	d_5	6.770	N_3	1.81100	ν_3 44.88
	r_6	−51.016					
			d_6	4.737			
S	r_7	∞					

aspheric surface coefficients		parameters	
A	= 0.0	N_3–N_1	= 0.320
B	= −0.40165 × 10^{-6}	N_2/N_3	= 0.875
C	= 0.33894 × 10^{-8}	d_2/d_4	= 3.224
D	= −0.38542 × 10^{-10}	$\|f_{12}\|/f$	= 0.587
E	= 0.14267 × 10^{-12}	f_3/f	= 0.335
F	= −0.17391 × 10^{-15}		

As can be readily appreciated, it is possible to deviate from the above embodiments of the present invention and, as will be readily understood by those skilled in the optical art, the invention is capable of many modifications and improvements within the scope and spirt thereof. Accordingly, it will be understood that the invention is not to be limited by these specific embodiments, but only by the scope and spirit of the appended claims.

What is claimed is:

1. A triplet type objective comprising,

(a) a lens system which includes from the object side;

a first positive meniscus lens element having an object side surface convex to the object side,

a second biconcave lens element,

a third biconvex lens element,

wherein, the first and the second lens elements are formed of plastic and the third lens element is formed of glass, and

(b) a diaphragm arranged behind the lens system,

(c) wherein the lens system fulfills the following conditions:

$$0.15<N_3-N_1<0.45$$

$$0.75<N_2/N_3<0.90$$

wherein:

N_1 represents the refractive index of the first lens element;

N_2 represents the refractive index of the second lens element;

N_3 represents the refractive power of the third lens element.

2. A triplet type objective as claimed claim 1, wherein the triplet type objective fulfills the following conditions:

$$2.5<d_2/d_4<4.0$$

$$0.55<|f_{12}|/f<0.8$$

$$0.3<f_3/f<0.6$$

wherein,

d_2 represents the axial distance between the first lens element and the second lens element;

d_4 represents the axial distance between the second lens element and the third lens element;

f_{12} represents the compound focal length of the first and the second lens elements;

f_3 represents the focal length of the third lens element;

f represents the focal length of the lens objective.

3. A triplet type objective as claimed claim 1, wherein one of the surfaces of the first lens element is an aspherical surface.

* * * * *

United States Patent [19]

Miyagawa et al.

[11] **Patent Number: 4,876,732**

[45] **Date of Patent: Oct. 24, 1989**

[54] **SYSTEM FOR DETECTING ROTATIONAL ANGLE OF OBJECTIVE PATTERN**

[75] Inventors: **Michiaki Miyagawa; Yutaka Ishizaka; Shoji Shimomura,** all of Kanagawa, Japan

[73] Assignee: **Fuji Electric Co., Ltd.,** Kanagawa, Japan

[21] Appl. No.: **50,578**

[22] Filed: **May 18, 1987**

[30] **Foreign Application Priority Data**

Jun. 4, 1986 [JP] Japan 61-128032

[51] **Int. Cl.**[4] **G06K 9/36**

[52] **U.S. Cl.** **382/41;** 382/46

[58] **Field of Search** 382/8, 27, 28, 41, 45, 382/46; 340/727; 364/463, 559

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Primary Examiner—Leo H. Boudreau

Attorney, Agent, or Firm—Finnegan, Henderson, Farabow, Garrett & Dunner

[57] **ABSTRACT**

A system and method for determining a rotational angle of an objective pattern which involves calculating the area A and linear moments M_x and M_y of the pattern from binary picture elements formed after optically sensing the pattern. The picture elements are stored in the memory in binary form. The center of gravity of the objective pattern is calculated on the basis of the area A and the linear moments M_x and M_y, and a circular or ring-like search region (a window) is formed about that center of gravity. Thereafter, significant picture information in the search region is extracted from the picture information stored in the memory (in either an inverted or non-inverted state). The rotational angle of the objective pattern is then determined either by using a moment of inertia method or a inter two-gravity centers method calculation. The selection between the moment of inertia method and the inter two-gravity centers method can be performed by means of pre-set switch state information.

4 Claims, 4 Drawing Sheets

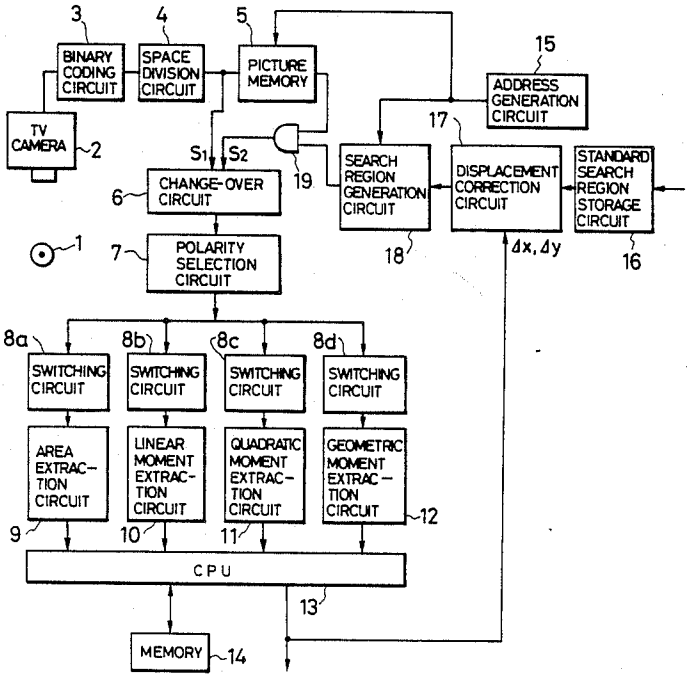


FIG. 1A

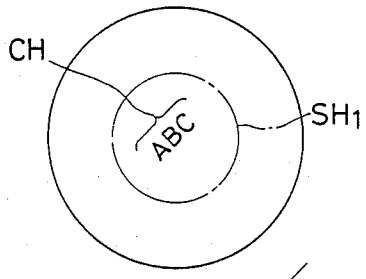


FIG. 1B

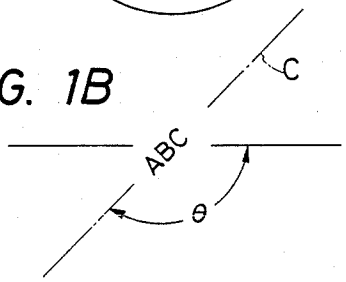


FIG. 2A

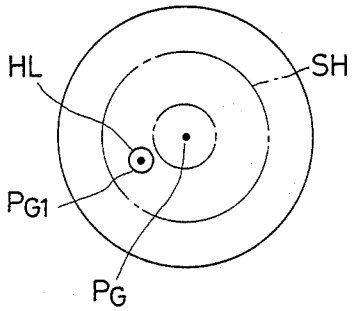


FIG. 2B

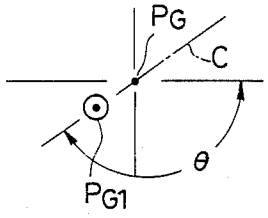


FIG. 3A

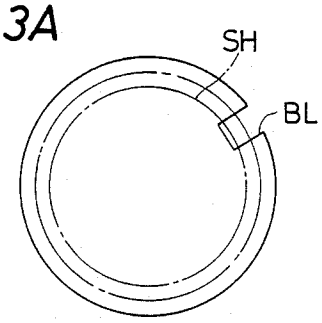


FIG. 3B

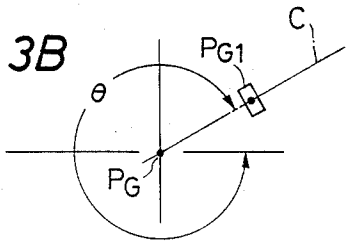


FIG. 4A

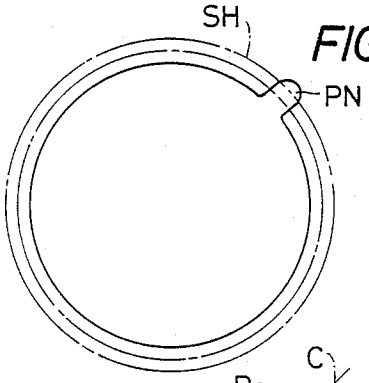


FIG. 4B

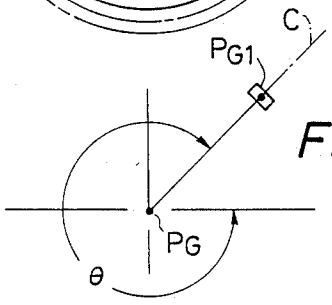


FIG. 5

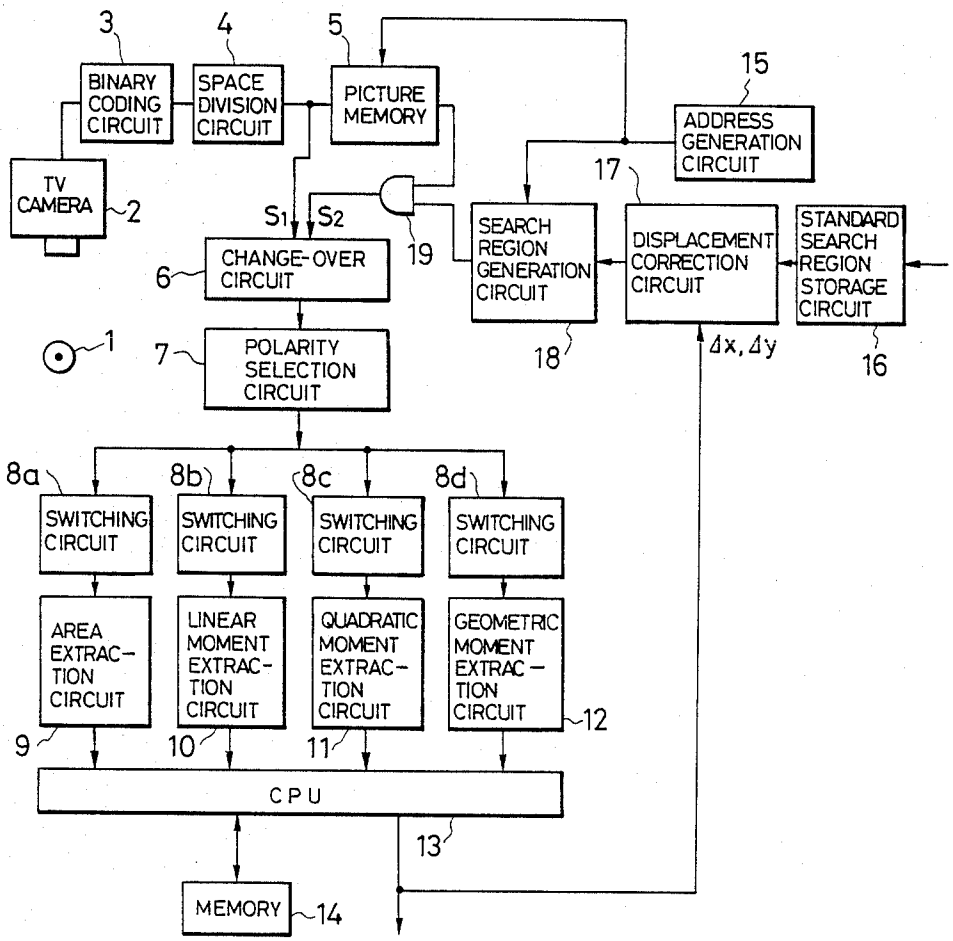

3
4
5
BINARY CODING CIRCUIT
SPACE DIVISION CIRCUIT
PICTURE MEMORY
15
ADDRESS GENERATION CIRCUIT
TV CAMERA
2
S1
S2
19
17
SEARCH REGION GENERATION CIRCUIT
DISPLACEMENT CORRECTION CIRCUIT
STANDARD SEARCH REGION STORAGE CIRCUIT
6
CHANGE-OVER CIRCUIT
1
7
POLARITY SELECTION CIRCUIT
18
Δx, Δy
16
8a
8b
8c
8d
SWITCHING CIRCUIT
SWITCHING CIRCUIT
SWITCHING CIRCUIT
SWITCHING CIRCUIT
AREA EXTRACTION CIRCUIT
LINEAR MOMENT EXTRACTION CIRCUIT
QUADRATIC MOMENT EXTRACTION CIRCUIT
GEOMETRIC MOMENT EXTRACTION CIRCUIT
12
9
10
11
CPU
13
MEMORY
14

FIG. 6

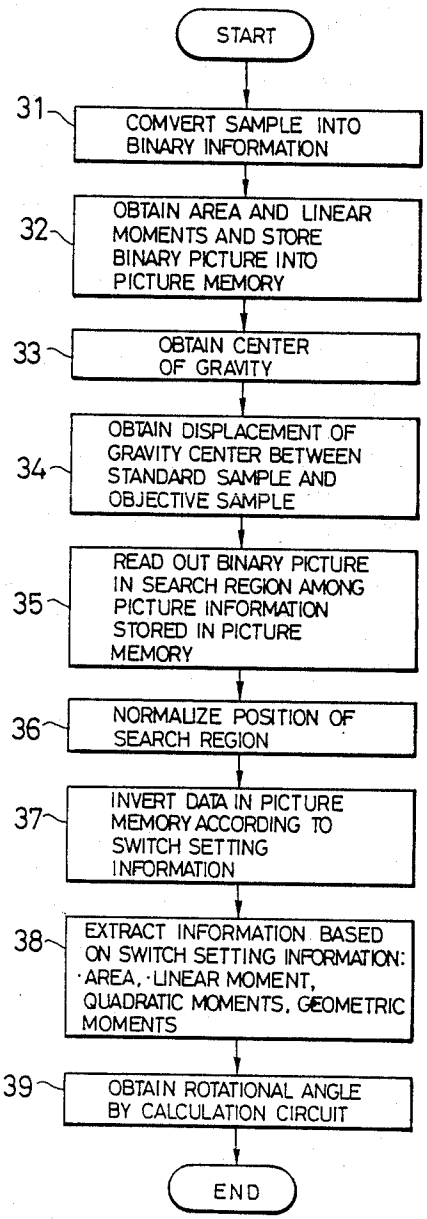

START
31
COMVERT SAMPLE INTO BINARY INFORMATION
32
OBTAIN AREA AND LINEAR MOMENTS AND STORE BINARY PICTURE INTO PICTURE MEMORY
33
OBTAIN CENTER OF GRAVITY
34
OBTAIN DISPLACEMENT OF GRAVITY CENTER BETWEEN STANDARD SAMPLE AND OBJECTIVE SAMPLE
35
READ OUT BINARY PICTURE IN SEARCH REGION AMONG PICTURE INFORMATION STORED IN PICTURE MEMORY
36
NORMALIZE POSITION OF SEARCH REGION
37
INVERT DATA IN PICTURE MEMORY ACCORDING TO SWITCH SETTING INFORMATION
38
EXTRACT INFORMATION BASED ON SWITCH SETTING INFORMATION: ·AREA, ·LINEAR MOMENT, QUADRATIC MOMENTS, GEOMETRIC MOMENTS
39
OBTAIN ROTATIONAL ANGLE BY CALCULATION CIRCUIT
END

FIG. 7

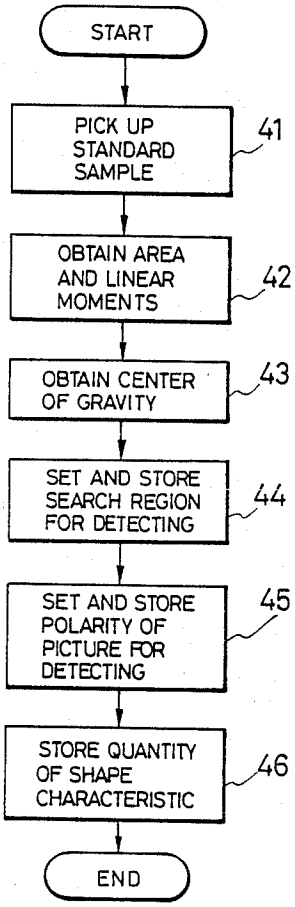
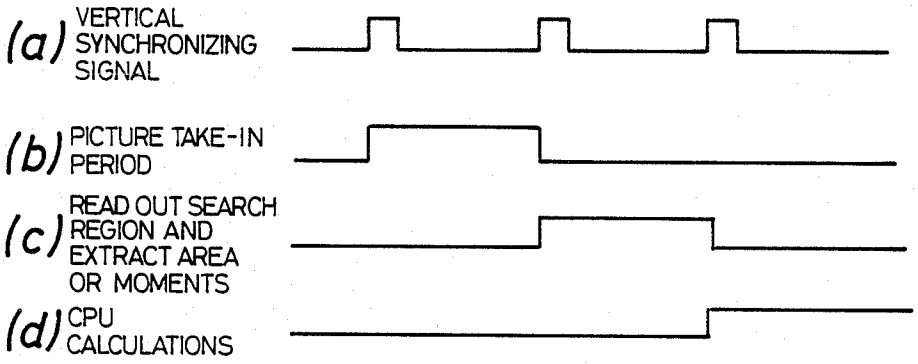

START
PICK UP STANDARD SAMPLE
41
OBTAIN AREA AND LINEAR MOMENTS
42
OBTAIN CENTER OF GRAVITY
43
SET AND STORE SEARCH REGION FOR DETECTING
44
SET AND STORE POLARITY OF PICTURE FOR DETECTING
45
STORE QUANTITY OF SHAPE CHARACTERISTIC
46
END

FIG. 8


(a) VERTICAL SYNCHRONIZING SIGNAL
(b) PICTURE TAKE-IN PERIOD
(c) READ OUT SEARCH REGION AND EXTRACT AREA OR MOMENTS
(d) CPU CALCULATIONS

SYSTEM FOR DETECTING ROTATIONAL ANGLE OF OBJECTIVE PATTERN

BACKGROUND OF THE INVENTION

The present invention relates generally to an apparatus in which an objective pattern is extracted by an image sensor, such as a television camera, then subjected to image processing to detect a rotational angle in order to inspect or recognize an objective pattern.

One conventional detection system utilizes a method, known as the moment of inertia method of calculation, in which an optically-sensed pattern is binary coded, and in which a main axis and a center of gravity of an equivalent ellipse are obtained from calculations using the linear moments, quadratic moments geometric moments and an area of the binary-coded pattern.

Thus, a rotational angle θ and a center of gravity P_G (P_{GX}, P_{GY}) are obtained through the following expressions (1) and (2):

$$\tan 2\theta = 2I_{xy}/(I_y - I_x) \quad (1)$$

$$P_{GX} = M_x/A,\ P_{GY} = M_y/A \quad (2)$$

where the various symbols are defined as follows:

M_x: the linear moment of the pattern with respect to the x-axis;

M_y: the linear moment of the pattern with respect to the y-axis;

I_x: the quadratic moment of the pattern with respect to the x-axis;

I_y: the quadratic moment of the pattern with respect to the y-axis;

I_{xy}: the synergistic moment of the pattern;

A: the area of the objective pattern; and

θ: the rotational angle.

Using this moment of inertia method of calculation, the rotational angle θ can be detected with relatively high accuracy for an elongated objective pattern, but not for an objective pattern which is more square or circular. In square or circular patterns, the quadratic moments I_x and I_y have similar values, and very small errors in quantization of the pattern are magnified when the denominator at the right hand side of the above-mentioned expression (1) approaches zero. Therefore, if rotation of an objective pattern is normalized by using a rotational angle obtained by the moment of inertia method described above, large errors could occur due to the introduction of errors based on shape-dependent calculations rendering any further pattern inspection and recognition of little practical use.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a system for detecting a rotational angle of an objective pattern in which accurate pattern detection can be achieved without shape-dependent errors.

Additional objects and advantages of the invention will be set forth in part in the description which follows, and in part will be obvious from the description, or may be learned by practice of the invention. The objects and advantages of the invention may be realized and attained by means of the instrumentalities and combinations particularly pointed out in the appended claims.

To achieve the objects and in accordance with the purpose of the invention, as embodied and broadly described herein, the method for detecting a rotational angle of an objective pattern comprises the steps of: (a) optically sensing an objective pattern by a picture sensor to form a sense signal; (b) binary coding the sense signal into picture elements; (c) calculating an area of the objective pattern and a plurality of linear moments of the objective pattern from the picture elements; (d) calculating a center of gravity of the objective pattern from the area and the linear moments; (e) storing the area, linear moments, center of gravity and the binary-coded picture elements into a memory; (f) calculating a displacement of the center of gravity corresponding to a difference between a center of gravity of a predetermined standard picture sample and the center of gravity of the objective pattern; (g) determining an appropriate search region from among the binary-coded picture elements and reading out data corresponding to the search region; (h) normalizing a position of the search region: and (i) calculating a rotational angle for the objective pattern based on predetermined mathematical formulae and utilizing the stored information.

The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate one embodiment of the invention and, together with the description, serve to explain the principles of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. **1A**, **1B**, **2A**, **2B**, **3A**, **3B**, **4A** and **4B** are objective pattern diagrams illustrating principle of the present invention;

FIG. **5** is a block diagram illustrating a system for detecting a rotational angle of an objective pattern in accordance with a preferred embodiment of the present invention;

FIG. **6** is a flow chart illustrating the operation of the system of FIG. **5**;

FIG. **7** is a flow chart illustrating a switch setting operation; and

FIG. **8** is a timing diagram for explaining the operation of the embodiment of FIG. **5**.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Reference will now be made in detail to the present preferred embodiment of the invention, an example of which is illustrated in the accompanying drawings in which like reference characters refer to corresponding elements.

First, referring to FIGS. **1A** through **4B**, a principle of the present invention called the inter two-gravity center method will be described. FIGS. **1A**, **2A**, **3A**, and **4A** each illustrate different objective patterns. Specifically, FIG. **1A** illustrates a case where black letters CH are written on a white circular pattern. FIG. **2A** illustrates a case where, for example, a hole HL is bored in a white circular pattern similar to the preceding one. FIG. **3A** illustrates a case where a notch BL is formed in a white circular pattern similar to FIG. **2A**. And FIG. **4A** illustrates a case where a protrusion PN is formed on a white circular pattern similar to FIG. **3A**. Each of these figures illustrates an example in which it is difficult to detect a rotational angle with high accuracy when using the moment of inertia method of calculation.

In determining the angle of rotation of the pattern illustrated in FIG. **1A** according to the present invention, a circular search region SH_1 is chosen, and a picture in this search region, that is, the letter portion CH,

is extracted as a significant picture. Next, a main axis C of the significant picture is obtained by using the moment of inertia method of calculation of the letter portion CH as shown in FIG. 1B and a rotational angle θ is determined as the angle of the main axis. If the search region SH_1 is set to be logic "1", the letter portion CH is set to be logic "0", and therefore, it is necessary to invert the logic state or the polarity when the letter portion CH is extracted.

This situation also applies in the cases of FIGS. 2A and 2B, and 3A and 3B. In the case of FIG. 2A, the circular hole HL is extracted as a significant picture, a center of gravity P_{G1} of the picture is obtained. The rotational angle θ is determined as the angle of a straight line C passing through the center of gravity P_{G1} of the significant picture and the center of gravity P_G of the entire objective pattern as shown in FIG. 2B.

In the case of FIG. 3A, processing is performed with respect to the notch BL in the same manner as in the case of FIG. 2A to obtain a rotational angle θ as shown in FIG. 3B.

In the case of FIG. 4A, processing is performed in the same manner as in the cases shown in FIGS. 2A and 2B, except that the protrusion PN is extracted without performing an inversion of the polarity or in an inversion of the logic states.

Next, the operation of the system of the present invention will be described with reference to FIG. 5. The system has two modes of operation, one being a judging mode (to be explained in greater detail with reference to FIG. 6) and the other mode being a setting mode (to be explained in greater detail with reference to FIG. 7). As shown in FIG. 5, the system according to the present invention includes a pick-up apparatus, such as a television camera 2, for forming a two-dimensional representation of a sample 1 to be detected; a binary coding circuit 3; a space division circuit 4 a picture memory 5; a change-over circuit 6; a polarity selection circuit 7 switching circuits 8*a* through 8*d*an area extraction circuit 9; a linear moment extraction circuit 10 a quadratic moment extraction circuit 11; a geometric moment extraction circuit 12; a central processing unit (CPU) 13; a memory 14; an address generation circuit 15; a standard search region storage circuit 16; a displacement correction circuit 17; a search region generation circuit 18; and an AND gate 19.

As shown at block 31 in FIG. 6, the detection according to this invention starts with the sample 1 to be detected being sensed by the television camera 2 and converted into binary, that is, black and white, information by the binary coding circuit 3. Next, at block 32, the binary information is spatially divided in two dimensions into picture elements, for example, 256×256 picture elements. These picture elements are then stored in the picture memory 5 which has sufficient capacity to store all of the picture elements. This operation is executed during the period, called the picture take-in period, in which one scene of the picture is scanned by the television camera 2. FIG. 8 shows an example of the relationship between the scanning period and the picture take-in period. FIG. 8(*a*) shows a vertical synchronizing signal and FIG. 8(*b*) shows a picture take-in period.

During the picture take-in period, and also shown by block 32 of FIG. 6 the area and linear moments are obtained. These operations are performed under the control of the CPU 13, which causes the change-over circuit 6 to select an input S_1 rather than an input S_2. The polarity selection circuit 7 selects "forward rotation" thereby turning the switching circuits 8*a* and 8*b* "ON" and the switching circuits 8*c* and 8*d* "OFF." Therefore, the picture information processed by the space division circuit 4 is applied to the area extraction circuit 9 and the linear moment extraction circuit 10, so that an area A and linear moments M_x and M_y are obtained.

Next, at block 33, when the picture take-in is terminated, the CPU 13 obtains coordinates P_{GX} and P_{GY} of the center of gravity of the entire pattern to be inspected. The CPU 13 can make its determination on the basis of expression (2) or on any other acceptable calculation. Then, as shown by block 34, CPU 13 compares the coordinates P_{GX} and P_{GY} with coordinates P_{GXS} and P_{GYS}, which represent the center of gravity of a standard sample obtained in advance during the setting mode. The comparison is performed to obtain a quantity of displacement (Δx, Δy) between the center of gravity coordinates.

Next, as shown by block 35 in FIG. 6, the CPU 13 reads picture polarity information out of the memory 14 corresponding to the shape characteristic of the objective pattern, and applies the information to the polarity selection circuit 7. At the same time, the CPU 13 reads various "ON"/"OFF" switch setting information out of memory 14, and applies that information to the switching circuits 8*a* through 8*d*. The process for initially setting the switches is shown in FIG. 7 and described below in detail. The switch setting information for the switching circuits 8*a* through 8*d* depends on the algorithm which is used for detecting the angle θ and the method of calculation, such as the moment of inertia method or the inter two-gravity center method.

Thus, the setting of the switches is performed in accordance with the shape characteristic of the objective pattern. For example, when the moment of inertia method is employed, the switching circuits 8*a* and 8*b* are turned "OFF" and the switching circuits 8*c* and 8*d* are turned "ON." Information with respect to a circular or ring-like search region to be searched, which had been set in advance by the standard sample, has been stored in the standard-region storage circuit 16 together with the information of the coordinates P_{GXS} and P_{GYS} of the center of gravity of the standard sample.

At this time, as shown by block 35, CPU 13 applies trigger signals to the address generation circuit 15 to scan the picture memory 5 and the search region generation circuit 18. As a result, the address generation circuit 15 generates addresses X and Y to the picture memory 5 to successively scan the picture memory 5 for every picture element in a manner similar to a television, so as to successively read picture information out of picture memory 5. The search region generation circuit 18 is arranged to read search region data (coordinates data) out of the standard search region stored circuit 16 to determine whether addresses generated by the address generation circuit 15 exist in the search region. Accordingly, the search region generation circuit 18 controls the data read out of picture memory 5 through the AND gate 19. Thus, only the picture data in the search region stored in picture memory 5 are read out through the AND gate 19.

Then, at block 36, the quantity of displacement (Δx, Δy) between the respective centers of gravity of the pattern to be detected in the standard sample is applied from CPU 13 to the displacement correction circuit 17. The quantity of displacement is added to the data from

the standard search region storage circuit **16** to thereby shift position of the standard search region by the quantity of displacement so that the position of the search region is normalized.

The change-over circuit **6** is then controlled to select an input S_2 at block **37**, so that the output of the AND gate **19** is applied to the extraction circuits **9** through **12** via the changeover circuit **6**, the polarity selection circuit **7**, and the switching circuits **8**. At this time, as shown in block **37**, the polarity of the picture information is inverted if necessary.

As described above, since the moment of inertia method is to be used in this case, only the switching circuits **8***c* and **8***d* are in the "ON" state, so that the quadratic moments I_x and I_y and the synergistic moment I_{xy} are extracted by the extraction circuits **11** and **12**, respectively (block **38**). FIG. **8**(*c*) shows the timing of the preceding operation. As is apparent from FIG. **8**(*c*), extraction of the area and the moments with respect to the significant picture information is performed after the picture take-in period.

As shown by block **39** of FIG. **6**, the outputs of the extraction circuits **11** and **12** are applied to the CPU **13**, so that the calculation shown in the above-mentioned expression (1) is performed in accordance with the setting of the switches to obtain the rotational angle θ. The timing for the operation which occurs at block **39** is shown in FIG. **8**(*d*).

The rotational angle is thus obtained by using the moment of the inertia method of the preceding example. As described above, there are some shapes of the objective pattern for which the rotational angle can be more accurately obtained by using the inter two-gravity center method and some cases where the rotational angle can be more accurately obtained by using the polarity inversion of the picture information method.

Therefore, the status of the switches is set in advance and stored in memory **14** using a standard sample according to which method should be used and according to whether the polarity of picture information should be inverted. As shown in FIG. **7**, at block **41**, a standard picture sample is obtained and then binary-coded similar to the procedure in block **31** of FIG. **6**. Next, at block **42**, CPU **13** calculates the area and linear moments of the binary-coded picture similar to the procedure in block **32** of FIG. **6**. At block **43**, CPU **13** calculates the center of gravity similar to the procedure in block **33** of FIG. **6**, and at block **44**, CPU **13** determines the search region and stores it in memory **14**. The polarity of the picture information is determined and stored in memory **14** at block **45**, then, at block **46**, the switch states are determined and set and stored in memory **14**.

When the inter two-gravity center method and the polarity inversion of the picture information are to be used, CPU **13** applies a command indicating the polarity inversion to the polarity selection circuit **7**, applies a command turning the switching circuits **8***a* and **8***b* "ON", and applies a command turning the switching circuits **8***c* and **8***d* "OFF." As a result, an area A′ and linear moments M'_x and M'_y are extracted from the information of the significant picture in the search region, and the center of gravity is obtained on the basis of the above-mentioned expression (2).

Therefore, a rotational angle θ can be obtained from the thus-obtained center of gravity of the pattern in the search region and the center of gravity of the entire pattern to be detected on the basis of the following expression (3):

$$\theta = \tan^{-1}\frac{Y_{Gi} - Y'_{Gi}}{X_{Gi} - X'_{Gi}} \quad (3)$$

where X_{Gi} and Y_{Gi} are the respective x- and y- coordinates of the center of gravity of the entire pattern to be detected, and X'_{Gi} and Y'_{Gi} represent the x- and y-coordinates of the center of gravity of the pattern in the search region.

The preceding description of the system in accordance with the present invention has been mainly concerned with objective patterns having only one kind of shape characteristic. If an objective pattern has various shape characteristics, it is possible to use the present invention with respect to portions of such an objective pattern so that data relating to sizes and positions of standard search regions, methods of angle detection, polarity of picture, etc., are set and stored in advance so that the data can be properly selected by CPU **13**.

The following advantages result from the use of the system of the present invention:

(1) Since angle detection with respect to an objective pattern is made by extracting the data of a significant picture in a search region, a correct angle can be detected even where a circular pattern is to be normalized. Accordingly, normalization of rotation in pattern inspection or pattern recognition can be more accurately performed. Furthermore, in a case where angle data are to be detected so as to be utilized for position control, position information can be obtained thereby making it possible to perform highly accurate position control.

(2) Since the angle detection can be performed by using one of several different methods and the picture polarity can be suitably changed, the system according to the present invention can widely apply to various samples with various shape characteristics.

(3) Furthermore, since the size of the search region can be suitably set, the system according to the present invention can deal with various objective samples, so that the system can operate as a flexible manufacturing system (FMS).

(4) Since the displacement of the position where the search region is generated can be corrected, not only can the inspection and recognition be performed with high accuracy independent of the region's displacement, but also the limitation in a carrying system caused by an objective sample is reduced resulting in a reduction in the of cost of the carrying system.

It will be apparent to those skilled in the art that various modifications and variations can be made in the methods and apparatus of the present invention without departing from the scope or spirit of the invention. Thus, it is intended that the present invention cover the modifications and variations of this invention provided they come within the scope of the appended claims and their equivalents.

What is claimed is:

1. A method for detecting a rotational angle of an objective pattern comprising the steps of:

(a) optically sensing an objective pattern by a picture sensor to form a sense signal;

(b) binary coding said sense signal into picture elements;

(c) calculating an area of said objective pattern and a plurality of linear moments of said objective pattern from said picture elements;

(d) calculating a center of gravity of said objective pattern from said area and said linear moments;

(e) storing said area, linear moments, center of gravity and said binary-coded picture elements into a memory;

(f) calculating a displacement of said center of gravity corresponding to a difference between a center of gravity of a predetermined picture sample and said center of gravity of said objective pattern;

(g) determining an appropriate search region from among said binary-coded picture elements and reading out data corresponding to said search region;

(h) normalizing a position of said search region;

(i) calculating a rotational angle for said objective pattern based on predetermined mathematical formulae and utilizing said stored information; and

(j) storing predetermined data for determining whether said logic state of said picture information is to be inverted, and as to which one of said methods of calculation are to be used in detection of said rotational angle of said objective pattern.

2. The method of claim **1**, further including the step of forming a search region by using a normalization process.

3. A system for detecting a rotational angle of a two-dimensional objective pattern converted into binary picture information, said system comprising:

memory means for storing said picture information;

first feature extraction means for extracting an area and a moment of inertia of said objective pattern from said picture information;

center of gravity means for determining a center of gravity of said objective pattern from said area and said moment of inertia of said objective pattern;

region forming means performing a search region having a predetermined shape about said center of gravity of said pattern;

second feature extraction means for extracting a selective portion of said picture information out of said memory means, whereby said rotational angle of said objective pattern is detected on the basis of said extracted portion by using a selected one of a moment of inertia method or an inter two-centers of gravity method of calculation; and

predetermined data storage means for determining whether said logic state of said picture information is to be inverted, and as to which one of said methods of calculation are to be used in detection of said rotational angle of said objective pattern.

4. A system for detecting rotational angle of an objective pattern according to claim **3**, in which said search region is formed by using a normalization process.

* * * * *

United States Patent [19]

Vogl

[11] **Patent Number: 4,867,547**

[45] **Date of Patent: Sep. 19, 1989**

[54] **MIRROR OBJECTIVE AND OPTICAL ARRANGEMENT COMPRISING TWO MIRROR OBJECTIVES**

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[73] Assignee: **U.S. Philips Corporation**, New York, N.Y.

[21] Appl. No.: **114,791**

[22] Filed: **Oct. 28, 1987**

[30] **Foreign Application Priority Data**

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[51] **Int. Cl.**[4] **G02B 17/00**

[52] **U.S. Cl.** **350/444**

[58] **Field of Search** 350/444, 6.1; 356/331

[56] **References Cited**

U.S. PATENT DOCUMENTS

2,378,301 6/1945 Kaprelian 350/444

3,930,728 1/1976 Pieuchard et al. 356/331

4,226,500 10/1980 Minoura et al. 350/6.1

Primary Examiner—Bruce Y. Arnold

Assistant Examiner—Rebecca D. Gass

[57] **ABSTRACT**

A primary mirror and a secondary mirror are arranged on a lens to form an eccentric radiation path through the mirror objective. The optical axis of the mirror objective follows an N-shaped path through the objective and central diaphragming is avoided. The object and consequently the image are situated outside the geometrical axis of the mirror objective, which shows a short distance between the object and the image. In an optical arrangement comprising two such mirror objectives, one is used for illuminating and the other is used for imaging.

5 Claims, 1 Drawing Sheet

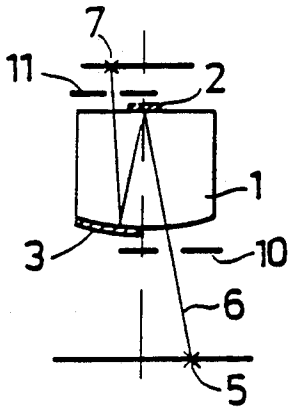


Fig. 1

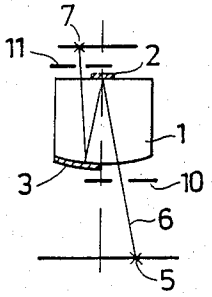


Fig. 2

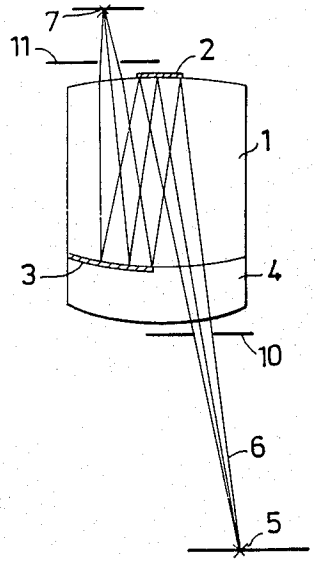


Fig. 3

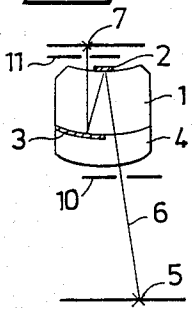


Fig. 4

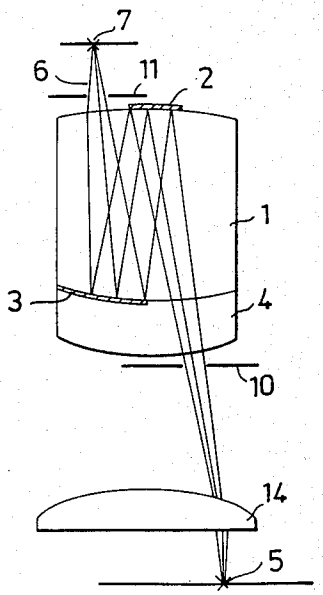


Fig. 5a

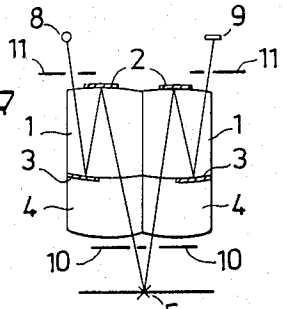
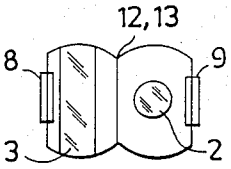


Fig. 5b



MIRROR OBJECTIVE AND OPTICAL ARRANGEMENT COMPRISING TWO MIRROR OBJECTIVES

BACKGROUND OF THE INVENTION

The invention relates to a monolithic mirror objective comprising a lens having a primary mirror on the output surface of the lens and a secondary mirror on the input surface of the lens to form an N-shaped radiation path through the mirror objective. In this case all of the N-shaped radiation path is within the lens and possible further lenses. The invention also relates to an optical arrangement comprising two such mirror objectives.

All standard mirror objectives consist of a primary mirror and a secondary mirror, which may be disposed in connection to one or a number of combined lenses. U.S. Pat. No. 2,378,301 shows such a mirror objective in the form of a camera objective. In a mirror objective of the prior art, the primary mirror images the object in its focal plane, the rays are caught by the secondary mirror and the rays are reflected through an aperture in the primary mirror and into the image plane of the camera of the field glass. The optical axis of the mirror objective coincides with the geometrical axis of the objective which passes through the central part of the objective. The aperture in the primary mirror causes a central obscuration on the entrance pupil of the objective (diaphragming in the centre), that is to say, light cones emanating from each object point become hollowed. In order to reach a given desired strength of light, the outer rays of the cone must be given a large angle with respect to the geometrical axis of the mirror objective. Furthermore, if it is desired to adapt the mirror objective to a small magnification, the diameter of the secondary mirror increases and hence the angle of outer rays increases further. When transferring symbols from a material of, for example, paper to a detector, such an objective is unusable because a depth movement of the material which may be very small results in an unacceptable defocus.

SUMMARY OF THE INVENTION

It is an object of the invention to use the advantages of mirror optics over lens optics, namely to obtain the same image quality and short length of the construction by using fewer elements whilst avoiding the great disadvantage of the mirror objective, namely the central diaphraming. This is obtained by putting the object and consequently the image outside the geometrical axis of the mirror objective. The optical axis is reflected between the mirrors as an N and there is no need for an aperture in the primary mirror. The imaged radiation beam assumes the same appearance as with a lens objective and the depth of focus will only be dependent on the entrance pupil and the object distance.

According to the invention the first mirror is arranged to cover the central part of the output surface, while the second mirror is arranged to cover a part of the input surface which is displaced aside relative to the center of the input surface, so that the first mirror and the second mirror together with the lens and possible further lenses can follow an eccentric, N-shaped path through the objective, the object and the image situated on each side of the geometrical axis of the mirror objective.

The mirror objective according to the invention is suitable for reading bar symbols, letters and digits having one detector line (array) and for reading optical discs and similar storage media. Until now a microobjective or a miniaturized photo objective have been used in connection with the examples of application. These objectives, however, have inconvenient dimensions. For example, in order to transfer a letter having a size of 10 mm to a detector having a size of 5 mm an astigmate having four lenses is needed and an overall length from the object to the detector of 40 to 60 mm. This length may be compared with the overall length of at least 20 mm in connection with the mirror objective according to the invention.

In its simplest form the mirror objective consists of two reflecting surfaces applied to a lens. In order to improve the image sharpness and adapt the mirror objective to different magnifications (the ratio of the object and the image dimensions), however, further lenses may be disposed which are preferably glued together with the lens. According to an advantageous embodiment of the mirror objective a further lens is disposed adjacent to the lens, one of the reflecting surfaces being enclosed between the two lenses.

According to another advantageous embodmient a collimator lens is disposed near the object. The collimator lens ensures that radiation beams which are mutually parallel are chosen for imaging. If the variations of the object distance are small, the image dimension by means of this arrangement remains unchanged. The mirror objective according to this embodiment is characterized in that a collimator lens is disposed near the object plane of the mirror objective.

The invention also relates to an arrangement comprising two mirror objectives according to the invention. One of the objectives is used for illuminating, while the other is used for reading. Normally the illuminating is carried out by means of a miniature lamp or a so called vertical illuminator. In the first case a large field is illuminated but only a narrow strip is used for reading. In the other case the light is reflected in an inclined transparent mirror, passes the objective and illuminates the object, the object being imaged by the objective by means of the mirror on the detector. Both of these illuminating systems require a lot of light and a great deal is lost and may also give rise to disturbing reflections. The eccentric radiation path causes the object to be situated at the periphery of the optics. Accordingly, two identical mirror objectives may be situated adjacent to one another and one of them may be used for projecting a light source on the object, which light source is shaped in accordance with the object, for example, a straight incandescent filament, if a line or a band on the object is to be read. The radiation paths for illuminating and reading are totally separated in this case, whilst no reflections occur and only the field to be read is illuminated.

The optical arrangement consisting of two mirror objectives is characterized in that the two mirror objectives are arranged with two parallel geometrical axes and adjacent to each other, and in that one of the mirror objectives is used for illuminating an object, while the other mirror objective is used for imaging the object in question.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 shows a simple embodiment of a mirror objective,

FIG. 2 shows a second embodiment of a mirror objective according to the invention comprising one further lens,

FIG. 3 shows a third embodiment of the mirror objective according to the invention,

FIG. 4 shows a fourth embodiment of the mirror objective according to the invention comprising a collimator lens, and

FIG. 5*a* is a side view an optical arrangement comprising two mirror objectives;

FIG. 5*b* is a top view of the arrangement show in FIG. 5*a*.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

The mirror objective of FIG. 1 consists of a plano-convex lens 1 provided with a primary mirror 2 and a secondary mirror 3. The object 5 is imaged by means of a radiation beam 6 on the detector or the detector line 7. In the Figure only the radiation path of the central ray is indicated. An input slot 10 is disposed between the object 5 and the lens 1 and an output slot 11 is disposed between the lens body 1 and the detector line 7. The mirror objective according to FIG. 1 is suitable for a magnification of 0.5. The magnification is not limited to this value, but it may assume other values, preferably by changing the refractive index. The lenses mentioned above and below are preferably of synthetic resin or glass material.

In the following description with reference to FIGS. 2–4 corresponding elements have been given the same reference numerals as in FIG. 1.

In addition to the lens 1, which in this case is convex, the embodiment shown in FIG. 2 comprises a further lens 4. These two lenses 1, 4 are disposed in such a way that the secondary mirror 3 is enclosed by the adjacent surfaces of the lenses. The second surface of the lens 4 facing the input slot 10 has a spherical shape permitting the radiation beam 6 to hit the last-mentioned surface at an essentially right angle.

FIG. 3 shows an embodiment in which the lens 1 is convex-concave and a further lens 4 is arranged to enclose the secondary mirror 3 together with the convex surface of the lens 1. As in FIG. 1, only the radiation path of the central ray is indicated.

FIG. 4 shows a mirror objective according to FIG. 2 which is provided with a collimator lens 14 close to the object. The collimator lens shows that radiation beams being mutually parallel are selected for the imaging.

An optical arrangement consisting of two mirror objectives of the above described kind is shown in FIGS. 5*a* and 5*b*. The two mirror objectives, the bodies, are disposed adjacent to each other and one of them (on the left) is used for illuminating an object 5, while the other one (on the right) is used for imaging the object 5 in question. The illuminating body as well as the imaging body each consist of a convex lens 1 and a further lens 4 which together enclose a secondary mirror 3, and a primary mirror 2 arranged in connection to the convex lens 1. Furthermore the bodies are provided with input and output slots 10, 11. The reference numeral 8 denotes a light body whose light is projected onto the object 5 and is then imaged on the detector line 9. As is shown in FIG. 5*b* the aperture of the primary mirror 2 in the illuminating body, the mirror objective on the left, may be larger than the primary mirror 2 in the imaging body, the mirror objective on the right. In the embodiment according to FIG. 5, the adjacent surfaces of the illuminating body and the imaging body consist of flat surfaces 12, 13. However, as in the case of the optical mirror systems described with reference to FIGS. 1–4, the bodies may be circular cylindrical. The object 5 is disposed in alignment with the flat surfaces 12, 13 in the embodiment shown.

What is claimed is:

1. An optical arrangement having a mirror objective for imaging a planar object onto an image plane, comprising

a lens having an input surface toward the object, an output surface toward the image plane, and a geometric axis extending between said surfaces,

a primary mirror arranged on the output surface and centrally located on the geometric axis,

a secondary mirror on the input surface and displaced from the geometric axis so that the first and second mirrors together with the lens establish an eccentric N-shaped radiation path, the object and the image being situated on opposite sides of the geometric axis.

2. An optical arrangement as claimed in claim 1, characterized in that an input slot is disposed in front of the input surface and an output slot is disposed after the output surface in order to together with the shaping of the mirrors delimit the radiation beam passing through the mirror objective.

3. An optical arrangement as claimed in claim 1, characterized in that a further lens is disposed adjacent to said lens, one of the reflecting surfaces being enclosed between the two lenses.

4. An optical arrangement as claimed in claim 1, characterized in that a collimator lens is disposed near the object plane of the mirror objective.

5. An optical arrangement as claimed in cliam 1, having the further including a second mirror objective said two mirror objectives arranged with parallel geometrical axes and adjacent to each other, and in that one of the mirror objectives is used for illuminating the object while the other mirror objective is used for imaging the object.

* * * * *

United States Patent [19]

Suda et al.

[11] **Patent Number: 4,855,777**

[45] **Date of Patent: Aug. 8, 1989**

[54] **APPARATUS FOR DETECTING THE FOCUS ADJUSTED STATE OF AN OBJECTIVE LENS**

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[73] Assignee: **Canon Kabushiki Kaisha,** Tokyo, Japan

[21] Appl. No.: **162,575**

[22] Filed: **Mar. 1, 1988**

[30] **Foreign Application Priority Data**

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Mar. 2, 1987 [JP] Japan 62-047246
Mar. 2, 1987 [JP] Japan 62-047247
Mar. 2, 1987 [JP] Japan 62-047248

[51] **Int. Cl.**[4] **G03B 3/00**
[52] **U.S. Cl.** **354/402;** 354/404
[58] **Field of Search** 354/400, 402, 404

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Primary Examiner—Russell E. Adams
Attorney, Agent, or Firm—Fitzpatrick, Cella, Harper & Scinto

[57] **ABSTRACT**

An focus detecting apparatus has a scanning plate disposed on or near the predetermined imaging plane of an objective lens and reciprocally movable to grating-scan the image of an object, a mask having an aperture adjacent to the scanning plate and movable to a desired position in a plane perpendicular to the optic axis of the objective lens to determine a range for detection, a plurality of light-receiving devices for receiving light fluxes passed through the scanning plate and the mask and outputting a signal regarding the focus adjusted state of the objective lens, and a field lens for relating the light fluxes entering the light-receiving devices to each other so as to pass through different areas of the exit pupil of the objective lens.

14 Claims, 6 Drawing Sheets

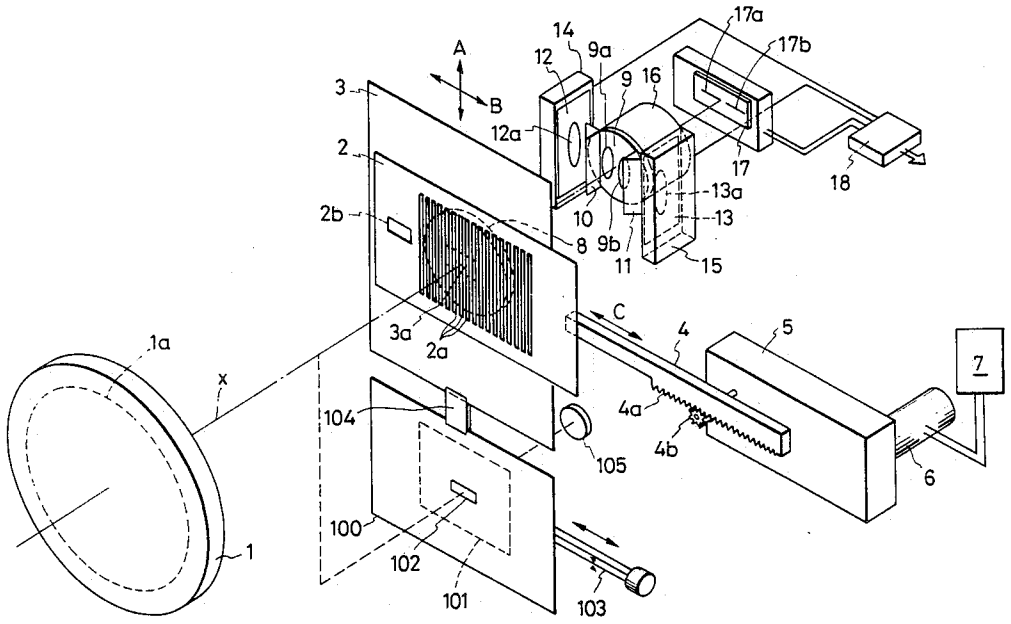


FIG. 1A

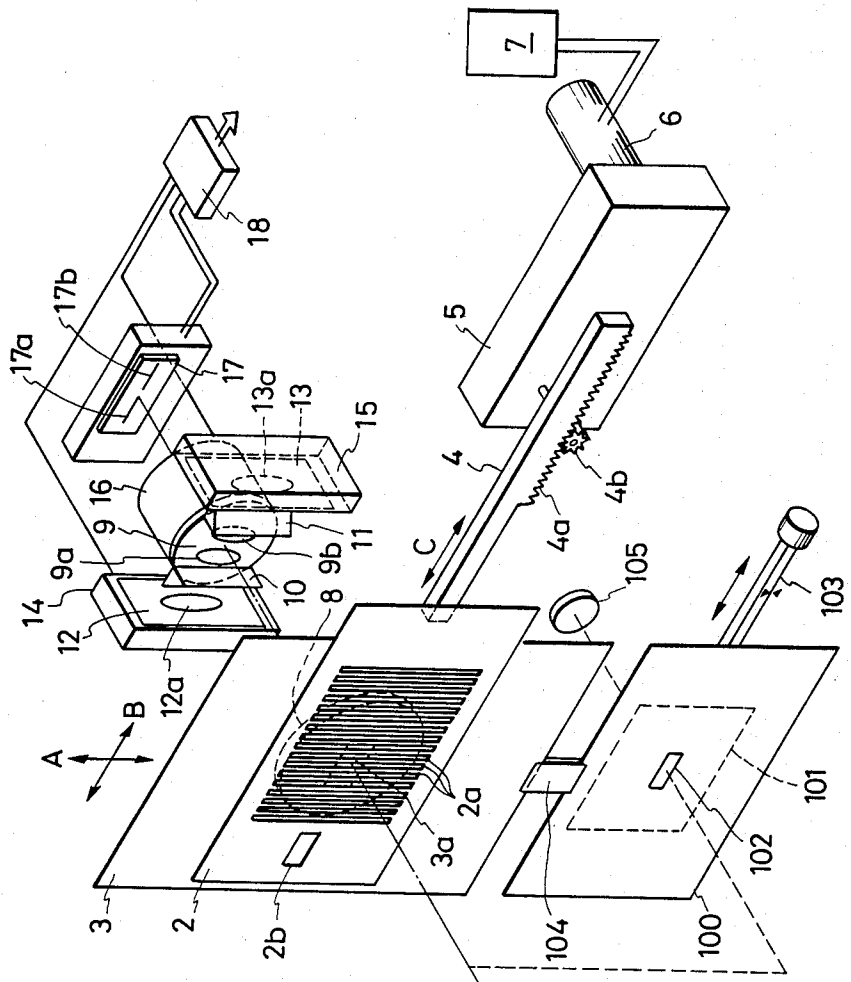

7
6
18
17b
17a
17
13a
13
15
5
4
4b
4a
16
9
9a
14
12
11
9b
10
8
C
105
103
12a
A
B
2a
3a
101
102
3
2
2b
104
100

FIG. 1B

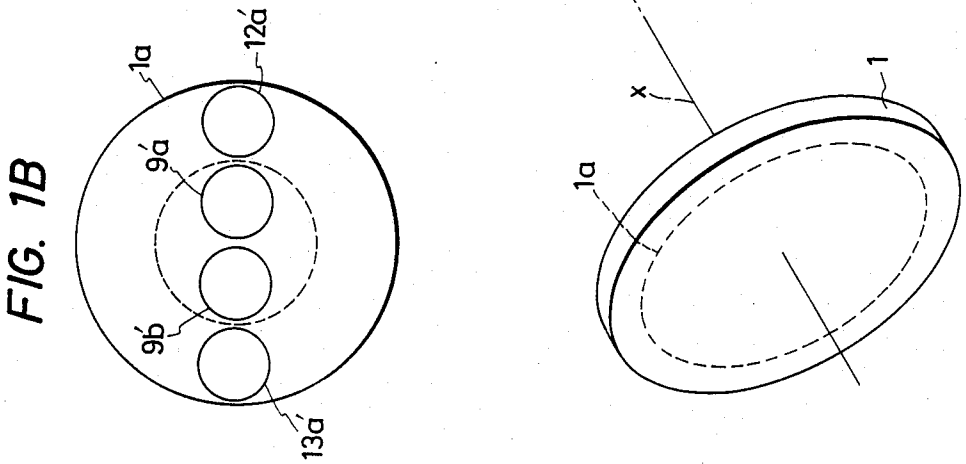

1a
12á
9á
9b́
13á
x
1
1a

FIG. 2

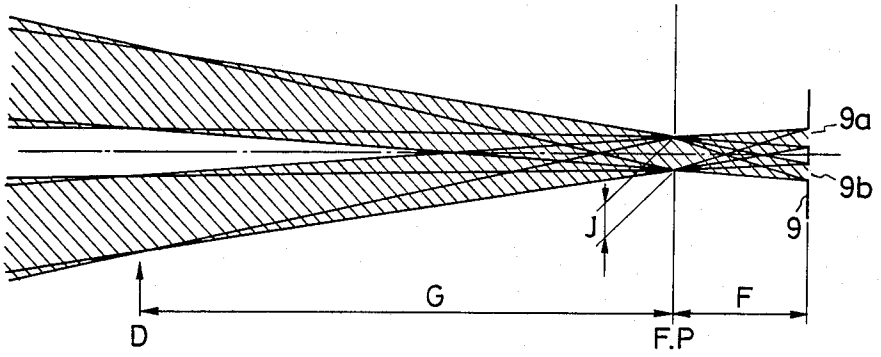


FIG. 3

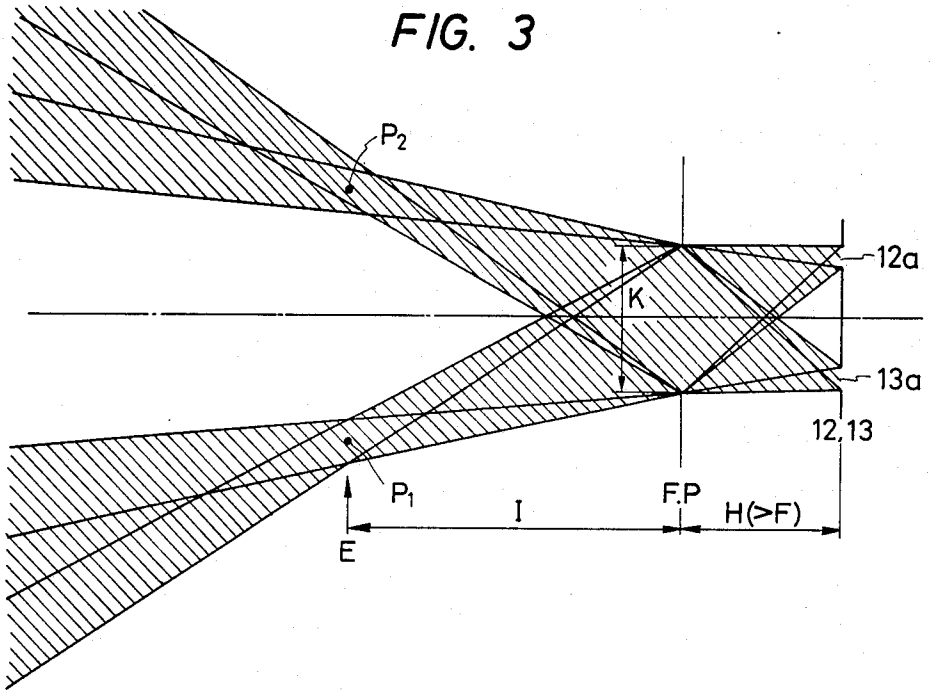


FIG. 4

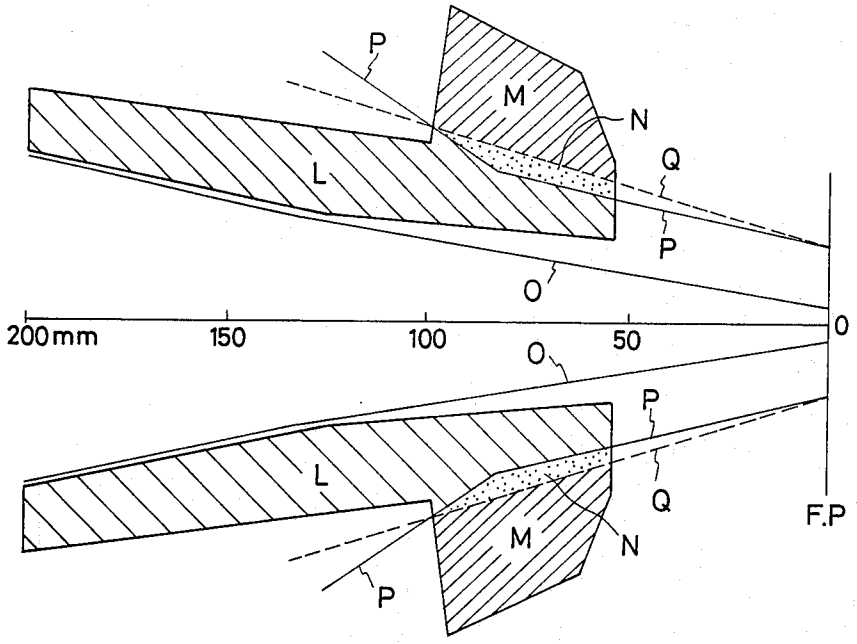


FIG. 5

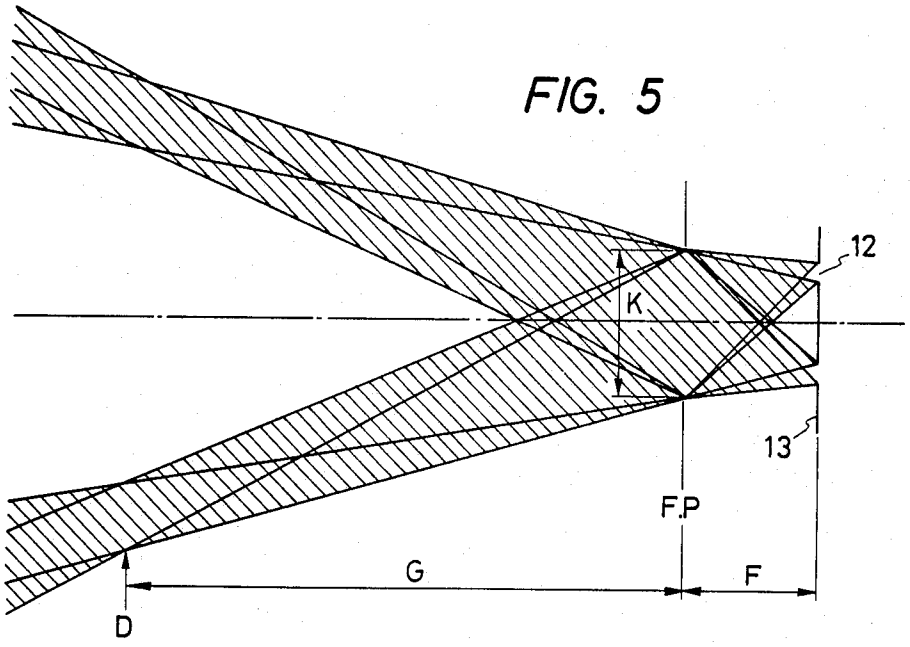


FIG. 6

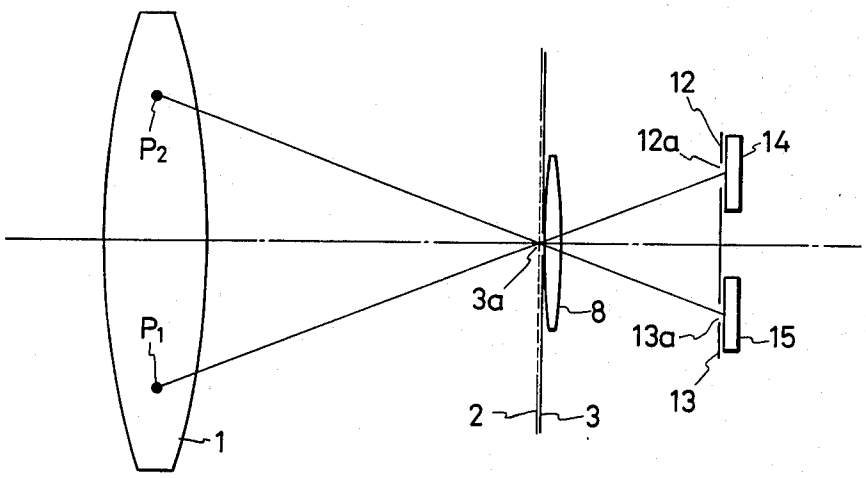


FIG. 7

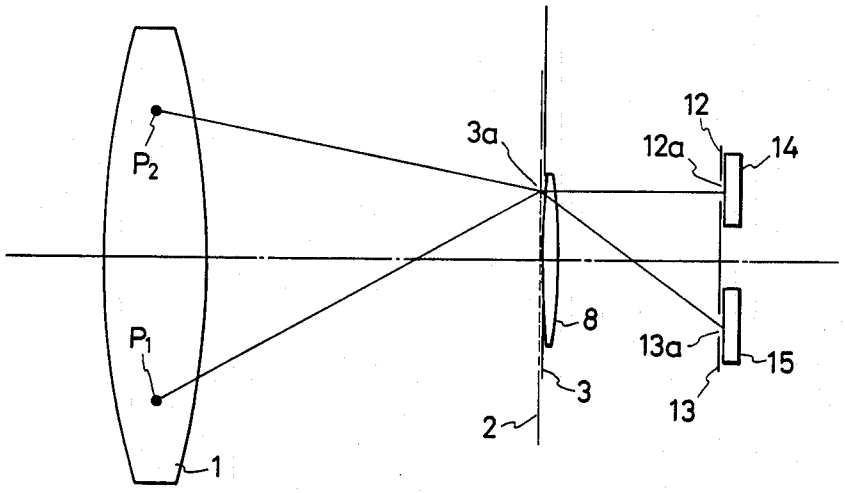


FIG. 8

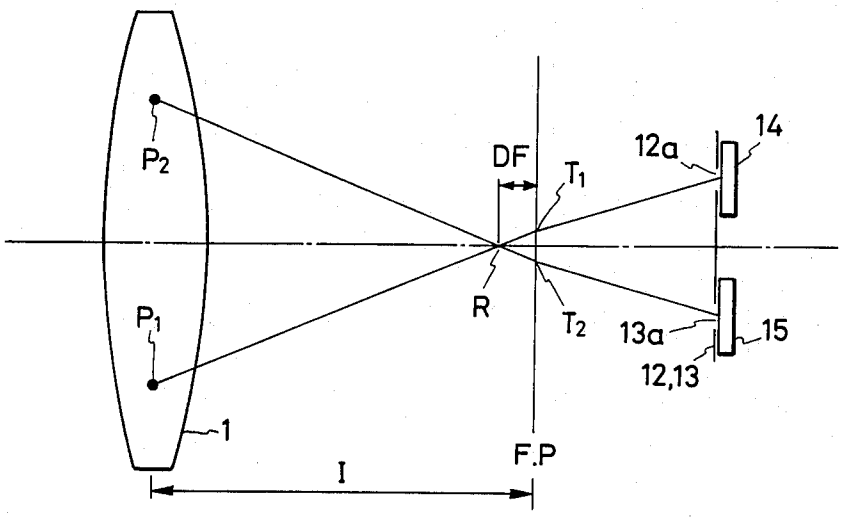

P2
P1
1
I
DF
T1
R
T2
F.P
12a
14
13a
15
12,13

FIG. 9

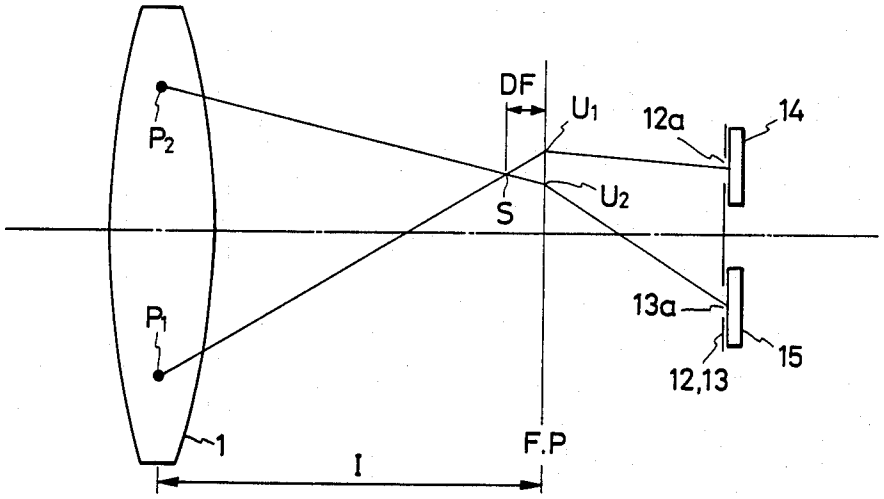

P2
P1
1
I
DF
U1
S
U2
F.P
12a
14
13a
15
12,13

FIG. 10A

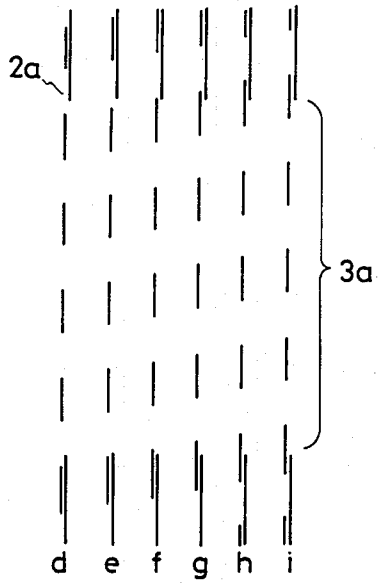


FIG. 10B

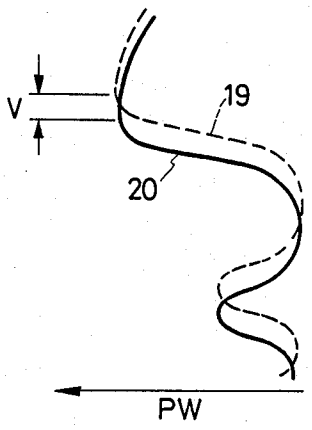
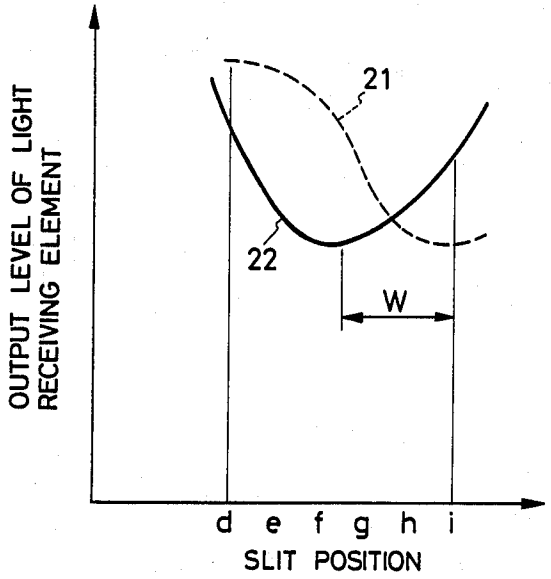


FIG. 11



APPARATUS FOR DETECTING THE FOCUS ADJUSTED STATE OF AN OBJECTIVE LENS

BACKGROUND OF THE INVENTION

Field of the Invention

This invention relates to a focus detecting apparatus, and in particular to a focus detecting apparatus suitable for a photographic camera, a video camera or the like in which distance measurement can be accomplished at any position of an object.

Focus detecting apparatuses of various types have heretofore been proposed, and in principle, in any of them, distance measurement has been effected at the center of the picture plane of the finder field, i.e., on the optic axis of the objective lens, irrespective of the size of the distance measuring area. Therefore, there has been no problem when the main portion of an object to which the objective lens is to be focused is set at the center of the picture plane. However, when it is desired to set the main portion of the object at a position other than the center of the picture plane, it has been necessary to turn the camera so that the main portion of the object lies at the center of the picture plane and focus the objective lens, and then return the object to a desired position on the picture plane and re-set the picture plane. So, if a focus detecting apparatus which enables the distance measuring field to be moved is constructed, the above-noted problem will be solved, but in such case, the range in which distance measurement is possible, i.e., the length of the distance measuring field, must naturally be made great.

For example, when a light flux passed through the photo-taking lens is utilized and a light-receiving element for focus detection is fixed and focus detection is to be effected within this length of the distance measuring field, it is necessary to form the object image on the light-receiving element even if the imaged point of the object image moves. This has led to the problem that the light-receiving surface of the light-receiving element must have a wide area.

On the other hand, U.S. Pat. No. 3,553,455 shows an apparatus in which two images of an object (which have a parallax) are scanned by a slit. In addition, an apparatus in which two images formed by a light flux passed through an objective lens are scanned by a slit is known from Japanese Patent Publication No. 37957/1971. However, any of these apparatuses is such that the center of the distance measuring field coincides with the optic axis of the objective lens. That is, distance measurement is effected in the central region of the picture plane of the viewfinder.

Also, German Patent No. 2156617 discloses a technique in which the image is scanned, but distance measurement is effected at the center of the picture plane. As other focus detecting apparatuses, there are known U.S. Pat. Nos. 4,636,627, 4,634,255, 4,634,557, 4,670,645, 4,632,532 and 4,560,863.

SUMMARY OF THE INVENTION

It is an object of the present invention to enable the focus detection of an objective lens to be accomplished for an object at a desired position in the field of view.

It is another object of the present invention to enable a desired one of a plurality of detecting methods to be selected.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. **1A** and **1B** and FIGS. **3** to **11** illustrate various elements in an embodiment of the present invention.

FIG. **1A** is a perspective view of the optical system of a focus detecting apparatus.

FIG. **1B** illustrates the divided condition of the exit pupil of an objective lens.

FIG. **2** illustrates the effective light fluxes when a focus detecting system according to the prior art is used with the focus detecting system of the present invention.

FIG. **3** illustrates the effective light fluxes of the focus detecting system.

FIG. **4** illustrates the exit pupil position of a popular interchangeable objective lens for a single-lens reflex camera.

FIG. **5** illustrates the effective light fluxes when the position of the stop of the focus detecting system is changed.

FIG. **6** illustrates the optical path when the distance measuring field of the focus detecting system is on the optic axis.

FIG. **7** illustrates the optical path when the distance measuring field of the focus detecting system is off the optic axis.

FIGS. **8** and **9** illustrate the image positions by defocus in the focus detecting system, FIG. **8** showing a case where the distance measuring field is on the optic axis, and FIG. **9** showing a case where the distance measuring field is off the optic axis.

FIGS. **10A** and **10B** illustrate the relative positional relation between two object images and slits.

FIG. **11** illustrates the relation between the slits and the output values from two light-receiving elements.

DESCRIPTION OF THE PREFFERRED EMBODIMENT

FIG. **1** is a perspective view of an embodiment of a focus detecting apparatus according to the present invention. In FIG. **1**, there is shown a first focus detecting system according to the present invention and also an auxiliary second focus detecting system. In the figure, the reference numeral **1** designates an objective lens for forming an object image, and X denotes the optic axis thereof. The first and second focus detecting systems are provided rearwardly of the predetermined imaging plane of the objective lens **1**. The predetermined imaging plane may be either a primary imaging plane or a re-imaging plane relaying it. The reference numeral **2** designates a slit member having, for example, a rectangular opening portion **2***b* and a grating portion having a plurality of slits **2***a* and movable in the scanning direction of arrow C. The slit member **2** is positioned substantially on the predetermined imaging plane of the objective lens **1**. A rack **4***a* is secured to the slit member **2** and is driven by a motor **6** through a pinion gear **4***b* and a gear box **5**. The reference numeral **7** denotes a control circuit for reciprocally moving the member **2** so that the slits **2***a* scan the image and setting the member **2** so that the rectangular opening **2***b* is positioned on the optic axis of the objective lens. The reference numeral **3** designates a field mask having, for example, a rectangular aperture **3***a* and movable in the directions of arrows A and B.

The rectangular aperture **3***a* of the field mask **3** is designed such that the length thereof in the direction of arrangement of the slits **2***a* of the slit member **2** is about

an integer times the length of one pitch of the slits, said integer including 1.

The reference numeral 8 denotes a field lens disposed near the predetermined imaging plane, the reference numerals 12 and 13 designate the stops of the first focus detecting system, the reference numeral 9 denotes the stop of the second focus detecting system, and the reference numerals 14 and 15 designate light-receiving elements constituting first light-receiving means. The light-receiving elements 14 and 15 are arranged in the scanning direction with the optic axis X interposed therebetween. The reference numeral 17 denotes second light-receiving means, i.e., a light-receiving device, having two light-receiving element arrays 17*a* and 17*b*. Instead of two light-receiving element arrays, two ranges of a single element array may be electrically designated. The reference numeral 16 designates a secondary imaging lens having convex lenses behind stop openings 9*a* and 9*b*, respectively. The reference numerals 10 and 11 denote reflecting members for bending the optical path to make the apparatus compact.

The reference numeral 18 designates a calculating circuit using the output signals from the light-receiving elements 14 and 15 and the output signal of the light-receiving device 17 to calculate information indicative of the focus adjusted state of the objective lens.

The reference numeral 100 denotes a transparent finder field member, the reference numeral 101 designates the finder field, the reference numeral 102 denotes a frame for indicating the range of distance measurement in the finder field, and the reference numeral 103 designates a distance measuring position selecting lever which can be moved by the operator from the outside of a casing, not shown. The reference numeral 104 denotes a connecting member for connection with the field mask 3, and the reference numeral 105 designates an eyepiece. A viewfinder optical system for directing a light flux from the view field to the finder field is not shown.

The finder field member 100 may be moved through the connecting member 104 in response to the movement of the field mask 3 so as to display the range of distance measurement in the finder field.

Instead of the field mask 3 being moved, a plurality of ranges of distance measurement may be set on a liquid crystal display plate and one of these ranges may be selectively made transparent and the surroundings thereof may be made opaque, whereby the distance measuring field may be designated.

The first focus detecting system according to the present invention will now be described. The first focus detecting system is for effecting the distance measument at any position in the finder field, and functions when the aperture 3*a* of the field mask 3 is set at any position in the effective aperture of the field lens, particularly, a position off the optic axis, and the aperture 3*a* overlaps the slits 2*a* of the slit member 2. The constituent members of the first focus detecting system disposed subsequently to the field mask 3 are the field lens 8 common to the second focus detecting system, the reflecting members 10 and 11 disposed outside the openings 9*a* and 9*b* of the second stop 9 and each having a trigonal inclined surface as a reflecting surface, the stop 12 for limiting the light flux reflected by the reflecting member 10, the stop 13 for limiting the light flux reflected by the reflecting member 11, and the light-receiving elements 14 and 15.

In the first focus detecting system, as will be described later, the slit member 2 is scanned in the direction of arrow C and at this time, correspondingly to said scanning, the phases of the variations in the output signals from the light-receiving elements 14 and 15 are detected to thereby accomplish focus detection.

FIG. 1B illustrates the divided condition of the exit pupil of the objective lens 1 in the present invention. In the figure, the reference character 1*a* designates the exit pupil of the objective lens 1, the reference characters 12*a*′ and 13*a*′ denote the inversely projected images of the stop openings 12*a* and 13*a*, respectively, of the stops 12 and 13 onto the surface of the exit pupil 1*a* by the field lens 8, and the reference characters 9*a*′ and 9*b*′ designate the inversely projected images of the stop openings 9*a* and 9*b*, respectively, of the stop 9 onto the surface of the exit pupil 1*a* by the field lens 8.

In the present embodiment, the exit pupil 1*a* of the objective lens 1 is divided into two pairs of areas as previously described by disposing the stop openings 12*a* and 13*a* of the stops 12 and 13 in more spaced apart relationship with the optic axis than the stop openings 9*a* and 9*b* of the stop 9.

The second focus detecting system will now be described. The second focus detecting system functions only when the rectangular opening 2*b* of the slit member 2 and the aperture 3*a* of the field mask 3 are both set on the optic axis of the objective lens 1. At this time, the light flux of the second focus detecting system is limited by the aperture 3*a* of the field mask 3 because the rectangular aperture 3*a* of the field mask 3 is made smaller than the opening 2*b* of the slit member 2.

The constituent members of the second focus detecting system disposed subsequently to the field mask 3 are the field lens 8, the stop 9 having two openings 9*a* and 9*b*, the secondary imaging lens 16 and the second light-receiving means 17 having two light-receiving element arrays 17*a* and 17*b*.

The second focus detecting system is particularly suitable for effecting focus detection highly accurately when the defocus amount of the objective lens 1 is great. The focus detection of the second focus detecting system is accomplished by the already known method proposed, for example, in Japanese Laid-Open patent application No. 101513/1985.

In the present embodiment, the first focus detecting system and the second focus detecting system share the field lens 8.

In many objective lenses used in photographic cameras, video cameras, etc., when the focal length is short and the lens is bright, the exit pupil position from the imaging plane is generally short, and when the focal length is long and the lens is dark, the exit pupil position from the imaging plane is long. Therefore, the first stop openings 12*a* and 13*a* in the first focus detecting system chiefly directed to bright objective lenses and having a variable distance measuring field are set so as to lie more outwardly relative to the optic axis than the second stop openings 9*a* and 9*b* in the second focus detecting system having a fixed distance measuring field, thereby achieving effective utilization of a light beam.

Also, the distance from the principal point of the image space of the field lens 8 to the first stop openings 12*a*, 13*a* is set so as to be longer than the distance from the pincipal point of the image space of the field lens 8 to the second stop openings 9*a*, 9*b*.

Thus, the inversely projected images of the first and second stop openings onto the objective lens side by the

field lens **8** may be formed near the exit pupil position of the objective lens, and even if an objective lens of any focal length is mounted, effective utilization of the light flux can be ensured and improved accuracy of focus detection is achieved.

That is, the first stop openings **12***a* and **13***a* are such that the inversely projected images thereof are formed at positions near the predetermined imaging plane of the objective lens **1**, and the second stop openings **9***a* and **9***b* are such that the inversely projected images thereof are formed at positions far from said predetermined imaging plane.

A description will now be given of effective light fluxes entering the light-receiving means in the first and second focus detecting systems. FIGS. **2** to **5** are optical path diagrams showing the light fluxes from the exit pupil of the objective lens **1** which enter the stops **9**, **12** and **13** disposed in the front faces of the light-receiving means in the respective focus detecting systems. FIG. **2** shows the case of the second focus detecting system, and FIG. **3** shows the case of the first focus detecting system.

In these figures, P1 and P2 designate the positions of the light rays passing through the centers of the openings **12***a* and **13***a* of the stops **12** and **13** in the exit pupil of the objective lens **1**. F.P denotes the predetermined imaging plane of the objective lens **1**, and the objective lens is positioned at the left side thereof and the first and second focus detecting systems are positioned at the right side thereof.

In the present embodiment, it is to be understood that the object image is formed near the predetermined imaging plane. The stops **9**, **12** and **13** are designed so as to be conjugate with the vicinity of the exit pupil position of the objective lens **1** with respect to the field lens **8**.

In FIG. **2**, a surface D designates a surface conjugate with the stop **1**, and in FIG. **3**, a surface E denotes a surface conjugate with the stops **12** and **13**.

In the present embodiment, the surface D is positioned more distantly from the predetermined imaging plane F.P than the surface E by setting the first stop openings **12***a*, **13***a* and the second stop openings **9***a*, **9***b* as previously described. J represents the length of the distance measuring field of the second focus detecting system, and K represents the length of the distance measuring field of the first focus detecting system. In FIGS. **2** and **3**, the portions indicated by hatching represent the effective light fluxes in the respective focus detecting systems. Generally, in order that focus detection maybe accurately accomplished in the first and second focus detecting systems when the phase difference between two images is detected to thereby effect focus detection, it is necessary that the exit pupil of the objective lens **1** have a width including the range of the effective light fluxes represented by hatching in FIGS. **2** and **3**. Therefore, the length K of the distance measuring field of the first focus detecting system in FIG. **3** means the total range over which the opening **3***a* of the field mask **3** is movable, and is relatively great as compared with that of the second focus detecting system. Thus, in the first focus detecting system, it becomes necessary to use an objective lens of small F-number which is relatively bright, that is, has a large exit pupil.

FIG. **4** shows, for information, the exit pupil position of an objective lens for a single-lens reflex camera such as a popular photographic camera and the size thereof.

In the figure, F.P indicates the predetermined imaging plane of the objective lens, the horizontal axis represents the optic axis, the scale indicates the distance from the predetermined imaging plane, and the vertical axis represents the size of the exit pupil. Ranges L, M and N represent areas in which the exit pupil of the objective lens in present. Depicting the effective light fluxes of the first and second focus detecting systems shown in FIGS. **3** and **2** while superposing them upon these areas, the effective light fluxes are present inside a straight line **0** in the second focus detecting system, and the effective light fluxes are present inside a straight line P in the first focus detecting system. That is, the second focus detecting system permits the use of an objective lens of the total range of the areas L, M and N, among objective lenses having an exit pupil within the range shown in FIG. **4**, and the first focus detecting system permits the use of a photo-taking lens having an exit pupil in the areas M and N in FIG. **4**.

In FIG. **4**, broken line Q indicates the effective light flux in a case where the position when the stop in the first focus detecting system has been projected onto the exit pupil of the objective lens is indentical to the projection position when the stop in the second focus detecting system has been projected onto the exit pupil of the objective lens. In this case, if use is made of an objective lens having an exit pupil position in the area N, the light flux is eclipsed and thus, the accuracy of distance measurement is reduced.

FIG. **5** shows the optical path of the then effective light flux. In this figure, the distance from the surface D conjugate with the stops **12** and **13** near the exit pupil position of the objective lens to the predetermined imaging plane F.P is shown as a distance G identical to that in the second focus detecting system shown in FIG. **2**.

FIGS. **6** to **11** illustrate the principle of distance measurement of the first focus detecting system of the present invention. Of these figures, FIGS. **6** and **7** are developed cross-sectional views of the first focus detecting system when the objective lens **1** is in the in-focus state. FIG. **6** depicts the principal ray passing through the center of the opening **3** *a* in the field mask **3** in a case where the opening **3***a* in the field mask **3***a* is positioned on the optic axis. FIG. **7** depicts the principal ray in a case where the opening **3***a* in the field mask **3** is positioned off the optic axis. In these figures, P1 and P2 are similar to those in the optical path diagram shown in FIG. **3**, that is, the projection positions of the light rays passing through the centers of the openings **12***a* and **13***a* of the stop on the exit pupil of the objective lens.

That is, P1 and P2 indicate the positions of the center of light intensity when the openings **12***a* and **13***a* of the stop have been projected onto the exit pupil. The surfaces of the stops **12** and **13** and the surface containing the points P1 and P2 are at positions conjugate with each other with respect to the field lens **8** and therefore, irrespective of the position of the opening **3***a* in the field mask **3**, the light rays from the points P1 and P2 arrive at the light-receiving elements **14** and **15**, respectively. Accordingly, even if the position of the opening **3***a* in the field mask **3** is set anywhere in the range of the length K of the distance measuring field shown in FIG. **3**, that is, even if distance measurement is effected anywhere with the opening **3***a* moved, the light flux from the object image enters the light-receiving elements **14** and **15** and therefore, distance measurement can be accomplished with the locations of the light-receiving elements fixed.

FIGS. 8 and 9 are developed cross-sectional views of the focus detecting system when the objective lens 1 is defocused by a predetermined amount DF. FIG. 8 is an illustration depicting the principal ray passing through the imaging point R on the optic axis, and FIG. 9 is an illustration depicting the principal ray passing through the imaging point S off the optic axis. The focus detecting system for detecting the phase difference between two images to thereby detect the in-focus state calculates the defocus amount from the spacing between the centers of light intensity of two object images on the predetermined imaging plane F.P. Therefore, it is necessary that irrespective of the position of the opening 3*a* in the field mask 3, the spacing between the centers of light intensity of two object images (for example, in FIG. 8, $\overline{T1, T2}$) be constant for a predetermined defocus amount. The relation between the then defocus amount DF and the spacing $\overline{T1, T2}$ will now be described with reference to FIGS. 8 and 9.

In FIG. 8,

$\angle P2, R, P1 = \angle T2, R, T1$ and $\angle R, P2, P1 = \angle R, T2, T1$.

Accordingly, $\Delta P2, p1, R \infty \Delta T2, T1, R$ and when the distance from the exit pupil of the objective lens 1 to the predetermined imaging plane F.P is I, the following equation is established:

$$\overline{T1, T2} = \frac{DF}{I - DF} \overline{P1, P2} \quad (1)$$

Likewise, in FIG. 9,

$\angle P2, S, P1 = \angle U2, S, U1$ and $\angle S, P2, P1 = \angle S, U2, U1$.

Accordingly, $\Delta P2, P1, S \infty \Delta U2, U1, S$ and the following equation is established:

$$\overline{U1, U2} = \frac{DF}{I - DF} \overline{P1, P2} \quad (2)$$

From equations (1) and (2),

$$\overline{T1, T2} = \overline{U1, U2}.$$

That is, when the defocus amount DF is constant, the spacing between the centers of light intensity of two images does not vary for any of the imaging points R and S. Accordingly, even if the opening 3*a* in the field mask 3 is moved to any position in the distance measuring field, the defocus amount can be found with good accuracy. That is, in the present embodiment, the opening 3*a* in the field mask 3 may be located anywhere, and it is not necessary to use a different focus detecting system depending on the difference in the distance measuring field, and stable focus detection can be accomplished by only the first focus detecting system.

FIGS. 10A, 10B and 11 illustrate output signals obtained from the light-receiving elements 14 and 15 which have received the light flux passing through the slits 2*a* of the slit member 2 and the opening 3*a* in the field mask 3 when the slit member 2 is scanned. The basic principle of the detecting method shown in these figures in the heretofore practised method of detecting the amount of deviation between two images.

In the present embodiment, the length of the opening 3*a* the field mask 3 in the direction of arrangement of the slits 2*a* is constructed in such rectangular shape which is, for example, about four times the length of a slit 2*a* (the sum of the area transmitting the light beam therethrough and the area not transmitting the light beam therethrough), whereby the output signals from the light-receiving elements 14 and 15 when the slit member 2 is moved are obtained in a stable state.

In FIG. 10A, d, e, f, g, h and i indicate the moved positions of the slits 2*a* , and in FIG. 10B, there are schematically shown the distributions of quantity of light of two object images 19 and 20 in the opening 3*a*. In FIG. 10B, the reference numerals 19 and 20 indicate the illumination distributions of the object images on the predetermined imaging plane F.P of the objective lens formed by the light fluxes passing through the openings 12*a* and 13*a*, respectively, of the stops 12 and 13.

In FIG. 10B, the horizontal axis represents illumination PW and the vertical axis represents the position on the predetermined imaging plane. The object images 19 and 20 having such illumination distributions are sampled by the slits 2*a* of the slit member 2 disposed substantially on the predetermined imaging plane and the opening 3*a* in the field mask 3, and enter the light-receiving elements 14 and 15, respectively. As shown in FIG. 1, the slit member 2 is moved in the direction of arrow C by the motor 7, and the then positional relations thereof with the object images are as indicated by d to i in FIGS. 10A and 10B. The width of the opening 3*a* in the field mask 3 is designed so as to be an integer times (in FIG. 10A, four times) the slit pitch and therefore, in any of the positions d to i, the area of the light-transmitting area formed by the opening 3*a* in the field mask 3 and the slits 2*a* is kept constant. Accordingly, the outputs from the respective light-receiving elements 14 and 15 conforming to the positions d to i of the slits vary with a phase difference corresponding to the amount of deviation between the two object images. In the case of the object images having the illumination distributions shown in FIG. 10B, the outputs from the light-receiving elements 14 and 15 conforming to the positions d to i of the slits are as indicated by curves 21 and 22 in FIG. 11. In FIG. 11, the horizontal axis represents the position of the slits 2*a* and the vertical axis represents the output values from the light-receiving elements 14 and 15. The curve 21 indicated by broken line corresponds to the illumination distribution 19 of the object image in FIG. 10B, and the curve 22 indicated by solid line corresponds to the illumination distribution 20 of the object image in FIG. 10B. Also, the amount of deviation V between the object images in FIG. 10B is equal to the phase difference W between the output distributions 21 and 22 from the light-receiving elements 14 and 15 in FIG. 11.

The calculation of the defocus amount of the objective lens 1 can be accomplished in the following manner. When the defocus amount is *DF*, $\overline{T1, T2} = V$ in FIG. 8 and there is the relation that $V: \overline{P1, P2} = DF:(I - DF)$. Accordingly, the following equation is derived:

$$DF = \frac{VI}{P1, P2 + V} \quad (3)$$

Accordingly, the defocus amount DF can be found from equation (3).

As a method of detecting the amount of image deviation in the present embodiment, the outputs from the light-receiving elements 14 and 15 corresponding to the position of the slit member 2 may be dealt with instead of the outputs from the light-receiving elements 17*a* and 17*b* of the second focus detecting system, and according

to this, the first focus detecting system and the second focus detecting system can utilize a single method of detecting and calculating the amount of image deviation.

As described above, in the present embodiment, the focus detection at any position in the finder field is possible by the first focus detecting system. Alternatively, by using the first and second focus detecting systems together, the design may be made such that for example, in the second focus detecting system, detection of great defocus of the order of 30 mm is effected chiefly on the optic axis and in the first focus detecting system, movement of the distance measuring field is effected. From these features of the respective focus detecting systems, for example, the following application is conceivable. Where this focus detecting apparatus is applied to a single-lens reflex camera or the like, the second focus detecting system is used to focus the photo-taking lens to a main object at the center of the picture plane, and then the main object is framed to any position on the picture plane, whereafter the main object is pursued by the first focus detecting system to thereby accomplish photographing.

According to the present invention, there can be achieved a focus detecting apparatus which can move the distance measuring field to any position to accomplish focus detection by a very simple construction in which the slit member having a plurality of slits is scanned and the opening in the field mask is made movable to any position in the finder field and the light beam passed through the slits and the opening is received by two light-receiving elements through a stop.

Also, according to the present invention, there can be achieved a focus detecting apparatus which uses the two first and second focus detecting systems set as previously described, whereby for example, in the first focus detecting system, focus detection of small defocus is possible in any distance measuring field and in the second focus detecting system, focus detection of great defocus is possible in a predetermined distance measuring field on the optic axis.

Particularly, there can be achieved a focus detecting apparatus in which the exit pupil of the objective lens is divided into four areas forming two pairs and used as previously described, whereby in the second focus detecting system, focus detection of great defocus in a predetermined field in a dark objective lens of great F-number to a bright objective lens of small F-number is accomplished and in the first focus detecting system, focus detection of small defocus of a variable distance measuring field chiefly in a bright objective lens of small F-number is accomplished.

Further, there can be achieved a focus detecting apparatus of simple construction in which some optical members of the first and second focus detecting systems are made common, whereby bulkiness of the entire apparatus is effectively prevented in spite of the two focus detecting systems being used.

I claim:

1. An apparatus for detecting the focus adjusted state of an objective lens, comprising:

scanning means having optical slits and disposed on or near a predetermined imaging plane of said objective lens for scanning the image of an object in a predetermined scanning direction;

aperture setting means disposed on or near said predetermined imaging plane for (1) providing an aperture which determines a range for detection, (2) moving the aperture to a desired position in the field of view, and (3) masking a light beam from entering portions other than the aperture;

a plurality of light-receiving device for receiving light fluxes passed through said optical slits and said aperture, and for outputting a signal regarding the focus adjusted state of said objective lens; and

means for relating the light fluxes entering said light-receiving devices with each other so that they pass through different areas of the exit pupil of said objective lens.

2. An apparatus according to claim **1**, wherein the length of said aperture is substantially an integer times the pitch of the optical slits arranged in the scanning direction.

3. An apparatus according to claim **1**, wherein said means for relating has a field lens.

4. An apparatus according to claim **1**, wherein said scanning means has an opaque plate having slits arranged in the scanning direction, and drive means for reciprocally moving said opaque plate.

5. An apparatus according to claim **1**, wherein said aperture setting means has a mask provided with said aperture, and displacing means for displacing said mask in a direction perpendicular to the optic axis of said objective lens.

6. An apparatus according to claim **1**, wherein said light-receiving devices are disposed with the optic axis of said objective lens interposed therebetween.

7. An apparatus according to claim **6**, wherein each of said light-receiving devices is a single light-receiving element.

8. An apparatus according to claim **1**, further comprising with a viewfinder, display means for displaying said range for detection in the field of said viewfinder, and changing means for changing the position of the display by said display means in conformity with the movement of the position of said aperture.

9. An apparatus for detecting the focus adjusted state of an objective lens, comprising:

a first focus detecting system, including first and second photodetector means, for receiving light fluxes passed through first and second areas of the exit pupil of said objective lens onto said first and second photodetector means, and for forming a signal regarding the focus adjusted state of said objective lens, said first focus detecting system being capable of changing a detection range;

a second focus detecting system, including third and fourth photodetector means, for receiving light fluxes passed through third and fourth areas of the exit pupil of said objective lens onto said third and fourth photodetector means, and for forming a signal regarding the focus adjusted state of said objective lens, said second focus detecting system having a fixed detection range;

optical means for relating the light flux entering said first photodetector means and passed through said first area, the light flux entering said second photodetector means and passed through said second area, the light flux entering said third photodetector means and passed through said third area, and the light flux entering said fourth photodetector means and passed through said fourth area; and

means for causing said first focus detecting system and said second focus detecting system to function alternatively.

10. An apparatus according to claim 9, wherein said optical means comprises a field lens disposed on or near the predetermined imaging plane of said objective lens.

11. An apparatus according to claim 9, wherein said means for causing said first and second focus detecting systems to function alternatively has a mask provided with a grating structure for scanning the light fluxes entering said first and second photodetector means and an aperture for regulating the light fluxes entering said third and fourth photodetector means.

12. An apparatus according to claim 9, wherein said first and second areas are set more inside than said third and fourth areas.

13. An apparatus according to claim 9, wherein said first and second photodetector means comprise photosensors, and said third and fourth photodetector means comprise arrays of photosensors.

14. An apparatus according to claim 10, wherein said first focus detecting system has first and second stops for regulating the light fluxes entering said first and second photodetector means, said second focus detecting system has third and fourth stops for regulating the light fluxes entering said third and fourth photodetector means, and the distance from the image field side principal point of said field lens to said first and second stops is longer than the distance from the image field side principal point of said field lens to said third and fourth stops.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 4,855,777

DATED : August 8, 1989

INVENTOR(S) : Suda, et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

[57] ABSTRACT:

Line 1, change "An" to --A--.

COLUMN 3:

Line 53, change "measument" to --measurement--.

COLUMN 4:

Line 65, change "pincipal" to --principal--.

COLUMN 5:

Line 37, change "stop 1" to --stop 9--.

Line 50, change "maybe" to --may be--.

Line 66, change "camera" to --camera,--.

COLUMN 6:

Line 41, change "opening 3 a" to --opening 3a--.

Line 42, change "field mask 3a" to --field mask 3--.

UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 4,855,777

DATED : August 8, 1989

INVENTOR(S) : Suda, et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

COLUMN 7:

Line 22, change " P2, p1, R∞ T2, T1, R" to -- P2, P1, R∞ T2, T1, R--.

Line 61, change "in" to --is--.

Line 64, change "3a the" to --3a in the--.

Line 65, change "rectangular" to --a rectangular--.

COLUMN 8:

Line 58, change "$DF = \frac{VI}{P1,\ P2 + V}$ (3)" to

$$--DF = \frac{VI}{\overline{P1,\ P2 + V}}$$ (3)--

COLUMN 9:

Line 59, change "I claim" to --We claim--.

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 4,855,777 Page 3 of 3

DATED : August 8, 1989

INVENTOR(S) : Suda, et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

COLUMN 10:

Line 4, change "light-receiving device" to --light-receiving devices--.

Line 34, delete "with".

COLUMN 11:

Line 12, change "more inside than" to --inside--.

Signed and Sealed this

Eleventh Day of September, 1990

Attest:

HARRY F. MANBECK, JR.

Attesting Officer

Commissioner of Patents and Trademarks

United States Patent [19]

Corbasson

[11] **Patent Number: 4,854,685**

[45] **Date of Patent: Aug. 8, 1989**

[54] **VARIABLE-FOCUS OBJECTIVE-LENS DEVICE AND A METHOD FOR THE CONTROL OF SAID DEVICE**

[75] Inventor: **Gérard Corbasson**, Saint-Heand, France

[73] Assignee: **Etablissements Pierre Angenieux**, Saint-Heand, France

[21] Appl. No.: **191,029**

[22] Filed: **Apr. 28, 1988**

[30] **Foreign Application Priority Data**

Apr. 29, 1987 [FR] France 87 06074

[51] **Int. Cl.**[4] **G02B 7/10**; G02B 15/16

[52] **U.S. Cl.** **350/427**; 350/429

[58] **Field of Search** 350/429, 427

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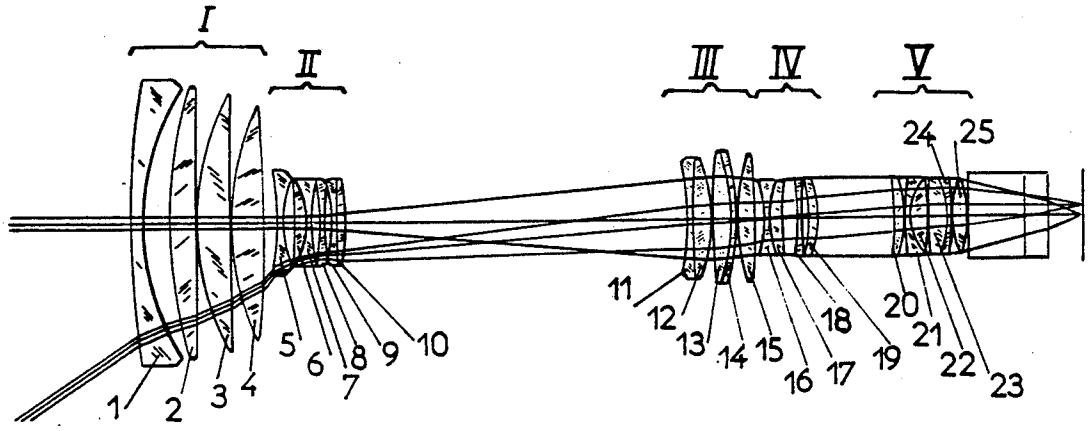
Primary Examiner—Bruce Y. Arnold
Assistant Examiner—Rebecca D. Gass
Attorney, Agent, or Firm—Young & Thompson

[57] **ABSTRACT**

Two movable groups of lenses forming a variator are controlled by means of a computer and these groups are accordingly subjected not only to the necessary displacements of each group for the progressive variations of focal length but also to a complementary longitudinal displacement for applying to the objective-lens system a focal-length multiplier coefficient having a value chosen by the operator. The device in accordance with the invention comprises a control system associated with a computer and capable of subjecting the two movable groups of lenses to a complementary longitudinal displacement in order to apply a focal length multiplier coefficient to the objective-lens system, another function of the computer being to produce the desired variation of the iris and the complementary displacements of the focusing groups in respect of each focal length. The longest possible focal length can thus be chosen as a function either of the selected numerical aperture or of the field to be covered.

3 Claims, 4 Drawing Sheets



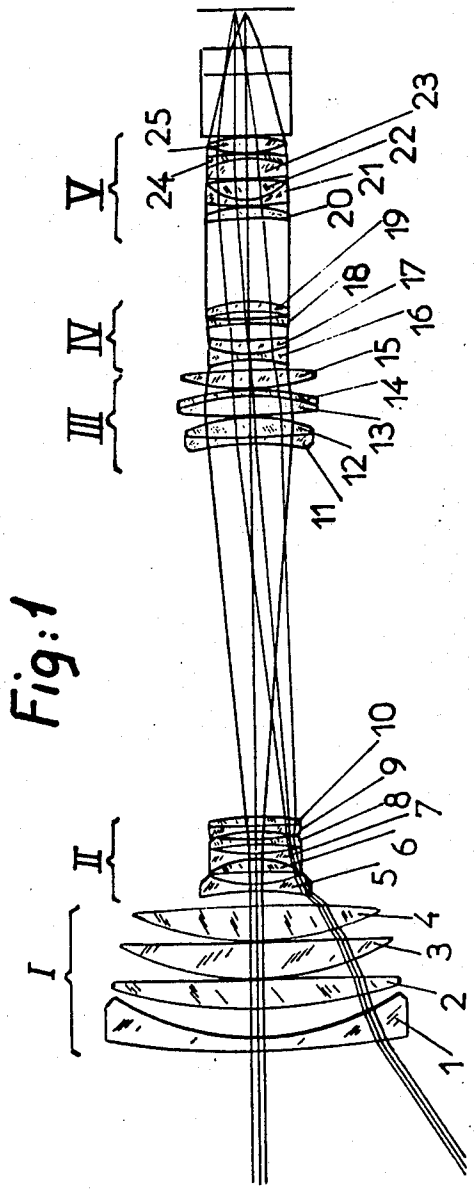

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Fig. 1

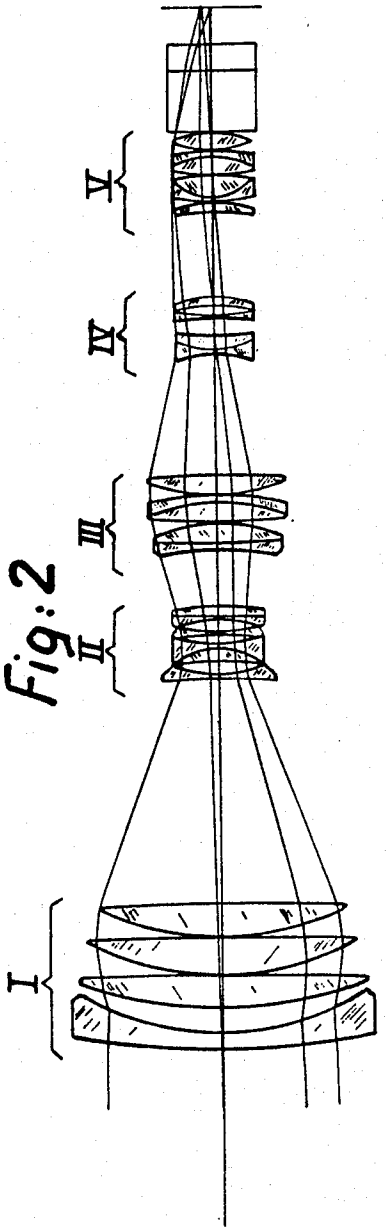
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Fig. 2

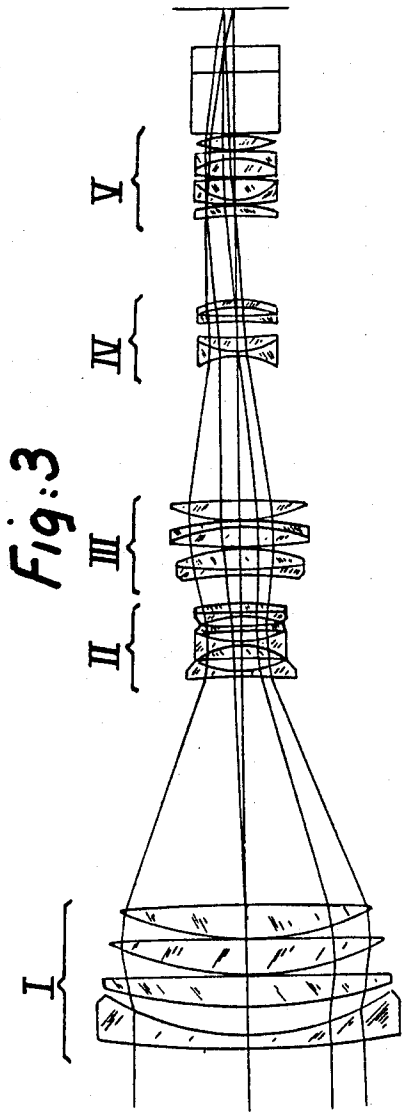


Fig. 3

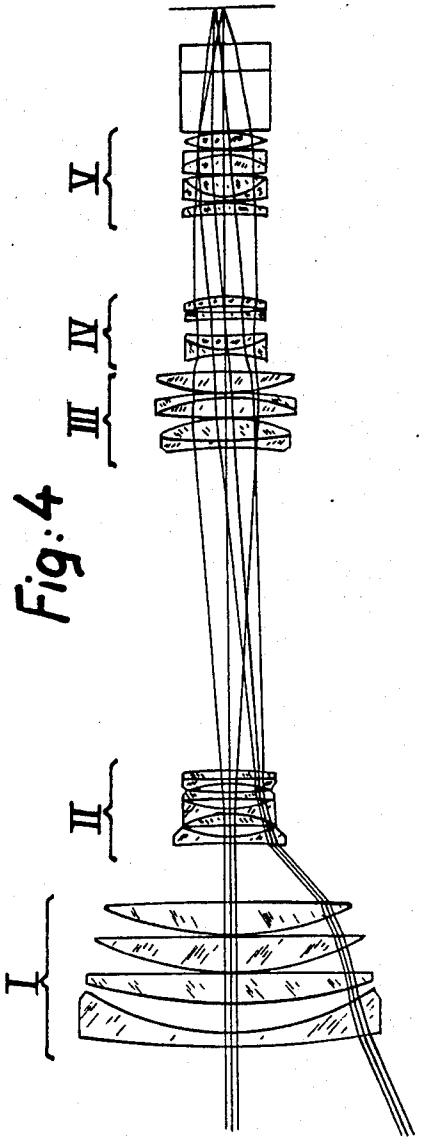


Fig. 4

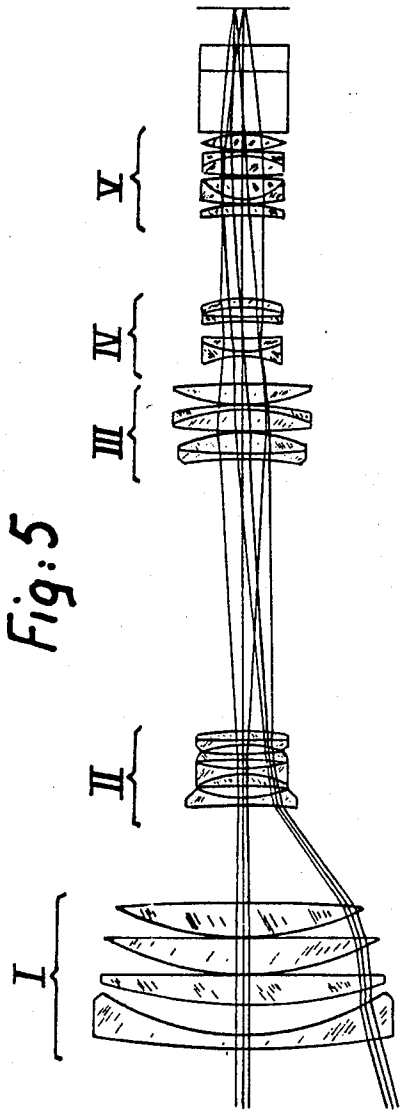


Fig. 5

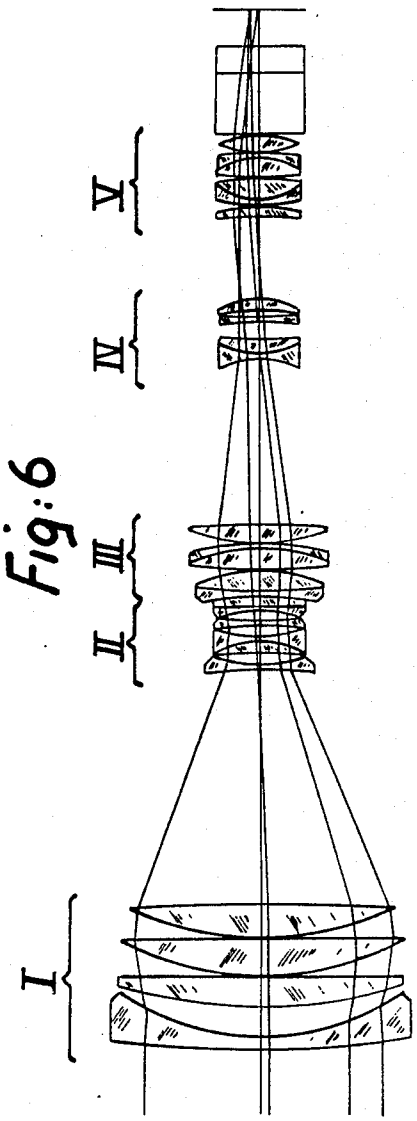
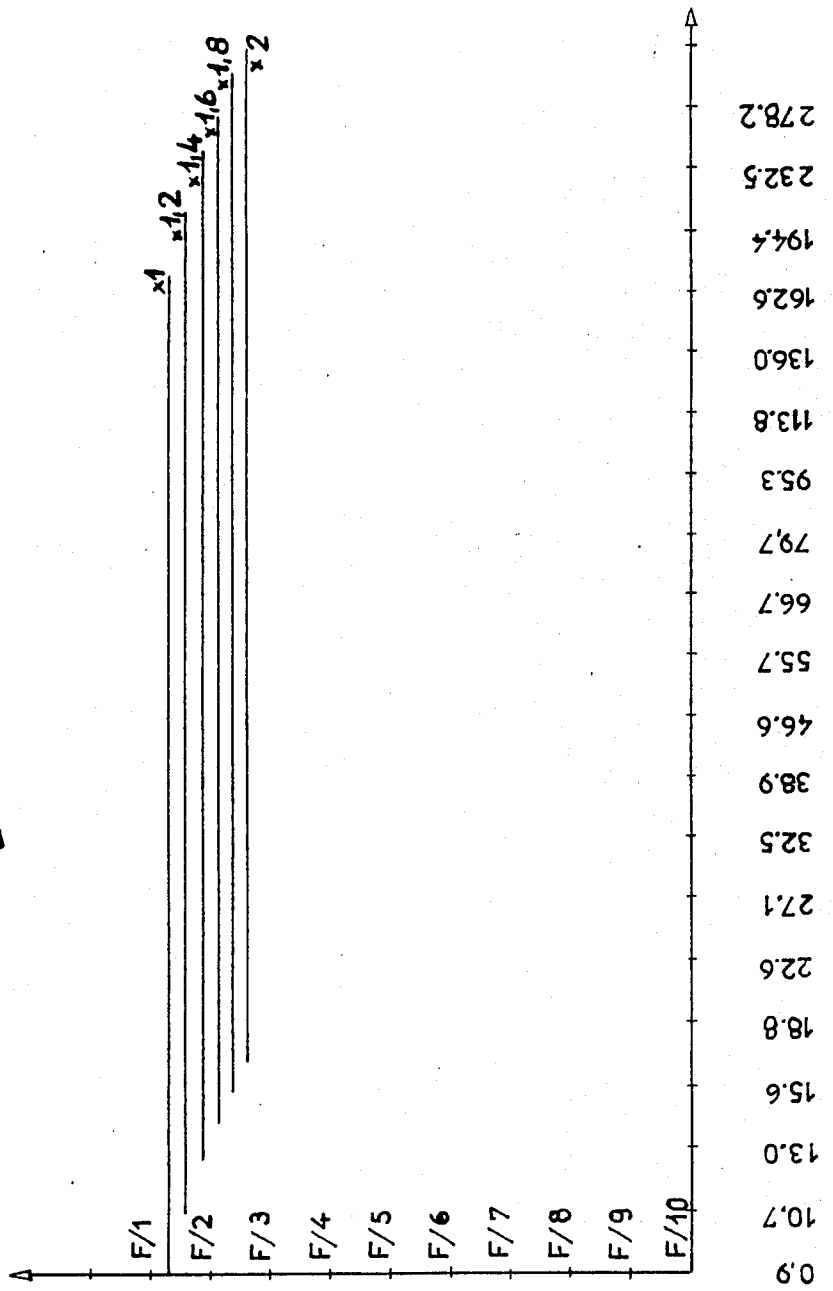


Fig. 6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136.0
162.6
194.4
232.5
278.2

Fig. 7

VARIABLE-FOCUS OBJECTIVE-LENS DEVICE AND A METHOD FOR THE CONTROL OF SAID DEVICE

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to variablefocus objective lenses which are more particularly intended to be employed in television studios.

2. Description of the Prior Art

Devices of this type are made up of several groups of lens elements, the displacements of which make it possible to obtain a variation of field at the same time as a still picture on the receiver irrespective of the focusing distance chosen. As a general rule, the function of variation of focal lengths is performed by two movable groups of lenses constituting a so-called "variator" whilst the other groups undergo suitable displacements in order to adjust focusing under the best possible conditions of picture quality up to minimal distances, that is, practically against the front element. In order to obtain the still picture, the laws of displacements of the movable groups are computed and applied in real time as a function of the desired focal length and distance.

In the majority of objective-lens systems employed in television studios, a system is provided in addition for carrying out multiplication of the basic focal length. This system consists of a rotary lens turret placed behind the iris and adapted to carry a number of quasi-afocal lens elements, each of which may thus be put into service in order to obtain a different multiplier coefficient.

This makes it possible to obtain a constant variation ratio and to choose the basic focal length as a function of the field angles which can be employed. However, since the maximum available f-number is proportional to the basic focal length, this must be taken into account in the choice of the multiplier. In fact, by choosing a situation which is conducive to long focal lengths, it may happen that the lens aperture is stopped-down too far. The ideal arrangement, in the event that the quantity of light is critical and that it is therefore desired to give priority to the lens aperture, would be to have a large number of multipliers and to be in a position to choose the best compromise. This is not possible, however, with current systems consisting of a lens turret which carries a limited number of quasi-afocal lens elements corresponding to as many different multiplier coefficients.

Another characteristic of existing objective-lens systems of the type under consideration is that the multiplier system thus provided is located in a quasi-afocal region behind the iris. This actually has the effect of significantly changing the position of the exit pupil and therefore the distribution of colors in the picture (colored spot) as a result of the changes in angle of incidence of the principal beams on the dichroic mirrors of the camera separator. This phenomenon is aggravated when the exit pupil is relatively close to the image and also when "ramping" occurs or in other words when the f-number varies with the focal length. In this case, the exit pupil is in fact the image of the diameter of any one group of the variator and often of the front element, the dimensions of which are always limited so as to reduce the weight and volume, and is no longer the image of the iris. Furthermore, the spectrum transmission is modified by introduction of additional lenses.

It is for the reasons given above that the object of the invention is to permit the application of multiplier coefficients for multiplication of the basic focal length of an objective-lens system of the type considered while removing the disadvantages of the system discussed in the foregoing.

SUMMARY OF THE INVENTION

To this end, the invention has for its primary object a particular method of control of an objective-lens system of this type which is so designed as to permit application of a plurality of multiplier coefficients for multiplication of the basic focal length without any need to have recourse to a lens-turret system of the type recalled earlier. This method is designed for the control of a variable-focus objective-lens system consisting of at least two movable groups of lenses forming a variator and at least two other groups which have the function of focusing by displacement and the position of which is defined as a function of the two variables consisting of focal length and focusing distance.

The distinctive feature of this method lies in the fact that, since the displacements of the two movable groups forming a variator are controlled by means of a computer, these groups are subjected not only to the necessary displacements of each group for the variations of focal length but also to a complementary longitudinal displacement for applying to the objective-lens system a focal-length multiplier coefficient having a value chosen by the operator, another function of the computer being accordingly to produce the required variation of the iris and the complementary displacements of the focusing groups in respect of each focal length.

Thus the multiplier function is performed by means of complementary displacements of the movable groups which also serve as a variator. As will become apparent hereinafter, this offers considerable advantage over the system used in the prior art.

However, it is another object of the invention to provide an objective-lens device designed for implementation of the method defined in the foregoing. This device is distinguished by the following features:

(1) the two movable groups of lenses forming a variator have characteristics such that, in addition to the ability to produce variations in focal length of the lens system, they are capable under the action of a complementary longitudinal displacement of carrying out multiplication of the basic focal length and the arrangement is such that, in their end positions, these two groups are still capable of undergoing a similar complementary displacement;

(2) in combination with this lens system, the device under consideration is provided for the purpose of producing displacements of the movable groups of lens elements with a control system associated with a compute and capable of subjecting these two movable groups of lenses not only to the displacements required for each group in order to produce a progressive variation in focal length but also to a complementary longitudinal displacement in order to apply to the objective-lens system a focal length multiplier coefficient having a value chosen by the operator, another function of said computer being to produce the desire variation of the iris and the complementary displacements of the focusing groups in respect of each focal length.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a longitudinal sectional view of an objective-lens system according to the invention in its normal situation in which the groups of lenses are shown in a position of short focal length.

FIG. 2 is a similar view showing the groups of lenses of said objective-lens system in a position of long focal length, said lens system being again shown in its normal situation.

FIG. 3 is a similar view showing the same objective-lens system in a situation of multiplication of its basic focal length by a coefficient of 1.4, the groups of lenses being shown in a position of short focal length.

FIG. 4 is a view illustrating said objective-lens system in the same situation but in this case the groups of lenses are in a position of long focal length.

FIG. 5 is a similar view showing the objective-lens system in a different situation, namely a multiplication of the basic focal length corresponding to the coefficient 2, the groups of lenses being shown in a position of short focal length.

FIG. 6 is a similar view showing the objective-lens system in the same situation but in this case said groups of lenses are in a position of long focal length.

FIG. 7 is a table indicating the different possible apertures as a function of the focal length of the objective-lens system.

DETAILED DESCRIPTION OF THE INVENTION

The objective-lens system illustrated in FIGS. 1 to 6 is made up of five groups of lenses I, II, III, IV, V. Among these latter, the two groups II and III are movable and have the function of constituting the "variator" element for varying the focal length of the objective-lens system as a function of a predetermined optical law. The two groups I and V are also movable but do not take part in the variation in focal length of the objective-lens system. The function of these two groups is in fact to adjust focusing by means of their displacements, their positions being defined as a function of the two variables consisting of focal length and focusing distance.

Group I is convergent as is also the case with groups III and V. In regard to groups II and IV, they are divergent.

In the lens system being considered, and proceeding from left to right as in the drawings, group I comprises a first divergent lens **1** and three other convergent lenses **2, 3** and **4**. Group II comprises a divergent lens **5**, a divergent doublet **6–7**, a divergent lens **8** and a divergent doublet **9–10**.

So far as group III is concerned, this group is constituted from the front end to the rear end by a first convergent doublet **11–12**, a second convergent doublet **13–14** and a convergent lens **15**.

Group IV comprises a convergent doublet **16–17**, a divergent lens **18** and a convergent meniscus lens **19**.

Finally, group V comprises a convergent meniscus lens **20**, a first convergent doublet **21–22**, a second convergent doublet **23–24** and a convergent lens **25**.

The objective-lens system thus constituted is a variable-focus lens system having a basic focal length of 8.5 and a coefficient of variation of twenty times this focal length. Its maximum aperture is accordingly f-1.3.

The four groups I, II, III and IV and the various lenses of these groups comply with the following inequalities in which:

F'1, F'2, F'3 and F'4 each correspond to the focal length of a group considered from front to rear,

f'1, f'2 . . . f'5 each correspond to the focal length of a lens considered from front to rear,

R1, R2 . . . correspond to the radius of each surface of curvature considered from front to rear,

(a) General relations

$$2(F'2) < (F'3) < 3(F'2)$$
$$2(F'3) < (F'1) < 3(F'3)$$

(b) Relations in Group I

$$\frac{1}{2}F'1 < R2 < \frac{3}{2}F'1$$
$$\frac{1}{2}F'1 < R5 < \frac{3}{2}F'1$$
$$\frac{1}{2}F'1 < R7 < 2(F'1)$$
$$(F'1)\,(f'4) < 2(F'1)$$

(c) Relations in Group II

$$(F'2) < R10 < 3(F'2)$$
$$(F'2 < (f'5) < 3(F'2)$$
$$(F'2) < (f'6) < 3(F'2)$$
$$(F'2) < (f'6) < 3(F'2)$$
$$1.65 < n9 < 1.85$$

(d) Relations in Group III

$$(F'3) < (R21) < 2(F'3)$$
$$(F'3) < (R25) < 2(F'3)$$
$$(F'3) < (f'12) < 3(F'3)$$
$$(F'3) < (f'13) < 3(F'3)$$
$$(F'3) < (f'15) < 3(F'3)$$

In regard to the numerical values of the radii of the different lenses as well as the intermediate air spaces existing in each group, they are indicated in the table given hereinafter. In this table, the radii of curvatures are designated by the indications R1, R2, R3 . . . following the order of the different surface areas of lenses from the front end to the rear end. In regard to the air spaces, they are designated by the indications E1, E2, E3 . . . , these latter being numbered according to their position from the front end to the rear end.

TABLE

ZOOM LENS 20 × 8.5
APERTURE = f-1.3

R1 =	574.233	E1 =	7.000	785259
R2 =	147.083	E2 =	16.000	AIR
R3 =	271.402	E3 =	17.000	516642
R4 =	−17101.590	E4 =	.200	AIR
R5 =	169.226	E5 =	20.000	516642
R6 =	−55807.890	E6 =	.200	AIR
R7 =	171.489	E7 =	19.000	603655
R8 =	−1365.530	E8 =	8.279	AIR
R9 =	−333.416	E9 =	2.400	883408
R10 =	63.099	E10 =	7.300	AIR
R11 =	−400.732	E11 =	7.500	785257
R12 =	−46.469	E12 =	2.000	620603
R13 =	93.146	E13 =	5.500	AIR
R14 =	−185.314	E14 =	2.400	620603
R15 =	225.379	E15 =	5.600	AIR
R16 =	−70.541	E16 =	2.000	620603
R17 =	−2632.278	E17 =	5.500	785257
R18 =	−134.123	E18 =	203.890	AIR
R19 =	−213.828	E19 =	2.800	728284
R20 =	456.882	E20 =	11.800	620603

TABLE-continued

ZOOM LENS 20 × 8.5 APERTURE = f-1.3				
R21 =	−90.853	E21 =	.200	AIR
R22 =	465.654	E22 =	11.800	620603
R23 =	−101.472	E23 =	2.800	728284
R24 =	−172.477	E24 =	.200	AIR
R25 =	111.958	E25 =	11.200	516642
R26 =	−454.108	E26 =	5.750	AIR
R27 =	−58.702	E27 =	1.800	652587
R28 =	44.822	E28 =	8.000	755275
R29 =	183.422	E29 =	10.000	AIR
R30 =	−168.681	E30 =	2.000	652587
R31 =	341.707	E31 =	4.300	AIR
R32 =	−93.665	E32 =	6.000	806409
R33 =	−52.237	E33 =	45.000	AIR
R34 =	−253.235	E34 =	5.700	497816
R35 =	−74.636	E35 =	.200	AIR
R36 =	129.994	E36 =	1.800	772497
R37 =	30.625	E37 =	12.400	497816
R38 =	−177.671	E38 =	.200	AIR
R39 =	326.308	E39 =	11.300	497.816
R40 =	−45.166	E40 =	1.800	806409
R41 =	−506.625	E41 =	.200	AIR
R42 =	56.736	E42 =	9.300	497816
R43 =	−61.245	E43 =	1.000	AIR
R44 =	999999999.000	E44 =	33.000	603380
R45 =	999999999.000	E45 =	14.500	517642
R46 =	999999999.000	E46 =	.000	AIR

As already mentioned earlier, FIGS. **1** and **2** illustrate the objective-lens system in its normal situation, that is to say in the case of a basic focal length of 8.5. In FIG. **1**, the movable groups II and III are shown in their positions corresponding to a short focal length. On the other hand, in FIG. **2**, the same two groups are shown in their position of short focal length.

In the last-mentioned position, groups II and III are not in closely spaced relation but there exists a relatively large gap which permits closer spacing in other cases at the time of multiplication of the basic focal length. This is made possible by suitably determining the characteristics of the different elements of the objective-lens system and especially a judicious reduction in overall length of groups II and III. The reduction of overall length is obtained by making use of glasses having high refractive indices in certain lenses of elements II and III, thus having the effect of reducing the curvatures and therefore the volume.

The essential characteristic of the objective lens system in accordance with the invention lies in the fact that the two groups II and III have configurations and characteristics such that they are capable of performing two separate and distinct functions as follows:

(1) their normal function of variator for progressively varying the focal length of the objective-lens system;

(2) a function of multiplier for multiplying the basic focal length in accordance with a very large number of possible multiplication coefficients.

Moreover, the different movable groups of the objective-lens system considered are made dependent on a control device comprising a computer and capable of subjecting the two movable groups II and III not only to the displacements required for progressive variation in focal length but also to a complementary longitudinal displacement for applying to the objective-lens system a focal length multiplication coefficient having a value chosen by the operator. Accordingly, the operator need only depress a push-button of this control device in order to obtain a multiplication of the basic focal length in accordance with a predetermined coefficient. This accordingly produces the desired complementary displacements of the two groups II and III in order to carry out the corresponding multiplication of focal length. In such a case, however, the computer also determines the requisite variation of the iris and the complementary displacements of the focusing groups in respect of each focal length.

Thus FIGS. **3** and **4** represent the movable groups II and III of the present objective-lens system, respectively in their position of short focal length and in their position of long focal length in the case considered in which a multiplication coefficient g of 1.4× has been applied to the objective-lens system by means of a suitable complementary displacement of the two groups II and III. In consequence, the basic focal length now becomes 1.9 and the objective-lens system is thus a variable-focus lens system of 20×11.9.

In regard to FIGS. **5** and **6**, they illustrate the movable groups II and III of the objective-lens system under consideration, respectively in their position of short focal length and in the long focal length position whereas a multiplier coefficient g of 2×a has been applied to this latter. In consequence, the basic focal length of this objective-lens system now becomes 17, with the result that it constitutes a variable-focus objective of 20×17. It is worthy of note that, in this case, there exists in the long focal-length position a relatively substantial spacing both between groups I and II on the one hand and between groups III and IV on the other hand. This is necessary to permit a close spacing in the short focal-length position in the case of the normal situation of the objective-lens system (as shown in FIG. **1**). The characteristics of the different groups and of their lenses are therefore determine accordingly.

However, the two cases illustrated respectively in FIGS. **3** and **4** and in FIGS. **5** and **6** constitute only examples which are given by way of indication. It is in fact possible to apply to the objective-lens system a large number of multiplier coefficients having different values subject to the condition that the control device is determined in consequence and that the computer has a program which is also established for this purpose.

The essential feature of the device in accordance with the invention therefore lies in the fact that the multiplying function which had thus far been performed by a turret of quasi-afocal lenses located in the rear stationary portion of the objective-lens system and usually limited to one or two positions is replaced in this device by a complementary longitudinal displacement of the elements of the variator.

It thus becomes possible to choose very precisely the longest focal length desired as a function of the numerical aperture chosen or of the field to be covered Thereupon, the variation in focal length always takes place in the same maximum ratio with a constant aperture. It is thus possible in actual fact to give priority of choice to the aperture and to improve the compromise.

This novel situation in fact consists in making provision for an unlimited number of multipliers between the two end values. Management of these positions, of the iris whose aperture is adapted to each situation and of the complementary displacements of the focusing groups which are adapted to each focal length is accordingly performed by the computer provided in the control device.

The basic concept of this device is such that an operator has the possibility of controlling the focal length exactly in dependence on the level of light chosen. He may accordingly place the objective in the position

which corresponds most effectively to the useful field, the aperture being determined by the maximum aperture which is permissible for the longest variable focal length chosen.

The table of FIG. 7 in any case indicates the variations in values of aperture of the objective as a function of the different focal lengths. The operator should therefore consult this table in order to adopt any coefficient of multiplication of the basic focal length which is best suited to his particular case of utilization. The variation in focal length may thus be centered with accuracy as a function of the extreme field angles chosen.

In addition to this essential advantage of utilization, the present device offers a certain number of other advantages.

One of these advantages lies in the fact that the exit pupil is not affected by the application of a coefficient of multiplication of the basic focal length and that the image is not impaired by any colored spot. This is due to the fact that no optical element is added behind the iris in the case under consideration and that the focal length ratio is chosen so as to ensure that there is no "ramping" or in other words no variation of the numerical aperture with the focal length. The light spectrum transmission is therefore unchanged.

Yet another advantage arises from the fact that the objective in accordance with the invention has a smaller number of lenses than in the objectives at present used for the application considered. This produces a reduction in absorption of light at the time of application of a focal-length multiplier by virtue of the fact that, in the present instance, the number of surfaces traversed accordingly remains the same. This also achieves a reduction in cost price. Yet a further advantage lies in the reduction in weight of the assembly as a result of elimination of the afocal-lens turret provided in current objectives of the type recalled earlier.

What is claimed is:

1. A method of control of a variable-focus objective lens system comprising two groups of lenses which are capable of moving along the optic axis so as to produce variations in the focal lengths as initiated by the operator while the final image remains stationary during these variations, and also comprising two other groups which carry out focusing by displacement and the position of which is defined as a function of two variables consisting of focal length and focusing distance, wherein the displacements of the two movable groups forming a variator are controlled by means of a computer and these groups are accordingly subjected not only to the necessary displacements of each group for the progressive variations of focal length but also to a complementary longitudinal displacement for applying to the objective-lens system a focal-length multiplier coefficient having a value chosen by the operator, another function of the computer being accordingly to produce the required variation of the iris and the complementary displacements of the focusing groups in respect of each focal length.

2. An objective-lens device according to claim 1, wherein the four groups of lenses and the various lenses of these groups comply with the following inequalities in which:

F'1, F'2, F'3 and F'4 each correspond to the focal length of one group in a direction away from the object viewed,

f'1, f'2, . . . f'25 each correspond to the focal length of one lens in a direction away from the object viewed,

R1, R2, . . . correspond to the radius of each surface of curvature in a direction away from the object viewed,

(a) General relations

$2(F'2) < (F'3) < 3(F'2)$

$2(F'3) < (F'1) < 3(F'3)$

(b) Relations in Group I

$\frac{1}{2} F'1 < R2 < \frac{3}{2} F'1$

$\frac{1}{2} F'1 < R5 < \frac{3}{2} F'1$

$\frac{1}{2} F'1 < R7 < 2(F'1)$

$(F'1)\,(f'4) < 2(F'1)$

(c) Relations in Group II

$(F'2) < R10 < 3(F'2)$

$(F'2) < (f'5) < 3(F'2)$

$(F'2) < (f'6) < 3(F'2)$

$(F'2) < (f'6) < 3(F'2)$

$1.65 < n9 < 1.85$

(d) Relations in Group III

$(F'3) < (R21) < 2(F'3)$

$(F'3) < (R25) < 2(F'3)$

$(F'3) < (f'12) < 3(F'3)$

$(F'3) < (f'13) < 3(F'3)$

$(F'3) < (f'15) < 3(F'3)$.

3. An objective-lens device for a variable-focus objective lens system comprised by two groups of lenses which are capable of moving along the optic axis so as to produce variations in focal lengths as initiated by the operator while the final image remains stationary during these variations, and also comprised by two other groups which carry out focusing by displacement and the position of which is defined as a function of the two variables consisting of focal length and focusing distance, wherein

(1) the two movable groups of lenses forming a variator have characteristics such that, in addition to the ability to produce variations in focal length of the lens system, they are capable under the action of a complementary longitudinal displacement of carrying out multiplication of the basic focal length and the arrangement is such that, in their end positions, these two groups are still capable of undergoing a similar complementary displacement; combination with this lens system, the device in

(2) in combination with this lens system, the device in accordance with the invention is provided for the purpose of producing displacements of the movable groups of lens elements with a control system associated with a computer and capable of subjecting these two movable groups of lenses not only to the displacements required for each group in order to produce variations in focal length but also to a complementary longitudinal displacement in order to apply to the objective-lens system a focal length multiplier coefficient having a value chosen by the operator, another function of said computer being to produce the desired variation of the iris and the complementary displacements of the focusing groups in respect of each focal length.

* * * * *

United States Patent [19]

Kitagishi et al.

[11] **Patent Number: 4,842,386**

[45] **Date of Patent: Jun. 27, 1989**

[54] **VARIABLE FOCAL LENGTH OBJECTIVE**

[75] Inventors: **Nozomu Kitagishi**, Tokyo; **Hiroki Nakayama**, Kanagawa; **Shigeyuki Suda**, Tokyo; **Jun Hattori**, Kanagawa; **Akihisa Horiuchi**, Tokyo, all of Japan

[73] Assignee: **Canon Kabushiki Kaisha**, Tokyo, Japan

[21] Appl. No.: **877,102**

[22] Filed: **Jun. 23, 1986**

[30] **Foreign Application Priority Data**

Jun. 26, 1985 [JP] Japan 60-139915

[51] **Int. Cl.**[4] **G02B 15/00**; G02B 15/16; G02B 15/14

[52] **U.S. Cl.** **350/427**; 350/413; 350/423; 350/426

[58] **Field of Search** 350/413, 423, 426, 427

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Primary Examiner—Bruce Y. Arnold
Assistant Examiner—Ronald M. Kachmarik
Attorney, Agent, or Firm—Fitzpatrick, Cella, Harper & Scinto

[57] **ABSTRACT**

A variable focal length objective having a plurality of lens units with at least one unit separation being varied to vary the focal length of the entire system, in which at least one of the plurality of lens units has at least gradient-index lens having a refractive index distribution of the form: $N(h)=N_0+N_1h^2+N_2h^4+N_3h^6+\ldots$ where h is the height from the optical axis, N_0 is the refractive index on the optical axis, and N_1, N_2, N_3, . . . are constants, satisfying the following conditions:

$$\phi_G \cdot N_1 < 0$$

$$K \cdot \phi_G \cdot N_2 < 0$$

where ϕ_G is the refractive power of that lens unit which has that gradient-index lens, and K is $+1$ or -1 when the stronger of the curvatures of both surfaces of that gradient-index lens is convex or concave to the air respectively.

4 Claims, 12 Drawing Sheets

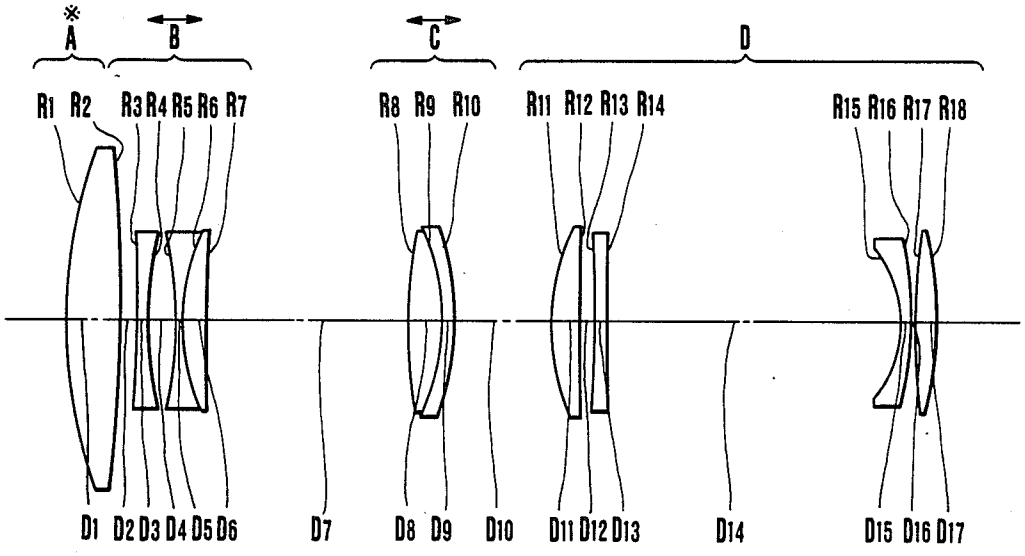
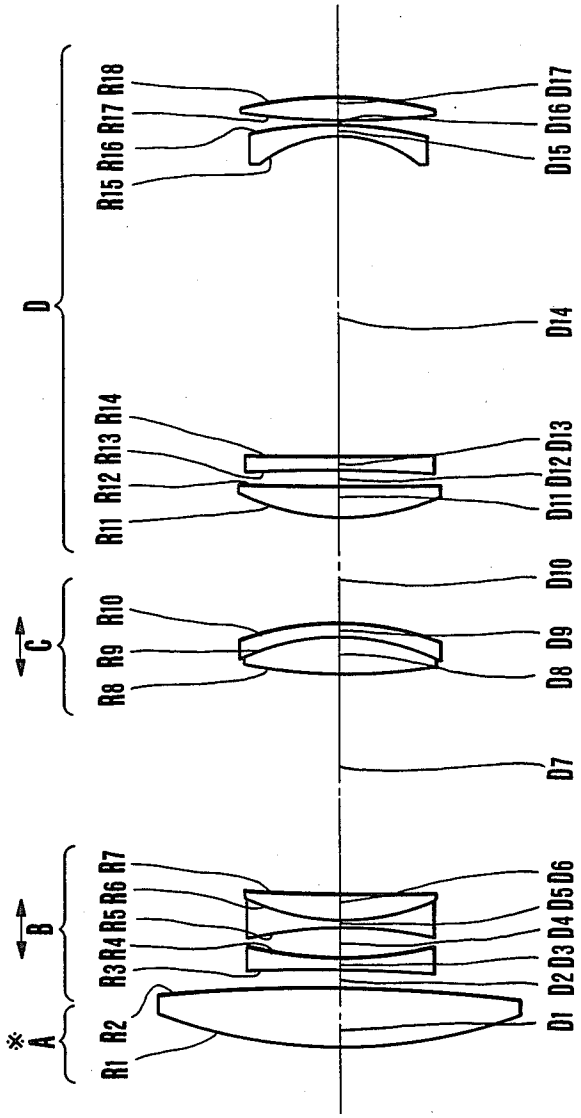


FIG. 1


R1
R2
R3
R4
R5
R6
R7
R8
R9
R10
R11
R12
R13
R14
R15
R16
R17
R18
D1
D2
D3
D4
D5
D6
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D12
D13
D14
D15
D16
D17
※A
B
C
D

FIG.2

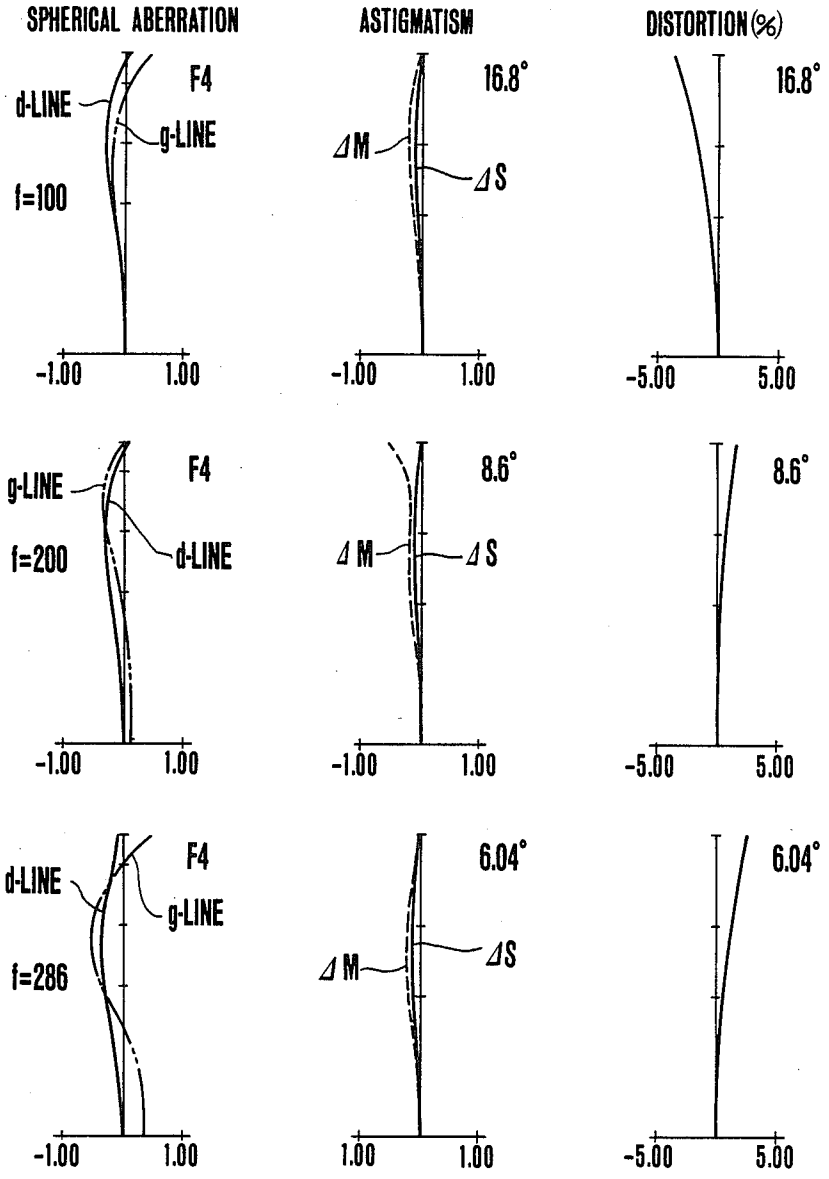

SPHERICAL ABERRATION
ASTIGMATISM
DISTORTION (%)
F4
d-LINE
g-LINE
f=100
16.8°
ΔM
ΔS
-1.00
1.00
-5.00
5.00
F4
g-LINE
d-LINE
f=200
8.6°
ΔM
ΔS
F4
d-LINE
g-LINE
f=286
6.04°
ΔM
ΔS

FIG.3

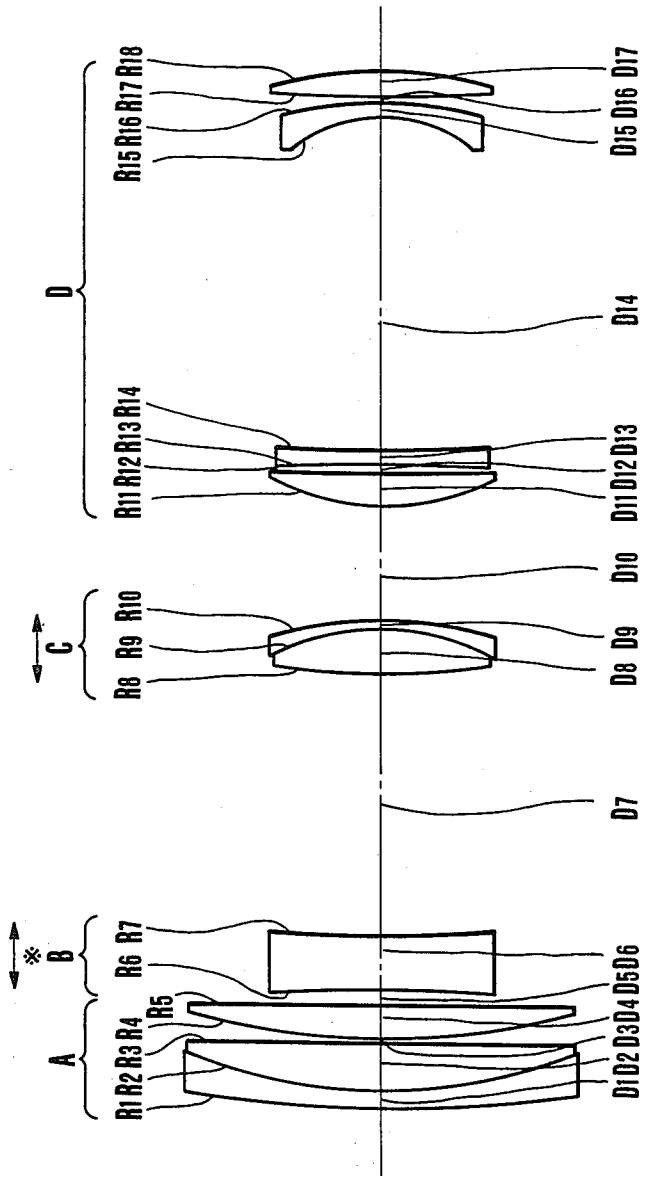

R1 R2 R3 R4 R5 R6 R7 R8 R9 R10 R11 R12 R13 R14 R15 R16 R17 R18
D1 D2 D3 D4 D5 D6 D7 D8 D9 D10 D11 D12 D13 D14 D15 D16 D17
A
B
C
D
※

FIG.4

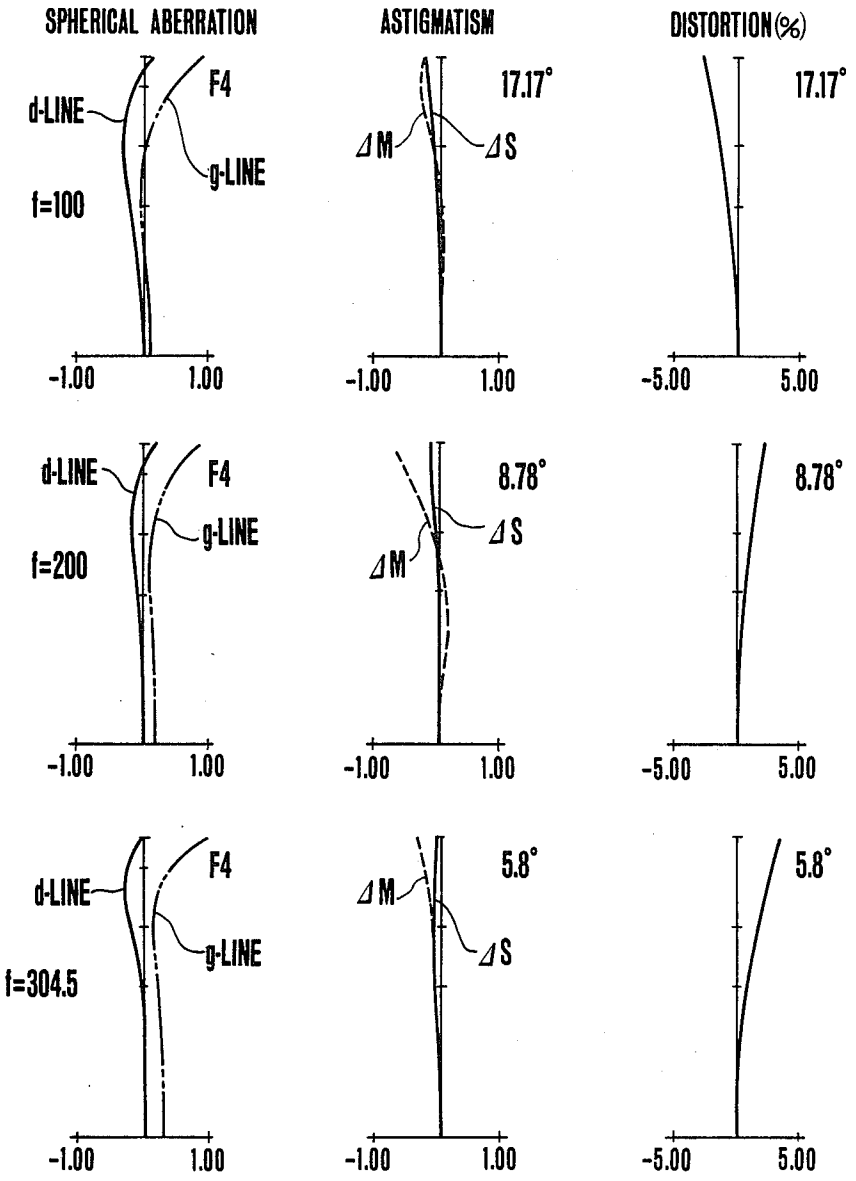
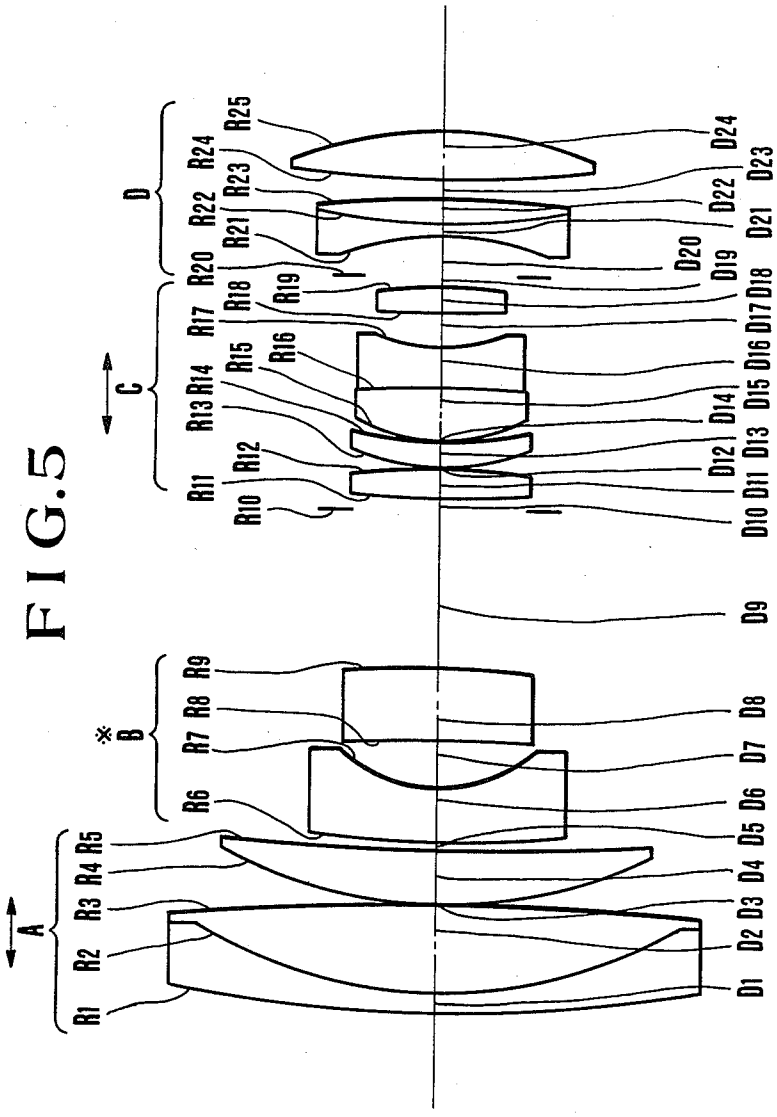

SPHERICAL ABERRATION
ASTIGMATISM
DISTORTION(%)
d-LINE
F4
g-LINE
f=100
17.17°
ΔM
ΔS
-1.00
1.00
-5.00
5.00
f=200
8.78°
f=304.5
5.8°

FIG.5


A
R1
R2
R3
R4
R5
※B
R6
R7
R8
R9
C
R10
R11
R12
R13
R14
R15
R16
R17
R18
R19
D
R20
R21
R22
R23
R24
R25
D1
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D20
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D22
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D24

FIG.6

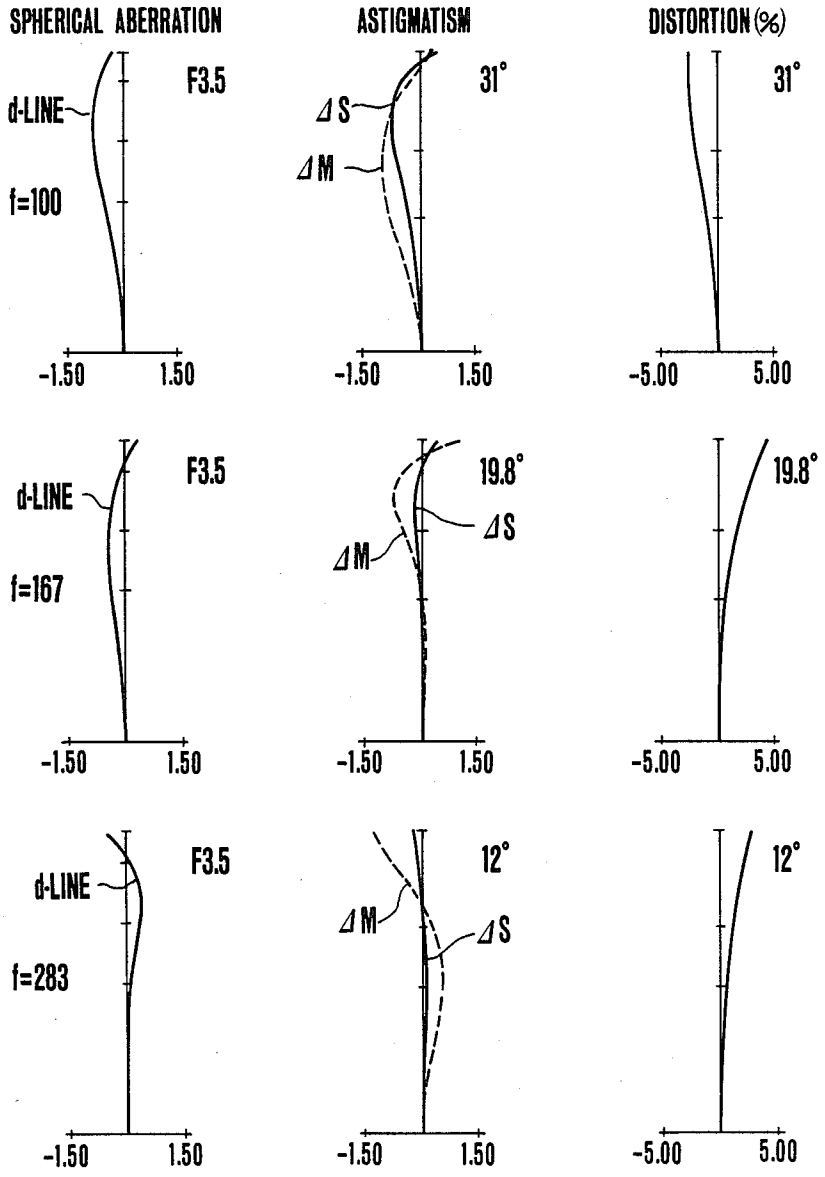

SPHERICAL ABERRATION
ASTIGMATISM
DISTORTION (%)
F3.5
d-LINE
f=100
31°
ΔS
ΔM
-1.50
1.50
-5.00
5.00
F3.5
d-LINE
f=167
19.8°
ΔS
ΔM
F3.5
d-LINE
f=283
12°
ΔM
ΔS

FIG.7

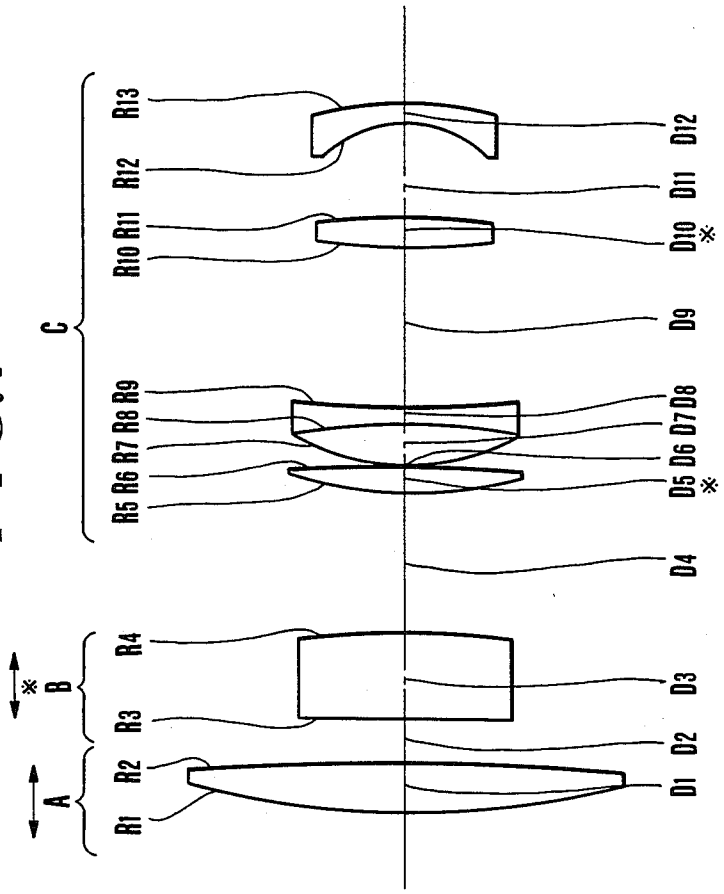

R13
R12
R11
R10
C
R9
R8
R7
R6
R5
※
B
R4
R3
A
R2
R1
D12
D11
D10 ※
D9
D8
D7
D6
D5 ※
D4
D3
D2
D1

FIG.8

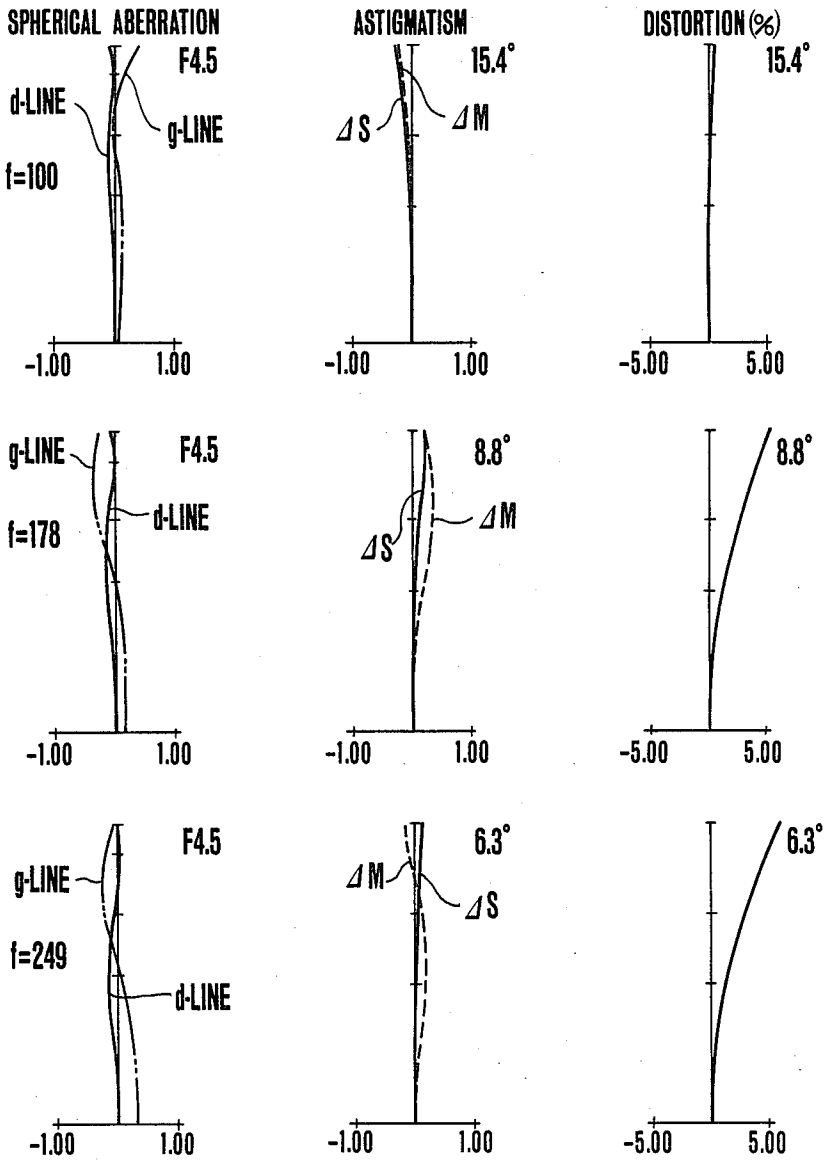

SPHERICAL ABERRATION
ASTIGMATISM
DISTORTION (%)
F4.5
15.4°
15.4°
d-LINE
g-LINE
ΔS
ΔM
f=100
-1.00
1.00
-1.00
1.00
-5.00
5.00
g-LINE
F4.5
8.8°
8.8°
d-LINE
ΔS
ΔM
f=178
-1.00
1.00
-1.00
1.00
-5.00
5.00
F4.5
6.3°
6.3°
g-LINE
ΔM
ΔS
f=249
d-LINE
-1.00
1.00
-1.00
1.00
-5.00
5.00

FIG.9

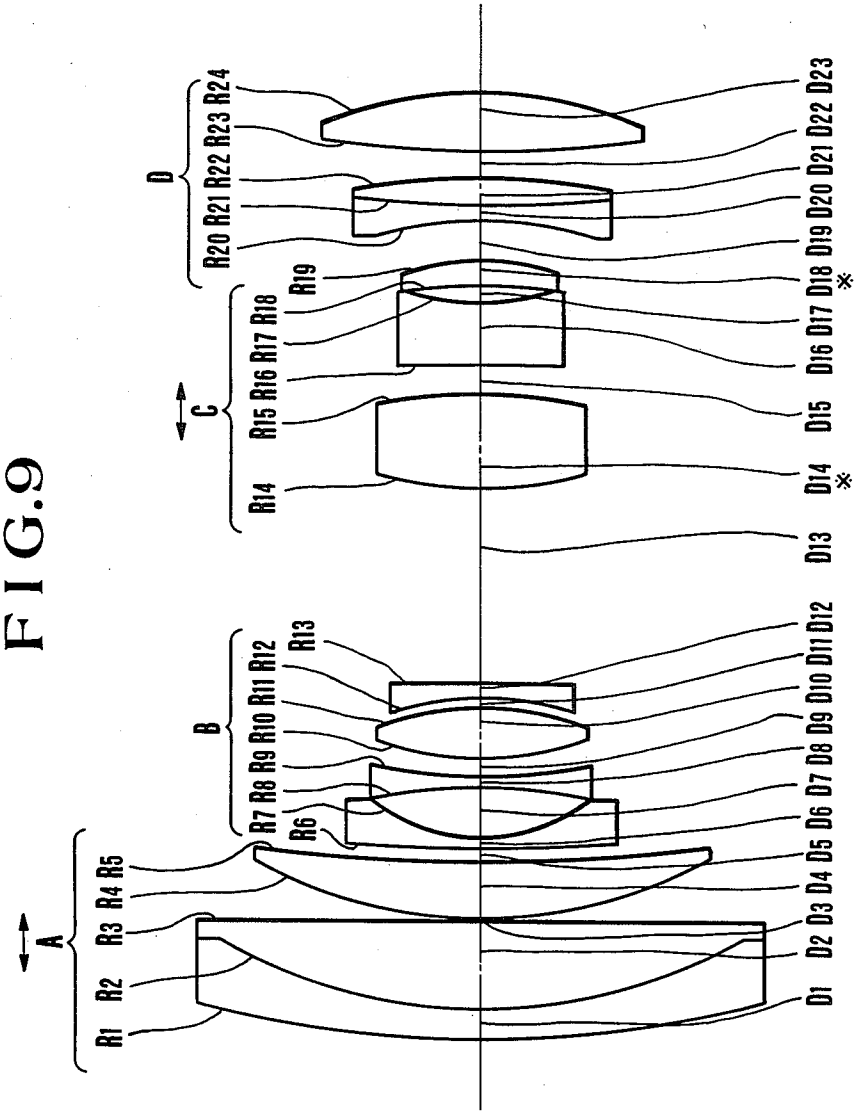

A
B
C
D
R1 R2 R3 R4 R5 R6 R7 R8 R9 R10 R11 R12 R13 R14 R15 R16 R17 R18 R19 R20 R21 R22 R23 R24
D1 D2 D3 D4 D5 D6 D7 D8 D9 D10 D11 D12 D13 D14 D15 D16 D17 D18 D19 D20 D21 D22 D23
※
※

FIG.10

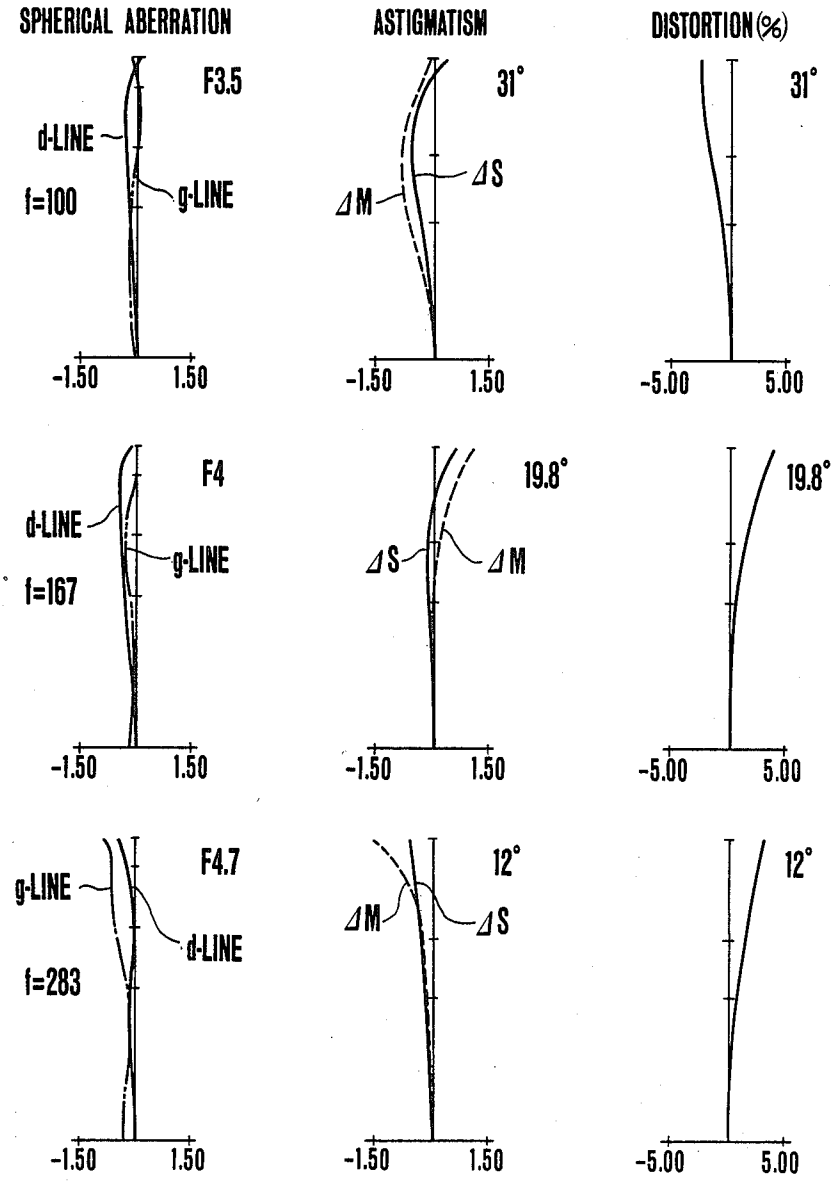

SPHERICAL ABERRATION
ASTIGMATISM
DISTORTION (%)
F3.5
d-LINE
g-LINE
f=100
31°
ΔS
ΔM
31°
-1.50
1.50
-1.50
1.50
-5.00
5.00
F4
d-LINE
g-LINE
f=167
19.8°
ΔS
ΔM
19.8°
-1.50
1.50
-1.50
1.50
-5.00
5.00
F4.7
g-LINE
d-LINE
f=283
12°
ΔM
ΔS
12°
-1.50
1.50
-1.50
1.50
-5.00
5.00

FIG.11

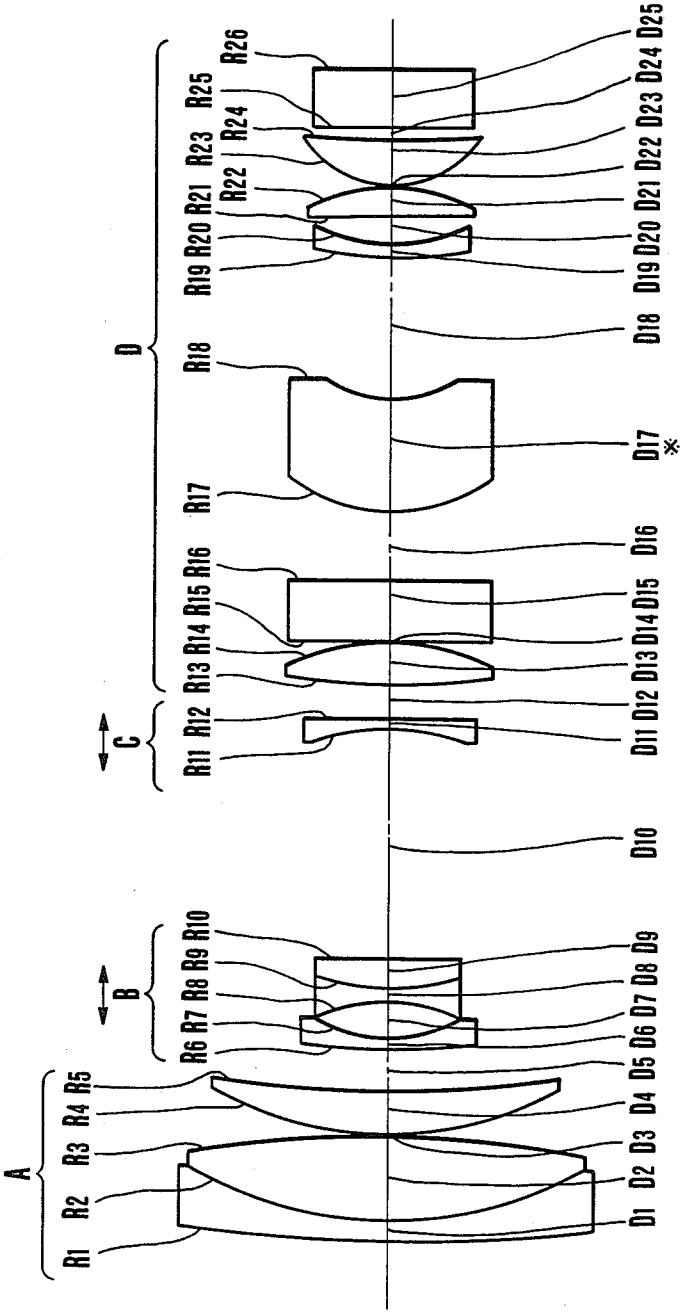
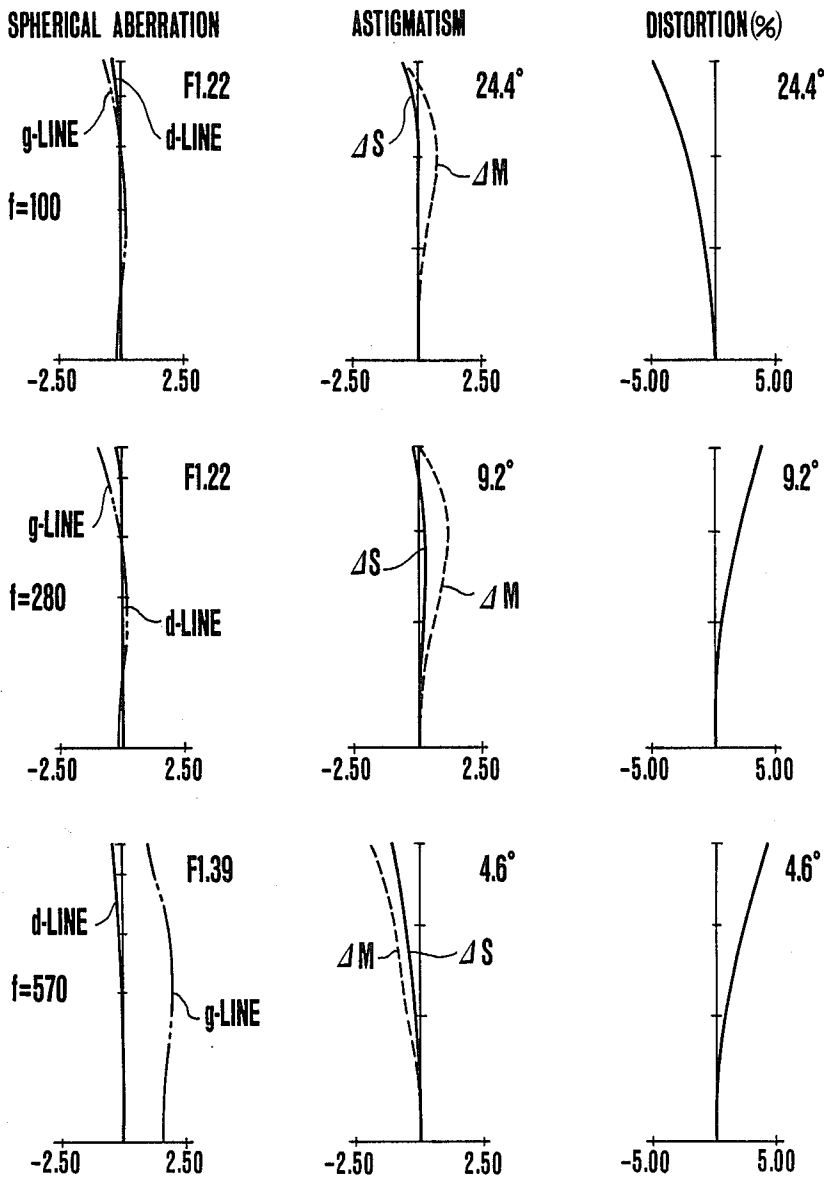

A
B
C
D
R1 R2 R3 R4 R5
R6 R7 R8 R9 R10
R11 R12
R13 R14 R15 R16
R17 R18
R19 R20 R21 R22 R23 R24 R25 R26
D1 D2 D3 D4 D5 D6 D7 D8 D9 D10 D11 D12 D13 D14 D15 D16 D17 ※ D18 D19 D20 D21 D22 D23 D24 D25

FIG.12


SPHERICAL ABERRATION
ASTIGMATISM
DISTORTION(%)
F1.22
g-LINE
d-LINE
f=100
24.4°
ΔS
ΔM
24.4°
-2.50
2.50
-2.50
2.50
-5.00
5.00
F1.22
g-LINE
f=280
d-LINE
9.2°
ΔS
ΔM
9.2°
-2.50
2.50
-2.50
2.50
-5.00
5.00
F1.39
d-LINE
f=570
g-LINE
4.6°
ΔM
ΔS
4.6°
-2.50
2.50
-2.50
2.50
-5.00
5.00

VARIABLE FOCAL LENGTH OBJECTIVE

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to variable focal length objectives, and more particularly to such objective which has a plurality of lens units with the separation between the first and second lens units being varied to vary the focal length of the entire system.

2. Description of the Related Art

The aberration problem of the variable focal length objective, especially the zoom lens that varies its focal length continuously, must be solved, besides the good correction of aberrations in the standard setting, for as far minimized variation with zooming of the aberrations as possible. To achieve this, all the lens units are required to be at least individually corrected well for spherical aberration, coma and astigmatism in each unit. It has, therefore, been the prior art practice that each lens unit is made up by using several lens elements.

Because the total sum of the lens elements of all the units became enormous, the weight and size of the entire system were very heavy and very long in the longitudinal direction, and the assembly and adjustment of the lens elements in each unit was very difficult to perform with high accuracy in respect to the axial alignment and the spacing.

Recently, much interest has aroused in developing a variable focal length objective of more compact form with an increased range of magnifications. Yet, from the obstacle of the above-described problem of aberration correction it was also very difficult to achieve it by relying on the method of trimming some lenses from each lens unit.

For example, in the type of zoom lens comprising a plurality of lens units of which the first and second counting from the front are respectively positive and negative in power and the separation between the first and second lens units, its bulk and size can be reduced, speaking in the concept of Gauss theory, either by strengthening the power of each lens unit, or by shortening the intervals between the principal points of the successive two of the lens units. As to extend the zooming range, the method of strengthening the power of each lens unit may also be employed. There is another method of increasing the total zooming movement. When the requirements of reducing the size of the zoom lens of the type described above and of increasing the zoom ratio are to be fulfilled simultaneously, it is certainly natural in the concept of Gauss theory to choose the method of increasing the power of each lens unit. In an actual lens system, however, the increase in the power of the lens unit calls for an increase in the number of constituent lens elements in order to achieve good stability of aberration correction over the entire zooming range. This may otherwise be achieved by increasing the power per one lens element with its surface curvatures being strengthened. To allow for the minimum acceptable edge thickness of every lens element, the central thickness of the positive lens and the axial air separation between the adjacent concave surfaces are caused to become very large. In either case, therefore, the physical length of each of the lens units increases. Also since the principal point interval has to be increased, the optical total length of the entire system can no longer be shortened. Such an increase of the length of the lens unit gives rise to another problem that as the space in which the lens unit movable for zooming makes excursion becomes small, a desired increase of the zoom ratio can no longer be achieved.

Further with the first or second lens unit having an increased overall thickness due to the increase of the number of constituent elements, to admit of the oblique pencile, the diameter of the first or front lens unit must be increased. Thus, the attempt to advance the compactness was frustrated. Therefore, the use of any of the prior known methods, because of effecting the result of such a vicious cycle, could not filfill both requirements of achieving a much-desired reduction of the bulk and size of the zoom lens and of achieving a much desired increase of the zoom ratio while preserving good stability of aberration correction throughout the entire zooming range.

SUMMARY OF THE INVENTION

An object of the present invention is to eliminate the above-described drawbacks of the prior art, and to provide a variable focal length objective of extended range with a lessened total number of lens elements while still permitting good stability of aberration correction to be achieved throughout the zooming range.

BRIEF DESCRIPTION OF THE DRAWINGS

Odd numbered FIGS. **1** to **11** are longitudinal section views of six examples of specific zoom lenses of the invention.

Even numbered FIGS. **2** to **12** are graphic representations of the aberrations of the first to the sixth lenses respectively.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention is applied to the variable focal length objective comprising a plurality of lens units of which the first and second counting from front are a positive lens unit and a negative lens unit respectively, and in which when varying the image magnification, the air separation between the first and second lens units is varied. A feature of the invention in such objective is that at least one of the plurality of lens units is included with at least one gradient-index lens having a refractive index distribution over the radius given by the expression:

$$N(h)=N_0+N_1h^2+N_2h^4+N_3h^6+ \quad (1)$$

where h is the radial distance from the optical axis, N_0 is the refractive index on the optical axis, and N_1, N_2, N_3, . . . are constants, and is made with a refractive power ϕ_G satisfying the following conditions:

$$\phi_G \cdot N_1 < 0 \quad (2)$$

$$K \cdot \phi_G \cdot N_2 < 0 \quad (3)$$

where K is the coefficient representing the sign-convention for the one of the surfaces of the gradient-index lens which has a stronger curvature than the other, in which when that surface is convex, $K=+1$, and, for the concave surface, $K=-1$.

As is understandable from the equation (1), the gradient-index lens herein used has a distribution of refractive indices along the radial direction of the lens, or so-called radial gradient of refractive index. Particularly when such a gradient-index lens is introduced to

that lens unit which contributes to variation of the image magnification, or, in the usual zoom lens concept, the variator, or to that lens unit which contributes to compensate for the image shift, or, in the usual zoom lens concept, the compensator, it becomes possible to realize a variable focal length objective in which the bulk and size and weight are reduced in such a manner that a good stability of aberration correction over the extended range of variation of the focal length is achieved.

The radial gradient-index lens differs from the ordinary lens of homogeneous material in that its interior has a converging action (hereinafter referred to as "positive transition of power"), or a diverging action (hereinafter referred to as "negative transition of power"). Further since a refractive index pattern appears from the lens surface, the refracting action of that surface on the rays of light also becomes different from that of the usual lens.

Here, if, as the inequality (2) is to be satisfied, the aforesaid gradient-index lens is given such a refractive index distribution that $\phi_G \cdot N_1 < 0$ results, it exerts a surplus power of $\phi = -2N_1D$ owing to the gradient of refractive index, where D is the axial thickness of the lens. This implies that the medium of the gradient-index lens shares the required power of that lens unit which contains that gradient-index lens by the amount ϕ. Therefore, the curvatures of each of the lenses constituting that lens unit can be weakened with an advantage of reducing the aberrations.

When the inequality (3) or $K \cdot \phi_G \cdot N_2 < 0$ is satisfied simultaneously, the refracting action at the surface of the gradient-index lens in cooperation with the above-described power of the gradient permits a higher degree of aberration correction to be obtained.

The rules of design of the invention are next discussed based on the aberration theory in detail below.

Whilst P. J. Sands et al. have derived the third order aberration coefficients for the gradient-index lens, the terminology in "Lens Design Method" by Yoshiya Matsui (published from Kyoritsu Shuppan Co. 1962) is used here for defining the third-order aberration coefficients by the following formulae (4) to (18). For note, the aberration coefficients of the gradient-index lens are grouped to three sets of terms: (A) the terms of refraction arising when it is assumed to be a sphare of homogeneous medium are exposed by the formulae (4) to (8); (B) the terms of refraction due to the refractive index distribution over the surface of the gradient-index lens are exposed by the formulae (9) to (13); and (C) the terms of aberrations ascribable to the power of gradient of the medium of the gradient-index lens (hereinafter referred to as the "terms of gradient") are expressed by the formulae (14) to (18).

$$\text{(A): } I_\nu = h_\nu^4 Q_\nu^2 \Delta\left(\frac{1}{Ns}\right) \tag{4}$$

$$II_\nu = h_\nu^3 \bar{h}_\nu Q_\nu \bar{Q}_\nu \Delta_\nu\left(\frac{1}{Ns}\right) \tag{5}$$

$$III_\nu = h_\nu^2 \bar{h}_\nu^2 \bar{Q}_\nu^2 \Delta_\nu\left(\frac{1}{Ns}\right) \tag{6}$$

$$IV_\nu = III_\nu + P_\nu ; P_\nu = \frac{\phi\nu}{N\nu\, N\nu} \tag{7}$$

-continued

$$V_\nu = h_\nu \bar{h}_\nu^3 \bar{Q}_\nu^2 \Delta_\nu\left(\frac{1}{Ns}\right) + \bar{h}_\nu^2 \bar{Q}_\nu \Delta_\nu\left(\frac{1}{Nt}\right) \tag{8}$$

$$\text{(B): } I_\nu = h_\nu^4 \Psi_{in,\nu} \tag{9}$$

$$II_\nu = h_\nu^3 \bar{h}_\nu \Psi_{in,\nu} \tag{10}$$

$$III_\nu = \bar{h}_\nu^2 \bar{h}_\nu \Psi_{in,\nu} \tag{11}$$

$$IV_\nu = III_\nu + P_\nu \tag{12}$$

$$V = h_\nu \bar{h}_\nu^3 \Psi_{in,\nu} \tag{13}$$

where

$$\Psi_{in,\nu} = \frac{4}{r_\nu}(\Delta N_{1\nu}) + \frac{1}{r_\nu^2}\left(\Delta \frac{dN_{0\nu}}{dx}\right) \tag{14}$$

$$\text{(C): } I_\nu^t = V_\nu\left(\frac{h\alpha^3}{N_0^2}\right) - \int_{\nu \to \nu+1}\left[8 N_2 h^4 + \frac{4N_1 h^2 \alpha^2}{N_0^2} - \frac{\alpha^4}{N_0^3}\right]dx \tag{15}$$

$$II_\nu^t = V_\nu\left(\frac{h\alpha^2\bar{\alpha}}{N_0^2}\right) - \int_{\nu \to \nu+1}\left[8 N_2 h^3 \bar{h} + \frac{2N_1 h\alpha}{N_0^2}(h\bar{\alpha} + \bar{h}\alpha) - \frac{\alpha^3\bar{\alpha}}{N_0^3}\right]dx \tag{16}$$

$$III_\nu^t = V_\nu\left(\frac{h\alpha\bar{\alpha}^2}{N_0^2}\right) - \int_{\nu \to \nu+1}\left[8 N_2 h^2 \bar{h}^2 + \frac{4N_1 h\bar{h}\alpha\bar{\alpha}}{N_0^2} - \frac{\alpha^2\bar{\alpha}^2}{N_0^3}\right]dx$$

$$IV_\nu^t = III_\nu^t + P_\nu^t ; P_\nu^t = -2\int_{\nu \to \nu+1}(N_1/N_0^2)dx \tag{17}$$

$$V_\nu^t = V_\nu \frac{h\bar{d}^3}{N_0^2} - \int_{\nu \to \nu+1}\left[8 N_2 h\bar{h}^3 = \frac{2 N_1 \bar{h}\bar{\alpha}}{N_0^2}(h\bar{\alpha} + \bar{h}\alpha) - \frac{\alpha\bar{\alpha}^3}{N_0^3}\right]dx \tag{18}$$

Taking an example of spherical aberration, in what way it is corrected is explained below. Since the gradient-index lens adopted in the invention is of the radial type, $\Psi_{in,\nu}$ in the terms for refraction due to the refractive index distribution, or the formulae (9) to (13) reduces to

$$\Psi_{in,\nu} = 4(\Delta N_{1\nu})/r\nu \tag{19}$$

It follows from (9) and (19) that, for, as the medium surrounding the front or rear surface of the gradient-index lens is homogeneous, the distribution coefficient N_1 in the equation (1) is of negative sign, when the surface of stronger curvature is convex, $\Psi_{in,\nu} < 0$ (hereinafter the suffix ν will be omitted), so that the value of $h^4\Psi_{in}$ in the formula (9) is negative. Hence the spherical aberration is produced in direction to over-correction. When that surface is concave, $\Psi_{in} > 0$, so that $h^4\Psi_{in}$ has

a positive value. Hence the spherical aberration is produced in direction to under-correction. For the distribution coefficient N_1 is of positive sign, on the other hand, when that surface is convex, $\Psi_{in}<0$, so that the value of $h^4\Psi_{in}$ is positive. Hence the spherical aberration is produced in direction to under-correction. When that surface is concave, $\Psi_{in}<0$, so that the value $h^4\Psi_{in}$ is negative. Hence the spherical aberration is produced in direction to over-correction. In summary, depending on whether the sign of the power of that lens unit which is selected for incorporation of the gradient-index lens is positive or negative, and, because the sign of the distribution coefficient N_1 is determined according to the above-stated inequality (2), depending on whether that surface of the gradient-index lens whose curvature is stronger than the other is convex or concave, which correction of spherical aberration that surface gives can be discriminated by finding the sign of the coefficient for spherical aberration as shown in the following table.

Lens Unit	Equation (1)	Spherical Aberration: Gradient-Index Lens, Convex (K = +1)	Spherical Aberration: Gradient-Index Lens, Concave (K = −1)
$\phi_G > 0$	$N_1 < 0$	$h^4\Psi_{in} < 0$	$h^4\Psi_{in} > 0$
$\phi_G < 0$	$N_1 > 0$	$h^4\Psi_{in} > 0$	$h^4\Psi_{in} < 0$

Next, the term of the gradient for spherical aberration given by the expression of the equation (14) is of the very complicated form including terms of integrations. But, in the case of the radial type of gradient-index lens, N_0, N_1 and N_2 when to integrate with respect to X or the axial direction can be treated as constants. Further, on assumption that the ray of light travelling in interior of the gradient-index lens does not largely change its height h or $\bar{h}$, the equation (14) can be simplified to and approximated by

$$It \approx \frac{h}{N_0^2}\nabla(\alpha^3) - 8N_2h^4D - \frac{4N_1h^2}{N_0}\int \alpha^2\,dx + \frac{1}{N_0^3}\int \alpha^4\,dx \quad (20)$$

Of the four terms of the equation (20) it is in the usual zoom lens that the second one gives a largest contribution to spherical aberration, and is, therefore, predominant. For this reason, the term of gradient for the spherical aberration of the gradient-index lens has an important parameter as a function of the value of the distribution coefficient N_2 of the equation (1).

In other words, by choosing an appropriate value of the distrubution coefficient N_2, the term of gradient for the spherical aberration can be controlled. For example, when $N_2>0$, the spherical aberration is produced in direction to over-correction. For $N_2<0$, the spherical aberration is produced in direction to under-correction.

The present invention sets forth the conditions under which the third-order aberrations of the gradient-index lens in terms of refraction and gradient of the above-described refractive index distribution cancel out each other for a higher degree of correction. The simple expression of these conditions is of the above-described form of the inequalities (2) and (3). The combination of these inequalities (2) and (3) means that the direction of production of the aberrations ascribable to the refractive index pattern on that surface of the gradient-index lens which has a stronger curvature than the other has is made opposite to the direction of production of the aberrations ascribable to the gradient of refractive index. For example, in the case of spherical aberration, with the lens unit containing the gradient-index lens when being of positive power $\phi_G>0$, the inequality (2) determines $N_1<0$. If the surface of stronger curvature of the gradient-index lens is convex (K = +1), the term of refraction for spherical aberration is $h^4\Psi_{in}<0$. As it then follows that the term of gradient for spherical aberration should be $I^t>0$, the value of N_2 is determined to be $N_2<0$, according to the inequality (3). If that surface is concave (K = −1), after the same reasoning, the opposite sign for N_2 should be chosen. Conversely when the lens unit is of negative power: $\phi_G<0$, the sign for N_1 should be changed to $N_1>0$ according to the inequality (2). If that surface is convex (K = +1), $h^4\Psi_{in}>0$. Then, the inequality (3) determines $N_2>0$ so that the term of gradient for spherical aberration becomes $I^t<0$. If that surface is concave (K = −1), the sign for N_2 should be changed to $N_2<0$ according to the inequality (3).

As has been described above, in the present invention, the choosing of which sign to determine the coefficients N_1 and N_2 of the equation for the refractive index distribution of the gradient-index lens is made controlled in accordance with the critical conditions set forth above, when a higher degree of aberration correction is obtained. It is to be noted that what is referred to by the term radial type gradient-index lens in the invention must be taken that the radial gradient of refractive index is dominant on the performance of the lens itself. Therefore, regardless of the inclusion of another or longitudinal gradient of refractive index, if its effect is far weaker than that of the radial type, it should be understood that it falls within the scope and spirit of the invention.

The invention will next be described in connection with specific embodiments thereof in great detail.

FIG. 1 in longitudinal section view illustrates the construction and arrangement of the elements of an example of a specific zoom lens according to the present invention, and FIG. 2 shows its aberrations. The zoom lens comprises, from front to rear, a first lens unit A, a second lens unit B, a third lens unit C and a fourth lens unit D with the surfaces denoted by Ri (i=1, 2, 3, . . .) for the i-th surface counting from front, and the axial thicknesses or air separations denoted by Di (i=1, 2, 3, . . .) for the one between the i-th and (i+1)th surfaces. The spherical aberrations d and g for spectral d- and g-lines respectively, the astigmatisms M and S in the meridional and sagittal planes respectively, and the distortion of the lens of FIG. 1 are shown in different zooming positions of f=100, 200 and 286 mm.

The first lens unit A is of positive power and is held stationary during zooming. The second lens unit B is of negative power and axially moves with zooming to contribute to variation of the image magnification, and the third lens unit C is of positive power and also axially moves with zooming to compensate for the image shift. The fourth lens unit D of positive power remains stationary during zooming. The positive first lens unit A is constructed in the form of a singlet defined by surfaces R_1 and R_2 and having a radial gradient of refractive index defined by the equation (1) where the coefficients N_1 and N_2 take the signs: $N_1<0$, and $N_2<0$.

The above-defined gradient-index lens, unlike the usual lens of homogeneous medium, gives a converging function at the medium as it has a positive transition of power. Letting the overall power and thickness of the

gradient-index lens A be denoted by ϕ_I and D respectively, since the gradient of refractive index is made of $N_1<0$ according to the inequality of condition (2) or $\phi_I \cdot N_1<0$, because the power ϕ in terms of the gradient of the gradient-index lens A then takes a value of $\phi=-2N_1D$, the positive power assigned to the first lens unit A is shared by the medium of the gradient-index lens with its refracting surfaces. In the zoom lens of FIG. 1, due to the weakened curvatures of both surfaces of one lens constituting the positive first lens unit A, the aberrations are, therefore, primarily reduced remarkably.

The use of the convex form in the positive first lens unit in combination with such a gradient of refractive index as to give a positive transition of power as in this zoom lens is advantageous at correcting spherical aberrations in the telephoto positions. Other aberrations, for example, coma and astigmatism, can be also well corrected. Thus, it is made possible that only one gradient-index lens suffices for making up the positive first lens unit A.

In more detail, since the front and rear surfaces of the positive first lens unit A or the gradient-index lens are both convex, and the coefficient N_1 is of negative sign, the third-order spherical aberration in terms of refraction in the telephoto positions is largely over-corrected. Further since, as $K=+1$, the sign of the coefficient N_2 is made negative according to the inequality of condition (3), the spherical aberration in terms of gradient is under-corrected. Thus, a possibility of achieving a good balance is provided. In such a manner, by controlling the values of the terms of refraction and gradient for the third-order aberrations, not only the spherical aberration but also coma and astigmatism can be corrected as well.

The numerical data in accordance with which the zoom lens of FIG. 1 can be constructed are given in Tables 1-1 to 1-3 for the focal length f of the entire system, F-number FNO, the image angle 2ω, the radii of curvature, R, the axial thicknesses or air separations, D, and the refractive indices, N, and Abbe numbers, ν, of the glasses of the lens elements with the subscripts numbered consecutively from front to rear, along with the values for the spectral d- and g-lines of the refractive index distribution coefficients N_0 to N_4.

TABLE 1-1

f = 100–286 mm FNO = 4 2ω = 33.7°–12.1°

Radius of curvature	Axial thickness or air separation	Refractive index	Abbe number
R 1 = 113.846	D 1 = 12.65	N 1 = N 1 (h)	ν 1 =
R 2 = −297.528	D 2 = Variable		
R 3 = −304.656	D 3 = 2.09	N 2 = 1.71300	ν 2 = 53.8
R 4 = 68.065	D 4 = 6.50		
R 5 = −95.975	D 5 = 2.09	N 3 = 1.72000	ν 3 = 50.2
R 6 = 49.300	D 6 = 4.73	N 4 = 1.84666	ν 4 = 23.9
R 7 = 329.983	D 7 = Variable		
R 8 = 140.022	D 8 = 8.08	N 5 = 1.50977	ν 5 = 62.1
R 9 = −44.591	D 9 = 2.09	N 6 = 1.75520	ν 6 = 27.5
R 10 = −79.152	D 10 = Variable		
R 11 = 50.796	D 11 = 6.27	N 7 = 1.61272	ν 7 = 58.7

TABLE 1-1-continued

f = 100–286 mm FNO = 4 2ω = 33.7°–12.1°

Radius of curvature	Axial thickness or air separation	Refractive index	Abbe number
R 12 = 1452.507	D 12 = 3.40		
R 13 = −297.076	D 13 = 2.78	N 8 = 1.80518	ν 8 = 25.4
R 14 = 748.143	D 14 = 65.71		
R 15 = −27.591	D 15 = 2.78	N 9 = 1.80610	ν 9 = 40.9
R 16 = −61.394	D 16 = 0.28		
R 17 = 256.247	D 17 = 5.01	N 10 = 1.59551	ν 10 = 39.2
R 18 = −75.128			

TABLE 1-2

Di	f = 100	f = 200	f = 286
D 2	3.5538	48.6550	62.2338
D 7	46.7806	21.9370	0.5503
D 10	24.5758	4.3182	12.1261

TABLE 1-3

Ni (h)	λ	N_0	N_1	N_2	N_3	N_4
N1 (h)	d	1.53113	-1.00768×10^{-5}	-4.05391×10^{-10}	3.24621×10^{-13}	6.74961×10^{-18}
	g	1.54160	-5.10666×10^{-6}	2.91498×10^{-9}	-1.87763×10^{-12}	4.16037×10^{-15}

FIG. 3 illustrates another specific zoom lens of the invention whose aberrations are shown in FIG. 4. The symbols in these figures have the same meanings as those in FIGS. 1 and 2. The aberration curves represent the spherical aberration, astigmatism and distortion in different zooming positions of the focal length f=100, 200 and 304.5 mm.

The zoom lens comprises, from front to rear, a positive first lens unit A which is held stationary during zooming, a negative second lens unit B which axially moves with zooming to contribute to variation of the image magnification, a positive third lens unit C which axially moves with zooming to compensate for the image shift, and a positive fourth lens unit D which remains stationary during zooming. The second lens unit B, usually called the variator, is constructed with a gradient-index lens of the radial type with the surfaces R_6 and R_7. The gradient-index lens is made of a gradient of refractive index defined by the equation (1) where the coefficients N_1 and N_2 are of opposite sign such that $N_1>0$, and $N_2<0$.

The above-defined gradient-index lens, unlike the usual lens of homogeneous medium, gives a diverging function at its medium, and has a negative transition of power. Letting ϕ_{II} denote the required power of the negative second lens unit B and D the thickness of the gradient-index lens, it follows from the inequality of condition (2) that as $\phi_{II} \cdot N_1<0$, the gradient-index lens should be made with a gradient of refractive index of $N_1>0$. Then, the power ϕ owing to the term of gradient of the gradient-index lens is $\phi=-2N_1D$. This implies that the negative power of the lens unit B is partly borne by the term of gradient of the gradient-index lens. In this zoom lens, the negative second lens unit B can be constructed with one lens whose surfaces both are weak in curvature. Therefore, the zoom lens is fundamentally corrected to minimums of aberrations produced.

When the second lens unit B is constructed in the form of a bi-concave lens having a gradient of refractive index for the negative transition of power, the spherical aberration in the telephoto positions can be advanta-

geously corrected. And, other various aberrations, for example, coma and astigmatism, can also be corrected well. This permits only one gradient-index lens to suffice for constituting the negative second lens unit.

Both surfaces of the aforesaid gradient-index lens of the negative second lens unit B are concave, and the coefficient N_1 in the equation for the gradient of refractive index is made $N_1>0$, so that the third-order spherical aberration in terms of refraction at the concave surface is largely over-corrected in the telephoto positions. Since both surfaces of the gradient-index lens of the negative second lens unit B are concave, because $K=-1$, the gradient of refractive index is made with $N_2<0$, according to the inequality of condition (3), thereby the spherical aberration in terms of the gradient is produced in the opposite direction to that in which the spherical aberration in terms of the refraction is produced. Thus, a possibility of taking a balance is provided.

In such a manner the spherical aberration can be corrected by controlling the terms of the gradient and refraction for the third-order aberration. Similarly the coma and astisgmatism can be corrected.

Whilst it has been usual in the prior art that the negative second lens unit B is constructed by using three lens elements and that the spherical aberration is corrected by the cemented surface of the cemented lens, it is in the zoom lens of the invention that despite the negative second lens unit B is constructed by using only one lens element, the spherical aberration can be well corrected.

Further, the Petzval sum can be corrected when the gradient-index lens of the negative second lens unit B is made of the gradient of refractive index that satisfies the inequality of condition (2), or the gradient of refractive index of $N_1>0$ as in the zoom lens of FIG. 3. Letting ϕ denote the power owing to the converging or diverging effect of the medium of the gradient-index lens referred to the normalized focal length of the entire system to unity, and N_0 the basic refractive index, the Petzval sum varies as a function of $P=\phi/N_2{}^0$, being inversely proportional to the square of N_0, while the Petzval sum of the spherical system produces a larger Petzval sum, because the latter is expressed by $P=\phi/N_0$. Therefore, in the case of the zoom lens of the invention, a smaller Petzval sum is produced in the negative sense. On assumption that the power arrangement is the same as that of the zoom lens of the invention, the variator of the spherical system produces a Petzval sum of -1.25 to 1.3 in contrast to the negative second lens unit B as the variator of FIG. 3 which has a Petzval sum of -1.025 from the reason described above.

This means that the power of the zoom section may be strengthened or the telephoto ratio of the relay section may be reduced in order to shorten the optical total length of the entire system as compared with the spherical system. That is, the largest drawback of the conventional method for shortening the total length by strengthening the power of the zoom section, or by reducing the telephoto ratio of the relay section was that the Petzval sum became too large in the negative sense to be corrected. In the zoom lens of the invention, however, the variator produces a smaller Petzval sum in the negative sense, thus increasing the possibility of shortening the optical total length of the entire system by the above-described method.

In the zoom lens of the invention, the telephoto ratio of the relay section comprised of the positive fourth lens unit D is reduced so that the ratio of the total length of the entire system of 254.8 mm to the longest focal length of the entire ratio, or the telephoto ratio of the entire system can be reduced to a very small value of 0.836. Further, by the room for freedom created in the Petzval sum, the power of the positive first lens of the surfaces R_{11} and R_{12} in the positive fourth lens unit D is made higher to permit a higher degree of spherical aberration correction to be achieved.

Usually the variator of the zoom lens is constructed with three to five lens elements of strong power, and the tolerances for the thicknesses of the lens elements, the air spacings and the decentering of the lens elements from the common axis must be very rigorous. But, now that it can be constructed with only one element as in the zoom lens of the invention, the assembly and the adjusting operation becomes extremely easy.

The numerical data of the zoom lens of FIG. 3 along with the separations between the lens units during zooming, and the values of the coefficients for the gradient-index lens ar given in Tables 2-1 to 2-3 below. For note, the symbols in the tables have the same meanings as those stated in connection with the first example.

TABLE 2-1

f = 100–304.5 mm FNO = 4 2ω = 33.34°–11.6°

Radius of curvature	Axial thickness or air separation	Refractive index	Abbe number
R 1 = 210.378	D 1 = 3.90	N 1 = 1.80518	ν 1 = 25.4
R 2 = 95.402	D 2 = 9.40	N 2 = 1.61272	ν 2 = 58.7
R 3 = −4243.836	D 3 = 0.14		
R 4 = 135.346	D 4 = 6.68	N 3 = 1.61272	ν 3 = 58.7
R 5 = −2643.187	D 5 = Variable		
R 6 = −279.005	D 6 = 10.53	N 4 = N4 (h)	
R 7 = 258.188	D 7 = Variable		
R 8 = 133.470	D 8 = 8.08	N 5 = 1.51633	ν 5 = 64.1
R 9 = −46.653	D 9 = 2.09	N 6 = 1.75520	ν 6 = 27.5
R 10 = −84.501	D 10 = Variable		
R 11 = 49.541	D 11 = 6.27	N 7 = 1.71300	ν 7 = 55.2
R 12 = 1079.685	D 12 = 1.11		
R 13 = −380.726	D 13 = 2.78	N 8 = 1.80518	ν 8 = 25.4
R 14 = 271.435	D 14 = 64.41		
R 15 = −25.406	D 15 = 2.78	N 9 = 1.76200	ν 9 = 40.1
R 16 = −72.472	D 16 = 0.28		
R 17 = 227.126	D 17 = 5.01	N 10 = 1.59551	ν 10 = 30.5
R 18 = −75.129			

TABLE 2-2

	f		
Di	100	200	304.5
D 5	2.7787	47.8801	63.3781
D 7	51.0469	26.2032	0.2132
D 10	23.2531	2.9954	13.4873

TABLE 2-3

Ni (h)	λ	N_0	N_1	N_2	N_3
N 4 (h)	d	1.47069	8.0759×10^{-4}	-3.1382×10^{-7}	8.9457×10^{-11}
	g	1.47925	8.0465×10^{-4}	-3.1744×10^{-7}	9.5646×10^{-11}

FIG. 5 is a longitudinal section view illustrating another specific zoom lens of the invention, and FIG. 6 shows its aberrations. The symbols in these figures have the same meanings as in the foregoing examples. The aberration curves are of the spherical aberration, astigmatism and distortions at the focal lengths of f=100, 167 and 283 mm.

The zoom lens comprises, from front to rear, a positive first lens unit A which axially moves with zooming to contribute to variation of the image magnification, a negative second lens unit B which is held stationary during zooming, a positive third lens unit C which axially moves with zooming to contribute to a variation of the image magnification and also to compensate for the image shift, and a positive fourth lens unit D which remains stationary during zooming. The negative second lens unit B is constructed with a first radial gradient-index lens having surfaces R_6 and R_7 and a second radial gradient-index lens having surfaces R_8 and R_9. Since, in this zoom lens, the negative second lens unit which is most sensitive to decentering is held stationary, it becomes possible to improve the assembly accuracy.

The above-described two gradient-index lenses, unlike the usual lens, have diverging actions at the interiors thereof, providing a negative transition power. Letting the refractive power of the negative second lens unit be denoted by ϕ_{II} and the sum of the thicknesses of the gradient-index lenses by D, since, according to the inequality of condition (2), $\phi_{II} \cdot N_1 < 0$, that is, $\phi_{II} < 0$, for the gradient-index lenses are made with refractive index gradients of $N_1 > 0$, they produce a power $\phi = -2N_1D$ owing to the term of gradient. This implies that the negative power of the lens unit B is partly borne by the term of gradient of the gradient-index lenses. Whilst the prior art would necessitate four to five lens elements, it is in the zoom lens of FIG. 5 that only two lens elements suffice for constituting the negative second lens unit B.

For example, the first gradient-index lens R_6, R_7, has its rear surface R_7 made of a stronger concave curvature. This concave surface R_7 in combination with $N_1 > 0$ produce over-corrected third-order spherical aberration in terms of refraction in the telephoto positions.

On this account, the direction in which the spherical aberration in terms of gradient is produced should be made opposite to that of the spherical aberration in terms of refraction so that a balance can be taken. Since the rear surface of the first gradient-index lens is of stronger curvature than the front surface, because it is concave or $K = -1$, when the inequality of condition (3) is satisfied by making the gradient of refractive index with $N_2 < 0$, the spherical aberration in terms of gradient can be produced as opposed to that in terms of refraction to permit the balance to be obtained.

Therefore, the term of refraction for third-order spherical aberration, the term of gradient for third-order spherical aberration and the term of refraction for fifth-order spherical aberration allow the spherical aberrations to be balanced out, thus making it possible to correct the spherical aberration for a higher grade of imagery as the coma and astigmatism also can be well corrected in a similar manner.

The zoom lens of FIG. 5 can be constructed in accordance with the numerical data given in Tables 3-1 to 3-3 below.

TABLE 3-1

f = 100–283 mm FNO = 3.5–4.5 2ω = 62°–24°

Radius of curvature	Axial thickness or air separation	Refractive index	Abbe number
R 1 = 407.450	D 1 = 6.94	N 1 = 1.80518	ν 1 = 25.4
R 2 = 137.500	D 2 = 25.00	N 2 = 1.60311	ν 2 = 60.7
R 3 = −1037.545	D 3 = 0.33		
R 4 = 127.463	D 4 = 16.39	N 3 = 1.69680	ν 3 = 55.5
R 5 = 614.861	D 5 = Variable		
R 6 = 468.216	D 6 = 15.25	N 4 (h)	
R 7 = 39.286	D 7 = 13.44		
R 8 = 967.214	D 8 = 22.92	N 5 (h)	
R 9 = −669.488	D 9 = Variable		
R 10 = 0.	D 10 = 2.78		
R 11 = 217.164	D 11 = 8.89	N 6 = 1.77250	ν 6 = 49.6
R 12 = −223.324	D 12 = 1.06		
R 13 = 62.499	D 13 = 7.50	N 7 = 1.59551	ν 7 = 39.2
R 14 = 127.754	D 14 = 10.39		
R 15 = 53.560	D 15 = 15.86	N 8 = 1.51742	ν 8 = 52.4
R 16 = −410.952	D 16 = 12.36	N 9 = 1.84666	ν 9 = 23.9
R 17 = 40.082	D 17 = 10.22		
R 18 = 256.491	D 18 = 8.33	N 10 = 1.67003	ν 10 = 47.3
R 19 = −127.251	D 19 = Variable		
R 20 = 0.	D 20 = Variable		
R 21 = −113.395	D 21 = 3.33	N 11 = 1.77250	ν 11 = 49.6
R 22 = 227.778	D 22 = 8.06	N 12 = 1.51742	ν 12 = 52.4
R 23 = −426.515	D 23 = 6.92		ν 13 = 58.2
R 24 = 392.060	D 24 = 15.00	N 13 = 1.62279	
R 25 = −103.840			

TABLE 3-2

Di	f = 100	f = 167	f = 283
D 5	4.06	33.33	56.32
D 9	48.63	27.00	3.14
D 19	3.16	14.45	18.09
D 20	11.11	21.44	41.67

TABLE 3-3

Ni (h)	N_0	N_1	N_2	N_3	N_4
N 4 (h)	1.58646	2.395×10^{-4}	-9.34648×10^{-8}	5.07906×10^{-11}	-1.16755×10^{-14}
N 5 (h)	1.85000	1.47898×10^{-5}	-6.09657×10^{-8}	-1.52336×10^{-11}	-1.97975×10^{-14}

A third example of the specific zoom lens of the invention is illustrated in FIG. 7, and its spherical aberration, astigmatism and distortion are shown in different focal length positions of f=100, 170 and 278 mm.

This zoom lens comprises, from front to rear, a positive first lens unit A which axially moves with zooming, a negative second lens unit B which axially moves with zooming to contribute to variation of the image magnification, and positive third lens unit C which remains stationary during zooming. The positive first lens unit A consists of a radial gradient-index lens having surfaces R_1 and R_2. The negative second lens unit B consists of a radial gradient-index lens having surfaces R_3 and R_4 front part of the third lens unit C includes a radial gradient lens of bi-convex form having surfaces R_5 and R_6 at the frontmost position, followed rearwardly after a very short spacing by an axial gradient-index lens of bi-convex form having surfaces R_7 and R_8, and a rear part

includes a radial gradient-index lens of convex form having surfaces R_{10} and R_{11}.

When the positive first lens unit is constructed in the form of a convex lens, and is made with such a gradient of refractive index that a positive transition power is produced as in the zoom lens of the invention, an advantage of correcting spherical aberration in the telephoto positions is produced. And, because other various aberrations can be well corrected, it has been made possible that only one lens element having the gradient of refractive index sufficies for contructing the positive first lens unit A.

Also, the radial gradient-index lens having the negative transition power in the negative second lens unit B, because the negative transition power of the interior thereof can partly bear the power of the lens unit B, enables the curvature of the surfaces of the lens to be weakened with an advantage of correcting spherical aberration and Petzval sum.

For example, if the power arrangement is the same, the negative lens unit B which would otherwise be made of homogeneous material only would produce a Petzval sum of -1.45 to -1.6 referred to the normalized focal length of the entire system to unity. But, in the zoom lens of the invention, as it is constructed with the radial gradient-index lens, the Petzval sum is reduced to a very small value of -1.06.

Thus, the adoption of the gradient-index lens as the second lens unit B enables the Petzval sum to be suppressed. This permits the telephoto ratio of the relay lens, that is, the positive third lens unit C to be minimized with an advantage of shortening the optical total length of the entire system.

The third lens unit C is divided into the front and rear parts spaced apart by a longest distance D_9 in that lens unit. As the frontmost lens in the front part use is made of a gradient-index lens of bi-convex form. At the same time, as the frontmost lens in the rear part also, use is made of a gradient-index lens which is also of bi-convex form. The first-named and second-named gradient-index lenses have positive and negative transition powers respectively, and their gradients of refractive index are formed so as to satisfy the inequalities (2) and (3). By using such a construction and arrangement, the spherical aberration and coma of the front part and the spherical aberration, curvature of field and distortion of the rear part which would usually by deteriorated when the powers of the front and rear parts are strengthened in order to achieve a shortening of the entire system, are made possible to correct well.

Next explanation is given to how such advantages are produced by the adoption of the gradient-index lens as the positive first lens unit A.

The above-described gradient-index lens, unlike the usual lens of homogeneous medium, has a converging action even at its medium, getting a positive transition power. Letting the refractive power of the positive first lens unit A be denoted by ϕ_I and the thickness of the gradient-index lens by D, since, according to the inequality of condition (2), or $\phi_I \cdot N_1 < 0$, as $\phi_I > 0$, the gradient of refractive index is made with $N_1 < 0$, because such a gradient-index lens produces a power ϕ in terms of gradient given by the expression $\phi = -2N_1D$, it should be understood that the positive power of the lens unit A is partly borne by the term of gradient of that gradient-index lens.

As the curvatures of both convex surfaces of the positive first lens unit A, therefore, become weaker, smaller spherical aberrations are produced. A good result of the other aberrations, for example, coma and astigmatism, can also be attained. These facts enable the positive first lens unit A to be constructed with only one gradient-index lens.

Since both surfaces of the gradient-index lens constituting the positive first lens unit A are convex, and $N_1 < 0$, the third-order spherical aberration in terms of refraction is over-corrected in the telephoto positions. Further since, as both surfaces of the gradient-index lens in the positive first lens unit A are convex, $K = +1$, for, as the inequality of condition (3) is satisfied, the gradient of refractive index is made with $N_2 < 0$, the spherical aberration in terms of gradient is produced as opposed to that in terms of refraction, thus permitting a balance of them to be taken.

Further, with the gradient of refractive index of $N_2 < 0$, the fifth-order spherical aberration in terms of refraction is over-corrected. Thus, the third-order spherical aberrations in terms of refraction and gradient and the fifth order spherical aberration in terms of refraction are balanced out with one another to achieve a higher degree of correction of spherical aberration. In a similar manner, higher degrees of correction of coma and astigmatism can be obtained.

Next, concerning the advantages arising from the use of a gradient-index lens as the negative second lens unit B, letting the refractive power of the negative second lens unit B be denoted by ϕ_{II} and the thickness of the aforesaid gradient-index lens by D, since, according to the inequality of condition (2), or $\phi_{II} \cdot N_1 < 0$, as $\phi_{II} < 0$, the gradient of refractive index is made with $N_1 > 0$, for the aforesaid gradient-index lens produces a power ϕ owing to the gradient given by the expression $\phi = -2N_1D$ the negative power of the lens unit B is partly borne by the term of gradient. Therefore, it is in the zoom lens of the invention that the negative second lens unit can be constructed by using one lens element whose both surfaces are of weaker curvature.

Since both surfaces of the gradient-index lens constituting the negative second lens unit B are convex, for a refractive index pattern with $N_1 > 0$ appears at that surface, the third-order spherical aberration in terms of refraction is under-corrected in the telephoto positions. Further since, as both surfaces of the aforesaid gradient-index lens are convex, $K = +1$, because the gradient of refractive index is made with $N_2 > 0$, according to the inequality of condition (3), the spherical aberrations in terms of gradient and refraction are produced as opposed to each other to permit a balance to be taken.

Further, with the gradient of refractive index of $N_2 > 0$, the fifth-order spherical aberration in terms of refraction is under-corrected. Therefore, the third-order spherical aberrations in terms of gradient and refraction and the fifth-order spherical aberration in terms of refraction are balanced out with one another to achieve a higher degree of correction of spherical aberration. In a similar manner, higher degrees of corection of coma and astigmatism can be achieved.

Usually, the negative second lens unit B is constructed with three lens elements, and the spherical aberration is corrected by the cemented surface of them. In the present invention, on the other hand, despite the number of constituent lens elements is only one, the various aberrations can be corrected.

Next, concerning the advantages arising the incorporation of the gradient-index lens into the front part of the positive third lens unit C, letting the refractive

power of the front part of the third lens unit C be denoted by $\phi_{III\text{-}1}$, and the thickness of the radial gradient-index lens by D_1, since, as $\phi_{III\text{-}1}>0$, $N_1<0$, or since, as the inequality of condition (2) is satisfied, the gradient of refractive index is made with $N_1<0$, for that gradient-index lens produces a transition power $\phi=-2N_1D_1$ which is positive, the positive power of the front part is partly borne by the transition power of the gradient-index lens. Also since, as both surfaces of that gradient-index lens are convex, $K=+1$, the gradient of refractive index is made also according to the inequality of condition (3).

Therefore, the spherical aberration can be well corrected, and other aberrations for example, coma and astigmatism, can also be well corrected. Therefore, the total length can be shortened by strengthening the power of the front part. That is, regarding the correction of spherical aberration, for the gradient of refractive index is made of $N_1<0$, the third-order spherical aberration in terms of refraction is over-corrected in the telephoto positions, and the spherical aberration in terms of gradient is produced as opposed to that in terms of refraction to permit a balance to be taken. Further since the gradient of refractive index is made of $N_2<0$, the fifth-order spherical aberration in terms of refraction is over-corrected. The third-order spherical aberrations in terms of refraction and gradient and the fifth-order spherical aberration in terms of refraction are delicately balanced out with one another to permit a higher degree of correction of spherical aberration to be obtained. In a similar manner, higher degrees of correction of coma and astigmatism can also be obtained.

Next, concerning the advantages arising from the incorporation of the gradient-index lens in the rear part of the positive third lens unit C, letting the refractive power of the rear part be denoted by $\phi_{III\text{-}2}$, and the thickness of the gradient-index lens by D_2, since, according to the inequality of condition (2), as $\phi_{III\text{-}2}<0$, $N_1>0$, for the gradient of refractive index is made with $N_1>0$, that gradient-index lens produces a negative transition power $\phi=-2N_1D_2$ which is to partly bear the power of the rear part. Therefore, even if the negative refractive power of the rear part of the positive third lens unit C is strengthened, the various aberrations can be well corrected to permit the total length to be shortened. Since both refracting surfaces of the gradient-index lens, similarly to the front part, are convex, because $N_1>0$, the third-order spherical aberration in terms of refraction is under-corrected. Also since $K=+1$, for the inequality of condition (3) is satisfied, the spherical aberration in terms of gradient is produced as opposed to that in terms of refraction to permit a balance to be taken.

Further since the gradient of refractive index is made of $N_2>0$, the fifth-order spherical aberration in terms of refraction is under-corrected. Similarly to the gradient-index lens in the front part, the third-order spherical aberration and the fifth-order spherical aberration in terms of refraction are balanced out to achieve a higher degree of correction of spherical aberration. Also, higher degrees of correction of coma, astigmatism, and distortion can be obtained.

It will be appreciated that a great reduction of the size of the entire system can be achieved by incorporating the gradient-index leses into the last lens unit while maintaining a good stability of aberration correction throughout the entire system when the inequalities of condition (2) and (3) are satisfied.

Though this specific example has been described in connection with the last or positive third lens unit C which is held stationary during zooming, it is to be understood that the present invention is applicable to another zoom type in which the last or third lens unit axially moves with zooming, while preserving the above-described advantages to obtain a compact zoom lens.

The fourth example of the specific zoom lens can be constructed in accordance with the numerical data given in Tables 4-1 to 4-3. As the fourth lens counting from front in the zoom lens is a gradient-index lens of the axial type, the gradient of refractive index $N_4(x)$ can be expressed by the following equation in terms of the distance x measured from the front vertex toward the rear in the direction parallel to the optical axis.

$$N4\ (x)=N_0+N_1x+N_2x^2+N_3x^3+N_4x^4+\ldots$$

where N_0 is the refractive index at the front vertex, and N_1, N_2, N_3, . . . are coefficients similarly to the radial type.

TABLE 4-1

f = 100 -249 mm FNO = 4.5 2ω = 15.4°-6.3°

Radius of curvature	Axial thickness or air separation	Refractive index	Abbe number
R 1 = 152.141	D 1 = 6.45	N 1 = N 1 (h)	
R 2 = −364.417	D 2 = Variable		
R 3 = 1791.055	D 3 = 11.89	N 2 = N 2 (h)	
R 4 = −232.978	D 4 = Variable		
R 5 = 58.465	D 5 = 3.11	N 3 = N 3 (h)	
R 6 = −310.150	D 6 = 0.13		
R 7 = 33.218	D 7 = 5.94	N 4 = N 4 (x)	
R 8 = −105.627	D 8 = 1.92	N 5 = 1.76182	ν 5 = 26.7
R 9 = 144.548	D 9 = 22.45		
R 10 = 78.968	D 10 = 3.74	N 6 = N 6 (h)	
R 11 = −129.162	D 11 = 13.14		
R 12 = −18.251	D 12 = 2.55		
R 13 = −63.480		N 7 = 1.51633	ν 7 = 65.0

TABLE 4-2

Di	f = 100	f = 178	f = 249
D 2	6.1093	60.9511	80.5207
D 4	19.4808	10.5103	2.5538

TABLE 4-3

	λ	N_0	N_1	N_2	N_3	N_4
N 1 (h)	d	1.60311	-1.03484×10^{-5}	-1.43773×10^{-9}	-3.77260×10^{-13}	-3.27796×10^{-15}
	g	1.61539	-1.46124×10^{-6}	7.45671×10^{-9}	-7.54785×10^{-12}	-1.90601×10^{-14}
N 2 (h)	d	1.51633	1.18942×10^{-3}	2.19747×10^{-7}	1.65968×10^{-10}	-2.56728×10^{-13}
	g	1.52621	1.19257×10^{-3}	2.09285×10^{-7}	1.45862×10^{-10}	-2.57532×10^{-13}
N 3 (h)	d	1.60311	-1.49443×10^{-4}	1.68071×10^{-8}	2.21414×10^{-11}	-7.55521×10^{-14}
	g	1.61539	-1.27794×10^{-4}	4.27907×10^{-8}	-2.69545×10^{-11}	-2.73292×10^{-13}
N 4 (x)	d	1.60311	5.07740×10^{-3}	-3.02946×10^{-4}	2.20784×10^{-5}	
	g	1.61539	3.10865×10^{-3}	-3.06770×10^{-4}	-3.15046×10^{-6}	

TABLE 4-3-continued

	λ	N_0	N_1	N_2	N_3	N_4
N 6 (h)	d	1.51633	5.65029×10^{-4}	1.95324×10^{-6}	3.48922×10^{-9}	2.96608×10^{-11}
	g	1.52621	5.35259×10^{-4}	1.88101×10^{-6}	1.63007×10^{-9}	3.22708×10^{-11}

A fifth example of the specific zoom lens of the invention is illustrated in FIG. **9** and its spherical aberration, astigmatism and distortion in the focal length positions of f=100, 167 and 283 mm are shown in FIG. **10**.

This zoom lens comprises, from front to rear, a positive first lens unit A which axially moves with zooming to contribute to variation of the image magnification, a negative second lens unit B which is held stationary during zooming, a positive third lens unit C which axially moves with zooming to contribute to a variation of the image magnification and to compensate for the image shift, and a positive fourth lens unit D which remains stationary during zooming. The third lens unit C comprises, front from to rear, positive, negative and positive lenses, of which the first positive is a radial gradient-index lens having a positive transition power with the surfaces R_{14} and R_{15}, and the second positive is a radial gradient-index lens having a negative transition power with the surfaces R_{18} and R_{19}. Because, in this zoom lens, the position of the negative second lens unit B relative to the image plane does not change, this type is suited to facilitate simplification of the structure of the operating mechanism.

The rays of light emerging from the negative second lens unit B are divergent on the positive first lens of the third lens unit C. As the height of incidence of the principal ray is higher than in the other types of zoom lens, under-correction of spherical aberration is liable to result. On this account, use is made of the gradient-index lens so that it is corrected in direction to over-correction. And, since the positive first or gradient-index lens has a positive transition power, for, as the positive power of that lens is so much strengthened, the principal point of the positive third lens unit C is brought to a more forward position, the interval between the principal points of the negative second and positive third lenses can be reduced, contributing to a shortening of the entire system.

Also, as the height of incidence of the oblique pencile on the positive third lens is high, the use of another gradient-index lens as this lens allows for correcting particularly astigmatism.

It has been customary that the positive third lens unit C in this kind of zoom lens is constructed with at least five lens elements. In the invention, on the other hand, only three lens elements suffice, contributing to a compactness of the entire system. Another advantage arising from the reduction of the number of lens elements is that the assembly and the adjusting operation become easier, making it possible to simplify the structure of the operating mechanism.

In more detail, letting the refractive power of the positive third lens unit C be denoted by ϕ_{III} and the thickness of the gradient-index lens by D, since, according to the inequality of condition (2), or $\phi_{III} \cdot N_1 < 0$, as $\phi_{III} > 0$, $N_1 < 0$, for the gradient-index lens made of such a gradient of refractive index gets a power $\phi = -2N_1D$ owing to the term of gradient, the positive power of the lens unit C is partly borne by the term of gradient of that gradient-index lens.

With both convex surfaces of the gradient-index lens, for the gradient of refractive index is made of $N_1 < 0$, the third-order spherical aberration in terms of refraction is over-corrected in the telephoto positions. Since, as both surfaces of the gradient-index lens are convex, $K = +1$, for, according to the inequality of condition (3), the gradient of refractive index is further made of $N_2 < 0$, the spherical aberration in terms of the gradient is produced as opposed in direction to that in terms of the refraction, to permit a balance to be taken.

Further, with the gradient of refractive index of $N_2 < 0$, over-correction of the fifth-order spherical aberration in terms of the refraction results. So, the third-order spherical aberration in terms of the refraction, the third-order spherical aberration in terms of the gradient and the fifth-order spherical aberration in terms of the refraction are balanced out to permit a higher correction of spherical aberration to be obtained. In a similar manner, higher degrees of correction of coma and astigmatism can also be obtained.

The zoom lens of FIG. **9** can be constructed in accordance with the numerical data given in Tables 5-1 to 5-3 below.

TABLE 5-1

f = 100–283 mm FNO = 3.5–4.7 2ω = 62°–24°

Radius of curvature	Axial thickness or air separation	Refractive index	Abbe number
R 1 = 329.775	D 1 = 6.94	N 1 = 1.80518	ν 1 = 25.4
R 2 = 137.307	D 2 = 25.00	N 2 = 1.60311	ν 2 = 60.7
R 3 = −2316.906	D 3 = 0.33		
R 4 = 127.715	D 4 = 16.11	N 3 = 1.69680	ν 3 = 55.5
R 5 = 589.863	D 5 = Variable		
R 6 = 349.552	D 6 = 3.33	N 4 = 1.88300	ν 4 = 40.8
R 7 = 49.444	D 7 = 13.33		
R 8 = −147.683	D 8 = 3.06	N 5 = 1.88300	ν 5 = 40.8
R 9 = 179.196	D 9 = 5.14		
R 10 = 96.122	D 10 = 13.33	N 6 = 1.84666	ν 6 = 23.9
R 11 = −88.957	D 11 = 3.71		
R 12 = −68.016	D 12 = 3.06	N 7 = 1.83400	ν 7 = 37.2
R 13 = −955.505	D 13 = Variable		
R 14 = 83.717	D 14 = 26.71	N 8 = N 8 (h)	
R 15 = −156.910	D 15 = 7.80		
R 16 = 11044.891	D 16 = 16.47	N 9 = 1.84666	ν 9 = 23.9
R 17 = 56.388	D 17 = 5.28		
R 18 = −455.820	D 18 = 6.94	N 10 = N 10 (h)	
R 19 = −69.670	D 19 = Variable		
R 20 = −95.749	D 20 = 3.33	N 11 = 1.77250	ν 11 = 49.6
R 21 = 282.765	D 21 = 8.06	N 12 = 1.51633	ν 12 = 64.1
R 22 = −169.580	D 22 = 6.53		
R 23 = 227.054	D 23 = 15.00	N 13 = 1.51742	ν 13 = 52.4
R 24 = −115.070			

TABLE 5-2

	f		
Di	100	167	283
D 5	2.92	32.18	55.18
D 13	52.25	30.63	6.77
D 19	11.11	32.74	56.59

TABLE 5-3

Ni (h)	λ	N_0	N_1	N_2	N_3	N_4
N 8 (h)	d	1.60342	-1.43316×10^{-4}	-2.49536×10^{-8}	-8.04703×10^{-12}	-6.64964×10^{-15}
	g	1.62382	-1.43595×10^{-4}	-2.82066×10^{-8}	5.33417×10^{-12}	-1.80972×10^{-14}
N 10 (xh)	d	1.50137	2.16886×10^{-5}	-3.60780×10^{-9}	7.16738×10^{-12}	-2.03457×10^{-14}
	g	1.51250	1.85615×10^{-5}	6.03319×10^{-8}	-3.72674×10^{-10}	6.14045×10^{-13}

A sixth example of the specific zoom lens of the invention is illustrated in FIG. **11**, whose spherical aberration, astigmatism and distortion in the focal length positions of f=100, 280 and 570 mm are shown in FIG. **12**.

This zoom lens comprises, from front to rear, a positive first lens unit A which is held stationary during zooming, a negative second lens unit B which axially moves with zooming to contribute to variation of the image magnification, a negative third lens unit C which axially moves with zooming to compensate for the image shift, and a positive fourth lens unit D which is held stationary during zooming. As this zoom lens is adapted to be used with an image pickup device, the fourth lens unit D is usually included with a positive lens for making afocal the arriving rays of divergence in passing therethrough at the front most position and a prism (not shown) as a beam splitter for the finder, and, in many cases, also with a diaphragm. Also, since the image plane is immediately preceded by a low pass filter, a stripe filter and a face plate, the rays emerging from the positive fourth lens unit D are almost telecentric.

In the invention, a lens group of positive power which is usually constructed with three or four lens elements just behind the diaphragm is replaced by one gradient-index lens having surfaces R_{17} and R_{18}. For the medium of the gradient-index lens as having a positive transition power bears part of the overall positive power of that lens, the curvature of its surfaces can be weakened to suppress aberrations to minimum. Also, the surfaces R_{17} and R_{18} each have lower refractive indices from the paraxial region toward the margin. So, the more marginal the incident ray, the smaller it refracts as compared with the lens of homogeneous material, and the smaller the spherical aberration and coma produced become. Further, for $N_2>0$, the excessively undercorrected spherical aberration by the presence of the refractive index pattern over the surface R_{18} can be corrected when the rays pass through the interior thereof.

In such a manner, the aberrations can be corrected. Whilst the conventional relay section has had many troubles due to the optical misalignment, the positive fourth lens unit D as the relay section can be constructed with only one lens element for the positive lens group just behind the diaphragm, thereby giving an advantage of facilitating the assembly and the adjusting operation. Also, as the residual aberrations of the front part of the relay section become small, the curvatures of the surfaces of the lens elements constituting the rear part of the relay section can be weakened. So, the assembly and adjusting operation become easier.

Concerning the advantages produced by incorporating the gradient-index lens into the positive fourth lens unit D, a more detailed explanation is given below.

Since the gradient-index lens with the surfaces R_{17} and R_{18} satisfies the inequality of condition (2), or $\phi_G \cdot N_1 < 0$, the power of the positive fourth lens unit D is partly borne by the term of gradient of that gradient-index lens. Therefore, the surface curvature of each of the lens elements constituting the fourth lens unit D can be weakened, thereby it being made possible to decrease the aberrations. Another advantage is that when the minimum acceptable edge thickness or marginal separation is taken, the axial air spacing can be minimized, thereby it being made possible to shorten the fourth lens unit D and therefore to achieve an advance in the compactness of the entire system.

Further since the inequality of condition (3) or $K \cdot \phi_G \cdot N_2 < 0$, is simultaneously satisfied, the direction of correction of aberrations by the surface of stronger curvature is made opposed to that of correction of those aberrations by the gradient of refractive index. This implies that the convex gradient-index lens though being only one is equivalent in the aberration correcting effect to several number of convex and concave lenses in combination. Thus, the spherical aberration, coma and astigmatism can be well corrected.

The sixth example of the zoom lens of the invention can be constructed in accordance with the numerical data given in Tables 6-1 to 6-3 below.

TABLE 6-1

f = 100–570 mm FNO = 1.22–1.39 2ω = 49°–9°

Radius of curvature	Axial thickness or air separation	Refractive index	Abbe number
R 1 = 1656.780	D 1 = 22.73	N 1 = 1.80518	ν 1 = 25.4
R 2 = 460.895	D 2 = 92.04	N 2 = 1.60311	ν 2 = 60.7
R 3 = −1206.452	D 3 = 1.70		
R 4 = 355.491	D 4 = 51.14	N 3 = 1.69680	ν 3 = 55.5
R 5 = 1154.930	D 5 = Variable		
R 6 = 971.149	D 6 = 11.36	N 4 = 1.77250	ν 4 = 49.6
R 7 = 155.806	D 7 = 43.84		
R 8 = −202.438	D 8 = 11.36	N 5 = 1.73500	ν 5 = 49.8
R 9 = 213.710	D 9 = 36.36	N 6 = 1.84666	ν 6 = 23.9
R 10 = −2717.151	D 10 = Variable		
R 11 = −276.943	D 11 = 11.36	N 7 = 1.69680	ν 7 = 55.5
R 12 = 15112.844	D 12 = Variable		
R 13 = 621.683	D 13 = 47.73	N 8 = 1.71300	ν 8 = 53.8
R 14 = −310.849	D 14 = 2.27		
R 15 = 0.0	D 15 = 68.18	N 9 = 1.51633	ν 9 = 64.1
R 16 = 0.0	D 16 = 77.84		
R 17 = 188.081	D 17 = 129.89	N 10 (h)	
R 18 = 130.653	D 18 = 160.23		
R 19 = 436.232	D 19 = 12.50	N 11 = 1.80518	ν 11 = 25.4
R 20 = 191.471	D 20 = 30.68		
R 21 = 1800.375	D 21 = 34.09	N 12 = 1.51633	ν 12 = 64.1
R 22 = −204.201	D 22 = 1.14		
R 23 = 125.316	D 23 = 51.14	N 13 = 1.72000	ν 13 = 50.2
R 24 = 1653.314	D 24 = 14.77		
R 25 = 0.0	D 25 = 62.50	N 14 = 1.51633	ν 14 = 64.1
R 26 = 0.0			

TABLE 6-2

Di	f = 100	f = 280	f = 570
D 5	21.50	196.44	269.14
D 10	257.50	60.72	29.30
D 12	37.91	59.75	18.47

TABLE 6-3

Ni (h)	λ	N_0	N_1	N_2	N_3	N_4	N_5
N 10 (h)	d	1.8457	-5.76408×10^{-6}	6.72888×10^{-11}	1.83029×10^{-15}	6.51016×10^{-20}	6.69015×10^{-24}
	g	1.86557	-5.45905×10^{-6}	8.8922×10^{-11}	8.24188×10^{-16}	1.50515×10^{-20}	1.51127×10^{-23}

It is to be understood from the above-described specific embodiments of the invention that when a gradient-index lens that satisfies the inequalities (2) and (3) is incorporated into a desired one or ones of the lens units, for the lens unit is of positive power, the gradient-index lens has an almost equivalent effect to that of a lens system of two positive lenses and one negative lens which are of homogeneous medium, and for the lens unit is of negative power, it has an almost equivalent effect to that of a lens system of two negative lenses and one positive lens.

Therefore, the above-described advantages on the aberration correction can be obtained when at least one of the plurality of lens units of the zoom lens is included with at least one gradient-index lens provided that the above-stated conditions (2) and (3) are satisfied. Further, the necessary number of constituent lens elements in that lens unit can be remarkably reduced. It is, therefore, obvious that as the number of gradient-index lenses used and the number of lens units employing those gradient-index lenses increase, a further improvement of the performance and compactness of the zoom lens can be achieved.

What is claimed is:

1. A variable focal length objective comprising a plurality of lens units of which the first from the object side is a positive lens unit, the second from the object side is a negative lens unit, and in which when varying the image magnification, the separation between said first and said second lens units varies, wherein at least one of the plurality of lens units has at least one gradient-index lens having a gradient of refractive index defined by the following equation:

$$N(h)=N_0+N_1h^2+N_2h^4+\ldots$$

wherein h is the height from the optical axis; N_0 is the refractive index on the optical axis, and N_1, N_2, . . . are constants, and wherein when the refractive power of said at least one lens unit is denoted by ϕ_G, and when the sign of the strongest curvature surface of said gradient-index lens is denoted by K such that $K=+1$ when said strongest curvature surface is convex, and $K=-1$ when said strongest curvature surface is concave, the following conditions are satisfied:

$$\phi_G \cdot N_1 < 0$$

$$K \cdot \phi_G \cdot N_2 < 0.$$

2. A variable focal length objective according to claim **1**, wherein said gradient-index lens is provided in said first lens unit.

3. A variable focal length objective according to claim **1**, wherein said gradient-index lens is arranged in at least a lens unit which moves to effect variation of the image magnification.

4. A variable focal length objective according to claim **1**, wherein of said plurality of lens units, there is a last lens unit that is furthest from the object side and comprises a front part and a rear part that are separated from each other by a distance that is larger than the distance separating a front and a rear part of any other of the plurality of lens units, and wherein at least one of said front and said rear parts of said last lens unit has at least one gradient-index lens that satisfies said equation and conditions.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 4,842,386

DATED : June 27, 1989

INVENTOR(S) : Nozomu Kitagishi, et al

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

At column 2, line 7, "pencile," should read --pencil,--;

At column 2, line 27, "Odd numbered" should read --Odd-numbered--; and

At column 2, line 30, "Even numbered" should read --Even-numbered--.

At column 3, line 46, "sphare" should read --sphere--.

At column 4, formula 18, "$[\ 8N_2h\bar{h}^3 = \frac{2N_1\bar{h}\bar{a}}{N_o^2}$"

should read --$[\ 8N_2h\bar{h}^3 + \frac{2N_1\bar{h}\bar{a}}{N_o^2}$--

At column 5, line 51, "distrubution" should read --distribution--.

UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 4,842,386

DATED : June 27, 1989

INVENTOR(S) : NOZOMU KITAGISHI ET AL

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

At column 12, line 63, "R_3 and R_4" should read --R_3 and R_4.--;

and

At column 12, line 64, "front" should read --A front--.

At column 14, line 58, "corection" should read --correction--.

At column 15, line 37, "$\phi_{III-2,}$" should read --$\phi_{III-2'}$--.

Signed and Sealed this

Nineteenth Day of June, 1990

Attest:

HARRY F. MANBECK, JR.

Attesting Officer

Commissioner of Patents and Trademarks

United States Patent [19]

Koyama et al.

[11] **Patent Number: 4,841,326**

[45] **Date of Patent: Jun. 20, 1989**

[54] **APPARATUS FOR DETECTING THE FOCUS ADJUSTED STATE OF AN OBJECTIVE OPTICAL SYSTEM**

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[73] Assignee: **Canon Kabushiki Kaisha,** Tokyo, Japan

[21] Appl. No.: **115,905**

[22] Filed: **Nov. 2, 1987**

[30] **Foreign Application Priority Data**

Nov. 5, 1986 [JP] Japan 61-264355

[51] **Int. Cl.**[4] **G03B 3/00**

[52] **U.S. Cl.** **354/406;** 354/402; 354/408

[58] **Field of Search** 354/400, 402, 406, 408

[56] **References Cited**

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Primary Examiner—Russell E. Adams

Attorney, Agent, or Firm—Fitzpatrick, Cella, Harper & Scinto

[57] **ABSTRACT**

A focus detecting apparatus is provided with a plurality of pattern forming lenses for forming light patterns whose relative positional relation varies in conformity with the focus adjusted state of an objective optical system from lights passed through different areas on the pupil of the objective optical a sensing device is included for sensing the light patterns and producing a signal regarding the relative positional relation between the light patterns. A light divider is inclined along an optical path passing through the areas on the pupil and has a light-transmitting area through which light is refracted and transmitted. The light divider is disposed between the objective optical system and the pattern forming lenses. The pattern forming lenses are different in shape and are formed asymmetrically with respect to the optic axis of the objective optical system to correct the destruction of the light patterns caused by the light divider.

13 Claims, 4 Drawing Sheets

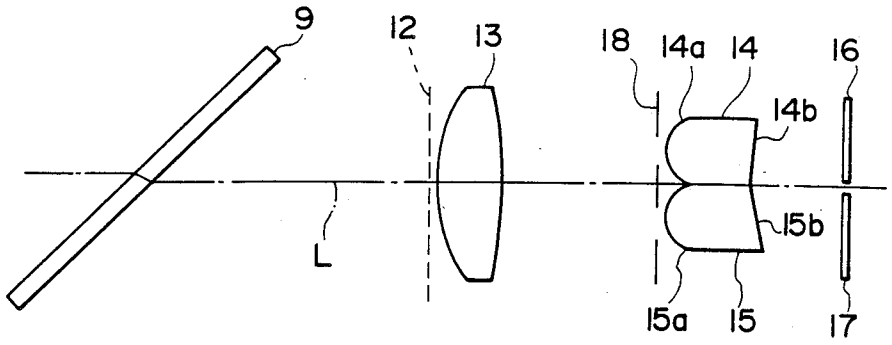


FIG. 1

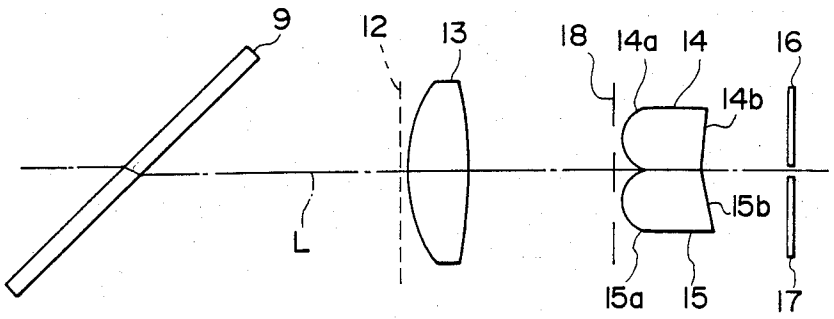


FIG. 2

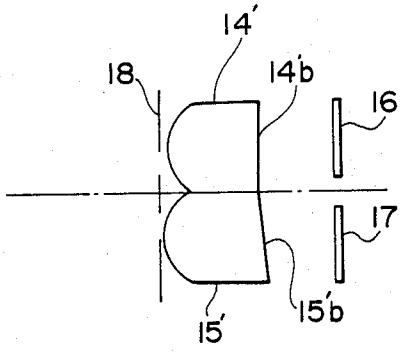


FIG.3

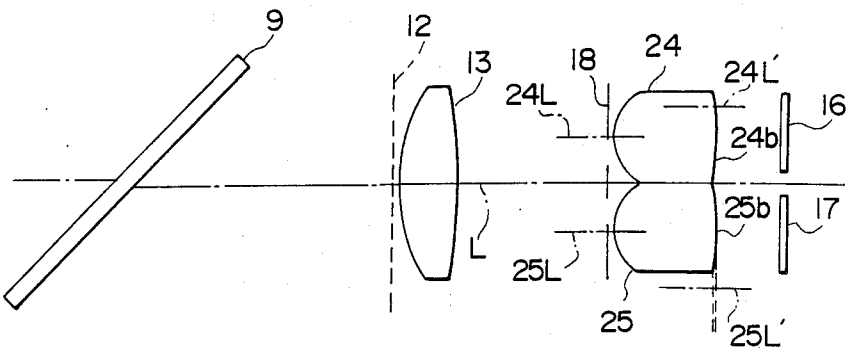


FIG.4A FIG.4B

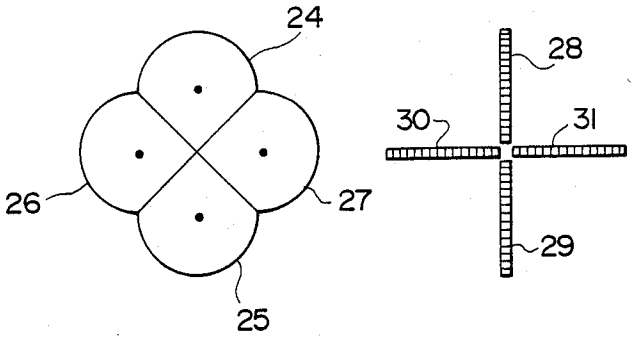


FIG.5

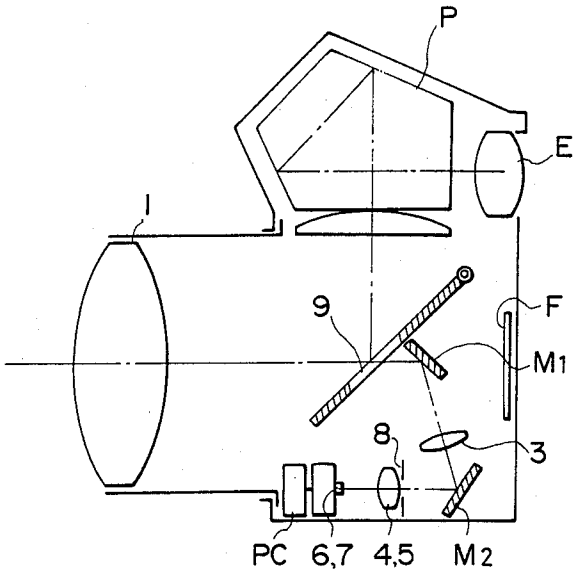


FIG.6

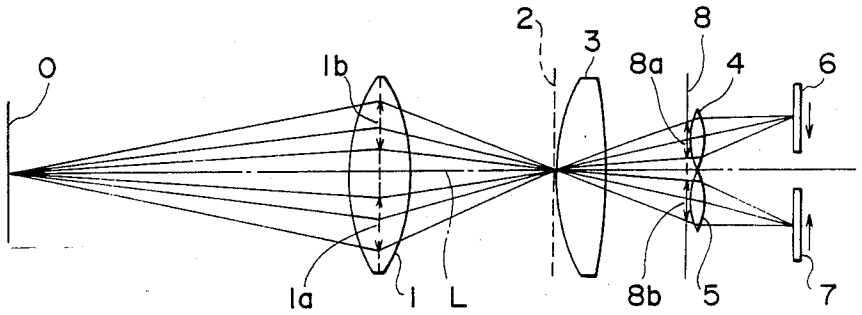


FIG.7

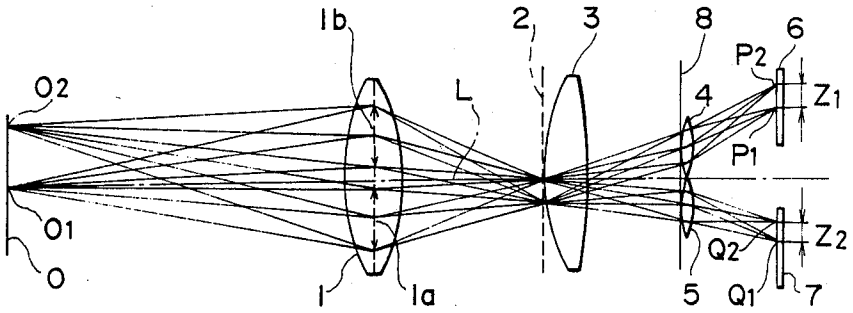


FIG.8

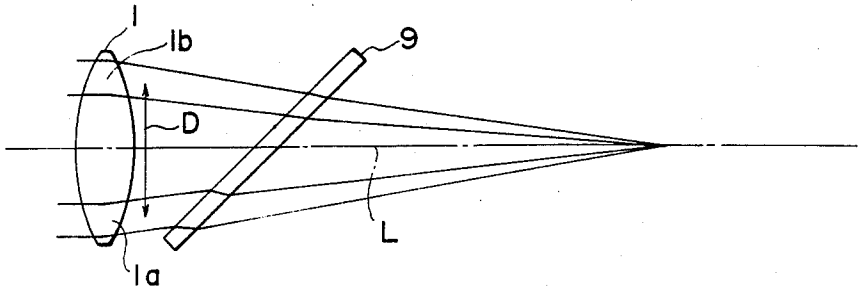
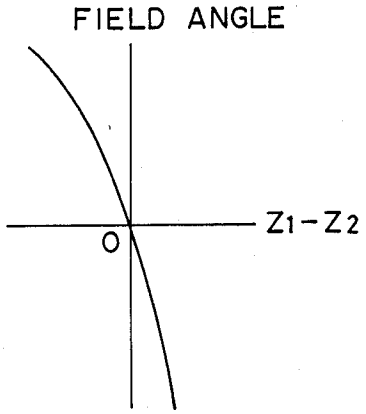


FIG.9



APPARATUS FOR DETECTING THE FOCUS ADJUSTED STATE OF AN OBJECTIVE OPTICAL SYSTEM

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to a focus detecting apparatus suitable for an optical machine such as a camera, and in particular to a focus detecting apparatus for detecting the focus adjusted state of an objective lens.

2. Related Background Art

In single-lens reflex cameras or the like, a focus detecting system of the so-called image deviation type is known in which light distributions regarding two object images are formed from light beams from two different portions of the pupil of the photo-taking lens and the focus state of the photo-taking lens is detected from the relative positional relation between the light distributions.

FIG. **5** of the accompanying drawings depicts a longitudinal sectional shape of a single-lens reflex camera provided with a focus detecting unit of the image deviation type, and FIG. **6** of the accompanying drawings is a transverse sectional view in which only the optical system is developed and depicted to illustrate the focus detecting action.

In these figures, the reference numeral **1** designates an interchangeably mounted or fixed photo-taking lens, the reference numeral **3** denotes a field lens provided near the predetermined imaging plane **2** of the photo-taking lens **1** (the focal plane in a camera), the reference numerals **4** and **5** designate secondary imaging lenses disposed symmetrically about the optic axis L of the photo-taking lens **1** for forming two object images on the basis of light beams passing through different portions **1***a* and **1***b* of the pupil of the photo-taking lens **1**, and the reference numerals **6** and **7** denote photoelectric conversion arrays for detecting the respective object images formed by the secondary imaging lenses **4** and **5**. The arrays **6** and **7** are constructed, for example, of CCDs (charge coupled devices) or the like on a chip.

The reference numeral **8** designates a mask provided near the secondary imaging lenses. The field lens **3** causes the opening portions **8***a* and **8***b* of the mask **8** to be imaged on the different portions **1***a* and **1***b* on the pupil of the photo-taking lens **1**.

The reference numeral **9** denotes a quick return mirror which is mirror-surface-treated on a light-transmitting substrate except for the aperture near the optic axis, and which is obliquely disposed in the photo-taking optical path during observation and is retracted out of the optical path during photographing. A pentaprism P and an eyepiece E are successively disposed on the reflecting optical path of the quick return mirror **9**, and a sub-mirror M, the field lens **3**, an optical path inverting mirror M2, the secondary imaging lenses **4** and **5** and the photoelectric conversion arrays **6** and **7** are successively disposed on the transmitting optical path of the quick return mirror **9**. PC designates a signal processing circuit which calculates a value indicative of the focus adjusted state of the objective lens **1** on the basis of the signals of the arrays **6** and **7**. F denotes the imaging plane on which a silver chloride film or an image pickup element is disposed.

In such an apparatus, when for example, the photo-taking lens **1** is moved leftwardly as viewed in FIG. **6** to provide the so-called forward focusing, light patterns, for example, object images, formed on the light-receiving surfaces of the respective photoelectric conversion arrays **6** and **7** by the secondary imaging lenses **4** and **5** deviate in the direction of arrow and thus, the fact of forward focusing and the amount thereof are detected from the variation in the outputs of the photoelectric conversion arrays **6** and **7** corresponding to the relative deviation of the pair of light patterns. Also, in the case of backward focusing, the respective images deviate in the direction opposite to that in the case of forward focusing and therefore, the fact of backward focusing and the amount thereof are detected.

FIG. **7** of the accompanying drawings depicts the optical action during in-focus in greater detail. The point of intersection between the optic axis L and the surface O of an object to be photographed is O1, and a point off the axis is O2. A light beam emitted from the point O1 is imaged on the photoelectric conversion arrays **6** and **7** by the action of the secondary imaging lenses **4** and **5**, and the points at which the light beam is imaged on the arrays are P1 and Q1.

Paying attention to the light beam emitted from the point O2 off the axis, this light beam having a field angle is once imaged on or near the predetermined imaging plane, whereafter it is re-imaged on the photoelectric conversion arrays **6** and **7** by the secondary imaging lenses **4** and **5**. The points at which the light beam is re-imaged on the arrays are P2 and Q2. The spacing Z1 between the points P1 and P2 and the spacing Z2 between the points Q1 and Q2 correspond to the images linking the points O1 and O2 together and must therefore be equal to each other.

However, as can be seen from FIG. **5**, if an attempt is made to provide a focus detecting unit at the bottom of a camera, the light beam refracted and passed through the substrate of the quick return mirror **9** will be measured. If, at that time, the direction of arrangement of the secondary imaging lenses is made orthogonal to the direction of arrangement shown in FIG. **5**, it means that as shown in FIG. **8** of the accompanying drawings, the quick return mirror **9** is disposed in the optical path while being inclined with respect to the direction of division D of the pupil of the photo-taking lens **1**. The imaged states of the light beams passed through the portions **1***a* and **1***b* of the pupil differ from each other and therefore, even if the various aberrations of the optical system are corrected well, the position of the imaging plane which provides the reference differs depending on the field angle and the aforementioned spacings Z1 and Z2 become unequal. More specifically, as shown in FIG. **9** of the accompanying drawings, Z1–Z2 by the field angle exhibits an inclined characteristic and therefore, even in the case of objects at the same object distance, there arises an inconvenience that the discrimination of the focus state of the lens differs between the central area and marginal area of the distance measurement field.

Accordingly, in the case of an ordinary single-lens reflex camera, optical elements must avoidably be disposed so that the direction of division of the pupil becomes horizontal, and this has been a limitation in the optical arrangement.

SUMMARY OF THE INVENTION

It is the object of the present invention to realize accurate detection even in the case of a detecting optical system including optical elements asymmetrical

disposed with respect to the direction of division of the pupil.

To achieve this object, an optical system for forming a pair of light distributions based on an object having their relative spacing varied in conformity with the focus adjusted state of an objective lens is a system optically asymmetrical with respect to the direction of division of the pupil of the objective lens.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is an optical sectional view showing a first embodiment of the present invention.

FIG. **2** is a partial sectional view of a modification of the first embodiment.

FIG. **3** is an optical sectional view showing another embodiment of the present invention.

FIG. **4** is a front view of the FIG. **3** embodiment,

FIG. **5** is a cross-sectional view of a single-lens reflex camera.

FIGS. **6**, **7** and **8** illustrate the optical action.

FIG. **9** is a graph of the performance.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

An embodiment of the present invention will hereinafter be described with reference to FIG. **1**.

Left in FIG. **1**, there lies a photo-taking lens, although not shown. Letter L designates the optic axis of the photo-taking lens. The reference numeral **9** denotes a quick return mirror similar to that described previously. That portion of the quick return mirror **9** which is near the optic axis L is a light-transmitting area.

The reference numeral **12** designates the predetermined imaging plane of the photo-taking lens, and the reference numeral **13** denotes a field lens. In the present embodiment, the field lens **13** is somewhat spaced apart from the predetermined imaging plane **12**, but alternatively, it may be disposed on the predetermined imaging plane **12**. The reference numerals **14** and **15** designate secondary imaging lenses arranged in the direction of inclination of the mirror **9**. In the present embodiment, the secondary imaging lenses **14** and **15** are formed as a unit of plastics with the sides of the two lenses cut off and joined together. The reference numerals **16** and **17** denote photoelectric conversion arrays. In FIG. **1**, they are shown divided into two rows, but alternatively, they may be used with a single row being divided into two detecting areas. The reference numeral **18** designates a two-aperture stop. The centers of the respective apertures of this stop **18** are coincident with the optic axes of the secondary imaging lenses, respectively.

The front surfaces of the secondary imaging lenses **14** and **15** provide spherical surfaces **14***a* and **15***a* and the rear surfaces provide planar surfaces **14***b* and **15***b*. In the present embodiment, the planar surfaces **14***b* and **15***b* are both inclined in the direction of arrangement of the photoelectric conversion arrays, and this has been caused due to two angles overlapping each other, and for the matters so far called in question, correction can be made simply by inclining one of these two surfaces. In FIG. **2**, the rear surface **14'***b* of one of secondary imaging lenses, **14'**, is optically parallel to the light-receiving surface of the photoelectric conversion array **16**, while the rear surface **15'***b* of the other photoelectric conversion array **15'** is inclined with respect to the light-receiving surface of the photoelectric conversion array **17**. To correct the deviation of the imaging plane shown in FIG. **8**, correction can be made with the angle put either upward or downward, and in the arrangement of FIG. **2**, correction is made by the rear surface **15'***b*. Only a light beam of one field angle is depicted in FIG. **8**, but actually, it is necessary to correct light beams of various field angles and therefore, the form of the inclined surface like the planar surface **15'***b* is taken. In this embodiment, the surface **15'***b* assumes a gentle rightwardly downward inclination, but this is determined by an optical arrangement including other optical elements such as a field lens, etc., and a leftwardly downward inclination is also possible.

The reason why the rear surfaces **14***b* and **15***b* of the secondary imaging lenses of FIG. **1** are both inclined will now be mentioned. This correction is already proposed in Japanese Patent Application No. 143126/1985 (U.S. application Ser. No. 877,850), and in the optical action illustration of FIG. **7**, paying attention to light rays travelling from a point lying on the predetermined imaging plane **2** and deviating downwardly from the optic axis L toward the photoelectric conversion arrays **6** and **7**, the angle of incidence differs between the secondary imaging lenses **4** and **5** and therefore, a delicate difference occurs between spacings Z1 and Z2 under the influence of the residual aberrations of the lenses. In order to correct this difference, one surface of each of the two secondary imaging lenses is made into a planar surface and these surfaces are equally inclined in the direction of arrangement of the photoelectric conversion arrays. Again in this case, however, the direction of inclination is varied by the optical arrangement.

It is of course more convenient to improvement in accuracy that this correction is used in all the focus detecting systems, but actually, this correction can be adopted in conformity with the practical tolerance limits required of each camera, and there is also an electrically correcting method and in that case, it will suffice to incline one planar surface alone.

In the embodiment of FIG. **1**, the correction of both surfaces is adopted to achieve highly accurate detection and avoid the burden of the electrical system and therefore, both planar surfaces **14***b* and **15***b* are inclined with respect to the direction of arrangement of the photoelectric conversion arrays and are asymmetrical with respect to the extension of the optic axis L of the objective lens. Also in the present embodiment, the rear surfaces of the secondary imaging lenses are planar surfaces, but alternatively, the front surfaces may be planar surfaces and the rear surfaces may be spherical surfaces.

An example of numerical values will be shown below.

First, the thickness of the quick return mirror **9** disposed in the camera body is 1 mm. Hereinafter, the unit is mm. The imaging plane lies at a distance of **21** from the entrance surface of the mirror **9** along the optic axis, and the first surface of the field lens **13** lies at a distance of 4.6 therefrom.

In the table below, R1 and R2 correspond to the first and second surfaces, respectively, of the field lens, and R3 corresponds to the first surface of the secondary imaging lenses. R is the radius of curvature, D is the spacing between lens surfaces, Nd is the refractive index for d-line, and νd is the abbe number.

TABLE

	R	D	Nd	νd
1	18.8	2	1.492	57.4
2	−12.8	16.5	1	
3	2.7	5	1.583	30.2

TABLE-continued

	R	D	Nd	νd
4	∞		1	

However, the R4 planar surfaces of the two secondary imaging lenses are valley-shaped, the surface **14***b* is inclined by 2°10′, and the surface **15***b* is inclined by 2°45′. The spacing between the optic axes of the two secondary imaging lenses **14** and **15** is 3.6.

The vertically asymmetrical bend of the Z1–Z2 shown in FIG. **8** by the field angle has been corrected by the above-described construction.

FIG. **3** shows another embodiment of the present invention, in which optical elements identical to those in the embodiment of FIG. **1** are given identical reference numerals. The reference numerals **24** and **25** designate secondary imaging lenses whose front surfaces are spherical surfaces. The optic axes of these front surfaces are designated by **24**L and **25**L, respectively. The rear surfaces of the secondary imaging lenses **24** and **25** are also spherical surfaces, but have a radius of curvature differing from that of the front surfaces, and their respective optic axes are designated by **24**L′ and **25**L′. The optic axis **24**L′ is optically parallel-displaced relative to the optic axis **24**L in the direction of arrangement of the photoelectric conversion arrays, and the optic axis **25**L′ is likewise parallel-displaced relative to the optic axis **25**L. The amounts of displacement are asymmetrical with respect to the extension of the optic axis L of the photo-taking lens. However, again in the present embodiment, it is for the aforedescribed two kinds of corrections that both optic axes are displaced, and if the influence of the quick return mirror **9** which the present application calls in question is eliminated, correction can be made by displacing only one of the optic axes. Alternatively, the optic axes may be displaced in the front surfaces of the secondary imaging lenses.

Further, the secondary imaging lenses each may be comprised of a plurality of lenses. A method of correcting the reduction in performance by displacing lens surfaces is proposed in U.S. application Ser. No. 907,588.

In the above-described embodiment, the apertures of the stop **18**, the secondary imaging lenses **24** and **25** and the photoelectric conversion arrays **16** and **17** have been shown vertically disposed in pairs, respectively, but if combination is made with a system in which secondary imaging lenses are horizontally disposed as in the conventional focus detecting system, accurate detection can be realized without being affected by the directionality of an object to be photographed. Such an optical system is proposed in U.S. application Ser. No. 919,506. FIG. **4** depicts the front form of only the unit of secondary imaging lenses, and as shown there, the displacement of the optic axes of the front and rear surfaces of secondary imaging lenses **26** and **27** arranged horizontally is symmetrical.

According to the present invention described above, highly accurate detection can be realized without being affected by an optical member which is rotation-asymmetrical with respect to the optic axis like the quick return mirror, and the inconvenience that the arrangement of the focus detecting system is limited by such kind of optical member can be eliminated.

We claim:

1. An apparatus for detecting the focus adjusted state of an objective optical system, comprising:

a plurality of pattern forming optical means for forming energy patterns whose relative positional relation varies in conformity with the focus adjusted state by the use of energy passed through different areas of a pupil of the objective optical system;

sensing means having a plurality of portions and producing a signal regarding a relative positional relation between the energy patterns; and

optical means disposed between the objective optical system and said pattern forming optical means for asymmetrically varying optical paths passing through said areas of the pupil;

said pattern forming optical means being arranged in the direction passing through said areas on the pupil and forming an asymmetrical shape with respect to the optic axis of said objective optical system, a first pattern forming optical means having a different shape from a second pattern forming optical means.

2. An apparatus according to claim **1**, wherein said optical means comprises a light-transmitting plane parallel plate inclined with respect to the optical paths passing through said areas on the pupil.

3. An apparatus according to claim **2**, wherein said light-transmitting plane parallel plate comprises a portion of a quick return mirror incorporated in a camera body.

4. An apparatus according to claim **1**, wherein said plurality of pattern forming optical means comprise a plurality of convexo-planar lenses which differ in the inclination of their planar surfaces.

5. An apparatus according to claim **1**, wherein each of said plurality of pattern forming optical means includes a biconvex lens having a second lens surface displaced relative to a first lens surface, the biconvex lenses each being different in a magnitude of displacement between the two lens surfaces.

6. An apparatus according to claim **1**, wherein each of said plurality of pattern forming optical means has a stop and a lens.

7. An apparatus according to claim **1**, further having another plurality of pattern forming optical means arranged in a direction differing from a direction of arrangement of said pattern forming optical means and forming separate energy patterns whose relative positional relation varies in conformity with the focus adjusted state of the objective optical system, and wherein said sensing means further has third and fourth portions each having a plurality of sensors and sensing said separate energy patterns.

8. A camera body used with an objective lens, comprising:

a quick return mirror having a reflecting area for reflecting a part of a light beam from the objective lens toward a viewfinder and a transmitting area for refracting and transmitting another part of the light beam therethrough;

an optical assembly having secondary imaging lenses optically arranged in a direction in which said quick return mirror is inclined for receiving the light beam transmitted through said transmitting area and forming energy patterns whose relative positional relation varies in conformity with the focus adjusted state of the objective lens; and

sensing means for receiving said energy patterns, said sensing means having two portions each having a

plurality of sensors, said sensing means producing a signal regarding the relative positional relation between said energy patterns;

said secondary imaging lenses being of an asymmetrical shape with respect to the optic axis of said objective lens, a first secondary imaging lens having a different shape from a second secondary imaging lens.

9. A camera body according to claim **9**, wherein said second imaging lenses include convexo-planar lenses which differ in the inclination of their planar surfaces.

10. A camera body according to claim **8**, wherein said secondary imaging lenses each include a biconvex lens having a second lens surface displaced relative to a first lens surface, said biconvex lenses differing in the magnitude of the displacement between the lens surfaces.

11. A camera body according to claim **8**, wherein said optical assembly has separate secondary imaging lenses arranged in a direction orthogonal to the direction of arrangement of said secondary imaging lenses.

12. An apparatus for detecting the focus adjusted state of an objective optical system, comprising:

a plurality of pattern forming optical means for forming energy patterns whose relative positional relation varies in conformity with the focus adjusted state by the use of energy passed through different areas of a pupil of the objective optical system;

sensing means having a plurality of portions and producing a signal regarding a relative positional relation between the energy patterns; and

optical means disposed between the objective optical system and said pattern forming optical means for asymmetrically varying optical paths passing through said areas of the pupil, said optical means comprising a light-transmitting plane parallel plate inclined with respect to the optical paths passing through said areas of the pupil; and

said pattern forming optical means being arranged in the direction passing through said areas of the pupil and forming an asymmetrical shape with respect to the optic axis of said objective optical system, a first pattern forming optical means having a different shape from a second pattern forming optical means, said plurality of pattern forming optical means comprising a plurality of convexo-planar lenses which differ in the inclination of their planar surfaces.

13. An apparatus for detecting the focus adjusted state of an objective optical system, comprising:

a plurality of pattern forming optical means for forming energy patterns whose relative positional relation varies in conformity with the focus adjusted state by the use of energy passed through different areas of a pupil of the objective optical system;

sensing means having a plurality of portions and producing a signal regarding a relative positional relation between the energy patterns; and

optical means disposed between the objective optical system and said pattern forming optical means for asymmetrically varying optical paths passing through said areas of the pupil, said optical means comprising a light-transmitting plane parallel plate inclined with respect to the optical paths passing through said areas of the pupil; and

said pattern forming optical means being arranged in the direction passing through said areas of the pupil and forming an asymmetrical shape with respect to the optic axis of said objective optical system, a first pattern forming optical means having a different shape from a second pattern forming optical means, each of said plurality of pattern forming optical means including a biconvex lens having a second lens surface displaced relative to a first lens surface, the biconvex lenses each being different in a magnitude of displacement between the two lens surfaces.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 4,841,326

DATED : June 20, 1989

INVENTOR(S) : Koyama et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

AT [57] IN THE ABSTRACT:

Line 6, "optical a" should read --optical system. A--

COLUMN 7

Line 9, change "claim 9," to --claim 8,--.

Line 10, change "second imaging lenses" to --secondary imaging lenses--.

Signed and Sealed this

Tenth Day of July, 1990

Attest:

HARRY F. MANBECK, JR.

Attesting Officer

Commissioner of Patents and Trademarks

United States Patent [19]

Wakamiya

[11] **Patent Number: 4,836,665**

[45] **Date of Patent: Jun. 6, 1989**

[54] **OBJECTIVE LENS**

[75] Inventor: **Koichi Wakamiya**, Tokyo, Japan

[73] Assignee: **Nikon Corporation**, Tokyo, Japan

[21] Appl. No.: **242,684**

[22] Filed: **Sep. 9, 1988**

[30] **Foreign Application Priority Data**

Sep. 26, 1987 [JP] Japan 62-242298

[51] **Int. Cl.**[4] **G02B 9/20**

[52] **U.S. Cl.** **350/476**; 350/450

[58] **Field of Search** 350/474, 475, 476, 450

[56] **References Cited**

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Primary Examiner—John K. Corbin
Assistant Examiner—Scott J. Sugarman
Attorney, Agent, or Firm—Shapiro and Shapiro

[57] **ABSTRACT**

An objective lens having a stop provided most adjacent to the image side comprises, in succession from the object side, a first lens which is a positive meniscus lens having its convex surface facing the object side, a second lens which is a biconcave lens, a third lens which is a biconvex lens, and a fourth lens which is a negative meniscus lens having its convex surface facing the image side and is joined to the third lens and formed into a compositely positive cemented lens. The objective lens satisfies the following conditions:

(1) $0.28f < \Sigma d < 0.36f$
(2) $1.58 < n2 < 1.745$
(3) $n1 < n2$
(4) $0.24 < n3 - n4 < 0.30$
(5) $0.6f < f1 < 1.0f$
(6) $0.30f < -r6 < 0.40f$
(7) $f < -r7 < 2f$
(8) $10 < \nu 4 - \nu 3 < 25$
(9) $2 < (d5 + d6)/d3 < 9.9$
(10) $0.18f < d1 + d5 + d6 < 0.24f$
(11) $0.28f < r1 < 0.31f$

where

Σd: the full length of the lens system
f: the focal length of the lens system
ri: the radius of curvature of the ith surface from the object side
di: the spacing of the ith surface from the object side
ni: the refractive index of the ith lens from the object side
νi: the Abbe number of the ith lens from the object side
f1: the focal length of the first lens.

8 Claims, 1 Drawing Sheet

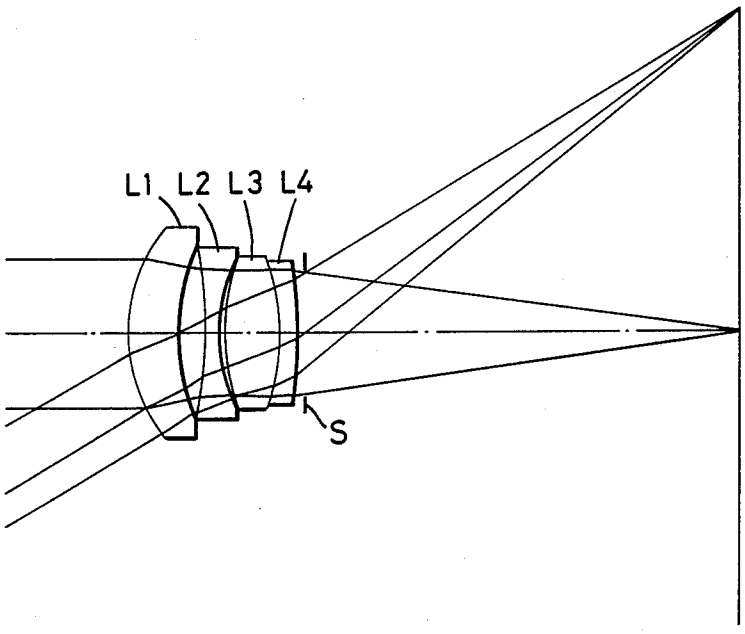


FIG. 1

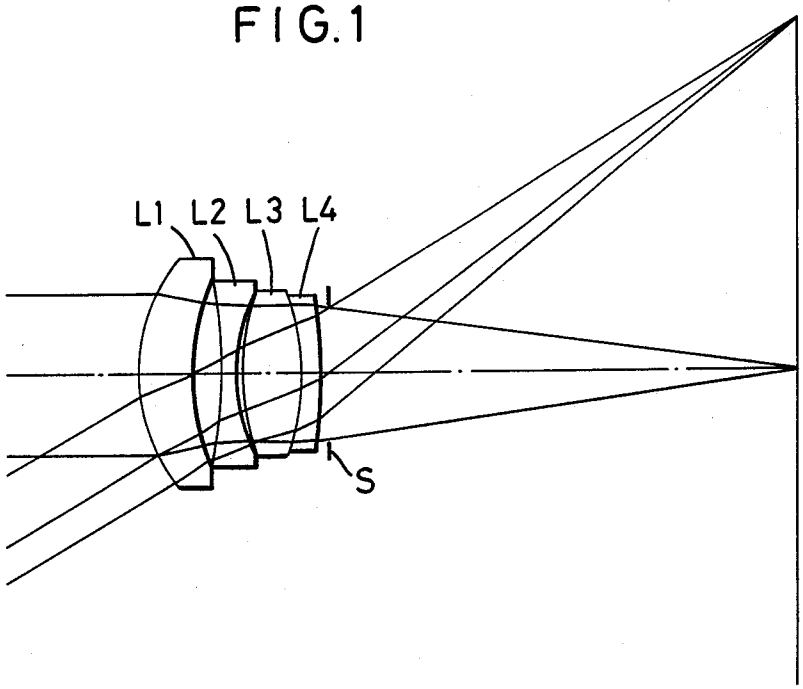
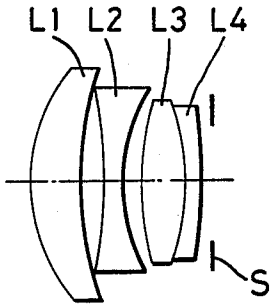


FIG. 2



OBJECTIVE LENS

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to improvements in a triplet objective lens, and in particular to a behind stop modified Tessar type objective lens of compact three-group four-lens construction in which the angle of view amounts to 60° or greater and the brightness amounts to F3.5.

2. Related Background Art

A so-called Tessar type lens which is an objective lens comprising three components, i.e., a diverging biconcave lens and two converging portions with the diverging biconcave lens interposed therebetween has the features that its full length is relatively short and that the fluctuations of aberrations by the object distance are relatively small, and is known as a compact objective lens optical system. Particularly, a lens of the behind stop type in which a stop is provided rearwardly (on the image side) of the lens system permits distance adjustment to be accomplished by fixing the stop on the optic axis and axially moving only the lens and therefore is most suitable for the distance adjusting mechanism of a compact auto focus camera, and has often been put into practical use. In the ordinary Tessar type lens, a third component has a cemented surface convex relative to the object side, but many modified Tessar type lenses in which the third component has a cemented surface concave relative to the object side are also known. In such modified Tessar type, the sagittal plane is somewhat flat and the full length of the lens can be balanced to a slightly short length.

Generally, however, in the case of an objective lens provided with a behind stop, the light ray of an oblique light flux which passes through the marginal portion of a first lens passes through a location near the center of the stop and therefore, a decrease in the marginal light is liable to become conspicuous, and this leads to the disadvantage that it is difficult to correct the deficiency of the quantity of marginal light even if the variable stop is stopped down. In a Tessar type lens comprised of three components, it is possible to reduce the decrease in the marginal light considerably by making the effective diameter of the first lens large, but occurrence of coma and chromatic coma is conspicuous. Particularly, in the conventional modified Tessar type lens in which a third component has a cemented surface concave relative to the object side, occurrence of chromatic coma has been remarkable.

SUMMARY OF THE INVENTION

It is therefore an object of the present invention to provide a behind stop objective lens in which a compact form is kept and yet various aberrations, particularly, coma and astigmatism, are corrected better than in the conventional lens and moreover chromatic coma which is the above-noted disadvantage is corrected well in a modified Tessar type lens system of three-group four-lens construction.

The objective lens according to the present invention is a behind stop lens which comprises, in succession from the object side, a first lens L1 which is a positive meniscus lens having its convex surface facing the object side, a second lens L2 which is a biconcave lens, and a positive composite lens comprising a third lens L3 which is a biconvex lens and a fourth lens L4 which is a negative meniscus lens having its convex surface facing the image side, said third and fourth lenses L3 and L4 being cemented together, and in which is stop is provided most adjacent to the image side, and is characterized in that the values of the full length Σd of the lens system from that surface of the first lens L1 which is adjacent to the object side to that surface of the fourth lens L4 which is adjacent to the image side, the refractive index n2 of the second lens L2, the difference n3−n4 between the refractive indices of the third lens L3 and the fourth lens L4, the focal length f1 of the first lens L1, the radius of curvature r4 of that surface of the first lens L1 which is adjacent to the object side, the radius of curvature r6 of the cemented surface of the third lens L3 and the fourth lens L4, the radius of curvature r7 of that surface of the fourth lens L4 which is adjacent to the image side, the difference $\nu 4-\nu 3$ between the Abbe numbers of the fourth lens L4 and the third lens L3, the ratio (d5+d6)/d3 of the thickness (d5+d6) of the composite lens L3, L4 to the thickness (d3) of the second lens L2, and the sum d1+d5+d6 of the thicknesses of the first lens L1 and the composite lens L3, L4 are limited within ranges which will hereinafter be described.

According to the present invention, there is provided a behind stop modified Tessar type lens which is a compact lens in which the angle of view is 60° or greater and the brightness amounts to F3.5 and yet various aberrations are corrected well and particularly, coma and astigmatism are corrected better than in the conventional lens and at the same time, chromatic coma is also corrected well and further, distortion is small.

Other objects, features and effects of the present invention will become more fully apparent from the following description.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is the optical path diagram of a behind stop objective lens showing a first embodiment of the present invention.

FIG. 2 is a cross-sectional view of a second embodiment of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The objective lens of the present invention is a behind stop lens which, as shown in FIGS. 1 and 2, comprises in succession from the object side a first lens L1 which is a positive meniscus lens having its convex surface facing the object side, a second lens L2 which is a biconcave lens, a third lens L3 which is a biconvex lens, and a fourth lens L4 which is a negative meniscus lens having its convex surface facing the image side, said third lens L3 and said fourth lens L4 being joined together and form into a compositely positive cemented lens, and which further has a stop S on the side most adjacent to the image side of the lens system, and which satisfies the following conditions:

(1) $0.28f<\Sigma d<0.36f$
(2) $1.58<n2<1.745$
(3) $n1>n2$
(4) $0.24<n3-n4<0.30$
(5) $0.6f<f1<1.0f$
(6) $0.30f<-r6<0.40f$
(7) $f<-r7<2f$
(8) $10<\nu 4-\nu 3<25$
(9) $2<(d5+d6)/d3<9.9$

(10) $0.18f < d1 + d5 + d6 < 0.24f$

(11) $0.28f < r1 < 0.31f$

where

Σd: the full length of the lens system, i.e., the distance from the foremost lens surface to the last lens surface

f: the combined focal length of the lens system

ri: the radius of curvature of the ith surface from the object side

di: the spacing of the ith surface from the object side

ni: the refractive index of the ith lens from the object side

νi: the Abbe number of the ith lens from the object side

f1: the focal length of the first lens.

The above-mentioned conditions will hereinafter be described in detail.

Condition (1) is a condition for correcting coma and the quantity of marginal light well. If the full length is great beyond the upper limit of this condition, to secure a predetermined quantity of marginal light, it becomes necessary that an oblique light ray enter from a height distant from the optic axis. Thus, the light flux necessarily passes through the portions of the first lens L1 and the second lens L2 which are nearer to the edges thereof, and high-order aberrations occur and particularly coma is aggravated. If the full length exceeds the lower limit of this condition, the aggravation of coma tends to decrease, but the lens thickness and the air thickness become small and therefore, the effective diameter of each lens becomes small and the oblique light flux is intercepted by the first lens L1 and the second lens L2, and the quantity of marginal light becomes insufficient.

Conditions (2), (3) and (4) are conditions for correcting the Petzval sum well. In a popular phototaking lens, the entire system has a positive power and therefore has a positive Petzval sum, and to correct this, it is effective to make the convex lens high in refractive index and make the concave lens low in refractive index. The condition (3) that $n2 < n1$ is a condition necessary to correct the Petzval sum. If the refractive index n2 of the second lens L2 which is a negative lens exceeds the upper limit of condition (2), the refractive index is too high relative to the convex lens and therefore, correction of the Petzval sum is not done. If n2 exceeds the lower limit of condition (2), it is effective for the correction of the Petzval sum, but the radius of curvature of the second lens L2 becomes small to keep the focal length and therefore, high-order aberrations of divergent property occur in the marginal portion of the lens and coma is aggravated and good correction is not accomplished.

If the difference between the refractive indices of the third lens L3 and the fourth lens L4, i.e., the value of condition (4), exceeds the lower limit, the Petzval sum is also under-corrected. Also, as the difference in refractive index between the third lens L3 which is a positive lens and the fourth lens L4 which is a negative lens ($n3 - n4$) is greater, it is more advantageous for the correction of the Petzval sum, but if the upper limit of condition (4) is exceeded, the converging action in the cemented surface becomes too strong with a result that the bulge of spherical aberration increases and this cannot be corrected.

Condition (5) is a condition effective for the correction of distortion. In the behind aperture lens, positive distortion is usually liable to occur. Particularly, if the focal length of the positive lens (e.g. L1) farthest from the stop becomes short and the refractive power thereof increases, positive distortion is increased. If the power limit of condition (5) is exceeded, positive distortion becomes strong and is not corrected well. As the value of the focal length fl of the first lens L1 is greater, correction of distortion is easier, but the focal length of the composite positive lens comprising the third lens L3 and the fourth lens L4 cemented together becomes short in order that the focal length as the entire system may be of a predetermined value. If the value of the focal length f1 of the first lens L1 exceeds the upper limit of condition (5), the converging action of the cemented positive lens comprising the third lens L3 and the fourth lens L4 becomes too strong, and particularly, as the angle of view becomes greater, the coma above the principal ray is sharply aggravated and becomes difficult to correct.

Conditions (6) and (7), with condition (5), are conditions for correcting coma well. First, condition (6) prescribes the direction and curvature of the cemented surface between the third and fourth lenses L3 and L4. This cemented surface has its sharper concave surface facing the object side and particularly has the strong action of converging the light flux below the principal ray of the oblique light flux. By well balancing the strong converging property of this cemented surface with the strong diverging property in the second lens L2, the coma below the principal ray can be well balanced. If the radius of curvature r6 of the cemented surface exceeds the upper limit of condition (6), the converging action of the cemented surface weakens and the diverging property in the second lens L2 is relatively strongly influenced and coma, particularly, the lower coma, is aggravated and is not corrected. Also, the second lens L2 is a flint lens having a high dispersing power and therefore, causes a light of short wavelength (g-line) to diverge sharply, and chromatic coma becomes aggravated and is not corrected. If the lower limit of condition (6) is exceeded, the converging property of the cemented surface becomes relatively strong and the lower coma occurs in the opposite direction and is not corrected well.

Condition (7) prescribes the range of the radius of curvature of the last lens surface, which is a surface for converging the light rays. This converging action converges the light flux below the principal ray of the oblique light flux more effectively, but the last surface does not cause high-order aberrations to occur so much as the cemented surface between the third and fourth lenses L3 and L4. Therefore it has the effect of converging the lower light flux in the entire picture plane. Accordingly, by well balancing the converging action which affects the entire picture plane of the last surface with the converging action of the cemented surface between the third and fourth lenses L3 and L4 which works particularly remarkably at a great angle of view and the diverging action of the second lens L2, it becomes possible to correct the coma below the principal ray of the oblique light flux well. If the radius of curvature r7 of the last surface of the fourth lens L4 exceeds the upper limit of condition (7) and the converging action thereof weakens, the lower coma of a small angle of view becomes negative and aggravated and good correction thereof is not accomplished. Also, if the converging action strengthens beyond the lower limit of condition (7), the lower coma of a small angle of view conversely becomes positive and aggravated and again, good correction thereof is not accomplished.

Condition (8) is a condition for correcting chromatic coma better. The second lens L2 is flint glass and therefore, in a Tessar type lens, a light of short wavelength (g-line) is made excessively divergent by the second lens L2 and chromatic coma occurs. To correct this more effectively, it is better to utilize the converging action of the cemented positive lens comprising the third and fourth lenses L3 and L4, and the light of short wavelength (g-line) can be converged sharply by the surfaces of these lenses. Condition (8) is a condition effective for this, and as the difference ($\nu 4 - \nu 3$) between the Abbe numbers of the third lens L3 and the fourth lens L4 has a greater value, the influence of high-order aberrations strengthens and good correction is ensured. If the upper limit of condition (8) is exceeded, the dispersion of the third lens L3 becomes relatively great and therefore, the on-axis chromatic aberration becomes under-corrected and cannot be corrected well. On the other hand, if the lower limit of this condition (8) is exceeded, the correcting effect for chromatic coma becomes small and good correction of chromatic coma becomes difficult.

Condition (9) regards the center thickness of the composite positive lens comprising the third lens L3 and the fourth lens L4 cemented together. In a positive lens, generally, spherical aberration and curvature of meridional image field have negative values. In the rearward cemented positive lens component in a popular Tessar type lens, the cemented surface has a converging action and therefore, spherical aberration and curvature of meridional image field are caused to occur more negatively. These are corrected chiefly by a negative lens, but when the aberrations by the negative lens are great, the influence of high-order aberrations resulting from correction becomes strong and the bending of spherical aberration and the bending of curvature of meriodional image field become remarkable. Also, to reduce the occurrence of negative spherical aberration and negative curvature of image field caused by the positive lens, it is generally known that it is effective to increase the center thickness of the positive lens. So, in the present invention, by prescribing the combined center thickness (d5+d6) of the third and fourth lenses L3 and L4 forming the composite positive lens as shown in condition (9) relative to the center thickness d3 of the negative lens L2, the bulge of spherical aberration and the bending of curvature of meridional image field are corrected. As the value of condition (9) is greater, it is possible to reduce the bulge of spherical aberration and the bending of curvature of meridional image field, but as the thickness of the cemented positive lens comprising the third and fourth lenses L3 and L4 becomes greater, the oblique light ray tends to become farther from the optic axis at the position of the stop and at last, deficiency of the quantity of marginal light results. If the upper limit of condition (9) is exceeded, the quantity of marginal light is insufficient, and if the lower limit of condition (9) is exceeded, the bulge of spherical aberration and the bending of curvature of meridional image field become great and good correction of aberrations cannot be accomplished.

Condition (10) prescribes the total center thickness of the positive lens components of the lens system in the present invention. If the upper limit of condition (10) is exceeded, the quantity of marginal light decreases, and if the lower limit of condition (10) is exceeded, curvature of image field becomes remarkable. Also, condition (11) prescribes an appropriate radius of curvature of the foremost lens surface. If the upper limit of this condition (11) is exceeded, curvature of image field increases, and if the lower limit of this condition is exceeded, spherical aberration becomes remarkable and good correction thereof becomes difficult. In the aforedescribed condition (10), it is desirable that the thickness d1 of the first lens L1 satisfy the following condition:

(12) $0.08f < d1 < 0.1f$

Further, in the present invention, the quantity of marginal light of the lens is secured sufficiently and moreover, the first lens L1 and the second lens L2 contact with each other at the marginal portions thereof as shown in FIG. 1 and the second lens L2 and the third lens L3 contact with each other at the marginal portions thereof as shown in FIG. 1, whereby the objective lens can be constructed without the use of a spacer. As the condition therefor, it is desirable that

(13) $d2 > d4$.

Also, as a condition for keeping the upper coma good, it is desirable that the radius of curvature r5 of that surface of the third lens L3 which is adjacent to the object side satisfy the following condition:

(14) $0.45f < r5 < 0.70f$

Furthermore, as a condition for keeping astigmatism good, it is desirable that the radius of curvature r2 of that surface of the first lens L1 which is adjacent to the image side satisfy the following condition:

(15) $0.45f < r2 < 0.75f$

Tables 1 and 2 below show the data of two embodiments, respectively, of the present invention. The first embodiment shown in Table 1 and the second embodiment shown in Table 2 are ones in which the focal length f=100 and F-number is 3.5. In the tables below, the numbers at the left end represent the order from the object side. Also, Bf represents the back focal length, f1 represents the focal length of the first lens, f2 represents the focal length of the second lens, and f3 represents the combined focal length of the third and fourth lenses.

TABLE 1

(First Embodiment)
Focal length f = 100, F3.5

No.	Radius of curvature r	Center thickness and space d of the lens	Refractive index n	Abbe number ν
1	30.652	9.860	1.76684	46.76
2	46.915	3.483		
3	−97.714	3.055	1.69895	30.09
4	30.640	1.186		
5	46.123	10.554	1.79668	45.42
6	−38.252	2.777	1.51680	64.12
7	−134.225			
		Bf = 81.155		
		Σd = 30.914		
		f1 = 91.287		
		f2 = −33.049		
		f3 = 36.848		

TABLE 2

(Second Embodiment)
Focal length f = 100, F3.5

No.	Radius of curvature r	Center thickness and space d of the lens	Refractive index n	Abbe number ν
1	29.565	8.608	1.74400	45.06
2	69.379	3.055		
3	−141.814	3.332	1.71736	29.48
4	29.647	3.332		
5	66.804	7.775	1.76684	46.76
6	−33.811	2.499	1.51680	64.12
7	−85.944			

TABLE 2-continued

(Second Embodiment)
Focal length f = 100, F3.5

No.	Radius of curvature r	Center thickness and space d of the lens	Refractive index n	Abbe number ν
		Bf = 81.140		
		Σd = 28.602		
		f1 = 63.397		
		f2 = −33.907		
		f3 = 47.495		

These embodiments are ones in which positive distortion liable to occur in a behind stop modified Tessar type lens like the lens according to the present invention is corrected to a further smaller value. As a condition for correcting distortion to a smaller value as in the embodiments, it is desirable that the following condition be satisfied:

(16) $1.3<(f1/f3)<2.6$,

where f1 is the focal length of the first lens, and f3 is the combined focal length of the third lens L3 and the fourth lens L4. If the upper limit of condition (16) is exceeded, distortion becomes negative, and if the lower limit of condition (16) is exceeded, distortion becomes positive.

I claim:

1. An objective lens having a stop provided most adjacent to the image side, comprising, in succession from the object side, a first lens which is a positive meniscus lens having its convex surface facing the object side, a second lens which is a biconcave lens, a third lens which is a biconvex lens, and a fourth lens which is a negative meniscus lens having its convex surface facing the image side and is joined to said third lens and formed into a compositely positive cemented lens, characterized in that said objective lens satisfies the following conditions:

(1) $0.28f<\Sigma d<0.36f$
(2) $1.58<n2<1.745$
(3) $n1>n2$
(4) $0.24<n3-n4<0.30$
(5) $0.6f<f1<1.0f$
(6) $0.30f<-r6<0.40f$
(7) $f<-r7<2f$
(8) $10<\nu4-\nu3<25$
(9) $2<(d5+d6)/d3<9.9$
(10) $0.18f<d1+d5+d6<0.24f$
(11) $0.28f<r1<0.31f$

where

Σd: the full length of the lens system
f: the focal length of the lens system
ri: the radius of curvature of the ith surface from the object side
di: the spacing of the ith surface from the object side
ni: the refractive index of the ith lens from the object side
νi: the Abbe number of the ith lens from the object side
f1: the focal length of the first lens.

2. An objective lens according to claim 1, characterized in that the thickness d1 of said first lens satisfies the following condition:

$0.08f<d1<0.1f$.

3. An objective lens according to claim 1, characterized in that the spacing d2 between said first lens and said second lens and the spacing d4 between said second lens and said third lens satisfy the following condition:

$d2>d4$.

4. An objective lens according to claim 1, characterized in that the radius of curvature r5 of that surface of said third lens which is adjacent to the object side satisfies the following condition:

$0.45f<r5<0.70f$.

5. An objective lens according to claim 1, characterized in that the radius of curvature r2 of that surface of said first lens which is adjacent to the image side satisfies the following condition:

$0.45f<r2<0.75f$.

6. An objective lens according to claim 1, characterized in that the ratio (f1/f3) of the focal length f1 of said first lens to the combined focal length f3 of said third lens and said fourth lens satisfies the following condition:

$1.3<(f1/f3)<2.6$.

7. An objective lens according to claim 1, characterized by the following data:

Focal length f=100, F3.5

No.	Radius of curvature r	Center thickness and space d of the lens	Refractive index n	Abbe number ν
1	30.652	9.860	1.76684	46.76
2	46.915	3.483		
3	−97.714	3.055	1.69895	30.09
4	30.640	1.186		
5	46.123	10.554	1.79668	45.42
6	−38.252	2.777	1.51680	64.12
7	−134.225			
	Bf = 81.155		f1 = 91.287	
	Σd = 30.914		f2 = −33.049	
			f3 = 36.848	

8. An objective lens according to claim 1, characterized by the following data:

Focal length f=100, F3.5

No.	Radius of curvature r	Center thickness and space d of the lens	Refractive index n	Abbe number ν
1	29.565	8.608	1.74400	45.06
2	69.379	3.055		
3	−141.814	3.332	1.71736	29.48
4	29.647	3.332		
5	66.804	7.775	1.76684	46.76
6	−33.811	2.499	1.51680	64.12
7	−185.944			
	Bf = 81.140		f1 = 63.397	
	Σd = 28.602		f2 = −33.907	
			f3 = 47.495	

* * * * *

United States Patent [19]

Hiesinger et al.

[11] **Patent Number: 4,831,396**

[45] **Date of Patent: May 16, 1989**

[54] **OBJECTIVE FOR PHOTOGRAPHIC CAMERAS**

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[73] Assignee: **Firma Novoflex Fotogeratebau Karl Muller**, Memmingen, Fed. Rep. of Germany

[21] Appl. No.: **143,044**

[22] Filed: **Jan. 12, 1988**

[30] **Foreign Application Priority Data**

Feb. 27, 1987 [DE] Fed. Rep. of Germany 3706409

[51] **Int. Cl.**[4] **G03B 1/18**

[52] **U.S. Cl.** **354/195.1**; 354/195.12; 350/255; 350/430

[58] **Field of Search** 354/195.1, 195.12; 350/427-430, 255

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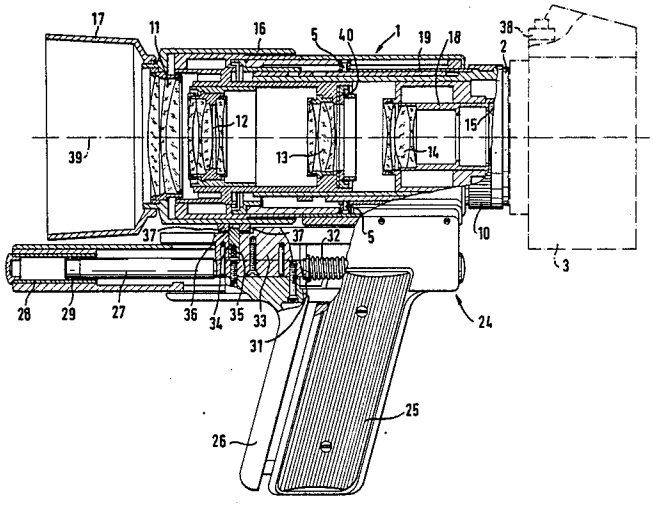
Primary Examiner—L. T. Hix
Assistant Examiner—David M. Gray
Attorney, Agent, or Firm—Holman & Stern

[57] **ABSTRACT**

An objective for a photographic camera is mounted on a carrier having a squeezable handle by which the focusing device can be actuated. The objective has a zoom facility and may also have a macro facility which is actuated by the camera acting on the zoom facility or the macro facility by means of a sliding or a turning movement.

2 Claims, 2 Drawing Sheets



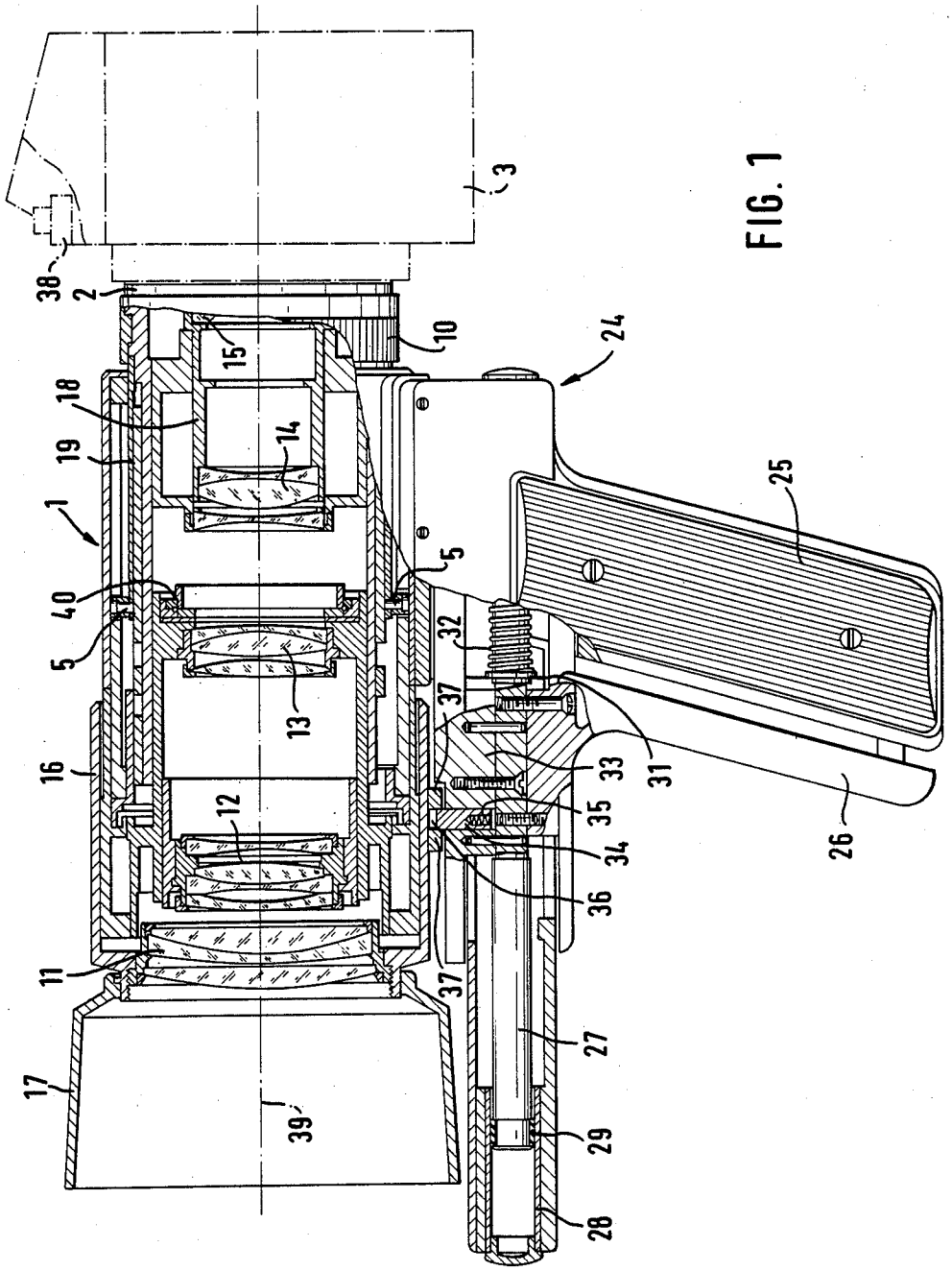

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FIG. 1

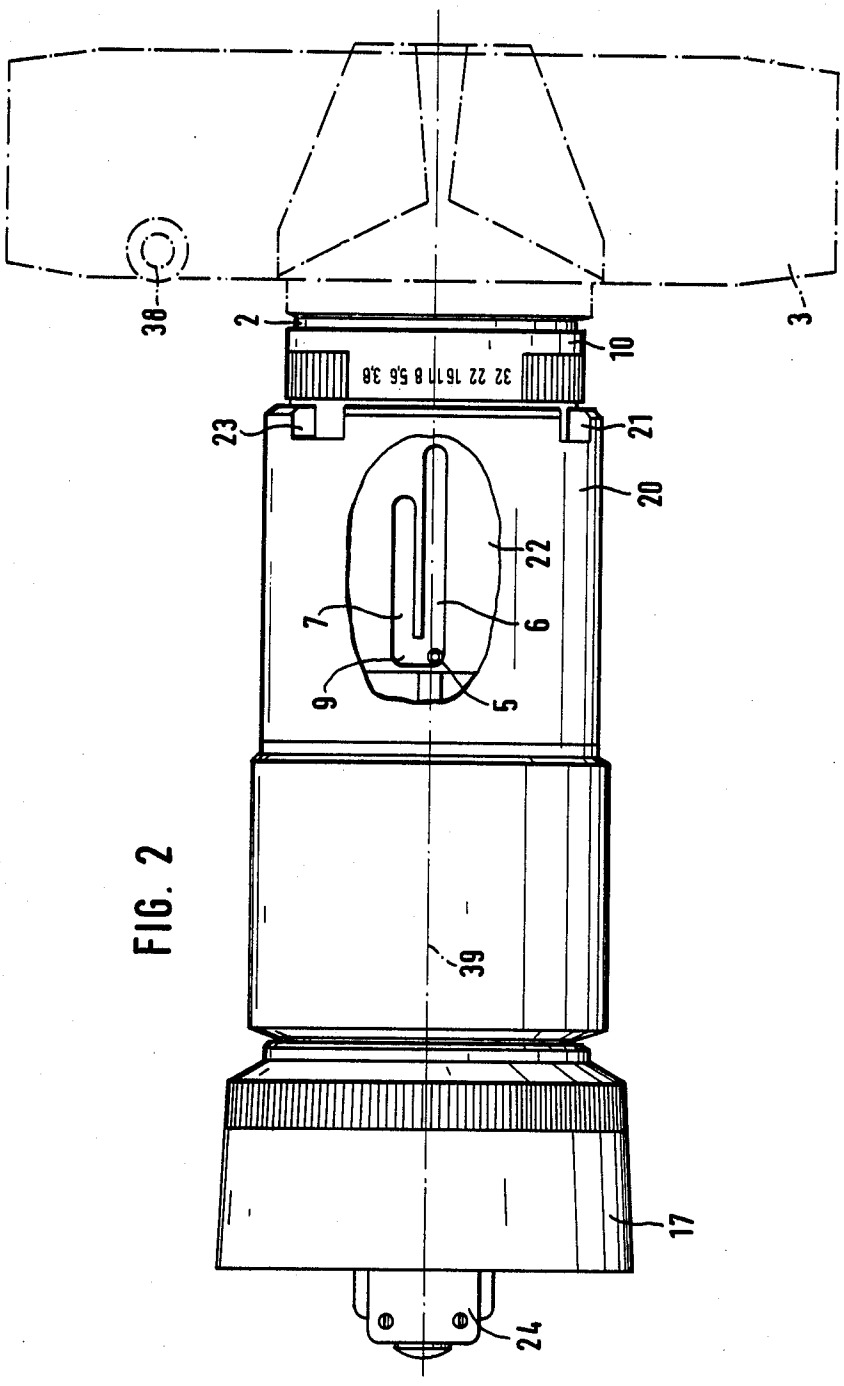

FIG. 2

OBJECTIVE FOR PHOTOGRAPHIC CAMERAS

FIELD OF THE INVENTION

The invention concerns an objective (by which is meant a lens assembly, and herein termed an "objective") for photographic cameras, having an objective housing, a focusing device on the front part of the objective and having a zoom facility, and if required also a macro facility, controllable by a sliding movement, in the direction of the optical axis of the objective relative to the objective housing, of a connecting element arranged at the end of the objective nearer the camera, which element serves to connect the objective with the camera.

DESCRIPTION OF THE PRIOR ART

Objectives having a zoom facility, and if required also a macro facility, of the type set out hereinbefore, are known. Such objectives are used in the following way: the objective is supported by one hand at the objective housing, while the other hand of the operator operates the camera. Adjustment of the desired focal distance when using a zoom facility, or of the desired enlargement when using a macro facility, is performed by a sliding movement of the camera towards the objective housing. In order to change from operation of the zoom facility to operation of the macro facility, the camera is turned through a small angle relative to the objective housing, so that in each case the facility being used becomes effective and the other facility becomes inoperative.

For the purpose of focusing, these known objetives have at the front end of the objective an adjusting ring which permits screw movement. This screw movement is indirectly or directly transferred to the focusing part of the objective lenses, thus enabling fine adjustment.

These known objectives and their relevant cameras are troublesome to use. While one hand supports the camera, the other hand has to operate not only the focusing device at the front end but also the shutter and the release, and possibly also the zoom facility at the rearward end of the objective. In the case of moving objects, fine adjustment can become impossible, particularly when e.g., the zoom facility has to be adjusted subsequently.

The invention has as an object to find an arrangement which considerably facilitates and accelerates operation of such an objective and its relevant camera.

SUMMARY OF THE INVENTION

To solve this problem, a start is made from an objective of the kind set out in the opening paragraph of this specification. According to the invention it is proposed that the objective housing be mounted on a carrier having a handle consisting of two parts which are compressible together against a restoring force and which acts on a slidable sleeve of the objective movable in the direction of the optical axis and carrying the focusing part of the objective lenses.

This problem is solved by the invention in a surprisingly simple way. One hand of the operator supports the objective by means of the carrier and also actuates the focusing device while the other hand of the operator actuates the zoom facility or the macro facility and also operates the camera. This hand can also actuate the shutter without any substantial change in the position of the hand on the camera being necessary.

Thus both hands can support the camera and the objective, since the position of the hand on the camera need not be changed substantially and in particular need not actuate the focusing device.

In the practical use of such an objective and a camera it is further found that the focusing device can be operated at the same time that the zoom facility is actuated, thus enabling a sharply-defined picture to be quickly obtained. As the camera cn be released without changing the hand position, operating time is considerably shortened. This has a considerable advantage when photographing moving objects, for example when taking sports pictures and the like.

There is a further advantage which has an effect particularly with regard to the taking of macro photographs. In taking macro photographs, the distance between the object and the objective is relatively small. If living animals are to be photographed, movement of the hand to the front end of the objective or to a device for fine adjustment often spoils the picture.

Use of a carrier for supporting an objective, and actuating a focusing device by a compressible handle, is known per se. Hitherto, however, such a device has been used with objectives having relatively long focal distances and corresponding weight, and has served merely to accelerate focusing. This invention however has a further advantage, that, when using a relatively light objective, such objectives having a zoom facility can be provided with a sliding arrangement which actuates both the focusing and the zoom or macro facility.

A further feature of the invention provides a sliding sleeve enclosing the objective housing. Although this means that a part of the length of the objective housing is lost for the purpose of support by the carrier, this mode of construction permits a simple coupling of the movement of the movable handling part with the slidable sleeve of the focusing part.

In particular, the invention proposes that one part of the handle be connected with a carriage which is movable on the carrier and acts on the slidable sleeve with a pin extending from the carriage and engaging said one part of the handle; and preferably two spaced stops are mounted on the outside of the slidable sleeve, between which the pin engages.

BRIEF DESCRIPTION OF THE DRAWINGS

The drawing is a diagrammatic representation of an embodiment of an objective for use on a camera in accordance with the invention. In the drawing,

FIG. 1 is a side view, partly in section, of the objective according to the invention, and

FIG. 2 shows a top view of the objective shown in FIG. 1.

DESCRIPTION OF THE PREFERRED EMBODIMENT

In the drawing, the camera 3 is indicated by chain lines. The camera is attached to the connecting ring 2 of the objective 1, for example by being screwed into this ring or else held by means of a bayonet attachment. A ring 10 for adjusting the automatic shutter 40 of the objective 1 is arranged on the connecting ring 2.

The objective 1 shown has, as is known per se, a zoom facility and also a macro facility. The objective 1 consists of a total of five sets of lenses. The lens set 11

serves for focusing. It is carried by a sliding sleeve **16** to which is also secured a sun shield **17**.

In the central region of the objective **1** there are lens sets **12** and **13** which are displaceable relative to each other and also to the other sets of lenses. The lens sets **14** and **15** are accommodated together in a displaceable sleeve **18**. The lens setse **12**, **13**, **14** and **15** represent essentially the zoom facility and serve to alter the focal distance.

An objective structure of the type described so far is known per se. If the zoom facility is to be used, the lens sets **12**, **13** and the sleeve **18** with the lens sets **14** and **15** are displaced relative to each other. If the macro facility is actuated, the camera **3** only is displaced towards the rear in the direction of the optical axis **39**, the focal distance being unchangeable. The mechanical elements for actuating the zoom or the macro facility are however not fully represented in the drawing. These mechanical elements, which, regarded separately, are known, are driven in the embodiment of this invention, via the connecting ring **2** or the sleeve-shaped extension **19**. On this extension **19** there are two guide pins **5** (see also FIG. **2**) which are each movable in longitudinal slots **6** and **7**. By a rotary movement on the camera **3**, the connecting ring **2**, which is firmly connected therewith, can be turned so that each guide pin **5** is aligned with either a slot **6** or a slot **7**. When the guide pins **5** move in the slots **6**, the macro facility is actuated. When the guide pins **5** move in the slots **7**, the zoom facility is actuated.

On the housing **20**, which encloses both the extension **19** and the sleeve **22** in which the longitudinal slots **6** and **7** are provided, there are recesses **21** and **23**. If the guide pins **5** are aligned with the slots **6**, a marking is visible in the recess **21** to indicate that the macro facility is actuated. If however the guide pins **5** are aligned with the slots **7**, the relevant focal distance of the lens can for example be read in the recess **23**.

In the embodiment shown, the longitudinal slots **6** and **7** are joined together at their ends **9** in such a way that, in the appropriate position of the objective, a change can be made from actuation of the macro facility to actuation of the zoom facility. In the embodiment shown, the zoom facility is in the position having the shortest focal distance. In the case of other objectives the arrangement may be different. This is not essential for an understanding of the invention.

The objective **1** with its housing **20** is mounted on a carrier **24** which has a handle consisting of two parts **25** and **26**. The part **26** of the handle is held on a guide rod **27** which is displaceably mounted with its two ends in the carrier **24**. One mounting, which is shown in section, consists essentially of a fixed sleeve **28** in which the rod **27** with a sliding member **29** slides.

On a collar **31** of the guide rod **27** there is supported a spring **32** which is located on an abutment in the interior of the carrier **24**.

When the parts **25** and **26** of the handle squeezed together, the guide rod **27** is displaced against the force of the spring **32** and the spring **32** pushes the guide rod **27** forward in a direction paralell to the optical axis when the handle is released.

The guide rod **27** is connected with a carriage **33**. A pin **34** is mounted in the carriage **33** and is pressed towards the objective **1** by a small spring **35**. The pin **34** thereby engages in a recess **36** between two stops **37** on the sliding sleeve **16** of the lens. By compression of the handle which consists of the parts **25** and **26**, the sliding sleeve **16** together with the first lens set **11** is moved and the objective **1** can be focused.

In use of the objective according to the invention, the operator holds the handle comprising the parts **25** and **26** with one hand and thus is able to actuate the focusing device, that is to say the sliding sleeve **16** for the first lens set **11**, and grasps the camera **3** with the other hand with one finger on the release **38**. With the hand holding the camera **3**, the operator by a pushing or a turning movement is able to actuate the macro facility or the zoom facility of the objective **1** as desired.

What we claim as our invention and desire to secure by Letters Patent of the U.S. is:

1. An objective for a photographic camera, the objective including an objective housing; a focusing device in said objective; means in said objective providing a zoom facility and a connecting element at one end of said objective for connecting said objective to a camera, said connecting element being movable in the direction of an optical axis of the objective relative to said objective housing to enable said zoom facility to be actuated, a carrier on which said objective housing is mounted; a two-part handle having one part fixed to said carrier and the other part movable towards said one part when said handle is gripped in one hand by an operator; a slidable sleeve surrounding the objective housing, said sleeve being movable in the direction of the optical axis and carrying said focusing device, restoring means acting to urge said two parts of said handle apart, said two parts of said handle being squeezable in said one hand against the action of said restoring means to effect sliding of said sleeve and actuation of said focusing device; a carriage on which said one part of the handle is mounted, the carriage being movable with respect to said carrier, a pin mounted in said carriage and extending therefrom, two spaced stops mounted on the outside of said sleeve, said pin engaging between said stops for sliding the sleeve to provide actuation of the focussing device, and the objective also including means providing a macro facility, said connecting element being movable in the direction of the optical axis of said objective relative to said objective housing to enable said macro facility to be actuated, and selector means in said objective housing having two alternative settings of which one corresponds to said zoom facility and the other corresponds to said macro facility, said selector means being selectively movable into each of said settings whereby one only of said zoom and macro facilities is actuated for each setting.

2. An objective as claimed in claim **1** in which said selector means comprises a further sleeve positioned coaxially within said objective housing and having thereon two altenrative slots of unequal length and each extending parallel to said optical axis of said objective and spaced apart in the circumferential direction of said further sleeve and a pin fixed with respect to said connecting element and selectively engageable in one or other of said slots on turning said connecting element with respect to said objective housing about said optical axis.

* * * * *

United States Patent [19]

Matsuda et al.

[11] **Patent Number: 4,800,409**

[45] **Date of Patent: Jan. 24, 1989**

[54] **CONTROL DEVICE FOR USE IN A CAMERA HAVING AN OBJECTIVE LENS**

[75] Inventors: **Motonobu Matsuda**, Kawachinagano; **Yoshihiro Tanaka**, Osaka; **Motohiro Nakanishi**, Kobe; **Nobuyuki Taniguchi**, Nishinomiya; **Hiroshi Ootsuka**, Sakai, all of Japan

[73] Assignee: **Minolta Camera Kabushiki Kaisha**, Osaka, Japan

[21] Appl. No.: **43,616**

[22] Filed: **Apr. 28, 1987**

[30] **Foreign Application Priority Data**

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Jul. 16, 1986	[JP]	Japan	61-167467
Jul. 16, 1986	[JP]	Japan	61-167468
Jul. 16, 1986	[JP]	Japan	61-167470

[51] **Int. Cl.**[4] **G03B 3/00**; G03B 7/08; G03B 15/02; G02B 7/11

[52] **U.S. Cl.** **354/402**; 354/403; 354/413; 354/423; 354/432; 354/446

[58] **Field of Search** 354/400–409, 354/429–434, 413, 419, 446, 423, 422, 415

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Primary Examiner—W. D. Perkey

Attorney, Agent, or Firm—Burns, Doane, Swecker & Mathis

[57] **ABSTRACT**

The present invention can be applied to a control device wherein the probability of giving the proper exposure to the primary object photographed is high even when the regions to be found in range within the photographing distance are plural, thereby to being capable of more positively judging the backlight condition, an automatic focus adjusting apparatus capable of more reflecting the photographing intention of the photographer, an exposure control apparatus capable of normally providing the proper exposure amount with respect to the photographed object independently of the distance to the object photographed even when the daylight synchronized flash photographing operation is performed, and a control device which does not need a switching circuit and the switching operation by it.

24 Claims, 17 Drawing Sheets

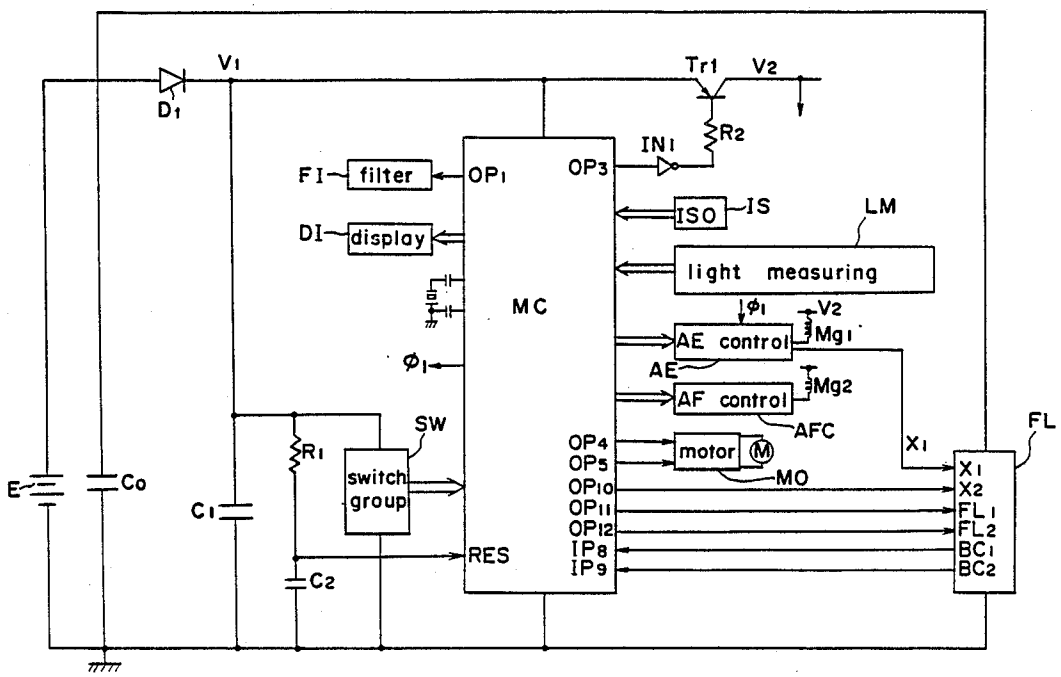


Fig. 1

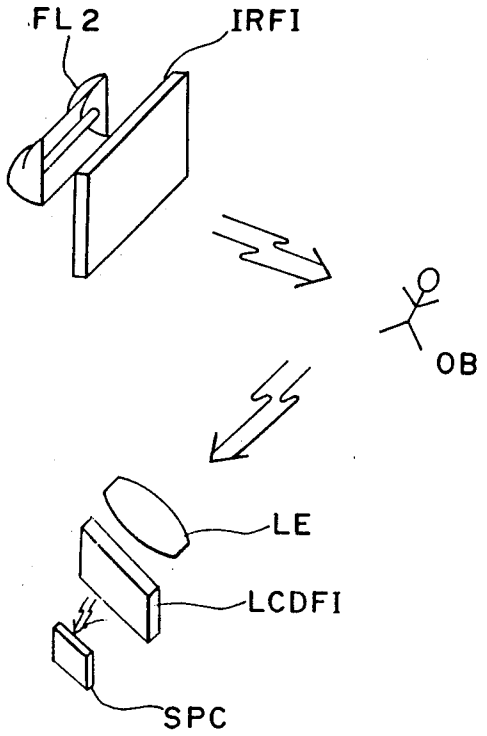


Fig. 3

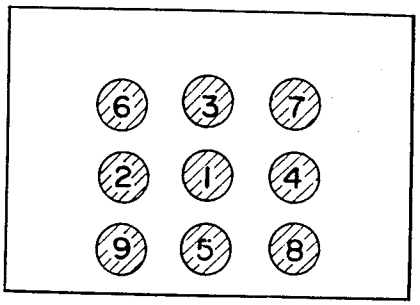
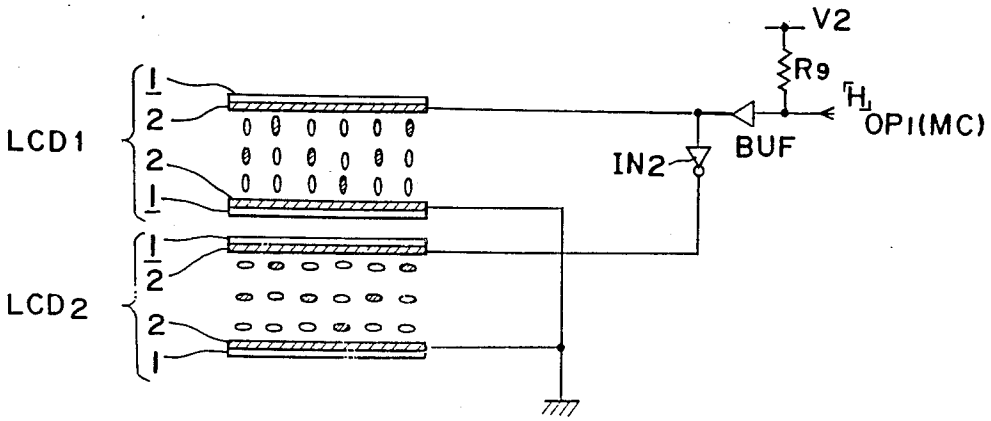


Fig. 2



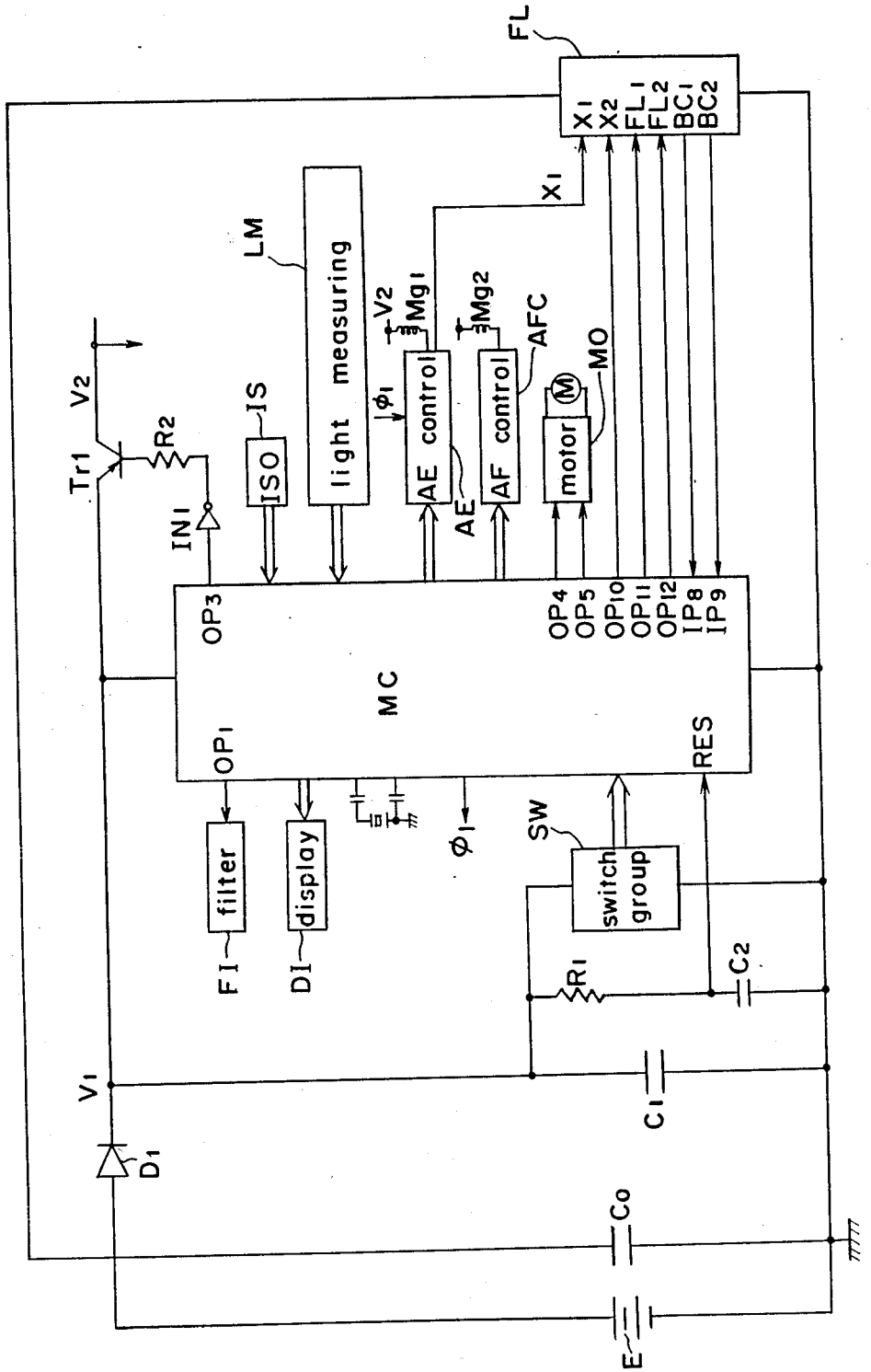
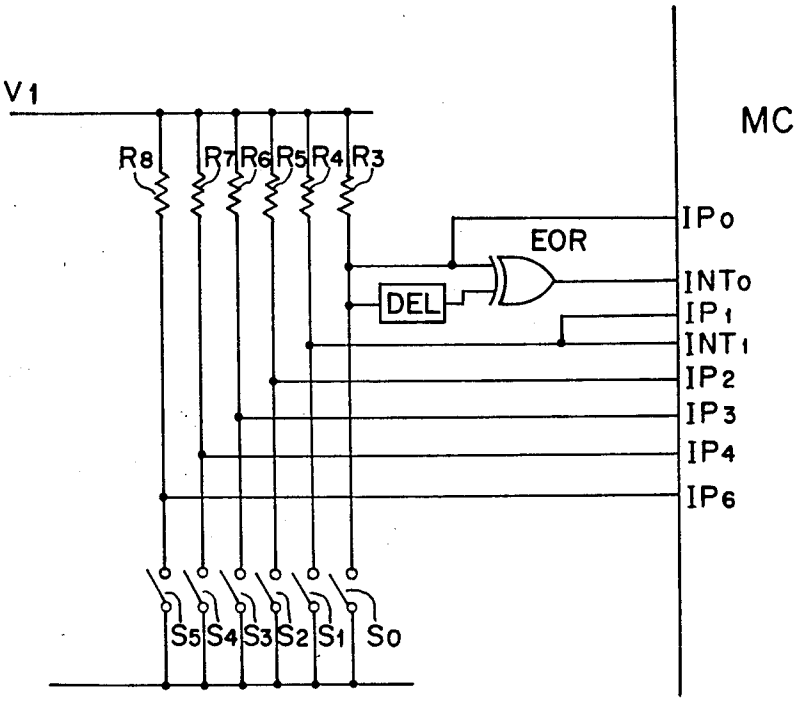

FL
X1
X2
FL1
FL2
BC1
BC2
LM
light measuring
V2
Mg1
Mg2
AFC
AE control
AF control
motor
M
MO
AE
IS
ISO
Tr1
R2
IN1
OP3
OP1
MC
OP4
OP5
OP10
OP11
OP12
IP8
IP9
RES
filter
display
F1
D1
SW
switch group
R1
C2
C1
V1
D1
C0
E

Fig. 4

Fig. 5


V1
MC
R8
R7
R6
R5
R4
R3
EOR
DEL
IP0
INT0
IP1
INT1
IP2
IP3
IP4
IP6
S5
S4
S3
S2
S1
S0

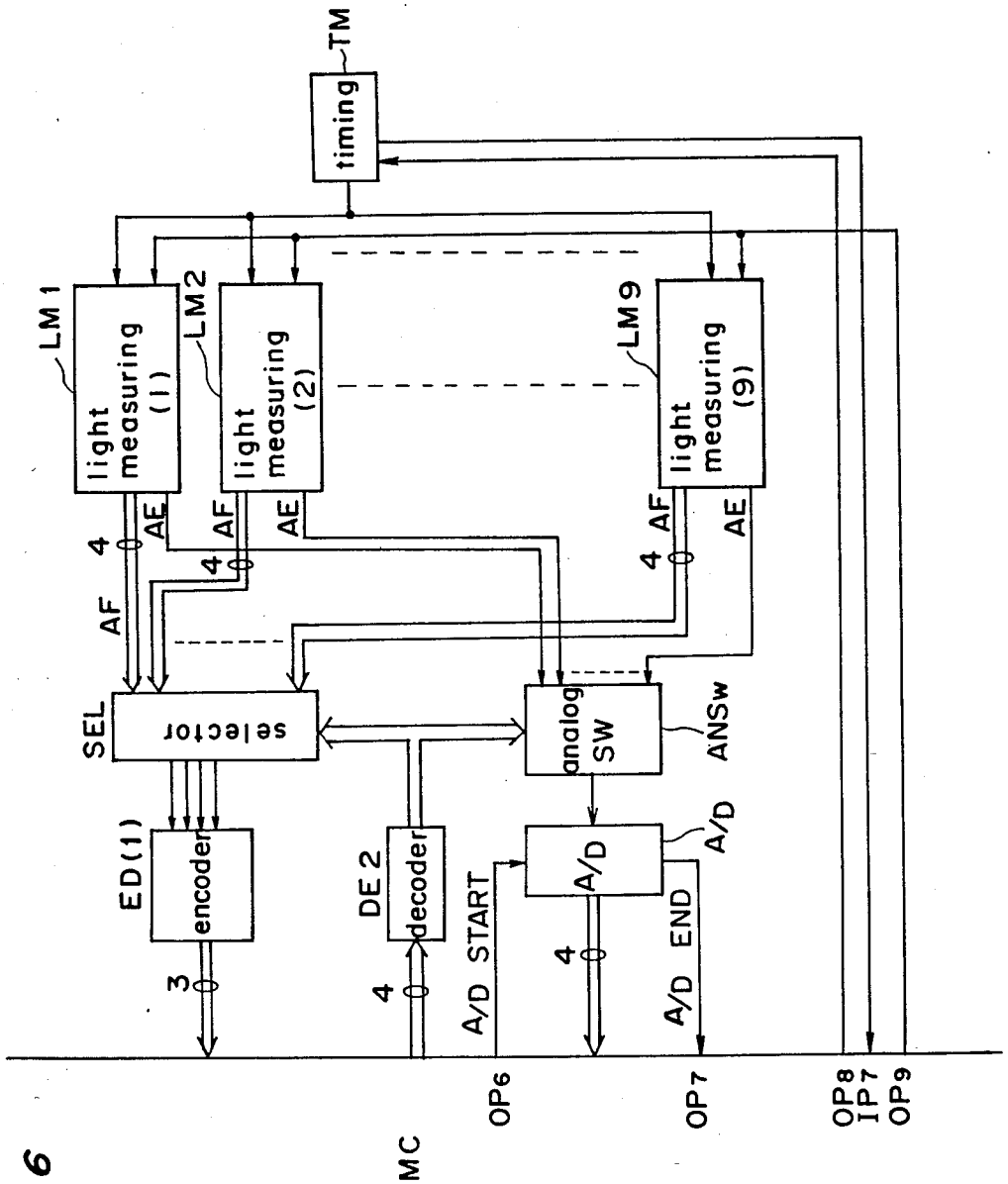

TM
timing
LM 1
light measuring (1)
LM2
light measuring (2)
LM 9
light measuring (9)
4
AF
AE
SEL
selector
analog SW
ANSw
ED(1)
encoder
DE 2
decoder
A/D
START
END
3
MC
OP6
OP7
OP8
IP7
OP9

Fig. 6

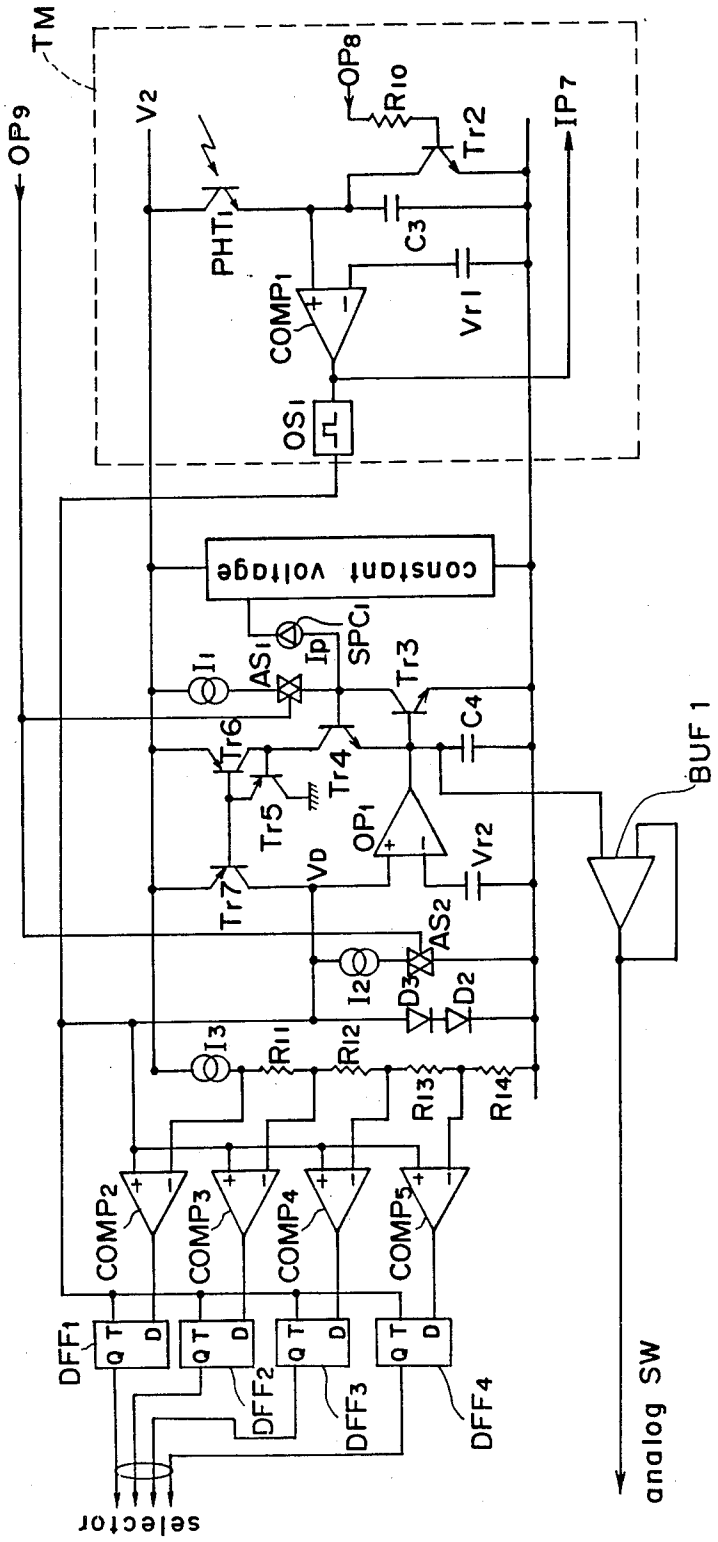

TM
OP9
V2
OP8
R10
Tr2
IP7
PHT1
C3
COMP1
Vr1
OS1
constant voltage
I1
AS1
Ip
SPC1
Tr3
C4
Tr6
Tr4
Tr5
OP1
Vr2
VD
Tr7
AS2
I2
D3
D2
I3
R11
R12
R13
R14
COMP2
COMP3
COMP4
COMP5
DFF1
DFF2
DFF3
DFF4
selector
BUF 1
analog SW

Fig. 7

Fig. 8

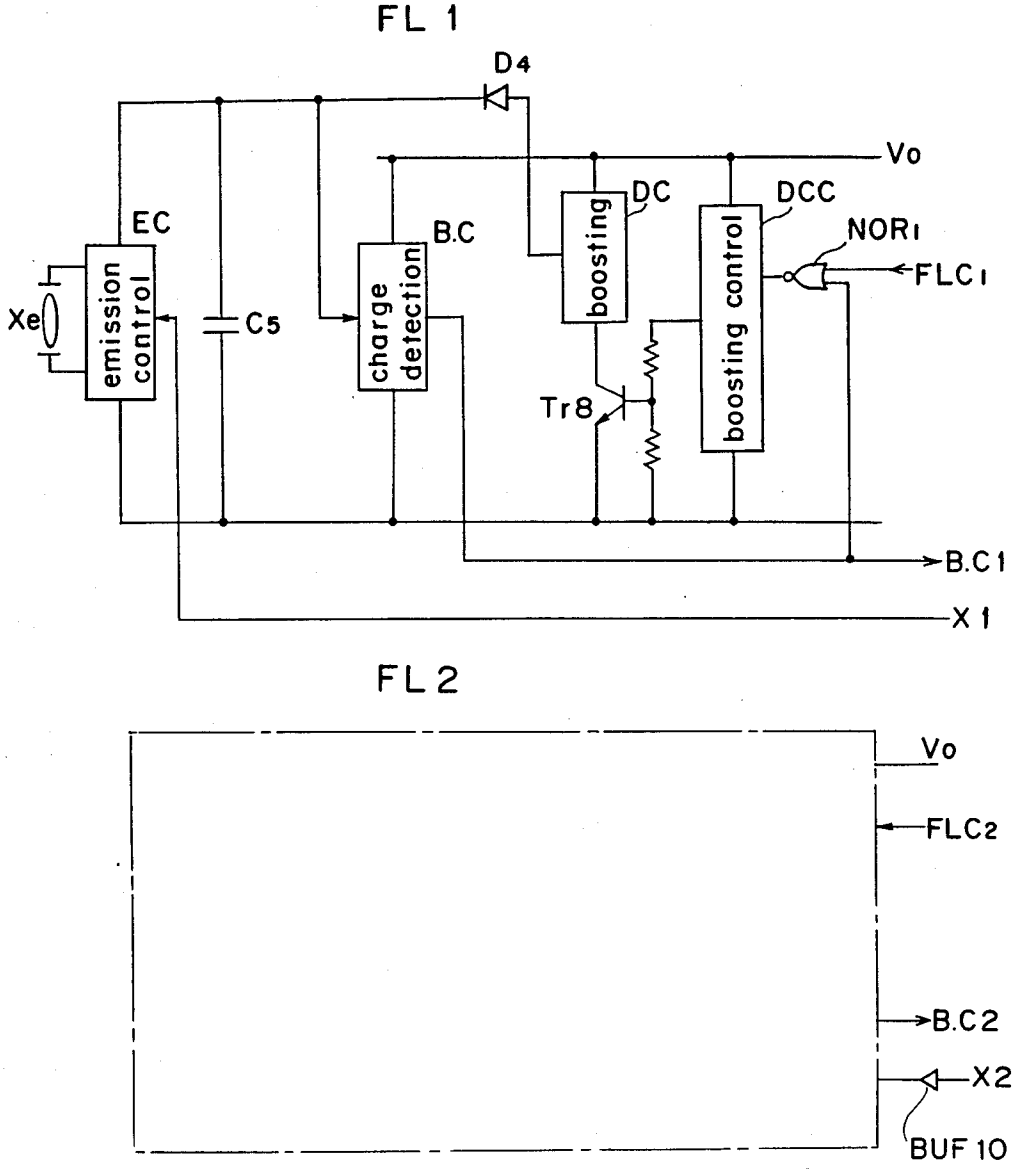
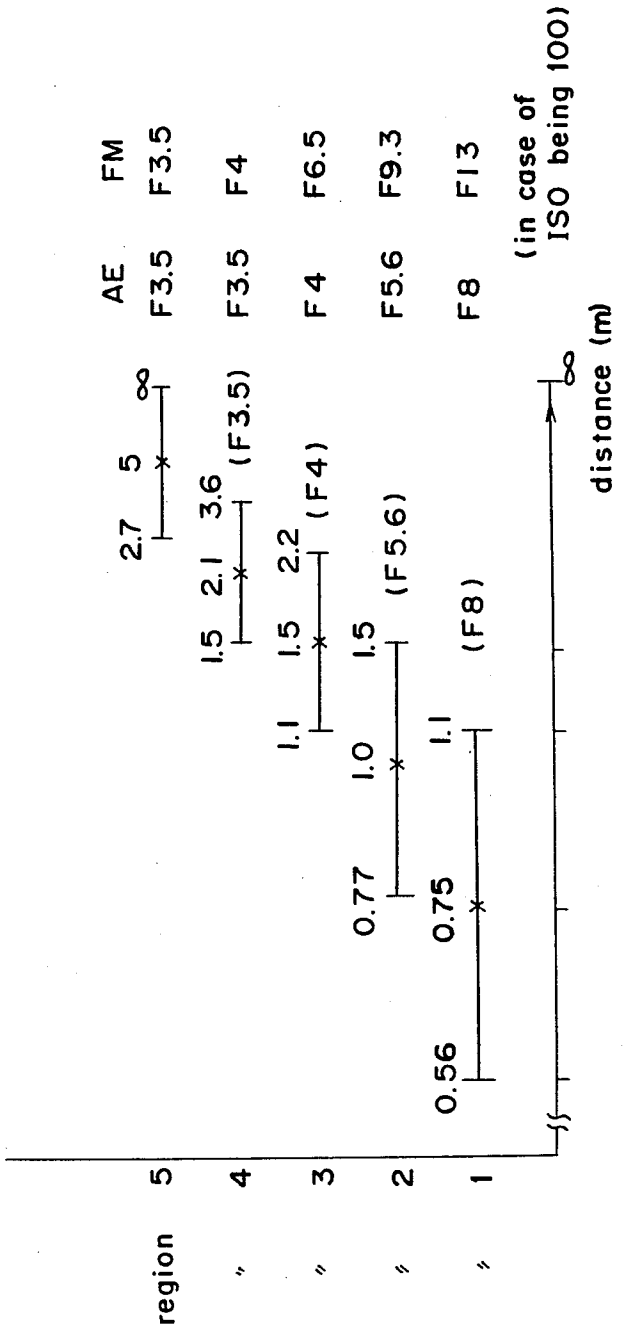

FL 1
D4
Vo
EC
B.C
DC
DCC
NOR1
FLC1
Xe
emission control
C5
charge detection
boosting
boosting control
Tr8
B.C1
X1
FL 2
Vo
FLC2
B.C2
X2
BUF 10

Fig. 9


AE
FM
F3.5
F3.5
F4
F3.5
F4
F6.5
F5.6
F9.3
F8
F13
(in case of ISO being 100)
distance (m)
region 5
4
3
2
1
2.7 5 ∞
(F3.5)
1.5 2.1 3.6
(F4)
1.1 1.5 2.2
(F5.6)
0.77 1.0 1.5
(F8)
0.56 0.75 1.1

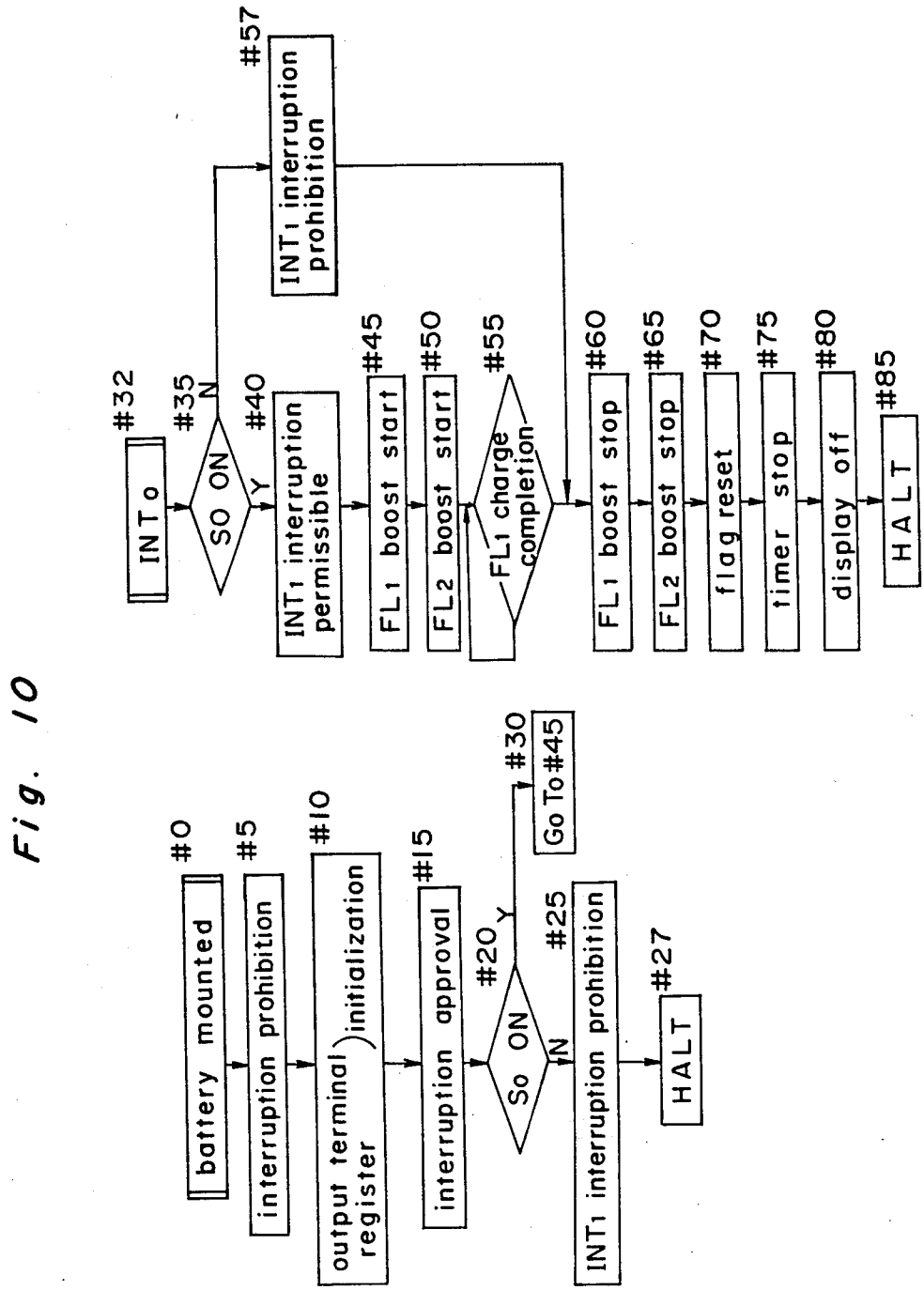

#0
battery mounted
#5
interruption prohibition
#10
output terminal register initialization
#15
interruption approval
#20
So ON
Y
#30
Go To #45
N
#25
INT1 interruption prohibition
#27
HALT
#32
INT o
#35
SO ON
N
Y
#40
INT1 interruption permissible
#45
FL1 boost start
#50
FL2 boost start
#55
FL1 charge completion
#57
INT1 interruption prohibition
#60
FL1 boost stop
#65
FL2 boost stop
#70
flag reset
#75
timer stop
#80
display off
#85
HALT

Fig. 10

Fig. 11(a)

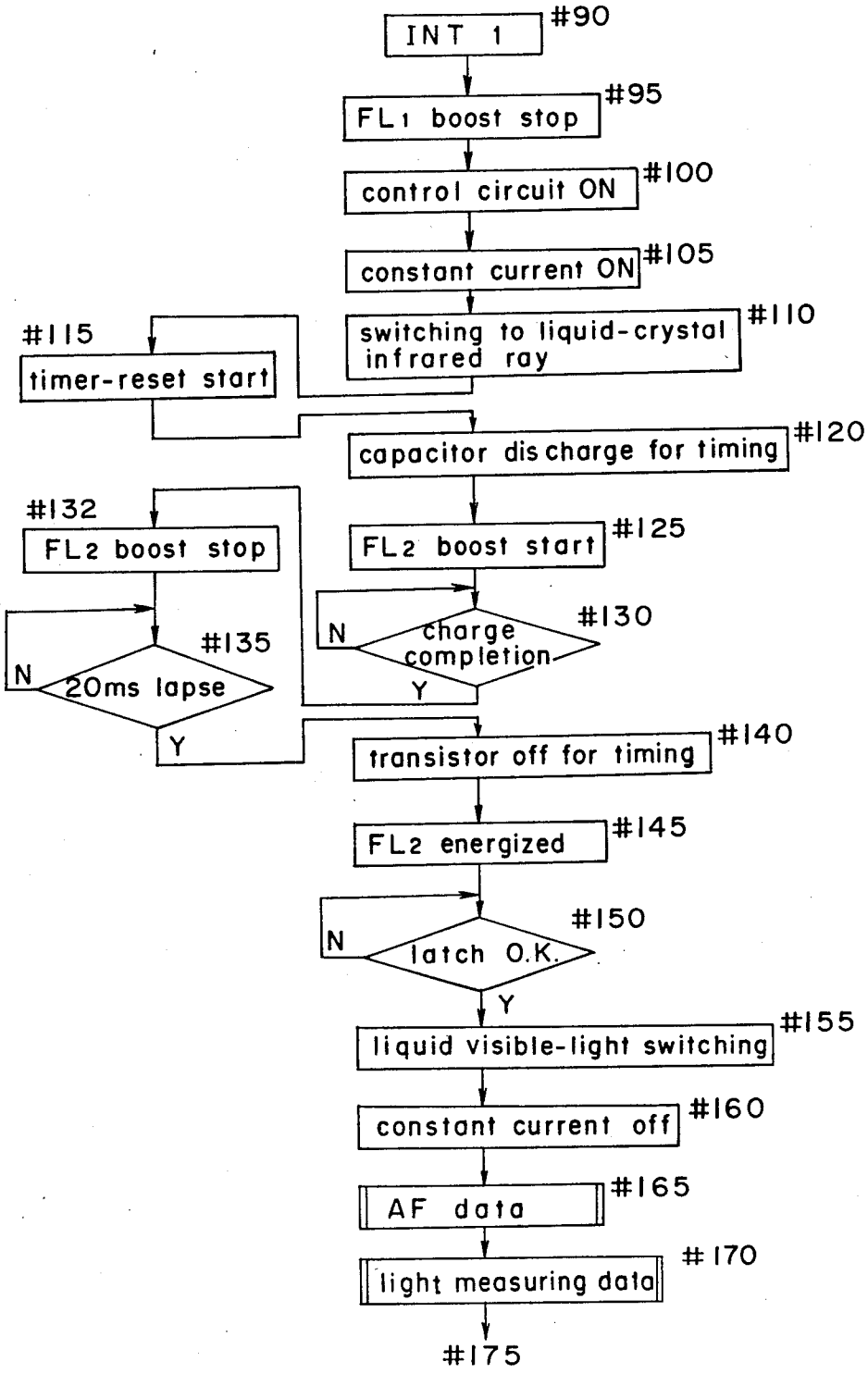

INT 1
#90
FL1 boost stop
#95
control circuit ON
#100
constant current ON
#105
switching to liquid-crystal infrared ray
#110
#115
timer-reset start
capacitor discharge for timing
#120
#132
FL2 boost stop
FL2 boost start
#125
N
charge completion
#130
#135
N
20ms lapse
Y
Y
transistor off for timing
#140
FL2 energized
#145
N
latch O.K.
#150
Y
liquid visible-light switching
#155
constant current off
#160
AF data
#165
light measuring data
#170
#175

Fig. 11(b)

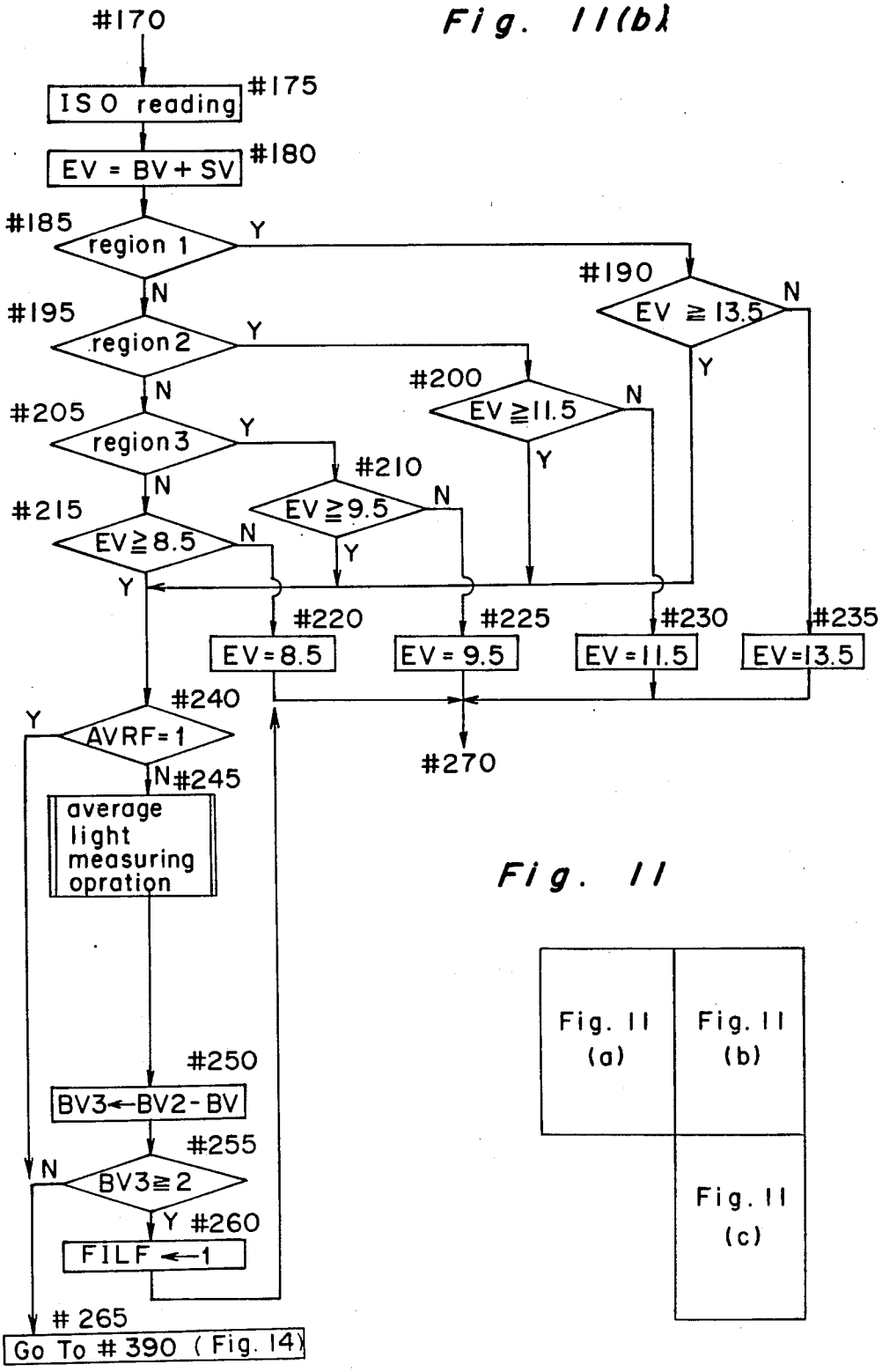


Fig. 11

Fig. 11(c)

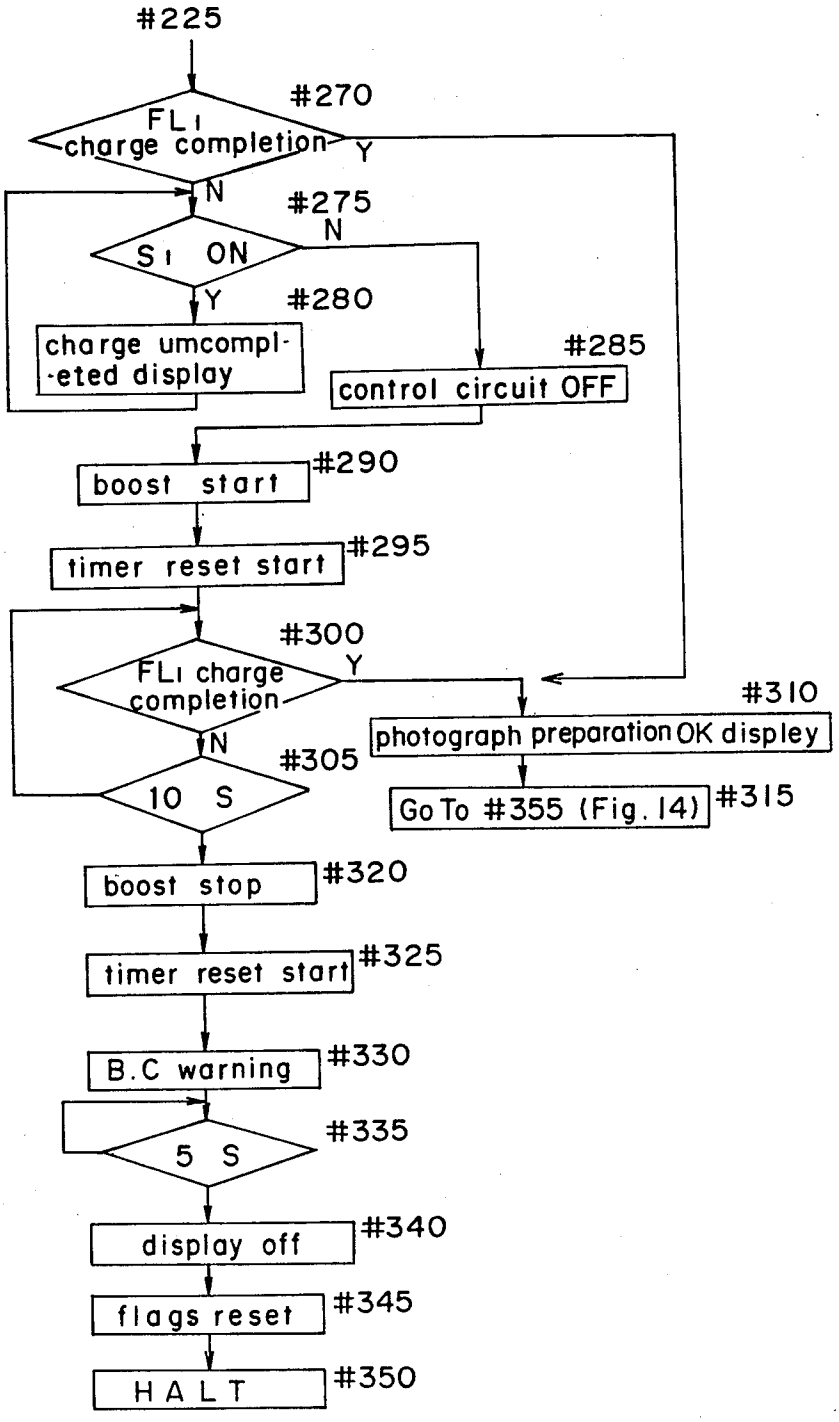

#225
#270
FL1 charge completion
Y
N
#275
S1 ON
N
Y
#280
charge umcompl-eted display
#285
control circuit OFF
boost start
#290
timer reset start
#295
#300
FL1 charge completion
Y
#310
photograph preparation OK displey
N
#305
10 S
Go To #355 (Fig. 14)
#315
boost stop
#320
timer reset start
#325
B.C warning
#330
#335
5 S
display off
#340
flags reset
#345
HALT
#350

Fig. 12(b)

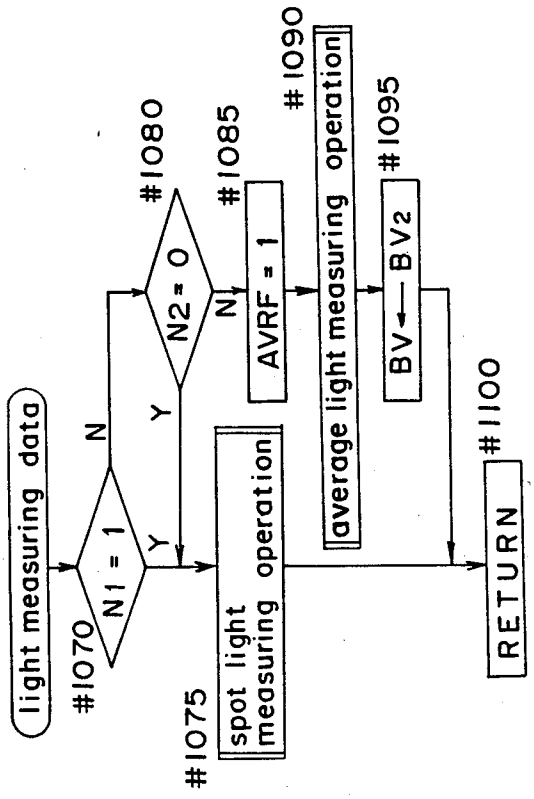


Fig. 12(a)

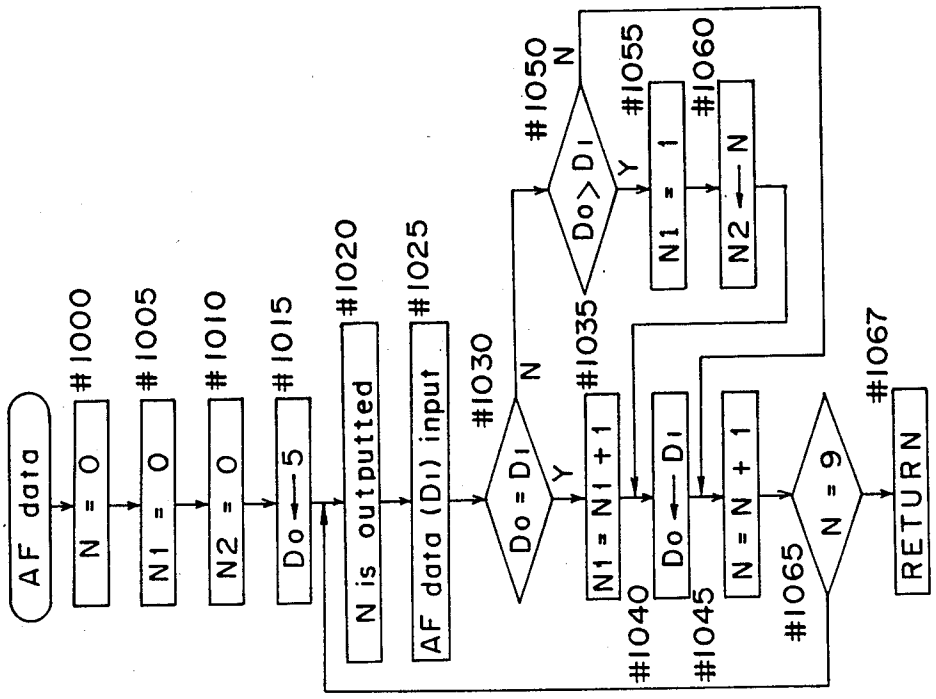


Fig. 13(b)

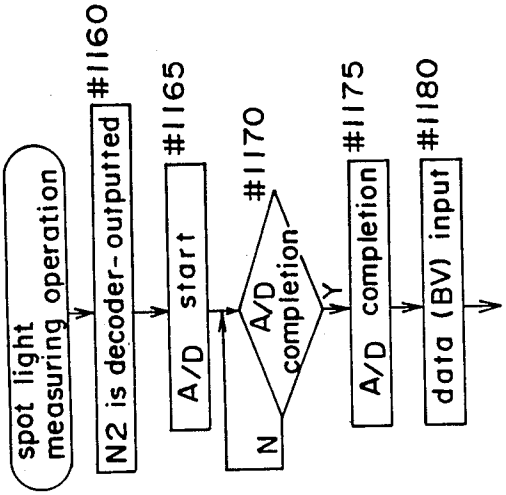


Fig. 13(a)

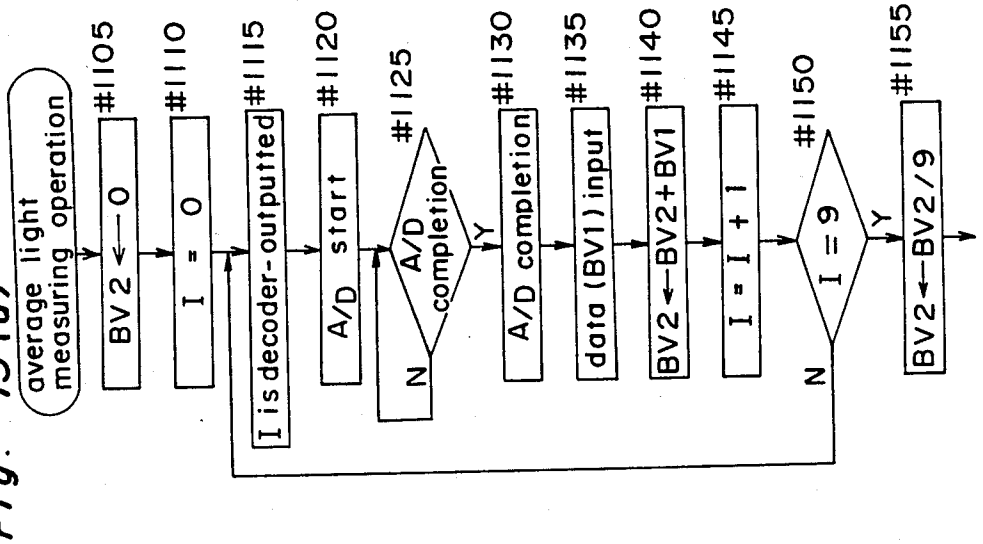


Fig. 14(a)

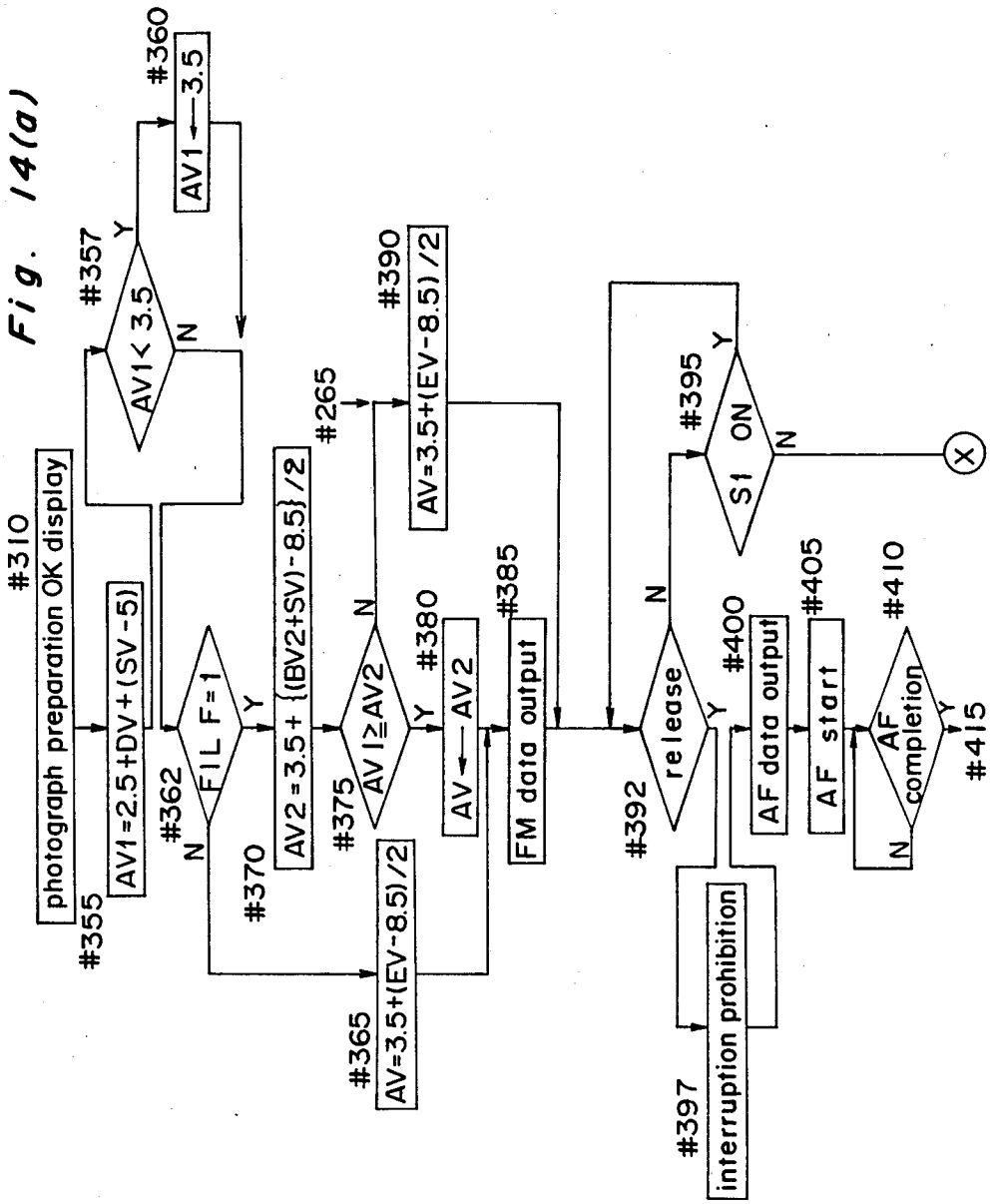


Fig. 14

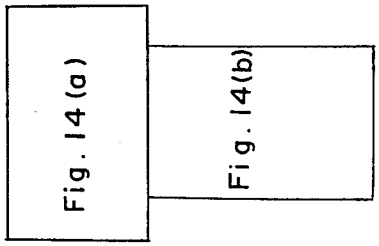


Fig. 14(b)

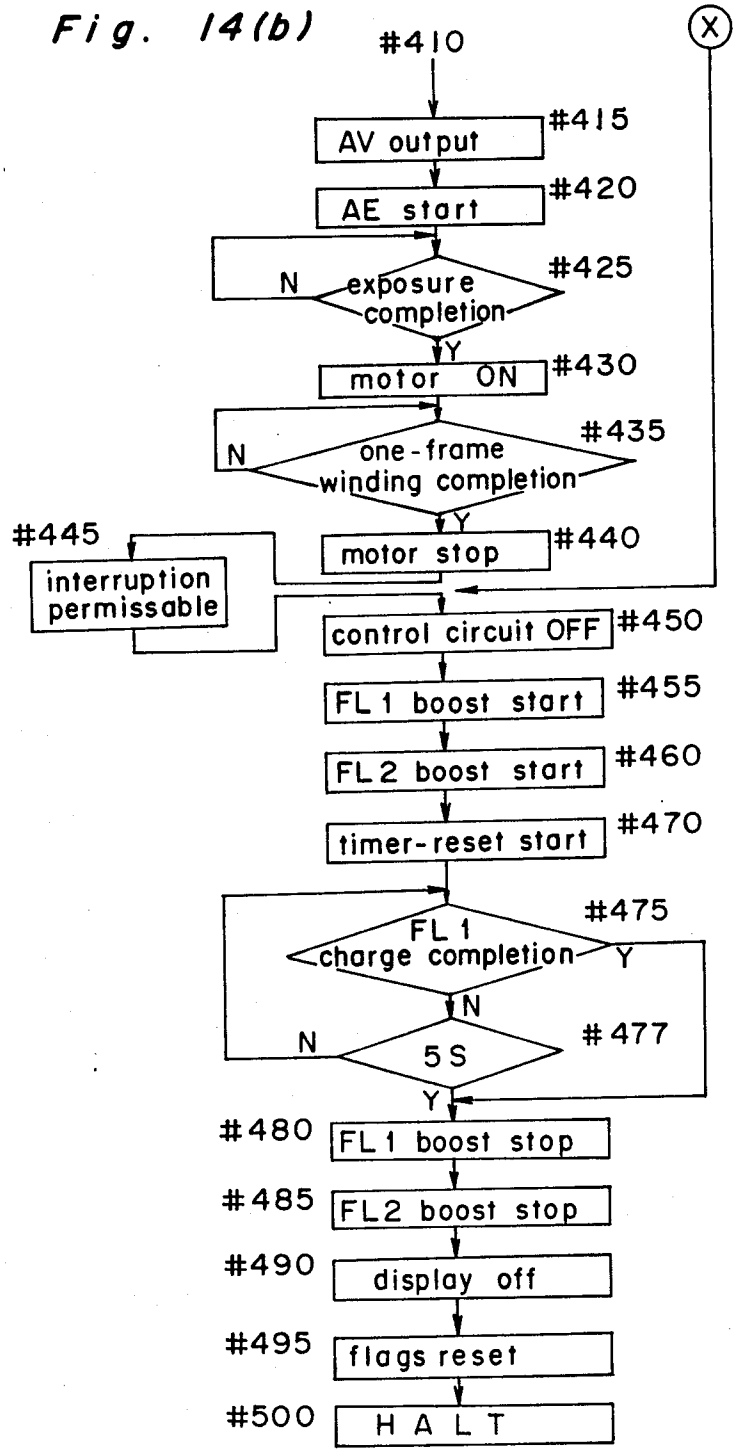

#410
X
AV output
#415
AE start
#420
N
exposure completion
#425
Y
motor ON
#430
N
one-frame winding completion
#435
Y
#445
interruption permissable
motor stop
#440
control circuit OFF
#450
FL 1 boost start
#455
FL 2 boost start
#460
timer-reset start
#470
FL 1 charge completion
#475
Y
N
N
5 S
#477
Y
#480
FL 1 boost stop
#485
FL 2 boost stop
#490
display off
#495
flags reset
#500
H A L T

Fig. 15

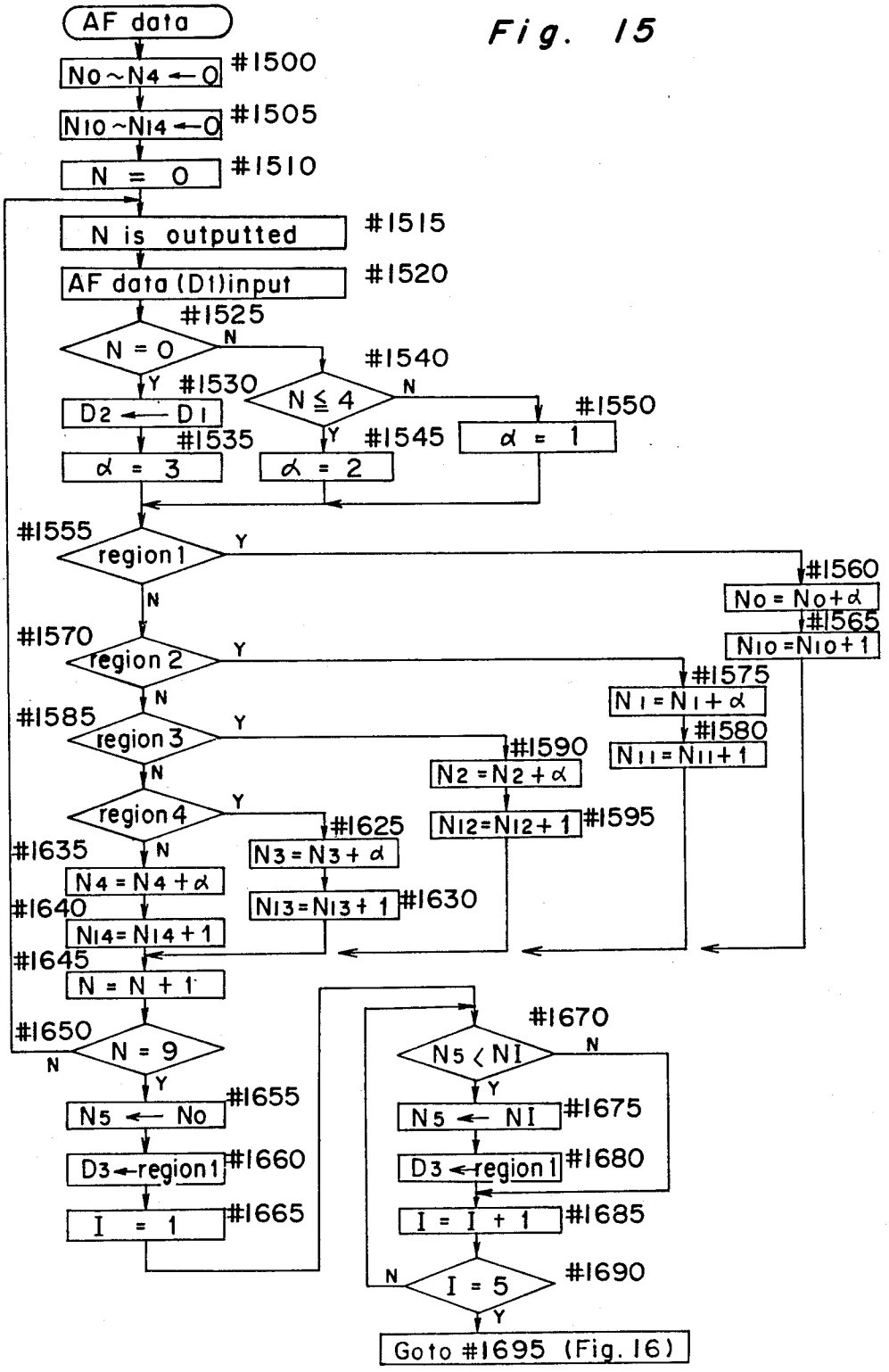
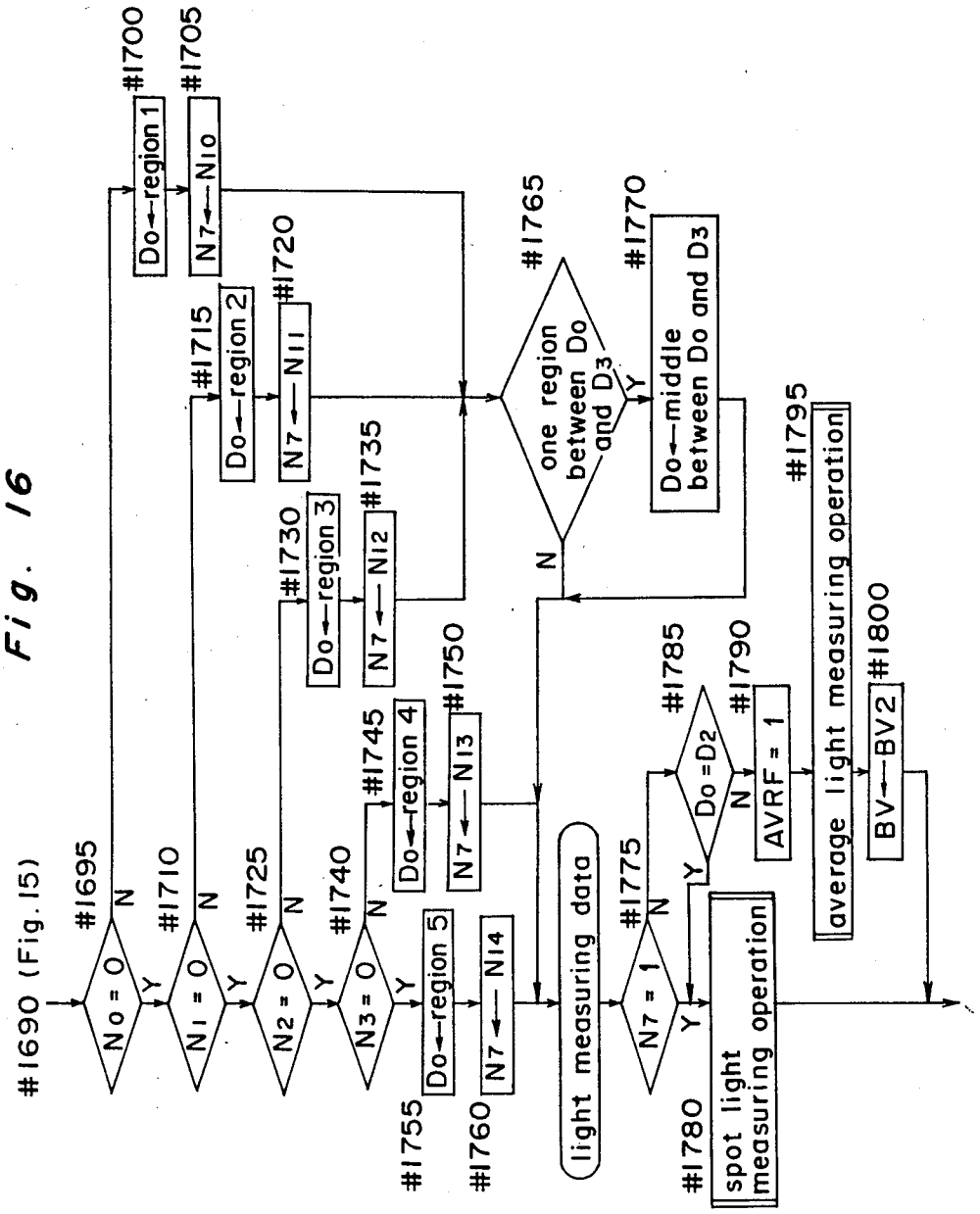

AF data
No~N4 ← 0
#1500
N10~N14 ← 0
#1505
N = 0
#1510
N is outputted
#1515
AF data (D1)input
#1520
#1525
N = 0
N
Y
#1530
D2 ← D1
#1535
α = 3
#1540
N ≦ 4
N
Y
#1545
α = 2
#1550
α = 1
#1555
region 1
Y
N
#1560
No = No+α
#1565
N10 = N10+1
#1570
region 2
Y
N
#1575
N1 = N1+α
#1580
N11 = N11+1
#1585
region 3
Y
N
#1590
N2 = N2+α
#1595
N12 = N12+1
region 4
Y
N
#1625
N3 = N3+α
#1630
N13 = N13+1
#1635
N4 = N4+α
#1640
N14 = N14+1
#1645
N = N + 1
#1650
N = 9
N
Y
#1655
N5 ← No
#1660
D3 ← region 1
#1665
I = 1
#1670
N5 < NI
N
Y
#1675
N5 ← NI
#1680
D3 ← region 1
#1685
I = I + 1
#1690
I = 5
N
Y
Goto #1695 (Fig. 16)

Fig. 16


#1690 (Fig. 15)
#1695
No = 0
#1700
Do←region 1
#1705
N7←N10
#1710
N1 = 0
#1715
Do←region 2
#1720
N7←N11
#1725
N2 = 0
#1730
Do←region 3
#1735
N7←N12
#1740
N3 = 0
#1745
Do←region 4
#1750
N7←N13
#1755
Do←region 5
#1760
N7←N14
light measuring data
#1765
one region between Do and D3
#1770
Do←middle between Do and D3
#1775
N7 = 1
#1780
spot light measuring operation
#1785
Do=D2
#1790
AVRF = 1
#1795
average light measuring operation
#1800
BV←BV2
Y
N

CONTROL DEVICE FOR USE IN A CAMERA HAVING AN OBJECTIVE LENS

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a control device for use in a camera, and more particularly to a control device which controls both the focusing operation of an objective lens of the camera and exposure operation of the camera.

2. Description of the Prior Art

There has been proposed, in U.S. Pat. No. 4,423,936, a control device in which distance detection for the focusing operation and a light measuring for the exposure operation are performed with respect to a plurality of regions in an object area to be photographed, and a distance is selected among the detected distances for the focusing operation. If the selected distance is detected with respect to a single region, a light measurement value measured with respect to the single region is used for exposure operation to control exposure value. On the other hand, if the selected distance is detected with respect to plural regions, plural light measurement values measured with respect to the detected regions are averaged to be used for the exposure operation to control exposure value.

However, in the conventional device as described above, since a primary object to be focused is not always positioned at the detected plural regions, the possibility for obtaining proper exposure for the primary object is relatively low.

Furthermore, in the conventional device, backlight condition is detected in the case that, difference between a first light measurement value measured with respect to the region in which the selected distance is detected and a second light measurement value calculated by averaging all of other light measurement values, is over a predetermined value. Here, if the selected distance is detected with respect to plural regions, the first light measurement value is calculated by averaging plural light measurement values of the plural regions. However, the difference is not always indicating whether the backlight condition or not in the latter case. Fore example, if the selected distance is detected in two regions arranged symmetrically with an optical axis of the objective lens, it is impossible to judge at which region a primary object is positioned in the device. In such case, it would be improper to detect the backlight condition.

There has been proposed, in Japanese Laid-Open patent application No. 60-129732, another control device in which a common ligh receiving device is used for the light measuring and for the distance detection. In the device, one calculating circuit for distance detection and the other calculating circuit for light measuring are provided, and the output of the common light receiving device is sent to two calculating circuits in time-sharing manner or in time-dividing manner. The distance detection calculation and exposure calculation are performed in respective circuits. However, such device has disadvantages that the construction thereof becomes comples since two calculating circuits and switching circuit for selectively transmitting the output of the light receiving device to the two calculating circuits are necessary, and that the operation of the entire device becomes complex since switching operation of the switching means is necessary.

SUMMARY OF THE INVENTION

Accordingly, an object of the present invention is to provide a control device for use in a camera having an objective lens wherein the probability of giving the proper exposure to the primary object photographed is high even when the selected distance is detected with respect to plural regions.

Also, another object of the invention is to provide a control device for use in a camera having an objective lens which is capable of more positively judging the backlight condition.

An additional object is to provide a control device for use in a camera having an objective lens which does not need a switching circuit for finding a range even when regions to be found in the range within the photographing distance are plural.

In accomplishing these and other objects, according to the present invention, there is provided a control device for use in a camera having an objective lens, comprising means for producing a plurality of distance signals necessary for focusing the objective lens on a plurality of first regions of an object area to be photographed; means for determining a distance on the basis of the plurality of distance signals to produce a determined distance signal for focusing the objective lens; means for driving the objective lens in accordance with the determined distance signal; means for measuring a plurality of brightnesses of second regions of the object area to produce a plularity of brightness signal each corresponding to the measured brightnesses respectively, each of the second regions being substantially similar to each of the first regions, respectively; means for counting the number of the distance signals used in the distance determining means for determining the distance; means for discriminating whether the number counted by the counting means is single or plural; means for determining a light measuring value by a first calculation when the discriminating number is single, while determining the light measuring value by a second calculation which is different from the first calculation and which is independent of the discriminated number when the discriminated number is plural; and means for calculating exposure value of the camera in accordance with the light measuring value, so that satisfactory exposure may be provided, judging from the experiences even when the selected distance is detected with respect to plural regions.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other objects and features of the present invention will become apparent from the following description taken in conjunction with the preferred embodiments thereof with reference to the accompanying drawings, in which:

FIG. 1 is an illustrating view showing one arrangement of a light measuring optical system to be used in a first embodiment of the present invention;

FIG. 2 is an illustrating view showing the construction of a liquid-crystal filter of transmission wavelength switch type;

FIG. 3 is an illustrating view showing the light measuring range;

FIG. 4 is a block diagram showing a light measuring circuit employed in the first embodiment of the present invention;

FIG. 5 is a circuit diagram showing the switch groups in FIG. 4;

FIG. 6 is a further detailed block diagram of the light measuring circuit in FIG. 4;

FIG. 7 is a circuit diagram showing the construction of the light measuring circuit and the timing circuit thereof;

FIG. 8 is a block diagram showing the circuit construction of an electronic flashing apparatus in the first embodiment of the present invention;

FIG. 9 is a graph showing the relationship among the distance region of the photographed object, the focusing range and the aperture value (so-called lens opening);

FIGS. 10 through 14 are flow charts showing the operation of the microcomputer of FIG. 4; and

FIGS. 15 and 16 are flow charts showing about the decision of the distance region for the photographing operation in the second embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

Before the description of the present invention proceeds, it is to be noted that like parts are designated by like reference numerals throughout the accompanying drawings.

The embodiment wherein the present invention has been applied upon the lens shutter camera will be described with reference to the accompanying drawings. First, the distance detection and the light measurement to be used in the embodiment will be described in principle. The distance detecting apparatus is composed of a projecting means for projecting the light onto the entire region of the photographed field to be detected in distance, a light-receiving means for receiving the light to be reflected from the object, and a circuit for processing the signals from the light-receiving means to detect the distance.

The light-receiving means is composed of a plurality of light-receiving elements, by which the photographed field is divided into a plurality of regions to detect the respective distances. And one of the distances is selected as a distance where the photographing lens is focused, thereby the brightness of the selected region is detected as supposing that a primary object is positioned in the selected distance. In the present embodiment, the common light-receiving elements are used for both the distance detection and the brightness detection.

Referring now to FIG. 1, there is shown a concrete example of the optical system with the light-receiving element being provided for common use. An electronic flashing apparatus FL2 is the projecting means which projects the light on the entire region of the photographed field through the filter IRF1 provided on the front face, through which the infrared light of particular wavelength or wavelength range is transmitted. The light-quantity emitted by the electronic flashing apparatus FL2 is by far less than the light-quantity emitted by the electronic flashing apparatus for object illumination use to be employed in the photographing operation. A condenser lens LE collects the light reflected from the object OB to guide into the light receiving element SPC. A filter LCDF1 which is adapted to be capable of switching to a filter for transmitting the infrared light of particular wavelength or wavelength range through it, and a filter having the characteristics of visual sensitivity is provided between the condenser lens LE and the light-receiving element SPC.

This filter is constructed as shown in FIG. 2. Namely, the filter LCDF1 is composed of a guest-host type liquid crystal devices LCD1 and LCD2. When the signal of the "High" level (hereinafter referred to as "H") is outputted from a terminal OP1 of a microcomputer MC shown in FIG. 4, a predetermined voltage V2 is applied upon a first liquid crystal device LCD1 through a buffer BUF, and the first liquid crystal device LCD1 comes to let the infrared light of the particular wavelength or wavelength range pass through it. On the other hand, when the signal of the "Low" level (hereinafter referred to as "L") is outputted from the output terminal OP1 of the microcomputer MC, the predetermined voltage V2 is applied upon a second liquid crystal device LCD2 through a buffer BUF and an inverter IN2, so that the second liquid crystal device LCD2 comes to operate as a visible-sensitivity filter through which the light of the visible sensitivity range may pass. The buffer BUF and the inverter IN2 are adapted to be fed by the power voltage to be described later. Accordingly, when the release button (not shown) is not depressed, both the liquid crystal devices remain colorless in light transmission condition without application of the voltage.

The light-receiving element SPC shown in FIG. 1 is composed of a plurality of elements as described hereinabove and is adapted to measure each of a plurality of regions ① through ⑨ of the object field shown by rectangular frame in FIG. 3. A plurality of the light-receiving elements are arranged to measure the region which is deviated a little downwardly of the object field as a whole, and are composed of nine elements in total arranged symmetrically in the horizontal, vertical relation with the No. 1 light-receiving element as a center being provided to measure the region a little lower than the center of the object field. They are adapted to detect the distance and brightness of the regions ① through ⑨ shown in the oblique-line portions. The reason where they are arranged somewhat downwardly with respect to the field to be photographed is that the object or the person regarded as the primary object is often provided in the lower portion, but in the upper portion with the lens shutter camera having a comparatively wide-angle lens.

The camera system which performs the above-described described distance detection and brightness detection will be described hereinafter. In the block diagram of FIG. 4 showing the circuit construction of the entire camera, a power battery E consists of direct connection of two lithium cells each producing 3 V. A diode D1 is provided for preventing the voltage applied to the microcomputer MC from becoming lowered during the operation of the boosting circuit in the electronic flashing apparatus FL. A capacitor C0 is provided to prevent the noises and to hasten the charging operation to the main capacitor in the electronic flashing apparatus FL. A capacitor C1 has comparatively large in capacity for the back-up operation of the microcomputer MC. A resistor R1 and a capacitor C2 for resetting use are adapted to reset the microcomputer MC when the power batter E is mounted. A group of switches SW have a plurality of switches which are required for the operation of the apparatus of the present embodiemnt. The group of switches will be described in detail with reference to FIG. 5.

A display circuit DI displays the photographing information. A liquid-crystal filter FI, which is shown in FIG. 2, becomes an infrared filter or a visible-light filter. The microcomputer MC is provided to control the entire circuit. A film sensitivity setting circuit IS converts the film sensitivity, which is read from the code pattern provided on the film container or is manually set, into the film sensitivity value represented by A.P.E.X. system to output it into the microcomputer MC. A light measuring circuit LM is composed of a distance detection circuit for receiving the light, which are emitted from the electronic flashing apparatus FL for distance detection to be described later and are reflected from the object to detect the distance of the object, and a light measuring circuit for measuring the brightness BV of the object. An exposure control circuit AE for controlling the exposure in accordance with the exposure value EV to be outputted from the microcomputer MC outputs the flash starting signal X1 to the electronic flashing apparatus FL at a given timing. An AF controlling circuit AFC drives the objective lens to an in-focus position in accordance with the AF data to be outputted from the microcomputer MC. A motor controlling circuit MO controls the motor M for the winding operation of the film. The electronic flashing apparatus FL is composed of the electronic flashing apparatus FL2 for distance detection use and the electronic flashing apparatus FL1 for object illumination use during the exposure. A transistor Tr1 feeds the power voltage to the filter FI, the film sensitivity setting circuit IS, the light measuring circuit LM, the exposure controlling circuit AE, the AF control circuit AFC, and the motor control circuit MO in accordance with a signal from the microcomputer MC.

FIG. 5 shows the concrete example of a group of switches SW in FIG. 4. A lens cover switch S0 turns on and off through the operative cooperation of the opening, closing operations of a lens cover (not shown). The pulse signal is outputted into the interruption terminal INT0 of the microcomputer MC through a circuit composed of a delay circuit DEL and an exclusive OR circuit EOR by turning on and off of the switch SO. When it is inputted into the microcomputer MC, the microcomputer executes a given interruption routine INT0. A photograph preparing switch S1 turns on when the release button (not shown) is depressed as far as the first stroke. If the switch S1 is turned on when the lens cover is open, the interruption routine INT1 is executed. A release switch S2 turns on when the release button is depressed as far as a second stroke provided deeper than the first stroke. An exposure completion switch S3 turns off at the charging completion of the shutter charging member (not shown) and turns on at the exposure completion.

A one frame winding switch S4 turns off at the exposure completion and turns on at the completion of one frame winding completion. A switch S5 turns on when the objective lens is driven to the given position corresponding to the control signal and turns off at the charge completion of the shutter charging member.

The details of the light measuring circuit LM of the distance detection and the brightness detection to be used in the present embodiment will be described hereinafter with reference to the block diagram of FIG. 6.

The light measuring circuits LM1 through LM9 perform the distance detection and the brightness detection of the regions ① through ⑨ shown in FIG. 3, respectively. Each of the circuits for the distance detection latches the signals from the light-receiving element, i.e., the distance signal in response to a signal of the timing circuit TM, so that the signals from the light-receiving elements are latched at the timing when the intensity of the light projected from the electronic flashing apparatus FL2 becomes maximum in the variation thereof, thereby to output the signal to the selector SEL. The selectro SEL selects the signals from the light measuring circuits LM1 through LM9 by the signal from a decoder DE2, which is adapted to decode the signal from the microcomputer MC to output the selected signals to the encoder ED. The encoder ED converts the inputted signals into given forms to output them into the microcomputer MC. The distance signals of the light measuring circuis LM1 through LM9 are outputted to the microcomputer, by the signal from the microcomputer MC, sequentially through the selector SEL and the encoder DE1.

On the other hand, signals of the detected brightnesses are outputted as analog signals to the analog switch ANSW. The analog switch ANSW is composed of nine FETs, which are connected with the light measuring circuits LM1 through LM9 respectively, so that the respective brightness signals may be inputted, all the outputs being integrated into one, and are connected with the A/D converting circuit A/D. The selection of the analog switch ANSW is performed by the signal of the decoder DE2, which is adapted to decode the signal from the microcomputer MC as in the distance signal, and is sequentially performed from the light measuring circuits LM1 through LM9. The brightness signal which has been outputted to the A/D converting circuit A/D through the analog switch ANSW is converted into digital forms and is outputted into the microcomputer MC.

The details of the light measuring circuit LM1 and the timing circuit TM1 are the above-described diagram will be described in FIG. 7. The portion surrounded by the dotted lines in the drawing shows the timing circuit, and the portion except for it shows the light measuring circuit.

First, the timing circuit TM1 will be described. When the release button is depressed, the signal of "H" is outputted from the terminal OP8 of the microcomputer MC before the electronic flashing apparatus FL2 starts to emit the light, and the transistor Tr2 turns on to discharge the capacitor C3. The transistor Tr2 is turned off immediately before the light emission to wait therefor. A phototransistor PHT1 which charges the capacitor C3 is disposed near the light emitting portion of the electronic flash apparatus FL2 and is adapted to directly receive the emitted light. When the electronic flashing apparatus FL2 emits the light in this condition, the current corresponding to the intensity of the light received by the phototransistor PHT1 is charged into the timing capacitor C3 through the phototransistor PHT1. When the voltage of the capacitor C3 exceeds a reference voltage Vr1, the comparator COMP1 is reversed to output the signal of the "H". The signal of the "H" is pulsed by the one-shot circuit OS1 and is outputted into the terminals T of the D flip-flops to be described later to latch the amplification signal from the light-receiving element SPC1. The reference voltage Vr1 is adapted to reverse the comparator COMP1 at the time point when the intensity of light emitted by the electronic flashing apparatus FL2 is slightly lower from the maximum intensity.

The light measuring circuit LM1 will be described hereinafter. The voltage is applied through the power supply line V2 by the depression of the first stroke of the release button to feed the power to each circuit. At once, the signal of the "H" is outputted from the terminal OP9 of the microcomputer MC to turn on the analog switches AS1, AS2 so that constant current circuits I1, I2 start to flow constant currents, respectively. After the lapse of a predetermined time (as the lowest 20 msec is assigned to that time in the present embodiment), the light measuring circuit LM1 remains stable.

The circuit operation before the stability of the circuit LM1 will be briefly described. As the voltage of the capacitor C4 is extremely low when the constant current circuits I1, I2 start to flow constant currents, the transistor Tr3 does not turn on. Constant current I1 flown by the constant current circuit I1 and the photocurrent IP which corresponds to the brightness of the particular wavelength light passing through the filter flow to the base of the transistor Tr4 to be amplified there. The amplified current flows through the transistor Tr6, and the equivalent current flows through the transistor Tr7 which constitutes a known current mirror circuit with the transistor 6. One part of the current becomes current of the constant current circuit I2 and the remaining current flows through the diodes D2, D3 to cause the voltage VD corresponding to two steps of the diode. The operation amplification OP1 has a reference voltage Vref inputted into the inversion input terminal, and has the voltage VD inputted into the non-inversion input terminal, and the negative feedback is applied upon the transistor Tr3 so that the voltage VD may become always constant.

As the current flowing through the transistor Tr7 corresponds to the current which has amplified most of all the photocurrent IP and the constant current I1, the voltage VD to be caused by this current becomes higher than the reference voltage Vref. Accordingly, the operation amplifier OP1 charges the capacitor C4 to boost the base voltage of the transistor Tr3. This capacitor C4 is charged through the transistor Tr4. When the voltage of the capacitor C4 is boosted to turn on the transistor Tr3, the constant current I1 and the photocurrent IP flow through the collector of the transistor Tr3 to reduce the current flowing through the base of the transistor Tr4. Thus, the current flowing through the transistor Tr6 and the transistor Tr7 is reduced to lower the voltage VD, so that the above-described operation is performed until the voltage VD becomes equal to the reference voltage Vref. During this operation, the voltage VD may become lower than the reference voltage Vref. At this time, the operation amplifier OP1 operates for discharging the charge of the capacitor C4 to reduce the voltage thereof, which reduces the current through the transistor Tr3 within the constant current I1 and the photocurrent IP so as to increase the base current of the transistor Tr4. Accordingly, the current which flows through the transistors Tr6 and Tr7 increases to boost the voltage VD.

This circuit is stabilized by the above-described operation to flow the current almost equal to the total of the constant current I1 and the photocurrent IP through the transistor Tr3, so that the voltage of the capacitor C4 for becomes equal to the base voltage corresponding to the current.

When the electronic flashing apparatus FL2 emits the light, the light reflected from the object is received by the light-receiving element SPC1 to cause the photocurrent IP' (which is referred to as IP' hereinafter to distinguish it from the above-described ambient photocurrent IP) corresponding to the light including a reflected light component reflected by the object and the ambient light component. The current IP of the ambient light component within the photocurrent flows through the collector of the transistor Tr3, and the current IP'-IP corresponding to the reflected light component flow as the base current of the transistor Tr4. At this time, the capacitor C4 has the capacity, in which the transistor Tr4 does not respond by the current while the reflected light is received by the light receiving element. And the current IP-IP' is amplified by the transistor Tr4 to flow the diodes D2, D3 through the transistors Tr6, Tr7. Thus, the voltage VD is increased to compare the voltage VD with the reference voltage determined by the constant current circuit I3 and the resistors R11 through R14, so that the distance signal is represented as the outputs of the comparators COMP2 through COMP5. The output signals of the comparators COMP2 through COMP5 are latched into the D flip-flops DFF1 through DFF4 by the signal from the timing circuit TM to output the latch signal to the selector SEL.

After the distance detection has been performed in the above-described way, the filter arranged in front of the light-receiving element SPC1 is changed from a characteristic for permitting that the infrared light having the particular wavelength pass therethrough to the other characteristic for permitting that the visual light pass therethrough. Furthermore, the constant current circuit I1 is switched off to remove the voltage of the constant current I1 with respect to the charging voltage of the capacitor C4. The constant current circuit I2 is also turned off to cut off the route of the feedback of the transistor Tr3 through this constant current I2 so that the voltage of the capacitor C4 may become only the voltage which depends upon only the intensity of the ambient light component received by the light-receiving element SPC1. The voltage is outputted into the analog-switch ANSW through the buffer BUF1.

The other light measuring circuits LM2 through LM9 shown in FIG. 6 are also completely the same in construction as in FIG. 7.

The electronic flashing apparatus FL1 for photograph use and the electronic flashing apparatus FL2 for distance detection use to be used in the embodiment will be described hereinafter with reference to FIG. 8. Except for the point that the electronic flashing apparatus FL2 for distance detection use is much smaller (approximately 1/25 in the maximum light emitting amount) than the electronic flashing apparatus FL1 for photographing use, the former is completely the same in the circuit construction as the latter FL1, thus removing the illustration of the concrete construction of the former with the circuit being shown simply in block.

In the circuit of the electronic flashing apparatus FL1 for photographing use, a boost controlling circuit DCC receives the boost controlling signal FLC1 from the microcomputer MC and produces the changing completion signal B.C1 to be described later to control the transistor Tr8 for boosting circuit DC. The rectification diode is represented by D4. A charge detecting circuit B.C detects the charging condition of a main capacitor C5. An emission control circuit EC energizes a xenon tube Xe in accordance with the emission signal X1 from the exposure control circuit AE to illuminate the object area. The emission signal X2 of the electronic flashing

apparatus FL2 for distance detection use is fed through the buffer BUF10 from the microcomputer MC.

The operation of the electronic flashing apparatus FL1 for photographing use will be described. When the charging operation to the main capacitor C5 has not been completed, the charge completion signal B.C1 is in the "L" level. When the boosting control signal FLC1 of the "L" showing the boosting start is sent from the microcomputer MC, the NOR circuit NOR1 outputs the signal of "H", and the boost controlling circuit DCC receives it to control the transistor Tr8 to turn it on and starts the boosting operation. When the charging completion signal B.C1 becomes "H" level by the completion of the charging operation to the main capacitor C5 or the boosting control signal FLC1 from the microcomputer MC becomes "H" level, the NOR circuit NOR1 outputs "L" level, so that the boost controlling circuit DCC turns off the transistor Tr8 to stop the boosting operation of the boosting circuit DC. It is to be noted that a neon tube showing this condition lights on independently of the control circuit and the microcomputer MC when the charging operation of the main capacitor C5 is completed.

The entire operation of the camera in the embodiment will be described hereinafter. Before it, the number of the distance zones detected by the distance detection, the in-focus range in each region, and how to determine it will be described.

The distances to the objects located at each of the regions are detected in accordance with the absolute amounts of the light reflected by the objects as described hereinabove. However, as each of the objects has a reflectance different from that of the other objects, the distance detected by the detection apparatus is not always equal to the distance to the object. In the present embodiment, the in-focus range of each region is provided wider or the range is provided across two regions so that the focusing operation may be performed without fail on the object. However, if the distance range from the nearest focusing distance such as 0.6 m to the infinity distance is divided into five ranges, it is impossible to achieve the in-focus condition of the objective lens with respect to any object located within the distance range in the condition in which the aperture of the objective lens is fully opened, due to the focusing performance of the objective lens. Thus, in the embodiment the maximum aperture value is decreased in accordance with the decrease of the distance. Therefore, an in-focus range of particular distance zone can be extended to achieve the in-focus condition with respect to any object within the distance range, by dividing the latter into five ranges.

Here, since the embodiment uses a shutter serving as an aperture diaphragm, the reduction of the aperture value causes the shutter speed to shorten. Therefore, the brightness range in which the natural light photographing may be performed becomes narrower, the underexposure is likely to be caused. In this case, the flash photographing operation is performed to compensate for it. The shutter, also serving as an aperture diaphragm, which is used in the present embodiment, is a type showing the triangular waveform in time-variation characteristics of the opening degree. The shutter gradually opens to reach the given aperture value, and is adapted to move to the closed operation.

Five ranges determined in accordance with the above-described idea and their in-focus ranges, the maximum aperture value of the use limit at this time, and the aperture value at the flash photographing operation will be described in FIG. 9.

In the drawing, the axis of ordinates shows the regions 1, 2, 3, 4, 5 arranged in order from the near distance side. The axis of abscissa shows the distance as far as 0.6 m through ∞. The focusing range of each region will be described. As shown in FIG. 9, in the region 1, the open aperture value is limited to F/8, and the object distance of the objective lens is set to 0.75 m. Thus, the object positioned within a distance range from 0.56 m to 1.1 m can be in-focus condition on the predetermined focal plane by the objective lens. In the region 2, the open aperture value is limited to F/5.6, and the object distance is set to 1.0 m, thereby the objective lens is set to be in in-focus condition with respect to an object positioned within a distance range from 0.77 m to 1.5 m. In the region 3, the open aperture value is limited to F/4, and the object distance is set to 1.5 m, thereby the objective lens is set to be in in-focus condition with respect to an object positioned within a range from 1.1 m to 2.2 m. In the region 4, the open aperture value is limited to F/3.5, and the object distance is set to 2.1 m, thereby the objective lens is set to be in in-focus condition with respect to an object positioned within a distance range from 1.5 m to 3.6 m. In the region 5, the open aperture value is limited to F/3.5 and the object distance is set to 5 m, thereby the objective lens is set to be in in-focus condition with respect to an object positioned within a distance range from 2.7 m to ∞.

The aperture value used in flash photographing operation is determined as shown in "FM" in FIG. 9. The guide number of the flashing apparatus is determined to be 10 with respect to a film sensitivity of ISO=100. In the region 1, the aperture value in flash photographing operation is set to F/13, so that under- or over-exposure is provided by 1 step with respect to the object located at the nearest or farthest distance within the distance range of region 1. Only the same exposure amount is designed to become over or under with respect to both the ends. In the region 5, the flash photographing operation is adapted to be performed as far as possible with F/3.5 in the open aperture value.

FIGS. 10 through 14 show the flow charts of the microcomputer MC. The controlling operation of the camera will be described with reference to the flow charts.

The operation with the battery E being mounted on the camera will be described with reference to FIG. 10. When the battery E is mounted thereon, the signal which changes from "L" to "H" is inputted into the reset terminal RES, the microcomputer MC executes the flow to prohibit the interruption (#5) and to initially set (#10) the output terminals, the registers. Then, the signal of the terminal IP6 shown in FIG. 5 is inputted and the microcomputer MC allows the interruption to decide whether or not the lens cover is open. When it is closed, the interruption to the interruption terminal INT1 to be described later is prohibited to come to a stop (#25 through #27). On the other hand, the program proceeds to step #45 to be described later when the lens cover is open.

The interruption INT0 which is executed through the opening and closing operation of the lens cover will be described hereinafter. If the lens cover is opened or closed in the condition where the interruption to the flow is allowed, the pulse is inputted into the terminal INT0, so that the microcomputer MC executes the interruption INT0 operation from the step #32. At first,

the decision is made as to whether the lens cover has been opened or closed (#35). When the lens cover has been closed, the interruption of the flow of the interruption to the flow of the interruptions INT1 to be described later is prohibited (#57) to proceed to the step #60 (§35, 37). When the lens cover has been opened, the interruption to the terminal INT1 is allowed (#40), the signals of "H" to the output terminals FLC1, FLC2 are outputted (#40 through 50) to start the boosting operation of the electronic flashing apparatus FL1, FL2 for photographing use and distance detecting use so as to decide whether the charging operation of the main capacitor of the electronic flashing apparatus FL1 for photographing use has been completed through the output signal BC1 (#55). Even when the lens cover is open with the battery being mounted on, the program proceeds to the step #45. When the charging completion of the main capacitor is decided at the step #55, the signals of "L" are outputted to the terminals FLC1, FLC2 (#60, 65) to stop the boosting operation of both the electronic flashing apparatuses FL1, FL2 for photographing use and distance detection use. And all the flags are reset at the step #70. The counting timer started in the interruption flow ot the INT1 shown in FIG. 11 is stopped to turn off the display, and the microcomputer MC becomes halt condition (#70 through 85).

Then, in FIG. 11, when the release button is depressed to the first stroke with the lens cover being opened, the signal which changes from "H" to "L" is inputted to the terminal INT1 and the microcomputer MC executes the flow of the interruption INT1 from the step #90.

In order to perform the distance detection and the brightness detection, the boosting operation of the electronic flashing apparatus FL1 for photographing use is stopped operation and the decrease in the battery voltage (#95). Then, the transistor Tr1 is turned on to supply the power supply to each control circuits (#100). The analog switches AS1, AS2 are turned on to flow the constant current for distance detection use (#105), and the output of the terminal OP1 is turned into "H" so that the filter is switched for infrared ray use to detect the distance (#110). The timer for counting the time required for the circuit stability is reset and started (#115), and the transistor Tr2 for timing use is turned on (#120) to discharge the timing capacitor C3 for the determination of the timing to latch the output of the distance detecting circuit. Then, the controlling operation is performed to start the boosting operation of the electronic flashing apparatus FL2 for distance detection use to wait for the completion of the charging operation of the capacitor C5 (#125, 130). After the charging operation of the capacitor C5 completes, the boosting operation is stopped (#132). And the decision is made whether or not 20 msec have passed from the timer start of the step #115. If they have not passed, the lapse is waited for. If they have passed, the transistor Tr2 for timing use is turned off (#135, 140). The signal of "H" is outputted into the terminal X2 to detect the distance and thereby the flashing apparatus FL2 for distance detection use is energized (#145). The signal from the timing circuit is inputted to detect whether or not the data of the result of the distance detection has been latched to wait for the data to be latched (#150). When the detection is performed that the data has been latched, the terminal OP1 is turned into "L" to detect the brightness to put the filter into the visible sensitivity use (#155). The analog switches AS1, AS2 are turned off (#160), and the subroutine for taking in the data for the latched distance detection use comes in preparation for the following brightness detection.

The subroutine will be described with reference to FIG. 12. The microcomputer MC sets variables N, N1, N2 into 0, and D0 into 5 (#1000 through 1015). This variable N is outputted into the decoder DE2 shown in FIG. 6 (#1020). The distance data detected by the light measuring circuit selected by the selector SEL which receives the output of the decoder DE2 are converted into a given coded data D1 by the encoder ED, and the coded data are inputted into the microcomputer MC at the step #1025. This data D1 corresponds to the detected distance region, that is either of the regions 1 through 5. For example, the coded data D1 shows 1 if the detected distance region is the region 1, while the data D1 shows 5 if the detected distance region is the region 5.

The nearest distance region among the distance regions detected by each of the light receiving circuits LM1 through LM5 is selected in accordance with the data D1. First, a decision is made as to whether or not the data D0, wherein the data corresponding to the distance region 5 is set, are equal to the input data D1. If they are equal to each other, 1 is added to the variable N1 (#1030, 1035). This variable N1 is provided for deciding if the number of the light measuring circuits which detect if the nearest distance region is single or plural. The data D0 are set in D1 to add 1 to the variable N (#1045, 1065). On the other hand, in the step #1030, the program proceeds to the step #1050 when the set data D0 are not equal to the input data D1 to decide whether or not the input data D1 is in the distance region nearer than the set data D0. The program proceeds to the step #1045 when it is not in the nearer distance region. When it is in the nearer distance region, the variable N1 is set in 1, and the variable N2 is set to the variable N to proceed to #1040 (#1055, 1060). This variable N2 shows either of the light receiving regions ① through ⑨ shown in FIG. 3. In the step #1065, the decision is made whether or not the variable N is 9, i.e., whether or not the distance data of the light-receiving regions①through⑨have been inputted after the addition of 1 to the variable N at the step #1045. If the inputting operation of the distance data has not been finished, the step returns to the step #1020 to repeat the loop. If the inputting operation of the distance data has been finished, the program returns to the original flow of FIG. 11 at the step #1067 to proceed to the next light measuring data subroutine of the step #1070.

The subroutine is shown from the step #1070 of FIG. 12(*b*). In the step #1070, the decision is made as to whether or not the variable N1 is 1, i.e., the number of the light receiving regions in which the nearest distance region is detected is single. If it is single (N1=1), the program proceeds to the spot light measurement subroutine of the step #1075. When the number of the light receiving regions in which the nearest distance region is detected is plural, the program proceeds to the step #1080 to decide whether or not the light receiving region ① of the central portion is included in the plurality of regions in which the nearest distance region is detected. Even when it is included, the program proceeds to the step #1075. When the light receiving region of the central portion is not included at the step #1080, the average light measurement flag AVRE is set at the step #1085. The program proceeds to the average

light measurement subroutine, and returns to the original flow with BV2 (average light measurement value) as the light measurement data BV.

The spot light measurement and average light measurement subroutine among the light measuring data subroutine will be described with reference to FIG. **13**. First, in the spot light measurement subroutine shown in FIG. **13**(*b*), the microcomputer MC outputs the variable N2, showing the number of the light receiving regions, to the decoder DE2 (#**1160**). The decoder DE2 decodes the inputted variable N2, and controls to turn on one of the analog switches ANSW in order to output the analog light measuring signal which corresponds to the brightness of the region related to the variable N2, to the A/D converting circuit A/D. The microcomputer MC outputs the A/D conversion start signal from the terminal OP6 to convert the light measuring signal of this analog form into the digital form at the step #**1165**, and decides with the signal of the terminal OP7 whether or not this A/D conversion has been completed at the step #**1170**. After the completion of the A/D conversion, the A/D completion signal is outputted from the terminal OP6 at the step #**1175** and the digital-converter light measuring data are inputted to the microcomputer MC as the brightness value BV.

The average light measurement subroutine shown in FIG. **13**(*a*) will be described hereinafter. The variables BV2 and I are set to 0 (#**1105**, **1110**) and this variable I is outputted to the decoder DE2. As in the case of the above-described spot light measurement operation, the light measuring output of the analog form showing the brightness of the light receiving region corresponding to this variable I is converted in digital form by the A/D converter A/D to input the light measuring data as BV1 (#**1120** through **1135**). The data BV1 are added to the data BV2 at the step #**1180** and 1 is added to the variable I at the step #**1145**. And it is decided whether or not the variable I has reached 9 (#**1150**). If it reaches 9, it is assumed that the light measuring data showing the brightness has been inputted from all the light-receiving regions ① through ⑨, and the program goes to the next step. If it is not 9, the program returns to the step #**1115** to repeat this loop to perform the data inputting operation. After the inputting operation of all the data is over, the microcomputer MC divides the data BV2, i.e., the light measuring data of all of the respective light-receiving regions, by 9 to obtain the average brightness data at the step #**1155**. It may be modified to obtain the average brightness data by averaging all of the light measuring data, even if a plurality of light receiving regions detect the nearest distance region. The step #**1080** should be omitted for this modification.

Returning to the flow of FIG. **11**, the film-sensitivity data SV from the film sensitivity setting circuit IS are read in A.P.E.X. system at the step #**175** to add the brightness data BV to this value SV to obtain the exposure value EV (#**180**). The limited exposure value (EV) for switching from the natural light photographing mode to the flash photographing mode will be explained. The limited exposure value (EV) is changed in accordance with the detected distance region. In the step #**185**, the decision is made as to whether or not the distance region is region **1**. If it is 1, the program goes to the step #**190** to decide whether or not the exposure value EV is 13.5 or more. If the exposure value EV is less than 13.5, the exposure value EV is fixed to 13.5 (#**235**) to go to the step #**270**. If the distance region is region **2**, the exposure value is secured to 11.5 when the exposure value EV is less than 11.5 at the step #**230**. If the distance region is region **3**, the exposure value EV is secured to 9.5 when the exposure value EV is less than 9.5 at the step #**225**. If the distance region is region **4** or **5**, the exposure value EV is fixed to 8.5 when the exposure value EV is less than 8.5 at the step #**230**. The program moves to the step #**270** respectively to enter into the flash photographing mode (#**195** through **235**).

If the exposure value EV is 13.5 or more when the distance region is region **1**, if the exposure value is 11.5 or more when the distance region is region **2**, if the exposure value EV is 9.5 or more when the distance region is region **3**, and if the exposure value EV is 8.5 or more when the distance region is region **4** or **5**, the program moves to the step #**240** to decide whether or not the average light measurement flag AVRF is set. When this flag AVRF is not set, the program goes to the step #**245** to execute the average light measurement subroutine to obtain the average brightness data BV2 for getting the difference between the obtained spot brightness data BV and it so as to decide whether or not the difference is 2EV or more at the step #**255**. If this difference is 2EV or more, the daylight synchronous flag FILF is set because a primary object is in backlight condition. The program moves to the step #**270** to enter the flash photographing mode (#**250** through **260**).

When the average light measurement flag AVRF is set in the step #**240**, or when the difference between the average brightness data and the spot brightness data value is less than 2EV, the program moves to the step #**265**, and moves to the step #**390** to be described later to calculate the aperture value AV to move to the flow of the shutter release operation.

The flash photography mode from the step #**270** will be described hereinafter. The decision is made as to whether or not the charging operation of the main capacitor of the electronic flashing apparatus FL1 for photographing use has been completed at the step #**270**. If it has been completed, the program moves to the step #**310** to display the completion of the photograph preparation. If the charging operation has not been completed, the decision is made as to whether or not the release button is depressed to the first stroke. When the release button is depressed to the first stroke, it is displayed that the charging operation of the electronic flashing apparatus FL1 is not completed. Then, the removal of the depression of the release button is waited for (#**275**, **280**). After the depression of the release button is removed, the microcomputer MC turns off the transistor Tr1 to cut out the power supply to the control circuit to start the boosting operation of the electronic flashing apparatus FL1 for photographing use (#**285**, **290**). And the timer for battery check use is reset and is started to decide whether or not the charging operation has been completed within ten seconds. When the charging operation has not been completed within ten seconds, the boosting operation is stopped at the step #**320**, the timer for warning display use is reset and is started at the step #**325**, the battery check warning is performed for five minutes at the steps #**330** and **335**. Then, all of the displays are turned off at the step #**340**, and the flags are reset at the step #**345**. Thereafter, the microcomputer MC becomes in halt condition at the step #**350**. If the charging operation is completed within ten seconds, the program moves to the step #**310** to display the completion of the photographing preparation, and moves to the step #**355**.

In the step #355, the aperture value AV1 used in the flash photographing mode is calculated. The distance value DV in the step #355 is the value which becomes 5, 4, . . . 1 in response to the distance regions 1, 2, . . . 5. For example, supposing that the guide number of the electronic flashing apparatus FL1 is 10 with respect to the film sensitivity of ISO 100, and that the distance region detected is the region 2, the distance value DV is 4 and the film sensitivity SV is 5, respectively, if the amount of light emitted by the flashing apparatus FL1. In the case, the calculated aperture value AV1 is 6.5, that is, the F-number of F/9.3. Then, the decision is made as to whether or not this calculated aperture value AV1 is less than 3.5 at the step #357. When it is less than 3.5, it is secured to 3.5 at the step #360 and the program goes to step #362. And the decision is made as to whether or not the daylight synchronous flag FILF is set. When the flag FILF is not set, the aperture value for exposure use is calculated from the exposure value EV fixed by each region to output the data of the aperture value AV1 showing the light emitting timing of the flash photographing operation (#385). When the flag FILF is set, the aperture value AV2 based on the average brightness data BV2 is obtained at the step #370 to compare it with the aperture value AV1 of the flash photographing operation (#375). Here, the decision is made whether or not the exposure amount of the primary object becomes proper in the daylight synchronized flash mode.

Generally, the exposure amount of the primary object becomes proper by the flash light while the background thereof becomes in proper exposure by the natural light, in the daylight synchronized flash mode. In the case where the aperture value is determined for the natural light photographing condition, the aperture value AV1 for flash photographing should be compared with the aperture value AV for discriminating whether the primary object located at the detected distance region becomes in proper exposure by the flash light whose intensity is constant. Since the shutter serving also as an aperture diaphragm is gradually opening, the start of flash light emission can be performed at any timing during the opening. Therefore, if the aperture value AV1 is equal to or greater than the aperture value AV, proper exposure can be reproduced with respect to the primary object. Namely, when the aperture value AV1 for the flash photographing operation is equal to or greater than the aperture value AV for the natural-light photographing operation, the proper daylight synchronized flash photographing is performed. In the daylight synchronized flash mode, the microcomputer MC outputs the data of the aperture value AV1 as the light emitting timing data of the flash apparatus at the step #385 with the aperture value AV2 of the average light measurement as the control aperture value AV at the step #380. When the primary object is not exposed to the proper exposure by the flash photographing operation even in the backlight condition, the control aperture value AV is obtained in accordance with the brightness value in the spot light measurement to perform the natural-light photographing operation only (#390).

At this time, the microcomputer MC decides whether or not the release operation, i.e., the depression of the release button as far as the second stroke is effected at the step #392. When the release operation is not effected, the program moves to the step #395 to decide whether or not the release button is depressed as far as the first stroke. When the release button is in its depressed position, it returns to the step #390 to wait for the release operation. When the release button is not depressed as far as the first stroke, the program moves to the step #450 to be described later.

When the computer decides, at the step #392, that the release operation is affected, the program enters the release control operation to, first, prohibit the interruption to this flow at the step #397, and the microcomputer MC outputs the distance region data to the AF control circuit AFC at the step #400. Then, the microcomputer MC outputs the start signal to start the driving operation of the objective lens. When the objective lens is driven to the given position in accordance with the data, the switch (S5) showing the AF control completion is turned on, so that the microcomputer MC detects the AF control completion (#410). Then, the date of the control aperture value AV is outputted to the AE control circuit AE, and the AE control start signal is outputted (#415, #420) to the AE control circuit AE. When the light emitting timing data of the flash during the flash photographing operation is sent from the microcomputer MC in the AE control circuit AE, a flash signal is outputted to the electronic flashing apparatus FL1 for photographing use at the given timing in accordance with the data.

When the exposure control is performed in the AE control circuit and the switch S3 showing the exposure completion is turned on, the motor is driven to wind up one frame of the film. When the film is wound up by one frame, the motor is stopped (#425 through 440). The microcomputer MC permits the interruption to this flow at the step #445, and turns off the control circuit at the step #450. Then, the microcomputer MC starts the boosting operation of the electronic flashing apparatuses FL1, FL2 in preparation for the next photographing operation, and the timer for the boosting control use is reset and started at the step #470. The respective boosting operations are stopped when the charging operation is completed in five seconds or five seconds pass, and the display is turned off thereafter. Then, all the flags are reset and the microcomputer MC is in halt condition.

Though the first embodiment of the present invention is described hereinabove in such a manner that, the nearest distance region among the plurality of detected distance regions is provided as the distance region for the focusing operation, in the second embodiment described hereinafter, each light-receiving region is weighted when the distance region is obtained, and the weighted value is added for each distance region to detect which distance region is the most frequent. And the interval between the most frequent distance region and the nearest distance region, for example, in the case of the distance region 1 and the distance region 3 the intermediate distance region, that is, the distance region 2 in the above-described example, is applied as the distance for focusing operation. In the intervals except for it, the nearest distance is provided as the distance for the focusing operation. The brightness detection and the backlight detection are performed as in the first embodiment.

The flow chart for the operation of the microcomputer MC which executes the second embodiment is shown in FIG. 15, FIG. 16. This flow chart shows the modified example of the AF data subroutine shown in FIG. 12(*a*), and the light measurement data subroutine

shown in FIG. 12(*b*) with the entire flow being completely the same as FIG. 11, FIG. 13 and FIG. 14.

The flow chart will be described hereinafter. First, the microcomputer MC sets variables N0 through N4, N10 through N14, and N to 0 at all (#1500 through 1510). The variable N is outputted to the decoder DE2, and the data D1 of the distance region coming from the given light receiving region is inputted (#1515, 1520). Then, the microcomputer MC operates the weighting operation of 3, 2, 1 respectively to the light receiving regions 1, 2 through 5, 6 through 9 with respect to each light-receiving region. When the light-receiving region is 1 (N=0), the α as the weighting data is assumed as 3 (#1535) with this input data D1 being as the data D2 (#1530). If the light-receiving region is 2 through 5 likewise, the α is set to 2. If the light-receiving region is 6 through 9, the α is set to 1 (#1540 through 1550).

Then, the microcomputer MC adds the sum of the number of light receiving regions belonging to each distance region and the weighting data. When the distance region of the light receiving region is 1, 2, . . . 5, the weighting data are added respectively to N0, N1, . . . N4, and the number of the light-receiving regions are added to N10, N11 . . . N14 (#1555 through 1640). The decision is made as to whether or not N has become 9 through addition of 1 to the N. If the N has not become 9, the program returns to the step #1515 to repeat this loop until the N becomes 9. If the N is 9, the program moves to the step #1655 (#1645, #1650), considering that all the distance data have been inputted, and the microcomputer MC obtains the distance region including the light receiving region of the most frequent. In the step #1655, the value of the N0 showing the addition value of the weighted data of the distance region 1 is shifted to the N5, then the data showing that the distance region is 1 is inputted into the variable D3 and the variable I is set to 1 (#1660, 1665). Then, the weighted data N5 established is compared with the NI (I is the established value), for example, the addition value of the weighted value corresponding to the distance region 2 if I=1. If the NI is larger, the value of the N5 is changed to the value NI and the distance region at this time is inputted into D3 (#1670 through 1680).

Even when the NI is equal to or less than N5, the program goes to the next step #1685 to add 1 to the I. And the decision is made whether or not the I has become 5. If the I has not become 5, the program returns to the step #1670. If the I becomes 5, the microcomputer MC obtains the nearest distance region and the distance between this region and the distance region of the most frequent value to obtain the distance region for the focusing operation. The microcomputer MC obtains the distance region where the value of the weighted data is not 0 in order from the distance region 1 to the distance region 4. The data showing this distance region at a time when the value of the weighted data not been 0 is inputted into D0 to input the number of the light receiving regions in that region into N7 (#1695 through 1760).

When the nearest distance region is one of the regions 1 through 3, the decision is made whether or not the distance between the nearest distance region and the distance region of the most frequent value is only one region. When the distance is one region, the data in the middle region is inputted into the D0 (#1765, #1770), and the program proceeds to the step #1775 of the light measurement data subroutine. When the nearest distance region is the region 4 or 5, the distance between the nearest distance region and the distance region of the the most frequent value does not become 1, the program moves to the step #1775 as soon as the inputting operation to D0, N7 is completed. In the light measurement data subroutine as compared with FIG. 12, the processed content of the microcomputer MC is completely the same except for the N1 being changed into N7.

The present invention is not restricted to this embodiment described hereinabove. The following modified embodiments may be applied.

(1) In the first and second embodiments, the brightness data obtained by the average light measurement of all regions are used for controlling the exposure amount, when the number of light receiving regions in which the nearest distance region is detected or when the central region is not included for detecting the distance region for the focusing operation. However, the exposure amount may be controlled in accordance with the average of the brightness data in all the light receiving regions showing the nearest distance region may be used. Thus, the number of the light receiving region in which the nearest distance region is detected is required to be memorized. The brightness data of the light receiving region are required to be inputted in accordance with this number to provided this average. Also, when the number of the light receiving regions in which the nearest distance region is detected are plural, the average light measurement value of all the regions may be used.

(2) Though the electronic flashing apparatus which is disposed separately from the electronic flashing apparatus for the photographing use is provided as the light emitting means for the distance detection means of the present embodiment, this may use the electronic flashing apparatus for photographing use in common. In the case of the distance detection, the infrared transmission filter of the particular wavelength is required to be provided on the entire face of the light emitting portion. In the case of the photographing operation, such mechanical construction as to remove this filter is required to be provided. Also, the light emitting means may be such a plurality of LEDs as shown in Japanese Patent Application Laid-open Publication Tokkaisho No. 59-146032. Also, one LED may be required with being sequentially scanned.

(3) If the primary object does not become proper with the flashing photographing operation only in the embodiment when the backlight light condition is detected, the photographing operation is switched from the flash photographing mode to the natural-light photographing mode. In addition, in the natural-light photographing operation, the light measuring operation is switched from the average light measurement to the spot one. However, since the film has a latitude, there is no necessity to provide the most proper exposure amount of the primary object. Concretely, if the exposure amount of the primary object is low by 1.5 steps than the most proper exposure amount, the image of the primary object can be reproduced sufficiently by the latitude of the film. Thus, it may be permitted that the exposure amount of the primary object by the flash light is lower by 1.5 steps than the calculated proper exposure amount in daylight synchronized flash photographing.

(4) In addition, the (1) through (3) of the above-described examples may be properly combined with the first, and second embodiments.

(5) Though the distance from the camera to the object is detected with a plurality of regions in the object area to be photographed in the embodiments, the defocus amount of the objective lens may be detected with the plurality of regions.

(6) Since the distance detection and the brightness detection use the common light measuring circuits LM1 through LM9 in the embodiments, the distance detection regions are completely similar to the brightness detection regions, respectively. However, both of the regions may be deviated from each other, or the size of both regions may be different from each other.

Although the present invention has been fully described by way of example with reference to the accompanying drawings, it is to be noted here that various changes and modifications will be apparent to those skilled in the art. Therefore, unless otherwise such changes and modifications depart from the scope of the present invention, they should be constructed as included therein.

What is claimed is:

1. Control device for use in a camera having an objective lens, comprising:
- means for producing a plurality of distance signals on a plurality of first regions of an object area to be photographed;
- means for determining a distance on the basis of the plurality of distance signals to produce a determined distance signal for focusing the objective lens;
- means for driving the objective lens in accordance with the determined distance signal;
- means for measuring a plurality of brightnesses of second regions of the object area to produce a plurality of brightness signals each corresponding to the measured brightness respectively, each of the second regions being substantially similar to each of the first regions, respectively;
- means for counting the number of the distance signals representing an identical distance to a distance represented by the determined distance signal;
- means for discriminating whether the number counted by the counting means is single or plural;
- means for determining a light measuring value on the basis of a brightness signal of a single second region corresponding to a single first region whose corresponding distance signal represents an identical distance to a distance represented by the determined distance signal when the discriminated number is single, while determining a light measuring value which corresponds to a brightness of almost the entire object area when the discriminated number is plural; and,
- means for calculating exposure value of the camera in accordance with the light measuring value.

2. Control device as claimed in claim 1, wherein the light measuring value determining means includes means for averging the plurality of brightness signals to determine a light measuring value, when the discriminated number is plural.

3. Control device as claimed in claim 1, wherein the distance signals producing means includes a plurality of light receiving elements each corresponding to each of first regions, and the brightnesses measuring means includes means for measuring a plurality of brighnesses on the basis of output signals of the light receiving elements.

4. Control device for use in a camera having an objective lens, comprising:
- means for producing a plurality of distance signals on a plurality of first regions of an object area to be photographed;
- means for determining a distance on the basis of the plurality of distance signals to produce a determined distance signal for focusing the objective lens;
- means for driving the objective lens in accordance with the determined distance signal;
- means for measuring a plurality of brightnesses of second regions of the object area to produce a plurality of brightness signals each corresponding to the measured brightnesses respectively, each of the second regions being substantially similar to each of the first regions, respectively;
- means for counting the number of the distance signals representing an identical distance to a distance represented by the determined distance signal;
- means for discriminating whether the number counted by the counting means is single or plural;
- means for determining a light measuring value on the basis of a single brightness signal of a single second region corresponding to a single first region whose corresponding distance signal represents an identical distance to a distance represented by the determined distance signal when the discriminated number is single, while determining the light measuring value on the basis of a plurality of brightness signals of at least a plurality of second regions corresponding to a plurality of first regions whose corresponding distance signals represent an identical distance to a distance represented by the determined distance signal when the discriminated number is plural; and,
- means for calculating exposure value of a camera in accordance with the light measuring value.

5. Control device as claimed in claim 4, wherein the light measuring value determining means includes means for determining a light measuring value which corresponds to a brightness of almost the entire object area, when the discriminated number is plural.

6. Control device as claimed in claim 5, wherein the light measuring value determining means includes means for averaging the plurality of brightness signals to determine a light measuring value, when the discriminated number is plural.

7. Control device as claimed in claim 4, wherein the distance signals producing means includes a plurality of light receiving elements each corresponding to each of first regions, and the brightnesses measuring means includes means for measuring a plurality of brightnesses on the basis of output signals of the light receiving elements.

8. Control device for use in a camera having an objective lens, comprising:
- means for producing a plurality of distance signals on a plurality of first regions of an object area to be photographed, the plurality of first regions including a central region of the object area and the plurality of distance signals corresponding to respective ones of the first regions;
- means for determining a distance on the basis of a selected group of the plurality of distance signals to produce a determined distance signal for focusing the objective lens;

means for driving the objective lens in accordance with the predetermined distance signal;

means for measuring a plurality of brightnesses of second regions of the object area to produce a plurality of brightness signals each corresponding to the measured brightnesses respectively, each of the second regions being substantially similar to each of the first regions, respectively;

means for discriminating whether the selected group includes the distance signal corresponding to the central region;

means for determining a light measuring value by a first calculation when the distance signal corresponding to the central region is discriminated to be included in the selected group, while determiningthe light measuring value by a second calculation different from the first calculation when the distance signal corresponding to the central region is discriminated not to be included in the selected group; and

means for calculating exposure value of the camera in accordance with the light measuring value.

9. Control device as claimed in claim **8**, wherein the light measuring value determining means includes means for averaging the brightness signals of the second regions corresponding to the first regions whose corresponding distance signals are included in the selected group used for producing the determined distance signal when the distance signal corresponding to the central region is discriminated not to be included in the selected group.

10. Control device as claimed in claim **8**, wherein the light measuring value determining means includes means for determining the light measuring value on the basis of all of the plurality of brightness signals when the distance signal corresponding to the central region is discriminated not to be included in the selected group.

11. Control device as claimed in claim **10**, wherein the light measuring value determining means includes means for averaging the plurality of brightness signals to determine a light measuring value.

12. Control device as claimed in claim **8**, wherein the distance signals producing means includes a plurality of light receiving elements each corresponding to each of first regions, and the brightnesses measuring means includes means for measuring a plurality of brightnesses on the basis of output signals of the light receiving elements.

13. Control device for use in a camera having an objective lens, comprising:

means for producing a plurality of distance signals necessary for focusing the objective lens on a plurality of first regions of an object area to be photographed;

means for determining a distance on the basis of the plurality of distance signals to produce a determined distance signal for focusing the objective lens;

means for driving the objective lens in accordance with the determined distance signal;

means for measuring a plurality of brightnesses of second regions of the object area to produce a plurality of brightness signals each corresponding to the measured brightnesses respectively, each of the second regions being substantially similar to each of the first regions, respectively;

means for counting the number of the distance signals representing an identical distance to a distance represented by the determined distance signal;

means for discriminating whether the number counted by the counting means is single or not;

means for determining a first light measuring value on the basis of the brightness signals of the second regions corresponding to the first regions whose corresponding distance signals represent an identical distance to a distance represented by the determined distance signal;

means for determining a second light measuring value corresponding to a brightness of almost the entire object area;

means for detecting whether a primary object is in backlight condition or not in accordance with the first and second light measuring signals; and

means for controlling exposure of the camera in accordance with the result of the detecting means when the discriminated number is single, while controlling the exposure independently of the result of the detecting means when the discriminated number is plural.

14. Control device as claimed in claim **13**, wherein the second light measuring value determining means includes means for determining the second light measuring value on the basis of the brightness signals of at least the second regions corresponding to the first regions whose corresponding distance signals do not represent an identical distance to a distance represented by the determined distance signal.

15. Control device as claimed in claim **13**, wherein the second light measuring value determining means includes means for determining the second light measuring value on the basis of all of the brightness signals of the second regions.

16. Control device as claimed in claim **13**, further comprising means for interruping operation of the detecting means when the discriminating number is plural.

17. Control device as claimed in claim **13**, further comprising means for illuminating the object area for photographing, and wherein the exposure controlling means includes means for controlling the illuminating means to energize the illuminating means for flash photography when the discriminated number is single, while de-energizing the illuminating means when the discriminated number is plural.

18. Control device as claimed in claim **13**, wherein the distance signals producing means includes a plurality of light receiving elements each corresponding to each of first regions, and the brightnesses measuring means includes means for measuring a plurality of brightnesses on the basis of output signals of the light receiving elements.

19. Control device for use in a camera having an objective lens, comprising:

means for producing a plurality of distance signals on a plurality of first regions of an object area to be photographed, the plurality of first regions including a central region of the object area and the plurality of distance signals corresponding to respective ones of the first regions;

means for determining a distance on the basis of a selected group of the plurality of distance signals to produce a determined distance signal for focusing the objective lens;

means for driving the objective lens in accordance with the determined distance signal;

means for measuring a plurality of brightnesses of second regions of the object area to produce a plurality of brightness signals each corresponding to the measured brightnesses respectively, each of the second regions being substantially similar to each of the first regions, respectively;

means for discriminating whether the selected group includes the distance signal corresponding to the central region;

means for determining a first light measuring value on the basis of the brightness signals of the second regions corresponding to the first regions whose corresponding distance signals are included in the selected group used for producing the determined distance signal;

means for determining a second light measuring value corresponding to a brightness of substantially the entire object area;

means for detecting whether a primary object to be photographed is in backlight condition or not in accordance with the first and second light measuring signals; and

means for controlling exposure of the camera in accordance with a result of the detecting means when the distance signal corresponding to the central region is discriminated to be included in the selected group, while controlling the exposure independently of the result of the detecting means when the distance signal corresponding to the central region is discriminated not to be included in the selected group.

20. Control device as claimed in claim **19**, wherein the second light measuring value determining means determines the second light measuring value on the basis of the brightness signals of at least the second regions corresponding to the first regions whose corresponding distance signals are not used to produce the determined distance signal.

21. Control as claimed in claim **20**, wherein the second light measuring value determining means determines the second light measuring value on the basis of all of the brightness signals of the second regions.

22. Control device as claimed in claim **20**, further comprising means for counting a number of the distance signals in the selected group, means for discriminating whether the number counted by the counting means is single or plural; and means for interrupting operation of the detecting means when the discriminated number is plural.

23. Control device as claimed in claim **20**, wherein the exposure controlling means includes:

means for calculating a first aperture value for a normal photographing on the basis of the second light measuring value,

means for calculating a second aperture value for a flash photographing on the basis of the determined distance signal,

means for comparing the first aperture value with the second aperture value,

means for controlling exposure operation of the camera on the basis of the first light measuring value when the second aperture value is less than the first aperture value, while controlling the exposure operation on the basis of the second light measuring value when the first aperture value is less than the second aperture value,

means for illuminating the object area in flash photographing, and

means for energizing the illuminating means when the first aperture value is less than the second aperture value.

24. Control device as claimed in claim **20**, wherein the distance signals producing means includes a plurality of light receiving elements each corresponding to each of first regions, and the brightnesses measuring means includes means for measuring a plurality of brightnesses on the basis of output signals of the light receiving elements.

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United States Patent [19]

Akashi

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[54] **APPARATUS FOR DETECTING FOCUSING STATE OF OBJECTIVE LENS**

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[57] **ABSTRACT**

Light intensity distributions of object images whose relative positions vary with a focusing state of an objective lens are formed by a lens assembly based on light fluxes transmitted through the objective lens, and the distributions are sensed by sensing devices having a plurality of photo-sensors to produce first and second signals for the respective light intensity distributions. The first and second signals are processed by relatively displacing the first and second signals under a first relationship and by relatively displacing the first and second signals under a second relationship different from the first relationship to determine a relative positional relationship of the light intensity distributions. If there is identical or essentially identical portion is found in the processing of the first signal and the second signal, the previous processing result is utilized to shorten the processing time.

5 Claims, 6 Drawing Sheets

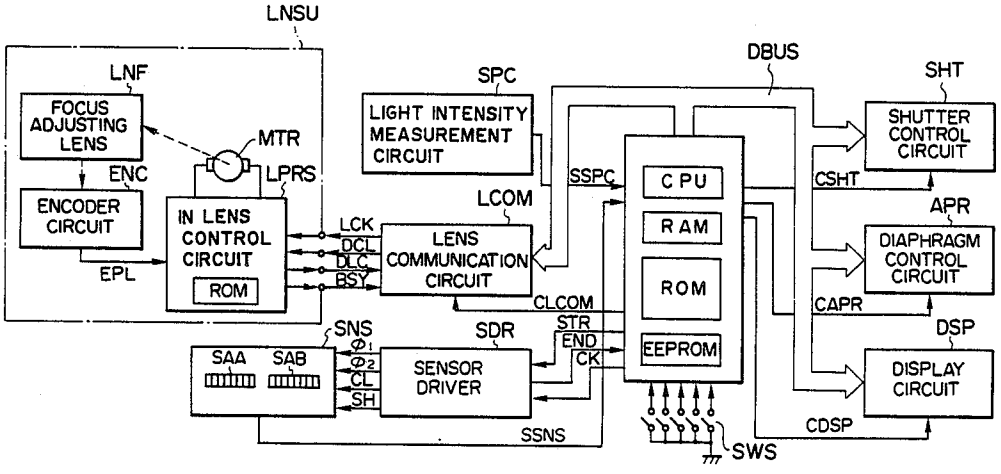


FIG. 1

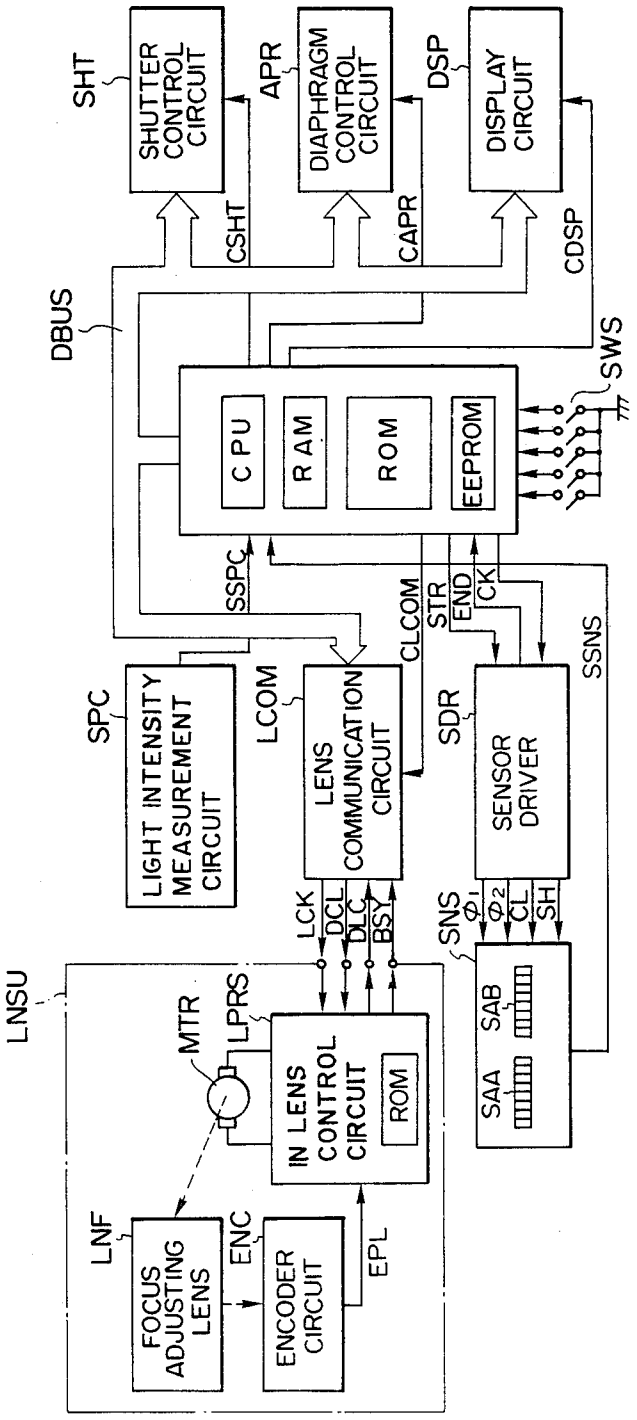

SHT
SHUTTER CONTROL CIRCUIT
APR
DIAPHRAGM CONTROL CIRCUIT
DSP
DISPLAY CIRCUIT
CSHT
CAPR
CDSP
DBUS
SWS
CPU
RAM
ROM
EEPROM
SSPC
CLCOM
STR
END
CK
SSNS
SPC
LIGHT INTENSITY MEASUREMENT CIRCUIT
LCOM
LENS COMMUNICATION CIRCUIT
SDR
SENSOR DRIVER
LCK
DCL
DLC
BSY
SNS
ϕ_1
ϕ_2
CL
SH
LNSU
MTR
LPRS
IN LENS CONTROL CIRCUIT
ROM
SAB
SAA
LNF
FOCUS ADJUSTING LENS
ENC
ENCODER CIRCUIT
EPL

FIG. 2

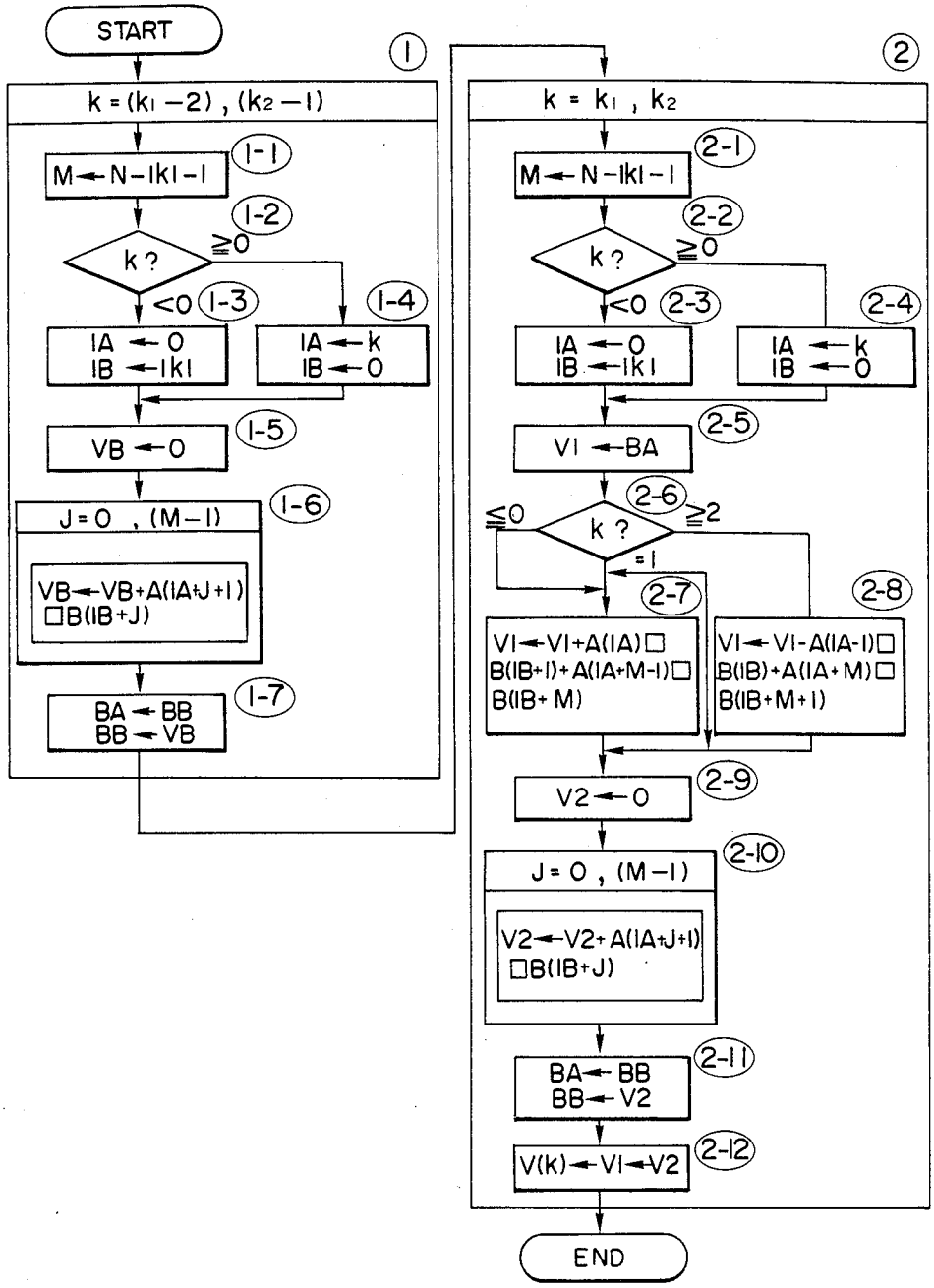

START
①
k = (k1 −2) , (k2 −1)
1-1
M ← N−|k|−1
1-2
k ?
≧0
<0
1-3
IA ← 0
IB ← |k|
1-4
IA ← k
IB ← 0
1-5
VB ← 0
1-6
J = 0 , (M−1)
VB ← VB+A(IA+J+1) □B(IB+J)
1-7
BA ← BB
BB ← VB
②
k = k1 , k2
2-1
M ← N−|k|−1
2-2
k ?
≧0
<0
2-3
IA ← 0
IB ← |k|
2-4
IA ← k
IB ← 0
2-5
VI ← BA
2-6
≦0
k ?
≧2
=1
2-7
VI ← VI+A(IA) □B(IB+1)+A(IA+M-1) □B(IB+M)
2-8
VI ← VI-A(IA-1) □B(IB)+A(IA+M) □B(IB+M+1)
2-9
V2 ← 0
2-10
J = 0 , (M−1)
V2 ← V2+A(IA+J+1) □B(IB+J)
2-11
BA ← BB
BB ← V2
2-12
V(k) ← VI ← V2
END

FIG. 3

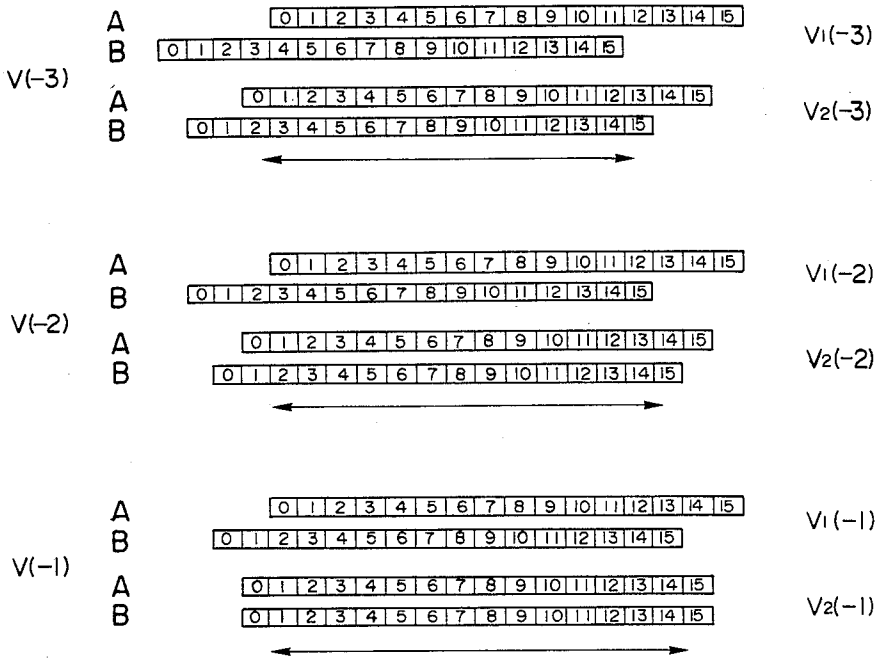

V(-3)
A
B
A
B
V1(-3)
V2(-3)
V(-2)
V1(-2)
V2(-2)
V(-1)
V1(-1)
V2(-1)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

FIG. 4

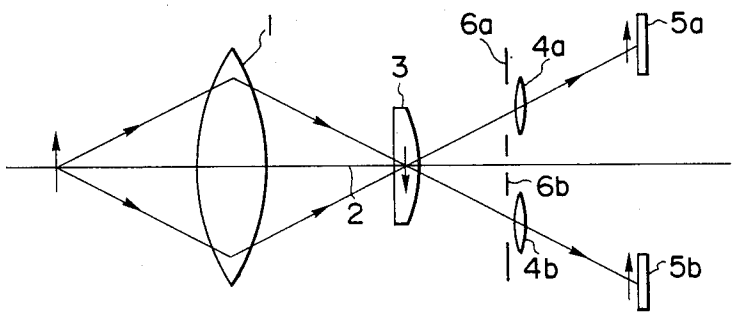

1
2
3
6a
4a
5a
6b
4b
5b

FIG.5A

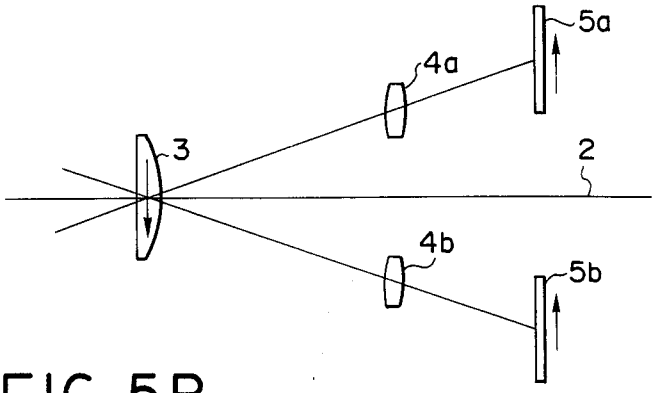


FIG.5B

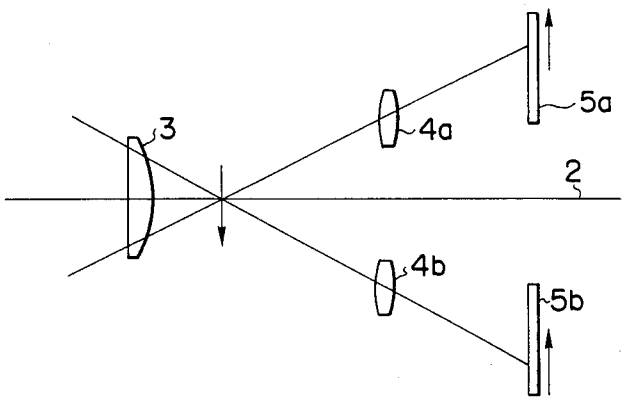


FIG.5C

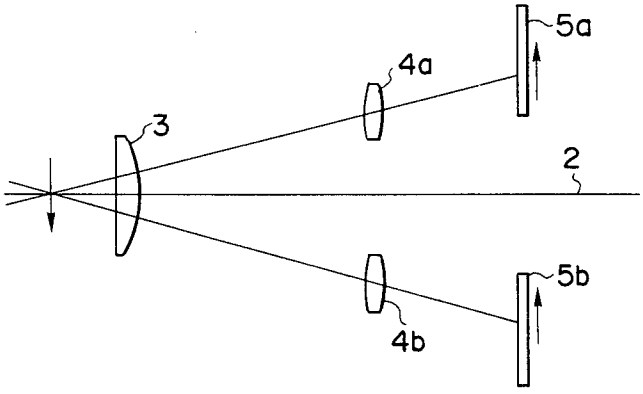


FIG. 6

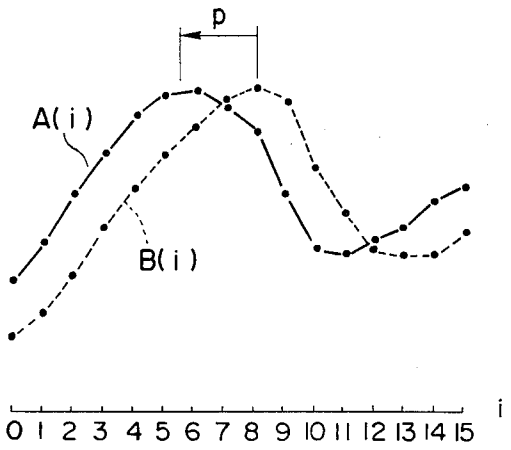


FIG. 7

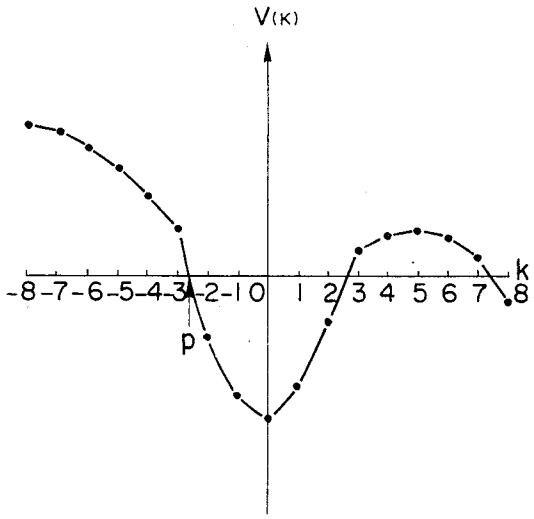
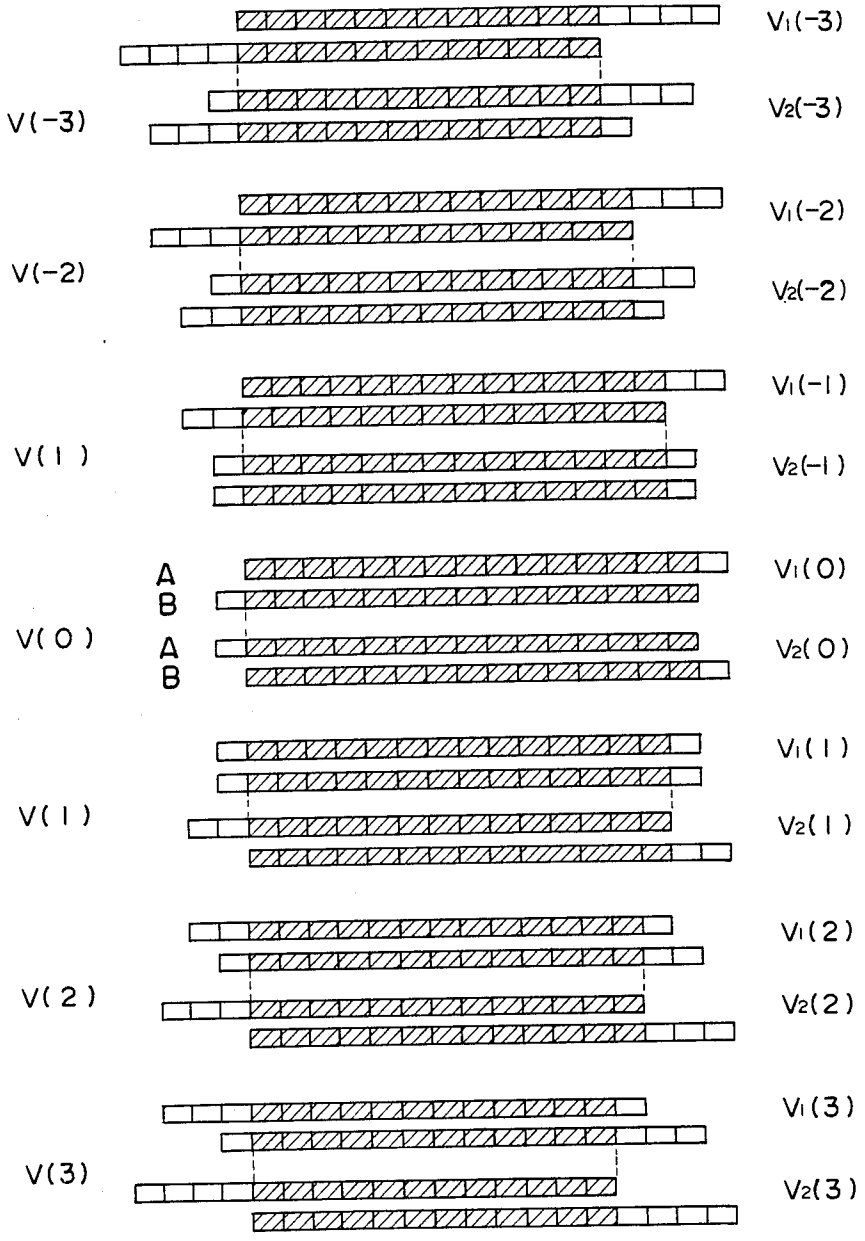


FIG. 8


V(-3)
V1(-3)
V2(-3)
V(-2)
V1(-2)
V2(-2)
V(1)
V1(-1)
V2(-1)
V(0)
A
B
A
B
V1(0)
V2(0)
V(1)
V1(1)
V2(1)
V(2)
V1(2)
V2(2)
V(3)
V1(3)
V2(3)

APPARATUS FOR DETECTING FOCUSING STATE OF OBJECTIVE LENS

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to an improvement in a focusing state detection system which detects a focusing state by a relative positional relationship of two images of an object.

2. Related Background Art

In a prior art focus state detection apparatus for a camera, an exit pupil of an imaging lens is divided into two pupil areas and relative positional displacement of two images formed by light fluxes transmitted through the pupil areas are observed to determine an in-focus state. For example, Japanese Laid-open Patent Application Nos. 118019/1980 and 155331/1985 disclose a secondary focusing system in which a spatial image formed on a predetermined focus plane (corresponding to a film plane) by two secondary focusing optical systems is guided to two sensor planes so that relative positional displacement of the two images is detected.

The secondary focusing type focusing state detection apparatus is shown in FIG. 4. A field lens 3 is arranged coaxially with an optical axis 2 of an imaging lens 1 whose focusing state is to be detected. Two secondary focusing lenses 4*a* and 4*b* are arranged behind the field lens 3 symmetrically with respect to the optical axis 2. Photo-electric conversion element arrays 5*a* and 5*b* are arranged behind the lenses 4*a* and 4*b*. Diaphragms 6*a* and 6*b* are arranged in the vicinity of the secondary focusing lenses 4*a* and 4*b*. The field lens 3 essentially focuses an exit pupil of the imaging lens 1 onto pupil planes of the two secondary focusing lenses 4*a* and 4*b*. As a result, light fluxes applied to the secondary focusing lenses 4*a* and 4*b* correspond to those light fluxes which are emitted from non-overlapping equi-space areas on the exit pupil plane of the imaging lens 1, corresponding to the secondary focusing lenses 4*a* and 4*b*. When a spatial image formed in a vicinity of the field lens 3 is refocused on the planes of the photo-electric conversion element arrays 5*a* and 5*b* by the secondary focusing lenses 4*a* and 4*b*, the positions of the two images on the photo-electric conversion element arrays 5*a* and 5*b* change in accordance with the displacement of the spatial image along the optical axis. FIG. 5 shows this. In FIG. 5A which shows an in-focus state, the two images are positioned at the centers of the photo-electric conversion element arrays 5*a* and 5*b*, in FIG. 5B which shows a near-focus state, the two images are moved away from the optical axis 2, and in FIG. 5C which shows a far-focus state, the two images are moved toward the optical axis 2. This image intensity distribution is photo-electrically converted and the converted electrical signal is processed to detect a relative positional deviation of the two images. In this manner, the focus state of the imaging lens 1 can be detected.

Methods for processing the photo-electrically converted signal from the photo-electric conversion element arrays 5*a* and 5*b* are disclosed in Japanese Laid-open Patent Application No. 142306/1983 (U.S. Pat. No. 4,559,446) and U.S. Pat. No. 4,333,007. Specifically, the following formula is operated for $k_1 \leqq k \leqq k_2$ (for example, $k_1 = -N/2$, $k_2 = N/2$).

$$V(k) = \sum_{i=0}^{M-1} A(i) \square B(i + |K| + 1) - \sum_{i=0}^{M-1} A(i+1) \square B(i + |k|) \quad (k < 0)$$

$$= \sum_{i=0}^{M-1} A(i + k) \square B(i+1) - \sum_{i=0}^{M-1} A(i + k + 1) \square B(i) \quad (k \geqq 0)$$

$$= V_1(k) - V_2(k) \tag{1}$$

where N is the number of photo-electric conversion elements of the photo-electric conversion element array 5*a* or 5*b*, A(i) and B(i) are image signals from the i-th elements of the photo-electric conversion element arrays 5*a* and 5*b*, and M is the number of pixels processed ($M = N - |k| - 1$). $A(i) \square B(j)$ is an operator for A(i) and B(j). For example,

$$A(i) \square B(j) = |A(i) - B(j)| \tag{2}$$

$$A(i) \square B(j) = |A(i) - B(j)|^n \tag{3}$$

$$A(i) \square B(j) = \max[A(i), B(j)] \tag{4}$$

$$A(i) \square B(j) = \min[A(i), B(j)] \tag{5}$$

The formula (2) represents an absolute value of a difference between A(i) and B(i), the formula (3) represents accumulated product, the formula (4) represents a larger one of A(i) and B(j), and the formula (5) represents a smaller one. By the above definition, $V_1(k)$ and $V_2(k)$ can be considered as correlation amounts in a broad sense. From the formula (1), $V_1(k)$ represents the correlation amount at a displacement $(k-1)$ and $V_2(k)$ represents the correlation amount at a displacement $(k+1)$. Accordingly, an evaluation amount V(k) which is the difference between $V_1(k)$ and $V_2(k)$ represents a change of correlation amount of the image signals A(i) and B(i) at a relative displacement k. Since a change is zero at the peak of the correlation amount, it is assumed that the peak of the correlation amount exists in a section [k, k+1] represented by

$$V(k) \cdot V(k+1) < 0 \tag{6}$$

and V(k) and V(k+1) are interpolated to detect the deviations of the image signals A(i) and B(i). FIG. 6 shows the image signals A(i) and B(i) for the two images formed when the number of photo-electric elements is 16 (N=16). There is a deviation of P. FIG. 7 shows the evaluation amount V(k) of the formula (2) when the relative displacement k is changed within a range of $-N/2 \leqq k \leqq N/2$. As described above, V(k) and V(k+1) which meet $V(k) \cdot V(k+1) < 0$ are linearly interporated to detect the deviation P. FIG. 8 shows a relationship between the image signals A(i) and B(i) when the evaluation amount V(k) is calculated while the relative displacement k changes in a range of $-3 \leqq k \leqq 3$. Hatched areas show the photo-electric conversion elements which are subject of the correlation.

Because the operation of the evaluation amount V(k) is done by correlation, the number of steps of operation increases as a function of N^2, where N is the number of photo-electric conversion elements. As a result, as the number N increases, the correlation operation time increases and the focus state detection time increases.

SUMMARY OF THE INVENTION

It is an object of the present invention to reduce a processing time so that a focusing state detection time is significantly shortened.

It is another object of the present invention to determine a first correlation amount for each relative displacement by utilizing a second correlation amount previously determined for other relative displacement so that common portions of correlation processing may be omitted.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows a block diagram of one embodiment of a focusing state detection apparatus of a camera in accordance with the present invention,

FIG. 2 shows a flow chart of an embodiment of the present invention,

FIG. 3 illustrates a processing method,

FIG. 4 shows an arrangement of an optical system of a conventional secondary focusing type focusing state detection apparatus,

FIGS. 5A, 5B and 5C show relationships between a focusing state in the secondary focusing system and an image deviation,

FIG. 6 shows image signals produced by two sensor arrays in the secondary focusing system,

FIG. 7 shows a change of evaluation amount in the secondary focusing system, and

FIG. 8 shows a relationship between two images in focusing state detection processing in the secondary focusing system.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

In a process of calculating $V(k)=V_1(k)-V_2(k)$ for each relative displacement k, the processing of $V_1(k)$, for example, may utilize $V_2(k-2)$ which has been processed for the relative displacement $(k-2)$ in order to shorten the processing time for the evaluation amount V(k). This is explained with reference to FIG. 8. The correlation processing of $V_1(-1)$ for determining the evaluation amount $V(-1)$ is almost identical to the correlation processing of $V_2(-3)$ for determining the evaluation amount $V(-3)$, and the correlation processing of $V_1(1)$ for determining the evaluation amount V(1) is identical to the correlation processing of $V_2(-1)$ for determining the evaluation amount $V(-1)$. In this manner, the processing of $V_1(k)$ is identical or almost identical to the correlation processing of $V_2(k-2)$ which has been done two pixel displacements before. Thus, the identical portions are not processed again but the previous results are utilized. This is more fully explained with reference to FIG. 3. As shown,

$$V_2(-3) = \sum_{i=0}^{11} A(i+1)\square B(i+3)$$
$$= A(1)\square B(3) + A(2)\square B(4) + \ldots + A(12)\square B(14)$$

Because $V(-1) = V_1(-1) - V_2(-1)$,

then

-continued

$$V_1(-1) = \sum_{i=0}^{13} A(i)\square B(i+2)$$
$$= A(0)\square B(2) + A(1)\square B(1) + \ldots + A(13)\square B(15)$$
$$= A(0)\square B(2) + V_2(-3) + A(13)\square B(15)$$

Accordingly, the correlation amount $V_1(-1)$ is a sum of the correlation amount $V_2(-3)$ and A(0)□B(2) and A(13)□B(15). Thus, the processing of the correlation amount $V_1(k)$ is attained by adding only two terms to the correlation amount $V_2(k-2)$, and the processing of the evaluation amount V(k) can be carried out almost in a time necessary to calculate the correlation amount $V_2(k)$. When the evaluation amount V(k) is to be calculated for k which is within a range of $k_1 \leqq k \leqq k_2$, the correlation amounts $V_2(k_1-2)$ and $V_2(k_1-1)$ for the relative displacements (k_1-2) and (k_1-1) are previously processed. Thus, the evaluation amount V(k) can be calculated in essentially one half the number of steps.

The above processing is equivalent to calculating and storing $V_1(k)$ for k which is within the range of $k_1 \leqq k \leqq k_2$, but the latter is disadvantageous in cost and circuit configuration. In the former method, it is necessary to store only V_2 which is two pixel displacements before and hence no large capacity memory is required to attain the shortening of the processing time.

A method for detecting a deviation of two images by using the above processing method is explained with reference to a flow chart of FIG. 2.

In a step 1, the correlation amounts V_2 for the relative displacements (k_1-2) and (k_1-1) are calculated. Loop calculation is carried out in a block over the relative displacement (k_1-2) to (k_1-1).

(Step 1-1) Determine the number M of pixels to be processed (corresponding to the hatched area in FIG. 8) based on the relative displacement k.

(Step 1-2) Check a sign of the relative displacement k.

(Step 1-3) If $k<0$, set $iA=0$, $iB=|k|$, where iA and iB are processing start addresses for images A and B, as shown in the formula (1). Namely, the image B is displaced.

(Step 1-4) If $k \geqq 0$, set $iA=|k|$, $iB=0$. In this case, the image A is displaced.

(Step 1-5) Set a process variable VB to "0".

(Step 1-6) For a processing relative address J which is within a range of 0 to (M−1), execute

$$VB \leftarrow VB + A(iA+J+1)\square B(iB+J)$$

(Step 1-7) At this point, the processing variable VB is equal to $V_2(k)$. A content of a work area BB which contains the process result before one pixel displacement is transferred to a work area BA which contains the process result before two pixel displacement, and the processing variable VB is transferred to the work area BB.

At the end of the step 1, the work area BA contains the correlation amount $V_2(k_1-2)$ and the work area BB contains the correlation amount $V_2(k_1-1)$.

In a step 2, the evaluation amount V(k) is calculated for the relative displacement k $(k_1 \leqq k \leqq k_2)$.

(Step 2-1) to (Step 2-4) Same as the Step 1-1 to Step 1-2.

(Step 2-5) The pre-processed content of the work area BA is transferred to the processing variable V_1.

The correlation amount V_2 for the relative displacement (k−2) has been stored in the work area BA.

(Step 2-6) Check the relative displacement k. If k=1, it means that the correlation amount V_1 has already been determined.

(Step 2-7) If k≦0, add A(iA)□B(iB+1) and A(iA+M−1)□B(iB+M) to the processing variable V1 to determine the correlation amount $V_1(k)$ for the relative displacement k.

(Step 2-8) If k≧2, subtract A(iA−1)□B(iB) and A(iA+M)□B(iB+M+1) from the processing variable V1, as opposed to the step 2-7, to determine the correlation amount $V_1(k)$ for the relative displacement k.

(Step 2-10) For the processing relative address J (0≦J≦M−1), execute

V2←V2+A(iA+J+1)□B(iB+J)

(Step 2-11) At this point, the processing variable V2 is equal to $V_2(k)$. The content of the work area BB is transferred to the work area BA, and the processing variable V2 is transferred to the work area BB. Thus, the work area BA contains the correlation amount $V_2(k-2)$ and the work area BB contains the correlation amount $V_2(k-1)$, for the next relative displacement k.

In this manner, the processing time can be reduced to substantially one half of the processing time required when the formula (1) is processed for each relative displacement k. The deviation P of the two images can be determined based on the evaluation amount V(k).

FIG. 1 shows a block diagram of an embodiment of a focusing state detection apparatus for a camera in accordance with the present invention. PRS denotes a control circuit of the camera which proceeds the correlation processing in accordance with the procedure shown in FIG. 2 to detect the deviation P of a pair of light intensity distributions of object images, that is, the focusing state in order to control the focusing of the imaging lens. It may be a one-chip microcomputer which contains CPU, RAM, ROM, EEPROM (electrically erasable programmable ROM) and input/output ports. The ROM and EEPROM store a series of controlling softwares and parameters including those for AF control. DBUS denotes a data bus, SHT denotes a shutter control circuit which accepts data supplied from the data bus DBUS while a control signal CSHT is supplied thereto from the control circuit PRS and controls the drive of a shutter leading curtain and trailing curtain in accordance with the input data. APR denotes a diaphragm control circuit which accepts data supplied from the data bus DBUS while the control signal CAPR is applied thereto and controls a diaphragm mechanism (not shown) in accordance with the input data. DSP denotes a display circuit which accepts data supplied from the data bus DBUS while the control signal CDSP is applied thereto and displays imaging information based on the input data. SWS denotes a group of switches such as release switch, continuous photographing mode switch and information setting switches.

SPC denotes a light intensity measurement circuit. An analog light intensity signal SSPC from the circuit SPC is supplied to the control circuit PRS where it is A/D converted for use as light intensity data to control the shutter control circuit SHT and the diaphragm control circuit APR. LCOM denotes a lens communication circuit which accepts data supplied from the data bus DBUS while the control signal CLCOM is applied thereto and serially communicates with a lens unit to be described later in accordance with the input data. It transmits data DCL for driving the lens in synchronism with a clock signal LCK to an in-lens control circuit to be described later and serially receives from the in-lens control circuit, lens information DLC such as current position of the imaging lens. BSY denotes a signal to inform to the camera that the imaging lens is moving. When this signal is present, the serial communication is not undertaken.

LNSU denotes the lens unit, and LPRS denotes the in-lens control circuit for driving a motor MTR in accordance with the serial input data DCL to move the imaging lens LNF. It includes a ROM which stores a focal distance of the imaging lens LNF and an open F value. ENC denotes an encoder which detects a pulse signal generated as a lens body tube which holds the imaging lens LNF is moved and supplies to the in-lens control circuit LPRS a current position signal of the imaging lens LNF. SDR denotes a sensor drive circuit for controlling a line sensor SNS such as DDC sensor having two sensor lines SAA and SAB in accordance with the input signals from the control circuit PRS. The sensor lines SAS and SAB may be two sections of one sensor line.

The operation is now described. Since the operation of the shutter control circuit SHT, diaphragm control circuit APR, display circuit DSP and light intensity measurement circuit SPC is not directly related to the present invention, the explanation thereof is omitted.

The control circuit PRS checks the state of the release switch of the switch group SWS and if it detects that the release switch has been actuated, it starts a series of focusing operations. It first supplies a start of storage signal STR and drives the photo-electric converter SNS through the sensor drive circuit SDR to produce image signals A(i) and B(i) for the light intensity distributions of the two images. The operation of the control circuit PRS, sensor drive circuit SDR and line sensor SNS is briefly explained below. When the control circuit PRS generates the start of storage signal STR, the sensor drive circuit SDR supplies a clear signal CL to the line sensor SNS to clear charges of the photo-electric converters of the sensor lines SA and SAB. Then, the line sensor SNS starts photo-electric conversion of light images formed on the sensor lines SAA and SAB by the secondary focusing lenses (which are not shown in FIG. 1 but are arranged as shown in FIG. 4) and to store the charges. After a predetermined time period since the start of the above operation, the sensor drive circuit SDR supplies a transfer signal SH to the line sensor SNS to transfer the charges stored in the photo-electric converter to the CCD. The sensor drive circuit SDR also supplies an end of storage signal END to the control circuit PRS and waits for a CCD drive clock CK to be supplied from the control circuit PRS. When the CCD drive clock CK is supplied, the sensor drive circuit SDR generates CCD drive signals $\phi 1$ and $\phi 2$ and supplies them to the line sensors SNS. The line sensor SNS, when it receives those signals, supplies the analog image signal SSNS to the control circuit PRS. Thus, the control circuit PRS A/D converts the analog image signal SSNS in synchronism with the CCD drive clock CK and stores the converted image signals A(i) and B(i) of the light intensity distributions of the two images in predetermined addresses in the RAM.

After the image signals A(i) and B(i) of the light intensity distributions of the two images have been stored, the control circuit PRS carries out the focusing

state detection processing to detect the focusing state of the imaging lens LNF. This information is sent to the lens communication circuit LCOM by the control signal CLCOM through the data bus DBUS. If a signal BSY is not supplied, the lens communication circuit LCOM determines that the imaging lens LNF is now in a stopped condition and supplies the focusing state information sent from the control circuit PRS to the in-lens control circuit LPRS, that is, supplies the data DCL in synchronism with the clock signal LCK. It also receives the lens information DLC from the in-lens control circuit LPRS. This information includes parameters such as conditions of the imaging lens LNF and is used for the imaging operation of the camera. On the other hand, the in-lens control circuit LPRS drives the motor MTR in accordance with data supplied from the camera to move the imaging lens LNF to a position corresponding to the data, that is, until the number of encoder pulses EPL supplied from the encoder ENC reaches the number specified by the data. While the motor MTR is driven, the signal BSY is supplied to the camera.

In this manner, the series of focusing state detection operation is completed.

The processing method of the present invention is not limited to the correlation processing shown by the formulas (2)–(5) but it may be applicable to broad correlation processing between two signals.

In accordance with the present invention, the first correlation amount to be determined for each relative displacement is determined by utilizing the second correlation amount previously determined for other relative displacement so that the correlation processing which is same as that previously done is omitted. As a result, the processing time is shortened and the focusing state detection time is significantly shortened.

What I claim is:

1. An apparatus for detecting a focusing state of an objective lens comprising:

optical means for receiving light fluxes transmitted through an objective lens and forming light intensity distributions based on an object whose relative position varies with a focusing state of the objective lens,

sense means having a plurality of photo-sensors for sensing the light intensity distributions to produce first and second signals for the respective light intensity distributions; and

processing means for manipulating the first and second signals to sequentially and relatively displace the first and second signals under a first relationship to determine a first correlation amount $V_1(k)$, manipulating the first and second signals to sequentially and relatively displace the first and second signals under a second relationship to determine a second correlation amount $V_2(k)$, subtracting the second correlation amount from the first correlation amount to determine an evaluation amount V(k), calculating the evaluation amount for each relative displacement, and calculating the relative position of the light intensity distributions based on the evaluation amounts to produce a signal indicating the focusing state of the objective lens;

said processing means calculating one of the first and second correlation amounts by utilizing another correlation amount previously calculated for another relative displacement.

2. An apparatus for detecting a focusing state of an objective lens according to claim 1, wherein said processing means calculates the first correlation amount for each relative displacement by utilizing the second correlation amount previously calculated for other relative displacement.

3. An apparatus for detecting a focusing state of an objective lens according to claim 1, wherein the evaluation amount V(k), first correlation amount $V_1(k)$ and second correlation amount $V_2(k)$ meet the following relationship:

$$\begin{aligned} V(k) &= V_1(k) - V_2(k) \\ &= \sum_{i=0}^{M-1} A(i) \square B(i + |k| + 1) - \sum_{i=0}^{M-1} A(i+1) \\ &\quad \square B(i + |k|) \qquad (k < 0) \\ &= \sum_{i=0}^{M-1} A(i + k) \square B(i+1) - \sum_{i=0}^{M-1} A(i + k + 1) \\ &\quad \square B(i) \qquad (k \geqq 0) \end{aligned}$$

where $M = N - |k| - 1$ is the number of pixels processed, N is the number of photo-sensors used to sense one of the light intensity distributions, A(i) is the first signal, B(i) is the second signal, and $i = 0, \ldots N-1$.

4. An apparatus for detecting a focusing state of an objective lens according to claim 1, wherein said optical means includes secondary focusing lenses having parallel optical axes.

5. A method for detecting a focusing state of an objective lens comprising the steps of:

forming light intensity distributions based on an object whose relative position varies with a focusing state of the objective lens, based on light fluxes transmitted through the objective lens;

sensing the light intensity distributions by sensing means having a plurality of photo-sensors to form first and second signals for the respective light intensity distributions; and

manipulating the first and second signals to relatively displace the first and second signals under a first relationship and to relatively displace the first and second signals under a second relationship different from the first relationship to produce a signal for indicating the focusing state of the objective lens based on the relative displacement of the light intensity distributions;

the calculation for one relative displacement utilizing a calculation result previously obtained for an identical or essentially identical portion under another relationship.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 4,800,261

DATED : January 24, 1989

INVENTOR(S) : AKIRA AKASHI

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

On the title page:

IN [57] ABSTRACT

Line 14, "is" should be deleted.

COLUMN 2

Line 56, "porated" should read --polated--.

COLUMN 6

Line 22, "sensor lines SAS and SAB" should read --sensor lines SAA and SAB--.

Line 42, "sensor lines SA" should read --sensor lines SAA--.

Line 58, "line sensors SNS." should read --line sensor SNS.--.

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 4,800,261

DATED : January 24, 1989

INVENTOR(S) : AKIRA AKASHI

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

COLUMN 8

Line 12, "other" should read --another--.

Signed and Sealed this

Fourteenth Day of August, 1990

Attest:

HARRY F. MANBECK, JR.

Attesting Officer

Commissioner of Patents and Trademarks

United States Patent [19]

Kaplan et al.

[11] **Patent Number: 4,799,077**

[45] **Date of Patent: Jan. 17, 1989**

[54] **COMMON DRIVE FOR SHUTTER BLADES AND OBJECTIVE LENS ASSEMBLY**

[75] Inventors: **Jonathan I. Kaplan**, West Newton; **Stephen M. Pero**, Medford, both of Mass.

[73] Assignee: **Polaroid Corporation**, Cambridge, Mass.

[21] Appl. No.: **124,033**

[22] Filed: **Nov. 23, 1987**

[51] **Int. Cl.**[4] **G03B 3/00**

[52] **U.S. Cl.** **354/400**; 354/402; 354/195.1; 354/195.11

[58] **Field of Search** 354/400, 401, 402, 195.1, 354/195.11

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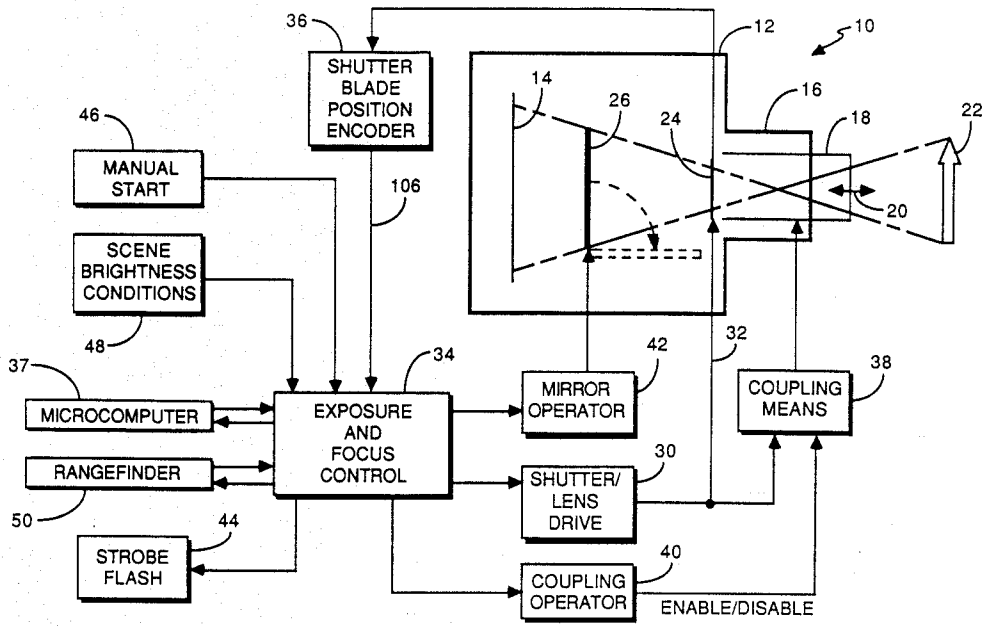
Primary Examiner—Russell E. Adams
Attorney, Agent, or Firm—John J. Kelleher

[57] **ABSTRACT**

The shutter blades of a scanning blade shutter and the movable element of an adjustable focus lens in a single lens reflex camera are actuated by a single or common drive. The scanning blade shutter is coupled to the common drive by a rotatably mounted beam member. The movable lens element is also coupled to the common drive through a drive link assembly and the same beam member. Actuation of the beam member by the common drive simultaneously moves the shutter blades in the single lens reflex camera toward their closed positions and moves the lens element coupled thereto by a drive link assembly toward a rangefinder-determined lens focal position. A solenoid coupled to a drive link in the drive link assembly and responsive to rangefinder-derived object distance signals actuates the drive link to uncouple the movable lens element from the beam member when the movable lens element has been moved to a particular focal position determined by the rangefinder. The common drive then moves the shutter blades to their full closed positions after the movable lens element has been uncoupled. The drive link connection between the beam member and the movable lens element is re-established subsequent to film exposure to thereby enable the common drive to return the movable lens element to its initial focal position while moving the shutter of the single lens reflex camera to its full open position.

16 Claims, 4 Drawing Sheets



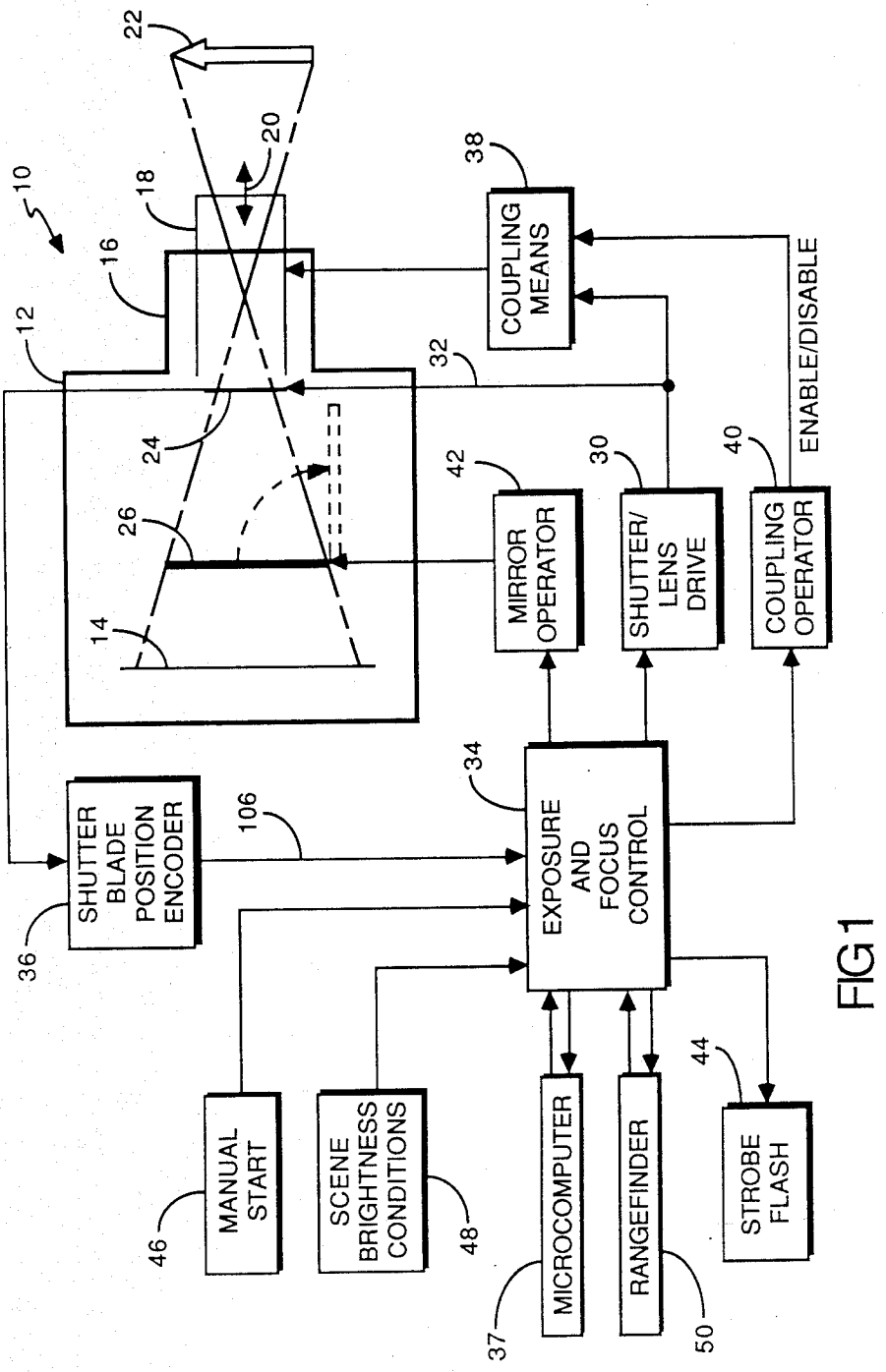
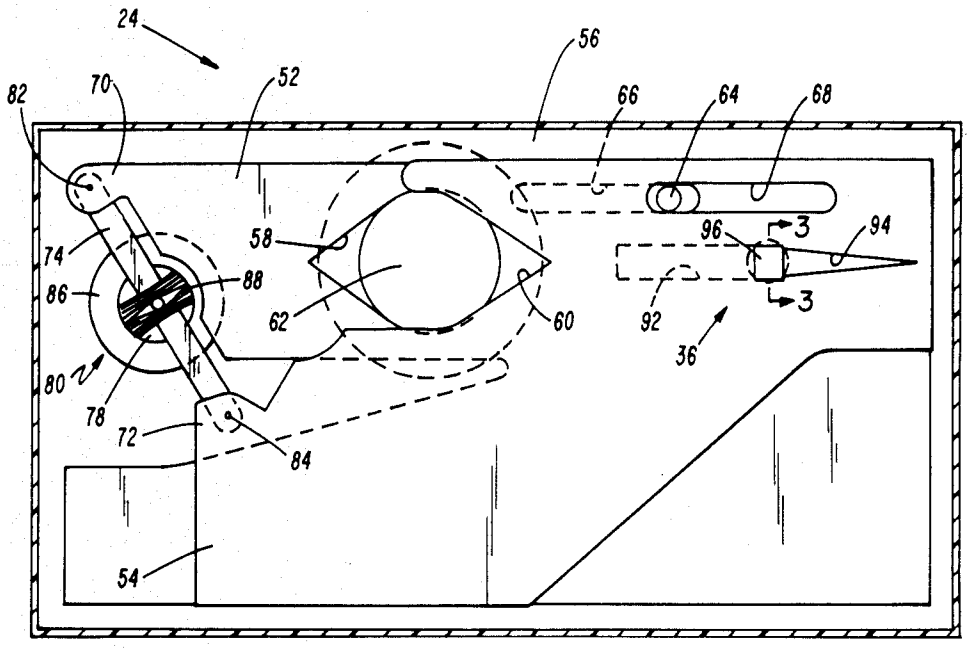

22
20
10
18
16
12
38
COUPLING MEANS
32
ENABLE/DISABLE
24
42
30
40
26
MIRROR OPERATOR
SHUTTER/ LENS DRIVE
COUPLING OPERATOR
14
34
SHUTTER BLADE POSITION ENCODER
106
EXPOSURE AND FOCUS CONTROL
36
44
MANUAL START
SCENE BRIGHTNESS CONDITIONS
MICROCOMPUTER
RANGEFINDER
STROBE FLASH
46
48
37
50

FIG 1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70
66
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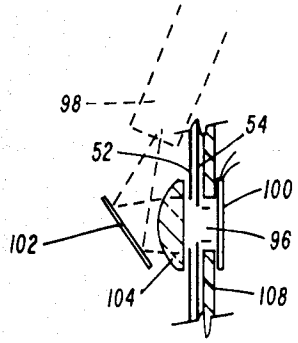
FIG 2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100
102
96
104
108

FIG 3

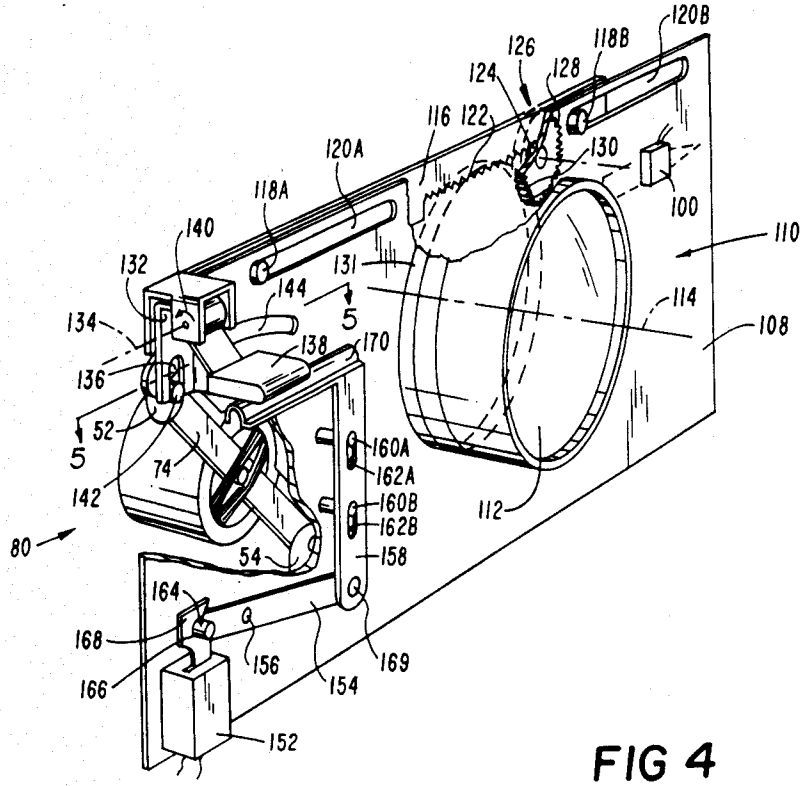

FIG 4

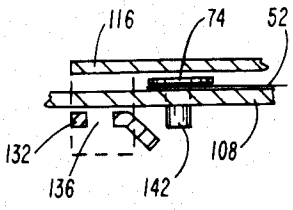

FIG 5A

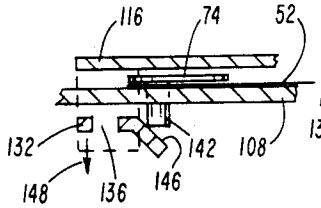

FIG 5B

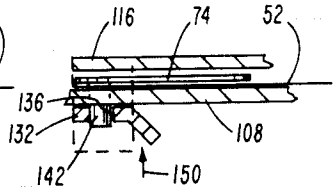

FIG 5C

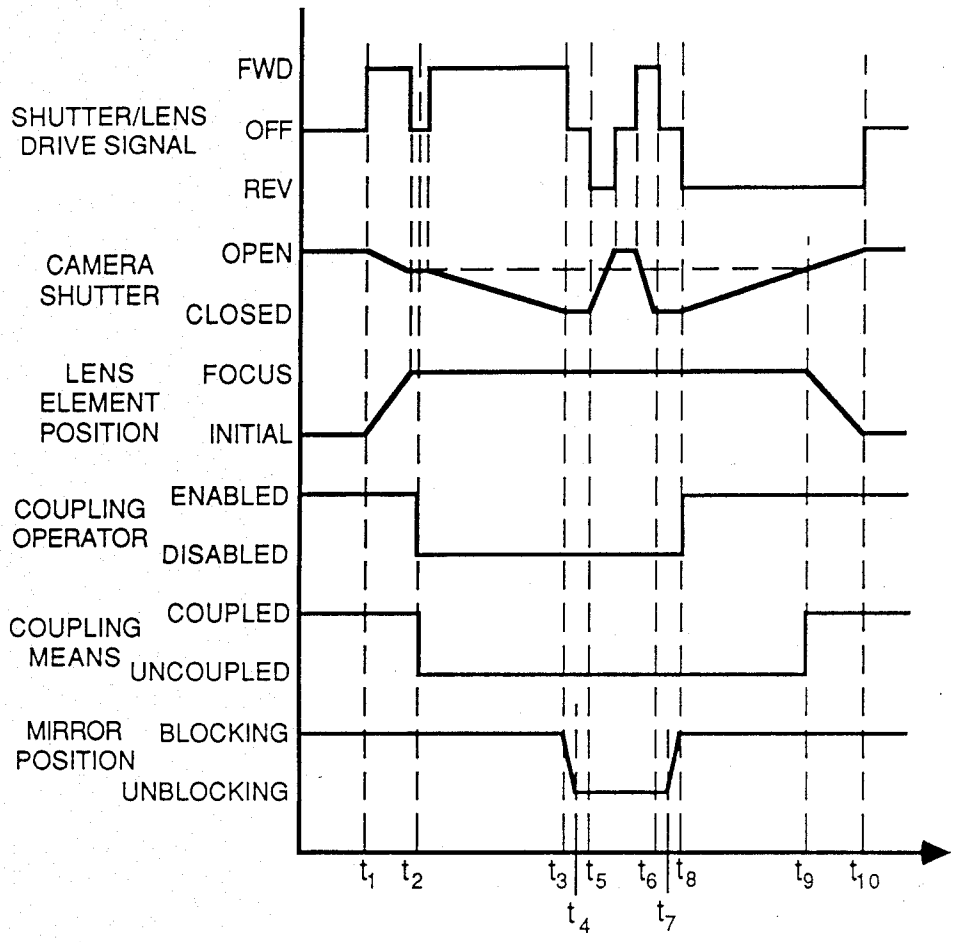
SHUTTER/LENS DRIVE SIGNAL
FWD
OFF
REV
CAMERA SHUTTER
OPEN
CLOSED
LENS ELEMENT POSITION
FOCUS
INITIAL
COUPLING OPERATOR
ENABLED
DISABLED
COUPLING MEANS
COUPLED
UNCOUPLED
MIRROR POSITION
BLOCKING
UNBLOCKING
t1 t2 t3 t4 t5 t6 t7 t8 t9 t10

FIG 6

COMMON DRIVE FOR SHUTTER BLADES AND OBJECTIVE LENS ASSEMBLY

BACKGROUND OF THE INVENTION

The present invention relates to a common shutter blade and lens focusing system drive for a photographic camera, in general, and to such a drive for a single lens reflex camera employing a scanning blade type shutter, in particular.

Photographic apparatus employing shutter blade mechanisms, in general, and scanning blade shutters, in particular, as well as a lens mechanism that may be automatically focused in accordance with a rangefinder-determined camera-to-subject distance are well known in the art. A camera employing a scanning blade shutter and a lens mechanism responsive to a rangefinder-determined subject distance signal is described in, for example, U.S. Pat. No. 4,192,587, entitled "Proportioned Fill Flash", by A. G. La Rocque, et al, issued Mar. 11, 1980, in common assignment herewith. For convenience, the disclosure in said LaRocque et al patent is specifically incorporated herein by reference.

Scanning shutter blade mechanisms are normally driven from a scene light blocking position toward a maximum aperture defining position and thereafter returned to their initial scene light blocking position during an exposure interval. Such scanning blade shutter mechanisms generally comprise a pair of scanning blade shutter elements each having a primary aperture therethrough. The shutter blade elements overlap for reciprocal movement with respect to each other. This movement drives the primary aperture into overlapping relationship with each other so as to define a progressively increasing and then decreasing effective primary aperture. The shutter blade mechanisms are normally driven by a spring and solenoid arrangement as shown in La Rocque et al, supra, or by a microcomputer controlled stepper motor incorporating a digitally encoded scanning blade position sensor as shown, for example, in U.S. Pat. No. 4,325,614, entitled "Exposure Control System With Shutter Operation Controlled by a Microcomputer", by D. L. Grimes, issued Apr. 20, 1982, in common assignment herewith.

Autofocus cameras of the aforementioned type generally embody a motor driven objective lens mechanism which must be stopped at an appropriate focal position corresponding to a previously determined camera-to-subject distance. In such cameras, it is desirable to provide a lens position encoder system to identify the instantaneous focal position of a lens element driven by said lens mechanism as it is moved through its plurality of different focal positions in order to precisely position the lens element at a previously determined object-distance-related focal position as shown, for example, in La Rocque et al, supra.

In prior adjustable focus lens cameras employing scanning shutter blades, the objective lens and shutter blade mechanisms are driven by a common drive either that sequentially drives the objective lens and the shutter blades or are driven by separate shutter blade and lens drive means. U.S. Pat. No. 4,278,340 to Toyama et al is an example of such a sequential lens and shutter blade drive and U.S. Pat. No. 4,199,244 to Shenk is an example of a camera employing separate shutter blade and lens drives. In addition, if an encoder system were to be employed in such cameras to determine the instantaneous focal position of the movable lens element as in, for example, La Rocque et al, supra, and the instantaneous blade position of the scanning shutter blades as in, for example, Grimes, supra, the prior art teaches the use of separate encoders for each such position sensing function. The use of duplicate drive means and encoders in an autofocus camera necessarily increases camera cost, size and complexity.

It is a primary object of the present invention, therefore, to provide a single or common drive for a photographic camera that is capable of driving the movable element of an adjustable focus lens to a previously determined lens focal position and of driving a scanning blade type shutter mechanism during an exposure interval.

It is another object of the present invention to provide a rangefinder-derived signal-responsive common drive that is capable of simultaneously driving both the shutter and focusing mechanisms in a single lens reflex camera.

It is a further object of the present invention to provide a single position-encoder that is capable of determining both the instantaneous blade position of a shutter blade mechanism and the instantaneous focal position of the movable lens element in an adjustable focus lens camera.

Other objects and/or advantages of our invention will be made readily apparent by referring to the preferred embodiment thereof described in detail below.

SUMMARY OF THE INVENTION

In accordance with the present invention, a single or common drive is provided that is capable of actuating both the objective lens and shutter and/or aperture mechanisms in an adjustable focus lens camera to a lens focal position corresponding to a previously determined camera-to-subject distance or other desired focal position and through an exposure interval, respectively. The shutter is directly coupled to the common drive and the objective lens mechanism is coupled to the common drive through a drive link assembly. Actuation of the common drive moves the initially open shutter mechanism towards its closed or light-blocking position and moves the objective lens mechanism coupled thereto by said drive link assembly toward a previously determined lens focal position. Means coupled to the drive link assembly and responsive to a signal representative of said previously determined camera-to-subject distance actuates said drive link assembly to uncouple the objective lens mechanism from the common drive when said lens mechanism has been moved to a focal position corresponding to said previously determined camera-to-subject distance. The common drive subsequently moves the shutter mechanism to its full closed position prior to the initiation of a film exposure interval. The drive link assembly connection between the common drive and said objective lens mechanism is re-established subsequent to a film exposure interval to thereby enable the common drive to return the objective lens mechanism to its initial focal position while moving the shutter to its initial open position.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram showing a photographic camera embodying the combination lens and shutter drive of the prevent invention.

FIG 2 is a front elevational view of the scanning shutter blades and associated drive mechanism of the present invention.

FIG. 3 is a sectional view taken on the line 3—3 in drawing FIG. 2.

FIG. 4 is a diagrammatic perspective view of the lens and associated lens drive mechanism of the present invention showing portions thereof removed to reveal otherwise hidden structure.

FIGS. 5A, 5B and 5C are sectional views taken on the line 5—5 in drawing FIG. 4 sequentially showing the lens-to-drive coupling means in an uncoupled, a transitional and coupled state, respectively.

FIG. 6 is a timeline showing a typical operational sequence of various lens and shutter drive related elements in the camera of FIGS. 1–5.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to FIG. 1 of the drawings, there is shown at 10 a block diagram of a photographic camera incorporating a preferred embodiment of the combination lens and shutter drive mechanism of the present invention. Camera 10 is of the single lens reflex type and said camera includes housing 12 within which film is supported at focal plane 14 opposite hub 16. Lens assembly or lens mount 18 is positioned within hub 16 and is displaceable in axial direction 20 to form an in-focus image of subject 22 at said plane 14 when shutter mechanism 24 is actuated to generate an exposure interval after mirror 26 has been moved from its vertical or viewing position to its horizontal or film exposure position (shown in phantom) as functionally illustrated in said drawing FIG. 1. Exemplary of a single lens reflex camera of the type described above is U.S. Pat. No. 3,714,879 to Land et al and of the above-described displaceable or adjustable focus lens camera is the U.S. Patent to Shenk, supra.

Shutter mechanism 24 is driven by shutter/lens drive 30 through path 32 in response to drive signals from exposure and focus control 34 in a closed loop system that includes shutter blade position sensor 36, under the control of microcomputer 37. Lens mount 18 is also driven by said shutter/lens drive 30 through coupling means 38. Coupling means 38 is actuated between its coupled and uncoupled states by coupling operator 40 in response to coupling means control signals from exposure and focus control 34. Similarly, mirror 26 is actuated between its viewing and film exposure positions by mirror operator 42 and strobe flash 44 is fired, in response to mirror position control signals and flash fire signals, respectively, from said exposure and focus control 34. The coupling operator 40, the mirror operator 42 control signals and the flash fire signals from exposure and focus control 34 are also under the control of said microcomputer 37.

Microcomputer 37 is, in turn, responsive to a plurality of inputs. These include manual start input 46 provided in response to an operator manually actuating an exposure cycle start button and automatically provided inputs such as pre-exposure and exposure interval scene brightness conditions, designated 48, and a camera-to-scene distance input, designated 50, which is preferably provided by a sonar ranging system of the type disclosed in commonly assigned U.S. Pat. No. 4,081,626 to Muggli et al. Microcomputer 37 stores a plurality of selectable blade trajectory programs in a manner similar to that described in U.S. Pat. No. 4,427,276 to Feinerman et al and the implementation of any one particular trajectory program is automatically determined, in part, by such microcomputer 37 inputs as rangefinder determined subject distance and scene brightness conditions.

Shutter mechanism 24 functionally illustrated in drawing FIG. 1, is of the scanning shutter blade type, and is shown in much greater detail in drawing FIG. 2. FIG. 2 is a front elevational view of the scanning blade shutter forming said shutter mechanism 24. With respect to FIG. 2, shutter mechanism 24 comprises two overlapping shutter blade elements 52, 54 disposed for reciprocal sliding movement with respect to one another on baseblock 56. Shutter blade elements 52, 54 are respectively provided with scene light admitting primary apertures 58 and 60 to collectively define a progressive variation of effective aperture opening 62 in accordance with the simultaneous longitudinal and lateral displacement of one blade element with respect to the other blade element in a manner as is fully described in U.S. Pat. No. 3,942,183, entitled "Camera With Pivoting Blades" by George D. Whiteside, issued Mar. 2, 1976, in common assignment herewith and now specifically incorporated herein by reference. Effective aperture 62 may be varied between a light blocking and an infinite number of light unblocking positions and is shown in FIG. 2 in its fully open, light unblocking position. The primary apertures 8, 60 are selectively shaped and positioned so as to overlap and form a light entry exposure aperture 62 in baseblock 56 to thereby define said effective aperture 62, of varying size, as a function of the position of blade elements 52, 54.

Projecting from the baseblock 56 at a location spaced laterally apart from light entry exposure aperture 62 in drawing FIG. 2 is pivot pin or stud 64 which pivotally and translatably engages slots 66 and 68 respectively formed near one end of shutter blade elements 52, 54. Pin 64 may be integrally formed with the baseblock 56 and blade elements 52, 54 may be retained in engaging relation with respect to the pin 64 by any suitable retaining means. The opposite ends of blade elements 52, 54 include extended portions 70 and 72, respectively, which pivotally connect to opposite ends of walking beam member 74. Walking beam 74, in turn, is integrally formed with and is located at one end of rotor 78 of galvanometer actuator 80 and said actuator 80 is mounted in a fixed position with respect to said baseblock 56. In the preferred embodiment, walking beam 74 is pivotally connected at its distal ends to the shutter blade elements 52, 54 by coupling pins 82, 84, respectively.

Galvanometer actuator 80 provides the drive force required to displace scanning shutter blades 52, 54 with respect to each other and with respect to baseblock 56 over their complete aperture-forming operational range. Galvanometer actuator 80 is, in effect, a combination d'Arsonval galvanometer and a DC electric motor. Galvanometer actuator 80 includes cylindrically shaped permanent magnet 86 formed of magnetic segments, supported in cylindrically shaped soft iron support structure, that is mounted in a fixed position with respect to camera housing 12 (FIG. 1). The rotor 78, having multiple turn coil 88 wound thereon is mounted for rotation within cylindrically shaped magnet 86 and within the magnetic field of said permanent magnet 86. A rotational force is generated by multiple turn coil 88 and rotor 78 on which said coil 88 is wound in either a clockwise or counterclockwise direction when a DC current having a particular magnitude and direction is

passed through said coil **88** by exposure and focus control **34** (FIG. **1**) under the control of microcomputer **37** (FIG. **1**). Galvanometer actuator **80** has some of the characteristics of an electric motor in that it utilizes the forces produced by a magnetic field on a current-carrying conductor and some of the characteristics of a galvanometer in that the rotor rotates less than one complete revolution when actuated to drive shutter blade elements **52, 54** between their scene light blocking and unblocking positions.

Shutter blade mechanism **24** is provided with analog-type, blade displacement sensing encoder system **36** for continuously monitoring the position of shutter blade elements **52, 54** during the course of an exposure interval. As shown in FIG. **2**, encoder system **36** preferably includes laterally extending rectangular and triangular shaped secondary apertures **92, 94** respectively formed in scanning blades **52, 54** for movement therewith. However, other aperture shapes could be employed to form said secondary apertures. Apertures **92, 94** collectively define a progressive variation of effective secondary aperture opening **96** in accordance with the simultaneous lateral displacement of blade element **52** with respect to blade element **54**.

As is more clearly shown in drawing FIG. **3**, which is a sectional view taken on the line **3—3** in FIG. **2**, encoder system **36** additionally includes light emitting diode **98** and light sensing diode **100** mounted on opposite sides of the combination of shutter blades **52, 54** and lens mounting plate **108** (FIG. **4**). In this particular arrangement, light emitted by light emitting diode **98** is directed to light sensing diode **100** through effective secondary aperture opening **96** by reflecting mirror **102** and lens **104**. Light emitting diode **98** is energized prior to the initiation of a film exposure cycle actuating shutter blade mechanism **24**. Actuation of shutter blades **52, 54** of said shutter mechanism **24** by galvanometer actuator **80** causes a change in the size of effective secondary aperture opening **96** which, in turn, causes a progressive change in the amount of light sensed by the photosensitive surface of light sensing diode **100** through aperture opening **96**. An electrical signal representative of the instantaneous position of shutter blade elements **52, 54** in the form of an electrical current is generated by light sensing diode **100** in correspondence with the amount of light sensed by said diode **100**. This shutter blade position signal is subsequently transmitted by shutter blade position sensing encoder **36** to exposure and focus control **34** (FIG. **1**) through path **106**.

As shown in FIG. **4** of the drawings, lens mounting plate **108** is mounted in a fixed position with respect to camera housing **12** (FIG. **1**), immediately in front of galvanometer actuator **80**, walking beam **74** and shutter blades **52, 54**. Adjustable focus lens assembly **110** is mounted in a fixed position on said lens plate **108**. Lens assembly **110** includes front lens element **112** that is translatable along optical axis **114** by a conventional cam ring where it serves to focus images of subjects positioned in various locations within a range of subject distances at image plane **14** (FIG. **1**) of said single lens reflex camera **10**.

Drive link **116** is attached to lens mounting plate **108** by pins **118A** and **118B** projecting from said drive link **116** and through laterally extending elongated slots **120A** and **120B**, respectively, for reciprocating movement with respect to said mounting plate **108**. A portion of the lower edge of drive link **116** is formed with a gear rack **122** that is meshed with smaller gear **124** of compound gear **126** rotatably mounted on said lens mounting plate **108**. Larger gear **128** of said compound gear **126** is, in turn, in mesh with gear **130** formed in the periphery of conventional lens element translating cam ring **131** of lens assembly **110**. Latch **132** is attached to that end of drive link **116** remote from gear rack **122**, for rotation about latch axis **134**. Latch **132** is provided with bifurcation or open slot **136** at one end and lever arm **138** at the other. A spring (not shown) is provided to resist (i.e., to provide a biasing force against) the rotation of latch **132** about latch axis **134** in direction **140**.

Pin **142** projecting from the upper end of walking beam member **74** extends through arcuate clearance slot **144** in mounting plate **108** for limited arcuate movement therein. Pin **142** engages open slot **136** in latch **132** for pivotal movement therein when walking beam member **74** is actuated to drive link **116** through said latch **132**. If latch **132** is rotated in direction **140**, open slot **136** will move out of engagement with walking beam pin **142**. Subsequent rotational movement of walking beam member **74** after slot **136** has been so disengaged, will not be transmitted to drive link **116** nor to front lens element **112** of lens assembly **110** coupled thereto. Also, if walking beam member **74** is uncoupled from latch **132** and is subsequently moved relative to said latch **132**, pin **142** will move out of alignment with said slot **136**. FIG. **5A**, which is a sectional view taken on the line **5—5** in drawing FIG. **4** illustrates such movement. As shown in said FIG. **5A**, pin **142** projecting from walking beam **74** has moved laterally away from latch slot **136** under the influence of galvanometer actuator **80** coupled thereto and then latch **132**, now in its unlatch state, has biased back to its initial rotational position or the rotational position it assumes when in its walking beam **74** to drive link **116** latch state. The mechanical link between said latch **132** and walking beam **74** is re-established in the following manner as additionally illustrated in drawing FIGS. **5B** and **5C**.

Like FIG. **5A**, FIGS. **5B** and **5C** are also sectional views taken on the line **5—5** in drawing FIG. **4**. In FIG. **5B**, galvanometer actuator **80** (FIG. **4**) initially drives pin **142** projecting from walking beam member **74** toward latch **132**. Pin **142** is subsequently driven into cam surface **146** of latch **132**, thereby causing the slot **136** portion of latch **132** to cam outward in direction **148** away from mounting plate **108**. As pin **142** continues to move toward latch **132**, it ultimately becomes aligned with slot portion **136** thereof, as shown in drawing FIG. **5C**, thereby enabling slot **136** to pivot inward in direction **150** under the force of the above-noted force bias spring (not shown) of latch **132** to thereby mechanically couple said walking beam member **74** to drive link **116**.

As shown in drawing FIG. **4**, electrically actuated solenoid **152** is attached, in a fixed position, to lens mounting plate **108** and pivot link **154** is rotatably attached to said plate **108** by pin **156**. In addition, L-shaped slide link **158** is attached to mounting plate **108** by pins **160A** and **160B** projecting from said plate **108** through vertically extending, elongated slide link slots **162A** and **162B**, respectively, for reciprocating vertical movement with respect to said mounting plate **108**. Pin **164** projecting from one end of pivot link **154** engages slot **166** in solenoid armature **168** for pivotal movement therein and the other end of said pivot link **154** is, in turn, pivotally attached to the lower end of said slide link **158** by pin **169**. Arm **170** of slide link **158** at the upper end of said link **158** is in sliding contact with the

bottom surface of the lever arm **138** portion of latch **132**. The function of link arm **170** is to maintain contact between slide link **158** and latch arm **138** whenever drive link **116** moves in slots **120A** and **120B** relative to said slide link **158**. When electrical solenoid **152** is energized, armature portion **168** is electromagnetically attracted downward, causing pivot link **154** to rotate about pin **156** and thereby cause link **158** to slide upward on support pins **160A**, **160B**. This upward motion of slide link **158** is transferred to lever arm **138** through link arm **170**, causing latch **132** to rotate in direction **140** and thereby uncouple drive link **116** from walking beam member **74**.

DISCUSSION

A typical combined lens and shutter drive operational sequence will now be described in detail with respect to the above-described drawing FIGS. **1-5** and with respect to drawing FIG. **6**, which is a time line showing the sequence of operation of various lens and shutter drive related elements of single lens reflex camera **10**. Prior to the initiation of a typical exposure sequence employing the combined lens and shutter drive of the present invention, it should be noted that shutter mechanism **24** is in its full open position, walking beam member **74** is mechanically coupled to drive link **116** through latch **132** and mirror **26** is in its viewing or blocking position precluding any and all scene light from reaching image plane **14**.

A lens focusing and film exposure sequence is initiated by an operator actuation of manual start **46**. The actuation of manual start **46** causes initial scene brightness conditions to be determined by light sensing means (not shown) within scene brightness condition determining means **48** and causes rangefinder **50** to ultrasonically produce an electrical signal representative of subject distance. As shown in the time line of FIG. **6**, at t_1 which occurs subsequent to the determination of initial scene brightness conditions and subject distance, exposure and focus control **34** under the control of microcomputer **37** generates a forward shutter/lens drive signal causing galvanometer actuator **80** to translate front lens element **112**, through drive link **116**, to the focus position determined by rangefinder **50**. The focus position of lens element **112** is sensed by shutter blade encoder system **36** in that blades **52**, **54** are directly coupled to said lens element **112** through walking beam member **74** and drive link **116**.

When lens element **112** of lens assembly **110** has been driven to the desired focal position just prior to t_2 by galvanometer actuator **80**, solenoid **152** is energized at t_2 by exposure and focus control **34**, causing the downward movement of solenoid armature **168** to rotate pivot link **154** about pin **156** and slide link **158** to move vertically upward on pins **160A** and **160B**. The upward movement of slide link **158** is transferred to arm **138** of latch **132** by arm **170** of slide link **158** to thereby rotate latch **132** out of engagement with walking beam **74** as said latch **132** is rotated in direction **140** by such slide link **158** movement. After latch **132** has been disengaged from drive link **116**, galvanometer actuator **80**, moving in the same direction, drives shutter mechanism **24** to its full closed position at t_3. It should be noted that the forward drive signal to galvactuator **80** is interrupted just prior to t_2 or when lens element **112** has reached the desired focal position, and during the period of time that walking beam **74** is being uncoupled from drive link **116**.

Mirror **26** is actuated to its unblocking position between times t_3 and t_4 by mirror operator **42** and microcomputer controlled exposure and focus control **34**. A shutter mechanism **24** actuating exposure interval is initiated at t_5 and terminated at t_6 by exposure and focus control **34** in correspondence with the blade aperture size versus time trajectory program stored within microcomputer **37** that, if the sensed lighting conditions deem it necessary, includes the firing of scene illuminating strobe flash **44**. Mirror **26** is then returned to its scene light blocking position between t_7 and t_8 and coupling operator **40** is enabled by de-energizing solenoid **152** at said time t_8. In addition, at t_8, a reverse shutter/lens drive signal is also generated by microcomputer controlled exposure and focus control **34** causing galvanometer actuator **80** to drive shutter blades **52**, **54** in shutter mechanism **24** toward their open or light unblocking positions.

As galvanometer actuator **80** continues to move shutter mechanism **24** toward its full scene light unblocking position, pin **142** projecting from galvactuator coupled walking beam **74** engages cam surface **146** (FIG. **5B**) of latch **132**, causing slot **136** formed therein to pivot outward in direction **148** away from lens mounting plate **108**. At time t_9 with pin **142** moving in the same direction, said pin **142** becomes aligned or is moved into registration with latch slot **136**. When this occurs, the said slotted end of latch **136** is pivoted inward in direction **150** (FIG. **5C**) under the .force of the latch **132** bias spring (not shown) as said pin **142** enters said slot **136**. At this time, drive link **116** and movable lens element **112** once again become mechanically coupled to galvanometer actuator **80** through latch **132**. Galvanometer actuator **80** continues to drive shutter mechanism **24** to its full open position while simultaneously driving the now-coupled movable lens element **112** toward its initial focus position. At time t_{10}, shutter mechanism **24** has been moved to its full open position, movable lens element **112** has been moved to its initial focus position, and the shutter/lens drive signal from microcomputer controlled exposure and focus control **34** has been terminated.

As hereinabove described, a single actuator (galvanometer actuator **80**) has been employed to simultaneously drive the blade elements of a shutter mechanism while at the same time driving the movable element of an adjustable focus lens to a desired focus position during at least a portion of the shutter blade actuation cycle. In addition, it should be noted that, with the exception of pin **142** projecting from walking beam **74**, movable element **112** of lens assembly **110** and all of the means coupling said lens element to walking beam **74** are uncoupled from said walking beam **74** prior to the initiation of an image forming exposure interval. By uncoupling lens element **112** from walking beam **74** in this manner, inertial loading of galvanometer actuator **80** that might otherwise alter a programmed aperture size versus time scanning blade trajectory, is thereby precluded.

It will be apparent to those skilled in the art from the foregoing description of our invention that various improvements and modifications can be made in it without departing from its true scope. The embodiments described herein are merely illustrative and should not be viewed as the only embodiments that might encompas our invention.

What is claimed is:

1. A photographic camera, comprising:

means for defining a focal plane;

an adjustable focus lens for directing scene light along a given path to said focal plane, said lens having a movable element mounted for displacement over a given operational range for adjustment of said lens to focus images of subjects positioned in various locations within a range of subject distance at said focal plane;

a blade mechanism;

means for mounting said blade mechanism for displacement between a blocking arrangement precluding transmission of scene light along said given path to said focal plane and an unblocking arrangement, said blade mechanism including at least one blade portion displaceable during displacement of said blade mechanism;

means for detecting each progressive position of said one blade portion and for deriving an electrical signal representative of each such progressive blade position;

means for producing a subject distance signal representative of the distance between said camera and a particular subject within said focusing range;

drive means actuatable for displacing said blade mechanism between its said blocking and unblocking arrangements;

a light blocking member actuatable between light blocking and unblocking positions for independently controlling scene light transmission along said given path from said lens to said focal plane;

a drive link assembly for coupling said movable lens element to said blade mechanism, said assembly being actuatable between a first arrangement where said lens element is uncoupled from said blade mechanism and a second arrangement where said lens element becomes coupled to said blade mechanism; and

energizeable control means for actuating said drive means to initially displace said blade mechanism toward its said blocking arrangement in preparation for exposure while simultaneously displacing said movable lens element coupled thereto from an initial toward a particular focus position, to then displace said blade mechanism toward its said unblocking arrangement and back again so as to define an exposure interval during which scene light is transmitted to the focal plane and for finally actuating said light blocking member for its said light unblocking position to its said light blocking position subsequent to said exposure interval, said control means including means responsive to said subject distance signal and said blade position signal for actuating said drive link assembly to its said first arrangement during initial displacement of said blade mechanism to uncouple said lens element from said blade mechanism when said lens element has been positioned to a particular subject distance related focus position, and responsive to a signal indicating the end of an exposure interval for actuating said light blocking member to its said light blocking position, for actuating said drive means to displace said blade mechanism toward its said unblocking arrangement, and for actuating said drive link assembly to its said second arrangement to couple said lens element to said blade mechanism so as to simultaneously return said movable lens element and said blade mechanism to their respective initial position.

2. The invention of claim 1 wherein said blade mechanism includes a pair of scanning blade shutter elements mounted in an overlapping relationship for reciprocal movement with respect to one another, with each element having a primary aperture therethrough and with said reciprocal movement defining a progressively increasing and then decreasing effective primary aperture to thereby provide an exposure interval.

3. The invention of claim 1, wherein said control means includes means for generating an electromagnetic force inducing electrical current corresponding to a desired blade mechanism aperture size versus time trajectory curve and said drive means comprises:

a pair of permanent magnets of opposite polarity mounted in a spaced relation, said magnets having a magnetic field of predetermined intensity established therebetween; and

a rotor coupled to said blade mechanism, said rotor including a coil of electrical wire coupled to said control means and supported for limited rotation within said magnetic field in response to said electrical current.

4. The invention of claim 1, wherein said means for detecting each progressive position of said one blade comprises:

said one blade includes an encoder aperture disposed for displacement along a predetermined path in correspondence with the displacement of said one blade; and

a light emitting device and a light sensing device mounted in a spaced relation on opposite sides of the said encoder aperture displacement path for providing an output signal indicative of the progressive position of said one blade when the light emitted by said light emitting device is transmitted to said light sensing device by way of said encoder aperture as said encoder aperture moves along said predetermined path.

5. The invention of claim 4, wherein said blade mechanism includes a pair of shutter blades with each such blade incorporating an encoder aperture disposed for displacement along a predetermined path, in an overlapping relationship, between said light emitting and light sensing devices, in correspondence with its associated shutter blade, for progressively varying the amount of light transmitted therebetween to thereby provide an output signal indicative of the position of said shutter blades relative to one another.

6. The invention of claim 1, wherein said means for producing a subject distance signal representative of subject distance is an ultrasonic rangefinder.

7. The invention of claim 1, wherein said light blocking member is a mirror actuatable between said light blocking position where it reflects an image of a scene to be photographed for scene framing and focusing purposes and a reflex position where it permits scene light transmission between said lens and said focal plane.

8. The invention of claim 1, wherein said control means comprises:

means for deriving an electrical signal representative of scene lighting conditions;

means for storing a plurality of different trajectory signal programs defining corresponding blade trajectory curves that are appropriate for different photographic conditions;

means responsive to a program of trajectory signals for actuating said blade mechanism drive means in

a manner whereby the operation of said blade mechanism coupled thereto is characterized by an aperture size versus time trajectory curve defined by said program of trajectory signals; and

means responsive to said scene lighting conditions signal for selecting the appropriate trajectory signal program from said storage means and feeding a correlated program of trajectory signals to said blade mechanism driving means.

9. The invention of claim **1**, wherein said drive link assembly comprises:

a rotatably mounted compound gear having large and small diameter gear portions;

an elongated member mounted for reciprocating movement having an edge portion in the form of a rack gear with its gear teeth in mesh with the small diameter gear portion of said compound gear;

a lens mount for supporting and translatably focusing said movable lens element, said lens mount having gear teeth formed at its periphery with said gear teeth being in mesh with the teeth of said large diameter gear portion wherein reciprocating movement of said elongated member is coupled to said lens element for lens element focusing movement;

a latch assembly for coupling said drive means to said elongated member comprising a pin member coupled to said drive member and a latch member pivotally attached to an end portion of said elongated member having a recess therein for receiving said pin member; and

an electrical solenoid responsive to said blade position and subject distance signals and coupled to said latch member, actuatable between an uncoupled condition where said pin member is precluded from entering said latch member recess and a coupled condition where said pin member is permitted to enter said latch member recess to thereby couple said drive means to said elongated member.

10. The invention of claim **1**, wherein said photographic camera is a single lens reflex camera.

11. A photographic camera comprising:

means defining a focal plane;

an adjustable lens for directing scene light along a given path to said focal plane, said lens including a movable element displaceable over a given operational range for adjustment of said lens to focus an image at said focal plane of a subject at a location determined in accordance with a subject distance signal;

an exposure control mechanism including at least one blade member displaceable over a select path to facilitate control of the passage of scene light to said focal plane;

drive means actuatable for displacing said blade member along its select path;

coupling means operable, responsive to a first signal, for coupling said movable lens element to said blade member for displacement therewith and, responsive to a second signal for decoupling said lens element from said blade member;

means for producing said first signal for coupling said lens element to said blade member, and for actuating said drive means for displacement of said blade member along its said select path for movement of said lens element therewith; and

means responsive to said subject distance signal for producing said second signal to decouple said lens element from said blade member when said lens element is displaced to a suitable location for focusing an image of a subject located at a distance represented by said subject distance signal.

12. The invention of claim **11** including means for detecting the progressive displacement of said blade element and for deriving a blade position signal in accordance therewith, and wherein said means responsive to said subject distance signal includes means responsive to said blade position signal for producing said second signal to decouple said lens element when said blade position signal represents a blade displacement sufficient to displace said lens element to its said suitable location in accordance with said distance subject signal.

13. The invention of claim **12** wherein said subject distance signal defines the displacement of said blade element necessary to displace said lens element to a suitable location in accordance with subject distance, and said means responsive to said subject distance signal incudes means responsive to a blade position signal selected in accordance with said subject distance signal for producing said second signal to decouple said lens element from said blade element.

14. The invention of claim **13** wherein said blade member is actuatable for displacing said blade member from an initial position toward a terminal position and subsequently back to its said initial position, and said first signal is provided prior to displacement of said blade member from its initial position so as to displace said lens element from an initial position upon displacement of said blade member, said second signal is provided during displacement of said blade member toward its said terminal position so as to release said lens element at a focus position, and said first signal is subsequently provided during a displacement of said blade member back to its initial position so as to carry said lens element back to its said initial position.

15. A photographic method for use with photographic apparatus having an exposure mechanism including a blade member displaceable over the camera exposure path from an initial position towards a terminal position and back toward its initial position, and an adjustable focus lens including a lens element displaceably mounted for adjustment of said lens to focus images of subjects positioned at various distances from the camera on the camera focal plane, said method comprising the steps of:

coupling said lens element to said blade member so that said lens element is in an initial position when said blade element is in its initial position;

moving said blade member toward its said terminal position;

decoupling said lens element from said blade member during its movement in accordance with the distance of a subject from the camera so as to position said lens element at a location for focusing said subject at the focal plane of said camera; and

recoupling said lens element to said blade member as said blade member is returned to its said initial position so as to return said lens element to its said initial position in anticipation of subsequent movement of said blade element.

16. The method of claim **15** wherein said camera is an SLR camera and includes a displaceable reflex member for varying said camera between a viewing mode in which said reflex member blocks the taking path and an exposure mode in which said reflex member is in unblocking relation to the exposure path, and said initial

position of said blade member is a full open position of said exposure mechanism which is utilized for viewing in the viewing mode of said camera, and said recoupling step includes the coupling of said lens element to said blade member as said blade member is moved toward its initial position for viewing purposes and said decoupling step includes decoupling said lens element from said blade member as said blade member is moved toward its terminal position prior to varying of said camera to said exposure mode.

* * * * *

United States Patent [19]

Akashi et al.

[11] **Patent Number: 4,792,668**

[45] **Date of Patent: Dec. 20, 1988**

[54] **APPARATUS FOR DETECTING FOCUSING STATE OF OBJECTIVE LENS**

[75] Inventors: **Akira Akashi; Akira Ishizaki; Yasuo Suda,** all of Yokohama; **Ichiro Ohnuki,** Tokyo; **Keiji Ohtaka,** Tokyo; **Takeshi Koyama,** Tokyo, all of Japan

[73] Assignee: **Canon Kabushiki Kaisha,** Tokyo, Japan

[21] Appl. No.: **936,746**

[22] Filed: **Dec. 2, 1986**

[30] **Foreign Application Priority Data**

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Dec. 5, 1985 [JP] Japan 60-272564
Dec. 5, 1985 [JP] Japan 60-272565
Dec. 5, 1985 [JP] Japan 60-272566

[51] **Int. Cl.**[4] **G03B 3/00**
[52] **U.S. Cl.** **250/201;** 354/408
[58] **Field of Search** ..... 250/201 PF, 204; 354/406–408

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Primary Examiner—David C. Nelms
Assistant Examiner—Stephone B. Allen
Attorney, Agent, or Firm—Fitzpatrick, Cella, Harper & Scinto

[57] **ABSTRACT**

An apparatus for detecting a focusing state of an objective lens comprises optical means for forming light intensity distributions of object images whose relative positional relationship changes with the focusing state of the objective lens, sensing means having a plurality of sensors for sensing the light intensity distributions to produce first and second signals relating to the light intensity distributions, signal processing means for relatively displacing the first and second signals by determining correlation information and producing a signal for adjusting the focusing state of the objective lens in accordance with the correlation information, and altering means for altering a displacement range within which the first and second signals are relatively displaced.

10 Claims, 11 Drawing Sheets

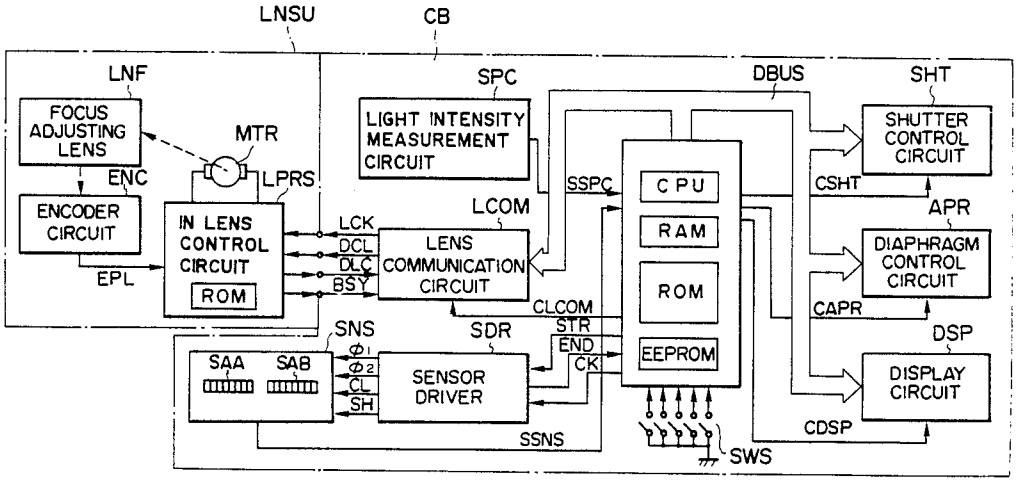
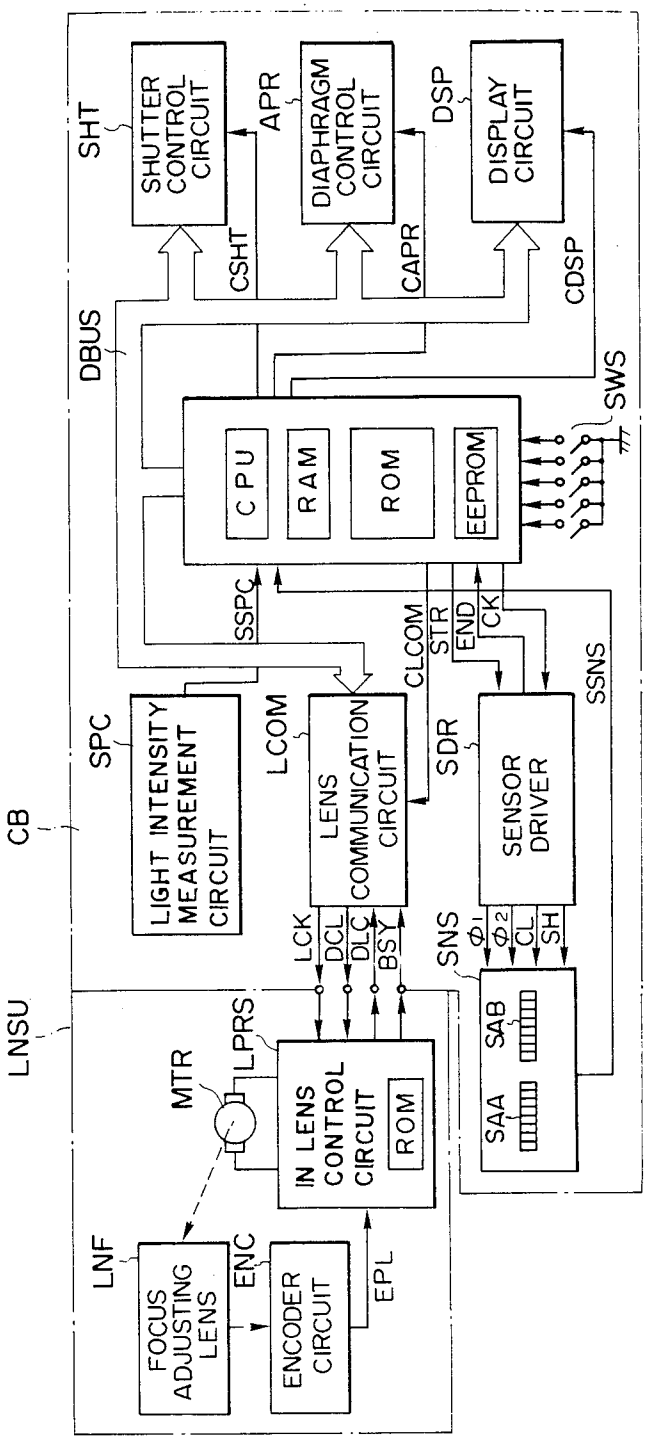


FIG. 1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APR
DIAPHRAGM CONTROL CIRCUIT
DSP
DISPLAY CIRCUIT
CSHT
CAPR
CDSP
DBUS
SWS
CPU
RAM
ROM
EEPROM
SSPC
CLCOM
STR
END
CK
SSNS
SPC
LIGHT INTENSITY MEASUREMENT CIRCUIT
LCOM
LENS COMMUNICATION CIRCUIT
SDR
SENSOR DRIVER
CB
LCK
DCL
DLC
BSY
SNS
Φ1
Φ2
CL
SH
LNSU
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ROM
SAB
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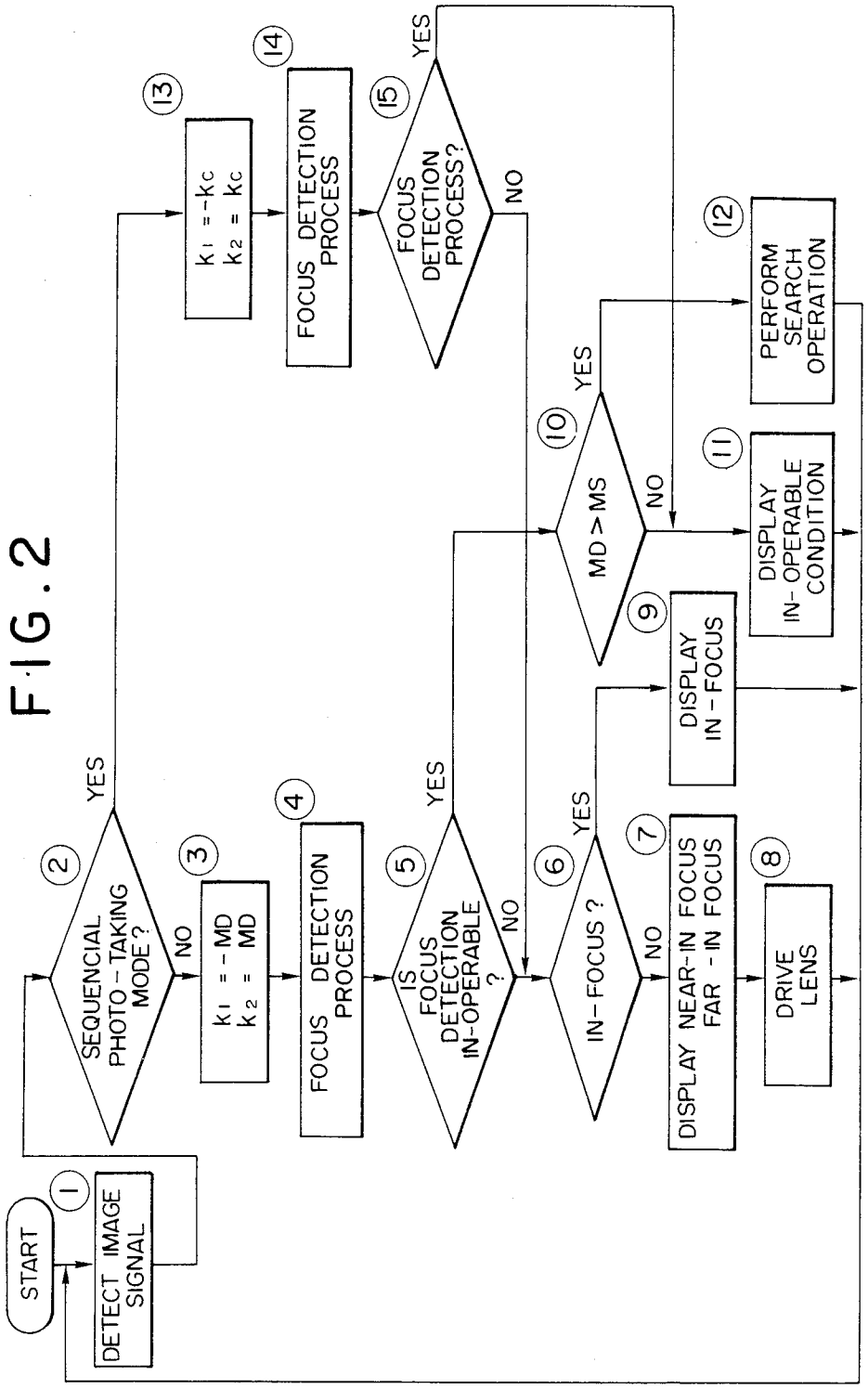
LNF
FOCUS ADJUSTING LENS
ENC
ENCODER CIRCUIT
EPL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DETECT IMAGE SIGNAL
SEQUENCIAL PHOTO-TAKING MODE?
YES
NO
k1 = -MD
k2 = MD
FOCUS DETECTION PROCESS
IS FOCUS DETECTION IN-OPERABLE ?
YES
NO
IN-FOCUS ?
YES
NO
DISPLAY NEAR-IN FOCUS FAR-IN FOCUS
DRIVE LENS
DISPLAY IN-FOCUS
MD > MS
YES
NO
DISPLAY IN-OPERABLE CONDITION
PERFORM SEARCH OPERATION
k1 = -kc
k2 = kc
FOCUS DETECTION PROCESS
FOCUS DETECTION PROCESS?
YES
NO
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15

FIG. 2

FIG. 3

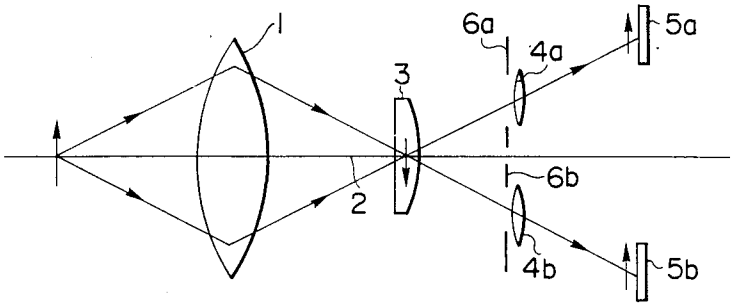


FIG. 4A

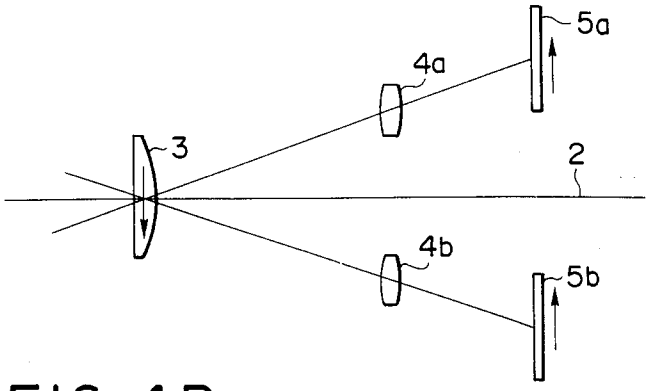


FIG. 4B

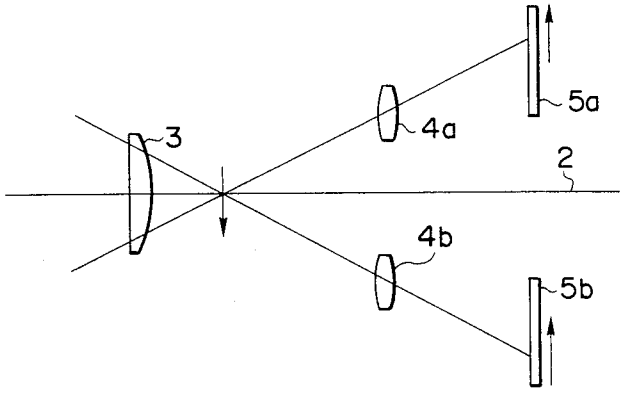


FIG. 4C

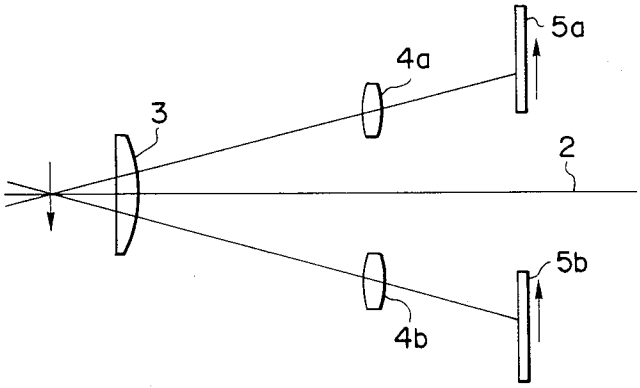


FIG. 5

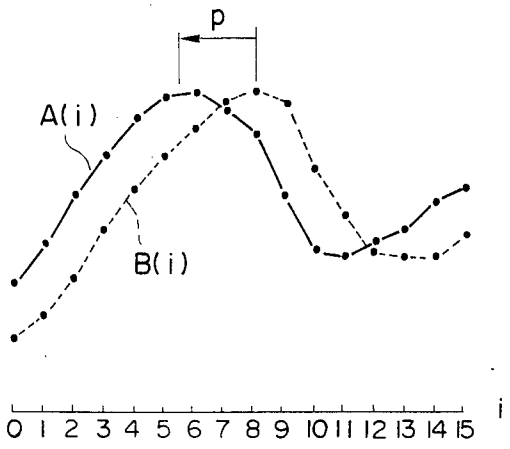


FIG. 6

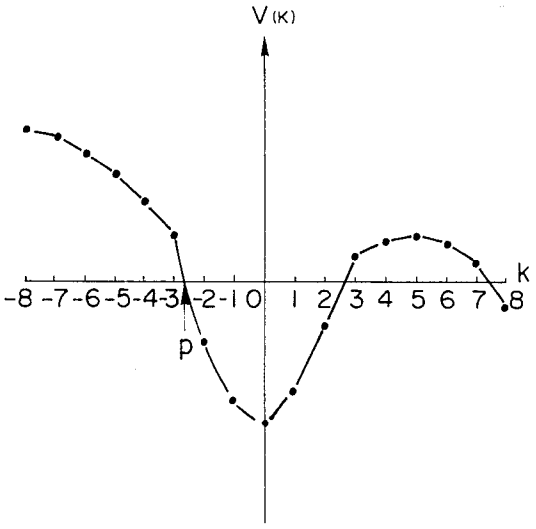


FIG. 7

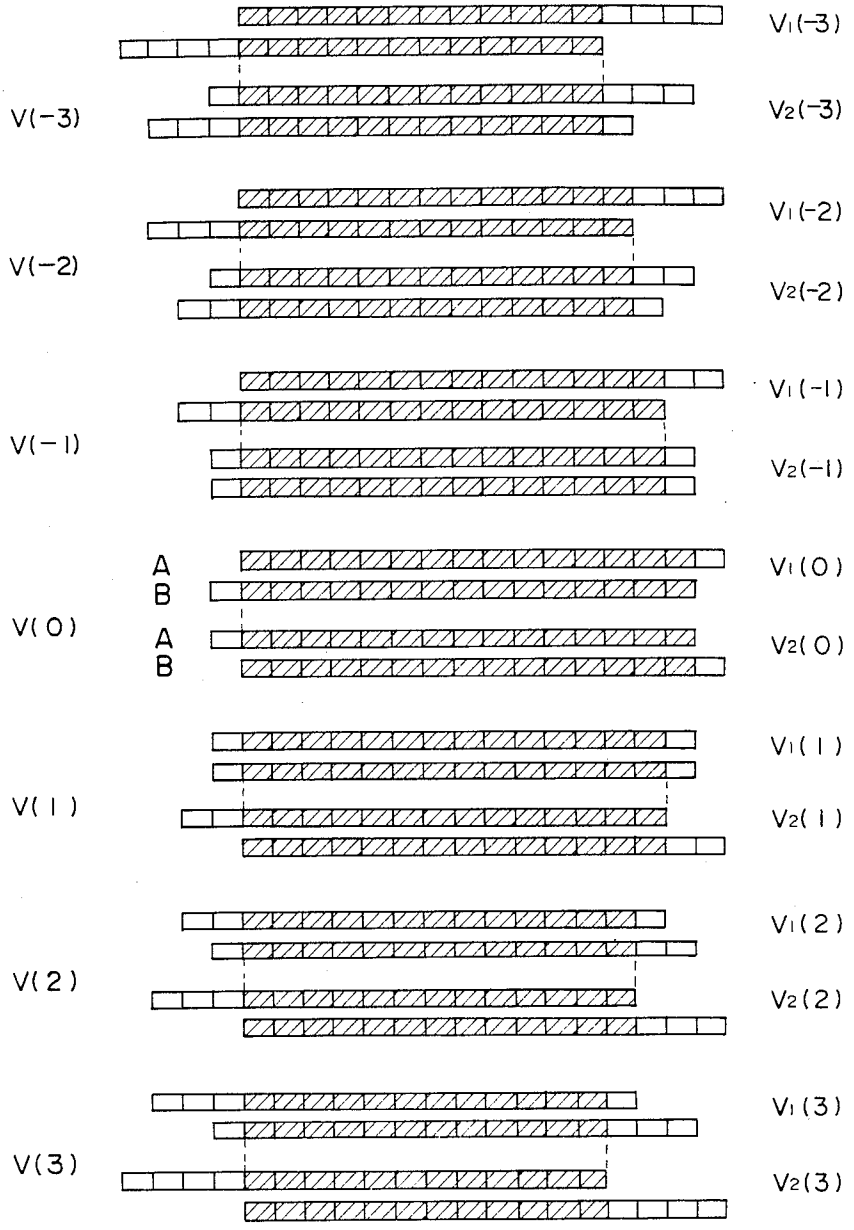
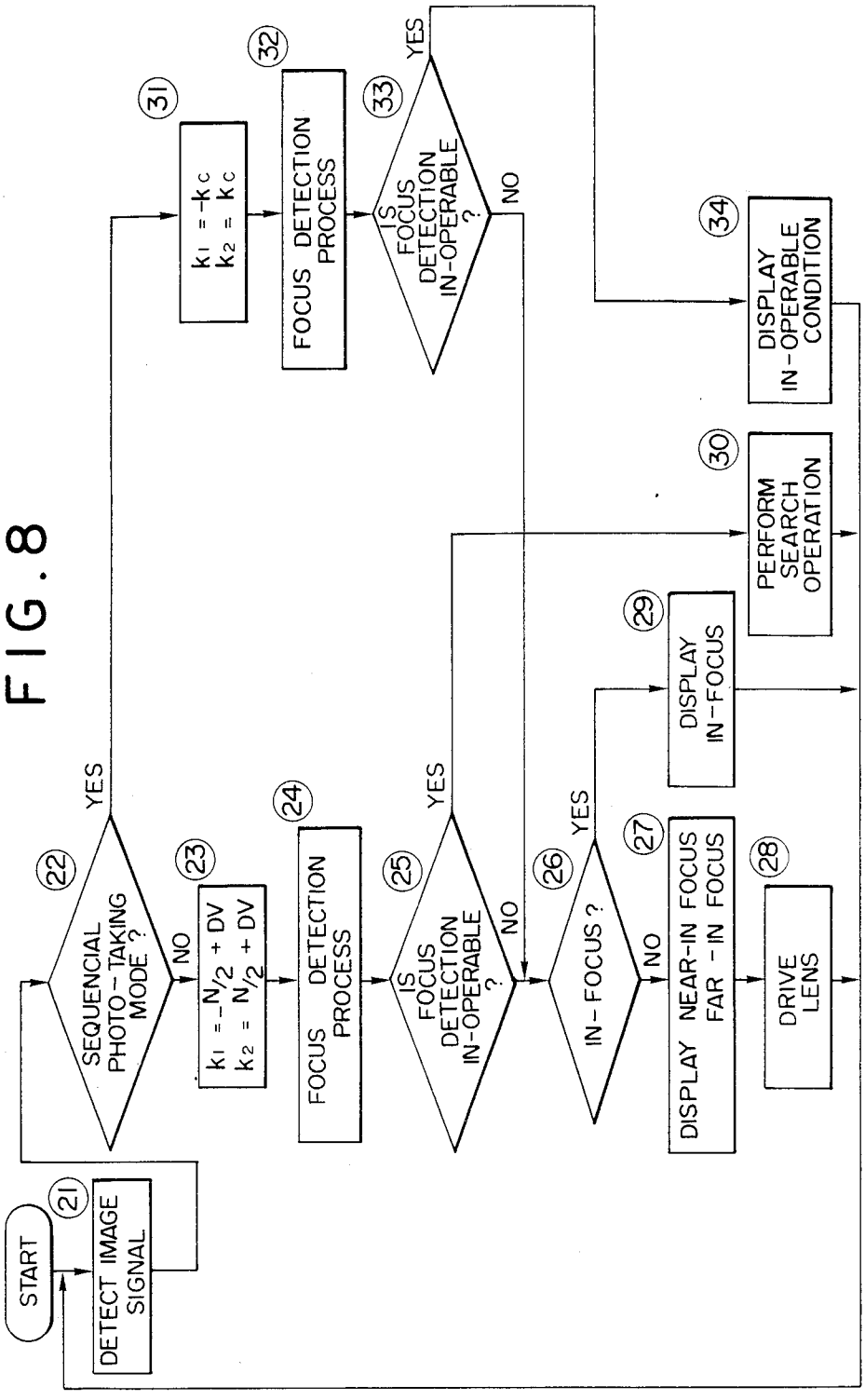
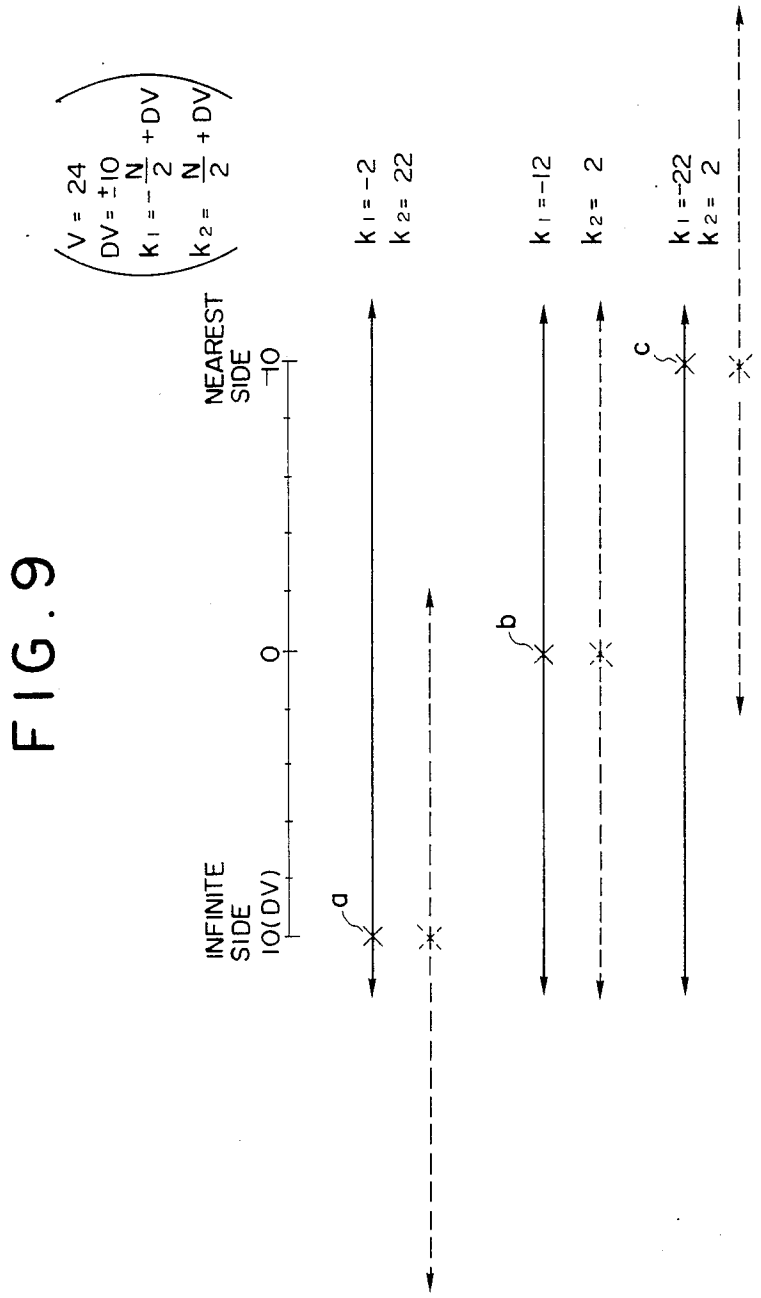

V(-3)
V1(-3)
V2(-3)
V(-2)
V1(-2)
V2(-2)
V(-1)
V1(-1)
V2(-1)
V(0)
A
B
A
B
V1(0)
V2(0)
V(1)
V1(1)
V2(1)
V(2)
V1(2)
V2(2)
V(3)
V1(3)
V2(3)

FIG. 8


START
DETECT IMAGE SIGNAL
21
SEQUENCIAL PHOTO-TAKING MODE ?
22
YES
NO
$k_1 = -k_c$
$k_2 = k_c$
31
FOCUS DETECTION PROCESS
32
IS FOCUS DETECTION IN-OPERABLE ?
33
YES
NO
DISPLAY IN-OPERABLE CONDITION
34
$k_1 = -N/2 + DV$
$k_2 = N/2 + DV$
23
FOCUS DETECTION PROCESS
24
IS FOCUS DETECTION IN-OPERABLE ?
25
YES
NO
PERFORM SEARCH OPERATION
30
IN-FOCUS ?
26
YES
NO
DISPLAY IN-FOCUS
29
DISPLAY NEAR-IN FOCUS FAR-IN FOCUS
27
DRIVE LENS
28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DV = ±10
k1 = −N/2 + DV
k2 = N/2 + DV
NEAREST SIDE
10
0
INFINITE SIDE
10(DV)
a
b
c
k1 = −2
k2 = 22
k1 = −12
k2 = 2
k1 = −22
k2 = 2

FIG. 9

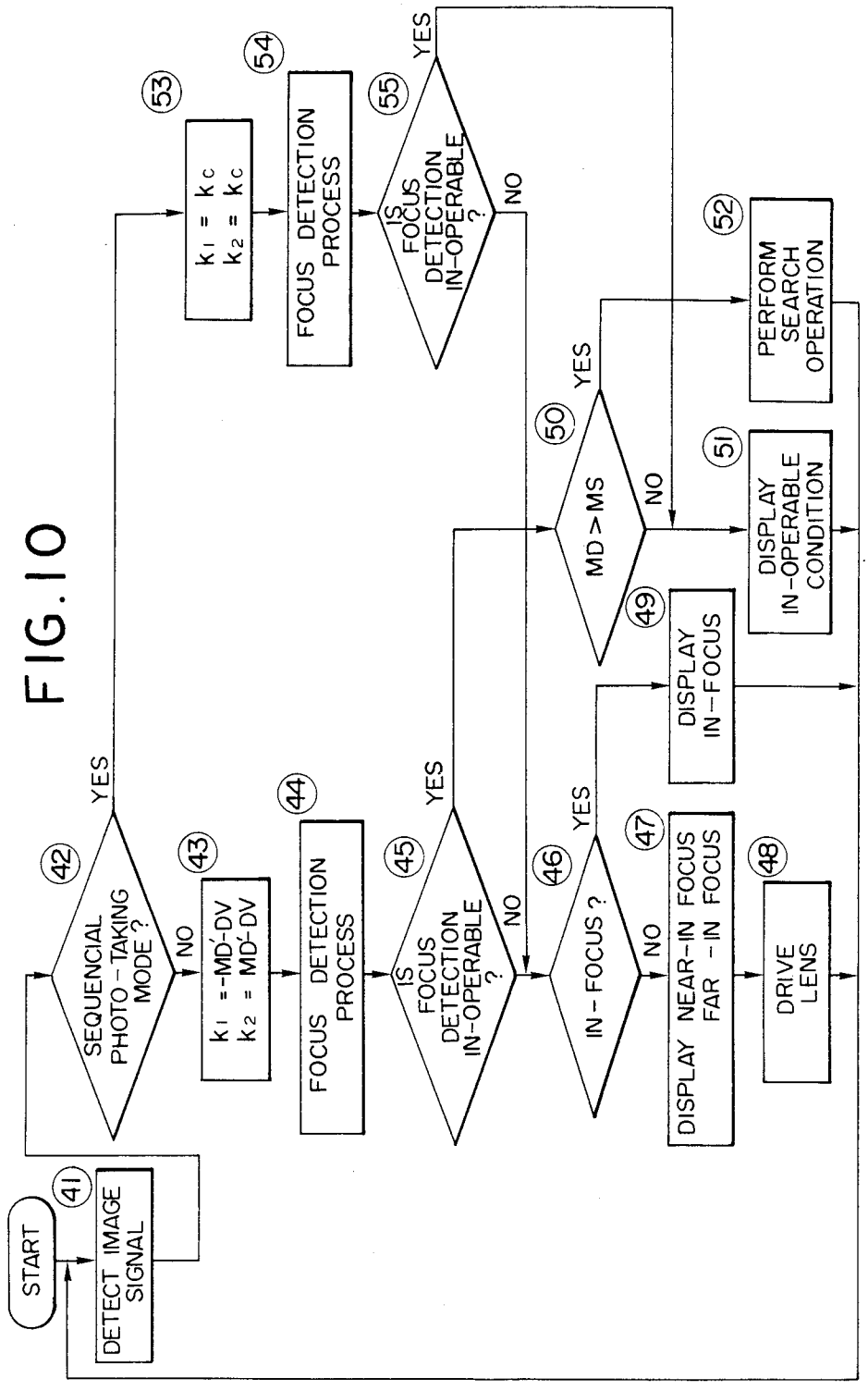

START
DETECT IMAGE SIGNAL
41
SEQUENCIAL PHOTO-TAKING MODE ?
42
YES
NO
k1 = -MD'DV
k2 = MD'DV
43
FOCUS DETECTION PROCESS
44
IS FOCUS DETECTION IN-OPERABLE ?
45
YES
NO
IN-FOCUS ?
46
YES
NO
DISPLAY NEAR-IN FOCUS FAR-IN FOCUS
47
DRIVE LENS
48
DISPLAY IN-FOCUS
49
MD > MS
50
YES
NO
DISPLAY IN-OPERABLE CONDITION
51
PERFORM SEARCH OPERATION
52
k1 = kc
k2 = kc
53
FOCUS DETECTION PROCESS
54
IS FOCUS DETECTION IN-OPERABLE ?
55
YES
NO

FIG. 10

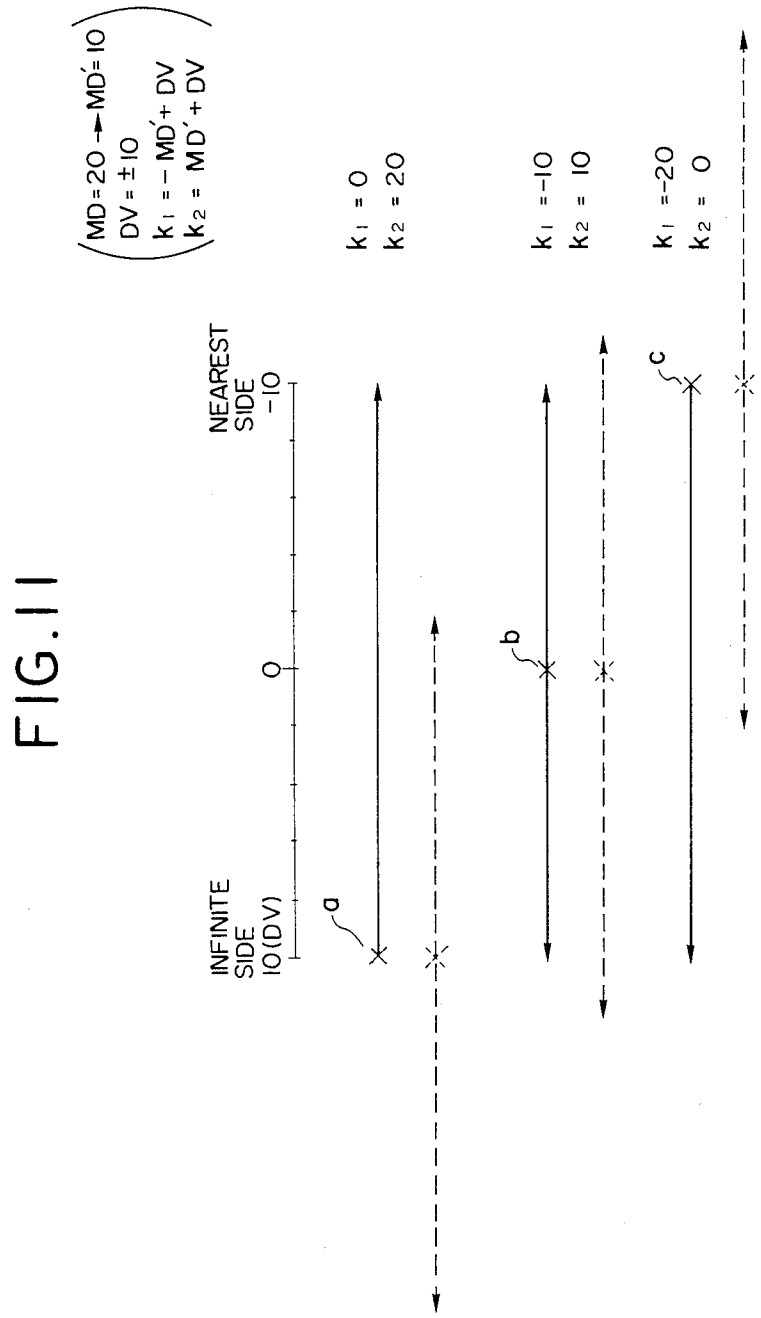
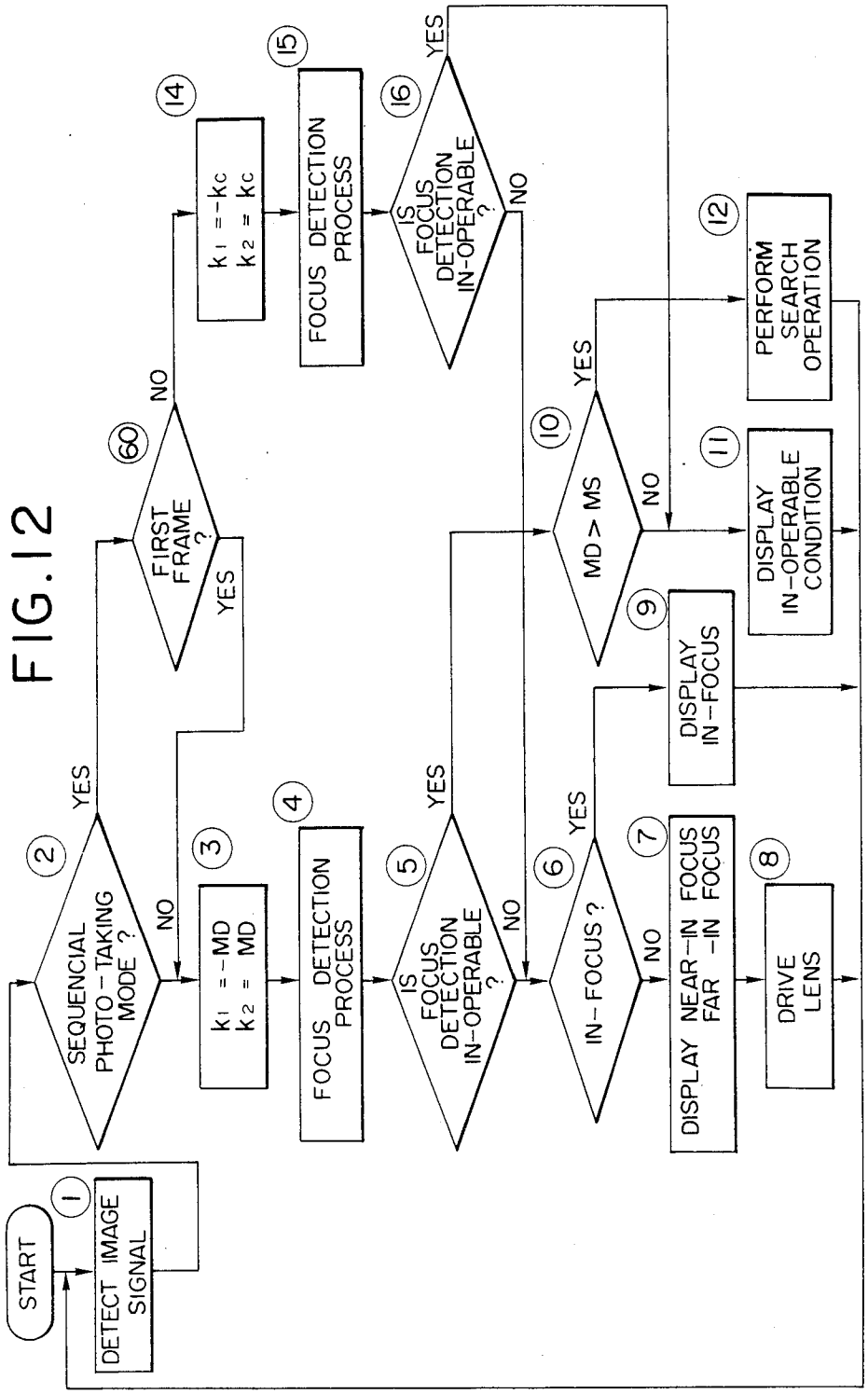

MD=20 → MD'=10
DV=±10
k1 = − MD'+ DV
k2 = MD'+ DV
k1 = 0
k2 = 20
k1 =-10
k2 = 10
k1 =-20
k2 = 0
NEAREST SIDE
-10
0
INFINITE SIDE
10(DV)
a
b
c

FIG. 11

FIG. 12


START
DETECT IMAGE SIGNAL
SEQUENCIAL PHOTO-TAKING MODE ?
YES
NO
FIRST FRAME ?
YES
NO
k1 = -MD
k2 = MD
FOCUS DETECTION PROCESS
IS FOCUS DETECTION IN-OPERABLE ?
YES
NO
IN-FOCUS ?
YES
NO
MD > MS
YES
NO
k1 = -kc
k2 = kc
FOCUS DETECTION PROCESS
IS FOCUS DETECTION IN-OPERABLE ?
YES
NO
DISPLAY IN-FOCUS
DISPLAY NEAR-IN FOCUS FAR-IN FOCUS
DRIVE LENS
DISPLAY IN-OPERABLE CONDITION
PERFORM SEARCH OPERATION
1
2
3
4
5
6
7
8
9
10
11
12
60
14
15
16

APPARATUS FOR DETECTING FOCUSING STATE OF OBJECTIVE LENS

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to an improvement in a focusing state detection apparatus which detects a focusing state by a relative positional relationship of light intensity distribution of two images of an object.

2. Related Background Art

In a prior art focus state detection apparatus for a camera, an exit pupil of an imaging lens is divided into two pupil areas and relative positional displacement of two light intensity distributions of two images formed by light fluxes transmitted through the pupil areas are observed to determine an in-focus state. For example, Japanese Patent Application Laid-Open Nos. 118019/1980 and 155331/1980 disclose a secondary focusing system in which a spatial image formed on a predetermined focus plane (corresponding to a film plane) by two secondary focusing optical systems is guided to two sensor planes so that relative positional displacement of the two images is detected.

The secondary focusing type focusing state detection apparatus is shown in FIG. 3. A field lens **3** is arranged coaxially with an optical axis **2** of an imaging lens **1** whose focusing state is to be detected. Two secondary focusing lenses **4***a* and **4***b* are arranged behind the field lens **3** symmetrically with respect to the optical axis **2**. Sensor arrays (Photo-electric conversion element arrays) **5***a* and **5***b* are arranged behind the lenses **4***a* and **4***b*. Diaphragms **6***a* and **6***b* are arranged in the vicinity of the secondary focusing lenses **4***a* and **4***b*. The field lens **3** essentially focuses an exit pupil of the imaging lens **1** onto pupil planes of the two secondary focusing lenses **4***a* and **4***b*. As a result, light fluxes applied to the secondary focusing lenses **4***a* and **4***b* correspond to those light fluxes which are emitted from non-overlapping equispace areas on the exit pupil plane of the imaging lens **1**, corresponding to the secondary focusing lenses **4***a* and **4***b*. When a spatial image formed in a vicinity of the field lens **3** is refocused on the planes of the arrays **5***a* and **5***b* by the secondary focusing lenses **4***a* and **4***b*, the positions of the two light intensity distributions of the two images on the sensor arrays **5***a* and **5***b* change in accordance with the displacement of the spatial image along the optical axis. FIG. **5** shows it. In FIG. **4**A which shows an in-focus state, the two light intensity distributions are positioned at the centers of the sensor arrays **5***a* and **5***b*, in FIG. **4**B which shows a near-focus state, the two light intensity distributions are moved away from the optical axis **2**, and in FIG. **4**C which shows a far-focus state, the two light intensity distributions are moved toward the optical axis **2**. These light intensity distributions are photo-electrically converted and the converted electrical signal is processed to detect a relative positional deviation of the two light intensity distributions. In this manner, the focusing state of the imaging lens **1** can be detected.

Methods for processing the photo-electrical converted signal from the sensor arrays **5***a* and **5***b* are disclosed in Japanese Patent application Laid-Open No. 142306/1983 and U.S. Pat. No. 4,333,007. Specifically, the following formula is operated for $k_1 \leqq k \leqq k_2$.

$$\begin{aligned} V(k) &= \sum_{i=0}^{M-1} A(i)\square B(i+|k|+1) - \sum_{i=0}^{M-1} A(i+1)\square B(i+|k|)\ (k<0) \\ &= \sum_{i=0}^{M-1} A(i+k)\square B(i+1) - \sum_{i=0}^{M-1} A(i+k+1)\square B(i)\ (k \geqq 0) \\ &= V_1(k) - V_2(k) \end{aligned} \tag{1}$$

where N is the number of sensors of the sensor array **5***a* or **5***b*, A(i) and B(i) are image signals from the i-th elements of the sensor arrays **5***a* and **5***b*, and M is the number of pixels processed ($M=N-k|-1$) $A(i)\square B(j)$ is an operator for A(i) and B(j). For example,

$$A(i)\square B(j) = |A(i)-B(j)\uparrow \tag{2}$$

$$A(i)\square B(j) = |A(i)-B(j)\uparrow^n \tag{3}$$

$$A(i)\square B(j) = \max|A(i), B(j)\uparrow \tag{4}$$

$$A(i)\square B(j) = \min|A(i)\ B(j)\uparrow \tag{5}$$

The formula (2) represents an absolute value of a difference between A(i) and B(i), the formula (3) represents accumulated product, the formula (4) represents a larger one of A(i) and B(j), and the formula (5) represents a smaller one. By the above definition, $V_1(k)$ and $V_2(k)$ can be considered as correlation amounts in a broad sense from the formula (1), $V_1(k)$ represents the correlation amount at a displacement $(k-1)$, and $V_2(k)$ represents the correlation amount at a displacement $(k+1)$. Accordingly, an evaluation amount V(k) which is the difference between $V_1(k)$ and $V_2(k)$ represents a change of correlation amount of the image signals A(i) and B(i) at a relative displacement k. Since a change is zero at the peak of the correlation amount, it is assumed that the peak of the correlation amount exists in a section [k, k+1] represented by

$$V(k)\cdot V(k+1) < 0 \tag{6}$$

and V(k) and V(k+1) are interpolated to detect the deviations of the image signals A(i) and B(i). FIG. **6** shows the light intensity distribution signals A(i) and B(i) for the two images formed when the number of sensors is 16 (N=16). There is a deviation of P. FIG. **7** shows the evaluation amount V(k) of the formula (2) when the relative displacement k is changed within a range of $-N/2 \leqq k \leqq N/2$. As described above, V(k) and V(k+1) which meet $V(k)\cdot V(k+1)<0$ are linearly interporated to detect the deviation P. FIG. **7** shows a relationship between the image signals A(i) and B(i) when the evaluation amount V(k) is calculated while the relative displacement k changes in a range of $-3 \leqq k \leqq 3$. Hatched areas show the sensors which are subject of the correlation.

The processing time of the evaluation amount V(k) significantly varies with a range of processing of the relative displacement k. Accordingly, it is preferable to limit the processing range to a narrow one. However, if the range is too narrow, the deviation of the two images when the imaging lens is in a large defocus state may depart from the processing range of the relative displacement k so that exact focusing state is not detected. Accordingly, a lower limit $k_1$and an upper limit k_2 of

the processing range are frequently set to $k_1 = -N/2$ and $k_2 = N/2$, where N is the number of sensors of the sensor array. However, where the processing range for the relative displacement k is preset, the processing may be done over unnecessary range if an imaging lens has a small defocusing state like a wide angle lens. In other words, excess processing is performed and unnecessary processing time is spent for the focusing state detection.

When the deviation P is calculated, contrasts of the two images are usably calculated. If the contrast is lower than a predetermined level, it is determined that the reliability of the resulting deviation P is low and the foucsing state detection is disabled. The disabling operation includes a so-called searching operation, in which the imaging lens is driven by a predetermined distance or continuously while expecting the increase of the contrast necessary for the focusing state detection. However, in the imaging lens having a relatively small maximum defocus amount such as a wide angle lens, the increase of the contrast by the searching operation is not expected because the defocus amount is inherently small.

On the other hand, if the imaging lens has a large maximum defocus amount such as a telescopic lens and the lens is in a large defocus state, a probability that the deviation P of the two images departs from the relative displacement k is high and the focusing state may not be detected.

In the prior art apparatus, since the focusing state detection operation takes a long processing time, high speed photographing cannot be attained particularly in a continuous photographing mode.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a focusing state detection apparatus which can reduce excess processing to detect the focusing state with a high response.

It is another object of the present invention to provide a focusing state detection apparatus which can exactly detect the focusing state for an exchange lens of an angle.

It is another object of the present invention to provide a focusing state detection apparatus which can exactly detect the focusing state, reduce waste processing and shorten focusing state detection time for an exchange lens of any angle.

It is another object of the present invention to provide a focusing state detection apparatus which can detect the focusing state to allow high speed continuous photographing.

In order to achieve the above objects, in an embodiment of the present invention, the processing range within which first and second signals are relatively displaced is varied with a maximum defocus amount inherent to an objective lens so that the smaller the maximum defocus amount of the objective lens is, the narrower is the processing range. When the focusing state detection is disabled, the maximum defocus amount of the objective lens is compared with a predetermined value, and if the former is smaller, the searching is inhibited so that the waste operation is prevented when the probability that the focusing state detection is enabled by searching is very low.

The processing range is varied in accordance with position information of a focusing component along an optical axis so that the processing range fully covers the movable range of the focusing component along the optical axis.

The processing range is varied in accordance with the maximum defocus amount of the objective lens and the position information of the focusing component along the optical axis so that the smaller the maximum defocus amount of the objective lens is, the narrower is the processing range, and the processing range always corresponds to the movable range of the focusing component along hhe optical axis.

In the continuous photographing mode, the processing range is narrower, compared to than a normal processing range after at least two frames of the continuous photographing mode so that the focusing state detection time is shortened.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** shows a block diagram of an embodiment of a focusing state detection apparatus of a camera in accordance with the present invention,

FIG. **2** shows a flow chart thereof,

FIG. **3** shows an arrangement of an optical system of a conventional secondary focusing type focusing state detection apparatus,

FIG. **4** shows a relationship between a focusing state and an image deviation in the secondary focusing system,

FIG. **5** shows image signals produced by two sensors in the secondary focusing system,

FIG. **6** shows a change of evaluation amount in the secondary focusing system,

FIG. **7** shows a relationship between two images in the focusing state detection in the secondary focusing system,

FIG. **8** shows a flow chart of another embodiment,

FIG. **9** shows a processing range for a relative displacement when position information of an imaging lens is used,

FIG. **10** shows a flow chart of another embodiment,

FIG. **11** shows a processing range for a relative displacement when position information of an imaging lens is used, and

FIG. **12** shows a flow chart of another embodiment.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The preferred embodiments of the present invention will now be described.

FIG. **1** shows a block diagram of an embodiment of a focusing state detection apparatus for a camera in accordance with the present invention. CB denotes a camera body. PRS denotes a control circuit of the camera which may be a one-chip microcomputer which contains CPU, RAM, ROM, EEPROM (electrically erasable programmable ROM) and input/output ports. The ROM and EEPROM store a series of controlling software and parameters including those for AF control, DBUS denotes a data bus, SHT denotes a shutter control circuit which accepts data supplied from the data bus DBUS while a control signal CSHT is supplied thereto from the control circuit PRS and controls the drive of a shutter leading curtain and trailing curtain in accordance with the input data. APR denotes a diaphragm control circuit which accepts data supplied from the data bus DBUS while the control signal CAPR is applied thereto and controls a diaphragm mechanism (not shown) in accordance with the input data. DSP denotes a display circuit which accepts data

supplied from the data bus DBUS while the control signal CDSP is applied thereto and displays imaging information based on the input data. SWS denotes a group of switches such as release switch, continuous photographing mode switch and information setting switches.

SPC denotes a light intensity measurement circuit. An analog light intensity signal SSPC from the circuit SPC is supplied to the control circuit PRS where it is A/D converted for use as light intensity data to control the shutter control circuit SHT and the diaphragm control circuit APR. LCOM denotes a lens communication circuit which accepts data supplied from the data bus DBUS while the control signal CLCOM is applied thereto and serially communicates with a lens unit to be described later in accordance with the input data. It transmits data DCL for driving the lens in synchronism with a clock signal LCK to an in-lens control circuit to be described later and serially receives from the in-lens control circuit, lens information DLC such as current position of the imaging lens. BSY denotes a signal to inform the camera that the imaging lens is moving. When this signal is present the serial communication is not undertaken.

LNSU denotes the lens unit, and LPRS denotes the in-lens control circuit for driving a motor MTR in accordance with the serial input data DCL to move the imaging lens LNF. It includes a ROM which stores the maximum defocus amount, a focal distance and an open F value of the imaging lens LNF. ENC denotes an encoder which detects a pulse signal generated as a lens bodytube (which holds the imaging lens LNF) is moved and supplies to the in-lens control circuit LPRS current axial position information DV of the imaging lens LNF, that is, current focusing state information. SDR denotes a sensor drive circuit for controlling a line sensor SNS such as CCD sensor having two sensor arrays SAA and SAB in accordance with the input signals from the control circuit PRS. The sensor arrays SAS and SAB may be two sections of one sensor array.

The operation is now explained with reference to a flow chart of FIG. 2. Because the operations of the shutter control circuit SHT, diaphragm control circuit APR, display circuit DSP and light intensity measurement circuit SPC are not directly related to the present invention, the explanation thereof is omitted.

(Step 1) The line sensor SNS is driven through the sensor drive circuit SDR to produce image signals A(i) and B(i) of the two images. The operations of the control circuit PRS, sensor drive circuit SDR and line sensor SNS are briefly explained. When a start of storage signal STR is generated in the control circuit PRS, the sensor drive circuit SDR supplies a clear signal CL to the line sensor SNS to clear charges of the photo-electric converters of the sensor arrays SAA and SAB. Then, the line sensor SNS starts the photo-electric conversion and charge storage of the optical images formed on the sensor arrays SAA and SAB by the secondary focusing lens (not shown in FIG. 1 but arrayed as shown in FIG. 3). After a predetermined time period since the above operation has been started, the sensor drive circuit SDR supplies a transfer signal SH to the line sensor SNS to transfer the charges stored in the photo-electric converters to the CCD. The sensor drive circuit SDR also senss an end of storage signal END to the control circuit PRS and waits for a CCD drive clock CK to be supplied from the control circuit PRS. When the CCD drive clock CK is supplied, the sensor drive circuit SDR generates CCD drive signals ϕ_1 and ϕ_2, which are supplied to the line sensor SNS. When the CCD drive signals ϕ_1 and ϕ_2 are supplied, the line sensor SNS supplies an analog image signal SSNS to the control circuit PRS. Thus, the control circuit PRS A/D converts the analog image signal SSNS in synchronism with the CCD drive clock CK and stores the image signals A(i) and B(i) of the two images at predetermined addresses in the RAM.

(Step 2) The state of the continuous photographing mode switch of the switch group SWS is checked, and if it is in the continuous photographing mode, the process proceeds to a step 13, and if not, the process proceeds to a step 3.

(Step 3) Communication is made with the lens unit LNSU through the lens communication circuit LCOM to obtain the maximum defocus amount MD of the imaging lens LNS currently mounted from the lens information DLC. The relative displacement k is then set in the processing range of $-MD \leqq k \leqq MD$, that is, $k_1 = -MD$ and $k_2 = MD$.

(Step 4) The correlation processing shown in the formulas (2)–(5) is performed to obtain the focusing state detection information or the deviation P of the two images.

(Step 5) If the contrast of the signal is too low to assure the reliability of the result even if the deviation P is detected, the focusing state cannot be detected. Thus, the process proceeds to a step 10. Otherwise, the process proceeds to a step 6.

(Step 6) The absolute value of the deviation P is compared with a predetermined value, and if the former is smaller, that is, in an in-focus state, the process proceeds to a step 9, and otherwise the process proceeds to a step 7.

(Step 7) A sign (plus or minus) of the deviation P is checked to determine near-focus or far-focus. The data thereof is sent to the display circuit DSP to display the focusing state.

(Step 8) The movement of the imaging lens LNF is calculated in accordance with the deviation P determined in the step 4 and the data thereof is sent to the in-lens control circuit LPRS through the lens communication circuit LCOM. The in-lens control circuit LPRS drives the motor MTR to move the imaging data to the position corresponding to the data, that is, until the number of encoder pulse signals EPL supplied from the encoder ENC reaches the number designated by the data.

(Step 9) Data indicating the in-focus state is sent to the display circuit DSP to display the in-focus state.

(Step 10) The maximum defocus amount MD obtained in the step 3 is compared with a fixed defocus amount MS, and if $MD > MS$, the process proceeds to a step 12, and and if $MD \leqq MS$, the process proceeds to a step 11.

(Step 11) If $MD \leqq MS$, it means that the maximum defocus value of the imaging lens LNF currently mounted is relatively small. In this case, even if the imaging lens LNF is driven by a predetermined distance, that is, searched to retry the focusing state detection, the increase of the contrast is not expected because the maximum defocus amount is inherently small and hence a probability that the focusing state detection is enabled is low. Accordingly, in such a case, the searching is not carried out and the data indicating that the focusing state detection is disable is supplied to the

display circuit DSP and displayed thereby. Then, the process returns to the step 1.

(Step 12) If MD>MS, a probability that the focusing state detection is enabled by the searching is high, as opposed to the case where MD≦MS. Thus, the searching is carried out.

(Step 13) In the continuous photographing mode, the focusing state must be detected in a shorter time than the single photographing mode. During the continuous photographing mode, it is expected that the change of defocus amount of the object is small. Accordingly, a relative displacement k_c in a relatively narrow processing range is set, that is, $k_1=-k_c$ and $k_2=k_c$ to speed up the processing.

(Step 14) The correlation processing is performed in the processing range set in the step 13 to obtain the focusing state detection information.

(Step 15) Whether the focusing state detection is enabled or not is determined like in the step 5. If the focusing state detection is disabled, the searching in the continuous photographing mode is not desirable in view of high speed photographing. Accordingly, the process proceeds to the step 11 to display the disabling. If the focusing state detection is enabled, the process proceeds to the step 6 to determine whether in-focus state is attained or not. Then, the process proceeds to the step 9 or steps 7 and 8.

In the present embodiment, the maximum defocus amount MD of the lens currently mounted is obtained from the ROM in the in-lens control circuit LPRS, the processing range for the correlation processing is set in accordance with the maximum defocus amount MD, that is, the range of the relative displacement k is set widely if a lens having a large maximum defocus amount such as a telescopic lens is mounted and the range of the relative displacement k is set narrowly if a lens having a small maximum defocus amount MD such as a wide angle lens is mounted. Accordingly, in the former case, the disabling of the focusing state detection due to loss of common intensity distribution when the defocus amount is large is prevented, and in the latter case, a excess processing time is omitted and the focusing state detection time is shortened.

In the present embodiment, the maximum defocus amount MD of the lens mounted is obtained from the lens unit LNSU. The present invenion is also applicable to a case where such information is manually set. A zoom lens having a selectable focal distance may be used.

In the present embodiment, the maximum defocus amount MD of the lens currently mounted is obtained from the ROM of the in-lens control circuit LPRS and whether the searching is to be carried out or not is determined in accordance with MD. Namely, if the imaging lens (such as a wide angle lens which does not bring an expected effect even if the searching is carried when the focusing state detection is disabled) is mounted, the searching is not carried out. Accordingly, the focusing state detection time is shortened and waste power consumption is prevented.

In the present embodiment, the maximum defocus amount of the imaging lens is compared with the fixed defocus amount MS. An intensity may be added to the fixed defocus amount. That is, if the intensity is low, the fixed defocus amount MS may be somewhat lowered to broaden the range of the searching.

An operation of another embodiment is explained with reference to FIGS. **8** and **9**.

(Step 21) This step is identical to the step **1** of FIG. **2**.

(Step 22) The state of the continuous photographing mode switch of the switch group SWS is checked. If it is the continuous photographing mode, the process proceeds to a step **31**, and if not, the process proceeds to a process **23**.

(Step 23) Communication is established with the lens unit LNSU through the lens communication circuit LCOM to obtain the position information DV of the imaging lens LNF from the lens information DLC, and the processing range for the relative displacement k is set to $-N/2+DV\leqq k\leqq N/2+DV$, that is, $k_1=-N/2+DV$, $k_2=N/2+DV$, in accordance with the position information DV.

The position information DV is zero when the imaging lens LNF is at the center of the movable range, negative when it moves toward a near position. and positive when it moves toward an infinite position Accordingly, the imaging lens LNF is displaced in a direction at which all of the above described processing range can be covered, keeping the relative displacement k in the processing range constant.

That is explained in further detail with reference to FIG. **3**.

For example, in view of that the number of pixels in a sensor arrays SAA and SAB is 24 (N=24), the processing range of the displacement k is set to be $-12\leqq k\leqq 12$. Let us assume, in view of the above state, that the movable range of the imaging lens LNF is 20 mm, and the displacement of one pixel of the sensor corresponding to 1 mm in the movable range of the imaging lens LNF. When the imaging lens LNS is at an arrow position a (infinite position), the position information DV is (+10) and the processing range is

$$k_1=-12+10=-2$$

$$k_2=12+10=22$$

In the above case, where the processing range of the relative displacement k is constant, the displacement in the processing range becomes large, as shown in FIG. **3**.

In the prior art system the processing range for the relative displacement k is that shown by broken lines and hense the focusing state detection is disabled when the defocus amount is large. By the use of the positional information DV, the area which could not heretofore been covered can be included in the processing range and the disabling of the focusing state detection is prevented. On the other hand, when the imaging lens LNF is at an arrow position c (very near position), the position information DV is −10 and the processing range is

$$k_1=-12+(-10)=-22$$

$$k_2=12+(-10)=2$$

In that case, the displacement in a indifinite direction to be covered with the process becomes larger. When the imaging lens LNF is at an arrow position b (center of the movable range), the operation is the same as that in the prior art.

(Step 24) The correlation processing shown in the formula (1) is carried out to obtain the focusing state detection information or the deviation P of the two images.

(Steps 25 to 28) These steps are identical to the steps 5 to 8.

(Step 30) The imaging lens LNF is driven by a predetermined distance for searching.

(Step 31) In the continuous photographing mode, the focusing state must be detected in a shorter time than the single photographing mode, and the change of the defocus amount of the object is small. Thus, the relative displacement k_c is set to a relatively narrow processing range, that is, $k_1 = -k_c$ and $k_2 = k_c$ to speed up the processing.

(Step 32) The correlation processing is carried out to obtain the focusing state detection information in the processing range set in the step 31.

(Step 33) Whether the focusing state detection is enabled or not is detected as is done in the step 25. If the focusing state detection is disabled, the process proceeds to a process **34**, and if it is enabled, the process proceeds to a step 26 to determine if the in-focus state is attained. Then, the process proceeds to the step 29 or the steps 27 and 28.

(Step 34) Since it is not desirable to carry out the searching during the continuous photographing mode in view of speed, data indicating that the focusing state detection is disabled is sent to the display circuit DSP for displaying it.

In the embodiment shown in FIGS. **8** and **9**, the range of the relative displacement k is set in accordance with the position information DV of the imaging lens LNF at the start of the focusing state detection. Accordingly, the focusing state detection is assured even if an imaging lens LNF having the defocus amount of as large as N/2 is mounted.

The operation where the position information DV and the maximum defocus amount MD of the imaging lens LNF are used is explained with reference to FIGS. **10** and **11**.

(Step 41) The line sensor SNS is driven through the sensor drive circuit SDR to obtain the image signals A(i) and B(i) of the two images.

(Step 42) The state of the continuous photographing mode switch of the switch group SWS is checked. If it is the continuous photographing mode, the process proceeds to a step 53, and if not, the process proceed to a step 43.

(Step 43) Communication is established with the lens unit LNSU through the lens communication circuit LCOM to obtain the maximum defocus amount MD' of the imaging lens LNF currently mounted (for example, one half of the maximum defocus amount MD of the actual imaging lens LNF) and the position information DV of the imaging lens LNF from the lens information DLC, and the relative displacement k is set in the range of $-MD'+DV \leqq k \leqq MD'+DV$, that is, $k_1 = -MD'+DV$, $k_2 = ML'+DV$, in accordance with the above information. As described above, the position information DV is zero when the imaging lens LNF is at the center of the movable range, negative when it moves toward a near position, and positive when it moves toward an infinite position. Accordingly, when the processing range for the relative displacement k is determined, the maximum defocus amount MD' which is, for example, one half of the maximum defocus amount MD of the actual imaging lens LNF is used. Thus, this value is used as the maximum defocus amount of the imaging lens LNF.

This is explained in further detail with reference to FIG. **11**. Let us assume that the maximum defocus amount MD' of the imaging lens LNF is 10 mm (actual maximum defocus amount MD is 20 mm) and the movable range of the imaging lens LNS is 20 mm. When the imaging lens LNS is at an arrow position a (infinite position), the position information DV is 10 and the processing range is

$$k_1 = -10+10=0$$

$$k_2 = 10+10=20$$

Thus, as shown in FIG. **11**, the processing range coincides with the movable range of the imaging lens LNS, and the disabling of the focusing state detection is prevented and no waste processing is carried out. In the prior art system (which the number of pixels is 24 (N=24)), the processing range for the relative displacement k is that shown by broken lines and hence a long time is required for the focusing state detection (this is remarkable for a wide angle lens) and the focusing state detection is disabled when the defocus amount is large. By the use of the maximum defocus amount MD', the processing range coincides with the movable range of the imaging lens LNF. By the use of the position information DV, the portion which could not heretofore been covered can be included in the processing range. Accordingly, the focusing state detection time can be shortened and the disabling of the focusing state detection is prevented. When the imaging lens is at an arrow position C (very near position), the positional information DV is -10 and the processing range is

$$k_1 = -10+(-10)=-20$$

$$k_2 = 10+(-10)=0$$

when the imaging lens LNF is at an arrow position b (center of the movable range), the position information DV is 0 and the processing range is

$$k_1 = -10+0=-10$$

ti $k_2 = 10+0=10$

[Step 44] The correlation processing shown in the formula (1) is carried out to obtain the focusing state detection information or the deviation P of the two images.

[Step 45]If the reliability of the result is low because the contrast of the signal is low even if the deviation P can be detected, the focusing state detection is disabled. In this case, the process proceeds to a step 50, and if the focusing state detection is enabled, the process proceeds to a step 46.

[Step 46] The absolute value of the deviation P is compared with a predetermined value, and if the former is smaller, that is, if the displacement is such that the focusing state can be regarded as in-focus state, the process proceeds to a step 49, and if the former is larger, the process proceeds to a step 47.

[Step 47] Whether the focusing state is near-focus or far-focus is determined by the sign (plus or minus) of the deviation P, and the detected data is sent to the display circuit DSP to display the focusing state.

[Step 48] The distance of drive of the imaging lens LNF is calculated based on the deviation P obtained in the step 44, and the calculated data is sent to the in-lens control circuit LPRS through the lens communication circuit LCON. The operation of the lens unit LNSU is briefly explained. The in-lens control circuit LPRS drives the motor MTR to drive the imaging lens LNS to the position corresponding to the above data, that is, to

drive the imaging lens LNS until the number of encoder pulse signals EPL supplied from the encoder ENC searches the value specified by the data.

[Step 49] The data indicating the in-focus state is sent to the display circuit DSP to display it.

[Step 50] The maximum defocus amount MD obtained in the step 43 and determined to disable the focusing state detection in the step 45 is compared with the fixed defocus amount MS, and if MD>MS, the process proceeds to a step 52, and if MD≦MS, the process proceeds to a step 51.

[Step 51] If MD≦MS, it means that the maximum defocus amount of the imaging lens LNF currently mounted is relatively small. In this case, even if the imaging lens LNF is moved by a predetermined distance, that is, searching is carried out to detect the focusing state, the increase of the contrast is not expected because the defocus amount is inherently small. Thus, a probability that the focusing state detection is enabled is low. Accordingly, in such a case, the searching is not carried out and the data indicating that the focusing state detection is disabled is supplied to the display circuit DSP to display it. Then, the process returns to the step 41.

[Step 52] If MD>MS, a probability that the focusing state detection is enabled by the searching is high a opposed to the case where MD≦MS. Thus, the searching is carried out.

[Step 53] This is identical to the step 31 of FIG. **8**.

[Step 54] This is identical to the step 32 of FIG. **8**.

[Step 55] Like in the step 45, whether the focusing state detection is enabled or not is determined, and if the focusing state detection is disabled, the searching during the continuous photographing mode is not preferable from the standpoint of speed. Thus, the process proceeds to the step 51 to display the disabling. If the focusing state detection is enabled, the process proceeds to the step 46 where whether the in-focus state is attained or not is checked. Then, the process proceeds to the step 49 or the steps 47 and 48.

In the embodiment of FIG. **10**, the maximum defocus amount MD of the lens currently mounted is obtained from the ROM in the in-lens control circuit LPRS, and the processing range for the relative displacement k is set in accordance with the maximum defocus amount MD. That is, when a lens having a large maximum defocus amount such as a telescopic lens is mounted, the processing range is set widely, and if a lens having a small maximum defocus amount MD such as a wide angle lens is mounted, the processing range is set narrowly. The position information DV of the imaging lens LNF at the start of the focusing state detection is obtained and the relative displacement k is displaced in an effective direciton to determine the processing range. Accordingly, the processing range coincides with the movable range of the imaging lens LNF and whatever focusing lens is mounted the focusing state detection is assured and excess processing time can be saved so that the focusing state detection time can be shortened.

FIG. **12** shows a flow chart of another embodiment. Most portions of this flow chart correspond to the flow chart of FIG. **2** and a step 60 is newly added.

[Step 60] Whether a frame is the first one in the continuous photographing mode or not is checked. If it is, the process proceeds to the step 3, and if not, the process proceeds to the step 14.

In the present embodiment, during the continuous photographing mode, the range of correlation processing, that is, the processing range is narrowed. Accordingly, the focusing state detection time is shortened and the focusing state detection compatible to the high speed continuous photographing can be carried out. At a second frame in the continuous photographing mode, the operation is the same as that of the normal photographing mode (single photographing mode). The range of displacement is set to the relative displacement kc in or after the second frame. Accordingly, a probability that the focusing state detection is disabled is lowered.

In the present embodiment, the operation in the first frame of the continuous photographing mode is the same as that of the normal photographing mode. Alternatively, in the continuous photographing mode, the process may immediately proceed to the step 14, that is, the processing range may be set to the relative displacement kc. As a result, a probability that the focusing state detection is enabled is lowered but photographing suitable to the continuous photographing mode is attained.

We claim:

1. An apparatus for detecting a focusing state of an objective lens, comprising:

light intensity forming optical means for forming light intensity distributions concerning images whose relative positional relationship changes with the focusing state of the objective lens;

sensing means having a plurality of sensors for sensing said light intensity distributions to produce first and second signals relating to the light intensity distributions;

signal processing means for relatively shifting the first and second signals by determining correlation information and producing a focusing signal for the objective lens in accordance with the correlation information; and

altering means for altering a displacement range within which the first and second signals are relatively displaced.

2. An appartus for detecting a focusing state of an objective lens according to claim **1** wherein said altering means alters the displacement in accordance with a maximum defocus amount inherent to the objective lens.

3. An apparatus for detecting a focusing state of an objective lens according to claim **1** wherein said altering means alters a displacement in accordance with a current focus setting of the objective lens.

4. An apparatus for detecting a focusing state of an objective lens according to claim **1** wherein said altering means alters a displacement in accordance with a maximum defocus amount inherent to the objetive lens and a position of a focusing area of the objective lens on a optical axis.

5. An apparatus for detecting a focusing state of an objective lens according to claim **1** wherein said altering means alters a displacement smaller than a normal displacement in and after a second frame in a continuous photographing mode.

6. A camera system comprising: an imaging lens assembly removably mounted on a camera body and having a focusing lens unit including focusing lens means for forming an object image and information storage means for storing defocus information on a maximum defocus amount;

said camera body including light intensity distribution forming means for forming light intensity distributions concerning images whose relative posi-

tional relationship changes in accordance with a focusing state of the focusing lens means, sensing means having a plurality of sensors for sensing the light intensity distributions to produce first and second signals relating to the light distributions, signal processing means for relatively displacing the first and second signals by determining correlation information and producing a signal for adjusting the focusing state of said focusing lens means in accordance with said correlation information, and altering means for altering a displacement range within which said first and second signals are relatively displaced in accordance with defocus information stored in said information storage means.

7. A camera system according to claim **6** wherein said camera body further includes position detection means for detecting a position of said focusing lens unit on an optical axis to produce position information, and said altering means alters the diplacement range in accordance with said position information.

8. A camera system according to claim **6** wherein said camera body further includes mode selection means for (1) selecting a continuous photographing mode or a single photographing mode, and (2) producing continuous photographing mode information indicating at least a second frame in the continuous photographing mode, and wherein said altering means narrows the displacement range in accordance with the continuous photographing mode information.

9. A camera system according to claim **6** wherein said signal processing means causes said camera system to operate in a non-standard manner if a focusing state of said focusing lens means cannot be detected, and said camera body further includes inhibit means for inhibiting the non-standard operation when said defocus information is smaller than a predetermined value.

10. An apparatus for detecting a focusing state of an objective lens, comprising:

light intensity distribution forming means for forming light intensity distributions concerning images whose relative positional relationship changes with the focusing state of the objective lens;

sensing means having a plurality of sensors for sensing the light intensity distributions to produce first and second signals relating to the light intensity distributions;

signal processing means for (1) relatively shifting said first and second signals by determining correlation information and producing a signal for adjustng the focusing state of the objective lens in accordance with said correlation information, and (2) producing a search signal for causing the objective lens to search when the focusing state detection is disabled; and

search inhibit means for inhibiting the searching when a maximum defocus amount of the objective lens is smaller than a predetermined value.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 4,792,668

DATED : December 20, 1988

INVENTOR(S) : Akashi, et al

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

COLUMN 2

Line 16, change "(M=N-k|-1)" to --(M=N-|k|-1),--;
Lines 18-23, In each of equations (2) and (3), change "*B(j)*↑" to --*B(j)*|--; and
In each of equations (4) and (5), change "|*A(i),B(j)*↑" to --*[A(i),B(j)]*--.

COLUMN 3

Line 65, change "is" to --which is--.

COLUMN 4

Line 10, change "hhe" to --the--; and
Line 12, delete "than".

COLUMN 6

Line 56, change "and and" to --and--.

COLUMN 7

Line 42, delete "a".

COLUMN 8

Line 18, change "position" to --position.--;
Line 26, delete "a"; and
Line 47, change "heretofore" to --have heretofore--.

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 4,792,668

DATED : December 20, 1988

INVENTOR(S) : Akashi, et al

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

COLUMN 10
Line 39, delete "ti".

COLUMN 11
Line 26, change "a" to --as--.

COLUMN 12
Line 40, change "appartus" to --apparatus--.

Signed and Sealed this

Seventeenth Day of October, 1989

Attest:

Attesting Officer

DONALD J. QUIGG

Commissioner of Patents and Trademarks

United States Patent [19]

Kudo et al.

[11] **Patent Number: 4,787,724**

[45] **Date of Patent: Nov. 29, 1988**

[54] **TRIPLET TYPE OBJECTIVE WITH A DIAPHRAGM ARRANGED BEHIND THE LENS SYSTEM**

[75] Inventors: **Yoshinobu Kudo**, Sakai; **Akira Fukushima**, Osaka; **Kazuo Kimura**, Sakai, all of Japan

[73] Assignee: **Minolta Camera Kabushiki Kaisha**, Osaka, Japan

[21] Appl. No.: **11,980**

[22] Filed: **Feb. 6, 1987**

[30] **Foreign Application Priority Data**

Feb. 7, 1986 [JP] Japan 61-26610

[51] **Int. Cl.**[4] **G02B 9/14**

[52] **U.S. Cl.** **350/475**; 350/449

[58] **Field of Search** 350/475, 449, 474, 463, 350/432

[56] **References Cited**

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59-160120	9/1984	Japan .
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60-162217	8/1985	Japan .
60-177313	9/1985	Japan .
60-107612	6/1986	Japan .

Primary Examiner—John K. Corbin
Assistant Examiner—Ronald M. Kachmarik
Attorney, Agent, or Firm—Price, Gess & Ubell

[57] **ABSTRACT**

In a triplet type objective for a compact lens shutter camera with a diaphragm arranged behind the lens system, the first lens element is formed of glass and the second and third lens elements are formed of plastic, so that it is advantageous in manufacturing cost and weight. Furthermore, sufficient marginal light rays and flatness of the image field can be obtained.

9 Claims, 8 Drawing Sheets

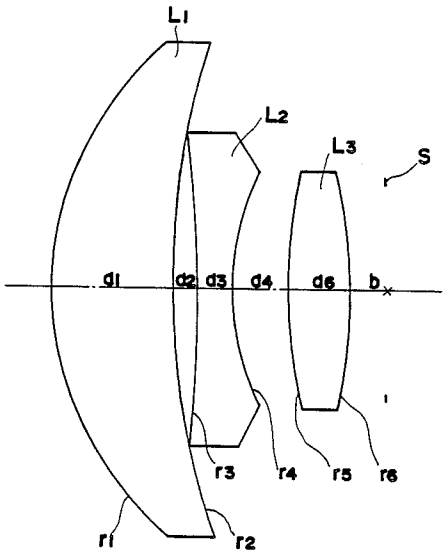


FIG.1

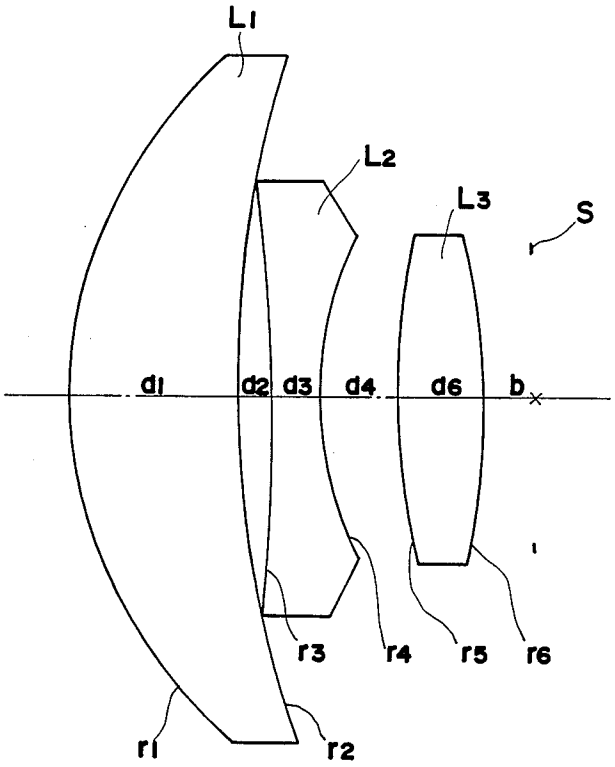


FIG.2A

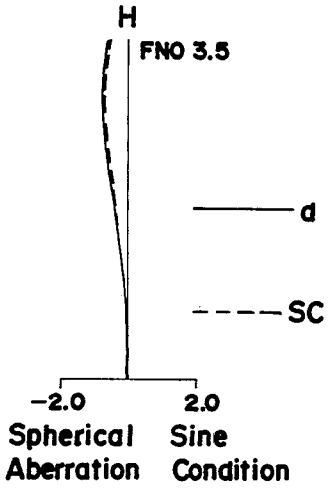


FIG.2B

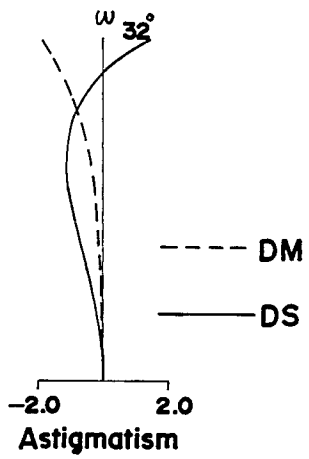


FIG.2C

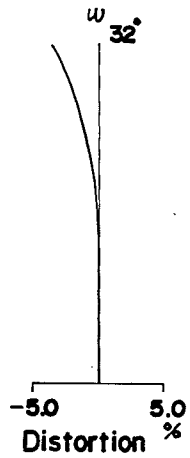


FIG.3A

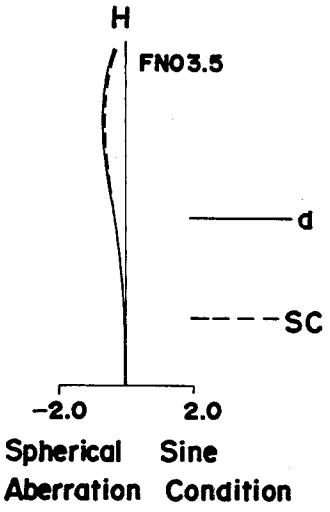


FIG.3B

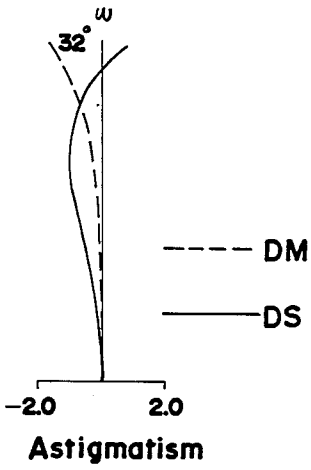


FIG.3C

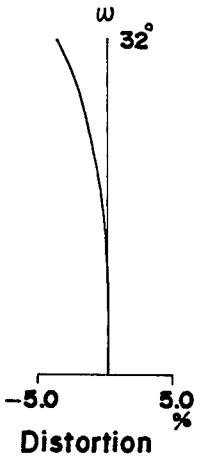


FIG.4A

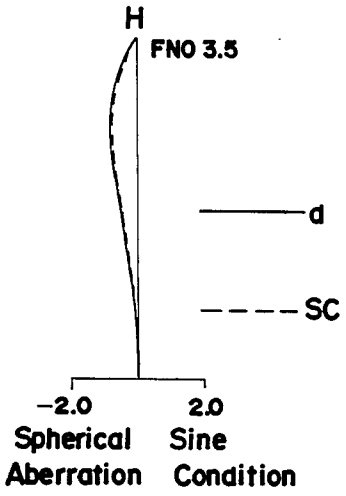


FIG.4B

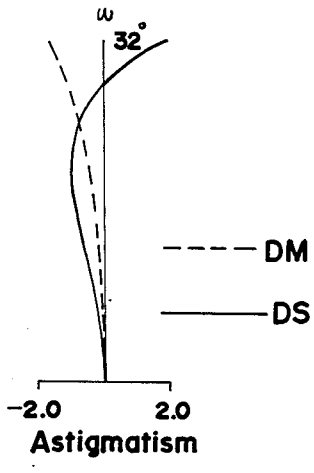


FIG.4C

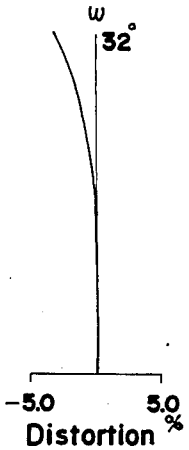


FIG.5A

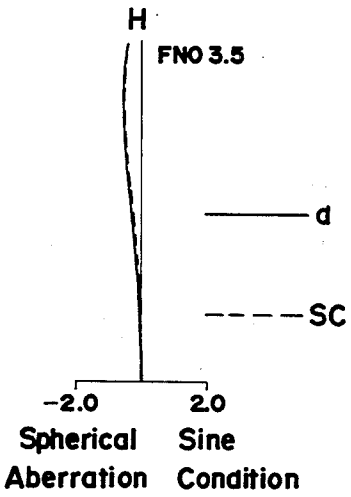


FIG.5B

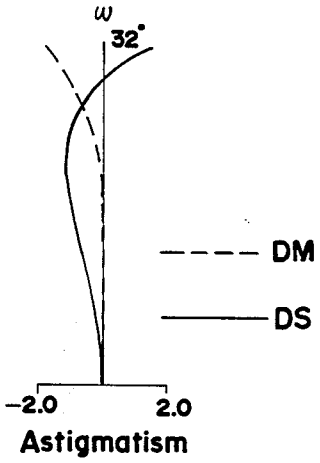


FIG.5C

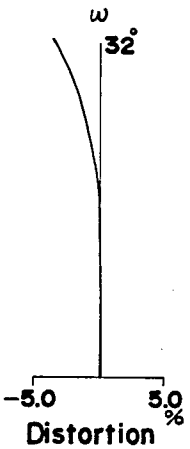


FIG.6A

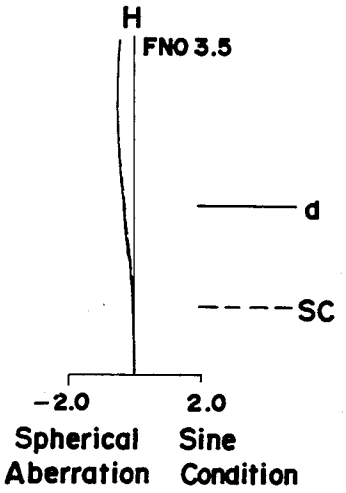


FIG.6B

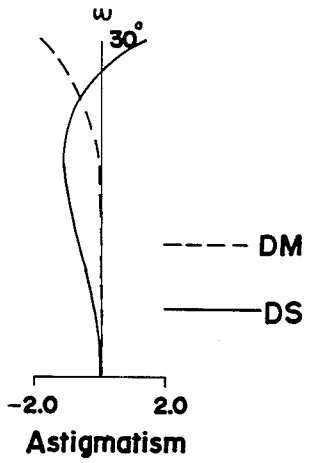


FIG.6C

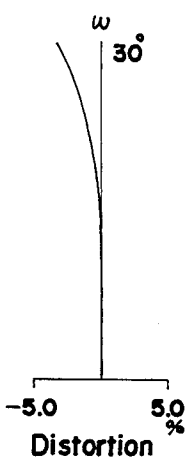


FIG.7A

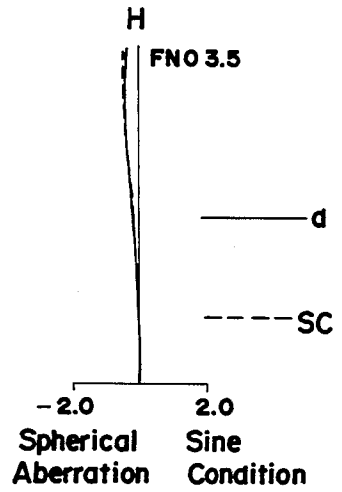


FIG.7B

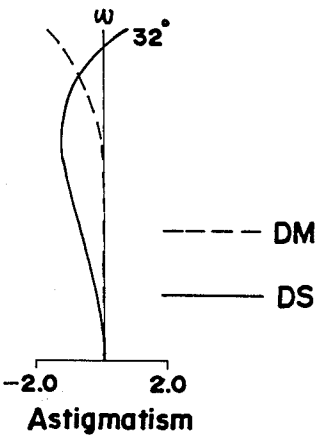


FIG.7C

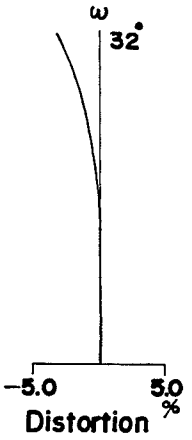


FIG.8A

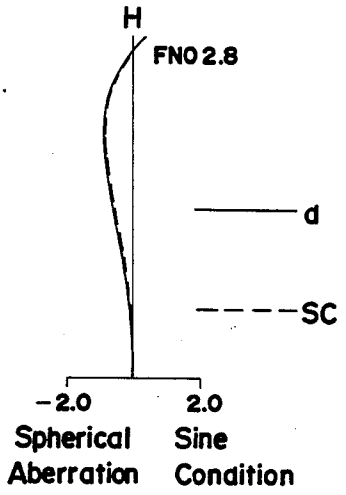


FIG.8B

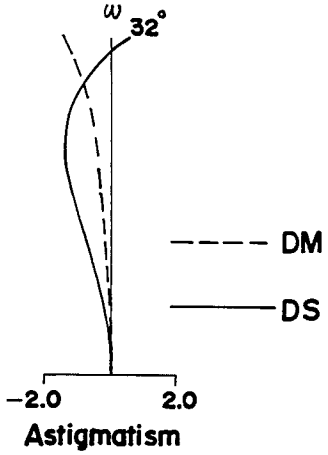


FIG.8C

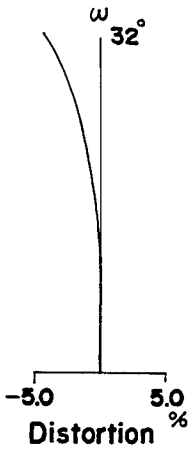


FIG.9A

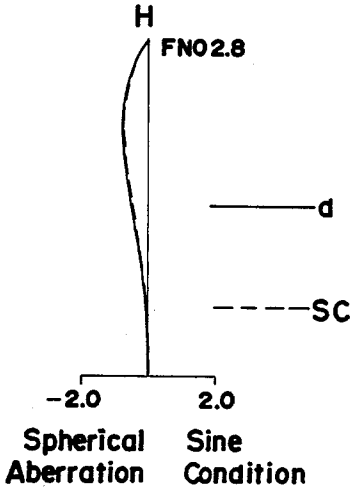


FIG.9B

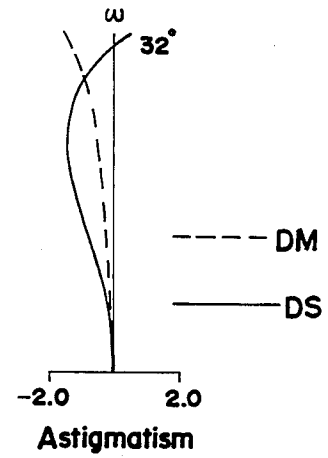


FIG.9C

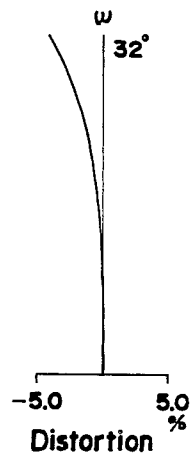


FIG.10A

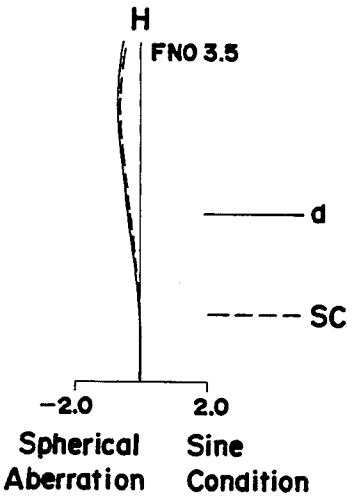


FIG.10B

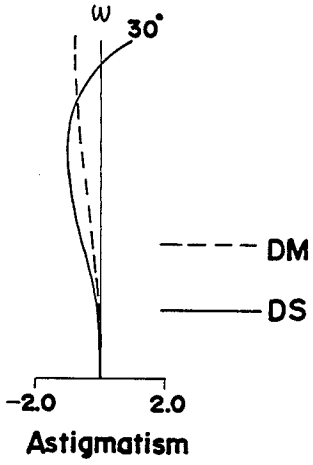


FIG.10C

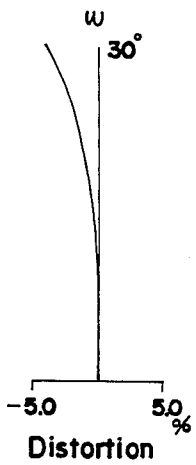


FIG.11A

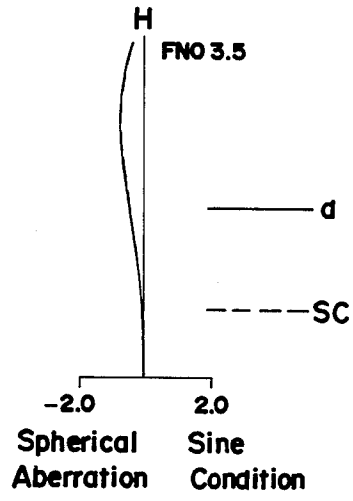


FIG.11B

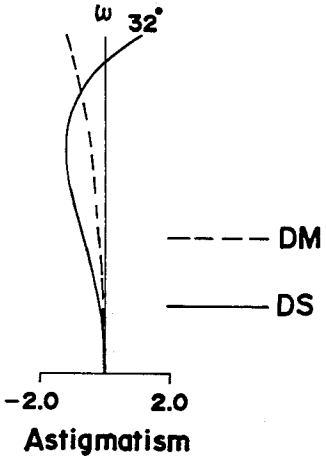


FIG.11C

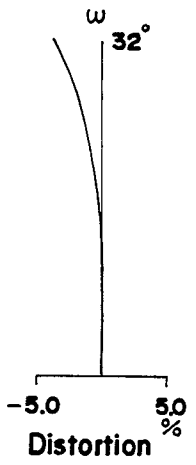


FIG.12A

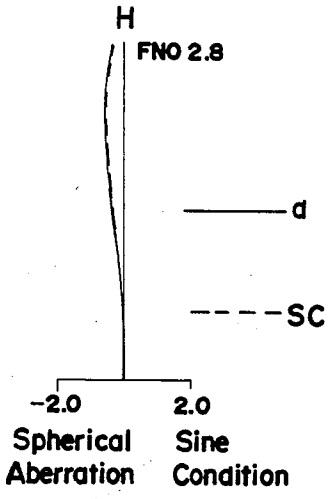


FIG.12B

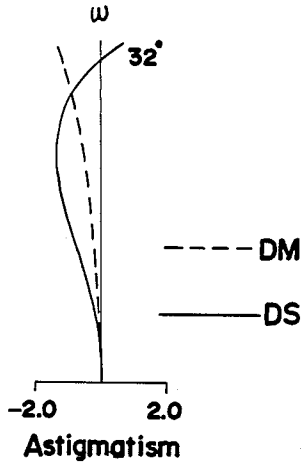


FIG.12C

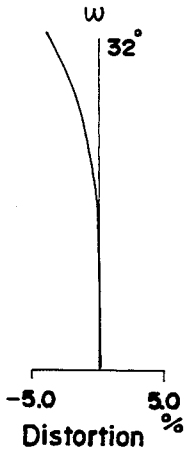


FIG.13A

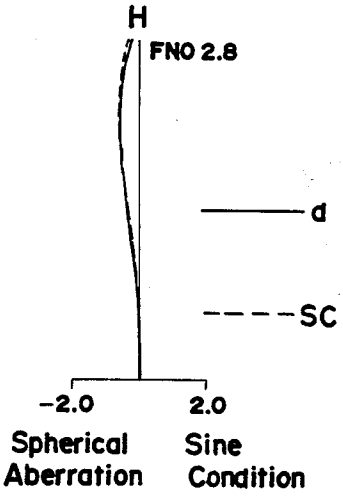


FIG.13B

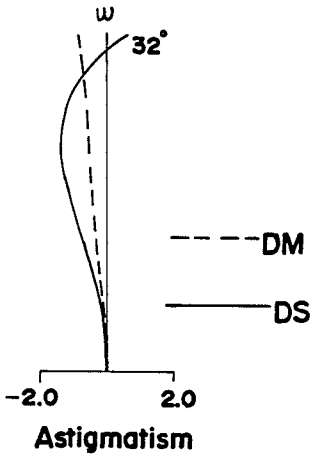


FIG.13C

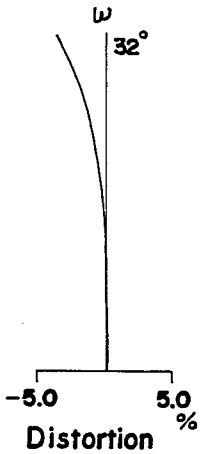


FIG.14A

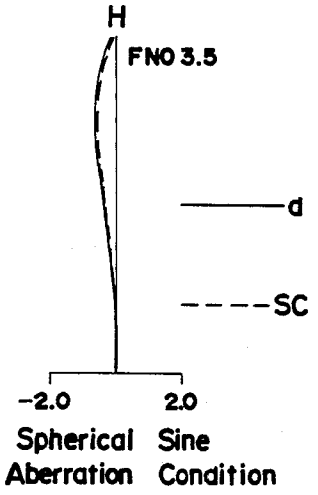


FIG.14B

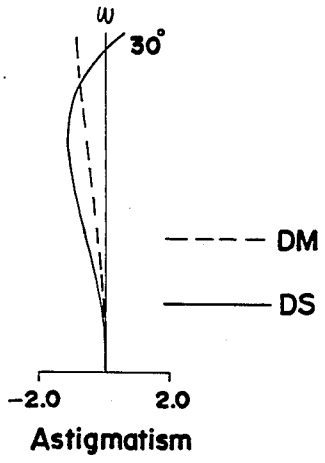


FIG.14C

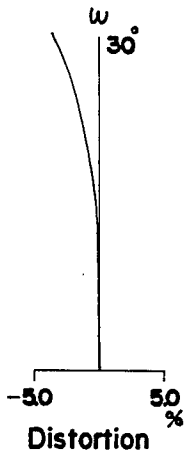


FIG.15A

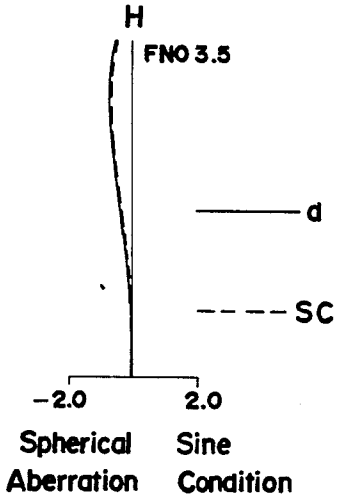


FIG.15B

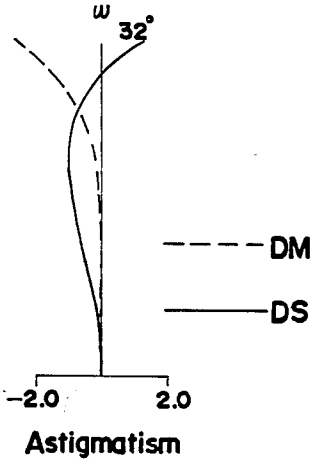
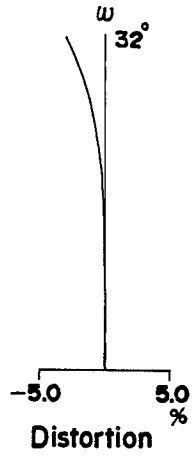


FIG.15C



TRIPLET TYPE OBJECTIVE WITH A DIAPHRAGM ARRANGED BEHIND THE LENS SYSTEM

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to an objective for compact lens-shutter cameras whose diaphragm is arranged behind the whole optical system, and more particularly to a compact wide angle objective with a simple construction for cameras for a spread use.

2. Description of the Prior Art

With a compact lens-shutter camera for cameras for a spread use, a wide angle objective with a diaphragm arranged behind the whole lens system is advantageous for accommodation in the camera, for compactization of the camera or the objective itself and for realization of precise focusing. As this kind of objective, triplet type objectives with $F_{No.}$ of 4–2.8 and a total angular field coverage of 60°–64° have been proposed. With a wide angle triplet type objective, since an astigmatic difference tends to become large at a marginal angular field, it was conventional to construct this type of objective by the use of lens elements formed of a glass with a high refractive index. For example, in Japanese patent application laid-open No. Sho. 59-34510, all lens elements, one or two of which have an aspherical surface, are formed of glass with a high refractive index to construct an objective with a total angular field coverage of 64°, and $F_{No.}$ of 3.5. In Japanese patent application laid-open No. Sho. 57-2012, an objective with $F_{No.}$ of 4 and a total angular field of 64° has been realized with the use of a glass with a high refractive index. But forming a lens element of glass of a high refractive index incurs an increase in the manufacturing cost.

Besides, with a triplet type objective with a diaphragm arranged behind the whole lens system, a problem exists in that the amount of marginal light rays tends to become insufficient and this promblem has not been solved.

SUMMARY OF THE INVENTION

An object of the present invention is to provide a triplet type wide angle objective with a compact size and light weight, which can secure a sufficient amount of marginal light rays, whose manufacturing cost is low, whose construction is advantageous in manufacturing of lens elements and whose aberrations are corrected well.

To achieve these objects a triplet type objective according to the present invention, as shown in FIG. 1, comprises a lens system and a diaphragm (S) arranged behind the lens system. The lens system consists of, from the object side, a first positive meniscus lens element (L_1) having a positive refractive power on the object side surface, a second biconcave lens element (L_2) and a third biconvex lens element (L_3). The first lens element (L_1) is formed of glass and the second (L_2) and third lens (L_3) elements are formed of plastic. Further, the lens systems fulfills the following conditions:

$$0.25f<\Sigma d+b<0.45f \quad (1)$$

$$0.15<N_1-N_3<0.4 \quad (2)$$

wherein,

f represents the focal length of the lens system;

Σd represents the axial distance from the first surface (r_1) to the last surface (r_6) of the lens system, b represents the axial distance from the last surface (r_6) of the lens system to the diaphragm (S), N_1 represents the refractive index of the first lens element (L_1), and N_3 represents the refractive index of the third lens element (L_3).

Condition (1) is to increase the amount of marginal light rays which, otherwise would tend to be insufficient with a wide angle triplet type objective having a diaphragm arranged behind the whole lens system. If the upper limit of the condition (1) is violated, it becomes difficult to secure a sufficient amount of marginal light rays and the objective becomes bulky in size. On the other hand, if the lower limit of condition (1) is violated, the curvature of the field deteriorates, and further, the thickness of the peripheral portion of the positive lens elements decreases so much that manufacturing of the lens elements becomes difficult.

According to the present invention, the second negative lens element (L_2) and the third positive lens element (L_3) are made of plastic, so that the change of back focus caused by a change of the temperature is cancelled, and both the weight of the objective and the cost for manufacturing of the lens elements can decrease. Although the third plastic lens element (L_3) has a week refractive index, the first lens element (L_1) made of glass with a stronger refractive index prevents the petzval sum from becoming great, so that the astigmatic difference is corrected well. Thus, the present invention is characterized in that the refractive index of the first lens element (L_1) is much greater than that of the third lens element (L_3) as represented by the condition (2). When the condition (2) is satisfied, an image field of the objective can be ketp substatially flat over an angular field of 65°. If the lower limit of the condition (2) is violated, the petzval sum cannot be made small and the astigmatic difference at a large angular field becomes great. On the other hand, the upper limit of the condition (2) shows the highest limit of the refractive index of the glass which is normally available as the first lens element (L_1).

Furthermore, according to the present invention, it is desirable to fulfill the following conditions:

$$1.1/f<\phi_1<1.9/f \quad (3)$$

$$-0.75/f<\phi_{23}<0.02/f \quad (4)$$

$$0.8f<-r_3<3.0f \quad (5)$$

$$0.38f<r_5<0.76f \quad (6)$$

$$0.35f<-r_6<0.64f \quad (7)$$

wherein, ϕ_1 represents the refractive power of the first lens element (L_1), ϕ_{23} represents the composite refractive power of the second and the third lens elements (L_2) and (L_3), r_3 represents the radius of curvature of the object side surface of the second lens element (L_2), r_5 represents the radius of curvature of the object side surface of the third lens element (L_3) and r_6 represents the radius of curvature of the image side surface of the third lens element (L_3).

Condition (3) is desirable for compactization of the objective and for security for the marginal light rays.

When the condition (3) is satisfied, the objective can be constructed compactly and the marginal light rays required for providing an object image being bright

even at marginal portions can be secured. If the lower limit of condition (3) is violated, marginal light rays are cut off, so that vignetting at a large angular portion of the field increases. In contrast thereto, if the upper limit of the condition (3) is violated, the petzval sum increases so much that it becomes difficult to correct the curvature of field and the positive distortion is caused remarkably, while the marginal light rays can be secured to more of a extent and the objective can be constructed more compactly.

Condition (4) is desirable for decreasing the change of the back focus depending on the change of temperature which is caused by use of plastic lenses. As the composite refractive power of the second and the third lens elements (L_2) and (L_3) becomes small, the change of the back focus can be well cancelled. But, if the composite refractive power (ϕ_{23}) becomes small beyond the lower limit of condition (4), the refractive power of the first lens element should be so great that the curvature of field cannot be corrected well. On the contrary, if the upper limit of condition (4) is violated, the change of back focus depending on the change of temperature becomes great, so that a means for mechanically changing the back focus should be accommodated in a lens barrel.

Conditions (5), (6) and (7) are for correcting spherical aberration, curvature of field and the coma well. The radius of curvature (r_3) of the object side surface of the second lens element (L_2) is effective for correcting the coma caused by the lower marginal ray in the intermediate and marginal area, whereas the radius of curvature (r_6) of the image side surface of the third lens element (L_3) is effective for correcting the coma caused by the upper marginal ray.

If the upper limit of condition (5) is violated, spherical aberration and curvature of field undergo over-correction. On the contrary, if the lower limit of condition (5) is violated, spherical aberration is in an undercorrection state and the coma towards the outward direction is produced at the intermediate area of the picture format.

If the upper limit of condition (6) is violated, spherical aberration and curvature of field are in an over-correction state and if the lower limit of condition (6) is violated, spherical aberration and curvature of field are in an undercorrection.

If the upper limit of condition (7) is violated, spherical aberration is in overcorrection state and the coma towards the inward direction is produced in the marginal area. In contrast thereto the lower limit of condition (7) is violated, spherical aberration and curvature of field are not corrected well.

For still better correction of aberrations, it is desirable that conditions (5), (6) and (7) have the following range:

$$0.9f < -r_3 < 1.3f \quad (5)'$$

$$0.38f < r_5 < 0.65f \quad (6)'$$

$$0.35f < -r_6 < 0.62f \quad (7)'$$

When a plastic lens element is used, it becomes easier to employ an aspherical surface. According to this invention it is desirable to employ an aspherical surface for one of the surfaces of the second and third lens elements (L_2) and (L_3), so that spherical aberration, distortion, curvature of field and coma which are not so satisfactory corrected in case of an objective consisting of only spherical lens elements can be corrected almost completely. Furthermore, it is better to employ one more aspherical surface for another surface of the second and third lens elements (L_2) (L_3) in order to correct aberrations in high degrees.

Another triplet type objective of the present invention comprises a lens system and a diaphragm (S) arranged behind the lens system. The lens system consists of, from the object side, a first positive meniscus lens element (L_1) having a positive refractive power on the object side surface, a second biconcave lens element (L_2) and a third biconvex lens element (L_3). The first lens element (L_1) is formed of glass and the second and third lens elements (L_2, L_3) are formed of plastic. Further, the lens system fulfills following conditions:

$$0.15 < N_1 - N_3 < 0.4 \quad (8)$$

$$1.4 < N_2 < 1.65 \quad (9)$$

$$1.4 < N_3 < 1.65 \quad (10)$$

wherein

N_2 represents the refractive index of the second lens element.

Condition (8) is the same as condition (2) and has the same meaning.

The upper limit of conditions (9) and (10) is set in consideration of the refractive index of plastics which are normally available for a lens. If the lower limit of condition (9) is violated, the curvature of field is in an overcorrection state and the coma to the inward direction becomes difficult to be corrected. On the other hand, if the lower limit of condition (10) is violated, the spherical aberration is in an undercorrection state.

The features of the present invention which are believed to be novel are set forth with particularity in the appended claimed. The present invention, both as to its organization and manner of operator, together with further objects and advantages thereof, may best be understood by reference to the following description, taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a cross sectional view of an objective according to the respective embodiments of the present invention;

FIGS. **2A** to **2C** represent the aberration curves of the embodiment **1** respectively;

FIGS. **3A** to **3C** represent the aberration curves of the embodiment **2** respectively;

FIGS. **4A** to **4C** represent the aberration curves of the embodiment **3** respectively;

FIGS. **5A** to **5C** represent the aberration curves of the embodiment **4** respectively;

FIGS. **6A** to **6C** represent the aberration curves of the embodiment **5** respectively;

FIGS. **7A** to **7C** represent the aberration curves of the embodiment **6** respectively;

FIGS. **8A** to **8C** represent the aberration curves of the embodiment **7** respectively;

FIGS. **9A** to **9C** represent the aberration curves of the embodiment **8** respectively;

FIGS. **10A** to **10C** represent the aberration curves of the embodiment **9** respectively;

FIGS. **11A** to **11C** represent the aberration curves of the embodiment **10** respectively;

FIGS. 12A to 12C represent the aberration curves of the embodiment 11 respectively;

FIGS. 13A to 13C represent the aberration curves of the embodiment 12 respectively;

FIGS. 14A to 14C represent the aberration curves of the embodiment 13 respectively;

FIGS. 15A to 15C represent the aberration curves of the embodiment 14 respectively.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The following description is provided to enable any person skilled in the optical and camera field to make and use the invention and sets forth the best modes contemplated by the inventors for carrying out their invention. Various modifications, however, will remain readily apparent to those skilled in the art, since the generic principles of the present invention have been defined herein specifically to provide a relatively economical and easily manufactured triplet type objective. The derivation of the formulas and the relation of the powers set forth herein can be accomplished with the assistance of a computer. The present invention represents the parameters of a compromise balance of acceptable aberrations which can be relatively easily manufactured to provide a low cost lens system for utilization with a compact lens shutter camera.

In the drawings, FIG. 1 shows the position of the lens elements. Values of radii of curvature and axial distances for each lens element and air spaces in the respective embodiments are provided in the accompanying tables set forth herein, and the schematic cross sectional view of FIG. 1 follows the normal conventions of an object at the left-hand side of the drawing and the image plane at the right-hand side. The lens system of all embodiments fulfill the following conditions:

$$1.7<N_1<1.9,\ 35<\nu_1<50 \quad (11)$$

$$1.4<N_2<1.65,\ 27<\nu_2<50 \quad (12)$$

$$1.4<N_3<1.65,\ 35<\nu_3<65 \quad (13)$$

wherein, N_2 represents the refractive index of the second lens element (L_2), ν_1 represents abbe number of the first lens element (L_1), ν_2 represents abbe number of the second lens element (L_2) and ν_3 represents abbe number of the third lens element.

The following tables 1 to 14 disclose, respectively design parameters of embodiments 1 to 14 of the present invention. In the embodiments L_1, L_2, L_3 are the lens elements from the object side, r_1, r_2, r_3... is respectively the radius of curvature from the object side, and the d_1, d_2, d_3 . . . is respectively the axial thickness including both air spaces and the actual thickness of a lens element. Nd_1, Nd_2, Nd_3 is respectively the refractive index of the first through third lens element and νd_1, νd_2, νd_3 is respectively the abbe number of the first (L_1) through third lens element (L_3). A surface with the mark * represents an aspherical surface, whose configuration is defined as follows:

$$X = \frac{Y^2}{ri + ri\sqrt{1-\left(\frac{Y}{ri}\right)^2}} + AY^2 + BY^4 + CY^6 + DY^8 + EY^{10} + FY^{12} + \ldots$$

wherein, X represents the coordinate along the optical axis measured from an imaginary plane tangent to the aspherical surface perpendicularly to the optical axis, Y represents the coordinate perpendicular to the optical axis from the optical axis, ri represents a paraxial radius of curvature, and A, B, C, D, . . . is aspherical coefficient.

TABLE 1

[Embodiment 1]

f = 100 2ω = 64° $F_{No.}$ 3.5

	radius of curvature		axial distance		refractive index		Abbe number
r_1	32.638						
		d_1	12.57	Nd_1	1.78850	νd_1	45.68
r_2	75.166						
		d_2	2.71				
r_3	−126.741						
		d_3	3.71	Nd_2	1.58400	νd_2	31.0
r_4	27.191						
		d_4	6.00				
r_5	54.404						
		d_5	6.57	Nd_3	1.49140	νd_3	57.8
r_6	−51.527						
		b	3.71				
r_7	∞						

$\Sigma d + b = 0.35f$
$\phi_1 = 1.55/f$
$\phi_{23\ 23} -0.40/f$
$N_1 - N_3 = 0.297$

TABLE 2

[Embodiment 2]

f = 100 2ω = 60° $F_{No.}$ 3.5

	radius of curvature		axial distance		refractive index		Abbe number
r_1	32.888						
		d_1	13.36	Nd_1	1.78100	νd_1	44.55
r_2	76.148						
		d_2	1.97				
r_3	−108.471						
		d_3	3.42	Nd_2	1.58400	νd_2	31.0
r_4	27.718						
		d_4	6.70				
r_5	57.053						
		d_5	5.53	Nd_3	1.49140	νd_3	57.8
r_6	−47.602						
		b	5.26				
r_7	∞						

$\Sigma d + b = 0.36f$
$\phi_1 = 1.53/f$
$\phi_{23} = -0.35/f$
$N_1 - N_3 = 0.290$

TABLE 3

[Embodiment 3]

f = 100 2ω = 64° $F_{No.}$ 3.5

	radius of curvature		axial distance		refractive index		Abbe number
r_1	30.47						
		d_1	11.14	Nd_1	1.77250	νd_1	49.77
r_2	72.753						
		d_2	2.57				
r_3*	−97.730						
		d_3	3.14	Nd_2	1.56790	νd_2	34.6
r_4	25.066						
		d_4	5.43				
r_5	49.947						
		d_5	6.00	Nd_3	1.49140	νd_3	57.8
r_6	−50.009						

TABLE 3-continued

[Embodiment 3]

		b	3.71				
r7	∞						

A = 0.0
B = 0.15540 × 10^{-5}
C = −0.22578 × 10^{-8}
D = 0.38316 × 10^{-11}
E = 0.59368 × 10^{-16}

Σd + b = 0.32f
ϕ_1 = 1.64/f
ϕ_{23} = 0.51/f
N_1-N_3 = 0.281

TABLE 4

[Embodiment 4]

f = 100 2ω = 64° $F_{No.}$ 3.5

	radius of curvature		axial distance		refractive index		Abbe number
r1	34.747						
		d_1	14.12	Nd_1	1.8050	νd_1	40.97
r2	67.767						
		d_2	3.53				
r3	−104.876						
		d_3	3.71	Nd_2	1.59160	νd_2	30.9
r4	30.319						
		d_4	5.26				
r5	48.657						
		d_5	6.78	Nd_3	1.49140	νd_3	57.8
r6*	−49.214						
		b	3.71				
r7	∞						

A = 0.0
B = 0.13795 × 10^{-5}
C = 0.42654 × 10^{-9}
D = 0.66053 × 10^{-15}
E = 0.58736 × 10^{-20}
F = 0.26860 × 10^{-25}

Σd + b = 0.37f
ϕ_1 = 1.34/f
ϕ_{23} = −0.18/f
N_1-N_3 = 0.314

TABLE 5

[Embodiment 5]

f = 100 2ω = 64° $F_{No.}$ 3.5

	radius of curvature		axial distance		refractive index		Abbe number
r1	35.498						
		d_1	15.37	Nd_1	1.82050	νd_1	43.00
r2	58.788						
		d_2	3.14				
r3	−98.477						
		d_3	3.71	Nd_2	1.59160	νd_2	30.9
r4	31.727						
		d_4	4.35				
r5	46.432						
		d_5	7.80	Nd_3	1.49140	νd_3	57.8
r6	−44.766						
		b	3.71				
r7	∞						

A = 0.0
B = 0.83081 × 10^{-6}
C = 0.13132 × 10^{-7}
D = 0.34506 × 10^{-13}
E = 0.84807 × 10^{-19}
F = 0.20775 × 10^{-24}

Σd + b = 0.38f
ϕ_1 = 1.19/f
ϕ_{23} = 0.004/f
$N_1 - N_3$ = 0.329

TABLE 6

[Embodiment 6]

f = 100 2ω = 64° $F_{No.}$ 3.5

	radius of curvature		axial distance		refractive index		Abbe number
r1	34.668						
		d_1	15.06	Nd_1	1.78850	νd_1	45.68
r2	58.279						
		d_2	3.00				
r3	−90.762						
		d_3	3.71	Nd_2	1.58400	νd_2	31.0
r4	31.607						
		d_4	4.30				
r5	42.876						
		d_5	7.59	Nd_3	1.49140	νd_3	57.8
r6*	−47.054						
		b	3.71				
r7	∞						

TABLE 6-continued

[Embodiment 6]

A = 0.0
B = 0.28310 × 10^{-5}
C = −0.11696 × 10^{-8}
D = −0.10162 × 10^{-13}
E = −0.18068 × 10^{-19}
F = −0.11907 × 10^{-25}

Σd + b = 0.37f
ϕ_1 = 1.18/f
ϕ_{23} = 0.007/f
$N_1 - N_3$ = 0.297

TABLE 7

[Embodiment 7]

f = 100 2ω = 64° $F_{No.}$ 2.8

	radius of curvature		axial distance		refractive index		Abbe number
r1	32.444						
		d_1	10.52	Nd_1	1.78850	νd_1	45.68
r2	86.049						
		d_2	2.57				
r3	−152.892						
		d_3	3.42	Nd_2	1.58400	νd_2	31.0
r4	27.815						
		d_4	7.16				
r5*	66.730						
		d_5	7.14	Nd_3	1.49140	νd_3	57.8
r6	−54.200						
		b	4.29				
r7	∞						

A = 0.0
B = −0.55372 × 10^{-7}
C = 0.79659 × 10^{-9}
D = 0.29407 × 10^{-13}
E = 0.18795 × 10^{-17}
F = 0.98693 × 10^{-20}

Σd + b = 0.35f
ϕ_1 = 1.64/f
ϕ_{23} = −0.48/f
$N_1 - N_3$ = 0.297

TABLE 8

[Embodiment 8]

f = 100 2ω = 64° $F_{No.}$ 2.8

	radius of curvature		axial distance		refractive index		Abbe number
r1	32.968						
		d_1	11.09	Nd_1	1.78850	νd_1	45.68
r2	89.664						
		d_2	2.57				
r3	−168.474						
		d_3	3.42	Nd_2	1.58400	νd_2	31.0
r4*	28.269						
		d_4	7.62				
r5	69.240						
		d_5	7.14	Nd_3	1.49140	νd_3	57.8
r6	−56.455						
		b	4.29				
r7	∞						

A = 0.0
B = 0.49278 × 10^{-6}
C = −0.70317 × 10^{-9}
D = −0.47634 × 10^{-14}
E = −0.23096 × 10^{-17}
F = −0.96018 × 10^{-21}

Σd + b = 0.36f
ϕ_1 = 1.64/f
ϕ_{23} = −0.48/f
$N_1 - N_3$ = 0.297f

TABLE 9

[Embodiment 9]

f = 100 2ω = 60° $F_{No.}$ 3.5

radius of curvature	axial distance	refractive index	Abbe number

TABLE 9-continued

[Embodiment 9]

r_1	31.599						
		d_1	10.19	Nd_1	1.78850	νd_1	45.68
r_2	96.621						
		d_2	2.76				
r_3*	−121.117						
		d_3	3.15	Nd_2	1.58400	νd_2	31.0
r_4	25.934						
		d_4	8.36				
r_5	64.650						
		d_5	5.01	Nd_3	1.49140	νd_3	57.8
r_6	−53.464						
		b	5.26				
r_7	∞						

$A = 0.0$
$B = 0.90180 \times 10^{-6}$
$C = 0.67468 \times 10^{-11}$
$D = 0.22279 \times 10^{-12}$
$E = 0.13483 \times 10^{-13}$
$F = -0.52105 \times 10^{-16}$

$\Sigma d + b = 0.35f$
$\phi_1 = 1.80/f$
$\phi_{23} = -0.62/f$
$N_1 - N_3 = 0.297$

TABLE 10

[Embodiment 10]

$f = 100 \quad 2\omega = 64° \quad F_{No.}\ 3.5$

radius of curvature		axial distance		refractive index		Abbe number	
r_1	30.452						
		d_1	9.43	Nd_1	1.78100	νd_1	44.55
r_2	85.753						
		d_2	2.57				
r_3	−153.986						
		d_3	3.42	Nd_2	1.58400	νd_2	31.0
r_4*	25.326						
		d_4	7.14				
r_5*	66.485						
		d_5	5.44	Nd_3	1.49140	νd_3	57.8
r_6	−52.762						
		b	4.29				
r_7	∞						

$A = 0.0$
$B = 0.10283 \times 10^{-5}$
$C = 0.83570 \times 10^{-11}$
$D = 0.26781 \times 10^{-16}$
$E = 0.37346 \times 10^{-20}$
$F = 0.81422 \times 10^{-25}$

$A' = 0.0$
$B' = 0.18452 \times 10^{-5}$
$C' = 0.75265 \times 10^{-10}$
$D' = 0.97872 \times 10^{-12}$
$E' = 0.23635 \times 10^{-14}$
$F' = -0.415123 \times 10^{-17}$

$\Sigma d + b = 0.32f$
$\phi_1 = 1.78/f$
$\phi_{23} = -0.64/f$
$N_1 - N_3 = 0.290$

TABLE 11

[Embodiment 11]

$f = 100 \quad 2\omega = 64° \quad N_{No.}\ 2.8$

radius of curvature		axial distance		refractive index		Abbe number	
r_1	31.824						
		d_1	10.00	Nd_1	1.78850	νd_1	45.68
r_2	91.542						
		d_2	2.57				
r_3	−202.258						
		d_3	3.42	Nd_2	1.58400	νd_2	31.0
r_4*	26.758						
		d_4	7.95				
r_5	73.592						
		d_5	7.14	Nd_3	1.49140	νd_3	57.8
r_6°	−57.027						
		b	4.29				
r_7	∞						

$A = 0.0$
$B = 0.10452 \times 10^{-5}$
$C = -0.13199 \times 10^{-9}$
$D = -0.29700 \times 10^{-14}$
$E = -0.20207 \times 10^{-17}$

$A' = 0.0$
$B' = -0.61739 \times 10^{-6}$
$C' = -0.42239 \times 10^{-9}$
$D' = -0.15244 \times 10^{-11}$
$E' = -0.13200 \times 10^{-13}$

$\Sigma d + b = 0.35f$
$\phi_1 = 1.74/f$
$\phi_{23} = -0.57/f$
$N_1 - N_3 = 0.297$

TABLE 11-continued

[Embodiment 11]

$F = -0.10080 \times 10^{-20}$ $F' = 0.10401 \times 10^{-16}$

TABLE 12

[Embodiment 12]

$f = 100 \quad 2\omega = 64° \quad F_{No.}\ 2.8$

radius of curvature		axial distance		refractive index		Abbe number	
r_1	32.150						
		d_1	10.00	Nd_1	1.78850	νd_1	45.68
r_2	99.546						
		d_2	2.57				
r_3*	−153.739						
		d_3	3.42	Nd_2	1.58400	νd_2	31.0
r_4	27.437						
		d_4	7.95				
r_5	66.224						
		d_5	7.14	Nd_3	1.49140	νd_3	57.8
r_6*	−62.351						
		b	4.29				
r_7	∞						

$A = 0.0$
$B = 0.68768 \times 10^{-6}$
$C = 0.23651 \times 10^{-9}$
$D = -0.42567 \times 10^{-14}$
$E = -0.68117 \times 10^{-17}$
$F = -0.60955 \times 10^{-20}$

$A' = 0.0$
$B' = 0.93209 \times 10^{-6}$
$C' = -0.29337 \times 10^{-9}$
$D' = -0.10900 \times 10^{-12}$
$E' = -0.51595 \times 10^{-14}$
$F' = 0.34096 \times 10^{-17}$

$\Sigma d + b = 0.35f$
$\phi_1 = 1.77/f$
$\phi_{23} = -0.61/f$
$N_1 - N_3 = 0.297$

TABLE 13

[Embodiment 13]

$f = 100 \quad 2\omega = 60° \quad N_{No.}\ 3.5$

radius of curvature		axial distance		refractive index		Abbe number	
r_1	32.025						
		d_1	10.19	Nd_1	1.78850	νd_1	45.68
r_2	96.343						
		d_2	2.76				
r_3*	−125.127						
		d_3	3.15	Nd_2	1.58400	νd_2	31.0
r_4	27.024						
		d_4	8.36				
r_5*	67.093						
		d_5	5.01	Nd_3	1.49140	νd_3	57.8
r_6	−54.605						
		b	5.26				
r_7	∞						

$A = 0.0$
$B = 0.82271 \times 10^{-6}$
$C = 0.18044 \times 10^{-10}$
$D = 0.74521 \times 10^{-16}$
$E = 0.17643 \times 10^{-19}$
$F = 0.11194 \times 10^{-23}$

$A' = 0.0$
$B' = -0.44095 \times 10^{-6}$
$C' = -0.29946 \times 10^{-11}$
$D' = -0.84125 \times 10^{-14}$
$E' = -0.20598 \times 10^{-14}$
$F' = -0.16315 \times 10^{-15}$

$\Sigma d + b = 0.35f$
$\phi_1 = 1.76/f$
$\phi_{23} = -0.59/f$
$N_1 - N_3 = 0.297$

TABLE 14

[Embodiment 14]

$f = 100 \quad 2\omega = 64° \quad F_{No.}\ 3.5$

radius of curvature		axial distance		refractive index		Abbe number	
r_1	31.254						
		d_1	11.26	Nd_1	1.78831	νd_1	47.32

TABLE 14-continued

[Embodiment 14]

r_2	70.614						
		d_2	3.09				
r_3	−132.278						
		d_3	3.58	Nd_2	1.584	νd_2	31.0
r_4	26.374						
		d_4	5.73				
r_5	52.869						
		d_5	6.16	Nd_3	1.4914	νd_3	57.8
r_6	−52.869						
		b	2.58				
r_7	∞						
S	0						

$\Sigma d + b = 0.32f$
$\phi_1 = 1.58/f$
$\phi_{23} = -0.45/f$
$N_1 - N_3 = 0.297$

What is claimed is:

1. A triplet type objective lens system with a diaphragm arranged behind the lens system, comprising from the object side:
   - a first positive meniscus lens element made of a glass material and having a positive refractive power on the object side surface;
   - a second biconcave lens element made of a plastic material;
   - a third biconvex lens element made of a plastic material, and
   - a diaphragm, wherein the lens system fulfills the following conditions:

$$0.25f<\Sigma d+b<0.45f$$

$$0.18<N_1-N_3<0.4$$

wherein:
   - f represents a focal length of the whole lens system;
   - Σd represents an axial distance from the object side surface of the first lens element to the image side surface of the third lens element;
   - b represents an axial distance from the image side surface of the third lens element to the diaphragm;
   - N_1 represents a refractive index of the first lens element, and
   - N_3 represents a refractive index of the third lens element.

2. A triplet type objective lens system as claimed in claim 1, wherein the triplet type objective lens system fulfills the following conditions:

$$0.8f<-r_3<3.0f$$

$$0.38f<r_5<0.76f$$

$$0.35f<-r_6<0.64f$$

wherein
   - r_3 represents the radius of curvature of the object side surface of the second lens element;
   - r_5 represents the radius of carvature of the object side surface of the third lens element and
   - r_6 represents the radius of curvature of the image side surface of the third lens element.

3. A triplet type objective lens system as claimed in claim 1, wherein one of the surfaces of the second and the third lens elements is an aspherical surface.

4. A triplet type objective lens system as claimed in claim 1, wherein two surfaces of the second and the third lens elements are aspherical surfaces.

5. A triplet type objective lens system as claimed in claim 1, wherein the lens system further fulfills the following conditions:

$$1.1/f<\phi_1<1.9/f$$

$$-0.75/f<\phi_{23}<0.02/f$$

$$0.9f<-r_3<1.3f$$

$$0.38f<r_5<0.65f$$

$$0.35f<-r_6<0.62f$$

wherein:
   - ϕ_1 represents the refractive power of the first lens element;
   - ϕ_{23} represents the compound refractive power of the second and third lens elements;
   - r_3 represents the radius of curvature of the object side surface of the second lens element;
   - r_5 represents the radius of curvature of the object side surface of the third lens element, and
   - r_6 represents the radius of curvature of the image side surface of the third lens element.

6. A triplet type objective comprising,
   - (a) a lens system which comprises from the object side;
     - a first positive meniscus lens element having a positive refractive power on the object side surface,
     - a second biconcave lens element,
     - a third biconvex lens element,
     - wherein, the first lens element is formed of glass and the second and third lens elements are formed of plastic, and
   - (b) a diaphragm arranged behind the lens system,
   - (c) wherein the lens system fulfills the following conditions:

$$0.18<N_1-N_3<0.4$$

$$1.4<N_2<1.65$$

$$1.4<N_3<1.65$$

wherein
   - N_1 represents the refractive index of the first lens element;
   - N_2 represents the refractive index of the second lens element; and
   - N_3 represents the refractive index of the third lens element.

7. A triplet type objective as claimed in claim 6, wherein the triplet type objective fulfills the following condition:

$$-0.75/f<\phi_{23}<0.02/f$$

wherein:
   - ϕ_{23} represents the composite refractive power of the second and third lens elements; and
   - f represents the focal length of the lens system.

8. A triplet type objective, wherein the triplet type objective having the following values.

	radius of curvature		axial distance		refractive index		Abbe number
		f = 100 2ω = 64° $F_{No.}$ 3.5					
r_1	32.638						
		d_1	12.57	Nd_1	1.78850	νd_1	45.68
r_2	75.166						
		d_2	2.71				
r_3	−126.741						
		d_3	3.71	Nd_2	1.58400	νd_2	31.0
r_4	27.191						
		d_4	6.00				
r_5	54.404						
		d_5	6.57	Nd_3	1.49140	νd_3	57.8
r_6	−51.527						
		b	3.71				
r_7	∞						

9. A triplet type objective lens system with a diaphragm arranged behind the lens system, comprising from the object side:

a first positive meniscus lens element made of a glass material and having a positive refractive power on the object side surface;

a second biconcave lens element made of a plastic material;

a third biconvex lens element made of a plastic material, and

a diaphragm, wherein the lens system fulfills the following conditions:

$$1.1/f < \phi_1 < 1.9/f$$

$$-0.75./f < \phi_{23} < 0.02/f$$

$$0.8f < -r_3 < 3.0f$$

$$0.38f < r_5 < 0.76f$$

$$0.35f < -4_6 < 0.64f$$

wherein:

ϕ_1 represents the refractive power of the first lens element;

ϕ_{23} represents the compound refractive power of the second and third lens elements;

r_3 represents the radius of curvature of the object side surface of the second lens element;

r_5 represents the radius of curvature of the object side surface of the third lens element, and

r_6 represents the radius of curvature of the image side surface of the third lens element.

* * * * *

United States Patent [19]

Vogt

[11] **Patent Number: 4,783,673**

[45] **Date of Patent: Nov. 8, 1988**

[54] **HOLDING APPARATUS FOR AN IMAGE FRAME OR OBJECTIVE FRAME OF A PROFESSIONAL CAMERA**

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[21] Appl. No.: **896,608**

[22] Filed: **Aug. 13, 1986**

[30] **Foreign Application Priority Data**

Aug. 14, 1985 [CH] Switzerland 03486/85

[51] **Int. Cl.**[4] **G03B 5/02**

[52] **U.S. Cl.** **354/189**

[58] **Field of Search** 354/160, 188, 189, 191, 354/192, 195.1

[56] **References Cited**

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Primary Examiner—A. A. Mathews

Attorney, Agent, or Firm—Saul Jecies

[57] **ABSTRACT**

A holding apparatus for turning an image frame or objective frame of a professional camera includes a first device which defines a vertical swivelling axis, and a second device with a worm gear whose worm wheel axle defines a horizontal swivelling axis in such a manner that it extends transversely to and in vicinity of the camera base.

11 Claims, 2 Drawing Sheets

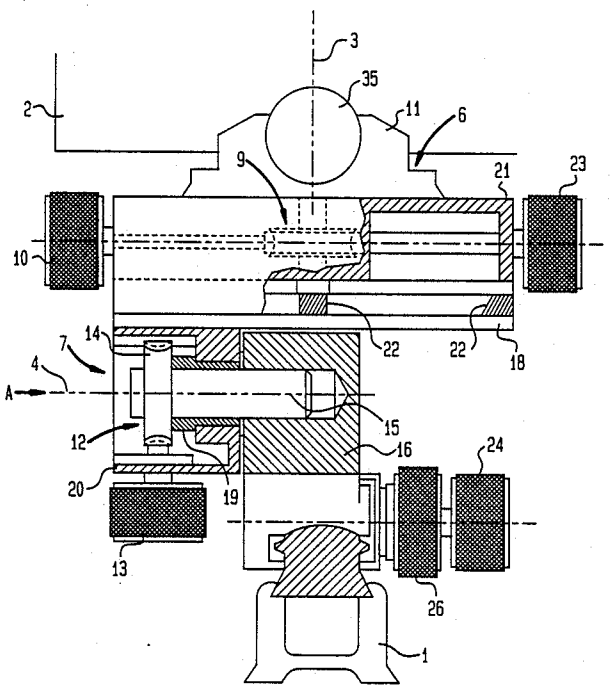


FIG. 1

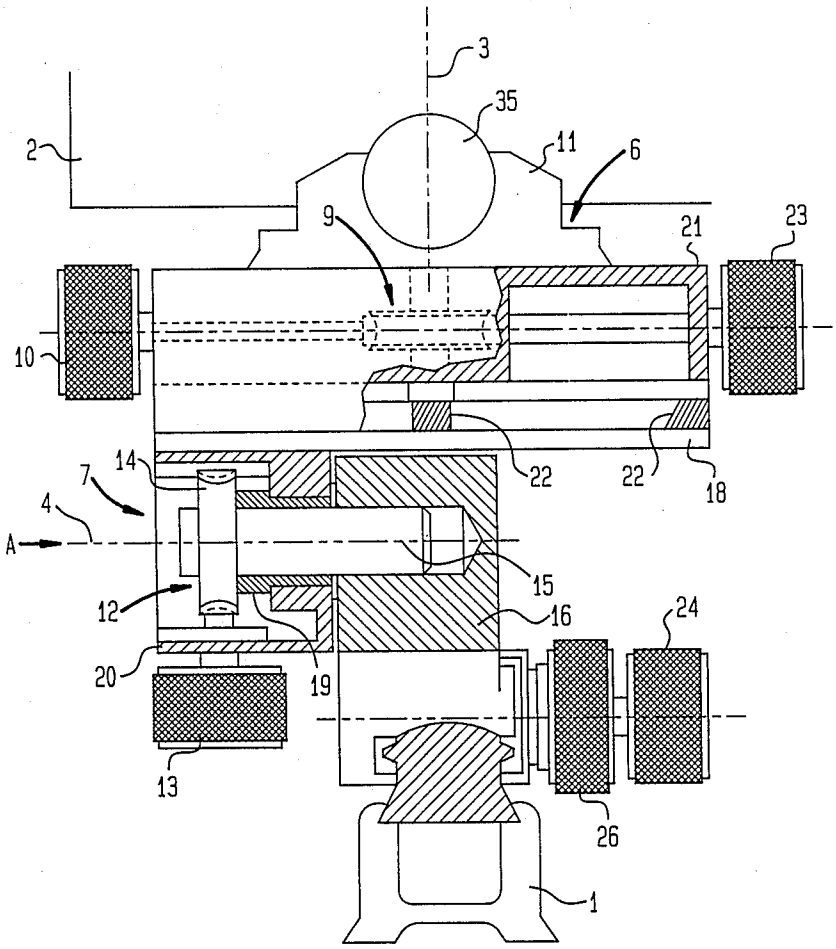


FIG. 2

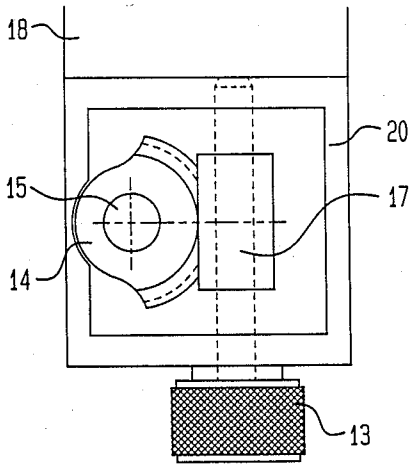


FIG. 3

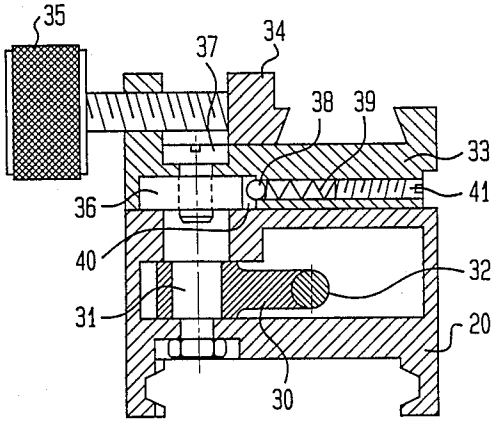
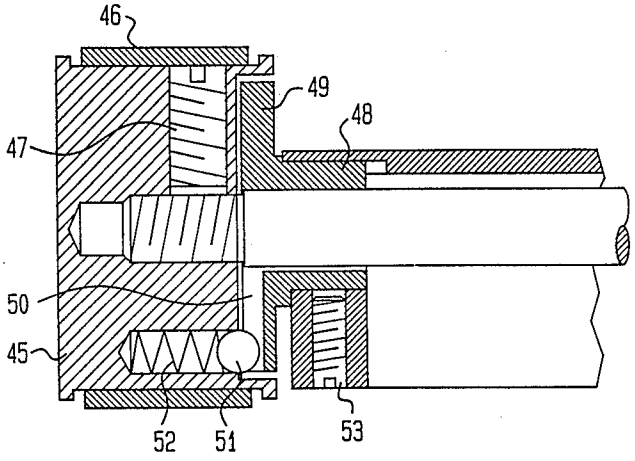


FIG. 4



HOLDING APPARATUS FOR AN IMAGE FRAME OR OBJECTIVE FRAME OF A PROFESSIONAL CAMERA

The present invention is concerned with a holding apparatus for an image frame or objective frame of a professional camera and for attachment to the base of the latter which holding apparatus has at least a first and second device and is turnable with respect to a camera base about at least two swivelling axes intersecting each other at a right angle wherein the first device which defines a swivelling axis such that it extends vertically through or parallel to the focal plane or the principal plane of the objective and which includes a swivelling device with an actuating mechanism for turning the image frame or objective frame is arranged above the second device which defines a second swivelling axis such that it extends transversely to the camera base and to the first swivelling axis and which is adjustably mounted on the camera base by means of a focussing device with an actuating mechanism.

Such cameras, with which two or three object points located at various distances from the camera are sharply projected simultaneously and/or compensation of perspective distortions is possible are known.

The rotation of the image frame or objective frame is obtained in a manner known per se by arranging the device defining the vertical swivelling axis above the device defining the horizontal swivelling axis. This manner of proceedings is justified in the technical world so as to prevent the so-called wobble movement of the image frame or objective frame. To prevent these wobble movements, in a manner known per se, the turning about the horizontal swivelling axis must occur prior to the swivelling about the vertical swivelling axis.

In known designs of professional cameras, the image carrier or objective carrier is connected to the camera base via a holder in such a manner that it is merely shiftable on the camera base, or is additionally turnable with respect to the camera base. This turning is obtained only when the swivelling range of the device respectively provided at the top is not sufficient and when adjusting the approximate inclination of the image carrier or objective carrier.

The invention is based on the object to create an apparatus of the above-mentioned kind whose swivelling range is not limited and which is accurately and easily adjustable over the entire swivelling range.

This object is solved according to the invention by the characterizing features of patent claim **1**.

The advantage of the invention resides primarily in the formation of a precise compact unit of the holding apparatus with small dimensions.

In the following, the invention is described with reference to the accompanying drawings.

It shows:

FIG. **1** a partly broken up view of an embodiment of a holding apparatus according to the invention,

FIG. **2** a view in direction "A" in FIG. **1**,

FIG. **3** a section through the first device, and

FIG. **4** a section through an actuating unit.

FIG. **1** shows an embodiment of a holding apparatus adjustably mounted on a camera base **1** and on top of which the image frame or objective frame **2** is detachably affixed. The image frame or objective frame **2** is turnable with the holding apparatus according to FIG. **1** with respect to the camera base **1** through the known base rotation about two swivelling axes **3**, **4** intersecting each other at right angle. The first swivelling axis **3** extends through or closely parallel to the focal plane or principal frame of the objective, and the second swivelling axis **4** extends in vicinity of the camera base **1** transversely to the latter and to the first swivelling axis **3**.

The holding apparatus illustrated in FIG. **1** includes a first device **6** which defines the first swivelling axis **3**, and a second device **7** which defines the second swivelling axis **4**. The first device **6** is mounted above the second device **7**.

The first device **6** includes a worm gear with an actuating mechanism **10**, a holder **11** for the image frame orobjective frame **2** and a locking clutch which is arranged between holder and worm gear in order to limit the torque acting on the worm.

The second device includes a worm gear **12** with an actuating mechanism **13**. The worm wheel **14** of the worm gear is mounted in non-rotational manner on a worm wheel axle **15** which defines the second swivelling axis **4** and is mounted in non-rotational manner in a bottom part **16** which is slidable on the camera base **16**. The worm **17** is rotatably mounted in a top part **18** and connected with the actuating mechanism **13** (FIG. **2**). Top part **18** is pivoted on the worm wheel axis **15** by means of a bearing **19**. Top part **18** includes a housing **20** which embraces the worm gear **12** and is pivoted on the worm wheel axis **15**, and an adjusting device **21** which has a fine motion **22** with actuating mechanism **23** and in which the first device **6** is mounted for adjusting the image frame or objective frame **2** transversely to the camera base **1**. Bottom part **16** is provided with a focussing device **24** to shift the holding apparatus in longitudinal direction of the camera base **1**.

The holding apparatus can further include a second adjusting device which is provided with an actuating mechanism and **26** arranged between bottom part **16** and the to adjust the image frame or objective frame **2** vertical to the camera base **1**.

FIG. **3** shows a section through the first device **6** mounted in the first adjusting device **21**. As already mentioned, the first device **6** includes a worm gear whose worm wheel **30** is mounted in non-rotational manner on a worm wheel axle **31**, and whose worm **32** is connected with the actuating mechanism **10**. Worm wheel **30** and the worm **32** are supported in the first adjusting device. Holder **11** includes a plate **33** mounted on the worm wheel axle **32**, a clamping element **34** with a screw for clamping the image frame or objective frame **2** or a third device for turning about its horizontal center axis. The worm wheel axle **31** has a collar **36** on which the plate **33** is arranged. Plate **33** is fixed to the worm wheel axle by means of a screw **37**. As already mentioned, the first device **6** includes a locking clutch. As shown in FIG. **3**, the locking clutch includes a sphere **38**, a spring **39** which forces the sphere in a V-shaped notch **40** within the collar **36** of the worm wheel axle **31**, and a screw **41** by which the pressure force acting on the sphere **38** is adjustable.

It follows from the above-stated description that the holding apparatus includes several actuating mechanisms which can be classified into two groups, that is a first group of at least the actuating mechanisms **23** and **24** and **26** which cause a displacement i.e. a vertical adjustment, a cross motion and a focussing, and a second group of at least the actuating mechanisms **10**, **13** which cause a turning. As can be seen from FIG. **1**, the holding apparatus is designed in such a manner that the

actuating mechanisms of the first group are located with respect to the camera base **1** at the one side and the actuating mechanisms of the second group are located at the other side of the camera base **1**. Through this arrangement, the adjustment on a professional camera is simplified.

In order to further simplify the adjustment, the actuating mechanisms **10** and **13** of the second group are provided with a locking clutch. FIG. **4** shows such an actuating mechanism. The actuating mechanism includes a turning knob **45** which is provided with a gripping surface at the circumference. The turning knob **45** is screwed to the worm shaft **17** or **32** and secured by a locking screw **47**. The locking mechanism includes a bushing **48** with a flange **49** which has a recess **50** at the upper side, a sphere **51** movably arranged within the turning knob **45**, and a compression spring **52** which is arranged within the turning knob **45** and pushes the sphere **51** against the flange **49**. Bushing **48** is retained by a locking pin **53**. During rotation of the actuating mechanism, per revolution the sphere **51** is forced once into the recess **50**. Through the design of the respectively actuated mechanism, upon each engaging of the sphere **51** into the recess by means of the locking device, an information is delivered about the angle about which the respective device is swivelled.

Instead of the actuating mechanisms or in addition thereto, also driving motors can be provided controlled by an electric unit.

I claim:

1. In a professional camera having a camera base, an objective frame and image frame, and a holding device arranged on the camera base for adjusting independently the objective frame and the image frame about a first and a second swivelling axis intersecting each other at a right angle; said holding device comprising:

a top part and a bottom part shiftable on the camera base;

first swivelling means accommodated in said top part and provided with a first actuating mechanism for adjustment about said first swivelling axis; and

second swivelling means arranged below said first swivelling means for adjustment about said second swivelling axis which extends perpendicular to and in vicinity of said camera base, said second swivelling means including a worm gear with a worm wheel axle mounted in said bottom part in non-rotational manner and rotatably supporting said top part, said worm wheel axle defining said second swivelling axis, a worm wheel fixedly arranged on said worm wheel axle, and a worm mounted in said top part and meshing with said worm wheel for providing adjustment about said second swivelling axis.

2. The camera as defined in claim **1** wherein said first swivelling means includes

a holder in which the image frame and objective frame are respectively insertable and clamped, and

a locking clutch to limit the torque acting on said first swivelling means during adjustment about said first swivelling axis.

3. The camera as defined in claim **2** wherein said first swivelling means includes a worm gear having a worm wheel axle provided with a recess, said locking clutch being a spring-loaded sphere which engages in said recess in said worm wheel axle of said first swivelling means.

4. The camera as defined in claim **1**, and further comprising focusing means for adjusting said holding device along the camera base in a longitudinal direction thereof, said focusing means being arranged in said bottom part.

5. The camera as defined in claim **1**, and further comprising a second actuating mechanism connected to said worm for adjusting the camera about said second swivelling axis, said worm being rotatably arranged in said top part.

6. The camera as defined in claim **1**, and further comprising:

first adjusting means connected to said top part and including a fine motion with a further actuating mechanism for moving the camera transversely with respect to the camera base, said first swivelling means being mounted in said first adjusting means.

7. The camera as defined in claim **4**, and further comprising:

second adjusting means including a fine motion with a further actuating mechanism for moving the camera vertically with respect to the camera base, said second adjusting means being arranged between said bottom part and said focusing means.

8. The camera as defined in claim **5** wherein each of said first and second actuating mechanisms includes a turning knob and locking means associated to said turning knob to deliver an information about the angle by which said first and second swivelling means are adjusted.

9. The camera as defined in claim **8** wherein said turning knob is screwed to said worm wheel axle, said locking means including

a bushing surrounding said worm wheel axle and including a flange extending at a distance to said turning knob and provided with a recess,

a sphere accommodated in said turning knob, and

a compression spring arranged within said turning knob and acting on said sphere in direction of said flange, said sphere being pushed into said recess by said spring once per revolution of said turning knob.

10. The camera as defined in claim **5**, and further comprising:

first adjusting means including a third actuating mechanism for moving the camera transversely with respect to the camera base, and

second adjusting means including a fourth actuating mechanism for moving the camera vertically with respect to the camera base, said first and second actuating mechanisms which cause an adjustment of the camera about said first and second swivelling axes and said third and fourth actuating mechanisms which cause a displacement of the camera are arranged on opposite sides of a vertical plane extending along the camera base.

11. The camera as defined in claim **10** wherein at least one of said actuating mechanisms being a servo mechanism actuated by an electric unit.

* * * * *

United States Patent [19]

Murphy et al.

[11] **Patent Number: 4,779,967**

[45] **Date of Patent: Oct. 25, 1988**

[54] **OBJECTIVE LENS ASSEMBLY**

[75] Inventors: **Robert A. Murphy**, Lakewood; **Mark G. Arenal**, Laguna Niguel, both of Calif.

[73] Assignee: **Ram Optical Instrumentation, Inc.**, Huntington Beach, Calif.

[21] Appl. No.: **880,777**

[22] Filed: **Jul. 1, 1986**

[51] **Int. Cl.**[4] **G02B 7/04**; G02B 21/06; G02B 21/02

[52] **U.S. Cl.** **350/518**; 350/525; 350/414

[58] **Field of Search** 350/506-507, 350/518, 520-521, 525, 572-573, 414

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Primary Examiner—William H. Punter
Attorney, Agent, or Firm—Nilsson, Robbins, Dalgarn, Berliner, Carson & Wurst

[57] **ABSTRACT**

An objective lens system having a pair of plano-convex lenses disposed adjacent each other with the convex surfaces facing each other and aligned along common optical axis. A plurality of optical fibers surround the plan-convex lenses to convey light and illuminate an object to be viewed by the objective lens assembly. Adjustably positioned adjacent the second plano-convex lens is a field lens system including an elongate rod lens for conducting the intermediate image from the plano-convex lenses and to relay it to an ocular lens system for viewing by the user.

5 Claims, 1 Drawing Sheet

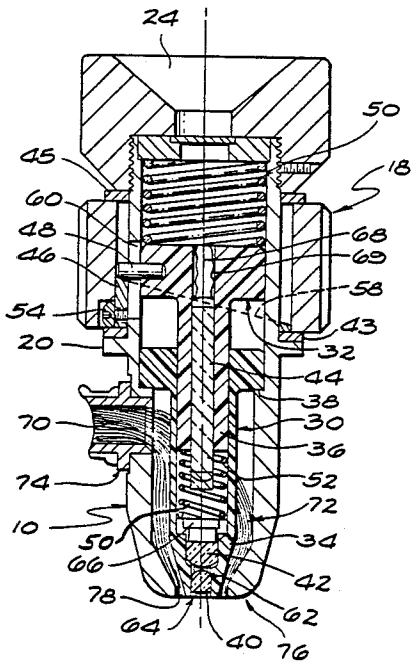
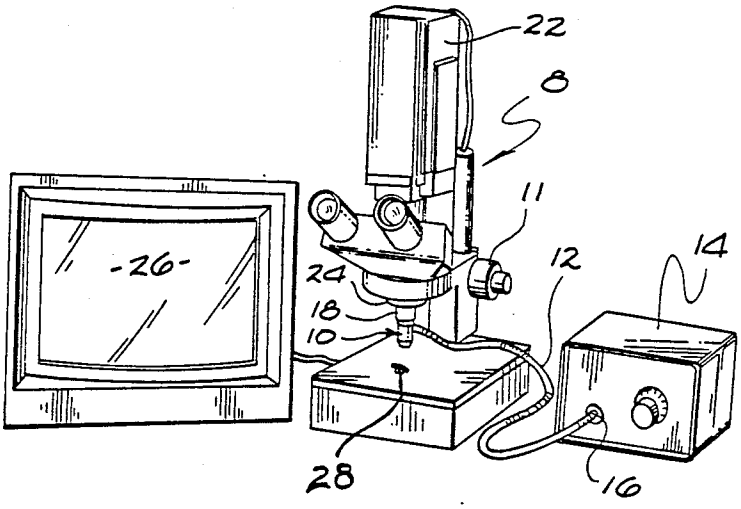


FIG. 1



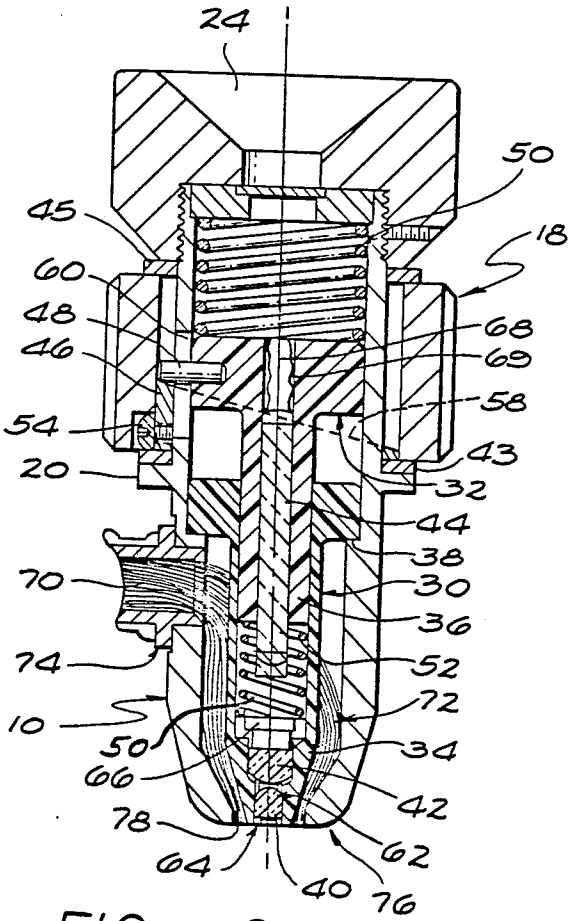


FIG. 2

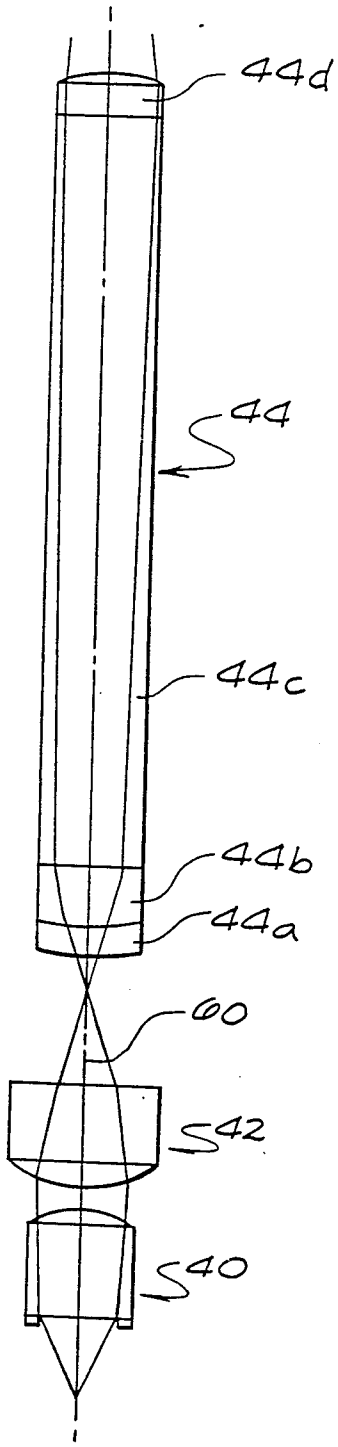


FIG. 3

OBJECTIVE LENS ASSEMBLY

BACKGROUND OF THE INVENTION

The present invention relates to microscope devices and more particularly to objective lens assemblies for use in visually inspecting small-sized parts.

It is frequently desirable to visually inspect small-sized articles of manufacture having parts with substantial depth dimensions such as small diameter bore holes. Traditionally, microscopes having conventional lens systems adapted for viewing slides of specimens have been used to inspect parts which are too small to be clearly viewed by the naked eye. However, such microscopes generally have a very shallow fields at the object plane. Consequently, if the part to be inspected has any significant depth dimensions associated with its features the microscope must be repeatedly refocused in order for the user to be able to examine the entire part. Refocusing takes time and is tiring on the eyes of the user. Further, these microscopes generally do not provide for adequate surface illumination of the part being inspected which makes the inspection of contoured and recessed surfaces even more difficult.

The present invention provides an objective lens assembly which features substantial depth of field at the object plane so that parts can be easily viewed with clarity throughout their depth with a minimum amount of refocusing. Further, the present invention provides a lens assembly which efficiently furnishes illumination to the object being inspected and which is compact in design and is adaptable to be fitted on most conventional microscope bodies.

SUMMARY OF THE INVENTION

The present invention comprises an objective lens assembly for use in inspecting small-sized parts. The present invention includes a pair of adjacent plano-convex lenses, a field lens system and a mechanism for illuminating the part being inspected. The plano-convex lenses are positioned with their convex surfaces facing each other and are aligned along a common optical axis with the field lens system.

In the preferred embodiment, the plano-convex lenses have short radii of curvature of about one-eighth of an inch and form a comparably small aperture opening. The field lens system includes an elongate rod lens and is positionally adjustable for accomplishing any focusing that may be required. The illumination mechanism includes a set of light conducting fibers coaxially mounted in a ring around the plano-convex lenses.

In operation, the pair of plano-convex lenses receives light from the object being inspected and focuses that light into an image characterized by substantial depth of field. The field lens system receives light from that image, processes the light and relays it to an ocular lens system for viewing by the user. The illumination mechanism directs light onto the object being inspected so that it can be clearly viewed by the user.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** shows a perspective view of the objective lens assembly of the present invention mounted for use on a binocular microscope.

FIG. **2** shows a cross-section of the objective lens assembly of the present invention.

FIG. **3** shows a schematic light ray diagram for the lens components of the objective lens assembly.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to FIG. **1**, a perspective view of the objective lens assembly which constitutes the present invention is shown as mounted for use on an otherwise conventional binocular microscope **8**. The assembly includes a circular body **10** which is tapered toward its lower end and a light fiber containing cable **12** attached to one side of the body **10**. The cable **12** is also attached to a high intensity light source **14** through a connector **16** at the far end of the cable opposite the body **10**. The middle part of the body **10** is concentrically surrounded by a rotatable focusing ring **18** which is used to provide a manually operated focusing capability. The upper part of the body **10** is secured to a mounting piece **24**. The mounting piece **24** is detachable from the body **10** and can be replaced by way of a variety of couplers suitable for connecting the objective lens assembly to any of a number of microscopes. The microscope **8** also includes a video camera **22** for recording the image produced by the objective assembly which is connected to a video monitor **26** for providing a video display.

Referring now to FIG. **2**, a cross-section of the objective lens assembly is shown. The objective assembly includes an objective housing **30** and a field lens housing **32** which are secured within the interior of the body **10** and function to hold the lenses **40**, **42** and **44** in position. The housings **30** and **32** are both circular in construction and fit concentrically within the body **10** so that their positions are horizontally fixed. Further, both housings **30** and **32** have cylindrically shaped elements **34** and **36** which extend downward toward the object being viewed **28** and provide the actual mounting locations for the optical lenses **40**, **42** and **44**. The objective housing **30** is secured to the shoulder **38** of the body **10** so that its position is also vertically fixed. However, the position of the field lens housing **32** is vertically adjustable through rotation of the focusing ring **18**, the action of the cam sleeve **46**, the drive pin **48** and the springs **50** and **52**. The spring **50** bears on the upper axial end of the housing **32** while the spring **52** bears on the lower axial end of the housing **32**. Together the two springs preload the housing so that the position of the housing **32** with respect to the body **10** can be smoothly adjusted. The focusing ring **18** is mounted between the retaining ledge **20** and a washer **43** and the mounting piece **24** and a washer **45** so that its movements are vertically constrained. The cam sleeve **46** is positioned between the focusing ring **18** and the body **10**. The cam sleeve **46** is rotationally secured to the focusing ring **18** by the stop bolt **54** and its upper surface **58** is in sliding contact with the drive pin **48**. The cam sleeve **46** is sloped around its circumference on its upper surface as shown by the dashed line **58**. The drive pin **48** is attached to the housing **32** but is vertically movable in the slot **60** in the body **10** in response to the position of the cam sleeve **46** and the focusing ring **18**. The structural elements of the lens asssembly such as the body **10**, housings **30** and **32**, focusing ring **18** and cam sleeve **46** may be manufactured of conventional metals such as brass using traditional metal working machines and techniques such as lathes and milling machines.

The lens **40** and **42** are mounted immediately adjacent to one another within circular cavities in the lower end of the housing **30**. The lenses **40** and **42** are separated by

a small spacer **62** which is of much lesser width than the radii of curvature of the lenses. The lens **40** and **42** are held in position by the washer **64** and the objective retainer **66** which is loaded by the spring **50**. The lens **44** is mounted in the circular passage **68** in the housing **32**. The lens **44** is cemented into the passage **68** along with a convoluted spacer **69** having a black matt finish for absorbing any stray light.

The cable **14** contains a bundle **70** of light conducting fibers. The cable **14** connects to the inlet fixture **74** of the body **10**. The bundle **70** is split into groups **72** of separate fibers which extend coaxially around the housing **30** and the lenses **40** and **42** in the annular spaces between the body **10** and housing **30**. The lower tips **76** of the fibers are cemented into a ring **78** concentric with the lens **40**. The ends of the fibers which form the ring are cut flush the body **10** and polished to allow them to efficiently emit light toward the object **28** being viewed.

Referring now to FIG. **3**, an enlarged view of the lens system without its supporting structure is illustrated. The lenses **40, 42** and **44** are aligned in the order given along a common optical axis **60**. The lens **40** is a thick plano-convex lens having a very small radius of curvature which will preferably range between 0.05 and 0.3 inch and a comparably small aperture which will preferably range between 0.04 to 0.25 inch. The lens **42** is also a thick plano-convex lens having the same radius of curvature as the lens **40**. The lens **42** is wider than the lens **40** to allow it to be more easily mounted within the housing **30**. The lenses **40** and **42** are mounted in close proximity so that they are separated by a distance which is much less the radii of the curvature of the lenses and are mounted in opposed fashion so that their convex surfaces face one another. The lenses **40** and **42** act to receive light from the object being inspected and transmit an image of that object characterized by a substantial depth of field to the field lens **44**. The lens **44** actually includes four separate lens parts, **44*a***, **44*b***, **44*c*** and **44*d***. The lens parts **44*a*** and **44*b*** form an achromatic lens pair for magnifying the image and for correcting the image for chromatic aberrations. The lens part **44*c*** is a rod lens with a ground surface around its cylindrical circumference for transmitting an image with a minimum of divergence, diffusion and reflective losses. The lens part **44*d*** is a focusing lens for helping to properly relay the image to an ocular lens system. The exact characteristics of a set of suitable lenses for an objective lens assembly as shown in FIG. **2** and **3** are given in Table I below.

TABLE I

	Lens 40	Lens 42	Lenses 44a, 44b, 44c, 44d
Radius of Curvature	.123"	.123"	.530/.290", .290", 0", .545"
Diameter	.106"	.152"	.183", .183", .183", .183"
Thickness	.105"	.105"	.040", .080", 1.25", .070"
Index of Refraction	1.51680	1.51680	1.78831, 1.72000, 1.62041, 1.720
Dispersion	64.17	64.17	47.7, 50.2, 60.3, 50.2

The lenses described above may be manufactured using conventional lens grinding techniques. The lenses described in Table I would provide an assembly adapted for inspecting efficiently parts having dimensions typically in the range of 1 to 100 thousandths of an inch in size and depth dimensions of up to 1 to 3 inches.

Referring now again to FIG. **1**, in operation the objective lens assembly may be attached to a conventional microscope **8**. The cable **12** is connected to a high intensity light source **14**. The object to be viewed **28** is then placed under the objective lens assembly and the light source **14** turned on. The height of the objective assembly is adjusted to the appropriate range for the magnification desired using the microscope positioning controls **11**. If necessary, the focusing ring **18** is then rotated to adjust the position of the field lens system **44** (see FIG. **2**) and bring the object into proper focus. The object may then be visually examined through the microscope **8**. The light fibers and ring **72** provide the required illumination. The lenses **40** and **42** (see FIGS. **2** and **3**) cooperate to provide an image characterized by substantial depth of field and only minor aberrations. The lens system **44** helps to correct any aberrations in the image and relays it (directly or indirectly) up to the ocular lens system for the microscope with a limited amount of divergence and light loss.

While the system of this invention has been described in conjunction with particular embodiments, it should be apparent that certain changes could be made without departing from the principles of the invention. Consequently, the embodiments provided are intended to be illustrative only and are not meant to limit the scope of the following claims.

We claim:

1. An objective lens assembly for use in visually inspecting small sized parts microscope applications for viewing an object, comprising:

a pair of plano-convex lenses for receiving light from an object and forming an optical image of the same, said lenses having equal radii of curvature of from 0.05 to 0.3 inch and said lenses mounted so that they are maintained in close proximity to one another and the convex surfaces of the lenses face one another; means for illuminating said object with high intensity light;

means for receiving light from image formed by said pair of plano-convex lens and relaying said image to an ocular lens system comprising a field lens system including an achromatic lens pair for correcting for chromatic abberations, an elongate rod lens for transmitting the image with reduced divergence and a relay lens for focusing the image for further transmission.

2. The objective lens assembly of claim **1**, wherein said means for illuminating comprises a ring of light conducting fibers coaxial with said pair of plano-convex lenses.

3. An objective lens assembly for use in microscope applications for viewing an object, comprising:

a pair of plano-convex lenses for receiving light from an object and forming an optical image of the same, said lenses having equal radii of the curvature of from 0.05 to 0.3 inch and said lenses mounted so that they are maintained in close proximity to one another and the convex surfaces of the lenses face one another;

a plurality of light conducting fibers mounted in a ring coaxial with said pair of plano-convex lenses for illuminating said object;

a field lens system including an achromatic lens pair of plano-convex lenses, processing the image and relaying it to an ocular lens system.

4. The objective lens assembly of claim **1**, further including focusing means for adjusting the position of said field lens system relative to said pair of plano-convex lenses, said focusing means including a drive pin attached to said lens system, a cam sleeve in slidable

contact with said drive pin and a rotatable focusing ring attached to said cam sleeve.

5. The objective lens assembly of claim 4 which further includes a housing for receiving said field lens system; and spring means disposed at opposite ends of said housing to support said housing for smooth focusing adjustment of said field lens system.

* * * * *

United States Patent [19]

Schitthof

[11] **Patent Number: 4,773,745**

[45] **Date of Patent: Sep. 27, 1988**

[54] **COMPACT WIDE-ANGLE OBJECTIVE**

[75] Inventor: **Hiltrud Schitthof,** Schweppenhausen, Fed. Rep. of Germany

[73] Assignee: **Jos. Schneider Optische Werke Kreuznach GmbH & Co. KG,** Bad Kreuznach, Fed. Rep. of Germany

[21] Appl. No.: **92,259**

[22] Filed: **Sep. 2, 1987**

[30] **Foreign Application Priority Data**

Sep. 2, 1986 [DE] Fed. Rep. of Germany 3629773

[51] **Int. Cl.**[4] **G02B 9/62**

[52] **U.S. Cl.** **350/464**

[58] **Field of Search** 350/464

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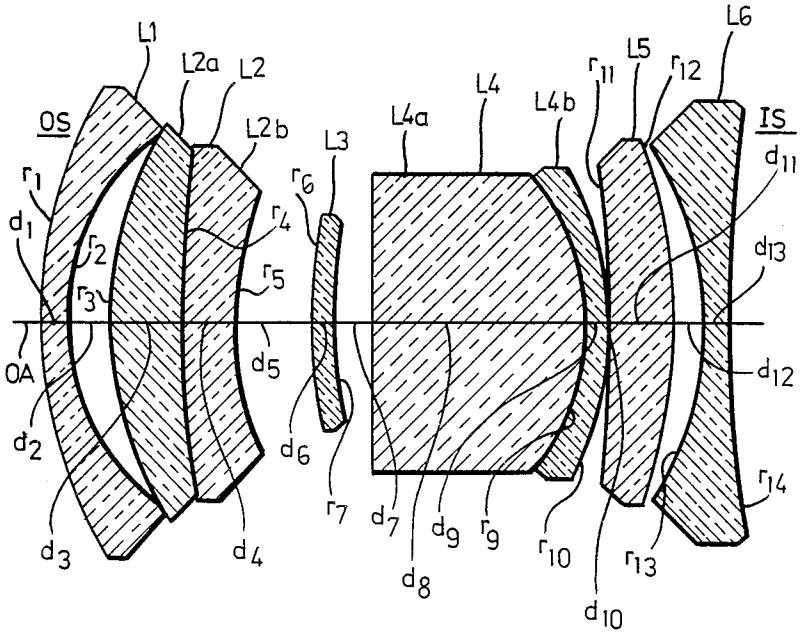
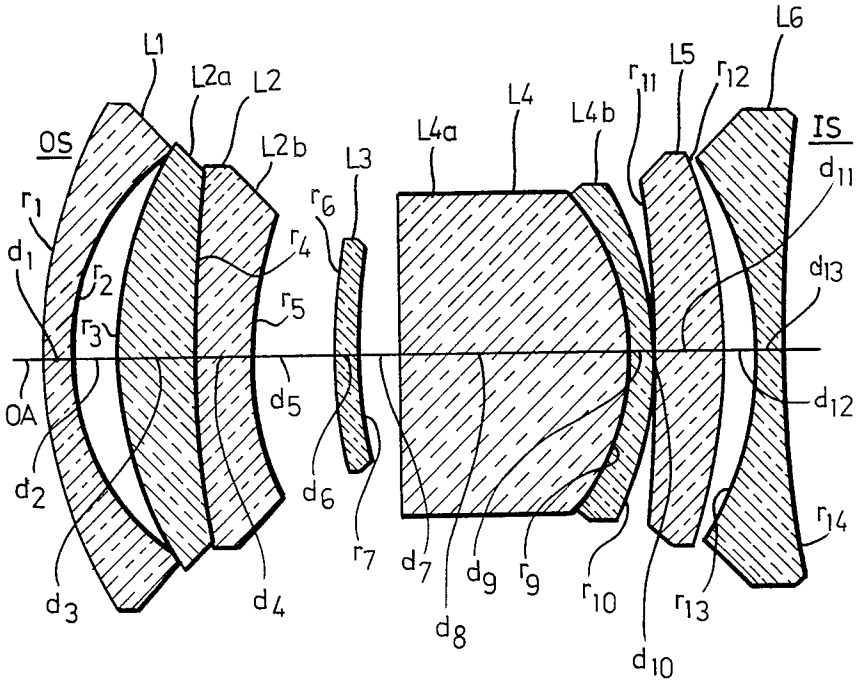
Primary Examiner—John K. Corbin
Assistant Examiner—Rebecca D. Gass
Attorney, Agent, or Firm—Herbert Dubno

[57] **ABSTRACT**

A wide-angle objective of compact construction and comparatively small diameter has its first lens element formed as a convex negative meniscus and its last or sixth lens element formed as a biconcave construction with the fourth lens element being a thick cemented lens.

4 Claims, 3 Drawing Sheets

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L2
L2b
L3
L4a
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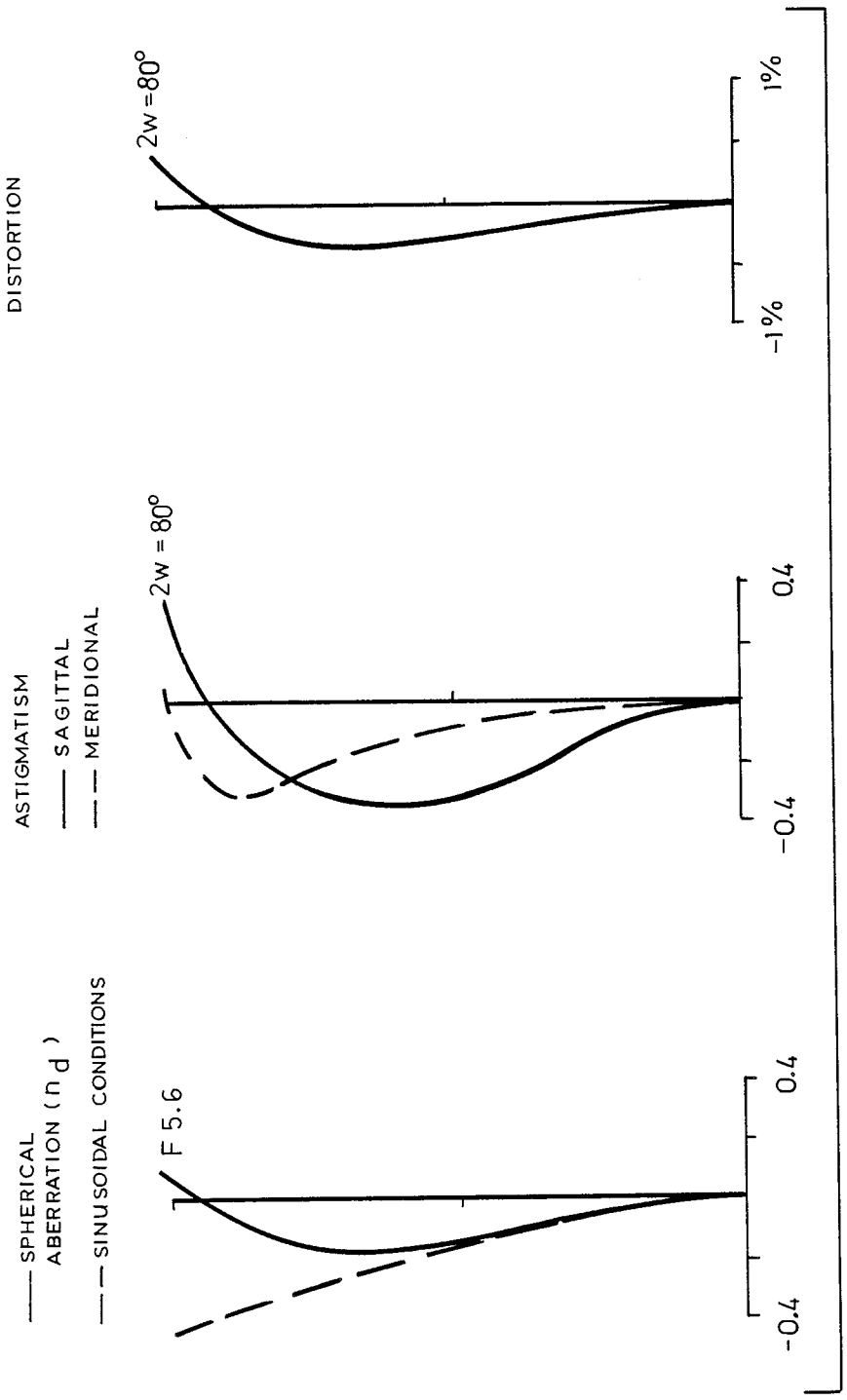
FIG.1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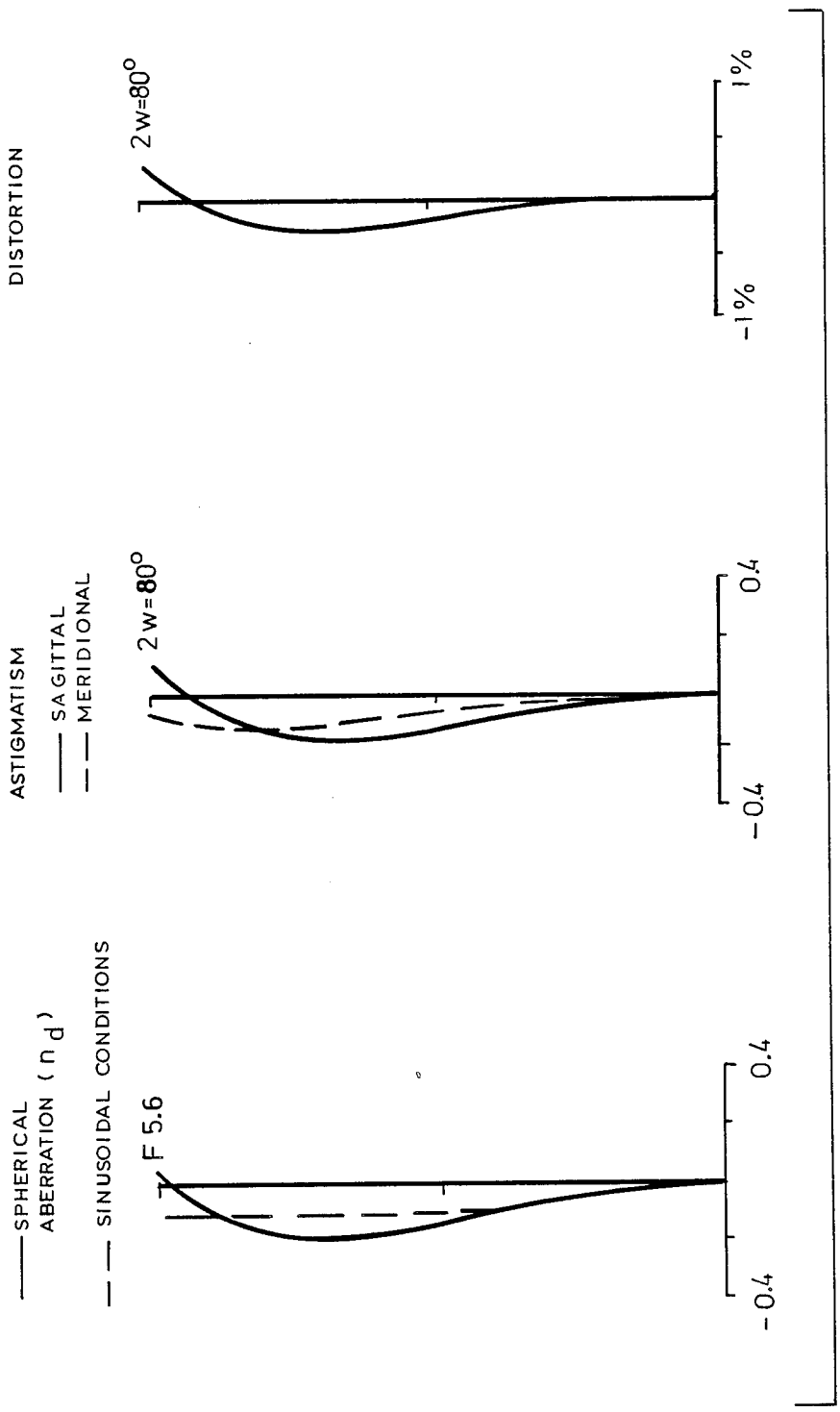
-0.4
DISTORTION
2w = 80°
1%
-1%

FIG.2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SAGITTAL
MERIDIONAL
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0.4
-0.4
DISTORTION
2w=80°
1%
-1%

FIG. 3

COMPACT WIDE-ANGLE OBJECTIVE

FIELD OF THE INVENTION

My present invention relates to a photographic wide-angle objective and, more particularly, to a comparatively short wide-angle objective whose field of view is comparatively wide both at small apertures and with larger apertures.

BACKGROUND OF THE INVENTION

Wide angle objectives are, of course, known in the art. Typical of such objectives are those designed in accordance with L. Bertele, which generally provide a symmetrical arrangement of the individual lenses and cemented-lens components or elements.

A disadvantage of such earlier lens systems is that they have a relatively long construction, are comparatively large and bulky and require front and rear lens diameters which are so large that difficulties are encountered in building them into cameras. They also limit the adjustment capabilities of so-called large-format cameras.

OBJECTS OF THE INVENTION

It is, therefore, the principal object of the present invention to provide an improved wide-angle objective, which can be used highly effectively for large-format cameras, in which these drawbacks are eliminated or reduced.

Another object of the invention is to provide an alternative to conventional objectives and which will yield a wide field of view in a compact construction and with good correction for all lens apertures. It is another object of this invention to provide a compact wide-angle objective which can be used as an alternative to a normal objective and compact construction and excellent correction for all apertures as well as an alternative for bulky wide-angle objectives which are dimensionally sensitive and can guarantee sharpness only with stepped-down apertures, the improved objective being of comparatively short construction, using comparatively small lens diameters and nevertheless having excellent sharpness over the full range of apertures and at various distances with an image angle of at least 70° in the fully open state of the lens and of at least 80° with a stepped-down aperture.

SUMMARY OF THE INVENTION

These objects and others which will become apparent hereinafter are attained, in accordance with the present invention in a six-element eight-lens wide angle objective which consists essentially of, from the object side to the image side of the objective:

a first element constituted by a convex negative meniscus first lens **L1** with radii r_1 and r_2 and a thickness along the axis of d_1 and a refractive index of n_1;

a second positive-meniscus element **L2** separated from the first element by a spacing d_2 measured along the axis and constituted by a second lens **L2***a* cemented to a third lens **L3**, the second lens **L2** being of refractive index n_2 and having radii r_3 and r_4 and a thickness along the axis of d_3, the third lens **L2***b* being of refractive index n_3 and having radii r_4 and r_5 and a thickness along the axis of d_4;

a third element **L3** separated from the second element by a spacing d_5 along the axis and constituted by a positive meniscus fourth lens having radii r_6 and r_7, a refractive index n_4, and a thickness along the axis of d_6;

a fourth positive element **L4** spaced from the third element along the axis by a spacing d_6 and constituted of a fifth lens **L4***a* cemented to a sixth lens **L4***b*, the fifth lens **L4***a* having radii r_8 and r_9 and being of a thickness d_8 along the axis and of a refractive index n_5, the sixth lens **L4***b* having radii r_9 and r_{10} and being a lens with a refractive index n_6 and a thickness along the axis of d_9;

a fifth positive meniscus element **L5** spaced along the axis by a spacing d_{10} from the fourth element and consisting of a seventh lens with a refractive index n_7, radii r_{11} and r_{12} and a thickness d_{11} along the axis; and

a sixth negative element **L6** in the form of an eighth lens of biconcave configuration, separated by a spacing d_{12} along the axis from the fifth element and having a refractive index n_8, radii r_{13} and r_{14} and a thickness d_{13} along the axis, and wherein:

the radius r_{14} is greater than the radius r_{13} of the eight lens and is turned toward an image side of the objective, and the following conditions are also satisfied:

$$(d_2+d_{12})<(d_8+d_9)/2, \text{ and}$$

$$(d_7+d_8+d_9+d_{10}+d_{11}+d_{12}+d_{13})>0.48D$$

where D is the sum of all of the thicknesses and spacings.

The essential features of the new angle objective of the invention is thus that the first lens element is a negative meniscus convex toward the image side and the six-lens element **L6** is biconcave with its larger radius r_{14} turned toward the image side, the objective satisfying the conditions given above. Throughout this description, whenever the summation sign is used, it will be understood to represent D, the total of the lens thicknesses and of the air spacings d_1–d_{13}.

According to a feature of the invention, the wide-angle objective further satisfies the conditions:

$$n_1<1.55$$

$$n_8<1.55$$

$$(n_2+n_3+n_4+n_5+n_6+n_7)/6>1.62.$$

Best results are obtained when the lenses or lens elements are characterized by the following parameters (where in practical terms the units are mm) for a focal length of 100 units the image distance is 81.9 units, the image angle is 70° for an aperture ratio of 1:5.6 and is 80° for an aperture ratio of 1:11.0, and said radii, thicknesses and spacings are given below in said units:

$r_1 = 39.152$			
	$d_1 = 2.517$	$n_1 = 1.4645$	$\nu_1 = 65.77$
$r_2 = 20.221$			
	$d_2 = 3.510$		
$r_3 = 29.616$			
	$d_3 = 6.623$	$n_2 = 1.7550$	$\nu_2 = 52.30$
$r_4 = 87.298$			
	$d_4 = 4.967$	$n_3 = 1.6254$	$\nu_3 = 35.56$
$r_5 = 29.998$			
	$d_5 = 7.000$		
$r_6 = 48.217$			
	$d_6 = 1.987$	$n_4 = 1.7725$	$\nu_4 = 49.60$
$r_7 = 55.911$			
	$d_7 = 3.312$		
$r_8 = 321.496$			
	$d_8 = 19.312$	$n_5 = 1.6204$	$\nu_5 = 60.33$
$r_9 = -19.009$			

-continued

	$d_9 = 1.987$	$n_6 = 1.6668$	$\nu_6 = 33.01$
$r_{10} = -27.981$			
	$d_{10} = 0.338$		
$r_{11} = -117.436$			
	$d_{11} = 5.841$	$n_7 = 1.6204$	$\nu_7 = 60.33$
$r_{12} = -44.848$			
	$d_{12} = 2.583$		
$r_{13} = -28.475$			
	$d_{13} = 2.517$	$n_8 = 1.4787$	$\nu_8 = 58.70$
$r_{14} = 131.465$			
	$\Sigma d = 62.494$		

wherein ν_1 to ν_8 are the Abbe numbers of the first, second, third, fourth, fifth, sixth, seventh and eight lenses, respectively, and Σd is the sum D of all of said thicknesses and spacings.

Alternatively the objective conforms to the parameters (also with the units being mm):

for a focal length of 100 units the image distance is 79.98 units, the image angle is 70° for an aperture ratio of 1:5.6 and is 80° for an aperture ratio of 1:11.0, and the radii, thicknesses and spacings are given below in the units:

$r_1 = 40.585$			
	$d_1 = 2.512$	$n_1 = 1.4645$	$\nu_1 = 65.77$
$r_2 = 20.329$			
	$d_2 = 2.942$		
$r_3 = 28.243$			
	$d_3 = 6.611$	$n_2 = 1.7550$	$\nu_2 = 52.30$
$r_4 = 78.065$			
	$d_4 = 4.958$	$n_3 = 1.6254$	$\nu_3 = 35.56$
$r_5 = 29.234$			
	$d_5 = 6.988$		
$r_6 = 48.279$			
	$d_6 = 1.983$	$n_4 = 1.7725$	$\nu_4 = 49.60$
$r_7 = 61.979$			
	$d_7 = 3.303$		
$r_8 = 735.997$			
	$d_8 = 19.278$	$n_5 = 1.6180$	$\nu_5 = 63.40$
$r_9 = -18.981$			
	$d_9 = 1.983$	$n_6 = 1.6668$	$\nu_6 = 33.01$
$r_{10} = -27.595$			
	$d_{10} = 0.337$		
$r_{11} = -100.513$			
	$d_{11} = 5.831$	$n_7 = 1.6180$	$\nu_7 = 63.40$
$r_{12} = -44.952$			
	$d_{12} = 2.578$		
$r_{13} = -27.416$			
	$d_{13} = 2.512$	$n_8 = 1.4645$	$\nu_8 = 65.77$
$r_{14} = 158.107$			
	$\Sigma d = 61.816$		

wherein ν_1 to ν_8 are the Abbe numbers of the first, second, third, fourth, fifth, sixth, seventh and eight lenses, respectively, and Σd is the sum D of all of the thicknesses and spacings.

The compact wide-angle objective has been found to be especially advantageous for large format cameras, i.e. those which expose a negative with an image format of 90 mm × 120 mm or some other large format camera.

The compact wide-angle objective of the invention is surprisingly short and compact by comparison with wide-angle lenses used heretofore. The combination of a highly compact construction with high image quality to the edge of the image angle of 80 combined with the fact that the wide angle characteristics are retained even at relatively high openings has proven to be of great advantage in large format photography with respect to the ease of working in this medium and the high image quality which is obtained at all distances.

BRIEF DESCRIPTION OF THE DRAWING

The above and other objects, features and advantages of the present invention will become more readily apparent from the following description, reference being made to the accompanying drawing in which:

FIG. 1 is a schematic axial section of a compact wide-angle lens according to the invention;

FIG. 2 is a graph showing the spherical aberration, the deviation from a sinosoidal characteristic of the astigmatism and the characteristics of a first embodiment of the invention; and

FIG. 3 is a graph similar to FIG. 2 of a second embodiment.

SPECIFIC DESCRIPTION

FIG. 1 shows a wide-angle compact objective having an optical axis OA along which are arranged from the object side OS to the image side IS six lens elements and a total of eight lenses.

These include a first lens element L1 of negative refractivity consisting of a single lens with radii of curvature r_1 and r_2 and a thickness d_1 as measured along the axis.

At a spacing d_2 from the first lens element L1 is a second lens element L2 consisting of two lenses L2*a* and L2*b* which are cemented together. The radii of curvature of these lenses are represented at r_3, r_4 and r_5 and the respective thicknesses are d_3 and d_4. Both lenses L2*a* and L2*b* are positive refracting lenses. At a spacing d_5 there follows a third lens element L3, also of positive refractivity and consisting of a single lens with radii r_6 and r_7 and a thickness of d_6.

The fourth positive lens element L4 is separated by a distance d_7 from the third element L3 and consists of two cemented positive lenses L4*a* and L4*b* with respective radii r_8, r_9 and r_{10} and thicknesses d_8 and d_9.

A spacing d_{10} can separate the fifth lens element L5 which is also of positive refractivity from the lens element L4.

The lens element L5 also consisting of a single lens has radii r_{11} and r_{12} and a thickness d_{11}.

A spacing d_{12} is provided between the sixth and final lens element L6 and the lens element L5. The lens element L6 is a negative lens with radii r_{13} and r_{14} and a thickness d_{13}. The refractive indices of the lenses L1, L2*a*, L2*b*, L3, L4*a*, L4*b*, L5 and L6 are represented at n_1–n_8, respectively.

According to the invention, these lenses fulfill the following criteria:

(1) $r_1 > r_2$

(2) $r_{13} < r_{14}$

(3) $n_1 < 1.55$ and $n_8 < 1.55$

(4) $(n_2+n_3+n_4+n_5+n_6+n_7)/6 > 1.62$.

(5) $(d_2+d_{12}) < (d_8+d_9)/2$

(6) $(d_7+d_8+d_9+d_{10}+d_{11}+d_{12}+d_{13}) > 0.48D$

Criteria (1) and (2) concern the first and sixth lens elements L1 and L6 of the system.

For correction of the image field curvature and a uniform image field illumination of a large format objective having an image angle of at least 70° or 80°, the first

lens L1 should have a negative refractivity. For correction purposes, a negative meniscus lens L1 is used with a convex curvature turned toward the object side.

For the correction of coma, distortion and transverse color correction over the total image field, a symmetrical refractive index sequencing of the individual lenses is selected for the sequence of individual lenses and lens elements (L1–L6) is not symmetrical itself, the last lens L6 nevertheless having a negative refractivity.

This lens is formed as a biconcave lens (contrast with lens L1) whose radius r_{14} turned toward the image plane is greater than its radius r_{13} turned away from the image plane. This relationship has been found to improve the correction of coma for all openings and for color correction and the correction of color coma over the total image field while the air spacing d_{13} is held to a minimum.

The use of glasses with low refractive index in the outermost negative lenses L1 and L6 (criterion 3) and of high refractivity glasses in all other lenses (criterion 4) has been found to be especially advantageous for the correction of the Petzval sum with simultaneous correction of chromatographic error and all other image defects and allows flattened lens structures or large radii structures in the lens elements L12–L5.

The use of large lens thicknesses for the inner lens elements L2–L5 has been found to be advantageous for correction of systems having large image angles. In conventional wide-angle objectives, this approach has been used close to the diaphragm. For a system of the present type with an image angle of at least 70° or 80°, it suffices to have as the largest thickness element the fourth element L4 (d_8+d_9) This provides an advantage of the present system over conventional systems in that the overall weight of the objective is less. Simultaneously it allows the air spaces d_2 and d_{13} to be very small (criterion 5) which is important for good correction of image field curvature, coma and chromatographic errors and chromatographic coma even with short object distances.

Known objectives of the wide Gauss type with large air spaces between the outermost negative meniscus lenses and the neighboring positive lens elements show, by comparison to the lenses of the invention, clearly poorer image quality as one moves into the short object-distance ranges.

The limitation of a single very thick lens in the region of the diaphragm and the minimalization of the air spaces d_2 and d_3 ensure a short axial length of the objective in conjunction with a small diameter of the objective based upon the small diameters of the first and last lens elements L1 and L6, thereby making the objective particularly suitable for large format cameras by comparison with earlier wide angle lenses.

For correction of all image defects, it has been found to be advantageous that the length of the first part of the system formed by the lenses L1–L3 should be similar to that of the second part of the system formed by the elements L4–L6. This is assured by the criterion 6.

FIGS. 2 and 3 show the image reproduction quality graphically. The first tubular example given herein corresponds to FIG. 2 while FIG. 3 corresponds to the second tabular example herein.

I claim:

1. A wide-angle objective consisting essentially of six elements and eight lenses aligned along an optical axis, said lenses consisting, in succession from an object side, of:

a first element constituted by a convex negative meniscus first lens L1 with radii r_1 and r_2 and a thickness along said axis of d_1 and a refractive index of n_1;

a second positive-meniscus element L2 separated from said first element by a spacing d_2 measured along said axis and constituted by a second lens L2*a* cemented to a third lens L3, said second lens L2 being of refractive index n_2 and having radii r_3 and r_4 and a thickness along said axis of d_3, said third lens L2*b* being of refractive index n_3 and having radii r_4 and r_5 and a thickness along said axis of d_4;

a third element L3 separated from said second element by a spacing d_5 along said axis and constituted by a positive meniscus fourth lens having radii r_6 and r_7, a refractive index n_4, and a thickness along said axis of d_6;

a fourth positive element L4 spaced from said third element along said axis by a spacing d_6 and constituted of a fifth lens L4*a* cemented to a sixth lens L6*a*, said fifth lens L4*a* having radii r_8 and r_9 and being of a thickness d_8 along said axis and of a refractive index n_5, said sixth lens L4*b* having radii r_9 and r_{10} and being a lens with a refractive index n_6 and a thickness along said axis of d_9;

a fifth positive meniscus element L5 spaced along said axis by a spacing d_{10} from said fourth element and consisting of a seventh lens with a refractive index n_7, radii r_{11} and r_{12} and a thickness d_{11} along said axis; and

a sixth negative element L6 in the form of an eighth lens of biconcave configuration, separated by a spacing d_{12} along said axis from said fifth element and having a refractive index n_8, radii r_{13} and r_{14} and a thickness d_{13} along said axis, and wherein:

said radius r_{14} is greater than the radius r_{13} of said eight lens and is turned toward an image side of the objective, and the following conditions are also satisfied:

$$(d_2+d_{12})<(d_8+d_9)/2, \text{ and}$$

$$(d_7+d_8+d_9+d_{10}+d_{11}+d_{12}+d_{13})>0.48D$$

where D is the sum of all of said thicknesses and spacings.

2. The wide-angle objective defined in claim 1, further satisfying the criteria:

$$n_1<1.55$$

$$n_8<1.55$$

$$(n_2+n_3+n_4+n_5+n_6+n_7)/6>1.62.$$

3. The wide-angle lens defined in claim 2 wherein, for a focal length of 100 units the image distance is 81.9 units, the image angle is 70° for an aperture ratio of 1:5.6 and is 80° for an aperture ratio of 1:11.0, and said radii, thicknesses and spacings are given below in said units:

$r_1 = 39.152$			
	$d_1 = 2.517$	$n_1 = 1.4645$	$\nu_1 = 65.77$
$r_2 = 20.221$			
	$d_2 = 3.510$		
$r_3 = 29.616$			
	$d_3 = 6.623$	$n_2 = 1.7550$	$\nu_2 = 52.30$
$r_4 = 87.298$			
	$d_4 = 4.967$	$n_3 = 1.6254$	$\nu_3 = 35.56$

-continued

$r_5 = 29.998$			
	$d_5 = 7.000$		
$r_6 = 48.217$			
	$d_6 = 1.987$	$n_4 = 1.7725$	$\nu_4 = 49.60$
$r_7 = 55.911$			
	$d_7 = 3.312$		
$r_8 = 321.496$			
	$d_8 = 19.312$	$n_5 = 1.6204$	$\nu_5 = 60.33$
$r_9 = -19.009$			
	$d_9 = 1.987$	$n_6 = 1.6668$	$\nu_6 = 33.01$
$r_{10} = -27.981$			
	$d_{10} = 0.338$		
$r_{11} = -117.436$			
	$d_{11} = 5.841$	$n_7 = 1.6204$	$\nu_7 = 60.33$
$r_{12} = -44.848$			
	$d_{12} = 2.583$		
$r_{13} = -28.475$			
	$d_{13} = 2.517$	$n_8 = 1.4787$	$\nu_8 = 58.70$
$r_{14} = 131.465$			
	$\Sigma d = 62.494$		

wherein ν_1 to ν_8 are the Abbe numbers of the first, second, third, fourth, fifth, sixth, seventh and eight lenses, respectively, and Σd is the sum D of all of said thicknesses and spacings.

4. The wide-angle lens defined in claim 2 wherein, for a focal length of 100 units the image distance is 79.98 units, the image angle is 70° for an aperture ratio of 1:5.6 and is 80° for an aperture ratio of 1:11.0, and said radii, thicknesses and spacings are given below in said units:

$r_1 = 40.585$			
	$d_1 = 2.512$	$n_1 = 1.4645$	$\nu_1 = 65.77$
$r_2 = 20.329$			
	$d_2 = 2.942$		
$r_3 = 28.243$			
	$d_3 = 6.611$	$n_2 = 1.7550$	$\nu_2 = 52.30$
$r_4 = 78.065$			
	$d_4 = 4.958$	$n_3 = 1.6254$	$\nu_3 = 35.56$
$r_5 = 29.234$			
	$d_5 = 6.988$		
$r_6 = 48.279$			
	$d_6 = 1.983$	$n_4 = 1.7725$	$\nu_4 = 49.60$
$r_7 = 61.979$			
	$d_7 = 3.303$		
$r_8 = 735.997$			
	$d_8 = 19.278$	$n_5 = 1.6180$	$\nu_5 = 63.40$
$r_9 = -18.981$			
	$d_9 = 1.983$	$n_6 = 1.6668$	$\nu_6 = 33.01$
$r_{10} = -27.595$			
	$d_{10} = 0.337$		
$r_{11} = -100.513$			
	$d_{11} = 5.831$	$n_7 = 1.6180$	$\nu_7 = 63.40$
$r_{12} = -44.952$			
	$d_{12} = 2.578$		
$r_{13} = -27.416$			
	$d_{13} = 2.512$	$n_8 = 1.4645$	$\nu_8 = 65.77$
$r_{14} = 158.107$			
	$\Sigma d = 61.816$		

wherein ν_1 to ν_8 are the Abbe numbers of the first, second, third, fourth, fifth, sixth, seventh and eight lenses, respectively, and Σd is the sum D of all of said thicknesses and spacings.

* * * * *

United States Patent [19]

Hata et al.

[11] **Patent Number: 4,767,202**

[45] **Date of Patent: Aug. 30, 1988**

[54] **OBJECTIVE LENS SYSTEM FOR OPTICAL RECORDING TYPE DISKS**

[75] Inventors: **Kazuyoshi Hata; Sachiko Takamura,** both of Sakai, Japan

[73] Assignee: **Minolta Camera Kabushiki Kaisha,** Osaka, Japan

[21] Appl. No.: **692,766**

[22] Filed: **Jan. 18, 1985**

[30] **Foreign Application Priority Data**

Jan. 20, 1984 [JP] Japan 59-9109
Jan. 23, 1984 [JP] Japan 59-10728

[51] **Int. Cl.**[4] **G02B 13/18;** G02B 9/06
[52] **U.S. Cl.** **350/432;** 350/480
[58] **Field of Search** 350/432–435, 350/480

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Optical Systems for Optical Disk Technology by P. Kuttner, Optical Disk Technology (1982).

Primary Examiner—John K. Corbin
Assistant Examiner—Scott J. Sugarman
Attorney, Agent, or Firm—Price, Gess & Ubell

[57] **ABSTRACT**

The present invention provides an objective lens system for optical recording type disks, comprising from a light source side to a disk side; a first lens element having a positive refractive power, said first lens element having at least an aspherical surface; a second lens element having a positive refractive power; and wherein the objective lens system fulfills the following condition:

$$-\frac{1}{2}<\beta<-\frac{1}{8}$$

wherein β represents the magnification of the whole lens system.

5 Claims, 29 Drawing Sheets

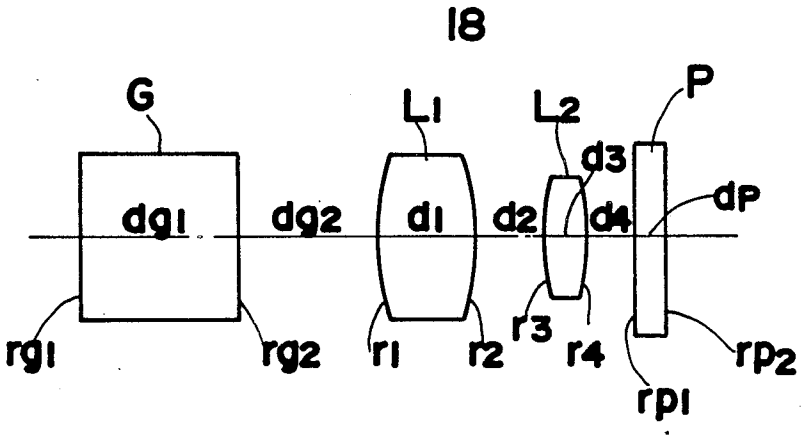


FIG.1 Prior Art

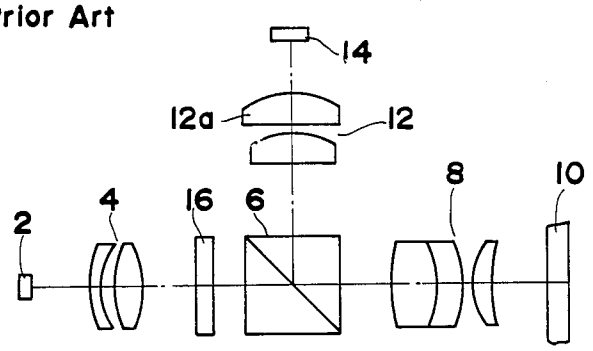


FIG.2 Prior Art

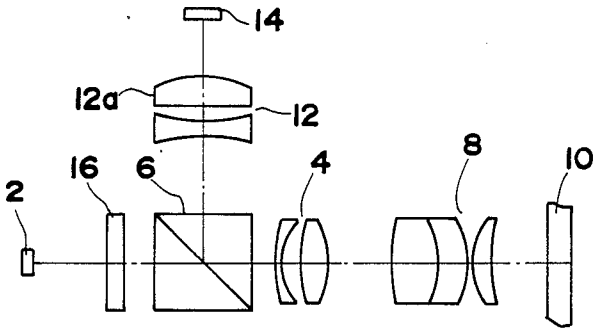


FIG.3

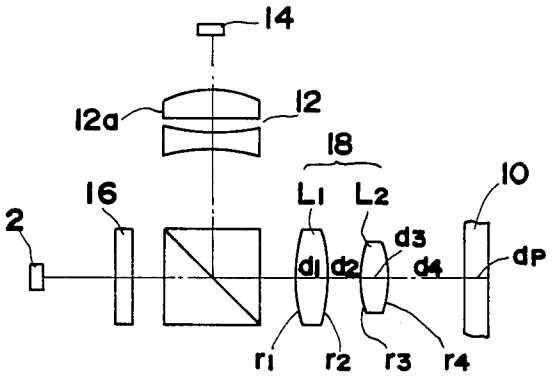


FIG.4

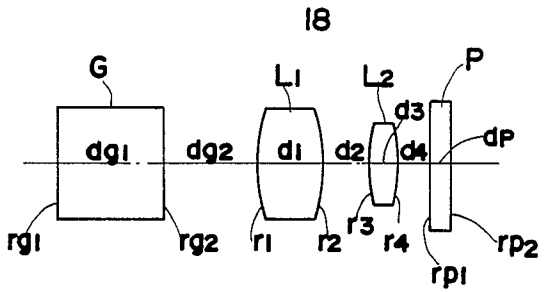


FIG.5

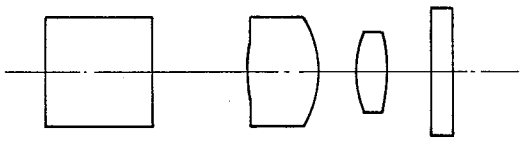


FIG.6

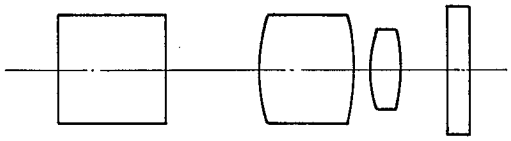


FIG.7

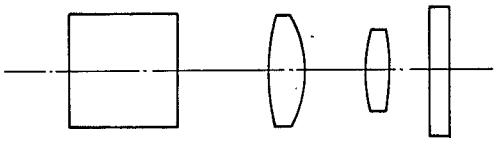


FIG.8

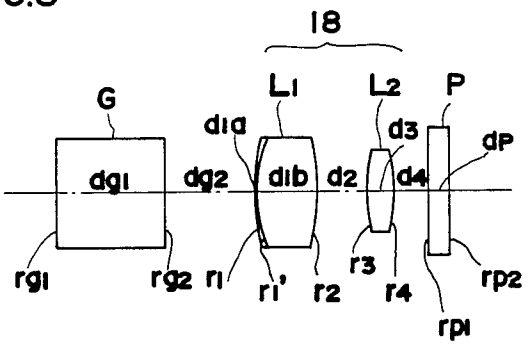

18
G
L1
L2
P
d1a
d3
dP
dg1
dg2
d1b
d2
d4
rg1
rg2
r1
r1'
r2
r3
r4
rp2
rp1

FIG.9A

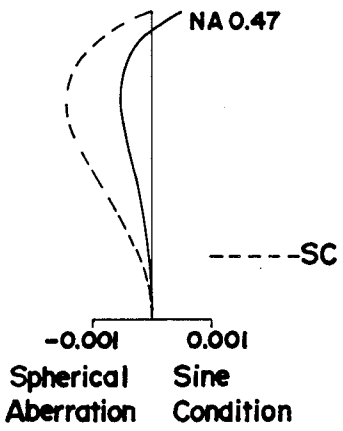


FIG.9B

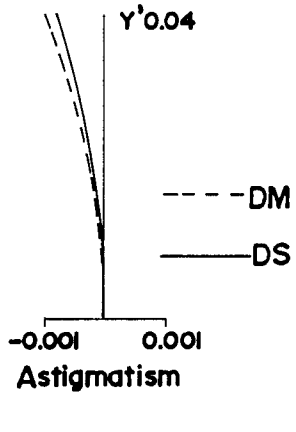


FIG.9C

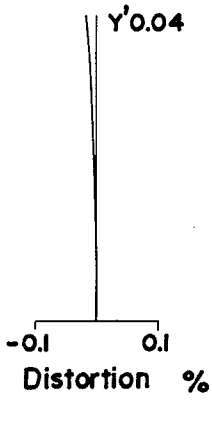


FIG.10A

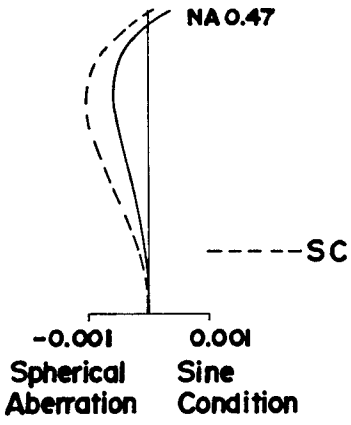


FIG.10B

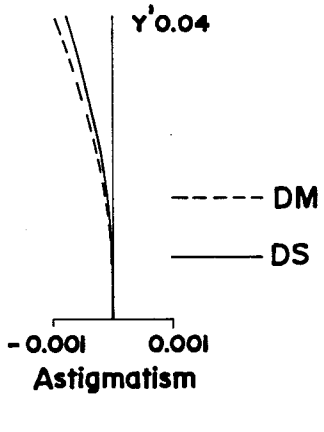


FIG.10C

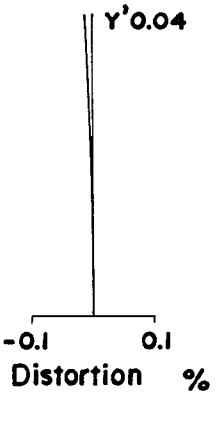


FIG.1 1A

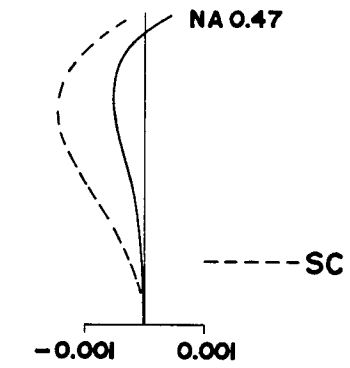


FIG.1 1B

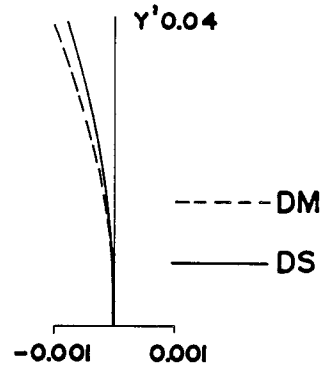


FIG.1 1C

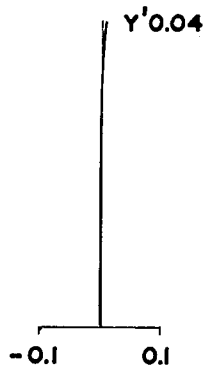


FIG.12A

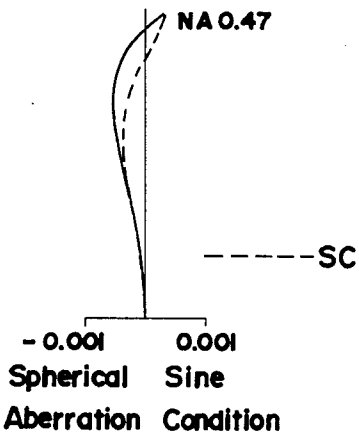


FIG.12B

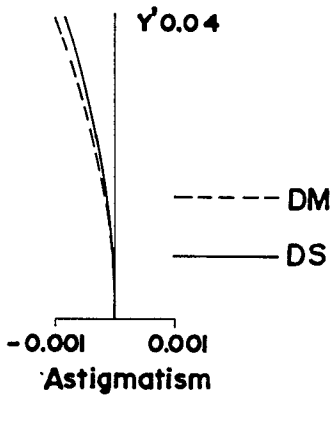


FIG.12C

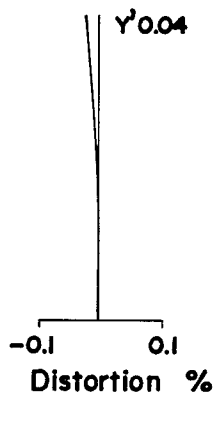


FIG.13A

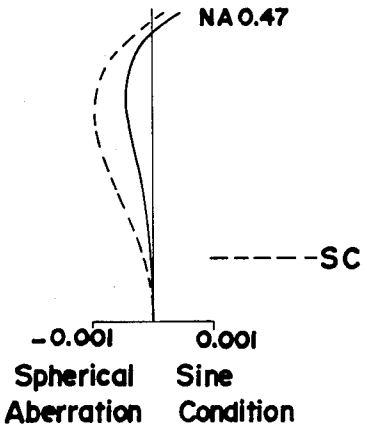


FIG.13B

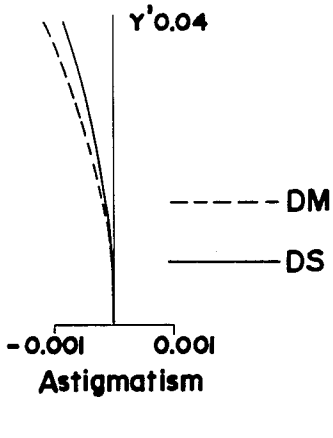


FIG.13C

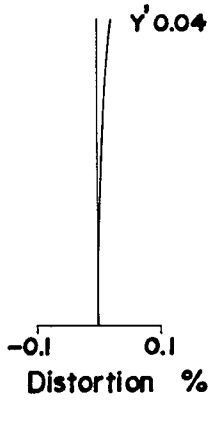


FIG.14A

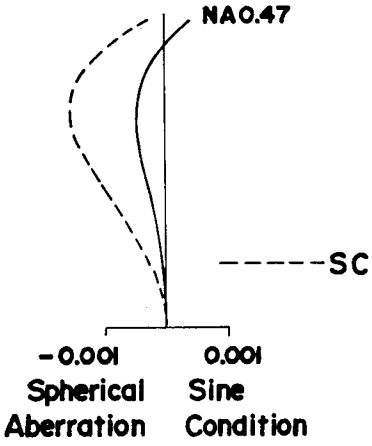


FIG.14B

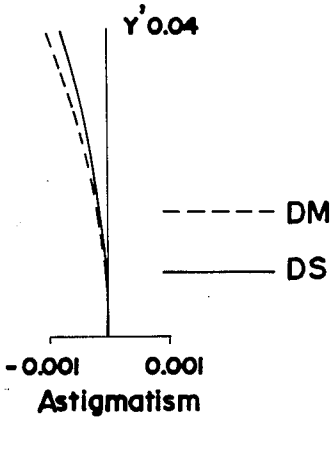


FIG.14C

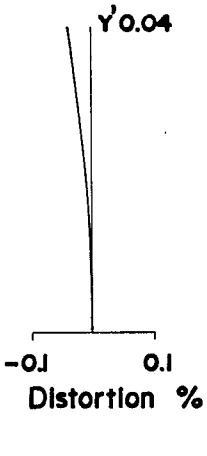


FIG.15A

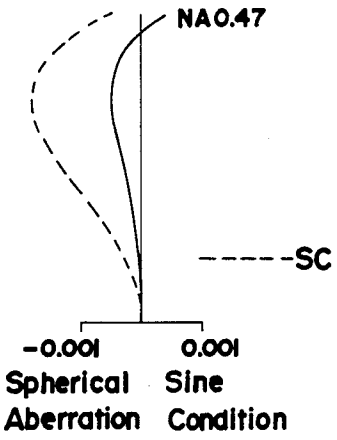


FIG.15B

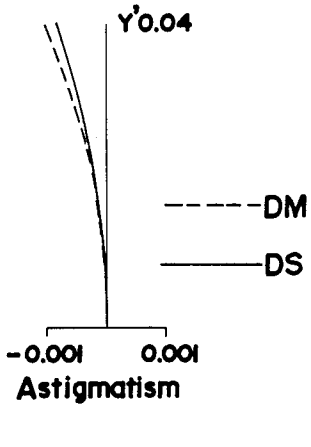


FIG.15C

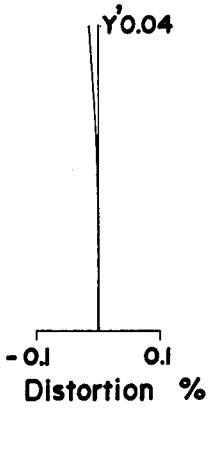


FIG.16A

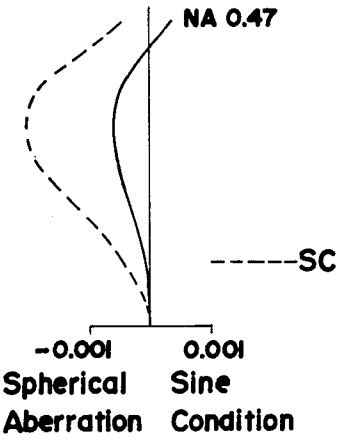


FIG.16B

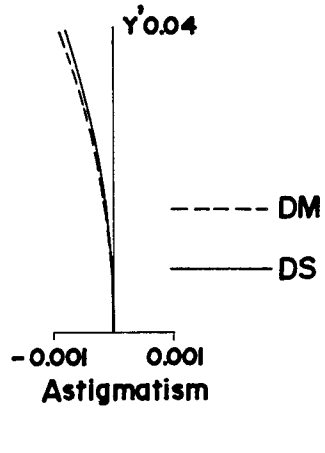


FIG.16C

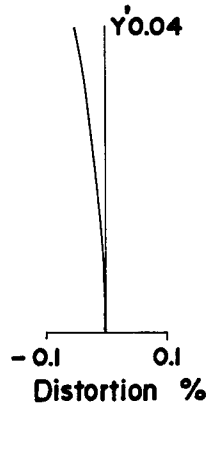


FIG.17A

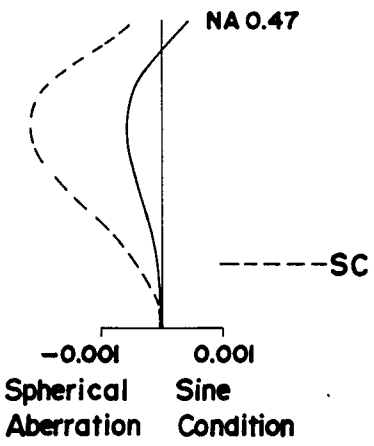


FIG.17B

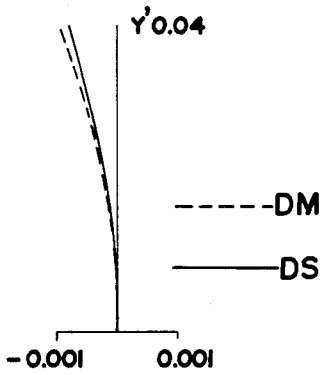


FIG.17C

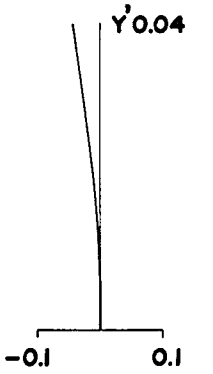


FIG.18A

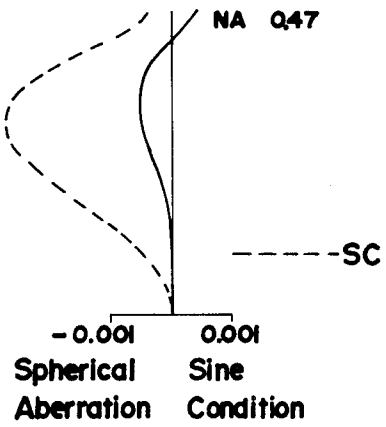


FIG.18B

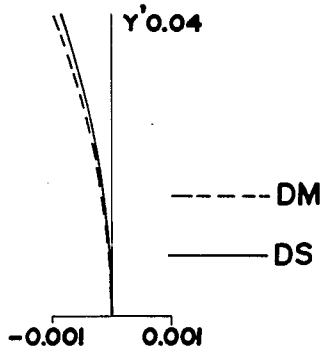


FIG.18C

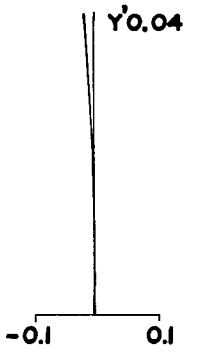


FIG.19A

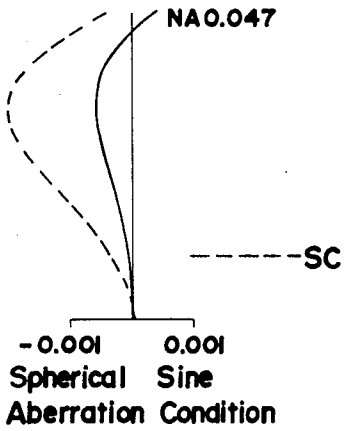


FIG.19B

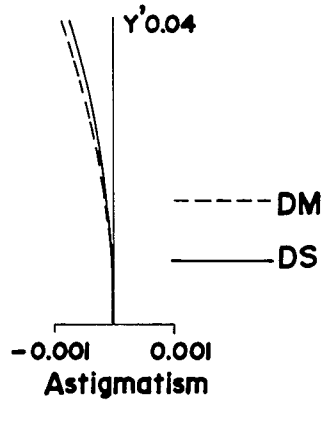


FIG.19C

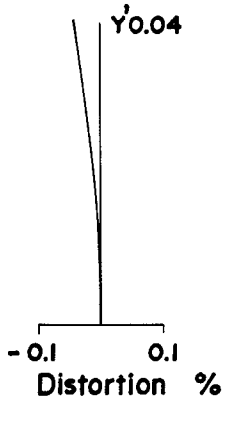


FIG.20A

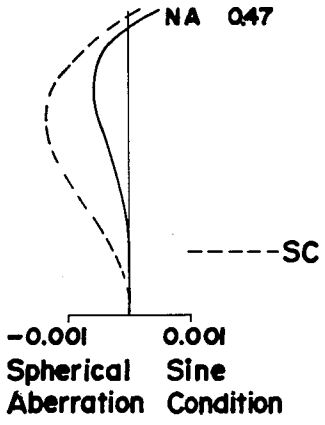


FIG.20B

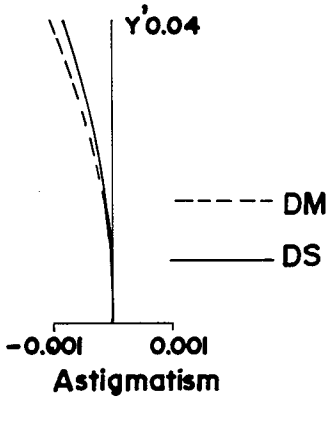


FIG.20C

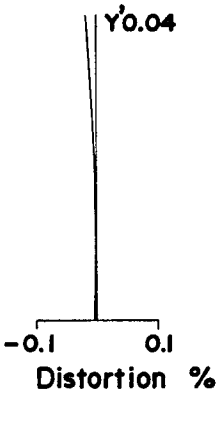


FIG.21A

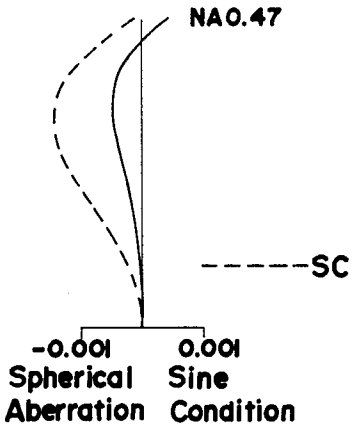


FIG.21B

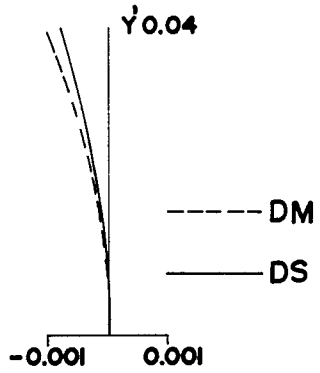


FIG.21C

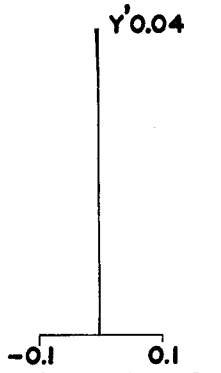


FIG.22A

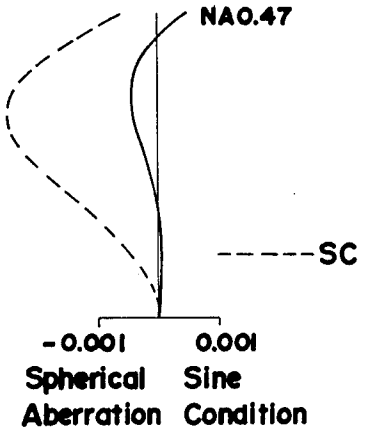


FIG.22B

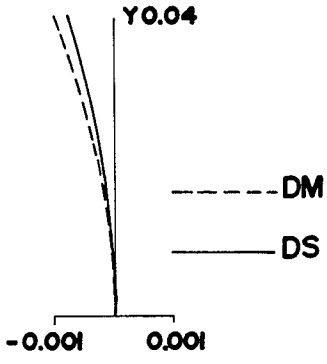


FIG.22C

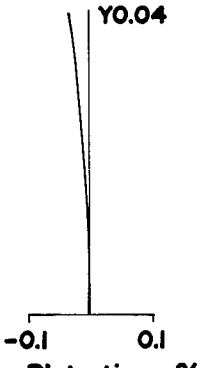


FIG.23A

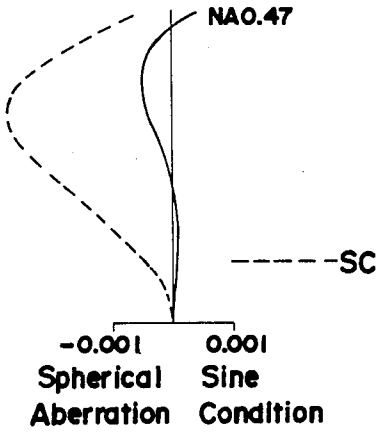


FIG.23B

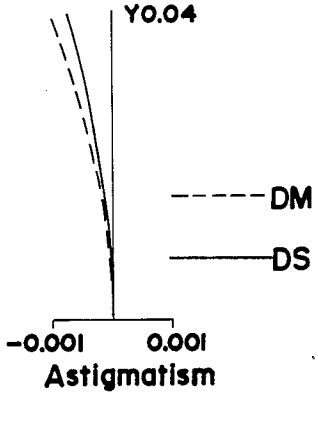


FIG.23C

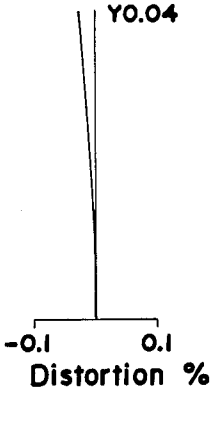


FIG.24A

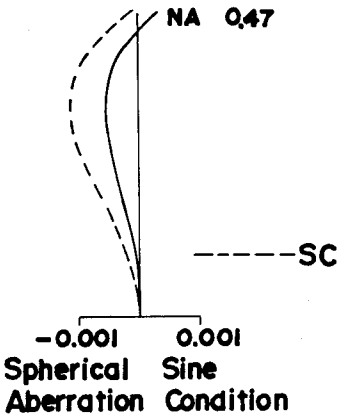


FIG.24B

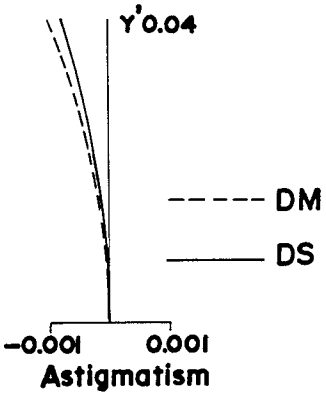


FIG.24C

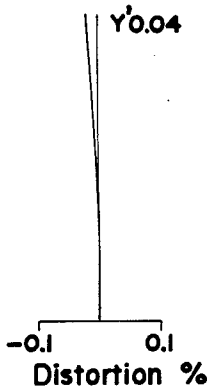


FIG.25

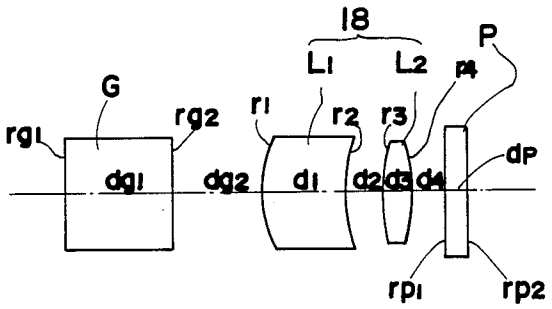


FIG.26A

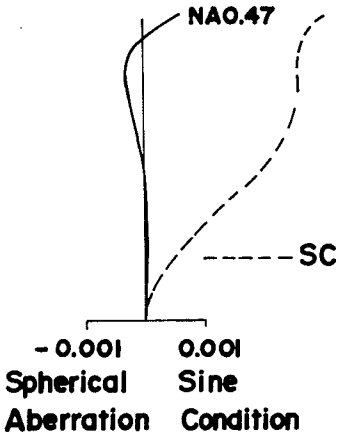


FIG.26B

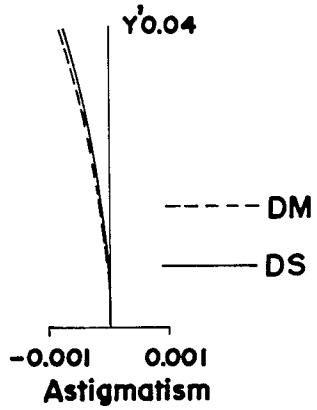


FIG.26C

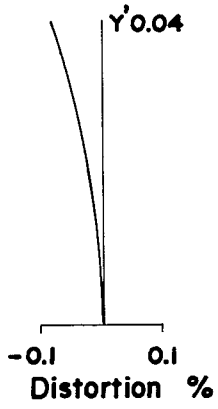


FIG.27

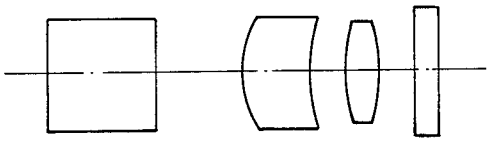


FIG.28A

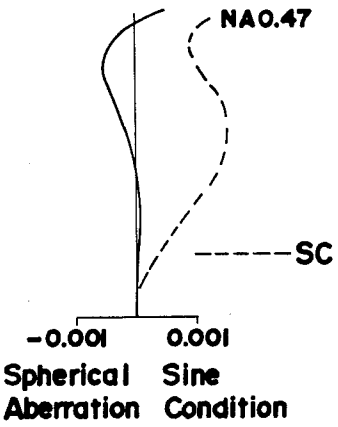


FIG.28B

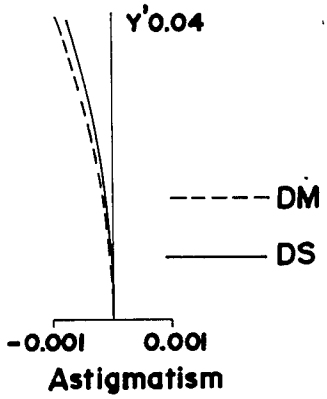


FIG.28C

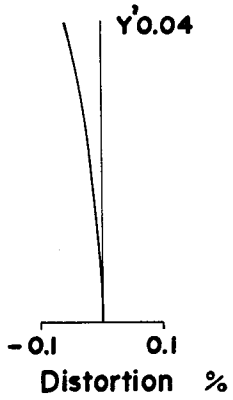


FIG.29

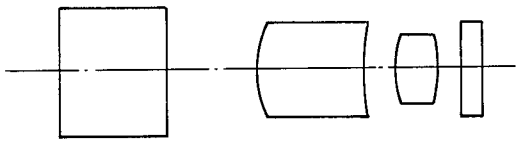


FIG.30A FIG.30B FIG.30C

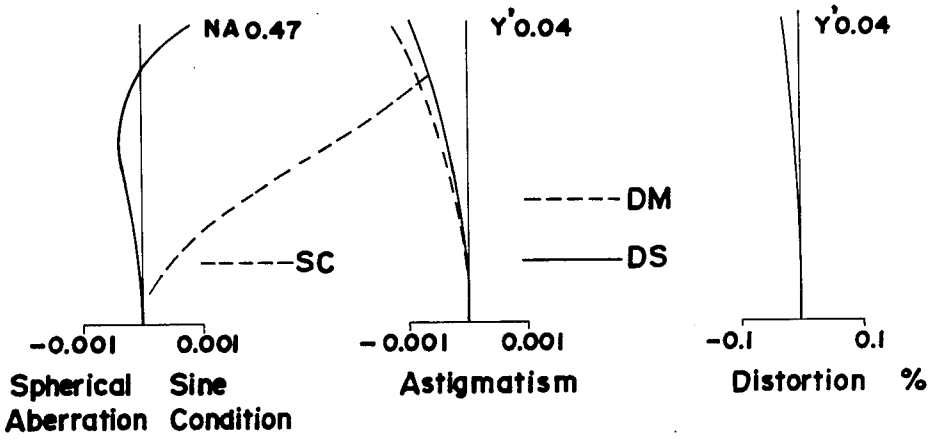


FIG.31

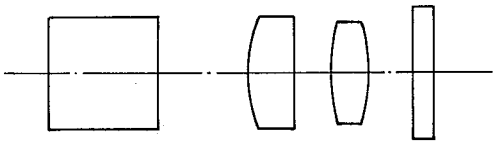


FIG.32A FIG.32B FIG.32C

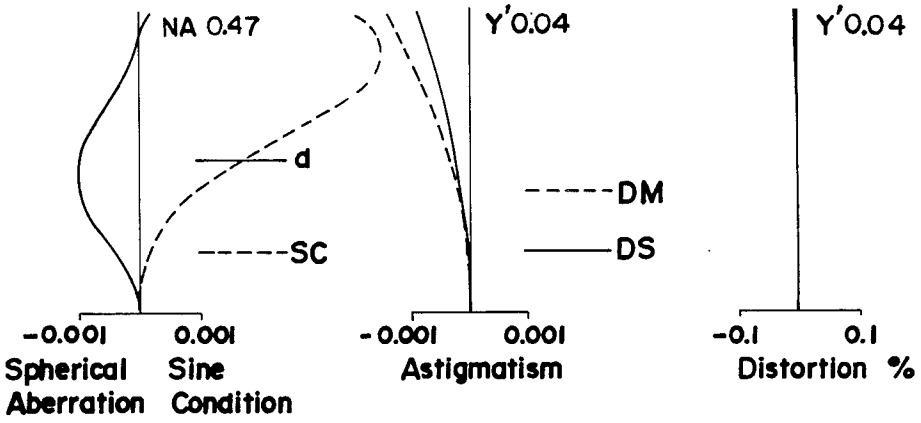


FIG.33

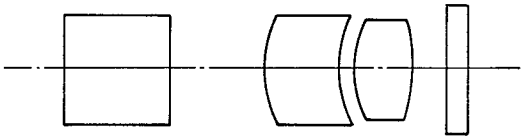


FIG.34

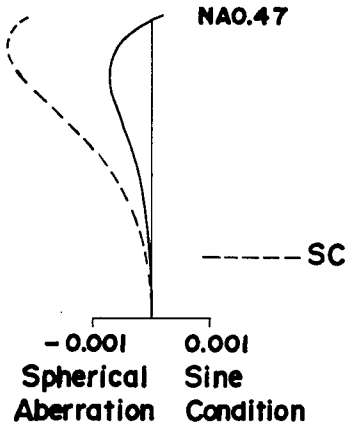


FIG.34

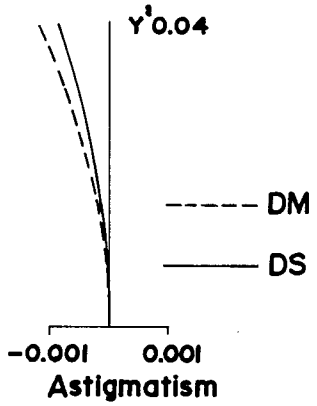


FIG.34

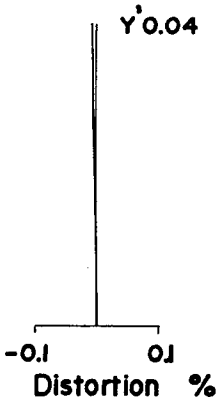


FIG.35

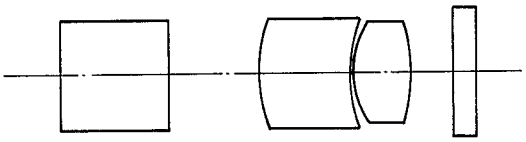


FIG.36A

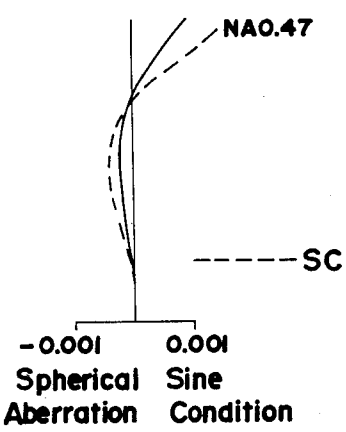


FIG.36B

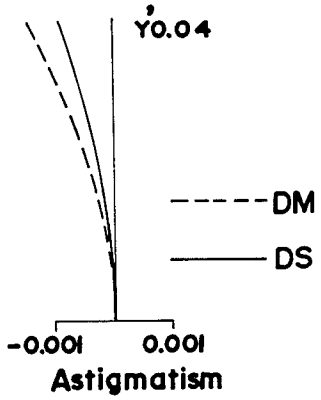


FIG.36C

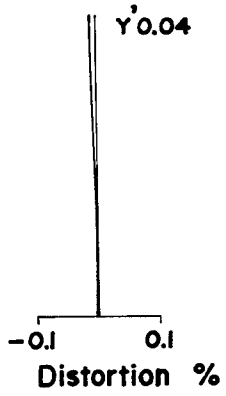


FIG.37

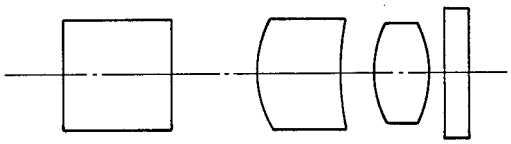


FIG.38A FIG.38B FIG.38C

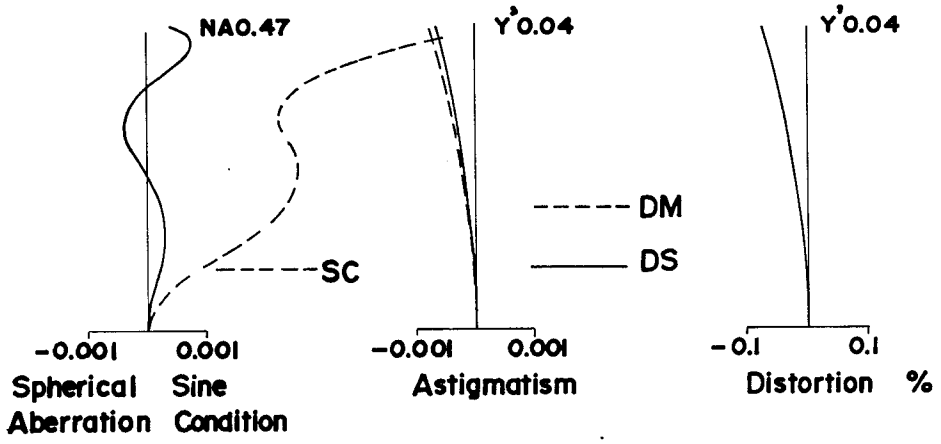


FIG.39

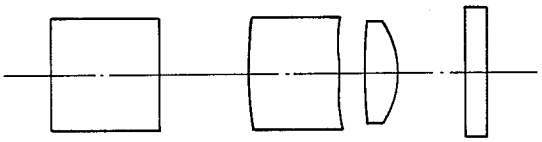


FIG.40A

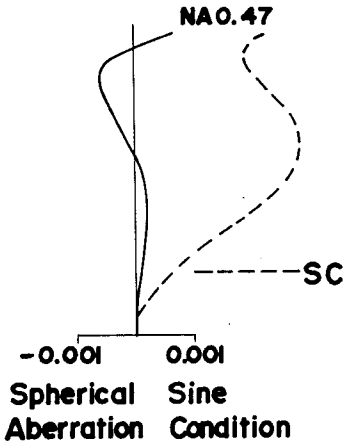


FIG.40B

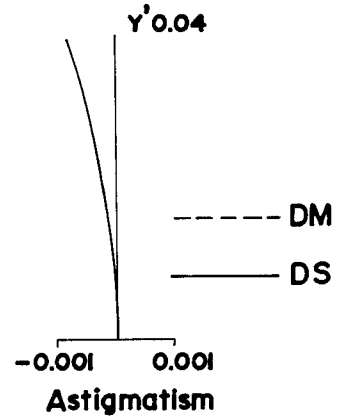


FIG.40C

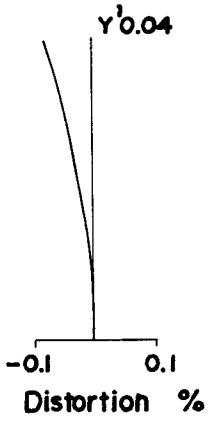


FIG.41

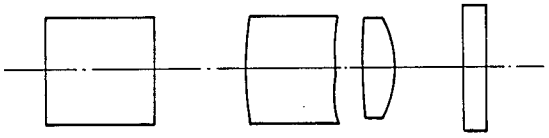


FIG.42A

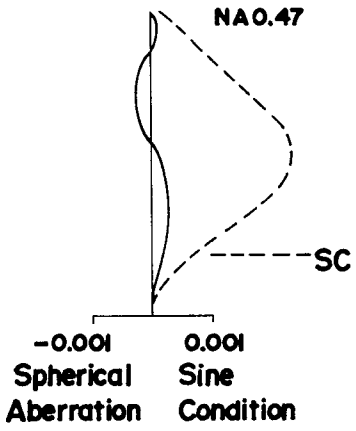


FIG.42B

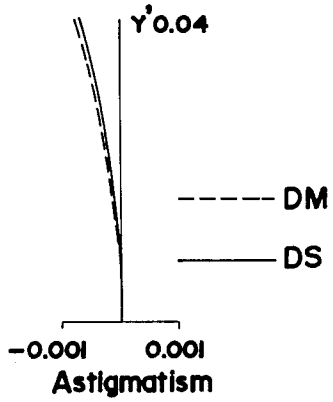


FIG.42C

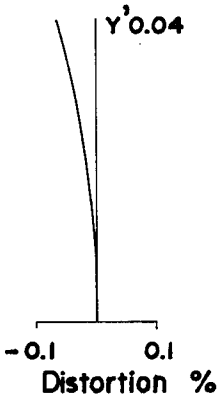


FIG.43

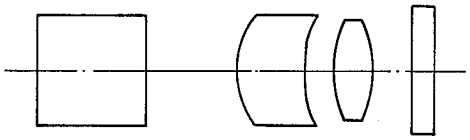


FIG.44A

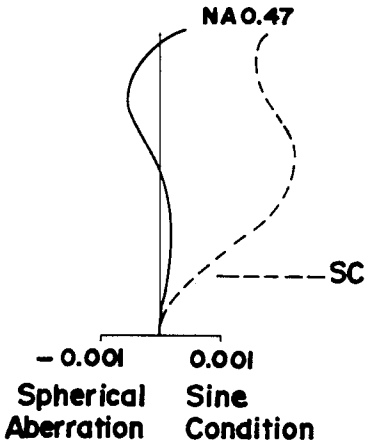


FIG.44B

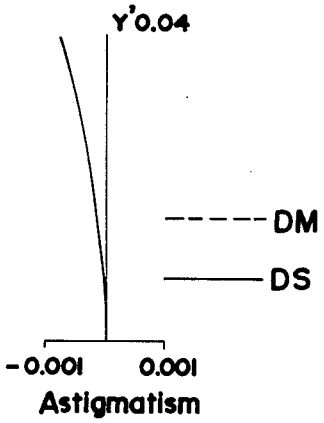


FIG.44C

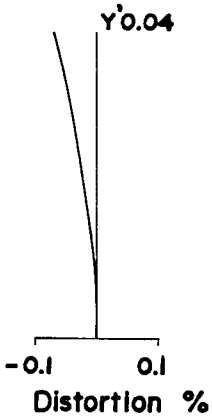


FIG.45

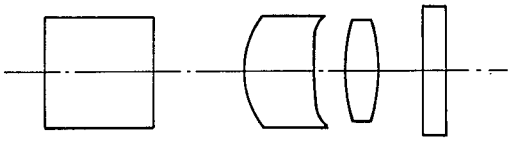


FIG.46A FIG.46B FIG.46C

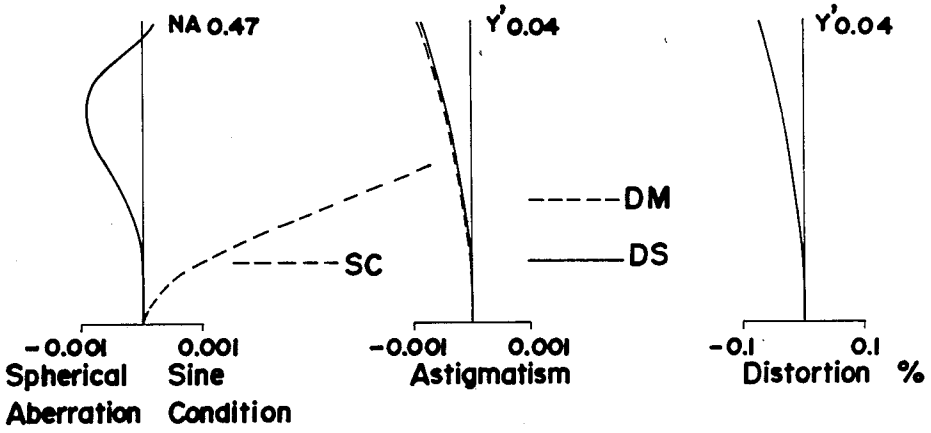


FIG.47

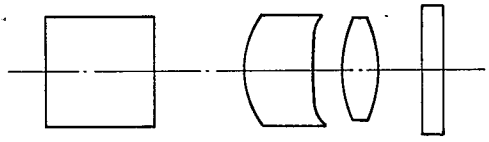


FIG.48A

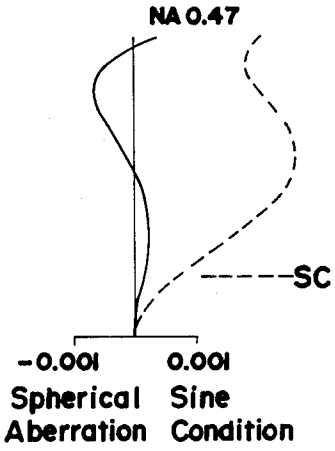


FIG.48B

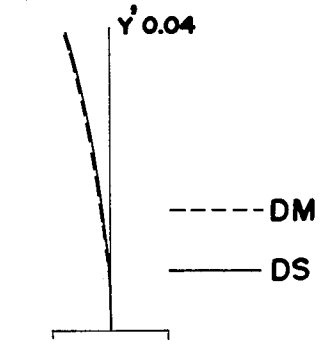


FIG.48C

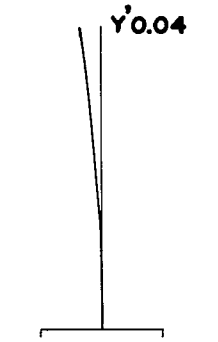


FIG.49

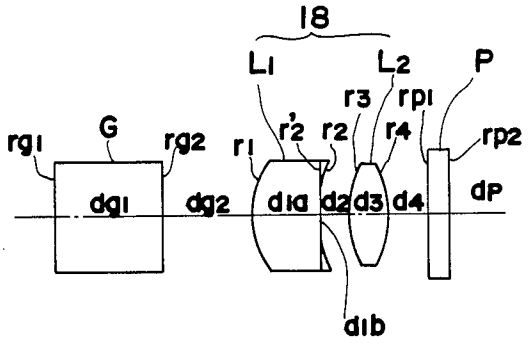


FIG.50A

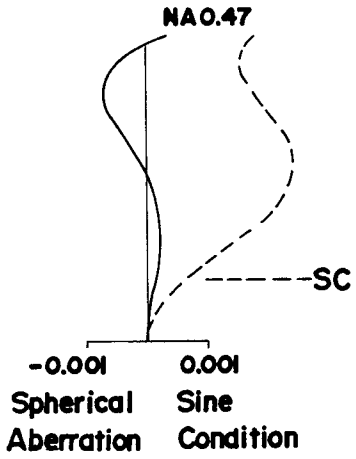


FIG.50B

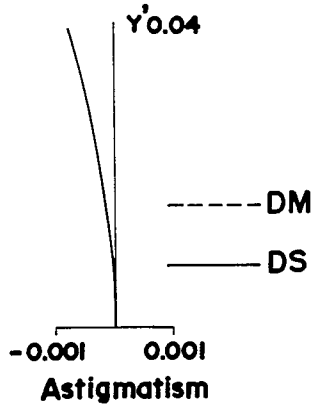


FIG.50C

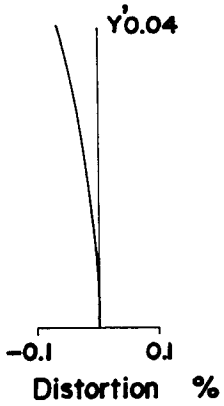


FIG.51

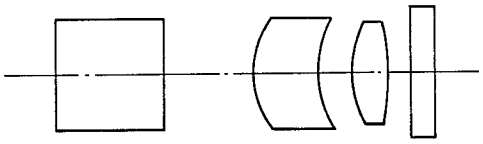


FIG.52A

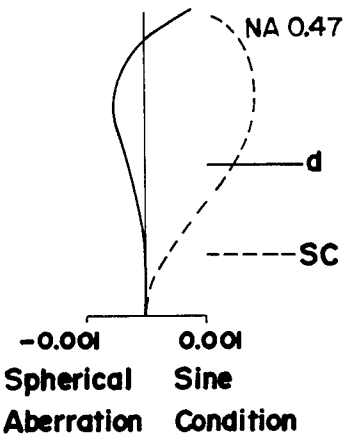


FIG.52B

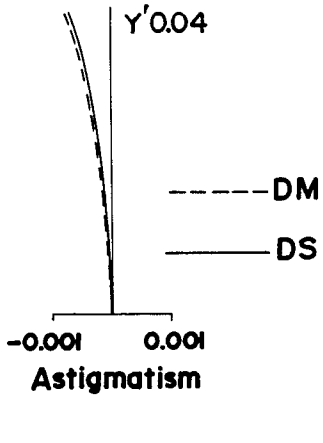


FIG.52C

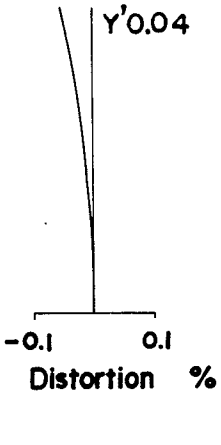


FIG.53

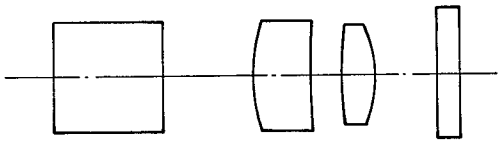


FIG.54A

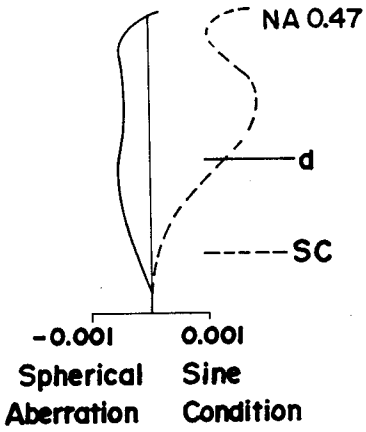


FIG.54B

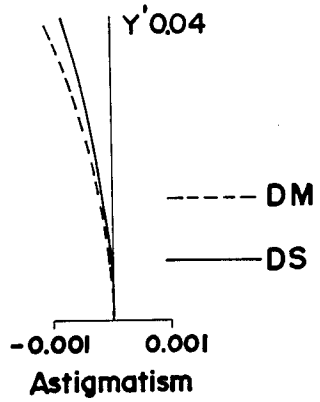


FIG.54C

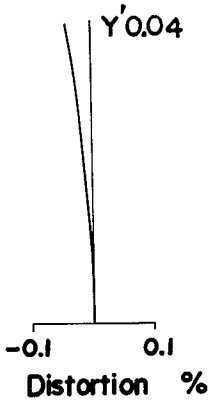


FIG.55

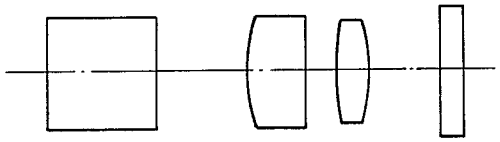


FIG.56A

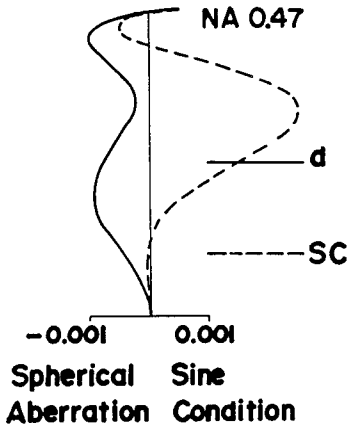


FIG.56B

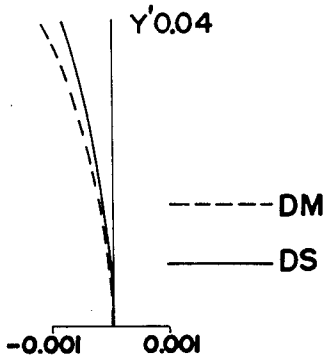


FIG.56C

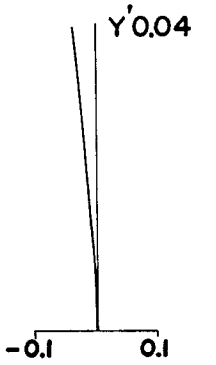


FIG.57

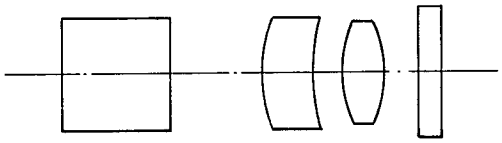


FIG.58A

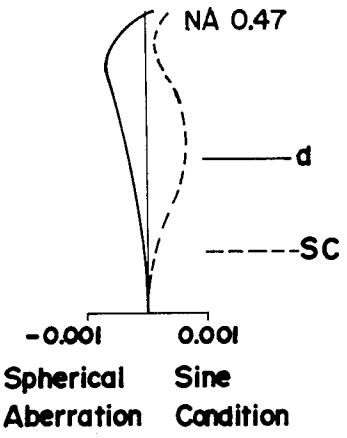


FIG.58B

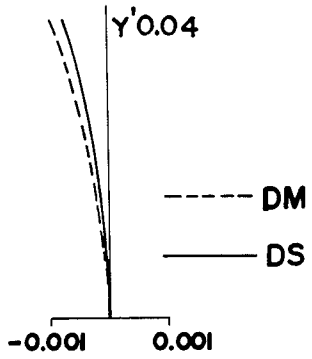


FIG.58C

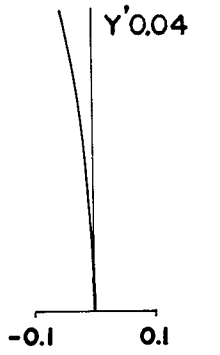


FIG.59

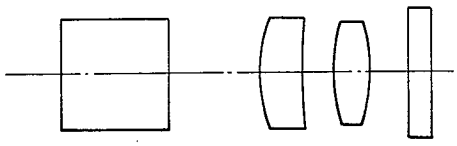


FIG.60A

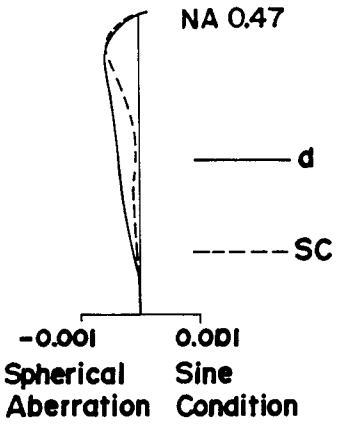


FIG.60B

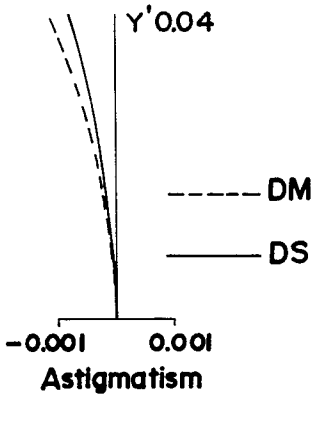
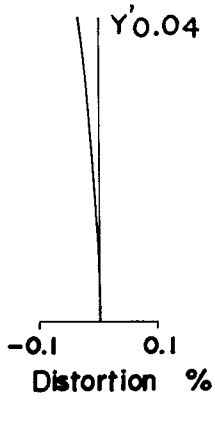


FIG.60C



OBJECTIVE LENS SYSTEM FOR OPTICAL RECORDING TYPE DISKS

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to an objective lens system for optical recording type disks, such as digitally recorded audio disks, video disks, etc. .

2. Description of the Prior Art

In such objective lens system, it is required to correct the aberrations to an extraordinarily high degree and to achieve a high resolving power, in order to form, on the disk, an extreme small spot image whose size is determined in accordance with the limit of the diffraction of light. Thus, a numerical aperture about 0.4~0.5 is necessary in type of lens system.

An objective lens system of this type has been proposed, for example, in Japanese Laid-Open Patent Application No. SHO No. 55-4068. However, a conventional optical recording type disk device is constructed as shown in FIG. 1. In FIG. 1, a light bundle emitted from a laser light source (2) is converted to a parallel light bundle by a collimating lens system (4). The parallel light bundle is incident on a beam splitter (6) from the light source side. The beam splitter (6) has a half mirror for dividing the light incident thereon by reflection and transmission. Thus, the parallel light bundle transmitted through the beam splitter (6) is concentrated into a spot on a rear surface of disk (10) by an objective lens system (8). The reflected light bundle from the disk (10) is incident on the beam splitter (6) from the disk side through the objective lens system (8). One part of such light bundle is reflected on the beam splitter (6) toward a lens system for focus detection (12), and another part thereof is transmitted through the beam splitter (6). The light bundle reflected toward the lens system (12) is incident on a light receiving device (14) through the lens system (12).

The lens system (12) is used for detecting the focusing condition of the objective lens system (8) on the rear surface of the disk (10). This lens system (12) includes a cylindrical lens element (12*a*) in order to generate a great amount of astigmatism in a predetermined direction perpendicular to the optical axis. The light receiving device includes plurality of light receiving cells which are arranged symmetrically with respect to the optical axis. Thus, the focusing condition of the objective lens system is detected in accordance with the output signals from such light receiving cells. A diffraction grating (16) is arranged so that the tracking condition of the light bundle incident on the disk (10) is detected a well-known three beam method.

FIG. 2 shows another arrangement of the prior art in which the collimating lens system (4) is arranged on the disk side of the beam splitter (6).

In the above arrangement, two methods for tracking of the light bundle incident on the disk (10) are known. One of the methods is to use a galvano mirror which is vibrated for changing the position of the light spot on the disk (10). However, in this method, it is necessary to correct various aberrations of the objective lens system with respect to the off-axial rays, since the light rays incident on the objective lens system would have some inclination angle to its optical axis. Thus, it causes to increase the number of the lens elements in the objective lens system, and to deteriorate the compactness of the objective lens system due to the extension of the focal length thereof.

Therefore, another method is often applied. This method is to shift the objective lens system perpendicularly to its optical axis for tracking of the light bundle. This method has an advantage in that it requires to correct the aberrations of the objective lens system only with respect to the paraxial rays, because the light rays incident on the objective lens system are always parallel to its optical axis. However, in this method, the construction of the objective lens system is required to be light in weight and to be simple, because the objective lens system itself is shifted for tracking.

Furthermore, it should be raised to make a pick-up device for disks more compact. Two methods would be considered for making the optical system in the pick-up device more compact. One of them is to shorten the focal length of the objective lens system for decrease the distance between the laser light source and the disk. However, the radius of curvature of any refractive surface in the objective lens system become small in proportion to the shortening of the focal length of the objective lens system. The sensitivity of the optical performance to a manufacturing error is undesirably increased in proportion to shortening of the focal length of the objective lens system. Thus, this method has a limit in minimizing the focal length of the objective lens system.

Another method is to increase the numerical aperture NA of the collimating lens system. However, this method requires the designer to increase the number of the lens elements in the collimating lens system. Thus, it causes and increase in the cost. Furthermore, in this method, the dispersion of the astigmatic difference in the laser light source becomes another problem.

SUMMARY OF THE INVENTION

An object of the present invention is to provide an objective lens system which is useful for making the pick-up device compact in construction.

Another object of the present invention is to provide an objective lens system which is suitable for tracking by shifting the objective lens system.

According to the present invention, an objective lens system for optical recording type disks, comprising from a light source side to a disk side;

a first lens element having a positive refractive power, said first lens element having at least an aspherical surface;

a second lens element having a positive refractive power; and

wherein the objective lens system fulfills the following condition:

$$-\frac{1}{2}<\beta<-\frac{1}{8}$$

wherein:

β represents the magnification of the whole lens system.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 represents a cross sectional view of the optical system for optical recording type disks according to the prior art;

FIG. 2 represents a cross sectional view of the optical system for optical recording type disks according to another prior art;

FIG. 3 represents a cross sectional view of the optical system for optical recording type disks according to the present invention:

FIG. 4 represents a cross sectional view of the objective lens system for optical recording type disks according to the embodiments 1, 2, 3, 4 and 7 of the present invention;

FIG. 5 represents a cross sectional view of the objective lens system according to the embodiments 8, 9, 11, 13, 15 of the present invention;

FIG. 6 represents a cross sectional view of the objective lens system according to the embodiments 6 and 14 of the present invention;

FIG. 7 represents a cross sectional view of the objective lens system according to the embodiments 5, 10 and 12 of the present invention;

FIG. 8 represents a cross sectional view of the objective lens system according to the embodiment 16 of the present invention;

FIGS. 9A to 9C represent the aberration curves of the embodiment 1;

FIGS. 10A to 10C represent the aberration curves of the embodiment 2;

FIGS. 11A to 11C represent the aberration curves of the embodiment 3;

FIGS. 12A to 12C represent the aberration curves of the embodiment 4;

FIGS. 13A to 13C represent the aberration curves of the embodiment 5;

FIGS. 14A to 14C represent the aberration curves of the embodiment 6;

FIGS. 15A to 15C represent the aberration curves of the embodiment 7;

FIGS. 16A to 16C represent the aberration curves of the embodiment 8;

FIGS. 17A to 17C represent the aberration curves of the embodiment 9;

FIGS. 18A to 18C represent the aberration curves of the embodiment 10;

FIGS. 19A to 19C represent the aberration curves of the embodiment 11;

FIGS. 20A to 20C represent the aberration curves of the embodiment 12;

FIGS. 21A to 21C represent the aberration curves of the embodiment 13;

FIGS. 22A to 22C represent the aberration curves of the embodiment 14;

FIGS. 23A to 23C represent the aberration curves of the embodiment 15;

FIGS. 24A to 24C represent the aberration curves of the embodiment 16;

FIG. 25 represents a cross sectional view of the objective lens system according to the embodiment 17 of the present invention;

FIGS. 26A to 26C represent the aberration curves of the embodiment 17;

FIG. 27 represents a cross sectional view of the objective lens system according to the embodiment 18 of the present invention;

FIGS. 28A to 28C represent the aberration curves of the embodiment 18;

FIG. 29 represents a cross sectional view of the objective lens system according to the embodiment 19 of the present invention;

FIGS. 30A to 30C represent the aberration curves of the embodiment 19;

FIG. 31 represents a cross sectional view of the objective lens system according to the embodiment 20 of the present invention;

FIGS. 32A to 32C represent the aberration curves of the embodiment 20;

FIG. 33 represents a cross sectional view of the objective lens system according to the embodiment 21 of the present invention;

FIGS. 34A to 34C represent the aberration curves of the embodiment 21;

FIG. 35 represents a cross sectional view of the objective lens system according to the embodiment 22 of the present invention;

FIGS. 36A to 36C represent the aberration curves of the embodiment 22;

FIG. 37 represents a cross sectional view of the objective lens system according to the embodiment 23 of the present invention;

FIGS. 38A to 38C represent the aberration curves of the embodiment 23;

FIG. 39 represents a cross sectional view of the objective lens system according to the embodiment 24 of the present invention;

FIGS. 40A to 40C represent the aberration curves of the embodiment 24;

FIG. 41 represents a cross sectional view of the objective lens system according to the embodiment 25 of the present invention;

FIGS. 42A to 42C represent the aberration curves of the embodiment 25;

FIG. 43 represents a cross sectional view of the objective lens system according to the embodiment 26 of the present invention;

FIGS. 44A to 44C represent the aberration curves of the embodiment 26;

FIG. 45 represents a cross sectional view of the objective lens system according to the embodiment 27 of the present invention;

FIGS. 46A to 46C represent the aberration curves of the embodiment 27;

FIG. 47 represents a cross sectional view of the objective lens system according to the embodiment 28 of the present invention;

FIGS. 48A to 48C represent the aberration curves of the embodiment 28;

FIG. 49 represents a cross sectional view of the objective lens system according to the embodiment 29 of the present invention;

FIGS. 50A to 50C represent the aberration curves of the embodiment 29;

FIG. 51 represents a cross sectional view of the objective lens system according to the embodiment 30 of the present invention;

FIGS. 52A to 52C represent the aberration curves of the embodiment 30;

FIG. 53 represents a cross sectional view of the objective lens system according to the embodiment 31 of the present invention;

FIGS. 54A to 54C represent the aberration curves of the embodiment 31;

FIG. 55 represents a cross sectional view of the objective lens system according to the embodiment 32 of the present invention;

FIGS. 56A to 56C represent the aberration curves of the embodiment 32;

FIG. 57 represents a cross sectional view of the objective lens system according to the embodiment 33 of the present invention;

FIGS. **58A** to **58C** represent the aberration curves of the embodiment **33**;

FIG. **59** represents a cross sectional view of the objective lens system according to the embodiment **34** of the present invention; and

FIGS. **60A** to **60C** represent the aberration curves of the embodiment **34**;

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The following description is provided to enable any person skilled in the optical field to make and use the invention and sets forth the best modes contemplated by the inventors for carrying our invention. Various modifications, however, will remain readily apparent to those skilled in the art, since the generic principles of the present invention have been defined herein specifically to provide a relatively economical and easily manufactured objective lens system. The derivation of the formulas and the relation of the powers set forth herein can be accomplished with the assistance of a computer. The present invention represents the parameters of a compromise balance of acceptable aberrations which can be relatively easily manufactured to provide a low cost lens system.

In the drawings, schematic cross sectional views disclose the position of the lens elements. Due to the number of lens elements involved, it was not deemed appropriate to include individual designation of the radii of curvature and axial distances for each lens element and air space. These values, however, are provided in the accompanying tables set forth herein, and the schematic cross sectional views of the respective embodiments follow the normal conventions of the light source at the left-hand side of the drawing and the disk at the right-hand side.

The features of the present invention which are believed to be novel are set forth with particularity in the appended claims. The present invention, both as to its organization and manner of operation, together with further objects and advantages thereof, may best be understood by reference to the following description, taken in conjunction with the accompanying drawings.

As shown in FIG. **3**, the present invention provides the objective lens system (**18**) for optical recording type disks, comprising from the light source side to the disk side, a first lens element (L_1) having a positive refractive power, said first lens element (L_1) having at least an aspherical a second lens element (L_2) having a positive refractive power, and wherein the objective lens system (**18**) fulfills the following condition:

$$-\frac{1}{2}<\beta<-\frac{1}{8} \quad (1)$$

wherein, β represents the magnification of the whole lens system (**18**).

The objective lens system according to the present invention consist of only two lens elements (L_1) (L_2). If one of such two lens elements has a negative refracting power, a positive refracting power of another lens element must be too strong for obtaining a predetermined positive power of the whole lens system. Therefore, in the present invention, both of two lens elements have positive refracting powers, respectively.

In the present invention, the objective lens system (**18**) concentrate into a spot on the disk (**10**) the light emitted from the laser light source, without converting the light to a parallel light bundle by the conventional collimating lens system. Thus, the objective lens system according to the present invention must be corrected well in various aberrations with respect to a finite object. It is different from the conventional objective lens system which must be well corrected in various aberrations with respect to an infinite object, since the conventional objective lens system is located in a parallel light bundle formed by the collimating lens system. Thus, the magnification β of the conventional objective lens system is zero.

On the other hand, the magnification β of the objective lens system according to the present invention is limited as shown in the condition (1). If the upper limit of the condition (1) is violated, it is difficult to shorten the distance between the laser light source (**2**) and the disk (**10**). Contrary, if the lower limit of the condition (**1**) is violated, the following defects is present: At first, a space for locating the beam splitter or the diffraction grating is too decreased. Next, it becomes difficult to read the correct information memorized by the disk, since the information of high density memorized by the disk can not be magnified enough, and since the offaxial aberrations are generated. Therefore, the magnification β of the objective lens system according to the present invention is limited as shown in the condition (1).

Here, even if the conventional objective lens system used in the magnification $\beta=0$ is applied to the optical system relating to the present invention in which the objective lens system is used in the magnification β limited in the condition (1), it is impossible to achieve a high resolving power reaching to 1 μm because the numerical aperture NA is decreased. Namely, the following relationship is held:

$$NA\beta=NA\infty/(1-\beta)$$

wherein, $NA\beta$ represents the numerical aperture of the lens system when $\beta<0$, $NA\infty$ represents the numerical aperture thereof when $\beta=0$, and β represents the magnification thereof. Thus, if the objective lens system having a numerical aperture $NA\infty=0.45$ is used in the condition $\beta=-\frac{1}{4}$, the numerical aperture $NA\beta$ in such condition is 0.36. Therefore, it is impossible to achieve the resolving power of 1 μm. Here, if the diameter of the objective lens system is increased in order to increasing the numerical aperture thereof in such condition, it becomes difficult to correct the various aberrations well. Therefore, the conventional objective lens system used in the condition $\beta=0$ can not used in the magnification limited in the condition (1).

However, if the conventional objective lens system itself is shifted for tracking such lens system should be corrected in various aberrations with respect only to the paraxial rays, because the parallel light rays are always incident on such lens system. On the other hand, if the objective lens system according to the present invention is shifted for tracking, various aberrations must be also corrected well for the offaxial rays. Thus, the objective lens system according to the present invention must be corrected well in various aberrations not only for the paraxial rays but also for the offaxial rays.

In the present invention, an aspherical surface is introduced in order to correct the aberrations well. Here, it is not effective for improving the aberrations to introduce an aspherical surface to the second lens element (L_2). The reason is as follows: In the objective lens system according to the present invention, the light rays emitted from the light source (**2**) are incident on the

second lens element (L_2) after they has been refracted by the first lens element (L_1). Thus, a height of a light ray incident on the first lens element (L_1) is relatively larger than that on the second lens element (L_2). Therefore, if an aspherical surface is introduced to any surface of the second lens element (L_2) for correcting the spherical aberration, the large coma aberration is generated in the offaxial region and can not be corrected.

Therefore, in the present invention, an aspherical surface is introduced to either of the two surfaces of the first lens element (L_1). In the case when the light source side surface (r_1) of the first lens element (L_1), the positive spherical aberration is generated too much by the surface (r_1), and other three surfaces (r_2) (r_3) and (r_4) of the first and second lens elements (L_1) and (L_2) not only correct the coma aberration and the astigmatism well, but also generate the negative spherical aberration for cancelling the above positive spherical aberration. Thus, good correction of the aberrations is achieved in both of the paraxial and offaxial regions.

The light source side surface (r_1) of the first lens element (L_1), should meet the following conditions to be effective for correcting the aberrations and for securing a proper working distance.

$$0.70<f_1/f_2<1.50 \quad (2)$$

$$0.33<f_1/f<1.30 \quad (3)$$

$$-1.00<\frac{r_1+r_2}{r_1-r_2}<1.00 \quad (4)$$

wherein, f_1 represents the focal length of said first lens element (L_1), f_2 represents the focal length of the second lens element (L_2), d_1 represents the axial thickness (d_1) of the first lens element (L_1), f represents the focal length of the whole lens system, r_1 represents the paraxial radius of curvature of the light source side surface (r_1) of the first lens element (L_1), and r_2 represents the radius of curvature of the disk side surface (r_2) of the first lens element (L_1).

Condition (2) defines the ratio in refraction index between the first and second lens element (L_1) and (L_2). If the focal length f_1 of the first lens element (L_1) becomes short over the lower limit of the condition (2), the working distance of such lens system becomes too short. Therefore, such lens system is impractical since it is in danger to collide with the disk by the vibration. On the other hand, if the focal length f_1 of the first lens element (L_1) becomes long over the upper limit of the condition (2), since the refractive power of the second lens element (L_2) becomes great compared with that of the first lens element (L_1), it becomes difficult to correct the coma aberration and the astigmatism in the offaxial region well.

Condition (3) limits the axial thickness d_1 of the first lens element (L_1). The axial thickness d_1 mainly influences the working distance WD of the objective lens system and the correction of the astigmatism and the coma aberration in the offaxial region. If the lower limit of the condition (3) is violated, it becomes impossible to secure enough working distance, because the axial distance d_2 between the disk side surface (r_2) of the first lens element (L_1) and the light source side surface (r_3) of the second lens element (L_2) must become large for correcting the aberrations in the offaxial region. Furthermore, the aberrations in the offaxial region are deteriorated considerably compared with that in the paraxial region, because the inclination of the image plane of the objective lens becomes large. On the other hand, if the upper limit of the condition (3) is violated, although the working distance WD is secured enough, the compactness of the objective lens system is deteriorated and the weight thereof becomes too heavy, since the axial thickness (d_1) of the first lens element (L_1) becomes excessively large.

Condition (4) limits the shape of the first lens element (L_1). It means that the first lens element (L) is a bi-convey lens element. If the lower limit of the condition (4) is violated, the astigmatism is generated excessively. Here, although such astigmatism would be corrected well by means of the second lens element (L_2), it becomes difficult to correct the coma aberration. If the upper limit of the condition (4) is violated, it becomes difficult to correct the aberrations, since the refractive power of the first lens element (L_1) becomes too weak so that the height of the light rays incident on the second lens element (L_2) becomes too large.

In addition to the above conditions (1) to (4), the following conditions is effective for correcting the aberrations in both of the paraxial and offaxial region.

$$0.2<\phi_3<0.7 \quad (5)$$

$$0.6<\phi_2+\phi_3<1.0 \quad (6)$$

$$|\phi_2-\phi_3|<0.6 \quad (7)$$

provided by, $\phi_2=(1-N_1)\cdot f/r_2$, and $\phi_3=(N_2-1)\cdot f/r_3$, wherein, N_1 represents the refractive index of the first lens element (L_1), N_2 represents the refractive index of the second lens element (L_2) and r_3 represents the radius of curvature of the light source side surface (r_3) of the second lens element (L_2).

Condition (5) defines the refractive power of the light source side surface (r_3) of the second lens element (L_2). If the lower limit of the condition (5) is violated, it is necessary to increase the refractive power of the disk side surface (r_4) of the second lens element (L_2) for achieving a predetermined magnification, which causes to generate the coma aberration undesirably, and to increase undesirably the sensitivity of the optical performance to a manufacturing error, since the radius of curvature of the disk side surface (r_4) of the second lens element (L_2) becomes too small. On the other hand, if the upper limit of the condition (5) is violated, the optical performance in the offaxial region is excessively deteriorated since the astigmatism is considerably generated.

Conditions (6) and (7) relate to the balance in refractive power between the disk side surface (r_2) of the first lens element (L_1) and the light source side surface (r_3) of the second lens element (L_2). If the lower limit of the condition (6) is violated, the coma aberration is undesirably generated, since it is necessary to increase the refractive powers of the light source side surface (r_1) of the first lens element (L_1) and the disk side surface (r_4) of the second lens element (L_2) for achieving the predetermined magnification. Contrary, if the upper limit of the condition (6) is violated, the radii of curvature of the disk side surface (r_2) of the first lens element (L_1) and the light source side surface (r_3) of the second lens element (L_2) become considerably smaller since the refractive indices of such two surfaces (r_2) and (r_3) become too strong, and causes an increase in the sensitivity of the optical performance to manufacturing errors. If the upper or lower limit of the condition (7) is violated, the

proper balance between the refractive power of the disk side surface (r_2) of the first element (L_1) and that of the light source side surface (r_3) of the second lens element (L_2) can not be maintained, and results the correction of the aberrations in the offaxial region, especially the correction of the astigmatism therein, becomes difficult.

In the case when an aspherical surface is introduced on the disk side surface (r_2) of the first lens element (L_1), it is possible to correct not only the spherical aberration but also to correct the astigmatism and the coma aberration in the offaxial region. In this case, the following conditions are effective for correcting the aberrations;

$$0.47<d_1/f<1.25 \quad (8)$$

$$0<d_2/d_1<1.00 \quad (9)$$

wherein, f represents the focal length of the whole lens system, d_1 represents the axial thickness (d_1) of the first lens element (L_1), and d_2 represents the axial distance (d_2) between the disk side surface (r_2) of the first lens element (L_1) and the light source side surface (r_3) of the second lens element (L_2).

Condition (8) is effective for correcting the astigmatism. If the lower limit of the condition (8) is violated, it is difficult to correct the astigmatism, and to secure the proper edge thickness of the first lens element (L_1) since the axial thickness thereof becomes too small. If the upper limit of condition (8) is violated, it is difficult to correct the spherical aberration even though an aspherical surface is introduced to the lens system. Furthermore, the total weight of the objective lens system becomes too heavy for practical use since the thickness of the first lens element (L_1) becomes too thick.

On the other hand, if the upper limit of condition (9) is violated by increasing the axial distance (d_2), it becomes difficult to correct the spherical aberration since the refractive power of the disk side surface (r_2) of the first lens element (L_1) must be increased, even though an aspherical surface is introduced to such surface (r_2). Furthermore, if the upper limit of the condition (9) is violated by increasing the axial distance (d_2), it becomes difficult to correct the coma aberration. Namely, although the coma aberration, which is increased in proportion to an increase in the axial distance (d_2), may be corrected by increasing the axial thickness (d_1) of the first lens element (L_1), such correction is improper since the axial thickness (d_1) is limited in the condition (8).

In the case when an aspherical surface is introduced on the disk side surface (r_2) of the first lens element (L_1), the following conditions are further effective for correcting the coma aberration in addition to the above conditions (8) and (9):

$$0.80<f\cdot(\phi_1+\phi_4)<1.30 \quad (10)$$

$$0.10<f\cdot\phi_4<0.80 \quad (11)$$

provided by, $\phi_4=(1-N_2)/r_4$, $\phi_1=(N_1-1)/r_1$, wherein, N_1 represents the refractive index of the first lens component (L_1), N_2 represents the refractive index of the second lens component (L_2), r_1 represents the radius of curvature of the light source side surface (r_1) of the first lens element (L_1), and r_4 represents the radius of curvature of the disk side surface (r_4) of the second lens element (L_2).

In order to correct the coma aberration well, a proper balance between the refractive power of the light source side surface (r_1) of the first lens element (L_1) and that of the disk side surface (r_4) of the second lens element (L_2), is necessary. The condition (10) defines such balance. If the lower limit of the condition (10) is violated, spherical aberration is undesirably generated. Here, although such spherical aberration may be corrected by increasing the refractive power of the light source side surface (r_1) of the first lens element (L_1), such correction generates excessive coma aberration, since the above proper balance is not maintained. Such coma aberration can not be corrected by introducing an aspherical surface to the disk side surface (r_2) of the first lens element (L_1). On the other hand, if the upper limit of the condition (10) is violated, the coma aberration is generated excessively, which can not be corrected by introducing an aspherical surface.

The condition (11) defines the refractive power of the disk side surface (r_4) of the second lens element (L_2). If the lower limit of the condition (11) is violated, the refractive power of the light source side surface (r_1) of the first lens element (L_1) must become too strong, in order to achieving a predetermined refractive power of the objective lens system. This generates undesirable the coma aberration, which can not be corrected by introducing an aspherical surface. If the upper limit of the condition (11) is violated, the refractive power of the disk side surface (r_4) of the second element (L_2) becomes too strong. This results in the generation of coma aberration on such surface (r_4), which would not be corrected well.

In the present invention, a method for manufacturing a lens element having an aspherical surface is not limited at all. For example, such a lens element can be manufactured by a press, if it is constituted of a glass material. On the other hand, such a lens element can be manufactured by well-known molding method, if it is constituted of a plastic material. Furthermore, such a lens element can be manufactured by cementing a thin layer of a synthetic resin or a plastic material, which has an aspherical surface of desired shape, to a predetermined spherical surface of a lens element made of a glass material, the spherical surface having paraxial radius of curvature of the desired aspherical surface, as shown in the embodiments 16 and 29 indicated below.

The following Tables 1 to 34 disclose, respectively, the first through thirty-fourth embodiments of the present invention. In the Tables, f equals the focal length, r is the radius of curvature with respective sub numbers indicating the surfaces from the light source to disk side along the optical axis, d represents the axial distance and includes both the air spaces and the actual thickness of the lenses along the optical axis, and finally n equals the refractive index in the wavelength $\lambda=800$ nm and again, the sub numbers refer to the particular optical element from the light source to disk side. The asterisk (*) represents the aspheric surface defined as follows, and its coefficients are shown at the bottom of respective Tables:

$$X = 1 + \frac{Coh2}{\sqrt{1-\epsilon Co^2h^2}} + \Sigma Cih^{2i} \; (i = 1, 2, 3 \ldots)$$

wherein, X represents the coordinate along the optical axis measured from the top of the basic surface, h represents the coordinate perpendicular to the optical axis measured from the optical axis (height from the optical axis), Co represents the curvature (1/r) of the basic surface, Ci represent the aspherical surface coefficients,

and ϵ represents the quadric surface coefficient of the basic surface.

To all Tables, in addition to the objective lens system according to each embodiment, a glass block (G) is shown in the light source side of the objective lens system, which corresponds to the beam splitter (**6**), the diffraction grating (**16**) or a cover glass of the laser light source (**2**). The radii of curvature of the light source side surface (r_{g1}) of the glass block (G) and the disk side surface (r_{g2}) thereof are indicated as r_{g1} and r_{g2}, respectively, in the Tables. The axial thickness (d_{g1}) of the galss block (G) is indicated as d_{g1}, and the axial distance (d_{g2}) between the disk side surface (r_{g2}) of the glass block (G) and the light source side surface (r_1) of the first lens element (L_1). The refractive index of the glass block (G) in the wavelength of 800 nm is indicated as Ng. Furthermore, in all embodiments, a plate (P) is located on the disk side of the objective lens system, which corresponds to the disk (**10**). The radii of curvature of the plate (P) are indicated as r_{p1} and r_{p2} from the light source to the disk side, respectively. The axial distance between the disk side surface (r_4) of the second lens element (L_2) and the light source side surface (r_{p1}) of the plate (P) is indicated as d_4, and the axial thickness of the plate (P) is indicated as dp. The refractive index of the plate (P) in the wavelength of 800 nm is indicated as Np.

Furthermore, in all Tables, NA represents the numerical aperture of the objective lens system according to the embodiment of the disk side, f represents the focal length thereof, WD represent the working distance thereof, and β represents the magnification thereof.

TABLE 1

[Embodiment 1]
NA = 0.47 f = 1.0 WD = 0.38 β = −0.23

		radius of curvature	axial distance		refractive index
G	r_{g1}	∞	d_{g1} 1.200	n_g	1.51078
	r_{g2}	∞			
			d_{g1} 1.000		
L_1	r_1*	1.717	d_1 0.690	n_1	1.76492
	r_2	−2.691			
			d_2 0.530		
L_2	r_3	1.394	d_3 0.298	n_2	1.76492
	r_4	−3.651			
			d_4 0.380		
P	r_{p1}	∞	d_p 0.240	n_p	1.57147
	r_{p2}	∞			

ϵ = 1.0
aspherical surface coefficients

$C_1 = 0.0$, $C_2 = -0.1265$, $C_3 = -0.24749 \times 10^{-1}$,
$C_4 = -0.29344 \times 10^{-1}$, $C_5 = 0.29848 \times 10^{-2}$
$f_1/f_2 = 1.09$
$d_1/f = 0.69$
$\frac{r_1 + r_2}{r_1 - r_2} = -0.22$
$\phi_3 = 0.55$
$\phi_2 + \phi_3 = 0.83$
$|\phi_2 - \phi_3| = 0.27$

TABLE 2

[Embodiment 2]
NA = 0.47 f = 1.0 WD = 0.38 β = −0.23

		radius of curvature	axial distance		refractive index
G	r_{g1}	∞	d_{g1} 1.200	n_g	1.51078
	r_{g2}	∞			
			d_{g2} 1.000		
L_1	r_1*	1.857	d_1 0.580	n_1	1.78458
	r_2	−2.817			
			d_2 0.620		
L_2	r_3	1.681	d_3 0.306	n_2	2.00000
	r_4	−4.519			
			d_4 0.380		
P	r_{p1}	∞	d_p 0.240	n_p	1.57147
	r_{p2}	∞			

TABLE 2-continued

[Embodiment 2]
NA = 0.47 f = 1.0 WD = 0.38 β = −0.23

ϵ = 1.0
aspherical surface coefficients

$C_1 = 0.0$, $C_2 = -0.12097$, $C_3 = -0.21258 \times 10^{-1}$,
$C_4 = -0.28685 \times 10^{-1}$, $C_5 = 0.30060 \times 10^{-2}$
$f_1/f_2 = 1.20$
$d_1/f = 0.58$
$\frac{r_1 + r_2}{r_1 - r_2} = -0.21$
$\phi_3 = 0.59$
$\phi_2 + \phi_3 = 0.87$
$|\phi_2 - \phi_3| = 0.31$

TABLE 3

[Embodiment 3]
NA = 0.47 f = 1.0 WD = 0.35 β = −0.23

		radius of curvature	axial distance		refractive index
G	r_{g1}	∞	d_{g1} 1.200	n_g	1.51078
	r_{g2}	∞			
			d_{g2} 1.000		
L_1	r_1*	1.862	d_1 0.600	n_1	1.78458
	r_2	−2.033			
			d_2 0.608		
L_2	r_3	2.088	d_3 0.240	n_2	1.78458
	r_4	−2.264			
			d_4 0.350		
P	r_{p1}	∞	d_p 0.240	n_p	1.57147
	r_{p2}	∞			

ϵ = 1.0
aspherical surface coefficients

$C_1 = 0.0$, $C_2 = -0.16199$, $C_3 = -0.27646 \times 10^{-1}$
$C_4 = -0.30012 \times 10^{-1}$, $C_5 = 0.29488 \times 10^{-2}$
$f_1/f_2 = 0.94$
$d_1/f = 0.60$
$\frac{r_1 + r_2}{r_1 - r_2} = -0.04$
$\phi_3 = 0.38$
$\phi_2 + \phi_3 = 0.77$
$|\phi_2 - \phi_3| = 0.01$

TABLE 4

[Embodiment 4]
NA = 0.47 f = 1.0 WD = 0.36 β = −0.15

		radius of curvature	axial distance		refractive index
G	r_{g1}	∞	d_{g1} 1.200	n_g	1.51078
	r_{g2}	∞			
			d_{g2} 1.000		
L_1	r_1*	1.746	d_1 0.632	n_1	1.65870
	r_2	−2.176			
			d_2 0.530		

TABLE 4-continued

[Embodiment 4]
NA = 0.47 f = 1.0 WD = 0.36 β = −0.15

L_2	r_3	1.248	d_3	0.280	n_2	1.62728
	r_4	−2.228				
			d_4	0.360		
P	r_{p1}	∞	d_p	0.240	n_p	1.57147
	r_{p2}	∞				

ϵ = 1.0
aspherical surface coefficients

$C_1 = 0.0$, $C_2 = -0.15705$, $C_3 = -0.52788 \times 10^{-1}$
$C_4 = -0.46595 \times 10^{-1}$, $C_5 = 0.18594 \times 10^{-2}$
$f_1/f_2 = 1.19$
$d_1/f = 0.63$
$\frac{r_1 + r_2}{r_1 - r_2} = -0.11$
$\phi_3 = 0.50$
$\phi_2 + \phi_3 = 0.80$
$|\phi_2 - \phi_3| = 0.20$

TABLE 5

[Embodiment 5]
NA = 0.47 f = 1.0 WD = 0.31 β = −0.23

		radius of curvature		axial distance		refractive index
G	r_{g1}	∞	d_{g1}	1.200	n_g	1.51078
	r_{g2}	∞				
			d_{g2}	1.000		
L_1	r_1*	1.532	d_1	0.372	n_1	1.78458
	r_2	−3.025				
			d_2	0.718		
L_2	r_3	1.399	d_3	0.236	n_2	1.78458
	r_4	−3.360				
			d_4	0.310		
P	r_{p1}	∞	d_p	0.240	n_p	1.57147
	r_{p2}	∞				

ϵ = 1.0
aspherical surface coefficients

$C_1 = 0.0$, $C_2 = -0.12854$, $C_3 = -0.20694 \times 10^{-2}$
$C_4 = -0.28258 \times 10^{-1}$, $C_5 = 0.30658 \times 10^{-2}$
$f_1/f_2 = 1.04$
$d_1/f = 0.37$
$\frac{r_1 + r_2}{r_1 - r_2} = -0.33$
$\phi_3 = 0.56$
$\phi_2 + \phi_3 = 0.82$
$|\phi_2 - \phi_3| = 0.30$

TABLE 6

[Embodiment 6]
NA = 0.47 f = 1.0 WD = 0.56 β = −0.23

		radius of curvature		axial distance		refractive index
G	r_{g1}	∞	d_{g1}	1.200	n_g	1.51078
	r_{g2}	∞				
			d_{g3}	1.000		
L_1	r_1*	1.892	d_1	1.000	n_1	1.78458
	r_2	−3.630				
			d_2	0.220		
L_2	r_3	1.627	d_3	0.300	n_2	1.78458
	r_4	−3.469				
			d_4	0.560		
P	r_{p1}	∞	d_p	0.240	n_p	1.57147
	r_{p2}	∞				

TABLE 6-continued

[Embodiment 6]
NA = 0.47 f = 1.0 WD = 0.56 β = −0.23

ϵ = 1.0
aspherical surface coefficients

$C_1 = 0.0$, $C_2 = -0.12306$, $C_3 = -0.37974 \times 10^{-1}$,
$C_4 = -0.34173 \times 10^{-1}$, $C_5 = 0.27858 \times 10^{-2}$
$f_1/f_2 = 1.19$
$d_1/f = 1.00$
$\frac{r_1 + r_2}{r_1 - r_2} = -0.31$
$\phi_3 = 0.48$
$\phi_2 + \phi_3 = 0.70$
$|\phi_2 - \phi_3| = 0.26$

TABLE 7

[Embodiment 7]
NA = 0.47 f = 1.0 WD = 0.37 β = −0.23

		radius of curvature		axial distance		refractive index
G	r_{g1}	∞	d_{g1}	1.200	n_g	1.51078
	r_{g2}	∞				
			d_{g2}	1.000		
L_1	r_1*	1.736	d_1	0.760	n_1	1.78458
	r_2	−2.193				
			d_2	0.460		
L_2	r_3	1.300	d_3	0.280	n_2	1.51078
	r_4	−1.990				
			d_4	0.370		
P	r_{p1}	∞	d_p	0.240	n_p	1.57147
	r_{p2}	∞				

ϵ = 1.0
aspherical surface coefficients

$C_1 = 0.0$, $C_2 = -0.14583$, $C_3 = -0.34597 \times 10^{-1}$,
$C_4 = -0.29690 \times 10^{-1}$, $C_5 = 0.29757 \times 10^{-2}$
$f_1/f_2 = 0.85$
$d_1/f = 0.76$
$\frac{r_1 + r_2}{r_1 - r_2} = -0.12$
$\phi_3 = 0.39$
$\phi_2 + \phi_3 = 0.75$
$|\phi_2 - \phi_3| = 0.03$

TABLE 8

[Embodiment 8]
NA = 0.47 f = 1.0 WD = 0.51 β = −0.23

		radius of curvature		axial distance		refractive index
G	r_{g1}	∞	d_{g1}	1.200	n_g	1.51078
	r_{g2}	∞				
			d_{g2}	1.000		
L_1	r_1*	2.255	d_1	0.766	n_1	1.51078
	r_2	−1.175				
			d_2	0.424		
L_2	r_3	1.126	d_3	0.316	n_2	1.51078
	r_4	−2.141				
			d_4	0.510		
P	r_{p1}	∞	d_p	0.240	n_p	1.57147
	r_{p2}	∞				

ϵ = 1.0
aspherical surface coefficients

$C_1 = 0.0$, $C_2 = -0.32781$, $C_3 = -0.14437$,
$C_4 = -0.63998 \times 10^{-1}$, $C_5 = 0.17108 \times 10^{-2}$
$f_1/f_2 = 1.10$
$d_1/f = 0.77$

TABLE 8-continued

[Embodiment 8]
NA = 0.47 f = 1.0 WD = 0.51 $\beta = -0.23$

$\frac{r_1 + r_2}{r_1 - r_2} = 0.31$
$\phi_3 = 0.45$
$\phi_2 + \phi_3 = 0.88$
$|\phi_2 - \phi_3| = 0.02$

TABLE 9

[Embodiment 9]
NA = 0.47 f = 1.0 WD = 0.54 $\beta = -0.23$

		radius of curvature	axial distance		refractive index
G	r_{g1}	∞	d_{g1} 1.200	n_g	1.51078
	r_{g2}	∞			
			d_{g2} 1.000		
L_1	r_1*	2.032	d_1 0.778	n_1	1.48366
	r_2	−1.188			
			d_2 0.340		
L_2	r_3	1.080	d_3 0.344	n_2	1.48366
	r_4	−2.159			
			d_4 0.540		
P	r_{p1}	∞	d_p 0.240	n_p	1.57147
	r_{p2}	∞			

$\epsilon = 1.0$
aspherical surface coefficients

$C_1 = 0.0$, $C_2 =$, $C_3 = -0.14273$,
$C_4 = -0.72364 \times 10^{-1}$, -0.32925, $C_5 = 0.13826 \times 10^{-2}$
$f_1/f_2 = 1.09$
$d_1/f = 0.78$

$\frac{r_1 + r_2}{r_1 - r_2} = 0.26$

$\phi_3 = 0.45$
$\phi_2 + \phi_3 = 0.86$
$|\phi_2 - \phi_3| = 0.04$

TABLE 10

[Embodiment 10]
NA = 0.47 f = 1.0 WD = 0.47 $\beta = -0.23$

		radius of curvature	axial distance		refractive index
G	r_{g1}	∞	d_{g1} 1.200	n_g	1.51078
	r_{g2}	∞			
			d_{g2} 1.000		
L_1	r_1*	1.642	d_1 0.530	n_1	1.48366
	r_2	−1.107			
			d_2 0.440		
L_2	r_3	1.707	d_3 0.346	n_2	1.48366
	r_4	−1.302			
			d_4 0.470		
P	r_{p1}	∞	d_p 0.240	n_p	1.57147
	r_{p2}	∞			

$\epsilon = 1.0$
aspherical surface coefficients

$C_1 = 0.0$, $C_2 =$, $C_3 = -0.15543$,
$C_4 = -0.73095 \times 10^{-1}$, -0.42504, $C_5 = 0.11456 \times 10^{-2}$
$f_1/f_2 = 0.92$
$d_1/f = 0.53$

$\frac{r_1 + r_2}{r_1 - r_2} = 0.19$

$\phi_3 = 0.28$

TABLE 10-continued

[Embodiment 10]
NA = 0.47 f = 1.0 WD = 0.47 $\beta = -0.23$

$\phi_3 + \phi_3 = 0.72$
$|\phi_2 - \phi_3| = 0.16$

TABLE 11

[Embodiment 11]
NA = 0.47 f = 1.0 WD = 0.58 $\beta = -0.23$

		radius of curvature	axial distance		refractive index
G	r_{g1}	∞	d_{g1} 1.200	n_g	1.51078
	r_{g2}	∞			
			d_{g2} 1.000		
L_1	r_1*	1.889	d_1 0.760	n_1	1.48366
	r_2	−1.514			
			d_2 0.330		
L_2	r_3	1.632	d_3 0.390	n_2	1.78458
	r_4	−2.959			
			d_4 0.580		
P	r_{p1}	∞	d_p 0.240	n_p	1.57147
	r_{p2}	∞			

$\epsilon = 1.0$
aspherical surface coefficients

$C_1 = 0.0$, $C_2 =$, $C_3 = -0.73128 \times 10^{-1}$,
$C_4 = -0.76365 \times 10^{-1}$, -0.27612, $C_5 = 0.11852 \times 10^{-2}$
$f_1/f_2 = 1.35$
$d_1/f = 0.76$

$\frac{r_1 + r_2}{r_1 - r_2} = 0.11$

$\phi_3 = 0.48$
$\phi_2 + \phi_3 = 0.80$
$|\phi_2 - \phi_3| = 0.16$

TABLE 12

[Embodiment 12]
NA = 0.47 f = 1.0 WD = 0.44 $\beta = -0.23$

		radius of curvature	axial distance		refractive index
G	r_{g1}	∞	d_{g1} 1.200	n_g	1.51078
	r_{g2}	∞			
			d_{g2} 1.000		
L_1	r_1*	1.598	d_1 0.400	n_1	1.51078
	r_2	−1.465			
			d_2 0.660		
L_2	r_3	1.637	d_3 0.260	n_2	1.78458
	r_4	−2.308			
			d_4 0.440		
P	r_{p1}	∞	d_p 0.240	n_p	1.57147
	r_{p2}	∞			

$\epsilon = 1.0$
aspherical surface coefficients

$C_1 = 0.0$, $C_2 =$, $C_3 = -0.36326 \times 10^{-1}$,
$C_4 = -0.77710 \times 10^{-1}$, -0.28974, $C_5 = 0.11074 \times 10^{-2}$
$f_1/f_2 = 1.25$
$d_1/f = 0.40$

$\frac{r_1 + r_2}{r_1 - r_2} = 0.04$

$\phi_3 = 0.48$
$\phi_2 + \phi_3 = 0.83$

TABLE 12-continued

[Embodiment 12]
NA = 0.47 f = 1.0 WD = 0.44 β = −0.23

$|\phi_2 - \phi_3| = 0.13$

TABLE 13

[Embodiment 13]
NA = 0.47 f = 1.0 WD = 0.48 β = −0.30

		radius of curvature	axial distance		refractive index
G	r_{g1}	∞	d_{g1} 1.200	n_g	1.51078
	r_{g2}	∞			
			d_{g2} 1.000		
L_1	r_1	2.204	d_1 0.640	n_1	1.78458
	r_2	−1.956			
			d_2 0.560		
L_2	r_3	1.998	d_3 0.270	n_2	1.78458
	r_4	−2.512			
			d_4 0.480		
P	r_{p1}	∞	d_p 0.240	n_p	1.57147
	r_{p2}	∞			

ϵ = 1.0
aspherical surface coefficients

$C_1 = 0.0$, $C_2 =$ −0.16855, $C_3 = -0.17197 \times 10^{-1}$,
$C_4 = -0.30416 \times 10^{-1}$, $C_5 = 0.29400 \times 10^{-2}$

$f_1/f_2 = 0.97$
$d_1/f = 0.64$

$$\frac{r_1 + r_2}{r_1 - r_2} = 0.06$$

$\phi_3 = 0.39$
$\phi_2 + \phi_3 = 0.79$
$|\phi_2 - \phi_3| = 0.01$

TABLE 14

[Embodiment 14]
NA = 0.47 f = 1.0 WD = 0.73 β = −0.40

		radius of curvature	axial distance		refractive index
G	r_{g1}	∞	d_{g1} 1.200	n_g	1.51078
	r_{g2}	∞			
			d_{g2} 1.000		
L_1	r_1*	2.755	d_1 0.830	n_1	1.66175
	r_2	−1.520			
			d_2 0.390		
L_2	r_3	1.831	d_3 0.300	n_2	1.73269
	r_4	−2.915			
			d_4 0.732		
P	r_{p1}	∞	d_p 0.240	n_p	1.57147
	r_{p2}	∞			

ϵ = 1.0
aspherical surface coefficients

$C_1 = 0.0$, $C_2 =$ −0.24769, $C_3 = -0.22302 \times 10^{-2}$,
$C_4 = -0.82317 \times 10^{-1}$, $C_5 = 0.11152 \times 10^{-2}$

$f_1/f_2 = 1.02$
$d_1/f = 0.83$

$$\frac{r_1 + r_2}{r_1 - r_2} = 0.29$$

$\phi_3 = 0.40$
$\phi_2 + \phi_3 = 0.84$
$|\phi_2 - \phi_3| = 0.04$

TABLE 15

[Embodiment 15]
NA = 0.47 f = 1.0 WD = 0.76 β = −0.45

		radius of curvature	axial distance		refractive index
G	r_{g1}	∞	d_{g1} 1.200	n_g	1.51078
	r_{g2}	∞			
			d_{g2} 1.000		
L_1	r_1*	3.609	d_1 0.770	n_1	1.79132
	r_2	−1.552			
			d_2 0.450		
L_2	r_3	2.953	d_3 0.290	n_2	1.79132
	r_4	−2.316			
			d_4 0.760		
P	r_{p1}	∞	d_p 0.240	n_p	1.57147
	r_{p2}	∞			

ϵ = 1.0
aspherical surface coefficients

$C_1 = 0.0$, $C_2 =$ $C_3 = 0.10044 \times 10^{-2}$,
$C_4 = -0.47100 \times 10^{-1}$, −0.23581, $C_5 = -0.73097 \times 10^{-1}$

$f_1/f_2 = 0.87$
$d_1/f = 0.77$

$$\frac{r_1 + r_2}{r_1 - r_2} = 0.40$$

$\phi_3 = 0.27$
$\phi_2 + \phi_3 = 0.78$
$|\phi_2 - \phi_3| = 0.24$

TABLE 16

[Embodiment 16]
NA = 0.47 f = 1.0 WD = 0.40 β = −0.23

		radius of curvature	axial distance		refractive index
G	r_{g1}	∞	d_{g1} 1.200	n_g	1.51078
	r_{g2}	∞			
			d_{g2} 1.000		
L_1	r_1*	1.843	d_{1a} 0.0006	n_1'	1.51539
	r_1'	1.843	d_{1b} 0.676	n_1	1.78458
	r_2	−2.817			
			d_2 0.538		
L_2	r_3	1.681	d_3 0.290	n_2	1.78458
	r_4	−4.519			
			d_4 0.400		
P	r_{p1}	∞	d_p 0.240	n_p	1.57147
	r_{p2}	∞			

ϵ = 1.0
aspherical surface coefficients

$C_1 = 0.0$, $C_2 =$ $C_3 = -0.42903 \times 10^{-1}$,
$C_4 = -00.30672 \times 10^{-1}$, −0.18873, $C_5 = 0.29445 \times 10^{-2}$

$f_1/f_2 = 0.95$
$d_1/f = (d_{1a} = d_{1b})/f = 0.68$

$$\frac{r_1 + r_2}{r_1 - r_2} = -0.21$$

$\phi_3 = 0.47$
$\phi_2 + \phi_3 = 0.75$
$|\phi_2 - \phi_3| = 0.19$

TABLE 17

[Embodiment 17]
NA = 0.47 f = 1.0 WD = 0.36 β = −0.23

		radius of	axial		refractive

TABLE 17-continued

[Embodiment 17]
NA = 0.47 f = 1.0 WD = 0.36 β = −0.23

		curvature		distance		index	
G	r_{g1}	∞	d_{g1}	1.200	N_g	1.51078
	r_{g2}	∞	d_{g2}	1.000		
L_1	r_1	1.255	d_1	0.940	N_1	1.76492
	r_2*	13.527	d_2	0.347		
L_2	r_3	1.217	d_3	0.380	N_2	1.76492
	r_4	−1.724	d_4	0.360		
P	r_{p1}	∞	d_p	0.240	N_p	1.57147
	r_{p2}	∞				

ϵ = 0.03563
aspherical surface coefficients

$C_1 = 0.0$ $C_2 = 0.38111$ $C_3 = 0.14592$
$C_4 = 0.56315$ $C_5 = 0.21450 \times 10^1$
$d_1/f = 0.94$
$d_2/d_1 = 0.37$
$f \cdot (\phi_1 + \phi_4) = 1.05$
$f \cdot \phi_4 = 0.44$

TABLE 18

[Embodiment 18]
NA = 0.47 f = 1.0 WD = 0.42 β = −0.23

		radius of curvature		axial distance		refractive index	
G	r_{g1}	∞	d_{g1}	1.200	N_g	1.51078
	r_{g2}	∞	d_{g2}	1.000		
L_1	r_1	1.206	d_1	0.756	N_1	1.76492
	r_2*	9.184	d_2	0.347		
L_2	r_3	1.391	d_3	0.380	N_2	1.76492
	r_4	−1.942	d_4	0.420		
P	r_{p1}	∞	d_p	0.240	N_p	1.57147
	r_{p2}	∞				

ϵ = 0.03562
aspherical surface coefficients

$C_1 = 0.0$ $C_2 = 0.32778$ $C_3 = 0.75377 \times 10^{-1}$
$C_4 = 0.32070$ $C_5 = 0.10427 \times 10^1$
$d_1/f = 0.756$
$d_2/d_1 = 0.46$
$f \cdot (\phi_1 + \phi_4) = 1.02$
$f \cdot \phi_4 = 0.39$

TABLE 19

[Embodiment 19]
NA = 0.47 f = 1.0 WD = 0.264 β = −0.23

		radius of curvature		axial distance		refractive index	
G	r_{g1}	∞	d_{g1}	1.200	N_g	1.51078
	r_{g2}	∞	d_{g2}	1.000		
L_1	r_1	1.367	d_1	1.220	N_1	1.76492
	r_2*	264.760	d_2	0.317		
L_2	r_3	0.924	d_3	0.481	N_2	1.76492
	r_4	−1.764	d_4	0.264		
P	r_{p1}	∞	d_p	0.240	N_p	1.57147
	r_{p2}	∞				

ϵ = 0.03563
aspherical surface coefficients

$C_1 = 0.0$ $C_2 = 0.36364$ $C_3 = 0.26455$
$C_4 = 0.58608$ $C_5 = 0.21457 \times 10^1$
$d_1/f = 1.22$
$d_2/d_1 = 0.26$
$f \cdot (\phi_1 + \phi_4) = 0.99$
$f \cdot \phi_4 = 0.43$

TABLE 20

[Embodiment 20]
NA = 0.47 f = 1.0 WD = 0.492 β = −0.23

		radius of curvature		axial distance		refractive index	
G	r_{g1}	∞	d_{g1}	1.200	N_g	1.51078
	r_{g2}	∞	d_{g2}	1.000		
L_1	r_1	1.521	d_1	0.500	N_1	1.76492
	r_2*	−10.770	d_2	0.420		
L_2	r_3	1.574	d_3	0.420	N_2	1.76492
	r_4	−2.360	d_4	0.492		
P	r_{p1}	∞	d_p	0.240	N_p	1.57147
	r_{p2}	∞				

ϵ = 0.03562
aspherical surface coefficients

$C_1 = 0.0$ $C_2 = 0.16157$ $C_3 = 0.18676$
$C_4 = -0.58918$ $C_5 = 0.10081 \times 10^1$
$d_1/f = 0.50$
$d_2/d_1 = 0.84$
$f \cdot (\phi_1 + \phi_4) = 0.82$
$f \cdot \phi_4 = 0.32$

TABLE 21

[Embodiment 21]
NA = 0.47 f = 1.0 WD = 0.388 β = −0.23

		radius of curvature		axial distance		refractive index	
G	r_{g1}	∞	d_{g1}	1.200	N_g	1.51078
	r_{g2}	∞	d_{g2}	1.000		
L_1	r_1	1.206	d_1	0.863	N_1	1.76492
	r_2*	2.312	d_2	0.140		
L_2	r_3	1.053	d_3	0.658	N_2	1.76492
	r_4	−1.770	d_4	0.388		
P	r_{p1}	∞	d_p	0.240	N_p	1.57147
	r_{p2}	∞				

ϵ = 0.03627
aspherical surface coefficients

$C_1 = 0.0$ $C_2 = 0.36198$ $C_3 = 0.30250$
$C_4 = 0.32240$ $C_5 = 0.21385 \times 10^1$
$d_1/f = 0.86$
$d_2/d_1 = 0.16$
$f \cdot (\phi_1 + \phi_4) = 1.06$
$f \cdot \phi_4 = 0.43$

TABLE 22

[Embodiment 22]
NA = 0.47 f = 1.0 WD = 0.478 β = −0.23

		radius of curvature		axial distance		refractive index
G	r_{g1}	∞	d_{g1}	1.200	N_g	1.51078
	r_{g2}	∞	d_{g2}	1.000		
L_1	r_1	1.510	d_1	1.000	N_1	1.76492
	r_2*	1.849	d_2	0.020		
L_2	r_3	0.876	d_3	0.657	N_2	1.76492
	r_4	−1.807	d_4	0.478		
P	r_{p1}	∞	d_p	0.240	N_p	1.57147
	r_{p2}	∞				

ϵ = 0.03669
aspherical surface coefficients

C_1 = 0.0 C_2 = 0.35427 C_3 = 0.42634
C_4 = 0.19830 C_5 = 0.21349 × 10^1
d_1/f = 1.00
D_2/d_1 = 0.02
$f \cdot (\phi_1 + \phi_4)$ = 0.93
$f \cdot \phi_4$ = 0.42

TABLE 23

[Embodiment 23]
NA = 0.47 f = 1.0 WD = 0.206 β = −0.23

		radius of curvature		axial distance		refractive index
G	r_{g1}	∞	d_{g1}	1.200	N_g	1.51078
	r_{g2}	∞	d_{g2}	1.000		
L_1	r_1	1.232	d_1	0.940	N_1	1.76492
	r_2*	−11.476	d_2	0.346		
L_2	r_3	1.206	d_3	0.580	N_2	1.76492
	r_4	−1.757	d_4	0.206		
P	r_{p1}	∞	d_p	0.240	N_p	1.57147
	r_{p2}	∞				

ϵ = 0.03563
aspherical surface coefficients

C_1 = 0.0 C_2 = 0.31974 C_3 = −0.12133
C_4 = 0.61135 C_5 = 0.21464 × 10^1
d_1/f = 0.94
d_2/d_1 = 0.37
$f \cdot (\phi_1 + \phi_4)$ = 1.06
$f \cdot \phi_4$ = 0.44

TABLE 24

[Embodiment 24]
NA = 0.47 f = 1.0 WD = 0.748 β = −0.23

		radius of curvature		axial distance		refractive index
G	r_{g1}	∞	d_{g1}	1.200	N_g	1.51078
	r_{g2}	∞	d_{g2}	1.000		
L_1	r_1	4.000	d_1	0.988	N_1	1.76492
	r_2*	−3.609	d_2	0.302		
L_2	r_3	4.649	d_3	0.376	N_2	1.76492
	r_4	−1.043	d_4	0.748		
P	r_{p1}	∞	d_p	0.240	N_p	1.57147
	r_{p2}	∞				

TABLE 24-continued

[Embodiment 24]
NA = 0.47 f = 1.0 WD = 0.748 β = −0.23

ϵ = 0.03563
aspherical surface coefficients

C_1 = 0.0 C_2 = 0.41177 C_3 = 0.36202
C_4 = 0.88670 C_5 = 0.32104 × 10^1
d_1/f = 0.99
d_2/d_1 = 0.31
$f \cdot (\phi_1 + \phi_4)$ = 0.92
$f \cdot \phi_4$ = 0.73

TABLE 25

[Embodiment 25]
NA = 0.47 f = 1.0 WD = 0.624 β = −0.23

		radius of curvature		axial distance		refractive index
G	r_{g1}	∞	d_{g1}	1.200	N_g	1.51078
	r_{g2}	∞	d_{g2}	1.000		
L_1	r_1	2.402	d_1	0.988	N_1	1.76492
	r_2*	−3.718	d_2	0.302		
L_2	r_3	4.513	d_3	0.376	N_2	1.76492
	r_4	−1.050	d_4	0.624		
P	r_{p1}	∞	d_p	0.240	N_p	1.57147
	r_{p2}	∞				

ϵ = 0.03563
aspherical surface coefficients

C_1 = 0.0 C_2 = 0.41684 C_3 = 0.28059
C_4 = 0.94603 C_5 = 0.32636 × 10^1
d_1/f = 0.99
d_2/d_1 = 0.31
$f \cdot (\phi_1 + \phi_4)$ = 1.05
$f \cdot \phi_4$ = 0.73

TABLE 26

[Embodiment 26]
NA = 0.47 f = 1.0 WD = 0.468 β = −0.23

		radius of curvature		axial distance		refractive index
G	r_{g1}	∞	d_{g1}	1.200	N_g	1.51098
	r_{g2}	∞	d_{g2}	1.000		
L_1	r_1	0.937	d_1	0.756	N_1	1.48366
	r_2*	41.264	d_2	0.335		
L_2	r_3	1.426	d_3	0.387	N_2	1.76492
	r_4	−1.579	d_4	0.468		
P	r_{p1}	∞	d_p	0.240	N_p	1.57147
	r_{p2}	∞				

ϵ = 0.03562
aspherical surface coefficients

C_1 = 0.0 C_2 = 0.69239 C_3 = 0.18423
C_4 = 0.23118 × 10^1 C_5 = 0.11321 × 10^1
d_1/f = 0.76
d_2/d_1 = 0.44
$f \cdot (\phi_1 + \phi_4)$ = 1.00

TABLE 26-continued

[Embodiment 26]
NA = 0.47 f = 1.0 WD = 0.468 β = −0.23

$f \cdot \phi_4 = 0.48$

TABLE 27

[Embodiment 27]
NA = 0.47 f = 1.0 WD = 0.36 β = −0.23

		radius of curvature	axial distance		refractive index
G	r_{g1}	∞	d_{g1} 1.200	N_g	1.51078
	r_{g2}	∞	d_{g2} 1.000		
L_1	r_1	0.828	d_1 0.760	N_1	1.48366
	r_2*	−9.996	d_2 0.307		
L_2	r_3	0.833	d_3 0.368	N_2	1.48366
	r_4	−1.609	d_4 0.360		
P	r_{p1}	∞	d_p 0.240	N_p	1.57147
	r_{p2}	∞			

ϵ = 0.03562
aspherical surface coefficients

$C_1 = 0.0$ $C_2 = 0.70769$ $C_3 = 0.24786$
$C_4 = 0.24631 \times 10^1$ $C_5 = 0.11423 \times 10^1$
$d_1/f = 0.76$
$d_2/d_1 = 0.40$
$f \cdot (\phi_1 + \phi_4) = 0.88$
$f \cdot \phi_4 = 0.30$

TABLE 28

[Embodiment 28]
NA = 0.47 f = 1.0 WD = 0.478 β = −0.23

		radius of curvature	axial distance		refractive index
G	r_{g1}	∞	d_{g1} 1.200	N_g	1.51078
	r_{g2}	∞	d_{g2} 1.000		
L_1	r_1	1.024	d_1 0.756	N_1	1.51078
	r_2*	−20.573	d_2 0.335		
L_2	r_3	1.521	d_3 0.387	N_2	1.76492
	r_4	−1.590	d_4 0.478		
P	r_{p1}	∞	d_p 0.240	N_p	1.57147
	r_{p2}	∞			

ϵ = 0.03562
aspherical surface coefficients

$C_1 = 0.0$ $C_2 = 0.58336$ $C_3 = 0.96587 \times 10^{-1}$
$C_4 = 0.14862 \times 10^1$ $C_5 = 0.10923 \times 10^1$
$d_1/f = 0.76$
$d_2/d_1 = 0.44$
$f \cdot (\phi_1 + \phi_4) = 0.98$
$f \cdot \phi_4 = 0.48$

TABLE 29

[Embodiment 29]
NA = 0.47 f = 1.0 WD = 0.466 β = −0.23

		radius of curvature	axial distance		refractive index
G	r_{g1}	∞	d_{g1} 1.200	N_g	1.51078
	r_{g2}	∞	d_{g2} 1.000		

TABLE 29-continued

[Embodiment 29]
NA = 0.47 f = 1.0 WD = 0.466 β = −0.23

L_1	r_1	0.987	d_{1a} 0.750	N_{1a}	1.51078
	r_2'	−437.002	d_{1b} 0.006	N_{1b}	1.51539
	r_2*	−437.002	d_2 0.335		
L_2	r_3	1.457	d_3 0.387	N_2	1.76492
	r_4	−1.615	d_4 0.466		
P	r_{p1}	∞	d_p 0.240	N_p	1.57147
	r_{p2}	∞			

ϵ = 0.03562
aspherical surface coefficients

$C_1 = 0.0$ $C_2 = 0.60626$ $C_3 = 0.11403$
$C_4 = 0.17038 \times 10^1$ $C_5 = 0.11046 \times 10^1$
$d_1/f = 0.75$
$d_2/d_1 = 0.45$
$f \cdot (\phi_1 + \phi_4) = 0.99$
$f \cdot \phi_4 = 0.47$

TABLE 30

[Embodiment 30]
NA = 0.47 f = 1.0 WD = 0.283 β = −0.23

		radius of curvature	axial distance		refractive index
G	r_{g1}	∞	d_{g1} 1.200	N_g	1.51078
	r_{g2}	∞	d_{g2} 1.000		
L_1	r_1	0.909	d_1 0.756	N_1	1.76492
	r_2*	2.579	d_2 0.340		
L_2	r_3	1.029	d_3 0.391	N_2	1.76492
	r_4	−4.147	d_4 0.283		
P	r_{p1}	∞	d_p 0.240	N_p	1.57147
	r_{p2}	∞			

ϵ = 0.03571
aspherical surface coefficients

$C_1 = 0.0$ $C_2 = 0.53477$ $C_3 = 0.34228$
$C_4 = 0.16180 \times 10^1$ $C_5 = 0.10883 \times 10^1$
$d_1/f = 0.76$
$d_2/d_1 = 0.18$
$f \cdot (\phi_1 + \phi_4) = 1.02$
$f \cdot \phi_4 = 0.18$

TABLE 31

[Embodiment 31]
NA = 0.47 f = 1.0 WD = 0.674 β = −0.35

		radius of curvature	axial distance		refractive index
G	r_{g1}	∞	d_{g1} 1.200	N_g	1.51078
	r_{g2}	∞	d_{g2} 1.000		
L_1	r_1	1.648	d_1 0.660	N_1	1.76492
	r_2*	−6.626	d_2 0.336		
L_2	r_3	2.572	d_3 0.380	N_2	1.76492
	r_4	−1.457	d_4 0.674		
P	r_{p1}	∞	d_p 0.240	N_p	1.57147
	r_{p2}	∞			

TABLE 31-continued

[Embodiment 31]
NA = 0.47 f = 1.0 WD = 0.674 β = −0.35

ϵ = 0.03562
aspherical surface coefficients

$C_1 = 0.0$ $C_2 = 0.27689$ $C_3 = 0.20247$ $C_4 = -0.22495$
$C_5 = 0.10345 \times 10^1$
$d_1/f = 0.66$
$d_2/d_1 = 0.51$
$f \cdot (\phi_1 + \phi_4) = 0.99$
$f \cdot \phi_4 = 0.53$

TABLE 32

[Embodiment 32]
NA = 0.47 f = 1.0 WD = 0.774 β = −0.45

		radius of curvature	axial distance		refractive index
G	r_{g1}	∞	d_{g1} 1.200	N_g	1.51078
	r_{g2}	∞			
			d_{g2} 1.000		
L_1	r_1	1.762	d_1 0.660	N_1	1.76492
	r_2*	−4.248			
			d_2 0.337		
L_2	r_3	2.927	d_3 0.379	N_2	1.76492
	r_4	−1.479			
			d_4 0.774		
P	r_{p1}	∞	d_p 0.240	N_p	1.57147
	r_{p2}	∞			

ϵ = 0.03562
aspherical surface coefficients

$C_1 = 0.0$ $C_2 = 0.25724$ $C_3 = 0.23282$ $C_4 = -0.42688$
$C_5 = 0.10254 \times 10^1$
$d_1/f = 0.66$
$d_2/d_1 = 0.52$
$f \cdot (\phi_1 + \phi_4) = 0.95$
$f \cdot \phi_4 = 0.52$

TABLE 33

[Embodiment 33]
NA = 0.47 f = 1.0 WD = 0.416 β = −0.15

		radius of curvature	axial distance		refractive index
G	r_{g1}	∞	d_{g1} 1.200	N_g	1.51078
	r_{g2}	∞			
			d_{g2} 1.000		
L_1	r_1	1.294	d_1 0.602	N_1	1.76492
	r_2*	15.142			
			d_2 0.351		
L_2	r_3	1.769	d_3 0.403	N_2	1.76492
	r_4	−1.709			
			d_4 0.416		
P	r_{p1}	∞	d_p 0.240	N_p	1.57147
	r_{p2}	∞			

ϵ = 0.03562
aspherical surface coefficients

$C_1 = 0.1$ $C_2 = 0.25992$ $C_3 = 0.99020 \times 10^{-1}$
$C_4 = 0.47836 \times 10^{-1}$ $C_5 = 0.10387 \times 10^1$
$d_1/f = 0.60$
$d_2/d_1 = 0.58$
$f \cdot (\phi_1 + \phi_4) = 1.04$
$f \cdot \phi_4 = 0.45$

TABLE 34

[Embodiment 34]
NA = 0.47 f = 1.0 WD = 0.432 β = −0.15

		radius of curvature	axial distance		refractive index
G	r_{g1}	∞	d_{g1} 1.200	N_g	1.51078
	r_{g2}	∞			
			d_{g2} 1.000		
L_1	r_1	1.422	d_1 0.500	N_1	2.00000
	r_2*	6.910			
			d_2 0.351		
L_2	r_3	2.122	d_3 0.403	N_2	1.76492
	r_4	−1.724			
			d_4 0.432		
P	r_{p1}	∞	d_p 0.240	N_p	1.57147
	r_{p2}	∞			

ϵ = 0.03565
aspherical surface coefficients

$C_1 = 0.0$ $C_2 = 0.17123$ $C_3 = 0.11894$ $C_4 = -0.24577$
$C_5 = 0.10316 \times 10^1$
$d_1/f = 0.50$
$d_2/d_1 = 0.70$
$f \cdot (\phi_1 + 1004) = 1.15$
$f \cdot \phi_4 = 0.44$

What is claimed is:

1. An objective lens system for optical recording type disks, comprising from a light source side to a disk side;

a first lens element of a positive refractive power; and

a second lens element of a positive refractive power,

wherein the light source side surface of the first lens element is aspherical while all of the other surfaces are spheric, and wherein the lens system fulfills the following conditions:

$$-\tfrac{1}{2} < \beta < -\tfrac{1}{8}$$

$$0.70 < f_1/f_2 < 1.50$$

$$0.47 < d_1/f < 1.25$$

wherein:

β represents the magnification of the whole lens system;

d_1 represents the axial thickness of the first lens element;

f_1 represents the focal length of the first lens element;

f_2 represents the focal length of the second lens element; and

f represents the focal length of the whole lens system.

2. An objective lens as claimed in claim **1**, wherein the lens system further fulfills the following condition:

$$-1.00 < (r_1+r_2)/(r_1-r_2) < 1.00$$

wherein:

r_1 represents the paraxial radius of curvature of the light source side surface of the first lens element; and

r_2 represents the radius of curvature of the disk side surface of the first lens element.

3. An objective lens system as claimed in claim **2**, wherein the lens system further fulfills the following conditions:

$$0.2 < \phi_3 < 0.7$$

$0.6<\phi_2+\phi_3<1.0$

$|\phi_2-\phi_3|<0.6$

provided by:

$\phi_2=(1-N_1)\cdot f/r_2$

$\phi_3=(N_2-1)\cdot f/r_3$

wherein:

N_1 represents the refractive index of the first lens element;

N_2 represents the refractive index of the second lens element; and

r_3 represents the radius of curvature of the light source side surface of the second lens element.

4. An objective lens system for optical recording type disks, comprising from a light source side to a disk side;

a first lens element of a positive refractive power; and

a second lens element of a positive refractive power, wherein the disk side surface of the first lens element is aspherical while all of the other surfaces are spheric, and wherein the lens system fulfills the following conditions:

$-\frac{1}{2}<\beta<-\frac{1}{8}$

$0.47<d_1/f<1.25$

$0<d_2/d_1<0.85$

wherein:

β represents the magnification of the whole lens system;

d_1 represents the axial thickness of the first lens element;

d_2 represents the axial distance from the disk side surface of the first lens element to the light source side surface of the second lens element; and

f represents the focal length of the whole lens system.

5. An objective lens system as claimed in claim **4**, wherein the lens system further fulfills the following conditions:

$0.80<f\cdot(\phi_1+\phi_4)<1.30$

$0.10<f\cdot\phi_4<0.80$

provided by:

$\phi_1=(N_1-1)/r_1$

$\phi_4=(1-N_2)/r_4$

wherein:

N_1 represents the refractive index of the first lens element;

N_2 represents the refractive index of the second lens element;

r_1 represents the radius of curvature of the light source side surface of the first lens element; and

r_4 represents the radius of curvature of the disk side surface of the second lens element.

* * * * *

United States Patent [19]

Takamura

[11] **Patent Number: 4,765,723**

[45] **Date of Patent: Aug. 23, 1988**

[54] **OBJECTIVE LENS SYSTEM FOR OPTICAL READING DEVICE**

[75] Inventor: **Sachiko Takamura,** Kyoto, Japan

[73] Assignee: **Minolta Camera Kabushiki Kaisha,** Osaka, Japan

[21] Appl. No.: **926,644**

[22] Filed: **Nov. 3, 1986**

[30] **Foreign Application Priority Data**

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Apr. 24, 1986 [JP] Japan 61-095400

[51] **Int. Cl.**[4] **G02B 13/18;** G02B 3/00
[52] **U.S. Cl.** **350/432;** 350/409
[58] **Field of Search** 350/432, 409

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Primary Examiner—John K. Corbin
Assistant Examiner—Ronald M. Kachmarik
Attorney, Agent, or Firm—Price, Gess & Ubell

[57] **ABSTRACT**

An objective lens system for use in a device for optically reading digital data on an optical disk is constituted by a single objective lens without use of a collimator lens element. A light source side aspherical surface of the objective lens element has a positive refractive power and a disk side surface thereof has a positive refractive power, too. The objective lens system is used with the projecting magnification β which falls within the range $-\frac{1}{2}<\beta<-\frac{1}{8}$.

The objective lens system fulfills the following condition:

$$0.9 \leqq (N_1-1)r_1/f \leqq 3.9$$

$$1.4 \leqq d_1 r_1/f^2 \leqq 4.0$$

$$1.4 \leqq d_1^2/f^2(N_1-1) \leqq 4.0$$

wherein,

f represents the focal length of the single lens element;

r_1 represents the paraxial radius of curvature of the light source side surface of the single lens component;

N_1 represents the refractive index of the single lens element; and

d_1 represents the axial thickness of the single lens element.

10 Claims, 9 Drawing Sheets

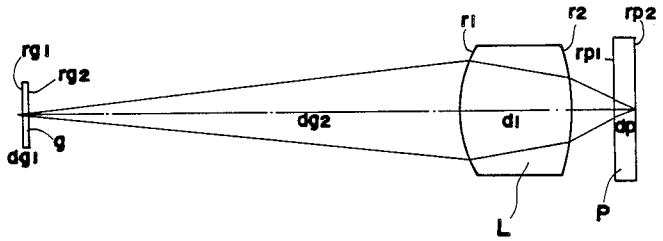
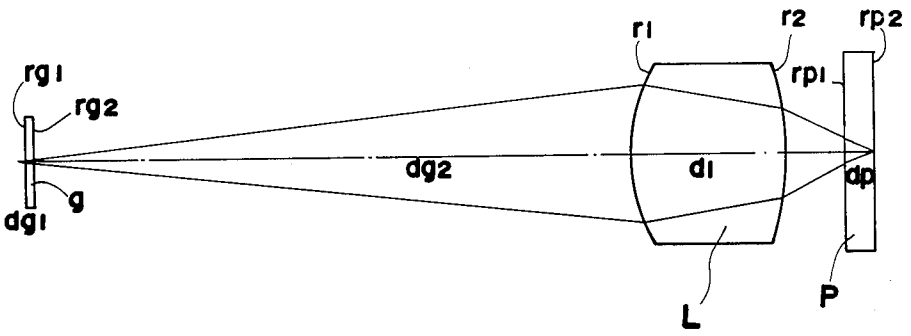


FIG.1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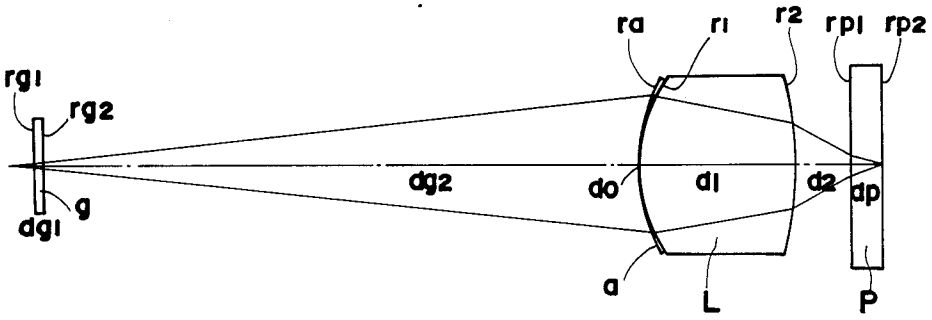
g
dg2
r1
r2
rp2
rp1
d1
dp
L
P

FIG.2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rg2
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rp2
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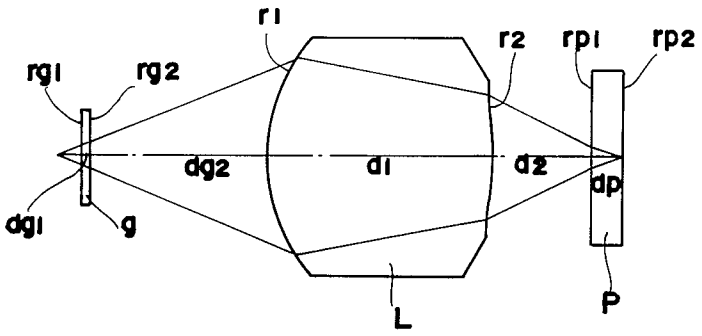
d2
dp
a
L
P

FIG.3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rp1
rp2
rg1
rg2
dg2
d1
d2
dp
dg1
g
L
P

FIG.4

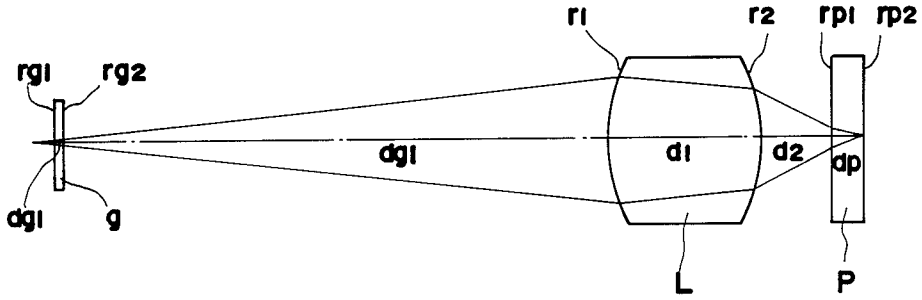
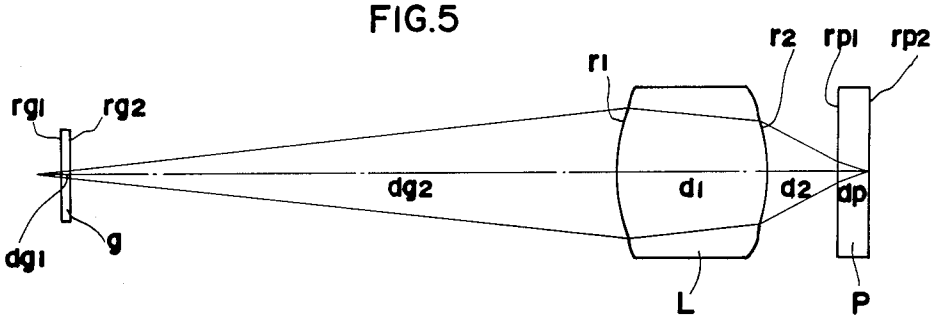
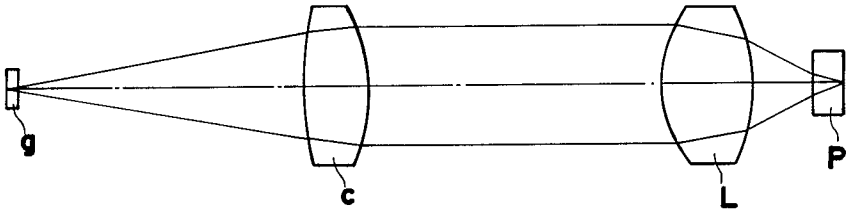

r1
r2
rp1
rp2
rg1
rg2
dg1
d1
d2
dp
dg1
g
L
P

FIG.5



PRIOR ART
FIG.6



PRIOR ART
FIG.7

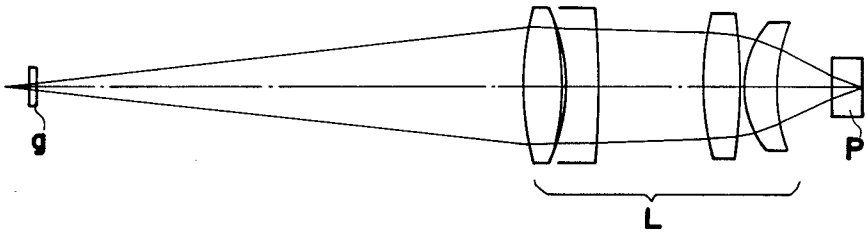


FIG.8A

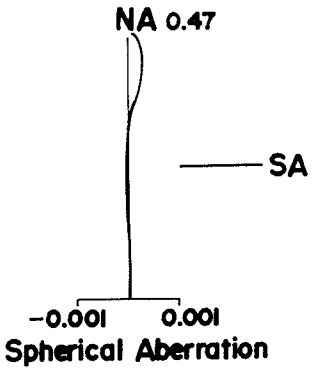


FIG.8B

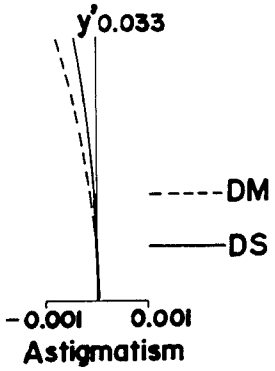


FIG.8C

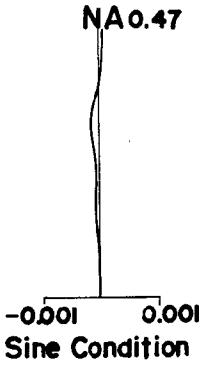


FIG.9A

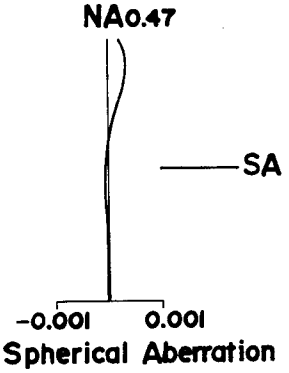


FIG.9B

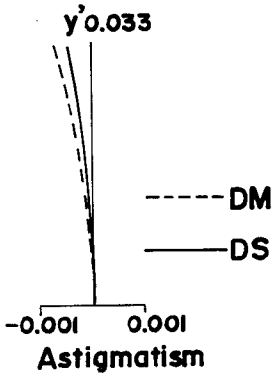


FIG.9C

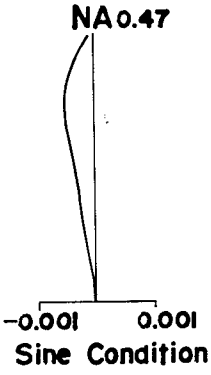


FIG.10A

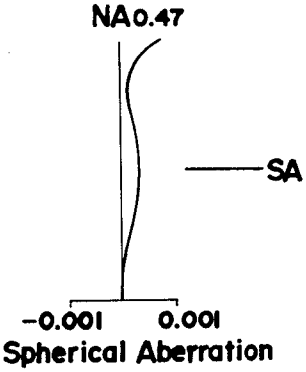


FIG.10B

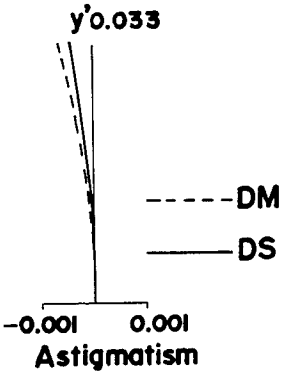


FIG.10C

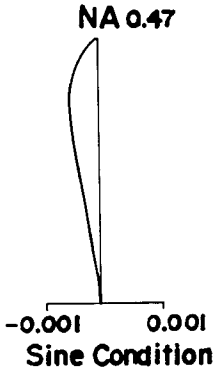


FIG.11A

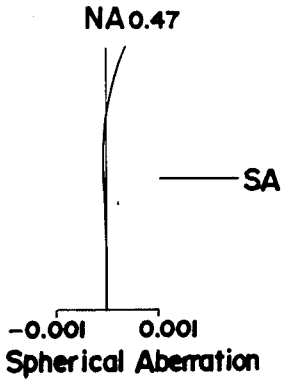


FIG.11B

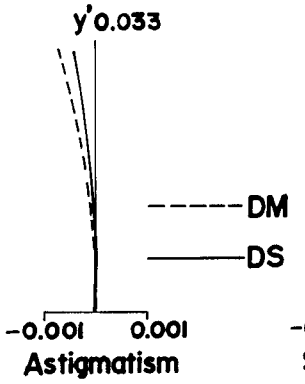


FIG.11C

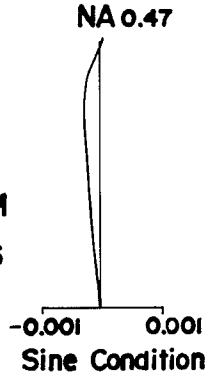


FIG.12A

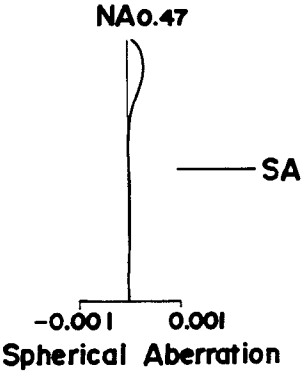


FIG.12B

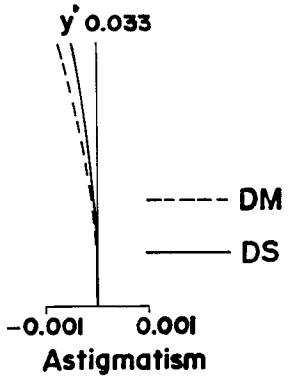


FIG.12C

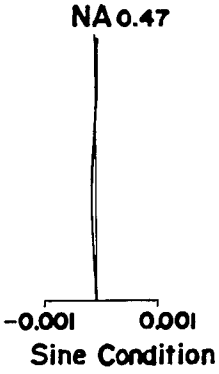


FIG.13A

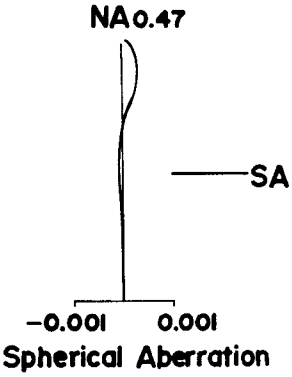


FIG.13B

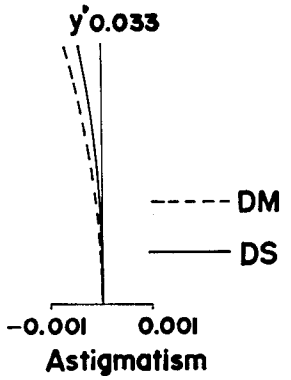


FIG.13C

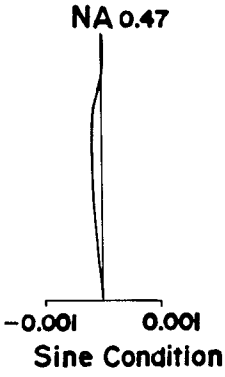


FIG.14A

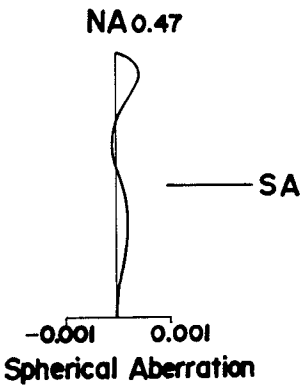


FIG.14B

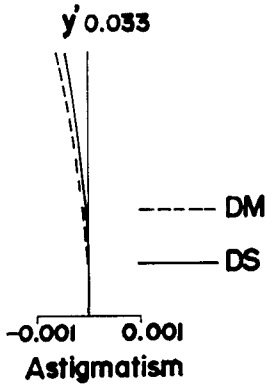


FIG.14C

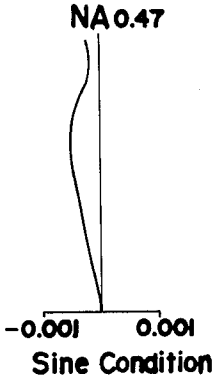


FIG.15A

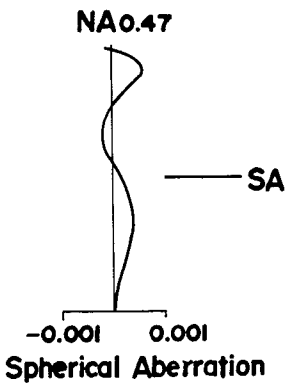


FIG.15B

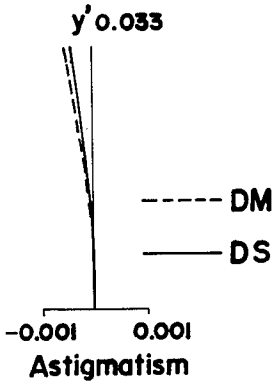


FIG.15C

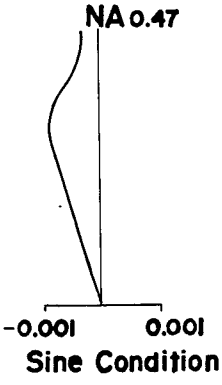


FIG.16A

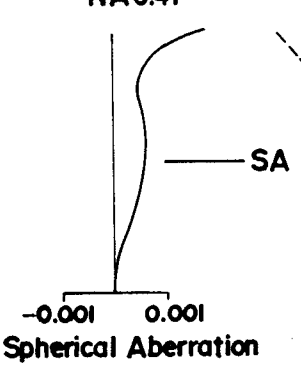


FIG.16B

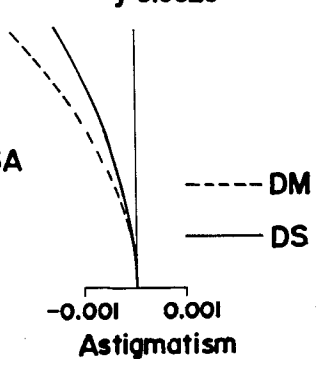


FIG.16C

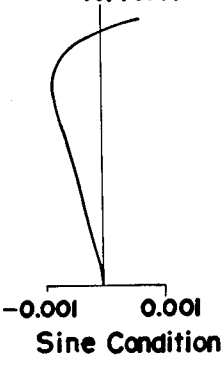


FIG.17A

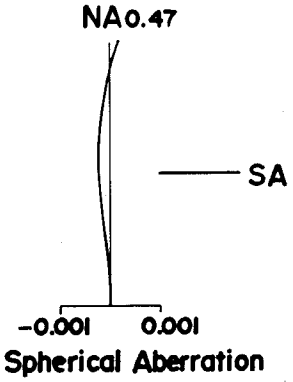


FIG.17B

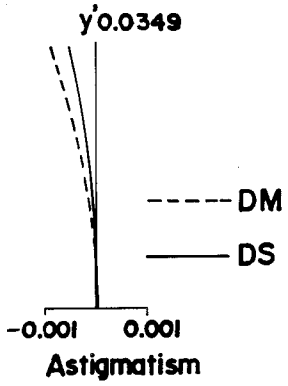


FIG.17C

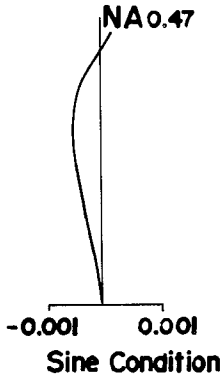


FIG.18A

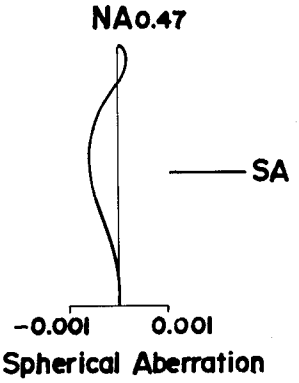


FIG.18B

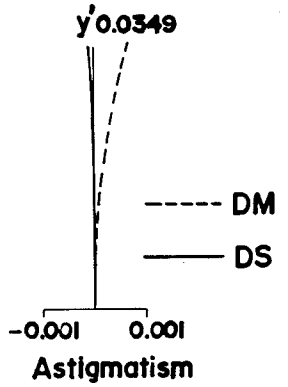


FIG.18C

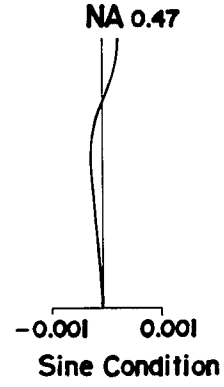


FIG.19A

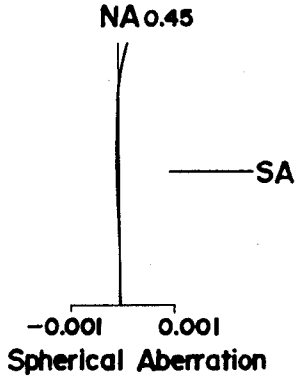


FIG.19B

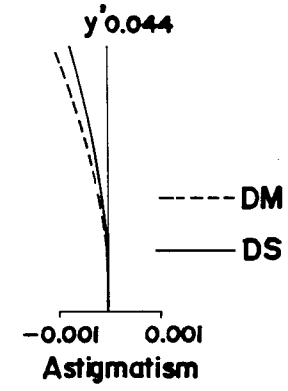


FIG.19C

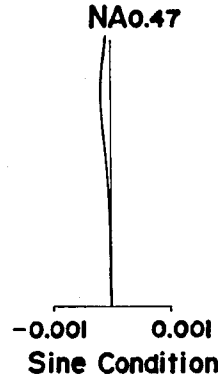


FIG.20A

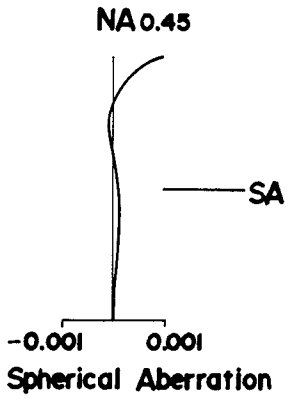


FIG.20B

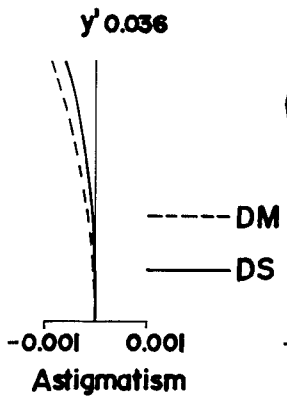


FIG.20C

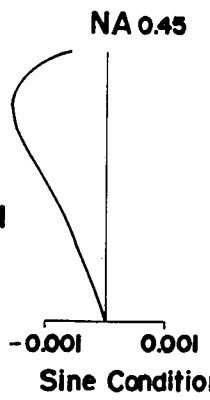


FIG.21A

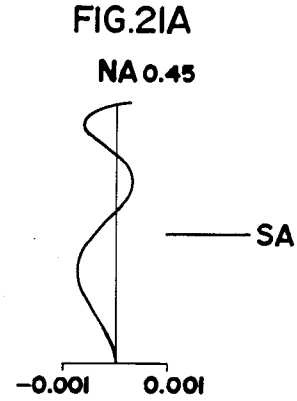


FIG.21B

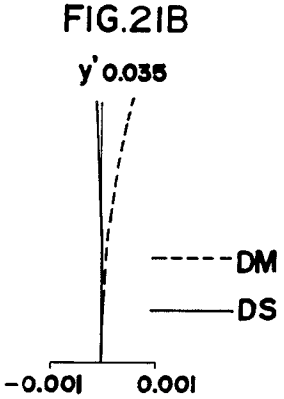


FIG.21C

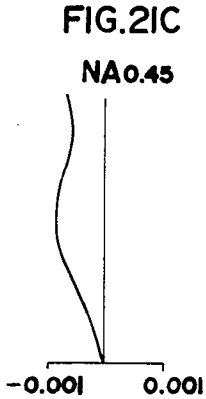


FIG.22A

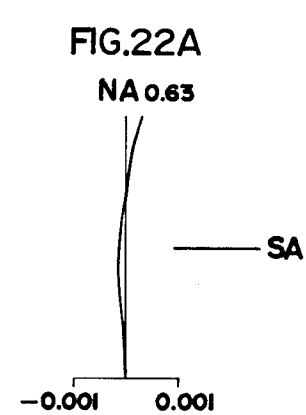


FIG.22B

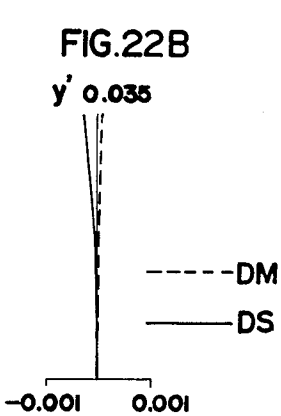


FIG.22C

FIG.23A

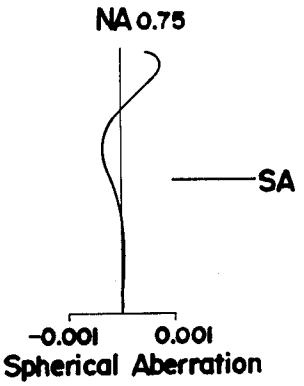


FIG.23B

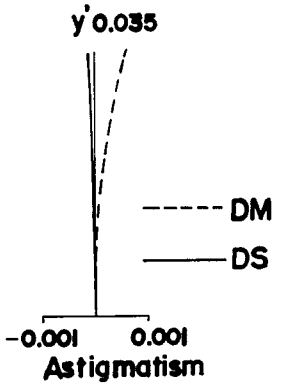


FIG.23C

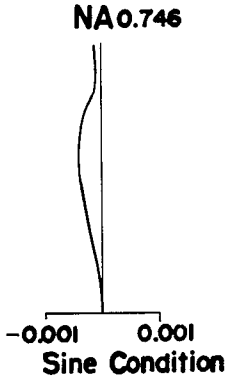


FIG.24A

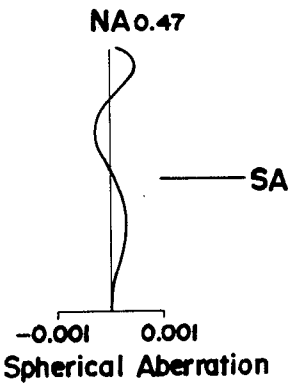


FIG.24B

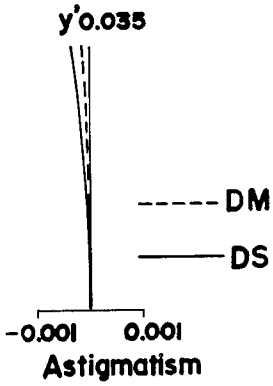


FIG.24C

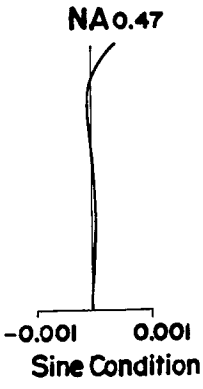


FIG.25A

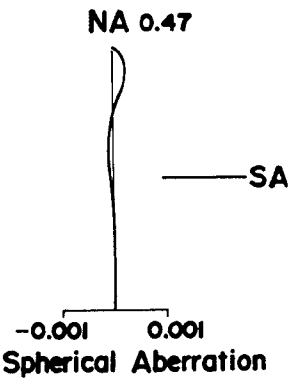


FIG.25B

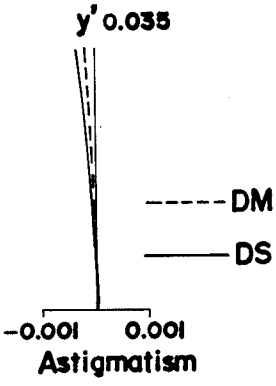
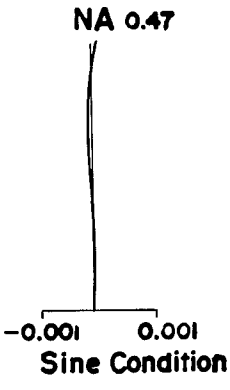


FIG.25C



OBJECTIVE LENS SYSTEM FOR OPTICAL READING DEVICE

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to an objective lens system for a device for optically reading digitalized information on an optical disk such as DAD.

2. Description of the Prior Art

Conventional objective lens systems for use in a device for optically reading digitalized information need a collimator lens element (c) as shown in FIG. **6** when an objective lens is constituted by a single lens element or need an objective lens constituted by a plurality of lens elements as shown in FIG. **7** when no collimator lens element (c) is provided. In case of the former type, the collimator lens element (c) is always fixed while the objective lens element (L) is shifted, so that two lens-barrels are needed, resulting in difficulty of adjustment of the optical axis of the whole optical system.

As the objective lens systems of this type usually has an aspherical surface on the single objective lens element, optical performance is seriously deteriorated due to misalignment of the objective lens with the whole optical system and thus the adjustment of the optical axis of the single lens element to the whole optical system should be carried out very precisely. Also in case of the latter type, in which the objective lens element comprises a plurality of lens elements, it is necessary to arrange the lens barrel very precisely to maintain sufficient optical performance although an objective lens systems of this type need a larger space for the arrangement of the lens barrel as compared with those of the former type and distortion of the lens barrel due to the change of temperature causes misalignment of the lens elements, so that the optical performance tends to be deteriorated.

SUMMARY OF THE INVENTION

An object of the present invention is to provide an improved objective lens system for an optical reading device.

Another object of the present invention is to provide an objective lens system which does not have a collimator lens element but has an objective lens constituted by a single lens element adapted to receive directly light rays from a semiconductor laser and to converge the light rays on an optical disk.

Still another object of the present invention is to provide an objective lens system of the above mentioned type, in which the diameter of the single objective lens element can be finished with less precision so long as the centers of both sides of the lens element coincide with one another, and in which lens barrels can be manufactured with less precision, whereas the optical performance of the single objective lens element can be maintained when the lens barrel supporting the single objective lens element is provided with an adjusting mechanism which adjusts the inclination and deviation of the lens element relative to the optical axis of the whole optical system.

Further object of the present invention is to provide an objective lens system which can be used with definite magnification.

Still further object of the present invention is to provide an objective lens system of the above mentioned type, wherein aberrations are well corrected.

To achieve these objects, an objective lens system according to the present invention has an objective lens constituted by a single lens element; having a light source side aspherical surface with a positive refractive power and a disk side surface with a positive refractive power. The objective lens system is used with the projecting magnification β which falls within the range, $-\frac{1}{2}<\beta<-\frac{1}{8}$, wherein the objective lens system fulfills the following conditions:

$$0.9 \leqq (N_1-1)r_1/f \leqq 3.9$$

$$1.4 \leqq d_1 r_1/f^2 \leqq 4.0$$

$$1.4 \leqq d_1^2/f^2(N_1-1) \leqq 4.0$$

wherein f represents the focal length of the single lens element, r_1 represents the paraxial radius of curvature of the light source side surface of the single lens element, N_1 represents the refractive power of the single lens element and d_1 represents the axial thickness of the single lens element.

The objects and features of the present invention which are believed to be novel are set forth with particularly in the appended claims. The present invention, both as to its orgainzation and manner of operation, together with further objects and advantages thereof, may best be understood by reference to the following description, taken in connection with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWING

FIG. **1** is a cross sectional view of the objective lens system according to embodiments 1, 3, 4, 5, 7, 8, 9, 10, 11, 12 of the present invention;

FIG. **2** is a cross sectional view of the objective lens system according to embodiments 2, 6, 13 of the present invention;

FIG. **3** is a cross sectional view of the objective lens system according to embodiments 14, 15, 16 of the present invention;

FIG. **4** is a cross sectional view of the objective lens system according to embodiment 17 of the present invention;

FIG. **5** is a cross sectional view of the objective lens system according to embodiment 18 of the present invention;

FIG. **6** is a cross sectional view of a conventional objective lens system;

FIG. **7** is a cross sectional of another conventional objective lens system.

FIGS. **8A** to **8C** represent the aberration curves of the embodiment 1;

FIGS. **9A** to **9C** represent the aberration curves of the embodiment 2;

FIGS. **10A** to **10C** represent the aberration curves of the embodiment 3;

FIGS. **11A** to **11C** represent the aberration curves of the embodiment 4;

FIGS. **12A** to **12C** represent the aberration curves of the embodiment 5;

FIGS. **13A** to **13C** represent the aberration curves of the embodiment 6;

FIGS. **14A** to **14C** represent the aberration curves of the embodiment 7;

FIGS. **15**A to **15**C represent the aberration curves of the embodiment 8;

FIGS. **16**A to **16**C represent the aberration curves of the embodiment 9;

FIGS. **17**A to **17**C represent the aberration curves of the embodiment 10;

FIGS. **18**A to **18**C represent the aberration curves of the embodiment 11;

FIGS. **19**A to **19**C represent the aberration curves of the embodiemnt 12;

FIGS. **20**A to **20**C represent the aberration curves of the embodiment 13;

FIGS. **21**A to **21**C represent the aberration curves of the embodiment 14;

FIGS. **22**A to **22**C represent the aberration curves of the embodiment 15;

FIGS. **23**A to **23**C represent the aberration curves of the embodiment 16;

FIGS. **24**A to **24**C represent the aberration curves of the embodiment 17;

FIGS. **25**A to **25**C represents the aberration curves of the embodiment 18;

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The following description is provided to enable any person skilled in the optical field to make and use the invention and sets forth the best modes contemplated by the inventor for carrying out my invention. Various modifications, however, will remain readily apparent to those skilled in the art, since the generic principles of the present invention have been defined herein specifically to provide a relatively economical and easily manufactured objective lens system. The derivation of the formulas and the relation of the powers set forth herein can be accomplished with the assistance of a computer. The present invention represents the parameters of a compromise balance of acceptable aberrations which can be relatively easily manufactured to provide a low cost lens system.

In the drawings, schematic cross sectional views disclose the position of the lens element. Values of the radii of curvature and axial distances for each lens element and air space are provided in the accompanying tables set forth herein. The schematic cross sectional views of the respective embodiments follow the normal conventions of the light source at the left-hand side of the drawing and the disk at the right hand side.

As shown in FIGS. **1** and **2**, the present invention provides an objective lens system for a device for optically reading digital data on an optical disk with a single lens element (L) whose light source side aspherical surface (r_1) has a positive refractive power, and whose disk side surface (r_2) has a positive refractive index, and the objective lens system is used with the projecting magnification β which falls within the range,

$$-\frac{1}{2}<\beta<-\frac{1}{8}. \quad (2)$$

With no collimator lens arranged in front of the single objective lens element (L), incident light rays come into the single lens element (L) from an oblique direction inclined to the optical axis, so that the objective lens system according to this invention is used with a definite projecting magnification. The range of the magnification is limited in condition (1). If the magnification β becomes greater beyond the upper limit of condition (1), the distance between the light source and the disk cannot be shortened to the extent leading to satisfactory compactization of the objective lens system.

On the other hand, if the magnification β becomes smaller beyond the lower limit of condition (1), a space for arrangement of a beam splitter and so on cannot be assured and the image height required for correcting aberrations well cannot be provided in case that the objective lens element (L) is arranged inclined.

Assume here that a conventional objective lens element whose aberrations are corrected well at the magnification $\beta=0$ is used with the magnification 8 remaining in the range $-\frac{1}{2}<\beta<-\frac{1}{8}$ as an objective lens of an objective lens system not necessitating a collimator lens. In this case, the numerical aperture decreases, so that sufficient resolving power of 1 μm, cannot be achieved. This can be understood from the following equation

$$NA\beta=NA\infty/(1-\beta)$$

in which $NA\infty$ is the numerical aperture of the disk side surface at the magnification $\beta=0$ and $NA\beta$ is the numerical aperture of the disk side surface of the objective lens element at the magnification $\beta<0$. If the objective lens element with $NA\infty=0.45$ is used and at the magnification $\beta=-\frac{1}{4}$, the $NA\beta$ becomes 0.36. The resolving power becomes poorer as the numerical aperture $NA\beta$assumes a smaller value. Therefore at the magnification $\beta=-\frac{1}{4}$ with $NA\beta=0.36$ resolving power of 1 μm, cannot be achieved. If the aperture of the objective lens element (L) is increased in order to make $NA\beta$ great, spherical aberration in the on-axial region, and the coma aberration in the off-axial region, are caused considerably. To correct these aberrations the objective lens system according to the present invention fullfills the following conditions:

$$0.9\leqq(N_1-1)r_1/f\leqq3.9 \quad (2)$$

$$1.4\leqq d_1r_1/f^2\leqq4.0 \quad (3)$$

$$1.4\leqq d_1^2/f^2(N_1-1)\leqq4.0 \quad (4)$$

wherein, f represents the focal length of the single lens element, r_1 represents the paraxial radius of curvature of the light source side surface of the single lens element, N_1 represents the refractive index of the single lens element and d_1 represents the axial thickness of the single lens element.

If the radius of curvature of the light source side surface (r_1) becomes small beyond the lower limit of the condition (2), the coma is generated, which is hard to be corrected. If the refractive power of the single lens element (L) becomes small beyond the lower limit of the condition (2), the absolute value of the radius of curvature of the light source side surface or the disk side surface of the lens element should be small in order to keep the predetermined focal length, but in either case the coma is generated, which is hard to be corrected. On the other hand, if the radius of curvature of the light source side surface (r_1) increases, considerable coma flare is generated near the pupil of the single lens element. This coma flare can be corrected by forming the lens element of a glass with high refractive power, but the refractive power of the lens element becomes great beyond the upper limit of the condition (2), resulting in generation of the astigmatism and failure to keep the optical performance in off-axial region well.

If the axial thickness (d_1) or the radius of curvature (r_1) of the light source side surface of the single lens element (L) becomes small beyond the lower limit of the condition (3), the absolute value of the radius of curvature of the disk side surface (r_2) should be made greater in order to keep the predetermined focal length so that the astigmatism becomes difficult to be corrected. In contrast thereto, if the axial thickness (d_1) or the radius of curvature (r_1) of the light source side surface of the single lens element (L) becomes great beyond the upper limit of the condition (3), the absolute value of the radius of curvature of the disk side surface (r_2) should be made small, so that even with the effect of the aspherical surface the coma is generated, which is difficult to be corrected.

If the axial thickness (d_1) becomes small or the positive refractive power of the single lens element (L) becomes great beyond the lower limit of the condition (4), the absolute value of the radius of curvature of the light source side surface (r_1) or the disk side surface (r_2) should be made great. If, here, the absolute value of the radius of curvature of the disk side surface (r_2) becomes great, the astigmatism becomes difficult to be corrected, and if that of the light source side surface (r_1) becomes great, the coma flare is generated, which is difficult to be corrected even with the effect of the aspherical surface. On the other hand, if the axial thickness (d_1) becomes great or the positive refractive power becomes small beyond the upper limit of the condition (4), the absolute value of the radius of curvature of either side surface should be made small, so that the coma is generated, which cannot be corrected well even with the effect of the aspherical surface.

It is desired that the disk side surface is aspherical for better correction of the comma.

Additionally the following condition is effective in combination with the conditions (2), (3), (4) in order to correct the coma much btter:

$$0 \leqq f(N_1^2 - N_1 - 1)/|r_2| \leqq 1.2 \quad (5)$$

wherein, r_2 represents the radius of curvature of the disk side surface of the single lens.

If the refractive power of the single lens element (L) becomes small beyond the lower limit of the condition (5), the absolute value of the radius of curvature of the light source side surface (r_1) or the disk side surface (r_2) should be small, so that the coma cannot be corrected well. Furthermore, in case the disk side surface is aspherical, the absolute value of radius (r_2) of this surface becomes small, causing the radius of curvature of the disk side surface (r_2) assume a small value so that the distance from the aspherical surface to the imaging plane tangent to the top point of the aspherical surface becomes great, much precision is needed to manufacture a cast and to form the aspherical surface by molding. On the other hand, if the absolute value of the radius of curvature of the disk side surface (r_2) becomes small beyond the upper limit of the condition (5), the coma becomes hard to be corrected.

According to the present invention, the following conditions are effective instead of the above conditions, (2), (3), and (4):

$$1.4 \leqq (N_1 - 1)r_1/f \leqq 3.9 \quad (6)$$

$$1.6 \leqq d_1 r_1/f^2 \leqq 4.0 \quad (7)$$

wherein, f represents the focal length of the single lens element, r_1 represents the paraxial radius of curvature of the light source side surface of the single lens element, N_1 represents the refractive index of the single lens element, and d_1 represents the axial thickness of the single lens element.

This example of the invention is shown in FIGS. **1** and **2**.

In the case where the light source side surface is aspherical and the disk side surface is spherical, it is desired to form the single lens element of a glass with a higher refractive power in order to correct the coma better. To this end it is desired to fulfill conditions (6) and (7). These conditions have the same meanings respectively as the conditions (2) and (3) and if the lower and upper limits are violated, the same aberrations as in the case of violations of the conditions (2) and (3) are generated.

Additionally, the following condition is effective in combination with the conditions (6) and (7) in order to correct the coma much better:

$$0 \leqq f(N_1^2 - N_1 - 1)/|r_2| \leqq 1.2 \quad (8)$$

wherein, r_2 represents the radius of curvature of the disk side surface of the single lens element.

This condition is the same as condition (5) and if the lower and upper limits are violated, the same aberrations are generated.

Furthermore, according to the present invention, the following conditions are effective instead of the above conditions (1), (2), (3) and (4):

$$0.9 \leqq (N_1 - 1)r_1/f \leqq 3.9 \quad (9)$$

$$1.2 \leqq d_1 r_1/f^2 \leqq 4.0 \quad (10)$$

$$0.7 \leqq r_1(N_1 - 1)(1 + |\beta|)/-r_2 \leqq 3.0 \quad (11)$$

wherein,

f represents the focal length of the single lens element,

r_1 represents the paraxial radius of curvature of the light source side surface of the single lens element,

N_1 represents the refractive index of the single lens element,

d_1 represents the axial thickness of the single lens element,

r_2 represents the radius of curvature of the disk side surface of the single lens element and

β represents the magnification of the single lens element.

This example of the invention is shown in FIGS. **3**, **4** and **5**.

The conditions (9) and (10) have the same meanings respectively as conditions (2) and (3) and the same aberrations as in the case of violation of the conditions (2) and (3) are generated if the upper or lower limits are violated.

Condition (11) shows the relation between the shape of the single lens element (L) and the magnification. If the magnification becomes greater beyond the upper limit of the condition (11), aberrations in the off-axial region, especially the coma become difficult to be corrected. And if the absolute value of the radius of curvature of the light source side surface (r_1) becomes greater as compared with that of the disk side surface (r_2) beyond the upper limit of condition (11), aberrations in the off-axial region, especially coma cannot be corrected

well. On the other hand, if the absolute value of the radius of curvature of the light source side surface (r_1) becomes smaller as compared with that of the disk side surface (r_2) beyond the lower limit of condition (11), coma flare is generated at the marginal ray, and it cannot be corrected well.

The disk side surface is desired to be aspherical so that the coma may be corrected well.

It is desired that conditions (9) and (10) have the following ranges respectively in order to correct abberations better.

$$1.4 \leqq (N_1-1)r_1/f \leqq 3.9 \quad (12)$$

$$1.6 \leqq d_1 r_1/f_2 \leqq 4.0 \quad (13)$$

According to the present invention the following conditions are effective instead of the above conditions (2), (3) and (4):

$$0.9 < (N_1-1)r_1/f < 3.9 \quad (14)$$

$$0.6 < r_1/r_2 \cdot (N_1-1) < 1.7 \quad (15)$$

$$0.5 < \epsilon < 1.5 \quad (16)$$

wherein, f represents the focal length of the single lens element, r_1 represents the paraxial radius of curvature of the light source side surface of the single lens element, N_1 represents the refractive index of the single lens element, r_2 represents the radius of curvature of the disk side surface of the single lens element, and ϵ represents the conic constant.

This example of the invention is shown in FIGS. 1 and 2.

Condition (14) is the same as condition (2) and has the same meaning.

Condition (15) is the condition for correcting aberrations in the off-axial region. If the refractive power of the single lens element at the predetermined focal length becomes greater than the upper limit of the condition (15), the absolute value of the radius of curvature of the disk side surface (r_2) is increased, so that the astigmatism is generated. If the ratio of the radius of curvature of the light source side surface (r_1) to that of the disk side surface (r_2) becomes greater than the upper limit of condition (15), the absolute value of the radius of curvature of the disk side surface (r_2) becomes excessively small, so that the coma is generated, which cannot be corrected well. On the other hand, if the refractive power of the single lens element becomes smaller than the lower limit of condition (15), the absolute value of the radius of curvature of the disk side surface is decreased, so that the coma is generated. And if the ratio of the radius of curvature of the light source side surface (r_1) to that of the disk side surface (r_2) decreases beyond the lower limit of condition (15), the absolute value of the radius of curvature of the disk side surface (r_2) becomes excessively great, so that the astigmatism is generated and a satisfactorily good optical performance at the desired image height cannot be obtained.

Condition (16) is the condition for correcting aberrations in off-axial region. If the conic constant becomes great beyond the upper limit of condition (16), spherical aberration undergoes under-correction especially at the marginal ray. On the other hand, if the conic constant becomes small over the lower limit of condition (16), spherical aberration undergoes over-correction, which is difficult to be corrected.

The aspherical surface of the single lens element (L) can be provided by forming an aspherical layer of grease on the spherical glass.

The following tables 1 to 18 disclose, respectively, design parameters of the first through 18th embodiments of the present invention. In the tables, f equals the focal length of the whole lens system, rg_1 and rg_2 is the radius of curvature of the light source side and disk side surface of the cover glass (G) of the semiconductor laser, r_1 and r_2 are the radii of curvature respectively of the light source side surface and the disk side surface, rp_1 and rp_2 are the radius of curvature of the light source side and disk side surface of the cover glass (P) of the disk, dg_1, dg_2, (d_0), d_1, d_2 and dp represent the axial distance including both air spaces and the actual thickness of the lens element, cover glass of the semiconductor and the disk and finally Ng, N_1, and Np represent respectively the refractive index of the cover glass of the semiconductor (G), the single lens element (L), and the cover glass of the disk (P) at the wavelength λ=800 nm. The asterisk (*) represents the aspherical surface defined as follows, and values for coefficients appearing in the formula are shown at the bottom of respective tables:

$$x = \frac{Coh^2}{1+\sqrt{1-\epsilon Coh^2}} + \Sigma c_i h^{2i} \; (i = 1,2,3,\ldots m)$$

wherein, x represents the coordinate along the optical axis measured from an imaginary plane tangent to the aspherical surface perpendicularly to the optical axis, h represents the coordinate perpendicular to the optical axis measured from the optical axis, Co represents paraxial curvature ($1/r_1$) of the light source side surface of the lens (L), ϵ represents the conic constant and c_i represent the aspherical surface coefficients. Furthermore, NA represents the numerical aperture of the objective lens system, and β represents the magnification.

Among the following embodiments, it should be noted that the paraxial curvature ($Co=1/r_1$) of the aspherical surface is zero in the first to third embodiments. This is favorable to a test or measurement of the formed shape of the aspherical surface in manufacturing, since the paraxial curvature can be left out of consideration.

TABLE 1

[Embodiment 1]

NA = 0.47 f = 1.0 β = −0.17

	radius of curvature	axial distance	refractive index
rg_1	∞		
		dg_1 0.067	Ng 1.49000
rg_2	∞		
		dg_2 6.643	
r_1*	1.2686		
		d_1 1.356	N_1 2.10000
r_2*	−3.6447		
		d_2 0.440	
rp_1	∞		
		dp 0.267	Np 1.57147
rp_2	∞		

aspherical surface coefficients

r_1* ϵ = 1.0
C_1 = 0.0 $C_2 = -0.62371 \times 10^{-1}$ $C_3 = -0.35855 \times 10^{-1}$
$C_4 = -0.34573 \times 10^{-1}$ $C_5 = -0.10152 \times 10^{-2}$

r_2* ϵ = 1.0
C_1 = 0.0 $C_2 = 0.94476 \times 10^{-1}$ $C_3 = -0.31391$
$C_4 = -0.34388 \times 10^{-4}$ $C_5 = 0.26302 \times 10^{-4}$

$(N_1 - 1)r_1/f = 1.47$
$d_1 r_1/f^2 = 1.73$

TABLE 1-continued

[Embodiment 1]

NA = 0.47 f = 1.0 $\beta = -0.17$

$d_1^2/f^2(N_1 - 1) = 1.68$

$f(N_1^2 - N_1 - 1)/|r_2| = 0.36$

$r_1(N_1 - 1)(1 + |\beta|)/-r_2 = 0.45$

$\frac{r_1}{-r_2} \cdot (N_1 - 1) = 1.0$

$\epsilon = 0.38$

TABLE 2

[Embodiment 2]

NA = 0.47 f = 1.0 $\beta = -0.17$

	radius of curvature	axial distance	refractive index
rg_1	∞		
		dg_1 0.067	Ng 1.49000
rg_2	∞		
		dg_2 6.450	
ra*	1.6576		
		d_0 0.007	N_0 1.51539
r_1	1.6576		
		d_1 1.422	N_1 2.14000
r_2	−1.9751		
		d_2 0.540	
rp_1	∞		Np 1.57147
		dp 0.267	
rp_2	∞		

aspherical surface coefficients

ra* $\epsilon = 1.0$

$C_1 = 0.0$ $C_2 = -0.20762$ $C_3 = -0.13173$

$C_4 = -0.64485 \times 10^{-1}$ $C_5 = -0.36803 \times 10^{-2}$

$(N_1 - 1)r_1/f = 1.89$

$d_1r_1/f^2 = 2.36$

$d_1^2/f^2(N_1 - 1) = 1.77$

$f(N_1^2 - N_1 - 1)/|r_2| = 0.73$

$r_1(N_1 - 1)(1 + |\beta|)/-r_2 = 1.12$

$\frac{r_1}{-r_2} \cdot (N_1 - 1) = 1.0$

$\epsilon = 0.96$

TABLE 3

[Embodiment 3]

NA = 0.47 f = 1.0 $\beta = -0.17$

	radius of curvature	axial distance	refractive index
rg_1	∞		
		dg_1 0.067	N_g 1.49000
rg_2	∞		
		dg_2 6.454	
r_1*	1.6617		
		d_1 1.422	N_1 2.14000
r_2	−1.9756		
		d_2 0.542	
rp_1	∞		
		d_p 0.267	Np 1.57147
rp_2	∞		

aspherical surface coefficients

r_1* $\epsilon = 1.0$

$C_1 = 0.0$ $C_2 = -0.96367 \times 10^{-1}$ $C_3 = -0.48541 \times 10^{-1}$

$C_4 = -0.57170 \times 10^{-1}$ $C_5 = -0.34961 \times 10^{-2}$

$(N_1 - 1)r_1/f = 1.89$

$d_1r_1/f_2 = 2.36$

$d_1^2/f^2(N_1 - 1) = 1.77$

$f(N_1^2 - N_1 - 1)/|r_2| = 0.73$

$r_1(N_1 - 1)(1 + |\beta|/-r_2 = 1.12$

$\frac{r_1}{-r_2} \cdot (N_1 - 1) = 1.0$

$\epsilon = 0.96$

TABLE 4

[Embodiment 4]

NA = 0.47 f = 1.0 $\beta = -0.17$

	radius of curvature	axial distance	refractive index
rg_1	∞		
		dg_1 0.067	Ng 1.49000
rg_2	∞		
		dg_2 6.502	
r_1*	1.7487		
		d_1 1.700	N_1 2.39000
r_2	−2.9453		
		d_2 0.435	
rp_1	∞		
		dp 0.267	Np 1.57147
rp_2	∞		

aspherical surface coefficients

r_1* $\epsilon = 1.0$

$C_1 = 0.0$ $C_2 = -0.51488 \times 10^{-1}$ $C_3 = -0.26625 \times 10^{-1}$

$C_4 = -0.11890 \times 10^{-1}$ $C_5 = 0.69239 \times 10^{-3}$

$(N_1 - 1)r_1/f = 2.43$

$d_1r_1/f^2 = 2.97$

$d_1^2/f^2(N_1 - 1) = 2.08$

$f(N_1^2 - N_1 - 1)/|r_2| = 0.79$

$r_1(N_1 - 1)(1 + |\beta|)/-r_2 = 0.97$

$\frac{r_1}{-r_2} \cdot (N_1 - 1) = 1.0$

$\epsilon = 0.83$

TABLE 5

[Embodiment 5]

NA = 0.47 f = 1.0 $\beta = -0.22$

	radius curvature	axial distance	refractive index
rg_1	∞		
		dg_1 0.067	Ng 1.49000
rg_2	∞		
		dg_2 5.271	
r_1*	1.2502		
		d_1 1.333	N_1 2.05000
r_2	−2.9756		
		d_2 0.504	
rp_1	∞		
		dp 0.267	Np 1.57147
rp_2	∞		

aspherical surface coefficients

r_1* $\epsilon = 1.0$

$C_1 = 0.0$ $C_2 = -0.71690 \times 10^{-1}$ $C_3 = -0.29855 \times 10^{-1}$

$C_4 = -0.50256 \times 10^{-1}$ $C_5 = -0.16435 \times 10^{-2}$

r_2* $\epsilon = 1.0$

$C_1 = 0.0$ $C_2 = 0.13636$ $C_3 = -0.32847$

$C_4 = 0.57220 \times 10^{-3}$ $C_5 = 0.36914 \times 10^{-4}$

$(N_1 - 1)r_1/f = 1.31$

$d_1r_1/f^2 = 1.66$

$d_1^2/f^2(N_1 - 1) = 1.68$

$f(N_1^2 - N_1 - 1)/|r_1^2| = 0.39$

$r_1(N_1 - 1)(1 + |\beta|)/-r_2 = 0.54$

$\frac{r_1}{-r_2} \cdot (N_1 - 1) = 1.0$

$\epsilon = 0.44$

TABLE 6

[Embodiment 6]

NA = 0.47 f = 1.0 $\beta = -0.22$

	radius curvature	axial distance	refractive index
rg_1	∞		
		dg_1 0.067	Ng 1.49000
rg_2	∞		
		dg_2 5.293	
ra*	1.2169		
		d_0 0.007	N_0 1.51539
r_1	1.2169		
		d_1 1.333	N_1 2.05000

TABLE 6-continued

[Embodiment 6]

NA = 0.47 f = 1.0 β = −0.22

r_2^* −3.3292

d_2 0.487

r_{p1} ∞

dp 0.267 Np 1.57147

r_{p2} ∞

aspherical surface coefficients

$r_a^* \epsilon = 1.0$

$C_1 = 0.0$ $C_2 = -0.14089$ $C_3 = -0.57431 \times 10^{-1}$

$C_4 = -0.56260 \times 10^{-1}$ $C_5 = -0.18309 \times 10^{-2}$

$r_2^* \epsilon = 1.0$

$C_1 = 0.0$ $C_2 = 0.14537$ $C_3 = -0.31199$

$C_4 = 0.95588 \times 10^{-3}$ $C_5 = 0.40854 \times 10^{-4}$

$(N_1 - 1)r_1/f = 1.25$

$d_1r_1/f_2 = 1.62$

$d_1^2/f^2(N_1 - 1) = 1.68$

$f(N_1^2 - N_1 - 1)/|r^2| = 0.35$

$r_1(N_1 - 1)(1 + |\beta|/-r_2 = 0.47$

$\frac{r_1}{-r_2} \cdot (N_1 - 1) = 1.0$

$\epsilon = 0.38$

TABLE 7

[Embodiment 7]

NA = 0.47 f = 1.0 β = −0.38

radius of curvature		axial distance		refractive index
r_{g1}	∞			
		d_{g1} 0.067	Ng	1.49000
r_{g2}	∞			
		d_{g2} 3.262		
r_1^*	1.2610			
		d_1 1.289	N_1	1.95000
r_2^*	−1.9338			
		d_2 0.712		
r_{p1}	∞			
		dp 0.267	Np	1.57147
r_{p2}	∞			

aspherical surface coefficients

$r_1^* \epsilon = 1.0$

$C_1 = 0.0$ $C_2 = -0.10852$ $C_3 = -0.16503 \times 10^{-1}$

$C_4 = -0.58946 \times 10^{-1}$ $C_5 = -0.35616 \times 10^{-2}$

$r_2^* \epsilon = 1.0$

$C_1 = 0.0$ $C_2 = 0.15569$ $C_3 = -0.18428$

$C_4 = 0.19846 \times 10^{-1}$ $C_5 = 0.56733 \times 10^{-3}$

$(N_1 - 1)r_1/f = 1.20$

$d_1r_1/f^2 = 1.63$

$d_1^2/f^2(N_1 - 1) = 1.75$

$f(N_1^2 - N_1 - 1)/|r_2| = 0.44$

$r_1(N_1 - 1)(1 + |\beta|/-r_2 = 0.85$

$\frac{r_1}{-r_2} \cdot (N_1 - 1) = 1.0$

$\epsilon = 0.62$

TABLE 8

[Embodiment 8]

NA = 0.47 f = 1.0 β = −0.45

radius of curvature		axial distance		refractive index
r_{g1}	∞			
		d_{g1} 0.067	Ng	1.49000
r_{g2}	∞			
		d_{g2} 2.798		
r_1^*	1.2955			
		d_1 1.267	N_1	1.90000
r_2^*	−1.5827			
		d_2 0.817		
r_{p1}	∞			
		dp 0.267	Np	1.57147
r_{p2}	∞			

aspherical surface coefficients

$r_1^* \epsilon = 1.0$

$C_1 = 0.0$ $C_2 = -0.13844$ $C_3 = -0.12271 \times 10^{-1}$

TABLE 8-continued

[Embodiment 8]

NA = 0.47 f = 1.0 β = −0.45

$C_4 = -0.83257 \times 10^{-1}$ $C_5 = -0.58614 \times 10^{-2}$

$r_2^* \epsilon = 1.0$

$C_1 = 0.0$ $C_2 = 0.15549$ $C_3 = -0.17051$

$C_4 = 0.49442 \times 10^{-1}$ $C_5 = 0.16965 \times 10^{-2}$

$(N_1 - 1)r_1/f = 1.17$

$d_1r_1/f^2 = 1.65$

$d_1^2/f^2(N_1 - 1) = 1.79$

$f(N_1^2 - N_1 - 1)/|r_2| = 0.45$

$r_1(N_1 - 1)(1 + |\beta|/-r_2 = 1.07$

$\frac{r_1}{-r_2} \cdot (N_1 - 1) = 1.0$

$\epsilon = 0.74$

TABLE 9

[Embodiment 9]

NA = 0.49 f = 1 β = −0.17

radius of curvature		axial distance		refractive index
r_{g1}	∞			
		d_{g1} 0.125	Ng	1.49000
r_{g2}	∞			
		d_{g2} 6.474		
r_1^*	1.6060			
		d_1 1.333	N_1	2.14000
r_2	−2.1913			
		d_2 0.408		
r_{p1}	∞			
		dp 0.500	Np	1.57147
r_{p2}	∞			

aspherical surface coefficients

$r_1^* = 1.0$

$C_1 = 0.0$ $C_2 = -0.871129 \times 10^{-1}$ $C_3 = -0.316098 \times 10^{-1}$

$C_4 = -0.571065 \times 10^{-1}$ $C_5 = -0.349594 \times 10^{-2}$

$(N_1 - 1)r_1/f = 1.83$

$d_1r_1/f^2 = 2.14$

$d_1^2/f^2(N_1 - 1) = 1.55$

$f(N_1^2 - N_1 - 1)/|r_2| = 0.66$

$r_1(N_1 - 1)(1 + |\beta|)/-r_2 = 0.98$

$\frac{r_1}{-r_2} \cdot (N_1 - 1) = 1.0$

$\epsilon = 0.84$

TABLE 10

[Embodiment 10]

NA = 0.47 f = 1 β = −0.17

radius of curvature		axial distance		refractive index
r_{g1}	∞			
		d_{g1} 0.083	Ng	1.49000
r_{g2}	∞			
		d_{g2} 6.537		
r_1^*	1.4224			
		d_1 1.278	N_1	2.06500
r_2	−2.2750			
		d_2 0.494		
r_{p1}	∞			
		dp 0.333	Np	1.57147
r_{p2}	∞			

aspherical surface coefficients

$r_1^* = 1.0$

$C_1 = 0.0$ $C_2 = -0.906604 \times 10^{-1}$ $C_3 = -0.633411 \times 10^{-1}$

$C_4 = -0.149674 \times 10^{-1}$ $C_5 = -0.177734 \times 10^{-3}$

$(N_1 - 1)r_1/f = 1.51$

$d_1r_1/f^2 = 1.82$

$d_1^2/f^2(N_1 - 1) = 1.54$

$f(N_1^2 - N_1 - 1)/|r_2| = 0.53$

$r_1(N_1 - 1)(1 + |\beta|)/-r_2 = 0.78$

$\frac{r_1}{-r_2} \cdot (N_1 - 1) = 0.67$

$\epsilon = 1.0$

TABLE 11

[Embodiment 11]

NA = 0.47 f = 1.0 β = −0.22

	radius of curvature		axial distance		refractive index
	r_{g1}	∞			
			dg_1 0.067	Ng	1.49000
	r_{g2}	∞			
			dg_2 4.752		
	r_1*	1.4015			
			d_1 1.911	N_1	2.06500
	r_2*	−1.3162			
			d_2 0.347		
	r_{p1}	∞			
			dp 0.267	Np	1.57147
	r_{p2}	∞			

aspherical surface coefficients

r_1* ϵ = 1.0
C_1 = 0.0 $C_2 = -0.702213 \times 10^{-1}$ $C_3 = -0.397707 \times 10^{-1}$
$C_4 = -0.256511 \times 10^{-1}$ $C_5 = -0.810222 \times 10^{-2}$
r_2* ϵ = 1.0
C_1 = 0.0 C_2 = 0.571793 C_3 = −1.278405
$C_4 = 0.286478 \times 10^{-2}$ $C_5 = 0.974928 \times 10^{-4}$
$(N_1 - 1)r_1/f$ = 1.49
d_1r_1/f^2 = 2.68
$d_1^2/f^2(N_1 - 1)$ = 3.43
$f(N_1^2 - N_1 - 1)/|r_2|$ = 0.91
$r_1(N_1 - 1)(1 + |\beta|)/-r_2$ = 1.13
$\frac{r_1}{-r_2} \cdot (N_1 - 1)$ = 1.38
ϵ = 1.0

TABLE 12

[Embodiment 12]

Na = 0.45 f = 1.0 β = −0.17

	radius of curvature		axial distance		refractive index
	r_{g1}	∞			
			dg_1 0.094	Ng	1.49000
	r_{g2}	∞			
			dg_2 6.340		
	r_1*	2.2222			
			d_1 1.700	N_1	2.39000
	r_2	−2.0603			
			d_2 0.487		
	r_{p1}	∞			
			dp 0.375	Np	1.57222
	r_{p2}	∞			

aspherical surface coefficients

r_1* ϵ = 1.0
C_1 = 0.0 $C_2 = -0.759242 \times 10^{-1}$ $C_3 = -0.484883 \times 10^{-1}$
$C_4 = -0.330197 \times 10^{-1}$ $C_5 = -0.443189 \times 10^{-2}$
$(N_1 - 1)r_1/f$ = 3.09
d_1r_1/f^2 = 3.78
$d_1^2/f^2(N_1 - 1)$ = 2.08
$f(N_1^2 - N_1 - 1)/|r_2|$ = 1.13
$r_1(N_1 - 1)(1 + |\beta|)/-r_2$ = 1.76
$\frac{r_1}{-r_2} \cdot (N_1 - 1)$ = 1.50
ϵ = 1.0

TABLE 13

[Embodiment 13]

NA = 0.45 f = 1.0 β = −0.20

	radius of curvature		axial distance		refractive index
	r_{g1}	∞			
			dg_1 0.077	Ng	1.49000
	r_{g2}	∞			
			dg_2 5.615		
	ra*	1.1758			
			do 0.008	No	1.51509
	r_1	1.3811			
			d_1 1.031	N_1	1.79215
	r_2	−1.3811			
			d_1 0.636		
	r_{p1}	∞			
			dp 0.306	Np	1.57222
	r_{p2}	∞			

aspherical surface coefficients

r_1* ϵ = 0.55
C_1 = 0.0 C_2 = −0.292694 C_3 = −0.228172
C_4 = −0.223349 $C_5 = -0.351381 \times 10^{-2}$
$(N_1 - 1)r_1/f$ = 0.93
d_1r_1/f^2 = 1.22
$d_1^2/f^2(N_1 - 1)$ = 1.36
$f(N_1^2 - N_1 - 1)/|r_2|$ = 0.30
$r_1(N_1 - 1)(1 + |\beta|)/-r_2$ = 0.81
$\frac{r_1}{-r_2} \cdot (N_1 - 1)$ = 0.67
ϵ = 0.55

TABLE 14

[Embodiment 14]

NA = 0.45 f = 1.0 β = −0.84

	radius of curvature		axial distance		refractive index
	r_{g1}	∞			
			dg_1 0.066	Ng	1.49000
	r_{g2}	∞			
			dg_2 1.672		
	r_1*	1.1384			
			d_1 1.890	N_1	2.05000
	r_2*	−2.0223			
			d_2 0.819		
	r_{p1}	∞			
			dp 0.264	Np	1.57147
	r_{p2}	∞			

aspherical surface coefficients

r_1* ϵ = 1.0
C_1 = 0.0 C_2 = −0.144466 $C_3 = 0.412891 \times 10^{-1}$
$C_4 = -0.339208 \times 10^{-1}$ $C_5 = -0.236439 \times 10^{-1}$
r_2* ϵ = 1.0
C_1 = 0.0 C_2 = 0.327563 $C_3 = 0.575198 \times 10^{-1}$
$C_4 = 0.956025 \times 10^{-1}$ $C_5 = 0.328127 \times 10^{-2}$
$(N_1 - 1)r_1/f$ = 1.20
d_1r_1/f^2 = 2.15
$d_1^2/f^2(N_1 - 1)$ = 3.40
$f(N_1^2 - N_1 - 1)/|r_2|$ = 0.57
$r_1(N_1 - 1)(1 + |\beta|)/-r_2$ = 1.09
$\frac{r_1}{-r_2} \cdot (N_1 - 1)$ = 0.59
ϵ = 1.0

TABLE 15

[Embodiment 15]

NA = 0.63 f = 1.0 β = −0.23

	radius of curvature		axial distance		refractive index
	r_{g1}	∞			
			dg_1 0.067	Ng	1.49000
	r_{g2}	∞			
			dg_2 4.757		
	r_1*	1.2866			
			d_1 1.667	N_1	2.00000
	r_2*	−1.5815			
			d_2 0.414		
	r_{p1}	∞			
			dp 0.267	Np	1.57147
	r_{p2}	∞			

aspherical surface coefficients

r_1* ϵ = 1.0
C_1 = 0.0 $C_2 = -0.803740 \times 10^{-1}$ $C_3 = -0.418108 \times 10^{-1}$
$C_4 = -0.584431 \times 10^{-2}$ $C_5 = -0.609765 \times 10^{-1}$
r_2* ϵ = 1.0
C_1 = 0.0 C_2 = 0.380735 C_3 = −0.904315

TABLE 15-continued

[Embodiment 15]

NA = 0.63 f = 1.0 β = −0.23

$C_4 = 0.909523$ $C_5 = 0.201477 \times 10^{-1}$

$(N_1 - 1)r_1/f = 1.29$

$d_1r_1/f^2 = 2.14$

$d_1^2/f^2(N_1 - 1) = 2.78$

$f(N_1^2 - N_1 - 1)/|r_2| = 0.63$

$r_1(N_1 - 1)(1 + |\beta|)/-r_2 = 1.00$

$\frac{r_1}{-r_2} \cdot (N_1 - 1) = 0.81$

$\epsilon = 1.0$

TABLE 16

[Embodiment 16]

NA = 0.75 f = 1.0 β = −0.23

	radius of curvature	axial distance	refractive index
rg_1	∞		
		dg_1 0.067	Ng 1.49000
rg_2	∞		
		dg_2 4.503	
r_1*	1.4099		
		d_1 2.044	N_1 2.15000
r_2*	−1.4000		
		d_2 0.286	
rp_1	∞		
		dp 0.267	Np 1.57147
rp_2	∞		

aspherical surface coefficients

$r_1^* \epsilon = 1.0$

$C_1 = 0.0$ $C_2 = -0.611556 \times 10^{-1}$ $C_3 = -0.587792 \times 10^{-1}$

$C_4 = 0.850492 \times 10^{-1}$ $C_5 = -0.1018804$

$r_2^* \epsilon = 1.0$

$C_1 = 0.0$ $C_2 = 0.566623$ $C_3 = -1.17033$

$C_4 = 1.02242$ $C_5 = 0.22239 \times 10^{-1}$

$(N_1 - 1)r_1/f = 1.62$

$d_1r_1/f^2 = 2.88$

$d_1^2/f^2(N_1 - 1) = 3.63$

$f(N_1^2 - N_1 - 1)/|r_2| = 1.05$

$r_1(N_1 - 1)(1 + |\beta|)/-r_2 = 1.43$

$\frac{r_1}{-r_2} \cdot (N_1 - 1) = 1.16$

$\epsilon = 1.0$

TABLE 17

[Embodiment 17]

NA = 0.47 f = 1.0 β = −0.23

	radius of curvature	axial distance	refractive index
rg_1	∞		
		dg_1 0.067	Ng 1.49000
rg_2	∞		
		dg_2 4.806	
r_1*	1.1969		
		d_1 1.300	N_1 1.78650
r_2*	−1.1969		
		d_2 0.583	
rp_1	∞		
		d_p 0.267	Np 1.57147
rp_2	∞		

aspherical surface coefficients

$r_1^* \epsilon = -5.0$

$C_1 = 0.0$ $C_2 = 0.276720$ $C_3 = -0.570105$

$C_4 = 0.260641$ $C_5 = -0.582865 \times 10^{-1}$

$r_2^* \epsilon = 0.4$

$C_1 = 0.0$ $C_2 = 0.288344$ $C_3 = -0.853167$

$C_4 = 1.12124$ $C_5 = 0.272954 \times 10^{-1}$

$(N_1 - 1)r_1/f = 0.94$

$d_1r_1/f^2 = 1.56$

$d_1^2/f^2(N_1 - 1) = 2.15$

$f(N_1^2 - N_1 - 1)/|r_2| = 0.34$

$r_1(N_1 - 1)(1 + |\beta|)/-r_2 = 0.97$

TABLE 17-continued

[Embodiment 17]

NA = 0.47 f = 1.0 β = −0.23

$\frac{r_1}{-r_2} \cdot (N_1 - 1) = 0.79$

$\epsilon = -5.0$

TABLE 18

[Embodiment 18]

NA = 0.47 f = 1.0 β = −0.23

	radius of curvature	axial distance	refractive index
rg_1	∞		
		dg_1 0.067	Ng 1.49000
rg_2	∞		
		dg_2 4.806	
r_1*	1.1969		
		d_1 1.300	N_1 1.78650
r_2*	−1.1969		
		d_2 0.583	
rp_1	∞		
		dp 0.267	Np 1.57147
rp_2	∞		

aspherical surface coefficients

$r_1^* \epsilon = 3.0$

$C_1 = 0.0$ $C_2 = -0.292512$ $C_3 = -0.504495$

$C_4 = 0.800770$ $C_5 = -3.24710$

$r_2^* \epsilon = 4.0$

$C_1 = 0.0$ $C_2 = 0.522586$ $C_3 = -0.288872$

$C_4 = 1.73011$ $C_5 = 1.82717$

$(N_1 - 1)r_1/f = 0.94$

$d_1r_1/f^2 = 1.56$

$d_1^2/f^2(N_1 - 1) = 2.15$

$f(N1^2 - N_1 - 1)/|r_2| = 0.34$

$r_1(N_1 - 1)(1 + |\beta|)/-r_2 = 0.97$

$\frac{r_1}{-r_2} \cdot (N_1 - 1) = 0.79$

$\epsilon = 3.0$

What is claimed is:

1. An objective lens system with a single lens element for use in a device for optically reading digital data on an optical disk, said single lens element including:

a light source side aspherical surface having a positive refractive power; and

a disk side surface having a positive refractive power; and wherein

said objective lens system is used with the projecting magnification β, $-\frac{1}{2} < \beta < -\frac{1}{8}$ and the objective lens system fulfills the following conditions:

$$0.9 \leqq (N_1 - 1)r_1/f \leqq 3.9$$

$$1.4 \leqq d_1r_1/f^2 \leqq 4.0$$

$$1.4 \leqq d_1^2/f^2(N_1 - 1) \leqq 4.0$$

wherein:

f represents the focal length of the single lens element;

r_1 represents the paraxial radius of curvature of the light source side surface of the single lens element;

N_1 represents the refractive index of the single lens element; and

d_1 represents the axial thickness of the single lens element.

2. An objective lens system as claimed in claim 1, wherein said disk side surface is an aspherical surface.

3. An objective lens system as claimed in claim 2, wherein the objective lens system further fulfills the following condition:

$$0 \leqq f(N_1^2 - N_1 - 1)/|r_2| \leqq 1.2$$

wherein:

r_2 represents the radius of curvature of the disk side surface of the single lens element.

4. An objective lens system with a single lens element for use in a device for optically reading digital data on an optical disk;

said single lens element including:

a light source side aspherical surface having a positive refractive power; and

a disk side surface having a positive refractive power; and wherein

said objective lens system is used with the projecting magnification β, $-\frac{1}{2} < \beta < -\frac{1}{8}$ and the objective lens system fulfills the following conditions:

$$1.4 \leqq (N_1 - 1)r_1/f \leqq 3.9$$

$$1.6 \leqq d_1 r_1/f^2 \leqq 4.0$$

wherein:

f represents the focal length of the single lens element;

r_1 represents the paraxial radius of curvature of the light source side surface of the single lens element;

N_1 represents the refractive index of the single lens element; and

d_1 represents the axial thickness of the single lens element.

5. An objective lens system as claimed in claim 4, wherein the objective lens system further fulfills the following condition:

$$0 \leqq f(N_1^2 - N_1 - 1)/|r_2| \leqq 1.2$$

wherein:

r_2 represents the radius of curvature of the disk side surface of the single lens element.

6. An objective lens system with a single lens element for use in a device for optically reading digital data on an optical disk, said single lens element including:

a light source side aspherical surface having a positive refractive power; and

a disk side surface having a positive refractive power; and wherein the objective lens system fulfills the following conditions:

$$0.9 \leqq (N_1 - 1)r_1/f \leqq 3.9$$

$$1.2 \leqq d_1 r_1/f^2 \leqq 4.0$$

$$0.7 \leqq r_1(N_1 - 1)(1 + |\beta|)/-r_2 = 3.0$$

wherein:

f represents the focal length of the single lens element;

r_1 represents the paraxial radius of curvature of the light source side surface of the single lens element;

N_1 represents the refractive index of the single lens element;

d_1 represents the axial thickness of the single lens element;

r_2 represents the radius of curvature of the disk side surface of the single lens component; and

β represents the magnification of the single lens element.

7. An objective lens system as claimed in claim 6, wherein said disk side surface is an aspherical surface.

8. An objective lens system as claimed in claim 6, herein the objective lens system further fulfills the following conditions:

$$1.4 \leqq (N_1 - 1)r_1/f \leqq 3.9$$

$$1.6 \leqq d_1 r_1/f^2 \leqq 4.0.$$

9. An objective lens system with a single lens element for use in a device for optically reading digital data on an optical disk, said single lens element including:

a light source side aspherical surface having a positive refractive power; and

a disk side surface having a positive refractive power; and wherein

said objective lens system is used with the projecting magnification β, $-\frac{1}{2} < \beta < -\frac{1}{8}$ and wherein the objective lens system fulfills the following conditions:

$$0.9 < (N_1 - 1)r_1/f < 3.9$$

$$0.6 < r_1/-r_2 \cdot (N_1 - 1) < 1.7$$

$$0.5 < \epsilon < 1.5$$

wherein:

f represents the focal length of the single lens element;

r_1 represents the paraxial radius of curvature of the light source side surface of the single lens element;

N_1 represents the refractive index of the single lens element;

r_2 represents the radius of curvature of the disk side surface of the single lens element; and

ϵ represents the conic constant.

10. An objective lens system with a single lens element for a device for optically reading digital data on an optical disk, comprising the following design parameters:

NA = 0.47 f = 1.0 β = −0.17

radius of curvature		axial distance		refractive index	
rg_1	∞				
		dg_1	0.067	Ng	1.49000
rg_2	∞				
		dg_2	6.643		
r_1*	1.2686				
		d_1	1.356	N_1	2.10000
r_2*	−3.6447				
		d_2	0.440		
rp_1	∞				
		d_p	0.267	Np	1.57147
rp_2	∞				

aspherical surface coefficients

r_1* ϵ = 1.0
C_1 = 0.0 $C_2 = -0.62371 \times 10^{-1}$ $C_3 = -0.35855 \times 10^{-1}$
$C_4 = -0.34573 \times 10^{-1}$ $C_5 = -0.10152 \times 10^{-2}$

r_2* ϵ = 1.0
C_1 = 0.0 $C_2 = 0.94476 \times 10^{-1}$ $C_3 = -0.31391$
$C_4 = -0.34388 \times 10^{-4}$ $C_5 = 0.26302 \times 10^{-4}$

wherein NA is the numerical aperture, f is the focal length, β is the magnification, subletter g refers to a cover glass, subletter p refers to a plate glass, and the aspherical surface is defined as follows:

$$x = \frac{Coh^2}{1 \times 1 - \sqrt{Coh^2}} + \Sigma c_i h^{2i} \ (i = 1,2,3, \ldots m)$$

wherein, x represents a coordinate along the optical axis measured from an imaginary plane tangent to the aspherical surface perpendicularly to an optical axis, h represents the coordinate perpendicular to the optical axis measured from the optical axis, Co represents paraxial curvature ($1/r_1$) of the light source side surface of the lens (L), ϵ represents the conic constant and c_i represents the aspherical surface coefficients.

* * * * *

United States Patent [19]

Yokota

[11] Patent Number: 4,764,001

[45] Date of Patent: Aug. 16, 1988

[54] **RETROFOCUS-TYPE OBJECTIVE FOR AN ENDOSCOPE**

[75] Inventor: **Akira Yokota**, Tokyo, Japan

[73] Assignee: **Olympus Optical Co., Ltd.**, Tokyo, Japan

[21] Appl. No.: **127,256**

[22] Filed: **Dec. 1, 1987**

Related U.S. Application Data

[63] Continuation of Ser. No. 743,356, Jun. 10, 1985.

[30] **Foreign Application Priority Data**

Jun. 13, 1984 [JP] Japan 59-119936

[51] **Int. Cl.**[4] **G02B 9/60**

[52] **U.S. Cl.** **350/465**; 350/462

[58] **Field of Search** 350/462, 465, 450, 96.26

[56] References Cited

U.S. PATENT DOCUMENTS

4,403,837 9/1983 Nakahashi 350/465

Primary Examiner—John K. Corbin
Assistant Examiner—P. M. Dzierzynski
Attorney, Agent, or Firm—Cushman, Darby & Cushman

[57] **ABSTRACT**

A retrofocus-type objective for an endoscope which comprises a first lens component comprising a negative lens, a stop, a second lens component comprising a positive meniscus lens, a third lens component comprising a positive lens, a fourth lens component comprising a cemented doublet which consists of a positive lens and a negative lens, and a fifth lens component comprising positive lens, the retrofocus-type objective for an endoscope being arranged to be focused by advancing the third and fourth lens components.

5 Claims, 7 Drawing Sheets

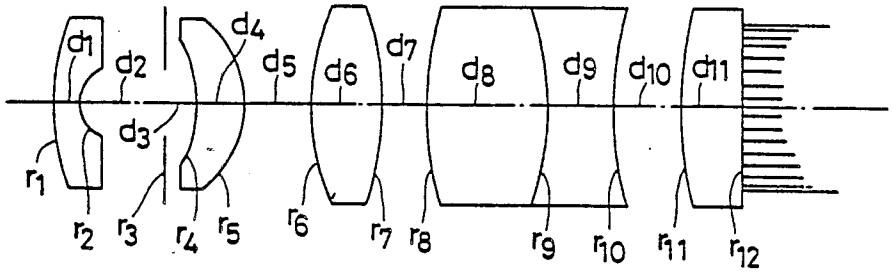


FIG. 1

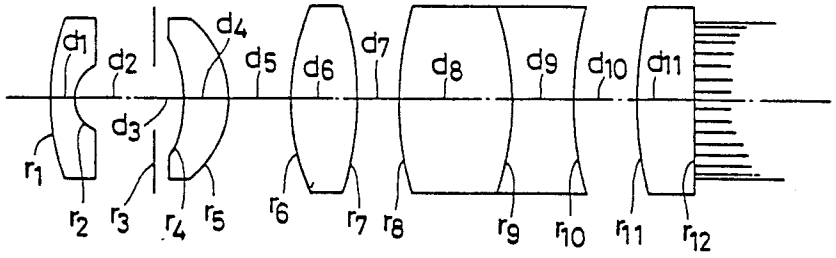
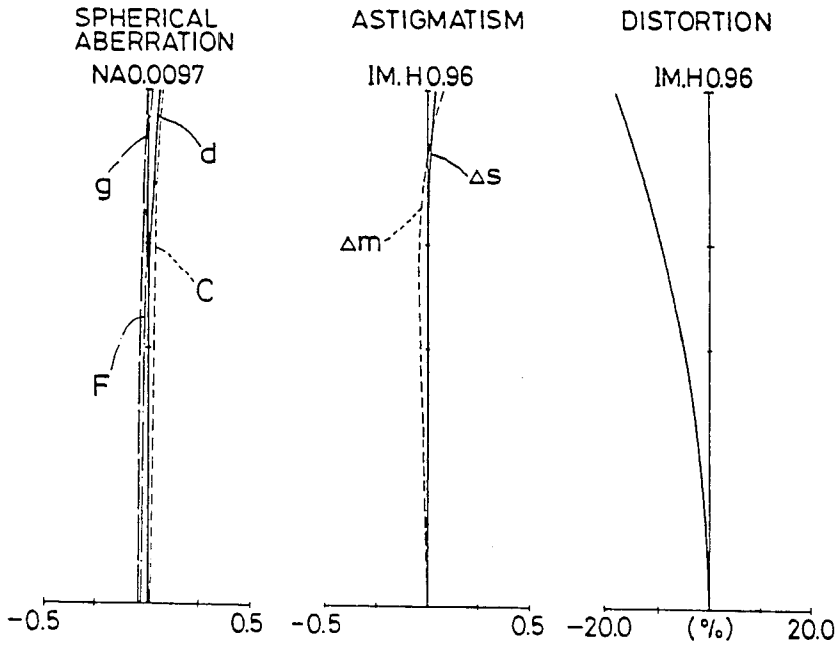

d1
d2
d3
d4
d5
d6
d7
d8
d9
d10
d11
r1
r2
r3
r4
r5
r6
r7
r8
r9
r10
r11
r12

FIG. 2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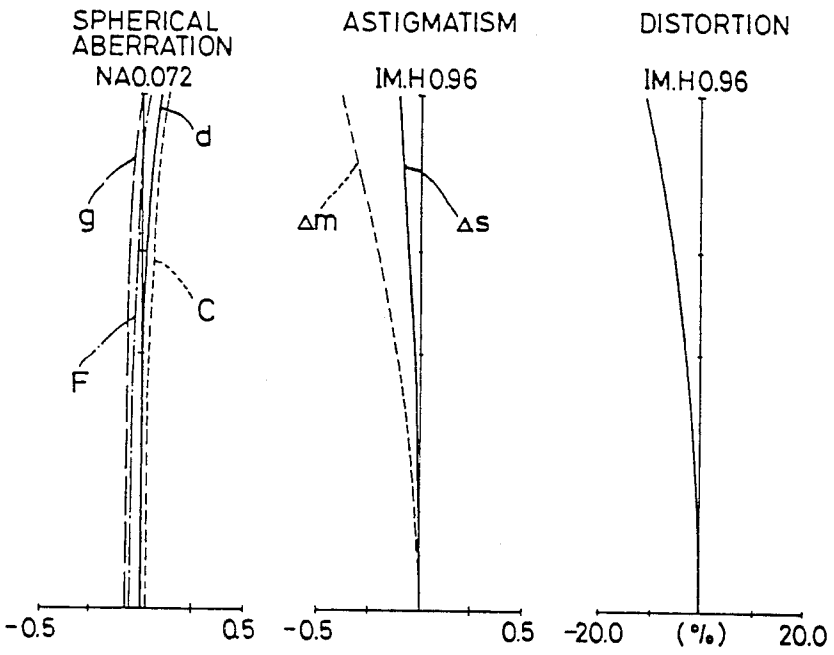
NA0.0097
g
d
C
F
-0.5
0.5
ASTIGMATISM
IM.H0.96
ΔS
Δm
-0.5
0.5
DISTORTION
IM.H0.96
-20.0
(%)
20.0

FIG. 3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Δs
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DISTORTION
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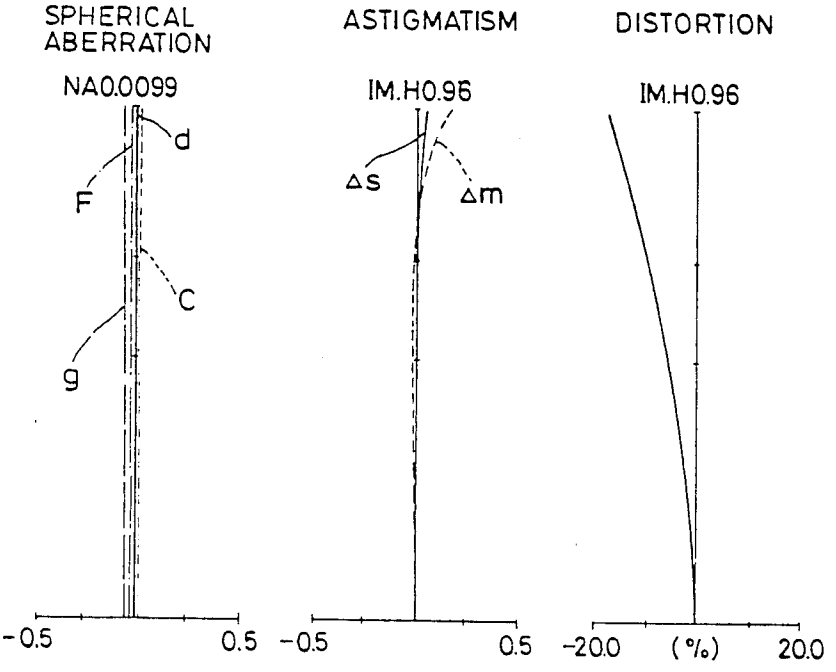
-20.0
(%)
20.0

FIG. 4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Δm
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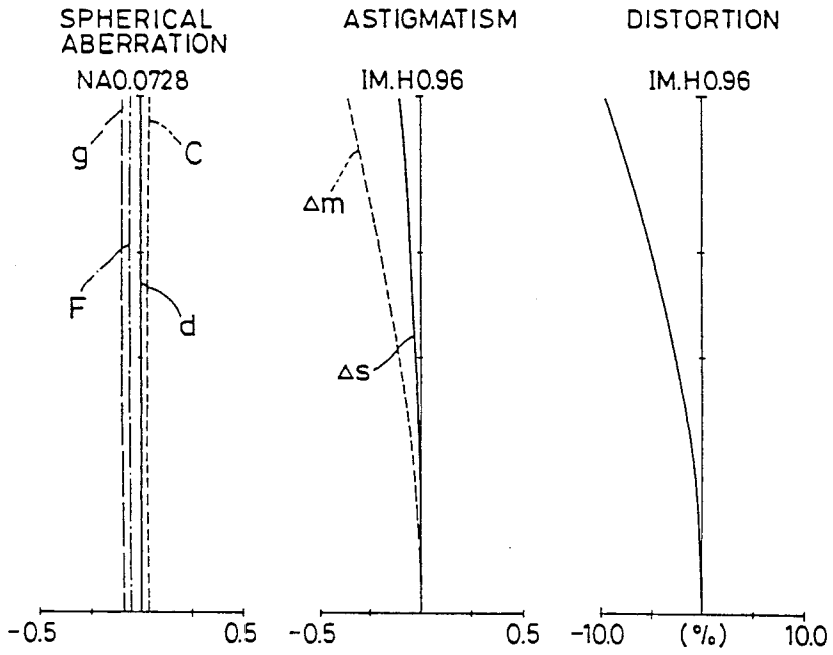
DISTORTION
IM.H0.96
-20.0
(%)
20.0

FIG. 5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F
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Δs
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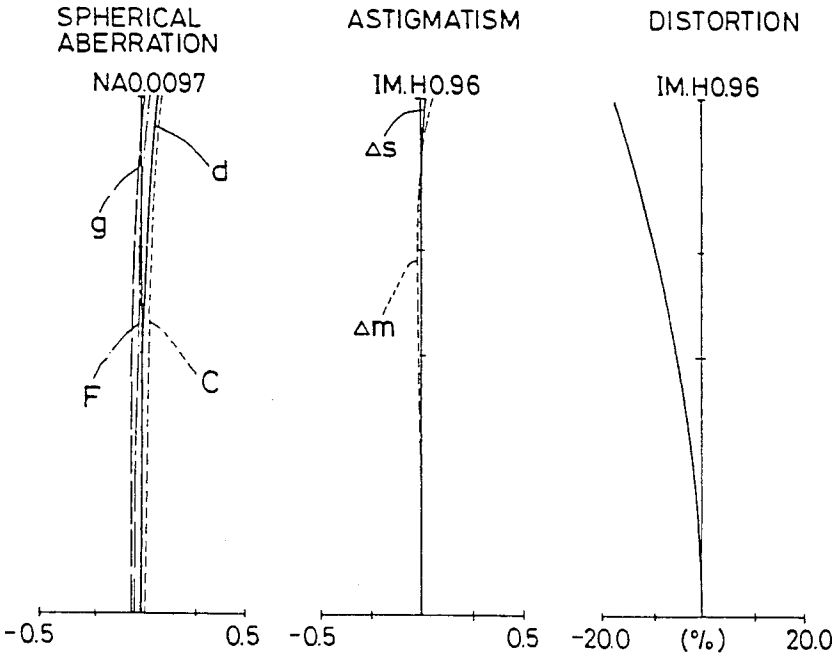
0.5
DISTORTION
IM.H0.96
-10.0
(%)
10.0

FIG. 6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g
F
C
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0.5
ASTIGMATISM
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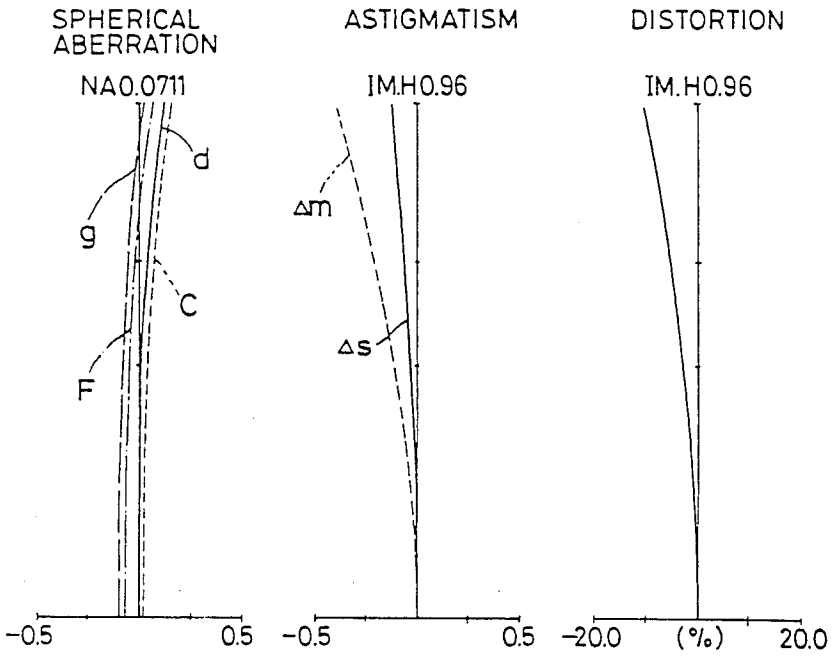
Δs
Δm
-0.5
0.5
DISTORTION
IM.H0.96
-20.0
(%)
20.0

FIG. 7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ASTIGMATISM
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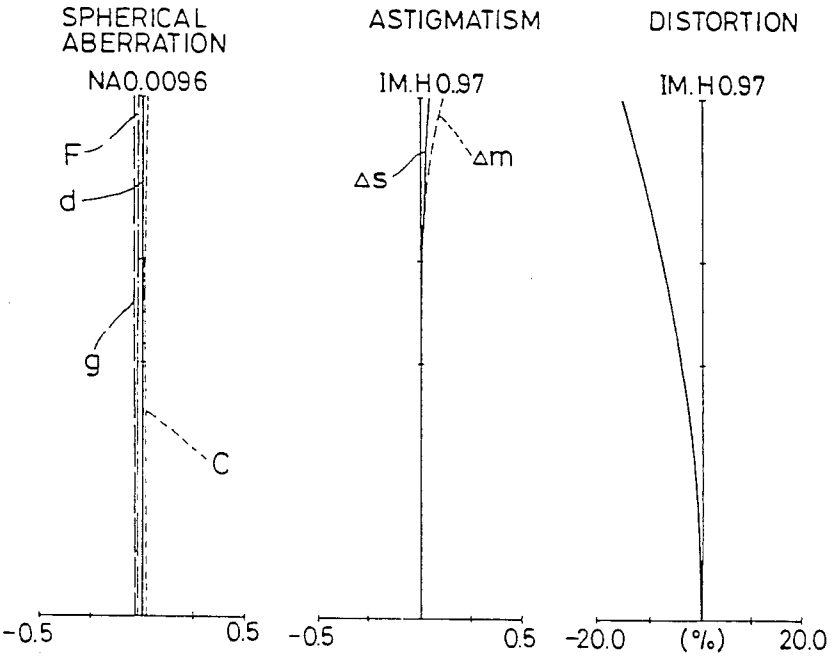
Δm
Δs
-0.5
0.5
DISTORTION
IM.H0.96
-20.0
(%)
20.0

FIG. 8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ASTIGMATISM
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Δm
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0.5
DISTORTION
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-20.0
(%)
20.0

FIG. 9

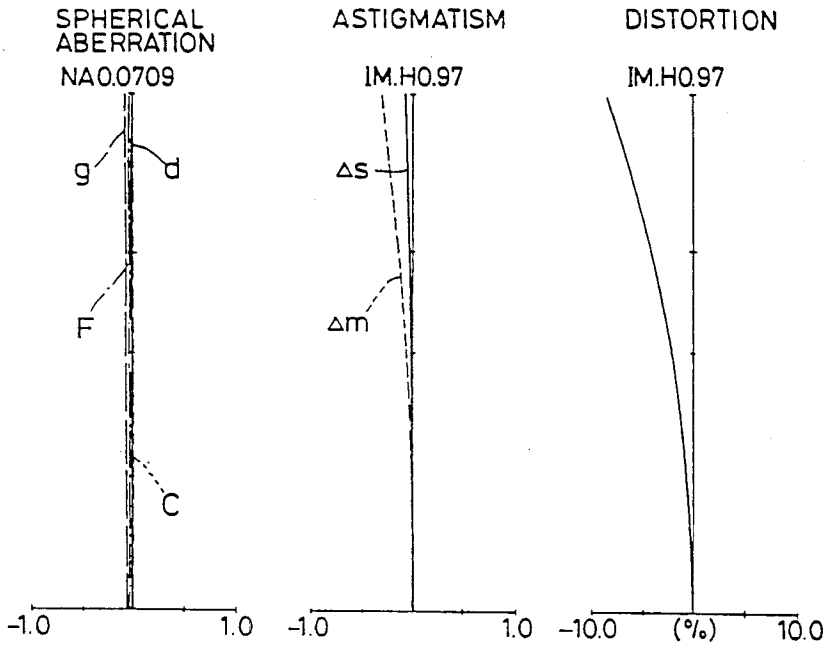


FIG. 10
PRIOR ART

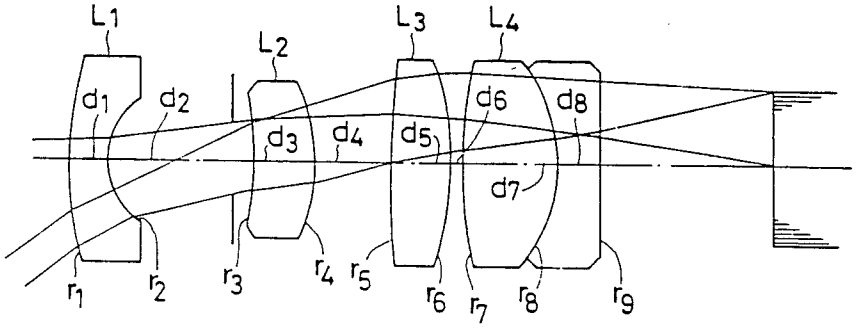
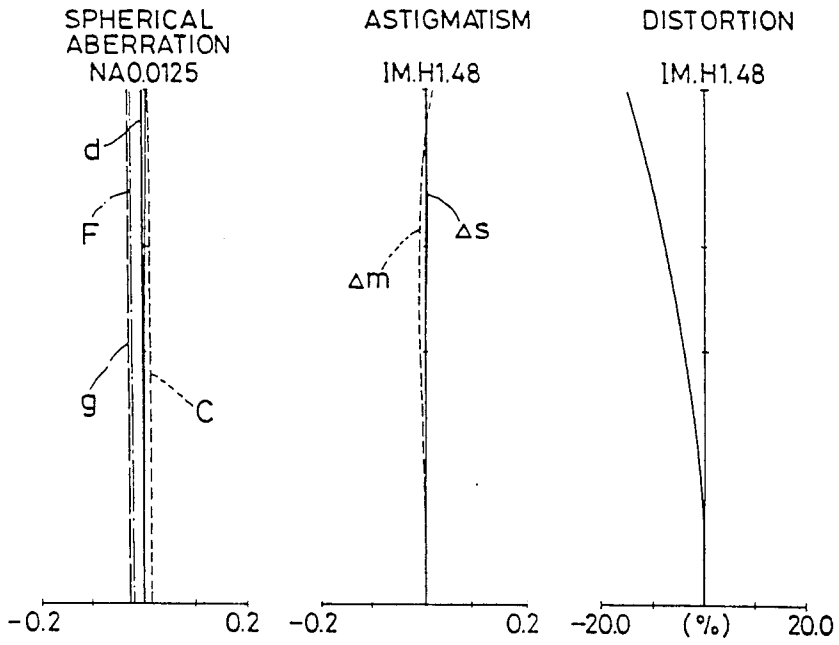


FIG. 11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F
g
C
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0.2
ASTIGMATISM
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Δs
Δm
-0.2
0.2
DISTORTION
IM.H1.48
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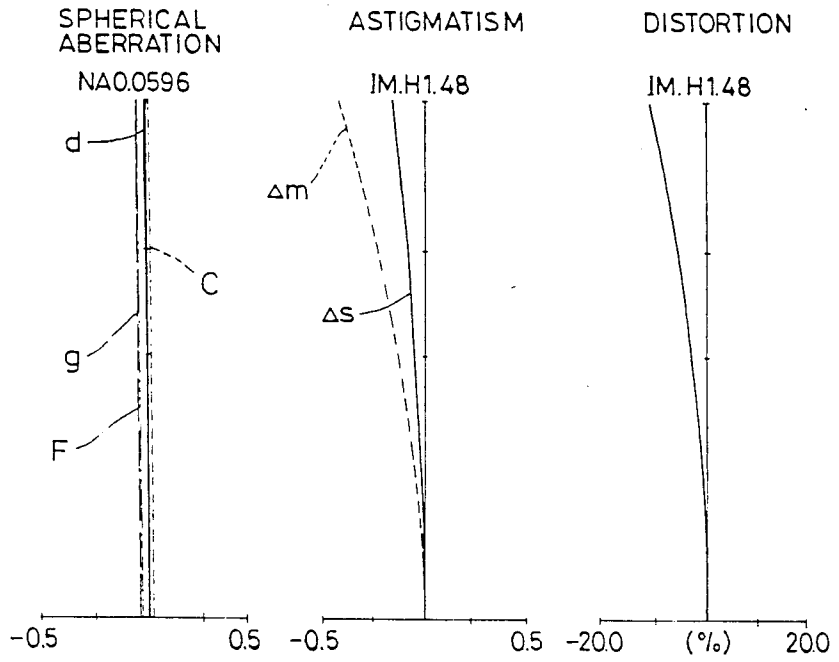
(%)
20.0

FIG. 12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g
F
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ASTIGMATISM
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Δs
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0.5
DISTORTION
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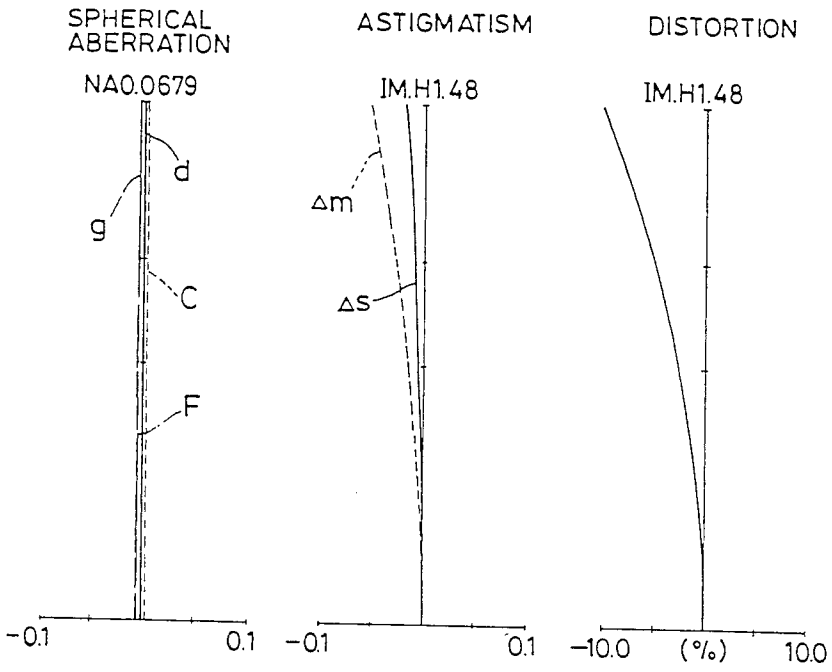
(%)
20.0

FIG. 13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g
C
F
-0.1
0.1
ASTIGMATISM
IM.H1.48
Δm
ΔS
-0.1
0.1
DISTORTION
IM.H1.48
-10.0
(%)
10.0

RETROFOCUS-TYPE OBJECTIVE FOR AN ENDOSCOPE

This is a continuation of application Ser. No. 743,356, filed June 10, 1985.

BACKGROUND OF THE INVENTION

(a) Field of the Invention

The present invention relates to a retrofocus-type objective for an endoscope and, more particularly, to a retrofocus-type objective for an endoscope of which aberrations are corrected favourably in all of the states that said objective is focused, i.e., the state focused on an object at a short distance, state focused on an object at a long distance, and respective states of focusing on objects at intermediate distance.

(b) Description of the Prior Art

An endoscope should have such overall structure that liquid will not enter the inside thereof. Therefore, an object for an endoscope is so arranged that the front lens thereof serves also as a cover glass. This means that, for an object for an endoscope, it is impossible to adopt the focusing method to advance the lens system as a whole or focusing method to advance the front lens through those focusing methods are widely adopted for lens systems in general. As a method devised in order to solve the above-mentioned problem, there is a known focusing method to keep the front lens group fixed and to move the rear lens group.

An objective for an endoscope disclosed in U.S. Pat. No. 4,059,344 is known as an objective for which the above-mentioned focusing method is adopted. Said known objective is designed as a retrofocus-type objective which comprises a front lens group comprising a diverging lens L_1, and a rear lens group comprising converging lenses L_2, L_3 and L_4, and which is arranged to be focused by moving the lens L_2 along the optical axis, said known objective being suitable for the use with a device which constructed so that liquid will not enter the inside.

However, said known objective has disadvantages as explained below. That is, though aberrations thereof are corrected favourably when said known objective is focused on an object at a long distance, it is difficult to say that aberrations when focused on an object at a short distance are corrected satisfactorily favourably, i.e., astigmatism is undercorrected. Therefore, the resolving power in the marginal portion is not satisfactory.

Besides, in recent years, it is strongly desired to observe an object by enlarging it as far as possible at the time of observation by an endoscope. Therefore, also in the field of objectives for endoscopes, there is an increasing demand for a lens system which can be focused on an object at the infinite distance up to an object at an extremely short distance that corresponds to the object distance at the time of photographing by a camera using a macro lens. From the above-mentioned view point, the known objective according to the afore-mentioned patent has a disadvantage that it cannot be focused on an object at an extremely short distance at which the object can be observed with a satisfactorily high magnification.

SUMMARY OF THE INVENTION

It is, therefore, a primary object of the present invention to provide a retrofocus type objective for an endoscope of which aberrations are corrected favourably in well balanced state for both cases that the objective is focused on an object at a long distance and that the objective is focused on an object at an extremely short distance, and which makes it possible to obtain a satisfactorily high magnification for observation.

The objective according to the present invention has a lens configuration as shown in FIG. **1**. That is, the objective according to the present invention comprises, in the order from the object side, a first lens component comprising a negative lens, a stop, a second lens component comprising a positive meniscus lens which is concave toward the object side, a third lens component comprising a positive lens, a fourth lens component comprising a positive lens and a negative lens, and a fifth lens component comprising a positive lens. Besides, the objective according to the present invention is arranged to be focused by advancing the third and fourth lens components and, moreover, arranged to fulfill the conditions (1) and (2) shown below:

$$-0.9 < f_1/f_a \tag{1}$$

$$1.0 < f_2/f_a < 1.3 \tag{2}$$

where, reference symbol f_1 represents the focal length of the first lens component, reference symbol f_2 represents the total focal length of the second through the fifth lens components, and reference symbol f_a represents the focal length of the lens system as a whole when focused on an object at a short distance.

Generally, retrofocus-type objectives have such tendency that astigmatism becomes considerably undercorrected as the object point approaches the lens system and, as a result, the image surface inclines toward the "minus" side. Therefore, when it is desired to focus the lens system on an object at a short distance, it is important to correct the above-mentioned inclination of image surface. Especially in case of objectives for endoscopes, correction of image surface is difficult because the field angle is generally large.

On the other hand, to arrange that a satisfactorily high magnification can be obtained when the lens system is focused on an object at a short distance, the distance l from the front focal point of the lens system as a whole to the object should be made satisfactorily small compared with the focal length f_a of the lens system as a whole.

Besides, as an objective for an endoscope is to be arranged in a distal end of an endoscope with a small diameter, lens diameters whould be made small. Therefore, balance of heights of rays which pass through respective lens groups should be also taken into consideration.

Out of the above-mentioned requirements, the problem to prevent the image surface from inclining toward the "minus" side is extremely important in order to arrange that the marginal portion of image can be observed favourably. For this purpose, in case of the objective for an endoscope according to the present invention, Petzval's sum is corrected by controlling the power of the rear lens group thereof comprising the second through the fifth lens components and having positive refractive power.

The condition (2) is established for the above-mentioned purpose. If f_2/f_a is made smaller than 1.0, Petzval's sum will be overcorrected. If, on the contrary, f_2/f_a is made larger than 1.3, Petzval's sum will be un-

dercorrected. In either case, it is impossible to obtain favourable quality of image. Besides, if f_2/f_a is made smaller than 1.0 and power of the rear lens group becomes considerably strong, the heights of offaxial rays become high in the front lens groups thereof comprising the first lens component whihc is arranged as a negative lens. As a result, the diameter of the front lens becomes large, and this is not desirable.

To obtain a high magnification when the objective is focused on an objective at a short distance in the state that the focal length f_2 is selected in the range defined by the condition (2), it is necessary to fulfill the condition (1).

If f_1/f_a is made smaller than the lower limit of the condition (1) and power of the front lens group becomes weak, the airspace between the front and rear lens groups should be made large in order to obtain the desired value of field angle. As a result, the distance between the object and front focal point of the lens system as a whole becomes long when the lens system is focused on an object at a short distance and, consequently, it is impossible to made the magnification high.

The objective which fulfills the conditions (1) and (2) shown in the above is capable of accomplishing the object of the present invention. However, when said objective is arranged that the airspace D between the first and second lens components fulfills the condition (3) shown below, it is possible to make the available focusing range satisfactorily wide when the objective is focused by means of the rear lens group, which is a positive lens group, and it is possible to make the magnification satisfactorily high when the objective is focused on an object at a short distance.

$$D/f_a<0.7 \quad (3)$$

That is, when D/f_a is made smaller than 0.7, the length of a system comprising the first lens component and the second lens component becomes short, and the heights of rays which go out from the second lens component become low. As a result, the space available for moving a focusing group, which comprises the third lens component and the fourth lens component, can be made large and it is possible to arrange that the objective can be focused up to an object at an extremely short distance. Moreover, as the heights of rays which enter the above-mentioned focusing group do not become so high, it is also possible to correct aberrations favourably and to make the variation of aberrations small.

By limiting the values of f_1 and f_2 in relation to the focal length of the lens system as a whole as described so far, it is possible to obtain an objective of which the enlarging magnification when observing an object at a short distance is satisfactorily high. Furthermore, by limiting the airspace D between the first and second lens components as described in the above, it is possible to obtain an objective with a satisfactorily wide focusing range.

Besides, to obtain favourable quality of image in both cases of observation, i.e., at the time of ordinary observation of an object at a long distance and at the time of observation of an object at a short distance by magnifying the object, it is preferable to arrange that the objective according to the present invention further fulfills the conditions (4), (5) and (6) shown below:

$$1.0 < r_1/fa < 4.0 \quad (4)$$

$$-1.5 < r_4/fa < -1.0 \quad (5)$$

-continued

$$1.3 < R < 4.0 \quad (6)$$

$$1/R = 1/r_6 + 1/r_{10}$$

where, reference symbol r_1 represents the radius of curvature of the surface of the object side of the first lens component, reference symbol r_4 represents the radius of curvature of the surface on the object side of the second lens component, reference symbol r_6 represents the radius of curvature of the surface on the object side of the third lens component, and reference symbol r_{10} represents the radius of curvature of the surface on the image side of the fourth lens component.

Generally, regarding the retrofocus-type lens systems which are arranged to be focused by advancing the positive lens group arranged as the rear lens group, it is known that, when aberrations to be caused at the time of ordinary observation of an object at a long distance are corrected favourably, aberrations at the time of observation of an object at a short distance comes to the state that astigmatism becomes a "minus" value with a large absolute value and, consequently, the resolving power decreases considerably. Besides, it is known that astigmatism is defined by the difference between the converging point of sagittal rays and converging point of meridional rays and that astigmatism to be caused becomes smaller when the shapes of respective surface of lenses becomes closer to the shapes concentric with the stop. The conditions (4) and (5) shown in the above are established by taking the above-mentioned point into consideration.

If, in the conditions (4) and (5), r_1/f_1 and/or r_4/f_a is made smaller than the lower limit thereof, astigmatic difference will be overcorrected. If r_1/f_a and/or r_4/f_a is made larger than the upper limit thereof, astigmatic difference will be undercorrected.

The objective according to the present invention is arranged that the third lens component and the fourth lens component are movable. Therefore, when it is considered that the third and fourth lens components constitute a movable lens group, it is possible to correct astigmatic difference by limiting the radius of curvature r_6 of the foremost surface of said movable lens group and the radius of curvature r_{10} of the rearmost surface of said movable lens group as defined by the condition (6).

If, in the condition (6), the value of R becomes smaller than the lower limit, i.e., 1.3, astigmatic difference will be undercorrected. If the value of R becomes larger than the upper limit, i.e., 4.0, astigmatic difference will be overcorrected.

As described so far, the objective according to the present invention is arranged that the absolute value of astigmatic difference, which is generally caused in the retrofocus-type objectives, is made small by means of the surface r_1 and surface r_4 in the front lens group by arranging that said surfaces fulfill the conditions (4) and (5). Besides, by limiting the values of r_6 and r_{10} as defined by the condition (6), it is possible to correct astigmatic difference in well balanced state also in case that the objective is arranged to be focused by moving the lens components in the rear lens group.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows a sectional view of the retrofocus-type objective for an endoscope according to the present invention;

FIGS. **2** and **3** respectively show graphs illustrating aberration curves of Embodiment 1 of the present invention when the object distance is 14.2450 and 1.5385 respectively;

FIGS. **4** and **5** respectively show graphs illustrating aberration curves of Embodiment 2 of the present invention when the object distance is 14.2045 and 1.53609 respectively;

FIGS. **6** and **7** respectively show graphs illustrating aberration curves of Embodiment 3 of the present invention when the object distance is 14.2045 and 1.53409 respectively;

FIGS. **8** and **9** respectively show graphs illustrating aberration curves of Embodiment 4 of the present invention when the object distance is 14.27755 and 1.54198 respectively;

FIG. **10** shows a sectional view of a known objective for an endoscope; and

FIGS. **11**, **12** and **13** respectively show graphs illustrating aberration curves of said known objective for an endoscope when the object distance is 10.5965, 1.56986 and 1.2755 respectively.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Now, preferred embodiments of the retrofocus-type objective for an endoscope according to the present invention described so far as shown below.

EMBODIMENT 1

$r_1 = 2.6667$		
$d_1 = 0.1994$	$n_1 = 1.51633$	$\nu_1 = 64.15$
$r_2 = 0.3493$		
$d_2 = 0.4274$		
$r_3 = \infty$	(stop)	
$d_3 = 0.1083$		
$r_4 = -1.0188$		
$d_4 = 0.4387$	$n_2 = 1.51633$	$\nu_2 = 64.15$
$r_5 = -0.6439$		
$d_5 = 0.1673$	(variable)	
$r_6 = 2.9248$		
$d_6 = 1.1453$	$n_3 = 1.51633$	$\nu_3 = 64.15$
$r_7 = -2.0177$		
$d_7 = 0.1766$		
$r_8 = 1.4803$		
$d_8 = 1.2137$	$n_4 = 1.51633$	$\nu_4 = 64.15$
$r_9 = -1.0849$		
$d_9 = 0.7123$	$n_5 = 1.84666$	$\nu_5 = 23.78$
$r_{10} = 5.3578$		
$d_{10} = 0.7729$	(variable)	
$r_{11} = 3.6279$		
$d_{11} = 0.4217$	$n_6 = 1.51633$	$\nu_6 = 64.15$
$r_{12} = \infty$		

$f_a = 1.0$, NA $= -0.00972$, image height $= 0.54986$
$f_1/f_a = -0.8017$, $f_2/f_a = 1.1698$
$D/f_a = 0.5356$, $r_1/f_a = 2.6667$
$r_4/f_a = -1.0188$, R $= 1.89$

object distance	magnification	d_5	d_{10}
14.2450	−0.059	0.7123	0.2279
1.5385	−0.563	0.1673	0.7729

Embodiment 2

$r_1 = 2.8409$		
$d_1 = 0.1988$	$n_1 = 1.51633$	$\nu_1 = 64.15$
$r_2 = 0.3615$		
$d_2 = 0.4257$		
$r_3 = \infty$	(stop)	
$d_3 = 0.1705$		
$r_4 = -1.0429$		
$d_4 = 0.4372$	$n_2 = 1.51633$	$\nu_2 = 64.15$
$r_5 = -0.6563$		
$d_5 = 0.1705$	(variable)	
$r_6 = 2.4944$		
$d_6 = 1.0228$	$n_3 = 1.51633$	$\nu_3 = 64.15$
$r_7 = -2.2139$		
$d_7 = 0.1763$		
$r_8 = 1.4502$		
$d_8 = 1.2104$	$n_4 = 1.51633$	$\nu_4 = 64.15$
$r_9 = -0.9766$		
$d_9 = 0.5683$	$n_5 = 1.84666$	$\nu_5 = 23.78$
$r_{10} = 3.6813$		
$d_{10} = 0.767$	(variable)	
$r_{11} = 2.7899$		
$d_{11} = 0.4207$	$n_6 = 1.51633$	$\nu_6 = 64.15$
$r_{12} = \infty$		

$f_a = 1.0$, NA $= -0.00985$, image height $= 0.54830$
$f_1/f_a = -0.825$, $f_2/f_a = 1.1045$
$D/f_a = 0.5962$, $r_1/f_a = 1.8409$
$r_4/f_a = -1.0429$, R $= 1.49$

object distance	magnification	d_5	d_{10}
14.2045	−0.058	0.7102	0.2273
1.53409	−0.566	0.1705	0.7670

Embodiment 3

$r_1 = 3.6957$		
$d_1 = 0.1989$	$n_1 = 1.51633$	$\nu_1 = 64.15$
$r_2 = 0.3701$		
$d_2 = 0.4676$		
$r_3 = \infty$	(stop)	
$d_3 = 0.1272$		
$r_4 = -1.4476$		
$d_4 = 0.3888$	$n_2 = 1.51633$	$\nu_2 = 64.15$
$r_5 = -0.6918$		
$d_5 = 0.1708$	(variable)	
$r_6 = 3.2891$		
$d_6 = 0.6936$	$n_3 = 1.51633$	$\nu_3 = 64.15$
$r_7 = -2.0554$		
$d_7 = 0.4029$		
$r_8 = 1.5486$		
$d_8 = 1.2372$	$n_4 = 1.51633$	$\nu_4 = 64.15$
$r_9 = -1.0511$		
$d_9 = 0.3899$	$n_5 = 1.84666$	$\nu_5 = 23.78$
$r_{10} = 19.7115$		
$d_{10} = 0.7667$	(variable)	
$r_{11} = 3.7001$		
$d_{11} = 0.6818$	$n_6 = 1.51633$	$\nu_6 = 64.15$
$r_{12} = \infty$		

$f_a = 1.0$, NA $= -0.00966$, image height $= 0.54830$
$f_1/f_a = -0.8131$, $f_2/f_a = 1.1386$
$D/f_a = 0.5948$, $r_1/f_a = 3.6959$
$r_4/f_a = -1.4476$, R $= 2.82$

object distance	magnification	d_5	d_{10}
14.20454	−0.060	0.7101	0.2274
1.53409	−0.561	0.1708	0.7667

Embodiment 4

$r_1 = 1.9989$		
$d_1 = 0.1714$	$n_1 = 1.51633$	$\nu_1 = 64.15$
$r_2 = 0.3480$		
$d_2 = 0.4689$		
$r_3 = \infty$	(stop)	
$d_3 = 0.1389$		
$r_4 = -1.2988$		
$d_4 = 0.3433$	$n_2 = 1.6968$	$\nu_2 = 55.52$
$r_5 = -0.6881$		
$d_5 = 0.1694$	(variable)	
$r_6 = 52.6913$		
$d_6 = 0.5319$	$n_3 = 1.6968$	$\nu_3 = 55.52$

-continued

$r_7 = -1.8710$		
$d_7 = 0.2159$		
$r_8 = 2.3843$		
$d_8 = 0.9709$	$n_4 = 1.7130$	$\nu_4 = 53.84$
$r_9 = -0.8613$		
$d_9 = 0.4555$	$n_5 = 1.78472$	$\nu_5 = 25.71$
$r_{10} = 1.8834$		
$d_{10} = 0.7814$	(variable)	
$r_{11} = 1.4427$		
$d_{11} = 0.7476$	$n_6 = 1.51633$	$\nu_6 = 64.15$
$r_{12} = \infty$		

$f_a = 1.0$, NA $= -0.00959$, image height $= 0.55682$
$f_1/f_a = -0.8458$, $f_2/f_a = 1.2798$
$D/f_a = 0.6078$, $r_1/f_a = 1.9989$
$r_4/f_a = -1.2988$, R $= 1.82$

object distance	magnification	d_5	d_{10}
14.27755	−0.057	0.7377	0.2130
1.54198	−0.533	0.1694	0.7813

In respective embodiments shown in the above, reference symbols r_1 through r_{12} respectively represent radii of curvature of respective lens surfaces, reference symbols d_1 through d_{11} respectively represent thicknesses of respective lenses and airspaces between respective lenses, reference symbols n_1 through n_6 respectively represent refractive indices of respective lenses, and reference symbols ν_1 through ν_6 respectively represent Abbe's numbers of respective lenses.

All of embodiments shown in the above are arranged to integrally advange the third and fourth lens components so as to make it possible to observe an object at a short distance by enlarging the object. In other words, respective embodiments are arranged that both of ordinary observation of an object at a long distance and observation of an object at a short distance by enlarging the object are performed by varying the airspaces d_5 and d_{10} as shown in the numerical data of respective embodiments.

For the purpose of comparison, the numerical data of the objective for an endoscope disclosed in Japanese published examined patent application No. 15005/80 (U.S. Pat. No. 4,059,344) are shown below.

$r_1 = 2.7033$		
$d_1 = 0.2747$	$n_1 = 1.51633$	$\nu_1 = 64.15$
$r_2 = 0.5675$		
$d_2 = 0.9851$		
$r_3 = \infty$	(stop)	
$d_3 = 0.1688$		
$r_4 = -2.7559$		
$d_4 = 0.4710$	$n_2 = 1.6968$	$\nu_2 = 55.52$
$r_5 = -1.3991$		
$d_5 = 0.1682$	(variable)	
$r_6 = 7.7147$		
$d_6 = 0.4710$	$n_3 = 1.6968$	$\nu_3 = 55.52$
$r_7 = -2.2877$		
$d_7 = 0.0784$		
$r_8 = 3.0546$		
$d_8 = 0.7849$	$n_4 = 1.6968$	$\nu_4 = 55.52$
$r_9 = -1.1111$		
$d_9 = 0.2747$	$n_5 = 1.78472$	$\nu_5 = 25.71$
$r_{10} = 16.9937$		
$d_{10} = 1.7760$	(variable)	
$r_{11} = \infty$	(image surface)	

object distance	magnification	d_5	d_{10}
10.5965	−0.087	0.5616	1.3827
1.56986	−0.475	0.1682	1.7760
1.2755	−0.563	0.0770	1.8673

In the numerical data shown in the above, the values for the object distance 1.2755 are reference values obtained by converting the numerical data of said known objective into the case of magnification −0.563 which is aimed at by the present invention. The actual numerical data of said known objective are given on the basis of object distances 10.5965 and 1.56986.

Besides, in case of said known objective having the numerical data shown in the above, the values which correspond to respective conditions of the present invention are as shown below.

$f_a = 1$, image height $= 0.58281$
$f_1/f_a = -1.442$, $f_2/f_a = 1.3482$
$D/f_a = 1.144$, $r_1/f_a = 2.6802$
$r_4/f_a = -2.7323$, R $= 5.31$

Said known objective does not satisfy any of the conditions given in the present invention except the condition (4).

As described in datail in the above and as it will be evident from respective embodiments, the retrofocus-type objective for an endoscope according to the present invention is arranged that the magnification at the time of observation of an object at a short distance is higher compared with known objectives for endoscopes and, at the same time, arranged that the resolving power when observing an object at a short distance is favourable and is well balanced with the resolving power at the time of observation of an object at a long distance so that favourable quality of image is obtained in both of the above-mentioned cases of observation.

I claim:

1. A retrofocus-type objective for an endoscope comprising a first lens component comprising a negative lens, a stop, a second lens component comprising a positive meniscus lens arranged to be concave toward the object side, a third lens component comprising a positive lens, a fourth lens component comprising a cemented doublet consisting of a positive lens and a negative lens, and a fifth lens component comprising a positive lens in the order from the object side, said retrofocus-type objective being arranged to be focused by advancing said third lens component and said fourth lens component and, moreover, to fulfill the conditions (1) and (2) shown below:

$$-0.9 < f_1/f_a \quad (1)$$

$$1.0 < f_2/f_a < 1.3 \quad (2)$$

where reference symbol f_1 represents the focal length of the first lens component, reference symbol f_2 represents the total focal length of the second through the fifth lens components, and reference symbol f_a represents the focal length of the lens system as a whole when focused on an object at a short distance,

said objective further satisfying the following conditions:

$$D/f_a < 0.7 \quad (3)$$

where reference symbol D represents the airspace between the first and second lens components,

and further fulfilling the conditions (4), (5) and (6) shown below:

$$1.0 < r_1/f_a < 4.0 \quad (4)$$

$$-1.5 < r_4/f_a < -1.0 \quad (5)$$

$$1.3 < R < 4.0 \quad (6)$$

$$1/R = 1/r_6 + 1/r_{10}$$

where reference symbol r_1 represents the radius of curvature of the surface on the object side of the first lens component, reference symbol r_4 represents the radius of curvature of the surface on the object side of the second lens component, reference symbol r_6 represents the radius of curvature of the surface of the object side of the third lens component, and reference symbol r_{10} represents the radius of curvature of the surface on the image side of the fourth lens component.

2. A retrofocus-type objective for an endoscope according to claim 1 having the following numerical data:

$r_1 = 2.6667$		
$d_1 = 0.1994$	$n_1 = 1.51633$	$\nu_1 = 64.15$
$r_2 = 0.3493$		
$d_2 = 0.4274$		
$r_3 = \infty$	(stop)	
$d_3 = 0.1083$		
$r_4 = -1.0188$		
$d_4 = 0.4387$	$n_2 = 1.51633$	$\nu_2 = 64.15$
$r_5 = -0.6439$		
$d_5 = 0.1673$	(variable)	
$r_6 = 2.9248$		
$d_6 = 1.1453$	$n_3 = 1.51633$	$\nu_3 = 64.15$
$r_7 = -2.0177$		
$d_7 = 0.1766$		
$r_8 = 1.4803$		
$d_8 = 1.2137$	$n_4 = 1.51633$	$\nu_4 = 64.15$
$r_9 = -1.0849$		
$d_9 = 0.7123$	$n_5 = 1.84666$	$\nu_5 = 23.78$
$r_{10} = 5.3578$		
$d_{10} = 0.7729$	(variable)	
$r_{11} = 3.6279$		
$d_{11} = 0.4217$	$n_6 = 1.51633$	$\nu_6 = 64.15$
$r_{12} = \infty$		

$f_a = 1.0$, NA $= -0.00972$, image height $= 0.54986$
$f_1/f_a = -0.8017$, $f_2/f_a = 1.1698$
$D/f_a = 0.5356$, $r_1/f_a = 2.6667$
$r_4/f_a = -1.0188$, R $= 1.89$

object distance	magnification	d_5	d_{10}
14.2450	−0.059	0.7123	0.2279
1.5385	−0.563	0.1673	0.7729

where, reference symbols r_1 through r_{12} respectively represent radii of curvature of respective lens surfaces, reference symbols d_1 through d_{11} respectively represent thicknesses of respective lenses and airspaces between respective lenses, reference symbols n_1 through n_6 respectively represent refractive indices of respective lenses, and reference symbols ν_1 through ν_6 respectively represent Abbe's numbers of respective lenses.

3. A retrofocus-type objective for an endoscope according to claim 1 having the following numeral data:

$r_1 = 2.8409$		
$d_1 = 0.1988$	$n_1 = 1.51633$	$\nu_1 = 64.15$
$r_2 = 0.3615$		
$d_2 = 0.4257$		
$r_3 = \infty$	(stop)	
$d_3 = 0.1705$		
$r_4 = -1.0429$		
$d_4 = 0.4372$	$n_2 = 1.51633$	$\nu_2 = 64.15$
$r_5 = -0.6563$		
$d_5 = 0.1705$	(variable)	
$r_6 = 2.4944$		
$d_6 = 1.0228$	$n_3 = 1.51633$	$\nu_3 = 64.15$
$r_7 = -2.2139$		
$d_7 = 0.1763$		
$r_8 = 1.4502$		
$d_8 = 1.2104$	$n_4 = 1.51633$	$\nu_4 = 64.15$
$r_9 = -0.9766$		
$d_9 = 0.5683$	$n_5 = 1.84666$	$\nu_5 = 23.78$
$r_{10} = 3.6813$		
$d_{10} = 0.767$	(variable)	
$r_{11} = 2.7899$		
$d_{11} = 0.4207$	$n_6 = 1.51633$	$\nu_6 = 64.15$
$r_{12} = \infty$		

$f_a = 1.0$, NA $= -0.00985$, image height $= 0.54830$
$f_1/f_a = -0.825$, $f_2/f_a = 1.1045$
$D/f_a = 0.5962$, $r_1/f_a = 2.8409$
$r_4/f_a = -1.0429$, R $= 1.49$

object distance	magnification	d_5	d_{10}
14.2045	−0.058	0.7102	0.2273
1.53409	−0.566	0.1705	0.7670

where, reference symbols r_1 through r_{12} respectively represent radii of curvature of respective lens surfaces, reference symbols d_1 through d_{11} respectively represent thicknesses of respective lenses and airspaces between respective lenses, reference symbols n_1 through n_6 respectively represent refractive indices of respective lenses, and reference symbols ν_1 through ν_6 respectively represent Abbe's numbers of respective lenses.

4. A retrofocus-type objective for an endoscope according to claim 1 having the following numerical data:

$r_1 = 3.6957$		
$d_1 = 0.1989$	$n_1 = 1.51633$	$\nu_1 = 64.15$
$r_2 = 0.3701$		
$d_2 = 0.4676$		
$r_3 = \infty$	(stop)	
$d_3 = 0.1272$		
$r_4 = -1.4476$		
$d_4 = 0.3888$	$n_2 = 1.51633$	$\nu_2 = 64.15$
$r_5 = -0.6918$		
$d_5 = 0.1708$	(variable)	
$r_6 = 3.2891$		
$d_6 = 0.6936$	$n_3 = 1.51633$	$\nu_3 = 64.15$
$r_7 = -2.0554$		
$d_7 = 0.4029$		
$r_8 = 1.5486$		
$d_8 = 1.2372$	$n_4 = 1.51633$	$\nu_4 = 64.15$
$r_9 = -1.0511$		
$d_9 = 0.3899$	$n_5 = 1.84666$	$\nu_5 = 23.78$
$r_{10} = 19.7115$		
$d_{10} = 0.7667$	(variable)	
$r_{11} = 3.7001$		
$d_{11} = 0.6818$	$n_6 = 1.51633$	$\nu_6 = 64.15$
$r_{12} = \infty$		

$f_a = 1.0$, NA $= -0.00966$, image height $= 0.54830$
$f_1/f_a = -0.8131$, $f_2/f_a = 1.1386$
$D/f_a = 0.5948$, $r_1/f_a = 3.6959$
$r_4/f_a = -1.4476$, R $= 2.82$

object distance	magnification	d_5	d_{10}
14.20454	−0.060	0.7101	0.2274
1.53409	−0.561	0.1708	0.7667

where, reference symbols r_1 through r_{12} respectively represent radii of curvature of respective lens surfaces, reference symbols d_1 through d_{11} respectively represent thicknesses of respective lenses and airspaces between

respective lenses, reference symbols n_1 through n_6 respectively represent refractive indices of respective lenses, and reference symbols ν_1 through ν_6 respectively represent Abbe's number of respective lenses.

5. A retrofocus-type objective for an endoscope according to claim **1** having the following numerical data:

$r_1 = 1.9989$		
$d_1 = 0.1714$	$n_1 = 1.51633$	$\nu_1 = 64.15$
$r_2 = 0.3480$		
$d_2 = 0.4689$		
$r_3 = \infty$	(stop)	
$d_3 = 0.1389$		
$r_4 = -1.2988$		
$d_4 = 0.3433$	$n_2 = 1.6968$	$\nu_2 = 55.52$
$r_5 = -0.6881$		
$d_5 = 0.1694$	(variable)	
$r_6 = 52.6913$		
$d_6 = 0.5319$	$n_3 = 1.6968$	$\nu_3 = 55.52$
$r_7 = -1.8710$		
$d_7 = 0.2159$		
$r_8 = 2.3843$		
$d_8 = 0.9709$	$n_4 = 1.7130$	$\nu_4 = 53.84$
$r_9 = -0.8613$		

-continued

$d_9 = 0.4555$	$n_5 = 1.78472$	$\nu_5 = 25.71$
$r_{10} = 1.8834$		
$d_{10} = 0.7814$	(variable)	
$r_{11} = 1.4427$		
$d_{11} = 0.7476$	$n_6 = 1.51633$	$\nu_6 = 64.15$
$r_{12} = \infty$		

$f_a = 1.0$, NA $= -0.00959$, image height $= 0.55682$
$f_1/f_a = -0.8458$, $f_2/f_a = 1.2798$
$D/f_a = 0.6078$, $r_1/f_a = 1.9989$
$r_4/f_a = -1.2988$, R $= 1.82$

object distance	magnification	d_5	d_{10}
14.27755	−0.057	0.7377	0.2130
1.54198	−0.533	0.1694	0.7813

where, reference symbols r_1 through r_{12} respectively represent radii of curvature of respective lens surfaces, reference symbols d_1 through d_{11} respectively represent thicknesses of respective lenses and airspaces between respective lenses, reference symbols. n_1 through n_6 respectively represent refractive indices of respective lenses, and reference symbols ν_1 through ν_6 respectively represent Abbe's numbers of respective lenses.

* * * * *

United States Patent [19]

Arai et al.

[11] **Patent Number: 4,755,759**

[45] **Date of Patent: Jul. 5, 1988**

[54] **TEMPERATURE COMPENSATING METHOD IN AUTOMATIC DIAPHRAGM CONTROL AMPLIFIER USED WITH OBJECTIVE FOR CCTV CAMERA**

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[73] Assignee: **Asahi Seimitsu Kabushiki Kaisha,** Tokyo, Japan

[21] Appl. No.: **913,257**

[22] Filed: **Sep. 30, 1986**

[30] **Foreign Application Priority Data**

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[51] **Int. Cl.**[4] **H04N 5/235**

[52] **U.S. Cl.** **358/228**

[58] **Field of Search** 358/228, 209

[56] **References Cited**

FOREIGN PATENT DOCUMENTS

0064580 4/1985 Japan 358/228

Primary Examiner—Michael A. Masinick

Attorney, Agent, or Firm—Birch, Stewart, Kolasch & Birch

[57] **ABSTRACT**

A temperature compensating method an automatic diaphragm control amplifier used with an objective lens for a CCTV camera lowers or raises an adjusted level of video signal as an ambient temperature rises of lowers, respectively. The temperature compensating means compensates for a temperature-dependent variations in the DC component of the video signal coming from the camera and thereby to prevents the level of video signal from lowering as the ambient temperature rises or lowers.

8 Claims, 2 Drawing Sheets

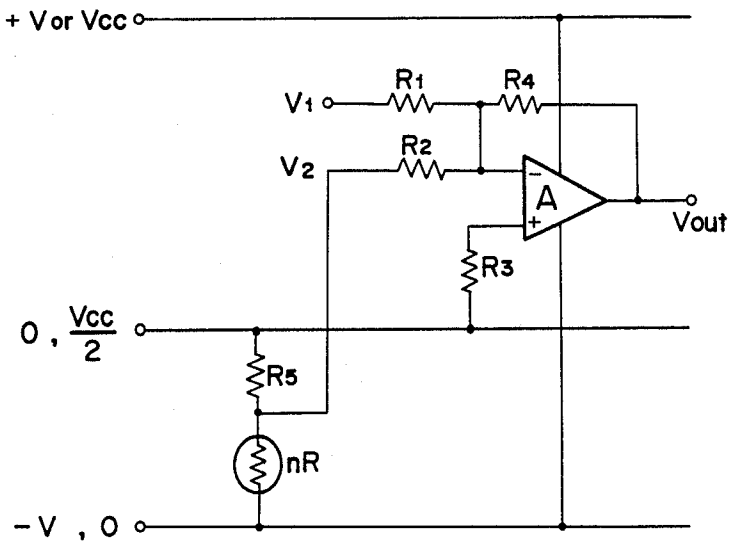


FIG. 1

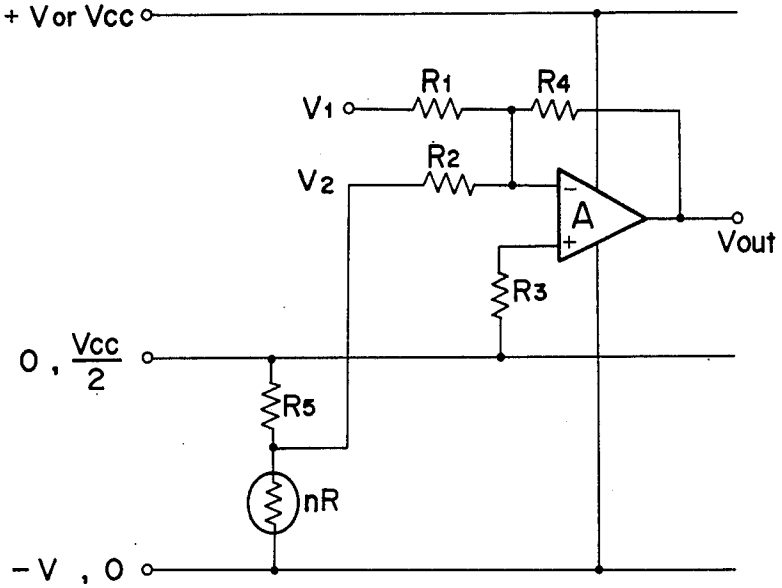

+ V or Vcc
V1
R1
R4
V2
R2
A
Vout
R3
0 , Vcc/2
R5
nR
-V , 0

FIG. 2

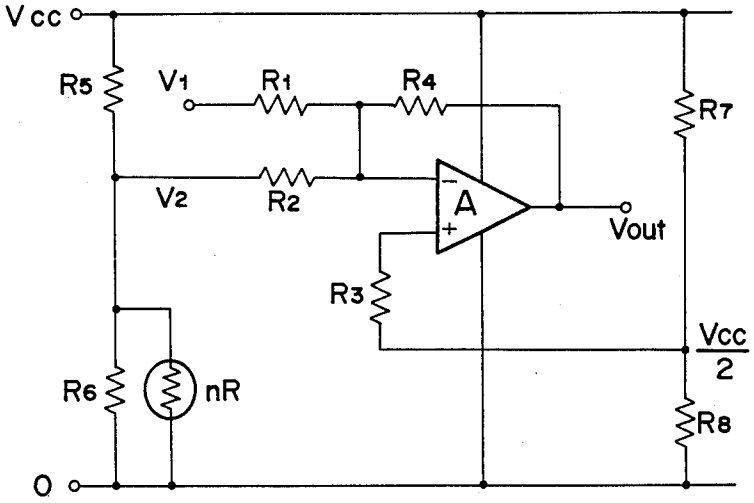

Vcc
R5
V1
R1
R4
R7
V2
R2
A
Vout
R3
Vcc/2
R6
nR
R8
0

FIG. 3

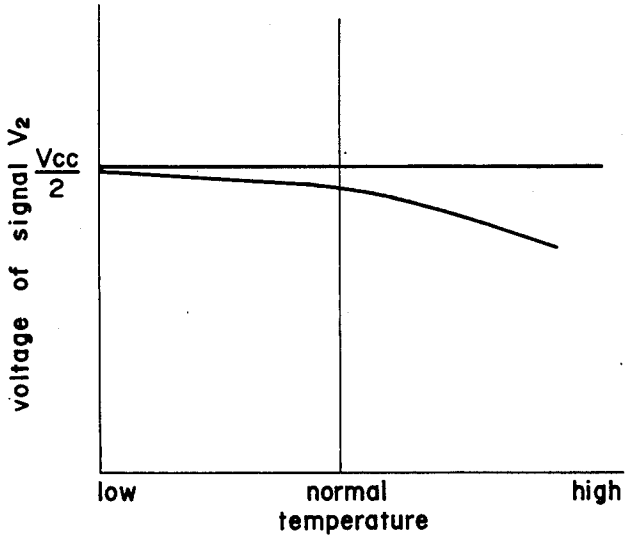
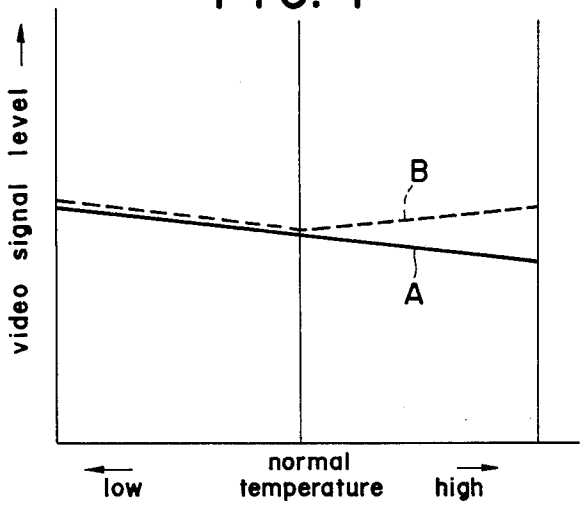

voltage of signal V_2
$\frac{Vcc}{2}$
low
normal temperature
high

FIG. 4


video signal level
B
A
low
normal temperature
high

TEMPERATURE COMPENSATING METHOD IN AUTOMATIC DIAPHRAGM CONTROL AMPLIFIER USED WITH OBJECTIVE FOR CCTV CAMERA

BACKGROUND OF THE INVENTION

Industrial Field of Application

The present invention relates to an automatic diaphragm control amplifier used with an objective for a closed circuit television (CCTV) camera.

Prior Art

In the prior art there has been no means provided for temperature compensation of a video signal level and, even if the level of a video signal actually varied due to a temperature variation, this video signal was usually processed by the built-in circuit arrangement of the camera as if the signal included no such level variation.

Problems to be Solved by Invention

In the camera employing pickup means other than a pickup tube such as a vidicon tube which is able to vary its sensitivity by changing its target voltage, this variation is often used in order to obtain optimal performance of said pickup tube or pickup element, so that a high quality picture of good S/N ratio is obtained for a bright scene and a high sensitivity takes preference over S/N ratio for a dark scene so that the function of the video gain control circuit incorporated in the camera is based on a brightness of the scene. This prior art camera has been inconvenient to use as an adequately bright scene would often result in a low quality picture of inferior S/N, since a level value set by changing the gain of the video amplifier is variable regardless of the brightness. For example, the video signal level may be lowered for the bright scene due to a temperature rise during shooting of this scene, and this signal level may function to increase the video amplifier gain of the camera as if the scene was darkened.

Furthermore, the pickup tube or the solid state pickup element is likely to be accompanied with increased dark current as a temperature rise resulting in that a portion of the picture which should be dark becomes bright. In addition to this tendency, lowering of the signal level due to the temperature rise may affect the function of the automatic diaphragm control amplifier to such an extent that an effective portion of the video signal is reduced and, in an extreme case, there will be no recognizable picture.

SUMMARY OF THE INVENTION

Measures to Solve Problems

Such a circuit arrangement having no means for temperature compensation and exhibiting such a characteristic that a level of video signal is alternated with increasing temperature is indicated by a solid line A in FIG. 4. In this Figure, the characteristic corresponding to a situation in which a scene has been darkened may result, as a temperature rises, even when the scene really remains bright. Such an influence of temperature can be overcome by a compensating element applying a compensation amount, which is more than a variation amount which would occur in the circuit arrangement having no means for temperature compensation, within a range of temperature higher than the normal temperature. This compensation amount may be less than a variation amount which would occur in the circuit arrangement having no means for temperature compensation, within a range of temperature lower than the normal temperature, as indicated by a broken line B in FIG. 4.

Thus, the present invention broadly resides in a temperature compensating method in an automatic diaphragm control amplifier used with an objective lens for CCTV camera, in which an adjusted level of video signal lowers or rises as an ambient temperature rises or lowers, respectively, characterized in that there in provided temperature compensating means adapted to compensate a temperature dependent variation in the DC component of the video signal coming from the camera and thereby to prevent the level of video signal from becoming lower than a value adjusted at the normal temperature as the ambient temperature rises or lowers. More specifically, the present invention resides in a temperature compensating method in an automatic diaphragm control amplifier used with an objective lens for a CCTV camera wherein the automatic diaphragm control amplifier is energized from a single source or double source and when a mid-point voltage (0 or Vcc/2) is stable, between a ground and a negative source voltage or between the mid-point voltage and ground, a bleeder resistance is provided. The bleeder resistance includes a fixed resistance and thermistor, a resistance value of said fixed resistance being selected to be infinitely small relative to a resistance value of said thermistor, and a voltage thus obtained from said bleeder resistance being applied to an operational amplifier in parallel with the video signal coming from the camera in order to achieve a desired temperature compensation. In an alternative embodiment, the present invention further resides in a temperature compensating method in an automatic diaphragm control amplifier used with an objective lens for a CCTV camera wherein the automatic diaphragm control amplifier is energized from a double source or a single source and when a mid-point voltage (0 or Vcc/2) is unstable, a bleeder resistance is provided consisting of two fixed resistances of same value connected between the source and a ground, and a thermistor connected between the mid-point voltage and the ground in parallel with the one of said two fixed resistances which is connected to the ground. A voltage thus obtained from said bleeder resistance is applied to an operational amplifier in parallel with the video signal coming from the camera in order to achieve a desired temperature compensation.

Operation

With the automatic diaphragm control amplifier having the characteristic as indicated by the solid line A in FIG. 4, the level of video signal lowers as a temprature rises above the normal temperature, resulting in an exposure as if a scene (i.e., an object to be shot) is darkened and resulting in a corresponding rise in a gain of the pickup tube and the solid state pickup element, so that the lens aperture is enlarged and a picture of inferior S/N ratio is produced. In contrast therewith, according to the temperature compensating method of this invention, the video signal is compensated by an amount smaller than a variation amount occurring at the normal temperature when the ambient temperature is lower than the normal temperature but by an amount larger than a variation amount occurring at the normal temperature when the ambient temperature is higher than the normal temperature. In this manner, the video signal can be compensated so that its level is always maintained higher than a level at the normal temperature and, as a consequence, the automatic diaphragm

control amplifier is free from any influence of the temperature.

BRIEF DESCRIPTION OF DRAWING

FIG. **1** is a circuit diagram illustrating an important part of an embodiment of the method according to the present invention;

FIG. **2** is a circuit diagram similar to FIG. **1** but concerning another embodiment;

FIG. **3** is a graphic diagram illustrating a characteristic of a compensated signal; and

FIG. **4** is a graphic diagram illustrating compensating characteristic curves of the automatic diaphragm control amplifier with respect to the video signal level.

EMBODIMENTS

In an embodiment as illustrated by FIG. **1**, the circuit is energized from a double source (+V, −V) or single source (Vcc) and a mid-point voltage (0 or Vcc/2) thereof is stable. A video signal **V1** coming from the camera is coupled through a resistance **R1** to an inverting terminal (−) of an operational amplifier A while the mid-point voltage is input through a resistance **R3** to a non-inverting terminal (+). The inverting terminal (−) is connected through a feedback resistance **R4** to an output terminal and an output signal Vout is amplified to (**R4/R1**) **V1**. The inverting terminal (−) and the non-inverting terminal (+) are in a state of imaginary short-circuit and both of them are at a voltage equal to the mid-point voltage (Vcc/2).

When the ambient temperature rises above the normal temperature and, as a result, the video signal level of the automatic diaphragm control amplifier including the operational amplifier A lowers as indicated by the solid line A in FIG. **4**, a rectified portion **V1** of the video signal increases in proportion to the temperature rise and the lens aperture is correspondingly reduced with respect to the aperture at the normal temperature so that the gain of the solid state pickup element or like increases.

In view of this, the present invention provides an arrangement such that a fixed resistance **R5** is serially connected to a thermistor nR between the mid-point voltage (0 or Vcc/2) and the negative source (−V) or the ground (**0**), and a signal **V2** obtained from a bleeder resistance consisting of said fixed resistance and said thermistor is coupled through a resistance **R2** to the inverting terminal (−) of the operational amplifier A in parallel with the video signal **V1**. A resistance value of said fixed resistance **R5** is selected to be infinitely smaller than the resistance value of the thermistor nR.

With such arrangement, it will be obvious from FIG. **3** that the signal **V2** lowers below the mid-point voltage (Vcc/2) as the ambient temperature rises above the normal temperature and the resistance value of the thermistor nR correspondingly decreases. Thus, the video signal **V1** in parallel with said signal **V2** is compensated so as to be correspondingly reduced. The signal **V2** infinitely approches the mid-point voltage (Vcc/2) as the ambient temperature lowers below the normal temperature and the resistance value of the thermistor nR correspondingly increases. As a consequence, the video signal level based on the output signal Vout is kept above the level at the normal temperature, as indicated by the broken line in FIG. **4**.

A secondary embodiment is given for the case in which the circuit arrangement is energized from double source (+V, −V) or single source (Vcc) and the mid-point voltage is unstable.

Referring to FIG. **2** illustrating the case of a single source voltage, the non-inverting terminal (+) of the operational amplifier A is applied via the resistance **R3** with a mid-point voltage (Vcc/2) across two fixed resistance **R7**, **R8** of same resistance value connected between the source Vcc and the ground **0**. This mid-point voltage is unstable and the inverting terminal (−) in synchronization therewith is also unstable. Thus, these terminals are in imaginary short-circuit state. Concerning the signal **V2** for temperature compensation, two fixed resistances **R5**, **R6** of same resistance value are connected between the source Vcc and the ground **0** while the thermistor nR is connected in parallel with said fixed resistance **R6** on the ground side between the mid-point voltage (Vcc/2) and the ground **0** so that the signal **V2** is input from the bleeder resistance consisting of said thermistor nR and said fixed resistance **R5** to the inverting terminal (−) of the operational amplifier A via the resistance **R3**, in parallel with the video signal **V1** coming from the camera.

In such a case, the signal **V2** for temperature compensation maintains the same relationship with the mid-point voltage (Vcc/2) as the relationship indicated by FIG. **3** as the ambient temperature varies, even though the mid-point voltage is unstable. Thus, there is provided the output signal Vout derived from the video signal which has supplied from the camera and then appropriately compensated.

Effect

With the temperature compensating method according to the present invention, as has been described hereinabove, there is provided the temperature compensating means for the automatic diaphragm control in which the adjusted level of video signal lowers or rises as the ambinent temperature rises or lowers, respectively, so that said temperature compensating means compensates for a temperature-dependent variation in DC component of the video signal coming from the camera and thereby prevents the level of video signal from becoming lower than the value adjusted at the normal temperature as the ambient temperature rises or lowers. Accordingly, when the temperature compensating method of the present invention may be employed in the camera utilizing a high sensitivity pickup tube and the solid state pickup element so devised, in order to obtain the optimal performance of said pickup tube or said pickup element, so that a high quality picture of good S/N ratio is obtained for a bright scene and a high sensitivity takes preference over S/N ratio for a dark scene, i.e., the video gain control circuit incorporated in the camera is activated as the scene is darkened, the level of video signal coming from the camera is appropriately compensated so as to prevent this level from lowering and thereby the desired performance of the automatic diaphragm control amplifier is maintained regardless of the temperature variation, even if the level value set to change the gain of the video amplifier is variable independently of the brightness, for example, the video signal level lowers for the bright scene due to the temperature rise during shooting of this scene.

What is claimed is:

1. A method of compensating for variations in video signal gain caused by variations in ambient temperature in an automatic diaphragm control of a video camera comprising:

receiving said video signal;

varying a DC component of said video signal in response to variations in ambient temperature to thereby compensate for temperature-dependent variations in said DC component of said video signal.

2. The method of compensating as set forth in claim 1 wherein said step of varying a D.C. component attenuates said video signal.

3. A method of compensating for variations in video signal gain caused by variations in ambient temperature in an automatic diaphragm control of a video camera comprising:

receiving said video signal;

variably attenuating at least a component of said video signal in response to variations in ambient temperature to thereby compensate for temperature-dependent variations in said video signal.

4. A temperature compensating circuit for an automatic diaphragm control amplifier of a video camera wherein said video signal has a level which varies with variations in ambient temperature comprising:

means for amplifying said video signal; and

temperature compensation means, operatively connected to said means for amplifying, for varying the level of said video signal supplied to said means for amplifying.

5. The temperature compensating circuit of claim 2 further comprising:

a voltage source having first and second source voltages and a stable midpoint voltage level therebetween;

said temperature compensation means including,

a voltage divider including first and second resistances connected between said midpoint voltage and the lower of said first and second source voltage levels, and

a bleeder resistance connected between said means for amplifying and said voltage divider,

said second resistance having a resistance value which varies in relation to ambient temperature to control the amount of attenuation of said video signal occurring through said bleeder resistance.

6. The temperature compensating circuit of claim 5 wherein increased ambient temperature reduces the resistance of said second resistance to increase the attenuation of said video signal.

7. The temperature compensating circuit of claim 4 further comprising:

a voltage source having first and second source voltages and a floating midpoint voltage level therebetween; said temperature compensator means including,

a voltage divider including first and second resistances connected across said first and second source voltages to establish a midpoint voltage,

a bleeder resistance connected between said means for amplifying and said voltage divider,

a third resistance, connected in parallel to said second resistance, having a resistance value which varies in relation to ambient temperature to control the amount of said video signal occurring through said bleeder resistance.

8. The temperature compensating circuit of claim 7 wherein increased ambient temperature reduces the resistance of said third resistance to increase the attenuation of said video signal.

* * * * *

United States Patent [19]

Chrosziel

[11] **Patent Number: 4,752,798**

[45] **Date of Patent: Jun. 21, 1988**

[54] **SWINGABLE HOLDER FOR ANTERIOR ACCESSORIES OF AN OBJECTIVE LENS**

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[73] Assignee: **Filmtechnik Alfred Chrosziel GmbH**, Munich, Fed. Rep. of Germany

[21] Appl. No.: **73,735**

[22] Filed: **Jul. 15, 1987**

[30] **Foreign Application Priority Data**

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[51] **Int. Cl.**[4] **G03B 11/04**

[52] **U.S. Cl.** **354/287**; 350/581

[58] **Field of Search** 354/287, 295; 350/580, 350/581

[56] **References Cited**

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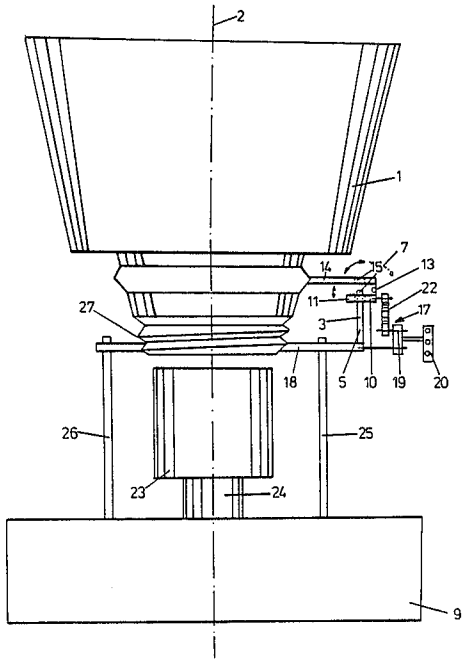
Primary Examiner—Michael L. Gellner

Attorney, Agent, or Firm—Frishauf, Holtz, Goodman & Woodward

[57] **ABSTRACT**

A mounting for a sun shade, a filter or both for the usual bulky lens of a professional video camera can be moved forward or backward parallel to the lens axis on two parallel guide rails (**3, 4**), the rear ends of which are fixed on a frame (**18**) supported forward of the lens mounting support (**9**) by rods (**25, 26**) and a structure (**9**) which supports the lens. On the guide rails extending foward from the frame (**18**) there is mounted a back-and-forth shiftable articulation device (**10, 13, 14**) which permits swinging of its outer member (**14**), only in the forward position of the device, about the articulation joint (**13**). Movement of the accessory towards and away from the lens is driven by an eccentric arm (**19**) which is linked to a swinging member (**22**) for transmitting linear motion. A manipulation member **21** serves to move the eccentric arm **19**. When the articulation device is in its forward position, the free ends (**7, 8**) of the guide rails (**3, 4**) come out of the holes (**15, 16**) in the front member (**14**) of the shiftable articulation device and thus release the locking of the articulation joint (**13**), so that the sun shade, etc., and its bellows (**27**) can be swung out of the field of view of the lens.

7 Claims, 4 Drawing Sheets



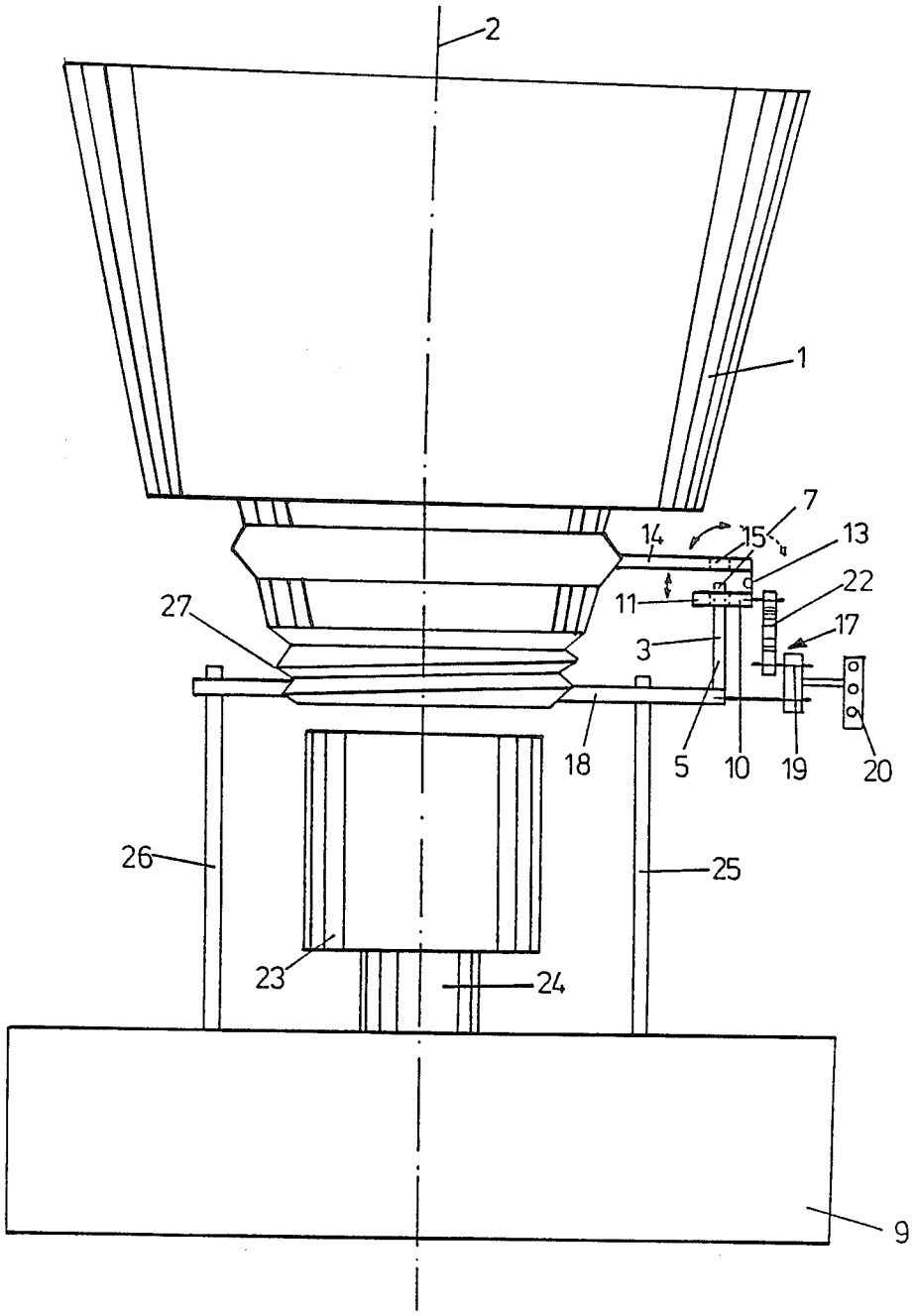


FIG. 1

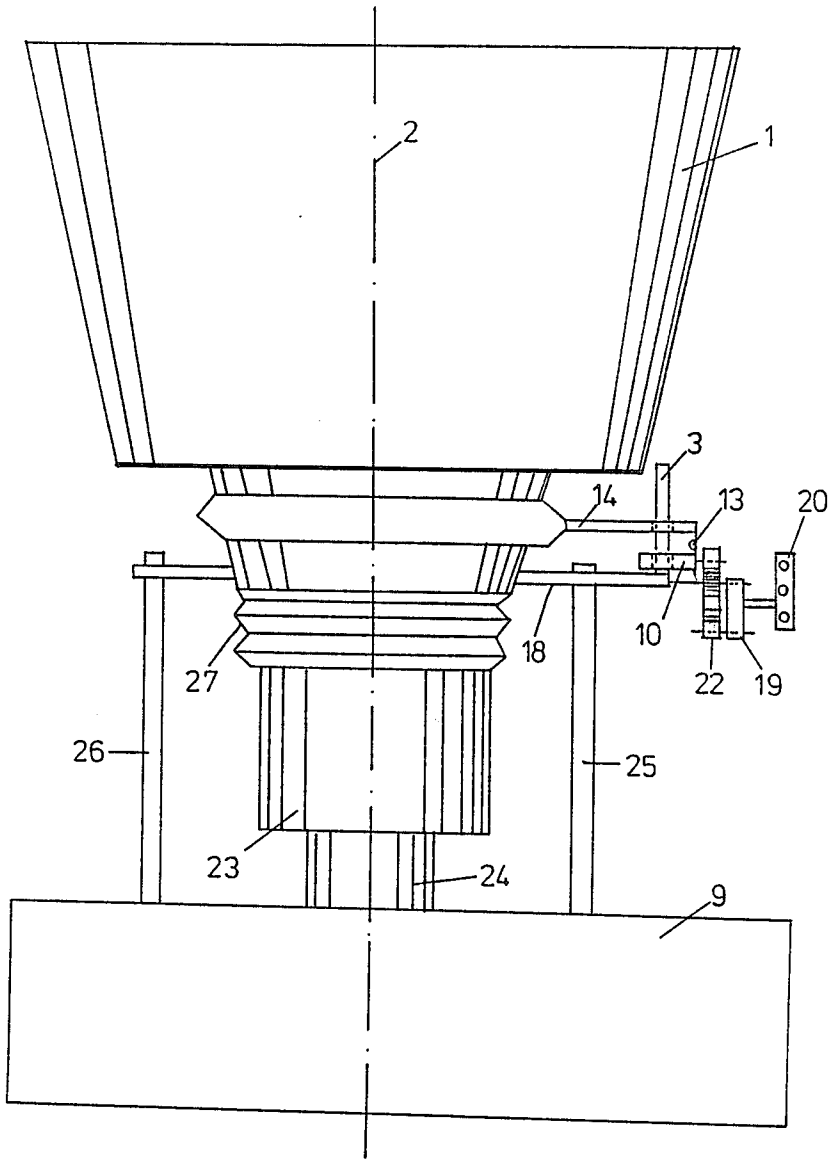


FIG. 2

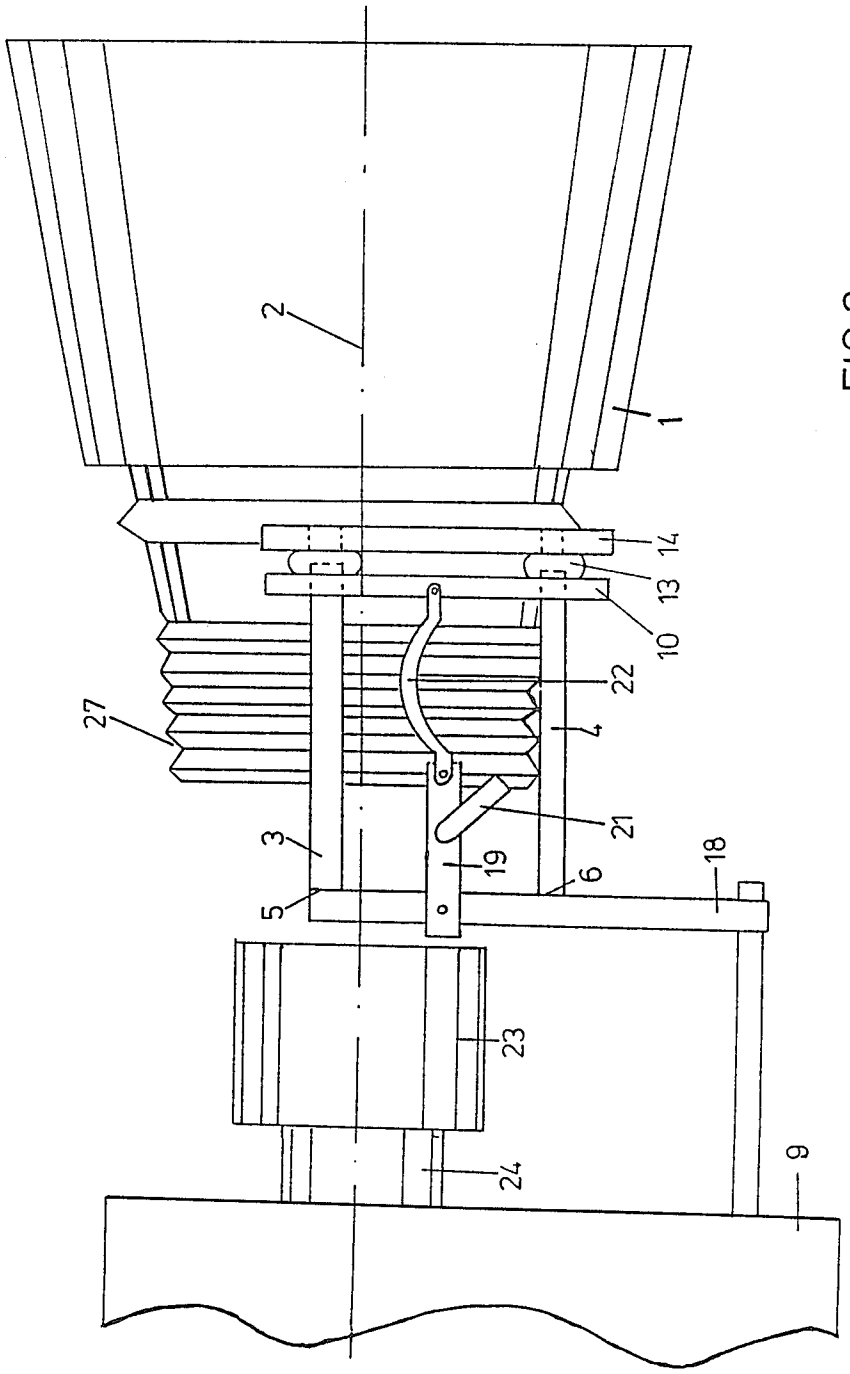


FIG.3

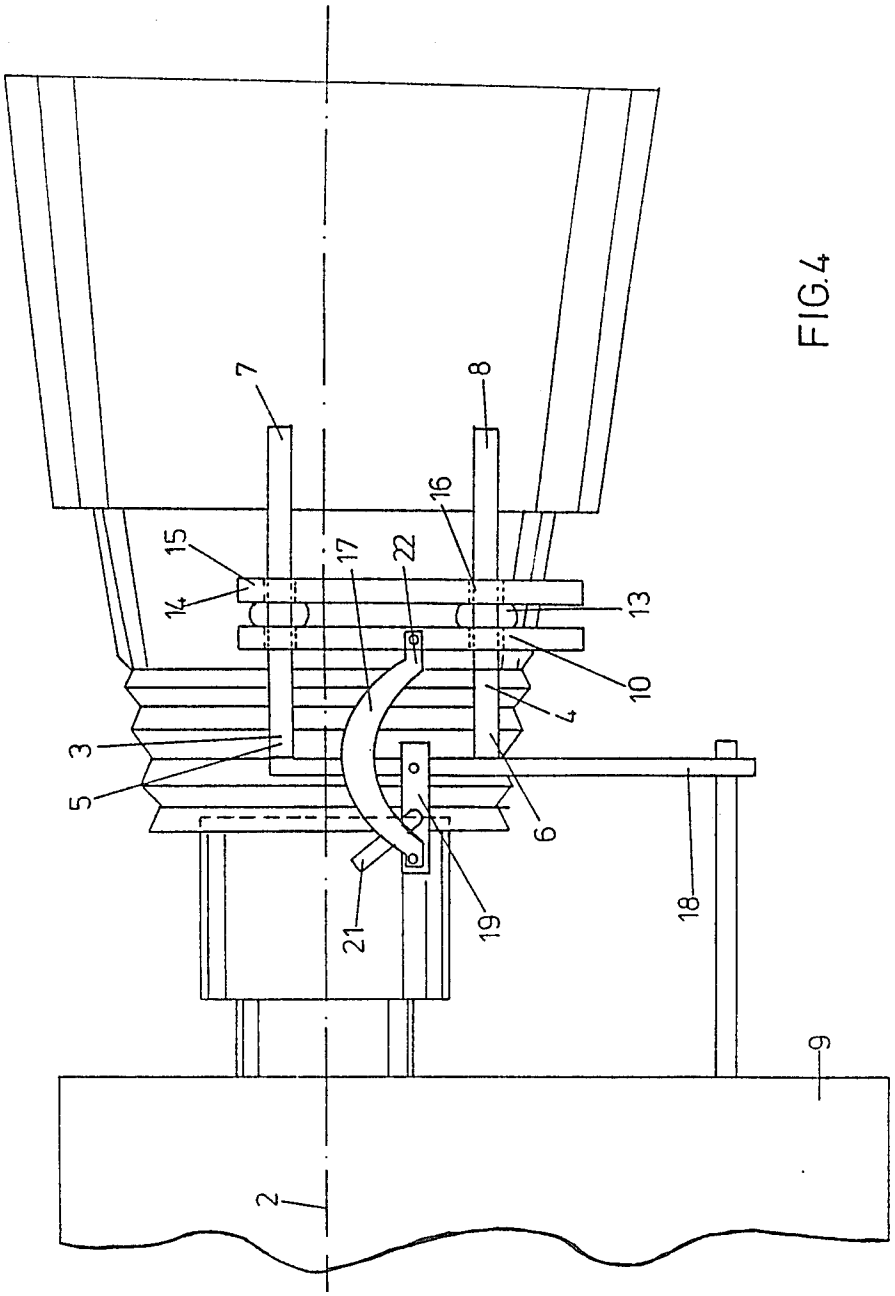


FIG.4

SWINGABLE HOLDER FOR ANTERIOR ACCESSORIES OF AN OBJECTIVE LENS

This invention concerns a holder for front-of-lens accessories for the objective lens of an optical system such as a photographic or television camera such that an accessory can be swung away from the optical path in use and swung back so that it fits over the front end of the objective lens. Such holders are particularly important for large objective lenses such as are used in professional motion picture and television cameras. In such cases, the objective lens mounting of the camera itself is integrated with the camera mount or holder, so that it is, as a rule, movably mounted on a stable stationary structure.

Such objective lenses in many cases have a relatively large diameter. The same holds also for the accessories to be mounted in front of it (hereinafter referred to as anterior accessories) such as sunshades, which are sometimes called "mattboxes", filter holders or combinations of sunshade and filter holders. These anterior accessories must fit closely over the lens in order to exclude stray light to a great extent, as a result of which the connection usually involves the provision of a flexible bellows. The anterior accessory must have a sufficiently large opening in order not to cut off any part of the field of wide angle objectives. In general, for certain sizes of wide angle objectives, only particular anterior accessories designed for such wide angle service can be used. The anterior accessories are so bulky and heavy that removing them by unscrewing or the like, as is done in the case bf cameras for amateur use, no longer makes sense. For these reasons, such anterior accessories are connected with the objective lens support by a displacement mechanism in order to shift the entire anterior accessory forward, thereby also making possible removal of the bellows which surrounds the objective lens at its free front end to keep out stray light when the accessory is in working position. Furthermore, in addition to the displacement mechanism, the holder for anterior accessories of the kind above discussed also has a mechanism for swinging the accessories out of the optical path. This has form of a two-part articulation which makes it possible, after the forward displacement of the accessory holder, to swing the entire anterior accessory to one side, or up, or down, away from the objective lens.

In the known holders above described for anterior accessories suitable for large lenses, the mount for the anterior accessories must first be brought forward with effort and some difficulty, then a positioning catch for the swing mechanism must be released and finally, the anterior accessory must be swung outside of the picture angle of the lens in order to carry out various necessary operations, such as removal of the lens for checking it and possibly cleaning of the film plate, or replacing the lens with another objective lens. After any of these operations for checking or replacing the lens, all of the described stages must be carried out in reverse sequence to put the anterior accessory back in working position.

Displacing the anterior accessory holder away from the lens requires much effort and the releasing of the positioning catch or lock is troublesome, all of which, in situations requiring a quick change of lens, can have the result that certain scenes cannot be correctly recorded on tape or film or correctly given live television reproduction.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a mounting for anterior accessories for objective lenses in such a form that the release of the swinging mechanism is simplified.

Briefly, a guide rail, and preferably two of them, are disposed parallel to the axis of the lens having one end fixed in place on the lens support, which may be the camera body or similar structure. The guide rail has free ends at which an articulation structure is provided having an inner member mounted shiftably on the guide rails and an outer member articulated to the inner member by a swing joint and connectable also to an anterior accessory for the lens, the inner and outer members being, in working position, essentially parallel to each other and at right angles to the guide rails. The easy release of positioning for permitting swinging is made possible by providing apertures in the outer member directed towards the guide rails for locking the articulation of outer member in working position.

An important concept involved in the invention is to couple the positioning of the swinging mechanism with the linear displacement mechanism of the anterior accessory holder in such a way that the positioning is automatically released when the forward displacement of the anterior accessory is complete and that after the swinging of the anterior accessory onto the lens axis and pushing it back towards the lens, the positioning lock snaps in place automatically. This is provided in such a way that, in the swingable outer member of the articulation, positioning holes are provided which are directed to and face guide rail ends when the accessory holder is in its forward position. When the anterior accessory is pushed onto the lens, the guide rails catch in these positioning holes and when the anterior accessory is shifted fully forwards, the free ends of the guide rails come out of the positioning apertures so that the swinging mechanism is automatically set free.

In a preferred embodiment, a drive is provided between the attachment frame for the fixed ends of the guide rails and the inner member of the articulation which can displace the anterior accessory forward and back over a predetermined distance. The most varied kinds of means can be used for such a drive, for example, an electric motor, a rack rod engaging a rotatable gear or a spring mechanism.

The drive preferably consists of an eccentric device, of the over-center lever type. An eccentric arm has a forward position in which its length is additive to that of a swinging lever actuated by it and a rearward position where its length is subtracted from that of the swinging lever, in determining the distance of the articulation from the mounting frame for the fixed ends of the guide rails. A manipulation lever is linked or fastened to the eccentric lever to supply torque to the eccentric movement. The length of the guide rails, the size relations and the dimensional ratios of eccentric arm and swinging lever can be so determined that by rotation of the eccentric arm in a first direction by 180° a defined positioning of the anterior accessory at or against the lens can be obtained and by rotation about 180° in the opposite direction a shifting away of the anterior accessory from the lens by a defined distance results as well as a simultaneous clearing of the positioning openings. It is particularly useful for the middle section of the swinging member to be arcuately shaped to facilitate handling and also the development of the

necessary torque for the actuation of the eccentric drive.

With such a drive, an anterior accessory at a working position at or against the front of the objective lens can be shifted forward with a single lever movement by a precisely defined amount and with a small use of force up to a final stop position and the rotary mechanism will thus be immediately freed and the anterior accessory can then be swung out of the field of view of the lens for a lens change or other necessary operation. When that operation is completed, the anterior accessory can be swung back to the optic axis of the lens after which a single lever movement of 180° in the opposite direction can lock the accessory in position and perform the exact return of the bellows of the accessory onto the lens. Furthermore, on account of the frictional conditions present intermediate positioning of the eccentric arm by its manipulating lever is possible to a certain degree. That can produce a somewhat modified spacing of the anterior objective from the lens for the same lens focal length, or adapt an anterior accessory for a somewhat larger range of lens focal lengths. Changing the spacing modifies the angle of incidence conditions at the accessory.

Another possible use of the intermediate positioning of the advance and retraction lever is to accommodate to a certain extent the use of lenses of different physical (barrel) length. In this case, an intermediate positioning of the displacement lever can provide a precise placing of the bellows on the end of the lens for different lens barrel lengths.

The accessory mounting of the present invention makes single-handed manipulation possible with minimum amount of applied force, whereas heretofore displacement required effort with the use of both hands and a danger of putting the overall camera support out of adjustment.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention is further described by way of illustrative example with reference to the annexed drawings, in which

FIG. 1 is a top view of a laterally disposed anterior accessory holder with the anterior accessory shifted into its forward (non-working) position;

FIG. 2 is a top view like FIG. 1 with the anterior accessory in its working position on the lens;

FIG. 3 is a side view corresponding to the top view shown in FIG. 1, and

FIG. 4 is a side view corresponding to the top view in FIG. 2.

DESCRIPTION OF THE ILLUSTRATED EMBODIMENT

In the several figures of the drawings, the same parts are designated with the same reference numerals.

FIG. 1 shows the accessory 1 in a location centered on the optic axis 2 of the lens 23. The lens 23 is mounted on the objective lens support 9 by means of an intermediate member 24. For reasons of simplification of the drawings, the remaining components are not shown, especially those in the light transmission path from the lens 23 to the camera (not shown) located behind the end support 9 which may be a front surface of the camera. The stationary structure to which the end support 9 and the rest of the camera are fixed is likewise not shown.

Beneath the lens 23 two rods 25 and 26, parallel to the optic axis of the lens are provided on which a sliding frame 18 can be shifted in forward and back adjustment to serve, in fixed position, as a mounting frame. At one side of the frame 18, a guide rail 3 is provided which is again parallel to the optic axis 2 and has a fixed end 5 connected rigidly to the frame 18. Parallel to the mounting frame 18 there is in FIG. 1 an outer member 14 of an articulation device which is connected by an articulation joint 13 with the inner member which runs parallel to the outer member 14. The inner member 10 of the articulation device has a guiding feature, such as an aperture, collar or sleeve, which runs along the guide rail 3 and as can be seen in the side views of FIGS. 3 and 4, it also has a similar guiding feature 12 on a second guide rail 4 running parallel to the guide rail 3. Thus, as the inner articulation member 10 slides back and forth on the guide rails 3 and 4, the outer member 14 of the articulation and the complete accessory 1 connected to the outer member 14 likewise run back and forth on the guide rails 3 and 4.

FIG. 1 also shows a mechanical drive 17 which consists essentially of an eccentric arm 19, a swinging eccentric drive member 22 and a manipulating lever 20. The front section of the swinging member 22 is mounted so as to pivot on the inner member 10 of.the articulation device. The free rear end of the swinging member 22 is connected to rotate with the free end of the eccentric arm 19, whereas the other end of the eccentric arm 19 is mounted so as to rotate about a pin on the mounting frame 18. In the neighborhood of the bearing pin on which the eccentric 19 turns, an actuating lever, already mentioned, is provided which has openings in which, if needed, there can be fastened a rod for more easily actuating the lever 20 and the eccentric arm 19.

FIG. 2 clearly shows the same arrangement as FIG. 1, except that the accessory 1 is in this case placed at the front end of the lens 23. Such placing of the accessory is produced by means of a mechanical drive by rotating the actuating lever 20 and the arm 19 by 180°. In contrast with FIG. 1, FIG. 2 shows the free end 7 of the guide rail 3 projecting through the positioning aperture 15 of the outer member 14 of the articulation device, so that in this case, the accessory 1 is fixed against swinging movements. The bellows 27 at the rear end of the accessory 1 surrounds the free front end of the lens 23. It can further be seen from FIG. 2 that the eccentric 19 is turned by 180° to the rear and likewise the actuating lever 20 connected to it, as compared with FIG. 1. The rotation of the lever 20 by 180° to the rear produces a corresponding rotation of the eccentric 19 on which the lever is fixed and which is mounted to rotate on the free end of the swinging member 22. In that way, the articulation device 10, 13, 14 connected with the swinging member 22 and the accessory 1 fastened thereto are rearwardly displaced towards the front of the lens 23.

FIG. 3 shows a side view of the accessory holder of the invention in its position shown in top view in FIG. 1, i.e., with the accessory 1 shifted forwards. It is particularly evident from FIG. 3 that there are two guide rails 3 and 4 which are parallel to each other and parallel to the optic axis 2 of the lens and that their respective rear ends are fixed in place on the mounting frame 18 which is mounted from below and from the rear and is itself connected with a rod 25 (and a rod 26 as shown in FIG. 1), preferably in a swingable but also fixable manner, the

rods 25 and 26 being connected to the lens support structure 9.

The shift lever 21 is in this case (FIG. 3), unlike the shift lever of 20 of FIGS. 1 and 2, shown in an oblique position extending downward and forward although it preferably lies in the same plane as the eccentric arm 19. It is so shown for reasons of making it more readily seen. For simplifying handling and manipulation, and to some extent for increasing the available torque, the middle section of the swinging member 22 is arched or bowed, preferably upwards. The articulation structure with its inner member 10, outer member 14 and the articulation joint 13 inbetween, is also visible in FIG. 3. The inner member 10 has guideways 11 and 12 respectively for the upper guide rail 3 and the lower guide rail 4. The outer member 14 has positioning (locking) holes 15 and 16 which are located and directed to receive the free ends 7 and 8 of the guide rails 3 and 4.

FIG. 4 is a side view of the subject matter shown in top view in FIG. 2, namely the accessory 1 in place, in its holder, on the lens 23. In contrast with FIG. 3, it is here noticeable that the accessory 1 is displaced rearwardly, to the left in the drawing, so that the free ends 7 and 8 of the respective guide rails 3 and 4 pass through the positioning or locking apertures 15 and 16 FIG. 4 furthermore shows an altered position of the eccentric 19 and of the actuating lever 21, rotated by 180° counterclockwise compared to FIG. 3. It can be seen that in FIG. 3 the eccentric arm effectively adds its length to that of the swinging link member 22, and in FIG. 4 subtracts its length therefrom in determining the spacing of the member 13 from the frame 18.

Although the invention has been described with reference to a particular illustrative embodiment, it will be understood that variations and modifications are possible within the inventive concept. For example, a single guide rail of suitable profile, perhaps of cross-shaped cross-section, might be used instead of the two guide rails 3 and 4, or, on the other hand, three or four guide rails could be used instead of two, in each case modifying the aperture pattern in the outer articulation member 14 and, if necessary, the shape and dimensions of the latter to fit the new guide rail pattern.

I claim:

1. Accessory holder for holding accessories in front of an objective lens of an optical system, said lens having an optic axis and being mounted on a supporting structure located rearwardly thereof, comprising:

at least one guide rail (3, 4) disposed parallel to said optic axis (2) of said lens (23), said at least one guide rail having one end (5, 6) fixed in place on said supporting structure (9) of said lens and having another end (7, 8) which is a free end;

articulation structure comprising inner (10) and outer (14) members held together by an articulation joint (13) having an axis, for permitting swinging of said outer member (14) relative to said inner member (10) about said joint axis, said inner member (10) being mounted for movement along said at least one guide rail in a manner maintaining said articulation axis perpendicular to said at least one guide rail and said outer member (14) having a locked position relative to said inner member wherein at least one aperture of said outer member are penetrated by said at least one guide rail thereby locking said outer member (14) in an orientation perpendicular to said optic axis, and;

means for mounting, on said outer member (14) of said articulation structure, at least one accessory for said lens having an optic axis so that in said locked position of said outer member (14) said optic axis of said accessory substantially coincides with said optic axis of said lens, and

said inner member (10) of said articulation structure being displaceable along said at least one guide rail from a first position in which said accessory is in a working position at the front end of said lens to a second position in which said inner member (10) is located on said at least one guide rail near its said free end while said outer member (14) of said articulation structure is beyond said free end of said at least one guide rail, and back from said second position to said first position,

said outer member being provided with at least one said aperture corresponding to the location of said at least one guide rail for locking said outer member against swinging about said articulation axis when said articulation structure occupies its said first position and during its approach to and travel away from its said first position.

2. Accessory holder for holding accessories in front of an objective lens of an optical system, said lens having an optic axis and being mounted on a supporting structure located rearwardly thereof, comprising:

a plurality of guide rails (3, 4) disposed parallel to said optic axis (2) of said lens (23), said guide rails each having one end (5, 6) fixed in place on said supporting structure (9) and each having another end (7, 8) which is a free end;

an articulation structure comprising inner (10) and outer (14) members held together by an articulation joint (13) having an axis, for permitting swinging of said outer member (14) relative to said inner member (10) about said joint axis, said inner member (10) being mounted for movement along said guide rails (3, 4) in a manner maintaining said articulation axis perpendicular to said guide rails (3, 4) and said outer member (14) having a locked position relative to said inner member wherein apertures of said outer member (14) are respectively penetrated by said guide rails, thereby locking said outer member (14), in an orientation perpendicular to said optic axis; and

means for mounting, on said outer member (14) of said articulation structure, at least one accessory for said lens having an optic axis so that in said locked position of said outer member (14) said optic axis of said accessory substantially coincides with said optic axis of said lens,

said inner member (10) of said articulation structure being displaceable along said guide rails (3, 4) from a first position in which said accessory mounted on said outer member is in a working position at the front end of said lens (23) to a second position in which said inner member (10) is located on said guide rails (3, 4) near their respective free ends (7, 8) while said outer member (14) of said articulation structure is beyond said free ends (7, 8) of said guide rails,

said apertures (15, 16) of said outer member (14) having a size and shape corresponding to the respective sizes and shapes of the cross-sections of said respective guide rails and a disposition corresponding to the disposition of said guide rails with respect to each other, for locking said outer member

against swinging about said articulation axis when said articulation structure occupies its said first position and during its approach to and travel away from its said first position.

3. The accessory holder of claim 2 including also a frame (18) mounted on said supporting structure (9) of said lens, on which said frame said fixed ends (5, 6) of said guide rails (3, 4) are fastened, and means (17) for facilitating and controlling the shifting of said inner member (10) of said articulation structure back and forth on said guide rails for displacing a said accessory mounted on said outer member (14) back and forth over a predetermined path length.

4. The accessory holder of claim 3, wherein said means for facilitating and controlling displacement comprise:

an eccentric member (19) having a first pivot about which it is rotatable and an eccentric pivot spaced therefrom;

a link member (22) pivotally linked at one end to said eccentric member at said eccentric pivot thereof and having a pivot at its other end defining one working end of said means for facilitating and controlling the displacement of said inner member, the other working end thereof being said first pivot of said eccentric member, said two working ends of said means for facilitating and controlling displacement of said inner member being respectively fixed on said inner member (10) and on said frame (18), and

an appendage (20, 21) extending from said eccentric member for manually applying force thereto and capable of rotating said eccentric member (19) at least 180° about its said first pivot.

5. The accessory holder of claim 4, wherein said first pivot of said eccentric member (19) is disposed for permitting said eccentric member to rotate about a fixed location on said frame (18) and said pivot of said link member at its end remote from said eccentric pivot of said eccentric member is located to permit to said link member (22) to swing about a fixed location on said inner member (10) of said articulation structure, the length of said guide rails and the dimensional ratios of the distances between the pivots of said eccentric member and between the pivots of said link member are such that 180° rotation of said eccentric member in one direction produces an accurate apposition of a said accessory mounted on said outer member (14) at the front of said lens (23) and a rotation by 180° of said eccentric member in the opposite direction provides a displacement of said accessory away from said lens for a predetermined distance to a location where said apertures (15, 16) of said outer member (14) of said articulation structure are cleared and said outer member (14) is thereby released for swinging about said articulation axis.

6. The accessory holder of claim 5, wherein the mid portion of said link member (22) is bowed so as to assure clearance between said link member and said first pivot of said eccentric member when said accessory is held close to said lens by said accessory holder.

7. The accessory holder of claim 5, wherein said outer member (14) of said articulation structure holds a sun shade, a filter, or both a sun shade and a filter.

* * * * *

United States Patent [19]

Muraoka et al.

[11] **Patent Number: 4,750,812**

[45] **Date of Patent: Jun. 14, 1988**

[54] **OBJECTIVE OBSERVATION OPTICAL MATERIAL**

[75] Inventors: **Koji Muraoka**, Sabae; **Fumiki Tatibana**; **Katsuhiko Nakatsuka**, both of Fukui; **Hiroyuki Niwa**, Sabae; **Tadahiro Yamatani**, Fukui, all of Japan

[73] Assignee: **Kabushika Kaisha Shuho**, Fukui, Japan

[21] Appl. No.: **820,937**

[22] Filed: **Jan. 21, 1986**

[30] **Foreign Application Priority Data**

Jan. 24, 1985 [JP] Japan 60-9849
Feb. 15, 1985 [JP] Japan 60-26473
Feb. 28, 1985 [JP] Japan ..... 60-27244[U]

[51] **Int. Cl.**[4] **G02B 27/02**; G02C 7/16

[52] **U.S. Cl.** ..... **350/319**; 350/276 R; 351/46

[58] **Field of Search** ..... 350/319, 322, 276 R; 351/44-46; 206/294, 485; 283/105; 281/29, 42, 50; 224/164

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Primary Examiner—John K. Corbin
Assistant Examiner—Loha Ben
Attorney, Agent, or Firm—Thomas H. Whaley

[57] **ABSTRACT**

An objective observation optical material comprises a sheet material composed of a plurality of spot-like transparent portions and an opaque portion and each of the spot-like transparent portions is formed into a circular shape having preferably a diameter of 0.7 to 2.0 mm or substantially a polygonal shape (including one whose sides are curved arcuately) inscribing or circumscribing such circle. The spot-like transparent portions are arranged to scatter in uniformly arranged positions so as to form connected regular triangles or squares whose sides are for example in the range from 2.0 to 5.5 mm.

13 Claims, 4 Drawing Sheets

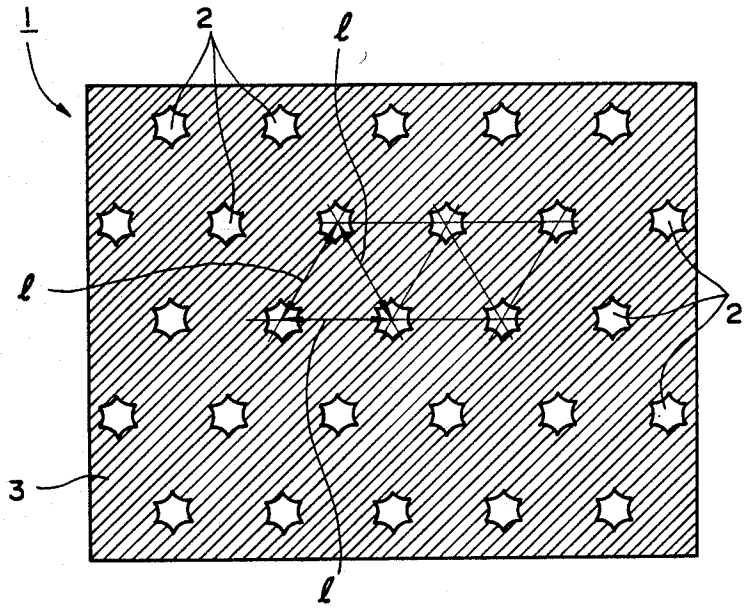


FIG. 1

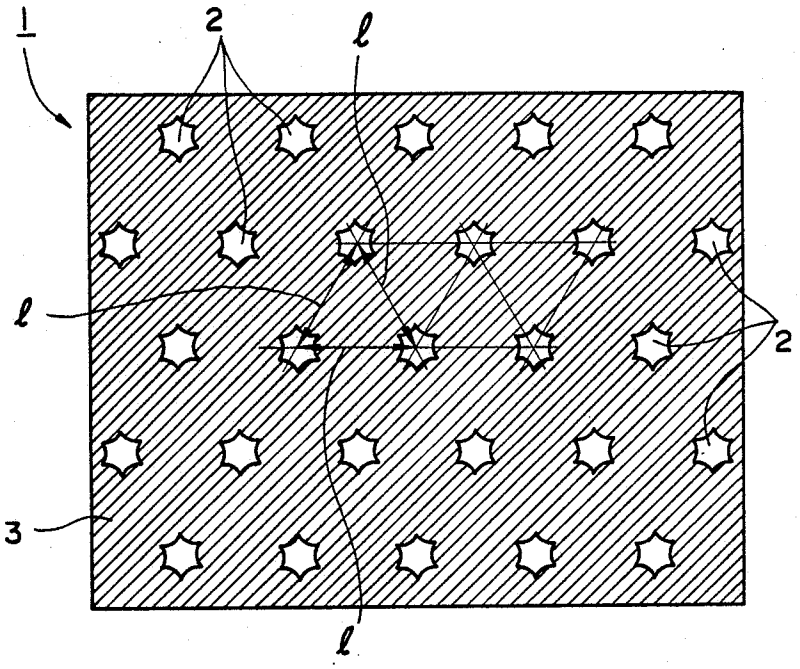


FIG.2A FIG.2B FIG.2C

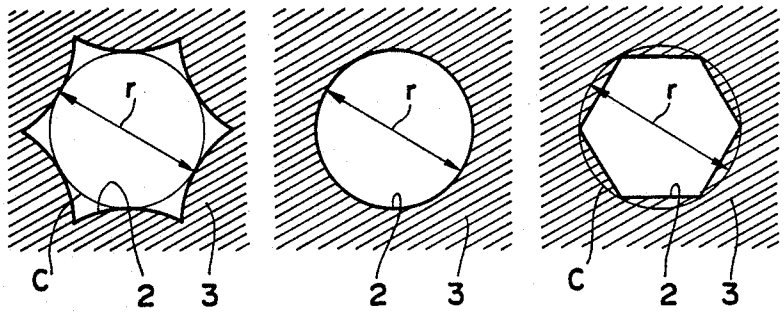


FIG. 3

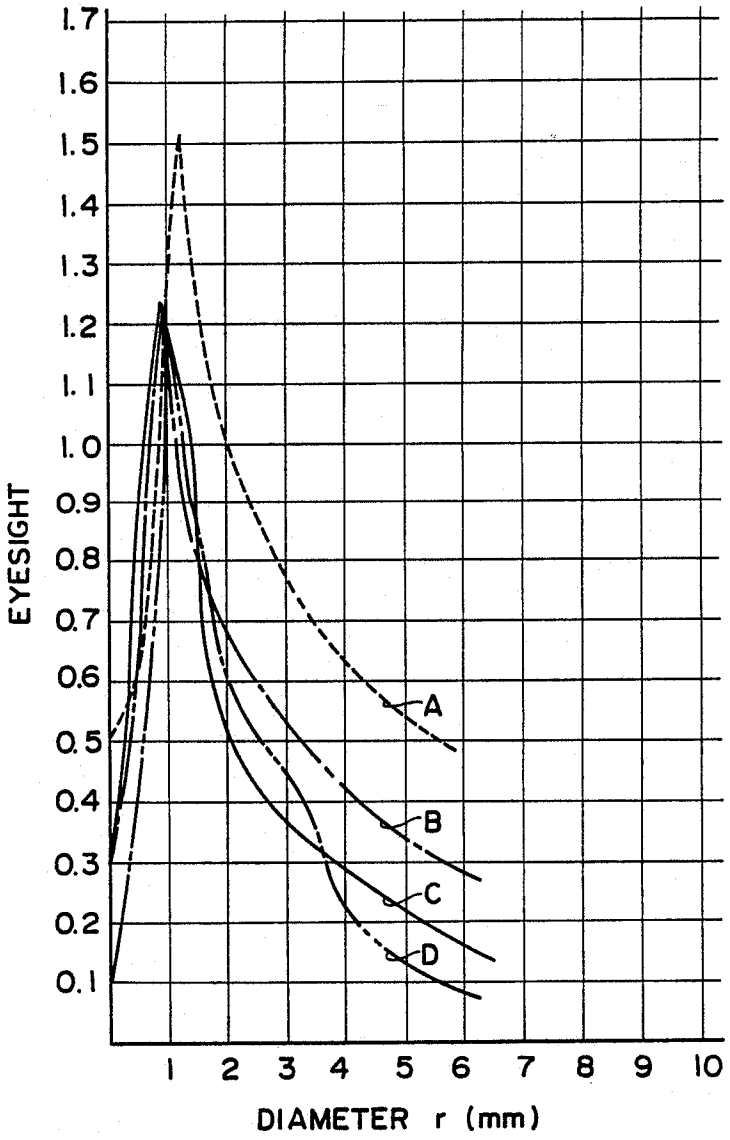

1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
EYESIGHT
A
B
C
D
1 2 3 4 5 6 7 8 9 10
DIAMETER r (mm)

FIG.4

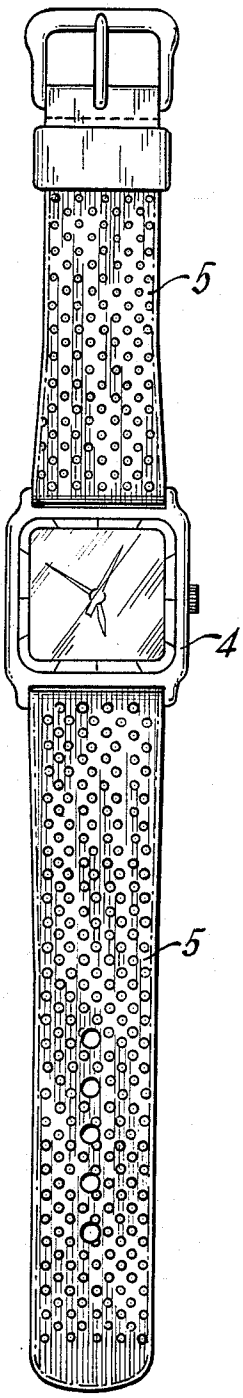


FIG.6

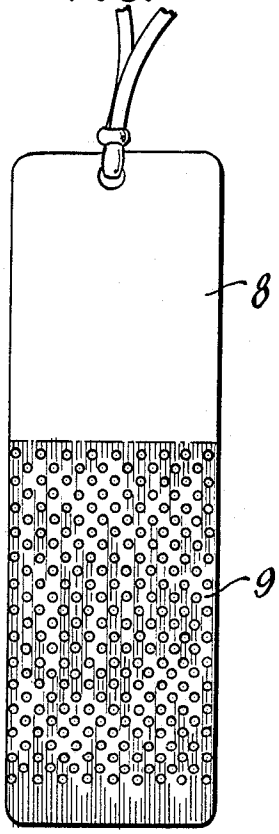


FIG.7

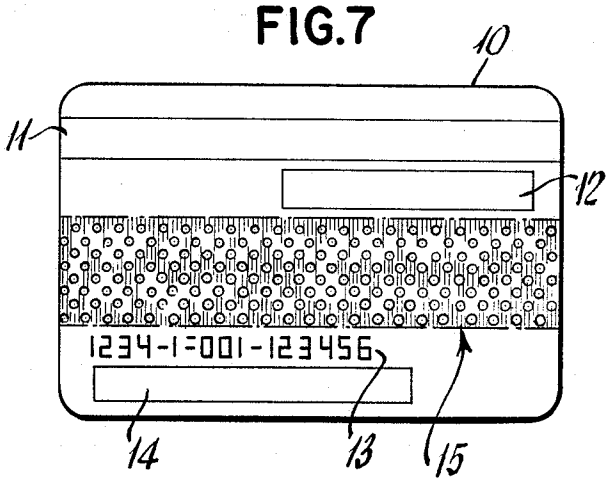
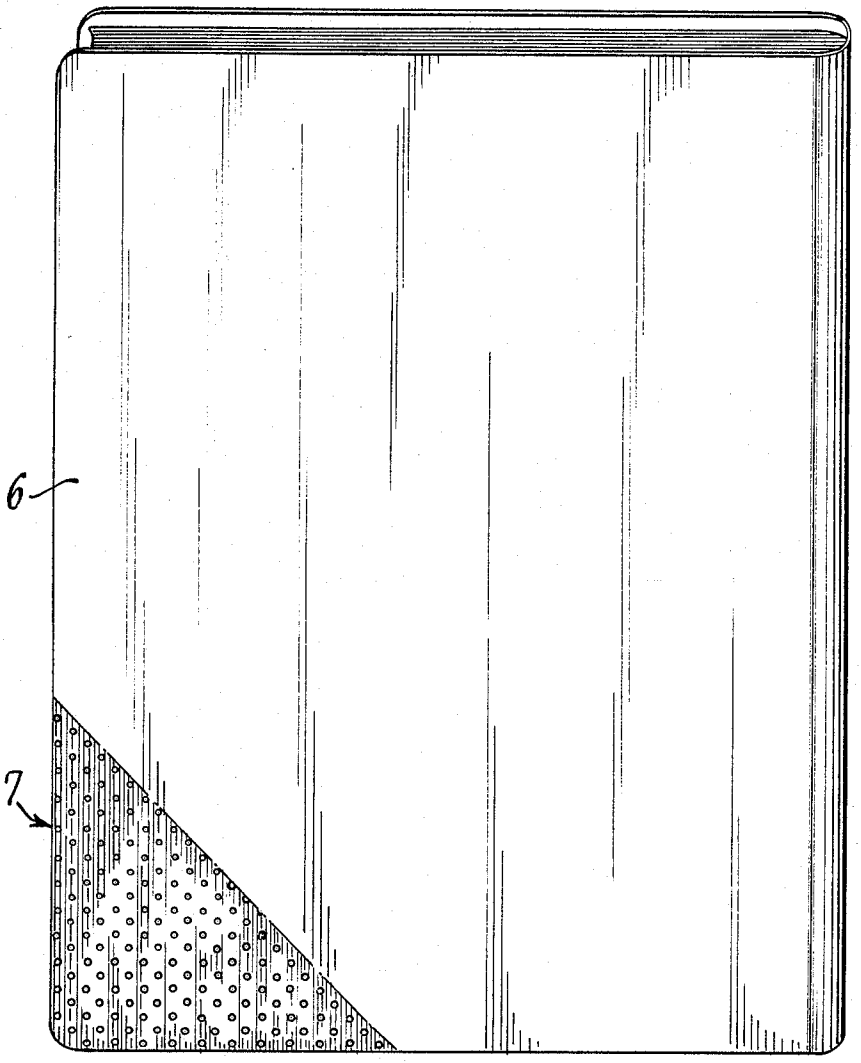


FIG. 5



OBJECTIVE OBSERVATION OPTICAL MATERIAL

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to an objective oberservation optical material capable of screening ultraviolet rays and correcting such defects of vision as nearsightedness, farsightedness, astigmatism and presbyopia.

2. Description of the Prior Art

In the past, generally the incidence of ultraviolet rays to the eyes has been prevented by the use of glasses made by providing parallel-surface glasses or plastic pieces with suitable light screening properties and/or absorbing properties with respect to specific wavelengths by adding a light screening or absorbing substance during their raw material stage, coloring the transparent glasses or applying a coating to the surface of the glasses, i.e., so-called sunglasses and in the case of the wearer having nearsightedness, farsightedness, astigmatism or presbyopia the glasses have consisted of lenses or other glasses have been worn on the sunglasses for correcting the defect of vision.

However, such sunglasses are expensive and often they are not used habitually thus requiring the provision of a case for carrying or accommodating the glasses. Also, in everyday life or when going out, particulary or for protection from the intense sunshine in the summer, the sunshine on a snowy day or the reflected light of such sunshine, it is necessary to use a more powerful ultraviolet screening substitute for glasses in place of the sunglasses and the same applies to any person having nearsightedness farsightedness, astigmatism or presbyopia.

SUMMARY OF THE INVENTION

It is the primary object of the present invention to provide an objective observation optical material which is so designed that where such a situation occurs in a moment and sunglasses and correction glasses are not on hand but a person is required to look at a thing, it is possible to use the material for providing in place of such glasses any of those things kept at one's side or carried on the person, e.g., a stationery such as an underlaying sheet or ruler, a book cover, a bookmarker, a corner of a book cover, a cash card, credit card or member's card, a watch band, a shoulder belt for bags or a tag.

In other words, in accordance with the invention the objective observation optical material comprises an opaque sheet formed with a large number of uniformly scattered spot-like transparent portions and each of the spot-like transparent portions is formed into a circular shape having a diameter in the range of 0.7 to 2.0 mm or substantially a polygonal shape inscribing or circumscribing this circle (including one whose sides are each curved arcuately). The transparent portions should preferably be scattered uniformly in a staggered manner, for example, so that their center distance becomes 2.0 to 5.5 mm. Suitable materials for the above-constructed optical material of this invention must be substances having a suitable strength, physical properties, elegance and durability required for use as the materials for the previously mentioned articles as well as the capacity for maintaining the transparency of the transparent portions for a comparatively long period of time and these substances include for example plastics such as soft or hard polyvinyl chloride, polyacrylic, methacrylic acid, polyurethane, polyolefin and polyester plastics. It is to be noted that the transparent portions may take the form of holes made through the material and the material may be an opaque material such as a metal sheet. There is no particular need to limit the material to the above-mentioned plastics.

On the other hand, means for forming the spot-like transparent portions and the opaque portion separately from each other may be a method in which an opaque portion is printed by photogravure on the surface of a transparent sheet of such plastic material so as to leave spot-like blank portions and then a transparent film is applied onto the printed surface or it may be a method of printing an opaque layer over the whole surface of a transparent film and forming transparent portions or holes by such means as etching or punching. Also, any of various other methods may be used.

The thus constructed objective observation optical material of this invention is used daily in conformity with the purpose for which the article is primarily intended so that when a need occurs in a moment to confirm an object in a place where ultraviolet rays are abundant irrespective of indoor or outdoor, the optical material is held in front of the eyes to face and look at the object or view a field. In such a case, the amount of the incident light to the eyes through the spot-like transparent portions is restricted considerably by the opaque portion and one may gaze or stare at the object with open eyes. As a result, the eyes unconsciously make movements to distinguish the object in sight so that the ciliary body or the structure for adjusting the curvature of the crystalline lens in front of the eyeball of each eye functions naturally in such a manner that the curvature is decreased if the person is nearsighted and the curvature is increased if the person is farsighted thereby permitting detailed observation of the object.

Thus, not only a person of the normal vision but also a person having nearsightedness, farsightedness, astigmatism or presbyopia can comparatively accurately look at an object through the optical material according to the invention.

This principle is similar to that of a pinhole camera which takes a picture through a minute aperture so that even if there are variations in the relative distance of an object corresponding to the object to be photographed in the case of a camera, the focal point is not varied much owing to the long depth of focus and therefore the object can be seen clearly through the optical material.

The above and other objects as well as advantageous features of the invention will become more clear from the following description taken in conjunction with the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a partial plan view showing in enlarged form an embodiment of an optical material according to the invention.

FIGS. **2A**, **2B** and **2C** show some exemplary geometrical shapes of the spot-like transparent portions.

FIG. **3** is a graph showing the relation between the hole diameter and the eyesight (directional eyesight or the definition of an object viewed through the holes formed in the optical material of FIG. **1**.

FIG. **4** is a plan view of a watch band made of the optical material shown in FIG. **1**.

FIG. 5 is a plan view of a book cover incorporating in corner thereof the optical material shown in FIG. 1.

FIG. 6 is a plan view of a bookmarker incorporating in a part thereof the optical material shown in FIG. 1

FIG. 7 shows an example in which the optical material of FIG. 1 is incorporated in a cash card.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to FIGS. 1, 2A, 2B and 2C, numeral 1 designates an optical material according to the invention, and 2 a plurality of spot-like transparent portions formed into a polygonal shape such as one whose sides circumscribe a circle of a diameter r and are arcuately curved as shown in FIG. 2A, a circular shape of a diameter r as shown in FIG. 2B or a polygonal shape inscribing a circle of a diameter r as shown in FIG. 2C. A plurality of such spot-like transparent portions 2 are each arranged at the apex of each of a plurality of contiguous regular triangles whose sides have a length of 2.0 to 5.5 mm as shown at l in FIG. 1 and thus the transparent portions 2 are arranged in a staggered manner. Numeral 3 designates an opaque portion. FIGS. 2A and 2C show the hexagonal transparent portions and in FIG. 2A the sides of the hexagonal shape are curved inwardly.

Referring to FIG. 3, there is illustrated a graph showing the relation between the diameter r of the spot-like transparent portions 2 and the eyesight (directional eyesight) when looking at an object by using the optical material according to the embodiment of FIG. 1. From this Figure it will be seen that an essential requirement of the invention resides in that the diameter r of the plurality of spot-like transparent portions is selected between 0.7 and 2.0 mm and preferably between 1.0 and 1.2 mm.

It is to be noted that the spot-like transparent portions may take the form of spot-like holes formed through the material and it has been confirmed that from the standpoint of reducing the interference in the field of view it is preferable to arrange the transparent portions 2 uniformly at such positions that their center distance becomes 3.0 and 5.0 mm, that is, they are arranged to scatter in a staggered manner so as to form regular triangles or squares whose sides are between 2.0 and 5.5 mm.

While it is more desirable to use a plastic material for forming the optical material 1 in the light of physical properties, working properties in manufacture, cost and elegancy as mentioned previously, the invention is not necessarily limited to such plastic materials and the use of materials having the same effects is of course within the scope of the invention. Also, while a description has been made of suitable means for forming the holes or transparent portions 2 and the opaque portion 3, the invention is not limited to these means and a metal sputtering employing a mask and the like may also be used as effective means for the purpose.

From the foregoing description it will be seen that in addition to an essential application of an article made by using as its material the optical material of the invention, e.g., an underlaying sheet, ruler, book cover, corner of a book cover, part of a bookmarker, cash card, member's card, commutation ticket holder, watch band, shoulder belt for bags or tag, the optical material of this invention is not only effective for use as an objective observation optical material in place of sunglasses when its use is required to protect the user from the glare of ultraviolet rays such as the intense sunlight or the reflection from deep snows but also effective to correct such defect of vision as the nearsightedness, farsightedness, astigmatism or presbyopia. These effects are attained by the fact that the shape and size (area) of the plurality of spot-like transparent portions 2 as well as their positions in the opaque portion 3 are specified such that the adjacent transparent portions overlap in the field of view and there is no break in the field of view thereby providing the continuous field of view. On the other hand, a greater part of the ultraviolet rays to the field of view is blocked by the opaque portion 3 and also the field of view is continuous as mentioned previously. Thus, there is no obstruction from the vision point of view thus permitting to accurately look at an object in the intense ultraviolet rays.

FIG. 4 shows by way of example a watch band made of the optical material 1 shown in FIG. 1. In the Figure, numeral 4 designates the watch proper and 5 the band made of the optical material.

FIG. 5 shows an exemplary application in which the optical material 1 of FIG. 1 is incorporated in a portion 7 of a cover of a book cover 6 and the portion 7 is cut off the cover to read the book through it in place of glasses for far vision.

FIG. 6 also shows an exemplary application in which the optical material 1 of FIG. 1 is incorporated in a bookmarker 8 and a portion 9 of the bookmarker 8 is made of the optical material 1.

FIG. 7 shows another exemplary application in which the optical material of the invention is incorporated in a bank cash card. In the Figure, numeral 10 designates a card, 11 a magnetic recording zone, 12 a bank name stamping portion, 13 a registration number stamping portion, 14 a depositor's name stamping portion, and 15 scattering arranged spot-like transparent portions arranged in a centralized area of the card.

We claim:

1. An optical objective sheet material which is capable of permitting sufficient light transmission therethrough to support human vision, at least a part of the sheet being generally opaque but with a large number of spot-like transparent portions distributed uniformly thereover, each spot-like transparent portion being formed of substantially hexagonal shape inscribing a circle having a diameter in the range of 0.7 to 2.0 mm, the sides of the hexagonal shape being arcuately concaved and the transparent portions arranged in a staggered manner such that lines connecting their adjacent central points form regular triangles.

2. An optical material as claimed in claim 1 wherein the centers of adjacent transparent portions are spaced at distances in the range from 2 to 5.5 mm.

3. An optical material as claimed in claim 1 wherein the centers of adjacent transparent portions are uniformly spaced from one another at a distance in the range of 3 to 5 mm.

4. An optical material as claimed in claim 1, wherein each spot-like transparent portion comprises a hole formed through the sheet material.

5. A dual function assembly device comprising a readily portable and/or accessible object having, as a part of it, or associated with it, another object having a primary function, and also as a part of it, or associated with it, a piece of sheet material at least a portion of which has a secondary function of forming an optical objective which is capable of permitting sufficient light transmission therethrough to support human vision, at

least a part of the sheet being generally opaque but with a large number of spot-like transparent portions distributed uniformly thereover, each spot-like transparent portion being formed of substantially hexagonal shape inscribing a circle having a diameter in the range of 0.7 to 2.0 mm, the sides of the hexagonal shape being arcuately concaved and the transparent portions arranged in a staggered manner such that lines connecting their adjacent central points form regular triangles.

6. A device according to claim **5** wherein said device is a wrist watch band comprising said sheet material.

7. A device according to claim **5** wherein said sheet material forms a part of a book cover.

8. A device according to claim **2** wherein said spot-like transparent portions of said sheet material are confined to one corner of a book cover.

9. A device according to claim **5** wherein said sheet material comprises a bookmark.

10. A device according to claim **9** wherein said spot-like transparent portions are confined to an area no more than half the area of the bookmark.

11. A device according to claim **5** wherein said sheet material comprises a credit card or cash card.

12. A device according to claim **11** wherein said spot-like transparent portions are confined to a centralized area of said card.

13. A dual function device according to claim **5** wherein the centers of adjacent transparent portions are uniformly spaced from one another at a distance in the range of from 2 to 5 mm.

* * * * *

United States Patent [19]

Takamura

[11] **Patent Number: 4,741,606**

[45] **Date of Patent: May 3, 1988**

[54] **OBJECTIVE LENS SYSTEM FOR OPTICAL RECORDING AND READING DEVICE**

[75] Inventor: **Sachiko Takamura,** Kyoto, Japan

[73] Assignee: **Minolta Camera Kabushiki Kaisha,** Osaka, Japan

[21] Appl. No.: **894,636**

[22] Filed: **Aug. 8, 1986**

[30] **Foreign Application Priority Data**

Aug. 19, 1985 [JP] Japan 60-182320

[51] **Int. Cl.**[4] **G02B 13/18;** G02B 9/12

[52] **U.S. Cl.** **350/432;** 350/478

[58] **Field of Search** 350/432–435, 350/478

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Primary Examiner—John K. Corbin

Assistant Examiner—Scott J. Sugarman

Attorney, Agent, or Firm—Price, Gess & Ubell

[57] **ABSTRACT**

The present invention provides an objective lens system specifically designed for optically recording and reading digital data on an optical disc. The lens system includes three lenses, with one of the lenses having an aspherical surface. The first lens element can have a positive power with a spherical surface on its light source side. The second lens element can have a positive refractive power while a third lens element can also have a positive refractive power. The lens system can fulfill the following conditions.

$$-0.3 < f/r_1 < 0.25$$

$$|r_4/r_3| < 0.5$$

wherein:

f represents the focal length of the whole lens system;

r_1 represents the paraxial radius of curvature of the light source side aspherical surface of the first lens element;

r_3 represents the radius of curvature of the light source side surface of the second lens element; and

r_4 represents the radius of curvature of the disk side surface of the second lens element.

3 Claims, 6 Drawing Sheets

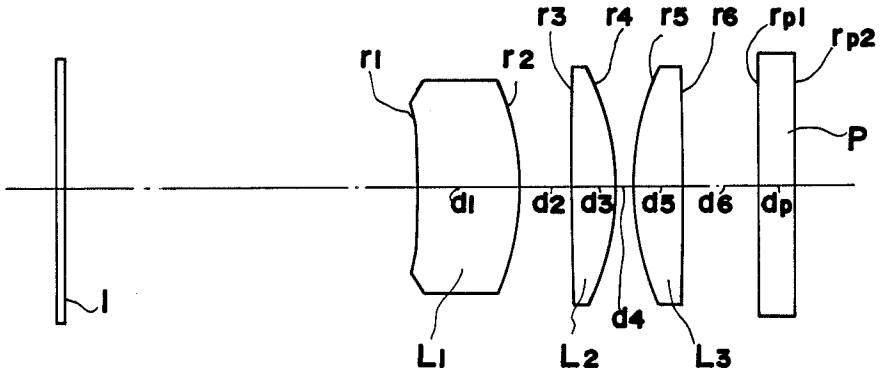


FIG.1

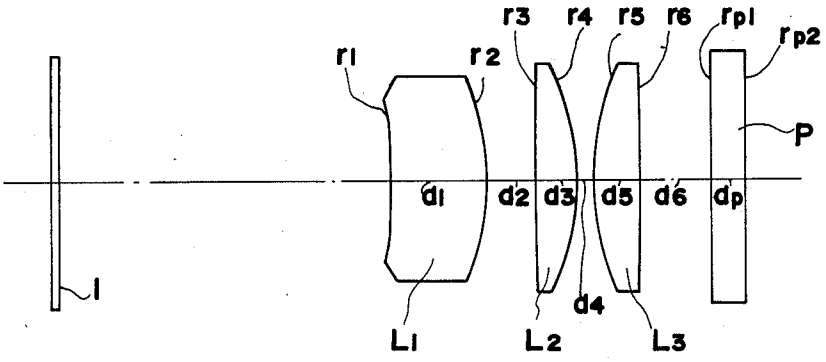


FIG.2

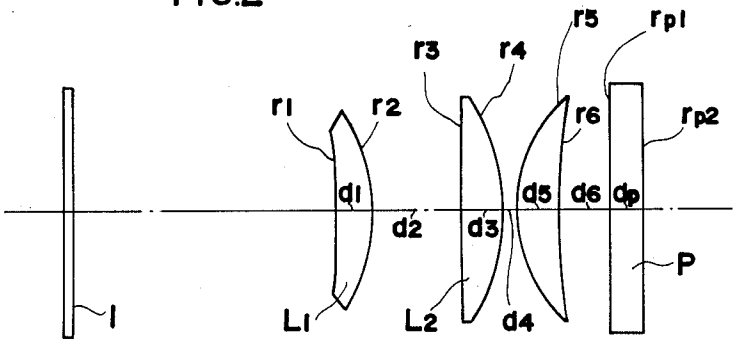


FIG.3

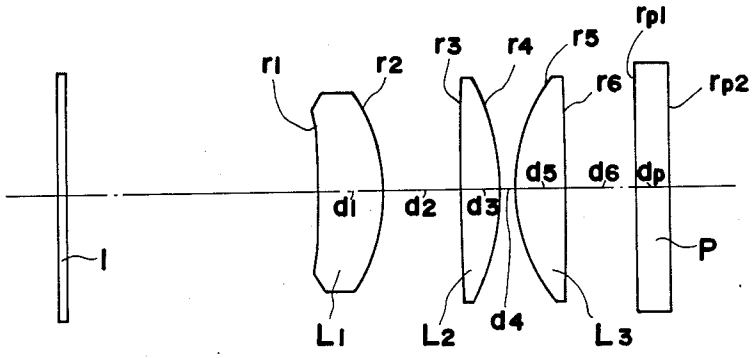


FIG.4A

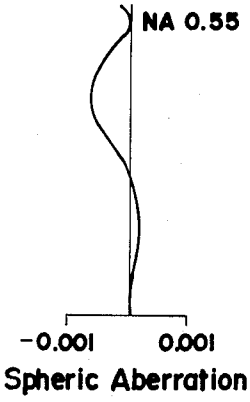


FIG.4B

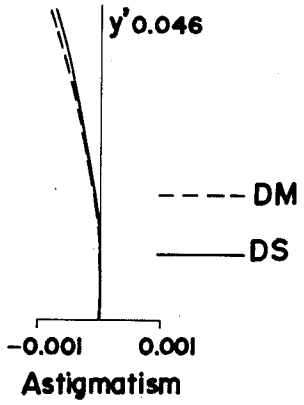


FIG.4C

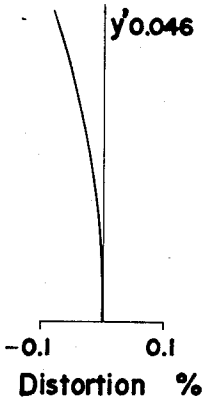


FIG.5A

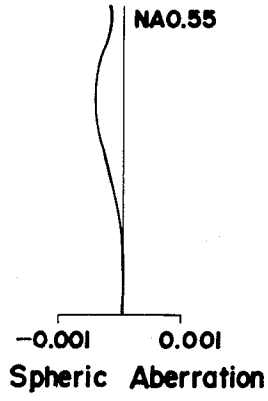


FIG.5B

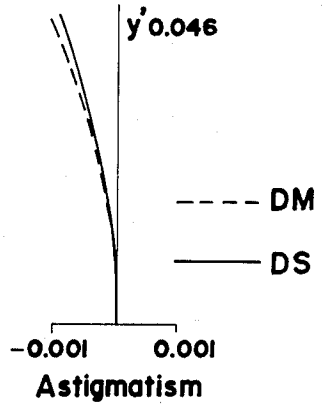


FIG.5C

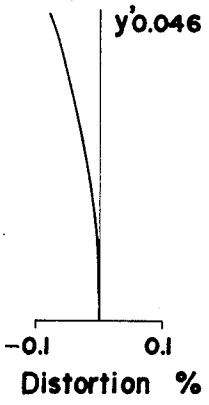


FIG.6A

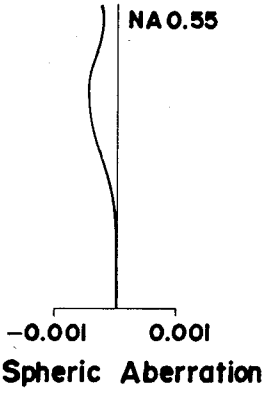


FIG.6B

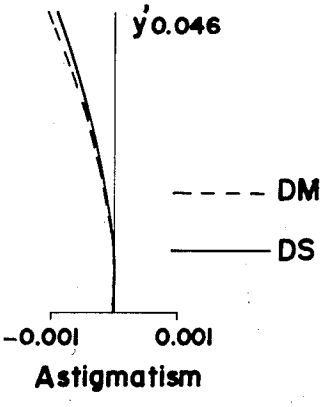


FIG.6C

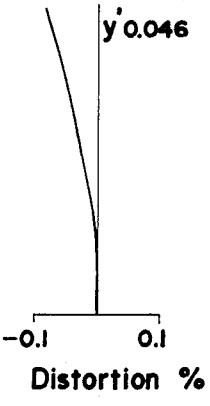


FIG.7A

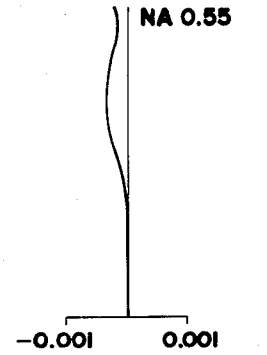


FIG.7B

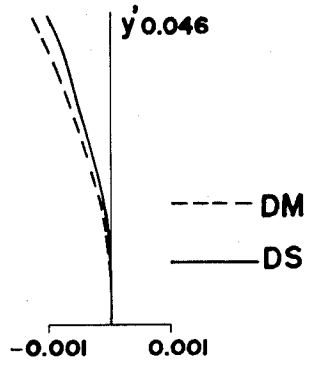


FIG.7C

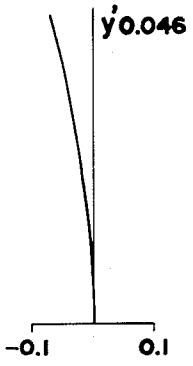


FIG.8A

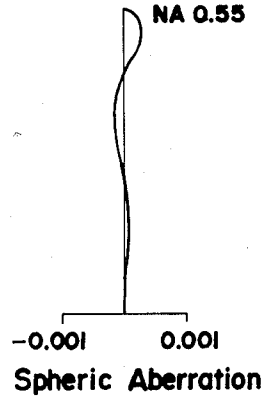


FIG.8B

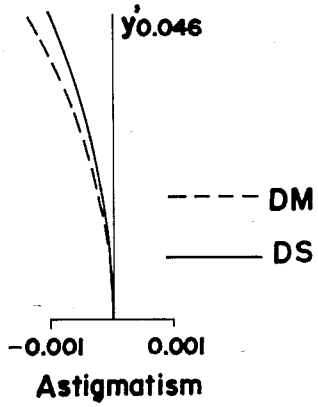


FIG.8C

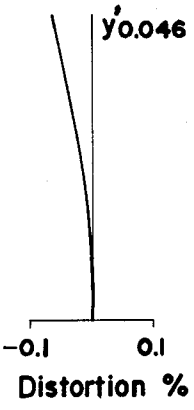


FIG.9A

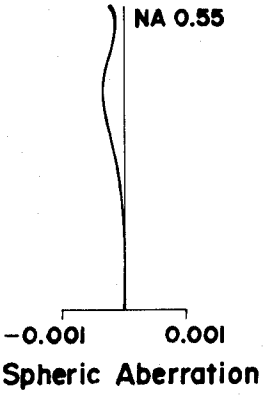


FIG.9B

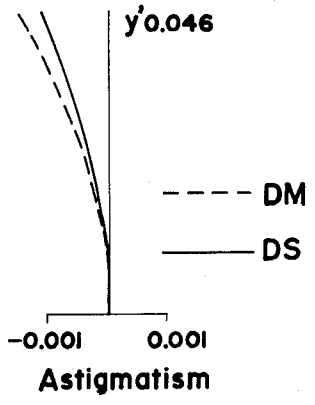


FIG.9C

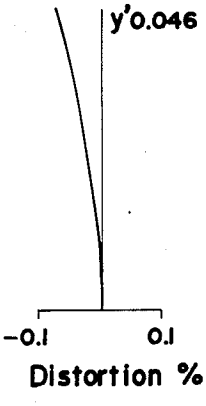
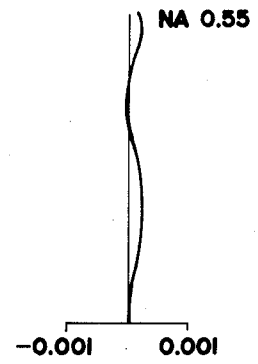
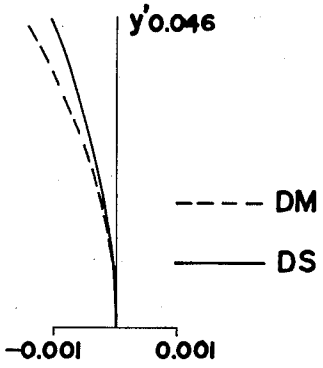


FIG.10A



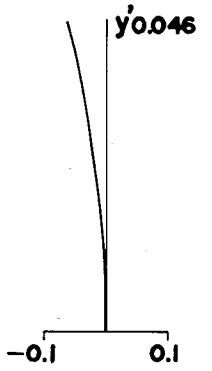
Spheric Aberration

FIG.10B



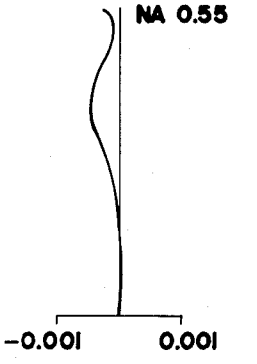
Astigmatism

FIG.10C



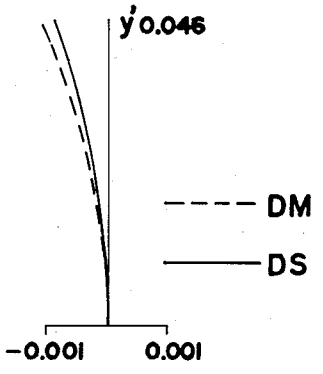
Distortion %

FIG.11A



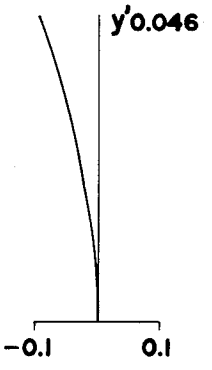
Spheric Aberration

FIG.11B



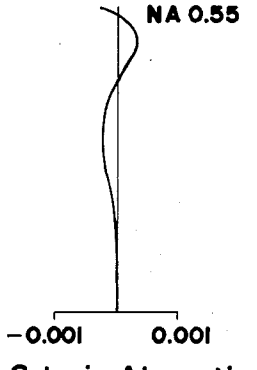
Astigmatism

FIG.11C



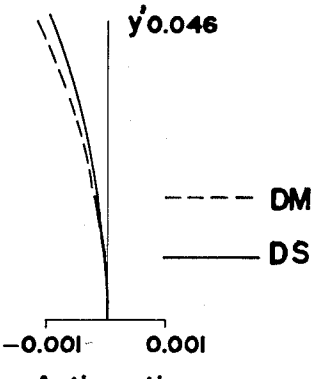
Distortion %

FIG.12A



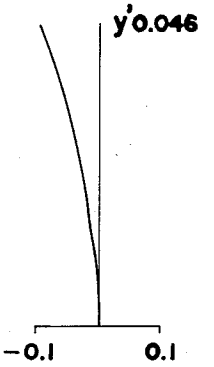
Spheric Aberration

FIG.12B



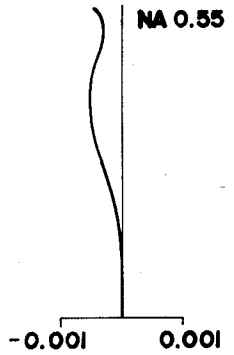
Astigmatism

FIG.12C



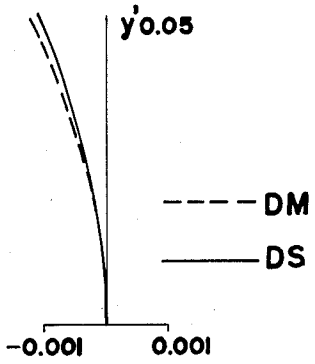
Distortion %

FIG.13A



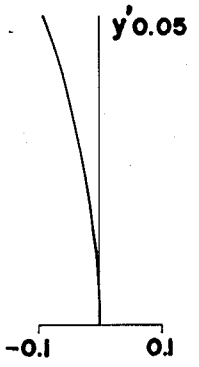
Spheric Aberration

FIG.13B



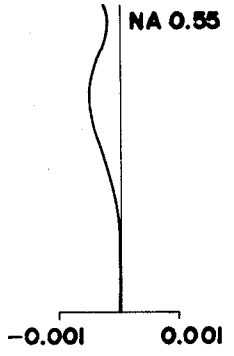
Astigmatism

FIG.13C



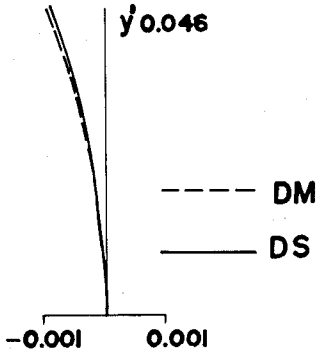
Distortion %

FIG.14A



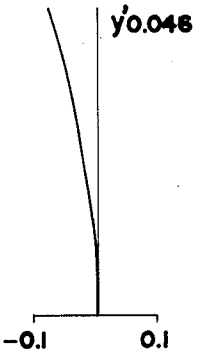
Spheric Aberration

FIG.14B



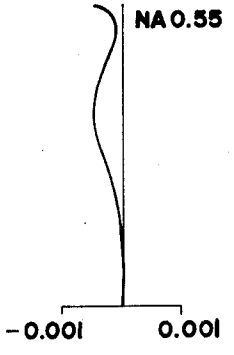
Astigmatism

FIG.14C



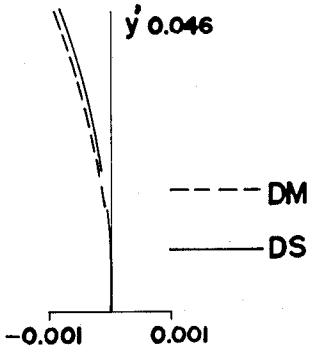
Distortion %

FIG.15A



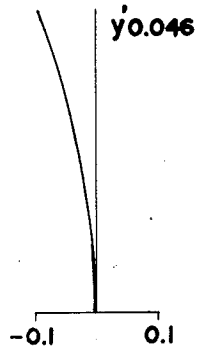
Spheric Aberration

FIG.15B



Astigmatism

FIG.15C



Distortion %

FIG.16A

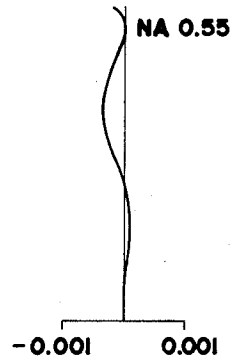


FIG.16B

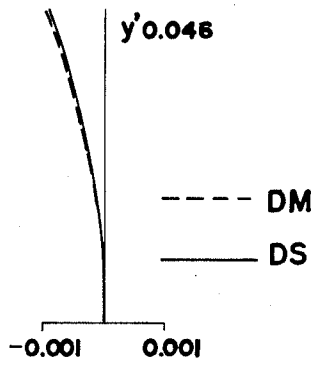


FIG.16C

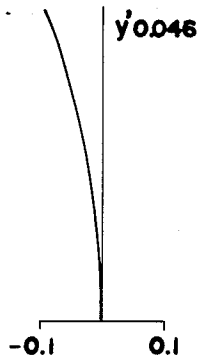


FIG.17A

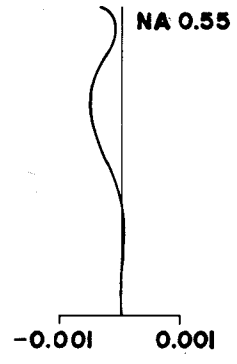


FIG.17B

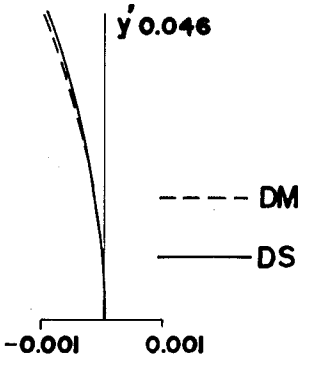


FIG.17C

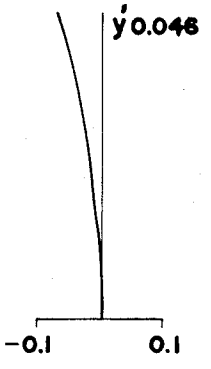


FIG.18A

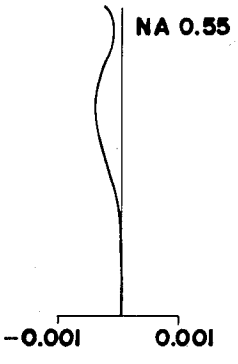


FIG.18B

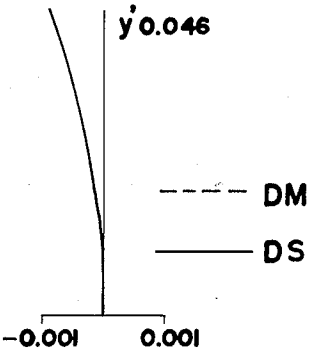
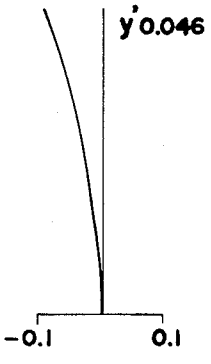


FIG.18C



OBJECTIVE LENS SYSTEM FOR OPTICAL RECORDING AND READING DEVICE

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to an objective lens system for a device for optically recording and reading digitalized information on an optical disk which is utilized as a document file or the like.

2. Description of the Prior Art

In case of recording the information on the disk, a more intensive light energy is required than the case of reading the information. Therefore, not only the numerical aperture, NA on the disk side but also that the numerical aperture NA' on the light source side should be increased in comparison with the case of an objective lens for exclusive use of reading the information. An increase of the magnification, $\beta(=NA'/NA)$ of the objective lens system may suit the above purpose. As magnification becomes greater, however, an angle of incidence becomes so greater as to cause both spherical aberration and coma which are difficult to be corrected well. An attempt to correct such aberrations with a combination of only spherical lens elements would necessitate a greater number of lens elements forming the objective lens system with its size and weight inevitably increased.

Japanese patent applications laid open Nos. 58-211729, 57-154213 and 59-157607 are cited to show prior art objective lens systems in this field of art.

SUMMARY OF THE INVENTION

An object of the present invention is to provide an improved objective lens system for an optical recording and reading device.

Another object of the present invention is to provide an objective lens system that is available for both recording and reading the information.

Still another object of the present invention is to provide such an objective lens system with one aspherical lens element and two spherical lens elements.

Further object of the present invention is to provide an objective lens system of the above mentioned type which has a great numerical aperture with the aberrations well corrected over its full image height (such as $y'=0.2$), for all its increased magnification (such as $|\beta| \geqq 0.37$)

Still further object of the present invention is to provide the objective lens system with a compact size and a light weight.

According to the present invention, an objective lens system for optical recording and reading device, comprises from a light source side to a disk side, a first lens element having a positive refractive power, said first lens element having an aspherical surface on the light source side, a second lens element having a positive refractive power, and a third lens element having a positive refractive power, wherein the objective lens system fulfills the following conditions:

$$-0.3 < f/r_1 < 0.25$$

$$|r_4/r_3| < 0.5$$

wherein f represents the focal length of the whole lens system; r_1 represents the paraxial radius of curvature of the light source side aspherical surface of the first lens element; r_3 represents the radius of curvature of the light source side surface of the second lens element and r_4 represents the radius of curvature of the disk side surface of the second lens element.

The objects and features of the present invention which are believed to be novel are set forth with particularity in the appended claims. The present invention, both as to its organization and manner of operation, together with further objects and advantages thereof, may best be understood by reference to the following description, taken in connection with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWING

FIG. **1** represents a cross sectional view of the objective lens system according to embodiment 1 of the present invention;

FIG. **2** represents a cross sectional view of the objective lens system according to embodiments 2, 3, 4, 8, 10 of the present invention;

FIG. **3** represents a cross sectional view of the objective lens system according to embodiments 5, 6, 7, 9, 11, 12, 13, 14, 15 of the present invention;

FIGS. **4A** to **4C** represent the aberration curves of the embodiment 1;

FIGS. **5A** to **5C** represent the aberration curves of the embodiment 2;

FIGS. **6A** to **6C** represent the aberration curves of the embodiment 3;

FIGS. **7A** to **7C** represent the aberration curves of the embodiment 4;

FIGS. **8A** to **8C** represent the aberration curves of the embodiment 5;

FIGS. **9A** to **9C** represent the aberration curves of the embodiment 6;

FIGS. **10A** to **10C** represent the aberration curves of the embodiment 7;

FIGS. **11A** to **11C** represent the aberration curves of the embodiment 8;

FIGS. **12A** to **12C** represent the aberration curves of the embodiment 9;

FIGS. **13A** to **13C** represent the aberration curves of the embodiment 10;

FIGS. **14A** to **14C** represent the aberration curves of the embodiment 11;

FIGS. **15A** to **15C** represent the aberration curves of the embodiment 12;

FIGS. **16A** to **16C** represent the aberration curves of the embodiment 13;

FIGS. **17A** to **17C** represent the aberration curves of the embodiment 14; and

FIGS. **18A** to **18C** represent the aberration curves of the embodiment 15;

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The following description is provided to enable any person skilled in the optical field to make and use the invention and sets forth the best modes contemplated by the inventor for carrying out my invention. Various modifications, however, will remain readily apparent to those skilled in the art, since the generic principles of the present invention have been defined herein specifically to provide a relatively economical and easily manufactured objective lens system. The derivation of the formulas and the relation of the powers set forth herein can be accomplished with the assistance of a computer. The present invention represents the parameters of a

compromise balance of acceptable aberrations which can be relatively easily manufactured to provide a low cost lens system.

In the drawings, schematic cross sectional views disclose the position of the lens elements. Values of the radii of curvature and axial distances for each lens element and air space are provided in the accompanying tables set forth herein. The schematic cross sectional views of the respective embodiments follow the normal conventions of the light source at the left-hand side of the drawing and the disk at the right hand side.

As shown in FIGS. **1**, **2**, **3**, which show the objective lens system according to the present invention along with the cover glass(**1**) of the semiconductor laser and the cover glass(P) of the laser disk, the present invention provides the objective lens system available for optically recording and reading information on an optically disk, comprising from the light source side to the disk side, a first lens element (L_1) having a positive refractive power, said first lens element(L_1) having a aspherical surface on the light source side, a second lens element(L_2) having a positive refractive power, and a third lens element(L_3) having a positive refractive power, in which the objective lens system fulfills the following conditions:

$$-0.3<f/r_1<0.25 \quad (1)$$

$$|r_4/r_3|<0.5 \quad (2)$$

wherein, f represents the focal length of the whole lens system, r_1 represents the paraxial radius of curvature of the light source side aspherical surface of the first lens element, r_3 represents the radius of curvature of the light source side surface of the second lens element and r_4 represents the radius of curvature of the disk side surface of the second lens element.

As is already explained, the magnification (=NA'/NA) of the objective lens system should become greater in order to increase the numerical aperture NA' on the light source side. This makes the angle of ray incidence to the objective lens system too large, which causes spheric aberration and coma. Although the spherical aberration may be corrected by means of an aspherical surface, the coma cannot be corrected well even with other spherical surfaces when the absolute value of the paraxial radius (r_1) of curvature of the light source side of the first lens element(L_1) is made excessively small. In order to correct the coma the condition (1) limits the paraxial radius (r_1) of curvature of the light source side of the first lens (L_1). If the absolute value of the paraxial radius(r_1) of curvature of the light source side of the first lens (L_1) becomes small to an extent violating the lower or upper limit of the condition (1), the coma cannot be corrected well, so that sufficient optical performance can be achieved only at a small image height.

The condition(2) defines the shape of the second lens element(L_2) with positive power. If the absolute value of the radius of the curvature of the light source side surface (r_3) compared with that of the disk side surface (r_4) becomes smaller in the second lens element (L_2), the astigmatism is increasing and the working distance is decreasing. Although such an astigmatism may be theoretically corrected by both increasing the thickness (d_1) of the first lens element and widening the air space (d_2) between the first and the second lens elements, this approach would fail to maintain the necessary working distance.

In addition to the above conditions, it is recommended to fulfill the following conditions:

$$1.5<f_3/f<4.0 \quad (3)$$

$$-0.41\leqq f_1/r_1\leqq 0.41 \quad (4)$$

wherein, f_3 represents the focal length of the third lens element(L_3) and f_1 represents the focal length of the first lens element(L_1).

The condition (3) defines the positive refractive power of the third lens element(L_3). If the positive refractive power of the third lens element (L_3) becomes great beyond the lower limit of the condition (3), the working distance becomes too short. On the other hand, if the positive refractive power becomes weak beyond the upper limit of the condition (3), the positive refractive power of the first lens element(L_1) and the second lens element (L_2) have to become too strong for the coma to be satisfactorily corrected.

Furthermore, the condition(4) is to prevent the absolute value of the power for the light source side surface (r_1) from excessively increasing in comparison with the power for the first lens element(L_1). If the power of the light source side of the first lens element(L_1) becomes great and positive beyond the upper limit of condition (4), the coma is generated, which is not corrected easily. On the other hand, if the power of the light source side of the first lens element (L_1) becomes great and negative beyond the lower limit of the condition (4), the first lens element (L_1) becomes a meniscus lens element with a small radius of curvature, and the astigmatism is generated, which cannot be corrected well. The following tables 1 to 15 disclose, respectively, design parameters of the first through fifteenth embodiments of the present invention. In the tables, f equals the focal length of the whole lens system, r is the radius of curvature with respective sub numbers indicating the surface of the lens elements from the light source side along the optical axis, r_{p1} and r_{p2} are the radius of curvature of the light source side and disk side of the cover glass(P) of the disk, d_1 to d_5 represent the axial distance including both air spaces and the actual thickness of the lenses, d_p represents the thickness of the cover glass(P) of the disk, and finally N_1, N_2, N_3, and N_p represent respectively the refractive index of the first lens element(L_1), the second lens element(L_2), the third lens element(L_3) and the cover glass(P) at the wavelength $\lambda=870$ nm. The asterisk(*) represents the aspherical surface defined as follows, and values for coefficients appearing in the formula are shown at the bottom of respective tables:

$$x=\frac{Coh^2}{1+\sqrt{1-\epsilon Coh^2}}+\Sigma C_i h^{2i}\ (i=1,2,3,\ldots m) \quad .$$

wherein, x represents the coordinate along the optical axis measured from an imaginary plane tangent to the aspherical surface perpendicularly to the optical axis, h represents the coordinate perpendicular to the optical axis measured from the optical axis, Co represents paraxial curvature ($1/r_1$) of the light source side surface of the first lens(L_1), ϵ represents the quadratic surface coefficient and C_i represent the aspherical surface coefficients. Furthermore, NA represents the numerical

aperture of the objective lens system, and β represents the magnification.

Among the following embodiments, it should be noted that the paraxial curvature ($Co=1/r_1$) of the aspherical surface is zero in the first to third embodiments. This is favorable to a test or measurement of the formed shape of the aspherical surface in manufacturing, since the paraxial curvature can be left out of consideration.

TABLE 1

[Embodiment 1]
NA = 0.55 f = 1.0 β = −0.37

radius of curvature	axial distance	refractive index
r_1* ∞		
	d_1 0.784	N_1 1.78866
r_2 −1.945		
	d_2 0.386	
r_3 44.884		
	d_3 0.341	N_2 1.78866
r_4 −1.947		
	d_4 0.114	
r_5 2.088		
	d_5 0.386	N_3 1.78866
r_6 −27.205		
	d_6 0.659	
r_{p1} ∞		
	d_p 0.273	N_p 1.56923
r_{p2} ∞		

aspheric surface coefficients ϵ = 1.0

$C_1 = 0.0$ $C_2 = -0.22153$ $C_3 = -0.58226 \times 10^{-2}$
$C_4 = -0.20176$ $C_5 = -0.12423 \times 10^{-1}$
$f/r_1 = 0$
$|r_4/r_3| = 0.04$
$f_3/f = 2.47$
$f_1/r_1 = 0$

TABLE 2

[Embodiment 2]
NA = 0.55 f = 1.0 β = −0.37

radius of curvature	axial distance	refractive index
r_1* ∞		
	d_1 0.341	N_1 1.78866
r_2 −1.584		
	d_2 0.716	
r_3 ∞		
	d_3 0.341	N_2 1.73009
r_4 −1.689		
	d_4 0.114	
r_5 1.291		
	d_5 0.341	N_3 1.78866
r_6 13.370		
	d_6 0.464	
r_{p1} ∞		
	d_p 0.273	N_p 1.56923
r_{p2} ∞		

aspheric surface coefficients ϵ = 1.0

$C_1 = 0.0$ $C_2 = -0.18414$ $C_3 = -0.37177 \times 10^{-2}$
$C_4 = -0.12311$ $C_5 = -0.27545 \times 10^{-1}$
$f/r_1 = 0$
$|r_4/r_3| = 0$
$f_3/f = 1.79$
$f_1/r_1 = 0$

TABLE 3

[Embodiment 3]
NA = 0.55 f = 1.0 β = −0.37

radius of curvature	axial distance	refractive index
r_1* ∞		
	d_1 0.341	N_1 1.78866
r_2 −1.566		
	d_2 0.716	
r_3 ∞		
	d_3 0.341	N_2 1.70433
r_4 −1.658		
	d_4 0.114	
r_5 1.271		
	d_5 0.341	N_3 1.78866
r_6 13.703		
	d_6 0.455	
r_{p1} ∞		
	d_p 0.273	N_p 1.56923
r_{p2} ∞		

aspheric surface coefficients ϵ = 1.0

$C_1 = 0.0$ $C_2 = -0.18466$ $C_3 = -0.35226 \times 10^{-2}$
$C_4 = -0.12227$ $C_5 = -0.27499 \times 10^{-1}$
$f/r_1 = 0$
$|r_4/r_3| = 0$
$f_3/f = 1.76$
$f_1/r_1 = 0$

TABLE 4

[Embodiment 4]
NA = 0.55 f = 1.0 β = −0.45

radius of curvature	axial distance	refractive index
r_1* 9.574		
	d_1 0.318	N_1 1.78866
r_2 −1.537		
	d_2 0.705	
r_3 28.882		
	d_3 0.341	N_2 1.71000
r_4 −1.634		
	d_4 0.114	
r_5 1.268		
	d_5 0.341	N_3 1.78866
r_6 5.895		
	d_6 0.441	
r_{p1} ∞		
	d_p 0.273	N_p 1.56923
r_{p2} ∞		

aspheric surface coefficients ϵ = 1.0

$C_1 = 0$ $C_2 = -0.19185$ $C_3 = 0.23537 \times 10^{-1}$
$C_4 = -0.10565$ $C_5 = -0.23430 \times 10^{-1}$
$f/r_1 = 0.1$
$|r_4/r_3| = 0.06$
$f_3/f = 1.98$
$f_1/r_1 = 0.18$

TABLE 5

[Embodiment 5]
NA = 0.55 f = 1.0 β = −0.55

radius of curvature	axial distance	refractive index
r_1* 6.308		
	d_1 0.500	N_1 1.78866
r_2 −1.457		
	d_2 0.636	
r_3 49.422		
	d_3 0.341	N_2 1.70000
r_4 −1.661		
	d_4 0.114	
r_5 1.288		
	d_5 0.341	N_3 1.78866
r_6 3.064		
	d_6 0.500	
r_{p1} ∞		
	d_p 0.273	N_p 1.56923
r_{p2} ∞		

aspheric surface coefficients ϵ = 1.0

$C_1 = 0$ $C_2 = -0.21793$ $C_3 = 0.39242 \times 10^{-1}$

TABLE 5-continued

[Embodiment 5]
NA = 0.55 f = 1.0 β = −0.55

$C_4 = -0.77439 \times 10^{-1}$ $C_5 = -0.43870 \times 10^{-1}$
$f/r_1 = 0.16$
$|r_4/r_3| = 0.03$
$f_3/f = 2.59$
$f_1/r_1 = 0.24$

TABLE 6

[Embodiment 6]
NA = 0.55 f = 1.0 β = −0.50

radius of curvature	axial distance	refractive index
r_1* 9.828		
	d_1 0.318	N_1 1.78866
r_2 −1.502		
	d_2 0.705	
r_3 21.362		
	d_3 0.341	N_2 1.70000
r_4 −1.640		
	d_4 0.114	
r_5 1.239		
	d_5 0.341	N_3 1.78866
r_6 4.498		
	d_6 0.477	
r_{p1} ∞		
	d_p 0.273	N_p 1.56923
r_{p2} ∞		

aspheric surface coefficients ϵ = 1.0

$C_1 = 0$ $C_2 = -0.19223$ $C_3 = 0.28266 \times 10^{-1}$
$C_4 = -0.89550 \times 10^{-1}$ $C_5 = -0.43669 \times 10^{-1}$
$f/r_1 = 0.10$
$|r_4/r_3| = 0.08$
$f_3/f = 2.07$
$f_1/r_1 = 0.17$

TABLE 7

[Embodiment 7]
NA = 0.55 f = 1.0 β = −0.55

radius of curvature	axial distance	refractive index
r_1* 6.532		
	d_1 0.409	N_1 1.78866
r_2 −1.489		
	d_2 0.659	
r_3 31.805		
	d_3 0.341	N_2 1.70000
r_4 −1.648		
	d_4 0.114	
r_5 1.275		
	d_5 0.341	N_3 1.78866
r_6 3.327		
	d_6 0.500	
r_{p1} ∞		
	d_p 0.273	N_p 1.56923
r_{p1} ∞		

aspheric surface coefficients ϵ = 1.0

$C_1 = 0$ $C_2 = -0.20542$ $C_3 = 0.47882 \times 10^{-1}$
$C_4 = -0.86333 \times 10^{-1}$ $C_5 = -0.43779 \times 10^{-1}$
$f/r_1 = 0.15$
$|r_4/r_3| = 0.05$
$f_3/f = 2.44$
$f_1/r_1 = 0.24$

TABLE 8

[Embodiment 8]
NA = 0.55 f = 1.0 β = −0.37

radius of curvature	axial distance	refractive index
r_1* −11.364		
	d_1 0.341	N_1 1.78866

TABLE 8-continued

[Embodiment 8]
NA = 0.55 f = 1.0 β = −0.37

r_2 −1.654		
	d_2 0.659	
r_3 −16.624		
	d_3 0.341	N_2 1.73009
r_4 −1.636		
	d_4 0.114	
r_5 1.428		
	d_5 0.341	N_3 1.78866
r_6 10.060		
	d_6 0.591	
r_{p1} ∞		
	d_p 0.273	N_p 1.56923
r_{p2} ∞		

aspheric surface coefficients ϵ = 1.0

$C_1 = 0$ $C_2 = -0.19120$ $C_3 = -0.13389 \times 10^{-1}$
$C_4 = -0.18165$ $C_5 = -0.30203 \times 10^{-1}$
$f/r_1 = -0.09$
$|r_4/r_3| = 0.10$
$f_3/f = 1.83$
$f_1/r_1 = 0.21$

TABLE 9

[Embodiment 9]
NA = 0.55 f = 1.0 β = −0.52

radius of curvature	axial distance	refractive index
r_1* 8.677		
	d_1 0.648	N_1 1.58000
r_2 −1.211		
	d_2 0.591	
r_3 10.256		
	d_3 0.341	N_2 1.68000
r_4 −1.849		
	d_4 0.114	
r_5 1.325		
	d_5 0.386	N_3 1.76000
r_6 4.921		
	d_6 0.570	
r_{p1} ∞		
	d_p 0.273	N_p 1.56923
r_{p2} ∞		

aspheric surface coefficients ϵ = 1.0

$C_1 = 0$ $C_2 = -0.35020$ $C_3 = 0.46926 \times 10^{-1}$
$C_4 = -0.21665$ $C_5 = -0.23700 \times 10^{-1}$
$f/r_1 = 0.12$
$|r_4/r_3| = 0.18$
$f_3/f = 2.28$
$f_1/r_1 = 0.22$

TABLE 10

[Embodiment 10]
NA = 0.55 f = 1.0 β = −0.37

radius of curvature	axial distance	refractive index
r_1* −57.156		
	d_1 0.375	N_1 1.78866
r_2 −1.509		
	d_2 0.675	
r_3 31.767		
	d_3 0.350	N_2 1.70000
r_4 −1.675		
	d_4 0.125	
r_5 1.433		
	d_5 0.386	N_3 1.78866
r_6 32.750		
	d_6 0.418	
r_{p1} ∞		
	d_p 0.300	N_p 1.56923
r_{p2} ∞		

aspheric surface coefficients ϵ = 1.0

$C_1 = 0$ $C_2 = -0.19387$ $C_3 = -0.24468 \times 10^{-2}$

TABLE 10-continued

[Embodiment 10]
NA = 0.55 f = 1.0 $\beta = -0.37$

$C_4 = -0.13200$ $C_5 = -0.21165 \times 10^{-1}$
$f/r_1 = -0.02$
$|r_4/r_3| = 0.05$
$f_3/f = 1.89$
$f_1/r_1 = 0.03$

TABLE 11

[Embodiment 11]
NA = 0.55 f = 1.0 $\beta = -0.37$

radius of curvature	axial distance	refractive index
r_1* 82.944		
	d_1 0.636	N_1 1.78866
r_2 −1.415		
	d_2 0.522	
r_3 42.161		
	d_3 0.341	N_2 1.48135
r_4 −1.575		
	d_4 0.114	
r_5 1.662		
	d_5 0.386	N_3 1.78866
r_6 −9.321		
	d_6 0.455	
r_{p1} ∞		
	d_p 0.273	N_p 1.56923
r_{p2} ∞		

aspheric surface coefficients $\epsilon = 1.0$

$C_1 = 0$ $C_2 = -0.23832$ $C_3 = -0.87594 \times 10^{-2}$
$C_4 = -0.11755$ $C_5 = -0.21020 \times 10^{-1}$
$f/r_1 = 0.01$
$|r_4/r_3| = 0.04$
$f_3/f = 1.82$
$f_1/r_1 = 0.02$

TABLE 12

[Embodiment 12]
NA = 0.55 f = 1.0 $\beta = -0.37$

radius of curvature	axial distance	refractive index
r_1* 7.438		
	d_1 0.500	N_1 1.48135
r_2 −1.403		
	d_2 0.523	
r_3 86.655		
	d_3 0.341	N_2 1.75000
r_4 −1.837		
	d_4 0.114	
r_5 1.597		
	d_5 0.386	N_3 1.78866
r_6 −33.185		
	d_6 0.591	
r_{p1} ∞		
	d_p 0.273	N_p 1.56923
r_{p2} ∞		

aspheric surface coefficients $\epsilon = 1.0$

$C_1 = 0$ $C_2 = -0.34037$ $C_3 = 0.56587 \times 10^{-2}$
$C_4 = -0.23482$ $C_5 = -0.24800 \times 10^{-1}$
$f/r_1 = 0.13$
$|r_4/r_3| = 0.02$
$f_3/f = 1.94$
$f_1/r_1 = 0.33$

TABLE 13

[Embodiment 13]
NA = 0.55 f = 1.0 $\beta = -0.37$

radius of curvature	axial distance	refractive index
r_1* 5.483		
	d_1 0.500	N_1 1.48135
r_2 −1.246		
	d_2 0.523	
r_3 9.466		
	d_3 0.341	N_2 1.48135
r_4 −1.484		
	d_4 0.114	
r_5 1.401		
	d_5 0.386	N_3 1.78866
r_6 −36.428		
	d_6 0.511	
r_{p1} ∞		
	d_p 0.273	N_p 1.56923
r_{p2} ∞		

aspheric surface coefficients $\epsilon = 1.0$

$C_1 = 0$ $C_2 = -0.35560$ $C_3 = 0.30654 \times 10^{-1}$
$C_4 = 0.27703$ $C_5 = -0.26457 \times 10^{-1}$
$f/r_1 = 0.18$
$|r_4/r_3| = 0.16$
$f_3/f = 1.77$
$f_1/r_1 = 0.4$

TABLE 14

[Embodiment 14]
NA = 0.55 f = 1.0 $\beta = -0.37$

radius of curvature	axial distance	refractive index
r_1* 42.659		
	d_1 0.636	N_1 1.78866
r_2 −1.350		
	d_2 0.523	
r_3 38.564		
	d_3 0.341	N_2 1.70000
r_4 −1.765		
	d_4 0.114	
r_5 1.598		
	d_5 0.386	N_3 1.51000
r_6 −5.462		
	d_6 0.409	
r_{p1} ∞		
	d_p 0.273	N_p 1.56923
r_{p1} ∞		

aspheric surface coefficients $\epsilon = 1.0$

$C_1 = 0$ $C_2 = -0.26456$ $C_3 = -0.63330 \times 10^{-2}$
$C_4 = -0.13300$ $C_5 = -0.21656 \times 10^{-1}$
$f/r_1 = 0.02$
$|r_4/r_3| = 0.05$
$f_3/f = 2.47$
$f_1/r_1 = 0.04$

TABLE 15

[Embodiment 15]
NA = 0.55 f = 1.0 $\beta = -0.37$

radius of curvature	axial distance	refractive index
r_1* 11.904		
	d_1 0.545	N_1 1.58000
r_2 −1.325		
	d_2 0.591	
r_3 17.779		
	d_3 0.341	N_2 1.68000
r_4 −1.783		
	d_4 0.114	
r_5 1.449		
	d_5 0.386	N_3 1.76000
r_6 68.973		
	d_6 0.489	
r_{p1} ∞		
	d_p 0.273	N_p 1.56923
r_{p2} ∞		

aspheric surface coefficients $\epsilon = 1.0$

$C_1 = 0$ $C_2 = -0.30006$ $C_3 = 0.10981 \times 10^{-2}$

TABLE 15-continued

[Embodiment 15] NA = 0.55 f = 1.0 β = −0.37
$C_4 = -0.19225$ $C_5 = -0.22984 \times 10^{-1}$
$f/r_1 = 0.08$
$\lvert r_4/r_3 \rvert = 0.1$
$f_3/f = 1.94$
$f_1/r_1 = 0.18$

What is claimed is:

1. An objective lens system for a device for optically recording and reading digital data on an optical disk, comprising from a light source side to a disk side,

a first lens element having a positive refractive power, said first lens element having an aspherical surface on the light source side;

a second lens element having a positive refractive power; and

a third lens element having a positive refractive power, wherein the objective lens system fulfills the following conditions:

$$-0.3 < f/r_1 < 0.25$$

$$|r_4/r_3| < 0.5$$

wherein:

f represents the focal length of the whole lens system;

r_1 represents the paraxial radius of curvature of the light source side aspherical surface of the first lens element,

r_3 represents the radius of curvature of the light source side surface of the second lens element and

r_4 represents the radius of curvature of the disk side surface of the second lens element.

2. An objective lens system as claimed in claim 1, wherein the objective lens system further fulfills the following conditions:

$$1.5 < f_3/f < 4.0$$

$$-0.41 \leqq f_1/r_1 \leqq 0.41$$

wherein:

f_3 represents the focal length of the third lens element(L_3) and

f_1 represents the focal length of the first lens element(L_1).

3. An objective lens system for a device for optically recording and reading digital data on an optical disk, comprising the following design parameters:

NA = 0.55 f = 1.0 β = −0.37		
radius of curvature	axial distance	refractive index
r_1* ∞		
	d_1 0.784	N_1 1.78866
r_2 −1.945		
	d_2 0.386	
r_3 44.884		
	d_3 0.341	N_2 1.78866
r_4 −1.947		
	d_4 0.114	
r_5 2.088		
	d_5 0.386	N_3 1.78866
r_6 −27.205		
	d_6 0.659	
r_{p1} ∞		
	d_p 0.273	N_p 1.56923
r_{p2} ∞		

aspheric surface coefficients ϵ = 1.0
$C_1 = 0.0$ $C_2 = -0.22153$ $C_3 = -0.58226 \times 10^{-2}$
$C_4 = -0.20176$ $C_5 = -0.12423 \times 10^{-1}$
$f/r_1 = 0$
$\lvert r_4/r_3 \rvert = 0.04$
$f_3/f = 2.47$
$f_1/r_1 = 0$

* * * * *

United States Patent [19]

Alfredsson et al.

[11] **Patent Number: 4,741,605**

[45] **Date of Patent: May 3, 1988**

[54] **MULTIFOCAL OBJECTIVE**

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[58] **Field of Search** 350/422, 431, 437, 449, 350/415

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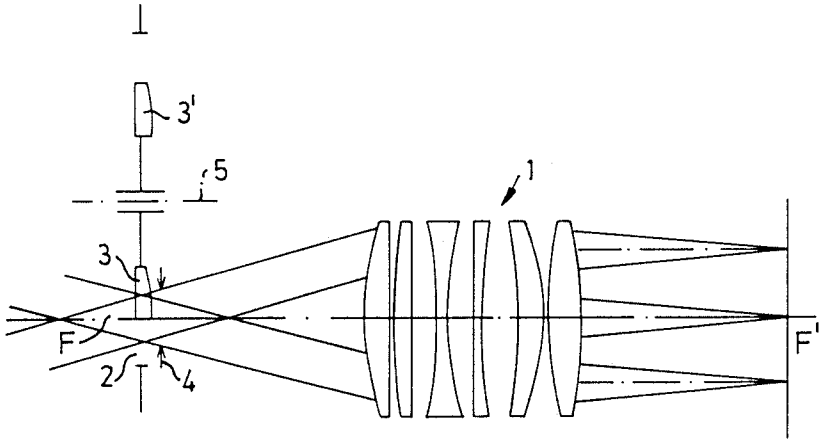
[57] **ABSTRACT**

The present invention relates to an image-forming objective which is capable of forming sharp images of objects at at least two different distances from the objective, there being arranged at one focal plane of the objective a corrective element divided into at least two fields in which the refractive power differs between them.

8 Claims, 1 Drawing Sheet



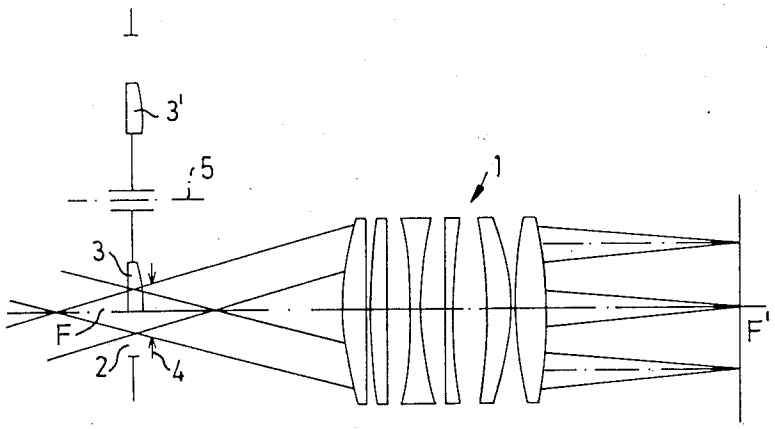


FIG. 1

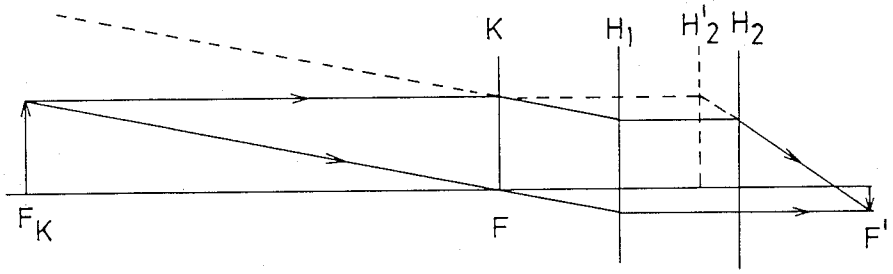


FIG. 2

MULTIFOCAL OBJECTIVE

DESCRIPTION OF THE PRIOR ART

An objective with these properties is known from U.S. Pat. No. 3,588,227 and is designed to serve as a microscope objective. Two objects in front of the objective are imaged sharply in the focal plane and with the same magnification. According to the principle of the known design, at the image-side focus of the objective, an optical element is arranged which in one half of this focal plane functions as a positive lens, acting to focus the closest object on the focal plane, and in the other half thereof functions as a plane-parallel disc without any net refraction (thus only the refractive power of the objective itself acts on beams in this half) so that the beams from the more distant object are not refracted as much and, because of a choice of suitable dimensions, are focused in the very same focal plane.

SUMMARY OF THE INVENTION

One object of the present invention is to produce a photographic objective, which is of particular use in moving picture and TV-cameras, making it possible in a single scene to provide sharp images of two objects at different distances, i.e., each with its own depth of field. The image thus combined should have a natural appearance, and if two different optical systems are used, it is particularly important that the unsharp image of one object made by the system which makes a sharp image of the other object, disrupt the sharp image of the other system as little as possible. Otherwise, the unsharp image could create a visible ghost image. If, however, the fuzzy image is of the same size as and is superimposed on a sharp image, the image will be perceived as sharp.

It is previously known to achieve this purpose by using two different objectives and mirror devices. Major mechanical stability problems are encountered in this case, however. Furthermore, it is difficult to make two images coincide exactly, one with a sharp object A and an unsharp object B and the other with an unsharp object A and a sharp object B. The two images of A, one sharp and one unsharp, must be superimposed on each other even if they do not lie in the center of the image surface, which means that the objective must provide the same magnification. One purpose of the invention is to achieve such a consolidation of images, and to do this with a single objective, suited to photography, cinematography, TV, etc.

The objective revealed by the above-mentioned patent specification does not constitute a solution to the problem according to the invention. Two objects A and B at different distances will each be sharply imaged in individual halves by the known objective and be of the same size, but at the same time the unsharp images will be of different sizes, and therefore an unsharp and different-sized image of A, for example, will be superimposed on the sharp image of A. This will have a very disturbing effect in a cinematographic picture, for example.

In other designs, relating to photographic objectives, lenses divided into zones are used, similar to Fresnel lenses, for instance, and are revealed in, for example, No. GB-A-335 696 and U.S. Pat. Nos. 2,546,996 and 2,651,237. While the zones do provide sharp images of objects at different distances, the problem of the unequal magnifications of the unsharp ghost images of the different objects has not been addressed and therefore the purpose of the present invention has not been achieved. It is true that U.S. Pat. No. 2,651,238 discusses this problem, but the solution there indicated was that the ghost images be so greatly out of focus that they do not disturb the sharp images, which can be difficult to achieve except with very small individual depths of field and with a large aperture.

The above-mentioned purpose and other purposes and advantages are achieved according to the invention, which has an image-forming objective of the type described by way of introduction, in which the corrective element is arranged in the objective focal plane closest to the object. The unsharp image of an object, which is also giving a sharp image, will be of the same size as the sharp image. It is true that the contrast of the composite image will be poorer than the contrast in a normal image, but the effect thereof will not be disturbing and can even provide an artistically pleasing soft focus, which is otherwise achieved with special diffusion discs. This effect can be enhanced further by providing one or even both of the fields in the corrective element with a diffusion disc or the like.

The different fields in the corrective element can, if required, be placed anywhere in the front focal plane of the objective. It is particularly advantageous, however, to arrange the fields symmetrically in relation to the optical axis. In a bifocal design, for example, it is advisable to have the boundary between the fields be a diameter which intersects the optical axis. For more than two objects and fields, the fields can be made in the form of circular sectors with the points on the optical axis. This has the advantage that a diaphragm placed closely thereto will stop down all of the images the same amount. Otherwise, other field distributions can provide a number of special effects. For example, with an annular zone the associated image can be made soft and diffused by stopping down, in many cases to interesting effects. It can be worth mentioning that one of the fields in the corrective element can suitably be open, and in a simple and practical embodiment of a bifocal objective, the corrective element can consist of a thin lens system which is semicircular, and can be considered to be a half fore-lens.

Several such corrective systems can be mounted on an arrangement in front of the objective, so that they can be easily interchanged, e.g., in a revolver mounting. If "half fore-lenses" are used, the focusing for one image will be done in the usual manner (as a rule by moving the objective relative to the film plane), while the focus of the other image is obtained by suitable selection of the fore-lens. Instead of a simple thin system, it is also possible to set in a system with variable refraction, more or less along the lines of a zoom lens. The objective behind it can of course also be a zoom lens, and this may require a certain calculated effort, which does, however, lie within the capacity of the optical designer.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention is clearly revealed in the drawings,

FIG. 1 of which shows schematically an objective according to the invention, while FIG. 2 shows a schematic beam path.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The composite objective shown in FIG. **1** comprises a cinematographic objective **1** with a focal length of 50 mm represented in approximately natural size. The foci are located at F and F′ and a film plane has been drawn in at the rear focal plane. In the front focal plane there is a "half" lens **3** which extends as far as the optical axis, and an iris **4**.

Since it is well known how objectives are designed (see for example Conrady, Applied Optics and Optical Design, parts I and II, New York 1957, Dover), it is unnecessary to describe the seven-lens objective shown. As regards the element **3**, it is drawn as a single, thin lens, and such a design is usually satisfactory, especially if the diopter number does not need to be high. An achromatization may be advisable, although this should be determined in relation to the actual lack of sharpness already there due to the unsharp image superimposed on the sharp image.

With a setting for one of the objects, as in the figure, at infinity, the focal length for the lens element **3** should be equal to the distance to the other object, with the lens **3** forming a virtual image at infinity.

The functioning of the system may be clearer by applying Gullstrand's formula for refractive power in two combined lens systems:

$$D=D_1+D_2-\delta\cdot D_1\cdot D_2$$

where D_1 and D_2 are the diopter number (m^{-1}) of the systems and δ is the distance between the systems (or their principal-facing planes in Gauss' approximation). If, as here, the lens element **3** (diopter number D_2) is at the focus of the composite objective (diopter number D_1), the result will be $D=D_1$.

Thus the corrective element does not effect the focal length of the system. FIG. **2** shows a schematic optical path, the main objective being represented by the focal points F and F′ and the principal planes H_1 and H_2. The corrective element K is shown as a thin lens with focal point F_K. Two rays are shown for an object at F_K, and it can be seen therefrom that the front principal plane of the system coincides with that of the main objective, while the rear principal plane of the system will be displaced towards the object just enough so that the object at F_K will be in focus at F′.

When using a thin lens **3** in the form of a half lens, its edge should be well blackened to avoid light scattering. Experience has shown that the corrective element must also be well centered in relation to the optical axis. Otherwise the sharp and the unsharp image will not coincide but will be somewhat laterally displaced (net wedge effect). In a cinematographic objective with a movable or interchangeable corrective element, for purely practical reasons there must be a reproducible and exact centering, of the order of a few hundredths of a millimeter (for 50 mm focal length).

In order to avoid difficult vignetting problems, an objective should be used which is computed so that its entrance pupil is located at the forward focus (socalled telecentric objective). The diaphragm **4** will then also be at the actual entrance pupil of the objective.

FIG. **1** also shows schèmatically a revolver mechanism with an axis of rotation **5** and two corrective elements **3** and **3′**. Several different corrective elements can suitably be mounted in holes in the revolver disc, leaving one hole empty, so that the objective **1** can also be used as an ordinary objective. As already pointed out, this revolver mechanism should be made with high precision and the corrective elements be well centered; this does not present any insurmountable technical problems, but should be kept in mind during its design.

The invention provides a photographic objective which solves the problem of imaging sharply in a single scene objects located at different distances from the camera, each of the objects having its own depth of field. To date, such imaging, has in practice had to be done by stopping way down. As an example of what can be achieved with an objective with F=50 mm, it is possible with a stop-number of 4 (with a resolution requirement of 0.03 mm) to obtain the two depths of field 1.8–2.2 m and 6.7–19 m (settings 2 m and 10 m). If one stops down to f-stop **14**, the combined depth of field will then be 1.5 m−∞. A comparable depth of field achieved with conventional stopping-down would require f-stop 28.

In addition to the great increase in usable depth of field, one should also mention the previously unknown, purely artistic unique effects which can be obtained through the invention, whereby the focus can be concentrated to selected dramatic areas of a filmed scene. In still-photography as well, the invention can provide a new means for achieving new artistic effects free of the limitations previously, considered unavoidable and dictated by the technology. Ideally, pictures should be true to nature, and the lack of deep focus, which the human eye unconsciously compensates for by continually changing focus, must create an unnatural impression, which can be largely eliminated by the invention.

We claim:

1. A lens system having an image-forming objective which is capable of forming sharp images of objects at at least two different distances from said objective, a corrective element (3) divided into at least two fields of differing refractive power being arranged at one focal plane (F) of the objective, said corrective element (3) being arranged in the objective focal plane (F) which is located closest to a said object, and an entrance pupil of said objective being located at its forward focus in the direction of said object.

2. A lens system objective according to claim **1**, wherein said fields are symmetrically arranged in relation to an optical axis of said objective.

3. A lens system objective according to claim **1** or **2**, including an aperture device at the forward, object-directed focus of said objective.

4. A lens system according to claim **1** or **2**, wherein said corrective element consists of a single or composite lens, which is halved along a diameter, which intersects said optical axis of said objective.

5. A lens system according to claim **3**, wherein said corrective element has a variable focal length.

6. A lens system according to claim **1**, wherein said corrective element is removably mounted.

7. A lens system according to claim **6**, comprising a plurality of corrective elements with different focal lengths mounted in openings in a revolver mechanism.

8. A lens system according to claim **1**, wherein one of said fields is provided with a means for reducing sharpness to achieve a so-called soft focus effect.

* * * * *

United States Patent [19]

Arai et al.

[11] **Patent Number: 4,737,855**

[45] **Date of Patent: Apr. 12, 1988**

[54] **AUTOMATIC DIAPHRAGM CONTROL DEVICE FOR TV CAMERA OBJECTIVE**

[75] Inventors: **Masayuki Arai; Terumi Ogasawara,** both of Tokyo, Japan

[73] Assignee: **Asahi Seimitsu Kabushiki Kaisha,** Tokyo, Japan

[21] Appl. No.: **875,094**

[22] Filed: **Jun. 17, 1986**

[30] **Foreign Application Priority Data**

Jul. 10, 1985 [JP] Japan 60-151630

[51] **Int. Cl.**[4] **H04N 5/238**

[52] **U.S. Cl.** **358/228**

[58] **Field of Search** 358/228, 169, 213.13, 358/213.19, 225

[56] **References Cited**

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Primary Examiner—Jin F. Ng
Assistant Examiner—Stephen Brinich
Attorney, Agent, or Firm—Birch, Stewart, Kolasch & Birch

[57] **ABSTRACT**

An automatic diaphragm control device for a TV camera objective utilizing a video signal from the TV camera includes a circuit for adjustment of a low contrast video signal, a circuit for adjustment of a high contrast video signal and for preventing variations of the low contrast video output signal previously adjustment, a circuit for stabilization of a source voltage used as a power supply, a servo circuit for halting the operation of a servomotor driving said diaphragm in response to the adjusted video signals and a feedback signal from a detecting coil of the servomotor, and for driving the servomotor by supplying a stabilized driving voltage to a driving coil, and a circuit for activating operational amplifiers respectively associated with the adjustment and voltage stabilization circuits.

6 Claims, 3 Drawing Sheets

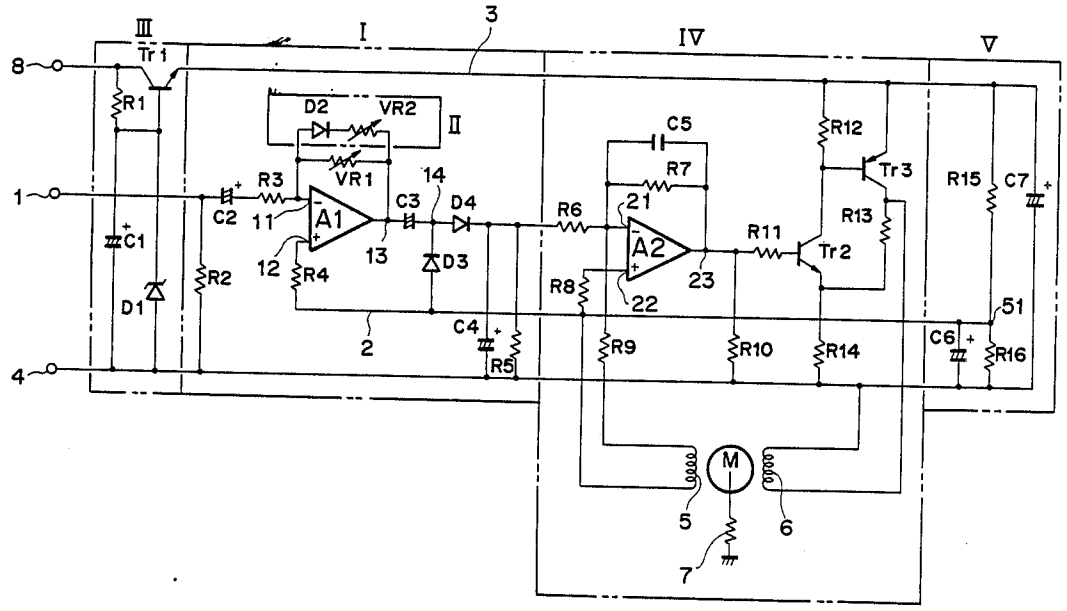


FIG. 1

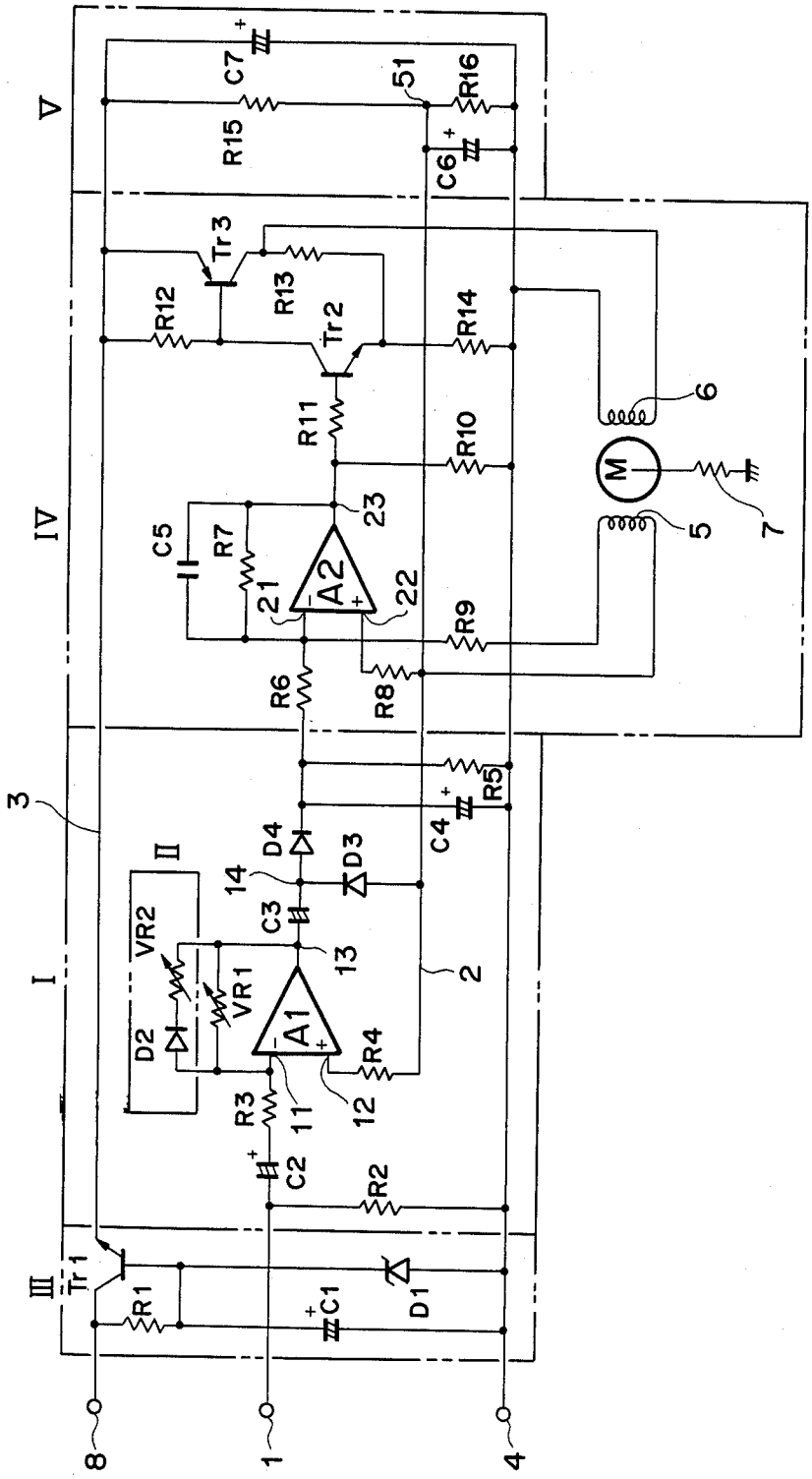

V
IV
III
II
I
C7
R15
51
R16
C6
Tr3
R12
R13
Tr2
R14
R11
R10
6
M
7
5
C5
R7
21
A2
22
23
R9
R6
R8
R5
C4
3
D4
D3
14
C3
VR2
VR1
13
2
D2
A1
R4
R3
11
12
C2
R2
Tr1
R1
C1
D1
8
1
4

FIG. 2

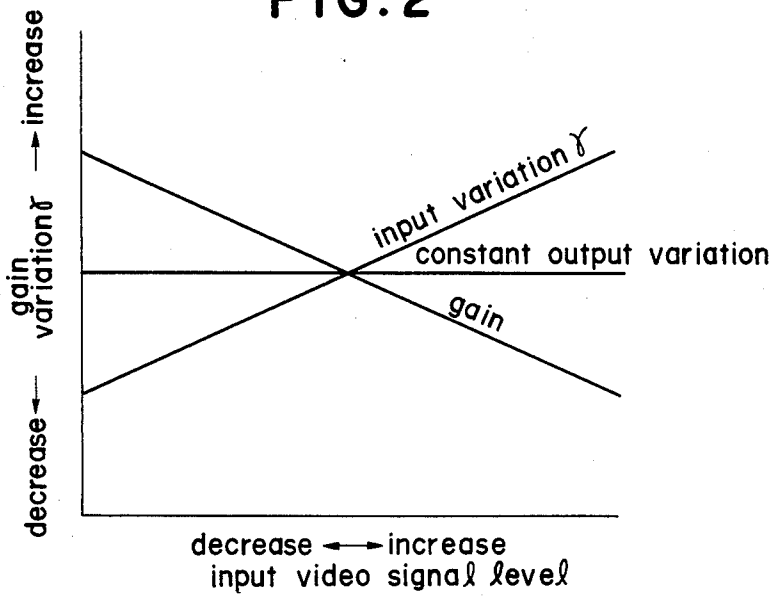

gain variation γ
increase
decrease
input variation γ
constant output variation
gain
decrease
increase
input video signal level

FIG. 3

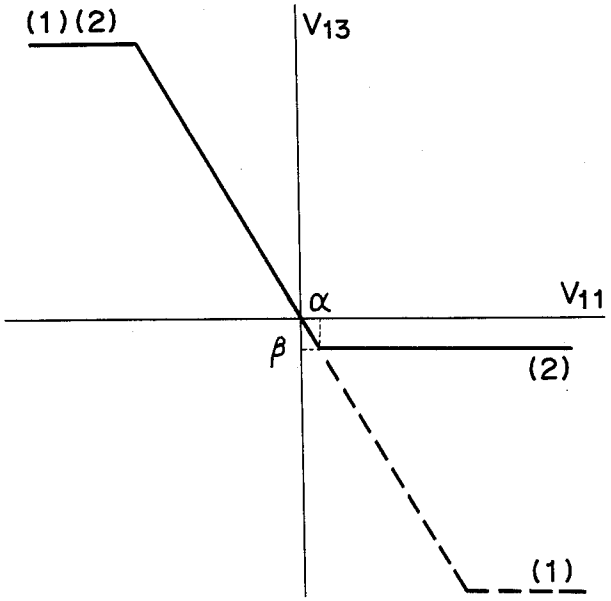

(1)(2)
V13
α
V11
β
(2)
(1)

FIG. 4

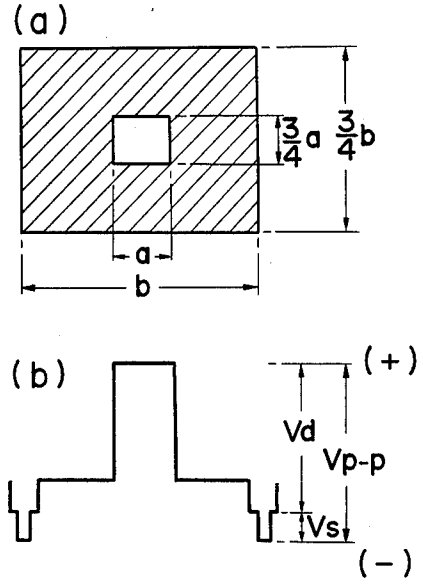


FIG. 5

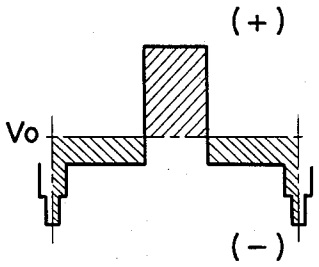


FIG. 6

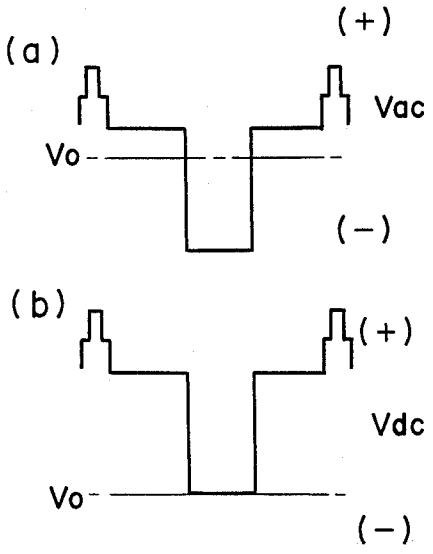
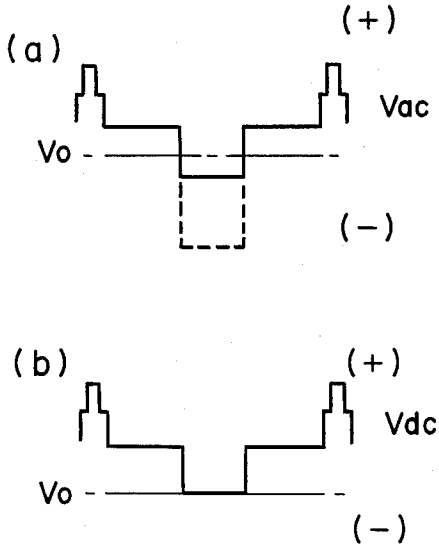


FIG. 7



AUTOMATIC DIAPHRAGM CONTROL DEVICE FOR TV CAMERA OBJECTIVE

BACKGROUND OF THE INVENTION

1. Industrial field of application

The present invention relates to an automatic diaphragm control device for TV camera objective.

2. Prior art

As an automatic diaphragm control device for TV camera objective, a so-called one-way spring driven type has already been well known but has rarely been adopted in practice in view of its inconveniently limited range of useful driving voltage and poor reliability. A control device adapted for controllably driving the diaphragm in both directions, i.e., so as to open and close the diaphragm, respectively, has also been known and has been commonly employed, because the latter type provides a higher reliability and permits the consumed current to be effectively reduced.

However, demand for a more compact TV camera has recently increased and it has been found that the conventional control device of the bidirectional driving type cannot satisfactorily serve the objective of such a compact TV camra, since the conventional control device is too complicated in its structure to be correspondingly made compact.

3. Problems to be solved by the invention

A principal object of the present invention is, in view of the above-mentioned inconveniences, to provide an improved diaphragm control device of high reliability for a TV camera objective which includes a drive mechanism simplified and made compact by adopting the conventional one-way spring driven type while overcoming its inherent drawbacks, permitting both drive and control of the diaphragm to be achieved with a single power source, and leads to a reduction in current consumption.

SUMMARY OF THE INVENTION

Measures to solve the problems

To achieve the object as set forth above, the present invention provides an automatic diaphragm control device for a TV camera objective utilizing video signals from a TV camera, said automatic diaphragm control device comprising: first means primarily for adjustment of the video signals during a low contrast; second means primarily for adjustment of the video signals during a high contrast and also adapted to keep video output signals previously adjusted and set by the first means during the low contrast from any substantial variation; third means for stabilization of a source voltage in order to inhibit a possible variation of the video output signals preset by said first and second means or a possible increase of current; fourth means by which a braking can be effected on the basis of amplification of rectified signals provided by said first and second means and on the basis of a feedback signal from a detecting coil of a diaphragm driving servomotor, and, to drive the servomotor, for supplying the servomotor with a stabilized driving voltage substantially amplified in a one-way drive circuit having a voltage gain according to an obtained control signal; and fifth means to activate operational amplifiers respectively used in said first, second and fourth means with a single power source, and thereby realizing a highly reliable automatic diaphragm control device for TV camera objective having a variable photometric function, which is operable with a reduced current consumption and a compact structure.

Operation

It is well known that a video signal from a TV camera has an amplitude varying within a wide range depending upon a total brightness of an object to be shot and also upon a type of the TV camera used. According to the present invention, the first means adjusts the video output signals from the TV camera first on the basis of the overall brightness or the average brightness of the bright area and the dark area of the object during low contrast. More specifically, a level of the video output signal from the TV camera is greatly amplified when the level is low and slightly amplified when the level is high so that a constant output variation may be obtained. The second means is adapted to obtain a video signal based on the low contrast area by cutting the video signal portion corresponding to the bright area when the bright area and the dark area exhibit a high contrast in the object to be shot. Accordingly, even when the second means cuts the video signal portion corresponding to the bright area with respect to the object having a low contrast, the video signal previously adjusted and set by the first means during the low contrast is never varied by the second means because the video signal portion corresponding to the bright area has a relatively low level when the object is of a low contrast and cutting of this signal portion will not affect the overall video signal. Subsequently, the third means functions to stabilize the source voltage. In view of the fact that the video signal obtained by the first and second means, the diaphragm control signal obtained from this video signal and a diaphragm driving voltage depending upon said diaphragm control signal are all based on the source voltage, the source voltage serving the electric circuit of the device is kept by this third means at a constant level and thereby becomes highly reliable. The fourth means is adapted to effect a desired control on the basis of amplification of a rectified signal provided by said first and second means and on the basis of a feedback signal from a detecting coil of a diaphragm driving servomotor, and to drive the servomotor by supplying the servomotor with a stabilized driving voltage substantially amplified in a one-way drive circuit having a voltage gain according to an obtained control signal. Finally, the fifth means is adapted to provide a reference voltage in the first, second and fourth means as a mid-range voltage of the source voltage and thereby to activate said respective means with a single source voltage.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a circuit diagram illustrating one embodiment of the device according to the present invention;

FIG. **2** is a functional diagram of the first means thereof;

FIG. **3** is a functional diagram of the second means thereof;

FIG. **4** is a diagram illustrating a relationship between the object to be shot and the corresponding video signal;

FIG. **5** is a schematic diagram illustrating an input waveform before controlled by the means according to the present invention; and

FIGS. **6** and **7** are schematic diagrams illustrating the control waveforms provided by the means according to the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention will be now described more in detail with respect to embodiments as illustrated by the accompanying drawings. Referring to FIG. **1**, reference numeral **1** designates an input terminal adapted to input a video signal Vin from a TV camera and connected to an inverted amplifier/rectifier I. In this circuit I, the input terminal **1** is connected through a resistor R2 to a ground side **4** and through a capacitor C2 and a resistor R3 to an inverted input terminal **11** of an operational amplifier A1 associated with the first and second means according to the present invention. A non-inverted input terminal **12** of the operational amplifier A1 is connected through a resistor R4 to a mid-range voltage terminal **2** described hereafter in detail and there is provided a variable resistor VR1 serving as a feedback resistor between the inverted input terminal **11** and an output terminal **13**. Such circuit I is adapted to remove the DC component of the video signal Vin by said capacitor C2 and provides at the output terminal **13** an inversely amplified signal Vac, wherein said variable resistor VR1 may be adjusted for continuously changing a gain (amplification factor) of the operational amplifier A1. Thus, this circuit I constitutes the first means according to the present invention. Specifically, the gain increases as a resistance value of the variable resistor VR1 is increased and conversely decreases as said resistance value is reduced. This is illustrated by FIG. **2** in which an input variation γ becomes large when an optimal video signal level for the camera is relatively high and the input video signal Vin is also high. In such a situation, the resistance value may be adjusted to a lower level so as to reduce the gain. For a small input variation γ of the video signal Vin, on the contrary, the resistance value may be adjusted to a higher level to increase the gain and thereby obtain an inversely amplified signal Vac of a constant level. During this process, the input video signal Vin should be adjusted to have an amplitude in accordance with the overall brightness of the object to be shot, namely, the function of circuit I is principally to adjust the video output signal for objects of low contrast.

Reference numeral II designates a limiter circuit adapted for continuous limitation of a negative side output (video signal output portion corresponding to a bright area in the overall object) of the video signal inversely amplified by said operational amplifier A1 and constitutes the second means according to the present invention. The limiter circuit II is provided in parallel to said variable resistor VR1 and comprises a diode D2 and a variable resistor VR2 adapted to control current flowing through said diode D2, in which the inverted input terminal **11** of the operational amplifier A1 is connected to an anode of the diode D2 while a cathode of the diode D2 is connected through the variable resistor VR2 to the output terminal **13**. As shown by solid line(**2**) in FIG. **3**, this limiter circuit II is adapted to obtain an input/output characteristic such that a negative side of the output voltage from the operational amplifier A1 is forcibly suppressed by the diode D1. Referring to FIG. **3**, the abscissa indicates an input voltage V11 apearing at the inverted input terminal **11** of the operational amplifier A1 and the ordinate indicates an output voltage **13** appearing at the output terminal **13**. As shown, the output voltage V13 is limited to a constant level of β as the input voltage V11 exceeds a level of α. It should be noted here that a broken line (**1**) corresponds to a characteristic which would be exhibited without any limitation.

The inverted signal Vac obtained in said inverted amplifier is then rectified by a voltage multiplying rectifier which is provided immediately subsequent to said inverter amplifier. In this voltage multiplying rectifier, a voltage multiplying capacitor C3 is connected to said output terminal **13**, an output terminal **14** of said capacitor C3 is connected through a diode D3 to the midrange voltage terminal **2** to produce a voltage multiplied signal V14 corresponding to the inverted signal Vac containing both a positive side and a negative side, and a diode D4 is forwardly connected to said output terminal **14** so as to provide a rectified signal Vdc. There are provided a capacitor C and a resistor R5 between the voltage multiplying rectifier and ground for the purpose of smoothing said rectified signal Vdc.

Said rectified signal Vdc is coupled through a resistor R6 to an inverted input terminal **21** of an operational amplifier A2 constituting the fourth means according to the present invention adapted to provide a control signal for an automatic diaphragm controlling servomotor. There is provided between the inverted input terminal **21** and an output terminal **23** of the operational amplifier A2 a resistor R7 serving as a feedback resistor adapted to determine an amplification degree or factor in conjunction with said resistor R6. Reference C5 designates an integrating capacitor provided in parallel with the resistor R5. The input terminal **21** is also connected through a resistor R9 to an output terminal of a detecting coil **5** adapted to detect operation of the servomotor M for diaphragm control so that a feedback signal with which the servomotor M is stopped may be obtained. Another output terminal of said detecting coil **5** is connected to the mid-range voltage terminal. Additionally, a non-inverted input terminal **22** is connected through a resistor R8 to the mid-range voltage terminal **2** so that said rectified signal Vdc and the braking signal provided from the detecting coil **5** are compared with a mid-range voltage Vo as a reference voltage. As a result of such comparison, a difference relative to the mid-range voltage Vo appearing at the non-inverted input terminal **22** is relatively low and, in consequence, a control signal Vout appearing at the output terminal **23** is low when the signal appearing at the inverted input terminal **21** is relatively high while a difference relative to the mid-range voltage Vo appearing at the non-inverted input terminal **22** is relatively high and, in consequence, the control signal appearing at the output terminal **23** is high when the signal appearing at the inverted input terminal **21** is relatively low.

Said control signal is applied to an immediately subsequent one-way drive circuit having a voltage gain and thereby said diaphragm control servomotor M is driven with a substantially amplified driving voltage. A resistor R10 is inserted between the output terminal **23** of said operational amplifier A2 and the ground **4**, and said output terminal **23** is also connected through a resistor R11 to the base of a transistor TR2. The collector of said transistor TR2 is connected through a resistor R12 to the positive terminal **3** of the source, and is also connected to the base of a transistor TR3 which is provided with said transistor TR2 as a pair. The emitter terminal of the transistor TR2 is connected through a resistor R14 to the ground **4**, and it also connected through a feedback resistor **13** to the collector terminal of said transistor TR3. The emitter terminal of the transistor

TR3 is connected to the positive terminal 3 of the source. Reference numeral 6 designates a driving coil of the one-way drive circuit associated with the servomotor M and this coil 6 is connected at one terminal with the collector of said transistor TR3 and at the other terminal connected to the ground 4 of the source circuit. Transistors TR2 and TR3 form a Darlington connection by which a voltage having an extremely high amplification factor is applied to the driving coil 6 in proportion to the control signal Vout applied to the base of the transistor TR2.

The diagphragm driving servomotor M is, in the embodiment shown, normally biased under action of a spring 7 to be rotated in the diaphragm closing direction while the driving coil 6 drives the servomotor M against said spring 7 in the diaphragm opening direction so that diaphragm control may be performed under a balance with the spring 7.

Reference numeral III designates a power supply circuit constituting the third means adapted to stabilize the source voltage for the device according to the present invention at a constant level. In this power supply circuit, the collector of a transistor TR1 is connected to a positive terminal 8 of the source and serially connected through a resistor R1 and a capacitor C1 to the ground terminal 4, a junction of said resistor R1 and said capacitor C1 is connected to the base of the transistor TR1 and said base is connected through a Zener diode D1 to the ground terminal 4 so that the base voltage may be kept constant independently of a voltage variation at the positive terminal 8 to supply the positive terminal 3 of the source corresponding to the emitter terminal of the transistor TR1 with constant voltage and current.

Reference numeral V designates a mid-range voltage supply circuit constituting the fifth means according to the present invention connected to said power supply circuit III. This circuit V is adapted to output an intermediate (preferably $\frac{1}{2}$) of the stabilized source voltage to the mid-range voltage terminal 2. In the specific embodiment as shown, a smoothing capacitor C7 and serial resistors R15, R16 having the same resistance value are provided in parallel across the positive terminal 3 and the ground 4, and a junction point 51 of said resistors R15, R16 is connected to the mid-range voltage terminal 2 so that a voltage equal to $\frac{1}{2}$ of the source voltage is output to the mid-range voltage terminal 2. Reference C6 designates a smoothing capacitor connected between the mid-range voltage terminal 2 and the ground 4.

The manner in which the device according to the present invention operates will now be considered in reference to the embodiment of the above-mentioned arrangement. Assuming that the video signal Vin is input to the input terminal 1 with a waveform (b) as illustrated in the test chart (a) of FIG. 4, this waveform will have a positive rectangular area corresponding to the bright area of the scene of a video level Vd, a synchro level Vs and an amplitude Vp-p. Such a video signal Vin has its DC component removed by the capacitor C2 and, in consequence, the positive side area and the negative side area are biased with respect to the reference voltage Vo, as seen in FIG. 5. This signal is then inversely amplified by the operational amplifier A1, as seen in FIG. 6 (*a*), on the basis of the mid-ranged voltage Vo applied from the mid-range voltage terminal 2 and appears at the output terminal 13 as Vac. The gain of this operational amplifier A1, namely, the amplification factor, depends on a ratio of the resistance value of the variable resistor VR1 to that of the resistor R3, so that it is possible to increase or decrease the gain and, therefore, the amplitude of the inverted signal Vac by regulation of the resistance value of said variable resistor VR1. Thus, the first means according to the present invention is implemented for appropriate adjustment of the video signal during the low contrast.

Now in the limiter circuit II, the variable resistor VR2 may be regulated to limit the portion of the video signal corresponding to the bright area and thereby obtaining an object to be shot principally adjusted on the basis of the dark area during the high contrast. More specifically, the variable resistor VR2 may be first regulated so as to have an infinite resistance value to obtain the inverted signal Vac having a waveform similar to one illustrated in FIG. 6. When this inverted signal Vac is applied to the capacitor C3 of the voltage multiplying/rectifying circuit, the diode D3 becomes conductive with the negative side signal and thereupon the capacitor C3 is charged. The immediately following positive side signal is applied thereto and the multiplied voltage is DC rectified with its amplitude remaining unchanged, as illustrated in FIG. 7 (*b*), providing a control signal suitable for detection of the video level Vd of FIG. 4 (*b*) in order to adjust the object on the basis of the bright area therein. When the resistance value of the variable resistor VR2 is adjusted to 0, the diode D2 becomes conductive and the the limitation is effected as seen in FIG. 3 (2), so that the bright portion of the video signal Vin is cut as seen in FIG. 7 (*a*), resulting in the inverted signal Vac free form the portion indicated by broken line. This inverted signal Vac is rectified by the multiplied voltage signal and DC-regenerated as illustrated in FIG. 7 (*b*), as in the previous case. Here is provided the control signal suitable to adjust the object on the basis of the dark area therein corresponding to the video signal Vin with its bright portion having been cut. During the low contrast, the video output signal preset by the first means will be hardly affected by the limiter circuit even when the latter is activated, since the bright portion of the video signal Vin has a relatively small amplitude during this low contrast.

The rectified signal Vdc is applied to the inverted input terminal 21 of the operational amplifier A2 and compared with the mid-range voltage appearing at the non-inverted input terminal 22 to obtain the control signal Vout at the output terminal 23. Simultaneously the feedback signal also is applied from the detecting coil 5 of the servomotor M to the inverted input terminal 21 and, therefore, the control signal Vout contains also the braking signal for the servomotor M.

The control signal Vout is input to the one-way drive circuit having the voltage gain of the Darlington connection consisting of two transistors TR2, TR3 and it is thus possible to supply the driving coil 6 of the servomotor M with an extremely high driving voltage even when the control signal is of a relatively low level. More specifically, in proportion to a variation in the control signal Vout applied to the base of the transistor TR2, the voltage applied from the source terminal 3 to the collector of the transistor TR3 is amplified over a wide range. For example, assuming that the control signal Vout derived from the optimal video signal for a given object causes the driving coil 6 to maintain the diaphragm at a predetermined opening angle relative to the normal biasing of servomotor M in the diaphragm

closing direction by force of the spring 7, there occurs no variation in the control signal Vout and the driving coil 6 continues to be supplied with a constant voltage from the source, so long as there occurs no change in the object condition. Upon occurrence of a change in the object condition, e.g., the object becomes brighter, the rectified signal Vdc increases, the above-mentioned comparison with the mid-range voltage in the operational amplifier A2 provides a lower voltage (control signal Vout) at the output terminal 23, the base voltage of the transistor TR2 in the one-way drive circuit decreases, the voltage applied to the driving coil 6 is reduced and the diaphragm is driven by the spring 7 in the closing direction, then the diaphragm is held at the subsequent condition of the optimal video signal. When the object becomes darker, reversely, the rectified signal Vdc decreases, the output signal (i.e. control signal) from the operational amplifier A2 increases, the voltage supplied to the driving coil 6 increases and the servomotor M is driven in the diaphragm opening direction against the action of the spring 7, then the diaphragm is held at the subsequent condition of the optimal video signal.

The source stabilizer circuit III serving as the third means according to the present invention now maintains the base voltage of the transistor TR1 by the resistor R1, the capacitor C1 and the Zener diode D1 so that the voltage applied from the power supply terminal 8 to the collector thereof may be constant at the emitter side of the source 3, the mid-range voltage of said first and second means according to the present invention may be kept constant, the source voltage of the Fourth means also may be kept constant, and thus the reliability thereof may be improved.

Finally, the mid-range voltage supply circuit serving as the fifth means according to the present invention supplies the mid-range voltage intermediate of said stabilized source voltage to the operational amplifiers A1, A2 associated with said first, second and fourth means so that the control voltage Vout based on such mid-range voltage may be obtained with a single source and the diaphragm controlling servomotor may be driven by amplifying this control voltage.

Effect

As obviously understood from the foregoing description, there is provided, in accordance with the present invention, an automatic diaphragm control device for a TV camera objective utilizing a video signal from a TV camera, said automatic diaphragm control device comprising the first means primarily for adjustment of the video signals during the the low contrast, the second means primarily for adjustment of the video signal during high contrast and also adapted to keep the video output signal previously adjusted and set by the first means during the low contrast against any substantial variation, the third means for stabilization of the source voltage in order to inhibit a possible variation of the video output signal preset by said first and second means or a possible increase of current, the fourth means by which braking of the servomotor can be effected on the basis of amplification of the rectified signal provided by said first and second means and on the basis of the feedback signal from the detecting coil of the diaphragm driving servomotor, and in order to drive the servomotor, supplying the servomotor with the stabilized voltage substantially amplified in the one-way drive circuit having a voltage gain according to the obtained control signal, and the fifth means to activate the operational amplifiers respectively used in said first, second and fourth means with a single power source. With such arrangement, a variable photometric function is provided, for example, it is possible to regulate the video signal coming from the TV camera on the basis of the overall brightness of the object to be shot and, during high contrast, the optimal video signal can be obtained by cutting the signal portion corresponding to the particularly bright area. Moreover, by stabilizing the source voltage and deriving the control signal based on the mid-range voltage intermediate of this stabilized source voltage, both driving and control of the diaphragm can be achieved with a single source. Furthermore, the source voltage can be amplified over an extremely wide range based on the control signal and then supplied via the one-way drive circuit to the servomotor in order to drive the diaphragm. Thus a highly reliable automatic control device of a TV camera objective is provided which can be easily made compact.

What is claimed is:

1. An automatic diaphragm control device for a TV camera objective comprising:
   - first adjustment means for adjusting a low contrast video signal from said TV camera;
   - second adjustment means for adjusting a high contrast video signal from said TV camera and for preventing a video signal adjusted by said first adjustment means from being substantially varied;
   - voltage stabilization means for stabilizing a source voltage used as a power supply for said device, to prevent variations in the video signals adjusted by said first and second adjustment means;
   - a servomotor for driving a diaphragm of said TV camera objective including a driving coil and a detecting coil;
   - control means for halting the operation of said servomotor in response to said adjusted video signals and a feedback signal from said detecting coil, and for driving said servomotor by applying a stabilized voltage to said driving coil; and
   - means for providing a voltage supply to said first and second adjustment means and said control means, which voltage supply is of a predetermined value that is less than said source voltage.

2. An automatic diaphragm control device for a TV camera objective according to claim 1, wherein said first adjustment means comprises an operational amplifier adapted to inversely amplify a DC component of the low contrast video signal in a gain-variable manner.

3. An automatic diaphragm control device for a TV camera objective according to claim 1, wherein said first adjustment means comprises an operational amplifier adapted to inversely amplify a DC component of the low contrast video signal in a gain-variable manner and said second adjustment means comprises a diode adapted to suppress a negative signal portion of an output signal from the operational amplifier serving as the first adjustment means.

4. An automatic diaphragm control device for a TV camera objective according to claim 1, wherein said voltage stabilization means comprises a transistor having a base voltage held at a constant level under action of a resistor, a capacitor and a Zener diode and outputs at its emitter a voltage supplied from a power supply terminal to its collector which is stabilized at a constant level;

wherein said constant voltage outputted at the emitter is supplied to the first and second adjustment means and the control means.

5. An automatic diaphragm control device for a TV camera objective according to claim 1, wherein the control means comprises an operational amplifier for amplifying a multiplied and rectified signal based on adjusted signals from the first and second adjustment means and said feedback signal from said detecting coil in order to provide a control signal, and a Darlington transistor connection consisting of two transistors for supplying said control signal to said driving coil as an extremely high driving voltage.

6. An automatic diaphragm control device for a TV camera objective according to claim 1, wherein the voltage supply means functions to supply operational amplifiers respectively used in the first and second adjustment means and control means with a mid-range voltage intermediate of said source voltage stabilized by the voltage stabilization means as a reference voltage so that both diaphragm driving and diaphragm control can be achieved with a single source.

* * * * *

United States Patent [19]

Shikano et al.

[11] **Patent Number: 4,717,960**

[45] **Date of Patent: Jan. 5, 1988**

[54] **AUTOMATIC DIAPHRAGM CONTROL DEVICE OF VARIABLE PHOTOMETRY TYPE USED IN OBJECTIVE FOR TELEVISION CAMERA**

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[73] Assignee: **Asahi Seimitsu Kabushiki Kaisha,** Tokyo, Japan

[21] Appl. No.: **906,546**

[22] Filed: **Sep. 12, 1986**

[30] **Foreign Application Priority Data**

Sep. 12, 1985 [JP] Japan 60-202172

[51] **Int. Cl.**[4] **H04N 5/238**

[52] **U.S. Cl.** **358/228**

[58] **Field of Search** 358/228

[56] **References Cited**

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Primary Examiner—Michael A. Masinick

Attorney, Agent, or Firm—Birch, Stewart, Kolasch & Birch

[57] **ABSTRACT**

An automatic diaphragm control device for the objective of a television camera, utilizing a video signal coming from the television camera to effect the diaphragm control The present invention provides a device including a fixed photometric circuit of a drastic peak characteristic in a part of a variable photometric circuit so as to be readily switched to perform a drastic peak photometric adjustment, in addition to an ordinary variable photometric adjustment, and also provides an automatic diaphragm control device of variable photometry type used in a television camera in which the variable photometric circuit is also arranged so as to be switched between the variable peak mode and the variable average mode so that a simple operation of changing over on one and the same circuit permits the variable photometry of both types to be selectively performed in order to obtain not only the drastic peak photometric characteristic but also versatile photometric characteristics optimized for various requirements.

5 Claims, 12 Drawing Figures

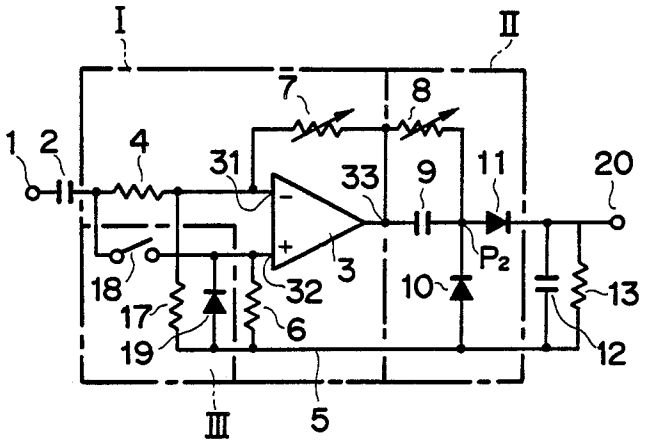
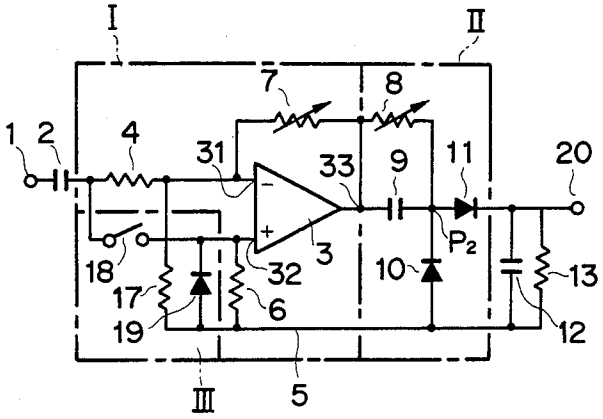


FIG. 1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II
III
1
2
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33
3
P2

FIG. 2

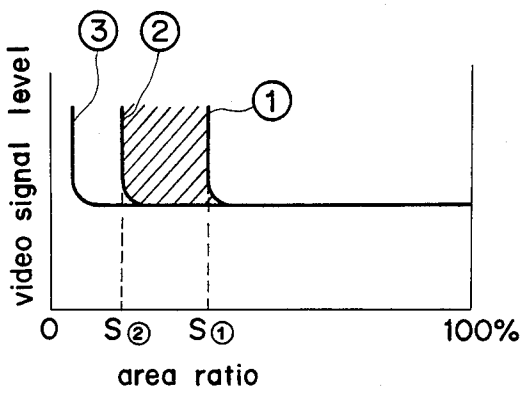
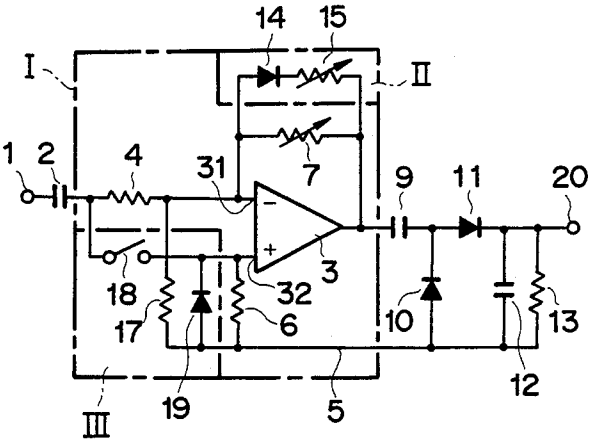

video signal level
0
S②
S①
100%
area ratio
①
②
③

FIG. 3


14
15
I
II
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19
5
III

FIG. 4

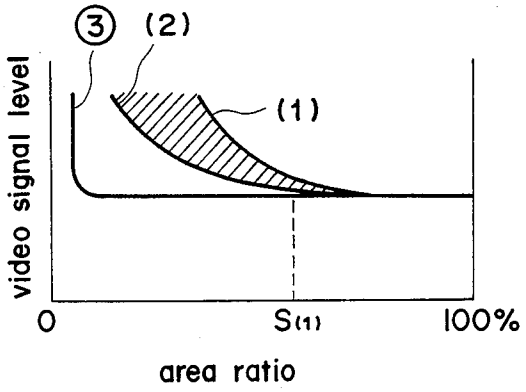
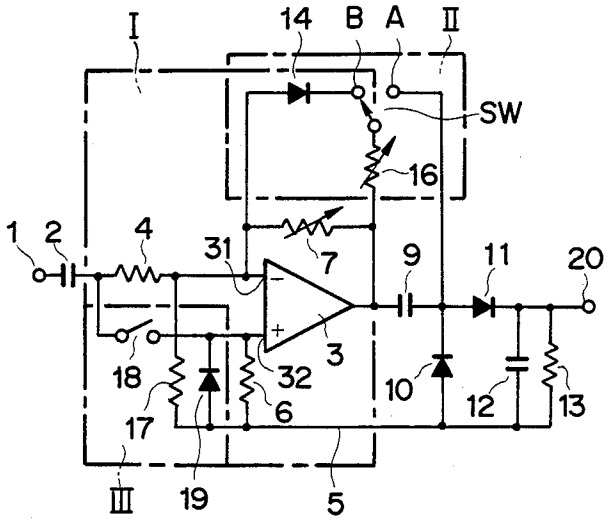

③
(2)
(1)
video signal level
0
S(1)
100%
area ratio

FIG. 5


I
14
B
A
II
SW
16
1
2
4
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7
9
11
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3
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32
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12
13
17
6
III
19
5

FIG. 6

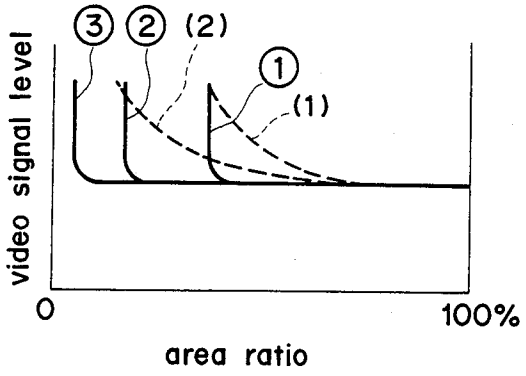

③
②
(2)
①
(1)
video signal level
0
100%
area ratio

FIG. 7

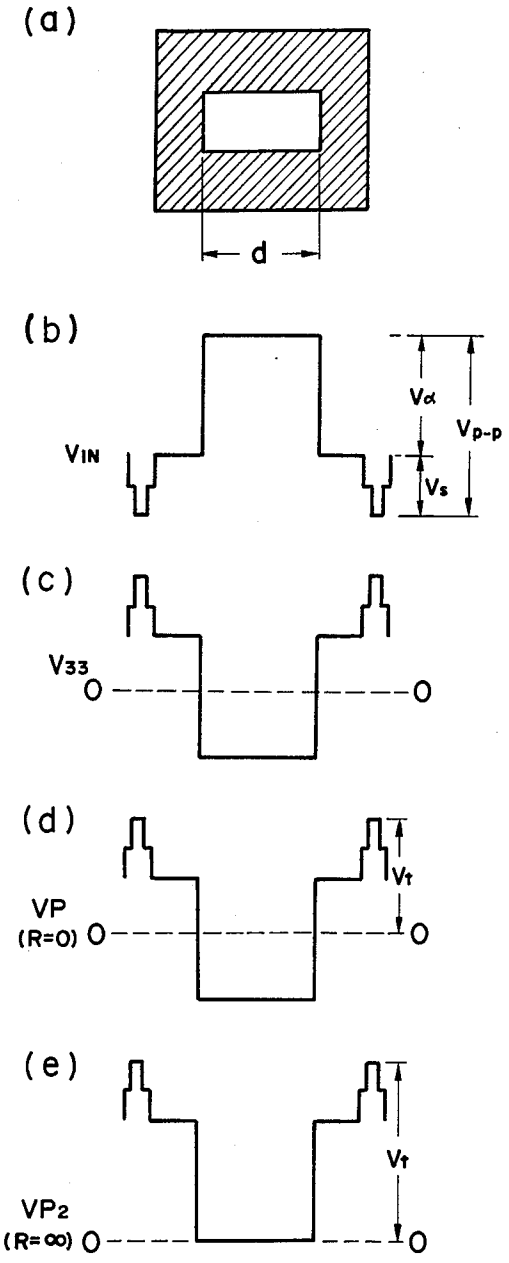


FIG. 8

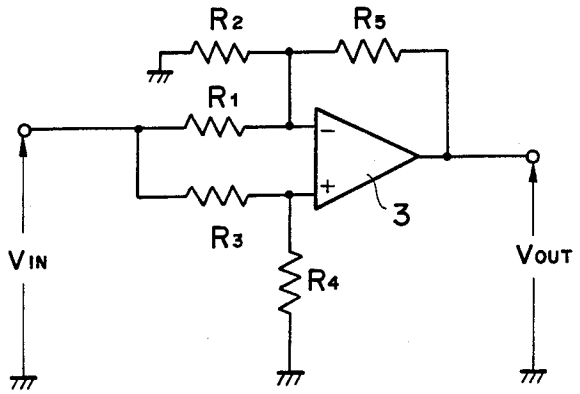


FIG. 10

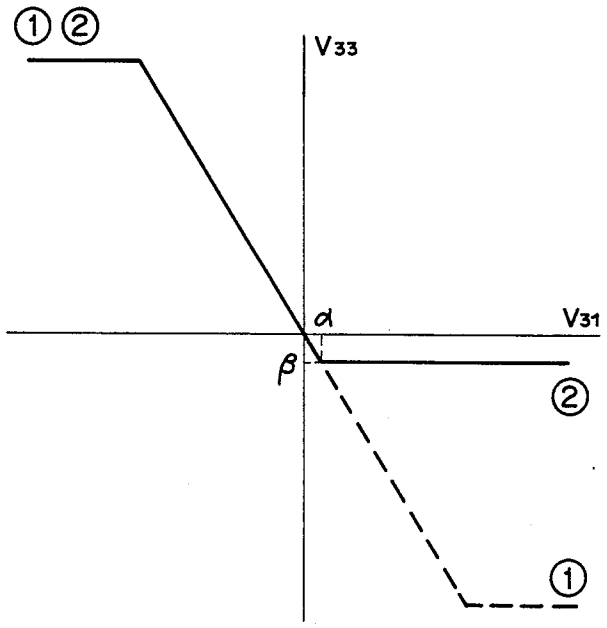


FIG. 9

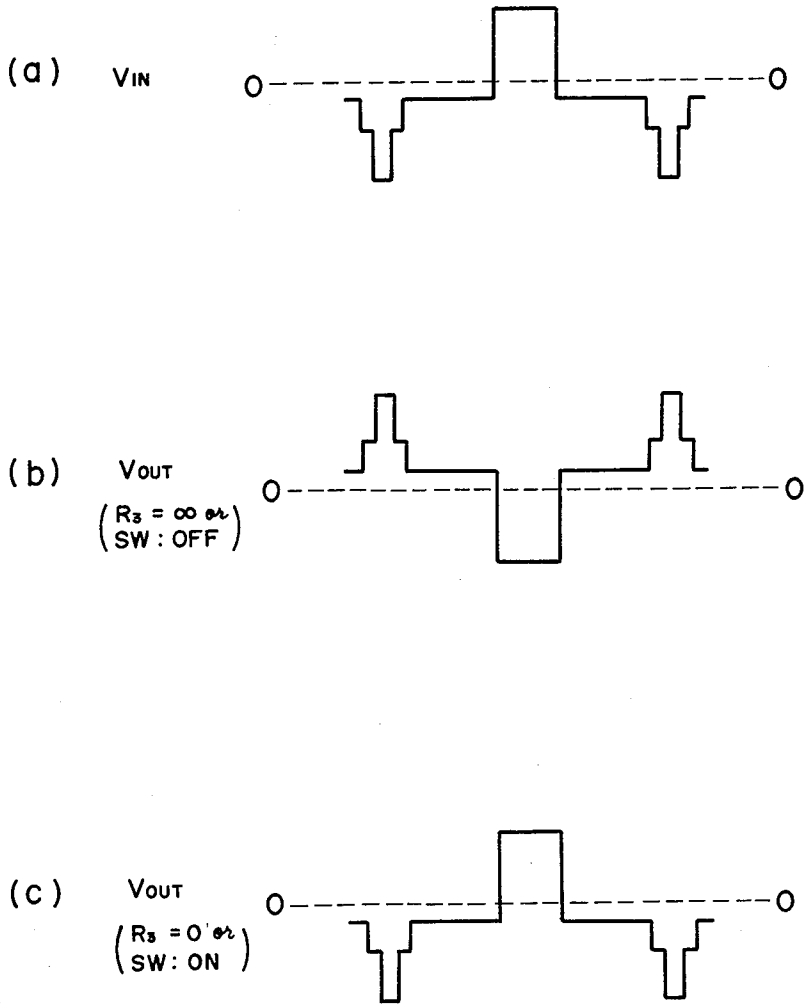


FIG. 11

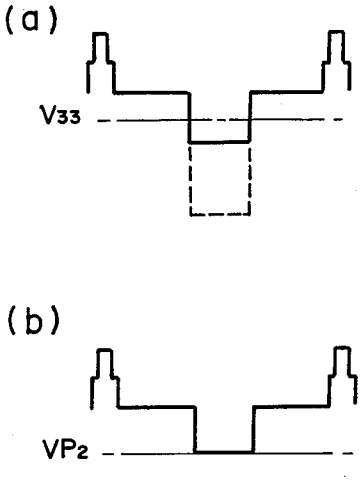
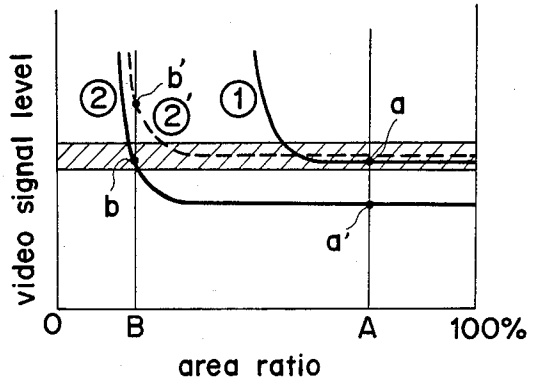


FIG. 12



AUTOMATIC DIAPHRAGM CONTROL DEVICE OF VARIABLE PHOTOMETRY TYPE USED IN OBJECTIVE FOR TELEVISION CAMERA

BACKGROUND OF THE INVENTION

Industrial field of application

The present invention relates to an automatic diaphragm control device of variable photometry type where its objective is for television cameras that are adapted for automatically controlling the objective diaphragm utilizing a video signal supplied from the television camera.

Prior art

As has already been disclosed, for example, in the specifications of U.S. Pat. No. 4,451,851 and U.S. Pat. No. 4,472,743, the conventional television camera utilizing the video signal for automatic diaphragm control is provided with the control circuit having the photometric mode converting function and the sensitivity adjusting function so as to adapt to various shooting environments.

To obtain the optimum picture, in addition to the proper sensitivity adjustment depending on the absolute luminance of an object to be shot, the luminance ratio of bright and dark areas, i.e., the range of contrast is one of the important factors. The range of contrast in the natural world is as high as an order of 10:1 even under clouded sky and often an order of 100:1 under bright sky while the range of contrast which can be represented on the television-reproduced picture is as low as 30 to 40:1. Accordingly, for the picture simultaneously including a bright area and a dark area, it is impossible for a viewer to see both of these areas simultaneously and it must be determined whether the bright area should be selected as the main object to be shot or the dark area should be selected as the main object to be shot.

Theoretically, so-called average photometry mode is suitable for the case in which the dark area is selected as the main object to be shot while so-called peak photometry mode is preferable for the case in which the bright area is selected as the main object to be shot. As the video photometric method of prior art utilizing the video signal coming from the television camera for diaphragm control, any one of the abovementioned types. However, use of such photometric method in a fixed manner has caused various inconveniences. Specifically, for the picture simultaneously including the bright area and the dark area, the average photometry mode has often resulted in the bright area being solidly white or gradientless while the peak photometry mode has often made the dark area, which should be adequately visible in view of the camera sensitivity, almost invisible. With both the peak photometry mode and the average photometry mode, it is required to determine whether the bright area should be selected as the main object to be shot or the dark area should be selected as the main object to be shot, for the scene simultaneously including these bright and dark areas. It is preferred, therefore, that when the object to be shot has no extremely dark area, namely it is in a low contrast condition, the video signal of a same level is obtained even after the photometry mode has been variable adjusted.

Referring to FIG. 12, for example, with a photometric adjuster circuit having its characteristic change from the curve (1) to the curve (2), which provides a steeper gradient of the video signal level, as the photometric mode is variably adjusted from the average photometry mode to the peak photometric mode for a low constrast object, it is assumed that an area ratio of the bright zone to the overall scene is A, a video signal level a covered by the optimum range (shaded zone) has obtained by selecting the characteristic (1). If the area ratio is changed by zooming from A to B, the video signal level would be substantially in excess of said optimum level range and result in an over-luminance. Certainly, the photometry mode may be variably adjusted to the characteristic (2) at this time point to obtain a video signal level b covered also by said optimum range again. However, when the area ratio A is restored by zooming, there occurs an under-luminance a'. To restore the optimum level range a, the photometric mode must be adjusted again to the characteristic (1) or the characteristic (2) must have a sensitivity adjustment to obtain the characteristic (2)'. According to the characteristic curve (2)', an over-luminance b' appears at the area ratio B. Thus, with the photometry adjuster circuit presenting the steeper gradient of the video signal level in the low contrast condition, the selective adjustment between the sensitivity adjustment and the photometric mode adjustment is so difficult that the adjustment may often be disturbed.

To avoid such disturbance, it is desirable that the characteristic video signal level exhibits no substantial variation in the low contrast condition whether the average photometry mode or the peak photometry mode is selected and, therefore, adjustment of the video signal level can be achieved only by the sensitivity adjustment in the low contrast condition while variable adjustment of the photometry mode is effective only in the high contrast condition.

SUMMARY OF INVENTION

Problems to be solved by invention

FIG. 2 illustrates characteristic curves exhibited by photometric adjuster means of variable peak photometry type which will be described in detail later, in which (1) represents a characteristic curve of the average photometry mode and (2) represents a characteristic curve of the peak photometry mode. The photometry adjuster means of this type maintains the video signal level constant until the area ratio of the bright zone to the scene overall decreases to a certain value S (1) or S (2), respectively, and cannot maintain the peak value as said area ratio is further reduced, since there occurs then an over-luminance. Accordingly, during variation in the area of the bright zone, particularly during variation of the focal distance by zooming, an abrupt change of the video signal level at the certain point S (1) or S (2) sometimes gives a viewer an unnatural impression. Nevertheless, such photometry adjuster means is suitable for a case in which the main object to be shot is limited to the bright zone of the scene and only this bright zone is continuously regarded.

FIG. 4 illustrates characteristic curves exhibited by photometry adjuster means of variable average photometry type which will be mentioned more in detail later, in which a curve (1) represents a characteristic obtained when the average photometry mode is selected and a curve (2) represents a characteristic obtained when the peak photometry mode is selected. The photometry adjuster means of this type is characterized in that the video signal level gradually varies as the area of the bright zone varies and such gradual variation

occurs also when the area ratio of the bright zone is changed by zooming. With the consequence, unnatural impression encountered by the photometry adjuster means of the previously mentioned type can be eliminated by the photometry adjuster means of this type but the latter is not suitable for the case in which only the bright zone is concentratively regarded.

As will be obvious from the foregoing description, all of these photometric adjustments are adapted to adjust a variation of the video signal level according to the area ratio of the bright zone to the overall scene, when the latter is of a relatively high contrast, and the over-luminance occurs as said area ratio of the bright zone is further reduced not only when the variable average photometry mode is selected but also when the variable peak photometry mode is selected, although such over-luminance is remarkable particularly when the variable average mode is selected. To solve this problem of the over-luminance, it will be advantageous that the photometry adjuster means can selectively have a drastic peak characteristic as represented by a curve (3) in FIGS. 2 and 4.

However, incorporation of the two photometric circuits into the objective as diaphragm control circuits which may be changed over to each other as desired will be extremely difficult, because a space for these photometric circuits is restricted in view of a serious demand for a compact objective.

A first and principal object of the present invention is to provide a device including a fixed photometric circuit of a drastic peak characteristic in a part of a variable photometric circuit so as to be readily switched by switching means to perform a drastic peak photometric adjustment, in addition to an ordinary variable photometry adjustment.

A second object of the present invention is to provide an automatic diaphragm control device of variable photometry type used in a television camera in which the variable photometric circuit is also arranged so as to be switched between the variable peak mode and the variable average mode so that a simple operation of changing over on one and the same circuit permits the variable photometry of both types to be selectively performed in order to obtain not only said drastic peak characteristic but also versatile photometric characteristics optimum for various requirements.

Measures to solve problems

These objects are achieved, according to the present invention, by providing an automatic diaphragm control device of variable photometry type used in the objective of a television camera including the variable photometry adjuster means as illustrated by FIG. 2 or 4 and the photometric means having drastic peak characteristic and utilizing a video signal coming from the television camera to effect the diaphragm control, said automatic diaphragm control device comprising: first means consisting of sensitivity adjusting means principally to adjust a video output signal in a low contrast condition; second means consisting of variable photometry adjusting means principally to adjust a video output signal in a high contrast condition; third means for photometric adjustment of a video output signal in a drastic peak mode independently of the photometric adjustment by said second means; and means permitting said second and third means to be selectively used as desired by switching therebetween. As another solution, the present invention provides an automatic diaphragm control device of variable photometry type used in the objective of television camera having said variable peak photometric characteristic as illustrated in FIG. 2 and said variable average photometric characteristic as illustrated in FIG. 4 incorporated into one and the same circuit so as to be readily changed over therebetween for selective use thereof and utilizing a video signal coming from the television camera to effect the diaphragm control, said automatic diaphragm control device comprising: first means consisting of sensitivity adjusting means principally to adjust a video output signal in a low contrast condition; second means consisting of variable photometry adjusting means principally to adjust a video output signal in a high contrast condition; third means for photometric adjustment of a video output signal in a drastic peak mode independently of the photometric adjustment by said second means; means permitting said second means to be selectively used as means for the variable photometry in an extreme peak mode and means for the variable photometry in an extreme average mode as desired by switching therebetween; and means permitting said third means to be selectively used as desired by switching. As a further solution, the present invention provides an automatic diaphragm control device of variable photometry type used in the objective for television camera, said automatic diaphragm control device comprising: first means consisting of an inverted amplifier adapted for inverted amplification of a video signal output from the television camera with a variable amplification ratio relative to a reference voltage; second means adapted to be selectively used as desired, by switching, as means for peak photometric adjustment consisting of a voltage doubling rectifier including a capacitor of which the charging voltage can be adjusted by voltage doubling and rectifying the video signal inversionally amplified in said inverted amplifier and means for an average photometric adjustment consisting of a limiter circuit adapted to adjustably limit a negative component of the video signal inversionally amplified in said inverted amplifier; third means for photometric adjustment of the video output signal in an extreme peak mode independently of the variable photometric adjustment performed by said second means; and means permitting said second and third means to be selectively used as desired by switching therebetween.

Functions

A first function of the device constructed according to the present invention is based on a feature such that a fixed photometric circuit of a drastic peak characteristic is a part of a variable photometric circuit so to be readily switched as by switching means to perform a drastic peak photometric adjustment, in addition to an ordinary variable photometric adjustment. A second function of the device according to the present invention is based on a feature such that the variable photometric circuit is also arranged so as to be switched between the variable peak mode and the variable average mode so that a simple operation of changing over on one and the same circuit permits the variable photometry of both types to be selectively performed in order to obtain not only said drastic peak characteristic but also versatile photometric characteristics optimum for various requirements.

BRIEF DESCRIPTION OF DRAWING

FIG. 1 is a circuit diagram illustrating an important part in an embodiment of the device constructed according to the present invention;

FIG. 2 is a diagram schematically showing a variation in characteristics of the device depending on a photometric adjustment;

FIG. 3 is a circuit diagram similar to FIG. 1 but concerning another embodiment;

FIG. 4 is a diagram similar to FIG. 2 but concerning the embodiment of FIG. 3;

FIG. 5 is a circuit diagram similar to FIGS. 1 and 3 but concerning still another embodiment;

FIG. 6 is a diagram similar to FIGS. 2 and 4 but concerning the embodiment of FIG. 5;

FIG. 7 is a diagram illustrating an object to be shot and waveforms of the video signal in the respective circuit stages:

FIG. 8 is a circuit diagram illustrating a basic circuit in the third means;

FIG. 9 is a diagram illustrating waveforms of the video signal depending on the characteristics;

FIG. 10 is a diagram illustrating characteristics exhibited by another embodiment of the limiter circuit in the second means;

FIG. 11 is a diagram illustrating waveforms of the video signal depending on characteristics; and

FIG. 12 is a diagram illustrating the characteristics involving various problems in the prior art.

EMBODIMENTS

The present invention will be described more in detail with reference to preferred embodiments as illustrated by the accompanying drawing.

Referring to a circuit diagram illustrated by FIG. 1, reference numeral 1 designates a video signal input terminal adapted to input a video signal coming from the television camera to the device according to the present invention, and this terminal is connected through a capacitor 2 to first means I consisting of an inverted amplifier including components such as a resistor 4, a variable resistor 7 and an operational amplifier 3.

In the inverted amplifier, an inverted input terminal 31 of the operational amplifier 3 is connected through the resistor 4 to said capacitor 2 while a non-inverted input terminal 32 is connected through a resistor 6 to a reference voltage terminal 5 regulated to a mid-point voltage corresponding to a half of a source voltage. The variable resistor 7 is disposed as a feedback resistor between the inverted input terminal 31 and an output terminal 33. The inverted amplifier is adapted to inversionally amplify the video signal having its DC component removed in said capacitor 2 and to adjust a resistance value of said variable resistor 7 relative to said resistor 4 in order to change an amplification ratio of the operational amplifier 3.

Reference numeral II designates second means consisting of a voltage doubling rectifier adapted for voltage doubling amplification of the video signal which has been inversionally amplified by said inverted amplifier, in which a voltage doubling capacitor 9 including a variable resistor 8 connected in parallel therewith is connected to the output terminal 33 of said operational amplifier 3, the reference voltage terminal 5 is connected through a diode 10 to an output terminal P2 of said capacitor 9 and a diode 11 is serially connected to said output terminal P2. The variable resistor 8 functions to change a charging voltage of the voltage doubling capacitor 9 and is so arranged that said charging voltage becomes zero when said variable resistor 8 has a resistance value of zero and increases as the resistance value increases. The diode 11 serves to DC rectify a signal appearing at the output terminal P2 of the capacitor 9. To smooth this rectified signal, there is provided a capacitor 12 and a resistor 13 between an output terminal of said diode 11 and the reference voltage terminal 5.

Reference numeral III designates the third means according to the present invention which is adapted to adjust the charging voltage of the capacitor 2 so as to convert the photometric characteristic to that of a drastic peak mode. In the embodiment illustrated, the output terminal of the capacitor 2 is connected through a switch 18 and a diode 19 to the reference voltage terminal 5.

A circuit characteristic of the third means III will be now considered in reference with a principle diagram of FIG. 8. A relationship between an input voltage Vin and an output voltage Vout is given by a following equation:

$$Vout = \left[\frac{R4}{R3 + R4} \left(1 + \frac{R5}{R1} + \frac{R5}{R2} \right) - \frac{R5}{R1} \right] Vin$$

In the equation above, Vout may take various values as a function of R3 and when R3=infinity

$$Vout = -(R5/R1) \cdot Vin,$$

and when R3=0

$$Vout = (1 + R5/R2) \cdot Vin.$$

Thus, the output voltage Vout has opposite polarities according to the values of R3, i.e., those of infinity and zero.

In the embodiment illustrated by FIG. 1, the resistor R3 comprises the switch 18, and a state of the switch OFF corresponds to R3=infinity while a state of switch ON corresponds to R3=0.

Assuming that a signal having a waveform Vin of FIG. 9(*a*) is applied as an input signal to the circuit of FIG. 8, an inverted output signal Vout as illustrated by FIG. 9(*b*) is provided when the variable resistor R3 is set to infinity (i.e., switch OFF) and a non-inverted output signal Vout as illustrated by FIG. 9(*c*) when the variable resistor R3 is set to zero. Both of these output signals contain no DC component and, therefore, are in a stabilized state in which positive and negative areas are equal to each other with respect to a base line 0—0.

In this way, the circuit functions as an average photometric circuit when R3=infinity (switch OFF). Specifically, the circuit is affected by a variation in the amplitude so long as a bright zone (central rectangular zone) is relatively large and such influence decreases as the bright zone becomes small. The circuit functions as a peak photometric circuit when R3=0 (switch ON) and can detect a variation of the amplitude even if the bright zone becomes small.

The diode 19 which is connected through the switch 18 to the reference voltage terminal 5 as illustrated by FIG. 1 is turned ON with the negative component of the input signal Vin when the switch 18 is in the state of ON and charges the capacitor 2, and turned OFF with the following positive signal component, a positive voltage results that is added to the previously charged negative voltage to achieve amplification. Thus, there is established a circuit having a drastic peak characteristic

which can detect the signal corresponding to a small bright zone even for a low contrast object to be shot.

In the circuit arrangement as mentioned above, it is assumed that a video signal Vin of a waveform as illustrated by FIG. 7(*b*) is applied to the video signal input terminal **1** with respect to a test chart of FIG. 7(*a*) when the switch **18** in the third means III is in the state of OFF. In this waveform a rectangular portion at the positive side corresponds to a bright zone of the picture, Vd represents a video level and Vs represents a synchro level. This video signal Vin is inversionally amplified in the inverted amplifier as illustrated by FIG. 7(*c*) and is output as an inverted signal V33 on the output terminal **33** of said inverted amplifier. This inverted signal V33 has its DC component already removed by the capacitor **2** and, in consequence, it is in a stabilized state in which the positive area and the negative area are equal to each other with respect to the base line (mid-point voltage line 0—0). Now the variable resistor **7** may be adjusted so as to increase its resistance value relative to the resistor **4** to increase an amplification ratio of the inverted amplifier proportionally and vice versa. Thus, the amplification ratio may be changed to adjust the amplitude Vp-p of the inverted signal V33 and thereby to achieve the sensitivity adjustment which is the function of the first means I according to the present invention.

The inverted signal V33 is then rectified in the voltage doubling rectifier. At this point, adjustment of the variable resistor **8** to the resistance value of 0 results in that the capacitor **9** does not function at all and a signal VP2 appearing at the output terminal P2 of said capacitor **9** becomes equal to the inverted signal V33 as seen in FIG. 7(*d*). Although the diode **10** is turned on with the negative component of the inverted signal V33, passage through the resistor **8** (R=0) prevents the capacitor **9** from being charged and the positive voltage V+ depends on an average value. Therefore, such photometric mode can be considered as the average photometric mode as indicated by the characteristic curve (**1**) in FIG. **2**, which is suitable for the case in which a dark zone is selected as the main object to be shot. When the variable resistor **8** is adjusted to the resistance value of infinity, on the other hand, the diode **10** is turned on with the negative component of the inverted signal V33 and the capacitor **9** is charged. A following positive signal is added to the previously charged voltage and the output signal VP2 is DC rectified as illustrated by FIG. 7(*e*), so that the amplitude of the video level Vd can be detected even when a width d of the bright zone is relatively small. Accordingly, such photometric mode with the variable resistor **8** being adjusted to the resistance value of infinity can be considered as the peak photometric mode as indicated by the characteristic curve (**2**) in FIG. **2**, which is suitable for the case in which the bright zone is selected as the main object to be shot. It should be understood that the variable resistor **8** may be adjusted to the intermediate resistance value to obtain the corresponding intermediate photometric mode which may be indicated by a curve having its rising portion within the shaded zone in FIG. **2**.

In the low contrast condition, an amplitude Vd corresponding to the bright zone is low relative to the full amplitude Vp-p of FIG. 7(*b*) and there is no variation in the amplitude V+ of FIGS. 7(*d*) and (**3**). As a result, the video signal level is not substantially affected by conversion of the photometric mode. Referring to FIG. **2** illustrating characteristics of the respective photometric modes, the curve (**1**) indicates the characteristic of the peak photometric mode and the curve (**2**) indicate the characteristic of the peak photometric mode. As will be obvious from FIG. **2**, in which the abscissa indicates the area ratio of the bright zone (with respect to the overall scene) and the ordinate indicates the video signal level, the video output signal level is substantially constant no matter whether the average photometric mode (**1**) is selected or the peak photometric mode (**2**) is selected so long as the area ratio is higher than S (**1**). This means that the video signal level is not affected by the photometric adjustment in the low constrast condition. Furthermore, even if said area ratio is varied by the operation of zooming, the video signal level is maintained substantially constant for the object to be shot, in which the area ratio of the bright zone is higher than S (**1**).

In this manner, the sensitivity adjusting means relying upon the variable resistor **7** of said inverted amplifier constitutes the first means principally serving to adjust the video output signal during the low contrast while the photometric adjusting means relying upon the variable resistor **8** of said voltage doubling rectifier constitutes the second means principally serving to adjust the video output signal during the high contrast, and the video output signal level once adjusted by the first means is free from any substantial variation even when said second means is adjustably activated during the low contrast.

When the switch **18** of the third means III according to the present invention is turned ON, a non-inverted amplified signal forming a drastic peak appears on the output terminal **33** of the operational amplifier **3**, as has previously been mentioned, and thus a photometric characteristic as indicated by the curve (**3**) in FIG. **2** is obtained at the circuit output terminal **20**, permitting a drastic peak photometry to be achieved with respect to a small spot in the bright zone.

In the circuit arrangement as illustrated in FIG. **3**, the basic construction of the voltage doubling rectifier and the third means III is identical to that of FIG. **1** and the circuit elements of similar functions are designated by the similar reference numerals. Specifically, the circuit arrangement corresponds to the circuit arrangement of FIG. **1** except that the variable resistor **8** for photometric adjustment is replaced by a limiter circuit for photometric adjustment as the second means II provided in the inverted amplifier. The limiter circuit functions to limit the negative output of the video signal inversionally amplified in the operational amplifier **3** and connected in parallel with the variable resistor **7** for sensitivity adjustment.

The limiter circuit comprises a diode **14** and a variable resistor **15** adapted to control the current flowing through said diode **14**. The anode of said diode **14** is connected to the inverted input terminal **31** of the operational amplifier **3** and the cathode thereof is connected through the variable resistor **15** to the output terminal **33**. The limiter circuit is so arranged that, as indicated by a solid line (**2**) in FIG. **10**, an input/output characteristic may be obtained, in accordance with the negative side of the operational amplifier **3** which is forcibly suppressed by the diode **14**. More specifically, referring to FIG. **10** in which the abscissa indicates an input voltage V31 on the input terminal **31** and the ordinate indicates an output voltage V33 on the output terminal **33**, the negative output voltage V33 would be represented by a broken line (**1**) in FIG. **10** as the input voltage V31 increases in excess of α, so as in accordance with the

normal input/output characteristic. However, said limiter circuit III is adapted to limit the output voltage V33 so as to be maintained at the level of β as indicated by a solid line (2), even when the input voltage increases beyond α. The variable resistor **15** of the limiter circuit may be properly adjusted to obtain the peak photometric mode, the average photometric mode or the intermediate photometric mode.

First, when the variable resistor **15** is adjusted to the resistance value of infinity, the limiter circuit is not activated and, as a consequence, the inverted signal V33 has a waveform as illustrated by FIG. 7(*c*). This inverted signal V33, when input to the voltage doubling capacitor **9** of the voltage doubling rectifier, is DC-regenerated by the diode **10** as V+ without any change of its amplitude Vp-p as seen in FIG. 7(*e*), thus providing the peak photometric mode in which the bright zone is selected as the main object to be shot. When the variable resistor **15** of the limiter circuit is adjusted to the resistance value of zero, the diode **14** is turned on and the operational amplifier **3** is output-limited, with a result that a peak portion beyond α in FIG. **10** is cut off from the signal Vd corresponding to the bright zone of FIG. 7(*b*) and the inverted signal V33 as indicated by a solid line in FIG. **11**. This inverted signal V33 is DC-rectified in the voltage doubling rectifier, as shown in FIG. 11(*b*), providing a voltage doubled signal VP2 which has no signal component of amplitude Vp-p corresponding to the bright zone and is substantially approximate to the average value. Thus, the average photometric mode is established, this mode being suitable for the case in which the dark zone is selected as the main object to be shot. Finally, adjustment of the variable resistor **15** to the intermediate resistance value may provide the photometric mode intermediate of the above-mentioned peak and average photometric modes. Moreover, in the low contrast condition, the amplitude Vd corresponding to the bright zone is low relative to the full amplitude Vp-p of FIG. 7(*b*), so there is no difference in the amplitude between the peak photometry waveform of FIG. 7(*e*) and the average photometry waveform of FIG. 11(*b*). Accordingly, conversion of the photometric mode has no significant influence upon the video signal level. Referring to FIG. **4** which illustrates characteristics of the respective photometric modes for the low contrast scene, a curve (1) corresponds to the average photometric mode and a curve (2) corresponds to the peak photometric mode. Also in FIG. **4**, the abscissa indicates the area ratio of the bright zone (with respect to the overall picture) and the ordinate indicates the video signal level. At the area ratio higher than S2, the video output signal level exhibits almost no variation no matter whether the average photometric mode (1) or the peak photometric mode (2) is selected, indicating that the video signal level is not affected by the photometric adjustment in the low contrast situation. In this case, the photometric adjustment of variable average type accompanied with a gradual variation of the video signal is effected as the area ratio is varied by operation of zooming, and the video signal level is maintained substantially constant for the object including the bright zone of which the area ratio is higher than S (1).

In this manner, the sensitivity adjusting means relying upon the variable resistor **7** of said inverted amplifier constitutes the first means principally serving to adjust the video output signal during the low contrast, the photometric adjusting means relying upon the variable resistor **15** of said limiter circuit constitutes the second means principally serving to adjust the video output signal during the high contrast, and, even when said second means is adjusted during the low contrast, the video output signal level once adjusted by said second means is not significantly affected thereby. Furthermore, turning on of the switch **18** of the third means III provides, as in the previous embodiment, the drastic peak photometric characteristic ((3) in FIG. **4**).

In the circuit diagram of FIG. **5**, the circuit elements having the similar functions to those in the circuit diagrams of FIGS. **1** and **3** are designated by the similar reference numerals. Referring to FIG. **5**, a variable resistor **16** and a switch SW provided between the terminal **33** and the point **P2**, in parallel with the the capacitor **9** of the voltage doubling rectifier constitutes the second adjust means of the variable peak photometric type, as shown in FIG. **1**, adapted to adjust the charging voltage of the capacitor **9**. The diode **14**, the switch SW and the variable resistor **16** which are provided in parallel with the variable resistor **7** of the inverted amplifier constitutes the limiter circuit serving as the second adjusting means of variable average photometric type as shown in FIG. **3**. In such a manner, the relatively peak-characteristic photometric adjuster circuit included in the second means II is selected by connecting the switch SW to one connection terminal A, the average photometric characteristic (1) is selected by adjusting the variable resistor **16** to the resistance value of zero, and the peak photometric characteristic (2) is selected by adjusting the variable resistor **16** to the resistance value of infinity. The relatively average-characteristic photometric adjuster circuit relying on the limiter circuit in the second means II is selected by connecting the switch SW to another connection terminal B, the average photometric characteristic (1) is selected by adjusting the variable resistor **16** to the resistance value of zero, and the peak photometric characteristic (2) is selected by adjusting said variable resistor **16** to the resistance value of infinity.

Thus, the user can select the photometric adjustment of variable peak photometric type or variable average photometric type merely by changing over the switch SW, carrying out the average photometric adjustment or adjusting the common variable resistor **16** of the peak photometric adjustment, and obtain the drastic peak-characteristic photometric means as indicated by the curve (3) by turning the switch **18** of the third means III on.

Effects

With the device constructed according to the present invention in the manner as has been described hereinabove, the sensitivity adjustment can be achieved by the first measure, for example, adjusting the resistor for varying the amplification ratio of the inverted amplifier, the photometric mode is selected by the second measure, for example, adjusting the variable resistor for photometric adjustment among the average photometric mode, the peak photometric mode and intermediate photometric mode so as to achieve an appropriate photometric adjustment, and the drastic peak photometric means can be activated by operating the switch as the third measure. Additionally, the video signal level is almost not affected by changing over the photometric mode for the object being in the low contrast condition, so the optimum video signal level can be obtained only by the sensitivity adjustment in such low contrast situation and the photometric adjusting can be selectively

performed only for the scene of the high contrast. In this way, the sensitivity adjustment and the photometric adjustment may be effected as separate adjusting measures to facilitate adjustment of the optimum video signal level. Furthermore, both the sensitivity adjustment and the photometric adjustment may be performed only once for the object of the low contrast and for the object of the high contrast, respectively, to obtain the optimum picture over a wide contrast range from the lowest contrast to the highest contrast. Finally, the second means also may be selected as desired between the variable peak photometric type and the variable average photometric type. Thus, there is provided the automatic diaphragm control device for the objective of television camera that is useful for various applications.

What is claimed is:

1. An automatic diaphragm control device for objective of television camera utilizing a video signal coming from the television camera to effect the diaphragm control, said automatic diaphragm control device comprising:

first means consisting of sensitivity adjusting means principally to adjust a video output signal in a low contrast condition;

second means consisting of variable photometric adjusting means principally to adjust a video output signal in a high contrast condition;

third means for photometric adjustment of a video output signal in a drastic peak mode independently of the photometric adjustment by said second means; and

means permitting said third means to be selectively used as desired by switching.

2. An automatic diaphragm control device for objective of television camera as defined by claim 1, wherein the second means permits the variable photometry to be automatically controlled in a peak mode, on one hand, and the video output signal during the high contrast to be continuously adjusted in accordance with an area ratio of a bright zone with respect to an overall object to be shot, on the other hand.

3. An automatic diaphragm control device for objective of television camera as defined by claim 1, wherein the second means permits the variable photometry to be automatically controlled in an average mode, on one hand, and the video output signal during the high contrast to be continuously adjusted in accordance with an area ratio of a bright zone with respect to an overall object to be shot, on the other hand.

4. An automatic diaphragm control device for objective of television camera utilizing a video signal coming from the television camera to effect the diaphragm control, said automatic diaphragm control device comprising:

first means consisting of sensitivity adjusting means principally to adjust a video output signal in a low contrast condition;

second means consisting of variable photometric adjusting means principally to adjust a video output signal in a high contrast condition;

third means for photometric adjustment of a video output signal in a drastic peak mode independently of the photometric adjustment by said second means;

means permitting said second means to be selectively used as means to perform the variable photometry in a peak mode and means to perform the variable photometry in an average mode as desired by switching therebetween; and

means permitting said second and third means to be selectively used as desired by switching therebetween.

5. An automatic diaphragm control device for objective of television camera, said automatic diaphragm control device comprising:

first means consisting of an inverted amplifier adapted for inverted amplification of a video signal from the television camera with a variable amplification ratio relative to a reference voltage;

second means adapted to be selectively used as desired, by switching, as means for peak photometric adjustment consisting of a voltage doubling rectifier including a capacitor of which the charging voltage can be adjusted by voltage doubling rectifying the video signal inversionally amplified in said inverted amplifier and means for average photometric adjustment consisting of a limiter circuit adapted to adjustably limit a negative component of the video signal inversionally amplified in said inverted amplifier; third means for photometric adjustment of the video output signal in an extreme peak mode independently of the variable photometric adjustment performed by said second means; and means permitting said second and third means to be selectively used as desired by switching therebetween.

* * * * *

United States Patent [19]

Tsuji

[11] **Patent Number: 4,708,444**

[45] **Date of Patent: Nov. 24, 1987**

[54] **PHOTOGRAPHIC OBJECTIVE**

[75] Inventor: **Sadahiko Tsuji**, Kanagawa, Japan

[73] Assignee: **Canon Kabushiki Kaisha**

[21] Appl. No.: **582,457**

[22] Filed: **Feb. 22, 1984**

[30] **Foreign Application Priority Data**

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[51] **Int. Cl.**[4] **G02B 15/22**; G02B 9/34; G02B 9/14; G02B 9/10

[52] **U.S. Cl.** **350/427**; 350/255; 350/415; 350/428; 350/450

[58] **Field of Search** 350/255, 427, 428, 415, 350/450

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Attorney, Agent, or Firm—Toren, McGeady & Associates

[57] **ABSTRACT**

In the disclosed photographic objective, a focusing lens group is arranged on the image side of a stop. To focus, all or part of the lens group, or the stop and all or part of the lens group, are moved to maintain an exit pupil at a substantially constant position.

9 Claims, 3 Drawing Figures

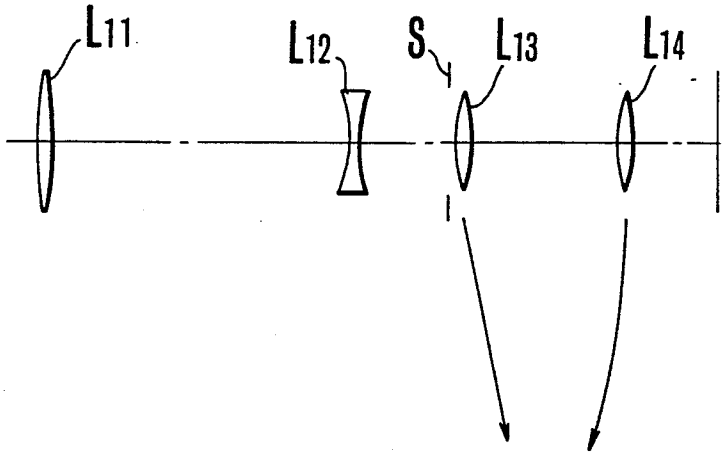


FIG.1

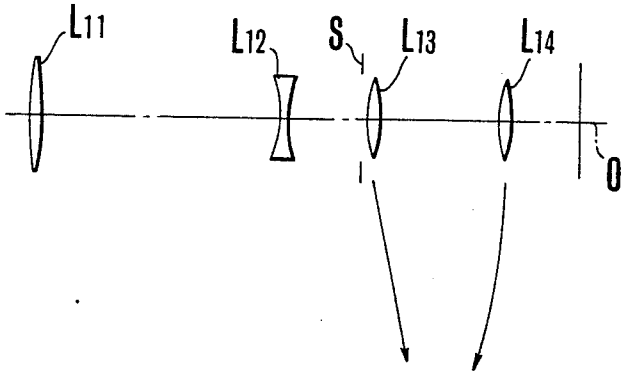


FIG.2

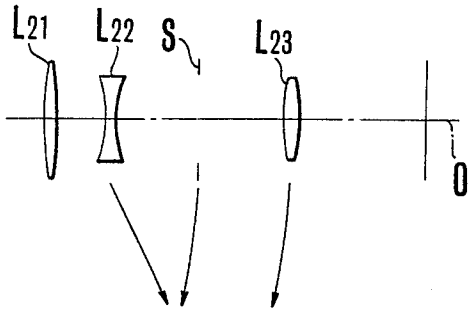
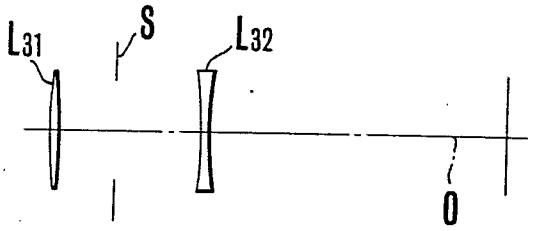


FIG.3



PHOTOGRAPHIC OBJECTIVE

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to photographic objectives and more particularly to photographic objectives of the rear focus type in which one or more lens components on the image side of a stop is or are movable for focusing the objective.

2. Description of the Prior Art

Color cameras having color separation prisms or other color separation optical systems such as stripe filters or mosaic filters should offer good color reproducing characteristics. To achieve this end it is generally recommended that their photographic objectives have an exit pupil at as long a distance as possible (preferably at least 200–300 mm, and ideally infinity) and that that distance be left unchanged. Even for an objective having a shortened exit pupil distance, as is sometimes necessary in actual practice, facilitating an electrical correction of the color reproduction makes it desirable that the exit pupil distance remain constant.

At the same time, the use of one of the constituent lens members which lies on the image side of the diaphragm for focusing purposes, or the employment of a so-called rear focus type of photographic objective, is advantageous for reducing the weight and the complexity of mechanical focus control signal transmission. This is so because the distance between the focusing member and the camera body is short. For this reason, a growing number of photographic objectives of this type have been developed in recent years.

As usual, the rear focus type of photographic objective is associated with a change of the position of the exit pupil resulting from the movement of the focusing member that lies behind the diaphragm. Therefore, application of this type of objective to color cameras with color separation optical systems poses a problem with respect to the color reproductivity.

This problem is also encountered when a zoom lens has its diaphragm in a space between the zoom components.

A proposal has been made to move the diaphragm of a zoom lens and one of the zoom components so as to maintain the position of the exit pupil constant. This appears in Japanese Patent Publication No. SHO 51-4135 (published Nov. 9, 1976).

SUMMARY OF THE INVENTION

It is an object of the invention to provide a photographic objective which focuses with a movable component or components on the image side of a diaphragm, i.e. an objective of the rear focus type, while still maintaining the position of an exit pupil constant.

To achieve this, one of the features of the invention is that at least two movable components for focusing are arranged on the image side of a diaphragm, and as these components are moved axially in different relation from each other, the paths of movement of the focusing components are so defined that in case the diaphragm is taken as an object point, the position of an image point is not caused to change by focusing while the diaphragm is made either stationary or movable with focusing. This makes it possible to maintain the position of the exit pupil.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. **1**, **2** and **3** are schematic diagrams indicating different configurations of embodiments of photographic objectives according to the present invention respectively.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. **1** illustrates a first embodiment of a photographic objective of the rear focus type according to the present invention. The objective includes, from front to rear, positive first and negative second components **L11** and **L12** which remain stationary during focusing, a stop S and positive third and positive fourth components **L13** and **L14** which are movable for focusing.

Shown in the lower half of the figure are arrow-marked lines indicating the different relations of the components **L13** and **L14** as they are moved axially during focusing.

In the above-described configuration, the components **L13** and **L14** which lie on the image side of the stop S are made movable for focusing. The ratio of their axial movements is determined so that as the stop S is taken as an object for the components **L13** and **L14**, an image point (corresponding to the position of an exit pupil of the entire system) remains constant. This maintains the constant position of the exit pupil against focusing despite independent movement of the components which lie on the image side of the stop (in this instance, **L13** and **L14**).

In the following equations **f3** designates the focal length of the lens component **L13**, **f4** the focal length of the lens component **L14**, **e3** the axial distance between the stop S and the lens component **L13**, **e4** the axial distance between the lens component **L13** and the lens component **L14**, $\alpha 3$ an inclination angle of the light beam between the stop S and the lens component **L13** with respect to the optical axis **0**, $\alpha 4$ an inclination angle of the light beam between the lens component **L13** and the lens component **L14** with respect to the optical axis **0**, h the height of the light beam in the lens component **L13** from the optical axis **0**, and d the axial distance between the lens component **L13** and an image of the stop S formed by the lens component **L13** when assuming the stop S to be an object point (a back focus of the lens component **L6**).

Then, in order to set the position of the exit pupil at infinity by means of the lens components **L13** and **L14**, it is necessary that the front focus of the lens component **L14** be arranged to coincide with the image point of the image of the stop S formed by the lens component **L13**. Thus, the formula (1) must be satisfied.

$$e4 = d + f4 \tag{1}$$

Here, if the paraxial tracing is performed assuming the stop S to be the object point, formulas (2), (3) and (4) are obtained.

$$\alpha 3 = -h/e3 \tag{2}$$

$$\alpha 4 = \alpha 3 + h/f3 \tag{3}$$

$$d = h/\alpha 4 \tag{4}$$

Therefore, d is represented by:

$$d = \frac{e3 \cdot f3}{e3 - f3} \quad (5)$$

Hence, the formula (1) is replaced by:

$$e4 = \frac{e3 \cdot f3}{e3 - f3} + f4 \quad (6)$$

Thus, if **e4** is changed so as to satisfy the formula (6) according to the change of **e3**, the position of the exit pupil can always be held at infinity. Values **f3**, **f4** and **e3** may be set as desired. Then if the paraxial reverse tracing of the entire lens system **L11–L14** is performed from the image point so as to make the image point constant in space, the position of the object can be obtained as the conjugate point.

A numerical specific embodiment shown in FIG. **1** can be constructed in accordance with the data given in the following table in which:

f: the focal length of the entire system;

f1–f4: the focal lengths of the individual components **L11–L14**, respectively;

e1–e4: the axial spacings between the successive two components and the stop;

s'k: the back focal length;

t'k: the distance of the exit pupil;

s1: the object distance measured from the first component **L11**; and

subscripts A–D: different focusing positions from one another.

	f=52.15	A	B	C	D
L11	f1=60				
		e1A=41.61			
L12	f2=−12				
		e2A=13			
S					
		e3A=2	e3B=4	e3C=6	e3D=8
L13	f3=24				
		e4A=21.82	e4B=19.2	e4C=16	e4D=12
L14	f4=24				
		s'kA=12.18	s'kB=12.8	s'kC=14	s'kD=16
		t'kA=−∞	t'kB=−∞	t'kC=−∞	t'kD=−∞
		s1A=−∞	s1B=−5597 mm	s1C=−1301 mm	s1D=−3139 mm

As is obvious from the table listed above, it will be understood that the position of the exit pupil is left unchanged despite focusing.

An operating mechanism for the lens components **L13** and **L14** may be constructed in the form of cam means or the like.

Though the first embodiment has been illustrated as applied to a fixed-focal length objective, it can be applied to a zoom objective whose zoom components lie on the front side of the stop without any alteration of the paths of focusing movement of the components **L13** and **L14**. In this case, however, the positions of the lens components **L13** and **L14** must be adjusted in accordance with not only the object distance but also the focal length of the entire system. This is so because the distance each focusing component moves from the position with an infinitely distant object to focus on the same object distance varies as zooming is performed. It is also possible to make movable the components on the image side of the stop during zooming to contribute to a variation of the image magnification. If so, it results in the components **L13** and **L14** having both the zooming and focusing functions.

Also if there are at least three components on the image side of the stop, another modification becomes possible. As is generally well known, the optically compensated zoom lens is operated by moving two components as a unit on either side of a component which remains stationary during zooming while still maintaining substantially constant the position of an image plane. In this analogy, for focusing purposes, the intermediate one of the three components is made stationary, and the other two are constructed in the form of an optically compensated zoom lens for the stop as an object and arranged to move axially as a unit to effect focusing on an object to be photographed. This affords the advantage of excluding an elaborate operating mechanism such as cam means when the object of the present invention is accomplished.

FIG. **2** schematically illustrates the configuration of a zoom lens of the rear focus type constituting a second embodiment of the present invention. The zoom lens includes, from front to rear, a positive first component **L21** which remains stationary during zooming, a negative second component **L22** for zooming, a stop S, and a positive third component **L23** for zooming and focusing.

Shown in the lower half of FIG. **2** is a different relation in which the zoom components **L22** and **L23** and stop S move axially to effect zooming.

In the aforesaid configuration, the stop S is arranged to move during zooming, though not essential to the present invention, to maintain the position of the exit pupil constant when zooming.

In this embodiment, the third component **L23**, which lies on the image side of the stop S, is made to also serve as a focusing component. When focusing, this component **L23** moves axially. Therefore, despite the position of the stop S having been adjusted in accordance with the zooming position, moving the third component **L23** later to effect focusing causes the exit pupil to shift as the stop S remains stationary.

On this account, the stop S is made to move in connection with the third component **L23** when focusing, so the position of the exit pupil is always maintained constant even when focusing. This constitutes a feature of this embodiment.

For example, in order always to maintain the exit pupil of the entire lens system at an infinite distance during focusing so as to render the exit pupil constant in the present embodiment, it is sufficient to keep the following relation between the diaphragm DS and the lens group **L23**. Thus, in the present embodiment, as the image of the stop S formed by the lens group **L23** is the exit pupil of the entire lens system, it is enough to move the stop S and the lens group **L23** so as to always make

the space e7 therebetween coincide with the focal length of the lens group L23.

A numerical specific second embodiment can be constructed in accordance with the data given in the following table in which:

f: the focal length of the entire system;

f5–f7: the focal lengths of the first to third components, respectively;

e5–e7: the axial spacings between the successive two components and the stop;

s'k: the back focal length;

t'k: the distance from the component L3 to the exit pupil; and

subscripts W and T: the wide angle and telephoto settings, respectively.

		fW = 20	fT = 53.33
L21	f5 = 80		
		e5W = 20	e5T = 40
L22	f6 = −20		
		e6W = 30	e6T = 5
S			
		e7W = 30	e7T = 30
L23	f7 = 30		
		s'kW = 45	s'kT = 50
		t'kW = −∞	t'kT = −∞

In this second specific example, when in the wide angle position, a forward axial movement of the third component L23 along with the stop S by 0.329 mm results in focusing down to an object distance s1 = −1588.57 mm measured from the first component L21, leaving the position of the exit pupil unchanged from t'k = −∞. This makes it possible to maintain the position of the exit pupil constant during focusing.

Also, in the telephoto position, forward axial movement of the third component L23 along with the stop S by 4 mm results in focusing down to an object distance s1 = −1588.57 mm leaving the position of the exit pupil unchanged from t'k = −∞. This makes it possible to maintain the position of the exit pupil constant during focusing as well as during zooming.

Thus, in the objective having the focusing facility in only one component on the image side of the stop, imparting a concurrent movement with the movement of the focusing component into the stop, makes it possible to maintain the position of the exit pupil constant throughout the entire focusing range. This advantageously eliminates the problem that would otherwise arise were the rear focus type employed in designing photographic objectives for color cameras having the color separation optical system for the purpose of reducing the bulk and size of the camera as a whole.

FIG. 3 illustrates another embodiment of the invention applied to a fixed focal length objective of the telephoto type having a positive front component L31 and a negative rear component L32 for focusing with a stop S therebetween.

As described herein later, the embodiment is limited in the position of the exit pupil so that if the space e9 between the stop S and the lens group L32 is kept constant, the position of the exit pupil measured on the basis of the image plane changes. In such a case, it is necessary to change the space e5 between the stop S and the lens group L32 in correspondence to the focusing. The change of the space e5 may be determined by the following relation. Supposing the space when the lens group L32 has moved d' from the state of the space e9' is e9, and the position of the exit pupil measured from the initial lens group L32 is t'ko,

$$\frac{1}{t'ko} + \frac{1}{e9'} = \frac{1}{f9}$$

$$\frac{1}{t'ko + d'} + \frac{1}{e9} = \frac{1}{f9}$$

From the above relation, the space e9 required for maintaining constant the position of the exit pupil measured on the basis of the image plane can be obtained. An example of an objective of this configuration can be constructed in accordance with the following numerical data:

L31	f8 = 100	
		e8 = 20
S		
		e9 = 30
L32	f9 = −100	

where the focal length of the entire system f = 200; the back focal length s'k = 100; and the exit pupil distance from the negative component L32, t'k = −23.07692 (from the image plane, −123.07692).

Now assuming that the negative component L32 is solely moved axially rearward, for example, 10 mm to effect focusing down to an object distance s1 = −1457.14 mm, then the exit pupil is shifted to t'k = −28.57142 (from the image plane, −118.57143). According to the invention, simultaneously with this, the stop S is made to move forward 9.42528 mm, leaving the exit pupil stationary at t'k = −23.07692 (from the image plane, −123.07692).

Such concurrent movement of the stop with focusing and, in the second embodiment, with zooming can be realized by using cam means. It is also to be noted that upon consideration of preventing the aperture ratio from changing as the stop moves, it is desirable in actual practice to provide a suitable automatic diaphragm aperture adjusting mechanism.

Also in the present invention, the sentence "the exit pupil position is maintained substantially constant" implies, of course, the case when it is held in exactly constant a position, but also another case when the exit pupil position is allowed to shift within an acceptable range for actual performance with respect to the color reproductivity.

The present invention is applicable to other lens types and zoom types than those shown in connection with its embodiments. For example, in fixed focal length objectives, it is applicable not only to the telephoto type, but also to the retrofocus type suited for wide angle objectives, and to various other types for use in standard objectives; in zoom lenses, it is not confined to the 3-component type shown in the foregoing embodiments, but also to more-than-3-component types, for example, the 4-component type; conversely in the 2-component type; and further regardless of what relative position the zoom components take, and the number of zoom components, to all other types of zoom lenses, to effect an equivalent result.

As has been described in greater detail above, according to the present invention, the use of a component or components which lies or lie on the image side of the stop for, focusing purposes, or the employment of the so-called rear focus type in single lenses and zoom

lenses for color cameras provides a possibility of stabilizing good color reproductivity against focusing so that a minimization of the bulk and size of the camera due to the employment of the rear focus type can be advantageously achieved without involving any decrease in optical performance.

What I claim:

1. A photographic objective comprising:
a stop stationary during focusing;
a plurality of lens components located on the image side of said stop and movable for focusing;
said plurality of lens components moving in such a way as to maintain an image point of the stop at a substantially constant position when the stop is assumed as an object point.

2. A photographic objective according to claim 1, further including:
a further lens component arranged on the object side of said stop.

3. A photographic objective according to claim 2, wherein said further lens component is a zoom lens.

4. A photographic objective according to claim 1, further including:
a further lens component for zooming arranged on the object side of said stop and wherein at least one of said plurality of lens components moves together with said further lens component.

5. A photographic objective comprising:
a front lens component stationary during focusing;
a stop located on the image side of said front lens component and movable during focusing;
a movable lens component located on the image side of said stop and movable for focusing;
said stop and said movable lens component moving in such a way as to maintain an image point at a substantially constant position when the stop is assumed as an object point.

6. A photographic objective according to claim 5, wherein said front lens component moves simultaneously with said movable lens component for zooming.

7. A photographic objective according to claim 6, wherein said stop and said movable lens component move contrary to each other during focusing.

8. A photographic objective according to claim 5, wherein said stop and said movable lens component move all together during focusing.

9. A photographic objective comprising:
a plurality of lens components stationary during focusing;
a stop located on the image side of said plurality of lens components; and
a movable lens component located on the image side of said stop and movable for focusing;
said movable lens component moving in such a way as to maintain an image point at a substantially constant position when the stop is assumed as an object point.

* * * * *

United States Patent [19]

Sato et al.

[11] **Patent Number: 4,679,913**

[45] **Date of Patent: Jul. 14, 1987**

[54] **VARI-FOCAL OBJECTIVE LENS OF SHORT TOTAL LENGTH**

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[73] Assignee: **Canon Kabushiki Kaisha**, Japan

[21] Appl. No.: **750,698**

[22] Filed: **Jun. 28, 1985**

[30] **Foreign Application Priority Data**

Jul. 2, 1984 [JP] Japan 59-137019

[51] **Int. Cl.**[4] **G02B 15/00**; G02B 13/18

[52] **U.S. Cl.** **350/423**; 350/432

[58] **Field of Search** 350/423, 426, 427, 464, 350/454, 455, 432

[56] **References Cited**

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Primary Examiner—John K. Corbin

Assistant Examiner—P. M. Dzierzynski

Attorney, Agent, or Firm—Toren, McGeady & Associates

[57] **ABSTRACT**

An objective lens comprising a front lens unit and a rear lens unit with the separation between the two lens units being varied to vary the focal length of the entire system, wherein the front lens unit has a positive refractive power and consists of a positive lens of strong convex curvature toward the front, a negative doublet lens of a negative lens and a positive lens cemented together in this order from the front, and a positive lens sub-unit, and the rear lens unit has a negative refractive power and comprises a positive lens and a negative lens. Particularly the double lens is so designed that the comatic aberration in the intermediate zone of the image frame is stabilized throughout the entire range of variation of the focal length, and the halo in the intermediate zone in the telephoto end is well corrected.

10 Claims, 13 Drawing Figures

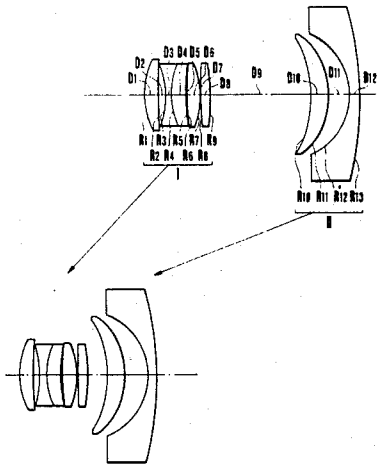


FIG. 1

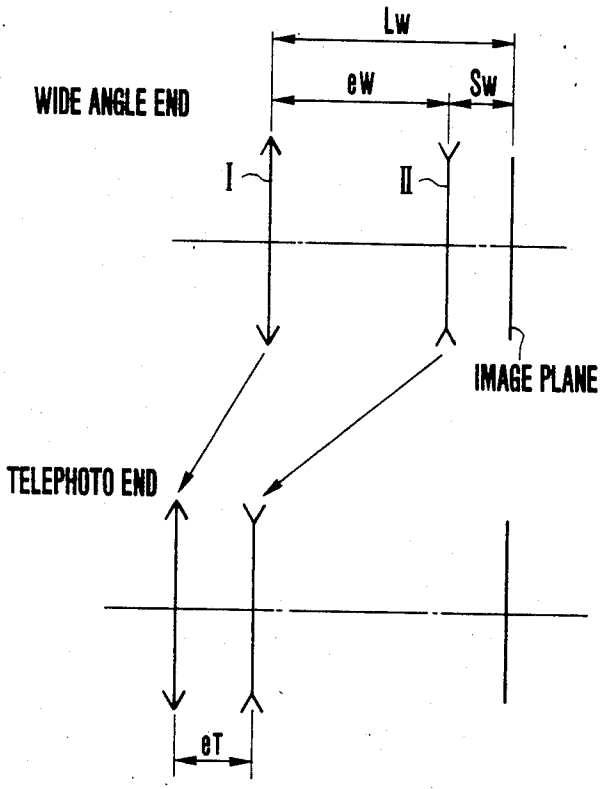


FIG.2

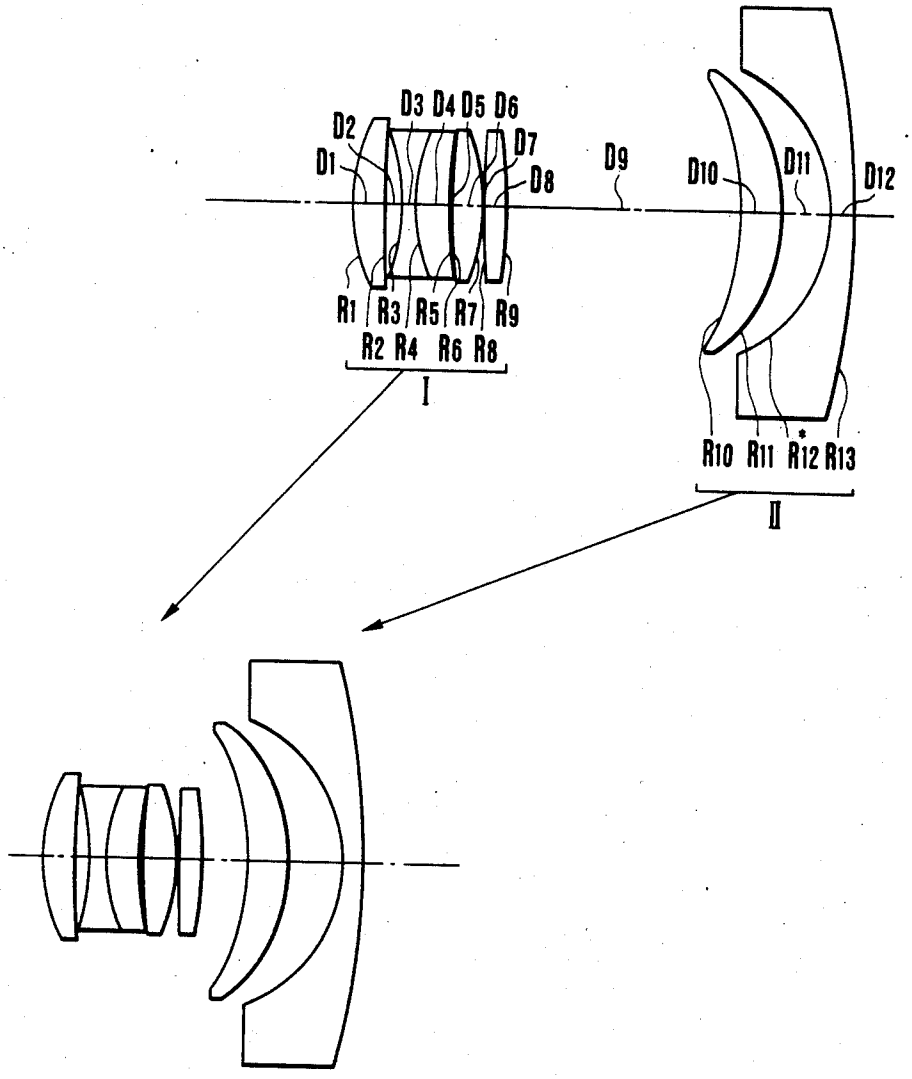

D1
D2
D3
D4
D5
D6
D7
D8
D9
D10
D11
D12
R1
R2
R3
R4
R5
R6
R7
R8
R9
R10
R11
R12
R13
I
II

FIG.3

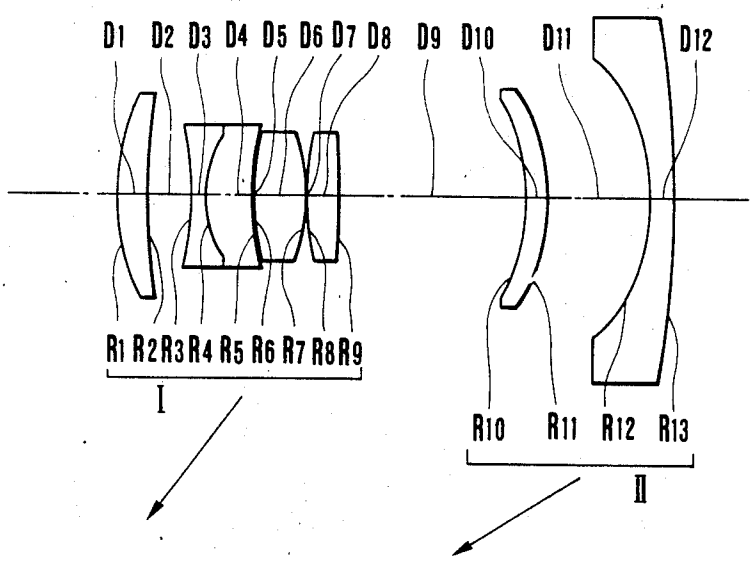

D1 D2 D3 D4 D5 D6 D7 D8 D9 D10 D11 D12
R1 R2 R3 R4 R5 R6 R7 R8 R9
I
R10 R11 R12 R13
II

FIG.4

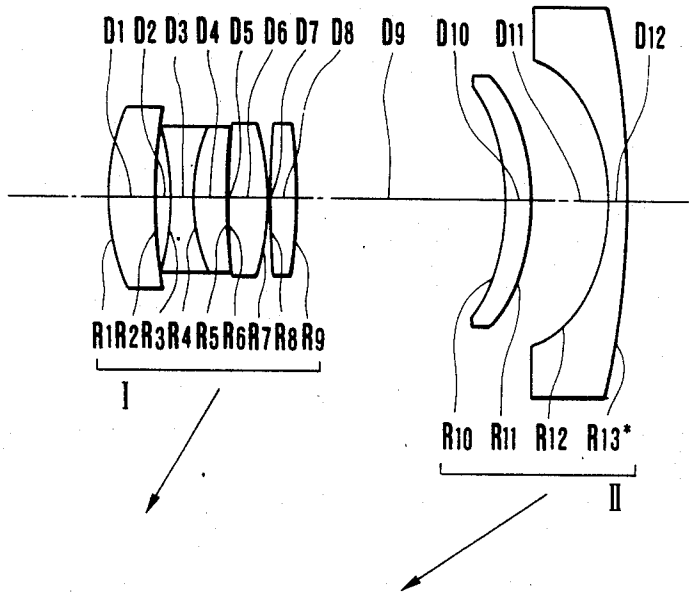
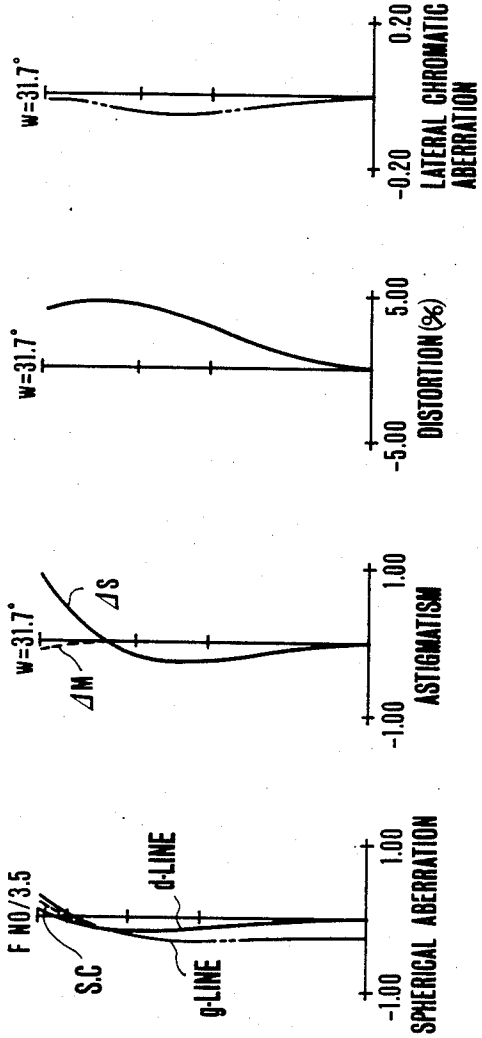

D1 D2 D3 D4 D5 D6 D7 D8 D9 D10 D11 D12
R1 R2 R3 R4 R5 R6 R7 R8 R9
I
R10 R11 R12 R13*
II

FIG.5A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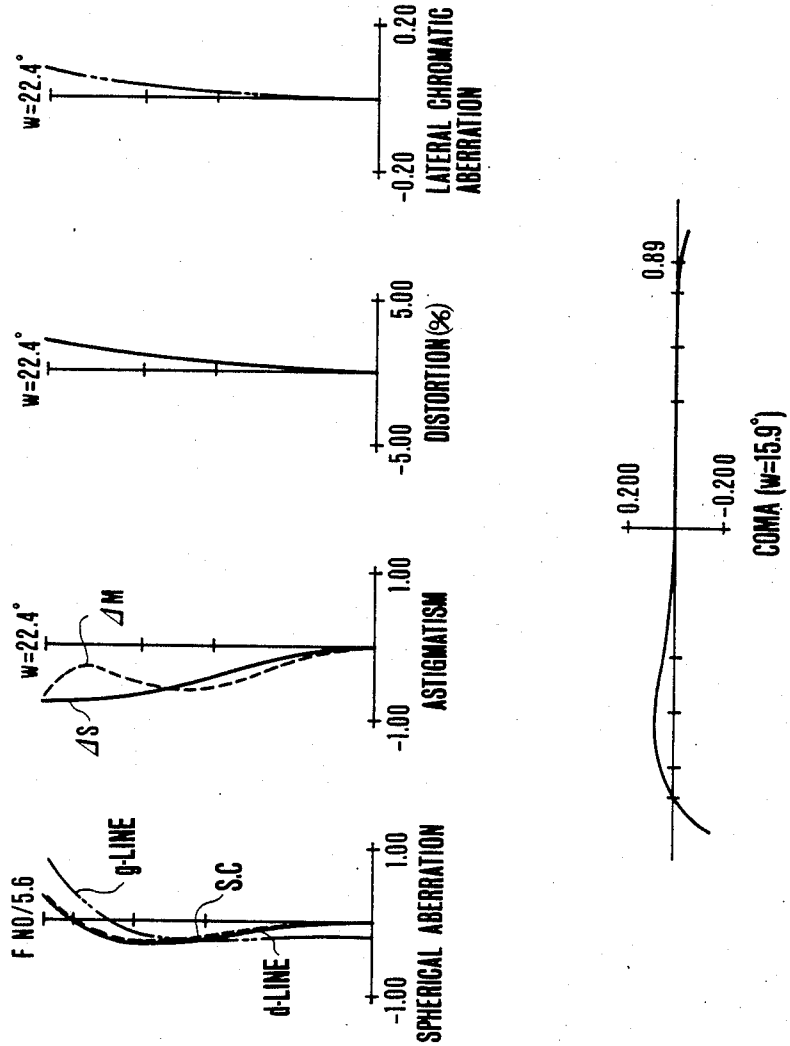
d-LINE
1.00
-1.00
SPHERICAL ABERRATION
w=31.7°
ΔM
ΔS
1.00
-1.00
ASTIGMATISM
w=31.7°
5.00
-5.00
DISTORTION (%)
w=31.7°
0.20
-0.20
LATERAL CHROMATIC ABERRATION
0.8
+0.200
+0.200
COMA (w=23.2°)

FIG.5B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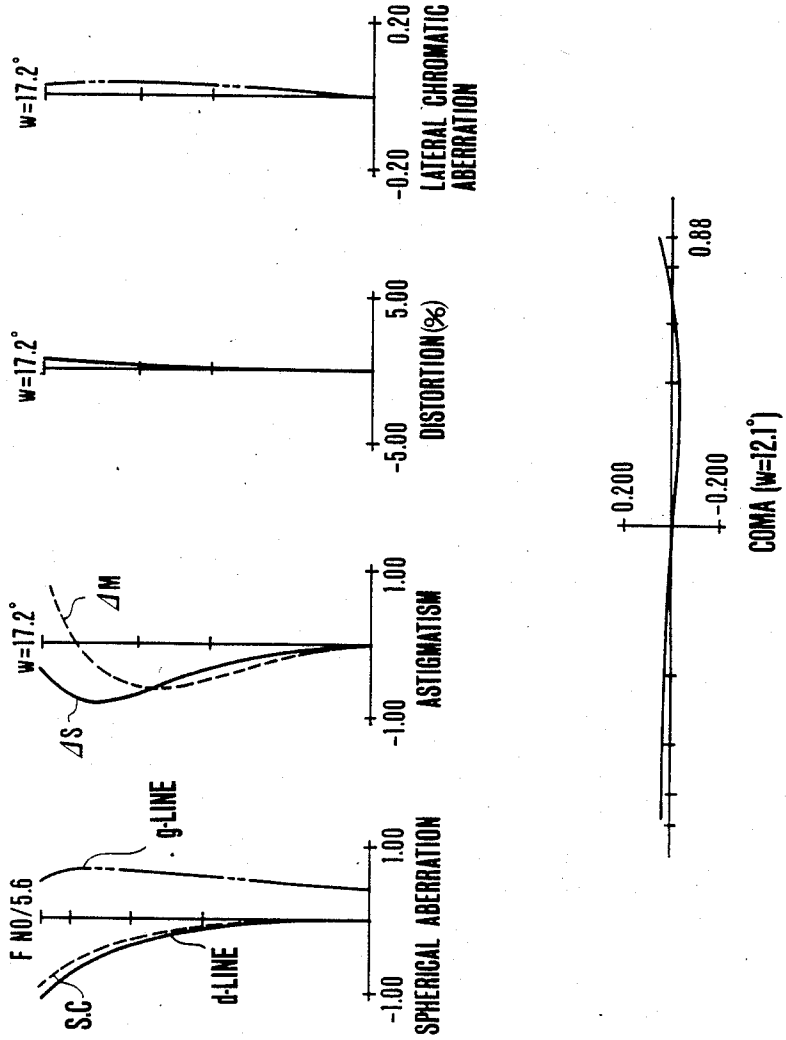
S.C
d-LINE
-1.00
1.00
SPHERICAL ABERRATION
w=22.4°
ΔM
ΔS
-1.00
1.00
ASTIGMATISM
w=22.4°
-5.00
5.00
DISTORTION(%)
w=22.4°
-0.20
0.20
LATERAL CHROMATIC ABERRATION
0.89
0.200
-0.200
COMA (w=15.9°)

FIG.5C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d-LINE
S.C
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1.00
SPHERICAL ABERRATION
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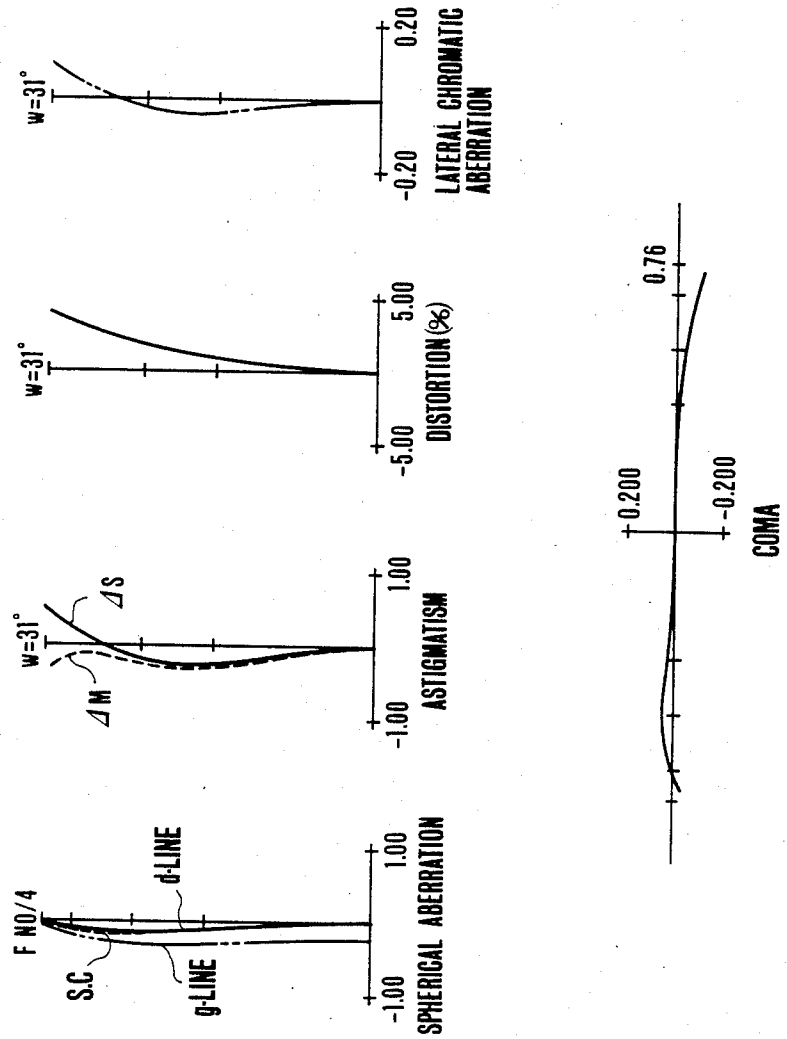
ΔM
ΔS
-1.00
1.00
ASTIGMATISM
W=17.2°
-5.00
5.00
DISTORTION(%)
W=17.2°
-0.20
0.20
LATERAL CHROMATIC ABERRATION
+0.200
-0.200
0.88
COMA (W=12.1°)

FIG.6A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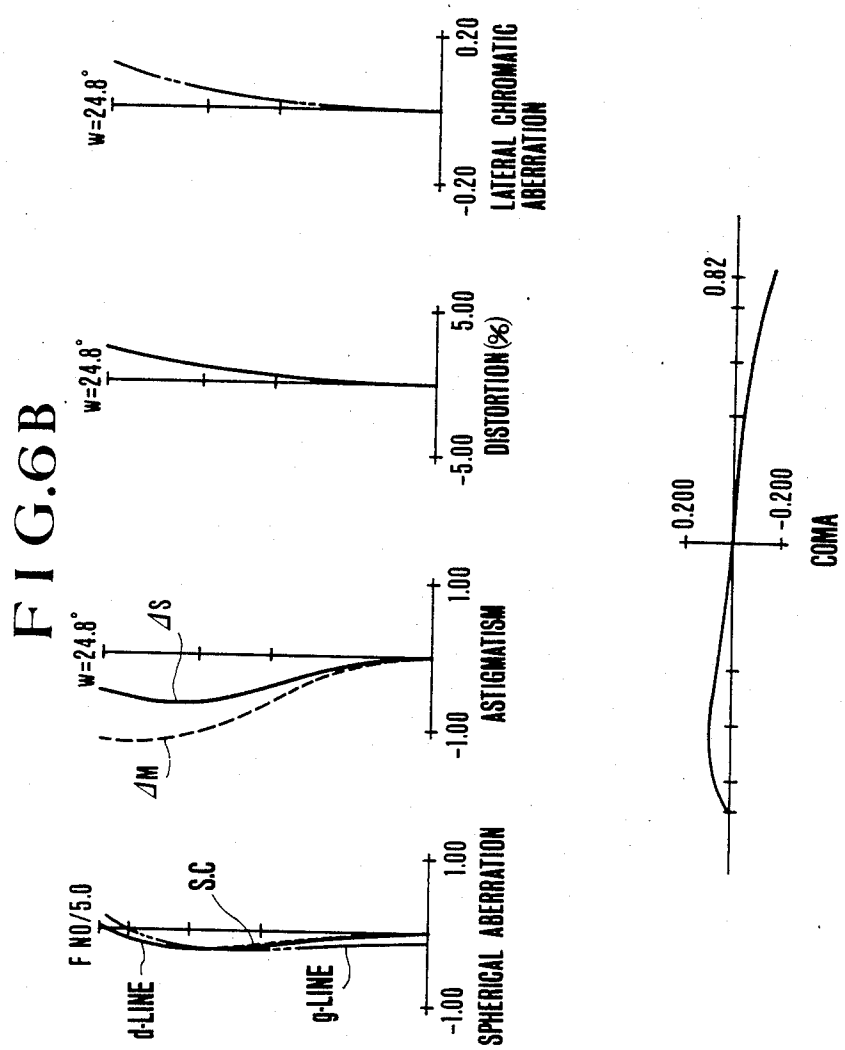
SPHERICAL ABERRATION
W=31°
ΔM
ΔS
-1.00
1.00
ASTIGMATISM
W=31°
-5.00
5.00
DISTORTION(%)
W=31°
-0.20
0.20
LATERAL CHROMATIC ABERRATION
+0.200
-0.200
0.76
COMA

FIG.6B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S.C
g-LINE
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1.00
SPHERICAL ABERRATION
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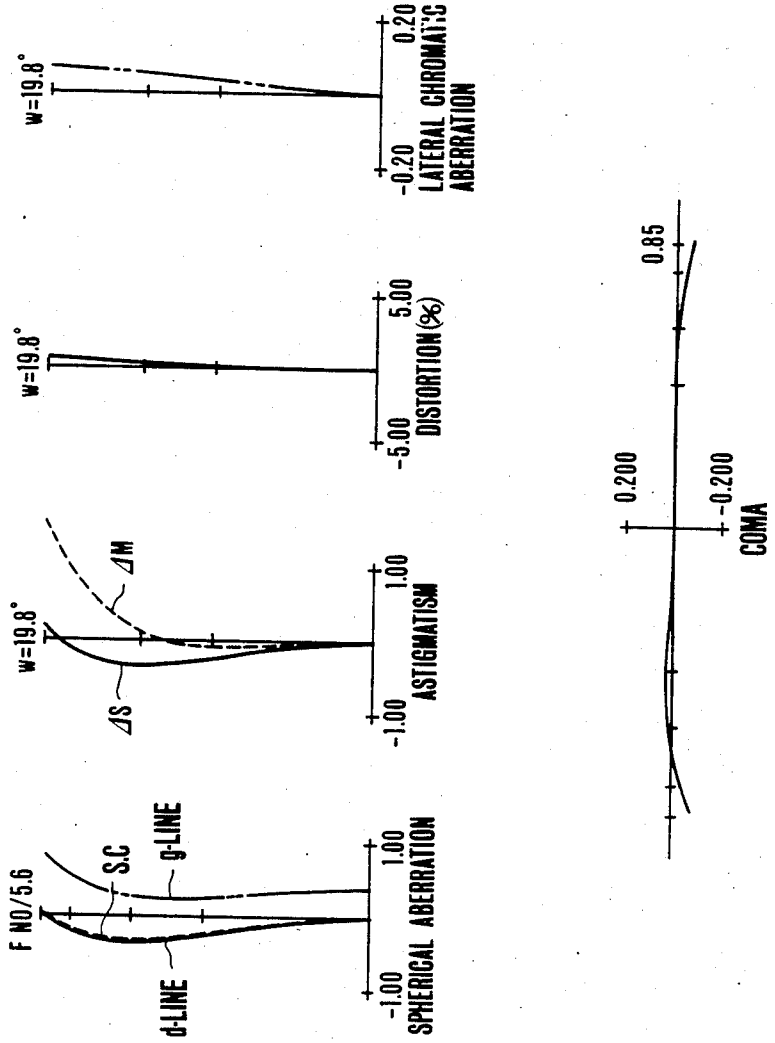
ΔS
ΔM
-1.00
1.00
ASTIGMATISM
w=24.8°
-5.00
5.00
DISTORTION(%)
w=24.8°
-0.20
0.20
LATERAL CHROMATIC ABERRATION
0.82
0.200
-0.200
COMA

FIG.6C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ΔS
ΔM
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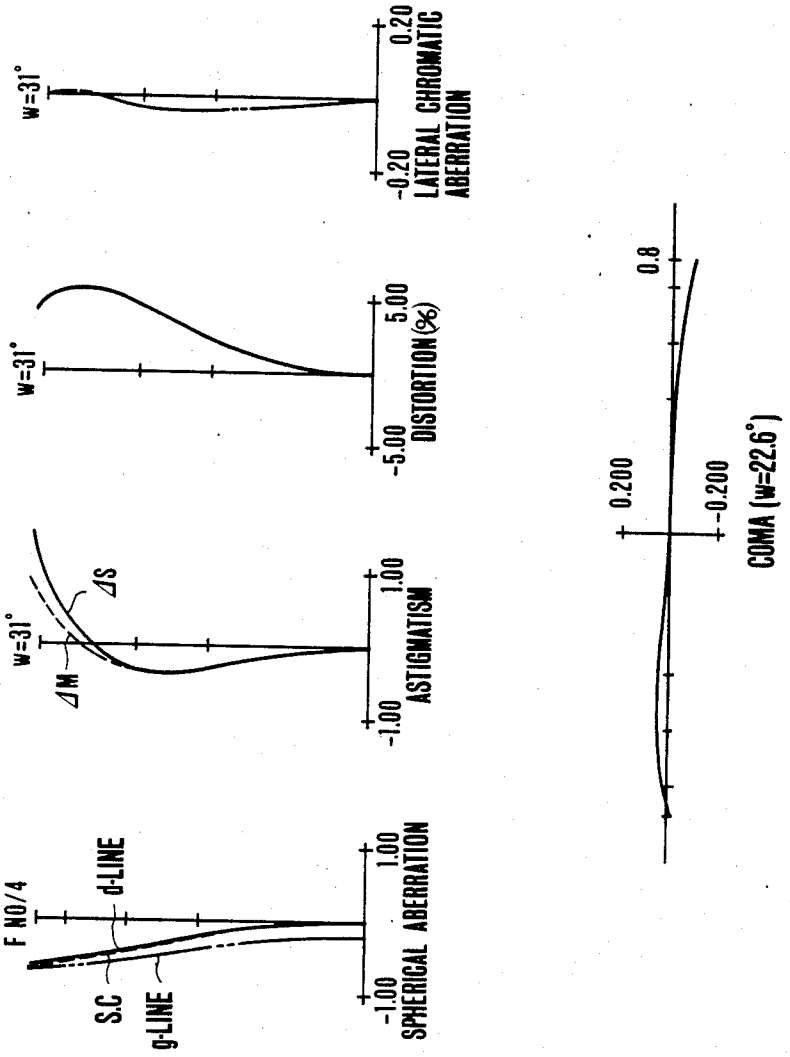
1.00
ASTIGMATISM
W=19.8°
-5.00
5.00
DISTORTION (%)
W=19.8°
-0.20
0.20
LATERAL CHROMATIC ABERRATION
0.200
-0.200
0.85
COMA

FIG.7A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ΔM
ΔS
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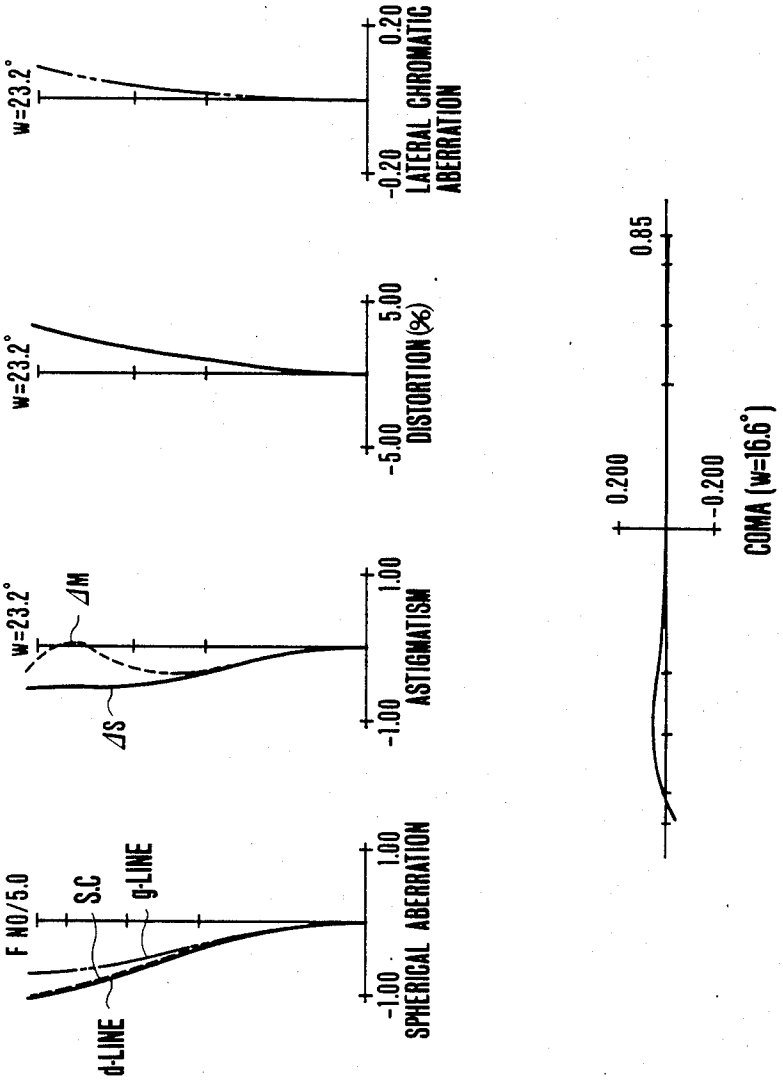
1.00
ASTIGMATISM
w=31°
-5.00
5.00
DISTORTION(%)
w=31°
-0.20
0.20
LATERAL CHROMATIC ABERRATION
0.200
-0.200
0.8
COMA (w=22.6°)

FIG.7B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1.00
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ΔM
ΔS
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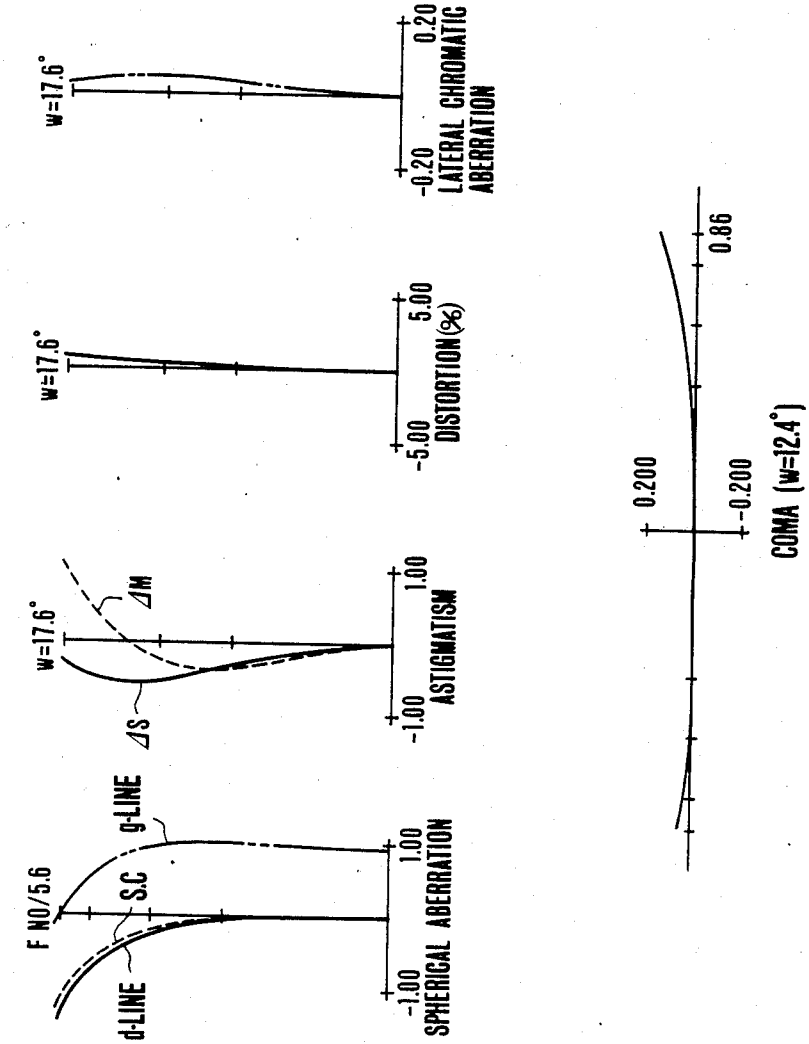
1.00
ASTIGMATISM
w=23.2°
-5.00
5.00
DISTORTION (%)
w=23.2°
-0.20
0.20
LATERAL CHROMATIC ABERRATION
0.200
-0.200
0.85
COMA (w=16.6°)

FIG.7C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ΔS
ΔM
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1.00
ASTIGMATISM
w=17.6°
-5.00
5.00
DISTORTION(%)
w=17.6°
-0.20
0.20
LATERAL CHROMATIC ABERRATION
0.200
-0.200
0.86
COMA (w=12.4°)

VARI-FOCAL OBJECTIVE LENS OF SHORT TOTAL LENGTH

BACKGROUND OF THE INVENTION

1. Field of the Invention:

This invention relates to compact zoom lenses, and more particularly to compact zoom lenses of short total length (the distance from the front vertex to the image plane) suited to lens-shutter cameras, video cameras or the like.

2. Description of the Prior Art:

The recent trend of reducing the size of lens shutter cameras, video cameras, or the like demands for compact zoom lenses of short total length. Particularly in the field of small size cameras whose objective lenses are not interchangeable, too, it is desired to use zoom lenses. For this purpose, the total length of the zoom lens has to be reduced to the same level as the fixed focal length lens that has so far been used has.

Many zoom lenses whose range includes the standard image angle for the ordinary lens-shutter cameras (the total angle of field $2\omega=47°$ with a focal length of about 50mm for 35mm still cameras) have been proposed in, for example, Japanese Patent Publication No. SHO 49-29146. The zoom lens of this kind is constructed by two lens units of which the front is of negative power and rear is of positive power, and its focal length is varied by varying the separation between the two lens units. However, because its refractive power arrangement is negative-positive in this order from the front, the back focal distance is relatively long. This tends to make too long the total length of the lens when it applies to the lens-shutter camera, though it is suited to the single lens reflex camera.

Further in Japanese Laid-Open patent application No. SHO 56-128911 (corresponding to U.S. patent application Ser. No. 243,209 field Mar. 12, 1981 assigned to the assignee of this invention) and Japanese Laid-Open patent application No. SHO 57-201213 there have been proposed compact zoom lenses each comprising a front lens unit of positive power and a rear lens unit of negative power with the separation therebetween being varied to vary the focal length of the entire system. The use of such positive-negative power arrangement leads not only to relatively shorten the back focal distance but also to achieve a zoom lens of short total length.

SUMMARY OF THE INVENTION

A first object of the present invention is to provide a vari-focal objective lens in which the distance from the front lens surface to the image plane is short.

A second object is to increase the zoom ratio while preserving the entire system.

A third object is to correct coma in the intermediate zone of the image frame throughout the entire range of variation of the focal length, and correct halo in the intermediate zone in the telephoto end.

A fourth object is to correct image aberrations that are liable to deteriorate with zooming.

And, in the present invention, by specifying the form of each lens of the front and rear lens units, the amount of aberrations produced in each lens unit is lessened so that variation of aberrations with zooming is lessened. Particularly a second lens of the front lens unit is constructed in the form of a 2-1st lens of negative power and a 2-2nd lens of positive power cemented together, thereby good correction of coma in the intermediate zone of the image frame is maintained stable throughout the entire range of variation of the focal length, and halo in the intermediate zone in the telephoto end is well corrected.

Also, first and second lenses of the rear lens unit are both formed to meniscus shapes of rearward convexity, thereby variation with zooming of image aberrations is improved.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic view of the optical arrangement of a zoom lens according to the present invention.

FIG. **2** is a block diagram of an example 1 of the lens.

FIG. **3** is block diagram of another example 2 of the lens.

FIG. **4** is a block diagram of another example 3 of the lens.

FIGS. **5A–5C** are aberration curves of example 1.

FIGS. **6A–6C** are aberration curves of example 2.

FIGS. **7A–7C** are aberration curves of example 3.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

In the optical arrangement shown in FIG. **1**, when to vary the focal length from the wide angle end to the telephoto end, a front lens unit I and a rear lens unit II are moved forward independently of each other while varying the separation between these two lens units.

The total length of such a zoom lens takes a minimum value at the wide angle end and a maximum value at the telephoto end. Upon consideration of the easiness of carrying the camera around, it is advantageous to reduce the total length of the lens in the wide angle end.

Now letting LW denote the total length of the lens in the wide angle end, SW the back focal distance, eW and eT the intervals between the principal points of the first and second lens units I and II in the wide angle and telephoto ends respectively, ϕW and ϕT the refractive powers of the entire system in the wide angle and telephoto ends respectively, and $\phi 1$ and $\phi 2$ the refractive powers of the front and rear lens units I and II respectively, we have

$$LW = eW + SW$$

$$SW = \frac{1 - eW \cdot \phi 1}{\phi W}$$

From these, the total length of the lens LW becomes

$$LW = eW + \frac{1 - eW \cdot \phi 1}{\phi W} \qquad (A)$$

$$= \frac{1}{\phi W} + \left(1 - \frac{\phi 1}{\phi W}\right) \cdot eW$$

Now assuming that the refractive power of the wide angle end ϕW has a constant value, then, from equation (A), the larger the refractive power $\phi 1$ and the smaller the principal point interval eW, the shorter the total length of the lens becomes.

Meanwhile, the refractive powers ϕW and ϕT of the entire system in the wide angle and telephoto ends may be expressed as:

$$\phi W = \phi 1 + \phi 2 - eW \cdot \phi 1 \cdot \phi 2 \qquad (B)$$

$$\phi T = \phi 1 + \phi 2 - eT \cdot \phi 1 \cdot \phi 2 \quad (C)$$

Here the refractive powers ϕW and ϕT have given values, and the value of the principal point interval eT must be made as small as possible provided that the front and rear lens units do not interfere with each other when in the telephoto end, as is advantageous to minimize the bulk and size of the zoom lens, and, therefore, takes a certain value.

Therefore, the formulae (B) and (C) represent a relationship of the refractive powers $\phi 1$ and $\phi 2$ and the principal point interval eW. For a given value of any one of these variables, simultaneous equations with two unknowns are then obtained. Thus, a refractive power distribution over the zoom lens can be determined.

By taking the refractive power $\phi 1$ of the front lens unit I at a larger value with a corresponding smaller value of the interval between the principal points of the front and rear lens units I and II in the wide angle end, eW, the total length of the lens, LW, can be shortened. However, when the refractive power, $\phi 1$, is made too large, the refractive power, $\phi 2$, of the rear lens unit II, too, becomes large. This results in an increase of the Petzval sum in the negative sense with over-correction of the field curvature, depriving the image surface of flatness. Moreover, the comatic aberration in the intermediate zone of the image frame is increased and becomes difficult to correct for high grade imaging performance. Also when the principal point interval eW is made too small, the refractive powers $\phi 1$ and $\phi 2$ must be both largely increased in the positive and negative senses respectively to obtain the prescribed zoom ratio. Therefore, similar phenomena to the above are caused to take place. This is objectionable.

So, in order to achieve good stability of aberration correction throughout the entire range of variation of the focal length, it is preferred that within the framework of the above-described general lens configuration, the following various conditions are satisfied. That is, the values of the refractive powers $\phi 1$ and $\phi 2$ of the front and rear lens units I and II and the principal point interval eW fall within the following respective ranges:

$$\phi W < \phi 1 < 1.5\phi W \quad (a)$$

$$-1.5\phi W < \phi 2 < -0.5\phi W \quad (b)$$

$$0.4/\phi W < eW < 1.0/\phi W \quad (c)$$

The technical significance of each of the conditions will next be explained.

Either when the refractive power $\phi 1$ of the front lens unit I exceeds the upper limit of inequalities of condition (a), or when the refractive power $\phi 2$ of the rear lens unit II exceeds the lower limit of inequalities of condition (b), though the total length of the lens becomes shorter, as has been described above, over-correction of field curvature results, and large coma is produced in the intermediate zone of the image frame. These aberrations are difficult to correct well. Conversely when the refractive power $\phi 1$ exceeds the lower limit of inequalities of condition (a) or when the refractive power $\phi 2$ exceeds the upper limit of inequalities of condition (b), the total length of the lens becomes longer, and the rear lens unit II will interfere with the image plane, so that it is difficult to use it as the photographic lens.

When the interval between the principal points of the front and rear lens units I and II in the wide angle end, eW, exceeds the upper limit of inequalities of condition (c), the rear lens unit II comes to interfere with the image plane so that similarly to the above, it is difficult to use it as the photographic lens. When the lower limit is exceeded, the refractive powers $\phi 1$ and $\phi 2$ of the front and rear lens units I and II must be increased in the positive and negative senses respectively to obtain the prescribed zoom ratio. This results in over-correction of field curvature, and coma is increased in the intermediate zone of the image frame. These aberrations become difficult to correct well.

The concrete lens figurings that have taken into account all the above-stated conditions are shown in FIGS. 2, 3 and 4.

Each of the zoom lenses depicted in the figures is constructed with two lens units of which the front lens unit I is of positive refractive power, and the rear lens unit II is of negative refractive power, these lens units being axially moved in differential relation to effect zooming, wherein the front lens unit I is made to comprise, from front to rear, a meniscus-shaped first lens of positive refractive power convex toward the front, a second lens of a 2-first element of negative refractive power and a 2-second element of positive refractive power cemented together, whose overall power is negative, and third and fourth lenses of positive refractive powers, and the rear lens unit II is made to comprise a meniscus-shaped fifth lens of positive power convex toward the rear, and a meniscus-shaped sixth lens of negative power convex toward the rear.

To achieve good stability of, in particular, chromatic aberrations throughout the entire zooming range so that all the aberrations are corrected in good balance, it is preferred to satisfy the following conditions:

$$-0.6\,\phi W < (N22 - N21/R4) < -0.1\phi W \quad (1)$$

$$-10 < \nu 22 - \nu 21 < 10 \quad (2)$$

where N21 and $\nu 21$ are the refractive index and Abbe number of the glass of the 2-first lens element, N22 and $\nu 22$ are the refractive index and Abbe number of the glass of the 2-second lens element and R4 is the radius of curvature of the cemented lens surface of the second lens.

Inequalities of condition (1) are to stabilize coma in the intermediate zone of the image frame throughout the entire zooming range and correct well halo in the intermediate zone when in the telephoto end. Particularly when the refractive power of the cemented lens surface is made negative, positive spherical aberration and upward coma are produced. However, by making negative the refractive power of the rearmost lens surface of the second lens, as this surface bears part of the negative refractive power, the amounts of positive spherical aberration and upward coma produced are reduced from those when the cemented surface is not used.

When the upper limit of inequalities of condition (1) is exceeded, the negative refractive power of the cemented lens surface becomes too large, causing production of downward coma throughout the entire zooming range. When the lower limit is exceeded, the negative refractive power of the cemented lens surface becomes too small, causing production of upward coma throughout the entire zooming range, and causing the halo to increase in the telephoto end with decrease in the grade of imaging performance.

Inequalities of condition (2) are to correct longitudinal and lateral chromatic aberrations in good balance. When the upper limit is exceeded, over-correction of longitudinal chromatic aberration and under-correction of lateral chromatic aberration result over the entire zooming range.

When the lower limit of inequalities of condition (2) is exceeded, under-correction of longitudinal chromatic aberration and over-correction of lateral chromatic aberration result over the entire zooming range, each of which causes the imaging performance to lower objectionably.

In the present invention, to obtain an improved optical performance throughout the entire area of the image frame, it is preferred to make at least one of the surfaces of the sixth lens an aspherical surface of such shape that as the radial distance from the optical axis increases, the negative refractive power decreases. By this, the tendency of the curvature of field to vary to under-correction particularly in the intermediate region of the zooming range can be lessened.

For note, in the present invention, focusing is preferably by moving the lens system as a whole because variation of aberrations is little. But, another focusing method of moving only either one of the front and rear lens units I and II may be employed with an advantage of simplifying the operating mechanism.

When the above-stated rules of design of the invention are satisfied, a zoom lens of very compact form of about 1.25 in telephoto ratio for the wide angle end (total length of the lens/focal length in the wide angle end) well corrected for the various aberration can be achieved.

Examples of specific zoom lens of the invention can be constructed in accordance with the numerical data given in the following tables for the radii of curvature, R, the axial thicknesses and air separations, D, and the refractive indices, N, and Abbe numbers, ν, of the glasses of the lens elements with the subscripts numbered from front to rear.

Taking an X-axis in the axial direction, a Y-axis in a direction perpendicular to the optical axis, and the direction in which light advances as positive with the original point at the vertex, an equation for the aspherical surface may be expressed by

$$X = \frac{(1/R)Y^2}{1+\sqrt{1-(Y/R)^2}} + a1 \cdot Y^2 + a2 \cdot Y^4 + a3 \cdot Y^6 + a4 \cdot Y^8 + a5 \cdot Y^{10} + |b1| \cdot Y^3 + |b2| \cdot y^5 + |b3| \cdot y^7 + |b4| \cdot y^9$$

where R is the radius of curvature of the paraxial region of the lens surface of the sixth lens, and a1, a2, a3, a4, a5, b 1, b2, b3 and b4 are aspherical coefficients.

Numerical Example 1

F = 100–200 FNO = 1:3.5–5.6 2ω = 63.4°–34.3°

R1 = 45.13	D1 = 7.43	N1 = 1.60311	ν1 = 60.7
R2 = 210.53	D2 = 3.93		
R3 = −59.11	D3 = 3.12	N2 = 1.80610	ν2 = 40.9
R4 = 40.14	D4 = 7.97	N3 = 1.70154	ν3 = 41.2
R5 = 92.01	D5 = 0.95		
R6 = 147.63	D6 = 7.13	N4 = 1.60311	ν4 = 60.7
R7 = −49.47	D7 = 0.43		
R8 = 616.09	D8 = 5.53	N5 = 1.60311	ν5 = 60.7
R9 = −98.23	D9 = Variable		
R10 = −59.57	D10 = 9.37	N6 = 1.71700	ν6 = 47.9
R11 = −41.47	D11 = 11.89		
*R12 = −40.00	D12 = 4.57	N7 = 1.60311	ν7 = 60.7
R13 = −229.68			

Aspherical Coefficients of the Surface R12

a1 = -3.507×10^{-3}	b1 = -2.953×10^{-6}
a2 = -2.834×10^{-7}	b2 = -3.852×10^{-8}
a3 = 6.186×10^{-10}	b3 = -5.282×10^{-11}
a4 = 2.261×10^{-12}	b4 = -2.447×10^{-14}
a5 = 2.813×10^{-16}	

	f	D8
(1) ϕ1 = 1.129 ϕW	100	54.93
(2) ϕ2 = −1.003 ϕW	150	25.49
(3) eW = 0.772/ϕW	200	10.78

(4) $\frac{N22 - N21}{R4} = -0.26\ \phi W$

(5) $\nu 22 - \nu 21 = 0.3$

Numerical Example 2

F = 100.00000–166.7 FNO = 1:4–5.6 2ω = 62°–39.7°

R1 = 53.07	D1 = 7.00	N1 = 1.60311	ν1 = 60.7
R2 = 126.68	D2 = 10.74		
R3 = −56.27	D3 = 2.93	N2 = 1.80610	ν2 = 40.9
R4 = 28.88	D4 = 10.95	N3 = 1.70154	ν3 = 41.2
R5 = 74.15	D5 = 0.27		
R6 = 65.88	D6 = 11.99	N4 = 1.60311	ν4 = 60.7
R7 = −50.44	D7 = 0.42		
R8 = 126.46	D8 = 7.68	N5 = 1.60311	ν5 = 60.7
R9 = −155.94	D9 = Variable		
R10 = −49.26	D10 = 5.17	N6 = 1.71700	ν6 = 47.9
R11 = −44.18	D11 = 23.72		
R12 = −43.41	D12 = 4.44	N7 = 1.60311	ν7 = 60.7
R13 = −602.45			

	f	D9
(1) ϕ1 = 1.161 ϕW	100	43.89
(2) ϕ2 = −1.031 ϕW	130	24.62
(3) eW = 0.726/ϕW	166.7	10.48

(4) $\frac{N22 - N21}{R4} = -0.362\ \phi W$

(5) $\nu 22 - \nu 21 = 0.3$

Numerical Example 3

F = 100.00000–188.9 FNO = 1:4–5.6 2ω = 62°–35.3°

R1 = 47.50	D1 = 10.44	N1 = 1.61800	ν1 = 63.4
R2 = 112.77	D2 = 3.53		
R3 = −63.77	D3 = 5.37	N2 = 1.80440	ν2 = 39.6
R4 = 39.88	D4 = 7.46	N3 = 1.66755	ν3 = 41.9
R5 = 216.70	D5 = 0.73		
R6 = 284.61	D6 = 8.56	N4 = 1.61800	ν4 = 63.4
R7 = −67.97	D7 = 0.42		
R8 = 161.84	D8 = 6.57	N5 = 1.61800	ν5 = 63.4
R9 = −94.24	D9 = Variable		
R10 = −52.36	D10 = 6.17	N6 = 1.75700	ν6 = 47.9
R11 = −44.12	D11 = 17.28		
R12 = −36.95	D12 = 4.44	N7 = 1.60311	ν7 = 60.7
*R13 = 332.43			

Aspherical Coefficients of the Surface R13

a1 = -3.337×10^{-3}	b1 = 3.551×10^{-7}
a2 = -1.878×10^{-7}	b2 = 1.204×10^{-8}
a3 = -6.771×10^{-11}	b3 = 4.151×10^{-12}
a4 = -2.614×10^{-13}	b4 = -5.406×10^{-15}
a5 = 1.339×10^{-16}	

	f	D9
(1) ϕ1 = 1.161 ϕW	100	47.66
(2) ϕ2 = −1.031 ϕW	140	23.80
(3) eW = 0.726/ϕW	188.9	8.35

(4) $\frac{N22 - N21}{R4} = -0.343\ \phi W$

-continued

(5) $\nu 22 - \nu 21 = 2.3$

What is claimed is:

1. An objective lens comprising a front lens unit and a rear lens unit with a separation between said two lens unit being varied to vary the focal length of the entire system,

said front lens unit having a positive refractive power and consisting of, from front to rear, a positive lens of strong convex curvature toward the front, a negative doublet lens of negative and positive elements cemented together, and a positive lens sub-unit; and

said rear lens unit having a negative refractive power and having a positive lens and a negative lens.

2. An objective lens according to claim 1, wherein the negative element of said doublet lens is of bi-concave form, and the positive element is of meniscus form.

3. An objective lens according to claim 1, satisfying the following conditions:

$$-0.6\phi W < (N22 - N21/R4) < -0.1\phi W$$

$$-10 < \nu 22 - \nu 21 < 10$$

where N21 and $\nu 21$ are the refractive index and Abbe number of the negative element of said doublet lens, N22 and $\nu 22$ are the refractive index and Abbe number of the positive element, R4 is the radius of curvature of the cemented surface of the negative and positive elements, and ϕW is the refractive power of the entire system in the wide angle end.

4. An objective lens according to claim 1, wherein said positive lens sub-unit consists of two positive lenses.

5. An objective lens according to claim 4, wherein the front one of said two positive lenses is of bi-convex form.

6. An objective lens according to claim 1, wherein said rear lens unit comprises a positive meniscus lens of forward concavity and a negative meniscus lens of forward concavity arranged in this order from front.

7. An objective lens according to claim 6, wherein said rear lens unit has at least one aspherical surface.

8. An objective lens according to claim 1, wherein said front lens unit and said rear lens unit move forward while shortening the separation between said two units as the focal length increases.

9. A zoom lens comprising:

a front lens unit having a positive refractive power and consisting of, from front to rear, a positive lens with its front surface of strong convex curvature toward the front, a negative doublet lens of a bi-convex element and a positive meniscus element cemented together in this order from the front, and a plurality of positive lenses; and

a rear lens unit arranged on the image side of said front lens unit, axially movable along with, and independently of said front lens unit, having a negative refractive power, and comprising a positive meniscus lens of forward concavity, and a negative meniscus lens of forward concavity.

10. A zoom lens according to claim 9, satisfying the following condition:

$$-0.6\phi W22 - N21/R4) < -0.1\phi W$$

$$-10 < \nu 22 - \nu 21 < 10$$

where N21 and $\nu 21$ are the refractive index and Abbe number of the bi-concave element of said doublet lens, N22 and $\nu 22$ are the refractive index and Abbe number of the positive meniscus element, R4 is the radius of curvature of the cemented surface of the negative and positive elements, and ϕW is the refractive power of the entire system in the wide angle end.

* * * * *

373787 OR 4,647,160

United States Patent [19]

Ikemori

[11] **Patent Number: 4,647,160**

[45] **Date of Patent: Mar. 3, 1987**

[54] **SMALL-SIZED WIDE ANGLE ZOOM OBJECTIVE**

[75] Inventor: **Keiji Ikemori, Kanagawa, Japan**

[73] Assignee: **Canon Kabushiki Kaisha, Japan**

[21] Appl. No.: **733,856**

[22] Filed: **May 13, 1985**

Related U.S. Application Data

[63] Continuation of Ser. No. 450,742, Dec. 17, 1982, abandoned.

[30] **Foreign Application Priority Data**

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Apr. 13, 1982 [JP] Japan 57-61531
May 19, 1982 [JP] Japan 57-84171
Jul. 23, 1982 [JP] Japan 57-128565

[51] **Int. Cl.**[4] **G02B 15/14**
[52] **U.S. Cl.** **350/426**
[58] **Field of Search** 350/423, 426, 427

[56] **References Cited**

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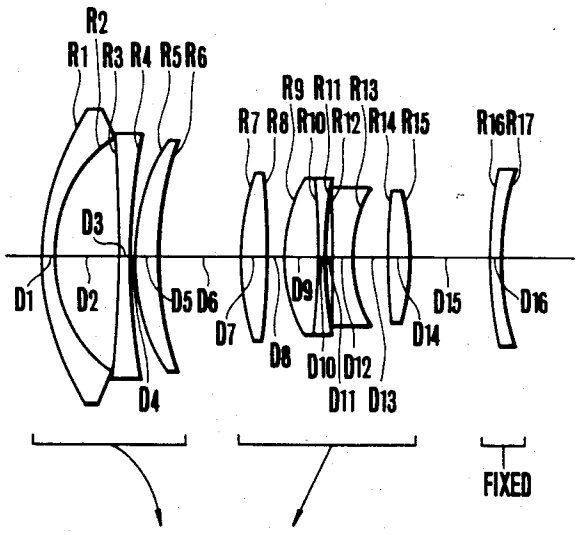
Primary Examiner—John K. Corbin
Assistant Examiner—Rebecca D. Gass
Attorney, Agent, or Firm—Toren, McGeady and Goldberg

[57] **ABSTRACT**

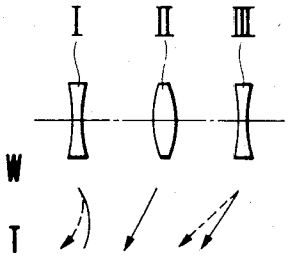
A small-sized wide angle zoom objective comprising, from front to rear, a 1st lens unit of negative power, a 2nd lens unit of positive power and a 3rd lens unit, wherein the 1st and 2nd units are made axially movable to effect zooming.

19 Claims, 109 Drawing Figures



PRIOR ART

FIG.1



PRIOR ART

FIG.2a

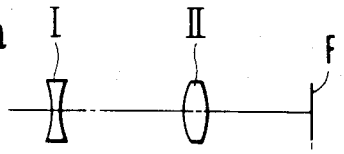
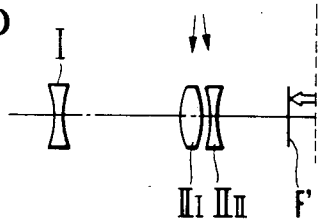


FIG.2b



PRIOR ART

FIG.3a

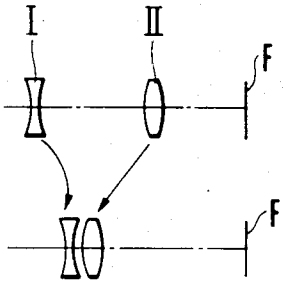
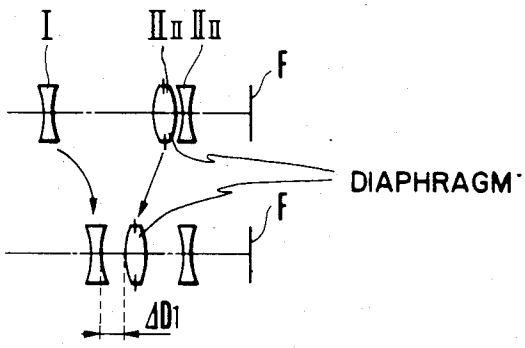


FIG.3b



PRIOR ART

FIG.4a

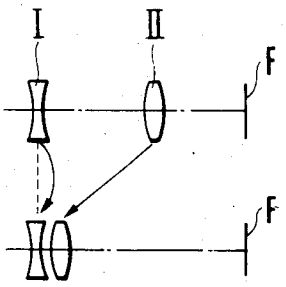


FIG.4b

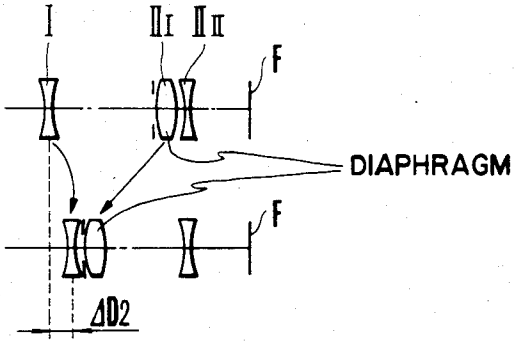


FIG.5

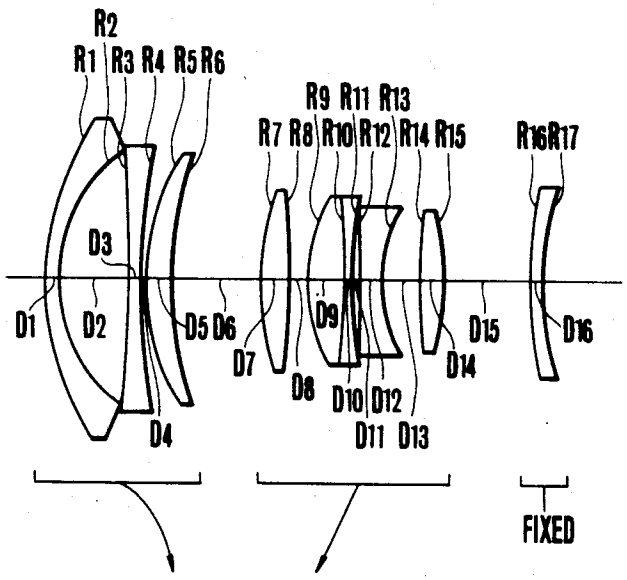

R2
R1 R3 R4 R5 R6
R9 R11 R13
R7 R8 R10 R12 R14 R15
R16 R17
D3
D1 D2 D5 D6
D9
D15
D16
D7
D14
D8
D10 D12
D4
D11 D13
FIXED

FIG.6

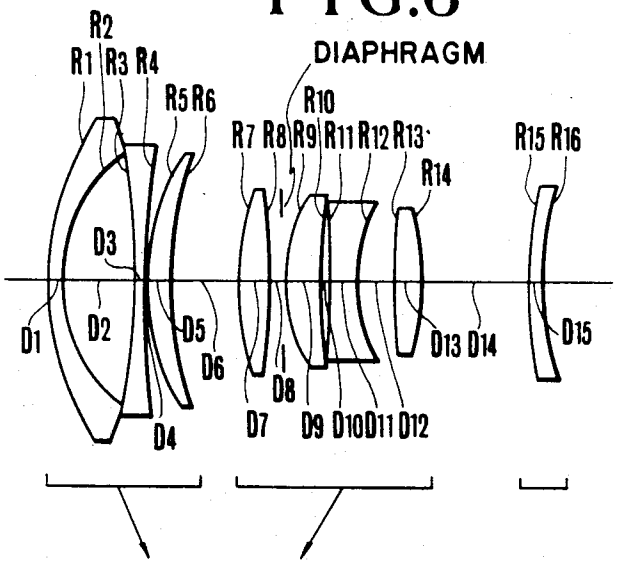

R2
R1 R3 R4
DIAPHRAGM
R5 R6
R10
R7 R8 R9 R11 R12 R13
R15 R16
R14
D3
D1 D2 D5
D13 D14
D15
D6
D8
D4
D7 D9 D10 D11 D12

FIG.7

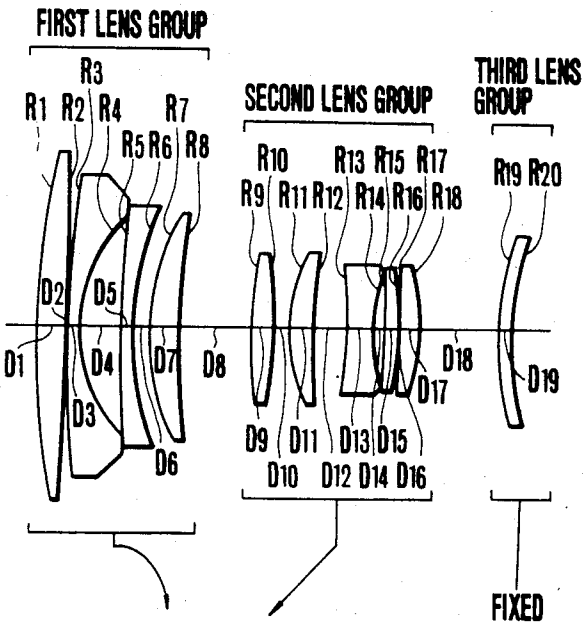

FIRST LENS GROUP
SECOND LENS GROUP
THIRD LENS GROUP
R1 R2 R3 R4 R5 R6 R7 R8
R9 R10 R11 R12 R13 R14 R15 R16 R17 R18
R19 R20
D1 D2 D3 D4 D5 D6 D7 D8
D9 D10 D11 D12 D13 D14 D15 D16 D17 D18
D19
FIXED

FIG.8

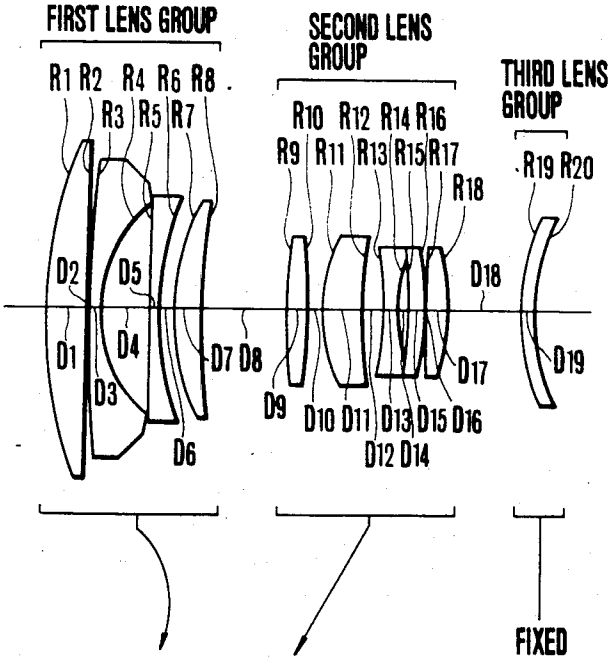

FIRST LENS GROUP
SECOND LENS GROUP
THIRD LENS GROUP
R1 R2 R3 R4 R5 R6 R7 R8
R9 R10 R11 R12 R13 R14 R15 R16 R17 R18
R19 R20
D1 D2 D3 D4 D5 D6 D7 D8
D9 D10 D11 D12 D13 D14 D15 D16 D17 D18
D19
FIXED

FIG.9

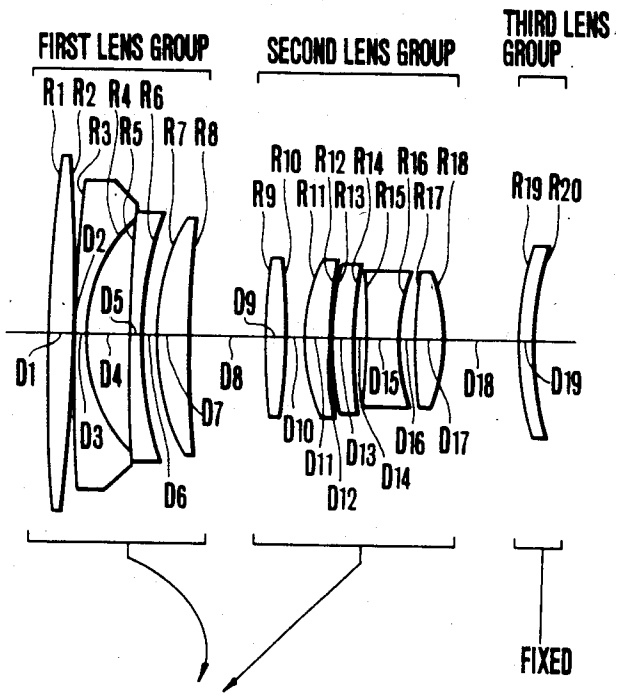

FIRST LENS GROUP
SECOND LENS GROUP
THIRD LENS GROUP
R1 R2 R4 R6
R3 R5 R7 R8
R10 R12 R14 R16 R18
R9 R11 R13 R15 R17
R19 R20
D2
D5
D9
D1
D4
D8
D15
D18
D19
D3
D7
D10
D16 D17
D11 D13
D14
D12
D6
FIXED

FIG.10

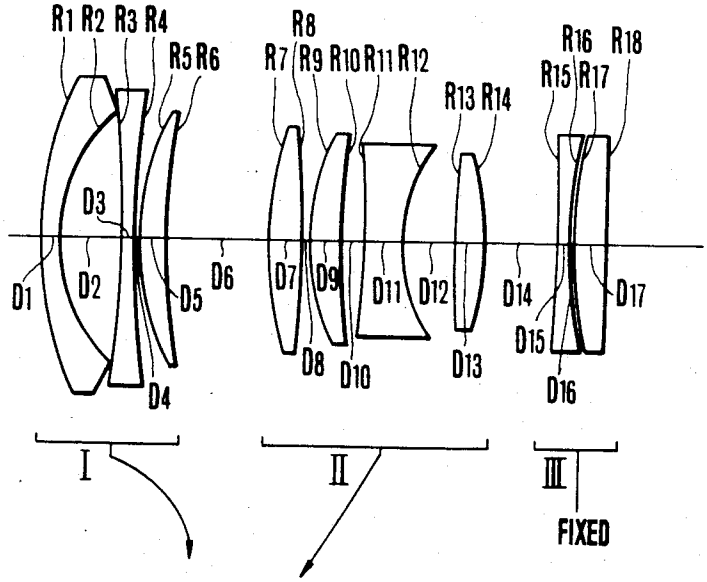

R1 R2 R3 R4
R5 R6
R8
R7 R9 R10 R11 R12
R13 R14
R16 R18
R15 R17
D3
D1
D2
D5
D6
D7
D9
D11
D12
D14
D17
D15
D4
D8
D10
D13
D16
I
II
III
FIXED

FIG.11

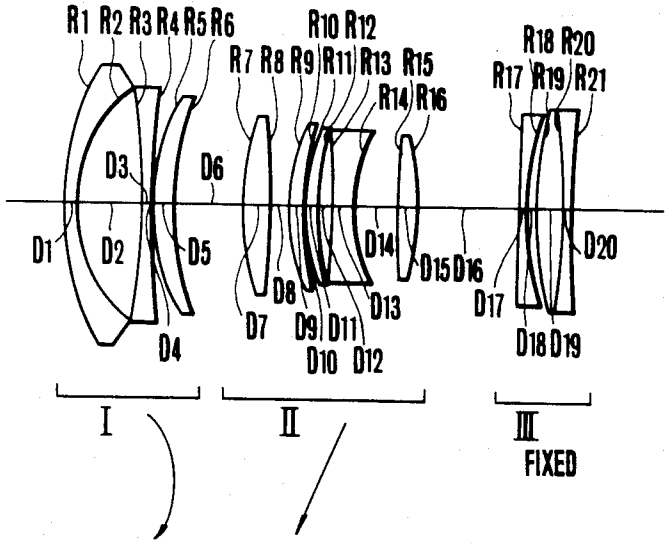

R1 R2 R3 R4 R5 R6
R10 R12
R7 R8 R9 R11 R13 R15
R14 R16
R18 R20
R17 R19 R21
D3
D6
D1
D2
D5
D14
D15 D16
D20
D8
D13
D17
D7
D9 D11
D18 D19
D4
D10 D12
I
II
III
FIXED

FIG.12

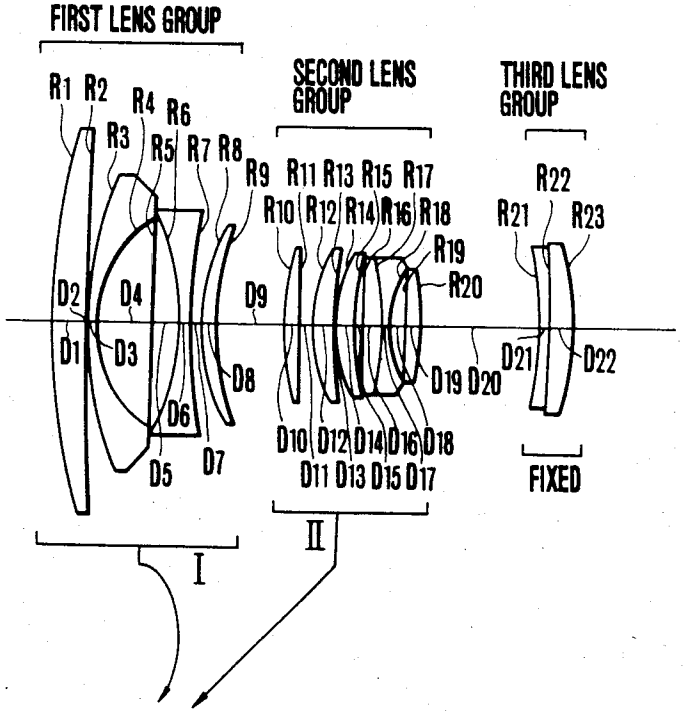

FIRST LENS GROUP
SECOND LENS GROUP
THIRD LENS GROUP
R1 R2 R4 R6
R3 R5 R7 R8
R9
R11 R13 R15 R17
R10 R12 R14 R16 R18
R19
R20
R22
R21 R23
D2 D4
D9
D1 D3
D8
D6
D19 D20
D21
D22
D5 D7
D10 D12 D14 D16 D18
D11 D13 D15 D17
I
II
FIXED

FIG.13

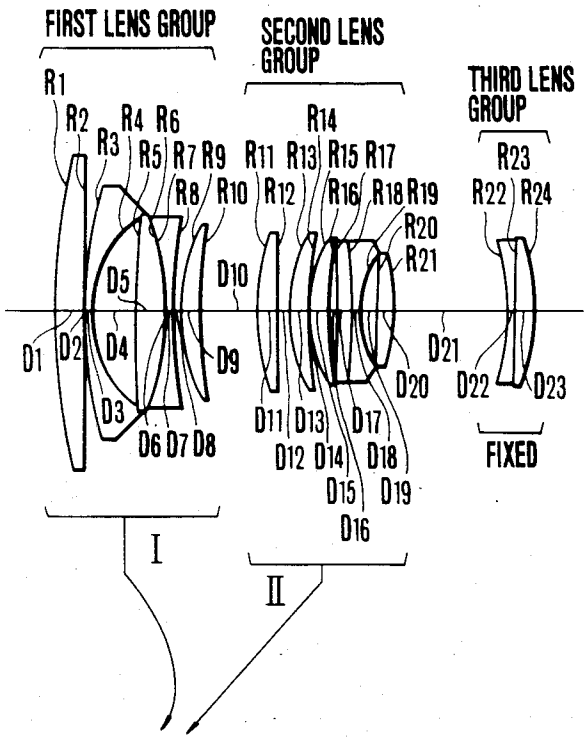

FIRST LENS GROUP
SECOND LENS GROUP
THIRD LENS GROUP
R1
R2
R3
R4
R5
R6
R7
R8
R9
R10
R11
R12
R13
R14
R15
R16
R17
R18
R19
R20
R21
R22
R23
R24
D1
D2
D3
D4
D5
D6
D7
D8
D9
D10
D11
D12
D13
D14
D15
D16
D17
D18
D19
D20
D21
D22
D23
FIXED
I
II

FIG.14a1

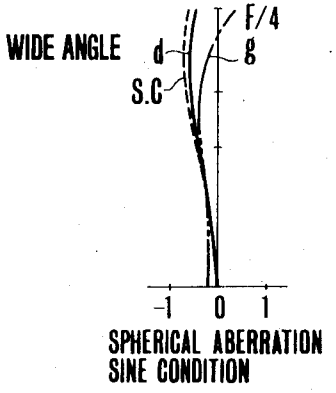


FIG.14a2

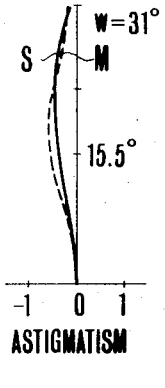


FIG.14a3

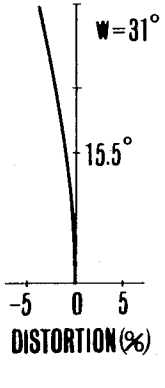


FIG.14a4

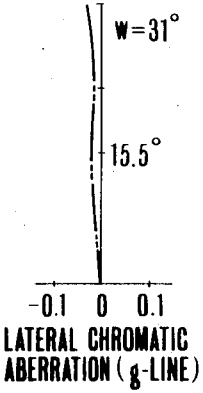


FIG.14b1

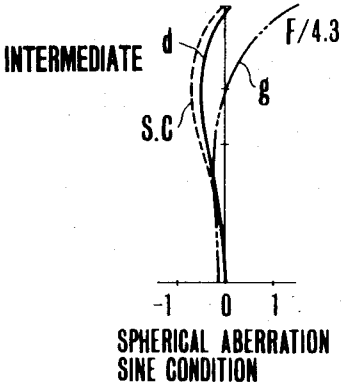


FIG.14b2

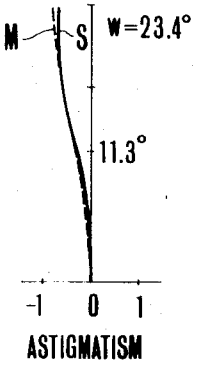


FIG.14b3

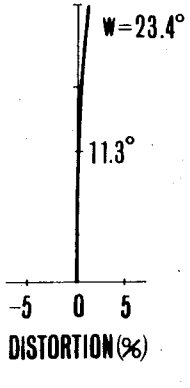


FIG.14b4

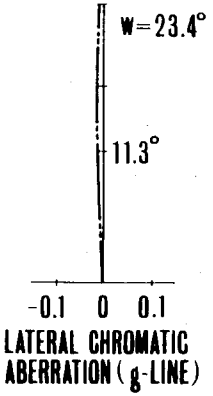


FIG.14c1 FIG.14c2 FIG.14c3 FIG.14c4

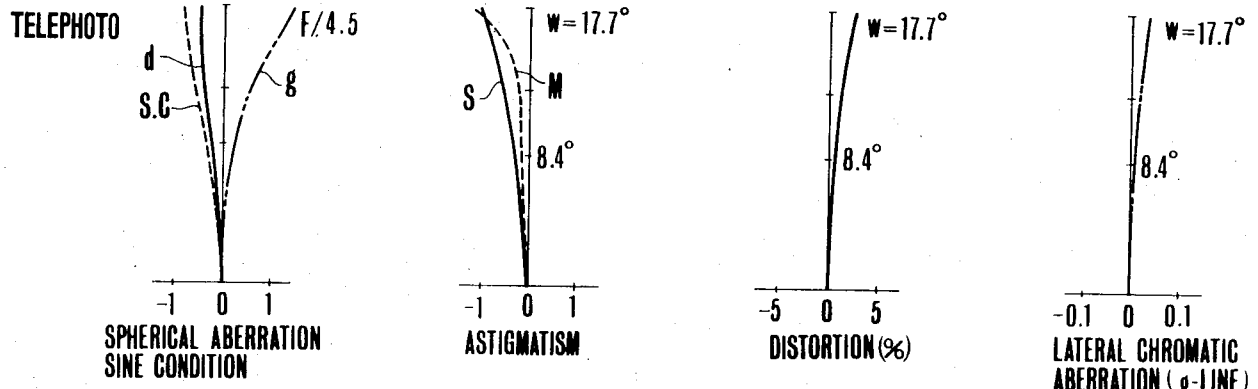


FIG.15a1 FIG.15a2 FIG.15a3 FIG.15a4

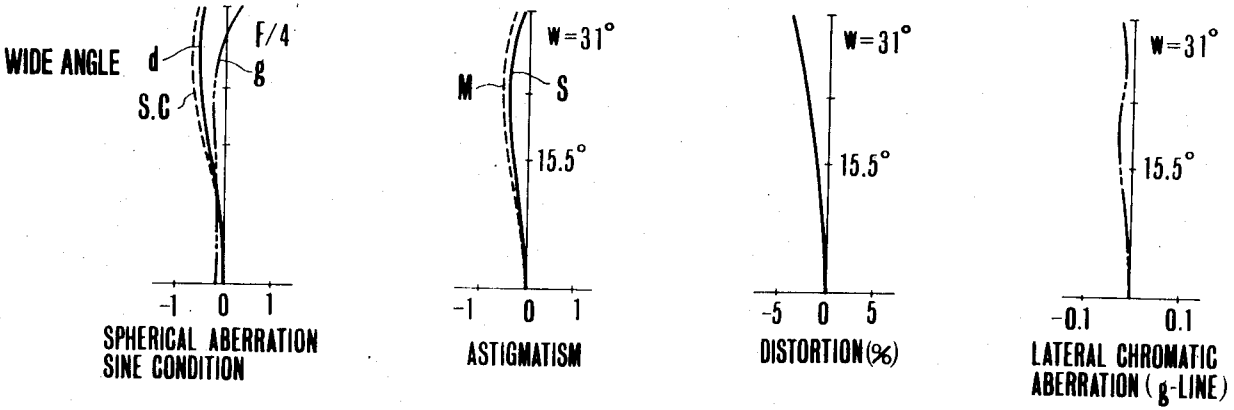


FIG.15b1 FIG.15b2 FIG.15b3 FIG.15b4

FIG.15c1 FIG.15c2 FIG.15c3 FIG.15c4

FIG.16a1 FIG.16a2 FIG.16a3

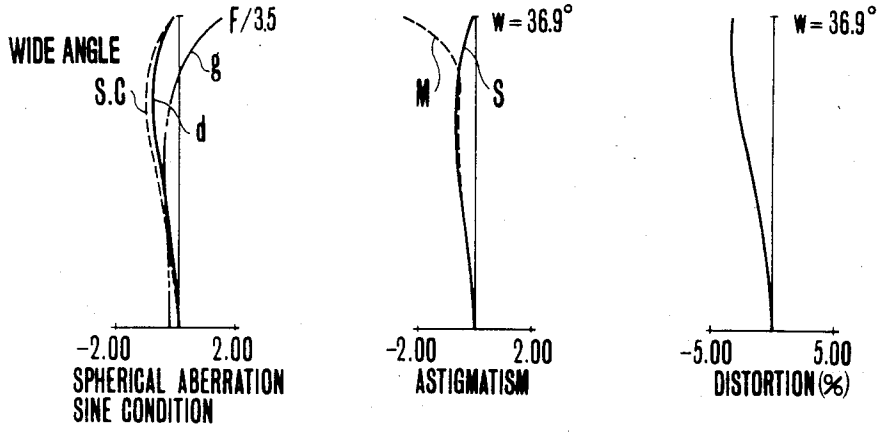


FIG.16b1 FIG.16b2 FIG.16b3

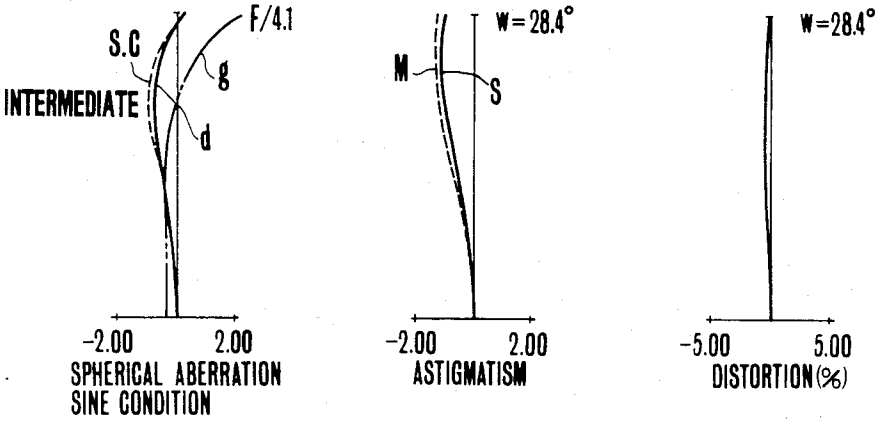


FIG.16c1 FIG.16c2 FIG.16c3

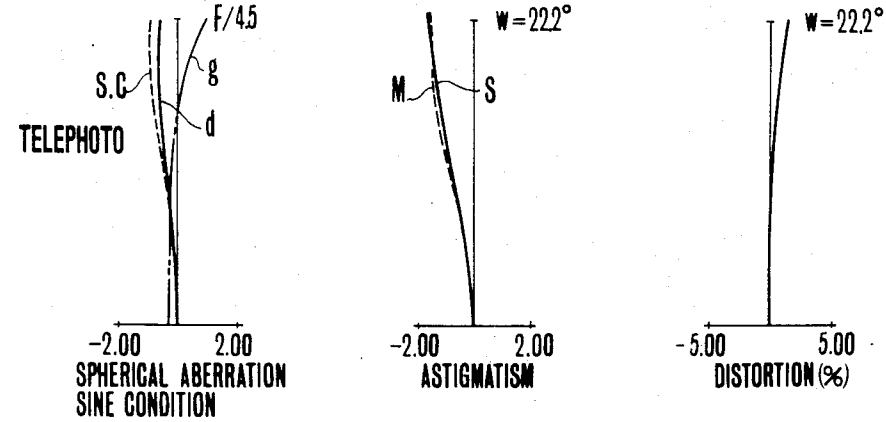


FIG.17a1 FIG.17a2 FIG.17a3

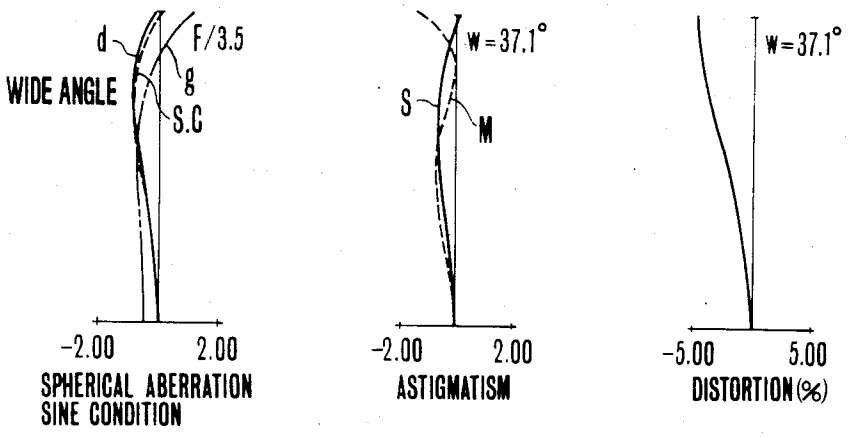


FIG.17b1 FIG.17b2 FIG.17b3

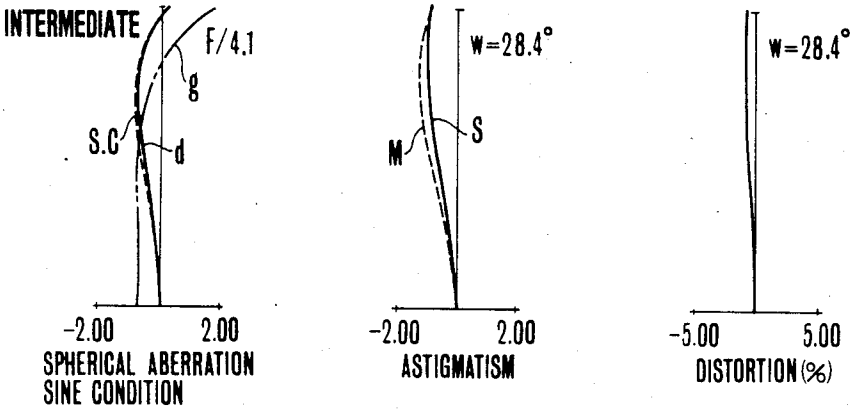


FIG.17c1 FIG.17c2 FIG.17c3

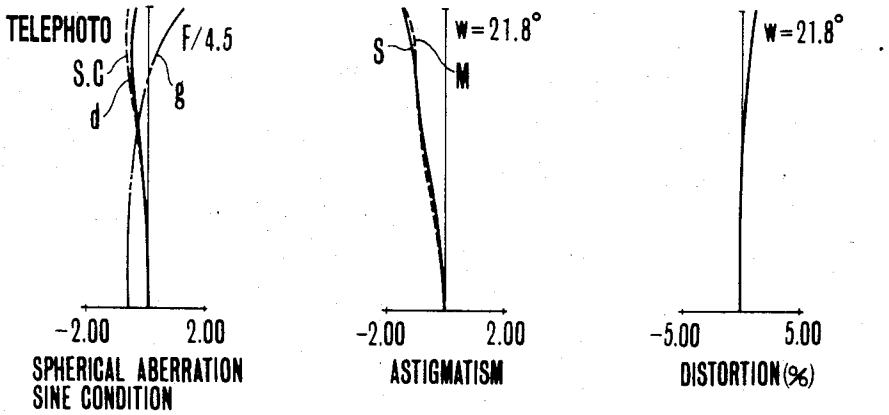


FIG.18a1 FIG.18a2 FIG.18a3

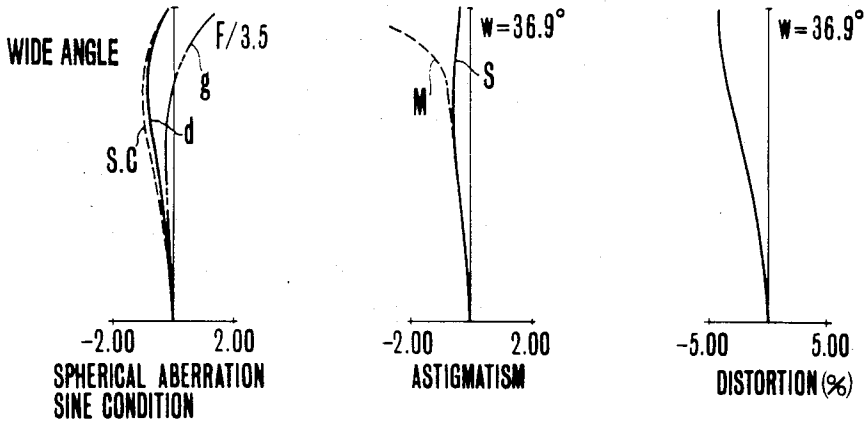


FIG.18b1 FIG.18b2 FIG.18b3

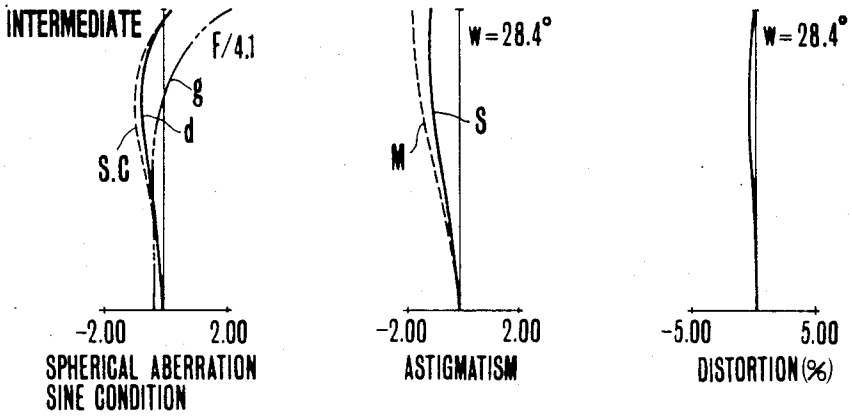
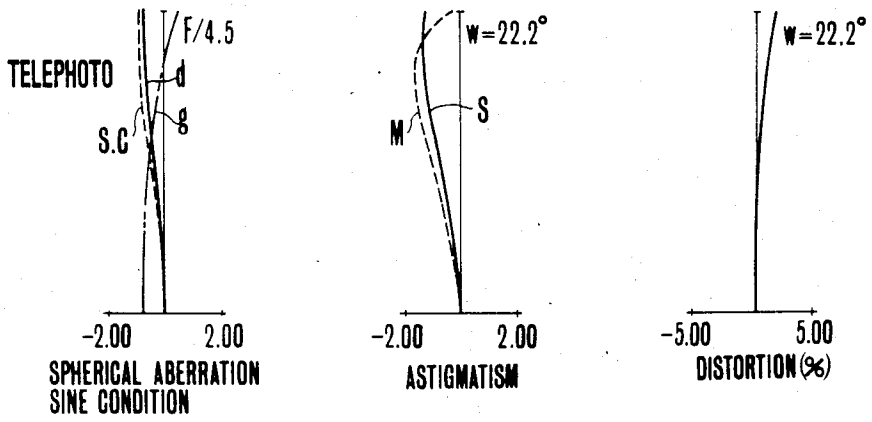


FIG.18c1 FIG.18c2 FIG.18c3



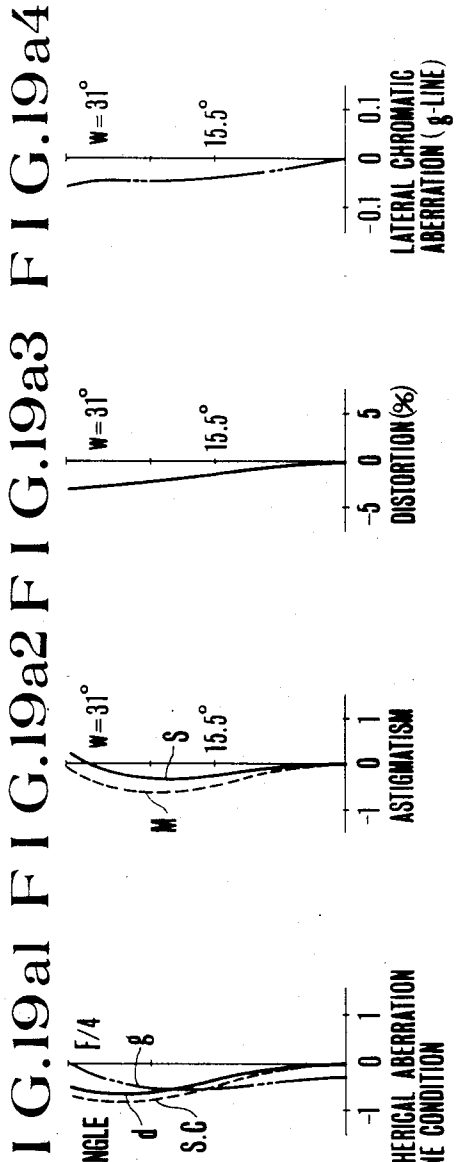


FIG.19a1 FIG.19a2 FIG.19a3 FIG.19a4

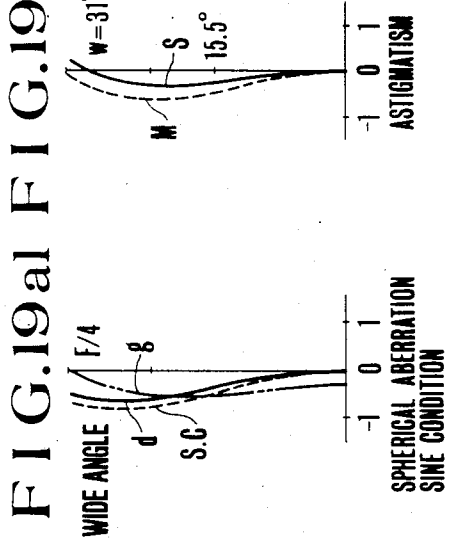


FIG.19b1 FIG.19b2 FIG.19b3 FIG.19b4

FIG.19c1 FIG.19c2 FIG.19c3 FIG.19c4

FIG.20a1 FIG.20a2 FIG.20a3 FIG.20a4

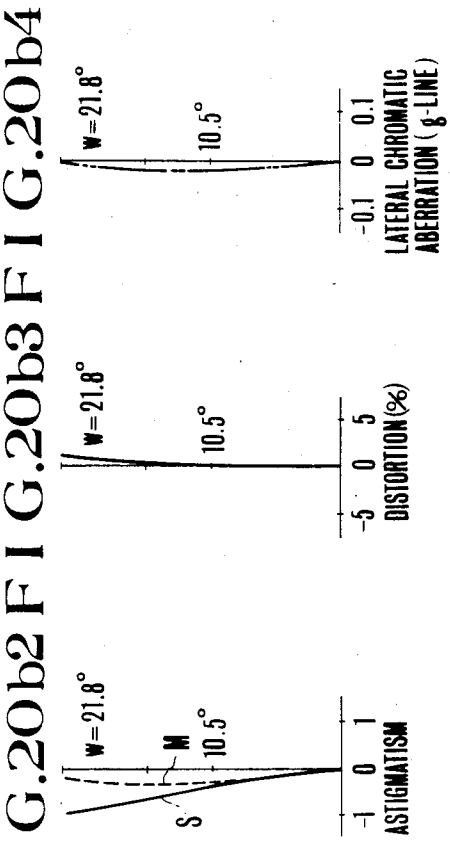


FIG.20b1

FIG.20b2

FIG.20b3

FIG.20b4

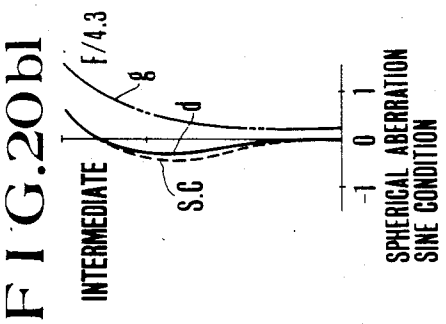


FIG.20c1

FIG.20c2

FIG.20c3

FIG.20c4

FIG.21a1

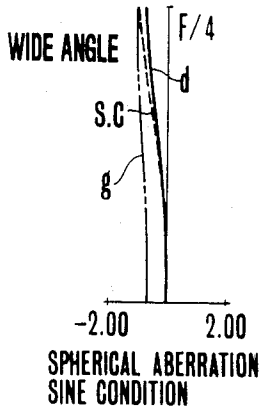


FIG.21a2

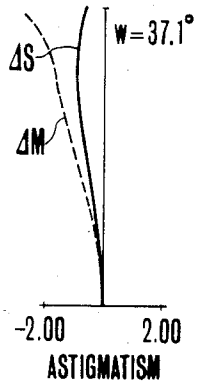


FIG.21a3

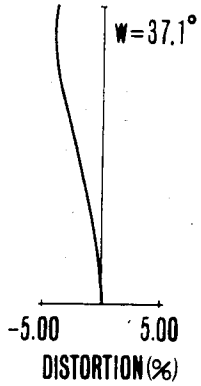


FIG.21b1

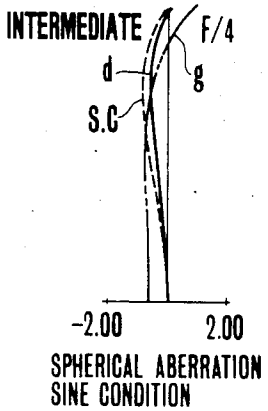


FIG.21b2

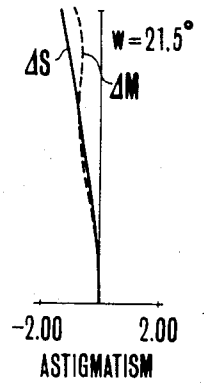


FIG.21b3

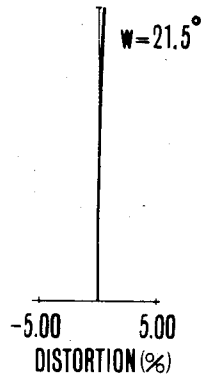


FIG.21c1

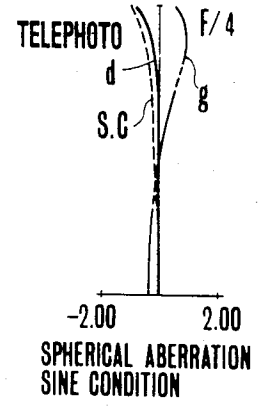


FIG.21c2

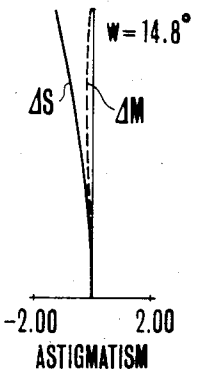


FIG.21c3

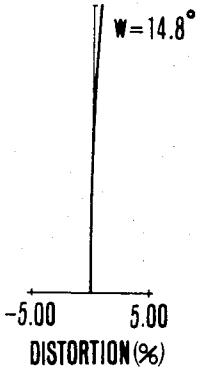


FIG.22a1 FIG.22a2 FIG.22a3

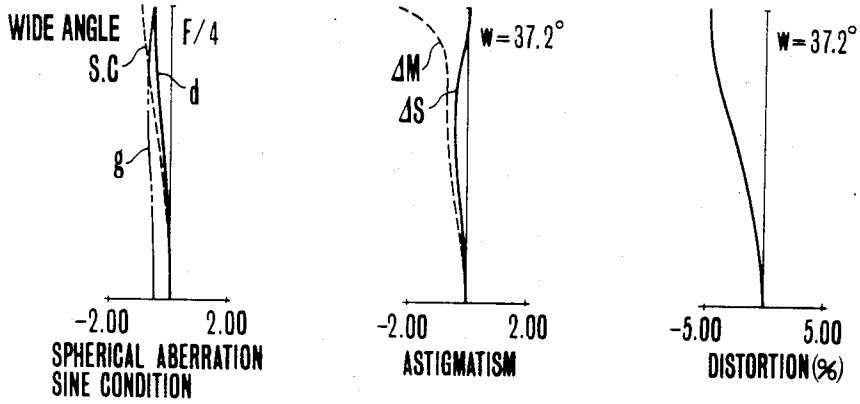


FIG.22b1 FIG.22b2 FIG.22b3

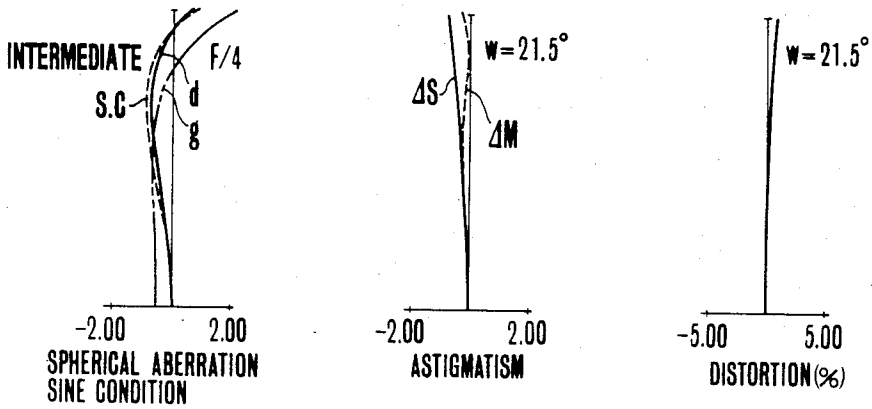
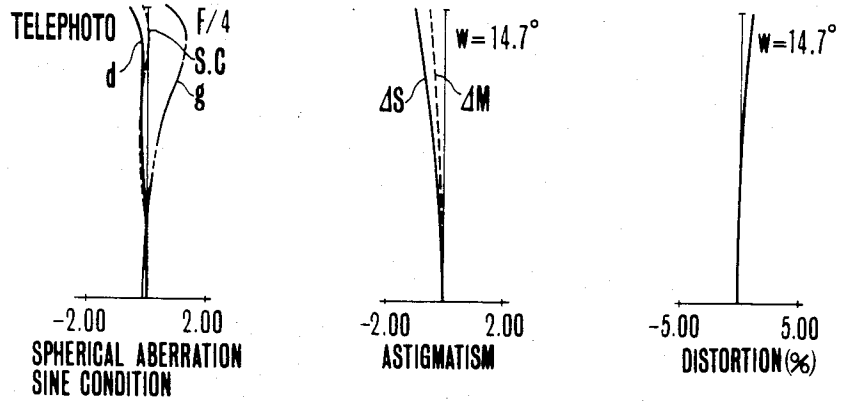


FIG.22c1 FIG.22c2 FIG.22c3



SMALL-SIZED WIDE ANGLE ZOOM OBJECTIVE

This is a continuation of application Ser. No. 450,742, filed Dec. 17, 1982, now abandoned.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to zoom objectives, and, more particularly, to small-sized, wide angle zoom objectives having three lens units with the first two lens units counting from front made movable to effect zooming.

2. Description of the Prior Art

In the past, in order to achieve a reduction of the bulk and size of a zoom objective lens, such lens has been formed by a diverging 1st lens unit and a converging 2nd lens unit with the air separation therebetween being varied to effect zooming, or to the so-called two-component type, and many zoom objectives of this type have been proposed. The present applicant also has made proposals in Japanese Laid Open Patents Nos. Sho 53-132360 and 56-19022. In the former, the diverging front or 1st lens unit is made up of three lens members, and its power is somewhat strengthened to reduce the interval between the principal points of the front and rear lens units in the telephoto position to some extent. In this manner a valuable decrease in the diameter of the front lens members and the total length of the objective (the distance from the front vertex to the image plane) particularly in the wide angle position is achieved. In the latter, on the other hand, the front or 1st lens unit is imparted with linearly progressive axial movement when zooming, thus providing achievement of a valuable decrease in the total length of the objective in the telephoto position, although the power of the diverging front or 1st lens unit is weaker than that in the former zoom objective. To achieve a further advance in the compactness of the zoom lens system, in the former case, the power of the diverging front or 1st lens unit may be further strengthened with an advantage that the total length of the complete objective in the wide angle position can be further shortened. Conversely when in the telephoto position, however, the total length becomes progressively longer, finally exceeding that when in the wide angle position. In the latter case, on the other hand, it is advantageous at shortening the total length in the telephoto position. It is, however, in the wide angle position that the total length tends to increase and further that a large increase in the diameter of the front lens members will result. For a general solution of the problem of most effectively shortening the total length of the zoom objective of the two-component type, it is preferred to employ the rule of design that the total lengths in the wide angle and telephoto positions are equal to each other.

SUMMARY OF THE INVENTION

An object of the present invention is to provide a wide angle zoom objective of reduced size having features found in the two-component type of zoom objective with achievement of shortening the total length by employing a new form and construction and arrangement of the lens members, while still preserving very high grade imaging performance.

Another object of the present invention is to provide a wide angle zoom objective of reduced size with a high range of image magnifications and with limitation of the bulk and size to a minimum while still permitting good correction of aberrations.

To achieve these objects, one of the features of the present invention is that the zoom objective is constructed with three lens units of which the 1st after counting from the front, is divergent and the 2nd is convergent whereby the aforesaid 1st lens unit and 2nd lens unit are made axially movable for zooming in front of the 3rd lens unit, which remains stationary.

Additional features are that the 1st lens unit, 2nd lens unit and 3rd lens unit are given respective appropriate refractive powers, and each lens unit has a suitable configuration. When these features are within the limits stated, greatly improved results are attained.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic view illustrating the zooming method employed in the conventional zoom lenses.

FIGS. **2**-*a* and -*b*, FIGS. **3**-*a* and -*b*, and FIGS. **4**-*a* and -*b*, are schematic views each illustrating the predesigns of the conventional zoom objective in comparison with an embodiment of the zoom objective according to the present invention.

FIGS. **5** through **13** are lens block diagrams of embodiments 1 through 9 of the present invention respectively.

FIGS. **14** through **22** are graphic representations of all aberrations of the objectives of FIGS. **5** to **13** respectively.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The zoom objective of the present invention may be considered in analogy to the conventional two-component zoom objective as comprising a converging rear or 2nd lens unit which is divided into two parts with the front one of convergence and the rear one of either divergence or convergence, whereby the converging front part only is made axially movable together with the diverging 1st lens unit to effect zooming.

As is known in the art, there has been another proposal for the zoom objective comprising, as illustrated in FIG. **1**, a diverging 1st unit I, a converging 2nd unit II and a diverging 3rd unit III, that the 2nd and 3rd units are moved forward, while the 1st unit is simultaneously moved in non-linear progression, when zooming from the wide angle to the telephone position. With such zoom type, to retain the zoom ratio in somewhat high a level, it is required that the total movement of the 2nd unit be increased, and the paths of movement of the 1st and 3rd unit be changed as indicated by dashed line curves in the same drawing. In this case, the 1st unit tends to project farther ahead in the telephoto setting than in the wide angle setting. The expansion of the total length of the objective in the telephoto position will increase the bulk and size of the lens system.

As the total zooming movement of the 3rd unit reduces, the proportion of that part of the zooming movement of the 1st unit which directs toward the rear increases so that the equivalent zoom ratio can be obtained by a lesser zooming movement of the 2nd unit.

The zoom objective of the present invention has features with use of such properties of the zoom lens and such features of the two-component zoom type to achieve a further minimization of the bulk and size of the zoom lens while still permitting high grade optical performance.

Next, with regard to the zoom lens according to the present invention, taking an example of the lens predesign that the 3rd lens unit is made of divergence, and comparing with that type which has been proven to be advantageous for achieving minimization of the bulk and size of the zoom objective, or the so-called two-component zoom type, the rules of design of the invention, which are suited for facilitating a minimization of the bulk and size of the zoom objective, will be explained by reference to the drawings.

FIGS. 2-*a* and 2-*b* are the predesigns of the conventional two-component zoom objective and of a zoom objective of the present invention respectively. I is a negative 1st lens unit; II is a positive 2nd unit; and F is a film plane. As illustrated in FIG. 2-*b*, the division of the converging rear or 2nd unit into two parts II_I and II_{II} of positive and negative powers respectively gives a similar configuration to that of the zoom objective of the present invention which may be considered for these two parts to constitute a telephoto type lens with the result that the film plane F is shifted forward and takes its place at a position indicated by F', and, therefore, that the back focus is shortened. This makes it possible to shorten the total length of the lens system in both the wide angle and telephoto positions.

What change results in the total zooming movement by that division is illustrated in FIGS. 3-*a* and -*b* and 4-*a* and -*b*. Since the rear part II_{II} has a negative power, the positive power of the front part II_I is necessarily stronger than that of the original unit II. Therefore, the required total zooming movement of the front part II_I for the same zoom ratio can be lessened by a distance ΔD_1 illustrated in FIG. 3-*b* as compared with FIG. 3-*a*. This allows for the interval between the principal points of the diverging 1st unit I and the converging front part II_I to be reduced by the ΔD_1. Thus a further reduction of the total length of the lens system can be achieved.

In addition to the advantage which is produced based on the assumption that the power of the diverging 1st unit is left unchanged from that of the diverging 1st unit of the conventional two-component zoom objective, according to the zoom lens predesign of the invention, it is also made possible to facilitate a further reduction of the total length of the lens system than when the conventional method, i.e., that which has been found to be very effective in reducing the bulk and size of the two-component zoom objective by increasing the power of the 1st unit so as to make the total length in the wide angle position almost equal to that in the telephoto position, is in use.

In this connection, it should be explained that, as has been stated above, the zoom objective of the present invention admits of reducing the total zooming movement of the converging 2nd unit from that of the conventional two-component zoom objective, while still maintaining the constant equivalent zoom ratio. With the wide angle position as the start point, therefore, when zoomed to the telephoto position, the diverging 1st unit I may be located backward at a distance ΔD_2 indicated in FIG. 4-*b* from the point in position of the conventional one illustrated in FIG. 4-*a*. Since, therefore, the total length in the telephoto position becomes shorter than that in the wide angle position, a possibility of shortening the total length in the wide angle position is produced. Thus, a further minimization of the total length of the lens system can be achieved when the power of the diverging 1st lens unit is further strengthened. For a better understanding, the foregoing discussion on the primary features of a new type of zoom objective according to the present invention has been presented as compared with the conventional or two-component zoom type.

In the alternative case where the 3rd unit of the zoom objective of the invention is divergent, the total length of the lens system tends to become slightly longer than when it is convergent. But, because of the convergence of the 3rd unit, particularly regarding a high-range zoom objective, all aberrations become easy to correct throughout the entire zooming range. This allows for the power of the 1st unit to be strengthened. As a result, even when the 3rd unit is divergent, achievement of a valuable decrease in the total length of the lens system is provided as well.

According to the present invention, a zoom objective of the type described above has the rules of design which are sufficient to achieve a valuable decrease in the bulk and size of the lens system and good correction of aberrations. However, with the diverging 3rd unit, in order to obtain a further improvement of the optical performance and to achieve a further reduction of the total length of the lens system, it is preferred to satisfy the following conditions:

The 1st condition is that, letting f_{III} denote the focal length of the 3rd unit, $|f_{III}|$ is equal to or larger than the longest focal length f_T of the entire system, or $|f_{III}| \geqq f_T$. This leads to limit the power of the 2nd unit so as not to produce extremely large aberrations and also to provide a necessary back focus in the wide angle position. When out of this range, the aberrations ascribable to the 2nd unit increase so greatly that it is difficult to perform good correction of image aberrations, and the back focus becomes too short to provide a clearance for mirror-up even in the wide angle position when in use with a 35 m/m TTL type single lens reflex camera.

The 2nd condition is that, letting f_I denote the focal length of the 1st unit, $|f_I|$ is equal to or smaller than f_T, or $|f_I| \leqq f_T$. This results in a shortened total length of the entire system, and a decreased diameter of the front members of the zoom objective. When this condition is violated, the total length of the lens system in the wide angle position and the diameter of the front members of the objective become too large to achieve an advance in the compactness with ease. Further, for a zoom ratio of less than 2 and a full open F-number of about F/4, as in embodiments of the invention to be described later, it is preferred to construct the diverging 3rd unit in the form of a single lens. This is advantageous in order to make the entire system of the zoom objective compact within the scope such that the aberrations of the entire system of the zoom objective are not deteriorated badly. In the case where an aperture stop is positioned within the 2nd unit, with regard to the fact that somewhat strong power of the 1st unit is liable to result in production of large barrel type distortion in the wide angle position, the location of the 3rd unit on the image side of the aperture stop provides assurance that this distortion can be well corrected. To perform such correction effectively, a 1st good method is by constructing the 3rd unit in the form of a meniscus-shaped single lens of concave curvature toward the rear.

While the state of correction of the image aberrations is maintained excellent as such, the zoom lens system as a whole is made compact, provided that the following various conditions, which are severer than the aforesaid ones, are preferably satisfied.

$$0.5 \leqq |f_I|/f_T \leqq 0.9 \quad (1)$$

$$1.4 \leqq |f_{III}|/f_T \leqq 19 \quad (2)$$

Here, when below the lower limit of condition (1), the total length of the lens system in the telephoto position tends to be longer than in the wide angle position, and further it becomes difficult to perform good correction of spherical aberration in the telephoto position. When above the upper limit, the total length in the wide angle position is insufficiently shortened.

When below the lower limit of condition (2), it becomes difficult to take the back focus at a required value in the wide angle position and, further, the construction of the 3rd unit in the simple form becomes difficult from the standpoint of physical characteristics. When above the upper limit, this power of the 3rd unit is too weak to achieve a great advance in the compactness.

As a 2nd method, the 3rd unit is preferably constructed in the form of at least one positive lens and at least one negative lens with the axial separation, t, between the frontmost and rearmost lens surfaces of the 3rd unit falling within the following range:

$$0.04 \leqq t/f_T \leqq 0.25 \quad (3)$$

This also contributes to the reduction of the bulk and size of the entire lens system while still preserving good correction of aberrations.

When the upper limit of condition (3) is exceeded, the excessive thickness of the 3rd unit has an adverse effect on the reduction of the bulk and size of the entire lens system. When the lower limit is exceeded, the lens thickness becomes too thin to give a desired radius of curvature so that it becomes difficult to perform good correction of aberrations.

As to the 1st unit, according to the present invention, it is preferred to arrange a positive lens in the rearmost position with an air lens defined by the front surface of that positive lens and the rear surface of a preceding lens having a converging action. For the 2nd unit, it is preferred to use, first, two or more lenses of positive and negative powers and, second, positive lenses in this order from the front of the zoom lens.

Such construction and arrangement of the constituent lenses enables the spherical aberrations of each unit to be removed to some extent, and, therefore, facilitate an achievement of good stability of correction of spherical aberrations throughout the entire zooming range.

Besides, to achieve the valuable decrease in the bulk and size of the entire zoom lens system in such a manner as to make it possible to maintain good stability of aberration correction throughout the entire zooming range, according to the present invention, it is better to construct the diverging 1st unit of strong power in a very simple form and to suppress the amount of aberrations ascribed to this component to as small a level as possible. In this respect, the 1st lens unit is made up of, from front to rear, a meniscus-shaped negative 1st lens of forward convexity, a bi-concave negative 2nd lens, and a meniscus-shaped positive 3rd lens of forward convexity. The use of the air lens of converging action defined by the negative 2nd and positive 3rd lenses enables good correction of all aberrations to be easily performed in the telephoto positions.

The 1st unit may be otherwise constructed as comprising, from front to rear, a positive lens, a negative meniscus lens of rearward concavity, a negative lens with its rear surface having a stronger refractive power, and a positive lens with its front surface having a stronger refractive power.

With a widened angular field, to correcting the zoom objective of the invention well particularly for distortion in the wide angle positions, it is better to arrange a positive lens at the frontmost position in the 1st unit so that correction of barrel type distortion is performed by this positive lens.

Since the 1st unit has an overall refractive power of negative sign, it is required that the aforesaid positive lens be followed by a plurality of negative lenses in view of the use of an additional positive lens of which the front surface has a strong refractive power in the rear of those negative lenses with the production of an air lens of convergence between the negative and positive lenses, to thereby enable good correction of spherical aberrations in the telephoto position, thus contributing to the good stability of aberration correction over the entire zooming range.

It is to be noted here that when the number of negative lenses stated above is two, it is preferred to form the front or 1st negative lens to a meniscus shape of concave curvature toward the rear, and the negative 2nd lens to a shape of strong refractive power in the rear surface thereof, with an advantage that the spherical aberrations in the telephoto positions and the coma in the wide angle positions are well corrected.

Next, the 3rd unit when constructed by a converging or diverging lens unit has additional featues that a lens of negative power and a lens of positive power are at least included, and that, letting f_{III} denote the focal length of the aforesaid 3rd lens unit and fw the shortest focal length of the entire lens system, the following condition is satisfied:

$$-0.3/fw < 1/f_{III} < 0.2/fw \quad (4)$$

In order to achieve an increase in the zoom ratio up to more than two for the two-component zoom type which has found many use in zoom objectives, while still permitting the entire lens system to take a compact form, according to the prior art, it is required particularly for the positive power of the 2nd unit to be strengthened so that the prescribed equivalent zoom ratio can be obtained despite the total axial movement is lessened. In addition thereto, the negative power of the 1st unit is also strengthened so that the total length of the lens system from the front vertex to the focal plane in the wide angle position can be shortened. As has been stated above, however, the increase in the positive power of the 2nd unit results in the production of very large astigmatism as under-corrected in the wide angle positions and as over-corrected in the telephoto positions, which are difficult to cancel out.

It will be appreciated from this standpoint that the use of the additional or 3rd unit which remains stationary during zooming to the conventional two-component zoom lens system provides assurance that all aberrations can be well corrected with ease over the extended zooming range. For this purpose, the 3rd unit is constructed as comprising at least one negative lens and at least one positive lens. When the refractive power of the 3rd unit lies within the range defined by inequalities (4), good balance of aberrations in the wide angle and telephoto positions can be maintained.

Further, it is preferred that the negative and positive lenses of the third unit are cemented together at their

adjoining surfaces to form a doublet of meniscus shape convex toward the rear, and the index of refraction of the glass from which the negative lens of the third unit is made up is made higher than that of refraction of the glass from which the positive lens of the third unit is made up. Such doublet produces either over-corrected or under-corrected astigmatism when in the wide angle or telephoto positions respectively, thereby the stabilization of the astigmatism can be obtained. The use of the glass having the higher index of refraction in the negative lens of the third unit provides improvement in that the Petzval sum, which would otherwise go negative, is directed toward positive.

For assisting in accomplishing the object of the present invention, the following condition is satisfied:

$$|f_I| \leqq |f_T| \tag{5}$$

In this connection, it should be explained that when an independent focusing movement is imparted into the 1st unit, the required diameter of the front member tends to rapidly increase for an object at shorter distances. To account for this, it is better to strengthen the power of the 1st unit to some extent so that the total forward movement is reduced. The above-stated condition (5) represents a range of refractive powers allowable for the 1st unit. Though too great an increase in the refractive power of the 1st unit is advantageous at reducing the diameter of the front member, the barrel type distortion in the wide angle positions and the spherical aberration in the telephoto positions are caused to rapidly increase. Thus, it becomes difficult to maintain good stability of aberration correction throughout the zooming range. Therefore, it is preferred that the refractive power of the 1st unit is not too strengthened, leaving it to be on the order:

$$|f_I| \geqq |f_T/2|$$

As to the diaphragm, for the zoom objective of the present invention, it is preferred from the standpoint of aberration correction that the diaphragm is positioned in a space within the 2nd unit, or adjacent the front or rear surface thereof and made movable in the same direction as the 2nd unit during zooming. When it is not desired to move the diaphragm, it is better to arrange it in a space between the 2nd and 3rd unit.

Next, explanation will be made about the function and effect of the 3rd unit based on the theory of aberrations. Taking a specific example 2 of the invention, to be described later, with the aperture stop in a space between the 1st and 2nd lenses counting from front in the 2nd lens unit, the 1st, 2nd and 3rd lens units have Seidel's aberration coefficients of 3rd order listed in Table 1.

As is evident from Table 1, the 3rd lens unit has, despite zooming the ability to give constant spherical aberration (SA), but astigmatism (AS) and distortion (DS) both act toward providing over-correction, and astigmatism (AS) is shown to be strong in the wide angle positions, and weak in the telephoto positions. Since, in the zoom objective of the invention, the powers of the 1st and 2nd lens units are strengthened to some extent, the combined lens system of the 1st and 2nd units is liable to produce under-corrected astigmatism particularly in the wide angle positions. To balance out the resultant aberrations, therefore, the aforesaid rules of design for the 3rd unit are very important. Also, since the barrel type distortion is liable to increase in the wide angle positions, such design of the 3rd unit is advantageous to the compensation of this aberration.

It will be appreciated that the zoom objective of the present invention is provided with the 3rd lens unit having the function of compensating for the aberrations produced from the 1st and 2nd lens units. In this respect, as compared with the mere combination of the conventional two-component zoom objective of which the aberration correction is completed in itself and an additional lens releasably inserted into the space between that objective and the image plane, or a so-called rear attachment lens (which is corrected for aberrations of itself only) to convert the range of focal lengths, that is, as compared with an apparent 3-component zoom objective, the zoom objective of the present invention has fundamentally different provisions, features and results. It is therefore remarkably improved over the prior art system obtained by adding a new converter lens to the zoom objective comprised of the negative and positive lens units to change the focal length range.

Another example of the 3rd lens unit when being either converging or diverging is given in Table 2 for the 3rd order aberration coefficients of an embodiment 9 of the invention. With reference to Table 2, what results are practically attained by the use of the 3rd lens unit is concretely clarified below. The sum of the 3rd order astigmatic aberration coefficients produced from the 1st and 2nd lens units is 0.077 in the wide angle position and −0.05 in the telephoto position as seen in Table 2, representing the residual astigmatism as under-corrected when in the wide angle position, and over-corrected when in the telephoto position. On the other hand, the 3rd lens unit gives a value of −0.0551 when in the wide angle position and 0.0504 when in the telephoto position. Therefore, the entire lens system of the 1st through 3rd lens units has values of 0.0219 and 0.0004 in the wide angle and telephoto positions respectively, thus giving good balance. Such improved results are attained when the refractive power of the 3rd lens unit falls within the range defined by the aforesaid inequalities (4). When the lower limit of condition (4) is exceeded, as the negative refractive power becomes too strong, it becomes difficult to retain the required value of back focus in the wide angle positions. Further, as the refractive power of the 2nd lens unit is caused to increase, the good stabilization of aberrations against zooming also becomes very difficult to hold. Conversely when the upper limit is exceeded, the power of the 2nd lens unit becomes too weak to reduce the bulk and size of the lens system without having difficulty in the limitation that the zooming range be maintained in extended manner.

It is to be noted that focusing of the zoom objective of the invention may be performed either by moving the entire lens system, or by moving the 1st and 2nd lens units, while the 3rd lens unit remains stationary during focusing, or by moving only either one of the 1st and 2nd lens units.

Though the embodiments 8 and 9 of the invention has been illustrated in connection with the 3rd lens unit of the cemented form consisting of the negative and positive lenses, it is, of course, also possible to make use of two or more singlets, thereby giving an advantage that the focusing provision can be made at part of the 3rd lens unit by an operating mechanism of simplified structure.

Examples of specific zoom objectives of the invention can be constructed in accordance with the following numerical data for the radii of curvature, R, the axial thicknesses or air separations, D, and the refractive indices, N, and the Abbe numbers, ν, of the glasses of the lens elements, with subscripts numbered consecutively from front to rear.

EXAMPLE 1

F = 100–189 FNO = 1:4–4.5 2ω = 62°–35.3°

R1 = 82.39	D1 = 4.31	N1 = 1.69680	ν1 = 55.5		
R2 = 45.34	D2 = 21.70				
R3 = −328.65	D3 = 3.75	N2 = 1.69680	ν2 = 55.5		
R4 = 252.09	D4 = 1.12				
R5 = 67.23	I = 7.42	N3 = 1.75520	ν3 = 27.5		
R6 = 103.13	D6 = Variable				
R7 = 83.86	D7 = 8.39	N4 = 1.69680	ν4 = 55.5		
R8 = −288.84	D8 = 5.56				
R9 = 46.77	D9 = 11.62	N5 = 1.59551	ν5 = 39.2		
R10 = −243.86	D10 = 2.50	N6 = 1.80518	ν6 = 25.4		
R11 = 146.60	D11 = 2.20				
R12 = −638.19	D12 = 6.95	N7 = 1.80518	ν7 = 25.4		
R13 = 43.96	D13 = 11.30				
R14 = 182.85	D14 = 6.93	N8 = 1.67270	ν8 = 32.1		
R15 = −90.59	D15 = Variable				
R16 = 133.50	D16 = 4.17	N9 = 1.48749	ν9 = 70.1		
R17 = 93.05					

f	100	139	189	f_I = −132.11
D6	65.1762	27.5967	2.0509	f_{III} = −652.02
D15	4.1667	26.4948	55.1514	

EXAMPLE 2

F = 100–189 FNO = 1:4–4.5 2ω = 62°–35.3°

R1 = 82.65	D1 = 4.31	N1 = 1.69680	ν1 = 55.5		
R2 = 45.31	D2 = 21.19				
R3 = −315.25	D3 = 3.75	N2 = 1.69680	ν2 = 55.5		
R4 = 262.54	D4 = 0.71				
R5 = 66.92	D5 = 7.10	N3 = 1.75520	ν3 = 27.5		
R6 = 103.67	D6 = Variable				
R7 = 83.95	D7 = 8.49	N4 = 1.69680	ν4 = 55.5		
R8 = −326.95	D8 = 5.56				
R9 = 46.73	D9 = 10.61	N5 = 1.60729	ν5 = 49.2		
R10 = 144.02	D10 = 2.57				
R11 = −493.88	D11 = 8.93	N6 = 1.84666	ν6 = 23.9		
R12 = 43.65	D12 = 11.16				
R13 = 195.02	D13 = 8.10	N7 = 1.68893	ν7 = 31.1		
R14 = −95.78	D14 = Variable				
R15 = 121.54	D15 = 4.17	N8 = 1.48749	ν8 = 70.1		
R16 = 88.20					

f	100	150	189	f_I = −133.33
D6	65.6161	20.5836	2.0744	f_{III} = −687.9

EXAMPLE 2-continued

D14	4.1469	32.9514	55.3056

TABLE 1

		Seidel's 3rd Order Aberration Coefficients						
		L	T	SA	CM	AS	PT	DS
1st	(W)	−0.00276	0.00261	−0.6184	0.1603	−0.1954	−0.4682	0.5524
Lens	(M)	−0.00622	0.00208	−3.1308	0.0940	−0.1567	−0.4682	0.1616
Group	(T)	−0.00985	0.00178	−7.8578	−0.0916	−0.1549	−0.4682	0.0734
2nd	(W)	0.00586	−0.00068	2.9153	−0.0218	0.2849	0.6529	−0.1534
Lens	(M)	0.00781	−0.00080	6.4473	0.0790	0.2019	0.6529	−0.1020
Group	(T)	0.00944	−0.00086	10.6158	0.1208	0.1561	0.6529	−0.0780
3rd	(W)	−0.00289	−0.00068	−0.0026	0.1545	−0.0474	−0.1019	−0.1048
Lens	(M)	−0.00289	−0.00094	−0.0026	0.1543	−0.0193	−0.1019	−0.1232
Group	(T)	−0.00289	−0.00109	−0.0026	0.1542	−0.0033	−0.1019	−0.1302
Total	(W)	0.00020	0.00124	2.2942	0.2930	0.0420	0.0827	0.2940
Sum	(M)	−0.00129	0.00033	3.3138	0.3273	0.0258	0.0827	−0.0636
	(T)	−0.00329	−0.00017	2.7552	0.1834	−0.0021	0.0827	−0.1347

W: Wide Angle Setting
L: Longitudinal Chromatic Aberration
M: Intermediate Setting
T: Transverse Chromatic Aberration
T: Telephoto Setting
SA: Spherical Aberration
CM: Coma
AS: Astigmatism
PT: Petzval Sum
DS: Distortion

EXAMPLE 3

F = 100–183 FNO = 1:3.5–4.5 2ω = 73.8°–44.4°

R1 = 374.93	D1 = 11.66	N1 = 1.60311	ν1 = 60.7		
R2 = −1407.76	D2 = 0.69				
R3 = 581.66	D3 = 4.98	N2 = 1.80610	ν2 = 40.9		
R4 = 61.37	D4 = 17.44				
R5 = 721.08	D5 = 4.39	N3 = 1.77250	ν3 = 49.6		
R6 = 123.67	D6 = 7.67				
R7 = 94.58	D7 = 11.69	N4 = 1.80518	ν4 = 25.4		
R8 = 368.29	D8 = Variable				
R9 = 231.88	D9 = 8.58	N5 = 1.57250	ν5 = 57.8		
R10 = −232.39	D10 = 6.90				
R11 = 62.52	D11 = 10.22	N6 = 1.71300	ν6 = 53.8		
R12 = 264.24	D12 = 13.95				
R13 = −175.13	D13 = 10.82	N7 = 1.84666	ν7 6 23.9		
R14 = 67.54	D14 = 3.82				
R15 = 3053.40	D15 = 6.11	N8 = 1.59551	ν2 = 39.2		
R16 = −264.50	D16 = 0.69				
R17 = 558.05	D17 = 9.17	N9 = 1.63636	ν9 = 35.4		
R18 = −78.28	D18 = Variable				
R19 = 137.93	D19 = 5.17	N10 = 1.48749	ν10 = 70.1		
R20 = 116.59					

f	100	138	183	f_I = −134.48
D8	73.17	30.36	2.57	f_{III} = −1679.4
D18	3.79	32.37	66.33	

EXAMPLE 4

F = 100–187.5 FNO = 1:3.5–4.5 2ω = 74.2°–43.6°

R1 = 179.97	D1 = 16.61	N1 = 1.60311	ν1 = 60.7		
R2 = 12603.22	D2 = 0.69				
R3 = 665.08	D3 = 5.01	N2 = R1 ν2 = 49.6			
D4 = 54.55	D4 = 19.70				
D5 = 6112.91	D5 = 4.42	N3 = 1.71300	ν3 = 53.8		
R6 = 143.50	D6 = 5.70				
R7 = 85.53	D7 = 11.12	N4 = 1.75520	ν4 = 27.5		
R8 = 232.34	D8 = Variable				
R9 = 231.21	D9 = 8.66	N5 = 1.60311	ν5 = 60.7		
R10 = −228.38	D10 = 6.74				
R11 = 62.02	D11 = 17.23	N6 = 1.69680	ν6 = 55.5		
R12 = 223.95	D12 = 8.08				
R13 = −154.30	D13 = 6.62	N7 = 1.80518	ν7 = 25.4		
R14 = 70.50	D14 = 4.06				
R15 = −428.90	D15 = 6.68	N8 = 1.58144	ν8 = 40.7		
R16 = −133.81	D16 = 0.67				
R17 = 998.25	D17 = 9.44	N9 = 1.60342	ν9 = 38.0		

EXAMPLE 4-continued

R18 = −77.29 D18 = Variable
R19 = 93.76 D19 = 5.21 N10 = 1.48749 ν10 = 70.1
R20 = 86.46

f	100	138.9	187.5	f_I = −128.0
D8	67.00	29.86	3.79	f_{III} = −2971.8
D18	3.82	35.17	74.35	

EXAMPLE 5

F = 100–183 FNO = 1:3.5–4.5 2ω = 73.8°–44.4°

R1 = 527.97 D1 = 10.61 = 1.60311 ν1 = 60.7
R2 = −835.09 D2 = 0.69
R3 = 834.67 D3 = 4.98 N2 = 1.80610 ν2 = 40.9
R4 = 62.46 D4 = 17.27
R5 = 664.30 D5 = 4.39 N3 = 1.80400 ν3 = 46.6
R6 = 117.47 D6 = 6.79
R7 = 94.41 D7 = 12.65 N4 = 1.80518 ν4 = 25.4
R8 = 557.13 D9 = Variable
R9 = 233.32 D9 = 8.37 N5 = 1.62280 ν5 = 57.0
R10 = −266.37 D10 = 7.94
R11 = 68.97 D11 = 10.57 N6 = 1.71300 ν6 = 53.8
R12 = 265.65 D12 = 0.52
R13 = 134.55 D13 = 9.15 N7 = 1.56732 ν7 = 42.8
R14 = 268.61 D14 = 4.89
R15 = −172.48 D15 = 13.01 N8 = 1.84666 ν8 = 23.9
R16 = 65.89 D16 = 6.70
R17 = 382.00 D17 = 10.99 N9 = 1.62004 ν9 = 36.3
R18 = −68.01 D18 = Variable
R19 = 137.93 D19 = 5.17 N10 = 1.48749 ν10 = 70.1
R20 = 113.60

f	100	137.9	183	f_I = −134.46
D8	74.17	31.16	3.24	f_{III} = −1419.97
D18	3.79	31.77	65.02	

EXAMPLE 6

F = 100–189 FNO = 1:4–4.5 2ω = 62°–35.3°

R1 = 84.825 D1 = 4.17 N1 = 1.69680 ν1 = 55.5
R2 = 42.356 D2 = 14.77
R3 = −269.874 D3 = 3.33 N2 = 1.69680 ν2 = 55.5
R4 = 253.751 D4 = 1.20
R5 = 64.681 D5 = 5.18 N3 = 1.64769 ν3 = 33.8
R6 = 146.374 D6 = Variable
R7 = 82.793 D7 = 8.55 N4 = 1.65844 ν4 = 50.9
R8 = −254.758 D8 = 0.42
R9 = 51.671 D9 = 8.70 N5 = 1.66892 ν5 = 45.0
R10 = 228.819 D10 = 5.80
R11 = −292.325 D11 = 10.01 N6 = 1.84666 ν6 = 23.9
R12 = 43.462 D12 = 12.27
R13 = 364.553 D13 = 7.56 N7 = 1.63636 ν7 = 35.4
R14 = −74.877 D14 = Variable
R15 = −658.084 D15 = 2.78 N8 = 1.60311 ν8 = 60.7
R16 = 98.754 D16 = 1.04
R17 = 113.422 D17 = 8.33 N9 = 1.57099 ν9 = 50.8
R18 = −4278.609

f	100	150	189	f_I = −133.33
D6	71.8061	24.8926	5.6103	f_{III} = −549.96
D14	4.1667	31.0787	51.9624	

EXAMPLE 7

F = 100–189 FNO = 1:4–4.5 2ω = 62°–35.3°

R1 = 85.496 D1 = 4.17 N1 = 1.69680 ν1 = 55.5
R2 = 44.543 D2 = 19.14
R3 = −244.153 D3 = 3.33 N2 = 1.69680 ν2 = 55.5
R4 = 395.064 D4 = 0.16
R5 = 66.007 D5 = 5.82 N3 = 1.75520 ν3 = 27.5
R6 = 105.219 D6 = Variable
R7 = 75.991 D7 = 8.31 N4 = 1.62299 ν4 = 58.2
R8 = −341.577 D8 = 5.56
R9 = 54.235 D9 = 5.08 N5 = 1.67003 ν5 = 47.3
R10 = 98.156 D10 = 0.42
R11 = 58.163 D11 = 4.28 N6 = 1.51742 ν6 = 52.4
R12 = 114.480 D12 = 3.52

EXAMPLE 7-continued

R13 = −772.289 D13 = 7.02 N7 = 1.84666 ν7 = 23.9
R14 = 42.489 D14 = 13.62
R15 = 221.276 D15 = 6.12 N8 = 1.68893 ν8 = 31.1
R16 = −94.558 D16 = Variable
R17 = 833.334 D17 = 2.78 N9 = 1.58913 ν9 = 61.0
R18 = 91.667 D18 = 2.22
R19 = 112.083 D19 = 8.33 N10 = 1.56883 ν10 = 56.3
R20 = −277.778 D20 = 2.78 N11 = 1.58267 ν11 = 46.4
R21 = 464.309

f	100	150	189	f_I = −133.33
D6	68.2795	21.3655	2.0831	f_{III} = −525.25
D16	4.1667	31.0781	51.9614	

EXAMPLE 8

F = 100–282.8 FNO = 1:4 2ω = 74.2°–29.6°

R1 = 493.48 D1 = 22.60 N1 = 1.58913 ν1 = 61.0
R2 = 43207.35 D2 = 0.56
R3 = 271.10 D3 = 7.23 N2 = 1.80400 ν2 = 46.6
R4 = 83.08 D4 = 36.24
R5 = 1141.79 D5 = 20.35 N3 = 1.63636 ν3 = 35.4
R6 = −169.91 D6 = 5.28 N4 = 1.81600 ν4 = 46.6
R7 = 348.65 D7 = 8.15
R8 = 134.93 D8 = 11.19 N5 = 1.84666 ν5 = 23.9
R9 = 216.32 D9 = Variable
R10 = 193.19 D10 = 9.57 N6 = 1.65160 ν6 = 58.6
R11 = −2225.65 D11 = 9.47
R12 = 104.05 D12 = 14.53 N7 = 1.65160 ν7 = 58.6
R13 = 300.97 D13 = 0.56
R14 = 101.53 D14 = 15.09 N8 = 1.65160 ν8 = 58.6
R15 = 286.37 D15 = 4.50
R16 = −13040.32 D16 = 13.16 N9 = 1.84666 ν9 = 23.9
R17 = −295.65 D17 = 5.62 N10 = 1.80518 ν10 = 25.4
R18 = 64.59 D18 = 10.12
R19 = 443.95 D19 = 11.21 N11 = 1.74950 ν11 = 35.3
R20 = −197.19 D20 = Variable
R21 = −224.63 D21 = 4.88 N12 = 1.80400 ν12 = 46.6
R22 = −925.08 D22 = 17.63 N13 = 1.57501 ν13 = 41.5
R23 = −166.38

f	100	189.7	282.8	f_I = −175.04
D9	162.172	46.79	4.415	f_{II} = 137.94
D20	13.745	83.638	156.22	f_{III} = 3461.5

EXAMPLE 9

F = 100–282.8 FNO = 1:4 2ω = 74.4°–29.4°

R1 = 454.86 D1 = 17.61 N1 = 1.58913 ν1 = 61.0
R2 = ∞ D2 = 0.52
R3 = 258.52 D3 = 6.65 N2 = 1.80400 ν2 = 46.6
R4 = 77.29 D4 = 30.08
R5 = 1060.71 D5 = 18.75 N3 = 1.63636 ν3 = 35.4
R6 = −209.21 D6 = 1.72
R7 = 181.99 D7 = 4.86 N4 = 1.81600 ν4 = 46.6
R8 = 315.91 D8 = 6.32
R9 = 130.35 D9 = 10.20 N5 = 1.84666 ν5 = 23.9
R10 = 237.08 D10 = Variable
R11 = 172.07 D11 = 12.40 N6 = 1.65160 ν6 = 58.6
R12 = −2054.55 D12 = 8.41
R13 = 95.77 D13 = 13.37 N7 = 1.65160 ν7 = 58.6
R14 = 258.71 D14 = 0.52
R15 = 93.62 D15 = 13.89 N8 = 1.65160 ν8 = 58.6
R16 = 274.40 D16 = 4.03
R17 = −15615.92 D17 = 11.78 N9 = 1.84666 ν9 = 23.9
R18 = −311.75 D18 = 5.17 N10 = 1.80518 ν10 = 25.4
R19 = 59.55 D19 = 10.65
R20 = 376.39 D20 = 11.37 N11 = 1.74950 ν11 = 35.3
R21 = −183.24 D21 = Variable
R22 = −157.12 D22 = 4.48 N12 = 1.81600 ν12 = 46.6
R23 = −2321.56 D23 = 13.89 N13 = ν13 = 40.7

EXAMPLE 9-continued

			1.58144		
R24 = −128.98					
f	100	189.7	282.8	f_I =	−161.1
D10	148.058	41.857	2.854	f_{II} =	127.
D21	12.651	76.983	143.79	f_{III} =	−3089.

TABLE 2

		Seidel's 3rd Order Aberration Coefficients						
		L	T	SA	CM	AS	PT	DS
1st	(W)	0.00106	0.00342	−0.1799	0.1869	−0.1371	−0.3309	0.5066
Lens	(M)	0.00380	0.00372	−2.3269	0.4908	−0.0464	−0.3309	0.0941
Group	(T)	0.00845	0.00390	−11.4974	0.8476	−0.0053	−0.3309	0.0337
2nd	(W)	0.00493	−0.00386	2.1780	−0.1784	0.2142	0.3852	−0.1630
Lens	(M)	0.00009	−0.00465	6.7741	−0.3345	0.0565	0.3852	−0.0950
Group	(T)	−0.00986	−0.00512	13.6937	−0.9185	−0.0447	0.3852	−0.0610
3rd	(W)	−0.00147	0.00161	−0.6479	0.3381	−0.0551	0.0026	−0.0014
Lens	(M)	−0.00147	0.00144	−0.6479	0.2609	0.0162	0.0026	−0.0075
Group	(T)	−0.00147	0.00133	−0.6479	0.2144	0.0504	0.0026	0.0000
1st +	(W)	0.00599	−0.00044	1.9981	0.0085	0.0770	0.0543	0.3436
2nd	(M)	0.00389	−0.00093	4.4472	0.1563	0.0102	0.0543	−0.0008
Groups	(T)	−0.00141	−0.00122	2.1963	−0.0709	−0.0500	0.0543	−0.0272
	(W)	0.00451	0.00117	1.3502	0.3466	0.0219	0.0569	0.3422
Total	(M)	0.00242	0.00051	3.7993	0.4173	0.0264	0.0569	−0.0083
Sum	(T)	−0.00289	0.00011	1.5484	0.1435	0.0004	0.0569	−0.0272

What I claim is:

1. A wide angle zoom objective of reduced size comprising:
- a first lens unit, a second lens unit, and a third lens unit arranged from the object side;
- said first lens unit being divergent, said second lens unit being convergent, and said third lens unit being stationary during zooming; and
- a diaphragm for controlling a light flux passing through the zoom objective,
- said first lens unit and said second lens unit moving for zooming along the optical axis and said diaphragm being associated with said second lens unit.

2. A wide angle zoom objective of reduced size according to claim 1, wherein said 3rd lens unit is a diverging lens unit.

3. A wide angle zoom objective of reduced size according to claim 2, wherein letting f_{III} denote the focal length of said 3rd lens unit and f_T the longest focal length of the entire lens system, we have

$$|f_{III}| \geqq f_T.$$

4. A wide angle zoom objective of reduced size according to claim 3, wherein letting f_I denote the focal length of said 1st lens unit, we have

$$|f_I| \leqq f_T.$$

5. A wide angle zoom objective of reduced size according to claim 4 wherein said 3rd lens unit comprises a meniscus-shaped lens of negative refractive power concave toward the rear.

6. A wide angle zoom objective of reduced size according to claim 4, wherein said 3rd lens unit has at least one positive lens and at least one negative lens, and the following condition is satisfied:

$$0.04 \leqq t/f_T \leqq 0.25$$

where t is the thickness from the front-most lens surface of the third lens unit to the rear-most lens surface.

7. A wide angle zoom objective according to claim 4, wherein
- said 1st lens unit comprises, from front to rear,
- a meniscus-shaped lens of negative refractive power convex toward the front,
- a bi-concave lens of negative refractive power, and
- a meniscus-shaped lens of positive refractive power convex toward the front.

8. A wide angle zoom objective according to claim 4, wherein
- said 1st lens unit comprises, from front to rear,
- a lens of positive refractive power,
- a meniscus-shaped lens of negative refractive power concave toward the rear,
- a lens of negative refractive power with its rear lens surface having a stronger refractive power, and
- a lens of positive refractive power with its front lens surface having a stronger refractive power.

9. A wide angle zoom objective according to claim 1, wherein
- said 3rd lens unit has at least one negative lens and at least one positive lens; and
- letting f_{III} denote the focal length of said 3rd lens unit, and fw the shortest focal length of the entire lens system,
- the following condition is satisfied:

$$-0.3/fw < 1/f_{III} < 0.2/fw.$$

10. A wide angle zoom objective of reduced size according to claim 9, wherein
- said negative lens and said positive lens are cemented together to form a meniscus-shaped doublet convex toward the rear; and
- the refractive index of the glass of said negative lens is higher than that of the glass of said positive lens.

11. A wide angle zoom objective of reduced size according to claim 10, wherein
- letting f_I denote the focal length of said 1st lens unit, and f_T the longest focal length of the entire lens system,
- the following condition is satisfied:

$$|f_I| \leqq f_T.$$

12. A wide angle zoom objective according to claim 1, in which the first lens unit occupies a position closer to the image when it is at the telescope end of zooming than when it is at the wide angle end.

13. A wide angle zoom objective of reduced size comprising:

a first lens unit, a second lens unit, and a third lens unit arranged from the object side;

said first lens unit being divergent, said second lens unit being convergent, and said third lens unit being stationary during zooming; and

letting f_I denote the focal length of said first lens unit and f_T the longest focal length of the entire lens system, the following condition is satisfied:

$$|f_I| \leqq f_T.$$

14. A wide angle zoom objective of reduced size comprising:

a first lens unit, a second lens unit, and a third lens unit arranged from the object side;

said first lens unit being divergent, said second lens unit being convergent, and said third lens unit being stationary during zooming; and

the following condition is satisfied:

$$0.04 \leqq t/f_T \leqq 0.25$$

where t is the thickness from the front-most lens surface of the third lens unit to the rear-most lens surface.

15. A wide angle zoom objective of reduced size according to claim **14**, wherein said third lens unit has at least one positive lens and at least one negative lens.

16. A wide angle zoom objective of reduced size comprising:

a first lens unit, a second lens unit, and a third lens unit arranged from the object side;

said first lens unit being divergent, said second lens unit being convergent, and said third lens unit being stationary during zooming and being composed of a single lens.

17. A wide angle zoom objective or reduced size comprising:

a first lens unit, a second lens unit, and a third lens unit arranged from the object side;

said first lens unit being divergent, said second lens unit being convergent, and said third lens unit being stationary during zooming and being composed of a cemented lens.

18. A wide angle zoom objective of reduced size comprising:

a first lens unit, a second lens unit, and a third lens unit arranged from the object side;

said first lens unit being divergent, said second lens unit being convergent, and said third lens unit being stationary during zooming and being composed of a negative single lens, and a positive single lens, separated by air from said negative lens.

19. A wide angle zoom objective of reduced size comprising:

a first lens unit, a second lens unit, and a third lens unit arranged from the object side;

said first lens unit being divergent, said second lens unit being convergent, and said third lens unit being stationary during zooming and being composed of a single lens and a cemented lens separated by airs from said single lens.

* * * * *

United States Patent [19]

Nakai et al.

[11] **Patent Number: 4,639,112**

[45] **Date of Patent: * Jan. 27, 1987**

[54] **CAMERA SYSTEM CAPABLE OF INTERCHANGING ITS OBJECTIVE LENS**

[75] Inventors: **Masaaki Nakai**, Nara; **Masayoshi Sahara**, Sennan; **Nobuyuki Taniguchi**, Tondabayashi; Toshihiko Ishimura, Habikino; all of Japan

[73] Assignee: **Minolta Camera Kabushiki Kaisha**, Osaka, Japan

[*] Notice: The portion of the term of this patent subsequent to Oct. 16, 2001 has been disclaimed.

[21] Appl. No.: **632,405**

[22] Filed: **Jul. 19, 1984**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 478,910, Mar. 25, 1983, Pat. No. 4,560,267.

[30] **Foreign Application Priority Data**

Mar. 26, 1982	[JP]	Japan	57-49768
Mar. 30, 1982	[JP]	Japan	57-52740
Apr. 1, 1982	[JP]	Japan	57-55187
Nov. 5, 1982	[JP]	Japan	57-194968
Apr. 26, 1984	[JP]	Japan	59-85599

[51] **Int. Cl.**[4] **G03B 7/20**; G03B 7/26

[52] **U.S. Cl.** **354/455**; 354/286; 354/484

[58] **Field of Search** 354/441–443, 354/445, 455, 484, 271.1, 286, 289.12

[56] **References Cited**

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FOREIGN PATENT DOCUMENTS

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Primary Examiner—William B. Perkey
Attorney, Agent, or Firm—Price, Gess & Ubell

[57] **ABSTRACT**

A camera system comprising a camera body and an interchangeable lens assembly adapted to be coupled to the camera body. The interchangeable lens assembly has no manipulatable aperture adjusting ring, but has an aperture mechanism and a read-only memory both built therein. The read-only memory stores therein various data peculiar to such lens assembly. The camera body communicates with and power the lens assembly through a set of terminals connectable with associated terminals provided in the lens assembly. The terminals in each of the camera body and lens assembly are arranged in a generally arcuate row with the data transmitting terminal located at one extremity of the arcuate row on the leading side with respect to the direction of turn of the lens assembly which is effected when the lens assembly is to be completely coupled to the camera body.

4 Claims, 11 Drawing Figures

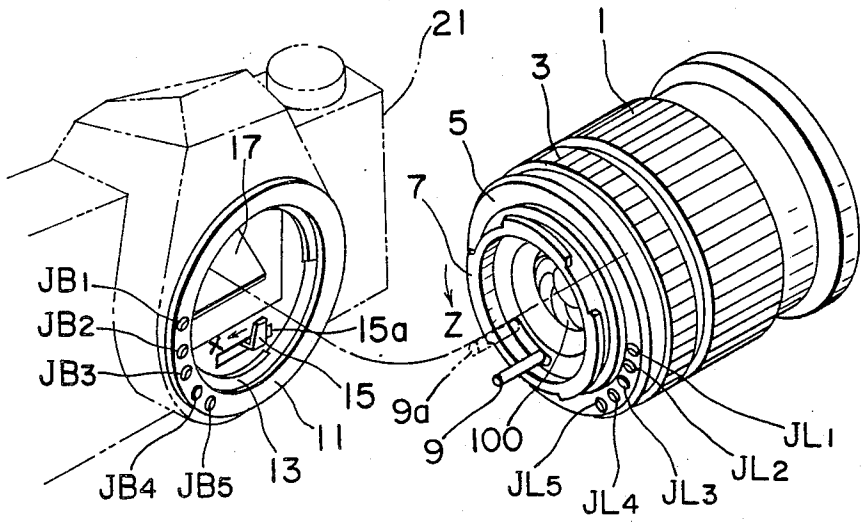

Fig. 1

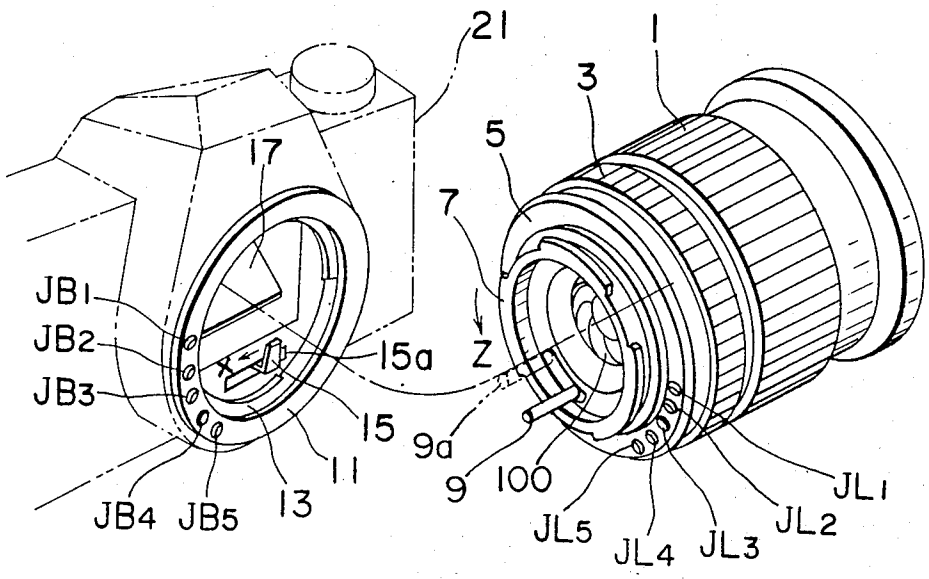
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Fig. 2

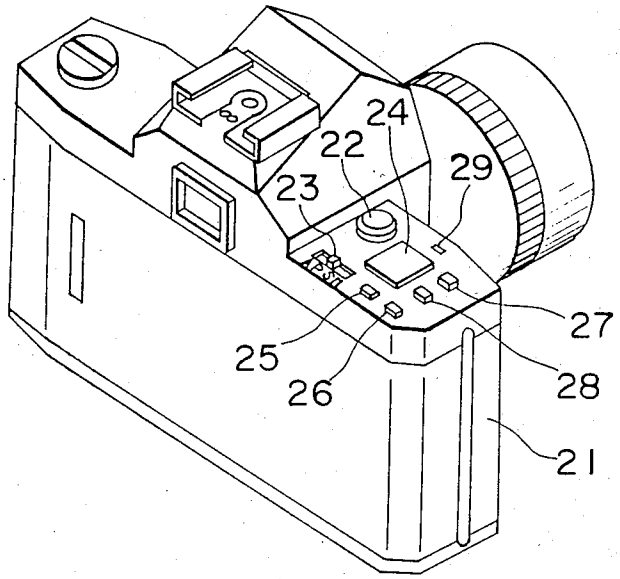
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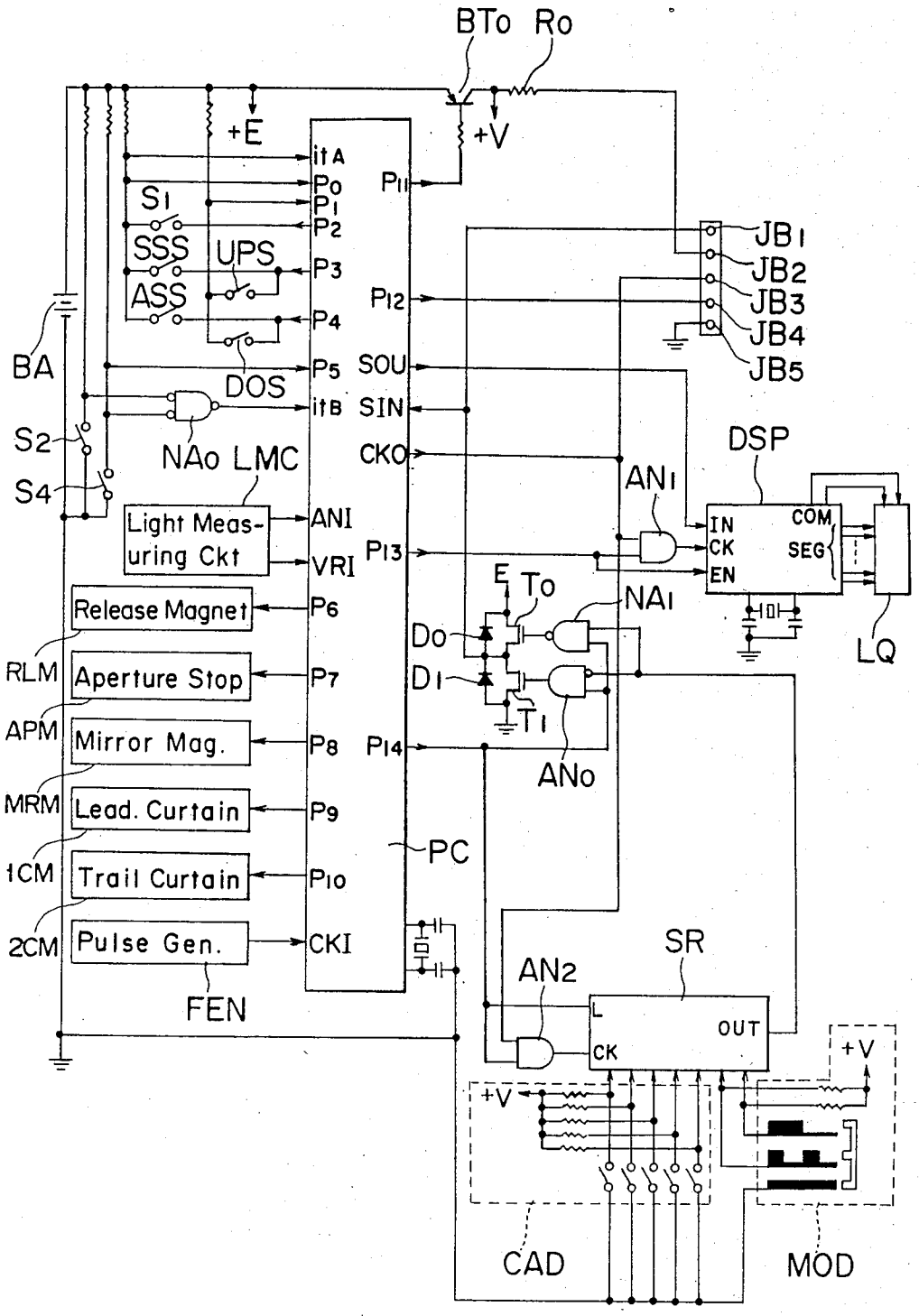
Fig. 3(a)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ANI
VRI
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Aperture Stop
Mirror Mag.
Lead. Curtain
Trail Curtain
Pulse Gen.
FEN
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APM
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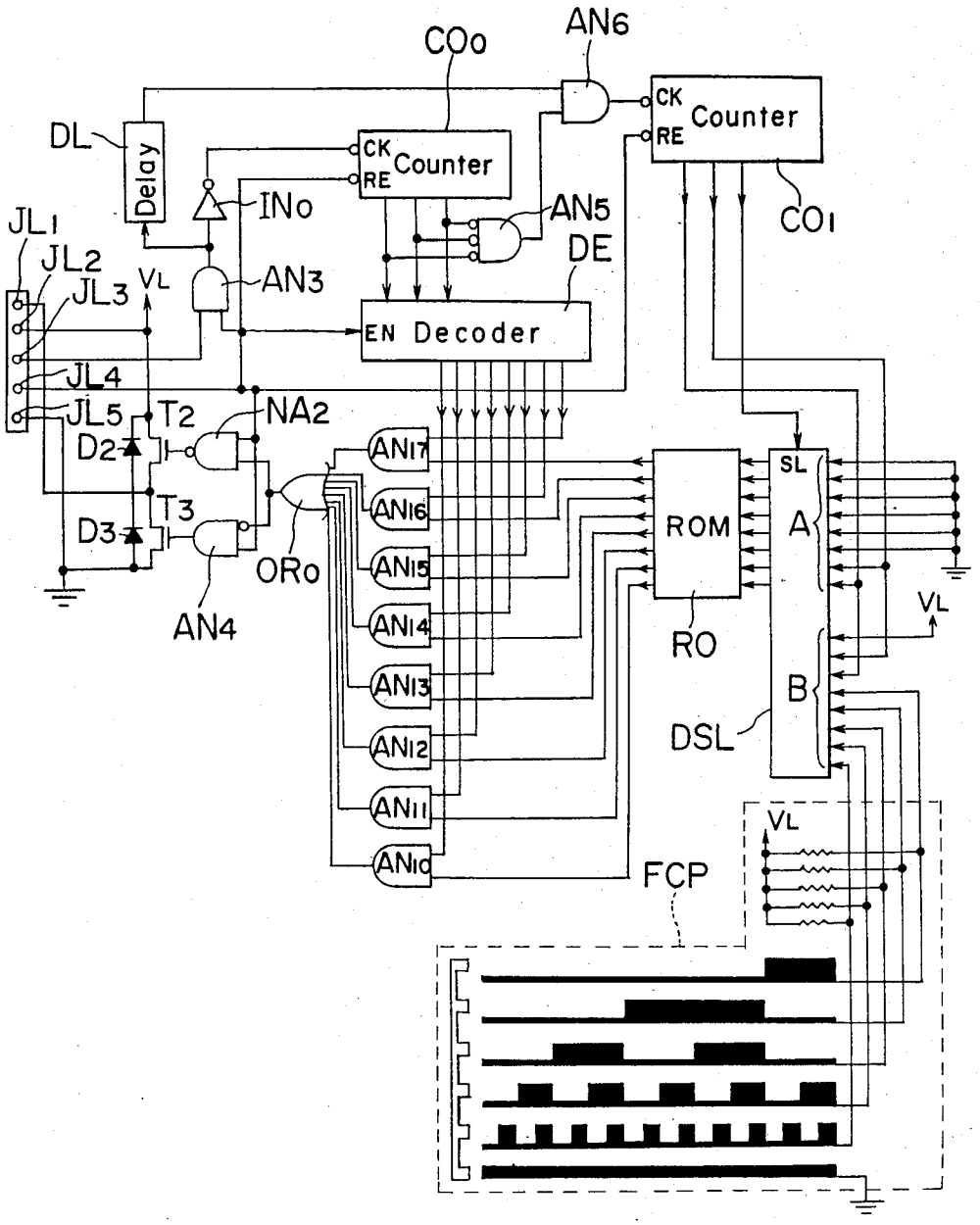
Fig. 3(b)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D3
ORo
AN4
ANi7
ANi6
ANi5
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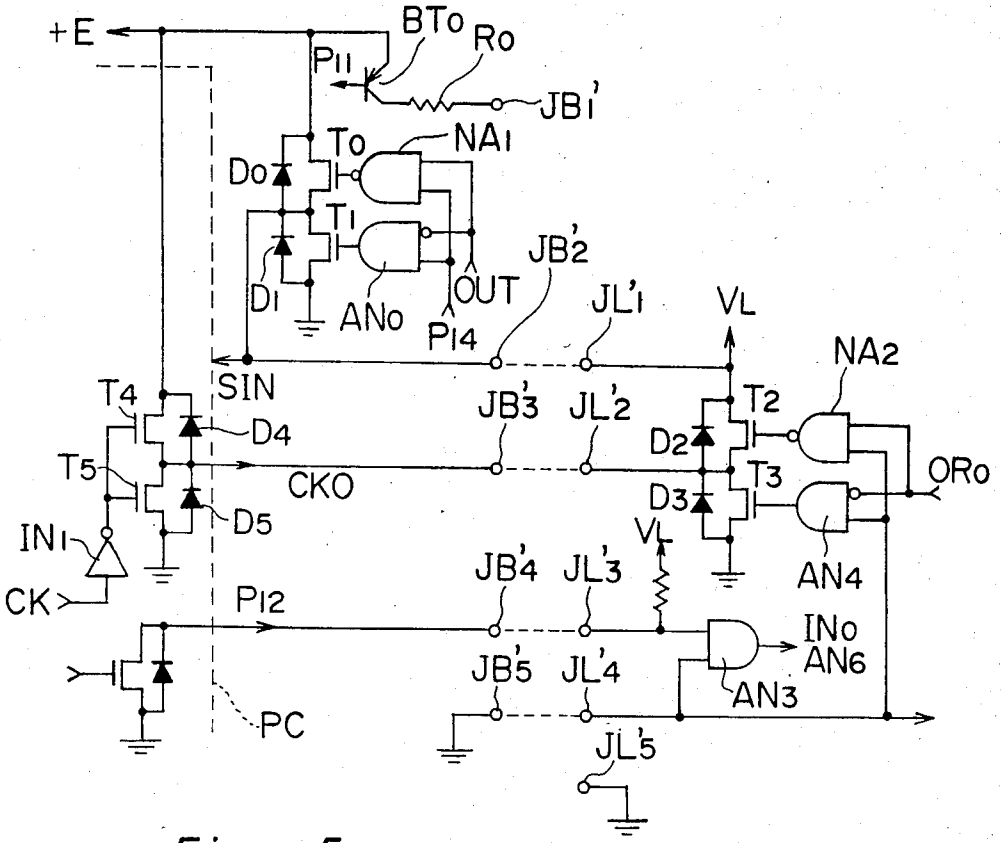
Fig. 4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D2
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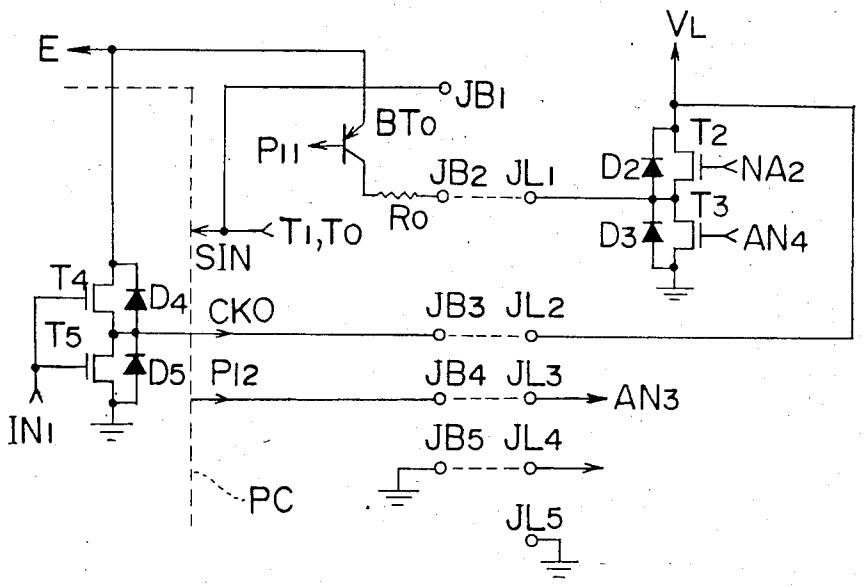
Fig. 5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CKO
JB3
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AN3
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JB5
JL4
PC
JL5

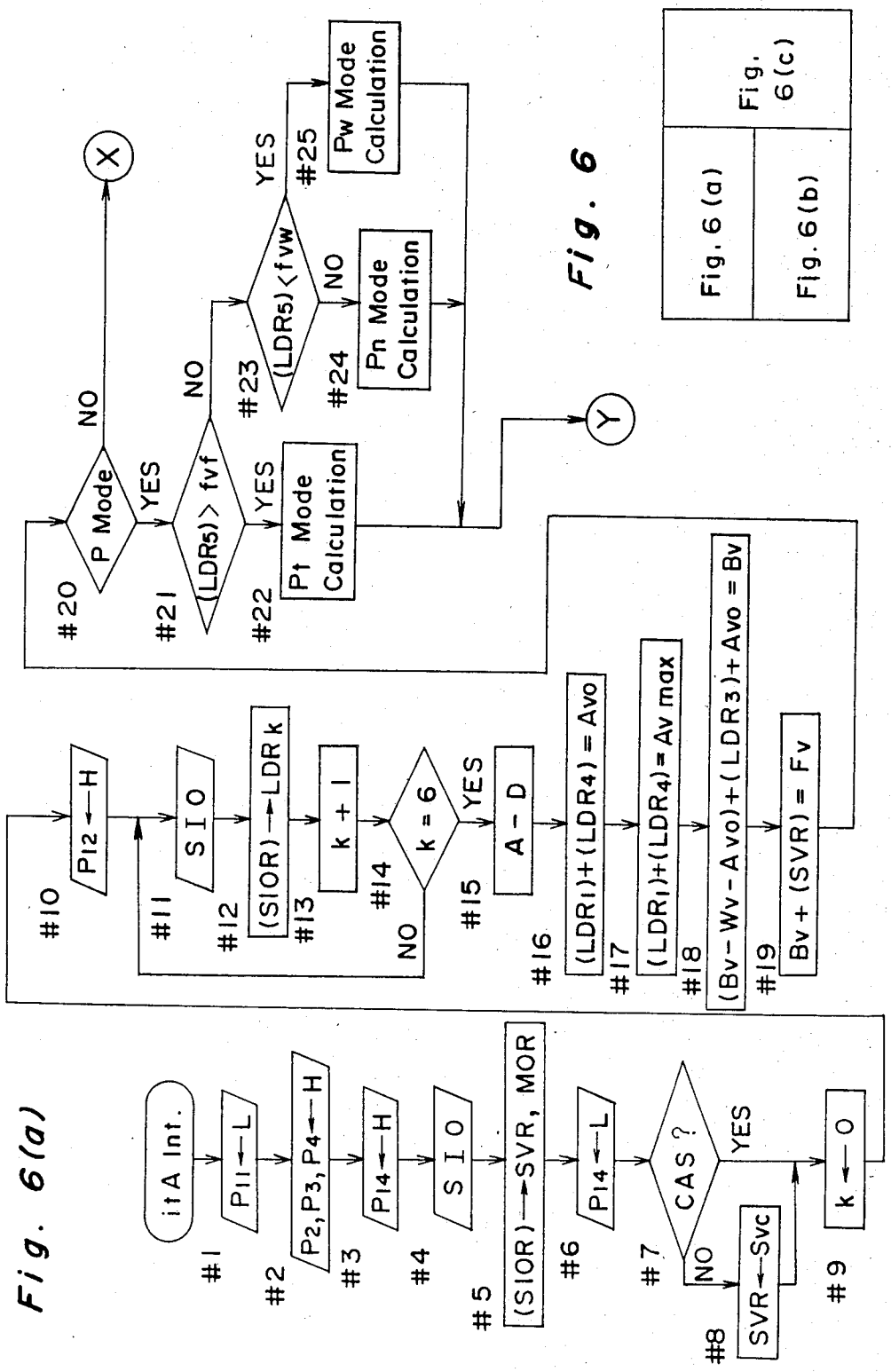

itA Int.
#1
P11←L
#2
P2, P3, P4←H
#3
P14←H
#4
S I O
#5
(SIOR)←SVR, MOR
#6
P14←L
#7
CAS ?
YES
NO
#8
SVR←Svc
#9
k←0
#10
P12←H
#11
S I O
#12
(SIOR)←LDR k
#13
k + 1
#14
k = 6
YES
NO
#15
A - D
#16
(LDR1)+(LDR4) = Avo
#17
(LDR1)+(LDR4) = Av max
#18
(Bv-Wv-Avo)+(LDR3)+Avo = Bv
#19
Bv + (SVR) = Fv
#20
P Mode
YES
NO
#21
(LDR5) > fvf
YES
NO
#22
Pt Mode Calculation
#23
(LDR5) < fvw
YES
NO
#24
Pn Mode Calculation
#25
Pw Mode Calculation
X
Y

Fig. 6(a)

Fig. 6(a)
Fig. 6(b)
Fig. 6(c)

Fig. 6

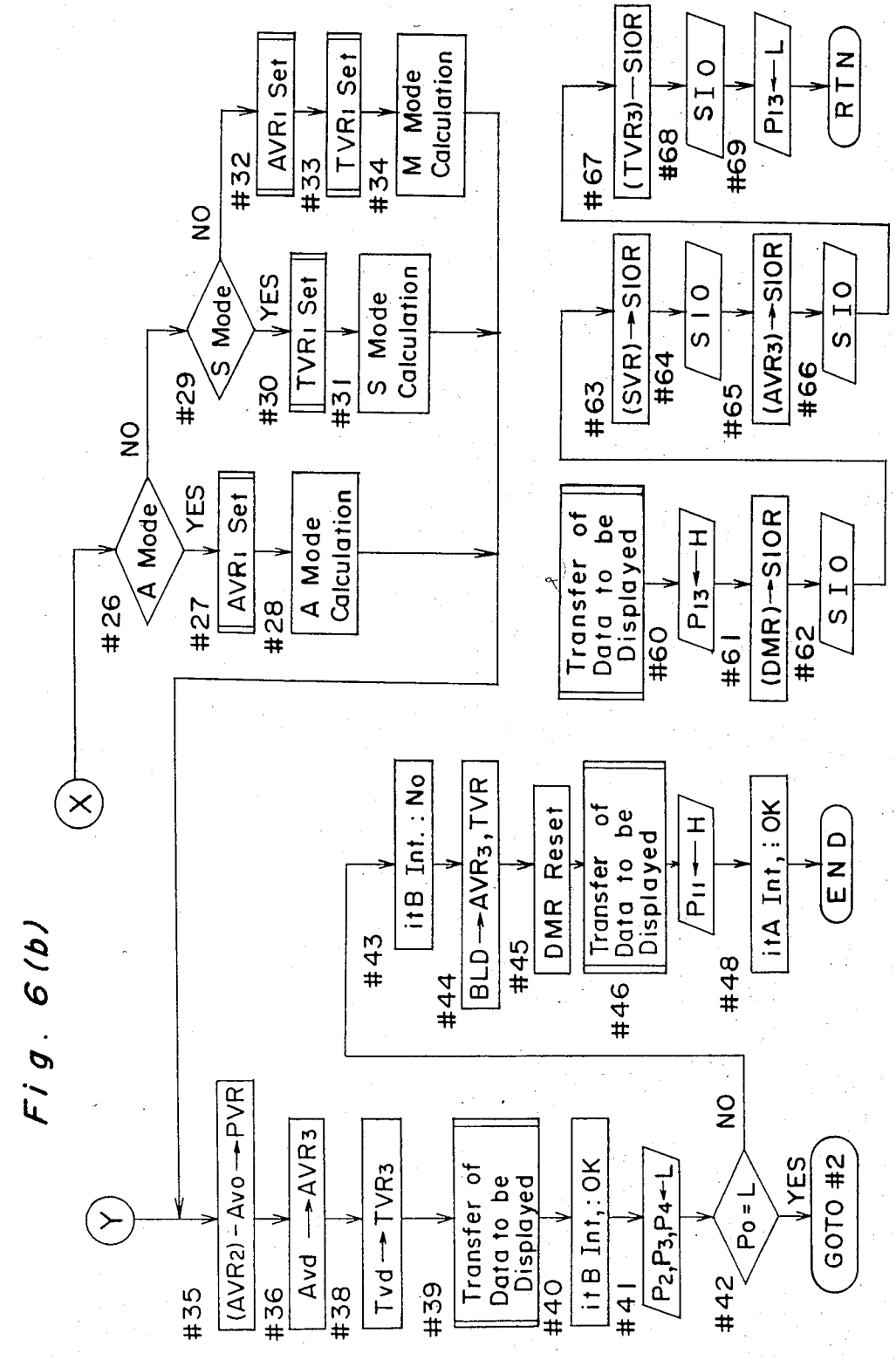

X
#26
A Mode
NO
YES
#27
AVR1 Set
#28
A Mode Calculation
#29
S Mode
NO
YES
#30
TVR1 Set
#31
S Mode Calculation
#32
AVR1 Set
#33
TVR1 Set
#34
M Mode Calculation
Transfer of Data to be Displayed
#60
P13←H
#61
(DMR)→SIOR
#62
SIO
#63
(SVR)→SIOR
#64
SIO
#65
(AVR3)→SIOR
#66
SIO
#67
(TVR3)→SIOR
#68
SIO
#69
P13←L
RTN
Y
#35
(AVR2)-Avo→PVR
#36
Avd →AVR3
#38
Tvd→TVR3
#39
Transfer of Data to be Displayed
#40
itB Int.: OK
#41
P2,P3,P4←L
#42
Po=L
NO
YES
GOTO #2
#43
itB Int.: No
#44
BLD→AVR3,TVR
#45
DMR Reset
#46
Transfer of Data to be Displayed
P11←H
#48
itA Int.: OK
END

Fig. 6(b)

Fig. 6(c)

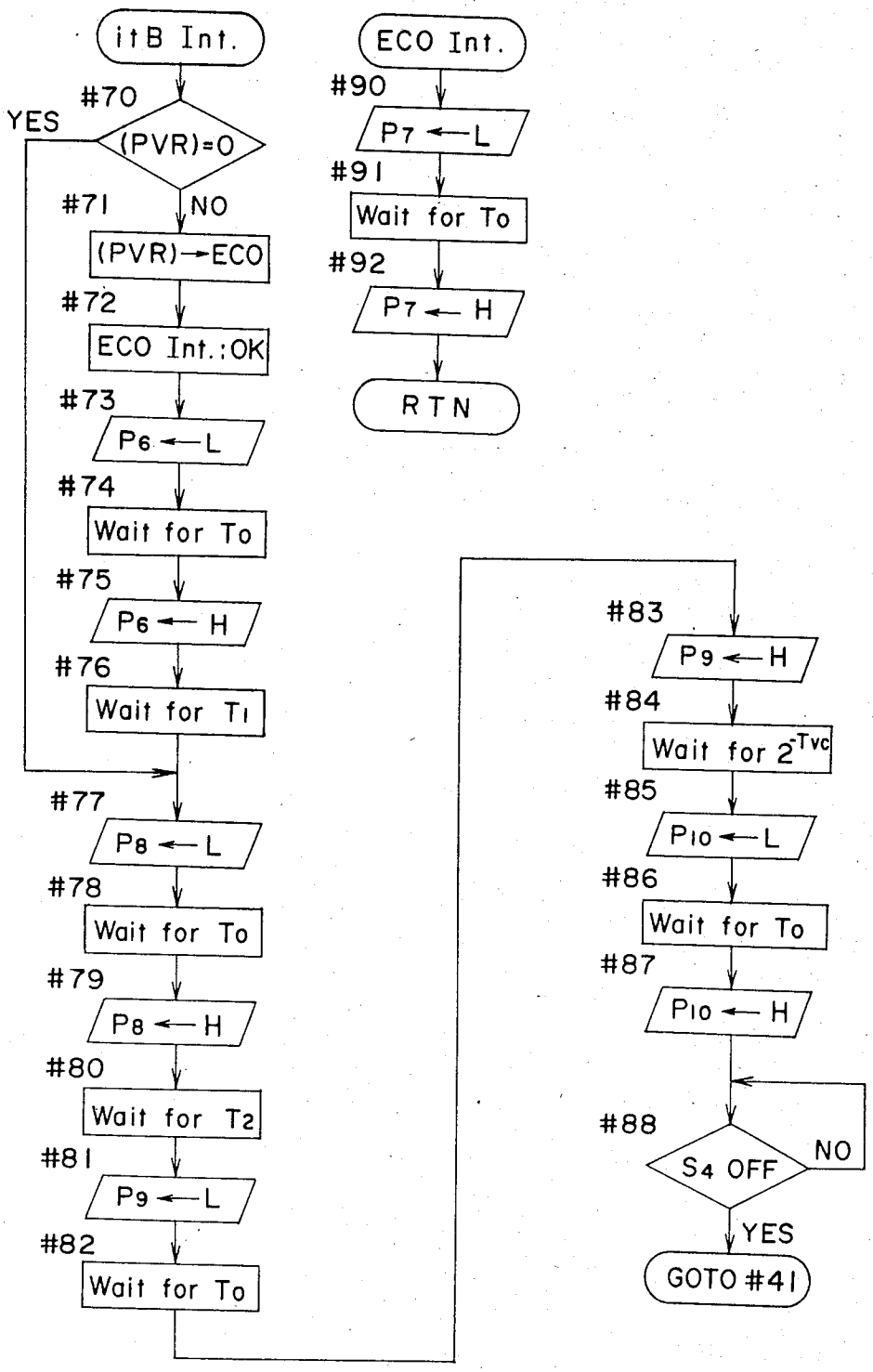
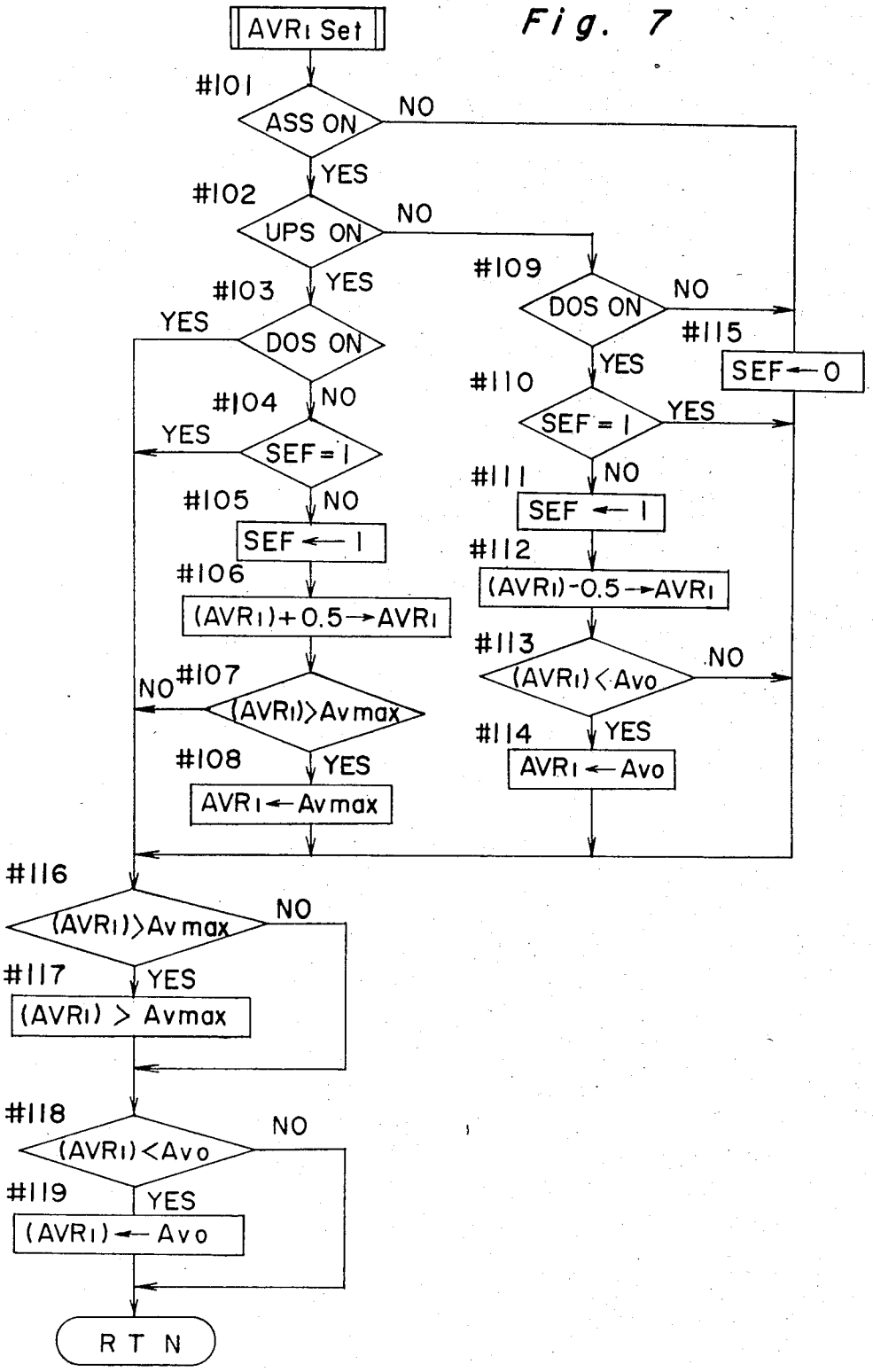

itB Int.
#70
YES
(PVR)=0
#71
NO
(PVR)→ECO
#72
ECO Int.:OK
#73
P6 ← L
#74
Wait for To
#75
P6 ← H
#76
Wait for T1
#77
P8 ← L
#78
Wait for To
#79
P8 ← H
#80
Wait for T2
#81
P9 ← L
#82
Wait for To
ECO Int.
#90
P7 ← L
#91
Wait for To
#92
P7 ← H
RTN
#83
P9 ← H
#84
Wait for 2^-Tvc
#85
P10 ← L
#86
Wait for To
#87
P10 ← H
#88
S4 OFF
NO
YES
GOTO #41

Fig. 7


AVR1 Set
#101
ASS ON
NO
YES
#102
UPS ON
NO
YES
#103
DOS ON
YES
NO
#104
SEF=1
YES
NO
#105
SEF ← 1
#106
(AVR1)+0.5→AVR1
#107
(AVR1)>Avmax
NO
YES
#108
AVR1←Avmax
#109
DOS ON
NO
YES
#110
SEF=1
YES
NO
#111
SEF ← 1
#112
(AVR1)-0.5→AVR1
#113
(AVR1)<Avo
NO
YES
#114
AVR1←Avo
#115
SEF←0
#116
(AVR1)>Avmax
NO
YES
#117
(AVR1) > Avmax
#118
(AVR1)<Avo
NO
YES
#119
(AVR1)←Avo
RTN

CAMERA SYSTEM CAPABLE OF INTERCHANGING ITS OBJECTIVE LENS

This is a continuation-in-part application of U.S. application Ser. No. 478,910, filed Mar. 25, 1983, Pat. No. 4,560,267, issued Dec. 24, 1985.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention generally relates to a photographic camera system utilizing interchangeable objective lens assemblies one at a time and, more particularly, to an improvement in coordination between the camera body and the interchangeable objective lens assembly then coupled thereto.

2. Description of the Prior Art

In a photographic camera system utilizable with interchangeable objective lens assemblies one at a time, one of the most important coordinations between the camera body and the lens assembly then coupled thereto lies in the manual aperture setting required to be performed at the time of manual exposure control, automatic exposure control under the aperture-priority mode, or the like. As is well known to those skilled in the art, interchangeable lens assemblies generally have a manipulatable aperture adjustment such as an aperture setting ring mounted exteriorly on the lens barrel for the access to a photographer.

On the other hand, there is also known a photographic camera system wherein the aperture adjustment is not provided on an interchangeable lens assembly, but on the body of a photographic camera so that the setting of the aperture adjustment can be transmitted to the lens assembly to control the aperture in such lens assembly. In this camera system, since the available aperture range, i.e., the available range from the maximum settable aperture (the smallest available f-stop number) to the minimum settable aperture (the largest available f-stop number), varies from one interchangeable lens assembly to another, a mechanism comprising a mechanical signaling element, provided in any one of the interchangeable lens assemblies and indicating the aperture range available in the respective lens assembly, and an engagement element provided in the camera body for engagement with the signaling element is employed to inhibit the aperture adjustment in the camera body to set the aperture of a value outside the available aperture range.

In either of the above described camera systems, there are many limitations and/or requirements imposed on the manufacture of the interchangeable lens assemblies such as, for example, a space for accommodating an arrangement necessary to permit the aperture setting ring to rotate, a precise arrangement of both the signaling element and the engagement element, the precise machining of the associated component parts and so on. These limitations and/or requirements often render the camera system as a whole to be complicated and expensive.

Another one of the most important coordinations between the camera body and the lens assembly lies in the transmission of various electric signals therebetween. Numerous techniques and arrangements have hitherto been utilized for transmitting electric signals through terminals between the camera body and the lens assembly. As is well known to those skilled in the art, the utmost care is required to permit the electric signals to be correctly transmitted between the camera body and the lens assembly and, therefore, an improvement has long been desired to avoid any possible inadvertent transmission of one or more of the electric signals from the camera body to the lens assembly or from the lens assembly to the camera body which would result in the erroneous operation of the camera.

SUMMARY OF THE INVENTION

An essential object of the present invention is to improve the conventional camera utilizing an interchangeable lens assembly to permit the camera system as a whole to be reasonably constructed and also to simplify the interchangeable lens assembly.

Another important object of the present invention is to provide an improved camera system wherein the manipulatable aperture adjustment is not provided on the interchangeable lens assembly, but on the body of a camera to permit the setting of the aperture of the lens assembly to be carried out on the side of the camera body.

A further object of the present invention is to provide an improved interchangeable lens assembly having its utility in the camera system of the type referred to above.

A still further object of the present invention is to improve the system so as to avoid the possibility that the camera body may process erroneous information in the event of the incorrect mounting of the lens assembly to the camera body.

A yet further object of the present invention is to provide an improved interchangeable lens assembly having its utility in the system of the type referred to in the preceding paragraph.

The present invention provides a camera system that includes a compatible camera body and interchangeable lens assembly particularly adaptable for automatic focusing. The camera body has a series of terminals for providing electrical power, enabling signals and clock signals plus the ability to receive information from the interchangeable lens assembly. The interchangeable lens assembly has complementary terminals and can have the ability to store various data peculiar to the specific lens assembly such as aperture size.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other objects and features of the present invention will be readily understood by those skilled in the art upon the reading of the following description taken in conjunction with a preferred embodiment with reference to the accompanying drawings, in which:

FIG. **1** is a perspective view showing an essential portion of the camera with an interchangeable lens assembly shown as separated therefrom;

FIG. **2** is a perspective view of the camera of FIG. **1** as viewed from a different direction;

FIG. **3**(*a*) is a circuit diagram showing an electric circuit incorporated in the camera body according to the present invention;

FIG. **3**(*b*) is a circuit diagram showing an electric circuit incorporated in the lens assembly according to the present invention;

FIG. **4** is a circuit diagram showing an essential portion of a circuit shown for the purpose of comparison with the operation of the embodiment in FIGS. **3**(*a*) and **3**(*b*) according to the present invention;

FIG. **5** is a circuit diagram showing an essential portion of the embodiment in FIGS. **3**(*a*) and **3**(*b*) accord-

ing to the present invention, shown for the purpose of comparison with the circuit of FIG. 4;

FIG. 6 comprises FIGS. 6(*a*) to 6(*c*) and altogether shows a flow chart of the sequence of operation of the camera system according to the present invention; and

FIG. 7 is a flow chart showing a subroutine executed during the process flow of FIG. 6.

DETAILED DESCRIPTION OF THE EMBODIMENT

Before the description of the present invention proceeds, it is to be noted that like parts are designated by like reference numerals throughout the accompanying drawings.

Referring first to FIG. 1 showing a combination of an interchangeable zoom lens assembly and the body of a photographic camera utilizable with the zoom lens assembly, the zoom lens assembly includes a distance setting ring 1 for setting the camera-to-object distance, and a zooming ring 3 for the adjustment of the focal length of the zoom lens assembly. When the zooming ring 3 is rotated, the focal length of the zoom lens assembly can be adjusted and, at the same time, a slide member provided in a focal length code plate FCP as shown in FIG. 3(*b*) slides a coded pattern in contact therewith to enable the code plate FCP to generate an output data indicative of the focal length to which the lens assembly has been set by the rotation of the zooming ring 3. The lens assembly has a rear end provided with a ring-shaped abutment plate 5 fixed coaxially thereto and carrying five electric terminals JL1 to JL5, said electric terminals JL1 to JL5 being arranged in a circle coaxial with the abutment plate 5 about the optical axis of the lens assembly. Rigidly mounted on the rear end of the lens assembly adjacent the abutment plate 5 is a coupling ring having a plurality of, for example, three, radially outwardly flanged bayonet pawls 7, the function of which will be described later. The lens assembly also has a stop-down pin 9 protruding axially outwardly from the rear end of the lens assembly and normally angularly biased by a spring in a direction shown by the arrow Z, said stop-down pin 9 being so operatively associated with an aperture control mechanism 100 built in the lens assembly that the aperture of the lens assembly can be adjusted to the minimum aperture size (the largest f-stop number) with the pin 9 located at the position shown by solid line and the full open aperture size (the smallest f-stop number) when the stop-down pin 9 is angularly moved to a position 9*a* shown by the broken line in a direction counter to the biasing direction Z.

The camera body 21 has a ring-shaped abutment plate 11 rigidly secured thereto for engagement with the abutment plate 5 fast with the lens assembly and carrying an equal number of electric terminals JB1 to JB5, said electric terminals JB1 to JB5 being so positioned and so arranged that, when and after the lens assembly has been completely coupled to the camera body 21 with the abutment plate 5 held in contact with the abutment plate 11, the terminals JB1 to JB5 on the camera body 21 can be electrically connected with the associated terminals JL1 to JL5 on the lens assembly, respectively. The camera abutment plate 11 has an equal number of bayonet flanges 13 extending radially inwardly therefrom and engageable with the lens bayonet pawls 7 when the lens assembly is mounted onto the camera body and subsequently turned in the direction Z so as to assume a locked position. It is to be noted that the complete coupling of the lens assembly to the camera body 21 is intended to mean that the lens assembly mounted onto the camera body 21 and then turned so as to assume the locked position is held in such locked position and that, although not shown because of the well known expedient in the related art, the camera body 21 is to be understood as provided with a releasable locking member for holding the lens assembly in the locked position. The camera body 21 also has an aperture stop-down control lever 15 having a side edge 15*a* engageable with the stop-down pin 9 when and after the lens assembly has been completely coupled. Accordingly, the aperture of the lens assembly depends on the position of the aperture stop-down control lever 15. Although in practice the aperture stop-down control lever 15 is spring-loaded so as to move in a direction shown by the arrow X, it is held in a position shown by the solid line during a period other than during the exposure control operation and, therefore, the aperture of the lens assembly is set to the maximum aperture size, i.e., the full open aperture size. When the exposure control operation takes place, the control lever 15 is disengaged from the solid line position to move in the direction X accompanied by the angular movement of the stop-down pin 9 in the direction Z with the aperture of the lens assembly consequently stopped down. After the control lever 15 has been moved in the direction X by a predetermined distance corresponding to the stopping-down degree to attain a required aperture size, the control lever 15 is brought to a halt and, at the same time, the stop-down pin 9 having been following to the control lever 15 is brought to a halt with the aperture of the lens assembly consequently set to the predetermined value. The camera body 21 also has a reflective mirror 17 supported for pivotal movement between an up position, at which the incoming light passing through the lens assembly is allowed to reach a photosensitive film, and a down position as shown and at which the incoming light is reflected towards a viewfinder of the camera.

To mount onto the camera body 21, the lens assembly is first inserted into the camera body 21 until the lens abutment plate 5 contacts the camera abutment plate 11 and then is turned in the direction Z to allow it to be held in the locked position. When the lens assembly is so locked, the bayonent pawls 7 are held in position between the bayonet flanges 13 and spring members (not shown) provided in the camera body 21 and positioned on one side of the bayonet pawls 7 opposite to the associated bayonet flanges 13 and, at the same time, the lens terminals JL1 to JL5 are aligned and electrically connected with the camera terminals JB1 to JB5, respectively. The paired terminals JB1 and JL1 are utilized to transmit data from the lens assembly onto the camera body; the paired terminals JB2 and JL2 are utilized to supply an electric power from the camera body onto the lens assembly; the paired terminals JB3 and JL3 are utilized to supply synchronizing clock pulses from the camera body onto the lens assembly; the paired terminals JB4 and JL4 are utilized to supply from the camera body onto the lens assembly a chip select signal necessary to activate a circuit built in the lens assembly; and the paired terminals JB5 and JL5 are utilized to make the ground common to both the camera body and the lens assembly.

As can readily be understood from FIG. 1, it is clear that, except for a mechanical linkage associated with the control of the lens aperture, no other mechanical

linkage intended for the transmission of pieces of information is employed between the camera body and the lens assembly. Accordingly, not only can the lens assembly have enough space to spare, but also no substantial care is required in designing and machining component parts of the mechanical linkage necessitated to transmit a physical information concerned of the lens aperture.

In addition, since the paired terminals for the transmission of the electric signals are arranged in the manner as hereinabove described, the data transfer terminal JB1 on the camera body **21** contacts none of the lens terminals JL1 to JL5 during the mounting of the lens assembly and prior to the complete coupling of the lens assembly to the camera body, but contacts the associated lens terminal JL1 only when the lens assembly has been completely coupled to the camera body having been held in the locked position. Accordingly, as will be described later, even when the lens assembly is incompletely coupled to the camera body, there is no possibility that electric current may flow from any of the other terminals to this data transfer terminal through the circuit built in the lens assembly. This is advantageous in that the possibility is eliminated that the data may be destroyed by the current flowing from any of the other terminals while a microcomputer is in operation to transact the data with blocks other than the lens assembly, thereby permitting the data to be correctly read.

FIG. **2** illustrates the appearance of the camera body viewed from the rear. As shown, the camera body has a shutter release button **22**, a mode selector slide **23**, a liquid crystal display unit **24**, an aperture setting button **25**, an exposure time setting button **26**, an up-shift button **27**, a down-shift button **28** and a frame counter window **29** all arranged at convenient places readily accessible to and noticeable by the photographer. The shutter release button **22** when depressed is moveable in two stages between inoperative and operated positions past an intermediate position, and the first stage of movement from the inoperative position to the intermediate position results in the closure of a light measuring switch S1, shown in FIG. **3**(*a*), to initiate the light measurement, the calculation and the display operation, but the subsequent second stage of movement from the intermediate position to the operated position results in the closure of a release switch S2, shown in FIG. **3**(*a*), to initiate the exposure control if an exposure control mechanism has already been charged. The mode selector slide **23** is selectively movable to any one of the four clock positions marked "A", "P", "S" and "M", respectively. When this mode selector slide **23** is in the A position, the camera is brought in position to operate under an aperture priority mode (hereinafter referred to as A mode) at which the exposure time is automatically controlled in reference to the preset aperture, but when the slide **23** is moved to the P position, the camera is brought in position to operate under a programmed mode (hereinafter referred to as P mode) at which a combination of the exposure time and the aperture are automatically controlled in dependence on the amount of light. It is to be noted that, during the P mode of operation, the program line varies dependent on the data fv fed from the lens assembly indicating the focal length, to which the zooming ring **3** has been adjusted, in such a way that, when $fv > fvt$, wherein fvt represents the data indicative of the focal length of, for example, 80 mm, a Pt mode is established in which a priority is given to the high shutter speed in determining the combination of aperture and exposure time, but when $fvw > fv$, wherein fvw represents the data indicative of the focal length of, for example, 35 mm, a Pw mode is established in which a priority is given to the small aperture in determining the combination of exposure time and aperture. However, when and so long as $fvt \geqq fv \geqq fvw$, a normal Pn mode is established. When the mode selector slide **23** is set at the S position, the camera is brought in position to operate under an exposure time priority mode at which the aperture is automatically controlled in reference to the preset exposure time, which mode is hereinafter referred to as S mode. On the other hand, when the slide **23** is in the M position, the camera is brought in position to operate under a manual mode at which both the exposure time and the aperture can be manually set according to the photographer's desire, which mode is hereinafter referred to as M mode.

The aperture setting button **25** is adapted to be depressed at the time of setting of the aperture, and the depression of this button **25** results in the closure of a switch ASS, shown in FIG. **3**(*a*), to initiate the light measurement, the calculation and the display operation and also to modify the aperture in dependence on the state of any one of the upshift and down-shift buttons **27** and **28**. The exposure time setting button **26** is adapted to be depressed at the time of setting of the exposure time, and when this button **26** is depressed, a switch SSS shown in FIG. **3**(*a*) is closed to initiate the light measurement, the calculation and the display operation and also to modify the aperture in dependence on the state of any one of the upshift and down-shift buttons **27** and **28**. When the up-shift button **27** is depressed, a switch UPS shown in FIG. **3**(*a*) is closed. When at this time the aperture setting button **25** is depressed while the camera is operable under any one of the A and M mode, the aperture size once set changes to a size smaller than it by 0.5 Ev. However, when at this time the exposure time setting button **26** is depressed while the camera is operable under any one of the S and M modes, the exposure time once set changes to a value shorter than it by 0.5 Ev. The depression of the down-shift button **28** results in the closure of a switch DOS shown in FIG. **3**(*a*). When at this time the aperture setting button **25** is depressed while the camera is operable under any one of the A and M modes, the aperture size once set changes to a size larger than it by 0.5 Ev, but when at this time the exposure time setting button **26** is depressed while the camera is operable under any one of the S and M modes, the exposure time once set changes to a value longer than it by 0.5 Ev. The liquid crystal display unit **24** is used to display various pieces of information such as, for example, the ISO value, the combination of the exposure time and the aperture both used for the control, a camera wobbling warning, and the out-of-coupling range warning. The frame counter window **24** is used to display the count of film frames exposed.

FIGS. **3**(*a*) and **3**(*b*) altogether illustrate an electric circuit of the camera system as a whole embodying the present invention, wherein FIG. **3**(*a*) shows the circuit incorporated in the camera body while FIG. **3**(*b*) shows the circuit incorporated in the lens assembly. The circuit incorporated in the camera body, which is hereinafter referred to as camera circuit in contrast to a lens circuit which is the circuit shown in FIG. **3**(*b*) and incorporated in the interchangeable lens assembly, includes a source BA of electric power which may be constituted by one or more batteries. This power source

BA feeds, through a power supply line +E, a microcomputer, a display circuit DSP, a shift register SR, AND gates AN0, AN1, AN2, and NAND gates NA0 and NA1. The camera circuit also includes the switch S1, which is a light measuring switch adapted to be closed upon the first stage of depression of the release button 22; the switch SSS which is a Tv switch adapted to be closed when the exposure time setting button 26 is depressed, the switch ASS which is an Av switch adapted to be closed when the aperture setting button 25 is depressed; the switch UPS which is an up-shift switch adapted to be closed when the up-shift button 27 is depressed; and the switch DOS which is a down-shift switch adapted to be closed when the down-shift button 28 is depressed.

A transistor BTo acts as a power supply transistor and is adapted to conduct, when the microcomputer PC initiates its operation, to supply an electric power from the power supply line +V to a light measuring circuit LMC, a release magnet circuit RLM, an aperture stop magnet circuit APM, a mirror magnet circuit MRM, a leading curtain magnet circuit 1CM, a trailing curtain magnet circuit 2CM, an aperture stop-down pulse generator FEN, an ISO data detecting circuit CAD, and an exposure control mode data generator MOD. Moreover, when and so long as the transistor BTo is in conduction, an electric power is supplied to the camera terminal JB2 through a protecting resistor Ro and then to a power line VL of the lens circuit of FIG. 3(*b*) through the lens terminal JL2 then connected with the camera terminal JB2. The protecting resistor Ro is used to avoid any possible shortcircuiting which may happen to occur between the power supply line +V and the ground when, for example, forceps touch the camera terminal JB2. It is to be noted that, except for the circuits LMC, RLM, APM, MRM, 1CM, 2CM and FEN, the camera circuit is fabricated in C-MOS.

The operation of the camera system as a whole will now be described with reference to the flow charts of FIGS. 6 and 7 showing the sequence of operation of the microcomputer PC. Assuming that the microcomputer PC is in the inoperative position, terminals P2, P3 and P4 are all in a low level state. When any one of the light measuring switch S1, the Tv switch SSS and the Av switch ASS is subsequently closed, an input to an interruption terminal itA sets down to a low level state and the microcomputer PC consequently starts its operation from the initial step #1. At step #1, a terminal P11 is rendered in a low level state wherefor the transistor BTo is caused to conduct to initiate the electric power supply from the power supply line +V and also the electric power supply through the resistor Ro. By rendering the terminals P2, P3 and P4 in a high level state, a terminal P14 is rendered in a high level state. When the terminal P14 is rendered in the high level state, ISO data and mode data are latched in the shift register SR in response to the positive edge of the high level signal emerging from the terminal P14. An ISO data output circuit CAD is a circuit operable to read a coded pattern indicative of the ISO data, which coded pattern is provided on a film container as is well known to those skilled in the art, whereas the mode data generator MOD is operable to generate the mode data from a coded pattern depending on the position of a slide member movable together with the mode selector slide 23 shown in FIG. 3(*a*). In addition, at the same time as the terminal P14 is rendered in the high level state, the NAND gate NA1 and the AND gates AN0 and AN2 are brought in position ready to be enabled. At step #4, the microcomputer PC undergoes a serial input and output operation with the consequence that eight clock pulses are outputted from a terminal CKO on the one hand and data fed to a data input terminal SIN are taken in a serial input/output register SIOR, provided internally of the microcomputer PC, in response to the negative edge of each positive edge of the eight clock pulses on the other hand. Substantially at the same time, the shift register SR sequentially outputs the data, which have been latched therein, on the basis of the eight clock pulses successively fed to the AND gates AN2. When the data so outputted are in the high level state, and output from both of the gates AN0 and NA1 is in a low level state and, accordingly, a field-effect transistor To is brought in a conductive state thereby permitting a high level signal to be fed to the data input terminal SIN. On the other hand, when the data outputed from the shift register SR are in the low level state, an output from both of the gates AN0 and NA1 is in a high level state and, accordingly, a field-effect transistor T1 is brought in a conductive state thereby permitting a low level signal to be fed to the data input terminal SIN. It is to be noted that, when and so long as the terminal P14 of the microcomputer PC is in a low level state, the NAND gate NA1 and the AND gate AN0 generate high and low level signals, respectively, and therefore both of the field-effect transistors T0 and T1 are held in a non-conducting state, thereby avoiding any possible adverse influence which would otherwise occur when data taken from the lens circuit of FIG. 3(*b*) are fed to the data input terminal SIN. Upon termination of step #4, of the data taken in the serial input/output register SIOR, the mode data are set in a register MOR, and the ISO data are, after having converted the data taken in into data for the calculation, set in a register SVR. Then, the microcomputer PC renders the terminal P14 in a lower level state and proceeds to step #7.

At step #7, a decision is made as to whether or not data appropriate to the law of the coded pattern on the film container have been read out from the ISO data taken in the serial input/output register SIOR. If it proves that the data appropriate to the law of the coded pattern have been read out, the contents of the register SVR remain unchanged, but if it proves to the contrary, it connote that the film container having no coded pattern is loaded or any film container is not loaded and, in such case, data representative of the ISO sensitivity which is most often utilized, for example, ISO 100, can be set in the register SVR.

Subsequently, the microcomputer PC proceeds to the reading of data out from the lens circuit shown in FIG. 3(*b*). In the first place, the content of a register k is rendered "0" and a terminal P12 is rendered in a high level state. The register k serves to select one of the data setting registers LDR0 to LDR5 according to the content stored therein. More specifically, when the content of the register k is "0", "1", "2", "3", "4" or "5", the register LDR0, LDR1, LDR2, LDR3, LDR4 or LDR5, can be selected, respectively. When the terminal P12 is rendered in the high level state as hereinabove described, this high level signal is fed to the lens circuit through the terminal JB4 and then the terminal JL4. By this high level signal, all of the AND gates AN3 and AN4, the NAND gate NA2 and a decoder DE are brought in position ready to be enabled and, on the other hand, counters CO0 and CO1 are released from their reset states. Then, the microcomputer undergoes

the serial input and output operation to sequentially read in the data, which are fed to the data input terminal SIN from the lens circuit through the coupled terminals JL1 and JB1, in response to the negative edge of the same clock signal as the clock signal outputed from the clock output terminal CKO, the data so read in being subsequently set in a register LDRK to add "1" to the register k. Then, a decision is made as to whether or not the content of the register k has become "6". If the content of the register k is determined "6", the process flow proceeds to step #15, but if it is not, the process flow proceeds to step #11 to read in the next succeeding data fed from the lens circuit. By repeating the above described process flow, six types of data can be read in the microcomputer PC and set in the register LDR0 to LDR5, respectively.

Referring to FIG. 3(*b*) showing the lens circuit, that is, the circuit built in the interchangeable lens assembly, a counter CO0 is a 3-bit counter operable to count the number of negative edges of the respective clock pulses which have been fed from the clock output terminal through the coupled terminals JB3 and JL3 and then the AND gate AN3 and subsequently inverted by an inverter IN0, that is, the number of positive edges of the respective clock pulses outputed from the clock output terminal CKO. The decoder DE sequentially generates a high level signal from its left-hand terminal to its right-hand terminal in correspondence with an output from the counter CO0, thereby bringing AND gates AN10 to AN17 in position ready to be enabled. Accordingly, each of the AND gates is held in position ready to be enabled during a period from the positive edge of one clock pulse to the positive edge of the next succeeding clock pulse, thereby generating one-bit data. On the other hand, when the outputs from the counter CO0 are all rendered in a low level state upon completion of its counting operation up to eight clock pulses and an AND data AN5, therefore generates a high level output, a counter CO1 receives the clock pulses, which have been outputed from an AND gate AN3 and subsequently delayed by a delay circuit DL, and counts the number of negative edges of the clock pulses so received thereby. The delay circuit DL is utilized to inhibit the AND gate AN6 from outputing a pulse in response to the positive edge of the first clock pulse. Accordingly, each time the eight clock pulses are fed thereto, one clock pulse is counted. Reference character DSL represents a data selector adapted to output the input data, which have been fed to an input section A, when and so long as the most significant bit of the counter CO1 is in a low level state, but to output the input data, which have been fed to an input section B, when and so long as it is in a high level state. And, RO fixedly stores various data of the interchangeable lens assembly at respective addresses. When one of the addresses is specified by address data fed from the data selector, the data stored and fixed at such specified address are then outputted through the AND gates AN10 to AN17 bit to bit from the least significant bit. The data outputted from the AND gates AN10 to AN17 emerges from an OR gate OR0 and, when and so long as the output from the OR gate OR0 is in a high level state, a field-effect transistor T2 is rendered conductive with the high level signal consequently fed to the data input terminal SIN through the coupled terminals JL1 and JB1. However, when and so long as the output from the OR gate OR0 is in a low level state, a field-effect transistor T3 is rendered conductive with the low level signal consequently fed to the data input terminal SIN through the coupled terminals JL1 and JB1.

Hereinafter, the reason will be discussed that, even if the lens assembly is incompletely coupled to the camera body, the transmission of various data between the lens assembly and the camera body will not be adversely affected. For this purpose, reference will now be made to FIGS. 4 and 5. It is to be noted that FIG. 4 illustrates the case employed only for the purpose of comparison, in which the power terminal on each of the camera body and the interchangeable lens assembly is positioned at one extremity of the arcuate row of the terminals and the lens assembly is incompletely coupled to the camera body. FIG. 5 illustrates the case in which the lens assembly incorporating the lens circuit of FIG. 3(*b*) is incompletely coupled to the camera body incorporating the camera circuit of FIG. 3(*a*).

Referring first to FIG. 4, the lens assembly is incorrectly coupled to the camera body such that a data terminal JB2' and a clock terminal JB3', both on the camera body, are electrically connected with a power terminal JL1' and a data terminal JL2' both on the lens assembly, respectively. At the outset, a discussion will be made as to what will happen when, in the incomplete condition, the clock pulses are generated from the clock terminal CKO to permit data from other data output sections, that is, the shift register SR, provided internally of the camera body, to be read in the data input terminal SIN. A high level signal of the clock is generated upon the conduction of a field-effect transistor T4. Then, a voltage from the power supply line +V is supplied through the field-effect transistor T4 and the coupled terminals JB3' and JL2' to the lens assembly and then to a power supply line VL in the lens assembly through a diode D2 which is essentially formed by a CMOS circuit. This signal is in turn fed to the data input terminal SIN in the camera body through the coupled terminals JL1' and JB2'. At this time, it is assumed that the data from the shift register SR in the camera body are in the low level state, an N-channel field-effect transistor T1 is conducting and the low level signal is to be read in the data input terminal SIN. However, when and so long as the field-effect transistor T1 is conducting, the potential at the data input terminal SIN is equal to the potential of the electric power +E divided by the on-resistance of a field-effect transistor T4, and the on-resistance of both the diode D2 and the field-effect transistor T1 and is not clear as to whether it becomes a high level state or whether it becomes a low level state. Accordingly, there is a possibility that incorrect data will be read in the data input terminal SIN. (It may be contemplated to employ a resistor of relatively high resistance between the terminal JB2' and the data input terminal SIN or between the clock output terminal CKO and the terminal JB3' to avoid the reading of the incorrect data. However, where such a resistor is employed, it may happen that a low-pass filter having a large time constant will be formed by the above described resistor and the parasitic capacitance of the data transfer line or the clock transfer line, in which case a high speed data transmission will be hampered.) On the contrary thereto, in the embodiment according to the present invention, since the data terminal JL1 for transmitting the data from the lens assembly to the camera body is positioned on the leading extremity of the row of the lens terminals with respect to the direction of turn of the lens assembly which is effected when the lens

assembly is coupled to the camera body, even if any erroneous connection between the terminals such as corresponding to that described with reference to and shown in FIG. 4, no voltage will be imposed on the data terminal JB1 on the camera body as shown in FIG. 5 and, therefore, no adverse effect will occur when the data input terminal SIN in the camera body reads in the output from the shift register SR. In general, in the case of the embodiment according to the present invention, the terminal JB1 for receiving the data of the camera is electrically connected with the terminal JL1 only when and after the interchangeable lens assembly has been completely coupled to the camera body and hence held in the locked position, and will not be connected to any one of the other terminals JL2 to JL5 during the mounting of the lens assembly. Accordingly, even if while the lens assembly is incompletely coupled to the camera body the ISO data are read in through the data input terminal SIN, there is no factor that adversely affect the data and the ISO data are, therefore, correctly read in by the microcomputer PC. It is to be noted that, in the case of the embodiment according to the present invention, although a current tends to flow in through the transistor BTo, the resistor Ro, the coupled terminals JB2 and JL1, the diode D2, a power source VL and the coupled terminals JL2 and JB3, the waveform of the clock signal will not be adversely affected because the impedance is increased by the protecting resistor Ro.

The relationship between the data stored and fixed in a read-only memory RO and the addresses of the read-only memory RO as well as the operation necessary to specify the addresses will now be described.

TABLE 1

Counter (CO1)	Addresses	Data	Registers
000	000 00000	Check data	LDR0
001	000 00001	AVo: Full Open Aperture Size	LDR1
010	000 00010	Avmax: Minimum Aperture Size (maximum F-number)	LDR2
011	000 00011	Wv: Error in Full Open Aperture Metering	LDR3
100	100 *****	Avz: Deviation in Effective Aperture Size from A Standard	LDR4
101	101 *****	fv: Focal Length	LDR5

Table 1 illustrates the relationship among the output from the counter CO1, the address of the read-only memory RO to be specified, the data stored at the specified address, and the register to which the data are set within the microcomputer PC. Each time the eight clock pulses are fed to the counter CO1, the latter increases its count by one increment. Accordingly, at the outset, the output from the counter CO1 is "000". As a result, the data, "000 00000", from an input section A are outputed from the data selector DSL to the read-only memory RO. Subsequently, check data (for example, "10101010") common to all of the available interchangeable lens assemblies is transferred from the read-only memory RO to the camera body. When the output from the counter CO1 subsequently become "001", an address data "000 00001" from the input section A is outputed from the data selector DSL and a data Avo representative of the full open aperture size is outputed from the read-only memory RO. In the case of the zoom lens assembly having its effective aperture variable with change in focal length, a data representative of the full open aperture size at the shortest focal length, that is, the greatest aperture size available in the lens system, is outputed. When the output from the counter CO1 becomes "010", an address data "000000010" from the input section A is outputted from the data selector DSL and a data Avmax representative of the minimum aperture size (the maximum f-stop number) is outputted from the read-only memory RO. Also, as for this minimum aperture size, in the case of the zoom lens assembly having its effective aperture variable with change in focal length, a data representative of the minimum aperture size at the shortest focal length is outputed. When the output from the counter CO1 becomes "011",an address data "00000011" is outputted from the data selector DSL and a data Wv representative of an error in full open aperture metering is outputted. When the output from the counter CO1 becomes "100", an address data "100*****" from the input section B is outputtted from the data selector DSL. The five-bit data represented by "*****" is a data outputted from the focal length code plate FCP in correspondence with the focal length set by the zooming ring 1. At this address, a data representative of the deviation in effective aperture size from that at the shortest focal length is fixedly stored. It is, however, to be noted that, in the case of a zoom lens assembly having its effective aperture not variable with change in focal length, a data "00000000" is fixedly stored. In addition, in the case of a lens assembly of a fixed focal length, no focal length code plate is employed and, at the same time, no data selector DSL is employed, and the address in the read-only memory RO is specified "00000100" and, therefore, data "00000000" is outputted from the read-only memory RO. When the output from the counter CO1 becomes "101", a data "101*****" from the input section B is outputted from the data selector DSL and a data fv corresponding to the focal length set be the zooming ring 1 is outputted. In the case of the lens assembly of a fixed focal length, the address of "00000101" is specified and a data fv representative of the fixed focal length is outputted.

Referring to the flow chart of FIG. 6, the operation of the microcomputer PC will now be described. After the data has been taken in from the lens circuit, the analog-to-digital conversion of an output from the light measuring circuit LMC is carried out at step #15. The output from the light measuring circuit LMC is fed to an analog input terminal AN1 so that a reference voltage created within the light measuring circuit LMC can be utilized as a reference voltage for a digital-to-analog converter build in the microcomputer PC for the analog-to-digital conversion and the output from the light measuring circuit LMC is subjected to the analog-to-digital conversion on the basis of this reference voltage. Subsequently, at steps #16 and #17, both the full open aperture size and the minimum aperture size at the focal length once set are calculated, the resultant data being designated by Avo and Avmax, respectively. Then, at step #18, the error Wv, included in the data of the output from the light measuring circuit LMC which has been subjected to the analog-to-digital conversion, and a factor of the full open aperture size Avo are subtracted on the basis of the data read out from the lens assembly to calculate Bv to which the film sensitivity data set in a register SVR is added to calculate an exposure value EV.

Upon the completion of the above described operation, an exposure calculation operation starting from step #20 starts. At step #20, based on the data taken in a register MOR, a decision is made as to whether or not it is the P mode. If it is the P mode, the program flow

proceeds to step #21 at which a decision is made as to whether or not the focal length data fv from the lens assembly is greater than fvt. If fv>fvt, the programmed calculation for the high speed shutter priority is performed at step #21 which is followed by step #35. However, if the determination at step #21 shows fv≦fvt, a decision is made at step #23 to find if fv<fvw. If fv<fvw, the program flow proceeds to step #25 at which the programmed calculation for the small aperture priority is performed, which step #25 is subsequently followed by step #35. When the determination at step #23 shows fv≧fvw, the normal programmed calculation is performed at step #24 which is followed by step #35. On the other hand, if the determination at step #20 is such that it is not the P mode, a decision is made at step #26 to find if it is the A mode. If it is the A mode, the aperture is set in a register AVR1 depending on the states of the respective buttons 25, 27 and 28, and at subsequent step #26, the calculation for the A mode is performed, followed by step #35. If it is not the A mode as determined at step #26, a decision is performed at step #29 to determine if it is the S mode. If it is the S mode, an exposure time is set in a register TVR1 at step #30 in dependence on the states of the respective buttons 26, 27 and 28 and, after the calculation for the S mode has been performed at step #31, the program flow proceeds to step #35. If it is not the S mode as determined at step #29, this means the M mode and, therefore, at step #32, the aperture determined in dependence on the states of the respective buttons 25, 27 and 28, and the exposure time determined in dependence on the states of the respective buttons 26, 27 and 28 are set in registers AVR1 and TVR1, respectively, at step #32 which is followed by step #34 at which the calculation for the M mode is performed, the program flow thereafter proceeding to step #35.

The aperture for the control obtained from one of the above described calculations for the respective modes is set in a register AVR2 while the exposure time for the control obtained from one of the above described calculations for the respective modes is set in a register TVR2. Moreover, an over exposure warning, an under exposure warning, a camera wobbling warning and the data of the displacement from a proper exposure during the M mode are all set in a register DMR. The preset aperture and exposure time are set in the registers AVR1 and TVR1. If during the calculation for the S mode the calculated aperture AV is such that AV>Avmax, Avmax and the data on the preset exposure time are set in the registers AVR2 and TVR2, respectively, with the over exposure warning effected. On the other hand, if Av<Avo, Avo and the data on the preset exposure time are set in the registers AVR2 and TVR2, respectively, with the under exposure warning effected. During the P mode, if Avmax+Tvmax<Ev, Avmax and Tvmax are set in the registers AVR2 and TVR2, respectively, with the over exposure warning effected. Moreover, if the calculated Av is smaller than Avo, Avo is set in the register AVR2 and, if Tv which is obtained by Ev−Avo=Tv is higher than Tvmin, the Tv so obtained is set in the register TVR2, but if Tv<Tvmin, Tvmin is set in the register TVR2 with the under exposure warning effected. At step #35, the number of steps to be stopped-down is calculated from both the data on the aperture size for the control and the data on the full open aperture size, the calculated data being set in a register PVR. At the subsequent step #36, data Avd on the aperture for the display, of which minimum unit is 0.5 Ev, is calculated from the data on the aperture for the control and is then set in a register AVR3. At step #38, data Tvd on the exposure time for the display, of which minimum unit is 0.5 Ev, is calculated from the data on the exposure time for the control and is then set in a register TVR3. After the above described operation has been completed, the program flow proceeds to step #39 at which a subroutine for the transfer of the data to be displayed is executed.

The subroutine for the transfer of the data to be displayed will now be described. At step #60, a terminal P13 is rendered in a high level state, the AND gate AN1 is brought in position ready to be enabled, and the display circuit DSP is set in position ready to receive inputs. The content of the register DMR is set in a serial input/output register SIOR and the serial input and output operation is performed. Thereby, the content of the register DMR is taken in the display circuit DSP. Subsequently, the content (ISO data) of the register SVR is set in the register SIOR and the serial input and output operation is performed. After the data in the register AVR3 on the aperture for the display and the data in the register TVR3 on the exposure time for the display have been fed to the display circuit DSP, the terminal P13 is rendered in a low level state, followed by the return to the main routine. Then, the display circuit DSP outputs a signal, corresponding to the data so read out, to a segment terminal SEG and a display corresponding to the data fed together with a signal from a common terminal COM is carried out by means of a liquid crystal display unit LQ.

After the completion of the transfer of the data to be displayed, and at step #40, interruption to a terminal itB is enabled. This is such that, if the release switch S2 shown in FIG. 3 is closed and, at the same time, the exposure control mechanism has been charged with the switch S4 consequently closed, the output from the NAND gate NA0 changes to a low level state with an interruption signal consequently fed to the terminal itB, and the microcomputer performs an exposure control operation from step #70 if the interruption to the terminal itB is in condition ready to be enabled, no matter what operation it has performed. When the interruption to the terminal itB is enabled, the terminals P2, P3 and P4 are rendered in a low level state and a decision is made as to whether or not an input terminal P0 is rendered in a low level state as a result of at least one of the switches S1, SSS and ASS having been closed. If the terminal P0 is rendered in the low level state, the program flow returns to step #2, thereby repeating the above described operation. On the other hand, if the terminal P0 is in the high level state, the program flow proceeds to step #43 at which the interruption to the terminal itB is disabled and a blank data BLD for turning off the display is set in the registers AVR3 and TVR3 and, further, the register DMR in which display data such as for warning is set is reset, followed by the subroutine for the transfer of the data to be displayed. After the completion of the data transfer starting from step #60 in the manner as hereinbefore described, the terminal P11 is rendered in a high level state to interrupt the power supply by means of the transistor BTo while the interruption to a terminal itA is enabled to interrupt the operation of the microcomputer PC. Accordingly, at the time of interruption of the operation of the microcomputer, the display unit LQ merely displays only the ISO data.

Hereinafter, a subroutine for the aperture setting will be described with reference to FIG. 7. At step #101, a decision is made to find if the switch ASS is closed. This is to determine if, while a terminal P4 is rendered in a low level state, the terminal P0 is rendered in a low level state and to render the terminal P4 in a high level state. If the switch ASS is not closed, a flag SEF is set to "0" at step #115 followed by step #116. On the other hand, if the switch ASS is closed, a decision is made at step #102 as to whether or not the switch UPS is closed. This operation is to determine if, while the terminal P3 is rendered in a low level state, the terminal P1 is rendered in a low level state and to render the terminal P3 in a high level state. If the switch UPS is closed, a decision is made at step #103 as to whether or not the down-shift switch DOS is closed. This operation is to determine if, while the terminal P4 is rendered in a low level state, the terminal P1 is in a low level state and to render the terminal P4 in a high level state. If the down-switch DOS is, too, closed, it means that the up-shift button 27 and the down-shift button 28 are simultaneously depressed and, therefore, the program flow proceeds to step #116 with no set value altered. If it proves at step #103 that the switch DOS is not closed, a decision is made at step #104 to find if the flag SEF is "1". If the flag SEF has been found to be "1", this means that the up-shift button 27 is kept depressed and, therefore, the program flow proceeds to step #116. On the other hand, if the flag SEF has been found to be "0", this means that the up-shift button 27 is first depressed and, therefore, the flag SEF is set to "1" at the subsequent step #105 followed by step #106 at which 0.5 is added to the content of the register AVR1. At step #107, the minimum aperture size Avmax obtained at step #17 is compared with the content of the register AVR1. If (AVR1)>Avmax, Avmax is set in the register AVR1 at step #108 followed by step #116. On the other hand, if (AVR1)≦Avmax, the data of the register AVR1 remains unchanged and the program flow proceeds to step #116.

If the determination at step #102 is such that the switch UPS is not closed, step #102 is followed by step #109 at which a decision is made to find if the switch DOS is closed. If the switch DOS is not closed, too, the flag SEF is set to "0" at step #115 followed by step #116. On the other hand, if the switch DOS is closed, a decision is made at step #110 to find if the flag SEF is set to "1". If the result at step #110 indicates that the flag SEF is "1", this means that the down-shift button 28 is kept depressed and, therefore, the program flow proceeds to step #116 without the data being altered. On the other hand, if the result at step #110 indicates that the flag SEF is "0", this means that the down-shift button 28 is first depressed and, at this time, the flag SEF is set to "1" at step #111 followed by step #112 at which 0.5 is subtracted from the content of the register AVR1. If the result of comparison carried out at the step between the content of the register AVR1 and the data Avo of the full open aperture size obtained at step #16 shows (AVR1)≧Avo, the content of the register AVR1 remains unchanged and the program flow proceeds to step #116. On the other hand, if it shows (AVR1)<Avo, the full open aperture size Avo is set in the register AVR1 at step #114, followed by step #116.

At step #116, a decision is made as to whether or not the content of the register AVR1 is greater than the value representative of the minimum aperture size Avmax, and if it not greater than Avmax, the content of the register AVR1 remains unchanged, but if it is greater than Avmax, the minimum aperture size Avmax is set in the register AVR1 at step #117 in place of the original content in the register AVR1. At step #118, a decision is made as to whether the content of the register AVR1 is smaller than the value representative of fuller open aperture size Avo determined at step #16. If the result of comparison at step #118 indicates that the content of the register AVR1 is smaller than Avo, Avo is set in the register AVR1 at step #119 in place of the original contents in the register AVR1, but if it shows the content of the register AVR1 not smaller than Avo, the content of the register AVR1 remains unchanged and the program flow subsequently returns to the main routine. The program flow from step #116 to step #119 is provided for the purpose of avoiding any possible departure of the data, set in the register AVR1 prior to the lens assembly being interchanged, from a controllable range when the lens assembly is interchanged. In addition, as shown in the subroutine, a single depression of any one of the up-shift and down-shift buttons results in the change of the set value by 0.5 Ev.

The subroutine for the determination of the exposure time is similar to the subroutine shown in FIG. 7 except that step #101 is substituted by a decision step to determined if the switch SSS is closed; the register AVR1 at each of the steps #106, 107, 108, 112, 113 and 114 is substituted by the register TVR1; Avmax is substituted by the data Tvmax on the shortest exposure time; Avo is substituted by the data Tvmin on the longest exposure time; and steps #116 to #119 are omitted because of no change occurring in any one of the shortest and longest exposure times.

Referring to FIG. 6, particularly to FIG. 6(c), the operation which takes place when an interruption signal is fed to the interruption terminal itB will now be described. At step #60, a decision is made as to whether or not the data of a register PVR associated with the number of f-stop steps to be stopped down is "0". If it is not "0", the content of the register PVR is set in an event counter ECO to enable the interruption by the event counter ECO. And, a low level pulse of a duration To is generated from a terminal P6 to activate the release magnet circuit RLM. Then, the engagement of the control lever 15 shown in FIG. 1 is released and the control lever 15 starts its movement in the direction X to initiate the aperture stop-down operation. In addition, in response to the movement of the control lever 15, the pulse generator FEN generates a pulse which is in turn fed to a clock input terminal of the microcomputer PC at which, in response to each pulse, the data of the number of f-stop steps to be stopped down, which is preset in the event counter ECO, is subtracted. The microcomputer, after the lapse of a time T1 subsequent to the generation of a low level pulse from the terminal P6, generates from a terminal P8 a pulse of a duration To necessary to activate the mirror magnet circuit MRM. When the mirror magnet circuit MRM is so activated, the engagement of the reflective mirror 17 shown in FIG. 1 is released and the reflective mirror 17 is therefore pivoted upwards. After the lapse of a time T2 subsequent to the generation of the low level pulse from the terminal P8, the program flow proceeds to step #81 at which a low level pulse of a duration To is generated from a terminal P9. During a period from the generation of the low level pulse from the terminal to step #81, the aperture spends time enough to allow it to be stopped down from the full open aperture size to the

minimum aperture size regardless of the type of an interchangeable lens assembly, and during this time pulses equal in number of the number of f-stop steps to be stopped down are generated from the encoder FEN and the content of the event counter ECO is zeroed. By this operation, the interruption by the event counter ECO is effected and the operation starting from step #90 is initiated. In this program flow, a low level pulse of a duration To is generated from a terminal P7, thereby returning to the main routine. In this way, the aperture stop magnet circuit APM is activated to stop the movement of the control lever **15** so that the aperture can be controlled to a preset aperture. When a time T2 elapses subsequent to the generation of the low level pulse from the terminal P8, the upward pivotal movement of the mirror **17** has completed, and a low level pulse is generated from the terminal P9 to initiate the travel of the leading curtain.

Upon the initiation of the travel of the leading curtain incident to the generation of the low level pulse from the terminal P9, a time 2^{-Tvc} based on the data Tvc of the exposure time for the control, set in a register TVR2, is counted, and upon the completion of the counting of this time, a low level pulse is generated from a terminal P10 to activate the trailing curtain magnet circuit 2CM so that the travel of the trailing curtain can be initiated. After the completion of the travel of the trailing curtain, and the subsequent closure of a switch S4, the program flow proceeds to step #41 with the subsequent operation taking place in a manner similar to that hereinbefore described.

As hereinbefore fully described, according to the present invention, except for the aperture stop-down quantity transmission means essentially required to control the aperture mechanism of the interchangeable lens assembly from the side of the camera body, neither the aperture adjusting ring in the interchangeable lens assembly nor mechanical component parts such as mechanical linkage members associated with the aperture between the interchangeable lens assembly and the camera body are employed. Therefore, not only can the number of component parts of one or both of the lens assembly and the camera body be minimized, but also they can have enough space to spare. In addition, in these component parts, neither the machining precision nor the accurate positioning, which have hitherto been considered important problems, need be required to be taken into consideration. Furthermore, although information to be transmitted between the interchangeable lens assembly and the camera body includes information on the error in full aperture metering, and, in the case of the zoom lens assembly, the focal length, changes in aperture resulting from the zooming as the case may be, and the like, if these pieces of information are stored in the read-only memory in a manner similar to information of the full open aperture size and the minimum aperture size, the construction of the present invention can be concurrently utilized to transmit these pieces of information between the lens assembly and the camera body. Yet, while in the case of the customary interchangeable lens assembly having an aperture adjusting ring and an aperture mechanism mechanically associated therewith, a manipulation to set the aperture adjusting ring to a particular position to prevent a mechanical control by the aperture adjusting ring from interfering with this is required even though the aperture is set on the side of the camera body, such complicated procedures are not required according to the present invention. What is more, according to the present invention, any possible confusion which would occur in transmitting electric signals between the lens assembly and the camera body in the event of the incorrect coupling therebetween can advantageously be eliminated.

Although the present invention has fully been described in connection with the preferred embodiment thereof with reference to the accompanying drawings, it is to be noted that various changes and modifications are apparent to those skilled in the art. Such changes and modifications are to be understood as included within the true scope of the present invention as defined by the appended claims unless they depart therefrom.

We claim:

1. A camera system capable of interchanging an objective lens assembly with another lens assembly, which comprises:

an interchangeable lens assembly comprising

first and second terminals adapted to receive electrical power from a camera body and connectable respectively to a high voltage side and a ground side;

a lens circuit constituted by a C-MOS construction and adapted to receive the electric power from the first and second terminals;

a third terminal adapted to receive an enabling signal from the camera body for bringing the lens circuit into a condition ready to be enabled;

a fourth terminal adapted to receive the clock pulses from the camera body; and

a fifth terminal adapted to transmit there through to the camera body the various data peculiar to the interchangeable lens assembly which are serially outputted from the lens circuit, said first to fifth terminals being arranged in a row along the direction in which the lens assembly is turned, said fifth terminal being located at one end of said row on the leading side with respect to the direction of the turn of the lens assembly when coupled to the camera body; and

said camera body comprising:

sixth to tenth terminals adapted to be connected respectively with the first to fifth terminals when the lens assembly has been completely coupled to the camera body;

means for outputting a power supply initiating signal in dependence on a manipulation;

a source of the electric power for supplying a voltage on the high voltage side to the sixth terminal through a protective resistor and also for providing the seventh terminal with a ground level;

means for outputting to the eighth terminal a first enabling signal for bringing the lens circuit into a condition ready to be enabled;

means for outputting the clock pulses to the ninth terminal;

a data output means for serially outputting data within the camera body on the basis of the clock pulses;

means for outputting a second enabling signal for bringing the data output means into a condition ready to be enabled at a timing different from the timing at which the lens circuit is enabled; and

a read-out circuit constituted by a C-MOS construction for sequentially reading through a common input terminal on the basis of the clock pulses not only of the various data peculiar to the lens assem-

bly which have been inputted from the tenth terminal, but also the data with in the camera body fed from the data output means.

2. An interchangeable lens assembly capable of connection to a camera body having electrical power and providing control signals comprising:

first and second terminals adapted to receive electrical power from the camera body and connectable respectively to a high voltage side and a ground side;

a lens circuit constituted by a C-MOS construction and adapted to receive the electric power from the first and second terminals;

a third terminal adapted to receive an enabling signal from the camera body for bringing the lens circuit into a condition ready to be enabled;

a fourth terminal adapted to receive the clock pulses from the camera body; and

a fifth terminal adapted to transmit there through to the camera body the various data peculiar to the interchangeable lens assembly which are serially outputted from the lens circuit, said first to fifth terminals being arranged along the direction in which the lens assembly is turned, said fifth terminal being located on the leading side with respect to the direction of the turning of the lens assembly when it is to be coupled to the camera body.

3. In a camera system having a camera body capable of providing electrical power and various control signals and an interchangeable objective lens removably coupled with the camera body, an improvement comprising:

a terminal for receiving electric powder fed from the camera body to the interchangeable objective lens;

a terminal for introducing a digital signal from the camera body into the interchangeable objective lens;

a lens circuit constituted by a C-MOS construction to be powered through the power receiving terminal, including means for outputting data in response to the digital signal; and

a terminal for serially transmitting the data from the outputting means to the camera body;

wherein the above mentioned terminals are arranged in a row around an optical axis of the objective lens, the data transmitting terminal being located at one end of the row on the leading side with respect to the direction of movement of the objective lens when it is coupled to the camera body.

4. A camera system capable of interchanging an objective lens assembly, which comprises an interchangeable lens assembly having an aperture mechanism, but having no manipulatable aperture control member for manually setting the aperture to a predetermined value, and a camera body capable of providing electrical power from a power source having a high voltage terminal and a ground terminal, to which said lens assembly is removably coupled, said lens assembly comprising:

first and second terminals adapted to receive electric power supplied from the camera body;

a lens circuit adapted to receive the electric power from the first and second terminals;

a third terminal adapted to receive a signal fed from the camera body for bringing the lens circuit into a condition ready to be enabled;

a fourth terminal adapted to receive clock pulses fed from the camera body;

a fifth terminal adapted to output data from the lens circuit to the camera body, said lens circuit including a read-only memory in which various data peculiar to the lens assembly includng the full open aperture size and the minimum available aperture size are fixedly stored at particular addresses, means for counting the number of the clock pulses from the fourth terminal to sequentially specify the addresses of the read-only memory, and means for serially outputting the various data, outputted from the read-only memory, to the fifth terminal; and

said camera body comprising:

means for outputting an initiating signal for initiating an exposure calculating operation;

sixth and seventh terminals for supplying the electric power to the first and second terminals on the basis of the initiating signal;

a protective resistor inserted between a high voltage side of the power source and the sixth terminal;

a junction between a ground side of the power source and the seventh terminal;

means for outputting a first enabling signal for bringing the lens circuit into a condition ready to be enabled;

an eighth terminal for supplying the enabling signal to the third terminal;

means for generating the clock pulses;

a ninth terminal for supplying the clock pulses to the fourth terminal;

a data output means provided in the camera body for serially outputting data on the basis of the clock pulses;

means for outputting a second enabling signal for enabling said data output means at a timing different from the timing at which the lens circuit is enabled;

a tenth terminal adapted to receive the various data serially outputted from the fifth terminal;

means for sequentially reading the various data on the basis of the clock pulses;

means for outputting a preset aperture size signal on the basis of a manipulation;

means for adopting, when the preset aperture size signal exceeds the limit of the full open aperture size of the minimum available aperture size based on the data read out by the reading means, the full open aperture size or the minimum available aperture size in place of the preset aperture size;

means for controlling the aperture stop-down quantity in the aperture mechanism of the lens assembly on the basis of the full open aperture size and one of the preset aperture sizes, or the full open aperture size or the minimum available aperture size adopted in place of the preset aperture size; and

a transmission means for transmitting the aperture stop-down quantity to the aperture mechanism of the lens assembly, wherein at least said lens circuit and said reading means are constituted by a C-MOS construction, said reading means capable of reading, in addition to the various data peculiar to the lens assembly, sequentially the data from the data output means through a common input terminal on the basis of the clock pulses, said first to fifth terminals as well as said sixth to tenth terminals, corresponding respectively thereto, being arranged in a respective row extending in a direction in which the lens assembly is turned, said fifth terminal being located on the leading side of said row with respect to the direction of turn of the lens assembly for coupling to the camera body.

* * * * *

United States Patent [19]

Yoshino et al.

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[45] **Date of Patent: Jul. 22, 1986**

[54] **STEREO-MICROSCOPE WITH A COMMON OBJECTIVE LENS SYSTEM**

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[73] Assignee: **Tokyo Kogaku Kikai Kabushiki Kaisha,** Tokyo, Japan

[21] Appl. No.: **637,503**

[22] Filed: **Aug. 1, 1984**

[30] **Foreign Application Priority Data**

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Aug. 8, 1983 [JP] Japan 58-143686

[51] **Int. Cl.**[4] **G02B 21/22**
[52] **U.S. Cl.** **350/516;** 350/286
[58] **Field of Search** 350/516, 515, 514, 145

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Primary Examiner—Jon W. Henry
Attorney, Agent, or Firm—Browdy and Neimark

[57] **ABSTRACT**

A stereo-microscope is disclosed. It comprises a common objective lens system, a first and second imaging lens systems having optical paths parallel to that of the objective lens system producing intermediate images of an object, a first and second optical path deflecting devices arranged behind the respective imaging lens systems for deflecting the respective ejection bundle of rays outwardly relative to the optical path of the objective lens system, and a first and second ocular systems arranged behind the respective optical path deflecting devices for observing the respective intermediate images. It is characterized in that a stereo angle ω which is to be decided depending on the base length between the first and second imaging lens systems and an observation angle θ which is defined between the observation optical paths of the first and second ocular systems are arranged to be equal. Another stereo-microscope is also disclosed. It comprises an objective optical system, a first and second ocular systems, a first and second erecting optical systems and devices for varying an observation angle θ defined between the observation axes of the first and second ocular systems.

12 Claims, 8 Drawing Figures

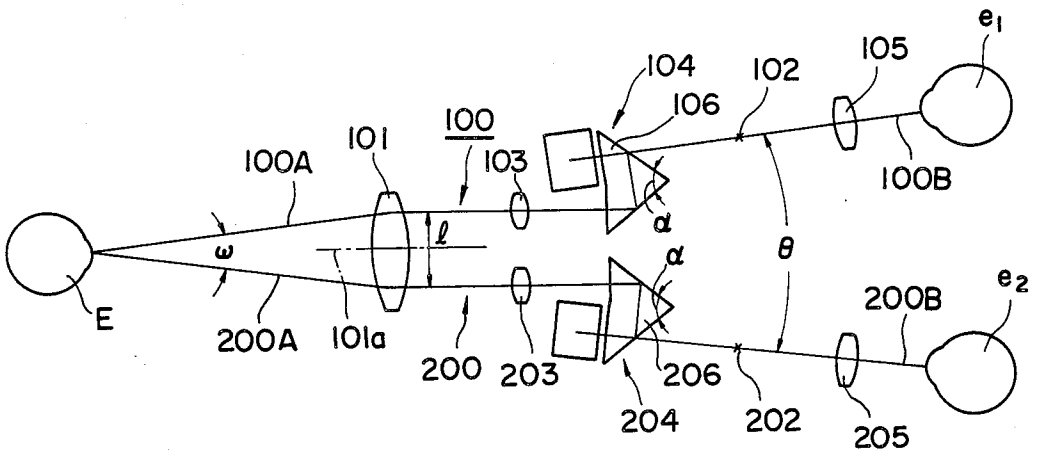


FIG. 1 PRIOR ART

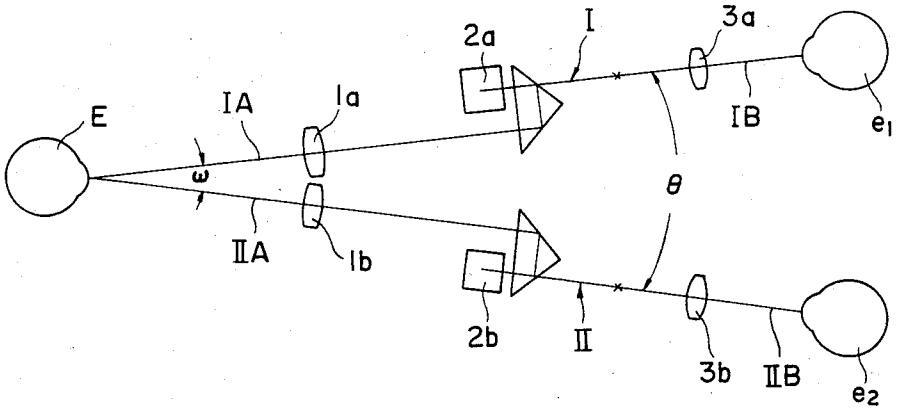


FIG. 2 PRIOR ART

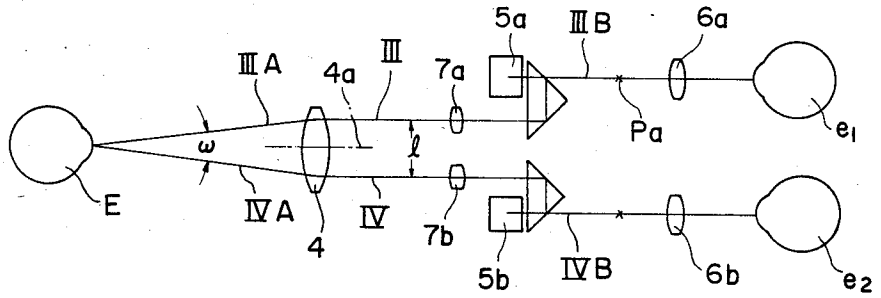


FIG. 3

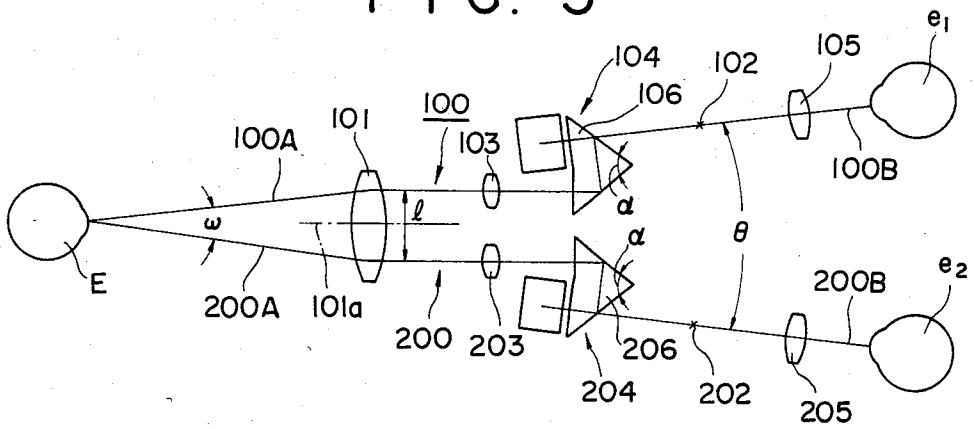


FIG. 5

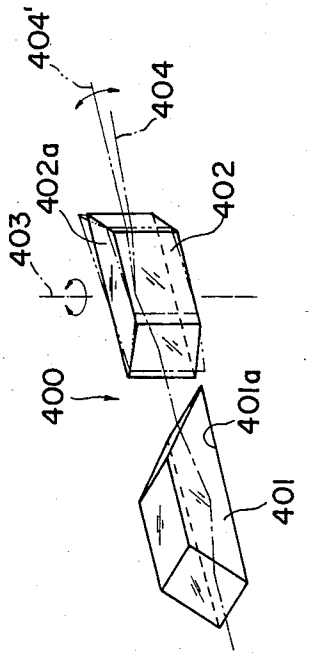


FIG. 4

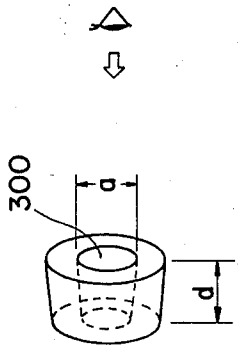


FIG. 7

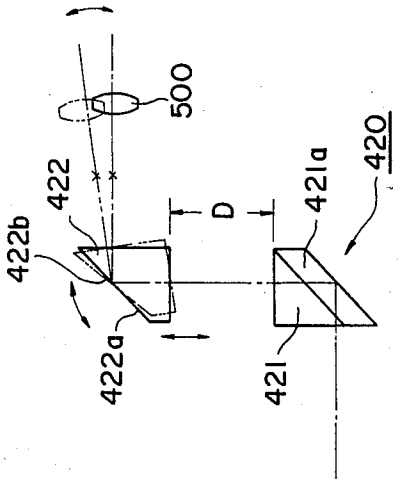


FIG. 6

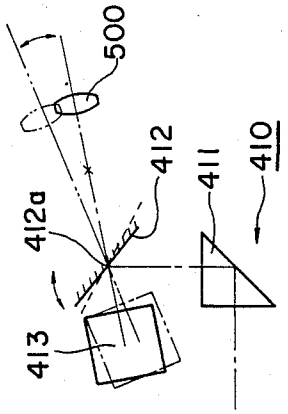
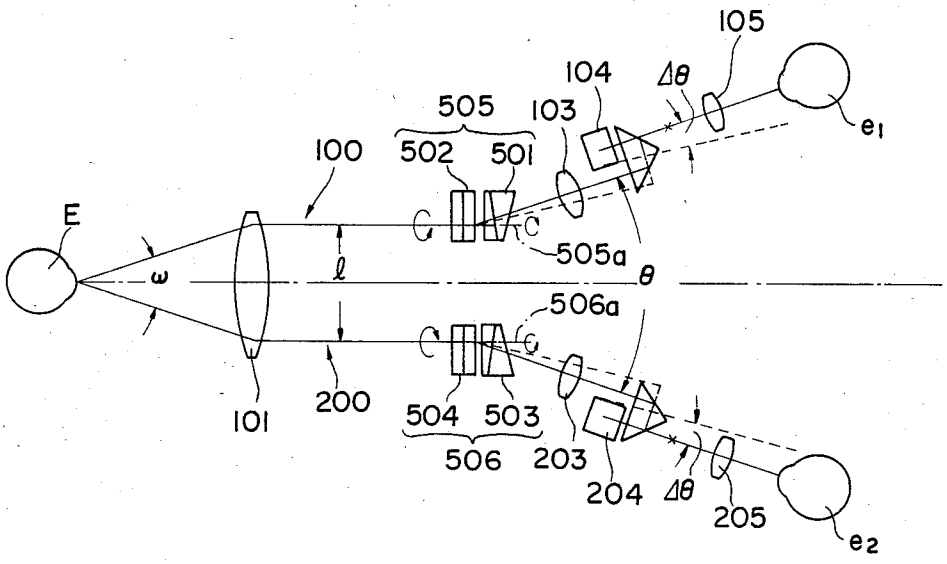


FIG. 8


105
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STEREO-MICROSCOPE WITH A COMMON OBJECTIVE LENS SYSTEM

BACKGROUND OF THE INVENTION

This invention relates to an optical constitution of a stereo-microscope and more particularly to an optical constitution of an ophthalmological slit lamp stereo-microscope.

The optical type of a stereo-microscope is largely classified into the Greenough type or the Galileo type. The Greenough type is, as shown in FIG. **1**, constituted as such that two optical paths I,II are crossed on a plane of an object to be observed at an included angle ω. The optical paths I,II have objective lens systems **1***a*,**1***b*, erecting optical systems **2***a*, **2***b* and ocular systems **3***a*, **3***b*, respectively, and are constituted as such that an incident optical axis IA toward the objective lens is parallel to an observation optical path **1**B of the ocular (likewise, in the optical path II, the incident optical axis IIA is parallel to the observation optical axis IIB). In this case, the included angle ω is set to be a convergent angle somewhere between from 10° to 16° which is very close to natural sighting, when an observer's naked eyes e_1, e_2 observe the object E from a near distance without using a microscope. Therefore, the Greenough type microscope has such an advantage as that a natural stereoscopic sighting can be obtained, since the included angle ω (hereinafter referred to as a stereo angle) defined between the incident optical axes IA, IIA toward the objective lens is equal to the included angle θ (hereinafter referred to as an observation angle) defined between the observation optical axes IB, IIB of the ocular systems **3***a*, **3***b* and the stereo angle ω is formed to be equal to the convergent angle of a natural sighting. However, it had such disadvantages that since the optical paths I, II are crossed, machining for mounting optical parts are complicated, and the constitution of the focussing and variable power optical systems (not shown) which are normally arranged between the objective lens system **1***a*, (**1***b*) and the erecting optical system **2***a*, (**2***b*) are also complicated.

On the other hand, the Galileo type stereo-microscope is, as shown in FIG. **2**, constituted as such that the optical paths are parallel to the optical axis, respectively. The optical path III comprises an objective lens system **4**, an imaging lens system **7***a* for producing an intermediate image Pa and an ocular system **6***a* for observing the intermediate image Pa. The optical path IV has the objective lens system **4** as a common objective lens and comprises an imaging lens system **7***b*, an erecting optical system **5***b* and an ocular system **6***b* same as in the case mentioned with regard to the optical path III. The optical axes of the both imaging systems **7***a*, **7***b* are parallel with respect to each other and also parallel to the optical axis **4***a* of the objective lens system **4**. The observation optical axes IIIB, IVB of the ocular systems **6***a*, **6***a* are likewise constituted to be parallel with respect to the axes of the imaging lens systems **7***a*, **7***b*. The stereo angle ω defined between the incident optical axes IIIA, IVA toward the objective lens system **4** is decided depending on the base length l which is defined by the distance between the imaging lens systems **7***a*, **7***b*. Because of the parallax due to this stereo angle ω, the object E can be observed stereoscopically, although the observation angle θ defined between the observation axes IIIB, IVB is 0. The Galileo type stereo-microscope had such advantages as that since the two optical paths III, IV are parallel with respect to each other as mentioned above, the constitution of the optical system is simple, the constitution of the focussing structure and variable power structure is simple, and attached optical paths such as, for example, a camera optical system and a side observation scope can be comparatively easily added.

Generally speaking, human eye does not have a convergence between the lines of sight of the both eyes when it is in the far distance sighting state, and can be maintained in a comfortable observation state with less fatigue and without accomodation of the crystalline lens. This is also true with respect to a microscopic observation. It is said that the Galileo type microscope in which the both observation optical axes IIIB, IVB are arranged to be parallel with respect to each other is advantageous when used for a long time observation compared with the Greenough type microscope in which the both axes are convergent with respect to each other since the former is less fatiguing during observation.

However, a microscope is a device for enlarging and observing a tiny object placed in a near position. In the Galileo type microscope, although the luminous flux is entered into the eye as if it were entered from an infinite far distance, optically, the human brain has a preliminary information that it is looking a near object. Therefore, it had such a disadvantage as that there is a gap between the natural sense of sighting and the optical sense of sighting. Particularly, due to the information of the convolution motion, or due to the observation of parallax caused by the stereo angle ω without the presence of the convergence motion information, the observer had an unnatural stereoscopic sighting stronger than normal stereoscopic sense.

Furthermore, in the case of, for example, a stereo-microscope of a slit lamp which is used in the ophthalmological field, a doctor is often required to observe the eyes to be observed with the naked eye in order to adjust, for example, the illumination position, the width and length of the slit, or to conduct a simple operational treatment, the doctor's observation eye is put in a near range sighting state. Then, the doctor has to look through the microscope and diverges the eye so that it becomes in a far range sighting state for observing the object stereoscopically. However, there was such disadvantage as that instant image separation and stereoscopic sighting were difficult to be effected.

The exaggeration of a stereoscopic sense and the necessity of effecting the divergence motion from the naked eye sighting to the stereoscopic sighting deny the littleness of the observation fatigue hitherto advocated with regard to the Galileo type stereo-microscope. On the contrary, the observation fatigue is found to be greater than the Greenough type microscope. In addition, there found to be such disadvantages as, for example, incorrect observation, or mis-treatment due to erroneous recognition of the actual distance. All these disadvantages with respect to the Galileo type microscope are remained yet to be solved in spite of the afore-mentioned advantages it has.

On the other hand, in the Greenough type microscope, although it had such advantage as that the object can be observed in the same stereoscopic sighting as that with respect to the near sighting with the naked eye even under the microscopic observation as mentioned above, when it is required to observe a very small un-

evenness, there are instances where it is difficult to observe such unevenness with the stereoscopic sense which is close enough to the natural sighting. Therefore, there was a request to strengthen the stereoscopic sense with regard to the Greenough type microscope.

SUMMARY OF THE INVENTION

The present invention is accomplished in order to eliminate the above-mentioned disadvantages and also to meet with the request with regard to the conventional stereo-microscope.

In order to achieve the above object and others there is essentially provided a stereo-microscope comprising a common objective lens system, a first and a second imaging lens system having optical paths parallel to that of the objective lens system and producing intermediate images of an object to be observed, a first and a second optical path deflecting means arranged behind said respective imaging lens systems for deflecting the respective ejection bundle of rays outwardly with respect to the optical path of said objective lens system and a first and second ocular systems arranged behind said respective optical path deflecting means for observing the respective intermediate images, characterized in that a stereo angle ω which is to be decided depending on the base length between said first and second imaging lens systems and an observation angle θ which is defined between the observation optical paths of said first and second ocular systems are equal.

There is also provided a stereo-microscope comprising an objective optical system for producing a first and second intermediate images of an object to be observed, a first and second ocular systems for observing said first and second intermediate images, respectively, a first and a second erecting optical system arranged in front of said first and second ocular systems such that said intermediate images can be observed as erecting images, and means for varying an observation angle θ defined between the observation optical axes of said first and second ocular systems so that the stereoscopic observation sense of an observer can be varied.

BRIEF DESCRIPTION OF THE DRAWING

The novel features and advantages of the present invention will become more apparent from the following description and claims when read together with the accompanying drawings wherein:

FIG. **1** illustrates the optical arrangement showing a conventional Greenough type stereo-microscope;

FIG. **2** is the optical arrangement showing a conventional Galileo type stereo-microscope;

FIG. **3** illustrates the optical arrangement showing the first embodiment of the present invention;

FIG. **4** is a perspective view of the object to be observed which was used for a stereoscopic test;

FIG. **5** is the second embodiment of the present invention wherein the second embodiment is shown by way of only an erecting optical system of one of the optical paths;

FIG. **6** illustrates the third embodiment of the present invention wherein the third embodiment is shown by way of an erecting optical system of one of the optical paths only;

FIG. **7** is the fourth embodiment of the present invention wherein the fourth embodiment is shown by way of only an erecting optical system of one of the optical paths; and

FIG. **8** is the optical arrangement showing the fifth embodiment of the present invention.

DETAILED DESCRIPTION OF THE EMBODIMENTS

Preferred embodiments of the present invention will be described hereunder with reference to the accompanying drawings wherein like numerals denote like or corresponding parts throughout.

FIG. **3** illustrates the optical arrangement of a stereo-microscope of a slit lamp as an example. This stereo-microscope is constituted with a first optical path **100** and a second optical path **200**. The first optical path **100** comprises a common single objective lens system **101**, an imaging lens system **103** for producing an intermediate image **102** and having its optical axis parallel to the optical axis **101***a* of said common single objective lens system **101**, a modified Porro prism as an erecting optical system which serves to deflect the optical path and an ocular lens system **105** for observing the intermediate image **102**. On the other hand, the second optical path **200** comprises the common single objective lens system **101**, an imaging lens **203** for producing an intermediate image **202** and having its optical path parallel to the optical axis **101***a* of said single objective lens system **101** and a modified Porro prism **204** as an erecting optical system which serves to deflect the optical path and an ocular lens system **205** for observing the intermediate image **202**.

The respective apical angle α of prisms **106**, **206** constituting the modified Porro prisms **104**, **204** are arranged to be $90°-\omega/4$. ω is a stereo angle defined between an incident optical axis **100**A of the first optical path **100** and an incident optical axis **200**A of the second optical path **200** toward the object E which is decided depending on the base length l between the two imaging lenses **103** and **203**. Because of the relationship between said α and ω, an observation angle θ defined between the observation optical axis **100**B of the first optical path **100** and the observation optical axis **200**B of the second optical path **200** is constituted to be equal to the stereo angle ω.

The following test results proved the fact that when the stereo angle ω and the observation angle θ are constituted to be equal, an observation sense which is closest enough to the natural stereoscopic sense can be obtained.

As shown in FIG. **4**, the test was carried out as such that an object of a hollow cylindrical member 300 having an inner diameter a=2.0 mm and a depth d=2.0 mm (depth/inner diameter=1) was subjected to the observation with the naked eye of 10 persons shown in Table 1 and thereafter said object was subjected to the observation of the 10 persons using 5 different kinds of stereo-microscopes shown in Table 2. The 10 persons were requested to answer in five grades evaluation from 1 to 5 whether the ratio between the inner diameter a and the depth d under each kind of microscopic observation was larger or smaller compared with that observed with the naked eye. In this case, numeral **3** represents the equal degree as that observed with the naked eye. The numerals **4** and **5** represent the stronger stereoscopic sense, i.e., the larger ratio of the depth/the inner diameter, and the numerals **2** and **1** represent the reversed fashion, i.e., the smaller ratio of the depth/the inner diameter. The results are shown in Table 3.

TABLE 1

OBSERVER	SEX	AGE	RACE
A	♂	31	JAPANESE
B	♂	32	"
C	♂	35	"
D	♂	40	"
E	♂	45	"
F	♂	45	"
G	♂	45	"
H	♂	50	"
I	♂	30	AMERICAN (WHITE)
J	♀	22	JAPANESE

TABLE 2

KIND	TYPE	STEREO ANGLE ω	OBSERVATION ANGLE θ	OBSERVATION MAGNIFICATION
NO. 1	GREENOUGH	13°	13°	16×
NO. 2	GALILEO	13°	0 (PARALLEL)	16×
NO. 3	INVENTION (GALILEO)	13°	8°	16×
NO. 4	INVENTION (GALILEO)	13°	13°	16×
NO. 5	GREENOUGH	13°	0 (PARALLEL)	16×

Remark:
The above NO. 3 INVENTION (GALILEO) means the present invention of a Galileo type.

TABLE 3

	KIND				
OBSERVER	NO. 1	NO. 2	NO. 3	NO. 4	NO. 5
A	3	5	4	3	5
B	3	5	4	3	5
C	3	5	3	3	5
D	3	5	4	3	5
E	3	5	3	3	5
F	3	5	3	3	5
G	3	5	4	3	5
H	3	5	4	3	5
I	3	5	3	3	5
J	3	5	3	3	5
AVERAGE	3	5	3.5	3	5

As apparent from the results shown in Table 3, the observers' stereoscopic sense is most intimately related to the observation angle θ; the smaller the observation angle θ, the stronger the stereoscopic sense regardless of whether the microscope of the present invention, Galileo type, or Greenough type is used. Also, it is confirmed with regard to the both types that when the stereo angle θ and the observation angle θ are equal, a natural stereoscopic sense like that observed with the naked eye can be obtained.

As described in the foregoing, according to the above embodiment, since the optical axes of the imaging lens systems **103, 203** remain parallel with respect to each other, a variable power optical system and a focussing optical lens system (the imaging lens system may serve as this) as well as the driving mechanism thereof, all of which are arranged at the front or back of said imaging lenses **103, 203** can be constituted simply compared with the Greenough type microscope. Furthermore, it has not only an advantage which the Galileo type stereo-microscope has, i.e., attaching optical systems such as a camera optical system and the like can be mounted simply, but also an advantage which the Greenough type stereo-microscope has, i.e., a microscope observation without losing a natural observation sense can be obtained as in the case when observed with the naked eye, thus achieving a new Galileo type stereo-microscope.

In the above first embodiment, the stereo angle ω and the observation angle θ are arranged to be equal. However, the observation angle θ may be varied in the both Greenough type and the Galileo type stereo-microscopes so that the stereoscopic sense under the microscopic observation can be greater or smaller than the one observed with the naked, eye, where necessary.

FIG. **5** illustrates an embodiment of the present invention having such observation angle adjusting means which is the means for deflecting the optical path of the both types shown in FIGS. **1** and **2**, and shows a modified embodiment of an erecting optical system by way of only one optical path of the erecting optical system. An erecting optical system **400** as means for deflecting the optical path comprises two Dove prisms **401** and **402**. The reflection plane **402***a* of the second Dove prism **402** is arranged to be perpendicular with respect to the reflection plane **401***a* of the first Dove prism **401**. The erecting optical system is constituted as such that the reversing image can be observed as an erecting image by means of said both Dove prisms. Furthermore, it has means for adjusting the observation angle by rotating the second Dove prism **402** around a rotary axis **403** so that the observation optical axis **404** can be moved within a horizontal plane and is constituted as such that a varied stereoscopic sense can be obtained by varying the observation angle θ.

FIG. **6** illustrates another embodiment for varying the stereoscopic sense. An erecting optical system **410** as means for deflecting the optical path of one optical path comprises a first right angle prism **411**, a rotary mirror **412**, and a second right angle prism **413** having a ridgeline within a plane perpendicular to the ridgeline of the first right angle prism **411** and has such means for adjusting the observation angle in such a manner as that the rotary mirror **412** and the second right angle prism **413** can be rotated around a rotary axis **412***a* integrally with an ocular **500**. With such constitution, the observation angle θ is varied so that a varied stereoscopic sense can be obtained.

FIG. **7** illustrates another embodiment for varying the stereoscopic sense. An erecting optical system **420** as means for deflecting the optical path of one optical path comprises a roof right angle prism **421** having a roof plane **421***a*, and a second right angle prism **422**. Said second right angle prism **422** is constituted with means for adjusting the observation angle so that it can be rotated integrally with the ocular **500** around a rotary axis **422***b* within the reflection plane **422***a*. With such constitution, the observation angle θ is varied so that a varied stereoscopic sense can be obtained. Furthermore, the distance D between the second right angle prism **422** and the roof right angle prism **421** can be varied so that the observation optical system can be

adjusted in accordance with the distance between the observer's pupils.

The above-mentioned means for adjusting the observation angle can be applied not only to the embodiment in FIG. **3** but also to the Greenough type stereo-microscope in FIG. **1** and the Galileo type stereo-microscope in FIG. **2**. In such cases, the objective lens system and the imaging lens system are commonly used with regard to the Greenough type, and the objective optical system comprises a first objective lens system **1***a* for producing the first intermediate image and a second objective lens system **1***b* for producing the second intermediate image and said first and second objective lens systems **1***a*, **1***b* are crossed with respect to the optical axes in order to define a stereo angle ω.

As described in the foregoing, when a stereo-microscope having means for adjusting the observation angle in FIGS. **5** to **7** is used, a stereoscopic sense under a microscopic observation can be freely chosen and it is very convenient for a stereoscopic observation.

Furthermore although the above-mentioned embodiments use a reflection plane in order to obtain the observation angle θ, the present invention is not limited to it. Alternatively, the refraction action of a prism can be used. FIG. **8** illustrates such one example, wherein a deflection prism **505** is arranged between the objective lens **101** and the imaging lens **103** of the first optical path **100** and a deflection prism **506** is likewise arranged between the objective lens **101** and the imaging lens **203** of the second optical path **200** in order to obtain an observation angle θ. According to this embodiment, the deflection prism **505** is constituted with a rotary prism comprising achromatic tiny prisms **501** and **502**. These employ rotary prisms which are rotated in the opposite direction and in the same amount, respectively, around a rotary axis **505***a*. The deflection prism **506** is likewise constituted with a rotary prism comprising achromatic tiny prisms **503**, **504**. When the rotary prisms as means for adjusting the observation angle are activated, the observation angle θ is varied. In this case, the ocular systems arranged at the right and left sides after the imaging lenses **103**, **203** move with rotary prisms in such a manner that their crossing angle changes with the observation angle θ, so that no axial inconsistency takes place.

While the present invention has been particularly shown and described in its preferred forms with certain degree of particularity, it will be understood by those skilled in the art that the foregoing and other changes may be made without departing from the spirit and the scope of the invention as hereinafter claimed.

What is claimed is:

1. In a stereo-microscope comprising a common objective lens system with a stereo angle ω defined as the angle between an incident optical axis of a first optical path and an incident optical axis of a second optical path toward an object; a first and second imaging lens systems having optical axes parallel to that of the objective lens system and producing intermediate images of said object to be observed; a first and second optical path deflecting means arranged behind said respective imaging lens systems for deflecting the respective ejection bundle of rays outwardly with respect to the optical axis of said objective lens system; and a first and second ocular systems arranged behind said respective optical path deflecting means for observing the respective intermediate images, characterized in that said stereo angle ω and an observation angle θ which is defined as the angle between the observation optical axes of said first and second ocular systems are equal.

2. A stereo-microscope according to claim **1**, wherein said first and second optical path deflecting means serve also as erecting optical systems.

3. A stereo-microscope according to claim **2**, wherein said first and second optical path deflecting means each comprise a first prism having a first and second reflecting plane for inverting the horizontal direction of the bundle of rays ejected from the imaging lens systems, a second prism having a third and fourth reflecting plane for inverting the vertical direction of the bundle of rays ejected from said first prism and for guiding the same to said ocular systems, characterized in that said first and second reflecting planes intersect each other at a crossing angle having the following relation: $\alpha=90°-\omega/4$.

4. A stereo-microscope comprising:

a common objective lens system in front of an object to be observed; said objective lens focusing at said object with a first and a second incident optical axis; said first and second incident optical axis intersecting each other with a stereo angle ω;

first and second imaging systems each having an optical axis corresponding to one of said first and second incident optical axis and producing an intermediate image of said object, said optical axes having a base distance l, said base distance l limiting the amount of said stereo angle ω;

first and second erecting optical systems arranged behind said respective imaging systems for erecting said intermediate images; and

first and second ocular systems arranged behind said respective erecting optical systems for observing said respective intermediate images, said first and second ocular systems having an observation angle θ between each other defined by their observation optical axes, said observation optical axes of said first and second ocular systems being parallel to said first and second incident optical axes respectively, and said observation angle θ being equal to said stereo angle ω.

5. The stereo-microscope of claim **4**, wherein said imaging system comprises a first and a second imaging lens systems having optical paths parallel to that of said objective lens system and producing intermediate images of said object to be observed.

6. The stereo-microscope of claim **5**, wherein said first and second erecting optical systems serve also as optical path deflecting means behind said respective imaging lens systems for deflecting the respective bundle of rays outwardly with respect to the optical axis of said objective lens system such that observation angle is equal to said stereo angle ω.

7. The stereo-microscope of claim **6**, wherein said erecting optical systems each comprise a first prism having a first and second reflecting plane for inverting the horizontal direction of the bundle of rays ejected from the imaging lens systems, a second prism having a third and a fourth reflecting plane for inverting the vertical direction of the bundle of rays ejected from said first prism and for guiding the same to said ocular systems, characterized in that the said first and second reflecting planes intersect each other at a crossing angle having the following relation: $\alpha=90°-\omega/4$.

8. The stereo-microscope of claim **6**, wherein said optical path deflecting means each comprise a first and a second Dove prism each having a reflecting plane and

means for adjusting the observation angle θ by rotating said second Dove prism around a rotary axis.

9. The stereo-microscope of claim **6**, wherein said optical path deflecting means each comprise a first right angle prism, a rotary mirror and a second right angle prism having a ridgeline perpendicular to the ridgeline of said first right angle prism, and means for adjusting observation angle θ by rotating rotary mirror and said second right angle prism around a rotary axis integrally with said corresponding ocular system.

10. The stereo-microscope of claim **6**, wherein said optical path deflecting means each comprise a roof right angle prism and a right angle prism; said right angle prism having means for adjusting said observation angle θ by rotating it integrally with said corresponding ocular system and having means for adjusting the distance between said roof right angle prism and said right angle prism.

11. The stereo-microscope of claim **4**, wherein said imaging system comprises a deflection prism and an imaging lens systems; said deflecting prism arranged between said objective lens and said imaging lens system in order to obtain said observation angle θ.

12. The stereo-microscope of claim **11**, wherein said deflection prism comprises two achromatic tiny prisms which are rotated in opposite direction and in the same amount integrally with said imaging lens system, said erecting system, and said ocular system as means for adjusting said observation angle θ.

* * * * *

United States Patent [19]

Schlapp et al.

[11] **Patent Number: 4,572,612**

[45] **Date of Patent: Feb. 25, 1986**

[54] **PHOTOGRAPHIC OBJECTIVE WITH A FASTENING DEVICE**

[75] Inventors: **Werner Schlapp**, Asslar; **Willi Wiessner**, Wetzlar, both of Fed. Rep. of Germany

[73] Assignee: **Ernst Leitz Wetzlar GmbH**, Wetzlar, Fed. Rep. of Germany

[21] Appl. No.: **537,700**

[22] Filed: **Sep. 30, 1983**

[30] **Foreign Application Priority Data**

Oct. 2, 1982 [DE] Fed. Rep. of Germany ... 8227716[U]

[51] **Int. Cl.**[4] **G02B 7/02**; G03B 17/00

[52] **U.S. Cl.** **350/257**; 354/293

[58] **Field of Search** 350/245, 251-252, 350/257; 354/81, 293; 248/187

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Primary Examiner—William H. Punter

Attorney, Agent, or Firm—Schwartz, Jeffery, Schwaab, Mack, Blumenthal & Evans

[57] **ABSTRACT**

Disclosed is a photographic objective with a long focal length and a fastening device for a stand comprises a tubular structural element carrying optical elements, surrounded by an essentially annular holder. This holder is stationary in the axial direction and rotatable around the structural part. In addition to the fastening element capable of being joined to the stand, there is mounted in the outer wall of the holder means for locking the holder in predetermined positions.

6 Claims, 2 Drawing Figures

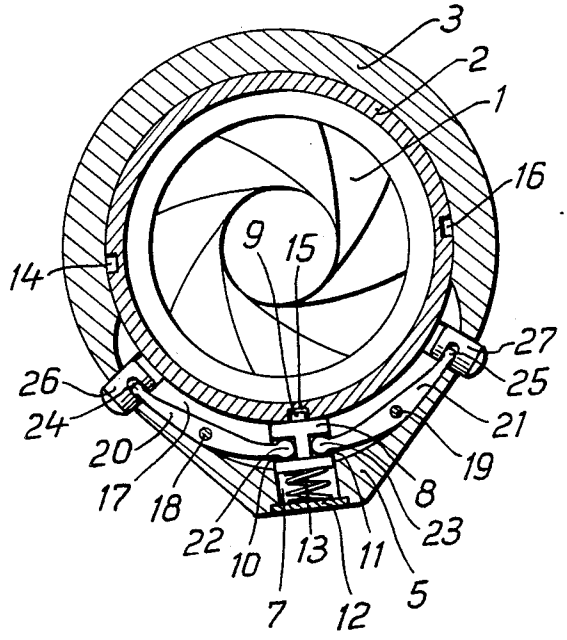

Fig. 1

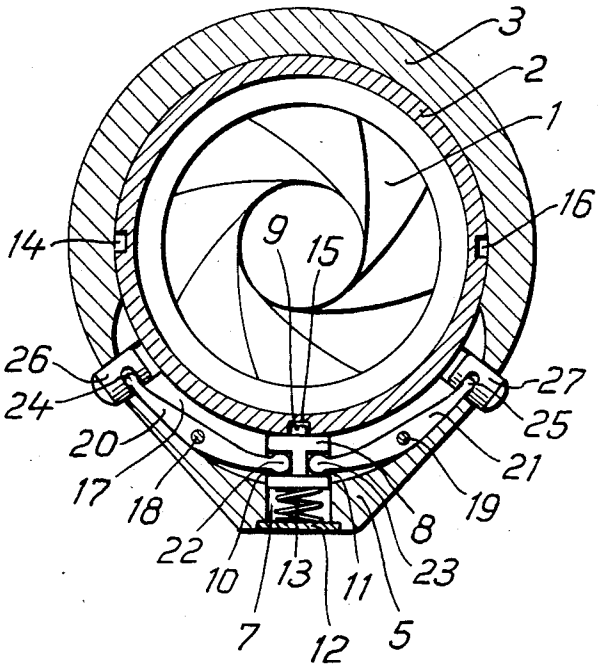
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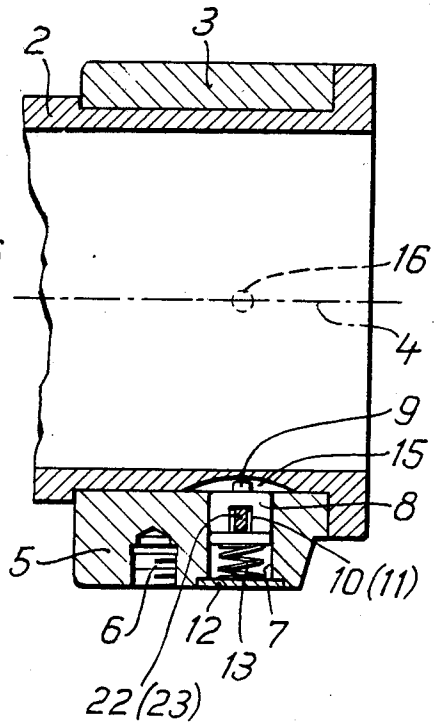
Fig. 2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PHOTOGRAPHIC OBJECTIVE WITH A FASTENING DEVICE

BACKGROUND OF THE INVENTION

The present invention relates to a photographic objective having a long focal length with a fastening device for a stand or tripod.

It is known to provide on the external wall of the tube of a photographic objective having a long focal length a permanent platform with a threaded receiver for a stand or tripod. The pivoting of a camera attached to such an objective for the selection of a desired image format is possible only with the use of additional adjustable means, such as, for example, a ball-and-socket joint.

In order to avoid such an unstable configuration, it is known to mount the platform having the threaded receiver for the tripod by means of an annular element which surrounds the tube of the objective, and is rotatable on the objective. The fixing of the pivoting position desired is effected by means of at least one clamping screw or clamping piece. The disadvantage of such an arrangement resides in the deformation of the objective tube by the pressure of the clamping screw(s) or the clamping pieces and the resulting stressing of the optical element mounted in the tube.

For this reason, there are already known certain fastening devices for a stand or tripod which are fixed in predetermined locations by means of notches or detends. The locked in positions are released by means of a push button arranged on one side of the tube. The disadvantages of this arrangement is the poor, cumbersome operability of the push button.

SUMMARY OF THE INVENTION

It is therefore an object of the present invention to provide a photographic objective with a long focal length having a fastening device for a stand or tripod whereby the release of the fastening device locked in a predetermined position may be effected in a simple and convenient manner.

In accordance with the present invention there has been provided a photographic objective having a long focal length and being adapted for attachment to a supporting device, comprising a tubular structural part of the objective which carries at least one optical element; an essentially annular holder which surrounds the tubular part, is stationary in the axial direction and is capable of rotating around the tubular part; a fastening element mounted on the holder for attachment to the support device; and means, mounted in the external wall of the holder, for locking the holder in predetermined positions with respect to the circumference of the tubular part. In a preferred embodiment of the invention, the holder includes a portion on one side thereof which is enlarged in the direction perpendicular to the optical axis of the objective, this enlarged portion forming a widened support element, and the fastening element and the locking means are mounted on the support element.

Further objects, features and advantages of the present invention will become apparent from the detailed description of the invention which follows, when considered in light of the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWING

In the drawing:

FIG. 1 is a rear elevation of an objective tube, partially in section; and

FIG. 2 is a lateral cross-sectional view of the tube.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

According to the invention, a tubular structural part of the objective, which carries the optical components, is surrounded by an essentially annular holder, immobilized in the axial direction and rotatable around the structural part. In addition to the fastening element which is joinable to the stand, means for the locking of the holder in predetermined positions are mounted in the external wall of said holder.

In the drawing the invention is represented schematically by an examplary embodiment, which shall be described in more detail hereinbelow.

In FIG. 1, optical elements are indicated by an iris diaphragm 1. They are carried by a tubular structural element 2 of a photographic objective, which is surrounded by an essentially annular holder 3. The holder 3 is mounted on said element 2 so as to be stationary in the direction of the axis 4, but capable of rotating around the element 2. Considered in section perpendicular to the optical axis 4, the holder 3 is expanded on one side and is widened into a support piece 5, in which a threaded piece 6 (FIG. 2) is mounted in a recessed fashion for the fastening of a photographic objective on a stand or tripod.

Adjacent to the threaded piece 6, a bore hole 7 is provided in the support piece 5, into which a locking bolt or pin 8 is inserted. The locking bolt or pin 8 is equipped with a rectangular nose 9 and with registering slots 10, 11 located perpendicularly to its longitudinal axis and extending parallel to each other. With its nose 9, the locking bolt 8 drops under the pressure of a spring 13, inserted in the bore 7 and resting against a cover plate 12 in the support piece 5, into the corresponding recesses 14, 15, 16 on the tubular structural part 2, thereby locking the holder 3 in the position selected.

A groove 17 is provided on the inside of the carrier piece 5, in which the levers 20, 21 pivot around the axles 18, 19, which extend parallel to the optical axis 4.

With their inner ends 22, 23, the levers 20, 21 engage the registering slots 10, 11 of the locking bolt or pin 8. Their outer ends 24, 25 are connected with the pressure pieces 26, 27, which are supported in the holder 3. Upon the actuation of one of the pressure pieces 26 or 27 the corresponding lever 20 or 21 lifts the nose 9 of the locking bolt or pin 8, against the force of the spring 13, from one of the recesses 14, 15 or 16.

What is claimed is:

1. A photographic objective having a long focal length and being adapted for attachment to a supporting device, comprising:

a tubular structural part of the objective which carries at least one optical element and which has a plurality of recesses arranged radially on the external wall thereof;

an essentially annular holder which surrounds said tubular part, is stationary in the axial direction and is capable of rotating around said tubular part;

a fastening element mounted on said holder for attachment to the support device; and

means, mounted in the external wall of said holder, for locking the holder in said recesses, said recesses arranged in predetermined positions with respect to the circumference of said tubular part;

wherein said holder includes a portion at one side thereof which is enlarged in the direction perpendicular to the optical axis of the objective, said enlarged portion forming a widened support element having a face for application to said supporting device, and wherein the fastening element and the locking means are mounted on said support element.

2. A photographic objective according to claim 1, wherein said locking means comprises at least one latching element inserted in a radially directed bore of the holder and a spring contained in said bore and biasing the latching element toward said tubular part for engaging said plurality of recesses.

3. A photographic objective according to claim 2, wherein said latching element comprises a latching pin.

4. A photographic objective according to claim 3, wherein the inwardly directed end of said latching pin has a conical shaped nose portion for engaging with one of said recesses.

5. A photographic objective according to claim 3, wherein said latching pin includes at least one recess on its side and said holder includes a circumferentially extending recess therein, and wherein said locking means further comprises at least a lever pivotably mounted in said holder recess, with one end of said lever engaging in said recess in said latching pin, and at least one actuating element located on the exterior of said holder and engaging the other end of said lever, for actuating said lever to lift said locking pin out of its locking position.

6. A photographic objective according to claim 5, wherein said latching pin comprises two recesses in opposite sides thereof and said latching means comprises two of said levers and two of said actuating elements positioned on opposite sides of said latching pin.

* * * * *

United States Patent [19]

Arai et al.

[11] **Patent Number: 4,547,808**

[45] **Date of Patent: Oct. 15, 1985**

[54] **PHOTOMETRIC CIRCUIT INCORPORATED IN OBJECTIVE PROVIDED WITH AUTOMATIC DIAPHRAGM FOR CLOSED CIRCUIT TELEVISION (CCTV) CAMERA**

[75] Inventors: **Masayuki Arai; Terumi Ogasawara; Tohru Shikano,** all of Tokyo, Japan

[73] Assignee: **Asahi Seimitsu Kabushiki Kaisha,** Tokyo, Japan

[21] Appl. No.: **505,460**

[22] Filed: **Jun. 17, 1983**

[30] **Foreign Application Priority Data**

Dec. 27, 1982 [JP] Japan 57-234113

[51] **Int. Cl.**[4] **H04N 5/26**

[52] **U.S. Cl.** **358/228**

[58] **Field of Search** 358/217, 209, 174, 228

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Primary Examiner—Gene Z. Rubinson
Assistant Examiner—Robert Lev
Attorney, Agent, or Firm—Birch, Stewart, Kolasch & Birch

[57] **ABSTRACT**

A control circuit for automatically opening and closing the diaphragm of the objective lens of a closed circuit television (CCTV) camera, including a variable gain inverting amplifier for amplifying and inverting video signals from the camera, a voltage doubler and rectifier coupled to the output of the inverting amplifier, a reference voltage generator, a diaphragm control assembly for comparing said reference voltage with signals output from said voltage doubler and opening and closing said diaphragm in response to the results of said comparison, and a series circuit including a clipping diode and variable resistor coupled between the input and output of the inverting amplifier. The clipping diode clips negative going portions of signals output from said inverting amplifier and adjustment of said variable resistor selects different light modes by controlling the degree of clipping.

3 Claims, 10 Drawing Figures

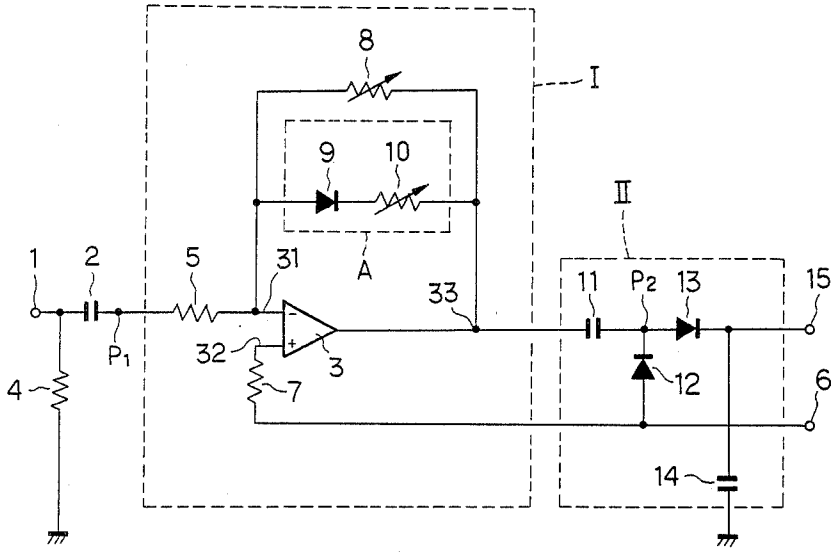


fig 1

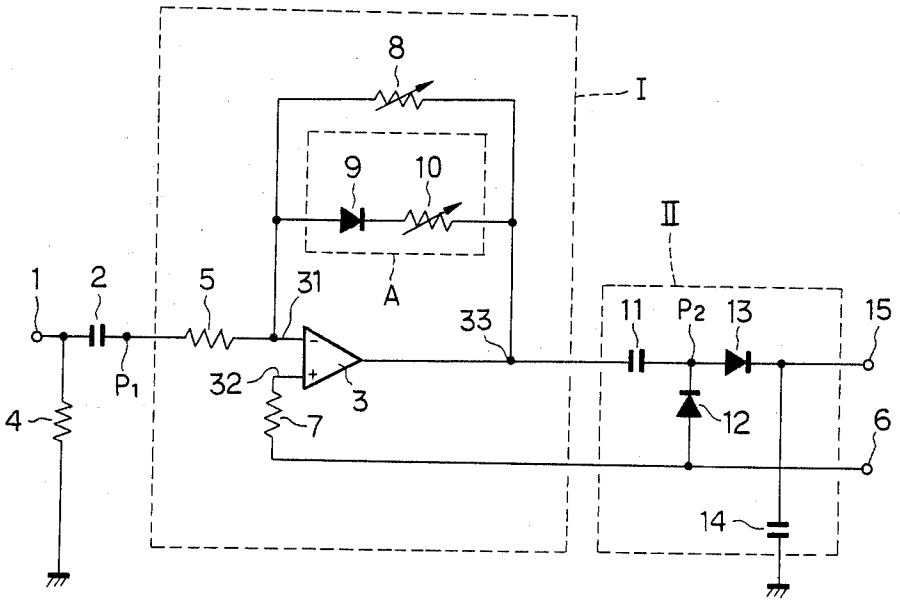


fig 2 (a)

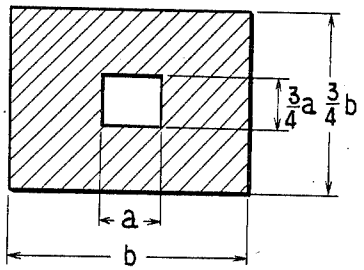


fig 3

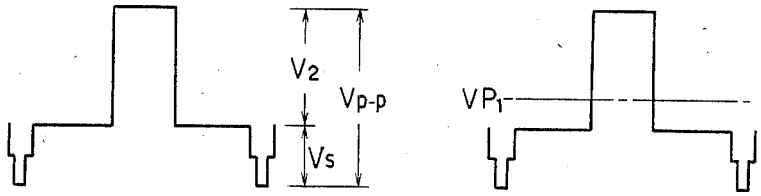
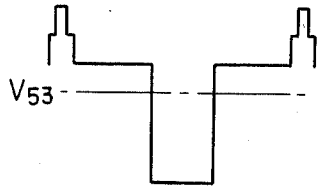


Fig. 2 (b)

Fig 4(a)



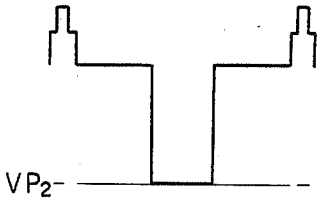
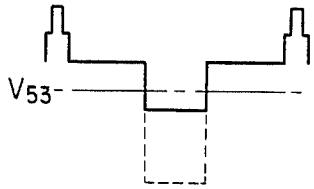


Fig. 4(b)

Fig 5(a)



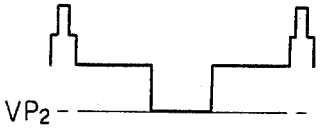


Fig. 5(b)

Fig 6

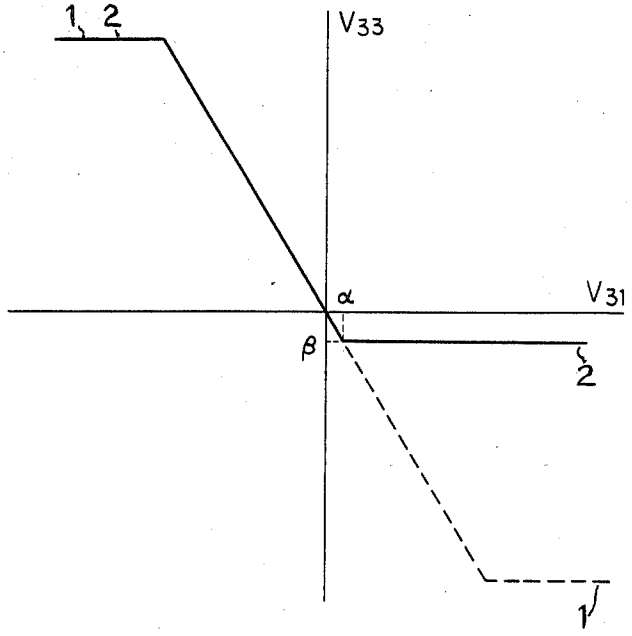
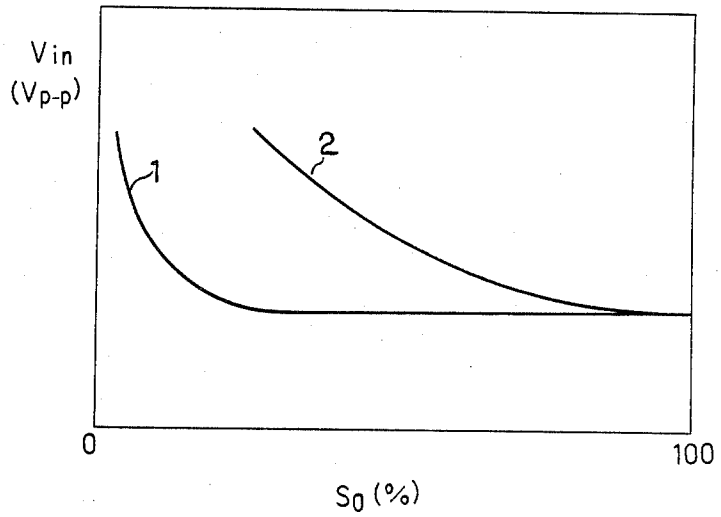


Fig 7



PHOTOMETRIC CIRCUIT INCORPORATED IN OBJECTIVE PROVIDED WITH AUTOMATIC DIAPHRAGM FOR CLOSED CIRCUIT TELEVISION (CCTV) CAMERA

BACKGROUND OF THE INVENTION

The present invention relates to a photometric circuit incorporated in an objective lens assembly including an automatic diaphragm for a closed circuit television (CCTV) camera.

In an objective lens assembly provided with an automatic diaphragm so arranged that the DC voltage obtained by rectifying video signals coming from the television camera are utilized as the control signals for diaphragm control to obtain the optimum image, the photometric circuit serving as means for detection of an object to be picked up is very important, since the photometric or light measuring mode for this objective lens depends on the capabilities of such a photometric circuit.

To obtain the optimum image, not only absolute brightness of an object to be picked up, but also light and shade ratios of different areas in the same object, i.e., contrast, are important factors to be considered. The contrast lies within a range of tens: one even in cloudy daylight and within a range of hundreds: one in cloudless daylight. In the image reproduced by a television, on the contrary, the contrast lies within a range as narrow as of 30 to 40:1. When a bright area and a dark area are simultaneously contained in the same object, therefore, it is necessary to decide whether said bright area is selected as the main object or said dark area is selected as the main object to be picked up, since it is impossible to see both areas at the same time.

In principle, a so-called average light measuring mode is suitable for the case in which the dark area is selected as the main object to be picked up, while a so-called peak light measuring mode is suitable for the case in which the bright area is selected as the main object to be picked up. These light measuring modes for a video system usually employ the video signals coming from the television camera to obtain a diaphragm control signal. However, rigid use of these light measuring modes would cause inconveniences. Specifically, in the case where the same object simultaneously contains the bright area and the dark area as previously mentioned, the average light measuring mode would often make the bright area a white solid area without any gradation while the peak light measuring mode would often make the dark area, which should be adequately discriminated, indiscriminate. The average average light measuring mode and the peak light measuring mode should be selectively adopted depending on whether the dark area or the bright area is used as the main object to be picked up when these two areas simultaneously exist in one and the same object to be picked up. Accordingly, it is preferred that a video signal of the same level is obtained regardless of the modes so far as the object contains no dark area, i.e., no contrast state is concerned.

In view of the fact that a condition of an object to be picked up is sensitive to not only said light and shade ratio, i.e., the contrast of the dark area and the bright area, but also the proportions of whole the object occupied by these areas, respectively, the present invention provides a photometric circuit permitting the light measuring modes to be selectively converted and, at the same time, permitting a video signal of the same level to be obtained even when the light measuring mode conversion takes place so far as the no contrast state is concerned.

FIG. 2(*a*) shows a test pattern in which a central blank area represents a bright area and a shaded area surrounding said blank area represents a dark area. In this test pattern, a proportion of the whole object occupied by the bright area, i.e., the ratio of bright area S_o is expressed by

$$S_o=(a/b)^2\times 100\ (\%).$$

$S_o=100$ (%) is established when the whole object is covered by the bright area and contains no dark area, i.e., in the no contrast state.

SUMMARY OF THE INVENTION

Accordingly, it is a primary object of the present invention to provide a photometric control circuit for automatically adjusting the diaphragm of the objective lens of a closed circuit television (CCTV) camera which takes into account the contrast of the dark and light areas of an object to be picked up.

It is a further object of the present invention to provide a photometric control circuit for the diaphragm in a CCTV camera with the capability of selecting either the dark or light areas of the object as the primary area of interest in forming the object image.

The objects of the present invention are fulfilled by providing a photometric circuit incorporated in the objective lens assembly, provided with an automatic diaphragm for a closed circuit television (CCTV) camera, including an inverting amplifier adapted to amplify and invert video signals coming from the television camera with respect to a reference voltage and a rectifier adapted for voltage doubling rectification of video signals inversely amplified by said inverting amplifier so that video signals thus processed are compared with separately provided reference voltages to obtain diaphragm control signals to open or close the diaphragm. The photometric circuit includes in said inverting amplifier, a limiter having, in parallel to a variable resistance adapted for adjustment of the amplification degree, a diode functioning to limit a negative portion of the amplified and inverted video signal and a variable resistance for current control of said diode.

BRIEF DESCRIPTION OF THE DRAWINGS

The objects of the present invention will become more fully apparent and understood by reference to the detailed description given hereinbelow and the accompanying drawings, which are given by way of illustration only, and thus are not limitative of the present invention and wherein:

FIG. **1** is a circuit diagram illustrating an embodiment of the control circuit according to the present invention;

FIG. **2**(*a*) is a diagram illustrating the relationship between a test object to be picked up and a corresponding waveform of a video signal to be input to the control circuit of FIG. **1**;

FIGS. **2**(*b*) and **3** are diagrams illustrating a signal waveform appearing at the output terminal P_1 in the circuit of FIG. **1**;

FIGS. 4(*a*) and 4(*b*) are diagrams illustrating a signal waveform before and after rectification in a peak light measuring mode by the circuit of FIG. 1;

FIGS. 5(*a*) and 5(*b*) are diagrams illustrating a signal waveform before and after rectification in an average light measuring mode by the circuit of FIG. 1;

FIG. 6 is a diagram showing an input and output characteristic line of the inverting amplifier of FIG. 1; and

FIG. 7 is a diagram showing a photometric characteristic line expressed as a relationship of the area ratio S_o versus a video signal $V_{in}(V_{p\text{-}p})$.

DETAILED DESCRIPTION OF THE INVENTION

The present invention will now be described by reference to an embodiment as shown by the accompanying drawings.

FIG. 1 is a circuit diagram illustrating an embodiment of the present invention. Reference numeral 1 designates a video signal input terminal applied with a video signal V_{in} coming from the television camera and connected via a capacitor 2 to an inverting amplifier I, including an operational amplifier 3. At an output terminal 33 of said inverting amplifier I, an amplified and inverted video signal (inverted signal) V_{33} containing no DC components appears. The video signal input terminal 1 is also connected by a resistance 4 to ground.

The inverting amplifier I includes the operational amplifier 3 having its input terminal 31 connected via a resistance 5 to said capacitor 2, its noninverting input terminal 32 connected via a resistance 7 to a reference voltage input terminal 6, and its output terminal 33 connected via a variable resistance 8 adapted for regulation of amplification degree to said noninverting input terminal 31. Thus, the inverting amplifier I functions to, on the basis of the voltage supplied from the reference voltage input terminal 6, amplify and invert the video signal having its DC component already eliminated by the capacitor 2, and its amplification degree is variable by adjusting said variable resistance 8. Reference symbol A designates a limiter provided in parallel to said variable resistance 8 to limit the negative output of the video signal inversely amplified by the operational amplifier 3. This limiter A consists of a diode 9 and a variable resistance 10 adapted to control electric current flowing through said diode 9, in which the inverting input terminal 31 of the operational amplifier is connected to an anode of the diode 9 while a cathode of said diode 9 is connected via a variable resistance 10 to the output terminal 33 of said operational amplifier 3. This limiter A is arranged, as shown by solid line ② in FIG. 6, so that the negative side of the output voltage from the operational amplifier 3 is forcibly suppressed by the diode 9. Referring to FIG. 6, the abscissa represents an input voltage V_{31} at the inverting input terminal 31 of the operational amplifier 3 and the ordinate represents the output voltage V_{33} appearing at the output terminal 33. Said limiter A functions so that the negative side of the output voltage V_{33} corresponding to the input voltage V_{31}, which would otherwise exhibit the input and output characteristic as shown by broken line ① as said input voltage V_{31} increases in excess of α, may be maintained constant at a level β as shown by solid line ②.

Reference numeral II designates a rectifier adapted for voltage doubling rectification of the video signal V_{33} inversely amplified by said inverting amplifier, and comprises a capacitor 11 for voltage doubling connected to the output terminal 33 of said operational amplifier 3 and a diode 12 via which an output terminal P_2 of said capacitor 11 is connected to the reference voltage input terminal 6. A diode 13 also is serially connected to said output terminal P_2 of the capacitor 11 so that a DC diaphragm control signal may be obtained at an output terminal 15. Reference numeral 14 designates a capacitor connected to the output terminal of the diode 13 and grounded to smooth the rectified signal coming from said diode 13.

In the embodiment of the photometric circuit constructed as described above according to the present invention, it is assumed that a video signal V_{in} of a waveform as shown in FIG. 2(*b*) corresponding to the test pattern of FIG. 2(*a*), is applied to the video signal input terminal 1. The video signal V_{in} has its DC component eliminated by the capacitor 2 and, as a result, a signal VP_1 appearing at an output terminal P_1 has positive and negative areas with respect to the reference voltage which are equal to each other. This signal VP_1 is inversely amplified by the inverting amplifier I with respect to the voltage supplied from the reference voltage input terminal 6, basically as shown in FIG. 4(*a*). It should be noted here that, in FIG. 2(*b*), an upper rectangular portion of the waveform corresponds to the central bright area of an object to be picked up, as illustrated in the test pattern of FIG. 2(*a*), reference symbol V_2 represents a video level and reference symbol V_s represents a synchronous level.

The amplification degree of the inverting amplifier I increases as the resistance value of the variable resistance 8 is adjustably increased, while said amplification degree decreases as said resistance value decreases. The amplification of the inverting amplifier I depends on the resistance value ratio of the resistance 5 and the variable resistance 8. Accordingly, the amplification degree may be regulated by adjustment of the variable resistance 8 to regulate the peak-to-peak amplitude $V_{p\text{-}p}$ of the inverted signal V_{33} appearing at the output terminal 33 of the operational amplifier 3, and thereby achieve sensitivity regulation.

The variable resistance 10 of the limiter A may be adjusted to set the light measuring mode to a peak light measuring mode, an average light measuring mode or an intermediate light measuring mode. When the resistance value of the variable resistance 10 is adjusted to infinity, the limiter A is activated and, therefore, the reversed signal V_{33} takes a waveform which is inverted compared to the signal VP_1 appearing at the output terminal P_1. Upon application of this inverted signal V_{33} to the capacitor 11 of the voltage doubler II, the negative portion of this inverted signal V_{33} changes the diode 12 to its conductive state and charges the capacitor 11. Then the plus portion thereof is additionally charged into said capacitor 11 so that a voltage doubled signal VP_2 appearing at the output terminal P_2 is DC regenerated without any change of the peak-to-peak amplitude $V_{p\text{-}p}$ as shown in FIG. 4(*b*). Thus, the voltage doubled signal VP_2 of the initial peak-to-peak amplitude $V_{p\text{-}p}$ is obtained, so the mode of light measuring is set to the peak light measuring mode in which the video level V_2 is detected, and the bright area is selected as the main object to be picked up. In the case where the resistance value of the variable resistance 10 in the limiter A is adjusted to zero, the diode 9 becomes conductive and the operational amplifier 3 is subjected to the limitation as shown in FIG. 6. More specifically, the input signal

V_{in} passes through the capacitor **2**, appears as the signal VP_1 at the input terminal P_1, as shown in FIG. **3**, and then is applied to the inverting amplifier I in which the portion of the signal increasing in excess of α (corresponding to the bright area) is clipped and an inverted signal V_{33}, indicated by a solid line ②, having no portion indicated by a broken line is formed (see FIG. **6**). In consequence, even when the input signal V_{in} contains a peak value, the resultant inverted signal V_{33} having its portion indicated by a broken line on the negative side is clipped away and said peak value is correspondingly clipped away. When this reversed signal V_{33} is rectified by the voltage doubler, the negative portion thereof turns the diode **12** to its conductive state, as in the case of peak light measuring and charges the capacitor **11**. The subsequent positive portion of the waveform is added to the previously charged voltage. Thus, the voltage doubled signal VP_2, appearing at the output terminal P_2 is DC regenerated, as shown in FIG. **5**(*b*). That is, the voltage doubled signal VP_2 is determined not by the peak-to-peak amplitude $V_{p\text{-}p}$, but a value substantially corresponding to an average value of the whole area of the object to be picked up having its negative portion of the signal clipped away. The above-described operation is the average light measuring mode in which the dark area is used as the primary object to be picked up. By adjusting said variable resistance **10** to an intermediate resistance value, the light measuring mode is converted to a mode intermediate of said peak light measuring mode and said average light measuring mode. In the embodiment shown, the diode **9** in the limiter A and the diodes **12**, **13** in the voltage doubler are so selected that the temperature coefficients of these diodes cancel one another adequately to provide a circuit substantially free from any temperature influence.

With the circuit constructed as has been described hereinabove in accordance with the present invention, sensitivity regulation can be achieved by adjusting the resistance B for regulation of the amplification degree in the inverting amplifier, while the light measuring mode can be selectively set to the peak light measuring mode, the average light measuring mode or the intermediate light measuring mode by adjusting the resistance **10** for current control of the diode **9** in the limiter. In both the average light measuring mode and the peak light measuring mode, the minus portion of the reversed signal V_{33} is rectified by the voltage doubler and, as a result, the rectified signal level, i.e., the diaphragm control signal level, is identical in both modes, particularly in the state of the area ratio $S_o=100$ (%) or in the no contrast state. In consequence, there is provided, according to the present invention, an ideal photometric circuit, in which the video signal V_{in} has an identical reference level in both the peak light measuring mode ① and the average light measuring mode ② as shown in FIG. **7**. Furthermore, the negative side of the signal is under the effect of the limiter in the average light measuring mode so that no useless electric current flows, and thereby energy consumption is effectively saved.

It should be understood that the control circuit of the present invention may be modified as would occur to one of ordinary skill in the art without departing from the spirit and scope of the present invention.

What is claimed is:

1. An automatic control circuit for opening and closing the diaphragm of the objective lens of a video camera comprising:

inverting amplifier means for receiving video signals output from said video camera and amplifying and inverting said signals;

voltage doubler means for doubling and rectifying the signals output from said inverting amplifier means;

reference signal generating means;

diaphragm control means for comparing said reference signal with signals output from said voltage doubler means and opening or closing said diaphragm in response to the results of the comparison;

means for clipping the negative going portion of signals output from said inverting amplifier; and

light mode selector means for adjusting said means for clipping to control the degree of clipping performed on said signals.

2. The control circuit of claim **1**, wherein said means for clipping comprises a diode coupled between an inverting input of said inverting amplifier and an output thereof.

3. The control circuit of claim **2**, wherein said light mode selector means comprises a variable resistor in series with said diode.

* * * * *

United States Patent [19]

Hamaguchi et al.

[11] **Patent Number: 4,545,661**

[45] **Date of Patent: Oct. 8, 1985**

[54] **FOLDING CAMERA WITH MOVABLE MEMBER MOUNTING AN OBJECTIVE LENS AND REFLEX MIRROR**

[75] Inventors: **Takehiko Hamaguchi; Kiyoaki Hazama; Kenichi Iwaida,** all of Hachioji; **Takeyoshi Iguchi,** Tokyo, all of Japan

[73] Assignee: **Konishiroku Photo Industry Co., Ltd.,** Tokyo, Japan

[21] Appl. No.: **492,493**

[22] Filed: **May 5, 1983**

[30] **Foreign Application Priority Data**

May 19, 1982 [JP] Japan 57-85586

[51] **Int. Cl.**[4] **G03B 17/04;** G03B 17/52; G03B 19/12

[52] **U.S. Cl.** **354/86;** 354/149.11; 354/158; 354/187

[58] **Field of Search** ..... 354/86, 187, 189, 192, 354/194, 158 X, 149.11

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Primary Examiner—A. A. Mathews
Attorney, Agent, or Firm—Jordan B. Bierman

[57] **ABSTRACT**

A foldable camera for self-developing film comprises a base housing and a movable member pivotable between a closed position integrated with the housing and an open, elevated position above the housing. The movable member is mounted to a supporting member which is pivotally coupled to the housing at the end opposite from the film exit end of the housing. An objective lens and a reflex mirror are fixedly mounted to the movable member in fixed relationship to each other such that they are in the proper positions for film exposure when the movable member is pivotted to the elevated position.

8 Claims, 19 Drawing Figures

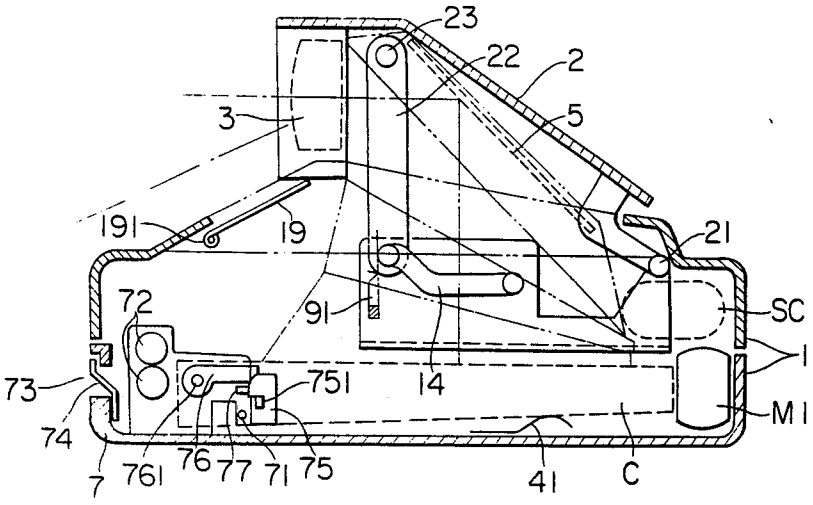
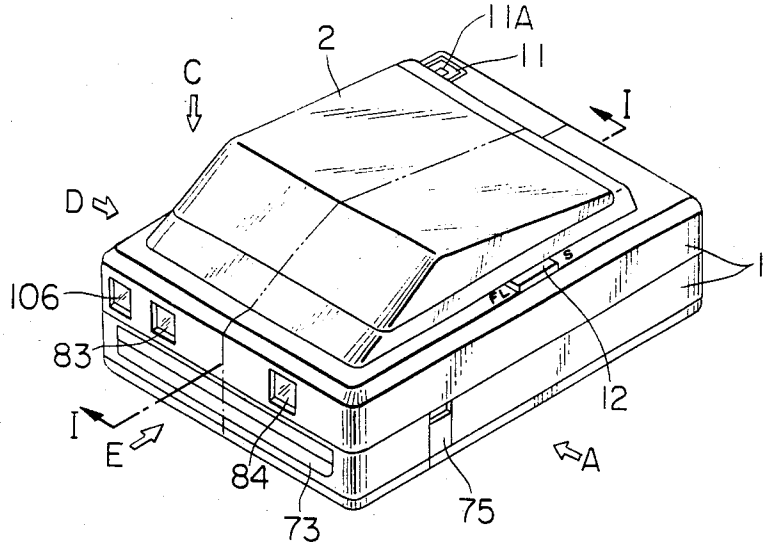


FIG. 1


11A
11
2
C
I
D
1
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12
I
E
A
84
75
73

FIG. 2

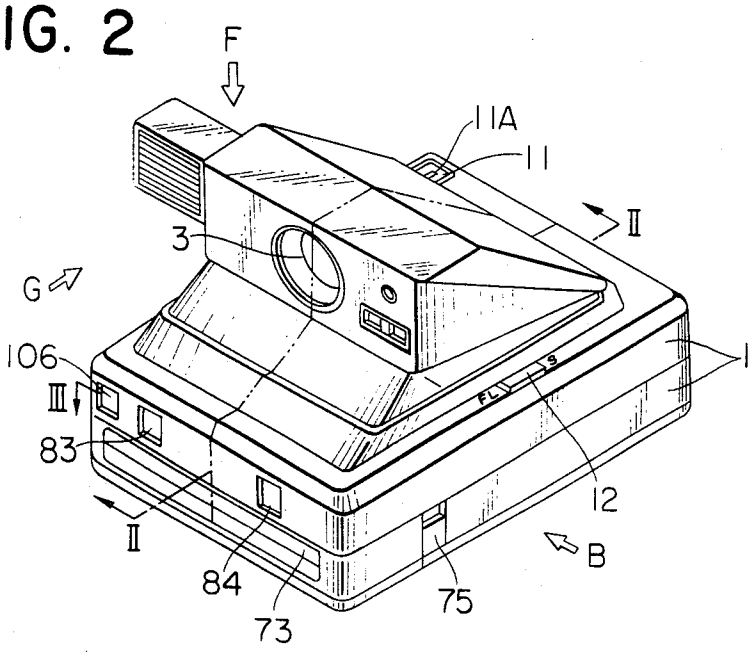

F
11A
11
II
3
G
1
106
III
83
12
II
B
84
75
73

FIG. 3(a)

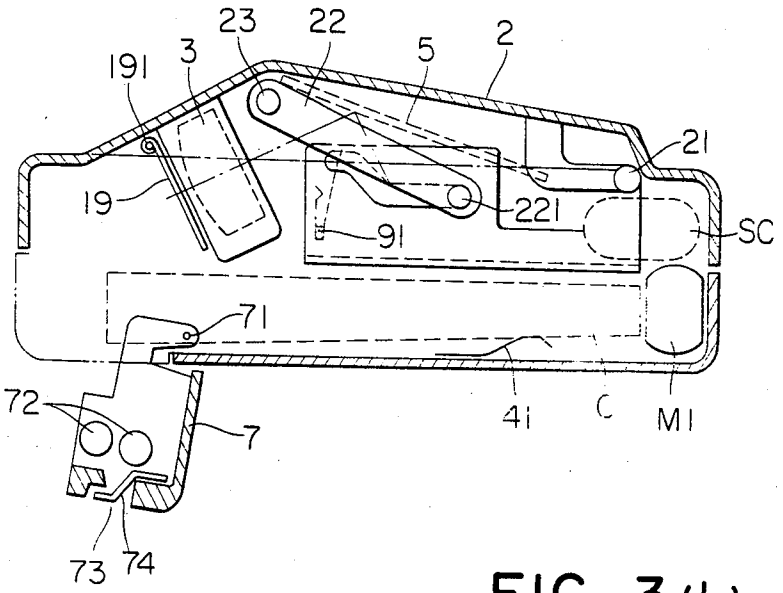
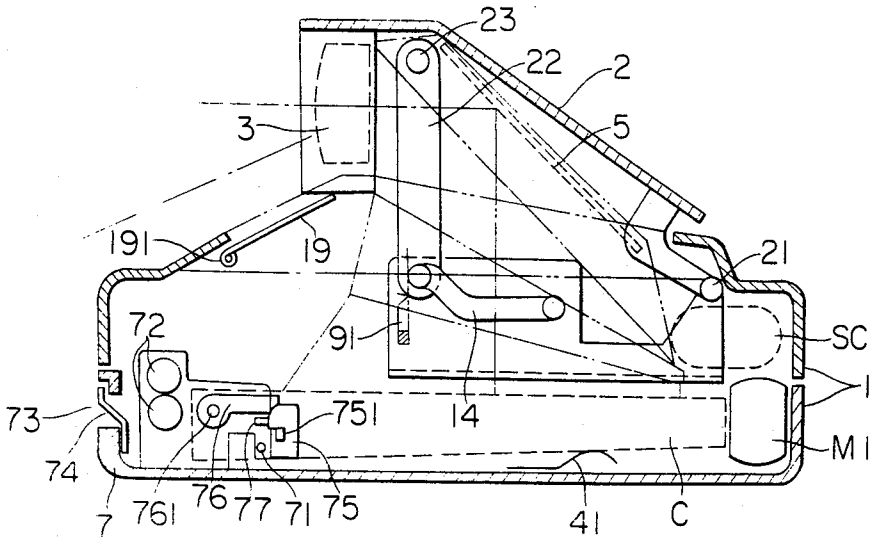

23
22
5
2
191
3
21
19
221
91
SC
71
72
7
41
C
M1
73
74

FIG. 3(b)


23
22
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3
5
191
19
21
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751
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M1
76
761
77
71
75
7
41
C

FIG. 4(a)

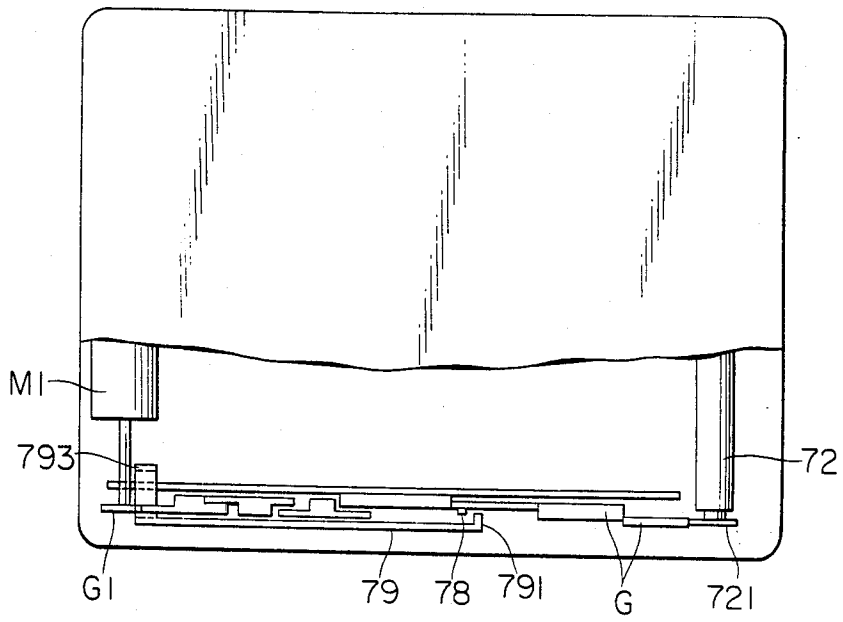


FIG. 4(b)

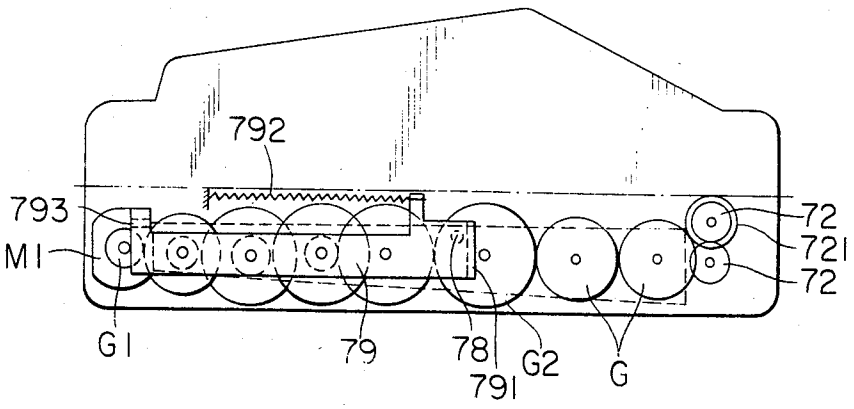


FIG. 5 (a)

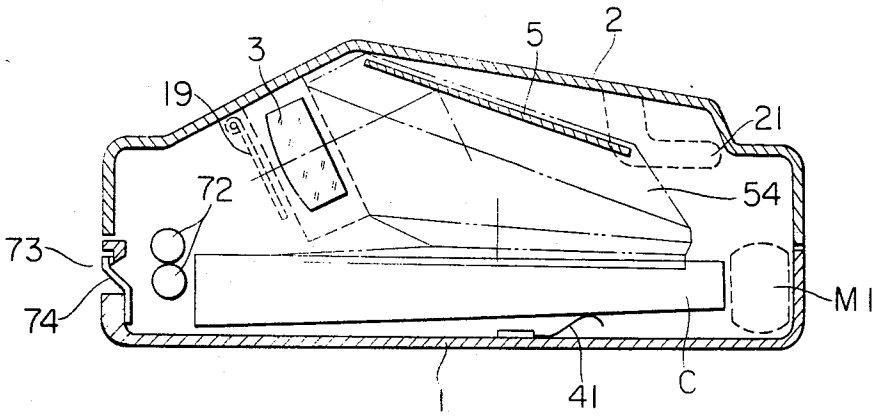


FIG. 5 (b)

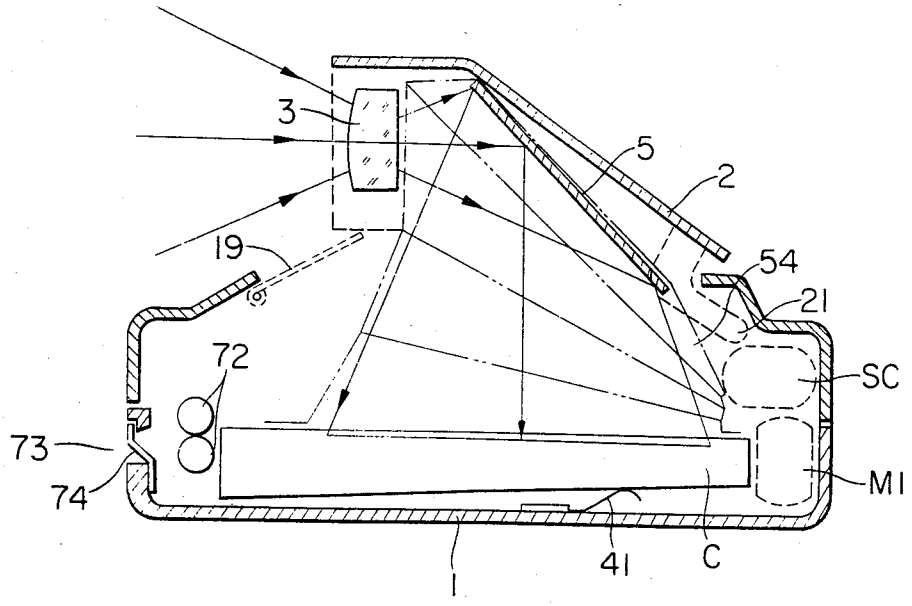


FIG. 6 (a)

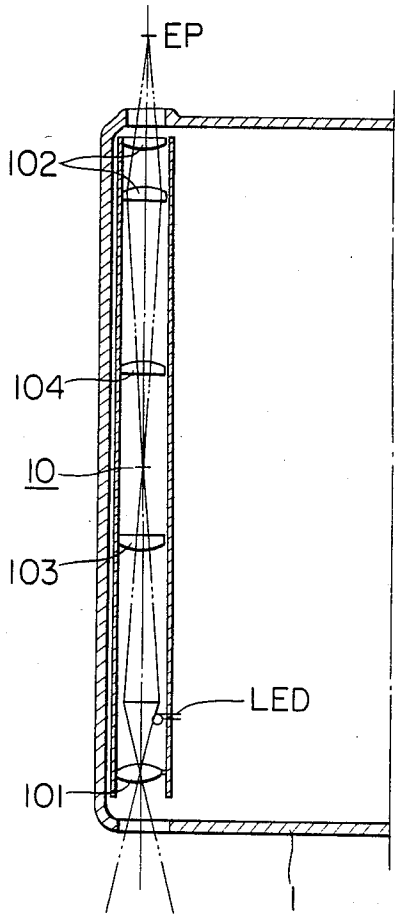


FIG. 6 (b)

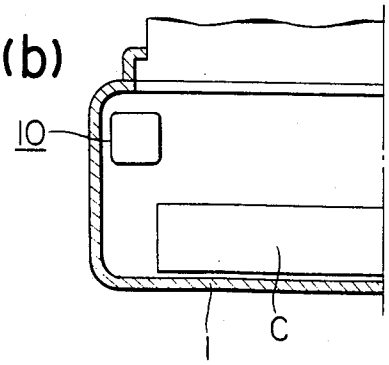


FIG. 7 (a)

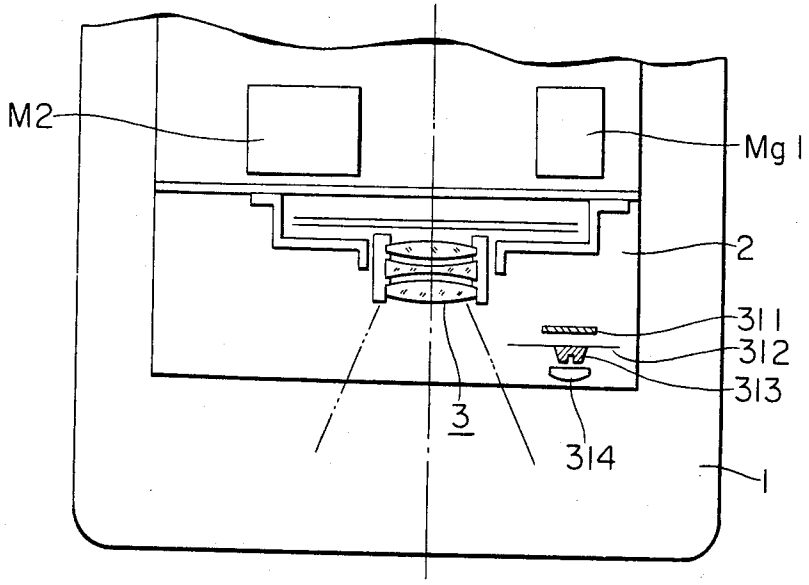
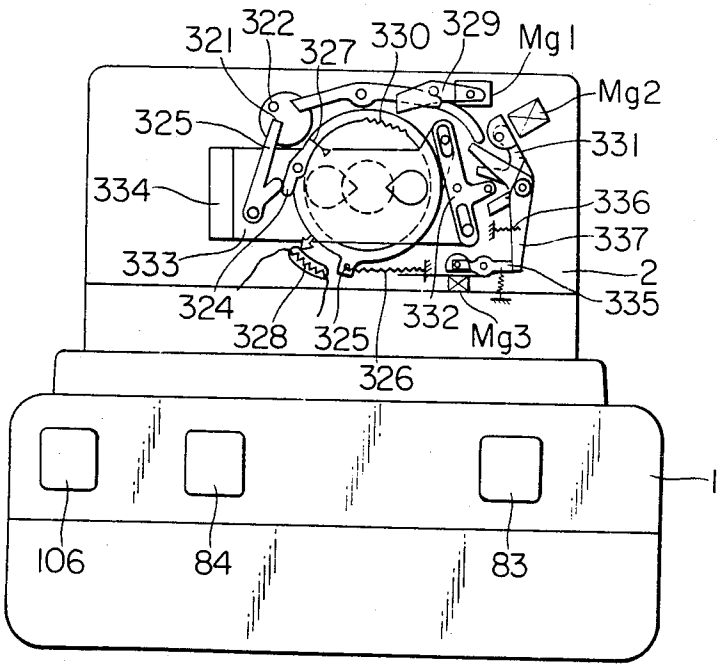

M2
Mg 1
2
311
312
313
3
314
1

FIG. 7 (b)


321
322
327
330
329
Mg 1
Mg2
325
331
334
336
337
333
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324
328
325
332
Mg3
326
1
106
84
83

FIG. 8 (a)

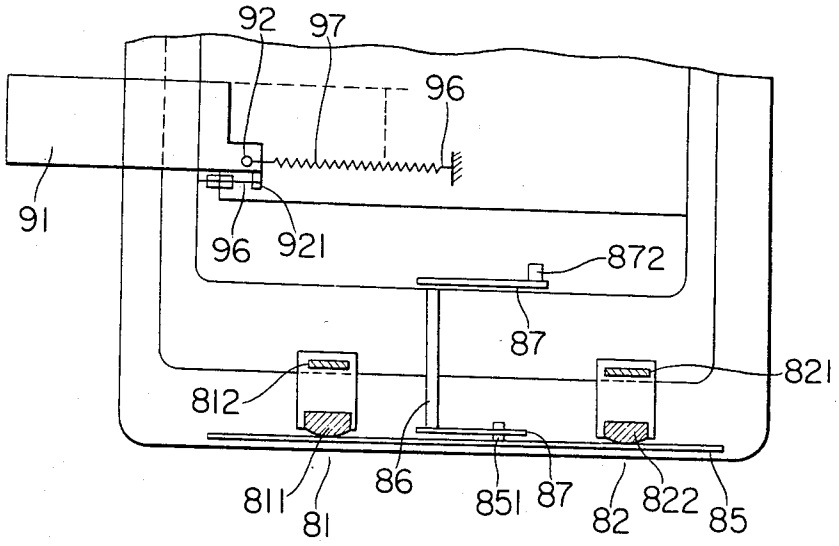
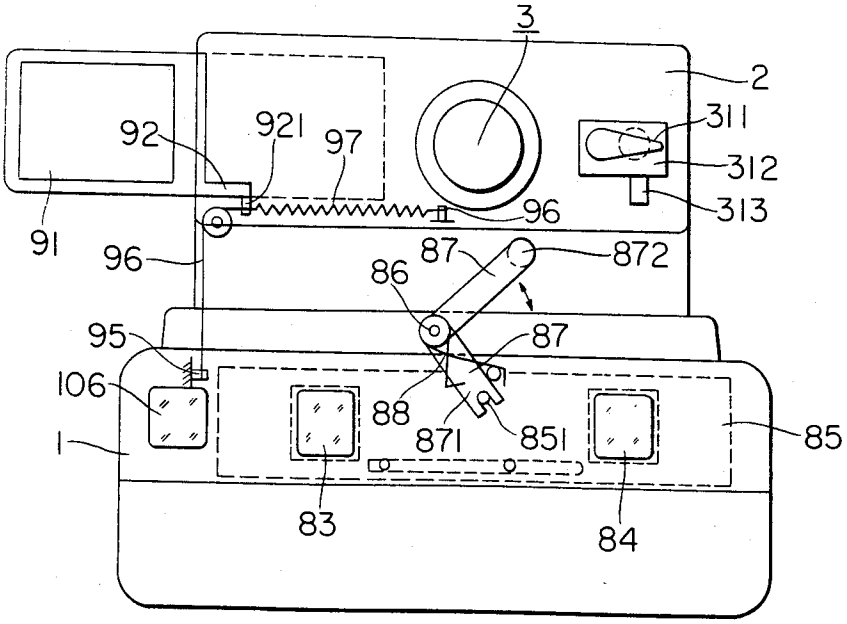

92
97
96
91
96
921
872
87
821
812
811
81
86
851
87
82
822
85

FIG. 8 (b)


3
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311
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92
921
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872
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871
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83
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FIG. 9 (a)

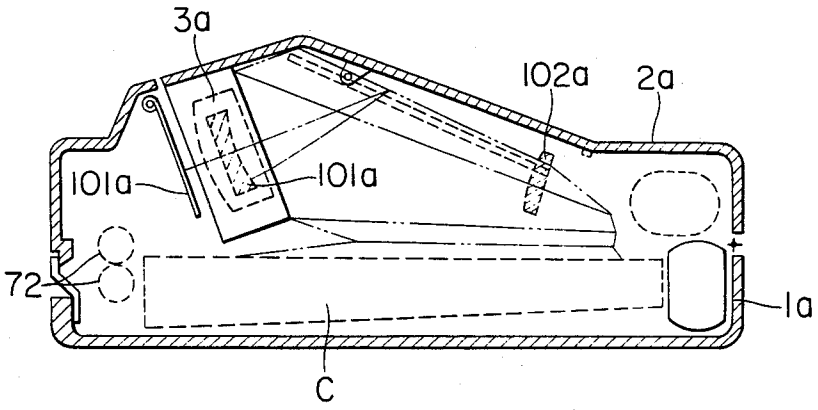


FIG. 9 (b)

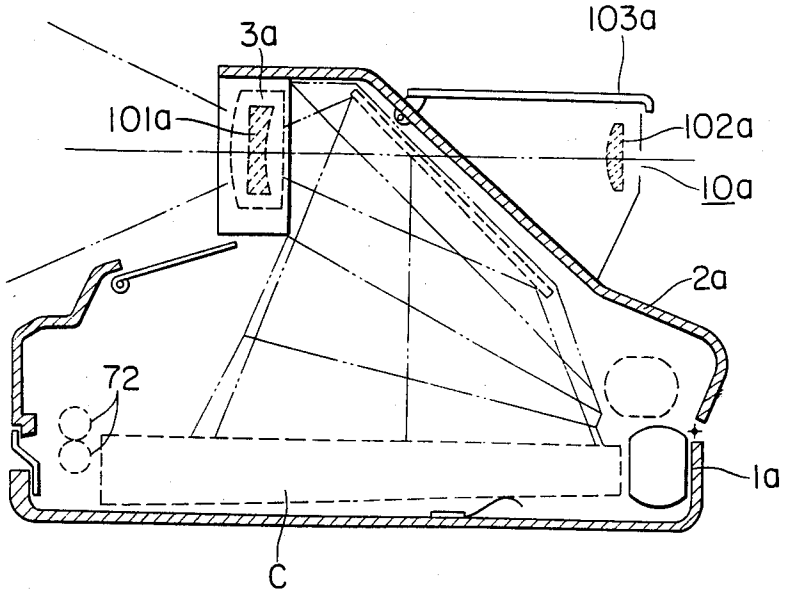


FIG. 10 (a)

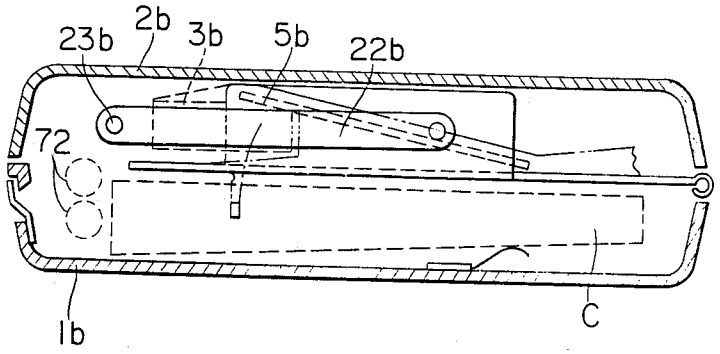
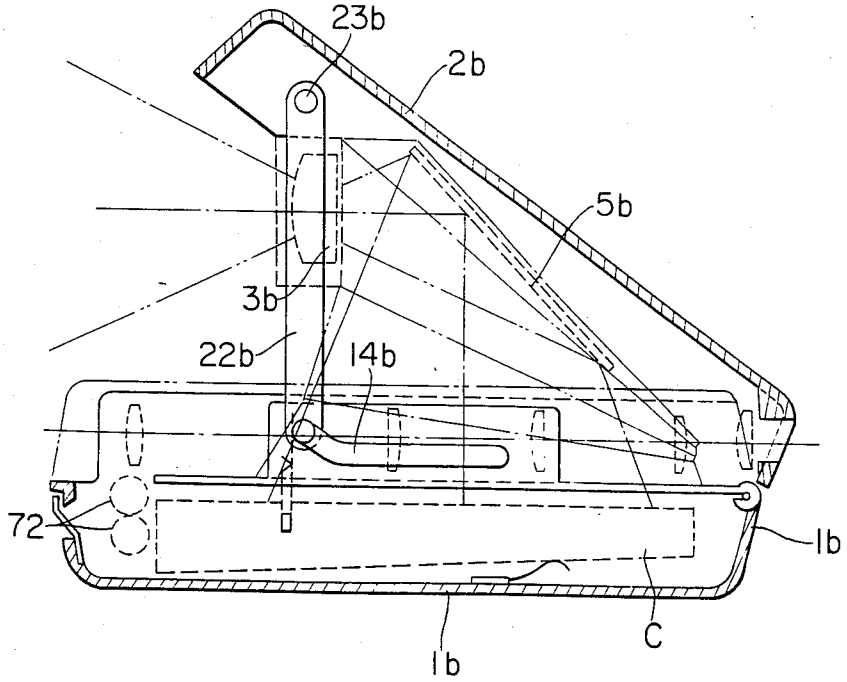


FIG. 10 (b)



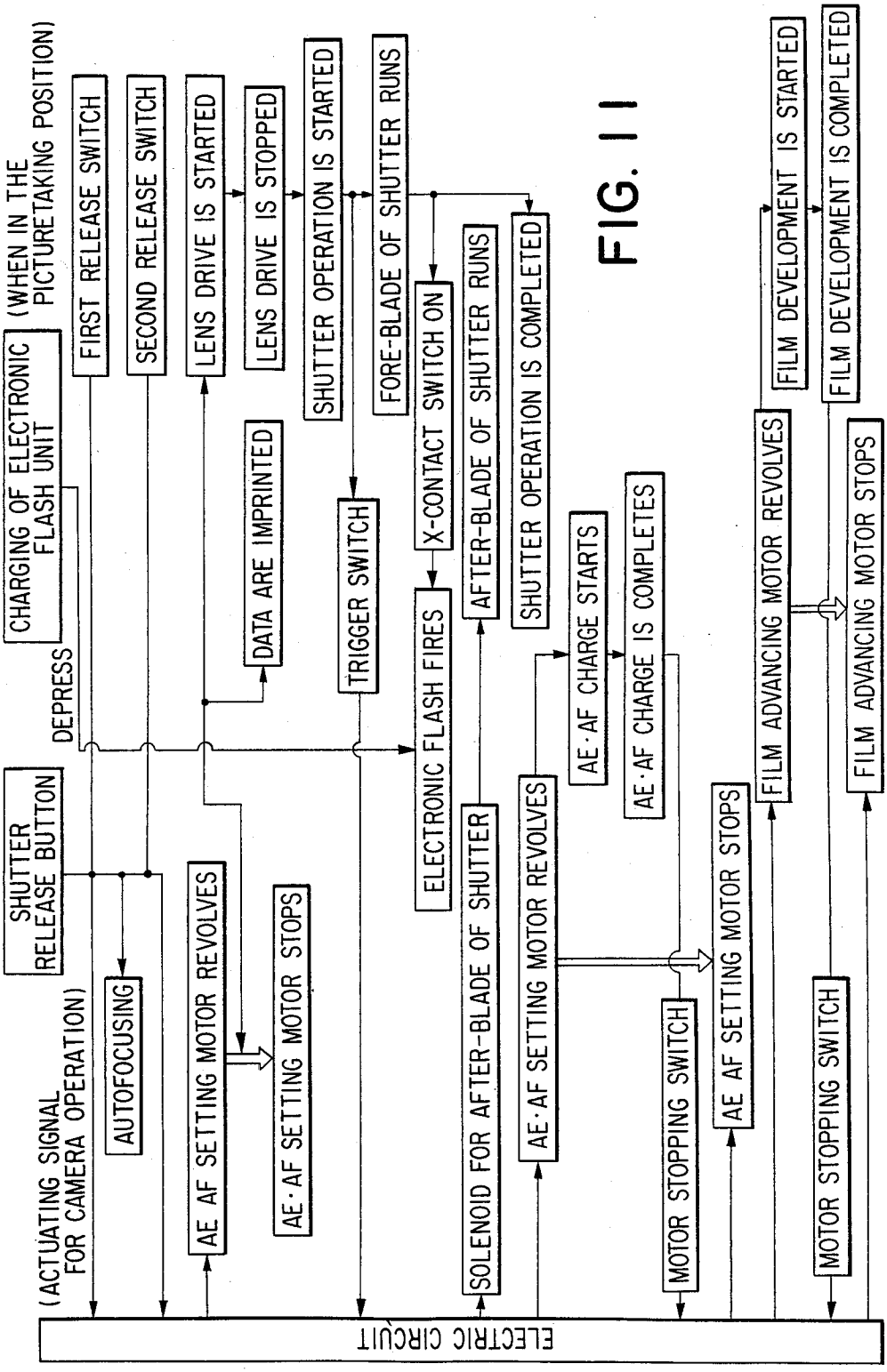

(ACTUATING SIGNAL FOR CAMERA OPERATION)
SHUTTER RELEASE BUTTON
AUTOFOCUSING
AE AF SETTING MOTOR REVOLVES
AE·AF SETTING MOTOR STOPS
DEPRESS
CHARGING OF ELECTRONIC FLASH UNIT
(WHEN IN THE PICTURETAKING POSITION)
FIRST RELEASE SWITCH
SECOND RELEASE SWITCH
LENS DRIVE IS STARTED
DATA ARE IMPRINTED
LENS DRIVE IS STOPPED
SHUTTER OPERATION IS STARTED
TRIGGER SWITCH
FORE-BLADE OF SHUTTER RUNS
X-CONTACT SWITCH ON
ELECTRONIC FLASH FIRES
AFTER-BLADE OF SHUTTER RUNS
SOLENOID FOR AFTER-BLADE OF SHUTTER
SHUTTER OPERATION IS COMPLETED
AE·AF SETTING MOTOR REVOLVES
AE·AF CHARGE STARTS
AE·AF CHARGE IS COMPLETES
MOTOR STOPPING SWITCH
AE AF SETTING MOTOR STOPS
FILM ADVANCING MOTOR REVOLVES
FILM DEVELOPMENT IS STARTED
MOTOR STOPPING SWITCH
FILM ADVANCING MOTOR STOPS
FILM DEVELOPMENT IS COMPLETED
ELECTRIC CIRCUIT

FIG. 11

FOLDING CAMERA WITH MOVABLE MEMBER MOUNTING AN OBJECTIVE LENS AND REFLEX MIRROR

BACKGROUND OF THE INVENTION

1. Field of the invention

The present invention relates to an improvement of a self-developing camera, also called an instant camera.

2. Description of the prior art

In self-developing cameras for amateur use which use self-developing film, the camera body itself tends to be larger because their image frame size is larger than that of general miniature cameras. However, it would be advantageous that the camera body be smaller and of lighter weight and handles more easily. There have been many proposals relating to such self-developing cameras. For example, U.S. Pat. No. 3,709,122 discloses a self-developing camera that is a finder-collapsible compact single lens reflex camera. This camera has the disadvantage that because of the single lens reflex type, it needs to oscillate the reflex mirror each time when an exposure is made, so that the time lag between the time the shutter button is depressed and the time when an actual exposure is made is so long that an object can move during the time interval or an exposure is made with the mirror insufficiently settled, thus causing the resulting image to be degraded. In addition, because the collapsing of the finder is made by pivotting on 4 pivots, the mechanism is complicated. And if the angle formed by and between the sheet film plane and the reflex mirror plane is made less than 45° and the space between the film plane and the mirror is small, the reflection is repeated many times between the film plane and the reflex mirror, tending to produce a ghost image. Further, if the self-developing camera has an exposure lens-foldaway structure wherein the lens is folded so as not to be superposed upon a film cassette when the camera is in the folded position because the image frame size thereof is relatively large, the camera body can be made flat, but instead its flat area becomes so large that its portability tends to be reduced.

Japanese Patent Publication Open to Public Inspection (hereinafter referred to as Japanese Patent O.P.I. Publication) No. 34530/1975 proposes a self-developing camera wherein an exposure lens member is pivotally coupled to an end of a film cassette holder, and also a reflex mirror is pivotally coupled to the other end of the holder, the two movable members being such as to be folded inwardly toward each other. In this camera, however, the exposure lens, as a barrier type, is difficult to fit inside the camera frame. In order to make the camera more compact, the exposure lens and reflex mirror are required to be located as close to each other as possible. If located too close to each other, the two become difficult to be folded inwardly toward each other, while if a sufficient space is provided between the two, the size of the camera in the picture-taking position becomes larger. In addition, the optical axis of the exposure lens, if brought closer to the film cassette holding position, produces a flare between the reflex mirror and the film plane, so that it may not be brought excessively close to the position. Accordingly, the proposed camera has the disadvantage that if the exposure lens and reflex mirror are to be folded inwardly toward each other with both ends of the holder as pivotal axes, the interval between both ends of the holder must be made larger,

and the camera can be folded flat but tends to become so large that the portability thereof is reduced.

SUMMARY OF THE INVENTION

The present invention has been made from the standpoint of human engineering of the optimum photographing angle of view and the like, and an object of the present invention is to remove the disadvantage of the above-described conventional products. The object is accomplished by the following self-developing camera: In a foldable self-developing camera wherein a film cassette is arranged in the exposure position, and a sheet film loaded inside the film cassette is exposed to the light coming through an exposure lens and a reflex mirror from an object, and then developed by developing rollers or the like, the camera comprises at least a fixed member having a film cassette-holding member, an exposure lens which is movable when folding the camera, a reflex mirror which is also movable when folding the camera's movable member that moves in relation to both the exposure lens and the reflex mirror, a pivotally supporting member which is pivotally coupled to the fixed member and provided at an edge of the reflex mirror, the edge being on the side closer to the film in the exposure position and in the proximity of the side of the film cassette opposite to the film exit side thereof, and a finder member whose optical axis, when the camera is in the picture-taking position, is in parallel or nearly in parallel with the film developing direction and which is located close to the exposure lens. When the camera is in the folded position, the exposure lens, interlockingly with the movement of the camera's movable member, is folded superposedly upon the point near the edge on the film cassette exit side of the image frame or upon a developing member such as the developing rollers. Namely, according to the present invention, the change in the camera position from the folded position to the picture-taking position is effected by a relatively simple operation, in which the opening degree of the camera's movable member can be small. And when in the folded position, the camera is well balanced in longitudinal, transverse and thickness dimensions for portability. Further, by providing the finder on the side of the exposure lens in the folded position, the camera can be of the well-operative box type and also can be of the barrier type structure in which the exposure lens may be readily covered by the movable member when in the folded position.

As is disclosed in Japanese Patent O.P.I. Publication No. 112330/1976, in order to prevent the flare in the image reversing type, the reflex mirror is not allowed to be brought excessively close to the film-holding section side. Therefore if the pivoting of the movable member is made at a point near the intersecting point of the fixed member's upper plane and the reflex mirror plane, the movable part can be made small in size because the optical path of the exposure optical system is considerably narrow, and about half of the optical path of the rectangular pyramidal body formed with the exposure lens as the vertex becomes folded into the lower half, so that the spacing between the fixed part and the movable part in the folded position can be small, thus enabling easily the miniaturization of the camera. Further the spacing in the portions held on both sides of the fixed member of the box type is easily securable, so that the camera may be as stably held by hand as if when a binocular is held. Consequently there could occur no unintentional touch by fingers to the film ejected from

the camera held by hand nor unintentionally covering with the hand the exposure lens of the light-receiving window at the time of shutter releasing, which can occur in conventional cameras.

The present invention which has been described above has the following advantages:

(1) The camera, when folded, has a rectangular form well-balanced in longitudinal, transverse and height dimensions and excellent in portability.

(2) The camera has no finder projection even when in the picture-taking position, so that the camera can be as stably held as a binocular is held. The shutter release button may be provided in any natural position that is readily depressible, so that there occurs little camera-shake and no unintentional touching with the fingers of the film being ejected out of the film exit.

(3) The finder is clearly viewable without use of any complex optical system and, because there is no projection underneath the finder eye piece portion, the finder is easily viewable.

(4) If a simple cover is provided inside, the camera may be carried with no camera case; i.e., may be of the barrier type, so that snap shooting can be readily conducted.

(5) The structure is simple: the operation of the camera from the folded position to the picture-taking position and vice versa is simple.

Other objects of the invention will be obvious evident as described hereinafter.

The invention accordingly comprises an apparatus possessing the construction, combination of elements and arrangement of parts which are exemplified in the following detailed disclosure, and the scope of which will be indicated in the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

For a fuller understanding of the nature and objects of the invention, reference should be made to the following detailed description taken in connection with the accompanying drawings wherein:

FIG. **1** and FIG. **2** are perspective views showing an example of the camera of this invention. FIG. **1** shows the camera in the folded posi while FIG. **2** shows the camera in the ready for-picture-taking position.

FIG. **3**(*a*) and FIG. **3**(*b*) are sectional views of the movable member opening-closing mechanism and film cassette entrance and holding sections viewed from Arrow A of FIG. **1** and Arrow B of FIG. **2**, respectively.

FIG. **4**(*a*) is a plan view and FIG. **4**(*b*) is a sectional view of the film-advancing mechanism viewed from Arrow C and Arrow D, respectively of FIG. **1**.

FIG. **5**(*a*) is a sectional view across the line I—I of FIG. **1**, and FIG. **5**(*b*) is a sectional view across the line II—II of FIG. **2**.

FIG. **6**(*a*) is a sectional view of the finder unit across the line III—III of FIG. **2**, and FIG. **6**(*b*) is a front view of the finder arrangement.

FIG. **7**(*a*) is a plan view viewed from Arrow C of FIG. **1**, and FIG. **7**(*b*) is a front view viewed from Arrow E of FIG. **1**.

FIG. **8**(*a*) is a plan view of the electronic flash unit viewed from Arrow F of FIG. **2**, and FIG. **8**(*b*) is a front view of the electronic flash unit viewed from Arrow G.

FIG. **9**(*a*) and (*b*) sectional views of the camera in the second example of the invention.

FIG. **10**(*a*) and (*b*) are sectional views of the camera in the third example of the invention.

FIG. **11** is a sequential time chart for the examples in the invention.

DETAILED DESCRIPTION OF THE INVENTION

Description of the preferred embodiment

Examples of the self-developing camera of the present invention will be illustrated in detail in the drawings wherein FIG. **1** and FIG. **2** are overall perspective views. FIG. **1** shows the folded nonpicture-taking position of the camera, and FIG. **2** shows the ready-for-picture-taking position of the camera wherein movable member **2** is moved to the up position from fixed member **1**. In these drawings, a shutter button **11** is in the corner of a side of fixed member **1**, and an electronic flash firing button **11A** is located adjacent to shutter button **11**. Shutter button **11** is so located that the shutter can be released with the camera held by hand. As electronic flash-firing button **11A** is adjacent to shutter button **11**, in normal photographing, shutter button **11** and electronic flash firing button **11A** can simultaneously depressed to enable quick shooting.

Numbered **12** is a self-focusing lock button which is moved backward to set a self-timer and moved forward to lock the autofocusing value. Self-autofocusing lock button **12** can also be operated with the camera held by hand.

FIG. **3**(*a*) is a sectional view showing the movable member opening-closing mechanism and film cassette entrance and holding section viewed from Arrow A of FIG. **1**. FIG. **3**(*b*) is a sectional view showing the movable member opening-closing mechanism and film cassette entrance and holding section viewed from Arrow B of FIG. **2**. Movable member **2** which is the picture-taking body having exposure lens **3** and reflex mirror **5** is supported by a pivotally supporting member **21** which is pivotally coupled to fixed member **1** which is the body holding film cassette C. Exposure lens **3** and reflex mirror **5** are fixed to movable member **2** so as to be integral parts thereof. Fixed member **1** comprises a holding means to hold film cassette C, a developing roller unit **72** and sheet film exit **73** from which a developed sheet is ejected. Pivot member **21** is located in the proximity of the intersecting point of the external upper surface plane of fixed member **1** and reflex mirror **5** plane in the picture-taking position.

The opening-closing mechanism of movable member **2** is illustrated below:

Movable member **2** has on both transverse sides thereof a pair of lock arms **22**. An end of each of lock arms **22** is mounted to pivot **23** provided on movable member **2**, and roller **221** provided at the other end of lock arm **22** is slidably fit in along cam slot **14** provided to for moving along the slot according to the opening and closing of movable member **2**. Lock arm **22** is resiliently biased in the clockwise direction by a spring (not shown) provided on pivot **23**. Movable member **2**, when raised in the clockwise direction, turns pivotally on supporting member **21** to move into the ready-for-picture-taking position. And when movable member **2** is moved to the down position by pushing lock arms **22** in the counterclockwise direction, the camera assumes the folded position. The opening and closing of movable member **2** are very simply carried out as has been described above. The front of fixed member **1** is provided

with a light-shield member **19** which is spring-biased in the counterclockwise direction to pivot on pivot member **191** to cover the inside while the camera is in the picture-taking position. In addition, fixed member **1** is provided with an electronic flash switch **91** which is turned ON when the switch is depressed by lock arms **22** at the time of raising movable member **2**, thus starting the charging of the capacitor for the electronic flash.

Next, the opening-closing mechanism of roller cover **7** is illustrated below:

Roller cover **7** is a cover that opens and closes pivoting on the opening-closing pivot **71** and has thereinside a pair of film-advancing rollers **72**. A film sheet ejected by film-advancing rollers **72** is ejected out of film exit **73**. Film exit **73** is provided with a movable cover **74** which serves to intercept light except when a processed film sheet is ejected from the exit.

When roller cover opening-closing button **75** which is slidably movable up and down is pushed upward, a projection **751** provided on the back of the opening-closing button **75** pushes a claw **76** up. When claw **76** is then pushed up in the counterclockwise direction pivoting on pivot member **761**, a projection **77** which is engaged with claw **76** becomes disengaged. Projection **77** is a projection that is provided to roller cover **7**, so that roller cover **7** opens pivoting on opening-closing pivot **71**. Film cassette C is loaded by opening roller cover **7** and pushing the film cassette rightward. Fixed member **1** is provided thereinside with a stopper (not shown), and when film cassette C is pushed as far as it goes, an electric connection with film cassette C is made by electric contact **41**. When roller cover **7** is closed, gear **721** provided on one of film-advancing rollers **72** is engaged with gear G provided inside fixed member **1** (FIG. **4**(*b*)). FIG. **4** shows the principal part of the film-advahcing section. FIG. **4**(*a*) is a sectional view viewed from Arrow C and FIG. **4**(*b*) is a sectional view viewed from Arrow D of FIG. **1**. The revolution of roller drive motor M1 is transmitted from a gear G1 mounted thereto through the gears of gear train G that engage with gear G1 to gear G2 so that gear G2 makes one revolution. Gear G2 is provided on one side thereof with a projection **78**. A movable plate **79** that engages at bent portion **791** thereof with projection **78** is resiliently biased leftward by a spring **792**, and movable plate **79** makes one lateral reciprocating motion by the revolution of gear G2, and then a raised portion **793** provided for pushing film on movable plate **79** pushes a corner of film cassette C to push rightward one film sheet inside cassette C. The film sheet pushed rightward is then ejected out through film exit **73** by film-advancing rollers **72**.

FIG. **5**(*a*) is a longitudinal sectional view as seen in the direction of arrows from the line I—I of FIG. **1**, and FIG. **5**(*b*) is a longitudinal sectional view as seen in the direction of arrows from the line II—II of FIG. **2**. With reference to these figures the operation of the movable mirror and the optical path will be illustrated below:

Exposure lens **3** and reflex mirror **5** are fixed to movable member **2**. When the camera is in the folded position, exposure lens **3** is covered with both fixed member **1** and movable member **2**. As movable member **2** is moved to the up position from the folded position of the camera as shown in FIG. **5**(*a*), reflex mirror **5** is gradually raised along with the movement of movable member **2**. In the picture-taking position, the light coming through the optical axis of exposure lens **3** is bent at an angle of 90 degrees by reflex mirror **5** to strike perpendicularly upon a film sheet. The side of reflex mirror **5** facing the sheet film is spaced from the sheet film so that no ghost appears on the photographed image. The optical path of the exposure optical system is considerably narrow at the reflective plane of reflex mirror **5**, so that the sizes of the reflex mirror and of movable member **2** may be made small.

In order to cover the above-mentioned optical path through exposure lens **3**, there is provided a bellows **54**, a light-shield member in the sleeve form made of cloth, paper, etc., having exposure lens **3** as its one opening and film cassette C mounting frame (aperture) as the other opening. Bellows **54** is in the form of having thereinside reflex mirror **5** and serves to cover the optical path when photographing and is folded to become flat when the camera is in the folded position.

FIG. **6** shows the finder system. FIG. **6**(*a*) is a longitudinal sectional view as seen in the direction of arrows from the line II—II of FIG. **2**. FIG. **6**(*b*) is a front view of the finder system. Finder **10** is a direct view finder provided in fixed member **1** and comprises a finder lens **101** and eye piece **102** and relay lenses **103** and **104** therebetween to define the photographable range (angle of view). A semi-transparent mirror (not shown) is provided in between the lenses of eye piece **102** to define as an Albada finder the autofocusing range. Further, in the visual field, a light source such as a light emission diode (LED) or the like is provided to tell completion of charging the capacitor for the electronic flash. In addition, the SC shown in FIG. **3** is the capacitor for the electronic flash.

FIG. **7** shows the mechanism related to the exposure lens shutter and AE, wherein FIG. **7**(*a*) is a plan view of the principal part viewed from Arrow C of FIG. **1**, and FIG. **7**(*b*) is a front view of the principal part viewed from Arrow E of FIG. **1**.

FIG. **8** shows interlocking relations between the AE, autofocusing unit and electronic flash unit **9** and the raising operation of movable member **2**, wherein FIG. **8**(*a*) is a plan view of the principal part of the electronic flash unit viewed from Arrow F of FIG. **2**, and FIG. **8**(*b*) is a front view of the same from Arrow G of FIG. **2**.

In FIG. **7**(*a*) and FIG. **8**(*b*), **31** is a EE light-receiving unit for exposure provided in movable member **2**. In front of light-receiving element **311** are condensor lens and comma-shaped light-receiving mask **312**. Moving laterally the print density control knob **313** that is an integral part of the light-receiving unit enables to vary the light-receiving area of light-receiving element **311** to thereby control the print density of an image to be photographed.

Autofocusing system **8** shown in FIG. **8**(*a*) is provided in fixed member **1**. Particularly, to avoid parallax, an infrared light emitter **81** for distance measurement is provided close to finder **10**, and the light axis of infrared light emitter **81** is nearly in parallel with the optical axis of finder **10**. **82** is the light receiving unit for distance measurement and is such that a spot light projected upon an object by light emitting element **811** of infrared light emitter **81** and lens **812** is focussed on a distance-measuring semiconductor element **822** by light-receiving unit's lens **821**, and distance measurement is made according to the spot position focussed on semiconductor **822**. Autofocusing system **8** is provided above the developing unit and nearly in parallel with the optical axis of exposure lens **3** inside fixed member **1**, so that the

system is of such a structure that greater accuracy is easily obtainable.

Next, the shutter operation is illustrated in the order of photographing steps with reference to FIG. 7(*b*).

The camera of the present invention has a motor in addition to the aforementioned roller drive motor M1. When shutter button **11** is depressed, photographing motor M2 reverses to rotate gear **321** in the counterclockwise direction. A pin **322** provided on the peripheral surface of gear **321** oscillates intermediate lever **323** in the clockwise direction and further oscillates stop lever **324** in the counterclockwise direction. The oscillation of stop lever **324** disengages the stoppage of lens unit **325** by hook **327** provided thereon, the lens unit being resiliently biased in the counterclockwise direction by spring **326**, to rotate lens unit **325** in the counterclockwise direction. Exposure lens **3** is mounted to lens unit **325**. Because lens unit **325** is helicoidally rotatably mounted to movable member **2**, with the rotation of lens unit **325**, exposure lens **3** is turned out. The rotation of lens unit **325** causes autofocusing position detecting resistor **328** to move slidingly to operate lens stopping magnet Mg1 by providing a comparative input into the comparator the detected voltage with the voltage obtained from autofocusing light-receiving element **822**, and oscillates lock claw **325** in the counterclockwise direction to cause the lock claw to plunge into the ratchet claw provided on lens unit **325** to stop the rotation of lens unit **325**, and then the movement of exposure lens **3** is stopped to effect autofocusing.

Shutter starting magnet Mg2 is then operated to turn fore-blade lever **321** in the counterclockwise direction. The turning of fore-blade lever **331** turns shutter link **332** in the clockwise direction which then moves laterally movable A-blade **333** and B-blade **334**. Namely, A-blade **333** moves leftward and B-blade **34** moves rightward simultaneously, and when the openings of both blades coincide with each other, the shutter diaphragm opens.

When shutter magnet Mg3 operates for closing the shutter due to the information from EE light-receiving unit **31**, after-blade stop lever **335** turns in the clockwise direction to disengage the engagement with after-blade drive member **337** that has been biased in the clockwise direction by spring **336**. After-blade drive member **337** turns in the clockwise direction to turn the foregoing shutter link **332** in the counterclockwise direction to thereby move A-blade **333** rightward and B-blade leftward simultaneously, thus closing the shutter diaphragm.

The autofocusing is made as has been described above, which is then followed by shutter exposure. As to the shutter charge, the aforementioned photographing motor M2 revolves normally, gear **321** rotates in the clockwise direction, and related members including lens unit **325** are restored to the initial conditions.

Interlocking relations between electronic flash unit **9** and the raising operation of movable member **2** are subsequently illustrated. Both FIG. **8**(*a*) and FIG. **8**(*b*) show electronic flash unit **9** in the condition of sticking out (pop-up) away from the optical axis of exposure lens **3**. Electronic flash unit **91** is mounted together with a laterally movable supporting member **92** to movable member **2**. And a projection **921** provided on supporting member **92** is connected to a less-contractive wire **96** one end of which is connected to a projection **95** on fixed member **1**, and further projection **921** is also connected to flexible spring **97** which is biased in the contractive direction. If movable member **2** is lifted, electronic flash unit **91** is pulled by wire **96** to stick out away from the optical axis of exposure lens **3**.

If movable member **2** is pushed down after completion of photographing, the tension of spring **97** moves electronic flash unit **91** into movable member **2**.

In this camera, with the folding of movable member **2**, a finder window **106**, autofocusing windows **83** and **84** which are provided on fixed member **1** are covered with a cover plate **85**. In FIG. **8**(*a*) and FIG. **8**(*b*), fixed member **1** has a pivot **86** and a L-shaped-lever **87** which pivots upon the pivot **86**. One end **871** of L-shaped lever **87** engages with a projection **851** provided on a laterally movable cover plate **85**, and a projection **872** provided on the other end engages with movable member **2**. L-shaped lever **87** is biased in the counterclockwise direction by spring **88**, so that projection **872** provided on L-shaped lever **87** pushes the under surface of movable member **2**. If movable member **2** is now raised, L-shaped lever **87** is turned in the counterclockwise direction by the force of biased spring **88** to move thin cover plate **85** so that the opening in the cover plate coincides with autofocusing windows **83** and **84**, and the cover plate moves out of its position for covering finder windows **106**, and thus finder window **106**, autofocusing windows **83** and **84** are all in the open condition.

And when movable member **2** is pushed down to be in the folded position, L-shaped lever **87** is turned in the clockwise direction by movable member **2** to move cover plate **85** leftward, and then finder window **106**, autofocusing windows **83** and **84** are all covered with cover plate **85** to be in the closed condition.

The first example of the present invention is as has been described above. FIG. **9**(*a*) and (*b*) and FIG. **10** (*a*) and (*b*) are sectional views of the second and third examples, respectively.

In the second example shown in FIG. **9**, what is different from the first example is that finder unit **10***a* is provided in movable member **2***a*. An objective lens **101***a* composed of a concave lens is fixed in parallel with exposure lens **3***a* to movable member **2***a*, and an eye piece **102***a* is mounted to a finder supporting member **103***a* which is movable with respect to movable member **2***a*. Finder supporting member **103***a* is mechanically interlockingly movable with movable member **2***a* or may be moved manually. When in the picture-taking position in which movable member **2***a* is raised, finder **10***a* is in the state of being viewable therethrough, while in the condition that movable member **2***a* is folded, finder **10***a* is also in the state of being folded. In this example, the optical axis of the finder is arranged so close to the optical axis of the exposure lens that the parallax is very small.

In the third example shown in FIG. **10**, what is, different from the foregoing first example is that, whereas in the first example exposure lens **3** and reflex mirror **5** are all fixed to movable member **2**, the third example is such that exposure lens **3***b* is movable with respect to moveable member **2***b* and reflex mirror **5***b* is fixed to movable member **2***b*. Exposure lens **3***b* is fixed to a lock lever **22***b* which has a pivot **23***b* on movable member **2***b* and which is slidably movable along a cam slot **14***b* that is provided on fixed member **1***b*. Therefore, when movable member **2***b* is raised to the up position, the optical axis of exposure lens **3***b* becomes nearly parallel with the sheet film plane and at an angle of about 45° to the plane of reflex mirror **5***b*, while in the folded position

that movable member **2***b* is pushed down, exposure lens **3***b* is in a position as shown in FIG. **10**(*a*). The mechanism in this example is slightly more complex than that in the first example, but has the advantage that the camera becomes thinner and more compact in the folded position.

The structure of the camera of the invention is as has been described above. The handling and mechanical operation of the camera in the examples are subsequently described below:

First, film cassette C is loaded. By depressing opening-closing button **75** of roller cover **7**, roller cover **7** opens. After that, when loading film cassette C and closing roller cover **7**, film-advancing rollers **72** are engaged with film-advancing gears to thereby rock the rollers.

When movable member **2** is raised to the up position, (1) a catch in the portable condition is disengaged, (2) electronic flash unit **91** is popped up, (3) exposure lens **3** and reflex mirror **5** are set, (4) bellows **54** is set, (5) electronic flash switch **91** is ON, (6) light-shield member **19** moves to the light-shield position, and (7) supporting member **4** is locked.

The picture-taking sequence is indicated in the sequence time chart.

The camera folding is made by pushing the lock levers **22** to push down movable member **2**.

Since certain changes may be made in the above photographic film assemblage and photographic apparatus without departing from the scope of the invention herein involved, it is intended that all matter containing in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. In a folding camera of the type having a base housing for holding a film cassette containing a plurality of film sheets, means for exposing a film sheet to light received from a subject by an objective lens and reflected from a reflex mirror to the film sheet at an exposure position in the base housing, and means for developing the film sheet and advancing it from an exit end of the base housing, the improvement wherein said means for exposing comprises a movable member supporting said objective lens and reflex mirror which is movable between a closed position forming a closure to the base housing and an open position in which said movable member is elevated above said base housing, said objective lens being riddily fixed to said movable member at a distal end thereof in an operative position for exposure, and a supporting member connected to the other end of said movable member and being pivotally coupled to said base housing at an end thereof opposite from the film exit end.

2. The folding camera as defined in claim **1**, wherein said objective lens is moved to an inoperative position within said base housing when said movable member is moved to the closed position.

3. The folding camera as defined in claim **1**, wherein said reflex mirror is mounted to said movable member so as to form an angle in the open position with an upper surface of said base housing, and said supporting means is pivotally coupled at a position of the upper surface of said base housing in proximity to one end of said reflex mirror.

4. The folding camera as defined in claim **1**, further comprising a built-in flash unit which is movable to an operative position in accordance with the movement of said movable member to said open position.

5. The folding camera as defined in claim **4**, wherein said flash unit includes a condenser, wherein a charging operation of said condenser is automatically started when said movable member is moved to the open position.

6. The folding camera as defined in claim **1**, further comprising a light shielding member for shielding an opening formed between said base housing and said movable member in the open position, said light shielding member being spring biased to close said opening when said movable member is moved to the open position.

7. The folding camera as defined in claim **1**, wherein said objective lens and said reflex mirror are rigidly mounted to said movable member in a fixed positional relationship to each other for exposing the film sheet at the exposure position when said movable member is in the open position.

8. In a folding camera of the type having a base housing for holding a film cassette containing a plurality of film sheets therein, means for exposing a film sheet with light from a subject received by an objective lens and reflected from a reflex mirror to the film sheet at an exposure position in the base mounting, and means for developing the film sheet and advancing it out from exit end of said housing, the improvement comprising a movable member mounting said objective lens and said reflex mirror which is movable between a closed position forming a closure to said base housing and an open position in which it is elevated above said base housing, and a supporting member connected to one end of said movable member and being pivotally coupled to the base housing, wherein said objective lens is rigidly mounted to a lock arm, one end of which is pivotally connected to a distal end of said movable member, and the other end of which is held in cam slot defined within said base housing and movable between an operative position for said objective lens and an inoperative position wherein said objective lens is folded in the base housing, and wherein said reflex mirror is rigidly mounted to said movable menber so as to be in an operative positional relationship with said objective lens when said movable member is moved to the open position.

* * * * *

United States Patent [19]

Arai et al.

[11] **Patent Number: 4,542,410**

[45] **Date of Patent: Sep. 17, 1985**

[54] **AUTOMATIC DIAPHRAGM CONTROL DEVICE OF OBJECTIVE PROVIDED WITH AUTOMATIC DIAPHRAGM FOR CLOSED CIRCUIT TELEVISION (CCTV) CAMERA**

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[73] Assignee: **Asahi Seimitsu Kabushiki Kaisha,** Tokyo, Japan

[21] Appl. No.: **504,860**

[22] Filed: **Jun. 16, 1983**

[30] **Foreign Application Priority Data**

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[51] **Int. Cl.**[4] **H04N 5/26**

[52] **U.S. Cl.** **358/228**

[58] **Field of Search** 358/228, 174, 217, 209

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Primary Examiner—Gene Z. Rubinson
Assistant Examiner—Robert Lev
Attorney, Agent, or Firm—Birch, Stewart, Kolasch & Birch

[57] **ABSTRACT**

A control circuit for automatically opening and closing the diaphragm of the objective lens of a closed circuit television (CCVT) camera including a variable gain inverting amplifier for amplifying and inverting video signals from the camera, a voltage doubler and rectifier with an adjustable capacitor coupled to the output of the inverting amplifier, a voltage level shifter coupled to the output of the voltage doubler for lowering signals output therefrom by a predetermined voltage, a power supply for providing bias voltage to said control circuit, an intermediate voltage supply circuit for providing a signal reference voltage to said circuit which is intermediate to the value of said bias voltage, and a comparator circuit for comparing the intermediate voltage with the signal output from said level shifter and opening or closing the diaphragm based on the results of the comparison.

4 Claims, 3 Drawing Figures

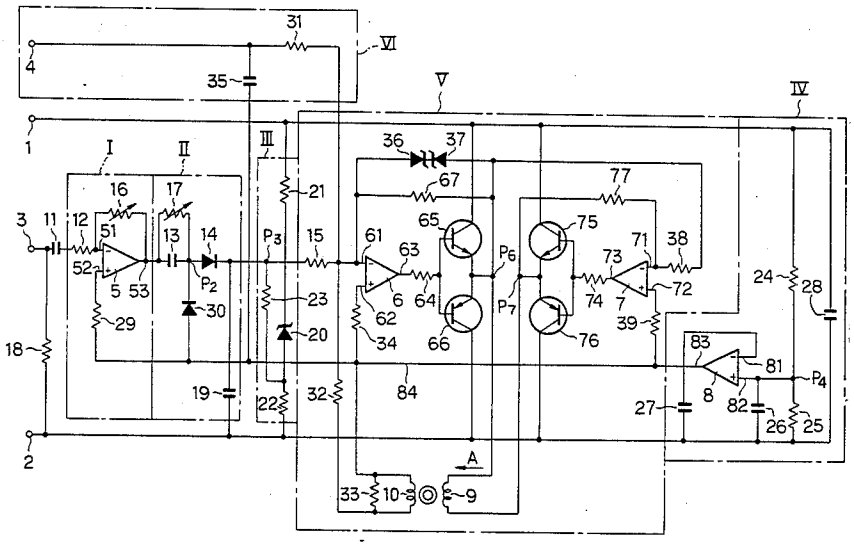
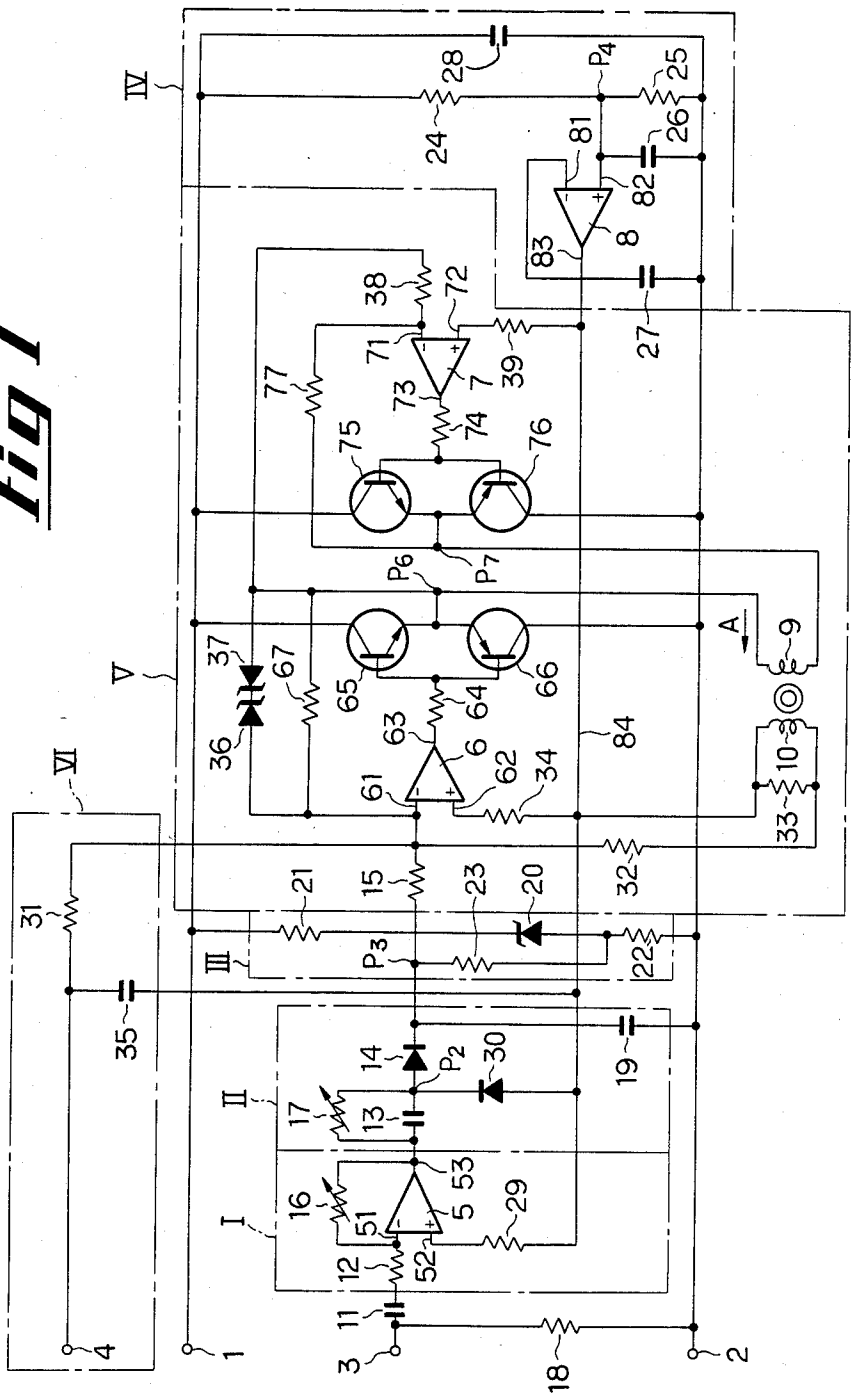


Fig 1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P7

fig 2(a)

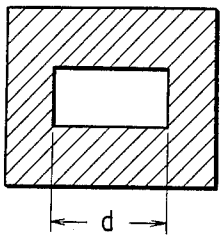


Fig. 2(b)

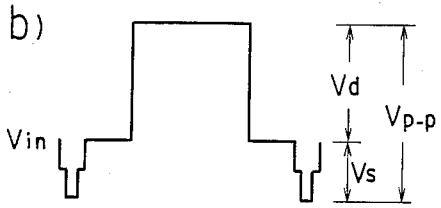


Fig. 2(c)

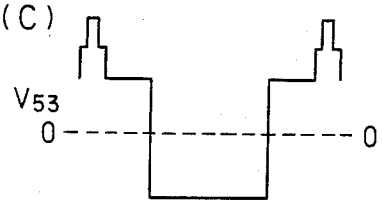


Fig. 2(d)

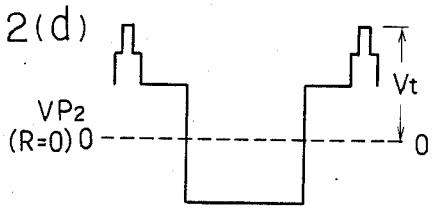


Fig. 2(e)

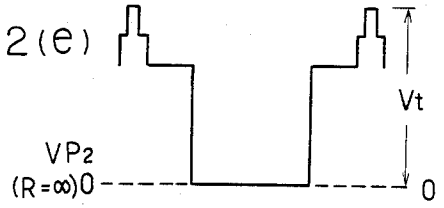


fig 3(a)

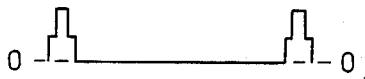
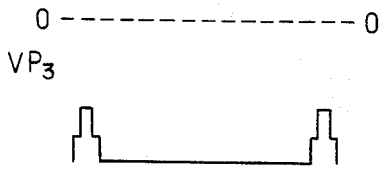


Fig. 3(b)



AUTOMATIC DIAPHRAGM CONTROL DEVICE OF OBJECTIVE PROVIDED WITH AUTOMATIC DIAPHRAGM FOR CLOSED CIRCUIT TELEVISION (CCTV) CAMERA

BACKGROUND OF THE INVENTION

The present invention relates to an automatic diaphragm control device for an objective lens provided with an automatic diaphragm in a closed circuit television (CCTV) camera. The objective lens diaphragm is controlled in response to brightness levels of video signals received by the television camera.

For the closed circuit television (CCTV) cameras in video systems, it has usually been necessary for the objective lens provided with an automatic diaphragm to contain a complicated control circuit comprising many elements and having functions not only of a light measuring mode conversion, but also of sensitivity regulation. Consequently, the objective lens has been too bulky to be easily handled. Further, there has recently been a tendency to provide lower source voltages for energization of such control systems as the development of a small-sized cameras has progressed, and there has developed a demand for a novel control circuit compatible with the lower power sources and small-sized cameras.

SUMMARY OF THE INVENTION

Accordingly, it is a primary object of the present invention to provide an automatic diaphragm control circuit for the objective lens of a closed circuit television (CCTV) camera with a reduced number of circuit elements , which results in a compact objective lens assembly that is compatible with small-sized cameras.

It is a further object of the present invention to provide an automatic control circuit for the automatic diaphragm of the objective lens of a CCTV camera which facilitates the desired diaphragm control at a relatively low source voltage.

The objects of the present invention are fulfilled by providing an automatic diaphragm control circuit for the objective lens of a closed circuit television (CCTV) camera comprising an inverting amplifier with a variable gain adapted to be applied to a video signal coming from the television camera and to invert and amplify said video signal, a voltage doubler including a capacitor with charging voltage adjustment means therefor for voltage doubling and rectification of the output signal coming from said inverting amplifier, a level shifter adapted to lower the level of the rectified signal by a predetermined voltage, an intermediate voltage supplying circuit adapted to supply an intermediate voltage with respect to a power source voltage, and a diaphragm driving circuit adapted to compare the intermediate voltage supplied from said intermediate voltage-supplying circuit with the rectified signal coming from said level shifter and to adjust the diaphragm on the basis of a result of such comparison.

BRIEF DESCRIPTION OF THE DRAWINGS

The objects of the present invention will become more fully understood from the detailed description given hereinbelow and the accompanying drawings which are given by way of illustration only and thus are not limitative of the present invention and wherein:

FIG. **1** is a circuit diagram illustrating an embodiment of the device according to the present invention;

FIG. **2** is a series of diagrams schematically illustrating the relationship established between a test object to be picked up by the camera and signal waveforms in each stage of the circuit of FIG. **1**; and

FIG. **3** is a diagram illustrating the signal waveform appearing at the output terminal P_3 of FIG. **1** when a relatively dark object is picked up by the camera.

DETAILED DESCRIPTION OF THE DRAWINGS

The present invention will be described in more detail with reference to an embodiment shown by the accompanying drawings.

FIG. **1** is a circuit diagram showing an embodiment of the device constructed according to the present invention, in which reference numeral **1** designates a plus voltage side and reference numeral **2** designates a grounded side, respectively, of a power source circuit. Reference numeral IV designates an intermediate voltage-supplying circuit connected to said power source circuit and adapted to provide a voltage of intermediate (preferably $\frac{1}{2}$) level with respect to a power source voltage at an intermediate voltage terminal **84**. In the embodiment shown, a smoothing capacitor **28** and series resistances **24**, **25** are connected in parallel across the positive voltage side **1** and the grounded side **2** of the power source. A node P_4 between said resistances **24**, **25** is connected to a noninverting input terminal **82** of an operational amplifier **8** while an inverting input terminal **81** is directly connected to an output terminal **83**, and said noninverting input terminal **82** and said output terminal **83** are connected via capacitors **26**, **27**, respectively, to the grounded side **2** so that said voltage of $\frac{1}{2}$ level relative to the power source voltage is output at the intermediate (middle point) voltage terminal **84**.

Reference numeral **3** designates a video signal input terminal adapted to input video signals from a television camera to the control circuit according to the present invention, and is connected via a resistance **18** to the grounded side **2** on one hand, and via a capacitor **11** to an inverting amplifier I, on the other hand.

In the inverting amplifier I, an inverting input terminal **51** of an operational amplifier **5** is connected via a resistance **12** to said capacitor **11** while a noninverting input terminal **51** is connected via resistance **29** to the intermediate voltage terminal **84**. A variable resistance **16** is connected, as a feedback resistance, between said inverting input terminal **51** and an output terminal **53**. The inverting amplifier I is adapted for amplifying and inverting the video signal of which the DC component has been eliminated in said capacitor **11** and permits an amplification degree of the operational amplifier **5** which may be controlled by adjusting the variable resistance **16**.

Reference numeral II designates a voltage doubler functioning to rectify the video signal which has been amplified and inverted by said inverting amplifier I and comprises a voltage doubling capacitor **13** connected to the output terminal **53** of said operational amplifier **5** in parallel with a variable resistance **17**, a diode **30** via which the intermediate voltage terminal **84** is connected to an output terminal P_2 of said capacitor **13**, and another diode **14** serially connected to said output terminal P_2. The variable resistance **17** is provided to regulate a charging voltage for the voltage doubling capacitor **13** so that when the charging voltage becomes zero, the

capacitor **13** is not activated at a resistance value of zero and the charging voltage rises as the resistance value increases. The diode **14** is adapted for DC rectification of the signal at the output P_2 of the capacitor **13**. Further, there is connected a capacitor **19** between the output terminal of the diode **14** and the grounded side **2** to smooth said rectified signal.

Reference numeral III designates a level shifter comprising a resistance **21**, a Zener diode **20** and a resistance **22** via which the plus voltage side of power source **1** is connected to the grounded side **2**, and a resistance **23** via which the minus side (i.e., anode side) of the Zener diode **20** is connected to an output terminal P_3 of the voltage doubler II. This level shifter functions to reduce the rectified signal from the voltage doubler toward the minus side of the power supply by a predetermined voltage, and thereby to level-shift said rectified signal so that the behaviour range thereof extends on the plus and minus sides with respect to the intermediate voltage.

Reference numeral V designates a diaphragm driving circuit adapted to compare the output signal from the level shifter III with the intermediate voltage and to drive the diaphragm in a direction according to a result of this comparison. In the diaphragm driving circuit V, an operational amplifier **6** has its inverting input terminal **61** connected via a resistance **15** to the output terminal P_3 of the voltage doubler II, its noninverting input terminal **61** connected via a resistance **34** to the intermediate voltage terminal **84**, and its output terminal **63** connected via a resistance **64** to the commonly-connected basis of transistors **65**, **66**. The transistor **65** functions as a switching element which takes a conductive state when the base voltage rises to a level higher than a predetermined value while the transistor **66** functions as a switching element, which takes a non-conductive state when the base voltage drops to a level lower than a predetermined value. The transistor **65** is of the NPN type with its collector connected to the emitter of the transistor **66**, the latter being of the PNP type. This transistor **66** has its collector connected to the grounded side **2**. To eliminate any unresponsive ranges of these switching transistors **65**, **66**, a feedback resistance **67** is connected between a common emitter terminal P_6 and the reversed input terminal **61** of the operational amplifier **6**, while a pair of mutually opposed Zener diodes **36**, **37** are arranged in parallel to said feedback resistance **67**. Said emitter terminal P_6 is connected via the resistance **38** to the inverting input terminal **71** of an operational amplifier **7**, while a noninverting input terminal **72** of said operational amplifier **7** is connected via a resistance **39** to the intermediate voltage terminal **84**. An output terminal **73** of the operational amplifier **7** is connected via a resistance **74** to the commonly-connected basis of transistors **75**, **76**. The transistor **76** functions as a switching element, adapted to take a conductive state when the base voltage drops to a level lower than a predetermined value. The transistor **75** is of the NPN type with its collector connected to the plus voltage side **1** of the power source circuit, and its emitter commonly connected to the emitter of transistor **76**, which is of the PNP type. The transistor **76** has its collector connected to the grounded side **2** of the power source circuit. To eliminate any unresponsive ranges of these switching transistors **75**, **76**, there is connected a feedback resistance **77** between a common emitter terminal P_7, and the inverting input terminal of the operational amplifier **7**. There is provided a diaphragm driving coil **9** between both common emitter terminals P_6, P_7, so that the diaphragm is driven in an opening direction as electric current flows in the direction of an arrow A. A braking coil **10**, adapted for control of the diaphragm speed is connected via a series resistance **32** and a parallel resistance **33** between the inverted input terminal **61** of the operational amplifier **6** and the intermediate voltage terminal **84**.

Reference numeral VI designates a remote voltage supplying circuit for remote control of sensitivity regulation and comprises a remote voltage input terminal **4** connected via a resistance **31** to the inverting input terminal **61** of the operational amplifier **6**, on one side, and connected via a capacitor **35** to the intermediate voltage terminal **84**.

In the embodiment of the device constructed, as has been described above according to the present invention, it is now assumed that the video signal input terminal **3** is supplied with a video signal V_{in} having a waveform as shown in FIG. **2**(*b*), corresponding to a test pattern of an object, as shown in FIG. **2**(*a*). Of this waveform, a rectangular portion of the plus side corresponds to a bright area of the image. Reference symbol V_d represents a video level and reference symbol V_s represents a synchronous level. Such video level V_{in} is inversely amplified, as shown in FIG. **2**(*c*) by the inverting amplifier I and appears in the form of an inverted signal V_{53}, with its DC component already eliminated by the capacitor **11**. In consequence, a steady state is established in which the positive and negative portions of the waveform occupy equal areas with respect to the base line (i.e., the line **0**—**0** corresponding to the intermedate voltage). The amplification degree of the reversing amplifier I may be increased as the variable resistance **16** is adjusted toward a higher resistance value, and may be decreased as said variable resistance **16** is reduced. By adjusting the amplification degree in this manner, it is possible to adjust an amplitude $V_{p\text{-}p}$ of the inverted signal V_{53}, and thereby achieve sensitivity regulation.

The inverted signal V_{53} is then rectified by the voltage doubler II. When the resistance value of the variable resistance **17** is adjusted to zero, the capacitor **13** is not activated at all, and a signal VP_2 appearing at the output terminal P_2 of said capacitor **13**, coincides with the inverted signal V_{53}, as shown in FIG. **2**(*d*). In this case, the diode **30** is responsive to the minus portion of the inverted signal V_{53} to become conductive; but this minus portion is passed through the resistance **17**(R=O) and never charged into the capacitor **13**. Thus, the plus voltage V+ is given in the form of an average value, so that such light measuring mode may be referred to as the average light measuring mode suitable for picking up an object to which is covered substantially by a relatively dark area. When the resistance value of the variable resistance **17** is adjusted to infinity, the diode **30** is responsive to the minus portion of the inverted signal V_{53} to become conductive, and this minus portion is charged into the capacitor **13**. The subsequent plus portion of the signal is added to the previously charged voltage, and the output signal VP_2 is subjected to DC regeneration as shown in FIG. **2**(*e*), so that it is possible to detect the amplitude of the video level V_d even when the width d of the lighter portion is small. Accordingly, the light measuring mode with the variable resistance **17** having a resistance value adjusted to infinity, may be referred to as the peak light measuring mode suitable for picking up an object which is

covered substantially by a relatively light area. Further, another mode of light measuring, referred to as the intermediate light measuring mode, is also possible. This mode is intermediate of said average light measuring mode and said peak light measuring mode, and achieved by adjusting the resistance value of the variable resistance **17** to an intermediate value.

The signal rectified by said voltage doubler II takes the similar waveform to the plus portion of the output signal VP_2 from the capacitor **13** and is positive with respect to the intermediate voltage (line **0—0**), as shown in FIG. **3**(*a*), even in the darkest object conditions, since the input signal V_{in} contains the synchronous level V_s. However, the device according to the present invention should function on the basis of the intermediate voltage. To meet this requirement, the rectified signal is level-shifted by the level shifter toward the minus side so that the signal level is lowered by a predetermined voltage, and the video signal corresponding to a relatively dark image is on the minus side with respect to the intermediate voltage. Thus, the signal VP_3, appearing at the output terminal P_3 has, as shown in FIG. **3**(*b*), its waveform on the minus side and is responsive to a darker video signal incoming to be lowered relative to the intermediate voltage. In this manner, the signal VP_3 at the output terminal P_3 can be used within equal ranges on both the plus side (when an object to be picked up is relatively bright) and the minus side (when the object is relatively dark), respectively.

The signal which has left the level shifter III is applied to the inverting input terminal **61** of the operational amplifier **6**. In the optimum video condition, an input voltage V_{61} is equal to the intermediate voltage, while an output voltage V_{63} at the output terminal **63** is equal to the intermediate voltage e/2, and neither the transistor **65** nor the transistor **66** is activated, so that the driving coil **9** is not energized. When an object to be picked up is relatively bright, i.e., the input voltage $V_{61}>e/2$, such input voltage V_{61} is inversely amplified by the operational amplifier **6** with respect to the intermediate voltage so that a relationship of the output voltage $V_{63}<e/2$ is established, thereby the transistor **66** becomes conductive across its collector and emitter, and a voltage $VP_6<e/2$ appears at the emitter terminal P_6. When this voltage VP_6 is inversely amplified again by the operational amplifier **7** with respect to the intermediate voltage, an output voltage $V_{73}>e/2$ appears at the output terminal **73** of said amplifier **7**, and the transistor **75** becomes conductive across its collector and emitter. The transistors **66**, **75** which have become conductive in this manner, permit the plus side **1** of the power source circuit to provide electric current flowing through the transistor **75**, and then in the direction opposite to the direction indicated by the arrow A. The diaphragm driving coil **9** is thereby activated to close the diaphragm.

When an object to be picked up is relatively dark, i.e., the input voltage $V_{61}<e/2$, on the contrary, such input voltage V_{61} is inversely amplified by the operational amplifier **6** with respect to the intermediate voltage so as to produce the output voltage $V_{63}>e/2$, and the transistor **65** becomes conductive across its collector and emitter, resulting in the voltage $VP_6>e/2$ appearing at the emitter terminal P_6. When this voltage VP_6 is inversely amplified again by the operational amplifier **7** with respect to the intermediate voltage, the output terminal **73** of this operational amplifier **7** now provides the output voltage $V_{73}>e/2$, in response to which the transistor **76** becomes conductive across its collector and emitter. Once the transistors **65**, **76** have become conductive in this manner, the electric current flows from the plus side of the power source circuit through the transistor **65**, and then, in the direction of the arrow A, through the diaphragm driving coil **9** which is thereby activated to open the diaphragm. Such opening and closing movement of the diaphragm generates an electromotive force in the braking coil **10**, so as to apply the inverted input terminal **61** of the operational amplifier **6** with feedback, and thereby prevents the diaphragm from oscillating. This assures that said opening or closing movement occurs at a constant speed. Application of a plus or negative constant voltage via the remote input terminal **4** to the inverted input terminal **61** of the operational amplifier **6** permits the signal level to be raised or lowered, and sensitivity regulation to be achieved by remote control without adjustment of the variable resistance **16** for the inverting amplifier I.

As will be clear from the foregoing description, the automatic diaphragm control circuit for the objective lens of a closed circuit television (CCTV) camera according to the present invention permits sensitivity regulation to be achieved by regulating the amplification degree of the inverting amplifier, and permits a relatively compact objective lens assembly to be employed therein, since the number of circuit elements used can be substantially reduced. Furthermore, the output voltage of the diaphragm control signal can be used over equal extensions on both the plus side and the minus side, because an intermediate voltage to the power supply voltage is used as the reference voltage according to the present invention. Thus, it is possible to achieve the desired diaphragm control within a range as wide as possible, even when the power source voltage is relatively low.

It should be understood that the present control circuit may be modified as would occur to one of ordinary skill in the art without departing from the spirit and scope of the present invention.

What is claimed is:

1. An automatic control circuit for opening and closing the diaphragm of the objective lens for a video camera comprising:

power source means foı providing a bias voltage to said control circuit;

inverting amplifier means for receiving video signals output from said video camera and amplifying and inverting said signals;

voltage doubler means including capacitor means for doubling and rectifying the signals output from said inverting amplifier means;

means for adjusting the sensitivity of said control circuit;

level shifter means for lowering the level of the doubled and rectified signals output from said doubler means by a predetermined voltage;

intermediate voltage supply circuit means for supplying said control circuit with a voltage which is intermediate with respect to said bias voltage; and

diaphragm control means for comparing said intermediate voltage with signals output from said level shifter means and opening or closing said diaphragm in response to the results of the comparison.

2. The control circuit of claim **1**, wherein said means for adjusting the sensitivity of said control circuit comprises a variable gain control for said inverting amplifier

and means for adjusting the charging current to the capacitor means.

3. The control circuit of claim 2, wherein said means for adjusting the charging current comprises a variable resistor in parallel with said capacitor.

4. The control circuit of claim 1, wherein said means for adjusting said sensitivity of said control circuit comprises control voltage for superimposing a sensitivity control voltage on the signals output from said level shifter means.

* * * * *

United States Patent [19]

Nakai et al.

[11] **Patent Number: 4,529,288**

[45] **Date of Patent: Jul. 16, 1985**

[54] **CAMERA SYSTEM WITH INTERCHANGEABLE OBJECTIVE LENS**

[75] Inventors: **Masaaki Nakai**, Nara; **Masayoshi Sahara**, Sennan; **Nobuyuki Taniguchi**, Tondabayashi, all of Japan

[73] Assignee: **Minolta Camera Kabushiki Kaisha**, Osaka, Japan

[21] Appl. No.: **529,969**

[22] Filed: **Sep. 7, 1983**

[30] **Foreign Application Priority Data**

Sep. 9, 1982 [JP] Japan 57-157895

[51] **Int. Cl.**[3] **G03B 7/097**; G03B 7/20

[52] **U.S. Cl.** **354/442**; 354/286

[58] **Field of Search** 354/410, 441-445, 354/455, 460, 456, 286, 289.12

[56] **References Cited**

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56-107221	8/1981	Japan	354/455

Primary Examiner—William B. Perkey

Attorney, Agent, or Firm—Joseph W. Price

[57] **ABSTRACT**

A camera system having an interchangeable objective lens selectively mountable to at least two different types of camera bodies of a, first type and second type, is involved. The camera system has a ROM located in the interchangeable objective lens for storing a plurality of compensation data: one is suitable for the first type camera body; and the other is suitable for the second type camera body. Each data compensates an error in fully-open aperture light measurement for each type of camera. The compensation data is transmitted from the lens to the camera body. A register is provided in the camera body for storing a selected compensation data which is necessary for the type of camera body mounted with the lens. A device is provided in the camera body for practicing a fully-open aperture light measurement through the interchangeable objective lens to produce a light measuring information including the light measurement error. A calculator is provided in the camera body for calculating a correct exposure information using the compensation data stored in the register and the light measuring signal, whereby the error included in the light measuring signal can be removed.

14 Claims, 19 Drawing Figures

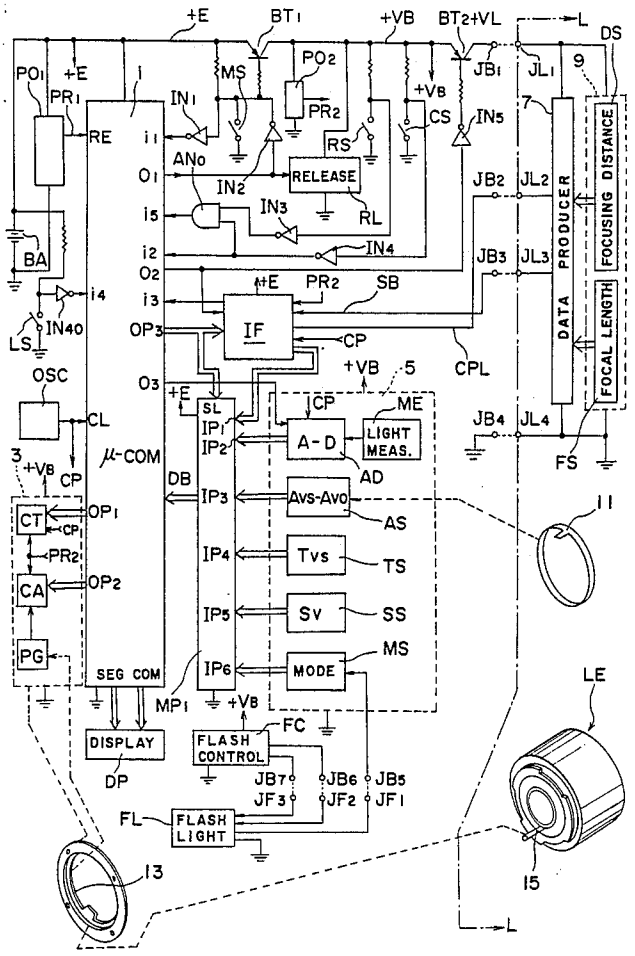


Fig. 1

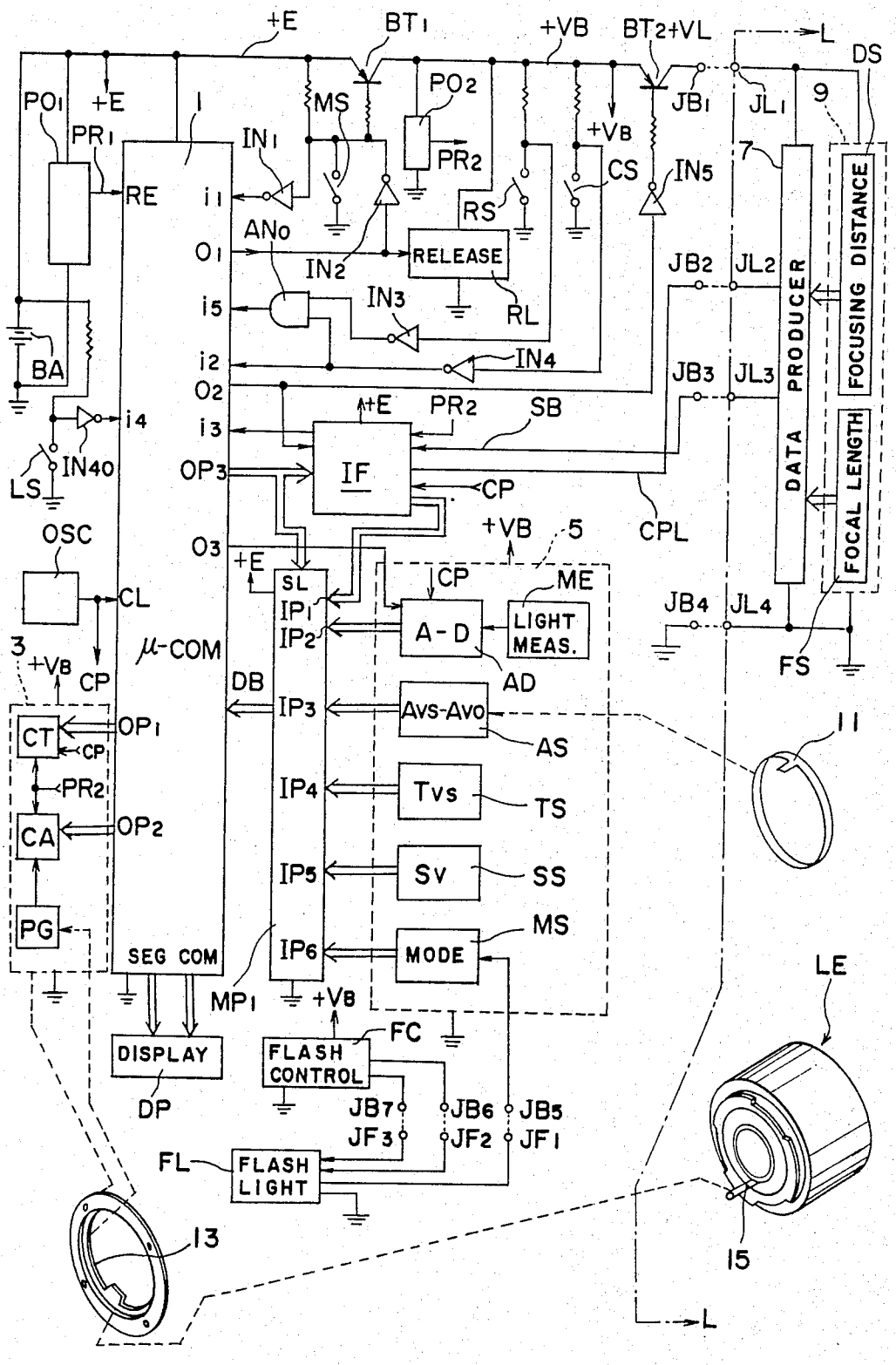

+E
BT1
+VB
BT2+VL
L
DS
PO1
PR1
RE
I
MS
PO2
PR2
IN1
i1
ANo
O1
IN2
RELEASE
RL
RS
+VB
CS
IN5
JB1
JL1
9
7
DATA PRODUCER
FOCUSING DISTANCE
FOCAL LENGTH
JB2
JL2
JB3
JL3
JB4
JL4
FS
BA
i5
IN3
i2
IN4
O2
i3
+E
PR2
SB
IF
CP
CPL
i4
IN40
LS
OP3
O3
OSC
CL
+VB
5
SL
IP1
IP2
A-D
ME
LIGHT MEAS.
AD
μ-COM
3
+VB
CP
DB
IP3
Avs-Avo
AS
11
CT
OP1
CP
PR2
IP4
Tvs
TS
CA
OP2
IP5
Sv
SS
PG
IP6
MODE
MS
SEG COM
MP1
+VB
FC
LE
DISPLAY
DP
FLASH CONTROL
JB7
JB6
JB5
JF3
JF2
JF1
FL
FLASH LIGHT
13
15
L

Fig. 2a

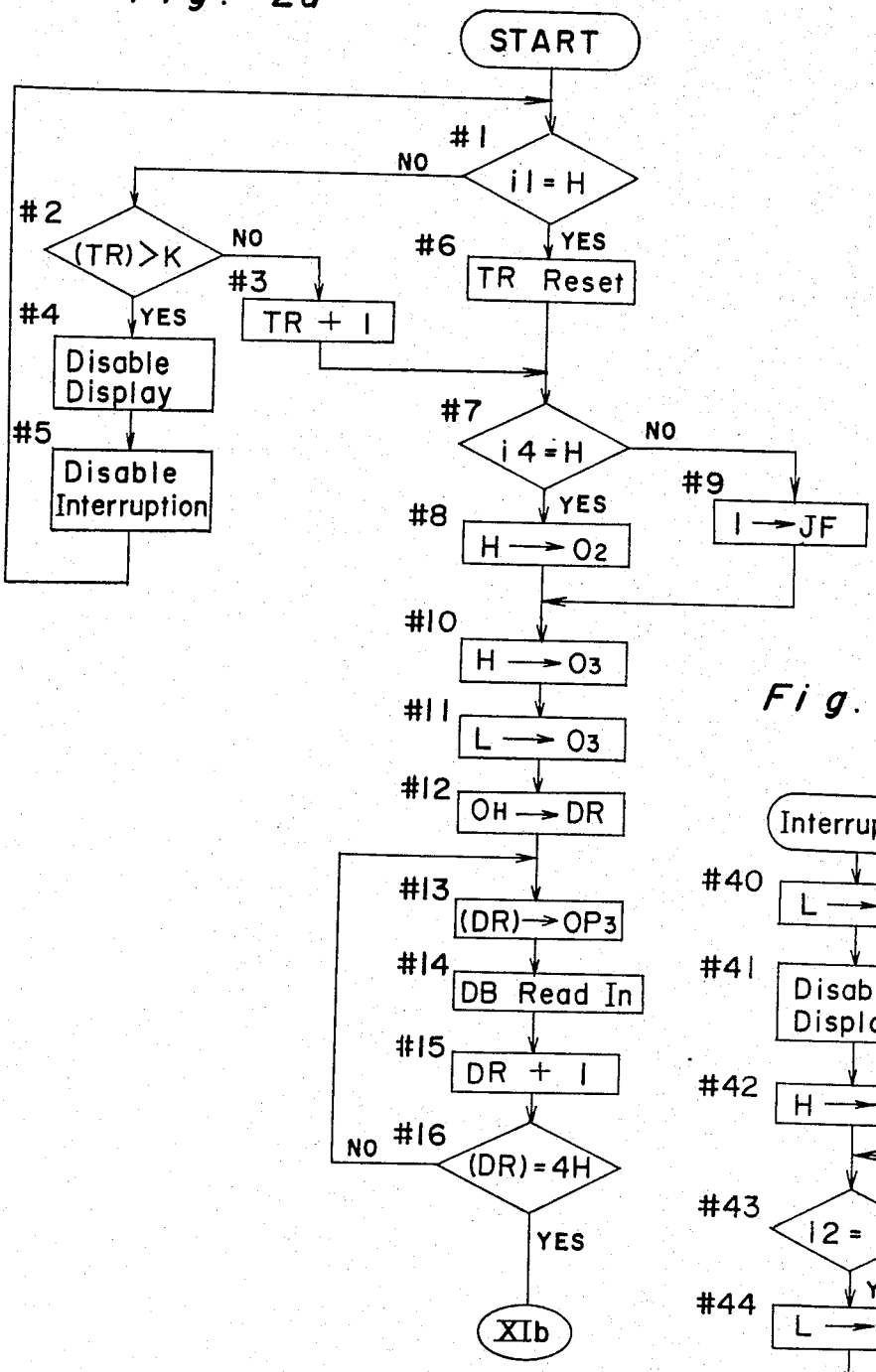

START
#1
i1 = H
NO
YES
#2
(TR) > K
NO
YES
#3
TR + 1
#4
Disable Display
#5
Disable Interruption
#6
TR Reset
#7
i4 = H
NO
YES
#8
H → O2
#9
1 → JF
#10
H → O3
#11
L → O3
#12
OH → DR
#13
(DR) → OP3
#14
DB Read In
#15
DR + 1
#16
(DR) = 4H
NO
YES
XIb

Fig. 2c

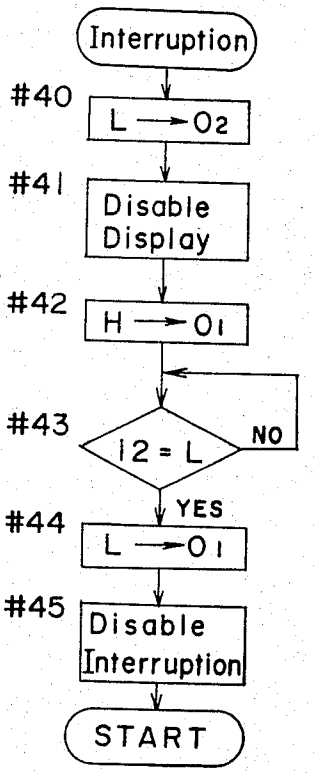

Interruption
#40
L → O2
#41
Disable Display
#42
H → O1
#43
I2 = L
NO
YES
#44
L → O1
#45
Disable Interruption
START

Fig. 2b

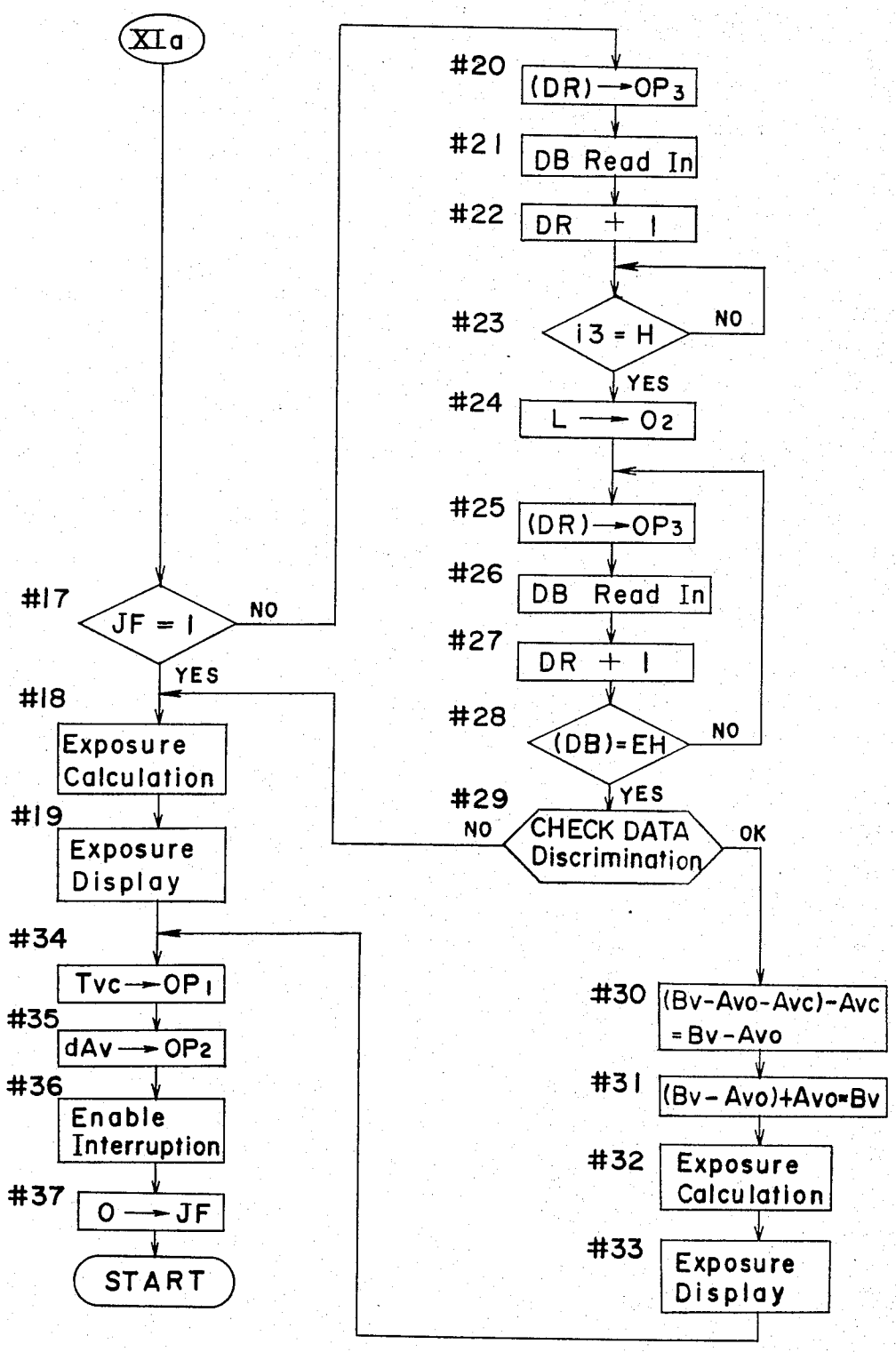

XIa
#17
JF = 1
NO
YES
#18
Exposure Calculation
#19
Exposure Display
#34
Tvc → OP1
#35
dAv → OP2
#36
Enable Interruption
#37
0 → JF
START
#20
(DR) → OP3
#21
DB Read In
#22
DR + 1
#23
i3 = H
NO
YES
#24
L → O2
#25
(DR) → OP3
#26
DB Read In
#27
DR + 1
#28
(DB) = EH
NO
YES
#29
CHECK DATA Discrimination
NO
OK
#30
(Bv-Avo-Avc)-Avc = Bv-Avo
#31
(Bv-Avo)+Avo=Bv
#32
Exposure Calculation
#33
Exposure Display

Fig. 3a

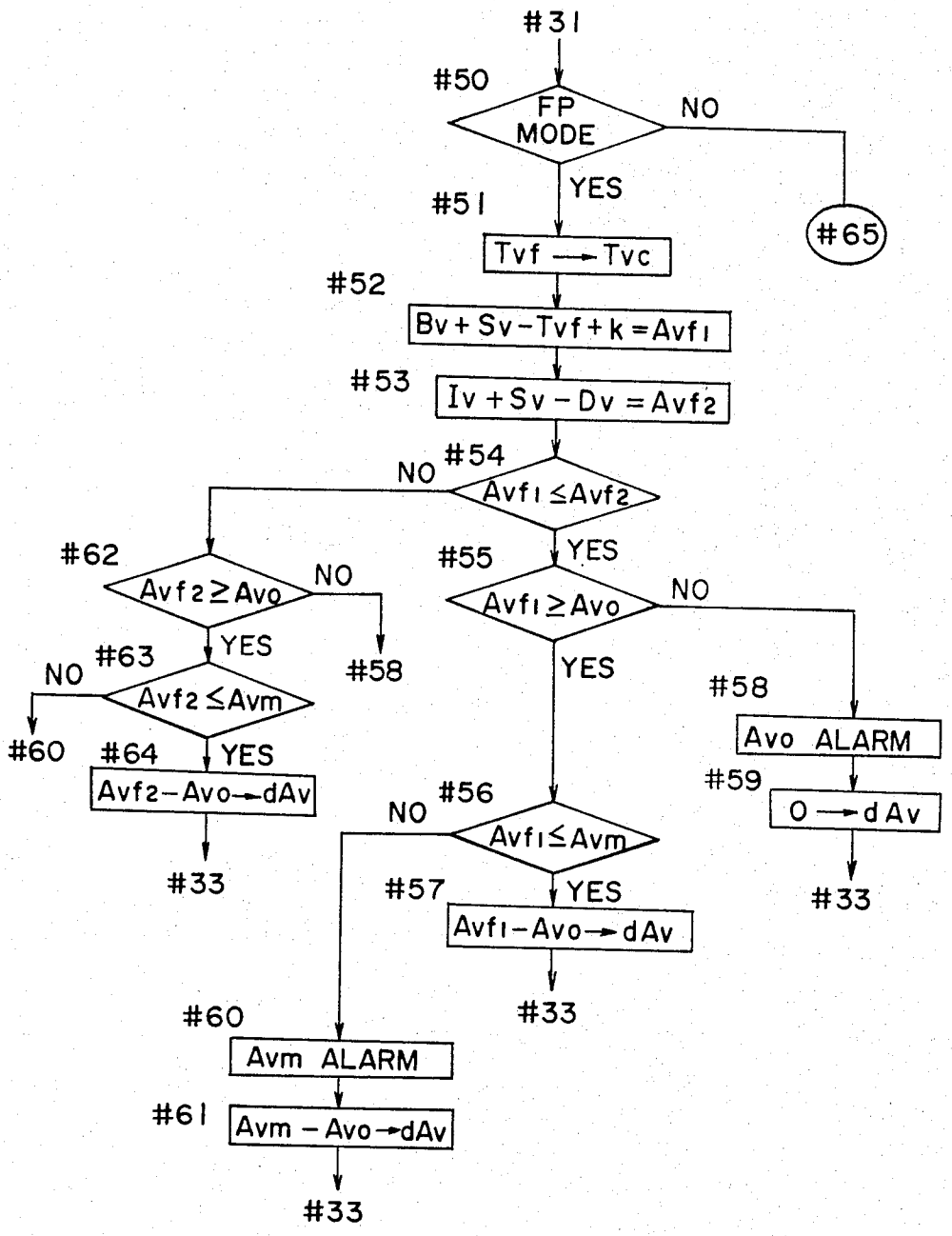

#31
#50
FP MODE
NO
YES
#65
#51
Tvf → Tvc
#52
Bv + Sv − Tvf + k = Avf1
#53
Iv + Sv − Dv = Avf2
#54
NO
Avf1 ≤ Avf2
YES
#62
Avf2 ≥ Avo
NO
YES
#55
Avf1 ≥ Avo
NO
YES
#63
NO
Avf2 ≤ Avm
#58
#60
#64
YES
Avf2 − Avo → dAv
#33
#58
Avo ALARM
#59
0 → dAv
#33
#56
NO
Avf1 ≤ Avm
#57
YES
Avf1 − Avo → dAv
#33
#60
Avm ALARM
#61
Avm − Avo → dAv
#33

Fig. 3b

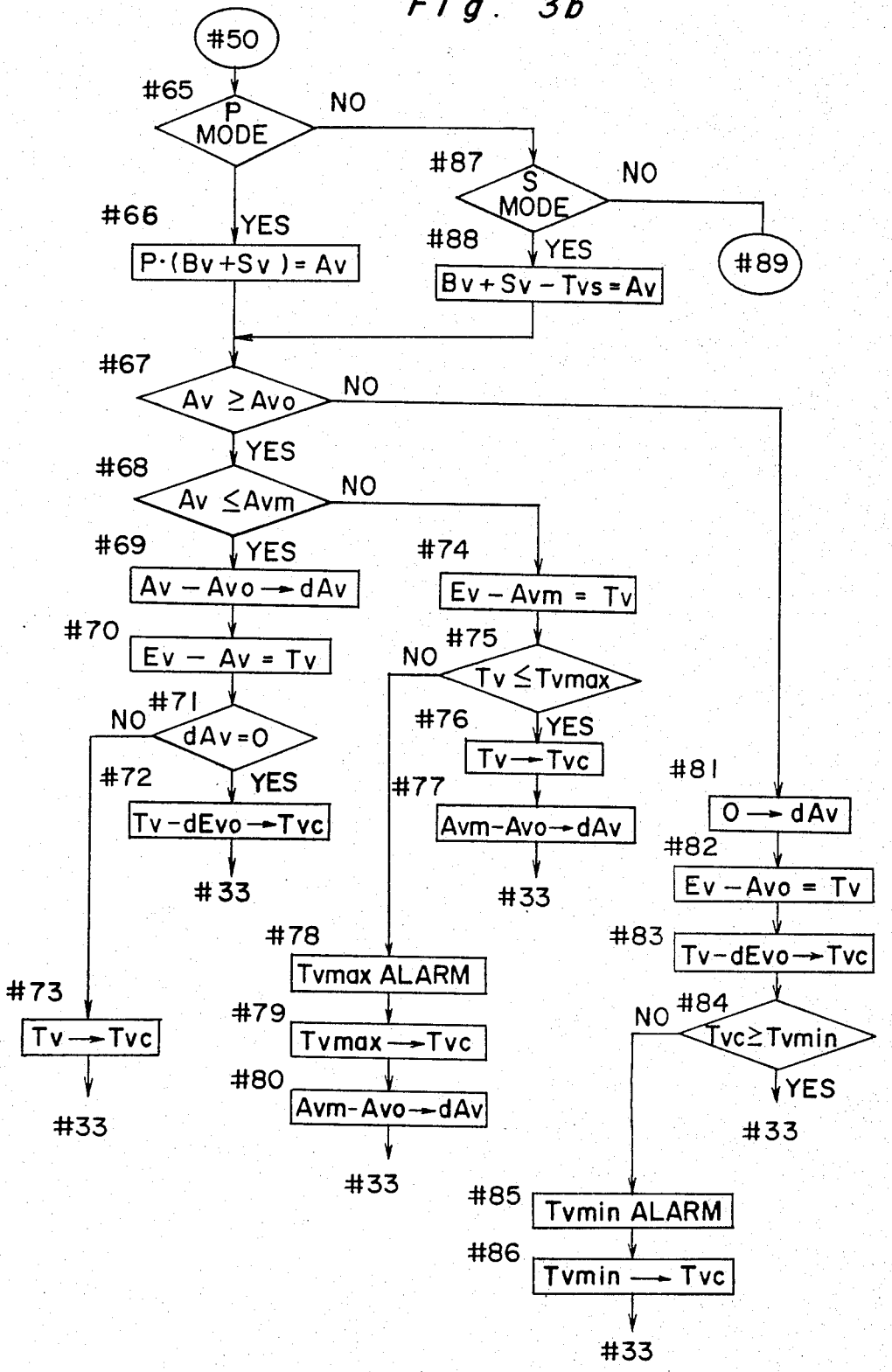

#50
#65
P MODE
NO
YES
#66
P·(Bv+Sv)=Av
#87
S MODE
NO
YES
#88
Bv+Sv−Tvs=Av
#89
#67
Av ≥ Avo
NO
YES
#68
Av ≤ Avm
NO
YES
#69
Av − Avo → dAv
#70
Ev − Av = Tv
#71
dAv=0
NO
YES
#72
Tv−dEvo→Tvc
#33
#73
Tv→Tvc
#33
#74
Ev − Avm = Tv
#75
Tv ≤ Tvmax
NO
YES
#76
Tv→Tvc
#77
Avm−Avo→dAv
#33
#78
Tvmax ALARM
#79
Tvmax→Tvc
#80
Avm−Avo→dAv
#33
#81
0 → dAv
#82
Ev − Avo = Tv
#83
Tv−dEvo→Tvc
#84
Tvc≥Tvmin
NO
YES
#33
#85
Tvmin ALARM
#86
Tvmin → Tvc
#33

Fig. 3c

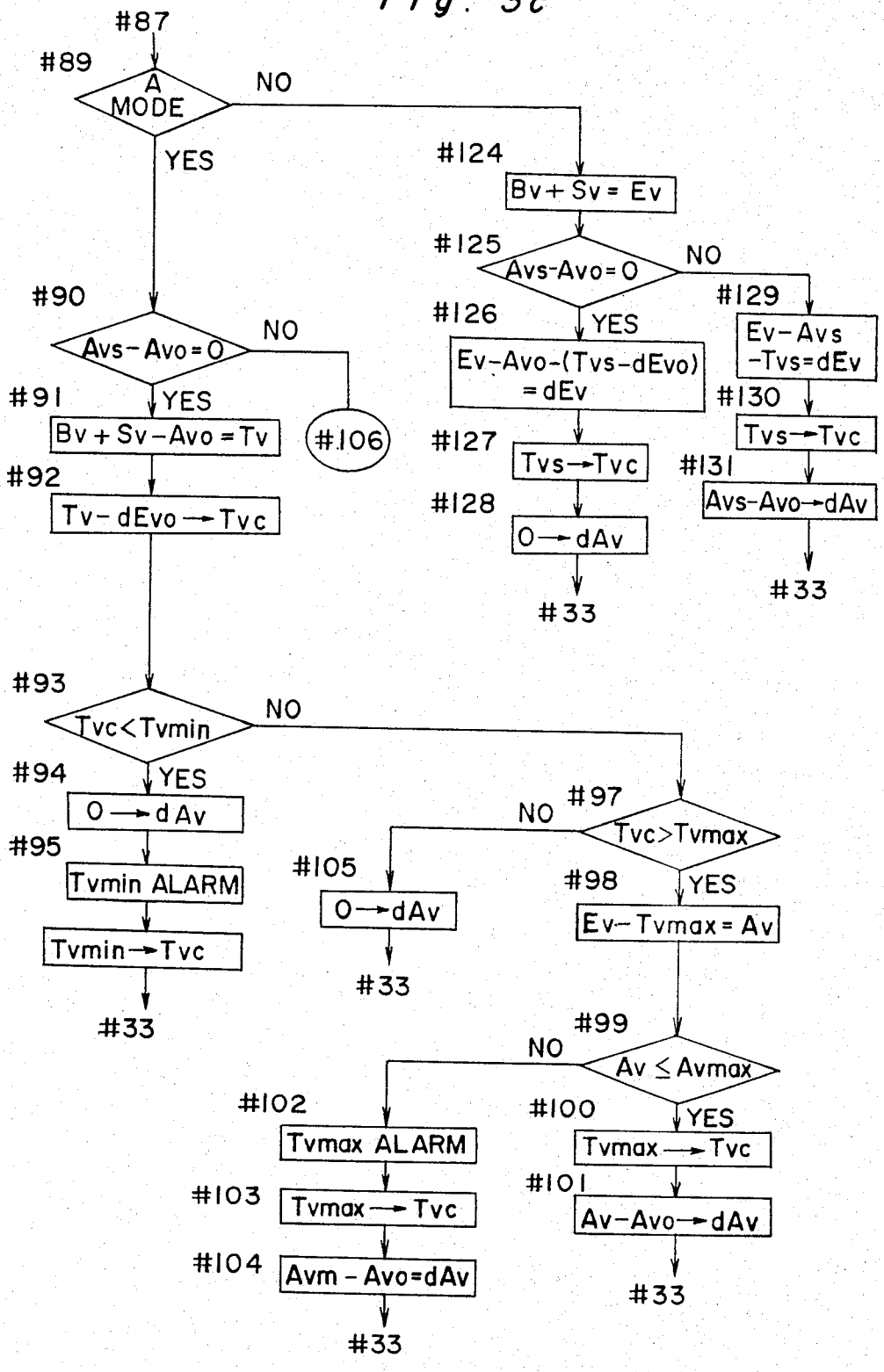
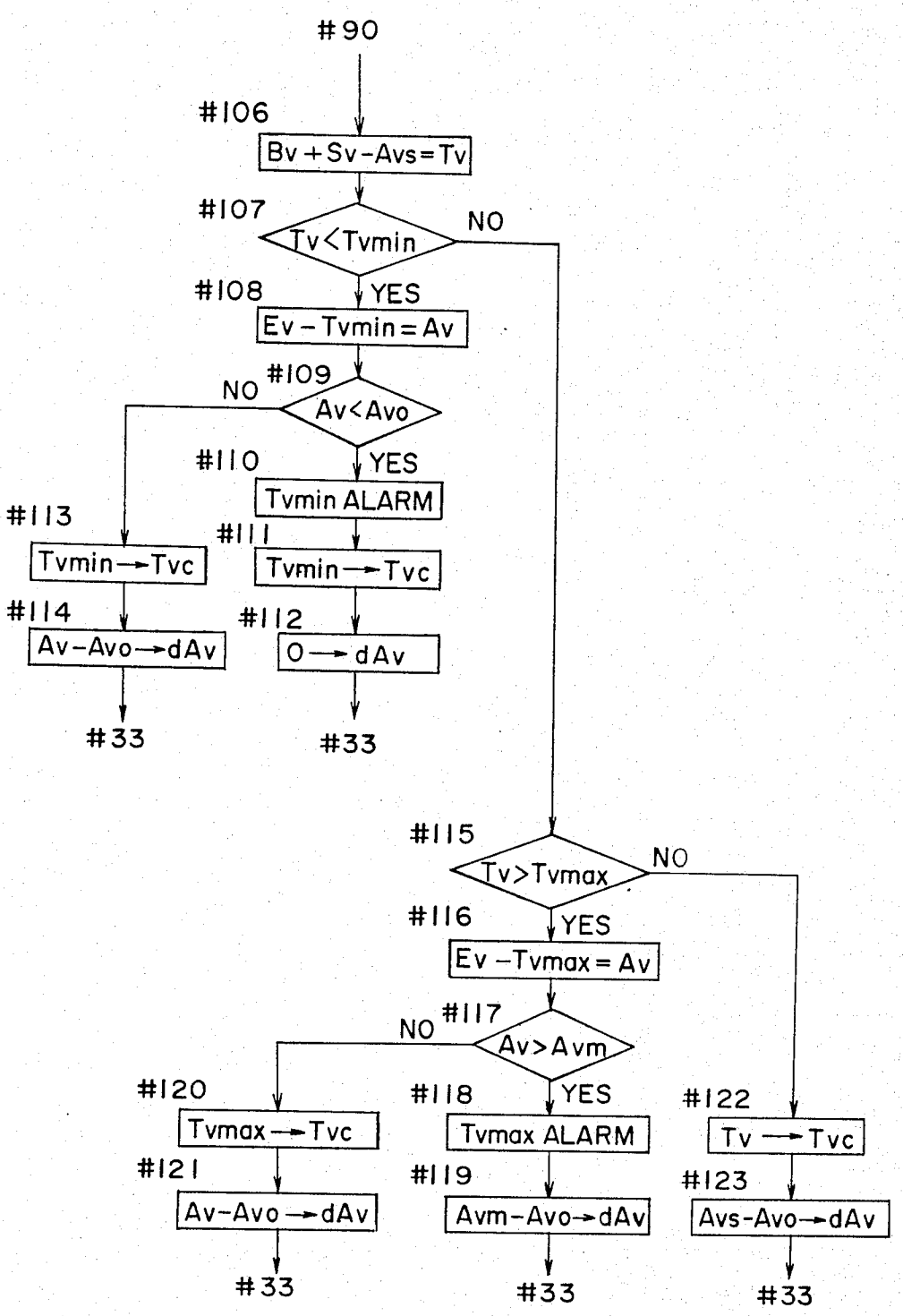

#87
#89
A MODE
NO
YES
#124
Bv+Sv=Ev
#125
Avs-Avo=0
NO
#129
Ev-Avs -Tvs=dEv
#90
Avs-Avo=0
NO
#126
YES
Ev-Avo-(Tvs-dEvo) =dEv
#130
Tvs→Tvc
#91
YES
Bv+Sv-Avo=Tv
#106
#127
Tvs→Tvc
#131
Avs-Avo→dAv
#92
Tv-dEvo→Tvc
#128
0→dAv
#33
#33
#93
Tvc<Tvmin
NO
#94
YES
0→dAv
#97
NO
Tvc>Tvmax
#95
Tvmin ALARM
#105
0→dAv
#98
YES
Ev-Tvmax=Av
Tvmin→Tvc
#33
#33
#99
NO
Av≤Avmax
#102
Tvmax ALARM
#100
YES
Tvmax→Tvc
#103
Tvmax→Tvc
#101
Av-Avo→dAv
#104
Avm-Avo=dAv
#33
#33

Fig. 3d


#90
#106
Bv+Sv-Avs=Tv
#107
Tv<Tvmin
NO
YES
#108
Ev-Tvmin=Av
#109
NO
Av<Avo
YES
#110
Tvmin ALARM
#113
Tvmin→Tvc
#111
Tvmin→Tvc
#114
Av-Avo→dAv
#112
0→dAv
#33
#33
#115
Tv>Tvmax
NO
#116
YES
Ev-Tvmax=Av
#117
NO
Av>Avm
#120
Tvmax→Tvc
#118
YES
Tvmax ALARM
#122
Tv→Tvc
#121
Av-Avo→dAv
#119
Avm-Avo→dAv
#123
Avs-Avo→dAv
#33
#33
#33

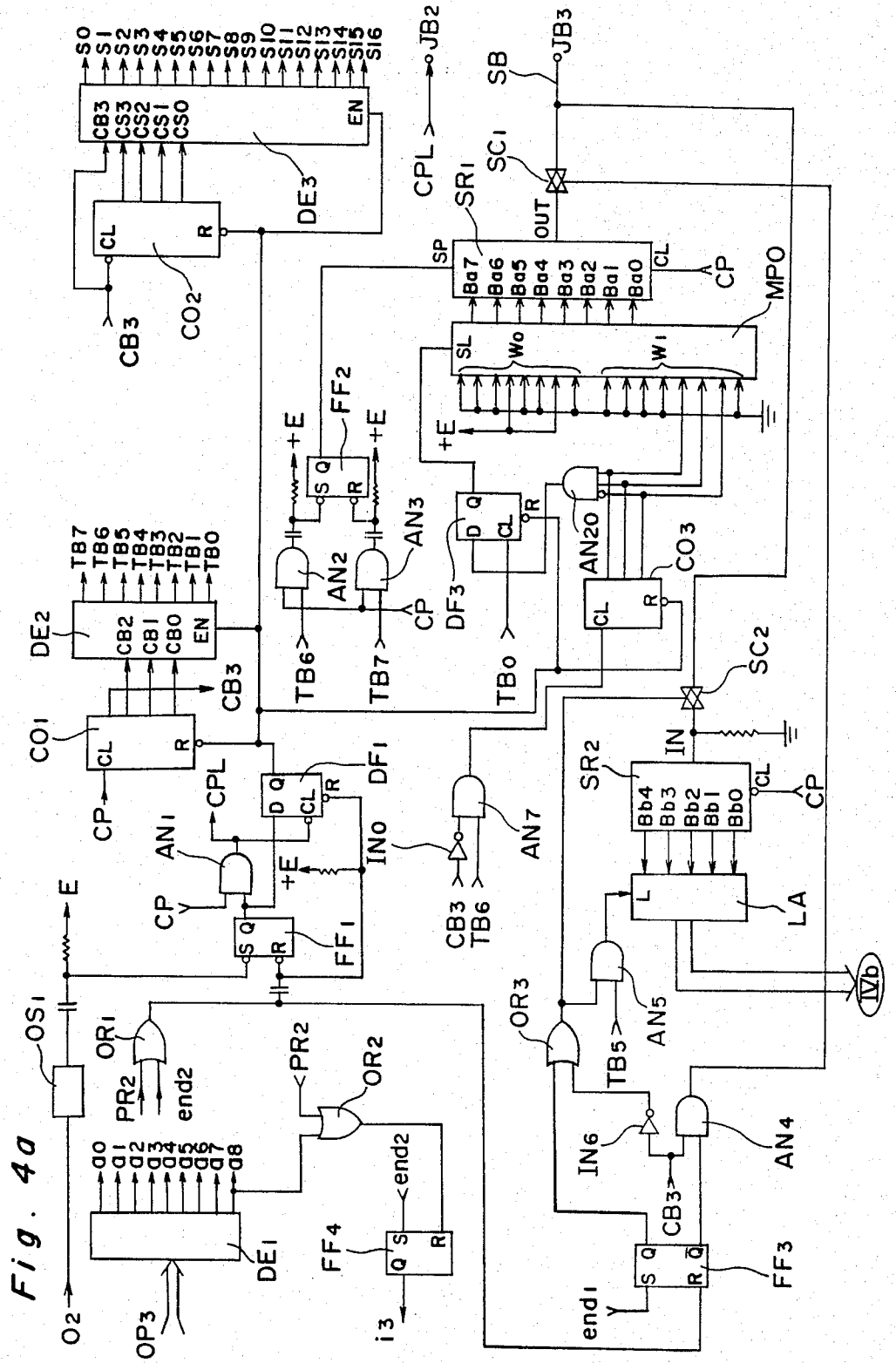

JB2
JB3
SB
CPL
SC1
SR1
OUT
SP
Ba7 Ba6 Ba5 Ba4 Ba3 Ba2 Ba1 Ba0
CL
CP
MPO
SL
Wo
W1
+E
FF2
S Q
R
AN2
AN3
DF3
D Q
CL
R
AN20
CO3
SC2
IN
SR2
Bb4 Bb3 Bb2 Bb1 Bb0
LA
L
IVb
AN7
IN0
CB3
TB6
TB7
TB0
DE2
CB2 CB1 CB0 EN
TB7 TB6 TB5 TB4 TB3 TB2 TB1 TB0
CO1
DF1
CPL
AN1
FF1
E
OS1
OR1
PR2
end2
OR2
DE1
FF4
i3
O2
OP3
OR3
AN5
TB5
IN6
AN4
CB3
end1
FF3
S0 S1 S2 S3 S4 S5 S6 S7 S8 S9 S10 S11 S12 S13 S14 S15
CB3 CS3 CS2 CS1 CS0 EN
DE3
CO2

Fig. 4a

Fig. 4b

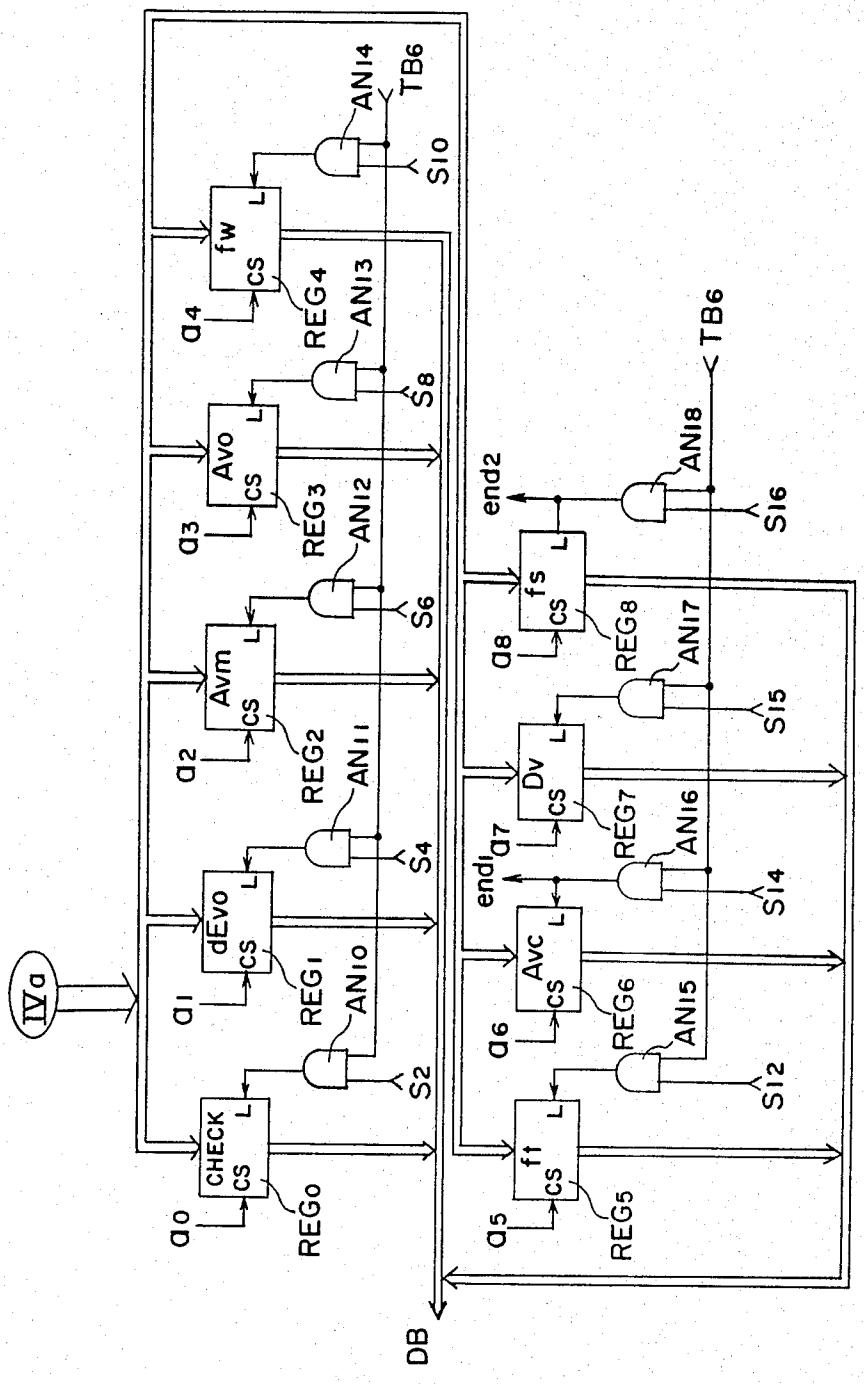
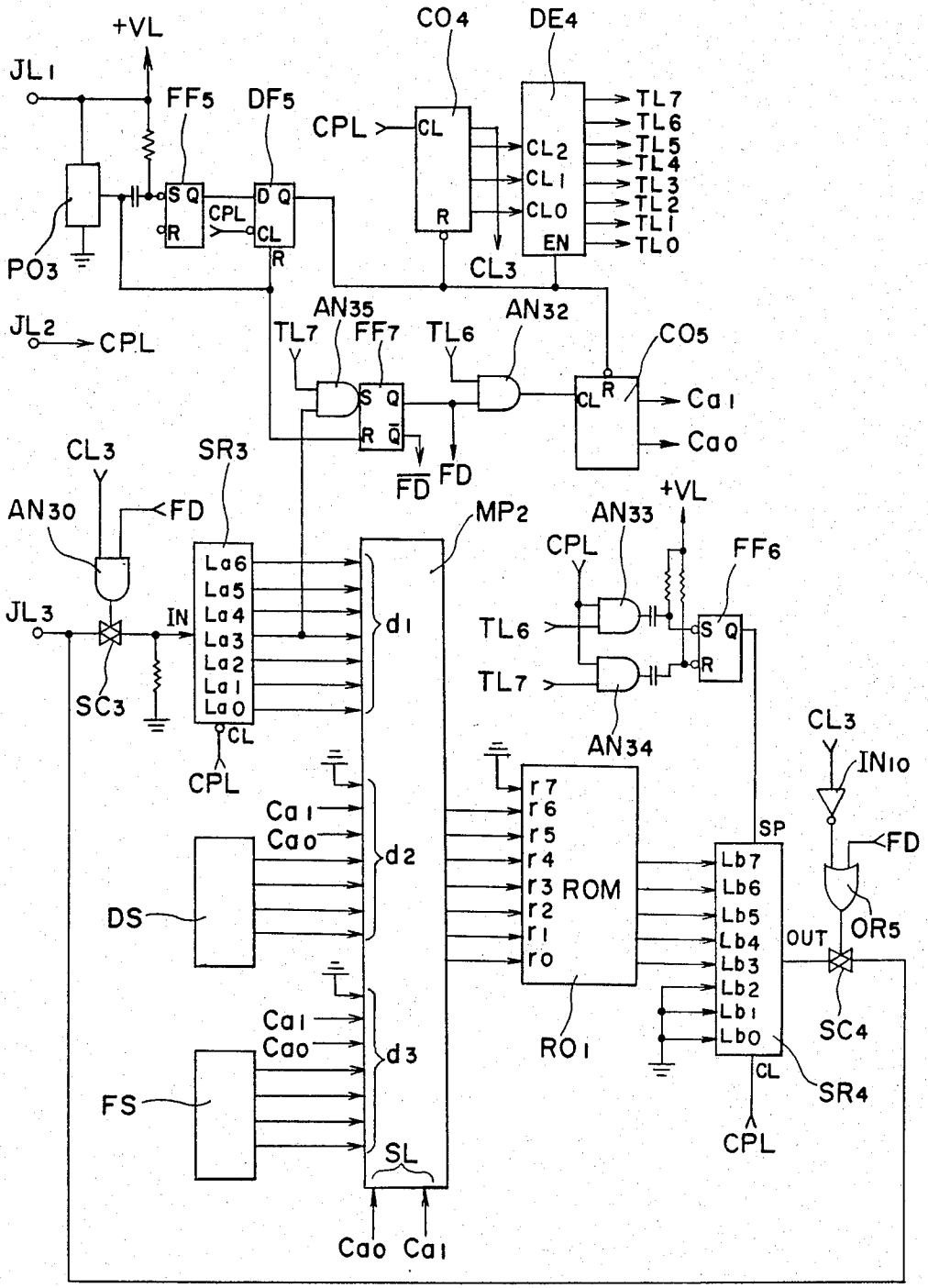

IVa
CHECK
dEvo
Avm
Avo
fw
Dv
Avc
fs
ft
CS
L
REG0
REG1
REG2
REG3
REG4
REG5
REG6
REG7
REG8
a0
a1
a2
a3
a4
a5
a6
a7
a8
AN10
AN11
AN12
AN13
AN14
AN15
AN16
AN17
AN18
S2
S4
S6
S8
S10
S12
S14
S15
S16
TB6
end1
end2
DB

Fig. 5


+VL
JL1
FF5
DF5
CO4
DE4
CPL
CL
CL2
CL1
CL0
EN
R
TL7
TL6
TL5
TL4
TL3
TL2
TL1
TL0
CL3
PO3
JL2
CPL
AN35
TL7
FF7
TL6
AN32
CO5
Ca1
Cao
FD
CL3
SR3
AN30
MP2
AN33
+VL
CPL
FF6
JL3
IN
La6
La5
La4
La3
La2
La1
La0
d1
TL6
TL7
SC3
AN34
CL3
IN10
FD
Ca1
Cao
d2
r7
r6
r5
r4
r3 ROM
r2
r1
r0
SP
Lb7
Lb6
Lb5
Lb4
Lb3
Lb2
Lb1
Lb0
OUT
OR5
DS
RO1
SC4
SR4
Ca1
Cao
d3
FS
SL
Cao
Ca1

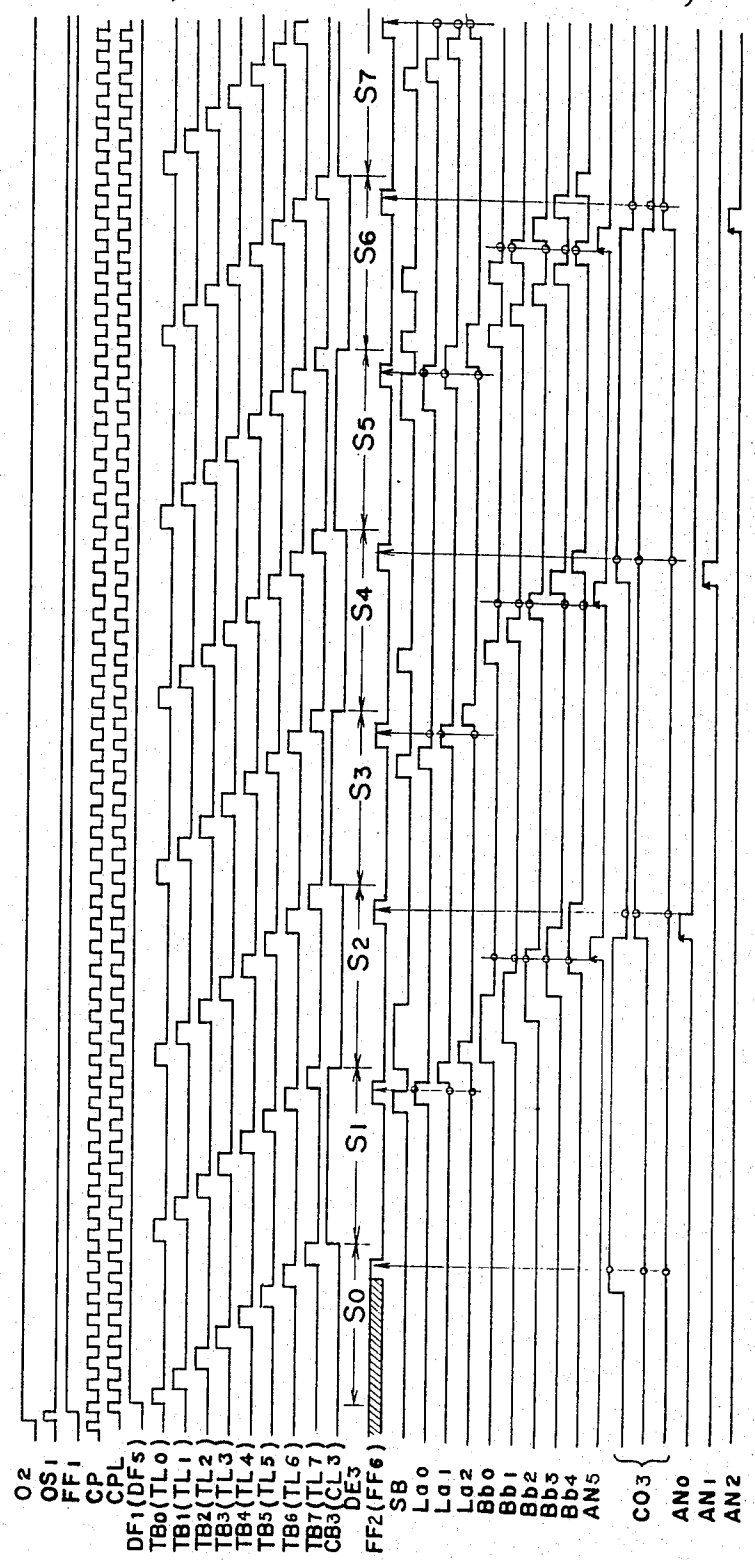

S7
S6
S5
S4
S3
S2
S1
S0
O2
OSI
FFI
CP
CPL
DF1(DFS)
TB0(TL0)
TB1(TL1)
TB2(TL2)
TB3(TL3)
TB4(TL4)
TB5(TL5)
TB6(TL6)
TB7(TL7)
CB3(CL3)
DE3
FF2(FF6)
SB
La0
La1
La2
Bb0
Bb1
Bb2
Bb3
Bb4
AN5
CO3
AN0
AN1
AN2

Fig. 6

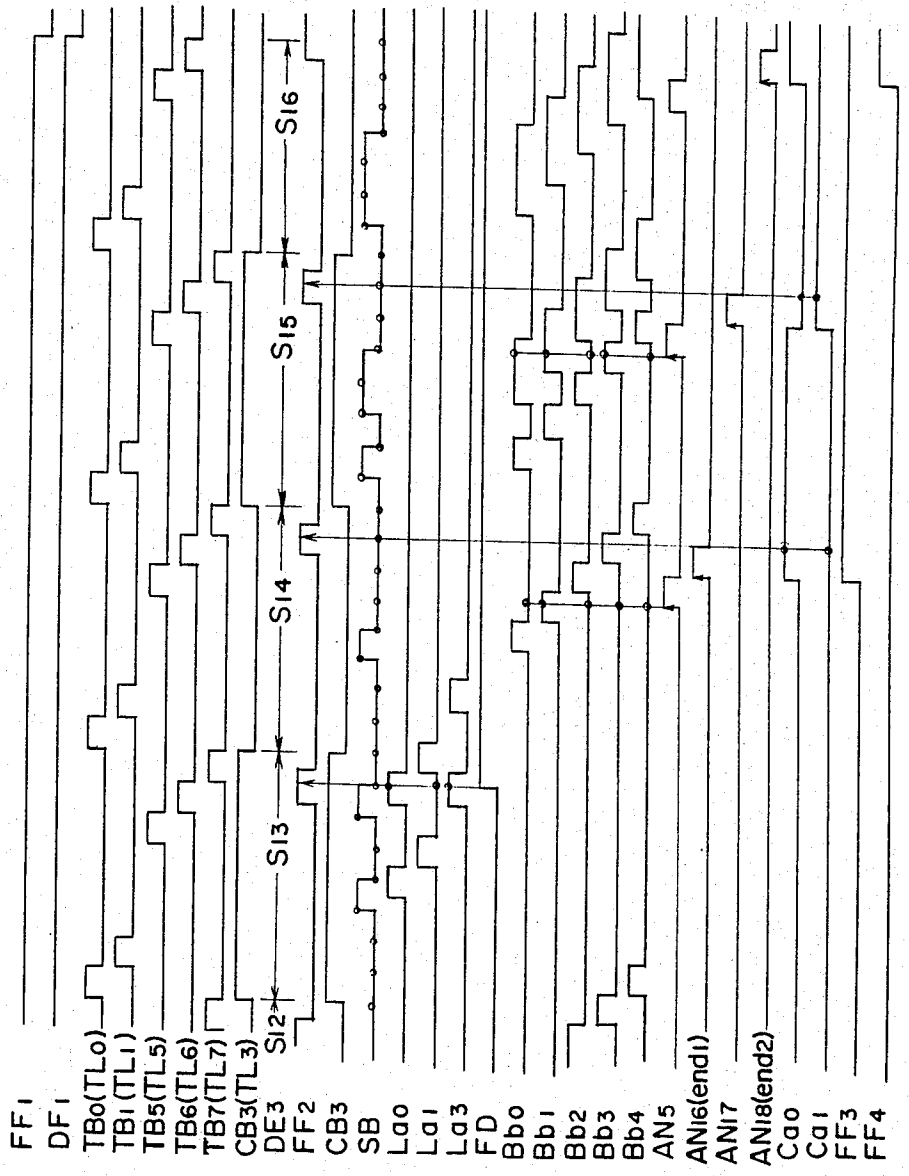

FF1
DF1
TB0(TL0)
TB1(TL1)
TB5(TL5)
TB6(TL6)
TB7(TL7)
CB3(TL3)
DE3
FF2
CB3
SB
La0
La1
La3
FD
Bb0
Bb1
Bb2
Bb3
Bb4
AN5
ANI6(end1)
ANI7
ANI8(end2)
Ca0
Ca1
FF3
FF4
SI2
SI3
SI4
SI5
SI6

Fig. 7

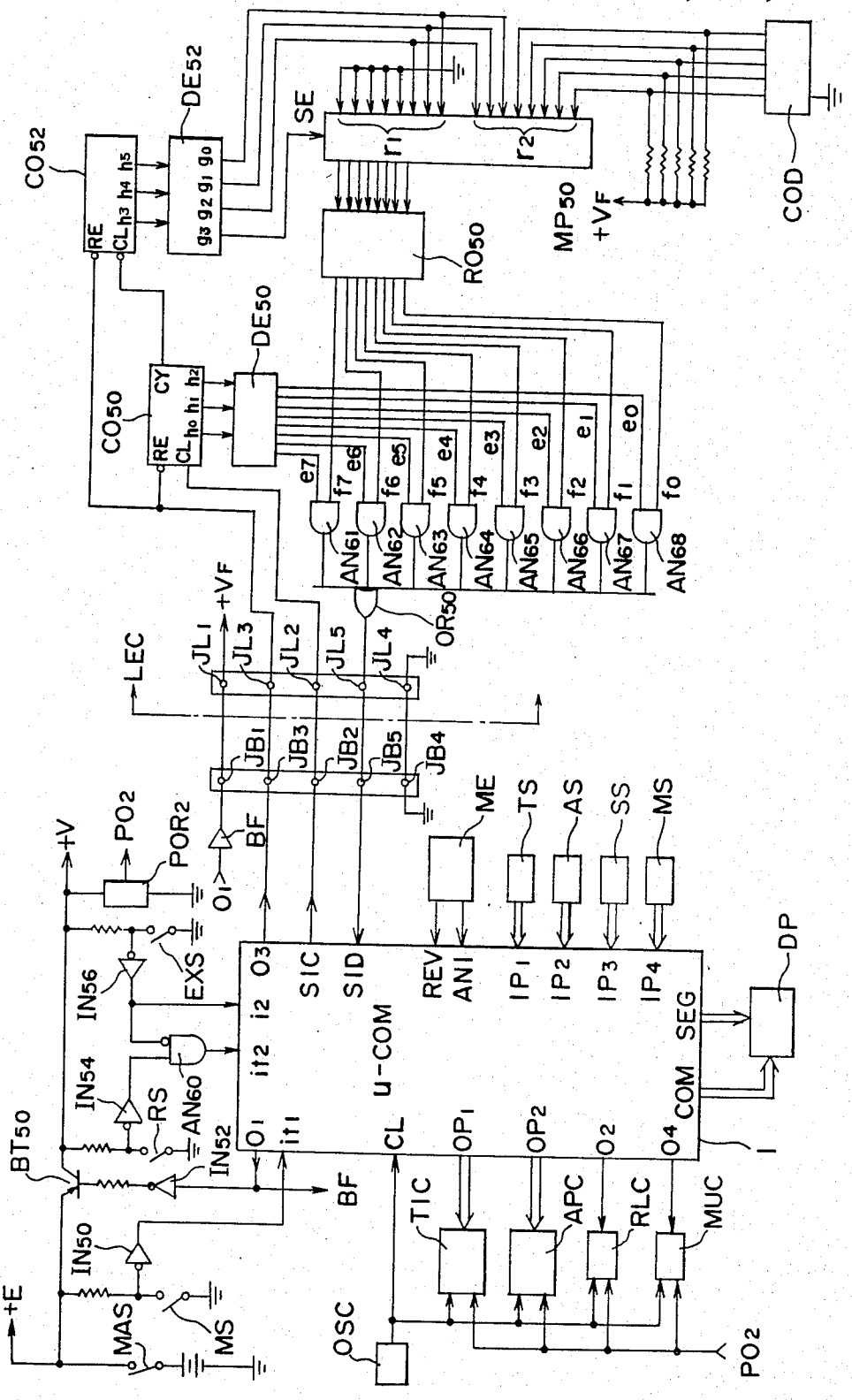

CO52
DE52
SE
r1
r2
COD
MP50
+VF
RO50
DE50
CO50
RE
CY
CL
h0 h1 h2
h3 h4 h5
g3 g2 g1 g0
e7 e6 e5 e4 e3 e2 e1 e0
f7 f6 f5 f4 f3 f2 f1 f0
AN61 AN62 AN63 AN64 AN65 AN66 AN67 AN68
OR50
LEC
JL1 JL3 JL2 JL5 JL4
JB1 JB3 JB2 JB5 JB4
+V
PO2
POR2
BF
O1
ME
TS
AS
SS
MS
DP
IN56
EXS
IN54
RS
AN60
IN52
BT50
IN50
+E
MAS
MS
O3
i2
i12
i11
SIC
SID
REV
ANI
IP1
IP2
IP3
IP4
SEG
COM
u-COM
CL
OP1
OP2
O2
O4
I
TIC
APC
RLC
MUC
OSC
PO2

Fig. 8

Fig. 12a

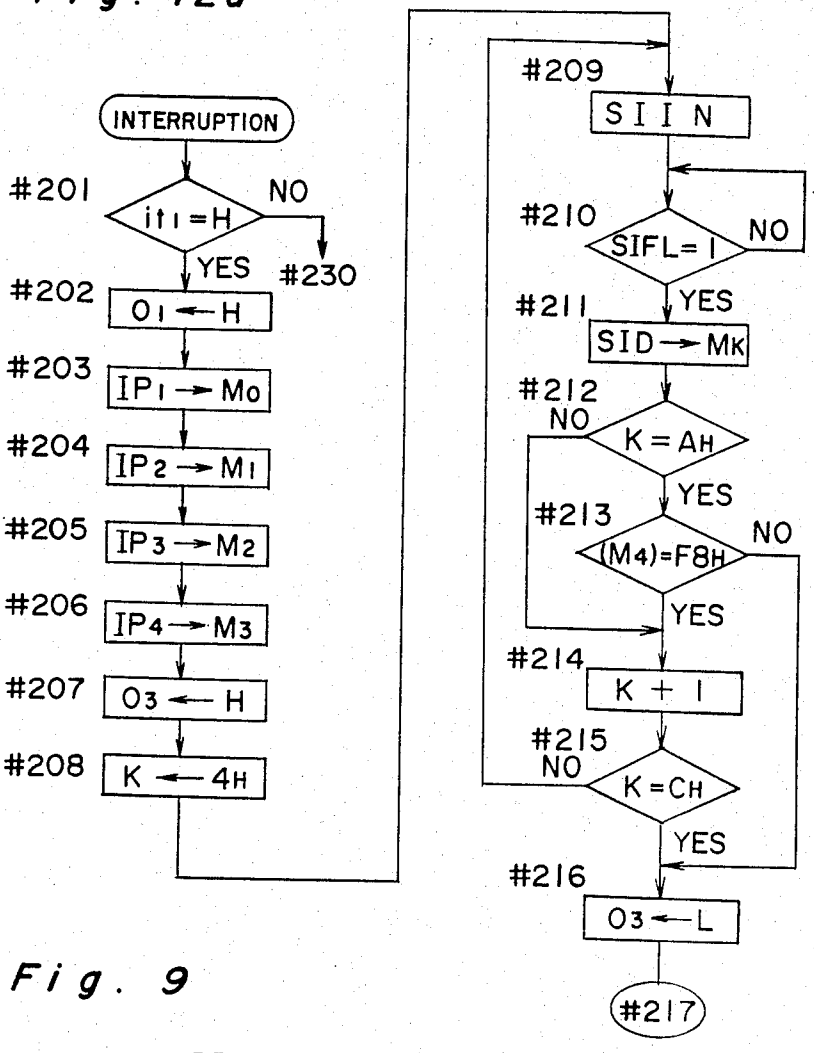


Fig. 9

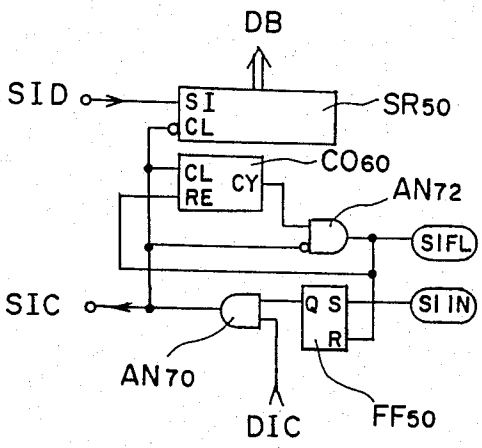
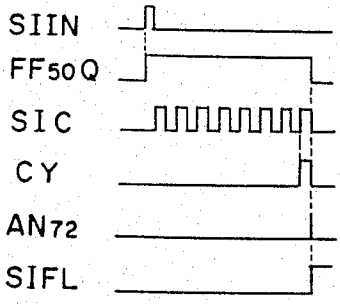


Fig. 10



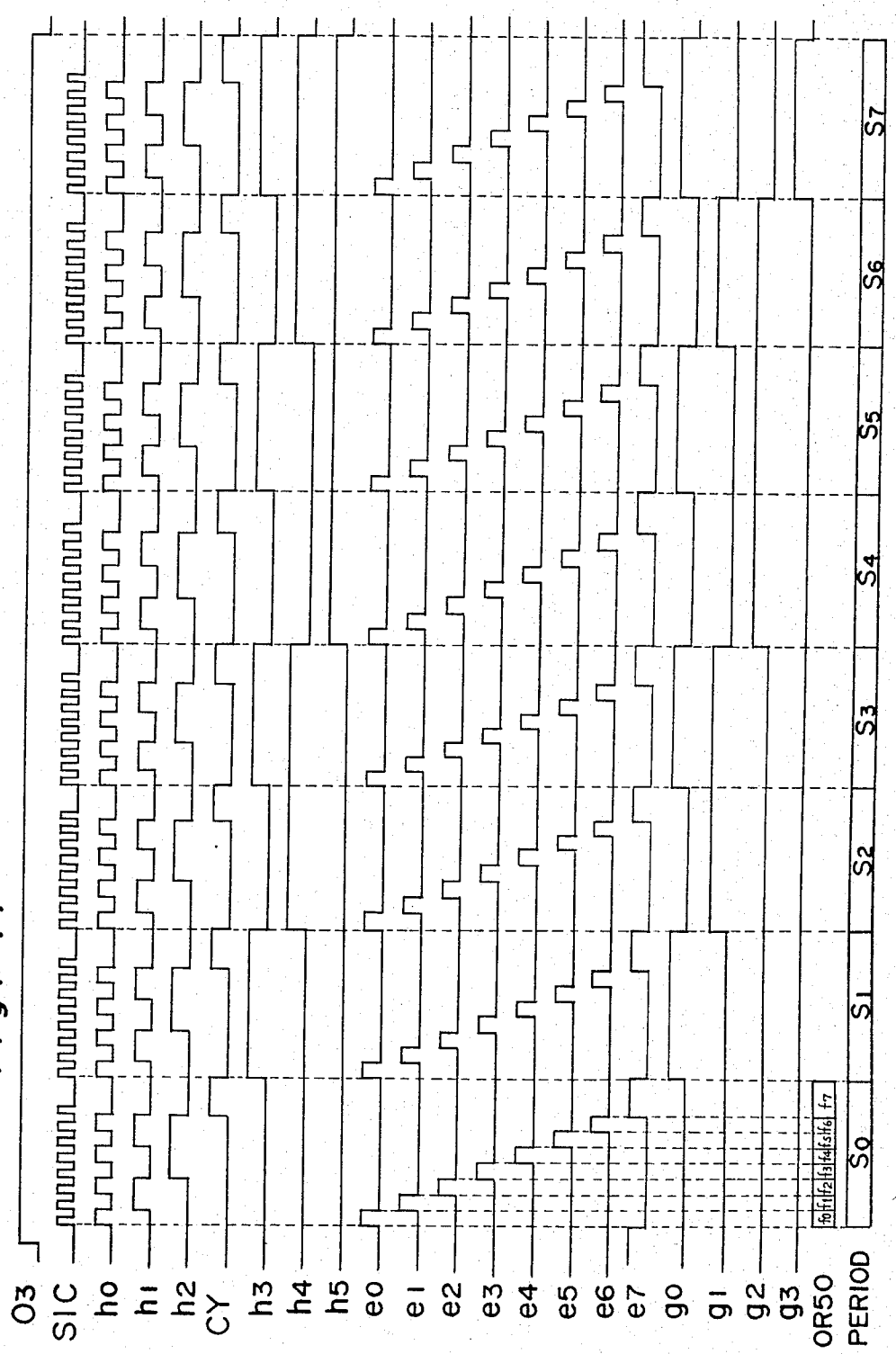
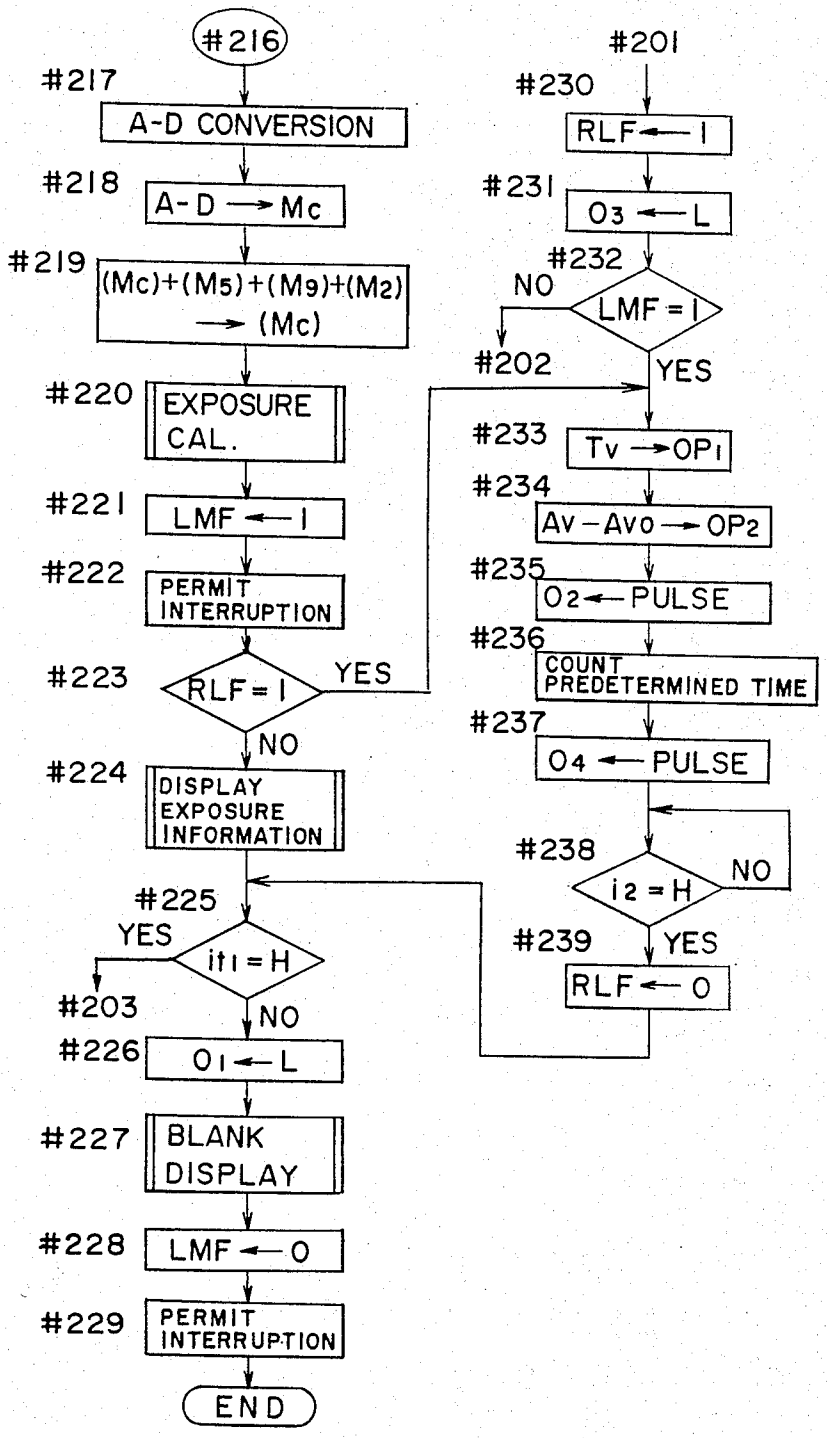

O3
SIC
ho
h1
h2
CY
h3
h4
h5
e0
e1
e2
e3
e4
e5
e6
e7
g0
g1
g2
g3
OR50
PERIOD
S0
S1
S2
S3
S4
S5
S6
S7

Fig. 11

Fig. 12b


#216
#217
A-D CONVERSION
#218
A-D → Mc
#219
(Mc)+(M5)+(M9)+(M2) → (Mc)
#220
EXPOSURE CAL.
#221
LMF ← 1
#222
PERMIT INTERRUPTION
#223
RLF = 1
YES
NO
#224
DISPLAY EXPOSURE INFORMATION
#225
YES
it1 = H
#203
NO
#226
O1 ← L
#227
BLANK DISPLAY
#228
LMF ← 0
#229
PERMIT INTERRUPTION
END
#201
#230
RLF ← 1
#231
O3 ← L
#232
NO
LMF = 1
#202
YES
#233
Tv → OP1
#234
Av − Avo → OP2
#235
O2 ← PULSE
#236
COUNT PREDETERMINED TIME
#237
O4 ← PULSE
#238
NO
i2 = H
#239
YES
RLF ← 0

CAMERA SYSTEM WITH INTERCHANGEABLE OBJECTIVE LENS

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a camera system with an interchangeable objective lens and, more particularly, to a compensation of an error related to the fully-open aperture in the camera system.

2. Description of the Prior Art

In the field of a camera system with an interchangeable objective lens, an error related to the fully-open aperture occurs when the light measuring is carried out through the fully-open aperture under the TTL light measuring system.

Generally, in a TTL camera system with an interchangeable objective lens designed to measure light through the fully-open aperture, the light measuring output characteristics vary with respect to the details of the optical system, e.g., the location and diameter of the exit pupil, or to the details of the light measuring optical system, e.g., a deviation between the position where a light receiving element is located and the optical equivalent position of a film surface or a manner of diffusion of incident light to the light receiving element.

When a light amount of an object having a certain brightness is measured with a camera mounted with a certain interchangeable lens, the camera shows a different measured amount of light with respect to the type of mounted interchangeable lens. Therefore, unless the measured amount of light is compensated, the correct exposure control cannot be accomplished. Generally, the error caused by this measured amount of light (referred to as a fully-open aperture light measurement error) is expressed by a difference between the measured amount of light with a standard interchangeable lens (for example, a 50 mm/F1.4 lens) and that with another interchangeable lens.

Conventionally, various ways to compensate the fully-open aperture light measurement error have been proposed, and they can be divided into two groups. The first group is disclosed, for example, in Japanese Patent Laid-Open Publication No. 56-107221. According to this article, a means for generating a signal corresponding to the fully-open aperture light measurement error inherent to each type of interchangeable lens is provided in each interchangeable lens. The generated signal is transferred to the camera body for compensating the amount of light measured by the camera body. The generating means can be a type that generates a signal directly representing the fully-open aperture light measurement error or a type that generates a signal representing an amount of shift to be effected in a device for transmitting an aperture signal.

The second group is disclosed, for example, in Japanese Patent Laid-Open Publication Nos. 55-143542 and 56-74226. According to these articles, the camera body calculates a fully-open aperture light measurement error based on information of fully-open aperture size or focal length, as obtained from an interchangeable lens. The calculated error is used for compensating a measured light amount.

According to the prior art camera systems, however, the amount of fully-open aperture light measurement error differs not only when a different type of lens is mounted on the same type of camera body, but also when the same type of lens is mounted on a different type of camera body having a different optical system for the light measurement. Therefore, the above-mentioned prior art camera system has follow disadvantages.

In regard to the first group, the generating means provided in each interchangeable lens is stored with a signal corresponding to the fully-open aperture light measurement error, but such a signal can be used properly in one particular type of camera body, and can not be used in the other types of camera bodies having a different light measuring system. In other words, when an interchangeable lens of the first group is mounted on a camera body of a type other than said one particular type, the signal produced from the generating means does not correspond to the fully-open aperture light measurement error and, therefore, the measured light amount will not be corrected properly. Although this disadvantage can be removed by providing the same optical light measurement system to each of different types of camera bodies, this is not appropriate because the design freedom and the specification of light measuring characteristic may be undesirably limited, resulting in a high manufacturing cost.

In regard to the second group, the camera body may be provided with a calculator which calculates various compensation values for different types of interchangeable lens to correct the error. But, such a calculator may be complicated and very difficult to prepare. Thus, according to the prior art, estimated corrections described below are carried out.

In the case of compensating the error of the measured amount of light based on the information of a fully-open aperture, the compensation corresponding to the diameter of the exit pupil of the interchangeable lens is carried out to some degree, but no compensation corresponding to the position of the exit pupil is carried out. And, in the case of compensating the error of the measured amount of light based on the information of focal length, the compensation corresponding to the position of the exit pupil is carried out to some degree, but no compensation corresponding to the diameter of the exit pupil is carried out. Thus, according to the prior art, compensation with a high accuracy can not be accomplished.

An error related to the fully-open aperture also occurs when exposure control is taking place. Generally, an image is formed by a picture-taking lens (objective lens) with a highest illumination at the center, where the optical axis passes, and the illumination is reduced towards the periphery of the image. Such a reduction of illumination at the peripheral portions is great particularly when the lens is set at the fully-open aperture position or around this position because of the phenomenon of the vignetting. Therefore, when the lens is set at the fully-open aperture position, the illumination of the image averagedly estimated within a predetermined extent of area, e.g., an 18 mm diameter circle, including its center will be considerably less than the case of a stopped-down aperture position due to the great reduction of illumination at the peripheral portions; although the central illumination may be identical regardless of the aperture position. Thus, in an exposure control system for controlling the exposure based on the calculated aperture value, the amount of light actually exposed will be averagedly estimated as an under exposure, when the aperture is to be set equal to or near the fully-

open position according to the calculated aperture value. In such a way, an exposure error takes place.

SUMMARY OF THE INVENTION

Accordingly, it is an object of the present invention to provide an improved camera system with an interchangeable lens which can compensate errors related to the fully-open aperture.

It is another object of the present invention to provide an improved camera system with an interchangeable lens which can control the exposure with a high accuracy.

It is a further object of the present invention to provide an improved camera system with an interchangeable lens which can compensate the fully-open aperture light measurement error.

It is a still further object of the present invention to provide an improved camera system with an interchangeable lens which can compensate the fully-open aperture light measurement error not only when a different type of interchangeable lens is mounted but also when an interchangeable lens is mounted on a different type of camera body.

It is another object of the present invention to provide an improved camera system with an interchangeable lens which can compensate the fully-open aperture light measurement error with a simple structure.

It is yet another object of the present invention to provide an improved camera system with an interchangeable lens which can compensate an error of exposure control which occurs when the aperture is set to its fully-open position, so as to provide an accurate exposure control.

In accomplishing these and other objects, an improved camera system according to the present invention has an outstanding feature in that the data necessary to compensate the error related to the fully-open aperture is stored in each interchangeable lens in digital form. The error is compensated in the camera body by reading and taking the data into the camera body.

According to the present invention, a camera system having a camera body and an interchangeable objective lens selectively attachable to the camera body and to at least one different camera body is involved. The camera system according to the present invention comprises: means located in the interchangeable objective lens for storing a plurality of compensation values suitable to the first mentioned camera body and to the at least one different camera body, respectively, to prepare for each case of compensating an error in fully-open aperture light measurement; means located in the interchangeable objective lens for transmitting the compensation data to the camera body to which the interchangeable objective lens is attached; means located in the first mentioned camera body for registering the compensation from the transmitting means; means located in the first mentioned camera body for controlling the camera system so that a predetermined one of the compensation values stored in the storing means is registered in the registering means; means located in the first mentioned camera body for practicing a fully-open aperture light measurement through the interchangeable objective lens to produce light measuring information including the error; and means located in the first mentioned camera body for calculating correct exposure information in response to the compensation data registered in the registering means and the light measuring signal, in which the error included in the light measuring signal is removed by utilizing the compensation value registered in the registering means.

By the above arrangement, the fully-open aperture light measurement error can be compensated with a high accuracy.

Also, according to the present invention, the camera system, having a camera body to be combined with an interchangeable objective lens which stores an exposure compensation value, which relates to exposure information other than the aperture size, such as the exposure time, for compensating an exposure error upon fully-open aperture size control, comprises: means for receiving the exposure compensating value from the interchangeable objective lens; means for practicing a light measurement to produce exposure information; means for providing aperture size information and exposure time information in response to the exposure information; means for determining whether or not the calculated aperture size information corresponds to the fully-open aperture size; means responsive to the determining means for modifying the exposure time information by the exposure compensating value when the calculated aperture size information corresponds to the fully-open aperture size, and for adopting the exposure time information as it is when the calculated aperture size information does not correspond to the fully-open aperture size; means for controlling the aperture size in response to the providing means; and means for controlling the exposure time in response to the modifying and adopting means.

By the above arrangement, the exposure error that takes place when the aperture is so controlled to be set to the fully-open position can be compensated with a high accuracy.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other objects and features of the present invention will become apparent from the following description taken in conjunction with preferred embodiments thereof with reference to the accompanying drawings, throughout which like parts are designated by like reference numerals, and in which:

FIG. **1** is a block diagram of a camera system according to a preferred embodiment of the present invention;

FIGS. **2***a* and **2***b* show a flow chart of the operation of the camera system according to one preferred embodiment of the present invention;

FIG. **2***c* is a flow chart of an interruption operation to be carried out within the flow chart of FIGS. **2***a* and **2***b;*

FIGS. **3***a*, **3***b*, **3***c* and **3***d* show a detailed flow cart of an exposure calculation step #32 shown in FIG. **2***b;*

FIGS. **4***a* and **4***b* show an exemplified circuit diagram of an interface circuit IF shown in FIG. **1**;

FIG. **5** shows an exemplified circuit diagram of a data producer **7** shown in FIG. **1**;

FIGS. **6** and **7** are time charts showing waveforms obtained from the circuit shown in FIGS. **4***a*, **4***b* and **5**;

FIG. **8** is a block diagram of a camera system according to another embodiment of the present invention;

FIG. **9** shows an exemplified circuit diagram of a serial data reading portion shown in FIG. **8**;

FIG. **10** is a time chart showing waveforms obtained from the circuit of FIG. **9**;

FIG. **11** is a time chart showing waveforms obtained from the circuit of FIG. **8**; and

FIGS. **12***a* and **12***b* show a flow chart according to said another embodiment of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to FIG. **1**, a camera system according to the present invention comprises a first portion to be employed in a camera body (not shown) and a second portion to be employed in a camera accessory, which is mountable on the camera body. The first portion is shown on the left-hand side of a line L—L shown in FIG. **1** and the second portion is shown on the right-hand side thereof. In a circuit diagram of FIG. **1**, and also in FIGS. **4***a*, **4***b*, **8**, **9** and **11**, a broad line indicates a bundle of wires for transmitting a signal comprising a plurality of bits.

In FIG. **1**, a reference number **1** designates a micro-computer or a micro-processor which sequentially controls the thorough operation of the camera system and also calculates to provide exposure information. When a battery BA is loaded in the camera, a power-on-reset circuit PO1 produces a power-on-reset signal PR1 which is applied to a reset terminal RE of the micro-computer **1**. Accordingly, the micro-computer **1** is turned to a reset condition. A clock pulse generating means defined by an oscillator OSC is provided for producing a train of reference clock pulses CP which are applied to a clock terminal CL of the micro-computer **1** and also to other circuits for synchronizing the entire operation of the camera system shown in FIG. **1**. A display device DP is formed, for example, by a liquid crystal and is operated in a time divided manner by signals obtained from segment terminal SEG and common terminal COM of the micro-computer **1** for the display of exposure control value, exposure control mode, warning indication, and so on. The micro-computer **1**, the oscillator OSC and the display device DP, as well as other circuits, such as interface circuit IF, data selector MP1, inverters IN1 to IN5 and IN40, and AND gate AN0, receive electric power directly from the battery BA through a power line +E.

A normally open switch MS is a light measuring switch that closes when carrying out the light measuring operation. When the light measuring switch MS closes, an inverter IN1 produces a "HIGH" which is applied to an input i1 of the micro-computer **1**. In response to the "HIGH" to the input il, the micro-computer **1** reads data necessary for the exposure control and, at the same time, starts A-D (analog to digital) conversion of the signal from the light measuring circuit, exposure calculation and display operation. Furthermore, when the light measuring switch MS closes, a transistor BT1 conducts to provide electric power to a power line +VB, thus permitting the electric power supply to circuits in the camera body other than those which have been already receiving power from the power line +E. Moreover, when the transistor BT1 conducts, a power-on-reset PO2 produces a reset signal PR2, which is applied to each of exposure time control device CT and aperture control device CA, described later, for resetting them.

A circuit **3** enclosed by a broken line is an exposure control portion comprising exposure time control device CT, aperture control device CA, and pulse generator PG. The exposure time control device CT receives a fixed, or calculated, exposure time data Tvc. Tvc represents a value of time given in APEX numbering system. Similarly, other reference characters with a suffix of v, such as Av, Avo, Bv, Sv, Ev, represent values in APEX numbering system. Tvc is received from an output terminal OP1 of the micro-computer **1** and the time control device CT establishes a period of time relative to the data Tvc (i.e., a period of time 2^{-Tvc} from open-operation to close-operation of a shutter mechanism) using clock pulses CP so as to control the exposure time. The aperture control device CA receives a fixed, or calculated, stop-down degree data dAv from an output terminal OP2 of the micro-computer **1**, and also pulses from the pulse generator PG. The pulse generator PG is provided operatively in association with a ring **13**, which rotates together with a pin **15** in the interchangeable lens LE, and produces a number of pulses corresponding to the degree of rotation of the ring **13**. More particularly, the interchangeable lens LE has a pin **15** connected to a diaphragm for the simultaneous movement about the axis of the lens LE with respect to the change of aperture size of the diaphragm, and is also connected to a first spring (not shown) for urging the diaphragm to fully open the aperture. On the other hand, the ring **13** has a projection which is held in contact with the pin **15** by an urging force of a second spring (not shown) connected to ring **13**. The ring **13** further has a rack (not shown) which is engageable to a pawl (not shown). Since the second spring connected to the ring **13** is stronger than the first spring connected to the pin **15**, the ring **13** starts to rotate by the force of the second spring when the pawl disengages from the rack, and, at the same time, the rotation of the ring **13** is transmitted to the pin **15** causing reduction of the aperture size of the diaphragm. During the rotation of the ring **13**, the aperture control device CA counts the number of pulses from the pulse generator PG; the number of pulses corresponds to the degree of reduction of aperture size of the lens LE. The counted number is compared with the stop-down degree data dAv from the output OP1 of the micro-computer **1**, and when these two match with each other, the pawl is so actuated as to stop the rotation of the ring **13**, thus setting the diaphragm to a controlled aperture size.

A switch LS is a normally open switch provided for detecting whether the interchangeable lens LE is properly mounted on the camera or not. The switch LS closes when the interchangeable lens LE is mounted and locked to a camera mount, but it is maintained open when the locking is incomplete. When the switch LS closes, an inverter IN40 produces a "HIGH" which is applied to the micro-computer **1** through an input i4. In response to this, the micro-computer **1** starts to read data from the mounted lens LE and carries out an exposure calculation. On the contrary, when the switch LS is maintained open to provide a "LOW" to the input **4**, the micro-computer reads no data from the lens, but carries out other calculations as will be described later.

Referring back to FIG. **1**, a circuit portion enclosed by a broken line **5** is provided for producing exposure control data, and it includes light measuring circuit ME, A-D (analog to digital) converter AD, set aperture size signal producing device AS, set exposure time signal producing device TS, film sensitivity signal producing device SS, and mode signal producing device MS. The light measuring circuit ME is, for example, a TTL (through-the-lens) fully-open aperture metering type, and it produces a signal Bv-Avo-Avc in analog form and it is determined by the brightness Bv of an object, fully-opened aperture size Avo, and fully-open aperture light measurement error Avc (the error determined by the deviation of the light receiving element, which should be positioned at a predetermined distance from

the film surface, and by the position of the exit pupil of the mounted lens) caused by the change of the lens. The A-D converter AD receives the signal Bv-Avo-Avc in analog form from the light measuring circuit ME, and converts it to digital form by a clock pulse CP in response to a positive going pulse from an output 03 of the micro-computer 1. The converted signal Bv-Avo-Avc in digital form is applied to a data selector MP1 at an input IP2.

The set aperture size signal producing device AS produces a data Avs-Avo and provides it to the data selector MP1 and an input IP3.

The set exposure time signal producing device TS produces a digital signal representing a manually set exposure time by way of an exposure time setting device (not shown) provided in the camera body. The output of the set exposure time signal producing device TS is connected to input IP4 of the data selector MP1.

The film sensitivity signal producing device SS produces a digital signal representing a manually set film sensitivity by way of a film speed setting device (not shown) provided in the camera body. The output of the film sensitivity signal producing device SS is connected to input IP5 of the data selector MP1.

And, the mode signal producing device MS produces a digital signal representing a manually selected mode by way of a mode selecting device (not shown), from a number of modes which are: exposure control mode; and a flash-light photographing mode wherein the mode signal producing device MS receives from the flash-light device FL through terminal JF1 of flash-light device side and terminal JB5 of camera body side, a charge completion signal indicating that a main capacitor (not shown) in the flash-light device FL is fully charged. The output of the mode signal producing device MS is connected to input IP6 of the data selector MP1.

An interface circuit IF sequentially reads various data from the lens LE when it receives a "HIGH" from an output O2 of the micro-computer 1. When the interface circuit IF completes reading the data from the lens LE, the read data is sequentially produced from the interface circuit IF and transmitted through data selector MP1 and external data bus DB to the micro-computer 1 in response to the 4-bit data from an output OP3 of the micro-computer 1. A detail of the interface circuit IF is shown in FIGS. 4*a* and 4*b* and will be described later. The data selector MP1 has inputs IP1 to IP6 for receiving various data and transmits this data through the data bus DB to the micro-computer 1 in a selected sequence controlled by a 4-bit signal applied thereto at a selection terminal SL from the output OP3 of the micro-computer 1. A relationship between the data applied to the selection terminal SL of the data selector MP1 and the data produced from the data selector MP1 through the data bus DB is shown in Table 1 below.

TABLE 1

Selection SL	Terminal	Data Selector (MP1) Data Bus (DB) Selected terminal	Signification
0 0 0 0	(0H)	IP4	Tvs
0 0 0 1	(1H)	IP5	Sv
0 0 1 0	(2H)	IP6	Mode
0 0 1 1	(3H)	IP2	Measured light amount
0 1 0 0	(4H)	IP3	Avs-Avo
0 1 0 1	(5H)	IP1	Interface

TABLE 1-continued

Selection SL	Terminal	Data Selector (MP1) Data Bus (DB) Selected terminal	Signification
:	:	"	"
1 1 0 1	(DH)	"	"

As apparent from Table 1, the data applied to the selection terminal SL is 4-bits long, and for the sake of brevity, this 4-bit signal is also indicated with a hexadecimal numbering system, as shown in parentheses in Table 1. When the data applied to the selection terminal SL from the output OP3 is "0H" (i.e., 0 hexadecimal), the data selector MP1 selects exposure time data Tvs inputted to the terminal IP4; when the data to the selection terminal SL is "1H", the data selector MP1 selects film sensitivity data Sv inputted to the terminal IP5; when the data to the selection terminal SL is "2H", the data selector MP1 selects exposure control mode data inputted to the terminal IP6; when the data to the selection terminal SL is "3H", the data selector MP1 selects measured light amount data inputted to the terminal IP2; when the data to the selection terminal SL is "4H", the data selector MP1 selects set aperture size data Avs-Avo inputted to the terminal IP3; and when the data to the selection terminal SL is any one of "5H" to "DH", the data selector MP1 selects data concerning the lens LE inputted to the terminal IP1 from the interface circuit IF. The selected data by the data selector MP1 is applied to the micro-computer 1 through the data bus DB.

It is to be noted that the interface circuit IF produces the read data from the lens LE in a sequence controlled by the data "5H" to "DH" from the output OP3. It is also to be noted that the micro-computer 1 only produces data "0H" to "3H" when the signal to the input i4 is "LOW", i.e., when the lens detecting switch LS is maintained off, whereby no signal related to the lens LE is fed to the micro-computer 1.

A reference character FC designates a flash-light control for controlling the amount of flash-light to be emitted from the flash-light device FL from the camera side. The flash-light control FC produces an emission-start signal which is applied to the flash-light device FL through terminal JB6 of camera side and terminal JF2 of flash device side for effecting the emission of flash-light. Also, the flash-light control FC produces an emission-stop signal which is applied to the flash-light device FL through terminal JB7 of camera side and terminal JF3 of flash device side for stopping the emission of flash-light. The emission-start signal is produced, e.g., when the shutter is fully opened, and the emission-stop signed is produced, e.g., when an integrated amount of light reflected from an object to be photographed and passed through an objective lens and further reflected on a film surface reaches a predetermined level. When the main capacitor (not shown) provided in the flash-light device FL is charged to a predetermined level, the flash-light device FL produces a "HIGH" representing the completion of electric charge, which is applied to the terminal JF1 and, thereafter, by the emission-start signal from the terminal JF2, a xenon lamp (not shown) provided in the flash-light device FL starts to emit light. Then, by an emission-stop signal from the terminal JF3, the xenon lamp stops the light emission.

A release switch RS is provided to close relative to the operation of a shutter release mechanism. A safety switch CS is provided, which closes upon completion of film wind-up for one frame and opens upon completion of exposure control operation, thereby preventing the shutter from being released before it is ready to take a photograph. The release switch RS and the safety switch CS are connected, respectively, to inverters IN3 and IN4, which are in turn connected to two inputs of an AND gate AN0. An output of the AND gate AN0 is connected to an interruption input i5 of the micro-computer 1.

The micro-computer 1 has an output O1 which is connected to a release circuit RL. When the output O1 produces a "HIGH", the release circuit RL starts the shutter release operation. The output O1 is also connected to an inverter IN2 which is further connected to a base of a transistor BT1 through a suitable resistor. Therefore, even if the light measuring switch MS is turned off during the shutter release, the transistor BT1 is maintained in the conductive state.

As a means for producing a start signal, the micro-computer 1 has an output O2 connected to the interface circuit IF. The output O2 produces a "HIGH" while the interface circuit IF is reading data from the lens. The output O2 is further connected to an inverter IN5 and, in turn, to a base of a transistor BT2 through a suitable resistor. The transistor BT2 is provided as a means for providing electric power to the camera accessory. Thus, when the output O2 is producing a "HIGH", the inverter IN5 produces a "LOW" causing turn on of the transistor BT2. Thus, electric power is supplied through the power lines +VB and +VL, terminal JB1 of camera body and terminal JL1 of lens, to circuits in the lens.

In the lens LE, a data producer 7 is provided including a ROM RO1 (FIG. 5) serving as a fixed data storing means and previously stored with various fixed data related to the lens. The clock pulses CPL produced from the interface circuit IF in the camera body are applied to the data producer 7 as a synchronizing signal through a terminal JB2 on camera and a terminal JL2 on lens so as to control the transmission of address signals from the interface circuit IF to the data producer 7 and the transmission of read out data from the data producer 7 to the interface circuit IF through the same path defined by a line SB, a terminal JB3 on the camera and terminal JL3 on the lens. A block 9 encircled by a broken line is an information producing device, and it includes a focusing distance data producing device DS, which produces data corresponding to a focusing distance of a mounted interchangeable lens as set by the turning of a focusing distance control ring (not shown), and a focal length data producing device FS, which produces data corresponding to a focal length of a mounted zoom lens as set by the turning of a zooming ring (not shown). The data produced from the focusing distance data producing device DS and from the focal length data producing device FS are applied to the data producer 7 as address signals specifying a particular location in the ROM RO1. Thus, the ROM RO1 produces data corresponding to the set focusing distance (in absolute amount) or set focal length (in absolute amount). The operation of the above described camera system is given hereinbelow.

Referring to FIGS. 2*a*, 2*b* and 2*c*, a flow chart of sequential operation of the micro-computer 1 is shown. In the step #1, it is determined whether the input i1 is carrying "HIGH" or not, i.e., whether the light measuring switch MS is turned on or not. If the light measuring switch MS remains open to provide "LOW" to the input i1, the procedure advances to the step #2 and further to the step #3 or to the step #4 and #5; the detail will be described later. When the light measuring switch MS is turned on to provide "HIGH" to the input i1, the procedure advances from the step #1 to #6 so as to reset a timer register TR for counting time. A detail of this timer register TR will also be described later.

Then, in the step #7, it is determined whether the input i4 is carrying "HIGH" or not, i.e., whether the lens detecting switch LS is turned on or not. When the input i4 is receiving "LOW", the procedure advances to the step "9" for setting "HIGH" in a 1-bit discrimination register JF and, then, advances to the step #10. On the other hand, when the input i4 is receiving "HIGH", the procedure advance to the step #8 so as to produce "HIGH" from the output O2 of the micro-computer 1. Thus, the inverter IN5 produces "LOW" to conduct the transistor BT2, resulting in supply of electric power to the circuits 7 and 9 in the lens LE and, at the same time, interface circuit IF is so actuated to read data from the lens. Thereafter, the procedure advances to the step #10.

A further detailed operation will be described later in connection with FIGS. 4*a* and 4*b*, but here, it is to be noted that the circuits in lens are reset by a power-on-reset signal that starts the power supply to the lens caused by a "HIGH" produced from the output O2, and thereafter, the system is in a condition ready to transmit data from the lens to the camera body. By the above arrangement, the terminal for the power supply to the lens can also be used for transmitting a start signal for starting the data read out, thereby reducing the number of terminals that interconnect the camera body and camera accessory, e.g., lens. Such a reduction of the number of the terminals not only reduces the manufacturing cost, but also increases the reliability and durability of the camera system.

In the step #10, the micro-computer 1 produces "HIGH" from its output 03 and, in the succeeding step #11, the output O3 is turned to "LOW", whereby an A-D conversion start pulse is applied to the A-D converter AD for starting the A-D conversion of a light signal produced from the light measuring circuit ME. Then, a 4-bit data "0H" is set up in a register DR (not shown) and then, the micro-computer 1 produces the 4-bit data "0H" from its output OP3. In response to the 4-bit data "0H", the data selector MP1 produces the exposure time data Tvs inputted to the terminal IP4, as shown in Table 1, and the produced data Tvs is sent through the data bus DB to the micro-computer 1 wherein the data Tvs is stored in a certain resistor. Then, in the step #15, "1" is added to the content of the register DR. And, in the step #16, it is determined whether the register DR is carrying "4H" or not. If not, the procedure returns back to repeat the steps #13, #14 and #15.

Therefore, until the register DR carries "4H", the micro-computer 1 sequentially reads in various data from the data selector MP1 such that: when the register DR is carrying "0H", the exposure time data Tvs is read in as mentioned above; when the register DR is carrying "1H", the film sensitivity data Sv is read in; when the register DR is carrying "2H", the data representing the exposure control mode is read in; and when the register DR is carrying "3H", the data Bv-Avo-Avc

representing the brightness of the object is taken in. It is to be noted that by the time when the register DR is carrying "3H", the A-D conversion of the light signal in the A-D converter AD is completed and, therefore, by this time, the A-D converter AD is applying the converted light signal to the input IP2 of the data selector MP1. Then, when the register DR carries "4H", the procedure advances to the step #17.

In the step #17, it is determined whether the content of the 1-bit register JF is "1" or not. If the content is "1" as occurred when the lens detecting switch LS is maintained off, the procedure advances to the step #18 in which exposure calculation effected in the case of no lens, as will be described later, is carried out. Contrary, if the content of the register JF is "0" as occurred when a lens is mounted and the lens detecting switch LS is turned on, the procedure advances to the step #20 wherein the content of the register DR, which is at present "4H", is outputted from the output OP3. By this signal, the data selector MP1 takes in the data Avs-Avo applied to its terminal IP3 and, in the step #21, the micro-computer 1 reads in the data Avs-Avo through the data bus DB. Then in the step #22, "1" is added to the content of the register DR, thus, the register DR is now holding "5H".

Then, in the step #23, the micro-computer 1 waits until the input i3 receives "HIGH" from the interface circuit IF indicating that all the fixed and variant data from the lens are now stored in the interface circuit IF. Since the moment when the output 02 produces "HIGH" at the step #8, the interface circuit IF has been repeating a cycle of operation of producing serially an address signal which is applied through the line SB and terminals JB3 and JL3 to the ROM RO1 provided in the data producer 7 and receiving serially fixed data stored at a designated location in the ROM RO1 through the same path. When this cycle of operation is repeated for a number of times to store all the fixed data in the interface circuit IF, the information producing circuits DS and FS provided in the lens are actuated to produce address signals for designating locations in the ROM RO1, whereby variant data such as focusing distance as set by the amount of shift of the lens and focal length data as set by zooming the lens are transmitted from the ROM RO1 to the interface circuit IF in the camera body. When all the fixed and variable data are stored in the interface circuit IF, the interface circuit IF produces "HIGH" which is applied to the input i3 of the microcomputer 1.

When the input i3 receives "HIGH", the procedure advances to the step #24 for producing "LOW" from the output 02, thereby turning the transistor BT2 to a non-conductive state for stopping the power supply from the power-line +VL to the lens. Then, in the steps #25 et seq., the micro-computer 1 reads in the data stored in the interface circuit IF.

Before describing the operations carried out in the steps #25 et seq., the operations up to the step #24 are summarized hereinbelow.

First, the address data for designating a location in the ROM RO1 provided in the data producer 7 is transmitted from the camera body to the lens, and the fixed data stored in the designated location in the ROM RO1 is transmitted from the lens to the camera body. This operation is repeated for a number of times to transfer all the fixed data to the camera body. Then, coded information data produced from the information producing circuit 9 is used without any change as address data to designate locations in the ROM RO1, thereby variant data stored in the ROM RO1 is transmitted to the camera body.

With the above arrangement, the fixed data and the variant data are transmitted from the ROM RO1 to the camera body through the same path, whereby only one pair of interconnecting terminals are necessary; one terminal JB3 on camera body and other terminal JL3 on lens. The information producing circuit 9 produces coded data corresponding to an amount of shift from a reference position. Since the ROM RO1 produces data in absolute value based on the data from the information producing circuit 9, the arrangement of the information producing circuit 9 is very simple when compared with an arrangement of a prior art producing circuit that directly produces the data in absolute value from the coded pattern, because the information producing circuit 9, according to the present invention, produces data which has less bits than that produced from the prior art producing circuit. Furthermore, the information producing circuit 9, according to the present invention, can be assembled in a compact size with a small coded pattern. Moreover, since the transmission of an address signal from the camera body to the lens and the signal transmission of read out data from the lens to the camera body are carried out alternately at different times, only one pair of interconnecting terminals is necessary for the mutual transmission, thereby reducing the number of terminals between the camera body and the lens.

Referring back to FIG. 2*b*, when the input i3 receives "HIGH", the micro-computer 1 starts to sequentially read in the data temporarily stored in the interface circuit IF, in the step #25. This operation is carried out in the follow steps. The output OP3 sequentially produces data "5H" to "DH", each designating a particular data. The produced data "5H" to "DH" are sequentially applied both to the interface circuit IF and to the data selector MP1. When the data produced from the output OP3 is "5H", the interface circuit IF produces check data. Similarly, when the output is "6H", data Ave representing the light measurement error caused by the change of the lens is produced; when the output is "7H", data Avm representing the minimum aperture size is produced; when the output is "8H", data Avo representing the maximum aperture size is produced; when the output is "9H", data fw representing the shortest focal length is produced; when the output is "AH", data ft representing the longest focal length is produced; when the output "BH", data dEvo representing the error compensating data necessary to compensate an exposure error upon exposure control under the fully-open aperture is produced; when the output is "CH", data representing set focusing distance is produced; and when the output is "DH", data representing set focal length is produced. In this case, the data applied to the terminal IP1 of the data selector MP1 is outputted through the data bus DB in a manner shown in Table 1. And, the micro-computer 1 sequentially takes in the data through the data bus DB. When the micro-computer 1 has taken in all the data from the interface circuit IF, the content of the register DR becomes "EH", whereby the step advances from #28 to #29.

The transmission of the data from the lens to the micro-computer 1 can be summarized as follows. First, each data is transmitted serially to the interface circuit IF in which the data is temporarily latched, each data comprising a plurality of bits. Then, in response to the

signals from the micro-computer **1** each designating a particular data, the temporarily latched data is transmitted to the micro-computer **1** one after another, with each data being transmitted parallelly. While the interface circuit IF is temporarily storing the data from the lens, the micro-computer **1** is reading other data. This arrangement has an advantage in time saving when compared with an arrangement wherein data is taken into the micro-computer serially bit-by-bit.

In the step **#29**, it is determined whether or not a check data, which is produced when and while the lens is properly mounted on the camera, is included in the data from the interface circuit IF. If the lens is mounted properly, the micro-computer **1** first receives the check data having a code which is common to all the lens. When the check data is present, the procedure advances to the step **#30**; but when it is absent, the procedure advances to the step **#18**. The absence of the check data occurs not only when the lens is improperly mounted, but also when a camera accessory, such as a bellows, a reverse adaptor, a teleconverter, an extension ring, or the like, is mounted between the camera body and the lens.

In the step **#30**, the following calculation is carried out using the read in data Avc and A-D converted data Bv-Avo-Avc,

$$(Bv-Avo-Avc)+Avc=Bv-Avo.$$

Then, in the step **#31**, the following calculation is carried out using the calculated data Bv-Avo and the fully-open aperture data Avo,

$$(Bv-Avo)+Avo=Bv$$

thereby obtaining the data Bv representing the brightness.

Then, in the step **#32**, an exposure calculation based on the selected mode of exposure control is carried out. The details of the calculations carried out in each mode of operation will be described later in connection with FIGS. *3a*, *3b*, *3c* and *3d*.

When the calculations carried out in the step **#32** end, the micro-computer displays various control values, exposure control mode, and warnings, if any, using the calculated value, through the display device DP. Thereafter, the micro-computer carries out the step **#34**.

In the meantime, when it is determined in the step **#29** that no check data from the lens LE is dispatched, the procedure advances to the step **#18**. Before describing the calculation carried out in the step **#18**, it is to be noted that the step advances from **#17** to **#18** even when it is determined that the lens LE is not mounted, so long as the content of the register JF is "1". In the case where the selected mode is an automatic mode, i.e., any one of program mode, aperture preferred mode, or shutter speed preferred mode, it is understood that the photographer desires to obtain the proper exposure settings automatically. When the effective aperture value of the automatically set aperture is given as Avn, the light measuring circuit LM produces a signal:

$$Bv-Avn$$

and, in the step **#18**, a calculation

$$(Bv-Avn)+Sv=Tv$$

is carried out, so as to control the shutter speed with the calculated value Tv. On the other hand, as to the aperture size, an output "0" is produced so as not to carry out the stop-down of the aperture. In other words, in the TTL stop-down light measuring system, the shutter speed is controlled automatically.

On the other hand, when the selected mode is a manual mode, the shutter speed is controlled by a manually set amount and, in this case, an output "0" is produced so as not to carry out the stop-down of the aperture.

Furthermore, when the selected mode is a flash-photographing mode, the shutter speed is controlled by Tvf representing the limit of synchronizing shutter speed. In this case, "0" is produced so as not to carry out the stop-down of the aperture. The amount of light to be emitted from the flash device is determined by the detected light which has been reflected on the film surface and the sensitivity of the film in use. Then, in the step **#19**, data of the exposure control value, selected mode, warnings, if any, are displayed through the display device DP. Thereafter, the procedure advances to the step **#34**. In this case, the data related to the aperture size of the lens is transmitted to the camera side and, therefore, such a data will not be displayed.

In the step **#34**, exposure time control data Tvc is transmitted from the output OP1 to the exposure time control device CT, and in the step **#35**, the stop-down degree data dAv is transmitted from the output OP2 to the aperture control device CA. Then, in the step **#36**, the interruption terminal **i5** is brought to a condition ready to receive "HIGH", thereby enabling the interruption procedure shown in FIG. *2c*, which will be described later. Then, "0" is stored in the register JF and, thereafter, the procedure returns back to "START". Here, it is to be noted that "enabling of interruption" means that the terminal **i5** is in a condition ready to receive an interruption signal.

When the procedure returns back to "START", it is determined whether or not the input terminal **i1** is receiving "HIGH", as occurred when the light measuring switch MS is turned on. If yes, the procedure so advances as to repeat the above described steps **#6** and **#37**. This procedure is repeated again and again so long as the light measuring switch MS is maintained on. If no, as occurs when the input **i1** is receiving "LOW", the procedure advances to the step **#2**, in which it is determined whether a register TR used as a timer is holding a value greater than a predetermined value K, or not. If not, the procedure advances to the step **#3** for adding "1" to the content of the register TR and further advances to the step **#7** for repeating the above described procedure of data reading, calculation and display. The purpose of providing a routine of steps **#1**, **#2**, **#3**, **#7** is to carry out the procedure of **#7** to **#36** repeatedly for a predetermined number of times (K times) even after the turning off of the light measuring switch MS. Then, when the content of the register TR becomes greater than K, the procedure advances to the step **#4** for producing data that effects disabling of the display device DP. Then, in the step **#5**, it is prohibited to transmit the interruption signal through the input terminal **i5** for disabling the interruption. Thereafter, the procedure returns back to the step **#1**. Then, until the light measuring switch MS is turned on again, a routine of steps **#2**, **#4**, **#5** and **#1** is repeated again and again.

In summary, the micro-computer **1** operates as follows. While the light measuring switch MS is turned on,

a successive operation of data reading, calculation and display is repeated again and again, and this successive operation is carried out for a predetermined number of times (until the content of the timer register TR becomes K+1) even after the light measuring switch MS is turned off. This extra repetition is repeated, for example, 15 seconds after the turn-off of the light measuring switch MS.

When one cycle of operation is completed for the first time after the turn-on of the light measuring switch MS, the terminal i5 is brought to a condition ready to receive an interruption signal. Then, after completing the film wind-up of one frame, and when the release switch RS is turned on with the safety switch CS being turned on, the AND gate AN0 produces "HIGH" which is applied to the terminal i5. At this moment, since the system has completed the exposure calculation and is ready to receive the interruption, an interruption procedure, as shown in FIG. 2*c*, is carried out. It is to be noted that once the exposure data is calculated and, interruption is enabled, the interruption procedure as shown in FIG. 2*c* can be inserted at any time during the procedure other than the routine procedure of steps #1, #2, #4, #5. When the micro-computer 1 receives the interruption signal to the input i5, the procedure in the micro-computer 1 jumps to a particular address and carries out a procedure stored in the particular address. In order to cope with the interruption procedure requested during the data reading from the lens LE, "LOW" is produced from the output O2 in the step #40, and the data for disabling the display device DP is produced in the step #41. Then, in the step #42, "HIGH" is produced from the output O1 for actuating the release circuit RL and, at the same time, maintaining the transistor BT1 on by "LOW" from the inverter IN2. Thereafter, even if the light measuring switch MS is turned off, the transistor BT1 continues to hold the conductive state. When the release circuit RL actuates, an exposure control mechanism (not shown) starts its operation.

In the first place, the stop-down operation is carried out by the ring 13, and from the pulse generator PG, a number of pulses corresponding to the degree of rotation of the ring 13 are produced. The aperture control device CA counts the pulses from the pulse generator PG and compares the counted number with the stop-down degree data dAv obtained from the output OP2 of the micro-computer 1. When the counted number coincides with the data dAv, the aperture control device CA so controls the ring 13 as to stop its rotation, thereby defining the aperture size. In the case where the camera provided with the system shown in FIG. 1 is a single-reflex camera, the flip-up operation of a reflex mirror (not shown) is also carried out simultaneously with the above mentioned aperture setting. When the aperture setting and the flip-up operation of the reflex mirror are complete, a leading curtain (not shown) starts to scan and, at the same time, the exposure time control device CT starts to count exposure time determined by the data Tvc obtained from the output OP1.

Particularly, if the selected mode is the flash-photographing mode, the flash control device FC produces, e.g., when the shutter is fully opened, an emission-start signal which is applied to a the flash-light device FL through terminal JB6 of camera side and terminal JF2 of flash device side for effecting the emission of flash light. The flash-light control FC integrates the light which has been reflected from an object to be photographed and has passed through an objective lens and further reflected on a film surface, and when the integrated amount reaches a predetermined level, it produces an emission-stop signal which is applied to the flash-light device FL through terminal JB7 of camera side and terminal JF3 of flash device side for stopping the emission of flash-light.

Then, regardless of the selected mode, whether it be the flash-photographing mode or daylight-photographing mode, the trailing curtain (not shown) starts to scan when the shutter speed control device CT has a number corresponding to the exposure time data obtained from the output OP1. When the scanning of the trailing curtain completes, the safety switch CS turns off and, thereafter, the reflex mirror flips down and the aperture is fully opened to its maximum size, thereby completing the exposure operation.

By the turning off of the safety switch CS as occurs upon completion of the exposure operation, the inverter IN4 produces "LOW", thereby producing "LOW" from the output O1 at the step #44. By the "LOW" from the output O1, the release circuit RL is turned to inoperative and, at the same time, self-holding of the transistor BT1 to conductive state is released. Then, in the step #45, the acceptance of the interruption signal to the interruption terminal i5 is prohibited and, thereafter, the procedure returns back to "START". In this case, if the light measuring switch MS is held turned on, or if it is within 15 seconds from the turn off of the light measuring switch MS, the successive operation of the data reading, calculation and display is carried out repeatedly. Also, if the light measuring switch MS is held turned on with the safety switch CS being turned off, the successive operation of the data reading, calculation and display is carried out repeatedly and, at the same time, the micro-computer 1 is in a condition ready to accept the interruption signal. Under this condition, even if the release switch RS is also turned on, the turn on of the safety switch CS prevents the signal from the release switch RS from being transmitted through the AND gate AN0 and, therefore, no interruption signal will be applied to the micro-computer 1 through the input terminal i5. Therefore, it is possible to prevent the micro-computer 1 from erroneously carrying out the exposure control.

It is to be noted that the successive operation of data reading, calculation and display can be stopped immediately upon turn off of the light measuring switch MS, when the turn off of the light measuring switch MS is carried out after the completion of exposure control operation and before the completion of the film wind up operation, i.e., while the safety switch CS is turned off. This can be done by the following procedure. When it is determined that the input i1 is not receiving "HIGH" in the step #1, it is further determined whether the input i2 is receiving "HIGH" or not in a step before the step #2. When it is determined that the input i2 is receiving "HIGH", the procedure advances to the step #2, but it is determined that the input i2 is not receiving "HIGH", a data K+1 is set up in the timer register TR and, thereafter, the procedure advances to the step #2. In this case, since the content of the timer register TR is already greater than K, the procedure advances from the step #2 to the step #4 and further to the step #5 and, thereafter, repeating the routine procedure of steps #1, #2, #4 and #5. Thus, the successive operation of data reading, calculation and display can be stopped immediately upon turn off of the light measuring switch MS.

FIGS. 3*a*, 3*b*, 3*c* and 3*d* show a detailed flow chart of the step #32 shown in FIG. 2*b* for carrying out the exposure calculations under a mode selected from any one of: flash-photographing mode (FP mode) in which a photograph is taken with an aid of auxiliary light; programmed mode (P mode) in which the shutter speed and aperture size are automatically determined according to the set program; shutter speed preferred mode (S mode) in which the aperture size is automatically determined with respect to the preferred shutter speed; aperture size preferred mode (A mode) in which the shutter speed is automatically determined with respect to the preferred aperture size; and manual mode (M mode) in which the shutter speed and aperture size are manually set.

Referring particularly to FIG. 3*a*, it is determined in the step #50 whether or not the charge completion signal has been transferred from the flash-light device FL through the terminals JF1 and JB5 to the mode signal producing device MS, that is whether or not the selected mode is the flash-photographing (FP) mode. If the selected mode is the FP mode, the procedure advances to the step #51 in which the data Tvf representing the limit of flash synchronizing shutter speed (for example Tv=6) is changed to the exposure time control device Tvc. Then, a calculation

$$Bv+Sv-Tvf+k=Avf1$$

is carried out, wherein k is equal to or greater than zero. By the above calculation, an aperture size data Avf1, which is equal to kEv degrees stopped down from the appropriate shutter speed for the flash synchronizing shutter speed, is obtained. Then, in the step #53,

$$Iv+Sv-Dv=Avf2$$

is calculated, wherein Iv represents data in APEX numbering system corresponding to the maximum light amount that the flash-light device FL can produce, and Dv represents data in APEX numbering system corresponding to the set focusing distance of the mounted lens LE. Therefore, the calculated data Avf2 indicates the limit of aperture value under the photographing with the aid of flash light.

In the step #54, the two calculated values Avf1 and Avf2 are compared with each other. When the comparison results as:

$$Avf1 \leqq Avf2,$$

it is understood that the calculated value Avf1 is within said limit of aperture value under the photographing with the aid of the flash light. Thus, in this case, the procedure advances to the to the step #55. In the steps #55 and #56, it is determined whether the calculated value Avf1 is within an available range of aperture size of the mounted lens LE. More particularly, in the step #55, the determined:

$$Avf1 \geqq Avo$$

is carried out, and in the step #56, the determination:

$$Avf1 \leqq Avm$$

is carried out. If the calculated value Avf1 has a value between Avo and Avm, the procedure advances to the step #57 in which

$$Avf1-Avo$$

is set up as a degree of stop down dAv. Thereafter, the procedure continues from the step #33 described above in connection with FIG. 2*b*.

Contrary, if it is determined that

$$Avf1<Avo$$

in the step #55, the procedure advances to the step #58 for setting a data that produces a warning indicating that the calculated value Avf1 is beyond the full-open aperture size, and further to the step #59 for setting 0 for the degree of stop down dAv. Then, the procedure continues from the step #33.

Furthermore, in the step #56, if it is determined that

$$Avf1>Avm,$$

the procedure advances to the step #60 for setting a data that produces a warning indicating that the calculated value Avf1 is below the minimum-open aperture size, and further to the step #61 for setting Avm−Avo for the degree of stop down dAv.

Back to the step #54, if it is determined that

$$Avf1>Avf2,$$

meaning that the amount of light will be insufficient if photographed with an aperture size controlled with a value Avf1, the procedure advances to the step #62. Similar to the above, it is determined in the steps #62 and #63, whether the calculated value Avf2 is within an available range of aperture size of the mounted lens LE. More particularly, in the step #62, the determination:

$$Avf2 \geqq Avo$$

is carried out, and in the step #63, the determination:

$$Avf2 \leqq Avm$$

is carried out. If the calculated value Avf2 has a value between Avo and Avm, the procedure advances to the step #64 in which

$$Avf2-Avo$$

is set up as a degree of stop down dAv. Thereafter, the procedure continues from the step #33 described above in connection with FIG. 2*b*.

Contrary, if it is determined that

$$Avf2<Avo$$

in the step #62, the procedure advances to the step #58 for producing a warning described above and continues to carry out the steps #59, #33 et seq.

Furthermore, in the step #63, if it is determined that

$$Avf2>Avm,$$

the procedure advances to the step #60 for producing a warning described above and continues to carry out the steps #61, #33, et seq.

According to the above described operation under the flash-photographing mode (FP mode), the calculated aperture value Avf1 is equal to a value which is

stopped down by an amount of kEv from a preliminarily calculated aperture value plainly determined by the brightness Bv of the object, film sensitivity Sv and flash synchronizing shutter speed limit Tvf. The reason for this is explained below. First of all, the light receiving elements for the average measurement are generally distributed not with an equal density within a picture taking frame but with an intensive distribution at the center and sparse at the peripheral portions. When taking a photograph, the main object is usually located at the center, and particularly, when taking a photograph under the flash-photographing mode, the main object located at the center is less bright than the background. Thus, from the light receiving elements distributed densely at the center and sparsely at the perimeter, a signal based on the brightness of the center object, which is less bright than the surrounding object, will be produced. If the aperture size is controlled by this signal, the photograph will be over-exposured. From this view point, the calculated aperture value Avf1 is made equal to a value which is stopped down by an amount of kEv from the preliminarily calculated aperture value so as to properly expose the main object located at the center of the frame. The amount kEv can be selected empirically by taking a number of scenes, and picking a most desirable amount, for example, 1 Ev.

As has been described before, since the flash-light control device FC controls the amount of the flash light in relation to the received light from the object through the aperture and reflected on the film surface, the object will be properly exposed with the aid of flash light controlled by the device FC. Also, when there is a high possibility that the flash-light is insufficient because the focusing distance data Dv is relatively great, the control is carried out with the use of calculated aperture value Avf2 corresponding to the focusing distance so as to avoid the under-exposure of the main object due to the lack of total light amount of the flash-light device FL.

Referring now to FIG. 3*b*, the description is directed to the automatic exposure control operation and particularly to the operation under the programmed mode (P mode). When it is determined in the step #50 that the selected mode is not the flash-photographing mode, the procedure advances to the step #65 in which it is determined whether the selected mode is the programmed mode or not. When the selected mode is the programmed mode, the procedure advances to the step #66 in which a calculation

$$p(Bv+Sv)=Av \quad 0<p<1$$

is carried out. Then, in the steps #67 and #68, it is determined whether the calculated aperture value Av is within a controllable range between Avo and Avm or not. If

$$Avo \leqq Av \leqq Avm,$$

the procedure advances to the step #69 in which Av—Avo is set up as a degree of stop down dAv. Then, in the step #70,

$$Ev-Av=Tv$$

is carried out. And in the step #71, it is determined whether the aperture is fully opened or not, i.e., whether

$$dAv=Av-Avo=0$$

is satisfied or not. When the aperture is not fully opened, a relation

$$dAv \neq 0$$

is obtained and, therefore, in the step #73, the calculated aperture value Tv is used as a control data Tvc. Thereafter, the procedure continues from the step #33. Contrary, when the aperture is fully opened, a relation $dAv=0$,

is obtained. In this case, the exposure error will occur if the light amount is evaluated uniformly on every spot within the picture taking frame. Thus, using an exposure error compensating data dEvo, a calculation

$$Tv-dEvo$$

is carried out, and the calculated amount is used as a control data Tvc, in the step #72. Thereafter, the procedure continues from the step #33.

It is to be noted here that, when the aperture is so controlled as to be fully opened, the calculated amount Tv is varied by an amount dEvo. The reason for this is explained below. It is found that phenomenon of making the center bright and the peripheral portions dark due to the vignetting will not take place when the aperture is set to a position between the most reduced aperture size and one step stopped down from the fully-opened aperture size, but said phenomenon takes place when the aperture is set to the fully-opened aperture size. More particularly, when the aperture size becomes close to the fully-open aperture size, the amount of incident light on the picture taking frame at positions away from the optical axis is reduced in a greater degree than the $\cos^4$ law. Therefore, when the light amount is averagedly evaluated within a predetermined extent of area including the center of the picture taking frame, the photograph will be taken with an under-exposure. Thus the exposure operation requires compensation. The compensation is carried out such that when the aperture is so controlled as to be fully opened, the exposure time is prolonged for a period corresponding to the exposure error, thereby obtaining a correct exposure when the light amount is averagedly evaluated within the predetermined extent of area. It is preferable to carry out the compensation to each aperture size, which is close to the fully opened aperture size, by an amount corresponding to respective aperture size. To this end, however, it is necessary to provide a memory means for storing exposure error data corresponding to various aperture sizes in each lens. The employment of such a memory means results in complication of the circuit arrangement in the lens and, at the same time, in increase of processing time delaying the data transmission from the lens to the camera.

Furthermore, the cases that require the aperture to be set close to the fully opened size are rare, when compared with the cases that require the aperture to be set to the fully opened size. Thus, from a practical point of view, according to the embodiment shown, the compensation is effected only when the aperture is set to the fully opened size. In this way, the circuit necessary for the compensation can be prepared with a simple structure (only one data is needed to be memorized).

Referring again to FIG. 3*b*, when it is determined in the step #68 that

$Av > Avm$,

the procedure advances to the step #74 in which a calculation

$Ev - Avm = Tv$

is carried out. Then, in the step #75, it is determined whether a relation

$Tv \leqq Tvmax$

is satisfied or not. If the relation

$Tv \leqq Tvmax$

is satisfied, the procedure advances to the step #76 in which the calculated exposure time Tv is used as a control data Tvc. Then, in the step #77, a data Avm−Avo is set up as a degree of stop down dAv, and, thereafter, the procedure continues from the step #33. If it is determined in the step #75 that the relation

$Tv \leqq Tvmax$

is not satisfied, the procedure advances to the step #78 in which an alarm indicating that the calculated exposure time Tv is shorter than the minimum available exposure time. In this case, the data Tvmax is set up as an exposure time control data Tvc. Then, in the step #80, a data Avm−Avo is set up as a degree of stop down dAv, and, thereafter, the procedure continues from the step #33.

Back to the step #67, if it is determined that

$Av < Avo$,

the procedure advances to the step #81 in which 0, representing the fully opened aperture, is set up as a degree of the stop down dAv. Then, in the step #82, a calculation

$Ev - Avo = Tv$

is carried out. Since the aperture is controlled to be fully opened, a calculation

$Tv - dEvo$

is carried out, and the calculated result is used as an exposure control data Tvc in the step #83. Then, in the step #84, it is determined whether a relation

$Tvc \geqq Tvmin$

is satisfied or not. If is it determined that the relation

$Tvc \geqq Tvmin$

is satisfied, the procedure continues from the step #33. Contrary, if it is determined that the relation is such that $Tvc < Tvmin$,

the procedure advances to the step #85 in which an alarm data indicating that the calculated exposure time Tv−dEvo is longer than the maximum available exposure time. In this case, the data Tvmin is set up as an exposure time control data Tvc. Thereafter, the procedure continues from the step #33.

If the selected mode is shutter speed preferred mode (S mode), the procedure advances from the step #65 to the step #87 and further to the step #88 in which a calculation

$Bv + Sv - Tvs = Av$

is carried out. Thereafter, the procedure continues from the step #67 with the use of aperture data Av as calculated in the step #88.

Next, the operation when the selected mode is aperture size preferred mode (A mode), is described.

Referring to FIG. 3c, when the selected mode is aperture size preferred mode, the procedure advances from the step #87 to the #89 and further to the step #90 in which it is determined whether the aperture is set to the fully opened size or not, i.e., whether a relation

$Avs - Avo = 0$

is satisfied or not. When the aperture is set to the fully opened size, a relation

$Avs - Avo = 0$

is satisfied and, in this case, the procedure advances to the step #91 in which a calculation

$Bv + Sv - Avo = Tv$

is carried out. Then, in the step #92, a calculation

$Tv - dEvo$

is carried out, and the calculated data is set up as a control data Tvc. Then, in the step #93, it is determined

$Tvc < Tvmin$,

or not. If

$Tvc < Tvmin$,

the procedure advances to the step #94 in which 0 is set up as a degree of stop down dAv. And in the step #95, an alarm data indicating that the calculated exposure time Tvc is longer than the maximum available exposure time. Then, Tvmin is set up as a data Tvc for controlling the exposure time. Thereafter, the procedure continues from the step #33.

Back to the step #93, if

$Tvc \geqq Tvmin$,

the procedure advances to the step #97 in which it is determined

$Tvc > Tvmax$,

or not. If

$Tvc > Tvmax$,

the procedure advances to the step #98 for carrying out a calculation

$Ev - Tvmax = Av$.

And then, in the step #99, it is determined

$Av \leqq Avmax$,

or not. If

$Av \leqq Avmax$,

the procedure advances to the step #100 in which Tvmax is set up as a control data, and in the step #101, Av−Avo is set up as a degree of stop down data. Thereafter, the procedure continues from the step #33. In the step #99, if it is determined that

$Av > Avmax$,

the procedure advances to the step #102 an alarm data indicating that the calculated exposure time Tvc is shorter than the minimum available exposure time. Then, Tvmax is set up as a data Tvc for controlling the exposure time. Thereafter, the procedure continues from the step #33. In the step #97, if it is determined that

$Tvc \leqq Tvmax$,

the procedure advances to the step #105 in which 0 is set up as a degree of stop down dAv. Thereafter, the procedure continues from the step #33.

Back to the step #90, if it is determined that

$Avs - Avo \neq 0$,

the procedure advances to the step #106.

Referring to FIG. 3*d*, in the step #106, a calculation

$$Bv + Sv - Avs = Tv$$

is carried out. Then, in steps #107–#123, in a similar manner described above, when

$Tvmin \leqq Tv \leqq Tvmax$,

the calculated Tv is used as an exposure time control data Tvc, and, at the same time, Avs−Avo is set up as a degree of stop down dAv. If

$Tv < Tvmin$,

a calculation

$$Ev - Tvmin = Av$$

is carried out, and the calculated Av is compared with Avo. If,

$Avo \leqq Av$,

Av−Avo is set up as a degree of stop down dAv, and Tvmin is set up as an exposure time control data Tvc. If,

$Avo > Av$,

0 is set up as a degree of stop down dAv, and Tvmin is set up as an exposure time control data Tvc. And at the same time, an alarm is produced. Furthermore, if,

$Tv > Tvmax$,

a calculation

$$Ev - Tvmax = Av$$

is carried out, and the calculated Av is compared with Avm. If,

$Av \leqq Avm$,

Av−Avo is set up as a degree of stop down dAv, and Tvmax is set up as an exposure time control data Tvc. Contrary, if,

$Av > Avm$,

Avm−Avo is set up as a degree of stop down dAv, and Tvmax is set up as an exposure time control data Tvc. And at the same time, an alarm is produced.

Referring again to FIG. 3*c*, when it is determined in the step #89 that the selected mode is not an aperture size preferred mode, that is when the selected mode is a manual mode, the procedure advances to the step #124 for carrying out the control under the manual mode. In the step #124, a calculation

$$Bv + Sv = Ev$$

is carried out, and in the step #125, it is determined whether

$$Avs - Avo = 0,$$

or not. If it is determined that

$$Avs - Avo = 0,$$

the procedure advances to the step #126 in which a calculation

$$Ev - Avo - (Tvs - dEvo) = dEv$$

is carried out. Then, in the steps #127 and #128, Tvs is set up as an exposure time control data Tvc, and 0 is set up as a degree of stop down dAv. Then, the procedure continues from the step #33.

In the step #125, if it is determined that

$Avs - Avo \neq 0$,

the procedure advances to the step #129 for carrying out a calculation

$$Ev - Avs - Tvs = dEv.$$

Then, in the steps #130 and #131, Tvs is set up as an exposure time control data Tvc, and Avs−Avo is set up as a degree of stop down dAv. Then, the procedure continues from the step #33.

FIGS. 4*a* and 4*b* show a circuit diagram which is an example of the interface circuit IF shown in FIG. 1, FIG. 5 shows a circuit diagram which is an example of data producer 7 shown in FIG. 1, FIG. 6 shows a time chart of initial operation of the interface circuit IF, and FIG. 7 shows a time chart of ending operation of the interface circuit IF. Next, the description will be directed to the interface circuit IF and data producer shown in FIGS. 4*a*, 4*b*, and 5. First, various data stored in a ROM at various locations with various addresses and the significance of such data will be described with reference to Tables 2 and 3 given below.

TABLE 2

Address $a_7a_6a_5a_4a_3a_2a_1a_0$	Significance	Data Example in ROM Meaning	$b_4b_3b_2b_1b_0$
0 0 0 0 0 0 0 1	Code for Check		1 1 1 0 0
0 0 0 0 0 0 1 0	dEvo	dEvo = 2/8	0 0 1 1 0
0 0 0 0 0 0 1 1	Avm	Avm=9=F22	1 1 0 1 0
0 0 0 0 0 1 0 0	Avo	Avo = 3.62	0 1 0 1 0
0 0 0 0 0 1 0 1	focal length fw*	fw = 50 mm	0 1 0 1 1
0 0 0 0 0 1 1 0	focal length ft**	ft = 135 mm	1 0 0 0 1
0 0 0 0 1 0 0 0	Avc	+2/8	0 1 0 1 0
0 0 0 0 1 0 0 1		−3/8	0 0 1 0 1
0 0 0 0 1 0 1 0		+1/8	0 1 0 0 1
0 0 0 1 0 0 0 0	Focusing	1.4 m	0 1 0 1 0
0 0 0 1 0 0 0 1	Distance	1.7	0 1 0 1 1
0 0 0 1 0 0 1 0		2	0 1 1 0 0
0 0 0 1 0 0 1 1		2.4	0 1 1 0 1
0 0 0 1 0 1 0 0		2.8	0 1 1 1 0
0 0 0 1 0 1 0 1		3.4	0 1 1 1 1
0 0 0 1 0 1 1 0		4	1 0 0 0 0
0 0 0 1 0 1 1 1		4.7	1 0 0 0 1
0 0 0 1 1 0 0 0		5.6	1 0 0 1 0
0 0 0 1 1 0 0 1		6.7	1 0 0 1 1
0 0 0 1 1 0 1 0		8	1 0 1 0 0
0 0 0 1 1 0 1 1		9.5	1 0 1 0 1
0 0 0 1 1 1 0 0		11	1 0 1 1 0
0 0 0 1 1 1 0 1		13	1 0 1 1 1
0 0 0 1 1 1 1 0		16	1 1 0 0 0
0 0 0 1 1 1 1 1		∞ m	1 1 1 1 1
0 0 1 0 0 0 0 0	Focal	50 mm	0 0 1 0 1
0 0 1 0 0 0 0 1	Length	50	0 0 1 1 0
0 0 1 0 0 0 1 0		50	0 0 1 1 1
0 0 1 0 0 0 1 1		70	0 1 0 0 0
0 0 1 0 0 1 0 0		75	0 1 0 0 1
0 0 1 0 0 1 0 0		75	0 1 0 1 0
0 0 1 0 0 1 1 0		85	0 1 0 1 1
0 0 1 0 0 1 1 1		85	0 1 1 0 0
0 0 1 0 1 0 0 0		100	0 1 1 0 1
0 0 1 0 1 0 0 1		100	0 1 1 1 0
0 0 1 0 1 0 1 0		105	0 1 1 1 1
0 0 1 0 1 0 1 1		105	1 0 0 0 0
0 0 1 0 1 1 0 0		105	1 0 0 0 1
0 0 1 0 1 1 0 1		135	1 0 0 0 1
0 0 1 0 1 1 1 0		135	1 0 0 0 1
0 0 1 0 1 1 1 1		135 mm	1 0 0 0 1

Note *: "fw" stands for minimum focal length when lens is zoomed to widest.
Note **: "ft" stands for maximum focal length when lens is zoomed to most telescopic side.

TABLE 3

Data in Rom $b_4b_3b_2b_1b_0$	Aperture Value F No.	Av	Focusing Distance m	Dv	Avc	Focal Length mm	dEvo
0 0 0 0 0	1.0	0	0.25	−4.0	−8/8	6.0	0
0 0 0 0 1	1.2	0.5	0.30	−3.5	−7/8	7.5	1/8
0 0 0 1 0	1.4	1.0	0.35	−3.0	−6/8	8.0	2/8
0 0 0 1 1	1.7	1.5	0.42	−2.5	−5/8	16	3/8
0 0 1 0 0	1.8	1.7	0.50	−2.0	−4/8	17	4/8
0 0 1 0 1	2.0	2.0	0.60	−1.5	−3/8	20	5/8
0 0 1 1 0	2.4	2.5	0.70	−1.0	−2/8	24	6/8
0 0 1 1 1	2.5	2.64	0.84	−0.5	−1/8	25	7/8
0 1 0 0 0	2.8	3.0	1.0	0.0	0	28	8/8
0 1 0 0 1	3.4	3.5	1.2	0.5	+1/8	35	
0 1 0 1 0	3.5	3.62	1.4	1.0	+2/8	45	
0 1 0 1 1	3.6	3.7	1.7	1.5	+3/8	50	
0 1 1 0 0	4.0	4.0	2.0	2.0	+4/8	70	
0 1 1 0 1	4.5	4.34	2.4	2.5	+5/8	75	
0 1 1 1 0	4.7	4.5	2.8	3.0	+6/8	85	
0 1 1 1 1	5.0	4.64	3.4	3.5	+7/8	100	
1 0 0 0 0	5.6	5.0	4.0	4.0	+8/8	105	
1 0 0 0 1	6.3	5.31	4.7	4.5		135	
1 0 0 1 0	6.5	5.4	5.6	5.0		150	
1 0 0 1 1	6.7	5.5	6.7	5.5		180	
1 0 1 0 0	8.0	6.0	8.0	6.0		200	
1 0 1 0 1	9.5	6.5	9.5	6.5		210	
1 0 1 1 0	11	7.0	11	7.0		250	
1 0 1 1 1	13	7.5	13	7.5		300	
1 1 0 0 0	16	8.0	16	8.0		400	
1 1 0 0 1	19	8.5	19	8.5		500	
1 1 0 1 0	22	9.0	22	9.0		600	

TABLE 3-continued

Data in Rom $b_4b_3b_2b_1b_0$	Aperture Value F No.	Av	Focusing Distance m	Dv	Avc	Focal Length mm	dEvo
1 1 0 1 1	27	9.5	27	9.5		800	
1 1 1 0 0	32	10.0	32	10.0		1000	
1 1 1 0 1	38	10.5	38	10.5		1200	
1 1 1 1 0	45	11.0	45	11.0		1600	
1 1 1 1 1			Infinite			Fixed	

The description is now directed to the data stored in ROM RO1 with reference to the above given Tables 2 and 3. It is to be noted that the data in Table 2 under the column "Data Example in ROM" are given as an example, and such data are for a zoom lens having a range of focal length between 50 mm and 135 mm, and a range of aperture size between F 3.5 and F 22. At a location specified by an address "00000001", data "11100" necessary for checking whether the lens is properly mounted or not is stored. The data "11100" is stored at the address "00000001" not only in the case of the above given zoom lens, but also in any other types of lenses. Also, the data for checking is not necessarily "11100", but can be any other combination of 5-bit data, so long as such data is common to all other types of lenses.

In the location specified by the address "00000010", a data dEvo, representing the fully-open aperture exposure error compensating data, is stored. Since the data dEvo for the exemplary zoom lens is dEvo=2/8, data "00010" corresponding to dEvo=2/8, as shown in Table 3, is stored. In the address "00000011", data Avm representing the minimum aperture size is stored, and in the exemplary case, Avm is F22 (=9 Av). Thus, a data "10010" representing F22 as indicated in Table 3, is stored in the address "00000011". In the address "00000100", a data Avo, representing the fully-open aperture size, is stored, and in the exemplary case, it is Avo=3.62 (=F 3.5). Thus, a data "01010" representing Avo=3.62, as indicated in Table 3, is stored in the address "00000100".

In the address "00000101", a data fw, representing the minimum focal length of the zoom lens, is stored, and in the exemplary case, the actually stored data is "01011" representing the focal length 50 mm, as understood from Table 3. In the address "00000110", a data ft, representing the maximum focal length of the zoom lens, is stored, and in the exemplary case, the stored data is "10001" representing the focal length 135 mm, as understood from Table 3. In the case where the interchangeable lens is not a zoom lens, i.e., a lens with a fixed focal length, a data indicating such a fixed focal length is stored in the address "00000101", and a data "11111" indicating that the interchangeable lens has a fixed focal length is stored in the address "00000110".

In each of the addresses "00001000", "00001001" and "00001010", data Avc representing the light measurement error caused by the exchange of the lens is stored. The reason for providing a plurality of data for the light measurement error is because, even when the lens to be mounted is the same, the light measurement error shows a different amount when the camera body has a different arrangement of the light receiving element, that is when the light receiving element is located at a different position relative to the exit pupil of the lens. According to the preferred embodiment, the ROM RO1 is prepared not only applicable to one type of the camera

body, but also to a number of types, such as 3, types of the camera bodies. From this point of view, if ROM RO1 is stored with only one data for the light measurement error, there will be an exposure error when the same lens is mounted on another type of camera body.

When a lens is mounted on a first type of the camera body, an address "00001000" is designated, when a lens is mounted on a second type of the camera body, an address "00001001" is designated, and when a lens is mounted on a third type of the camera body, an address "00001010" is designated. It is to be noted that, according to the embodiment described herein, the circuit shown in connection with FIGS. 4*a* and 4*b* is designed for the second type of the camera. And, according to the exemplification shown in Table 2, a data stored in the address "00001000" for the first type camera is "01010", representing Avc= +2/8; a data stored in the address "00001001" for the second type camera is "00101", representing Avc= $-\frac{3}{8}$; and a data stored in the address "00001010" for the third type camera is "01001", representing Avc= $+\frac{1}{8}$.

An example of data representing the light measurement error to be stored in other lenses is shown in Table 4 below.

TABLE 4

Lens	Address	Camera Type	Avc	Data
28 mm/F 2.8	08H	1st	0	01000
	09H	2d	+1/8	01001
	0AH	3d	−1/8	00111
35 mm/F 2.8	08H	1st	−1/8	00111
	09H	2d	0	01000
	0AH	3d	−2/8	00110
50 mm/F 1.4	08H	1st	0	01000
	09H	2d	0	01000
	0AH	3d	0	01000
85 mm/F 2	08H	1st	−2/8	00110
	09H	2d	−4/8	00100
	0AH	3d	−1/8	00111
135 mm/F 2.8	08H	1st	−4/8	00100
	09H	2d	−3/8	00101
	0AH	3d	−1/8	00111
300 mm/F 5.6	08H	1st	−4/8	00100
	09H	2d	+1/8	01001
	0AH	3d	0	01000

According to the example shown in Table 4, a 50 mm/F 1.4 lens is considered to be a standard lens. Accordingly, the light measurement error Avc for each of the first, second and third cameras in combination with the standard lens is rendered 0, and other errors Avc are calculated relatively to the standard lens. The above data are fixed data for the lens.

In the addresses "00010000" through "00011111", data of various focusing distances are stored as variable data. From the focusing distance data producing device DS, a 4-bit data corresponding to the shifted amount of the distance ring (not shown) from the nearest-focusing position is produced; and the produced 4-bit data is applied through a data selector MP2 to four least significant inputs r3, r2, r1 and r0 of the ROM RO1 for designating a particular location therein, thereby a data of focusing distance in absolute value stored in the designated location is read out from the ROM RO1. According to the example given in Table 3, if the data produced from the focusing distance data producing device DS is "0010", an address "00010010" defined by the data "0010" designates a particular location in the ROM RO1, whereby the ROM RO1 produces a data "01100" representing the focusing distance of 2 m (Dv=2). If the data produced from the device DS is "1011", an address "00011011" defined by the data "1011" is produced, designating a particular location in the ROM RO1, whereby the ROM RO1 produces a data "10101" representing the focusing distance of 9.5 m (Dv=6.5). It is to be noted that, since the focusing distance data is used for the flash-photographing calculation and, therefore, the data is given by the APEX numbering system, the produced data corresponds to a value $2^{\frac{1}{2}Dv}$ m wherein Dv changes with a rate of $\frac{1}{2}$. In contrast to this, it is possible to increase the range of data with a more precise rate of change by increasing the number of bits in the address data from the focusing distance data producing device DS and, at the same time, increasing the number of bits in the ROM RO1.

In the addresses "00100000" through "00101111", data of various focal lengths set by the zooming ring are stored for the case of zoom lens, and fixed data of "11111" indicating the fixed focal length is stored for the case of fixed focal length lens in each of said addresses. In a similar manner to the focusing distance, a 4-bit data corresponding to the shifted amount of zoom ring (not shown) from the minimum focal length is produced from the focal length data producing device FS; and the produced 4-bit data is applied through a data selector MP2 to four least significant inputs r3, r2, r1 and r0 of the ROM RO1 for designating a particular location therein, thereby a data of focal length in absolute value stored in the designated location is read out from the ROM RO1. According to the example given in Table 3, if the data produced from the focal length data producing device FS is "0010", an address "00100010" defined by the data "0010" designates a particular location in the ROM RO1, whereby the ROM RO1 produces a data "01011" representing the focal length of 50 mm. If the data produced from the device FS is "1010", an address "00101010" defined by the data "1010" is produced, designating a particular location in the ROM RO1, whereby the ROM RO1 produces a data "10000" representing the focal length of 105 mm. It is to be noted that, in the example shown in Table 3, the ROM RO1 is stored with various data of popular focal lengths, such as 50 mm, 85 mm, 100 mm, and so on; that is, focal lengths of fixed focal length lenses are available. In contrast to this, it is possible to obtain data of further precise focal lengths by increasing the number of bits in the address data and the focal length data.

Referring next to FIGS. 4*a* and 4*b*, the description is directed to the interface circuit IF. When the switches LS and MS close, the micro-computer 1 produces from its output O2 a "HIGH" (waveform O2 shown in FIG. 6) as a start signal for starting the data reading. The positive edge of this start signal actuates the one-shot circuit OS1, whereby the one-shot circuit OS1 produces a positive going pulse (waveform OS1 shown in FIG. 6). By the negative edge of this pulse, a flip-flop FF1 is turned to a set condition. The flip-flop FF1 is turned to a reset condition by a negative edge of a pulse from an OR gate OR1 which receives a pulse PR2 from the power-on-reset circuit PO2 (FIG. 1) or a pulse end 2 from an AND gate AN18 indicating the completion of data reading of the interface circuit IF, as will be described in detail later. The Q output of the flip-flop FF1 is connected to one input of AND gate AN1 and D input of D flip-flop DF1. The other input of the AND gate AN1 is connected to oscillator OSC shown in FIG. 1 for receiving a train of clock pulses CP. The output CPL of the AND gate AN1 is connected to clock termi-

nal CL of the D flip-flop DF1 and also to a terminal JB2, and further to a terminal JL2, when the lens LE is mounted, for supplying clock pulses CPL to the lens LE. Therefore, the D flip-flop DF1 accepts D input and produces "HIGH" (waveform DF1 in FIG. 6) from its Q output by the negative edge of a clock pulse CPL which is produced immediately after the setting of the flip-flop FF1. The Q output of the D flip-flop DF1 is connected to reset terminal of each of counters CO1, CO2 and CO3 and also to enable terminal of each of decoders DE2 and DE3, thereby releasing the reset condition of the counters CO1, CO2 and CO3 and turning the decoders DE2 and DE3 in a condition ready to produce a signal, by the "HIGH" from the Q output of the D flip-flop DF1. In other words, by the "HIGH" from the Q output of the D flip-flop DF1, it is ready to carry out the data transmission between the interface circuit IF and the lens. The output of the OR gate OR1 is also connected to a reset terminal of each of flip-flop FF3 and D flip-flops DF1, whereby the flip-flop FF3 is turned to a reset condition by the positive edge of the pulse from the OR gate OR1 and the D flip-flop DF1 is turned to a reset condition by the negative edge of the pulse from the OR gate OR1.

Referring now to FIG. 5, when the micro-computer 1 produces "HIGH" from its output 02, the transistor BT2 (FIG. 1) is turned on for supplying power from the camera body to the lens through the terminals JB1 and JL1. Accordingly, a power-on-reset circuit P03 is so actuated as to produce a pulse from its output. The output of the power-on-reset circuit PO3 is connected to each of flip-flops FF7 and FF5 and D flip-flop DF5. Thus, by the positive edge of the pulse from the power-on-reset circuit PO3, the flip-flop FF7 and D flip-flop DF5 are turned to reset condition, and by the negative edge of the pulse from the power-on-reset circuit PO3, the flip-flop FF5 is turned to set condition. It is to be noted that the power-on-reset PO3, flip-flop FF3 and D flip-flop DF5 are provided as a means for turning a timing control means (described later) to a condition ready to operate in response to the power supply to the lens through the terminals JB1 and JL1. Thereafter, by the negative edge of a clock pulse CPL, which is transmitted from the AND gate AN1 (FIG. 4*a*) through the terminals JB2 and JL2, the D flip-flop DF5 takes in a "HIGH" from the Q output of the flip-flop FF5 and, thus, the Q output of the D flip-flop DF5 produces "HIGH". The Q output of the D flip-flop DF5 is connected to reset terminal of counters CO4 and CO5 and also to enable terminal of a decoder DE4, whereby the "HIGH" from the Q output of the D flip-flop DF5 releases the reset condition of the counters CO4 and CO5 and, at the same time, turns the decoder DE4 to a condition ready to produce an output.

It is to be noted that by making the pulse width of the "HIGH" pulse from the one-shot-circuit OS1 wider than that from the power-on-reset PO3, the flip-flop FF1 shown in FIG. 4*a* will be turned to a set condition after the flip-flop FF5 shown in FIG. 5 is turned to a set condition. By the set condition of the flip-flop FF1, the AND gate AN1 produces a train of clock pulses and, therefore, by the negative edge of the first clock pulse CPL from the AND gate AN1, the D flip-flops DF1 and DF5 positively produce "HIGH" from their Q output, thereby the circuits in the camera body and those in the lens are released from the reset condition simultaneously.

The counter CO1 and decoder DE2 shown in FIG. 4*a* and the counter CO4 and decoder DE4 shown in FIG. 5 are provided for producing timing signals which synchronize the circuit operations between the circuits in the camera and the lens.

It is to be noted that the counter CO4 and decoder DE4 are provided as a means for controlling the timing of operations of data selector MP2, focusing distance data producing device DS, focal length data producing device FS, shift registers SR3 and SR4 and ROM RO1, and their associated elements such as, AND gates AN30, AN32, AN33, AN34 and AN35, OR gate OR5, inverter IN10, flip-flops FF6 and FF7, and counter CO5.

The counter CO1 is a 4-bit counter capable of counting 16 pulses, and it counts clock pulses CP. The counter CO4 is also a 4-bit counter, and it counts clock pulses CPL. The decoder DE2 has 3 inputs for receiving 3-bit signal from the least significant digit outputs CB2, CB1 and CB0 of the counter CO1 and, by the combination of 3-bit signal, the decoder DE2 produces a "HIGH" from one of its outputs TB7 to TB0. Similarly, the decoder DE4 has 3 inputs for receiving a 3-bit signal from the least significant digit outputs CL2, CL1 and CL0 of the counter CO4 and, by the combination of the 3-bit signal, the decoder DE4 produces a "HIGH" from one of its outputs TL7 and TL0. The waveforms of pulse signals from the outputs TB7 to TB0, which are identical to the pulse signals from the outputs TL7 to TL0, respectively, are shown in FIGS. 6 and 7. Also, the relationship between the combination of the 3-bit signal from the counter CO1 (or CO4) and the output signal produced from the decoder DE2 (or DE4) is shown in Table 5 below.

TABLE 5

Counter CO1 (CO4)				Decoder DE2 (DE4)						
CB2 or CL2	CB1 or CL1	CB0 or CL0	TB0 or TL0	TB1 or TL1	TB2 or TL2	TB3 or TL3	TB4 or TL4	TB5 or TL5	TB6 or TL6	TB7 or TL7
0	0	0	1	0	0	0	0	0	0	0
0	0	1	0	1	0	0	0	0	0	0
0	1	0	0	0	1	0	0	0	0	0
0	1	1	0	0	0	0	1	0	0	0
1	0	1	0	0	0	0	0	1	0	0
1	1	1	0	0	0	0	0	0	0	1

The counter CO2 shown in FIG. 4*a* is a 4-bit counter for counting pulses produced from output CB0 of the counter CO1, and has four outputs CS3, CS2, CS1 and CS0, which are connected to inputs of the decoder DE3, as well as the output CB0 of the counter CO1. By the combination of a 5-bit signal (CB0, CS3, CS2, CS1 and CS0), the decoder DE3 produces a "HIGH" from one of its outputs S16 to S0. The "HIGH" signal produced from the decoder DE3 is used for determining a transmitting address data from the interface circuit IF to the lens and the steps for reading data from the lens. From this viewpoint, a period in which the terminal S1 is producing "HIGH" is referred to as a period S1, and, in general terms, a period in which a terminal Sn (n is an integer between 1 and 16) is producing "HIGH" is referred to as a period Sn.

The relationship between the combination of the 5-bit signal applied to the decoder DE3 and the output signals produced from the decoder DE3 is shown in Table 6 below.

TABLE 6

Input					Decoder DE3 Output															
CS3	CS2	CS1	CS0	CB3	S0	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16
0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
0	0	1	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
0	0	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
0	0	1	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
0	1	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

Referring to FIG. 4*a*, one input of the AND gate AN7 is connected to the terminal TB6 of the decoder DE2, and the other input thereof is connected to the terminal CB3 of the counter CO1 through an inverter IN0. The output of the AND gate AN7 is connected to a clock terminal CL of the counter CO3. The counter CO3 is a 3-bit counter for providing data necessary for defining address data for the ROM RO1 provided in the lens, and has 3 outputs which are connected through a data selector MP0 to inputs Ba3, Ba2 and Ba1 of a shift register SR1. The counter CO3 counts pulses from the output TB6 of the decoder DE2 while the output CB3 of the counter CO1 is producing "LOW". Thus, when the output TB6 of the decoder DE2 produces "HIGH" during the period S0, the counter CO3 produces a 3-bit signal "001". Likewise, when the output TB6 produces "HIGH" during the period S2, the counter CO3 produces a 3-bit signal "010"; when the output TB6 produces "HIGH" during the period S4, the counter CO3 produces a 3-bit signal "011"; when the output TB6 produces "HIGH" during the period S6, the counter CO3 produces a 3-bit signal "100"; when the output TB6 produces "HIGH" during the period S8, the counter CO3 produces a 3-bit signal "101"; and when the output TB6 produces "HIGH" during the period S10, the counter CO3 produces a 3-bit signal "110".

The 3 outputs of the counter CO3 are also connected to 3 inputs of an AND gate AN20 with the output of the counter CO3 carrying the least significant bit being connected to an inverting input of the AND gate AN20. The output of the AND gate AN20 is connected to D input of a D flip-flop DF2. The D flip-flop DF2 has a clock terminal CL connected to the output TB0 of the decoder DE2, and a Q terminal connected to a select terminal SL of the data selector MP0. Thus, in response to the output "110" from the counter CO3 as produced when the output TB6 produces "HIGH" during the period S10, the AND gate AN20 produces a "HIGH". And then, when the output TB0 produces "HIGH" during the period S11, the D flip-flop DF2 produces "HIGH" from its Q terminal. Since the data selector MP0 is so designed that it produces an 8-bit signal as applied to its inputs in a group w0 when the signal applied to the select terminal SL is low, and that it produces an 8-bit signal as applied to its inputs in a group w1 when the signal applied to the select terminal SL is high, the data selector MP0 now produces an 8-bit signal as applied to its inputs in the group w1. The inputs in the group w1 have the lowest bit and the four upper bits connected to ground, as shown, and the remaining 3-bits connected to the counter CO3. While on the other hand, the 8 inputs in the group w2 are so connected to the ground and the power source +E as to produce a fixed signal "00010010".

Therefore, from the data selector MP0, a signal of the group w1 determined by the output of the counter CO3 is produced up to the period S10, and from the period S11 on, the signal of the group w0, i.e., the address data indicating the location where the light measurement error data Avc for the camera body is stored is produced.

The shift register SR1 shown in FIG. 4*a* is an 8-bit shift register having 8 inputs Ba0 to Ba7. While the switching terminal SP of the shift register SR1 is receiving "HIGH", and when the positive edge of a clock pulse CP is applied to the clock terminal CL, the shift register SR1 simultaneously and parallelly stores an 8-bit signal applied to its 8 inputs Ba7 to Ba0. Contrary, while the switching terminal SP of the shift register SR1 is receiving "LOW", the positive edges of the clock pulses CP sequentially send out the stored 8-bit signal bit-by-bit from the most significant bit serially through the output terminal.

One input of an AND gate AN2 is connected to the output TB6, and one input of an AND gate AN3 is connected to the output TB7. The other inputs of the AND gates AN2 and AN3 are connected to the pulse generator for receiving clock pulses CP. The output of the AND gate AN2 is connected to a set terminal of a flip-flop FF2, and the output of the AND gate AN3 is connected to a reset terminal of the flip-flop FF2. A Q output of the flip-flop FF2 is connected to the switching terminal SP of the shift register SR1. Therefore, the flip-flop FF2 is turned to a set condition by the negative edge of a clock pulse CP produced while the terminal TB6 is "HIGH", and is turned to a reset condition by the negative edge of a clock pulse CP produced while the terminal TB7 is "HIGH" (See waveforms FF2 shown in FIGS. 6 and 7.). Accordingly, the shift register SR1 stores the 8-bit signal by the positive edge of the "HIGH" from the terminal TB7, and sequentially sends out the stored 8-bit signal by the sequential "HIGH" signals from the terminals TB0 and TB6. The counter CO3, D flip-flop DF2, data selector MP0, flip-flop FF2, shift register SR1, AND gates AN2, AN3, AN7 and

AN20, and inverter IN0 define a means for producing address data for the camera accessory.

Referring to FIG. 4*a*, a set terminal of a flip-flop FF3 is connected to an output of AND gate AN16 (FIG. 4*b*) for receiving a signal end1. The AND gate AN16 has one input connected to the terminal TB6 of the decoder DE2 and the other input connected to the terminal S14 of the decoder DE3. Therefore, during a period S14 and when the terminal TB6 produces a pulse, the signal end1 is produced from the AND gate AN16 and is applied to the set terminal of the flip-flop FF3. The signal end1 is produced when the reading of fixed data from the lens is completed. Therefore, after the signal end1, it is not necessary to produce any address data from the interface circuit IF. Thus, when the flip-flop FF3 is turned to a set condition by the signal end1, it produces "LOW" from its $\overline{Q}$ terminal, whereby an AND gate AN4, having its one input connected to the $\overline{Q}$ terminal, produces "LOW" to turn a switching circuit SC1 off. The other input of the AND gate AN4 is connected to the output CB3 of the counter CO1. Thus, the AND gate AN4 produces "HIGH" when the terminal CB3 of the counter CO1 produces "HIGH" while the $\overline{Q}$ terminal of the flip-flop FF3 is producing "HIGH", i.e., during a period from the generation of "HIGH" from the OR gate OR1 until the generation of the signal end1. When the AND gate AN4 produces "HIGH", the switching circuit SC1 is turned on to transmit address data produced from the shift register SR1 to the lens through the terminals JB3 and JL3.

An OR gate OR3 has two inputs: one input is connected to the Q terminal of the flip-flop FF3; and the other is connected to the terminal CB3 of the counter CO1 through an inverter IN6. The output of the OR gate OR3 is connected to a control terminal of a switching circuit SC2 and also to one input of an AND gate AN5. The other input of the AND gate AN5 is connected to the terminal TB5 of the decoder DE2, and the output of the AND gate AN5 is connected to a latch terminal L of a latch circuit LA. The switching circuit SC2 is connected between the terminal JB3 and an IN terminal of a shift register SR2, provided as a means for reading accessory data. The shift register SR2 sequentially stores the signal applied at its IN terminal in synchronized relation with the negative edge of the clock pulse CP, and produces the stored signal from its outputs Bb0 and Bb4. Thus, the OR gate OR3 produces "HIGH" when the output CB3 of the counter CO1 produces "LOW" and when the flip-flop FF3 is in reset condition producing "HIGH" from its Q output (a period from the start of data reading in the lens until the end of fixed data reading of all the data in the lens). And, when the OR gate OR3 is producing "HIGH", the switching circuit SC2 is turned on to transmit signals from the terminal JB3 to the shift register SR2.

As apparent from the above, the switching circuits SC1 and SC2 are turned on alternately, thus preventing the simultaneous turn of the switching circuits SC1 and SC2. In this manner, the address data produced from the shift register SR1 is transmitted through the switching circuit SC1 and terminals JB3 and JL3 to the lens while the switching circuit SC1 is turned on, and the lens data from the lens is transmitted through the terminals JL3 and JB3 and the switching circuit SC2 to the shift register SR2 while the switching circuit SC2 is turned on, thereby preventing any interference between the address data and lens data. The outputs Bb4 and Bb0 of the shift register SR2 are connected to a latch circuit LA, so that the latch circuit LA latches the data at the outputs Bb4 to Bb0 in response to the positive edge of a pulse from the terminal TB5 while the OR gate OR3 is producing "HIGH". The switching circuits SC1 and SC2, flip-flop FF3, AND gate AN4, OR gate OR3 and inverter IN6 define a first switching means provided in the camera body for switching the direction of signal propagation between the camera body and the lens through the terminals JB3 and JL3.

Referring to FIG. 4*b*, the output of the latch LA is connected to each of registers REG0 to REG8. The registers REG0 to REG8, each having a latch terminal L, are connected to AND gates AN10 to AN18, at respective latch terminals L. One of the inputs of AND gates AN10 to AN18 are connected to each other and further to the terminal TB6 of the decoder DE2, and other of the inputs thereof are connected to terminals S2, S4, S6, S8, S10, S12, S14, S15 and S16 of the decoder DE3, respectively. The output of the AND gate AN18 produces an end2 signal indicating that reading and storing of all data from the lens are completed. The output of the AND gate AN18 is connected not only to the latch terminal L of the register REG8, but also to a set terminal S of a flip-flop FF4 (FIG. 4*a*). The Q terminal of the flip-flop FF4 is connected to the input i3 of the micro-computer 1 (FIG. 1), and the reset terminal R thereof is connected to an OR gate OR2. The OR gate OR2 has two inputs: one is connected to the output PR2 of the power-on-reset PO2 (FIG. 1); and the other is connected to output a8 of a decoder DE1, which will be described below. Therefore, the flip-flop FF4 is turned to reset condition when the power-on-reset circuit PO2 produces a pulse from its output PR2 in response to the turn on of the light measurement switch MS, and is turned to set condition when the AND gate AN18 produces the signal end2 upon completion of data reading and storing from the lens. The output a8 of the decoder DE1, as will be described below, produces "HIGH" at the end of data transmission from the interface circuit IF to the micro-computer 1 and, therefore, the flip-flop FF4 is turned to reset the condition at the end of data transmission from the interface circuit IF to the micro-computer 1.

Referring to FIG. 4*a*, the decoder DE1 receives data from the output OP3 of the micro-computer 1 and produces a "HIGH" from one of its outputs a0 to a8 depending on the received data from the micro-computer 1. A relationship between the input data and output data of the decoder DE1 is shown below in Table 7.

TABLE 7

Decoder DE1												
Inputs (OP3 output)				Outputs								
				a0	a1	a2	a3	a4	a5	a6	a7	a8
0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	1	0	0	0	0	0	0	0	0	0
0	0	1	0	0	0	0	0	0	0	0	0	0
0	0	1	1	0	0	0	0	0	0	0	0	0
0	1	0	0	0	0	0	0	0	0	0	0	0
0	1	0	1	1	0	0	0	0	0	0	0	0
0	1	1	0	0	1	0	0	0	0	0	0	0
0	1	1	1	0	0	1	0	0	0	0	0	0
1	0	0	0	0	0	0	1	0	0	0	0	0
1	0	0	1	0	0	0	0	1	0	0	0	0
1	0	1	0	0	0	0	0	0	1	0	0	0
1	0	1	1	0	0	0	0	0	0	1	0	0
1	1	0	0	0	0	0	0	0	0	0	1	0
1	1	0	1	0	0	0	0	0	0	0	0	1

The outputs a0 to a8 of the decoder DE1 are connected to chip select terminals CS of the registers REG0 to REG8, respectively. When the chip select terminal CS of a particular register receives "HIGH" from the decoder DE1, said particular register provides data stored therein to the input IP1 of the data selector MP1 and further to the micro-computer 1.

Referring to FIG. 5, an AND gate AN30 has two. inputs: one is connected to the output CL3 of the counter CO4; and the other is connected to output $\overline{FD}$ of $\overline{Q}$ terminal of the flip-flop FF7. The output of the AND gate AN30 is connected to the switching circuit SC3, which is connected between the terminal JL3 and input of a shift register SR3. Furthermore, the clock input CL of the shift register SR3 is connected to the terminal JL2 for receiving a train of clock pulses CPL. Thus, while the switching circuit SC3 is on, the shift register SR3 sequentially stores the address data a from the camera body through the terminals JB3 and JL3 in response to the negative edge of the clock pulses, thereby producing an address data from its terminals La0 to La6. An AND gate AN35 is provided having its one input connected to the output La3 of the shift register SR3, and the other input connected to the terminal TL7 of the decoder DE4. When the output La3 produces "HIGH" while the terminal TL7 is producing "HIGH", the AND gate AN35 produces "HIGH". That is, the AND gate AN35 produces "HIGH" when the last address data, which is either "00001000", "00001001" or "00001010" for designating the fixed data of light measurement error data Avc, is sent from the camera body to the lens. The output of the AND gate AN35 is connected to a set terminal of a flip-flop FF7. Therefore, the flip-flop FF7 is turned to a set condition when the output La3 produces "HIGH" (i.e., when the last address for the fixed data is applied to the shift register SR3) while the terminal TL7 is producing "HIGH". When the flip-flop FF7 is turned to the set condition, its output FD of Q terminal produces "HIGH" and its output $\overline{FD}$ of $\overline{Q}$ terminal produces "LOW". An AND gate AN32 has two inputs: one is connected to the output FD of Q terminal of the flip-flop FF7; and the other is connected to the terminal TL6 of the decoder DE4. The output of the AND gate AN32 is connected to a clock terminal CL of a counter CO5. Therefore, the outputs Ca1 and Ca0 of the counter CO5 produce a 2-bit signal "01" when the flip-flop FF7 produces "HIGH" from its output FD of the Q terminal and when the output TL6 produces "HIGH" during a period S12 in the next sequence. Furthermore, the outputs Ca1 and Ca0 of the counter CO5 produce a 2-bit signal "10" when the output TL6 produces "HIGH" during a period S13 in the next sequence.

The outputs Ca1 and Ca0 of the counter CO5 are connected to the data selector MP2 and, more particularly, to the data input portions d2 and d3 and also to selection terminal SL. The data input portion d1 of the data selector MP2 is connected to the outputs La0 to La6 of the shift register SR3. The data input portion d2 has its most significant bit terminal grounded, the second and third bit terminals from the most significant bit terminal are connected to the outputs Ca1 and Ca0 of the counter CO5, and the remaining 4 bit terminals are connected to the outputs of the focusing distance data producing device DS. The data input portion d3 has its most significant bit terminal grounded, the second and third bit terminals from the most significant bit terminal are connected to the outputs Ca1 and Ca0 of the counter CO5, and the remaining 4 bit terminals are connected to the outputs of the focal length data producing device FS.

When the selection terminal SL receives "00", the data selector MP2 produces data applied to its input portion d1. Similarly, when the selection terminal SL receives "01", the data selector MP2 produces data applied to its input portion d2, and when the selection terminal SL receives "11", the data selector MP2 produces data applied to its input portion d3. Therefore, until the terminal TL6 produces "HIGH" during a period of S14, the data selector MP2 produces address data which has been transmitted from the camera body through the shift register SR3. And from that time until the terminal TL6 produces a "HIGH" during a period S15, the data selector MP2 produces address data concerning the focusing distance applied to the input portion d2, and thereafter, the data selector MP2 produces address data concerning the focal length applied to the input portion d3. It is to be noted that the shift register SR3, data producing devices DS and FS and data selector MP2 are provided as a means for designating address in the ROM (RO1).

The 7 outputs of the data selector MP2 are connected to the lower 7 inputs r6 to r0 of the ROM RO1. The remaining input r7 of the ROM RO1 is connected to ground. As shown in Table 2, various data is stored in the ROM RO1 at various locations which can be specified by the addresses. Therefore, by the address data applied to the inputs r0 to r7 of the ROM RO1, data stored in a particular location is read out and produced as a 4-bit signal from the ROM RO1. The 4 outputs of the ROM RO1, serving as an accessory data producing means, are connected to 4 upper-bit inputs Lb4 to Lb7 of a shift register SR4. The remaining 3 inputs Lb2 to Lb0 of the shift register SR4 are grounded. The shift register SR4, AND gates AN33 and AN34, and flip-flop FF6 are arranged in the same manner as the above described shift register SR1, AND gates AN2 and AN3, and flip-flop FF2 shown in FIG. 4*a*. Thus, by the positive edge of a pulse from the terminal TL7, the shift register SR4 simultaneously stores the data applied to its inputs Lb7 to Lb0 and, thereafter, by the positive edge of clock pulses applied to the clock terminal CL, the stored data is sequentially sent out from its output bit-by-bit.

An OR gate OR5 has two inputs: one is connected to an output CL3 of a counter CO4 through an inverter IN10; and the other is connected to the output FD of the Q terminal of the flip-flop FF7. The output of the OR gate OR5 is connected to a control input of a switching circuit SC4, which is connected between the output of the shift register SR4 and the terminal JL3. By the arrangement of the OR gate OR5, switching circuit SC4, and by the arrangement of AND gate AN30 and switching circuit SC3, the switching circuits SC3 and SC4 turn on alternately. More specifically, the switching circuit SC3 turns on when the output FD of Q terminal of flip-flop FF7 is "LOW" (i.e., while the fixed data of the lens is transmitted) and when the output CL3 of the counter CO4 produces "HIGH", thereby transmitting address data from the camera body to the shift register SR3 through the terminals JB3 and JL3. And, the switching circuit SC4 turns on when the output CL3 of the counter CO4 produces a "LOW", thereby transmitting the data read out from the ROM RO1 to the camera body through the same terminals JL3 and

JB3. In this manner, address data and fixed data from the ROM RO1 are transmitted alternately through the same and single transmission line between the terminals JB3 and JL3. Thereafter, when the output FD of Q terminal of the flip-flop FF7 produces "HIGH", only the switching circuit SC4 is maintained turned on, thereby transmitting variable data, such as focusing distance data and focal length data, to the camera body through the same terminals JL3 and JB3. It is to be noted that the switching circuits SC3 and SC4, flip-flop FF7, AND gate AN30, OR gate OR5 and inverter IN10 define a second switching means provided in the lens for switching the direction of the signal propagation between the camera body and the lens.

Next, the description is directed to the operation of circuits of FIGS. 4*a*, 4*b* and 5 with reference to the time chart shown in FIGS. 6 and 7. When the output 02 of the micro-computer 1 produces "HIGH" (FIG. 6, waveform 02), the one-shot circuit OS1 produces a pulse (FIG. 6, waveform OS1) for turning the flip-flop FF1 to a set condition. Then, by the positive edge of a next clock pulse, the D flip-flop DF1 produces "HIGH" from its Q output, thereby releasing the reset condition of the counters CO1, CO2 and CO3 and, at the same time, setting the decoders DE2 and DE3 in a condition ready to produce an output. Furthermore, when the flip-flop FF1 is turned to the set condition, the AND gate AN1 produces clock pulses CPL (FIG. 6, waveform CPL), which is applied to the circuit of FIG. 5 provided in the lens through the terminals JB2 and JL2.

In the meantime, by the "HIGH" from the output O2 of the micro-computer 1, the power supply transistor BT2 conducts to supply electric power to the circuit of FIG. 5 through the terminals JB1 and JL1. When the terminal JL1 receives power from the camera body, the power-on-reset circuit PO3 produces a pulse; and by the positive edge of this pulse, the flip-flop FF7 and D flip-flop DF5 are turned to the reset condition; and also by the negative edge of this pulse, the flip-flop FF5 is turned to the set condition. Then, by the positive edge of the first clock pulse CPL, the Q output of the D flip-flop DF5 produces a "HIGH", thereby releasing the reset condition of the counters CO4 and CO5 and, at the same time, putting the decoder DE4 in a condition ready for producing an output. This completes the initial preparation for the data transfer operation.

Next, referring particularly to FIG. 4*a*, when the terminal TB6 produces "HIGH" during a period S0, the counter CO3 produces a data "001" which is applied to the shift register SR1 through a data selector MP0. Then when the terminal TB7 produces "HIGH" immediately thereafter, the shift register SR1 stores the data "001", thus, the shift register SR1 is now holding an 8-bit data "00000010". Then, in the next period S1, the shift register SR1 sequentially sends out the data "00000010" bit-by-bit in response to the positive edges of the pulses from the terminals TB0 to TB7. Thus sent out data is transmitted serially through the switching circuit SC1, terminals JB3 and JL3 to the lens. During this moment, since the switching circuit SC3 in FIG. 5 is on, the data is sequentially stored in the shift register SR3 in response to the negative edges of the clock pulses CPL (FIG. 6, waveforms La0, La1 and La2). It is to be noted that the shift register SR1 sends out 8 bits of signal, but the shift register SR3 accommodates only 7 bits. Therefore, when the shift register SR3 stores the upper 7 bits "0000001" from the shift register SR1, the stored data "0000001" is transmitted through the data selector MP2 to the inputs r6 to r0 of the ROM RO1 as a part of address data (FIG. 6, waveforms SB, La0, La1 and La2), and, thereupon, the ROM RO1 receives 8-bit address data "00000001" to its inputs r7 to r0, thereby producing a data stored in the designated address "00000001". More specifically, by the negative edge of a clock pulse produced when the terminal TL6 is "HIGH" during the period S1, the shift register SR3 produces from its outputs La6 to La0 the data "0000001" (FIG. 6, waveforms La0, La1 and La2), thereby specifying a location in the ROM RO1 with an address "00000001". In the specified location in the ROM RO1, a data for check "11100", as shown in Table 2, is stored, and is produced from the ROM RO1. The data "11100" produced from the ROM RO1 is stored in the shift register SR4 in response to the positive edge of a pulse from the terminal TL7.

Then, in the next period S2, since the output CL3 of the counter CO4 produces "LOW" while the terminals TL0 to TL7 produce pulses, the data sequentially produced from the outputs Lb7 to Lb0 of the shift register SR4 in response to the positive edges of the pulses from the terminals TL0 to TL7 is serially transmitted through the switching circuit SC4, terminals JL3 and JB3 to the camera body (FIG. 6, waveform SB).

In FIG. 4*a*, during the period S2 in which the data is transmitted from the lens to the camera body, the output CB3 of the counter CO1 is maintained "LOW", thereby turning on the switching circuit SC2. Thus, the data for check "11100" transmitted to the camera body through the terminals JL3 and JB3 is applied through the switching circuit SC2 and stored in the shift register SR2 in response to the negative edges of the clock pulses CP (FIG. 6, waveform Bb0 to Bb4). Then, by the negative edge of the clock pulse CP produced from the terminal TB4, the shift register SR2 produces "11100" (FIG. 6, waveforms Bb0 to Bb4). And by the positive edge of the pulse produced from the AND gate AN5 in response to the pulse from the terminal TB5 (FIG. 6, waveform AN5), that data from the shift register SR2 is latched in the latch circuit LA. Then, by the pulse from the terminal TB6, the AND gate AN10 produces a pulse. By the positive edge of this pulse, the register REG0 stores the data from the latch circuit LA (FIG. 6, waveform AN10).

During the period S2, the AND gate AN7 produces a pulse in response to the pulse from the terminal TB6, thereby producing data "010" from the counter CO3. Then, by the pulse produced from the terminal TB7, the shift register SR1 stores the data "010" from the counter CO3. Thus, the shift register SR1 is now holding a data "0000001". Then, in the next period S3, the output CB3 of the counter CO1 produces "HIGH", thereby turning the switching circuit SC1 on and, furthermore, the output CL3 of the counter CO4, shown in FIG. 5, produces "HIGH", thereby turning the switching circuit SC3 on. As a consequence, the upper 7-bit data "0000010" from the shift register SR1 is transferred to the shift register SR3 (FIG. 5), in a similar manner described above. The data "0000010" is further transferred through the data selector MP2 to the ROM RO1 at its terminals r6 to r0. Thus, the ROM RO1 receives an address data "00000010" to its inputs r7 to r0, thereby producing a data dEvo representing the exposure difference. According to the example given in Table 2, the exposure difference dEvo is shown as dEvo=2/8 (the address for this data in ROM RO1 is

"00010"), but in the time chart given in FIG. 6, the exposure difference dEvo is shown as dEvo=4/8 (the address for this data in ROM RO1 is "00100").

During a period S4, both the output CB3 of the counter CO1 and the output CL3 of the counter CO4 produce "LOW". Therefore, the switching circuits SC2 and SC4 turn on so as to transfer the data "00100" stored in the shift register SR4 to the shift register SR2 in a similar manner described above. And, thereafter, by a pulse produced from the terminal TB5, the data "00100" in the shift register SR2 is latched in the latch circuit LA. And then, by a pulse produced from the terminal TB6, the AND gate AN11 produces a pulse (FIG. 6, waveform AN11), thereby the data "00100" representing the exposure difference dEvo is stored in the register REG1.

In a similar manner, during a period S5, the address data "00000110" (which will be revised to "00000011" in later stage) is transmitted to the lens and, during a period S6, the Avm data representing the minimum aperture size, such as "11010" shown in Table 2, is transmitted from the ROM RO1 to the camera body and, in response to a pulse from the terminal TB6, the Avm data "11010" is stored in the register REG2.

During a period S7, the address data "00001000" (which will be revised to "00000100" in a later stage) is transmitted to the lens and, during a period S8, the data Avo representing the fully-opened aperture size, such as "01010" shown in Table 2, is transmitted from the ROM RO1 to the camera body and, in response to a pulse from the terminal TB6, the data Avo "00001" is stored in the register REG3.

During a period S9, the address data "00001010" (which will be revised to "00000101" in a later stage) is transmitted to the lens and, during a period S10, the fw data representing the minimum focal length, such as "01011" shown in Table 2, is transmitted from the ROM RO1 to the camera body and, in response to a pulse from the terminal TB6, the fw data "01011" is stored in the register REG4.

During a period S11, the address data "00001100" (which will be revised to "00000110" in a later stage) is transmitted to the lens and, during a period S12, the ft data representing the maximum focal length, such as "10001" shown in Table 2, is transmitted from the ROM RO1 to the camera body and, in response to a pulse from the terminal TB6, the ft data "10001" is stored in the register REG4.

During the period S10 and in response to a pulse from the terminal TB6, the counter CO3 produce "110" causing AND gate AN20 to produce a "HIGH". Then during the period S11 and in response to a pulse from the terminal TB0, the D flip-flop DF2 produces a "HIGH" from its Q terminal. Accordingly, the data selector MP0 produces a fixed data "00010010" as obtained from its inputs w0. This fixed data "00010010" indicates that the type of the camera body is the second type among the above-mentioned various types. And, during the period S11 and in response to a pulse from the terminal TB7 the fixed data "00010010" is transferred to and stored in the shift register SR1. Then, during a period S12, the stored data "00010010" are sequentially sent out from the shift register SR1 through its output OUT. Since, during the period S12, the switching circuit SC1 is de-activated, the data "00010010" will not be sent to the lens circuit (FIG. 5). During the period S12 and in response to a pulse from the terminal TB7 the fixed data "00010010" (which will be revised to "00001001" in a stage) is again transferred from the data selector MP0 to the shift register SR1. And, during a period S13, the data "00010010" stored in the shift register SR1 is transferred through the switching circuit SC1, terminals JB3 and JL3 to the lens circuit of FIG. 5, particularly to the shift register SR3. Then, during the period S13 and in response to a pulse from the terminal TL7, the data "00010" (Avc=−6/8) indicating the light measuring difference Avc as stored in ROM RO1 at the address "00001001", is transferred and stored in the shift register SR4, and this data "00010" will be sent to the camera body. FIGS. 4*a* and 4*b* show an embodiment of a camera body of the second type, but if it were the first type, a data "00010000" will be applied to the inputs w0 of the data selector MP0. This data "00010000" will be revised as an address data "00001000" in a later stage for designating a location in the ROM RO1, from which data of light measuring error of the first type camera will be produced. In a similar manner, if the camera body is the third type, a data "00010100" will be applied to the inputs w0 of the data selector MP0. Thus, the ROM RO1 is designated with an address "00001010" for producing data of light measurement error of the third type camera body. The above procedure completes the reading of fixed data from the lens.

During the period S13, by the negative edge of a clock pulse produced from the terminal TB6, the shift register SR3 produces "HIGH" from its output La3 (FIG. 7 waveforms La3). Then, by the positive edge of a pulse produced from the AND gate AN35 in response to the pulse produced from the terminal TL7, the flip-flop FF7 is turned to a set condition, thereby producing "HIGH" from the output FD of the Q terminal and "LOW" from the output $\overline{FD}$ of $\overline{Q}$ terminal. Thereupon, the AND gate AN30 produces "LOW" and the OR gate OR5 produces "HIGH" regardless of the output from the terminal CL3 of the counter CO4 and, therefore, the switch circuit SC3 turns off and the switch circuit SC4 turns on, ready for sending various variant data from the lens to the camera body in a manner described below.

During a period S14, the data transfer of the light measuring error data is carried out, and in response to a pulse produced from the terminal TB6 and applied through the AND gate AN16, the register REG6 stores the above-mentioned data and, at the same time, in response to pulse from the output end1 of the AND gate AN16, the flip-flop FF3 is turned to the set condition (FIG. 7 waveforms AN16, end1 and FF3). After that, regardless of signal produced from the output CB3 of the counter CO1, the AND gate AN4 produces a "LOW" and the OR gate OR3 produces a "HIGH". Thus, the switching circuit SC1 is de-activated and the switching circuit SC2 is activated. Thereafter, the data from the lens is transferred to the camera body.

During a period S14 and when the terminal TL6 produces a "HIGH", the counter CO5 counts a pulse from the AND gate AN32 so as to produce "01" (FIG. 7, waveforms Ca0 and Ca1) from its output, thereby actuating the data selector MP2 to select data from the data input portion d2. Thus, the ROM RO1 receives data from the input portion d2. It is to be noted that, in this case, the lower 4-bit inputs r0, r1, r2 and r3 of the ROM RO1 receive data from the focusing distance data producing device DS, the intermediate 2-bit inputs r4 and r5 thereof receives data "01" from the outputs Ca0 and Ca1 of the counter CO5, and the upper 2-bit inputs

r6 and r7 thereof receives data "00". Therefore, if the data from the focusing distance data producing device DS is "0000", the final address data applied to the ROM RO1 is "00010000". In this case, the ROM RO1 produces a focusing distance data Dv of "01010" indicating that the focusing distance is 1.4 m, as understood from Table 2. If the data from the device DS is "0001", the final address data applied to the ROM RO1 is "00010001". In this case, the ROM RO1 produces a Dv data "01011" indicating that the focusing distance is 1.7 m. Furthermore, if the data from the device DS is "1110", the final address data applied to the ROM RO1 is "00011110". In this case, the ROM RO1 produces a Dv data "11000" indicating that the focusing distance is 16 m, and, if the data from the device DS is "1111", the final address data applied to the ROM RO1 is "00011111". In this case, the ROM RO1 produces a Dv data "11111" indicating that the focusing distance is infinite.

The focusing distance data Dv produced from the ROM RO1 is stored in the shift register SR4 in response to a pulse produced from the terminal TL7, and by the positive edges of the clock pulses CP produced from the terminals TB0 to TB4 during a period S15 (FIG. 7, waveforms Bb0 to Bb4), the data Dv is stored in the shift register SR2 (FIG. 4*a*). And, thereafter, by a pulse from the terminal TB5, the data Dv is latched in the latch LA, and then, by a pulse from the terminal TB6, the AND gate AN16 produces a "HIGH" (FIG. 7, waveform AN16), thereby storing the data Dv in the register REG6.

In the step S15 and when the terminal TL6 produces "HIGH", the AND gate AN32 produces "HIGH", thereby producing "10" (FIG. 7, waveform Ca0 and Ca1) from the counter CO5. By the signal "10" from the outputs Ca0 and Ca1 of the counter CO5, the data selector MP2 selects data input portion d3. Thus, the ROM RO1 receives data from the input portion d3. It is to be noted that, in this case, the lower 4-bit inputs r0, r1, r2 and r3 of the ROM RO1 receives data from the focal length data producing device FS, the intermediate 2-bit inputs r4 and r5 thereof receives data "10" from the outputs Ca0 and Ca1 of the counter CO5, and the upper 2-bit inputs r6 and r7 thereof receives data "00". Therefore, if the data from the focal length data producing device FS is "0000", the final address data applied to the ROM RO1 is "00100000". In this case, the ROM RO1 produces a focal length data of "01011" indicating that the focal length is 50 mm, as understood from Table 2. If the data from the device FS is "1010", the final address data applied to the ROM RO1 is "00101010". In this case, the ROM RO1 produces a data "01111" indicating that the focal length is 105 mm. Furthermore, if the data from the device FS is "1111", the final address data applied to the ROM RO1 is "00101111". In this case, the ROM RO1 produces data "10001" indicating that the focal length is 135 mm.

The focal length data produced from the ROM RO1 is stored in the shift register SR4 in response to a pulse produced from the terminal TL7 during the period S15 in a similar manner as described above, and by the positive edges of the clock pulses CP produced from the terminals TB0 to TB4 during a period S16 (FIG. 7, waveforms Bb0 to Bb4), the focal length data is stored in the shift register SR2 (FIG. 4*a*). And, thereafter, by a pulse from the terminal TB5, the focal length data is latched in the latch LA, and then, by a pulse from the terminal TB6, the AND gate AN18 produces a "HIGH" (FIG. 10 waveform AN18), thereby storing the focal length data in the register REG8. At this moment, the "HIGH" produced from the AND gate AN18 serves as a signal end2 which is applied to the set terminal of the flip-flop FF4, thereby producing "HIGH" from the Q output of the flip-flop FF4 (FIG. 7, waveforms AN18, end2 and FF4). The "HIGH" from the Q output of the flip-flop FF4 is applied to the input i3 of the micro-computer 1. Thus, the micro-computer 1 is informed that reading of all the data from the lens has been completed and that the read out data is temporarily stored in the interface circuit IF and, thereupon, it produces "LOW" from its output 02 for stopping the power supply to the lens.

Next, the micro-computer 1 starts to read data from the interface circuit IF through the data bus DB. First, when the data from the output OP3 of the micro-computer 1 is "5H", the output a0 of the decoder DE1 produces a "HIGH" and, therefore, the check data stored in the register REG0 is transmitted through the data selector MP1 and data bus DB to the micro-computer 1. Then, when the data from the output OP3 of the micro-computer 1. Then, when the data from the output OP3 of the micro-computer 1 is "6H", the output a1 of the decoder DE1 produces "HIGH" and, therefore, the dEvo data stored in the register REG1 is transmitted to the micro-computer 1. Likewise, the various data stored in the other registers REG3 to REG8 is sequentially transmitted to the micro-computer 1. When all the data from the interface circuit IF has been transmitted to the micro-computer 1, the micro-computer 1 carries out the procedure described above in connection with FIGS. 2*a*, 2*b* and 2*c*.

It is to be noted that the shift register SR1 shown in FIG. 4*a* and provided for outputing address data, and the shift register SR4 shown in FIG. 5 and provided for outputing accessory data, operate such that, as shown in FIGS. 6 and 7, by the positive edge of the pulse produced from the terminal TB7 (TL7), the data is parallelly stored in at once and, thereafter, by the positive edges of the pulses produced from the terminals TB0 to TB7 (TL0 to TL7), the stored data is sent out bit-by-bit serially from its output OUT from the most significant bit. This type of shift-register can be formed as follows. First, 8 flip-flops are provided for parallelly receiving 8 bits of data at a time at respective present terminals. A flip-flop which receives the least significant bit signal has its output connected to the input of a flip-flop which receives the second significant bit signal. The other flip-flops are connected in the same manner, and the flip-flop which receives the most significant bit signal is connected to an input of another (ninth) flip-flop. Thus, by a clock pulse applied to all the flip-flops, the signal present in the Nth flip-flop (N is an integer between 1 and 8) is sent to the (N+1)th flip-flop. Therefore, by a train of clock pulses applied to all the flip-flops, the 8-bit signal is sequentially produced out bit-by-bit from the output of the 9th flip-flop with a delay of one clock pulse.

The camera system according to the preferred embodiment of the invention as described above can be modified as follows. First of all, most of the control operations for controlling the aperture size and the shutter speed can be carried out by the micro-computer, and from this view point, many external parts can be eliminated. Secondly, it is possible to send the data already stored in the interface circuit IF parallel from the interface circuit IF to the micro-computer 1 during

the reading and serial transmission of other data to the interface circuit IF. In this manner, the time for the data transmission from the lens to the micro-computer 1 can be shortened.

Furthermore, according to the flow chart shown in FIGS. 2a, 2b and 2c, the micro-computer 1 operates constantly and, therefore, it consumes electric power rather quickly. To prevent this, it is possible to reorganize the program so as to cut off the power when it is not necessary to run the micro-computer. Since such a reorganization of the program is not difficult to those skilled in the art, a further description therefor is omitted.

According to the first embodiment described above, the fixed data storing means, i.e., the ROM RO1, provided in each interchangeable lens is stored with 3 different address data for the light measurement error data corresponding respectively to 3 types of optical systems of the camera body. When one of the three different address data corresponding to the type of camera body on which the interchangeable lens is mounted is designated from said camera body, only a particular light measurement error data necessary for said camera body is read out and taken in to the camera body. It is to be noted that, according to the present invention, the manner in which the data is read out is not limited to the one described above, but can be done in other ways. For example, an address counter corresponding to the counter CO3 described as provided in the camera body can be provided in the interchangeable lens such that the address counter sequentially designates 3 different addresses, thereby producing 3 different light measurement error data. And in the camera body, only a necessary light measurement error data is selected. To this end, the camera body must be provided with a selecting means, which can be accomplished, for example, by providing a particularly designed input-device which permits the transmission of light measurement error data in a certain timed relation for a camera having a certain type of optical system. A second embodiment employing such an arrangement is described later in connection with FIGS. 8 to 12. As will be apparent from the description below, it is not necessary for the second embodiment to designate the address of ROM of the interchangeable lens from the camera body.

Furthermore, according to the first embodiment, the data producing device of the interchangeable lens is arranged such that the light measurement error data Avc is transferred as it is to the camera body. According to an alternative arrangement, the data Avc can be transferred to the camera body in a combined form with other data. For example, the ROM in the interchangeable lens may carry a combined data of Avo+Avc for each of 3 different camera bodies, so that when the interchangeable lens is mounted on one type of camera body, a combined data corresponding to said one type of camera body may be transferred from the lens to the camera body. Alternatively, instead of providing the set aperture size data to the camera body mechanically, as described in the above embodiment, it is possible to store the data Avs - Avc in ROM corresponding to the plurality of types of the camera bodies, in a similar manner to the other data, such as focusing distance data or focal length data, so that the aperture size data can be electrically transmitted from the lens to the camera body.

According to the first embodiment, although it is described that the signal corresponding to the light measurement error is transmitted in an electrical and digital form from the interchangeable lens to the camera body, such a signal can be prepared in other forms, for example, a mechanical signal. More specifically, the interchangeable lens may be provided with a plurality of signal producing elements (such as a plurality of pins each projecting in an amount corresponding to the amount of light measurement error) each having a mechanically arranged amount corresponding to the light measurement error for a particular type of camera body. In this case, the camera body may be so arranged as to receive a necessary light measurement error from one of the signal producing elements.

Moreover, according to the first embodiment, it has been described that the light measurement error signal has 3 different amounts, but can be any number other than 3 depending on the number of different optical systems available in the respective different camera bodies.

Referring now to FIG. 8, there is shown a block diagram of an interchangeable lens type camera system according to the second embodiment of the present invention. A circuit portion shown on the right-hand side of a chain line LEC is provided in an interchangeable lens, and the other is provided in a camera body. A reference character BA designates a battery, and MAS designates a manually operable switch for the power supply. When the switch MAS turns on, an electric power is supplied from a power supply line +E to the micro-computer 1 and also to the oscillator OSC, thereby resetting the micro-computer 1 and, at the same time, starting the sending of clock pulses from the oscillator OSC to the clock terminal CL of the micro-computer 1. The train of clock pulses is also applied to each of exposure time control circuit TIC, aperture control circuit APC, release circuit RLC and mirror release circuit MRC.

A reference character MS designates a light measuring switch that closes when a shutter release button (not shown) is depressed down to a first level. When the switch MS closes, an inverter IN50 produces "HIGH" from its output, and this "HIGH" is applied to an interruption input it1 of the micro-computer 1. When the micro-computer 1 receives "HIGH" to its interruption input it1, an output O1 produces "HIGH", whereby an inverter IN52 produces "LOW" causing a transistor BT50 to go to a conductive state. Thus, electric power is supplied from the power supply line +V to the circuit elements in the camera side other than the oscillator OSC and the micro-computer 1. Electric power is further supplied through a buffer BF, terminals JB1 and JL1 to a power supply line +VF in the interchangeable lens.

When the power supply starts from the power line +V in response to the turning on of the transistor BT50, a power-on-reset circuit POR2 so actuates as to provide a pulse to the exposure time control circuit TIC, aperture control circuit APC, release circuit RLC and mirror release circuit MRC, thereby resetting these circuits.

A reference character ME designates a light measuring circuit which produces an analog form output signal representing:

$$Bv-Avo-Avc$$

wherein Bv is the brightness of the object, Avo is the full open aperture value, and Avc is full open aperture

light measurement error. The signal produced from the light measuring circuit ME is applied to an A/D conversion input terminal ANI of the micro-computer **1**. Furthermore, an input terminal REV of the mirco-computer **1** is provided for inputting reference voltage for being used in an D/A converter provided in the micro-computer **1**. To the input terminal REV, a reference voltage from a constant voltage source provided in the light measuring circuit ME is applied.

A reference character TS designates a device for producing data of set exposure time which is applied to an input port IP1 of the micro-computer **1**. A reference character AS designates a device for producing data of set aperture amount which is applied to an input port IP2 of the micro-computer **1**. A reference character SS designates a device for producing data of film sensitivity which is applied to an input port IP3 of the micro-computer **1**. A reference character MS designates a device for producing data corresponding to the set exposure calculation mode which is applied to an input port IP4 of the micro-computer **1**. A reference character DP designates a display circuit for displaying various data, such as exposure control value. The data to be displayed is controlled by signals obtained from common terminal COM and segment terminal SEG which are provided to the micro-computer **1**.

An output O3 of the micro-computer **1** is connected through terminals JB3 and JL3 to a reset terminal RE of each of counters CO50 and CO52. The output O3 produces "HIGH" while reading data from the mounted interchangeable lens, thereby releasing the counters CO50 and CO52 from the reset condition. A terminal SIC of the micro-computer **1** is provided for producing clock pulses, and in a synchronized manner with the clock pulses, data from the lens is serially read out and taken into the micro-computer through a terminal SID. The terminal SIC is connected through terminals JB2 and JL2 to a clock input terminal CL of the counter CO50, and the terminal SID is connected through terminals JL5 and LB5 to an output of an OR gate OR **50**.

FIG. **9** shows an exemplary circuit to be provided in the micro-computer **1** and connected to the above-mentioned terminals SIC and SID for reading the serial data, and FIG. **10** shows waveforms of signals appearing in the circuit of FIG. **9**. In FIG. **9**, when a data-reading request signal SIIN (FIG. **10**, SIIN) is applied to a flip-flop FF50, the flip-flop FF50 turns to a set condition (FIG. **10**, FF50). Thus, an AND gate AN70 produces a train of clock pulses DIC. The clock pulses DIC are produced from a frequency divider provided in the micro-computer **1** so that the clock pulses DIC have a frequency lower than that of the clock pulses produced from the oscillator OSC. The clock pulses DIC are outputted from the terminal SIC and, at the same time, are applied to clock terminal CL of each of 3-bit binary counter CO60 and 8-bit shift register SR50. In response to the negative edge of each clock pulse applied to the clock terminal CL, the shift register SR50 takes in the data through the terminal SID. Then, in response to the positive edge of the 8th clock pulse, a carry terminal CY of the counter CO60 produces "HIGH" (FIG. **10**, CY), and in response to the negative edge of the 8th clock pulse, an AND gate AN72 produces "HIGH" (FIG. **10**, AN72), thereby resetting the flip-flop FF50 and counter CO60. Furthermore, the "HIGH" from the AND gate AN72 causes a flag SIFL (FIG. **10**, SIFL) to become "HIGH" for inputting serial data, thereby completing the operation.

Referring again to FIG. **8**, a switch RS is a release switch which closes when the shutter release button is depressed down to a second level, and a switch EXS is a switch that closes when an exposure control mechanism (not shown) completes its operation and opens when the exposure control mechanism is set to a charged condition ready to start its operation. When the switch EXS opens upon completion of charging of the exposure control mechanism, an inverter IN56 produces "LOW". While the inverter IN56 is producing "LOW", and when the release switch RS closes, an AND gate AN60 produces "HIGH" which is applied to the interruption terminal it2 of the micro-computer **1**. In response to the positive edge of the "HIGH" applied to the interruption terminal it2, the micro-computer **1** starts to carry out the exposure control operation no matter what operation has been carried out. Contrary, when the switch EXS is held closed as it is before the completion of charge of the exposure control mechanism, the inverter IN56 produces "HIGH". While the inverter IN56 is producing "HIGH", the AND gate AN60 continues to produce "LOW" even when the release switch RS closes. Thus, in this case, the micro-computer **1** will not carry out the exposure control operation.

An output port OP1 of the micro-computer **1** produces an exposure time data Tv and applies it to an exposure time control circuit TIC, and an output port OP2 produces aperture stop down data Av-Avo and applies it to an aperture control circuit APC. Furthermore, an output O2 of the mirco-computer **1** produces a pulse that effects the start of exposure control, and the produced pulse is applied to a release circuit RS. An output O4 of the micro-computer **1** also produces a pulse, but this pulse effects the start of mirror-up operation. The pulse produced from the output O4 is applied to the mirror release circuit MRC.

It is to be noted that the input ports IP1 to IP4 and output ports OP1 to OP2 can be replaced with a common data bus so that the signal transmission between the micro-computer **1** and each of the circuits TS, AS, SS, MS, TIC, and APC can be carried out in a time divided manner.

Next, the description is directed to the circuit provided in the lens. The counter CO50, which is a 3-bit binary counter, counts the positive edges of the clock pulses produced from the terminal SIC, and the counter CO52, hich is also a 3-bit binary counter, counts negative edges of the pulses produced from the carry terminal CY of the counter CO50. The three outputs h2, h1 and h0 of the counter CO50 are connected to the decoder DE50, which produces output relatively to the counted number of pulses from the counter CO50, as shown in Table 7 below.

TABLE 7

Counter CO50			Decoder DE50							
h2	h1	h0	e7	e6	e5	e4	e3	e2	e1	e0
0	0	0	H	L	L	L	L	L	L	L
0	0	1	L	L	L	L	L	L	L	H
0	1	0	L	L	L	L	L	L	H	L
0	1	1	L	L	L	L	L	H	L	L
1	0	0	L	L	L	L	H	L	L	L
1	0	1	L	L	L	H	L	L	L	L
1	1	0	L	L	H	L	L	L	L	L
1	1	1	L	H	L	L	L	L	L	L

The three outputs h2, h1 and h0 of the counter CO52 are connected to the decoder DE52. Thus, the decoder

DE52 produces a 4-bit signal from its output g3, g2, g1 and g0 in response to the signal from the counter CO52, as shown in Table 8, below.

TABLE 8

Counter CO52			Decoder DE52			
h5	h4	h3	g3	g2	g1	g0
0	0	0	0	0	0	0
0	0	1	0	0	0	1
0	1	0	0	0	1	0
0	1	1	0	0	1	1
1	0	0	0	1	0	0
1	0	1	0	1	0	1
1	1	0	0	1	1	0
1	1	1	1	0	0	1

Of the outputs of the decoder DE52, the output g3 is connected to the select terminal SE of the data selector MP50. When the data selector MP50 receives "LOW" to its select terminal SE from the output g3, it produces a signal applied to its input r1 and when the same receives "HIGH", it produces a signal applied to its input r2. The signal produced from the data selector MP50 is applied to a ROM RO50 as an address signal. The input r1 includes 8 terminals in which the terminals of the upper 5 bits are grounded, and the terminals of the lower 3 bits are connected to the outputs g2, g1 and g0 of the decoder DE52. Therefore, the ROM RO50 receives an address signal "00000000", "00000001", . . . , or "00000110" in response to the output "000", "001", . . . , or "110", respectively, of the counter CO52. The input r2 also includes 8 terminals in which the terminals of the upper 3 bits are connected to the outputs g2, g1 and g0 of the decoder DE52 and the terminals of the lower 5 bits are connected to a code plate of a focal length setting device (not shown) of a zoom lens. Therefore, when the counter CO52 produces "111", the data selector MP50 produces "001ØØØØØ" as an address signal, wherein the lower 5 bits ØØØØØ carry a signal obtained from the code plate COD.

Next, the signals stored in the ROM RO50 are described with reference to the Table 9 given below.

TABLE 9

Address	Significance
00000000	Zoom/Fixed Focal length
00000001	Fully-Open Aperture Value Avo
00000010	Maximum Open Aperture Value Avmax
00000011	Minimum/Fixed Focal length fw
00000100	
00000101	Fully-Open Aperture light measurement
00000110	error Avc
00100000	
	Set Focal length
00111111	

At the address "00H" (H indicates that the number is given in a hexadecimal numbering system) of the ROM RO50, a data "F8H" is stored if the mounted lens is a zoom lens, and "F0H" if it is a Fixed focal length lens. If neither of the data "F8H" or "F0H" is read-in in the camera, it is determined that no lens is mounted on the camera body. In this case, the exposure control is carried out under an aperture stop down light measuring mode. If either of the data "F8H" or "F0H" is read-in in the camera, the exposure control is carried out under fully-open aperture light measuring mode.

At the address "01H", data Avo representing the fully-opened aperture size is stored. At the address "02H", data Avmax representing the maximum aperture size is stored. At the address "03H", data representing the focal length of the lens, if the lens is fixed focal length type, is stored or data representing the minimum focal length, if the lens is a zoom lens, is stored.

At the addresses "03H", "04H" and "05H", three different data Avc representing the fully-opened aperture light measurement error for the three different types of camera bodies are stored.

If the mounted lens is a zoom lens, a number of focal length data corresponding to the data obtained from the code plate COD are stored at the addresses "00100000" to "00111111". Such data representing the focal length of the zoom lens is used for producing a warning signal of wobbling when the focal length becomes long.

Referring to FIG. 11, a time chart of various waveforms is given, showing the operation of data reading from the lens of the second embodiment of FIG. 8. Now, the description is directed to the data reading from the lens with reference to the time chart of FIG. 11. First, the output O3 of the micro-computer 1 produces "HIGH" so as to release the counters CO50 and CO52 from the reset condition. As has been described above in connection with FIGS. 9 and 10, the clock terminal SIC of the micro-computer 1 produces a train of 8 clock pulses each time a data of 1 bit-long is read-in. In the period S0 for reading the first data, a location in the ROM RO50 is specified by an address "00000000" so as to produce a check data "F0H" or "F8H". Then, as the counter CO50 counts up, the decoder DE50 sequentially produces "HIGH" from its outputs e0 to e7. Accordingly, AND gates AN68 to AN61 open one after another to transmit the 8-bit data produced from the terminals f0 to f7 of the ROM RO50 to an OR gate OR50, which then serially produces the 8-bit data bit-by-bit from the least significant bit. The serially produced 8-bit data is transmitted through the terminals JL5 and JB5 to the input SID of the micro-computer 1. The signal serially applied to the input SID is serially stored in the shift register SR50 of the micro-computer 1, in a similar manner described in connection with FIGS. 9 and 10, in response to the negative edges of the clock pulses which are the same as those applied to the terminal SIC.

In response to the positive edge of the 8th clock pulse, the counter CO50 produces "HIGH" from its carry terminal CY, thereby starting a new period S1. Then, in response to the positive edge of the 1st clock pulse, the counter CO50 produces "LOW" from its carry terminal CY, thereby effecting the count up of the counter CO52 by 1. Then, the ROM RO50 receives an address data "00000001" as obtained from the input r1 of the data selector MP50.

Thereafter, a similar operation is carried out repeatedly until the period S6 ends, whereby the micro-computer 1 reads data stored in various locations in the ROM RO50 as specified by the address "00H" to "06H". When the carry terminal CY produces "LOW" at the end of the period S6, the counter CO52 produces "111", thereby the decoder DE52 produces "1001". Thus, the data selector MP50 selects input r2, thereby producing an address data "001ØØØØØ", which is applied to the ROM RO50. Here, ØØØØØ represents a 5-bit signal obtained from the code plate COD. Thereupon, the ROM RO50 produces a data representing the set focal length in a similar manner described above, and the produced data is read-in in the micro-computer 1, thereby completing the data reading from the mounted zoom lens. When the data reading from the zoom lens

completes, the micro-computer 1 produces "LOW" from its output O3, thereby turning the counters CO50 and CO52 to the reset condition. In the case where the mounted lens is a fixed focal length type, the micro-computer 1 produces "LOW" from its output O3 at the end of the period S6, thereby turning the counters CO50 and CO52 to the reset condition and, at the same time, completing the data reading from the mounted lens.

Referring to FIGS. 12*a* and 12*b*, a flow chart is given, showing an operation of the micro-computer 1 according to the second embodiment. Now, the operation of the circuit of FIG. 8 is described with reference to the flow chart of FIGS. 12*a* and 12*b*.

When the light measuring switch MS turns on, an interruption signal is applied to the interruption terminal it1, thereby start actuating the micro-computer 1 from the step #201. In the step #201, it is determined whether the terminal it1 is receiving "HIGH" or not. When the interruption terminal it1 receives "HIGH", the procedure advances to the step #202 in which the output O1 produces "HIGH", whereby the inverter IN52 produces "LOW". Thus, the transistor BT50 conducts to supply power to the power line +V. The "HIGH" from the output O1 is also applied to through the buffer BF, terminals JB1 and JL1 to the lens. Then, the set data from the input ports IP1, IP2, IP3 and IP4 are sequentially transmitted and stored in registers MO, M1, M2 and M3 in the steps #203, #204, #205 and #206.

Then, in the step #207, the output O3 produces "HIGH", thereby releasing the counters CO50 and CO52 from the reset condition, and at the same time, setting "4H" in a k-register. And, in the step #209, the serial reading of the data from the lens to the camera is carried out in the manner described above until the completion flag SIFL holds "1". When the flag SIFL holds "1", the read-in data is stored in a register Mk (initially, it is M4) and, thereafter, it is determined in the step #212 whether the k-register is carrying "AH" or not. If the k-register is not carrying "AH", "1" is added to the content of the k-register and the procedure advances to the step #215, wherein it is determined whether k-register is carrying "CH" or not. In the step #215, if it is discriminated that the k-register is not carrying "CH", the procedure returns back to the step #210 to read in the next data. After carrying out the above procedure for a number of times and, when it is determined that the step #212 that the k-register is carrying "AH", it is further determined in the step #213 whether the content of the register M4 is "F8H" or not. If it is determined that the register M4 is not carrying "F8H", it is understood that the mounted lens is a focal length fixed type, or that no lens is mounted. In such a case, it is not necessary to further read-in any data from the lens and, accordingly, the procedure advances to the step #216. Contrary, if it is determined that the register M4 is carrying "F8H", it is understood that the mounted lens is a zoom lens. In such a case, the procedure advances to the step #214 and further to #215 to carry out the data reading Then, in the step #215, if it is determined that the k-register is carrying "CH", the procedure advances to the step #216. Thus, in the registers M4 to MB, various data as indicated below are stored.

register M4: check code;
register M5: Avo;
register M6: Avmax;
register M7: fw;
register M8: Avc1 for the first type of the camera;
register M9: Avc2 for the second type of the camera;
register MA: Avc3 for the third type of the camera; and
register MB: fs.

Then, in the step #216, the output O3 produces "LOW", thereby resetting the counters CO50 and CO52. And then, referring to FIG. 12*b*, in the step #217, the analog signal produced from the light measuring circuit ME is converted into digital form, and the converted digital signal Bv-Avo-Avc2 is stored in a register Mc. Then, in the step #219, the content Bv-Avo-Avc2 of the register Mc is added with the contents Avo, Avc2 and Sv of the registers M5, M9 and M2, respectively, thereby calculating an exposure value Ev as follows:

$$EV=(Bv-Avo-Avc2)+Avo+Avc2+Sv=Bv+Sv.$$

The obtained sum, i.e., the exposure value Ev is again stored in the register Mc.

It is to be noted that the above calculation is carried out when the camera body has the optical system of the second type. If the camera body has the optical system of the first type, the content of the register M8 should be added; and if the camera body has the optical system of the third type, the content of the register MA should be added. Then, using the obtained sum Ev, the exposure calculation is carried out in the step #220.

When the exposure calculation completes, the flag LMF carries "1" in the step #221, and then, the interruption routine is permitted in the step #222. In the next step #223, it is determined whether the flag RLF is carrying "1" or not. If the flag RLF is carrying "1", the procedure advances to the step #233, and if not, the procedure advances to the step #224 for displaying the exposure information. A detailed description on the flag RLF will be given later.

In the step #225, it is determined whether the interruption terminal it1 is receiving "HIGH" or not. If the interruption terminal it1 is receiving "HIGH", the procedure returns back to the step #203 to repeat the operation thereafter. If the terminal it1 is receiving "LOW", the output O1 produces "LOW", thereby cutting the power supply to the power line +V and also to the circuits in the lens. Then, in the step #227, nothing is displayed (blank display), and in the step #228, flag LMF for the light measuring carries "0". Then, the interruption routine is permitted (step #229) and ending the operation of the micro-computer 1 (step #230).

When the shutter release switch RS closes under the condition that the exposure control mechanism is charged and that the switch EXS is held open, the AND gate AN60 produces "HIGH", thereby providing "HIGH" to the interruption terminal it2. Then, the micro-computer 1 immediately starts the procedure from the step #201 (FIG. 12*a*) no matter what operation it is carrying out. Then, the procedure advances from the step #201 to the step #230 (FIG. 12*b*), because it is determined in the step #201 that the interruption terminal receiving "HIGH" is not it1, but it2. In the step #230, the flag RLF for the release holds "1", and in the step #231, the output O3 produces "LOW" just in case the interruption routine is requested while carrying out the serial reading of data. Then, in the step #232, it it determined whether the flag LMF is carrying "1" or not, i.e., whether the calculation for obtaining the exposure control data is completed or not. If not, the proce-

dure returns back to the step #202 to carry out the exposure calculation through the steps #202 to #223, and continues again from the step #233. If the flag LMF is carrying "1" in the step #232, the procedure advances directly to the step #233.

In the step #233, exposure time data Tv is supplied from the output OP1 to the exposure time control circuit TIC. Then, in the step #234, aperture stop down data Av-Avo is supplied from the output OP2 to the aperture control circuit APC. And, in the step #235, a pulse for the shutter release is supplied from the output O2 to the release circuit RLC of the exposure control mechanism.

In the next step #236, a predetermined time is counted and, thereafter, a pulse for effecting the shutter release is supplied to the mirror-up release circuit MRC. Then, the program waits until the input terminal i2 receives "HIGH", i.e., until the switch EXS closes upon completion of the exposure control operation. When the input terminal i2 receives "HIGH", the flag RLF holds "0", and thereafter, the procedure continues from the step #225. If the light measuring switch MS is held closed the procedure follows the steps of #225, #203 et seq., and if it is held open, the procedure follows the steps of #225, #226 et seq., thereby cutting the power supply, turning off the display, setting "0" in the flag LMF, and ending the operation of the micro-computer 1. Now it is ready to carry out another cycle of operation as carried out when an interruption signal is applied to the terminal it1 while the light measuring switch MS is held closed.

Although the present invention has been fully described with reference to several preferred embodiments, many modifications and variations thereof will now be apparent to those skilled in the art, and the scope of the present invention is therefore to be limited not by the details of the preferred embodiments described above, but only by the terms of appended claims.

What is claimed is:

1. In a camera system with an interchangeable objective lens a combination of, a camera and an interchangeable objective lens selectively attachable to said camera body and to at least one different camera body, comprising:

means located in said interchangeable objective lens for storing a plurality of compensation data suitable to said first mentioned camera body and to the at least one different camera body, respectively, to prepare for each case of compensating an error in a fully-open aperture light measurement;

means located in said interchangeable objective lens for transmitting said compensation data to the camera body to which said interchangeable objective lens is attached;

means located in said first mentioned camera body for registering said compensation data from said transmitting means;

means located in said first mentioned camera body for controlling the camera system so that a predetermined one of said compensation data stored in said storing means is registered in said registering means;

means located in said first mentioned camera body for practicing a fully-open aperture light measurement through said interchangeable objective lens to produce light measuring information including the error; and

means located in said first mentioned camera body for calculating correct exposure information in response to said compensation data registered in said registering means and said light measuring signal, in which the error included in said light measuring signal is removed by utilizing said compensation data registered in said registering means.

2. The invention of claim 1, wherein said controlling means includes means for forwarding a digital signal to said interchangeable objective lens, and said storing means includes a read only memory with a plurality of addresses at which said compensating data is located, respectively, and wherein said interchangeable objective lens further comprises means for determining an address of said storing means in response to said digital signal, whereby said compensation data located at the determined address is transmitted by said transmitting means.

3. The invention of claim 2, wherein said forwarding means includes means for selectively producing a predetermined address data as said digital signal for designating an address at which the predetermined one of said compensation data is stored, and said determining means includes means for passing said predetermined address data from said producing means to said storing means, whereby the predetermined one of said compensation data is transmitted to be registered in said registering means.

4. The invention of claim 2, wherein said forwarding means includes means for generating a train of clock pulses as said digital signal, and said determining means includes means for designating the addresses of said storing means one by one in response to said clock pulses from said generating means to transmit said plurality of compensation data one by one by means of said transmitting means, and wherein said controlling means further includes means for actuating said registering means to register the predetermined one of said compensation data in a timing when the predetermined one of said compensation data arrives at said first mentioned camera body.

5. The invention of claim 2, wherein said storing means further includes an address for storing exposure compensating data to be transmitted to said first mentioned camera body for the purpose of compensating an exposure error upon fully-open aperture size control, and said calculating means further includes means for providing aperture size information and at least another exposure factor information in response to said correct exposure information, and wherein said first mentioned camera body further comprises means for discriminating whether or not the calculated aperture size information corresponds to the fully-open aperture size, means responsive to said discriminating means for modifying said other exposure factor information by said exposure compensating data when the calculated aperture size information corresponds to the fully-open aperture size, and for adopting said other exposure factor information as it is when the calculated aperture size information does not correspond to the fully-open aperture size, means for controlling the aperture size in response to said providing means, and means for controlling another exposure factor in response to said modifying and adopting means.

6. In a camera system with an interchangeable objective lens, a camera body to be combined with an interchangeable objective lens which stores a plurality of compensation data suitable to the camera body and at

least one different camera body, respectively, to prepare for each case of compensating an error in fully-open aperture light measurement, comprising:

means for registering the compensation data to be transmitted from the interchangeable objective lens;

means for controlling the camera system so that a predetermined one of the plurality of compensation data is registered in said registering means;

means for practicing a fully-open aperture light measurement through the interchangeable objective lens to produce light measuring information including the error; and

means for calculating correct exposure information in response to said compensation data registered in said registering means and said light measuring signal, in which the error included in said light measuring signal is removed by utilizing said compensation data registered in said registering means.

7. The invention of claim 6, wherein said controlling means includes means for ordering the interchangeable objective lens to selectively transmit the predetermined one of the plurality of compensation data to said registering means.

8. The invention of claim 6, wherein said controlling means includes means for making the interchangeable objective lens transmit the plurality of compensation data one by one, and means for actuating said registering means to register the predetermined one of the compensation data in a timing when the predetermined one of the compensation data arrives at the camera body.

9. In a camera system with an interchangeable objective lens, an interchangeable objective lens selectively attachable to a plurality of different camera bodies each capable of fully-open aperture light measurement, comprising:

read only memory having a plurality of addresses for storing a plurality of compensation data suitable to the plurality of camera bodies, respectively, to prepare for each case of compensating an error in fully-open aperture light measurement;

means for receiving a digital signal from the camera body to which said interchangeable objective lens is attached;

means for determining an address of said read only memory in response to said digital signal; and

means for transmitting the compensation data stored in the determined address to the camera body to which said interchangeable objective lens is attached.

10. The invention of claim 9, wherein said receiving means includes means for introducing address data as said digital signal, and said determining means includes means for passing said address data from said introducing means to said read only memory to designate an address.

11. The invention of claim 9, wherein said receiving means includes means for introducing a train of clock pulses as said digital signal, and said determining means includes means for designating the address of said read only memory one by one in response to said clock pulses.

12. In a camera system with an interchangeable objective lens, an interchangeable objective lens attachable to a camera body capable of an automatic exposure control, comprising:

a read only memory having a plurality of addresses, one of which stores an exposure time compensating data for compensating an exposure error upon fully-open aperture size control;

means for receiving a digital signal from the camera body;

means for determining an address of said read only memory in response to said digital signal; and

means for transmitting the data stored in the determined address to the camera body.

13. In a camera system with an interchangeable objective lens, a camera body to be combined with an interchangeable objective lens which stores exposure compensating data for compensating an exposure error upon fully-open aperture size control, comprising:

means for receiving the exposure compensating data from the interchangeable objective lens;

means for practicing a light measurement to produce exposure information;

means for providing aperture size information and at least another exposure factor information in response to said exposure information;

means for discriminating whether or not the calculated aperture size information corresponds to the fully-open aperture size;

means responsive to said discriminating means for modifying said other exposure factor information by said exposure compensating data when the calculated aperture size information corresponds to the fully-open aperture size, and for adopting said other exposure factor information as it is when the calculated aperture size information does not correspond to the fully-open aperture size;

means for controlling the aperture size in response to said providing means; and

means for controlling an exposure factor in response to said modifying and adopting means.

14. A camera system capable of compensating an exposure error upon fully-open aperture size control comprising:

means for preparing exposure compensating data;

means for practicing a light measurement to produce exposure information;

means for providing aperture size information and at least another exposure factor information in response to said exposure information;

means for discriminating whether or not the calculated aperture size information corresponds to the fully-open aperture size;

means responsive to said discriminating means for modifying said other exposure factor information by said exposure compensating data when the calculated aperture size information corresponds to the fully-open aperture size, and for adopting said other exposure factor information as it is when the calculated aperture size information does not correspond to the fully-open aperture size;

means for controlling the aperture size in response to said providing means; and

means for controlling an exposure factor in response to said modifying and adopting means.

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United States Patent [19]

Defuans

[11] **Patent Number: 4,525,039**

[45] **Date of Patent: Jun. 25, 1985**

[54] **OBJECTIVE LENS**

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[51] **Int. Cl.**[3] **G02B 9/60**

[52] **U.S. Cl.** **350/465;** 350/449

[58] **Field of Search** 350/449, 450, 465, 414, 350/418, 410, 426, 462

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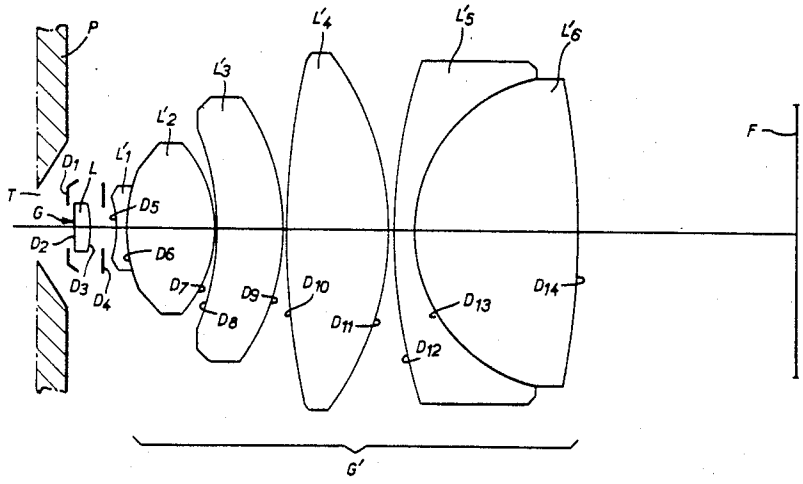
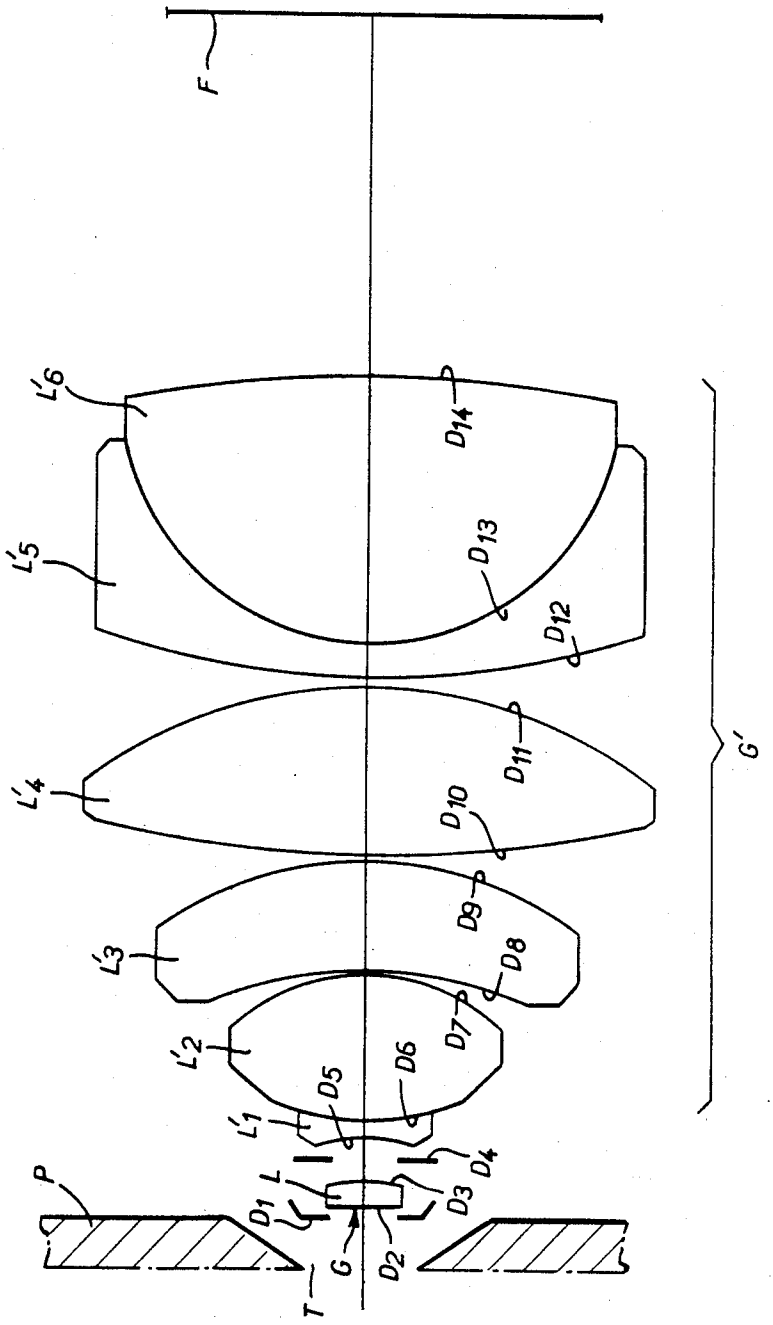
Assistant Examiner—Paul M. Dzierzynski
Attorney, Agent, or Firm—Charles A. Brown; Charles E. Brown

[57] **ABSTRACT**

An objective lens comprises an iris diaphragm (D_1) at the front and an optical assembly disposed behind the iris diaphragm. The optical assembly comprises a plano-convex front lens unit (G) with its plane surface facing the front of the lens, whereby the lens is suitable for use in media with different refractive indices (in practice, air and water). It further comprises a rear lens unit (G') adapted to apply the necessary correction to maintain abberations within reasonable limits and to achieve a required distance from the lens to the focal image plane. The invention is applicable, in particular, to discreet surveillance using a camera.

17 Claims, 1 Drawing Figure




F
L'6
D14
L'5
D13
D12
L'4
D11
D10
L'3
D9
D8
L'2
D7
D6
D5
L'1
D4
D3
D2
D1
L
G
P
T
G'

OBJECTIVE LENS

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention is concerned with an objective lens for a camera, comprising diaphragm disposed at the front of the lens and an optical assembly disposed behind the diaphragm.

2. Description of the Prior Art

French Pat. No. 2 321 713 filed Aug. 22, 1975 discloses a camera whose essential characteristic is that the iris diaphragm of its objective lens, that is to say the diaphragm of the objective lens which delimits the incident beam and thus conditions the aperture number, is situated in front of the objective lens.

It has become clear that this arrangement, originally devised in order to facilitate and simplify the practical implementation of underwater cameras, can with advantage by applied to cameras for discreet surveillance applications, including still cameras, movie cameras and video cameras, whether the need is for surveillance in an air or water medium, for monitoring the presence of persons therein.

A condition for the success of any surveillance system is that the camera by virtue of which it is exercised be hidden from view of the greatest possible extent.

If, as is usual, the iris diaphragm is disposed inside the objective lens, the entry lens elements thereof are necessarily of relatively large diameter, making it difficult to hide them.

This does not apply if, as described in the aforementioned French patent, the iris diaphragm of the objective lens is situated at the front of the lens.

The entry lens elements of the objective lens may then have a relatively small diameter, and the corresponding camera may thus be easily hidden behind a partition or closet door or any appropriate support, a small hole in the front surface, difficult to see, constituting the iris diaphragm of the objective lens of the camera thus hidden.

In practice, apart from this capacity for being hidden, it is desirable for other constraints to be met to obtain the widest possible application.

First of all, as already mentioned, it is desirable for the objective lens to be equally suitable for use in air or water.

It is also desirable to obtain a relatively large distance between the lens and the corresponding focal image plane to provide for the installation of any necessary accessory device, such as a shutter, reflex mirror or filter, for example.

These requirements are mutually contradictory, and are difficult to reconcile in practice.

In the aforementioned French patent, the objective lens described is in practice suitable only for underwater cameras, and the distance between it and the focal image plane is relatively small.

A general objective of the present invention is to provide an objective lens which provides a particularly satisfactory solution to the problem of meeting the stated requirements.

SUMMARY OF THE INVENTION

The invention consists in an objective lens for a camera, comprising an iris diaphragm disposed at the front of the lens and an optical assembly disposed behind the iris diaphragm and comprising a plano-convex front lens unit with its plane surface facing the front of the lens, whereby the lens is suitable for use in media with different refractive indices, and a rear lens unit adapted to apply the necessary correction to maintain abberations within reasonable limits and to achieve a required distance from the lens to the focal image plane.

The term "lens unit" used herein designates, in the usual manner, an optical component consisting of a single lens, a doublet pair of lenses or a multiple assembly of lenses, and designed to fulfil a specific function.

The plane entry optical surface of the front lens unit of the objective lens in accordance with the invention offers the advantage of enabling the lens to be used equally well in air or in water, and eliminates the unwanted "cat's eye" effect experienced with side lighting, an effect which would be unavoidable if the entry optical surface were curved, by virtue of the resulting focusing action. Also, by virtue of its convex exit optical surface, it provides the advantage of concentrating the incident beam and thus facilitates the minimizing of the inevitable abberations in the rear lens unit.

Thus in practice it has a two-fold function.

As a corollary to this, the rear lens unit of the objective lens in accordance with the invention provides the advantage that, after the divergence of the incident beam which is necessary to its expansion, the consequences of which are minimized, however, as indicated above, by virtue of the convergence previously brought about by the front lens unit, sufficient progressive convergence of the beam is brought about for the required distance to the focal image plane to be obtained.

Thus the objective lens in accordance with the invention represents a particularly advantageous compromise between the various requirements to be fulfilled.

Also, when applied to a camera, it enables the camera to be hidden particularly easily, since its overall dimension may be less than 50 mm, for example, for an iris diaphragm aperture of less than 3 mm, for example, and an overall focal length of the order of 11.3 mm.

Finally, if required, the invention is equally applicable to projection apparatus, for the purpose of projection between two walls, for example.

Other objects and advantages will appear from the following description of an example of the invention, when considered in connection with the accompanying drawing, and the novel features will be particularly pointed out in the appended claims.

IN THE DRAWING

The drawing is a cross-sectioned view in elevation of an objective lens in accordance with the invention, illustrating the application of the latter to a camera.

DESCRIPTION OF THE PREFERRED EMBODIMENT

In the embodiment shown in the drawing, the objective lens in accordance with the invention is used for purposes of surveillance, and is therefore disposed behind a panel or wall P formed for this purpose with a hole T.

For preference, and as shown, this hole T is generally frustoconical, its area increasing from the front towards the rear, with a cone angle sufficient to permit the objective lens in accordance with the invention to be tilted and thus aimed at different points in the field of view, without the incident light beam being obstructed.

In an alternative arrangement (not shown) particularly suitable for applications other than discreet surveillance, diaphragm D_1 may, for example, be formed by the rear surface of panel or wall P, the area of the frusto-conical hole T in which then decreases from the front towards the rear.

Be this as it may, as shown in the drawing, the objective lens in accordance with the invention is formed by a series of component parts, optical surfaces or diaphragms.

First of all, at the front, is a diaphragm D_1 constituting the iris diaphragm.

As represented schematically in full line in the drawing, diaphragm D_1 forms an integral part of the objective lens support device or body-tube, which will not be described in detail herein.

In practice, assuming a overall focal length of 1 mm, the effective aperture diameter of diaphragm D_1 may be of the order of 0.26 mm.

To the rear of diaphragm D_1, the objective lens in accordance with the invention comprises an optical assembly whose optical components are, in accordance with the invention, grouped and combined to form a front lens unit G and a rear lens unit G'.

In accordance with the invention, front lens unit G is plano-convex with its plane surface facing the front, that is to say towards diaphragm D_1.

In practice, in the embodiment shown, front lens unit G consists of a single plano-convex lens L which, in the usual manner, is defined by two optical surfaces, namely an optical surface D_2 which constitutes its front surface and which is plane, and an optical surface D_3 which constitutes its rear surface and which is convex.

Lens L has a refractive index of 1.45 and an Abbe number of 68. It may, for example, be manufactured from the material marketed under the trade name "Herasil", this kind of material having advantageous chemical and physical properties enabling it to withstand corrosive and abrasive environments so as to permit surveillance of such environments.

Assuming, by way of illustrative example, an overall focal length of 1 mm, it is at a distance from diaphragm D_1 consituting the iris diaphragm, as measured relative to its entry optical surface D_2, between 0.02 and 0.04 mm, its thickness at the center is between 0.08 and 0.11 mm, and the radius of optical surface D_3 which constitutes its rear surface is between 0.92 and 0.93 mm.

For preference, and as shown, rear lens unit G' is at a distance from front lens unit G which, as measured between exit optical surface D_3 of front lens group G and entry optical surface D_5 of rear lens group G', is between 0.14 and 0.18 mm, for an overall focal length of 1 mm.

Also for preference, and as shown, a diaphragm D_4 is disposed substantially midway between front lens unit G and rear lens unit G'.

For example, the distance between exit optical surface D_3 of front lens unit G and diaphragm D_4 may, given the conditions stated, be between 0.07 and 0.09 mm and, likewise, its distance from entry optical surface D_5 of rear lens unit G' may be between 0.07 and 0.09 mm.

Be this as it may, the effective diameter of diaphragm D_4 is for preference of the order of 0.25 mm, for an overall focal length of 1 mm.

In the embodiment shown, rear lens unit G' comprises a succession of six lenses L'_1, L'_2, L'_3, L'_4, L'_5, and L'_6.

Lens L'_1 is biconcave, delimited by an optical surface D_5 which constitutes the entry optical surface of rear lens unit G', and which also constitutes its front surface, and an optical surface D_6 which constitutes its rear surface.

Given the assumed overall focal length of 1 mm, it has a thickness at the center between 0.06 and 0.08 mm, an entry surface radius between 0.39 and 0.40 mm and an exit surface radius between 1.03 and 1.04 mm.

Its refractive index is in the region of 1.8, its Abbe number is 25, and it may be made, for example, from the optical material with reference E 05-25.

Lens L'_2 is biconvex and in contact with the preceding concave lens L'_1.

In other words, these two lenses share optical surface D_6, which constitutes the exit surface of one and the entry surface of the other.

In addition to optical surface D_6, lens L'_2 is further delimited by an optical surface D_7, which constitutes its exit surface.

Given the assumed overall focal length of 1 mm, lens L'_2 has a thickness at the center between 0.49 and 0.51 mm, an inlet surface radius between 1.03 and 1.04 mm and an exit surface radius between 0.71 and 0.72 mm.

Its refractive index is 1.49, its Abbe number is 70, and it may be made, for example, from the optical material with reference A 87-70.

Lens L'_3 is concave-convex with its concave side facing preceding lens L'_3.

It is defined by two optical surfaces D_8 and D_9, the former constituting its entry surface and the latter its exit surface.

It is disposed at a distance from preceding lens L'_2 which, as measured between corresponding optical surfaces D_7 and D_8 and given the assumed overall focal length of 1 mm, is between 0.01 and 0.02 mm.

For the assumed overall focal length of 1 mm, it has a thickness at the center between 0.39 and 0.41 mm, an entry surface radius between 1.62 and 1.63 mm and an exit surface radius between 1.28 and 1.29 mm.

Finally, its refractive index is 1.62, its Abbe number is 53, and it may be made, for example, from the optical material with reference C 23-53.

The fourth lens L'_4 is biconvex.

It is delimited by optical surfaces D_{10} and D_{11}, the former constituting its entry surface and the latter its exit surface. It is disposed at a distance from preceding lens L'_3 which, as measured between corresponding optical surfaces D_9 and D_{10} and given the assumed overall focal length of 1 mm, is between 0.01 and 0.02 mm.

For the assumed overall focal length of 1 mm, it has a thickness at the center between 0.60 and 0.62 mm, an entry surface radius between 5.08 and 5.14 mm and an exit surface radius between 1.65 and 1.66 mm.

Finally, its refractive index is 1.62, its Abbe number is 53, and it may be made, for example, from the optical material with reference C 23-53.

The fifth lens L'_5 is concave-convex, and has its convex side facing preceding lens L'_4.

It is defined between two optical surfaces D_{12} and D_{13}, the former constituting its entry surface and the latter its exit surface.

Given the assumed overall focal length 1 mm, it is disposed at a distance from preceding lens L'_4 which, as measured between corresponding optical surfaces D_{11} and D_{12}, is between 0.01 and 0.02 mm.

For the assumed overall total length of 1 mm, it has a thickness at the center between 0.13 and 0.15 mm, an

entry surface radius between 3.24 and 3.25 mm and an exit surface radius between 0.89 and 0.90 mm.

Finally, its refractive index is 1.72, its Abbe number is 30, and it may be made, for example, from the optical material with reference D 17-29.

Lens L'_6 is biconvex and is in contact with preceding lens L'_5.

Optical surface D_{13} thus forms its entry surface, whereas an optical surface D_{14}, which is the exit optical surface of rear lens unit G', constitutes its exit surface.

Given the assumed overall focal length of 1 mm, its thickness at the center is between 0.97 and 0.99 mm, its entry surface radius is between 0.89 and 0.90 mm and its exit surface radius is between 5.08 and 5.14 mm.

Finally, its refractive index is 1.62, its Abbe number is 53, and it may be made, for example, from the optical material with reference C 23-53.

Some of the numerical values specified hereinabove are summarized in table Ia below, which lists, for the references of the component parts, optical surfaces or diaphragms in question, the nature of the component and, in millimeters for the assumed overall focal length of 1 mm, the minimum and maximum distances from the adjacent component, the minimum and maximum radius, in the case of an optical surface, and the effective diameter.

In order to specify the orientation of the optical surfaces, the radii are assigned a sign, positive if the radius of the optical surface is on the other side thereof relative to the iris diaphragm, and negative in the contrary case.

Table Ib is based on the same numerical values and the same conditions, but relates these to the lenses involved, giving the distance from a lens to the preceding lens.

Table Ib also gives the nature and refractive index of each lens.

With the values indicated above, the distance between exit optical surface D_{14} and the focal image plane F, as shown in the drawing, is between 1.2 and 1.4 mm for the assumed overall focal length of 1 mm. Its overall dimension is thus between 4.11 and 4.55 mm.

TABLE Ia

Component (optical surface or diaphragm)	Nature of component	Distance to next component (mm) min	Distance to next component (mm) max	Radius (optical surface) (mm) min	Radius (optical surface) (mm) max	Effective diameter (mm)
	Assumed overall focal length 1 mm					
D_1	diaphragm	0.02	0.04			0.259
D_2	surface	0.08	0.11	∞		0.28
D_3	surface	0.07	0.09	−0.93	−0.92	0.28
D_4	diaphragm	0.07	0.09			0.25

TABLE Ia-continued

Component (optical surface or diaphragm)	Nature of component	Distance to next component (mm) min	Distance to next component (mm) max	Radius (optical surface) (mm) min	Radius (optical surface) (mm) max	Effective diameter (mm)
	Assumed overall focal length 1 mm					
D_5	surface	0.06	0.08	−0.40	−0.39	0.32
D_6	surface	0.49	0.51	+1.03	+1.04	0.47
D_7	surface	0.01	0.02	−0.72	−0.71	0.99
D_8	surface	0.39	0.41	−1.63	−1.62	1.17
D_9	surface	0.01	0.02	−1.29	−1.28	1.53
D_{10}	surface	0.60	0.62	+5.08	+5.14	1.99
D_{11}	surface	0.01	0.02	−1.66	−1.65	2.07
D_{12}	surface	0.13	0.15	+3.24	+3.25	1.99
D_{13}	surface	0.97	0.99	+0.89	+0.90	1.75
D_{14}	surface			−5.08	−5.14	1.76

Given the above-indicated value for the effective aperture diameter of the iris diaphragm, the aperture number of the objective lens in accordance with the invention is 3.86.

TABLE Ib

Lens	Distance to preceding lens (mm) min	Distance to preceding lens (mm) max	Nature	Index	Thickness at centre (mm) min	Thickness at centre (mm) max	Radius (mm) entry surface min	Radius (mm) entry surface max	Radius (mm) exit surface min	Radius (mm) exit surface max
	Assumed overall focal length 1 mm									
L			plano-convex	1.45	0.08	0.11	∞		+0.93	−0.92
L'_1	0.14	0.18	biconcave	1.80	0.06	0.08	−0.40	−0.39	+1.03	−1.04
L'_2	0		biconvex	1.49	0.49	0.51	+1.03	+1.04	−0.72	−0.71
L'_3	0.01	0.02	concave-convex	1.62	0.39	0.41	−1.63	−1.62	−1.29	−1.28
L'_4	0.01	0.02	biconvex	1.62	0.60	0.62	+5.08	+5.14	−1.66	−1.65
L'_5	0.01	0.02	concave-convex	1.72	0.13	0.15	+3.24	+3.25	+0.89	+0.90
L'_6	0		biconvex	1.62	0.97	0.99	+0.89	+0.90	−5.08	−5.14

The stated values and specifications show that front lens unit G of the objective lens in accordance with the invention is, generally speaking, adapted to use of the latter in media with different refractive indices, and in particular in air just as well as in water, and that rear lens group G' is, generally speaking, adapted to apply the necessary correction to maintain abberations within reasonable limits and to achieve a required value of focal length.

Tables IIa and IIb below give, by way of non-limiting example and in a manner similar to that of tables Ia and Ib above, numerical values for an objective lens with an overall focal length of 11.27 mm which is especially advantageous.

TABLE IIa

Component (optical surface or diaphragm)	Nature of component	Distance to next component (mm)	Radius (optical surface) (mm)	Effective diameter (mm)
	Overall focal length 11.27 mm			
D_1	diaphragm	0.4		2.92
D_2	surface	1.15	∞	3.10
D_3	surface	0.87	−10.43	3.10
D_4	diaphragm	0.99		2.80
D_5	surface	0.77	−4.45	3.63
D_6	surface	5.65	11.72	5.30
D_7	surface	0.19	−8.01	11.1
D_8	surface	4.62	−18.371	13.2
D_9	surface	0.19	−14.531	17.2
D_{10}	surface	6.92	57.652	22.4
D_{11}	surface	0.19	−18.700	23.3
D_{12}	surface	1.54	36.623	22.4
D_{13}	surface	11.00	10.110	19.7

TABLE IIa-continued

Component (optical surface or diaphragm)	Nature of component	Distance to next component (mm)	Radius (optical surface) (mm)	Effective diameter (mm)
	Overall focal length 11.27 mm			
D_{14}	surface		−17.652	19.8

TABLE IIb

Lens	Distance to preceding lens (mm)	Nature	Index	Thickness at centre (mm)	Radius (mm) entry surface	Radius (mm) exit surface
		Overall focal length 11.27 mm				
L		plano-convex	1.45	1.15	∞	−10.43
L'_1	1.86	biconcave	1.80	0.77	−4.45	11.72
L'_2	0	biconvex	1.49	5.65	11.72	−8.01
L'_3	0.19	concave-convex	1.62	4.62	−18.371	−14.531
L'_4	0.19	biconvex	1.62	6.92	57.371	−18.700
L'_5	0.19	concave-convex	1.72	1.54	36.623	10.110
L'_6	0	biconvex	1.62	11	10.110	−57.652

The distance to the focal image plane from this objective lens, as defined hereinabove, is then 14.56 mm, and its overall dimension 49 mm.

It will be understood that various changes in the details, materials and arrangements of parts, which have been herein described and illustrated in order to explain the nature of the invention, may be made by those skilled in the art within the principle and scope of the invention as expressed in the appended claims.

For example, lenses could if required be disposed between front lens unit G and rear lens group G', without departing from the scope of the present invention. Likewise, meniscus or biconvex lenses could if required be disposed between lenses L'_2 and L'_5 of rear lens unit G', without departing from the scope of the present invention.

In all cases, note that in the case of an application to industrial surveillance, the front diaphragm advantageously constitutes mechanical protection for the objective lens and the camera it equips, especially where there is risk of spattering of metal cuttings or other materials.

All numerical values cited in the appended claims relate to an overall focal length of 1 mm. Any actual overall focal length can be reduced to this value by application of the appropriate coefficient of division.

It is claimed:

1. An objective lens for a camera, said lens comprising an iris diaphragm being disposed at the front of said lens and an optical assembly being disposed behind said iris diaphragm, said optical assembly comprising a plano-convex front lens unit with its plane surface facing the front of said lens whereby said lens is suitable for use in media with different refractive indices, and a rear lens unit being adapted to apply the necessary correction to maintain abberations within reasonable limits and to achieve a required distance from said lens to the focal image plane, said iris diaphragm having an effective diameter of 0.25 mm., said plano-convex lens being disposed between 0.02 and 0.04 mm. from said iris diaphragm and having a refractive index of 1.45, an Abbe number of 68 and a thickness at the center between 0.08 and 0.11 mm., and wherein the rear surface of said plano-convex lens has a radius of between 0.92 and 0.93 mm.

2. An objective lens according to claim 1, wherein the effective diameter of said iris diaphragm is of the order of 0.25 mm.

3. An objective lens according to claim 1, wherein said rear lens unit is disposed between 0.14 and 0.18 mm from said front lens unit.

4. An objective lens for a camera, said lens comprising an iris diaphragm being disposed at the front of said lens and an optical assembly being disposed behind said iris diaphragm, said optical assembly comprising a plano-convex front lens unit with its plane surface facing the front of said lens whereby said lens is suitable for use in media with different refractive indices, and a rear lens unit being adapted to apply the necessary correction to maintain abberations within reasonable limits and to achieve a required distance from said lens to the focal image plane, said rear lens unit comprising a biconcave first lens which has a thickness at the center of between 0.06 and 0.08 mm, an entry surface radius of between 0.39 and 0.40 mm, an exit surface radius of between 1.03 and 1.04 mm, a refractive index of 1.80 and an Abbe number of 25.

5. An objective lens according to claim 4, wherein said rear lens unit comprises a biconvex second lens in contact with said first lens and which has a thickness at the center of between 0.49 and 0.51 mm, an entry surface radius of between 1.03 and 1.04 mm, an exit surface radius of between 0.71 and 0.72 mm, a refractive index of 1.49 and an Abbe number of 70.

6. An objective lens according to claim 5, wherein said rear lens unit comprises a concave-convex third lens which has its concave side facing said second lens, which is disposed between 0.01 and 0.02 mm from said second lens and which has a thickness at the center of between 0.39 and 0.41 mm, an entry surface radius of between 1.62 and 1.63 mm, an exit surface radius of between 1.28 and 1.29 mm, a refractive index of 1.62 and an Abbe number of 53.

7. An objective lens according to claim 6, wherein said rear lens unit comprises a biconvex fourth lens which is disposed between 0.01 and 0.02 mm from said third lens and which has a thickness at the center of between 0.60 and 0.62 mm, an entry surface radius of between 5.08 and 5.14 mm, an exit surface radius of between 1.65 and 1.66 mm, a refractive index of 1.62 and an Abbe number of 53.

8. A objective lens according to claim 7, wherein said rear lens units comprises a concave-convex fifth lens which has its convex side facing said fourth lens, which is disposed between 0.01 and 0.02 mm from said fourth lens and which has a thickness at the center of between 0.13 and 0.15 mm, an entry surface radius of between 3.24 and 3.25 mm, an exit surface radius of between 0.89 and 0.90 mm, a refractive index of 1.72 and an Abbe number of 30.

9. An objective lens according to claim 8, wherein said rear lens unit comprises a biconvex sixth lens in contact with said fifth lens and which has a thickness at the center of between 0.97 and 0.99 mm, an entry surface radius of between 0.89 and 0.90 mm, an exit surface radius of between 5.08 and 5.14 mm, a refractive index of 1.62 and an Abbe number of 53.

10. An objective lens according to claim 1, wherein the distance between the focal image plane of the lens

and the rearmost surface of said rear lens unit is between 1.2 and 1.4 mm.

11. An objective lens according to claim **4**, wherein the effective diameter of said iris diaphragm is of the order of 0.25 mm.

12. An objective lens according to claim **4**, wherein said rear lens unit is disposed between 0.14 and 0.18 mm from said front lens unit.

13. An objective lens according to claim **4**, wherein the distance between the focal image plane of the lens and the rearmost surface of the said rear lens unit is between 1.2 and 1.4 mm.

14. An objective lens for a camera, said lens comprising an iris diaphragm being disposed at the front of said lens and an optical assembly being disposed behind said iris diaphragm, said optical assembly comprising a plano-convex front lens unit with its plane surface facing the front of said lens whereby said lens is suitable for use in media with different refractive indices, and a rear lens unit being adapted to apply the necesary correction to maintain abberations within reasonable limits and to achieve a required distance from said lens to the focal image plane, said front lens unit comprising a single plano-convex lens with its plane surface facing the front of the lens, and having a thickness at the center of 1.15 mm, a rear surface radius of 10.43 mm and a refractive index of 1.45, and said rear lens unit comprising, in succession, a biconcave first lens which is disposed at a distance of 1.86 mm from a first preceding lens, and having a thickness at the center of 0.77 mm, an entry surface radius of 4.45 mm, an exit surface radius of 11.72 mm and a refractive index of 1.80; a biconcave seconds lens in contact with a second preceding lens and which has a thickness at the center of 5.65 mm, an entry surface radius of 11.72 mm, an exit surface radius of 8.01 mm and a refractive index of 1.49; a concave-convex third lens which is disposed at a distance of 0.19 mm from a third preceding lens with its concave side facing the front, which has a thickness at the center of 4.62 mm, an entry surface radius of 18.371 mm, an exit surface radius of 14.531 mm and a refractive index of 1.62; a biconvex fourth lens which is disposed at a distance of 0.19 mm from a fourth preceding lens, which has a thickness at the center of 6.92 mm, an entry surface radius of 57.652 mm, an exit surface radius of 18.700 mm and a refractive index of 1.62; a concave-convex fifth lens which is disposed at a distance of 0.19 mm from a fifth preceding lens with its convex side facing the front, which has a thickness at the center of 1.54 mm, an entry surface radius of 36.623 mm, an exit surface radius of 10.110 mm, and a refractive index of 1.72; and a biconvex sixth lens in contact with a sixth preceding lens, which has a thickness at the center of 11 mm, an entry surface radius of 10.14 mm, an exit surface radius of 57.652 mm and a refractive index of 1.62, said objective lens having an overall focal length of 11.27 mm and a distance between the rearmost surface of said rear lens units and its focal image plane of 14.56 mm.

15. An objective lens according to claim **14**, wherein the effective diameter of said iris diaphragm is of the order of 0.25 mm.

16. An objective lens according to claim **14**, wherein said rear lens unit is disposed between 0.14 and 0.18 mm from said front lens unit.

17. An objective lens according to claim **14**, wherein the distance between the focal image plane of the lens and the rearmost surface of said rear lens unit is between 1.2 and 1.4 mm.

* * * * *

United States Patent [19]

Metabi

[11] Patent Number: 4,525,037

[45] Date of Patent: Jun. 25, 1985

[54] OBJECTIVE LENS ASSEMBLY OF VARIABLE FOCAL LENGTH HAVING A DIAPHRAGM MECHANISM WITH ADJUSTABLE APERTURE

[75] Inventor: Tsuneyo Metabi, Sakai, Japan

[73] Assignee: Minolta Camera Kabushiki Kaisha, Osaka, Japan

[21] Appl. No.: 502,204

[22] Filed: Jun. 8, 1983

[30] Foreign Application Priority Data

Jul. 9, 1982 [JP] Japan 57-120320

[51] Int. Cl.³ G02B 9/08; G02B 7/10

[52] U.S. Cl. 350/450; 350/429

[58] Field of Search 350/450, 449, 448, 429, 350/430, 423–428; 354/195.11

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Primary Examiner—Jon W. Henry

Attorney, Agent, or Firm—Watson, Cole, Grindle & Watson

[57] ABSTRACT

A zoom lens assembly for use with a photographic camera having a capability of functioning two different modes one at a time. In one mode, the lens assembly is of a type having its aperture ratio variable with change in focal length, and in the other mode, it is of a type wherein change in aperture ratio resulting from the change in focal length is compensated for to give a uniform aperture ratio at all focal length settings. For this purpose, a unique change-over mechanism is built in the lens assembly for switching the lens assembly from one of the different modes onto the other of the different modes at the will of a photographer.

22 Claims, 37 Drawing Figures

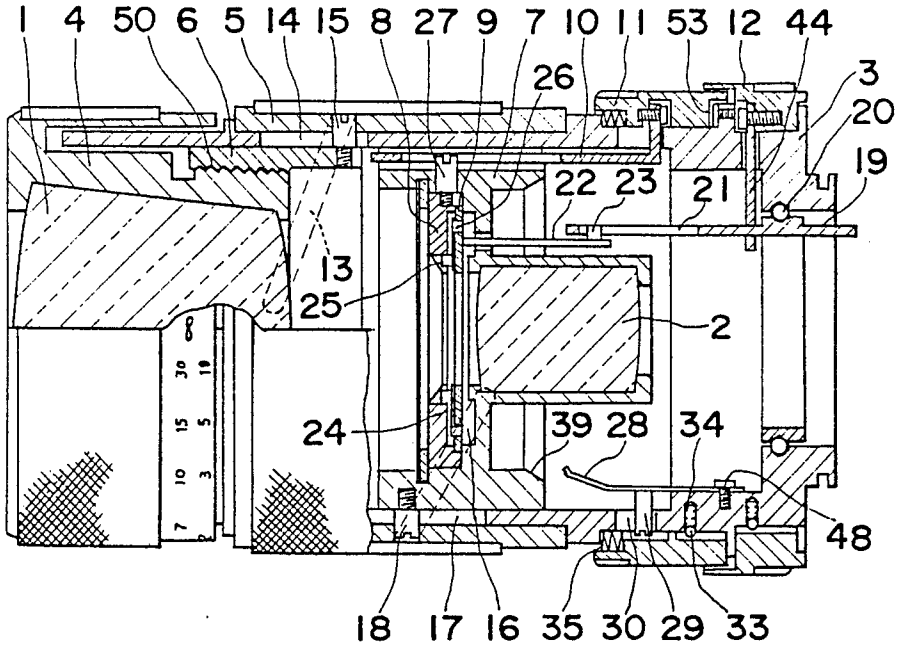

Fig. 1

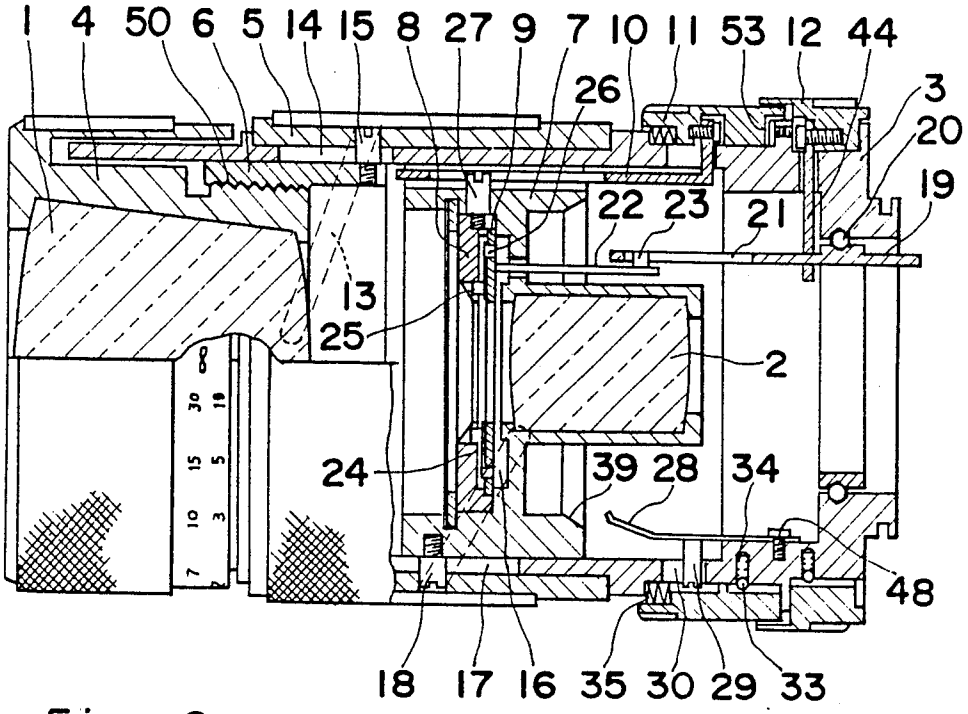
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Fig. 2

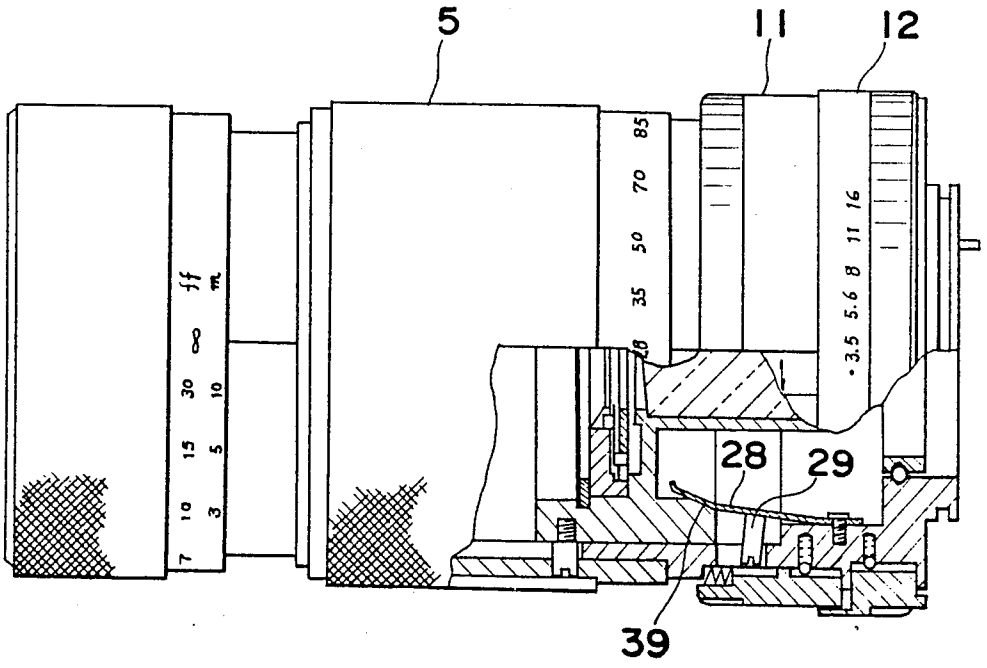
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Fig. 3

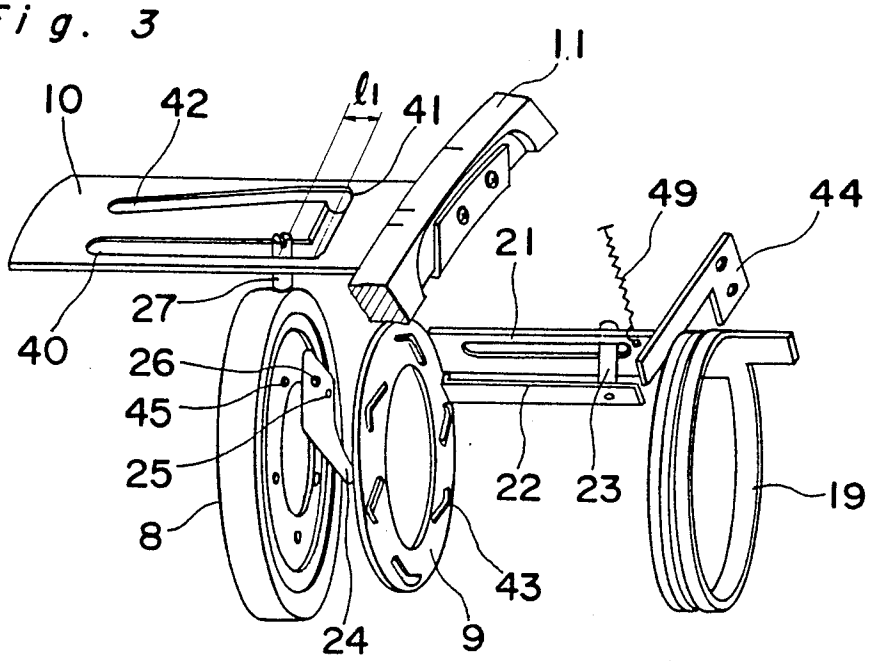
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Fig. 4

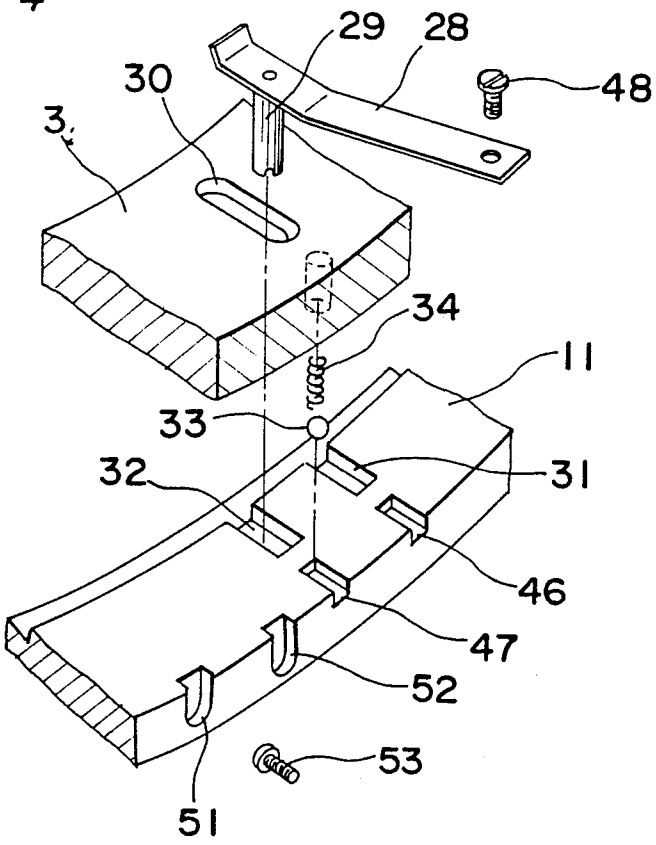
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Fig. 5

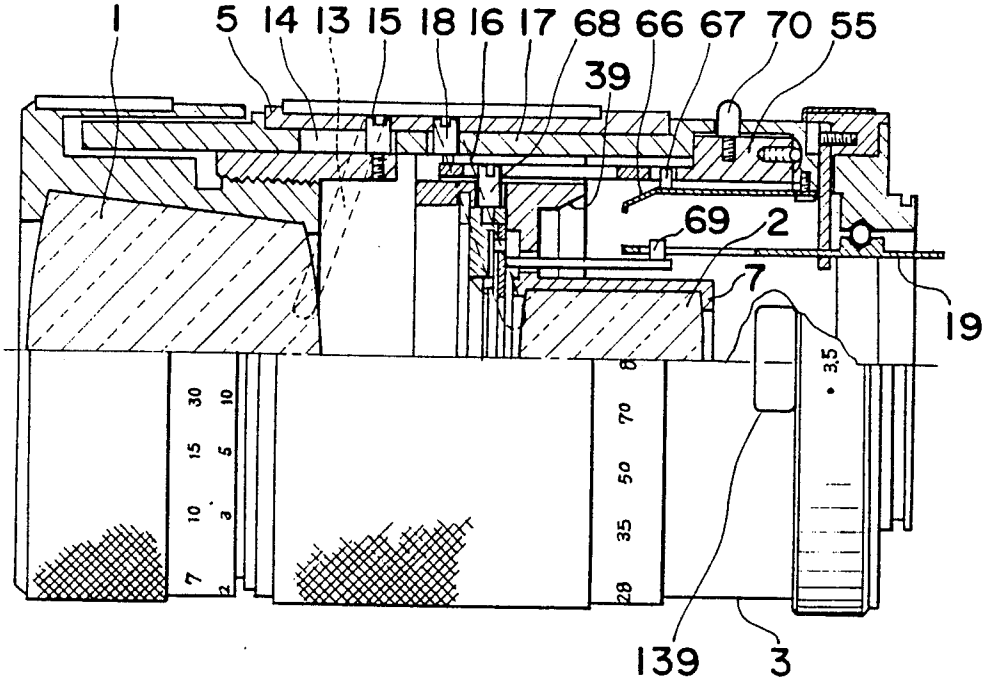
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Fig. 6

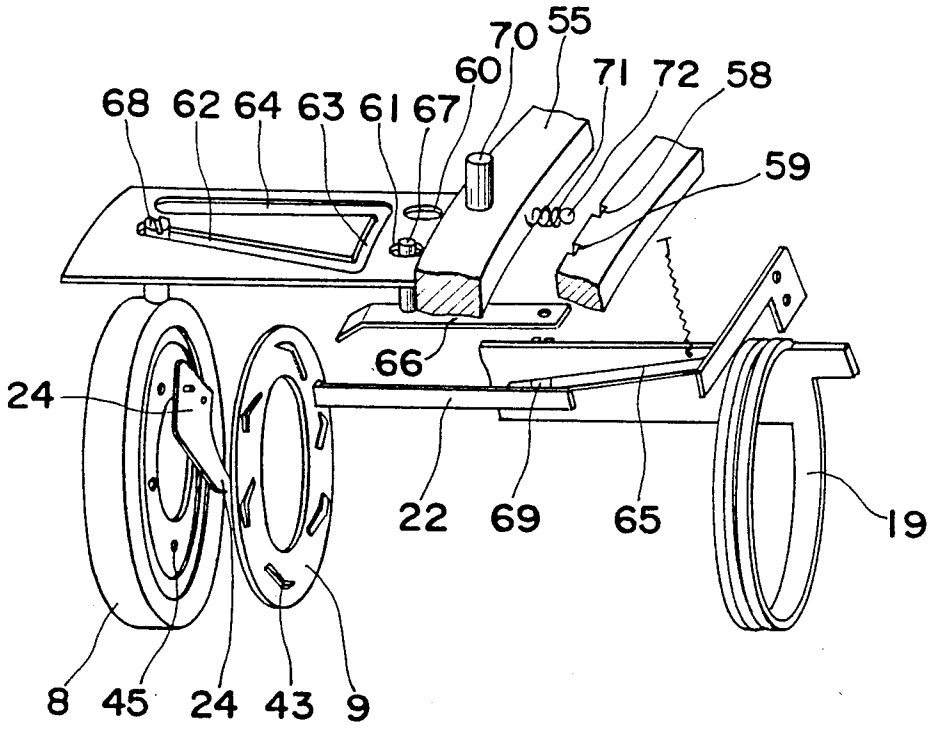
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Fig. 7

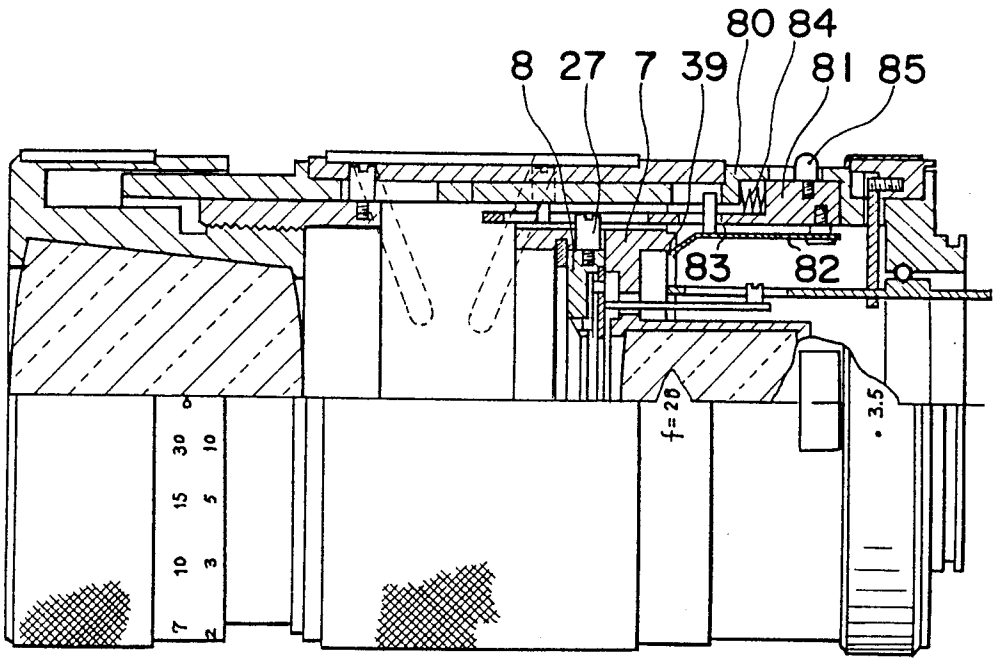


Fig. 11(a) Fig. 11(c) Fig. 11(e)
Fig. 11(b) Fig. 11(d)

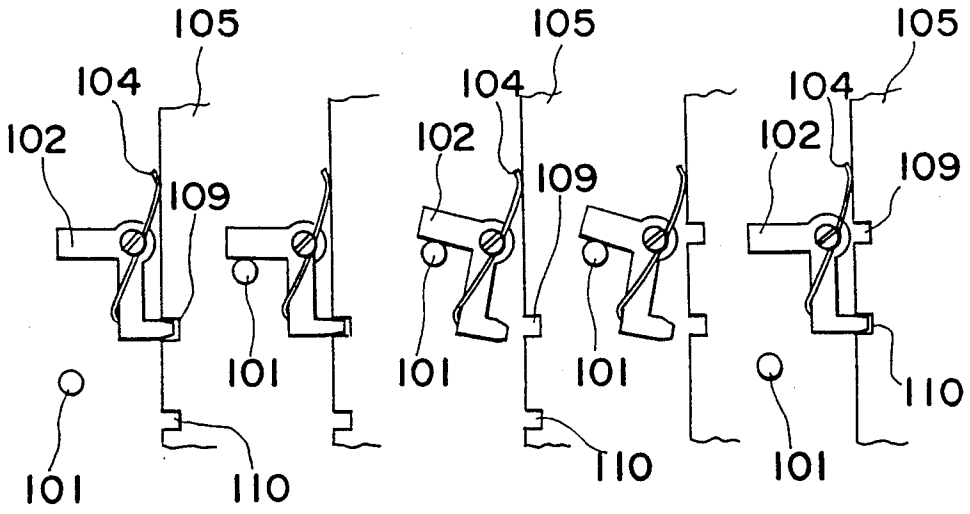


Fig. 8

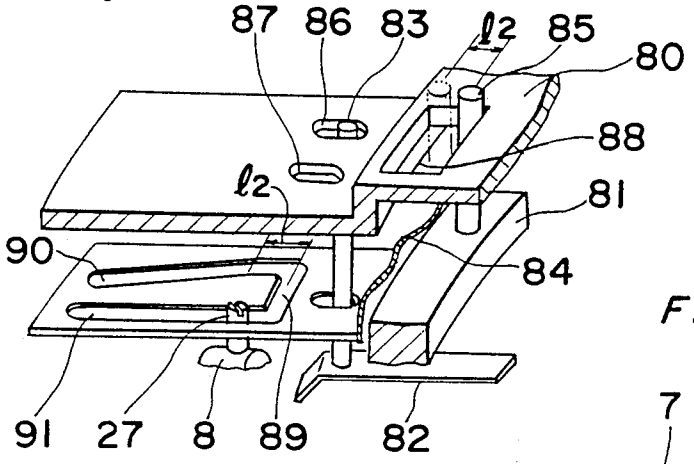


Fig. 9

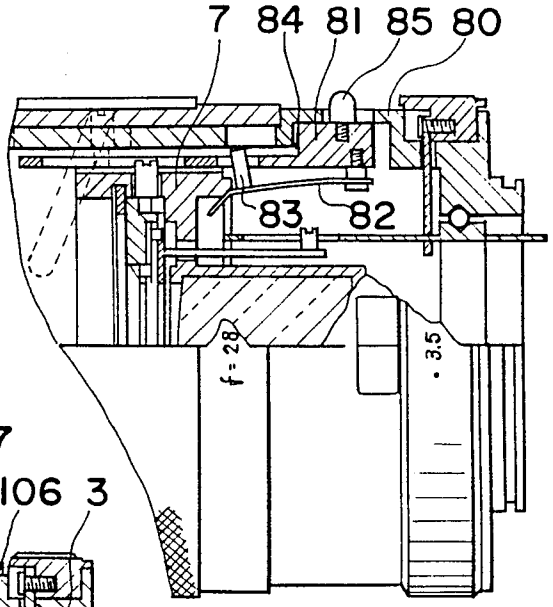


Fig. 10

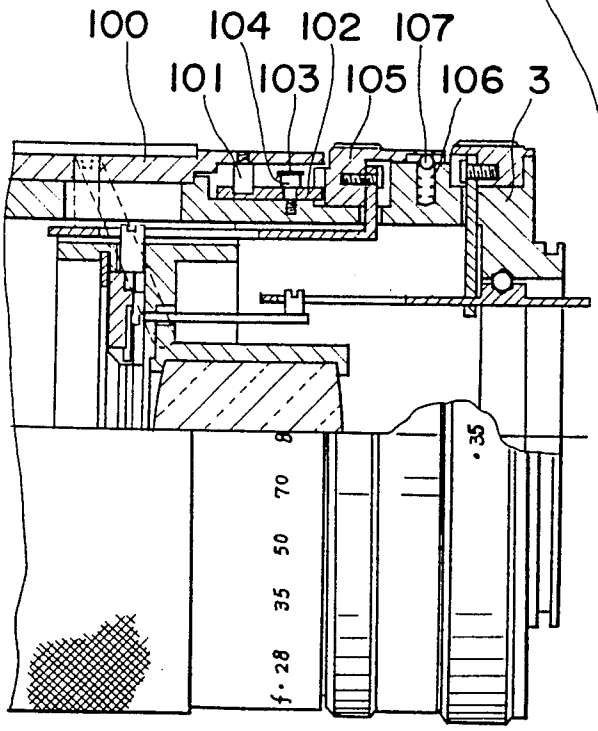


Fig. 12

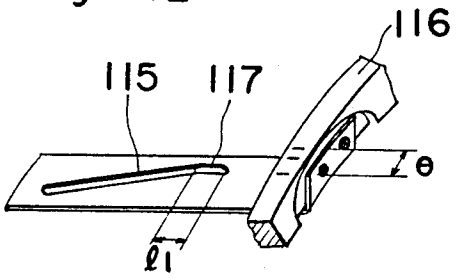


Fig. 13

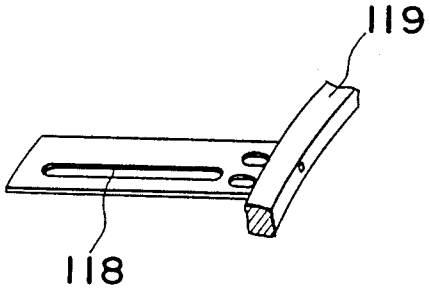


Fig. 14

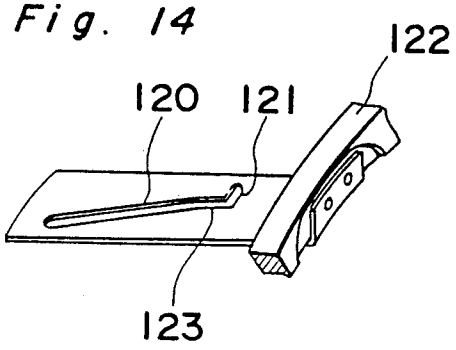


Fig. 15 (a)

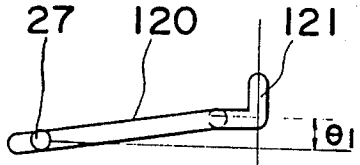
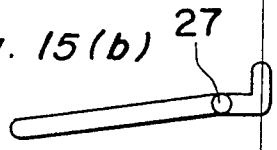


Fig. 15 (b)



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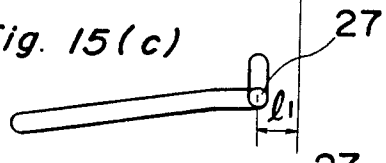


Fig. 15 (d)

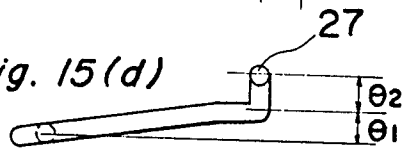


Fig. 16

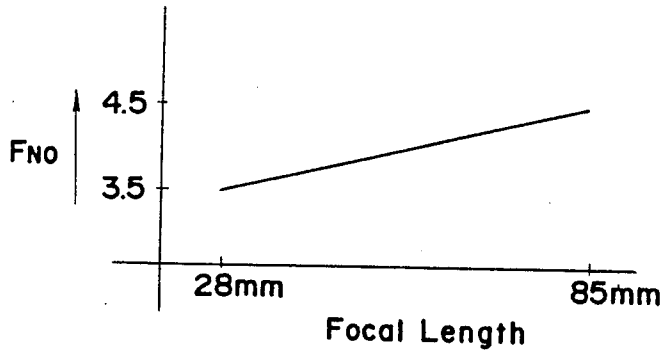
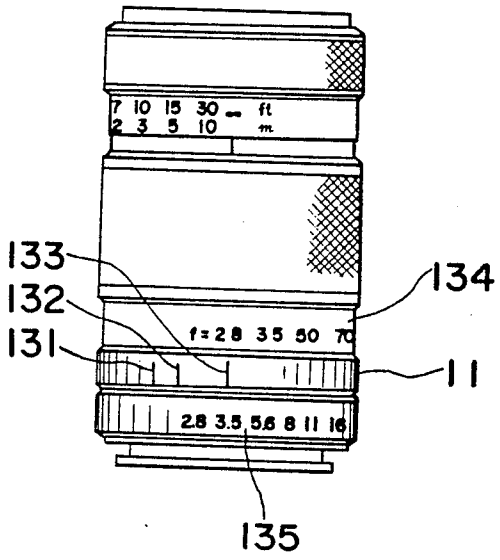


Fig. 17



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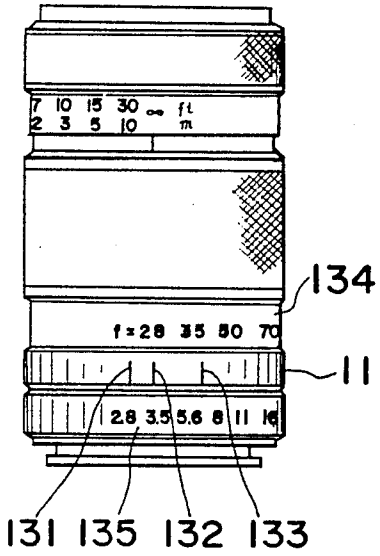


Fig. 19

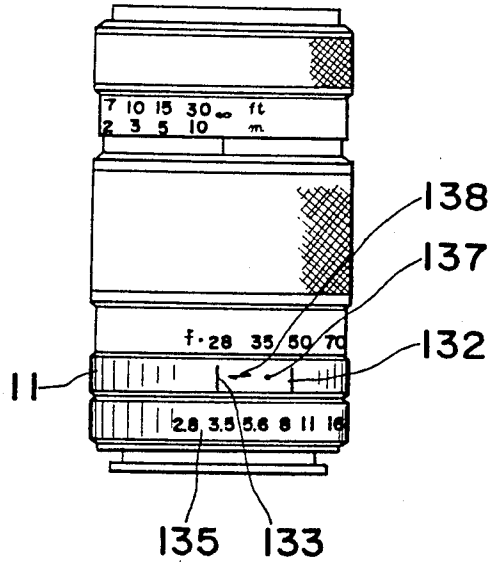


Fig. 20

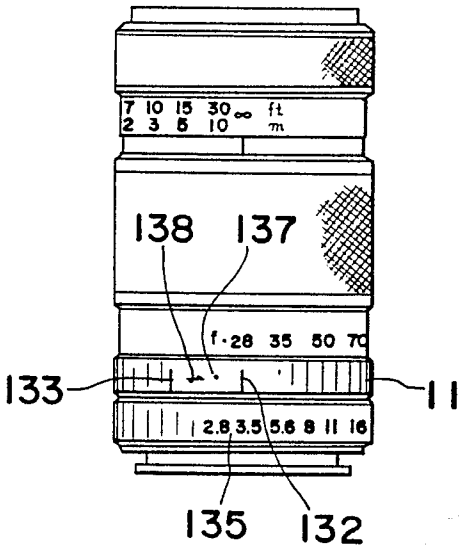


Fig. 21

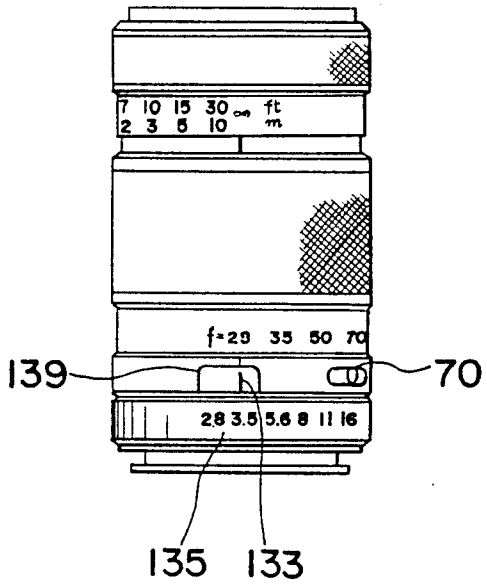
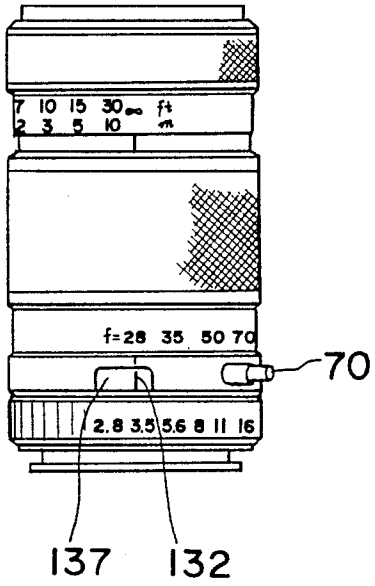


Fig. 22



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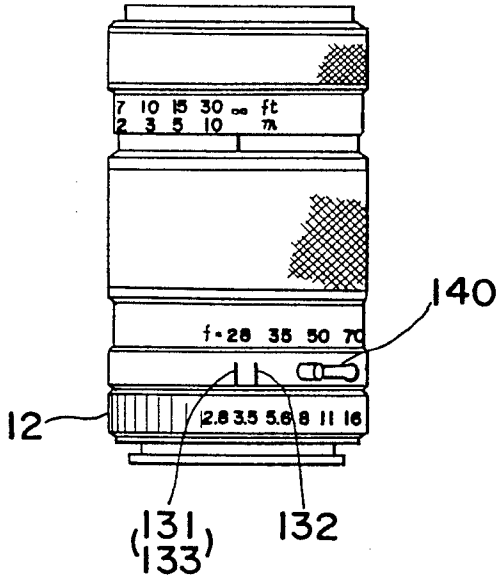

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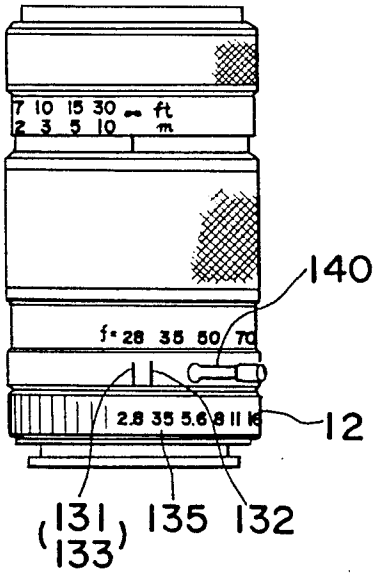

Fig. 25(a)

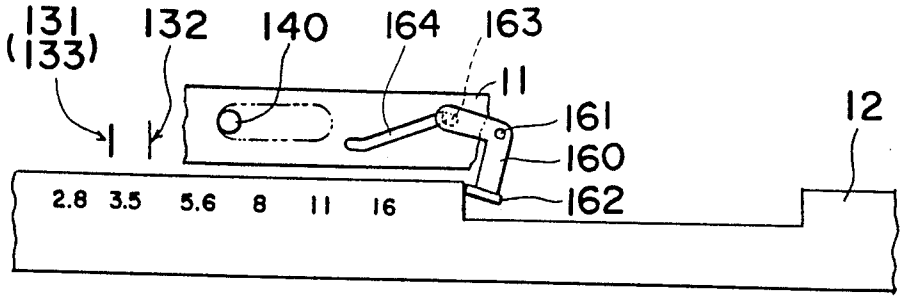

Fig. 25(b)

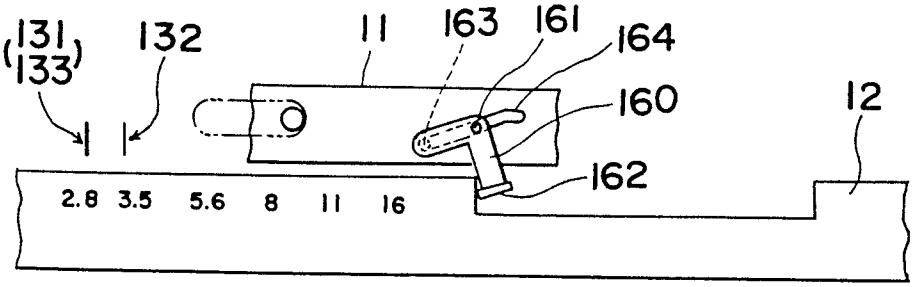

Fig. 26

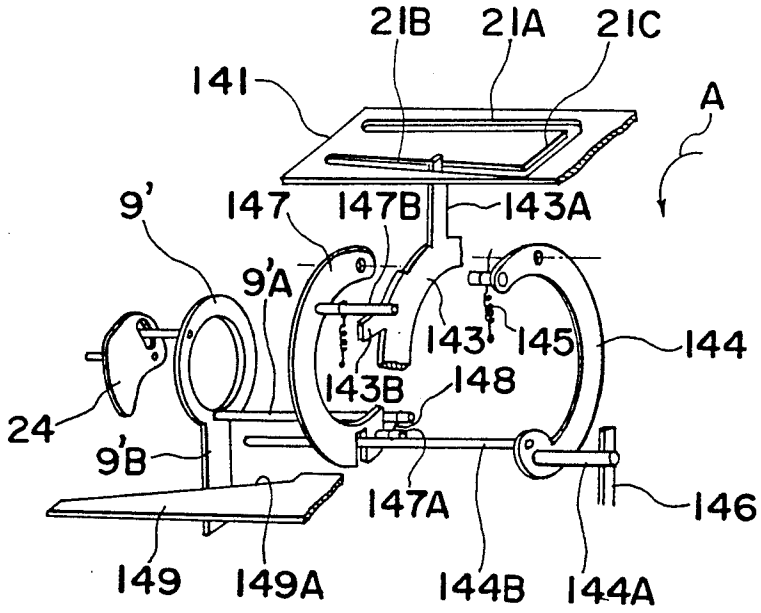

Fig. 27

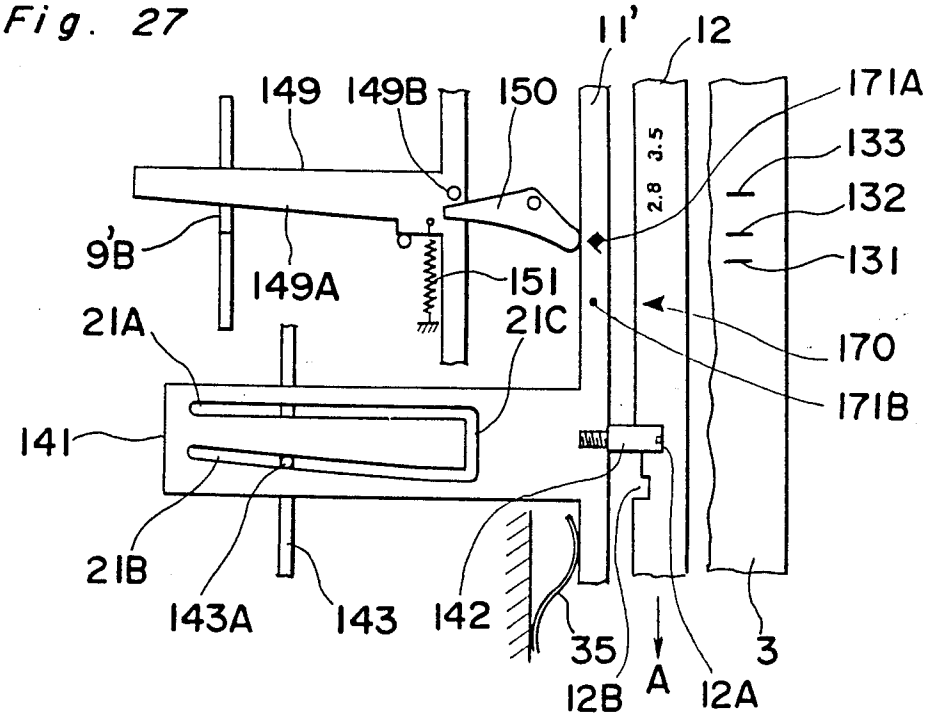
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Fig. 28

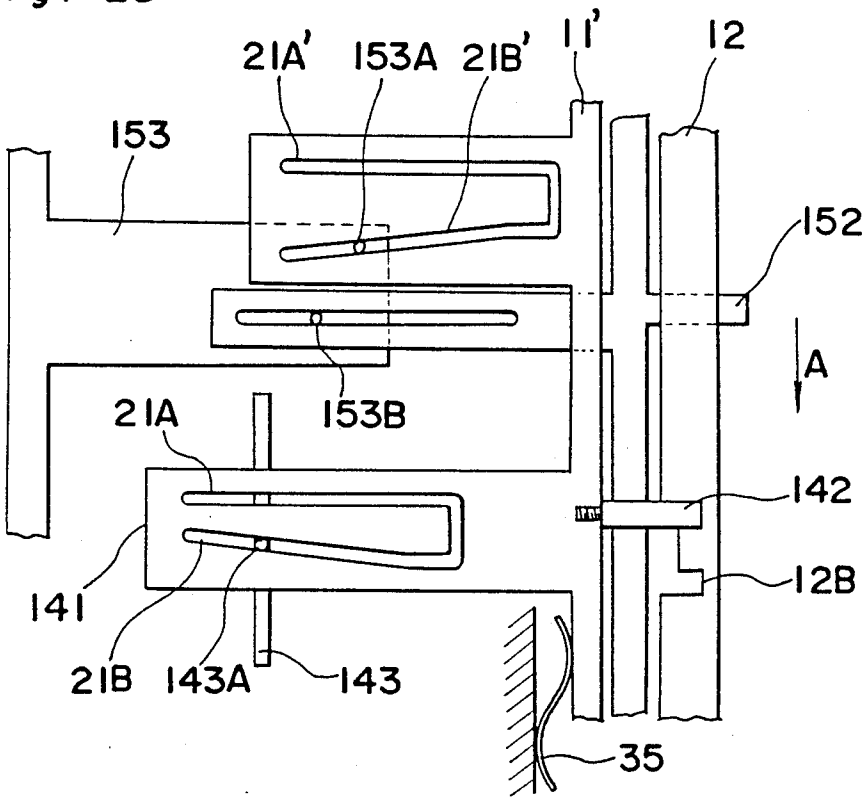
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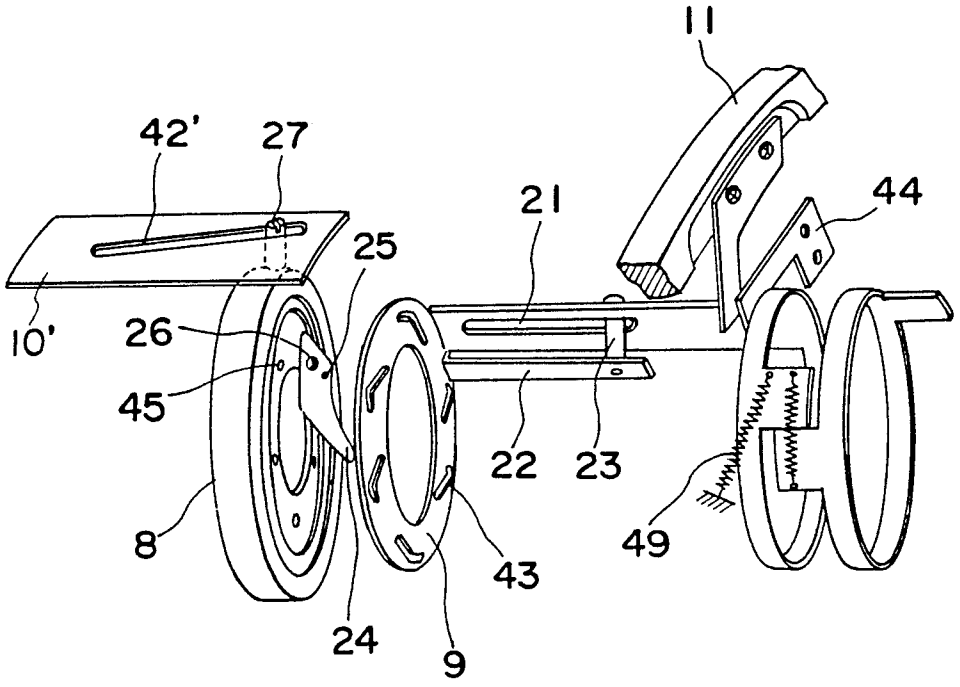
Fig. 29



OBJECTIVE LENS ASSEMBLY OF VARIABLE FOCAL LENGTH HAVING A DIAPHRAGM MECHANISM WITH ADJUSTABLE APERTURE

BACKGROUND OF THE INVENTION

This invention generally relates to an objective lens assembly of variable focal length for use with an optical picture taking apparatus, for example, a photographic still camera, a movie camera or a television camera. More particularly, this invention relates to a varifocal lens assembly of a type wherein the lens speed or the aperture ratio of the lens assembly varies with a change in the focal length.

Current commercially available zoom lens assemblies are generally classified into fixed speed types whose optical systems are designed such that the lens speed or the aperture ratio does not vary even when the focal length thereof is adjusted for zooming with the diaphragm aperture kept unchanged, and variable speed types whose optical systems are designed such that the lens speed or the aperture ratio varies when the focal length thereof is adjusted with the diaphragm aperture kept unchanged. The variable speed type zoom lens assemblies are furthermore classified into two subtypes: compensated types, wherein a mechanical compensator system is built in for compensating for change in lens speed resulting from an change in the focal length, and non-compensated type wherein the lens speed is allowed to vary with change in the focal length without any compensator system employed. Both of these subtypes have their own merits and demerits, however they play a role in the market to accommodate a diversity of customers' demands.

As is well known to those skilled in the art, for a given diaphragm aperture, the variable speed type is generally faster, i.e., has a smaller F-stop number at the shortest focal length setting than at the longest focal length setting. To compensate for the reduction of the lens speed to make the lens speed constant at all values of focal length, means must be provided for stopping down the diaphragm aperture as the focal length is adjusted to the shortest value, and this is currently embodied in the compensated model such as disclosed in, for example, U.S. Pat. No. 4,258,996. In this compensated model, the maximum available performance of the optical system of the zoom lens assembly cannot be enjoyed, particularly when the focal length is adjusted to a wide angle range. It should be noted that the term "wide angle" hereinabove and hereinafter used and the term "tele-angle" which will hereinafter be used in an opposite sense to the term "wide angle," are a relative notation applicable to a particular adjustable range of focal length of a given zoom lens assembly and correspond respectively to the reading on a focal length setting element such as, for example, a zooming ring, approaching the shortest focal length and that approaching the longest focal length. By way of example, for any zoom lens assembly having it focal length adjustable within a range of 28 mm to 55 mm, the focal length setting to a value on the side of the 55 mm position or the longest focal length may be said to be the setting to the "wide angle" range and that to the "tele-angle" range, respectively.

As hereinbefore described, in the variable speed zoom lens assembly of the compensated type, the maximum available performance of the optical system is sacrificed at the wide angle range to tailor the lens speed or aperture ratio to a value given at the longest available focal length setting. However, this compensated model is generally considered convenient in that, since in practice the smallest available aperture reading, that is, F-stop number, on the aperture setting ring is calibrated to a value given at the longest available focal length setting, the photographer need neither readjust the aperture setting ring in an attempt to compensate for reduction in lens speed resulting from the change of the focal length, nor keep in mind the necessity of such a readjustment, and, also, the lens assembly has a consistency with the exposure control system of a photographic camera. On the other hand, although the variable speed zoom lens of non-compensated type, such as disclosed in, for example, Modern Photography, November 1977, Vol. 41, No. 11, pages 164 to 168, is advantageous in that the maximum available performance of the optical system can be fully enjoyed at any focal length setting, not only does the layout in the non-compensated model of the aperture reading on the aperture setting ring in combination with an index marking pose a problem, but also the lens assembly lacks a consistency with the exposure control system.

Specifically, in the variable speed zoom lens assembly of the non-compensated type referred to above, the smallest aperture reading on the aperture setting ring includes two F-stop numbers available generally at the wide angle range and the tele-angle range, respectively, in combination with the index marking including the juxtaposed aperture-indicating indicia associated respectively with the smallest F-stop numbers. So far as the lens assembly disclosed in the Modern Photography, supra, is concerned, it is described that the 43–75 mm zoom lens assembly is an f/3.5 for most of its zoom, i.e., the focal length setting, but becomes f/4.5 at the maximum 75 mm setting, and two juxtaposed aperture-indicated indicia are employed in the form of a line and a dot on the fixed barrel around which the aperture setting ring can be rotated.

For better understanding of this invention, the merits and demerits of each of the compensated and non-compensated models of the variable speed zoom lens assemblies will be hereinafter discussed in detail under separate headings.

I. NON-COMPENSATED MODEL

Merits: The maximum available optical performance determined by the design of the optical system can be utilized at the short focal length setting or wide angle range. Since in most cases the wide angle range is used more frequently in indoor photography than in outdoor photography and, so far as the indoor photography is concerned, more frequently than the tele-angle range is, the utilizeability of the designed maximum available optical performance at the largest diaphragm aperture setting, i.e., the smallest F-stop number or aperture reading, has a great significance in that the non-compensated model can permit a picture taking in darker indoor condition than the other model does.

Demerits: With a photographic camera having an exterior metering system, not a TTL (through-the-lens) metering system, in which the determination of a particular exposure value depends on the incoming light not passing through the picture-taking lens assembly, or with a photographic camera having no exposure metering system built therein, it is necessary to line up the selected F-stop number or aperture reading with either

one of the two aperture-indicating indicia to be used respectively at the wide angle range and the tele-angle range. In particular, it is practically impossible for less skilled photographers to set an F-stop number intermediate of the available aperture setting range when the focal length is set to a value intermediate of the available focal length range, i.e., the available zooming range. In addition, in view of the necessity of the use of the two aperture-indicating indicia, it often occurs in great possibility that one of the two indicia might be inadvertently taken for the other of the indicia, resulting in the incorrect diaphragm aperture setting.

When it comes to the camera system utilizing an automatic flash unit of a type so designed as to enable the guide number for a given film speed to be manually adjustable by presetting an F-stop number to the aperture scale on the flash unit, there is a possibility that, unless the F-stop number is correctly preset to the aperture scale with due regard paid to the possible change in aperture setting in the lens assembly as a result of the zooming, the amount of flash light emitted from the flash unit may be controlled on the erroneous information to such an extent as to result in the improper exposure.

In addition, in a certain type of camera wherein the transmission of information of the smallest available F-stop number from an interchangeable lens assembly to the camera body is required when and so long as the lens assembly has been mounted on the camera body, the erroneous exposure setting may occur unless means is provided for transmitting information of the two smallest F-stop numbers available on the non-compensated model according to the focal length setting.

A similar erroneous exposure setting may occur when the focal length of the non-compensated model is adjusted to the shortest value after an AE lock has been effected at the longest focal length setting to memorize a particular diaphragm aperture setting at such longest focal length. This technique is known as a substitute for the center-weighted light measurement, taking advantage of the smallest angle of view the zoom lens assembly can achieve at the longest focal length setting. However, the diaphragm aperture setting once locked or memorized at the longest focal length setting does not remain the same when and after the focal length has been adjusted from the longest setting towards the smallest because of inherent change occurring in the lens speed of the non-compensated type with change in focal length.

II. COMPENSATED MODEL

Merits: The compensated type of the variable speed zoom lens assembly is substantially free from the demerits inherent in the non-compensated model and has a good consistency with the camera system.

Demerits: In designing the optical system of any zoom lens assembly of the variable speed type, the aperture ration thereof at a given diaphragm aperture setting is practically meant to be that attained when the focal length is adjusted to the longest setting and, accordingly, as hereinbefore briefly mentioned, for a given diaphragm aperture setting, the zoom lens assembly is lower at the longest focal length than at the shortest focal length. Therefore, in the manufacture of the compensated model wherein the previously described compensating means is incorporated to avoid the change of the lens speed which would result from change in focal length, the employment of unnecessarily large lens elements for the given smallest F-stop number is necessitated if the compensated model which is reasonably and competitively fast at the smallest focal length setting is desired. This means that not only does the resultant lens assembly become bulky and heavy, but also it cannot make the most of the size-increased lens elements. This is because, if it is desired to manufacture the compensated model reasonably and competitively fast at the smallest focal length setting for a given F-stop number, for example, the smallest available F-stop number. The aperture ratio at the longest focal length, which aperture ratio is known as a quotient of the effective aperture divided by the focal length, must be of a relatively small value and this is generally accomplished by the employment of the relatively large-sized lens elements.

The use of the relatively large-sized lens elements in turn results in the increased difficulty in designing the optical system as a whole and tend to constitute a cause of the reduced image forming performance of the resultant lens assembly. One may consider the possibility of designing the smallest F-stop number available at the longest focal length setting to be determined depending on that available at the shortest focal length setting, rather than to design the smallest F-stop number at the shortest focal length setting to be determined on that at the longest focal length setting. However, this is extremely difficult as a matter of practice in view of the previously described increased design difficulty and the extent of possible reduction in optical performance resulting from design errors. (The error sensitivity, which means the extent to which the optical aberrations, the lens-back and/or the focal length vary for a given error, is, in the case of a zoom lens assembly, apt to be higher at the longest focal length setting than at the short focal length setting range and to increase with increase of the size of the lens elements.)

As hereinbefore discussed, the compensated and non-compensated models of the zoom lens assemblies are compatible with each other in the sense that the demerits of one mode are compensated for by the other model, and vice versa.

SUMMARY OF THE INVENTION

Accordingly, this invention has been developed with a view to minimizing the embarrassment a camera hobbist has hitherto suffered in making a decision of what model of zoom lens assembly to purchase and is intended to provide a unique zoom lens assembly which can be used as compensated and non-compensated models one at a time without sacrificing the maximum available optical performance and without the required use of lens elements of substantially increased size.

According to this invention, the zoom lens assembly is provided with a manipulatable change-over mechanism for bringing the lens assembly selectively into one of the two modes, namely, compensated and non-compensated modes: the lens assembly in the compensated mode function in a manner similar to the previously discussed compensated model, and the same lens assembly in the non-compensated mode in a manner similar to the previously discussed non-compensated model.

The zoom lens assembly having the above-described dual function is believed to have a great significance in its existence as it may appeal to amateur and professional camera lovers, who have long been embarrassed with a diversity of choices of lens assemblies in addition to a diversity of makes of cameras available.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other objects and features of this invention will readily be understood from the following description taken in conjunction with preferred embodiments thereof with reference to the accompanying drawings, in which:

FIG. 1 is a longitudinal sectional view showing a zoom lens assembly according to a first embodiment of this invention with its focal length set to the longest value;

FIG. 2 is a longitudinal side view, with a portion broken away, showing the lens assembly of FIG. 1 with the focal length set in a wide-angle range;

FIG. 3 is a perspective view showing a manipulatable change-over mechanism used in the lens assembly of FIGS. 1 and 2;

FIG. 4 is a perspective view, on an enlarged scale, showing a detent arrangement operatively associated with the change-over mechanism of FIG. 3;

FIG. 5 is a longitudinal side view, with a portion broken away, showing the lens assembly according to a second embodiment of this invention;

FIG. 6 is a view similar to FIG. 3, showing the change-over mechanism used in the lens assembly of FIG. 5;

FIG. 7 is a view similar to FIG. 5, showing the lens assembly according to a third embodiment of this invention;

FIG. 8 is a perspective view showing the change-over mechanism used in the lens assemmbly of FIG. 7;

FIG. 9 is a view similar to FIG. 7, showing a portion of the lens assembly of FIG. 7 with the focal length set to the smallest value;

FIG. 10 is a view similar to FIG. 9, showing the lens assembly according to a fourth embodiment of this invention;

FIGS. 11(a) to 11(e) are schematic diagrams showing the sequence of operation of a safety mechanism used in the lens assembly of FIG. 10;

FIG. 12 to FIG. 14 are perspective views of a portion of the change-over mechanism according to fifth, sixth and seventh embodiments of this invention, respectively;

FIGS. 15(a) to 15(d) are schematic diagrams showing the sequence of operation of the change-over mechanism shown in FIG. 14;

FIG. 16 is a graph showing the relationship between the focal length setting and the aperture reading, i.e., F-stop numbers;

FIGS. 17, 19, 21 and 23 are side views of the zoom lens assembly set in a compensated mode, showing first, second, third and fourth embodiments of aperture-indicating marking, respectively;

FIGS. 18, 20, 22 and 24 are views similar to FIGS. 17, 19, 21 and 23, respectively, showing the zoom lens assembly set in a non-compensated mode;

FIGS. 25(a) and 25(b) are diagrams showing a diaphragm aperture adjusting ring of FIGS. 23 and 24 developed in a plane, together with a stopper in different operative positions, respectively;

FIG. 26 is a perspective view showing the change-over mechanism according to an eighth embodiment of this invention;

FIG. 27 is a schematic top plan view of the change-over mechanism of FIG. 26;

FIG. 28 is a view similar to FIG. 27, showing the change-over mechanism according to a ninth embodiment of this invention; and

FIG. 29 is a view similar to FIG. 26, showing a modified form of the change-over mechanism included within the scope of this invention.

DETAILED DESCRIPTION OF EMBODIMENTS

FIGS. 1 to 4 illustrate a zoom lens assembly according to a first embodiment of this invention. Referring to FIGS. 1 to 4, the lens assembly shown particularly in FIGS. 1 and 2 comprises its optical system including, for example, a front lens group 1 and a rear lens group 2, and a diaphragm mechanism movable together with the rear lens group 2 in a direction parallel to the optical axis of the system, the diaphragm mechanism being comprised of a ring-shaped diaphragm holder 8 and a diaphragm operating ring 9. The lens assembly also comprises a zooming ring 5 supported for rotation about the optical axis for the adjustment of the focal length of the lens assembly, a diaphragm aperture adjusting ring 12 operatively coupled to the diaphragm mechanism and mounted for rotation about the optical axis, and a change-over ring 11 mounted for rotation through a limited angle about the optical axis and positioned between the rings 5 and 12 in front of the ring 12, i.e., with respect to the direction in which the lens assembly mounted at its right-hand end to a camera body (not shown) is aimed at a target object to be photographed.

In addition to the diaphragm holder 8 and the diaphragm operating ring 9, the diaphragm mechanism is also comprised of, as best shown in FIG. 3, a plurality of diaphragm blades, only one of which is shown by 24, the blades 24 being so arranged and so supported in a manner known to those skilled in the art that, when the diaphragm operating ring 9 is rotated about the optical axis relative to the diaphragm holder 8, the aperture defined by the blades 24 in coaxial relation to the optical axis can be narrowed and widened one at a time depending on the direction of the relative rotation. It should be noted, however, that, the diaphragm holder 8 can also be rotatable relative to the diaphragm operating ring 9 for the purpose of this invention. The aperture adjusting ring 12 has a lever 44 rigidly secured thereto and extending generally radially inwardly for engagement with an aperture preset ring 19, whereby when the ring 12 is rotated, the rotation of the ring 12 can be transmitted to the diaphragm operating ring 9 through the engagement between a linear groove 21, defined in an axial arm extending axially from the preset ring 19, and a pin 23 received in the linear groove 21 and rigidly secured to the operating ring 9 through an axial lever 22 parallel to the axial arm of the preset ring 19. Thus, it will be readily be seen that, by rotating the aperture adjusting ring 12 to any one of the positions of aperture reading, that is, the F-stop numbers, the diaphragm aperture defined by the blades 24 can be adjusted to a diameter appropriate to the selected F-stop number to which the aperture adjusting ring 12 has been rotated. While the diaphragm mechanism can move together with the rear lens group 2 in a direction axially of the optical system during the zooming with the zooming ring 5 rotated because it is integrally mounted with the rear lens group 2, the rotation of the zooming ring 5 does not result in any angular displacement of the operating ring 9 because the linear groove 21 extends in parallel relation to the optical axis of the lens assembly.

The diaphragm holder 8 has a pin 27 rigidly mounted thereon and extending radially outwardly therefrom for engagement into a continuous guide groove of a generally U-shaped configuration defined in a cam plate 10 rigidly connected to the change-over ring 11, the continuous guide groove being comprised of an axially-extending guide groove portion 40 which extends in parallel relation to the optical axis, a cam groove portion 42 which extends diagonally frontwardly so as to converge with the axial guide groove portion 40 at a point away from the ring 11, and a connecting groove portion 41 located adjacent to the ring 11 and having its opposite ends communicated to the guide and cam groove portions 40 and 42, respectively. In FIG. 3 the pin 27 is shown as engaged in the axial guide groove portion 40 of the continuous guide groove in the cam plate 10 and, in this condition, the diaphragm holder 8 does not undergo any rotation about the optical axis even though the diaphragm mechanism, including the previously described elements 8, 9 and 24, is axially moved as a result of the rotation of the zooming ring 5 during the zooming operation. Thus, so long as the pin 27 is engaged in and guided by the axial guide groove portion 40, the zooming operation does not result in the adjustment of the diaphragm aperture and this means that, for a given diaphragm aperture setting, that is, wherever the aperture adjusting ring 12 is positioned, the lens speed, that is, the aperture ratio of the lens assembly can vary with change in focal length. It is, however, to be noted that the linkage between the holder 8 and the operating ring 9 is so designed as to render the diaphragm aperture at a maximum when the aperture adjusting ring 12 is set or positioned to the smallest available F-stop number.

FIG. 3 illustrates the condition which is attained when the zooming ring 5 has been moved to the shortest focal length position. Starting from this condition, and when the change-over ring 11 is pulled axially frontwardly, or leftwards as viewed in FIGS. 1 to 3, against a compression spring 35 to move the cam plate 10 a predetermined distance shown by 1, in FIG. 3, the pin 27 which has been situated within the axial guide groove portion 40 is brought into alignment with the connecting groove portion 41, the subsequent rotation of the change-over ring 11 from a non-compensated position to a compensated position resulting in the entry of the pin 27 into the cam groove portion 42 through the connecting groove portion 41. When an external pulling force applied to the change-over ring 11 is released therefrom after the ring 11 has been moved to the compensated position about the optical axis with the pin 27 having consequently brought into engagement in the cam groove portion 42, the subsequent zooming operation, that is, the subsequent rotation of the zooming ring 5, results in the angular movement of the diaphragm holder 8 about the optical axis relative to the operating ring 9 as the pin 27 is guided in and along the cam portion 42 in a direction away from the connecting groove portion 41. The result is that the diaphragm aperture defined by the blades 24 varies in a direction required to compensate for a change in aperture ratio resulting from the change in the focal length. This is possible because, as the zooming ring 11 is rotated from the shortest focal length position towards the longest focal length position while the aperture adusting ring 12 is set at a given F-stop number, for example, the smallest F-stop number, the diaphragm mechanism moves axially frontwardly in such a manner that, while the operating ring 9 is moved axially with the pin 23 guided in and along the linear groove 21, the diaphragm holder 8 undergoes axial and rotary motion with the pin 27 guided in and along the cam groove portion 42 of the groove in the cam plate 10.

FIGS. 5 and 6 pertain to a second embodiment of this invention which will now be described in connection with what makes this second embodiment differ from the preceding embodiment. Comparing FIG. 6 with FIG. 3, it will readily be seen that cam and axial guide groove portions 62 and 64, both shown in FIG. 6, take the position of axial guide and cam groove portions 40 and 42, respectively. In addition, the arrangement has been made such that, during the zooming operation, the diaphragm mechanism as a whole can undergo axial and rotary motion with respect to the optical axis with no relative rotation taking place between the diaphragm holder 8 and the operating ring 9 and, consequently, without the diaphragm aperture being varied. This is true when and so long as a pin 68 (which functionally corresponds to the pin 27 shown in FIG. 3) is engaged in the cam groove portion 62. However, when and after the pin 68 has been brought into engagement in the axial guide groove portion 64 (which functionally corresponds to the cam groove portion 42 shown in FIG. 3), and when the zooming operation is subsequently initiated, the diaphragm holder 8 does not rotate, but the operating ring 9 rotates and, accordingly, the diaphragm aperture changes in a manner so as to compensate for the change in aperture ratio resulting from the change in focal length.

FIGS. 7, 8 and 9 pertain to a third embodiment of this invention. While the lens assembly according to the embodiment shown in FIGS. 7 to 9 is basically identical with that according to the embodiment shown in FIGS. 1 to 4, this third embodiment is directed to an improvement in a lock mechanism. In general, in any one of the foregoing embodiments, the change-over of the zoom lens assembly from one of the compensated and non-compensated modes into the other of these modes can be effected when the zooming ring has been rotated to the shortest focal length position. While the lens assembly in any one of the foregoing embodiments employs a click-stop mechanism operable to avoid any unnecessary or accidental change-over of the modes, the lens assembly in this third embodiment shown in FIGS. 7 to 9 employs a lock pin 83.

As best shown in FIGS. 7 and 8, the lock pin 83 is carried by a change-over ring 81 (which functionally corresponds to the change-over ring 11 shown in FIGS. 1 to 4) through an elongated leaf spring 82 and has its free end normally engaged in one of the lock holes 86 and 87 defined in a portion of a fixed barrel 80 thereby to prevent the change-over ring 81 from being accidentally or unnecessarily rotated and, hence, to lock the lens assembly in one of the compensated and non-compensated modes. In this condition, the mode change-over of the lens assembly cannot be effected. However, when the zooming ring is rotated to the shortest focal length position with the rear lens group consequently moving rightwards as viewed in FIG. 7, a tapered area 39 at the righthand, rear end of a movable lens mount 7 for the rear lens group is brought into engagement with the leaf spring 82 ready to depress the latter downwards as viewed in FIG. 7. While the turn of the change-over ring 81 about the optical axis after the lock pin 83 has disengaged from the one of the lock holes 86 and 87 results in the change-over of the lens assembly from the

one of the compensated and non-compensated modes to the other of the compensated and non-compensated modes, this can be accomplished by pulling a change-over pin **85** on the change-over ring **81** in a direction leftwards, as viewed in FIG. **7**, to displace the leaf spring **82** together with the change-over ring **81** in a direction leftwards against a compression spring **84** so that the free end of the leaf spring **82** can be forced to displace downwards, as viewed in FIG. **7**, against its own resiliency in sliding contact with the tapered area **39** with the free end of the lock pin **83** consequently disengaged from the one of the lock holes **86** and **87** as best shown in FIG. **9**, thereby conditioning the lens assembly ready to be switched over from the one of the compensated and non-compensated modes. The actual change-over will be described in detail later.

The fourth embodiment of this invention shown in FIGS. **10** and **11** is similar to the foregoing embodiment shown in FIGS. **7** to **9** in that it pertains to the lock mechanism, but in a modified form.

FIG. **12**, FIG. **13** and FIGS. **14** and **15** pertain, respectively, to fifth, sixth and seventh embodiments of this invention, which will be described later in detail.

FIGS. **17** to **24** illustrate different embodiments of aperture-indicating markings provided on the zoom lens assembly according to this invention. While the aperture-indicating may be a simple aperture-indicating indicium, for example, either a line or a dot, so far as any one of the fixed speed type and the compensated model is concerned, the zoom lens assembly having the capability of functioning as the compensated and non-compensated models such as according to this invention must have two or more aperture-indicating indicia to be used one at a time according to the mode to which the lens assembly has been selected. For this purpose, the embodiments shown in FIGS. **17** to **24** are provided, the details of which will be set forth later.

FIGS. **26** and **27** illustrate different forms of application of this invention to lens assemblies having different types of diaphragm mechanisms, respectively, and FIGS. **28** and **29** illustrate other embodiments of this invention, reference to all of which will be made later.

While the various embodiments of this invention have been described briefly in the foregoing description, the details thereof including the embodiments not mentioned in the foregoing description will now be described.

FIRST EMBODIMENT (FIGS. 1 TO 4)

Referring to FIGS. **1** to **4**, the zooming operation (the focal length setting), the focusing operation (the distance setting) and the diaphragm aperture setting of the zoom lens assembly will be described. The zoom lens assembly shown in this embodiment has a two-component optical system including the front and rear lens groups **1** and **2** which are supported for movement in predetermined directions upon rotation of the zooming ring **5**. Particularly, during the zooming operation, the movement of the front lens group **1** is effected by the utilization of a diagonal cam groove **13** defined in the zooming ring **5**, an axial guide groove **14** defined in a fixed barrel **3**, and a guide pin **15**, and the movement of the rear lens group **2** is effected by the utilization of a diagonal cam groove **16** defined in the zooming ring **5**, an axial guide groove **17** defined in the fixed barrel **3**, and a guide pin **18**. The focusing operation can be done by rotating a focusing ring **4** to move the front lens group guided by a helicoid thread **50** defined in a movable lens mount **6** for the front lens group **1**. The diaphragm mechanism including the diaphragm blades can be moved together with the movable lens mount **7** for the rear lens group **2** in a direction parallel to the optical axis.

The diaphragm aperture setting will now be described. The diaphragm blades **24** have respective pairs of rivets **25** and **26** rigidly mounted thereon in spaced relation, the rivets **26** being engaged in respective cam slots **43** defined in the diaphragm operating ring **9**, while the rivets **25** are pivotally received in respective bearing holes **45** in the diaphragm holder **8**. The pin **27** rigidly mounted on the diaphragm holder **8** and extending radially outwardly therefrom is engaged in the continuous guide groove including the guide, connecting and cam portions **41**, **42** and **43** and defined in the cam plate **10** fast or integral with the change-over ring **11**. On the other hand, the pin **23** rigidly mounted on the axial lever **22** fast or integral with with operating ring **9** is engaged in the linear groove **21** in the preset ring **19**. The preset ring **19** is normally biased by a coil spring **49** in a direction counterclockwise as viewed in the direction in which the lens assembly is aimed (at the target object to be photographed), with the diaphragm blades **24** consequently stopped down to the smallest available aperture, that is, the greatest available F-stop number while the rotation of the preset ring **19** is restricted by the lever **44** fast with the aperture adjusting ring **12**. It is to be noted that, when the aperture adjusting ring **12** is rotated about the optical axis in a direction counterclockwise as viewed in the direction in which the lens assembly is aimed (at the target object), the lever **44** moves angularly together with the adjusting ring **12** and the preset ring **19** rotates as pulled by the coil spring **49** in pursuit of and after the lever **44**, the rotation of the preset ring **19** being consequently transmitted to the operating ring **9** through the arm of the ring **19**, then the pin **23** and, finally, the axial lever **22**, whereby the diaphragm blades **24** can be stopped down towards the smallest available aperture with the rivets **26** guided in and along the respective cam slots **43**.

Hereinafter, the manner of change of the diaphragm aperture defined by the diaphragm blades **24** as a result of the zooming operation will be described. As hereinbefore described, the diaphragm mechanism, including the blades **24**, the holder **8** and the operating ring **9**, can be axially moved together with the rear lens group when the zooming operation is initiated. So long as the pin **27** on the holder **8** is engaged in the axial guide groove portion **40** of the continuous guide groove of generally U-shaped configuration in the cam plate **10**, the cam holder **8** does not undergo rotary motion about the optical axis during the axial movement of the diaphragm mechanism as a whole. Similarly, even the operating ring **9** does not undergo rotary motion about the optical axis, but moves axially with the pin **23** guided in and along the linear groove **21** in the preset ring during the zooming operation. Thus, so long as the pin **27** is engaged in the guide portion **40** as shown in FIG. **3**, the lens assembly is held in the non-compensated mode in which the diaphragm aperture defined by the diaphragm blades **24** does not vary, that is, the aperture ratio of the lens assembly at any diaphragm aperture setting can vary with change in focal length. Given the 28–85 mm, f/3.5–4.5 zoom lens assembly, the smallest aperture ratio of 3.5 available at the shortest focal length setting of 28 mm varies to the aperture ratio of 4.5 when the focal length is adjusted to the longest

setting of 85 mm in a manner as shown in the graph of FIG. 16, so long as the pin 27 is engaged in the axial guide groove portion 40, that is, the lens assembly is held in the non-compensated mode.

However, when the zooming operation is effected while the pin 27 is engaged in the cam groove portion 42, the diaphram holder 8 undergoes not only axial motion, but also rotary motion about the optical axis because of the shape of the cam groove portion 42 while the operating ring 9, though moved axially together with the diaphragm holder 8, does not rotate about the optical axis. In this condition, the diaphragm aperture defined by the diaphragm blades 24 varies with change in focal length and the lens assembly is therefore in the compensated mode.

The change-over mechanism necessary for bringing the lens assembly selectively from one of the compensated and non-compensated modes into the other of the compensated and non-compensated modes at the will of the user will now be described. The change-over mechanism including the change-over ring 11 also includes a click-stop device for avoiding an unnecessary rotation of the change-over ring 11 during the zooming operation. The click-stop device is constituted by, as best shown in FIG. 4, a pair of spaced lock recesses 51 and 52, a pair of spaced lock recesses 31 and 32, and a pair of spaced click recesses 46 and 47. The pair of lock recesses 31 and 32 are utilized to permit the rotation of the change-over ring 11 only when the zooming ring 5 is set to the shortest focal length position so that the diaphragm holder 8 will not be unnecessarily displaced angularly about the optical axis during the zooming operation. More specifically, the fixed barrel 3 has a leaf spring 28 secured at one end thereto by means of a set screw 48 and also has defined therein a slot 30 slightly wider than the diameter of a lock pin 29 carried by the leaf spring 28. When and so long as the rear movable lens mount 7 for the rear lens group 2 is held at a position corresponding to the longest focal length setting as shown in FIG. 1, the lock pin 29 extending loosely through the slot 30 in the fixed barrel 3 is engaged in one of the lock recesses 31 and 32 both defined in the change-over ring 11 to avoid unnecessary or premature rotation of the change-over ring 11. Where the lens assembly is in the compensated mode, the lock pin 29 is engaged in the lock recess 31, but where it is in the non-compensated mode, the lock pin 29 is engaged in the lock recess 32.

However, when and after the rear movable lens mount 7 has been moved to the opposite position corresponding to the shortest focal length setting as a result of the rotation of the zooming ring 5 as shown in FIG. 2, the tapered area 39 at the rear end of the rear movable lens mount 7 is brought into contact with the free end of the leaf spring 28 thereby upwardly, as viewed in FIG. 2, or radially inwardly, shifting the free end of the leaf spring 28 against it own resiliency to disengage the lock pin 29 from the lock recess in the change-over ring 11. It is, however, to be noted that any accidental or premature rotation of the change-over ring 11 should not occur even when the zooming ring is set to the shortest focal length position. For this purpose, the lock recesses 51 and 52 are provided for engagement with a lock screw 53 rigidly threaded to the fixed barrel 3. In order to release this lock, the change-over ring 11 has to be pulled the predetermined distance, shown by 1_1, in FIG. 3, in the frontward direction against the compression spring 35 and then to be rotated until a detent ball 33 is seated in one of the click recesses 46 and 47. By so doing, the mode change-over is completed. The purpose of the provision of the click recesses 46 and 47 is to make the mode positions for the change-over ring 11 clear, and if a biasing spring 34 for the detent ball 33 is employed in the form as capable of exerting a relatively great biasing force, the lock recesses 51 and 52 as well as the lock screw 53 may not be always necessary and can be omitted.

SECOND EMBODIMENT (FIGS. 5 AND 6)

The lens assembly according to the second embodiment shown in FIGS. 5 and 6 is similar to that according to the first embodiment, but has been improved to enable the mode change-over to be carried out by manipulating a change-over knob 70 in the form of a pin rigidly mounted on and extending radially outwardly from a change-over ring 55, and also to simplify the structure by forming lock holes in the change-over ring 55 and a slant guide groove 65 in an axially extending arm of the preset ring 19. In FIGS. 5 an 6 the lens groups are shown as positioned corresponding to the longest focal length setting. When the zooming ring 5 is rotated, the front lens group 1 is axially moved in the leftward direction, that is, in a direction opposite to the film (not shown) in the camera body, by the utilization of the cam groove 13, the axial guide groove 14 and the guide pin 15 while the rear lens group 2 is moved axially inthe rightward direction, i.e., in the direction towards the film, by the utilization of the cam groove 16, the axial guide groove 17 and the guide pin 18, thereby setting the focal length of the lens assembly in the wide angle range. As a matter of course, the rear movable lens mount 7 is moved together with the rear lens group 2 during the zooming operation. When the rear movable lens mount 7 is subsequently moved righwards towards a position corresponding to the short focal length setting, the tapered area 39 at the rear end of the rear movable lens mount 7 is brought into contact with the bent free end of a leaf spring 66. However, at the moment the rear movable lens mount 7 arrives at such position, the free end of the leaf spring 66 is radially inwardly displaced against its own resiliency in sliding contact with the tapered area 39 of the rear movable lens mount 7 to allow a lock pin 67, rigidly mounted on the leaf spring 66, to disengage from one of the lock holes 60 and 61 defined in the change-over ring 55 so that the subsequent manipulation of the change-over pin 70 so as to turn the change-over ring 55 about the optical axis can result in the mode change-over of the lens assembly.

In addition, in the second embodiment shown, an arrangement is made such that, when and so long as the pin 68 fast with the diaphragm holder 8 is engaged in the cam groove portion 62, the zooming operation does not result in any movement of the diaphragm blades 24 and, therefore, the lens assembly is held in the non-compensated mode. In order to set the lens assembly in the compensated mode, it is necessary to turn the change-over pin 70 through a predetermined angular distance about the optical axis in a counterclockwise direction with respect to the aiming direction, i.e., the direction in which the lens assembly is aimed at the target object, while the lock pin 67 has been disengaged from the lock hole 61 at the shortest focal length setting. As the lock pin 67 is turned in this way, the pin 68 on the diaphragm holder 8 is guided in and along a connecting groove portion 63 towards the axial guide groove portion 64.

When the zooming operation is subsequently effected after the pin 68 has been aligned with the cam groove portion 64, the diaphragm holder 8, while moving axially does not rotate, but the operating ring 9 is rotated a predetermined angle about the optical axis during its axial movement together with the diaphragm holder 8. This is possible because a pin 69 rigidly carried by the operating ring 9 through the axial lever 22 is guided in and along the slant guide groove 65 defined in the arm of the preset ring 19. Accordingly, it is clear that, during the zooming operation, while the pin 68 is guided in the axial guide groove portion 64, the diaphragm blades 24 undergo movement to adjust the diaphragm aperture defined thereby with the lens assembly consequently held in the compensated mode. It is to be noted that a biasing spring 71, a detent ball 72 and click recesses 58 and 59 are all provided for preventing the movement from occurring unnecessarily during the mode change-over with the zooming ring set at the shortest focal length position.

THIRD EMBODIMENT (FIGS. 7 TO 9)

In any one of the foregoing embodiments, the release of the change-over ring from a locked condition has been automatically performed by the utilization of the tapered area 39 of the rear movable lens mount 7 when and so long as the zooming ring has been rotated to both of the smallest and longest focal length positions. In such case, the click or lock mechanism is necessitated to avoid unnecessary or accidental movement of the change-over ring at the shortest focal length setting. In addition, since the release from the locked condition is so designed as to take place against the force of the leaf spring, a higher load or resistance tends to be imposed on the rotation of the zooming ring as the latter is rotated towards the smallest focal length position. This problem can be eliminated by the embodiment shown in FIGS. 7 to 9, reference to which will now be made.

Referring first to FIG. 7, the rear movable lens mount 7 is shown as held at a position corresponding to the shortest focal length setting, in which condition the free end of the leaf spring 82 and the tapered area 39 of the lens mount 7 are held in close vicinity with each other. FIG. 9, however, illustrates the condition in which the change-over pin 85 connected with the change-over ring 81 has been manually pulled against the compression or corrugated spring 84 in a direction away from the camera body, i.e., frontwardly of the lens assembly. In this condition shown in FIG. 9, the leaf spring 82 is radially inwardly yielded with its free end slidingly engaged underneath the tapered area 39 of the lens mount 7, and, at the same time, the lock pin 83 fast with the leaf spring 82 has been disengaged from one of the lock holes 86 and 87.

The mode change-over of the zoom lens assembly according to the third embodiment will hereinafter be described with reference to FIG. 8. When the change-over pin 85 is pulled a predetermined distance, shown by l_2 in FIG. 8, in the direction away from the camera body or frontwardly of the lens assembly while the zooming ring is held in the shortest focal length position, in lock pin 83 is disengaged from the lock hole 86. Simultaneously therewith, since the change-over ring 81 has been displaced frontwardly a predetermined distance l_2 together with the frontward pull of the change-over pin 85, the pin 27 fast with the diaphragm holder 8 is brought in position ready to enter a connecting groove portion 89. When the change-over pin 85 is subsequently turned about the optical axis in the counterclockwise direction with respect to the aiming direction, the pin 27 which has been engaged in an axial guide groove portion 91 moves in and along the connecting groove portion 89 and is then brought in position ready to enter a cam groove portion 90. The release of the pulling force applied to the change-over pin 85 results in that the change-over ring 81 is returned rearwardly by the action of the spring 84 to allow the leaf spring 82 to restore the original shape with the lock pin 83 consequently engaged in the lock hole 87 to avoid unnecessary rotation of the change-over ring 81. It is to be noted that a fixed barrel 80 has an escape scuttle 88 defined therein within the range over which the change-over pin 85 is movable. Since the path of movement of the change-over pin 85 during the change-over operation is generally U-shaped, and if the escape scuttle 88 is so shaped as to be similar to and in alignment with the generally U-shaped path of movement of the change-over pin 85, it is possible to prevent the mode change-over from being performed unless the change-over pin 85 is pulled the distance l_2 frontwardly beforehand.

FOURTH EMBODIMENT (FIGS. 10 AND 11)

The fourth embodiment of this invention is directed to modification of the unlocking of a safety mechanism used to avoid unnecessary or accidental change-over of a change-over ring 105. While in the foregoing embodiments an internal movable member such as, for example, the rear lens mount is utilized, it is operatively associated with a zooming ring 100 which is an external operating member, in the embodiment shown in FIGS. 10 and 11. Specifically, while in the foregoing embodiments the mode change-over is possible the shortest focal length setting because the change-over position depends on the position in the direction parallel to the optical axis which corresponds to the zooming movement of the rear movable lens mount 7, the embodiment shown in FIGS. 10 and 11 is such that the mode change-over depends on the operating position of the zooming ring 100, whereby it is possible to design in such a way that the mode change-over can be performed not only at the shortest focal length setting, but also at the longest focal length setting.

Referring now to FIGS. 10 and 11, the zooming ring 100 has a release pin 101 rigidly secured thereto and extending radially inwardly therefrom. The fixed barrel 3 has a stepped bolt 103 rigidly threaded thereto so as to define the point of pivot for a lock lever 102. The lock lever 102 is normally biased counterclockwise by a torsion spring 104. The change-over ring 105 has a pair of spaced lock recesses 109 and 110 defined therein for engagement with the lock lever 102 one at a time for the purpose of avoiding any unnecessary or accidental rotation of the change-over ring 105. The locking and unlocking of the change-over ring 105 performed one at a time by the lock lever 102 will now be described with particular reference to FIG. 11 comprised of FIGS. 11(a) to 11(e).

Referring first to FIG. 11(a), the zooming ring 100 is shown as held at a position other than the shortest focal length position and, in this condition, the release pin 101 fast with the zooming ring 100 is spaced apart from the locking lever 102 while the latter is engaged in the lock recess 109 to lock the change-over ring 105 in a non-rotatable position. When the zooming ring 100 is rotated towards the shortest focal length position and is

then passed a slight distance over the shortest focal length position as shown in FIG. 11(c), the release pin 101 associated with the zooming ring 100 contacts the lock lever 102 and causes the lock lever 102 to pivot clockwise against the torsion spring 104, thereby releasing the lock lever 102 from engagement in the lock recess 109. When the change-over ring 105 is rotated clockwise with respect to the aiming direction while the condition of FIG. 11(c) has been established, the lock lever 102 moves away from the lock recess 109 relative to the change-over ring 105. Thereafter, the change-over ring 105 is rotated clockwise with respect to the aiming direction until a detent ball 107 is clicked into a click recess 106, their condition being shown in FIG. 11(d). When the zooming ring 100 is subsequently rotated counterclockwise with respect to the aiming direction to effect the focal length adjustment, the release pin 101 is disengaged from the lock lever 102 and the lock lever 102 is engaged in the lock recess 110, thereby locking the change-over ring 105 in the non-rotatable position to avoid any unnecessary or accidental rotation of the change-over ring 105.

FIFTH AND SIXTH EMBODIMENTS (FIGS. 12 AND 13)

FIG. 12 and FIG. 13 illustrate an essential portion according to the fifth and sixth embodiments of this invention, respectively. The lens assembly according to any one of the foregoing embodiments is of a design wherein, when and so long as it is set in the non-compensated mode, the aperture ratio thereof can continuously vary with change in focal length in the manner as shown in the graph of FIG. 16. The zoom lens assembly according to any one of the embodiments shown in FIGS. 12 and 13 is of such a design that the diaphragm mechanism can be adjusted to give a greater diaphragm aperture, that is, a smaller F-stop number, only at the shortest focal length setting.

Referring to FIG. 12, instead of the use of the cam plate 10 integral with the change-over ring 11, a change-over ring 116 having a slant cam groove 115 and an axial guide groove 117 contiguous to the cam groove 115 is employed. The function of the cam groove 115 is substantially identical with that of the cam groove 42 shown in FIGS. 1 to 4 and is so shaped and so designed that the diaphragm aperture defined by the diaphragm blades can vary with the zooming with the lens assembly consequently held in compensated mode (see the description of the first embodiment.). Since the function of the change-over ring 116 having the slant cam groove 115 is substantially identical with that of the change-over ring 11 shown in FIGS. 1 to 4, description concerning the possibility of adjustment with the change-over ring 116 to increase the diaphragm aperture to a greater diameter only at the shortest focal length setting will now be made with reference to not only FIG. 12 but also FIGS. 1 to 4.

As the zooming ring 5 is rotated towards the smallest focal length position, the rear movable lens mount 7 is moved together with the diaphragm mechanism towards the camera body with the tapered area 39, consequently displacing the leaf spring 28 radially inwardly against the resiliency of the leaf spring 28 as hereinbefore described. With the leaf spring 28 so displaced, the locking of the change-over ring 116 performed by the lock pin 29 is released (FIG. 2). When the change-over ring 116 is pulled the predetermined distance l_1 against the spring 35 and then rotated a predetermined angle θ counterclockwise about the optical axis with respect to the aiming direction, the diaphragm holder 8 is rotated together with the pin 27 to move the diaphragm blades 24 in such a direction as to increase the diaphragm aperture defined thereby. In this way, at the shortest focal length setting, operation is possible to adjust the diaphragm aperture to a greater diameter, that is, to adjust the F-stop number to a smaller reading.

Shown in FIG. 13 is a version in which the change-over ring 55 shown in FIG. 6 is replaced with a change-over ring 119 having an axial guide groove 118 defined therein for engagement with the pin 68 connected to or integral with the diaphragm holder 8. This version is applicable where the groove defined in the arm of the preset ring 19 is constituted by the slant guide groove 65 shown in FIG. 6. The operation necessary to adjust the diaphragm aperture to a greater diameter, i.e., to adjust the F-stop number to a smaller reading, is similar to that described in connection with the embodiment shown in FIG. 12 and, therefore, the description thereof will not be reiterated for the sake of brevity.

SEVENTH EMBODIMENT (FIGS. 14 AND 15)

Before the description of the seventh embodiment of this invention proceeds, it is to be noted that reference to the first embodiment shown in and described with reference to FIGS. 1 to 4 should be made so far as component parts of the lens assembly used in this embodiment, but neither shown in nor described with reference to FIGS. 14 and 15. The embodiment of FIGS. 14 and 15 is, however, an improved version of any one of the respective embodiments of FIGS. 12 and 13. More specifically, according to the embodiments shown respectively in FIGS. 12 and 13, although both of these embodiments are effective to provide the zoom lens assembly having a high speed at the maximum diaphragm aperture when and so long as the zooming ring is set to the shortest focal length position, it has been found that a problem might occur when the zooming ring is rotated about the optical axis towards the longest focal length position while the diaphragm aperture is set to a large value, that is, a small F-stop number at the shortest focal length setting. This problem is that, when the zooming ring is so rotated, the diaphragm blades 24 may be unnecessarily moved by the action of the slant cam groove 115 in case of the embodiment of FIG. 12 or the slant guide groove 65 in the preset ring 19 in the case of the embodiment of FIG. 13, in an attempt to increase the diaphragm aperture defined thereby to a diameter greater than that achieved at the shortest focal length setting, but do not attain a desired diaphragm aperture. In addition, there is a possibility in that, as the diaphragm blades 24 are so moved, the peripheral edges of these blades 24 adjacent the circumference of the diaphragm holder 8 may interfere with the circumference of the holder 8 to such an extent that deformation and/or breakage may occur.

In view of the above, a separate lock device operable to disable the zooming operation must be employed. Referring to FIG. 14, a change-over ring 122 has defined therein a slant cam groove 120, an axial guide groove 123 and a circumferential groove 121 on one side of the groove 123 opposite to the groove 120, all being continued with each other. FIG. 15 illustrates different positions of the pin 27 in these grooves, wherein FIG. 15(a) illustrates the position of the pin 27 connected to or integral with the diaphragm holder 8 assumed when the zooming ring 5 is in the longest focal

length position; FIG. 15(b) illustrates the condition established when the zooming ring 5 is rotated towards the wide angle range with the pin 27 consequently moved towards a position corresponding to the wide angle range; FIG. 15(c) illustrates the condition established when at the shortest focal length setting, the change-over ring 122 has been displaced a distance l leftwards, as viewed in FIG. 15, against a corrugated spring (not shown); and FIG. 15(d) illustrates the condition established when, starting from the condition of FIG. 15(c), the change-over ring 122 has been rotated an angular distance θ, necessary to increase the diaphragm aperture, that is, the total distance of $\theta_1+\theta_2$. It is to be noted that the angular distance θ_1 is equal to a distance θ used and shown in FIG. 12 and that the angular distance θ_2 is a distance required to cause the pin 27 to be engaged in the circumferential groove 121. Assuming that the pin 27 is positioned in the circumferential groove 121, the rotation of the zooming ring 5 towards the longest focal length position results in the pin 27 tending to move in a direction rearwardly of the lens assembly, that is, towards the camera body, because the pin 27 is rigidly mounted on the diaphragm holder 8. However, since the change-over ring 122, even though rotatable relative to the fixed barrel 3, can axially move only a small distance substantially equal to the amount of the deformation of the corrugated spring, resistance can be imposed on the rotation of the zooming ring 5, thereby disabling the zooming operation when and so long as the diaphragm aperture is large. It is to be noted that, if such a corrugated or compression spring as the spring 35 shown in FIG. 1 is inserted in a portion of the change-over ring 122, any possible entanglement of the pin 27 within the circumferential groove 121 which would occur when the zooming operation is unnecessarily performed, can advantageously be eliminated.

EMBODIMENTS OF APERTURE INDICATOR (FIGS. 17 TO 25)

In case of any zoon lens assembly wherein the aperture ratio does not vary with change in focal length, the aperture-indicating marking to be aligned with any one of the F-stop numbers calibrated on the diaphragm aperture adjusting ring generally comprises a single indicium, usually a line. On the other hand, the aperture-indicating marking generally comprise a pair of spaced indicia, main and auxiliary, in the case of any zoom lens assembly having its aperture ratio variable with change in focal length. When it comes to the zoom lens assembly according to this invention, since it can be considered a combined version of these types of the zoom lens assemblies, that is, it has the capability of functioning as the compensated and non-compensated models, the aperture-indicating marking is used in the form of at least two indicia arranged frontwardly of the diaphragm aperture adjusting ring.

Referring first to FIGS. 17 and 18, there is shown a first embodiment of the aperture-indicating marking to be used in the lens assembly utilizing the mode change-over mechanism according to the first and other embodiments of this invention. In FIGS. 17 and 18, reference numeral 133 represents a common indicium to be aligned with any one of the F-stop numbers 135 calibrated on the aperture adjusting ring 12 in a manner known to those skilled in the art. This common indicium 133 is utilized when and so long as the lens assembly according to this invention is set in the compensated mode. Reference numerals 131 and 132 represent main and auxiliary indicia, respectively, both adapted to be utilized, in a manner, as described subsequently, when and so long as the zoom lens assembly according to this invention is set in the non-compensated mode. Specifically, when the zooming ring is rotated to the shortest focal length position, the main indicium 131 is used to indicate the smallest F-stop number 135 available for such shortest focal length setting, whereas when the zooming ring is rotated to the longest focal length position, the auxiliary indicia 132 is used to indicate the smallest F-stop number 135 available for such longest focal length setting, it being to be noted that the smallest F-stop number available for the shortest focal length setting reads a smaller value than that available for the longest focal length setting. This means that, during the non-compensated mode, for a full diaphragm aperture, the lens assembly is faster at the shortest focal length setting than at the longest focal length setting.

These indicia 133, 131 and 132 are provided on the change-over ring 11 and may be distinguished in different color, for example, the common indicium 133 being colored white, the main indicium 131 yellow and the auxiliary indicium 132 blue. It is naturally desirable that, once the respective colors to be used for the main and auxiliary indicia 131 and 132 have been fixed, respective numerical readings for the shortest and longest focal length positions 134 (28 and 85 so far shown) should also be colored in the same color as that of the main and auxiliary indicia 131 and 132 to make it possible to avoid any possible confusion and to facilitate an easy and quick reading of the F-stop number relative to the focal length setting. Instead of the use of the colored indicia, they may be distinguished by employing different types of marking, for example, a combination of line, triangle and dot, with or without relevant numerical representation.

In FIG. 17, the change-over ring is shown as assuming a position established when and so long as the ring 11 is set in the compensated mode position, while in FIG. 18 it is shown as assuming a different position established when and so long as the ring 11 is set in the non-compensated mode position.

The aperture-indicating marking shown in FIGS. 19 and 20 is designed for use on the lens assembly according to the first and other embodiments of this invention. In FIG. 19, the main indicium 131 shown in FIG. 17 is replaced with a main indicium 137 and, in addition to the above difference, an arrow marking 138 is employed for the indication of the direction in which the change-over ring 11 can be rotated reciprocately. FIG. 20 illustrates the condition in which the lens assembly is set in the non-compensated mode.

Referring now to FIGS. 21 and 22, there is shown the aperture-indicating marking adapted for use on the lens assembly according to the second embodiment of this invention. FIG. 21 illustrates the condition in which the lens assembly is set in the compensated mode while FIG. 22 illustrates the condition in which the lens assembly is set in the non-compensated mode.

While the aperture-indicating marking shown in FIGS. 17 and 18 and FIGS. 19 and 20 has been described as comprising the three indicia and the use of three indicia may be confusing, the embodiment shown in FIGS. 21 and 22 is designed such that any one of the aperture-indicating indicia can be displayed exteriorly through a window 139 defined in the fixed barrel 3 in a manner as shown in FIG. 5. The aperture-indicating

indicia can be selectively brought into alignment with the window 139 for the visual presentation to the photographer by manipulating the change-over knob 70.

In the embodiment shown in FIGS. 24 and 25, the aperture-indicating indicia are so designed and so arranged that, while the respective positions of the aperture-indicating indicia does not vary, the position of a stopper (not shown) for the aperture adjusting ring 12 can be switched by manipulating a change-over lever 140. This embodiment of the aperture-indicating marking shown in FIGS. 23 and 24 is particularly suited for use in a SRL camera having its viewfinder system through which one of the F-stop numbers aligned with the relevant aperture-indicating indicium can be viewable. One method for switching the position of the stopper referred to above is shown in FIGS. 25(a) and 25(b). Although it is a currently employed practice to provide the aperture adjusting ring with an engagement recess in which a stopper pin can be engaged, a bell crank 160 is employed in place of the stopper pin referred to above, as shown in FIGS. 25(a) and 25(b). This bell crank 160 is pivotally mounted on the fixed barrel by means of a pivot pin 161 and has one end bent to define a stopper end 162 and the other end carrying a guide pin 163 rigidly secured thereto and loosely engaged in a guide groove 164. This system is so designed that the bell crank 160 can be pivoted in response to the movement of the change-over lever 140 to cause the position of the stopper to change automatically. It will readily be seen that FIG. 25(a) illustrates the condition assumed when the lens assembly is set in the compensated mode and, therefore, the F-stop number of 2.8 is inoperative, but FIG. 25(b) illustrates the condition assumed when the lens assembly is in the non-compensated mode with both aperture-indicating indicia being utilizeable one at a time according to the focal length setting.

EIGHTH EMBODIMENT FIGS. 26 AND 27)

The mode change-over mechanism according to the eighth embodiment shown in FIGS. 26 and 27 differs from that according to any one of the previously described first and fourth embodiments in the following two aspects. The first difference is that, while in the previously described embodiments the rotation of the aperture adjusting ring 12 can be transmitted to the diaphragm operating ring 9 by the utilization of the linear groove 21 (FIG. 3) and the other elements and the diaphragm holder 8 can be rotated for the compensation purpose by the utilization of the cam groove portion 42 (FIG. 3) and the other elements, the embodiment shown in FIGS. 26 and 27 is such that a groove 21B functionally corresponding to the linear groove 21 defined in the arm of the preset ring 9 for transmitting the rotation of the adjusting ring 12 to the operating ring 9 is constituted by a cam groove defined in a single component part which acts concurrently for the diaphragm aperture setting and compensation purposes. The other difference is that the lens assembly shown in FIGS. 26 and 27 has an automatically presettable diaphragm mechanism incorporated therein and also has the capability of being set selectively in the compensated and non-compensated modes one at a time. The automatically presettable diaphragm mechanism referred to above is operable to stop the diaphragm aperture down to a predetermined value selected in association with the picture taking operation of the camera which is performed after the light measurement has been carried out at the full aperture setting. As a matter of course, this selection can be done even during the picture taking.

The details of the embodiment shown in FIGS. 26 and 27 will now be described. Referring to these figures, reference numeral 141 represents a transmission plate rigidly secured to, or formed integrally with, the change-over ring 11'. As best shown in FIG. 27, the change-over ring 11' is coupled to the diaphragm aperture adjusting ring 12 by means of a coupling pin 142 for rotation together therewith. Therefore, as the aperture adjusting ring 12 is preset to a certain F-stop number, the transmission plate 141 also rotates together with the adjusting ring 12. An aperture control cam plate 143 of generally arcuate or ring-shaped configuration has a radially outwardly extending projection 143A having its free end slidingly engaged in one of the cam and axial guide grooves 21B and 21A, for example, in the cam groove 21B so far shown, both defined in the transmission plate 141. In this illustrated condition, the cam plate 143 can rotate together with the adjusting ring 12 when the latter is preset. By rotating the aperture adjusting ring 12 about the optical axis in a direction shown by the arrow A in FIGS. 26 and 27, the diaphragm aperture can be stopped down.

Reference numeral 144 represents a generally arcuate main drive lever supported for pivotal movement about the axis shown by the chain line in FIG. 26. This main drive lever 144 is normally biased counterclockwise by a biasing spring 145. Operatively associated with this main drive lever 144 is a transmission pawl 146 situated within and protruding radially inwardly in the camera body. This transmission pawl 146 is engaged to the main drive lever 144 through an engagement pin 144A fast with the main drive lever 144, the transmission pawl 146 being operable to urge the main drive lever 144 clockwise about the optical axis against the biasing spring 145 after the completion of actual picture taking. When the main drive lever 144 is so rotated clockwise, an aperture-defining lever 147 of generally arcuate shape which is operatively coupled with the main drive lever 144 through a connecting rod 144B connected with the main drive lever 144 can be pivoted clockwise about the pivot axis shown by the chain line in FIG. 26. This aperture-defining lever 147 is in turn operatively associated with the diaphragm operating ring 9' by means of a spring 148 extending between 9'A connected with the operating ring 9' and a pin 143A connected with the aperture defining lever 147 and, therefore, the pin 9'A is normally biased to contact a lower end of the aperture defining lever 147. For this reason, when the aperture defining lever 147 is rotated clockwise in response to the clockwise rotation of the main drive lever 144 in the manner as hereinbefore described, the operating ring 9' rotates clockwise in pursuit of the lever 147, thereby causing the diaphragm blades 24 to open wide. This operating ring 9' has an arm 9'B extending radially outwardly therefrom and contacting a cam edge 149A of a compensating cam plate 149. When this arm 9'B abuts the cam edge 149A during the clockwise rotation of the aperture defining lever 147 and, hence, that of the operating ring 9', the operating ring 9' can be brought to a halt independently of the aperture defining lever 147 which continues its clockwise rotation with the spring 148 pulled axially outwardly. As is the case with any one of the previously described embodiments, the diaphragm operating lever 9' can move leftwards and rightwards one at a time during the zooming operation as viewed in the drawing. Since the leftward movement

means the setting to the tele-angle range, as the focal length is adjusted towards the longest value, the operating ring 9' can be rotated clockwise a greater angular distance to increase the diaphragm aperture than as it is adjusted towards the shortest value. Therefore, when and so long as the focal length is adjusted towards the longest value, the operating ring 9' can be rotated clockwise a greater angular distance to increase the diaphragm aperture than as it is adjusted towards the shortest value. Therefore, when and so long as the focal length is adjusted to the longest reading, the diaphragm aperture is full open. In view of the foregoing, in a preset condition, the diaphragm aperture attains the maximum diameter at the longest focal length setting, and as the zooming ring is rotated towards the wide angle range, the diaphragm aperture is stopped down to make the maximum diaphragm aperture fixed at any focal length setting. When the aperture adjusting ring 12 is rotated in the direction of the arrow A to a desired aperture reading from smallest F-stop number, the aperture control cam plate 143 is rotated counterclockwise to a predetermined position corresponding to the desired aperture reading. Subsequent retraction of the transmission pawl 146 which takes place in association with the picture taking, causes the main drive lever 144 to rotate counterclockwise against the spring 145. Upon this counterclockwise rotation of the main drive lever 144, the aperture defining lever 147 coupled thereto through the connecting rod 144B is also rotated counterclockwise, thereby causing the aperture operating ring 9' to be rotated counterclockwise by means of the pin 9'A until a pin 147B rigidly mounted on the aperture defining lever 147 abuts a projection 143B integral with the cam plate 143. When the pin 147B on the aperture defining lever 147 is so engaged to the projection 143B integral with the cam plate 143 in the manner as hereinabove described, the aperture defining lever 147 is no longer rotated and the diaphragm aperture is therefore stopped down to a diameter corresponding to the desired, preset aperture reading. FIGS. 26 and 27 illustrate the condition in which the lens assembly is set in the compensated mode. Since the projection 143A integral with the cam plate 143 is engaged in the cam groove 21B, the cam plate 143 rotates, as the zooming ring is turned, with the pin 147B moving in contact with the projection 143B and, therefore, the diaphragm aperture is compensated for change in aperture ratio resulting from the change of the focal length.

Where the lens assembly is desired to be set in the non-compensated mode, the projection 143A integral with the cam plate 143 has to be brought into engagement with the axial guide groove 21A and the cam plate 149 has to be subsequently retracted from the path of angular movement of the arm 9'B integral with the diaphragm holder 9'. A mechanism for this purpose is shown in FIG. 27.

Referring particularly to FIG. 27, the aperture adjusting ring 12 has a pair of deep and shallow recesses 12A and 12B defined therein for engagement with the coupling pin 142 one at a time. The coupling pin 142 fast with the aperture adjusting ring 12 is engaged in the recess 12A so far shown in FIG. 27, in which condition the lens assembly is in the compensated mode. The change-over to the non-compensated mode can be carried out when and so long as the focal length is adjusted to the shortest reading. Assuming that the zooming ring is rotated to the smallest focal length position, and when the change-over ring 11' is pulled leftwards as viewed in FIG. 27 against the spring 35, the projection 143A of the cam plate 143 is brought in position ready to enter a connecting groove 21C. Subsequent turn of the change-over ring 11' in the direction of the arrow to bring the coupling pin 142 into engagement with the recess 12B results in that the projection 143A is brought in position ready to enter the axial guide groove 21A. The manner by which the change-over ring 11' is manipulated is substantially identical with that in any one of the foregoing embodiments and, therefore, the lock mechanism for avoiding the unnecessary or accidental change-over, which has been described in connection with any one of the foregoing embodiments can be employed. In any event, when the coupling pin 142 has been shifted from the recess 12A to the recess 12B in the manner as hereinbefore described, the change-over ring 11' is positioned a slight distance displaced leftwards as viewed in FIG. 27 as compared with the position occupied by the same ring 11' when the coupling pin 142 is engaged in the recess 12A. This is because the recess 12B has a depth smaller than the recess 12A. In this condition, a bell crank 150 engageable with the change-over ring 11' is pivoted clockwise, as viewed in FIG. 27, from the position shown by the solid line. Upon this pivot of the bell crank 150, one end of the bell crank 150 remote from the change-over ring 11' pushes a pin 149B, rigidly mounted on the cam plate 149, and, therefore, the cam plate 149 is moved upwards as viewed in FIG. 27 against a spring 151 with the cam edge 149A consequently brought in position out of the path of angular movement of the arm 9'B integral with the diaphragm operating ring 9', thereby completing the change-over of the lens assembly into the non-compensated mode.

The aperture-indicating marking to be used on the lens assembly according to the embodiment described with reference to and shown in FIGS. 26 and 27 is in the form as including, in addition to the indicia 131, 132 and 133 on the fixed barrel 3, a triangular reference indicium 170 provided on the aperture adjusting ring 12, and a pair of spaced indicia 171A and 171B provided on the change-over ring 11' and signifying the non-compensated mode and the compensated mode, respectively, the indicia 171A and 171B being adapted to be lined up with the reference indicium 170 one at a time to indicate the mode in which the lens assembly is set.

NINTH EMBODIMENT (FIG. 28)

The lens assembly according to this embodiment, shown in FIG. 28, employs the compensating mechanism for the preset aperture which is substantially identical with that shown in FIGS. 26 and 27, but does not employ a full aperture compensating member for the full aperture light metering system. This embodiment is a system wherein the stop-down number over which the diaphragm aperture should be stopped down from the smallest F-stop number is input to a photographic camera of full aperture metering system. A connecting lever 152 for transmitting the stop-down number shown in FIG. 28 is a member provided for this purpose. Even in this embodiment, the lens assembly shown in FIG. 28 is similar to that shown in FIGS. 26 and 27 in that the change-over ring 11' is rotatable together with the aperture adjusting ring 12 to adjust the diaphragm aperture and in that the mode change-over can be effected by selecting the position of the change-over ring 11' relative to the aperture adjusting ring 12. Although the lens assembly so far shown is in the compensated mode in which the diaphragm aperture is automatically compen-

sated with the focal length setting to maintain the diaphragm aperture at a predetermined value, since the lens assembly is not provided with a full aperture compensating cam to be used during the full aperture light measurement as is the case with the embodiment shown in FIGS. 26 and 27, the diaphragm aperture at the smallest F-stop number is fixed irrespective of the zooming operation and, therefore, the intensity of light falling on the light receiving face of a photo-cell forming a part of the light measuring device of the camera may vary to such an extent as to result in erroneous exposure. Therefore, in order to avoid the erroneous exposure, information of the stop-down number variable with the zooming operation is input to the camera instead of the use of the full aperture compensating cam. The function in which the stop-down number information is adjustably coupled to the camera body will now be described with reference to FIG. 28.

A linkage ring **153** for the compensation of the stop-down number has a pair of pins **153A** and **153B** rigidly mounted thereon. So far shown in FIG. 27, the pin **153A** is shown as engaged in the groove **21B'** in the change-over ring while the other pin **153B** is shown as engaged with the connecting lever **152**. During the zooming operation, the ring **153** is axially moved together with, for example, the rear movable lens mount and can also be rotatable freely. Therefore, as the aperture adjusting ring **12** is rotated, the ring **153** is also rotated by the engagement between the pin **153A** and the groove **21B'** in the change-over ring **12** rotatable together with the adjusting ring **12**. the rotation of the ring **153** being transmitted through the lever **152** to the camera body to vary the stop-down number input to the camera. By so doing, change in intensity of the light falling on the light receiving face of the photo-cell of a light meter incorporated in the camera can be compensated for to give a correct exposure value. Where the mode change-over is to be effected, the zooming ring has to be moved to the shortest focal length position and the change-over ring **11'** has to be subsequently moved leftwards, as viewed in FIG. 28, against the spring **35** before it is rotated in the direction of the arrow A. As is the case with the embodiment shown in FIGS. **26** and **27**, when the change-over ring **11**, which moved leftwards, is rotated, the coupling pin **142** can be brought into alignment with the recess **12B**, the actual engagement of the pin **142** into the recess **12B** taking place when an external pulling force applied to the ring **11'** to displace the latter leftwards is released. In this way, the projection **143A**, integral with the cam plate **143**, and the pin **153A** on the ring **153**, are engaged in an axial guide groove **21A** and an axial guide groove **21A'**, respectively, and therefore, not only can the lens assembly be set in the non-compensated mode, but also the adjustment of the stop-down number input to the camera is no longer effected. It is to be noted that a mechanism operable to permit the mode change-over to be performed only at the smallest or longest focal length setting may be the one described in connection with any one of the foregoing embodiments.

MODIFICATION (FIG. 29)

In the first embodiment shown in FIGS. **1** to **4**, the cam plate **10** has been described as rigidly secured to the change-over ring **11** and having the axial guide groove **40** and the cam groove **42** defined therein. However, in the modification shown in FIG. **29**, the cam plate is rigidly secured to the fixed barrel **3** as shown by **10'** and has only a cam groove **42'** corresponding functionally to the cam groove **42** best shown in FIG. **3**. In addition, in this modification, the preset ring is constituted by front and rear ring elements, the front ring element having the linear groove **21** defined in the arm thereof. The ring elements are normally held in a predetermined position relative to each other by a tension spring suspended therebetween, and an arm fast with or integral with the change-over ring **11** rotatable only at the shortest focal length setting is held in position ready to engage the front ring element whenever the necessity occurs. In this modification, where the diaphragm aperture is desired to be increased to a greater diameter, the change-over ring **11** has to be rotated so that the front ring element can be rotated relative to the rear ring element against the tension spring thereby causing the diaphragm, operating ring **9** to be rotated to a position corresponding to the smallest F-stop number available for the longest focal length setting. By so doing, the diaphragm aperture can be adjusted to give the greater diameter.

Although this invention has fully been described in connection with the numerous embodiments with reference to the accompanying drawings, it is to be noted that various changes and modifications are apparent to those skilled in the art upon the reading this disclosure. By way of example, the function of the change-over ring may be utilized to adjust the amount of extension of a signaling pin which is, in most cameras requiring the physical transmission of information concerning the speed of a selected interchangeable lens assembly, necessitated to transmit such information.

In addition, although reference has been made to the zoom lens assembly of a type wherein the optical system is so designed that the position of focus does not vary with the zooming, the concept of this invention can be equally applicable to a so-called varifocal lens assembly wherein the position of focus varies with the zooming.

Therefore, such changes and modification are to be understood as included within the scope of this invention as defined in the appended claims, unless they depart therefrom.

I claim:

1. An objective lens assembly of variable focal length comprising, in combination:

a varifocal lens system having its focal length adjustable within a predetermined range, said lens system including a diaphragm mechanism having an adjustable diaphragm aperture, the aperture ratio being variable during an operation for changing the focal length with the diaphragm aperture kept unchanged;

a diaphragm aperture adjustng mechanism for adjusting the diaphragm aperture for compensating for change in aperture ratio realtive to the change in focal length within the predetermined range;

a diaphragm aperture maintaining mechanism operable to maintain the diaphragm aperture while allowing the aperture ratio to change within a portion of the predetermined range; and

a manually operable change-over mechanism operable to bring the diaphragm aperture adjusting and maintaining mechanisms selectively into an operative position one at a time.

2. An assembly as claimed in claim **1**, wherein said maintaining mechanism is adapted to maintain the diaphragm aperture so as to vary the aperture ratio within the predetermined range.

3. An assembly as claimed in claim 1, wherein said maintaining mechanism is adapted to maintain the diaphragm aperture so as to vary the aperture ratio only at the shortest focal length setting or in the vicinity thereof within the predetermined range.

4. An assembly as claimed in claim 1, wherein said change-over mechanism includes a change-over member rotatable about the optical axis of the lens system and movable in a direction parallel to the optical axis, said adjusting and mantaining mechanisms being selectively brought into the operative position one at a time in response to the rotation and subsequent axial movement of the change-over member.

5. An assembly as claimed in claim 1, further comprising a locking means for releaseably locking the change-over means, said locking means operable to release the change-over mechanism only when the lens system is set to a particular focal length within the predetermined range.

6. An assembly as claimed in claim 5, wherein the lens system includes at least one lens group movable in a direction parallel to the optical axis of the lens system for changing the focal length, and further comprising a movable lens holder for the support of said lens group, said locking means including a locking mechanism for locking the change-over mechanism, and a detection means for detecting the movement of said movable lens holder in the direction parallel to the optical axis to a predetermined position at which the lens system is set at the particular focal length and for causing the locking mechanism to release the change-over mechanism from a locked position.

7. An assembly as claimed in claim 5, further comprising an operating member rotatable about the optical axis for changing the focal length.

8. An assembly as claimed in claim 7, wherein said locking means comprises a locking mechanism for locking the change-over mechanism, and a detection means for detecting the condition in which the operating member is operated to a position at which the lens system is set at the particular focal length and for causing the locking mechanism to release the change-over mechanism from a locked position.

9. An assembly as claimed in claim 1, further comprising a diaphragm preset ring for presetting the diaphragm mechanism, said preset ring having a series of numerical figures provided thereon, said numerical figures representing the F-stop numbers to which the diaphragm mechanism can be preset one at a time, respectively, a first indexing means cooperable with the series of numerical figures to indicate one of the numerical figures when the adjusting mechanism is brought into the operative position by the change-over mechanism, and a second indexing means cooperable with the series of numerical figures to indicate one of the numerical figures when the maintaining mechanism is brought into the operative position by the change-over mechanism.

10. An assembly as claimed in claim 9, wherein said change-over mechanism is rotatable about the optical axis of the lens system and movable in a direction parallel to the optical axis for bringing the adjusting and maintaining mechanisms selectively into the operative position one at a time, and wherein said first and second indexing means are provided on the change-over member in circumferentially spaced relation to each other.

11. An assembly as claimed in claim 9, further comprising a stationary barrel having the first and second indexing means provided in circumferentially spaced relation to each other, a restriction means for restricting the rotatable range over which the preset ring can be rotated, and means for changing the rotatable range of the preset ring in dependence on the selection of one of the adjusting and maintaining mechanisms performed by the change-over mechanism.

12. An objective lens assembly of variable focal length comprising, in combination:

a stationary barrel;

a varifocal lens system having its focal length adjustable within a predetermined range, and including at least one lens group axially movable in a direction parallel to the optical axis thereof for the adjustment of the focal length;

a manually operable member adapted to be operated relative to the stationary barrel for varying the focal length of the lens system;

a diaphragm mechanism including first and second member rotatable relative to each other about the optical axis, and a plurality of diaphragm blades defining a diaphragm aperture of a diameter determined by the relative rotation of the first and second members, said diaphragm mechanism being axially movable in a direction parallel to the optical axis in correspondence with the change in focal length of the lens system to vary the aperture ratio with the diameter of the diaphragm aperture kept unchanged;

a diaphragm aperture adjusting mechanism for varying the relative position between the first and second members at the time of axial movement of the diaphragm mechanism to adjust the diaphragm aperture for maintaining the aperture ratio at a constant value relative to the change in focal length within the predetermined range;

a diaphragm aperture maintaining mechanism for maintaining the relative position between the first and second members at the time of axial movement of the diaphragm mechanism to vary the aperture ratio for maintaining the diaphragm aperture at a constant value; and

a manually operable change-over mechanism for bringing the adjusting and maintaining mechanisms selectively into an operative position one at a time.

13. An assembly as claimed in claim 12, wherein said change-over member is rotatable about the optical axis of the lens system.

14. An assembly as claimed in claim 13, wherein said adjusting mechanism comprises a cam member integral with the change-over member, a cam follower provided on one of the first and second members, and a first cam provided on the cam member so as to be inclined relative to the direction parallel to the optical axis for engagement with the cam follower, wherein said maintaining mechanism comprises said cam member, said cam follower and a second cam provided on the cam member in parallel relation to the optical axis of the lens system for engagement with the cam follower, and wherein said change-over mechanism also includes a guide means on the cam member for guiding the cam follower from one of the first and second cams onto the other of the first and second cams at the time of rotation of the change-over member.

15. An assembly as claimed in claim 14, further comprising an aperture preset ring, a stop-down member for rotating the other of the first and second members relative to said one of the first and second members for

reducing the diaphragm aperture, and a restriction means for restricting the final operative position for the stop-down member in dependence on the position to which the preset ring has been rotated.

16. An assembly as claimed in claim 14, wherein the change-over member is displaceable a predetermined distance from a normal axial position in a direction parallel to the optical axis, said guide means being operable only when the change-over member is axially displaced the predetermined distance to guide the cam follower from the one of the first and second cams onto the other of the first and second cams.

17. An assembly as claimed in claim 16, further comprising a movable lens holder for supporting the lens group, a lock means for locking the change-over member to prevent the change-over member from being rotated, and means for disabling said locking means only when the movable lens holder is held at a position at which the lens system is set at a particular focal length within said predetermined range.

18. An assembly as claimed in claim 16, further comprising a lock means for locking the change-over member for preventing the change-over member from being rotated, and means for disabling the lock means only when the manually operable member is rotated to a position at which the lens system is set at a particularly focal length within the predetermined range.

19. An objective lens assembly of variable focal length which comprises, in combination:

a varifocal lens system having its focal length adjustable within a predetermined range, said lens system including a diaphragm mechanism having an adjustable diaphragm aperture, the aperture ratio being variable during an operation for changing the focal length with the diaphragm aperture kept unchanged;

a diaphragm aperture adjusting mechanism for adjusting the diaphragm aperture for compensating for change in aperture ratio relative to the change in focal length within the predetermined range;

a diaphragm aperture maintaining mechanism for maintaining the diaphragm aperture while allowing the aperture ratio to change within a portion of the predetermined range; and

a manually operable mechanism for setting the diaphragm aperture at a diameter necessary to increase the aperture ratio at the shortest focal length setting or in the vicinity thereof within the predetermined range, whereby the aperture ratio so increased is equal to the aperture ratio given by the diaphragm mechanism at the smallest focal length setting or in the vicinity thereof when no diaphragm aperture adjustment is performed by the diaphragm aperture adjusting mechanism.

20. An assembly as claimed in claim 19, wherein the manually operable mechanism includes a rotatable member adapted to be rotated a predetermined angle about the optical axis of the lens system, and wherein the diaphragm aperture adjusting mechanism includes a cam formed on the rotatable member so as to be inclined relative to the optical axis and a cam follower engaged with the cam for varying the diaphragm aperture.

21. An assembly as claimed in claim 20, wherein the rotatable member is displaceable a predetermined distance from a normal axial position in a direction parallel to the optical axis, said cam having one end extended a distance equal to the predetermined distance to provide a extension of the cam.

22. An assembly as claimed in claim 21, wherein said extension has one end opposite to the cam formed with an engagement cam extending in a direction parallel to the direction of rotation of the rotatable member, said engagement cam being operable to engage the cam follower to inhibit the adjustment of the diaphragm aperture by the diaphragm aperture adjusting mechanism while the aperture ratio has been increased.

* * * * *

United States Patent [19]

Hama

[11] **Patent Number: 4,518,238**

[45] **Date of Patent: May 21, 1985**

[54] **ROTATION CONTROL MECHANISM FOR DIAPHRAGM-OPERATING RING IN INTERCHANGEABLE OBJECTIVE FOR PHOTOGRAPHIC CAMERA**

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[73] Assignee: **Asahi Kogaku Kogyo Kabushiki Kaisha**, Tokyo, Japan

[21] Appl. No.: **520,723**

[22] Filed: **Aug. 5, 1983**

[30] **Foreign Application Priority Data**

Aug. 18, 1982 [JP] Japan ..... 57-124728[U]

[51] **Int. Cl.**[3] **G03B 9/02**

[52] **U.S. Cl.** **354/270**

[58] **Field of Search** 354/270-274; 350/449, 450

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Primary Examiner—John Gonzales
Attorney, Agent, or Firm—Christie, Parker & Hale

[57] **ABSTRACT**

An interchangeable objective with a variable lens aperture for a camera has a stationary support member and a diaphragm-operating member rotatable about an axis between first and second annular positions relative to the stationary support member. A first elongated leaf spring is mounted on the stationary member to bear against the diaphragm-operating member along a first plane perpendicular to the axis. A second elongated leaf spring is mounted on the stationary member to bear against the diaphragm-operating member along a second plane perpendicular to the axis. The second plane is spaced from the first plane in the direction of the axis. A locking groove is formed in the diaphragm-operating member so as to alternatively receive the first and second leaf springs in locking engagement when the diaphragm-operating member is positioned at the first and second angular positions, respectively. An unlocking button is mounted in the diaphragm-operating member over the locking groove to push the respective first and second leaf springs out of engagement with the locking groove upon depression of the unlocking button.

7 Claims, 18 Drawing Figures

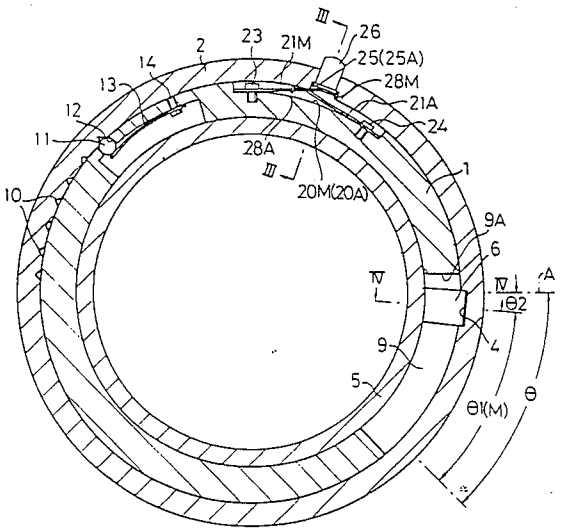


Fig. 1.

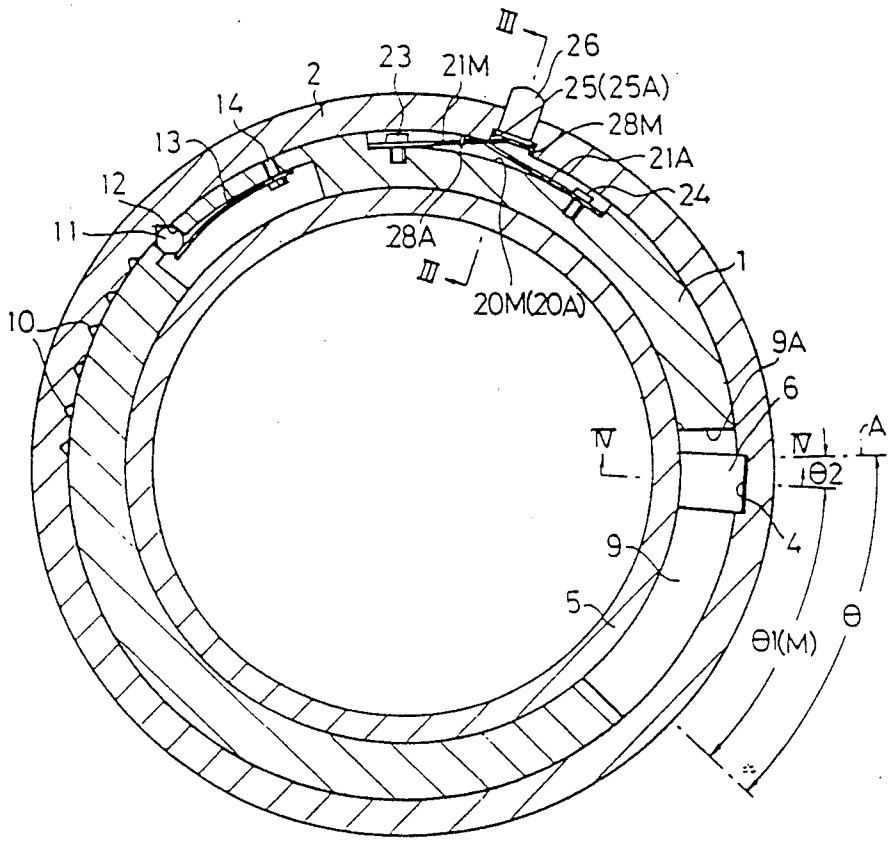
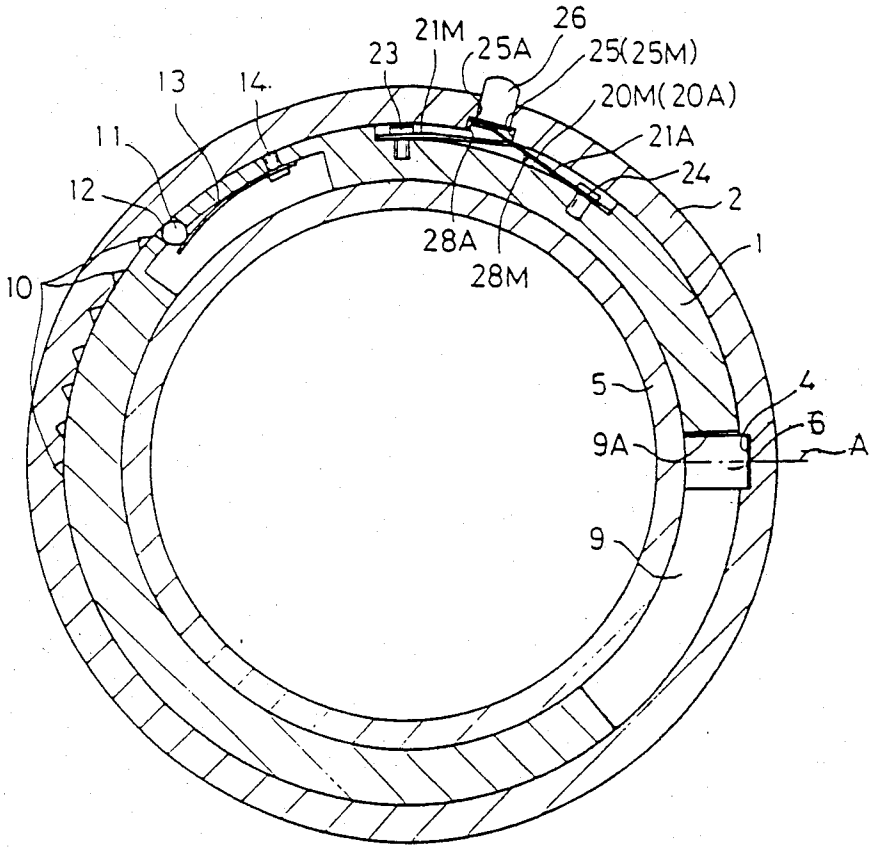

III
26
25(25A)
28M
21A
24
1
9A
6
A
IV
IV
θ2
4
9
5
θ1(M)
θ
2
23
21M
14
13
12
11
10
28A
III
20M(20A)

Fig.2.


21M
26
23
25A
25(25M)
13
14
20M(20A)
11
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12
24
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28M
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9A
A
9

Fig.3.

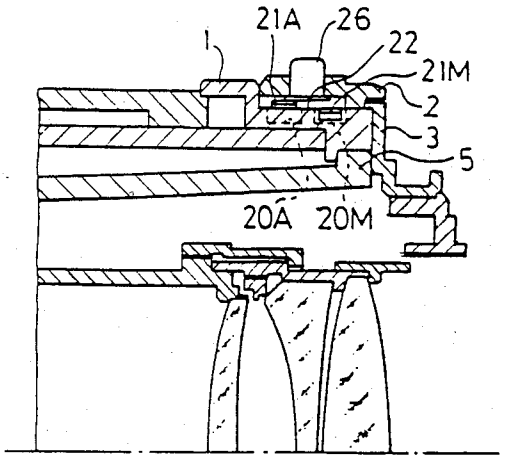


Fig.4.

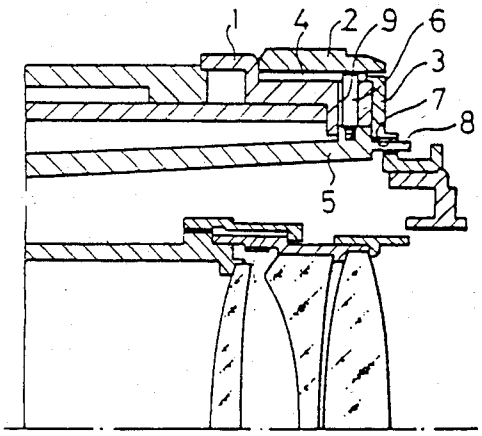


Fig. 5.

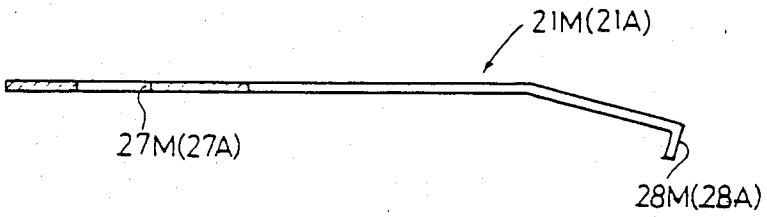


Fig. 9.

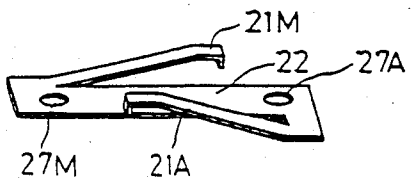


Fig. 10.

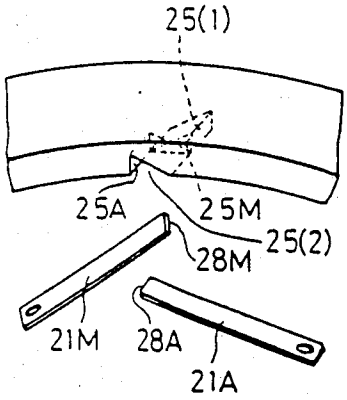


Fig.6A.

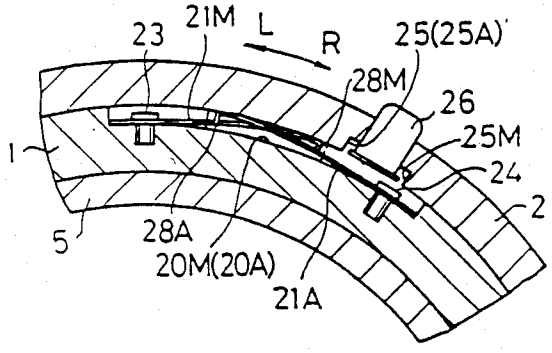


Fig.6B.

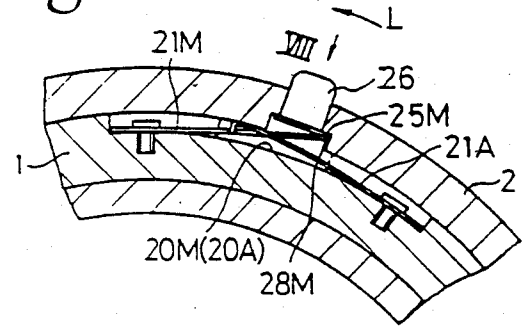


Fig.6C.

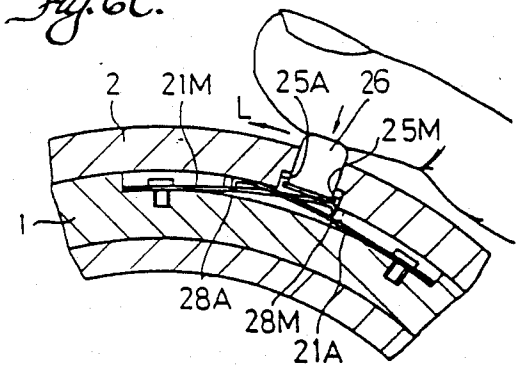


Fig.6D.

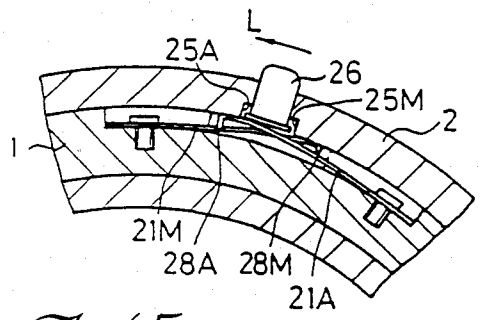


Fig.6E

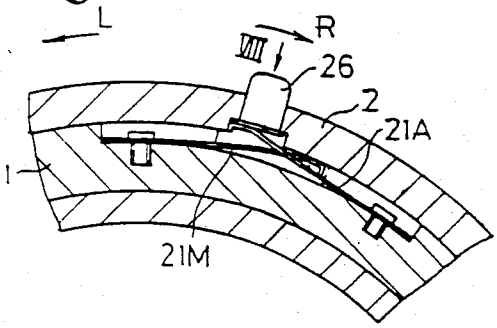


Fig.6F.

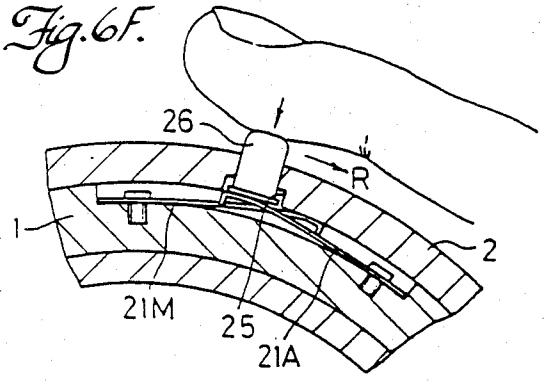


Fig.7A.

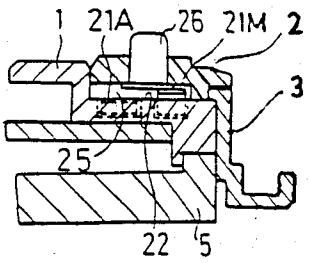


Fig.7B.

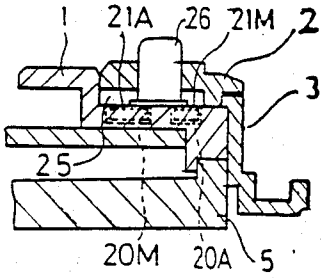


Fig.7C.

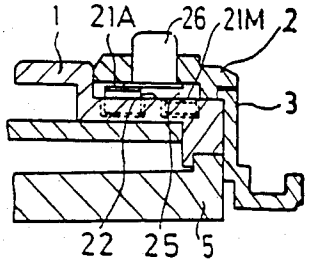


Fig.8A.

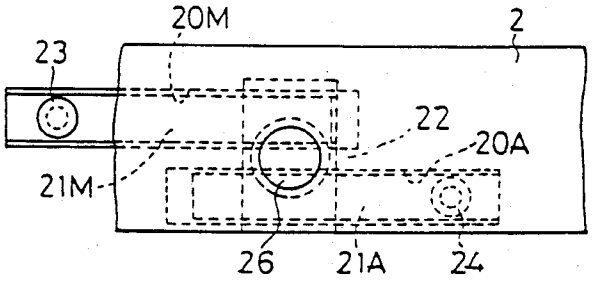
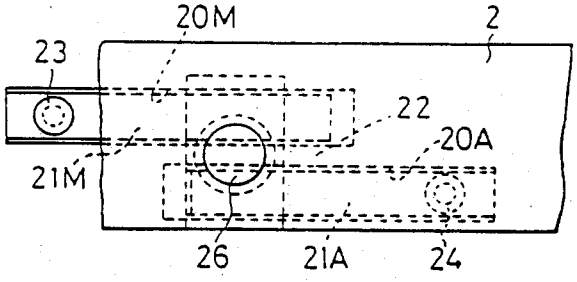


Fig.8B.



ROTATION CONTROL MECHANISM FOR DIAPHRAGM-OPERATING RING IN INTERCHANGEABLE OBJECTIVE FOR PHOTOGRAPHIC CAMERA

CROSS REFERENCE TO RELATED APPLICATIONS

This application is related to application Ser. No. 520,724, filed on even date herewith by Etsuro Nishio and Zenichi Okura, the disclosure of which is incorporated fully herein by reference.

BACKGROUND OF THE INVENTION

The present invention relates to an interchangeable objective provided with a diaphragm-operating ring which is rotatable between a rotatable range for diaphragm preset and a position for automatic diaphragm regulation and, more particularly, to a rotation control mechanism for the diaphragm-operating ring used for changeover between said rotatable range for diaphragm preset and said position for automatic diaphragm regulation.

A photographic camera of automatic exposure control type conventionally has a diaghragm priority mode in which a diaphragm value is preset by the user and a shutter speed for appropriate exposure is automatically regulated in the camera body, a shutter speed priority mode in which, inversely, a shutter speed is manually preset by the user and a lens aperture for appropriate exposure is automatically regulated, and a programmed mode in which a combination of diaphragm value and shutter speed is automatically regulated for appropriate exposure.

Interchangeable objectives used with a photographic camera adopting said three modes of automatic exposure control function or different exposure control functions must include a diaphragm-operating ring provided with a rotatable range for manually presetting the diaphragm value (referred to hereinafter as M-range), in said diaphragm priority mode and a position for automatic diaphragm regulation (referred to hereinafter as A-position) in said shutter speed priority mode and said programmed mode. Information as to whether the diaphragm-operating ring occupies the M-range or the A-position must be transferred to the camera body because different exposure control mechanisms are activated in these two cases.

Any unintentional changeover between the M-range and the A-position must be reliably prevented and, in consequence, a suitable changeover locking mechanism and unlocking mechanism are required. However, the structure for connection between the lens barrel and the camera body has made it difficult to obtain a large rotation angle for changeover between the end of the M-range and the A-position. This has given rise to various problems with respect not only to the strength but also to the degree of freedom for their design. Particularly in an objective of a relatively large diameter, the rotation angle within the M-range must be large but the rotation angle of a diaphragm information transferring lever which is rotatable together with the diaphragm-operating ring is restricted by the claw angle of the mount ring, so that the strength of the changeover locking mechanism may be compromised.

SUMMARY OF THE INVENTION

According to the invention, an interchangeable objective with a variable lens aperture for a camera has a stationary support member and a diaphragm-operating member rotatable about an axis between first and second annular positions relative to the stationary support member. (One angular position is the A-position and the other angular position is the end of the M-range nearest to the A-position.) A first elongated leaf spring is mounted on the stationary member to bear against the diaphragm-operating member along a first plane perpendicular to the axis. A second elongated leaf spring is mounted on the stationary member to bear against the diaphragm-operating member along a second plane perpendicular to the axis. The second plane is spaced from the first plane in the direction of the axis. A locking groove is formed in the diaphragm-operating member so as to alternatively receive the first and second leaf springs in locking engagement when the diaphragm-operating member is positioned at the first and second angular positions, respectively. An unlocking button is mounted in the diaphragm-operating member over the locking groove to push the respective first and second leaf springs out of engagement with the locking groove upon depression of the unlocking button. As a result of the placement of the leaf springs in different planes, a small rotation angle can be provided for changeover between the M-range and the A-position, without compromising the strength of the changeover locking mechanism.

BRIEF DESCRIPTION OF THE DRAWINGS

The feature of specific embodiments of the best mode contemplated of carrying out the invention are illustrated in the drawings, in which:

FIGS. **1** and **2** are front-sectional view of the pertinent parts of an interchangeable objective embodying principles of the invention, FIG. **1** showing the objective in the M-range and FIG. **2** showing the objective in the A-position;

FIGS. **3** and **4** are sectional views of the objective taken through lines III—III and IV—IV in FIG. **1**, respectively;

FIG. **5** is a side, partially cut-away view of one of the rotation-arresting members shown in FIGS. **1** and **2**;

FIGS. **6***a* through **6***f* are enlarged, front-sectional views of part of the objective in different positions of the diaphragm-operating ring;

FIGS. **7***a* through **7***c* are enlarged, side-sectional views of part of the objective in different positions of the diaphragm-operating ring;

FIGS. **8***a* and **8***b* are top views as seen in the direction of VIII—VIII in FIGS. **6***b* and **6***e*, respectively;

FIG. **9** is a perspective view of another embodiment of the rotation-arresting members; and

FIG. **10** is a perspective view of yet another embodiment of the locking groove in the diaphragm-operating ring and the rotation-arresting members.

DETAILED DESCRIPTION OF THE SPECIFIC EMBODIMENTS

In FIGS. **1** through **4**, reference numeral **1** designates a stationary mount support ring, and reference numeral **2** designates a diaphragm-operating ring rotatably supported by said mount support ring **1**. A mount **3** by which the objective is attached to the camera body is fixed to the mount support ring **1**. The diaphragm-

operating ring 2 is provided in its inner peripheral surface with an interlocking groove 4 into which an interlocking pin 6 fixedly mounted on a diaphragm-rotating ring 5 is engaged so that said diaphragm-rotating ring 5 may be rotated together with said diaphragm-operating ring 2. This diaphragm-rotating ring 5 is rotatably supported along the inner peripheral surface of the mount support ring 1 and is integrally provided with a diaphragm information transferring lever 8 projecting through a notch 7 formed in the mount 3 toward the camera body. Said diaphragm information transferring lever 8 is adapted to transfer information to the camera body whether said diaphragm information transferring lever 8 occupies the M-range or the A-position of the diaphragm operating ring 2. The diaphragm-rotating ring 5 is rotated to activate the diaphragm mechanism of well known type and thereby to preset a desired diaphragm value. Since such diaphragm mechanism is not part of the present invention, it is not described in detail.

The rotation angle of the diaphragm operating ring 2 is restricted by the circumferential length of the interlocking groove 9 formed in the mount support ring 1, in which said interlocking pin 6 rides. Both the M-range and the A-position are contained within an angle θ of the interlocking groove 9. In this embodiment, the M-range is arranged to cover an angle θ_1 and the A-position is arranged to be spaced by an angle θ_2 from one rotational end of said M-range (e.g., the minimum lens aperture position).

The diaphragm-operating ring 2 is provided in its inner peripheral within an angular extent corresponding to said M-range with a plurality of click-grooves 10 equal in number to the number of diaphragm value steps. The mount support ring 1 is formed with a guide hole 12 for containment of a click-ball 11 adapted to be received by said click-grooves 10 and a leaf spring 13 is fixed at one end by a screw 14 to the mount support ring 1 so as to bias said click ball 11 toward the clock-grooves 10.

The present invention is generally directed to the control of the rotation of the diaphragm-operating ring 2 between said one rotational end of the M-range (the minimum lens aperture) and the A-position. To this end, two leaf springs 21M, 21A serving as rotation arresting members are secured at one end by screws 23, 24 respectively to the mount support ring 1. Leaf springs 21M, 21A are mounted in leaf spring receiving grooves 20M, 20A respectively, are offset from each other in the direction of the optical axis, and face toward each other. The diaphragm-operating ring 2 is provided with a locking groove 25 and an unlocking member (button) 26 projecting outwardly from the upper boundary of this locking groove 25. Locking groove 25 is elongated in the direction of the optical axis to overlie both of grooves 20M, 20A in communication therewith. The bottom of unlocking member 26 has a plate that spans the space between grooves 20M, 20A and alternately engages members 21M, 21A as they enter locking groove 25.

The rotation arresting members 21M, 21A each comprise, as one of them is shown by FIG. 5, leaf springs formed at one end with a hole (27M, 27A) for fixation and at the other end with an arresting surface (28M, 28A). The portion of each leaf spring with the hole (27M, 27A) extends away from the receiving groove (20M, 20A) toward the locking groove. These rotation arresting members 21M, 21A are secured to the mount support ring 1 in a symmetrical relationship with respect to the optical axis so that said arresting surfaces 28M, 28A cross one another in a front view. The rotation arresting member 21M has its arresting surface 28M bearing against one of side walls (M-locking side wall) 25M circumferentially defining the locking groove 25 of the diaphragm-operating ring 2, as shown in FIG. 1, to arrest further rotation of said diaphragm operating ring 2, toward the A-position, when the diaphragm-operating ring 2 has been rotated to the minimum lens aperture position within the M-range. Accordingly, this arresting member may be referred to as the rotation arresting member 21M for M.

The other rotation arresting member 21A has its arresting surface 28A bearing against the other side wall (A-locking side wall) 25A circumferentially defining the locking groove 25 of the diaphragm operating ring 2, as shown in FIG. 2, to arrest further rotation of said diaphragm-operating ring 2 toward the M-range, when said diaphragm-operating ring 2 has been rotated to the A-position. Accordingly, this arresting member may be referred to as the rotation arresting member 21A for A.

Said unlocking member 26 is engageable with the outer surfaces of these two rotation arresting members 21M, 21A so that depression of unlocking member 26 permits said both rotation arresting members to be displaced out of the locking groove 25 under the effect of elastic deformation.

Thus, the diaphragm-operating ring 2 of the interchangeable objective constructed according to the present invention is controlled in the following manner. Within the M-range, both rotation arresting members 21M, 21A for M and A, respectively, are forcibly deflected by the inner surface of the diaphragm-operating ring 2 inwardly, as shown in FIG. *6a*, unless said diaphragm-operating ring 2 is rotated to the minimum lens aperture position. In consequence, these arresting members are never received by the locking groove 25 and the diaphram-operating ring 2 is freely rotatable in the directions both of arrows R and L.

When the diaphragm-operating ring 2 has been rotated in the direction as indicated by the arrow L (FIGS. *6a, b, c*) to the minimum lens aperture position, the arresting surface 28M of the rotation arresting members 21M for M bears against the M-locking side wall 25M of the locking groove 25, thereby arresting further rotation of the diaphragm-operating ring in the direction of the arrow L, i.e., toward the A-position, as shown in FIG. *6b*, FIG. *7a* and FIG. *8a*. Now the diaphragm-operating ring 2 is freely rotatable toward the maximum lens aperture position (i.e., upon rotation in this direction, the corner of the locking groove 25 deflects the arresting member 21M downward).

To rotate the diaphragm-operating ring 2 to the A-position, the unlocking member 26 is depressed to disengage the arresting surface 28M of the rotation arresting member 21M for M from the M-locking side wall 25M, as seen in FIGS. *6c* and *7b*. From such a state the diaphragm-operating ring 2 may be rotated in the direction of the arrow L, i.e., toward the A-position. When the diaphragm-operating ring has been rotated to the A-position, the arresting surface 28A of the rotation arresting members 21A for A is engaged with the A-locking side wall 25A of the locking groove 25, as seen in FIGS. *6e*, *7b*, and *8b*, thereby arresting rotation of the diaphragm-operating ring 2 in the direction of the arrow R, i.e., toward the M-range. The rotation in the direction of the arrow L is arrested by the interlocking pin 6 on

the diaphragm-rotating ring **5** abutting an end **9**A of the interlocking groove **9** formed in the support ring **1**.

To bring the diaphragm-operating ring **2** back to the M-range, the unlocking member **26** is depressed to displace the rotation arresting member **21**A for A inwardly, as shown in FIG. *6f*, thereby disengaging the arresting surface **28**A from the A-locking side wall **25**A. From this state, the diaphragm-operating ring **2** may be rotated toward the M-range. In the embodiment described hereinabove, the two rotation arresting members **21**M, **21**A are located in the leaf spring grooves **20**M, **20**A, respectively, and there is provided between these both leaf spring grooves **20**M, **20**A a land (position control surface) **22** adapted to control the maximum displacement of the unlocking member **26**. As a result, smooth operation is assured without extreme deformation of the rotation arresting members **21**M, **21**A.

FIG. **9** shows another embodiment of the rotation arresting members **21**M, **21**A. According to this embodiment, both rotation arresting members **21**M, **21**A for M and A, respectively, are formed in a one piece construction from a single piece of leaf spring material; there is provided between both arresting members a common surface for position control **22**.

In another embodiment shown in FIG. **10**, the locking groove **25** formed in the diaphragm-operating ring **2** comprises a combination of two locking grooves **25**(1), **25**(2) of triangular cross-sections, respectively, including M-locking side wall **25**M and A-locking side wall **25**A. In this embodiment, the rotation arresting members **21**M, **21**A may be formed from a linear, i.e., straight, leaf spring material and the forward ends of the respective rotation arresting members **21**M, **21**A may function as arresting surfaces **28**M, **28**A.

It should be noted here that the mount support ring **1** according to the present invention is a non-rotatable member adapted for rotatable support of the diaphragm-operating ring **2**.

It will be understood from the foregoing description that, in accordance with the present invention, changeover of the diaphragm-operating ring between the M-range and the A-position is accomplished by using two rotation arresting members comprising leaf springs for M-range and A-position, respectively, and the opposite side walls circumferentially defining the locking groove of the diaphragm-operating ring, which may be disengageably engaged with said both rotation arresting members. These both rotation arresting members are offset in the direction of the optical axis and displaceable by depression of the single unlocking member. Thus, it is possible to reduce the rotation angle for changeover between the M-range and the A-position by suitably arranging the positions of the respective leaf springs serving as rotation arresting members so that the degree of design freedom may be improved and the desired strength may be maintained. Furthermore, the change-over between the M-range and the A-position can be achieved merely by depressing the single unlocking member with a high maneuverability.

The disclosure of Japanese Utility Model Application No. 1982-124728, Japanese Utility Model Gazette No. 59(1984)-30123, laid open Feb. 24, 1984, is incorporated fully by reference.

What is claimed is:

1. An interchangeable objective with a variable lens aperture for a camera comprising:

a stationary support member;

a diaphragm-operating member rotatable about an axis between first and second angular positions relative to the stationary member;

a first elongated leaf spring mounted on the stationary member to bear against the diaphragm-operating member along a first plane perpendicular to the axis;

a second elongated leaf spring mounted on the stationary member to bear against the diaphragm-operating member along a second plane perpendicular to the axis, the second plane being spaced from the first plane in the direction of the axis;

locking groove means formed in the diaphragm-operating member so as alternately to receive the first and second leaf springs in locking engagement when the diaphragm-operating member is positioned at the first and second angular positions, respectively; and

an unlocking button mounted in the diaphragm-operating member over the locking groove means to push the respective first and second leaf springs out of engagement with the locking groove means upon depression of the locking button.

2. The objective of claim **1**, in which the stationary members has annular mounting groove means in communication with the locking groove means in which the first and second leaf springs are mounted.

3. The objective of claim **2**, in which each leaf spring comprises a first elongated portion attached to the stationary member in the mounting groove means and extending away therefrom toward the locking groove means and a second elongated portion forming an obtuse angle with the first portion and adapted to fit in the locking groove means.

4. The objective of claim **3**, in which the locking groove means has a rectangular cross-section with opposite corners and each leaf spring additionally comprises a third portion extending at an angle of about 90° from the end of the second portion such that the intersection of the second and third portions fits into one of the corners of the locking groove means when such leaf spring is in locking engagement therewith, the intersections of the leaf springs fitting in the respective opposite corners of the locking groove means.

5. The objective of claim **2**, in which the first and second leaf springs are straight and face toward each other and the locking groove means comprise first and second grooves having oppositely oriented triangular cross-sections with respective apexes adapted to receive the ends of the respective first and second leaf springs.

6. The objective of claim **2**, in which the first and second leaf springs are formed of respective first and second pieces of spring material.

7. The objective of claim **2**, in which the first and second leaf springs are formed of a single piece of spring material.

* * * * *

United States Patent [19]

Yamaguchi

[11] **Patent Number: 4,514,052**

[45] **Date of Patent: Apr. 30, 1985**

[54] **HIGH SPEED OBJECTIVE LENS SYSTEM WITH AN ASPHERIC SURFACE**

[75] Inventor: **Tamikazu Yamaguchi**, Sakai, Japan

[73] Assignee: **Minolta Camera Kabushiki Kaisha**, Osaka, Japan

[21] Appl. No.: **446,653**

[22] Filed: **Dec. 3, 1982**

[30] **Foreign Application Priority Data**

Dec. 7, 1981 [JP] Japan 56-197239

[51] **Int. Cl.**[3] **G02B 9/60**

[52] **U.S. Cl.** **350/466**; 350/432

[58] **Field of Search** 350/432, 466

[56] **References Cited**

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47-19386 6/1972 Japan .

56-75613 6/1981 Japan .

Primary Examiner—John K. Corbin

Assistant Examiner—Paul M. Dzierzynski

Attorney, Agent, or Firm—Jackson, Jones & Price

[57] **ABSTRACT**

A Gauss type objective lens system with a high speed of F1.2 for 35 mm SLR cameras is provided. The lens system consists of seven lenses, the object side surface of the second lens being aspheric, and fulfills the following conditions:

$$0.65 < Da/Db < 1.1$$

$$B < 0 \text{ and } C < 0$$

$$0.55f < R < f$$

wherein: Da represents the sum of axial distance from the object side surface of the second lens to the image side surface of the third lens; Db represents the sum of axial distance from the object side surface of the fourth lens to the image side surface of the fifth lens; B and C represent the aspheric surface coefficients of the fourth degree and of the sixth degree, respectively; f represents the focal length of the whole lens system; and R represents the paraxial radius of curvature of the object side surface of the second lens.

8 Claims, 21 Drawing Figures

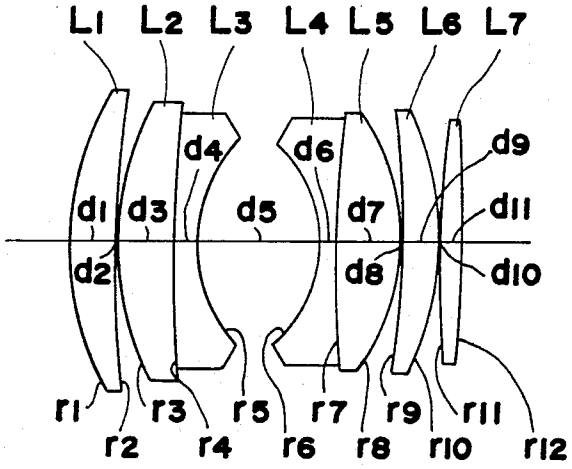


FIG.1

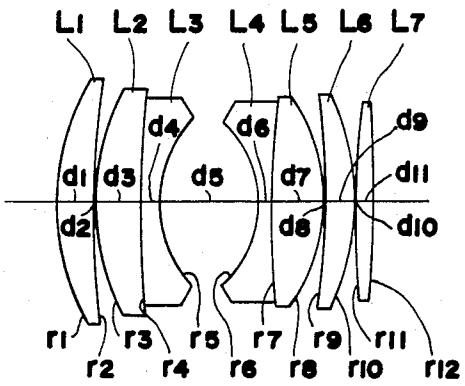


FIG.2

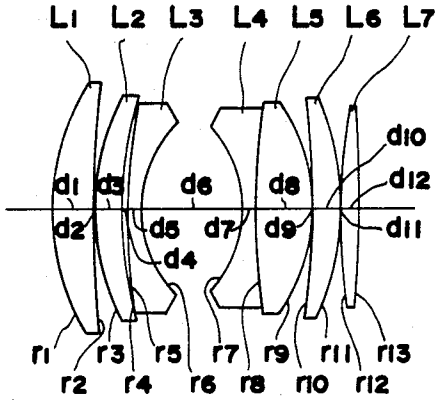


FIG.3

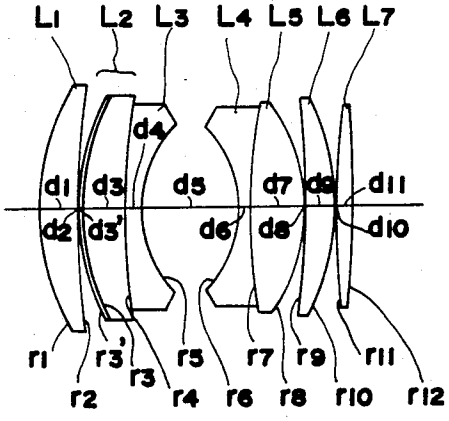
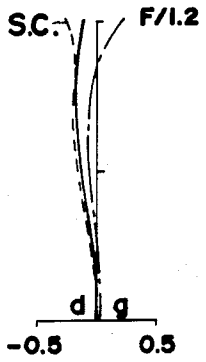
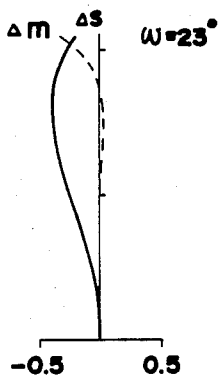


FIG.4a



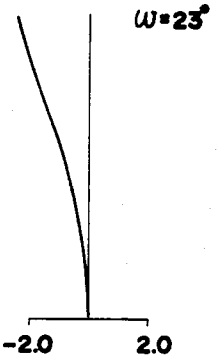
Spherical Aberration
Sine Condition

FIG.4b



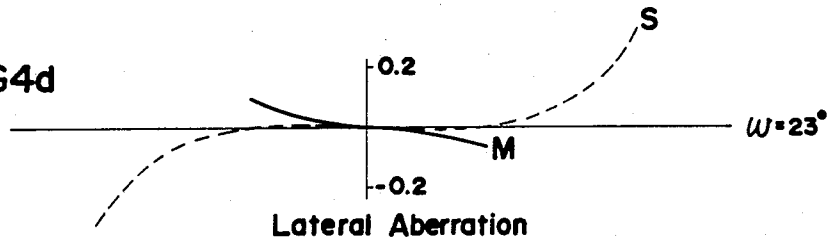
Astigmatism

FIG.4c



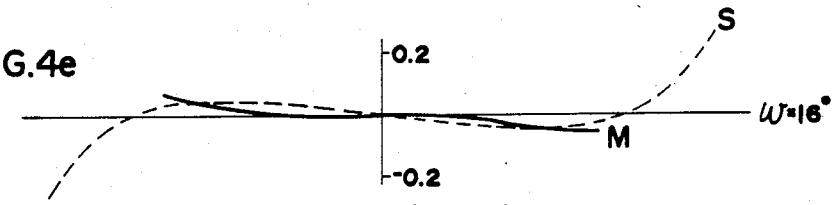
Distortion

FIG4d



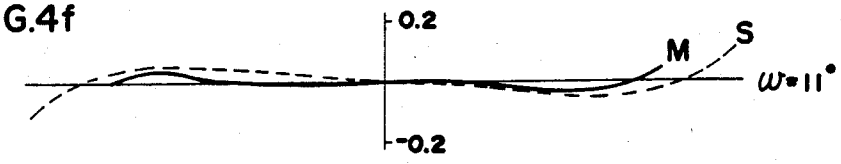
Lateral Aberration

FIG.4e



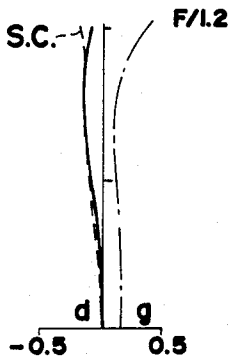
Lateral Aberration

FIG.4f



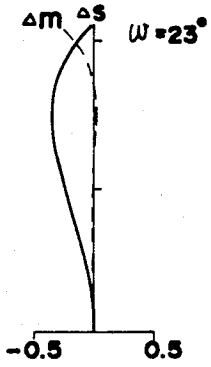
Lateral Aberration

FIG.5a



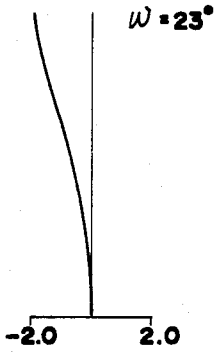
Spherical Aberration
Sine Condition

FIG.5b



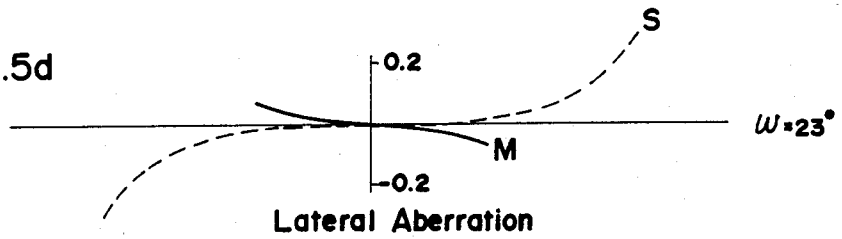
Astigmatism

FIG.5c



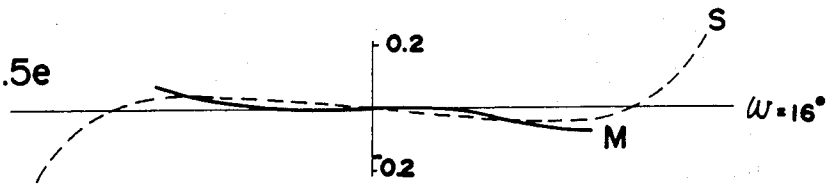
Distortion

FIG.5d



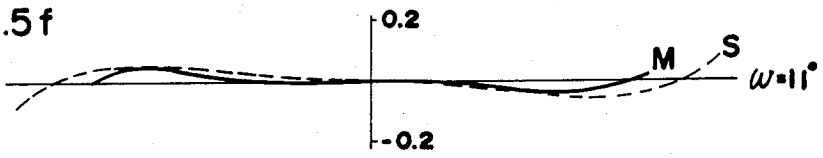
Lateral Aberration

FIG.5e



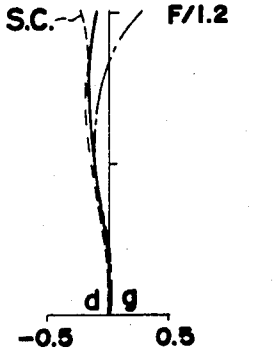
Lateral Aberration

FIG.5f



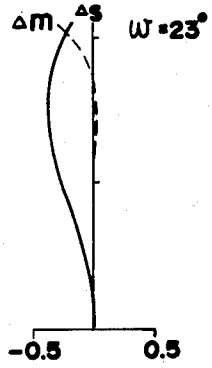
Lateral Aberration

FIG.6a



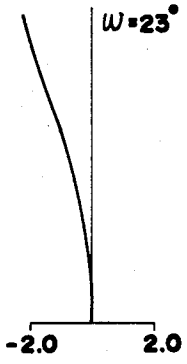
Spherical Aberration
Sine Condition

FIG.6b



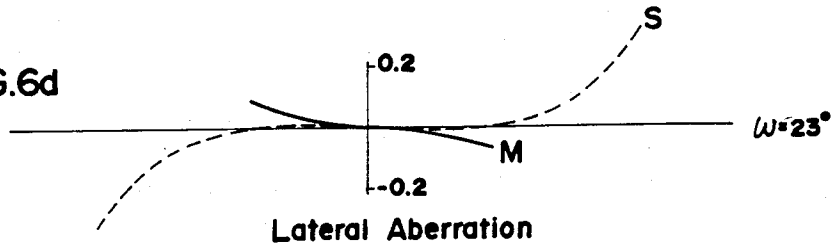
Astigmatism

FIG.6c



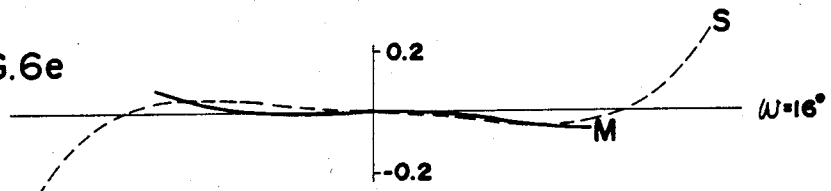
Distortion

FIG.6d



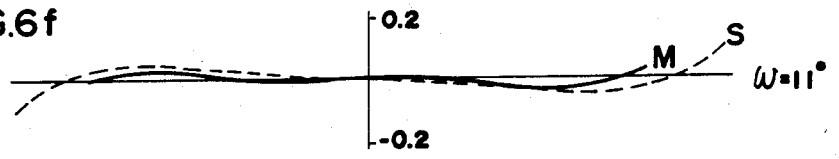
Lateral Aberration

FIG.6e



Lateral Aberration

FIG.6f



Lateral Aberration

HIGH SPEED OBJECTIVE LENS SYSTEM WITH AN ASPHERIC SURFACE

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to an objective lens system with a high speed of about F1.2 and a field angle of about 46 degrees, and more particularly to such an objective lens system with an aspheric surface.

2. Description of the Prior Art

It is generally known in the prior art that a Gauss-type lens system with a high speed of about F1.2 and a sufficiently long back focal distance achieves such a desirable correction for field curvature that the resolution of the image is satisfactory throughout the entire area. In such a Gauss-type lens system, however, the spherical aberration is generally in an overcorrection condition to remarkably deteriorate the contrast of the image due to the greatly generated sagittal flare. The overcorrection of the spherical aberration is caused by the steep curvatures of the negative lens elements sandwiching the aperture stop, and is hardly corrected even by utilizing a glass material of a high refractive index in the case of such a high speed lens system.

In this field of art, it has been known to utilize an aspheric surface for aberration correction.

Examples of the prior art which discloses a Gauss-type objective lens system with an aspheric surface can be found in U.S. Pat. No. 3,459,468, Japanese Patent Publication No. 47-19386 and Japanese laid open Patent Application No. 56-75613.

The prior art is still seeking to provide a high speed Gauss-type objective lens system with an improved optical performance.

SUMMARY OF THE INVENTION

An object of the present invention is to provide a high speed objective lens system with an improved aberration correction.

Another object of the present invention is to provide a high speed objective lens system capable of forming an image with high contrast.

Still another object of the present invention is to provide a high speed objective lens system utilizing an aspheric surface in an improved manner.

The present invention provides a Gauss-type lens system of seven lenses with an aspheric surface provided at the object side of the second lens, which fulfills the following conditions:

$$0.65 < Da/Db < 1.1$$

$$B < 0$$

$$c < 0$$

$$0.55f < R < f$$

wherein: Da represents the sum of the axial distance from the object side surface of the second lens to the image side surface of the third lens; Db represents the sum of the axial distance from the object side surface of the fourth lens to the image side surface of the fifth lens; B and C represent the aspheric surface coefficients, respectively, in the following equation provided that X represents the distance, measured toward the image side along a direction parallel with the optical axis, from the center of the aspheric surface to a point on the aspheric surface at the height, Y from the optical axis, and r_0 represents the paraxial radius of curvature of the aspheric surface:

$$X = \frac{Y^2}{r_0 + r_0\sqrt{1 - \left(\frac{Y}{r_0}\right)^2}} + AY^2 + BY^4 + CY^6 + DY^8 + \ldots;$$

f represents the focal length of the whole lens system; and R represents the paraxial radius of curvature of the object side surface of the second lens.

The features of the present invention which are believed to be novel are set forth with particularity in the appended claims. The present invention, both as to its organization and manner of operation, together with further objects and advantages thereof, may best be understood by reference to the following description, taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** represents a cross sectional view of the lens system according to a first embodiment of the present invention;

FIG. **2** represents a cross sectional view of the lens system according to a second embodiment of the present invention;

FIG. **3** represents a cross sectional view of the lens system according to a third embodiment of the present invention;

FIGS. **4***a* to **4***f* represent the aberration curves of the first embodiment;

FIGS. **5***a* to **5***f* represent the aberration curves of the second embodiment; and

FIGS. **6***a* to **6***f* represent the aberration curves of the third embodiment.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The following description is provided to enable any person skilled in the optical and camera field to make and use the invention and sets forth the best modes contemplated by the inventor for carrying out his invention. Various modifications, however, will remain readily apparent to those skilled in the art, since the generic principles of the present invention have been defined herein specifically to provide an improved high speed objective lens system. The derivation of the formulas and the relation of the powers set forth herein can be accomplished with the assistance of a computer. The present invention represents the parameters of a compromise balance of acceptable aberrations which can be relatively easily manufactured to provide a high speed objective lens system for utilization with a 35 mm SLR camera.

In the drawings, schematic cross sectional views disclose the position of the lens groups and lens elements, and follow the normal conventions of the object at the left-hand side of the drawing and the image plane at the right-hand side.

As disclosed in FIGS. **1** to **3**, the present invention provides a high speed Gauss-type objective lens system with an aspheric surface comprising, from the object to image side: a front lens group consisting of a first positive lens(L_1), a second positive lens(L_2) and a third negative lens(L_3); and a rear lens group consisting of a fourth negative lens(L_4), a fifth positive lens(L_5) ce-

mented to the fourth negative lens, a sixth positive meniscus lens(L_6) and a seventh biconvex lens(L_7), wherein the second positive lens(L_2) has an aspheric surface at its object side, the shape of the aspheric surface being designed so that the deviation of the aspheric surface from its paraxial radius to the object side is increased in accordance with the increase of the height from the optical axis. Further, the lens system according to the present invention fulfills the following conditions:

$$0.65 < Da/Db < 1.1 \quad (1)$$

$$B < 0 \text{ and } C < 0 \quad (2)$$

wherein: Da represents the sum of axial distance from the object side surface of the second positive lens(L_2) to the image side surface of the third negative lens(L_3); Db represents the sum of the axial distance from the object side surface of the fourth negative lens(L_4) to the image side surface of the fifth positive lens(L_5); B and C represent the aspheric surface coefficients, respectively, in the following equation provided that X represents the distance, measured toward the image side along a direction parallel with the optical axis, from the center of the aspheric surface to a point on the aspheric surface at the height, Y from the optical axis, and r_0 represents the paraxial radius of curvature of the aspheric surface:

$$X = \frac{Y^2}{r_0 + r_0\sqrt{1 - \left(\frac{Y}{r_0}\right)^2}} + AY^2 + BY^4 + CY^6 + DY^8 + \ldots .$$

In utilizing an aspheric surface for a lens system, the location of the aspheric surface should be carefully selected in view of the effect on the aberration correction and the easiness in manufacturing the aspheric surface. As is already mentioned, the contrast of the image formed by the Gauss-type lens system of a high speed such as F1.2 is unsatisfactory due to the flare caused by the steep curvatures of the negative lenses sandwiching the aperture stop. To overcome this disadvantage, it is generally required to relatively moderate the curvature of the surfaces sandwiching the aperture stop for balancing the aberration correction. This requirement is, however, difficult to realize by a lens system consisting of spherical lens elements even if a high index glass is used. Therefore, an aspheric surface is needed at a surface having a positive refractive power so as to lessen the curvature of the surface in accordance with the increase of the height from the optical axis. The effect of the aspheric surface of such a shape, however, depends on the specific location thereof in the lens system. Especially, the location of such an aspheric surface suitable for the correction of both the spherical aberration and coma is limited. Further, the degree of possible deviation of the aspheric surface from its paraxial radius is restricted. With the above factors carefully taken into consideration, the present invention selects the third surface of the lens system numbered from the object side, i.e., the object side surface of the second positive lens(L_2) as the most effective location of the aspheric surface in the case of and objective lens system with a high speed such as F1.2. If should be also noted that the paraxial radius of the aspheric surface is suitably designed.

The requirement in this type of lens system to secure a sufficiently long back focal distance also causes the undesirable steep curvatures of the pair of refractive surfaces sandwiching the aperture stop. To resolve this problem, the present invention provides the above mentioned condition(1), in which the relationship of the axial distance for the second and third lenses to that for the fourth and fifth lenses is defined for securing the sufficient back focal distance with the excessive curvatures of the pair of refractive surfaces sandwiching the aperture stop successfully avoided. If the upper limit of condition(1) is violated, the undesirable flare would increase, while the necessary marginal thickness of the second positive lens(L_2) having the aspheric surface would be insufficient if the lower limit of condition(1) is violated.

In designing the lens system according to the present invention, it should be noted that the above efforts to reduce the sagittal flare contradicts the demand for decreasing the Petzval Sum to improve the field curvature. For the purpose of overcoming such a contradiction, it is recommended to use a high index glass as the lenses of positive refractive power. In view of the selection of glass in the Gauss-type lens system, it is also recommended to use a relatively low Abbe number glass as the positive lenses in the rear lens group for sufficiently correcting both the lateral and longitudinal chromatic aberrations.

Conditions(2) relates to the shape of the aspheric surface located on the object side of the second positive lens(L_2). In utilizing the aspheric surface at the third surface of the high speed Gauss-type lens system for correcting spherical aberration, it is necessary to obtain, in addition to the reduced absolute value of spherical aberration at every ray height, a smooth shape of the spherical aberration curve by balancing between the spherical aberration of lower degree and that of higher degree. Conditions(2) which requires negative values for both the coefficients, B and C is necessary for this purpose. It is needless to say that the desired aspheric surface to correct the spherical aberration would be impossible if condition(2) is violated to result in $B>0$ and $C>0$. Further, if condition(2) is violated so that one of the coefficients, B and C is positive, the spherical aberration curve would show a shape of rough wave to deteriorate the Modulation Transfer Function(MTF) although the absolute value of spherical aberration may be within a limit at every ray height.

The MTF value for the d-line, $w=0°$, discloses a resolution of substantially 1.0 from 0 to 20 lines per millimeter. The MTF value is maintained substantially high through 50 lines per millimeter when condition (2) is maintained.

Further according to the present invention the following conditions are provided:

$$0.55f < R < f \quad (3)$$

$$\frac{N_1 + N_5 + N_6}{3} > 1.75 \quad (4)$$

$$\frac{\nu_5 + \nu_6}{2} > 40 \quad (5)$$

wherein: f represents the focal length of the whole lens system; R represents the paraxial radius of curvature of

the object side surface of the second positive lens(L_2); N_1, N_5 and N_6 represent the refractive index with respect to d-line of the first positive lens(L_1), the fifth positive lens(L_5) and the sixth positive meniscus lens(L_6), respectively; and ν_5 and ν_6 represent the Abbe number of the fifth positive lens(L_5) and the sixth positive meniscus lens(L_6).

Condition(3) defines the paraxial radius of curvature of the aspheric surface, which is located at the object side of the second positive lens(L_2). If condition(2) is violated, the desirable aspheric surface for sufficiently correcting both the spherical aberration and coma cannot be effectively located at the object side of the second positive lens(L_2).

Conditions(4) and (5) define the above mentioned requirements for the selection of glass in more detail. If condition(4) is violated, the correction of the field curvature would be difficult. On the other hand, the requirement of correcting both the lateral and longitudinal chromatic aberrations would not be attainable if condition(5) is violated.

The following Tables 1 to 3 disclose, respectively, the first through third embodiments of the present invention. In the Tables, f equals the focal length, r is the radius of curvature with respective sub numbers indicating the surfaces from the object to image side along the optical axis, d represents the axial distance and includes both the air spaces and the actual thickness of the lenses along the optical axis, N equals the refractive index and again, the sub numbers refer to the particular optical element from the object to image side, and finally, ν equals the Abbe number and the sub numbers refer to the specific lens elements from the object to image side. The asterisk(*) represents the aspheric surface, and its coefficients are shown at the bottom of the respective Tables.

TABLE 1

[Embodiment 1]

$f = 100.0\ F_{No.} = 1.2$

	Radius of Curvature		Axial Distance		Refractive Index		Abbe Number
L_1	r_1 83.157						
		d_1 11.982	N_1	1.78850	ν_1	45.68	
	r_2 281.998						
		d_2 0.398					
L_2	r_3* 79.065						
		d_3 15.219	N_2	1.74400	ν_2	44.93	
	r_4 336.229						
L_3		d_4 5.667	N_3	1.63980	ν_3	34.55	
	r_5 39.365						
		d_5 33.501					
L_4	r_6 −36.255						
		d_6 3.779	N_4	1.73300	ν_4	28.24	
	r_7 258.131						
L_5		d_7 17.728	N_5	1.77250	ν_5	49.77	
	r_8 −57.973						
		d_8 0.290					
L_6	r_9 −356.298						
		d_9 9.708	N_6	1.77250	ν_6	49.77	
	r_{10} −84.313						
		d_{10} 0.290					
L_7	r_{11} 240.134						
		d_{11} 6.213	N_7	1.77250	ν_7	49.77	
	r_{12} −323.023						

*Aspheric Surface
A = 0
B = $-0.1129681 \times 10^{-6}$
C = $-0.1817826 \times 10^{-10}$
D = $0.6096011 \times 10^{-14}$
$r_0 = r_3$

TABLE 2

[Embodiment 2]

$f = 100.0\ F_{No.} = 1.2$

	Radius of Curvature		Axial Distance		Refractive Index		Abbe Number
L_1	r_1 73.807						
		d_1 13.595	N_1	1.78850	ν_1	45.68	
	r_2 389.519						
		d_2 0.310					
L_2	r_3* 73.784						
		d_3 8.915	N_2	1.77250	ν_2	49.77	
	r_4 132.936						
		d_4 2.371					
L_3	r_5 218.882						
		d_5 4.083	N_3	1.65446	ν_3	33.86	
	r_6 39.249						
		d_6 34.487					
L_4	r_7 −37.953						
		d_7 3.389	N_4	1.76182	ν_4	26.55	
	r_8 222.559						
L_5		d_8 18.406	N_5	1.77250	ν_5	49.77	
	r_9 −62.659						
		d_9 0.288					
L_6	r_{10} −346.275						
		d_{10} 9.391	N_6	1.85000	ν_6	40.51	
	r_{11} −83.026						
		d_{11} 0.290					
L_7	r_{12} 208.213						
		d_{12} 6.218	N_7	1.77250	ν_7	49.77	
	r_{13} −424.675						

*Aspheric Surface
A = 0
B = $-0.1170173 \times 10^{-6}$
C = $-0.9056829 \times 10^{-11}$
D = $-0.4400188 \times 10^{-14}$
$r_0 = r_3$

TABLE 3

[Embodiment 3]

$f = 100.0\ F_{No.} = 1.2$

	Radius of Curvature		Axial Distance		Refractive Index		Abbe Number
L_1	r_1 81.901						
		d_1 12.574	N_1	1.78850	ν_1	45.68	
	r_2 290.998						
		d_2 0.407					
L_2	r_3'* 79.247						
		d_3' 0.078	N_2'	1.53300	ν_2'	34.30	
	r_3 79.247						
		d_3 14.926	N_2	1.74400	ν_2	44.93	
	r_4 237.110						
L_3		d_4 5.106	N_3	1.63980	ν_3	34.55	
	r_5 39.574						
		d_5 33.428					
L_4	r_6 −36.796						
		d_6 3.624	N_4	1.76182	ν_4	26.55	
	r_7 251.833						
L_5		d_7 17.587	N_5	1.77250	ν_5	49.77	
	r_8 −59.513						
		d_8 0.291					
L_6	r_9 −378.311						
		d_9 9.708	N_6	1.85000	ν_6	40.51	
	r_{10} −83.213						
		d_{10} 0.291					
L_7	r_{11} 249.413						
		d_{11} 6.214	N_7	1.77250	ν_7	49.77	
	r_{12} −356.655						

*Aspheric Surface
A = 0
B = $-0.1733578 \times 10^{-6}$
C = $-0.2088121 \times 10^{-10}$
D = $0.5421115 \times 10^{-14}$
$r_0 = r_3'$

As in the above embodiments 1 and 3, the third negative lens(L_3) may be cemented to the second positive lens(L_2).

Further, as in embodiment 3, the second positive lens(L_2) may consist of a spherical lens part(r_3–r_4) and a

thin layer part(r_3'—r_3) coated on the spherical lens part at its object side(r_3), the thin layer part(r_3'—r_3) being made of a transparent refractive material such as UV-curable resins, the object side surface(r_3') of which is molded to serve as the aspheric surface of the second positive lens(L_2). In such a construction of the second positive lens(L_2), the cost of manufacturing the aspheric surface is expected to be lowered.

As can be readily appreciated, it is possible to deviate from the above embodiments of the present invention and, as will be readily understood by those skilled in the optical art, the invention is capable of many modifications and improvements within the scope and spirit thereof. Accordingly, it will be understood that the invention is not to be limited by these specific embodiments, but only by the scope and spirit of the appended claims.

What is claimed is:

1. A high speed objective lens system with an aspheric surface comprising, from the object to image side:

a front lens group consisting of a first positive lens, a second positive lens and a third negative lens; and

a rear lens group consisting of a fourth negative lens, a fifth positive lens cemented to the fourth negative lens, a sixth positive meniscus lens and a seventh biconvex lens, wherein the second positive lens has an aspheric surface at its object side, which increases the deviation from its paraxial radius to the object side in accordance with the increase of the height from the optical axis, the d-line modulation transfer function being substantially 1.0 for a resolution of 0 to 20 lines/millimeter when the lens system fulfills the following conditions:

$$0.65 < Da/db < 1.1$$

$$B < 0$$

$$C < 0$$

wherein:

Da represents the sum of axial distance from the object side surface of the second positive lens to the image side surface of the third negative lens;

Db represents the sum of axial distance from the object side surface of the fourth negative lens to the image side surface of the fifth positive lens;

B and C represent the aspheric surface coefficients, respectively, in the following equation provided that X represents the distance, measured toward the image side along the direction parallel with the optical axis, from the center of the aspheric surface to a point on the aspheric surface at the height, Y from the optical axis, and r_0 represents the paraxial radius of curvature of the aspheric surface:

$$X = \frac{Y^2}{r_0 + r_0\sqrt{1 - \left(\frac{Y}{r_0}\right)^2}} + AY^2 + BY^4 + CY^6 + DY^8 + \ldots.$$

2. The invention of claim **1**, wherein the lens system further fulfills the following condition:

$$0.55f < R < f$$

wherein:

f represents the focal length of the whole lens system; and

R represents the paraxial radius of curvature of the object side surface of the second positive lens.

3. The invention of claim **1**, wherein the second positive lens consists of a spherical lens part and a thin layer part coated on the spherical lens part at its object side, the thin layer part being made of a transparent refractive material, the object side surface of which serves as the aspheric surface of the second positive lens.

4. The invention of claim **1**, wherein the third negative lens is cemented to the second positive lens.

5. The invention of claim **1**, wherein the lens system further fulfills the following conditions:

$$\frac{N_1 + N_5 + N_6}{3} > 1.75$$

$$\frac{\nu_5 + \nu_6}{2} > 40$$

wherein:

N_1, N_5 and N_6 represent the refractive index with respect to d-line of the first positive lens, the fifth positive lens and the sixth positive meniscus lens, respectively; and

ν_5 and ν_6 represent the Abbe number of the fifth positive lens and the sixth positive meniscus lens.

6. The invention of claim **2**, wherein the condition for R is as follows:

$$0.6f < R < f.$$

7. The invention of claim **2**, wherein the condition for R is as follows:

$$0.67f < R < f.$$

8. A high speed objective lens system with an aspheric surface comprising the following design parameters:

$f = 100.0$ $F_{No.} = 1.2$

		Radius of Curvature		Axial Distance		Refractive Index		Abbe Number
L_1	r_1	83.157	d_1	11.982	N_1	1.78850	ν_1	45.68
	r_2	281.998	d_2	0.398				
L_2	r_3*	79.065	d_3	15.219	N_2	1.74400	ν_2	44.93
	r_4	336.229	d_4	5.667	N_3	1.63980	ν_3	34.55
L_3	r_5	39.365	d_5	33.501				
L_4	r_6	−36.255	d_6	3.779	N_4	1.73300	ν_4	28.24
	r_7	258.131	d_7	17.728	N_5	1.77250	ν_5	49.77
L_5	r_8	−57.973	d_8	0.290				
L_6	r_9	−356.298	d_9	9.708	N_6	1.77250	ν_6	49.77
	r_{10}	−84.313	d_{10}	0.290				
L_7	r_{11}	240.134	d_{11}	6.213	N_7	1.77250	ν_7	49.77
	r_{12}	−323.023						

*Aspheric Surface

A = 0

B = $-0.1129681 \times 10^{-6}$

C = $-0.1817826 \times 10^{-10}$

D = $0.6096011 \times 10^{-14}$

$r_0 = r_3$.

* * * * *

United States Patent [19]

Taniguchi et al.

[11] **Patent Number: 4,509,842**

[45] **Date of Patent: Apr. 9, 1985**

[54] **CAMERA SYSTEM CAPABLE OF FOCUS DETECTION THROUGH AN INTERCHANGEABLE OBJECTIVE LENS**

[75] Inventors: **Nobuyuki Taniguchi**, Tondabayashi; **Norio Ishikawa**, Osaka; **Yasuaki Akada**, Sakai; **Takeshi Egawa**, Sennan; **Kunio Kawamura**, Sakai, all of Japan

[73] Assignee: **Minolta Camera Kabushiki Kaisha**, Osaka, Japan

[21] Appl. No.: **575,707**

[22] Filed: **Jan. 31, 1984**

[30] **Foreign Application Priority Data**

Feb. 1, 1983	[JP]	Japan	58-15860
Jun. 23, 1983	[JP]	Japan	58-113937
Jun. 23, 1983	[JP]	Japan	58-113938
Jul. 6, 1983	[JP]	Japan	58-123994
Jul. 25, 1983	[JP]	Japan	58-136059
Jul. 25, 1983	[JP]	Japan	58-136060

[51] **Int. Cl.**³ **G03B 17/00**; G03B 3/10

[52] **U.S. Cl.** **354/402**; 354/406; 354/286

[58] **Field of Search** 354/400, 401, 402, 406, 354/407, 408, 409, 286

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Primary Examiner—Russell E. Adams

Attorney, Agent, or Firm—Jackson, Jones & Price

[57] **ABSTRACT**

A camera system with an auto-focusing system includes a camera body and an interchangeable zoom lens. The interchangeable objective lens stores various data to be sent to the camera body for improving automatic focus adjustment, such as an information necessary to convert the detected defocus information into a movement of the driving power source to carry out the automatic focus adjustment. The driving power source in the camera body is controlled in response to the data from the interchangeable objective lens and the detected focus information, the driving power being transmitted to the interchangeable objective lens. The camera body is further capable of inhibiting the focus adjustment or focus indication in response to a data from the interchangeable objective lens under an unfavorable condition.

30 Claims, 30 Drawing Figures

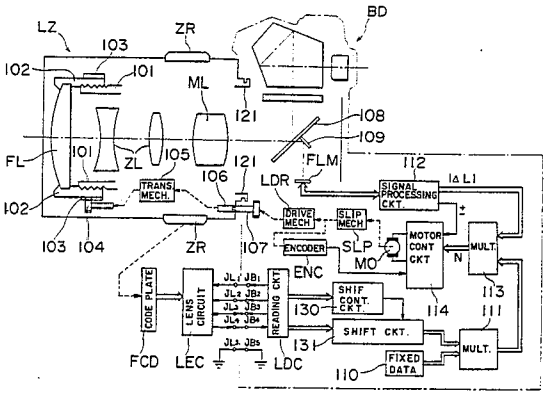


Fig. 1 Prior Art

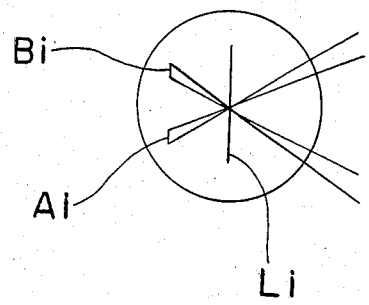


Fig. 3 Prior Art

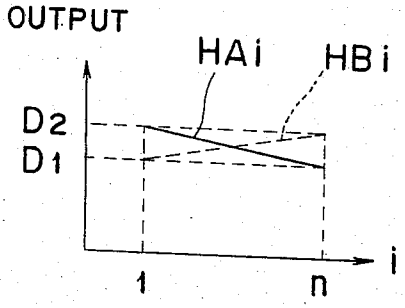


Fig. 2 Prior Art

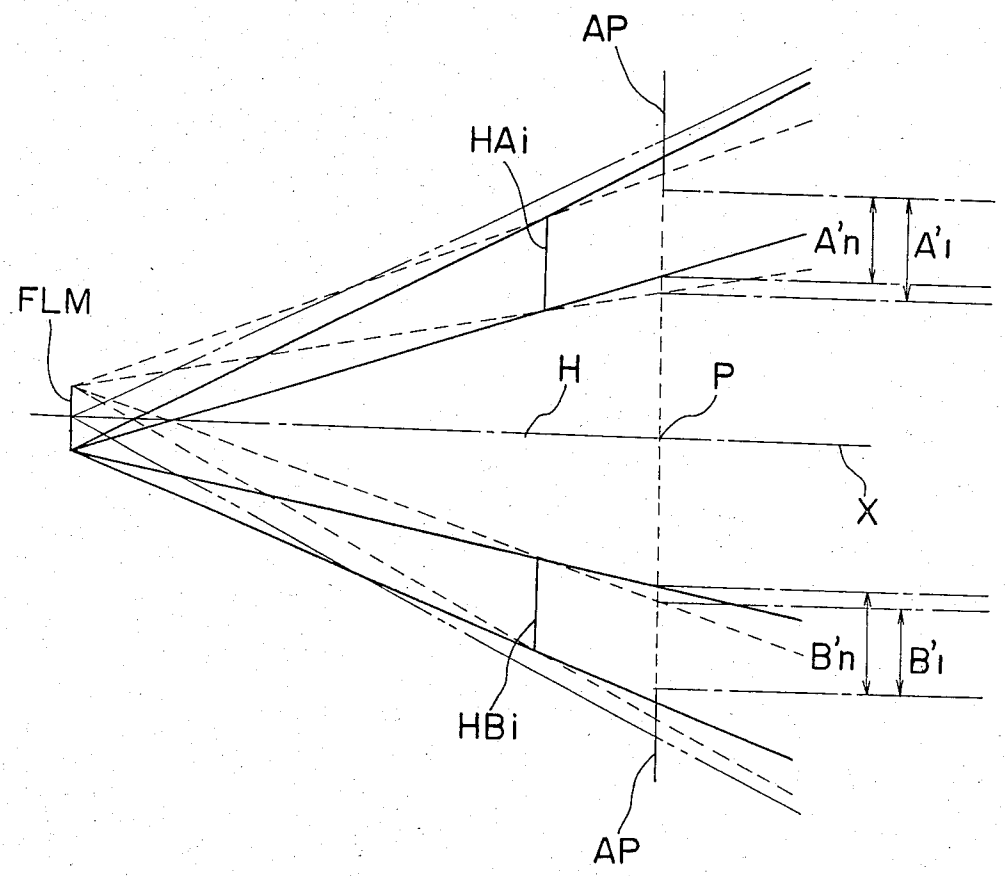
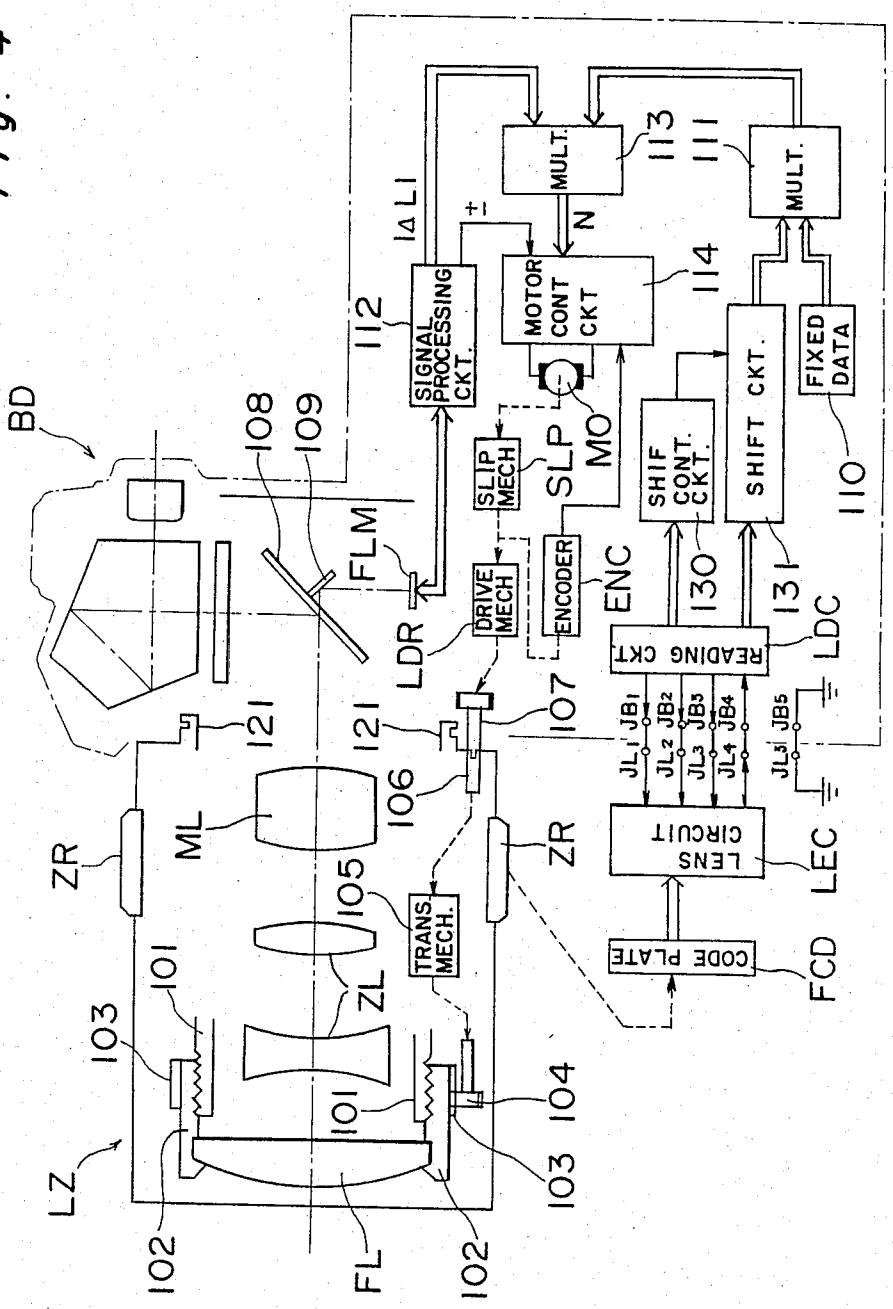


Fig. 4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ZR
ZR
105
TRANS. MECH.
LENS CIRCUIT
LEC
CODE PLATE
FCD
ZL
101
103
101
104
LZ
103
102
FL
102

Fig. 5

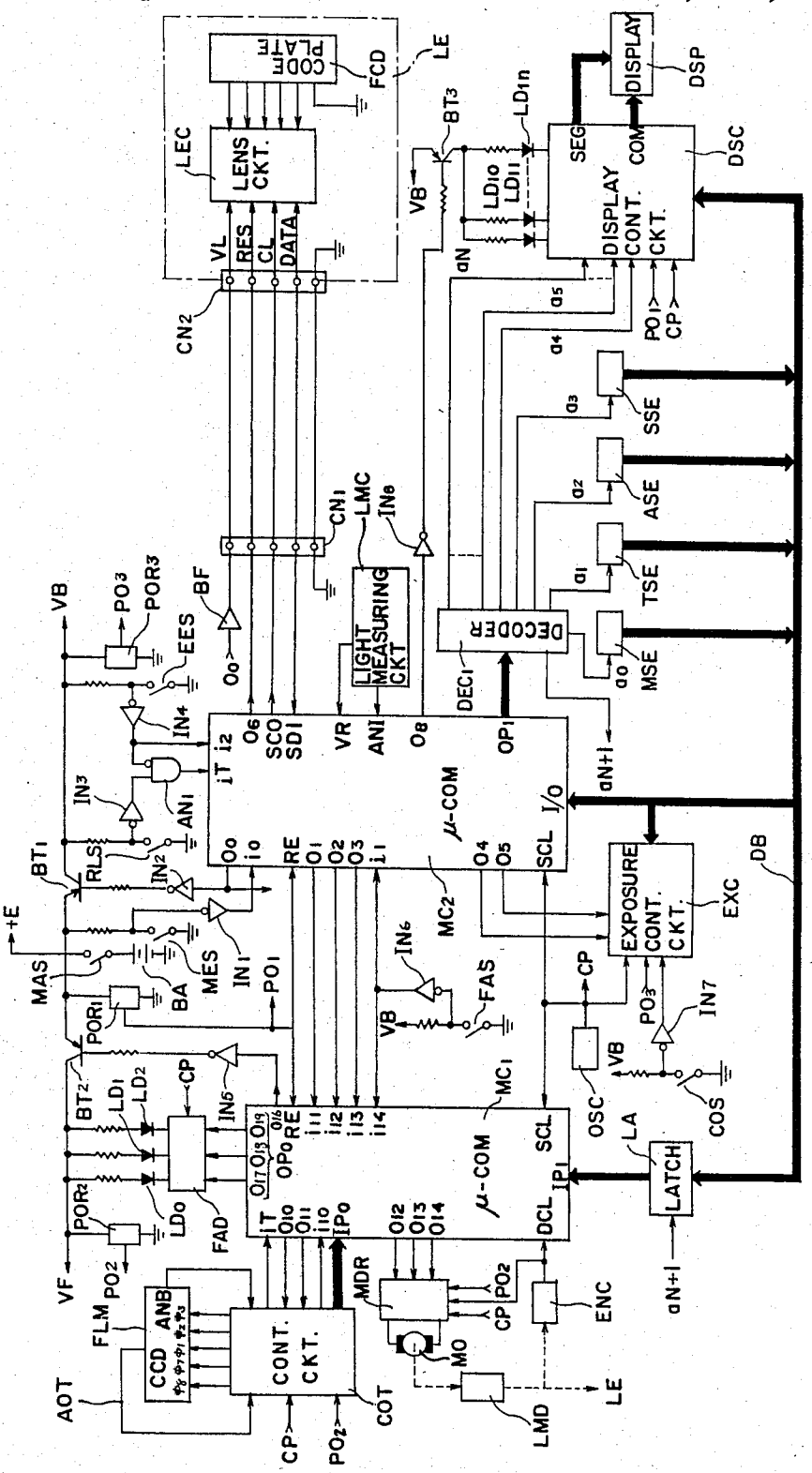

PCDET
FCD
LE
LEC
LENS CKT.
VL
RES
CL
DATA
CN2
DISPLAY
DSP
BT3
LD1n
LD10
LD11
SEG
COM
DISPLAY CONT. CKT.
DSC
aN
a5
a4
a3
a2
a1
a0
PO1
CP
SSE
ASE
TSE
MSE
DECODER
DEC1
CN1
LMC
IN8
LIGHT MEASURING CKT
BF
EES
VB
PO3
POR3
IN4
IN3
AN1
BT1
RLS
IN2
+E
MAS
BA
MES
IN1
POR1
BT2
LD1
LD2
LD0
POR2
FAD
VF
PO2
FLM
CCD ANB
CONT. CKT.
AOT
COT
CP
PO2
MDR
MO
LMD
LE
ENC
CP
PO2
aN+1
LATCH
LA
IP1
DCL
SCL
μ-COM
MC1
OSC
COS
VB
PO3
IN7
EXPOSURE CONT. CKT.
EXC
DB
MC2
IN6
FAS
VB
CP
SCL
I/O
μ-COM
OP1
aN+1
iT
SCO
SDI
VR
ANI
O8
O6
O0
i2
i1
i0
RE
O1
O2
O3
O4
O5
IN6
PO1
CP
IN6
OP0
O16
O19
O17
O13
i11
i12
i13
i14
iT
O10
O11
i10
IP0
O12
O13
O14

Fig. 6a

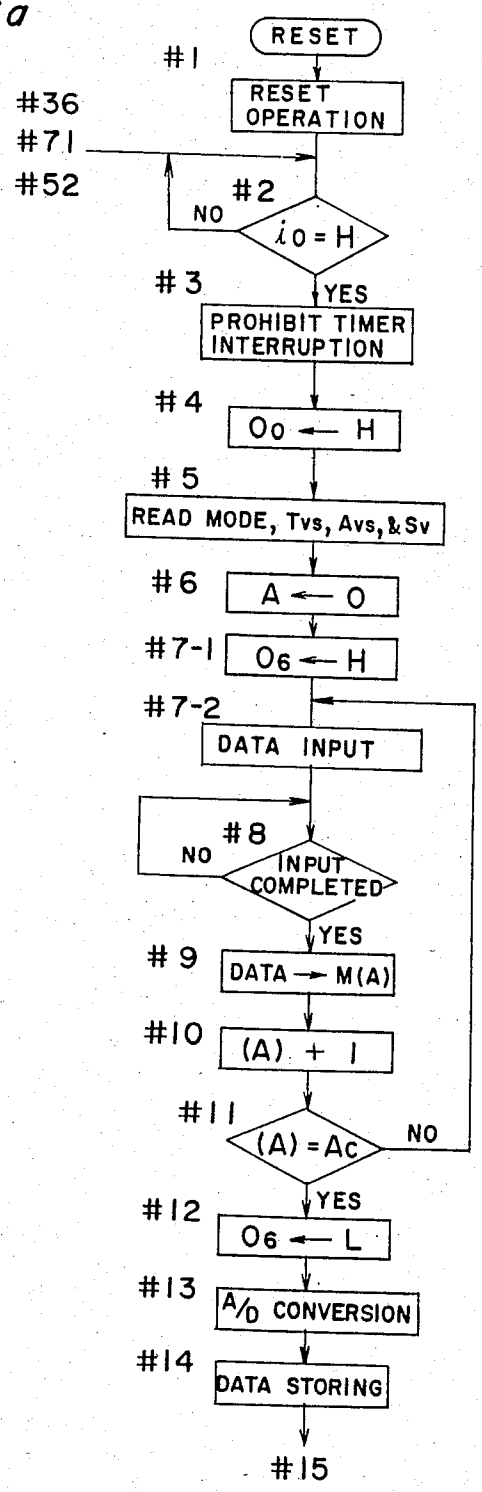

RESET
#1
RESET OPERATION
#36
#71
#52
#2
NO
i0 = H
YES
#3
PROHIBIT TIMER INTERRUPTION
#4
O0 ← H
#5
READ MODE, Tvs, Avs, & Sv
#6
A ← 0
#7-1
O6 ← H
#7-2
DATA INPUT
#8
NO
INPUT COMPLETED
YES
#9
DATA → M(A)
#10
(A) + 1
#11
(A) = Ac
NO
YES
#12
O6 ← L
#13
A/D CONVERSION
#14
DATA STORING
#15

Fig. 6b

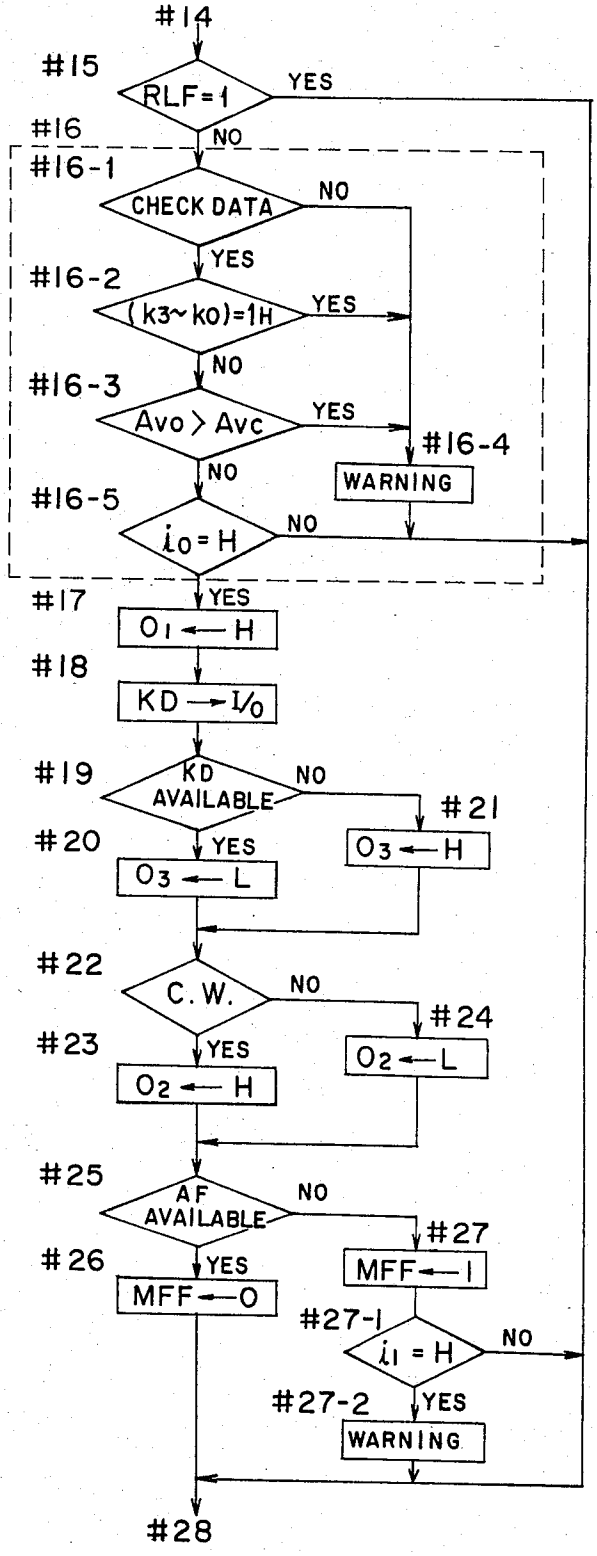

#14
#15
RLF=1
YES
NO
#16
#16-1
CHECK DATA
NO
YES
#16-2
(k3~k0)=1H
YES
NO
#16-3
Avo > Avc
YES
#16-4
WARNING
NO
#16-5
io = H
NO
YES
#17
O1 ← H
#18
KD → I/O
#19
KD AVAILABLE
NO
#21
O3 ← H
#20
YES
O3 ← L
#22
C.W.
NO
#24
O2 ← L
#23
YES
O2 ← H
#25
AF AVAILABLE
NO
#27
MFF ← 1
#26
YES
MFF ← 0
#27-1
i1 = H
NO
#27-2
YES
WARNING
#28

Fig. 6c

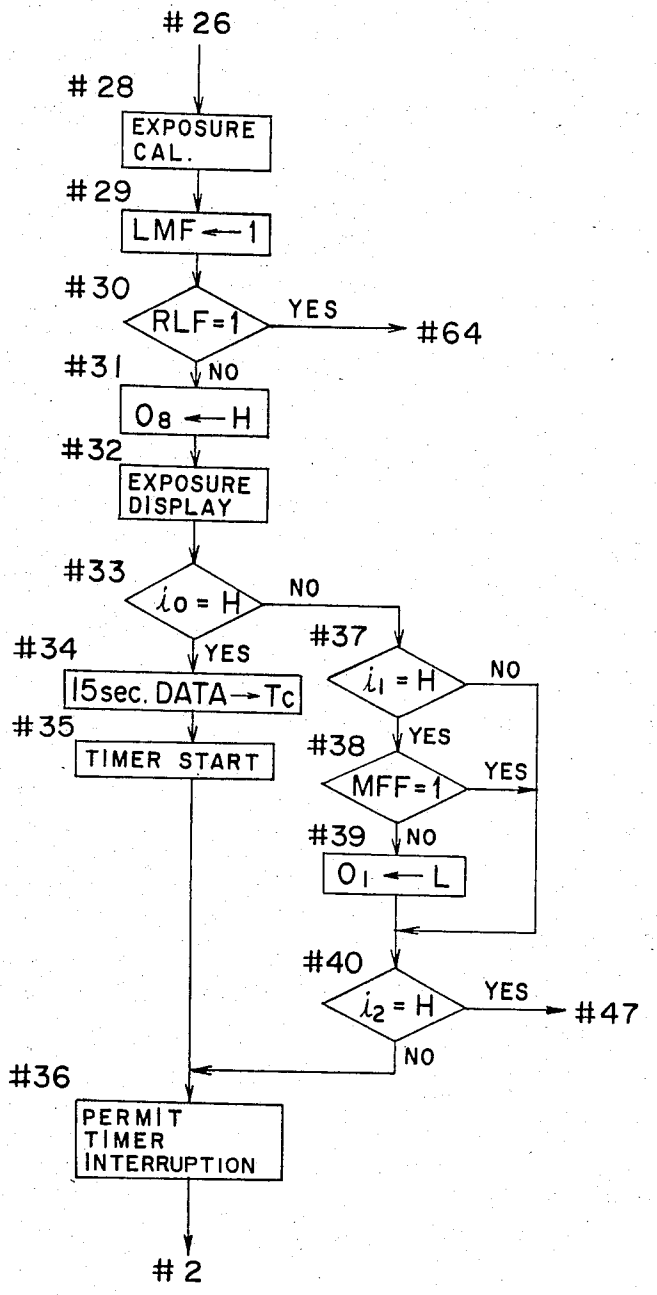

#26
#28
EXPOSURE CAL.
#29
LMF ← 1
#30
RLF=1
YES
#64
NO
#31
O8 ← H
#32
EXPOSURE DISPLAY
#33
io = H
NO
YES
#34
15sec. DATA → Tc
#35
TIMER START
#37
i1 = H
NO
YES
#38
MFF=1
YES
NO
#39
O1 ← L
#40
i2 = H
YES
#47
NO
#36
PERMIT TIMER INTERRUPTION
#2

Fig. 6d

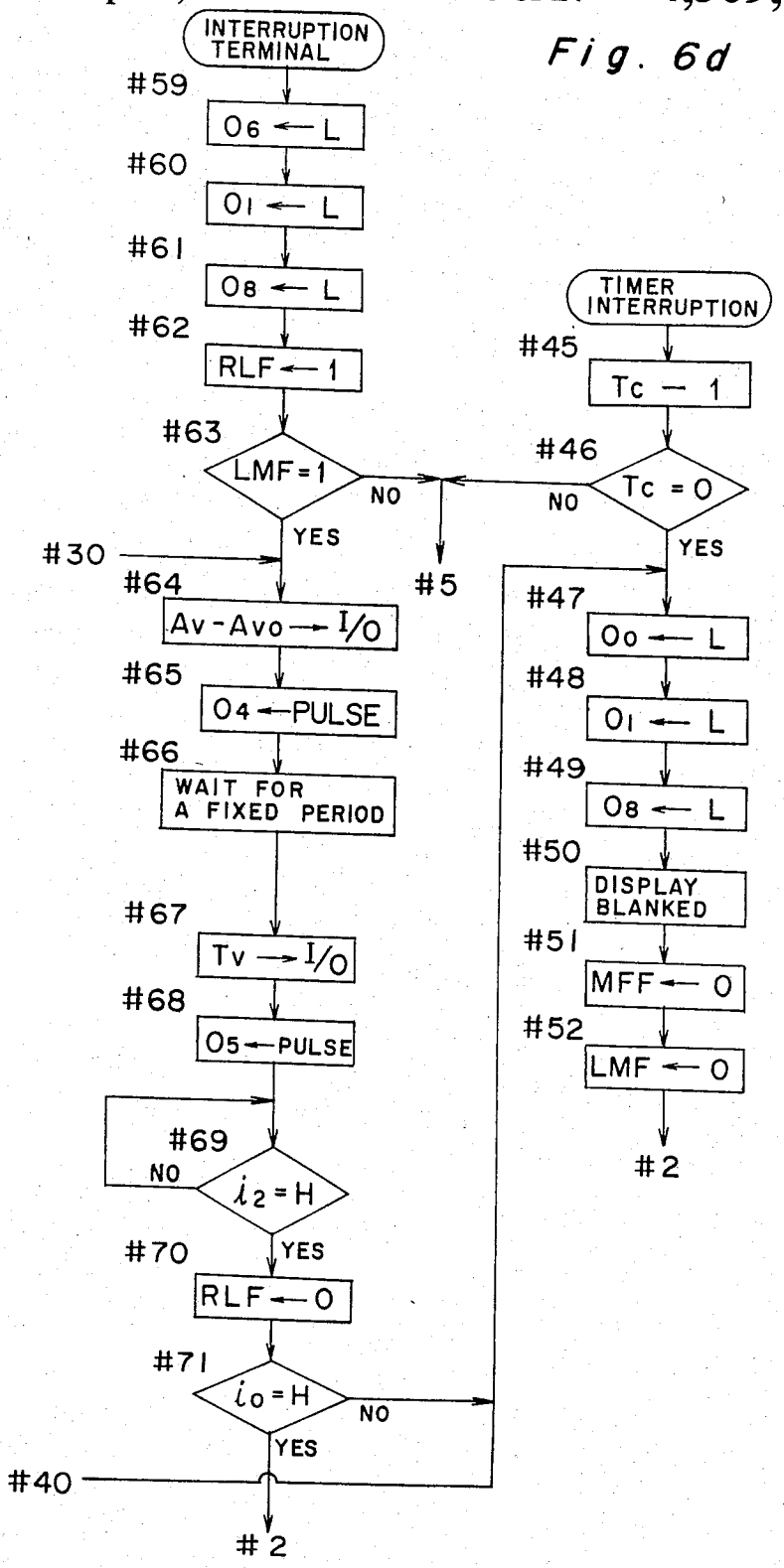

INTERRUPTION TERMINAL
#59
O6 ← L
#60
O1 ← L
#61
O8 ← L
#62
RLF ← 1
#63
LMF = 1
NO
YES
#30
#64
Av - Avo → I/O
#65
O4 ← PULSE
#66
WAIT FOR A FIXED PERIOD
#67
Tv → I/O
#68
O5 ← PULSE
#69
NO
i2 = H
#70
YES
RLF ← 0
#71
io = H
NO
YES
#40
#2
#5
TIMER INTERRUPTION
#45
Tc ← 1
#46
NO
Tc = 0
YES
#47
Oo ← L
#48
O1 ← L
#49
O8 ← L
#50
DISPLAY BLANKED
#51
MFF ← 0
#52
LMF ← 0
#2

Fig. 7

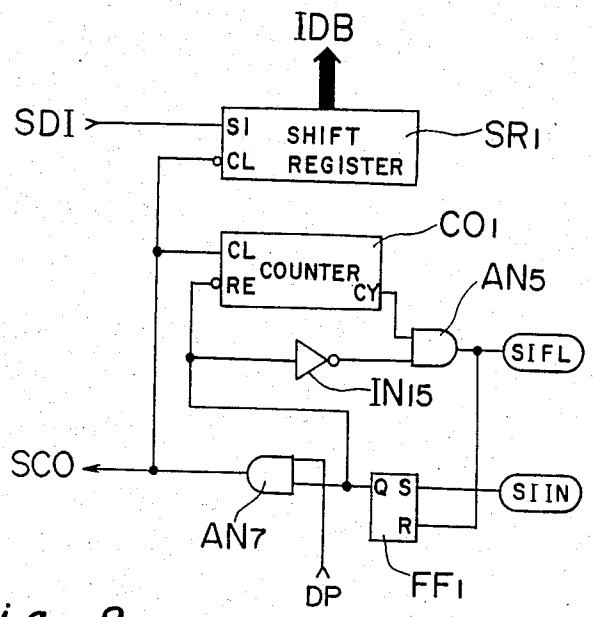

IDB
SDI
SI
CL
SHIFT
REGISTER
SR1
CO1
CL
RE
COUNTER
CY
AN5
SIFL
IN15
SCO
AN7
Q S
R
SIIN
DP
FF1

Fig. 9

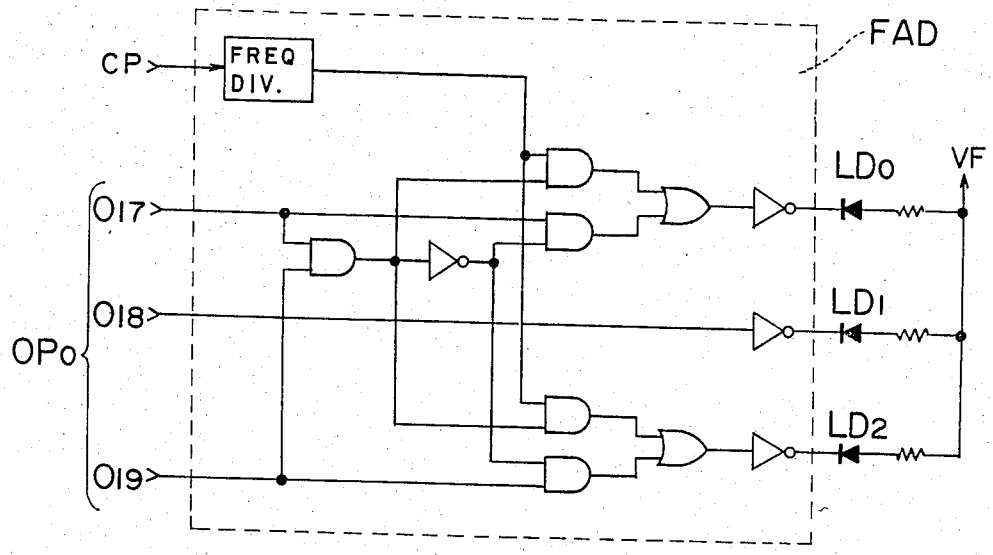

FAD
CP
FREQ
DIV.
LD0
VF
O17
O18
OP0
LD1
LD2
O19

Fig. 8

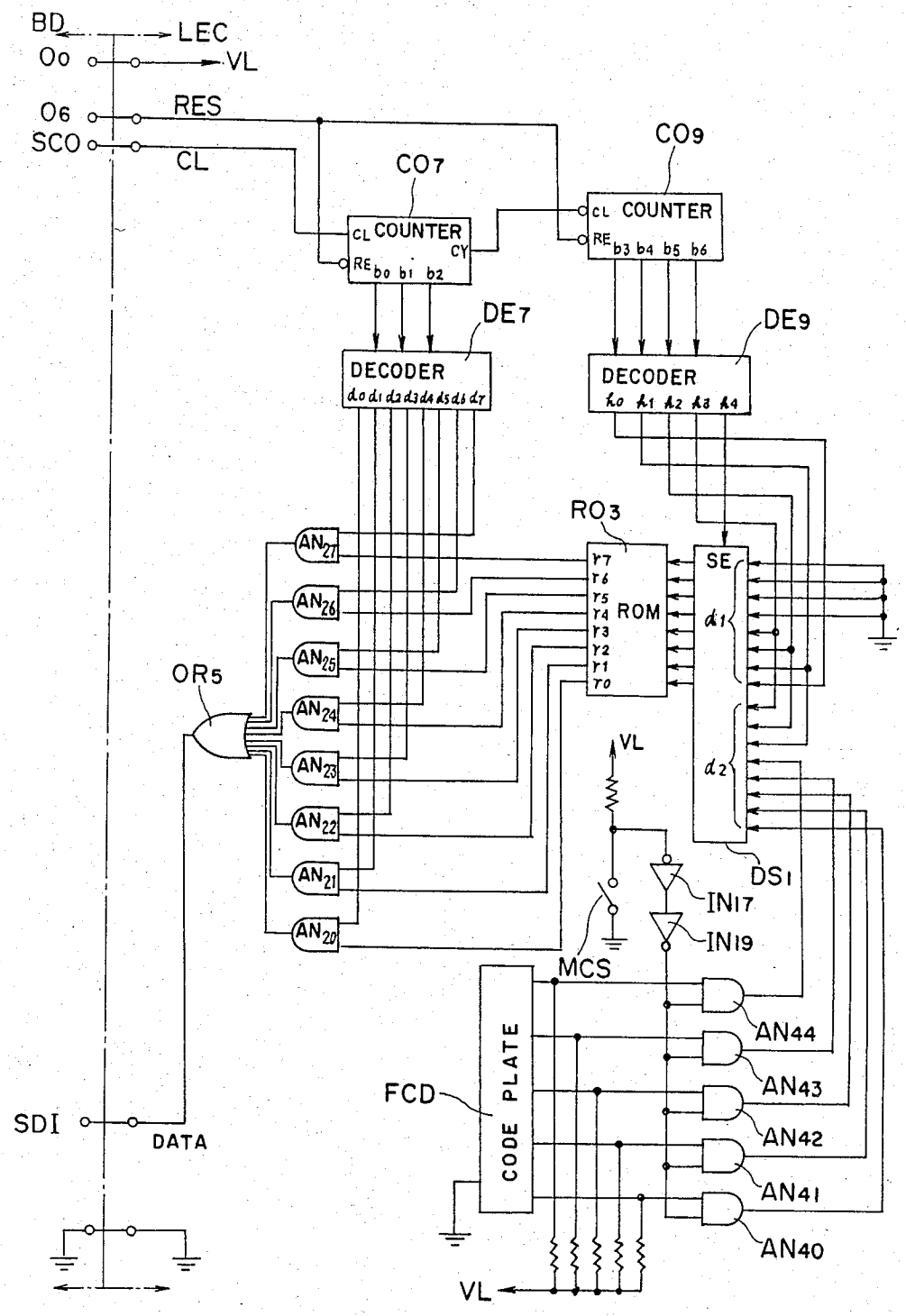

BD
LEC
Oo
VL
O6
RES
SCO
CL
CO7
CO9
CL COUNTER
RE
CY
b0 b1 b2
b3 b4 b5 b6
DE7
DE9
DECODER
d0 d1 d2 d3 d4 d5 d6 d7
A0 A1 A2 A3 A4
RO3
AN27
AN26
AN25
AN24
AN23
AN22
AN21
AN20
OR5
Y7 Y6 Y5 Y4 Y3 Y2 Y1 Y0
ROM
SE
d1
d2
VL
DS1
IN17
IN19
MCS
AN44
AN43
AN42
AN41
AN40
FCD
CODE PLATE
SDI
DATA
VL

Fig. 10

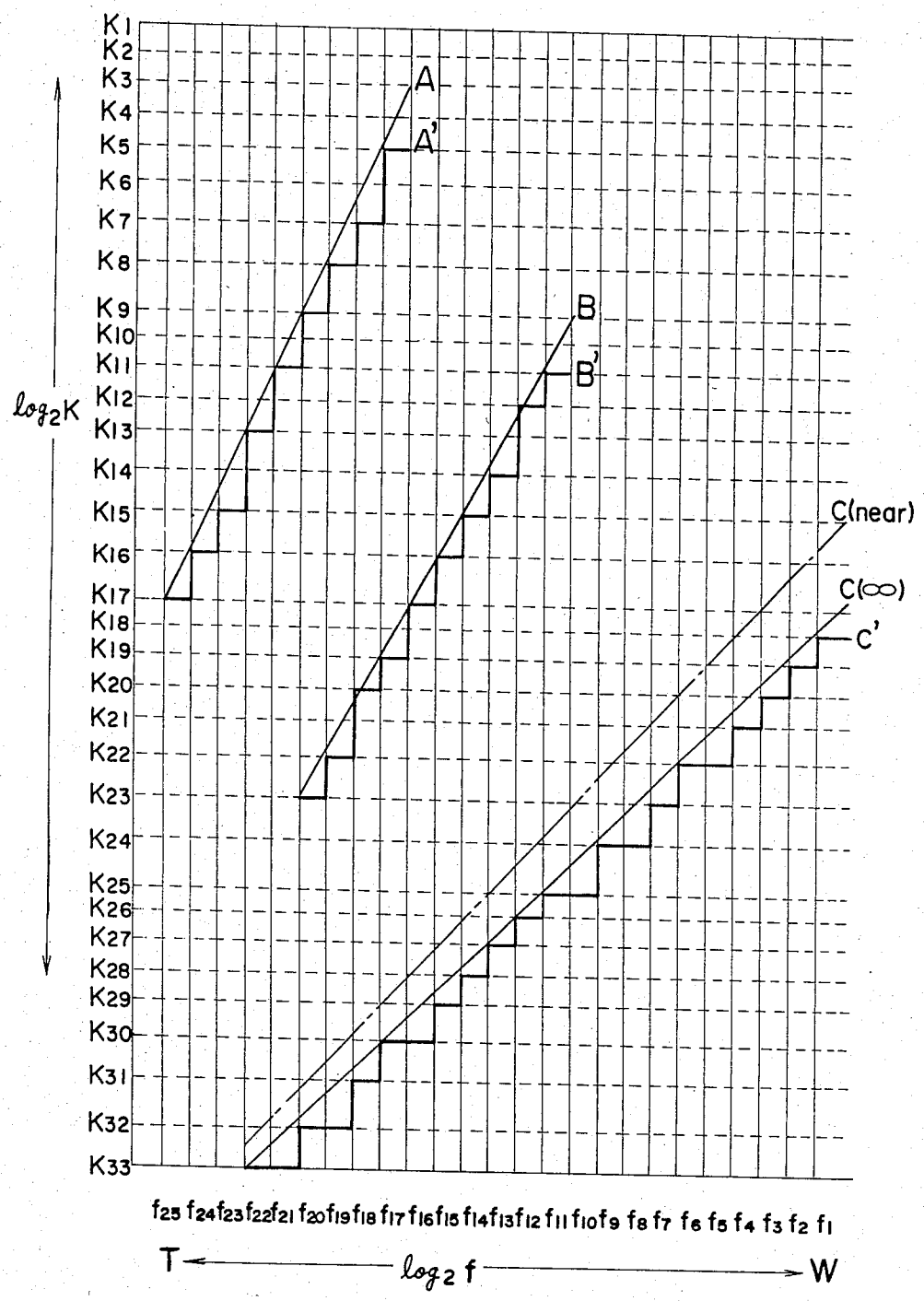

K1
K2
K3
K4
K5
K6
K7
K8
K9
K10
K11
K12
K13
K14
K15
K16
K17
K18
K19
K20
K21
K22
K23
K24
K25
K26
K27
K28
K29
K30
K31
K32
K33
log2K
A
A'
B
B'
C(near)
C(∞)
C'
f25 f24 f23 f22 f21 f20 f19 f18 f17 f16 f15 f14 f13 f12 f11 f10 f9 f8 f7 f6 f5 f4 f3 f2 f1
T
log2 f
W

Fig. 11a

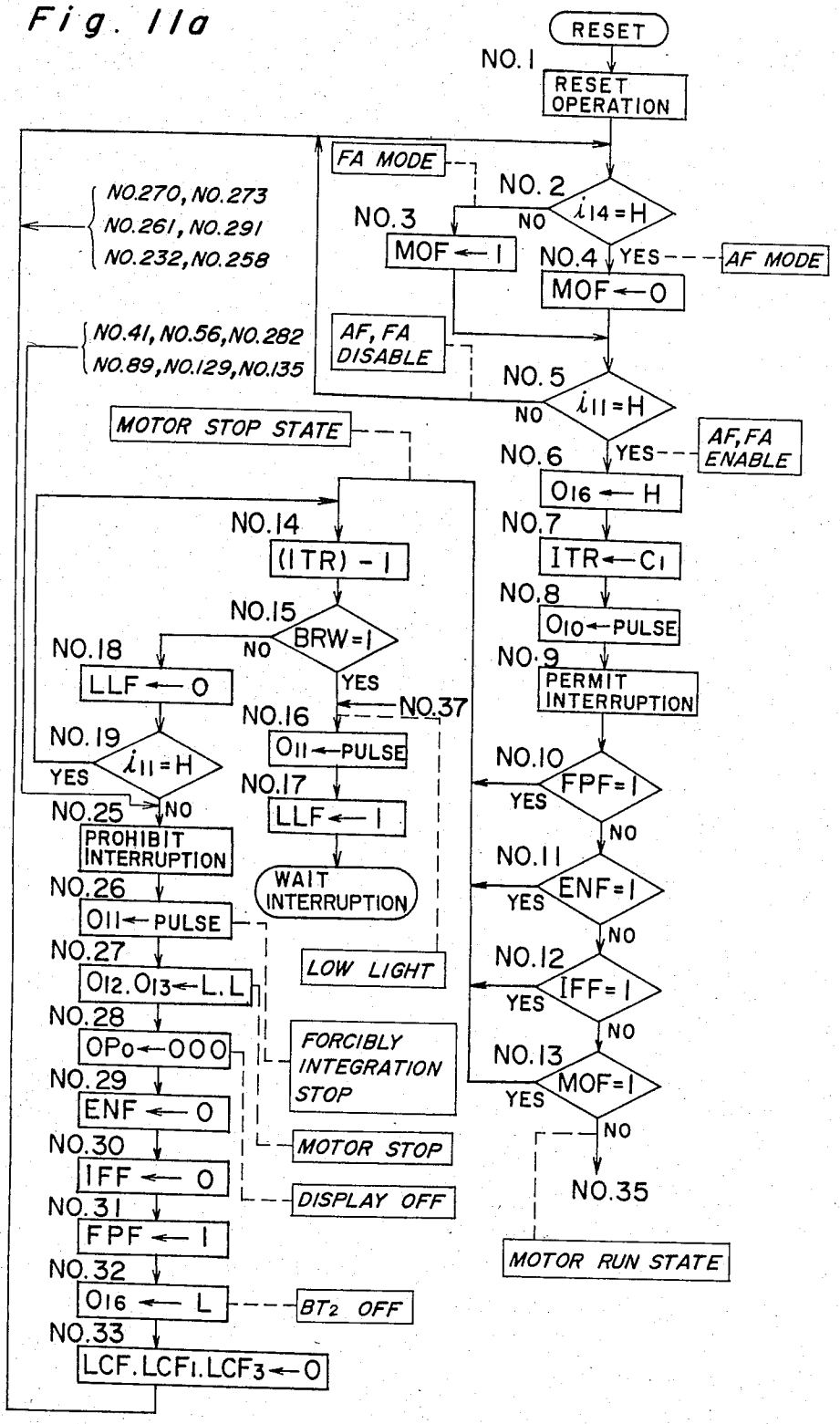

RESET
NO. 1
RESET OPERATION
FA MODE
NO. 2
i14=H
NO
NO. 3
MOF ← 1
NO. 4
YES
AF MODE
MOF ← 0
NO.270, NO.273
NO.261, NO.291
NO.232, NO.258
AF, FA DISABLE
NO.41, NO.56, NO.282
NO.89, NO.129, NO.135
NO. 5
i11=H
NO
MOTOR STOP STATE
YES
AF, FA ENABLE
NO.6
O16 ← H
NO.7
ITR ← C1
NO.8
O10 ← PULSE
NO.9
PERMIT INTERRUPTION
NO.10
FPF=1
YES
NO
NO.11
ENF=1
YES
NO
NO.12
IFF=1
YES
NO
NO.13
MOF=1
YES
NO
NO.35
MOTOR RUN STATE
NO.14
(ITR) - 1
NO.15
BRW=1
NO
YES
NO.18
LLF ← 0
NO.37
NO.16
O11 ← PULSE
NO.19
i11=H
YES
NO.17
LLF ← 1
NO.25
NO
PROHIBIT INTERRUPTION
WAIT INTERRUPTION
NO.26
O11 ← PULSE
LOW LIGHT
NO.27
O12. O13 ← L. L
NO.28
OP0 ← 000
FORCIBLY INTEGRATION STOP
NO.29
ENF ← 0
MOTOR STOP
NO.30
IFF ← 0
DISPLAY OFF
NO.31
FPF ← 1
NO.32
O16 ← L
BT2 OFF
NO.33
LCF. LCF1. LCF3 ← 0

Fig. 11b

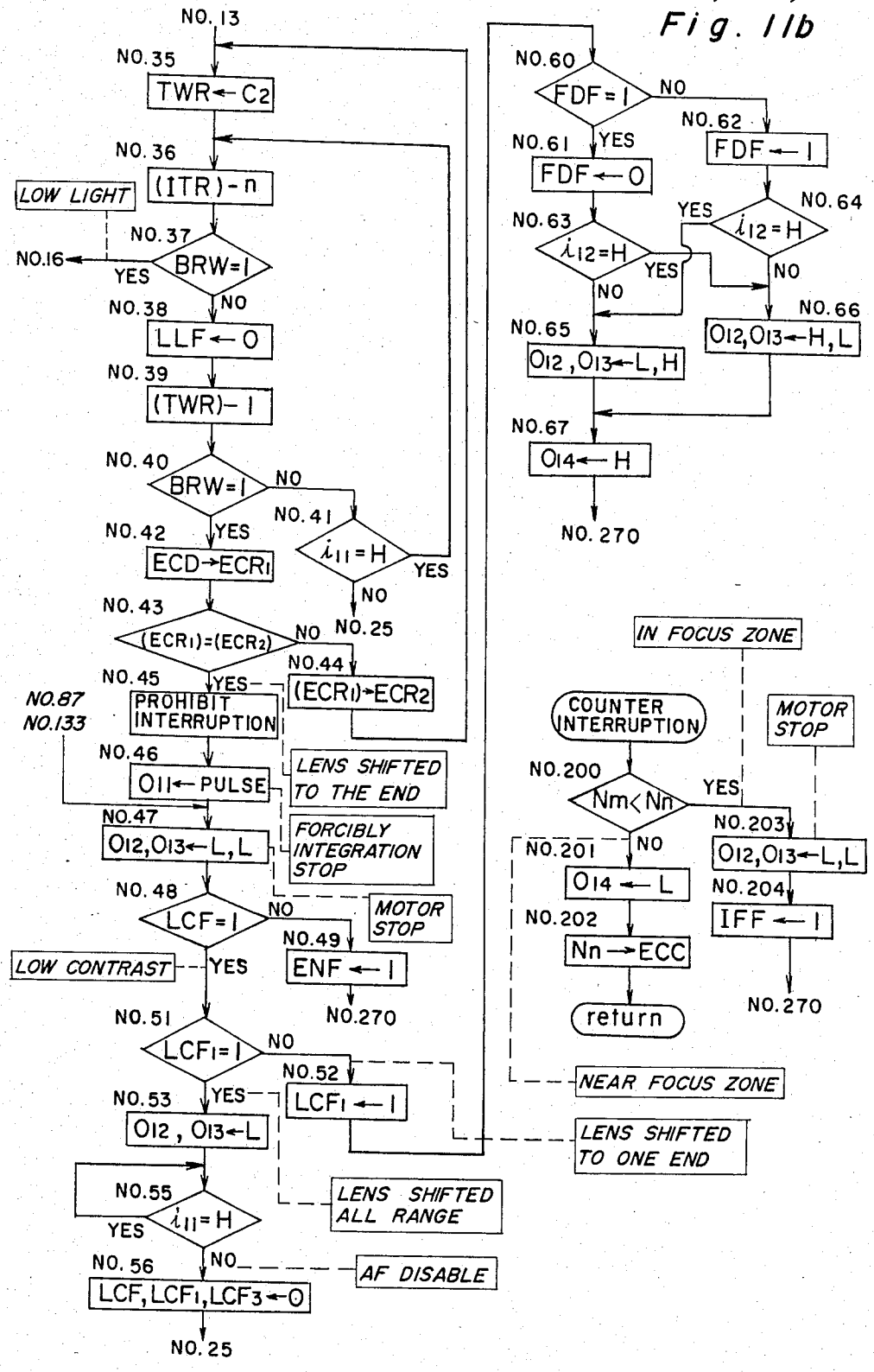

NO. 13
NO. 35
TWR ← C2
NO. 36
(ITR) - n
LOW LIGHT
NO. 37
BRW = 1
NO. 16
YES
NO
NO. 38
LLF ← 0
NO. 39
(TWR) - 1
NO. 40
BRW = 1
NO
NO. 41
i11 = H
YES
NO
NO. 42
YES
ECD → ECR1
NO. 43
(ECR1) = (ECR2)
NO
NO. 25
NO. 44
(ECR1) → ECR2
NO. 45
YES
NO. 87
NO. 133
PROHIBIT INTERRUPTION
NO. 46
O11 ← PULSE
NO. 47
O12, O13 ← L, L
NO. 48
LCF = 1
NO
MOTOR STOP
LOW CONTRAST
YES
NO. 49
ENF ← 1
NO. 270
NO. 51
LCF1 = 1
NO
NO. 52
LCF1 ← 1
NO. 53
YES
O12, O13 ← L
NO. 55
i11 = H
YES
NO. 56
NO
AF DISABLE
LCF, LCF1, LCF3 ← 0
NO. 25
LENS SHIFTED TO THE END
FORCIBLY INTEGRATION STOP
LENS SHIFTED ALL RANGE
NO. 60
FDF = 1
NO
NO. 62
FDF ← 1
NO. 61
YES
FDF ← 0
NO. 63
i12 = H
YES
NO
YES
NO. 64
i12 = H
NO
NO. 65
O12, O13 ← L, H
NO. 66
O12, O13 ← H, L
NO. 67
O14 ← H
NO. 270
LENS SHIFTED TO ONE END
IN FOCUS ZONE
COUNTER INTERRUPTION
MOTOR STOP
NO. 200
Nm < Nn
YES
NO. 203
O12, O13 ← L, L
NO. 201
NO
O14 ← L
NO. 204
IFF ← 1
NO. 202
Nn → ECC
return
NO. 270
NEAR FOCUS ZONE

Fig. 11c

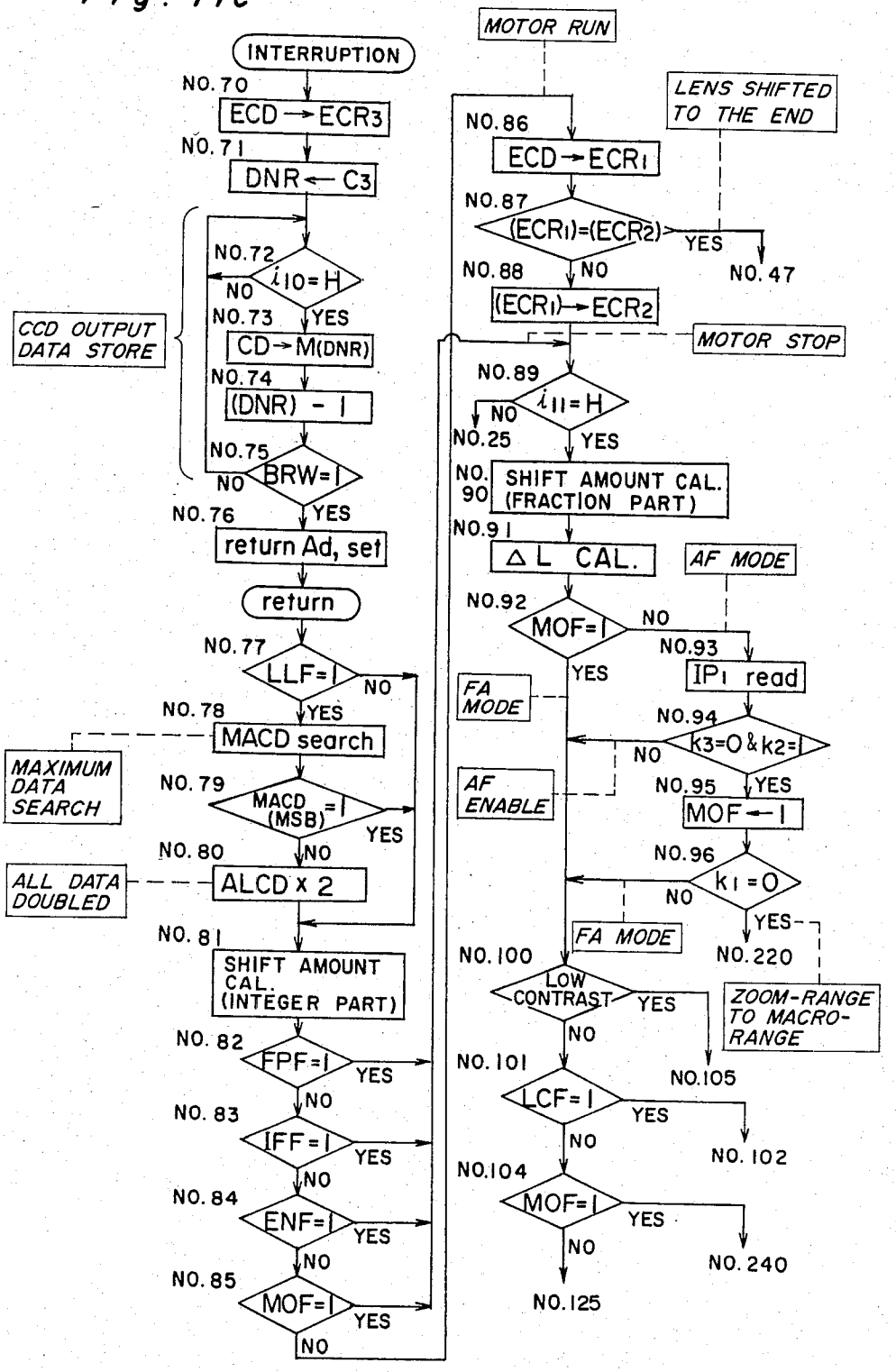

INTERRUPTION
NO. 70
ECD → ECR3
NO. 71
DNR ← C3
NO. 72
i10 = H
NO
YES
NO. 73
CD → M(DNR)
NO. 74
(DNR) - 1
NO. 75
BRW = 1
NO
YES
NO. 76
return Ad, set
return
NO. 77
LLF = 1
NO
YES
NO. 78
MACD search
NO. 79
MACD (MSB) = 1
YES
NO
NO. 80
ALCD x 2
NO. 81
SHIFT AMOUNT CAL. (INTEGER PART)
NO. 82
FPF = 1
YES
NO
NO. 83
IFF = 1
YES
NO
NO. 84
ENF = 1
YES
NO
NO. 85
MOF = 1
YES
NO
CCD OUTPUT DATA STORE
MAXIMUM DATA SEARCH
ALL DATA DOUBLED
MOTOR RUN
NO. 86
ECD → ECR1
NO. 87
(ECR1) = (ECR2)
YES
NO
NO. 88
(ECR1) → ECR2
LENS SHIFTED TO THE END
NO. 47
MOTOR STOP
NO. 89
i11 = H
NO
YES
NO. 25
NO. 90
SHIFT AMOUNT CAL. (FRACTION PART)
NO. 91
Δ L CAL.
AF MODE
NO. 92
MOF = 1
NO
YES
NO. 93
IP1 read
FA MODE
NO. 94
K3 = 0 & K2 = 1
NO
YES
AF ENABLE
NO. 95
MOF ← 1
NO. 96
K1 = 0
NO
YES
FA MODE
NO. 220
NO. 100
LOW CONTRAST
YES
NO
ZOOM-RANGE TO MACRO-RANGE
NO. 101
LCF = 1
YES
NO
NO. 105
NO. 102
NO. 104
MOF = 1
YES
NO
NO. 240
NO. 125

Fig. 12a

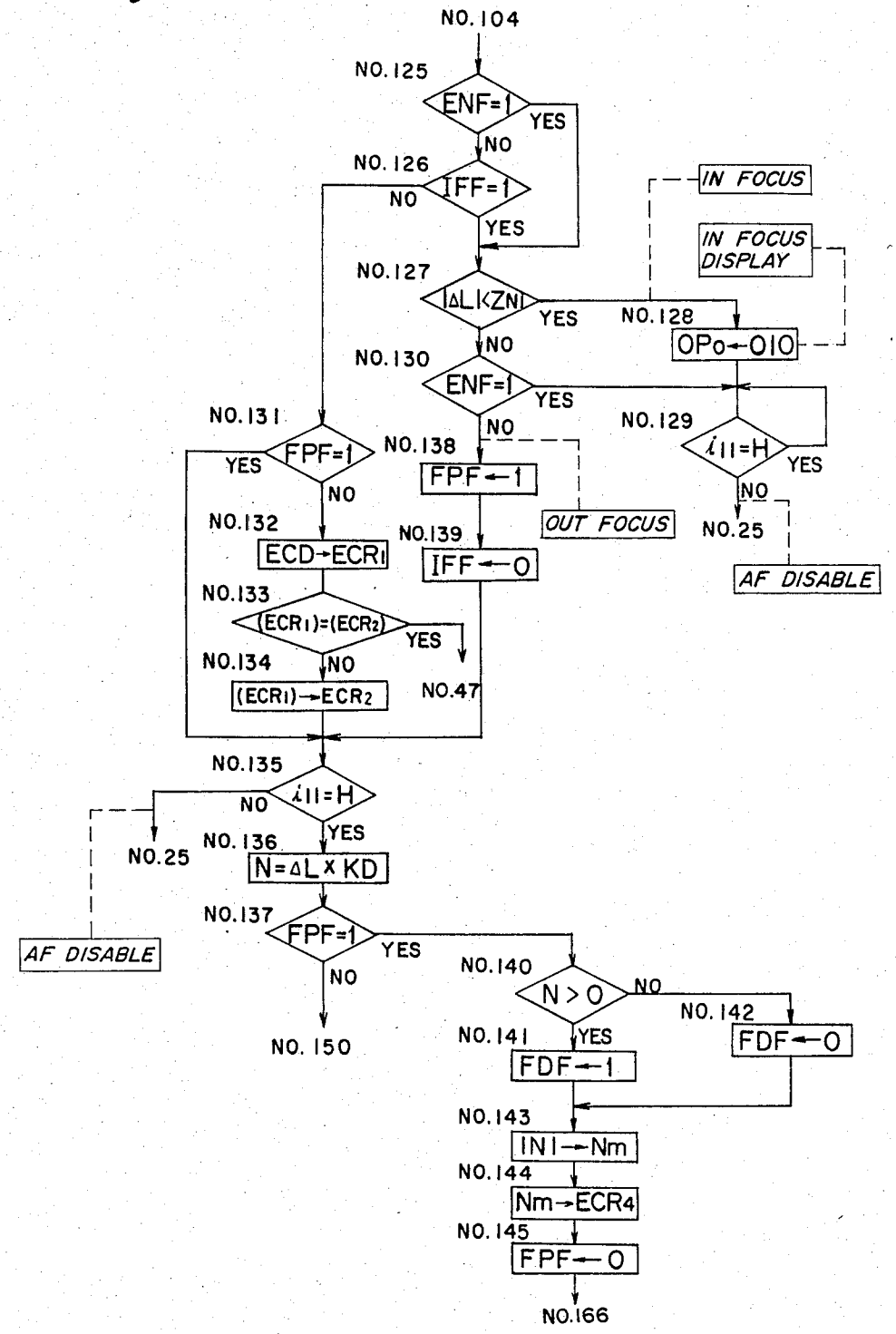

NO. 104
NO. 125
ENF=1
YES
NO
NO. 126
IFF=1
NO
YES
IN FOCUS
IN FOCUS DISPLAY
NO. 127
|ΔL|<ZN
YES
NO. 128
OPo←010
NO
NO. 130
ENF=1
YES
NO
NO. 129
i11=H
YES
NO
NO. 131
FPF=1
YES
NO
NO. 138
FPF←1
OUT FOCUS
NO. 25
AF DISABLE
NO. 132
ECD→ECR1
NO. 139
IFF←0
NO. 133
(ECR1)=(ECR2)
YES
NO. 134
NO
(ECR1)→ECR2
NO. 47
NO. 135
i11=H
NO
YES
NO. 25
NO. 136
N=ΔL x KD
AF DISABLE
NO. 137
FPF=1
YES
NO
NO. 150
NO. 140
N > 0
NO
YES
NO. 142
FDF←0
NO. 141
FDF←1
NO. 143
IN1→Nm
NO. 144
Nm→ECR4
NO. 145
FPF←0
NO. 166

Fig. 12b

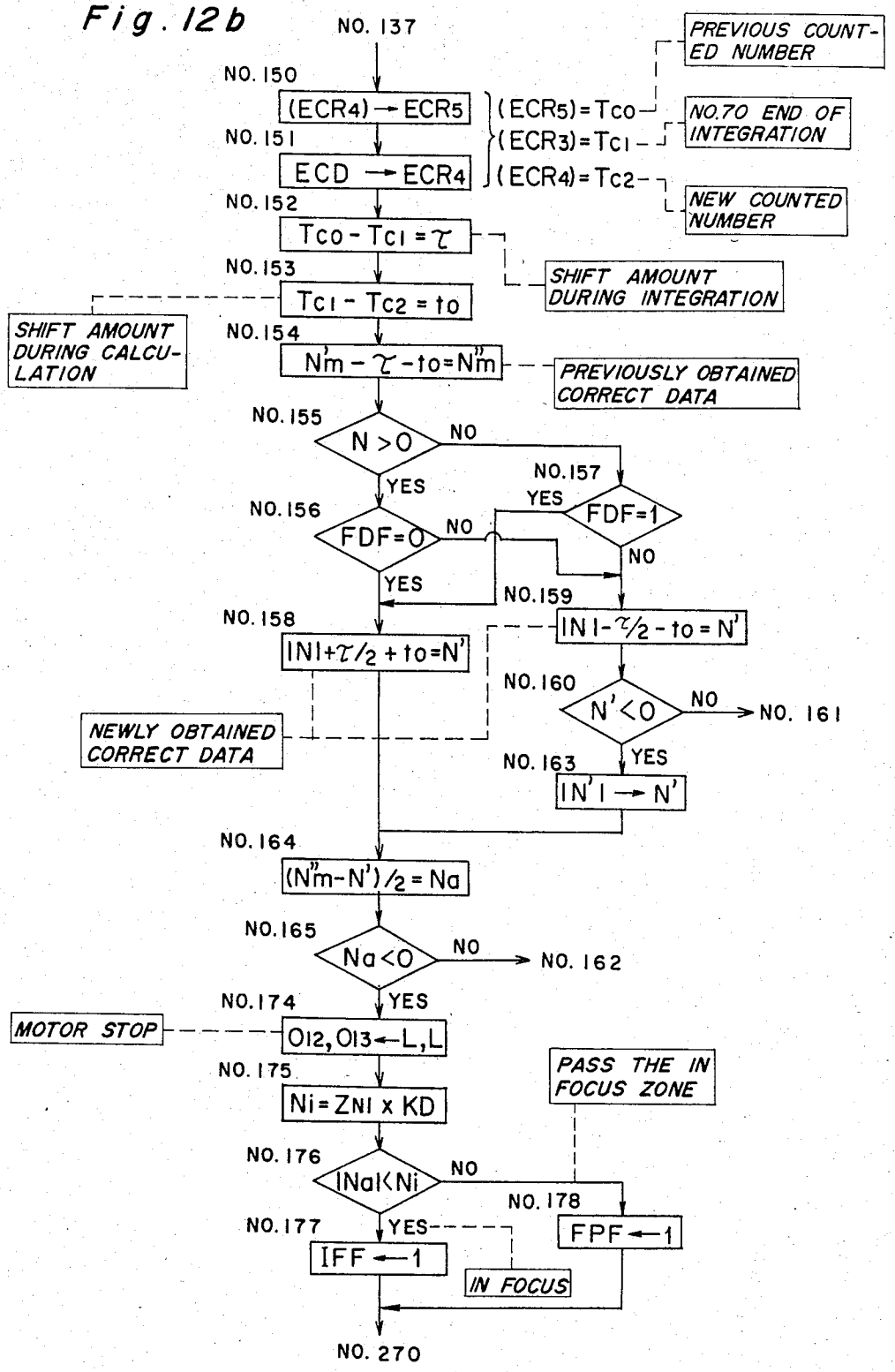

NO. 137
NO. 150
(ECR4) → ECR5
(ECR5) = Tco
(ECR3) = Tc1
(ECR4) = Tc2
PREVIOUS COUNTED NUMBER
NO.70 END OF INTEGRATION
NEW COUNTED NUMBER
NO. 151
ECD → ECR4
NO. 152
Tco - Tc1 = τ
SHIFT AMOUNT DURING INTEGRATION
NO. 153
Tc1 - Tc2 = to
SHIFT AMOUNT DURING CALCULATION
NO. 154
N'm - τ - to = N"m
PREVIOUSLY OBTAINED CORRECT DATA
NO. 155
N > 0
NO
YES
NO. 157
YES
FDF=1
NO
NO. 156
FDF=0
NO
YES
NO. 159
IN1 - τ/2 - to = N'
NO. 158
IN1 + τ/2 + to = N'
NO. 160
N' < 0
NO
NO. 161
NEWLY OBTAINED CORRECT DATA
YES
NO. 163
IN'1 → N'
NO. 164
(N"m - N') / 2 = Na
NO. 165
Na < 0
NO
NO. 162
YES
NO. 174
MOTOR STOP
O12, O13 ← L, L
NO. 175
Ni = ZN1 x KD
PASS THE IN FOCUS ZONE
NO. 176
INal < Ni
NO
NO. 178
FPF ← 1
NO. 177
YES
IFF ← 1
IN FOCUS
NO. 270

Fig. 12c

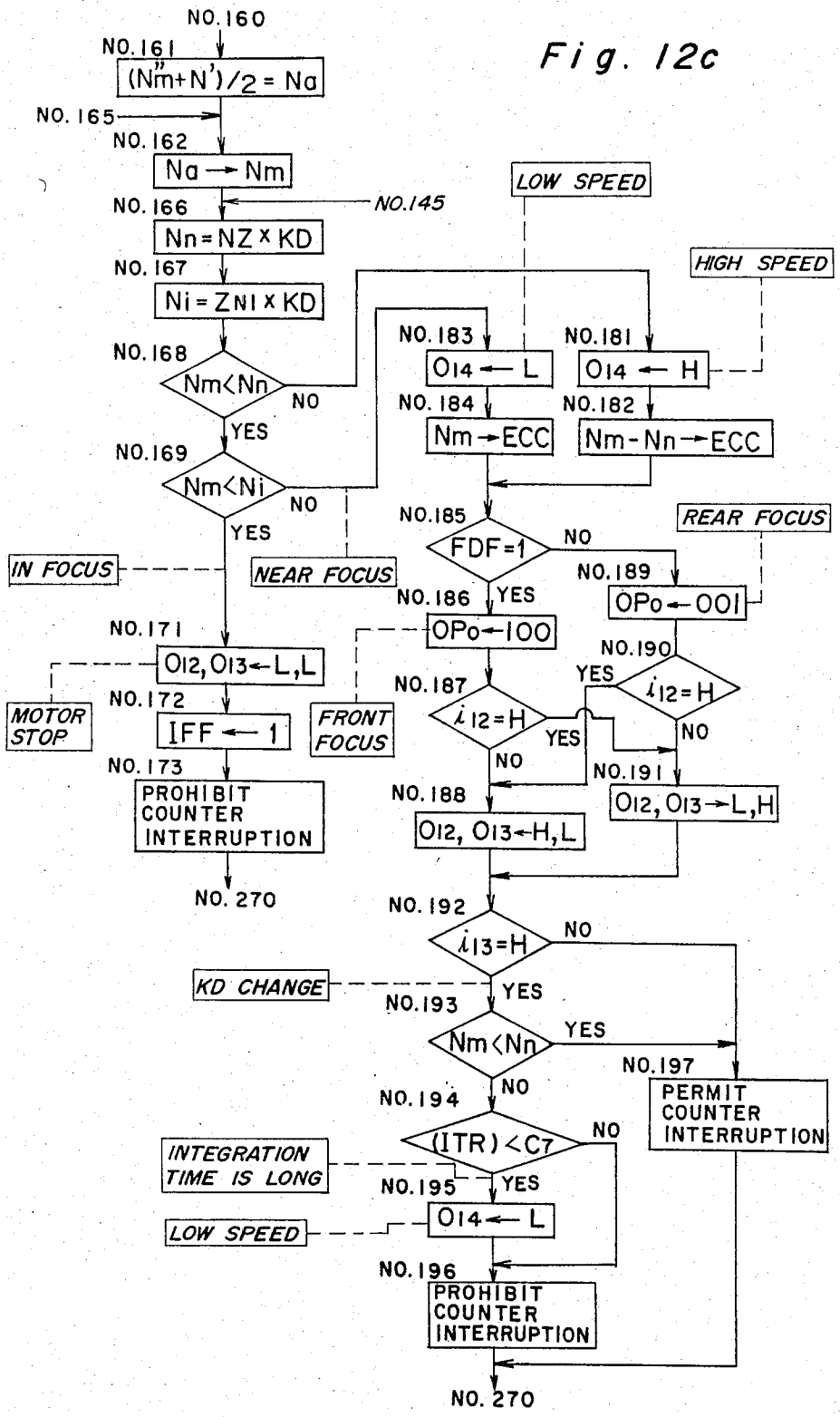

NO.160
NO.161
(Nm"+N')/2 = Na
NO.165
NO.162
Na → Nm
NO.166
NO.145
Nn = NZ × KD
NO.167
Ni = ZNI × KD
NO.168
Nm<Nn
NO
YES
NO.169
Nm<Ni
NO
YES
IN FOCUS
NEAR FOCUS
NO.171
O12, O13 ← L, L
MOTOR STOP
NO.172
IFF ← 1
FRONT FOCUS
NO.173
PROHIBIT COUNTER INTERRUPTION
NO. 270
LOW SPEED
HIGH SPEED
NO.183
O14 ← L
NO.181
O14 ← H
NO.184
Nm → ECC
NO.182
Nm - Nn → ECC
NO.185
FDF=1
NO
YES
REAR FOCUS
NO.189
OPo ← 001
NO.186
OPo ← 100
NO.190
YES
i12=H
NO
NO.187
i12=H
YES
NO
NO.191
O12, O13 → L, H
NO.188
O12, O13 ← H, L
NO.192
i13=H
NO
KD CHANGE
YES
NO.193
Nm<Nn
YES
NO.197
PERMIT COUNTER INTERRUPTION
NO.194
NO
(ITR)<C7
NO
INTEGRATION TIME IS LONG
NO.195
YES
LOW SPEED
O14 ← L
NO.196
PROHIBIT COUNTER INTERRUPTION
NO. 270

Fig. 13a

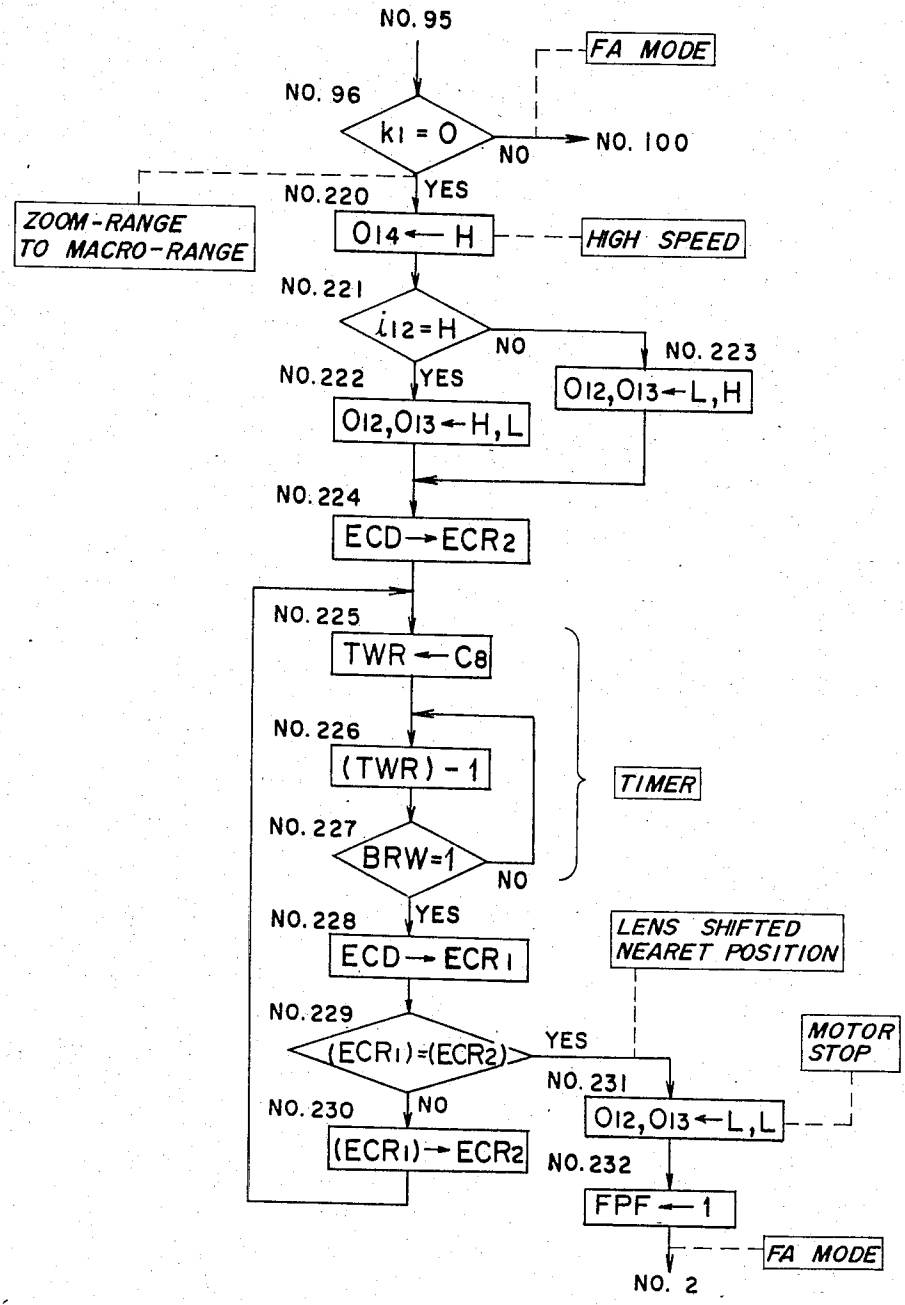

NO. 95
FA MODE
NO. 96
k1 = 0
NO
NO. 100
YES
ZOOM-RANGE TO MACRO-RANGE
NO. 220
O14 ← H
HIGH SPEED
NO. 221
i12 = H
NO
NO. 223
O12,O13 ← L,H
NO. 222
YES
O12,O13 ← H,L
NO. 224
ECD → ECR2
NO. 225
TWR ← C8
NO. 226
(TWR) - 1
TIMER
NO. 227
BRW=1
NO
YES
NO. 228
ECD → ECR1
LENS SHIFTED NEARET POSITION
NO. 229
(ECR1)=(ECR2)
YES
MOTOR STOP
NO. 231
O12,O13 ← L,L
NO. 230
NO
(ECR1) → ECR2
NO. 232
FPF ← 1
FA MODE
NO. 2

Fig. 13b

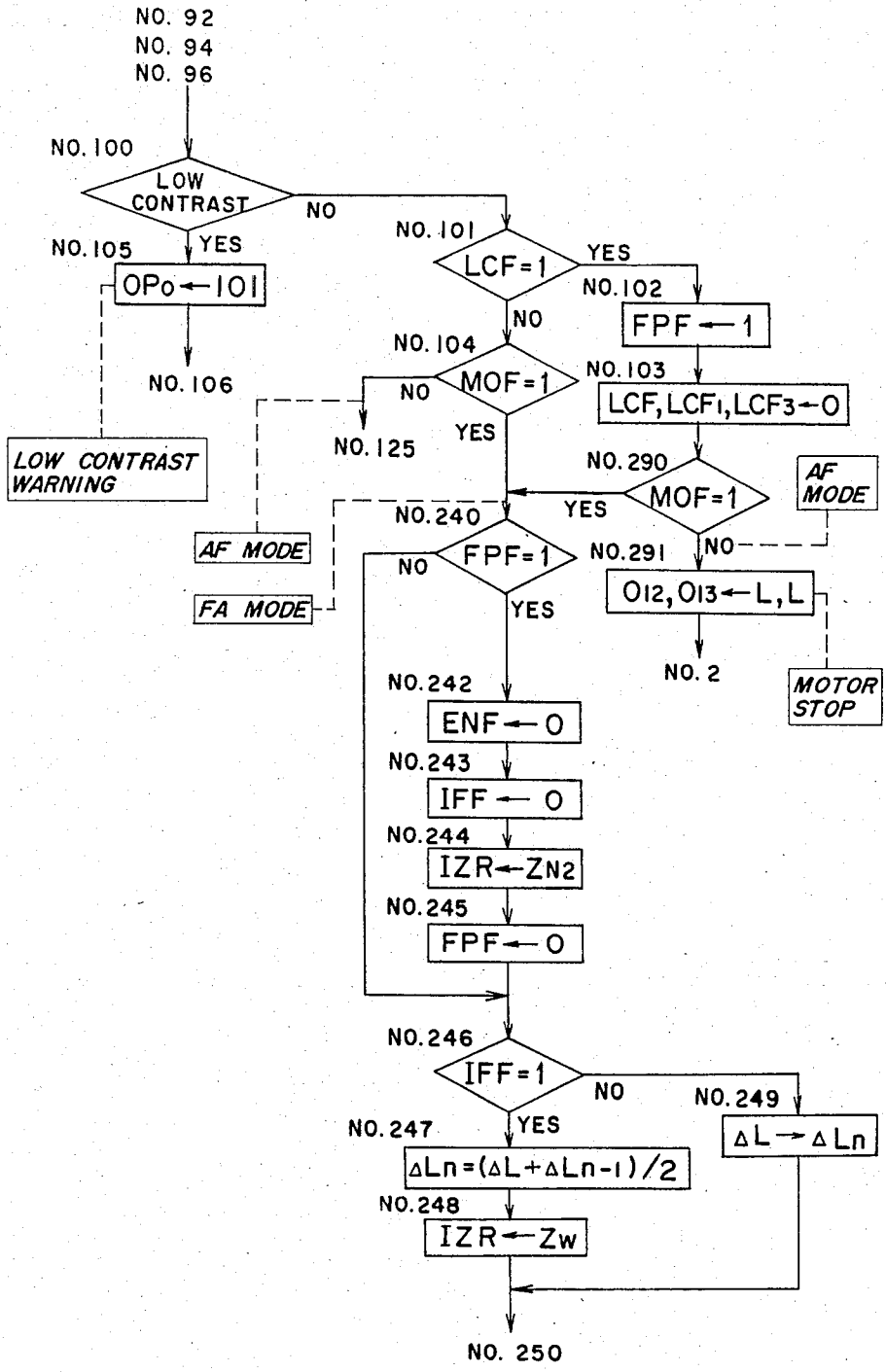

NO. 92
NO. 94
NO. 96
NO. 100
LOW CONTRAST
NO
YES
NO. 105
OPo←101
NO. 106
LOW CONTRAST WARNING
NO. 101
LCF=1
YES
NO. 102
FPF←1
NO
NO. 104
MOF=1
NO
YES
NO. 103
LCF, LCF1, LCF3←0
NO. 125
AF MODE
FA MODE
NO. 290
MOF=1
YES
AF MODE
NO. 240
FPF=1
NO
YES
NO. 291
NO
O12, O13←L, L
NO. 2
MOTOR STOP
NO. 242
ENF←0
NO. 243
IFF←0
NO. 244
IZR←ZN2
NO. 245
FPF←0
NO. 246
IFF=1
NO
YES
NO. 249
ΔL→ΔLn
NO. 247
ΔLn=(ΔL+ΔLn-1)/2
NO. 248
IZR←Zw
NO. 250

Fig. 13c

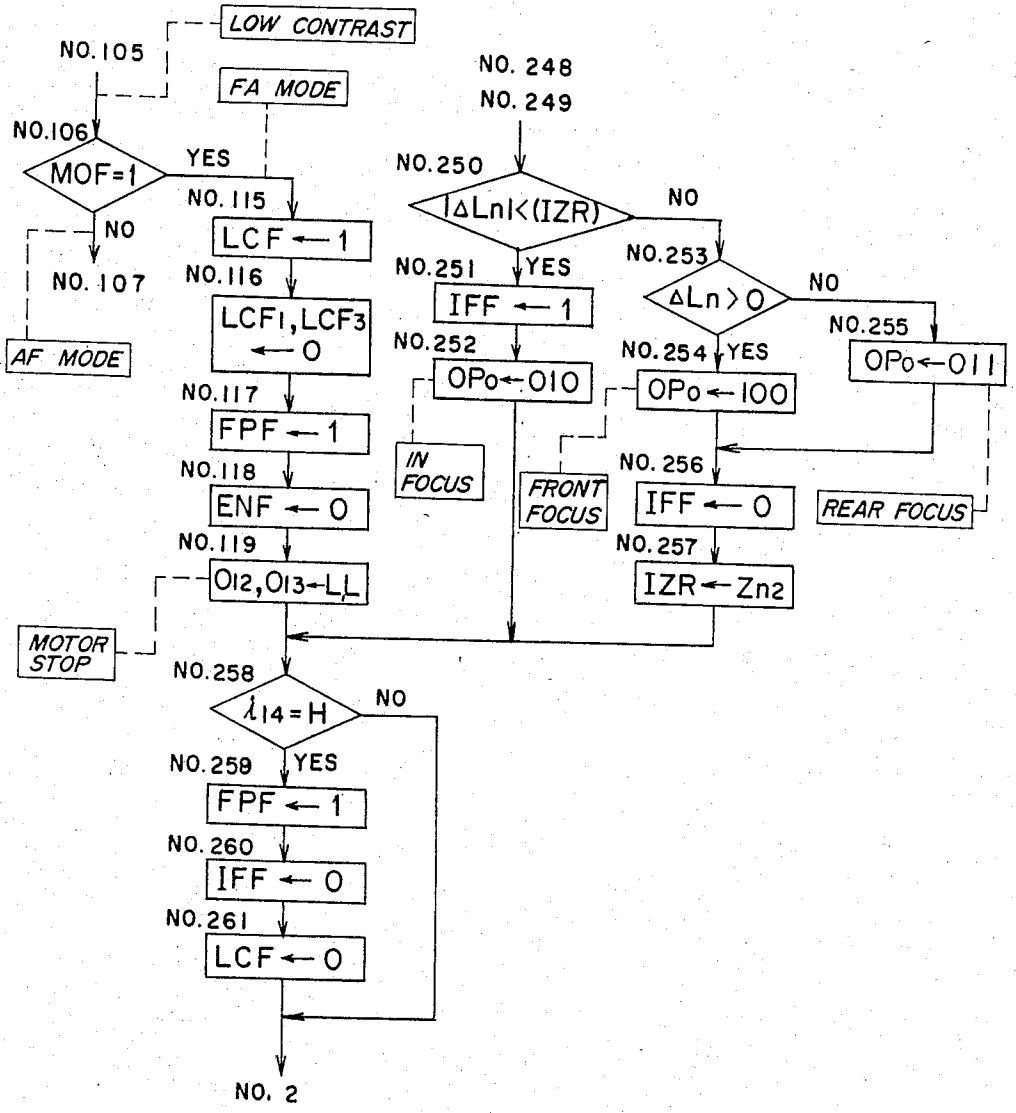
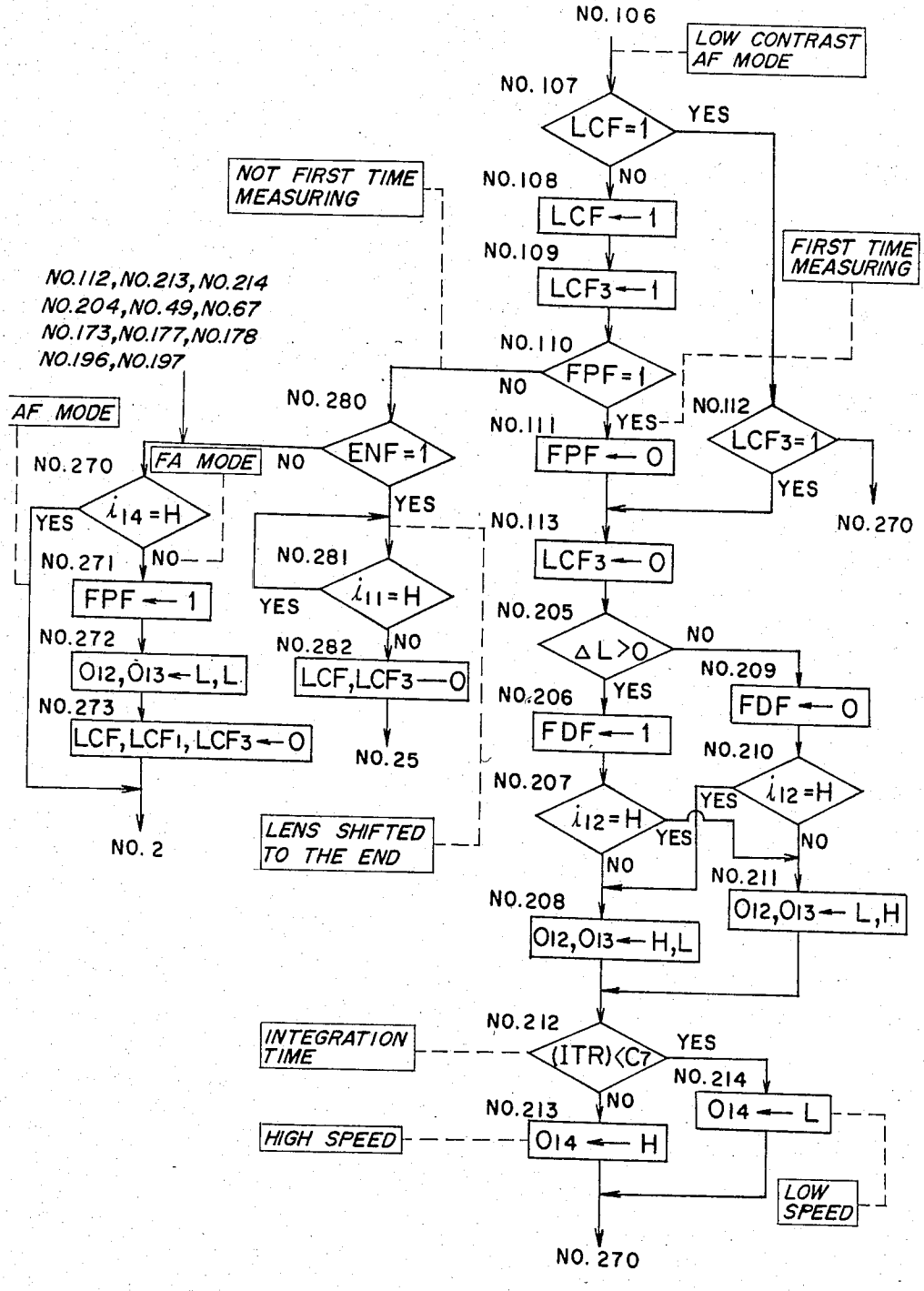

LOW CONTRAST
NO. 105
FA MODE
NO. 248
NO. 249
NO. 106
MOF=1
YES
NO
NO. 107
AF MODE
NO. 115
LCF ← 1
NO. 116
LCF1, LCF3 ← 0
NO. 117
FPF ← 1
NO. 118
ENF ← 0
NO. 119
O12, O13 ← LL
MOTOR STOP
NO. 250
|ΔLn|<(IZR)
NO
YES
NO. 251
IFF ← 1
NO. 252
OPo ← 010
IN FOCUS
NO. 253
ΔLn > 0
NO
YES
NO. 254
OPo ← 100
FRONT FOCUS
NO. 255
OPo ← 011
NO. 256
IFF ← 0
REAR FOCUS
NO. 257
IZR ← Zn2
NO. 258
l14 = H
NO
YES
NO. 259
FPF ← 1
NO. 260
IFF ← 0
NO. 261
LCF ← 0
NO. 2

Fig. 13d


NO. 106
LOW CONTRAST AF MODE
NO. 107
LCF=1
YES
NO
NOT FIRST TIME MEASURING
NO. 108
LCF ← 1
NO. 109
LCF3 ← 1
FIRST TIME MEASURING
NO. 110
FPF=1
NO
NO. 280
NO. 111
YES
FPF ← 0
NO. 112
LCF3=1
YES
NO. 270
NO. 113
LCF3 ← 0
NO. 112, NO. 213, NO. 214
NO. 204, NO. 49, NO. 67
NO. 173, NO. 177, NO. 178
NO. 196, NO. 197
AF MODE
FA MODE
NO
ENF=1
YES
NO. 270
i14=H
YES
NO
NO. 271
FPF ← 1
NO. 281
i11=H
YES
NO
NO. 272
O12, O13 ← L, L
NO. 282
LCF, LCF3 ← 0
NO. 273
LCF, LCF1, LCF3 ← 0
NO. 25
NO. 2
LENS SHIFTED TO THE END
NO. 205
ΔL>0
NO
YES
NO. 209
FDF ← 0
NO. 206
FDF ← 1
NO. 210
i12=H
YES
NO
NO. 207
i12=H
YES
NO
NO. 211
O12, O13 ← L, H
NO. 208
O12, O13 ← H, L
NO. 212
INTEGRATION TIME
(ITR)<C7
YES
NO
NO. 214
O14 ← L
NO. 213
HIGH SPEED
O14 ← H
LOW SPEED
NO. 270

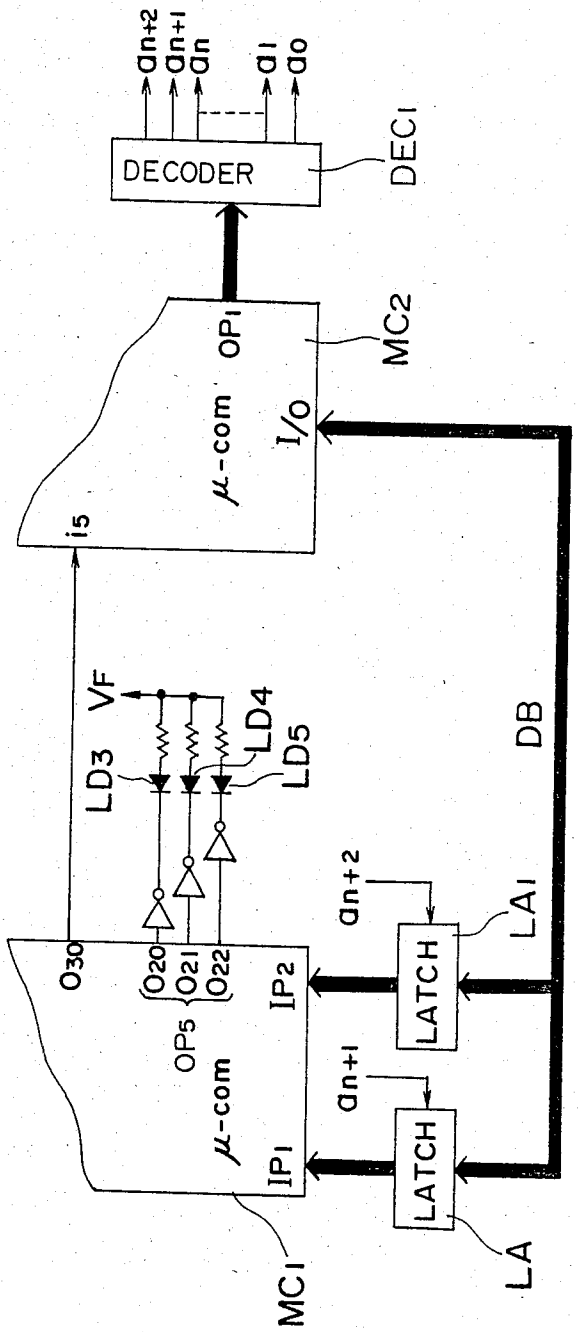

an+2
an+1
an
a1
a0
DECODER
DEC1
OP1
MC2
μ-com
I/O
i5
VF
LD3
LD4
LD5
DB
an+2
LA1
LATCH
O30
O20
O21
O22
IP2
OP5
μ-com
IP1
an+1
LATCH
MC1
LA

Fig. 14

Fig. 15

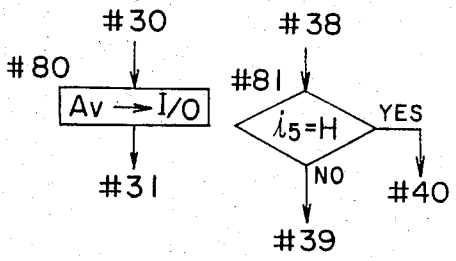
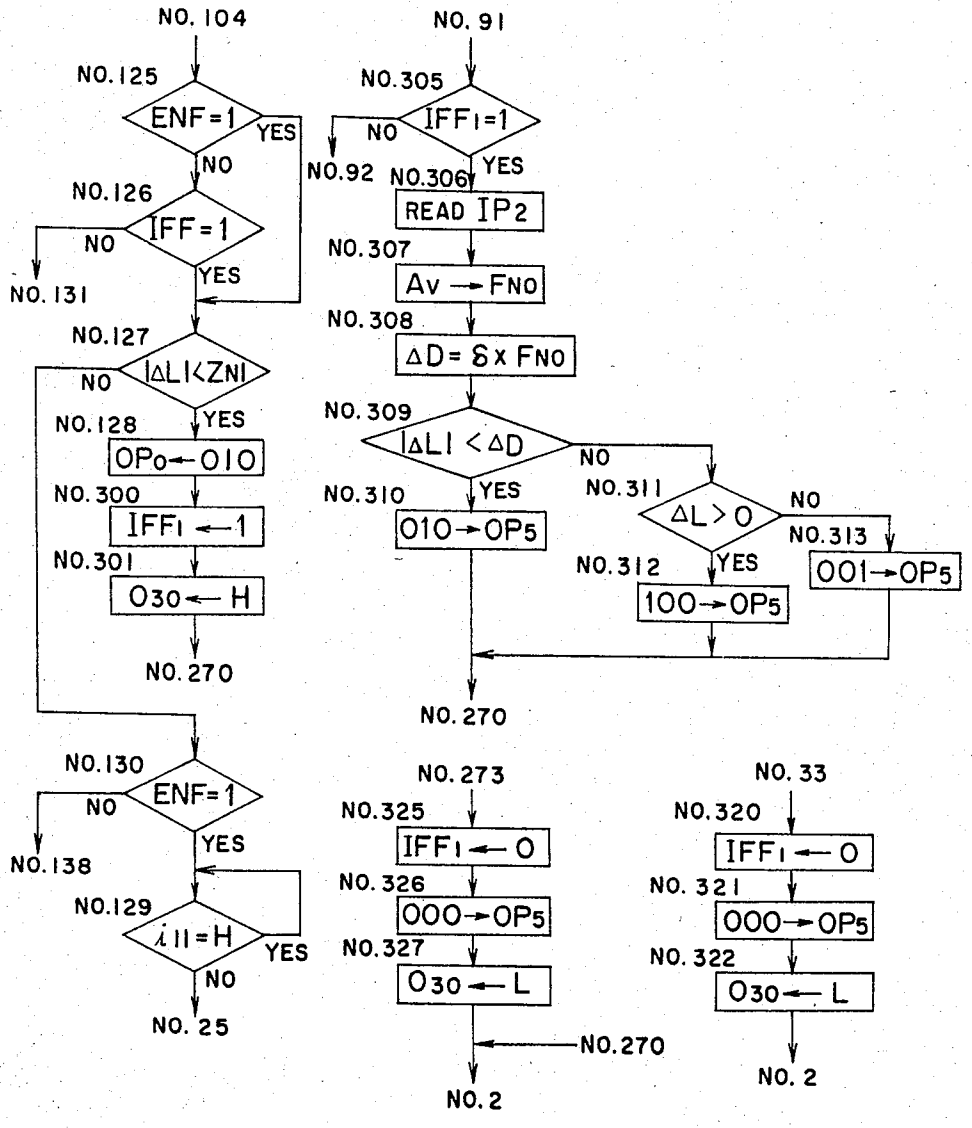

#30
#80
Av → I/O
#31
#38
#81
i5=H
YES
NO
#40
#39

Fig. 16


NO. 104
NO. 125
ENF=1
YES
NO
NO. 126
IFF=1
NO
YES
NO. 131
NO. 127
|ΔL|<ZN|
NO
YES
NO. 128
OP0←010
NO. 300
IFF1←1
NO. 301
030←H
NO. 270
NO. 130
ENF=1
NO
YES
NO. 138
NO. 129
i11=H
YES
NO
NO. 25
NO. 91
NO. 305
IFF1=1
NO
YES
NO. 92
NO. 306
READ IP2
NO. 307
Av → FNO
NO. 308
ΔD=δ×FNO
NO. 309
|ΔL| <ΔD
NO
YES
NO. 310
010→OP5
NO. 311
ΔL>0
NO
YES
NO. 313
001→OP5
NO. 312
100→OP5
NO. 270
NO. 273
NO. 325
IFF1←0
NO. 326
000→OP5
NO. 327
030←L
NO. 270
NO. 2
NO. 33
NO. 320
IFF1←0
NO. 321
000→OP5
NO. 322
030←L
NO. 2

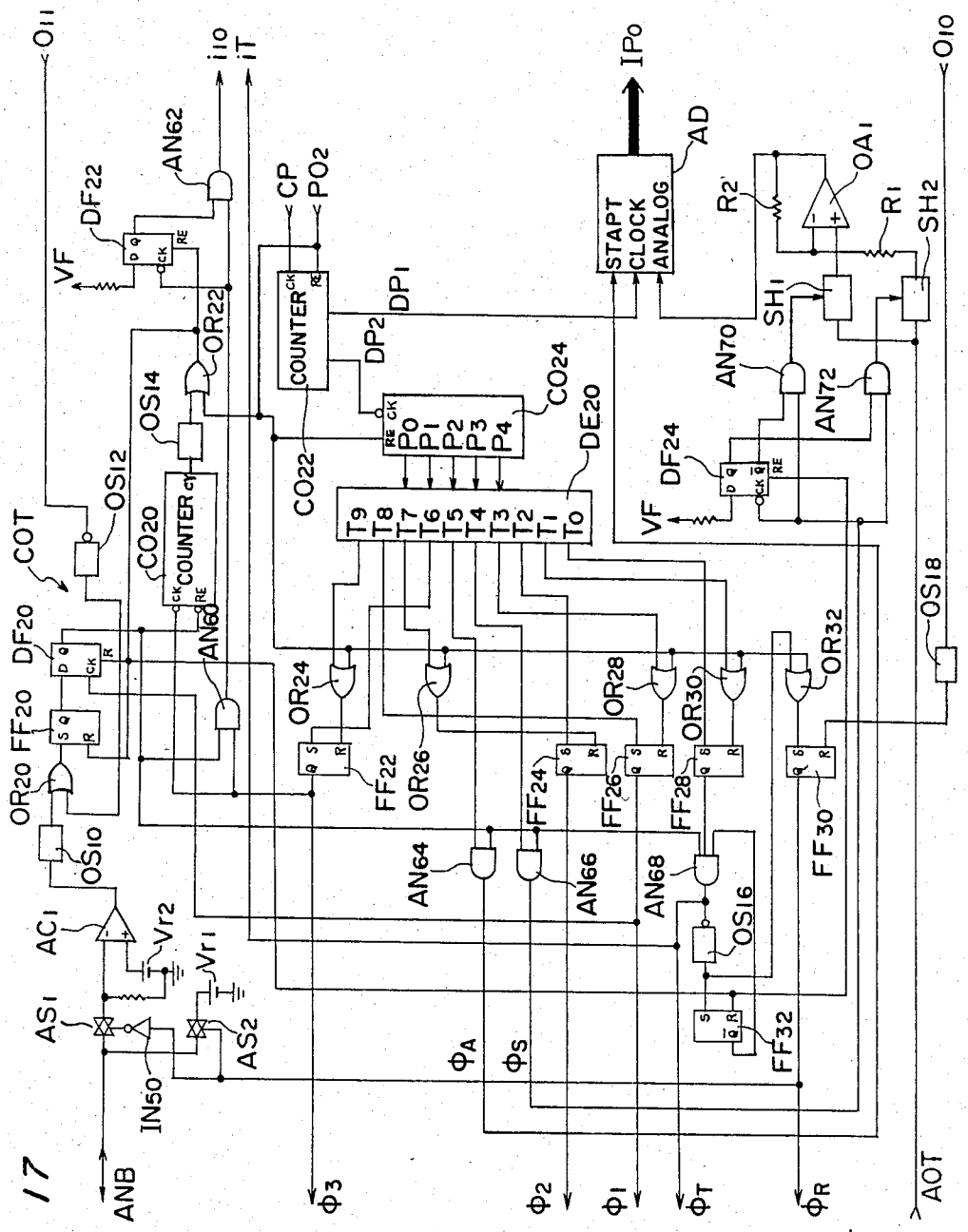

O11
i10
iT
IP0
O10
AN62
DF22
VF
CP
PO2
COUNTER
DP1
DP2
CO22
CO24
DE20
START
CLOCK
ANALOG
AD
R2
OA1
R1
SH2
SH1
OR22
OS14
OS12
COT
CO20
COUNTER
AN60
AN70
AN72
DF24
P0 P1 P2 P3 P4
T9 T8 T7 T6 T5 T4 T3 T2 T1 T0
DF20
FF20
OR20
OS10
OR24
OR26
OR28
OR30
OR32
OS18
FF22
FF24
FF26
FF28
FF30
FF32
AN64
AN66
AN68
OS16
AC1
Vr2
Vr1
AS1
AS2
IN50
ANB
ΦA
ΦS
Φ3
Φ2
Φ1
ΦT
ΦR
AOT

Fig. 17

Fig. 18

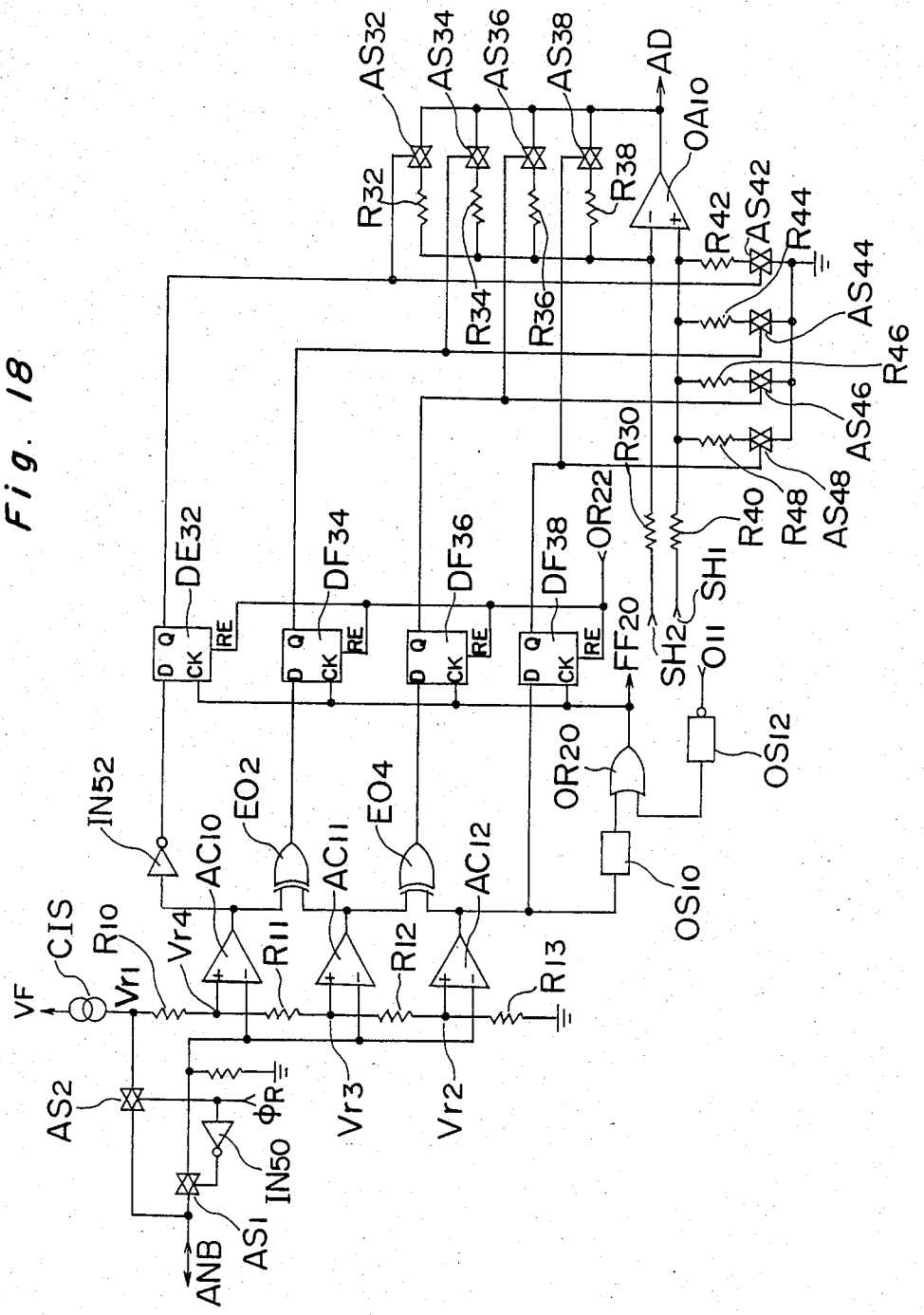
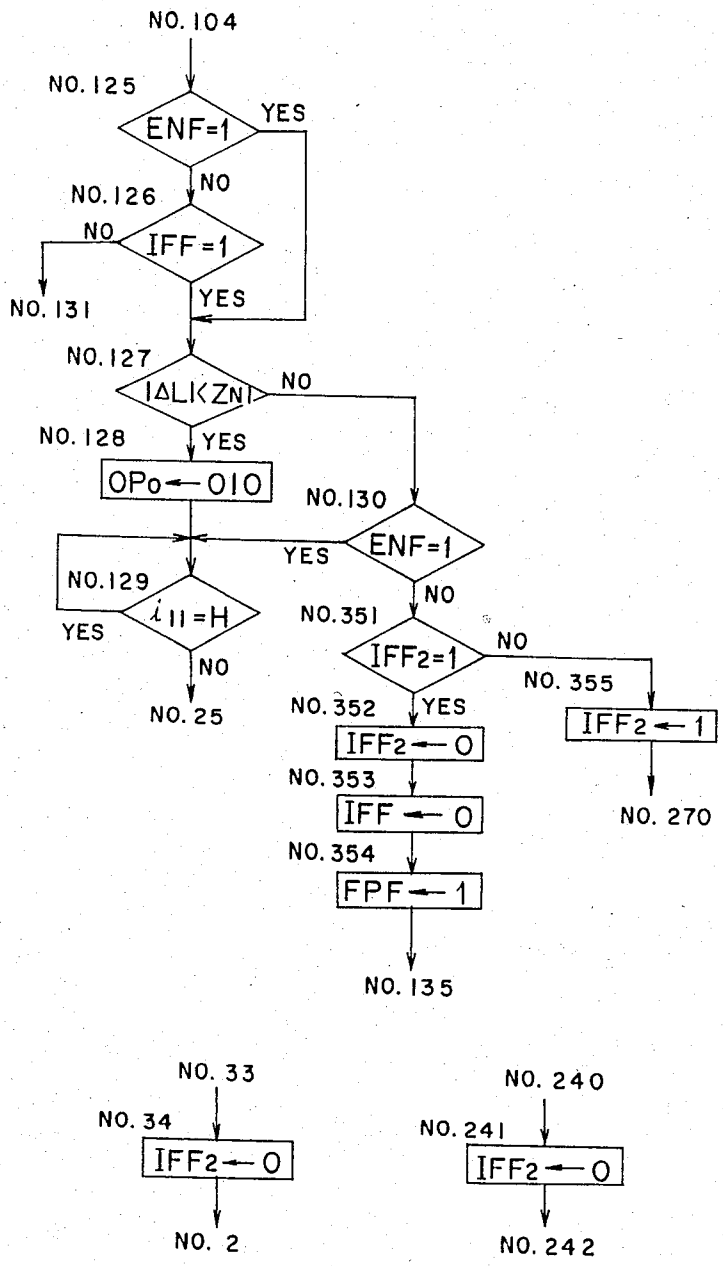
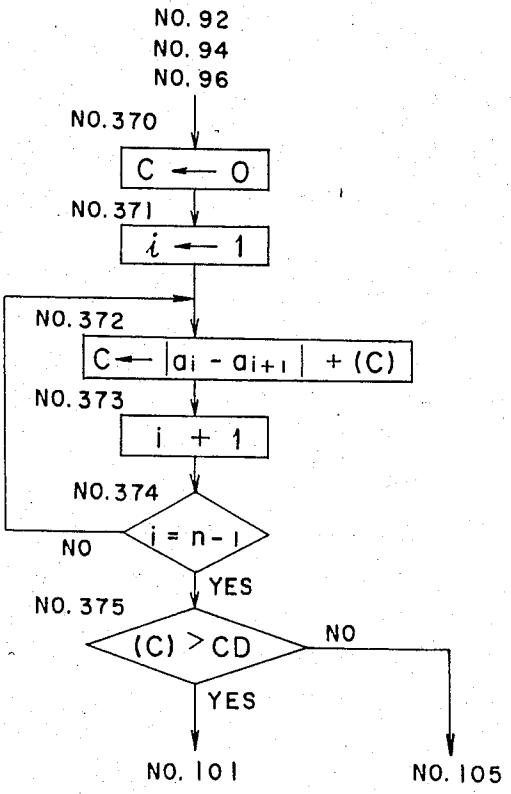

AS32
AS34
AS36
AS38
AD
OA10
R32
R38
R42
AS42
R44
AS44
R34
R36
R46
AS46
R30
R40
R48
AS48
OR22
SH1
SH2
O11
FF20
DE32
DF34
DF36
DF38
D Q
CK
RE
OR20
OS12
OS10
IN52
EO2
EO4
AC10
AC11
AC12
CIS
R10
Vr1
Vr4
R11
R12
R13
VF
AS2
Vr3
Vr2
ΦR
IN50
AS1
ANB

Fig. 19


NO. 104
NO. 125
ENF=1
YES
NO
NO. 126
NO
IFF=1
NO. 131
YES
NO. 127
|ΔL|<ZN|
NO
NO. 128
YES
OPo←010
NO. 130
YES
ENF=1
NO. 129
λ11=H
YES
NO
NO. 25
NO
NO. 351
IFF2=1
NO
NO. 355
IFF2←1
NO. 270
NO. 352
YES
IFF2←0
NO. 353
IFF←0
NO. 354
FPF←1
NO. 135

NO. 33
NO. 34
IFF2←0
NO. 2
NO. 240
NO. 241
IFF2←0
NO. 242

Fig. 20


NO. 92
NO. 94
NO. 96
NO. 370
C ← 0
NO. 371
i ← 1
NO. 372
C ← |ai - ai+1| + (C)
NO. 373
i + 1
NO. 374
i = n - 1
NO
YES
NO. 375
(C) > CD
NO
YES
NO. 101
NO. 105

CAMERA SYSTEM CAPABLE OF FOCUS DETECTION THROUGH AN INTERCHANGEABLE OBJECTIVE LENS

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a camera system capable of focus detection by means of receiving light through an interchangeable objective lens. More particularly, it relates to an improvement of the above-mentioned system and also to an improvement of the camera body and the interchangeable objective lens in that system.

2. Description of the Prior Art

Conventionally, a camera system has been proposed wherein the focus adjustment and the display of detected focus condition are controlled in accordance with a signal based on the light which has passed through the interchangeable objective lens and received by light receiving device provided in the camera body.

Generally, according to the camera system, a number of different types of interchangeable lenses can be mounted on a camera body, and one interchangeable lens can be mounted on a number of different types of camera bodies. In other words, according to the camera system to which the present invention pertains, there is a compatibility between a number of camera bodies and a number of interchangeable objective lenses, enabling a number of combinations of a camera body and an interchangeable lens.

In the camera system described above, there are a number of problems to be solved when the focus detection and focus adjustment are to be carried out with a signal based on the light which has passed through the interchangeable objective lens. A problem in the case of focus detection is, for example, the change in conditions, such as in the optical arrangement, every time when the combination of camera body and interchangeable lens changes. To establish a camera system of the above described type which can effect the focus detection with a high accuracy, it is necessary to consider all the possible conditions set up by various combinations, or otherwise, a high reliability on the focus detection can not be ensured. For example, when the fully open aperture size of an interchangeable lens is smaller than a predetermined size, there may be a case wherein a required focus detection can not be carried out properly. Such a case will be described later in connection with FIGS. **1** to **3**.

A problem in the case of focus adjustment carried out automatically by the motor drive of focusing lens in the interchangeable lens in accordance with the result of focus detection is in the driving source and its control. For example, the control of driving source according to even the same result of focus detection would have to vary depending on the various combination of camera body and interchangeable lens changes.

SUMMARY OF THE INVENTION

The present invention has been developed with a view to substantially solving the above described problems and has for its essential object to provide a camera system with an interchangeable lens with an improvement in both camera body and interchangeable lens from the view point of automatic focus detection.

It is also an object of the present invention to provide a camera system of the above described type with an

improvement in the focus adjustment of the interchangeable objective lens in accordance with the result of focus detection.

It is a further object of the present invention to provide a camera system of the above described type with an improvement wherein a camera body can be connected to every possible types of interchangeable lenses without causing any problem in operation.

It is another object of the present invention to provide a camera system of the above described type with an improvement wherein a camera body can be connected to every possible types of interchangeable lenses having different fully open aperture sizes without causing any problem in operation.

It is another object of the present invention to provide a camera system of the above described type with an improvement to make it possible to mount a zoom lens on the camera body without any problem in operation.

It is another object of the present invention to provide a camera system of the above described type with an improvement to make it possible to mount an interchangeable objective lens capable of macro photography on the camera body without any problem in operation.

It is another object of the present invention to improve a camera system with respect to a case that an interchangeable objective lens having no ability of automatic focus adjustment is mounted on the camera body which can carry out the automatic focus adjustment.

It is yet another object of the present invention to provide a camera system with an improvement to prevent a case that the camera system would receive possible disadvantageous affects on focus detection or focus adjustment from an incomplete mounting of the lens on the camera body.

According to one feature of the present invention, a means for generating a driving power for the automatic focus control is located inside the camera body. And, in accordance with a defocusing information, which is the result of focus detection, a first movable member provided in the generating means is moved. This movement is transmitted to interchangeable objective lens to automatically adjust the focus condition. In this case, converting information necessary to convert the defocusing degree in the defocusing information into a degree of movement of the first movable member varies in accordance with the type of mounted interchangeable objective lens, even if the defocusing degree is the same. Thus, according to the present invention, the converting information in the form of digital data is stored in ROM located in each interchangeable objective lens and sent to the camera body. The movement of the first movable member suitable for each particular interchangeable objective lens is determined in accordance with the defocusing degree with the aid of the converting information sent to the camera body from the ROM in the interchangeable objective lens. The converting information varies greatly with respect to the change of type of interchangeable objective lens. Therefore, according to the present invention, in order to effectively send the converting information to the camera body, the converting information is formed as a digital data composed of m-bit of significant digits part and n-bit of floating point coefficient part. In this manner, it is possible to express the converting information in a wide variation range with a small number of bits.

According to another feature of the present invention, an improvement is made to make it possible to mount a zoom lens on the camera body without any problem in automatic focus adjustment. Some zoom lenses have a converting information that changes in response to the change of focal length. In order to properly operate with such a type of zoom lens, it is required to prepare, from an ideal stand point, extremely great numbers of different converting information values corresponding to the change of focal length. But, it is not practical to prepare so many numbers of converting information values. According to the present invention, the variable focal length range of the zoom lens is divided into a plurality of zones, and one converting information value is given to each zone. In other words, within one zone, the variety of ideal converting information values are all approximated to one converting information value which is so selected that it causes an approximately minimum degree of movement of the first movable member within that zone. Accordingly, notwithstanding the use of such an approximate value, a case in which the first movable member overshoots its movement thereby requiring its return movement can be avoided. In other words, the movable member can be brought to a required position with its movement only in one direction.

According to another feature of the present invention, the converting information to be stored in a ROM of an interchangeable objective lens is a data for converting the defocus degree into the degree of movement of a movable member in the interchangeable objective lens for receiving the driving power. While in the camera body, means is provided for providing a supplemental converting data to convert the degree of movement of the the first movable member into that of another movable member to be coupled with the movable member of the interchangeable objective lens. According to this arrangement, any combination between camera body and interchangeable objective lens can be employed without any trouble.

For the automatic focus control, it is necessary to determine the direction of movement of the first movable member. Although the defocusing direction of defocusing information is the same, the direction of movement of the first movable member may differ depending on the type of interchangeable objective lens. Thus, according to a further feature of the present invention, the ROM in the interchangeable objective lens is stored with direction information, in addition to the converting information. This direction information is sent to the camera body. And, based on the direction information and defocusing direction of defocusing information, the direction to move the first movable member is determined to suit each interchangeable objective lens.

According to yet another feature of the present invention, the camera body has a means for inhibiting focus adjustment or focus indication, in the case where one of undesirable conditions owing to the exchange of lens takes place. For example, in the case where the fully open aperture size informed from the mounted interchangeable objective lens is too small to successfully carry out the focus detection, the inhibiting means, according to the present invention, is actuated.

Furthermore, the ROM of the interchangeable objective lens stores a check data for certifying that the interchangeable objective lens is correctly connected to the camera body by means of successful acceptance of the check data by the camera body. In the case where the check data is not accepted successfully by the camera body, the above-mentioned inhibiting means is actuated.

According to a still further feature of the present invention, means for generating a driving power to be transmitted to the interchangeable objective lens, and means for indicating the focus condition, both of which respond to the result of the focus detection, are provided in the camera body. And, in the interchangeable objective lens, in addition to the fully open aperture size information, an auto-focus information indicating whether or not the interchangeable objective lens is capable of automatic focus adjustment in response to the driving power from the camera body is provided to be sent to the camera body. When the fully open aperture size of the mounted interchangeable objective lens is sufficiently large to correctly carry out the focus detection, and at the same time, auto-focus information indicating that the interchangeable objective lens is incapable of automatic focus adjustment is accepted by the camera body, only the above-mentioned generating means is inhibited with the operation of the indicating means maintained. Accordingly, when such an interchangeable objective lens is mounted, a photographer can adjust the focus manually as he watches the focus indication.

When a mounted interchangeable objective lens is a type having a macro-photography mode, the ROM of interchangeable objective lens stores macro-photography information to be sent to the camera body only when the lens is set to macro-photography condition. And, when the macro-photography information is accepted by the camera body, the generating means is inhibited and indicating means is actuated, as similar to that described above. Accordingly, the manual focusing under the macro-photography can be carried out in accordance with the focus indication.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other objects and features of the present invention will become apparent from the following description taken in conjunction with a preferred embodiment thereof with reference to the accompanying drawings, throughout which like parts are designated by like reference numerals, and in which:

FIG. **1** is a diagrammatic view of an optical arrangement of a focus detecting device according to the prior art;

FIG. **2** is a diagrammatic view of an optical relationship between the focus detecting device of FIG. **1** and an interchangeable lens mounted on the camera;

FIG. **3** is a graph showing a relationship between outputs from two light receiving arrays Ai and Bi shown in FIG. **1**;

FIG. **4** is a block diagram of a camera system according to the present invention;

FIG. **5** is a circuit diagram of a camera system according to the present invention;

FIGS. **6***a*, **6***b*, **6***c* and **6***d* taken together show a flow chart of operations carried out by a microcomputer MC2 shown in FIG. **5**;

FIG. **7** is a circuit diagram of a serial data input portion SDI of microcomputer MC2 shown in FIG. **5**;

FIG. **8** is a circuit diagram of an interchangeable lens to be mounted on the camera body;

FIG. **9** is a circuit diagram of a light emitting diode driving circuit FAD controlled by microcomputer MC1;

FIG. **10** is graph showing a relationship between focal length and conversion coefficient of a zoom lens having an optical arrangement wherein the conversion coefficient varies with respect to the change of focal length;

FIGS. **11***a*, **11***b*, **11***c*, **12***a*, **12***b*, **12***c*, **13***a*, **13***b*, **13***c* and **13***d* show a flow of operations carried out by a microcomputer MC1 shown in FIG. **5**;

FIG. **14** is a fragmentary view of a circuit of FIG. **5**, particularly showing a modification thereof;

FIGS. **15** and **16** show flow charts to be effected in microcomputers MC2 and MC1, respectively, for the modification of FIG. **14**;

FIG. **17** shows a circuit diagram of control circuit COT controlled by microcomputer MC1;

FIG. **18** is a frangmentary view of a circuit of FIG. **17**, particularly showing a modification thereof;

FIG. **19** show a part of flow chart carried out by a microcomputer MC1 according to a modification; and

FIG. **20** is a flow chart showing a detail of step No. 100 of microcomputer MC1 shown in FIG. **11***c*.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to FIG. **4**, a block diagram of a camera system having an auto-focus system according to the present invention is shown. In the drawing, parts shown on the left-hand side of a chain line belong to a zoom lens LZ, and parts shown on the right-hand side of the same belong to camera body BD. The zoom lens LZ is an interchangeable lens and is mounted on the camera body BD. The transmission of driving force from body BD to lens LZ is effected by a clutch arrangement **106** and **107** and transmission of electric signals between body BD and lens LZ is effected by terminals JL1–JL5 and terminals JB1–JB5. According to the camera system shown, the light beams reflected or emitted from an object to be photographed path through focusing lens FL of the zoom lens LZ, zooming lens ZL, and master lens ML. The light beams further path through the central half-mirror portion of a reflection mirror **108** provided in the camera body BD, reflect on a sub-mirror **109**, and impinges on a light receiving device FLM for the focus detection.

A signal processing circuit **112** is provided to receive signals from light receiving device FLM, and based on such signals, it produces a defocus signal $|\Delta L|$ representing a degree of out of focus and a direction signal representing a direction of out of focus whether it is near focused or far focused. A motor MO is provided to be driven in accordance with these signals and its rotational force is transmitted to the zoom lens LZ through slip mechanism SLP, driving mechanism LDR and clutch **107** provided in the camera body. It is to be noted that the slip mechanism SLP is provided to cut the transmission of rotational force to the driving mechanism thereby preventing the motor MO from being over-loaded such that the slip mechanism SLP slips when a torque above a predetermined level is applied to a shaft after the slip mechanism SLP.

The zoom lens LZ shown has a focus adjustment member **102** for shifting the focusing lens FL. The focus adjustment member **102** is formed with a female-helicoid thread on its inner surface which engages with a male-helicoid thread on the outer surface of a cylinder **101** provided integrally to the lens mount **121**. A large gear **103** is fixedly mounted on the peripheral outer surface of the focus adjustment member **102**. The large gear **103** is engaged to a small gear **104** which is connected through a transmission mechanism **105** to the clutch **107** provided in the lens. By the above arrangement, the rotational force of the motor MO is transmitted to the focus adjustment member **102** through slip mechanism SLP in the camera body, clutch **107** in the camera body, clutch **106** in the lens, transmission mechanism **105** in the lens, small gear **104** and large gear **103**. Then, by the engagement between the male- and female-helicoid threads, the focusing lens FL is shifted in the optical axis direction, thereby effecting the focus adjustment. Also, in order to monitor the amount of shift the focusing lens LF, an encoder ENC is coupled to the driving mechanism in the camera body BD such that the encoder ENC produces a train of pulses with its number corresponding the the amount of shift of the lens FL.

When terms are defined as follows:

NM (rot): the number of rotation of the motor MO;

N: the number of pulses from the encoder ENC;

ρ (1/rot): resolving power of the encoder ENC;

μP: rate of speed reduction in mechanical transmission arrangement between the shaft of motor MO and the shaft of encoder ENC;

μB: rate of speed reduction in mechanical transmission arrangement between the shaft of motor MO and clutch **107** of the camera body;

μL: rate of speed reduction in mechanical transmission arrangement between clutch **106** of the lens and large gear **103**;

LH (mm/rot): a helicoid lead of the focus adjustment member; and

Δd (mm): amount of shift of the focusing lens FL,

following relationships are obtained.

$$N=\rho\cdot\mu P\cdot NM$$

$$\Delta d=NM\cdot\mu B\cdot\mu L\cdot LH$$

Thus,

$$\Delta d=N\cdot\mu B\cdot\mu L\cdot LH/(\rho\cdot\mu P). \quad (1)$$

Also, when a relation between the above given Δd and ΔL (mm) representing the amount of shift of the image forming plane when the lens is shifted Δd (mm) is defined as:

$$Kop=\Delta d/\Delta L, \quad (2)$$

a following equation (3) is obtained using equations (1) and (2).

$$N=Kop\cdot\Delta L\cdot\rho\cdot\mu P/(\mu B\cdot\mu L\cdot LH) \quad (3)$$

When terms are defined as:

$$KL=Kop/(\mu L\cdot LH) \quad (4)$$

and

$$KB=\rho\cdot\mu P/\mu B, \quad (5)$$

a following equation (6) is obtained.

$$N=KB\cdot KL\cdot\Delta L \quad (6)$$

In the equation (6) given above, ΔL is obtained from the signal processing circuit **112** using the defocus signal $|\Delta L|$ and the direction signal. Furthermore, the term

KL in equation (4) corresponds to the focal length of the zoom lens as set by the rotational operation of a zooming ring ZR, and is produced from a lens circuit LEC. In other words, a code plate FCD produces data representing the rotated position of the zooming ring ZR, and the produced data are applied to the lens circuit LEC. In the LEC, the received data are used for designating an address at which KL is stored. Data KL are read out serially bit-by-bit and are supplied to a reading circuit LDC in the camera body. Moreover, the term KB in equation (5) is a data determined by the type of camera body, and is produced from a fixed data producing circuit **110**.

From reading circuit LDC of the camera body to lens circuit LEC of the lens, electric power is supplied through terminals JB1 and JL1, synchronizing clock pulses are applied through terminals JB2 and JL2, and a read-start signal is applied through terminals JB3 and JL3. Contrary, from lens circuit LEC to reading circuit LDC, data KL are transmitted in series through terminals JL4 and LB4. Now, terminals JB5 and JL5 are connected with each other as a common ground.

The code plate FCD is arranged in a predetermined code pattern so as to produce data corresponding to the rotated position of the zooming ring ZR. The lens circuit includes a memory, such as a ROM, in which various data KL corresponding to various focal length set by the zooming ring ZR are stored at different addresses determined by the code plate FCD. Therefore, when the read-start signal is applied, lens circuit LEC produces bit-by-bit the data KL corresponding to the focal length set by the zooming ring in a synchronized manner with the clock pulses. And, the produced data KL are applied serially through terminals JL4 and JB4 to reading circuit LDC in which the data KL are aligned parallelly.

For the zoom lens having a focusing system in which focusing lens FL is disposed in front of zooming lens ZL, i.e., for the zoom lens of front lens shifting type, the above given amount Kop can be expressed as follows:

$$Kop = F1^2/f^2, \quad (7)$$

wherein f1 is a focal length of focusing lens FL. Thus, one zoom lens has a wide variation of a value KL. To memorize a wide variation of a value KL, the data of each value KL are defined by bits representing the significnat digits and bits representing the floating point coefficient. For example, if the data is 8-bit long, the upper four bits may be used as a part for designating the floating point coefficient, and the lower four bits may be used as a part for designating the significant digits. In the preferred embodiment shown in FIG. **4**, a shift circuit **131** receives lower four bits of the data KL for specifying the significant digits, and a shift control circuit **130** receives upper four bits of the data KL for specifying the floating point coefficient. The significant digits established in the shift circuit **131** is shifted to change its floating point in accordance with the data from the shift control circuit **130**. With this arrangement, shift circuit **131** can cover a widely changing value of the data KL.

A multiplication circuit **111** is provided to receive data KL from shift circuit **131** and data KB from fixed data producing circuit **110**, and it carries out a multiplication $KL \times KB = K$. Another multiplication circuit **113** receives defocus signal $|\Delta L|$ from signal processing circuit **112** and data K from multiplication circuit **111**, and it carries out a multiplication $K \times |\Delta L| = N$, thereby calculating the number of pulses to be detected by encoder ENC. A motor control circuit **114** drives motor MO in a clockwise or counterclockwise direction depending on the direction signal from the signal processing circuit **112**. The amount of rotation of the motor MO is controlled by the data N obtained from multiplication circuit **113** and the pulses obtained from the encoder ENC, such that motor MO stops when N pulses are produced from encoder ENC. When this is done, focusing lens FL is shifted a distance Δd towards an in-focus position.

According to the above description, the data K is produced by the multiplication of data KL from the lens by the data KB which is intrinsic to each type of camera body and is stored in fixed data producing circuit **110** in the camera body. Instead of the above steps, the data K can be obtained through other methods.

For example, one method is to arrange zoom lens LZ such that lens circuit LEC produces $K1 = KL \times KB1$ corresponding to a standard type of camera body in response to the setting of focal length. When this arrangement is employed, it is not necessary to provide fixed data producing circuit **110** and multiplication circuit **111** in the standard type camera body such that the data K1 from the reading circuit LDC are applied directly to multiplication circuit **113**. But when this zoom lens is mounted no a nonstandard type camera body having data KB2 ($\neq$KB1), the nonstandard type camera body must have fixed data producing circuit **110** and multiplication circuit **111** such that fixed data producing circuit **110** produces data KB2/KB1 and multiplication circuit **111** calculates

$$K2 = K1 \times KB2/KB1 = KL \times KB2,$$

thereby obtaining a wanted data $KL \times KB2$.

According to another example, every lens may be stored with various data, $K1 = KL \times KB1$, $K2 = KL \times KB2, \ldots$, and $Kn = KL \times KBn$ for the all types of camera body. And when in use, the camera body connected to that lens may selectively pick one data corresponding to the camera body. This can be accomplished by sending all the data in the lens to the camera body so that the necessary data are selected in the camera body, or by sending data representing the type of camera to the lens, and transmitting only the necessary data from the lens to the camera body. If this arrangement is employed, it is not necessary to provide fixed data producing circuit **110** and multiplication circuit **111**.

In the foregoing description, a camera system having an auto-focus system according to the present invention is described from the view point of hardwares, but according to a preferred embodiment, various functions of the circuits are accomplished by microcomputers as will be described below.

In the following description, a system is described in which only a standard type camera body with KB1 is available. And, in this case, a data $KL \times KB1$ is stored in the lens and sent to the camera body, such data $KL \times KB1$ being represented by simply KD hereinafter.

Referring to FIG. **5**, a block diagram of a circuit provided in the camera body is shown, together with a block diagram of a circuit provided in the lens, which is enclosed in a chain line LE. The circuit in the camera body BD is connected to the circuit in the lens through terminal arrays CN1 and CN2 so as to send various data

from lens LE to camera body BD. When a power switch MAS turns on, electric power is supplied through a power line +E to each of power-on reset circuit POR1, microcomputers MC1 and MC2, display control circuit DSC, oscillator OSC, inverters IN1 to IN8, and AND gate AN1. Upon power supply, power-on reset circuit POR1 produces a reset signal PO1, thereby resetting microcomputers MC1 and MC2 and display control circuit DSC.

Microcomputer MC2 is provided to govern the sequence of the overall operation of the camera system, and its operation will be described later in connection with a flow chart shown in FIG. 6. Microcomputer MC1 is provided to sequentially carry out the focus adjustment operation in response to the control signals from the microcomputer MC2, and its operation will be described later in connection with a flow chart shown in FIGS. 11 to 13.

A light measuring switch MES turns on when a shutter release button (not shown) is depressed to its halfway. And when light measuring switch MES turns on, microcomputer MC2 receives HIGH to its input i0 through inverter IN1. In response to this, microcomputer MC2 produces HIGH from its output O0, and thus inverter IN2 produces LOW, thereby turning a transistor BT1 on. By the turn on of transistor BT1, electric power is supplied through a power line VB to each of power-on reset circuit POR3, light measuring circuit LMC, decoder DEC1, transistor BT3 for driving light emitting diodes, film sensitivity setting device SSE, aperture setting device ASE, exposure time setting device TSE, exposure control mode setting device MSE, exposure control device EXC, and latch circuit LA. Upon power supply through power line VB, power-on reset circuit POR3 produces a reset signal PO3, thereby resetting exposure control device EXC. Furthermore, the HIGH from output O0 of microcomputer MC2 is applied through buffer BF and terminal arrays CN1 and CN2 to power line VL, thereby providing power to circuit LEC in the lens LE. Other than the terminals for the power supply, the terminal arrays CN1 and CN2 have other terminals, which are: signal transmission terminals connected to output O6 of microcomputer MC2 for releasing the reset condition of lens circuit LEC; clock transmission terminals for transmitting synchronizing clock pulses from clock output SCO of microcomputer MC2; data input terminals for inputting data from lens LE to serial data input SDI of microcomputer MC2; and common earth terminals. A circuit arrangement of serial data input of microcomputer MC2 is shown in FIG. 7, and circuit arrangement of circuit LEC of lens LE is shown in FIG. 8.

Still referring to FIG. 5, a light measuring circuit LMC provides measured-light signal in an analog form to analog input ANI of micrcomputer MC2, and a reference voltage for the D-A conversion to a reference voltage input VR of microcomputer MC2. Accordingly, using the reference voltage from light measuring circuit LMC, microcomputer MC2 converts the measured-light signal applied to input ANI from analog form to digital form.

Display control circuit DSC receives various data through data bus DB and displays exposure control values through liquid crystal display portion DSP and, also displays light emitting diodes LD10 to LD1n for the warning and other purposes. An output O8 of microcomputer MC2 continues to produce HIGH from the turn on of light measuring switch MES until the start of exposure control operation of the camera, and by an inverter IN8, transistor BT3 enables light emitting diodes LD10 and LD1n to emit light only within this period.

A decoder DEC1 receives signals from output port OP1 of microcomputer MC2 and produces output signals from its outputs a0 to aN+1 for indicating which one of devices MSE, TSE, ASE and SSE, and circuits DSC and LA should carry out data transmission with microcomputer MC2 through data bus DB. For example, when microcomputer MC2 produces from output port OP1 a particular data for effecting exposure control mode setting device MSE, output a0 produces HIGH and other outputs a2 to aN+1 produce LOW, thereby microcomputer MC2 reads data of exposure control mode from exposure control mode setting device MSE through data bus DB and input/output port I/O. In a similar manner, when it is necessary to read data of set aperture value, output a2 produces HIGH. Furthermore, when sending display data to exposure control circuit DSC, one of outputs a4 to aN produces HIGH, depending on the type of data to be sent. Also, when sending a conversion coefficient data KD of a lens, which will be described in detail later, first input/output port I/O produces conversion coefficient data through data bus DB for a period of time, and within this period of time, a particular data is produced from output port OP1 so that output aN+1 produces a pulse for effecting latch circuit LA to latch the conversion coefficient data.

Upon application of HIGH to interruption signal input iT of microcomputer MC2, exposure control device EXC starts an exposure control operation described below. For this purpose, release circuit, mirror drive circuit, aperture control circuit and exposure time control circuit are provided. When output O4 of micrcomputer MC2 produces a pulse, exposure control device EXC receives and intakes F stop-down step data on data bus DB, and thereafter, actuating the release circuit to start the exposure control operation. After a certain period of time from the start of exposure control operation, microcomputer MC2 produces exposure time data through data bus DB, and also a pulse from its output O5. Accordingly, the exposure control device EXC intakes exposure time data, and the mirror drive circuit is so operated as to flip up the reflection mirror. Furthermore, the aperture control circuit is so operated as to reduce the aperture size in accordance with the F stop-down step data. When the reflection mirror flips up completely, a leading shutter starts to scan. At the same time, a count switch COS turns on to actuate exposure time control circuit, thereby start counting a time corresponding to exposure time data. When the time counting ends, a trailing curtain starts to scan and, thereafter, the aperture opens to its maximum available size. Then, the reflection mirror flips down to complete one exposure control operation.

A release switch RLS closes when the release button (not shown) is depressed all the way. When release switch RLS closes, inverter IN3 produces HIGH, which is applied to one input of AND gate AN1, thereby enabling AND gate AN1. A switch EES closes when the exposure control operation completes, and it opens when an exposure control mechanism (not shown) is charged to an operable condition. A signal representing on and off conditions of this switch is applied through inverter IN4 to input i2 of microcomputer MC2 and also to the other input of AND gate

AN1. The output of AND gate AN1 is connected to interruption signal input iT of microcomputer MC2. Therefore, when the exposure control mechanism is not charged, AND gate AN1 is held in a disable condition, thereby producing LOW from AND gate AN1 even when release switch RLS closes. In this case, no interruption signal will be applied and, therefore, no exposure control operation will be started. On the contrary to this, when the exposure control mechanism is charged, AND gate AN1 is held in an enable condition, thereby producing HIGH from AND gate AN1 when release switch RLS turns on. Thus, the interruption signal is applied to interruption input iT of microcomputer MC2, whereby the microcomputer MC2 immediately starts the exposure control operation.

Outputs O1, O2 and O3 of microcomputer MC2 are connected, respectively, to inputs i11, i12 and i13 of microcomputer MC1. Output O1 produces HIGH, when it is necessary to carry out a focus detection by microcomputer MC1, and LOW when the focus detection is not needed. Output O2 produces HIGH, when the mounted lens is a type in which the focusing lens is shifted forward when the motor is driven clockwise, and LOW, when the mounted lens is a type in which the focusing lens is shifted forward when the motor is driven counterclockwise. Output O3 produces LOW when the mounted lens is a type in which the focus adjustment is carried out only by a system wherein the focusing lens is driven towards an in-focus position in accordance with signals representing degree and direction of out-of-focus (such a system is disclosed in U.S. Pat. No. 4,209,241 in detail and, hereinafter, referred to as a predictor system). And, output O3 produces HIGH when the mounted lens is a type in which the focus adjustment is carried out by the predictor system in combination with a system wherein the focusing lens is driven towards an in-focus position in accordance with a signal (front-focus condition, rear-focus condition, or in-focused condition) representing the direction of out-of-focus (such a system is disclosed in U.S. Pat. No. 4,303,321 and, hereinafter referred to as a trinomial indication system).

A switch FAS is a mode selecting switch operated manually. When it closes, AF mode is selected. Under AF mode, the focus adjustment is carried out automatically such that the focusing lens is shifted towards in-focus position in accordance with the result of focus detection. When switch FAS opens, FA mode is selected. Under FA mode, the focus adjustment is carried out manually in accordance with the display indicating the result of focus detection. A signal representing on and off conditions of switch FAS is applied through inverter IN6 to input i1 of microcomputer MC2 and also to input i14 of microcomputer MC1.

Output O16 of microcomputer MC1 is connected through inverter IN5 to the base of transistor BT2. Therefore, when output O16 produces HIGH, transistor BT2 conducts to supply power to each one of power-on-reset circuit PO2, light receiving device FLM for the focus detection, light receiving device FLM control circuit COT, motor drive circuit MDR, encoder ENC, light emitting diode drive circuit FAD and power line VF. By this power supply, power-on-reset circuit PO2 produces reset signal PO2.

Referring to FIG. 9, an example of light emitting diode drive circuit FAD is shown. Based on input signals from output port OP0 of microcomputer MC1, i.e., outputs O17, O18 and O19, circuit FAD drives light emitting diodes LD0, LD1 and LD2. More specifically, when either one of output O17, O18 and O19 produces HIGH, a corresponding one of light emitting diodes LD0, LD1 and LD2 is lit. When the light emitting diode LD0 is lit, it indicates the front-focus condition. When the light emitting diode LD1 is lit, it indicates the in-focused condition. And when the light emitting diode LD2 is lit, it indicates the rear-focus condition. Furthermore, when both outputs O17 and 018 produce HIGH at the same time, light emitting diodes LD0 and LD2 blink on and off repeatedly and simultaneously in accordance with clock pulses CP from oscillator OSC, thereby indicating that it is impossible to carry out the focus detection. Various operating conditions of light emitting diodes LD0, LD1 and LD2 will be shown in Table 1 below.

TABLE 1

Focus detection	OP0	LD0	LD1	LD2	Display
Non-operating	0 0 0	OFF	OFF	OFF	
Front-focus	1 0 0	ON	OFF	OFF	
Rear-focus	0 0 1	OFF	OFF	ON	
In-focused	0 1 0	OFF	ON	OFF	
Detection impossible	1 0 1	Blinking	OFF	Blinking	

Light receiving device FLM is defined by a CCD (Charge Coupled Device) having a plurality of light receiving elements for the focus detection. Control circuit COT so operates as to drive the CCD in accordance with the signal from the microcomputer MC1, to carry out the A-D conversion of output signals from the CCD, and to transmit the converted output signals to microcomputer MC1.

To start the integration operation in CCD FLM, microcomputer MC1 produces a pulse from its output O10 to control circuit COT, and to forcibly stop the integration operation in the CCD, microcomputer MC1 produces a pulse from its output O11 to control circuit COT. When the integration operation is completed in CCD FLM, control circuit COT produces a pulse which is applied to interruption input iT of microcomputer MC1. When the A-D conversion for each light receiving element in CCD FLM is completed, control circuit COT produces a pulse which is applied to input i10 of microcomputer MC1. And, each A-D converted data is applied to input port IP0 of microcomputer MC1. Furthermore, from control circuit COT, the CCD receives a reset signal to its input ØR, a transfer command signal to its input ØT, transfer clock pulses to its inputs Ø1, Ø2 and Ø3, and a reference voltage to its terminal ANB. And, control circuit COT receives from terminal ANB of the CCD a voltage signal representing a light amount received by a receiving element for monitoring, and from terminal AOT of the CCD charged voltage from each light receiving elements in the CCD. A detailed circuit arrangement of control circuit COT will be described later in connection with FIGS. 17 and 18.

Here, a brief description on operations of CCD FLM, control circuit COT and microcomputer MC1 is given. In accordance with the integration start signal from output O10 of microcomputer MC1, control circuit COT sends a reset signal $Ø_R$ to CCD FLM, thereby resetting the CCD, and at the same time, provides a reference voltage to CCD FLM through the terminal ANB. In each light receiving element of CCD FLM, the charge gradually increases in accordance with the

received light rays and, accordingly, a voltage level at terminal ANB decreases gradually. When the voltage level at the terminal ANB is reduced to a predetermined level, control circuit COT produces a transfer command signal $\emptyset_T$ to CCD, so that the charge in each light receiving element in the CCD is transferred to a transfer gate provided in the CCD, and at the same time, control circuit COT provides an integration completion signal to interruption input iT of microcomputer MC1. Then, in a synchronized manner with clock pulses applied to inputs $\emptyset$1, $\emptyset$2 and $\emptyset$3 of the CCD, control circuit COT receives charges at the transfer gate of the CCD, and converts it from analog form to digital form. When one A-D conversion for the charge in one light receiving element in CCD completes, the control circuit COT provides an A-D completion signal to input i10 of microcomputer MC1. In response to the A-D completion signal, microcomputer MC1 reads A-D converted data from control circuit COT through input port IP0. This reading operation is repeated for a number of times equal to the number of light receiving elements in the CCD, and when the final A-D converted data are read, microcomputer MC1 ends the transfer of data from CCD to control circuit COT.

It is to be noted that when microcomputer MC1 receives no interruption signal within a predetermined period of time after the start of integration, it produces from its output O11 a pulse which forcibly stops the integration in the CCD. In response to this pulse, control circuit COT provides the transfer command signal to input $\emptyset$T of the CCD and, at the same time, provides an interruption signal to microcomputer MC1, thereby carrying out the above described A-D conversion and data transfer.

Motor drive circuit MDR is provided to drive motor MO in accordance with the signals from outputs O12, O13 and O14 of microcomputer MC1. When output O12 produces HIGH, motor MO can rotate clockwise, when output O13 produces HIGH, motor MO can rotate counterclockwise, and when both outputs O12 and O13 produce LOW, motor MO stops. Furthermore, when output O14 produces HIGH, motor MO can be driven at a high speed and, when it produces LOW, motor MO can be driven at a low speed. Since the detail of motor drive circuit MDR is not necessary to understand the present invention, and it is known through Japanese Patent Application Laid-open No. 58-154015, assigned to the same assignee as the present application, its detailed description is omitted for the sake of brevity.

Encoder ENC is provided for monitoring the amount of drive effected by transmission mechanism LMD provided in the camera body to transmit the driving force of motor MO and is defined, e.g., by a photocoupler which produces a train of pulses which is in relation to the above-mentioned amount of drive. The pulses from encoder ENC are applied to clock input DCL of microcomputer MC1 in which the number of pulses are counted automatically. The counted value ECD will be used in the operation of microcomputer MC1 for the counter interruption, as well be described later with reference to the flow charts. Furthermore, the pulses are also applied to motor drive circuit MDR so as to control the speed of motor MO in accordance with the pulse width.

Referring to FIGS. 6*a*, 6*b*, 6*c* and 6*d*, a flow chart for the operation of microcomputer MC2 is shown. The operation of microcomputer MC2 can be roughly divided into three flows as described below.

The first flow, which is the main flow, starts from step #1 upon closure of power switch MAS. In the first flow, in response to the closure of light measuring switch MES (step #2), the procedures of: power supply (step #4) to the circuits other than the circuits for the focus adjustment; reading (step #5) exposure control information set in camera body BD; reading (steps #6–#12) data from lens LE; reading (steps #13 and #14) measured light amount; automatic setting (steps #16–#27) under AF or FA mode; calculation (step #28) for the exposure control values; and display (step #31 and #32) are repeated.

The second flow, which is a timer interruption flow, starts from step #45. In the second flow, in response to a timer signal produced periodically from a timer incorporated in microcomputer MC2, the above-mentioned main flow is carried out for a predetermined time (such as 15 seconds) after the opening of light measuring switch MES.

The third flow, which is a release interruption flow, starts from step #59. In the third flow, in response to the closure of release switch RLS, exposure control operations for the camera are carried out. The detail of these three flows will be given hereinbelow.

In response to the closure of power switch MAS, power-on reset POR1 produces a reset signal PO1. By this reset signal PO1, microcomputer MC2 carries out a reset operation at step #1 in the main flow. Then, whein input i0 receives HIGH by the closure of light measuring switch MES, the program advances from step #2 to step #3 at which the timer interruption is prohibited, and thereafter, output O0 produces HIGH at step #4. Accordingly, transistor BT1 conducts to supply power to power supply line VB in the camera body and also through buffer BF to power supply line VL in interchangeable lens. Then, at step #5, data from each one of exposure control mode setting device MSE, exposure time setting device TSE, aperture setting device ASE, and film sensitivity setting device SSE, are sequentially applied through data bus DB to input and output port I/O.

During steps #6 to #12, "0" is set in register A (step #6), output O6 produces HIGH, and the reset condition of lens circuit LEC is released (step #9). Then, "1" is added to register A (step #10). And, it is decided whether the content of register A has reached a predetermined amount, Ac. If (A)≠Ac ((A) means the content of register A.), the program returns back to step #7-2 to read next data. After repeating the reading operation for a predetermined number of times, (A) becomes equal to Ac, which means that all the necessary data from lens LE have been read. Thus, output O6 produces LOW at step #12 to reset the lens circuit LEC.

Referring to FIGS. 7 and 8, the manner for carrying out the data reading from the lens LE is explained in detail. FIG. 7 shows an input structure of microcomputer MC2 for receiving serial data applied to its input SDI from the lens LED in a synchronized relation with clock pulses DP produced from output SCO. As an example, a manner in which the microcomputer MC2 receives 8-bit long data to its input SDI from lens LE is described. When microcomputer MC2 produces input command signal SIIN for start receiving serial data from lens LE, flip-flop FF1 is changed to set condition, thereby releasing the reset condition of 3-bit binary

counter CO1 and, at the same time, enabling an AND gate AN7. Then, clock pulses DP from a frequency divider (not shown) provided in the microcomputer MC2 are transferred through AND gate AN7 and are sent out from output SCO to lens circuit LEC in the lens LE. The clock pulses DP are also applied to counter CO1 and shift register SR1 at respective clock terminals CL. In response to the negative edges of clock pulses DP, shift register SR1 stores 8-bit long data bit-by-bit from lens LE through input SDI, while counter CO1 counts up. When counter CO1 receives the eighth clock pulse, its carry terminal CY produces HIGH until it receives the ninth clock pulse. Before receiving the ninth clock pulse, shift register SR1 completes reading the 8-bit long data. The carry terminal CY of counter CO1 is connected to one input of an AND gate AN5, while the other input of AND gate AN5 is connected through an inverter IN15 to AND gate AN7. Thus, during a pulse interval between eighth and ninth pulses, AND gate AN5 produces HIGH, thereby setting a flag SIFL representing the completion of one data reading and, at the same time, resetting flip-flop FF1. Thus, counter CO1 is reset producing LOW from carry terminal CY, and AND gate AN7 is disabled. Now, it is ready for the next operation. By the flag SIFL, the data stored in shift register SR1 is transferred through a data bus IDB, provided inside microcomputer MC2, to a register M(A).

While the above operation is carried out in the microcomputer MC2, the following operation is carried out in lens circuit LEC. Referring to FIG. 8, when microcomputer MC2 produces HIGH from its output 06, counters CO7 and CO9 are released from their reset condition, thereby enabling these counters CO7 and CO9 to count clock pulses DP from output SCO of microcomputer MC2. The counter CO7, which is a 3-bit binary counter, counts the clock pulses DP in response to respective positive edges, and when it receives the eighth clock pulse, its carry terminal CY produces HIGH until it receives the positive edge of ninth clock pulse. The counter CO9, which is a 4-bit binary counter, is responsive to the negative edge of the pulse from the carry terminal CY of the counter CO7, thereby it counts pulses from the carry terminal CY of counter CO7. Therefore, counter CO9 count up by "1" in response to the positive edge of the first pulse of eight consecutive clock pulses DP.

The counter CO9 produces a 4-bit data representing the counted amount, and the 4-bit data is applied to a decoder DE9, which then changes the 4-bit data to 5-bit data. This 5-bit data is applied to a data selector DS1 which, by using the 5-bit data, produces an 8-bit data for addressing a ROM RO3. A relationship among the 4-bit data from counter CO9, the 5-bit data from decoder DE9, 8-bit data from data selector DS1 and 8-bit data produced from ROM RO3 is shown in Tables 2 and 3, in which Table 2 shows a relationship when the mounted lens is a focal length fixed type, and Table 3 shows a relationship when the mounted lens is a zoom lens.

TABLE 2

CO9 outputs	DE9 outputs	DS1 outputs	RO3 outputs
0000	00000	00000000	Check data (01010101)
0001	00001	00000001	Avo
0010	00010	00000010	Avmax
0011	00011	00000011	Measurement difference*
0100	00100	00000100	Rotation direction, KD change
0101	00101	00000101	Focal length
0110	00110	00000110	ΔAv (00000000)
0111	00111	00000111	KD
1000	01000	00001000	ØØØØØØØØ**
1001	01001	00001001	ØØØØØØØØ

Note
*: Measurement difference is fully open aperture light measurement error depending on individual objective lens, which is explained in detail in co-pending U.S. Pat. Application Ser. No. 529,969 assigned to the same assignee as the present invention.
Note
**: Ø indicates either "1" or "0".

TABLE 3

CO9 outputs	DE9 outputs	DS1 outputs	RO3 outputs
0000	00000	00000000	Check data (01010101)
0001	00001	00000001	Avo
0010	00010	00000010	Avmax
0011	00011	00000011	Measurement difference*
0100	00100	00000100	Rotation direction, KD change
0101	10010	00100000	
		00100001	
		~	Focal length
		00111110	
		00111111	
0110	10100	01000000	
		01000001	
		~	ΔAv
		01011110	
		01011111	
0111	10110	01100000	Macro change (ØØØØ0100)
		01100001	
		~	KD
		01111110	
		01111111	Macro (ØØØØ0110)
1000	01000	00001000	ØØØØØØØØ**
1001	01001	00001001	ØØØØØØØØ

Note
*: Measurement difference is fully open aperture light measurement error.
Note
**: Ø indicates either "1" or "0".

Still referring to FIG. 8, outputs b0, b1 and b2 of the counter CO7 are connected to decoder DE7. In accordance with 3-bit data from counter CO7, decoder DE7 produces 8-bit data, as shown in Table 4 below.

TABLE 4

Counter CO7			Decoder DE7							
b0	b1	b2	d0	d1	d2	d3	d4	d5	d6	d7
0	0	0	L	L	L	L	L	L	L	H
0	0	1	H	L	L	L	L	L	L	L
0	1	0	L	H	L	L	L	L	L	L
0	1	1	L	L	H	L	L	L	L	L
1	0	0	L	L	L	H	L	L	L	L
1	0	1	L	L	L	L	H	L	L	L
1	1	0	L	L	L	L	L	H	L	L
1	1	1	L	L	L	L	L	L	H	L

Therefore, in response to the positive edge of clock pulses, the 8-bit data produced from ROM RO3 are transferred bit-by-bit from the least significant bit r0 through AND gates AN20–AN27 and also through OR gate OR5 to terminal SDI of the microcomputer MC2 in the camera body.

In the case where the interchangeable lens is a zoom lens, lens circuit LEC further includes a code plate FCD which produces a 5-bit data representing the focal length changed by a zooming ring ZR mounted on the zoom lens. The 5-bit data from code plate FCD are applied through AND gates AN40–AN44 to 5 least

significant bits of 8-bit input array $\alpha 2$ of data selector DS1.

The data selector DS1 has a select terminal SE which is connected to output h4 of decoder DE9. When output h4 is producing LOW, data selector DS1 produces 8-bit data "0 0 0 0 h3 h2 h1 h0" from the input array $\alpha 1$, and when it is HIGH, data selector DS1 produces 8-bit data "h2 h1 h0 * * * * *" (* * * * * is a 5-bit data from code plate FCD) from the input array $\alpha 2$. The 8-bit data from the data selector DS1 is used for addressing ROM RO3.

Next, the description is given to the operations when counter CO9 changes from "0000" to "0111", as indicated in the above given Tables 2 and 3.

When counter CO9 produces "0000", data selector DS1 produces an 8-bit data "00000000" (The 8-bit data "00000000" can be expressed by a hexadecimal numbering system as "00H", wherein the first "0" represents four zeros in the most four significant bits, the second "0" represents four zeros in the least four significant bits, and H indicates the hexadecimal numbering system.) as an address designating a location in ROM RO3. And in the designated location, a check data, e.g., "01010101", is stored. This check data is common to all the types of interchangeable lenses. The check data is applied to the camera body and is read by microcomputer MC2 through input SDI.

When it is detected that an interchangeable lens is properly mounted on the camera body by the check data, the mode is set to full-aperture light measuring mode, and the aperture control is carried out by exposure control device EXC. On the contrary, when it is detected that the interchangeable lens is not properly mounted on the camera body by the check data, the mode is set to aperture stop-down light measuring mode, thereby carrying out no aperture control.

When counter CO9 produces "0001", data selector DS1 produces an 8-bit address data "01H" for designating a location in ROM RO3 so that ROM RO3 produces a full-open aperture data Avo. In the case where the zoom lens has an optical system in which the aperture value changes with respect to the change of focal length, ROM RO3 produces full-open aperture data Avo for the minimum focal length.

When counter CO9 produces "0010 ", data selector DS1 produces an 8-bit address data "02H" for designating a location in ROM RO3 so that ROM RO3 produces a maximum stop-down aperture data Avmax (data of aperture size when it is reduced to minimum size).

When counter CO9 produces "0011", data selector DS1 produces an 8-bit address data "03H" for designating a location in ROM RO3 so that ROM RO3 produces a data representing a measurement difference, which is the fully open aperture light measurement error.

When counter CO9 produces "0100", data selector DS1 produces an 8-bit address data "04H" for designating a location in ROM RO3 so that ROM RO3 produces a data representing the direction of rotation of motor MO for shifting the focusing lens FL forward, and a data representing whether or not the mounted interchangeable lens is a type which changes its conversion coefficient data KD in accordance with the change of focusing distance. For example, if the mounted lens is such a type that its focusing lens FL shifts forward when the motor is driven clockwise, the least significant bit of the data from ROM RO3 holds "1", but if the mounted lens is such a type that its focusing lens FL shifts forward when the motor is driven counterclockwise, the least significant bit of the data from ROM RO3 holds "0". Furthermore, if the mounted lens is a type which changes its conversion coefficient data KD in accordance with the change of focusing distance, the most significant bit of the data from ROM RO3 holds "1", and if the lens is not that type, it holds "0".

When counter CO9 produces "0101", decoder DE9 produces "00101" when the lens is a fixed focal length type lens. In this case, data selector DS1 produces an 8-bit address data "05H" for designating a location in ROM RO3 so that ROM RO3 produces a data representing $\log_2 f$, wherein f is the fixed focal length of the lens. But, when the lens is a zoom lens, decoder DE9 produces "1001Ø". In this case, data selector DS1 produces an 8-bit address data "001*****" (***** is a 5-bit data from code plate FCD.) capable of designating various locations in ROM RO3 so that ROM RO3 produces a data representing $\log_2 f$, wherein f is the focal length of the lens varied in accordance with the zooming operation.

When the counter CO9 produces "0110", decoder DE9 produces "1010Ø" when the lens is a zoom lens. In this case, the most significant bit (h4) of the data from decoder DE9 is "1". Therefore, the data selector DS1 produces data from its input array $\alpha 2$. Accordingly, data selector DS1 produces an 8-bit address data "010*****" capable of designating various locations in ROM RO3 so that ROM RO3 produces a data ΔAv representing the difference in aperture value between that obtained when the zoom lens is shifted to the minimum focal length and that obtained when the zoom lens is zoomed to other setting position. But, when the lens is a fixed focal length type lens, data $\Delta Av = 0$, and therefore, data selector DS1 produces an 8-bit address data "06H" for designating a location in ROM RO3 so that ROM RO3 produces a data "0".

The data ΔAv is used for the calculation:

$$(Bv - Avo - \Delta Av) - Avo - \Delta Av$$

for eliminating terms related to the aperture from a full-aperture light measured data, and also for the calculation:

$$Av - Avo - \Delta Av$$

for controlling the effective aperture in compliance with set or calculated aperture.

When the counter CO9 produces "0111", decoder DE9 produces "1011Ø" when the lens is a zoom lens. In this case, data selector DS1 produces an 8-bit address data "011*****" for designating various locations in ROM RO3 so that ROM RO3 produces a data representing conversion coefficient KD for the different set focal lengths. But, when the lens is a type having a fixed focal length, data selector DS1 produces an 8-bit address data "07H" for designating a location in ROM RO3 so that ROM RO3 produces a fixed data representing conversion coefficient KD for the set focal length of that lens.

The data of conversion coefficient KD is used for obtaining the amount of drive to be effected by motor drive mechanism LMD through a calculation:

$$|\Delta L| \times KD$$

wherein $|\Delta L|$ is a defocus amount produced from microcomputer MC1.

Furthermore, the data representing the conversion coefficient KD is, e.g., 8-bit long, which can be divided into upper four bits representing the digit place and lower four bits representing the digit number, as indicated in Table 5.

TABLE 5

k7 k6 k5 k4	k3 k2 k1 k0
Digit place	Digit Number

Using the data k7-k0, the conversion coefficient KD can be obtained through the following calculation:

$$KD=(k3\cdot 2^0+k2\cdot 2^{-1}+k1\cdot 2^{-2}+k0\cdot 2^{-3})\cdot 2^n\cdot 2^m$$

wherein

$$m=k4\cdot 2^0+k5\cdot 2^1+k6\cdot 2^2+k7\cdot 2^3$$

and

n=constant (for example −7)

Since k3 is the most significant bit of the digit number, it is always carrying "1". By the above calculation, the conversion coefficient KD having a large variation can be expressed with a small number of bits, and yet the calculation using the conversion coefficient KD in the microcomputer MC1 can be carried out easily.

Referring to FIG. 10, a graph is given for showing a relationship between data of conversion coefficient KD produced from the zoom lens and the focal length of the zoom lens, and wherein abscissa and ordinate represent, $\log_2 f$ (f is a focal length) and conversion coefficient data KD, respectively.

The conversion coefficient KD changes linearly with respect to the change of $\log_2 f$, as shown by lines A, B and C. But, according to the present invention, the relationship between $\log_2 f$ and conversion coefficient data KD is given in tiers, as shown by lines A', B' and C'. In other words, ROM RO3 holds the values of the conversion coefficient KD in steps from level K1 to K33. An example of these levels are given below:

When $K1=2^0$, KD="01111000" (This is read such that when it is defined that $K1=2^0$, ROM RO3 holds KD="01111000" as the value for K1.);

When $K2 = 2^{-1} + 2^{-2} + 2^{-3} + 2^{-4}$, KD = "01101111";

When $K3 = 2^{-1} + 2^{-2} + 2^{-3}$, KD = "01101110";

When $K4 = 2^{-1} + 2^{-2} + 2^{-4}$, KD = "01101101";

$\int$

When $K31 = 2^{-4} + 2^{-6}$, KD = "00101000";

When $K32 = 2^{-4} + 2^{-7}$, KD = "00111001"; and

When $K33 = 2^{-5}$, KD = "00101000".

Each zoom lens has its own zooming range in compliance with the available range of focal length. According to the preferred embodiment, the range of focal length is divided into a plurality of zones. And, code plate FCD provided in the zoom lens is so arranged as to produce a 5-bit signal corresponding to each zone. For example, a zoom lens, which has a focal length zone as depicted by a line A, has nine zones, f17-f25. For each zone, a level of the conversion coefficient is applied. A fundamental rule for choosing a level to each zone for the zoom lens of the above given example is such that a level which is closest to, and smaller than, the smallest point of line A within that zone should be chosen. For example, level K17 is chosen for zone f25, level K16 is chosen for zone f24, level K15 is chosen for zone f23, level K13 is chosen for zone f22, and so on.

As understood from the above rule, the level for the conversion coefficient is chosen to be smaller than the true conversion coefficient given by the straight line. Therefore, in operation, the pulse number $N=KDx|\Delta L|$ obtained by the use of conversion coefficient KD is smaller than the number of pulses produced from encoder ENC for shifting the focusing lens exactly to the in-focus position. Usually, this operation is repeated for a number of times to shift the focusing lens in one direction asymptotically towards the in-focus position, without any overshoot.

In contradiction to the above rule, if a conversion coefficient is chosen to be greater than the true conversion coefficient, the pulse number $N=KDx|\Delta L|$ obtained by the use of conversion coefficient KD becomes greater than the number of pulses produced from encoder ENC for shifting the focusing lens exactly to the in-focus position. Accordingly, the focusing lens overshoots the in-focus position. When this operation is repeated, the focusing lens overshoots in each operation, moving back and forth about the in-focus position. Thus, the focusing lens vibrates in a so-called hunting manner.

Furthermore, since the level of the conversion coefficient is chosen to be closest to the smallest point of line A within that zone, the focusing lens can be shifted towards the in-focus position in a short period of time.

As an exception to the above rule, the level of the conversion coefficient may be chosen to be greater than the smallest point of the line within that zone. For example, as depicted in zones f18 and f12 for the line B', the lines for the levels K20 and K12 are partly greater than the line B. This exception is applicable only when the level of the conversion coefficient is greater by a small amount than the smallest point of the line within that zone. By permitting this exception, the focusing lens may overshoot a small degree, and it can be shifted to the in-focus position in the next focusing operation without causing any hunting, resulting in a very short period of focus adjustment.

There is a zoom lens which changes its conversion coefficient along different lines depending on the set focusing distance such that, when the focusing distance is set to the infinite, its conversion coefficient changes along a real line $C(\infty)$ shown in the graph of FIG. 10, and when the focusing distance is set to the nearest point, its conversion coefficient changes along a chain line C(near) shown in FIG. 10. According to this type of zoom lens, referred to as a variant type zoom lens, the conversion coefficient KD changes, e.g., from $K17=2^{-2}$ to $K15=2^{-2}+2^{-4}$ when the focusing distance is changed from the infinite to the nearest, provided that the lens is zoomed to the zone f1.

In order to operate the camera system of the present invention even with this variant type zoom lens, ROM RO3 is stored with conversion coefficients based on the infinite zoomed position (real line $C(\infty)$). The focusing operation is carried out in such steps that, before the focusing lens reaches a position close to the in-focus position, it is shifted in accordance with the direction

signal of the defocus signal ΔL. When the focusing lens is shifted to the position close to the in-focus position, the focusing lens is then shifted in accordance with the value N obtained using the data KD representing the conversion coefficient and data |ΔL| representing the degree of out-of-focus to seek the accurate in-focus position.

Instead of the above, it is possible to provide, in addition to the code plate FCD, a code plate for producing a signal representing the set focusing distance. The signal produced from this code plate may be used as an address data for ROM RO3, thereby obtaining a precise data of the conversion coefficients for the variant type zoom lens. However, this alternative is not applicable from the practical point of view, because it result in the increase of parts, increase in bit number of address data, increase in the capacity of ROM RO3.

There is another type of zoom lens, which is called a zoom-plus-macro lens or "macro zoom lens". This type of lens is capable of a focusing in macro-photography range in addition to the zooming. For example, such a "macro zoom lens" is constructed to carry out macro photography by means of rotating the zoom ring beyond the conventional shortest focal length position to change over the lens from the zoom mode to macro-focusing mode, so that the lens serves as a closeup lens. When the range is changed to macro range, code plate FCD produces "11111" so that data selector DS1 produces an 8-bit address data "01111111" for designating a location in ROM RO3. When a photograph is taken with the macro range, it becomes difficult to carry out the focus adjustment under the AF mode because of various factors, such as the change in pupil position, reduction of the depth of focus, reduction in F-stop number, and change in the focus adjustment mechanism. Accordingly, ROM RO3 produces "ØØØØ0110", which indicates that the digit place k3 described above in connection with Table 5, i.e., the fourth digit place from the least significant bit, holds "0". Accordingly, by the detection of "0" at digit place k3, microcomputer MC2 decides that the range has changed to macro range, thereby automatically choosing the FA mode, notwithstanding that the mode manually selected by switch FAS is AF mode.

Within the zoom-plus-macro lenses, there is a type in which the change-over from the zooming mode to the macro photography mode is not possible unless the focusing is set to the closest photographic distance. For this type of lens, a switch MCS shown in FIG. **8** is provided. When switch MCS closes in response to a manual change-over operation, e.g. a depression of a button, from zoom mode to macro mode, inverter IN17 produces HIGH and inverter IN19 produces LOW. Thus, all of AND gates AN40 to AN44 produce LOW. Thus, data selector DS1 produces an address data "01100000" designating a location in ROM RO3. Accordingly, ROM RO3 produces "ØØØØ0100". By the detection of "0" at digit places k3 and k1 shown in Table 5, i.e., at the second and fourth digit places from the least significant bit in the produced data "ØØØØ0100", microcomputer MC1 decides that the range has changed to macro range, thereby automatically operating motor MO to shift focusing lens forward to bring the lens in nearest focused condition.

The light receiving portion for the focus detection is so arranged as to aim at a certain exit pupil of the photographing lens. By the diameter of the pupil and the position of the pupil in relation to the light receiving element (located at a position optically equivalent to the film surface), it is determined whether or not the light beams from the target object, which have passed through the photographing lens, impinges on the light receiving element. Accordingly, in some lenses, as is explained with respect to FIGS. **1**, **2** and **3**, a part of light receiving portion may not receive any light beams from the object. Since the focus detection can not be done with a reasonable accuracy with such a type of lenses, it is not preferable to carry out the AF mode or FA mode operation. Therefore, for this type of lenses, data selector DS1 produces address data "011*****" in the case of zoom lens and address data "00000111" in the case of fixed focal-length lens. And, in response to these address data, ROM RO3 produces "ØØØØ0001" as the data KD. By this data "ØØØØ0001", microcomputer MC2 prevents the microcomputer MC1 from carrying out the focus detection operation under AF mode or FA mode in the steps #16–2 described later.

By the change of range from zoom range to macro range, or vice versa, AND gates AN40–AN44 produces "00000", or "11111", whereby data selector DS1 produces address data "00100000", or 00111111", in one sequence, and address data "01000000", or 01011111", in another sequence. In response to the address data "00100000", or 00111111", ROM RO3 produces data corresponding to focal length f under the macro range, and in response to the address data "01000000", or "01011111", ROM RO3 produces data corresponding to ΔAv for the macro range.

Furthermore, in the case where the interchangeable lens is a type which has no mechanism for transmitting driving force from the camera body to the focus adjustment member in the lens, ROM RO3 stores "ØØØØ0110" as the data KD, in the same manner as the range change between the zoom range and macro range, thereby permitting only the FA mode.

Referring back to FIGS. **6***a*, **6***b*, **6***c* and **6***d*, when the data reading from the lens LE completes through the above described operations, A-D conversion of the output from light measuring circuit LMC is carried out (step #13), and the converted data representing the measured light amount is stored in a certain register (step #14).

At step #15, it is decided whether or not the release flag RLF is carrying "1". If the flag RLF is carrying "1", the program advances directly to step #28, but if it is carrying "0", the program advances to step #16–1. It is to be noted here that the release flag RLF carries "1" when release switch RLS is on for carrying out the interruption operation at step #59 et seq. During this interruption operation, if it is detected at step #63 that no exposure control values are calculated, the reading of the above data is carried out in step #5 et seq. Then, at step #15, if it is detected at step #15 that the flag RLF is carrying "1", the operation flow starting from step #16 for the focus detection under AF mode or FA mode is skipped. Therefore, in this case, the program follows the step #28 to calculate the exposure values and through step #30, the exposure control is carried out in step #64 et seq.

At step #16, it is decided whether it is possible to carry out the focus detection operation under AF mode or FA mode. If it is determined that the focus detection is possible, the program advances to step #17, but if not, the program advances to step #28. During the step #16, various conditions are examined sequentially in sub-steps. More particularly, at sub-step #16–1, it is exam-

ined whether the lens is properly mounted, or not; at sub-step #16-2, it is examined whether the conditions determined by the diameter and position of the exit pupil are in conformity with the light receiving portion, or not; at sub-step #16-3, it is examined whether the light beams from the target object are impinging on all the light receiving portion of the focus detection, or not; and at sub-step #16-5, whether or not the light measuring switch is turned on.

Since the focus detection operation under AF or FA mode is impossible when no check data "01010101" is detected at step #16-1, when bits in digit places k3 to k0 are "0001", or when the diameter of the exit pupil of the lens is so small that the data Avo, or Avo+ΔAv representing the full open aperture is smaller than a predetermined value Avc (such as F5.6), a warning is displayed at step #16-4 through display control circuit DSC for the indication that the focus detection can not be carried out after each of the above examination steps #16-1 to #16-3. Thereafter, the program advances to step #28. Furthermore, when input i0 is receiving LOW in compliance with the opening of the light measuring switch MES, the program advances to step #28 for carrying out the focus detection under FA mode only for 15 seconds.

On the contrary to the above, when a check data "01010101" is detected at step #16-1, when bits in digit places k3 to k0 are not "0001", when the diameter of the exit pupil of the lens is such that the data Avo, or Avo+ΔAv representing the full open aperture is greater than a predetermined value Avc, and when input i0 is receiving HIGH, the program advance to step #17.

At step #17, output O1 produces HIGH which is applied to input i11 of microcomputer MC1. Accordingly, microcomputer MC1 starts to carry out the focus detection under AF or FA mode. At step #18, data KD representing the conversion coefficient, which has been transferred from lens circuit LEC to the microcomputer MC2, is produced from input/output port I/O and applied through data bus DB to latch circuit LA. The data KD latched in latch circuit LA will be further transferred to microcomputer MC1 in the later stage at step No.93 described below.

At step #19, in accordance with the data transferred from lens circuit LEC to microcomputer MC2 when counter CO9 is producing "0100", it is detected whether or not the mounted lens is a variant type zoom lens, which changes the conversion coeficient data KD relatively to the change of focusing distance. If it is detected that the mounted lens is a variant type zoom lens, microcomputer MC2 produces HIGH from its output O3, which is applied to input i13 of microcomputer MC1. On the contrary, if the mounted lens is not a variant type zoom lens, microcomputer MC2 produces LOW from its output O3. Accordingly, microcomputer MC1 is so operated as to change the driving mode of motor MO under AF mode in accordance with a detection whether the image forming position is located within near-focusing zone or not, or a detection whether the integration time is longer than a predetermined period of time, as will be described in detail later in connection with steps No.192 to No.197.

At step #22, in accordance with the data transferred from lens circuit LEC to microcomputer MC2 when counter CO9 is producing "0100", the direction of rotation of motor MO is determined for effecting the forward shift of the focusing lens. If it is determined that motor MO should rotate clockwise to effect the forward shift of the focusing lens, microcomputer MC2 produces HIGH from its output O2, which is applied to input i12 of microcomputer MC1. If it is determined as counterclockwise, output O2 produces LOW. Using the signal applied to input i12 and a signal representing the direction of defocus, microcomputer MC1 determines the direction of rotation of motor MO.

At step #25, by the detection of a number, whether it is "1" or "0", given at the fourth digit place k3 of the data KD representing the conversion coefficient, it is determined whether it is possible to carry out the AF mode operation with the mounted lens LE. If the digit place k3 is carrying "1", it is possible to carry out the focus detection under AF mode by the mounted lens LE. In this case, "0" is set in flag MFF and, thereafter, the program advances to step #28. Contrary, if the digit plate k3 is carrying "0", it is impossible to carry out the AF mode operation with the mounted lens LE. In this case, "1" is set in flag MFF and, thereafter, it is detected which one of the two modes, AF or FA modes, is selected by switch FAS. If AF mode is selected to provide HIGH to input i1, a warning is displayed by display control circuit DSC indicating that the mode is automatically changed to FA mode even when the mode selected by switch FAS is AF mode. Thereafter, the program advances to step #28. If FA mode is selected to provide LOW to input i1, there is no need to give out such an warning, and therefore, the program directly advances to step #28.

At step #28, an exposure calculation through known steps is carried out in accordance with data obtained in previous steps #4 to #14, such as set exposure control values, measured light amount, and data from the lens. When data representing exposure time and data representing aperture value are obtained, "1" is set for flag LMF.

At step #30, it is detected whether the release flag RLF is carrying "1" or not. If it is carrying "1", the program jumps to step #64 for carrying out the exposure control operation. Contrary, if it is carrying "0", the program advances to step #31. At step #31, output O8 of microcomputer MC2 produces HIHG, thereby producing LOW from inverter IN8. Thus, a transistor BT3 conducts to permit the warning indication through light emitting diodes LD10 to LD1n. And, in the following step #32, obtained exposure control values are sequentially output at I/O port, which synchronously cause sequential changes into respective "High"'s at terminals a4 to an. In response to these, indication data are sequentially latched by display control part DSC, and display DSP carrys out the liquid crystal display according to the latched data.

At step #33, the on/off condition of light measuring switch MES is detected. If switch MES is on to provide HIGH to input i0, data for counting 15 seconds for the timer interruption is set in register Tc for the timer (step #34). Then, at step #35, timer starts to count 15 seconds, thereby allowing the timer interruption at step #36. Thereafter, the program returns to step #2. In this case, since input i0 is still receiving HIGH, i.e., light measuring switch MES is maintained on, the program advances to step #3, thereby prohibiting the timer interruption. Thereafter, the same procedure is repeated again.

On the contrary, if light measuring switch MES is turned off to apply LOW to input i0, it is detected at step #37 which one of the two modes, AF and FA

modes, is selected by switch FAS. Then, at step #38, the mode determined at step #25 by the data from the lens is detected. Here, the program advances to step #40, when FA mode is selected to provide LOW to input i1 (step #37), or when AF mode is selected, but flag MFF is carrying "1" to permit only FA mode operation in the lens. When AF mode is selected and flag MFF is carrying "0", output O1 produces LOW (step #39) to stop the operation of microcomputer MC1 and, thereafter, the program advances to step #40. In the case where FA mode is detected at step #37 or #38, the program advances to step #40 with output O1 continuously producing HIGH. Accordingly, the operation in microcomputer MC1 continues.

At step #40, it is detected whether switch EES is on or off. When the exposure control mechanism is not in the charged condition, switch EES is on to provide HIGH to input i2. In this case, the program goes to step #47 to carry out the initialization in a manner described later. When the exposure control mechanism is in the chraged condition to turn switch EES on to provide LOW to input i2, the program goes to step #36 and then returns to step #2, at which it is waited until light measuring switch MES turns on to provide HIGH to input i0 or until the timer interruption takes place.

When the timer interruption takes place, 1 is subtracted from the content of register Tc (step #45). Then, at step #46, it is detected whether the content of register Tc is equal to "0" or not. If it is not equal to "0", the program advances to step #5 et seq. to carry out the data reading and exposure calculation in a manner described above. In this case, if the mode is FA mode, since output O1 is producing HIGH, microcomputer MC1 repeats the FA mode operation. Contrary, if the mode is AF mode, microcomputer MC1 is held in non-operative, because output O1 is producing LOW as effected at step #39.

If Tc is equal to "0", outputs O0, O1 and O8 produce LOW (steps #47, #48 and #49), thereby cutting the power supply through transistor BT1 and buffer BF, stopping the operation of microcomputer MC1 under FA mode, and cutting the power supply through transistor BT3. Furthermore, liquid display portion DSP is blanked (step #50) and flags MFF and LMF are reset (steps #51 and #52). Then, the program returns back to step #2.

The above operation can be summarized as follows. During the closure of light measuring switch MES, data reading from the lens, operation by the microcomputer MC1, exposure calculation, and display are carried out repeatedly under both modes AF and FA. Then, when light measuring switch MES opens, the result is different between the modes AF and FA. Under AF mode, the operation by the microcomputer MC1 stops, and data reading from the lens, exposure calculation, and display are carried out repeatedly for 15 seconds. Under FA mode, data reading from the lens, the FA operation by the microcomputer MC1, exposure calculation, and display are carried out repeatedly for 15 seconds. Furthermore, when the charge in the exposure control mechanism is not completed, data reading from the lens, operation by the microcomputer MC1, exposure calculation, and display stops immediately in response to the opening of the light measuring switch MES.

It is to be noted that when a warning is displayed through step #16 -4 or #27-2, a signal for cancelling the warning is applied to display control circuit DSC if no warning is necessary in the subsequent flow.

Next, an operation when release switch RLS closes while the exposure control mechanism is in the charged condition is explained. In this case, microcomputer MC2 immediately starts the release interruption from step #59 no matter what operation it is carrying out. It is assumed that the release interruption is now requested while the data are being read from the lens. When the release interruption is requested, output O6 produces LOW, thereby resetting lens circuit LEC (step #59). Then, output O1 produces LOW to stop the AF or FA mode operation in microcomputer MC1 (step #60). And, output O8 produces LOW to cut off the power supply to light emitting diodes LD10 to LD1n to stop and indication (step #61). Then, flag RLF is set (step #62). At next step #63, it is detected whether flag LMF is set, i.e., carrying "1".

If flag LMF is carrying "1", which means that the exposure control values are calculated, the program advances to step #64. Contrary, if flag LMF is carrying "0", which means that the exposure control values are not ready yet, the program goes to step #5 to calculate the exposure control values, and thereafter, the program advances to step #64.

At step #64, calculated data representing the aperture stop down, such as:

$$Av-Avo;\ Av-(Avo+\Delta Av)$$

is produced on data bus DB. And, output O4 produces pulses for reading the data. Accordingly, exposure control device EXC reads data representing the aperture stop down to start the stop down of the aperture by the exposure control mechanism. This operation completes when the size of aperture is reduced to the required F-stop down.

When a predetermined period of time passes after the generation of pulses from output O4 (step #66), a calculated exposure time data Tv is produced on data bus DB (step #67). Then, output O5 produces pulses for reading data Tv (step #68). By these pulses, exposure control device EXC reads the data Tv and, at the same time, the mirror drive circuit (internally provided in the camera body) is actuated to start the mirror flip-up operation. When the mirror flips up completely, the leading curtain of the shutter mechanism starts to scan and, at the same time, count switch COS turns on to start count the time corresponding to the exposure time data Tv. When the counting of the time data Tv completes, the trailing curtain of the shutter mechanism starts to scan. When the trailing curtain completes its scan, the mirror flips down, and the aperture again opens to its full size. Then, switch EES closes.

When switch EES closes to provide HIGH to input i2 (step #69), release flag RLF resets (step #70). Then, it is detected whether light measuring switch MES is on or off, by the detection whether input i0 is receiving HIGH or LOW. If input i0 is receiving HIGH, which means that light measuring switch MES is on, the program returns back to step #2 to carry out data reading from the lens, operation by the microcomputer MC1, exposure calculation, and display repeatedly. Contrary, if input i0 is receiving LOW, which means that light measuring switch MES is off, the program advances to step #47 to initialize the microcomputer MC2 and, thereafter, the program returns back to step #2.

Referring to FIGS. 11*a*, 11*b*, 11*c*, 12*a*, 12*b*, 12*c*, 13*a*, 13*b*, 13*c* and 13*d*, a flow chart for the operation of mi-

crocomputer MC1 is shown. The flow can be roughly divided into three flows.

The first flow, starting from step No.1, is a main flow initiated by a focus-operation command. In the main flow, many operations are carried out such as: start operation of CCD FLM by control circuit COT (No.8); detection of motor drive (No.10 to No. 13); counting the maximum integration time in CCD and operations after the count of the maximum integration time (No.14 to No.19); detection of termination of focusing lens to the end and counting of maximum integration time (No.35 to No.44); stopping the motor at the termination of focusing lens to the end and restart of rotation when the contrast is low (No.43 to No.48, and No.51 to No.67); initial setting of microcomputer MC1 at a pause of operation (No.25 to No.33); conversion of CCD data when the light intensity is low (No.78 to No.80); calculation of defocus amount and the direction of defocus (No.81 to No.91); detection whether or not the mounted lens is applicable for the AF mode operation (No.92 to No.96); detection of the contrast (No.100); motor drive, under the AF mode operation, for shifting the focusing lens to an infocus zone, and focus detection (No.125 to No.196) (FIGS. **12***a*, **12***b* and **12***c*); focus detection under FA mode operation (No.240 to No.261) (FIGS. **13***a*, **13***b*, **13***c* and **13***d*); and motor drive for shift the zoom lens when the mounted lens is a type which can change the range between zoom range and macro range at near focusing position (No.220 to No.232).

The second flow, covering steps No.70 to No.76, is a terminal interruption flow effected to read data from CCD in accordance with a signal indicating the completion of CCD integration applied from control circuit COT to input terminal iT.

The third flow, covering steps No.200 to No.204, is a counter interruption flow, in which the interruption is carried out when the count number of counter ECC, which is located in microcomputer MC1 and responsive to pulses from encoder ENC, reaches a predetermined number.

Once the terminal interruption is requested, the counter interruption requested thereafter will not be prosecuted before the end of the operation by the terminal interruption. In this manner, there is a priority in the prosecution of two interruption flows. Now, the description is given to the operations under AF and FA modes.

When a main switch MAS turns on, power-on reset circuit POR1 produces a reset signal PO1. By reset signal PO1, microcomputer MC1 carries out a reset operation from a certain address (step No.1). At step No.2, it is detected whether or not switch FAS is on to provide HIGH to input i14. If input i14 is receiving HIGH, flag MOF is reset to "0" indicating that the selected mode is AF mode. If input i14 is receiving LOW, flag MOF is set to "1" indicating that the selected mode is FA mode.

At step No.5, it is detected whether or not input i11 is receiving HIGH from output O1 of microcomputer MC2. If input i11 is receiving LOW, the program returns back to step No.2 to repeat the above operation. Contrary, if input i11 is receiving HIGH, output O16 produces HIGH (step No.6), thereby producing LOW from inverter IN5 and causing transistor BT2 to conduct. Thus, power is supplied through power supply line VF. Then, a fixed data C1 corresponding to the maximum integration time is stored in a register ITR (step No.7) for counting the integration time in CCD FLM. Then, output O10 produces a HIGH pulse (step No.8), thereby starting the integration operation in CCD FLM by control circuit COT. Then, it is permitted to accept the interruption signal from the iT terminal (step 9). Thereafter, the program advances to step No.10.

At steps No.10 to No.13, the operations related to motor MO are detected sequentially. At step No.10, it is detected whether or not the first focus detection operation is being carried out by the detection of flag FPF. At step No.11, it is detected whether or not focusing lens FL is terminated at the end for the infinite focusing or at the other end for the nearest focusing, by the detection of flag ENF. At step No.12, it is detected whether or not the shifted position is located within infocus zone, by the detection of flag IFF. And, at step No.13, it is detected which one of the two modes, AF and FA modes, is selected by switch FAS, by the detection of flag MOF.

If it is assumed that the present situation is either such that the first focus detection operation is being carried out, that the focusing lens is terminated to its end, that the focusing lens is shifted to infocus zone, or that FA mode is selected, motor MO is not rotating. Accordingly, in this case, the program advances to step No.14.

If it is assumed that the present situation is either such that the second focus detection operation is not carried out, that the focusing lens is not terminated to its end, that the focusing lens is not shifted to infocus zone, or that AF mode is selected, motor MO is rotating. Accordingly, in this case, the program advances to step No.35.

It is to be noted that flag FPF is set to carry "1" while the first focus detection operation is being carried out, and it is reset to carry "0" while the focus detection operations of the second et seq. are carried out. The end flag ENF carries "1" when focusing lens FL is shifted all the way to the infinite focusing end or nearest focusing end so that no pulse is produced from encoder ENC even when the motor is further driven. And the focus flag IFF produces "1" when the lens is shifted to an infocus zone, and "0" when it is shifted out of the infocus zone.

At step No.14, "1" is subtracted from the content of register ITR for counting the integration time. Then, it is detected at step No.15 whether the register ITR is producing a borrow signal BRW or not. If it is not producing a borrow signal BRW, low brightness flag LLF is reset to "0" (step No.18). Then, at step No.19, it is detected whether or not input i11 of microcomputer MC1 is receiving HIGH from microcomputer MC2 so as to cause microcomputer MC1 to start its operation. If input i11 is receiving HIGH, the program returns back to step No.14 to repeat the same operation. Contrary, if input i11 is receiving LOW, the program advances to step No.25 to carry out the initialization and, thereafter, advances to step No.2 and waits for HIGH to be applied to input i11. On the contrary, when a borrow signal BRW is detected at step No.15, which means that the maximum integration time has passed, output O11 produces a pulse (step No.16) to forcibly stop the integration operation in CCD FLM and, also to set the low brightness flag LLF with "1". Then, it is waited for the interruption signal to be applied to interruption terminal iT from control circuit COT.

At step No.35, data C2 representing a predetermined period of time is set in a register TWR for counting time. At step No.36, "n" (for example "3") is subtracted

from the content of register ITR and, then, it is detected at step No.37 whether or not a borrow signal BRW is caused by the subtraction at step No.36. If a borrow signal BRW is appearing, which means that the maximum integration time has passed, the program goes to step No.16 to follow the sames steps described above, so that the integration operation in CCD FLM is forcibly stopped and, also the low brightness flag LLF is set with "1". Then, it is waited for the interruption signal to be applied to interruption terminal iT from control circuit COT.

If a borrow signal BRW is not appearing, low brightness flag LLF is reset to "0", and "1" is subtracted from the content of the register TWR. Thereafter, it is again detected whether a borrow signal BRW is caused or not by the subtraction at step No.39 (step No.40). Then, if there is still not appearing a borrow signal BRW, it is detected at step No.41 whether input **i11** is receiving HIGH or not. If input **i11** is receiving HIGH, the program returns back to step No.36, and if input **i11** is receiving LOW, it goes to step No.25. It is to be noted that the abovementioned **C2** is smaller than (**C1**/n) so that before the borrow signal BRW is detected at step No.37, the borrow signal BRW is produced a number of times at the detection of step No.40.

At step No.40, in response to borrow signal BRW, data ECD of the internal counter ECC representing the counted number of pulses from encoder ENC is shifted from the counter ECC to register **ECR1** (step No.42). At step No.43, the shifted data ECD is compared with data set in a register **ECR2**. It is to be noted that register **ECR2** is stored with a counted data obtained in the previous operation. If the content of register **ECR1** does not coincide with that of register **ECR2**, it is understood that the focusing lens is now shifting. In this case, the content of register **ECR1** is transferred to register **ECR2** (step No.44) and, thereafter, the program goes to step No.35.

If the content of register **ECR1** coincides with that of register **ECR2** at step No.43, it is understood that there is no change in the counted data, indicating that encoder ENC is producing no more pulses. Thus, it is understood that the focusing lens is now held still, shifted all the way to the infinite focusing end or nearest focusing end. Therefore, after this step, a condition is caused in which any interruption signal at input terminal iT is not accepted any more (step No.45), and output **O11** produces a pulse (step No.46) to forcibly stop the integration operation in CCD FLM. Furthermore, outputs **O12** and **O13** produce LOW to stop the rotation of motor MO. Thereafter, it is detected whether or not low contrast flat LCF is carrying "1" (step No.48). It is to be noted that when this flag LCF carries "1", it means that the object to be photographed has such a low contrast that the defocus amount ΔL calculated in accordance with the output from CCD FLM lacks the reliability. If it is so detected at step No.48 that flag LCF is carrying "0", end flag ENF carries "1" at step No.49, and thereafter, the program advances to step No.270 (FIG. **13***d*). At step No.270, it is detected whether input **i14** is still producing HIGH or not. If **i14** is still producing HIGH, which means that the AF mode is still selected, the program advances to step #2. On the contrary, if **i14** is producing LOW, which means that the mode is changed to FA mode, flag FPF is set to "1", and outputs **O12** and **O13** produce LOW to stop the motor MO. And, flags LCF, **LCF1** and **LCF3** are reset to "0" and, thereafter, the program returns back to step No.2.

The above operation can be summarized as follows. By the focus detection command from microcomputer **MC2**, the integration in the CCD is started and, at the same time, it is permitted to accept interruption operations, the counter is started to count the maximum integration period. At this time, if the motor MO is not rotating, it is waited to receive an interruption signal during the counting of the maximum integration period. If no interruption signal is applied during the counting of the maximum integration period, the integration in the CCD is forcibly stopped, and it is still waited to receive an interruption signal.

Contrary, if the motor MO is rotating at the start of the integration in the CCD, it is frequently detected whether or not the lens has reached the infinite focusing end or the nearest focusing end, and at the same time, it is waited to receive an interruption signal. If no interruption signal is applied during the counting of the maximum integration period, and if the lens is not shifted all the way to one of the ends, the integration in the CCD is forcibly stopped, and it is still waited to receive an interruption signal. If the lens is shifted all the way to one of the ends, the integration in the CCD is forcibly stopped, and the reception of the interruption signal at terminal iT is inhibited. Furthermore, in this case, motor MO is stopped, and the integration in the CCD is started again. Then, as will be described in detail later, it is detected whether the image is in focus or not by the use of ΔL. And thereafter, microcomputer **MC1** will not carry out the focus detection and focus adjustment operations even if HIGH is applied to input **i11** of microcomputer **MC1** from microcomputer **MC2** with the closure of light measuring switch MES maintained. When this signal at input **i11** once becomes LOW by opening light measuring switch MES and again becomes HIGH by closing light measuring switch MES again, the program returns back to step No.2.

When it is detected at step No.48 that flag LCF is carrying "1", next it is detected at next step No.51 whether flag **LCF1** is carrying "1" or not. Here, if flag **LCF1** is carrying "0", flag **LCF1** is set to "1" (step No.52) and, thereafter, at step No.60, it is detected whether or not infocus direction flag FDF is carrying "1". The flag **LCF1** is provided for scanning the lens to a position at which the contrast is higher than a predetermined level for the detection whether or not the image is extremely out of focus. The flag FDF carries "1" when it is necessary to shift the lens inwardly under the condition $\Delta L > 0$, and "0" when it is necessary to shift lens outwardly under the condition $\Delta L < 0$. In this case, if flag FDF is carrying "1", flag FDF is reset to carry "0", and vice versa. Then, it is detected in both cases (step Nos.63 and 64) whether input **i12** is receiving HIGH. In this way, the direction for rotating the motor to shift the lens outwardly is detected. At step No.63, if input **i12** is receiving HIGH, the program advances to step No.66 to produce HIGH from output **O12** and LOW from output **O13** so that the motor rotates clockwise to shift the lens outwardly. Contrary, if input **i12** is receiving LOW, the program advances to step No.65 to produce LOW from output **O12** and HIGH from output **O13** so that the motor rotates counterclockwise to shift the lens outwardly. Furthermore, at step No.64, if input **i12** is receiving HIGH, the program advances to step No.65 to rotate motor MO counterclockwise to shift the lens inwardly. And, if input **i12** is receiving

LOW, the program advances to step No.66 to rotate motor MO clockwise to shift the lens inwardly. Then, at step No.67, output O14 produces HIGH to rotate motor MO at a high speed. Thereafter, the program advances to step No.270.

At step No.51, if it is detected that flag LCF1 is carrying "1", that means that the image always has a low contrast while the lens is shifted to infinite focusing end or nearest focusing end, motor MO is stopped at step No.53. Then, it is waited until input i11 receives LOW (step No.55) and, thereafter, flags LCF, LCF1 and LCF3 are all reset to "0", and returning back to step No.25.

Next, a series of operations under low contrast will now be described. When an object having a low contrast under AF mode is aimed, output port OP0 produces "101" for the warning display (step No.105). Then, it is detected whether the flag LCF is carrying "1" or not (step No.107 in FIG. 13*d*). If the flag LCF is not carrying "1", and if the low contrast object is aimed for the first time, flags LCF and LCF3 are set to "1" (steps No.108 and No.109). And, at step No.110, it is detected whether the operation is for the first time (FPF=1) or not. If flag FPF is carrying "0", which means that the operations so far done are not under low contrast, there may be an error in the present measuring operation. Therefore, the program advances to step No.280, and through step No.270, it returns back to step No.2 to restart the measuring operation. In this case, the motor runs in a direction based on the calculated result obtained in the previous operation. If end flag ENF is carrying "1", which means that the motor is not running, and when the program advances through step No.110 to step No.280, it is waited until input i11 receives LOW (step No.281). Then, flags LCF and LCF3 are reset to carry "0" (step No.282) and, thereafter, initializations (step No.25 et seq.) are carried out to stop the operation of microcomputer MC1.

Also, at step No.110, if it is detected that the flag FPF is carrying "1", indicating that the operation is carried out for the first time, flags FPF and LCF3 are reset to carry "0" (steps No.111 and 113), and at step No.205, it is detected whether the defocus amount ΔL is positive or negative. If $\Delta L > 0$, which means that the image is focused in front of the ideal focal plane (this is referred to as front focused), flag FDF is set to carry "1" (step No.206). If $\Delta L < 0$, which means that the image is focused behind the ideal focal plane (this is referred to as rear focused), flag FDF is reset to carry "0" (step No.209). Thereafter, in a manner described above for the steps No.63 to No.66, motor MO is driven to rotate counterclockwise or clockwise in accordance with the type of lens to shift the lens outwardly. Then, at step No.212, it is detected whether the time consumed for the integration (which is stored in register ITR) is shorter than a predetermined length C7 or not. If the integration time is less than the predetermined time C7 ((ITR)$\geqq$C7), output O14 produces HIGH to run the motor MO at a high speed (step No.214). Thereafter, the program goes through step No.270 to step No.2 so as to restart the measuring operation. In this manner, unless the measured amount is changed to an amount which is not representing the low contrast, the lens is continuously shifted in a direction initially determined.

If the lens is shifted all the way to one end with the contrast being detected as low all the time, flag LCF1 is set to carry "1" at step No.52 to change the direction of lens shift. Then, the measuring is further carried out while shifting the lens in the opposite direction. If the lens is shifted all the way to the other end with the contrast being detected as low all the time, it means that the lens is shifted from one end to the other end without catching a high contrast point. In this case, the object can be considered as an object having no contrast, such as a plain wall or white cloud. Thus, the program advances to step No.55 to stop the operation. In this operation, if it is found that the contrast determined in accordance with the measurement has a level above the low contrast, the program advances to step No.101 (FIG. 13*b*) to carry out the lens control in accordance with the defocus amount described later. If the detected image shows low contrast suddenly after one or more measuring operations, the determined contrast in the first operation is disregarded of and the measuring operation is carried out again. In such a measurement, if the determined contrast still continues to show the low contrast, the flow advances from step No.107 to step No.112. Since flag LCF3 is set to carry "1" at step No.109, the flow advances from step No.112 to step No.113 to reset flag LCF3 to carry "0" and thereafter, the program advances to step No.205. In accordance with the measurement at this moment, the direction for shifting the lens is determined. Then, a point where the contrast level exceeds above a predetermined level is detected. During the shifting of the lens under the low contrast condition, flag LCF3 is set to carry "0", which causes a repetition of a flow advancing from steps Nos.107 and 112 to step No.270 and then returning again to the step of next measurement. This operation is continued until it is detected, at step No.43 or step No.87 or step No.113, that the lens reaches to one end of its shiftable range.

When an object having a low contrast under FA mode (MOF=1) is aimed, the program advances from step No.106 to No.115 to set flag LCF to carry "1", to reset flags LCF1 and LCF3 to carry "0", to set flag FPF to carry "1" and to reset end flag ENF to carry "0". Thus, outputs O12 and O13 produce LOW. Then, the program advances to step No.258 to carry out the operation described later. Then, the light measuring is carried out again.

When the integration operation in CCD FLM completes and control circuit COT provides HIGH to interruption terminal iT during microcomputer MC1 is carrying out a looped operation of step Nos.14, 15, 18 and 19, step Nos.35 to 40, step Nos.42 to 44, or step Nos.36 to 41, the program immediately jumps to step No.70 to start the interruption procedure, as described below.

In the interruption procedure, first register ECR3 is stored with an amount ECD representing the counted number of pulses from encoder ENC (step No.70). Then, the number of light receiving elements aligned in the CCD, i.e., the number (C3) of pieces of data to be applied to input port IP0 of microcomputer MC1 is stored in register DNR (step No.71). Then, at step No.72, it is waited until input i10 receives HIGH. When input i10 receives HIGH upon completion of analog-to-digital conversion of the CCD output, a piece of CCD output data CD, which has been applied to input port IP0, is stored in register M(DNR) at step No.73. Then, one is subtracted from the content of register DNR (step No.74), and these steps (step Nos.72 to 75) are repeated until a borrow signal BRW appears at step No.74. In this manner, CCD output data CDs are set in register M(DNR) piece by piece. When all the CCD data CDs are taken, return address is set up. And, in

response to that address, a return operation is carried out. Then, the program continues from step No.77 of the main flow.

As step No.77, it is detected whether flag LLF is carrying "1" or not. If flag LLF is carrying "1", data CDs from CCD are scanned for searching the maximum data MACD (step No.78). If the searched maximum data MACD carries "0" at its most significant bit, all the CCD data CDs (ALCD) are doubled (step No.80). If the searched maximum data MACD carries "1" at its most significant bit, all the CCD data CDs remain as they are, and the program directly goes to step No.81. Since if they are doubled, some data CDs may result in overflow. Contrary, if flag LLF is carrying "0", the program directly jumps to step No.81.

Amount of shift of two images on an image forming plain, which is equivalent to the film surface, is calculated at step No.81 and step No.90. More specifically, at step No.81, an integer portion of such an amount is calculated, and at step No.90, a fraction portion of such an amount is calculated. The detail of this calculation itself is known as disclosed in, e.g., U.S. Pat. No. 4,333,007 and, therefore, its description is omitted for the sake of brevity. In steps No.82 to No.85, it is detected whether motor MO is driven or not, in a manner similar to that described above in connection with steps No.10 to No.13. If the motor MO is driven, counted data ECD representing the number of pulses from encoder ENC is stored in register ECR1 (step No.86). Then, the data just now stored is compared with the data previously stored in register ECR2. If (ECR1)=(ECR2), which means that the lens is shifted all the way to the end, the program continues from step No.47 described above. If (ECR1)≠(ECR2), which means that the lens is still shifting, the content of register ECR1 is shifted to register ECR2, and then, the program advance to step No.89. Contrary, if motor MO is not driven, the program immediately advances to step No.89.

At step No.89, it is detected whether input i11 is receiving HIGH or not. If it is receiving LOW, the program advances to step No.25 to stop the focus detection operation and to carry out the initialization. If input i11 is receiving HIGH, the program advances to step No.90 to calculate the fraction portion of the shift amount, and at step No.91, defocus amount ΔL is calculated using the shift amount calculated in steps No.81 and No.90.

At step No.92, it is detected by the flag MOF whether the mode is AF mode or FA mode. If the present mode is AF mode, the program advances to step No.93, and if it is FA mode, the program advances to step No.100. In the case of AF mode, the conversion coefficient KD stored in latch LA from microcomputer MC2 is transferred to microcomputer MC1 through input port IP1 (step No.93). Then, it is detected at step No.94 whether the fourth digit place k3 of the data KD representing the conversion coefficient is carrying "0" or not, and whether the third digit place k2 of the data KD is carrying "1" or not. If the detected result is such that k3=0 and k2=1, it is understood from the above description that the mounted interchangeable lens can not operate under AF mode. Therefore, in this case, mode flag MOF is set to carry "1" (representing FA mode) and, thereafter, the program advances to step No.96. Contrary, if the detected result is such that k3=1 or k2=0, it is understood that the mounted interchangeable lens is a type which can operate under AF mode. Thus, in this case, the program advances to step No.100. Furthermore, at step No.96, it is detected whether or not k1=0. If k1=1, the program advances to step No.100. If k1=0, it is understood that the mounted interchangeable lens is a type wherein the lens must be shifted outwardly to nearest focusing position to change the range from zoom-range to macro-range, and that lens is about to change the range to macro-range. In this case, the program advances to step No.220 (FIG. 13*a*) to produce HIGH from output O14 to drive the motor at a high speed. Then, at step No.221, it is detected whether or not input i12 is receiving HIGH. If input i12 is receiving HIGH, which means that the mounted lens is a type which shifts the lens outward upon clockwise rotation, output O12 produces HIGH. If input i12 is receiving LOW, which means that the mounted lens is a type which shifts the lens outward upon counterclockwise rotation, output O13 produces HIGH. Thereafter, counted data ECD representing the number of pulses from encoder is stored in register ECR2 (step No.224).

Next, register TWR is stored with a constant data C8 (step No.225) representing a predetermined period of time. Then, "1" is subtracted from the content of the register TWR and then, it is detected whether or not a borrow signal BRW is produced. This operations are repeated, and when a borrow signal is produced after a predetermined period of time, counted data ECD representing the number of pulses from encoder is transferred to shift register ECR1 (step No.228). Then, the content of register ECR1 is compared with that of register ECR2 (step No.229). If (ECR1)≠(ECR2), the content of register ECR1 is transferred to register ECR2 (step No.230) and, thereafter, a routine of steps No.225 to No.230 is repeated. Contrary, if (ECR1)=(ECR2), which means that the lens is shifted all the way to nearest focusing position, outputs O12 and O13 produce LOW, thereby stopping motor MO (step No.231). Then, flag FPF is set to carry "1" (step No.232), and thereafter, the program returns back to step No.2. Thereafter, the program is carried out under FA mode operation.

At step No.100, it is detected whether or not the data from CCD is indicating low contrast. The detail of this step will be described later in connection with FIG. 20. If the data indicates low contrast, the program proceeds from step No.105 described above. Contrary, if the data does not indicate low contrast, it is detected whether or not flag LCF is carrying "1" at step No.101 (FIG. 13*b*). If flag LCF is carrying "1", flag FPF is set to carry "1" because the measured amount in the previous operation showed low contrast, and flags LCF, LCF1 and LCF3 are reset to carry "0". Then, the program goes to step No.290 to detect the condition of flag MOF. If MOF=0, that is, selected mode is AF mode, outputs O12 and O13 produce LOW to stop the motor. Thereafter, the program returns back to step No.2 to start the measuring operation again. Contrary, if MOF=1, that is, selected mode is FA mode, the program goes to step No.240 to carry out the operation for the FA mode, which will be described in detail later.

In the case where flag LCF is carrying "0" at step No.101 and when the measured amount in the previous operation did not show low contrast, the program goes to step No.104 to detect the condition of mode flag MOF. In this case, if MOF=1, indicating FA mode, the program advances to step No.240. Contrary, if

MOF=0, indicating AF mode, the program advances to step No.125.

During the procedure of steps No.125 to No.130, it is detected whether or not the defocus amount ΔL is within infocus zone ZN1. First, in the case where flag ENF is carrying "0" (step No.125) indicating that the lens is not shifted to the end and when infocus flag IFF is carrying "1" (No.126) indicating that the lens has once reached the infocus zone, the measured amount |ΔL| obtained in the present measuring operation is compared at step No.127 with infocus zone ZN1. If, |ΔL|<ZN1, infocus display is effected (step No.128). Then, it is waited until output i11 produces LOW (step No.129). Thereafter, the program goes to step No.25 and stops the operation.

On the contrary, if |ΔL|≧ZN1, flag FPF is set to carry "1" and flag IFF is reset to carry "0" and, thereafter, the program goes to step No.135 so as to carry out the lens control operation in accordance with the defocus amount based on the measured amount just obtained.

In the case where the flag ENF is carrying "1" indicating that the lens is shifted to the end, infocus display is effected at step No.128, under the condition that |ΔL|<ZN1 at step No.127. But if |ΔL|≧ZN1, the program goes to step No.129 with the indication of defocus direction being remained the same as before. Then, in the same manner described above, the operation stops when input i11 receives LOW. Here, when |ΔL|≧ZN1, the program goes to step No.129 with the indication of defocus direction being remained the same as before. In this case, the lens will not terminate to an infocus position even if it is shifted to its end position. Therefore, it is no use of shift the lens by the motor MO. Thus, the operation of microcomputer MC1 is forcibly stopped.

If it is detected at steps No.125 and No.126 that the lens is not yet reached its end position or an infocus zone, it is detected at step No.131 whether first-pass flag FPF is carrying "1" or not. If the flag FPF is carrying "0", it is detected whether the lens has shifted to its end position or not at steps No.132 to No.134, in a manner similar to steps No.86 to No.88. Thereafter, the program goes to step No.135. Contrary, if the flag FPF is carrying "1", the program goes directly to step No.135. At step No.135, the focus detection command signal from microcomputer MC2 is detected. If input i11 is receiving LOW, the program goes to step No.25 and then the operation stops. If input i11 is receiving HIGH, the program goes to step No.136.

At step No.136, the calculated defocus amount ΔL is multiplied by read conversion coefficient data KD to obtain data N representing the amount of drive of lens drive mechanism LDR. At step No.136, in more detail, a real conversion coefficient is obtained by means of shifting the lower four bits of read conversion coefficient data KD in accordance with the upper four bits of the data KD. And thus obtained real conversion coefficient is multiplied by defocus amount ΔL to calculate data N, which is the number of pulses expected from the encoder. Then, it is detected at step No.137 whether flag FPF is carrying "1" or not. If flag FPF is carrying "1", it is detected whether data N is positive or negative (step No.140). If data N is positive, focus direction flag FDF is set to carry "1", and if negative, it is reset to carry "0". Thereafter, an absolute of drive amount N, indicated as Nm, is stored in register ECR4 (step No.144). Then, flag FPF is reset to carry "0" and, thereafter, the program goes to step No.166 (FIG. 12*c*).

On the contrary, at step No.137, if flag FPF is carrying "0", the content of register ECR4, storing the data representing the amount of drive effected in the previous operation, is shifted to register ECR5 (step No.150 in FIG. 12*b*) and, then, register ECR4 is stored with a new data ECD representing the counted number of pulses from encoder ENC (step No.151). Accordingly, at this moment, register ECR3 is stored with count data Tc1 at the end of integration of CCD, and register ECR4 is stored with count data Tc2. Then, calculations are carried out to obtain lens-shift amount τ:

$$\tau = Tc0 - Tc1$$

representing the amount of lens shift effected during the integration of CCD, and lens-shift amount t0:

$$t0 = Tc1 - Tc2$$

representing the amount of lens shift effected during the calculation to obtain data N. If it is assumed that data N is obtained at the middle of the integration of CCD, at this moment the lens is shifted by an amount $\tau/2+t0$ from the moment when data N is obtained. Furthermore, a calculation is carried out to obtain corrected data N″m:

$$N''m = N'm - (\tau + t0)$$

wherein N′m is the data obtained in the previous flow, and $(\tau+t0)$ is the amount of lens shift effected after the previous flow. It is to be noted that the corrected data N″m always takes a positive value.

At steps No.155 to No.157, it is detected whether or not the lens-shift direction towards infocus zone has been changed, by the use of defocus amount data N and flag FDF. More specifically, at step No.155, it is detected whether defocus amount data N calculated in the present cycle of operation is positive or negative. If data N is positive, it is detected at step No.156 whether flag FDF is carrying 0 or not. If flag FDF is carrying 0, this means that the direction has been changed, the program goes to step No.158. If flag FDF is carrying 1, this means that the direction is not changed, the program goes to step No.159.

On the contrary to the above, if data N is negative, it is detected at step No.157 whether flag FDF is carrying "1" or "0". If flag FDF is carrying "1", this means that the direction has been changed, the program goes to step No.158. If flag FDF is carrying "0", this means that the direction is not changed, the program goes to step No.159.

When it is detected that the direction is not changed, i.e., when the program goes to step No.159, it is understood that the lens is shifted towards infocus position by the rotation of the motor. Thus, in this case, it is assumed that data N is obtained at the middle of the integration period, thereby carrying out a calculation:

$$|N| - \tau/2 - t0 = N'$$

to correct the shifted amount by the rotation of the motor. Then, it is detected whether the corrected data N′ is negative or not (step No.160). If corrected data N′ is negative, it is understood that the lens has moved passed the infocus position. Therefore, it is made such

that $|N'|=N'$ at step No.163 and, thereafter, the program goes to step No.164. Contrary to the above, if corrected data N' is positive, an average between data N''m obtained in the previous cycle of operation and the corrected data N' is taken to obtain a new data Na (step No.161 in FIG. 12*c*):

$$Na=(N''m+N')/2.$$

The new data Na is adapted as the data Nm (step No.162), and thereafter, the program goes to step No.166.

When it is detected that the direction has been changed, i.e., when the program goes to step No.158, it is understood that the lens is over shifted beyond the infocus position by an amount $\tau/2+t0$ in the defocus direction from the moment when the present data is obtained. Thus, in this case, a correction calculation:

$$|N|+\tau/2+t0=N'$$

is carried out and, thereafter, the program advances to step No.164. At step No.164, an average is taken between N''m and N' to obtain a new data Na:

$$Na=(N''m-N')/2.$$

Then, it is detected whether the new data Na is negative or not (step No.165).

If data Na is positive, the program goes to step No.162 (FIG. 12*c*) described above, and if it is negative, outputs **012** and **013** produce LOW to stop the motor (step No.174). Then, at step No.175, infocus zone data ZN1 is multiplied by conversion coefficient data KD, which has been changed into the real value at step No.136, to obtain data Ni representing the amount of rotation of motor in the infocus zone. Then, it is detected whether $|Na|<Ni$, or not. If $|Na|<Ni$, it is understood that the lens is shifted to the infocus zone. Therefore, in this case, infocus flag IFF is set to carry "1" and then, program follows step No.270 and returns back to step No.2. Contrary, if $|Na|>Ni$, it is understood that the lens has moved passed the infocus zone. Therefore, flag FPF is set to carry "1" and then, program follows step No.270 and returns back to step No.2, again carrying out the measuring operation.

At step No.166, data NZ representing a near-infocus zone is multiplied by data KD to obtain a data indicating an amount of lens shift from the near-infocus zone to infocus zone. Then, at step No.167, using data ZN1 for the near-infocus zone and data KD, a multiplication:

$$Ni=ZN1\times KD$$

is carried out to obtain data Ni representing an amount of lens shift within the infocus zone (step No.167). Then, at step No.168, data Nm is compared with data Nn. When, $Nm\geqq Nn$, i.e., when the lens is outside the near-infocus zone, the program goes to step No.181, thereby producing HIGH from output **O14** to run motor MO at a high speed and, at the same time, counter ECC is stored with Nm-Nn to count down in response to the pulses from encoder ENC (step No.182). Thereafter, the program advances to step No.185.

Contrary to the above, when $Nm<Nn$, i.e., when the lens is inside the near-infocus zone, it is detected at step No.169 whether $Nm<Ni$, or not. If $Nm\geqq Ni$, that means that the lens is within near-infocus zone, but not within infocus zone. Therefore, in this case, output **O14** produces LOW to run the motor MO at low speed (step No.183), and data Nm is stored in counter ECC (step No.184). Thereafter, the program advances to step No.185. In the case when the mounted lens is a type in which the conversion coefficient data KD changes with respect to the change of focusing distance, the lens shift is controlled only in accordance with a signal representing the direction of defocus. For the other types of lens, defocus amount is calculated and, for this purpose, the amount of lens shift is corrected in the procedure starting from step No.150. Therefore, for this correction, data Nm-Nn is stored in counter ECC at step No.182. Furthermore, when $Nm<Ni$, outputs **012** and **013** produces LOW to stop motor MO (step No.171), and then, infocus flag IFF is set to carry "1" (step No.172). Then, the counter interruption procedure is prohibited (step No.173), and thereafter, the program returns to step No.270 to carry out the measurement operation for the proof.

At step No.185, it is detected whether flag FDF is carrying "1" or not. If flag FDF is carrying "1", which means that the image is front focused, output port OP0 produces "100" to lit light emitting diode LD0 for the indication of near focus (step No.186). If flag FDF is carrying "0", which means that the image is rear focused, output port OP0 produces "001" to lit light emitting diode LD2 for the indication of far focus (step No.189). Then, by the content of flag FDF and signal applied to input **i12** for the indication of direction of rotation of interchangeable lens, motor MO is driven in clockwise or counterclockwise direction (step No.188 and No.191). Thereafter, the program advances to step No.192 to detect whether input **i13** is receiving HIGH or not. If the mounted lens is a type which changes the conversion coefficient data KD in accordance with the change of focusing distance, and if input **i13** is receiving HIGH, it is detected at step No.193 whether $Nm<Nn$, or not. In this case, if the lens is located out the near-infocus zone so that the detected result is $Nm\geqq Nn$, motor MO is controlled, irrespectively of the calculated data Nm, only by the signal representing the direction of rotation. Then, it is detected whether or not the integration period is longer than predetermined period of time corresponding to data C7 (step No.194). If it is longer, there may be a possibility that the lens moves past the infocus position. Therefore, output **O14** produces LOW to run motor MO at a low speed (step No.195), and the counter interruption is prohibited (step No.195). Thereafter, the program advances to step No.270 and returns back to step No.2. Contrary to the above, if it is detected that $Nm<Nn$, indicating that the lens is inside the near-infocus zone, it is permitted to carry out the counter interruption procedure (step No.197) and, thereafter, the program returns to step No.270. Furthermore, when input **i13** is receiving LOW, it is permitted to carry out the counter interruption procedure and, thereafter, the program returns to step No.270.

When counter ECC for down counting the pulses from encoder ENC is counted down to zero during the rotation of motor MO, a counter interruption procedure (FIG. 11*b*) starts. At step No.200, it is detected whether $Nm<Nn$, or not. If $Nm<Nn$, it is understood that motor MO has been rotated while the lens is in the near-infocus zone and, therefore, it can be assumed that the lens is now shifted to infocus zone. Thus, outputs

O12 and O13 produce LOW to stop motor MO (step No.203). Then, infocus flag IFF is set to carry "1" and, thereafter, the program returns to step No.270. Contrary, at step No.200, if it is detected that $Nm \geqq Nn$, it is understood that motor MO is now shifted to near-infocus zone. Thus, output O14 produces LOW to run motor MO at a low speed (step No.201), and then, data Nn is stored in counter ECC (step No.202). Then, it returns to an address with an interruption.

Next, when flag MOF is detected as carrying "1" at step No.104 or step No.290 (FIG. 13*b*), an operation under FA mode is carried out in a procedure starting from step No.240. At step No.240, it is detected whether or not flag FPF is carrying "1". If flag FPF is carrying "1", it is understood that the operation under FA mode is carried out for the first time. In case when the mode is changed from AF mode, end flag ENF is reset to carry "0", and infocus flag IFF is reset to carry "0". Furthermore, register IZR for the detection of infocus zone is stored with data ZN2 for indication the infocus zone. It is to be noted that the data ZN2 is greater than data ZN1 for the AF mode. This difference is provided because under the AF mode, the lens can be precisely adjusted by the motor drive, but under the FA mode, the lens is shifted manually and, therefore, it is difficult to adjust the lens with a preciseness as high as the motor drive. Then, at step No,245, first-pass flag FPF is reset to carry "0" and, thereafter, the program advances to step No.246. Contrary, if flag FPF is carrying "0", the program immediately advances to step No.246.

At step No.246, it is detected whether infocus flag IFF is carrying "1" or not. If infocus flag IFF is carrying "1", it is understood that the calculated value obtained through the calculation up to the previous cycle indicates that the lens is shifted to infocus zone. Thus, an average is taken between the calculated value ΔL_{n-1} in the previous cycle and the calculated value ΔL to obtain:

$$\Delta L_n = (\Delta L + \Delta L_{n-1})/2$$

at step No.247. Then, register IZR is stored with data Zw ($>$ZN2) representing the infocus zone (step No.248), followed by step No.250. In consideration of variation in the defocus amount determined in accordance with the measurement, the above operation is to widen the infocus zone once the lens is shifted into the infocus zone, so as to prevent the unstable display of infocus, particularly when the lens is shifted to a position adjacent to the border of the infocus zone at the inside thereof. Contrary, at step No.246, if infocus flag IFF is carrying "0", the measured amount ΔL in the present cycle is rendered as ΔL_n (step No.249), followed by step No.250 (FIG. 13*c*). At step No.250, it is detected whether or not $|\Delta L_n| < (IZR)$, that is whether the calculated value is within infocus zone or not. If it is within the infocus zone, infocus flag IFF is set to carry "1" (step No.251), and the infocus display is carried out by light emitting diode LD1 (step No.252). Then, the program advances to step No.258. If contrary it is outside the infocus zone, it is detected whether $\Delta L_n > 0$, or not (step No.253). If $\Delta L_n > 0$, light emitting diode LD0 is lit for the indication of the front focus. If $\Delta L_n < 0$, light emitting diode LD2 is lit for the indication of the rear focus. Then, infocus flag IFF is reset to carry "0", and data ZN2 is stored in register IZR. Then, the program goes to step No.258. At step No.258, it is detected whether input i14 is receiving HIGH. If it is receiving HIGH, indicating that the mode is changed to AF mode, flag FPF is set to carry "1", flag IFF is reset to carry "0", and flag LCF is reset to carry "0". Then, the program returns to step No.2. If it is receiving LOW, indicating that the mode is still FA mode, the program immediately returns to step No.2, thereby starting the next measuring operation.

In the procedure through step No.25 to step No.33 in FIG. 11*a*, the operations for stopping the focus detection and setting initial condition are carried out. At step No.25, the interruptions are prohibited, and at step No.26, output O11 produces to forcibly stop the integration of CCD. Then, outputs O12 and O13 produce LOW to stop motor MO (step No.27), and output port OP0 produces "000" to disable the light emitting diodes LD0, LD1 and LD2 (step No.28). Then, output O16 produces LOW to cut off power to power supply line VF (step No.32). And, flags ENF, IFF and LCF3 are all reset to carry "0", and flag FPF is set to carry "1" (step No.29 to step No.31, and step No.33). After the initial condition is set, the program returns to step No.2.

Next, a modification of the above described embodiment is given in connection with FIGS. 14, 15 and 16. According to this modification, when the main object is properly focused to be located within the infocus zone through a focus adjustment operation under AF mode, it is possible to detect whether a secondary object is also located with the depth of focus, or not. FIG. 14 is a fragmentary view of a circuit diagram showing only a portion which differs from the circuit diagram of FIG. 5. FIG. 15 is a flow chart showing only the steps which differ from the steps shown in FIG. 6*c*. And, FIG. 16 is a flow chart showing only the steps which differ from the steps shown in FIGS. 11*a*, 11*c*, 12*a* and 13*d*.

When it is detected at step No.127 that the lens is located within the infocus zone, a display indicating the infocus condition is effected at step No.128, flag IFF is set to carry "1" at step No.300, and output O30 of microcomputer MC1 produces HIGH at step No.301. The output O30 is connected to input i5 of microcomputer MC2. Thus, by the HIGH applied to input i5, the microcomputer MC2 detects that the lens is located within the infocus zone.

Then, the program for the microcomputer MC1 goes to step No.270, and if the mode is not changed to FA mode, the program returns back to step No.2 to again carry out the measuring. In this case, since flag IFF is carrying "1", the same procedure as in the case of focus proof is carried out and, thereafter, the program advances to step No.91. According to this modification, step No.91 is followed by detection step No.305 for detecting whether flag IFF1 is "1" or not. If not, the program goes to step No.92, but if flag IFF1 is carrying "1", the program goes to step No.306, at which data applied to input port IP2 are read in. As shown in FIG. 15, step #80 for producing an aperture value Av for the exposure control is provided between steps #30 and #31. This aperture value Av is latched in latch circuit LA1 in response to a pulse from output a_{n+2} of decoder DEC. Therefore, input port IP2 receives data of aperture value for the exposure control.

The read-in data Av is converted from APEX numbering system to F-stop number (step No.307), and a calculation:

$$\Delta D = \delta \times (\text{F-stop number})$$

is carried out at step No.308. Here, δ is a data representing the permissible circle of confusion, and ΔD is a data representing the depth of focus. Next, the data ΔD and the defocus amount |ΔL| obtained at step No.91 of the present cycle of operation are compared with each other at step No.309, and then, the focus condition is displayed in a manner described below, and thereafter, the program goes to step No.270.

When $|\Delta L| \leqq \Delta D$, which means that the measured portion of the object is located within the depth of focus, output port **OP5** produces "010", thereby lighting light emitting diode **LD4** for the indication of infocus. Contrary, if $|\Delta L| > \Delta D$, output port **OP5** produces "100" to light light emitting diode **LD3** for the indication of near focus, or output port **OP5** produces "001" to light light emitting diode **LD5** for the indication of far focus, depending on whether the data ΔL is positive or negative.

By the above operation, after adjusting the lens to infocus position under AF mode, it is possible to detect whether an object other than the object aimed at for the focus adjustment is located within depth of focus or is front or rear focused.

In the above described modification, the depth of focus is calculated with a high accuracy at step No.308. However, since it is difficult to exactly aim a desired spot for the light measuring, particularly when the camera is held by hands, and since the calculated amount ΔL varies during a number of cycle of operations, it is possible to widen the infocus zone in a manner similar to the operation under FA mode, or to widen the infocus zone once the lens is shifted to infocus zone, or to take an average after carrying out a number of cycle of operations. For example, in order to widen the infocus zone, a calculation:

$$\Delta D = I \times \delta \times FNo (I = 2 \sim 3)$$

is carried out.

Furthermore, according to the modification, further steps are added between steps No.33 and No.2 and between steps No.273 and No.2 so as to carry out the initial setting when the operation of microcomputer **MC1** is to be stopped or when the mode is changed to FA mode. More specifically, after step No. 33 or No.273, flag **IFF1** is reset to carry "0" (step No.320 or No.325), then output port **OP5** produce "000" to disable light emitting diodes **LD3**, **LD4**, and **LD5** (step No.321 or No.326), and thereafter, output **O30** produces LOW (step No.322 or No.327).

Also, according to the modification, step #81 shown in FIG. **15** is provided to produce data representing Av from input and output port I/O, and in order to continue the display of focusing condition for a predetermined period of time even after the turn off of light measuring switch MES, step #81 for detecting whether input **i5** is receiving HIGH or not is inserted between steps #38 and #39. More specifically, when light measuring switch MES is turned off and when it is detected that the present mode is AF mode, output **O1** continues to produce HIGH, so long as input **i5** is receiving HIGH to continue the operation of microcomputer **MC1** for detecting whether it is within the depth of focus mentioned above.

Referring to FIG. **17**, a detailed circuit diagram of control circuit COT for controlling CCD FLM is shown. Counter **CO24** counts negative edges of pulses **DP2**, which are clock pulses CP frequency divided by counter **CO22**. In response to the signals produced from outputs **p0** to **p4** of counter **CO24**, decoder **DE20** produces ten bit long binary signal from its output **T0** to **T9**. The signals produced from counter **CO24** and outputs from decoder **DE20**, flip-flops **FF22**, **FF24**, **FF26** and **FF28** are given in Table 6 below.

TABLE 6

Counter CO24					Decoder DE20										Flip-Flops									
P0	P1	P2	P3	T4	T0	T1	T2	T3	T4	T5	T6	T7	T8	T9	FF_{28}	FF_{26}	FF_{24}	FF_{22}	ϕ_1	ϕ_2	ϕ_3	ϕ_S	ϕ_A	ϕ_T
0	0	0	0	0	H	L	L	L	L	L	L	L	L	L	H	H	L	L						
0	0	0	0	1	L	L	L	L	L	L	L	L	L	L	H	H	L	L						
0	0	0	1	0	L	L	L	L	L	L	L	L	L	L	H	H	L	L						
0	0	0	1	1	L	H	L	L	L	L	L	L	L	L	L	H	L	L						
0	0	1	0	0	L	L	H	L	L	L	L	L	L	L	L	H	L	L						
0	0	1	0	1	L	L	L	L	L	L	L	L	L	L	L	H	L	L						
0	0	1	1	0	L	L	L	H	L	L	L	L	L	L	L	L	H	L						
0	0	1	1	1	L	L	L	L	L	L	L	L	L	L	L	L	H	L						
0	1	0	0	0	L	L	L	L	H	L	L	L	L	L	L	L	H	L						
0	1	0	0	1	L	L	L	L	H	L	L	L	L	L	L	L	H	L						
0	1	0	1	0	L	L	L	L	H	L	L	L	L	L	L	L	H	L						
0	1	0	1	1	L	L	L	L	H	L	L	L	L	L	L	L	H	L						
0	1	1	0	0	L	L	L	L	L	H	L	L	L	L	L	L	H	L						
0	1	1	0	1	L	L	L	L	L	L	L	L	L	L	L	L	H	L						
0	1	1	1	0	L	L	L	L	L	L	L	L	L	L	L	L	H	L						
0	1	1	1	1	L	L	L	L	L	L	L	L	L	L	L	L	H	L						
1	0	0	0	0	L	L	L	L	L	L	L	L	L	L	L	L	H	L						
1	0	0	0	1	L	L	L	L	L	L	L	L	L	L	L	L	H	L						
1	0	0	1	0	L	L	L	L	L	L	L	L	L	L	L	L	H	L						
1	0	0	1	1	L	L	L	L	L	L	L	L	L	L	L	L	H	L						
1	0	1	0	0	L	L	L	L	L	L	L	L	L	L	L	L	H	L						
1	0	1	0	1	L	L	L	L	L	L	L	L	L	L	L	L	H	L						
1	0	1	1	0	L	L	L	L	L	L	H	L	L	L	L	L	H	L						
1	0	1	1	1	L	L	L	L	L	L	L	L	L	L	L	L	H	L						
1	1	0	0	0	L	L	L	L	L	L	L	H	L	L	L	L	L	H						
1	1	0	0	1	L	L	L	L	L	L	L	L	L	L	L	L	L	H						
1	1	0	1	0	L	L	L	L	L	L	L	L	L	L	L	L	L	H						
1	1	0	1	1	L	L	L	L	L	L	L	L	L	L	L	L	L	H						
1	1	1	0	0	L	L	L	L	L	L	L	L	L	L	L	L	L	H						
1	1	1	0	1	L	L	L	L	L	L	L	L	H	L	L	H	L	H						

TABLE 6-continued

Counter CO24					Decoder DE20										Flip-Flops								
P0	P1	P2	P3	T4	T0	T1	T2	T3	T4	T5	T6	T7	T8	T9	FF_{28}	FF_{26}	FF_{24}	FF_{22}	ϕ_1	ϕ_2	ϕ_3	ϕ_S	ϕ_A	ϕ_T
1	1	1	1	0	L	L	L	L	L	L	L	L	L	L	L	H	L	H	↑		↓			
1	1	1	1	1	L	L	L	L	L	L	L	L	L	H	L	H	L	L	↑					

As apparent from Table 6, Q output **Ø1** of flip-flop FF26 produces HIGH while counter **24** is producing "11101" to "00101", Q output **Ø2** of flip-flop FF24 produces HIGH while counter **24** is producing "00100" to "10111", and Q output **Ø3** of flip-flop FF22 produces HIGH while counter **24** is producing "10110" to "11110". The signals from these outputs **Ø1**, **Ø2** and **Ø3** are applied to CCD FLM while power supply line VF is supplying power, so that the transmission of analog signal is continuously effected in the transmission gate. By this operation, the accumulated charge remaining in the transmission gate is discharged.

By the reset signal PO2 from power-on reset circuit POR2 produced in response to the power supply, flip-flops FF20 to FF28, FF32, D flip-flops DF20, DF22 and DF24, and counters CO20, CO22 and CO24 are reset. Furthermore, flip-flop FF30 is set to produce HIGH from its Q output **ØR**. By the HIGH from Q output **ØR**, analog switch AS2 turns on to supply output voltage from constant voltage source Vr1 through lead line ANB to CCD FLM. The charge accumulation portion of CCD FLM is set to this voltage.

When microcomputer MC1 produces HIGH from its output O10 to start the integration operation, one-shot circuit OS18 produces a pulse which resets flip-flop FF30. Accordingly, Q output **ØR** produces LOW. Thus, CCD FLM starts to accumulate charge corresponding to the amount of light received by each light receiving element. Also, through inverter IN50, analog switch AS1 conducts to transmit monitor output of CCD FLM from terminal ANB to the inverting input of comparator AC1. In accordance with the accumulated charge, CCD monitor output from terminal ANB drops from constant voltage Vr1, and when it reaches a constant voltage from constant voltage source Vr2, comparator AC1 produces HIGH. In response to this, it is detected that the charge in CCD FLM has completed. By the HIGH from comparator AC1, one-shot circuit OS10 produces HIGH, which is applied through OR gate OR20 to flip-flop FF20. Thus, flip-flop FF20 is set, thereby producing HIGH from its Q output. This HIGH is taken into D flip-flop DF20 in response to the positive edge of HIGH produced from the Q output (output **Ø1**) of flip-flop FF26, thereby producing HIGH from the Q output of D flip-flop DF20. By this HIGH, the reset condition of counter CO20 is released and, AND gates AN60, AN64, AN66 and AN68 are enabled.

When output T0 produced HIGH after the output **Ø1** produces HIGH, flip-flop FF28 is set by the HIGH from output T0, and is reset by the HIGH from output T1. The Q output of flip-flop FF28 is connected through AND gate AN68 to output **ØT**, thereby producing a HIGH pulse to CCD FLM. By this HIGH pulse, the accumulated charge is transmitted to the transfer gate. Furthermore, the signal appearing at the output **ØT** is applied to interruption terminal iT, whereby the microcomputer MC1 carries out the data reading of data from CCD FLM in a manner described above.

When the signal from output **ØT** steps down to LOW, one shot circuit OS16 produces HIGH, thereby setting flip-flop FF32. Thus, flip-flop FF32 produces LOW from its $\overline{Q}$ terminal. Thus, AND gate AN68 is disabled to cut off any further HIGH signal from Q output of flip-flop FF28. Furthermore, through one-shot circuit OS16 and OR gate OR32, flip-flop FF30 is set, thereby again producing HIGH from output **ØR**.

By the transfer signals from outputs **Ø1**, **Ø2** and **Ø3**, the accumulated charges from CCD FLM are sequentially produced from output AOT. The accumulated charges are produced while output **Ø2** is producing HIGH. When D flip-flop DF20 produces HIGH from its Q output and while output **Ø2** is producing HIGH, AND gate AN66 produces output signal **ØS** for the sample/hold in response to HIGH from terminal T4 and AND gate AN64 produces output signal **ØA** for the A-D conversion start in response to HIGH from terminal T5.

The first signal of accumulated charge which is transferred from terminal AOT of CCD FLM is used for off-set adjustment, wherein a charge corresponding to the leakage of light receiving portion is charged. This charge is approximately equal to the voltage Vr1. In this instance, since $\overline{Q}$ output of D flip-flop DF24 is producing HIGH, sample/hold signal **ØS** is applied through AND gate AN70 to sample/hold circuit SH1, thereby storing the voltage for off-set adjustment from CCD FLM, through terminal AOT, in sample/hold circuit SH1. In response to the negative edge of the first sample/hold signal **ØS**, Q output of D flip-flop DF24 produces HIGH. The subsequent sample/hold signals **ØS** are applied through AND gate AN72 to sample/hold circuit SH2, thereby sequentially memorizing in the sample/hold circuit SH2 the voltages corresponding to the amount of light received by light receiving elements thereafter.

When the Q output of D flip-flop DF20 produces HIGH, the signal **Ø3** is applied through AND gate AN60 to one input of AND gate AN62. In response to the first negative edge of the signal **Ø3**, D flip-flop DF22 produces HIGH from its Q output. Accordingly, the pulse signals **Ø3** occurring after the first one are applied to input i10 of microcomputer MC1 through AND gate AN62, thereby commanding the microcomputer MC1 to read in the data through input port IP0. At this moment, the reason for producing HIGH from Q output of D flip-flop DF20 to prevent the first pulse signal **Ø3** from being produced from AND gate AN60 through AND gate AN62 is because that the first data from CCD FLM is for the off-set adjustment, as mentioned above. The pulse signal **Ø3** is also applied to a clock input terminal of counter CO20. Accordingly, after the release of reset condition by the HIGH from Q output of D flip-flop DF20, counter CO20 counts in response to the negative edges of pulse signals **Ø3**. When counter CO20 counts the pulse signals **Ø3** for the number corresponding to the number of light receiving elements in CCD FLM, it produces HIGH from its carry terminal CY.

After the first pulse signal Ø3, output data from CCD FLM are sampled in response to pulse singals Ø3. Then, by a subtraction circuit defined by registers R1 and R2 and operational amplifier OA1, a difference between outputs from sample/hold circuits SH1 and SH2 is calculated. The calculated difference is applied to an analog input of A-D converter AD. The A-D converter AD starts its operation in response to the signal ØA, and in accordance with clock pulses DP1 from counter CO22, it carries out the A-D conversion of the input data. When it is assumed that the voltage from constant voltage source Vr1 is Vr1, the voltage drop caused by the leakage is Vd, and voltage drop by the received light amount is V1, the output from sample/hold circuit SH1 can be given as:

$$Vr1-Vd,$$

and the output from sample/hold circuit SH2 can be given as:

$$Vr1-V1-Vd.$$

Accordingly, the signal produced from the subtraction circuit has only the term V1 representing the received light amount. Preferably, A-D converter AD is capable of carrying out the A-D conversion at a high speed, such as a successive approximation A-D converter.

When all the data from CCD FLM are converted to digital form by A-D converter AD, counter CO20 produces HIGH from its carry terminal CY. Accordingly, the HIGH is transmitted through one-shot circuit OS14 and OR gate OR22, flip-flops FF20 and FF32 and D flip-flops DF20, DF22 and DF24 are reset. Thus, D flip-flop DF20 produces LOW from its Q output, thereby holding counter CO20 in reset condition. Thus, a condition, which is the same as that before producing HIGH from output O10, is established.

Also, when it is detected that a timer in microcomputer MC1 counts a predetermined integration time, output O11 produces a HIGH pulse. In response to the negative edge of this HIGH pulse applied through one-shot circuit OS12 and OR gate OR20, flip-flop FF20 is reset. Accordingly, an operation, which is the same as the case when comparator AC1 produces HIGH, is carried out to A-D convert the output data from CCD FLM, and the converted data are sequentially applied to input port IP0 of microcomputer MC1.

Referring to FIG. 18, a modification of control circuit COT of FIG. 17 is shown. According to the previous embodiment, in the case where output data from CCD is small, it is doubled after it is read in microcomputer MC1 in terms of software (FIG. 11*c*, steps No.78 to No.82) in microcomputer MC1. But, according to this modification, it is doubled in terms of hardware before it is A-D converted.

While output ØR is producing HIGH, a voltage Vr1 determined by constant current source CIS and resistors R10 to R13 is applied to CCD FLM, and while it is producing LOW, monitor output of CCD FLM is applied to inverting inputs of comparators AC10 to AC12. Then, when integration proceeds to cause the monitor output reach voltage Vr2, comparator AC12 produces HIGH, thereby producing a HIGH pulse from one-shot circuit OS10. By this HIGH pulse applied through OR gate OR20, flip-flop FF20 is reset and, thereafter, the same operation as described above is carried out.

Furthermore, this pulse is also applied to the clock terminals of D flip-flops DF32 to DF38. In this case, since comparator AC12 is producing HIGH, Q output of D flip-flop DF38 produces HIGH, thereby turning analog switches AS48 and AS38 on. The resistances of resistors R30 to R40 are as follows:

$$R30 = R40 = R38 = R48 = \frac{R36}{1.5} = \frac{R46}{1.5} = \frac{R34}{2} = \frac{R44}{2} = \frac{R32}{2.5} = \frac{R42}{2.5}.$$

By the turn on of analog switches AS38 and AS48 and since resistors R30, R40, R38 and R48 have the same resistance, operational amplifier OA10 produces a signal V1 without any change.

Contrary, when the object is so dark that comparator AC12 produces no HIGH signal during the maximum integration time, microcomputer MC1 produces HIGH from output O11, which is applied to one-shot circuit OS12 and further to OR gate OR20. In this case, depending on which one of the ranges Vr2-Vr3, Vr3-Vr4 and Vr4-Vr1 does the monitor output falls, one of EXCLUSIVE OR gates EO2 and EO4 and inverter IN52 produces HIGH, thereby producing HIGH from Q output of one of D flip-flops DF32, DF34 and DF36. Accordingly, one pair of analog switch pairs: AS36 and AS46; AS34 and AS44; and AS32 and AS42, is turned on. Thus, the integration operation is forcibly stopped and in accordance with the monitor output level at that moment, operational amplifier OA10 produces either one of 1.5V1, 2V1 or 2.5V1.

Next, a variation of operation flow of microcomputer MC1 described above in connection with FIGS. 11*a* to 13*d* is described. Referring to FIG. 19, only parts of the flow which are different from the above described flow are shown. This variation is directed to a case in which a number of out-of-focus detections are repeated consecutively after a detection of in focus. Between steps No.130 and No.138 (FIG. 12*a*), steps related to flag IFF are inserted. More specifically, when lens is so adjusted as to be shifted to infocus zone, and end flag ENF is carrying "0" (step No.130), it is detected at step No.351 whether flag IFF2 is carrying "1" or not. If it is detected that flag IFF2 is carrying "0", this flag IFF2 is set to carry "1" and, thereafter, the program advances to step No.270 to carry out the measuring operation again for the proof. Contrary, if flag IFF2 is carrying "1", which means that the measuring operation for the proof resulted out-of-focus ($|\Delta L| \geqq ZN1$) for two consecutive times, flags IFF and IFF2 are reset to carry "0", and flag FPF is set to carry "1" and, thereafter, the program advances to step No.135, thereby carrying out the focus adjustment operation again. Between steps No.33 and No.2, and between steps No.240 and No.242, a step (step No.34 or No.241) is provided to reset flag IFF2 to initialize it.

Referring to FIG. 20, a detail of step No.100 shown in FIG. 11*c*, which is for detecting whether the aimed object has a low contrast or not, is shown. At step No.370, the content of register C is made "0". Then, "1" is set in register i (step No.371). Thereafter, an absolute of a difference between output a_i from ith light receiving element and output a_{i+1} from i+1th light receiving element, i.e., $|a_i - a_{i+1}|$ is added to the contents of register C, and the added result is stored in register C (step No.372). Then, "1" is added to the contents of register i (step No.373), and at next step No.374, the contents of register i is compared with n (n is equal to

the total number of light receiving elements.). If $i<n-1$, the program goes to step No.372 so as to add up the absolute differences one after another. Then, when it becomes $i=n-1$, he program goes to step No.375. At step No.375, the contents of register C is equal to:

$$|a_1-a_2|+|a_2-a_3|+|a_3-a_4|+\ldots +|a_{n-2}-a_{n-1}|+|a_{n-1}-a_n|$$

which indicates the contrast of the object, as understood to those skilled in the art. At step No.375, it is detected whether the contents of register C is greater than a predetermined value CD or not. If (C)>CD, which means that the contrast is above a predetermined level, the program goes to step No.101. Contrary, if (C)≦CD, which means that the contrast is below the predetermined level, the program goes to step No.105.

In the case where the focus detection is carried out by the use of light receiving elements arranged in two arrays, the detection of contrast can be done with output signals only from one of the two arrays. Also, in the case where the data representing the contrast is obtained in the process for calculating the defocus amount and the direction of defocus, the contrast data is stored during the calculation. The contrast level is detected by a detection whether or not the stored data is within a predetermined level.

The conversion coefficient data KD produced from an interchangeable lens is read in microcomputer MC1 through microcomputer MC2 at step No.93 and, for example, it is used for the calculation of data N for driving the motor at step No.136. The data can be divided into two parts, in a manner described above in connection with Table 5, first part representing the floating point coefficient and the second part representing the significant digit. The above calculation is carried out by shifting the floating point of the significant digit in the second part in accordance with the floating point coefficient in the first part.

FIGS. **1**, **2** and **3** give a detailed explanation of a prior art optical system for the focus detection. Such an optical system, as it is, is incorporated in the embodiment of the present invention as a part thereof. Therefore, the following description should be considered as an explanation of a part of the embodiment of the present invention, and as an explanation of a problem which the optical system involves by itself.

An optical system for the focus detection employed in the prior art focus detection device includes a focus detection light receptor FLM comprising an array of n-number of light receiving elements, each of said light receiving elements being constituted, as shown in FIG. **1**, by a unitary structure of miniature lens Li and two light receiving elements Ai and Bi positioned rearwardly of the miniature lens Li. (It is to be noted that the character "i" affixed to each alphabetic reference character represents the number 1 to n). FIG. **2** illustrates the relationship between the focus detecting optical system of the light receptor FLM and the photo-taking optical system of an interchangeable lens assembly. In FIG. **2**, the point H depicted on the optical axis X represents the position at which images of the respective light receiving elements are formed by the respective miniature lens Li, and the solid lines HAi and HBi represent respective images corresponding to the images of the light receiving elements Ai and Bi. The position and the size of each of the images HAi and HBi are exclusively determined by the structure of the light receptor FLM. On the other hand, the broken line P represents an exit pupil corresponding to the image of an aperture AP at the smallest f-stop number in the interchangeable lens assembly, and the position and the diameter of the pupil change with the type of interchangeable lens assembly (e.g., a wide-angle, standard or telephoto lens assembly) and/or change in focal length of the lens assembly if the latter is a zoom lens assembly. Accordingly, depending on the type of the lens assembly mounted on the body of a photographic camera, it will happen that the incident beam of light rays falling on any one of the light receiving elements A1 to An will not be uniform with that falling on the associated light receiving elements B1 to Bn because of the vignetting of the lens assembly, as will be described later, and therefore the reliability of the result of the focus detection will be reduced. By way of example, as shown in FIG. **2**, if the point H is located closer to the light receptor FLM than to the position of the pupil and respective portions of the images formed by projecting the images HA and HB on the plane of the exit pupil protrude outwards from the exit pupil (Hereinafter, an aperture corresponding to the outer perimeter of these projected images will be referred to as "critical aperture".), a beam of light rays from a region A1′ and a beam of light rays from a region An′ fall respectively on the light receiving element A1 and the light receiving element An and, as is clear from FIG. **2**, A1′>An′. On the other hand, the light receiving elements B1 and Bn receive a beam of light rays from a region B1′ and that from a region Bn′ and B1′<Bn′. If, for the purpose of simplification, the brightness of a target object to which the distance is desired to be measured is uniform, outputs from the light receiving elements Ai and Bi vary in a manner as shown in FIG. **3**, and therefore it is not possible to determine the accurate correlation in phase difference between these outputs from the light receiving elements. In other words, where the full aperture is smaller than the critical aperture, even if data concerning the amount of deviation of the position, where the image of the target object is formed, relative to the position of an expected focus are obtained from these outputs, the result would be an erroneous detection of the focused condition. A similar description may equally apply even where the point H and the exit pupil are reversed in position with respect to each other.

As has been explained above, the optical system is of a nature that a required focus detection may not be correctly carried out when the fully open aperture size of an attached interchangeable objective lens is smaller than a predetermined size. According to the above explanation, it is believed that the reason why the improvement made by the present invention in adopting the optical system in the embodiment is needed is fully understood.

Although the present invention has been fully described with reference to a preferred embodiment, many modifications and variations thereof will now be apparent to those skilled in the art, and the scope of the present invention is therefore to be limited not by the details of the preferred embodiment described above, but only by the terms of appended claims.

What is claimed is:

1. In a camera system capable of focus detection by means of receiving light through an interchangeable objective lens, a camera body and an interchangeable

objective lens selectively attachable to the camera body comprising:

an opening, located in the camera body for detachably connecting with the interchangeable objective lens;

means, located in the camera body, for receiving light through the opening to produce electric signals;

means, located in the camera body, for processing the electric signals to generate a defocusing information indicative of defocusing degree and defocusing direction relative to an ideal focal plane;

means, located in the camera body, for generating a driving power for automatic focus control, including a first movable member;

means, located in the camera body, for accepting digital data to be transmitted from the interchangeable objective lens, the digital data including a converting information necessary to convert the defocusing degree of the defocusing information into a degree of movement of the first movable member;

means, located in the camera body, for calculating the degree of movement of the first movable member in response to the defocusing degree of the defocusing information and the converting information;

means, located in the camera body, for controlling the generating means to move the first movable member in response to the defocusing direction of the defocusing information and the calculated degree of movement;

means, located in the camera body, for transmitting the driving power of the generating means to the interchangeable objective lens, the transmitting means including a second movable member connectable with the interchangeable objective lens and responsive to the movement of the first movable member;

an optical system, located in the interchangeable objective lens, for forming an image of an object;

means, located in the interchangeable objective lens, for adjusting the focus of the optical system, the adjusting means including a third movable member connectable with the second movable member for a coupled movement therewith;

a read only memory, located in the objective lens, for storing various digital data at a plurality of addresses, the stored digital data including the converting information;

means, located in the interchangeable objective lens, for selectively designating one of the addresses of the read only memory; and

means for sending digital data stored in the designated address to the accepting means,

wherein the converting information is formed as a digital data composed of m-bit of significant digits part and n-bit of floating point coefficient part.

2. The invention of claim 1, further comprising means, located in the interchangeable objective lens, for varying the focal length of the optical system, means, located in the interchangeable objective lens, for classifying the focal length actually determined by the varying means into one of a plurality of prepared focal length zones to indicate a specific focal length zone to which the determined focal length belongs, wherein the designating means is responsive to the classifying means to designate an address corresponding to the indicated focal length zone, and the read only memory includes, in a plurality of respective addresses, a plurality of converting informations corresponding to the plurality of focal length zones, each of the converting informations being representative of focal lengths in each focal length zone with a value of causing an approximately minimum degree of movement in the first movable member within each focal length zone.

3. The invention of claim 1, further comprising means, located in the camera body, for providing a supplemental converting data to convert the degree of movement of the second movable member into that of the first movable member, wherein the converting information stored in the read only memory includes a data for converting the defocusing degree of the defocusing information into the degree of movement of the third movable member which is to be coupled with the second movable member in its movement, and the calculating means is further responsive to supplemental converting data in calculating the degree of movement of the first movable member.

4. The invention of claim 1, wherein the digital data stored in the read only memory includes a direction information indicative of the relation between the defocusing direction and the direction of the movement of the first movable member, and the controlling means includes means for determining the direction of movement of the first movable member in response to the defocusing direction of the defocusing information and the direction information accepted by the accepting means.

5. The invention of claim 1, further comprising means, located in the camera body, for inhibiting the camera body from automatically controlling the focus of the interchangeable objective lens, in response to the accepting means.

6. The invention of claim 5, wherein the receiving means includes a pair of groups of photosensitive elements, the groups being each responsive to light coming through different two parts of exit pupil of the optical system, and the digital data includes a fully open aperture information indicative of a fully open aperture size of the optical system, and wherein the inhibiting means includes means for comparing the fully open aperture information accepted at the accepting means with a reference aperture information indicative of a minimum aperture size allowing the pair of groups of photosensitive elements to properly respond to light coming through the respective two different parts of the exit pupil, the carry out the inhibition with the fully open aperture size less than the minimum aperture size.

7. The invention of claim 6, wherein the digital data includes an auto-focus information indicating that the interchangeable objective lens has the third movable member to be coupled with the second movable member for automatic focus control, wherein the camera body further includes means for indicating the focus condition in response to the processing means, the indicating means being also subject to the comparing means to be disabled when the fully open aperture size is less than the minimum aperture size, and wherein the inhibiting means further includes means for carrying out the inhibition with the function of the indicating means maintained, when the accepting means fails to accept the auto-focus information.

8. The invention of claim 5, wherein the digital data includes a check data for certifying that the interchangeable objective lens is correctly connected to the camera body by means of successful acceptance of the

check data by the accepting means, and wherein the inhibiting means includes means for carrying out the inhibition when the accepting means fails to accept the check data.

9. The invention of claim **5**, wherein the interchangeable objective lens further includes means for bringing the optical system into a macro-photography condition, the designating means being responsive to the bringing means for designating an address relating to the macro-photography condition, and the digital data includes a macro-photography information stored at the address, the macro-photography information indicating that the interchangeable objective lens is in the macro-photography condition, and wherein the camera body further includes means for indicating the focus condition in response to the processing means and the inhibiting means includes means for carrying out the inhibition with the function of the indicating means maintained, when the accepting means accepts the macro-photography information.

10. The invention of claim **1**, further comprising means, located in the camera body, for producing a train of clock pulses, and means located in the interchangeable objective leans, for introducing the clock pulses into the interchangeable objective lens, wherein the designating means includes means for making address data in response to the clock pulses, and the sending means includes means for serially forwarding the digital data under the control of the clock pulses.

11. In a camera system capable of focus detection by means of receiving light through an interchangeable objective lens, an interchangeable objective lens attachable to a camera body, comprising:

an optical system for forming an image of an object;

means for adjusting the focus of the optical system, the adjusting means including a movable member under a control of the camera body;

a read only memory for storing various digital data at a plurality of addresses, the stored digital data including a converting information necessary for the camera body to control the movable member in accordance with a result of the focus detection;

means for selectively designating one of the addresses of the read only memory; and

means for sending data stored in the designated address to the camera body,

wherein the converting information is formed as a digital data composed of m-bit of significant digits part and n-bit of floating point coefficient part.

12. The invention of claim **11** further comprising means for introducing a train of clock pulses from the camera body into the interchangeable objective lens, wherein the designating means includes means for making address data in response to the clock pulses, and the sending means includes means for serially forwarding the digital data under the control of the clock pulses.

13. In a camera system capable of focus detection by means of receiving light through an interchangeable objective lens, an interchangeable objective lens attachable to a camera body, comprising:

an optical system for forming an image of an object;

means for adjusting the focus of the optical system, the adjusting means including a movable member under a control of the camera body;

means for varying the focal length of the optical system;

means for classifying the focal length actually determined by the varying means into one of a plurality of prepared focal length zones to indicate a specific focal length zone to which the determined focal length belongs;

a read only memory for storing various digital data at a plurality of addresses, the stored digital data including, in a plurality of respective addresses, a plurality of converting informations necessary for the camera body to control the movable member in accordance with a result of the focus detection, the plurality of converting informations corresponding to the plurality of focal length zones so that each of the converting informations is representative of focal lengths in each focal length zone with a value of causing an approximately minimum degree of movement of the movable member within each focal length zone;

means for selectively designating one of the addresses of the read only memory corresponding to the indicated focal length zone in response to the classifying means; and

means for sending data stored in the designated address to the camera body.

14. The invention of claim **13** further comprising means for introducing a train of clock pulses from the camera body into the interchangeable objective lens, wherein the designating means includes means for making address data in response to the clock pulses, and the sending means includes means for serially forwarding the digital data under the control of the clock pulses.

15. In a camera system capable of focus detection by means of receiving light through an interchangeable objective lens, an interchangeable objective lens attachable to a camera body, comprising:

an optical system for forming an image of an object;

means for adjusting the focus of the optical system, the adjusting means including a movable member connectable with the camera body to receive a driving power of adjusting focus from the camera body;

a read only memory for storing various digital data at a plurality of addresses, the stored digital data including a converting information for converting a defocusing degree of the optical system into the degree of movement of the movable member;

means for selectively designating one of the addresses of the read only memory; and

means for sending data stored in the designated address to the camera body.

16. The invention of claim **15** further comprising means for introducing a train of clock pulses from the camera body into the interchangeable objective lens, wherein the designating means includes means for making address data in response to the clock pulses, and the sending means includes means for serially forwarding the digital data under the control of the clock pulses.

17. In a camera system capable of focus detection by means of receiving light through an interchangeable objective lens, a camera body connectable with an interchangeable objective lens, comprising:

an opening for detachably connecting with the interchangeable objective lens;

means for receiving light through the opening to produce electric signals;

means for processing the electric signals to generate a defocusing information indicative of defocusing degree and defocusing direction relative to an ideal focal plane;

means for generating a driving power for automatic focus control, including a first movable member;

means for transmitting the driving power of the generating means to the interchangeable objective lens, the transmitting means including a second movable member connectable with the interchangeable objective lens and responsive to the movement of the first movable member;

means for accepting digital data to be transmitted from the interchangeable objective lens, the digital data including a converting information for converting the defocusing degree of the defocusing information into a degree of movement of the second movable member;

means for providing a supplemental converting data to convert the degree of movement of the second movable member into that of the first movable member;

means for calculating the degree of movement of the first movable member in response to the defocusing degree of the defocusing information, the converting information and supplemental converting data; and

means for controlling the generating means to move the first movable member in response to the defocusing direction of the defocusing information and the calculated degree of movement.

18. In a camera system capable of focus detection by means of receiving light through an interchangeable objective lens, an interchangeable objective lens attachable to a camera body, comprising;

an optical system for forming an image of an object;

means for adjusting the focus of the optical system, the adjusting means including a movable member connectable with the camera body to receive a driving power of adjusting focus from the camera body;

a read only memory for storing various digital data at a plurality of addresses, the stored digital data including a converting information necessary for the camera body to control the movable member in accordance with a result of the focusing detection, and a direction information necessary for the camera body to determine the direction to drive the movable member in accordance with a result of the focusing detection;

means for selectively designating one of the addresses of the read only memory; and

means for sending data stored in the designated address to the camera body.

19. The invention of claim **18** further comprising means for introducing a train of clock pulses from the camera body into the interchangeable objective lens, wherein the designating means includes means for making address data in response to the clock pulses, and the sending means includes means for serially forwarding the digital data under the control of the clock pulses.

20. In a camera system capable of focus detection by means of receiving light through an interchangeable objective lens, a camera body connectable with an interchangeable objective lens, comprising:

an opening for detachably connecting with the interchangeable objective lens;

means for receiving light through the opening to produce electric signals;

means for processing the electric signals to generate a defocusing information indicative of defocusing degree and defocusing direction relative to an ideal focal plane;

means for generating a driving power for automatic focus control, including a first movable member;

means for transmitting the driving power of the generating means to the interchangeable objective lens, the transmitting means including a second movable member connectable with the interchangeable objective lens and responsive to the movement of the first movable member;

means for accepting digital data to be transmitted from the interchangeable objective lens, the digital data including a converting information necessary to convert the defocusing degree of the defocusing information into a degree of movement of the first movable member, and a direction information indicative of the relation between the defocusing direction and the direction of the movement of the first movable member;

means for calculating the degree of movement of the first movable member in response to the defocusing degree of the defocusing information and the converting information;

means for determining the direction of movement of the first movable member in response to the defocusing direction of the defocusing information and the direction information; and

means for controlling the generating means to move the first movable member in response to the calculating means and the determining means.

21. In a camera system capable of focus detection by means of receiving light through an interchangeable objective lens, a camera body connectable with an interchangeable objective lens, comprising:

an opening for detachably connecting with the interchangeable objective lens;

means for receiving light through the opening to produce electric signals, including a pair of photosensitive devices, the devices being each responsive to light coming through different two parts of exit pupil of the interchangeable objective lens;

means for processing the electric signals to generate a defocusing information with respect to an ideal focal plane;

means for accepting from the interchangeable objective lens an information of a fully open aperture size thereof;

means for controlling the receiving means and the processing means to inform of the result of focus detection in response to the defocusing information;

means for comparing the informed fully open aperture size of the interchangeable objective lens with a reference aperture size which is the minimum allowing the pair of photosensitive devices to properly respond to light coming through the respective two different parts of the exit pupil; and

means for inhibiting the controlling means from informing of the result of focus detection when the informed fully open aperture size is less than the reference aperture size.

22. The invention of claim **21**, further comprising means responsive to the controlling means for generating a control power to be transmitted to the interchangeable objective lens for automatic focus control, and means responsive to the controlling means for indicating the focus condition, wherein the information of a fully open aperture size is a form of digital data and the

accepting means is further capable of accepting an auto-focus information as a form of digital data from the interchangeable objective lens, the auto-focus information indicating whether or not the interchangeable objective lens is capable of automatic focus adjustment in response to the control power from the camera body, and wherein the camera body further includes means for governing the controlling means to inhibit the generating means from responding to the controlling means with the responsibility of the indicating means to the controlling means maintained, when the accepting means fails to accept the auto-focus information indicating that the interchangeable objective lens is capable of auto-focus adjustment.

23. In a camera system capable of focus detection by means of receiving light through an interchangeable objective lens, an interchangeable objective lens attachable to a camera body, comprising:

an optical system for forming an image of an object;

means for adjusting the focus of the optical system, the adjusting means including a movable member under a control of the camera body;

a read only memory for storing various digital data at a plurality of addresses, the stored digital data including a fully open aperture information indicative of a fully open aperture size of the optical system, and an auto-focus information indicating that the interchangeable objective lens has the movable member for automatic focus adjustment;

means for selectively designating one of the addresses of the read only memory; and

means for sending data stored in the designated address to the camera body.

24. The invention of claim **23** further comprising means for introducing a train of clock pulses from the camera body into the interchangeable objective lens, wherein the designating means includes means for making address data in response to the clock pulses, and the sending means includes means for serially forwarding the digital data under the control of the clock pulses.

25. In a camera system capable of focus detection by means of receiving light through an interchangeable objective lens, an interchangeable objective lens attachable to a camera body, comprising:

an optical system for forming an image of an object;

means for adjusting the focus of the optical system;

a read only memory for storing various digital data at a plurality of addresses, the stored digital data including a fully open aperture information indicative of a fully open aperture size of the optical system, and an auto-focus information indicating that the interchangeable objective lens has no means for automatically adjusting focus under the control of the camera body;

means for selectively designating one of the addresses of the read only memory; and

means for sending data stored in the designated address to the camera body.

26. The invention of claim **25** further comprising means for introducing a train of clock pulses from the camera body into the interchangeable objective lens, wherein the designating means includes means for making address data in response to the clock pulses, and the sending means includes means for serially forwarding the digital data under the control of the clock pulses.

27. In a camera system capable of focus detection by means of receiving light through an interchangeable objective lens, an interchangeable objective lens attachable to a camera body, comprising:

an optical system for forming an image of an object;

means for adjusting the focus of the optical system, the adjusting means including a movable member under a control of the camera body;

means for bringing the optical system into a macro-photography condition;

a read only memory for storing various digital data at a plurality of addresses, the stored digital data including a macro-photography information indicating that the interchangeable objective lens is in the macro-photography condition;

means for selectively designating one of the addresses of the read only memory, the designating means being responsive to the bringing means for designating an address at which the marco-photography information is stored; and

means for sending data stored in the designated addresses to the camera body.

28. The invention of claim **27** further comprising means for introducing train of clock pulses from the camera body into the interchangeable objective lens, wherein the designating means includes means for making address data in response to the clock pulses, and the sending means includes means for serially forwarding the digital data under the control of the clock pulses.

29. In a camera system capable of focus detection by means of receiving light through an interchangeable objective lens, a camera body connectable with an interchangeable objective lens, comprising:

an opening for detachably connecting with the interchangeable objective lens;

means for receiving light through the opening to produce electric signals;

means for processing the electric signals to generate a defocusing information with respect to an ideal focal plane;

means for accepting digital data to be transmitted from the interchangeable objective lens, the digital data including a macro-photography information indicating that the interchangeable objective lens is in a macro-photography condition;

means for controlling the receiving means and the processing means to inform of the result of focus detection in response to the defocusing information;

means responsive to the controlling means for generating a control power to be transmitted to the interchangeable objective lens for automatic focus control;

means responsive to the controlling means for indicating the focus condition; and

means for governing the controlling means to inhibit the generating means from responding to the controlling means with the responsibility of the indicating means to the controlling means maintained, when the accepting means accepts the macro-photography information.

30. In a camera system capable of focus detection by means of receiving light through an interchangeable objective lens, a camera body connectable with an interchangeable objective lens, comprising:

an opening for detachably connecting with the interchangeable objective lens;

means for receiving light through the opening to produce electric signals;

means for processing the electric signals to generate a defocusing information with respect to an ideal focal plane;

means for accepting digital data to be transmitted from the interchangeable objective lens, the digital data including a check data for certifying that the interchangeable objective lens is correctly connected to the camera body by means of successful acceptance of the check data by the accepting means;

means for controlling the receiving means and the processing means to inform of the result of focus detection in response to the defocusing information; and

means for inhibiting the controlling means from informing the result of focus detection when the accepting means fails to accept the check data.

* * * * *

United States Patent [19]

Kitagishi et al.

[11] **Patent Number: 4,508,433**

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[54] TELEPHOTO OBJECTIVE

[75] Inventors: **Nozomu Kitagishi; Sadahiko Tsuji,** both of Kanagawa, Japan

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[58] **Field of Search** 350/454, 455, 457, 450, 350/456

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Primary Examiner—John K. Corbin
Assistant Examiner—Scott J. Sugarman
Attorney, Agent, or Firm—Toren, McGeady and Stanger

[57] **ABSTRACT**

In a telephoto objective, a positive lens group and a negative lens group closer to the image than the positive lens group move simultaneously in axially opposite directions and relative to a stationary positive lens group which is closer to the image than both movable lens groups while the telephoto objective is being focused on an object. According to one embodiment of the invention, the diaphragm between the movable lens groups is varied in response to focusing so as to control the variation of the diameter of an on-axial light ray bundle.

13 Claims, 81 Drawing Figures

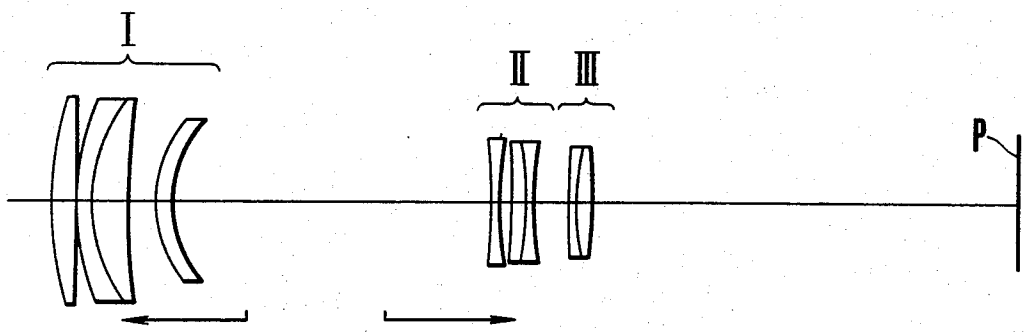
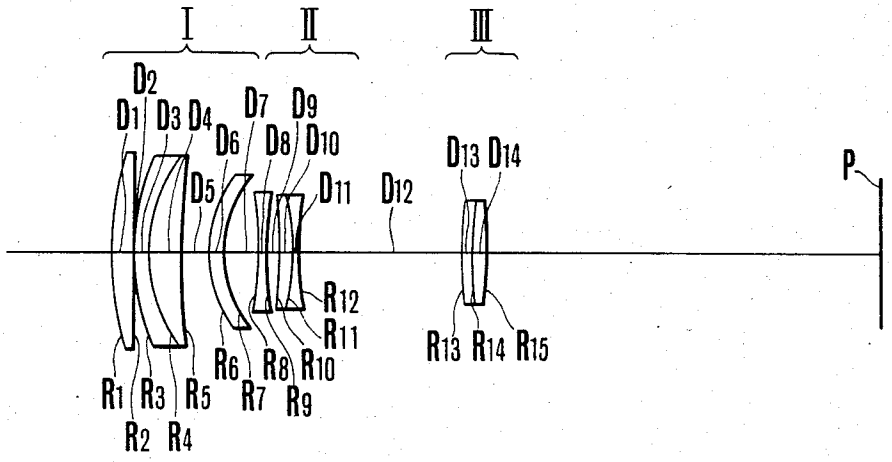


FIG. 1A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III
D2
D1
D3
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D5
D11
D12
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D14
P
R12
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R7
R9

FIG. 1B

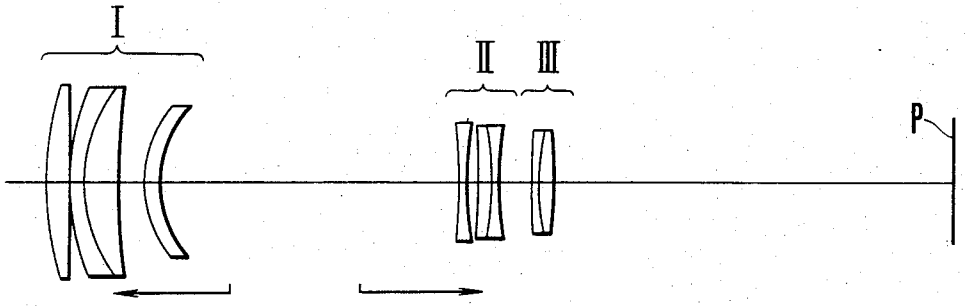

I
II
III
P

FIG.2A FIG.2B FIG.2C

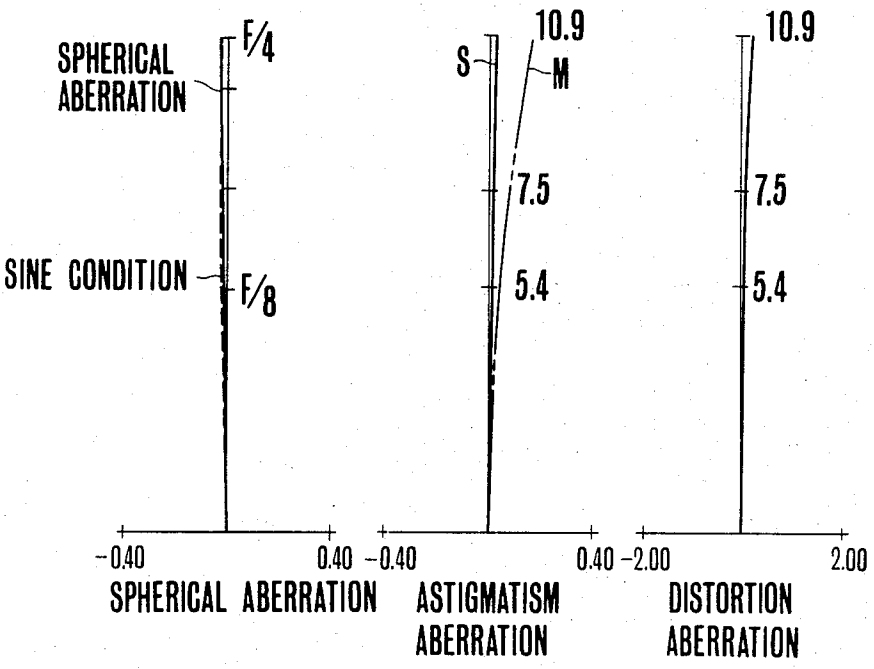


FIG.2D

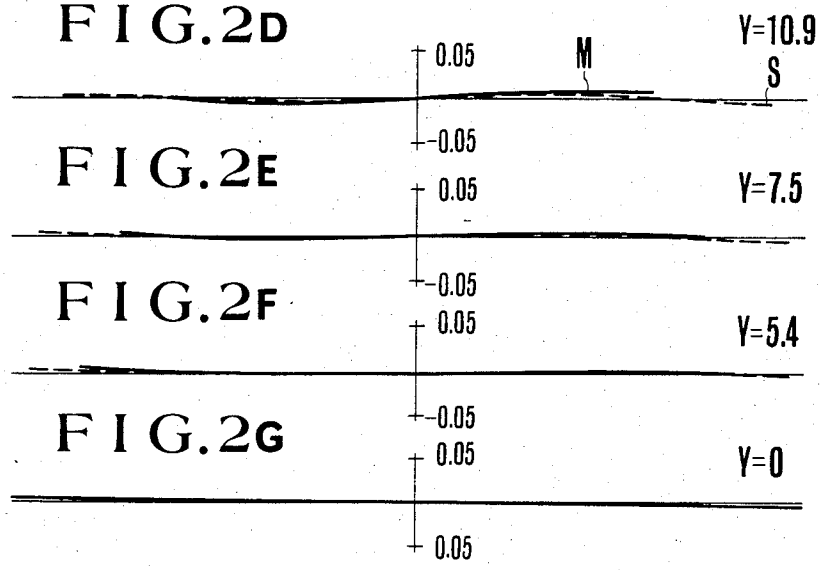


FIG.2E

FIG.2F

FIG.2G

FIG.3A FIG.3B FIG.3C

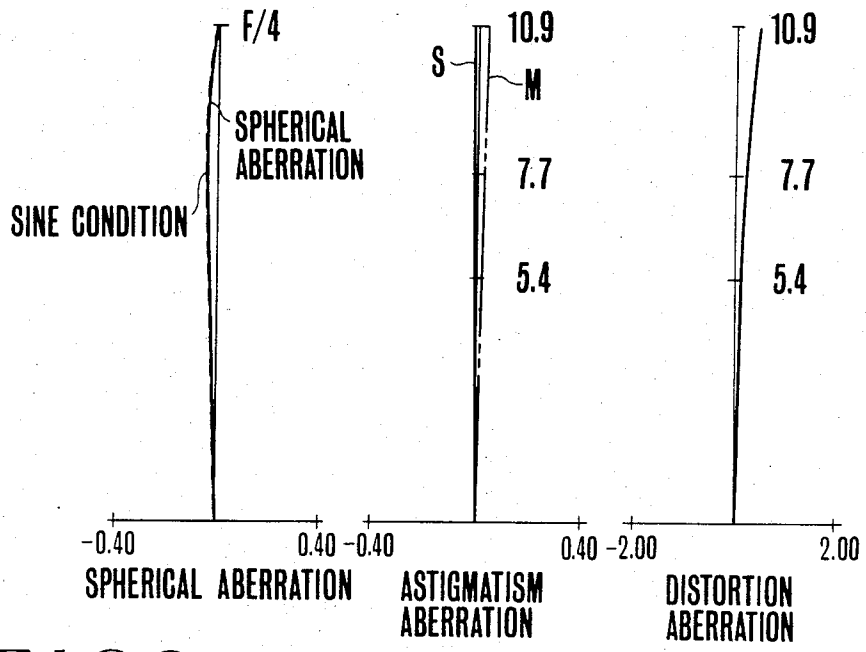
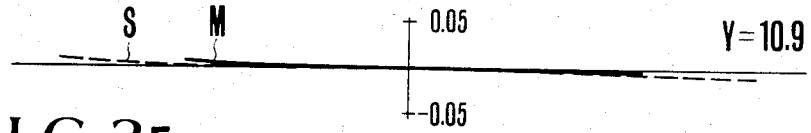


FIG.3D



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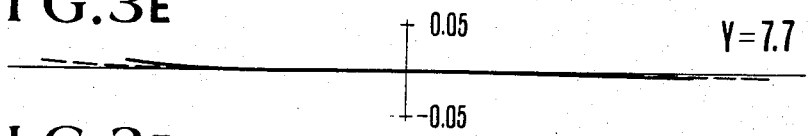

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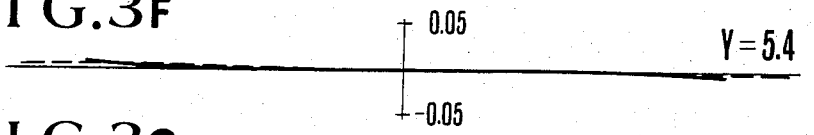


FIG.3G

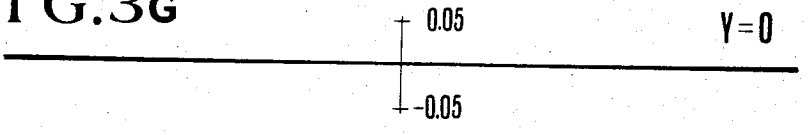


FIG.4A FIG.4B FIG.4C

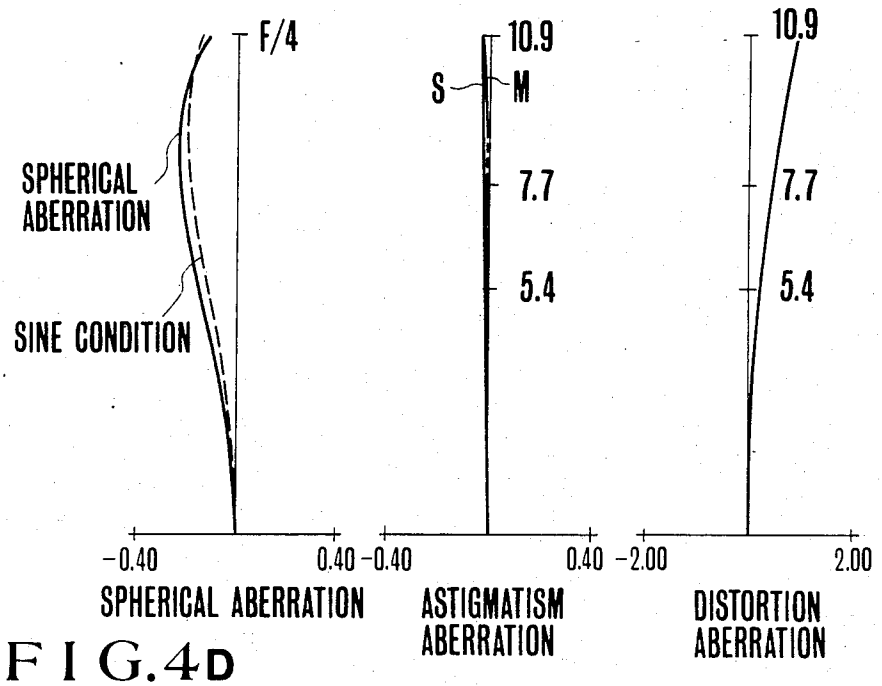


FIG.4D

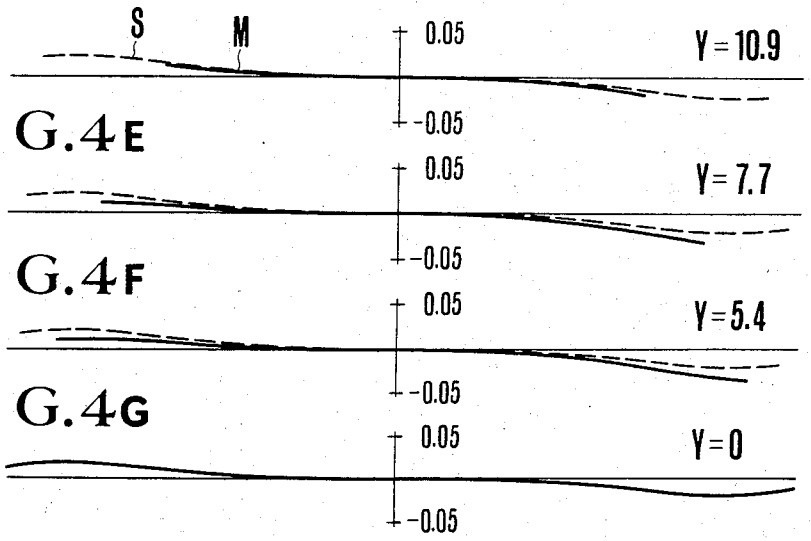


FIG.4E

FIG.4F

FIG.4G

FIG.5A FIG.5B FIG.5C

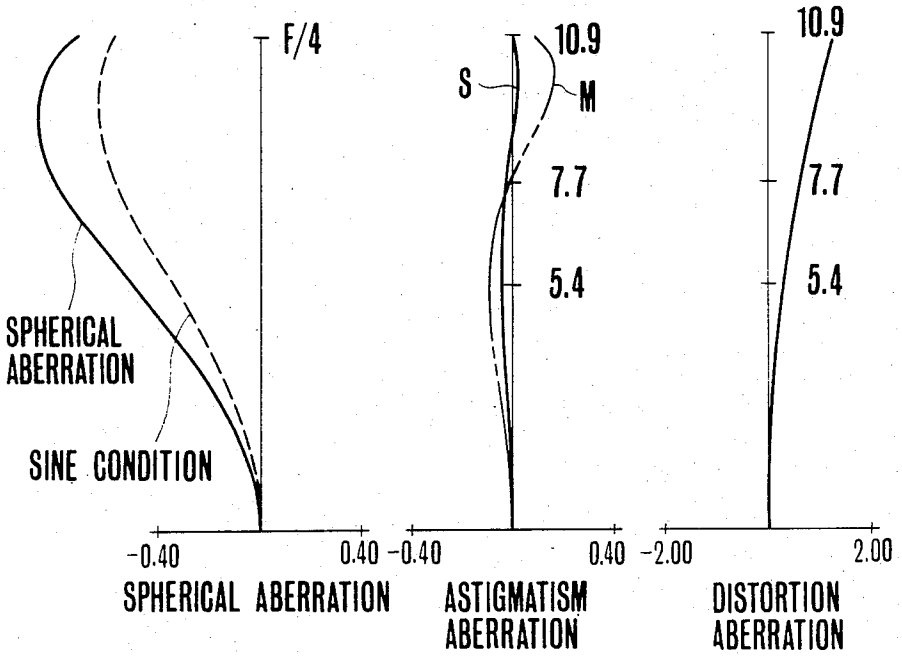


FIG.5D

FIG.5E

FIG.5F

FIG.5G

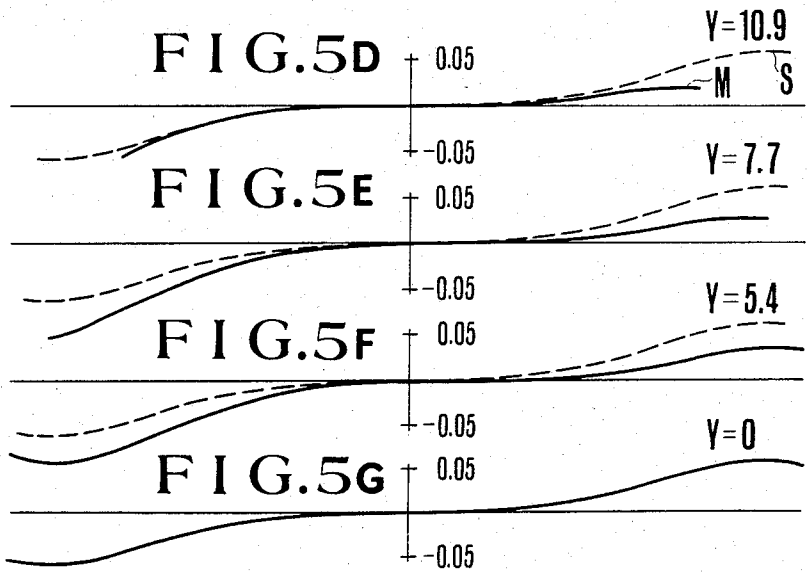
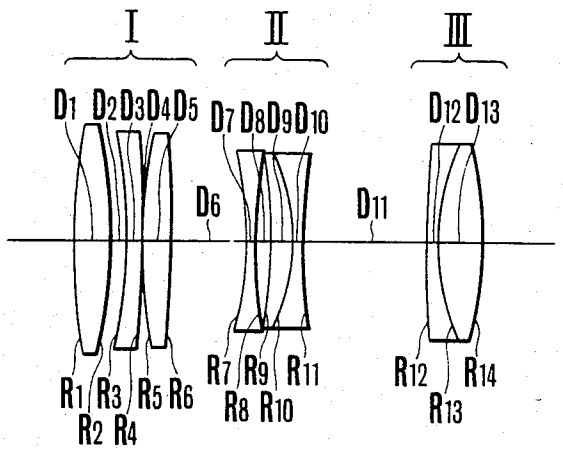


FIG.6A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II
III
D1 D2 D3 D4 D5
D6
D7 D8 D9 D10
D11
D12 D13
R1 R2 R3 R4 R5 R6
R7 R8 R9 R10 R11
R12 R13 R14

FIG.6B

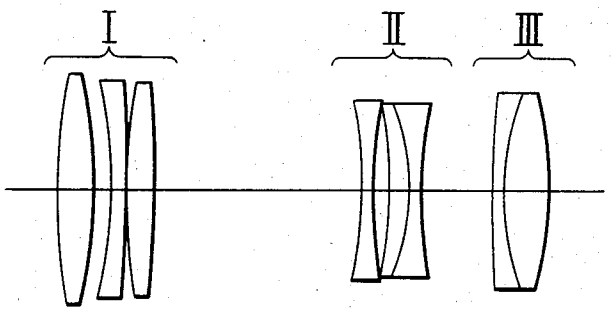

I
II
III

FIG.7A FIG.7B FIG.7C

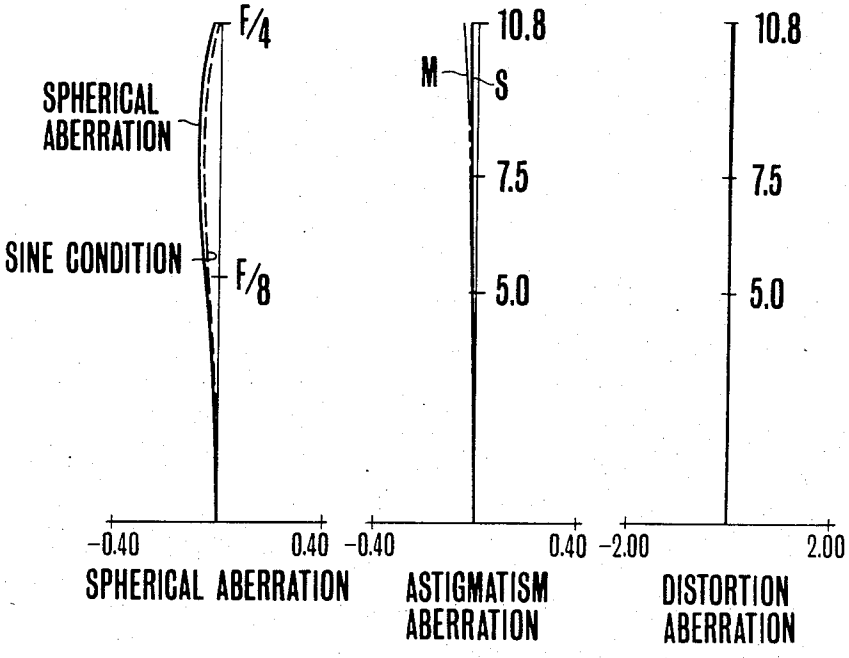
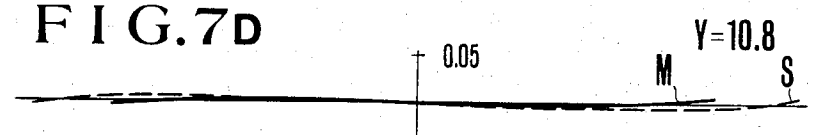


FIG.7D



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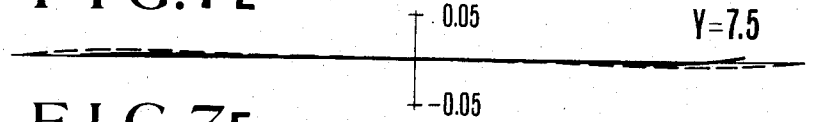


FIG.7F

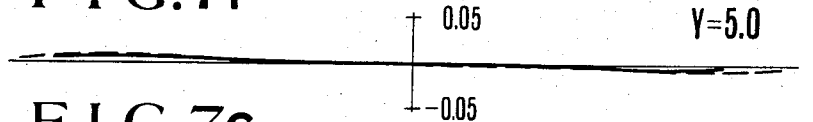


FIG.7G

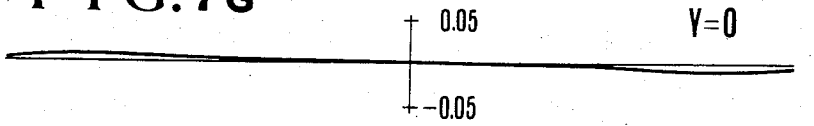
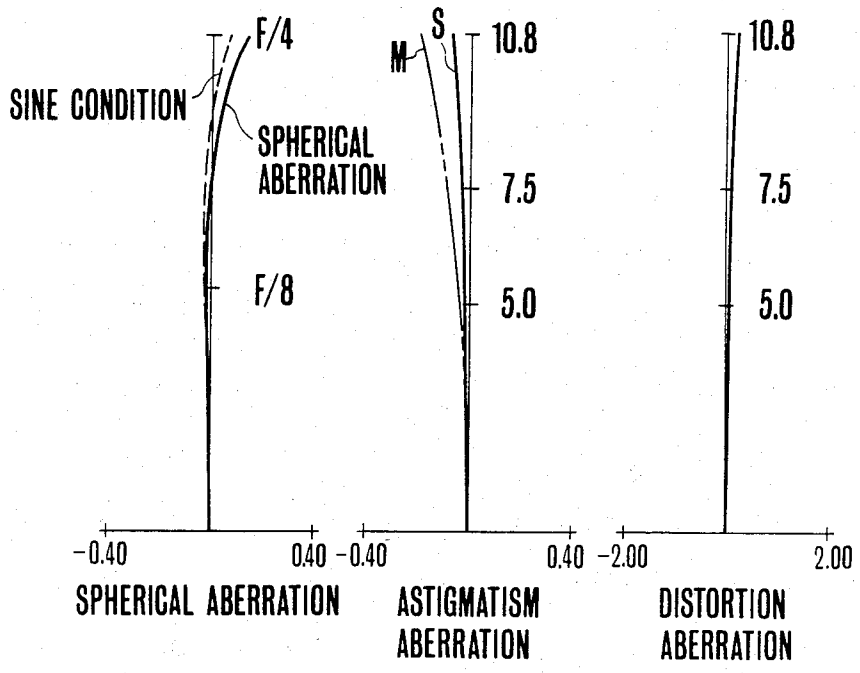


FIG.8A FIG.8B FIG.8C



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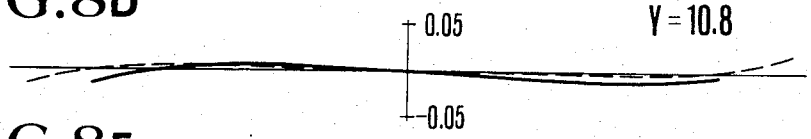

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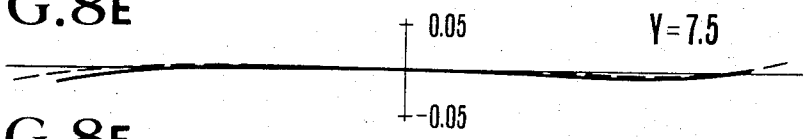

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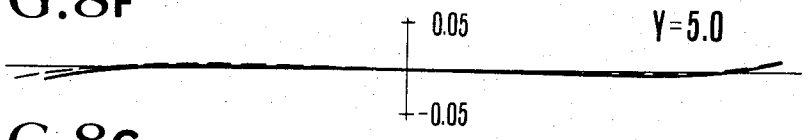

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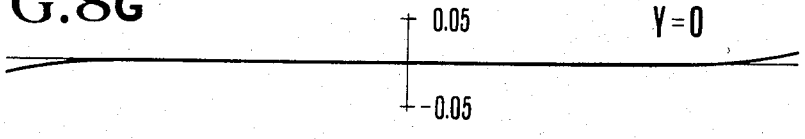


FIG.9A FIG.9B FIG.9C

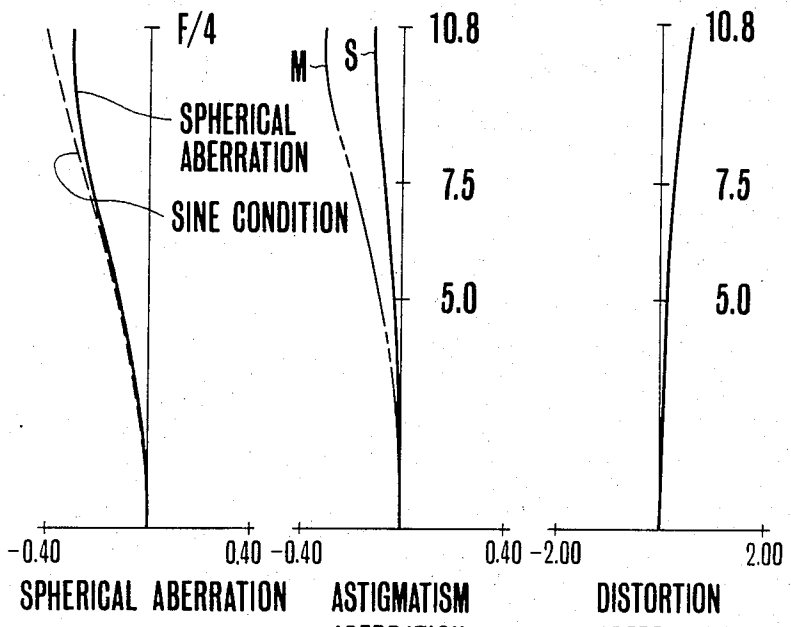
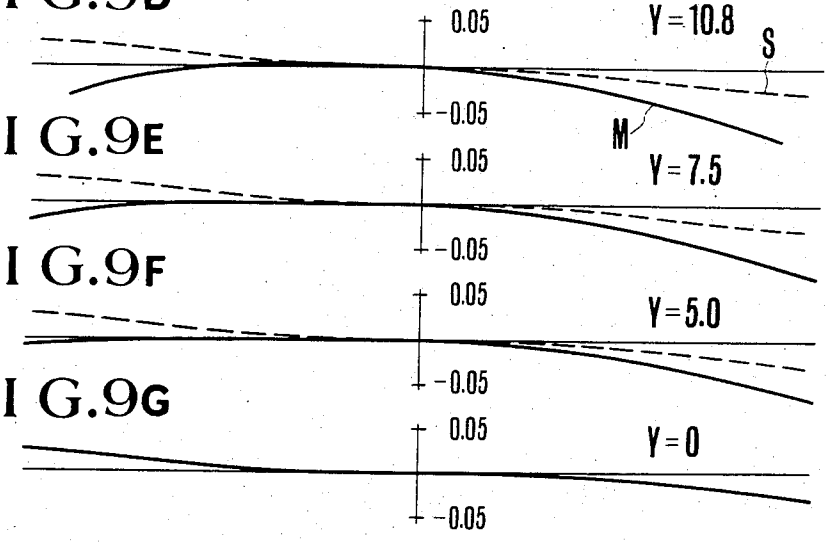


FIG.9D

FIG.9E

FIG.9F

FIG.9G



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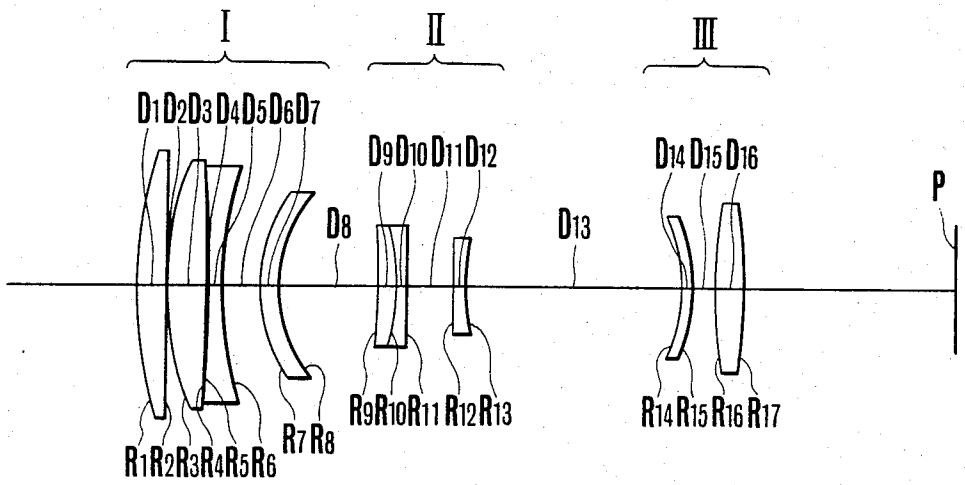


FIG.10B

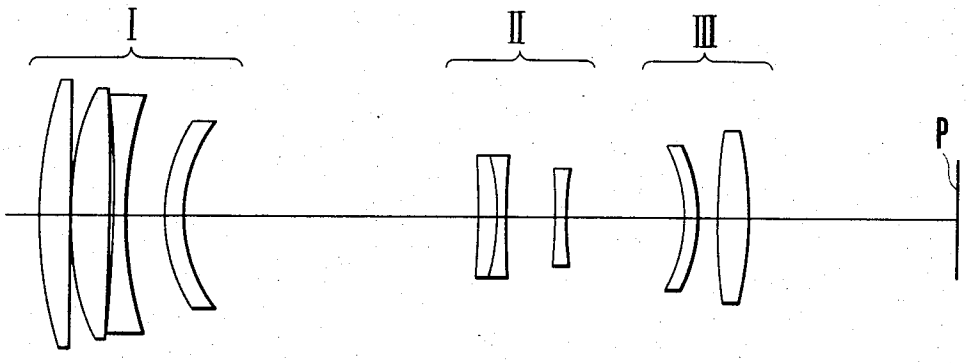


FIG.11A FIG.11B FIG.11C

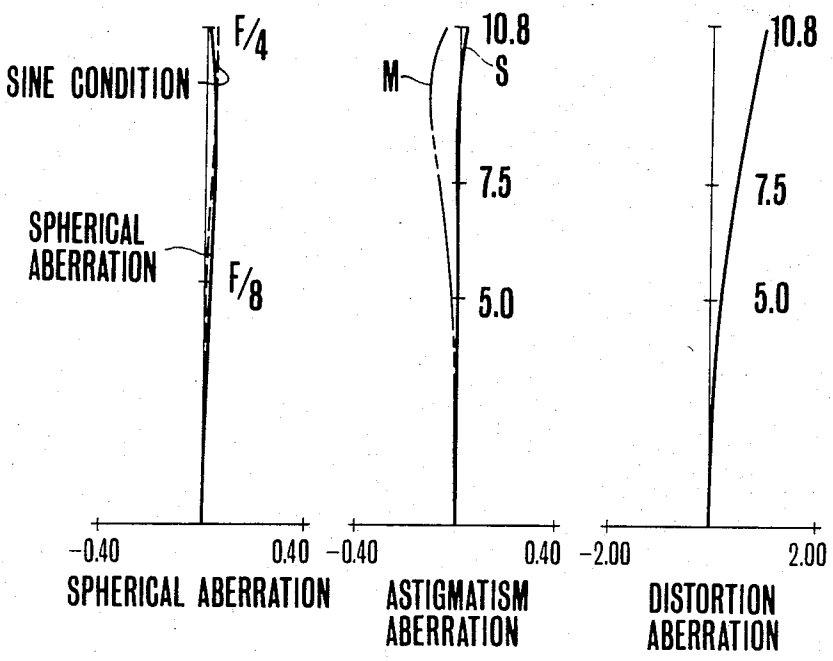
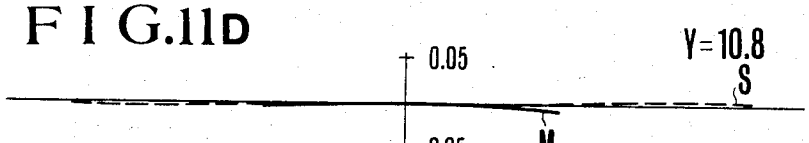


FIG.11D



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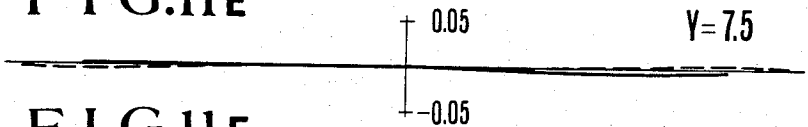


FIG.11F

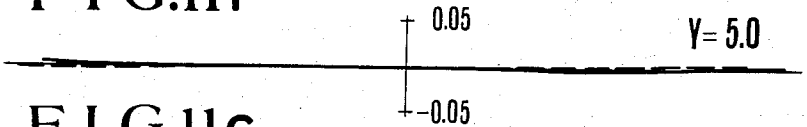


FIG.11G

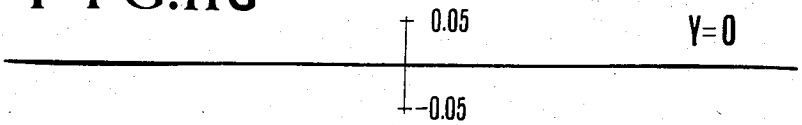
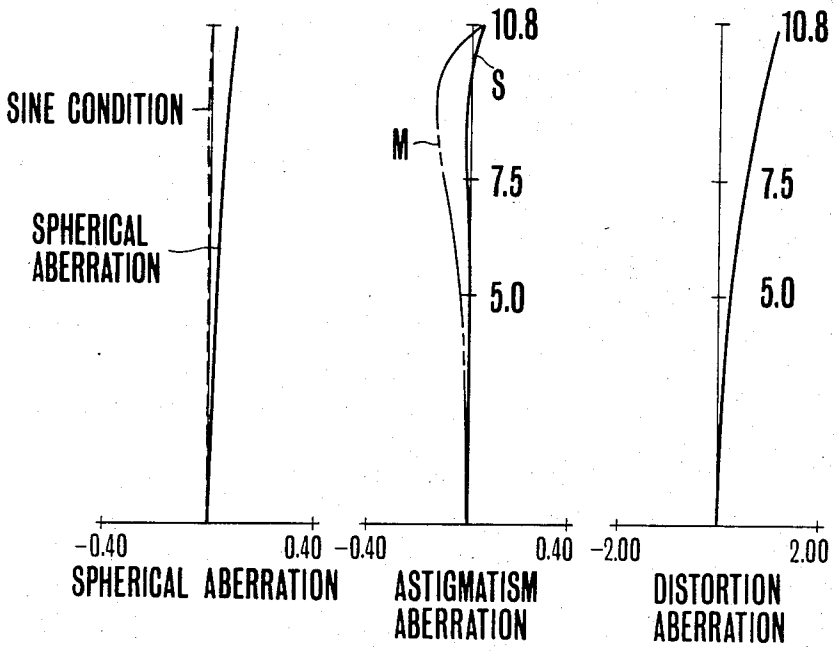


FIG.12A FIG.12B FIG.12C



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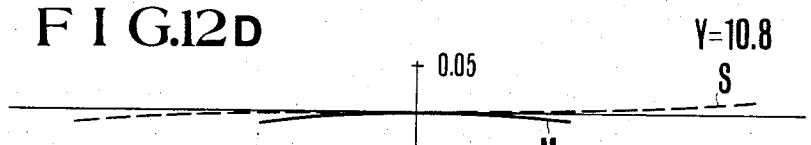

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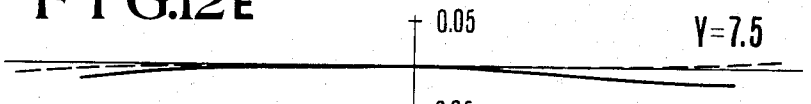

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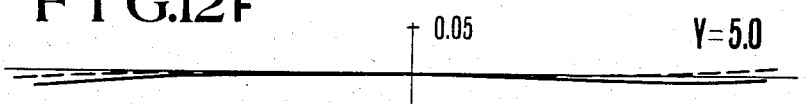


FIG.12G

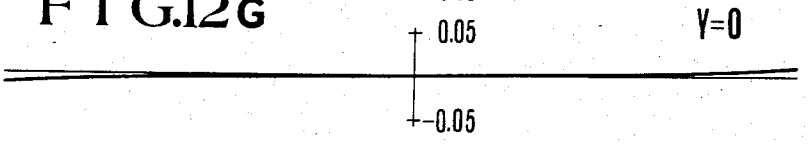


FIG.13A FIG.13B FIG.13C

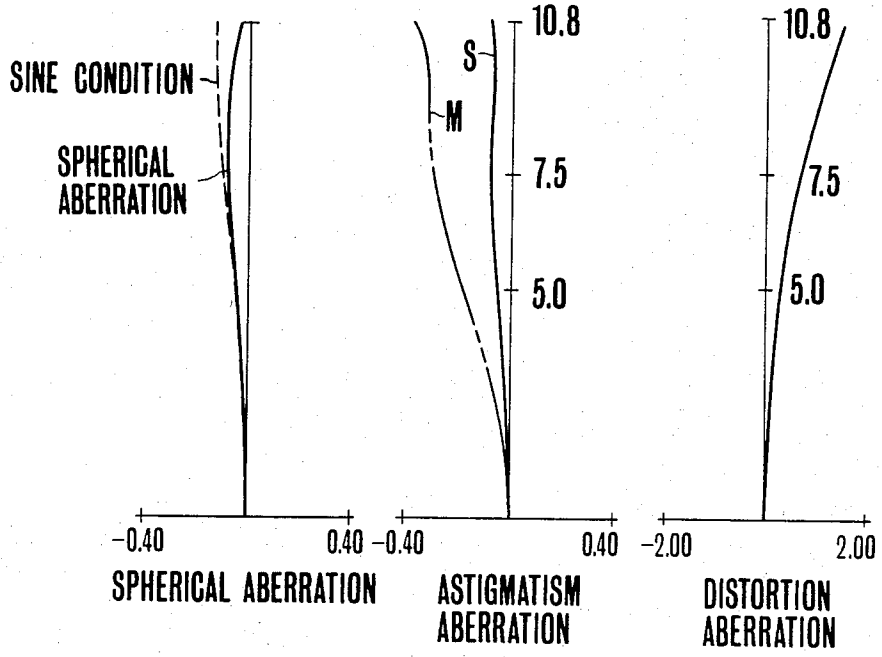


FIG.13D

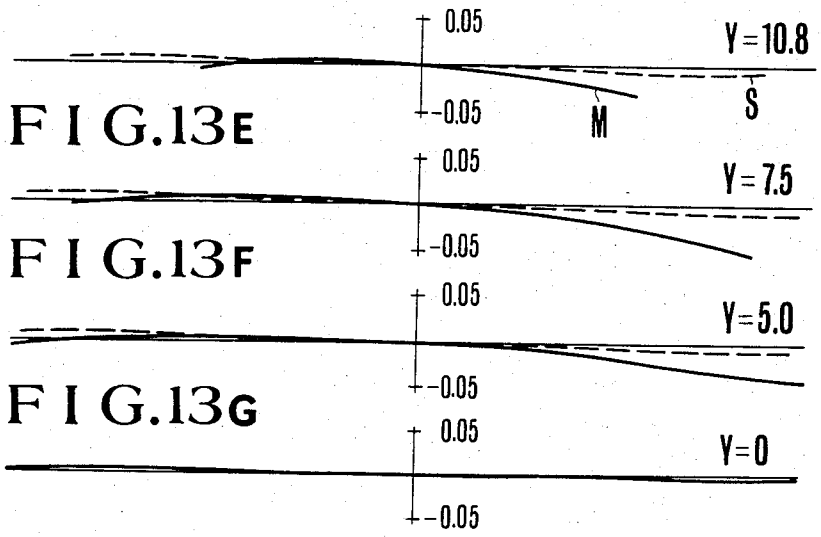


FIG.13E

FIG.13F

FIG.13G

FIG.14

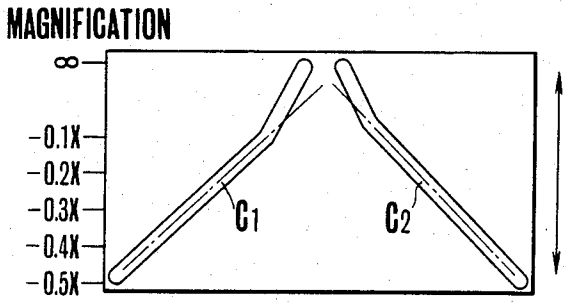


FIG.15

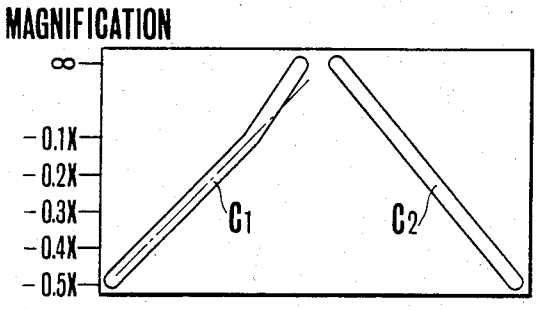


FIG.16

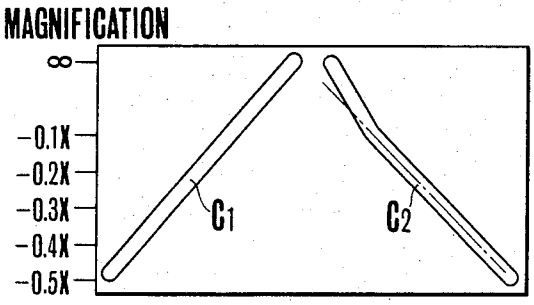


FIG.17

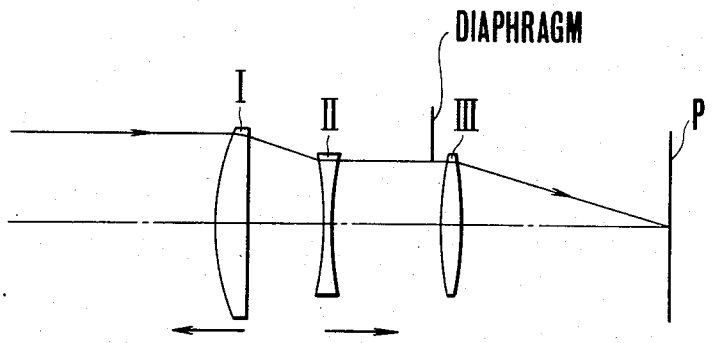
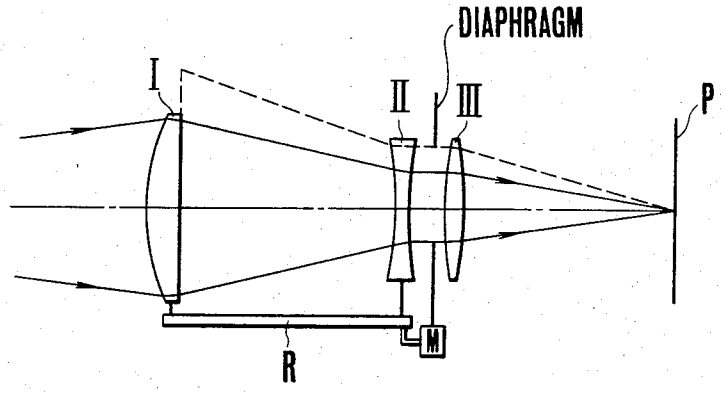


FIG.18



TELEPHOTO OBJECTIVE

This application is a continuation of application Ser. No. 139,764, filed Apr. 14, 1980, now abandoned.

BACKGROUND OF THE INVENTION

This invention relates to objectives for telephoto lenses and more particularly, to telephoto objectives suitable for close-up photography.

Most photographic objectives are focused by moving their constitutent components as a single unit. However, it is possible to focus an objective by moving either its front component or its rear component. With selective use of proper power distribution, moving the front component to focus offers the advantage of reducing the range of movement for the moving component from the range of movement required when the objective as a whole is moved. However, the front component itself must be properly corrected for aberrations. Otherwise, the overall aberrations would tend to vary substantially during focusing. On the other hand, focusing with the rear member has the advantage of taking place in a space where the height of incidence of on-axial rays is small and facilitates minimization of the weight of the movable focusing component. Moreover, focusing with the rear member prevents variation of the overall length of the objective during focusing and results in little shift of the center of gravity.

The telephoto objective of U.S. Pat. No. 4,045,128 is focused by moving a sub-group within the objective rear group. However, as this sub-group is axially moved to focus down on shorter object distances, the focal length of the entire optical system becomes shorter. For this reason, the image magnification at the same object distance is lowered as compared with the other focusing provision made at the entire system or the front member. It is known to provide a telephoto objective with its rear group having two sub-groups arranged to be axially moved in opposite direction to each other to effect focusing down, as disclosed in U.S. Pat. No. 3,854,797. It is also known to provide a telephoto objective in which either one of the front group or the front sub-group of the rear group is made movable for focusing as disclosed in U.S. Pat. No. 4,113,357. However, these conventional telephoto objectives when assessed from the point of view of a valuable increase in the image magnification, are incapable of satisfying a sufficient picture performance. If focusing is effected down to unduly short object distances, there will be a high possiblity of calling for a great increase in the range of movement of the focusing member, an objectionable lowering of the picture taking quality, or a large increase in the bulk and size of the entire lens system.

We see again that the optical system of the type capable of close-up photography is made axially movable usually as a whole toward the front to effect focusing. In this case, the amount of forward movement of the optical system is related to the image magnification by the following formula (1)

$$\beta = -x'/f \tag{1}$$

and the relationship between the image magnification and the object distance may be expressed by the following formula (2)

$$\hat{g}_1 = -(1-1/\beta)f \tag{2}$$

where

β: the image magnification;

x': the amount of forward movement from the position for an infinitely distant object;

f: the focal length of the entire optical system; and

$\hat{g}_1$: the distance from the front principal plane of the optical system to an object being photographed.

Therefore, to achieve a desirable increase in the image magnification for the same amount of forward movement, the use of smaller values of f is advantageous. On the other hand, for the same image magnification, the object distance may become greater if f is increased. In practice, for example, when photographing a moving object such as an insect or where a great degree of freedom is needed in selecting the position of the main light source, the so-called working distance should be increased. With a 50 mm lens being used for taking a close-up photograph of $\beta = -0.5x$, the required values of forward movement and working distance are 25 mm and 150 mm respectively. With a 200 mm lens, they become 100 mm and 600 mm respectively. However, the increase in the working distance imposes the requirement of imparting a large amount of forward movement to the lens. This makes it necessary to elongate the axial length of the usual helicoid focus control, or to use long bellows. Moreover, as the image mangification is varied by readjusting the position of the lens, the resulting large amount of forward movement adversely affects the ease and speed of handling, and the way the camera is held must be adapted to cope with a large shift in the center of gravity.

SUMMARY OF THE INVENTION

A first object of the present invention is to achieve a valuable increase in the image magnification of a telephoto objective.

A second object is to shorten the minimum object distance.

A third object is to reduce the amounts of movement of two lens groups for focusing down to the shortest object distance.

A fourth object is to provide an image of an object at a short distance which is well corrected for spherical aberration and astigmatism.

A fifth object is to prevent lowering of the luminance at the marginal portions of the area of the picture frame and vignetting which would be otherwise resulted when the frontmost movable lens group is moved to the front.

A sixth object is to facilitate the increase of the image magnification by increasing the synthetic focal length of the entire system as two movable lens groups are moved from a position for an infinitely distant object to effect focusing down to shorter object distances.

A seventh object is to make easy and quick focus adjustment by lowering the sensitivity of a focusing control mechanism as when the lens system is focused on an object at infinity, from that occurring when focused on an object at shorter distances.

An eighth object is to regulate the effective on-axial pencil as its diameter varies with focusing.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1A is a lens block diagram of a first embodiment of a telephoto objective according to the present invention when focused on an infinitely distant object.

FIG. 1B is a similar view of the objective when focused for the unity of image magnification.

FIGS. 2A to 2G are graphic representations of the spherical aberration, sine condition, astigmatism, distortion and lateral aberrations of the objective of FIG. 1 when focused at infinity.

FIGS. 3A to 3G are graphic representations of the spherical aberration, sine condition, astigmatism, distortion, and lateral aberrations of the objective of FIG. 1 when focused for an image magnification of 0.1.

FIGS. 4A to 4G are graphic representations of the spherical aberration, sine condition, astigmatism, distortion and lateral aberrations of the objective of FIG. 1 when focused for an image magnification of 0.5.

FIGS. 5A to 5G are graphic representations of the spherical aberration, sine condition, astigmatism, distortion and lateral aberrations of the objective of FIG. 1 when focused for the magnification of unity.

FIG. 6A is a lens block diagram of a second embodiment of a telephoto objective according to the present invention when focused on an object at infinity.

FIG. 6B is a similar diagram of the objective when focused for an image magnification of 0.5.

FIGS. 7A to 7G are graphic representations of the sherical aberration, sine condition, astigmatism, distortion and lateral aberrations of the objective of FIG. 6 when focused at infinity.

FIGS. 8A to 8G are graphic representations of the spherical aberration, sine condition, astigmatism, distortion and lateral aberrations of the objective of FIG. 6 when focused for an image magnification of 0.1.

FIGS. 9A to 9G are graphic representations of the spherical aberration, sine condition, astigmatism, distortion and lateral aberrations of the objective of FIG. 6 when focused for an image magnification of 0.5.

FIG. 10A is a lens block diagram of a third embodiment of a telephoto objective according to the present invention when focused on an object at infinity.

FIG. 10B is a similar diagram of the objective when focused for an image magnification of 0.5.

FIG. 11A to 11G are graphic representations of the spherical aberration, sine condition, astigmatism, distortion and lateral aberrations of the objective of FIG. 10 when focused at infinity.

FIGS. 12A to 12G are graphic representations of the spherical aberration, sine condition, astigmatism, distortion and lateral aberrations of the objective of FIG. 10 when focused for an image magnification of 0.1.

FIGS. 13A to 13G are graphic representations of the spherical aberration, sine condition, astigmatism, distortion and lateral aberrations of the objective of FIG. 10 when focused for an image magnification of 0.5.

FIGS. 14 to 16 are plan views of cam sleeves for moving the lens groups in a telephoto objective embodying features of the invention.

FIGS. 17 and 18 are lens diagrams illustrating the effect of the groups of lenses on pencil rays entering the lenses.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIGS. 1A, 6A and 10A depict three different examples of telephoto objectives in a focusing position for an infinitely distant object. I is a first lens group having a positive refractive power and arranged on the object side to be axially movable for focusing; II is a second lens group having a negative refractive power and arranged in a middle position to be axially moved simultaneously with and in the opposite direction to the first lens group; and III is a stationary lens group having a positive refractive power and arranged on the image side. P indicates the surface of a photo-sensitive material. Again, a rearmost lens element in the movable first lens group I takes a meniscus form convex toward the front and plays a role in preventing the picture taking quality of the telephoto objective having a comparatively long focal length to be lowered during focusing.

On the other hand, FIG. 1B depicts a lens position occurring when focusing is effected down to such an object distance that the image magnification is unity, and FIGS. 6B and 10B depict positions of the respective telephoto objectives where the image magnification is 0.5. As shown in each pair of figures, as the object distance is decreased, the first movable lens group I is moved to the front, while the second movable lens group II is moved to the rear. In this connection it should be noted that it is preferred to make negative the synthetic focal length of the second movable lens group II and stationary lens group III regardless of the movement of the second movable lens group II.

For a long lens covering a range of from an infinitely distant shot to a close-up shot, it is desired that the ratio of the amount of movement S1 of the first movable lens group I to the amount of movement S2 of the second movable lens group satisfies a condition of $0.7<|S1|/|S2|<1.4$, and that a power distribution suited for it is employed.

When the upper limit of this inequality is exceeded, the excess movement of the first movable lens group causes the spherical aberration and astigmatism to be varied to very large extent, and the image quality to be deteriorated when in close-up photography. Further when in close-up photography, as the distance from the diaphragm to the first movable lens group I is increased, there will be a high possibility of occurrence of a large loss of the brightness in the marginal portion of the picture frame and of a mutilation of the pencil which is to reach the corners of the picture frame. On the other hand, when the lower limit of the inequality is exceeded, the excess movement of the second movable lens group II causes the synthetic focal length of the lens to be shortened when in close-up photography so that this contradicts the need of facilitating the close-up photography.

In general, the amount of forward movement of the focusing member is almost proportional to the image magnification. With the objective covering an extended range of image magnifications from an infinitely small value to as large as 0.5 or unity, therefore, if the focusing control mechanism is so constructed that the ratio of the angle of rotation of the focus adjusting ring to the sum of the distances through which the two movable lens groups are displaced is maintained constant throughout the focusing range, the focusing control in the region of ordinary photography will become so far sensitive that upon slight rotation of the focus adjusting ring, the object distance to which focusing is effected is largely changed, thus fine adjustment of focusing is made very difficult to perform.

To compensate this drawback, the cam grooves controlling the movement of the two movable lens groups may be configured so that the amounts of movement of the first and second movable lens groups relative to the angle of rotation of the focus adjusting ring differ be-

tween when in ordinary photography and when in close-up photography.

FIG. **14** depicts a development surface of the cam sleeve for the telephoto objective capable of focusing with the variation of image magnification from an infinitely small value to 0.5. In the figure, **C1** is a cam groove controlling the axial movement of the first movable lens group I, and **C2** is a cam groove controlling the axial movement of the second movable lens group II. Engaged in these cam grooves **C1** and **C2** are cam pins (not shown) radially extending from respective movable lens cells. The cam grooves **C1** and **C2** each have two sections of different gradient so that when in ordinary photography with an object at infinity or down to a moderate distance, the amount of movement of each movable lens goup I, II to a certain angle of rotation of the cam sleeve becomes smaller, and when in focusing to shorter object distances, the relative amount of movement of the movable lens group becomes larger.

Although the cam sleeve of FIG. **14** changes the gradient of the both cam grooves, a telephoto objective having a comparatively short focal length may take a different form of the cam sleeve as shown in FIG. **15** or FIG. **16** where either one of the cam grooves **C1** and **C2** is made to vary the gradient in two sections so that the rate of cam lift is varied therebetween.

According to the foregoing description, the cam grooves and the cam pins are used in combination so as to move the two movable lens groups. However, one of the movable lens groups which does not change in the movement amount may be moved by the inner and outer helicoids. Also in the case where both of the two movable lens groups are not changed in their movement amounts both groups may be moved by a helicoid.

Another subject of the present invention is that the variation with focusing of the effective pencil is made to correlate with the variation of the diaphragm aperture. In this connection it should be explained that since the relative position of the diaphragm to the film plane does not change and the first lens group is moved away from the diaphragm as in the embodiment of the present invention, the effective diameter of the first movable lens goup is required to be large enough to unchange the effective F-number even when closing up. In general, however, the demand for compactness of the lens and like reasons often lead to the impossibility of imparting a sufficiently large effective diameter into the first movable lens group. Although the focusing method of the present invention is less susceptible to that factor because the amount of movement of the first lens group is smaller than when the conventional focusing method of making movable the front member only is employed, as the maximum possible image magnification fication is increased, the additional amount of movement becomes impossible to ignore. As schematically shown in FIG. **17** and particularly FIG. **18**, the effective diameter of the first movable lens group regulates the on-axial maximum pencil so that the effective pencil at the diaphragm plane is smaller than the maximum diameter of the aperture. Therefore, a zone is created where the brightness remains unchanged despite the closing down of the diaphragm from the full aperture, and photographic situations where an inaccurate exposure control is resulted may be encountered. FIG. **17** shows the tracing of a ray of light which is admitted by the full aperture of the diaphragm when the lens system is focused at infinity. FIG. **18** shows the tracing of rays which are admitted by the effective diameter of the first movable lens group when focusing is effected down to a shorter object distance. If the diameter of the first movable lens group is so large that the actually admitted pencil passes along a dashed line, the F-number is not subject to change. When the first lens group is moved to the front, the effect is substantially the same as if the first lens group were edged down to so small a diameter that, as the oblique pencils which the diaphragm allows to pass at points between the dashed and solid lines of FIG. **18** define the limit of the field of view, the closing down of the diaphragm is no longer effective to adjust the brightness due to the on-axial pencil.

To avoid this, it is proposed to provide a mechanism M for adjusting the diameter of the full aperture in response to the focusing ring R. With such mechanism, when focusing is performed, the diaphragm is automatically closed down to a diameter coincident with that of the effective pencil at the position of the diaphragm, thus preventing inconsistency between the actual aperture and the effective pencil when it nears the full one. It is noted that the diaphragm can be closed down to a desired F-number without the recourse to the mechanism M.

The provision of the above-described feature gives rise to an advantage that the compactness is facilitated by the reduction of the diameter of the first movable lens group. Another advantage is that the off-axial pencil can be taken off in portions to improve the picture taking quality.

To further facilitate the improvement of the picture taking quality, besides the diaphragm of regulating the F-number, use may be made of a second diaphragm arranged to be axially movable with focusing in such a manner that when the second lens group is moved to the front, this diaphragm is also moved to the front.

Taking one numerical example, the advantage of the present invention is clarified below. Letting **f1**, **f2** and **f3** denote the focal lengths of the first and second movable lens groups and the stationary lens group respectively, and **e1** and **e2** the intervals between the principal points of the first and second movable lens groups and between those of the movable second and stationary third lens groups, a telephoto objective in question is characterized by:

f1 = 119.33316	e1 = 42.8
f2 = −86.45656	e2 = 55.5
f3 = 143.29756	

We now set forth four different examples of ways in which the objective is focused down to shorter object distances as by (1) moving the first and the second lens groups I and II in opposite direction to each other, (2) bodily moving the entire lens system, (3) moving only the first lens group I to the front, and (4) moving only the second lens group II to the rear. For each of these ways, the focal length, f, object distance, g_1, and image magnification, β, have been evaluated in terms of the amount of movement, d, which are taken at two discrete values, and the results are listed in the following table.

d		1	2	3	4
10 mm	f	189.2	197.4	197.1	192.0
	g_1	−885.3	−4095.6	−1618.6	−1614.3
	β	−0.272	−0.051	−0.139	−0.135
20 mm	f	173.1	197.4	196.7	182.2

-continued

d	1	2	3	4
g_1	−496.0	−2146.5	−906.2	−866.6
β	−0.536	−0.101	−0.277	−0.266

It will be seen from the table that the amount of movement of the focusing lens necessary to effect production of an equivalent image magnification is far smaller in the present invention. Further, the amount of variation of the focal length with the production of an equivalent image magnification when in the focusing method (1) takes an intermediate value between those when in the methods (3) and (4). That is, according to the present invention, an elongation of the focal length and an increase of the image magnification can be achieved by a decreased amount of movement, and the shift of the center of gravity during focusing is made smaller next to the method of moving the second lens group to the rear.

Three examples of specific telephoto objectives may be constructed in accordance with the numerical data given below for the radii of curvature, R, the axial thicknesses and separations, D, along with the Abbe numbers, νd, and the indices of refraction, Nd, for the various lens elements. The focal length is normalized to 100 mm.

-continued

Focal length f = 100 Image angle 2ω = 12.35°
F-number = 1:4.0 Magnification β = 0.∼−1.0X

	R	D	νd	Nd
14	53.848	2.024	55.50	1.69680
15	−73.034			

Close-up D7 = 43.7838
D12 = 4.7219

Aberration Coefficient of 3rd Order

Surface No.	L	T	SA	CM	AS	PT	DS
1	0.01187	−0.00530	1.98373	−0.88630	0.39599	0.68179	−0.48154
2	0.00674	−0.01181	0.88512	−1.54991	2.71399	0.04387	−4.82920
3	0.02681	−0.00635	−0.16486	0.03906	−0.00925	1.10121	−0.25876
4	−0.04987	0.03225	−1.81104	1.17126	−0.75749	−0.37936	0.73524
5	0.00590	−0.01072	1.01704	−1.84648	3.35234	−0.20606	−5.71216
6	0.03115	−0.01051	−0.40857	0.13784	−0.04650	2.30745	−0.76278
7	−0.03082	0.00964	−0.03505	0.01096	−0.00343	−2.54430	0.79731
8	−0.00974	0.01224	−4.88417	6.13861	−7.71522	−0.45270	10.26575
9	−0.00250	−0.00407	0.01384	0.02254	0.03670	−0.63638	−0.97653
10	−0.01069	0.02222	−0.38624	0.80271	−1.66823	−0.32963	4.15205
11	0.02234	−0.02304	2.45610	−2.53319	2.61270	0.35605	−3.06194
12	−0.00400	−0.00343	−0.13908	−0.11922	−0.10220	−0.67096	−0.66277
13	0.00361	0.02347	−0.00088	−0.00576	−0.03746	0.34889	2.02213
14	−0.01142	−0.01512	−0.02034	−0.02694	−0.03568	−0.06570	−0.13427
15	0.00950	−0.00792	1.57015	−1.30901	1.09130	0.56227	−1.37856
Total	−0.00110	0.00152	0.07574	0.04615	−0.17245	0.11646	−0.28605

L: Longitudinal Chromatic Aberration
T: Transverse Chromatic Aberration
SA: Spherical Aberration
CM: Coma
AS: Astigmatism
PT: Petzval Sum
DS: Distortion

EXAMPLE 1

Focal length f = 100 Image angle 2ω = 12.35°
F-number = 1:4.0 Magnification β = 0.∼−1.0X

	R	D	νd	Nd
1	48.068	3.290	70.10	1.48749
2	−746.918	0.101		1.
3	37.358	2.024	30.10	1.69895
4	22.056	5.062	70.10	1.48749
5	159.043	3.821		1.
6	18.191	2.024	38.00	1.72342
7	16.497	D7		1.
8	−72.392	1.265	70.10	1.48749
9	51.498	1.648		1.
10	−137.953	2.024	37.20	1.83400
11	−35.673	1.012	70.10	1.48749
12	48.844	D12		1.
13	127.841	1.265	25.40	1.80518

EXAMPLE 2

f = 100 F/4.0 2ω = 12.35° β = 0.∼−0.5X

	R	D	νd	Nd
1	75.061	4.000	63.40	1.61800
2	−59.869	2.054		1.
3	−50.082	1.400	26.60	1.76182
4	−285.675	0.250		1.
5	68.510	3.000	63.40	1.61800
6	−185.718	D6		1.
7	−52.534	1.250	66.10	1.49388
8	51.928	1.868		1.
9	−69.542	2.250	25.40	1.80518
10	−23.953	1.250	60.70	1.60311
11	60.351	D11		1.
12	184.454	1.250	25.40	1.80518
13	31.489	5.000	49.60	1.77250
14	−49.163			

Close-up D6 = 23.4562
D11 = 8.0482

EXAMPLE 3

f = 100 F/4.0 2ω = 12.35° β = 0.∼−0.5X

	R	D	νd	Nd
1	49.178	3.500	53.90	1.71300
2	−3447.931	0.100		1.
3	37.103	4.250	53.90	1.71300
4	−526.460	0.382		1.
5	−321.772	1.500	26.60	1.76182
6	49.104	4.269		1.
7	19.552	2.000	35.80	1.66446
8	16.425	D8		1.
9	−103.727	2.250	38.00	1.72342
10	−22.829	1.064	60.70	1.60311
11	208.160	5.419		1.

-continued

	f = 100 F/4.0 R	2ω = 12.35° D	β = 0.~−0.5X νd	Nd
12	−1590.663	1.333	42.80	1.56732
13	29.947	D13		1.
14	−17.951	1.250	28.50	1.72825
15	−21.581	2.500		1.
16	66.671	3.250	53.90	1.71300
17	−61.480			

Close-up D8 = 19.1026
D13 = 13.2308

What is claimed is:

1. A telephoto objective comprising:
a first axially movable lens group having a positive refractive power;
a second axially movable lens group positioned on the image side of said movable first lens group and having a negative refractive power; and
a fixed lens group positioned on the image side of said movable second lens group and having a positive refractive power;
said first and said second movable lens groups being arranged to be moved simultaneously in opposite axial directions to focus the telephoto objective on an object and when focused at an infinite distance the distance between the first axially movable lens group and the second axially movable lens group being smaller than the distance between the second axially movable lens group and the fixed lens group.

2. A telephoto objective as in claim 1 in that the relationship

$$0.7<|S_1|/|S_2|<1.4$$

is satisfied, wherein S_1 and S_2 are the amounts of movement of said first and second lens group respectively when focusing.

3. A telephoto objective as in claim 1, further including:
a first focusing path for moving said first movable lens group and controlling the amount of movement thereof;
a second focusing path for moving said second movable lens group and controlling the amount of movement thereof; and
drive means for driving said first and said second focusing paths so as to cause the paths to move said first and second movable lens groups;
at least one of said first and said second focusing paths being configured so that the amount of movement of the movable lens group varies as said drive means moves a given amount.

4. A telephoto objective as described in claim 3, wherein each of said first and said second focusing paths is a bent-on-the-way linear focusing groove.

5. A telephoto objective as in claim 1, wherein the objective has a front for facing an object and a rear for facing an image and a plurality of lens elements, and said movable first lens group has a single negative meniscus lens convex toward the front and located separately after at least two lens elements from the front.

6. A telephoto objective according to claim 1, in which the first axially movable lens comprises at least two positive lens elements and one negative lens element as well as a rearmost meniscus lens element with a convex surface directed toward the object.

7. A telephoto objective according to claim 6, in which the meniscus lens element has a weak negative refractive power.

8. A telephoto objective according to claim 6, which when focused at an infinite distance the distance between the first axially movable lens group and the second axially movable lens group is larger than the distance between the meniscus lens element and other lens elements in the first axially movable lens group.

9. A telephoto objective comprising:
a first axially movable lens group having a positive refractive power;
a second axially movable lens group positioned on the image side of said movable first lens group and having a negative refractive power; and
a fixed lens group positioned on the image side of said movable second lens group and having a positive refractive power;
said first and said second movable lens group being arranged to be moved simultaneously in opposite axial directions to focus the telephoto objective on an object and when focused at an infinite distance the distance between the first axially movable lens group and the second axially movable lens group being smaller than the distance between the second axially movable lens group and the fixed lens group;
control means for driving each of said first and said second movable lens group to move said first and second movable lens groups and for controlling the amount of movement thereof; and
a diaphram positioned in a space between said movable second and said fixed lens groups and cooperative with said control means to limit light rays passing therethrough in response to focusing.

10. A telephoto objective comprising:
a first axially movable lens group having a positive refractive power;
a second axially movable lens group positioned on the image side of said movable first lens group and having a negative refractive power; and
a fixed lens group postioned on the image side of said movable second lens group and having a positive refractive power;
said first and said second movable lens group being arranged to be moved simultaneously in opposite axial directions to focus the telephoto objective on the object;
the relationship $0.7<|S_1|/|S_2|<1.4$ being satisfied, where S_1 and S_2 are the amounts of movement of said first and said second lens groups respectively when focusing for photography with a magnification ratio not less than 0.5.

11. A telephoto objective comprising:
a movable first lens group axially movable for focusing and having a positive refractive power;
a movable second lens group on the image side of said first lens group, axially movable for focusing the objective, and having a negative refractive power; and
a fixed lens group on the image side of said second lens group and having a positive refractive power, and satisfying the following data:

Focal Length f = 100 Image Angle 2ω = 12.35°
F-number = 1:4.0 Magnification β = 0.~−1.0X

	Axial	Abbe

-continued

	Radii of Curvature R	Thicknesses & Separation D	Numbers νd	Indices of Refraction Nd
1	48.068	3.290	70.10	1.48749
2	−746.918	0.101		1.
3	37.358	2.024	30.10	1.69895
4	22.056	5.062	70.10	1.48749
5	159.043	3.821		1.
6	18.191	2.024	38.00	1.72342
7	16.497	D7		1.
8	−72.392	1.265	70.10	1.48749
9	51.498	1.648		1.
10	−137.953	2.024	37.20	1.83400
11	−35.673	1.012	70.10	1.48749
12	48.844	D12		1.
13	127.841	1.265	25.40	1.80518
14	53.848	2.024	55.50	1.69680
15	−73.034			

	Infinity	Close-up
D7	5.208	43.7838
D12	24.009	4.7219

12. A telephoto objective comprising:

a movable first lens group axially movable for focusing of the objective and having a positive refractive power;

a movable second lens group on the image side of said first lens group, axially movable for focusing the objective, and having a negative refractive power; and

a fixed lens group on the image side of said second lens group and having a positive refractive power, and satisfying the following data:

Focal Length f = 100 Image Angle 2ω = 12.35° F-number = 1:4.0
Magnification β = 0.∼−0.5X

	Radii of Curvature R	Axial Thicknesses and Separation D	Abbe Numbers νd	Indices of Refraction Nd
1	75.061	4.000	63.40	1.61800
2	−59.869	2.054		1.
3	−50.082	1.400	26.60	1.76182
4	−285.675	0.250		1.
5	68.510	3.000	63.40	1.61800
6	−185.718	D6		1.
7	−52.534	1.250	66.10	1.49388
8	51.928	1.868		1.
9	−69.542	2.250	25.40	1.80518
10	−23.953	1.250	60.70	1.60311
11	60.351	D11		1.
12	184.454	1.250	25.40	1.80518
13	31.489	5.000	49.60	1.77250
14	−49.163			

	Infinity	Close-up
D6	8.338	23.4562
D11	14.095	8.0482

13. A telephoto objective comprising:

a movable first lens group axially movable for focusing the objective and having a positive refractive power;

a movable second lens group on the image side of said first lens group, axially movable for focusing the objective and having a negative refractive power; and

a fixed lens group on the image side of said second lens group, and a positive refractive power, and satisfying the following data:

Focal Length f = 100 Image Angle 2ω = 12.35° F-number = 1:4.0
Magnification β = 0.∼−0.5X

	Radii of Curvature R	Axial Thicknesses and Separations D	Abbe Numbers νd	Indices of Refraction Nd
1	49.178	3.500	53.90	1.71300
2	−3447.931	0.100		1.
3	37.103	4.250	53.90	1.71300
4	−526.460	0.382		1.
5	−321.772	1.500	26.60	1.76182
6	49.104	4.269		1.
7	19.552	2.000	35.80	1.66446
8	16.425	D8		1.
9	−103.727	2.250	38.00	1.72342
10	−22.829	1.064	60.70	1.60311
11	208.160	5.419		1.
12	−1590.663	1.333	42.80	1.56732
13	29.947	D13		1.
14	−17.951	1.250	28.50	1.72825
15	−21.581	2.500		1.
16	66.671	3.250	53.90	1.71300
17	−61.480			

	Infinity	Close-up
D8	11.051	19.1026
D13	24.230	13.2308

* * * * *

United States Patent [19]

Nishio et al.

[11] **Patent Number: 4,505,564**

[45] **Date of Patent: Mar. 19, 1985**

[54] **ROTATION CONTROL MECHANISM FOR DIAPHRAM-OPERATING RING IN INTERCHANGEABLE OBJECTIVE FOR PHOTOGRAPHIC CAMERA**

[75] Inventors: **Etsuro Nishio; Zenichi Okura,** both of Tokyo, Japan

[73] Assignee: **Asahi Kogaku Kogyo Kabushiki Kaisha,** Tokyo, Japan

[21] Appl. No.: **520,724**

[22] Filed: **Aug. 5, 1983**

[30] **Foreign Application Priority Data**

Aug. 16, 1982 [JP] Japan ..... 57-123842[U]

[51] **Int. Cl.**[3] **G03B 9/02**

[52] **U.S. Cl.** **354/270**

[58] **Field of Search** 354/270–274; 350/449, 450

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Primary Examiner—John Gonzales

Attorney, Agent, or Firm—Christie, Parker & Hale

[57] **ABSTRACT**

An interchangeable objective with a variable lens aperture for a photographic camera has a stationary support member and a diaphragm-operating member that is rotatable about an axis between first and second angular positions relative to the stationary support member. A first spring-loaded locking pin is located in the stationary member in a first plane perpendicular to the axis. A second spring-loaded locking pin is located in the stationary member circumferentially spaced at an angle to the first pin about the axis and in a second plane perpendicular to the axis. The second plane is spaced from the first plane in the direction of the axis. As a result, the distance between locking pins is greater than the angular distance of rotation of the diaphragm-operating member between the end of the M-range and the A-position. A locking groove is formed in the diaphragm-operating member so as alternatively to receive the first and second spring-loaded pins in locking engagement when the diaphragm-operating member is positioned at the first and second angular positions, respectively. An unlocking button is mounted in the diaphragm-operating member over the locking groove to push the respective first and second pins out of engagement with the locking groove upon depression of the unlocking button.

6 Claims, 16 Drawing Figures

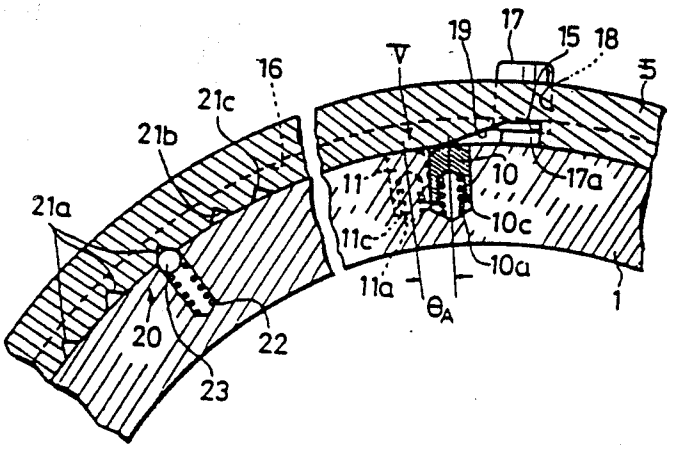


Fig. 1.

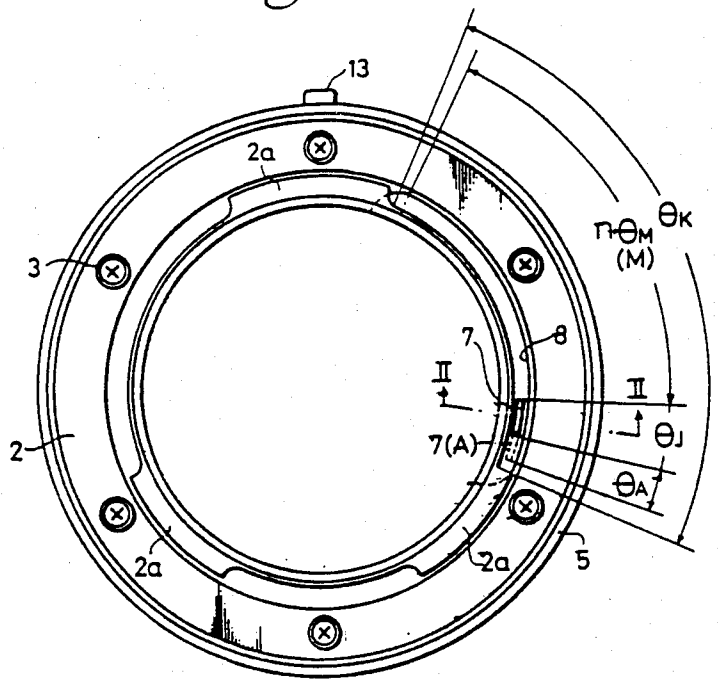


Fig. 2.

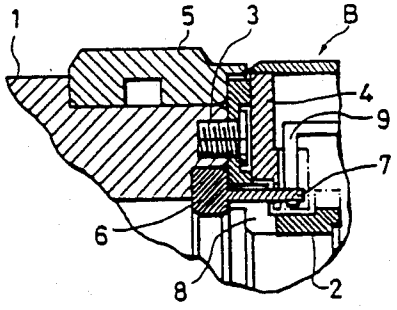


Fig.3.

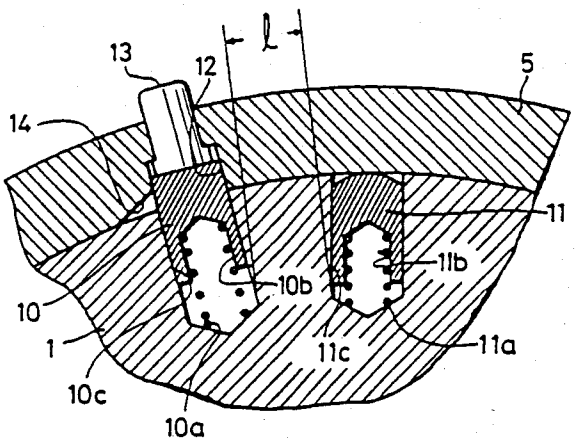


Fig.4.

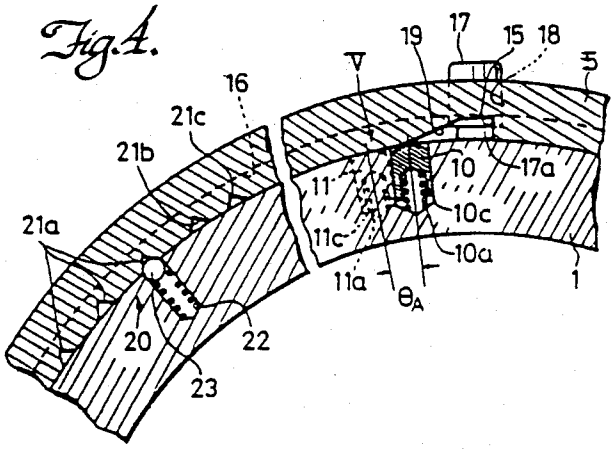


Fig.5.

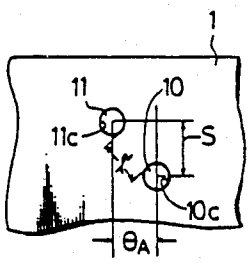


Fig.6.

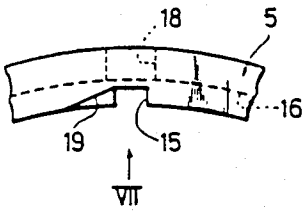


Fig.8.

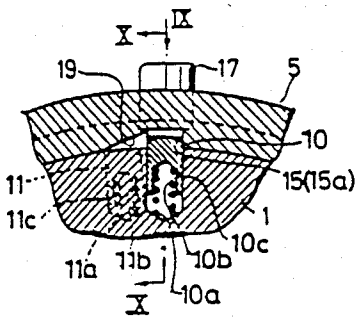


Fig.7.

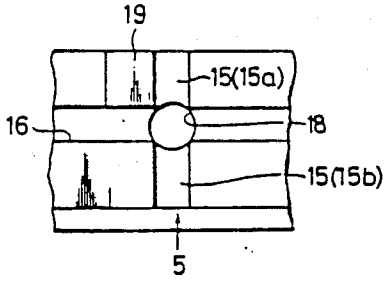


Fig.9.

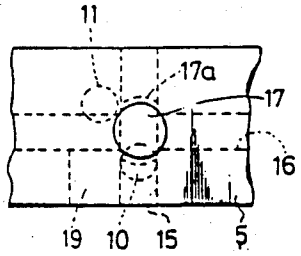


Fig.11.

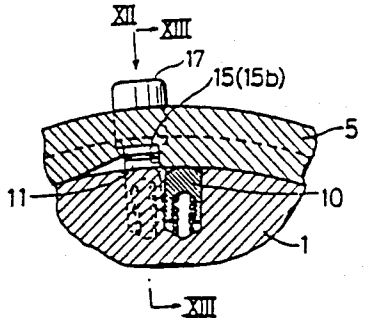


Fig.10.

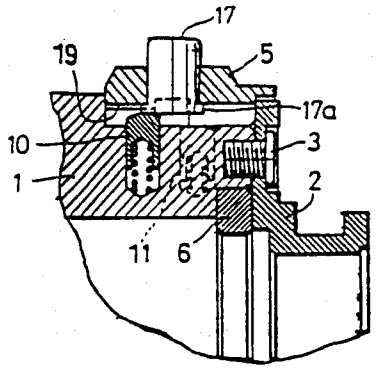


Fig.12.

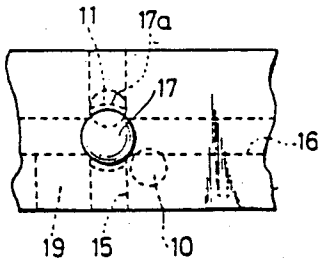


Fig.13.

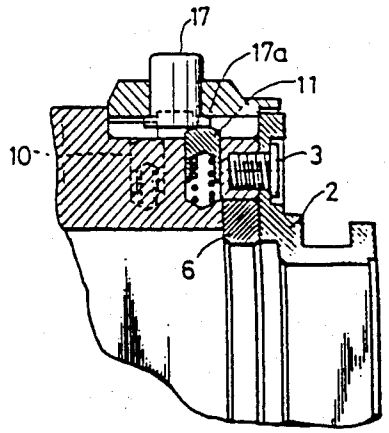


Fig.14.

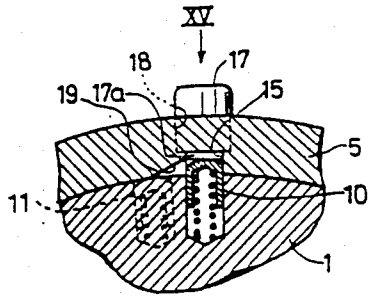


Fig.15.

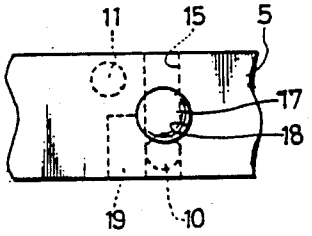
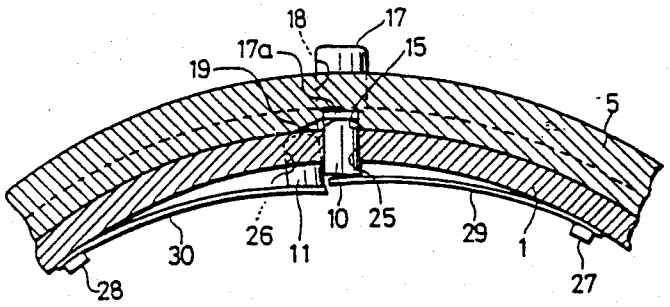


Fig.16.



ROTATION CONTROL MECHANISM FOR DIAPHRAM-OPERATING RING IN INTERCHANGEABLE OBJECTIVE FOR PHOTOGRAPHIC CAMERA

CROSS REFERENCE TO RELATED APPLICATIONS

This application is related to application Ser. No. 520,723, filed on even date herewith by Yoshihiro Hama, the disclosure of which is incorporated fully herein by reference.

BACKGROUND OF THE INVENTION

The present invention relates to an interchangeable objective provided with a diaphragm-operating ring which is rotatable between a rotatable range for diaphragm preset and a position for automatic diaphragm regulation and, more particularly, to a rotation control mechanism in such a ring for changeover between the rotatable range for diaphragm preset and the position for automatic diaphragm regulation.

A photographic camera of automatic exposure control type conventionally has a diaphragm priority mode in which a diaphragm value is preset by the user and a shutter speed for appropriate exposure is automatically regulated in the camera body, a shutter speed priority mode in which, inversely, a shutter speed is manually preset by the user and a lens aperture for appropriate exposure is automatically regulated, and a programmed mode in which a combination of diaphragm value and shutter speed is automatically regulated for appropriate exposure.

Interchangeable objectives used with a photographic camera adopting said three modes of automatic exposure control function or different exposure control functions must include a diaphragm-operating ring provided with a rotatable range for manually presetting the diaphragm value (referred to hereinafter as M-range) in said diaphragm priority mode and a position for automatic diaphragm regulation (referred to hereinafter as A-position) in said shutter speed priority mode and said programmed mode. Information as to whether the diaphragm-operating ring occupies the M-range or the A-position must be transferred to the camera body because different exposure control mechanisms are activated in these two cases.

Any unintentional changeover between the M-range and the A-position must be reliably prevented and, in consequence, a suitable changeover locking mechanism and unlocking mechanism are required. However, the structure peculiar to the lens barrel has made it difficult to obtain a large rotation angle for changeover between the end of the M-range and the A-position. This has given rise to various problems with respect not only to the strength of the objectives but also to the degree of freedom for their design.

SUMMARY OF THE INVENTION

According to the invention, a small rotation angle between the end of the M-range and the A-position is achieved comprising the strength of the objective or the degree of design freedom.

Specifically, an interchangeable objective with a variable lens aperture for a photographic camera has a stationary support member and a diaphragm-operating member that is rotatable about an axis between first and second angular positions relative to the stationary support member. A first spring-loaded locking pin is located in the stationary member in a first plane perpendicular to the axis. A second spring-loaded locking pin is located in the stationary member circumferentially spaced at an angle to the first pin about the axis and in a second plane perpendicular to the axis. The second plane is spaced from the first plane in the direction of the axis. As a result, the distance between locking pins is greater than the angular distance of rotation of the diaphragm-operating member between the end of the M-range and the A-position. A locking groove is formed in the diaphragm-operating member so as alternatively to receive the first and second spring-loaded pins in locking engagement when the diaphragm-operating member is positioned at the first and second angular positions, respectively. An unlocking button is mounted in the diaphragm-operating member over the locking groove to push the respective first and second pins out of engagement with the locking groove upon depression of the unlocking button.

BRIEF DESCRIPTION OF THE DRAWINGS

The features of specific embodiments of the best mode contemplated of carrying out the invention are illustrated in the drawings, in which:

FIG. **1** is a rear view of an objective's barrel showing by way of example how the M-range and the A-position of a diaphragm-operating ring are arranged;

FIG. **2** is a section taken along the line II—II in FIG. **1**, showing the objective's barrel of FIG. **1** as mounted onto a camera body;

FIG. **3** is a section showing the pertinent part of the prior art mechanism for changeover between the M-range and the A-position;

FIG. **4** is a section showing the pertinent part of the mechanism in an embodiment of the present invention;

FIG. **5** is a view of part of a diaphragm-operating ring as seen in the direction of an arrow V in FIG. **4**;

FIG. **6** is a front view showing the pertinent part of the diaphragm-operating ring;

FIG. **7** is a view of part of the diaphragm-operating ring as seen in the direction of an arrow VII in FIG. **6**;

FIGS. **8** through **10** show the diaphragm-operating ring in the lens barrel as held at the minimum lens aperture position within the M-range, FIG. **8** being a section of the pertinent part, FIG. **9** being a partial view as seen in the direction of an arrow IX in FIG. **8**, and FIG. **10** being a section taken along the line X—X in FIG. **8**;

FIGS. **11** through **13** show the diaphragm-operating ring in the lens barrel as held at the A-position, FIG. **11** being a section of the pertinent part, FIG. **12** being a partial view as seen in the direction of an arrow XII in FIG. **11** and FIG. **13** being a section taken along the line XIII—XIII in FIG. **11**;

FIG. **14** is a section showing the pertinent part of another embodiment of the present invention;

FIG. **15** is a partial view as seen in the direction of an arrow XV in FIG. **14**; and

FIG. **16** is a section showing the pertinent part of further another embodiment of the present invention.

DETAILED DESCRIPTION OF THE SPECIFIC EMBODIMENTS

In FIGS. **1** through **3**, which describe prior art, a mount ring **2** is integrally connected by screws **3** to a stationary mount support ring so that this mount ring **2** is detachably engaged into a mount ring **4** provided on

the camera body B. A diaphragm-operating ring **5** is rotatably mounted around the outer periphery of the mount support ring **1** and a diaphragm-rotating ring **6** adapted to be rotated integrally with this diaphragm-operating ring **5** is rotatably supported between said mount support ring **1** and the mount ring **2**. The diaphragm-rotating ring **6** is provided with a diaphragm information transferring lever **7** projecting from a part of said diaphragm-rotating ring **6** and this diaphragm information transferring lever **7** extends through a circular arc notch **8** of the mount ring **2** toward the camera body B and engages with a diaphragm information receiving lever **9** provided within the camera body. The diaphragm information receiving lever **9** is operatively associated with a variable resistor (not shown) of an automatic exposure control circuit and generates an electric signal corresponding to the angular position of the diaphragm-operating ring **5**. As represented in FIG. **1**, the following information is given to the camera body: (1) whether diaphragm information transferring lever **7** lies within the M-range, i.e., the diaphragm preset, or on the A-position, and (2) what diaphragm value is assumed by said diaphragm information transferring lever **7** within the M-range.

Referring to FIG. **3** showing by way of example the well known changeover mechanism for changing over between the M-range and the A-position, the mount support ring **1** is provided at a position corresponding to one rotational end in the M-range (e.g., the minimum lens aperture) and at a position corresponding to the A-position with radially extending rotation control pins **10, 11** respectively, which are retractable and outwardly biased by compression coiled springs **10***a*, **11***a*, respectively. The diaphragm-operating ring **5** is provided in the inner surface with a locking groove **12** adapted to receive these rotation control pins **10, 11** and supports an unlocking button **13** adapted for inwardly displacing these pins **10, 11** against the biasing effect of said compression coiled springs **10***a*, **11***a*. Reference numeral **14** designates a tapered flank, i.e., a ramp, allowing rotation of the diaphragm-operating ring **5** within the M-range.

With such prior art changeover mechanism, it has been possible to assure good operation without any problem when the distance l between the rotation control pins **10, 11** (FIG. **1**), i.e., the rotation angle for changeover between the M-range and the A-position is large. However, when the distance l is small, various problems are created such as insufficient strength of the rotation control pins **10, 11** and a restricted degree of freedom for the design.

Accordingly, the present invention provides an interchangeable objective in which the angle for changeover between the M-range and the A-position can be effectively reduced. Specifically, the mount support ring is provided respectively at the position corresponding to the one rotational end within the M-range and at the position corresponding to the A-position with two rotation control pins which are displaceable in the direction of the optical axis. Both rotation control pins can be resiliently biased into the locking groove formed in the diaphragm-operating ring, and said two rotation control pins can be depressed by the single unlocking member out of said locking groove to its initial position.

First, a procedure for determining the rotation angle for changeover between the M-range and the A-position and reasons why this angle should be made relatively small will be explained on the basis of specific numerical data. The rotatable range of the diaphragm information transferring lever **7** is limited by angle θ_k (FIG. **1**) defined by the angle between each pair of adjacent claws **2***a* formed in the mount ring **2**. This angle θ_k depends on factors as following:

(1) number of the claws **2***a* formed in the mount ring **2**

The number of points necessary for definition of a plane is three and the number of the claws also is preferably three. Thus it is assumed here that three claws are formed in this embodiment.

(2) positions of the claws **2***a* in the mount ring **2**

These three claws **2***a* should be positioned at irregular intervals, which permits the mount ring to be received in the mount ring of the camera body at only one angular position. However, putting these claws at irregular intervals tends to bring the optical axes of the objective and the camera body out of mutual alignment. To meet these mutually contradictory requirements, the claws **2***a* are arranged at intervals of 130°, 115°, and 115°.

(3) operating angle for mounting or detaching of objective and angular dimension of the claws

The operating angle, i.e., the amount of rotation required for mounting the objective onto the camera body depends on the intervals at which the claws **2***a* are arranged. When the angular dimension of each claw on the objective corresponds to the angular dimension of each claw on the camera body, the angular dimension of the claw must be less than one half of said 130° or 115°, as the case may be. Accordingly, the operating angle for mounting or detaching the objective will be more than one-half or 130° or 115°, for example, 70° or 60°. The angular dimension of every claw will be 50° with an allowance of 5° for mounting the objective onto the camera body.

(4) angular dimension θ_k of the notch formed between the claws **2***a*

It is preferred that the diaphragm information transferring lever **7** is rotatable within a range as wide as possible. Thus, the notch **8** is formed between the pair of claws **2***a* which are arranged at an interval of 130°. The angle θ_k therefore corresponds to the interval between the claws minus the claw angular dimension, i.e., $130° - 50° = 80°$.

The diaphragm information transferring lever **7** has its rotatable range of 75° with an allowance of 2.5° (circumference length of 1 mm with a radius of 23 mm) toward the maximum lens aperture and the A-position, respectively.

Within such range, the angle θk over which the diaphragm information transferring lever **7** can be rotated from the minimum lens aperture in the M-range to the A-position depends further upon the factor mentioned in the following paragraph.

(5) angle θ_J of the diaphragm information transferring lever **7** itself

The diaphragm information transferring lever must have a sufficient strength for exact transfer of diaphragm information. When such requirement is satisfied by a transferring lever having a circumferential length of 4 mm with a radius of 23 mm, the angle θ_J is obtained by

$$\theta_J = \frac{4 \times 360°}{23 \times 2 \times \pi} = 10°$$

(6) number of steps n from the maximum lens aperture to the minimum lens aperture within the M-range

The exposure control circuit in the camera body receives the diaphragm information within the M-range as the number of steps from the maximum lens aperture to an actually used diaphragm value (five steps when the maximum lens aperture is 1.4 and the actually used diaphragm value is 8). There are 9.5 steps for an objective having a maximum lens aperture of 1.2 and a minimum lens aperture of 32, so that such objective must be able to accommodate 10 steps, i.e., $n=10$.

(7) rotation angle θ_M of the diaphragm information transferring lever 7 per unit diaphragm value

As the minimum unit of diaphragm information, $\frac{1}{3}$ step must be reliably transferred to the exposure control circuit. Assuming that this requirement is satisfied with a circumferential displacement of the variable resistor of 1 mm, said variable resistor having a radius of 28 mm, $\frac{1}{3}\theta_M$, the rotation angle corresponding to $\frac{1}{3}$ step is obtained by

$$\frac{1}{3}\theta_M = \frac{1 \times 360^\circ}{28 \times 2 \times \pi} = 2^\circ$$

Accordingly, the rotation angle θ_M of the diaphragm information transferring lever itself per unit diaphragm value is 6°.

(8) rotation angle θ_A of the diaphragm information transferring lever 7 from the minimum lens aperture to the A-position within the M-range

$\theta_A = 75^\circ - \theta_J - n\theta_M$.

This gives

$\theta_A = 75^\circ - 10^\circ - 10 \times 6^\circ = 5^\circ$.

Thus the rotation angle θ_A is limited to an angle as small as 5°. Assuming that, in the prior art mechanism as shown in FIG. **3**, the rotation control pins **10, 11** are formed with holes **10***b*, **11***b* respectively having diameters of 1.5 mm to receive the compression coiled springs **10***a*, **11***a*, respectively, said pins **10, 11**, must have diameters of at least 2 mm. With the diaphragm-operating **5** having an inner radius of 28 mm, and holes **10***c*, **11***c* adapted to receive the pins **10, 11**, respectively, which are 3 mm deep, the distance l between said holes **10***c* and **11***c* is obtained by

$$l = \frac{(28 - 3) \times 2 \times \pi}{360^\circ} \times 5 - 2 = 0.2 \text{ mm}$$

when θ_A is 5°. If θ_A is so limited to 5°, the distance between the holes **10***c* and **11***c* is 0.2 mm at the narrowest position. In consequence, there is a danger that these holes **10***c*, **11***c* formed in the mount support ring **1** might be destroyed, for example, as the user violently rotates the diaphragm-operating ring **5** when the objective is mounted on the camera body.

According to the present invention, the two rotation control pins **10, 11** are spaced from each other in the direction of the optical axis, as seen in FIGS. **4** and **5**, so as to give the mount support ring **1** sufficient strength, even when the angle θ_A is as small as mentioned above. Specifically, the mount support ring **1** is provided at positions circumferentially spaced from each other by an angular distance corresponding to the rotation angle for changeover between the M-range and the A-position set as above mentioned and by a distance S in the direction of the optical axis also with two radial pin guide holes **10***c*, **11***c* adapted to receive the associated rotation control pins **10, 11** which are, in turn, outwardly biased under action of the compression coiled springs **10***a*, **11***a*, respectively.

The diaphragm-operating ring **5** is provided along its inner peripheral surface with a locking groove **15** extending in the direction of the optical axis to receive said rotation control pins **10, 11**. This locking groove **15** is separated by a circumferential relief groove **16**, which is necessary for machining, into a groove portion **15***a* and a groove portion **15***b* adapted to receive said rotation control pin **10** and said rotation control pin **11**, respectively. There is formed a guide hole **18** radially extending through the diaphragm-operating ring **5** at the intersection of said locking groove **15** and said relief groove **16** for slidably guiding an unlocking button **17**, which is, in turn, provided at the bottom with an extension place **17***a* extending transverse to the unlocking button over the two rotation control pins and lying within the locking groove **15** so that the plate **17***a* may bear against the heads of said two rotation control pins **10, 11**, respectively.

The rotation control pins **10, 11** serve the same function previously mentioned in reference to the well known embodiment, to hold the diaphragm-operating ring **5** against one rotational end (the minimum lens aperture) in the M-range when the pin **10** is received in the locking groove portion **15***a* and to hold said diaphragm-locking operating ring at the A-position when the other pin **11** is received in the locking groove portion **15***b*. Said locking groove portion **15***a* is formed with a tapered flank **19** allowing rotation of the diaphragm-operating ring **5** toward the maximum lens aperture of the M-range.

As shown in FIG. **4**, there is provide a click-stop mechanism **20** between the diaphragm-operating ring **5** and the mount support ring **1**. In this mechanism, the diaphragm-operating ring **5** is provided in the inner peripheral surface with click-grooves **21***a* corresponding to diaphragm value graduations other than the minimum lens aperture, a click-groove **21***b* corresponding to the minimum lens aperture and a click groove **21***c* corresponding to the A-position graduation, while the mount support ring **1** is provided with a click-ball **23** adapted to be received in these click-grooves under a biasing effect of a compression coiled spring **22**. It will be understood that the rotation control pin **10** is received in the locking groove **15** when the click-ball **23** is received in the click-groove **21***b* and the rotation control pin **11** is received in the locking groove **15** when said click-ball **23** is received in the click-groove **21***c*. The mechanism by which the lens aperture is adjusted by rotation of the diaphragm-operating ring **5** is well known and constitutes no part of the present invention. Thus, such mechanism will not be described in detail.

With the interchangeable objective constructed according to the present invention as has been described above, the changeover from the M-range to the A-position can be achieved by depression of the unlocking button **17**. Such changeover from the M-range to the A-position never occurs so long as said unlocking button **17** is not depressed. When the diaphragm-operating ring **5** is rotated to the minimum lens aperture within the M-range, the rotation control pin **10** is received in the locking groove **15** (more specifically, the groove portion **15***a*) as seen in FIGS. **8** through **10**, and thereby

said diaphragm-operating ring **5** is prevented from being further rotated. For rotational adjustment to the A-position, the unlocking button **17** is depressed so as to retract the rotation control pin **10** out of the locking groove **15***a* and then the diaphragm-operating ring may be rotated to the A-position. Then the rotation control pin **11** is received in the locking groove **15** (more specifically, the groove portion **15***b*), and thereby the diaphragm-operating ring **5** is prevented from rotating toward the M-range (as seen in FIGS. **11** through **13**). Changeover from the A-position to the M-range can also be achieved by a similar operation.

The rotation control pins **10, 11** are spaced from each other in the direction of the optical axis according to the present invention, so that the mount support ring **1** maintains the desired strength even when there is available a very small rotation angle for changeover between the M-range and the A-position. Assuming that such rotation angle θ_A for changeover is 5° and the rotation control pins **10, 11** having diameters of 2 mm are spaced from each other by 3 mm center-to-center in the direction of the optical axis, while the diaphragm-operating ring **5** has its inner radius of 28 mm and the pin guide holes **10***c*, **11***c* are 3 mm deep, the minimum aceptable dimension l′ between these guide holes **10***c*, **11***c* is obtained by

$$l' = \sqrt{\left[\frac{(28-3)\times 2\times \pi}{360}\times 5\right]^2 + 3^2} - 2 = 1.7 \text{ mm.}$$

This value is sufficient to maintain the desired strength of the mount support ring **1**.

The embodiment as has been described hereinabove adopts formation of the tapered flank **19** on the diaphragm-operating ring **5**, and, for convenience in machining such tapered flank **19**, there is provided the circumferential relief groove **16**. However, said circumferential relief groove **16** is not necessary, as seen in FIGS. **14** and **15**, when the diaphragm-operating ring **5** including the grooves and flanks comprises a molded synthetic resin or a die cast piece. Biasing of the rotation control pins **10, 11** may be achieved also by, instead of the compression coiled springs, leaf springs **29, 30** fixed at one end by pins **27, 28** respectively, on the inner peripheral surface of the support ring **1** so that the free ends of said leaf springs **29, 30** depress against the lower end surfaces of the rotation control pins **10, 11** inserted into associated through-holes **25, 26** formed in the support ring **1**, as shown in FIG. **16**. It should be noted that the mount support ring **1**, in accordance with the present invention, is a non-rotatable, i.e., stationary, member adapted for support of the diaphragm-operating ring **5**.

The two rotation control pins used for changeover of the diaphragm-operating ring between the M-range and the A-position are speced from each other in the direction of the optical axis in accordance with the present invention. In this way, the supporting member for the diaphragm-operating ring, i.e., the mount support ring **1** can maintain the necessary strength even when the rotation angle for changeover is relatively small. Furthermore, the distance between these two rotation control pins as measured in the direction of the optical axis can be adjusted for every objective in consideration of factors such as the length of the diaphragm-operating ring as measured in the direction of the optical axis. The degree of freedom for design inclusive of dimensioning of the M-range is effectively improved.

What is claimed is:

1. An interchangeable objective with a variable lens aperture for a camera comprising:

a stationary support member;

a diaphragm-operating member rotatable about an axis between first and second angular positions relative to the stationary support member;

a first spring loaded locking pin located in the stationary member in a first plane perpendicular to the axis;

a second spring loaded locking pin located in the stationary member circumferentially spaced at an angle with the first pin about the axis and in a second plane perpendicular to the axis, the second plane being spaced from the first plane in the direction of the axis;

a locking groove formed in the diaphragm-operating member so as alternatively to receive the first and second locking pins in locking engagement when the diaphragm-operating member is positioned at the first and second angular positions, respectively; and

an unlocking button mounted in the diaphragm-operating member over the locking groove to push the respective first and second pins out of engagement with the locking groove upon depression of the unlocking button.

2. The interchangeable objective of claim **1**, in which the first and second locking pins lie retractably in respective first and second bores formed in the stationary member, coil springs biasing the respective locking pins toward the diaphragm-operating member.

3. The interchangeable objective of claim **1**, in which the first and second locking pins retractably lie in respective first and second bores formed in the support member, leaf springs biasing the respective pins toward the diaphragm-operating member.

4. The interchangeable objective of claim **1**, in which the locking groove extends parallel to the axis spanning the distance between the first and second planes and the unlocking button has an extension plate in the locking groove sufficiently long to alternatively engage the first and second pins when the first and second pins lie in the locking groove.

5. The interchangeable objective of claim **4**, in which the locking groove has a tapered flank on one side to permit the diaphragm-operating member to continue to rotate away from the second angular position when the locking groove receives the first locking pin, the first angular position representing one end of an M-range and the second angular position representing an A-position.

6. The interchangeable objective of claim **5**, additionally comprising a plurality of click-grooves on one member and a click-ball on the other member that individually engages the click-grooves in the M-range depending on the lens aperture.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 4,505,564

DATED : March 19, 1985

INVENTOR(S) : Etsuro Nishio; Zenichi Okura

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 6, line 30, "diaphragm-locking operating ring" should read -- diaphragm-operating ring --.

Column 8, line 5, insert the following paragraph:

-- The disclosure of Japanese Utility Model Application No. 1982-123842, Japanese Utility Model Gazette No. 59 (1984)-27530, laid open February 21. 1984, is incorporated fully by reference. --

Signed and Sealed this

Sixth Day of January, 1987

Attest:

Attesting Officer

DONALD J. QUIGG

Commissioner of Patents and Trademarks

United States Patent [19]

Schlapp et al.

[11] **Patent Number: 4,504,134**

[45] **Date of Patent: Mar. 12, 1985**

[54] **PHOTOGRAPHIC OBJECTIVE WITH AUTOMATIC DIAPHRAGM**

[75] Inventors: **Werner Schlapp**, Asslar; **Werner Wiessner**, Wetzlar, both of Fed. Rep. of Germany

[73] Assignee: **Ernst Leitz Wetzlar GmbH**, Wetzlar, Fed. Rep. of Germany

[21] Appl. No.: **538,967**

[22] Filed: **Oct. 4, 1983**

[30] **Foreign Application Priority Data**

Oct. 6, 1982 [DE] Fed. Rep. of Germany 3236958

[51] **Int. Cl.**[3] **G03B 9/07**

[52] **U.S. Cl.** **354/272**; 354/152; 354/274

[58] **Field of Search** 354/152, 270, 272, 274

[56] **References Cited**

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Primary Examiner—A. A. Mathews

Attorney, Agent, or Firm—Schwartz, Jeffery, Schwaab, Mack, Blumenthal & Koch

[57] **ABSTRACT**

A compensating mechanism is provided on the leaf guide ring of a photographic objective for single-lens mirror reflex camera which opens to its largest value after a picture is taken in response to the hinge motion of the camera reflex mirror. The mechanism compensates for the advance of the diaphragm control lever on the camera side controlled by the reflex mirror.

6 Claims, 2 Drawing Figures

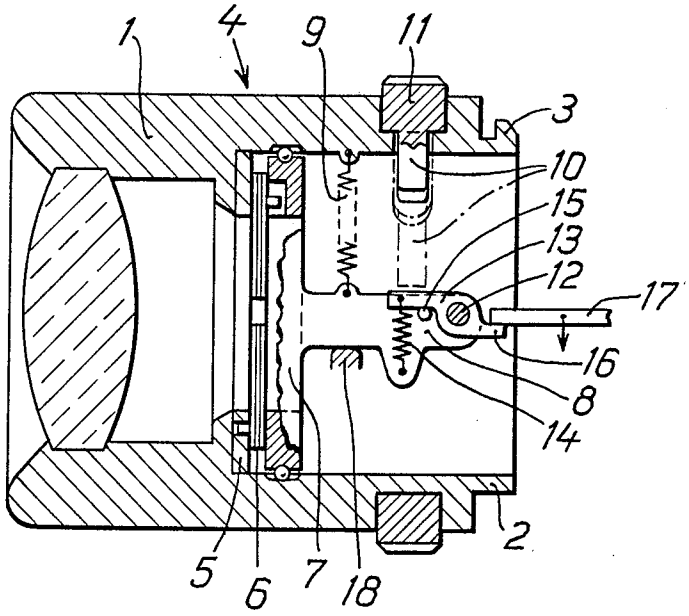


Fig. 1

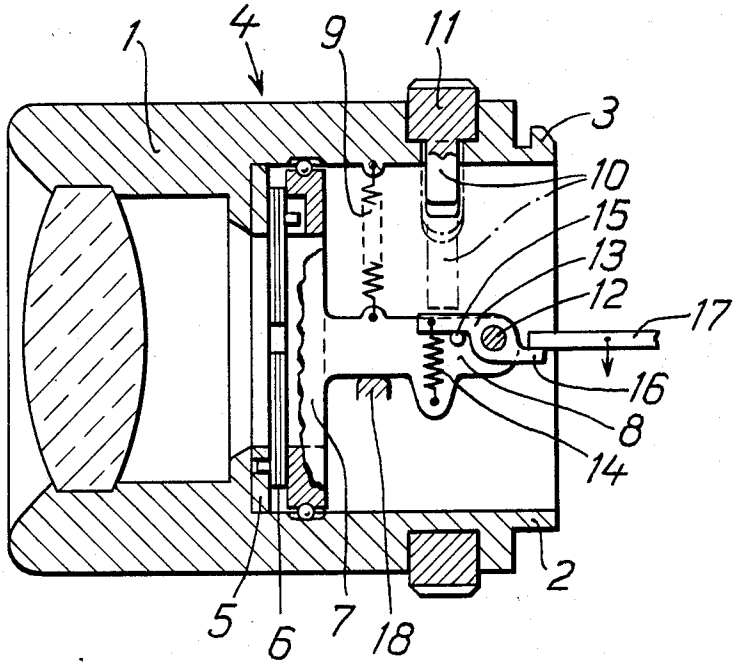
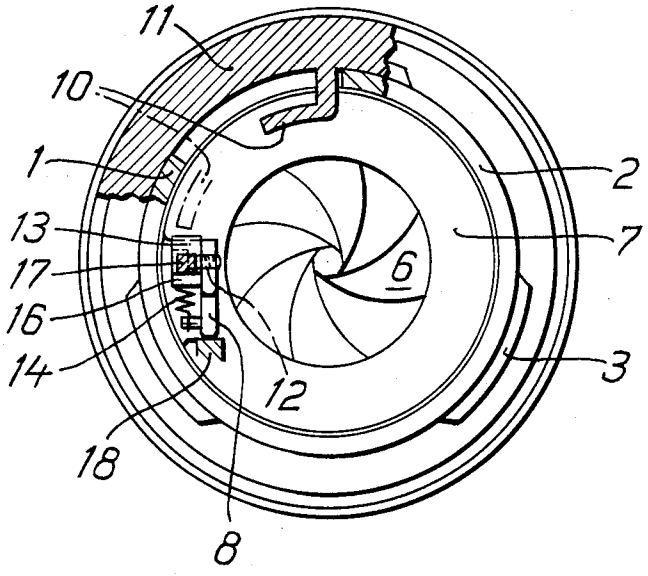


Fig. 2



PHOTOGRAPHIC OBJECTIVE WITH AUTOMATIC DIAPHRAGM

BACKGROUND OF THE INVENTION

The present invention relates to a photographic objective for single-lens mirror reflex cameras with a preselector iris system and with an automatic diaphragm comprising a spacially fixed leaf support ring supporting the diaphragm leaves as well as a leaf guide ring rotatable relative to the leaf support ring, and wherein, after a picture is taken, the automatic diaphragm opens to its largest value depending on the hinge motion of the reflex mirror.

After a picture has been taken, the reflex mirror performs an advance, that is a motion larger than required for opening the diaphragm to the full value. The advance assures that the hinge motion of the reflex mirror is sufficient to reach the largest opening value of each objective employed with the mirror reflex camera. The advance has to be compensated for in order to avoid damage occurring in the region of the diaphragm.

In order to compensate for the advance, it is known to provide the guide grooves of the leaf guide ring such that, on one hand, they cause a rapid closing of the diaphragm and, on the other hand, they effect little or no further motion of the diaphragm leaves after the leaves reach the largest opening which could be achieved under control of the diaphragm lever on the side of the camera. Such overflow curves at guide grooves can only be realized with objectives having a short or average focusing length without resulting in disadvantages relative to delays in the closing of the diaphragm. In contrast, objectives with longer focusing lengths and with openings relatively large with respect to this are furnished with leaf guide rings. The guide grooves of the leaf guide rings in fact allow a rapid closing of the diaphragm before the start of the camera shutter operating cycle, but they permit a compensation of the advance of the reflex mirror only under certain technical preconditions.

SUMMARY OF THE INVENTION

An object of the present invention is to provide a photographic objective for a single-lens mirror reflex camera which compensates for the reflex mirror advance.

Another object of the present invention is to provide a photographic objective with compensation for the mirror advance in which the compensation is effected relatively inexpensively and without using overflow curves following the guide grooves.

In accordance with the above and other objects, the present invention is a photographic objective provided with means on the leaf guide ring by way of which the advance of the diaphragm control lever on the camera side controlled by the reflex mirror is compensated.

The photographic objective comprises a diaphragm preset system and an automatic diaphragm. The automatic diaphragm comprises iris blades, a spacially fixed leaf support ring supporting the iris blades and a leaf guide ring rotatable relative to the leaf support ring. The automatic diaphragm is adapted to open to its largest possible value after a picture is taken in response to motion of the reflex mirror transmitted through a diaphragm control lever. A compensating structure is connected to the leaf guide ring for compensating for an advance of the diaphragm control lever whereby after

the diaphragm control lever has moved sufficiently to cause the automatic diaphragm to open to its largest possible value, further motion of the diaphragm control lever does not affect the automatic diaphragm.

In accordance with other aspects of the invention, the diaphragm control lever directly engages the compensating structure.

The compensating structure may comprise a tiltable rocking lever mounted to turn about an axis attached to the leaf guide ring, and a spring attached to bias the rocking lever. The rocking lever is rotated against the spring bias in response to the advance.

The automatic diaphragm includes a spring connected to bias the automatic diaphragm to a closed position. The spring force of the spring connected to said tiltable lever is greater than the spring force of the spring closing the automatic diaphragm.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and other objects will become more readily apparent as the invention becomes more fully understood in connection with the detailed description to follow, reference being had to the accompanying drawings in which like reference numerals represent like parts throughout, and which:

FIG. **1** is a side elevational sectional view of the tube body of a photographic objective; and

FIG. **2** is a rear part fragmentary view of the tube body according to FIG. **1**.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

A tube body **1** of a photographic objective, schematically shown in FIG. **1**, can be attached with a bayonet **3** disposed at its rear end **2** to a single-lens mirror reflex camera (not shown).

An automatic diaphragm **4** is disposed in the tube body **1**. The automatic diaphragm comprises a spacially fixed leaf support ring **5**, diaphragm blades **6** supported at the ring **5**, and a leaf guide ring **7** rotatable relative to the leaf support ring **5**. The automatic diaphragm **4** opens and closes in a known manner by tilting the diaphragm blades **6** upon a relative rotation between the leaf support ring **5** and the leaf guide ring **7**.

The automatic diaphragm **4** is maintained at a selected opening diameter by a tension spring **9** attached between the tube body **1** and a diaphragm catch **8**. Catch **8** is formed integrally in a single piece with the leaf guide ring **7**. The size of the opening diameter is determined by a stop **10** of a diaphragm stop ring **11** disposed on the outer circumference of the tube body **1**. At the selected opening, the diaphragm catch **8** is held against the diaphragm stop ring **11** by tension spring **9**.

A rocking lever **13** is tiltable around an axis **12** attached to the diaphragm catch **8**. Rocking lever **13** is positioned at the end of the diaphragm catch **8** disposed closest the mirror reflex camera. The rocking lever **13** is pulled by a tension spring **14** against a stop **15** on the diaphragm catch **8**. As would be apparent to one of ordinary skill in the art, the tension spring **14** can be replaced by other biasing devices, such as a torsion spring acting on the rocking lever **13** and placed around the axis **12**. The force of the spring acting on the rocking lever **13** is designed to be larger than the force of the spring **9** closing the automatic diaphragm **4**.

A diaphragm control lever **17** engages the free end **16** of the rocking lever **13**. The diaphragm control lever **17**

is mechanically linked to the hinge mirror of the mirror reflex camera (not shown) to transmit force from the hinge mirror to the automatic diaphragm **4**. The relative motion between the leaf support ring **5** and the leaf guide ring **7** is effected via the hinge motion of the reflex mirror through diaphragm control lever **17** after a picture has been taken. The diaphragm catch **8** contacts a stop **18** after reaching the largest diaphragm opening. The advance of the diaphragm control lever is now compensated by lifting the rocking lever **13** from the stop **15** against the force of the spring **14** and by turning the rocking lever around the axis **12** while maintaining the force transmitting coupling between the diaphragm control lever **17** and the free end **16** of the rocking lever **13**.

The foregoing description is presented to illustrate the present invention but is not deemed to limit the scope thereof. Clearly, numerous modifications can be made to the invention without departing from the scope thereof as defined in the appended claims.

What is claimed is:

1. Photographic objective for a single-lens mirror reflex camera having a reflex mirror and a diaphragm control lever for transmitting force from said reflex mirror to said objective, said objective comprising:

a diaphragm preset system;

an automatic diaphragm comprising:

iris blades;

a spacially fixed leaf support ring supporting said iris blades; and

a leaf guide ring rotatable relative to the leaf support ring, said automatic diaphragm being adapted to open to its largest possible value after a picture is taken in response to motion of the reflex mirror transmitted through said diaphragm control lever; and

means connected to said leaf guide ring for compensating for an advance of said diaphragm control lever whereby after said diaphragm control lever has moved sufficiently to cause said automatic diaphragm to open to its largest possible value, further motion of said diaphragm control lever does not affect said automatic diaphragm.

2. Photographic objective according to claim **1**, wherein said diaphragm control lever directly engages said compensating means.

3. Photographic objective according to claim **1**, wherein said compensating means comprises a tiltable rocking lever mounted to turn about an axis attached to said leaf guide ring, and a spring attached to bias said rocking lever, said rocking lever being rotated against said spring bias in response to said advance.

4. Photographic objective according to claim **2**, wherein said compensating means comprises a tiltable rocking lever mounted to turn about an axis attached to said leaf guide ring and a spring attached to bias said rocking lever, said rocking lever being rotated against said spring bias in response to said advance.

5. Photographic objective according to claim **3**, wherein said automatic diaphragm includes a spring connected to bias said automatic diaphragm to a closed position, and the spring force of the spring connected to said tiltable lever is greater than the spring force of the spring closing the automatic diaphragm.

6. Photographic objective according to claim **4**, wherein said automatic diaphragm includes a spring connected to bias said automatic diaphragm to a closed position, and the spring force of the spring connected to said tiltable lever is greater than the spring force of the spring closing the automatic diaphragm.

* * * * *

United States Patent [19]

Aklin, deceased et al.

[11] **Patent Number: 4,494,829**

[45] **Date of Patent: Jan. 22, 1985**

[54] **CURVED FIELD PHOTOGRAPHIC OBJECTIVE**

[76] Inventors: **George H. Aklin, deceased,** late of Fairport, N.Y.; **Marie M. Aklin,** Voluntary Administrator, 2 Woodside Rd., Fairport, N.Y. 14450

[21] Appl. No.: **420,581**

[22] Filed: **Sep. 20, 1982**

[51] **Int. Cl.**[3] **G02B 9/62**

[52] **U.S. Cl.** **350/464;** 350/412; 350/450

[58] **Field of Search** 350/464, 412, 450

[56] **References Cited**

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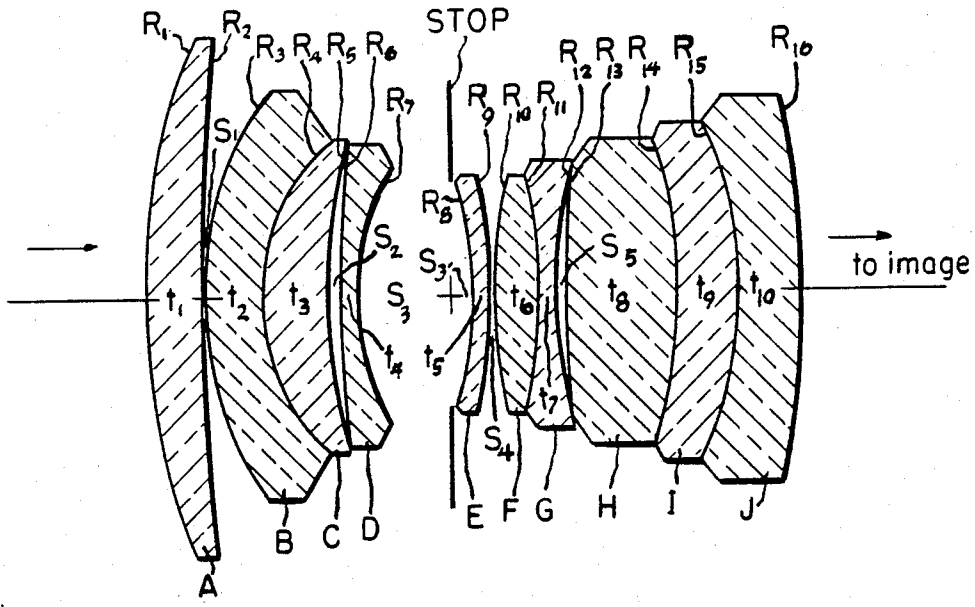
Primary Examiner—John K. Corbin
Assistant Examiner—Rebecca D. Gass

[57] **ABSTRACT**

The invention provides a highly corrected optical system comprising six groups consisting of ten elements, the indicies of refraction of which range from 1.654 to 1.807, the image surface being generally shallowly concave to the object.

2 Claims, 4 Drawing Figures



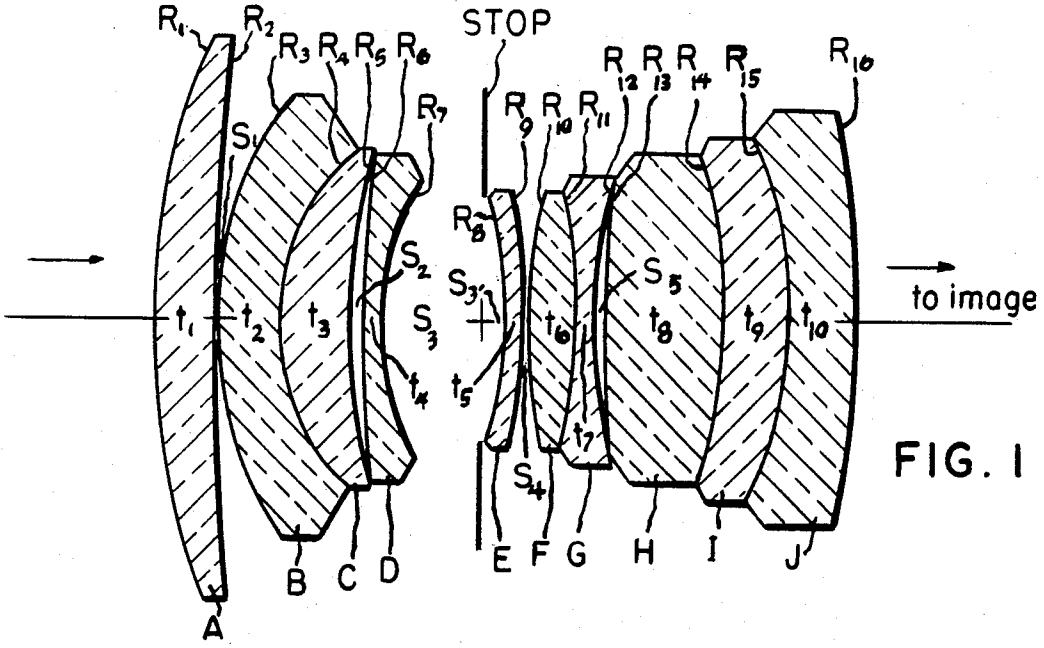


FIG. 1

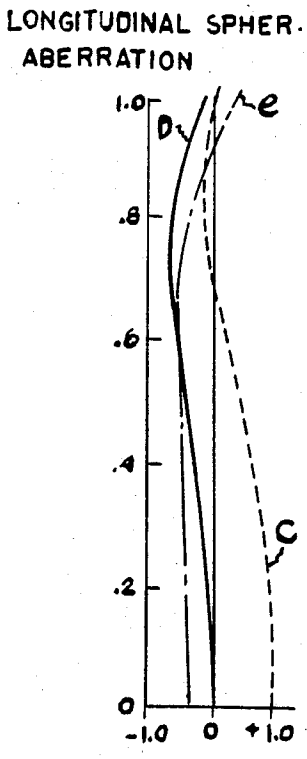


FIG. 2

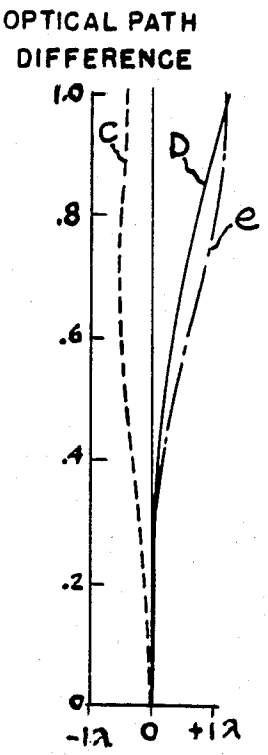


FIG. 3

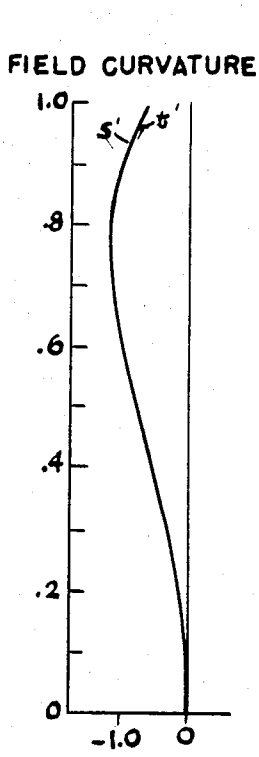


FIG. 4

CURVED FIELD PHOTOGRAPHIC OBJECTIVE

BACKGROUND OF THE INVENTION

The invention relates to photographic objectives of moderate aperture and high correction particularly suitable for aerial photography.

SUMMARY OF THE INVENTION

The improved lens system of the invention consists of four elements in three components forward of the stop and six elements in three components rearwardly of the stop. The elements forward of the stop, in order from the object space, are a positive singlet, a positive cemented doublet and a negative singlet, all surfaces of which are concave to the stop. Rearwardly of the stop are, in order, a negative meniscus concave to the stop, a cemented doublet in the form of a meniscus convex to the stop of comprising a biconvex and a biconcave element, and a biconvex cemented triplet comprising a biconvex element, a positive meniscus and a negative meniscus, the two latter elements being concave to the stop.

This arrangement yields a lens having a relative aperture of f/2.8 and a semi-field of 25.5 degrees producing a substantially astigmatism-free image with extremely low chromatic aberration and low distortion. The very low lateral color achieved herein results from the careful choice of indices and dispersions of the glasses used. Lateral color is less than one Airy disc anywhere in the field. The image surface is quasispherical, the maximum departure from a plane being approximately 1.2 mm at 0.7 field. For a 6 inch focal length lens the theoretical radius of curvature which the film must assume is approximately 1237 mm, an amount readily achieved with a field-curving camera back, and which leaves no residual deformation in the film after exposure. The actual radius of film curvature and the film position are arrived at experimentally to assure that the film intersects the surface of best imagery.

U.S. Pat. Nos. 2,343,627 and 2,771,817 previously issued to this applicant show curved-field lenses but with much more flare surrounding the off-axis images. Astigmatism in the lens of the present invention is virtually zero, the maximum difference between the sagittal and tangential fields of 0.025 mm at 0.9 field, being reduced to zero at 25½ degrees field, and with greatly reduced flare surrounding the off-axis image. Previous attempts to reduce the flare in a curved field lens were unsatisfactory.

A curved field lens and camera has also been described in a paper by Hopkins et al before the Optical Society of America in October 1948, the abstract of which appears in the Journal of the Optical Society of America, Vol. 38, No. 12, Dec. 1948, page 1102.

Other features and additional objectives of the invention will become apparent from the following description of preferred embodiment as illustrated in the accompanying drawing.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a conventional sectional view of the preferred embodiment of the lens

FIG. 2 shows the longitudinal spherical aberration for the lens for the C, D and e lines

FIG. 3 shows the optical path difference for the C, D and e lines

FIG. 4 shows the field curvature and the absence of astigmatism in the lens

The arrangement of the components as illustrated in FIG. 1 shows the position of the aperture stop in addition to showing all the lens elements. The construction is hybrid, the front groups being derived from the gauss type of lens and the rear groups from the quadruplet type.

The refractive index n_D and the Abbe number ν, together with the radii, thicknesses and spacings are shown in Table 1.

TABLE I

EFL = 152.40 · REL. APERT. f. 2.8 BACK FOCUS = 84.74

Element	radius	thickness & spacing	index n_D	ν
	$R_1 = +125.086$			
A		$t_1 = 10.616$	1.74931	35.0
	$R_2 = +442.245$			
		$S_1 = .25$		
	$R_2 = +65.984$			
B		$t_2 = 9.81$	1.67252	32.2
	$R_4 = +36.141$			
C		$t_3 = 12.205$	1.74500	46.4
	$R_5 = +104.861$			
		$S_2 = *$		
	$R_6 = +221.868$			
D		$t_4 = 2.80$	1.69875	30.1
	$R_7 = +46.207$			
		$S_3 = 17.327$ to stop $S_3' = 3.60$ stop to lens		
	$R_8 = -78.372$			
E		$t_5 = 2.77$	1.74931	35.0
	$R_9 = -93.697$			
		$S_4 = .25$		
	$R_{10} = +94.767$			
F		$t_6 = 7.75$	1.74500	46.4
	$R_{11} = -104.131$			
G		$t_7 = 2.53$	1.65429	33.7
	$R_{12} = +87.238$			
		$S_5 = **$		
	$R_{13} = +280.987$			
H		$t_8 = 19.368$	1.80785	40.7
	$R_{14} = -91.070$			
I		$t_9 = 10.914$	1.70166	41.0
	$R_{15} = -71.562$			
J		$t_{10} = 11.206$	1.71686	48.0
	$R_{16} = -184.989$			

*Edge contact at 26.5 mm semi aperture
**Edge contact at 22.0 mm semi aperture

The unusually high state of correction results from a number of factors including the use of high index glasses, none of the elements having an index lower than 1.654. Most of the glasses have relatively low dispersions for their index of refraction, the highest dispersion glass being Schott SF15 with a V-number of 30.1 used in meniscus element D. Another factor is the use of a majority of surfaces which are concave to the stop. All elements forward of the stop are concave to the stop, while all but two surfaces behind the stop are concave to the stop. Still another factor is the relatively shallow curvature of the surfaces immediately before and behind the stop, r_7 and r_8. In conventional lenses these radii are far steeper, as for example in the conventional double gauss lens in which the ratios of the radii of the forward and rearward surfaces adjacent the stop to the focal length of the objective are almost always between 0.29 and 0.40 respectively. In the present invention the ratios of r_7 and r_8 are 0.303 and 0.514 respectively.

An additional feature is the +, +, − arrangement of the rear cemented triplet in which the biconvex element H has considerably higher index relative to meniscus

element I, but with almost the same dispersion. The triplet can be separated at the last cemented surface with good results, but it has been found equally good or better results are achieved by cementing the last element with the additional advantage of simplifying manufacture. It should also be noted that the axial glass path is usually large; approximately 78% of the distance from the front vertex to the rear vertex is through glass. At the edge of the 25.5 degree semi field the illumination is 31.34%.

It is obvious from the disclosure given above that variations and modifications of the given example will suggest themselves to those skilled in the art.

What is claimed is:

1. In a six-component, ten-element photographic objective, a first lens section forward of the aperture stop comprising a singlet, a doublet and a singlet in order from the long conjugate, and a second lens section rearward of the aperture stop said rearward section consisting, in order from the stop, of a negative singlet concave to the stop, a doublet in the form of a meniscus with its outer surfaces convex to the stop and comprising a biconvex element and a biconcave element with the cemented surface concave to the stop, and a biconvex triplet comprising a biconvex element and two menisci, said biconvex element having a higher index of refraction than said menisci, the cemented surfaces within said biconvex triplet being concave to the stop.

2. A photographic objective as claimed in claim 1, wherein the elements have the following values

EFL = 152.40 REL. APERT. f/2.8 BACK FOCUS = 84.74

Element	radius	thickness & spacing	index n_D	ν
	$R_1 = +125.086$			
A		$t_1 = 10.616$	1.74931	35.0
	$R_2 = +442.245$			
		$S_1 = .25$		
	$R_3 = +65.984$			
B		$t_2 = 9.81$	1.67252	32.2
	$R_4 = +36.141$			
C		$t_3 = 12.205$	1.74500	46.4
	$R_5 = +140.861$			
		$S_2 = *$		
	$R_6 = +221.868$			
D		$t_4 = 2.80$	1.69875	30.1
	$R_7 = +46.207$			
		$S_3 = 17.327$ to stop $S_3' = 3.60$ stop to lens		
	$R_8 = -78.372$			
E		$t_5 = 2.77$	1.74931	35.0
	$R_9 = -93.697$			
		$S_4 = .25$		
	$R_{10} = +94.767$			
F		$t_6 = 7.75$	1.74500	46.4
	$R_{11} = -104.131$			
G		$t_7 = 2/53$	1.65429	33.7
	$R_{12} = +87.238$			
		$S_5 = **$		
	$R_{13} = +280.897$			
H		$t_8 = 19.368$	1.80785	40.7
	$R_{14} = -91.070$			
I		$t_9 = 10.914$	1.70166	41.0
	$R_{15} = -71.562$			
J		$t_{10} = 11.206$	1.71686	48.0
	$R_{16} = -184.989$			

*Edge contact at 26.5 mm semi aperture
**Edge contact 22.0 mm semi aperture

where v is the abbe number of the glass.

* * * * *

United States Patent [19]

Aoki et al.

[11] **Patent Number: 4,483,602**

[45] **Date of Patent: Nov. 20, 1984**

[54] **APPARATUS FOR DETECTING A FOCUSING CONDITION OF AN OBJECTIVE LENS**

[75] Inventors: **Masahiro Aoki**, Fussa; **Kenichi Oinoue**, Tokyo; **Masatoshi Ida**; **Asao Hayashi**, both of Hachioji, all of Japan

[73] Assignee: **Olympus Optical Co., Ltd.**, Japan

[21] Appl. No.: **362,993**

[22] Filed: **Mar. 29, 1982**

[30] **Foreign Application Priority Data**

Mar. 28, 1981 [JP] Japan 56-46086

[51] **Int. Cl.**[3] **G03B 7/08**; G03B 17/20

[52] **U.S. Cl.** **354/402**; 354/289.1

[58] **Field of Search** ..... 354/25 R, 25 A, 25 P, 354/25 N, 31, 31 F, 53-55, 60 L, 198-201, 288, 289, 402-404, 289.1, 219

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Primary Examiner—William B. Perkey
Attorney, Agent, or Firm—Parkhurst & Oliff

[57] **ABSTRACT**

In a single-lens reflex camera having an objective lens, a focusing screen and a view finder, a photodetector array is arranged to receive a central part of an object image formed by the objective lens and a focusing condition of the objective lens is detected by calculating an evaluation function from image signals supplied from the photodetectors. A presetting dial for selecting given photodetectors whose image signals are used for detecting the focusing condition is provided at such a position that a part of the dial is exposed to the outside through an opening formed in a rear wall of a camera body at a position underneath a film winding lever. A light emitting diode array is provided on the focusing screen so as to be seen by a user through the view finder. Only desired light emitting diodes are lighted on under the control of a signal supplied by the dial to indicate the region of the photodetector array which is used for detecting the focusing condition.

19 Claims, 10 Drawing Figures

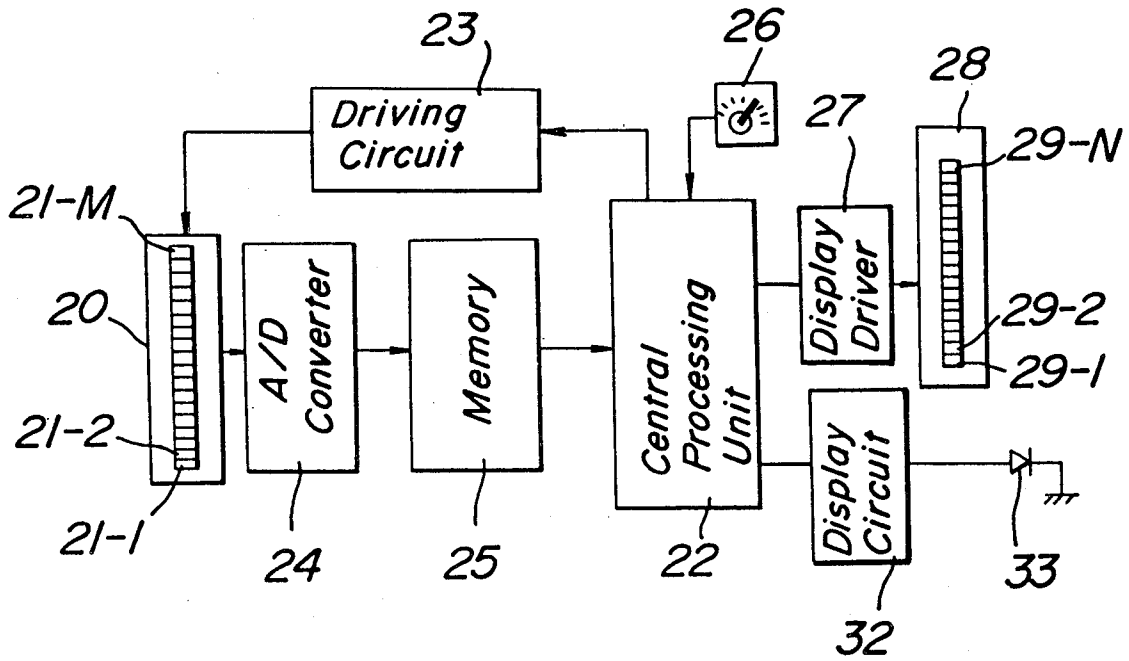


FIG. 1
PRIOR ART

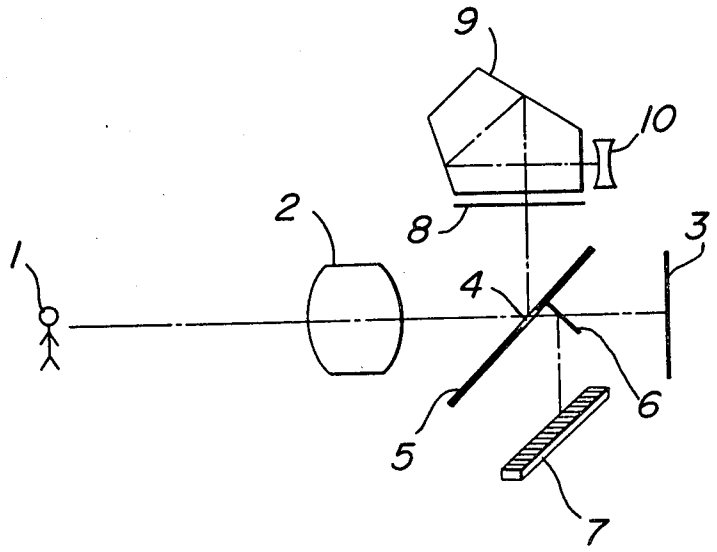


FIG. 2
PRIOR ART

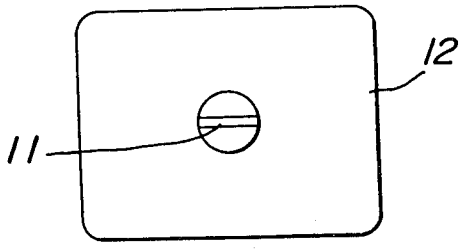


FIG. 3
PRIOR ART

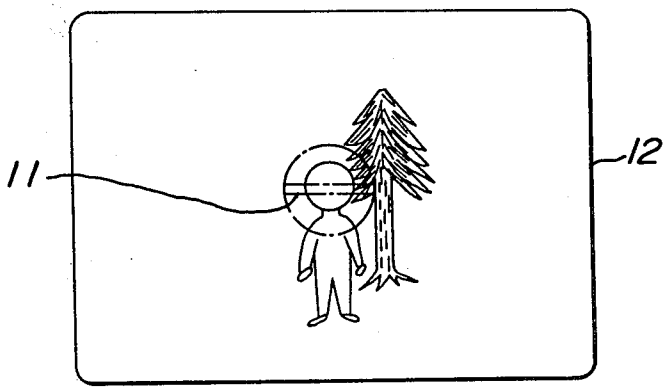


FIG. 4
PRIOR ART

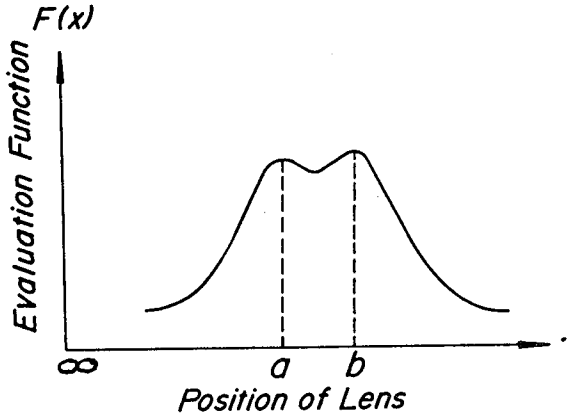


FIG_5

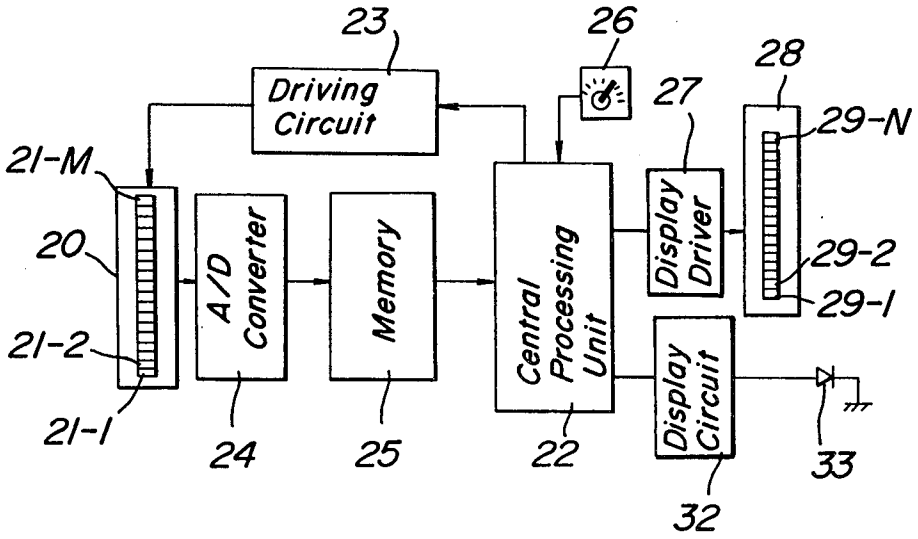

23
26
28
Driving Circuit
27
29-N
21-M
20
A/D Converter
Memory
Central Processing Unit
Display Driver
29-2
29-1
21-2
Display Circuit
21-1
24
25
22
33
32

FIG_6

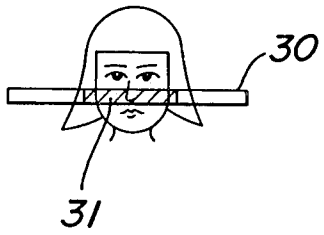

30
31

FIG. 7

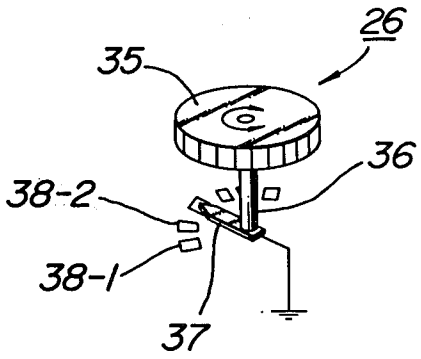
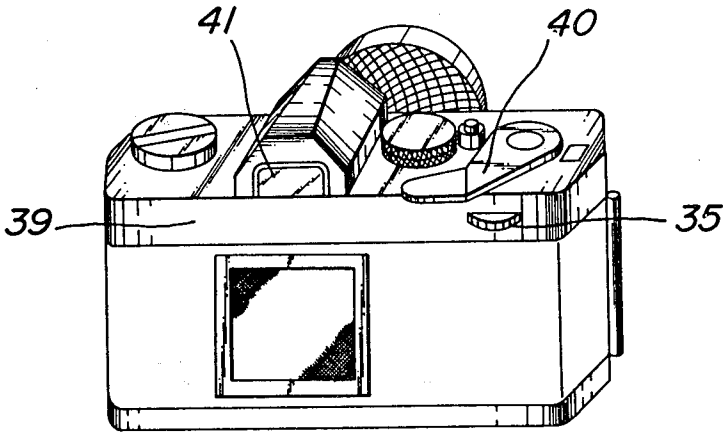


FIG. 8



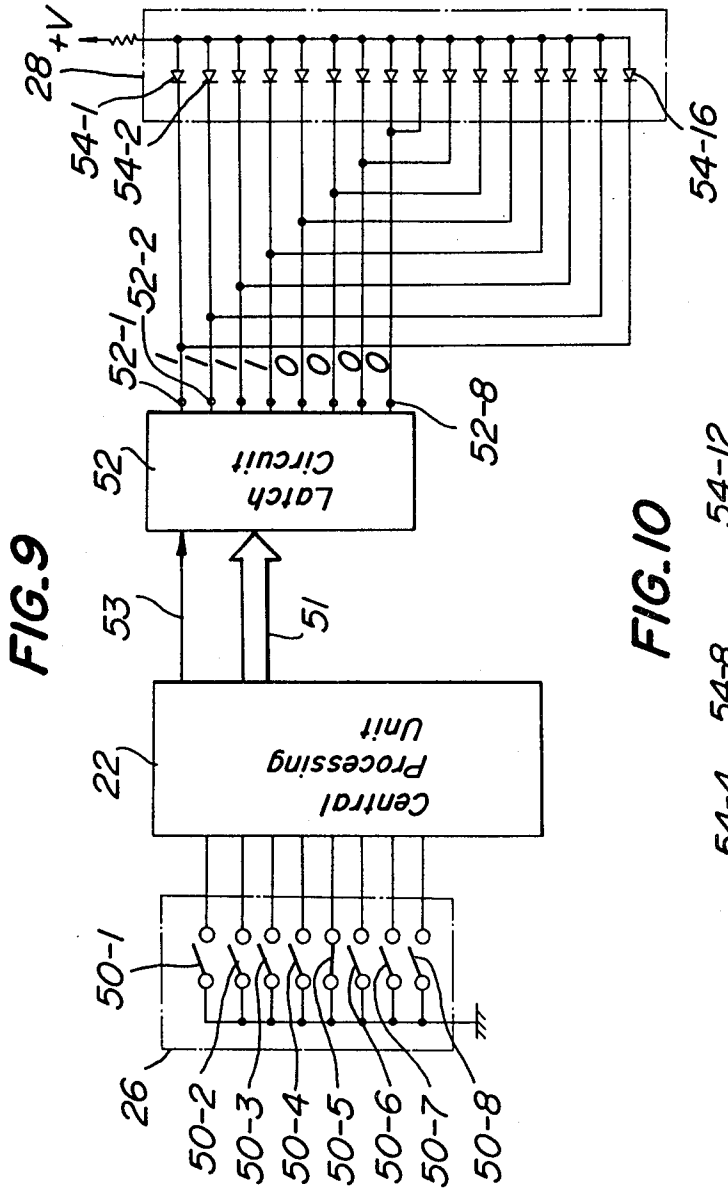

28
+V
54-1
54-2
54-16
52-2
52-1
1
1
1
0
0
0
0
52-8
52
Latch Circuit
53
51
22
Central Processing Unit
50-1
26
50-2
50-3
50-4
50-5
50-6
50-7
50-8

FIG. 9

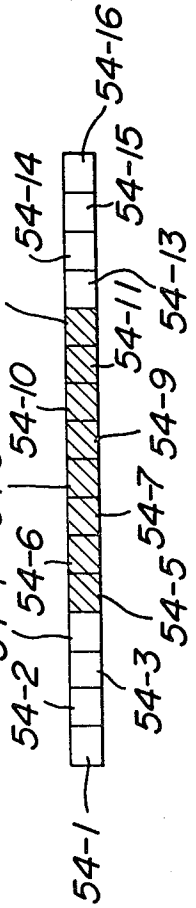

54-16
54-15
54-14
54-12
54-13
54-11
54-10
54-9
54-8
54-7
54-6
54-5
54-4
54-3
54-2
54-1

FIG. 10

APPARATUS FOR DETECTING A FOCUSING CONDITION OF AN OBJECTIVE LENS

BACKGROUND OF THE INVENTION

This invention relates to an apparatus for detecting a focusing condition of an objective lens provided in an optical machinery such as a still camera comprising a focusing screen arranged at a position optically conjugated with a predetermined focal plane such as a film plane, a view finder for inspecting an image of an object formed on the focusing screen, at least one photodetector array arranged on or near a plane optically conjugated with the predetermined focal plane, means for projecting a part of the object image upon the photodetector array, and a control unit for processing output image signals supplied from the photodetector array in accordance with a given evaluation function to derive a signal representing the focusing condition of the objective lens.

Such a focus detecting apparatus is known and is used in a still camera. The apparatus comprises the photodetector array comprising a number of photodetectors. A part of an optical image of an object to be photographed is projected upon the photodetector array in such a manner that when an infocused image is projected upon a film, an infocused image is also projected upon the photodetector array. Therefore, by detecting a contrast or sharpness of the image projected upon the photodetector array, it is possible to detect the focusing condition of the objective lens. Usually the image detected by the photodetector array is selected to a central portion in the field of view and thus, when the camera is directed toward the object in such a manner that a subject in a scene is situated at the center of the field of view, the focusing condition of the objective lens with respect to the interesting subject can be correctly detected. However, the subject image is not always situated at the center of the field of view or an image of object in foreground or background may be projected upon the photodetector array. In such a case, the focusing condition of the objective lens could not be detected accurately and the objective lens might be erroneously focused onto the object in the foreground or background.

SUMMARY OF THE INVENTION

The present invention has for its object to provide an apparatus for detecting a focusing condition of an objective lens, which can obviate the above mentioned drawback of the known focus detecting apparatus.

It is another object of the invention to provide an apparatus for detecting a focusing condition of an objective lens, in which an active region of a photodetector array used for detecting the focusing condition of the objective lens can be electrically adjusted at will in accordance with the size of a scene to be picked up.

It is still another object of the invention to provide an apparatus for detecting a focusing condition of an objective lens, in which a user or photographer can monitor or certify by means of a view finder which part of an image of an object is used for detecting the focusing condition.

According to the invention, in an apparatus for detecting a focusing condition of an objective lens of an optical machinery comprising a focusing screen arranged at a position optically conjugated with a predetermined focal plane, a view finder for inspecting an image of an object formed on said focusing screen, a photodetector array having a number of photodetectors arranged closely side by side on or near a plane which is optically conjugated with the predetermined focal plane, means for projecting a part of the image of the object upon said photodetector array, and means for receiving image signals supplied from said photodetectors and for processing the image signals in accordance with an evaluation function to detect the focusing condition of the objective lens, the improvement comprises means for selecting the size (magnitude) and/or position of an active region of said photodetector array used for detecting the focusing condition of the objective lens in accordance with the size of the image of the object projected upon the photodetector array.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic view showing a construction of a single-lens reflex camera comprising a known focus detecting apparatus;

FIGS. **2** and **3** are plan views illustrating finder images of the camera shown in FIG. **1**;

FIG. **4** is a graph representing a relationship between a position of an objective lens and a value of an evaluation function;

FIG. **5** is a block diagram showing an embodiment of the focus detecting apparatus according to the invention;

FIG. **6** is a plan view showing a finder image of the apparatus according to the invention;

FIG. **7** is a perspective view illustrating an embodiment of a device for selecting a region of a photodetector array used for detecting the focusing condition of the objective lens;

FIG. **8** is a perspective view depicting a single-lens reflex camera comprising the focus detecting apparatus according to the invention;

FIG. **9** is a circuit diagram showing an embodiment of a display control circuit according to the invention; and

FIG. **10** is a plan view illustrating an embodiment of a display device according to the invention.

DETAILED EXPLANATION OF THE PREFERRED EMBODIMENTS

FIG. **1** shows schematically a single-lens reflex camera comprising a known focus detecting apparatus. Prior to photographing by focusing an image of an object or subject **1** by means of an objective lens **2** onto a photographic film **3**, a light flux emanating from the lens **2** is divided by a half mirror **4** provided in a quick return mirror **5** and a divided light flux is made incident upon a photodetector array **7** by means of a small reflection mirror **6** secured to a rear surface of the quick return mirror **5**. In this manner, a part of the image of the object **1**, i.e. a central part of the object image is projected upon the photodetector array **7**. A light flux reflected by the quick return mirror **5** is focused on a focusing screen **8** to form an image and the image thus formed is inspected by means of a view finder comprising a penta prism **9** and an eye piece **10**. It should be noted that the photodetector array **7** and the focusing screen **8** are arranged in planes which are optically conjugated with the film **3**, i.e. a predetermined focal plane.

In such a camera it is preferable that a user or photographer knows which portion of the object image is made incident upon the photodetector array **7**. For this

purpose, as shown in FIG. **1**, a mark **11** corresponding to the photodetector array **7** is formed in the focusing screen **8**. Therefore, the user can see the mark **11** in an image **12** of a field of view by means of the finder. In the known focus detecting apparatus, since a magnitude and/or position of a region of the photodetector array **7** used for detecting the focusing condition of the objective lens is fixed, a size and/or position of the mark **11** is also fixed.

In case of taking a photograph of a person standing in front of a tree as illustrated in FIG. **3**, not only the image of the person, but also the image of the tree are projected upon the photodetector array **7**, because the mark **11** extends beyond the person into the tree in the background.

Now it is assumed that the photodetector array **7** comprises M photodetectors closely arranged side by side and each photodetectors produce image signals Xm. Then a sharpness of the image projected upon the photodetector array **7** may be represented by an evaluation function F(x) given by the following equation:

$$F(x) = \sum_{m=2}^{M} |Xm - Xm - 1|$$

In this case, an infocused condition may be detected when the evaluation function F(x) has the maximum value. However, in the situation shown in FIG. **3**, the evaluation function F(x) has two peak values as illustrated in FIG. **4**. When the objective lens **2** is moved along its optical axis from an infinite point and comes in a position a, the evaluation function F(x) has a first peak, because the focused image of the tree in the background is formed on the photodetector array **7**. When the lens is further moved toward the nearest point and comes into a point b, the evaluation function F(x) has a second peak, because the infocused image of the person is projected upon the photodetector array **7**. In this manner when the evaluation function has a plurality of peaks the objective lens **2** might be focused for the tree which is not a subject. This drawback occurs not only in an automatic focusing system, but also in a simple focusing system in which only the detected focusing condition is displayed in the view finder.

FIG. **5** shows an embodiment of the apparatus for detecting a focusing condition of an objective lens according to the invention. A photodetector array **20** comprises a number of photodetectors **21-1** to **21-M** closely arranged side by side and a part of an image of a scene is projected upon the photodetector array **20** by means of an objective lens. The photodetectors **21-1** to **21-M** are operated by a driving circuit **23** under the control of a center processing unit **22** so as to derive from the photodetectors analog image signals representing light intensities of light impinging upon respective photodetectors. The image signals thus derived are converted by an analog to digital converter **24** into digital signals which are then stored in a memory **25**. According to the invention in order to preset or select an active region of the photodetector array **21** used for detecting the focusing condition of the objective lens in an electrical manner in accordance with the size of the object image projected upon the photodetector array, there is provided a photodetector presetting dial **26** for presetting externally photodetectors which are used for detecting the focusing condition. The photodetector presetting information is supplied to the central processing unit **22** and the central processing unit **22** selects given image signals among the image signals supplied from the photodetector array **21** on the basis of the presetting information. In the present embodiment, the presetting dial **26** is so constructed to denote the number of photodetectors which are not used for the focus detection. It is assumed that when the preset number is n, the image signals supplied from n photodetectors **21-1** to **21-n** and **21-(M−n)** to **21-M** on both sides of the array **20** are neglected and only the image signals supplied from central (M−2n) photodetectors **21-(n+1)** to **21-(M−n+1)** are used for calculating an evaluation function. The evaluation function may be represented by any form. For instance, a sum of differences between image signals from adjacent photodetectors may be used as the evaluation function. Then the evaluation function is expressed as follows.

$$F(x) = \sum_{m=n+1}^{M-(n-1)} |Xm - Xm + 1|$$

In the central processing unit **22** only the image signals supplied from the photodetectors selected by the presetting dial **26** are used to calculate the evaluation function F(x) and the focusing condition of the objective lens can be detected in accordance with the calculated evaluation function.

At the same time, in order to indicate for the user a range or area of the photodetector array **20** which is used for detecting the focusing condition, the central processing unit **22** supplies a signal to a display driver **27** to actuate a display device **28**. The display device **28** has a construction similar to the photodetector array **20** and comprises a number of light emitting elements **29-1** to **29-M** closely arranged side by side. The indication of the region is effected by selectively driving the light emitting elements. The display device **28** is placed on the focusing screen **8** shown in FIG. **1** and thus, the user can see an image **30** of the display device **28** through the finder as shown in FIG. **6**. In the image **30** a selected range **31** of the photodetector array **20** used for calculating the evaluation function is indicated by a hatched area and emits light. Therefore, the user can easily know the region of the photodetector array **20**. At the same time, the central processing unit **22** actuates a focusing display circuit **32** in accordance with the result of calculation and a light emitting diode **33** is lighted on to indicate the infocussed condition. It should be noted that the objective lens may be driven by a lens driving circuit on the basis of the result of calculation.

FIG. **7** is a perspective view showing an embodiment of the photodetector presetting dial **26**. The dial **26** comprises a rotary disc **35** connected to a rotating shaft **36** and a brush electrode **37** connected to the earth. A plurality of electrodes **38-1, 38-2, . . .** are arranged along a locus of a tip of the brush electrode **37**. These electrodes **38-1, 38-2, . . .** are connected to the central processing unit **22** by means of separate conductors. Therefore, the central processing unit **22** receives information representing an electrode connected to the brush electrode **37**, i.e. the region of the photodetector array preset by the dial **26**.

FIG. **8** is a perspective view showing a single-lens reflex type camera in which the photodetector region presetting dial **26** is installed. The dial **26** is so provided that a part thereof is exposed outside from a rear wall **39** of a camera body at a position underneath a film winder lever **40**. The user can easily change a desired region of

the photodetector array **20** by rotating the dial **35** with a thumb of his right hand, while looking into a finder **41**.

FIG. **9** is a block diagram showing an embodiment of an electric circuit including a portion of the presetting dial **26** to the display device **28**. The presetting dial **26** is represented by eight switches **50-1** to **50-8** composed of the brush electrode **37** and fixed electrodes **38-1**, **38-2**, . . . shown in FIG. **7**. Now it is assumed that the switch **50-5** is closed. The central processing unit **22** detects this and latches data of (11110000) into a latch circuit **52** through a data bus **51**. A reference numeral **53** denotes a signal line. The display device **28** comprises sixteen light emitting diodes **54-1** to **54-16** which are connected to output terminals **52-1** to **52-8** of the latch circuit **52** as illustrated in FIG. **9**. Therefore, when the outputs of the latch circuit **52** are (11110000), eight diodes **54-1** to **54-4** and **54-13** to **54-16** on opposite sides of the display device **28** are not lighted on and only central eight diodes **54-5** to **54-12** are lighted on as shown by a hatched region in FIG. **10**. The user can see the display device **28** through the finder and can know the active region of the photodetector array **20** with the aid of the bright region of the display device **28**. In this manner the user can easily and accurately adjust the size of the field of view for the focus detection in accordance with the size of the subject image onto which the objective image is to be focused.

As explained above in detail, according to the invention a region of the photodetector array which is used for detecting the focusing condition of the objective lens can be electrically changed or adjusted at will in accordance with the subject image. Further, the user can monitor or certify the region of the photodetector array with the aid of the image of the display device through the view finder. In this manner by means of the focus detecting apparatus according to the invention, the objective lens can be focused accurately with respect to a subject in a scene.

The present invention is not limited to the embodiments explained above, but many modifications may be conceived within the scope of the invention. In the above embodiment the display device is composed of the light emitting diodes, but it may be formed by a liquid crystal. In such a case, a region of the display device which is not lighted on is transparent and thus, an inspection of the finder image is less hindered by the display device. Further, in the above embodiment the region of the photodetector array is divided precisely, but it may be divided much more roughly. In such a case the presetting means and display means may be much simpler. Moreover, in the above embodiment the photodetectors which are not used for the focus detection are preset by the dial, but photodetectors which are used for the focus detection may be preset. It should be noted that two photodetector arrays may be arranged on both sides of the predetermined focal plane and in this case the focusing condition may be detected by deriving a difference between two values of the evaluation function each calculated from the image signals supplied from respective photodetector arrays.

In the above embodiments the region of the photodetector array used for detecting the focusing condition of the objective lens is manually selected from the external and the selected region is displayed in the finder. According to the invention, it is also possible to select automatically the region of the photodetector array used for detecting the focusing condition of the objective lens by means of the central processing unit. In such a case, it is not always necessary to display the automatically selected region of the photodetector array and thus, the display device may be dispensed with. The automatic selection of the region of the photodetector array used for detecting the focusing condition of the objective lens may be effected in various manners. For instance, when the evaluation function has more than two peak values, the maximum peak point may be detected as the infocused position.

What is claimed is:

1. In an apparatus for detecting a focusing condition of an objective lens of an optical device comprising a focusing screen arranged at a position optically conjugated with a predetermined focal plane, a viewfinder for inspecting an image of an object formed on said focusing screen, a photodetector array having a number of photodetectors arranged closely side by side on or near a plane which is optically conjugated with the predetermined focal plane, means for projecting a part of the object image upon said photodetector array, and means for receiving image signals supplied from said photodetectors and for processing the image signals in accordance with a given evaluation function to detect the focusing condition of the objective lens, the improvement comprising:

means for selecting an active region portion of said photodetector array for use in detecting the focusing condition, to enable the active region portion to be selectively changed in size and position within the photodetector array to change the size and position of that part of the object image which is used to control focusing.

2. An apparatus according to claim **1**, further comprising means for displaying in said viewfinder, the selected active region portion of said photodetector array.

3. An apparatus according to claim **2**, wherein said selecting means comprises means for manually selecting the active region portion of said photodetector array.

4. An appaparatus according to claim **1**, wherein said selecting means comprises means for presetting desired photodetectors in the photodetector array whose image signals are used for detecting the focusing condition.

5. An apparatus according to claim **3**, wherein said selecting means comprises a dial rotatably arranged, a movable electrode arranged rotatably together with the dial, a plurality of electrodes arranged fixedly along a moving locus of said movable electrode and a plurality of conductors each for connecting respective one of said fixedly arranged electrodes to said processing means.

6. An apparatus according to claim **5**, wherein said dial is so arranged in a housing of the optical device that a part of the dial is exposed to the outside through an opening formed in said housing.

7. An apparatus according to claim **6**, for use in a camera, wherein said opening through which a part of the dial is exposed to the outside is provided in a rear wall of the camera housing beneath a film winding lever.

8. An apparatus according to claim **2**, wherein said displaying means comprises an array of a plurality of indicating elements arranged closely side by side and means for actuating given indicating elements in the array corresponding to the selected region of the photodetector array.

9. An apparatus according to claim 8, wherein said indicating elements are arranged on said focusing screen.

10. An apapratus according to claim 9, wherein said indicating element array is formed by an array of a plurality of light emitting diodes arranged closely side by side.

11. An apparatus according to claim 10, wherein said actuating means comprises a latch circuit having a plurality of output terminals each connected to respective light emitting diodes and said latch circuit is controlled to store an information signal representing the size of the active region portion of the photodetector array selected by said selecting means.

12. An apparatus according to claim 11, wherein said latch circuit is so constructed that said information signal denotes light emitting diodes which are not actuated.

13. An apparatus according to claim 1, wherein said latch circuit is so constructed that said light emitting diodes which are not actuated are selected symmetrically with respect to a center of the light emitting diode array.

14. An apparatus according to claim 1 wherein said means for selecting an active region includes means for selecting the size of said active region in response to the size of the object image projected upon the photodetector array.

15. An apparatus according to claim 1 wherein said means for selecting include means for selecting the position of the active region of said photodetector array in response to the size of the object image projected upon the photodetector array.

16. An apparatus for detecting the focusing condition of an objective lens comprising:

an objective lens for projecting an object image;

means having a detection region including an active region for detecting the focusing condition of the objective lens with respect to a part of an object image; and

means for selectively altering the size and position of said active region within the detection region of said means for detecting to change the size and position of that part of the object image used to control focusing.

17. The apparatus of claim 16 wherein said means for altering said active region includes means for altering the size of said active region in accordance with the size of said object image.

18. The apparatus of claim 16 wherein said means for altering includes a means for altering the position of the active region in response to the size of the object image.

19. The apparatus of claim 16 wherein said means for altering includes means for altering the size and position of the active region in response to the size of the object image.

* * * * *

United States Patent [19]

Suda et al.

[11] **Patent Number: 4,477,153**

[45] **Date of Patent: Oct. 16, 1984**

[54] **ULTRAWIDE ANGLE ZOOM OBJECTIVE**

[75] Inventors: **Shigeyuki Suda**, Tokyo; **Keiji Ikemori**, Kanagawa, both of Japan

[73] Assignee: **Canon Kabushiki Kaisha**, Tokyo, Japan

[21] Appl. No.: **375,667**

[22] Filed: **May 6, 1982**

[30] **Foreign Application Priority Data**

May 20, 1981 [JP] Japan 56-76301

[51] **Int. Cl.**[3] **G02B 13/04**

[52] **U.S. Cl.** **350/426**

[58] **Field of Search** 350/426, 184, 423, 459

[56] **References Cited**

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Primary Examiner—John K. Corbin
Assistant Examiner—Paul M. Dzierzynski
Attorney, Agent, or Firm—Toren, McGeady and Stanger

[57] **ABSTRACT**

Disclosed is a two-component zoom objective having a first lens component of negative power and a second lens component of positive power with the variable air separation between the first and second components effecting zooming. The aforesaid first lens component is constructed with four lenses. The first lens counting from the front is given an aspheric surface, and the air lens defined by the second and third lenses counting from the front and the four lenses in the aforesaid first lens component are appropriately configured to increase the angular field up to an ultrawide angle, while still permitting good correction of aberrations.

5 Claims, 54 Drawing Figures

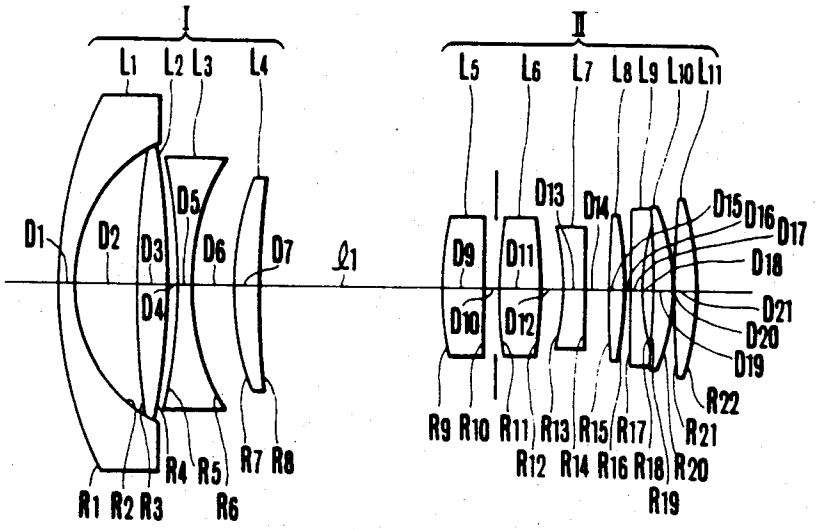


FIG. 1a

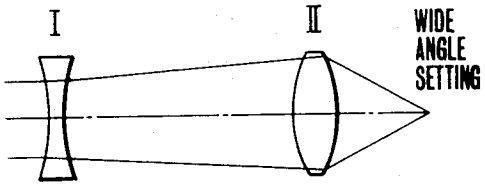


FIG. 1b

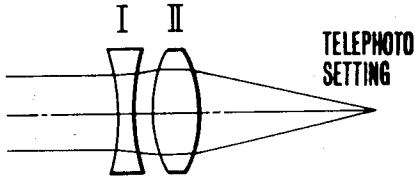


FIG. 2

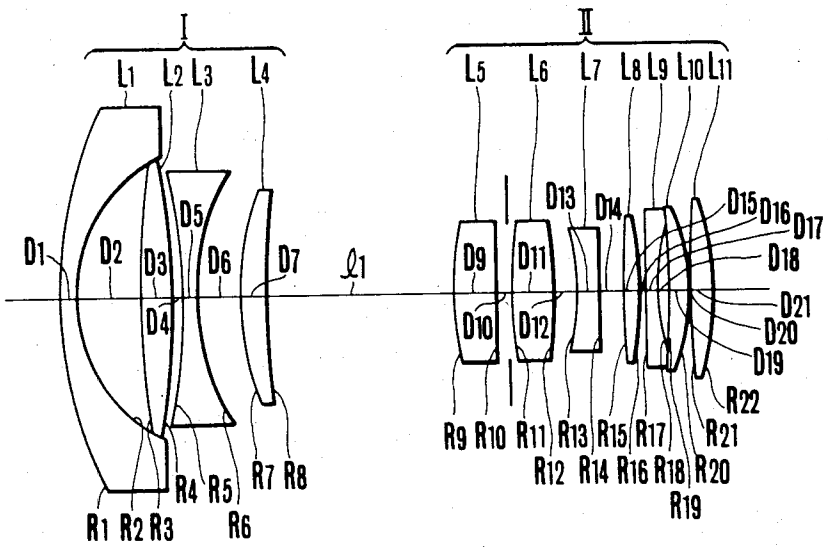


FIG. 3

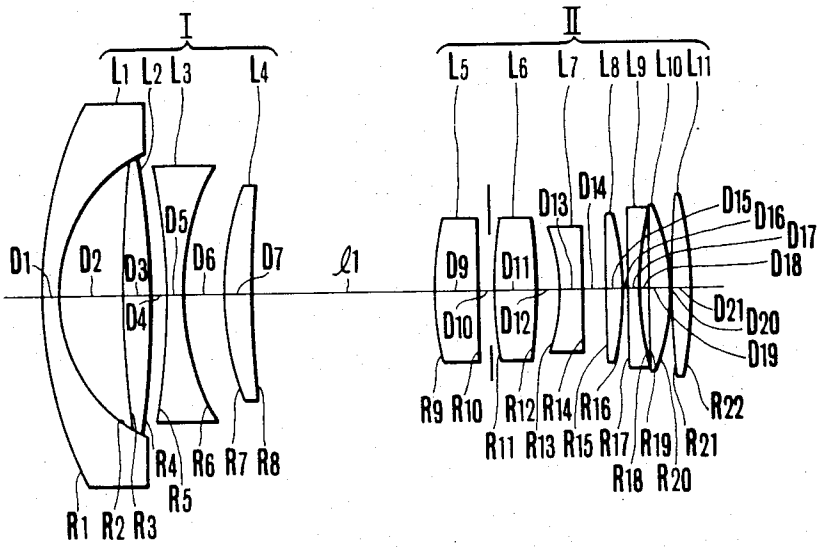
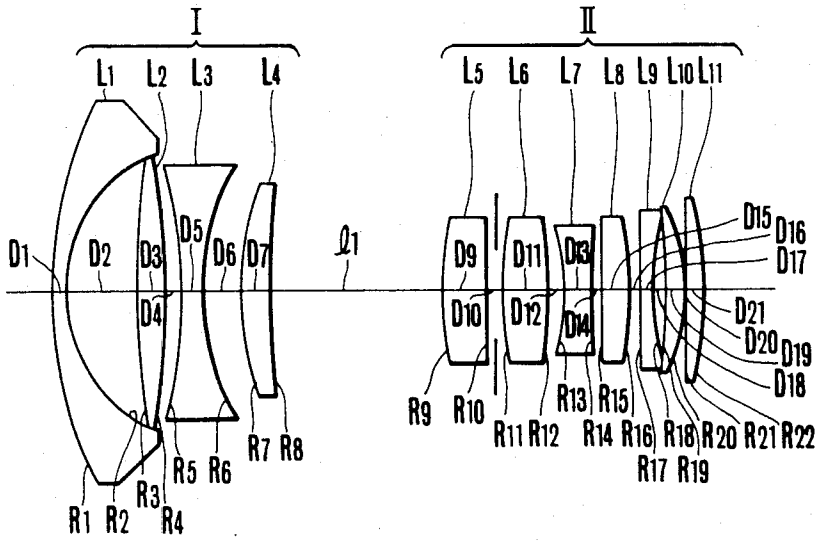


FIG.4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II
L1 L2 L3 L4
L5 L6 L7 L8 L9 L10 L11
D1 D2 D3 D4 D5 D6 D7
ℓ1
D9 D10 D11 D12 D13 D14
D15 D16 D17 D18 D19 D20 D21
R1 R2 R3 R4 R5 R6 R7 R8
R9 R10 R11 R12 R13 R14 R15 R16 R17 R18 R19 R20 R21 R22

FIG.5

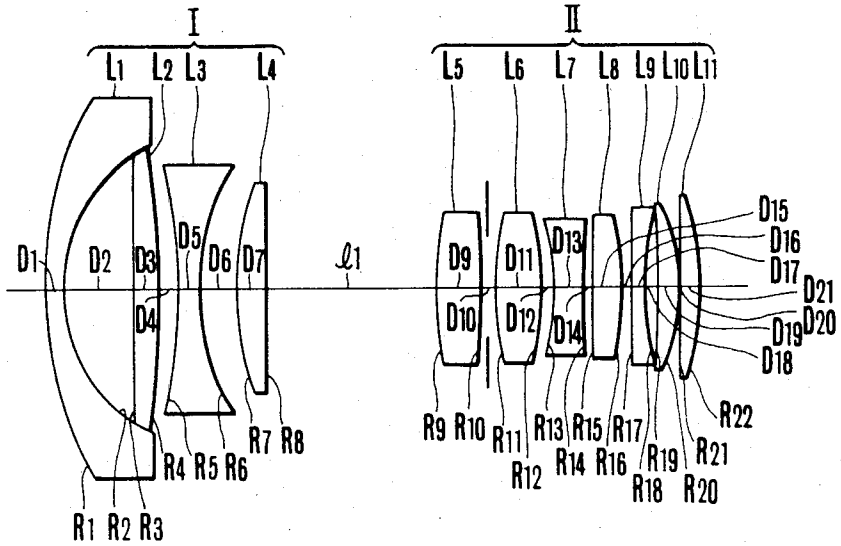

I
II
L1 L2 L3 L4
L5 L6 L7 L8 L9 L10 L11
D1 D2 D3 D4 D5 D6 D7
ℓ1
D9 D10 D11 D12 D13 D14
D15 D16 D17 D18 D19 D20 D21
R1 R2 R3 R4 R5 R6 R7 R8
R9 R10 R11 R12 R13 R14 R15 R16 R17 R18 R19 R20 R21 R22

FIG.6

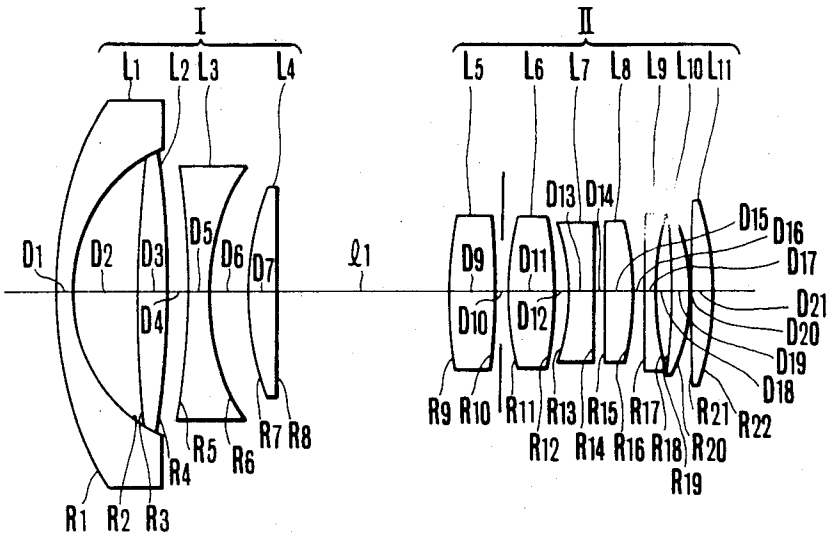


FIG.7

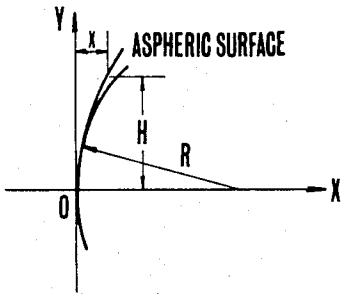


FIG.8

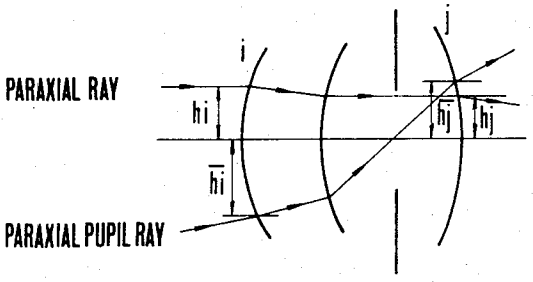


FIG.9a1

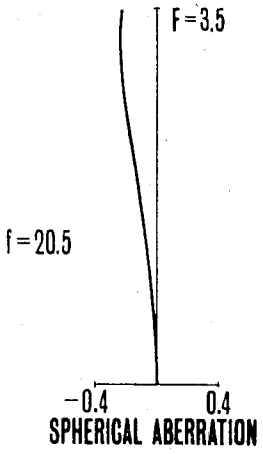
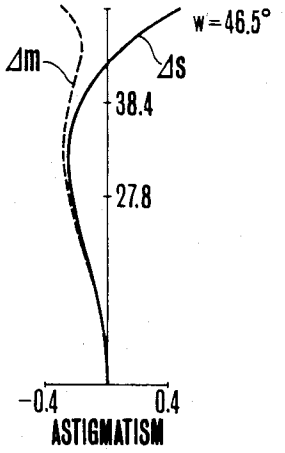


FIG.9a2



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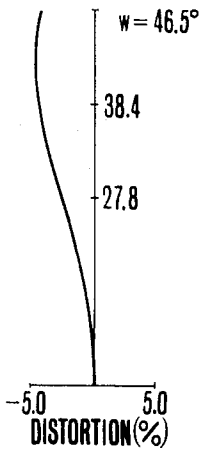
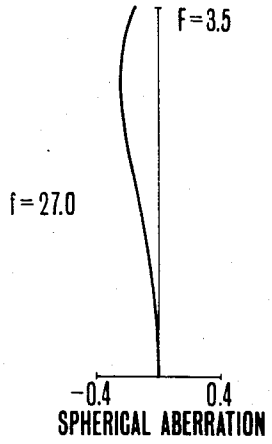


FIG.9b1



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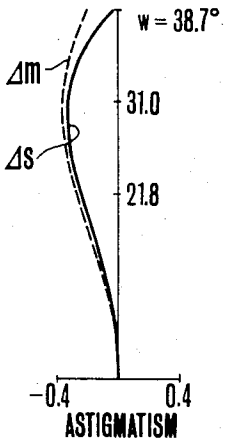

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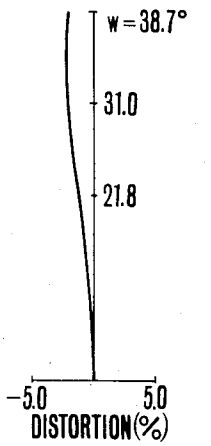

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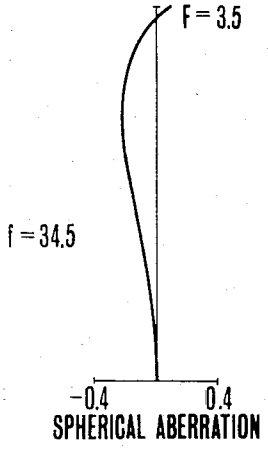

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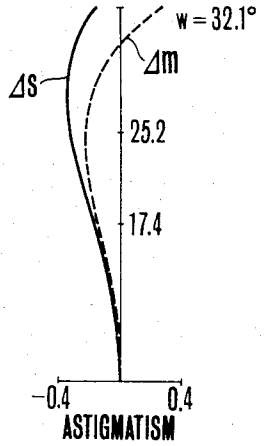
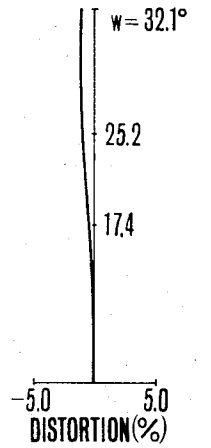


FIG.9c3



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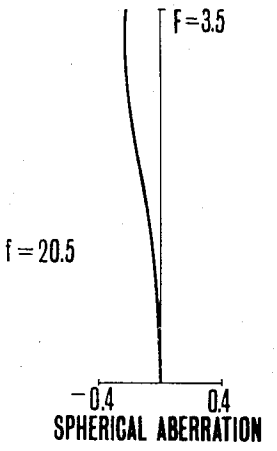

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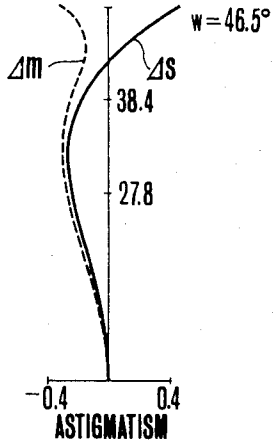

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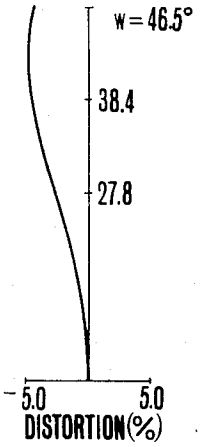

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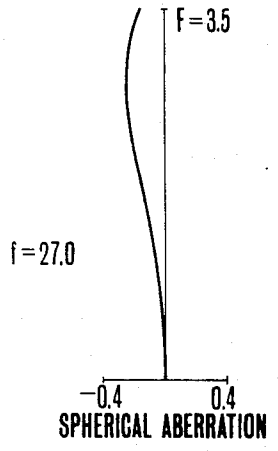

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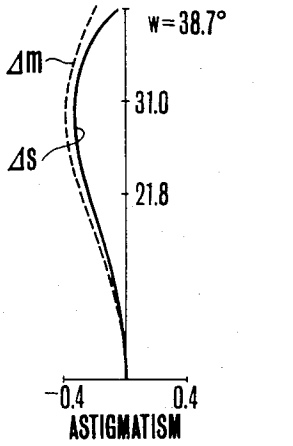

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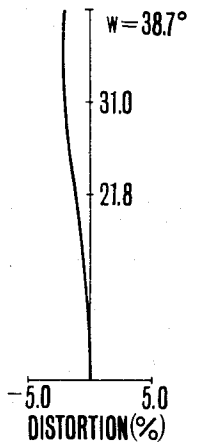

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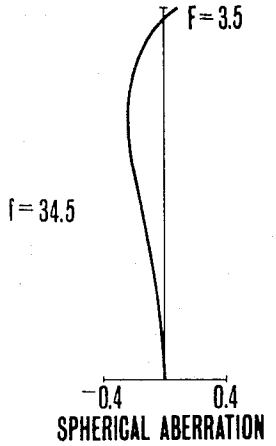

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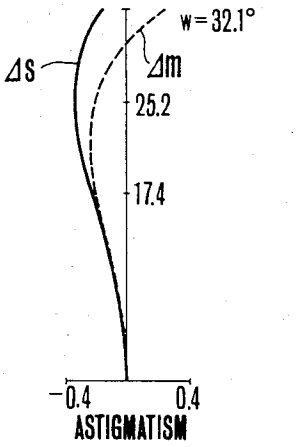

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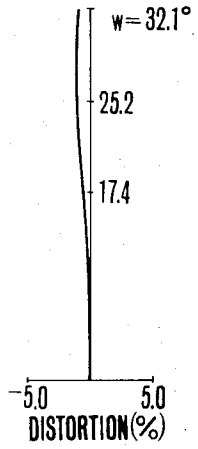

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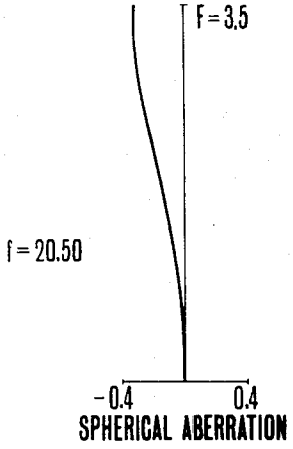

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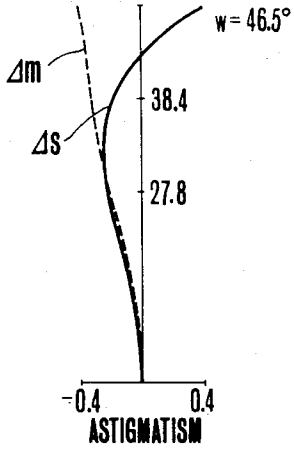

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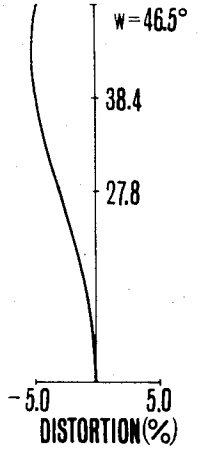


FIG.11b1

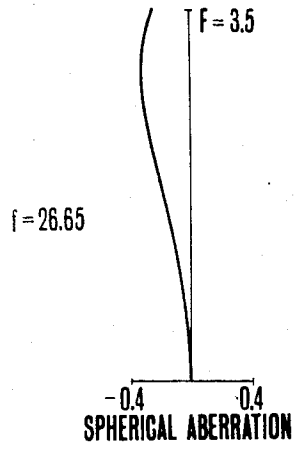


FIG.11b2

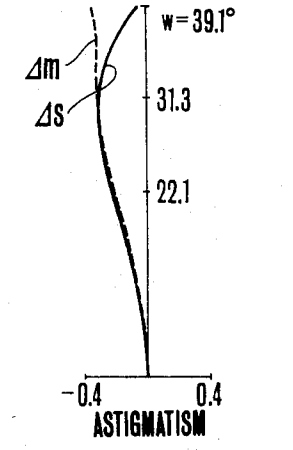
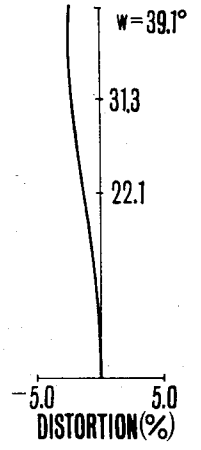


FIG.11b3



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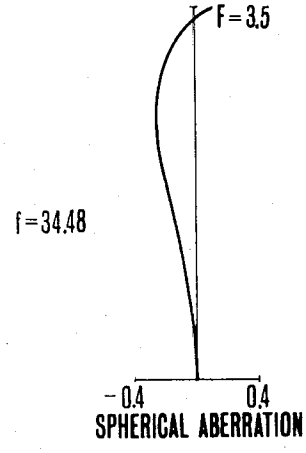


FIG.11c2

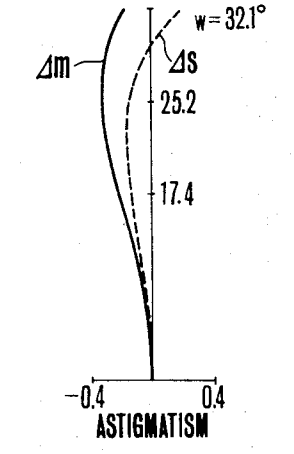
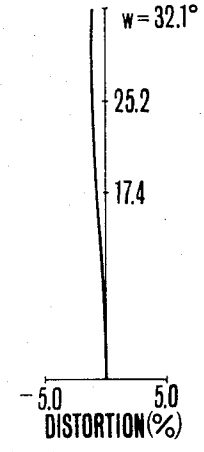


FIG.11c3



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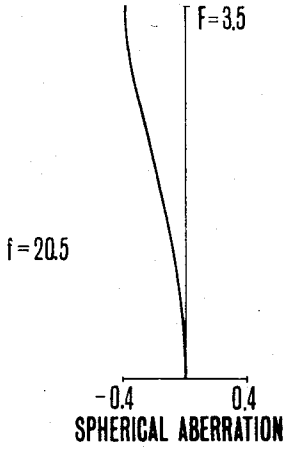

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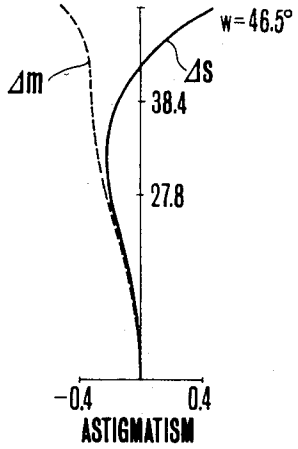
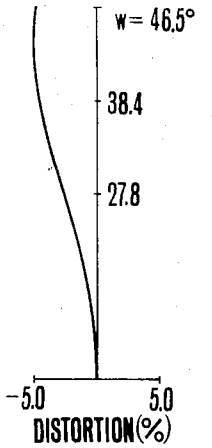


FIG.12a3



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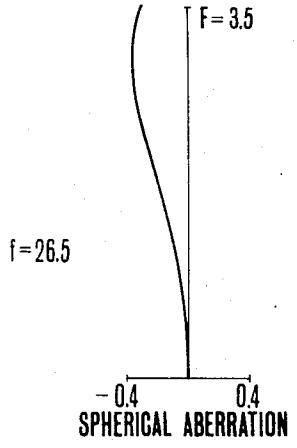


FIG.12b2

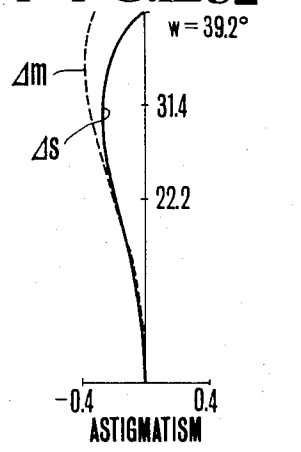


FIG.12b3

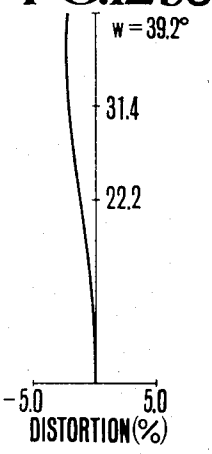


FIG.12c1

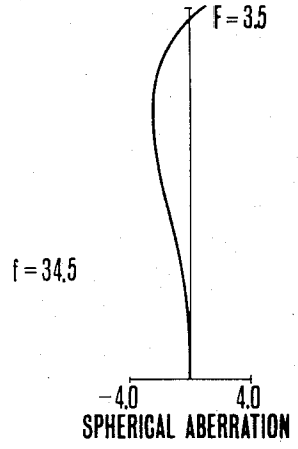


FIG.12c2

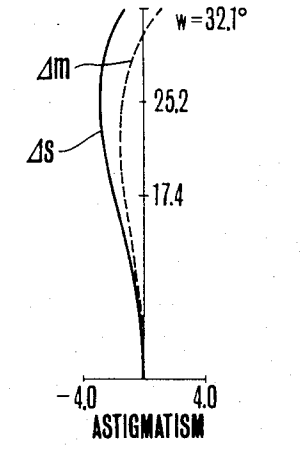


FIG.12c3

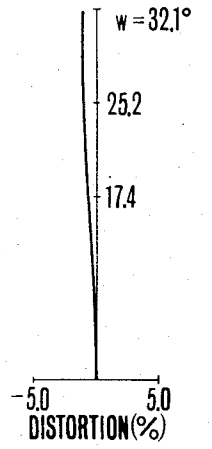


FIG.13a1

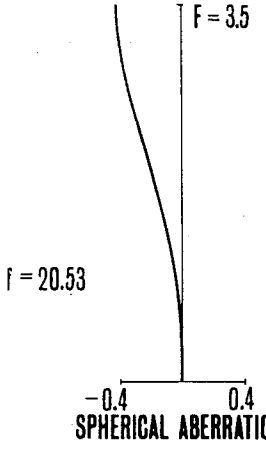


FIG.13a2

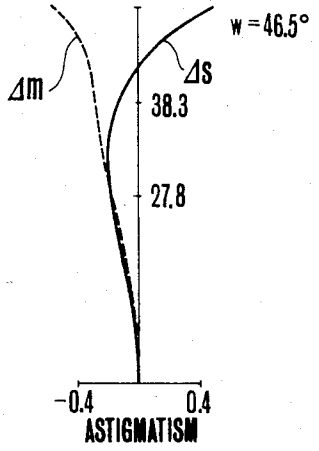


FIG.13a3

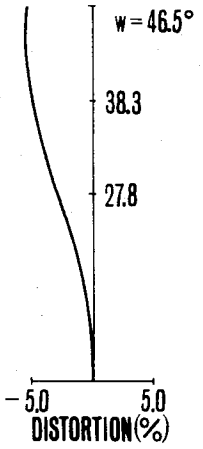


FIG.13b1

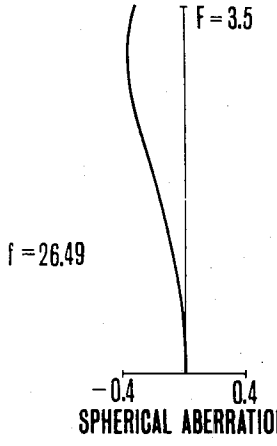


FIG.13b2

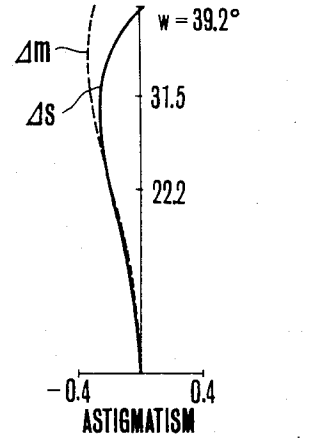


FIG.13b3

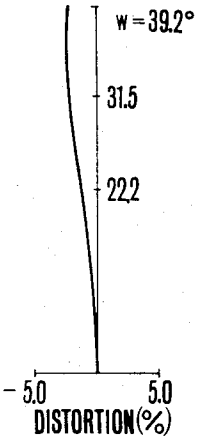


FIG.13c1

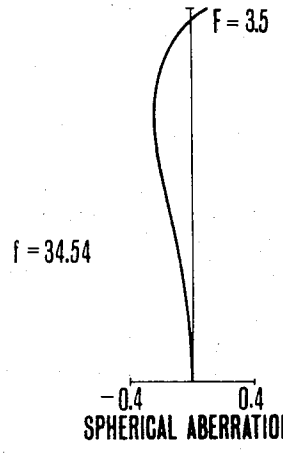


FIG.13c2

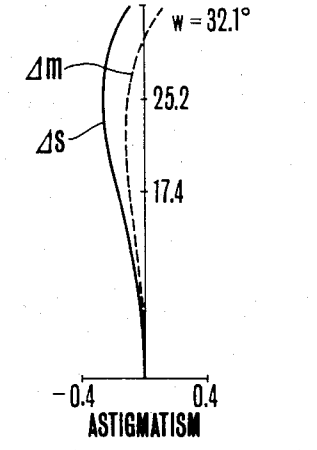
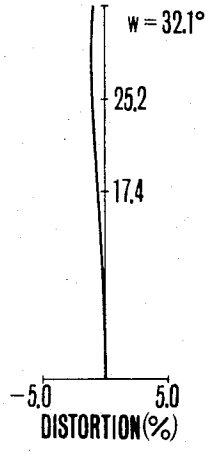


FIG.13c3



ULTRAWIDE ANGLE ZOOM OBJECTIVE

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to wide angle zoom objectives, and more particularly to two-component zoom objectives having a first lens component of negative power and a second lens component of positive power with the air separation therebetween variable to effect a change in the focal length of the entire system.

2. Description of the Prior Art

Up to now, a two-component zoom objective lens whose first component counting from the front is of negative power and whose second is of positive power as illustrated in FIG. 1, or a so-called inverted telephoto type, has represented a form of lens system offering a great advantage at an increase in the angular field. But, since the wide angle setting for the maximum possible angular field takes place when the first and second components I and II are most widely separated from each other, the diameter in the front members tends to increase as the maximum possible angular field increases. This tendency becomes prominent when a much-desired increase in the angular field is intended. With a lens system having such a wide angular field, when its bulk and size is reduced unduly, the barrel type distortion in the wide angle position increases so rapidly that correction thereof becomes very difficult to perform.

Conventionally, most wide angle two-component zoom objectives include, as the first lens L1 in the first component I, either a meniscus lens of negative power convex toward the front, or a meniscus lens of positive power convex toward the front. They contribute somewhat different advantages to their respective systems. It is generally known that, as stated in Japanese Laid Open Patent No. Sho 52-134452, the choice of the latter type is preferable to achieve good correction of distortion, and a minimization of the diameter of the front lens members is facilitated by employing the former type.

Examples of two-component wide angle zoom objectives are disclosed in U.S. Pat. Nos. 4,159,865 and 4,153,339.

SUMMARY OF THE INVENTION

The present invention is concerned with a two-component zoom objective, and aims to provide an ultrawide angle zoom objective with the front lens members of reduced diameter, while still permitting good correction of aberrations particularly regarding distortion in the wide angle position without causing this correction of distortion to deteriorate the other aberrations. For example, the spherical aberration in the telephoto position and the various aberrations in the intermediate zooming region.

According to the present invention, despite the fact that the zoom objective has an ultrawide angular field corresponding to a zoom lens having a range of 20 to 35 mm for the 35 mm single lens reflex camera, the various aberrations beginning with the distortion can be very well corrected by using a reduced number of lens elements. At the same time, a minimization of the bulk and size of the lens system as a whole can be achieved. Further since the lens system takes the mechanically-compensated form to maintain a constant image plane, the present invention has the advantage of providing an ultrawide angle zoom objective suitable for use particularly in still cameras, or in cinematographic camera or television-transmitting cameras.

One of the features of the present invention is that the ultrawide angle zoom objective is constructed such that a first lens group I of negative power and a second lens group II of positive power constitute a complete objective and are moved in differential relation to each other to effect a change in the focal length of the entire system, the aforesaid first lens group I comprises four lens elements of which the first L1 counting from the front is a meniscus lens of negative power convex toward the front, the second L2 is a bi-convex lens, the third L3 is a bi-concave lens with its rear surface of strong power, and the fourth L4 is a lens of positive power with its front surface convex towards the front, wherein the absolute value of the radius of curvature of the rear surface R4 of the aforesaid second lens L2 is made to be larger than that of the radius of curvature of the front surface R5 of the aforesaid third lens L3, and good correction of aberrations is facilitated by giving an aspheric surface to the first lens L1.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic view illustrating how the two-component zoom objective is zoomed.

FIGS. 2 to 6 are lens block diagrams of embodiments 1 to 5 of the invention respectively.

FIG. 7 is a diagram of geometry considered to define an aspheric surface.

FIG. 8 is a diagram of geometry considered to define factors in paraxial formulae.

FIGS. 9 to 13 are graphic representations of the various aberrations of the objectives of FIGS. 2 to 6 respectively.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention is described in connection with embodiments 1 to 5 thereof by reference to FIGS. 2 to 8.

An important feature of the invention is the design of the two-component zoom lens such that the first lens L1 of the first lens component is configured to a negative meniscus lens to achieve a minimization of the diameter of the front lens elements. Letting R4 denote the radius of curvature of the rear surface of the second lens L2 and R5 the radius of curvature of the front surface of the third lens L3. The absolute value of R4 is made larger than that of R5 so that the air separation D4 between the second and third lenses L2 and L3 is in the form of weak divergence to perform good correction of astigmatism, and the aforesaid first lens L1 is made aspheric to reduce the distortion, so that the necessary number of constituent lens elements is lessened. An ultrawide angle zoom objective in which the angular field reaches 93° in the wide angle setting is realized. In more detail, as regards the air separation D4 between the second and third lenses L2 and L3, according to the prior art, a converging action is taken. However, when the angular field is ultrawidened up to 90° or more, the aforesaid converging action of the air lens contributes to an under-correction of curvature in the field for the meridional rays with an increase of the astigmatic difference so that the lesser number of constituent lenses no longer suffices to correct the distortion and astigmatism in good balance. According to the present invention, the aforesaid air lens is imparted with a weak diverging action to achieve good correction of astigma-

tism. In addition thereto, the first lens L1 which makes the largest contribution to distortional correction not only fulfills the aforesaid requirement but also has an aspheric surface, thus providing an assurance in the correction of the various aberrations.

Further, in the present invention, to correct lens aberrations for higher grade imaging performance, the following conditions are set forth:

$$0.95 < |f_2/f_1| < 1.20 \quad \text{(i)}$$

$$1.25 < |f_1/f_w| < 1.95 \quad \text{(ii)}$$

$$1 < l_w/f_w < 1.5 \quad \text{(iii)}$$

$$0.2 < \Psi < 0.35 \quad \text{(iv)}$$

$$-0.4 < \Omega < -0.05 \quad \text{(v)}$$

where

f_1 is the focal length of the 1st lens component I;

f_2 is the focal length of the 2nd lens component II;

f_w is the shortest focal length of the entire lens system;

l_w is the distance (axial air separation) between the 1st and 2nd lens components I and II in the wide angle position;

Ψ is the sum of the 3rd order coefficients of the aspheric surface applied to the 1st lens L1; and

Conditions (i) to (iii) concern power distribution over the lens system. Condition (i) represents a compromise between the requirements of minimizing the bulk and size of the entire lens system and of increasing the angular field. When the lower limit of condition (i) is exceeded, the increase in the angular field exceeding 90° not only is unfeasible, but also the total length of the lens system in the wide angle position will be objectionably elongated. When the upper limit is exceeded, image aberrations cannot be stably maintained throughout the zooming range. To avoid this, it is necessary to increase the number of constituent lenses in the first lens component I that is incompatible with the minimization of the bulk and size of the lens system.

When the upper limit of condition (ii) is exceeded, it becomes difficult to achieve good correction of distortion and other various aberrations. When the lower limit is exceeded, though the aberrational problem decreases, a great increase in the bulk and size of the complete objective is involved, thus contradicting the object of obtaining a compact zoom objective. The upper limit of condition (iii) also is to minimize the bulk and size of the complete objective, and the lower limit of condition (iii) is determined to prevent a drawback in that the total zooming movement becomes too short to provide a desired zoom ratio.

Conditions (iv) and (v) represent factors for calculating an aspheric surface. The following is an explanation of these factors. In general, an equation for the aspheric surface is expressed as follows: In FIG. 7, putting the aspheric surface whose paraxial region has the radius of curvature R with its vertex at an original point of rectangular coordinates and taking the direction in which light advances on the optical axis as an x-axis, and the axis in a direction perpendicular to the optical axis and passing through the vertex as a y-axis, we have the deviation quantity x in the x-coordinate at H in the y-ordinate:

$$x = R\left\{1 - \sqrt{1 - \left(\frac{H}{R}\right)^2}\right\} + B^2H^4 + CH^6 + DH^8 + EH^{10} + \quad (1)$$

The first term of this equation (1) arises from only the aforesaid paraxial radius of curvature R, and the second term and those that follow give the complete information concerning the aspheric surface. Letting N denote the index of refraction of the medium ahead the aspheric surface, and N' the index of refraction of the medium behind the aspheric surface, the coefficient B in the second term is related to the third order aspheric coefficient Ψ as follows:

$$\Psi = 8\,(N' - N)B \cdot f_w^3 \quad (2)$$

Also the coefficient C in the third term is related to the fifth order aspheric coefficient Ω as follows:

$$\Omega = 48\,(N' - N)C \cdot f_w^5 \quad (3)$$

Here, the aspheric coefficient Ψ contributes to the third order aberrational coefficients of the theory of spherical aberration I, coma II, astigmatism III, sagittal curvature of the field IV and distortion V the following respective changes. That is, the use of the aspheric surface results in the changes of the third order aberrations expressed as follows:

$$\Delta I = h^4 \cdot \Psi \quad \text{(4a)}$$

$$\Delta II = h^3 \bar{h} \cdot \Psi \quad \text{(4b)}$$

$$\Delta III = h^2 \bar{h}^2 \cdot \Psi \quad \text{(4c)}$$

$$\Delta IV = h^2 \bar{h}^2 \cdot \Psi \quad \text{(4d)}$$

$$\Delta V = h \cdot \bar{h}^3 \cdot \Psi \quad \text{(4e)}$$

where h and $\bar{h}$ are the quantities for use in tracing two different paraxial rays, one of which advances along the optical axis to an image point on the optical axis while cutting all the lens surfaces at heights, h, and another ray which is incident on the frontmost lens surface at an angle of inclination with the optical axis and passes through the center of the area of the diaphragm opening (paraxial pupil ray), while cutting all the lens surfaces at heights, $\bar{h}$, measured from the optical axis. Upon consideration of a certain particular lens surface, the values of the h and $\bar{h}$ in the equations (4) vary with zooming. In other words, the introduction of a certain aspheric surface figuring constant Ψ leads to changing all the third order aberration coefficients by zooming.

The reason why the present invention makes use of an aspheric surface in the first lens L1 of the first lens component is, as has been stated before, to produce a great advantage in correcting the distortion in the wide angle positions which results from the increase in the angular field of, and the reduction in the bulk and size of, the lens system. And the satisfaction of conditions (iv) and (v) assures that, as the various aberrations for the telephoto positions are not adversely affected, good stability of aberration correction is maintained throughout the entire zooming range. When the lower limit of condition (iv) is exceeded, insufficient correction of

distortion in the wide angle region results. When the upper limit is exceeded, aberrations other than distortion deteriorate rapidly, and it becomes difficult to correct these aberrations by lens surfaces other than the aspheric one. Particularly astigmatism varies to a very large extent with the image angle and, even in magnitude also, becomes large. Therefore, good correction of the various aberrations can be achieved within condition (iv).

Also, condition (v) is to correct mainly higher order distortion and astigmatism in good balance. That is, the fifth order distortion coefficient $\widehat{V}$ is generally taken at a negative value from the start of design, or otherwise higher order of distortion would become large barrel type distortion. Since the fifth order aspheric surface figuring constant Ω affects the $\widehat{V}$ as

$$\Delta\widehat{V}=h\cdot\bar{h}^5\Delta\Omega$$

it follows that when the Ω has a large value of negative sign, $\Delta\widehat{V}>0$ results, causing a difficult problem of correcting higher order distortion. On the other hand, as for astigmatism, to correct higher order astigmatism to the positive direction, it is required that the following terms be of negative value

$$(\widehat{III}+\widehat{III}/4)-(3III+P)^2\cdot(f/2f_w)$$

where $\widehat{III}$ is the fifth order astigmatism coefficient, $\widehat{IV}$ is the fifth order sagittal field curvature coefficient, P is the Petzval sum and f is the overall focal length. Here, Ω affects the $\widehat{III}$ and $\widehat{IV}$ as:

$$\Delta\widehat{III}=h^2\cdot\bar{h}^4\cdot\Delta\Omega$$

$$\Delta\widehat{IV}=H^2\cdot\bar{h}^4\cdot\Delta\Omega$$

thereby offering the advantage of improving the state of correction of astigmatism which would otherwise be difficult to perform particularly in the wide angle region. Like this, the fifth order aspheric surface has reciprocal effects on the higher order distortion and astigmatism, and, therefore, correction of the various aberrations in good balance can be achieved only within condition (v).

Specific embodiments 1 to 5 of the present invention which have satisfied the foregoing conditions can be constructed in accordance with the following numerical data for the radii of curvature, R, the axial thicknesses and air separations, D and l1, and the refractive indices, N, of, and the Abbe numbers, ν, of, the glasses of the lens elements, which are all expressed with the subscripts numbered from front to rear.

Embodiment 1

R_1 =	72.90	D_1 =	2.10	N_1 =	1.72342	ν_1 =	38.0
R_2 =	20.24	D_2 =	8.89				
R_3 =	128.58	D_3 =	3.78	N_2 =	1.59551	ν_2 =	39.2
R_4 =	−109.49	D_4 =	1.94				
R_5 =	−81.11	D_5 =	1.94	N_3 =	1.77250	ν_3 =	49.6
R_6 =	33.06	D_6 =	5.90				
R_7 =	41.42	D_7 =	3.55	N_4 =	1.80518	ν_4 =	25.4
R_8 =	234.15	l_1					
R_9 =	44.81	D_9 =	5.85	N_5 =	1.77250	ν_5 =	49.6
R_{10} =	−398.69	D_{10} =	2.00				
R_{11} =	56.82	D_{11} =	5.85	N_6 =	1.80610	ν_6 =	40.9
R_{12} =	−63.65	D_{12} =	2.88				
R_{13} =	−27.40	D_{13} =	3.06	N_7 =	1.84666	ν_7 =	23.9
R_{14} =	559.54	D_{14} =	3.26				
R_{15} =	415.00	D_{15} =	2.36	N_8 =	1.61800	ν_8 =	63.4
R_{16} =	−47.28	D_{16} =	0.66				
R_{17} =	−1900.55	D_{17} =	1.60	N_9 =	1.83400	ν_9 =	37.2
R_{18} =	31.95	D_{18} =	1.51				
R_{19} =	−314.71	D_{19} =	2.81	N_{10} =	1.49700	ν_{10} =	81.6
R_{20} =	−26.03	D_{20} =	0.10				
R_{21} =	187.39	D_{21} =	2.85	N_{11} =	1.48749	ν_{11} =	70.1
R_{22} =	−47.90						

	f = 20.5	f = 27	f = 34.5
l_1	25.31	11.19	1.51

Aspheric Surface Figuring Constants for first Surface

B =	5.52×10^{-6}
C =	-3.09×10^{-9}
D =	4.57×10^{-12}
E =	-1.16×10^{-15}
f_1 =	−33.67
f_2 =	35.71

Embodiment 2

R_1 =	70.07	D_1 =	2.10	N_1 =	1.72342	ν_1 =	38.0
R_2 =	20.10	D_2 =	8.89				
R_3 =	149.05	D_3 =	3.78	N_2 =	1.59551	ν_2 =	39.2
R_4 =	−105.86	D_4 =	1.94				
R_5 =	−83.21	D_5 =	1.94	N_3 =	1.77250	ν_3 =	49.6
R_6 =	32.87	D_6 =	5.90				
R_7 =	41.09	D_7 =	3.55	N_4 =	1.80518	ν_4 =	25.4
R_8 =	223.27	l_1					
R_9 =	44.57	D_9 =	5.85	N_5 =	1.77250	ν_5 =	49.6
R_{10} =	−358.59	D_{10} =	2.00				
R_{11} =	57.24	D_{11} =	5.85	N_6 =	1.80610	ν_6 =	40.9
R_{12} =	−63.91	D_{12} =	2.88				
R_{13} =	−27.34	D_{13} =	3.06	N_7 =	1.84666	ν_7 =	23.9
R_{14} =	591.72	D_{14} =	3.26				
R_{15} =	707.20	D_{15} =	2.36	N_8 =	1.61800	ν_8 =	63.4
R_{16} =	−47.11	D_{16} =	0.66				
R_{17} =	−1883.81	D_{17} =	1.60	N_9 =	1.83400	ν_9 =	37.2
R_{18} =	32.14	D_{18} =	1.38				
R_{19} =	−657.36	D_{19} =	2.89	N_{10} =	1.49700	ν_{10} =	81.6
R_{20} =	−26.00	D_{20} =	0.10				
R_{21} =	234.25	D_{21} =	2.65	N_{11} =	1.48749	ν_{11} =	70.1
R_{22} =	−47.96						

	f = 20.5	f = 27	f = 34.5
l_1	25.13	11.18	1.61

Aspheric Surface Figuring Constants for first Surface

B =	5.38×10^{-6}
C =	-2.93×10^{-9}
D =	4.37×10^{-12}
E =	-9.41×10^{-16}
f_1 =	−33.39
f_2 =	35.58

Embodiment 3

R_1 =	65.30	D_1 =	2.10	N_1 =	1.69680	ν_1 =	55.5
R_2 =	19.79	D_2 =	9.04				
R_3 =	217.50	D_3 =	3.49	N_2 =	1.60311	ν_2 =	60.7
R_4 =	−93.53	D_4 =	2.17				
R_5 =	−70.55	D_5 =	2.89	N_3 =	1.78590	ν_3 =	44.2
R_6 =	31.34	D_6 =	5.15				
R_7 =	40.34	D_7 =	3.62	N_4 =	1.80518	ν_4 =	25.4
R_8 =	400.48	l_1					
R_9 =	45.58	D_9 =	5.85	N_5 =	1.77250	ν_5 =	49.6
R_{10} =	−263.00	D_{10} =	2.00				
R_{11} =	53.88	D_{11} =	5.85	N_6 =	1.80610	ν_6 =	40.9
R_{12} =	−55.05	D_{12} =	2.14				
R_{13} =	−27.41	D_{13} =	3.61	N_7 =	1.84666	ν_7 =	23.9
R_{14} =	246.01	D_{14} =	1.32				
R_{15} =	−1209.01	D_{15} =	3.65	N_8 =	1.60311	ν_8 =	60.7
R_{16} =	−49.48	D_{16} =	1.42				
R_{17} =	436.16	D_{17} =	1.70	N_9 =	1.83400	ν_9 =	37.2
R_{18} =	31.96	D_{18} =	1.63				
R_{19} =	−146.93	D_{19} =	2.44	N_{10} =	1.48749	ν_{10} =	70.1
R_{20} =	−24.71	D_{20} =	0.10				
R_{21} =	305.07	D_{21} =	2.69	N_{11} =	1.48749	ν_{11} =	70.1

Embodiment 3-continued

R_{22} =	−39.35						
	f = 20.5		f = 26.65		f = 34.48		
l_1	22.92		10.32		0.78		

Aspheric Surface Figuring Constants for first Surface

B =	5.42×10^{-6}
C =	-2.27×10^{-9}
D =	4.11×10^{-12}
E =	-4.47×10^{-16}
f_1 =	−32.40
f_2 =	34.55

Embodiment 4

R_1 =	61.22	D_1 =	2.10	N_1 =	1.69680	ν_1 =	55.5
R_2 =	19.81	D_2 =	9.03				
R_3 =	364.20	D_3 =	3.49	N_2 =	1.60311	ν_2 =	60.7
R_4 =	−102.73	D_4 =	2.42				
R_5 =	−78.86	D_5 =	2.42	N_3 =	1.77250	ν_3 =	49.6
R_6 =	28.18	D_6 =	4.99				
R_7 =	37.11	D_7 =	3.62	N_4 =	1.74000	ν_4 =	28.3
R_8 =	645.86	l_1					
R_9 =	49.21	D_9 =	5.85	N_5 =	1.77250	ν_5 =	49.6
R_{10} =	−194.70	D_{10} =	2.00				
R_{11} =	48.30	D_{11} =	5.85	N_6 =	1.80610	ν_6 =	40.9
R_{12} =	−50.01	D_{12} =	1.73				
R_{13} =	−28.55	D_{13} =	3.56	N_7 =	1.84666	ν_7 =	23.9
R_{14} =	174.26	D_{14} =	1.32				
R_{15} =	1143.68	D_{15} =	3.65	N_8 =	1.51633	ν_8 =	64.1
R_{16} =	−56.74	D_{16} =	1.42				
R_{17} =	388.24	D_{17} =	1.70	N_9 =	1.83400	ν_9 =	37.2
R_{18} =	31.03	D_{18} =	1.85				
R_{19} =	−108.43	D_{19} =	2.44	N_{10} =	1.48749	ν_{10} =	70.1
R_{20} =	−23.81	D_{20} =	0.10				
R_{21} =	270.05	D_{21} =	2.59	N_{11} =	1.48749	ν_{11} =	70.1
R_{22} =	−38.65						
	f = 20.5		f = 26.5		f = 34.5		
l_1	22.22		10.38		1.12		

Aspheric Surface Figuring Constants for first Surface

B =	5.19×10^{-6}
C =	-1.23×10^{-9}
D =	1.87×10^{-12}
E =	1.66×10^{-15}
f_1 =	−31.21
f_2 =	34.15

Embodiment 5

R_1 =	61.82	D_1 =	2.10	N_1 =	1.69680	ν_1 =	55.5
R_2 =	19.91	D_2 =	8.61				
R_3 =	221.15	D_3 =	3.49	N_2 =	1.60311	ν_2 =	60.7
R_4 =	−116.52	D_4 =	2.74				
R_5 =	−78.55	D_5 =	2.74	N_3 =	1.77250	ν_3 =	49.6
R_6 =	27.78	D_6 =	4.99				
R_7 =	36.86	D_7 =	3.62	N_4 =	1.74000	ν_4 =	28.3
R_8 =	560.95	l_1					
R_9 =	52.81	D_9 =	5.85	N_5 =	1.77250	ν_5 =	49.6
R_{10} =	−180.26	D_{10} =	2.00				
R_{11} =	45.53	D_{11} =	5.85	N_6 =	1.80610	ν_6 =	40.9
R_{12} =	−49.23	D_{12} =	1.76				
R_{13} =	−28.49	D_{13} =	3.56	N_7 =	1.84666	ν_7 =	23.9
R_{14} =	178.87	D_{14} =	1.32				
R_{15} =	−844.90	D_{15} =	3.65	N_8 =	1.51633	ν_8 =	64.1
R_{16} =	−49.24	D_{16} =	1.42				
R_{17} =	592.57	D_{17} =	1.70	N_9 =	1.83400	ν_9 =	37.2
R_{18} =	31.12	D_{18} =	1.85				
R_{19} =	−101.35	D_{19} =	2.44	N_{10} =	1.48749	ν_{10} =	70.1
R_{20} =	−23.65	D_{20} =	0.10				
R_{21} =	251.04	D_{21} =	2.59	N_{11} =	1.48749	ν_{11} =	70.1
R_{22} =	−39.70						
	f = 20.53		f = 26.49		f = 34.54		

Embodiment 5-continued

l_1	22.23	10.64	1.31

Aspheric Surface Figuring Constants for first Surface

B =	5.19×10^{-6}
C =	-1.23×10^{-9}
D =	1.87×10^{-12}
E =	1.66×10^{-15}
f_1 =	−31.11
f_2 =	34.04

What is claimed is:

1. An ultrawide angle zoom objective having the following conditions:

two lens components of which the first counting from the front is of negative power and the second is of positive power;

an air separation between said first and said second lens components being made variable to effect zooming,

said first lens component consisting of four lens elements from front to rear, the first being frontmost and the fourth being rearmost,

the first lens element being a meniscus lens of negative power convex toward the front,

the second lens element being a bi-convex lens,

the third lens element being a bi-concave lens with its rear surface having a stronger refractive power,

the fourth lens element being a lens of positive power with its front surface convex toward the front,

the absolute value of the radius of curvature of the rear surface of said second lens being larger than the absolute value of the radius of curvature of the front surface of said third lens, and

said first lens element having an aspheric surface.

2. An ultrawide angle zoom objective according to claim 1, satisfying the following condition:

$$|f_1| < f_T$$

where f_1 is the focal length of said lens component, and f_T is the longest focal length of the entire lens system.

3. An ultrawide angle zoom objective comprising two lens components of which the first counting from the front is of negative power and the second is of positive power;

an air separation between said first and said second lens components being made variable to effect zooming,

said first lens component consisting of four lenses from front to rear, the first being frontmost and the fourth being rearmost,

the first lens being a meniscus lens of negative power convex toward the front,

the second lens being a bi-convex lens,

the third lens being a bi-concave lens with its rear surface having a stronger refractive power,

the fourth lens being a lens of positive power with its front surface convex toward the front,

the absolute value of the radius of curvature of the rear surface of said second lens being larger than the absolute value of the radius of curvature of the front surface of said third lens, and

said first lens having an aspheric surface and further satisfying the following conditions:

$$0.95 < |f_2/f_1| < 1.20$$

$$1.25 < |f_1/f_w| < 1.95$$

$$1 < l_w/f_w < 1.5$$

where

f_1 is the focal length of said 1st lens component;

f_2 is the focal length of said 2nd lens component;

f_w is the shortest focal length of the entire system; and

l_w is the distance (air separation) between said 1st and said 2nd lens components in the wide angle position.

4. An ultrawide angle zoom objective comprising two lens components of which the first counting from the front is of negative power and the second is of positive power;

an air separation between said first and said second lens components being made variable to effect zooming,

said first lens component consisting of four lenses from front to rear, the first being frontmost and the fourth being rearmost,

the first lens being a meniscus lens of negative power convex toward the front,

the second lens being a bi-convex lens,

the third lens being a bi-concave lens with its rear surface having a stronger refractive power,

the fourth lens being a lens of positive power with its front surface convex toward the front,

the absolute value of the radius of curvature of the rear surface of said second lens being larger than the absolute value of the radius of curvature of the front surface of said third lens, and

said first lens having an aspheric surface and further satisfying the following conditions:

$$0.2 < \Psi < 0.35$$

$$-0.4 < \Omega < -0.05$$

wherein

Ψ is the sum of the third order aspheric surface coefficients applied to the first lens; and

Ω is the sum of the fifth order aspheric surface coefficients applied to the first lens.

5. An ultrawide angle zoom objective according to claim **3**, wherein

Ψ is the sum of the third order aspheric surface coefficients applied to the first lens; and

Ω is the sum of the fifth order aspheric surface coefficients applied to the first lens.

* * * * *

United States Patent [19]

Suzuki et al.

[11] **Patent Number: 4,467,188**

[45] **Date of Patent: Aug. 21, 1984**

[54] **DEVICE FOR SPLITTING LIGHT FROM AN OBJECTIVE LENS**

[75] Inventors: **Takashi Suzuki**, Yokohama; **Nozomu Kitagishi**, Inagi; **Susumu Matsumura**, Kawasaki, all of Japan

[73] Assignee: **Canon Kabushiki Kaisha**, Tokyo, Japan

[21] Appl. No.: **333,883**

[22] Filed: **Dec. 23, 1981**

[30] **Foreign Application Priority Data**

Jan. 6, 1981 [JP] Japan 56-565

[51] **Int. Cl.**[3] **G01J 1/36**

[52] **U.S. Cl.** **250/204**; 250/227

[58] **Field of Search** 350/167, 169; 250/201, 250/204, 216, 578, 227; 354/25; 356/4

[56] **References Cited**

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Primary Examiner—David C. Nelms
Assistant Examiner—J. Brophy
Attorney, Agent, or Firm—Fitzpatrick, Cella, Harper & Scinto

[57] **ABSTRACT**

A phase type diffraction grating and a microprism for splitting the light beam from an objective lens into three light beams. The three light beams are split in one direction by the diffraction grating and are directed onto three rows of line sensors disposed on the same plane. In the two optical paths between the diffraction grating and the line sensors, there is disposed an optical path length difference imparting element for forming on the line sensors images at a predetermined focal plane of the objective lens and planes forward and rearward of the predetermined focal plane. Thus, the line sensors detect the images at the predetermined focal plane and at planes forward and rearward of the predetermined focal plane.

4 Claims, 3 Drawing Figures

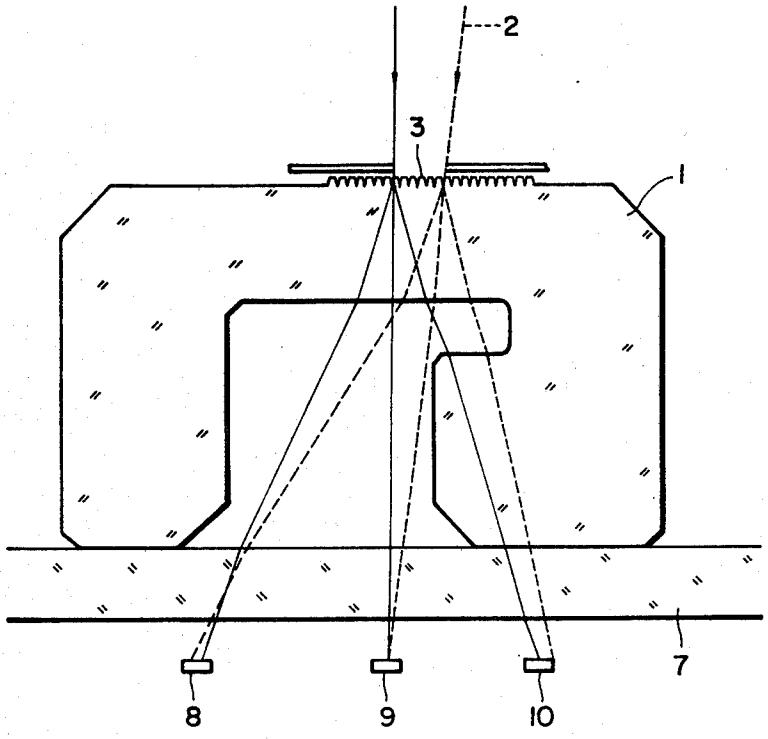


FIG. 1

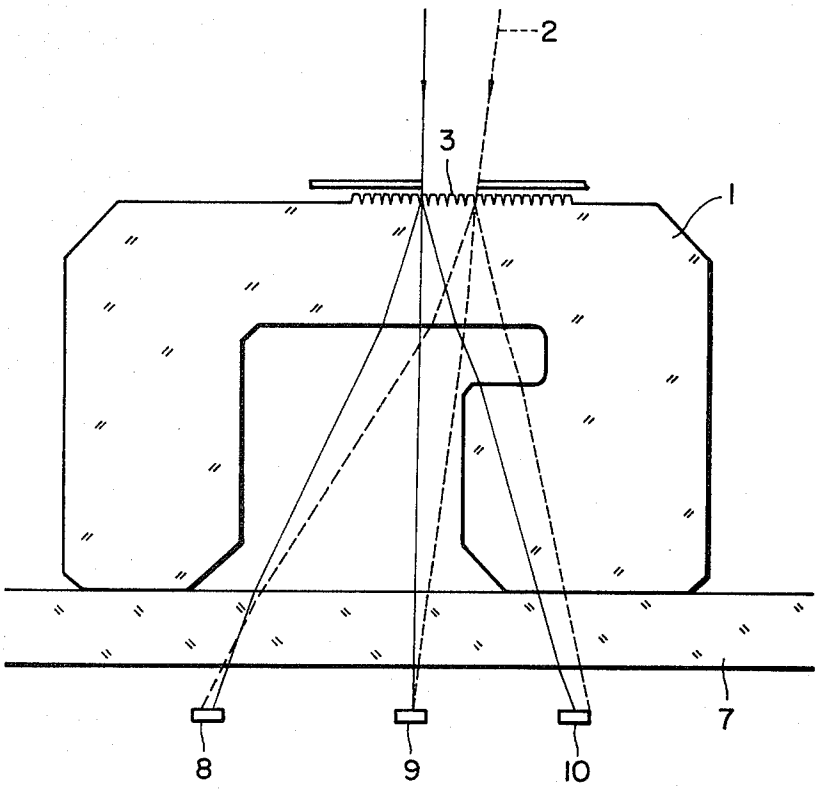


FIG. 2

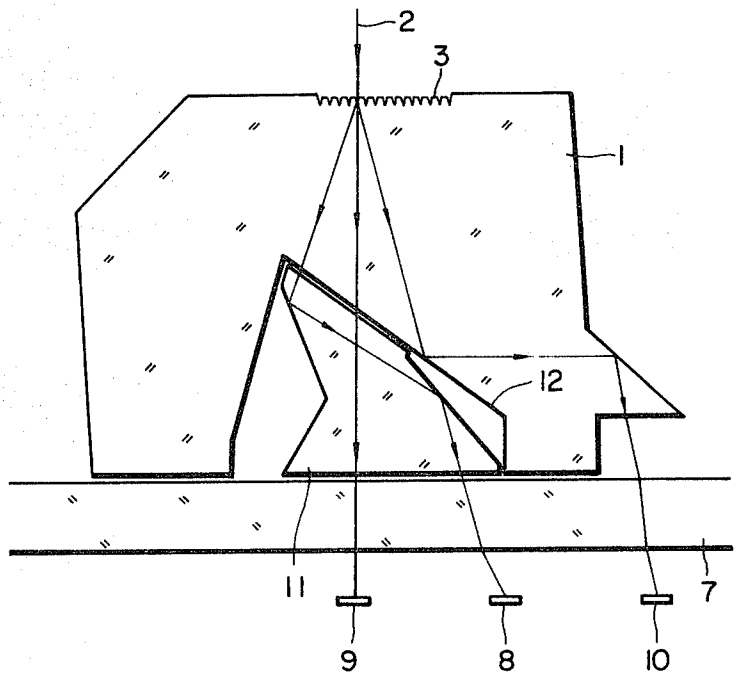
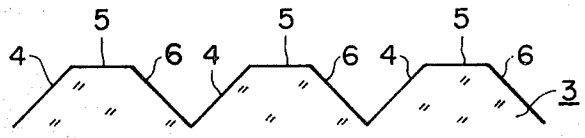


FIG. 3



DEVICE FOR SPLITTING LIGHT FROM AN OBJECTIVE LENS

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to a beam splitting device and more particularly to a beam splitting device in which the light beam from an objective lens is split by a beam splitter and an optical path length difference is imparted to at least one of the optical paths of the split light beams, so that at least two images having an optical path length difference are formed on a plurality of rows or sensors disposed substantially on the same plane, whereby these images are detected.

2. Description of the Prior Art

A device of the described type is applicable to a focus detecting system for a camera. As the means for splitting the light beam from the objective lens of this reading apparatus, the assignee of the subject application has already proposed an area-type beam splitter in Japanese patent application No. 98524/1980 filed on July 17, 1980 corresponding to U.S. patent application Ser. No. 283,001 filed on July 13, 1981. In this prior application, there is disclosed, as an example of the area-type beam splitter, a beam splitter comprising dot-like or stripe-like minute reflecting mirrors deposited on a glass substrate by evaporation and effecting beam splitting by reflection and transmission.

However, these beam splitter, which comprises minute reflecting mirrors deposited on a glass substrate by evaporation, is costly and difficult to manufacture.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a beam splitting device which eliminates the above-noted disadvantages.

The invention will become fully apparent from the following detailed description thereof taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** shows a first embodiment of the present invention.

FIG. **2** shows a second embodiment of the present invention.

FIG. **3** shows a diffraction grating.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

In FIG. **1**, reference numeral **1** designates a beam splitter unit. This beam splitter unit **1** is formed of a transparent material such as glass or acrylic resin, and comprises a portion performing the function of beam splitting and a portion imparting an optical path length difference, the two portions being constructed integrally with each other. The light beam **2** from an objective lens, not shown, which includes image information enters from the entrance surface of the beam splitter unit **1**. A beam splitter **3** is formed on this entrance surface. This beam splitter has a number of grating lines formed in the entrance surface thereof. In the present embodiment, the split light rays should only shift in one-dimensional direction and therefore, the grating lines are formed in one direction.

Turning back to FIG. **1**, reference numeral **7** designates a transparent substrate to the surface of which is fixed the beam splitter unit **1**. This substrate itself also has the function of imparting an optical path length difference. Denoted by **8**, **9** and **10** are photoarray sensors such as CCD's formed on the same substrate.

The light beam **2** from the objective lens which has entered the beam splitter **3** is diffracted by a diffraction grating.

That is, the positive first order diffracted light travels toward the array sensor **8**, the 0-order diffracted light rectilinearly travels toward the sensor **9** and the negative first order diffracted light travels toward the sensor **10**. These light beams travelling toward the sensors **8**, **9** and **10** differ in the length through the transparent body block **1** and the substrate **7**. Accordingly, there is created an optical path length difference. This optical path length difference is determined so that if an in-focus image is formed on the array sensor **9**, the array sensor **8** has its image formed in front thereof and the array sensor **10** has its image formed behind the sensor. These images having the optical path length difference are detected by the sensors **8**, **9** and **10**, respectively.

In the embodiment of FIG. **1**, the optical path length difference is imparted by a transparent body having a refractive index difference, but the split light rays may also be caused to by-pass i.e. by reflection.

FIG. **2** shows an embodiment in which the optical path length difference is imparted by such by-passing. In this embodiment, the block **1** has an air-plastic boundary surface **12** inclined with respect to the optical path, and has another plastic block **11**. The 0-order diffracted light passes through the boundary surface **12** and block **11** and travels toward the array sensor **9**. The positive first order diffracted light passed through the boundary surface **12** into the block **11** and is twice subjected to total reflection and travels toward the array sensor **8**. The negative first order diffracted light is subjected to total reflection by the boundary surface **12** and subjected to total reflection by the block **1** and travels toward the sensor **10**. The split light rays differ in optical path length by a reflection amount and therefore, images having an optical path length difference are formed on the respective sensors.

The above embodiments have been described with respect to a case where a phase type one-dimensional diffraction grating is used as the beam splitter, but the beam splitter provided on the plane orthogonal to the optical axis of the phototaking lens may be of another type.

FIG. **3** shows another form of the beam splitter. The beam splitter **3** is formed by three kinds of minute inclined surfaces **4**, **5** and **6** which differ in inclination with respect to the incident light. These inclined surfaces **4**, **5** and **6** are regularly formed at intervals of 30μ–90μ. The number of kinds corresponds to the number into which it is desired to split the light beam. The inclined surfaces **4**, **5** and **6** have no inclination in the direction perpendicular to the surface of the drawing sheet.

The light beam **2** from the objective lens which has entered the beam splitter **3** is split by the inclined surfaces **4**, **5** and **6**.

That is, the light ray which has entered the inclined surface **6** travels toward the array sensor **8** as in the FIG. **1** embodiment, the light ray which has entered the inclined surface **5** rectilinearly travels toward the sensor **9**, and the light ray which has entered the inclined surface **4** is deflected and travels toward the sensor **10**. These light beams travelling toward the sensors **8**, **9** and

10, respectively, differ in the length through the transparent body block 1 and the substrate 7.

Accordingly, there is created an optical path length difference. This optical path length difference is determined so that an in-focus image is formed on the array sensor 9, the array sensor 8 has its image formed in front of the sensor and the array sensor 10 has its image formed behind the sensor. These images having the optical path length difference are detected by the sensors 8, 9 and 10, respectively.

What we claim is:

1. A beam splitting device for causing a plurality of sensors disposed in the vicinity of a predetermined imaging plane of an objective lens to detect images of different imaging states, respectively, comprising:

light splitting means for splitting the light beam from the objective lens into a plurality of light beams, said splitting means having a light incidence surface disposed orthogonally with respect to the optical axis of the objective lens, said surface being formed with a grating of surface relief structure; and

optical means for establishing different optical path lengths for the split beams between said splitting means and the sensors, said optical means being disposed between said splitting means and the sensors so as to provide different effects on the plurality of split beams, respectively.

2. A beam splitting device according to claim 1, wherein said optical means establishes said different optical path lengths for the split beams by providing at least one of the paths of the split beams with a refractive index different from the refractive index of the other paths.

3. A beam splitting device according to claim 1, wherein said optical means establishes said different optical path lengths for the split beams by causing at least one of the split beams to be reflected a pluality of times.

4. A beam splitting device according to claim 1, wherein said light splitting means and optical beams constitute a unitary structure.

* * * * *

United States Patent [19]

Oinoue et al.

[11] **4,443,079**

[45] **Apr. 17, 1984**

[54] **METHOD AND APPARATUS FOR DETECTING FOCUS CONDITION OF OBJECTIVE LENS**

[75] Inventors: **Kenichi Oinoue**, Tokyo; **Asao Hayashi**; **Masatoshi Ida**, both of Hachioji; **Masahiro Aoki**, Fussa; **Junichi Nakamura**, Hachioji; **Kenji Fukuoka**, Fussa, all of Japan

[73] Assignee: **Olympus Optical Co. Ltd.**, Tokyo, Japan

[21] Appl. No.: **426,898**

[22] Filed: **Sep. 29, 1982**

[30] **Foreign Application Priority Data**

Oct. 6, 1981 [JP] Japan 56-159218

[51] **Int. Cl.**[3] **G03B 3/00**

[52] **U.S. Cl.** **354/407**

[58] **Field of Search** 354/25, 31

[56] **References Cited**

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4,185,191 1/1980 Stauffer ..... 354/25 X

4,387,975 6/1983 Araki 354/25

Primary Examiner—Michael L. Gellner

Attorney, Agent, or Firm—Parkhurst & Oliff

[57] **ABSTRACT**

A focus condition of an objective lens is detected on the basis of a lateral shift of two images formed by first and second light fluxes which are transmitted through right- and left-hand halves of the lens, respectively. In order to separate the first and second light fluxes, there is arranged an array of triangle prisms each having first and second surfaces which are inclined symmetrically with respect to the optical axis of lens by a critical angle so that one of the light fluxes is transmitted through the one of the surfaces, but is totally reflected by the other surface of each prism. The first and second light fluxes transmitted through the prisms are received by an array of light receiving elements in such a manner that the first and second light fluxes are selectively received by odd and even numbered light receiving elements, respectively.

12 Claims, 7 Drawing Figures

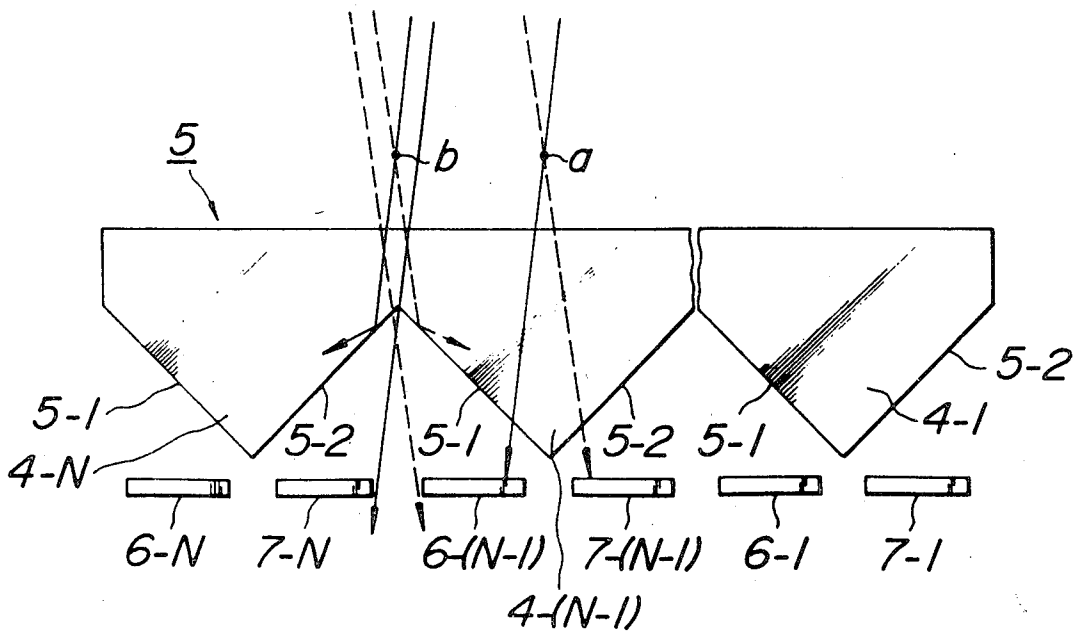


FIG. 1

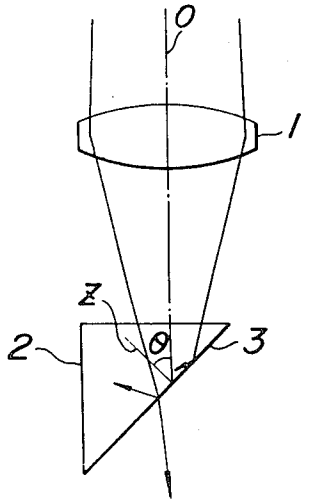


FIG. 2

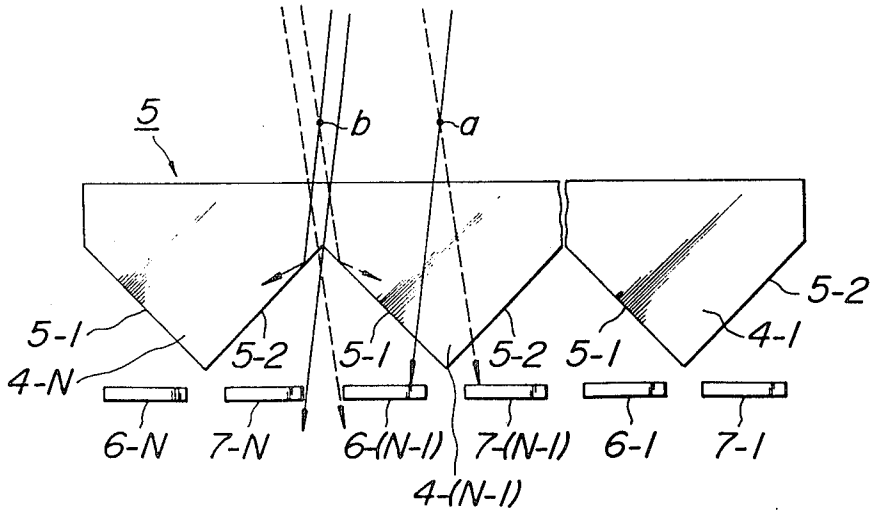


FIG_3A

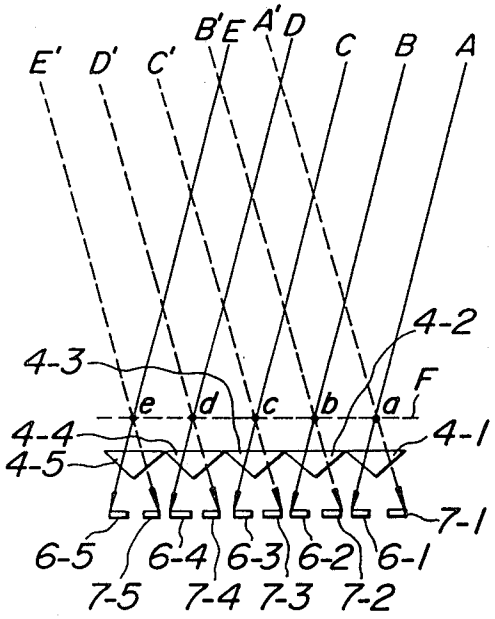


FIG. 3B

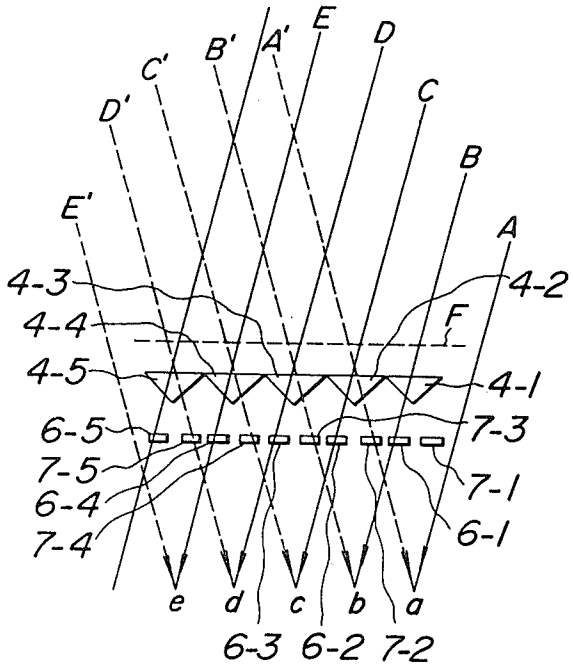


FIG_3C

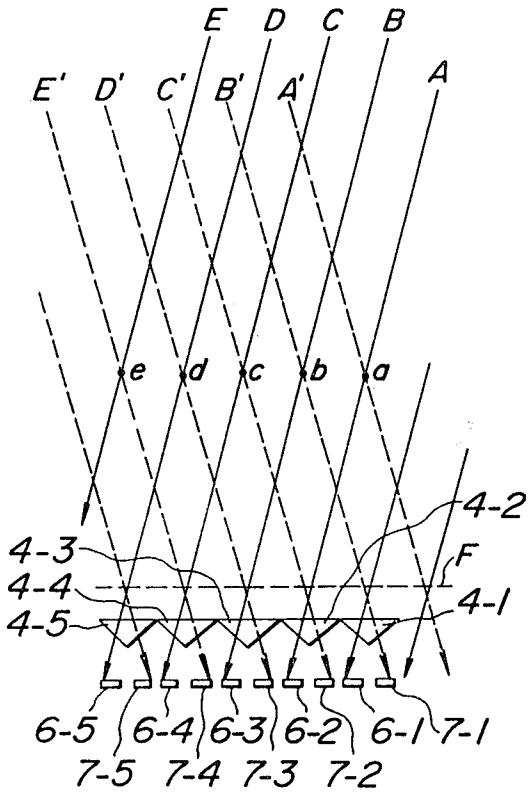


FIG_4

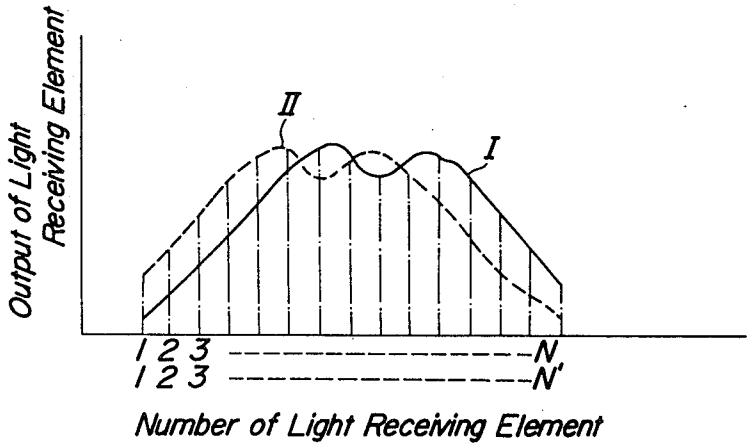
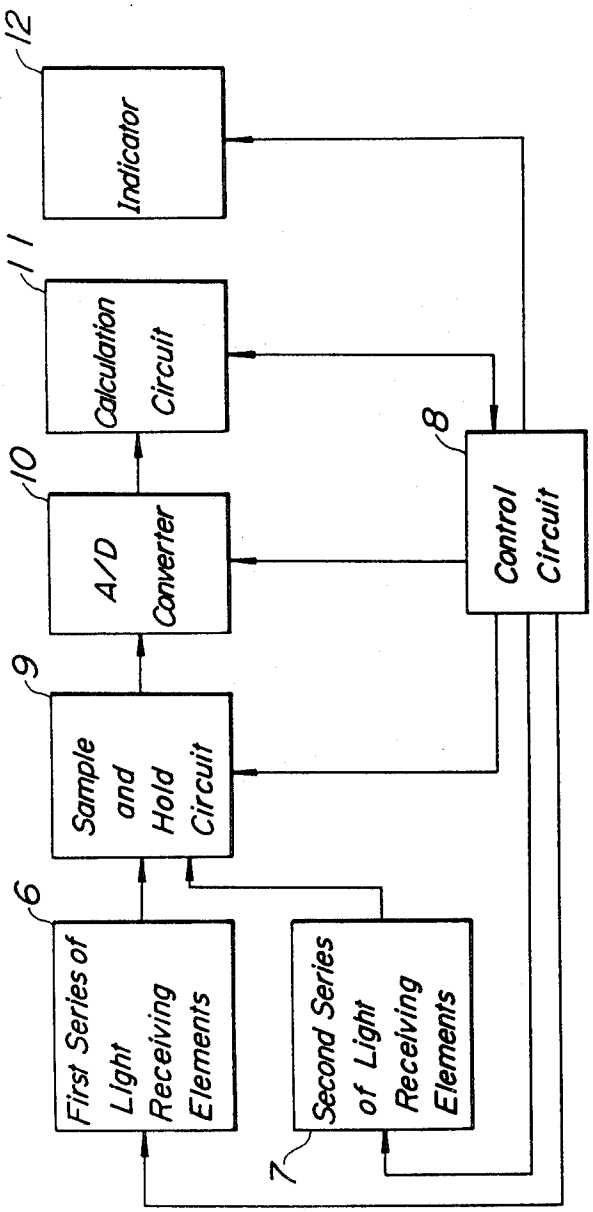

Output of Light Receiving Element
II
I
1 2 3
N
1 2 3
N'
Number of Light Receiving Element

FIG. 5


12
Indicator
11
Calculation Circuit
10
A/D Converter
9
Sample and Hold Circuit
8
Control Circuit
6
First Series of Light Receiving Elements
7
Second Series of Light Receiving Elements

METHOD AND APPARATUS FOR DETECTING FOCUS CONDITION OF OBJECTIVE LENS

BACKGROUND OF THE INVENTION

The present invention relates to a method and an apparatus for detecting a focus condition of an objective lens for use in a still camera, a cinecamera, an optical apparatus for taking microphotographs, etc.

Until now various types of the focus detection methods and apparatuses have been proposed. For example, in a Japanese Patent Laid-open Publication No. 60,645/73, the apparatus has been proposed wherein light fluxes transmitted through symmetric portions of an objective lens with respect to its optical axis are received by light receiving elements respectively through a vibrating lattice and a focus condition of the lens is detected on the basis of a difference between photoelectrically converted outputs derived from these light receiving elements. However, in such focus detection apparatus, the lattice must be supported movably and must be vibrated by a driving system, a whole apparatus becomes large in size and complex in construction.

In order to eliminate such drawbacks, another known detection apparatus has been further proposed in a Japanese Paten Laid-open Publication No. 142,512/77, wherein an image to be inspected is divided into two images by means of two wedge-shaped prisms arranged symmetrically and the two images are projected onto two series of photo receiving elements through a relay lens and a focusing condition is detected on the basis of a lateral shift of the divided images by suitably processing output difference between these series of light receiving elements. In the focus detection apparatus mentioned above, the system construction can be made relatively simple because it is not necessary to provide the lattice vibrating system and the movably supporting mechanism. However, since the images divided by the wedge-shaped prisms are projected onto the two series of light receiving elements by means of the relay lens, it is not possible to satisfy sufficiently a requirement for a compact system and is extremely difficult to adjust an optical positional relation between the relay lens, the series of the light receiving elements, etc. Moreover, since use is made of the two series of light receiving elements which are arranged side by side, it is not possible to perform the focus detection in a highly accurate manner due to differences of their characteristics.

SUMMARY OF THE INVENTION

The present invention has for its object to eliminate the drawbacks mentioned above and to provide a focus detection method which can perform a focus detection in a highly accurate manner.

According to the invention, in a method of detecting a focusing condition of an objective lens for forming an image of an object on a predetermined focal plane by selectively introducing first and second light fluxes each emanating from at least a part of respective one of first and second halves of objective lens divided along a plane including the optical axis of objective lens, onto first and second light receiving means, respectively, and by processing photoelectrically converted outputs supplied from the first and second light receiving means, the improvement comprises

introducing the first and second light fluxes into first and second light splitting means arranged between the objective lens and the first and second light receiving means, respectively, said first and second light splitting means including first and second optical surfaces, respectively, each of which is formed by an interface between higher refractive index material and lower refractive index material viewed in a light propagating direction and said first and second optical surfaces being inclined symmetrically with respect to the optical axis by such angles that the first light flux is transmitted through the first optical surface, but is totally reflected by the second optical surface and that the second light flux is transmitted through the second optical surface, but is totally reflected by the first optical surface.

Another object of the invention is to provide a focus detection apparatus for carrying out the above mentioned focus detection method by means of a compact optical system.

According to the invention, an apparatus for detecting a focus condition of an objective lens for forming an image of an object on a predetermined focal plane comprises

light splitting means comprising first and second optical surfaces each of which is formed by an interface between higher and lower refractive index materials, said first and second optical surfaces being inclined symmetrically with respect to an optical axis by an angle substantially equal to a critical angle;

means comprising first and second light receiving elements arranged to receive first and second light fluxes emanating from first and second halves of the objective lens and transmitted through said first and second optical surfaces, respectively; and

means for processing photoelectrically converted outputs from said first and second light receiving elements to detect the focus condition of the objective lens on the basis of a lateral shift of two images formed by said two light fluxes transmitted through the first and second optical surfaces.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic view showing a theory of separating a light flux on the basis of a critical angle according to the invention;

FIG. **2** is a schematic view illustrating one embodiment of the focus detection apparatus according to the invention;

FIGS. **3A** to **3C** are schematic views showing a relation between a focal position and a light flux deviation in in-focused, forwardly-defocused, and backwardly-defocused conditions respectively;

FIG. **4** is a graph showing output signal distributions of first and second series of light receiving elements; and

FIG. **5** is a block diagram illustrating an embodiment of a calculation unit of the focus detection apparatus according to the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. **1** is a schematic view explaining a theory of separating a light flux emanating from one half of an objective lens from a light flux emanating from the other half of the objective lens, said halves being divided along a plane including the optical axis of objective lens. In FIG. **1**, in an image side space of an objective lens such as a photographic lens **1** there is arranged a triangle prism **2**. An inclined surface **3** of the prism **2** is so set that an angle θ between an optical axis O and a

normal Z with respect to the inclined surface 3 is near a critical angle. For example, if it is assumed that the prism 2 is made of material having a refractive index n of 1.5 and is surrounded by an air, the angle $\theta(=\sin^{-1} 1/n)$ is set at about 42°. In this manner, light rays transmitted through a right-hand half portion of the lens 1 with respect to a plane perpendicular to the drawing and including the optical axis O are made incident upon the inclined surface 3 at angles greater than the critical angle, and thus a light beam consisting of these light rays is totally reflected by the inclined surface 3. On the contrary, light rays transmitted through a left-hand half portion of the lens 1 is made incident upon the inclined surface 3 at angles less than the critical angle, and thus a light beam consisting of these light rays is refracted by the inclined surface 3. In case of rotating the prism 2 about the optical axis O by 180°, the light beams transmitted through the right portion and the left portion of the lens 1 are refracted and reflected, respectively by the inclined surface 3. In this manner, by making use of the critical angle, it is possible to separate stably the light fluxes transmitted through the right and left portions of the lens 1 with respect to the plane perpendicular to the drawing and including the optical axis O.

In a preferred embodiment of the invention using the critical angle mentioned above, the light fluxes transmitted through the right portion (first region) and the left portion (second region) of the lens 1 are separated respectively by means of an array of prisms each having inclined surfaces which are so constructed that these light fluxes are made incident upon the inclined surfaces at the angles larger or smaller than the critical angle, and then at least a part of the light flux separated by the prism is received by a pair of light receiving elements.

FIG. 2 is a schematic view showing one embodiment of a construction of prisms and an arrangement of a pair of light receiving elements of the focus detection apparatus according to the invention. In the present embodiment, prisms 4-1, . . . , 4-(N-1), and 4-N are formed in one body and each prism has two inclined surfaces 5-1 and 5-2 upon which the light fluxes transmitted through the first and second regions are made incident. That is to say, the light flux transmitted through the first region (light rays shown by solid lines) is made incident upon the surface 5-1 at a smaller angle than the critical angle, but is made incident upon the surface 5-2 at an angle larger than the critical angle. This relation is entirely reversed for the light flux transmitted through the second region (light rays shown by dotted lines). In such a construction, as clearly seen from the light flux impinging upon a focal point a or b, the light fluxes transmitted through the first and second regions of the lens 1 are reflected by the inclined surfaces 5-2 and 5-1 respectively, so that only the light flux from the first region is transmitted through the inclined surface 5-1 and also only the light flux from the second region is transmitted through the inclined surface 5-2. Therefore, if a plurality of light receiving elements 6-1, 7-1; . . . ; 6-(N-1), 7-(N-1); 6-N, 7-N are arranged in an array in such a manner that the elements 6-1, 7-1; . . . 6-N, 7-N are symmetrical with respect to ridgelines of respective prisms 4-1, . . . , 4-(N-1), 4-N, only the light flux transmitted through the first region of the lens is made incident upon the light receiving elements 6-1~6-N (first series of light receiving elements) and also only the light flux transmitted through the second region is made incident upon the light receiving elements 7-1~7-N (second series of light receiving elements).

FIGS. 3A to 3C are schematic views showing a relation between a focal position and a light flux deviation. In FIGS. 3A to 3C, for the sake of simplicity, five prisms 4-1~4-5 and five light receiving element pairs 6-1~6-5; 7-1~7-5 are shown and the light fluxes transmitted through the first region of the lens are denoted by A~E, the light rays transmitted through the second region of the lens by A'~E', and focal points are denoted by a~e. In the present embodiment, the prisms 4-1~4-5 are arranged near a predetermined focal surface F which is conjugated with a focal plane on which an image of an object is to be formed. As shown in FIG. 3A, in case that the focal points a~e are located just on the focal surface F i.e. in an in-focused condition, the light rays A and A', B and B', . . . , E and E' are made incident upon the light receiving elements 6-1 and 7-1, 6-2 and 7-2, . . . , 6-5 and 7-5, respectively. In this case, since distributions of an incident light intensity upon the first series of light receiving elements 6-1~6-5 and the second series of light receiving elements 7-1~7-5 become the same, output distributions thereof are identical with each other. That is to say, the elements 6-1 and 7-1 receive the same light rays. Contrary to this, as shown in FIG. 3B, in case that the focal points a~e are situated backward the series of the light receiving elements i.e. in a forwardly-defocused condition, for example, the light rays B and B' are made incident upon the light receiving elements 6-1 and 7-3 respectively, the other light fluxes are made incident upon the light receiving elements each shifted from the in-focused condition. Therefore, in this case, distributions of the incident light intensity upon the first and second series of light receiving elements are different from each other and output distributions become also different as illustrated by curves I and II in FIG. 4. Moreover, as shown in FIG. 3C, in case that the focal points a~e are situated forward the focal surface F i.e. in a backwardly-defocused condition, the light fluxes A~E and A'~E' are shifted inversely in opposite directions as compared with the case shown in FIG. 3B, and thus output distributions of the first and second series of light receiving elements are shifted inversely as compared with the curves shown in FIG. 4.

Therefore, direction and amount of the defocused condition can be detected by detecting direction and amount of the relative shift of the two divided images impinging upon the light receiving elements. One preferred embodiment of the focus condition detecting method will be explained hereinbelow. At first, output differences between all the adjacent light receiving elements are measured to detect positions M and M' for the first and second series of the light receiving elements showing the maximum output differences of the same polarity. Then, the M and M' having the same polarity are compared with each other. Then the focusing condition is detected as follows; $M>M'$ . . . backwardly-defocused condition, $M<M'$ . . . forwardly-defocused condition, and $M=M'$ . . . in-focused condition. In addition, by calculating $M-M'$, a deviation amount from the in-focused condition can be obtained. It should be noted that if more than two maximum output differences having the same value are detected, the smallest numbers of positions may be chosen as the values M and M'.

FIG. 5 is a block diagram showing one embodiment of a calculation unit of the focus detection apparatus according to the invention. In the embodiment shown in FIG. 5, the first series of light receiving elements 6

comprising the light receiving elements 6-1~6-N and the second series of light receiving elements 7 comprising the light receiving elements 7-1~7-N are driven under the control of a control circuit 8. Then, photoelectrically converted output signals thereof are held by a sample and hold circuit 9 and then are successively converted into digital signals by means of an A/D converter 10. The digital signal are then supplied to a calculation circuit 11. In the calculation circuit 11, differences between successive light receiving elements of respective series are calculated so as to detect the positions M and M' of the light receiving elements producing the outputs which show the maximum difference and the same polarity, and then obtained M and M' are supplied to the control circuit 8 after comparing each other. The control circuit 8 functions to detect the focusing condition such as forwardly-defocused, backwardly-defocused, and in-focused conditions corresponding to the signal supplied from the calculation circuit 11, and to indicate the detected amount of deviation from the in-focused position on an indicator 12. In addition, in the defocused condition, the deviation amount from the in-focused condition is also represented on the indicator 12. Therefore, the focusing control can be effected manually or automatically corresponding to the information indicated on the indicator 12.

The present invention is not limited to the embodiments mentioned above, but various modifications and alternations are possible. For example, in the above embodiment the light fluxes transmitted through the first and second regions of the objective lens are separated by the triangular prism, but other polygonal prisms or a cone-shaped optical member can be used for such separation. In this case, such light dividing members may be arranged at the same position as the embodiment mentioned above. That is to say, each pair of the light receiving elements may be arranged symmetrically with respect to an apex or a ridgeline. Moreover, a parallel plate made of glass or plastics may be arranged on the bottom surface of the prism. In such a case, it is possible to receive only the desired light flux effectively by means of light receiving elements having a narrower width.

Further, the inclined surface of the prism is not always necessary to be formed by an interface between the prism and air, but may be formed by an interface between higher and lower refractive index materials.

According to the invention, since it is not necessary to provide the moving mechanism, the relay lens, etc., the whole apparatus can be made simple in construction and small in size. Moreover, since the light receiving elements for the first and second series can be formed integrally in an array, characteristic variation between the first and second series of the light receiving elements can be eliminated and thus the focus detection can be performed in a highly accurate manner.

What is claimed is:

1. In a method of detecting a focusing condition of an objective lens for forming an image of an object on a predetermined focal plane by selectively introducing first and second light fluxes each emanating from at least a part of respective one of first and second halves of objective lens divided along a plane including the optical axis of objective lens, onto first and second light receiving means, respectively, and by processing photoelectrically converted outputs supplied from the first and second light receiving means, the improvement comprising

introducing the first and second light fluxes into first and second light splitting means arranged between the objective lens and the first and second light receiving means, respectively, said first and second light splitting means including first and second optical surfaces, respectively, each of which is formed by an interface between higher refractive index material and lower refractive index material viewed in a light propagating direction and said first and second optical surfaces being inclined symmetrically with respect to the optical axis by such angles that the first light flux is transmitted through the first optical surface, but is totally reflected by the second optical surface and that the second light flux is transmitted through the second optical surface, but is totally reflected by the first optical surface.

2. A method according to claim 1, wherein said first and second light fluxes are introduced into an array of light receiving elements which are alternately belonging to said first and second light receiving means, by means of a prism member which includes an array of optical surfaces which are alternately belonging to said first and second light splitting means.

3. A method according to claim 2, wherein differences of outputs of successive elements of the first and second light receiving means are respectively derived to detect positions M and M' of the elements which produces the maximum differences of the same polarity, respectively, and the focus condition of the objective lens is detected in accordance with a difference M−M' of the detected positions.

4. A method according to claim 3, wherein a direction of a defocused condition is detected by a sign of said difference M−M'.

5. A method according to claim 3, wherein an amount of a defocused condition is detected by an amount of said difference M−M'.

6. An apparatus for detecting a focus condition of an objective lens for forming an image of an object on a predetermined focal plane comprising

light splitting means comprising first and second optical surfaces each of which is formed by an interface between higher and lower refractive index materials, said first and second optical surfaces being inclined symmetrically with respect to an optical axis by an angle substantially equal to a critical angle;

means comprising first and second light receiving elements arranged to receive first and second light fluxes emanating from first and second halves of the objective lens and transmitted through said first and second optical surfaces, respectively; and

means for processing photoelectrically converted outputs from said first and second light receiving elements to detect the focus condition of the objective lens on the basis of difference between said two light fluxes transmitted through the first and second optical surfaces.

7. An apparatus according to claim 6, wherein said first and second optical surfaces are formed by a prism.

8. An apparatus according to claim 7, wherein a plurality of prisms each having the first and second optical surfaces are arranged in an array and a plurality of pairs of the first and second light receiving elements are aligned in a corresponding array in such a manner that

the first and second light receiving elements are arranged alternately.

9. An apparatus according to claim 8, wherein said plurality of prisms are integrally formed in one body.

10. An apparatus according to claim 8, wherein said first and second light receiving elements are integrally formed in one body.

11. An apparatus according to claim 8, wherein said prisms are formed by triangle prisms.

12. An apparatus according to claim 8, wherein said processing means comprises a circuit for detecting the focus condition of the objective lens in accordance with a lateral shift of two images formed by the first and second light fluxes transmitted through the prisms.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 4,443,079

DATED : April 17, 1984

INVENTOR(S) : OINOUE et al

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 3, line 4, delete "an".

Column 4, line 25, after "backward" insert -- of --.

Column 4, line 37, after "forward" insert -- of --.

Signed and Sealed this

Fifth Day of *February 1985*

[SEAL]

Attest:

DONALD J. QUIGG

Attesting Officer *Acting Commissioner of Patents and Trademarks*

United States Patent [19]

Momiyama

[11] **4,437,735**

[45] **Mar. 20, 1984**

[54] **INVERTED TELEPHOTO TYPE WIDE ANGLE OBJECTIVE OF LARGE RELATIVE APERTURE**

[75] Inventor: **Kikuo Momiyama**, Yokohama, Japan

[73] Assignee: **Canon Kabushiki Kaisha**, Tokyo, Japan

[21] Appl. No.: **339,709**

[22] Filed: **Jan. 15, 1982**

[30] **Foreign Application Priority Data**

Jan. 22, 1981 [JP] Japan 56-7134

[51] **Int. Cl.**[3] **G02B 9/64**; G02B 13/04

[52] **U.S. Cl.** **350/458**; 350/450

[58] **Field of Search** 350/458, 450

[56] **References Cited**

U.S. PATENT DOCUMENTS

3,877,795 4/1975 Yamashita 350/458

Primary Examiner—John K. Corbin

Assistant Examiner—Rebecca D. Gass

Attorney, Agent, or Firm—Toren, McGeady and Stanger

[57] **ABSTRACT**

The wide angle objective of the inverted telephoto type with a high relative aperture. It includes from front to rear, a first lens group of negative power, a second lens group of positive power and a third lens group of positive power, well corrected for the various aberrations with predetermined conditions for the focal length of each lens group, lens form and refractive indices of the glasses of the lens elements.

5 Claims, 15 Drawing Figures

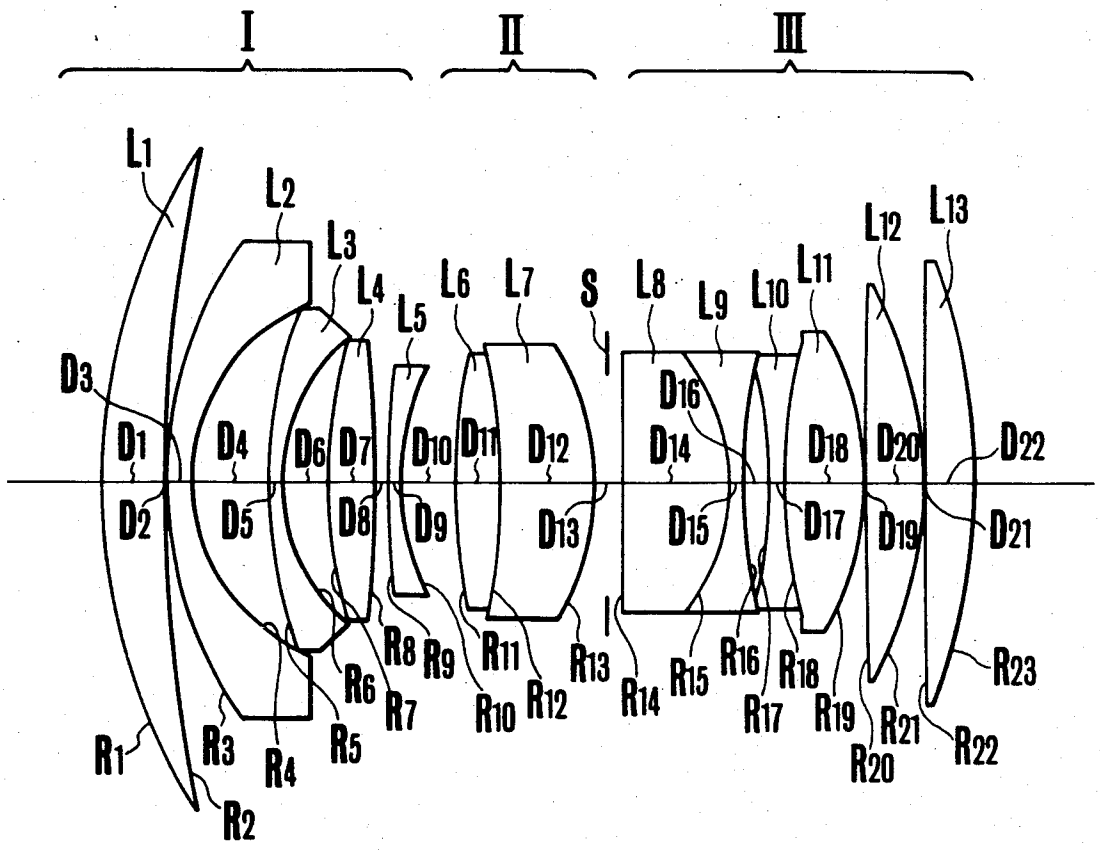


FIG. 1

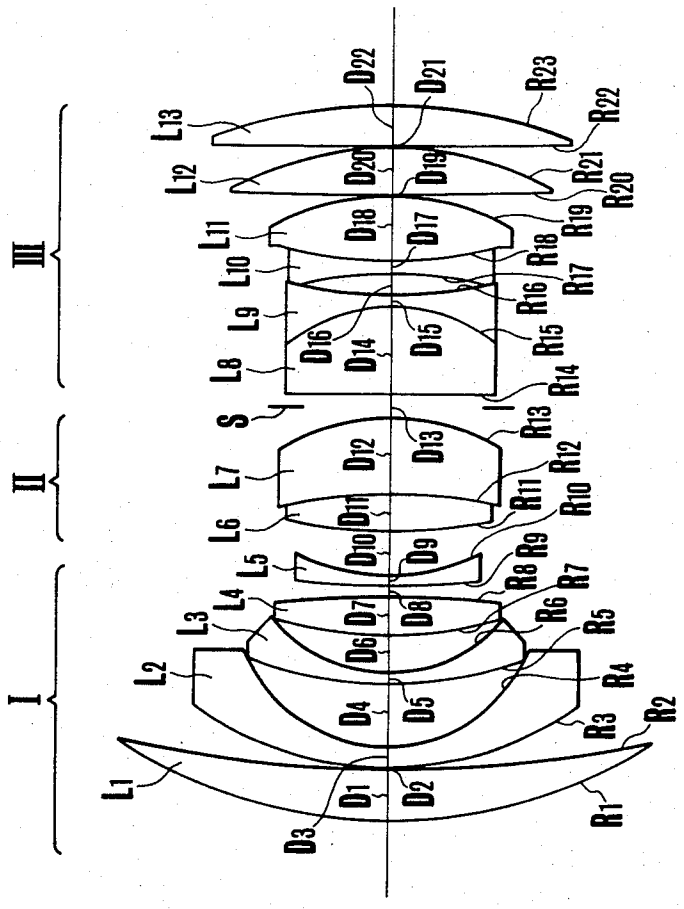

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FIG.2

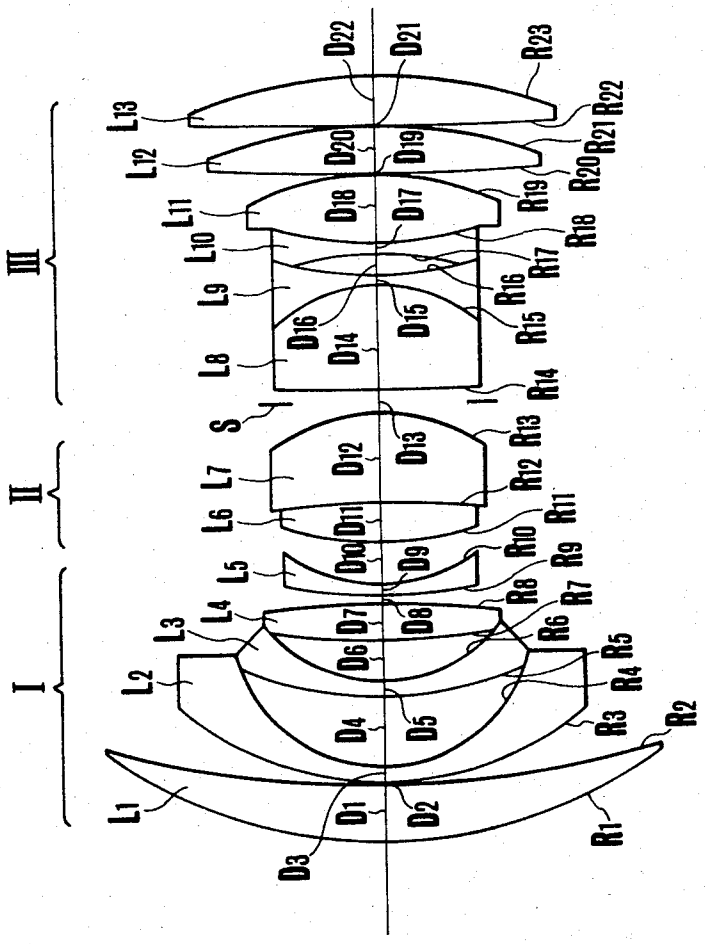
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FIG.3

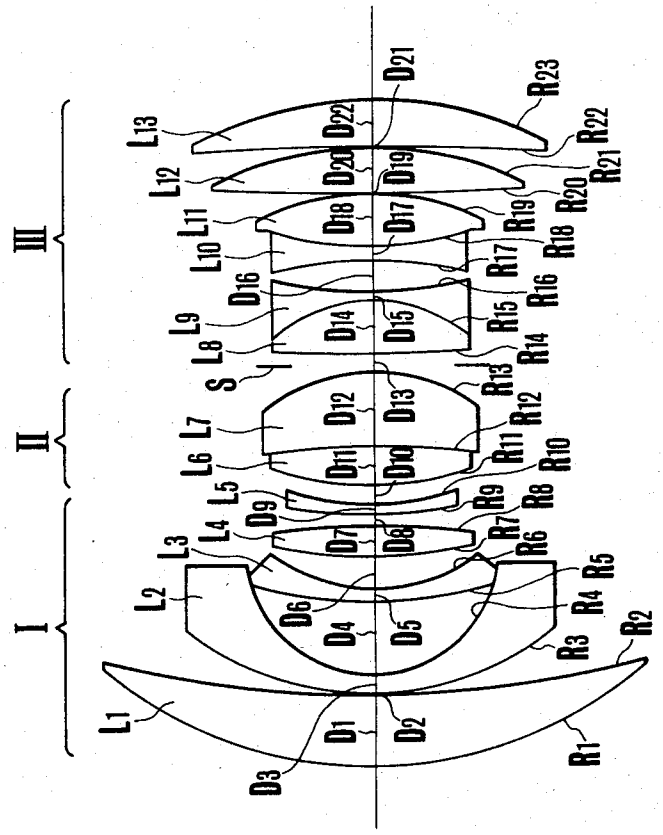
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FIG.4a FIG.4b FIG.4c FIG.4d

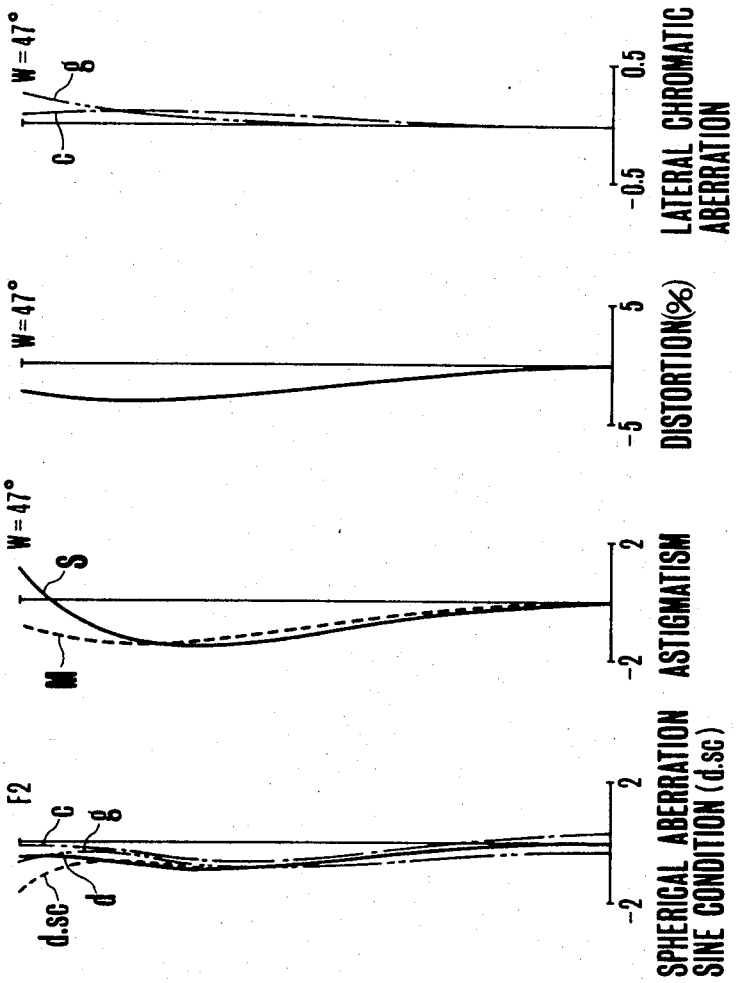
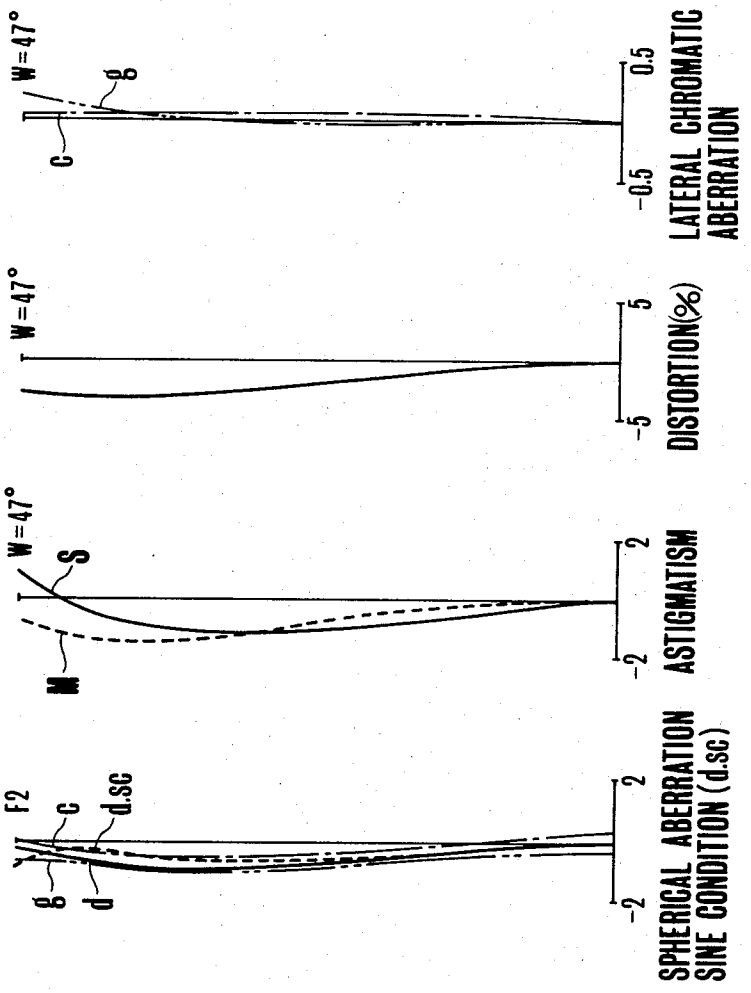


FIG.5a FIG.5b FIG.5c FIG.5d



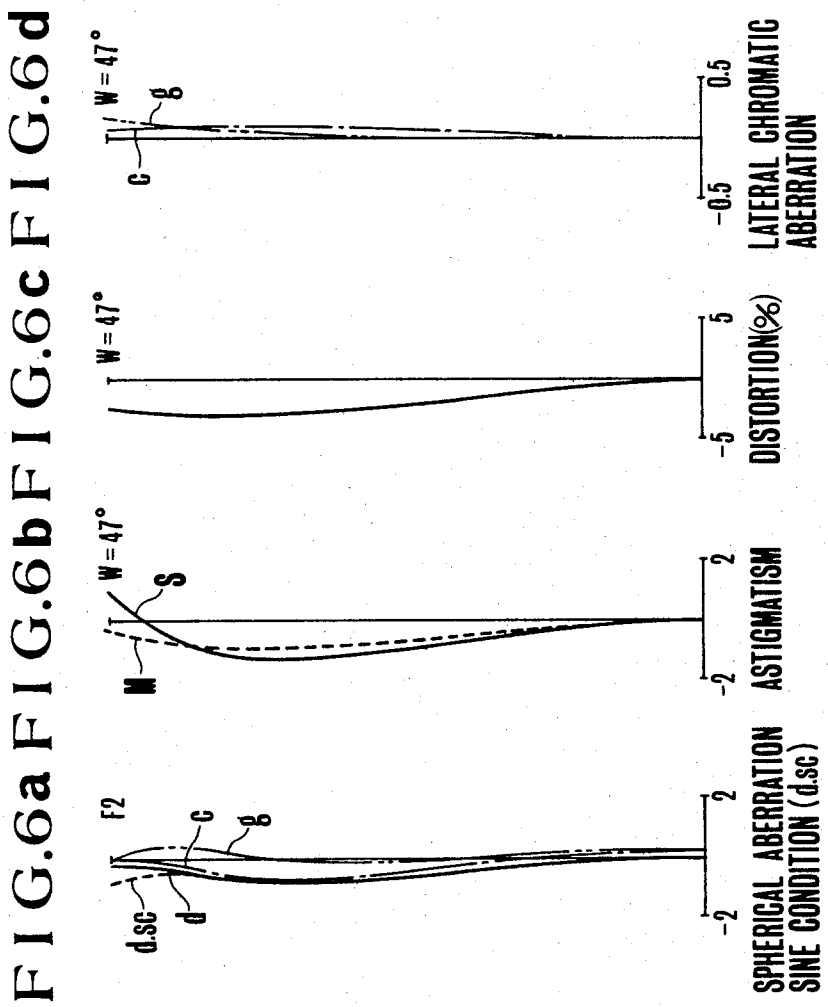


FIG.6a FIG.6b FIG.6c FIG.6d

INVERTED TELEPHOTO TYPE WIDE ANGLE OBJECTIVE OF LARGE RELATIVE APERTURE

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to inverted telephoto type wide angle objectives of high relative aperture including those having a semi-angular field of 47° with a relative aperture of F/2.0, whose bulk and size is reduced and which are well corrected for aberrations.

2. Description of the Prior Art

Recently, in the field of wide angle objectives for use in single lens reflex cameras, progress has been made in the reduction of the bulk and size of the lens system and increasing of its relative aperture. Most of these wide angle objectives employ the so-called inverted telephoto type lens configuration which offers the advantage that the back focal distance can be generally elongated. On the other hand, because the symmetry of lens configuration is broken, it becomes difficult to achieve good correction of aberrations. This difficulty tends to rapidly increase as the angular field of view and the relative aperture increase and the bulk and size of the lens system is reduced.

The use of the inverted telephoto type in the design of such lens system is disclosed in, for example, U.S. Pat. Nos. 3,748,021, 3,976,366, 3,981,563, 4,013,350, 4,061,421 and 4,188,092.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide an inverted telephoto type wide angle objective of high relative aperture for use in single lens reflex cameras in which despite the increases in the angular field of view and the relative aperture, all aberrations are well corrected, and further the lens system can be made compact.

The wide angle objective of the invention comprises three groups, of which the first counting from the front is of negative refractive power, the second is of positive refractive power and the third is of positive refractive power, the focal lengths of the lens groups, with the lens forms and the refractive indices of the glasses of the lens elements being determined to provide good correction of aberrations.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. **1**, **2** and **3** are lens block diagrams of Example 1, Example 2 and Example 3 of embodiment of inverted telephoto type wide angle objectives of large relative aperture according to the present invention respectively.

FIGS. **4**(*a*) to **4**(*d*), **5**(*a*) to **5**(*d*) and **6**(*a*) to **6**(*d*) are graphic representations of the various aberrations of the objectives of FIGS. **1**, **2** and **3** respectively.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention is next described in connection with embodiments thereof by reference to FIGS. **1** to **3**.

In the drawings, the first lens group I has a negative refractive power, the second lens group II has a positive refractive power and the third lens group III has a positive refractive power. The first lens group I consists of, from front to rear, a positive meniscus lens **L1** of forward convexity, a negative meniscus lens **L2** of forward convexity, a second negative meniscus lens **L3** likewise convex to the front, a positive lens **L4** and a third negative meniscus lens **L5** of forward convexity. The second lens group II consists of a bi-convex doublet **L6**, **L7**. The third lens group III consists of, from front to rear, a cemented lens of a positive element **L8** and a negative element **L9**, a second cemented lens of a negative element **L10** and a positive element **L11** and two positive lenses **L12** and **L13**. A stop S lies between the second and third lens groups II and III. Such lens configuration make it possible to achieve a wide angle objective of the invention. Then, in order to facilitate a further minimization of the bulk and size of the objective lens while still preserving the possibility of achieving good correction of the aberrations, the following conditions are preferably satisfied:

$$0.72<|f_I|/f<0.79 \text{ where } f_I<0 \quad (1)$$

$$2.9<D_T/f<3.6 \quad (2)$$

$$1.2<D_{I,II}/D_{III}<1.7 \quad (3)$$

$$f1>f4 \quad (4)$$

$$|f2|>|f3| \text{ where } f2, f3<0 \quad (5)$$

$$1.7<(n2+n3)/2 \quad (6)$$

$$\|1>\nu4 \quad (7)$$

$$0.75<|R13|/f<0.9 \text{ where } R13<0 \quad (8)$$

$$50<\nu7 \quad (9)$$

$$25<\nu6<30 \quad (10)$$

$$0.30<n10-n11 \quad (11)$$

$$1.4<R18/f<1.8 \quad (12)$$

$$35<\nu10 \quad (13)$$

$$\nu9<30 \quad (14)$$

$$1.7<(n12+n13)/2 \quad (15)$$

wherein

f is the focal length of the entire system;

f_I is the focal length of the 1st lens group;

D_T is the total length of the lens system;

$D_{I,II}$ is the distance from the 1st surface of the 1st lens group to the last surface of the 2nd lens group;

D_{III} is the distance from the 1st to the last surface of the 3rd lens group;

fi is the focal length of the i-th lens element counting from the front;

ni is the refractive index of the glass of the i-th lens element counting from the front;

νi is the Abbe number of the glass of the i-th lens element counting from the front; and

Ri is the radius of curvature of the i-th lens surface counting from the front.

The reason why these conditions are given is as follows. Condition (1), condition (2) and condition (3) represent fundamental features of lens design. Condition (1) serves to make the negative refractive power of the first lens group I relatively strong so that, as the lens system is adapted to be used in the single lens reflex camera, a sufficient back focal distance is assured, and at the same time, the diameter of the front member is main-

tained minimum. When the upper limit of this range (1) is violated, the assurance of the sufficient back focal distance and the maintenance of the minimum diameter of the front member become difficult. When the lower limit is violated, the first lens group I produces large positive spherical aberrations including those of higher order, and an increase in the relative aperture becomes difficult. Condition (2) serves relatively to shorten the total length of the lens system and to achieve compactness. When the upper limit of this condition is violated, attainment of compactness becomes difficult. When the lower limit is violated, overall aberration correction becomes difficult. Condition (3) serves to minimize the diameter of the front lens member under the condition (2) by arranging the stop S relatively forward as compared with a conventional objective. When the upper limit of this condition is violated, the maintenance of the minimum diameter of the front member becomes difficult. When the lower limit is violated, the diameter of the rear member increases, and the third lens group produces large off-axis aberrations which are difficult to correct.

To achieve good correction of aberrations, each of the lens groups is given the following features. The first lens group is constructed from the positive lens **L1**, negative lens **L2**, negative lens **L3**, positive lens **L4** and negative lens **L5** which have conditions (4) to (7) within the framework of condition (1). Conditions (4) and (5) concern the focal lengths of the first and fourth lenses **L1** and **L4** and the second and third lenses **L2** and **L3** in the first lens group I and state that on whichever lens the off-axis light ray is incident at a greater height has a longer focal length than the other of lower height of incidence. Under this condition, the off-axis light ray is allowed to refract with ease so that while distortion is being corrected, various off-axis aberrations can be well corrected. Condition (6) represents higher indices of refraction of the negative lenses **L2** and **L3** in the first lens group which are reflected to moderate the radii of curvature. Since this leads to the possibility of constructing the first lens group in a thinner form, the diameter of the front member can be further minimized, and at the same time the various off-axis aberrations ascribable to the negative lenses can be reduced. Condition (7) concerns what glasses are used in the positive lenses arranged in the first lens group to correct chromatic aberrations of the first lens group. By virtue of condition (7), while the chromatic aberrations of the first lens group I are corrected by making the Abbe number of the first lens larger than that of the fourth lens, the color distortion and color coma ascribable to the positive lenses are minimized.

Conditions (8), (9) and (10) concern the second lens group. Condition (8) serves to compensate for the over-correction of coma by the first lens group I. When the upper limit of this condition is violated, the compensation for the over-corrected coma becomes difficult. When the lower limit is violated, the surface **R13** produces large negative spherical aberration which makes it difficult to achieve the increase of an relative aperture. Condition (9) serves to prevent production of color coma from the surface **R13** which takes a strong convex form under condition (8). When this condition is violated, the color coma becomes objectionably large. Condition (10) is to compensate for the under-correction of lateral chromatic aberration of the first lens group I, and represents the use of a glass of small Abbe number in the front or positive lens element **L6** constituting part of the cemented lens of the second lens group II. When the upper limit of this condition is violated, under-correction of lateral chromatic aberration results. When the lower limit is violated, under-correction of longitudinal chromatic aberration results.

On the other hand, the residual unsymmetric aberrations of the first lens group I have to be compensated for by the divergent surfaces in the third lens group. As the diverging action in the third lens group is stronger, however, higher order aberrations are produced, so that an increase of the relative aperture becomes difficult to achieve. The lenses of the third lens group III are constructed so that a positive lens **L8** and a negative lens **L9** which are cemented together form a single component, a negative lens **L10** and a positive lens **L11** which are cemented together to form a second single component, a positive lens **L12** and a positive lens **L13** are arranged in this order from the front, that whilst the physical length of the third lens group III is made relatively long within the framework of condition (3), many diverging surfaces are provided along with conditions (11) and (12), and that additional conditions (13), (14) and (15) prevail. Condition (11) represents a large difference between the indices of refraction of the 10th and 11th lenses **L10** and **L11** of the doublet component, and cooperates with condition (12) to impart thereto a large diverging action. When this condition is violated, sufficient diverging action cannot be obtained even when condition (12) is satisfied, thus making it difficult to correct unsymmetrical aberrations. Condition (12) represents an optimum range of values which are to be taken by the radius of curvature of the cemented surface in view of condition (11). When the upper limit of this condition is violated, good correction of unsymmetric aberrations cannot be attained. When the lower limit is violated, aberrations of higher order are produced, thereby the increase of the relative aperture is difficult to achieve. Conditions (13) and (14) serve to correct chromatic aberrations of the third lens group III. Condition (13) represents the use of a relatively low dispersion glass in the 10th lens **L10** by there is an intent to suppress production of color coma and color distortion when this lens is cemented. When the lower limit of this condition is violated, correction of color coma and color distortion becomes difficult. When the upper limit is violated, chromatic aberrations tend to be under-corrected which is difficult to compensate for even by giving condition (14). Condition (14) represents the use of a high dispersion glass in the 9th lens **L9** to correct chromatic aberrations which tend to be under-corrected by condition (13). When this condition is violated, correction of the chromatic aberrations becomes difficult. Condition (15) represents an increase in the indices of refraction of the rearwardly arranged two convex lenses **L12** and **L13** by which spherical aberration and off-axis halo are to be corrected. When this condition is violated, correction of spherical aberration and off-axis halo becomes difficult.

In order to avoid a loss in the image quality when focusing down to shorter object distances, it is preferred for the objective of the invention to employ a focusing method that the entire lens system is axially moved forward while simultaneously the air space between the surfaces **R8** and **R9** or the axial air separation **D8** is shortened thus maintaining good stability of aberration correction throughout the focusing range.

Example 1, Example 2 and Example 3 of specific objectives which satisfy the above-mentioned various

conditions can be constructed in accordance with the following numerical data for the radii of curvature of the lens surfaces **R1** to **R23**, the axial thicknesses and air separations **D1** to **D22**, and the indices of refraction, **n1** to **n13** and the Abbe numbers $\nu 1$ to $\nu 13$ of the glasses of the lens elements.

EXAMPLE 1

	F = 100		FNo = 1:2		$2\omega = 94°$
R1 =	238.52	D1 =	24.42	n1 = 1.58913	$\nu 1 = 61.0$
R2 =	566.77	D2 =	0.73		
R3 =	150.61	D3 =	7.81	n2 = 1.78590	$\nu 2 = 44.2$
R4 =	68.82	D4 =	27.35		
R5 =	174.88	D5 =	5.86	n3 = 1.80610	$\nu 3 = 40.9$
R6 =	70.34	D6 =	16.60		
R7 =	177.05	D7 =	16.11	n4 = 1.80518	$\nu 4 = 25.4$
R8 =	−1764.08	D8 =	6.35		
R9 =	240.22	D9 =	4.88	n5 = 1.71300	$\nu 5 = 53.8$
R10 =	79.25	D10 =	20.36		
R11 =	178.37	D11 =	17.09	n6 = 1.75520	$\nu 6 = 27.5$
R12 =	−303.55	D12 =	36.53	n7 = 1.51633	$\nu 7 = 64.1$
R13 =	−86.89	D13 =	8.30		
R14 =	1014.00	D14 =	41.02	n8 = 1.77250	$\nu 8 = 49.6$
R15 =	−69.82	D15 =	4.88	n9 = 1.75520	$\nu 9 = 27.5$
R16 =	230.52	D16 =	10.65		
R17 =	−134.41	D17 =	4.88	n10 = 1.88300	$\nu 10 = 40.8$
R18 =	159.19	D18 =	29.54	n11 = 1.48749	$\nu 11 = 70.1$
R19 =	−107.77	D19 =	0.73		
R20 =	3555.27	D20 =	21.49	n12 = 1.69680	$\nu 12 = 55.5$
R21 =	−171.52	D21 =	0.73		
R22 =	−5794.06	D22 =	20.02	n13 = 1.77250	$\nu 13 = 49.6$
R23 =	−221.47				

EXAMPLE 2

	F = 100		FNo = 1:2		$2\omega = 94°$
R1 =	235.42	D1 =	24.39	n1 = 1.58913	$\nu 1 = 61.0$
R2 =	528.43	D2 =	0.73		
R3 =	157.25	D3 =	7.80	n2 = 1.71300	$\nu 2 = 53.8$
R4 =	71.55	D4 =	30.60		
R5 =	176.04	D5 =	5.85	n3 = 1.71300	$\nu 3 = 53.8$
R6 =	73.06	D6 =	19.08		
R7 =	291.49	D7 =	16.10	n4 = 1.80610	$\nu 4 = 25.4$
R8 =	−1122.11	D8 =	4.88		
R9 =	263.22	D9 =	4.88	n5 = 1.70154	$\nu 5 = 41.2$
R10 =	82.23	D10 =	19.88		
R11 =	162.32	D11 =	17.07	n6 = 1.71736	$\nu 6 = 29.5$
R12 =	−866.09	D12 =	42.61	n7 = 1.51118	$\nu 7 = 51.0$
R13 =	−92.68	D13 =	10.73		
R14 =	1474.59	D14 =	48.78	n8 = 1.70000	$\nu 8 = 48.1$
R15 =	−75.14	D15 =	4.88	n9 = 1.71736	$\nu 9 = 29.5$
R16 =	206.32	D16 =	9.61		
R17 =	−192.25	D17 =	4.88	n10 = 1.83400	$\nu 10 = 37.2$
R18 =	170.73	D18 =	31.71	n11 = 1.51633	$\nu 11 = 64.1$
R19 =	−122.60	D19 =	0.73		
R20 =	950.78	D20 =	21.46	n12 = 1.71300	$\nu 12 = 53.8$
R21 =	−210.78	D21 =	0.73		
R22 =	−5543.96	D22 =	21.95	n13 = 1.71300	$\nu 13 = 53.8$
R23 =	−228.12				

EXAMPLE 3

	F = 100		FNo = 1:2		$2\omega = 94°$
R1 =	184.76	D1 =	31.71	n1 = 1.61800	$\nu 1 = 63.4$
R2 =	439.81	D2 =	0.73		
R3 =	132.49	D3 =	7.80	n2 = 1.77250	$\nu 2 = 49.6$
R4 =	56.06	D4 =	32.00		
R5 =	179.46	D5 =	5.85	n3 = 1.82249	$\nu 3 = 42.7$
R6 =	64.15	D6 =	15.89		
R7 =	196.34	D7 =	13.66	n4 = 1.80518	$\nu 4 = 25.4$
R8 =	−1137.68	D8 =	4.88		
R9 =	215.95	D9 =	4.88	n5 = 1.77250	$\nu 5 = 49.6$
R10 =	96.96	D10 =	10.51		

-continued

	F = 100		FNo = 1:2		$2\omega = 94°$
R11 =	162.98	D11 =	17.07	n6 = 1.80518	$\nu 6 = 25.4$
R12 =	−324.22	D12 =	33.25	n7 = 1.49540	$\nu 7 = 65.9$
R13 =	−78.04	D13 =	8.29		
R14 =	2233.96	D14 =	24.39	n8 = 1.79952	$\nu 8 = 42.2$
R15 =	−63.41	D15 =	4.88	n9 = 1.80610	$\nu 9 = 25.4$
R16 =	204.84	D16 =	14.20		
R17 =	−139.35	D17 =	4.88	n10 = 1.88300	$\nu 10 = 40.8$
R18 =	146.34	D18 =	24.39	n11 = 1.49700	$\nu 11 = 81.6$
R19 =	−121.89	D19 =	0.73		
R20 =	1772.80	D20 =	19.51	n12 = 1.77250	$\nu 12 = 49.6$
R21 =	−172.03	D21 =	0.73		
R22 =	−2469.11	D22 =	20.49	n13 = 1.77250	$\nu 13 = 49.6$
R23 =	−181.21				

What is claimed is:

1. An inverted telephoto type wide angle objective of large relative aperture comprising:

three lens groups, from front to rear, the first lens group having a negative refractive power and having, front front to rear, a positive meniscus lens of convex curvature toward the front, a negative meniscus lens of convex curvature toward the front, a negative meniscus lens of convex curvature toward the front, a positive lens and a negative meniscus lens of convex curvature toward the front, the second lens group having a positive refractive power and having a cemented bi-convex lens, and the third lens group having a positive refractive power and having, from front to rear, a cemented lens of a positive lens and a negative lens, a cemented lens of a negative lens and a positive lens, and two positive lenses.

2. A wide angle objective as in claim **1**, including a stop in a space between the second and third lens groups and satisfying the following conditions:

$$0.72 < |f_I|/f < 0.79 \text{ where } f_I < 0 \quad (1)$$

$$2.9 < D_T/f < 3.6 \quad (2)$$

$$1.2 < D_{I,II}/D_{III} < 1.7 \quad (3)$$

where

f is the focal length of the entire system;

f_I is the focal length of the first lens group;

D_T is the total length of the objective;

$D_{I,II}$ is the distance from the first surface of the first lens group to the last surface of the second lens group; and

D_{III} is the distance from the first to the last surface of the third lens group.

3. A wide angle objective as in claim **2**, and satisfying the following conditions:

$$f1 > f4 \quad (4)$$

$$|f2| > |f3| \text{ where } f2, f3 < 0 \quad (5)$$

$$1.7 < (n2+n3)/2 \quad (6)$$

$$\nu 1 > \nu 4 \quad (7)$$

where

fi is the focal length of the i-th lens element counting from the front;

ni is the index of refraction of the glass forms i-th lens element counting from the front; and

νi is the Abbe number of the glass forming the i-th lens element.

4. A wide angle objective as in claim 3, and satisfying the following conditions:

$$0.75<|R13|/f<0.95 \text{ where } R13<0 \quad (8)$$

$$50<\nu 7 \quad (9)$$

$$25<\nu 6<30 \quad (10)$$

where Ri is the radius of curvature of the i-th lens surface counting from the front.

5. A wide angle objective as in claim 4, and satisfying the following conditions:

$$0.30<n10-n11 \quad (11)$$

$$1.4<R18/f<1.8 \quad (12)$$

$$35<\nu 10 \quad (13)$$

$$\nu 9<30 \quad (14)$$

$$1.7<(n12+n13)/2. \quad (15)$$

* * * * *

United States Patent [19]

Bergen et al.

[11] **4,425,577**

[45] **Jan. 10, 1984**

[54] **TELEVISION CAMERA EQUIPPED WITH A COLOR-SEPARATING ARRANGEMENT DISPOSED BEHIND THE OBJECTIVE**

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[73] Assignee: **U.S. Philips Corporation,** New York, N.Y.

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[22] Filed: **Dec. 3, 1981**

[30] **Foreign Application Priority Data**

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[51] **Int. Cl.**[3] **H04N 9/09**

[52] **U.S. Cl.** **358/55;** 350/172

[58] **Field of Search** 358/55, 50; 350/169, 350/170, 172, 173

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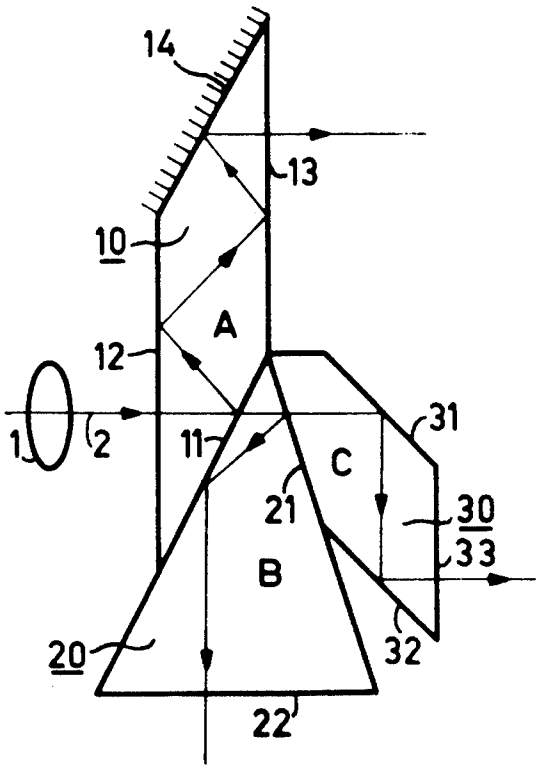
[57] **ABSTRACT**

In order to minimize the effects of magnetic fields in a color television camera, the color prism arrangement is constructed so that at least two camera tubes can be arranged parallel to each other.

6 Claims, 4 Drawing Figures



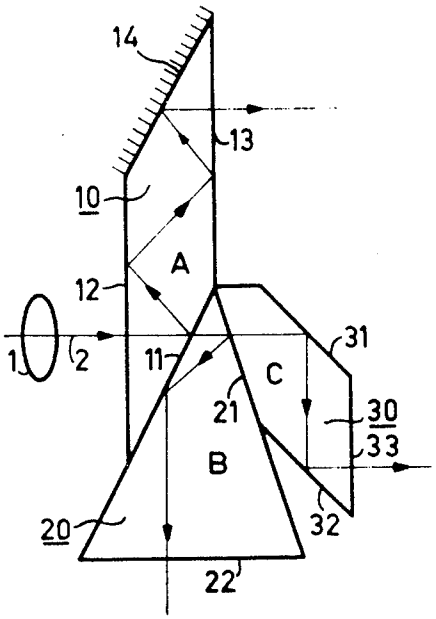


FIG.1

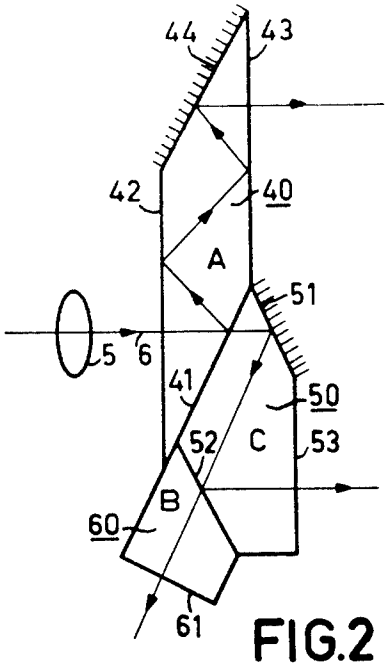


FIG.2

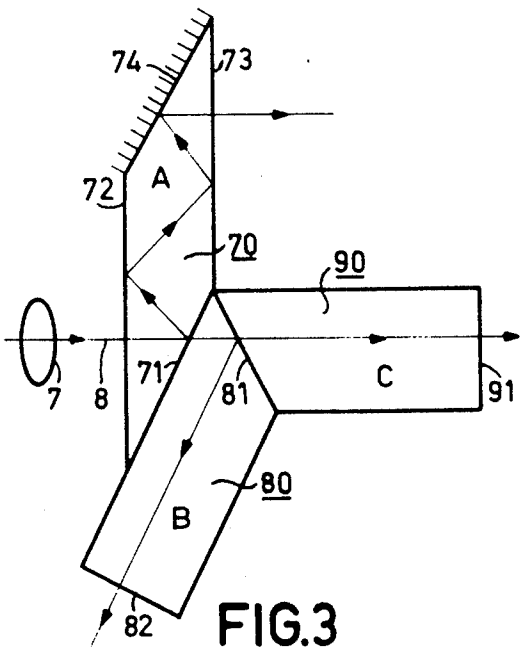


FIG.3

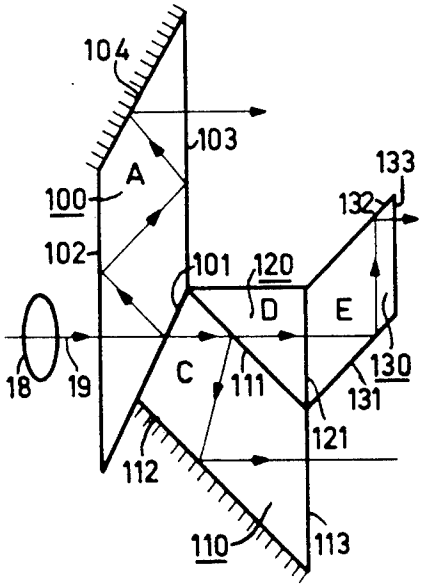


FIG.4

TELEVISION CAMERA EQUIPPED WITH A COLOR-SEPARATING ARRANGEMENT DISPOSED BEHIND THE OBJECTIVE

BACKGROUND OF THE INVENTION

The invention relates to a television camera equipped with a color-separating prism assembly disposed behind the objective. The assembly comprises a plurality of surfaces which adjoin dichroic layers of mutually different colors. In the camera, the separated light beams which emerge from the prism assembly, are transmitted to camera tubes. In the prism assembly, passing in the direction of the light which enters the prism assembly, there are provided, twice in succession, a plane air-glass transition and a dichroic layer. Each layer encloses an angle with the air-glass transition and adjoins a plane glass surface. At least one air-glass transition and the associated dichroic layer enclose an angle smaller than 30° with a plane which is normal to the nonreflected optical axis.

Such a television camera is known from U.S. Pat. No. 3,202,039 (Netherlands Patent Specification No. 113,911). The known television camera has the advantage that the glass-length of the prism assembly to be traversed by the light can be comparatively small. The prism assembly thus obtained can be comparatively compact because the totally reflecting air-glass transitions are plane. As a result of this, one zone of such an air-glass transition may serve both as an entrance surface for the light in the relevant prism section and as a totally reflecting surface for the light which is reflected by the dichroic layer associated with the air-glass transition. Since at least one air-glass transition and the associated dichroic layer enclose an angle smaller than 30° with a surface which is normal to the nonreflected optical axis, annoying polarization effects in the traversing light or color variations across the lens pupil and/or the image field are avoided.

In the known television camera the axes of the three camera tubes are arranged in different directions relative to each other. An arrangement of camera tubes in which the tube axes extend in different directions has the drawback that external magnetic fields, for example the earth's magnetic field, have a different influence on the electron beam in each tube. When the position of the television camera is changed this may give rise to registration errors. A further drawback is that with the known set-up of the prism assembly and camera tubes a compact design is not easy to realize.

SUMMARY OF THE INVENTION

It is an object of the invention to mitigate these problems. To this end a television camera of the type described above includes at least one prism having at least two interfaces of which are parallel to each other. At least one of the interfaces is provided with a dichroic layer.

Suitably, the parallel light beams emerging from the prism arrangement contain the green and the red spectral components of the light which is incident on the arrangement, because registration errors for red and green color pictures are most annoying. A compact set up of the prism arrangement and camera tubes is possible, so that a camera of small dimensions can be obtained. The third camera tube, which receives the blue spectral component of the light, may, for example, be accommodated in the grip of the camera.

BRIEF DESCRIPTION OF THE DRAWING

FIGS. **1**, **2**, **3** and **4** schematically show four embodiments of the television camera in according to the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

In FIG. **1**, the prism assembly comprises three prisms **10**, **20**, and **30**. The exit surface **11** of the prism **10** is provided with a dichroic layer which reflects the green component of the light. The exit surface **21** of the prism **20** is provided with a dichroic layer which reflects the blue component of the light. The light from the scene passes through the objective **1** and, via the entrance surface **12** of the prism **10**, it is incident on the exit surface **11**. The entrance surface **12** is normal to the optical axis **2**. The exit surface **11** makes an angle smaller than 30° with a plane perpendicular to the optical axis **2**.

The angle which the dichroic layer at surface **11** makes with the unreflected optical axis **2** is therefore greater than 30°. Since the dichroic layer on the exit surface **11** reflects the green component of the light, this layer determines the color separation both at the short wavelength end (blue edge) and at the long wavelength end (red edge). The dichroic layer on the exit surface **21** of the prism **20** may therefore comply with less stringent requirements as regards the accuracy of the wavelength edges. The green component of the light reflected by the surface **11** is reflected by the surface **12**, subsequently by the surface **13** of the prism **10** and finally by the reflecting surface **14** of the prism **10**. As the surface **14** is arranged parallel to the surface **11** and the surface **12** parallel to the surface **13**, the green light beam emerging from the prism **10** is parallel to the optical axis **2**.

The light beam transmitted by the dichroic layer on the surface **11** is incident on the exit surface **21** of the prism **20** which is also provided with a dichroic layer. The surface **21** subtends an angle greater than 30° with the plane perpendicular to the optical axis **2**. The red light component transmitted by the dichroic layer is reflected by the surface **31**, subsequently by the surface **32** of the prism **30** and emerges from the prism **30** via the surface **33**. As the surfaces **32** and **31** are parallel to each other and the surface **33** is parallel to the surface **12**, the red light beam emerging from the prism section **30** is parallel to the optical axis **2** and is thus parallel to the green light beam which emerges from the prism **10**.

The blue component of the light beam reflected by the dichroic layer on the surface **21** is reflected by the surface **11** and subsequently emerges from the prism **20** via the surface **22**.

In the embodiment shown in FIG. **2**, the prism **40** of the prism arrangement assembly is identical to the prism **10** of the prism assembly in FIG. **1**. The dichroic layer on the exit surface **41** of the prism **40** reflects the green component of the light beam which is incident on the entrance surface **42** via the lens **5**. This green component consequently emerges from the prism **40** after reflection by the is **6**surface **42**, the surface **43** and the reflecting surface **44**.

After reflection by the reflecting surface **51** of the prism **50** the light beam transmitted by the dichroic layer on the surface **41** is incident on the surface **52** of

the prism **50**, which surface **52** is provided with a dichroic layer. The surface **52** subtends an angle greater than 30° with a surface normal to the optical axis **6**. The red component of the light beam reflected by the dichroic layer emerges from the prism **50** via the surface **43**. As the surface **51** is parallel to the surface **52**, the red light beam emerging from the prism **50** is parallel to the optical axis **6** and thus parallel to the green light beam emerging from the prism **40**.

The blue component of the light beam transmitted by the dichroic layer on the surface **52** emerges from the prism **60** via the surface **61**.

In the embodiment shown in FIG. **3** the prism **70** of the prism assembly is identical to the prism **10** in the embodiment shown in FIG. **1**. The dichroic layer provided on the exit surface **71** reflects the green component of the light beam which is incident on the front surface **72** via the lens **7**. The green component emerges from the prism **70** via the exit surface **73** parallel to the optical axis **8** after reflection by the front surface **72**, the surface **73**, and the reflecting surface **74**.

The beam transmitted by the dichroic layer on the exit surface **71** is incident on the dichroic layer on the exit surface **81** of the prism **80**. The surface **81** makes an angle greater than 30° with a plane perpendicular to the optical axis **8**. The dichroic layer on the exit surface **81** reflects the blue component of the light beam and transmits the red component without refraction. The red beam which emerges from the prism via the exit surface **91** coincides with the optical axis **8** and is thus parallel to the green beam emerging from the prism **70**. The blue beam which is reflected by the dichroic layer on the surface **81** emerges from the prism **80** via the exit surface **82**.

In the embodiment shown in FIG. **4** the prism **100** of the prism assembly is identical to the prism **10** of the embodiment shown in FIG. **1**. It will therefore be evident that the green light beam emerging from the prism **100** is parallel to the optical axis **19**. The light beam which is transmitted by the dichroic layer on the exit surface **101** of the prism **100** is incident on the dichroic layer provided on the exit surface **111** of the prism **110**. This dichroic layer transmits, for example, the blue component of the light beam and reflects the red component. After reflection by the reflecting surface **112** of the prism **110** the red component emerges from the prism via the exit surface **113**. As the surfaces **112** and **111** are parallel to each other, the red beam emerging from the prism **110** is parallel to the optical axis **19** and thus parallel to the green beam. Via the prism **120** and the prism **130** the blue light beam transmitted by the dichroic layer on the surface **111** emerges from the prism **130** via the exit surface **133** after being reflected by the surface **131** and subsequently by the surface **132**. As the surfaces **131** and **132** are parallel, the blue beam which emerges from the prism **130** is parallel both to the red beam and to the green beam.

What is claimed is:

1. A television camera comprising:

an objective;

a color-separating prism assembly disposed behind the objective, said assembly having an entrance surface and three exit surfaces, light entering the assembly through the entrance surface being separated into different colors emerging from the exit surfaces;

three camera tubes, one tube arranged in the path of light emerging from each exit surface;

characterized in that the prism assembly comprises:

a first prism having an optical axis and a plurality of planar surfaces, one such surface being an entrance surface perpendicular to the optical axis, one other surface having a dichroic layer thereon; and

a second prism having a plurality of planar surfaces, one surface having a dichroic layer thereon;

wherein the surface of the first prism bearing the dichroic layer is arranged adjacent a surface of the second prism without a dichroic layer thereon, said adjacent surfaces being separated by an air gap, said first and second prisms arranged so that the optical axis passes through both dichroic layers;

wherein the surface of the first prism bearing the dichroic layer subtends an angle less than 30° with a plane perpendicular to the optical axis; and

wherein the first prism has at least one other surface parallel to the surface of the first prism bearing the dichroic layer.

2. A television camera as claimed in claim **1**, characterized in that the dichroic layer on the first prism reflects green light.

3. A television camera as claimed in claim **2**, characterized in that the dichroic layer on the second prism subtends an angle greater than 30° with a plane perpendicular to the optical axis.

4. A color-separating prism assembly having an entrance surface and three exist surfaces, said assembly comprising:

a first prism having an optical axis and a plurality of planar surfaces, one such surface being an entrance surface perpendicular to the optical axis, one other surface having a dichroic layer thereon; and

a second prism having a plurality of planar surfaces, one surface having a dichroic layer thereon;

wherein the surface of the first prism bearing the dichroic layer is arranged adjacent a surface of the second prism without a dichroic layer thereon, said adjacent surfaces being separated by an air gap, said first and second prisms arranged so that the optical axis passes through both dichroic layers;

wherein the surface of the first prism bearing the dichroic layer subtends an angle less than 30° with a plane perpendicular to the optical axis; and

wherein the first prism has at least one other surface parallel to the surface of the first prism bearing the dichroic layer.

5. A color-separating prism assembly as claimed in claim **4**, characterized in that the dichroic layer on the first prism reflects green light.

6. A color-separating prism assembly as claimed in claim **5**, characterized in that the dichroic layer on the second prism subtends an angle greater than 30° with a plane perpendicular to the optical axis.

* * * * *

United States Patent [19]

Hugues et al.

[11] **4,416,518**

[45] **Nov. 22, 1983**

[54] **OBJECTIVE COMPRISING ASPHERICAL SURFACES, WHOSE FOCAL LENGTH IS VARIABLE OVER A WIDE RANGE**

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[73] Assignee: **U.S. Philips Corporation**, New York, N.Y.

[21] Appl. No.: **192,158**

[22] Filed: **Sep. 29, 1980**

[30] **Foreign Application Priority Data**

Sep. 28, 1979 [FR] France 79 24154

[51] **Int. Cl.**[3] **G02B 13/18**; G02B 15/14

[52] **U.S. Cl.** **350/427**; 350/432

[58] **Field of Search** 350/427, 432

[56] **References Cited**

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Primary Examiner—John K. Corbin
Assistant Examiner—Rebecca D. Gass
Attorney, Agent, or Firm—Robert J. Kraus

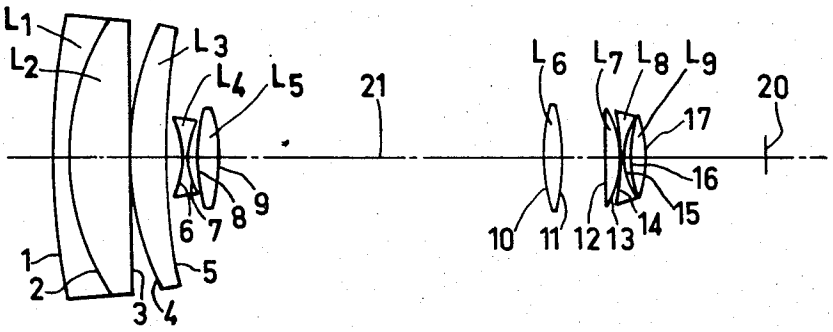
[57] **ABSTRACT**

The objective comprises a plurality of movable lens components and at least one stationary lens component group, at least two of said components including an aspherical surface. The movable components are constituted by single lenses of which at least one lens comprises an aspherical surface, while the stationary lens component group(s) may comprise at least one aspherical surface. Steadiness of the image plane is obtained by mechanical compensation for focal-length variations with a ratio greater than five, which may readily reach the value eight. The aspherical lenses are arranged so that for the same focal length variation the total number of lenses of the objective, which may be spherical or non-spherical, is smaller than in any other variable-focus objective with a stationary image plane comprising solely spherical lenses:

This results in a reduction of the mass of the objective, namely of the movable parts, and a reduction of the power necessary for moving said parts.

Application to color television camera.

10 Claims, 19 Drawing Figures



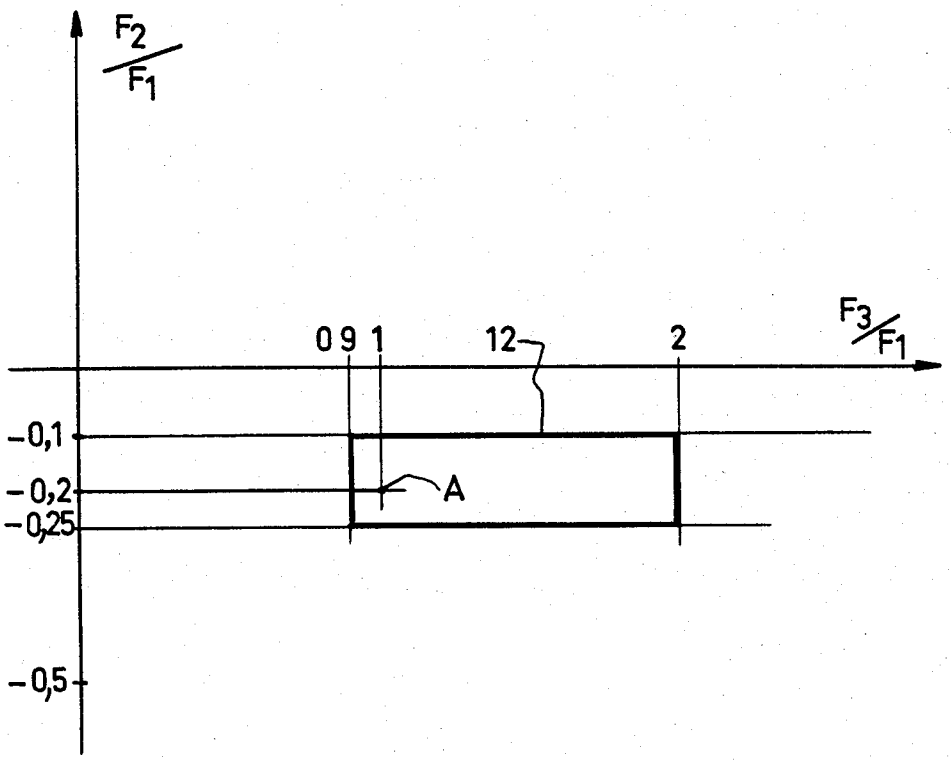


FIG.1

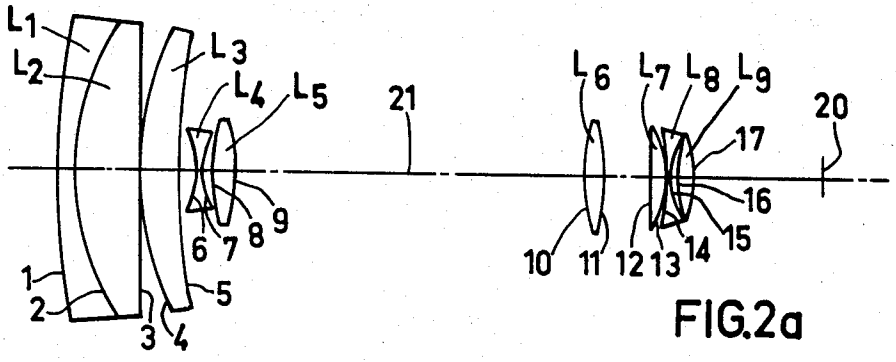


FIG.2a

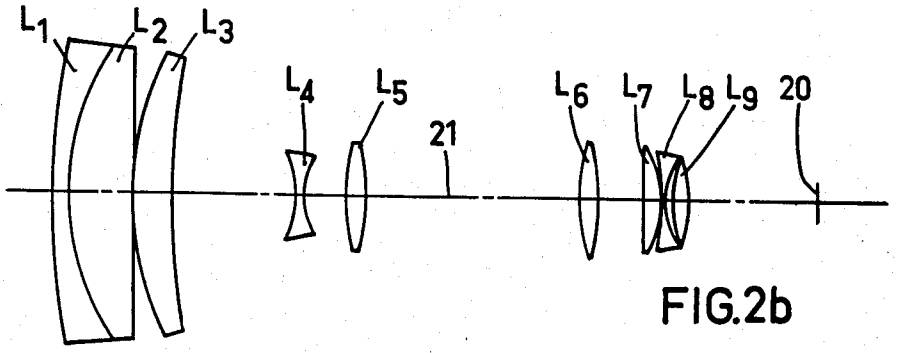


FIG.2b

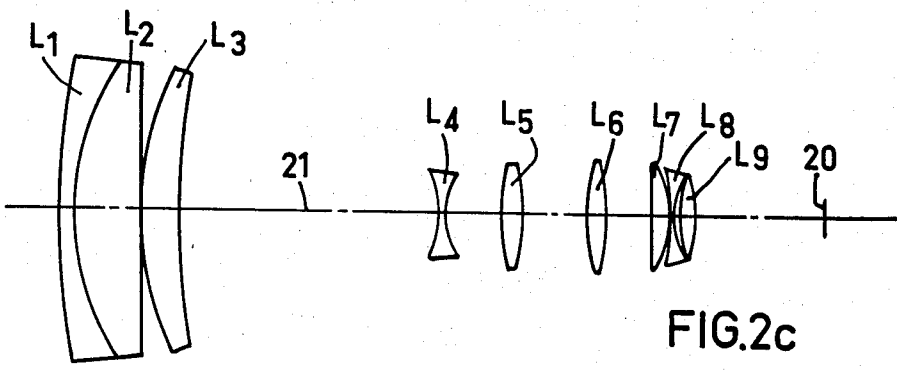


FIG.2c

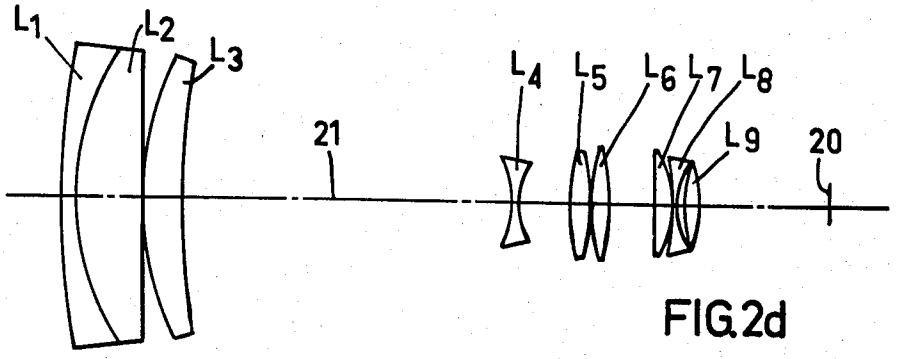


FIG.2d

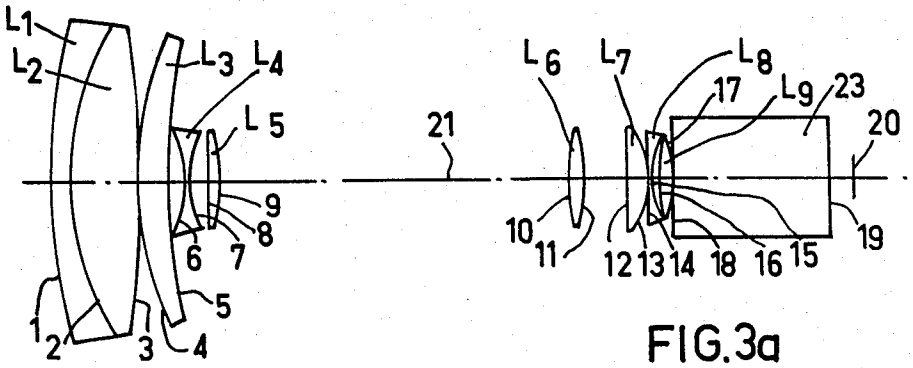


FIG.3a

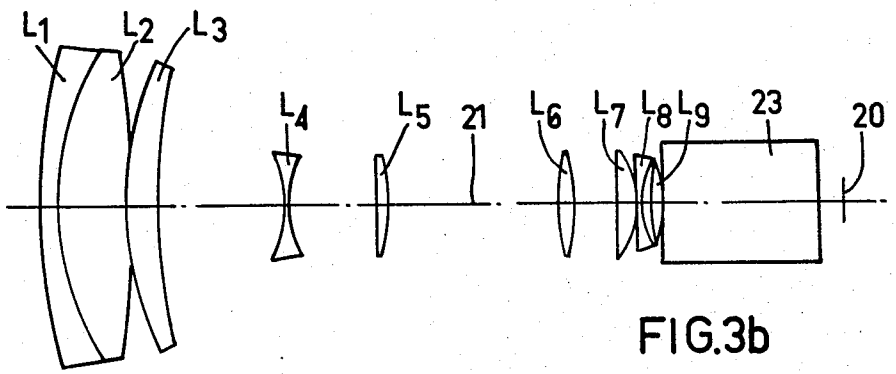


FIG.3b

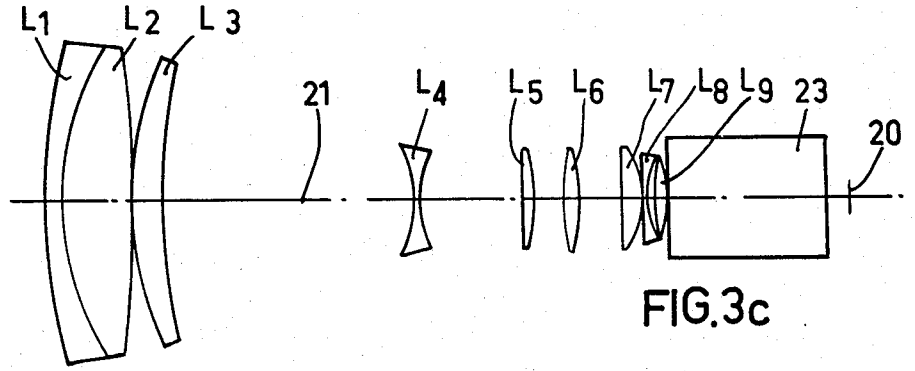


FIG.3c

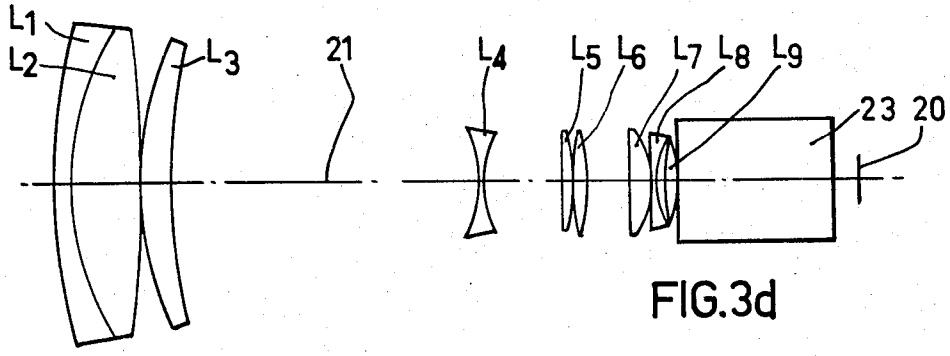


FIG.3d

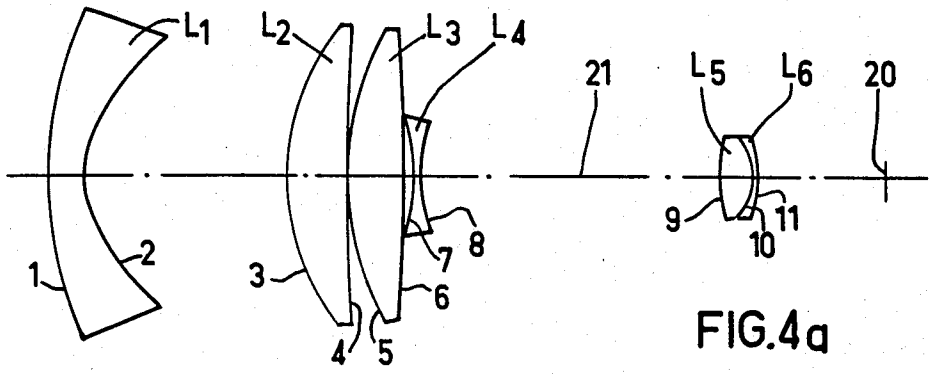


FIG.4a

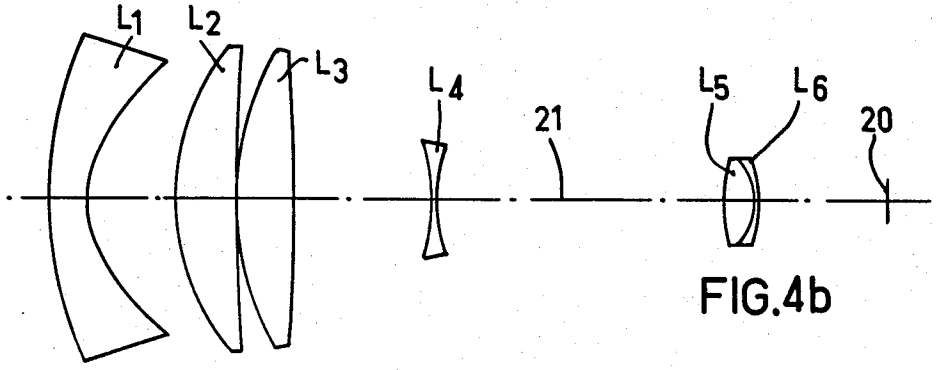


FIG.4b

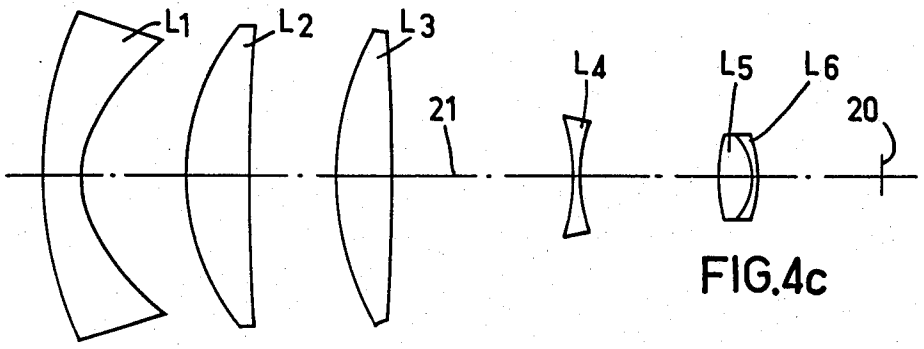


FIG.4c

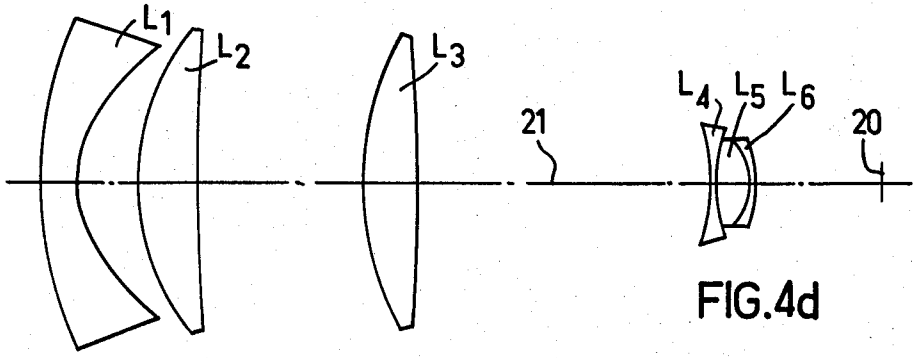


FIG.4d

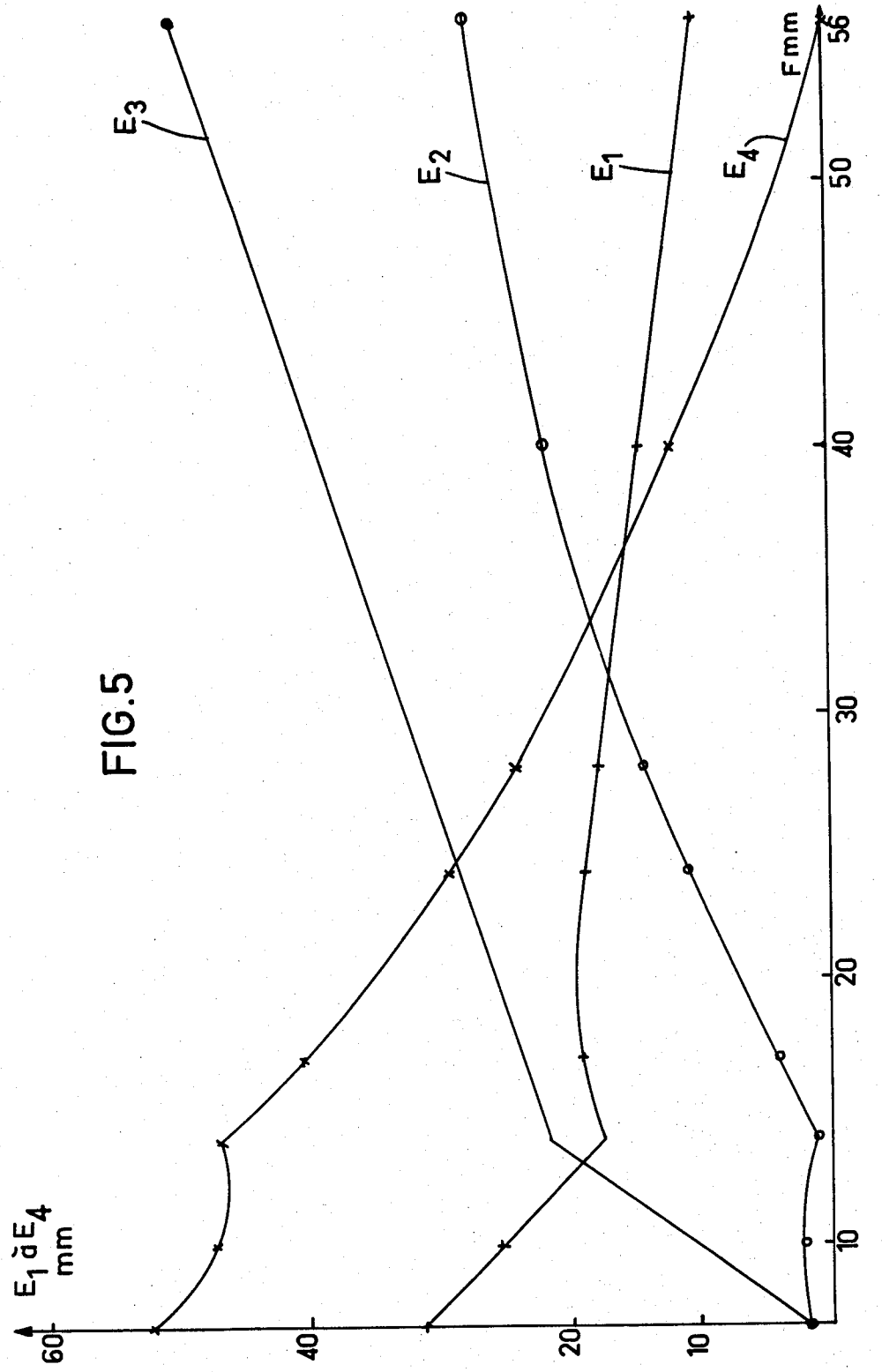


FIG.5

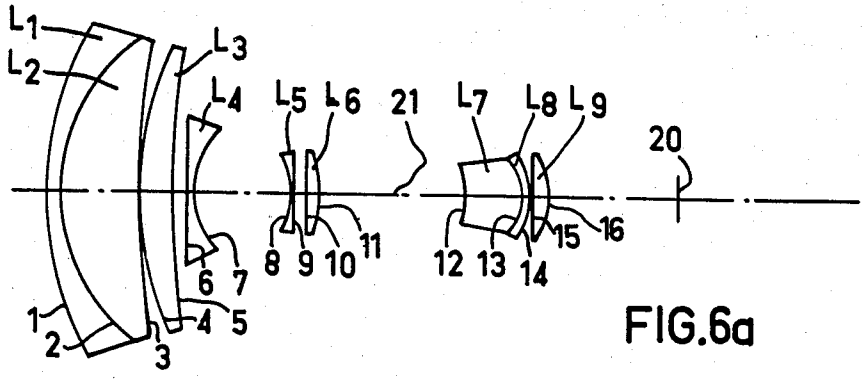


FIG.6a

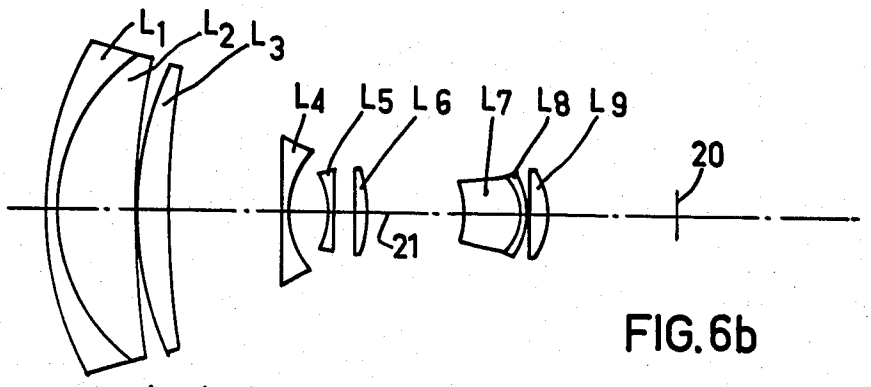


FIG.6b

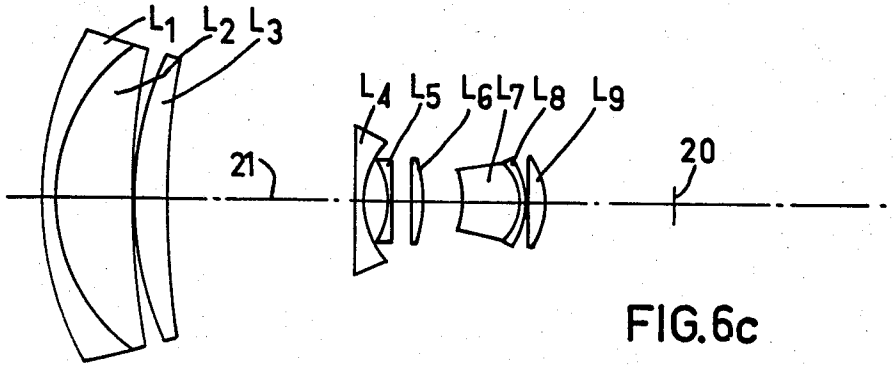


FIG.6c

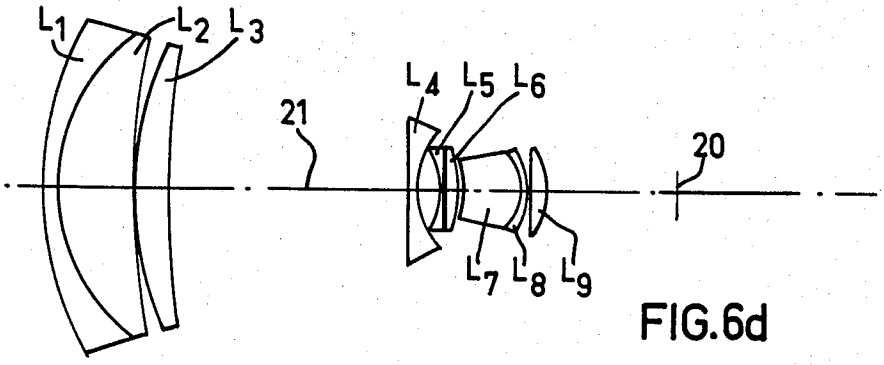


FIG.6d

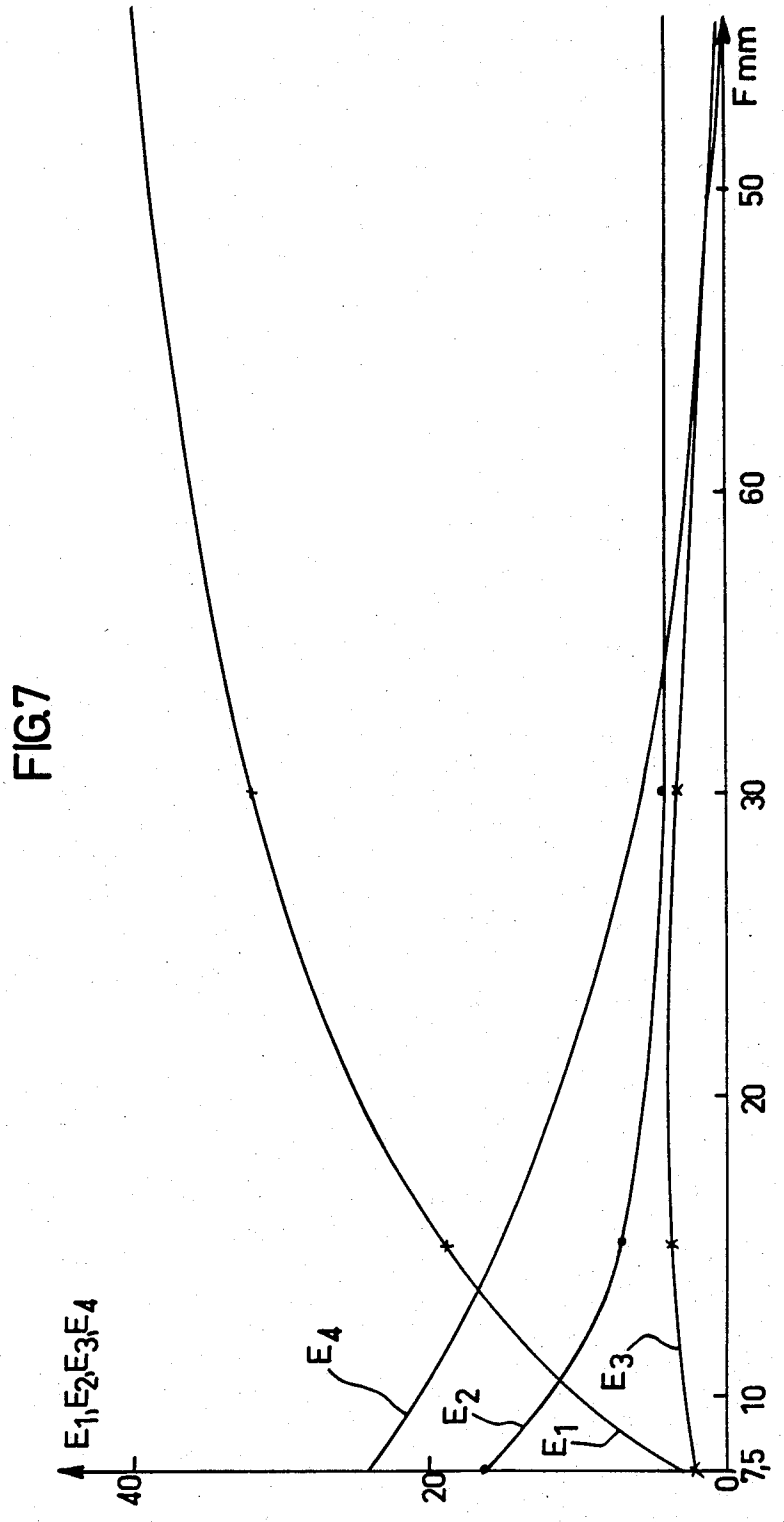


FIG.7

OBJECTIVE COMPRISING ASPHERICAL SURFACES, WHOSE FOCAL LENGTH IS VARIABLE OVER A WIDE RANGE

The invention relates to a variable focus objective with stationary image plane, comprising components including lenses; at least two of said components including a lens with an aspherical surface.

German Offenlegungsschrift No. 2,625,058 describes an objective of this type. A special feature of this objective is that it comprises only two components of lenses, which are both movable.

The objective in accordance with said Offenlegungsschrift has two sorts of drawbacks. Its optical performance is limited and provides a focal-length variation with a ratio between its maximum and minimum values which is hardly greater than 2 if allowance is made for the tolerances to be satisfied for chromatic and achromatic aberrations. On the other hand, although the number of constituent elements of each component is reduced by the inclusion of an aspherical surface in each of these components, this number remains high, which complicates the mechanical construction of the objective, specifically of the part by means of which the components are to be moved relative to each other.

It is the object of the invention to mitigate these drawbacks, and specifically to increase the range of focal-length variation. The invention also employs a certain number of aspherical surfaces in order to minimize the number of elements by means of which the objective is formed, the objective being of simple mechanical construction because the movable components comprise only one element. Since the movable components comprise only one optical element they have a low mass, so that they can be moved by means also having a low mass, for example employing microprocessors.

The invention utilizes methods of "compensating" for the focal-length variation, which are used in optical systems if the image plane is to remain satisfactory.

The so-called "optical compensation" method is not used, because it only provides a simple solution for the movable components if the focal-length variation is effected with a ratio smaller than 2.

The invention employs the "mechanical" method of compensating for the focal-length variation with stationary image plane. According to this method the spacing between the components and their displacement is subject to an analytical law obtained by computation. This method is extremely suitable for compensation in the case of focal-length variations with high ratios.

In the prior art this method has already been applied using the "Delano diagram" (see the article by Besenmatter "Analyse der primären Wirkung asphärischer Flächen mit Hilfe des Delano Diagrams" in Optik 51, 1978, pages 385 to 396). A prior-art objective obtained in accordance with this compensation method is the subject of the article by D. S. Volosov, entitled: "Design of complex photographic systems" in Gostekhizdat 1948. This objective has moderate specifications: a focal-length variation of 3 to 4 and an aperture from F/3 to F/5. The invention applies said method in such a way that it is more suitable for finding solutions yielding a higher performance. First of all the powers of the various components of stationary and movable lenses were examined and the ratios which should exist between said powers in order to obtain the desired focal-length variations and apertures, using the displacement rules for each component and the ratios between the diameters of the components and their focal lengths as feasibility criteria. Thus, a so-called "focal-length evaluation" diagram is obtained. If it is desired to have an objective comprising for example two stationary components and two movable components with the respective focal lengths F_1, F_4, F_2, F_3, the focal lengths of the movable components referred to F_1, i.e. the ratios F_2/F_1 are plotted as abscissae and ordinates on the axes of a two-dimensional diagram, those portions of the diagram which yield practical solutions then being selected on basis of considerations with respect to the focal-length variation and maximum power of the objective. According to the invention, a very limited portion of the diagram has thus been selected which corresponds to focal-length variations with a ratio of at least 5. For objectives comprising three movable components similar approaches consist in setting up a three-dimensional diagram of the powers and in selecting a three-dimensional zone yielding the desired great focal-length variations.

The objective in accordance with the invention, based on said investigations, is characterized in that it comprises a plurality of movable lens components and at least one stationary lens component group, in that the aspherical lenses are arranged so that for the same focal-length variation the total number of spherical or non-spherical lenses is smaller than in any other variable-focus objective with stationary image plane solely comprising spherical lenses, the steadiness of the image plane during a focal length variation greater than five being obtained through mechanical compensation, and that at least all the movable components are constituted by single lenses, of which at least one lens comprises an aspherical surface, whilst the stationary component(s) may comprise at least one aspherical surface.

In a first embodiment the objective comprises, from the object space to the image space, a first stationary component of positive power, a first movable component constituted by a single lens of negative power, a second movable component constituted by a single movable lens of positive power, and a second stationary component of positive power.

More specifically, when F_1, F_2, F_3 designate the respective optical focal lengths of the first stationary component, of the first movable component and of the second movable component, the focal lengths of these different components are such that:

$$-0.25 \leqq F_2/F_1 \leqq -0.1$$

$$0.9 \leqq F_3/F_1 \leqq 2$$

In a second embodiment the objective comprises 3 movable components.

In variants of these embodiments the focal-length variation ratio reaches values greater than 8, whilst half the field angle is greater than 24°, the aperture number ranging between F/2 and F/1.5, where F designates the focal length of the objective.

Furthermore, the image distance of the objective may be substantial and may be greater than 22 mm, which in accordance with the invention enables the use of said objective in a colour camera device with a colour-separating prism included between the objective and a camera with three camera tubes.

The invention will be more fully understood by means of the following description of some embodiments which are given by way of example, said description being accompanied by explanations and drawings of which:

FIG. **1** represents a diagram relating to the evaluation of the focal lengths of two movable components of an objective in accordance with a first embodiment of the invention;

FIG. *2a, 2b, 2c, 2d* represent the optical diagram of a first example of an objective with two movable components in accordance with the first embodiment of the invention, each of said Figures, in this order, corresponding to a value of the focal-length of the objective from its minimum to its maximum;

FIG. *3a, 3b, 3c, 3d* show the optical diagram of a second example of an objective with two movable components in accordance with the first embodiment of the invention, each of said Figures, in this order, corresponding to a value of the focal length of the objective from its minimum to its maximum;

FIGS. *4a, 4b, 4c, 4d* represent the optical diagram of a first example of an objective with three movable components in accordance with the second embodiment of the invention, each of said Figures, in this order, corresponding to a value of the focal length of the objective from its minimum to its maximum;

FIG. **5** represents a diagram relating to the movement of the movable components of the objectives of FIGS. *4a, 4b, 4c, 4d;*

FIGS. *6a, 6b, 6c, 6d:* show the optical diagram of a second example of an objective with three movable components in accordance with the second embodiment of the invention, each of said Figures, in this order, corresponding to a value of the focal length of the objective from its minimum to its maximum;

FIG. **7** represents diagrams relating to the movements of the movable components of the objective represented in FIGS. *6a, 6b, 6c, 6d.*

FIG. **1** relates to a first embodiment of the objective, which comprises two movable components between two stationary components. The focal lengths of the stationary components are F_1 and F_4 and those of the movable components F_2 and F_3. In a rectangular system of axes the ratios F_3/F_1 and F_2/F_1 are respectively plotted as abscissae and ordinates and the evaluation diagram for the focal lengths for said objective is drawn up. In accordance with the invention that zone in said diagram is selected which has a rectangular outline **12** defined by the relations:

$$-0.25 \leqq F_2/F_1 \leqq -0.1$$

$$0.9 \leqq F_3/F_1 \leqq 2$$

The points within 12 correspond to variable-focus objectives with a fixed image plane, which exhibit large fields of view of the order of 45° and focal-length variations of the order of 8. One of the best compromises for said objective is situated near point A in FIG. **1** with the coordinates:

$$(1)\begin{cases} \dfrac{F_2}{F_1} = -0.2 \\ \dfrac{F_3}{F_1} = 1 \\ \text{with } F_1 > 0 \end{cases}$$

This corresponds to an image size with a diagonal of 7 mm and an aperture of F/1.8, F being the focal length of the objective, which has a minimum value of the order of 6 to 8 mm and with a size, including the image distance, of the order of 140 mm. FIGS. *2a, 2b, 2c, 2d* represent a first example corresponding to this particular case, said Figures corresponding to focal length values of F=7.95 mm, F=15.00 mm, F=35 mm, and F=63.5 mm respectively. In these Figures the optical axis of the objective is designated **21** and the image field is designated **20**. The dioptric surfaces of the objective elements are designates **1** to **17** reckoned from the object field to the image field. The stationary component with a positive focal length F_1 is constituted by the lenses L_1, L_2, L_3, whilst the stationary component with a focal length F_4 is constituted by four lenses L_6 to L_9. The lenses L_1, L_2 constitute a convergent glued doublet, whilst the lens L_3 is a convergent meniscus lens. In the stationary component with the focal length F_4 the lens L_6 is convergent, its entrance surface **10** being aspherical, and the lenses L_7, L_8, L_9 constitute a non-glued triplet, the lens L_7 being convergent and substantially plano-convex, the lens L_8 being divergent and substantially plano-concave, and the lens L_9 being convergent and substantially equiconvex. The movable components are respectively constituted by a divergent lens L_4 with a focal length F_2 and a convergent lens L_5 with a focal length F_3. Each of said lenses comprises an aspherical surface, respectively corresponding to the dioptric surfaces **7** and **8**. The equation of the cross-sections of the aspherical dioptric surfaces **7**, **8**, **10** (rotationally symmetrical about the optical axis **21**) in the plane of the diagram of FIGS. *2a, 2b, 2c, 2d* plotted in a rectangular system of axes (x, y), is:

$$x = \frac{Cy^2}{1 + \sqrt{1 - (1 + \lambda)C^2y^2}} + \sum_{i=2}^{i=n} \epsilon_i y^{2i} \qquad (2)$$

the abscissae x being measured from the apex of the dioptric surface on the positively oriented optical axis of the lens L_1 towards the image field **20** and the ordinates y being measured perpendicularly to the optical axis. The right-hand side of said equation comprises a first term corresponding to a conic section with an apex C and a coefficient λ and a second term describing distortions, higher than the second order, of the dioptric surface relative to said conic section. The Tables I and II give the construction parameters of said objective. The Table I indicates the distances E between two consecutive dioptric surfaces for the focal distance F=7.95 mm, the radius of curvature R of the dioptric surfaces, the index of refraction n of the materials, and the Abbe number ν relating to their dispersion. When the dioptric surface is aspherical, the column R indicates the radius of the circle of osculation to said surface on the optical axis. The Table II specifies the values C, λ and ϵ_i of the equation (2) relating to each aspherical surface developed up to the order 2n=10. The total length of the objective is 108.25 mm, whilst its image

distance (distance available between the last dioptric surface and the image plane) is 22.14 mm.

TABLE I

Dioptric surface	E (mm)	R (mm)	n	ν
1		111.111		
	2.962		1.704485	29.88
2		43.910		
	11.099		1.622857	60.11
3		876.647		
	0.050		1.000000	
4		53.395		
	6.503		1.622857	60.11
5		129.296		
	2.936		1.000000	
6		−17.988		
	1.113		1.591288	60.94
7		8.261		
	1.896		1.000000	
8		35.029		
	3.542		1.550192	53.17
9		−39.013		
	59.841		1.000000	
10		25.384		
	2.982		1.654137	38.91
11		−62.563		
	7.889		1.000000	
12		309.102		
	3.025		1.622857	60.11
13		−18.230		
	0.050		1.000000	
14		−68.031		
	0.802		1.812529	25.30
15		13.760		
	1.032		1.000000	
16		25.702		
	2.726		1.622857	60.11
17		−30.820		
	0.000		1.000000	

Focal-length variation F: 7.95 to 63.50 mm
Image distance: 22.14 mm
Objective length: 108.25 mm

TABLE II

Dioptric surface	7	8	10
C	1,21048 10^{-1}	2,85479 10^{-2}	3,93954 10^{-2}
λ	−1,42139	−1,07632	−2,90598
ϵ_2	−1,68578 10^{-4}	−1,89696 10^{-5}	−2,27969 10^{-5}
ϵ_3	2,73671 10^{-6}	3,04327 10^{-7}	−1,91999 10^{-7}
ϵ_4	−6,58215 10^{-8}	−5,01920 10^{-9}	1,14049 10^{-9}
ϵ_5	5,46590 10^{-10}	2,90044 10^{-11}	−1,55755 10^{-11}

FIGS. 3*a*, 3*b*, 3*c*, 3*d* represent a second example of said first embodiment of the invention, which satisfies the relations (1) concerning the focal length, for a value of the focal length of F=8 mm, F=15 mm, F=35 mm and F=64 mm respectively. The structure of the objective is similar to that shown in FIGS. 2*a*, 2*b*, 2*c*, 2*d*, except that in this case a colour-splitting prism, known per se, is incorporated in the objective on the image-field side in such a way that the red, blue and green spectral components of the image are obtained spaced from each other. In FIGS. 3*a*, 3*b*, 3*c*, 3*d* the dioptric surfaces of the elements are designated 1 to 20, including the image field. In these Figures the shapes of the lenses L_1 to L_9 are found to be similar, the surfaces **7**, **8**, **10** being aspherical but having different construction parameters to allow for presence of the trichromatic separating prism. In each of the FIGS. 3*a*, 3*b*, 3*c*, 3*d* the movable lenses L_4 and L_5 are represented in a different position corresponding to one of the values of the focal length of the objective indicated in the foregoing. The reference numeral **23** designates the colour-splitting prism, which is schematically represented as a segment with parallel surfaces. The Tables III and IV, which correspond to Tables I and II, indicate the construction parameters relating to said second example, the equations for the sections of the aspherical dioptric surfaces being of the same form as (2). Table III relates to the value of the focal length F=7.90 mm. The total length of the objective, including the prism, is found to be 131.66 mm, the available image distance after the prism being 4.25 mm.

TABLE III

Dioptric surface	E (mm)	R	n	ν
1		115.145		
	2.935		1.723153	29.26
2		46.191		
	11.768		1.622857	60.11
3		−248.840		
	0.050		1.000000	
4		63.147		
	5.243		1.622857	60.11
5		135.414		
	2.507		1.000000	
6		−19.756		
	0.688		1.591288	60.94
7		11.786		
	3.279		1.000000	
8		237.568		
	1.680		1.584777	40.53
9		−51.002		
	59.431		1.000000	
10		42.857		
	2.329		1.584777	40.53
11		−31.066		
	7.373		1.000000	
12		550.809		
	3.487		1.622857	60.11
13		−16.221		
	0.040		1.000000	
14		−401.781		
	0.788		1.812529	25.30
15		13.928		
	1.259		1.000000	
16		42.759		
	2.200		1.622857	60.11
17		−26.586		
	0.050		1.000000	
18		∞		
	26.500		1.518727	64.04
19		∞		
	0.000		1.000000	

Focal-length variation F: 7.90 to 64 mm.
Image distance after prism: 4.25 mm.
Length: 131.66 mm.

TABLE IV

Dioptric surface	7	8	10
C	8,48454 10^{-2}	4,20932 10^{-3}	2,33336 10^{-2}
λ	−8,64111 10^{-1}	−6,87745 10^{-2}	−5,06288
ϵ_2	−1,01718 10^{-4}	2,05245 10^{-6}	−7,45166 10^{-5}
ϵ_3	−1,33362 10^{-7}	−4,29973 10^{-8}	−2,89507 10^{-7}
ϵ_4	−1,23607 10^{-8}	1,41858 10^{-9}	1,75248 10^{-9}
ϵ_5	1,19575 10^{-10}	−1,73662 10^{-11}	−5,15778 10^{-11}

It is evident that in these examples use can be made of any other combination of stationary components in accordance with the prior art which is compatible with the nature of the movable components constituted by the lenses L_4 and L_5 respectively.

In a second embodiment of the invention the objective comprises 3 movable components between two stationary components. The focal lengths of the stationary components, from the object field towards the image field, are in this order F_1 and F_5, those of the

movable components F_2, F_3, F_4. A preliminary evaluation of the powers demonstrates that in accordance with the invention the elements of the objective should be selected so that the ratios F_2/F_1, F_3/F_1, F_4/F_1 should be situated between certain limits.

In accordance with a variant of this embodiment, for which the first stationary component has a negative focal length F_1, these limits are such that:

$$-0.7 \leqq F_2/F_1 \leqq 0.3$$

$$-1 \leqq F_3/F_1 \leqq 0.4$$

$$0.12 \leqq F_4/F_1 \leqq 0.3$$

An example of an objective in accordance with this variant is that corresponding to

$$F_2/F_1 = -0.385;\ F_3/F_1 = -0.500;\ F_4/F_1 = -0.150$$

This objective is shown in FIGS. **4***a*, **4***b*, **4***c*, and **4***d*, which correspond to values of the focal length of F=7 mm, F=14 mm, F=28 mm and F=56 mm respectively.

The stationary component of a focal length F_1 is constituted by the diversing meniscus lens L_1, whilst the component with a focal length F_5 is constituted by the combined converging and diverging lenses L_5 and L_6 respectively. The 3 movable components are each constituted by a lens L_2, L_3 and L_4 respectively, L_2 being a quasi plano-convex converging lens, L_3 a biconvex converging lens and L_4 a biconcave diverging lens. The dioptric surfaces of all the elements are designated 1 to 11 from the object field to the image field. The surfaces of the elements L_1, L_2, L_3, L_4, L_5 corresponding to the respective dioptric surfaces **2, 3, 5, 8, 9** are aspherical. In FIGS. **4***a*, **4***b*, **4***c*, **4***d* the movable lenses L_2, L_3 and L_4 are represented in a position corresponding to one of the previously stated focal lengths. The construction parameters of the ovjective are given in Tables V and VI in analog to the preceding Tables III and IV. In Table V the focal length considered has the minimum value F=7 mm. The maximum value is F=56 mm. The image distance is 22.19 mm.

TABLE V

Dioptric surface	E (mm)	R (mm)	n	ν
1		62.852		
	6.300		1.677623	32.08
2		17.997		
	31.400		1.000000	
3		31.080		
	10.395		1.622857	60.11
4		403.858		
	1.100		1.000000	
5		50.717		
	9.458		1.622857	60.11
6		−279.735		
	1.750		1.000000	
7		−33.369		
	0.866		1.622857	60.11
8		21.567		
	52.400		1.000000	
9		18.083		
	5.662		1.622857	60.11
10		−10.914		
	0.396		1.812529	25.30
11		−21.976		
	0.000		1.000000	

Focal-length variation F: 7.0 to 56.0 mm
Image distance: 22.19 mm
Length: 120.42 mm.

TABLE VI

Dioptric surface	2	3	5	8	9
C	$5.55650\ 10^{-2}$	$3.21750\ 10^{-2}$	$1.97173\ 10^{-2}$	$4.63672\ 10^{-2}$	$5.53002\ 10^{-2}$
λ	$-6.96979\ 10^{-1}$	-1.13548	$-9.75088\ 10^{-1}$	$-1.52017\ 10^{-1}$	$-7.10788\ 10^{-1}$
ϵ_2	$-5.38859\ 10^{-6}$	$-9.88210\ 10^{-7}$	$1.30489\ 10^{-6}$	$-1.14601\ 10^{-5}$	$-1.99591\ 10^{-5}$
ϵ_3	$-9.03598\ 10^{-9}$	$-1.03273\ 10^{-9}$	$-3.89438\ 10^{-10}$	$9.99829\ 10^{-8}$	$2.71237\ 10^{-8}$
ϵ_4	$3.92014\ 10^{-12}$	$1.46391\ 10^{-12}$	$-6.31723\ 10^{-13}$	$-8,14572\ 10^{-10}$	$1.99891\ 10^{-9}$
ϵ_5	0.00000	0.00000	0.00000	0.00000	0.00000

In order to complete the description of the construction of said example of an objective, FIG. **5** is a diagram illustrating the movements of the lenses L_2, L_3, L_4 as a function of the value of the focal lengths F. The rules governing said movements are based on variations of the axial distances between certain stationary and movable dioptric surfaces and between certain movable dioptric surfaces, namely

E_1 between the dioptric surfaces **2** and **3**
E_2 between the dioptric surfaces **4** and **5**
E_3 between the dioptric surfaces **6** and **7**
E_4 between the dioptric surfaces **8** and **9**.

In the second variant of the embodiment of the objective with three movable components between two stationary components, when proceeding from the object space to the image space, the first stationary component has a positive focal length F_1 and the second stationary component a positive focal length F_5, whilst for the movable components, each constituted by a single element, the first one has a negative focal length F_2, the second one a negative focal length F_3 and the third component a positive focal length F_4. In accordance with the invention, a preliminary evaluation of the focal lengths of the movable components relative to those of the first stationary components, results in the selection of the focal lengths in such a way that the following inequalities are satisfied.

$$-0.5 \leqq F_2/F_1 \leqq -0.2$$

$$-0.5 \leqq F_3/F_1 \leqq -0.2$$

$$0.3 \leqq F_4/F_1 \leqq 0.8$$

FIGS. **6***a*, **6***b*, **6***c*, **6***d* given an example of said variant for different focal-length values, namely corresponding to

$$F_2/F_1 = 0.301;\ F_3/F_1 = 0.326;\ F_4/F_1 = 0.455$$

In these Figures the dioptric surfaces are designated 1 to 16 from the object field towards the image field. The first stationary component with a positive focal length F_1 is constituted by two combined lenses L_1, L_2, which are divergent and convergent respectively, the lens L_3 being convergent. The second stationary component with a positive focal length F_5 comprises the conver-

gent assembly constituted by the very thick lens L_7 and the lens L_8, which are cemented to each other, and the convergent lens L_9. In each of the FIGS. *6a, 6b, 6c, 6d* the movable components L_2, L_3, L_4 are shown in a different position, corresponding to focal-length values of the objective of F=7.5 mm, F=15 mm, F=13 mm and F=60 mm respectively. The first movable component with a negative focal length F_2 is the lens L_4, which is substantially planoconcave, the second movable component with a negative focal length F_3 is constituted by th lens L_5 which is also substantially planoconcave. The biconvex lens L_6 constitutes the third movable component with a positive focal length F_4. The lens surfaces corresponding to the dioptric surfaces **4, 7, 12** and **16** are aspherical. The Tables VII and VIII, which are analogous to the preceding sets of tables, give the construction parameters for this example, Table VII relating to a focal length value of F=15.00 mm.

TABLE VII

Dioptric surface	E (mm)	R (mm)	n	ν
1		52.985		
	2.499		1.734359	28.17
2		31.271		
	13.466		1.622857	60.11
3		180.118		
	0.050		1.000000	
4		60.986		
	5.533		1.622857	60.11
5		184.952		
	19.067		1.00000	
6		−318.707		
	0.940		1.591288	60.94
7		11.422		
	7.021		1.000000	
8		−10.909		
	0.636		1.591288	60.94
9		−136.669		
	3.649		1.000000	
10		135.620		
	1.848		1.734359	28.17
11		−24.210		
	16.404		1.000000	
12		−39.414		
	10.000		1.615176	58.34
13		−7.702		
	0.705		1.812529	25.30
14		−13.685		
	0.969		1.000000	
15		−99.112		
	2.417		1.622857	60.11
16		−14.931		
	000		1.000000	

Focal-length variation F: 7.5 to 60 mm.
Image distance: 22.20 mm.
Length: 85.20 mm.

TABLE VIII

Dioptric surface	4	7	12	16
C	1,63972 10^{-2}	8,75499 10^{-2}	−2.53715 10^{-2}	−6.69741 10^{-2}
λ	−1.68233 10^{-1}	−7.55918 10^{-1}	0.00000	0.00000
ϵ_2	−5.59326 10^{-8}	1.61978 10^{-5}	−2.23860 10^{-4}	−3.68018 10^{-6}
ϵ_3	1.64888 10^{-10}	−4.29937 10^{-7}	−1.06579 10^{-6}	2.28552 10^{-8}
ϵ_4	0.00000	0.00000	0.00000	0.00000
ϵ_5	0.00000	0.00000	0.00000	0.00000

Said focal length varies from 7.5 mm to 60 mm when the movable lenses perform the movements represented by the curves of FIG. 7. In this Figure, which is analogous to FIG. **5**, the movement of the movable lenses is represented by variations as a function of the focal length F of the distances E_1 to E_4 on the optical axis, namely

E_1 between the dioptric surfaces **5** and **6**
E_2 between the dioptric surfaces **7** and **8**
E_3 between the dioptric surfaces **9** and **10**
E_4 between the dioptric surfaces **11** and **12**.

The image distance of the objective is of the order of 22.2 mm.

Said objectives in accordance with the invention may be used in camera equipment. A variant of this application is a colour camera comprising three camera tubes for blue, green and red respectively. An objective with a long image distance (greater than or equal to 22 mm) is selected, which enables a colour-splitting prism to be included between the objective and the camera. The objective described with reference to FIG. **3**, which is designed so that it already incorporates said trichromatic separating prism, is particularly suitable for this application. In another variant of this application the camera equipment is formed by a simple camera with photosensitive film or a colour camera which comprising only one camera tube. It is then not necessary to include a trichromatic separating prism between the objective and the camera. The objective in accordance with the invention may then have a small image distance (smaller than 22 mm).

What is claimed is:

1. A variable focal length objective lens for focusing an image of an object at a stationary image plane, said lens having an aperture number between 1.5 and 2 and comprising components, each having at least one lens element, arranged along an optical axis, including:

(a) first and second stationary components arranged in order between an object field and the stationary image plane, said components having positive focal lengths; and

(b) first and second movable components each comprising a single element, arranged in order between the first and second stationary components, said first movable component having a negative focal length and said second movable component having a positive focal length, at least one of said single elements having an aspherical surface, said movable components being axially displacable relative to each other to effect a focal length variation of at least 5 to 1.

2. A variable focal length objective lens for focusing an image of an object at a stationary image plane, said lens having an aperture number between 1.5 and 2 and comprising components, each having at least one lens element arranged along an optical axis, including:

(a) first and second stationary components arranged in order between an object field and the stationary image plane, said first stationary component having a focal length F_1; and

(b) first, second and third movable components, each comprising a single element, arranged in order between the first and second stationary components and having focal lengths F_2, F_3 and F_4, respectively, where F_2/F_1 and F_3/F_1 are negative and F_4/F_1 is positive, at least one of said single elements having an

aspherical surface, said movable components being axially displaceable relative to each other to effect a focal length variation of at least 5 to 1.

3. A variable focal length objective lens for focusing an image of an object at a stationary image plane, said lens having a free image distance greater than 22 mm and comprising components, each having at least one lens element arranged along an optical axis, including:

(a) first and second stationary components arranged in order between an object field and the stationary image plane, said components having positive focal lengths; and

(b) first and second movable components, each comprising a single element, arranged in order between the first and second stationary components, said first movable component having a negative focal length and said second movable component having a positive focal length, at least one of said single elements having an aspherical surface, said movable components being axially displacable relative to each other to effect a focal length variation of at least 5 to 1.

4. A variable focal length objective lens for focusing an image of an object at a stationary image plane, said lens having a free image distance greater than 22 mm and comprising components, each having at least one lens element, arranged along an optical axis, including:

(a) first and second stationary components arranged in order between an object field and the stationary image plane, said first stationary component having a focal length F_1; and

(b) first, second and third movable components, each comprising a single element, arranged in order between the first and second stationary components and having focal lengths F_2, F_3 and F_4, respectively, where F_2/F_1 and F_3/F_1 are negative and F_4/F_1 is positive, at least one of said single elements having an aspherical surface, said movable components being axially displaceable relative to each other to effect a focal length variation of at least 5 to 1.

5. A variable focal length objective lens as in claim 3 or 4, characterized in that the aperture is F/1.8, and having the physical characteristics specified in the following Tables I and II, where the dioptric surfaces of the objective are designated 1 to 17 from the object field to the image field, where E designates axial distances between designated surfaces for a focal length F=7.97 mm, where n designates the refractive index, where ν designates the Abbe dispersion number, and where the symbols C, λ, ϵ_i represent coefficients in the following equation describing the cross sections of the aspherical dioptric surfaces 7, 8, 10 in a plane which passes through the optical axis

$$x = \frac{Cy^2}{1 + \sqrt{1 - (1 + \lambda)C^2 \cdot y^2}} + \sum_{i=2}^{i=n} \epsilon_i y^{2i}$$

the abscissa x being measured from the apex of the dioptric surface along the optical axis, and the ordinate perpendicularly to said axis:

TABLE I

Dioptric surface	E (mm)	R (mm)	n	ν
1		111.111		
	2.962		1.704485	29.88
2		43.910		
	11.099		1.622857	60.11
3		876.647		
	0.050		1.000000	
4		53.395		
	6.503		1.622857	60.11
5		129.296		
	2.936		1.000000	
6		−17.988		
	1.113		1.591288	60.94
7		8.261		
	1.896		1.000000	
8		35.029		
	3.452		1.550192	53.17
9		−39.013		
	59.841		1.000000	
10		25.384		
	2.982		1.654317	38.91
11		−62.563		
	7.889		1.000000	
12		309.102		
	3.025		1.622857	60.11
13		−18.230		
	0.050		1.000000	
14		−68.031		
	0.802		1.812529	25.30
15		13.760		
	1.032		1.000000	
16		25.702		
	2.625		1.622857	60.11
17		−30.820		
	0.000		1.000000	

Focal-length variation F: 7.95 to 63.50 mm
Image distance: 22.14 mm
Objective length: 108.25 mm

TABLE II

Dioptric surface	7	8	10
C	$1.21048\ 10^{-1}$	$2.85479\ 10^{-2}$	$3.93954\ 10^{-2}$
λ	−1.42139	−1.07632	−2.90598
ϵ_2	$-1.68578\ 10^{-4}$	$-1.89696\ 10^{-5}$	$-2.27969\ 10^{-5}$
ϵ_3	$2.73671\ 10^{-6}$	$3.04327\ 10^{-7}$	$-1.91999\ 10^{-7}$
ϵ_4	$-6.58215\ 10^{-8}$	$-5.01920\ 10^{-9}$	$1.14049\ 10^{-9}$
ϵ_5	$5.46590\ 10^{-10}$	$2.90044\ 10^{-11}$	$-1.55755\ 10^{-11}$

6. A variable focal length objective lens as in claim 3 or 4, characterized in that the aperture is F/1.8, and having the physical characteristics specified in the following Tables V and VI, where the dioptric surfaces of the objective are designated 1 to 11 from the object field to the image field, where E designates the axial distance between designated surfaces for the focal length F=17 mm, where n designates the refractive index, where ν designates the Abbe dispersion number, and where the symbols, C, λ, ϵ_i represent coefficients in the following equation describing the cross sections of the aspherical dioptric surfaces 2, 3, 5, 8, 9 in a plane which passes through the optical axis

$$x = \frac{Cy^2}{1 + \sqrt{1 - (1 + \lambda)C^2 \cdot y^2}} + \sum_{i=2}^{i=n} \epsilon_i y^{2i}$$

the abscissa x being measured from the apex of the dioptric surface along the optical axis and the ordinate perpendicularly to said axis:

TABLE V

Dioptric surface	E (mm)	R (mm)	n	ν
1		62.852		
	6.300		1.677623	32.08
2		17.997		

TABLE V-continued

Dioptric surface	E (mm)	R (mm)	n	ν
	31.400		1.000000	
3		31.080		
	10.395		1.622857	60.11
4		403.858		
	1.100		1.000000	
5		50.717		
	9.458		1.622857	60.11
6		−279.735		
	1.750		1.000000	
7		−33.369		
	0.866		1.622857	60.11
8		21.567		
	52.400		1.000000	
9		18.083		
	5.662		1.622857	60.11
10		−10.914		
	0.396		1.812529	25.30
11		−21.976		
	0.000		1.000000	

Focal-length variation F: 7.0 to 56.0 mm.
Image distance: 22.19 mm.
Length 2: 120.42 mm

TABLE VI

Dioptric surface	2	3	5	8	9
C	$5.55650\ 10^{-2}$	$3.21750\ 10^{-2}$	$1.97173\ 10^{-2}$	$4.63672\ 10^{-2}$	$5.53002\ 10^{-2}$
λ	$-6.96979\ 10^{-1}$	-1.13548	$-9.75088\ 10^{-1}$	$-1.52017\ 10^{-1}$	$-7.10788\ 10^{-1}$
ϵ_2	$-5.38859\ 10^{-6}$	$-9.88210\ 10^{-7}$	$1.30489\ 10^{-6}$	$-1.14601\ 10^{-5}$	$-1.99591\ 10^{-5}$
ϵ_3	$-9.03598\ 10^{-9}$	$-1.03273\ 10^{-9}$	$-3.89438\ 10^{-10}$	$9.99829\ 10^{-8}$	$2.71237\ 10^{-8}$
ϵ_4	$3.92014\ 10^{-12}$	$1.46391\ 10^{-12}$	$-6.31723\ 10^{-13}$	$-8.14572\ 10^{-10}$	$1.99891\ 10^{-9}$
ϵ_5	0.00000	0.00000	0.00000	0.00000	0.00000

7. A variable focal length objective lens as in claim **3** or **4**, characterized in that the aperture is equal to F/1.8, and having the physical characteristics specified in the following Tables VII and VIII, where the dioptric surfaces of the objective are designated 1 to 16 from the object field to the image field, where E designates the axial distance between designated surfaces for the focal length F = 15.00 mm, where n designates the refractive index, where ν designates the Abbe dispersion number, and where the symbols C, λ, ϵ_i represent coefficients in the following equation describing the cross sections of the aspherical dioptric surfaces **4**, **7**, **12**, **16** in a plane passing through the optical axis

$$x = \frac{Cy^2}{1 + \sqrt{1 - (1 + \lambda)C^2 \cdot y^2}} + \sum_{i=2}^{i=n} \epsilon_i y^{2i},$$

the abscissa x being measured from the apex of the dioptric surface along the optical axis and the ordinate perpendicularly to said axis:

TABLE VII

Dioptric surface	E (mm)	R (mm)	n	ν
1		52.985		
	2.499		1.734359	28.17
2		31.271		
	13.466		1.622857	60.11
3		180.118		
	0.050		1.000000	
4		60.986		
	5.533		1.622857	60.11
5		184.952		
	19.067		1.000000	
6		−318.707		
	0.940		1.591288	60.94
7		11.422		
	7.021		1.000000	
8		−10.909		
	0.636		1.591288	60.94
9		−136.669		
	3.649		1.000000	
10		135.620		
	1.848		1.734359	28.17
11		−24.210		
	16.404		1.000000	
12		−39.414		
	10.000		1.615176	58.34
13		−7.702		
	0.705		1.812529	25.30
14		−13.685		
	0.969		1.000000	
15		−99.112		
	2.417		1.622857	60.11
16		−14.931		
	000		1.000000	

Focal-length variation F: 7.5 to 60 mm
Image distance: 22.20 mm
Length: 85.20 mm.

TABLE VIII

Dioptric surface	4	7	12	16
C	$1.63972\ 10^{-2}$	$8.75499\ 10^{-2}$	$-2.53715\ 10^{-2}$	$-6.69741\ 10^{-2}$
λ	$1.68233\ 10^{-1}$	$-7.55918\ 10^{-1}$	0.00000	00000
ϵ_2	$-5.59326\ 10^{-8}$	$1.61978\ 10^{-5}$	$-2.23860\ 10^{-4}$	$-3.68018\ 10^{-6}$
ϵ_3	$1.644888\ 10^{-10}$	$-4.29937\ 10^{-7}$	$-1.06579\ 10^{-6}$	$2.28552\ 10^{-8}$
ϵ_4	0.00000	0.00000	0.00000	0.00000
ϵ_5	0.00000	0.00000	0.00000	0.00000

8. A variable focal length objective lens for focusing an image of an object at a stationary image plane, said lens having a free image distance smaller than 22 mm and comprising components, each having at least one lens element, arranged along an optical axis, including:

(a) first and second stationary components arranged in order between an object field and the stationary image plane, said components having positive focal lengths; and

(b) first and second movable components, each comprising a single element, arranged in order between the first and second stationary components, said first movable component having a negative focal length and said second movable component having a posi-

tive focal length, at least one of said single elements having an aspherical surface, said movable components being axially displaceable relative to each other to effect a focal length variation of at least 5 to 1.

9. A variable focal length objective lens for focusing an image of an object at a stationary image plane, said lens having a free image distance smaller than 22 mm and comprising components, each having at least one lens element, arranged along an optical axis, including:

(a) first and second stationary components arranged in order between an object field and the stationary image plane, said first stationary component having a focal length F_1; and

(b) first, second and third movable components, each comprising a single element, arranged in order between the first and second stationary components and having focal lengths F_2, F_3 and F_4, respectively, where $F_2/F1$ and F_3/F_1 are negative and F_4/F_1 is positive, at least one of said single elements having an aspherical surface, said movable components being axially displaceable relative to each other to effect a focal length variation of at least 5 to 1.

10. A variable focal length objective lens as in claim **8** or **9**, characterized in that the aperture is F/1.8, and having the physical characteristics specified in the following Tables III and IV, where the dioptric surfaces of the objective are designated 1 to 20 from the object field to the image field, where E designates the axial distance between designated surfaces for the focal length F=7.90 mm, where n designates the refractive index, where ν designates the Abbe dispersion number, and where the symbols C, λ, ϵ_i represent coefficients in the following equation describing the cross sections of the aspherical dioptric surfaces **7**, **8**, **10** in a plane which passes through the optical axis

$$x = \frac{Cy^2}{1 + \sqrt{1 - (1/\lambda)C^2 \cdot y^2}} + \sum_{i=2}^{i=n} \epsilon_i y^{2i}$$

the abscissa x being measured from the apex of the dioptric surface along the optical axis and the ordinate perpendicularly to said axis:

TABLE III

Dioptric surface	E (mm)	R (mm)	n	ν
1		115.145		
	2.935		1.723153	29.26
2		46.191		
	11.768		1.622857	60.11
3		−248.840		
	0.050		1.000000	
4		63.147		
	5.243		1.622857	60.11
5		135.414		
	2.507		1.000000	
6		−19.756		
	0.688		1.591288	60.94
7		11.786		
	3.279		1.000000	
8		237.568		
	1.680		1.584777	40.53
9		−51.022		
	59.431		1.000000	
10		42.857		
	2.329		1.584777	40.53
11		−31.066		
	7.373		1.000000	
12		550.809		
	3.487		1.622857	60.11
13		−16.221		
	0.040		1.000000	
14		−401.781		
	0.788		1.812529	25.30
15		13.928		
	1.259		1.000000	
16		42.759		
	2.200		1.622857	60.11
17		−26.586		
	0.050		1.000000	
18		∞		
	26.500		1.518727	64.04
19		∞		
	0.000		1.000000	

Focal-length variation F: 7.90 to 64 mm.
Image distance after prism: 4.25 mm
Length: 131.66 mm

TABLE IV

Dioptric surface	7	8	10
C	8,48454 10^{-2}	4,20932 10^{-3}	2,33336 10^{-2}
λ	−8,64111 10^{-1}	−6,87745 10^{-2}	−5,06288
ϵ_2	−1,01718 10^{-4}	2,05245 10^{-6}	−7,45166 10^{-5}
ϵ_3	−1,33362 10^{-7}	−4,29973 10^{-8}	−2,89507 10^{-7}
ϵ_4	−1,23607 10^{-8}	1,41858 10^{-9}	1,75248 10^{-9}
ϵ_5	1,19575 10^{-10}	−1,73662 10^{-11}	−5,15778 10^{-11}

* * * * *

United States Patent [19]

Uesugi

[11] **4,416,513**

[45] **Nov. 22, 1983**

[54] **AUTOMATIC AND MANUAL FOCUS CONTROL FOR OBJECTIVE LENS ASSEMBLY**

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[73] Assignee: **Minolta Camera Kabushiki Kaisha**, Osaka, Japan

[21] Appl. No.: **167,303**

[22] Filed: **Jul. 10, 1980**

[30] **Foreign Application Priority Data**

Jul. 16, 1979 [JP] Japan 54-90510

[51] **Int. Cl.**[3] **G02B 7/04**; G03B 3/00

[52] **U.S. Cl.** **350/255**; 354/195

[58] **Field of Search** 350/255, 430; 354/25, 354/195, 286

[56] **References Cited**

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4,231,646 11/1980 Iida 354/195

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Primary Examiner—F. L. Evans

Attorney, Agent, or Firm—Wolder, Gross & Yavner

[57] **ABSTRACT**

A lens is provided with a first and second lens groups which can focus not only with their concurrent movement along the optical axis but also with the movement of either one of the two lens groups. The first and second lens groups are respectively carried by first and second movable barrels. First means is provided for shifting both of first and second movable barrels concurrently in accordance with manual focus control. Second means is provided for shifting the second movable barrel without causing any movement of the first movable barrel. Thus, members to be moved for focusing upon automatic focus control are less in number in comparison with the members upon manual focus control.

13 Claims, 8 Drawing Figures

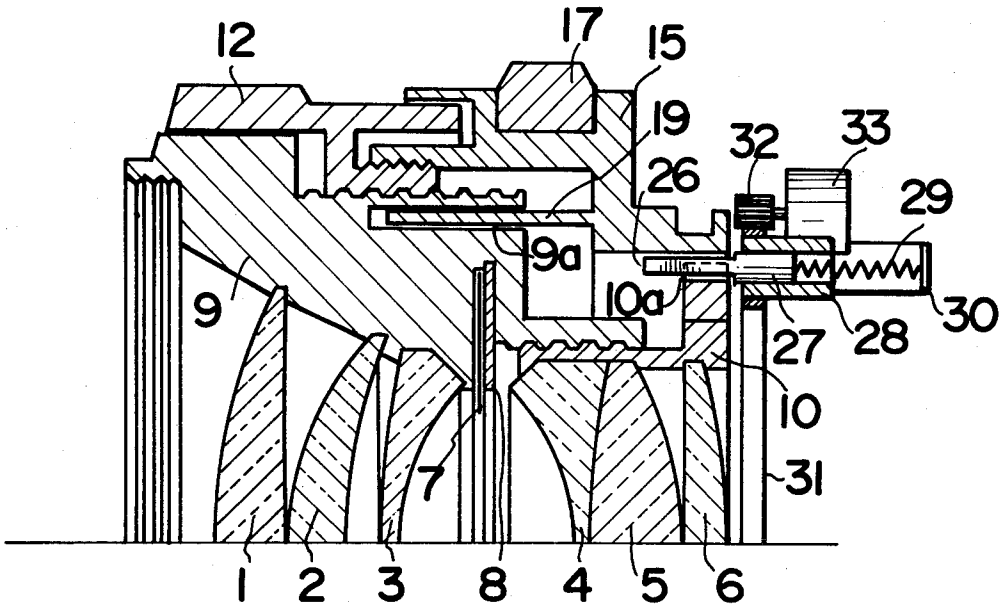


FIG.1

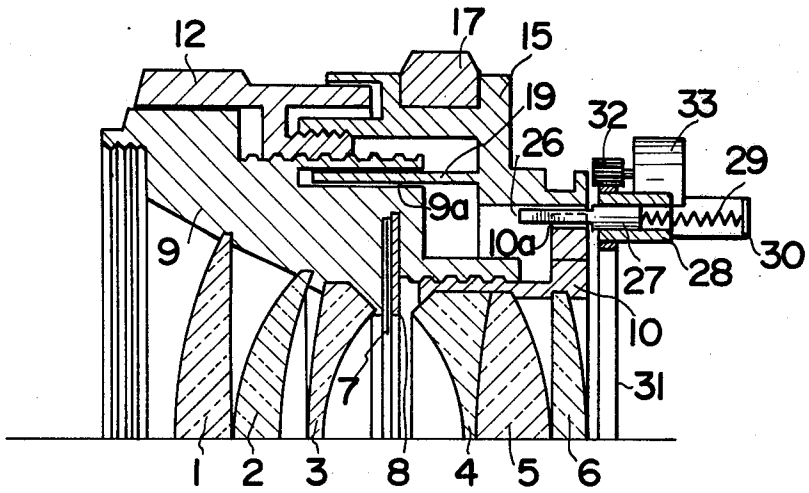


FIG.2

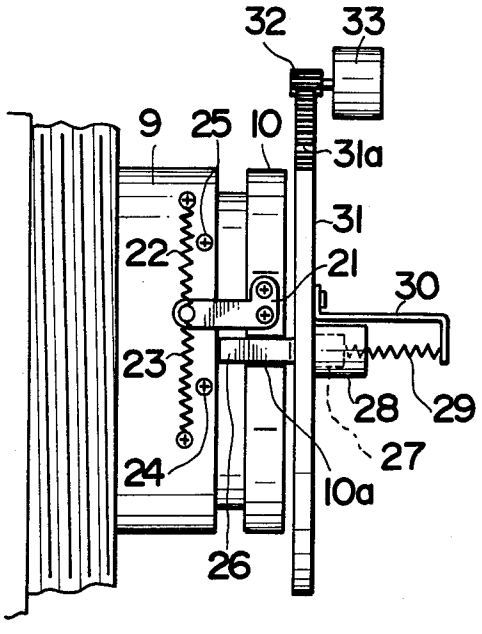


FIG.3

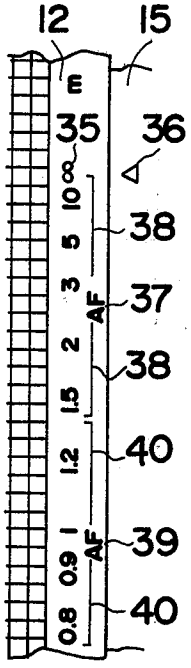


FIG.4

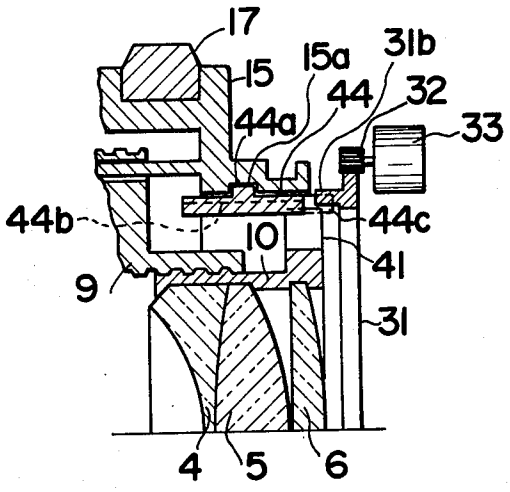


FIG.5

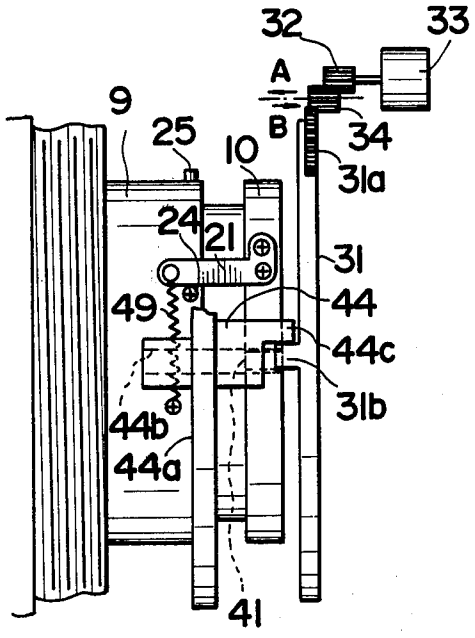


FIG.6

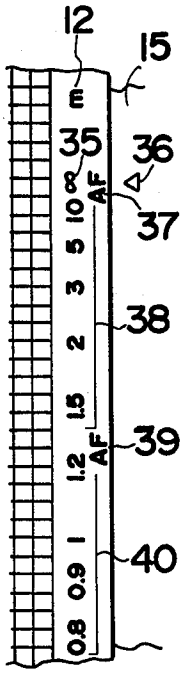


FIG.7

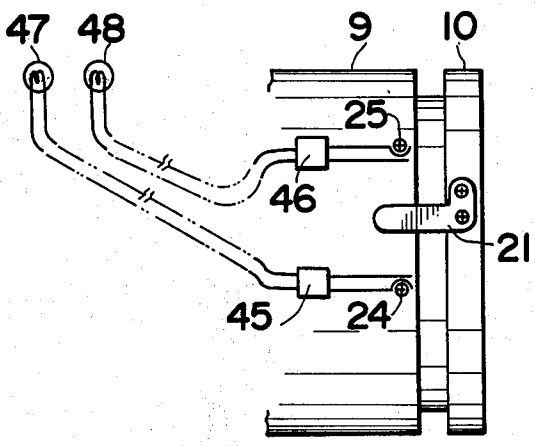
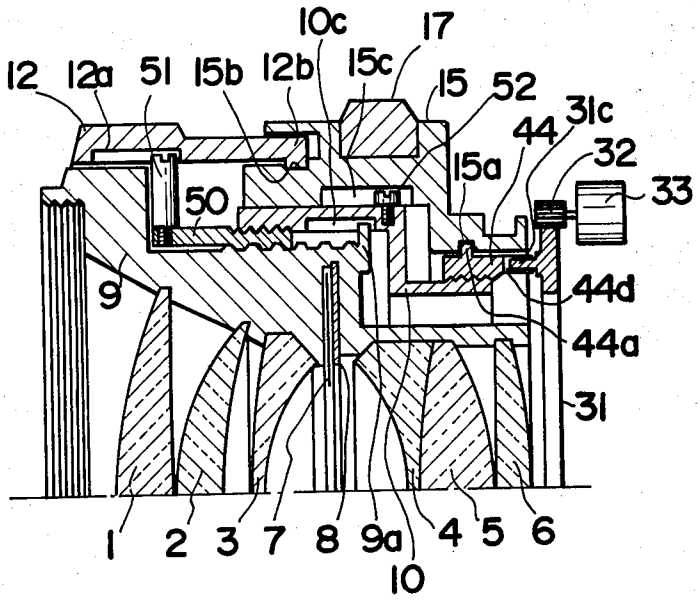

47
48
9
10
25
46
21
45
24

FIG.8


10c
17
12
12a
51
15b
12b
15c
15
52
31c
44
32
33
15a
50
9
44d
44a
31
1
2
3
7
8
9a
10
4
5
6

AUTOMATIC AND MANUAL FOCUS CONTROL FOR OBJECTIVE LENS ASSEMBLY

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to an objective lens barrel for use in cameras such as 35 mm single lens reflex (SLR) camera, motion picture cameras and TV cameras, and more particularly to a lens barrel capable of being automatically and manually controlled to adjust the focus of the objective lens.

2. Description of Prior Art

In prior art Japanese Patent Application laid open under No. 50-151144, an attachment for automatic focus control was proposed, which is driven by an automatic focus control device, and which may be coupled with the focus control ring of a lens barrel. In the case of automatic focus control, the attachment is coupled with the focus control ring for rotating it by the automatic focus control device. The attachment may be disengaged from the focus control ring for allowing the free rotation thereof for manual focus control. Thus, the focus control can be achieved alternatively by manual control means or automatic control means.

In the above mentioned prior art, however, the automatic focus control device is required to have considerable power in order to drive the attachment overcoming the resistance provided in the focus control ring of the lens barrel for preventing undesirable or unexpected movement thereof. Further, the use of such a prior art focus control device results in an inconvenience for manual focus control operation as well as bulkiness, and unshapeliness of the camera since the attachment is to be engaged with the lens barrel on the outside thereof at the focus control ring.

SUMMARY OF THE INVENTION

The object of the present invention is to provide a novel lens barrel capable of being controlled by both manual and automatic focus control means.

Another object of the present invention is to provide a lens barrel capable of being controlled by a focus control ring as in a conventional lens barrel, and also by an automatic focus control device having relatively small driving power.

Still another object of the present invention is to provide a lens barrel capable of being automatically controlled without interfering with manual focus control.

According to the present invention, the lens system is provided with first and second lens groups which can change focus of the lens system not only with their integral movement along the optical axis but also with the axial movement of either one of the two lens groups. The first and second lens groups are respectively carried by first and second movable barrels. First means is provided for shifting both of the first and second movable barrels concurrently in accordance with manual focus control. Second means is provided for shifting the second movable barrel without causing any movement of the first movable barrel. Thus, with the structure of the present invention, members to be moved for focusing by automatic focus control is less in number in comparison with the members upon manual focus control.

According to one feature of the present invention, the mechanisms for manual focus control and automatic focus control may be actuated independently of each other, and the automatic focus control can be carried out at any manually controlled focus condition. In other words, the operations of both mechanisms may be associated to provide a focus as a sum of the adjustments by the manual control and automatic control. With this feature, the second lens group may be moved for a small distance upon automatic focus control, which enables quick response of the automatic focus control system. In addition, due to the independence of each other, the two mechanisms can have respectively adequate operational torques for driving the lenses.

Further, selection of the manual and automatic focus control modes can be made only by decoupling and coupling the automatic focus control mechanism with the second movable barrel carrying the second lens group thereby facilitating the switching of the focus control mode. When the coupling is made, the second movable barrel is driven relative to the first movable barrel carrying the first lens group by the automatic focus control mechanism as well as with the first movable barrel by the manual focus control mechanism. In this case, if either one of the automatic and manual focus control mechanism is set to its initial position, the focusing depends on only the other.

According to an embodiment of the present invention, means are provided for returning the second movable barrel to its initial position relative to the first movable barrel when the second movable barrel is decoupled from the automatic focus control mechanism.

According to a feature of the embodiments, an indication means is provided for indicating one or more ranges of object distance for which the lens system can be focused by the automatic focus control system, thereby enabling the user to determine whether he should select the automatic or manual focus control mode. Furthermore, another indication means may be provided for warning the user when the second movable barrel is driven by the automatic focus mechanism to one extremity of the available range.

Other and further objects of this invention will become obvious upon an understanding of the illustrative embodiments about to be described or will be indicated in the appended claims, and various advantages not referred to herein will occur to one skilled in the art upon employment of the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a semi cross-sectional view of a first embodiment of the present invention;

FIG. **2** is a side elevational view illustrating engagement between movable barrels and the connection between the movable barrels and a driving mechanism in the first embodiment;

FIG. **3** is a schematic view of an indication scale of the first embodiment;

FIG. **4** is a fragmentary cross-sectional view of the principal part of a second embodiment;

FIG. **5** is a side elevational view illustrating the engagement between the movable barrels and the connection between the movable barrels and the driving mechanism of the second embodiment;

FIG. **6** is a schematic view of an indication scale of the second embodiment;

FIG. **7** is a schematic view of the principal part of an electric warning means; and

FIG. **8** is a semi cross-sectional view of a third embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

With reference to FIG. **1**, lenses **1** through **3** are supported by first movable barrel **9** and lenses **4** through **6** by second movable barrel **10**, respectively. Diaphragm blades **7** and diaphragm actuating plate **8** are disposed between lenses **3** and **4** and are supported by first movable barrel **9**. Diaphragm actuating plate **8** is rotatable in response to the manual operation of diaphragm setting ring **17** so as to vary the size of the diaphragm aperture formed by diaphragm blades **7**. It should be noted that lenses **1** through **6** are designed such that their image forming properties are relatively stable even when the space between lenses **3** and **4** varies slightly. Lenses **1** through **6** are so designed as to effect focusing by the movement of all of the lenses **1** through **6** along the optical axis or the movement of lenses **4** through **6** relative to the lenses **1** through **3**.

Manual focusing ring **12** is connected through a helicoid coupling to fixed barrel **15**, with diaphragm setting ring **17** for diaphragm aperture setting being rotatably supported by fixed barrel **15**. In addition, first movable barrel **9** supporting lenses **1** through **3** and the diaphragm mechanism is connected through a helicoid coupling to manual focusing ring **12**. Guide pin **19** formed integrally with fixed barrel **15** extends into guide hole **9***a* formed in first movable barrel **9** in parallel to the optical axis, whereby the rotation of first movable barrel **9** relative to fixed barrel **15** is restricted. Second movable barrel **10** supporting lenses **4** through **6** is connected through a helicoid coupling to first movable barrel **9**. Formed on the circumferential surface of barrel **10** is a guide recess **10***a* into which guide portion **26** is engageable.

With the above construction, when manual focusing ring **12** is rotated relative to fixed barrel **15**, first movable barrel **9** is moved along the optical axis without being rotated relative to fixed barrel **15** as stated above. Consequently, second movable barrel **10** is also moved along the optical axis integrally with first movable barrel **9** without being rotated relative to fixed barrel **15**.

Description will now be given of the relationship between first movable barrel **9** and second movable barrel **10**, and a drive system for second movable barrel **10** with reference to FIGS. **1** and **2**. Referring to FIG. **2**, arm member **21** is secured on second movable barrel **10**. Springs **22** and **23** are tensioned between arm member **21** and peripherally spaced fixed points on first movable barrel **10** to maintain second movable barrel **10** at a predetermined angular position relative to first movable barrel **9** when second movable barrel **10** is free from an external force. Fixed to first movable barrel **9** are stoppers **24** and **25** on which arm **21** fixed to second movable barrel **10** is abuttable when second movable barrel **10** is rotated relative to first movable barrel **9**.

With the above construction, when no external force is applied to second movable barrel **10**, the angular position of second movable barrel **10** relative to first movable barrel **9** is maintained constant by springs **22** and **23**. In addition, the rotational movement of second movable barrel **10** relative to first movable barrel **9** is blocked when arm member **21** fixed to second movable barrel **10** abuts upon stopper **24** or **25** fixed to first movable barrel **9**. Since first movable barrel **9** and second movable barrel **10** are connected each other through a helicoid coupling, the amount of angular movement of second movable barrel **10** relative to the first movable barrel **9** is limited to a predetermined angle by stoppers **24** and **25**. This means that the amount of the axial movement of second movable barrel **10** is also limited. In the present embodiment, second movable barrel **10** is constructed such that it is movable as much as ± 1 mm along the optical axis relative to first movable barrel **9**.

Actuating ring **31** is rotatably mounted to a camera body (not shown), and gear portion **31***a* is formed partially on the circumference of actuating ring **31**. Engaged with gear portion **31***a* is pinion gear **32** fixed to the drive shaft of a motor **33** that is controlled by an automatic focus control device (not shown). Also fixed to actuating ring **31** are electromagnet **28** and spring holding plate **30**. Electromagnet **28** is activated when an automatic focus operating or actuating switch (not shown) provided on the lens barrel or the camera body is closed, while it is deactivated when the automatic focus operating switch is opened. Core **27** of electromagnet **28** is movable parallel to the optical axis (i.e., in the horizontal or lateral direction in FIGS. **1** and **2**), and one end of spring **29** is fixed to the rear end of core **27**. The other end of spring **29** is fixed to spring holding plate **30**, thereby causing core **27** to be retracted (i.e., to the right in the Figures) when electromagnet **28** remains deactivated. Core **27** is moved forward (i.e., to the left in FIGS. **1** and **2**) against the action of spring **29** when electromagnet **28** is activated. Furthermore, fixed integrally to the tip of core **27** is guide portion **26** engageable into recess **10***a* formed on the circumferential portion of second movable barrel **10**.

With the above construction, when an automatic focus actuation switch (not shown) is closed, electromagnet **28** fixed to actuating ring **31** is activated to move forward guide portion **26** which is integrally formed with core **27**, whereby guide portion **26** is engaged into recess **10***a* of second movable barrel **10**, thereby coupling actuating ring **31** to second movable barrel **10**. So long as the automatic focus actuation switch is kept closed, guide portion **26** is always biased forward. Accordingly, if guide portion **26** is not at the position to align with and engage into recess **10***a* of second movable barrel **10**, actuating ring **31** is at first separately rotated by motor **33** to bring guide portion **26** into registration with recess **10***a* so that guide portion **26** engages recess **10***a* of second movable barrel **10** to couple the latter with actuating ring **31**. Second movable barrel **10** is then rotated by motor **33**, and at this moment, the amount of angular movement of second movable barrel **10** relative to first movable barrel **9**, and accordingly the amount of axial movement thereof is limited or restricted by stoppers **24** and **25**. With the present embodiment, the interval between stoppers **24** and **25** is set so that second movable barrel **10** is movable as much as ± 1 mm along the optical axis relative to first movable barrel **9** from the initial state where springs **22** and **23** are balanced in tension for arm member **21**.

When an automatic focus actuating switch (not shown) is opened, electromagnet **28** is deactivated, causing core **27** and guide portion **26** to be retracted under the action of spring **29**, whereby guide portion **26** is retracted from recess portion **10***a* of second movable barrel **10** and as a result, the rotation of actuating ring **31** is not transmitted to second movable barrel **10**. This means that external force is no longer applied to second movable barrel **10**, and arm member **21** fixed thereto is rotated by spring **22** or **23** until the tension of springs **22** and **23** for arm member **21** becomes balanced. With the

above construction, the relative position of first movable barrel **9** and second movable barrel **10** is always maintained constant when automatic focusing is not performed.

It should be understood that the lengths of guide portion **26**, core **27** and other related elements are determined such that guide portion **26** may engage recess **10***a* of second movable barrel **10** at any axial position of the latter when the automatic focus actuating switch is closed, while guide portion **26** may completely be retracted from recess portion **10***a* of second movable barrel **10** at any axial position of the latter when the automatic focus actuating switch is opened.

FIG. **3** is a schematic view of an indication scale or graduation for indicating the focusable distance of an objective with manual focus control and the focusable distance range with automatic focus control. With reference to FIG. **3**, distance scale **35** is provided on the circumferential surface of manual focusing ring **12**. Index **36** is disposed on the circumferential surface of fixed barrel **15**. In manual focus control, the number on distance scale **35** that is in registry with index **36** represents the object distance on which the objective lens is focused. Automatic focus mark **37** is provided on the circumferential surface of manual focusing ring **12**, and mark **38** indicates the focusable distance range when automatic focus mark **37** is coincident with index **36** to select automatic focus control mode. Similarly, mark **40** indicates the focusable distance range when automatic focus mark **39** is coincident with index **36** to select another automatic focus control mode. Since the amount of the axial movement of second movable barrel **10** relative to first movable barrel **9** is limited as mentioned earlier, the range indicated by the mark **38** or **40** corresponds to the amount of the movement of second movable barrel **10**. When automatic focusing is performed with automatic focus mark **37** being moved into registry with index **36**, for instance, an automatic driving or focusing mechanism automatically shifts the objective to be focussed on a predetermined object distance within the range of approximately 1.4 m to infinity (∞). It is to be noted that automatic focusing is possible even if automatic focus mark **37** or **39** is not in registration with index **36**. In this case, however, the focusable range is not the one indicated by mark **38** or **40**. When, for example, "1.5" on distance scale **35** is in registry with index **36**, the automatic focusing mechanism can adjust the focusing within the object distance of approximately 1 m to 3 m.

An explanation follows of the operation of the present embodiment with the above construction. First, for manual focus control, an automatic focus operating switch (not shown) is open to maintain electromagnet **28** deactivated. Therefore, no external driving force is applied to second movable barrel **10**, as described above, whereby the relative position between first movable barrel **9** and second movable barrel **10** is maintained constant under the action of springs **22** and **23**. Under such condition, when manual focusing ring **12** is rotated manually relative to fixed barrel **15**, focusing ring **12** is moved along the optical axis under the guidance of the helicoid thread of fixed barrel **15**. First movable barrel **9** connected to manual focusing ring **12** is also moved along the optical axis. However, since first movable barrel **9** is restrained by guide pin **19** from rotation relative to fixed barrel **15**, first movable barrel **9** is translated along the optical axis. When first movable barrel **9** is moved along the optical axis, second movable barrel **10**, whose relative position to first movable barrel **9** along the optical axis is maintained constant, is also translated integrally with first movable barrel **9**. Therefore, lenses **1** through **6** supported by first movable barrel **9** and second movable barrel **10** are integrally moved without rotation along the optical axis, whereby manual focusing is performed. The object distance focused in the manual focusing mode is indicated by the number on distance scale **35** which is confronted by index **36** on fixed barrel **15**.

For automatic focus control, the automatic focus operating switch (not shown) is closed to energize electromagnet **28**. Then, guide portion **26** rotatable integrally with actuating ring **31** engages recess **10***a* of second movable barrel **10** as described above, whereby a drive system including motor **33** is connected to second movable barrel **10**. Even if, the second movable barrel **10** is left at any position along the optical axis after the manual focusing operation, the second movable barrel **10** is, without fail, connected to the drive system when guide portion **26** is moved forward parallel to the optical axis (i.e., to the left in FIGS. **1** and **2**). This is because the recess **10***a* is always kept in alignment with guide portion **26** since the movement of the second movable barrel is restricted to a straight direction parallel to the optical axis. When motor **33** is driven under the control of an automatic focus control device (not shown), actuating ring **31** is rotated as described above, whereby second movable barrel **10** connected to actuating ring **31** is rotated. Since second movable barrel **10** is connected by helicoid coupling to first movable barrel **9** whose rotational movement relative to fixed barrel **15** is prevented, second movable barrel **10** is moved along the optical axis. At this time, the amount of axial movement of second movable barrel **10** relative to first movable barrel **9** is limited by stoppers **24** and **25**, as described earlier. Thus, lenses **4** through **6** supported by second movable barrel **10** are moved along the optical axis with rotation while lenses **1** through **3** held by first movable barrel **9** are not moved, whereby focussing is effected. At this condition, the entire lenses **1** through **6** may be moved along the optical axis by manually operating manual focussing ring **12**. In this case, the focusing of the entire lens system is a function of the combined effects of the movement of the lenses **1** through **6** relative to the fixed barrel by manual focusing ring **12** and the movement of lenses **4** through **6** relative to lenses **1** through **3** by actuating ring **31**. For automatic focus control, when automatic focus mark **37** on manual focusing ring **12** is manually brought into registry with index **36** on fixed barrel **15**, lenses **4** through **6** are moved relative to lenses **1** through **3** within the range limited by stoppers **24** and **25**, whereby automatic focusing is made in the range of approximately 1.4 m to infinity (∞) as indicated by mark **38**. As stated above, changeover from manual focusing control to automatic focus control is possible without bringing automatic focus mark **37** or **39** into registry with index **36**, and in this case, the only difference lies in that the focusable range does not correspond to the range shown by mark **38** or **40**.

A changeover from automatic focus control to manual focus control is possible at any time merely by opening an automatic focus actuating switch (not shown). When the automatic focus actuating switch (not shown) is opened, electromagnet **28** is deactivated, causing guide portion **26** to retract from recess portion **10***a* of second movable barrel **10** under the action of spring **29**.

As a result, the drive system and second movable barrel **10** are disconnected from each other, causing the external driving force to be no longer transmitted to second movable barrel **10**. This means that second movable barrel **10** is rotated by the spring **22** or **23** until it reaches a predetermined angular position where the respective tensions of spring **22** and **23** are balanced. When the second movable barrel reaches the predetermined angular position, the object distance being focused is indicated by the number on the scale **35** of manual focusing ring **12** that is confronted by index **36** on fixed barrel **15**.

FIGS. **4** through **6** show a second embodiment of the present invention, wherein the same reference numerals are used for members corresponding to those of the first embodiment in FIGS. **1** through **3**, and the description thereof is omitted. In FIG. **4**, the manual focusing mechanism is exactly the same as shown in FIG. **1** and is accordingly not shown in FIG. **4** for the simplicity of illustration.

With reference to FIGS. **4** and **5**, second movable barrel **10** is connected by a helicoid coupling to first movable barrel **9** as in the first embodiment. When rotated, second movable barrel **10** is movable along the optical axis relative to first movable barrel **9**. In addition, radially projecting guide portion **41** is fixed to the circumference at the rear end of second movable barrel **10** in place of recess **10***a* in the first embodiment. The head of guide portion **41** engages guide groove **44***b* of relay ring **44**. Relay ring **44** is rotatably supported by fixed barrel **15** with projection **44***a* being engaged by circumferential groove **15***a* formed circumferentially on the inner surface of fixed barrel **15**. Formed on the inner circumferential surface of relay ring **44** is guide groove **44***b* extending parallel to the optical axis, with which the head of guide portion **41** is slidably engaged. Also formed at the rear end of relay ring **44** is engaging claw **44***c* which is engageable with engaging claw **31***b* formed on actuating ring **31**. The length of guide groove **44***b* is set such that guide portion **41** of second movable barrel **10** remains unremoved from guide groove **44***b* of relay ring **44** even when second movable barrel **10** is translated along the optical axis. Furthermore, one end of spring **49** is fixed to the top end of arm member **21** which is fixed to second movable barrel **10**, while the other end of spring **49** is fixed to first movable barrel **9**. When second movable barrel **10** is free of external force, arm member **21** fixed to second movable barrel **10** abuts stopper **24** under the action of spring **49**.

With the present embodiment, second movable barrel **10** is maintained at a predetermined angular position relative to first movable barrel **9** by virtue of spring **49** and stopper **24**, and therefore, springs **22** and **23** in the first embodiment are not provided therein. In addition, the connection between actuating ring **31** and second movable barrel **10** is made in the present embodiment by way of engaging claw **31***b* of actuating ring **31** and engaging claw **44***c* of relay ring **44**. In the above embodiment, the amount of axial movement of second movable barrel **10** relative to first movable barrel **9** is also limited or restricted by stoppers **24** and **25**. The interval between stoppers **24** and **25** is set such that second movable barrel **10** is movable along the optical axis as much as ±2 mm for first movable barrel **9**. Furthermore, movable gear **34** is interposed between pinion gear **32** and gear portion **31***a* of actuating ring **31**, and movable gear **34** is movable in the direction of arrows A and B. When automatic focus operating switch (not shown) is opened, movable gear **34** is moved from the position shown in the Figure in the direction of arrow B to be disengaged from gear portion **31***a* of actuating ring **31**, whereby gear portion **31***a* is not driven by motor **33**.

With the above construction, manual focusing is performed in exactly the same manner as in the first embodiment. In the instant case, guide portion **41** fixed to second movable barrel **10** slides on guide groove **44***b* of relay ring **44**.

When the automatic focus operating switch (not shown) is closed, movable gear **34** is moved in the direction of arrow A to the position shown in FIG. **5** where it meshes with both pinion gear **32** and gear portion **31***a*. When motor **33** is rotated while it is controlled by an automatic focus control device (not shown), second movable barrel **10** is rotated through relay ring **44**, and thus moved along the optical axis relative to first movable barrel **9**. The amount of movement of second movable barrel **10** relative to first movable barrel **9** is restricted by stoppers **24** and **25**, as described earlier. Thus, lenses **4** through **6** held by second movable barrel **10** are moved relative to lenses **1** through **3** held by first movable barrel **9**, whereby automatic focusing is performed. In the second embodiment, automatic focus control is possible with lenses **1** through **6** being left at any position on the optical axis. Therefore, automatic focus control may be quickly performed when focusing for an object is roughly made by the manual focus control prior to changeover to automatic focus control.

When the automatic focus operating switch (not shown) is opened, motor **33** and actuating ring **31** are disconnected from each other, as described earlier, thereby causing second movable barrel **10**, relay ring **44** and actuating ring **31** to be all reset to the position as shown in FIG. **5**. With the above embodiment, motor **33** serves to rotate actuating ring **31** only in one direction. Accordingly the motor may be replaced by a spring to rotate actuating ring **31**, and the rotation of actuating ring **31** is stopped after a lapse of any desired time from the intiation of the rotation according to the output signal from an automatic focus control device.

FIG. **6** is a schematic view illustrating a distance indication scale of the second embodiment. The difference between the first and second embodiments lies only in the position of automatic focus marks **37** and **39** as seen in FIG. **3**. That is, in manual focusing mode with the second embodiment, second movable barrel **10** is spaced apart from first movable barrel **9** to the extremity of the available range along the optical axis, and second movable barrel **10** is driven from such extreme position toward first movable barrel **9** by means of an automatic focusing mechanism. Therefore, the automatic focusing mechanism can adjust the focusing of the objective for an object distance smaller than manually available. Accordingly, automatic focus marks **37** and **39** are disposed at each largest distance position of the automatically focusible range.

Shown below are the numerical examples of the relationships between the focused object distance and the amount of axial movement of second movable barrel **10** relative to first movable barrel **9** in the first and second embodiments, when the automatic focusing mechanism is actuated with automatic focus mark **37** or **39** in registry with index **36**:

In-focus distance (m)	Amount of shift (mm) First embodiment	Second embodiment
∞		
10	−1.00	AF 0.00
5	−0.73	+0.27
3	−0.47	+0.54
2	AF −0.09	+0.91
1.5	+0.40	+1.40
	+0.89	
1.2		AF +1.89
1	−0.59	+0.41
0.9	AF −0.05	+0.95
0.8	+0.32	+1.32
	+0.79	+1.79

FIG. 7 is a schematic view of an electric warning means which may be provided in the first and second embodiments. Referring to FIG. 7, switches **45** and **46** positioned on first movable barrel **9** can be closed respectively by arm member **21** fixed to second movable barrel **10** immediately before the arm member **21** abuts on stopper **24** or **25**. Warning lamps **47** and **48** provided on a camera body or inside a viewfinder light up and go out in response to the opening and closing of switches **45** and **46**, respectively. Switch **45** is closed immediately before the arm member **21** engages stopper **24**, thereby causing warning lamp **47** to light up, and conversely before the arm **21** engages stopper **25**, switch **46** is closed causing warning lamp **48** to light up.

With the above construction, it is possible to inform a photographer that second movable barrel is stopped whether in its most retracted position or most advanced position along the optical axis relative to the first movable barrel. This structure is convenient in selecting the focus adjustment range for an automatic focusing mechanism (e.g., either the range of mark **38** or that of mark **40** as shown in FIG. 3).

Furthermore, according to the first and second embodiments, even if an attachment is mounted to the front most end of first movable barrel **9**, the weight of such attachment does not affect the automatic focusing mechanism. Therefore, even in such case, the automatic focusing mechanism is capable of moving the lens group at high speed with a small power output.

FIG. **8** is a semi cross-sectional view of a third embodiment of the present invention, where the same reference numerals are used for members corresponding to those of the first and second embodiments, and the description thereof is omitted.

With reference to FIG. **8**, first movable barrel **9** supports all of lenses **1** through **6**, diaphragm blade **7** and diaphragm actuating plate **8**, and second movable barrel **10** supports no lens. Inner barrel **50** is connected by helicoid coupling to both first movable barrel **9** and second movable barrel **10**. Pin **51** carried by inner barrel **50** at the front end thereof is received by axially extending pin guide groove **12***a* formed on the inner surface of manual focusing ring **12**. Furthermore, formed at the rear end of manual focusing ring **12** is bent portion **12***b* which extends radially towards the optical axis and which is received by circumferential groove **15***b* formed circumferentially on fixed barrel **15**. With the above construction, when manual focusing ring **12** is manually rotated, the rotation thereof is transmitted to inner barrel **50**. Manual focusing ring **12** is arranged not to move along the optical axis relative to fixed barrel **15**. Further, when inner barrel **50** is otherwise translated along the optical axis, manual focusing ring **12** is not moved.

Formed on the circumference of first movable barrel **9** is projection **9***a* which is otherwise engaged by guide groove **10***c*; extending parallel to the optical axis and formed on the inner circumferential surface of second movable barrel **10**. Therefore, the rotational movement of first movable barrel **9** relative to second movable barrel **10** is restrained. In addition, second movable barrel **10** carries pin **52** which engages guide groove **15***c* extending parallel to the optical axis and formed on the inner circumferential surface of fixed barrel **15**, whereby the rotational movement of second movable barrel **10** relative to fixed **15** is restrained. Moreover, the rear of second movable barrel **10** is connected by a helicoid coupling to relay ring **44**, whose rear end is formed with recess **44***d* with which projection **31***c* of actuating ring **31** is engaged. With the third embodiment, when an automatic focus operating switch (not shown) is closed, motor **33** is driven under the control of an automatic focusing device. When the automatic focus operation switch is opened, motor **33** resets actuating ring **31** to a predetermined position and then stops its drive operation. In addition, the movement of second movable barrel **10** relative to fixed barrel **15** by the automatic focusing mechanism is restricted by stoppers **24** and **25** and arm **21** as in the first and second embodiments being provided on fixed barrel **15** and relay ring **44**, respectively.

With the above construction, motor **33** is not driven in the manual focusing mode, and second movable barrel **10** is always maintained at a predetermined position relative to fixed barrel **15**. When manual focusing ring **12** is rotated, first movable barrel **9** is translated relative to fixed barrel **15**, whereby focusing is performed.

When the automatic focus actuating switch (not shown) is closed and motor **33** is driven by the automatic focusing device (not shown), relay ring **44** is rotated through actuating ring **31**, whereby second movable barrel **10**, relay ring **44** and first movable barrel **9** are moved along the optical axis integrally with each other. In this case, it is possible to move first movable barrel **9** relative to second movable barrel **10** by manually operating manual focusing ring **12**, and consequently, the focusing effect by lenses **1** through **6** is obtained by the sum of the amount of shift of second movable barrel **10** relative to fixed barrel **15** and the amount of shift of first movable barrel **9** relative to second movable barrel **10**.

When the automatic focus actuating switch (not shown) is opened, actuating ring **31** is rotated to return to the predetermined position and remains in that position and therefore, the distance scale always indicates the distance which precisely corresponds to an object distance being manually focused.

Thus, according to the present embodiment, first movable barrel **9** supporting the lens group is moved along the optical axis both for manual focusing using a manual focusing mechanism alone, and automatic focusing using manual and automatic focusing mechanisms. This structure is advantageous when a diaphragm is provided.

With all of the above embodiments, it is possible to provide an adequate operational torque for a manual focusing mechanism, wherein grease lubrication is applied to the helicoid coupling between manual focusing ring **12**, fixed barrel **15** and first movable barrel **9**, respectively, in the first and second embodiments and the

helicoid coupling between inner barrel **50**, first and second movable barrels **9** and **10** in the third embodiment. It is also possible to move the lens group at high speed with a small output from an automatic focusing mechanism, wherein solid lubrication is applied to the helicoid coupling between relay ring **44** and second movable barrel **10** in the third embodiment.

It should be noted that the present invention is not limited to the above three embodiments, and helicoid coupling may be replaced by pin and cam-groove couplings. Also as the means for maintaining movable barrels in the predetermined positions for automatic focusing, a magnetic means may be employed which makes use of a magnet instead of springs in the preceding embodiments. Furthermore, the embodiments are shown as applied to an objective lens for a single-lens reflex camera. However, the present invention is not limited to that application but is also applicable to a lens of a coupled range finder camera.

As many apparantly widely different embodiments of this invention may be made without departing from the spirit and scope thereof, it is to be understood that the invention is not limited to the specific embodiments thereof except as defined in the appended claims.

What is claimed is:

1. An objective lens assembly for use with a camera which includes an automatic focus control device having a driving mechanism, comprising:

a manually movable focussing ring;

first and second lens groups disposed along a common optical axis, said first and second lens groups being capable of changing focus not only when said both lens groups are concurrently shifted along the optical axis but also when either one of said lens groups is shifted relative to the other along the optical axis;

a first movable barrel carrying said first lens group;

a second movable barrel carrying said second lens group, said second movable barrel being movably supported by said first movable barrel so as to be integrally moved with said first movable barrel;

first means interconnecting said manual focussing ring with said first movable barrel such that said first movable barrel is moved along the optical axis in response to the movement of said manual focussing ring, thereby moving said first and second lens groups concurrently along the optical axis; and

means for interconnecting said second movable barrel to said driving mechanism so that said second movable barrel is automatically moved, thereby said second lens group being moved relative to the first lens group along the optical axis.

2. An objective lens assembly as set forth in claim **1**, further comprising means for deenergizing said interconnecting means so that said second movable barrel is free from the control of said driving mechanism upon manual focus control and means for maintaining said second movable barrel at a predetermined position relative to said first movable barrel when said second barrel is free from the control of said driving mechanism.

3. An objective lens assembly as set forth in claim **1**, wherein said second movable barrel is rotatably engaged with said first movable barrel through a helicoid coupling, and said lens barrel further comprising means for limiting the amount of the rotational movement of said second movable barrel relative to said first movable barrel.

4. An objective lens assembly as set forth in claim **3**, further comprising electric warning means which is actuated when said second movable barrel reaches at end of rotational movement.

5. In a camera including an automatic focus electric drive motor, an objective lens comprising a pair of first and second lens groups having a common optical axis and each including at least one lens, first focusing means including a manual focusing member for manually axially shifting said first and second lens groups as an integral unit for adjusting the focus of said objective lens and second focusing means driven by said electric drive motor for axially shifting said first lens group relative to said second lens group while leaving said second lens group stationary.

6. The objective lens of claim **5** wherein said first focusing means has a greater operational resistance than said second focusing means.

7. The objective lens of claim **5** including means for alternative drive coupling and uncoupling said second focusing means with said motor.

8. The objective lens of claim **5** wherein the range of axial movement of said first lens group relative to said second lens group by said second focusing means is less than the range of axial movement of said lens groups as a unit by said first focusing means.

9. The objective lens of claim **5** further comprising a stationary member which movably supports said manual focusing member.

10. The objective lens of claim **9** further comprising an indicating means for indicating the distance of an object on which said first and second lens groups are focused by said manual focusing member.

11. The objective lens of claim **10** wherein said indicating means includes a distance scale on said manual focusing member and an index produced on said stationary member.

12. The objective lens of claim **6** wherein said first focusing means includes grease lubrication for providing a sufficient operational resistance to the operation of said manual focusing member so that a large torque is required to operate said manual focusing member.

13. The objective lens of claim **12** wherein said second focusing means includes solid lubrication for reducing the resistance of the operation of said second focusing means.

* * * * *

United States Patent [19]

Sato

[11] **4,413,888**

[45] **Nov. 8, 1983**

[54] COMPACT PHOTOGRAPHIC OBJECTIVE

[75] Inventor: **Yasuhisa Sato**, Yokohama, Japan

[73] Assignee: **Canon Kabushiki Kaisha**, Tokyo, Japan

[21] Appl. No.: **335,468**

[22] Filed: **Dec. 29, 1981**

[30] **Foreign Application Priority Data**

Jan. 13, 1981 [JP] Japan 56-3590

[51] **Int. Cl.**³ **G02B 9/34**; G02B 13/18

[52] **U.S. Cl.** **350/432**; 350/469

[58] **Field of Search** 350/432, 469

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Primary Examiner—John K. Corbin
Assistant Examiner—Scott J. Sugarman
Attorney, Agent, or Firm—Toren, McGeady and Stanger

[57] **ABSTRACT**

The disclosed photographic objective includes, from front to rear, a first lens of meniscus form convex toward the front and having a positive refractive power, a second lens having a negative refractive power, a third lens having a positive refractive power, and a fourth lens of meniscus form which is concave toward the front and has a negative refractive power and whose front surface is aspheric, with the refractive power and configuration of each lens appropriately set to achieve compactness while permitting good correction of aberrations.

2 Claims, 15 Drawing Figures

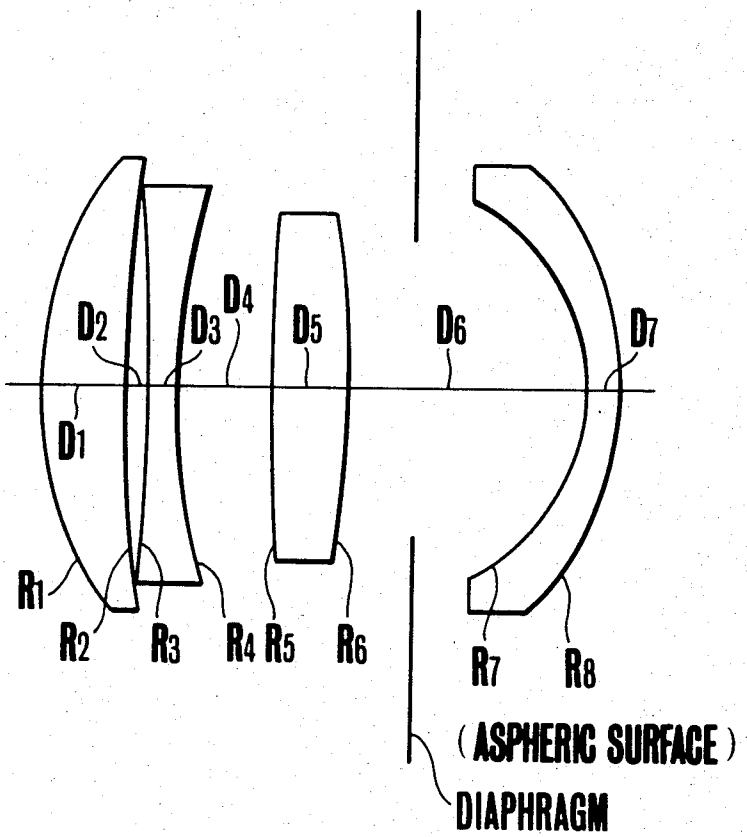


FIG. 1

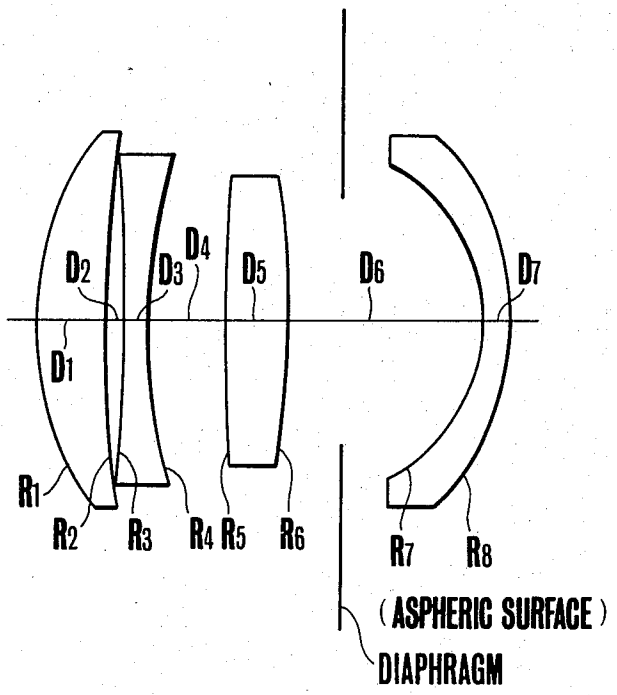

D2
D3
D4
D5
D6
D7
D1
R1
R2
R3
R4
R5
R6
R7
R8
(ASPHERIC SURFACE)
DIAPHRAGM

FIG.2
(a)

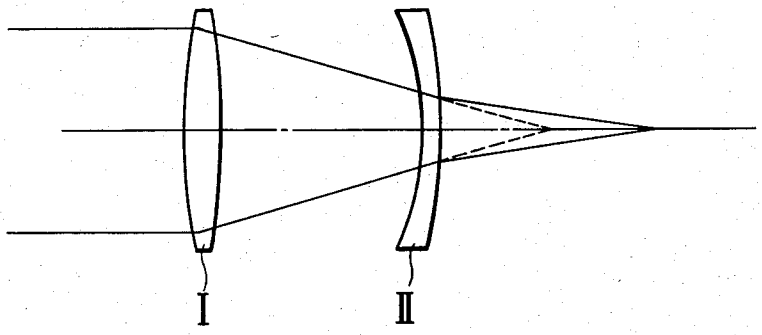


FIG.2
(b)

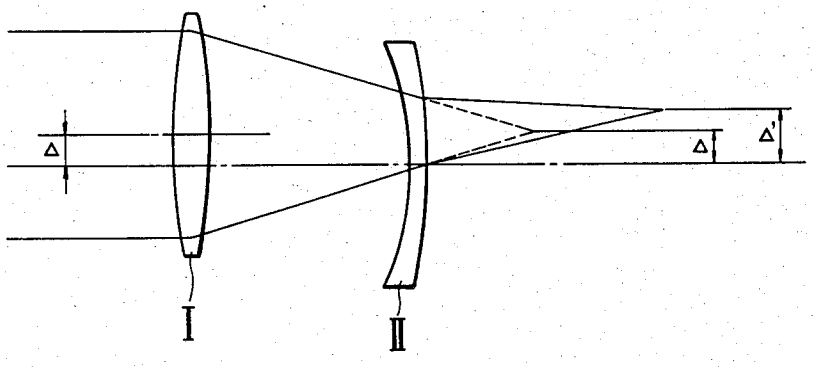


FIG.3a FIG.3b FIG.3c

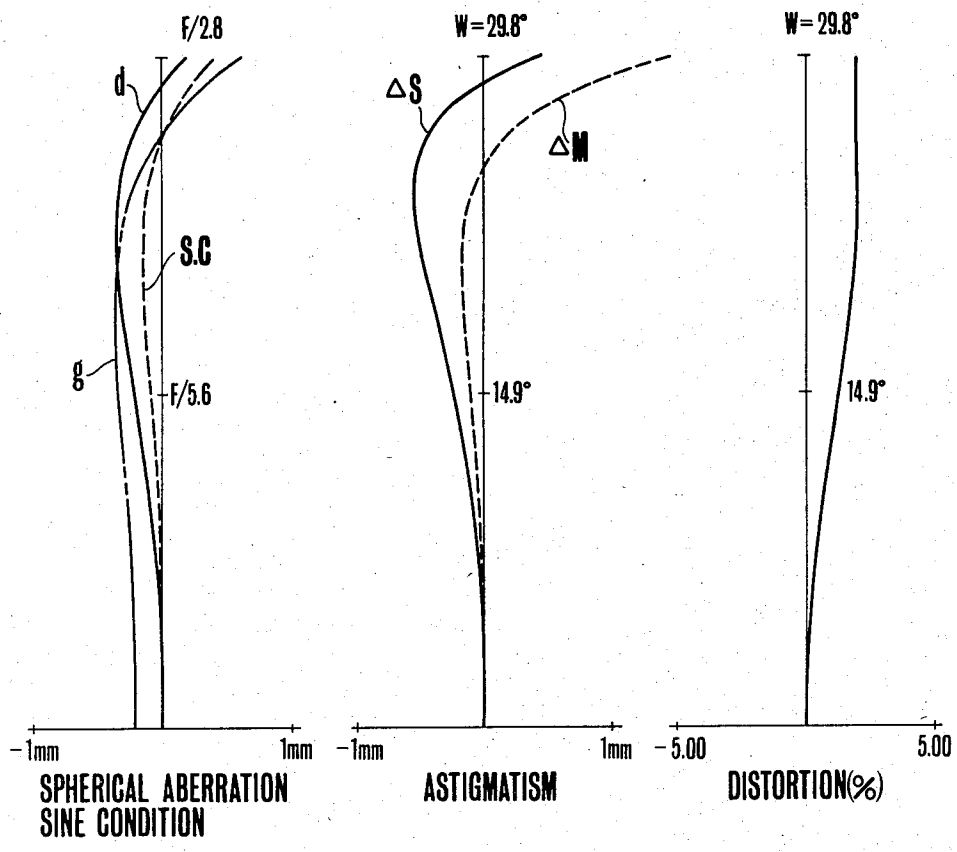


FIG.4a FIG.4b FIG.4c

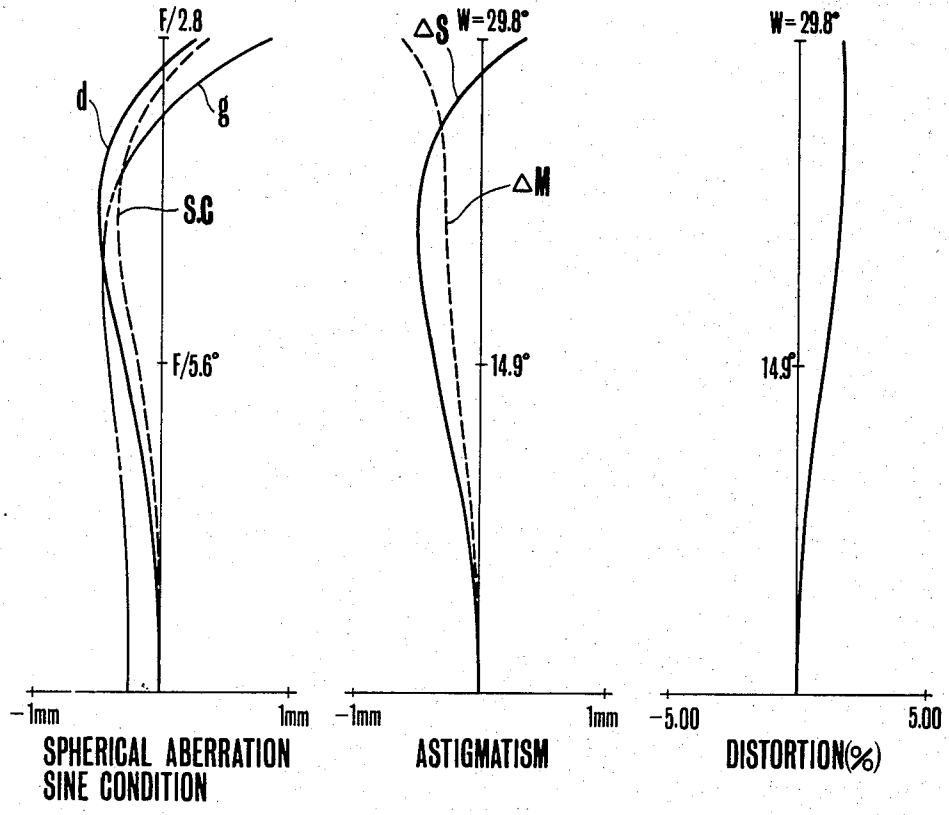


FIG.5a FIG.5b FIG.5c

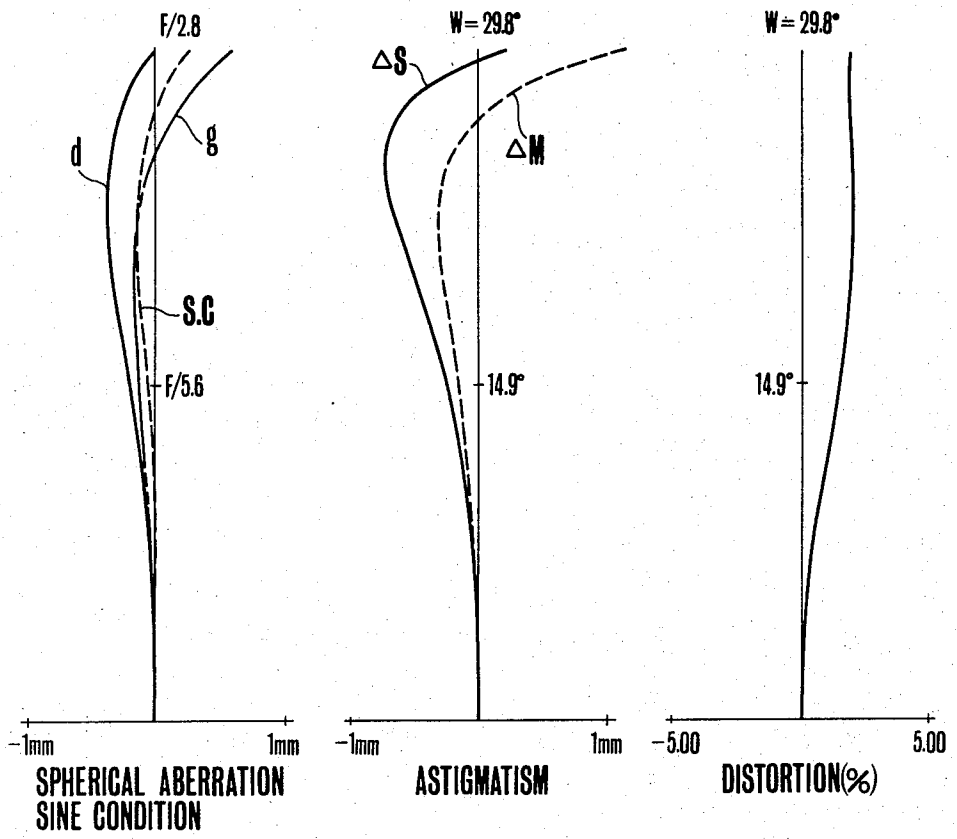
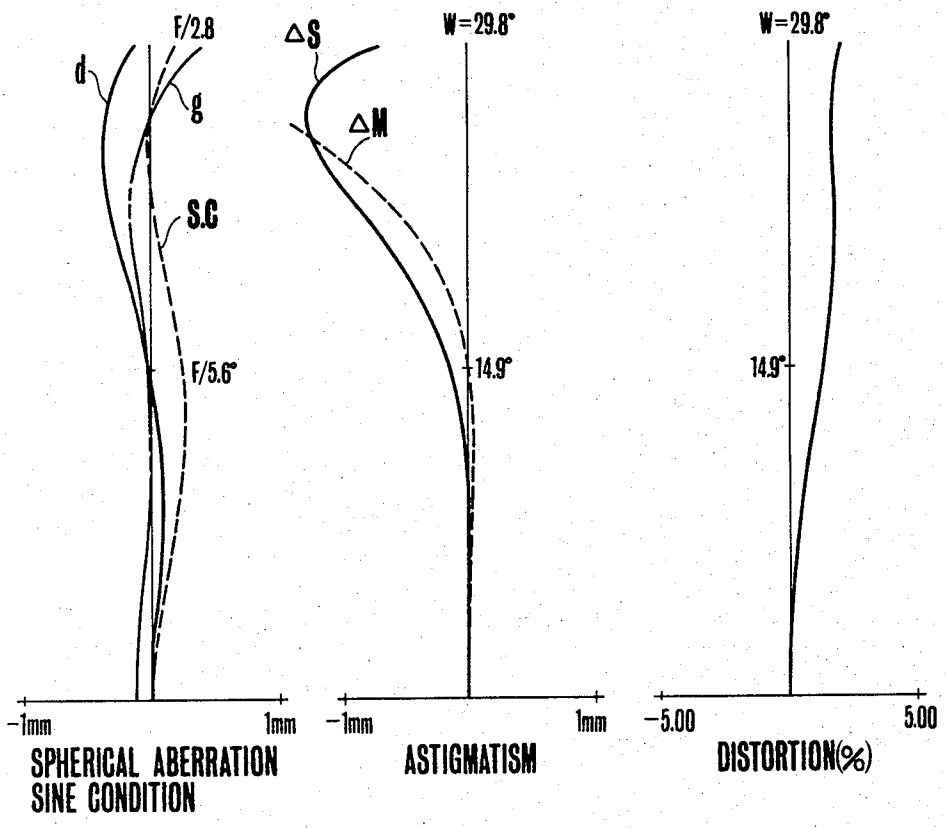


FIG.6a FIG.6b FIG.6c



COMPACT PHOTOGRAPHIC OBJECTIVE

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to photographic fast wide angle objectives in which the total length of the lens system is nevertheless short and compact.

2. Description of the Prior Art

In order to minimize the bulk and size of the camera, a demand has arisen for a compact photographic objective whose length from the first lens surface to the focal plane, or the total length of the lens system, is short. Particularly desirable is an objective with a lens system whose total length is in the order of its focal length. To obtain such a lens system, it is expedient to make the front group of the lens system of a positive refractive power and the rear group of a negative refractive power, or to employ a so-called telephoto type arrangement. The telephoto type of arrangement has been used in many photographic objectives of long focal lengths with relatively narrow angular fields, but has found very little use in objectives of wider than standard angular fields. The reason is that with the power distribution of a telephoto type arrangement, as the angle of the view field increases, distortion and astigmatism increase, and they become difficult to correct.

Japanese Pat. Sho Nos. 44-10831 and 52-48011 propose photographic objectives of the telephoto type which attempt to increase the angular field. The former has a relatively narrow angular field of about 46°, and the latter, though having a relatively wide angular field at 63° is slow, with an F-number of 4.5.

On the other hand, in telephoto type wide angle objectives, the positioning error of the front lens group in a direction perpendicular to the optical axis, or so-called parallel decentering error, causes an extraordinary decrease in the imaging performance. In the paraxial region particularly, uniform coma is produced, and the intermediate zone of the field has an unsymmetrical blur, thus extraordinarily lowering the image quality over the entire area of the picture frame. In the telephoto type of lens system, therefore, it is of great importance to choose a lens configuration and a refractive power distribution which allows for the assembling error to influence the result as little as possible.

Other prior techniques of interest of the invention of the present patent application appear in Japanese Laid Open Pat. Sho Nos. 50-145226 and 50-145227 and Japanese Pat. Sho No. 56-50248.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a photographic objective with a lens system whose total length is shortened to a compactness and which is fast with a wide angular field, while still permitting the loss of the image quality due to the assembling error to be as small as possible.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a lens block diagram of Example 1 of an embodiment of the present invention.

FIGS. 2(*a*) and 2(*b*) are geometrical diagrams to explain a result from the parallel decentering error of the front group of the lens system.

FIGS. 3-*a* to *c*, to 6-*a* to *c* are graphic representations of the various aberrations of Examples 1 to 4 of specific objectives of the invention respectively.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

One of the features of a photographic objective for accomplishing the objective of the present invention is to use, from front to rear, a first lens of meniscus form convex toward the front having a positive refractive power, a second lens having a negative refractive power, a third lens having a positive refractive power, and a fourth lens of meniscus form concave toward the front having a negative refractive power, and to satisfy the following conditions:

$$-4 < f4/f < -1.3 \quad (1)$$

$$-1.1 < \beta 4 < 1.4 \quad (2)$$

$$0.2 < D6/f < 0.3 \quad (3)$$

$$-0.5 < \frac{R6 + R5}{R6 - R5} < 0 \quad (4)$$

$$1.7 < N3 \quad (5)$$

where f is the focal length of the entire lens system;

f4 is the focal length of the fourth lens;

$\beta 4$ is the image magnification by the fourth lens;

D6 is the axial air separation between the third and fourth lenses;

R5 and R6 are the radii of curvature of the front and rear surfaces of the third lens respectively; and

N3 is the refractive index of the glass of the third lens.

Preferably, the following conditions are also satisfied: As the front surface of the fourth lens is made aspheric, an equation for that aspheric surface is defined by extending an x-axis in the optical axis, a y-axis along a direction perpendicular to the optical axis, the direction in which light advances as positive, and the vertex of the surface in the x-axis as the original point, and letting R7 denote the radius of curvature of the paraxial region of the aspheric surface, with the coefficients for the even number-order terms, bi the coefficients for the odd number-order terms and Δx the difference between the aspheric surface and a spherical surface of which the paraxial region is in common to that of the aspheric surface in a direction parallel to the x-axis, the equation being expressed in the expansion form:

$$\Delta x = \frac{(1/R7^*) \cdot y^2}{1 + \sqrt{1 - (y/R7^*)^2}} + a_1y^2 + a_2y^4 + a_3y^6 + a_4y^8 + a_5y^{10} + b_1y^3 + b_2y^5 + b_3y^7 + b_4y^9 - \frac{(1/R7)^2}{1 + \sqrt{1 - (y/R7)^2}}$$

where R7* is defined in the form of

$$R7 = \frac{1}{\frac{1}{R7^*} + 29_1}$$

Hence we have the following conditions to be satisfied:

$$-5 \times 10^{-3} < \frac{\Delta x[0.7R7]}{f} < 5 \times 10^{-3} \quad (6)$$

-continued

$$-5 \times 10^{-4} < \frac{\Delta x[0.5R5]}{f} < 5 \times 10^{-4} \quad (7)$$

where $\Delta x[0.7R7]$ and $\Delta x[0.5R5]$ are the values of Δx at the heights of $|R7| \times 0.7$ and $|R7| \times 0.5$ in the y-ordinate respectively.

Each of the above-cited conditions is explained below.

Conditions (1), (2) and (3) serve to shorten the total length of the lens system and at the same time achieve as small a loss as possible in the imaging performance due to the assembling error. In general, as the total length of the lens system is made shorter, the positive refractive power of the front lens group and the negative refractive power of the rear lens group both get stronger with an increase in the influence of the assembling error on the imaging performance. In particular the parallel decentering of the front lens group causes uniform coma in the image on the optical axis, and unsymmetric blur in the intermediate zone of the image in the picture frame area so that the resolving power and contrast are extraordinarily lowered. It is, therefore, of great importance to obtain a design of the lens system which is less sensitive to the assembling error.

Condition (1) has, because of this, to impart into the fourth lens an appropriate range of focal lengths. When a strong negative refractive power in excess of the upper limit is given, though the total length of the lens system becomes shorter, the loss in the imaging performance due to the parallel decentering of the front group is objectionably increased. Thus, such configuration is not practically acceptable from the lens manufacturing standpoint. When the lower limit is exceeded, as a weak negative refractive power results, the total length of the lens system becomes elongated, causing a lack of compactness, and further the Petzval sum is increased in a positive direction, with an increase of the field curvature in the intermediate zone of the picture area in the negative sense, causing a loss in the flatness of the image surface.

Condition (2) has, in accompaniment of condition (1), to limit the image magnification of the fourth lens so that the loss of the imaging performance due to the parallel decentering of the front group is lessened. In this connection, it should be explained by reference to FIGS. 2(*a*) and 2(*b*). FIGS. 2(*a*) and 2(*b*) illustrate an outlined configuration of the front and rear groups I and II of the invention, with FIG. 2(*a*) representing an ideal alignment of the front and rear groups I and II on a common optical axis, and FIG. 2(*b*) representing a parallel decentering of the front group I with reference to the rear group II by an erroneous difference, Δ. It is to be understood from FIG. 2(*b*) that an image formed by the front group I is made to shift perpendicularly to the optical axis by a distance equal to Δ and further that, as the image is focused by the rear group II on the film plane on an enlarged scale, the object point on the optical axis is transferred to an image point on the film plane as shifted by an amount, Δ',

$$\Delta' = \beta 4 \cdot \Delta$$

Therefore, when the front group I is parallel-decentered by the distance, Δ, the image shifts by the above-defined Δ'. This leads to a lower image quality. In other words, the parallel decentering of the front group gives rise to uniform coma in the central region of the area an the picture frame, and of unsymmetrical blurred image in the intermediate by the inclination of the image surface. In particular, the field curvature and others which are so-called longitudinal aberrations are proportional to the square of the image magnifications $\beta 4$. Accordingly, the image magnification $\beta 4$ is preferably taken at as small a value as possible. However, when the image magnification exceeds the lower limit of condition (2), the total length of the lens system is increased with consequent lack of compactness, and the Petzval sum is increased toward the positive direction so that a loss in the flatness of the image surface results. When the upper limit is exceeded, a slight parallel-decentering of the front group is occasion for a remarkable loss in the imaging performance.

Condition (3) represents a factor defining the air separation between the front and rear groups of the lens system. It is of importance to satisfy condition (3) in combination with conditions (1) and (2). When the upper limit is exceeded, the total length of the lens system is elongated with consequent lack of compactness, and the Petzval sum is increased with the loss of flatness of the image surface. When the lower limit is exceeded, while the total length of the lens system is shortened, the loss in imaging performance due to the parallel decentering of the front group becomes prominent.

Conditions (4) and (5) concern primary aberrations of the lens system.

Condition (4) represents a factor for configuration of the third lens and serves to achieve good correction of spherical aberration and coma. When the upper limit is exceeded, the spherical aberration is over-corrected, and inward coma is produced. When the lower limit is exceeded, the spherical aberration is under-corrected, and outward coma is produced.

Condition (5) involves restricting the refractive index of the glass from which the third lens is made, and serves to achieve a good correction of field curvature and astigmatism. When the refractive index N3 is not more than 1.7, the Petzval sum is increased with accompanying deterioration in the flatness of the image surface in the intermediate region of the area of the picture frame, and astigmatism is also increased.

The present invention serves, in addition to satisfying the above-described various conditions, to further make the first surface of the fourth lens aspheric with the advantage that the off-axis aberrations which would otherwise, with only a spherical system, be difficult to correct are well corrected.

Conditions (6) and (7) operate to restrict the aspheric quantity of the first surface of the fourth lens. When the upper limit of condition (6) is exceeded, it is impossible to correct positive distortion. When the lower limit is exceeded, while distortion can be corrected, over-correction of sagittal image surface results, and further inward coma is objectionably produced. Condition (7) serves to well correct aberrations in the intermediate zone of the area of the picture frame. When the upper limit is exceeded, halo is produced in the intermediate zone and under-correction of spherical aberration results. When the lower limit is exceeded, under-correction of meridional image surface results, and the astigmatic difference is increased, and inward coma is also produced.

It should be pointed out that, since, in the present invention, the first surface of the fourth lens using the aspheric surface is positioned relatively near to the

image plane, the area of the surface of the fourth lens through which the rays of light corresponding to all the image points pass is relatively small. As the surface accuracy of the fourth lens considerably is moderated, it becomes possible, instead of the glass material, to use a plastic molding and make the fourth lens inexpensively.

Also, focusing of the objective of the invention may be carried out either by manually moving the entire lens system which is the common practice in the art, or by imparting independent movement to the first to third lenses while the fourth lens remains stationary.

Four examples of specific objectives of the invention can be constructed in accordance with the numerical data given in the following tables for the radius of curvature of the i-th surface Ri counting from the front, the axial thickness or air separation Di between the i-th and (i+1)th lens surfaces, and the refractive index Ni and Abbe number Vi of the glass from which the i-th lens element counting from the front is made respectively.

EXAMPLE 1

Focal Length F = 100	F-number = 1:2.8		Image Angle 2ω = 59.0°
R1 = 33.67	D1 = 8.21	N1 = 1.77250	V1 = 49.6
R2 = 140.66	D2 = 2.24	N2 = 1.78472	V2 = 25.7
R3 = −177.92	D3 = 2.65	N3 = 1.80610	V3 = 40.9
R4 = 63.11	D4 = 8.99	N4 = 1.49171	V4 = 57.4
R5 = 185.28	D5 = 7.42		
R6 = −96.48	D6 = 22.86		
R7* = −19.52	D7 = 3.18		
R8 = −28.24			

Aspheric Coefficient:

$a_1 = -4.582 \times 10^{-4}$	$b_1 = -1.736 \times 10^{-5}$
$a_2 = 2.697 \times 10^{-6}$	$b_2 = -3.796 \times 10^{-7}$
$a_3 = 1.895 \times 10^{-8}$	$b_3 = 3.100 \times 10^{-9}$
$a_4 = -1.971 \times 10^{-10}$	$b_4 = -5.364 \times 10^{-12}$
$a_5 = 5.272 \times 10^{-13}$	

EXAMPLE 2

Focal Length F = 100	F-number = 1:2.8		Image Angle 2ω = 59.0°
R1 = 32.63	D1 = 8.17	N1 = 1.77250	V1 = 49.6
R2 = 110.23	D2 = 2.64	N2 = 1.76182	V2 = 26.6
R3 = −146.05	D3 = 2.64	N3 = 1.80610	V3 = 40.9
R4 = 53.99	D4 = 7.78	N4 = 1.49171	V4 = 57.4
R5 = 129.05	D5 = 5.54		
R6 = −91.20	D6 = 24.36		
R7* = −19.50	D7 = 3.16		
R8 = −27.21			

Aspheric Coefficient:

$a_1 = -2.157 \times 10^{-4}$	$b_1 = -2.631 \times 10^{-5}$
$a_2 = 6.903 \times 10^{-6}$	$b_2 = -6.241 \times 10^{-7}$
$a_3 = 1.247 \times 10^{-8}$	$b_3 = 3.341 \times 10^{-9}$
$a_4 = -1.795 \times 10^{-10}$	$b_4 = -4.787 \times 10^{-12}$
$a_5 = 4.700 \times 10^{-13}$	

EXAMPLE 3

Focal Length F = 100	F-number = 1:2.8		Image Angle 2ω = 59.0°
R1 = 33.87	D1 = 8.21	N1 = 1.77250	V1 = 49.6
R2 = 124.31	D2 = 2.19	N2 = 1.78472	V2 = 25.7
R3 = −198.26	D3 = 2.65	N3 = 1.72000	V3 = 50.2
R4 = 69.36	D4 = 11.23	N4 = 1.49171	V4 = 57.4
R5 = 132.77	D5 = 3.31		
R6 = −108.05	D6 = 23.70		
R7* = −19.48	D7 = 3.18		
R8 = −28.30			

Aspheric Coefficient:

$a_1 = -5.140 \times 10^{-4}$	$b_1 = -1.979 \times 10^{-5}$
$a_2 = 1.838 \times 10^{-6}$	$b_2 = -3.441 \times 10^{-7}$
$a_3 = 2.060 \times 10^{-8}$	$b_3 = 3.124 \times 10^{-9}$
$a_4 = -1.990 \times 10^{-10}$	$b_4 = -5.586 \times 10^{-12}$
$a_5 = 5.105 \times 10^{-13}$	

EXAMPLE 4

Focal Length F = 100	F-number = 1:2.8		Image Angle 2ω = 59.0°
R1 = 34.38	D1 = 8.20	N1 = 1.77250	V1 = 49.6
R2 = 110.67	D2 = 3.49	N2 = 1.76182	V2 = 26.6
R3 = −184.09	D3 = 2.65	N3 = 1.80610	V3 = 40.9
R4 = 50.22	D4 = 8.01	N4 = 1.49171	V4 = 57.4
R5 = 115.31	D5 = 5.56		
R6 = −107.02	D6 = 25.97		
R7* = −20.09	D7 = 3.17		
R8 = −24.71			

Aspheric Coefficient:

$a_1 = 4.422 \times 10^{-4}$	$b_1 = -5.585 \times 10^{-5}$
$a_2 = 5.967 \times 10^{-6}$	$b_2 = -4.613 \times 10^{-7}$
$a_3 = 1.353 \times 10^{-8}$	$b_3 = 3.007 \times 10^{-9}$
$a_4 = -1.928 \times 10^{-10}$	$b_4 = -5.191 \times 10^{-12}$
$a_5 = 4.639 \times 10^{-13}$	

What is claimed is:

1. A compact photographic objective comprising:

four lenses, from front to rear,

the first lens being a positive meniscus lens convex toward the front;

the second lens being a negative lens;

the third lens being a positive lens;

the fourth lens being a negative meniscus lens concave toward the front; and

said lenses satisfying the following conditions:

$$-4 < f4/f < -1.3$$

$$1.1 < \beta 4 < 1.4$$

$$0.2 < D6/f < 0.3$$

$$-0.5 < \frac{R6 + R5}{R6 - R5} < 0$$

$$1.7 < N3$$

wherein f is the focal length of the entire lens system;

R5 and R6 are the radii of curvature of the first and second surfaces of the aforesaid third lens;

N3 is the refractive index of the glass from which the same lens is made up;

D6 is the air separation between the aforesaid third lens and the aforesaid fourth lens;

f4 is the focal length of the aforesaid fourth lens; and

$\beta 4$ is the image magnification of the fourth lens.

2. A compact photographic objective according to claim 1, wherein said fourth lens has a first surface which is aspheric, and wherein an equation for said aspheric surface is expressed by taking an x-axis along the optical axis, a y-axis along a direction perpendicular to the optical axis, the direction in which light advances are positive, and the vertex of the surface on the x-axis as the original point, and letting R7 denote the radius of curvature of the first surface of the aforesaid fourth lens, ai the coefficients of the even number-order terms, bi the coefficients of the odd number-order terms, and Δx the difference between the aspheric surface of said fourth lens and the aspheric surface which contributes to the determination of the focal length, with the equation having the form:

$$\Delta x = \frac{(1/R7^*)\cdot y^2}{1+\sqrt{1-(y/R7^*)^2}} + a_1y^2 + a_2y^4 + a_3y^6 + a_4y^8 + a_5y^{10} + b_1y^3 + b_2y^5 + b_3y^7 + b_4y^9 - \frac{(1/R7)y^2}{1+\sqrt{1-(y/R7)^2}}$$

where R7* is defined by

$$R7 = \frac{1}{\frac{1}{R7^*} + 29_1},$$

the following conditions are satisfied:

$$-5\times10^{-3} < \frac{\Delta x[0.7R7]}{f} < 5\times10^{-3}$$

$$-5\times10^{-4} < \frac{\Delta x[0.5R5]}{f} < 5\times10^{-4},$$

and

where Δx[0.7R7] and Δx[0.5R5] are the values of the Δx at the heights of |R7|$\times$0.7 and |R7|$\times$0.5 in the y-ordinate respectively.

* * * * *

United States Patent [19]

Faatz et al.

[11] **4,411,510**

[45] **Oct. 25, 1983**

[54] **APPARATUS FOR COMPENSATING FOR THE REBOUNDING OF AN AUTOMATIC DIAPHRAGM IN A PHOTOGRAPHIC OBJECTIVE**

[75] Inventors: **Rudi Faatz**, Heuchelheim; **Siegfrid Moeller**, Eichenzell; **Friedel Ruehl**; **Adolf Steuernagel**, both of Wetzlar, all of Fed. Rep. of Germany

[73] Assignee: **Ernst Leitz Wetzlar GmbH**, Wetzlar, Fed. Rep. of Germany

[21] Appl. No.: **333,339**

[22] Filed: **Dec. 22, 1981**

[30] **Foreign Application Priority Data**

Jan. 9, 1981 [DE] Fed. Rep. of Germany 3100376

[51] **Int. Cl.**[3] **G03B 9/07**

[52] **U.S. Cl.** **354/272**

[58] **Field of Search** 354/270, 271, 272, 273, 354/274, 252

[56] **References Cited**

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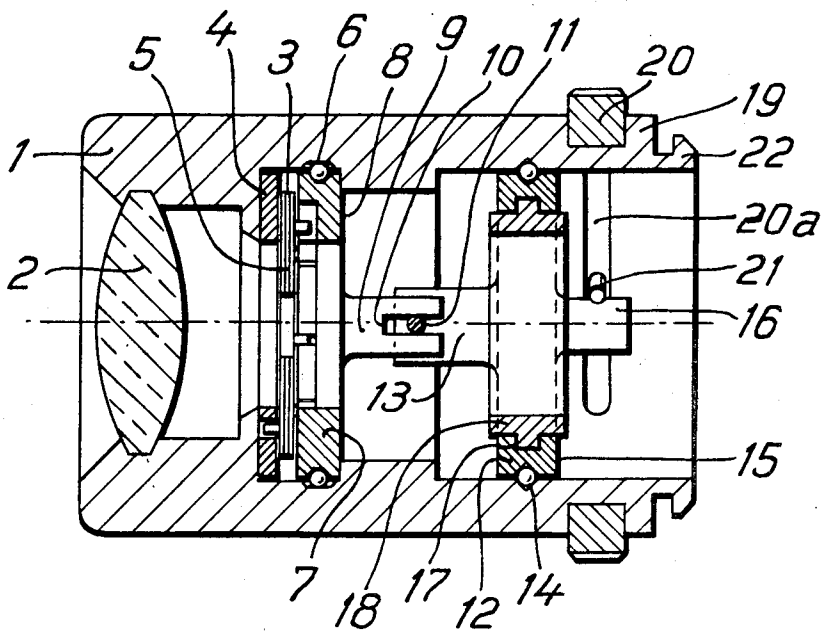
Primary Examiner—A. A. Mathews

Attorney, Agent, or Firm—Schwartz, Jeffery, Schwaab, Mach, Blumenthal & Koch

[57] **ABSTRACT**

Apparatus for at least partially compensating for the rebound impact of an automatic diaphragm in a photographic objective comprising a diaphragm control ring for driving the leaves of the diaphragm and a diaphragm preselector ring for predetermining the diaphragm aperture; the rebound impact being defined as the recoil produced according to the laws of elastic collisions when the diaphragm control ring which shuts the diaphragm engages the stop of the diaphragm preselector ring; said apparatus comprising at least one movable auxiliary mass which frictionally opposes the rebound movement.

9 Claims, 4 Drawing Figures



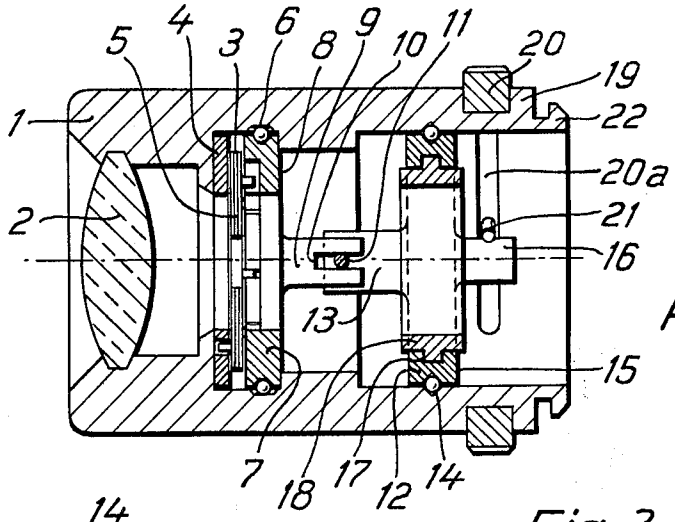


Fig. 1

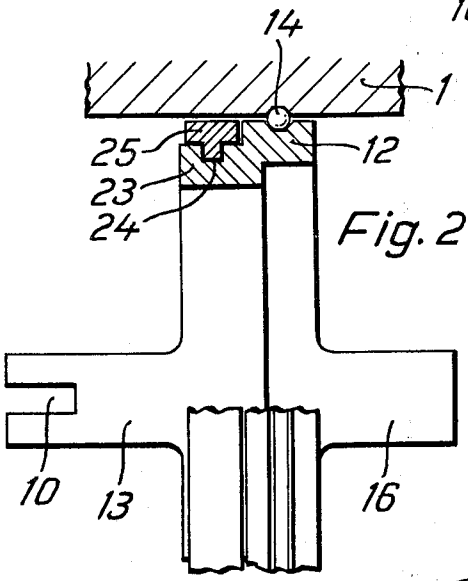
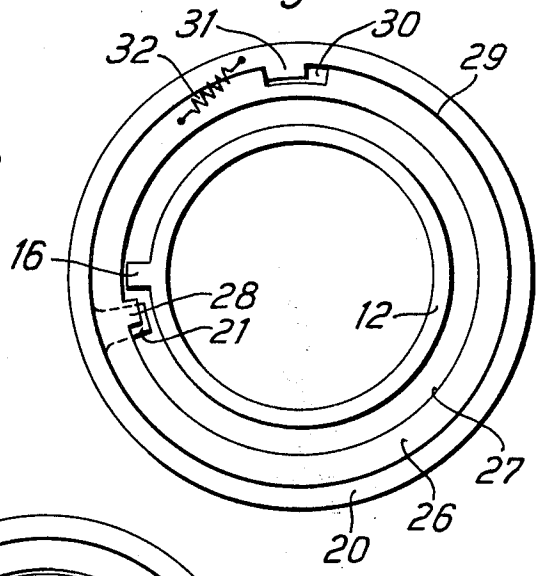


Fig. 2

Fig. 3



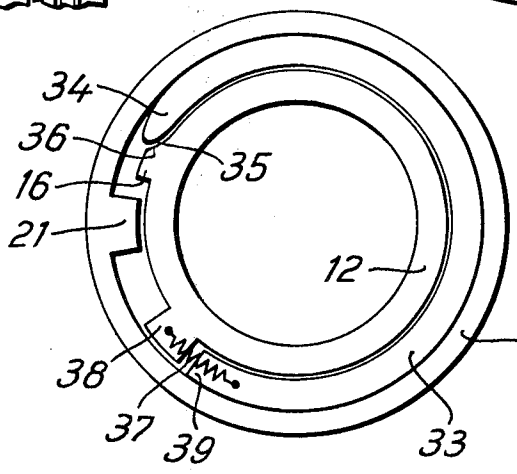


Fig. 4

APPARATUS FOR COMPENSATING FOR THE REBOUNDING OF AN AUTOMATIC DIAPHRAGM IN A PHOTOGRAPHIC OBJECTIVE

BACKGROUND OF THE INVENTION

The present invention relates to a device for at least partially compensating for the rebound impact of an automatic diaphragm in a photographic objective having a diaphragm preselector ring with a stop for preselecting the diaphragm aperture and a diaphragm control ring for actuating or driving the leaves of the automatic diaphragm.

It is known to at least partially compensate for the rebound impact, which is defined as the recoil generated by the impact of the diaphragm control ring closing the iris diaphragm of a photographic objective upon the stop of the diaphragm preselector ring, in accordance with the laws of elastic collisions, by providing a predetermined friction in the pivot bearing of the diaphragm control ring or by transmitting the kinetic energy to the diaphragm preselector ring. It is also known to eliminate the rebound impact by using so-called catch springs or straps which act directly or indirectly on the diaphragm preselector ring.

Another known approach is to attenuate the rebound of the diaphragm control ring with the "bumper block" effect, so that the effect of the rebound impact on the diaphragm aperture remains negligibly small. All of the known devices are subject to the disadvantages that no controlled damping of the rebound impact is possible and that the manufacture of the rebound damping means is difficult.

SUMMARY OF THE INVENTION

Accordingly, it is the object of the present invention to provide an improved device for compensating for the rebound impact of an automatic diaphragm in a photographic objective.

A further object of the present invention is to provide apparatus for compensating for the rebound impact which is capable of achieving a desired or controlled compensation of the rebounding effect.

Another object of the present invention is to provide apparatus for compensating for the rebound impact which substantially avoids the manufacturing and assembly difficulties attendant to known devices.

These and other objects of the invention are achieved by providing apparatus for at least partially compensating for the rebound impact of the automatic diaphragm in a photographic objective having a diaphragm preselector ring with a stop for preselecting the diaphragm opening and a diaphragm control ring for driving the leaves of the automatic diaphragm, said compensating apparatus comprising at least one movable auxiliary mass which frictionally opposes the rebound impact.

In one preferred aspect of the invention, the auxiliary mass has the form of a cylinder, and its dimensions are selected so that the frictional forces opposing the rebounding are produced between the auxiliary mass and the diaphragm control ring.

In another preferred aspect of the invention, the auxiliary mass is a rider on the diaphragm control ring, and its dimensions are selected such that a defined frictional force is produced between the rider and the diaphragm control ring.

In yet another preferred aspect of the invention, the auxiliary mass comprises a friction riing provided with an anvil, and its dimensions are chosen such that a defined frictional force is produced between the friction ring and the diaphragm preselector ring.

In a still further preferred aspect of the invention, the auxiliary mass is movably mounted on the diaphragm with a spring for controlling its movement and produces a defined frictional clamping force in conjunction with the diaphragm control ring and the diaphragm preselector ring.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be described in further detail with reference to the accompanying drawings, wherein:

FIG. 1 is a sectional side elevation of a photographic objective with an automatic diaphragm and a rebound impact compensating device according to the invention.

FIG. 2 is a sectional partial side elevational view of the details of an alternate embodiment of the invention.

FIG. 3 is a sectional rear detail view of a further embodiment of the invention in which the auxiliary mass is provided with an anvil.

FIG. 4 is a cross sectional rear detail view of a stll further embodiment of the invention in which the auxiliary mass produces a frictional clamping force.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

FIG. 1 schematically illustrates a photographic objective with an automatic diaphragm. For reasons of clarity, structural parts required for focusing of the objective have been omitted from the drawing.

The photographic objective comprises an objective tube **1** having an imaging system **2** mounted therein. An automatic diaphragm **3**, which closes under the force of a spring (not shown) is located behind the imaging system **2**. Automatic diaphragm **3** comprises a leaf mount **4**, diaphragm leaves **5** and a leaf guide ring **7** which moves on ball bearings **6**. The leaf guide ring **7** is provided on its surface **8** remote from the diaphragm leaves **5**, with a projection **9** having a U-shaped slot or recess **10** therein. A slide **11** of a driver **13**, which forms a unitary body with the diaphragm control ring **12**, is engaged in the U-shaped recess **10**. Slide **11** is adapted to move back and forth in slot **10** during focusing of the objective. The diaphragm control ring **12** is mounted on ball bearings **14** for easy rotation in the objective tube **1**. The diaphragm control ring **12** carries, on its side **15** opposite the driver **13**, a drive piece **16**, which drivably engages the camera (not shown) in a conventional manner.

The inner surface of the diaphragm control ring **12** is provided with a U-shaped annular groove **17**, and a suitably shaped friction ring **18** is inserted therein. The rear end **19** of the objective tube **1** carries a diaphragm preselector ring **20** with a diaphragm stop **21**, extending through a slit **20a** into the objective tube **1**. To secure the photographic objective to the camera, objective tube **1** is provided with a bayonet fitting **22**.

The operation of the above-described device is as follows:

Upon insertion of the photographic objective in a camera, the automatic diaphragm **3** is opened by the diaphragm control ring **12** which enters into driving engagement with the camera by means of drive piece **16**, and the spring (not shown) which closes the automatic diaphragm is stressed. By actuating the diaphragm preselection ring **20**, the diaphragm stop **21** is

brought into a position corresponding to a desired aperture size of the automatic diaphragm 3. When the camera is triggered, the automatic diaphragm 3 closes. The closing motion is stopped by the diaphragm stop 21, which is struck by drive piece 16. According to the laws of elastic collisions, a rebound of the diaphragm control ring 12 would now take place, whereby the diaphragm would open to an undesirable extent resulting in an erroneous exposure and in deviations in the depth of focus.

However, in the described apparatus, the rebound momentum is compensated for by friction ring 18, which works as an auxiliary mass within the diaphragm control ring 12. While the diaphragm control ring, which was accelerated by the force of the spring when the camera was triggered, is being suddenly braked, the friction ring 18, whose rotational movement is unrestricted, continues to rotate because of its inertia until it is gradually braked by the friction between it and the diaphragm control ring 12.

Turning now to FIG. 2, there is illustrated an alternate embodiment of the invention in which the diaphragm control ring 12, which moves on ball bearings 14 in the objective tube 1, is provided with a shoulder 23 and an annular groove 24 formed on its outer circumference. A friction ring 25, having a T-shaped cross section, "rides" on the diaphragm control ring 12 with the stem of the "T" received in annular groove 24. As in the case of the friction ring 18 described in connection with FIG. 1, the rotational range of friction ring 25 is unrestricted, and it functions in an analagous manner to attenuate or compensate for the rebound impact of the automatic diaphragm.

In contrast to the embodiments illustrated in FIGS. 1 and 2 in which the additional mass which compensates for the energy of the rebound impact cooperates with the diaphragm control ring 12, FIG. 3 schematically illustrates an embodiment in which the auxiliary mass cooperates with the diaphragm preselector ring 20.

For this purpose, a stop ring 26 is mounted for easy rotation within the diaphragm preselection ring 20. Stop ring 26 is provided on its inner circumference 27 with a stop nose or anvil 28. The outer circumference 29 of stop ring 26 is provided with a recess 30, which is engaged by a movement limiting cam 31 on the diaphragm control ring 20. Diaphragm preselection ring 20 and stop ring 26 are non-positively connected with each other by means of a spring 32 in such a way that the edge of the stop nose 28 adjacent to the drive piece 16 is located in front of the edge of the diaphragm stop 21.

During the closing of the automatic diaphragm 3, the drive piece 16 of diaphragm control ring 12 initially strikes the stop nose 28 of stop ring 26. Stop ring 26 is designed to have the same moment of inertia as diaphragm control ring 12. Consequently, stop ring 26 accepts all of the energy of diaphragm ring 12 and causes drive piece 16, driven by the force of the actuating spring closing the automatic diaphragm 3, to gently contact the diaphragm stop 21 of the diaphragm preselection ring 20. When automatic diaphragm 3 is returned to the "open" position, the spring 32 returns stop ring 26 to its initial position.

FIG. 4 illustrates a further embodiment of the invention in which diaphragm control ring 12 carries a spring supported auxiliary mass in the form of a cylindrical clamping piece 33. When drive piece 16 strikes the diaphragm stop 21 on diaphragm preselector ring 20, clamping piece 33 effects a clamping action. For this purpose, the end 34 of clamping piece 33 is provided with a bevel 35, while a similar bevel 36 is provided on drive piece 16. As drive piece 16 impacts against diaphragm stop 21, clamping piece 33 initially remains in motion because of its inertia and runs up with its bevel 35 on the bevel 36 on drive segment 16. In the process, it produces a clamping action between the diaphragm preselector ring 20 and the diaphragm control ring 12. The clamping action works against the recoil energy or rebound impact of the diaphgram control ring 12. The clamping action is then released by a spring 37, which extends between a nose 38 on diaphragm control ring 12 and the other end 39 of clamping piece 33.

The foregoing description of preferred embodiments has been set forth merely to illustrate the invention and is not intended to be limiting. Since modifications of the disclosed embodiments incorporating the spirit and substance of the invention may occur to persons skilled in the art, the scope of the invention is to be limited solely with respect to the appended claims and equivalents.

We claim:

1. Apparatus for at least partially compensating for the rebound impact of an automatic diaphragm in a photographic objective having a diaphragm preselector ring with a stop for preselecting the diaphragm opening and a diaphragm control ring for driving the leaves of the automatic diaphragm, said compensating apparatus comprising at least one movable auxiliary means frictionally engaging an element of said objective and set in motion in response to movement of said diaphragm control ring for counteracting said rebound impact by friction, whereby the energy of movement of said diaphragm control ring is at least partially dissipated by friction.

2. Apparatus according to claim 1, wherein the auxiliary mass has the form of a cylinder, and the dimensions of the auxiliary mass are selected so that the frictional forces which counteract the rebound impact are produced between the auxiliary mass and the diaphragm control ring.

3. Apparatus according to claim 2, wherein said auxiliary mass comprises an annular friction ring mounted for unrestricted rotation inside said diaphragm control ring.

4. Apparatus according to claim 2, wherein the auxiliary mass is disposed as a rider on the diaphragm control ring, and the dimensions of the auxiliary mass are selected such that a defined frictional force is produced between the rider and the diaphragm control ring.

5. Apparatus according to claim 4, wherein said auxiliary mass comprises an annular friction ring mounted for unrestricted rotation on a shoulder formed on the outer circumference of said diaphragm control ring.

6. Apparatus according to claim 1, wherein the auxiliary mass comprises a friction ring provided with an anvil, and the dimensions of the ring are chosen such that a defined frictional force is produced between the friction ring and the diaphgram preselector ring.

7. Apparatus according to claim 1, wherein said auxiliary mass comprises a stop ring frictionally engaging said diaphragm preselector ring, said stop ring being designed to have the same moment of inertia as said diaphragm control ring and bearing an anvil which is struck by a drive piece on the diaphragm control ring, whereby the momentum of the diaphragm control ring is transferred to the stop ring as the diaphragm control

ring contacts the stop of the diaphragm preselector ring.

8. Apparatus according to claim 1, wherein the auxiliary mass is movably mounted on the diaphragm control ring; spring means are provided to control the movement of the auxiliary mass, and the auxiliary mass produces a defined frictional clamping force in conjunction with the diaphragm control ring and the diaphragm preselector ring.

9. Apparatus according to claim 8, wherein said auxiliary mass comprises a clamping piece disposed around said diaphragm control ring, one end of said clamping piece being provided with a bevel; said clamping piece initially remaining in motion when a drive piece on the diaphragm control ring engages the stop on said diaphragm preselector ring and said bevel on said clamping piece engaging an opposing bevelled surface on said diaphragm control ring, whereby a clamping action is produced.

* * * * *

United States Patent [19]

Yokota et al.

[11] **4,407,568**

[45] **Oct. 4, 1983**

[54] **LARGE APERTURE OBJECTIVE WITH BEHIND THE LENS DIAPHRAGM**

[75] Inventors: **Hideo Yokota**, Tokyo; **Sadahiko Tsuji**, Yokohama, both of Japan

[73] Assignee: **Canon Kabushiki Kaisha**, Tokyo, Japan

[21] Appl. No.: **155,757**

[22] Filed: **Jun. 2, 1980**

[30] **Foreign Application Priority Data**

Jun. 7, 1979 [JP] Japan 54-71740

[51] **Int. Cl.**[3] **G02B 9/60**

[52] **U.S. Cl.** **350/467**; 350/449

[58] **Field of Search** 350/449, 467

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Primary Examiner—John K. Corbin
Assistant Examiner—Rebecca D. Gass
Attorney, Agent, or Firm—Toren, McGeady and Stanger

[57] **ABSTRACT**

A large aperture objective having a shorter physical length than 1.2 times the focal length thereof with an angular field of at least 54° and a diaphragm positioned on the image side of the rearmost lens surface. The objective comprises five elements constituting five components of which the first and second counting from the front are positive meniscus lenses of forward convexity, the third is a negative meniscus lens of rearward concavity, the fourth is a negative meniscus lens of forward concavity, and the fifth is a bi-convex lens with its rear surface of strong curvature. The objective is characterized by fulfilling the following conditions:

(1) $0.18\ f<D_1<0.28\ f$, where $D_1=d_1+d_2+d_3+d_4+d_5$

(2) $0.08\ f<D_2<0.13\ f$, where $D_2=d_7+d_8+d_9$

(3) $0.12\ f<d_6<0.15\ f$

(4) $0.35<(R_1/R_2)<0.5$

(5) $0.6<(R_7/R_8)<0.8$

(6) $|R_{10}/R_9|<0.3$

where f is the focal length of the overall lens system; R_i is the radius of curvature of the i-th surface; and d_i is the axial thickness or air separation between the i-th and (i+1)th surfaces.

5 Claims, 28 Drawing Figures

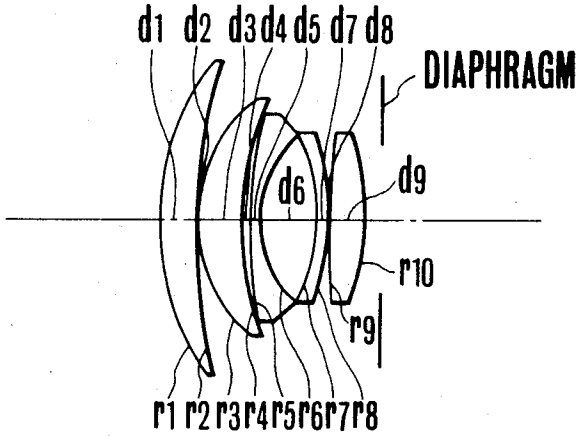


FIG.1

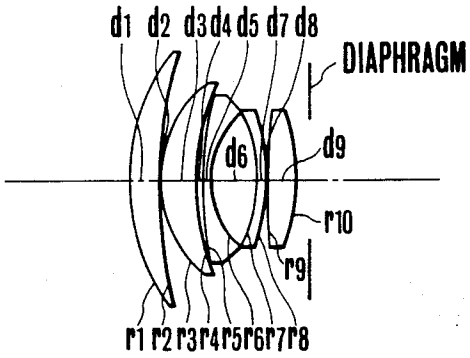


FIG.2

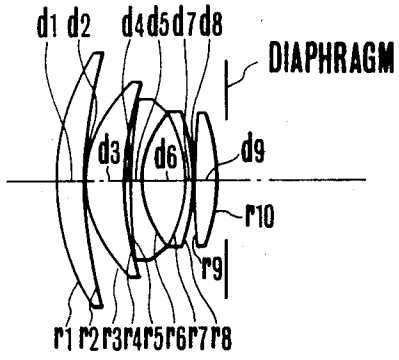


FIG.3

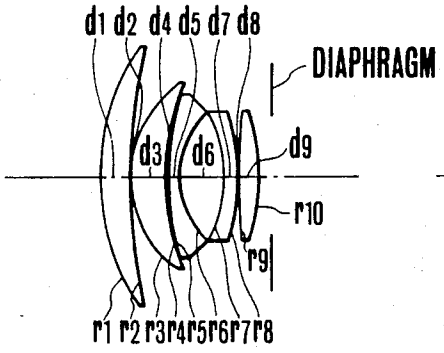


FIG.4

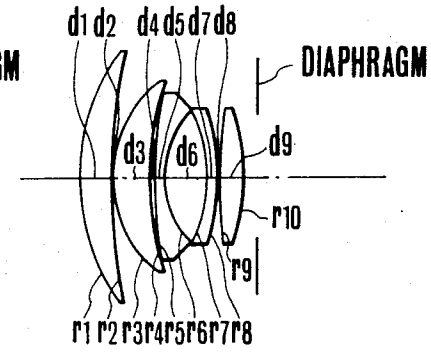


FIG.5A FIG.5B FIG.5C

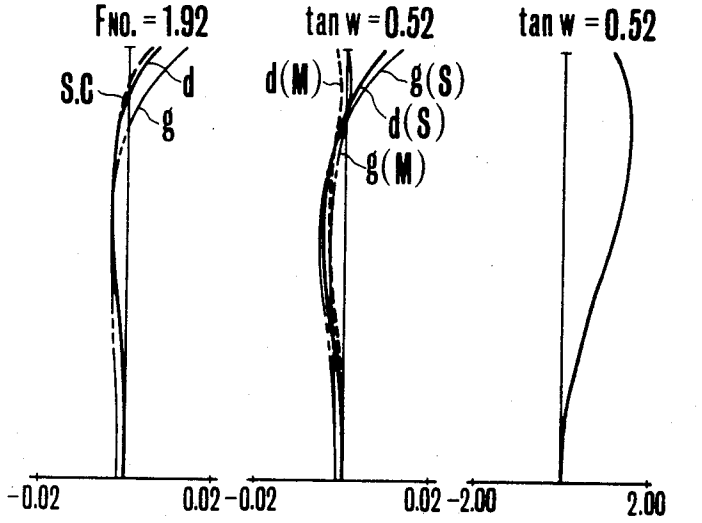


FIG.5D

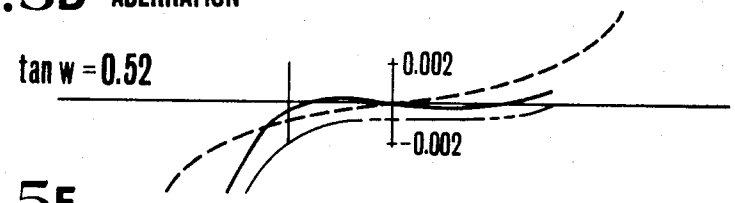


FIG.5E

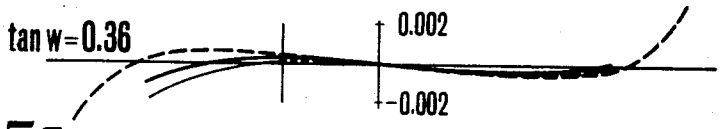
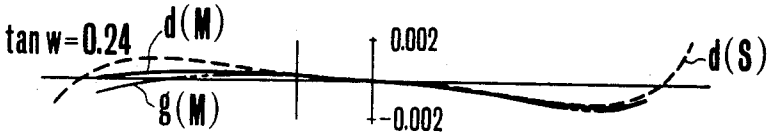


FIG.5F



LATERAL ABERRATION

FIG.6A FIG.6B FIG.6C

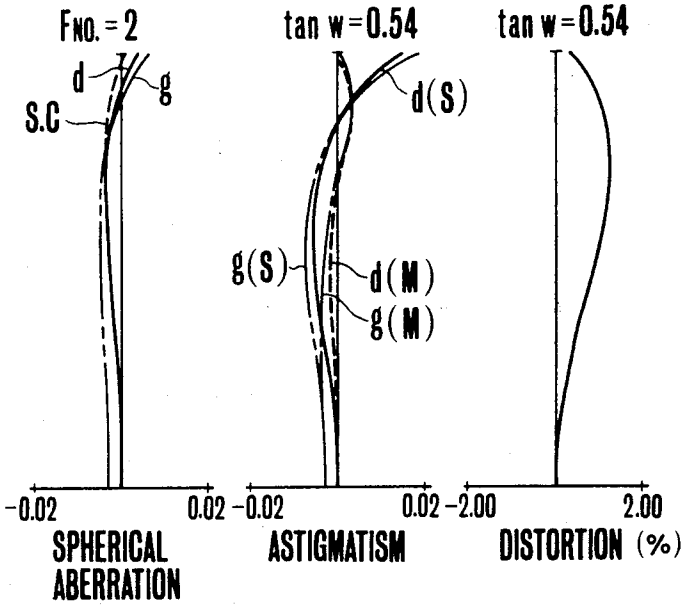


FIG.6D

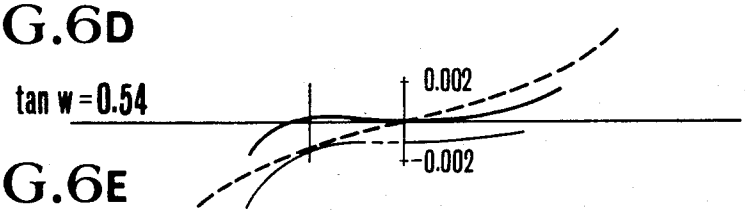


FIG.6E

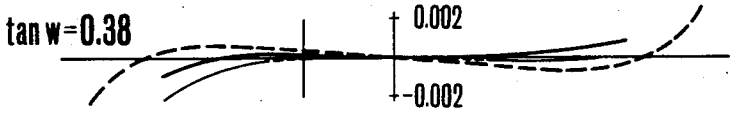
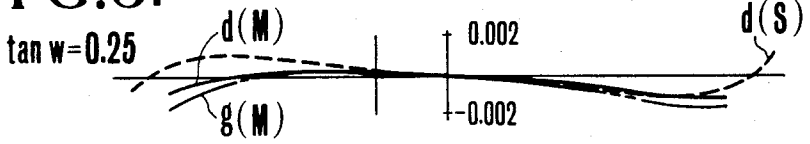


FIG.6F



LATERAL ABERRATION

FIG.7A FIG.7B FIG.7C

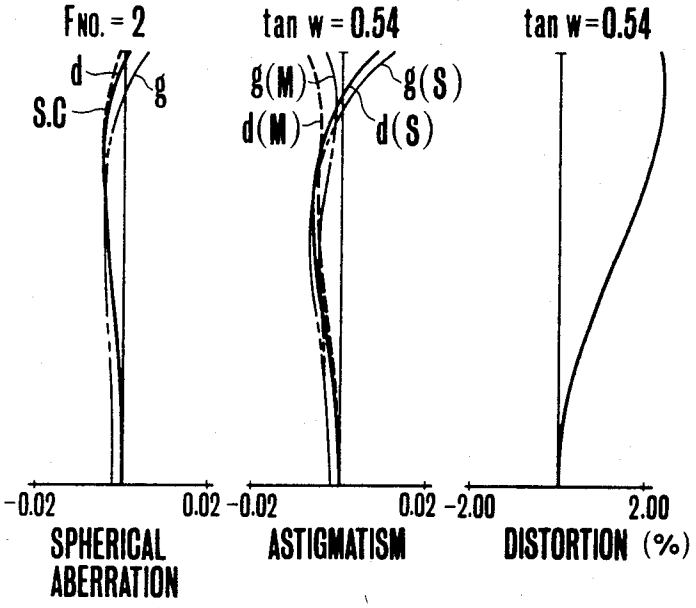


FIG.7D

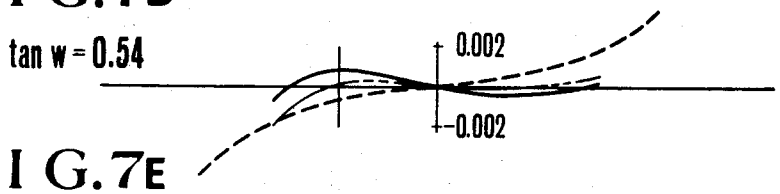


FIG.7E

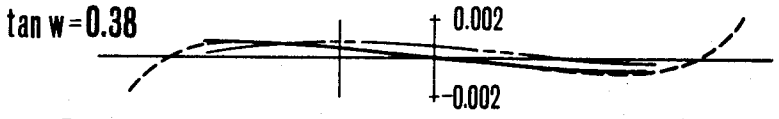


FIG.7F

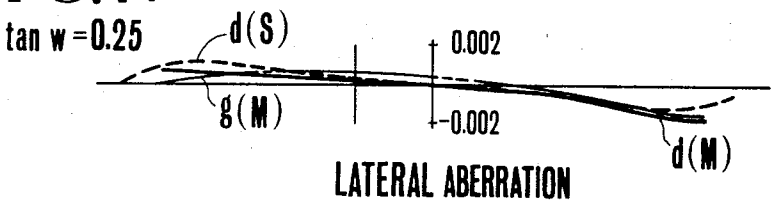


FIG.8A FIG.8B FIG.8C

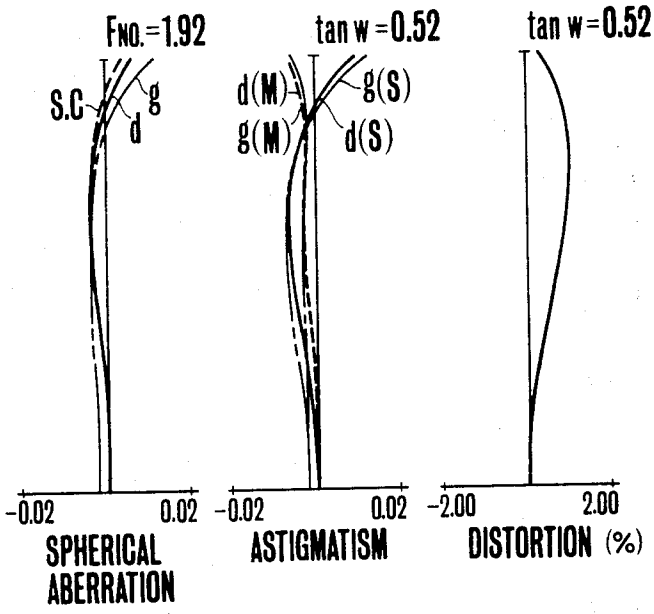


FIG.8D

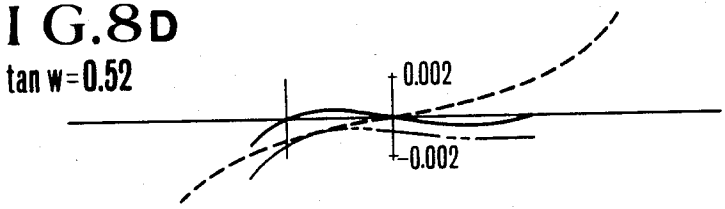


FIG.8E

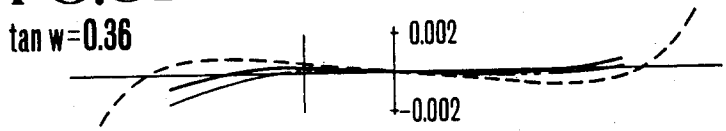
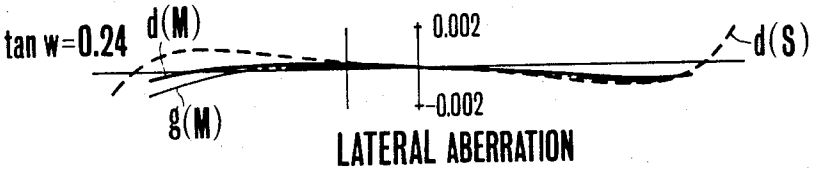


FIG.8F



LARGE APERTURE OBJECTIVE WITH BEHIND THE LENS DIAPHRAGM

BACKGROUND OF THE INVENTION

This invention relates to photographic objectives of the standard or quasi-standard angular field, and more particularly to objectives of a large aperture ratio with a diaphragm in the image space.

Lens shutter type cameras require standard objectives to be of small bulk and size with an angle of view exceeding 54°. A type of lens which has gained general acceptance for an objective having a relative aperture as large as F/2, is the diaphragm interspaced Gauss type. An example of a modified Gauss type objective is disclosed in British Pat. No. 865,530.

These diaphragm-interspaced Gauss type objectives through producing more or less flare in the intermediate to the marginal region of the image field have been proven to give good correction of field curvature for high grade imaging performance throughout the entire area of the image field.

At the present time, on the other hand, photo-electric sensing of an object distance for automatic adjustment of the objective, or so-called auto-focus mechanisms has become practical, thereby freeing many photographers from troublesome focusing operation.

Since this mechanism is powered by a tensioned spring or an electric motor as the drive source to effect focusing, the employment of the diaphragm interspaced Gauss type in the lens design leads to the necessity of moving along with the lens system, the large mass of the diaphragm device associated with a shutter and other mechanical parts. This gives rise to disadvantages, the first of which is that a strong torque is required to assure the satisfactory operation, and second is that the diaphragm, shutter and auto-focus mechanism are also made complicated. These problems have contributed to the difficulty of minimizing the bulk and size of the camera.

Arrangement of the shutter diaphragm behind the objective lens system is an effective way to solve these problems. But, as the objective becomes faster with the F-number down to as low as 2, use of the rear diaphragm arrangement creates various aberrational problems. To avoid the reduction of the image quality, therefore, a sacrifice must be made, for example, by narrowing the angular field and elongating the physical length. Even in the improved conventional objectives such as that shown in Japanese Patent Sho 41-15463 (1966), the total length from the front vertex to the image plane is limited to 1.23 times the focal length or longer, and the angle of view to 52° or less.

SUMMARY OF THE INVENTION

An object of the present invention is to provide a photographic objective having a standard or quasi-standard angular field with the total length from the front vertex to the image plane being shortened while increasing the relative aperture.

Another object is to improve the imaging performance and to assure a high contrast over the entire area of an image field and particularly in the intermediate to the marginal region thereof for which the production of flare is prevented.

An objective of the present invention has five elements constituting five components. A diaphragm space is provided on the image side of the rear vertex of the objective. The first and second elements counting from the front are positive meniscus lenses of convex surface toward the front. The third element is a negative meniscus lens of concave surface toward the rear. The fourth element is a negative meniscus lens of concave surface toward the front. The fifth element is a bi-convex lens with the rear surface being stronger in curvatuve. Letting Ri denote the radius of curvature of the i-th lens surface counting from the front, and di the lens thickness or air spacing between the i-th and (i+1)th surfaces, the objective fulfils the following specific requirements:

(1) $0.18\ f < D_1 < 0.28\ f$, where $D_1 = d_1 + d_2 + d_3 + d_4 + d_5$

(2) $0.08\ f < D_2 < 0.13\ f$, where $D_2 = d_7 + d_8 + d_9$

(3) $0.12\ f < d_6 < 0.15\ f$

(4) $0.35 < (R_1/R_2) < 0.5$

(5) $0.6 < (R_7/R_8) < 0.8$

(6) $|R_{10}/R_9| < 0.3$

where f is the compound focal length of the entire lens system.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is an optical diagram of an Example 1 of a Gauss type objective according to the present invention.

FIG. **2** is a similar diagram showing an Example 2 of the present invention.

FIG. **3** is a similar diagram showing an Example 3 of the invention.

FIG. **4** is a similar diagram showing an Example 4 of the invention.

FIGS. **5**A to **5**F are graphic representations of the various aberrations of Example 1.

FIGS. **6**A to **6**F are similar graphs of those of Example 2.

FIGS. **7**A to **7**F are similar graphs of those of Example 3.

FIGS. **8**A to **8**F are similar graphs of those of Example 4.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

In order to shorten the total length of the objective to 1.2 times the focal length or thereabout within the framework of the behind-diaphragm Gauss type configuration, the first and second lenses necessarily have to be strengthened in refractive power, and the divergent lenses that follow are required to have a strengthened effect on correction of the spherical aberration. It has been, therefore, found that the sagittal image surface which is curved in a negative sense at the intermediate region of the image field is turnel rapidly to a positive curvatuve when the half-angle of view of $\omega = 25°$ is exceeded, and that the flare is objectionably increased in a region from the intermediate to the margin. Considering the fact that for the improvement of the field curvature, a great effect can be expected from the use of lens thicknesses and spacings as thin as possible, according to the present invention, the fourth lens which usually takes the form of a cemented lens of positive and negative elements is constructed in the form of a negative meniscus singlet resulting in the advantage that the lens thickness is minimized. And, as for the improvement of the flare, an air lens is provided between the second and third lenses to facilitate the improvement.

In such an arrangement, fulfilment of the specific conditions described results in an excellent objective. This is explained below. First, improvement of the image quality is made very effective by the thinning of the sum of the axial separations defined by D_i. On the other hand, such thinning makes it more difficult to impart to the first and second lenses the refractive powers necessary to shorten the total length of the objective. Accordingly, the necessity of condition (1) arises. When the upper limit of inequality (1) is exceeded, the sagittal image surface will be strongly curved in a positive sense. When the lower limit is exceeded, the lens diameter cannot be sufficiently large, so that one cannot help but to increase the F-number with a loss in lens speed, or elongate the back focal length with an increase in the total length of the objective above 1.2 times the focal length.

Thinning another sum of axial separations defined by D_2 is also effective to improve the image quality as has been mentioned above. This, on the other hand, causes increasing outward coma. Therefore, condition (2) is necessary. When the upper limit of inequality (2) is exceeded, the sagittal image surface is strongly curved at the margin. When the lower limit is exceeded, the outward coma is objectionably increased in the intermediate region of the image field to the margin.

The total length is shortened by shortening the spacing d_6. This is also advantageous for correction of inward coma of a circular zone in the intermediate region of the image field. However, when the spacing is shortened too much, the diameter of an air lens defined by r_6, r_7 and d_6 will become so small that all the axial rays at an aperture of 2 in F-number cannot pass therethrough. On this account, condition (3) is necessary. When the upper limit of inequality (3) is exceeded, inward coma of a circular zone in the intermediate region of the image field is objectionably increased, and it is difficult to shorten the total length below 1.2 times the focal length. When the lower limit is exceeded, it is difficult to achieve an increase of the lens speed to as fast as 2 in F-number.

Consideration is next given to the significances of the radii of curvature of the various lens surfaces. Bending the first lens affects the spherical aberration and distortion. In the objective aimed at by the present invention with the first lens of strong power, it is from the first lens that a strong positive distortion is produced. To suppress the increase of such distortion it is advantageous to select a large value of R_1/R_2, but this is unfavorable to suppress spherical aberration. Therefore, condition (4) is necessary. When the upper limit of inequality (4) is exceeded, good correction of spherical aberration will be difficult. When the lower limit is exceeded, positive distortion is objectionably increased.

The axial rays after their angles of inclination have been moderated by the third lens, enter the fourth lens. Therefore, the fourth lens may take the form of a negative meniscus lens of forward concavity. This offers the advantage that even when the power is relatively weak it produces, a strong effect on correction of spherical aberration. However, inward coma is also objectionably increased. Therefore, condition (5) is necessary. When the upper limit of inequality (5) is exceeded, correction of inward coma will become difficult. When the lower limit is exceeded, correction of spherical aberration will become difficult.

Bending the fifth lens has a large effect on correction of spherical aberration and astigmatism. In correction of spherical aberration, it is advantageous to select a large value for R_{10}/R_9, but astigmatism is, on the other hand, caused to increase in the marginal region of the image field. Therefore, condition (6) is important. When the upper limit is exceeded, good correction of negative astigmatism in the marginal region will be difficult to perform.

It should be noted that the front surface r_5 of the third lens also seriously affects the various aberrations, and therefore great care must be taken in configuring it. The selection of a smaller value for the radius of curvature of the lens surface r_5 can suppress the increase of the flare of the meridional circular zone and the sagittal flare of the image field to the margin, but on the other hand allows for the spherical aberration of the sagittal rays to be objectionably increased in the intermediate region of the image field so that the foci of the intermediate rays incline in a negative sense beyond the foci of the sagittal principal rays. This leads to a tendency of deteriorating the resolution of the sagittal field at or near the angle of view of $\omega = 16°$. Therefore, it is desirable that the radius of curvature of the surface r_5 lies between 0.8 and 2.2 times the focal length of the entire lens system.

The following are four examples of specific objective lens systems with the numerical data for the radii of curvature, r, the lens thicknesses or air spacings, d, the refractive indices, Nd, for the various lens elements along with the corresponding Abbe numbers, νd. The various image aberrations of the lens systems when focused at infinity are shown in FIGS. **5A–5F**, FIGS. **6A–6F**, FIGS. **7A–7F** and FIGS. **8A–8F** where S.C.: since condition; d(S): the sagittal surface of d-line; d(M): the meridional surface of d-line; g(S): the sagittal surface of g-line; and g(M): the meridional surface of g-line. As is understandable from the lists of values of the aberrational coefficients and the aberration curves, each of the examples of the lens systems is well corrected for high grade imaging performance. This reveals that the conditions set forth in the present invention are adequate for the accomplishment of the objects thereof.

EXAMPLE 1 (FIG. 1)

Focal Length f = 1 F-number 1:1.92
Image Angle $2\omega = 54.9°$

No.	r	d	Nd	νd
1	0.6358	0.083	1.77250	49.6
2	1.3917	0.002		
3	0.3486	0.109	1.77250	49.6
4	0.7814	0.016		
5	1.3183	0.024	1.75520	27.5
6	0.2607	0.136		
7	−0.4056	0.024	1.72342	38.0
8	−0.6088	0.00239		
9	4.1728	0.08	1.78590	44.2
10	−0.6035			

Total Length (from First Surface to Focal Plane) = 1.1326

	Aberration Coefficient of Third Order						
No.	L	T	SA	CM	AS	PT	DS
1	0.0172	0.0025	0.9568	0.1424	0.0211	0.6855	0.1051

-continued

	Aberration Coefficient of Third Order						
No.	L	T	SA	CM	AS	PT	DS
2	0.0001	−0.0110	0.0000	−0.0041	0.3265	−0.3131	−1.0552
3	0.0207	0.0019	0.7346	0.0685	0.0063	1.2503	0.1172
4	0.0087	−0.0140	0.9280	−1.4928	2.4014	−0.5577	−2.9656
5	−0.0221	0.0277	−1.9203	2.4033	−3.0078	0.3263	3.3559
6	−0.0335	−0.0106	−1.4912	−0.4731	−0.1500	−1.6505	−0.5712
7	−0.0186	0.0142	−1.7089	1.3096	−1.0036	−1.0348	1.5622
8	0.0104	−0.0139	0.2275	−0.3021	0.4012	0.6895	−1.4486
9	0.0011	0.0126	0.0003	0.0033	0.0373	0.1054	1.5728
10	0.0172	−0.0101	2.7250	−1.6061	0.9466	0.7291	−0.9876
Total	0.0015	−0.0006	0.4519	0.0489	−0.0208	0.2301	−0.3149

L = Longitudinal Chromatic Aberration
T = Lateral Chromatic Aberration
SA = Spherical Aberration
CM = Coma
AS = Astigmatism
PT = Petzval Sum
DS = Distortion

EXAMPLE 2 (FIG. 2)

	Focal Length f = 1 F-number 1:2.0 Image Angle 2ω = 56.7°			
No.	r	d	Nd	νd
1	0.6676	0.080	1.77250	49.6
2	1.3831	0.003		
3	0.3610	0.114	1.77250	49.6
4	0.8351	0.022		
5	1.8175	0.025	1.74077	27.8
6	0.2741	0.133		
7	−0.3959	0.024	1.80518	25.4
8	−0.5236	0.0025		
9	2.6985	0.063	1.72342	38.0
10	−0.6085			

Total Length = 1.128

EXAMPLE 3 (FIG. 3)

	Focal Length f = 1 F-number 1:2.0 Image Angle 2ω = 56.7°			
No.	r	d	Nd	νd
1	0.6775	0.084	1.77250	49.6
2	1.6702	0.003		
3	0.3248	0.099	1.77250	47.7
4	0.6876	0.014		
5	1.0781	0.025	1.73233	27.3
6	0.2491	0.128		
7	−0.4378	0.045	1.66348	40.2
8	−0.6715	0.003		
9	2.9457	0.057	1.65844	50.8
10	−0.6185			

Total Length = 1.111

-continued

	Aberration Coefficient of Third Order						
No.	L	T	SA	CM	AS	PT	DS
1	0.0163	0.0036	0.7906	0.1738	0.0382	0.6432	0.1498
2	0.0014	−0.0116	0.0059	−0.0487	0.3978	−0.2609	−1.1179
3	0.0240	0.0018	1.0792	0.0826	0.0063	1.3417	0.1031
4	0.0084	−0.0143	0.7799	−1.3216	2.2395	−0.6338	−2.7209
5	−0.0209	0.0267	−1.7228	2.1928	−2.7910	0.3921	3.0532
6	−0.0344	−0.0107	−1.5050	−0.4712	−0.1475	−1.6970	−0.5776
7	−0.0163	0.0127	−1.6857	1.3146	−1.0251	−0.9110	1.5099
8	0.0096	−0.0121	0.2933	−0.3675	0.4604	0.5939	−1.3209
9	0.0004	0.0098	0.0001	0.0031	0.0693	0.1347	1.4411
10	0.0132	−0.0078	2.4536	−1.4636	0.8730	0.6419	−0.9037
Total	0.0019	−0.0020	0.4890	0.0879	−0.0176	0.2449	−0.3838

L = Longitudinal Chromatic Aberration
T = Lateral Chromatic Aberration
SA = Spherical Aberration
CM = Coma
AS = Astigmatism
PT = Petzval Sum
DS = Distortion

EXAMPLE 4 (FIG. 4)

	Focal Length f = 1 F-number 1:1.92 Image Angle 2ω = 54.9°			
No.	r	d	Nd	νd
1	0.6186	0.095	1.72000	50.2
2	1.6639	0.002		
3	0.3414	0.113	1.65844	50.9
4	0.8358	0.017		
5	1.5970	0.024	1.75520	2
6	0.2685	0.131		
7	−0.4132	0.037	1.72342	38.0
8	−0.6058	0.00239		
9	2.7705	0.007	1.78590	44.2
10	−0.6449			

Total Length = 1.1488

In the following, there are listed the values of the factors in the inequalities (1) to (6) for Examples 1 to 4.

Condition	Example 1	Example 2	Example 3	Example 4
(1)	0.23439	0.24351	0.22501	0.2512
(2)	0.10676	0.09019	0.10475	0.10916
(3)	0.13617	0.1326	0.1286	0.13086
(4)	0.4568	0.4827	0.4056	0.37179
(5)	0.6663	0.7561	0.652	0.6821
(6)	0.1446	0.2255	0.20995	0.2328

What is claimed is:

1. A large aperture objective with a behind the lens diaphragm comprising five components of which the first and the second counting from the front are positive meniscus lenses of convex surface toward the front, the third is a negative meniscus lens of concave surface toward the rear, the fourth is a negative meniscus lens of concave surface toward the front, and the fifth is a bi-convex lens with its rear surface of strong curvature toward the rear, said diaphragm being positioned on the image side of said fifth lens and said objective satisfying the following conditions:

(1) $0.18\ f<D_1<0.28\ f$, where $D_1=d_1+d_2+d_3+d_4+d_5$

(2) $0.08\ f<D_2<0.18\ f$, where $D_2=d_7+d_8+d_9$

(3) $0.12\ f<d_6<0.15\ f$

(4) $0.35<(R_1/R_2)<0.5$

(5) $0.6<(R_7/R_8)<0.8$

(6) $|R_{10}/R_9|<0.3$

wherein R_i is the radius of curvature of the i-th lens surface counting from the front; di is the axial thickness or air spacing between the i-th and (i+1)th lens surfaces; and f is the focal length of the entire lens system.

2. A large aperture objective as described in claim **1**, and where said objective has, with respect to a normalized focal length of f=1, the following numerical data:

	F-number 1:1.92	Image Angle 2ω = 54.9°		
No.	r	d	Nd	νd
1	0.6358	0.083	1.77250	49.6
2	1.3917	0.002		
3	0.3486	0.109	1.77250	49.6
4	0.7814	0.016		
5	1.3183	0.024	1.75520	27.5
6	0.2607	0.136		
7	−0.4056	0.024	1.72342	38.0
8	−0.6088	0.082		
9	4.1728	0.038	1.78590	44.2
10	−0.6035			

(r=the radii of curvature; d=the lens thicknesses or air spacings; Nd=the refractive indices; and νd=the Abbe numbers).

3. A large aperture objective as described in claim **1**, and wherein said objective has, with respect to a normalized focal length of f=1, the following numerical data:

	F-number 1:2.0	Image Angle 2ω = 56.7°		
No.	r	d	Nd	νd
1	0.6676	0.080	1.77250	49.6
2	1.3831	0.003		
3	0.3610	0.114	1.77250	49.6
4	0.8351	0.022		
5	1.8175	0.025	1.74077	27.8
6	0.2741	0.133		
7	−0.3959	0.024	1.80518	25.4
8	−0.5236	0.066		
9	2.6985	0.025	1.72342	38.0
10	−0.6085			

(r=the radii of curvature; d=the lens thicknesses or air spacings; Nd=the refractive indices; and νd=the Abbe numbers).

4. A large aperture objective as described in claim **1**, and wherein said objective has, with respect to a normalized focal length of f=1, the following numerical data:

	F-number 1:2.0	Image Angle 2ω = 56.7°		
No.	r	d	Nd	νd
1	0.6775	0.084	1.77250	49.6
2	1.6702	0.003		
3	0.3248	0.099	1.77250	47.7
4	0.6876	0.014		
5	1.0781	0.025	1.73233	27.3
6	0.2491	0.128		
7	−0.4378	0.045	1.66348	40.2
8	−0.6715	0.060		
9	2.9457	0.038	1.65844	50.8
10	−0.6185			

(r=the radii of curvature; d=the lens thicknesses or air spacings; Nd=the refractive indices; and νd=the Abbe numbers).

5. A large aperture objective as described in claim **1**, and wherein said objective has, with respect to a focal length normalized to unity, the following numerical data:

	F-number 1:1.92	Image Angle 2ω = 54.9°		
No.	r	d	Nd	νd
1	0.6186	0.095	1.72000	50.2
2	1.6639	0.002		
3	0.3414	0.113	1.65844	50.9
4	0.8358	0.017		
5	1.5970	0.024	1.75520	2
6	0.2685	0.131		
7	−0.4132	0.037	1.72342	38.0
8	−0.6058	0.072		
9	2.7705	0.038	1.78590	44.2
10	−0.6449			

(r=the radii of curvature; d=the lens thicknesses or air spacings; Nd=the refractive indices; and νd=the Abbe numbers).

* * * * *

United States Patent [19]

Momiyama

[11] **4,381,888**

[45] **May 3, 1983**

[54] **RETROFOCUS TYPE LARGE APERTURE WIDE ANGLE OBJECTIVE**

[75] Inventor: **Kikuo Momiyama**, Yokohama, Japan

[73] Assignee: **Canon Kabushiki Kaisha**, Tokyo, Japan

[21] Appl. No.: **272,379**

[22] Filed: **Jun. 10, 1981**

[30] **Foreign Application Priority Data**

Jun. 11, 1980 [JP] Japan 55-78704

[51] **Int. Cl.**[3] **G02B 9/64**; G02B 13/04

[52] **U.S. Cl.** **350/458**

[58] **Field of Search** 350/458, 462, 459, 460, 350/461

[56] **References Cited**

U.S. PATENT DOCUMENTS

3,748,021	7/1973	Tajima et al.	350/458
3,877,795	4/1975	Yamashita	350/458
4,310,222	1/1982	Ikemori	350/458

Primary Examiner—John K. Corbin

Assistant Examiner—Paul Dzierzynski

Attorney, Agent, or Firm—Toren, McGeady and Stanger

[57] **ABSTRACT**

A wide angle objective of the retrofocus type, with an increased aperture, is disclosed. This objective comprises three lens groups of which the first counting from the front has a negative power and includes, from front to rear, a positive lens in the meniscus form convex toward the front, a negative lens in the meniscus form convex toward the front, a negative lens likewise in the meniscus form convex toward the front, a positive lens, and a negative lens in the meniscus form convex toward the front. The second lens group includes a cemented bi-convex lens, and the third lens group includes a cemented lens of positive and negative lens elements, a positive lens in the meniscus form convex toward the rear, a cemented lens of negative and positive lens elements, and a positive lens. A diaphragm is positioned in the space between the second and third lens groups. Various conditions are prescribed for every lens group, and for every lens in each group.

5 Claims, 15 Drawing Figures

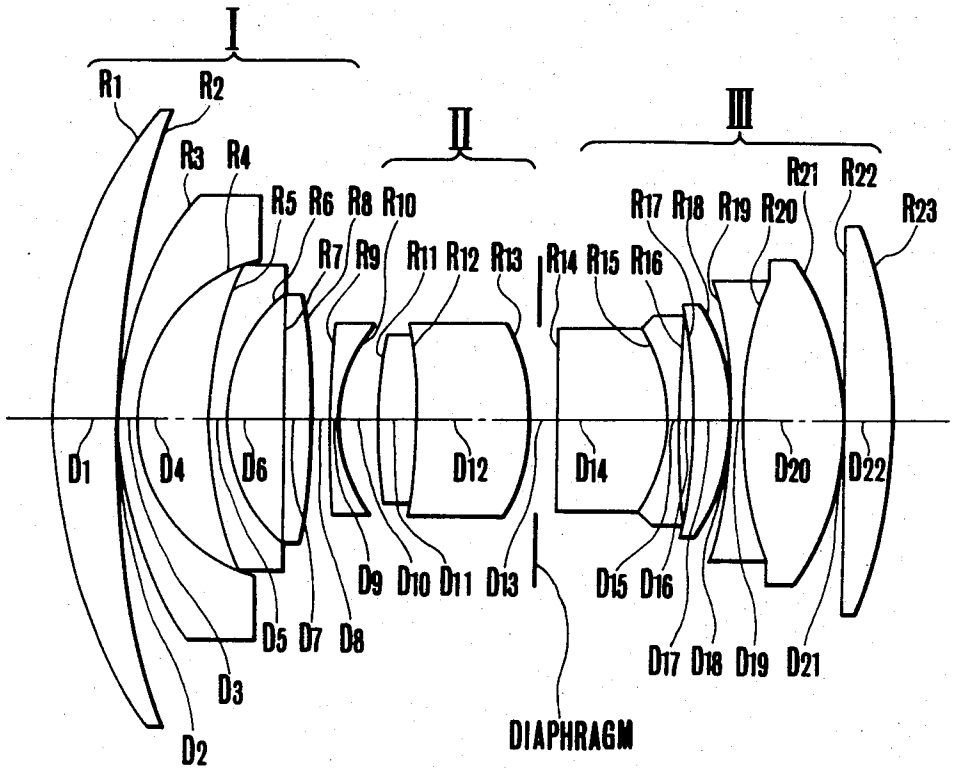
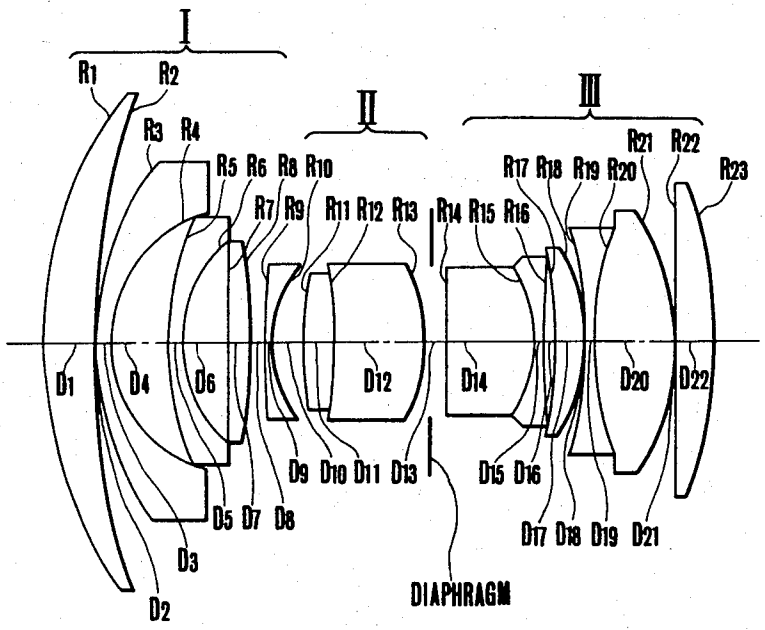


FIG. 1


I
II
III
R1
R2
R3
R4
R5
R6
R8
R10
R7
R9
R11
R12
R13
R14
R15
R16
R17
R18
R19
R20
R21
R22
R23
D1
D4
D6
D12
D14
D20
D22
D2
D3
D5
D7
D8
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D10
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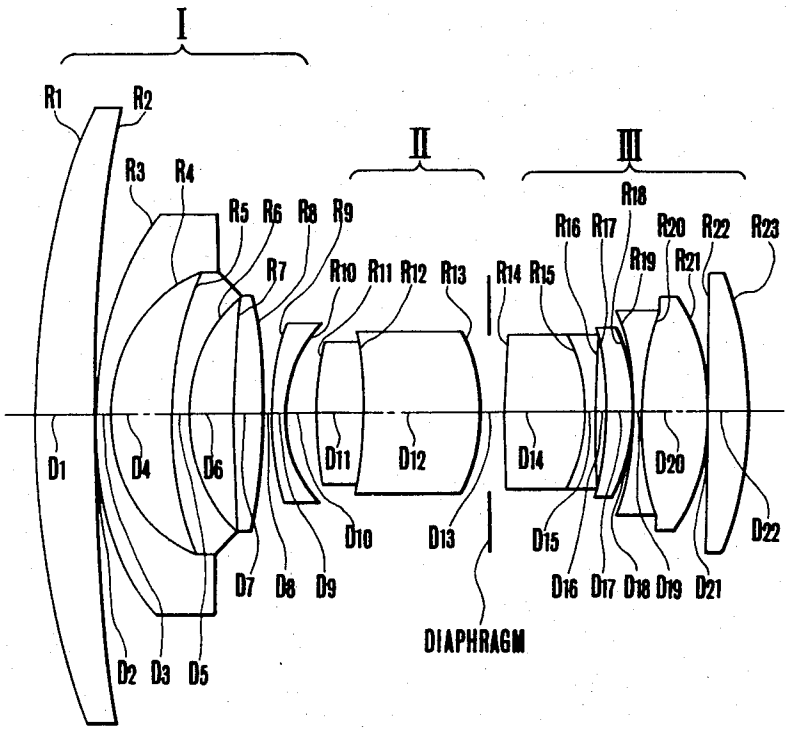
D13
D15
D16
D17
D18
D19
D21
DIAPHRAGM

FIG.2


I
II
III
R1
R2
R3
R4
R5
R6
R7
R8
R9
R10
R11
R12
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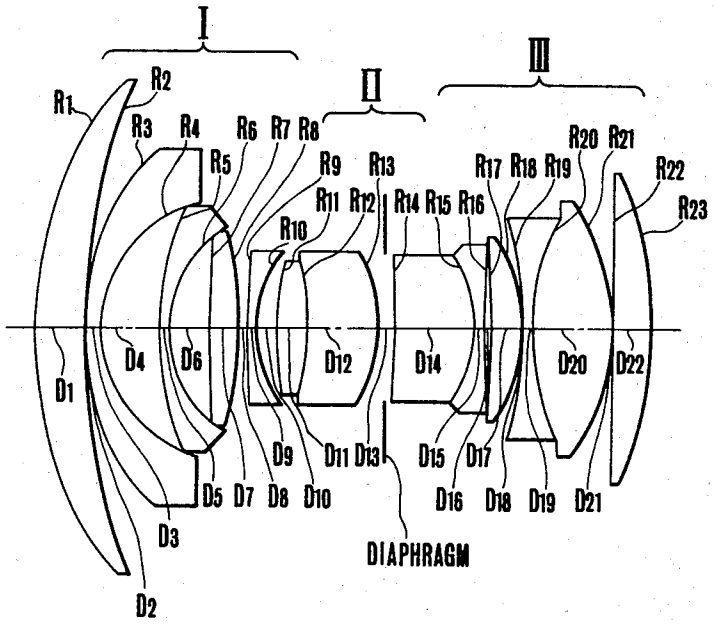
R14
R15
R16
R17
R18
R19
R20
R21
R22
R23
D1
D2
D3
D4
D5
D6
D7
D8
D9
D10
D11
D12
D13
D14
D15
D16
D17
D18
D19
D20
D21
D22
DIAPHRAGM

FIG.3


I
II
III
R1
R2
R3
R4
R5
R6
R7
R8
R9
R10
R11
R12
R13
R14
R15
R16
R17
R18
R19
R20
R21
R22
R23
D1
D2
D3
D4
D5
D6
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D17
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D20
D21
D22
DIAPHRAGM

FIG.4a

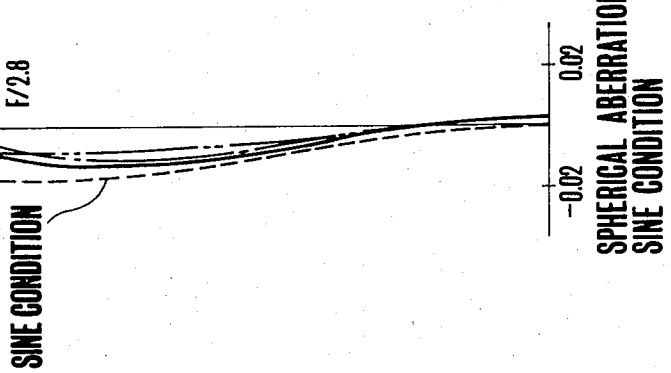


FIG.4b

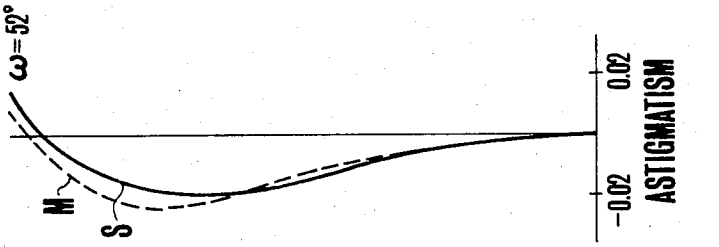


FIG.4c

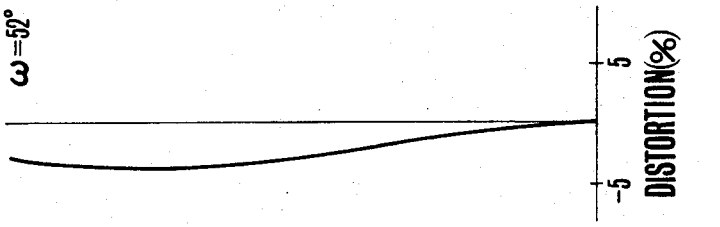
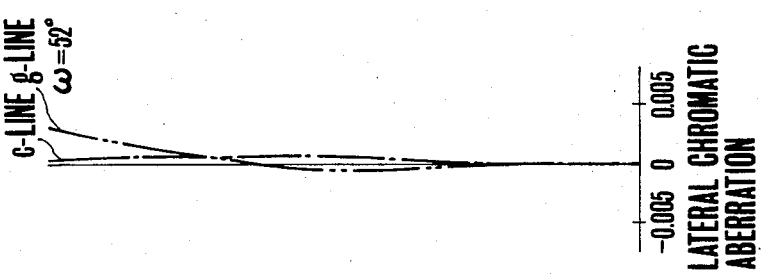


FIG.4d



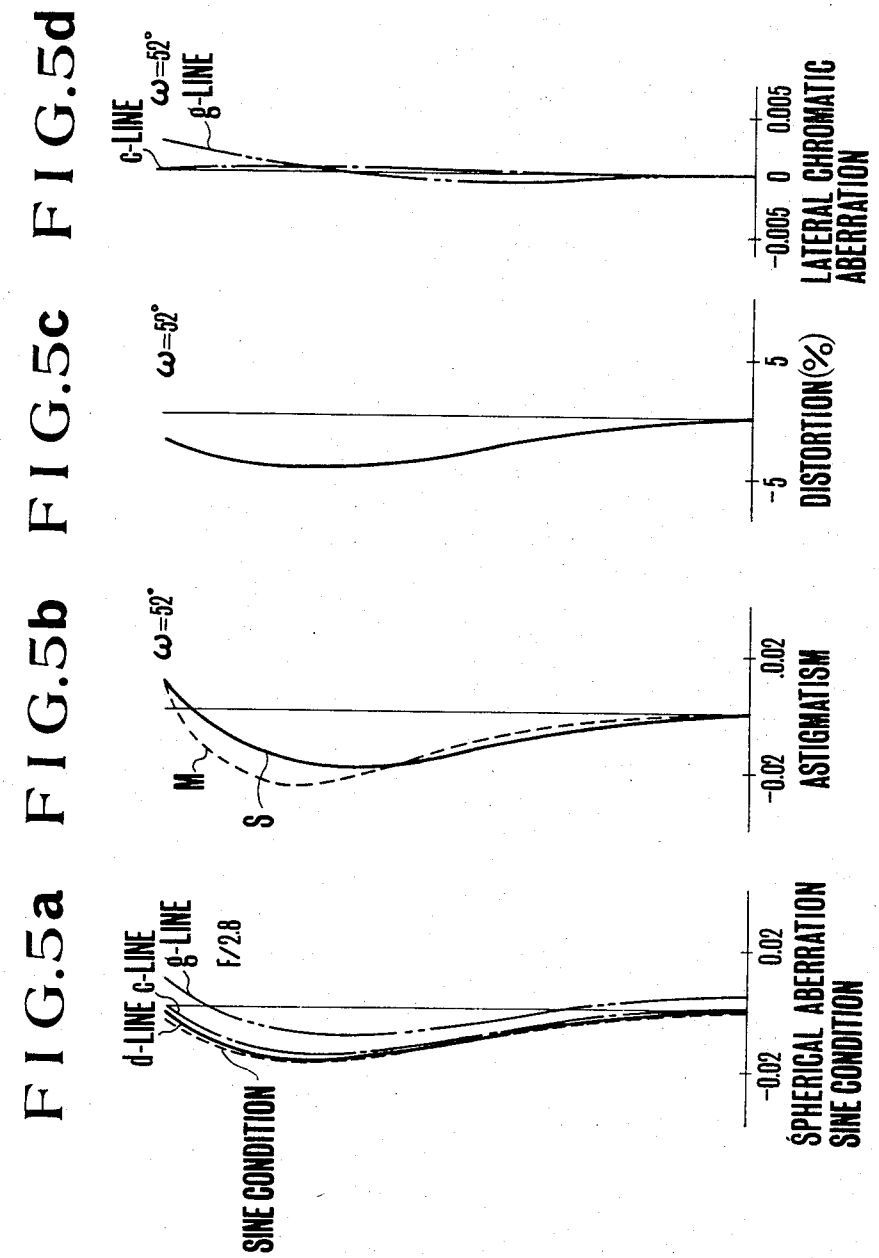


FIG.5a FIG.5b FIG.5c FIG.5d

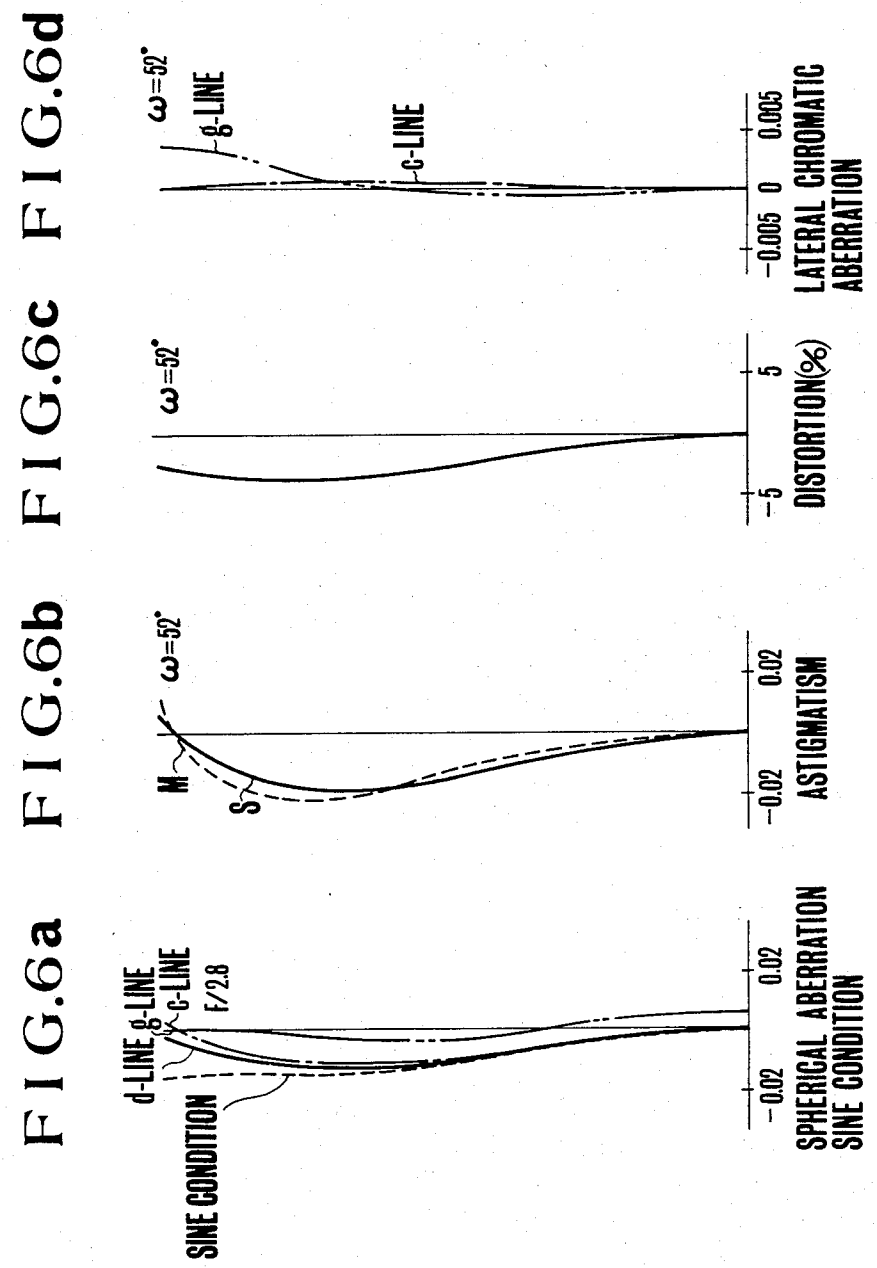


FIG.6a FIG.6b FIG.6c FIG.6d

RETROFOCUS TYPE LARGE APERTURE WIDE ANGLE OBJECTIVE

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to retrofocus type large aperture wide angle objectives, and more particularly to a compact retrofocus type wide angle objective having a field angle of 52° or thereabout with an F-number on the order of 2.8, and which is well corrected for aberrations.

2. Description of the Prior Art

In designing wide angle objectives for single lens relfex cameras, an increase in employment of compactness and large aperture ratio is occurring. Most of these wide angle objectives have been constructed in the form of an inverted telephoto type with the advantage that the back focal distance can be generally elongated. Since, on the other hand, the lens arrangement lacks symmetry, good correction of aberrations becomes difficult to perform. This difficulty tends to be intensified more and more as the field angle and the relative aperture are increased along with a further advance in the compactness of the entire system. It is known to provide a retrofocus type wide angle objective having an increased range with an increased relative aperture as, for example, in U.S. Pat. Nos. 3,748,021, 3,976,366, 3,981,563, 4,013,350, 4,061,421, and 4,188,092.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a retrofocus type wide angle objective for single lens reflex cameras having an increased range with an increased relative aperture while nevertheless permitting the various aberrations to be well corrected, and a further minimization of the bulk and size of the entire lens system to be made possible.

The retrofocus type large aperture wide angle objective of the invention has three lens groups, the first lens group counting from the front having a negative refractive power, the second lens group having a positive refractive power, and the third lens group having a positive refractive power. And, the first lens group has two positive lenses and three negative lenses. The second lens group has a cemented bi-convex lens. The third lens group has two cemented lenses and two positive lenses. A good state of correction of aberrations has been achieved by giving the configuration, refractive power, and material of lenses in each group and the total length of the lens system prescribed various conditions.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. **1**, **2** and **3** are longitudinal sectional views of Examples 1, 2 and 3 of specific objectives according to the present invention respectively.

FIGS. **4**(*a*), (*b*), (*c*) and (*d*), **5**(*a*), (*b*), (*c*) and (*d*), and **6**(*a*), (*b*), (*c*) and (*d*) are graphic representations of the various aberrations of the objectives of FIGS. **1**, **2** and **3** respectively.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention is next described in connection with embodiments thereof by reference to FIGS. **1**, **2** and **3**.

In these figures, the first lens group has a negative power, the second lens group has a positive refractive power, and the third lens group has a positive refractive power. And, the first lens group comprises, from front to rear, a positive meniscus lens of forward convexity, a negative meniscus lens of forward convexity, a negative meniscus lens of likewise or forward convexity, a positive lens, and a negative meniscus lens of forward convexity. The second lens group comprises a bi-convex doublet. The third lens group comprises, from front to rear, a doublet consisting of a positive lens and a negative lens cemented together, a positive meniscus lens of rearward convexity, a doublet consisting of a negative lens and a positive lens cemented together, and a positive lens. Positioned in the space between the second and third lens group is a diaphragm.

It is by such construction and arrangement that increases in the field angle and relative aperture and further an advance in the compactness of the lens system are achieved. For improvements of the imaging performance it is desirable to set forth the following conditions:

$$0.42 < |f_I| < 0.68, \text{ where } f_I < 0 \tag{1}$$

$$3.1 < \frac{D_T}{f} < 3.8 \tag{2}$$

$$1.3 < \frac{D_{I\,II}}{D_{III}} < 1.9 \tag{3}$$

$$f_1 > f_4 \tag{4}$$

$$|f_2| > |f_3| > |f_5|, \text{ where } f_2, f_3, f_5 < 0 \tag{5}$$

$$1.73 < \frac{N_1 + N_3 + N_5}{3} \tag{6}$$

$$\begin{matrix} 40 < \nu_1 < 65 \\ 40 < \nu_4 < 65 \end{matrix} \tag{7}$$

$$0.7 < \frac{|R_{13}|}{f} < 0.9, \text{ where } R_{13} < 0 \tag{8}$$

$$40 < \nu_7 \tag{9}$$

$$25 < \nu_6 < 32 \tag{10}$$

$$0.15 < N_9 - N_8 \tag{11}$$

$$0.25 < N_{11} - N_{12} \tag{12}$$

$$0.6 < \frac{|R_{15}|}{f} < 1, \text{ where } R_{15} < 0 \tag{13}$$

$$1.3 < \frac{R_{20}}{f} < 1.65 \tag{14}$$

where

f: the focal length of the entire system;

f_I: the focal length of the 1st lens group;

D_T: the total length of the objective;

$D_{I,II}$: the length from the first surface of the 1st lens group to the last surface of the 2nd lens group;

D_{III}: the length from the 1st surface of the 3rd lens group to the last surface;

f_1 to f_5: the focal lengths of the 1st to 5th lenses counting from front in the first lens group respectively;

N_i: the refractive index of the glass from which the i-th lens counting from front is made up;

ν_i: the Abbe number of the glass from which the i-th lens counting from front is made up; and

R_i: the radius of curvature of the i-th lens surface counting from front.

Explanation about why these conditions are given is next made below.

Conditions (1), (2) and (3) determine a basic construction and arrangement of the present invention. Condition (1) is to relatively strengthen the negative refractive power of the 1st lens group so that a sufficiently long back focal distance in view of the lens for the single lens reflex camera is secured, and the diameter of the front lens member is maintained at a minimum. When the upper limit of condition (1) is exceeded, it becomes difficult to secure a sufficiently long back focal distance and to maintain the diameter of the front lens member at minimum. When the lower limit is exceeded, the 1st lens group produces large positive spherical aberrations including higher order ones so that an increase in the relative aperture is difficult to achieve. Condition (2) is to relatively shorten the total length of the objective with an advantage of achieving compactness. When the upper limit of this condition is exceeded, an advance in the compactness is difficult to achieve. When the lower limit is exceeded, overall aberration correction becomes difficult to perform. Condition (3) has, despite the arrangement of the diaphragm at a relatively far ahead position as compared with the conventional objective under condition (2), to maintain the diameter of the front lens member at a minimum. When the upper limit of this condition is exceeded, maintenance of the minimum diameter of the front member becomes difficult. When the lower limit is exceeded, the diameter of the rear lens members becomes large, and the 3rd lens group is caused to produce large off-axis aberrations which are difficult to compensate for.

Further, in the present invention, in order to achieve good correction of aberrations, all the lens groups are individually given the following features.

The feature of the 1st lens group is that this group is constructed with a positive lens, a negative lens, a negative lens a positive lens and a negative lens and is given conditions (4), (5), (6) and (7) within the framework of condition (1). Conditions (4) and (5) define the refractive powers of all the lenses so as to almost progressively lower the heights of incidence of an off-axis ray of light on the lens surfaces as it advances through the 1st lens group while being refracted by the successive lens elements. By these conditions it is made possible to refract the off-axis ray moderately with an advantage that while distortion is corrected, the various off-axis aberrations can be well corrected, and further correction of astigmatism and coma can be achieved. Condition (6) assists in weakening the curvatures of the negative lenses in the 1st lens group. By this, the axial thickness of the 1st lens group can be made thinner so that the diameter of the front lens member can be maintained at a minimum, and at the same time it is made possible to reduce the various off-axis aberrations produced by the negative lenses. Condition (7) represents the use of glasses of large Abbe numbers in making up the two positive lenses arranged in the 1st lens group, with the advantage that color distortion and color coma produced by the positive lenses are minimized. When the lower limits of this condition are exceeded, both of the color distortion and color coma are over-corrected. When the upper limits are exceeded, under-correction of lateral chromatic aberration results.

Conditions (8), (9) and (10) are concerned with the 2nd lens group. Condition (8) compensates for the over-correction of coma by the 1st group. When the upper limit of this condition is exceeded, the compensation of the over-correction becomes difficult. When the lower limit is exceeded, the **R13** surface produces large negative spherical aberration, and an increase in the relative aperture becomes difficult to achieve. Condition (9) provides despite the configuration of the **R13** surface to a strong convex curvature for preventing the production of color coma by that surface. When this condition is violated, large color coma is produced. Condition (10) provides despite conditions (7) and (9) for preventing an under-correction of lateral chromatic aberration from tending to result, and represents the use of a glass of small Abbe number in the positive lens constituting the front element of the cemented lens of the 2nd group. When the upper limit of this condition is exceeded, under-correction of lateral chromatic aberration results. When the lower limit is exceeded, under-correction of longitudinal chromatic aberration results.

On the other hand, the residual asymmetric aberrations can be compensated for by the diverging surfaces in the 3rd lens group. But when the diverging action is strengthened, higher order aberrations are produced and it becomes difficult to achieve an increase in the relative aperture. The characteristic feature of the 3rd lens group of the invention is that this group is made to comprise a cemented lens of a positive element and a negative element, a positive lens, a cemented lens of a negative element and a positive element, and a positive lens, and, while its physical length is relatively elongated under condition (3), it is provided with many diverging surfaces, satisfying conditions (11), (12), (13) and (14). Conditions (11) and (12) represent large differences between the refractive indices of the two elements in either of the cemented lenses and cooperate with conditions (13) and (14) to impart a large diverging action. When conditions (11) and (12) are violated, a sufficient diverging action cannot be obtained even under conditions (13) and (14) thereby making it difficult to correct asymmetric aberrations. Conditions (13) and (14) represent the optimum radii of curvature of the cemented surfaces under conditions (11) and (12). When the upper limits of these conditions are exceeded, asymmetric aberrations no longer can be well corrected. When the lower limits are exceeded, higher order aberrations are produced to make it difficult to increase the relative aperture.

It is noted that the specific embodiments which will be later described employ the focusing method of moving the entire lens system forward as the object distance is shortened, while simultaneously shortening the axial air separation between the surfaces **R8** and **R9** (corresponding to that designated by **D8** in the drawings) to correct aberrations for the avoidance of lowering the imaging performance to an object at a shorter distance.

In the following, three examples of specific objectives of the invention satisfying the above-defined conditions are shown along with their numerical data, and 3rd order aberration coefficients of Example 1 objective are evaluated. Examples 1, 2 and 3 of the objective correspond to those shown in FIGS. **1**, **2** and **3** respectively. In the tables of the numerical data, Ri is the radius of curvature of the i-th surface counting from the front, Di the i-th axial thickness of air separation, and Ni and νi are the refractive index and Abbe number of the glass of the i-th lens element. Also in the table of the 3rd order aberration coefficient values, the surface numbers represent the lens surfaces numbered successively from the

front, I denotes spherical aberration, II coma, III astigmatism, P Petzval sum and V distortion.

The various aberrations of the Example 1 objective are shown in FIG. 4, the various aberrations of the Example 2 objective in FIG. 5, and the various aberrations of the Example 3 objective in FIG. 6. In these figures, M denotes the meridional focus line, and S the sagittal focus line.

In the last table, there are shown the numerical relationships of the above-described various conditions set forth to achieve the retrofocus large aperture, wide angle objective of the invention with the three examples of specific objectives cited in the present invention. It will be understood from FIGS. 4, 5 and 6 that any of the three specific objectives satisfying the conditions has a good state of correction of aberrations.

EXAMPLE 1

Focal Length F = 1,		F-number: 2.8		Image Angle 2ω = 104°		
R_1 2.1376	D_1	0.2628	N_1	1.58913	ν_1	61.0
R_2 3.9718	D_2	0.0057				
R_3 1.4701	D_3	0.0857	N_2	1.80610	ν_2	40.9
R_4 0.6970	D_4	0.2943				
R_5 1.6192	D_5	0.0685	N_3	1.79952	ν_3	42.2
R_6 0.7007	D_6	0.2246				
R_7 8.0445	D_7	0.1371	N_4	1.58913	ν_4	61.0
R_8 −2.9543	D_8	0.0744				
R_9 3.6069	D_9	0.0571	N_5	1.77250	ν_5	49.6
R_{10} 0.7194	D_{10}	0.1363				
R_{11} 1.4963	D_{11}	0.1714	N_6	1.80518	ν_6	25.4
R_{12} −1.9753	D_{12}	0.4726	N_7	1.51633	ν_7	64.1
R_{13} −0.7925	D_{13}	0.1143				
R_{14} −9.4189	D_{14}	0.4468	N_8	1.51633	ν_8	64.1
R_{15} −0.7249	D_{15}	0.0571	N_9	1.75520	ν_9	27.5
R_{16} 9.9349	D_{16}	0.0485				
R_{17} −3.3072	D_{17}	0.1485	N_{10}	1.51633	ν_{10}	64.1
R_{18} −1.0001	D_{18}	0.0057				
R_{19} −2.5532	D_{19}	0.0571	N_{11}	1.88300	ν_{11}	40.8
R_{20} 1.5645	D_{20}	0.4114	N_{12}	1.51633	ν_{12}	64.1
R_{21} −1.1703	D_{21}	0.0057				
R_{22} 31.5042	D_{22}	0.2114	N_{13}	1.77250	ν_{13}	49.6
R_{23} −2.2160						

Surface Number	3rd Order Aberration Coefficient I	II	III	P	V
1	0.0238	0.0265	0.0295	0.1734	0.2256
2	0.0002	0.0024	0.0217	−0.0933	−0.6446
3	0.0170	0.0202	0.0241	0.3035	0.3904
4	−1.6941	0.2825	−0.0471	−0.6403	0.1146
5	0.5126	0.2169	0.0917	0.2743	0.1549
6	−7.5986	0.5757	−0.0436	−0.6340	0.0513
7	1.3589	0.4711	0.1633	0.0460	0.0726
8	−0.0279	−0.0747	−0.2001	0.1254	−0.1998
9	1.0167	0.4481	0.1975	0.1208	0.1403
10	−40.4814	0.0852	−0.0001	−0.6057	0.0012
11	26.3653	1.7845	0.1207	0.2980	0.0283
12	−0.0120	0.0121	−0.0122	0.0534	−0.0414
13	17.7621	−2.9106	0.4769	0.4296	−0.1485
14	−0.4175	0.2673	−0.1712	−0.0361	0.1327
15	−8.3987	0.1991	−0.0047	−0.1237	0.0030
16	−0.1083	−0.1327	−0.1627	−0.0433	−0.2525
17	0.0055	−0.0106	0.0203	−0.1029	0.1581
18	6.7959	−0.4818	0.0341	0.3404	−0.0265
19	−1.2071	0.3593	−0.1069	−0.1836	0.0865
20	−3.0323	−1.1054	−0.4030	−0.0820	−0.1768
21	4.6517	−0.0111	0.0000	0.2909	−0.0006
22	−0.0067	0.0190	−0.0541	0.0138	0.1144
23	7.1767	0.0795	0.0008	0.1966	0.0021
Σ	2.7020	0.1231	−0.0248	0.1213	0.1855

EXAMPLE 2

Focal Length: f = 1		F-number: 2.8		Image Angle 2ω = 104°		
R_1 4.7267	D_1	0.2859	N_1	1.65844	ν_1	50.9
R_2 9.4579	D_2	0.0057				
R_3 1.7204	D_3	0.0857	N_2	1.71300	ν_2	53.9
R_4 0.8059	D_4	0.3409				
R_5 2.2325	D_5	0.0686	N_3	1.77250	ν_3	49.6
R_6 0.8596	D_6	0.2231				
R_7 4.8520	D_7	0.1429	N_4	1.68250	ν_4	44.7
R_8 −4.1846	D_8	0.0743				
R_9 1.6920	D_9	0.0571	N_5	1.77250	ν_5	49.6
R_{10} 0.6736	D_{10}	0.1781				
R_{11} 2.0083	D_{11}	0.2287	N_6	1.69895	ν_6	30.1
R_{12} −2.5651	D_{12}	0.6362	N_7	1.58921	ν_7	41.1
R_{13} 0.8941	D_{13}	0.1142				
R_{14} 8.6300	D_{14}	0.4174	N_8	1.51633	ν_8	64.1
R_{15} −0.9149	D_{15}	0.0571	N_9	1.75520	ν_9	27.5
R_{16} 4.8257	D_{16}	0.0457				
R_{17} −2.7075	D_{17}	0.1372	N_{10}	1.51633	ν_{10}	64.1
R_{18} −1.2062	D_{18}	0.0057				
R_{19} −1.9853	D_{19}	0.0571	N_{11}	1.80610	ν_{11}	40.9
R_{20} 1.6297	D_{20}	0.3545	N_{12}	1.51633	ν_{12}	64.1
R_{21} −1.0958	D_{21}	0.0057				
R_{22} −58.3060	D_{22}	0.1887	N_{13}	1.77250	ν_{13}	49.6
R_{23} −2.0181						

EXAMPLE 3

Focal Length: f = 1		F-Number: 2.8		Image Angle 2ω = 104°		
R_1 1.9994	D_1	0.2740	N_1	1.61800	ν_1	63.4
R_2 3.6523	D_2	0.0057				
R_3 1.3438	D_3	0.0742	N_2	1.80610	ν_2	40.9
R_4 0.6159	D_4	0.3006				
R_5 1.6039	D_5	0.0570	N_3	1.80400	ν_3	46.6
R_6 0.6185	D_6	0.2083				
R_7 6.5542	D_7	0.1370	N_4	1.58913	ν_4	61.0
R_8 −2.3202	D_8	0.0570				
R_9 5.1019	D_9	0.0570	N_5	1.80400	ν_5	46.6
R_{10} 0.7289	D_{10}	0.0808				
R_{11} 1.1996	D_{11}	0.1712	N_6	1.80518	ν_6	25.4
R_{12} −1.7084	D_{12}	0.3835	N_7	1.48749	ν_7	70.1
R_{13} −0.7172	D_{13}	0.0855				
R_{14} −5.0194	D_{14}	0.4167	N_8	1.58913	ν_8	61.1
R_{15} −0.6590	D_{15}	0.0570	N_9	1.75520	ν_9	27.5
R_{16} 24.4330	D_{16}	0.0399				
R_{17} −3.4649	D_{17}	0.1484	N_{10}	1.51633	ν_{10}	64.1
R_{18} −0.9369	D_{18}	0.0057				
R_{19} −2.4527	D_{19}	0.0570	N_{11}	1.88300	ν_{11}	40.8
R_{20} 1.3232	D_{20}	0.4224	N_{12}	1.48749	ν_{12}	70.1
R_{21} −1.1170	D_{21}	0.0057				
R_{22} −67.2607	D_{22}	0.1884	N_{13}	1.80400	ν_{13}	46.6
R_{23} −2.1609						

Condition	Example 1	Example 2	Example 3
(1) $0.42 < \lvert f_I \rvert < 0.68\ f_T < 0$	−0.5137	−0.6576	−0.4396
(2) $3.1 < \frac{D_T}{f} < 3.8$	3.497	3.711	3.233

-continued

Condition	Example 1	Example 2	Example 3
(3) $1.3 < \frac{D_{I\,II}}{D_{III}} < 1.9$	1.423	1.834	1.347
(4) $f_1 > f_4$	7.461 > 3.685	14.014 > 3.313	6.723 > 2.925
(5) $\lvert f_2\rvert > \lvert f_3\rvert > \lvert f_5\rvert$ $f_2, f_3, f_5 < 0$	f_2 −1.730 f_3 −1.598 f_5 −1.173	−2.213 −1.850 −1.485	−1.478 −1.285 −1.064
(6) $1.73 < \frac{N_1 + N_3 + N_5}{3}$	1.7927	1.7527	1.8047
(7) $40 < V_1, V_4 < 65$	61, 61	50.9, 44.7	63.4, 61
(8) $0.7 < \frac{\lvert R_{13}\rvert}{f} < 0.9\ R_{13} < 0$	−0.7925	−0.8941	−0.7173
(9) $40 < V_7$	64.1	41.1	70.1
(10) $25 < V_6 < 32$	25.4	30.1	25.4
(11) $0.15 < N_9 - N_8$	0.2389	0.2389	0.1661
(12) $0.25 < N_{11} - N_{12}$	0.3667	0.28977	0.3955
(13) $0.6 < \frac{\lvert R_{15}\rvert}{f} < 1.\ R_{15} < 0$	−0.7249	−0.9149	−0.6590
(14) $1.3 < \frac{R_{20}}{f} < 1.65$	1.5645	1.6297	1.3232

What is claimed is:

1. A large relative aperture, wide angle objective lens of the retrofocus type including, successively in the direction from front to rear, first, second and third lens groups, of which the first lens group has a negative refractive power and comprises, from front to rear, a positive meniscus lens convex toward the front, a negative meniscus lens convex toward the front, a negative meniscus lens convex toward the front, a positive lens and a negative meniscus lens convex toward the front, the second lens group has a positive refractive power and comprises a cemented bi-convex lens, and the third lens group has a positive refractive power and comprises, from front to rear, a cemented lens of a positive element and a negative element, a positive meniscus lens convex toward the rear, a cemented lens of a negative element and a positive element, and a positive lens, and a diaphragm positioned in a space between the second and third lens groups.

2. A large relative aperture wide angle objective lens according to claim 1, which satisfies the following conditions:

$$0.42 < |f_I| < 0.68 \text{ where } f_I < 0 \quad (1)$$

$$3.1 < \frac{D_T}{f} < 3.8 \quad (2)$$

$$1.3 < \frac{D_{I\,II}}{D_{III}} < 1.9 \quad (3)$$

wherein

f: the focal length of the entire system;

f_I: the focal length of the 1st lens group;

D_T: the total length of the objective;

$D_{I\,II}$: the length from the 1st surface of the 1st lens group to the last surface of the 2nd lens group;

D_{III}: the length from the 1st surface of the 3rd lens group to the last surface.

3. A large relative aperture wide angle objective lens according to claim 2, which satisfies the following conditions:

$$f_1 < f_4 \quad (4)$$

$$|f_2| > |f_3| > |f_5| \text{ where } f_2, f_3, f_5 < 0 \quad (5)$$

$$1.73 < \frac{N_1 + N_3 + N_5}{3} \quad (6)$$

$$40 < \nu_1 < 65$$
$$40 < \nu_4 < 65 \quad (7)$$

$$0.7 < \frac{|R_{13}|}{f} < 0.9 \text{ where } R_{13} < 0 \quad (8)$$

$$40 < \nu_7 \quad (9)$$

$$25 < \nu_6 < 32 \quad (10)$$

wherein

f_1: the focal length of the 1st lens counting from the front arranged in the 1st lens group;

f_2: the focal length of the 2nd lens in the 1st lens group;

f_3: the focal length of the 3rd lens in the 1st lens group;

f_4: the focal length of the 4th lens in the 1st lens group;

f_5: the focal length of the 5th lens in the 1st lens group;

N_i: the refractive index of the glass of the i-th lens counting from the front;

ν_i: the Abbe number of the glass of the i-th lens counting from the front; and

R_i: the radius of curvature of the i-th lens surface counting from the front.

4. A large relative aperture wide angle objective lens according to claim 2, which satisfies the following conditions:

$$0.15 < N_9 - N_8 \quad (11)$$

$$0.25 < N_{11} - N_{12} \quad (12)$$

-continued

$$0.6 < \frac{|R_{15}|}{f} < 1 \text{ where } R_{15} < 0 \quad (13)$$

$$1.3 < \frac{R_{20}}{f} < 1.65 \quad (14)$$

wherein

N_i: the refractive index of the glass of the i-th lens counting from the front;

ν_i: the Abbe number of the glass of the i-th lens counting from the front; and

R_i: the radius of curvature of the i-th lens surface counting from the front.

5. A large relative aperture, wide angle objective lens of the retrofocus type including first, second and third lens groups, of which the first has a negative refractive power and comprises, from front to rear, a positive meniscus lens convex toward the front, a negative meniscus lens convex toward the front, a negative meniscus lens convex toward the front, a positive lens and a negative meniscus lens convex toward the front, the second has a positive refractive power and comprises a cemented bi-convex lens, and the third has a positive refractive power and comprises, from front to rear, a cemented lens of a positive element and a negative element, a positive meniscus lens convex toward the rear, a cemented lens of a negative element and a positive element, and a positive lens, and a diaphragm positioned in a space between the 2nd and 3rd lens groups, said objective satisfying the following conditions:

$$0.42 < |f_I| < 0.68 \text{ where } f_I < 0 \quad (1)$$

$$3.1 < \frac{D_T}{f} < 3.8 \quad (2)$$

$$1.3 < \frac{D_{I\,II}}{D_{III}} < 1.9 \quad (3)$$

$$f_1 > f_4 \quad (4)$$

$$|f_2| > |f_3| > |f_5| \text{ where } f_2, f_3, f_5 < 0 \quad (5)$$

-continued

$$1.73 < \frac{N_1 + N_3 + N_5}{3} \quad (6)$$

$$40 < \nu_1 < 65$$
$$40 < \nu_4 < 65 \quad (7)$$

$$0.7 < \frac{|R_{13}|}{f} < 0.9 \text{ where } R_{13} < 0 \quad (8)$$

$$40 < \nu_7 \quad (9)$$

$$25 < \nu_6 < 32 \quad (10)$$

$$0.15 < N_9 - N_8 \quad (11)$$

$$0.25 < N_{11} - N_{12} \quad (12)$$

$$0.6 < \frac{|R_{15}|}{f} < 1 \text{ where } R_{15} < 0 \quad (13)$$

$$1.3 < \frac{R_{20}}{f} < 1.65 \quad (14)$$

wherein

f: the focal length of the entire system;

f_I: the focal length of the 1st lens group;

D_T: the total length of the objective;

$D_{I\,II}$: the length from the 1st surface of the 1st lens group to the last surface of the 2nd lens group;

D_{III}: the length from the 1st surface of the 3rd lens group to the last surface;

f_1: the focal length of the 1st lens counting from the front arranged in the 1st lens group;

f_2: the focal length of the 2nd lens in the 1st lens group;

f_3: the focal length of the 3rd lens in the 1st lens group;

f_4: the focal length of the 4th lens in the 1st lens group;

f_5: the focal length of the 5th lens in the 1st lens group;

N_i: the refractive index of the glass of the i-th lens counting from the front;

ν_i: the Abbe number of the glass of the i-th lens counting from the front; and

R_i: the radius of curvature of the i-th lens surface counting from the front.

* * * * *

United States Patent [19]

Suda et al.

[11] **4,380,376**

[45] **Apr. 19, 1983**

[54] **ZOOM OBJECTIVE**

[75] Inventors: **Shigeyuki Suda**, Ohashi; **Kazuo Tanaka**, Tokyo, both of Japan

[73] Assignee: **Canon Kabushiki Kaisha**, Tokyo, Japan

[21] Appl. No.: **159,492**

[22] Filed: **Jun. 16, 1980**

[30] **Foreign Application Priority Data**

Jun. 18, 1979 [JP] Japan 54-76528

[51] **Int. Cl.**³ **G02B 15/18**

[52] **U.S. Cl.** **350/427**

[58] **Field of Search** 350/423, 427

[56] **References Cited**

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Primary Examiner—John K. Corbin

Assistant Examiner—Scott J. Sugarman

Attorney, Agent, or Firm—Toren, McGeady and Stanger

[57] **ABSTRACT**

A zoom objective is composed of three components of which the first and the third each perform a one-round axial movement over the range of variation, while the second simultaneously performs a monotonic axial movement in one direction.

3 Claims, 14 Drawing Figures

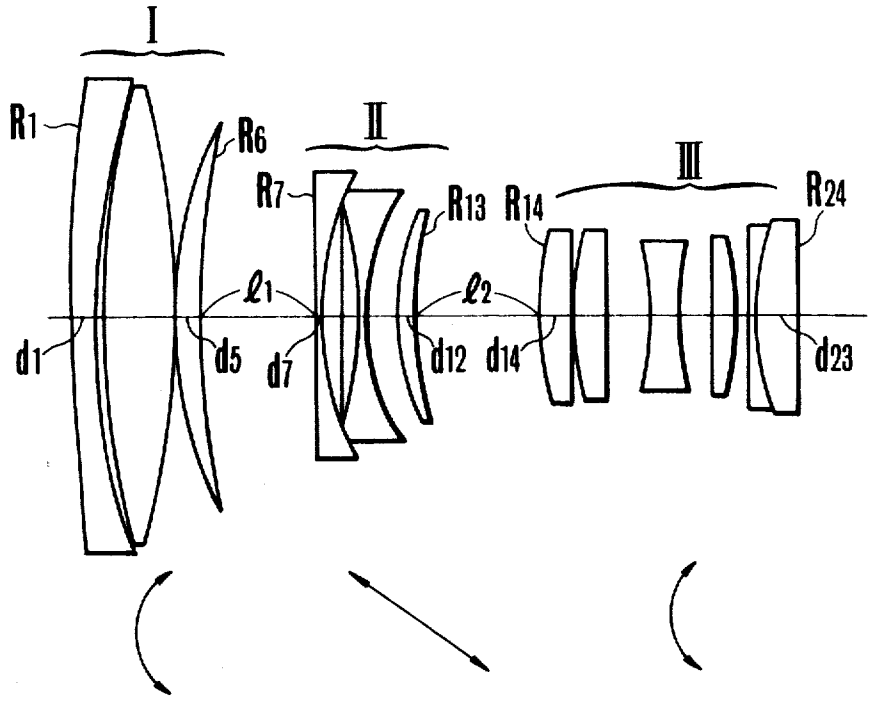


FIG. 1A

FIG. 1B

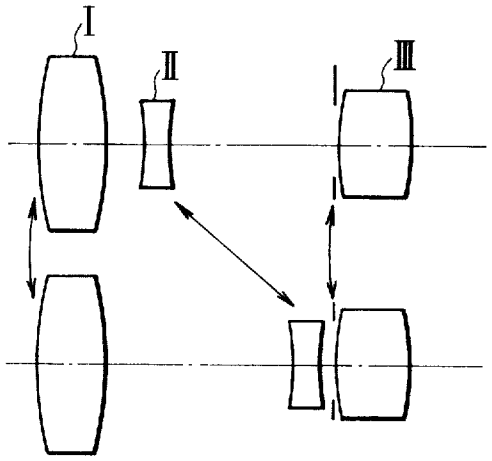


FIG. 2

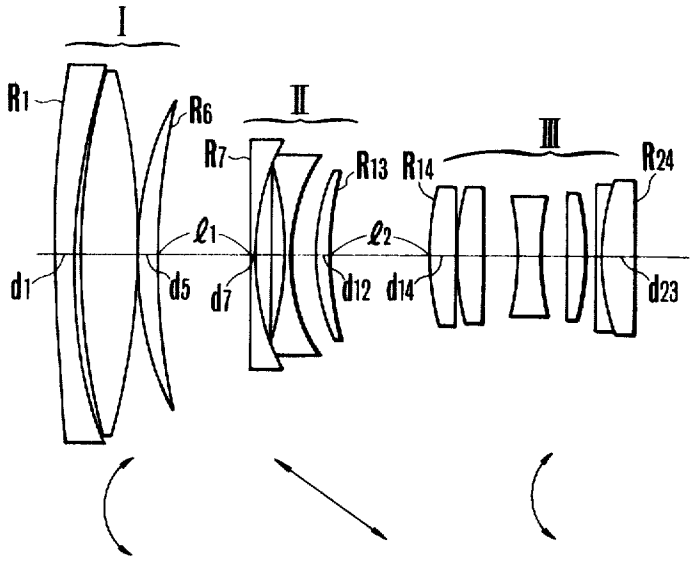


FIG.3

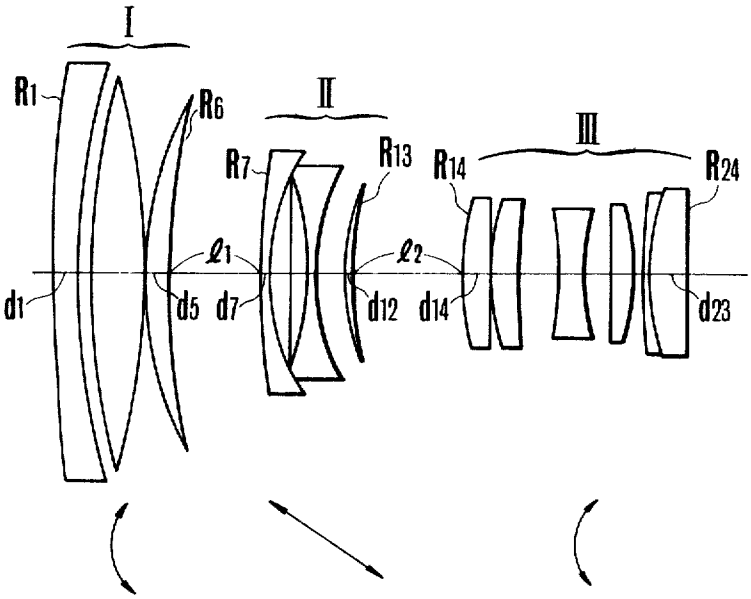

I
II
III
R1
R6
R7
R13
R14
R24
ℓ1
ℓ2
d1
d5
d7
d12
d14
d23

FIG.4

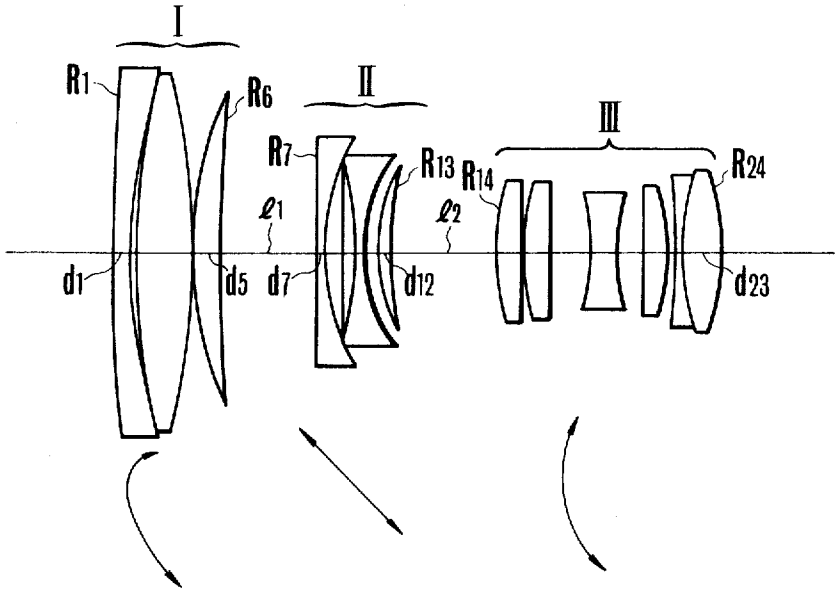

I
II
III
R1
R6
R7
R13
R14
R24
ℓ1
ℓ2
d1
d5
d7
d12
d23

FIG.5A

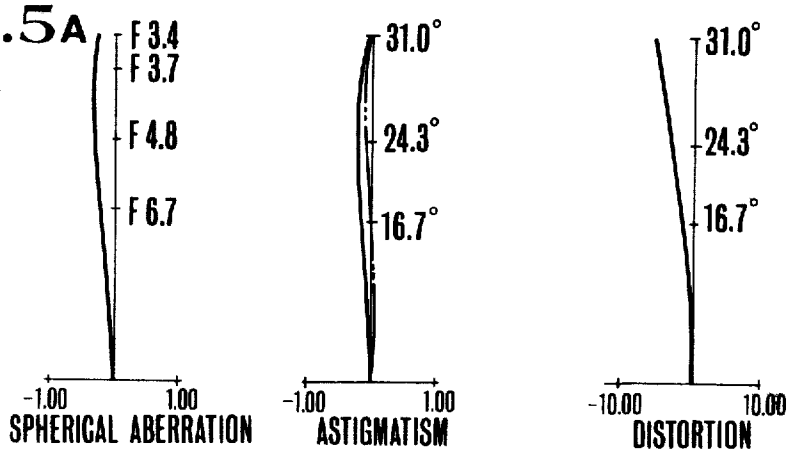


FIG.5B

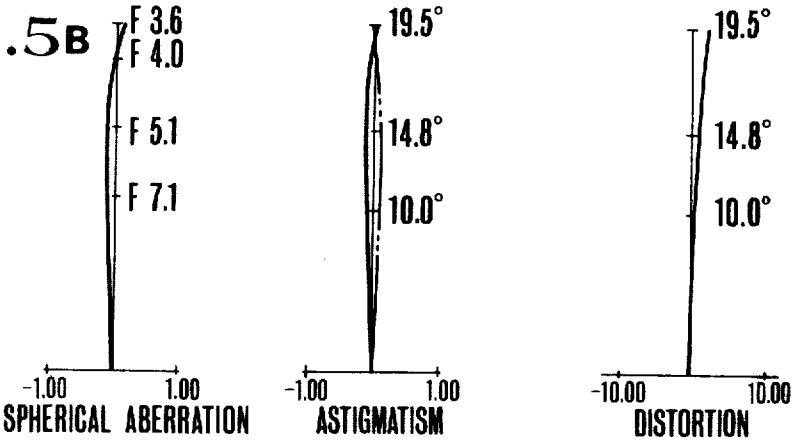


FIG.5c

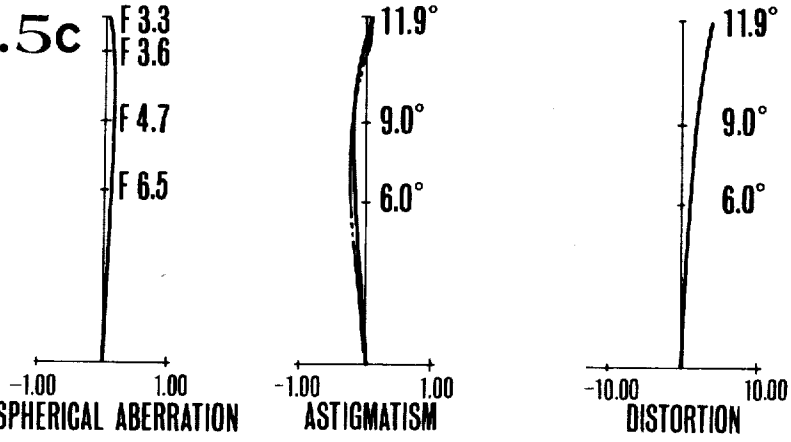


FIG.6A

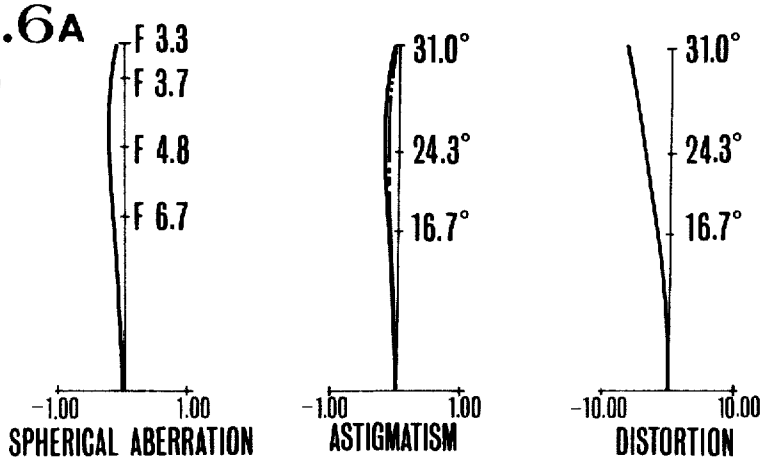


FIG.6B

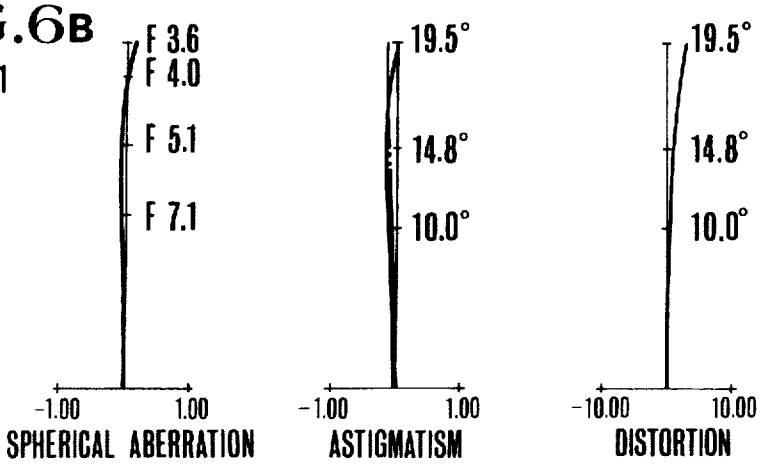


FIG.6C

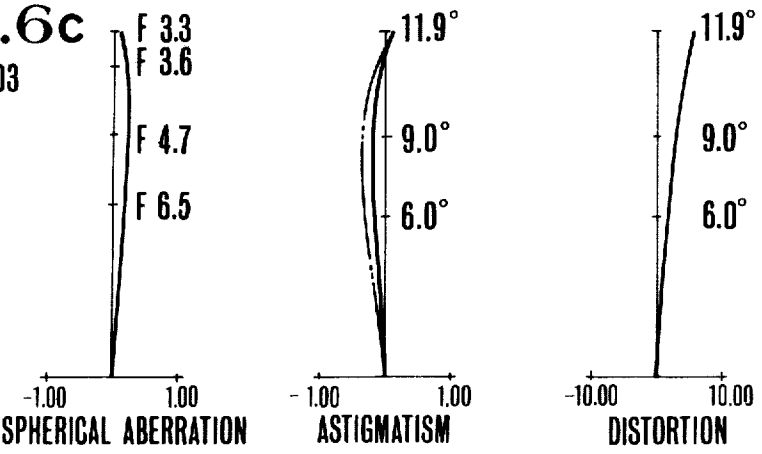


FIG.7A

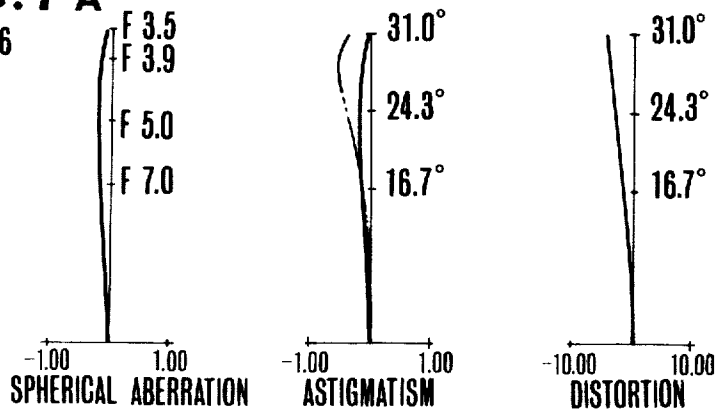


FIG.7B

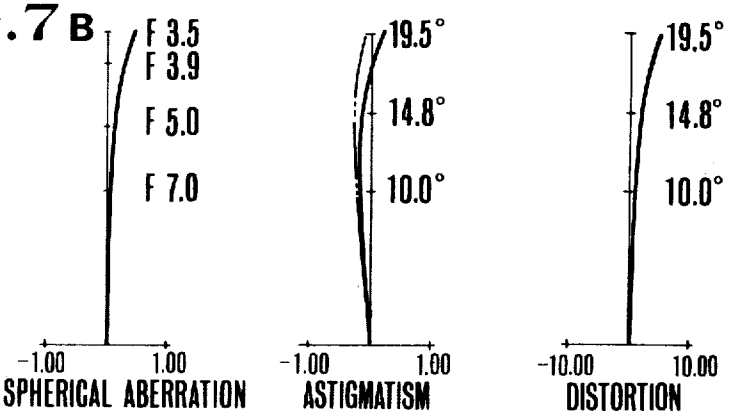
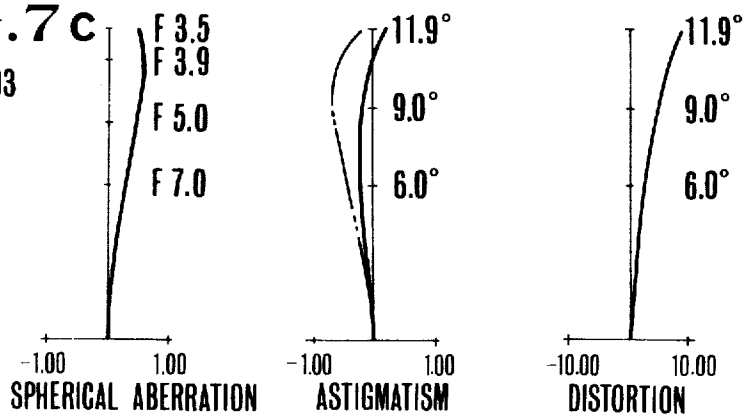


FIG.7C



ZOOM OBJECTIVE

BACKGROUND OF THE INVENTION

This invention relates to mechanically-compensated compact zoom objectives having a large zoom ratio including a wide angle region and extending up to a telephoto region.

In a zoom objective lens system it is necessary to employ at least two lens components which move axially for varying the focal length of the entire system while maintaining a constant image plane. Recently there has been a desire to increase the zoom ratio of this type zoom objective while keeping the bulk and size to a minimum.

The zoom ratio of about two has been found practical in objectives for still cameras. Most of these objectives are constructed in the so-called short zoom form comprising two lens components of negative and positive powers as, for example, disclosed in U.S. Pat. Nos. 3,143,590, 3,848,969, 4,153,339, 4,142,779, and 4,147,410. Of these, there is known a lens system whose rear component having a positive power is divided into a plurality of parts to facilitate a remarkable increase in the zoom ratio. For example, U.S. Pat. No. 4,170,402 describes a system where the rear group comprises two positive lenses made movable independently of each other. In Japanese Patent Application Laid-Open No. Sho 53-34539, the rear group also is divided into three parts of positive, negative and positive powers of which the positive two are moved in unison with each other, while the intermediate or negative lens is moved in differential relation to the positive lenses. U.S. Pat. No. 3,771,853 describes the construction of a rear group of positive, negative and positive lenses which assume respectively different loci.

Aside from the direction of development of the art in the field of zoom objectives of the type consisting of negative and positive lens groups as described above, there is another direction of development toward an increase in the zoom ratio and the compactness based on the fundamental zoom lens design which has been widely accepted from. This development involves objectives comprising four lens components, namely, a focusing member, a variator, a compensator and a relay lens. For example, DOLS 2,833,308 describes a positive first lens group counting from the front, a negative second lens group and a positive third lens group constituting an entire system with exclusion of the relay lens. Here, the function of varying the focal length is imparted into the second and third lens groups, and both of the functions of focusing adjustment and image shift compensation are imparted into the first lens group. This achieves the objects of high zoom ratio and compactness.

To obtain a compact zoom objective of a high zoom ratio it is the common practice to strengthen the refractive power of the each individual movable lens group and narrow the air spacings between the successive lens groups. In this case, the following problems arise:

(1) The aberrational correction becomes difficult.

(2) The requirement for accuracy of adjustment in position of the movable lens group is extremely rigorous. If this is not fulfilled, the ideal optical performance cannot be obtained in completed objectives.

(3) No real solution can be found for the locus of movement of the compensator relative to the variator.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a compact zoom objective for a still camera having as high a zoom ratio as 3 with an angle of view of at least 60° in the shortest focal length positions and a total length (the distance from the front vertex to the focal plane) reduced to shorter than 1.5 times the longest focal length, while still achieving good correction of aberrations throughout the entire zooming range.

In a zoom objective according to the present invention a first lens group, a second lens group and a third lens group are arranged on a common optical axis from the front in the order stated, and the second lens group is imparted with the function of varying the size of an image of an object located at a fixed distance from the objective, the third lens group with the function of compensator, and the first lens group with not only the focusing function but also the function of a compensator, to accomplish the above-described object of the invention.

In other words, according to the present invention, as the bulk and size of the lens system is minimized by putting the second and third lens groups as near to each other as possible, in order to avoid the above-mentioned problem (3), the function of the compensator is added to the first lens group. In the zoom lens system of the present invention, therefore, when in zooming, the first and third lens groups are reciprocatingly moved along the optical axis, while the second lens group is simultaneously axially moved monotonically in one direction in the range of variation. And, the loci of movement of the first and third lens groups are made non-parallel to each other.

With the zoom lens system of the present invention when the above-described first lens has a positive refractive power, the second lens has a negative refractive power and the third lens has a positive refractive power, it the first and third lens groups preferably perform axial movements in one round of convex locus toward the front during the zooming. At that time, preferably the second lens group is axially moved monotonically from the front to the rear as the lens is zoomed from the wide angle to the telephoto settings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. 1A and 1B are schematic diagrams of an embodiment of a zoom objective lens system according to the present invention in two operative positions.

FIG. 2, FIG. 3 and FIG. 4 are sectional views showing three different examples of specific zoom objectives according to the present invention.

FIGS. 5A to 5C are graphic representations of the various aberrations of the zoom objective of FIG. 2 in the shortest, middle and longest focal length positions respectively.

FIGS. 6A to 6C are similar graphs of the objective of FIG. 3.

FIGS. 7A to 7C are similar graphs of the objective of FIG. 4.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIGS. 1A and 1B are block diagrams of a zoom objective of the present invention. In FIG. 1A, the lens components are positioned the wide angle end of a zooming range and in FIG. 1B at the telephoto end thereof.

The lens system of FIG. 1 is constructed with three groups as a whole of which the first I counting from the front is of positive power, the second II of negative power and the third III of positive power. When zooming, the second lens group II is moved toward the first lens group I in the wide angle settings, and toward the third lens group III in the telephoto settings. Along with this, the first lens group I and the third lens group III each perform an axial movement of small range in one round of non-parallel and convex locus toward the front. Thus, the focal length of the entire system is varied throughout the range of axial movement of the lens groups while still maintaining a fixed focal plane throughout the entire range. This makes it possible to facilitate an extreme minimization of the bulk and size of the entire system and to increase the zoom ratio up to about 3 with the inclusion of a wide angle position at one end of a zooming range, the opposite end of which is extended up to produce a telephoto effect. In more detail, as the air spacings between the successive lens groups are shorter, the use of only the third lens group as the compensator for the variator of the second lens group II would lead to give rise to the above-described problem (3). But by using two compensators of the first and third lens groups I and III the equation for defining the movements of the individual zoom lens groups can be solved. Moreover, the refractive power of each of the lens groups may be weakened, and the aberrational problem is simplified. Further, as the first lens group serves as a focusing member, the entire system can be minimized to a compact size.

FIGS. 2 to 4 are longitudinal sections of embodiments of the zoom lens system of FIG. 1 with FIG. 2 showing Example 1, FIG. 3 Example 2, and FIG. 4 Example 3. The zoom objectives shown in Examples 1 to 3 have a range of variation of the focal length, f, between 36 mm and 103 mm, with a zoom ratio of about 2.9 and an F-number of 3.5.

The numerical data of the zoom objectives shown in Examples 1 to 3 for the radii of curvature, Ri, the axial thicknesses or axial air separations, di, the refractive indices, ni, for the spectral d line, and the Abbe numbers, νi, are given in Tables 1-1 to 3-1 below. The lens block separations l1 and l2 and back focus of each of the zoom objectives shown in Examples 1 to 3 during zooming with object at infinity are given in Tables 1-2 to 3-2.

Further, the various aberrations of the zoom objective of Example 1 in three different focal length positions are shown in FIGS. 5A to 5C, those of the zoom objective of Example 2 in FIGS. 6A to 6C, and those of the zoom objective of Example 3 in FIGS. 7A to 7C.

Example 1 (FIG. 2)

TABLE 1-1

	Radius of Curvature	Thickness & Separation		Refractive Index		Abbe Number
R_1	262.97106	d_1	2.50	n_1 1.80518	ν_1	25.4
R_2	77.86633	d_2	0.82			
R_3	81.68581	d_3	8.15	n_2 1.62041	ν_2	60.3
R_4	−233.25481	d_4	0.15			
R_5	50.93572	d_5	4.21	n_3 1.65160	ν_3	58.6
R_6	168.84094	l_1				
R_7	410.39580	d_7	1.00	n_4 1.78590	ν_4	44.2
R_8	33.49766	d_8	2.50			
R_9	165.71959	d_9	2.48	n_5 1.80518	ν_5	25.4
R_{10}	−58.57077	d_{10}	0.7	n_6 1.78590	ν_6	44.2
R_{11}	23.56871	d_{11}	4.36			
R_{12}	27.80333	d_{12}	2.32	n_7 1.80518	ν_7	25.4
R_{13}	53.31014	l_2				
R_{14}	40.56176	d_{14}	4.0	n_8 1.62041	ν_8	60.3
R_{15}	530.29479	d_{15}	0.15			
R_{16}	33.64676	d_{16}	4.43	n_9 1.62041	ν_9	60.3
R_{17}	165.70311	d_{17}	5.69			
R_{18}	−52.11176	d_{18}	4.09	n_{10} 1.66680	ν_{10}	33.0
R_{19}	29.61205	d_{19}	3.91			
R_{20}	164.83944	d_{20}	3.41	n_{11} 1.62299	ν_{11}	58.2
R_{21}	−33.92492	d_{21}	1.17			
R_{22}	150.08264	d_{22}	1.20	n_{12} 1.60342	ν_{12}	38.0
R_{23}	31.49986	d_{23}	5.78	n_{13} 1.69680	ν_{13}	55.5
R_{24}	−412.30446					

TABLE 1-2

	f = 36	f = 61	f = 103
l_1	0.007	15.007	33.007
l_2	32.809	16.292	1.082
Back Focus	52.573	58.090	50.300

Example 2 (FIG. 3)

TABLE 2-1

	Radius of Curvature	Thickness & Separation		Refractive Index		Abbe Number
R_1	242.74901	d_1	2.50	n_1 1.80518	ν_1	25.4
R_2	74.19608	d_2	1.78			
R_3	76.45520	d_3	7.64	n_2 1.61800	ν_2	63.4
R_4	−191.93288	d_4	0.15			
R_5	46.17825	d_5	4.10	n_3 1.65160	ν_3	58.6
R_6	104.75431	l_1				
R_7	224.21886	d_7	1.00	n_4 1.78590	ν_4	44.2
R_8	129.90925	d_8	2.61			
R_9	122.22262	d_9	3.50	n_5 1.80518	ν_5	25.4
R_{10}	−39.06172	d_{10}	0.7	n_6 1.88300	ν_6	40.8
R_{11}	27.36909	d_{11}	4.81			
R_{12}	32.70868	d_{12}	1.65	n_7 1.84666	ν_7	23.9
R_{13}	72.39283	l_2				
R_{14}	38.52506	d_{14}	4.00	n_8 1.61800	ν_8	63.4
R_{15}	320.61760	d_{15}	0.15			
R_{16}	30.50763	d_{16}	4.43	n_9 1.61800	ν_9	63.4
R_{17}	113.36060	d_{17}	5.82			
R_{18}	−65.66310	d_{18}	4.09	n_{10} 1.69895	ν_{10}	30.1
R_{19}	28.16587	d_{19}	4.04			
R_{20}	8990.92661	d_{20}	3.41	n_{11} 1.62041	ν_{11}	60.3
R_{21}	−33.31840	d_{21}	1.17			
R_{22}	53.60101	d_{22}	1.20	n_{12} 1.59270	ν_{12}	35.3
R_{23}	33.95955	d_{23}	5.78	n_{13} 1.69680	ν_{13}	55.5
R_{24}	223.72286					

TABLE 2-2

	f = 36	f = 61	f = 103
l_1	0.277	15.277	33.277
l_2	32.7848	16.267	1.058
Back Focus	51.540	57.058	49.267

Example 3 (FIG. 4)

TABLE 3-1

	Radius of Curvature	Thickness & Separation		Refractive Index		Abbe Number
R_1	328.38416	d_1	2.50	n_1 1.80518	ν_1	25.4
R_2	81.80170	d_2	0.82			
R_3	95.53598	d_3	8.02	n_2 1.62041	ν_2	60.3
R_4	−183.65376	d_4	0.15			
R_5	51.85476	d_5	4.83	n_3 1.65160	ν_3	58.6
R_6	203.13189	l_1				
R_7	596.67526	d_7	1.00	n_4 1.78590	ν_4	44.2
R_8	31.43494	d_8	3.03			
R_9	198.67344	d_9	2.16	n_5 1.80518	ν_5	25.4
R_{10}	−84.98376	d_{10}	0.70	n_6 1.78590	ν_6	44.2
R_{11}	22.19917	d_{11}	2.41			

TABLE 3-1-continued

Radius of Curvature		Thickness & Separation		Refractive Index		Abbe Number	
R_{12}	25.11164	d_{12}	2.46	n_7	1.80518	ν_7	25.4
R_{13}	63.75892	l_2					
R_{14}	40.94271	d_{14}	4.05	n_8	1.62041	ν_8	60.3
R_{15}	−480.44814	d_{15}	0.15				
R_{16}	35.60846	d_{16}	4.43	n_9	1.62041	ν_9	60.3
R_{17}	−231.79195	d_{17}	5.69				
R_{18}	−39.29927	d_{18}	4.09	n_{10}	1.66680	ν_{10}	33.0
R_{19}	26.19201	d_{19}	3.91				
R_{20}	1213.80872	d_{20}	3.41	n_{11}	1.62299	ν_{11}	58.2
R_{21}	−45.00678	d_{21}	1.17				
R_{22}	−94.99096	d_{22}	1.2	n_{12}	1.60342	ν_{12}	38.0
R_{23}	36.59736	d_{23}	5.78	n_{13}	1.69680	ν_{13}	55.5
R_{24}	−37.05299						

TABLE 3-2

	f = 36	f = 61	f = 103
l_1	0.150	15.150	33.150
l_2	32.612	16.095	0.885
Back Focus	50.804	56.322	48.531

What is claimed is:

1. A zoom objective comprising:

a first lens group, a second lens group and a third lens group arranged in the order mentioned from an objective end to an image end;

said first lens group having a positive refractive power and being axially movable forward and then rearward when zooming from a wide angle to a telephoto setting;

said second lens group having a negative refractive power and being axially movable from the objective end to the image end when zooming from the wide angle to the telephoto setting; and

said third lens group having a positive refractive power and being axially movable forward and then rearward when zooming from the wide angle to the telephoto setting.

2. A zoom objective as described in claim **1**, wherein the locus of movement of said first lens group and the locus of movement of said third lens group are non-parallel to each other during zooming.

3. A zoom objective comprising:

a first lens group, a second lens group, and a third lens group arranged in the order mentioned from an objective end to an image end;

said first lens group having a positive refractive power and focusing and compensating functions, and moving first toward the objective end and then toward the image end during zooming from a wide angle position to a tele position;

said second lens group having a negative refractive power and magnificating function, and moving only in one direction from the objective end to the image end during zooming from the wide angle position to the tele position; and

said third lens group having a positive refractive power and compensating function, and moving first toward the objective end and then to the image surface end during zooming from the wide angle position to the tele position.

* * * * *

3/15/83 OR 4,376,571

United States Patent [19]

Ikemori

[11] **4,376,571**

[45] **Mar. 15, 1983**

[54] PHOTOGRAPHIC SMALL SIZE OBJECTIVE

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[73] Assignee: **Canon Kabushiki Kaisha**, Tokyo, Japan

[21] Appl. No.: **269,902**

[22] Filed: **Jun. 3, 1981**

[30] **Foreign Application Priority Data**

Jun. 6, 1980 [JP] Japan 55-76419

[51] **Int. Cl.**[3] **G02B 9/60**

[52] **U.S. Cl.** **350/467**

[58] **Field of Search** 350/467

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Primary Examiner—John K. Corbin
Assistant Examiner—Scott J. Sugarman
Attorney, Agent, or Firm—Toren, McGeady & Stanger

[57] **ABSTRACT**

A photographic small size objective of the modified Gauss type which is well corrected for high grade imaging performance. The objective comprises, from front to rear, a first lens in a meniscus form of positive power with its convex curvature toward the front, a second lens in a similar form, a third lens in a meniscus form of negative power with its convex curvature toward the front, a fourth lens in a meniscus form of negative power with its convex curvature toward the rear, and a fifth lens of positive power with its rear surface having a strong refractive power.

2 Claims, 16 Drawing Figures

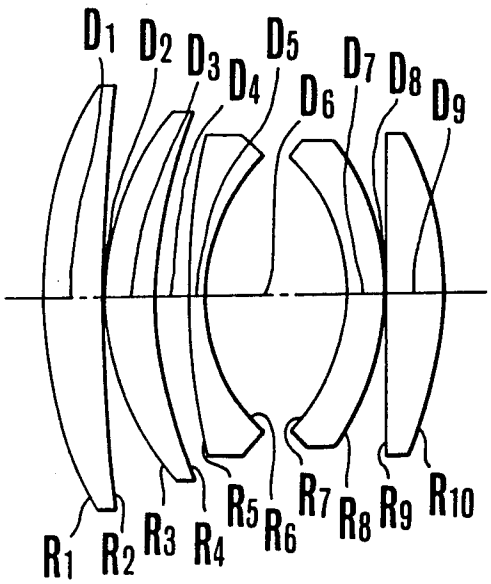


FIG.1

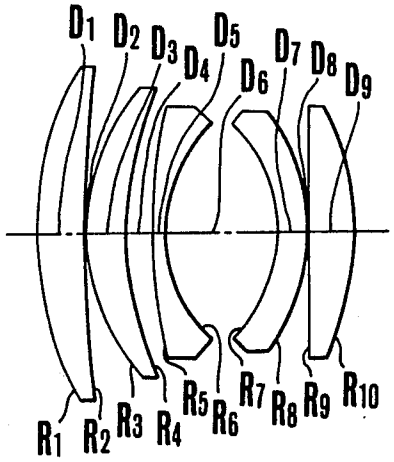


FIG.2(a) FIG.2(b) FIG.2(c) FIG.2(d)

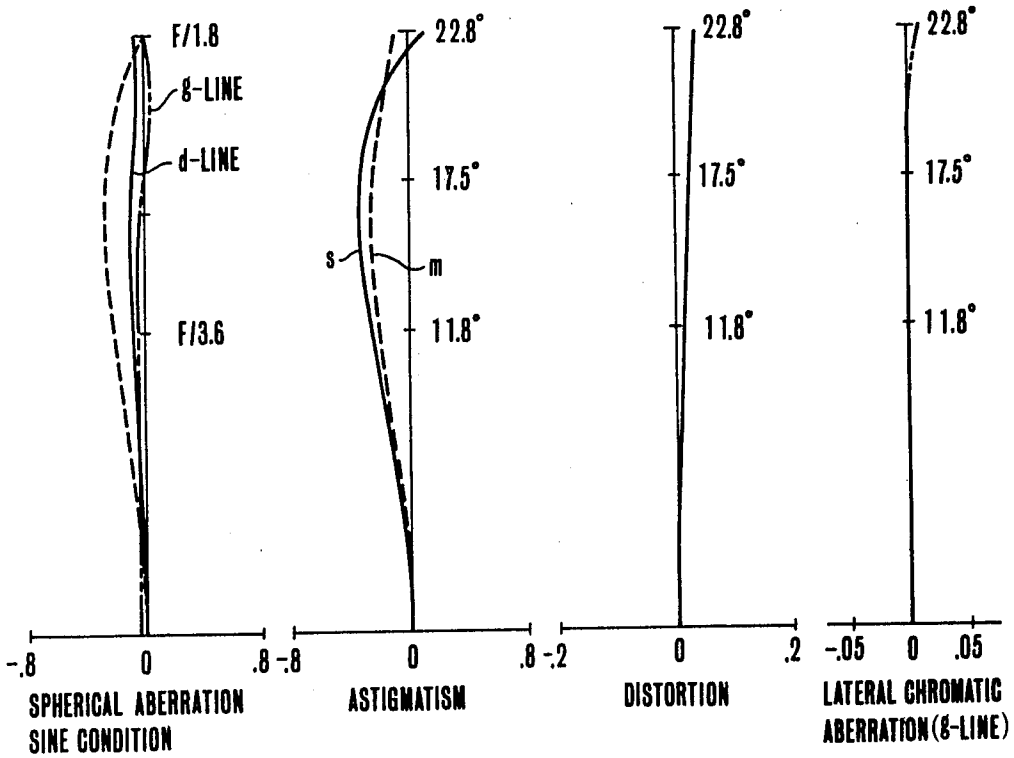


FIG.2(e)

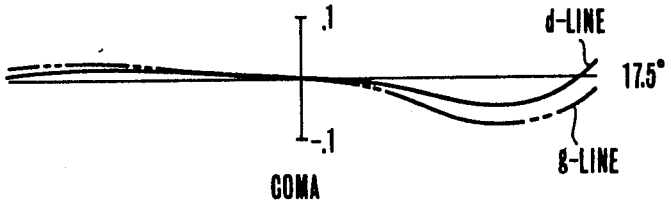


FIG.3(a) FIG.3(b) FIG.3(c) FIG.3(d)

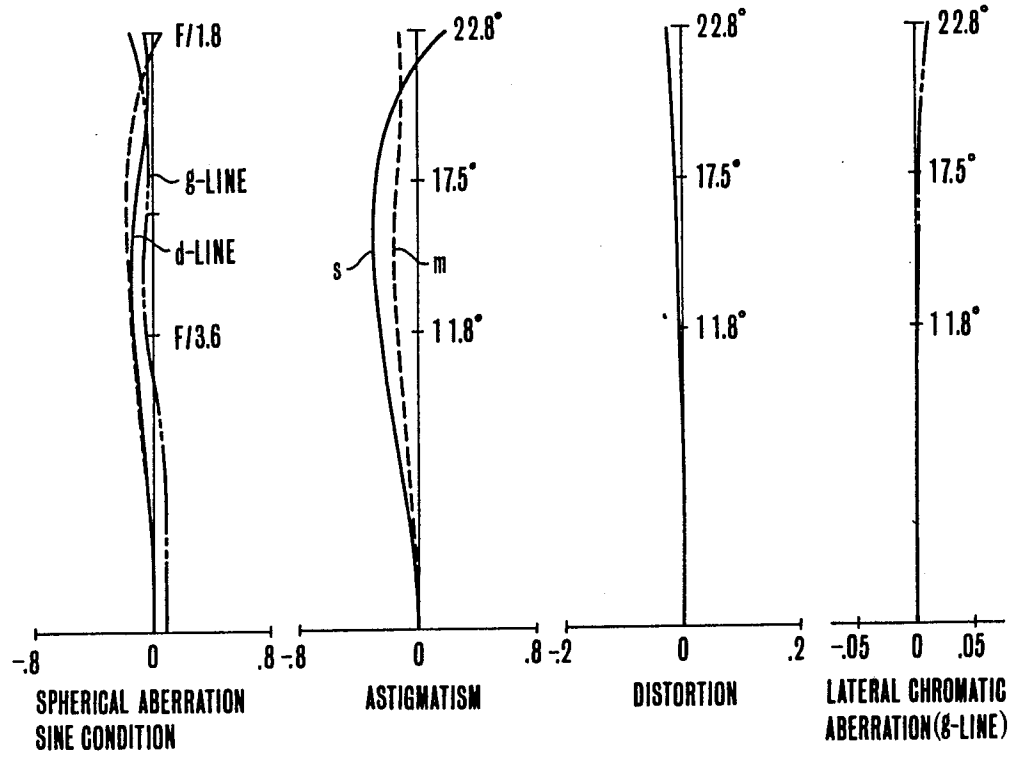


FIG.3(e)

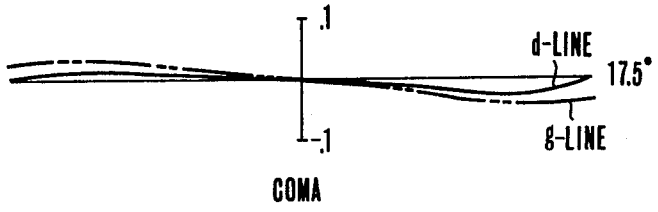


FIG.4(a) FIG.4(b) FIG.4(c) FIG.4(d)

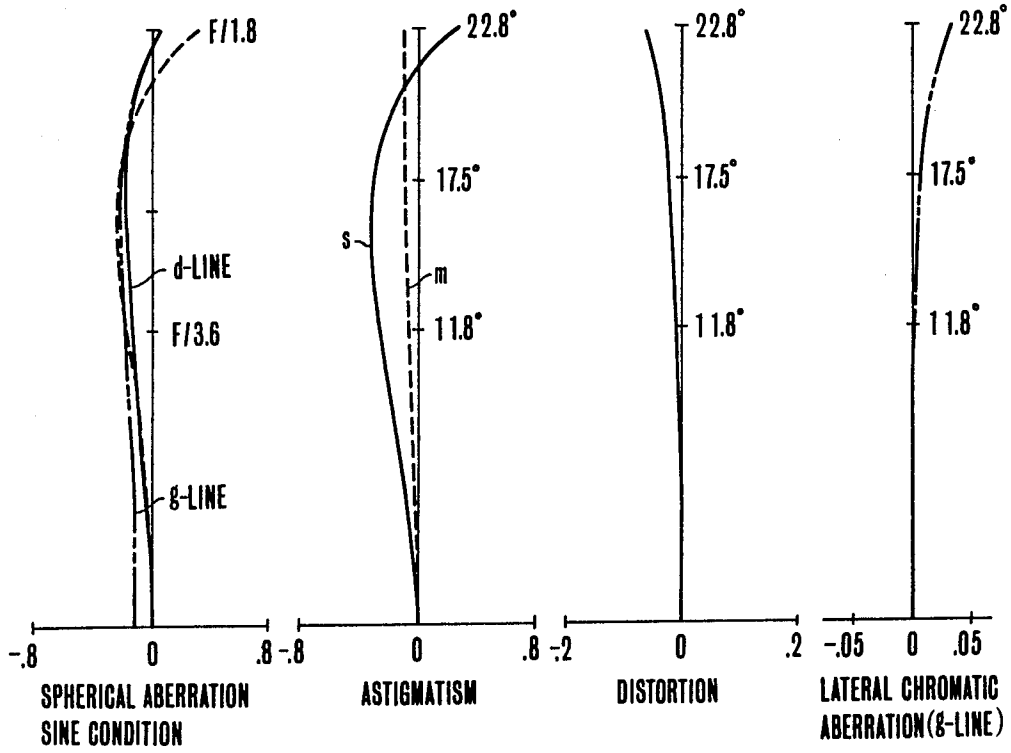
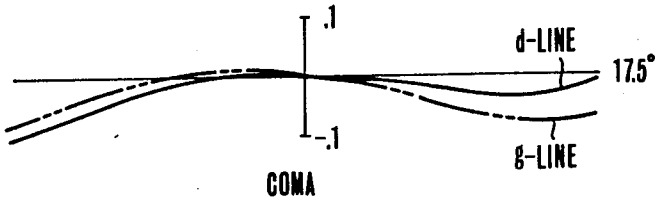


FIG.4(e)



PHOTOGRAPHIC SMALL SIZE OBJECTIVE

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to photographic objectives of the modified Gauss type, and more particularly to such objectives suited to be used as the standard lens for 35 mm single lens reflex cameras. In one form the objective includes four meniscus lenses and a fifth lens having positive power and a rear surface having a strong refractive power.

2. Description of the Prior Art

In general, the Gauss type objective is, because of its having a cemented lens just in the rear of the diaphragm, feasible to achieve good correction of chromatic aberrations such as longitudinal chromatic aberration, lateral chromatic aberration and color comatic aberration. On the other hand, an objective of what may be called the modified Gauss type with five elements constituting five components is disclosed, for example, in U.S. Pat. No. 2,720,139 and Japanese Pat. No. Sho 38-12983 where the first and second counting from the front are positive meniscus lenses of forward convexity, the third is a negative meniscus lens of forward convexity followed by a diaphragm, the fourth is a negative meniscus lens of rearward convexity, and the fifth is a positive meniscus lens. This type of objective is advantageous in minimizing the bulk and size of the apparatus. It is, however, very difficult to make the lens which follows the diaphragm, which is important to provide satisfactory correction of chromatic aberrations, since this lens is a singlet.

Therefore, this residual chromatic aberration must be compensated for by the suitable design of other lenses. It is, however, impossible in the present state of the art to achieve as good a correction as when the doublet is used in the rear of the diaphragm. Such substitution of the singlet for the doublet further aggravates other aberrations such as spherical aberration and curvature of field. As compared with the six-component Gauss type objective, there is a clear distinction in the optical performance. As a result, the general trend is to reduce the angular field, or the F-number to as dark a value as F2 or less in order to preserve the image quality.

SUMMARY OF THE INVENTION

An object of the present invention is to provide good compensation for the under-correction of chromatic aberrations which is a drawback of the conventional five-component-five-element objective, without negatively influencing other aberration correction, and to provide an objective having an imaging performance equal to or higher than that of the six-component Gauss type objective. It will be seen, from embodiments of the invention to be described later, that the objective in question has an F-number increased to f/1.8 which is common to the 6-component objectives, and is suited for use as the compact standard lens of high quality for 35 mm single lens reflex cameras.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram of an Example 1 embodiment of the invention.

FIGS. **2**(*a*), (*b*), (*c*), (*d*) and (*e*) are graphic representations of the various alternatives of the objective of FIG. **1**.

FIGS. **3**(*a*), (*b*), (*c*), (*d*) and (*e*) are graphic representations of Example 2 embodiments of the invention.

FIGS. **4**(*a*), (*b*), (*c*), (*d*) and (*e*) are graphic representations of Example 3 embodiments of the invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention is to provide an objective comprising, from front to rear, positive meniscus 1st and 2nd lenses each convex toward the front, a negative meniscus 3rd lens convex toward the front, a negative meniscus 4th lens convex toward the rear, and a positive 5th lens with its rear surface having a stronger curvature, and satisfying the following conditions:

$$0.04 < D_4/f < 0.06 \quad (1)$$

$$21.2 \leqq \nu 2 - \nu 3 < 28 \quad (2)$$

$$0.29 < |\psi 1| \cdot f < 0.75, \ \psi 1 < 0 \quad (3)$$

where f is the focal length of the entire system; D_4 is the axial air separation between the 2nd and 3rd lenses; $\nu 2$ and $\nu 3$ are the Abbe numbers (νd) of the 2nd and 3rd lenses respectively; and $\psi 1$ concerns with the air lens between the 2nd and 3rd lenses and is defined by $\psi 1 = (1 - N2)/R_4 + (N3 - 1)/R_5$ where N2 and N3 are the indices of refraction for d line of the 2nd and 3rd lenses respectively; R_4 is the radius of curvature of the rear surface of the 2nd lens; and R_5 is the radius of curvature of the front surface of the 3rd lens.

Each of the conditions is explained below.

Referring now to FIG. **1** condition (1) is, along with condition (2) desirable to provide amply chromatic aberration correction particularly color comatic aberration. The fact that a faster objective can be realized despite the decreased number of lens elements is largely ascribable to this condition. That is, the axial separation between the 2nd and 3rd lenses is wider than in the prior art to create an appreciable difference between the heights of incidence of off-axis rays of light from the optical axis on the surfaces R_4 and R_5. The use of a low dispersion glass in the 2nd lens and a high dispersion glass in the 3rd lens is made to increase the Abbe number difference to a considerable extent, thereby it being made possible to achieve good correction of longitudinal chromatic aberration, lateral chromatic aberration and even color comatic aberration. Further, spherical aberration and coma can be also amply corrected. When the lower limit of condition (1) is exceeded, under-correction of the color comatic aberration results. When the upper limit is exceeded, the back-focal distance can be no longer held in the prescribed value so that with the objective mounted on the single lens reflex camera when the mirror is flipped upward, the mirror will interfere with the rearmost lens element. When the lower limit of condition (2) is exceeded, not only under-correction of the color comatic aberration results, but also under-correction of the longitudinal chromatic aberration and over-correction of lateral chromatic aberration (for g line) result. When the upper limit is exceeded, the balance of the longitudinal and lateral chromatic aberrations will be broken.

Condition (3) is to amply correct spherical aberration and off-axis sagittal halo. When the lower limit is exceeded, under-correction of the spherical aberration and sagittal halo will result, which is unacceptable to the realization of as fast a lens speed as F/1.8 class.

When the upper limit is exceeded, large higher-order spherical aberrations are produced, and the spherical aberrations suddenly change from over-correction to under-correction as the aperture nears the full open, and a contrast loss result at full aperture.

To facilitate a further improvement of the overall image aberrations, it is preferred to satisfy the following conditions.

$$1.72<(N1+N2+N5)/3<1.81 \quad (4)$$

$$6.7<(1/R_6+1/|R_7|)\cdot f<8 \quad (5)$$

$$0.045<D_7/f<0.082 \quad (6)$$

$$20<\nu 3<28;\ 1.75<N3<1.93 \quad (7)$$

$$46<\nu 5<60 \quad (8)$$

where N1 and N5 are the refractive indices (for d line) of the 1st and 5th lenses respectively; R_6 is the radius of curvature of the rear surface of the 3rd lens; R_7 is the radius of curvature of the front surface of the 4th lens; D_7 is the axial thickness of the 4th lens; and $\nu 5$ is the Abbe number (νd) of the 5th lens.

Condition (4) is to provide good correction of field curvature. When the lower limit is exceeded, the Petzval sum becomes too large with an increase of the field curvature. When the upper limit is exceeded, even though the Petzval sum is improved, as the availability of existing glasses limits a range of Abbe numbers, the chromatic aberrations become difficult to correct, and, as the usable glasses are very expensive, the production cost is increased. Condition (5) is to facilitate an improvement of the sagittal halo and the coma in the intermediate zone of the picture area by limiting the curvatures of the surfaces R_6 and R_7 in front of and in the rear of the diaphragm respectively. This limitation causes the deterioration of the spherical aberration, field curvature and astigmatism, but condition (1) which strengthens the power of the air lens between the 2nd and 3rd lenses serves to effect good compensation therefor.

When the lower limit of condition (5) is exceeded, satisfactory correction of spherical aberration, field curvature and astigmatism is difficult. When the upper limit is exceeded, the production of sagittal halo and coma in the intermediate zone becomes serious. Condition (6) is to maintain a necessary back focus clearance by the limitation of the thickness of the 4th lens, and to provide ample correction of spherical aberration. That is, the 4th lens is thickened to some extent so that the back focal distance is increased, and the heights of the points from the optical axis at which a paraxial light ray crosses the both surfaces of that lens are differentiated for satisfactory correction of spherical aberration. When the lower limit is exceeded, the resultant back focus clearance and the spherical aberration are not acceptable. When the upper limit is exceeded, though the back focus clearance is kept long, the balance of the spherical aberration and astigmatism is broken, and further lateral chromatic aberration (for g line) is undercorrected.

The present invention employs a form of construction in which the lens elements that follow the diaphragm do not have a cemented surface as in the conventional 6-component standard objective of the Gauss type in order that longitudinal chromatic aberration and lateral chromatic aberration are both satisfactorily corrected. Accordingly it is required to select a glass of as low a dispersion as possible for employment in the 5th lens, and at least a range defined in condition (8) is necessitated. Again, the 3rd lens is also preferably made up of a glass of as high a dispersion as possible for the same purposes, and further this glass has to have a high refractive index for correction of spherical aberration and sagittal halo. Because of this, condition (7) is defined. Beyond these ranges, zonal spherical aberration becomes large, and the sagittal halo is largely increased so that it is difficult to achieve an increase in the imaging performance. Among the commercially available glasses, it is usual that $\nu 3$ is not less than 20, N3 is not more than 1.93, and $\nu 5$ is not more than 60. The glasses beyond these values are very expensive, and have poor chemical stability, and it is found that a photographic objective using these glasses is not practical.

Examples of specific objectives can be constructed in accordance with the following numerical data. The lens configuration of Example 1 is shown in FIG. **1**, and the spherical aberration, sine condition, astigmatism, distortion, lateral chromatic aberration and comatic aberration of the objective of FIG. **1** for infinitely distant object are represented in FIGS. **2**(*a*), (*b*), (*c*), (*d*) and (*e*) respectively. Also the various aberrations of Example 2 are represented in FIGS. **3**(*a*), (*b*), (*c*), (*d*) and (*e*) respectively, and also the various aberrations of Example 3 in FIGS. **4**(*a*), (*b*), (*c*), (*d*) and (*e*). It is to be understood from the above aberration curves particularly regarding the spherical aberration curves and comatic aberration curves for spectral d and g lines along with the lateral chromatic aberration curves that a good correction of the chromatic aberrations is achieved.

Example 1

Focal Length f = 100	Radius of Curvature		Thickness & Separation		Refractive Index (Nd)		Abbe Number (νd)
			F-number: 1.8		Image Angle 2ω = 45.5°		
R_1	66.583	D_1	8.573	N_1	1.8061	ν_1	40.9
R_2	366.202	D_2	0.31				
R_3	35.5245	D_3	6.151	N_2	1.804	ν_2	46.6
R_4	54.1095	D_4	4.167				
R_5	107.959	D_5	2.171	N_3	1.80518	ν_3	25.4
R_6	27.4583	D_6	18.268				
R_7	−29.4554	D_7	4.942	N_4	1.84666	ν_4	23.9
R_8	−40.447	D_8	0.271				
R_9	−602.818	D_9	8.281	N_5	1.804	ν_5	46.6
R_{10}	−48.164						

3rd Order Aberration Coefficients of Example 1

	L	T	SA	OM	AS	PT	DS
1	0.020831	0.006066	0.837171	0.243808	0.071004	0.670322	0.215895
2	0.009750	−0.017031	0.331366	−0.578833	1.011113	−0.121878	−1.553324
3	0.018538	0.006077	−0.105350	−0.034538	−0.011323	1.254560	0.407588
4	0.003535	−0.013003	0.096570	−0.355250	1.305844	−0.823656	−1.777489
5	−0.020967	0.027719	−1.223361	1.617292	−2.138072	0.413157	2.280350
6	−0.038954	−0.015947	−1.632320	−0.668229	−0.273555	−1.624422	−0.776982
7	0.043823	0.017162	−3.518107	1.377762	−0.539559	−1.556528	0.820870
8	0.029686	−0.018169	0.694290	−0.424923	0.260063	1.133535	−0.852917

-continued

	3rd Order Aberration Coefficients of Example 1						
	L	T	SA	OM	AS	PT	DS
9	−0.000145	0.011987	0.000008	−0.000687	0.056874	−0.073932	1.412118
10	0.021383	−0.004661	4.684623	−1.021228	0.222624	0.925335	−0.250250
total	−0.000167	0.000201	0.164890	0.155174	−0.033988	0.196493	−0.074141

L: Lateral Chromatic Aberration
T: Longitudinal Chromatic Aberration
SA: Spherical Aberration
CM: Comatic Aberration
AS: Astigmatic Aberration
PT: Petzval Sum
DS: Distortion

Example 2

Focal Length f = 100	F-number: 1.8	Image Angle 2ω = 45.5°				
Radius of Curvature	Thickness & Separation		Refractive Index (Nd)		Abbe Number (νd)	
R_1	61.726	D_1	8.42	N_1	1.8061	ν_1	40.9
R_2	250.22	D_2	0.232				
R_3	38.045	D_3	7.03	N_2	1.7725	ν_2	49.6
R_4	61.603	D_4	4.731				
R_5	103.01	D_5	2.317	N_3	1.80518	ν_3	25.4
R_6	26.1536	D_6	20.297				
R_7	−26.0623	D_7	5.543	N_4	1.80518	ν_4	25.4
R_8	−34.436	D_8	0.232				
R_9	∞	D_9	8.246	N_5	1.6968	ν_5	55.5
R_{10}	−45.386						

Example 3

Focal Length f = 100	F-number: 1.8	Image Angle 2ω = 45.5°				
Radius of Curvature	Thickness & Separation		Refractive Index (Nd)		Abbe Number (νd)	
R_1	82.194	D_1	6.4	N_1	1.8044	ν_1	39.6
R_2	352.6	D_2	0.31				
R_3	36.556	D_3	7.358	N_2	1.72916	ν_2	54.7
R_4	79.176	D_4	5.814				
R_5	120.979	D_5	2.171	N_3	1.7552	ν_3	27.5
R_6	26.078	D_6	19.372				
R_7	−30.546	D_7	7.752	N_4	1.80518	ν_4	25.4
R_8	−42.067	D_8	0.271				
R_9	484.21	D_9	7.162	N_5	1.6779	ν_5	55.3
R_{10}	−50.611						

Numerical Values of the Various Factors in the Conditions for the Examples

Factor	Example 1	Example 2	Example 3
$\|\phi_1\|.f$	0.74	0.47	0.3
D_4/f	0.042	0.047	0.058
$\nu_2 - \nu_3$	21.2	24.2	27.2
$(N_1 + N_2 + N_3).\frac{1}{3}$	1.8047	1.7585	1.7372
$(1/R_6 + 1/\|R_7\|).f$	7.04	7.66	7.11
D_7/f	0.049	0.055	0.078
ν_3	25.4	25.4	27.5
N_3	1.80518	1.80518	1.7552
ν_5	46.6	55.5	55.3

What is claimed is:

1. A photographic objective of small size consisting of five lens groups, each group having a single lens, including, from front to rear,

a meniscus 1st lens of positive power convex toward the front;

a meniscus 2nd lens of positive power convex toward the front;

a meniscus 3rd lens of negative power convex toward the front;

a meniscus 4th lens of negative power convex toward the rear; and

a 5th lens of positive power with its rear surface having a strong refractive power, and satisfying the following conditions:

$$0.04<D_4/f<0.06 \quad (1)$$

$$21.2\leqq\nu 2-\nu 3<28 \quad (2)$$

$$0.29<|\psi 1|\cdot f<0.75,\ \psi 1<0 \quad (3)$$

where:

f is the focal length of the entire system;

Ni and νi are the refractive index and Abbe number of the i-th lens counting from the front respectively;

Di is the i-th lens thickness or air separation counting from the front;

Ri is the radius of curvature of the i-th lens surface counting from the front; and

$$\psi 1=(1-N2)/R_4+(N3-1)/R_5.$$

2. A photographic objective of small size consisting of five lens groups, each group having a single lens including, from front to rear,

a meniscus 1st lens of positive power convex toward the front;

a meniscus 2nd lens of positive power convex toward the front;

a meniscus 3rd lens of negative power convex toward the front;

a meniscus 4th lens of negative power convex toward the rear; and

a 5th lens of positive power with its rear surface having a strong refractive power, and satisfying the following conditions:

$$0.04<D_4/f<0.06 \quad (1)$$

$$21.2\leqq\nu 2-\nu 3<28 \quad (2)$$

$$0.29<|\psi 1|\cdot f<0.75,\ \psi 1<0 \quad (3)$$

$$1.72<(N1+N2+N5)/3<1.81 \quad (4)$$

$$6.7<(1/R_6+1/|R_7|)f<8 \quad (5)$$

$$0.045<D_7/f<0.082 \quad (6)$$

$$20<\nu 3<28,\ 1.75<N3<1.93 \quad (7)$$

$$46<\nu 5<60 \quad (8)$$

where:

f is the focal length of the entire system;

Ni and νi are the refractive index and Abbe number of the i-th lens counting from the front respectively;

Di is the i-th lens thickness or air separation counting from the front;

Ri is the radius of curvature of the i-th lens surface counting from the front; and

$$\psi 1=(1-N2)/R4+(N3-1)/R5.$$

* * * * *

350-432
2/15/83 OR 4,373,786

United States Patent [19]

Yamada

[11] **4,373,786**

[45] **Feb. 15, 1983**

[54] **PHOTOGRAPHIC OBJECTIVE OF REDUCED SIZE**

[75] Inventor: **Yasuyuki Yamada**, Mitaka, Japan

[73] Assignee: **Canon Kabushiki Kaisha**, Tokyo, Japan

[21] Appl. No.: **291,630**

[22] Filed: **Aug. 10, 1981**

[30] **Foreign Application Priority Data**

Aug. 19, 1980 [JP] Japan 55-114199

[51] **Int. Cl.**[3] **G02B 3/04**; G02B 9/34

[52] **U.S. Cl.** **350/432**; 350/469

[58] **Field of Search** 350/432, 469

[56] **References Cited**

U.S. PATENT DOCUMENTS

2,446,402	8/1948	Aklin	350/469
3,951,523	4/1976	Nishimoto	350/432
3,998,527	12/1976	Ikada et al.	350/432
4,124,276	11/1978	Okano et al.	350/469 X

FOREIGN PATENT DOCUMENTS

55-73014	6/1980	Japan	350/469

Primary Examiner—John K. Corbin
Assistant Examiner—Scott J. Sugarman
Attorney, Agent, or Firm—Toren, McGeady and Stanger

[57] **ABSTRACT**

The disclosed photographic objective includes, from front to rear, a meniscus first lens of positive power convex toward the front, a bi-concave second lens, a bi-convex third lens, and a negative-power fourth lens whose front surface is concave toward the front and aspherical. The form of each of the lenses, the glass material, and the air separations between the successive lenses being chosen to reduce the overall size of the objective while still permitting good correction of aberrations.

1 Claim, 4 Drawing Figures

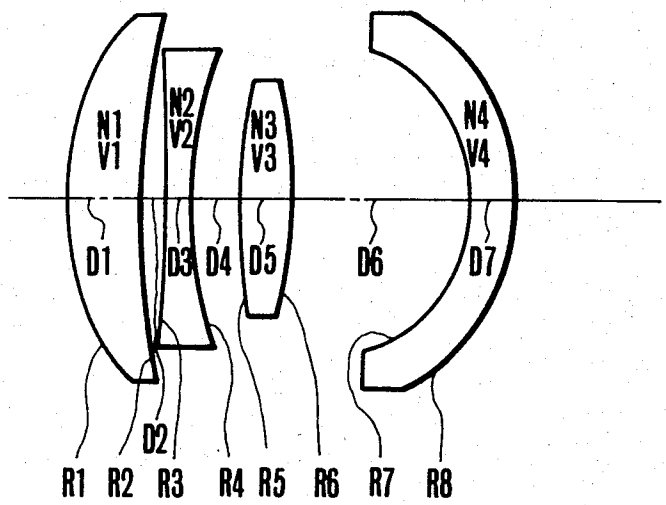


FIG.1

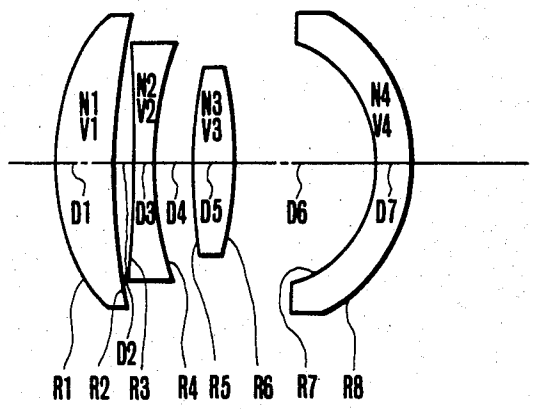
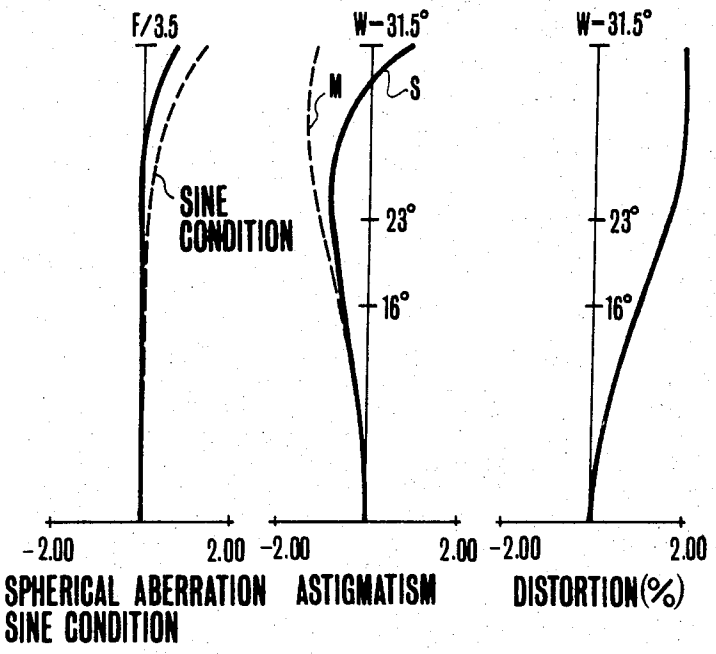


FIG.2a FIG.2b FIG.2c



PHOTOGRAPHIC OBJECTIVE OF REDUCED SIZE

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to lens systems of short total length measured from the front vertex to the focal plane, and more particularly to a small photographic objective with an angular field of about 63° and an F-number of about 3.5.

2. Description of the Prior Art

Recently, as cameras have been reduced in size, the demand has arisen for compact lenses of short focal length. Where the total length of a lens system is reduced to less than the focal length, it is desirable to distribute positive refractive power over the front group of lenses in the lens system and a negative refractive power over the rear group of lenses, or to employ a so-called telephoto-type system. Such power distribution has found many uses in long focal length lenses of narrow angular fields, but there are only a few examples of its application to wide angle objectives having angular fields of at least 60° in a short lens system with a large relative aperture.

With this type of power distribution, when the total length is reduced, and when the relative aperture is increased also, while the angular field is also widened, the distortion and astigmatism deteriorate badly or extremely large increases of coma and halo result.

U.S. Pat. No. 3,998,527 and Japanese Pat. Sho 44-10831 illustrate attempts to provide for photographic objectives of the telephoto type with increased angular fields. In the Japanese patent, the angular field is attained at a relatively narrow value, namely 46°, while the U.S. Patent illustrates a relatively wide angular field, namely 63°, but results in an F-number of 4.5.

SUMMARY OF THE INVENTION

The present applicant has proposed in Japanese Patent Application Sho 54-172405, a fast wide angle objective comprising, from front to rear, a meniscus lens of positive power, a lens of negative power, a lens of positive power and a meniscus lens of negative power with its front surface concave toward the front, said concave surface being strongly curved. Where this form of objective is employed for incorporation in a thin small-sized camera body, in order to give full play to the advantages of permitting the diaphragm mechanism to be positioned in the camera body in fixedly secured relation and the capability of lightening the weight of the movable lenses, it is desirable that the first three lenses constituting a front group be made to move for focusing purposes.

It is an object of the present invention to further improve the above-described proposal and to provide an objective lens of such construction that even when decentering of the lens groups occurs during focusing by the front group, the range of variation of the aberrations is limited to a minimum. To achieve this, the refractive power of the last lens is weakened to moderate the influence of the decentering. Though this provision leads to change the power distribution over the entire system, to cope with this change, the lens elements are formed that the various aberrations are well corrected.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a longitudinal sectional view of an embodiment of an objective according to the present invention.

FIGS. **2***a*, **2***b* and **2***c* are graphic representations of the aberrations of the objective of FIG. **1**.

DESCRIPTION OF PREFERRED EMBODIMENTS

In an embodiment of the present invention, the photographic objective has, as shown in FIG. **1**, from front to rear, a meniscus first lens of positive power convex toward the front, a second lens of bi-concave form, a third lens of bi-convex form and a meniscus fourth lens of negative power concave toward the front in strong curvature, the front lens surface of the fourth lens being aspherical. The equation for the aspherical surface is expressed by:

$$\Delta X = \frac{(1/R^*)Y^2}{1+\sqrt{1-(1/R^*)}} + A_1Y^2 + A_2Y^4 + A_3Y^6 \ldots + B_1Y^3 + B_2Y^5 + \ldots - \frac{(1/R)Y^2}{1+\sqrt{1-(Y/R)^2}}$$

where

ΔX, assuming that the optical axis is taken as X-axis, the direction perpendicular to the optical axis as Y-axis, the direction in which light advances as positive and the cross-point between the vertex of the objective and the optical axis at the original point, it is the difference along the X-axis between the aspherical surface and the extrapolation of a spherical surface contributing to the determination of the focal length;

R: the radius of curvature of the paraxial region;

R*: the radius of curvature of the lens standard spherical surface defined in $R^*=R/(1-2RA_1)$

Ai=the spheric even coefficients

Bi=the aspheric odd coefficients.

An example of a specific objective of the invention can be constructed in accordance with the following numerical data as related to a focal length F of 100 millimeters.

F = 100 F-number = 1:3.5 Image Angle 2ω = 63°

	Radius of Curvature	Thickness & Separation	Refractive Index (Nd)	Abbe Number (νd)
R1 =	28.32	D1 = 8.59	N1 = 1.77250	ν1 = 49.6
R2 =	86.00	D2 = 2.66		
R3 =	−159.52	D3 = 2.86	N2 = 1.80518	ν2 = 25.4
R4 =	43.65	D4 = 5.33		
R5 =	69.12	D5 = 5.44	N3 = 1.60342	ν3 = 38.0
R6 =	−69.12	D6 = 20.51		
R*7 =	−16.56	D7 = 4.58	N4 = 1.49171	ν4 = 57.4
R8 =	−22.20			

Aspherical Coefficients

A1 = -0.17023×10^{-2}	B1 = -0.54318×10^{-4}
A2 = 0.65538×10^{-5}	B2 = 0.73458×10^{-7}
A3 = -0.74579×10^{-7}	B3 = 0.15509×10^{-8}
A4 = 0.28740×10^{-9}	B4 = -0.13024×10^{-10}
A5 = 0.11786×10^{-12}	

By giving various dimensions to the above-listed values it is made possible to achieve a remarkable reduc-

tion in the size of the photographic objective while still permitting good correction of aberrations since the various aberrations vary to an extremely small extent even when the lens groups are decentered from each other during focusing by moving the front lens group.

What is claimed is:

1. A photographic objective of reduced size including the following various conditions:

from front to rear;

a first lens in the form of a positive meniscus lens convex toward the front;

a second lens in the form of a negative lens;

a third lens in the form of a positive lens;

a fourth lens with the front surface concave toward the front, said concave surface being aspheric and said aspheric surface being figured by the following equation:

$$\Delta X = \frac{(1/R^*)Y^2}{1+\sqrt{1-(Y/R^*)^2}} + A_1Y^2 + A_2Y^4 + A_3Y^6 + \ldots + B_1Y^3 + B_2Y^5 + \ldots - \frac{(1/R)Y^2}{1+\sqrt{1-(Y/R)^2}}$$

where the axial direction is taken as the X-axis, the direction perpendicular to the optical axis as the Y-axis, the direction in which light advances as positive, and the intersection of the vertex and the X-axis at the original point, and the difference along the X-axis direction between the aspheric surface and the surface obtained by extrapolating the spherical surface contributing to the determination of the focal length is denoted by ΔX, the radius of curvature of the paraxial region by R, the radius of curvature of the standard spherical surface of the lens defined as $R^*=R/(1-2RA_1)$, the aspheric even coefficients by Ai and the aspheric odd coefficients by Bi;

and being characterized by the following numerical values for the radii of curvature of the lens surface Ri numbered the i-th from the front, the lens thicknesses and axial air separations Di, the refractive indices for spectral d lines of the glasses of the lens elements Ni, and Abbe numbers νi of the glasses of the lens elements as related to a focal length of the entire lens system f=100:

F = 100 F-number = 1:3.5 Image Angle 2ω = 63°

Radius of Curvature	Thickness & Separation	Refractive Index (Nd)	Abbe Number (νd)
R1 = 28.32	D1 = 8.59	N1 = 1.77250	ν1 = 49.6
R2 = 86.00	D2 = 2.66		
R3 = −159.52	D3 = 2.86	N2 = 1.80518	ν2 = 25.4
R4 = 43.65	D4 = 5.33		
R5 = 69.12	D5 = 5.44	N3 = 1.60342	ν3 = 38.0
R6 = −69.12	D6 = 20.51		
R7 = −16.56	D7 = 4.58	N4 = 1.49171	ν4 = 57.4
R8 = −22.20			

Aspherical Coefficients (the Aspheric surface at R7)

A1 = -0.17023×10^{-2}	B1 = -0.54318×10^{-4}
A2 = 0.65538×10^{-5}	B2 = 0.73458×10^{-7}
A3 = -0.74579×10^{-7}	B3 = 0.15509×10^{-8}
A4 = 0.28740×10^{-9}	B4 = -0.13024×10^{-10}
A5 = 0.11786×10^{-12}	

* * * * *

350-432 SR
1/18/83 CR 4,368,956

United States Patent [19]

Yamada et al.

[11] **4,368,956**

[45] **Jan. 18, 1983**

[54] COMPACT PHOTOGRAPHIC OBJECTIVE

[75] Inventors: **Yasuyuki Yamada**, Tokyo; **Kikuo Momiyama**, Yokohama, both of Japan

[73] Assignee: **Canon Kabushiki Kaisha**, Japan

[21] Appl. No.: **218,576**

[22] Filed: **Dec. 22, 1980**

[30] **Foreign Application Priority Data**

Dec. 27, 1979 [JP] Japan 54-172405

[51] **Int. Cl.**[3] **G02B 3/04**; G02B 9/34

[52] **U.S. Cl.** **350/432**; 350/469

[58] **Field of Search** 350/469, 465, 432

[56] **References Cited**

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4,204,747	5/1980	Imai	350/465 X

FOREIGN PATENT DOCUMENTS

1269133	4/1972	United Kingdom	350/469
2036366	6/1980	United Kingdom	350/469

Primary Examiner—John K. Corbin
Assistant Examiner—Scott J. Sugarman
Attorney, Agent, or Firm—Toren, McGeady & Stanger

[57] **ABSTRACT**

The objective disclosed includes, from front to rear, a positive meniscus lens of forward convexity, a negative lens, a positive lens, and a negative meniscus lens having an aspheric front surface concave toward the front, and fulfills the following requirements:

$$-1.5f < fA < -0.5f$$

$$4.5 \times 10^{-4} < \left| \frac{\Delta x(0.7r_7)}{f} \right| < 4.0 \times 10^{-3}$$

$$6.5 \times 10^{-5} < \left| \frac{\Delta x(0.5r_7)}{f} \right| < 1.0 \times 10^{-3}$$

where

f is the focal length of the entire system;

fA is the focal length of the air lens defined by the opposing surfaces of the first and second lenses counting from the front; and

$$x(y) = \frac{(1/r_7^*)y^2}{1 + \sqrt{1 - (y/r_7^*)^2}} + a_1y^2 + a_2y^4 + a_3y^6 + \ldots + b_1y^3 + b_2y^5 + \ldots - \frac{(1/r_7)y^2}{1 + \sqrt{1 - (y/r_7)^2}}$$

wherein

r_7 is the paraxial radius of curvature of the front surface of the 4th lens; and

r_7^* is the radius of curvature of the lens reference spherical surface defined by

$$r_7 = \frac{1}{1/r_7^* + 2a_1}$$

5 Claims, 21 Drawing Figures

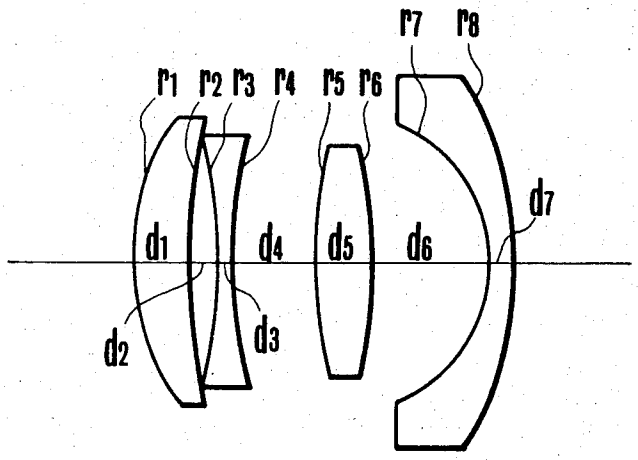


FIG. 1

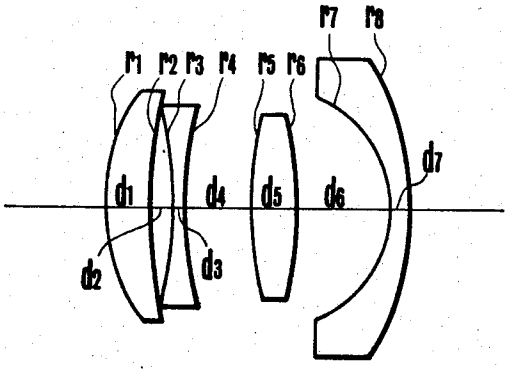


FIG.2a FIG.2b FIG.2c

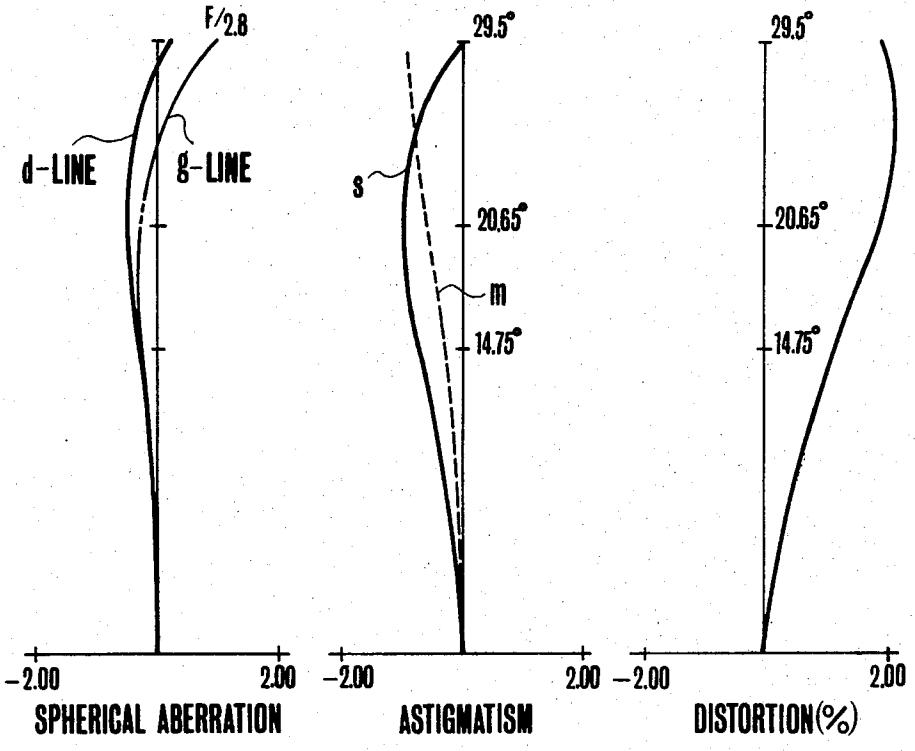


FIG.2d

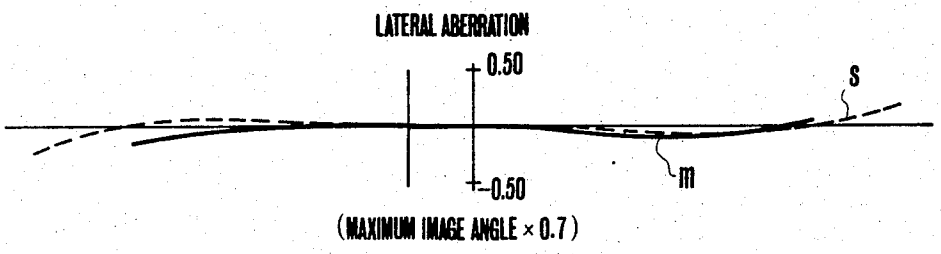


FIG.3a FIG.3b FIG.3c

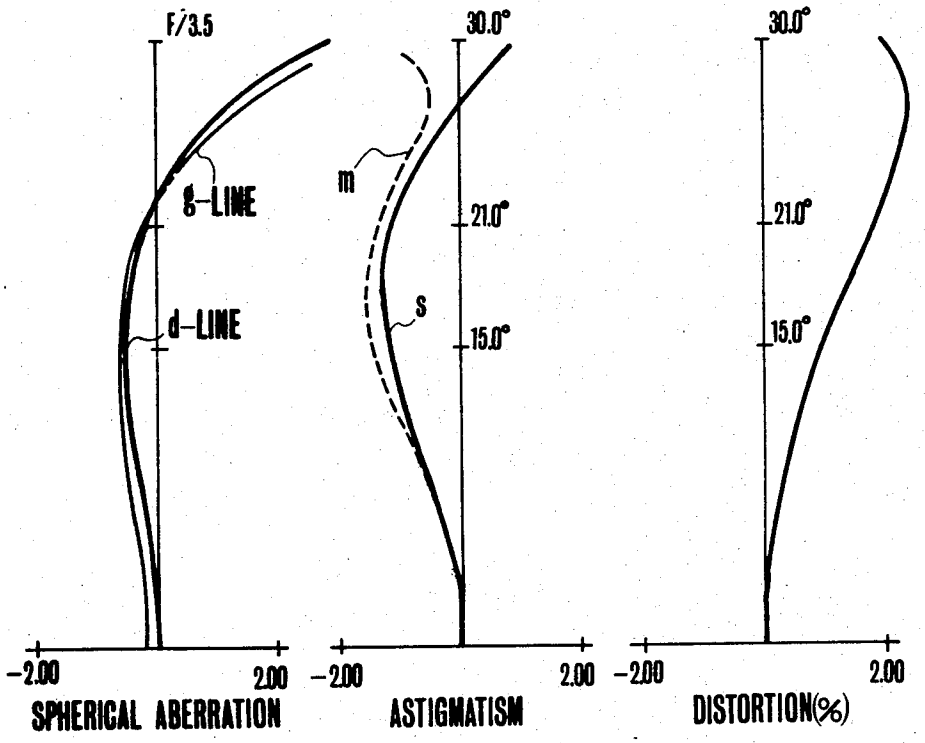


FIG.3d

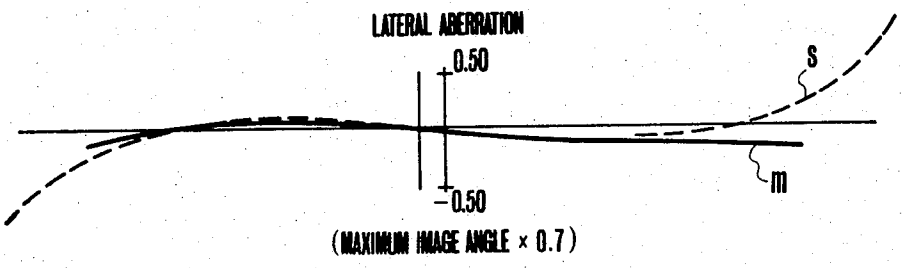


FIG.4a FIG.4b FIG.4c

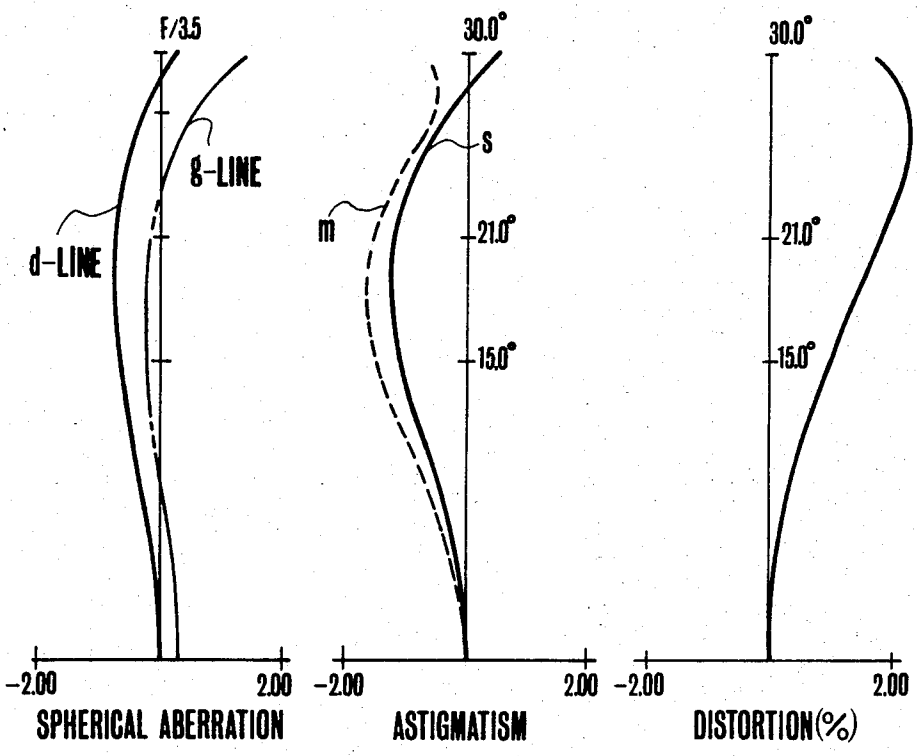


FIG.4d

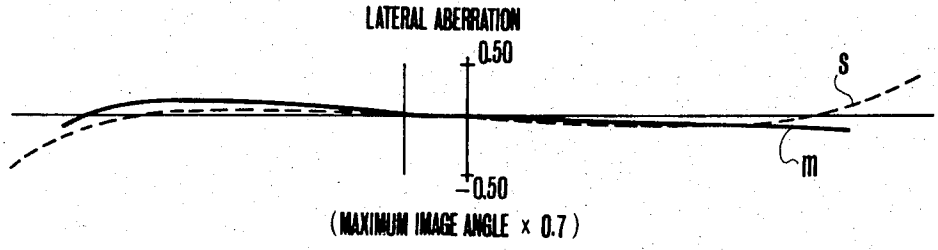


FIG.5a FIG.5b FIG.5c

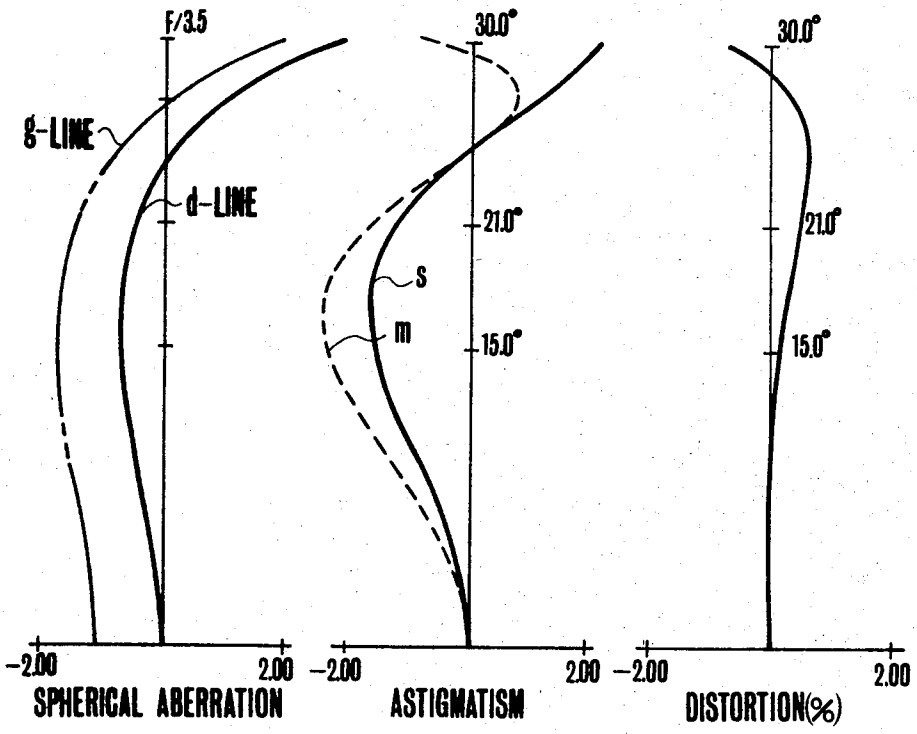


FIG.5d

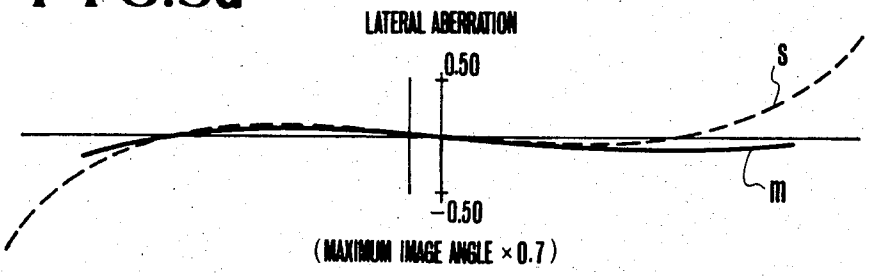


FIG.6a

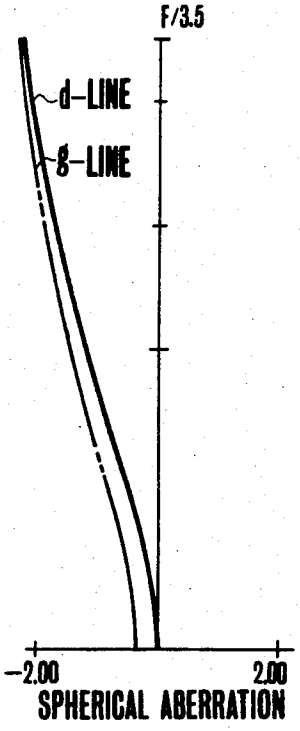


FIG.6b

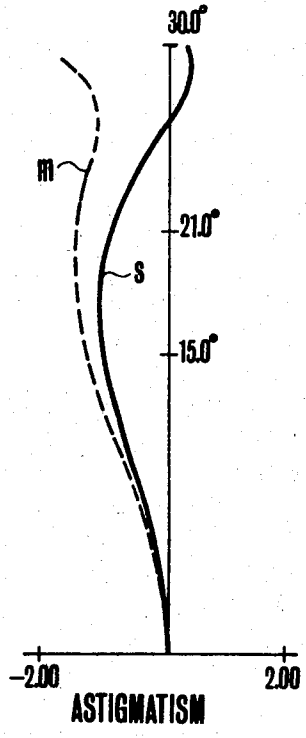


FIG.6c

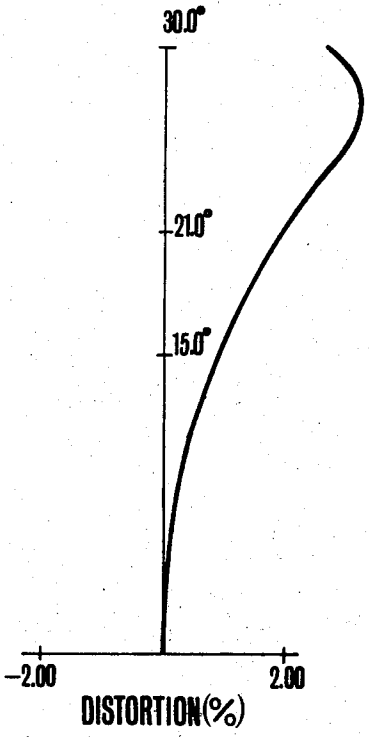
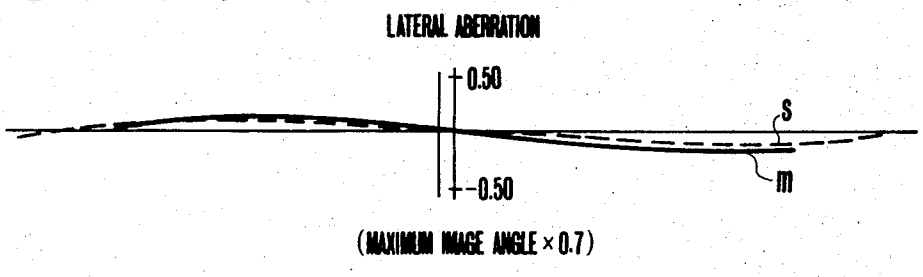


FIG.6d



COMPACT PHOTOGRAPHIC OBJECTIVE

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to lens systems of short total length (from the first surface of the lens to the focal plane) and more particularly to compact wide angle photographic objectives.

2. Description of the Prior Art

Recently, the trend toward minimizing the bulk and size of the camera has increased demands for compact lenses or objective lenses with shortened total lengths. When the total length of a lens system is reduced to less than one times the focal length, it is particularly desirable to make the front lens group of the lens system of a positive refractive power and the rear lens group of a negative refractive power. Such power distribution has found many uses in long lenses with narrow angular fields of view. However, there are a few examples of the application of this principle to objectives having wide angles at least 60° with large aperture ratios and short total lengths.

The reason for this deficiency is that this type of refractive power distribution increases the residual distortion and astigmatism objectionably, or produces extremely large comas and halo, as the total length decreases, the relative aperture increases and the angular field of view widens.

Japanese Patent Application Publication No. Sho 44-10831 discloses a lens system using this type of power distribution. However, the system described therein exhibits a field angle of 46°, that is, in the order of a standard lens. If an attempt is made to increase the angular field, the astigmatic difference will increase. U.S. Pat. No. 3,998,527 (Japanese Patent Application Publication No. Sho 52-48011) discloses a similar lens system. However, here the F number is 1:4.5.

SUMMARY OF THE INVENTION

It is an object of the present invention to minimize the number of constituent lens elements and shorten the total length of lens systems and to provide a compact faster wide angle objective lens with four elements constituting four components. In embodiments of the present invention to be described more fully later, an angular field of view of 59.7° with F/2.8 and 63.4° with F/3.5 has been achieved.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a longitudinal sectional view of an embodiment of an objective according to the present invention.

FIGS. 2(*a*), (*b*), (*c*) and (*d*) are graphic representations of the various aberrations of Example 1 of the objective.

FIGS. 3(*a*), (*b*), (*c*) and (*d*) are graphic representations of the various aberrations of Example 2 of the objective.

FIGS. 4(*a*), (*b*), (*c*) and (*d*) are graphic representations of the various aberrations of Example 3 of the objective.

FIGS. 5(*a*), (*b*), (*c*) and (*d*) are graphic representations of the various aberrations of Example 4 of the objective.

FIGS. 6(*a*), (*b*), (*c*) and (*d*) are graphic representations of the various aberrations of Example 5 of the objective.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention is to provide an objective comprising, from front to rear, a positive meniscus 1st lens component convex toward the front, a negative 2nd component, a positive 3rd component and a negative meniscus 4th component with its front aspheric surface concave toward the front, wherein letting f denote the focal length of the entire system and fA the focal length of the air lens forms in a separation between the 1st and 2nd components, the following requirement (1) is fulfilled:

$$-1.5f < fA < -0.5f \tag{1}$$

Further, taking the axial direction as the x-axis and the direction perpendicular to the optical axis as the y-axis, stipulating that the quantity measured in a direction in which the light progresses shall have the positive sign, and locating the original point at the intersection of the vertex of the front surface of the 4th component and the x-axis, the difference Δx between the aspheric surface and a spherical surface assumed to have a radius of curvature equal to that of curvature of the paraxial region of the aspheric surface which contributes to the determination of the focal length is expressed by the following formula:

$$\Delta x = \frac{\left(\frac{1}{r_7^*}\right) y^2}{1 + \sqrt{1 - \left(\frac{y}{r_7^*}\right)^2}} + a_1 y^2 + a_2 y^4 + a_3 y^6 + \ldots + b_1 y^3 + b_2 y^5 + \ldots - \frac{\left(\frac{1}{r_7}\right) y^2}{1 + \sqrt{1 - \left(\frac{y}{r_7}\right)^2}}$$

where r_7 is the radius of curvature of the paraxial region of the front surface of the 4th lens component;

r_7^* is the radius of the curfature of the reference spherical surface of the lens defined by the following formula:

$$r_7 = \frac{1}{\frac{1}{r_7^*} + 2a_1}$$

ai is the coefficient of the i-th even-numbered power term; and

bi is the coefficient of the i-th odd-numbered power term. Then, letting $\Delta x(0.7r_7)$ denote the value of Δx at the height $r_7 \times 0.7$ in y coordinate and $\Delta x(0.5r_7)$ the value of Δx at the height $r_7 \times 0.5$, the following requirements (2) and (3) are fulfilled

$$4.5 \times 10^{-4} < \left| \frac{\Delta \times (0.7r_7)}{f} \right| < 4.0 \times 10^{-3} \tag{2}$$

$$6.5 \times 10^{-3} < \left| \frac{\Delta \times (0.5r_7)}{f} \right| < 1.0 \times 10^{-3} \tag{3}$$

In this embodiment the 1st to 4th lens components take the form of a positive meniscus lens, a bi-concave lens, a bi-convex lens and a negative meniscus lens respectively.

The significance of each of these inequalities is as follows. When the lower limit of inequality (1) is ex-

ceeded, under-correction of spherical aberration results, and the astigmatic difference also increases, resulting in strong inward coma, and the transverse chromatic aberration also increases in the negative sense. When the upper limit is exceeded, over-correction of sagittal image surface results and the astigmatic difference also increases, resulting in strong halo, and the longitudinal chromatic aberration also increases in the negative sense. Therefore, in order to obtain a compact lens system which is well corrected for spherical aberration and astigmatism while keeping coma and halo and further longitudinal and transverse chromatic aberrations to a minimum, it is, of importance to fulfil requirement (1).

Requirement (2) has a particular concern with aberration correction of the marginal zone of the angular field of view.

A lens system with the negative meniscus lens at a rear position as in the present invention, is subject to deterioration of astigmatism in the negative sense as a result of this negative meniscus lens. This causes the production of positive distortion, inward coma and halo. Requirement (2) is to compensate for such deterioration of astigmatism, positive distortion, inward coma and halo. That is, when $|\Delta x(0.7r_7)/f|$ exceeds the lower limit, though the positive distortion and halo can be compensated for, over-correction of sagittal image surface results and strong inward coma is also produced. When the upper limit is exceeded, though correction of coma is possible, sufficient correction of positive distortion becomes impossible. To achieve a good state of correction of the aberrations at the marginal zone of the angular field of view, therefore it is important to fulfil requirement (2).

Requirement (3) concerns aberration correction particularly in the middle zone of the angular field of view.

That is, when $|\Delta x(0.5r_7)/f|$ exceeds the lower limit, under-correction of meridional image surface results and the astigmatic difference also increases, thereby causing strong inward coma. When the upper limit is exceeded, under-correction of spherical aberration results and halo is produced at the middle zone of the angular field of view. To achieve a good state of correction of the aberration at the middle zone, therefore, it is important to fulfil requirement (3).

The use of synthetic resin in making the 4th or aspherical lens can provide an inexpensive photographic objective.

Fulfillment of the following additional requirements (I) and (II) facilitates a shortening of the lens system while simultaneously maintaining the good state of correction of the image aberrations.

$$0.6 < \frac{F_{123}}{|F_4|} < 1.1 \quad \text{(I)}$$

$$0.1 < \frac{D_6}{f} < 0.25 \quad \text{(II)}$$

where

F_{123} is the overall focal length of the 1st, 2nd and 3rd lens components;

F_4 is the focal length of the 4th lens component; and

D_6 is the axial air separation between the 3rd and 4th lens components.

When the lower limit of inequality (I) is exceeded, the refractive power of the front group of the 1st, 2nd and 3rd lens components becomes too strong relative to the refractive power of the rear group, composed of the 4th lens component to shorten the back focal length. Therefore, the total length of the lens system cannot be shortened. When the upper limit is exceeded, under-correction of spherical aberration results, and the astigmatic difference also increases, thereby causing the production of strong halo.

With the total length of the lens system shortened, when the lower limit of inequality (2) is exceeded, sagittal image surface is over-corrected in the marginal zone and under-corrected in the middle zone, and the astigmatic difference also increases. This causes strong inward coma. When the upper limit is exceeded, spherical aberration is under-corrected, which causes the production of extremely large halo.

Five examples of specific objectives can be constructed in accordance with the numerical data given in the following tables. Example 1 of the specific objective is depicted in longitudinal section in FIG. 1. The spherical aberration, astigmatism, distortion and lateral aberration of the objective of FIG. 1 are graphically represented in FIG. 2. Examples 2 to 5 have these aberrations shown in FIGS. 3 to 6 respectively.

In the tables, r are the radii of curvature of the paraxial regions of the various lens surfaces; r_7* the radius of curvature of the reference spherical surface for the aspheric surface satisfying the following equation: $r_7 = 1/(1/r_7^* + 2a_1)$; d the axial thicknesses and air separations between the successive lens surfaces; n the indices of refraction for the spectral d-line of the glasses of which the various lens elements are made up; ν the Abbe numbers of the glasses of which the various lens elements are made up; ai the even coefficients of the aspheric surface; and bi the odd coefficients of the aspheric surface.

EXAMPLE 1

Focal Length f = 100		F-number = 1:2.8	
Image Angle 2ω = 59.7°		Back Focal Length = 44.592	
$r_1 = 32.515$			
	$d_1 = 7.431$	$n_1 = 1.77250$	$\nu_1 = 49.60$
$r_2 = 138.466$			
	$d_2 = 3.069$		
$r_3 = -170.178$			
	$d_3 = 2.654$	$n_2 = 1.80518$	$\nu_2 = 25.40$
$r_4 = 54.998$			
	$d_4 = 10.753$		
$r_5 = 72.652$			
	$d_5 = 6.633$	$n_3 = 1.58144$	$\nu_3 = 40.70$
$r_6 = -76.656$			
	$d_6 = 20.323$		
$r_7^* = -21.267$			
	$d_7 = 2.654$	$n_4 = 1.49171$	$\nu_4 = 57.40$

$a_1 = 0$	$b_1 = 0.$
$a_2 = 8.584793 \times 10^{-7}$	$b_2 = 0.$
$a_3 = -5.929712 \times 10^{-9}$	$b_3 = 0.$
$a_4 = 3.097644 \times 10^{-11}$	$b_4 = 0.$
$a_5 = 1.536608 \times 10^{-15}$	$\lvert\Delta \times (0.7r_7)/f\rvert = 5.316 \times 10^{-4}$
	$\lvert\Delta \times (0.5r_7)/f\rvert = 7.490 \times 10^{-5}$

EXAMPLE 2

Focal Length f = 100		F-number = 1:3.5	
Image Angle 2ω = 63.4°		Back Focal Length = 46.287	
$r_1 = 24.324$			
	$d_1 = 7.575$	$n_1 = 1.62299$	$\nu_1 = 58.20$
$r_2 = 97.118$			
	$d_2 = 2.077$		
$r_3 = -121.634$			

-continued

	$d_3 = 2.857$	$n_2 = 1.80518$	$\nu_2 = 25.40$
$r_4 = 71.875$			
	$d_4 = 9.248$		
$r_5 = 61.748$			
	$d_5 = 5.533$	$n_3 = 1.60342$	$\nu_3 = 38.00$
$r_6 = -72.560$			
	$d_6 = 13.491$		
$r_7^* = -18.486$			
	$d_7 = 2.857$	$n_4 = 1.49171$	$\nu_4 = 57.40$
$r_8 = -38.337$			

$a_1 = -4.723277 \times 10^{-3}$	$b_1 = 7.668476 \times 10^{-5}$
$a_2 = -1.116594 \times 10^{-5}$	$b_2 = -8.079283 \times 10^{-7}$
$a_3 = 7.937741 \times 10^{-8}$	$b_3 = -1.550163 \times 10^{-9}$
$a_4 = -2.674623 \times 10^{-10}$	$b_4 = 8.756197 \times 10^{-12}$
$a_5 = -6.168720 \times 10^{-14}$	$\lvert\Delta \times (0.7r_7)/f\rvert = 1.6403 \times 10^{-3}$
	$\lvert\Delta \times (0.5r_7)/f\rvert = 4.0760 \times 10^{-4}$

EXAMPLE 3

Focal Length f = 100	F-number = 1:3.5		
Image Angle $2\omega = 63.4°$	Back Focal Length = 42.888		
$r_1 = 25.374$			
	$d_1 = 8.148$	$n_1 = 1.62299$	$\nu_1 = 58.20$
$r_2 = 257.506$			
	$d_2 = 1.384$		
$r_3 = -190.781$			
	$d_3 = 2.857$	$n_2 = 1.80518$	$\nu_2 = 25.40$
$r_4 = 60.902$			
	$d_4 = 12.904$		
$r_5 = 65.657$			
	$d_5 = 5.592$	$n_3 = 1.60342$	$\nu_3 = 38.00$
$r_6 = -157.816$			
	$d_6 = 13.121$		
$r_7^* = -20.593$			
	$d_7 = 2.857$	$n_4 = 1.49171$	$\nu_4 = 57.40$
$r_8 = -32.946$			

$a_1 = -7.31674 \times 10^{-3}$	$b_1 = 6.039290 \times 10^{-5}$
$a_2 = -1.276859 \times 10^{-5}$	$b_2 = 8.819042 \times 10^{-7}$
$a_3 = 4.480833 \times 10^{-8}$	$b_3 = 1.273531 \times 10^{-9}$
$a_4 = -1.675822 \times 10^{-10}$	$b_4 = -6.598211 \times 10^{-12}$
$a_5 = 9.252578 \times 10^{-14}$	$\lvert\Delta \times (0.7r_7)/f\rvert = 1.9239 \times 10^{-3}$
	$\lvert\Delta \times (0.5r_7)/f\rvert = 4.4060 \times 10^{-4}$

EXAMPLE 4

Focal Length f = 100	F-number = 1:3.5		
Image Angle $2\omega = 63.4°$	Back Focal Length = 45.988		
$r_1 = 24.200$			
	$d_1 = 7.631$	$n_1 = 1.62299$	$\nu_1 = 58.20$
$r_2 = 64.557$			
	$d_2 = 2.790$		
$r_3 = -83.987$			
	$d_3 = 2.857$	$n_2 = 1.80518$	$\nu_2 = 25.40$
$r_4 = 165.675$			
	$d_4 = 9.509$		
$r_5 = 57.757$			
	$d_5 = 6.588$	$n_3 = 1.60342$	$\nu_3 = 38.00$
$r_6 = -60.352$			
	$d_6 = 11.783$		
$r_7^* = -20.022$			
	$d_7 = 2.855$	$n_4 = 1.49171$	$\nu_4 = 57.40$
$r_8 = -47.418$			

$a_1 = -7.92270 \times 10^{-3}$	$b_1 = 8.663171 \times 10^{-5}$
$a_2 = -1.077759 \times 10^{-5}$	$b_2 = -7.975899 \times 10^{-7}$
$a_3 = 4.093707 \times 10^{-8}$	$b_3 = -2.177460 \times 10^{-9}$
$a_4 = -5.164162 \times 10^{-11}$	$b_4 = 4.784007 \times 10^{-14}$
$a_5 = 1.170928 \times 10^{-14}$	$\lvert\Delta \times (0.7r_7)/f\rvert = 2.621 \times 10^{-3}$
	$\lvert\Delta \times (0.5r_7)/f\rvert = 6.633 \times 10^{-4}$

EXAMPLE 5

Focal Length f = 100	F-number = 1:3.5		
Image Angle $2\omega = 63.4°$	Back Focal Length = 35.113		
$r_1 = 29.407$			
	$d_1 = 6.646$	$n_1 = 1.62299$	$\nu_1 = 58.20$
$r_2 = 191.432$			
	$d_2 = 1.671$		
$r_3 = -117.630$			
	$d_3 = 2.857$	$n_2 = 1.80518$	$\nu_2 = 25.40$
$r_4 = 103.042$			
	$d_4 = 11.610$		
$r_5 = 72.040$			
	$d_5 = 5.250$	$n_3 = 1.60342$	$\nu_3 = 38.00$
$r_6 = -98.119$			
	$d_6 = 23.714$		
$r_7^* = -20.271$			
	$d_7 = 2.857$	$n_4 = 1.49171$	$\nu_4 = 57.40$
$r_8 = -41.485$			

$a_1 = -6.121587 \times 10^{-3}$	$b_1 = 2.108068 \times 10^{-4}$
$a_2 = -2.587921 \times 10^{-5}$	$b_2 = 1.464219 \times 10^{-7}$
$a_3 = 7.742172 \times 10^{-8}$	$b_3 = -2.253693 \times 10^{-9}$
$a_4 = -3.024633 \times 10^{-10}$	$b_4 = 1.766612 \times 10^{-11}$
$a_5 = -2.95977 \times 10^{-13}$	$\lvert\Delta \times (0.7r_7)/f\rvert = 3.4155 \times 10^{-3}$
	$\lvert\Delta \times (0.5r_7)/f\rvert = 9.3780 \times 10^{-4}$

What is claimed is:

1. A compact photographic objective comprising:

from the front,

a first positive meniscus lens convex toward the front and forming a surface toward the rear,

a second negative lens forming a surface toward the front,

a third positive lens,

a fourth negative meniscus lens having a surface concave toward the front, the concave surface being aspheric,

said first, second, third, and fourth lenses together forming a system having an axial direction and a focal length f,

the opposing surfaces of the first and second lenses forming an air lens having a focal length fA, the values f and fA being related so that

$$-1.5f < fA < -0.5f,$$

taking the axial direction an an x-axis, a direction perpendicular to the optical axis as a y-axis, the forward direction of the light as positive, and the intersection of the vertex of one of the lenses and the x-axis as an origin, the aspheric surface being defined by the following formula for the x-axis directional difference Δx between the aspheric surface and an ideal spherical surface, the latter of which contributes to the determination of the focal length:

$$\Delta x = \frac{\left(\frac{1}{r_7^*}\right) y^2}{1 + \sqrt{1 - \left(\frac{y}{r_7^*}\right)^2}} + a_1 y^2 + a_2 y^4 + a_3 y^6 + \ldots$$

$$+ b_1 y^3 + b_2 y^5 + \ldots - \frac{\left(\frac{1}{r_7}\right) y^2}{1 + \sqrt{1 - \left(\frac{y}{r_7}\right)^2}}$$

where r_7 is the radius of curvature of the paraxial region of the front surface of the 4th lens; r_7^* is the radius of curvature of the reference spherical surface of the lens defined by $r_7 = 1/(1/r_7^* + 2a)$; ai are the even coefficients of the aspheric surface; and bi are the odd coefficients of the aspheric surface, whereby letting $\Delta x\ (0.7r_7)$ denote the value of Δx at the height $r_7 x 0.7$ in y coordinate, and $\Delta x(0.5r_7)$ the value of Δx at the height of $r_7 x 0.5$, and the condition

$$4.5 \times 10^{-4} < \left| \frac{\Delta x(0.7r_7)}{f} \right| < 4.0 \times 10^{-3}$$

$$6.5 \times 10^{-5} < \left| \frac{\Delta x(0.5r_7)}{f} \right| < 1.0 \times 10^{-3}$$

$$0.1 < \frac{D_6}{f} < 0.25$$

being satisfied.

2. A compact photographic objective according to claim 1, wherein said second lens is a negative lens in bi-concave form, and the said third lens is a positive lens in bi-convex form.

3. A compact photographic objective according to claim 1, wherein said fourth lens is made of a synthetic resin.

4. A compact photographic objective according to claim 1, further satisfying the following conditions:

$$0.6 < \frac{F_{123}}{|F_4|} < 1.1$$

where F_{123} is the overall focal length of the 1st lens, said 2nd lens and said 3rd lens; F_4 is the focal length of said 4th lens; and D_6 is the axial air separation between said 3rd and said 4th lenses.

5. An objective as in claims 1, 2, 3, or 4, wherein the origin is the intersection of the vertex of the front surface of the fourth component and the x-axis.

* * * * *

United States Patent [19]

Masson

[11] **4,368,955**

[45] **Jan. 18, 1983**

[54] **VARIABLE-FOCAL-LENGTH OBJECTIVE**

[75] Inventor: **André Masson**, Saint-Heand, France

[73] Assignee: **Etablissements Pierre Angenieux**, Saint-Heand, France

[21] Appl. No.: **155,480**

[22] Filed: **Jun. 2, 1980**

[30] **Foreign Application Priority Data**

Jun. 26, 1979 [FR] France 79 16373

[51] **Int. Cl.**[3] **G02B 15/16**

[52] **U.S. Cl.** **350/427**

[58] **Field of Search** 350/427, 428

[56] **References Cited**

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Primary Examiner—John K. Corbin

Assistant Examiner—Scott J. Sugarman

Attorney, Agent, or Firm—Michael J. Striker

[57] **ABSTRACT**

The variable-focal-length objective for motion-picture cameras and especially color television cameras comprises two movable groups of lens elements placed between two stationary groups of lens elements and capable of displacement so as to produce a variation of the focal distance. In this objective, the two movable groups each take part in the total variation of magnification; each elementary magnification has a minimum and maximum absolute value during the variation, such that the ratio of maximum value to minimum value is higher than 1:1. However, only one of the two movable groups which does not pass through a magnification of unity performs both a magnification function and an additional focusing function. On the other hand, the other movable group which may pass through a position corresponding to a magnification of unity performs only a magnification function.

7 Claims, 6 Drawing Figures

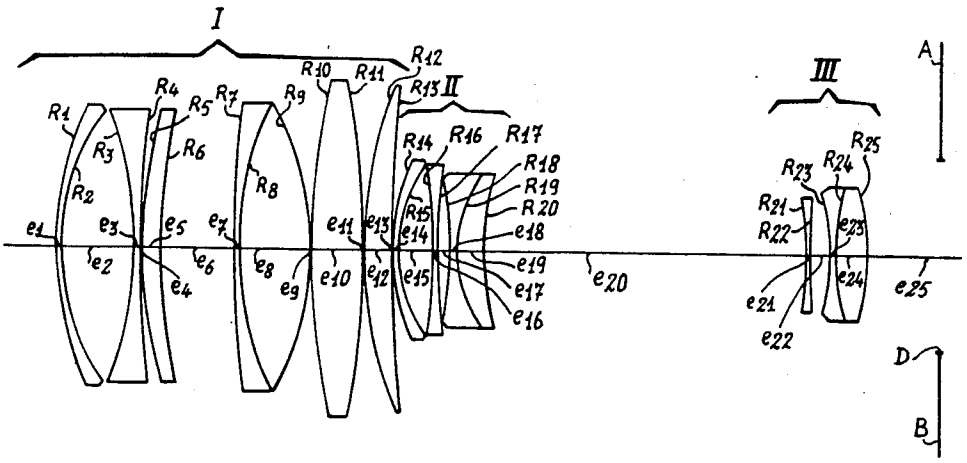
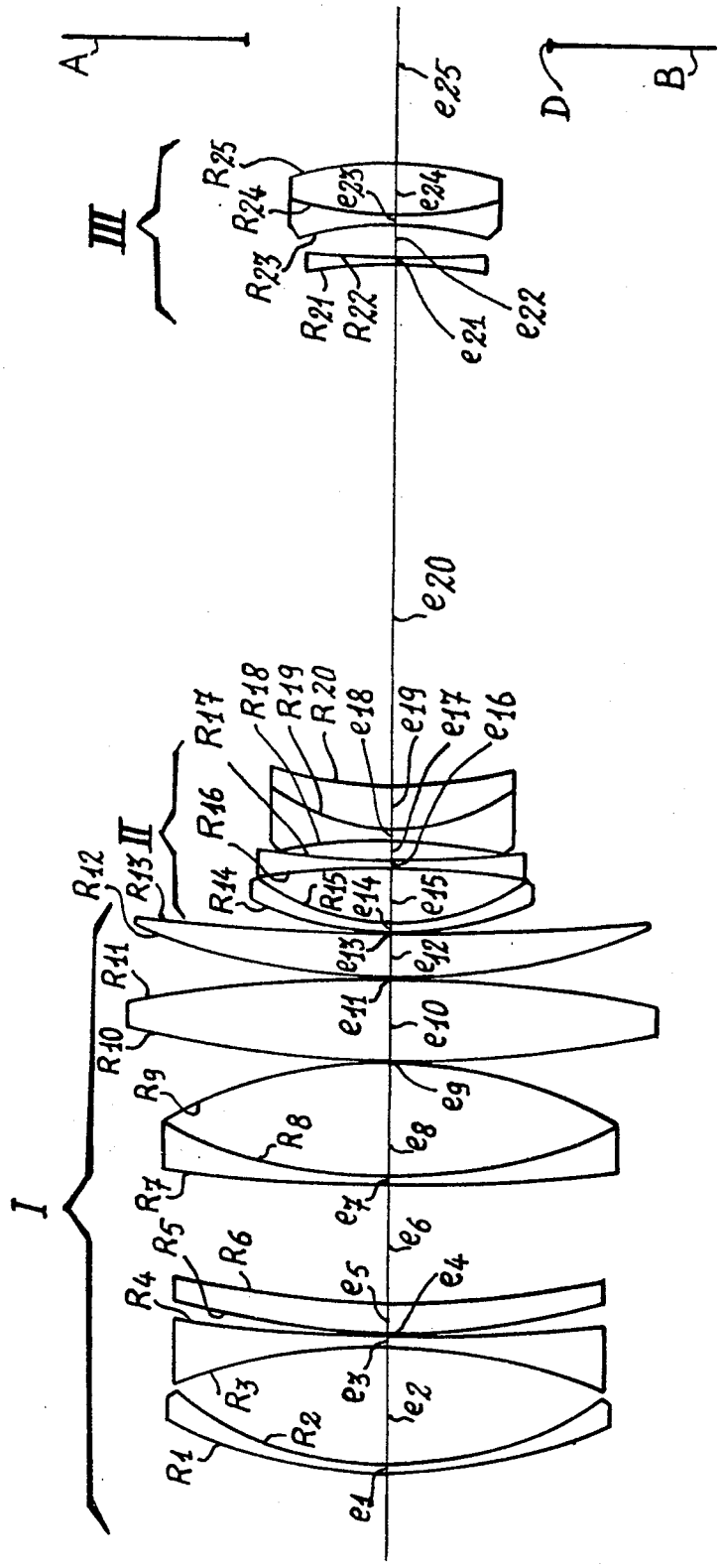


Fig: 1a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D
B
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III
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R24
R23
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R22
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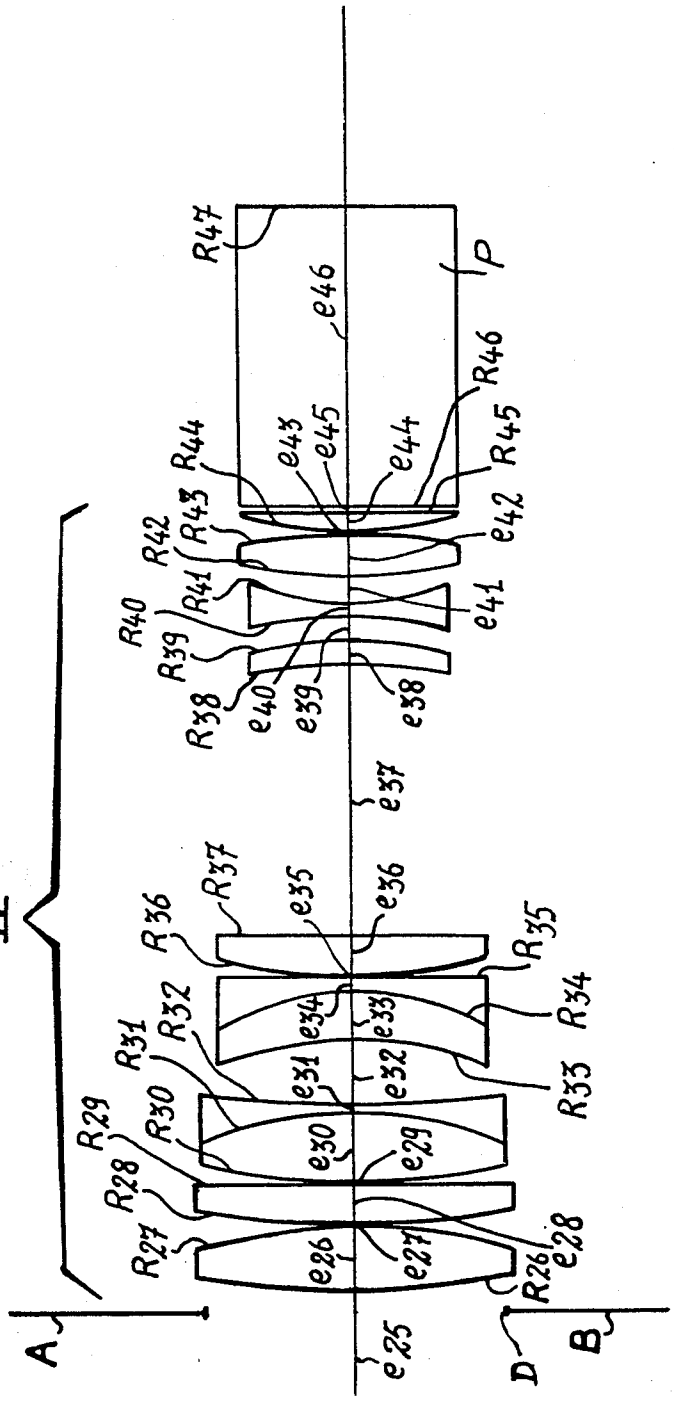
Fig: 1b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R30
R29
e30
e29
R28
R27
e26
e27
R26
e28
A
IV
I
e25
D
B

Fig:2a

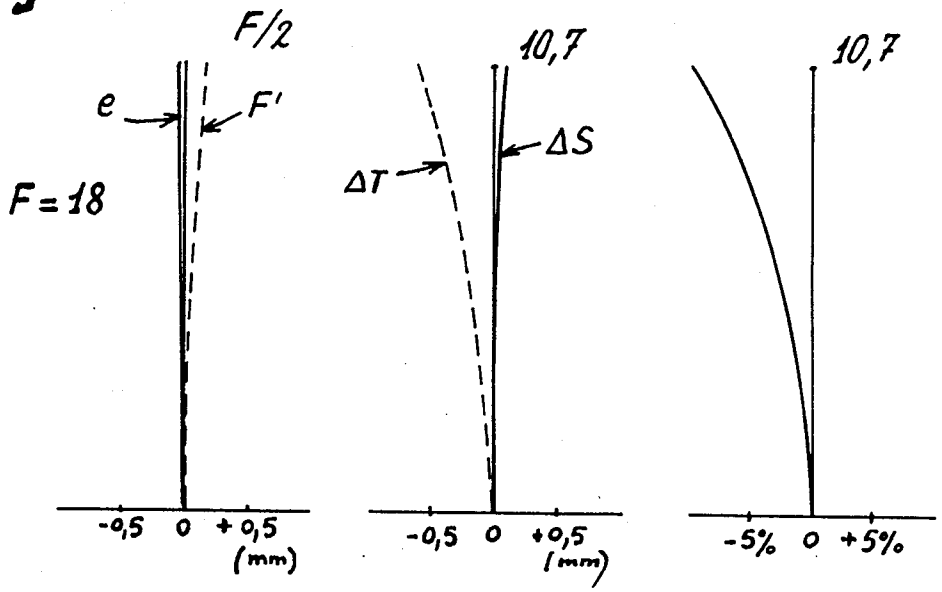
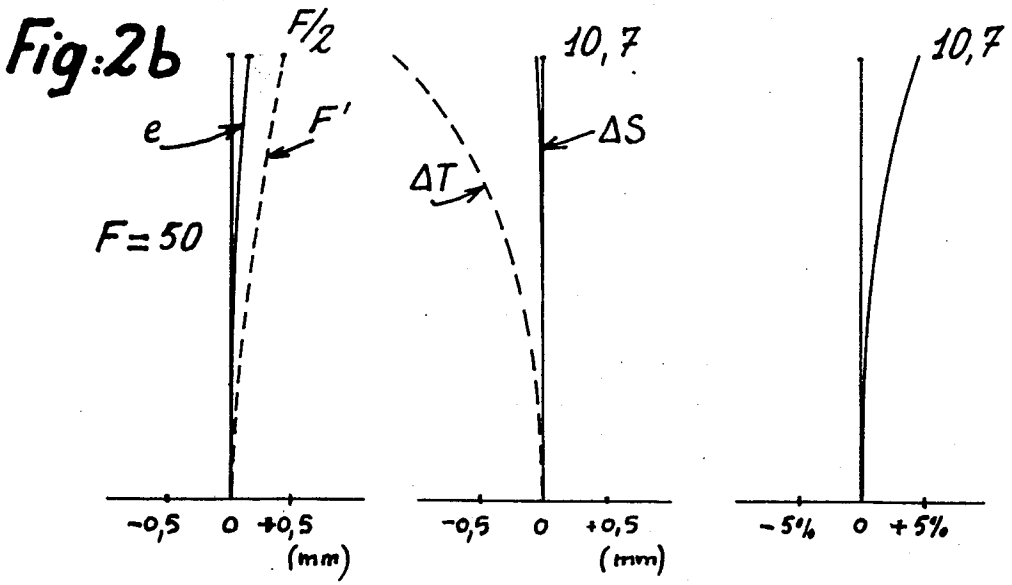

F/2
e
F'
F=18
-0,5
0
+0,5
(mm)
10,7
ΔT
ΔS
-0,5
0
+0,5
(mm)
10,7
-5%
0
+5%

Fig:2b


F/2
e
F'
F=50
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0
+0,5
(mm)
10,7
ΔT
ΔS
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0
+0,5
(mm)
10,7
-5%
0
+5%

Fig:2c

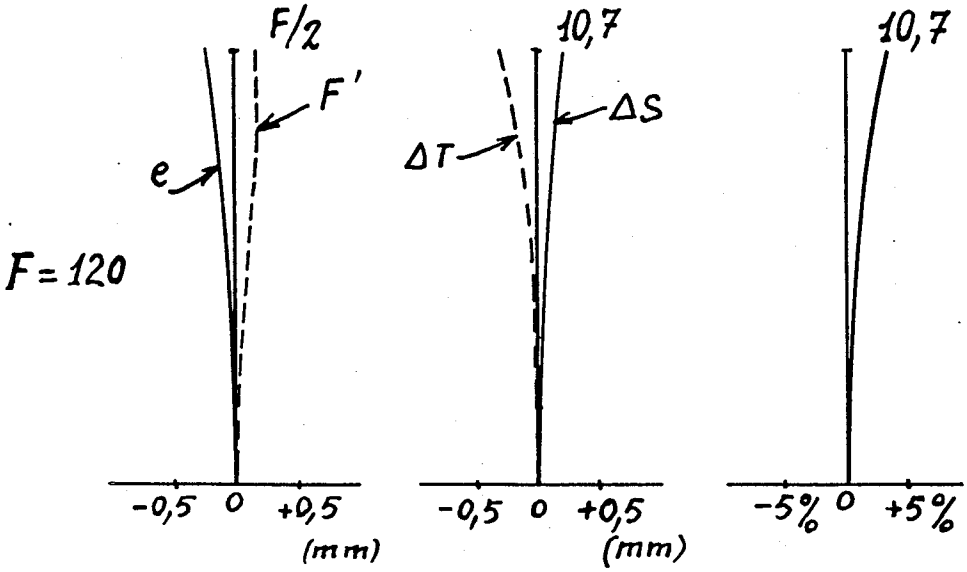
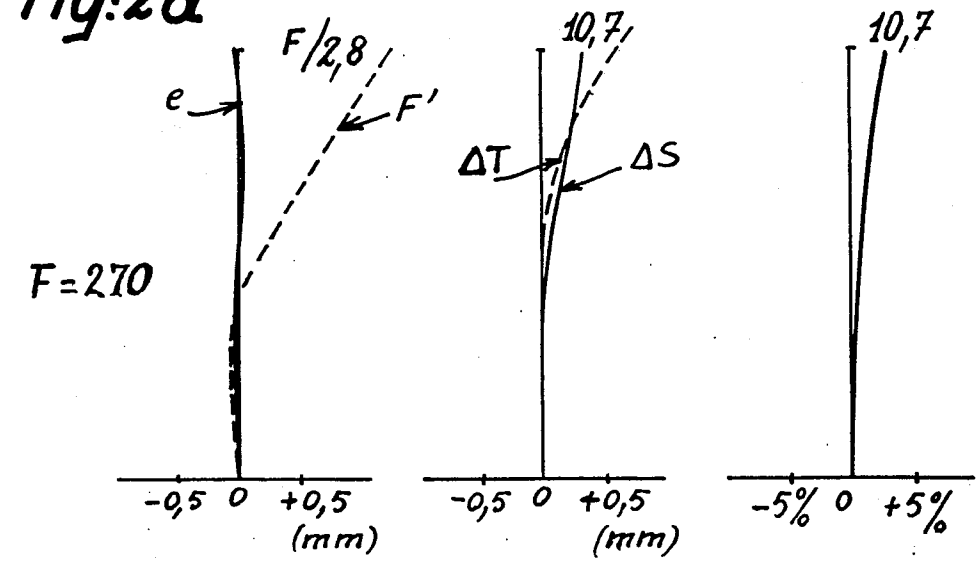

F/2
F'
e
F = 120
-0,5 0 +0,5
(mm)
10,7
ΔS
ΔT
-0,5 0 +0,5
(mm)
10,7
-5% 0 +5%

Fig:2d


F/2,8
e
F'
F = 270
-0,5 0 +0,5
(mm)
10,7
ΔT
ΔS
-0,5 0 +0,5
(mm)
10,7
-5% 0 +5%

VARIABLE-FOCAL-LENGTH OBJECTIVE

This invention relates to variable-focus objectives comprising several groups of lens elements which are respectively movable and stationary, the characteristics of these groups being such that the displacement of the movable groups in accordance with a predetermined optical law makes it possible to obtain a continuous variation of the focal length of the corresponding objective.

In more exact terms, the invention relates to variable-focus objectives of the most common type, namely those comprising at least four groups of lens elements, viz:

- a first group which is stationary when the object is placed at infinity but is displaced along the axis in order to adjust the focusing on objects located at a finite distance;
- second and third groups which are movable and permit displacement along the axis in order to vary the magnification produced by these two groups, thus producing a variation in focal length of the system;
- a final stationary group having the principal function of producing the image on a suitable scale.

However, the fact that the front group of lens elements is movable in order to adjust the focusing is subject to a certain number of disadvantages. One of the main disadvantages lies in the fact that objectives of this type have a substantial overall length by reason of the range of travel to be provided for said front group of lens elements.

In consequence, the center of gravity of the objective is located at a distance from the camera, which is a disadvantage since it is usually fixed in an overhung position. Provision must accordingly be made for reinforced fixing means.

Furthermore, by reason of the mobility of the first group of lens elements, steps must be taken to ensure that said elements have a relatively large useful diameter since they are moved to a distance away from the pupil. However, the size and diameter of lenses are attended by a certain number of drawbacks including in particular the weight and cost of fabrication of lenses.

The aim of the present invention is therefore to circumvent these disadvantages by maintaining in a fixed position the first group of lens elements of a variable-focus objective of the type recalled in the foregoing and by carrying out adjustment of focusing by additional displacement of one of the two groups which take part in the variation of magnification.

To this end, the invention is directed to a variable-focal-length objective consisting of two groups of movable lens elements which are capable of displacement along the axis and placed between a group of stationary lens elements at the front end and another group of stationary lens elements at the rear end. An essential feature of the invention lies in the fact that one of the two groups of movable lens elements does not pass through a magnification of unity and performs both a function of variation of magnification and an additional focusing function whilst the other group of movable lens elements which can pass through a position corresponding to a magnification of unity performs solely a function of variation of magnification.

This particular feature makes it possible to solve one of the most difficult problems presented by an objective of this type. In fact, if a movable group which passes through a magnification of unity were employed for performing the additional focusing function, the displacements of said movable group would in that case be excessive with respect to the dimensions of the objective itself. The objective in accordance with the invention overcomes this disadvantage by virtue of the fact that the additional focusing function is assigned to a movable group which does not pass through a magnification of unity.

The design concept of the objective under consideration is such as to provide a certain number of advantages over the variable-focus objectives at present in use.

Thus, irrespective of the focusing distance, the fixity of the first group of lens elements of said objective results in a reduction in diameter of the lens elements of this group by approximately 20%.

In point of fact, this reduction in dimensions secures the following advantages:

- higher relative precision of the active surfaces of the lenses as a result of reduction of deformations under the action of gravity and arising from contact of said lenses with the mechanical support components;
- reduction of the weight of the objective, thus making it easier to fix the objective on a motion-picture camera;
- the center of gravity of the objective is brought nearer to the camera, thus making it easier to balance the objective-camera assembly and permitting greater mobility of the assembly.

Furthermore, the fact that an additional displacement is applied for the purpose of focusing to a group which is already movable makes it possible to dispense with all the guiding means at the level of the front group which is then completely stationary.

In addition, the volume of the objective remains constant irrespective of the focusing distance, thereby limiting gaseous exchanges between the interior and the exterior of the objective while thus reducing any danger of condensation of steam.

In an advantageous embodiment:

- the movable group which takes part solely in the variation of magnification is the group located nearest the stationary element on the object side, said movable group being divergent;
- whilst the other movable group which ensures part of the variation of magnification and permits focusing is divergent.

Moreover, the different components of the objective under consideration comply with a certain number of predetermined conditions which make it possible to obtain a satisfactory objective, the function of these conditions being explained in detail hereinafter.

Thus:

- the absolute value of the focal distance f_1 of the first stationary group is within the range of one-half to double the sum of absolute values of the focal distances f_2 and f_3 of the two movable groups

$$0.5(|f_2|+|f_3|)<|f_1|<2(|f_2|+|f_3|)$$

- the absolute value of the focal distance f_3 of the second movable group is within the range of one to three times the absolute value of the focal distance f_2 of the first movable group

$$|f_2|<|f_3|<3|f_2|.$$

Furthermore, the first movable group satisfies the following conditions:

the group comprises in sequence three divergent lenses and one convergent lens;

the refractive index of these four lenses at a wavelength $\lambda=588$ nm is within the range of 1.60 to 1.85

$$1.60<n_d<1.85$$

and the Abbe number ν of the convergent lens is within the range of 20 to 35

$$20<\nu_d<35$$

the absolute value of the radius of curvature of the convergent lens located nearest the preceding divergent lens is within the range of one-half to double the absolute value of the focal distance f_2 of said movable group

$$0.5|f_2|<|R|<2|f_2|$$

the absolute value of the radius of curvature R nearest the object of the first divergent lens is comprised between the absolute value of the focal distance f_2 of said movable group and four times its absolute value

$$|f_2|<|R|<4|f_2|$$

In regard to the second movable group, this latter satisfies the following conditions:

said group comprises in sequence two divergent lenses and one convergent lens;

the refractive index of these three lenses at a wavelength $\lambda=588$ nm is within the range of 1.60 to 1.85

$$1.60<n_d<1.85$$

and the Abbe number ν of the convergent lens is within the range of 20 to 35

$$20<\nu_d<35$$

the absolute value of the radius of curvature of the convergent lens nearest the preceding divergent lens is within the range of one-half to double the absolute value of the focal distance f_3 of said movable group

$$0.5|f_3|<|R|<2|f_3|$$

the absolute value of the radius of curvature nearest the object of the first divergent lens is within the range of one-half to double the absolute value of the focal distance f_3 of said movable group

$$0.5|f_3|<|R|<2|f_3|.$$

Finally, the first convergent stationary group preferably comprises in sequence two divergent lenses, one convergent lens, a cemented doublet consisting of a divergent lens and a convergent lens, and two convergent lenses:

the absolute value of the radius of cementing of the doublet is within the range of one-half to three times the absolute value of the focal distance of said stationary group

$$0.5|f_1|<|R|<3|f_1|$$

the absolute value of the radius of curvature nearest the object of the first divergent lens is within the range of one-half to three times the absolute value of the focal distance of said stationary group

$$0.5|f_1|<|R|<3|f_1|$$

One example of construction of a variable-focal-length objective in accordance with the invention is described hereinafter with reference to the accompanying drawings which are given by way of indication and in which:

FIGS. 1A and 1B are the two complementary portions of an axial sectional view of the different groups of lens elements of the objective under consideration, these two portions being joined together along the line A-B which passes through the plane of the diaphragm of said objective;

FIGS. 2A to 2D show the curves of spherical aberration, the curves of field curvature and of distortion in respect of four positions of the movable groups corresponding to overall focal distances of the objective of 18, 50, 120 and 270 mm.

Below air spacings values e13, e20, e25 in the proposed example, in relationship with the four focal distances values F=18, F=50, F=120, and F=270, for which residual aberration curves are given.

	F = 18	F = 50	F = 120	F = 270
e13	0.288 mm	61.951 mm	96.069 mm	113.520 mm
e20	114.323 mm	47.646 mm	18.800 mm	29.742 mm
e25	30.000 mm	35.014 mm	29.742 mm	6.550 mm

The above values correspond to focussing at infinity.

The objective illustrated in the drawings comprises four groups of lens elements, namely two movable groups II and III placed between two stationary groups I and IV.

The three first groups I, II and III are placed in front of the diaphragm D whilst the fourth group IV is placed behind said diaphragm. This fourth and last group is stationary and has the function of forming an image having the desired size at a given distance which is relatively substantial with respect to the overall focal distance in order to make provision for a beam-splitting prism for spectral analysis of light in the particular application of camera shooting for color television and in order to perform corrections for aberrations introduced by the preceding groups. It should be noted in this connection that the fixity of this group and its arrangement behind the diaphragm constitute a particularly advantageous solution. In fact, this combination makes it possible to ensure fixity of the exit pupil of the objective, which is advantageous when the image produced by the objective is processed by another optical system such as a beam-splitting prism P or an optical relay, for example.

Of the two movable groups II and III, the group which is placed in front, namely group II, has the sole function of variation of the focal length of the objective. This group, however, is intended to pass through a magnification of unity.

On the other hand, the design concept of the system is such that the second movable group III does not pass at all through a magnification of unity. In accordance with the invention, this group possesses both a function

of variation in focal length of the objective and an additional function of focusing of the system.

Finally, the stationary front group I has the intended function of producing a real image of the object which is variable both in position and in magnification according to the position of the object 1.

The first group I, which is stationary, comprises seven lens elements, namely a divergent meniscus lens whose convex face is directed towards the object, a biconcave divergent lens, a convergent meniscus lens, a cemented doublet constituted by a divergent lens and a biconvex convergent lens, a biconvex convergent lens and a convergent meniscus lens whose convex face is directed towards the object.

In regard to the first movable group II, this group is made up of four lens elements, namely a divergent meniscus lens whose convex face is directed towards the object, a divergent lens, a doublet constituted by a biconcave divergent lens and a convergent lens.

So far as the second movable group III is concerned, this group is made up of three lens elements, namely a biconcave divergent lens, a doublet constituted by a biconcave divergent lens and a biconvex convergent lens.

Finally, the fourth group, which is stationary, can comprise eleven lens elements, namely two biconcave convergent lenses, a doublet constituted by a biconvex convergent lens and a divergent lens, a doublet constituted by a convergent lens and a divergent lens, a convergent lens, a convergent meniscus lens, a biconcave divergent lens, and two convergent lenses.

The table given hereinafter will in any case specify the values of the different radii of curvature of the lenses of these different groups as well as the values of the air spaces and thicknesses of lenses. The references R1, R2 and R3 designate the radii of curvature of the lenses and are followed by the + sign when their convex faces are directed towards the front and by the − sign in the contrary case. However, this table also indicates the other applied characteristics of the lenses Thus the reference n_d indicates the refractive index relating to each lens in respect of the spectral line d (λ=588 nm) whilst the reference ν_d designates the value of the Abbe number.

TABLE

	R			E	n_d	ν_d
I	R1	+	122.41	e1 2.49	1.68900	49.6
	R2	+	93.16	e2 25	air	
	R3	−	137.53	e3 2.088	1.68900	49.6
	R4	+	395.18	e4 0.5	air	
	R5	+	163.70	e5 7	1.80000	45.6
	R6	+	247.13	e6 26	air	
I	R7	+	488.60	e7 1.945	1.80510	25.5
	R8	+	158.05	e8 25	1.48725	70.4
	R9	−	139.46	e9 0.156	air	
	R10	+	282.29	e10 18	1.64050	60.1
	R11	−	362.36	e11 0.078	air	
	R12	+	140.62	e12 11	1.64050	60.1
	R13	+	560.32	e13 0.288	air	
II	R14	+	94.63	e14 2	1.80000	45.6
	R15	+	54.52	e15 11	air	
	R16	−	435.05	e16 2	1.80000	45.6
	R17	+	283.88	e17 4	air	
	R18	−	127.56	e18 2	1.71300	53.8
	R19	+	44.22	e19 10	1.78800	25.9
	R20	+	143.80	e20 114.323	air	
III	R21	−	77.95	e21 2	1.74400	44.8
	R22	+	270.34	e22 7	air	
	R23	−	61.02	e23 2	1.74400	44.8
	R24	+	76.42	e24 12	1.78800	25.9
	R25	−	81.91	e25 30	air	
IV	R26	+	257.07	e26 15	1.68900	49.6
	R27	−	100.76	e27 0.5	air	
	R28	+	291.24	e28 7	1.68900	49.6
	R29	−	4276.76	e29 0.5	air	
	R30	+	138.27	e30 16	1.62300	58.1
	R31	−	83.36	e31 2.32	1.73150	28.4
	R32	+	430.87	e32 14	air	
	R33	−	98.95	e33 10	1.62040	60.3
	R34	−	64.86	e34 2	1.73150	28.4
	R35	−	956.80	e35 0.20	air	
IV	R36	+	97.47	e36 10	1.62040	60.3
	R37	−	1670.30	e37 60	air	
	R38	−	100.92	e38 6	1.69900	30.1
	R39	−	64.28	e39 5	air	
	R40	−	80.25	e40 2.32	1.69600	36.5
	R41	+	51.18	e41 5.80	air	
	R42	+	80.82	e42 10	1.62040	60.3
	R43	−	89.41	e43 0.232	air	
	R44	+	78.15	e44 4.64	1.62000	36.3
	R45	+	5667.83	e45 1.16	air	
P	R46		∞	e46 65.20	1.51680	64.2
	R47		∞			

On the basis of the values thus established, the focal distances f1, f2 and f3 of the first three groups are respectively as follows: f1=131.143, f2=−45.384 and f3=−79.526.

In consequence, it can be observed that the objective herein described by way of example fully satisfies the different supplementary conditions which were set forth earlier.

The following inequalities may in fact be noted:

(1) $0.5|f1|-|R1|<3|f1|$

(2) $0.5|f1| < |R8| < 3|f1|$
(3) $1.60 < nd21\ 1.85$
(4) $20 < \nu_d < 35$
(5) $|f2| < |R14| < 4|f2|$
(6) $0.5|f2| < |R19| < 2|f2|$
(7) $0.5|f3| < |R21| < 2|f3|$
(8) $0.5|f3| < |R24| < 2|f3|$
(9) $0.5(|f2| + |f3|) < |f1| < 2(|f2| + |f3|)$
(10) $|f2| < |f3| < 3|f2|$

where R1 to R24 define in sequence the radius of curvature of the constituent surfaces of the lens elements of the objective which are numbered from the surface nearest the object.

n_d and ν_d represent the refractive indices for the wavelength $\lambda = 588$ nm and the Abbe number of the lens elements constituting the two movable groups.

The respective functions of the different conditions given above are as follows:

Condition (1) is necessary for correcting the distortion when the objective is employed at short focal distances.

Condition (2) is necessary for correcting spherical aberration and chromatic aberration when the objective is employed at long focal distances.

Condition (3) is necessary for correcting the Petzval curvature as well as the residual spherical aberration of the front stationary group.

Condition (4) is necessary for correcting the residual longitudinal chromatic aberration of the front stationary group.

Condition (5) is necessary for correcting the distortion of the objective.

Condition (6) is necessary for correcting the residual spherical aberration of the objective as well as part of the longitudinal chromatic aberration.

Condition (7) is necessary for correcting the residual distortion of the objective.

Condition (8) is necessary for correcting the residual spherical aberration of the objective as well as part of the longitudinal chromatic aberration.

Condition (9) is necessary for fabricating an objective having small overall size and weight.

Condition (10) is necessary for correcting the Petzval curvature throughout the positional variation of the two movable groups.

It should be noted that the objective in accordance with the invention is not limited solely to the embodiment which has been described in the foregoing and which constitutes only an example.

Thus the first movable group can be constituted in a different manner. Instead of comprising in sequence three divergent lenses and one convergent lens, said group could be constituted in sequence by: two divergent lenses, one convergent lens and one divergent lens.

So far as the second movable group is concerned, this group could comprise in sequence one divergent lens, one convergent lens and one divergent lens instead of being constituted by two divergent lenses and one convergent lens.

What is claimed is:

1. A variable-focal-length objective consisting of two movable groups of lens elements which are capable of displacement along the axis and placed between two other stationary groups of lens elements, the displacement of said two movable groups and solely of said two groups being such as to produce a variation of the focal distance and to maintain the image in a fixed plane in respect of any object located at distances chosen at will between finite values and infinity or focusing distance in front of the first stationary group of lenses, wherein:

the two movable groups are divergent and each takes part in the total variation of magnification, each elementary magnification being such as to have a minimum and maximum absolute value during the variation, the ratio of maximum value to minimum value being higher than 1:1;

only one of the two movable groups which does not pass through a magnification of unity performs both a magnification function and an additional focussing function;

the other movable group which may pass through a position corresponding to a magnification of unity performs only a magnification function, said other movable group being nearest the stationary element on the object side;

each movable group comprises at least three lens elements in the case of one group and two lens elements in the case of the other group.

2. A variable-focal-length objective according to claim **1**, wherein the respective focal values:

f_1 of the first stationary group
f_2 of the first movable group
f_3 of the second movable group

satisfy the following two conditions:

the absolute value of the focal distance f_1 of the first stationary group is within the range of one-half to double the sum of absolute values of the focal distances f_2 and f_3 of the two movable groups

$$0.5(|f_2| + |f_3|) < |f_1| < 2(|f_2| + |f_3|)$$

the absolute value of the focal distance f_3 of the second movable group is within the range of one to three times the absolute value of the focal distance f_2 of the first movable group

$$|f_2| < |f_3| < 3|f_2|$$

3. A variable-focal-length objective according to claim **2**, wherein the first movable group satisfies the following conditions:

said first movable group comprises in sequence three divergent lenses and one convergent lens;

the refractive index for the wavelength $\lambda = 588$ nm of the four lenses aforesaid is within the range of 1.60 to 1.85

$$1.60 < n_d < 1.85$$

and the Abbe number ν of the convergent lens is within the range of 20 to 35

$$20 < \nu_d < 35$$

the absolute value of the radius of curvature of the convergent lens which is nearest the preceding divergent lens is within the range of one-half to double the absolute value of the focal distance f_2 of said movable group

$$0.5|f_2| < |R| < 2|f_2|$$

the absolute value of the radius of curvature R nearest the object of the first divergent lens is comprised between the absolute value of the focal distance f_2 of said movable group and four times its absolute value

$|f_2| < |R| < 4|f_2|$

4. A variable-focal-length objective according to claim 2, wherein the first movable group satisfies the following conditions:

said first movable group comprises in sequence two divergent lenses, one convergent lens and one divergent lens;

the refractive index for the wavelength $\lambda = 588$ nm of the four lenses aforesaid is within the range of 1.60 to 1.85

$1.60 < n_d < 1.85$

and the Abbe number ν of the convergent lens is within the range of 20 to 35

$20 < \nu_d < 35$

the absolute value of the radius of curvature of the convergent lens located nearest the following divergent lens is within the range of one-half to double the absolute value of the focal distance f_2 of said movable group

$0.5|f_2| < |R| < 2|f_2|$

the absolute value of the radius of curvature R nearest the object of the first divergent lens is comprised between the absolute value of the focal distance f_2 of said movable group and four times its absolute value

$|f_2| < |R| < 4|f_2|$

5. A variable-focal-length objective according to claim 2, wherein:

the second movable group comprises in sequence two divergent lenses and one convergent lens,

the refractive index for the wavelength $\lambda = 588$ nm of the three lenses aforesaid is within the range of 1.60 to 1.85

$1.60 < n_d < 1.85$

and the Abbe number ν of the convergent lens is within the range of 20 to 35

$20 < \nu_d < 35$

the absolute value of the radius of curvature of the convergent lens located nearest the preceding divergent lens is within the range of one-half to double the absolute value of the focal distance f_3 of said movable group

$0.5|f_3| < |R| < 2|f_3|$

the absolute value of the radius of curvature nearest the object of the first divergent lens is within the range of one-half to double the absolute value of the focal distance f_3 of said movable group

$0.5|f_3| < |R| < 2|f_3|$

6. A variable-focal-length objective according to claim 2, wherein:

the second movable group comprises in sequence one divergent lens, one convergent lens and one divergent lens;

the refractive index for the wavelength $\lambda = 588$ nm of the three lenses aforesaid is within the range of 1.60 to 1.85

$1.60 < n_d < 1.85$

and the Abbe number ν of the convergent lens is within the range of 20 to 35

$20 < \nu_d < 35$

the absolute value of the radius of curvature of the convergent lens located nearest the following divergent lens is within the range of one-half to double the absolute value of the focal distance f_3 of said movable group

$0.5|f_3| < |R| < 2|f_3|$

the absolute value of the radius of curvature nearest the object of the first divergent lens is within the range of one-half to double the absolute value of the focal distance f_3 of said movable group

$0.5|f_3| < |R| < 2|f_3|$

7. A variable-focal-length objective according to claim 2, wherein the first convergent stationary group comprises in sequence two divergent lenses, one convergent lens, one cemented doublet constituted by a divergent lens and a convergent lens, and two convergent lenses:

the absolute value of the radius of cementing of the doublet is within the range of one-half to three times the absolute value of the focal distance of said stationary group

$0.5|f_1| < |R| < 3|f_1|$

the absolute value of the radius of curvature nearest the object of the first divergent lens is within the range of one-half to three times the absolute value of the focal distance of said stationary group

$0.5|f_1| < |R| < 3|f_1|$

* * * * *

United States Patent [19]

Knapp

[11] **4,365,884**

[45] **Dec. 28, 1982**

[54] **STILL CAMERA WITH RETRACTING OBJECTIVE**

[75] Inventor: **Helmut Knapp**, Biebertal, Fed. Rep. of Germany

[73] Assignee: **MINOX GmbH**, Giessen, Fed. Rep. of Germany

[21] Appl. No.: **265,779**

[22] Filed: **May 21, 1981**

[30] **Foreign Application Priority Data**

May 29, 1980 [DE] Fed. Rep. of Germany 3020340

[51] **Int. Cl.**[3] **G03B 17/04**

[52] **U.S. Cl.** **354/187**

[58] **Field of Search** 354/187-195, 354/288

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Primary Examiner—John Gonzales
Attorney, Agent, or Firm—Wells & Wells

[57] **ABSTRACT**

A still camera with a fold up cover, a retracting objective and a drive connection between these components acting within the light tight camera space on the objective mount so that the objective is advanced when the cover is opened and retracted when the cover is shut.

The camera has the following features:

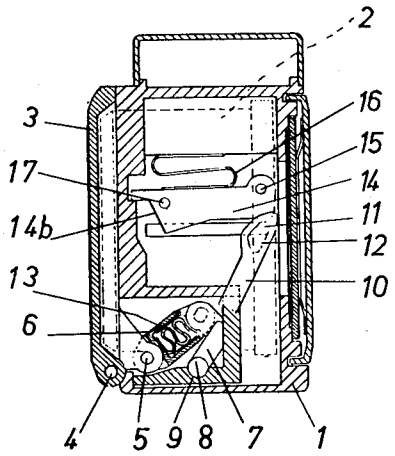
(a) the drive connection is divided into outer drive links (**4–5, 6, 7**) and inner drive links (**10, 11**);

(b) the outer drive links (**4–5, 6, 7**) are connected with the cover (**3**) so as to positively control the cover;

(c) the inner drive links (**10, 11**) are connected with the objective mount (**2**) so as to positively control the mount; and

(d) the connection between the outer and inner drive links consists of a round shaft (**8**) supported in a bore (**9**) of the housing (**1**) with a light tight snug fit.

7 Claims, 3 Drawing Figures



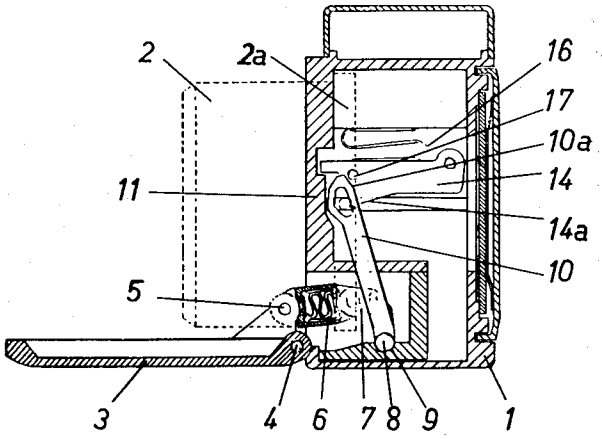


Fig.1

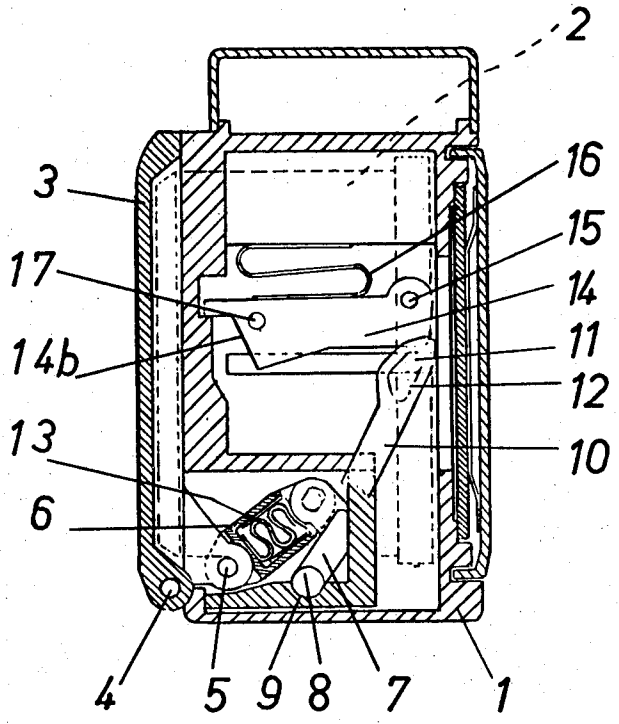

2
3
16
15
17
14
14b
11
12
13
10
6
4
5
9
8
7
1

Fig.2

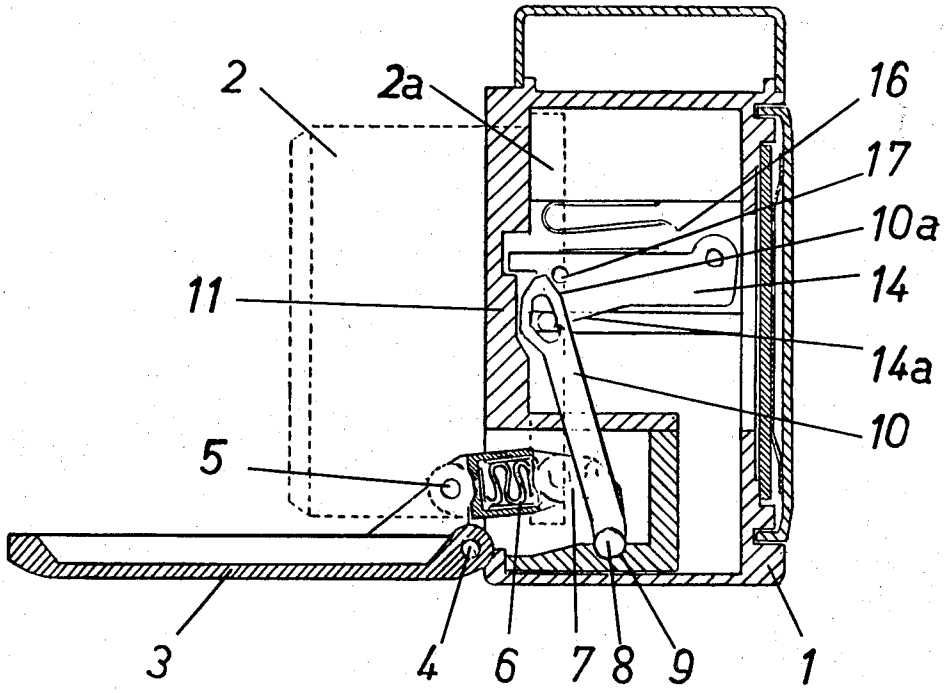
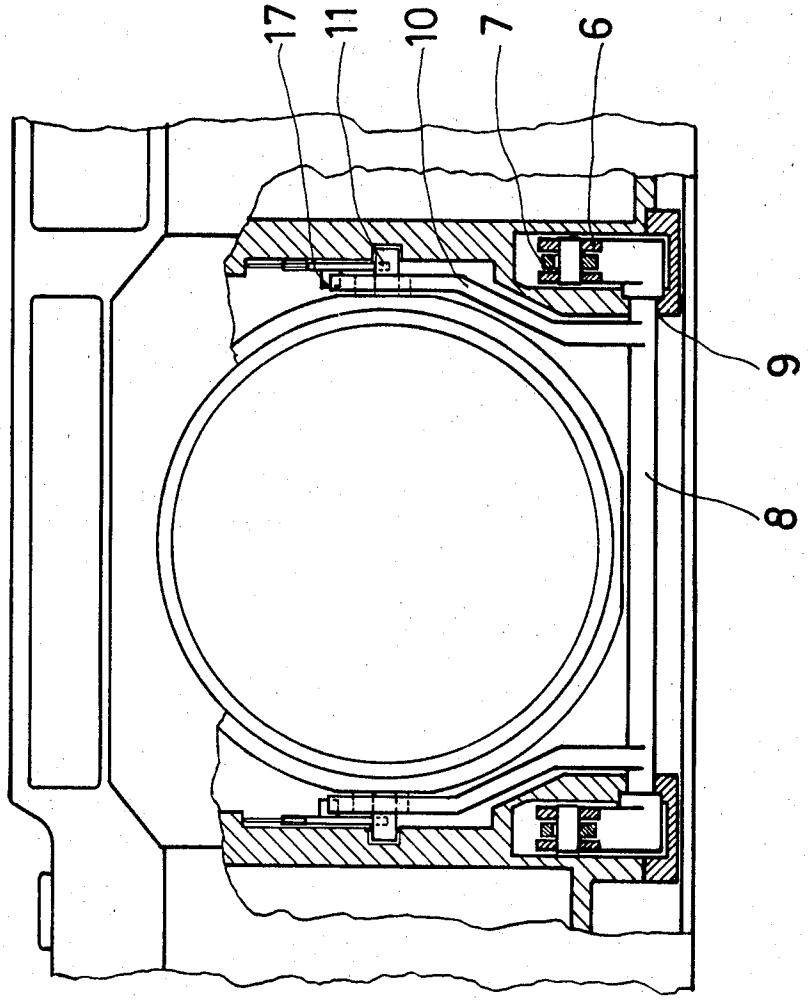

2
2a
16
17
10a
11
14
14a
10
5
3
4
6
7
8
9
1

Fig.3



STILL CAMERA WITH RETRACTING OBJECTIVE

CROSS REFERENCE TO RELATED APPLICATION

Applicant claims priority under 35 USC 119 for application P 30 20 340.8, filed May 29, 1980 in the Patent Office of the Federal Republic of Germany.

BACKGROUND OF THE INVENTION

The present invention relates to a still camera having a flip open cover and a retractable objective connected with the cover so that the objective is pulled out as the cover is folded open and is retracted when the cover is folded shut.

In the prior art still cameras of this kind, the light tightness is a special problem. This problem is solved for simple cameras by inserting a bellows between the objective seat and the camera housing, where this bellows can be folded together.

However, this kind of design is unsuited for small cameras with solid housings and where because of compactness the objective in the retracted position is fully sunk into the housing and thereby comes to rest directly on the film plane. The latter characteristic makes it impossible to implement a direct operational connection between the cover and a mount remaining outside for the retracted state, which otherwise would ensure light tightness. Only such an operational connection is possible, which on the one hand acts on the objective mount in the light tight camera space and on the other hand acts on the cover outside this light tight space. This necessitates a passageway through the housing wall in order to arrive from the outside cover to the inside mount by means of one or several drive links in order that, if possible at all, the objective be moved from its inside limit position into its picture taking position by one opening motion of the cover. This passageway must be light tight itself.

SUMMARY OF THE INVENTION

Having in mind the limitations of the prior art, it is an object of the present invention to provide such a passageway which shall be simple in design and construction and therefore easily manufactured and nevertheless absolutely light tight.

This object is achieved by the present invention for a camera having the following features:

(a) the operational connection between the flip cover and the objective mount is divided into outer and inner drive means;

(b) the outer drive means are connected to the cover so that they will be positively controlled by it;

(c) the inner drive means are connected with the objective mount so that it will positively control them; and

(d) the connection between the outer and inner drive means consists of a round shaft supported in a housing bore with a light tight fitted seat.

The passageway from the outer space into the light tight camera inner space therefore consists in accordance with the present invention solely of a round bore within which rotates a round shaft. This bore can be easily made commercially, and the bore and the shaft can easily be implemented with such respective fits that no light shall reliably enter the camera inner space. For increased safety the shaft moreover may be provided with an offset, a collar or the like which together with a matchingly shaped bore offset would form a labyrinth.

In a particular embodiment of the concept leading to the solution, the outer drive means are a four link device of which the fixed link is formed by the camera housing and of which the coupler is so connected to the swinging member by an elongated slot in this swinging member that the drive means, due to spring support when the cover is flipped shut, arrives at a top dead position where the cover is firmly resting against the housing by spring action.

The inner drive means consist of a plain swing lever comprising an elongated slot at its free end to act on a pin fixed into the objective mount. If the lever is pivoted, the objective is moved to and fro by this pin/elongated slot connection.

The present invention provides a further embodiment in the form of a locking system for the objective when in its front picture taking position, where the system cooperates with the swing lever. The system consists of a locking lever pivotably supported in the rear, light tight camera inside space and snapping into position under spring pressure by means of a locking surface behind the pin fixed to the objective mount.

The locking lever itself comprises a fixed pin cooperating by means of a bevel with the free end of the swing lever. Due to this cooperation, first the locking lever is lifted out of its locking position at the beginning of the fold in motion of the cover, before the retraction motion of the objective begins. To that end the elongated slot in the swing lever is somewhat widened at this location so that the swing lever at the beginning of motion moves through an idle path with respect to the objective mount, during which course it is lifted out of the locking position. Only the pin will thereafter be at the objective mount and hence the entire objective is carried along in the retraction motion.

BRIEF DESCRIPTION OF THE DRAWINGS

The appended drawings illustrate the present invention in relation to one embodiment, wherein:

FIG. **1** is a schematic section through a still camera with the retracting objective system of the present invention;

FIG. **2** is a schematic section through a camera as in FIG. **1** but with the extended objective; and

FIG. **3** is a front view of the camera shown partly in section.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

With particular reference to FIG. **1**, the camera housing is designated by **1** and holds at its front side an objective in a mount **2** which is displaceably supported. A light sealing element, for instance a felt strip, a rubber ring or the like is inserted in known manner between the front side and the objective mount, so that it is feasible to move the objective through the front side without light penetrating the camera inside space.

A cover **3** covers the objective at the camera front side and this cover pivots around a shaft **4** fixed to the housing.

A lever **6** is pivotably connected to the cover at point **5** and is connected at its other end in rotational manner to a lever **7**. This lever **7** is fixed to a point in the camera housing but is capable of rotation by means of a shaft.

The lever arms between the shaft **4** and the point **5** at the cover **3**, the lever **6** and the lever **7** are the outer

drive links of a drive linkage mounted between the cover **3** and the objective mount **2** and effecting the advance of the objective when the cover is folded open and the retraction of the objective when the cover is folded shut, as described further below.

In terms of linkages, these outer drive links form a four link structure, where the spacing between the shaft **4** and the point **5** represents the crank, the lever **6** the coupler and the lever **7** the swing means.

The motion of the lever **7** is transmitted by the shaft **8** to the inside drive links of the side drive linkage. This shaft **8** projects through a bore **9** (FIG. **3**) into the light tight camera inner space. The bore thus represents the transition from the light permeable outer space into the light tight inner space. As the bore and the shaft are round, they are easy to make commercially and for a sufficiently tight snug fit between shift and bore they provide a wholly light tight passageway.

The inside drive links consist of a swing lever **10** solidly connected at one end to the shaft **8**, and of a pin **11** which is fixed to the objective mount. The swing lever **10** at its free end is provided with an elongated slot **12** surrounding the pin **11**.

Due to the solid connection between the swing lever **10** and the shaft **8**, the swing lever is moved along with every shaft rotation and pivoted. If, therefore the cover **3** is folded open or shut, the outer drive links perforce are displaced and hence the swing lever **10** also is pivoted to and fro between two end positions. Therefore, the objective through its mount **2** also is advanced or retracted by means of the elongated slot **12** and the pin **11**.

As shown by FIG. **3**, the outer and inner drive links are present in duplicate, on each side of the objective mount **2** in a symmetrical arrangement to this mount. Therefore, the displacing force acts symmetrically on the objective mount and tilting of the objective during the displacement is prevented on account of the shaft **8** which is common to the swing levers **10** mounted on both sides of the objective.

In order that the cover **3** when in its folded shut position shall also always rest securely against the camera housing, the rotational connection between the levers **6** and **7** is designed in a special manner. To that end the lever **7** is provided with a small elongated slot within which the lever **6** can easily slide to and fro by means of a pin. Moreover, a compression spring **13** is mounted between the levers **6** and **7**. The arrangement is such that for the shut position of the cover **3**, the lever **6** arrives at a sort of top dead point position into which it is pressed by spring **13**. Accordingly, the cover **3** always rests under some stress against the housing **1** when in the closed position.

In the picture taking position of the objective, the mount **2** rests by means of a collar **2***a* against the inside of the front housing wall (FIG. **2**). This stop position is precisely defined. It is adjusted to the back lens/image distance of the objective. The objective also must be locked in this position so it cannot be accidentally displaced during picture taking. A locking lever **14** is provided for that purpose which is pivotably supported at **15** in the rear area of the light tight camera inside space and is stressed by a compression spring **16**. When now the objective is advanced by means of the swing lever **10**, then the pin **11** fixed to the mount slides underneath a slanted surface **14***a* of the lever **14** which thereby is raised against the force of the spring **16**. When the forward objective position is reached, the lever **14** with its slanted surface **14***b* falls behind the pin **11** of the objective and locks it into the picture taking position.

When it is desired to fold shut the cover **3** and hence to retract the objective, then first the locking lever **14** must be lifted out of its locked position. This takes place at the beginning of the pivoting motion of the lever **10** by means of a slanted surface **10***a* fashioned at the lever **10** and cooperating with a pin **17** which is firmly seated on the locking lever **14**. At the beginning of the fold shut motion of the cover **3**, this slanted surface—still before the objective mount **2** starts moving—impacts the pin **17** and raises the lever **14** and only then does the retraction of the mount **2** begin.

To make this possible, the elongated slot **12** is kept somewhat wide in this area. The swing lever **10** therefore at the beginning of the retraction first passes through a short idle path relative to the pin **11**. During this idle course the locking lever **14** is lifted against the force of the spring **16**, so that thereafter the objective together with its mount **2** is retracted.

I claim:

1. In a still camera having a housing, a fold up cover, a retracting objective and a drive connection between these components acting within the light tight camera space on an objective mount so that the objective is advanced when the cover is opened and retracted when the cover is shut, the improvement comprising the following features in combination:

(a) said drive connection divided into outer drive links (**4–5, 6, 7**) and inner drive links (**10, 11**);

(b) said outer drive links (**4–5, 6, 7**) connected with said cover (**3**) so as to positively control said cover;

(c) said inner drive links (**10, 11**) connected with said objective mount (**2**) so as to positively control said mount; and

(d) a connection between the outer and inner drive links consisting of a round shaft (**8**) supported in a bore (**9**) of said housing (**1**) with a light tight snug fit.

2. The still camera of claim **1**, wherein said round shaft (**8**) is provided with at least a first offset and said bore (**9**) comprises identically shaped second offsets which together with said first offset define a light tight labyrinth.

3. The still camera of claim **1**, wherein outer drive links consist of a four link mechanism comprising a crank (levers **4-5**) supported on a pivot shaft (**4**) of said cover (**3**) and a swing member (lever **7**) supported by said round shaft (**8**) extending into the camera inside.

4. The still camera of claim **3**, wherein a lever (**6**) is connected in rotational manner to said swing member (**7**) and to said crank (**4-5**) and a compression spring is mounted between said lever (**6**) and said swing member (**7**) which for said cover (**3**) folded shut effects a tilting of said lever (**6**) in an elongated slot in said swing lever into a top dead center position and thereby insures a firm rest of said cover (**3**) against said housing.

5. The still camera of claim **1**, wherein said inner drive links consist of a swing lever (**10**) solidly connected to said round shaft (**8**) for the purpose of common rotation and of a pin (**11**) fixed to said objective mount (**2**) and subjected to the action of said swing lever (**10**) by means of an elongated slot (**12**) therein.

6. The still camera of claim **2**, provided with a spring-loaded locking lever (**14**) in the light tight camera inside space to act on said objective mount (**2**) when it is in the picture taking position, said locking lever being pivotably supported in a rear camera space and being pro-

vided at its front end with a slanted locking surface (**14***b*) that engages behind a first pin (**11**) fixed to said objective mount when in the locked state and with a second pin (**17**) cooperating with a swing lever (**10**).

7. The still camera of claim **6**, wherein said swing lever (**10**) is provided with a slanted surface (**10***a*) against which rests said second pin (**17**) fixed to said locking lever when said objective is in the advanced position, where the slope of said slanted surface is such that at the beginning of the cover folding shut motion said locking lever (**14**) is first raised out of its locking position by said slanted surface (**10***a*) and said second pin (**17**).

* * * * *

United States Patent [19]

Ikemori

[11] **4,364,644**

[45] **Dec. 21, 1982**

[54] **GAUSS TYPE LARGE APERTURE PHOTOGRAPHIC OBJECTIVE**

[75] Inventor: **Keiji Ikemori**, Yokohama, Japan

[73] Assignee: **Canon Kabushiki Kaisha**, Tokyo, Japan

[21] Appl. No.: **209,493**

[22] Filed: **Nov. 24, 1980**

[30] **Foreign Application Priority Data**

Nov. 27, 1979 [JP] Japan 54-153258

[51] **Int. Cl.**[3] **G02B 9/62**; G02B 13/18

[52] **U.S. Cl.** **350/464**; 350/432

[58] **Field of Search** 350/464, 432

[56] **References Cited**

U.S. PATENT DOCUMENTS

3,738,739 6/1973 Glatzel et al. 350/464

FOREIGN PATENT DOCUMENTS

47-19386 6/1972 Japan .

Primary Examiner—John K. Corbin

Assistant Examiner—Rebecca D. Gass

Attorney, Agent, or Firm—Toren, McGeady & Stanger

[57] **ABSTRACT**

In the device disclosed, eight elements form a Gauss type wide or large aperture objective. The first element counting from the front is a positive meniscus lens of forward convexity, the second is a positive lens of convex curvature toward the front, the third is cemented to the second and is a negative lens of concave curvature toward the rear, the fourth is a negative lens of concave curvature toward the front, the fifth is cemented to the fourth and is a positive lens of convex curvature toward the rear, the sixth is a positive meniscus lens of rearward convexity, the seventh is a bi-convex lens with the rear surface of stronger curvature, and the eighth is a positive lens. The front surface of the second lens is aspherical so that as the distance from the optical axis increases, the deviation of the surface from the spherical surface of paraxial radius increases in a direction toward the front.

1 Claim, 33 Drawing Figures

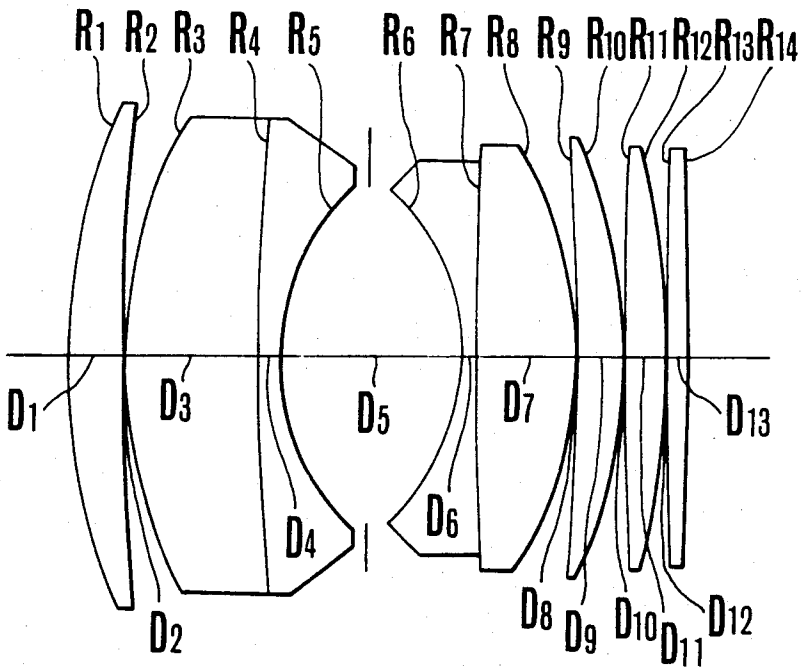
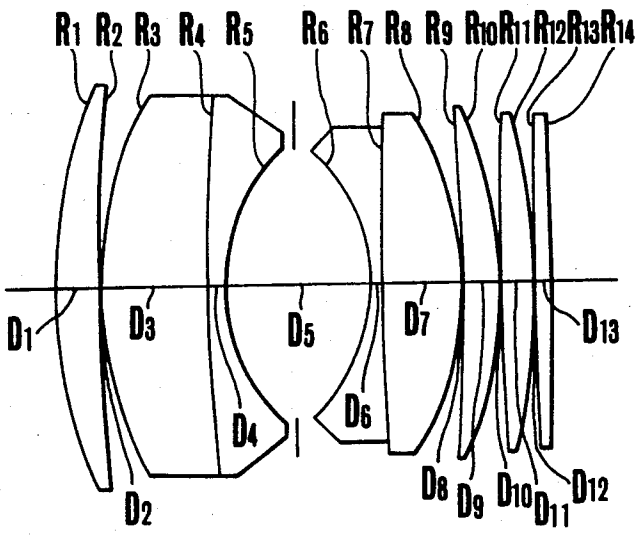


FIG.1


R1 R2 R3 R4 R5 R6 R7 R8 R9 R10 R11 R12 R13 R14
D1 D2 D3 D4 D5 D6 D7 D8 D9 D10 D11 D12 D13

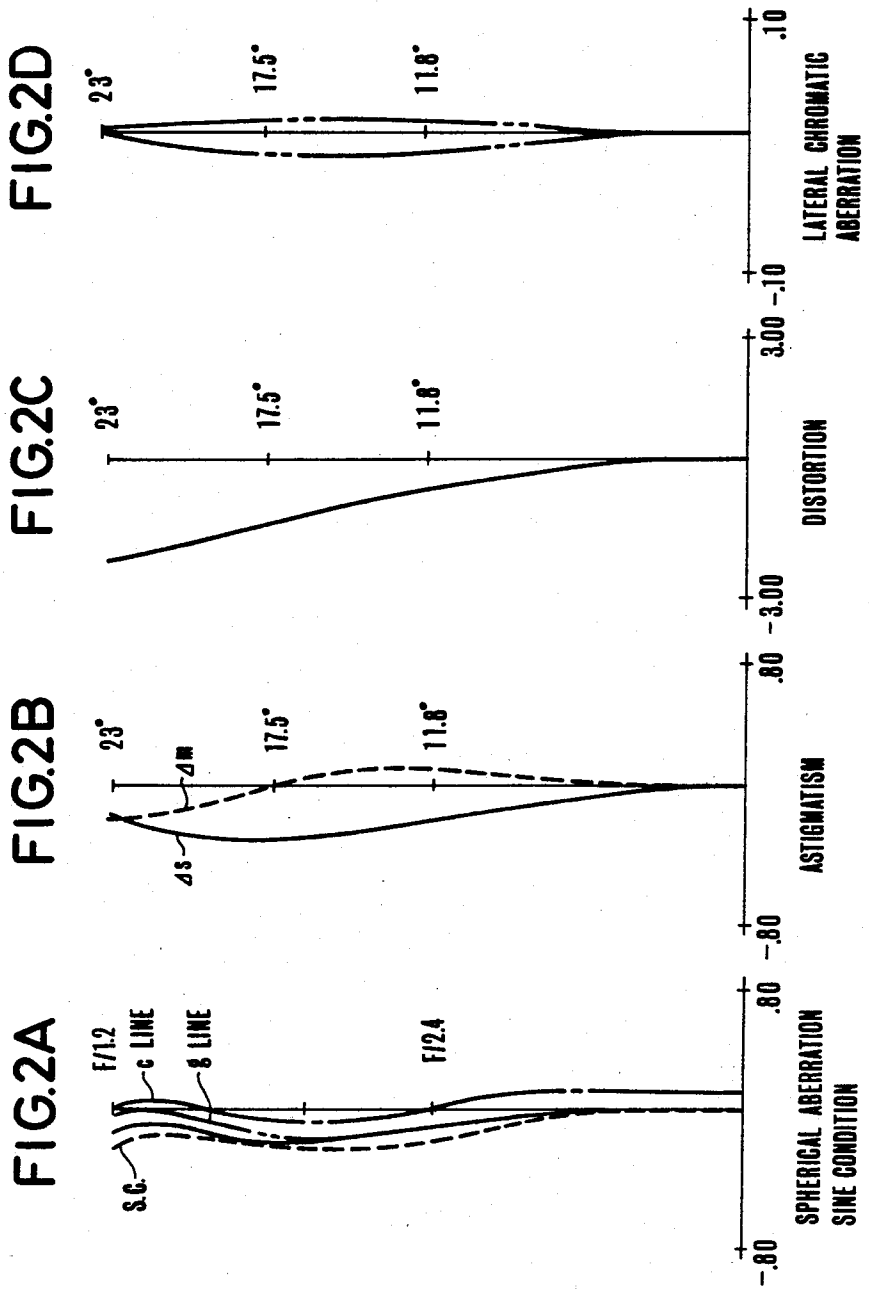


FIG.2A
F/1.2
c LINE
g LINE
S.C.
F/2.4
.80
-.80
SPHERICAL ABERRATION
SINE CONDITION
FIG.2B
23°
17.5°
11.8°
Δm
Δs
.80
-.80
ASTIGMATISM
FIG.2C
23°
17.5°
11.8°
3.00
-3.00
DISTORTION
FIG.2D
23°
17.5°
11.8°
.10
-.10
LATERAL CHROMATIC
ABERRATION

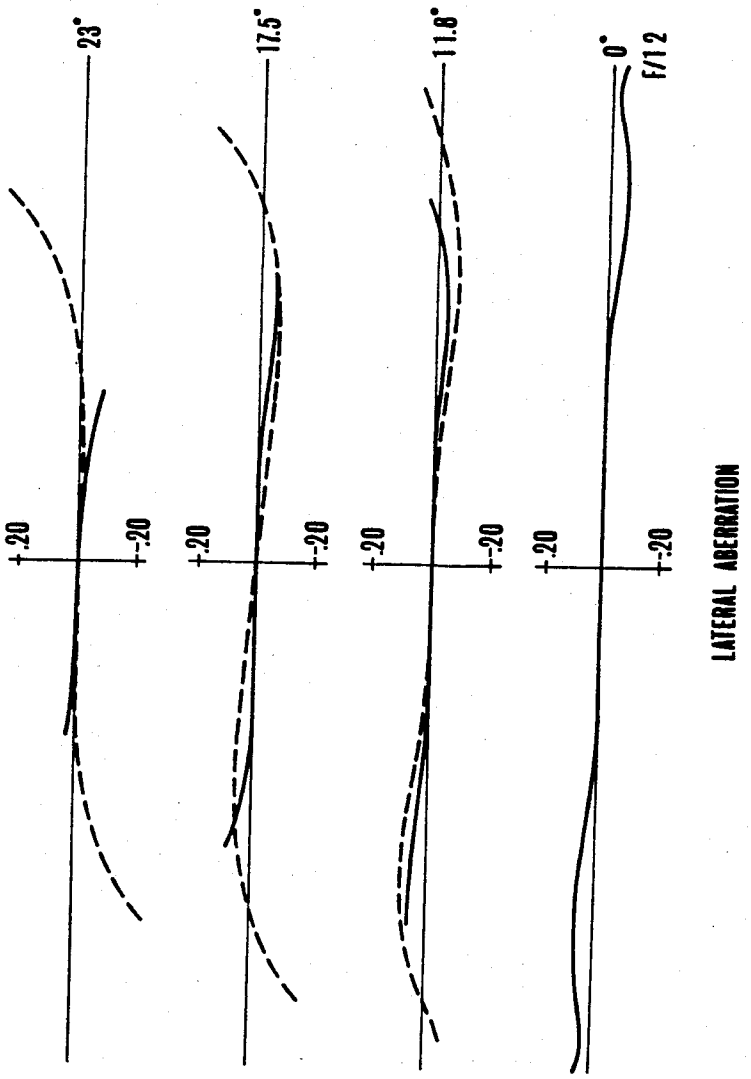


FIG.3A FIG.3B FIG.3C FIG.3D

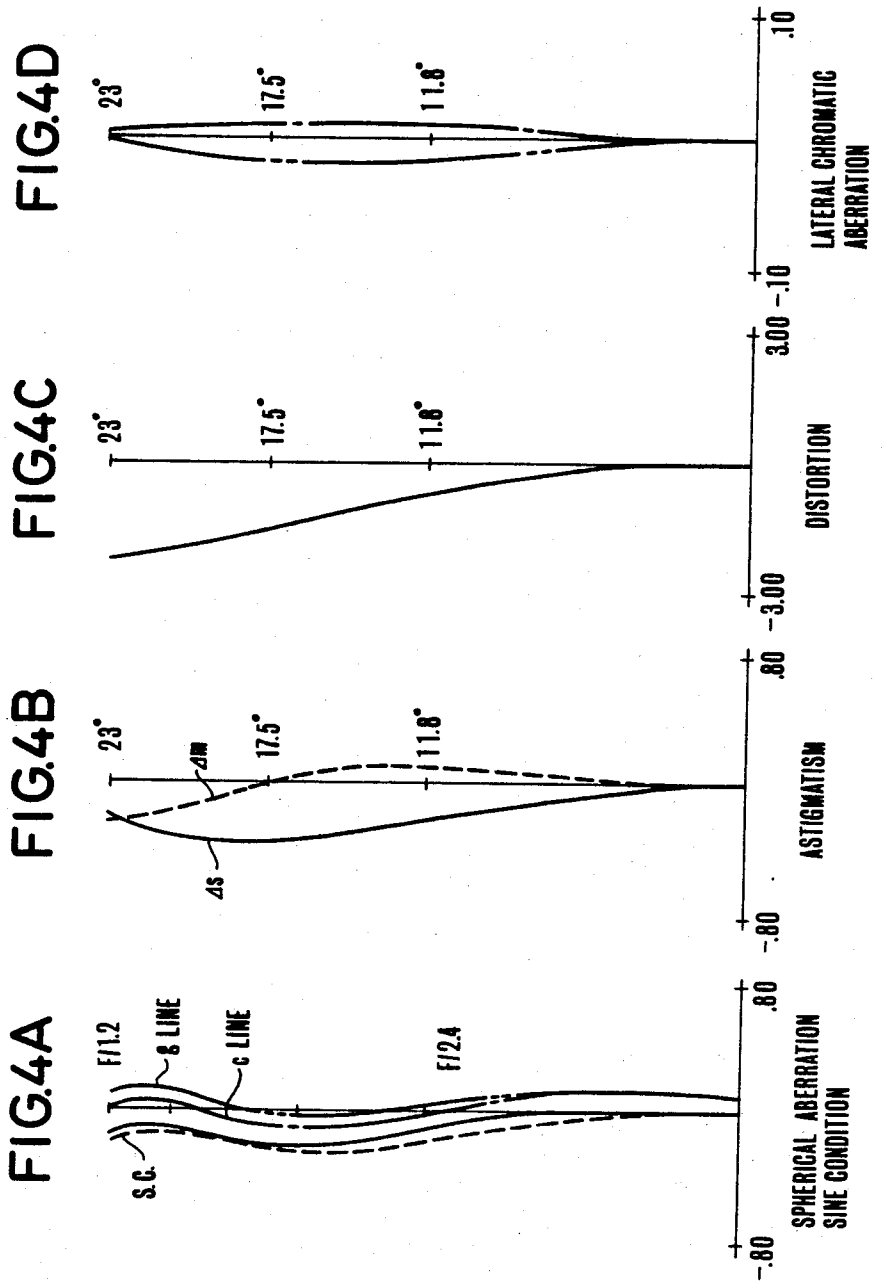


FIG.4A
F/11.2
g LINE
c LINE
F/2.4
S.C.
.80
-.80
SPHERICAL ABERRATION
SINE CONDITION
FIG.4B
23°
17.5°
11.8°
ΔM
ΔS
.80
-.80
ASTIGMATISM
FIG.4C
23°
17.5°
11.8°
3.00
-3.00
DISTORTION
FIG.4D
23°
17.5°
11.8°
.10
-.10
LATERAL CHROMATIC
ABERRATION

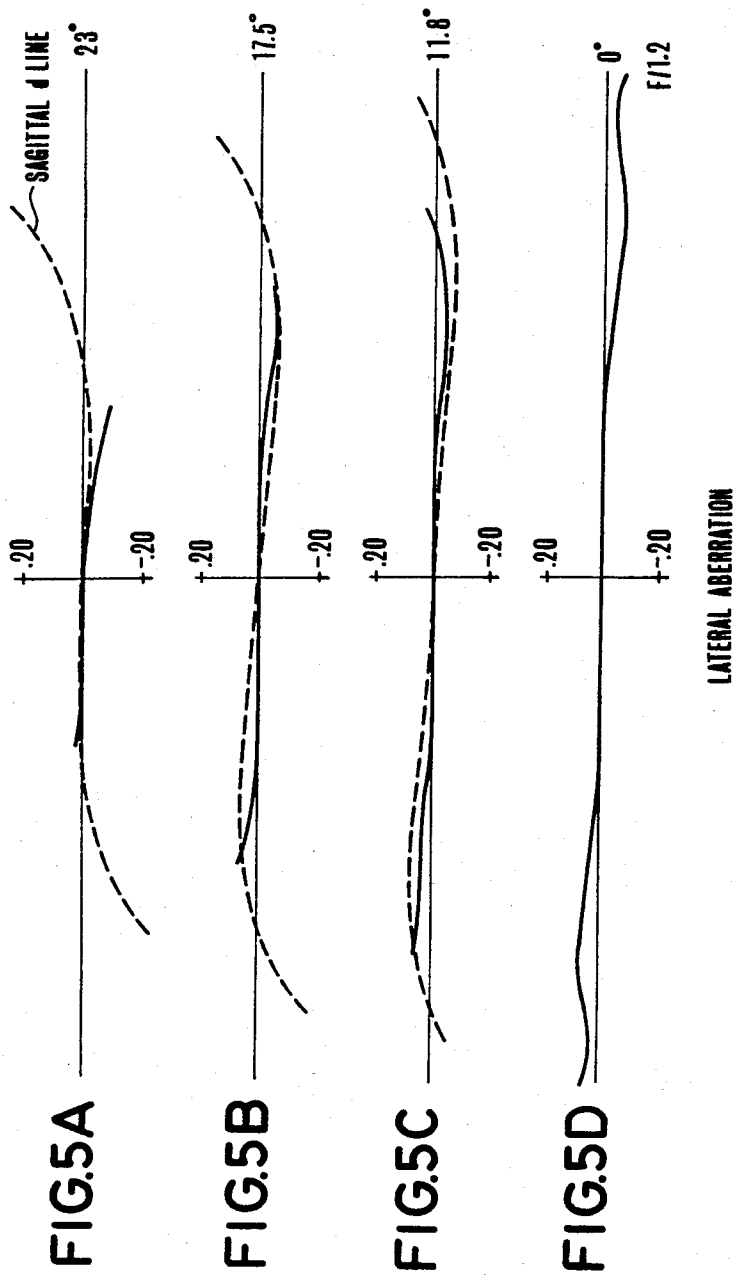


FIG.5A FIG.5B FIG.5C FIG.5D

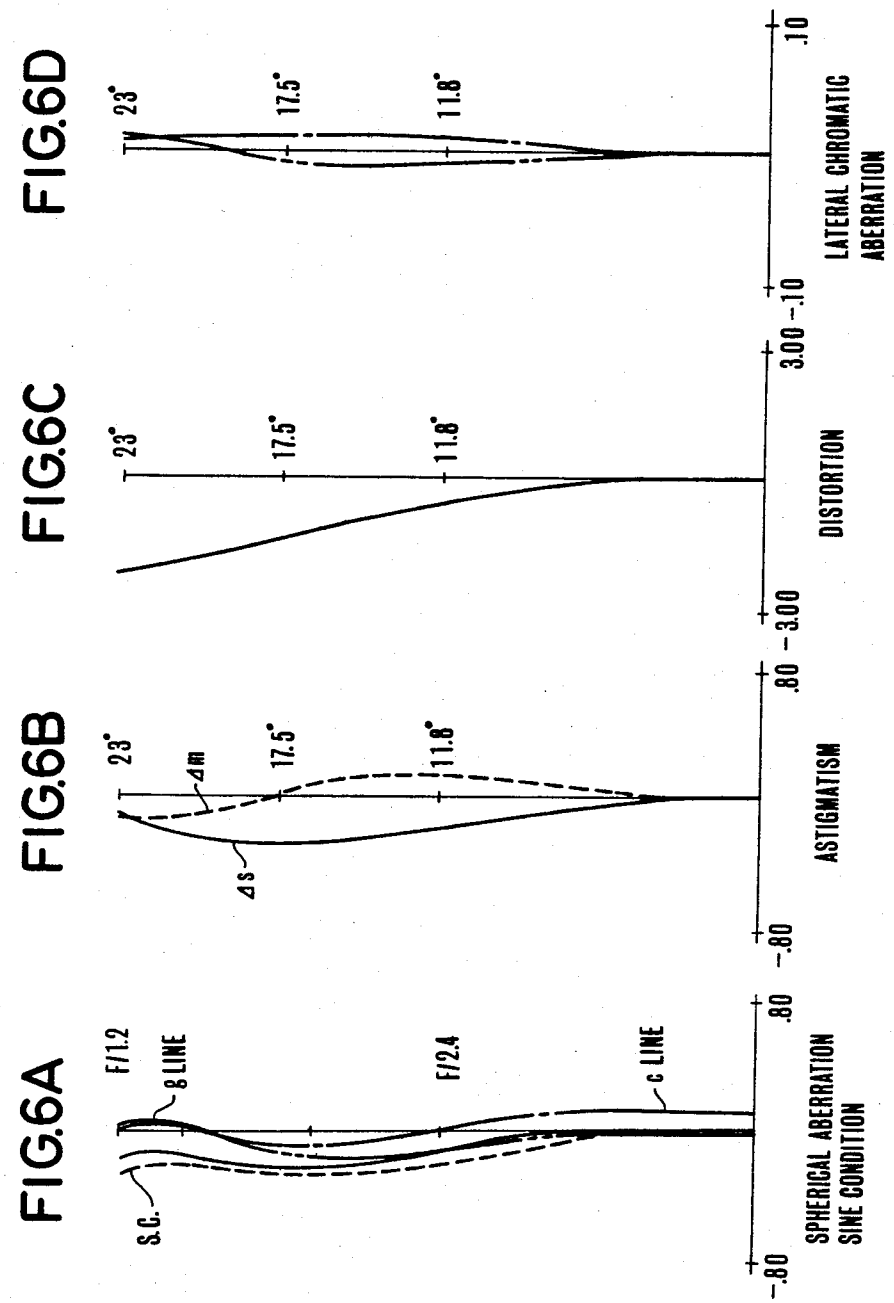


FIG.6A
F/1.2
B LINE
S.C.
F/2.4
c LINE
.80
-.80
SPHERICAL ABERRATION
SINE CONDITION
FIG.6B
23°
17.5°
11.8°
ΔM
ΔS
.80
-.80
ASTIGMATISM
FIG.6C
23°
17.5°
11.8°
3.00
-3.00
DISTORTION
FIG.6D
23°
17.5°
11.8°
.10
-.10
LATERAL CHROMATIC
ABERRATION

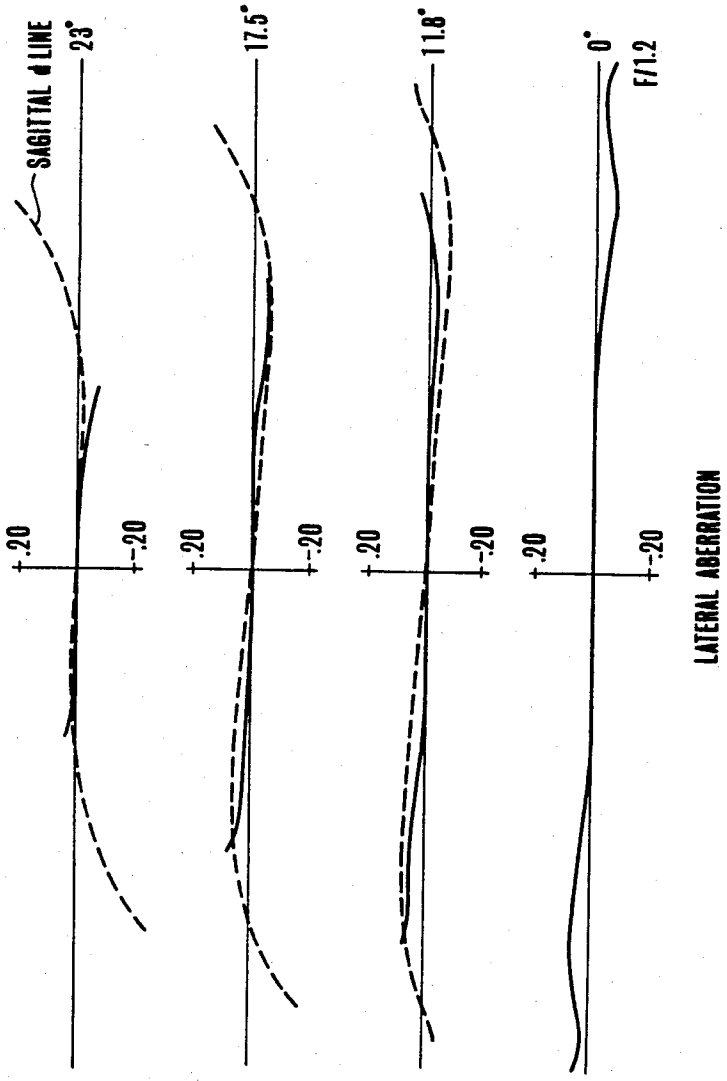


FIG.7A

FIG.7B

FIG.7C

FIG.7D

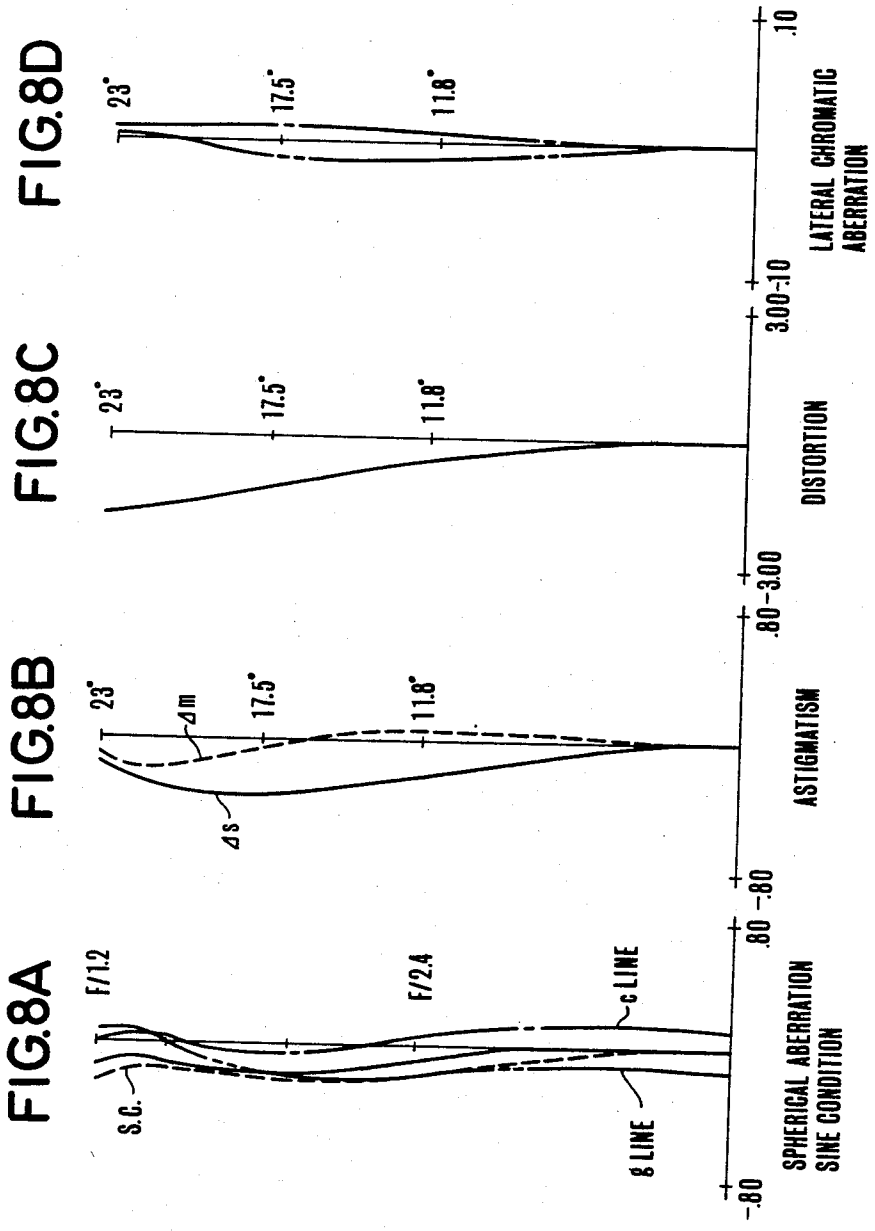


FIG.8A
F/1.2
F/2.4
S.C.
g LINE
c LINE
.80
-.80
SPHERICAL ABERRATION
SINE CONDITION
FIG.8B
23°
Δm
17.5°
11.8°
Δs
.80
-.80
ASTIGMATISM
FIG.8C
23°
17.5°
11.8°
3.00
-3.00
DISTORTION
FIG.8D
23°
17.5°
11.8°
.10
-.10
LATERAL CHROMATIC ABERRATION

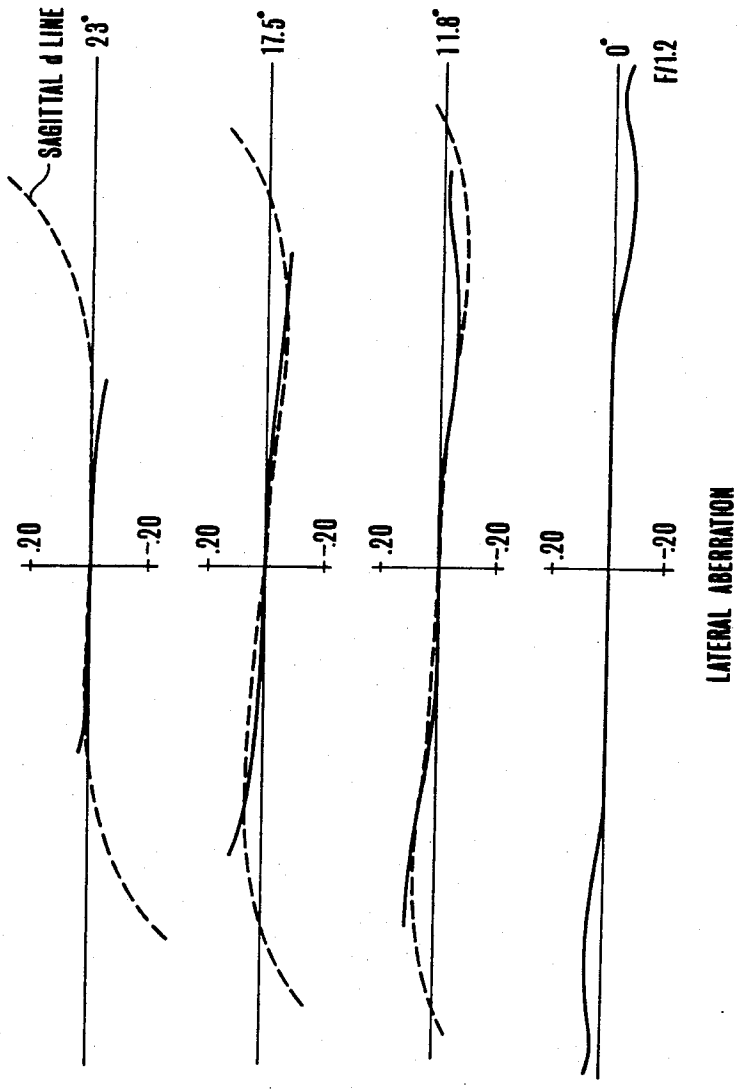


FIG.9A FIG.9B FIG.9C FIG.9D

GAUSS TYPE LARGE APERTURE PHOTOGRAPHIC OBJECTIVE

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to large, or wide, aperture photographic objectives, particularly in the 50 mm focal length, F/1.2 class, and more particularly, to objectives using an aspherical surface for maintaining a long back focus and providing extremely good correction for flare at the fully open aperture, and also providing good correction for spherical aberration, field of curvature, and coma.

2. Description of the Prior Art

A Gauss type lens produces flare (sagittal flare) mainly because the forward and rearward lens surfaces adjacent the diaphragm are strong in negative curvature. However, limiting the curvature of these surfaces causes rapid deterioration in quality due to spherical aberrations and field curvature.

The index of refraction of the positive lens may be increased to facilitate aberrational corrections. However, optical glasses having the high refractive indices required for this purpose are not available at the present time. Therefore, in F/1.2 class lenses, effective removal of flare at fully open aperture, spherical aberration, and curvature of field becomes difficult with a spherical system.

An objective which corrects for flare and various aberrations using an aspherical surface is disclosed in Japanese Patent Publication No. Sho 47-19386, assigned to the assignee of the present invention.

SUMMARY OF THE INVENTION

The present invention makes the first surface of the second lens aspherical like in the above-cited Japanese Patent Publication No. Sho 47-19386. The aspherical surface is configured so that proceeding radially outwardly from the optical axis, the positive power is weakened. This makes possible extremely good compensation for the deteriorated spherical aberration due to the weakening of the negative curvature of the lens surfaces forwardly and rearwardly adjacent to the diaphragm. Further the use of a positive lens made up of a higher refractive index glass than that used in the above-described lens makes it possible even to correct the field of curvature properly. This achieves good correction of flare at the fully open aperture and the various aberrations.

The main feature of the present invention is, as will be described later, to provide a Gauss type eight-element objective with a wider image angle than was in the prior art while nevertheless solving the aberrational problem by satisfying the following conditions.

$$1.24 < \frac{D3 + D4}{D6 + D7} < 1.4 \quad (1)$$

$$1 < \frac{L}{f} < 1.1 \left(L = \sum_{i=1}^{13} Di \right) \quad (2)$$

$$1.78 < \frac{N1 + N2 + N5 + N6 + N7}{5} < 1.89 \quad (3)$$

$$2.17 < \frac{f}{R5} < 2.56 \quad (4)$$

-continued

$$2.44 < \frac{f}{|R6|} < 2.7 \quad (5)$$

$$f6 < f7 < f8 \quad (6)$$

$$0.08 < n2 - n3 < 0.22 \quad (7)$$

$$0.1 < \frac{f}{R4} < 0.5 \quad (8)$$

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a lens block diagram of an embodiment of the present invention.

FIGS. **2** and **3** are aberration curves of Example 1 of the present invention.

FIGS. **4** and **5** are aberration curves of Example 2 of the present invention.

FIGS. **6** and **7** are aberration curves of Example 3 of the present invention.

FIGS. **8** and **9** are aberration curves of Example 4 of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

An embodiment of an objective according to the present invention comprises, from front to rear, a positive first lens of meniscus shape of convex curvature toward the front, a positive second lens of convex curvature toward the front, a negative third lens of concave curvature toward the rear, a negative fourth lens of concave curvature toward the front, a positive fifth lens of convex curvature toward the rear, a positive sixth lens of meniscus shape of convex curvature toward the rear, a bi-convex positive seventh lens with its rear surface of stronger curvature, and a bi-convex eighth lens, the 2nd and 3rd lens being cemented together, the 4th and 5th lenses being cemented together, and a diaphragm being arranged in a space between the 3rd and 4th lenses. Letting **R1** to **R14** denote the radii of curvature of the various lens surfaces, **D1** to **D13** the axial thicknesses of the various lenses and the axial separations between the successive lenses, **N1** to **N8** the indices of refraction (for d-line) of the various lenses, ν**1** to ν**8** the Abbe numbers of the various lenses, f the focal length of the entire system, **f6**, **f7** and **f8** the focal lengths of the 6th, 7th and 8th lenses respectively, and the first surface of the 2nd lens being an aspherical surface of such configuration that as is farther distant radially outwardly of the optical axis, the amount of deviation of the surface from the spherical surface of paraxial radius of curvature increases in a direction toward the front, the Gauss type large aperture photographic objective is characterized by satisfying the following conditions:

$$1.24 < \frac{D3 + D4}{D6 + D7} < 1.4 \quad (1)$$

$$1 < \frac{L}{f} < 1.1 \left(L = \sum_{i=1}^{13} Di \right) \quad (2)$$

$$1.78 < \frac{N1 + N2 + N5 + N6 + N7}{5} < 1.89 \quad (3)$$

$$2.17 < \frac{f}{R5} < 2.56 \quad (4)$$

-continued

$$2.44 < \frac{f}{|R6|} < 2.7 \quad (5)$$

$$f6 < f7 < f8 \quad (6)$$

$$0.08 < n2 - n3 < 0.22 \quad (7)$$

$$0.1 < \frac{f}{R4} < 0.5 \quad (8)$$

Thus, the objective of the present invention is of the Gauss type with eight elements, and provides good correction for the various aberrations and particularly flare over the extended range of the image angle without stress when the various afore-mentioned conditions are satisfied. These various conditions are next described in greater detail.

Condition (1) serves for maintaining the necessary back focus. Below the lower limit, when the back focus becomes longer than necessary, and the diameter of the rear lens is increased, thus increasing the bulk and size of the objective. If the entire length is maintained constant, it also becomes a cause of increasing the diameter of the diaphragm.

Conversely, above the upper limit, when the back focus becomes too short, the mirror up function of the camera now becomes too difficult to perform.

Condition (2) defines the total length of the objective. The more compact the objective, the more convenient for portability. Below the lower limit, it is difficult to properly remove the flare at the fully open aperture. Above the upper limit, in order to assure a sufficient marginal amount of light, the diameters of the front and rear lenses are both required to be increased, thus increasing the bulk and size of the objective as the total length is also increased.

Condition (3) is a condition for using a high refractive index glass particularly in the positive lens of strong power. Below the lower limit, it becomes difficult to correct both flare and field curvature. And, the upper limit represents the maximum refractive index value in the glasses available on the market at the present time.

Conditions (4) and (5) when combined with condition (3) to well remove the flare (mainly the sagittal flare) while maintaining good correction of field curvature. Above the upper limit, the negative curvature of each of these surfaces is strong so that the flare removal effect is too weak. Conversely below the lower limit, when the negative curvature becomes too weak, although the flare at the fully open aperture only can be effectively removed, the Petzval sum becomes too large to prevent the deterioration of the field curvature. This makes it difficult to achieve an increase in the performance.

Condition (6) when combined with condition (1) serves to reduce the diameter of the rear lens to a necessary minimum or thereabout (the diameter determined by the fully open F-number light bundle), while maintaining the necessary amount in back focus. That is, of the 6th, 7th and 8th positive lenses, the refractive power is made stronger in the order nearer to the diaphragm so that as the light bundle of the maximum image angle after having passed through the diaphragm is first refracted toward the optical axis by the 6th lens of strong refractive power, and then proceeds to the 7th and 8th lenses successively, the diameter of the rear lens can be decreased without difficulty. Also since the gentle passage of the light bundle is possible, spherical aberration and coma can be corrected with ease. When the conditions are not satisfied, an increase in the diameter of the rear lens and deterioration of the spherical aberration and coma result and an increase in performance becomes difficult to achieve.

Condition (7) prevents the field curvature from increasing when the range of image angles is extended and minimizes the Petzval sum by defining, for the cemented second and third lenses, somewhat of a difference in refractive indices. Below the lower limit, the Petzval sum deteriorates. Above the upper limit, no combinations of glasses for use in the positive and negative lenses corrected for chromatic aberrations is available at the present time and an under-correction of longitudinal chromatic aberration (g-line) results.

Condition (8) when combined with condition (7) and the aspherical configuration facilitates good correction of both astigmatism and distortion. That is, the first or aspherical surface of the second lens produces over-corrected astigmantism and barrel type distortion, a part of which must be compensated for by the cemented surface R4, and somewhat refractive power must be had. Also, for ease of correction, a concentric configuration to the diaphragm is preferred. When this condition is not satisfied, the balance of the astigmatism and distortion is broken, and it becomes difficult to properly correct both of them. Further a problem arises in selecting glasses for use in the second and third lenses to correct chromatic aberration.

By satisfying the conditions as above, it is possible to provide a photographic large aperture objective with an image angle of 46° where F-number = 1.2 which has flare limited to an extremely low level at the fully open aperture, and moreover, is properly corrected even for spherical aberration, curvature of the field and coma as will be seen from the examples of practical objectives of the invention.

Further, focusing of the objective in the embodiment of the present invention is performed by moving the 1st to 7th lenses only, while the 8th lens remains stationary. Hence, excellent image quality can be maintained throughout the focusing range. Particularly, when the range of variation of coma and astigmatism can be reduced to zero.

It is noted that the above-mentioned aspherical configuration may be expressed by the following formula:

$$X = R\{1-(1-H^2/R^2)^{\frac{1}{2}}\} + AH^2 + BH^4 + OH^6 + DH^8 + EH^{10}$$

where

R: the radius of curvature in the paraxial region.

H: the height from the optical axis.

X: the axial deviation of the surface at the height H from the optical axis with reference to the vertex of the surface (the direction in which the light advances is taken as plus)

A–E: aspheric coefficients.

In the following, the numerical data of examples of specific objectives of the invention are given. Table 1 shows the values of the factors in the above-described various conditions for Examples 1 to 4 of the invention.

TABLE 1

		Ex. 1	Ex. 2	Ex. 3	Ex. 4
1	$\frac{D_3 + D_4}{D_6 + D_7}$	1.367	1.382	1.263	1.279
2	$\frac{L}{f}$	1.049	1.052	1.051	1.021
3	$\frac{N_1 + N_2 + N_5 + N_6 + N_7}{5}$	1.8039	1.7868	1.8218	1.883
4	$\frac{f}{R_5}$	2.399	2.495	2.353	2.22
5	$\frac{f}{\lvert R_6 \rvert}$	2.644	2.673	2.558	2.493
6	f_6	131.43	146.17	135.2	142.05
	f_7	182.35	169.33	174.54	212.64
	f_8	743.87	747.52	701.96	584.58
7	$n_2 - n_3$	0.1076	0.1311	0.1663	0.2103
8	$\frac{f}{R_4}$	0.26	0.48	0.186	0.279

EXAMPLE 1

Focal Length f = 100 F-number F = 1:1.2 Image Angle 2ω = 46°

Radius of Curvature		Axial Thickness & Separation		Index of Refraction(Nd)		Abbe Number (νd)	
R_1	108.673	D_1	8.682	N_1	1.804	ν_1	46.6
R_2	416.217	D_2	0.291				
R_3	78.3267	D_3	22.87	N_2	1.744	ν_2	44.7
R_4	384.362	D_4	3.992	N_3	1.63636	ν_3	35.4
R_5	41.6885	D_5	30.851				
R_6	−37.8277	D_6	2.326	N_4	1.80518	ν_4	25.4
R_7	720.81	D_7	17.328	N_5	1.816	ν_5	46.6
R_8	−64.003	D_8	0.291				
R_9	−316.428	D_9	7.752	N_6	1.883	ν_6	40.8
R_{10}	−85.8858	D_{10}	0.194				
R_{11}	1219.053	D_{11}	6.492	N_7	1.7725	ν_7	49.6
R_{12}	−158.904	D_{12}	0.388				
R_{13}	745.854	D_{13}	3.488	N_8	1.62299	ν_8	58.2
R_{14}	−1221.648						

Aspherical Surface: R3
Aspherical Coefficients:
A = 0.
B = -1.172337×10^{-7}
C = 6.303928×10^{-11}
D = $-6.621355 \times 10^{-14}$
E = 2.08995×10^{-17}

EXAMPLE 2

Focal Length f = 100 F-number: 1:1.2 Image Angle 2ω = 46°

Radius of Curvature		Axial Thickness & Separation		Index of Refraction(Nd)		Abbe Number (νd)	
R_1	103.145	D_1	8.682	N_1	1.7725	ν_1	49.6
R_2	391.79	D_2	0.291				
R_3	75.892	D_3	22.541	N_2	1.757	ν_2	47.9
R_4	208.408	D_4	3.992	N_3	1.62588	ν_3	35.7
R_5	40.0794	D_5	31.12				
R_6	−37.4074	D_6	2.326	N_4	1.7847	ν_4	26.2
R_7	612.724	D_7	17.65	N_5	1.816	ν_5	46.6
R_8	−63.0719	D_8	0.291				
R_9	−326.673	D_9	7.752	N_6	1.816	ν_6	46.6
R_{10}	−88.3036	D_{10}	0.194				
R_{11}	1072.984	D_{11}	6.492	N_7	1.7725	ν_7	49.6
R_{12}	−148.571	D_{12}	0.388				
R_{13}	930.722	D_{13}	3.488	N_8	1.62299	ν_8	58.2
R_{14}	−930.722						

-continued

Focal Length f = 100 F-number: 1:1.2 Image Angle 2ω = 46°

Aspherical Surface: R3
Aspherical Coefficients:
A = 0.
B = -1.023571×10^{-7}
C = 6.311869×10^{-11}
D = $-6.418568 \times 10^{-14}$
E = 2.08995×10^{-17}

EXAMPLE 3

Focal Length f = 100 F-number: 1:1.2 Image Angle: 2ω = 46°

Radius of Curvature		Axial Thickness & Separation		Index of Refraction(Nd)		Abbe Number (νd)	
R_1	108.718	D_1	8.682	N_1	1.816	ν_1	46.6
R_2	362.048	D_2	0.291				
R_3	80.332	D_3	22.029	N_2	1.8061	ν_2	40.9
R_4	537.537	D_4	3.992	N_3	1.6398	ν_3	34.5
R_5	42.5072	D_5	30.887				
R_6	−39.0911	D_6	2.326	N_4	1.80518	ν_4	25.4
R_7	314.522	D_7	18.276	N_5	1.788	ν_5	47.4
R_8	−67.1236	D_8	0.291				
R_9	−313.046	D_9	7.752	N_6	1.883	ν_6	40.8
R_{10}	−87.4252	D_{10}	0.194				
R_{11}	1156.662	D_{11}	6.492	N_7	1.816	ν_7	46.6
R_{12}	−162.01	D_{12}	0.388				
R_{13}	939.922	D_{13}	3.488	N_8	1.67	ν_8	57.4
R_{14}	−939.922						

Aspherical Surface: R3
Aspherical Coefficients:
A = 0.
B = -1.102309×10^{-7}
C = 6.447527×10^{-11}
D = $-6.489253 \times 10^{-14}$
E = 2.08995×10^{-17}

EXAMPLE 4

Focal Length f = 100 F-number: 1:1.2 Image Angle 2ω = 46°

Radius of Curvature		Axial Thickness & Separation		Index of Refraction(Nd)		Abbe Number (νd)	
R_1	131.824	D_1	8.682	N_1	1.883	ν_1	40.8
R_2	391.918	D_2	0.291				
R_3	76.9526	D_3	20.347	N_2	1.883	ν_2	40.8

-continued

Focal Length f = 100 F-number: 1:1.2 Image Angle 2ω = 46°							
Radius of Curvature		Axial Thickness & Separation		Index of Refraction(Nd)		Abbe Number (νd)	
R_4	358.259	D_4	3.992	N_3	1.6727	ν_3	32.1
R_5	45.039	D_5	31.12				
R_6	−40.1116	D_6	2.326	N_4	1.84666	ν_4	23.9
R_7	872.505	D_7	16.703	N_5	1.883	ν_5	40.8
R_8	−66.6741	D_8	0.291				
R_9	−227.071	D_9	7.752	N_6	1.883	ν_6	40.8
R_{10}	−82.0924	D_{10}	0.194				
R_{11}	1116.827	D_{11}	6.492	N_7	1.883	ν_7	40.8
R_{12}	−225.097	D_{12}	0.388				

-continued

Focal Length f = 100 F-number: 1:1.2 Image Angle 2ω = 46°							
Radius of Curvature		Axial Thickness & Separation		Index of Refraction(Nd)		Abbe Number (νd)	
R_{13}	813.953	D_{13}	3.488	N_8	1.6968	ν_8	55.5
R_{14}	−813.953						

Aspherical Surface: R3
Aspherical Coefficients:
A = 0.
B = -1.056712×10^{-7}
C = 6.529709×10^{-11}
D = -6.54118×10^{-14}
E = 2.08995×10^{-17}

3rd-Order Aberration Coefficient					
Example 1:					
R	SA	CM	AS	PT	DS
1	0.192494	0.093189	0.045114	0.410108	0.220378
2	0.032586	−0.122998	0.464267	−0.107078	−1.348236
3	−0.630708	0.298742	−0.211479	0.544649	0.607456
4	0.055447	−0.085022	0.130373	−0.009813	−0.184866
5	−0.327933	−0.202072	−0.124517	−0.932841	−0.651544
6	−1.628909	0.741080	−0.337158	−1.179133	0.689844
7	0.003700	0.006144	0.010203	0.000458	0.017703
8	0.209744	0.140274	0.093814	0.702060	−0.532272
9	−0.000098	0.000763	−0.005916	−0.148196	1.194951
10	0.829482	−0.264598	0.084405	0.545996	−0.201093
11	−0.046065	0.110651	−0.265791	0.035751	0.552573
12	1.002910	−0.286839	0.082038	0.274270	−0.101906
13	−0.254418	0.249650	−0.244972	0.051465	0.189881
14	0.506250	−0.288645	0.164574	0.031421	−0.111749
Σ	−0.055519	0.109771	−0.115047	0.219116	0.341120
Example 2:					
R	SA	CM	AS	PT	DS
1	0.224067	0.094086	0.039507	0.422535	0.194012
2	0.030284	−0.117376	0.454937	−0.111239	−1.332132
3	−0.562610	0.266111	−0.191709	0.567712	0.584473
4	0.037455	−0.070395	0.132304	−0.022024	−0.207265
5	−0.371123	−0.213649	−0.122994	−0.960464	−0.623727
6	−1.622031	0.736874	−0.334755	−1.175388	0.686044
7	0.010308	0.017475	0.029625	0.001576	0.052895
8	0.253804	−0.156847	0.096930	0.712424	−0.500170
9	−0.000913	0.005881	−0.037868	−0.137550	−1.129509
10	0.699739	−0.249953	0.089286	0.508857	−0.213662
11	−0.037132	0.098762	−0.262679	0.040618	0.590623
12	1.039430	−0.268533	0.069374	0.293344	−0.093707
13	−0.268319	0.251127	−0.235037	0.041243	0.181378
14	0.518499	−0.282325	0.153727	0.041243	−0.106162
Σ	−0.048543	0.111238	−0.119353	0.222886	0.342110
Example 3:					
R	SA	CM	AS	PT	DS
1	0.192553	0.097280	0.049147	0.413306	0.233636
2	0.021005	−0.092789	0.409897	−0.124111	−1.262470
3	−0.641606	0.290575	−0.204403	0.555595	0.629857
4	0.106185	−0.149018	0.209130	−0.010446	−0.278831
5	−0.279175	−0.178521	−0.114157	−0.917891	−0.659954
6	−1.604196	0.749882	−0.350533	−1.141024	0.697229
7	−0.007599	−0.011648	−0.017854	−0.001692	−0.029961
8	0.170771	−0.125441	0.092144	0.656574	−0.549977
9	−0.000022	0.000173	−0.001382	−0.149796	1.207722
10	0.750372	−0.252290	0.084825	0.536381	−0.208862
11	−0.039303	0.101922	−0.264310	0.038848	0.584682
12	0.991451	−0.282182	0.080313	0.277353	−0.101797
13	−0.273565	0.256788	−0.241041	0.042684	0.186192
14	0.544326	−0.291828	0.156457	0.042684	−0.106765
Σ	−0.068802	0.112901	−0.111766	0.218465	0.340700
Example 4:					
R	SA	CM	AS	PT	DS
1	0.108713	0.084184	0.065190	0.355727	0.325946
2	0.010612	−0.058889	0.326782	−0.119651	−1.149395
3	−0.661759	0.317541	−0.163571	0.609379	0.555683
4	0.105227	−0.152508	0.221034	−0.018637	−0.293340
5	−0.219741	−0.149477	−0.101680	−0.892924	−0.676571
6	−1.695190	0.783603	−0.362221	−1.143016	0.695797
7	0.009906	0.016786	0.028444	0.001198	0.050230
8	0.262900	−0.175746	0.117484	0.703320	−0.548697
9	−0.006842	0.024066	−0.084651	−0.206514	1.024161
10	0.969773	−0.295295	0.089917	0.571225	−0.201317
11	−0.057876	0.131136	−0.297130	0.041988	0.578103
12	0.757457	−0.346764	0.158749	0.208325	−0.168047

-continued

	3rd-Order Aberration Coefficient				
13	−0.249139	0.263478	−0.278642	0.050452	0.241324
14	0.568903	−0.324838	0.185480	0.050452	0.134715
Σ	−0.097056	0.117277	−0.094815	0.211324	0.299161

Note:
SA: Spherical Aberration
CM: Coma
AS: Astigmatism
PT: Petzval Sum
DS: Distortion

What is claimed is:

1. A Gauss type large aperture photographic objective comprising eight elements of which:

the first is a positive meniscus lens of convex curvature toward the front,

the second is a positive lens of convex curvature toward the front,

the third is a negative lens of concave curvature toward the rear,

the fourth is a negative lens of concave curvature toward the front,

the fifth is a positive lens of convex curvature toward the rear,

the sixth is a positive meniscus lens of convex curvature toward the rear,

the seventh is a bi-convex positive lens with its rear surface of stronger curvature, and

the eighth is a positive lens,

said second and third lenses being cemented together,

said fourth and fifth lenses being cemented together,

the first surface of said second lens being aspherical, its aspherical configuration being such that as the distance from the optical axis increases, the deviation of the surface from the spherical surface of paraxial radius of curvature increases toward the front, and said objective being characterized by satisfying the following conditions:

$$1.24 < \frac{D3 + D4}{D6 + D7} < 1.4 \quad (1)$$

-continued

$$1 < \frac{L}{f} < 1.1 \left(L = \sum_{i=1}^{13} Di \right) \quad (2)$$

$$1.78 < \frac{N1 + N2 + N5 + N6 + N7}{5} < 1.89 \quad (3)$$

$$2.17 < \frac{f}{R5} < 2.56 \quad (4)$$

$$2.44 < \frac{f}{|R6|} < 2.7 \quad (5)$$

$$f6 < f7 < f8 \quad (6)$$

$$0.08 < n2 - n3 < 0.22 \quad (7)$$

$$0.1 < \frac{f}{R4} < 0.5 \quad (8)$$

wherein

R1, R2, . . . , R14 are the radii of curvature of the various lens surface,

D1, D2, . . . , D13 are the axial thicknesses of the various lenses and the axial separations between the successive lenses,

N1, N2, . . . , N8 are the indices of refraction of the various lenses (d-line),

ν1, ν2, . . . , ν8 are the Abbe numbers of the various lenses,

f is the focal length of the entire system,

f6, f7 and f8 are the focal lengths of the 6th, 7th and 8th lenses respectively.

* * * * *

United States Patent [19]

Matui

[11] 4,360,835

[45] Nov. 23, 1982

[54] **TELEVISION CAMERA OBJECTIVE HAVING DRIVING MECHANISM FOR ADJUSTING COMPONENTS OF ITS OPTICAL SYSTEM**

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[73] Assignee: **Fuji Photo Optical Co., Ltd.**, Omiya, Japan

[21] Appl. No.: **217,122**

[22] Filed: **Dec. 17, 1980**

[30] **Foreign Application Priority Data**

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[51] **Int. Cl.**[3] **H04N 5/26**

[52] **U.S. Cl.** **358/225**; 358/227

[58] **Field of Search** 358/209, 225, 227; 352/139, 140

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Primary Examiner—Robert L. Richardson

Attorney, Agent, or Firm—Young & Thompson

[57] **ABSTRACT**

A television camera objective has a driving mechanism for adjusting components of its optical system and is adapted selectively replaceably to receive either a servo control driving unit or a manual control driving unit. Either type of driving unit has a driving shaft that engages with a rotary transmission shaft that remains in place on the driving mechanism. To prevent the transmission shaft from rotating in the absence of a driving unit, the transmission shaft has a flange against which a sliding sleeve is spring urged into braking frictional engagement. The introduction of the driving unit pushes back this sleeve to disengage the frictional surfaces and release the transmission shaft for rotation. In addition, the sleeve can be manually pulled back and rotated to lock it in a disengaged position, so as intentionally to free the transmission shaft for rotation in the absence of a driving unit.

15 Claims, 4 Drawing Figures

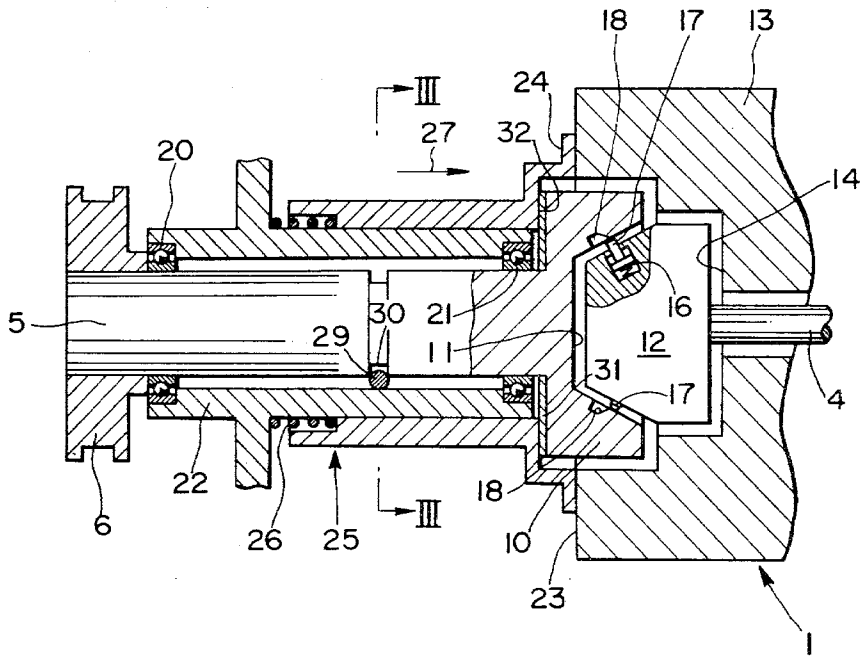


FIG. 1

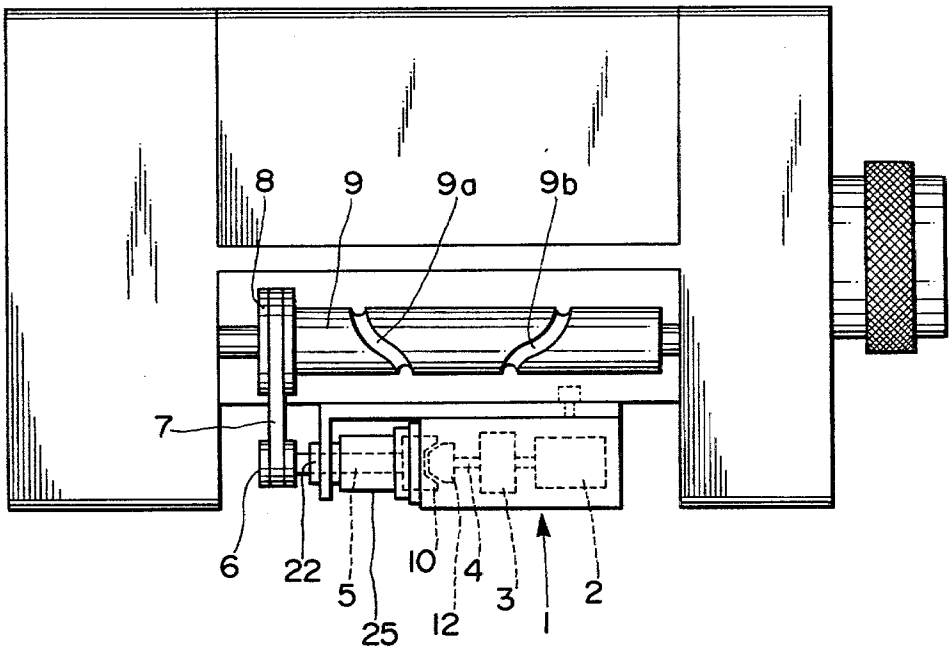


FIG. 2

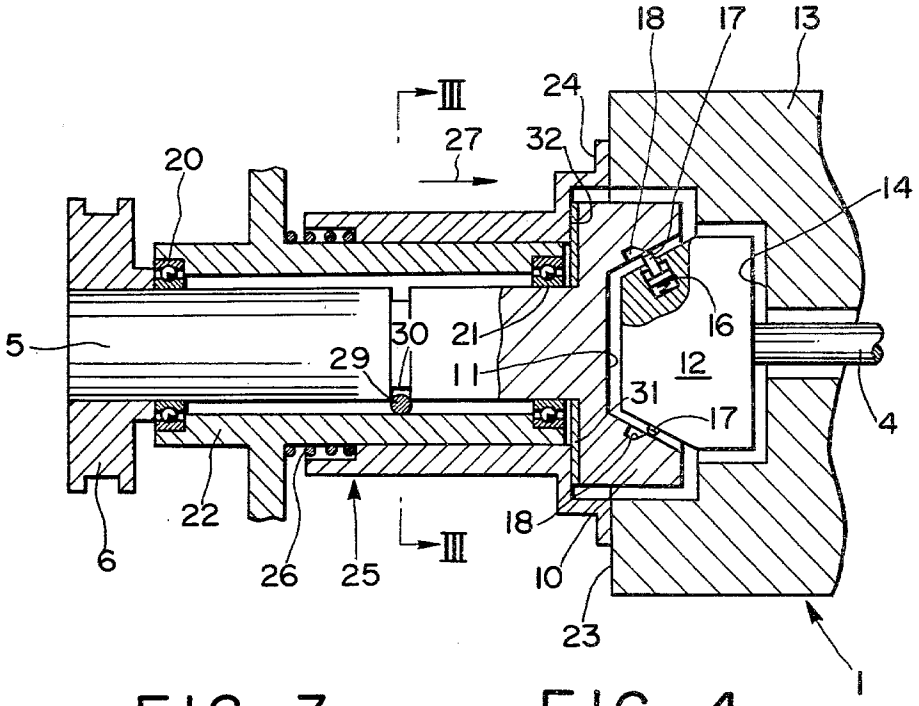


FIG. 3

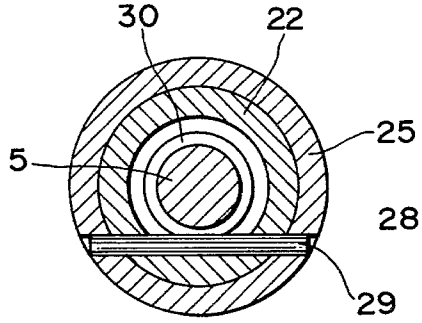
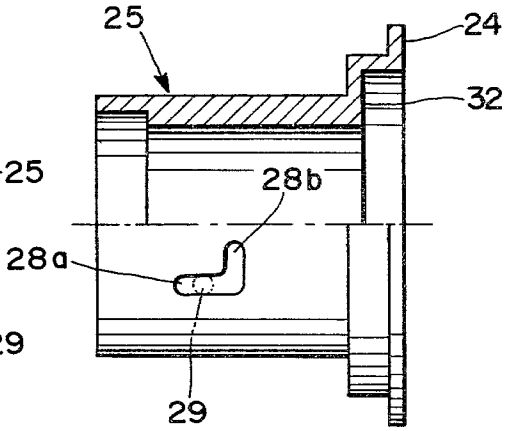


FIG. 4



TELEVISION CAMERA OBJECTIVE HAVING DRIVING MECHANISM FOR ADJUSTING COMPONENTS OF ITS OPTICAL SYSTEM

BACKGROUND OF THE INVENTION

The present invention relates to a television camera objective having a driving mechanism for adjusting components of an optical system, and more particularly relates to such an objective including an engaging mechanism for preventing a transmission shaft from rotating in the absence of a driving unit for controlling focusing components.

In usual television camera objectives having a driving mechanism for adjusting components of an optical system, a controlled displacement of at least one component of the optical system is caused by a driving force which, in turn, is transmitted from a driving unit to a lens component displacing mechanism through a transmission shaft. In zoom lenses, in which the focal length is variable, correlative displacements of lens components for varying the focal length and for compensating are attended by variations of magnification ratio. On the other hand the focusing control of an objective is performed by an axial displacement of focusing lens components. In standard television camera objectives, there are provided driving force transmission mechanisms on which driving units identical in their construction are detachably mounted for zooming control and focusing control.

There are two well known types of driving units. One of them is a servo control driving unit, or so-called servo module, into which a servo motor is built for motor-operated zooming control or motor-operated focusing control. The other is a manual control driving unit, or so-called manual module, having a flexible cable through which zooming or focusing control commands are manually given by an operator. Such driving units are a servo module or a manual module are selectively mounted on the driving force transmission mechanism according to the contemplated mode of operation.

Such driving units as described hereinbefore are usually demounted from the driving force transmission mechanism during shipment from the factory or during transportation from one studio to another. Generally, objectives for use with television cameras have an optical system with a large aperture number and components which are quite heavy in weight. Consequently, upon the objective without driving units being inclined, one or more movable lens components can shift in position. Such motions of these movable lenses finally cause the guide pin of a movable lens holder to come into collision with the end of a cam slot formed on a camming cylinder. As a result of that, the guide pin and/or cam slot can be damaged, and the movable lenses can break by impact of the guide pin and movable lens holder.

OBJECTS OF THE INVENTION

It is accordingly a principal object of the present invention to provide a television camera objective having a driving mechanism for adjusting components of an optical system, in which at least one movable lens component is prevented from accidentally moving in the absence of a driving unit on a transmission shaft.

Another object of the present invention is to provide a television camera objective having a driving mechanism for adjusting components of an optical system and which is adapted to allow or obstruct the rotation of a transmission shaft, depending on whether or not a driving unit is mounted on the transmission shaft.

Finally, it is an object of the present invention to provide a television camera objective having a driving mechanism for adjusting components of an optical lens system, in which an engaging member for obstructing the rotation of a transmission shaft can be selectively moved to a position in which the engaging member allows the transmission shaft to rotate.

SUMMARY OF THE INVENTION

The objects of the invention described above are achieved by the provision of a television camera objective which has a detecting member adapted to be displaced from a first position to a second position by the operation of coupling a driving unit with a transmission shaft and an engaging member which is forced to shift by the displacement of the detecting member. The engaging member is adapted to prevent the transmission shaft from rotating by its engagement with a part of the transmission shaft when the detecting member is in the first position but to allow the transmission shaft to rotate upon its disengagement therefrom when the detecting member is in the second position. The engaging member comes into contact with and brakes the transmission shaft to obstruct the rotation thereof. Although the engaging member and the detecting member are referred to as two separate members, it is desirable to unite these two as one member.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other objects, features and advantages of the present invention will become apparent from a consideration of the following description, taken in conjunction with the accompanying drawings, in which:

FIG. **1** is a side elevational view, with the cover removed, of a preferred embodiment of the present invention;

FIG. **2** is a sectional view illustrating the principal parts of the present invention;

FIG. **3** is a cross-sectional view taken along line III—III in FIG. **2**; and

FIG. **4** is a side view, the upper half in section, of the engaging member.

DETAILED DESCRIPTION OF THE INVENTION

Referring now to the drawings in greater detail, in FIG. **1** there is shown a television camera objective with the side cover removed, including a driving unit, for example a servo module driving unit **1** having a servo motor **2** therein, which is detachably mounted on the objective. The driving force produced by the servo motor **2** is transmitted to a driving shaft **4** through a reduction gear **3** and causes a transmission shaft **5** to rotate. A belt pulley **8** fixed to the end of a cylindrical shaft **9**, which in turn is formed with two curved cam slots **9***a* and **9***b* on its outer surface, is rotated by a drive belt **7** and a pulley **6** fixed to the end of the transmission shaft **5**.

Upon the camming cylinder **9** rotating, two lens holders (not illustrated), on which two movable lens components are mounted separately and each of which is slidably engaged with respective ones of the cam slots on the camming cylinder **9**, are caused to be displaced axially with these followers guided by a straight guide

provided on a fixed cylinder (not illustrated). Consequently, two movable lens components such as a lens of variable focal length and a compensating lens (not illustrated, nor are the other lens components comprising a zoom lens system) are correlatively displaced along an optical axis a distance corresponding to the amount of rotation of the camming cylinder shaft **9**, so as properly to vary the focal length. Such an assembly of camming cylinder shaft **9**, lens holders and a fixed cylinder comprise a well-known lens displacement control mechanism.

Referring now to FIG. **2**, on the end of the transmission shaft **5** opposite pulley **6**, a coupling head **10** similar to a flange is provided. The coupling head **10** of the transmission shaft **5** is provided with a frusto-conical depression **11** which coacts with a complementarily shaped coupling head **12** on the end of driving shaft **4**. The coupling head **12** is accommodated in a recess **14** on a housing **13** of the servo module **1**. A plurality of engaging pins **17** are urged by biasing coil compression springs **16** so as to retractably project from the truncated conical surface of the coupling head **12**. Therefore, as the coupling head **12** of the driving shaft **4** is inserted into the frusto-conical depression **11** of the coupling head **10** of the transmission shaft **5**, the interconnection between these two shafts **4** and **5** is completed by pins **17** seating in recesses **18** formed on the truncated conical surface of the frusto-conical depression **11** of the transmission shaft **5**.

The transmission shaft **5** is rotatably carried by a cylindrical fixed rigid member **22** through ball bearings **20** and **21** interposed therebetween as shown in FIG. **2**. The cylindrical rigid member **22** is surrounded by an engaging member **25** the rear end of which has a flanged portion **24** adapted to come into abutment against a front wall **23** of the housing **13**, the engaging member **25** being biased in the direction of the arrow **27** as shown in FIG. **2** by means of a coil compression spring **26** and being axially slidable and rotatable through only a portion of one turn.

As shown in FIG. **4**, the engaging member **25** is restricted in its sliding movements by an axial slot **28***a* formed thereon and a rigid rod **29** described hereinafter coacting with the slot **28***a*. The engaging member **25** is further restricted in rotation by a peripheral slot **28***b* formed thereon and by the rigid rod **29**.

Turning now to FIG. **3**, the cylindrical rigid member **22** holds fixedly and rigidly the rod **29** which is fitted into an annular groove **30** on the transmission shaft **5** and is further selectively engaged with slots **28***a* or **28***b* so as to restrict the sliding or rotating motion of the engaging member.

On the front face of the coupling head **10** of the transmission shaft **5** an annular member **31** having a relatively high frictional resistance is secured. The annular member **31** serves to prevent the transmission shaft from rotating when member **31** frictionally engages with the surface **32** of the engaging member **25**. Obviously, the same result is achieved if the annular frictional member **31** is instead secured to the opposed engaging surface of the engaging member **25**.

In the operation of a television camera objective embodying the present invention, as illustrated in FIGS. **1** and **2**, the housing is formed along one of its rectangular surfaces with a slot (not shown) adapted to receive a bayonet lug (see FIG. **1**) on the casing of servo module **1**, whereby the module casing may be emplaced in its socket by transverse and longitudinal motion to introduce the lug into the slot while connecting the driving shaft **4** with the transmission shaft **5** through coupling heads **10** and **12**. Longitudinal advancement of the servo module **1**, in the direction opposite to that of arrow **27** in FIG. **2**, causes the engaging member **25** to move axially against the biasing force of spring **26** with its guide slot **28***a* engaging with the rigid rod **29** secured to the cylindrical rigid member **22**.

At the end of the longitudinal advance of the servo module **1**, the driving shaft **4** and the transmission shaft **5** are interconnected with each other through the engagement between guide pins **17** and bores **18**. After the completion of the interconnection of the servo module **1** and the transmission shaft **5**, engaging surface **32** of the engaging member **25** is spaced from the annular frictional member **31** so that the driving force produced by the servo motor **2** is allowed to be transmitted to the transmission shaft **5** through coupling **10** and **12** without obstruction by the engaging member **25**. Consequently the zoom lens system is servo-controlled to vary its focal length by the servo module **1**.

Upon the servo module being required to be demounted, it may be enough to displace the casing from its socket by longitudinal (toward the arrow **27** shown in FIG. **2**) and transverse motion to withdraw the lug from the slot while disconnecting the driving shaft **4** from the transmission shaft **5** through disengagement between coupling heads **10** and **12**. On this occasion, the engaging member **25** is gradually moved in the direction of arrow **27** under the influence of the force of the biasing spring **26** with the withdrawing of servo module **1** and finally the surface **32** of the engaging member **25** will come into contact with the annular frictional member **31** secured to the coupling head **10** of the transmission shaft **5**.

Thereafter, the cylindrical rigid member **22**, with the axial slot **28***a* engaged by the rigid rod **29**, prevents the engaging member **25** from rotating, so that the transmission shaft is prevented from rotating, thanks to the frictional engagement between surface **32** and member **31**.

As is apparent from the above description, even though a television camera objective without driving units is tilted by mistake during its shipment from the factory or transportation or the like, the movable lens components will be prevented from falling by gravity due to the fact that the engaging member **25** is in contact with the annular frictional member **31**.

Furthermore when it is required to manually operate a television camera objective for zooming control without a servo module driving unit, that is, when it is desirable to adjust the focal length of the optical system through the transmission shaft **5** being operated manually and directly by an operator, the engaging member **25** is slid with axial and circumferential motion along slots **28***a* and **28***b* and locks in slot **28***b* against the force of the biasing spring **26**, with the result that the engaging member **25** is kept disengaged from the transmission shaft **5**. Consequently, the transmission shaft **5** can rotate under an extremely light load.

While the preferred embodiment of the present invention described above is explained with reference to a television camera objective with a servo module driving unit, the present invention can be applied to a television camera objective using a manual module driving unit in the same way as a servo module driving unit. And the present invention can be applied not only to a zooming control mechanism but also to a focusing control mechanism of a television camera objective. the

latter being, as a matter of course, identical in design and results, no matter whether the driving unit is a servo module or a manual module.

Naturally, the invention is not limited to the specific details described and illustrated but may be modified in various respects without departing from the spirit and scope of the invention as defined by the appended claims.

What is claimed is:

1. In a television camera objective having a transmission shaft to which a driving unit is adapted to be detachably connected and a driving mechanism for axially displacing at least one lens component of an optical system upon rotation of said transmission shaft; the improvement comprising:

means movable from a first position when said driving unit is dismounted from said transmission shaft to a second position when said driving unit is mounted on said transmission shaft, and

means releasably interconnecting said first-named means and said transmission shaft for preventing said transmission shaft from rotating upon said first-named means being in said first position but allowing said transmission shaft to rotate upon said first-named means being in said second position.

2. A television camera objective as claimed in claim **1**, in which said first-named means is moved from said first position to said second position by engagement with said driving unit upon connection of said driving unit to said objective.

3. A television camera objective as claimed in claim **1**, and spring means biasing said first-named means toward said first position.

4. A television camera objective as claimed in claim **1**, said first-named means engaging a portion of said transmission shaft in said second position to prevent rotation of said transmission shaft.

5. A television camera objective as claimed in claim **4**, said first-named means and said transmission shaft having surfaces that frictionally engage each other in said second position to brake said transmission shaft.

6. A television camera objective as claimed in claim **1**, and means for selectively locking said first-named means in said second position.

7. A television camera objective having a driving mechanism for axially displacing at least one lens component of an optical system by driving force transmitted from a detachable driving unit, said driving mechanism including a rotatable transmission shaft for receiving and transmitting driving force from said driving unit, a coupling element on one end of said transmission shaft selectively engageable with a complementary coupling element of said driving unit, a fixed member supporting said transmission shaft for rotation, engaging means slidably surrounding said fixed member, means on said transmission shaft engageable with said engaging means in a first position of said engaging means to prevent rotation of said transmission shaft, spring means yieldably urging said engaging means toward said first position, said engaging means being engageable with a said driving unit upon attachment of said driving unit to said objective to move said engaging means from said first position to a second position in which said engaging means is spaced from said engageable means on said transmission shaft, and means preventing rotation of said engaging means in said first position.

8. A television camera objective as claimed in claim **7**, said rotation preventing means comprising pin and slot means between said engaging means and said fixed member.

9. A television camera objective as claimed in claim **7**, said driving unit having a driving shaft, said driving shaft and said transmission shaft having enlarged adjacent ends which detachably couple together upon mounting of said driving unit on said objective.

10. A television camera objective as claimed in claim **9**, said engaging unit being engageable with said enlarged end of said transmission shaft in said first position.

11. A television camera objective as claimed in claim **9**, said enlarged ends of said shafts having complementary frusto-conical surfaces that mate to transmit rotation from said driving shaft to said transmission shaft.

12. A television camera objective as claimed in claim **11**, said enlarged end of said transmission shaft having a friction surface on its side opposite its said frusto-conical surface, said friction surface frictionally engaging said engaging means to brake said transmission shaft in said first position.

13. A television camera objective as claimed in claim **7**, said engaging means having frictional engagement with an enlarged portion of said transmission shaft to brake said transmission shaft in said first position.

14. A television camera objective as claimed in claim **7**, and means for selectively locking said engaging means in said second position in the absence of a said driving unit.

15. A television camera objective as claimed in claim **14**, said engaging means comprising a cylindrical sleeve, said locking means comprising pin and slot means that act between said sleeve and said fixed member, said slot means having a portion that extends peripherally of said sleeve to lock said engaging means in said second position and a portion that extends parallel to the axis of said sleeve to receive said pin and to prevent rotation of said sleeve in said first position.

* * * * *

United States Patent [19]

Tenne et al.

[11] **4,354,753**

[45] **Oct. 19, 1982**

[54] **REFLEX CAMERA HAVING A FOCAL PLANE SHUTTER AND AN INTERCHANGEABLE VARIABLE SHUTTER OBJECTIVE**

[76] Inventors: **Lave Tenne**, 434 Kungsbacha, Sweden; **Franz Starp**, Mittlere Steige 36, Wildbad; **Walter Holzapfel**, Richard-Wagner-Strasse 42, both of Fed. Rep. of Germany

[21] Appl. No.: **261,535**

[22] Filed: **May 7, 1981**

[30] **Foreign Application Priority Data**

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Nov. 28, 1980 [DE] Fed. Rep. of Germany 3044882

[51] **Int. Cl.**[3] **G03B 9/00**

[52] **U.S. Cl.** **354/232**; 354/236; 354/289

[58] **Field of Search** 354/228, 231, 232, 233, 354/236, 289, 272

[56] **References Cited**

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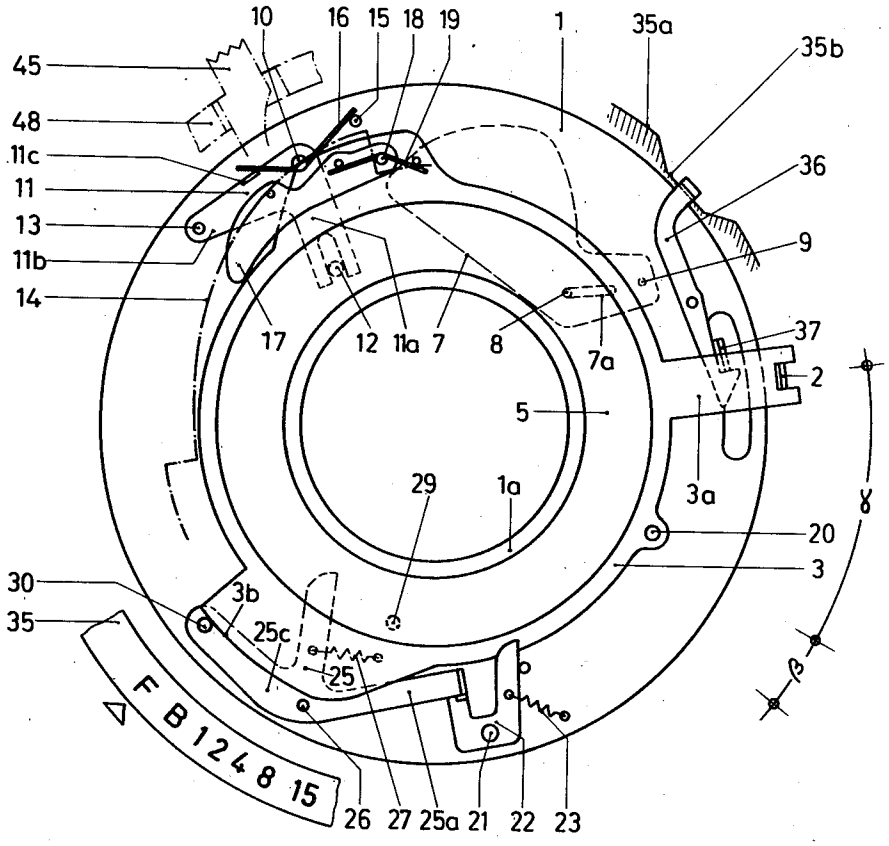
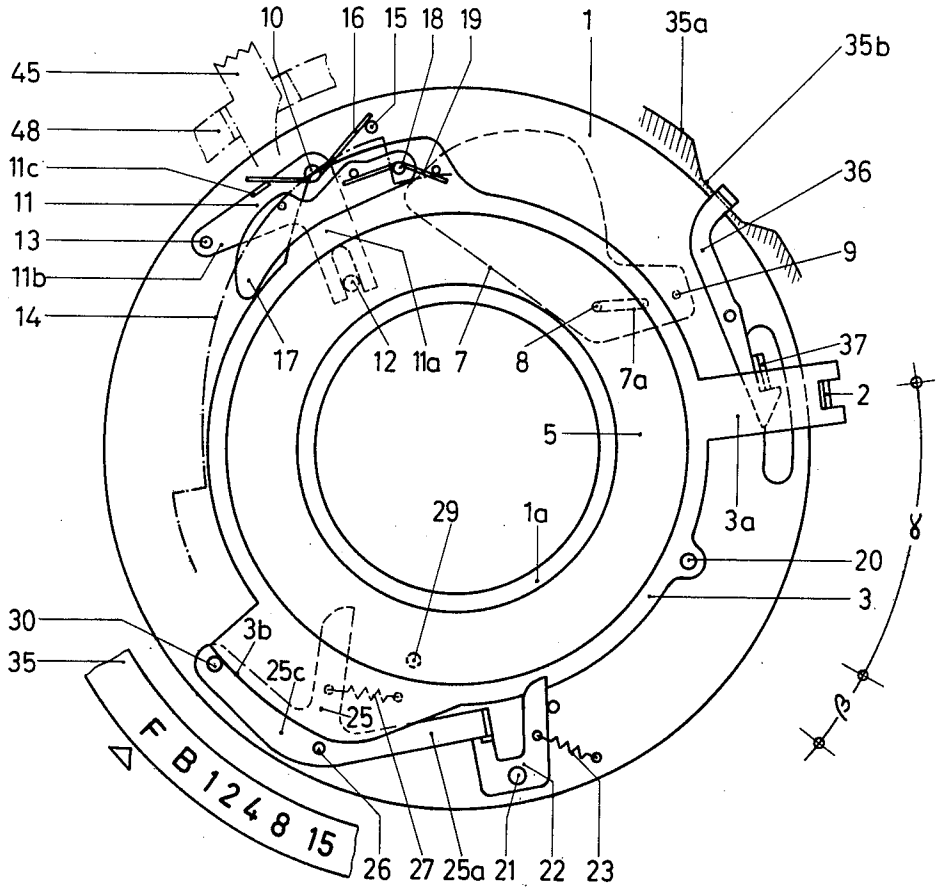
Primary Examiner—John Gonzales

[57] **ABSTRACT**

Reflex camera having a focal plane shutter in the camera body and a time adjuster associated with the focal plane shutter, and an interchangeable variable central shutter objective and a time adjuster associated with the central shutter, the focal plane shutter adjuster having a setting position "C" (central shutter) in which the central shutter of the objective can be used for exposure settings, and the objective shutter adjuster having a setting position "F" (focal plane shutter) in which a lock is operated to block the closure drive of the shutter segment system of the central shutter so that the focal plane shutter can be used.

10 Claims, 8 Drawing Figures

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11b
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11a
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8
7a
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1a
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3b
25c
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F B 1248 15
26
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25a
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α
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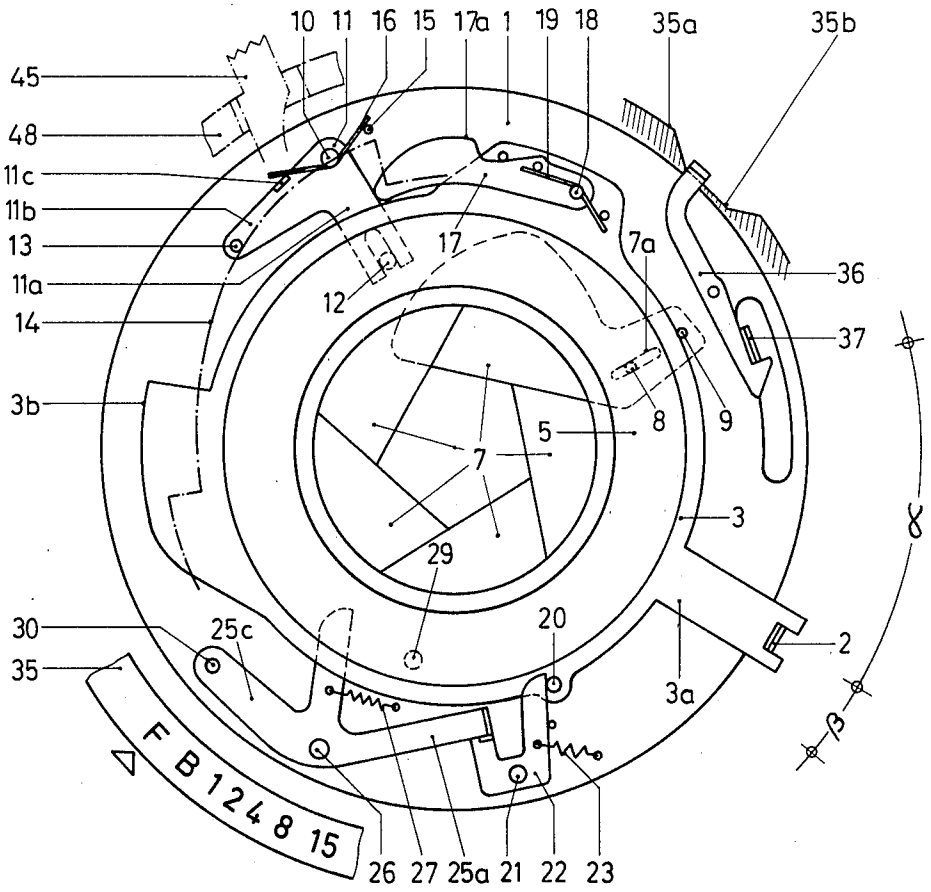
Fig. 1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7a
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F B 1248 15
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Fig. 2

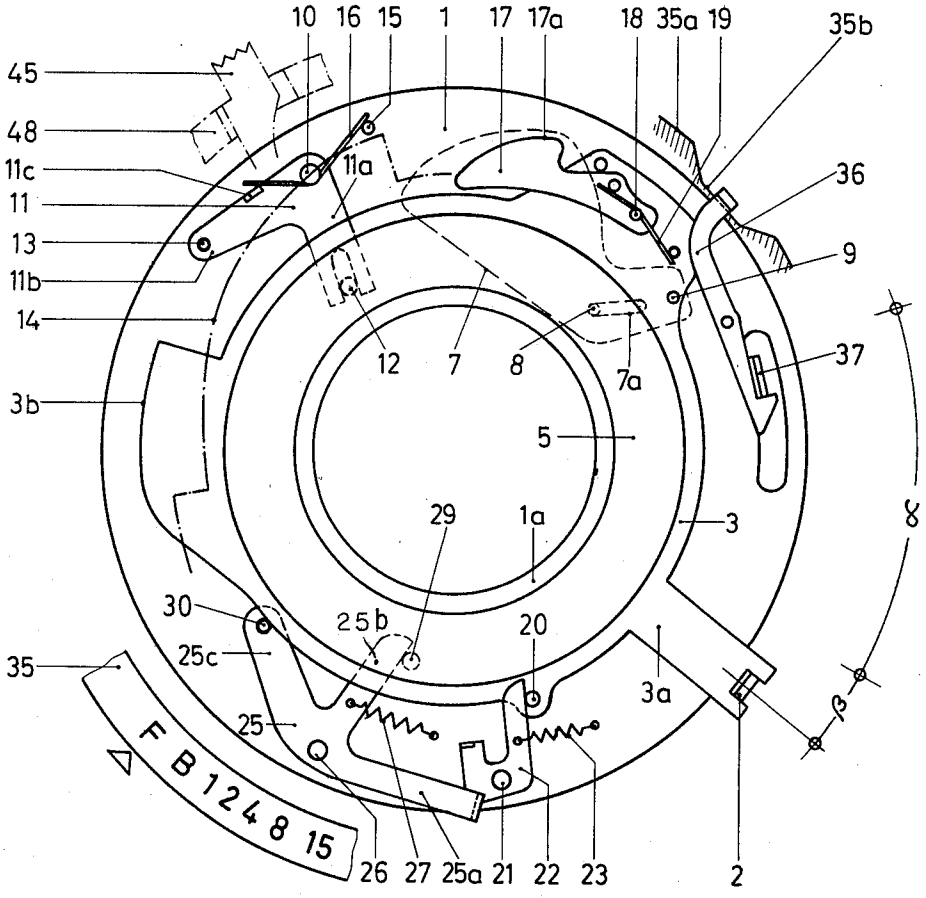

Fig. 3

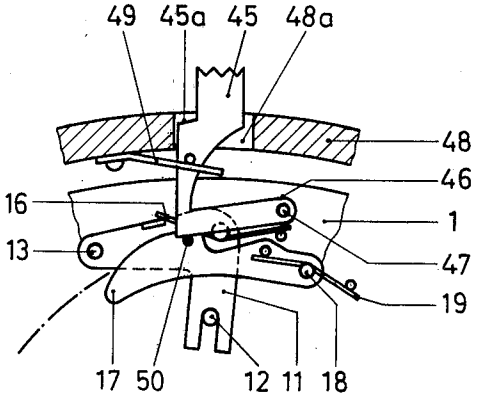

Fig. 4

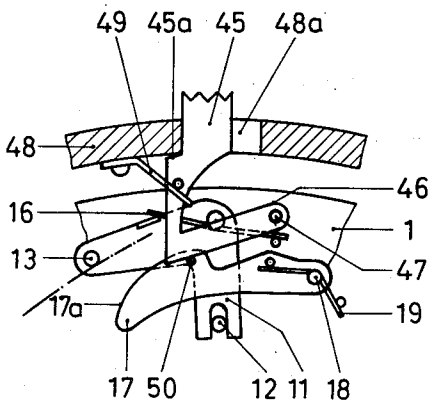

Fig. 5

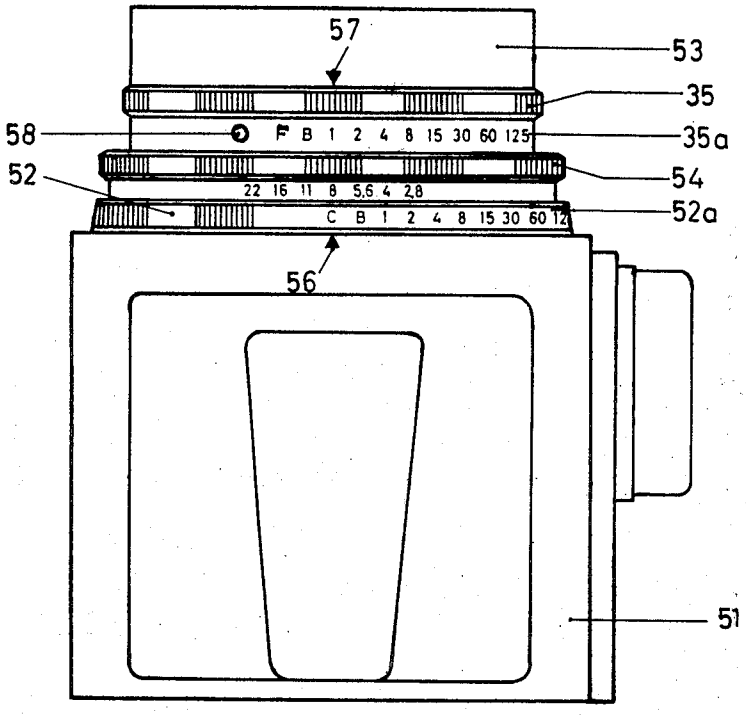

Fig. 6

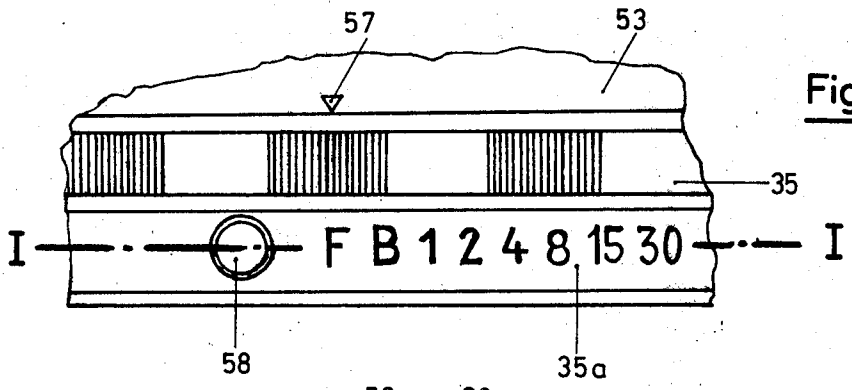

Fig. 7

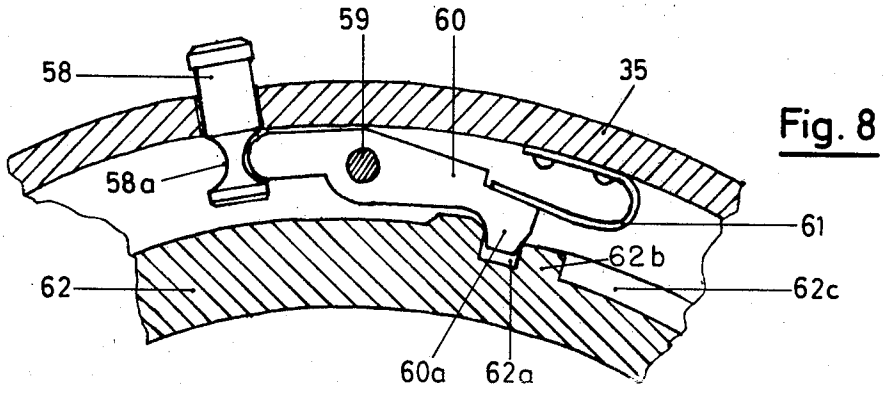

Fig. 8

REFLEX CAMERA HAVING A FOCAL PLANE SHUTTER AND AN INTERCHANGEABLE VARIABLE SHUTTER OBJECTIVE

The present invention relates to a reflux camera having a focal plane shutter, a time adjuster associated with the focal plane shutter and which can be set to a particular position "C", and an interchangeable variable shutter objective which has a segment system which, in the basic position, fully clears the lens aperture of the objective and is mounted so as to be able to pivot backwards and forwards. The objective also has a time adjuster which has a set position "F" with "B" function, and a diaphragm which, before the segment system commences its operating movement, approaches a specific working aperture, which is preselectable by means of a diaphragm adjuster.

A reflex camera is already known which, because it does not itself have a shutter system, can only use that type of interchangeable objective which has a central interlens shutter and diaphragm, the diaphragm concept and arrangement being selected so that the diaphragm blades open fully when the shutter is cocked and move to a preselected aperture width in an automatically controlled manner upon the release of the shutter and before the central shutter opens and closes again.

A reflux camera is also alread known which is provided with a focal plane shutter and to which interchangeable objectives of various types are selectively attachable, these objectives in fact being both interchangeable objectives which have only one diaphragm and interchangeable objectives of the above described type having a central shutter and diaphragm.

Interchangeable objectives of the first-mentioned category, which merely have a diaphragm and consequently may also only be used with focal plane shutter cameras, are, as is well known, of such a technical concept that, when the camera is released, the diaphragm blades spring from the fully open position towards the aperture width which corresponds to a manually preselected value and retain this aperture for the duration of the operating movement of the focal plane shutter in order to return again to the fully open position immediately afterwards, whereby the objective passage for observing the image is completely clear again.

If, however, an interchangeable objective which has a central shutter and diaphragm is in fact attached to a reflex camera which is fitted with a focal plane shutter, and if the camera user intends to take flash photographs with an extremely short exposure time, which photographs presuppose the use of an electronic flash device using the central shutter on the objective then, as explained in German Patent Specification No. 2 001 406, before taking the picture, he firstly has to set the time adjuster, which is on the camera body and which is provided with an additional set position "C" (central shutter), for the focal plane shutter correspondingly to this position "C". With this setting operation an electromechanical control device is actuated which, after the camera has been released, clears the focal plane shutter prematurely for the full aperture and permits it to return to the closed position only after the central shutter has functioned. If, however, the camera user wishes to take photographs which require the use of the focal plane shutter, then he has first to set the time adjuster of the central shutter to the particular set position "F" with "B" shutter function. This setting operation in turn acts upon the electromechanical control device in such a way that the movement procedure of the focal plane shutter is delayed until the central shutter has reached the fully open position, from which it returns again to the closed position.

When taking photographs with such a camera provided both with a central shutter and with a focal plane shutter, it is disadvantageous to the camera user if the central shutter on the objective always fully closes again at the end of the exposure to fulfil its function, while the diaphragm remains at its set value, since the camera user does not have at his disposal a ground-glass screen image until the camera is again ready to take photographs by actuating the cocking mechanism and, as a result thereof, the central shutter has again been transferred to the open position.

The object of the invention is to eliminate the disadvantage discussed above of a variable shutter objective which is provided with a diaphragm and central shutter, i.e. to modify such a shutter in such a way that:

(a) as in the case of interchangeable objectives provided only with a diaphragm, the ground-glass screen image is available again through the focal plane shutter directly subsequent to the exposure operation, and

(b) with a low cocking moment and with regular use of the focal plane shutter and central shutter, a long service life is insured for the camera and the objective shutter.

According to the present invention there is provided a reflex camera having a focal plane shutter, a time adjuster associated with the focal plane shutter and which can be set to a particular position "C", and a variable shutter objective, which has a shutter segment system which, in the basic position, fully clears the lens aperture of the objective and is mounted so as to be able to pivot backwards and forwards, and a time adjuster associated with the objective shutter which can be set to a particular position with "B" function, and a diaphragm which, before the shutter segment system commences the operating movement, approaches a specific working aperture which is preselectable by means of a diaphragm adjuster, wherein by setting the time adjuster associated with the central shutter of the objective to the set position "F" which effects an "B" function, a lock is operated which blocks the closure drive for the shutter segment system.

Compared with known shutters of this type, an objective shutter having this feature according to the present invention enjoys the advantage that the ground-glass screen image is available again immediately after the exposure operation has ended. It is also advantageous if, on the one hand, by not involving the central shutter in the operating procedure of the camera when taking photographs through the focal plane shutter, an additional tensioning moment for transferring the central shutter to the cocked condition does not need to be applied and, on the other hand, the service life of the central shutter can be extended because of the consequential lack of stress and the resultant sparing of the central shutter from extra operating wear to which it would be otherwise subjected.

In a preferred embodiment of an objective shutter arrangement according to the present invention, which is advantageous from the design point of view and insures an absolutely problem-free use of the camera, the objective shutter can have an adjuster which is provided with radial cams which serve to clear a spring-loaded feed lever, which acts upon the diaphragm in the

closing direction, and to clear and return a further return lever, which is likewise spring-loaded and acts upon the diaphragm in the opening direction, to the initial position. The return lever may have a lock which keeps it in the initial position and can be driven out of the locked position by the adjuster after a first phase of motion (α), i.e. and a short intermediate stop, i.e. in motion, necessary for the functioning of the focal plane shutter on the camera body, in a second phase of motion (β), i.e. beta.

Further, for the manual actuation of the diaphragm for the purpose of observing the depth of focus, the radial cam, which releases the feed lever into the initial position, may be disposed on a pin-mounted lever and this lever may be disposed on the adjuster so as to be resiliently flexible. Consequently, the camera user is then able to change the diaphragm manually from the fully open position to the preselected aperture width and/or to view the object while judging the depth of field.

An arrangement which positively excludes operating errors and is also easy to handle for the manual adjustment of the diaphragm can be achieved according to the present invention, in that the pin-mounted lever, which is provided with a radial cam, may have a push-button or the like which serves to actuate the feed lever manually.

In order to prevent an unintentional setting of the time adjuster, belonging to the central shutter, to the set position "F" which, from the point of view of its functional significance, differs basically from the other scale values, and to secure the time adjuster in the set position "F" so that a return from this position can only ever be effected deliberately by the camera user, a lock mechanism is preferably provided with the time adjuster for the central shutter, so that a setting of the adjuster to the set position "F" or correspondingly a return from this position to a time value can only be effected after a previous actuation of the lock mechanism, whereby incorrect settings of the camera can be avoided in a simple manner and also with absolute certainty.

A preferred embodiment of the lock mechanism, which is both structurally simple and reliable in operation, is achieved if this mechanism is designed according to the present invention as a spring-loaded, double-armed lever which is actuated by a push-button and cooperates with an annular groove, corresponding to the extent of the time range of the time adjuster, and with a specific additional recess which fixes the time adjuster in the set position "F".

The present invention will be described further, by way of example, with reference to the accompanying drawings, in which:

FIG. 1 shows the diaphragm drive of a variable shutter in the initial position;

FIG. 2 shows the diaphragm set to the preselected aperture width after completion of the α , i.e. alpha, phase of motion;

FIG. 3 shows the diaphragm returned to the initial position or correspondingly the open position after the completion of the α and β, i.e. alpha and beta, phases of motion;

FIG. 4 shows the unactuated push-button for setting the diaphragm manually to a preselected aperture width;

FIG. 5 shows the push-button of FIG. 4 after it has been actuated into the locked position;

FIG. 6 shows a variable shutter objective and the front portion of a reflex camera seen from above;

FIG. 7 is a partial view of the time adjuster of the camera of FIG. 6 set to the position "F"; and

FIG. 8 is a partial cross-section through the variable shutter objective along the section line I—I indicated in FIG. 7.

In the drawings, the reference numeral **1** denotes the base plate of a central shutter which is suitable for installation in a variable objective and is provided with a cocking and releasing member which, when the variable objective or variable shutter is attached to the housing of a reflex camera by way of a shaft, can be disengaged from the transmission of the cocking and releasing mechanism on the camera body by removing the objective or shutter. Positively connected to the annular cocking and releasing member, which is rotatably mounted on the rear side of the base plate **1**, and of which only one coupling part **2** can be seen in the drawing, is an adjuster **3** on which a radially directed arm **3***a*, which engages with the part **2**, is disposed.

The adjuster **3** is rotatably mounted in a conventional manner on a concentric extension **1***a* of the base plate **1**. It serves specifically to control a backward and forward movement of the iris ring or diaphragm ring **5**, which is likewise mounted on the extension **1***a* and is effectively connected to diaphragm blades **7** rigidly mounted at **9** in a conventional manner by means of a slot and pin connection **7***a*, **8**. For reasons of clarity, only one diaphragm blade **7** is shown, of which there are usually five in number, and which are distributed around the aperture and, as shown in the drawing, are disposed beneath the base plate **1**.

On the side facing the viewer, the iris ring **5** is provided with a driving pin **12** which is drivingly connected to one end of a feed lever **11**, which is mounted on the base plate **1** by means of pin **10** and is designed as an angled lever, the lever arm **11***a*, which is fork-shaped at the free end, positively embracing the pin **12** for this purpose. The end of the other lever arm **11***b* is in turn provided with a stop pin **13**, which cooperates with a radial cam **14** which, in FIGS. **1** to **3** is indicated by dash-dot lines and, is presettable by means of a diaphragm adjuster which is manually actuable, but is not shown fully in these views. This occurs in such a way that, due to the effect of the driving spring **16**, which is supported at one end on a tab **11***c* and at the other end on a rigid pin **15** on the base plate **1** with an initial tension, the feed lever **11**, which in the position of rest lies on a supporting part which is more fully described hereinafter, experiences an anticlockwise rotational movement about the bearing pin **10** with the simultaneous driving of the iris ring **5**, this rotational movement continuing until the stop pin **13** meets the radial cam **14**. This in turn signifies that, depending upon the relative set position of the radial cam **14**, the feed lever **11** passes through a greater or smaller angle of rotation range and thereby sets the diaphragm blades **7** to a specific aperture width, as shown, for example in FIG. **2**, by way of the iris ring **5**, from the fully open position shown in FIG. **1**.

The feed lever **11** could per se be supported by a radial cam which is securely disposed on the adjuster **3** and engages with the tab **11***a* but, in order to enable an intermediate observation of the depth of field, provision is made for the radial cam **17***a* to be disposed on a lever **17** which, for its part, is rotatably mounted on the adjuster **3** by means of a bearing pin **18** and abut the tab

11*a* of the feed lever **11** under the influence of a spring **19** which is under relatively high initial tension.

The object of the control lever **17** is to support the feed lever **11** in the initial position so that the feed lever **11** also retains its position under the compression force of the spring **16** which acts upon it. The initial tension of the spring **19** must therefore be selected to be higher than that of the spring **16**. It follows from this that, when the adjuster **3**, driven by the cocking and releasing member, leaves the initial position shown in FIG. **1** and the radial arm **3***a* passes through the α, i.e. alpha, phase of motion as far as an intermediate stop located at the end thereof, the feed lever **11** follows the radial cam **17***a* and thereby sets the diaphragm blades **7** to the preselected aperture width fixed by the position of the diaphragm radial cam **14**. Once the end of the α, i.e. alpha, phase of motion is reached, the operating movement of the adjuster **3** is interrupted for an interval of time within which the focal phase shutter in the camera body opens exposing the film material at the set diaphragm aperture width. After the operation of the focal plane shutter, the adjuster **3**, again driven by the cocking and releasing member, continues its rotational movement, whereby a driving pin **20**, disposed on the adjuster **3***a*, approaches a locking catch **22**, which is rotatably mounted on the base plate **1** by means of pin **21** and drives this catch **22** against the action of a spring **23** associated with the catch **22** and thereby releases a multi-armed lever **25** which acts as a return lever for the diaphragm blades **7**.

The return lever **25**, which was previously supported by its arm **25***a* against the locking catch **22**, is now under the tensioning effect of a spring **27** which now acts with the lever arm **25***b* upon a driving pin **29** located on the iris ring **5**, and drives this driving pin **29** along with it, thereby returning the diaphragm blades **7** into the open position shown in FIG. **3**. The adjuster **3** thus passes through the β, i.e. beta, phase of motion entirely and stops at the end thereof.

If, subsequent to the above described movements the cocking transmission on the camera body is actuated, a torque is applied via the shaft connection which rotates the adjuster **3** counter-clockwise and acts upon the cocking and releasing member of the shutter, this member being disposed on the shutter side. During the return of the adjuster **3**, a fixed radial cam **3***b* on the adjuster **3** approaches a pin **30** on the free end of a lever arm **25***c*, disposed on the return lever **25**, whereby the return lever **25** is displaced progressively from the position shown in FIG. **3** towards the cocked position shown in FIG. **1**. This cocked position is reached when the locking catch **22** is again located under the bent-over tab of the lever arm **25***a* under the tensioning effect of the spring **23**, as indicated in FIG. **1**. Once the end position of the adjuster **3** has been reached, the radial cam **17***a* (cf. FIGS. **2** and **3**), as can also be seen from FIG. **1**, adopts a position relative to the feed lever **11**, in which position the tab **11***a* of the feed lever **11** is actually located on the cam **17***a*.

The prerequisite for achieving the above described mode of operation is, however, that the time adjuster **35** of the central shutter, indicated only symbolically in FIGS. **1** to **3**, has been set, as shown, before the release of the camera to an additional set position denoted, for example, by "F" (focal shutter). If this happens, a radial cam **35***a*, which is also only indicated in the drawing which and is nonrotationally connected to the time adjuster **35**, receives such a setting relative to a rigidly mounted locking lever **36** that this locking lever can engage with a driving tab **37**, which is disposed on the shutter segment ring of the shutter, and can thus prevent the central shutter from fulfilling its function. For this purpose, the radial cam **35***a* is provided with a radial recess **35***b* which enables the locking lever **36** to enter the locked position.

In order to give the camera user the opportunity of making an intermediate observation so as to judge the depth of focus with the preselected diaphragm aperture in the set position "F" of the time adjuster **35** with the above described arrangement of diaphragm mechanics, a push-button **45** is provided which is disposed securely, but resiliently flexibly, on a lever **46** which sits on a bearing pin **47** inserted in the base plate **1**. In this case, the resiliently designed push-button **45** is guided in a slot-like recess **48***a* of the shutter housing **45**, which is merely indicated in FIGS. **4** and **5**, this being so that, when the push-button **45** is pressed down and the spring **49**, which engages therewith, is overcome, the outer end of the lever **46** acts upon an adjusting pin **50**, which is disposed on the control lever **17**.

In turn, this adjusting pin **50** transfers the compression force to the control lever **17** which executes a rotational movement in a counter-clockwise direction about the bearing pin **18**, resulting in the feed lever **11** losing its support. In this case, under the pressure of the pretensioned spring **16**, the feed lever **11** follows the control lever **17** until such time as the stop pin **13** comes to rest on the radial cam **14**. Consequently, in turn, the diaphragm blades **7**, which participate in the adjusting movement of the feed lever **11** via the iris ring **5**, have reached the aperture width corresponding to the preselected diaphragm valve.

In order to be able to keep the push-button **45** in the active position for undertaking further setting manipulations which have to be effected on the camera, a locking edge **45***a* is provided thereon which, as shown in FIG. **5**, engages with the housing **48***a* at the end of the push-button actuation and consequently locks the button **45** until such time as it is able to return again into the initial position, shown in FIG. **4**, by a transversely directed pressure stress, causing lateral deflection to be exerted upon the button **45**. With the return of the push-button **45**, the pressure is absorbed by the control lever **17**, this pressure acting upon the feed lever **11** under the influence of the relatively strong spring **19** by way of the tab **11***a* and consequently returning the diaphragm blades **7** again from the pre-selected aperture width to the fully open position according to FIG. **1**.

FIG. **6** shows the housing **51** of a reflex camera which comprises a focal plane shutter with a time adjusting ring **52** and a variable shutter objective **53** which can be detachably attached to the camera housing **51** by means of a bayonet connection, the objective being designed with a central shutter and provided with a diaphragm mechanism and a segment system, i.e. of shutter segments, which is mounted so as to pivot backwards and forwards, and which is preferably driven mechanically. Disposed concentrically to the objective barrel are rotatably mounted adjuster rings **54** and **35** of which one adjuster, denoted by **54**, serves to pre-select the diaphragm aperture width and the other serves to set the exposure time.

As can be seen from FIG. **6**, the time adjuster **52**, belonging to the focal plane shutter, is provided additionally with a particular set position "C" (central shutter) in addition to the actual time scale **52***a*, and the time

adjuster 35, belonging to the central shutter, is provided with a particular set position "F" (focal shutter), i.e. which effects a "B" function, in addition to the time setting scale 35*a*. The purpose of this is to enable the camera user to be in a position to expose one or other shutter arrangement, depending upon the selection of one or other set position "C" or "F", respectively.

If, as shown in FIG. 6, the focal plane shutter time adjuster 52 on the camera side is set to the particular set position "C" opposite the fixed mark 56, and if the camera is released, the film exposure is effected through the central shutter in the objective with the exposure time pre-set at its central shutter time adjuster 35. If, however, the central shutter time adjuster 35 on the objective side is set to the additional set position "F" opposite the fixed mark 57, as is shown in FIG. 7, then the focal plane shutter in the camera body exposes the film with the exposure time pre-selected at the focal plane time adjuster 52 when a photograph is taken.

Since the set position "F" in respect of its functional significance differs basically from that of the scale values of the central shutter time adjuster 35, precautions are to be taken to avoid incorrect settings, such precautions, on the one hand, preventing the camera user from setting the central shutter time adjuster 35 unintentionally to the particular set position "F" and, on the other hand, not permitting an inadvertent unintentional return of the time adjuster to one of the scale values of the time scale 35*a*.

To effect this precautionary measure, the central shutter time adjuster 35 is provided with a locking mechanism. This locking mechanism includes a manually actuable push-button 58 and a double lever 60 which is rotatably mounted on an axle 59, one end of which lever 60 is loaded by a spring 61, preferably a leaf spring, and the other end of which lever 60 cooperates with the push-button 58 and engages in a groove-like recess 58*a* of the push-button 58. As can be seen especially from FIG. 8, the locking mechanism, which at one end is provided with a locking tooth 60*a*, cooperates with a recess 62*a* which is disposed on a rigid part 62, preferably the barrel, of the objective. Because of the positive and constant engagement of the locking tooth 60*a* in this recess 62*a*, the time adjuster 35 is protected from unintentional actuation after being set to the particular set position "F".

Opposite the recess 62*a*, defined by a material shoulder 62*b*, an annular groove 62*c* is incorporated into the barrel of the objective and its length corresponds at least to the extent of the time setting range of the time adjuster 35. If the camera user wishes to set the time adjuster 35 to the set position "F" shown in FIG. 7, or to change it from this position to a time value corresponding to the time scale 35*a*, both setting manipulations always presuppose the previous positive releasing actuation of the push-button 58 of the positive locking mechanisms 58–61 which permits the range change.

We claim:

1. Reflex camera of the type having a focal plane shutter, comprising:

an objective containing a lens aperture and provided with a variable central shutter of the type adapted for operation between a basic open shutter position in which the lens aperture is fully open and a closed shutter position, and a central shutter drive for effecting opening and closing shutter operating movement, the central shutter being arranged for mounting a shutter segment system for operating movement adjustably backwards and forwards for opening and closing the lens aperture and which in the basic open shutter position fully clears the lens aperture,

a focal plane time adjuster associated with the focal plane shutter and arranged for setting to a particular central shutter position "C" for operating the central shutter,

a central shutter time adjuster associated with the central shutter and arranged for setting to a particular focal plane shutter position "F" which effects a "B" function for operating the focal plane shutter while the central shutter is in the basic open position,

a diaphragm and a diaphragm preselecting adjuster arranged such that, before commencement of the operating movement of the central shutter, the diaphragm approaches a specific working aperture which is preselectable by means of the diaphragm preselecting adjuster, and

a central shutter lock arranged such that upon setting the central shutter time adjuster to the focal plane shutter position "F" which effects a "B" function, the lock operates to block the central shutter drive from effecting closing shutter operating movement of the central shutter whereby to permit the focal plane shutter to be operated while the central shutter is in the basic position.

2. Camera according to claim 1 wherein the diaphragm is adjustable in an opening direction and in a closing direction, a spring loaded feed lever is provided for acting under a feed force upon the diaphragm in the closing direction, a spring loaded return lever is provided for acting under a return force upon the diaphragm in the opening direction, the central shutter is provided with a diaphragm cam adjuster having radial cams for urging the feed lever in the opposite direction against such feed force to an initial position for opening the diaphragm and for urging the return lever in the correspondingly opposite direction against such return force to an initial position for reloading the return lever, and a return lever lock is provided for locking the return lever in its initial position and which is drivable out of the locking position by the cam adjuster after a first phase of motion and a short intermediate stop in motion, as required for the functioning of the focal plane shutter in the camera, in a following second phase of motion.

3. Camera according to claim 2 wherein the corresponding radial cam for urging the feed lever to such initial position is disposed on a pin mounted cam lever which is resiliently flexibly disposed on the cam adjuster.

4. Camera according to claim 3 wherein a cam lever push button or the like is arranged for controlling the pin mounted cam lever for permitting manual actuation of the feed lever.

5. Camera according to claim 1 wherein the central shutter time adjuster is provided with a time value adjustment scale corresponding to the extent of the time setting range of said time adjuster, and an actuatable central shutter time adjuster releasable lock mechanism arranged for permitting a setting of said time adjuster to the set position "F", or correspondingly a return from such set position "F" to a time value of the corresponding adjustment scale at another set position thereof, to be effected only after a previous releasing actuation of said lock mechanism.

6. Camera according to claim 5 wherein the lock mechanism is provided as a spring loaded double armed lever, which is arranged for actuation by a time adjuster push button, and which cooperates with an annular groove corresponding in extent to the extent of the time setting range of the central shutter time adjuster, and which also cooperates with a selective specific additional recess for releasably fixing said time adjuster in the set position "F".

7. Reflex camera of the type having a focal plane shutter, comprising:

an objective containing a lens aperture and provided with a central shutter of the type adapted for operation between a basic open shutter position in which the lens aperture is fully open and a closed shutter position, and central shutter drive means for opening and closing shutter operating movement,

a focal plane time adjuster associated with the focal plane shutter and arranged for setting to a particular central shutter control position for operating the central shutter,

a central shutter time adjuster associated with the central shutter and arranged for setting to a particular focal plane shutter control position which effects a "B" function for operating the focal plane shutter while the central shutter remains in the basic open position,

a diaphragm and diaphragm aperture preselecting adjustment means arranged for adjusting the diaphragm to a preselected working aperture before commencement of the operating movement of the central shutter, and

central shutter drive lock means arranged, upon setting the central shutter time adjuster to the focal plane shutter control position which effects a "B" function, for blocking the central shutter drive means from effecting closing shutter operating movement of the central shutter whereby to permit the focal plane shutter to be operated while the central shutter remains in the basic open position.

8. Camera according to claim 7 wherein the diaphragm is adjustable in an opening direction and in a closing direction, diaphragm closing means are provided for resiliently urging the diaphragm in the closing direction under a closing force, diaphragm opening means are provided for resiliently urging the diaphragm in the opening direction under an opening force, diaphragm control adjustment means are provided for effecting operating phases of motion for correspondingly urging the diaphragm closure means in the opposite direction against the closing force to relieve the diaphragm from such closing force and for correspondingly urging the diaphragm opening means in the correspondingly opposite direction against the opening force to a basic cocked position to relieve the diaphragm from such opening force, and diaphragm opening means catching lock means are provided for releasably locking the diaphragm opening means in the basic cocked position, said diaphragm control adjustment means also being arranged such that, after a first operating phase of motion in which the diaphragm control adjustment means are released from urging the diaphragm closure means and from urging the diaphragm opening means while the diaphragm opening means remains locked in the basic cocked position, and after a short intermediate stop in motion corresponding to that required for the functioning of the focal plane shutter, said diaphragm control adjustment means in turn release the catching lock means in a following second phase of motion to permit the diaphragm opening means to urge the diaphragm in the opening direction.

9. Camera according to claim 8 wherein the diaphragm control adjustment means are operatively releasably connected with the diaphragm closing means, and manually controlled releasing means are provided for operatively disconnecting the diaphragm control adjustment means from the diaphragm closing means to permit manual control of the diaphragm closing means.

10. Camera according to claim 7 wherein the central shutter time adjuster is provided with a time value adjustment scale corresponding to the extent of the time setting range of said time adjuster, and a manually controlled releasable positive lock mechanism is arranged for permitting a setting of said time adjuster to the focal plane shutter control position which effects a "B" function, or correspondingly a return from said control position to a time value of the corresponding adjustment scale at another set position thereof, to be effected only after the preliminary positive releasing actuation of said locking mechanism.

* * * * *

United States Patent [19]

Himmelsbach

[11] **4,353,634**

[45] **Oct. 12, 1982**

[54] FOCUSING MECHANISM FOR CAMERA OBJECTIVE

[75] Inventor: **Paul Himmelsbach,** Bad Kreuznach, Fed. Rep. of Germany

[73] Assignee: **Jos. Schneider & Co. Optische Werke Kreuznach,** Bad Kreuznach, Fed. Rep. of Germany

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[30] **Foreign Application Priority Data**

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[51] **Int. Cl.**[3] **G02B 7/10;** G03B 3/10

[52] **U.S. Cl.** **354/195;** 350/255; 350/429

[58] **Field of Search** 354/25, 195-197; 352/139, 140; 350/187, 255, 429, 430; 355/55; 353/76

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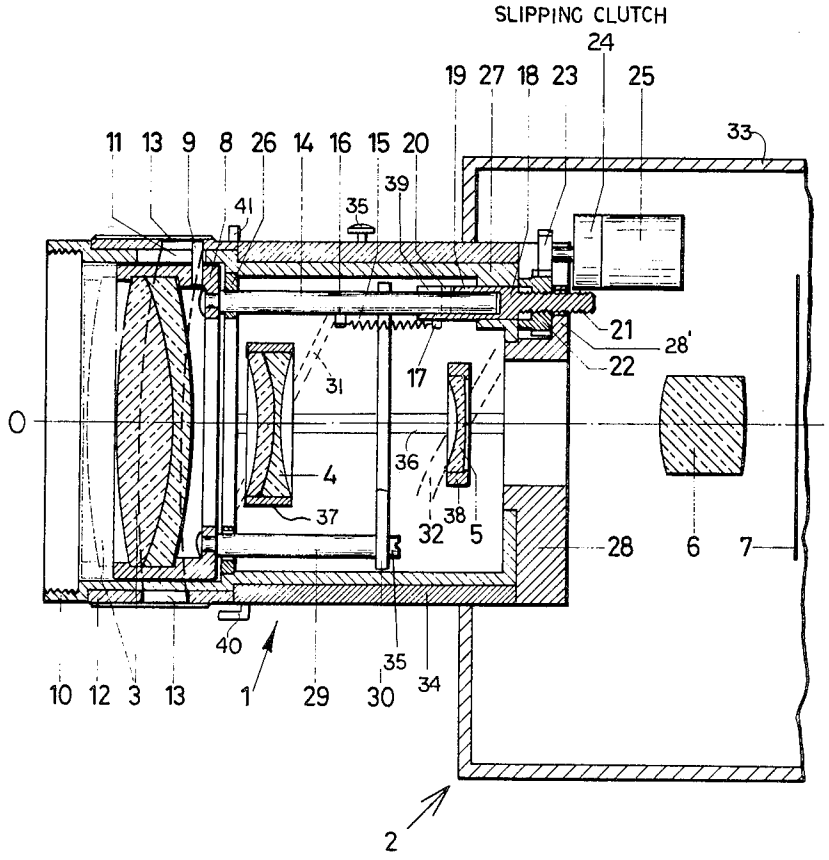
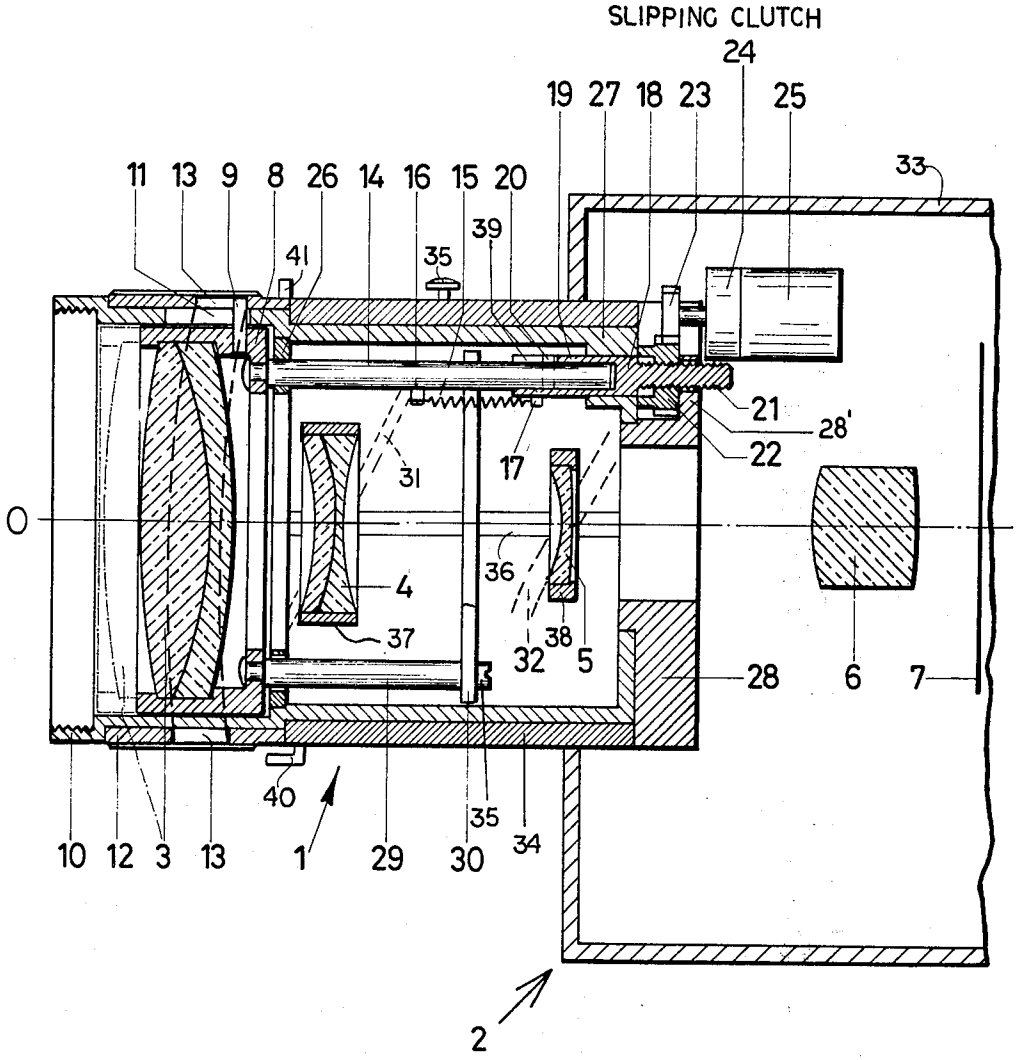
Primary Examiner—John Gonzales
Attorney, Agent, or Firm—Karl F. Ross

[57] **ABSTRACT**

A front component of a varifocal camera objective, axially shiftable for focusing purposes, is provided with a lens mount held by an axially extending guide rod which is slidably received in an inner annular flange and an end wall of a lens barrel. The lens mount has a pin projecting through an axial guide slot in the lens barrel into a camming groove in a surrounding milled setting ring. A rearward extension of the guide rod, nonrotatable but axially slidable with reference thereto against the force of a tension spring, is provided with male threads engaged by a drive nut held captive in the end wall, the nut being provided with outer gear teeth meshing with a pinion which is driven by a reversible electric motor via a slipping clutch. Upon retraction of the threaded extension by the drive nut, the tension spring holds the pin of that lens mount against the rear edge of its camming groove; the width of that groove and the axial length of the guide slot are sufficient to let the motor drive the lens mount over at least part of the available focusing range in a given position of the setting ring.

8 Claims, 1 Drawing Figure

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FOCUSING MECHANISM FOR CAMERA OBJECTIVE

FIELD OF THE INVENTION

My present invention relates to a photographic or cinematographic camera whose objective includes one or more lenses that are axially shiftable for focusing purposes.

BACKGROUND OF THE INVENTION

Conventional cameras with focusable objectives are provided with an outer, axially fixed setting ring rotatably mounted on a lens barrel and provided with female threads engaging male threads of an inner guide ring which is held against rotation and is rigid with a lens mount supporting the shiftable lens or lenses, the latter usually constituting a front component of the objective. The two rings are centered on the objective axis and are therefore of a rather large diameter, resulting in considerable friction along their threaded contact surfaces.

In commonly owned U.S. Pat. No. 3,482,500 there has been disclosed a control mechanism for manual and automatic focusing in which a lens mount is supported by several axially extending guide rods, one of these rods having threads engaged by a nut which is integral with the shiftable lens mount. It has also been proposed to provide a shiftable lens support with an axially extending rack engaged by a rotatable worm; see German Pat. No. 1,101,801.

In commonly owned U.S. patent application Ser. No. 894,031, filed Apr. 6, 1978 by Karl-Heinz Holderbaum, now U.S. Pat. No. 4,200,377, there has been disclosed and claimed a focusing mechanism comprising a guide rod which is fastened to a shiftable lens mount and is slidably but nonrotatably held in stationary bearings inside a lens barrel, this guide rod extending parallel to the optical axis of the objective and terminating within a camera housing in a threaded rear extremity which is engaged by a captive drive nut. The nut is provided with external gear teeth in mesh with a motor-driven pinion and also with a manually rotatable toothed wheel, the latter being rigid with a scale-carrying setting ring projecting from the housing. A slipping clutch inserted between the motor and its pinion allows the lens mount to be manually displaced even if the motor is of the self-locking (e.g. stepping) type remaining stationary when not energized. That system is advantageous for its low frictional resistance and for the accurate guidance given to the movable lens mount.

OBJECTS OF THE INVENTION

An object of my present invention is to provide a modified focusing mechanism, generally similar to the above-identified Holderbaum application, which retains the aforementioned advantages of that system while allowing greater flexibility in the positioning of the manually operable setting ring.

Another object is to provide means in such a system for enabling a manual preselection of a distance range and automatic focusing or scanning within that selected range.

SUMMARY OF THE INVENTION

In accordance with my present invention, a guide rod similar to that referred to, fastened to a lens mount and extending rearwardly therefrom parallel to the optical axis while being slidably and nonrotatably held in internal bearing means of a lens barrel, coacts with a threaded member forming a coaxial rearward extension thereof, this member being nonrotatably held in the camera housing with freedom of axial displacement and being engaged by a threaded drive element such as a captive nut. The guide rod and its extension, which are relatively axially shiftable, are urged by biasing means such as a contractile spring into a predetermined relative axial position so as to constitute, in effect, a lost-motion link which converts a rotation of the drive element into an axial motion of the lens mount; such rotation is brought about by a reversible motor having a pinion in mesh with gear teeth of the drive element, preferably with interposition of a slipping clutch as in the system of the Holderbaum application. A manually rotatable setting ring, carried on the lens barrel in an axially fixed position, has a camming groove registering with an axially extending slot in the lens barrel, the shiftable lens mount being provided with a pin or similar radial projection which extends through the slot into engagement with the camming groove but is received therein with sufficient play to enable an axial shift of the lens mount by the motor independently of the position of the setting ring; conversely, the lens mount is axially entrainable via its projection by the setting ring against the force of the biasing means for the manual establishment of a selected focusing position.

In this way, as more fully explained hereinafter, the projection of the lens mount is held by the biasing means against an edge of the camming groove when the threaded extension of the guide rod is retracted by the drive motor, this edge defining one of the limits (usually the more remote one) of a selected distance range within which the lens mount can be displaced by operation of the motor. The extent of that range is determined by the width of the camming groove.

BRIEF DESCRIPTION OF THE DRAWING

The above and other features of my invention will now be described in detail with reference to the accompanying drawing the sole FIGURE of which illustrates, somewhat diagrammatically and in axial section, a motion-picture camera with a varifocal objective focusable by a mechanism according to my invention.

SPECIFIC DESCRIPTION

The camera shown in the drawing comprises a varifocal or zoom-type objective, generally designated **1**, and a camera body, generally designated **2**. The objective **1** is provided with a lens barrel **10** which projects from the camera housing **33** and is centered on an optical axis O. Also centered on this axis are several lens members constituting a positively refracting front component **3**, two negatively refracting intermediate components **4**, **5** and a stationary rear component **6**; the latter, disposed outside lens barrel **10** within housing **33**, consists of a plurality of lenses not illustrated individually.

As is well known per se, an axial shifting of the second component **4** changes the focal length of lens assembly **3** - **6** and must be accompanied by a compensatory displacement of the third component **5** in order to keep the image plane of the objective coincident with the sensitive surface of a film **7**. The concurrent shifting of components **4** and **5** is brought about by the rotation of a sleeve **34**, provided for this purpose with a knob **35**, which has camming grooves **31**, **32** engaged by respective pins that pass through an axially extending slot **36**

of the lens barrel 10 and are rigid with their respective lens mounts 37, 38. The lens mounts are slidably supported by axially extending guide rods not shown.

Front component 3, here shown as a compound lens, is provided with a lens mount 8 which is axially movable between an infinity position (full lines) and a closeup position (dot-dash lines), independently of lens mounts 37, 38, for focusing the objective upon an object to be photographed, either manually or automatically under the control of a conventional distance finder. Lens mount 8 is cantilevered on an axially extending guide rod 14 that is slidably and nonrotatably received in an inner annular flange 26 of lens barrel 10 and has a rear extremity sliding in a bore 19 of an extension member 18 which is guided in a bearing block 27 forming part of a rear wall 28. A transverse pin 20 of guide rod 14 engages in an axial slit 39 of member 18 to prevent relative rotation of the two relatively axially shiftable members 14 and 18. Member 18 terminates beyond bearing block 27, thus within camera housing 33, in a threaded stem 21 matingly engaged by a captive nut 22 which is held against axial displacement by the block 27 and by an extension 28' of end wall 28. A tension spring 16, anchored to rod 14 at 16 and to member 18 at 17, tends to contract the extensible link 14, 18 by urging these members into a limiting position in which the end of rod 14 abuts the bottom of the bore 19.

Nut 22 carries external gear teeth in mesh with a pinion 23 driven, via a slipping clutch 24, by a reversible electric motor 25 which is energizable (e.g. as described in my commonly owned U.S. Pat. No. 3,165,044) from a nonillustrated power supply. The automatic displacement of lens mount 8 by motor 25 via nut 22 and lost-motion connection 14–21, under the control of the aforementioned distance finder for example, is limited by the edges of a camming groove 13 formed in a milled setting ring 12 which is held against axial displacement on the front end of lens barrel 10, the groove 13 being engaged by a pin 9 on lens mount 8 penetrating an axially extending slot 11 of the lens barrel. With motor 25 arrested in a position in which member 18 is retracted to tension the spring 15, pin 9 is held against the rear edge of groove 13. Manual rotation of setting ring 12 thus establishes the remote limit of a distance range within which fine focusing can be carried out automatically. Ring 12 is provided with a distance scale (not shown) coacting with a stationary pointer.

In order to hold the lens mount 8 against rotation, and to prevent jamming or canting, I provide that lens mount with an ancillary guide rod 29 also slidable in flange 26 and terminating short of end wall 28. The two parallel rods 14 and 29 are fixedly interconnected, inside lens barrel 10, by a bracing ring 30 fastened to the rear end of rod 29 by a screw 35 and frictionally fitted onto an intermediate portion of the driven guide rod 14. It will be observed that ring 30 lies between the cam tracks 31 and 32 of components 4 and 5 so as not to interfere with their displacement by sleeve 34. Such a precaution, however, will not be necessary if the shifting of these components for zooming purposes is controlled by a camming sleeve of smaller diameter lodged inside ring 30. In either case, lens mount 8 forms with the two diametrically opposite rods 14 and 29 as well as ring 30 a rigid cage insuring precise axial movement of component 3 upon rotation of drive 22 or setting ring 12.

With pinion 23 of smaller diameter than nut 22, a favorable transmission ratio exists between motor 25 and guide rod 14 so that the frictional resistance encountered by the motor is small, its energy consumption is low and precise focusing is possible, e.g. under the control of an electronic comparator measuring contrasts between adjacent image points against a locally generated reference parameter. Other known distance meters usable for automatic focusing control operate with emitters of infrared radiation or radar pulses and corresponding receivers on the camera.

Though the combination of manual and automatic adjustability of lens mount 8 by setting ring 12 and drive motor 25 makes available a large focusing range, it may be desirable to restrict that range in certain positions of the zooming-control sleeve 34. Thus, focusing upon nearby objects may not yield sharp images with larger focal lengths. Sleeve 34 and ring 12 may therefore be provided with coacting formations, such as a lug 40 and a pin 41, limiting the excursion of front component 3 from its infinity position at the telephoto end of the varifocal range.

It will be apparent that more than a single component of an objective—possibly the entire lens assembly thereof—can be axially shifted for focusing purposes by the mechanism according to my invention.

I claim:

1. In a camera provided with a housing and an objective projecting forwardly from said housing, said objective including a lens barrel centered on an optical axis and a plurality of lenses in said lens barrel, at least one of said lenses being provided with an axially shiftable lens mount,

the combination therewith of:

stationary bearing means in said lens barrel;

a guide rod slidably and nonrotatably held in said bearing means, said guide rod being fastened to said lens mount and extending rearwardly therefrom parallel to said optical axis;

a threaded member forming a coaxial rearward extension of said guide rod nonrotatably held in said housing with freedom of axial displacement, said guide rod and said member being relatively axially shiftable;

a threaded drive element matingly engaging said member, said element being provided with gear teeth and being held against axial displacement in said housing;

a reversible motor provided with a pinion in mesh with said gear teeth;

a manually rotatable setting ring carried on said lens barrel in an axially fixed position, said setting ring being provided with a camming groove registering with an axially extending slot in said lens barrel, said lens mount being provided with a projection extending through said slot into engagement with said camming groove; and

biasing means urging said guide rod and said member into a predetermined relative axial position, said camming groove and said slot receiving said projection with sufficient play to enable an axial shift of said lens mount by said motor independently of the position of said setting ring, said lens mount being axially entrainable by said setting ring via said projection against the force of said biasing means.

2. The combination defined in claim 1 wherein said biasing means comprises a contractile spring anchored to said guide rod and to said member, said spring hold-

ing said projection onto a rear edge of said camming groove in a retracted position of said member.

3. The combination defined in claim 1 wherein said element is a captive nut.

4. The combination defined in claim 1, further comprising a slipping clutch interposed between said motor and said pinion.

5. The combination defined in claim 1, further comprising an ancillary rod parallel to said guide rod and shorter than the latter, said bearing means including an internal annular flange of said lens barrel close to said lens mount, said ancillary rod being slidably guided in said flange.

6. The combination defined in claim 5, further comprising annular bracing means rigidly connecting the rear end of said ancillary rod with a portion of said guide rod ahead of said member.

7. The combination defined in claim 1 or 2 wherein said one of said lenses is part of a front component of the objective, said lenses further forming additional components provided with control means for axially shifting same to vary the focal length of the objective.

8. The combination defined in claim 7 wherein said control means and said setting ring are provided with coacting formations limiting the displaceability of said lens mount in certain positions of said additional components.

* * * * *

United States Patent [19]

Engelsmann et al.

[11] **4,350,423**

[45] **Sep. 21, 1982**

[54] **STILL CAMERA WITH A RETRACTABLE OBJECTIVE**

[75] Inventors: **Dieter Engelsmann,** Unterhaching; **Reinhard Nicko,** Munich; **Wilfried Bittner,** Alxing; **Horst Karl,** Munich, all of Fed. Rep. of Germany

[73] Assignee: **Agfa-Gevaert Aktiengesellschaft,** Leverkusen, Fed. Rep. of Germany

[21] Appl. No.: **281,892**

[22] Filed: **Jul. 9, 1981**

[30] **Foreign Application Priority Data**

Jul. 26, 1980 [DE] Fed. Rep. of Germany 3028452

[51] **Int. Cl.**[3] **G03B 1/12;** G03B 13/02; G03B 3/00

[52] **U.S. Cl.** **354/173;** 354/195; 354/219

[58] **Field of Search** 354/173, 212, 195

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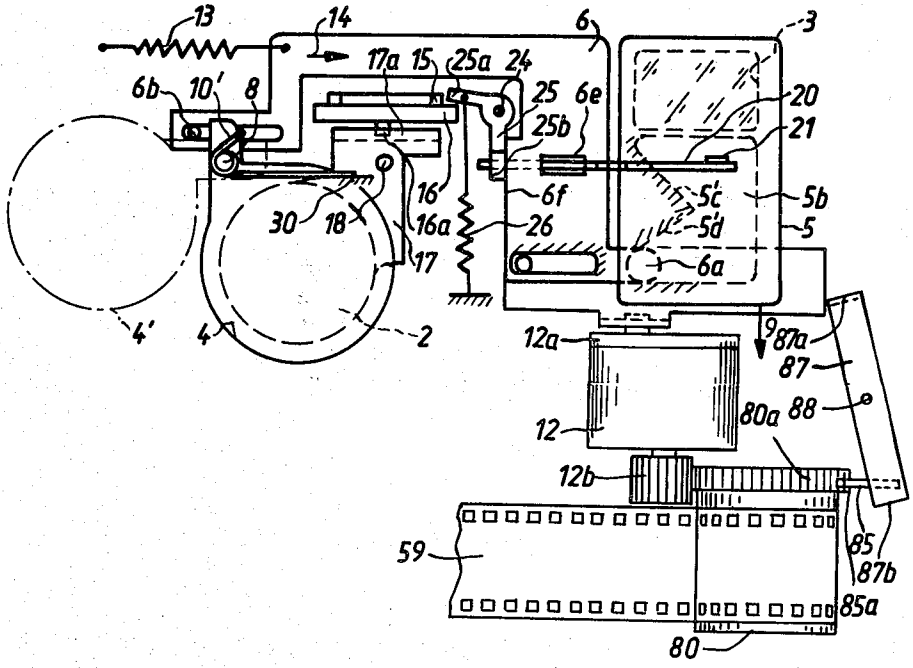
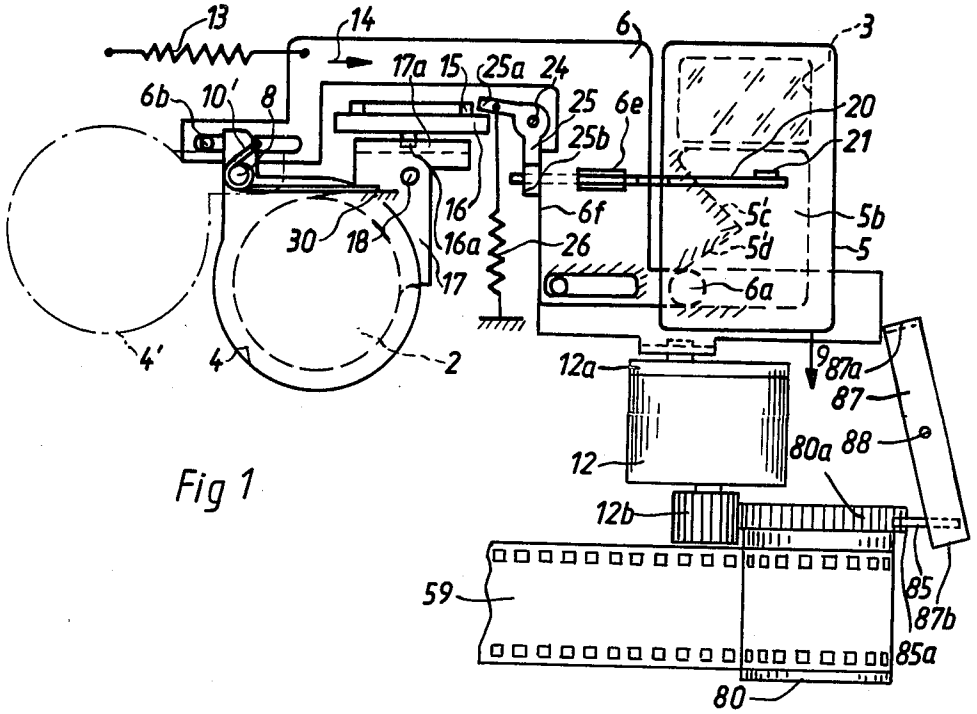
Primary Examiner—Donald A. Griffin
Attorney, Agent, or Firm—Michael J. Striker

[57] **ABSTRACT**

A photographic camera has a housing, a viewfinder, an objective displaceable between extended and retracted positions relative to the housing, a device for displacing the objective between the extended and retracted positions, a film transporting device, a film take-up spool, an electric motor rotatable in two opposite directions and arranged so that when the electric motor rotates in one of the directions it is coupled with the objective displacing device, and when the motor rotates in the other of the directions it is coupled with the film transporting device and the film take-up spool, a switching element for reversing the electric motor, and a locking device for the film take-up spool, coupled with the switching element so that when the electric motor is switched for rotation in the one direction for displacing the objective and is coupled with the objective displacing device the film take-up spool is locked against rotation, and when the electric motor is reversed and uncoupled the film take-up spool is released.

13 Claims, 2 Drawing Figures

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14
6
3
17a
15
25a
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21
16
6f
5'c
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16a
26
5'd
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17
6a
4'
4
2
12a
87a
87
12
80a
88
12b
59
85
87b
85a
80

Fig 1

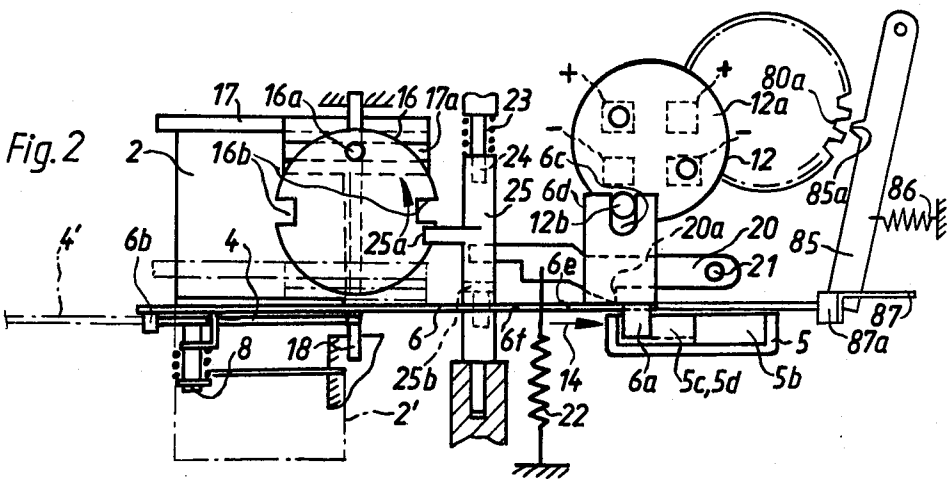
17
16a
16
17a
23
80a
12a
2
16b
24
6c
12
25
6d
85a
86
12b
20a
20
85
4'
6b
4
25a
6e
21
87
8
18
6
6f
5
87a
25b
14
6a
5c,5d
5b
2'
22

Fig. 2

STILL CAMERA WITH A RETRACTABLE OBJECTIVE

BACKGROUND OF THE INVENTION

The present invention relates to still cameras, advantageously miniature cameras, with a viewfinder, an extensible and retractible objective, and a reversible electric motor which during its rotation in one direction is coupled with an objective-displacing device and during its rotation in the opposite direction is coupled with a film transport transmission and a film take-up spool, wherein a switching device is provided for reversing the motor.

Cameras of the above-mentioned general type are known in the art. In cameras of the above described construction, it is possible that overlapping of the picture field for individual pictures in the film gate of the camera takes place, as a result of the film pulling action on the film take-up spool.

SUMMARY OF THE INVENTION

Accordingly, it is an object of the present invention to provide a camera in which during the displacement of the objective and simultaneous uncoupling of the film take-up spool from the motor, no overlapping of the picture fields for the individual pictures takes place in the film gate of the camera.

In keeping with this object, and with others which will become apparent hereinafter, one feature of the present invention resides, briefly stated, in a photographic camera in which locking means is provided for the film take-up spool and coupled with the motor switching means, so that when the electric motor is switched for rotation in a direction for displacing the objective and coupled with the objective-displacing device, the film take-up spool is locked against rotation, and when the electric motor is reversed and uncoupled, the film take-up spool is released. When the photographic camera is designed in accordance with the present invention, the above-mentioned overlapping of the picture fields for individual pictures cannot take place.

The novel features which are considered characteristic for the present invention are set forth in particular in the appended claims. The invention itself, however, both as to its construction and its method of operation, together with additional objects and advantages thereof, will be best understood from the following description of specific embodiments when read in connection with the accompanying drawing.

BRIEF DESCRIPTION OF THE DRAWING

FIG. **1** is a view showing a photographic camera in accordance with the present invention in direction toward the objective and the film plane with a removed housing, wherein parts located one behind the other are shown for the sake of clarity as located partially one below the other; and

FIG. **2** is a plan view of the photographic camera of FIG. **1**.

DESCRIPTION OF THE PREFERRED EMBODIMENT

A photographic camera, preferably a miniature photographic camera, is shown in the drawing. Its housing is removed for the sake of clarity.

The camera has an objective or an objective mount which is identified by reference numeral **2**. A viewfinder is arranged laterally adjacent to the objective **2** in the upper part of the housing. The viewfinder has an inlet opening or a front lens which is identified by reference numeral **3**. A cover plate **4** is movably arranged in front of the objective **2** and is insertable or pivotable behind the front side of the camera housing. When the camera is not used, the cover plate **4** is displaced so that it is located in front of the objective **2**, and the latter is protected against damage and dirtying. The front lens **3** of the viewfinder is arranged in a cavity of the front side of the camera. A cover slider **5** is arranged displaceably so that it moves between one end position in which it covers the front lens **3** of the viewfinder and another end position in which it releases the same.

There is a possibility that a user displaces only the cover slider **5** to the working position shown in dotted lines and, since he can now look through the viewfinder, forgets that the objective **2** is still closed by the cover plate **4**. In order to avoid this, the cover slider **5** is formed as a handle for joint displacement of the cover slider **5** of the viewfinder and the cover plate **4** of the objective to their working positions, for example **4'**, or their closed positions.

In FIG. **2**, the objective **2** is shown in its nonworking position, in which it is inserted into the camera, as shown in solid lines. For the use of the camera, the objective **2** is displaced out of the camera housing to the working position shown in dotted lines, after withdrawing of the cover plate **4**. The joint movement of the cover slider **5** of the viewfinder, the cover plate **4** of the objective, and the objective itself is performed with the aid of an electric motor **12** which can alternately rotate in opposite directions for driving a film take-up spool **80** and a film transport of the film **59**, on the one hand, and for the displacement of the objective, on the other hand. For this purpose, a drive coupling is provided between the motor **12** and a motor pinion **12*b'*** or between a spool gear **80*a*** and a spool **80** at respective locations. The drive coupling acts only in a direction of film take-up on the spool **80** so that the spool can be taken along only in the winding direction when the motor **12** rotates in a direction which is opposite to the objective-displacement direction.

The motor **12** is provided with a rotary switch **12*a*** which changes polarity in the event of rotation from the position shown in FIG. **2** for film transporting by an angle of 90°. A pin **12*b*** of the rotary switch **12*a*** engages in a slot **6*c*** of a strip **6*d*** of a slider **6**, whereby the pin **12*b*** and the slot **6*d*** are so arranged that during movement of the slider **6** from its one end position to its other end position, the motor changes the polarity. Simultaneously, during the movement of the slider **6** in its position which corresponds to the working position of the viewfinder **3** and the cover plate **4** of the objective **2**, not only the motor changes the polarity relative to its position corresponding to the film transport position, but it is also simultaneously switched on. The cover slider **5** of the viewfinder has a control slot **5*b*** which is formed as a large recess with two oppositely running identical control curves **5*c*** and **5*d***. The pin **6*a*** of the slider **6** abuts against the control curves **5*c*** and **5*d*** under the action of a spring **13**. The cover plate **4** of the objective and a driving part **6*b*** are so arranged that during the movement of the cover slider **5** of the viewfinder in direction of the arrow **9**, the slider **6** first moves in direction of the arrow **14** and thereby pivots the cover plate **4** of the objective into its working position **4'**

shown in dotted lines. In this position, the slider **6** and the cover plate **4** are locked, as will be described hereinbelow. During further displacement of the cover slider **5** of the viewfinder into its position which releases the viewfinder **3**, the motor **12**, **12***a* changes its polarity in the above-described manner and is switched on, and the slider **6** locked with the interval is released by the control curve **5***c* to allow return to its inoperative position.

A known gear transmission with a one-way coupling (not shown in the drawing) is provided between the motor **12** and the objective **2** or its mount. As a result of this, a gear **15** can be driven only in the clockwise direction. The gear **15** is connected with an eccentric disk **16**, **16***a*. The eccentric disk has two recesses **16***b* which are offset by 90° relative to an eccentric pin **16***a* and arranged diametrically opposite to one another. The objective mount **3** is provided with a carrier plate **7** which is displaceable along an axis **15** extending parallel to the axis of the objective and has a groove **17***a* normal to the axis **18**. An eccentric pin **16***a* engages in the groove **17***a*.

When the eccentric rotates by 180° by the slider **6** when the motor **12** is switched on, the objective **2** is displaced from the position shown in solid lines in FIG. **2** to the position shown in dotted lines outwardly of the camera, after removal of the cover plate **4**. The latter position is identified by reference numeral **2'**. The pin **6***a* and the slot **6***c* are so dimensioned that the motor **12**, **12***a* is first switched on when the cover plate **4** fully releases the objective **2**. When the cover slider **5** of the viewfinder thereby moves opposite to the direction of arrow **9** for closing the camera, the slider **6** is moved in direction of the arrow **14** through the control curve **5***c* and changes the polarity of the motor from its condition corresponding to the film transport position and switches on the same. In this case, the eccentric **16***a* rotates in the counterclockwise direction by 180° further and displaces back the objective **2** into the housing of the camera.

After the movement of the slider **6** in the direction of arrow **14**, despite the preparatory release of the slider **6** by the respective oppositely running curves **5***c*, **5***d* during opening of the camera or closing of the same, the slider **6** holds the switch **12***a* in the changed-pole closed position until the objective **2** is completely withdrawn from or inserted into the camera, the slider **6** will be temporarily locked in its position in direction of the arrow **14**. For this purpose, the slider **6** has a raised strip **6***e*, and a projection **20***a* of a lever **20** pivotable about an axle **21** abuts against the strip **6***e* in the non-working position of the slider **6**. The lever **20** is pulled against the strip **6***e* under the action of a spring **22** so that the projection **20***a* lowers behind the strip **6***e* when the slider **6** reaches its end position in direction of the arrow **14**. Finally, a lever **25** is provided which is displaceable under the action of a spring **23** on an axle **24**. The lever **25** has a lever arm **25***a* which is pulled under the action of a spring **26** against the outer surface of the eccentric disk **16** or its recesses **16***b*.

When the eccentric disk **16** rotates by approximately 180° after the extension or retraction of the objective **2**, the lever arm **25***a* engages in the directly passing recess **16***b* and is displaced by the same against the action of the spring **23** on the axle **24**. Thereby, a projection **25***b* takes along the lever **20** in clockwise direction so that its projection **20***a* is lifted from the strip **6***e*. The slider **6** is released for return to its non-working position against the direction of the arrow **14** and runs down under the action of the spring **13**. The switch **12**, **12***a* displaces in clockwise direction to its open initial position shown in FIG. **2**. Approximately near the end of its return movement, the slider **6** acts by its edge **6***f* on the lever arm **25***b* of the lever **25** and rotates the same in clockwise direction to the position shown in FIG. **1**. During this rotation, the lever arm **25***a* runs out of engagement with the recess **16***b* and somewhat moves back under the action of the spring **23** to the position shown in FIG. **2**, so that it again lies above the eccentric disk **16**; compare FIG. **1**. During the next actuation of the cover slider **5** and the slider **6**, the lever arm is again released by the edge **6***f* for abutting against the eccentric disk **16** or engaging in a recess **16***a*.

During return movement of the slider **6** against the direction of arrow **14** after the release by the lever **20**, the slider **6**, **6***b* releases at the end of its movement also the cover plate **4** for displacement to its position in which the cover plate **4** closes the objective **2**. When in the respective position of the slider **6**, as a result of the release of the viewfinder **3** by the cover slider **6**, the objective is extended out of the camera, the cover plate **4** abuts against the objective mount and is thereby held in its open position. The viewfinder and the objective are in their preparatory positions. When the slider **6** assumes its returned position after the movement of the cover slider **5** of the viewfinder in which the viewfinder is closed, the cover plate **4** is released from the objective inserted into the camera and pivots under the action of the spring **10** in front of the objective **2** so as to close the latter. An abutment **30** fixedly connected with the housing is provided for the closed position of the cover plate **4** of the objective.

Since during the motor-driven movement of the objective out of and into the housing of the camera the spool **80** is not coupled with the motor **12**, it can rotate during this phase under the pulling action of the film. This leads to displacement of the film **59** in the film gate of the camera and to overlapping of individual pictures. Because of this, the take-up spool **80** must be secured against rotation during the movement of the objective by the motor **12**.

For this purpose, an arm **87***a* of a lever **87** rotatable about an axle **88** abuts against the end of the slider **6**. Another arm **87***b* of the lever **87** abuts against a locking lever **85** with a locking tooth **85***a*. Its spring **86** pulls the locking tooth **85***a* out of engagement with the gear **80** and thereby holds the arm **87***a* in abutment against the slider **6**.

When the movement of the objective is performed by displacing the cover slider **5** in one of its two possible directions of movement, the slider **6** moves in the direction of arrow **14** and pivots via the lever **87** the locking tooth **85***a* into engagement with the gear **80***a*, so that the take-up spool **80** is secured against rotation and thereby the film **59** is secured in its position. Since the slider **6** assumes this position at the end of the movement of the objective, the spool **80** remains locked by the locking tooth **85***a* until the end of each movement of the objective and change of polarity of the motor **12** in the film transport position. When at the end of the movement of the objective—either for extension from the camera or retraction into the camera—the slider **6** is released for return to its shown initial position and thereby the motor **12** is reset to its film transport position, the lever arm **87** follows under the action of the spring **86**. The locking lever **85** also follows the same under the action of the spring **86**, so that the locking tooth **85***a* is lifted out of the gear **80***a* and it rotates during renewed actua-

tion of the motor **12** in a take-up direction of the take-up spool.

Thus, during the rotation of the motor in one direction for the transport of the objective and in the other direction for driving of the film spool, it is guaranteed that the film spool and thereby the film cannot assume during the movement of the objective not moving and damaging intermediate positions.

It is to be understood that a slider can be utilized instead of the levers, and an interengaging coupling can be utilized instead of the frictional coupling, and vice versa. Instead of the cover slider **5** for reversing the motor **12**, a special switching handle can be utilized for cooperating with the slider **6**.

It will be understood that each of the elements described above, or two or more together, may also find a useful application in other types of constructions differing from the types described above.

While the invention has been illustrated and described as embodied in a photographic camera, it is not intended to be limited to the details shown, since various modifications and structural changes may be made without departing in any way from the spirit of the present invention.

Without further analysis, the foregoing will so fully reveal the gist of the present invention that others can, by applying current knowledge, readily adapt it for various applications without omitting features that, from the standpoint of prior art, fairly constitute essential characteristics of the generic or specific aspects of this invention.

What is claimed as new and desired to be protected by Letters Patent is set forth in the appended claims:

1. A photographic camera, comprising a housing; a viewfinder; an objective displaceable between extended and retracted positions relative to said housing; means for displacing said objective between said extended and retracted positions; film transporting means; and film take-up spool; an electric motor rotatable in two opposite directions and arranged so that when said electric motor rotates in one of said directions it is coupled with said objective displacing means and when said electric motor rotates in the other of said directions it is coupled with said film transporting means and said film take-up spool; switching means for reversing said electric motor; and locking means for said film take-up spool, coupled with said switching means so that when said electric motor is switched for rotation in said one direction for displacing said objective and is coupled with said objective displacing means said film take-up spool is locked against rotation, and when said electric motor is reversed and uncoupled said film take-up spool is released.

2. A photographic camera as defined in claim **1**; and further comprising means for coupling said electric motor with said objective displacing means, on the one hand, and said film transporting means and said film take-up spool, on the other hand, said coupling means including a transmission and one-way clutch means.

3. A photographic camera as defined in claim **1**, wherein said switching means includes a switching element displaceable between two different positions in dependence upon the switching of the electric motor to a respective one of said directions of rotation, said locking means including a locking element connected with said switching element of said switching means.

4. A photographic camera as defined in claim **3**, wherein said locking element of said locking means is connected with said switching element of said switching means in a frictional manner.

5. A photographic camera as defined in claim **3**, wherein said locking element of said locking means is connected with said switching element of said switching means in interengaging manner.

6. A photographic camera as defined in claim **3**, wherein said switching element of said switching means is formed as a slider, said locking element of said locking means being formed as a lever connected with said slider.

7. A photographic camera as defined in claim **3**, wherein said switching element of said switching means is formed as a lever, said locking element of said locking means being formed as a slider connected with said lever.

8. A photographic camera as defined in claim **1**; and further comprising a cover movable relative to said viewfinder between closed and open positions so as to cover and expose said viewfinder, respectively, said switching means being connected with said cover so that when said cover moves between said closed and open positions, said objective is displaced between said retracted and extended positions.

9. A photographic camera as defined in claim **8**; and further comprising a further switching means arranged so that after terminating the displacement of said objective said first mentioned switching means is returned to its condition in which it is coupled with said film transporting means.

10. A photographic camera as defined in claim **8**, wherein said cover of said viewfinder is formed as a handle.

11. A photographic camera as defined in claim **1**, wherein said film take-up spool has a transmission including a toothed wheel, said locking means having a displaceable member provided with a locking tooth which is engageable with said toothed wheel of said transmission of said film winding spool.

12. A photographic camera as defined in claim **11**, wherein said displacing member of said locking means is formed as a lever, said locking tooth being provided on said lever.

13. A photographic camera as defined in claim **11**, wherein said displaceable member of said locking means is formed as a slider, said locking tooth being provided on said slider.

* * * * *

6/29/82 XR 4,336,996

United States Patent [19]

Cattelani et al.

[11] **4,336,996**

[45] **Jun. 29, 1982**

[54] **VARIABLE-FOCAL-LENGTH OBJECTIVE AND AN OPTICAL SYSTEM EQUIPPED WITH OBJECTIVES OF THIS TYPE FOR THE PRODUCTION OF SPECIAL EFFECTS ON FILM**

[76] Inventors: **Claude Cattelani,** 1, Square de la Mayenne, F-75017 Paris; **Catherine Perichon,** 5, Square de la Beauce, F-77100 Meaux/Beauval, both of France

[21] Appl. No.: **172,639**

[22] Filed: **Jul. 25, 1980**

[30] **Foreign Application Priority Data**

Mar. 12, 1980 [FR] France 80 05519

[51] **Int. Cl.**[3] **G03B 27/32;** G03B 27/52; G02B 9/00; G02B 15/18

[52] **U.S. Cl.** **355/39;** 350/427; 355/43; 355/57

[58] **Field of Search** 355/18, 21, 39, 40–43, 355/50, 51, 55–59; 350/423, 427, 469, 38; 352/85, 90

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Primary Examiner—Richard A. Wintercorn
Attorney, Agent, or Firm—Young & Thompson

[57] **ABSTRACT**

A variable-focal-length objective for equipping optical printers and caption stands for the production of special effects on films is constituted by four groups of lenses, namely a first convergent group of four lenses, a second divergent group of four lenses, a third convergent group of six lenses, and a fourth convergent group of two lenses, the first and third groups being coupled together and movable.

6 Claims, 8 Drawing Figures

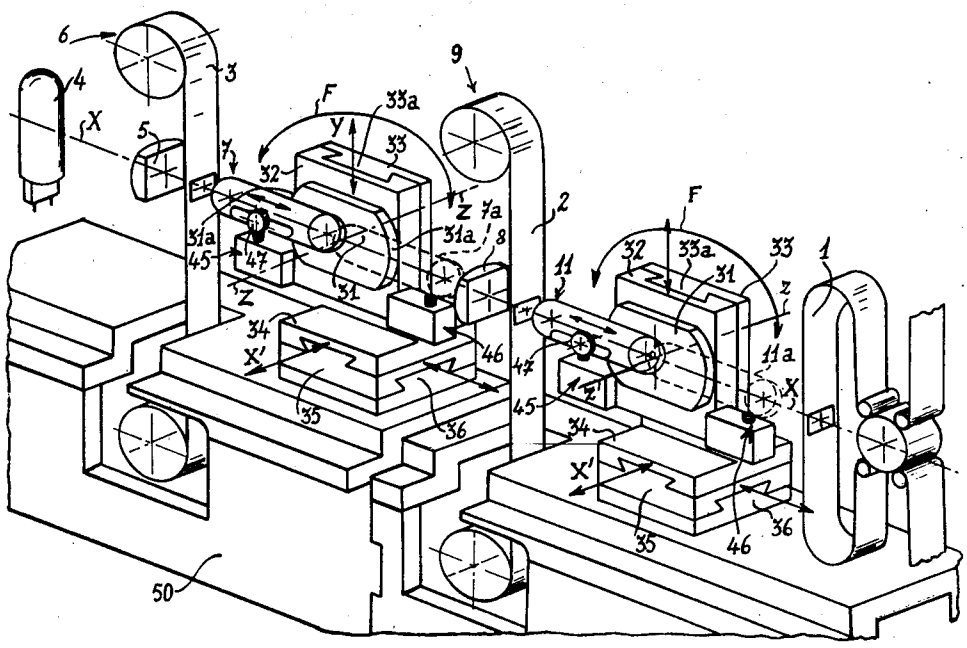
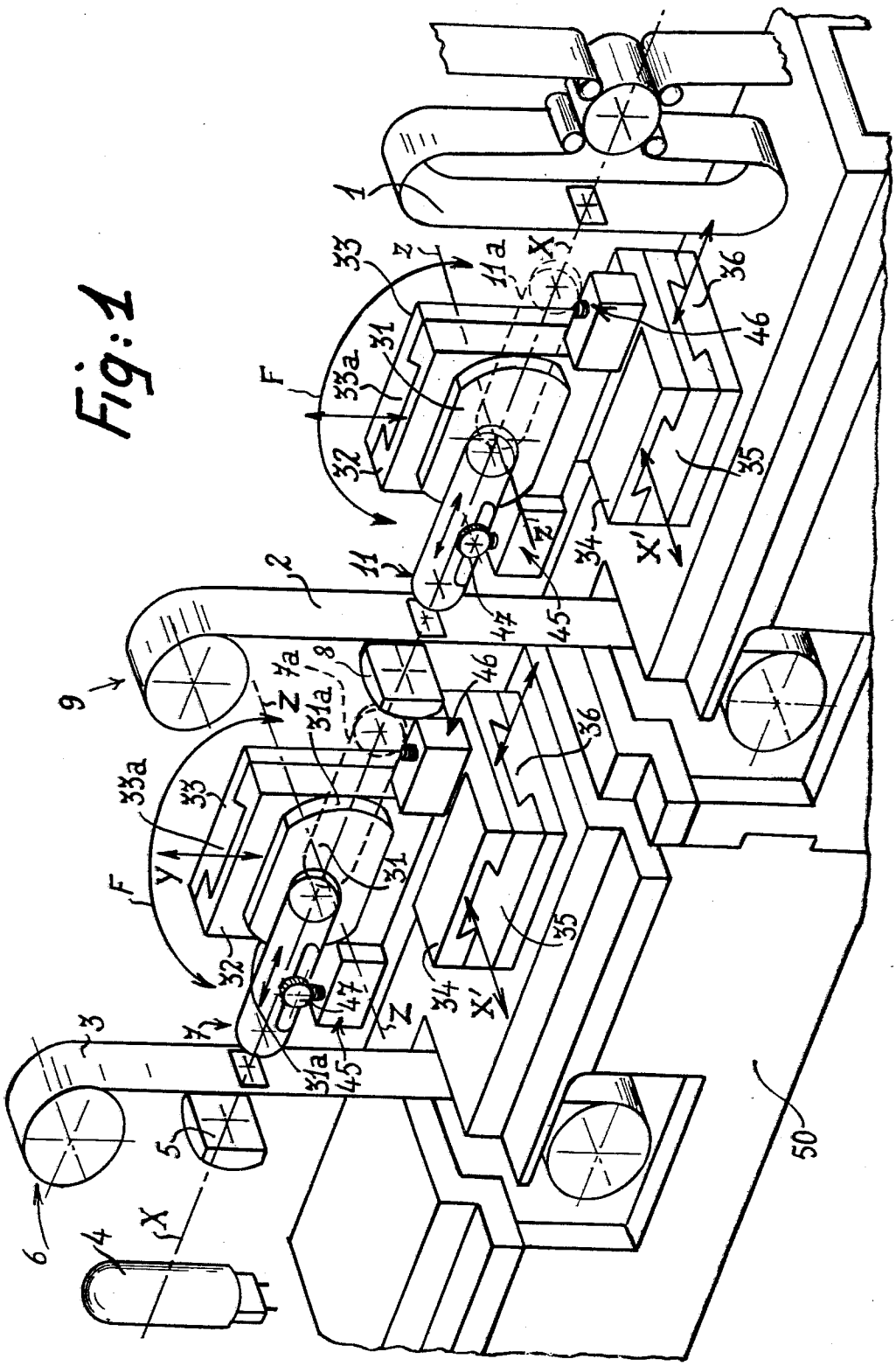


Fig: 1



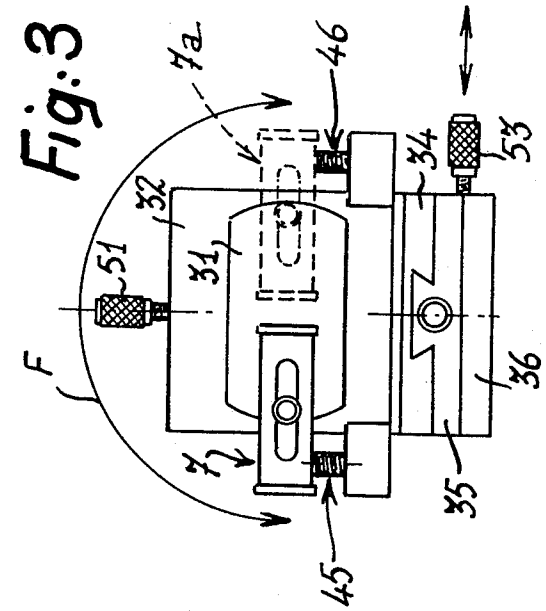


Fig. 3
7a
46
34
53
32
51
31
F
36
7
35
45

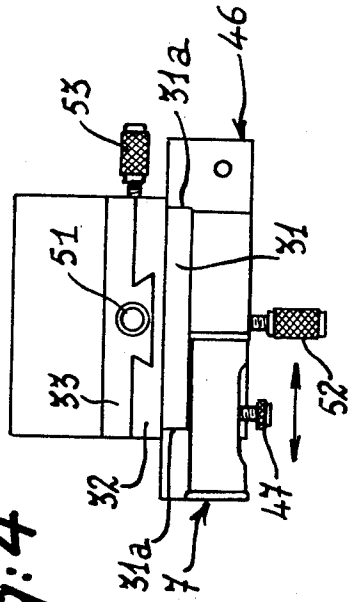


Fig. 4
53
31a
46
51
31
33
52
32
47
31a
7

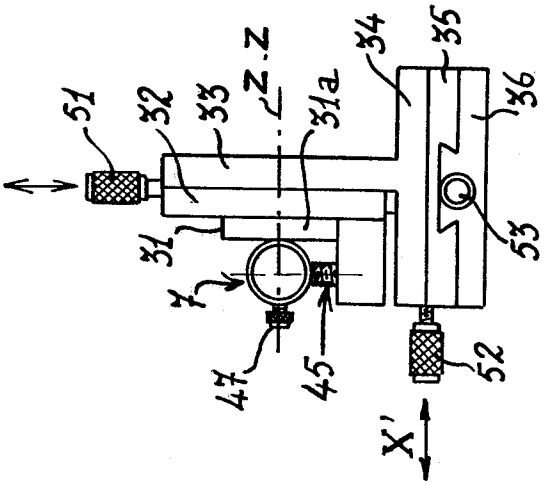


Fig. 2
Z
34
35
51
32
33
31a
36
31
53
7
47
45
52
X'

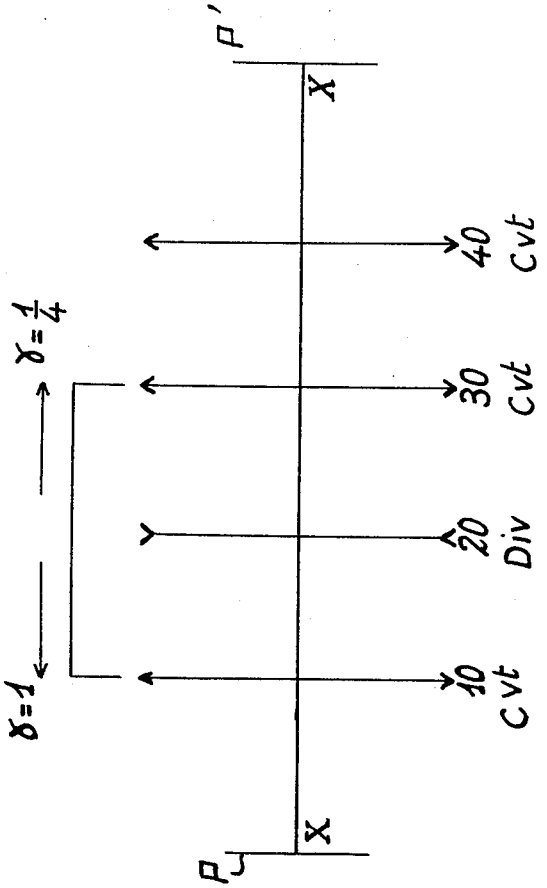

P'
X
40
Cvt
30
Cvt
20
Div
10
Cvt
X
P
γ=1/4
γ=1
Y

Fig:5

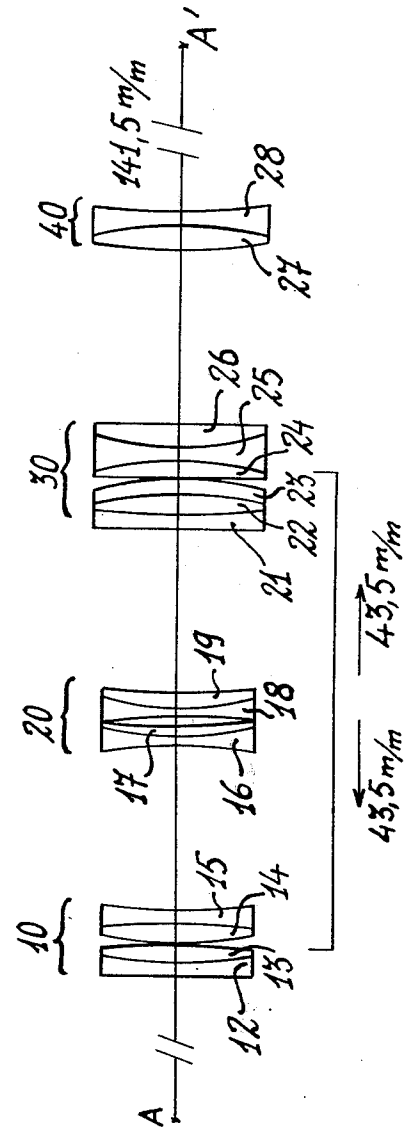
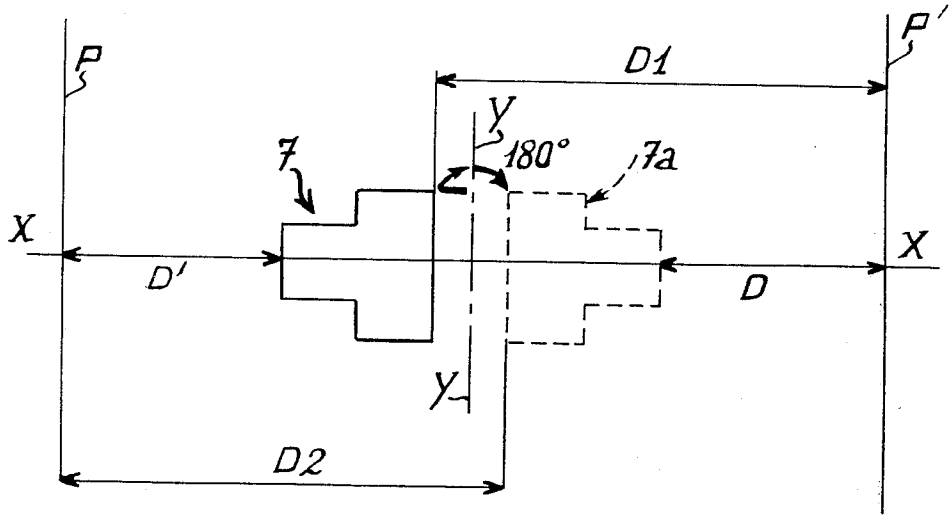

A'
141,5 m/m
40
28
27
30
26
25
24
23
22
21
20
19
18
17
16
10
15
14
13
12
A
43,5 m/m
43,5 m/m

Fig:6

Fig:7



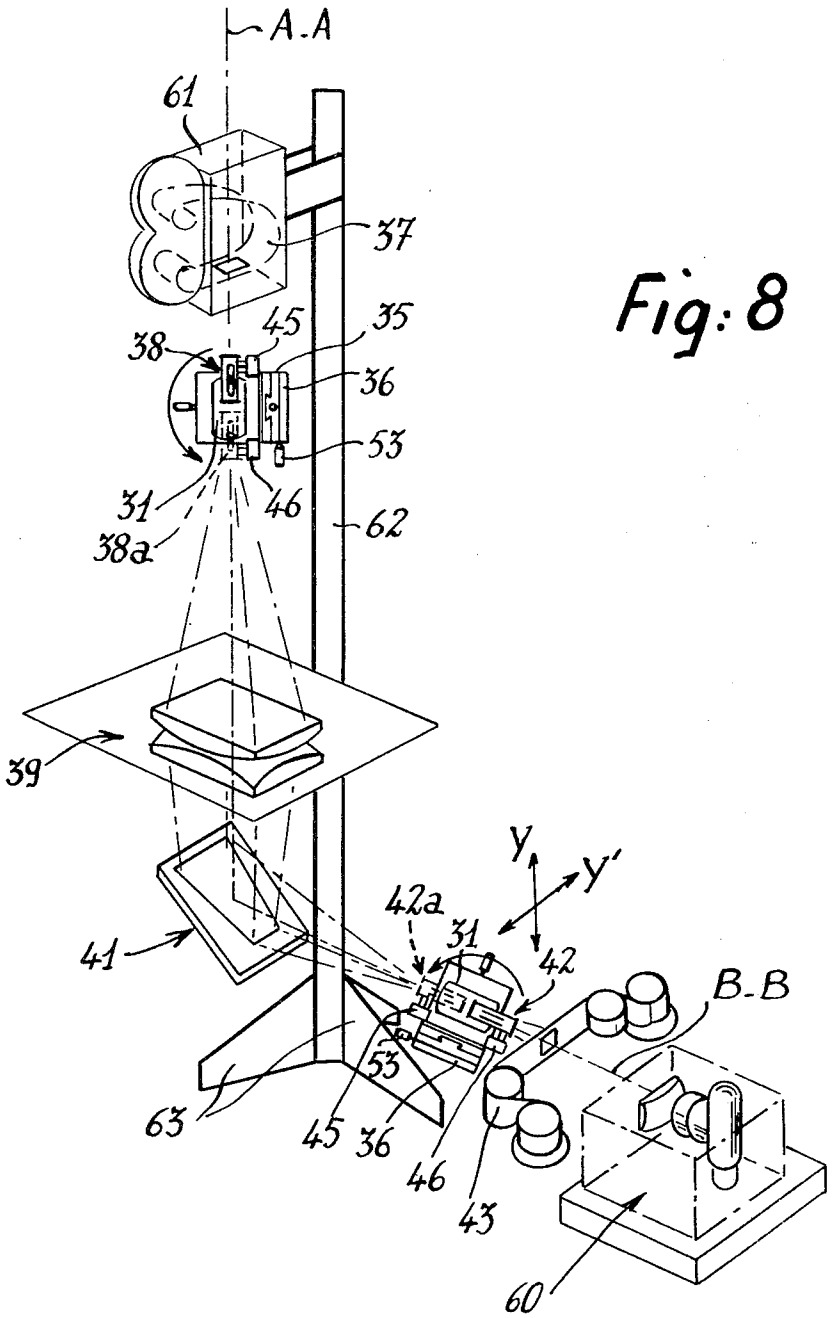

A.A
61
37
45
35
38
36
53
31
46
62
38a
39
41
Y
Y'
42a
31
42
B.B
53
63
45
36
46
43
60

Fig. 8

VARIABLE-FOCAL-LENGTH OBJECTIVE AND AN OPTICAL SYSTEM EQUIPPED WITH OBJECTIVES OF THIS TYPE FOR THE PRODUCTION OF SPECIAL EFFECTS ON FILM

This invention relates to a variable-focal-length objective as well as to optical systems equipped with said objective for producing special effects on unexposed films.

Optical systems designed for the production of special effects on an unexposed film by superimposing at least one previously exposed film on this latter are commonly designated as "optical printers" or as "caption stands", depending on whether the camera which unwinds the unexposed film and the objectives of the device move respectively in a horizontal or in a vertical direction. A fixed-focal-length objective is associated with each projector; an optical printer can thus comprise a main projector, an aerial-image projector and a beam-splitter projector for producing a 90° deviation with respect to the axis of the camera.

Known systems are equipped with a mechanical combination which makes it possible to displace the camera, camera objective and aerial projector objective as well as the projector in a horizontal direction in order to obtain either an enlargement or a reduction according to the direction of displacement, this being achieved while maintaining the focus on the plane of the unexposed film throughout the range of travel of the objective.

In the case of caption stands, the principle is the same; in this case, the camera dolly moves in the vertical direction and the plane of sharpness is located on the table of the stand.

However, it proves virtually impossible to eliminate the mechanical play which exists in optical systems of this type. In consequence, the focus does not remain constant and may be displaced either to the front or to the rear with respect to the plane of the unexposed film on which the films mounted on the projectors are to be combined. The aim of the invention is to overcome these disadvantages by replacing the fixed-focal-length objectives of conventional optical printers and caption stands by automatic-focusing varifocal objectives.

In accordance with the invention, the variable-focal-length objective which is intended to equip optical printers and caption stands for the production of special effects on films is constituted by four groups of lenses, viz:

a first convergent group of four lenses,
a second divergent group of four lenses,
a third convergent group of six lenses,
a fourth convergent group of two lenses,

the first and third groups being coupled together and movable.

This objective has a well-determined lens formula or silhouette, the numerical characteristics of which will be given in the following description.

The optical system for the production of special effects on an unexposed film, constituting an optical printer or a caption stand according as the movable elements undergo either a horizontal or a vertical displacement, comprises at least one objective associated with means for projecting at least one exposed film on the unexposed film with a view to obtaining the special effects.

In accordance with the invention, at least one of the aforesaid objectives is of the automatic-focusing varifocal type and has the characteristics mentioned in the foregoing.

According to another essential feature of the invention, the automatic-focusing varifocal objective which equips the optical system is pivotally mounted on an axis located at the midpoint between the object plane and the image plane and parallel to said planes so as to be capable of taking up two symmetrical positions with respect to said axis by reversal of said objective and so as to ensure that:

when the objective is located between the axis aforesaid and the object, the magnification corresponding to the limits of displacement in translational motion of the first and third groups varies substantially between 1 and 4 and that

when the objective is placed in its second position after reversal about the axis from the previous position, the reduction obtained by translational motion of the first and third groups varies substantially between 1 and 0.25.

In the case of a caption stand, the automaticfocusing varifocal objective provided by the invention makes it possible to obtain magnifications or reductions with a ratio of 1 to 20.

These and other features of the invention will be more apparent upon consideration of the following description and accompanying drawings in which two embodiments of the invention are shown by way of example but not in any limiting sense, and in which:

FIG. **1** is a simplified view in perspective showing a first embodiment of the invention constituted by an optical printer equipped with two variable-focal-length objectives in accordance with the invention;

FIG. **2** is a view in partial elevation along the optical axis of the optical printer of FIG. **1** and showing the assembly of a variable-focal-length objective;

FIG. **3** is a view in side elevation of the variable-focal-length objective of FIG. **2** together with its support;

FIG. **4** is an overhead plan view of the variable-focal-length objective of FIGS. **2** and **3** together with its support;

FIG. **5** is an optical diagram showing the design principle of the objective in accordance with the invention;

FIG. **6** is a diagram showing the elements constituting the different groups of lenses of the variable-focal-length objective in accordance with the invention;

FIG. **7** is an explanatory diagram showing the possibility of reversal of the variable-focal-length objective about an axis which is equidistant from the object and the image, in accordance with an essential feature of the invention;

FIG. **8** is a schematic view in perspective showing a second embodiment of the invention in which the automatic-focusing varifocal objective serves to equip a caption stand.

The optical system shown diagrammatically in FIG. **1** is an optical printer or in other words a device for producing special effects on an exposed film **1** unwound by a camera (not shown), starting from a combination of two exposed films **2**, **3** projected respectively by a main projector **9** and an aerial image projector **6**.

Starting from the end remote from the film-unwinding camera **1**, the device comprises in known manner a lamp **4**, a condenser **5**, the aerial image projector **6** which unwinds the film **3**, a first objective **7**, a con-

denser **8**, the main projector **9** for projecting the second film **2**, and a second objective **11**. All these elements are mounted on a support frame **50** along a general optical axis X—X of the system.

The optical printer shown in FIG. **1** is equipped with two automatic-focusing varifocal objectives **7**, **11** which are intended to permit enlargements or reductions of images which pass in front of the projectors **6**, **9** within predetermined limits while maintaining the image obtained strictly in the plane of the unexposed film **1**.

The objectives **7** and **11** are each rigidly fixed to a lateral shoe **31**, said shoe being disposed vertically and rotatably mounted on a block **32** about a horizontal axis Z—Z which is perpendicular to the optical axis X—X.

The block **32** is in turn slidably mounted in a vertical plane parallel to the axis X—X, on a vertical plate **33**. By way of example, the sliding connection between the plate **33** and the associated block **32** can be provided by an arrangement of the tenon and mortise type forming a dovetail assembly as illustrated in FIG. **1**; this figure shows that the plate **33** is provided with a dovetail tenon **33***a* engaged within a corresponding mortise of the block **32**.

The assembly constituted by the objective **7** (or **11**) together with its support **32**, **33** is in turn mounted on a solepiece **34** which is capable of sliding on a base **35** along an axis X' parallel to the axis Z—Z. Finally, the base **35** is also slidably mounted on a solepiece **36** for displacement along the optical axis X—X. The sliding connections between on the one hand the solepiece **36** and the base **35** and on the other hand between this latter and the plate **34** are obtained by means of "tenon and mortise" assemblies of the dovetail type as in the case of the assembly formed by the plate **33** and the block **32**.

All the displacements along the axis X—X, the axis X', the vertical axis Y of sliding motion of the block **32** can be adjusted by means of micrometer screws **51**, **52**, **53**.

The horizontal axis Z—Z on which the shoe **31** carrying the objective **7**, **11** is pivotally mounted is located at the midpoint between the object plane P (FIG. **5**) and the image plane P' corresponding to the unexposed film **1** and is parallel to these planes. In consequence, and in accordance with an essential feature of the invention, a pivotal movement of the shoe **31** about the axis Z—Z and through a sector of 180 degrees as indicated by the arrows F in FIG. **1** makes it possible to reverse the objective **7** or **11** so as to cause this latter to take up a position **7***a*, **11***a* which is symmetrical with the previous position with respect to the axis Z—Z. It should also be noted that these positions **7***a*, **7** and **11***a*, **11** are also symmetrical in each case with respect to the corresponding vertical axis Y.

In the case of each objective **7**, **11**, the support is provided with two lateral stops **45**, **46** having vertical rods and secured to the base of the block **32** on each side of the shoe **31**. By means of said stops **45**, **46**, the horizontality of the objective **7** or **11** can be suitably adjusted in each of its two positions in which the objective is applied against either of the two rods. The opposite edges **31***a* of the shoe **31** are rounded so as to permit pivotal motion of this latter and of the objective (**7**, **11**) between the stops **45**, **46**.

The possibility of reversal of the objective **7** (or **11**) is shown diagrammatically in FIG. **7**. Thus, in accordance with the invention, the objective is capable of assuming either of the two symmetrical positions with respect to the vertical axis Y—Y after a pivotal displacement about the horizontal axis Z—Z through an angle of 180 degrees. In position **7***a*, the distance D between the objective and the image plane D' is equal to the distance D' between the object plane P and the objective. Correlatively, the distance **D1** between the objective **7** which is placed in the position shown in full outline and the image plane P' is equal to the distance **D2** between the rear face of the objective after reversal at **7***a* and the object plane P. The objective **7**, **11** has a lens formula or "silhouette" which will be described in detail hereinafter and the numerical values are as follows:

D1 = D2 = 355.05 mm
D = D' = 141.5 mm

The objective (**7** or **11**) will now be described with reference to FIGS. **5** and **6**.

The objective **7** in accordance with the invention is constituted by four groups of lenses, viz:

- a first convergent group **10** of four lenses **12** to **15** (shown in detail in FIG. **6**),
- a second divergent group **20** of four lenses **16** to **19**,
- a third convergent group **30** of six lenses **21** to **26**,
- a fourth convergent group **40** of two lenses **27**, **28**,

the first and third groups **10**, **30** being coupled together and movable.

The displacement of these coupled groups **10**, **30** is effected by means of a micrometer knob **47** in a manner known per se, each group **10** and **30** being thus capable of moving over a distance of 43.5 mm. Given that P is the object plane and P' is the plane of the film **1**, a displacement of the movable groups **10**, **30** in the direction of the plane P produces an enlargement of the image in the plane P'. Conversely, a displacement of the groups of lenses **10**, **30** towards the plane P' produces a reduction of the image.

In FIG. **6**, the plane P corresponds to the point A and the point P' corresponds to the point A'.

The formula or "silhouette" of the automaticfocusing varifocal objective in accordance with the invention is given in the following table, in which:

- R is the radius of curvature of the successive faces of the lenses with a precision of 0.002 mm,
- E is the thickness of the lenses in millimeters with a precision of 0.1 mm,
- Nd is the refractive index of the lenses,
- NU (ν) is a complementary characteristic of the lenses.

		R	E	Nd	NU
	1	PLANE			
			3.00000	1.696500	36.5
	2	103.0000			
			6.00000	1.697000	56
	3	−202.4481			
			0.10000	AIR	
GROUP	4	109.0000			
1			5.50000	1.697000	56
	5	−184.0000			
			0.05000	AIR	
	6	−175.8000			
			3.00000	1.696500	36.5
	7	264.6000			
			45.86100	AIR	
	8	−102.2700			
			2.00000	1.464500	65.7
	9	83.8300			

-continued

		R	E	Nd	NU
			3.50000	1.740000	28.1
	10	163.9200			
			1.50000	AIR	
GROUP	11	−200.3200			
2			2.00000	1.464500	65.7
	12	59.8200			
			3.50000	1.740000	28.1
	13	91.8607			
			46.76600	AIR	
	14	1991.4000			
			3.00000	1.613099	44.4
	15	200.0000			
			6.00000	1.608750	59
	16	−185.8000			
			0.10000	AIR	
GROUP	17	−212.8000			
3			5.00000	1.608750	59
	18	−91.9756			
			0.10000	AIR	
	19	PLANE			
			6.00000	1.608750	59
	20	−65.0000			
			3.00000	1.613099	44.4
	21	65.0000			
			6.00000	1.608750	59
	22	PLANE			
			47.34500	AIR	
	23	93.2200			
			7.00000	1.603500	64
	24	−135.8300			
GROUP			0.50000	AIR	
	25	−114.6300			
4			3.00000	1.613099	44.4
	26	242.8000			
			141.53047	AIR	

When the objective has been placed in the position shown in full outline in FIG. **7**, the displacement of the first and third groups of coupled lenses **10, 30** towards the left or in other words towards the object plane P produces an enlargement of the image in the plane P' which can vary between 1 and 4 approximately. After reversal of the objective **7** about the axis Z—Z through an angle of 180 degrees to the position **7***a*, the displacement of the groups of lenses **10, 30** by means of the knob **47** between the limits determined by the characteristics of the objective makes it possible to obtain a reduction of the image in a ratio which varies between 1 and 0.25.

The advantages of the objective and of the optical system equipped with said objective for the production of special effects (optical printer illustrated in FIG. **1** or caption stand) are as follows:

By virtue of the fact that the fixed-focal-length objective of cameras or projectors of optical printers or caption stands is replaced by the variable-focal-length objective in accordance with the invention, cameras or projectors equipped with this variable-focal-length objective can accordingly be allowed to remain stationary. It is in fact solely the focal length of the objective which gives rise to the phenomenon of reduction or enlargement of the desired field by undergoing a variation. This device therefore has an enormous advantage in that it permits complete elimination of play of mechanical parts which could not be suppressed in known systems of the prior art and produced differences in sharpness in the images obtained on the unexposed film. Elimination of mechanical parts and the consequent possibility of moving the cameras or the projectors also simplifies manufacture to a considerable extent and produces a correlative reduction in cost price of the optical system.

The ratio of extreme focal lengths is considerably reduced and permits better correction of aberrations.

Since the variable-focal-length objective in accordance with the invention is incorporated in a pivoting system of the type shown in FIG. **1**, said objective can readily be rotated either in one direction or in the other in order to carry out reductions or enlargements of the image.

In the enlargement or reduction operations, it is not necessary to carry out any correction of diaphragm with the variable-focal-length objective in accordance with the invention. This dispenses with the need for the electromechanical or electronic light-compensating systems which are necessary in conventional systems by reason of the substantial displacements of the film plane and of the objective (increase and decrease as a function of the square of the distance).

The elimination of moving mechanical parts of known devices by installation of at least one variable-focal-length objective in a stationary system simplifies the manufacture of optical printers or caption stands and reduces their overall size to a very appreciable extent.

Finally, if the optical printer or the caption stand is equipped with an additive or subtractive lamphouse, the luminous flux of this latter is not modified during enlargement and reduction operations, which is not the case in a conventional system.

There is shown in a simplified manner in FIG. **8** a caption stand which can be equipped with two variable-focal-length objectives in accordance with the invention.

The system comprises: a first film **43** unwound by a projector **60**, a variable-focal-length objective **42** on a pivoting system of similar design to the system shown in FIG. **1**, a reflecting mirror **41** which reflects the luminous flux towards a condenser device **39** on which a document (not shown) is placed. The supports provided for the elements **39** and **41** are known per se and have therefore not been illustrated. This aerial image and the document aforesaid are re-taken by a variable-focal-length objective **38** mounted on a pivoting system which is similar to the system of FIG. **1**. The resultant image is received by an unpexposed film **37** unwound by a camera **61** secured in such a manner as to be adjustable for height to a vertical upright member **62** which is provided at its base with supporting fins **63**.

The axis A—A of the objective **38** and of the condenser **39** is vertical whereas the axis B—B of the objective **42** and of the projector **50** which unwinds the film **43** is horizontal.

As shown in the figure, the supports provided for the objectives **42** and **38** are similar to those provided for the objectives **7** and **11** and are therefore designated by the same reference numerals. Correlatively, the objective **38** is capable of pivotal displacement about a horizontal axis at right angles to the shoe **31** and to the plane of FIG. **8** as well as to the vertical optical axis A—A in order to take up the position **38***a* shown in dashed outline. Similarly, the objective **42** is capable of pivotal displacement about a vertical axis at right angles to the horizontal optical axis B—B whilst the shoe **31** is capable of pivotal displacement about said vertical axis together with the objective **42**.

The automatic-focusing varifocal objective contemplated by the invention makes it possible in the case of the caption stand of FIG. **8** to obtain enlargements or reductions with a ratio of 1 to 20.

The invention is not limited to the embodiments hereinabove described and can include a large number of alternative forms of construction. Thus it is apparent that, in the case of an optical printer or of a caption stand provided with two objectives, either or both of said objectives may be in accordance with the invention. It is also possible to produce a number of different combinations in which a plurality of objectives are employed either partly or wholly in accordance with the invention. The objectives can be mounted on pivoting systems of any suitable type which is equivalent to the device shown in the drawings.

What is claimed is:

1. A variable-focal-length objective which is intended to equip optical printers and caption stands for the production of special effects on films, wherein said objective is constituted by four groups of lenses, viz:

a first convergent group of four lenses,

a second divergent group of four lenses,

a third convergent group of six lenses,

a fourth convergent group of two lenses,

the first and third groups being coupled together and movable, and wherein said objective has the following lens formula in which:

R is the radius of curvature of the successive faces of the lenses with a precision of 0.002 mm,

E is the thickness of the lenses in millimeters with a precision of 0.1 mm,

Nd is the refractive index of the lenses,

NU (ν) is a complementary characteristic of the lenses.

		R	E	Nd	NU
	1	PLANE			
			3.00000	1.696500	36.5
	2	103.0000			
			6.00000	1.697000	56
	3	−202.4481			
			0.10000	AIR	
GROUP 1	4	109.0000			
			5.50000	1.697000	56
	5	−184.0000			
			0.05000	AIR	
	6	−175.8000			
			3.00000	1.696500	36.5
	7	264.6000			
			45.86100	AIR	
	8	−102.2700			
			2.00000	1.464500	65.7
	9	83.8300			
			3.50000	1.740000	28.1
	10	163.9200			
			1.50000	AIR	
GROUP 2	11	−200.3200			
			2.00000	1.464500	65.7
	12	59.8200			
			3.50000	1.740000	28.1
	13	91.8607			
			46.76600	AIR	
	14	1991.4000			
			3.0000	1.613099	44.4
	15	200.0000			
			6.00000	1.608750	59
	16	−185.8000			
			0.10000	AIR	
GROUP 3	17	−212.8000			
			5.00000	1.608750	59
	18	−91.9756			
	19	PLANE			
			6.00000	1.608750	59
	20	−65.0000			
			3.00000	1.613099	44.4
	21	65.0000			
			6.00000	1.608750	59
	22	PLANE			
			47.34500	AIR	
	23	93.2200			
			7.00000	1.603500	64
GROUP 4	24	−135.8300			
			0.50000	AIR	
	25	−114.6300			
			3.00000	1.613099	44.4
	26	242.800			
			121.53047	AIR.	

2. An optical system for the production of special effects on an unexposed film, constituting an optical printer or caption stand and comprising at least one objective associated with means for projecting at least one exposed film on the unexposed film in order to obtain special effects, wherein at least one of the objectives is constituted by four groups of lenses, viz:

a first convergent group of four lenses,

a second divergent group of four lenses,

a third convergent group of six lenses,

a fourth convergent group of two lenses, the first and third groups being coupled together and movable.

3. An optical system according to claim **2**, wherein said variable-focal-length objective is pivotally mounted on an axis located at the midpoint between the object plane and the image plane and parallel to said planes so as to be capable of taking up two symmetrical positions with respect to said axis by reversal of said objective, and wherein:

when the objective is located between the axis aforesaid and the object, the magnification corresponding to the limits of displacement in translational motion of the first and third groups varies substantially between 1 and 4, and

when the objective is placed in its second position after reversal about the axis from the previous position, the reduction obtained by translational motion of the first and third groups varies substantially between 1 and 0.25.

4. An optical system according to claim **3** in which the general optical axis is horizontal, wherein said system comprises means for producing a pivotal displacement of the variable-focal-length objective about a horizontal axis at right angles to the optical axis of the system in order to cause said system to take up successively two symmetrical positions with respect to said axis after reversal through an angle of 180 degrees.

5. An optical system according to claim **4**, wherein the means for producing a pivotal displacement of the objective about the axis aforesaid comprise a vertical shoe mounted on a support block and rotatable about said axis, stops for adjusting the positions of the objective being placed on each side of said shoe.

6. An optical system according to claim **3**, constituted by a caption stand comprising a projector having a horizontal optical axis which is capable of unwinding a first film, a mirror for reflecting the luminous flux to a condenser which is intended to receive a document, an unexposed film unwound by a camera located above the

condenser and carried by a supporting element in such a manner as to ensure that the optical axis of said element and of the camera is vertical, and two variable-focal-length objectives, one objective being mounted between the projector and the reflector for pivotal displacement about a vertical axis at right angles to the horizontal optical axis, the other objective being placed between the condenser and the camera for pivotal displacement about a horizontal axis at right angles to the vertical optical axis.

* * * * *

United States Patent [19]

Prochnow

[11] **4,336,986**

[45] **Jun. 29, 1982**

[54] **CAMERA HAVING AN INDEPENDENTLY FOCUSED RETRACTABLE OBJECTIVE LENS**

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[73] Assignee: **Rollei-Werke Franke & Heidecke GmbH & Co. KG**, Brunswick, Fed. Rep. of Germany

[21] Appl. No.: **164,497**

[22] Filed: **Jul. 2, 1980**

[30] **Foreign Application Priority Data**

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[52] **U.S. Cl.** **354/187**; 354/195

[58] **Field of Search** 354/187, 188, 189, 190, 354/191, 192, 193, 194, 195, 198

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Primary Examiner—L. T. Hix

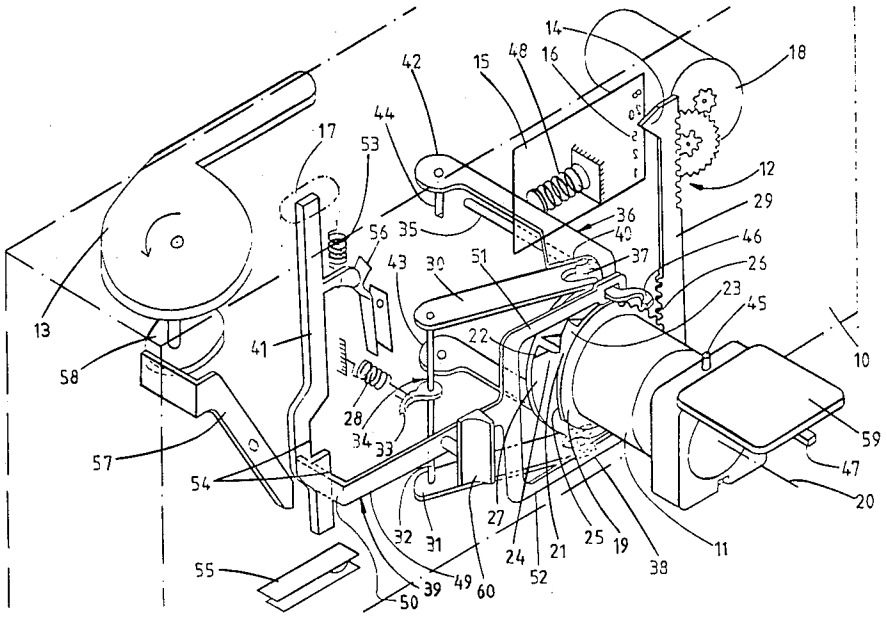
Assistant Examiner—Alan Mathews

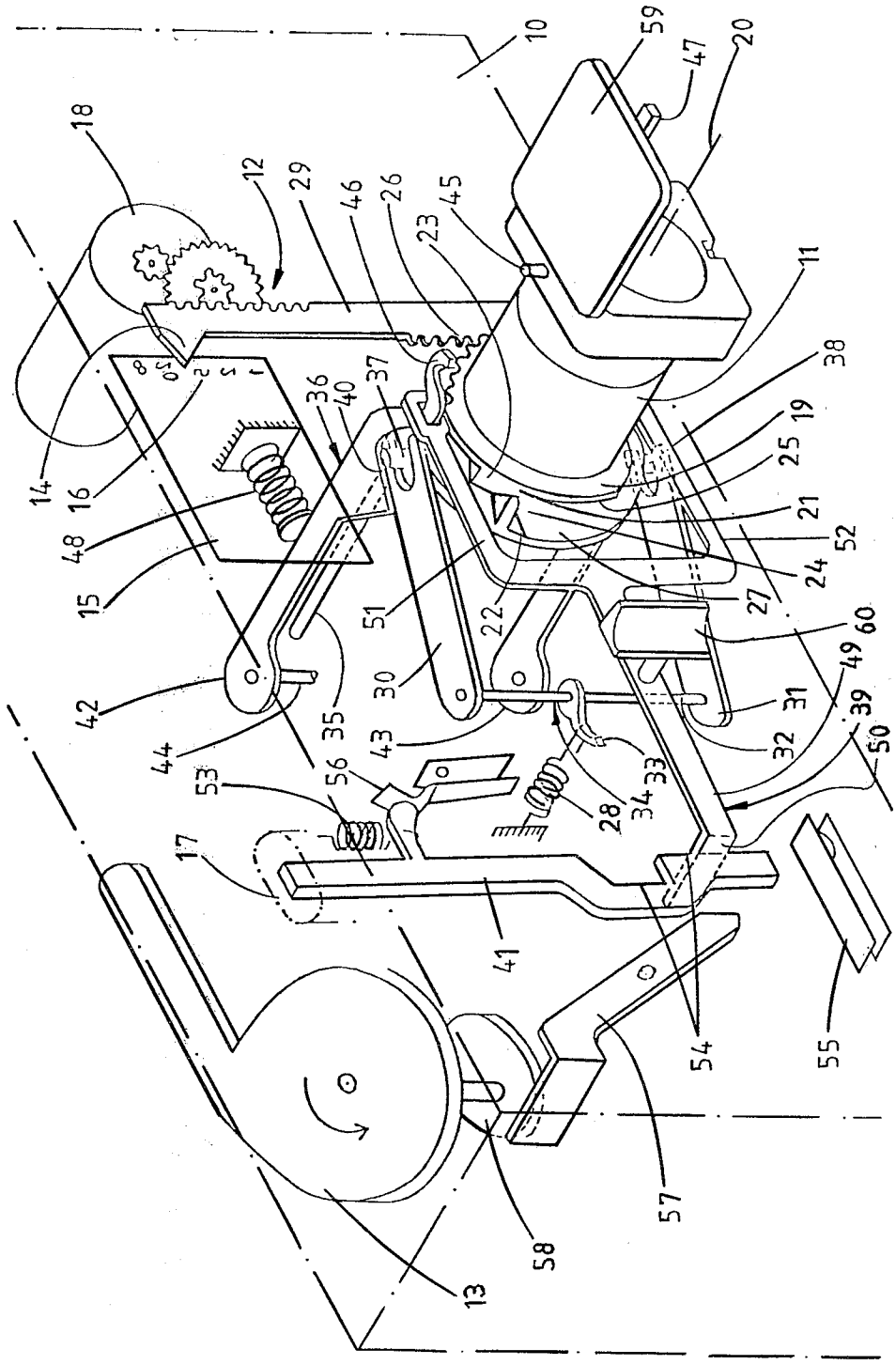
Attorney, Agent, or Firm—Schwartz, Jeffery, Schwaab, Mack, Blumenthal & Koch

[57] **ABSTRACT**

Disclosed is a camera including a camera housing and an objective lens having an image axis. The objective lens for the camera is mounted in a tube which is movable between an extended exposure position and a retractive storage position. When the tube is in the extended exposure position, a locking device responsive to operation of the shutter release, increases the biasing force on the objective lens towards its extended position. The locking device is made up of several cams spring biased against two pins radially projecting from the objective tube. The cams are prevented from bearing against the pins by a control linkage which prevention is released during shutter actuation.

8 Claims, 1 Drawing Figure

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CAMERA HAVING AN INDEPENDENTLY FOCUSED RETRACTABLE OBJECTIVE LENS

BACKGROUND OF THE INVENTION

The present invention generally concerns a photographic camera and particularly, a miniature camera having a retractable focusable objective lens.

In copending patent application Ser. No. 100,358 entitled "Camera Having an Independently Focused Retractable Objective Lens," filed Dec. 5, 1979, now U.S. Pat. No. 4,280,762, a camera is disclosed which has a relatively small size when the objective lens is retracted. It has good handling, a control means for focusing the camera and viewing through the viewfinder which all facilitate the quick, simple taking of snapshots.

In the above-described camera, the objective tube is spring-biased in its extended position against an adjustable cam which accomplishes the focusing of the camera. Additionally, the same spring force is primarily responsible for extending the objective tube from its retracted position to its extended position. Thus, it is desirable on one hand to have a relatively strong spring force to extend the objective tube and at the same time maintain the objective tube in firm contact with the cam for focusing purposes and on the other hand for ease of focusing and to reduce frictional loads, it is desirable to have a very light biasing of the tube. An additional problem occurs when a relatively light spring is used in that a very small accidental pressure on the side of the objective tube can cause the tube to deflect so that the camera is not focused.

The conflicting interests created by wanting a strong spring on one hand and a weak spring on the other requires a compromise which does not optimally satisfy either of the two requirements.

SUMMARY OF THE INVENTION

It is therefore an object of the present invention to provide an improved independently focused retractable objective lens camera, said improvement comprising a mechanism which permits ease of focusing and relatively small forces involved in focusing while at the same time provides precise locking in place of the objective tube in its focused position.

The above and other objects are achieved by providing a camera housing and an objective lens with an image axis, said lens is mounted for movement substantially parallel to the image axis between an extended exposure position and a retracted storage position. The camera includes a means for manually setting the focal range of the camera. A means for variably limiting axial movement of the mount in the extended position in response to the range setting means is provided through means of a ring and cam assembly. A means for variable biasing the mount towards the extended position assures that a minimum bias is provided prior to shutter actuation to facilitate focusing but a high degree of bias is utilized during actual shutter actuation to ensure that the camera is correctly focused.

In a preferred embodiment of the present invention, a locking system is used which, simultaneously with the actuation of the shutter release, engages the objective tube to increase the bais forcing the objective tube against the means limiting axial movement.

BRIEF DESCRIPTION OF THE DRAWING

A more complete appreciation of the invention and the attendant advantages thereof will be more clearly understood by reference to the following drawing, wherein:

The drawing is a front perspective view of an independently focused retractable objective lens system with a shutter-actuated locking means for firmly positioning the objective lens in its extended position.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Referring now to the drawing, a photographic still camera is shown which is one embodiment would use 35 mm roll film. The camera housing **10** indicated in dash-dot lines has an axially displaceable objective tube **11** mounted therein. In the extended position (the position necessary to take a picture with the camera) the objective tube **11** projects from housing **10** and assumes an optically proper arrangement with respect to the film (not shown) which would be located in the camera in its window. When the camera is not in use, the objective tube **11** can be completely retracted inside housing **10** so that the camera provides relatively planar external surfaces facilitating its storage or packaging.

The film transport and shutter reset lever **13** and shutter release **17** (shown in dash-dot lines) are illustrated on the upper side of housing **10**. In order to clarify the presentation of the internal parts of the camera, the conventional knobs for setting aperture size, exposure speed and film speed have been omitted.

In a preferred embodiment, a motorized focusing arrangement **12** is provided with includes an electric setting motor **18** which may be controlled by a known auto-focusing system (again omitted for clarity). A pointer **14** of focusing system **12** is visible in the viewing field **15** of the camera and illustrates on range scale **16**, the distance in viewer **15** which was set by the focusing arrangement **12**.

A focusing ring **19** which is fixed with respect to movement along optical axis **20** is supported concentrically with respect to objective tube **11** and is free to rotate thereabout. The focusing ring **19** includes a cam means **21** which is in contact with projection **22** which is part of the objective tube **11**. Cam means **21** and projection **22** cooperate to form a means for variable limiting axial movement of the objective tube **11** and it can be seen that if focusing ring **19** is revolved about optical axis **20**, the extended position of objective tube **11** will vary slightly in the axial direction.

Cam means **21** and projection **22** are biased into contact with each other when the objective tube **11** extends from housing **10**.

In the specific embodiment shown, cam means **21** and projection **22** are designed as wedge-shaped projections **23** and **24**. Projection **23** is located on the focusing ring **19** on its backside **25** extending towards the inside of the camera housing. Lug **24** is mounted on flange **27** which projects from objective tube **11** and is solidly connected therewith. As will be obvious to one of ordinary skill in the art, a plurality of projections **23** and lugs **24** can exist at different radial positions around the periphery of the focusing ring and flange **27**. Finally, focusing ring **19** includes a segment of a gear crown **26** which meshes with a gear rack **29** of focuser **12**.

The primary bias of objective tube **11** in the axial direction is provided by spring **28** which is prestressed

in its extended position. This spring is of such design that after the objective tube **11** has been moved into the extended position shown, it maintains a small residual force generating a given compression or bias between cam means **21** and projection **22**. This bias is so chosen so as to be lower than the bias necessary to maintain the cam means and the projection in proper contact during film exposure. This lower than adequate bias permits ease of operation of the focusing means **12** especially during auto-focusing.

The extension spring **28** can be either a tension or compression spring and in the present instance is a tension spring acting on double arm rocker assembly **34**. The rocker **34** comprises two arms **30** and **31** which are mutually parallel and rigidly mounted to pivot shaft **32**. A third arm **33** is rigidly mounted to shaft **32** and has extension spring **28** connected thereto. In this manner, the two free ends of arms **30** and **31** are biased in the direction of extension for objective tube **11**.

Objective tube **11** includes pins **37** and **38** mounted on flange **27** which projects radially outward and serve both as extension limit stops and on the other hand move in guideslot **35** to prevent rotation of the objective tube and ensure only axial displacement when the tube is retracted or extended in housing **10**.

In a preferred embodiment, this slotted guide **35** in housing **10** would be present in two locations to handle diametrically opposite pins **37** and **38**, although only one slotted guide **35** is shown for the sake of clarity. At the end of each of the arms **30** and **31** of double rocker **34** is a slot which encloses pins **37** and **38** forming an articulating linkage between rocker **34** and objective tube **11**.

Housing **10** also includes a locking system **36** which is associated with the objective tube **11** and acts only slightly prior to and during image exposure to generate an additional compression between cam means **21** and projection **22** to ensure reliable locating of the objective tube **11** in housing **10** during actual shutter operation. This additional compression must be high enough such that accidental lateral contact of the objective tube **11** by the camera user cannot cause a deflection of the objective tube axis from the optical axis. Ideally, the additional compression for biasing is triggered by the triggering of the exposure process and lasts through closure of the camera shutter.

In a preferred embodiment, locking system **36** is coupled by means of a control linkage **39** to shutter release **17**. The control linkage is so designed that locking system **36** can only engage objective tube **11** essentially simultaneously with the actuation with the shutter release **17**. The locking system **36** in the embodiment shown comprises two spring loaded levers **42** and **43**, which coact with pins **37** and **38** located on the objective tube **11**. The levers pivot about common pivot shaft **44** which is perpendicular to the optic axis **20** and the levers are biased in a direction transverse to the optic axis **20** by compression spring **48**. Each lever includes a cam portion **40** which is essentially an acute angle with respect to the optic axis **20**.

A control bar **41** connected to the shutter release **17**, is displaced upon actuation of the shutter release, and control slider **49** acts upon levers **42** and **43** of the control linkage **39**. The control slider **49** has a tang **50** which rests against control bar **41**, which has a notch **54** into which controlled tang can move when shutter release **17** is displaced a predetermined amount. Control slider **49** in the preferred embodiment is fork-shaped, having tines **51** and **52** which engage levers **42** and **43**. The control bar **41** is longitudinally displaceable against the bias of return spring **53** by means of the operator pressing upon the shutter release **17**. It will be seen that the bias of spring **48** on levers **42** and **43** will force cam **40** to bias the objective tube in its extended position. This bias is additional to the bias in the extended position provided by extension spring **28**. Movement of levers **42** and **43** is prevented by virtue of control linkage **39** bearing against control bar **41**. Thus, spring **48** biases levers **42** and **43** against the forkshaped tines **51** and **52** of control linkage **39** which in turn is then biased against the slide of control bar **41**. However, when shutter release **17** has been depressed to the extent that control linkage **39** can pass into slot **54**, spring **48** causes levers **42** and **43** to move further towards control bar **41**. This further movement permits cam **40** to bear against pins **37** and **38** and thus further bias in a stronger manner, the objective tube towards its extended position. This biasing ensures firm and complete contact between the cam means **21** and projection **22** during the shutter release operation.

A camera shutter release switch **55** is located at the end of travel of control bar **41** and thus the shutter will only be released after the control bar has moved sufficiently in its longitudinal direction to permit control linkage **39** and tang **50** to move into slot **54** thereby locking the objective lens into position for shutter release. An additional camera switch may be mounted so as to be engaged during initial displacement of control bar **41** for the switching on of automatic aperture control or an auto-focus system. It may be advantageous to locate this switch such that it will close a specific time before control bar **41** releases slider **49** such that any auto-focusing will take place prior to the release of the locking system **36** which will then force cam member **21** and projection **22** together locking the objective tube **11** in housing **10**. This locking system then obviates any danger of objective tube misalignment and permits highly accurately focused pictures to be taken. Of course, until shutter release **17** is depressed, cam means **40** will be prevented at least to a large extent from additionally biasing objective tube **11** in its extended position such that under the light biasing pressure of extension spring **28**, the reduced friction between cam means **21** and projection **22** permits easy focusing especially by the auto-focusing system shown.

The camera shown in the drawing is in its picture-taking condition with objective tube **11** projection from housing **10** and biased in this extended position by double rocker **34**. Lug **24** of projection **22** rests upon cam means **21** on the backside of the focusing ring **19**. In this condition, the bias between the projection and cam means is relatively low and thus there are relatively low frictional forces therebetween facilitating ease of rotation of focusing ring **19**. As shown, the locking system **36** is still inactivated and control tang **50** rests against the side of control bar **41**. Thus, the control bar **41** keeps levers **42** and **43** of the locking system biased against the force of compression spring **48** such that cams **40** of the levers do not to a substantial degree anyway, press against pins **37** and **38**.

When the shutter release **17** is depressed, the control bar **41** is displaced longitudinally downward against return force **53**. In a preferred embodiment, the operating sequence permits switch **56** to close whereby an auto-focus system is activated. This auto-focus system in a known manner measures the range to the picture

object and in accordance with any discrepancy between the measured range and the focus of the objective tube **11**, will emit a corresponding control signal to setting motor **18**. This motor drives the gear rack **29** which in turn rotates the focusing ring **19**. The objective tube **11** is displaced in its axial direction by means of cam means **21** bearing on projection **22** until the objective is sharply focused on the film plane. The range set by the auto-focus system is displayed by pointer **14** on the distance scale **16** in the viewer **15** of the camera. During this focusing process, the position of control tang **50** and hence control slider **49** has remained unchanged in view of the design of slot **54** of control bar **41** with an end result that the locking system **36** remains inactive.

As the control bar **41** is further displaced in the longitudinal direction, control tang **50** is permitted to move into slot **54** permitting control slider **49** to move transversely with respect to the optic axis **20** (to the left in the drawing) by a predetermined amount. Compression spring **48**, biasing levers **42** and **43**, permits cams **40** of control levers **41** and **42** to bear against pins **37** and **38** further biasing objective tube **11** in its extension direction. Lugs **24** of projections **22** are strongly pressed against cam means **21** on the backside of focusing ring **19**. Inasmuch as the focusing ring **19** is fixed against axial movement, the objective tube will now be fixed with respect to the housing with a high degree of force in the position previously determined by the auto-focusing system. Thus, the objective tube is now locked in its optically accurate position for taking a picture with respect to the camera housing.

Upon further depressing the shutter release **17**, control bar **41** is displaced until it closes shutter release switch **55** whereupon the shutter is opened and closed in a known manner exposing the photographic film and completing the picture-taking process.

In order to reset the locking system **36** into its inactive position with cams **40** not heavily bearing against pins **37** and **38** such that focusing ring **19** is again rotatable with very light forces, a return lever **57** is provided in the control linkage **39** which is coupled to the shutter reset and/or film advance lever. In a preferred embodiment, a control cam **58** is mounted to the film advance lever **13**, said cam **58** revolving when the lever **13** is advanced in the direction of the arrow shown. Return lever **57** is pivoted about the axis shown and when cam **58** bears against one end of the lever, the other end bears against control tang **50**. When the film advance lever **13** is pivoted (counter-clockwise in the illustrated embodiment) the free end of the lever arm resting against control tang **50** will move towards the optic axis **20**. Control slider **49** is moved so as to lift control tang **50** out of slot **54** permitting control bar **41** under the influence of return spring **53** to move the shutter release **17** to its initial position. When the film advance lever **13** is released, the biasing of lever **57** by cam **58** will be terminated and control tang **50** will again rest against control bar **41** as shown in the drawing. In this position, the objective is no longer locked in position and instead is biased in its extended position primarily by extension spring **28** and thus, the camera assembly is ready for a further sequence of auto-focusing and picture-taking.

Objective tube **11** can be retracted into the camera housing **10** by axially pressing on the objective tube. With pins **37** and **38** sliding in guide slot **35**, arms **30** and **31** of the double rocker **34** pivoted to the rear placing extension spring **28** in further tension. The objective tube **11** completely disappears into housing **10** whereupon the objective tube **11** is locked against the bias of extension spring **28**. Levers **42** and **43** of the locking system **36** further act as retaining levers having at their free end an indexing latch **46** which engage indexing pins **45** and **47** on the objective tube **11**. In a preferred embodiment, pins **45** and **47** can be mounted with one radially projecting outward from the front-end of the objective tube and the other radially projecting from an objective cover **59** which is hinged on the front of the objective tube **11**. When the cover is pushed down into position over the objective tube **11**, pin **47** will extend radially outward with respect to the optical axis **20**. When the objective tube **11** is pressed all the way into the camera with the cover **59** closed, pins **45** and **47** engage latches **46** which retain the objective tube **11** in its retracted position against the bias of extension spring **28**. Additionally, the cover is maintained in its covered position against the bias of an opening spring (not shown).

When it is desired to convert the camera from its storage or shipping condition into a manner for taking pictures, objective tube **11** must be released such that the tube can be extended to its proper position. Actuation knob **60** which is accessible for manual activation on the outside of the camera housing, forces lever **49** in a direction transverse to the optic axis which also displaces levers **42** and **43** against the force of compression spring **48**. This causes latches **46** to disengage the two indexing pins **45** and **47** releasing the objective tube **11** for extension. The extension spring **28** biases the double rocker **34** which moves objective tube **11** into its extended position while at the same time cover **59** is unlatched to move into its extended position.

Although the invention has been described relative to a specific embodiment thereof, it is not so limited and many modifications and variations thereof will be readily apparent to those skilled in the art in light of the above teachings. It is, therefore, to be understood that, within the scope of the appended claims, the invention may be practiced otherwise then as specifically described.

The preferred embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. A camera including a camera housing, an objective lens having an image axis and a shutter release mechanism, said camera further including:

means for setting a focal range of said camera;

means for mounting said objective lens for movement substantially parallel to said image axis, between an extended exposure position and a retracted storage position;

means for variably limiting axial movement of said mounting means in said extended position;

means, responsive to said range setting means, for varying said limiting means; and

means for variably biasing said mounting means towards said extended position, such that said mounting means is less strongly biased toward said extended position during operation of said varying means and more strongly biased toward each extended position during operation of shutter release mechanism.

2. A camera according to claim **1**, wherein said means for variably biasing is operatively connected to and responsive to said shutter release mechanism for more strongly biasing said mounting means towards said ex-

tended position when said shutter release means is activated.

3. The camera of claim 2, wherein said mounting means comprises a tube with said lens mounted therein, said varying means comprises an annulus surrounding said tube and axially fixed with respect to said housing, said limiting means comprising a projection fixed on said tube and in contact with a cam on said annulus when said tube is in said extended exposure position.

4. The camera according to one of claims 1-3, wherein said means for variably biasing includes locking means for biasing said objective tube towards its extended position, and control linkage means for coupling said locking means to said shutter release means such that said locking means biases said objective tube only during actuation of said shutter release means.

5. The camera according to claim 4 wherein said locking means comprises at least one spring loaded lever, and said mounting means includes at least one abutment pin coacting with said locking means.

6. The camera according to claim 5, wherein said spring loaded lever comprises a lever biased by a spring in a direction transverse to the image axis, said lever including a cam means, coacting with said abutment pin, for biasing said mounting means towards said extended exposure position.

7. The camera according to claim 6, wherein said control linkage means comprises a linkage connected to said lever, said shutter release mechanism including a detent, said linkage located between said shutter release mechanism and said lever and preventing movement of said lever toward said shutter release mechanism beyond a predetermined amount, said linkage permitting said lever to move toward said shutter release mechanism beyond said predetermined amount when said shutter release mechanism is at least partially actuated and said linkage extends into said detent.

8. A camera including a camera housing, an objective lens having an image axis and a shutter release mechanism, said camera further including:

means for setting a focal range of said camera;

means for mounting said objective lens for movement between an extended exposure position and a retracted storage position;

means for variably limiting movement of said mounting means in said extended position;

means for varying said limiting means in response to said range setting means; and

means for biasing said mounting means against said limiting means such that said mounting means is less strongly biased against said limiting means during operation of said varying means and more strongly biased against said limiting means during operation of said shutter release mechanism.

* * * * *

United States Patent [19]

Kawamura et al.

[11] **4,326,783**

[45] **Apr. 27, 1982**

[54] **INTERCHANGEABLE OBJECTIVE LENS SINGLE-LENS REFLEX CAMERA FOCUSING DEVICE**

[75] Inventors: **Kunio Kawamura**, Sakai; **Hiroshi Ueda**, Nara, both of Japan

[73] Assignee: **Minolta Camera Kabushiki Kaisha**, Osaka, Japan

[21] Appl. No.: **247,189**

[22] Filed: **Mar. 24, 1981**

[30] **Foreign Application Priority Data**

Mar. 26, 1980 [JP] Japan 55-39325

[51] **Int. Cl.**[3] **G03B 3/10**; G03B 7/08

[52] **U.S. Cl.** **354/25**; 354/195; 354/198; 354/201; 354/286

[58] **Field of Search** 354/25, 152, 187, 188, 354/195, 201, 286, 198

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Primary Examiner—John Gonzales
Attorney, Agent, or Firm—Wolder, Gross & Yavner

[57] **ABSTRACT**

A single lens reflex camera includes a vertical open topped U-shaped bracket mounted in the camera body below the pentaprism, a forwardly located lens mount separably coupled to an objective lens and pairs of links mutually pivoted between their ends connected between the bracket arms and corresponding edges of the lens mount to support the latter in a fixed orientation for linear longitudinal movement along the camera optical axis. A light tight collapsible conduit extends between the camera body and lens mounts and includes telescoping members with relatively slidable side and bottom walls and an accordian top wall. A rack carrying slide arm projects rearwardly from the lens mount and is engaged by a motor driven gear to longitudinally shift the lens mount. The motor is controlled manually or in response to a focus detecting device and the lens mount may be motor advanced and retracted or motor advanced and spring retracted. The lens diaphragm is automatically stopped down by a camera housed mechanism and diaphragm control information is transmitted from the lens mount to the camera body.

20 Claims, 8 Drawing Figures

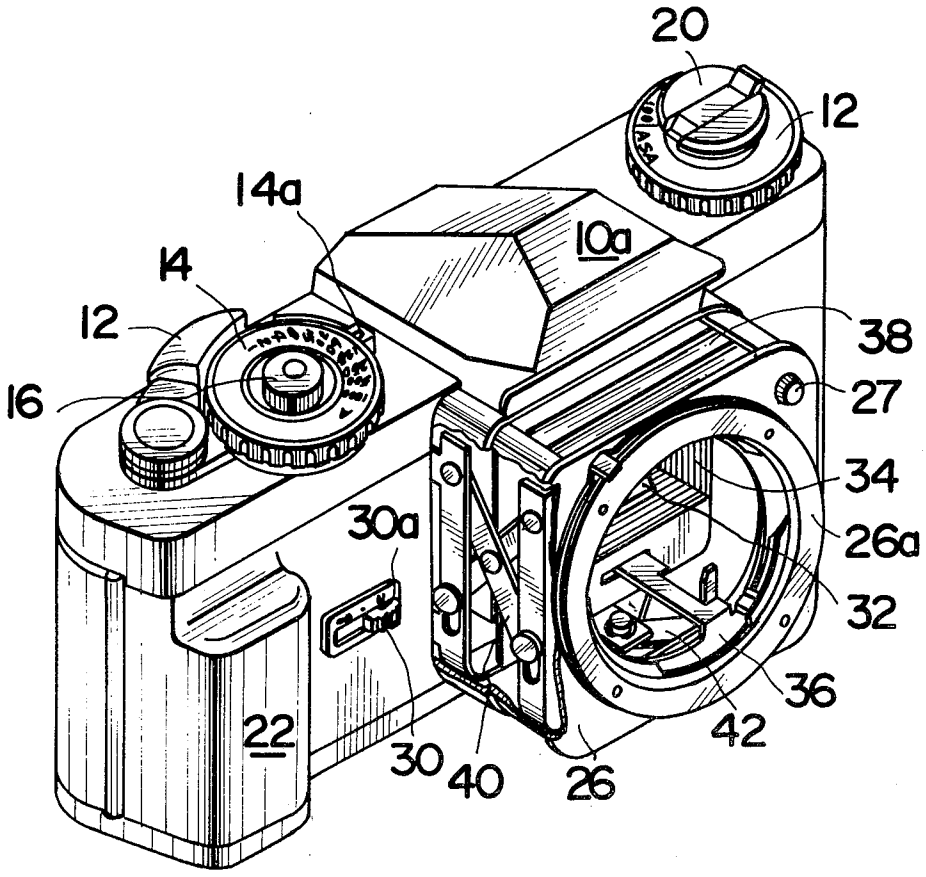

FIG.1

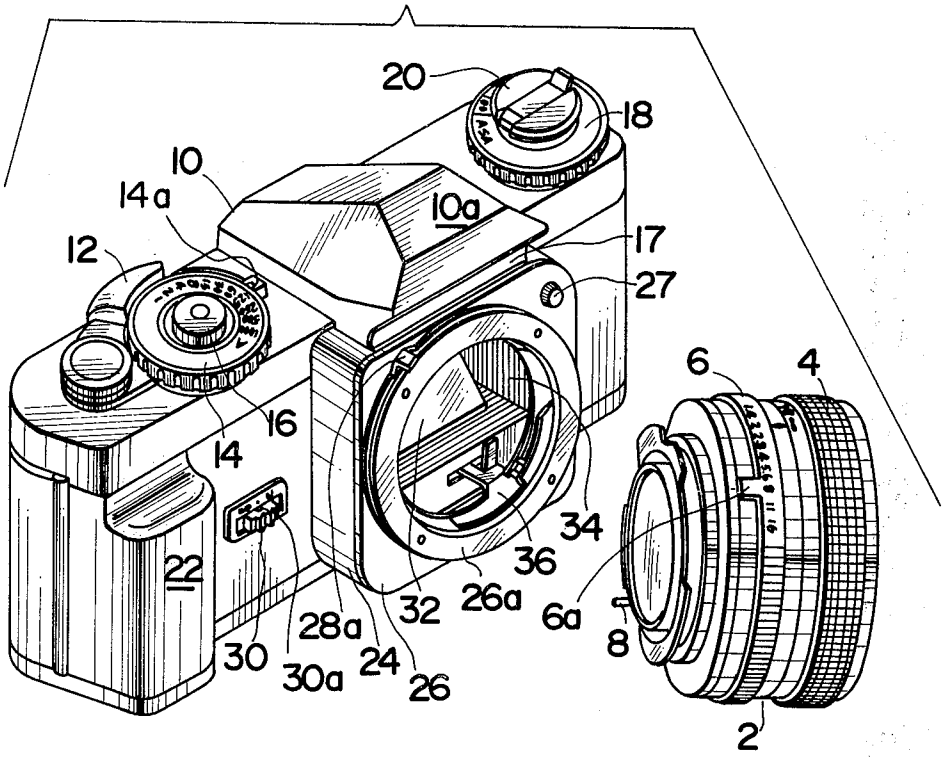
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FIG.2

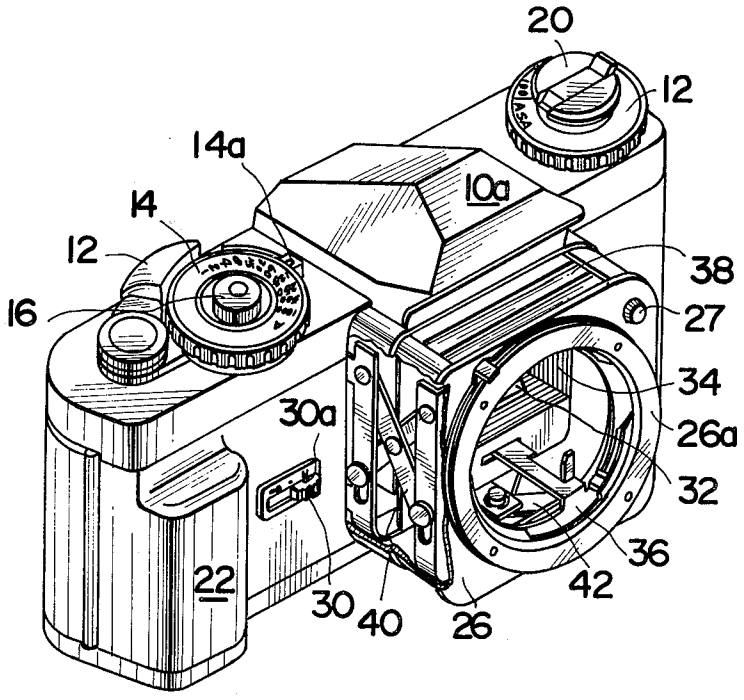
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FIG.3

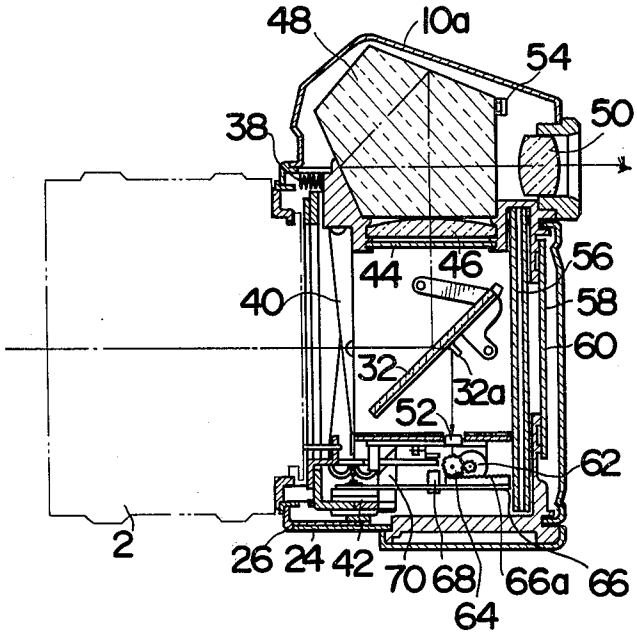
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FIG.4

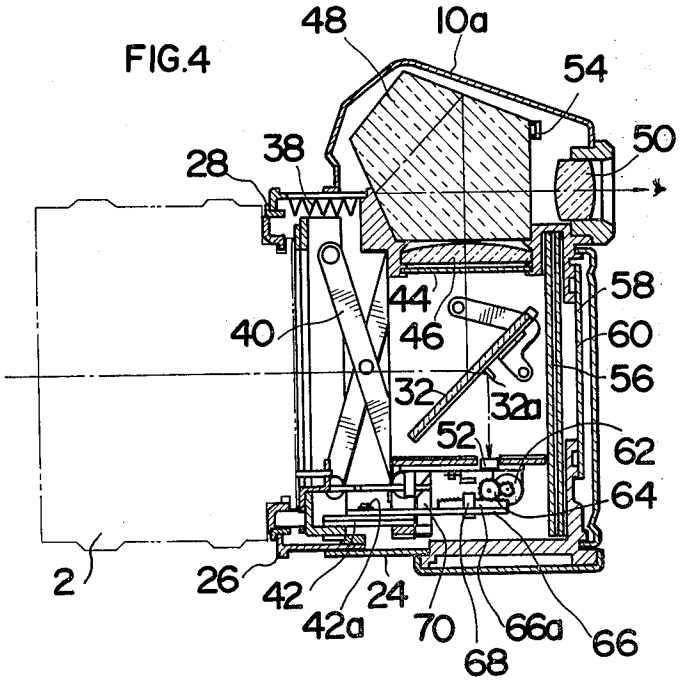
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FIG.5

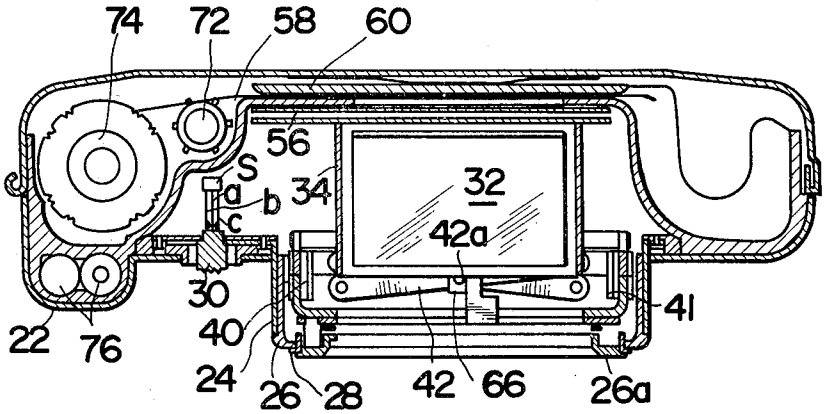
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FIG.6

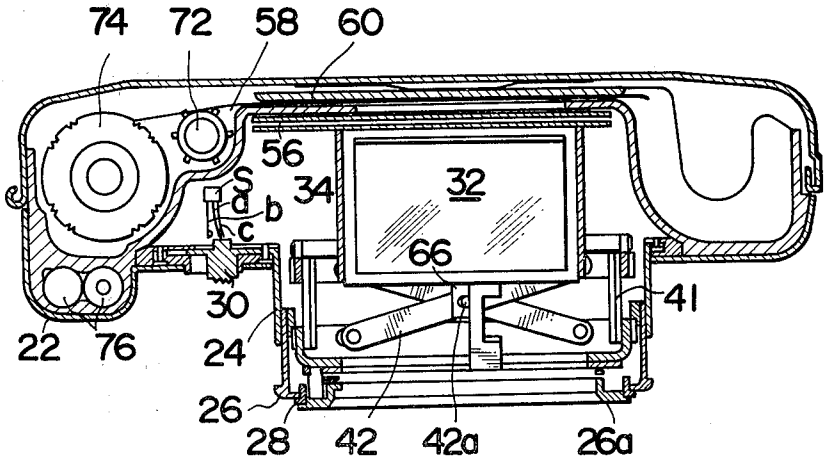
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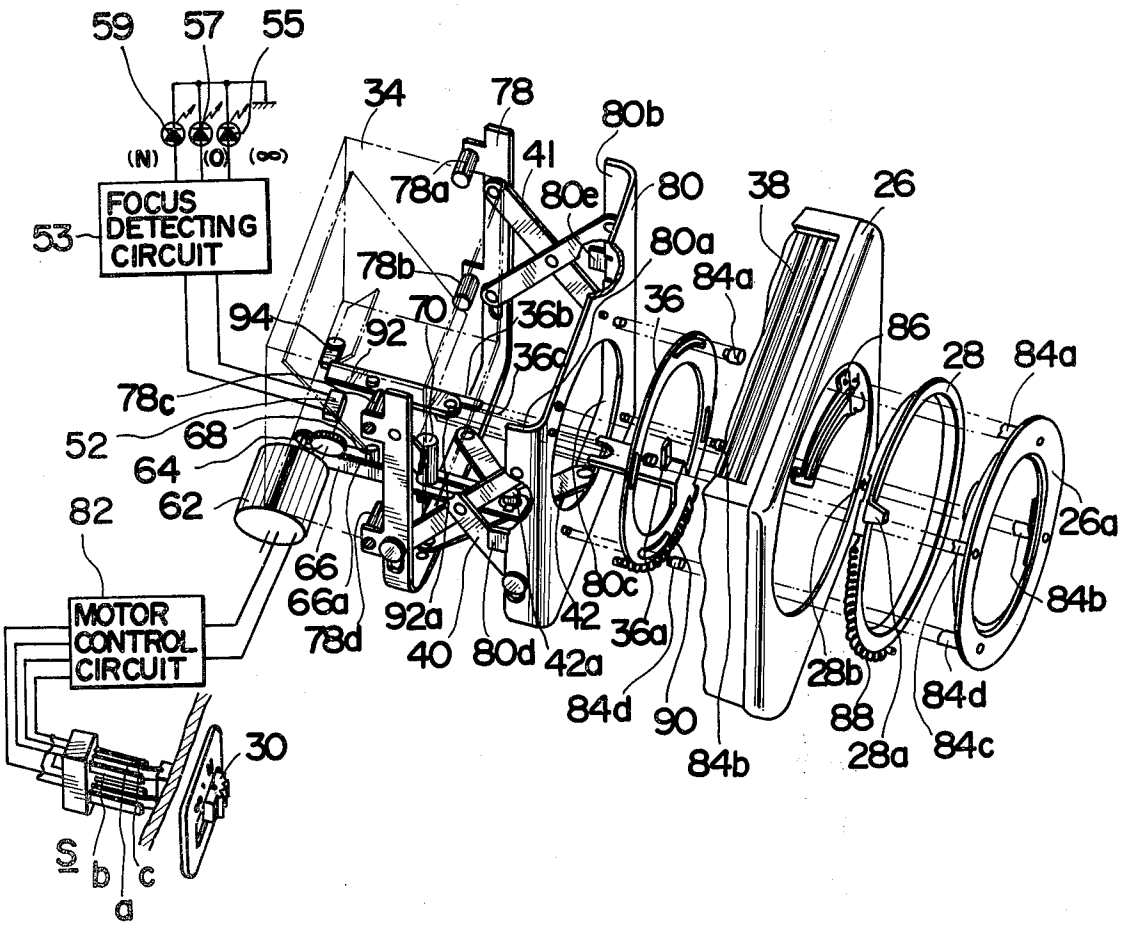
FIG.7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MOTOR CONTROL CIRCUIT
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78
41
80b
78a
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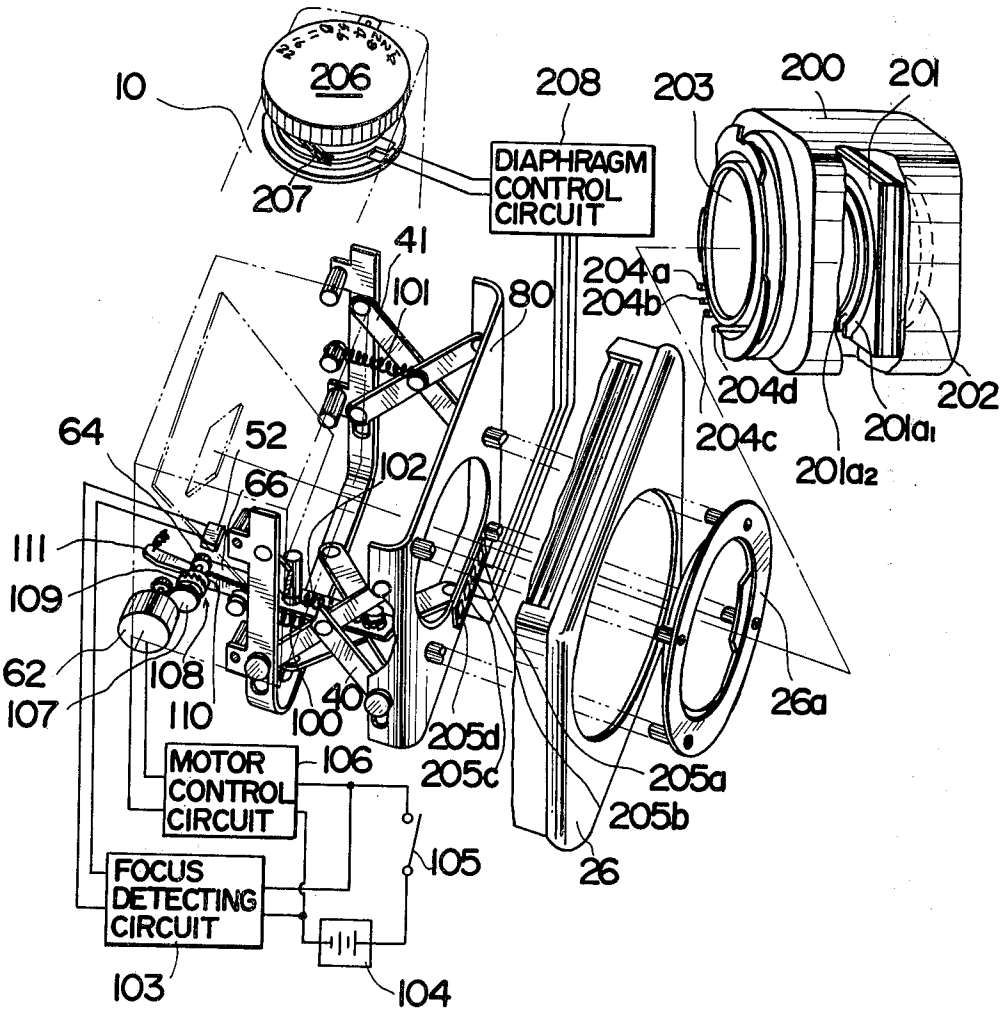
80a
78b
84a
70
36b
36
94
92
86
28
84a
36c
78c
52
68
64
62
26a
66
66a
78d
92a
40
80d
42a
80c
42
36a
84b
84d
90
84b
28b
88
28a
84c
84d

FIG.8


10
206
207
208
DIAPHRAGM CONTROL CIRCUIT
203
200
201
41
101
80
204a
204b
204d
204c
202
201a1
201a2
64
52
66
102
111
109
62
107
108
110
100
40
205d
205c
205a
205b
26
26a
MOTOR CONTROL CIRCUIT
106
105
FOCUS DETECTING CIRCUIT
103
104

INTERCHANGEABLE OBJECTIVE LENS SINGLE-LENS REFLEX CAMERA FOCUSING DEVICE

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates generally to improvements in cameras and it relates particularly to an improved motor focussed, single-lens reflex camera of the interchangeable objective lens type.

In the conventional objective lens exchangeable single-lens reflex cameras, focussing of the objective lens is performed by rotating a focussing ring provided on the objective lens barrel. However, when an automatic focussing device is incorporated in the single-lens reflex camera and a drive device such as an electric motor controlled by the automatic focussing device is used to rotate the focussing ring for focussing an objective lens, it is almost impossible to control the focus of all types of objective lenses, since the distance between the focussing and the camera body varies with the type of objective lens, as does the force required for rotating the focussing ring. Even if, in such type of camera, it is possible to automatically control the focus of all types of objective lenses a complex interlocking mechanism must be provided, thereby posing the problem of an appreciable increase in the size and price of the camera. In an attempt to solve this problem, there has been proposed a device in which an entire objective lens is longitudinally moved along the camera optical axis for controlling focus (U.S. Pat. No. 3,798,660 granted Mar. 19, 1979). With such device, however, the lens mounting member of the camera to which the exchangeable objective lens is mounted, is supported by a ring rotated by a motor within the camera and the rotatable ring itself serves as a guide member therefor, or the lens mounting member is restricted to movement along the optical axis by a guide pin fixed to the camera body. As a result, the length of the available lens shift is greatly limited, posing a further problem. Increasing the length of the available lens shift in such a device requires that the length of a rotatable ring supporting the lens mounting member be increased along the optical axis or that the guide pin be lengthened. However, such increase in size results in a larger camera body, causing much inconvenience. Consequently, the devices heretofore proposed possess the drawback that the length of available lens shift cannot be increased without an increase in the camera size.

Furthermore, with the earlier structures, a lens mounting member on which an exchangeable objective lens is mounted is formed as a cylindrical member, part of which is positioned near the viewer penta prism. In addition, the lens mounting member and its support must be thick and sturdy enough to withstand the weight of an exchangeable objective lens which is coupled to the lens mounting member, thereby necessitating the provision of a large space near the penta prism. Therefore, the earlier structures have the lens mounting member and the supporting member therefore assembled near the camera viewer penta prism, the design freedom of which is greatly impeded in terms of the penta prism arrangement.

SUMMARY OF THE INVENTION

It is a principal object of the present invention to provide improved single lens reflex camera focussing mechanism.

Another object of the present invention is to provide an improved focussing mechanism in an interchangeable objective lens single-lens reflex camera with which focussing is effected by moving the entire objective lens along its optical axis.

Still another object of the present invention is to provide an improved focussing mechanism in which an increase in the length of the available lens shift along the optical axis is achieved without any increase in the size of the camera body.

A further object of the present invention is to provide a focussing mechanism which includes almost none of its component parts near the camera pentaprism thereby permitting freedom of design without interfering with the pentaprism arrangement.

Still a further object of the present invention is to provide a mechanism of the above nature characterized by its reliability, ruggedness, ease and efficiency of operation, minimum space consumption, low cost and great versatility and adaptability.

The above and other objects of the present invention will become apparent from a reading of the following description taken in conjunction with the accompanying drawings which illustrate a preferred embodiment thereof.

A single lens reflux camera in accordance with the present invention comprises a body member having a front aperture and a pentaprism, an apertured mounting member having coupling means for separably engaging an interchangeable objective lens, a pair of laterally spaced longitudinally extendable retractable support members extending between the body member and mounting member and supporting the mounting member for longitudinal movement only at a fixed orientation, an extendable collapsible light tight conduit extending between the mounting and body members in registering with the apertures therein and control motor means in said body member for longitudinally advancing and retracting the mounting member.

In accordance with a preferred form of the improved camera a laterally extending U-shaped bracket is affixed to the body member and includes a bottom cross arm and side arms in opposite sides of the body member front aperture and is open at its top and the mounting member comprises a plate with a bottom and vertical side flanges. Each of the support members comprises a pair of levers or links mutually pivoted intermediate their ends and each lever being pivotally connected at its ends to the bracket side and bottom arms and to a mounting plate flange respectively, one end of each lever being vertically slidably coupled to the bracket side arm or mounting plate flange. The control motor means includes a motor controlled in response to a manual switch or a focus detecting network and coupled to the mounting plate by a motion translator defining rack and gear arrangement.

The improved focussing mechanism permits a wide range of axial movement of the mounting plate coupled objective lens without interfering with the camera components, including the pentaprism, requires no increase in the size of the camera, is reliable, rugged and efficient and is of great versatility and adaptability.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a perspective view of a camera embodying the present invention, and illustrated with the objective lens separated;

FIG. **2** is a partially fragmented, perspective view of the camera shown in FIG. **1**, illustrated in a lens mount extended position;

FIG. **3** is a vertical axial longitudinal sectional view of the camera shown in FIG. **1**;

FIG. **4** is a vertical axial longitudinal sectional view of the camera shown in FIG. **2**;

FIG. **5** is a horizontal cross-sectional view of the camera shown in FIG. **1**;

FIG. **6** is a horizontal cross-sectional view of the camera shown in FIG. **2**;

FIG. **7** is an exploded perspective and diagrammatic view of the essential parts of the embodiment of FIG. **1**; and

FIG. **8** is an exploded perspective and diagrammatic view illustrating only the essential parts of another embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to the drawings, particularly FIGS. **1** to **7** thereof which illustrated a preferred embodiment of the present invention, the reference numeral **2** generally designates an objective lens which is equipped with a focussing ring **4**, diaphragm setting ring **6**, a transmission lug **6***a* extending rearwardly from diaphragm setting ring **6** for the transmission of a diaphragm aperture value preset by manually operating diaphragm setting ring **6**, and a diaphragm preset pin **8**.

A camera body **10**, to which objective lens **2** is replaceably mounted, includes a pentaprism portion **10***a*, a film advancing lever **12**, a shutter speed setting dial **14**, a shutter release button **16**, a film speed setting dial **18**, a rewind knob **20** and a cell chamber **22** which also serves as a hand grip. Displayed on the top surface of shutter speed setting dial **14** is a scale of numerals corresponding to shutter speed and a mark "A" for automatic shutter speed control. With a numeral on the scale set to index **14***a*, a shutter mechanism (not shown) operates at a shutter speed corresponding to the set numeral. With mark "A" set to index **14***a*, photography in a diaphragm priority automatic shutter speed control mode is established. Moreover, provided beneath pentaprism portion **10***a* at the front of camera body **10**, is a fixed housing **24**, which is connected through a link assembly to a lens mount **26**, on which objective lens **2** is interchangably mountable, as shown in FIG. **2**. Lens mount **26** is box shaped and open at its rear and top and slidably telescopes into fixed housing **24** and includes rearwardly projecting bottom and side walls at the rear of lens mount **26** which extend along inside the bottom and sides of fixed housing **24**, the inner surfaces thereof overlapping the outer surfaces of lens mount **26**. The top surface of lens mount **26** is connected to fixed housing **24** by means of an accordion wall or collapsible bellows **38**, so that lens mount **26** is joined to fixed housing **24** for external light shielding even when moved along the optical axis. Mounted on the front wall of lens mount **26** are flange ring or annulus **26***a* of lens mount **26**, lens-lock release button **27** which unlocks an objective lens when it is to be removed, and transmission ring **28** with interlocking lug **28***a* which interlocks with transmission lug **26***a* when objective lens **2** is mounted on lens mount **26** to thereby transmit the diaphragm aperture value preset by the objective lens to mechanism in the camera body **10**.

A changeover switch **30** is arranged on the front face of camera body **10** and is manually operable and connected and designed to energize a motor, as hereinafter described, for shifting lens mount **26** along the optical axis when index **30***a* on switch **30** is set to a mark "N" and for retracting lens mount **26** along the optical axis when index **30***a* is set to mark " ". When index **30***a* is set to mark ".", the motor is stopped to cease the movement of lens mount **26**. FIG. **1** shows the condition of lens mount **26** in its fully retracted position along the optical axis.

Disposed within the camera body **10** are a movable mirror **32**, a mirror box **34** and a diaphragm preset ring **36**. Diaphragm preset ring **36** is movable along the optical axis integrally with lens mount **26** so that it is maintained in engagement with diaphragm preset pin **8** of objective lens **2**, when lens mount **26** is shifted to any position within its overall range of shifting along the optical axis. Diaphragm preset ring **36** is rotated clockwise in response to the shutter release operation to permit the rotation of preset pin **8** which is urged to follow diaphragm preset ring **36** and to stop down the diaphragm mechanism.

FIG. **2** shows the condition of lens mount **26** advanced along the optical axis from its fully retracted position as shown in FIG. **1**. Referring to FIG. **2**, the contractable bellows or accordian wall **38** connects fixed housing **24** and lens mount **26** for external light shielding, the bellows being provided only on the top side thereof. The bottom and sides of the bellows or contractable conduit are defined by the fixed housing **24** and lens mount **26** which overlap for external light shielding. Consequently, even when lens mount **26** is shifted along the optical axis, as described later, fixed housing **24** and lens mount **26** are always connected together to shield external light, a light tight expandable chamber being established between housing **24** and lens mount **26**. X-shaped link assemblies **40**, **41** and **42**, as best seen in FIG. **7**, are provided between fixed housing **24** and lens mount **26**, and are longitudinally expandable or extendable along the optical axis, each link assembly moving in a plane parallel to the optical axis. These link assemblies are provided on the bottom and sides of fixed housing **24**, not on the top side thereof, i.e., not near pentaprism portion **10***a* since this would restrict or limit the positioning of the pentaprism, due to the provision of a link assembly on the top side. It is to be noted that although link assemblies provided on the bottom and one side alone are sufficient, their provision along three quadrilateral surfaces, as in the present embodiment, increase the over rigidity and strength of the structure.

With reference to FIGS. **3** and **4** which show the lens mount **26** in its fully retracted and advanced positions respectively, a light transmitting portion is formed in the center of movable mirror **32**, on the rear of which is mounted an auxiliary mirror **32***a* for rotation therewith. With this construction, scene light passing through objective lens **2** is reflected on movable mirror **32** and is directed toward a viewfinder optical system comprising focussing screen **44**, condenser lens **46**, pentaprism **48** and eyepiece **50**. Part of the scene light is transmitted through the center of movable mirror **32** and is reflected by auxiliary mirror **32***a*, and is directed toward a light receiving element **52** arranged at a position optically equivalent to the film surface for the detection of the

focus condition. A light sensing or responsive element **54** for automatic exposure control is arranged at the upper rear face of pentaprism **48**. Also shown in the drawings are shutter mechanism **56**, film **58** and film pressure plate **60**. The focus condition of objective lens **2** is detected by light responsive element **52** for the detection of focussing and is indicated within a viewfinder. As shown in FIG. **7**, the output signal of light responsive element **52** is transmitted as an input to a focus detecting circuit **53**, which detects an in-focus or out-of-focus condition which is displayed by LEDs **55**,**57** and **59** provided inside the viewfinder. When, in the case of the present embodiment, objective lens **2** is focussed closer than an object to be photographed, LED **55** is energized when the lens is focussed at a greater distance than the object, LED **59** is energized and when the object is in proper focus, LED **57** is energized.

A motor **62** is selectively rotated in forward and reverse directions when changeover switch **30** is correspondingly manually operated. Motor **62** which is mounted in the camera body is connected through a pinion and gear **64** to a rack portion **66***a*, a slide or drive arm or lever **66**. Slide arm **66** is restricted to only longitudinal movement parallel to the optical axis by a guide pin **68** carried by mirror box **34** and a guide shaft **70** slidably engaging an elongated longitudinal slot in side arm **66**, as hereinafter described. Formed at the rear of side arm **66** is rack portion **66***a*, and the front end of side arm **66** is connected to the central connecting pivot **42***a* of link assembly **42**. With the above construction, motor **62** is rotated to advance or retract slide arm **66** along the optical axis, whereby link assemblies **42**, **40** and **41** are respectively expanded or contracted, so that lens mount **26** is correspondingly shifted along the optical axis under the guidance of the link assemblies.

As shown in FIGS. **5** and **6** which illustrate lens mount **26** in its fully retracted and advanced positions respectively, a sprocket **72**, a spool **74** and a cell **76** are housed in and proximate grip **22**. Cell **76** is a power supply source for motor **62** to move lens mount **26**. A switch S is electrically transferred by manually operated changeover switch member **30**, and is provided with one movable contact piece a and two fixed contact pieces b and c. When index **30***a* of changeover switch **30** shown in FIGS. **1** and **2** is set to mark " ", contact pieces a and b of switch S are inter-engaged to deliver power from cell **76** to motor **62**, which is thus driven to retract lens mount **26** along the optical axis to the condition shown in FIG. **5**. On the other hand, when index **30***a* is set to mark "N", contact pieces a and c of switch S are inter-engaged, energizing motor **62** to rotate in the reverse direction, whereby lens mount **26** is shifted along the optical axis toward its forwardmost position.

As best seen in FIG. **7**, a fixed mounting frame **78** is secured to mirror box **34** by four inwardly directed pins **78***a* through **78***d*, and is of open topped approximately U-shaped configuration with a lateral bottom cross arm and vertical laterally spaced side arms laterally offset from the pentaprism. Furthermore, provided between fixed frame **78** and mirror box **34** is guide pin **70**, engaging and guiding slide arm **66**. Guide pin **70** also serves as a fastener to secure fixed frame **78** to mirror box **34**. The respective side and bottom arms of fixed frame **78** are connected with the ends of the individual link bars in X-shaped link assemblies **40**, **41** and **42** which are all expandable and contractable in directions parallel to the optical axis. A movable vertical rectangular base plate **80** is provided with a central circular opening and is provided along its side and bottom edges with rearwardly directed flanges **80***a*, **80***b* and **80***c*, to which the other ends of the link bars in the link assemblies are connected, respectively. In other words, the other ends of the link bars or levers of link assembly **40** are rotatably connected to flange **80***a*, those of link assembly **41** to flange **80***b* and those of link assembly **42** to flange **80***c*, respectively. Furthermore, formed on flanges **80***a*, **80***b* and **80***c* are rearwardly projecting tabs **80***d* and **80***e* and a tab **80***f* (not shown), to which lens mount **26** is bonded or secured by screws. Fixed to central connection pivot **42***a* of link assembly **42** is the front end of slide arm **66** which is longitudinally slidable parallel to the optical axis. When motor **62** is energized and driven through control circuit **82** by the manual operation of changeover switch **30**, slide arm **66** is longitudinally moved parallel to the optical axis, whereby link assembly **42** is longitudinally expanded or contracted parallel to the optical axis, and link assemblies **40** and **41** are also expanded or contracted in directions parallel to the optical axis.

Another flange member **26***a* is secured to four fastener pins **84***a* through **84***d* projecting forwardly from movable base plate **80**.

Provided between flange member **26***a* and movable base plate **80** are transmission ring **28**, sliding resistor element **86** described hereinafter, lens mount **26** and diaphragm preset ring **36**. Transmission ring **28** is rotatably supported between flange member **26***a* and lens mount **26**, and is biased counterclockwise by a spring **88**. Interlocking lug **28***a* formed on transmission ring **38** press engages transmission lug **6***a* of objective lens **2**, as shown in FIG. **1**, whereby the angular position thereof is set. In addition, a sliding brush **28***b* is fixed to and projects rearwardly from ring **28**, and is in slidable engagement with sliding resistor element **86** fixed to movable base plate **80**. With the above construction, rotated angular the position of transmission ring **28** is set depending on the rotated angular position of the diaphragm ring of objective lens **2**, and in response thereto, a positional relationship is set between sliding brush **28***b* and sliding resistor **86**, whereby the present aperture value information of the objective lens is transmitted to an exposure control circuit (not shown) in the camera body in the form of a resistance responsive signal.

Diaphragm preset ring **36** includes four circumferentially spaced peripheral slots respectively slidably engaged by pins **84***a* through **84***d*. Accordingly, diaphragm preset ring **36** is rotatable for the length of the peripheral slots, and is biased in a clockwise direction by a spring **90**. Formed on diaphragm preset ring **36** is a rearwardly offset radially inwardly projecting lug **36***a* positioned so that it is engaged by diaphragm preset pin **8** of objective lens **2**, when objective lens **2** shown in FIG. **1** is mounted on lens mount **26**. Furthermore, diaphragm preset ring **36** is provided with arm **36***b* supporting tab **36***a* and extending rearwardly parallel to the optical axis, and a longitudinal slot **36***c* is formed in arm **36***b*. Slidably engaging longitudinal slot **36***c* is a pin **92***a* provided at the end of a diaphragm preset lever **92**, the movement of which is controlled by a well-known diaphragm preset mechanism (not shown) located inside camera body **10**. The lengths of arm **36***b* and slot **36***c* of diaphragm preset ring **36** are set so that follower pin **92***a* of diaphragm preset lever **92** engages slot **36***c* within the overall range of longitudinal movement of lens mount **26**. A stop lever **94** engages diaphragm pre-

set lever **92**, to prevent the rotation thereof and disengages lever **92** in response to the shutter release operation to release the diaphragm preset lever from its stop condition, thereby allowing it to be rotated. With the above construction, the diaphragm of an objective lens is aperture presettable in the overall movable range of lens mount **26** by means of the diaphragm preset mechanism provided inside a camera body. Lens mount **26** is secured to tabs **80***d*, **80***e* and **80***f* of movable base plate **80**.

Considering now the operation of the improved mechanism described above, with the objective lens **2** being mounted on lens mount **26** of camera body **10** and being focussed at infinity, the lens mount **26** is fully retracted along the optical axis as shown in FIGS. **1**, **3** and **5**. Under this condition, the objective lens is in focus when an object is located at infinity, and this condition is indicated in the viewfinder by the illumination of LED **57**. Moreover, under the aforesaid condition, the objective lens is out of focus on an object at a close distance, and this is observed in the viewfinder with the illumination of LED **59**. While looking through the viewfinder, a photographer sets index **30***a* of changeover switch **30** to mark "N". This energizes and drives motor **62** to expand or extend link assemblies **40**, **41** and **42**, whereby lens mount **26** with objective lens **2** mounted thereon is guided and advanced by the link assemblies along the optical axis. While observing the focus condition displayed inside the viewfinder, the photographer sets index **30***a* of changeover switch **30** to mark "." when objective lens **2** is focussed on a desired object, i.e., when LED **57** lights up. This stops motor **62** and any further movement of lens mount **26** whereby their stop and focussed condition is maintained.

When lens mount **26** is at a forward position and the focussing position of objective lens **2** is set at a greater distance than that of the desired object, LED **55** lights up inside the viewfinder, advising the photographer to retract lens mount **26** along the optical axis by setting index **30***a* of changeover switch **30** to mark " ". Thus, the focussing position of objective lens **2** is retracted toward the camera, and when it corresponds to the distance of the desired object, LED **57** momentarily illuminates to indicate the in-focus condition. At this time, the photographer sets index **30***a* of changeover switch **30** to mark "." to stop the movement of objective lens **2**.

With shutter release button **16** then depressed, the diaphragm of objective lens **2** is stopped down to the preset diaphragm aperture value by means of a diaphragm preset mechanism, movable mirror **32** and auxiliary mirror **32***a* are retracted outside the photographic optical path, and thereafter shutter **56** is opened for the time set by shutter speed setting dial **14**. With mark "A" on shutter speed setting dial **14** set to index **14***a*, diaphragm aperture information on objective lens **2** set by sliding resistor **86** and ring **28**, film speed information set by film speed setting dial **18** and the light measurement information output at light responsive element **54** are transmitted as inputs to an automatic exposure control circuit, and the exposure time is controlled by the automatic exposure control circuit.

Thus, in accordance with the embodiment of the present invention described above, focusing of objective lens **2** may be performed without using focusing ring **4**, and focus control changeover switch **30** is arranged near shutter release button **16**, thus allowing focusing and shutter release operations to be accomplished with one hand. In addition, all mechanisms necessary for focusing can be assembled into a camera body, and no focusing interlocking mechanism between the camera body and objective lens is required, resulting in a simple, inexpensive construction. Moreover, according to the present embodiment, the flange back of a camera is changeable by shifting lens mount **26** forward, whereby the closest photographic distance of an objective lens is further shortened by setting the shift of lens mount **26** to an appropriate length to make close-up photography without the use of an extension bellows or close-up ring. In addition, link assemblies **40**, **41** and **42** are simple and compact in construction, yet strong enough to withstand high external forces, thereby assuring the movement and positioning of objective lens **2** along and coaxial with the optical axis. At the same time, the link assemblies require a minimum of applied force for their expansion and contraction and are capable of guidance over great lengths thereby minimizing the required output of the drive device such as a motor, whereby shifting over a longer length is efficiently achieved.

It should be understood that while the mechanism of the present embodiment is constructed such that the drive device is driven in response to a manual operation to control the movement of the objective lens, the present invention is not limited thereto, and the drive device may be automatically controlled by a focus detection device. In this latter case, there are numerous known methods and devices available for focus detection. These include a method utilizing the space frequency of an image formed by an objective lens, that utilizing contrasts, that utilizing a split image, that utilizing the phase difference between the outputs of two light receiving elements disposed symmetrically to the optical axis behind the plane optically equivalent to the film plane by scanning such planes vertically to the optical axis using a grid or the like.

When, moreover, a focus detection method detects a direction in which an objective lens may be moved for focusing a desired object, the rotation direction and speed of motor **62** are controllable based on the output of the focus detection device. With the above construction, changeover switch **30** may be connected and employed as the main switch of the focusing mechanism. Furthermore, when the main switch is constructed and associated such that it is closed upon depression of shutter release button **16**, focusing and photography are initiated by shutter release button **16**, thereby requiring that shutter release button **16** only be depressed by a photographer.

In addition, with the present embodiment, lens mount **26** is shifted forwardly and rearwardly along the optical axis in response to the forward and reverse rotations of motor **62**. However, the improved mechanism may be so construed that link assemblies **40**, **41** and **42** are biased toward their contracted conditions by springs, against whose influence lens mount **26** is shifted forward by the drive device, such as a motor, and lens mount **26** is retracted to its fully retracted position under the action of the springs after its disconnection from the drive devices.

FIG. **8** illustrates another embodiment of the present invention, in which the above construction is achieved. The same reference numbers are used for members corresponding to those in the first embodiments in order to simplify the description. Springs **100**, **101** and **102** are provided between the camera body and the respective

pivoted intersecting point of paired link bars constituting each of the link assemblies **40**, **41** and **42**. These link assemblies are biased by springs **100**, **101** and **102** in the direction of their contraction. In the present embodiment, an automatic focusing mechanism is provided for automatically focusing objective lens **200**. The automatic focusing mechanism includes light receiving element **52**, focus detection circuit **103**, power supply source **104**, start switch **105**, motor control circuit **106** and motor **62** connected as illustrated. Motor control circuit **106** supplies power to rotate motor **62** when start switch **105** is manually closed externally of the camera, and cuts off power when receiving an in-focus signal from focus detection circuit **103** to thereby stop motor **62**. On the other hand, focus detection circuit **103** receives a signal from light receiving element **52** to detect an in-focus or out-of-focus condition of objective lens **200**, and sends an in-focus signal to motor control circuit **106** when objective lens **200** is focused on a desired object. Drive gear **107** drive coupled to motor **62** is connected through a one-way clutch mechanism **108** to gear **64**. Clutch mechanism **108** includes a first clutch gear or member **109** connected to drive gear **107** and second clutch gear or member **110** connected to gear **64**, second clutch gear **110** being axially movable together with gear **64** and biased by a spring (not shown) into engagement with first clutch gear **109**. Clutch mechanism **108** is constructed such that it transmits only the one-way rotation of drive gear **107**, i.e., only the counterclockwise rotation of drive gear **107** under the present embodiment, to gear **64**. A clutch control lever **111** is rotated counterclockwise by an exposure completion signal, e.g., a signal responsive to the completion of travel of the trailing shutter curtain in the case of focal-plane shutter camera, and is reset to the position shown in FIG. **8** in response to the film advance operation.

With the above construction, focusing is enabled by the external manual closing of start switch **105** first to be closed manually and when start switch **105** is closed, drive motor **62** is energized and rotates drive gear **107** counterclockwise, which rotation is transmitted through clutch mechanism to gear **64**, causing rack carrying slide arm **66** engaged therewith to be shifted along the optical axis. As slide arm **66** is shifted forwardly, link assemblies **40**, **41** and **42** are expanded, causing lens mount **26** to be linearly shifted along the optical axis at a fixed vertical orientation. On the other hand, focus detection circuit **103** detects the in-focus or out-of-focus condition by a signal from light receiving element **52** during the shift of objective lens **200**, and generates an in-focus signal when objective lens is focussed on a desired object. With the input of an in-focus signal, motor control circuit **106** interrupts the supply of power to drive motor **62**, which, in turn, stops. Upon the shutter being released when the infocus condition is reached, the film is exposed in the well-known manner, and after exposure with a lapse of a predetermined period of time, clutch control lever **111** is swung counterclockwise by a mechanism (not shown). With clutch control lever **111** swung counterclockwise, gear **64** is retracted to a position out of engagement with rack portion **66***a* of slide arm **66**. In addition, second clutch gear **110** formed integrally with gear **64** is moved to a position where it is disengaged from first clutch gear **109**. With these clutches thus disengaged, the link assemblies are immediately contracted under the action of springs **100**, **101** and **102**, respectively, and lens mount **26** is rapidly shifted to its fully retracted position along the optical axis. With the film advance operation, clutch control lever **111** is rotated clockwise to reset gear **64** and second clutch gear **110** to the positions shown in FIG. **8** in readiness for focusing in the above manner.

It is to be noted that a camera in accordance with the last described embodiment uses an objective lens **200** equipped with an electrical diaphragm mechanism unlike the camera according to the first embodiment. That is, objective lens **200** is provided with a common transparent electrode and ring-shaped transparent electrodes **201***a*$_1$, **201***a*$_2$ . . . **201***an*, each different in diameter and being concentrically arranged to overlap each other. Liquid crystal plate **201** is disposed between lenses **202** and **203**, and pins **204***a*, **204***b*, **204***c* and **204***d* electrically connected to these transparent electrodes, respectively, projected rearwardly from the rear edge of the lenses. On the other hand, movable base plate **80** is provided with contact pieces **205***a*, **205***b*, **205***c* and **205***d* which engage respective pins **204***a*, **204***b* **204***c* and **204***d* when objective lens **200** is mounted on lens mount **26**.

A diaphragm setting dial **206** is rotatably mounted on camera body **10**, and the brush **207** of a slide resistor is connected thereto. A diaphragm control circuit **208** is arranged to actuate a corresponding number of contact pieces **205***a* through **205***d* in response to the adjusted resistance value of the slide resistor. Moreover, the diaphragm control circuit receives an exposure termination signal and a shutter release signal, thereby actuating the preceding contact pieces only when receiving a shutter release signal, and, in contrast, deactuating the contact pieces when receiving an exposure termination signal.

Consequently, when the shutter is released with objective lens **200** mounted on lens mount **26**, a selected plurality of the specified contact pieces **205***a* through **205***d* are turned on in response to preset position of diaphragm setting dial **206**. When an electrical signal applied to the contact pieces is transmitted as an input to objective lens **200** through signal pins **204***a* through **204***d*, the common electrode and the specified ring-shaped electrodes are energized, whereby the transparent electrodes form opaque rings. As a voltage is sequentially applied to the selected successive ring-shaped electrodes **201***a*$_1$ through **201***an*, the round transparent portion in the center of liquid crystal plate **201** gradually decreases in diameter. This is equivalent to the diaphragm being stopped down.

As described above, the camera of the present invention is constructed such that a lens mount on which an exchangeable objective lens is mounted is supported by expandable and contractable link assemblies on a camera body for shifting along the camera optical axis and the link assemblies are expanded and contracted by drive means provided inside the camera body, whereby the entire mount coupled objective lens is moved for focusing. Consequently, all the component parts required for the focusing mechanisms are assembled in the camera body, and as a result, it is possible to eliminate any special interlocking mechanism which interlocks the camera body and an exchangeable objective lens for focusing, thereby achieving a simple and inexpensive construction. In addition, as the objective lens need only be mounted on the lens mount, conventional interchangeable objective lenses may be employed, including objective lenses equipped with no focusing mechanism. Furthermore, the flange back of a camera is changeable by expanding the lens mount, and thus close-up photography is possible without using any

special attachment for close-up photography, such as bellows or a close-up ring. Furthermore, with the mechanism of the present invention, link assemblies are provided to guarantee that the objective lens shifts along and is maintained coaxial with the optical axis. The link assemblies are simple and compact in construction and sufficiently withstand external forces so that the lens mount ensures the accurate shift of the objective lens parallel to the optical axis. In addition, the link assemblies require a minimum of applied force for expansion and contraction and are capable of guidance over a long distance so that great freedom of drive means and other mechanism design is available.

Moreover, when a drive means is arranged for manual control, manual focusing is possible without turning a focusing ring. With the drive means automatically controlled in response to the output of a focus detection device, the earlier focusing operations are unnecessary.

When a diaphragm control mechanism provided inside a camera body is arranged to control the diaphragm of an objective lens within the overall shift range of the lens mount, the diaphragm of the objective lens is controllable based on the information supplied from the camera, although the objective lens is shifted by the drive means to any desired position.

In addition, when the link assemblies are disposed on the three sides other than that of the pentaprism side, the link assemblies are more durable under external forces so that the construction and positioning of the pentaprism and other camera components are not restricted.

While there have been described and illustrated preferred embodiments of the present invention, it is apparent that numerous alterations, additions and omissions may be made without departing from the spirit thereof.

What is claimed is:

1. A single lens reflex camera including a body member and housed in the upper part of said body member, a pentaprism having a downwardly facing bottom face, comprising a lens mount disposed forwardly of said body member, an objective lens separably coupled to said lens mount coaxially with the optical axis of said body member, a pair of laterally spaced extendable contractable extension members extending between said lens mount and body member and supporting said lens mount for longitudinal linear advance and retraction along said optical axis at a fixed orientation of said lens mount, an extendable contractable light tight conduit extending between said body member and lens mount and means located in said body member and coupled to said lens mount for shifting said lens mount along said optical axis.

2. The camera of claim **1** wherein each of said extension members comprises a pair of links swingably pivoted to each other between their respective ends and swingably connected at their inner and other ends to said body member and lens mount respectively.

3. The camera of claim **2** wherein the inner ends of said links of each pair are swingably connected at a fixed point and a vertically movable point respectively on said body member and the opposite outer ends of said links are swingably connected at a vertically movable point and a fixed point respectively on said lens mounts.

4. The camera of claim **3** wherein said link pairs lie in parallel vertical longitudinal planes and including a third contractable extendable pair of swingably connected links lying in a longitudinal horizontal plane below said vertical link pairs and extending between said body member and lens mount.

5. The camera of claim **3** comprising an open topped, laterally extending vertical U-shaped bracket mounted on said body member below said pentaprism and including a bottom cross arm and vertical side arms, the inner ends of said links being connected to said bracket side arms.

6. The camera of claim **3** wherein said conduit comprises a pair of slidably telescoping open topped peripheral walls of substantially U-shaped transverse cross section extending between said body member and lens mount, and a longitudinally contractable extendable accordian wall extending rearwardly from the upper edge of said lens mount to said body member and sealing the upper part of said conduit against light entry.

7. The camera of claim **6** wherein said link pairs are disposed within said conduit.

8. The camera of claim **1** wherein said lens mount shifting means comprises an electric motor located in said body member and means including rotational translational motion translation means coupling said motor to said lens mounts.

9. The camera of claim **8** wherein said motion translation means comprises: a third extendable contractable extension member extending between said lens mount and body member; a slide arm, one end of which is connected to said third extendable contractable extension member, said slide arm extending rearwardly from said extendable contractable extension member and provided with a rack; and a gear driven by said motor and engaging said rack.

10. The camera of claim **8** comprising means including an externally manually operable switch for selectively energizing said motor to rotate in a forward or reverse direction to respectively advance and retract said lens mount.

11. The camera of claim **8** comprising spring means urging said lens mount to a longitudinally retracted position, manually operable means for energizing said motor to advance said lens mount and means for uncoupling said motor from said lens mount to permit the retraction of said lens mount under the influence of said spring.

12. The camera of claim **8** comprising manually operable means for energizing said motor to longitudinally shift said lens mount means for detecting the focus condition of said objective lens on an object and means responsive to said detecting means for de-energizing said motor when said object is in focus.

13. The camera of claim **8** including means for providing a visual signal indicating the condition of focus of said objective lens on a selected object.

14. A focusing device for an exchangeable lens camera which includes a body provided with a finder optical system and a mirror diagonally located within a photographic optical path for reflecting object light upwardly to said finder optical system, comprising:

a lens support member on which an exchangeable lens is mounted;

first and second similar, linearly longitudinally extendable contractable link assemblies extending between and connected to said lens support member and the camera body, said first link assembly lying in a first plane positioned below said mirror and said second link assembly lying in a second plane normal to said first plane;

an extendable and contractable shielding means extending between and secured to said lens support member and the camera body for establishing a light tight chamber between said lens support member and the camera body;

an externally manually operable switch means;

an electric motor actuated in response to the closure of said switch means; and

drive means connected to said electric motor for moving said lens support member.

15. A focusing device as set forth in claim **14**, further comprising a third linearly longitudinally extendable contractable link assembly extending between and connected to said lens support member and the camera body, said third link assembly lying in a plane parallel to said second plane.

16. A focusing device as set forth in claim **14**, wherein said operable switch means is transferable between alternate respective positions for intercepting the current to said motor, for energizing said motor to rotate in a predetermined direction and for energizing said motor to rotate in a reversed direction.

17. A focusing device as set forth in claim **16**, further comprising a light receiving element disposed in a plane optically equivalent to the camera focal plane, a focus detecting circuit for detecting the focus condition of an image projected onto said light receiving element and means for indicating said focus condition in accordance with an output signal from said focus detecting circuit.

18. A focusing device as set forth in claim **14**, further comprising a light receiving element provided in a plane optically equivalent to the camera focal plane, a focus detecting circuit for detecting a focus condition and providing a predetermined output signal when an image projected onto said light receiving element is in focus, and a motor control circuit for actuating said motor in response to the closure of said operable switch means and deactuating said motor in response to said predetermined output signal.

19. A focusing device as set forth in claim **18**, wherein said drive means includes a clutch mechanism having a first condition drive coupling said motor to said link assemblies and a second condition drive uncoupling said motor from said link assemblies, and further comprising means for urging said link assemblies to one extreme position thereof within the focus of the movement of said link assemblies and a control member for displacing said clutch mechanism from its first to second condition in response to the completion of the exposure by the camera.

20. A focusing device as set forth in claim **14**, wherein said exchangeable lens to be mounted on said lens support member includes a diaphragm mechanism and a movable member connected to the diaphragm mechanism and wherein said exchangeable lens camera includes diaphragm control means for stopping down the diaphragm mechanism in said exchangeable lens through said movable member and further comprising extendable contractable interlocking means for interlocking said control means and said movable member, said interlocking means being movable integrally with said lens support member.

* * * * *

United States Patent [19]

Sato

[11] **4,324,458**

[45] **Apr. 13, 1982**

[54] **TELE-OBJECTIVE LENS WITH A MOVABLE SUB-GROUP FOR FOCUSING**

[75] Inventor: **Yasuhisa Sato**, Kanagawa, Japan

[73] Assignee: **Canon Kabushiki Kaisha**, Tokyo, Japan

[21] Appl. No.: **136,086**

[22] Filed: **Apr. 10, 1980**

Related U.S. Application Data

[63] Continuation of Ser. No. 870,228, Jan. 17, 1978, abandoned.

[30] **Foreign Application Priority Data**

Jan. 20, 1977 [JP] Japan 52-5182

[51] **Int. Cl.**[3] **G02B 9/60**; G02B 9/34

[52] **U.S. Cl.** **350/454**; 350/469

[58] **Field of Search** 350/216, 220, 176, 454-456, 350/469

[56] **References Cited**

U.S. PATENT DOCUMENTS

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Primary Examiner—John K. Corbin
Assistant Examiner—Bruce Y. Arnold
Attorney, Agent, or Firm—Toren, McGeady & Stanger

[57] **ABSTRACT**

A telephoto objective lens consisting of a positive front lens group and a negative rear lens group which is divided into sub-groups, the rear one being movable for focusing and the front one remaining stationary, thereby the weight of the complete objective is minimized. As the front lens group consists of only one positive and only one negative lens element, since the provision for focusing is made at such lens, this objective lens tends to produce aberrations of which the spherical and comatic aberrations are particularly deteriorated. According to the invention, therefore, the frontmost surface and rearmost surface of the front lens group and the rearmost surfce of the movable subgroup are specified in radius of curvature to achieve good stability of correction of the aberrations throughout the focusing range.

7 Claims, 36 Drawing Figures

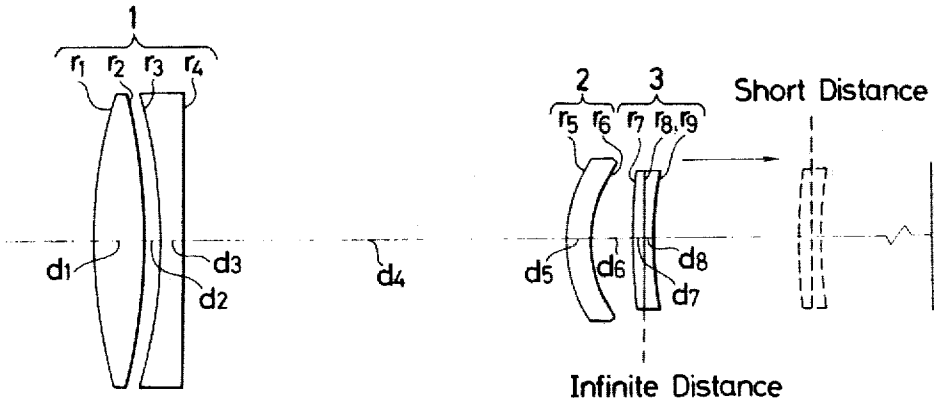

FIG.1

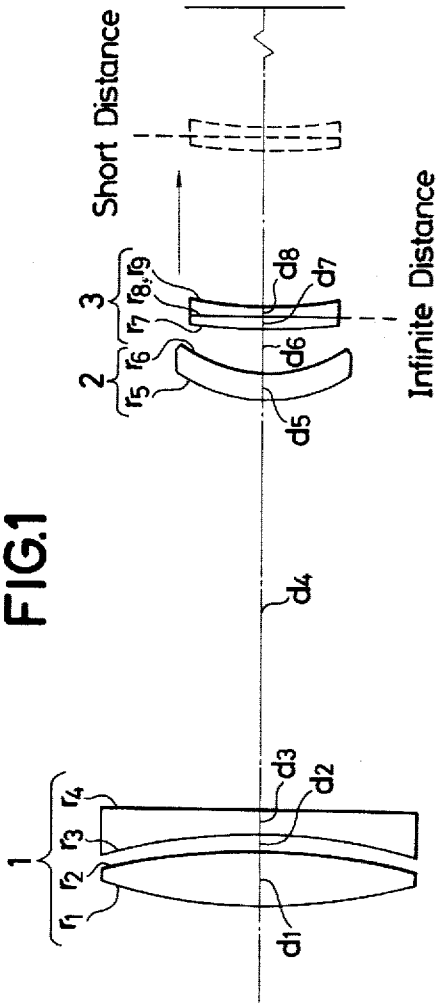
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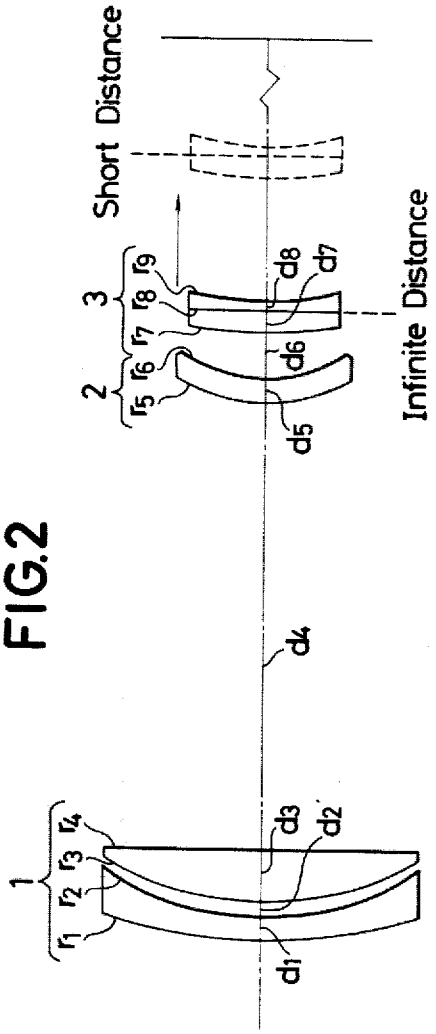
FIG.2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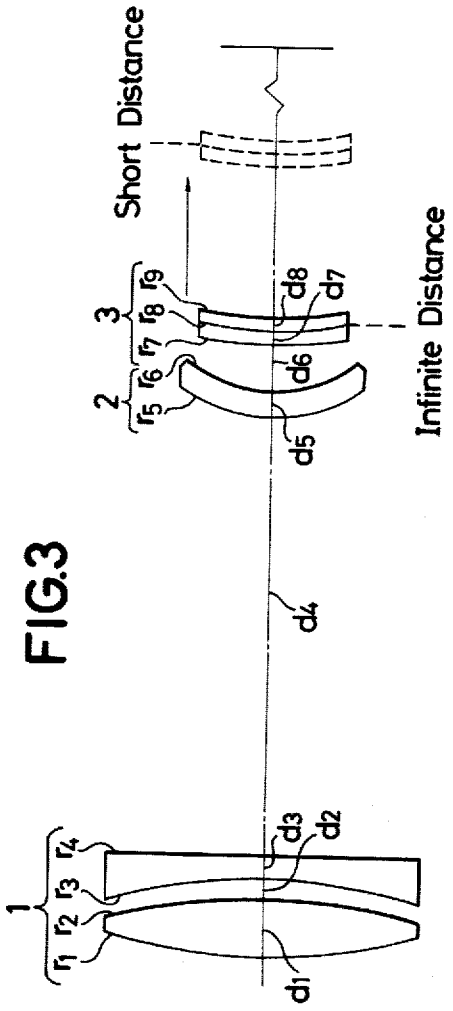
d8

FIG.3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r4
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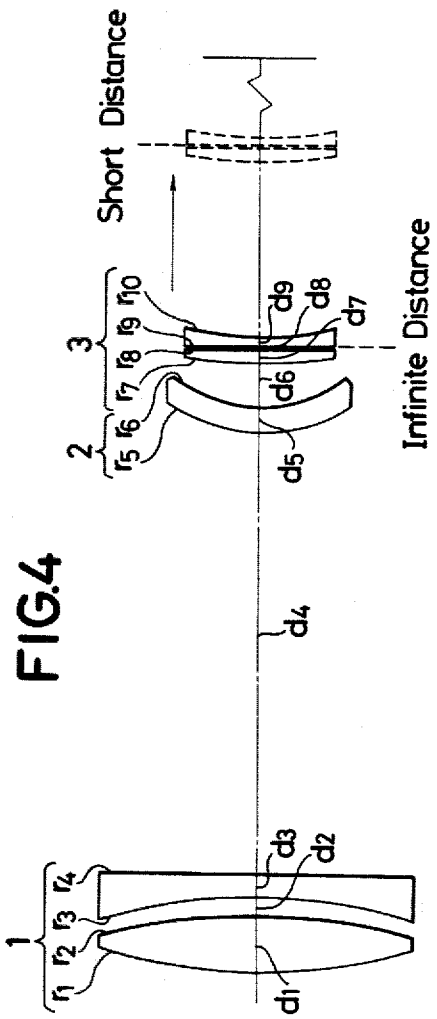
d7
d8

FIG.4


Short Distance
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r5
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d6
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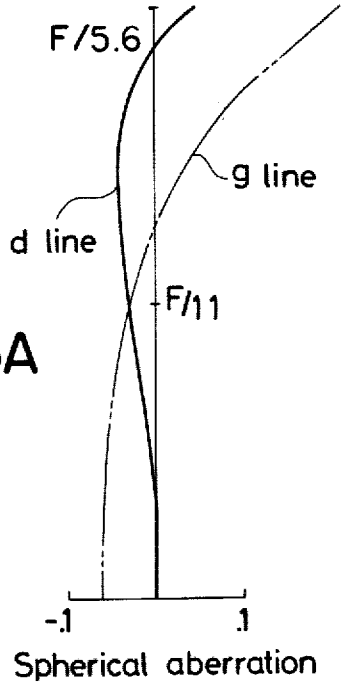
d8
d9

FIG. 5A



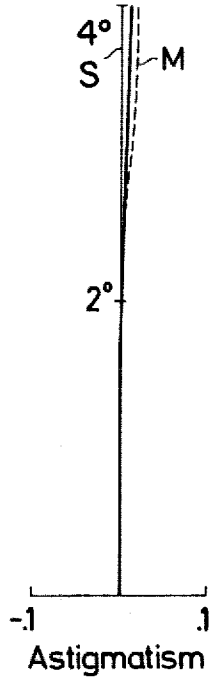


FIG. 5B

FIG. 5C

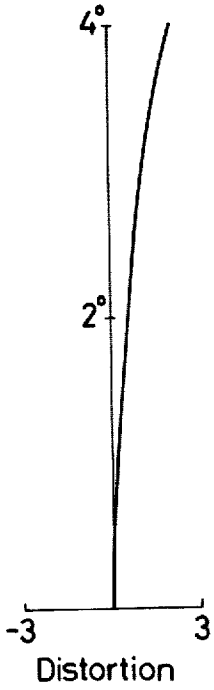


FIG. 5D

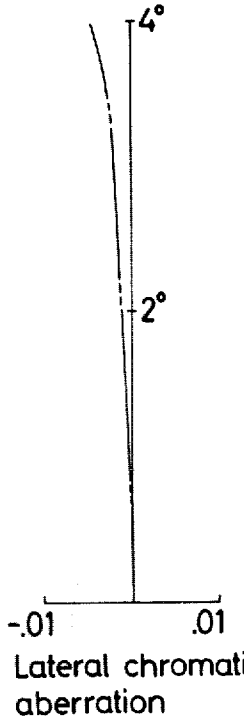


FIG.6A

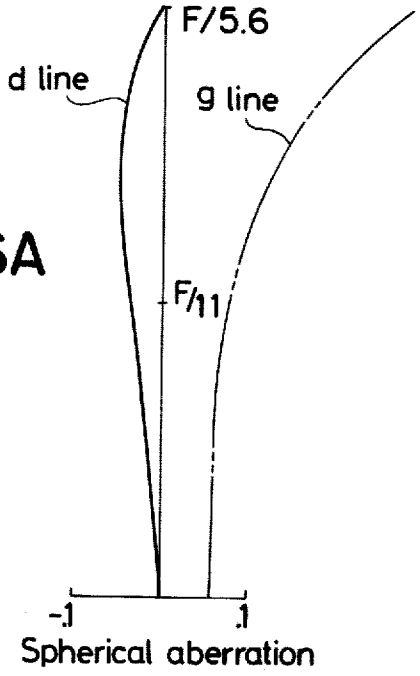


FIG.6B

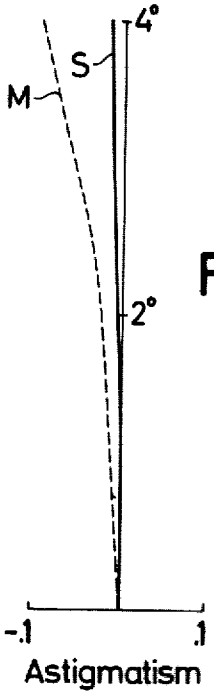


FIG.6C

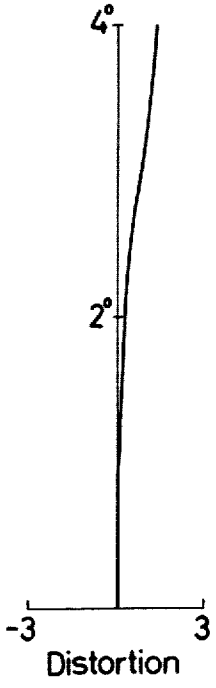


FIG.6D

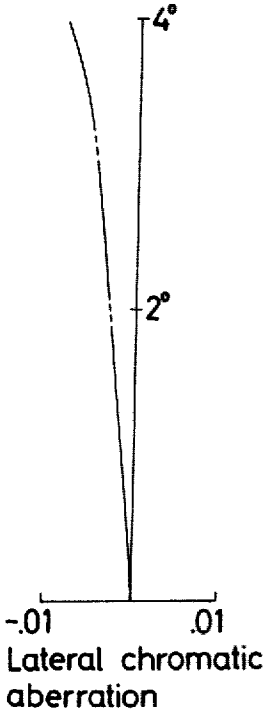


FIG.7A

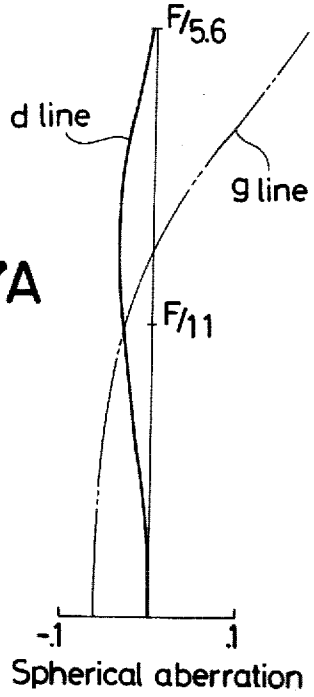


FIG.7B

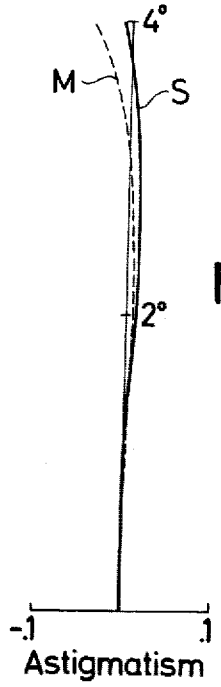


FIG.7C

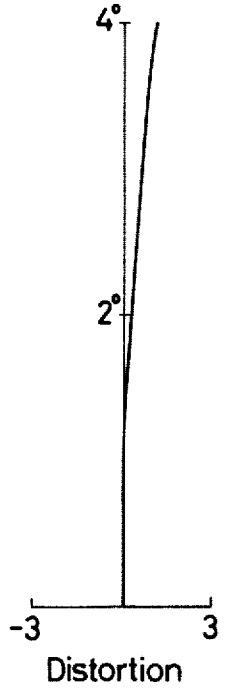


FIG.7D

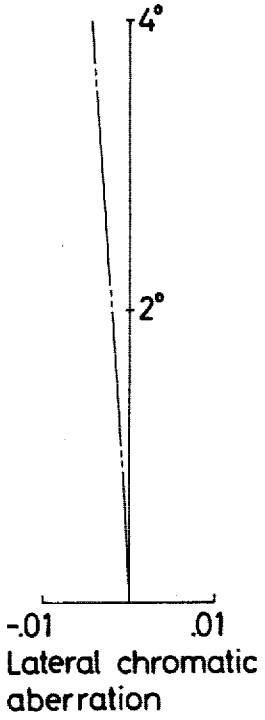


FIG. 8A

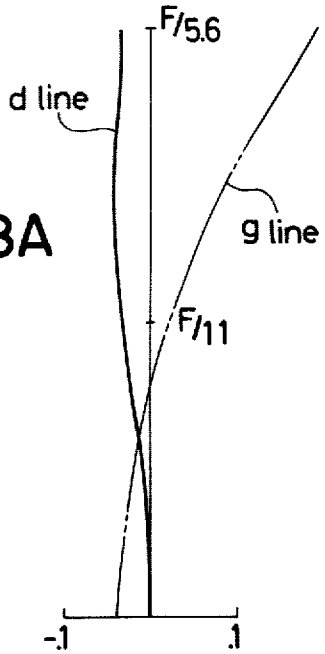


FIG. 8B

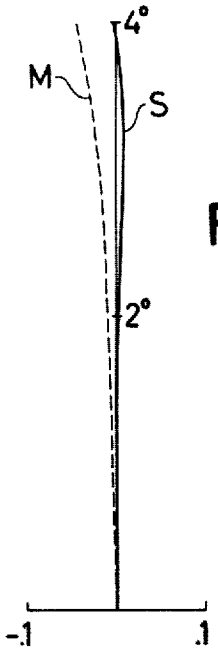


FIG. 8C

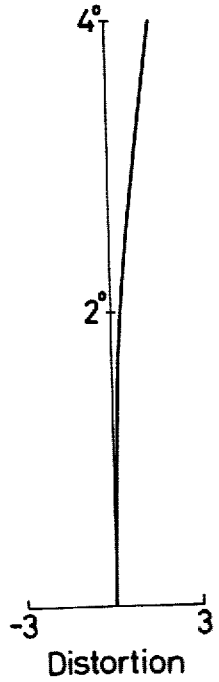
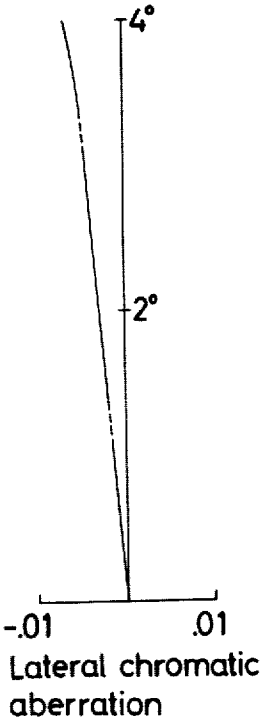


FIG. 8D



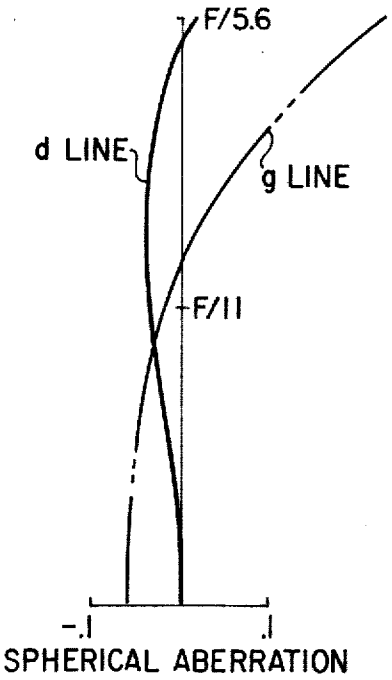


FIG. 9A

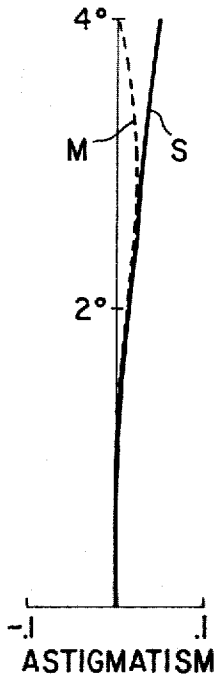


FIG. 9B

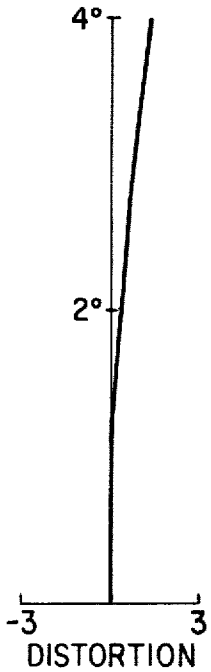


FIG. 9C

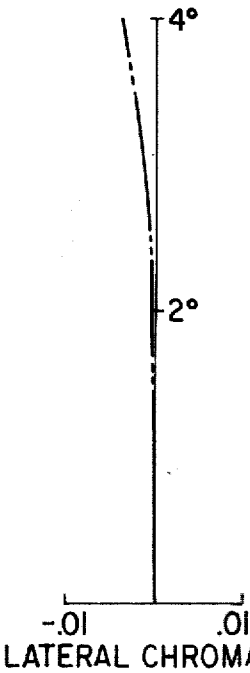
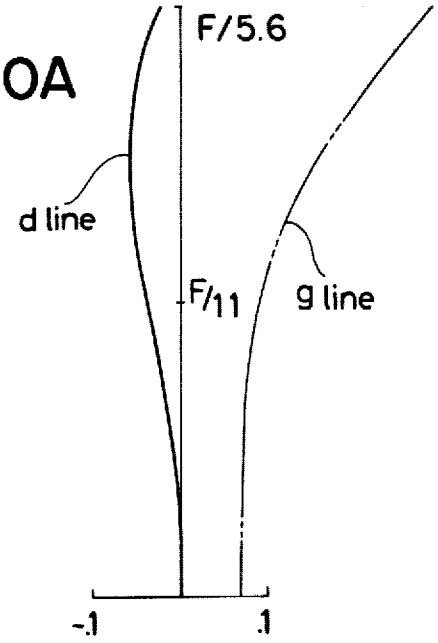


FIG. 9D

FIG.10A



Spherical aberration

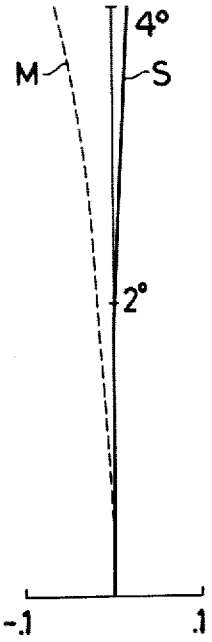
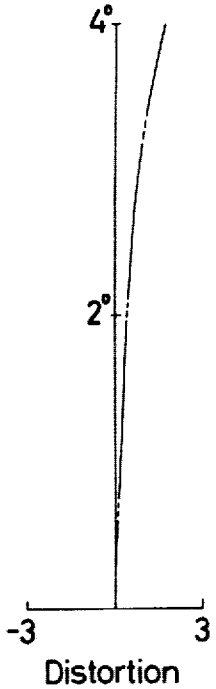


FIG.10B

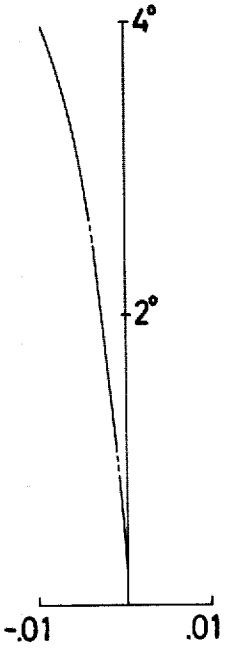
Astigmatism

FIG.10C



Distortion

FIG.10D



Lateral chromatic aberration

FIG.11A

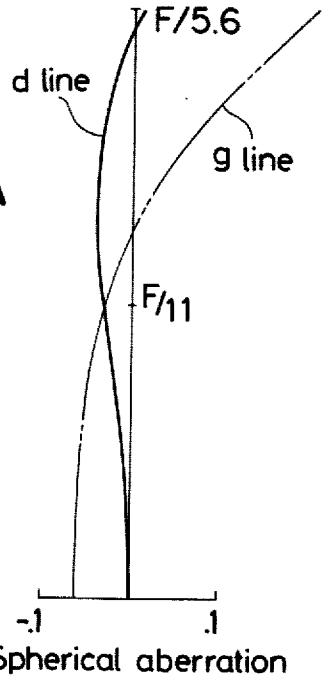


FIG.11B

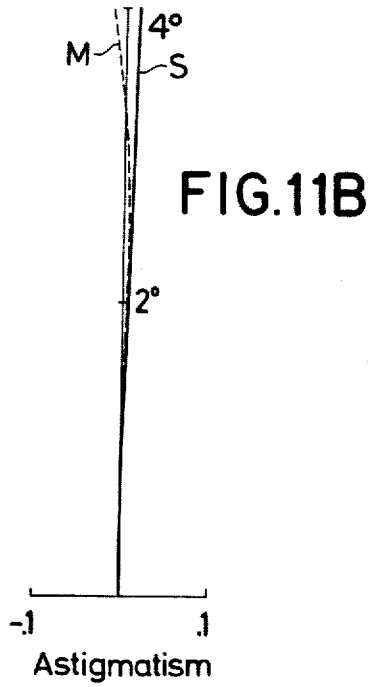


FIG.11C

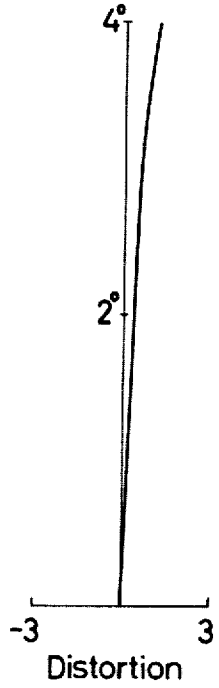
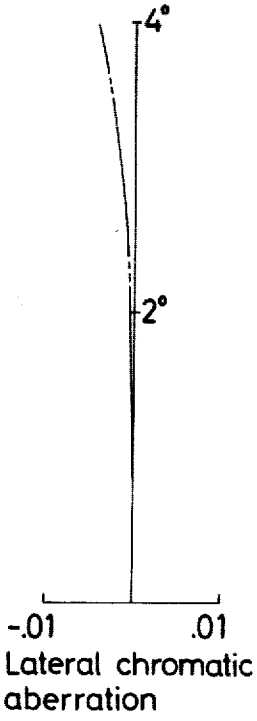


FIG.11D



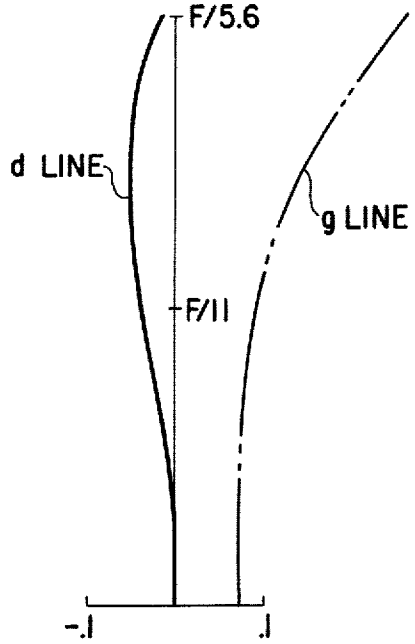


FIG. 12A

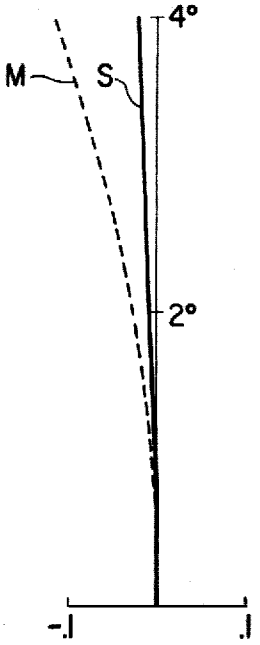


FIG. 12B

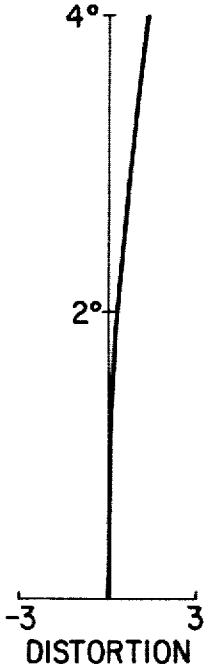


FIG. 12C

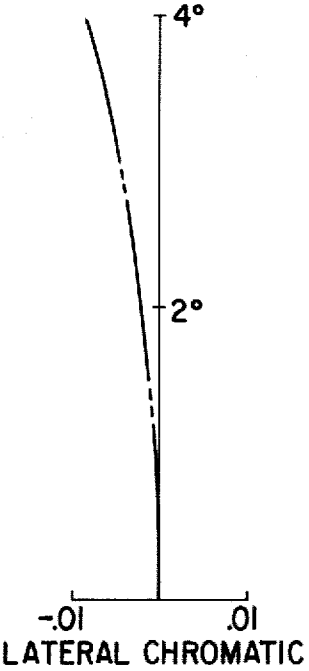


FIG. 12D

TELE-OBJECTIVE LENS WITH A MOVABLE SUB-GROUP FOR FOCUSING

This is a continuing application of application Ser. No. 870,228, filed Jan. 17, 1978 now abandoned.

BACKGROUND OF THE INVENTION

This invention relates to a tele-objective lens consisting of a front lens group having a positive refractive power and a rear lens group having a negative refractive power.

With the telephoto objective lens, it has been the general practice to move the lens as a whole to effect focusing. In U.S. Pat. No. 4,045,128, however, an inventive type of telephoto objective lens is disclosed wherein the provision for focusing is made at a subgroup thereof. The present invention is related to improvements in the objective system of the type described in U.S. Pat. No. 4,045,128.

The widely accepted design for tele-objective lens developed about 15 years ago was to construct the front lens group from only one positive and only one negative elements. Recently, the general trend is to make use of an additional positive lens element for the purpose of facilitating correction of aberrations.

Because of the relatively large dimensions of the lenses constituting the front lens group to those of lenses rearwardly subsequent thereto, however, increases in the number of lens elements lead to a rapid increase in the production cost, and to a corresponding increase in the weight of the complete objective so that it is inconvenient for a hand-held camera to employ such objective lens, as the so established camera is difficult to manage in performing photography.

SUMMARY OF THE INVENTION

An object of the present invention is to provide a tele-objective lens with the front lens group constructed from only one positive lens element and only one negative lens element, while nevertheless achieving good correction of aberrations.

Another object is to provide a tele-objective lens having a focusing provision made at a part thereof with assurance that it is made possible to maintain a high standard of aberration correction throughout the entire focusing range.

While the present invention is applicable to tele-objective lens system which are movable in whole for focusing purposes, it is described hereinafter particularly with reference to its presently preferred forms in which the rearmost lens group is made movable for focusing. It is, therefore, to be understood that the invention is not limited to the specific embodiment thereof that is illustrated in the accompanying drawing and described hereinafter, but includes all forms thereof that fall within the scope of the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is an axial sectional view of one embodiment of a tele-objective lens system according to the present invention in two different operative positions for focusing at infinity and close-up.

FIG. **2** is a similar view showing a second embodiment of the invention.

FIG. **3** is a similar view showing a third embodiment of the invention.

FIG. **4** is a similar view showing a fourth embodiment of the invention.

FIGS. **5A** to **5D** are graphic representations of spherical aberration, astigmatism, distortion and lateral chromatic aberration of Example 1 lens system respectively when set at infinity.

FIGS. **6A** to **6D** are graphic representations of the various aberrations of Example 1 lens system when set at close-up.

FIGS. **7A–7D** and **8A–8D** are similar representations of Example 2 lens system when set at infinity and close-up respectively.

FIGS. **9A–9D** and **10A–10D** are similar representations of Example 3 lens system when set at infinity and close-up respectively.

FIGS. **11A–11D** and **12A–12D** are similar representations of Example 4 lens system when set at infinity and close-up respectively.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Four examples of embodiments of a tele-objective lens system according to the present invention are represented in FIGS. **1** to **4**, each of which may conveniently be considered as comprising a front lens group **1** of positive power and a rear lens group of negative power axially spaced apart from each other. The rear lens group is divided into two parts or groups **2** and **3**, of which the rear or third group **3** is movable for focusing purposes, while the front part or second group **2** remaining stationary. As focusing is effected from infinity down to close-ups, the third lens group **3** is moved in a rearward direction from a solid line position to a dashed line position. This constitutes one of the features of the present invention. As has been noted before, the entire system may be moved in whole with reference to the film plane to effect focusing. In this case, it is recommended that the third lens group **3** is stationary to occupy the solid line position at which the system is otherwise set for infinitely distant object.

According to the present invention, the first lens group **1** consists of two lenses, one of which is of positive power and another one which is of negative power. The second lens group **2** consists of a substantially single lens of negative power in the form of a meniscus lens rearwardly concave. This lens may be constructed from plano-convex and plano-concave lens elements to form an achromatic doublet. Though such aberrational correction is considered as unnecessary from the appropriate residual aberrations of the entire system, the employment of such doublet will be amendable to low cost production techniques. The third lens group **3** is overall of a negative refractive power and consists of two lenses one of which is of positive power and another one which is of negative power.

In FIGS. **1**, **3** and **4**, as the positive and negative lenses in the first group **1**, use is made of a double convex lens and a forwardly concave lens respectively arranged in the order named from the front to create an air lens therebetween, while, in FIG. **2**, such arrangement is reversed comprising a forwardly convex negative meniscus lens and a forwardly convex positive lens axially spaced from each other to create an air lens. The rearmost surface of the first group **1** is configured to a radius of curvature extremely near the infinite one. In FIGS. **1**, **2** and **3**, the third group **3** is constructed in the form of a doublet of the positive and negative lenses arranged in this order for the first two objectives and of

the negative and positive ones arranged in this order for the last, while in FIG. 4, the positive and negative lenses are arranged in this order from the front to create an air space therebetween.

In a preferred embodiment with the above mentioned basic construction and arrangement of the lens elements, the objective of the invention fulfills at least one of the following requirements:

$$-0.01<F/(F_{1p}\cdot V_{1p})+F/(F_{1n}\cdot V_{1n})<0.01 \quad (1)$$

$$0.85<(R'_1+R_1)/(R'_1-R_1)<1.1 \quad (2)$$

$$-3.5F<F_A<-1.5F \quad (3)$$

$$0.07F<R'_2<0.1F \quad (4)$$

$$0.7F<|F_3|<1.3F \quad (5)$$

$$-0.015<F/(F_{3p}\cdot V_{3p})+F/(F_{3n}\cdot V_{3n})<0.015 \quad (6)$$

$$0.15F<R'_3<0.35F \quad (7)$$

wherein F is the focal length of the entire system when focused for infinitely distant object; F_1 is the focal length of the first group; F_{1p} is the focal length of the positive lens in the first group; F_{1n} is the focal length of the negative lens in the first group; V_{1p} is the Abbe number of the positive lens in the first group; V_{1n} is the Abbe number of the negative lens in the first group; R_1 is the radius of curvature of the first surface (r_1) of the first group; R'_1 is the radius of curvature of the rearmost surface (r_4) of the first group; F_A is the focal length of the air lens (r_2, r_3) in the first group; R'_2 is the radius of curvature of the rearmost surface (r_6) of the second group; R'_3 is the radius of curvature of the rearmost surface (r_9 or r_{10}) of the third group; R_3 is the focal length of the third group; F_{3p} is the focal length of the positive lens in the third group; F_{3n} is the focal length of the negative lens in the third group; V_{3p} is the Abbe number of the positive lens in the third group; and V_{3n} is the Abbe number of the negative lens in the third group.

Whilst the tele-objective lens adapted to be bodily movable for focusing enables the residual aberrations generally to be maintained substantially stable through the entire focusing range, that type of tele-objective lens which makes the focusing provision at a part thereof gives rise to the high possibility of producing a great variation of aberrations and particularly spherical aberration ascribable to the fosusing member itself, as focusing is performed, thereby the balance in aberration correction of the entire system is lost so that high grade imaging performance can not be preserved throughout the entire focusing range.

In order to eliminate such variation of the various aberrations with focusing, the following two prerequisites must be satisfied simultaneously.

(1) The spherical aberration and coma of the focusing lens group are made minimized in terms of aberration coefficients, and the proper balance between the both aberration coefficients is established, and

(2) the entire system is well corrected for the various aberrations.

In this connection, it should further be explained that, in a two-group tele-objective lens system made movable in whole for focusing, the spherical aberration of the front group tends to be under-corrected, and, therefore, is required to be balanced out by the suitable design of the rear group to achieve a high standard of aberration correction through the entire system. If accommodation for change of object position is provided by imparting an independent movement to the rear group of the objective lens, the residual spherical aberration will be varied to a correspondingly large extent, as the height of incidence of image forming rays of light at the rear group is changed.

According to the formulated features of the invention, the second lens group is designed under condition (4) to provide an appropriate amount of aberration which contributes to the high standard of aberration correction of the entire system, while permitting the spherical aberration and coma of the focusing or third group to be limited to minimum and to be balanced out with each other. The design features of the first group are set forth at (1), (2) and (3), and those of the third group at (5), (6) and (7) each of which will be explained below.

Conditions (1) and (6) gives assistance in the stabilization of longitudinal chromatic aberration throughout the focusing range. As the objective of the invention is adapted to operate with a semi-angular field of view not exceeding 4 degrees, when these conditions are established, it is possible to limit the lateral chromatic aberration also to an acceptable level.

Conditions (2) and (3) are concerned with the configuration of the first group which constitutes the most important ones of the design features of the entire system particularly when the system is question is of the type described, and which affects the state of aberration connection of the entire system to a large proportion. What is generally called "shape factor" in the art of single lenses corresponds to condition (2). When any one of the upper and lower limits of this condition is exceeded, under-corrected spherical aberration will be resulted. Condition (3) determines a value of refractive power of the air lens defined by the positive and negative lenses. This air lens affects spherical aberration, comatic aberration, field of curvature and others. With regard to the spherical aberration, when the upper limit is exceeded, it will be over-corrected, while when the lower limit is exceeded, it will become under-corrected or increated in the ring band form.

Condition (4) inparts to the second group, or the negative meniscus lens that amounts of spherical aberration and coma which are over-corrected as seen in itself. This is so set forth by taking into account the fact that, if the third group movable for focusing is designed under condition (7) to have the rearmost surface of rearward concavity with limitation of spherical aberration and coma to minimum, the complete system with such third group produces under-corrected spherical aberration and coma.

Condition (5) controls the range of movement of the third group for focusing adjustments. When the upper limit is exceeded, the range of movement is so largely extended that mechanical interference due to the practical photographic lens structure can not be avoided. When the lower limit is violated, it is made difficult to correct the aberrations to satisfactory level.

Condition (7) is, as mentioned above, concerned with the configuration of the third group. When the upper limit is violated, the spherical aberration becomes under-corrected as the object distance is decreased. When the lower limit is violated, the spherical aberration becomes over-corrected with decrease in the object distance.

Four specific examples of preferred embodiments of the tele-objective lens system of the invention may be

constructed in accordance with the numerical data given below for the radii of curvature, r, the lens thicknesses and axial separations, d, along with the corresponding indices of refraction, nd, for the spectral D line of sodium and the Abbe numbers for the various lens elements. The minus values of the radii, r, indicate surfaces concave toward the front. The variable separation, d_6, with focusing is taken at the value shown when the objective is set forth infinitely distant object.

Example 1:

	F = 100.0 r	FNo. 1:5.6 d	2ω = 8° nd	vd
1	33.5058	2.949	1.58913	61.1
2	36.2942	1.912		
3	33.4085	1.424	1.6727	32.1
4	−671.5298	23.725		
5	8.9708	1.356	1.58913	61.1
6	8.1227	2.749		
7	41.4383	0.712	1.69895	30.1
8	1156.5338	0.542	1.713	53.9
9	25.6539			

Example 2:

	F = 100.0 r	FNo. 1:5.6 d	2ω = 8° nd	vd
1	30.1688	1.424	1.69895	30.1
2	17.7817	0.946		
3	18.4847	2.902	1.58913	61.1
4	6059.6105	25.502		
5	10.4502	1.356	1.58913	61.1
6	9.3380	2.729		
7	31.6054	1.210	1.69895	30.1
8	110.6620	0.542	1.713	53.9
9	19.9742			

Example 3:

	F = 100.0 r	FNo. 1:5.6 d	2ω = 8° nd	vd
1	32.8478	3.214	1.58913	61.1
2	35.5624	1.075		
3	32.2451	1.424	1.6727	32.1
4	622.9698	25.403		
5	9.5414	1.356	1.58913	61.1
6	8.6190	2.749		
7	32.9044	0.542	1.713	53.9
8	15.3051	0.685	1.80518	25.4
9	17.9393			

Example 4:

	F = 100.0 r	FNo. 1:5.6 d	2 ω = 8° nd	vd
1	33.7136	3.108	1.58913	61.1
2	37.1715	1.054		
3	33.8288	1.424	1.6727	32.1
4	773.2559	1.675		
5	9.5251	1.356	1.58913	61.1
6	8.6254	2.749		
7	34.5403	0.695	1.69893	25.4
8	179.4034	0.088		
9	176.2224	0.542	1.713	53.9
10	22.7308			

The calculated values of the formulae (1) to (7) for Examples 1 to 4 are compiled in the table below.

(1)	0.0047	0.0011	0.0061	−0.0055
(2)	0.905	0.990	0.900	0.916
(3)	3.05F	1.60F	2.55F	2.70F
(4)	0.0918F	0.0934F	0.0862F	0.0863F
(5)	1.034F	0.794F	0.831F	0.954F
(6)	0.0047	0.0009	0.0057	0.0138
(7)	0.274F	0.1997F	0.199F	0.227F

What is claimed is:

1. A tele-objective lens, with a movable sub-group for focusing, comprising:

a positive lens group, consisting of one positive lens and one negative lens spaced from each other, and the curvature of the frontmost lens surface thereof being stronger than that of the rearmost lens surface, and

a negative lens group, being located axially in the image side of said positive lens group and consisting of a stationary meniscus lens and a movable sub-group for focusing;

said stationary meniscus lens facing with its concave surface toward said movable sub-group, and said movable sub-group including positive and negative lenses; and wherein, when the focal length of the whole system is F and the focal length of said movable sub-group is F_3, said tele-objective lens satisfies the condition of $0.7F < |F_3| < 1.3F$.

2. A tele-objective lens according to claim **1**, wherein said positive lens group consists of a double convex lens and a forwardly concave negative lens arranged in this order from the front.

3. A tele-objective lens according to claim **1**, wherein said positive lens group consists of a forwardly convex negative meniscus lens and a forwardly convex positive lens arranged in this order from the front.

4. The tele-objective lens of claim **1**, wherein the lens elements have the following values:

	F = 100.0 r	FNo. 1:5.6 d	2ω = 8° nd	vd
1	33.5058	2.949	1.58913	61.1
2	−36.2942	1.912		
3	−33.4085	1.424	1.6727	32.1
4	−671.5298	23.725		
5	8.9708	1.356	1.58913	61.1
6	8.1227	2.749		
7	41.4383	0.712	1.69895	30.1
8	1156.5338	0.542	1.713	53.9
9	25.6539			

and wherein F is a focal length, 2ω is a view angle, r is a radius of the lens surface, d is an axial length or air gap of a lens, nd represents the refractive index of the lens medium and vd represents Abbe number of the lens medium.

5. The tele-objective lens of claim **1**, wherein the lens elements have the following values:

	F = 100.0 r	FNo. 1:5.6 d	2ω = 8° nd	vd
1	30.1688	1.424	1.69895	30.1
2	17.7817	0.946		
3	18.4847	2.902	1.58913	61.1
4	−6059.6105	25.502		
5	10.4502	1.356	1.58913	61.1
6	9.3380	2.729		
7	31.6054	1.210	1.69895	30.1
8	110.6620	0.542	1.713	53.9
9	19.9742			

and wherein F is a focal length, 2ω is a view angle, r is a radius of the lens surface, d is an axial length or air gap of a lens, nd represents the refractive index of the lens medium and vd represents Abbe number of the lens medium.

6. The tele-objective lens of claim **1**, wherein the lens elements have the following values:

	F = 100.0	FNo. 1:5.6	2ω = 8°	
	r	d	nd	vd
1	32.8478	3.214	1.58913	61.1
2	−35.5624	1.075		
3	−32.2451	1.424	1.6727	32.1
4	−622.9698	25.403		
5	9.5414	1.356	1.58913	61.1
6	8.6190	2.749		
7	32.9044	0.542	1.713	53.9
8	15.3051	0.685	1.80518	25.4
9	17.9393			

and wherein F is a focal length, 2ω is a view angle, r is a radius of the lens surface, d is an axial length or air gap of a lens, nd represents the refractive index of the lens medium and vd represents Abbe number of the lens medium.

7. The tele-objective lens of claim **1**, wherein the lens elements have the following values:

	F = 100.0	FNo. 1:5.6	2ω = 8°	
	r	d	nd	vd
1	33.7136	3.108	1.58913	61.1
2	−37.1715	1.054		
3	−33.8288	1.424	1.6727	32.1
4	−773.2559	1.675		
5	9.5251	1.356	1.58913	61.1
6	8.6254	2.749		
7	34.5403	0.695	1.69893	25.4
8	179.4034	0.088		
9	176.2224	0.542	1.713	53.9
10	22.7308			

and wherein F is a focal length, 2ω is a view angle, r is a radius of the lens surface, d is an axial length or air gap of a lens, nd represents the refractive index of the lens medium and vd represents Abbe number of the lens medium.

* * * * *

United States Patent [19]

Kamata et al.

[11] **4,322,150**

[45] **Mar. 30, 1982**

[54] **MECHANICAL MOUNTING SYSTEM FOR ZOOM OBJECTIVE**

[75] Inventors: **Shigeru Kamata; Takashi Isobe,** both of Tokyo, Japan

[73] Assignee: **Canon Kabushiki Kaisha,** Tokyo, Japan

[21] Appl. No.: **173,182**

[22] Filed: **Jul. 28, 1980**

[30] **Foreign Application Priority Data**

Jul. 30, 1979 [JP] Japan 54-97766
Aug. 27, 1979 [JP] Japan 54-108911

[51] **Int. Cl.**[3] **G02B 7/10;** G03B 13/02
[52] **U.S. Cl.** **354/195;** 350/255
[58] **Field of Search** 354/286, 195, 196; 350/255, 430

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Primary Examiner—Donald A. Griffin
Attorney, Agent, or Firm—Toren, McGeady & Stanger

[57] **ABSTRACT**

A mechanical mounting system for a zoom objective having provision for close-up operation includes an actuator serving to perform both focusing and zooming operations as it is turned and axially moved respectively. When the actuator is axially moved to the wide angle position and when it is turned to the lower limit of the focusing range, a drive connection between the actuator and a camming cylinder for the zoom and close-up control is established even in the transverse direction. Upon transverse movement of the actuator beyond the focusing range, the camming cylinder is turned to axially move the variator forwardly while the compensator remains stationary in the wide angle position thereby effecting a close-up operation.

8 Claims, 22 Drawing Figures

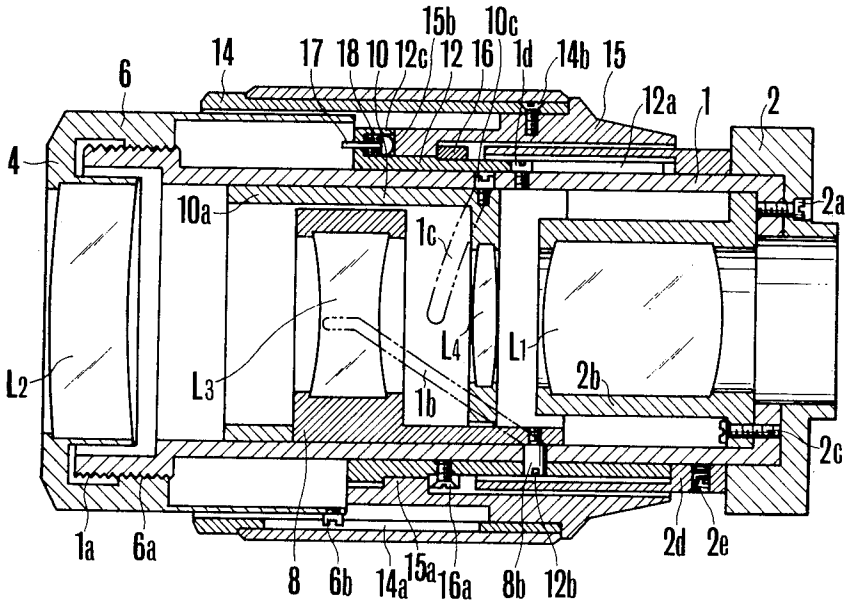


FIG. 1

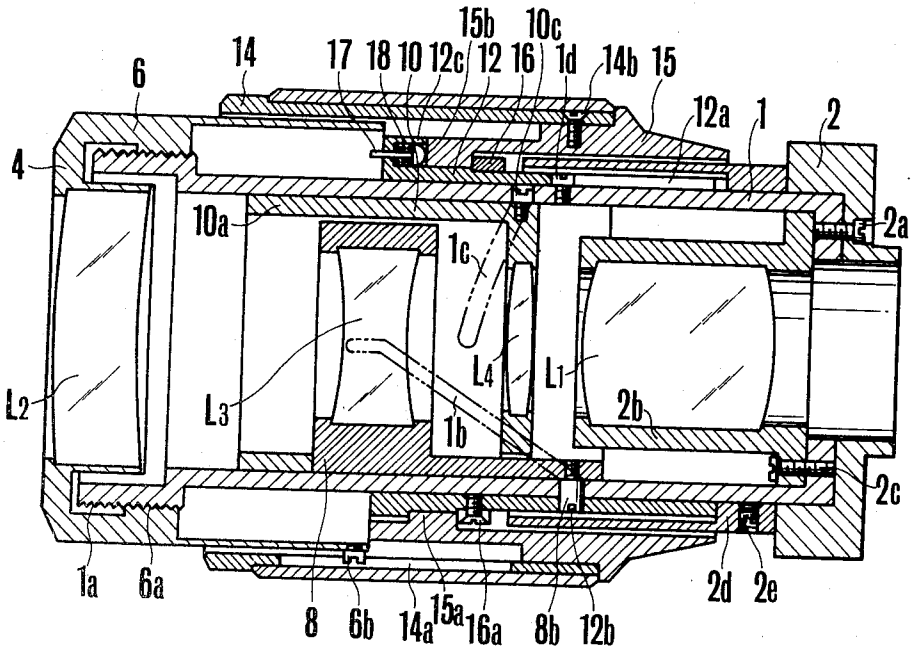

15b
10c
14
17
18
10
12c
12
16
1d
14b
15
6
12a
1
2
4
10a
2a
1c
L4
L1
L2
L3
2b
1b
2c
1a
6a
8
6b
14a
15a
16a
8b
12b
2d
2e

FIG.2

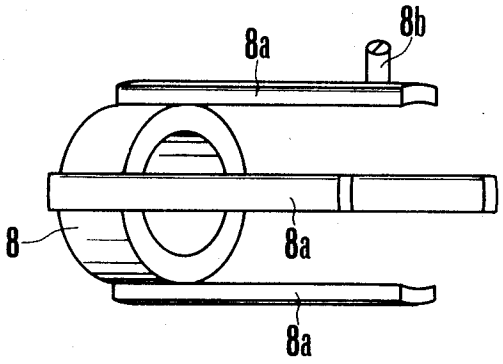


FIG.3

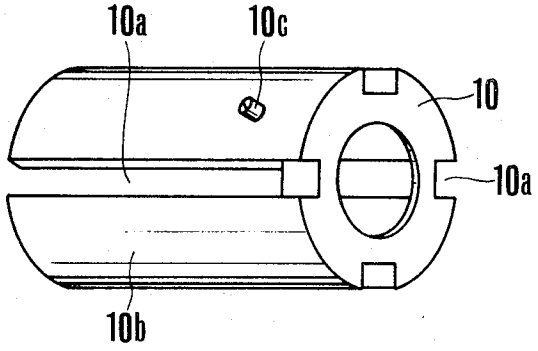


FIG.4

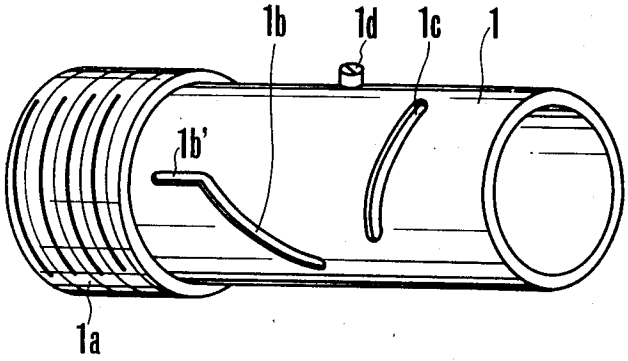


FIG.5

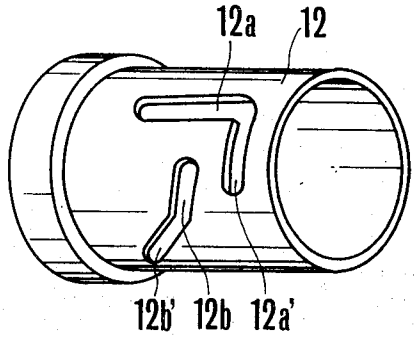


FIG.6

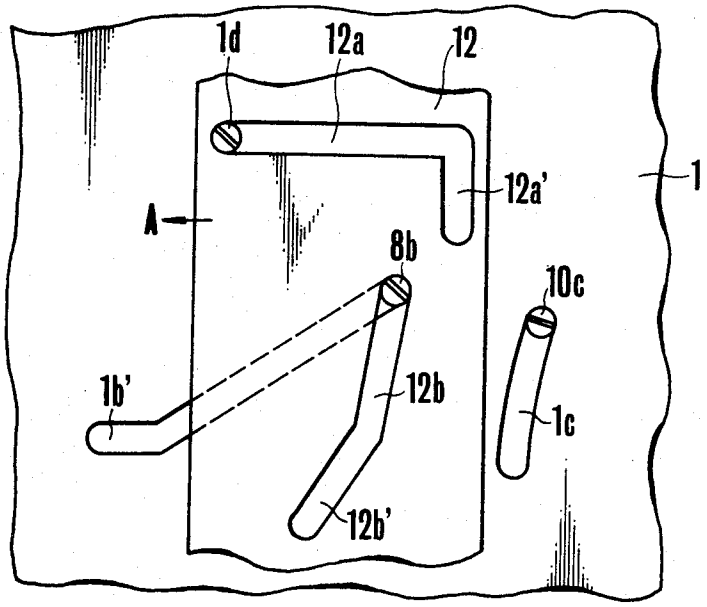

1d
12a
12
12a'
1
A
8b
10c
1b'
12b
1c
12b'

FIG.7

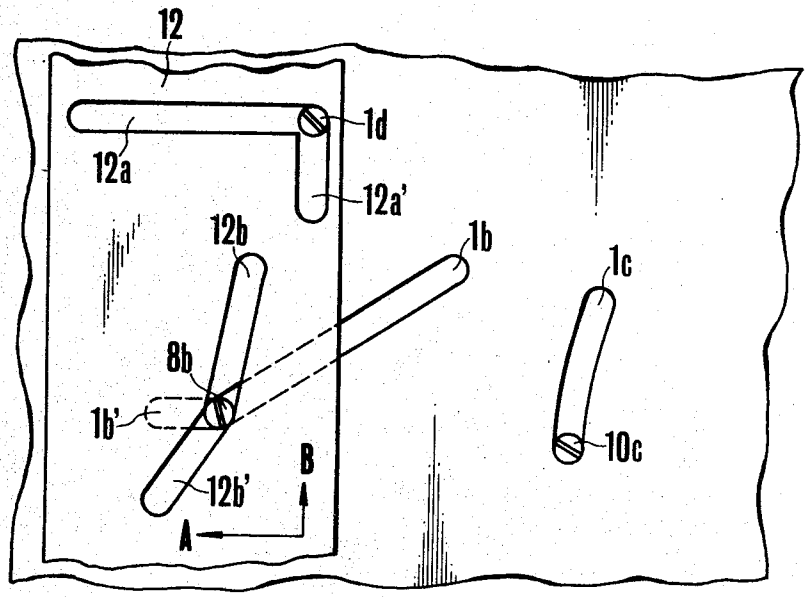

12
1d
12a
12a'
12b
1b
1c
8b
1b'
10c
B
12b'
A

FIG.8

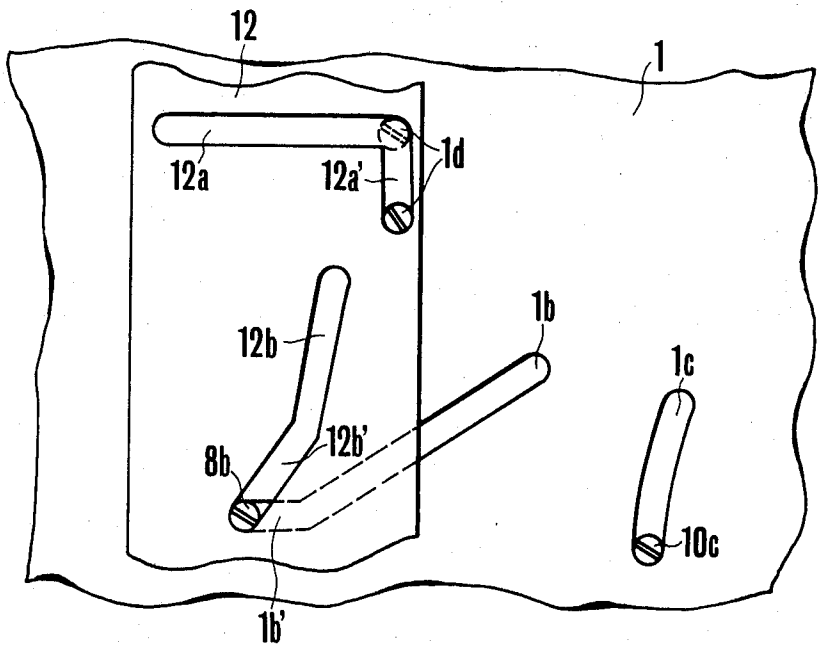


FIG.9

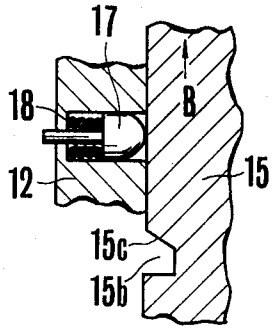


FIG.10

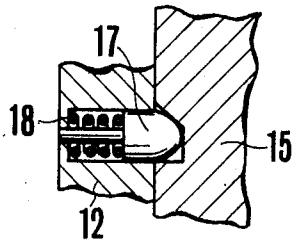


FIG.11

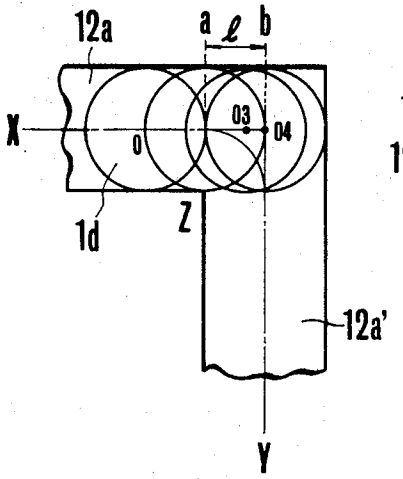


FIG.12

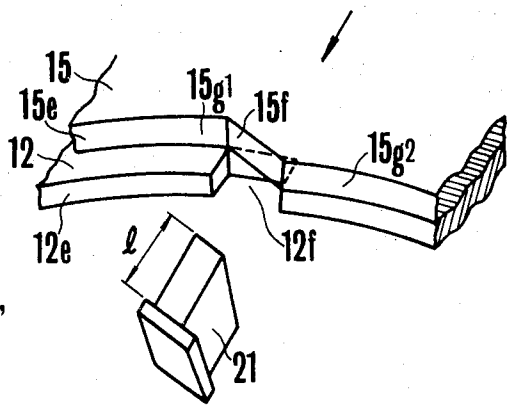


FIG.13

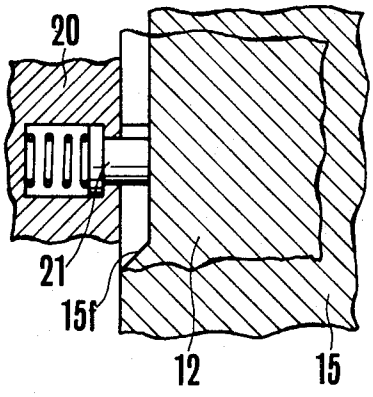


FIG.14

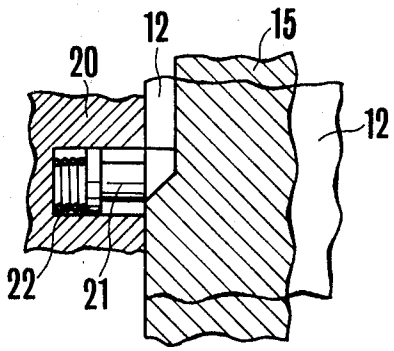


FIG.15

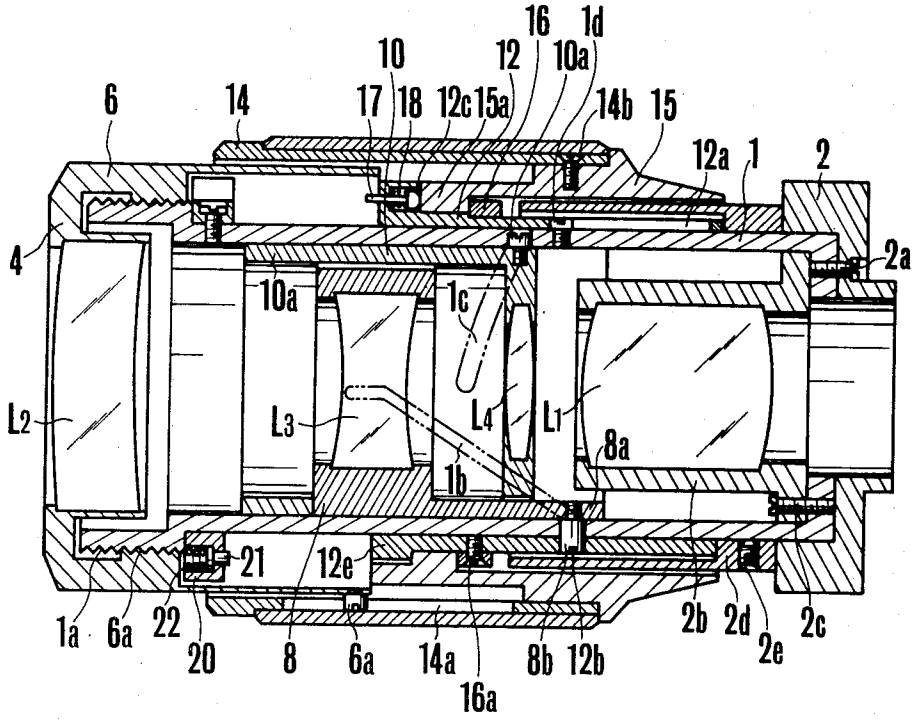

16
1d
10
12
10a
6
14
17
18
12c
15a
14b
15
12a
1
2
4
2a
10a
1c
L2
L3
L4
L1
8a
1b
21
12e
1a
6a
22
20
8
6a
14a
16a
8b
12b
2b
2d
2e
2c

FIG.16

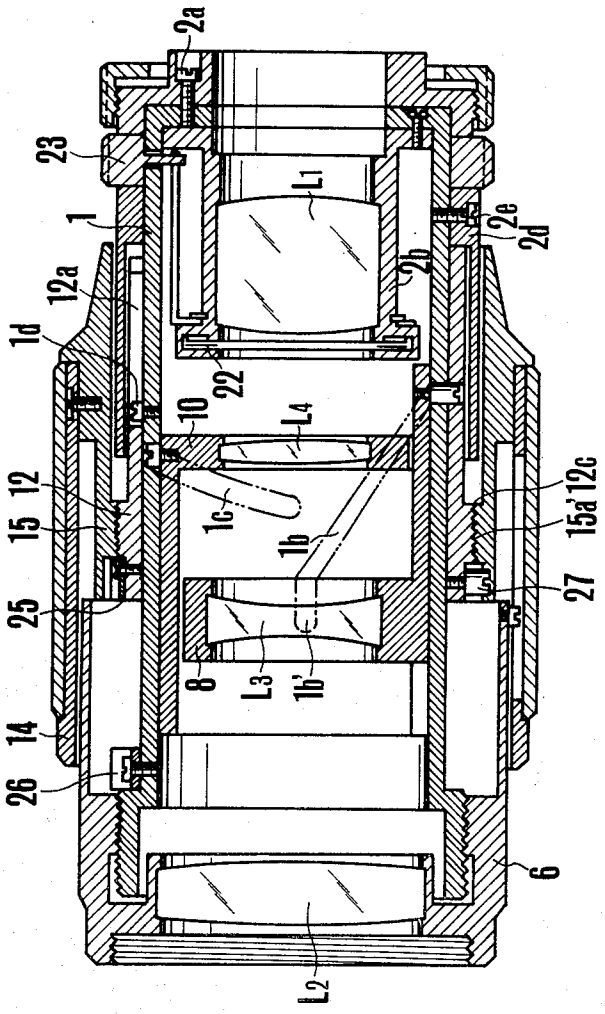

2a
23
1
12a
1d
22
10
12
15
25
14
26
L1
2b
2e
2d
L4
1c
1b
15a'
12c
27
8
L3
1b'
6
L2

FIG.17

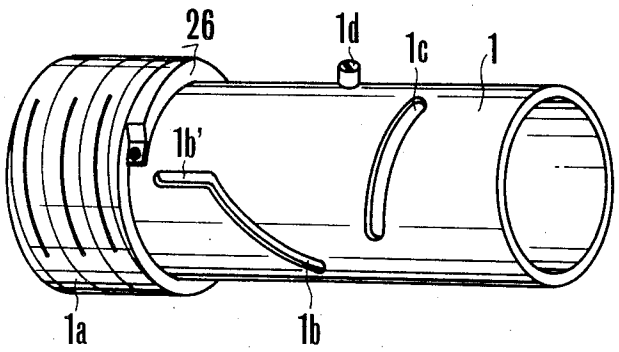


FIG.18

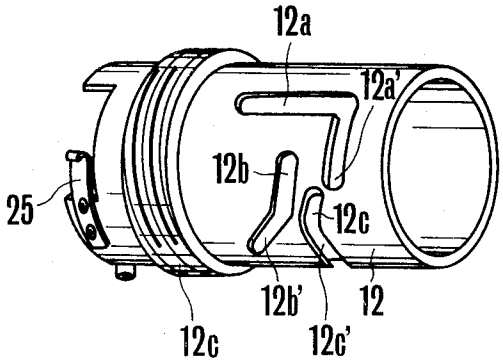


FIG.19

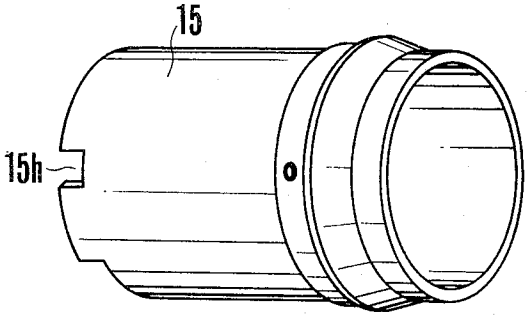


FIG.20

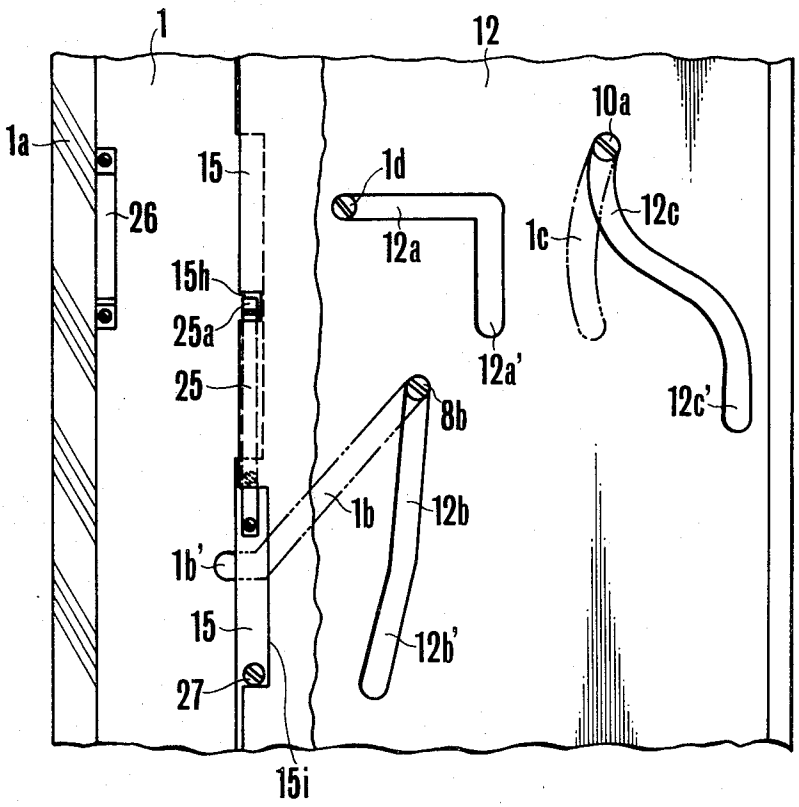

1
12
10a
1a
15
1d
26
12a
12c
1c
15h
25a
12a'
25
12c'
8b
1b
12b
1b'
15
12b'
27
15i

FIG.21

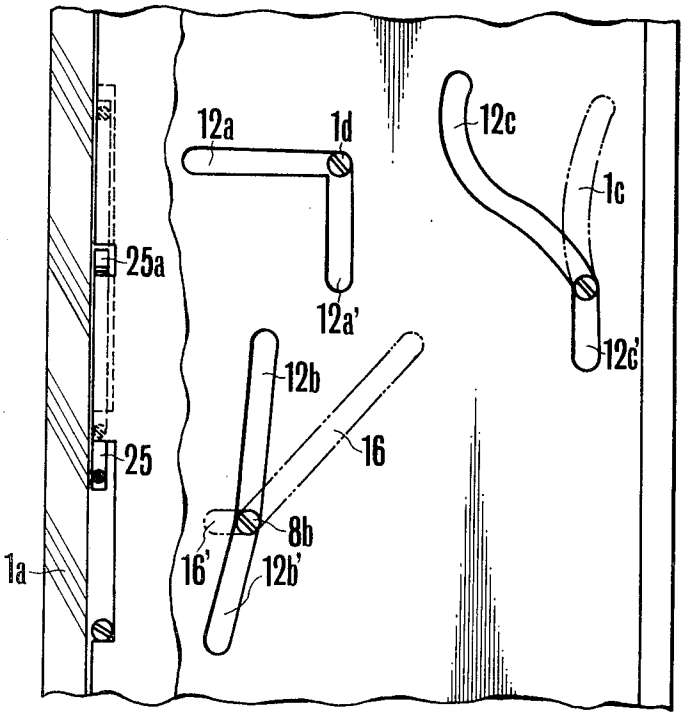
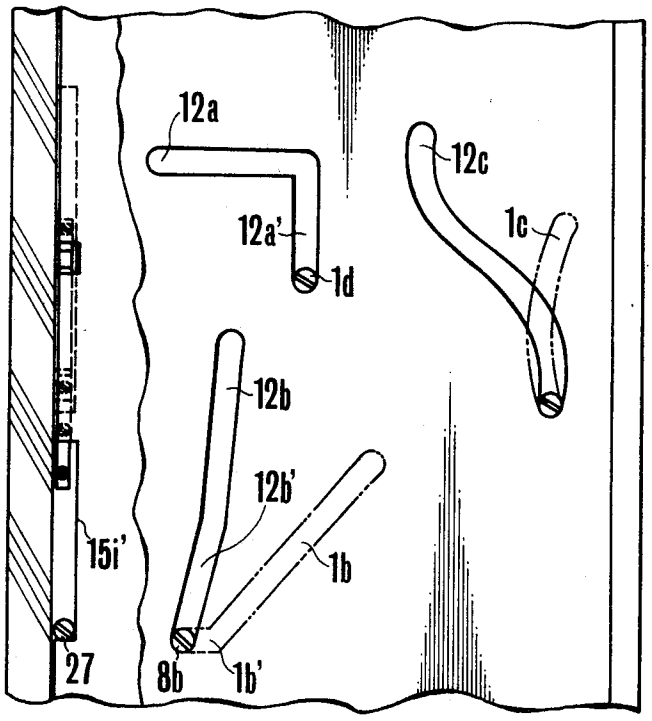


FIG.22



MECHANICAL MOUNTING SYSTEM FOR ZOOM OBJECTIVE

The present invention relates generally to photographic lens devices and more particularly to zoom lens assemblies wherein provision is made for a close-up mechanism therein.

In the prior art, a wide variety of mechanical mounting systems for zoom lenses having close-up capability have been proposed. An example of such a system is disclosed in U.S. Pat. No. 4,097,124 wherein in the mounting for the zoom lens focusing and close-up operation are performed by a common actuator **13** of the zoom control which is rotated about the optical axis of the lens assembly or moved axially, respectively. When it is desired to select operation in the close-up range, the operator must however rotate a mode ring **18** so that engagement of a pin **30** in a slot is changed from a zoom control slot Z1 to a macro-control slot M1. That is, in the mechanical mounting system of this prior art reference, the zooming operation and the close-up operation are entirely independent of each other and their exists no consecutive relationship therebetween. Of course, it will be apparent that the type of zoom lens assembly described in this reference is meritorious in that accidental changeover of the optical system to the close-up range when zooming is being performed may be prevented.

In this context it should be considered that the usefulness of a zoom lens may be enhanced if the action of focusing a lens assembly upon an object to be photographed may be followed by a series of actuations of the shutter release mechanism with different magnifications of an image of the object as desired. Furthermore, the manageability and convenience of the lens assembly will be improved also when focusing operation, zooming operation and close-up operation may be performed consecutively relative to each other by a single actuating member.

Since, in conventional zooming systems, the total axial movement of the actuator member must be equal to that of the variator, the longitudinal length of the mounting unit must be considerably increased thereby sacrificing ease of handling and portability of the device.

A further more serious problem will be encountered when total axial movement of the variator is increased since it is difficult to hold the variator truly normal to the tubular body of the lens assembly during its entire excursion. Thus, the fitting accuracy of the movable lens cell in the tubular body of the assembly must be increased. This tends to lead to requirements for supplying high-precision mechanical parts and for employing much more delicate assembly techniques.

With regard to the zoom control mechanism, it has been common practice in the prior art, as disclosed for example in U.S. Pat. No. 4,097,924, that the variator and the compensator are fixedly carried by respective movable sleeves which are arranged in a superimposed relationship relative to each other. It is therefore of great importance that the dimensions of the sleeves be limited to very close tolerances and the assembly procedure particularly with regard to the fitting adjustment must be so fine that there can be no looseness or play between the sleeve and the tubular body of the assembly while insuring smooth operation of the control mechanism.

This will contribute to an increase in the production costs of the system.

In view of the foregoing, the present invention is directed toward provision of a mechanical mounting system for a zoom objective having three ranges of zooming, focusing and close-up operation selectively rendered by only one actuator sleeve without requiring recourse to selector means.

A further aim of the invention is to provide a mounting system for a zoom objective having a close-up mechanism operating with a common actuator for zooming and for focusing in such a manner that the three operations may be formed consecutively.

A further goal of the invention is the provision of a zoom lens assembly characterized by high accuracy while limiting to a minimum deviation of the points of positioning of each individual moving part from prescribed ideal positions as the magnification varying lens holder and the image shift compensating lens holder are moved along a common optical axis. A further aim of the invention is to provide a novel zoom control mechanism having a shorter total axial movement of the actuator than that of the variator and to provide a zoom objective having improved manageability and portability.

SUMMARY OF THE INVENTION

In accordance with the present invention, a zoom lens assembly is provided wherein a single actuator ring is arranged in the mechanical mounting system to effect zooming operation upon axial movement thereof and upon rotative movement thereof about the optical axis to effect close-up operation whereby the transition from the axial to the rotative phase of movement may be caused to occur only after passage of the wide-angle end. In the assembly of the invention, means are provided for preventing accidental selection of the close-up range which would otherwise occur when the actuator nears the wide angle end of movement thereof. Utilization of such means makes it possible to eliminate the drawback that the sharp focus condition will be broken after the close-up range is selected.

In order to achieve high accuracy of zoom control, there is provided in accordance with another feature of the invention a novel and improved differentiating mechanism for the variator and the compensator mounting members which is also adapted for suitable use in axial movement of the variator independently of the compensator which remains stationery in the wide angle position when a close-up operation is being performed.

The most characteristic feature of the invention resides in the fact that in order to enable an operator to perform zooming and close-up operations consecutively, i.e. without having to remove his hand from the actuator member, an intermediate member is provided causing axial movement of the actuator to effect zooming operation and causing rotative movement thereof about the optical axis to effect close-up operation with a detent mechanism being provided for bringing and taking this intermediate member into and out of drive connection with the actuator member.

The various features of novelty which characterize the invention are pointed out with particularity in the claims annexed to and forming a part of this disclosure. For a better understanding of the invention, its operating advantages and specific objects attained by its use, reference should be had to the accompanying drawings

and descriptive matter in which there are illustrated and described preferred embodiments of the invention.

DESCRIPTION OF THE DRAWINGS

In the drawings:

FIG. **1** is an axial sectional view of one embodiment of a lens assembly in accordance with the present invention;

FIG. **2** is a prospective view of a variator mounting member of the assembly of FIG. **1**;

FIG. **3** is a perspective view of a compensator mounting member of the assembly of FIG. **1**;

FIG. **4** is a perspective view of a tubular body of the assembly of FIG. **1** having provided thereon guide means and pin means operating as an engaging device;

FIG. **5** is a perspective view of a cam sleeve or intermediate member of the assembly arranged between the tubular body shown in FIG. **4** and an operational member of the lens assembly of FIG. **1** and provided with longitudinal guide means for axial movement of the operational member, with transverse guide means and with variator guides for the zooming and close-up regions, respectively;

FIGS. **6–8** are developed representations of the tubular body and the cam sleeve with the engaging means of the variator and compensator holders assuming the telephoto, wide angle and close-up positions relative to the guide slots, respectively;

FIGS. **9** and **10** are partial sectional views of a detent mechanism for a drive connection between the operational member and the cam sleeve shown in the idle and the active positions, respectively;

FIGS. **11–14** show an example of an improvement in the lens assembly of FIGS. **1–10** with a mechanism for assuring occurrence of a transition from the zooming to the close-up position past the wide angle end, with FIG. **11** being a schematic diagram showing the normal and erroneous paths of movement of the engaging means of the tubular body in the contiguous guide slot means;

FIG. **12** being a perspective view of the main parts of the changeover mechanism, and FIGS. **13** and **14** being sectional views of the mechanism shown in two operative positions;

FIG. **15** is a longitudinal sectional view of a lens assembly provided with the changeover mechanism of FIGS. **11–14**;

FIG. **16** is a longitudinal sectional view of a lens assembly comprising another embodiment of the invention including a detent mechanism between the actuator member and the cam sleeve in the close-up position;

FIG. **17** is a perspective view of the tubular body of the embodiment of FIG. **16**;

FIG. **18** is a perspective view of the cam sleeve having a spring member fixedly mounted at the end thereof;

FIG. **19** is a perspective view of a contiguous sleeve having a cut-out therein; and

FIGS. **20–22** are developed representations showing the main parts for purposes of depicting the detent mechanism of this embodiment.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to the drawings, wherein similar parts are identified with like reference numerals throughout the various figures thereof, the present invention is shown in various embodiments by application thereof to interchangeable lens mounting systems for single lens reflex cameras.

The lens mounting assembly of the invention includes a tubular body **1** and an adapter **2** which is fixedly mounted at the rear end of the tubular body by means of screw fasteners **2***a*. The adapter **2** is equipped with coupling means to enable attachment of the lens assembly to a camera body (not shown).

A relay lens group **L1** is held within the tubular body. A screw fastener **2***c* is provided for fixing a cell member **2***b* containing the first lens group **L1** to the tubular body **1**. At the other end of the tubular body **1** there is shown a front barrel member **6** coupled in unison with a cell **4** containing a second lens group **L2** which is movable for effecting the focusing of the lens assembly. The cell **4** and the tubular body **1** are in threaded engagement with each other by means of helicoid portions **1***a* and **6***a*. A relay sleeve **2***d* has thereon a distance scale and is fixedly mounted on the tubular body **1** by a screw **2***e*.

Lens holder members **8** and **10**, shown in FIGS. **2** and **3**, respectively, containing a magnification varying lens group **L3** and an image shift compensating lens group **L4**, respectively, are movably fitted in the inner diameter of the tubular body **1**. The holder **8** of the third lens group **L3** is formed with four longitudinally elongated arms **8***a* which are slideably fitted in respective recesses **10***a* of the holder **10** of the fourth lens group **L4**.

Guide pins **8***b* and **10***c* arranged, respectively, on the holders **8** and **10** are engaged in respective slots **1***b* and **1***c* provided through the wall of the tubular body **1**, as shown in FIG. **4**, to control movement of the variator **L3** and the compensator **L4**.

Movably fitted on the outer diameter of the tubular body **1** is a cam sleeve **12**, shown in FIG. **5**, having a first cam slot **12***a* with a longitudinal orientation and a second cam slot **12***a'* having a transverse orientation. Third and fourth cam slots **12***b* and **12***b'* are also provided in the sleeve **12**. In the first cam slot **12***a* there is engaged the guide pin **1***d* mounted on the tubular body **1**. In the other cam slot **12***b* there is engaged the guide pin **8***b* which extends radially from the lens holder **8** through the cam slot **1***b* of the tubular body **1** (see FIG. **1**).

An actuating member **14** is fitted on the outer diameter of the lens barrel and it is provided with a longitudinal groove **14***a* into which the pin **6***b* of the front barrel member **6** enters. Axial movement of the actuator **14** leaves the second lens group **L3** stationery in its position. On the other hand, rotative movement about the optical axis causes axial movement of the front barrel **6** through the helicoid connection **1***a*, **6***a*.

An interlocking sleeve **15** is inserted into a space between the actuator **14** and the cam sleeve **12** and is fixedly secured to the actuator **14** by a fastener screw **14***b*. The interlocking sleeve **15** has an inner integral flange formed in a front end portion **15***a* thereof and arranged between an outward flange **12***c* of the cam sleeve **12** and a ring **16** which is fixedly fitted on the sleeve **12** so that the interlocking sleeve **15** is rotatable relative to the cam sleeve **12** while being restrained from axial movement.

As best seen in FIGS. **9** and **10**, a pin **17** and a spring **18** are arranged to constitute a locking means together with a detent hole **15***b* for simultaneous rotation of the actuator **14**, the interlocking sleeve **15** and the cam sleeve **12** in predetermined positions (the close-up positions). The pin **17** is movably fitted in a hole provided in the wall of a flange at the front end of the cam sleeve **12** and it is pressed by the spring **18** against the radial shoulder of the interlocking sleeve **15**, the arrangement

being such that when the actuator **14** is turned beyond the normal focusing range toward the close-up operating range, the pin **17** will enter the detent hole **15***b* and thereby a drive connection will be established between the actuator ring **14** and the cam member **12**.

In the operation of the embodiment of the mounting mechanism for the zoom objective of the present invention depicted in FIGS. **1–8**, when the actuator member **14** is moved axially, since the interlocking sleeve **15** is clamped between the ring member **16** and the radial flange of the cam member **12**, the actuator **14**, the interlocking sleeve **15** and the cam member **12** will be moved axially as a unit. The total axial movement of the actuating member will be defined by the longitudinal length of the path of possible relative movement of the pin **1***d* on the tubular body **1** in the first cam slot **12***a* of the cam member **12**.

As the actuator member **14** is axially moved from the telephoto position shown in FIG. **6** to the wide angle position of FIG. **7**, with the cam sleeve **12** being simultaneously axially moved and guided by the pin and slot connection **1***d*, **12***a*, the third lens group or variator L3 is axially and rotatably moved toward the front of the assembly by the pin **8***b* extending through both slots **1***b* and **12***b* in the tubular body **1** and the cam sleeve **12**, respectively. At the same time, the rotative component of motion of the variator lens cell **8** is transmitted through the elongated arms/fitted slots connection **8***a*, **10***a* of FIGS. **2** and **3** to the compensator lens cell **10** whereby the latter is caused to move axially toward the front of the assembly guided by the pin **10***c* engaging in the slot **1***c*.

It should be noted that in this embodiment, the lens holding members **8** and **10** are axially elongated in order to slideably engage with each other over the entire zooming range. Also, the armed portions **8***a* and the slotted portions **10***a* are maintained in overall surface contact with each other with the lens holding members **8** and **10** fitted in the common inner diameter of the tubular body **1**. Therefore, it is possible to hold the variator and the comparator in a truly normal position relative to the common optical axis during the entire range of movement thereof. It is also possible to avoid the existence of play between the lens holders and the tubular body while still permitting a smooth axial movement of the individual lens holders **8** and **10**. Furthermore, the motion of the member **8** may be transmitted to the member **10** with a relatively small amount of force.

When the actuating member **14** is rotated about the optical axis, motion of the actuating member **14** is transmitted through the pin/axial slot connection **6***b*, **14***a* in order to turn the front barrel **6** while simultaneously causing the barrel **6** to move axially by virtue of the helicoid coupling **6***a*, **1***a* thus moving the second group L2 in order to effect focusing to accommodate differing object positions.

It is noted that when in the focusing mode of operation, the third and the fourth lens groups L3 and L4 will remain stationary since, although the interlocking sleeve **15** is clamped by the cam member **12** and the restraining member **16**, it is rotatable so as not to transmit the driving torque of the actuating member **14** to the cam sleeve **12** and the lens holders **8** and **10**.

It is further noted that in this embodiment it is necessary to provide stopper means arranged between the interlocking sleeve **15** and the cam member **12** to enable focusing to be performed at any zooming station. This will be more fully explained hereinafter in connection with a further embodiment of the invention.

Since the linearly advancing operation of the actuator member **14** contributes only to movement of the cam sleeve **12** cooperative with the one cam follower pin **8***b* on the variator holder **8**, and since the pin **8***d* always occupies the intersection of the lead slot **1***b* and the second cam slot **12***b*, of which the latter is inclined with respect to the optical axis, the variator holder **8** will move axially at a faster rate than that of the actuator **14**. As a result, the total axial movement of the actuating member **14** may be made shorter than that of the variator holder **8**. The relationship between the amounts of movement of the actuator **14** and the lens holder **8** may be termed an accelerating relationship.

As a result of this accelerating function, it is possible to employ an increased range of variation of image magnification for an equivalent amount of movement of the actuator **14**. That is, the actuator may be shortened in the longitudinal direction to effect a zooming function equivalent to that provided by conventional devices.

In order to operate the lens assembly of the invention for close-up photography, the operator may first move the actuator **14** forwardly from the telephoto position to the wide angle position where the pin **1***d* on the tubular body **1** lies in the rear end of the longitudinal slot **12***a* and is aligned to the transverse slot **12***a'* to permit rotative movement of the cam sleeve **12**. As the actuating member **14** assumes an intermediate focusing position where the detent hole **15***b* is out of alignment with the pin **17**, when the actuating member **14** is turned to the lower limit of the normal focusing range, the interlocking sleeve **15** will be drivingly connected to the cam sleeve **12** by the pin **17** engaging in the detent hole, as shown in FIG. **10**, and thus there will be completed the selection of the close-up range.

As the actuator member **14** is further rotated, the third lens group L3 is moved forwardly without the accompanyment of any rotative movement because of the guidance of the pin **8***b* by the axial slot **1***b'*. Therefore, the fourth lens group L4 is maintained stationery in the same position when in the wide angle setting during close-up operation.

Thereafter, when the actuating member **14** and the interlocking sleeve **15** are to be returned from the close-up range to the zooming range, the actuating member **14** is turned in the direction opposite to that indicated by the arrow B to move the detent hole **15***b* away from the pin **17** as the hemispheric head of the pin **17** is slideably moved on the tapered surface **15***c* against the force of the spring **18** so that the interlocking sleeve **15** is then disconnected from the cam sleeve. The pin **1***d* returns from the solid-line position to the dashed-line position shown in FIG. **8** and thus the zooming range is rendered operative.

It will be seen from the foregoing that the present invention provides for the fixed sleeve **1** having the cammed portions **1***b* and **1***c* controlling movement of the optical lenses L3, L4 which contributes to change of the image magnification and image shift compensation. Only one operating member in the form of an outer sleeve on the fixed sleeve **1** is sufficient to effect zooming, focusing and close-up operation selectively. For this purpose, the camming member **12** is arranged to cooperate with the operating member **14** and it is formed with cammed portions **12***a'*, **12***b* and **12***b'* controlling the transition to and the adjustment of the close-

up range. Furthermore, there is provided interlocking means **15***c*, **17** and **18** for placing the operating member into and out of drive connection with the cam member **12**. When it is desired to shift the operating member **14** from one range to another, the interlocking means is rendered either effective or ineffective in order to make it possible for zooming, focusing and close-up adjustments to be consecutively performed.

With this construction and arrangement, the features of the present invention may be embodied in a fixed sleeve **1**, a cam sleeve **12**, operating member **14** and lenses L2, L3 and L4 alone. Thus, a relatively simple structure may be provided for the mounting mechanism.

The present invention has been described in connection with the embodiment of FIGS. **1–8** as applied to a four-component zoom objective with a focusing lens, variator, compensator and relay lens. However, it should be understood that the invention is applicable to a three-component zoom objective with the exclusion of the relay lens. Further, the invention is described in the form of an interchangeable lens assembly as an example of an embodiment thereof but it should be understood that it is applicable to a built-in zoom lens assembly for photographic instruments.

FIGS. **11–15** show an example of improvements in the first embodiment previously described herein. Since in the embodiment of FIGS. **1–10**, the direction of movement of the actuator is changed through a right angle as a transition occurs between the zooming and the close-up ranges, and since the pin **1***d* engaging in the slots **12***a*, **12***a*′ is round in cross-sectional configuration, a looseness or play is produced when the pin **1***d* enters the corner of the slots **12***a* and **12***a*′ as shown in FIG. **11**. Because of this there exists a rather high possibility that there will occur abnormal transition particularly when the zooming range is exchanged for the close-up range.

FIG. **11** shows two extreme paths of movement of the pin **1***d* as it is guided by the slots **12***a* and **12***a*′, one of which is indicated by perpendicularly crossed lines X and Y and considered to be normal, and the other of which is indicated by the curved line Z. In the latter connection it should be explained that the actuator **14** may change its movement from the axial direction to the transverse direction when it reaches a point at a distance equal one-half of the width of the slot **12***a*′ ahead of the wide angle position. In other words, the actuator **14** while having already entered the close-up range may be further moved axially forwardly to effect the balance of the zooming function. This gives rise to a problem in that as zooming is being performed in the close-up range it becomes difficult to perform a focusing adjustment for close-ups.

FIGS. **12–14** show an example of a mechanism to overcome this drawback. In FIG. **12**, the same reference numerals are utilized to denote similar parts as those depicted in FIGS. **1–10**. As is also shown in FIG. **15**, the tubular body **1** is provided with sensing means **20**, **21**, **22** at the forward part thereof. The sensing means is arranged in axial alignment with the front ends of the overlapped cam sleeve **12** and interlocking sleeve **15** so that the position of the actuator **14** in the axial direction may be sensed. The sensing means comprises the ring member **20** fixedly mounted on the tubular body **1** and having a hole or groove in which a flanged pin **21** is movably fitted with a spring **22** urging the pin **21** to project outwardly of the ring **20** toward the cam and interlocking sleeves **12** and **15**.

The cam sleeve **12** is provided with a cut-out **12***f* formed in a front end portion thereof and arranged in alignment with the projected portion of the pin **21** of the sensing means. The front end surface **15***e* of the interlocking sleeve **15** is also configured with a slope **15***f* radially aligned with the cut-out **12***f* intervening between axially differentiated stages **15***g***1** and **15***g***2**.

With the mechanism described, as the actuator **14** is moved forwardly when it reaches the wide angle position the projected portion of the pin **21** will be pushed into the hole or groove by the action of the tapered surface **15***f* of the interlocking sleeve **15**. Assuming a situation before the actuator **14** has been moved forwardly through the full range to the wide angle position, i.e. after having been stopped at a position within a range of distances of from a to b as shown in FIG. **11**, if the actuator is turned about the optical axis then the projected portion of the pin **21** engages the cut-out **12***f* to hinder further movement of the actuator **14**. That is, as shown in FIG. **13**, although the center of the pin **1***d* lies at a point O_3 in the range of a to b in FIG. **11** in order to permit transverse movement of the actuator **14**, the pin **21** will be allowed to enter the cut-out **12***f* so that the actuator **14** cannot be fully turned. Then when the actuator **14** is turned in a reverse direction and followed with actual movement to the wide angle end, the pin **21** is pushed by the tapered surface **15***f* of the interlocking sleeve **15** against the force of the spring **22** thereby being disengaged from the cut-out **12***f* to permit the full range of close-up operation.

FIGS. **16–22** show another embodiment of the change-over mechanism for selection of the zooming and close-up ranges. In this embodiment, the variator and the compensator holders are of different construction from that shown in FIGS. **2** and **3**.

The intermediate or cam member **12** is not only provided with the guide slots **12***a*, **12***a*′, **12***b*, **12***b*′ but it is also provided with a new guide slot **12***c* into which a pin **10***c* on the compensator holder **10** will extend through the guide slot **1***c* of the tubular body **1**. The guide slot **12***c* is arranged contiguously to a transverse guide slot **12***c*′.

On the other hand, the variator and compensator holders are modified so that the arms and the open slots are not in surface contact with each other. That is, the armed portions **8***a* although lying in the respective cut-outs **10**′ formed in the portions of the compensator holder **10** are arranged so as not to constitute the motion transmitting intermediary as the cut-outs **10**′ are over-slotted. With this construction, axial movement of the compensator is controlled by the pin **10***c* engaging in the guide slots **12***c* and **1***c*. The two methods of axially moving the compensator holder **10**, **10**′ each have advantages and disadvantages and the selection of either one of the methods may be optional depending upon the type of mechanical mounting involved.

Referring now to the axial sectional view of FIG. **15**, it is noted that the operating means (the actuator **14** and the inner sleeve **15** contiguous thereto) and the cam sleeve **12** are maintained in threaded relationship with a short pitch. The device includes a diaphragm unit **22** carried by the fixed support member **26**, a diaphragm presetting ring **23** and a signal transmitting member **24**, these parts constituting a mechanism of known construction in the art whose detailed explanation is therefore omitted. In FIGS. **16–22**, a spring member **25**, an interconnecting plate **26** and a cut-out **15***h* of the cam sleeve **15** constitute an interlocking mechanism for the

operating means and the cam member when in the close-up range. The spring member **25** is affixed to the cam member **12** at one end, i.e. the front side thereof, by means of screws and the interconnecting plate **26** is affixed to the tubular body **1** also at one end, i.e. the object side, by means of screws.

The free end of the spring member **25** is formed with an outwardly folded portion **25***a* which has a spring property so that when the axial movement of the actuating member **14** (**15**) to the wide angle position is followed by rotative movement about the optical axis, the actuating member **14** and the cam member **12** will be connected to each other and will be simultaneously rotated about the optical axis in order to effect close-up operation guided by the pin **1***d* on the tubular body **1** engaging in the transverse slot **12***a*′ of the cam sleeve **12**.

With reference to FIGS. **20–22**, this connecting operation is explained with greater detail and FIG. **20** is a developed view of the tubular body **1** and the cam member **12** with the actuating member **14** in the telephoto position showing an arrangement of the various parts constituting the interlocking mechanism. In this state, the free end **25***a* of the spring member **25** is seated in the cut-out **15***h* formed in an end portion of the cam member **15**.

FIG. **21** is a developed view showing the changed positions of the various parts when the actuating member is axially moved from the telephoto to the wide angle position. In the zooming range between the positions shown in FIGS. **21** and **22**, only the longitudinal slot **12***a* of the cam member **12** is operative with pin **1***d* so that while the free end **25***a* of the spring **25** is engaged in the cut-out **15***h*, the cam member **12**, the intermediate sleeve **15** and the actuator member **14** are moved as a unit. During focusing, the actuator member **14** and the intermediate sleeve **15** are axially moved relative to the cam member **12**. However, since the pitch of the screw threads is made very fine, the influence of this movement upon the optical system will be negligible. It should be noted that the pin **27** shown in FIG. **16** is a stopper means between the cam member **12** and the actuating member **14** or the intermediate sleeve **15** during focusing. This pin **27** is fixedly mounted to the cam member **12** and positioned so as to engage in the hole **15***i* formed in the front end portion of the intermediate sleeve **15**.

Therefore, during focusing, the pin **27** shown in FIG. **20** is movable from one end of the hole **15***i* to the other. Within this range, the actuating member **14** and the intermediate sleeve **15** are moved freely relative to the cam sleeve. With this angle of rotation, the focusing lens L2 is caused to axially move through a distance corresponding to the pitch of the helicoids **6***a* and **1***a* between the front barrel **6** and the tubular body **1**.

When the actuating member **14** is next turned about the optical axis from the wide angle position, the member **14** and the intermediate sleeve **15** abut with the stopper pin **27** against the end of the opening **15***i*. Upon further rotation of the actuating member **14** about the optical axis, the pin **1***d* moves along the transverse guide slot **12***a*′ and the spring member **25** will ride upon the upper part of the interconnecting plate **26** (see FIG. **22**).

The rotative movement of the actuating member **14** and the intermediate member **15** about the optical axis is also transmitted by the spring member **25** to the cam member so that they turn as a unit about the optical axis. By rotation of the cam member **12** due to this connecting function, the pin **8***b* on the variator holder **8** is moved along the cross point of the guides **12***b*′ and **1***b*′ and the lens holder **8** moves in the axial direction toward the front of the lens assembly with variation of the spacing between the variator and the compensator thus effecting close-up operation.

To return from the close-up positions to the zooming positions, the actuating member **14** is turned in the reverse direction until the pin **1***d* reaches the changeover point of the guides **12***a* and **12***a*′ shown in FIG. **21** where the spring member **25** is disengaged from the interconnecting plate **26**. By axially moving the actuating member **14**, the cam sleeve **12** is restricted from rotative movement about the optical axis and only the axial movement is effective to achieve zooming.

It will be seen from the foregoing that the zoom lens assembly of the invention is capable of consecutively performing zooming operation followed by close-up operation and that therefore it is superior in its manageability with a mechanism for connecting and separating the actuating means and the intermediate member when in the transit to the close-up range being simple in structure and capable of meeting the demands of the market for a low price and high quality product.

Furthermore, the magnification varying lens holding member **8** and the image shift compensating lens holding member **10**, **10**′ can be accelerated in axial movement by engagement of the pins **8***b* and **8***c* in the guide slots **1***b*, **12***b*, **1***c*, **12***c* with the advantage that the longitudinal length of the lens assembly may be shortened to a considerable degree.

While specific embodiments of the invention have been shown and described in detail to illustrate the application of the inventive principles, it will be understood that the invention may be embodied otherwise without departing from such principles.

What is claimed is:

1. A zoom lens assembly having a single operational member adapted to selectively perform zooming operation and close-up operation comprising:

(a) first and second lens mounting members for holding first and second lens groups movable for zooming operation with variation of image magnification while image shift is compensated for respectively;

(b) a cylindrical member in which said first and said second lens mounting members are fitted and which has first and second guide means for guiding said first and said second lens mounting member, with third guide means being formed contiguous to said first guide means for guiding said first lens mounting member to close-up range;

(c) an intermediate member fitted between said operational member and said cylindrical member having contiguous first and second guide means formed therein to guide said operational member either axially or transversely, said first or said second guide means being penetrated by engaging means on said cylindrical member, and having third and fourth guide means cooperative with said first guide means of said cylindrical member to control movement of said first lens mounting member;

(d) interlocking means for said operational member and said first lens mounting member, and engaging means on said first lens mounting member extending through said first guide means of said cylindrical member to engage said third or said fourth guide means of said intermediate member so that as

said operational member is actuated, said first lens mounting member is moved;

(e) drive connection means between said first lens mounting member and said second lens mounting member, one of said two lens mounting members being provided with axially elongated armed portions, the other of said lens mounting members having engaging portions for engagement with said armed portions so that motion of said first lens mounting member is transmitted to said second lens mounting member; and

(f) interlocking means for close-up operation arranged upon changeover of said operational member from the zooming range to the close-up range to interlock said intermediate member and said operational member with each other in transverse directions.

2. A zoom lens assembly according to claim **1**, wherein said interlocking means comprises an engaging pin provided in an opposite position to said operational member and said intermediate member, and a detent portion for engagement with said engaging pin, said operational member when changed over to close-up range being interlocked with said intermediate member.

3. A zoom lens assembly according to claim **1**, wherein said third guide means of said cylindrical member is provided in axially parallel relationship therewith so that when said operational member is actuated for close-up operation, the spacing between said first and said second lens groups is varied as the first lens group is axially moved while the second lens group remains stationary at a zooming position.

4. A zoom lens assembly according to claim **1**, further including means for changing over to said second guide means only when said engaging means of said cylindrical member has come to a predetermined position of said first guide means of said intermediate means.

5. A zoom lens assembly according to claim **4**, including sensing means comprising:

(a) a pin positioned to face at both of said operational member and said intermediate member and urged to move in an axial direction while being supported by said cylindrical member;

(b) a recess formed in a portion of said intermediate member to engage said pin, said recess engaging said pin when said engaging means of said cylindrical member is out of a predetermined position of said first guide means of said intermediate member, said operational member being thereby incapable of performing closeup operation; and

(c) means for releasing said pin from the engagement with said recess, said means operating to take said pin out of the engagement with the recess when said operational member is changed from zooming range to close-up range.

6. A zoom lens assembly having a single operational member capable upon rotation thereof about an optical axis of said lens assembly to effect focusing of said assembly and upon axial movement thereof to effect zooming operation of said assembly, comprising:

(a) an elongated cylindrical member having first and second guide means for controlling axial movement of first and second movable lens groups contributing to a change of image magnification and to image shift compensation during zooming operation;

(b) first and second lens mounting members for containing said first movable lens group and said second movable lens group, said lens mounting members being individually fitted in the inner diameter of said cylindrical member;

(c) means for controlling the movement of said first lens mounting member by the axial movement of said single operational member, said means including a pin member radially extending from said first lens mounting member and engaging in said first guide means so that it is controlled by said first guide means;

(d) means for controlling the movement of said second lens mounting member by said first lens mounting member, said controlling means comprising arms axially extending from one of said two lens mounting members to engage respective cutouts formed in the other of said lens mounting members in surface-contacting relation, said first lens mounting member being adapted to be axially moved while turned about said optical axis to impart rotative motion to said second lens mounting member;

(e) an intermediate member arranged between said cylindrical member and said operational member, said intermediate member being provided with axially elongated first guide means and second guide means inclined with respect to said optical axis, with engagement means extending radially from said cylindrical member passing through said first guide means of said intermediate member and with engagement means extending radially from said first lens mounting member passing through said second guide means of said intermediate member after having passed through said first guide means of said cylindrical member so that said first lens mounting member is accelerated in axial movement of the combined action of both guide means of said intermediate and said cylindrical members; and

(f) means for controlling movement of said second lens mounting member comprising engagement means extending radially from said second lens mounting member and said second guide means of said cylindrical member, with said engagement means engaging in said second guide means to control movement of said second lens mounting member.

7. A zoom lens assembly having a single operational member adapted to selectively perform zooming operation and closeup operation including

(a) first and second lens mounting members for holding first and second lens groups movable for zooming operation with variation of image magnification while the image shift is compensated respectively;

(b) a cylindrical member in which said first and said second lens mounting members are fitted;

(c) a third lens mounting member for holding a third lens movable for focusing; and

(d) first guide means responsive to said operational member for axially moving said third lens mounting member to effect focusing, said zoom lens assembly comprising:

(A) an intermediate member fitted in a space between said cylindrical member and said operational member; said intermediate member having second guide means for guiding said single operational member responsive to zooming operation and closeup operation, and third and fourth guide means for guiding said first and second

lens mounting members responsive to zooming operation and closeup operation;

(B) interlocking means for interlocking said operational member and said intermediate member, said interlocking means being interlocked when said operational member is operated beyond the normal focusing range toward the closeup operating range;

(C) fifth guide means for changing the distance between said first and second lens mounting members in response to closeup operation of said operational member, said fifth guide means being formed continuously with at least one of said third and fourth guide means, at least one of said lens groups being shifted to the closeup direction when said interlocking means is made effective and said intermediate member is guided in proportional relationship with said fifth guide means.

8. A zoom lens assembly according to claim **7** or **1**, wherein said interlocking means comprises:

(a) a spring member affixed to said intermediate member; and

(b) an interconnecting plate affixed to said cylindrical member, and arranged so that the movement of said operational member to one terminal end of the zooming range is followed by a rotative movement thereof, said spring member riding thereon to interlock said intermediate member and said operational member.

* * * * *

United States Patent [19]

Dziemba

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[45] **Dec. 29, 1981**

[54] ADJUSTABLE OBJECTIVE HOLDER

[76] Inventor: **Peter Dziemba,** Ahornweg 17, 6350 Bad Naubeim, Fed. Rep. of Germany

[21] Appl. No.: **130,258**

[22] Filed: **Mar. 13, 1980**

[30] **Foreign Application Priority Data**

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[51] **Int. Cl.**[3] **G02B 7/02**

[52] **U.S. Cl.** ..... **350/255;** 74/99 R; 248/178

[58] **Field of Search** ..... 350/255, 429–430, 350/247, 114–116; 354/195, 197–198, 286; 352/140; 353/76, 101; 74/96, 99 R, 99 A; 248/178, 183, 185, 585, 592

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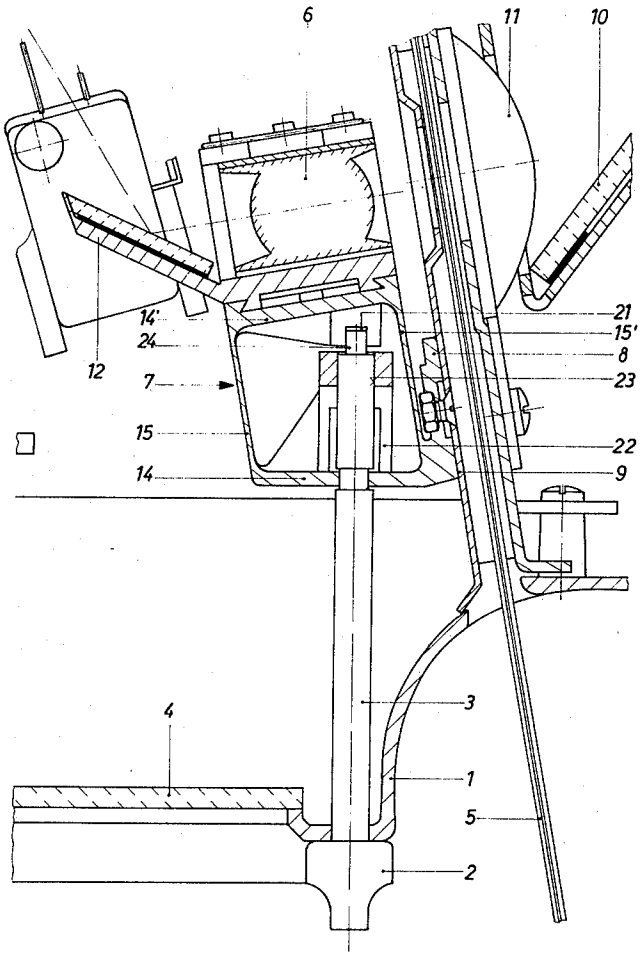
Attorney, Agent, or Firm—Michael J. Striker

[57] **ABSTRACT**

The adjustable objective holder for optical projectors has a focussing support formed as a single piece defining two pairs of juxtaposed walls forming a parallelogram. The walls of one pair are rigid whereas the walls in the other pair are flexible. One rigid wall is fixedly mounted to the apparatus and supports for rotation a control shaft. The opposite rigid wall has on its inner surface a control groove which engages an eccentric formed on the end of the control shaft so that during the rotation of the eccentric the flexible walls are uniformly swung and due to the parallel linkage the movable rigid wall together with the objective performs a linear movement at right angles to the transparency.

7 Claims, 4 Drawing Figures



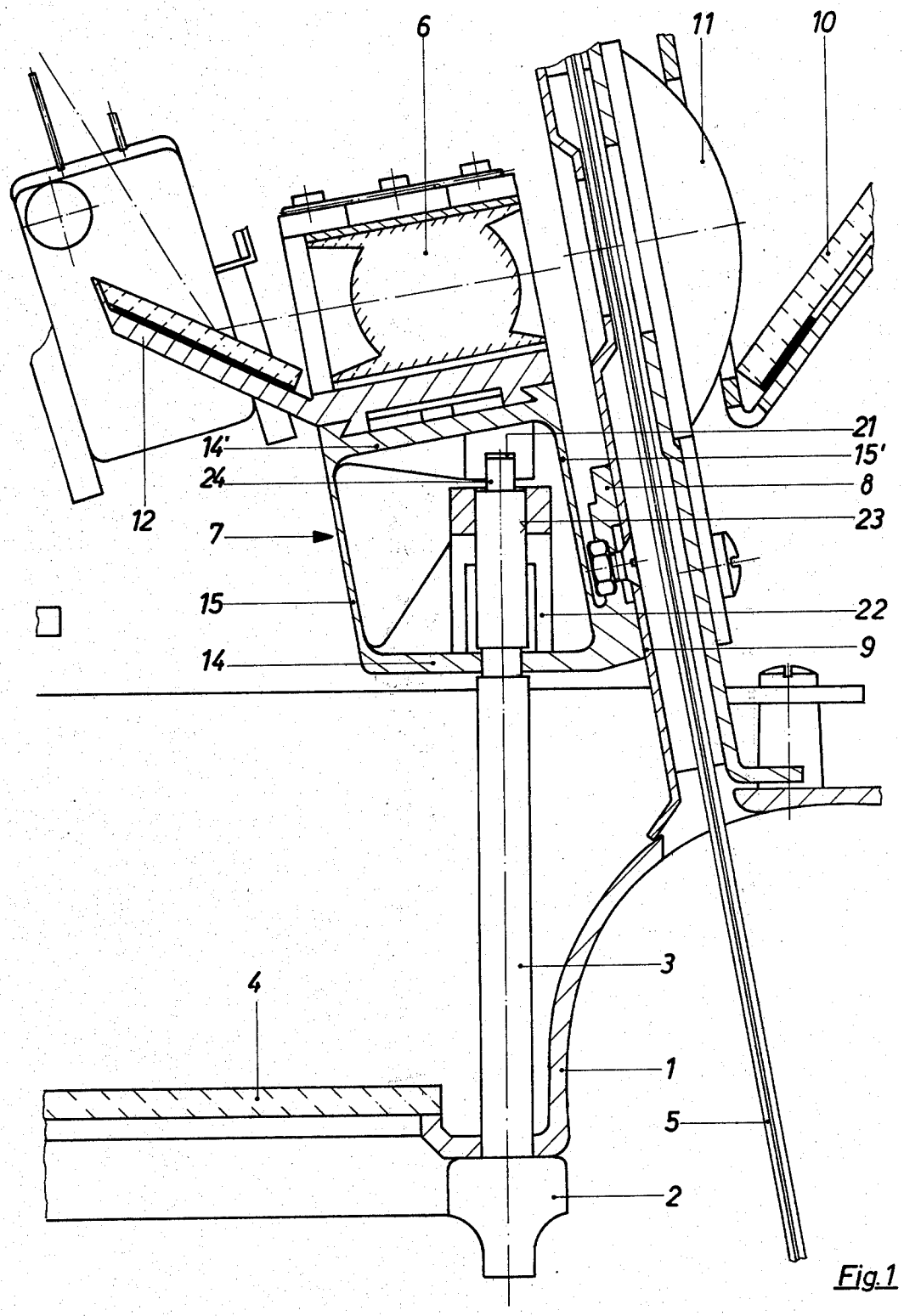


Fig.1

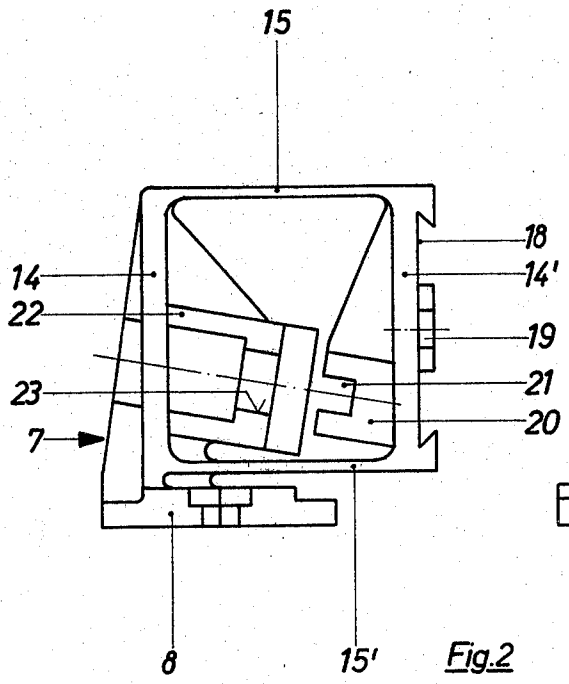


Fig.2

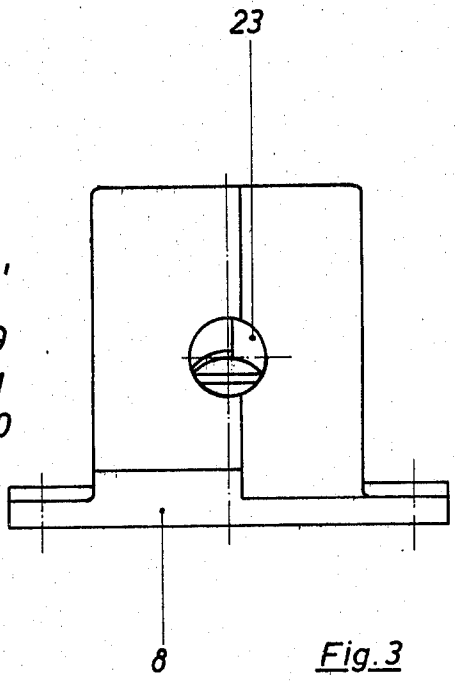


Fig.3

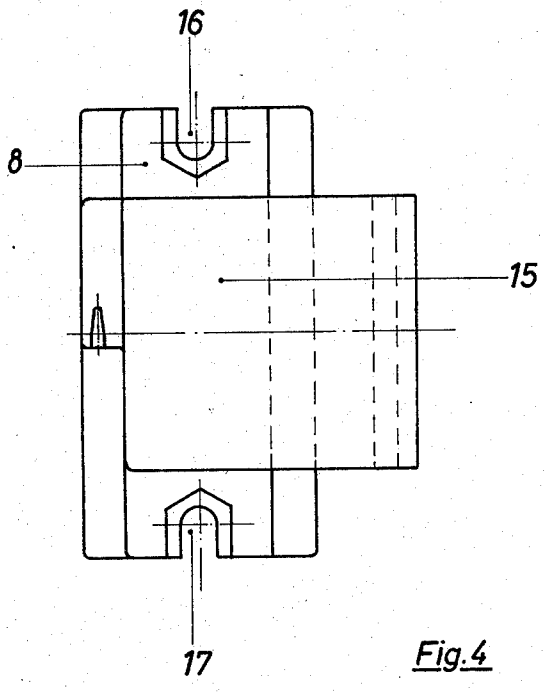


Fig.4

ADJUSTABLE OBJECTIVE HOLDER

BACKGROUND OF THE INVENTION

This invention relates in general to optical devices and in particular to an adjustable objective holder in such devices like microfiche readers, overhead projectors and the like in which the objective has to be displaceable at right angles to a film carrier in order to adjust a sharp focus.

The objective holders or optical devices of the aforedescribed type are generally known in the art. The construction of such holders, however, has to meet various contradicting requirements which are frequently difficult to meet. For instance to achieve a uniformly sharp projected image it is necessary that the objective be exactly displaceable at right angles to the film. Also, for the sake of a good quality of the projected image the objective holder is to be designed without any play. Inasmuch as optical devices in many cases are subject to vibrations, the objective holder has to be designed such as to prevent any unintentional displacement of the objective which would require a repeated manual readjustment of the sharp focus. In the case of microfiche readers it is frequently also desired that the objective be changeable in a simple and fast manner for another one. Furthermore, since optical apparatuses are mostly mass produced, it is of importance that in order to achieve a low price the objective holder be also inexpensive in manufacture.

Prior art optical devices only partially meet the above-mentioned requirements. For example, a conventional objective holder employs a tubular piece having an inner thread in which the objective which is provided with an outer thread is screwed. The focussing is made exactly as in a photographic camera by turning the objective in the tubular piece.

Such a known objective holder, however, requires high manufacturing tolerances and is therefore expensive to manufacture. For instance, in microfiche film readers in many cases only a small marginal area of the objective is used for the transmission of the light beam. Furthermore, the objectives used in such mass produced optical devices have not for economic reasons the same optical quality over their entire lens surface. It may happen, therefore, that in an objective which is focussed by turning, the projected light beam passes through such an area of the objective surface in which the optical quality is relatively poor.

Also known is an objective holder which axially displaces the objective lens in order to adjust the sharp focus. This arrangement has the advantage that in the case of an assymetric transmission of the light beam it is possible during the installation of the objective into the holder to select such a position or range on the objective surface which ensures the best quality of the projection. This selected range or position is not changed during the axial displacement of the objective. Conventionally, the objective holders of this kind are assembled of two sleeves of which the inner sleeve supports the objective and is provided with a groove cooperating with an excenter so that by operating the excenter by means of an adjustment shaft the inner sleeve is axially displaced. This known construction also requires an extremely high manufacturing accuracy and therefore is also expensive. Any play between the two sleeves produces optical deterioration because due to the one-sided

engagement of the excenter the inner sleeve has a tendency to tilt relative to the outer sleeve.

SUMMARY OF THE INVENTION

It is, therefore, a general object of the present invention to overcome the aforementioned disadvantages.

More particularly, it is an object of the invention to provide an improved objective holder of the aforedescribed type which enables an exact focus adjustment by a nonrotational displacement move.

Another object of this invention is to provide such an objective holder which is compact in structure and unsensitive to vibrations.

Still another object of this invention is to provide such an improved objective holder which is inexpensive to manufacture.

In keeping with these objects and others which will become apparent hereafter, one feature of the invention resides in the provision of a focussing support having two pairs of juxtaposed walls forming a parallelogram; one pair of the walls being rigid and the other pair being flexible, the outer surface of one of the rigid walls including means for mounting an objective thereon and the inner surface of this one rigid wall being formed with a control groove or bore extending transversely relative to the outer surface, the other rigid wall supporting for rotation a control shaft having an eccentric end portion, the eccentric portion engaging the control bore to swing the pair of flexible walls and thus to displace the one rigid wall during the rotation of the shaft, and means for fixedly mounting the other rigid wall in the optical device.

The advantageous features of this invention result from the application of the principle of a parallel linkage such as used for example in drafting machines, in a mounting support or holder for an objective. Two parallel pairs of walls are lined together into a parallelogram to provide parallel motion of the objective supporting wall at right angles to the film carrier. When this focussing parallel linkage support is die cast as of a suitable synthetic material the manufacture is relatively simple without requiring highly accurate machining and consequently the resulting one-piece objective support of this invention enables the production of high-quality optical devices at reduced costs.

Due to the fact that the objective is displaced by means of an excenter which engages a control groove or bore in the rigid supporting wall of the focussing support, it is possible to rotate the control knob on the shaft of the excenter in both opposite directions without encountering any limit stop. The objective itself during the continuous rotation of the control eccentric performs only a straight reciprocating movement. As a consequence, the optical apparatus equipped with the objective holder of this invention is safeguarded against operational errors and cannot be damaged by improper turning of the focus control knob.

It is also of advantage that to adjust the focus of the objective only minute frictional forces are present since the objective holder operates without any guiding grooves. In spite of this easy control, there is no danger of a self-induced midadjustment of the objective inasmuch as the frictional forces in the bearing of the control shaft are sufficient to hold the objective in any of its adjusted positions. Furthermore, since the objective is held in the desired position without the use of any guiding surfaces, it cannot become jammed by thermal effects on such surfaces when the optical apparatus radi-

ates heat during its operation. By virtue of the fact that the objective performs a straight axial displacement only without any rotational movement to attain its sharp focussing position, it is possible prior to its installation into an optical apparatus which employes assymetrical light beams, to select such a range of the objective surface which exhibits the best optical quality.

As an additional advantage of the objective holder of this invention should be mentioned also the fact that it is insensitive to vibrational effects and requires negligible setting work or expenditures during its installation in the optical apparatus. The construction of the focussing support has a low mass and by virtue of the fact that the whole focussing support can be manufactured exclusively of a suitable plastic material, it has a negligible weight and is therefore suitable particularly for portable optical devices.

In a preferred embodiment of this invention the control shaft is supported for rotation in a bearing sleeve formed in a projection extending from the inner surface of the fixed rigid wall of the support and terminating close to the control groove for the eccentric in the opposite rigid wall carrying the objective. This arrangement has the advantage that the swinging movement of the flexible walls of the support has only a negligible influence on the position of the eccentric. Accordingly, it is only the rotary movement of the eccentric which changes the sharp focus adjustment and not the pendulum-like movement of the flexible walls.

A particularly inexpensive manufacture of the objective holder of this invention will result when, according to another feature of this invention, the entire focussing support is manufactured as a single piece by injection molding of a suitable plastic material. It is also possible to employ in this injection molding process a complementary form having a configuration which eliminates any movable part of the casting die thus further reducing the manufacturing cost and ensuring a long working life.

According to still another feature of this invention, the rigid wall of the focussing support which carries the objective is shaped with a dove-tail guiding groove engaging a correspondingly shaped mounting plate of the objective. In this manner, the objective can be easily exchanged and mounted on the focussing support.

It is also advantageous when an arresting member is provided between the dove-tailed guiding surfaces of the objective in its mounting position. This arresting member determines automatically the working position of the objective and of its supporting plate relative to the dovetailed guide.

According to still another feature of this invention the whole focusing support is made of a material which is elastically deformable. Due to this elastic deformability the distance between the objective and the film carrier in any focussing position is maintained stable inasmuch as the walls exert a small bias against the eccentric and against the control shaft. In this manner any play in the objective holder of this invention is completely eliminated.

The novel features which are considered as characteristic for the invention are set forth in particular in the appended claims. The invention itself, however, both as to its construction and its method of operation, together with additional objects and advantages thereof, will be best understood from the following description of specific embodiments when read in connection with the accompanying drawing.

BRIEF DESCRIPTION OF THE DRAWING

FIG. **1** is a sectional top view of a portion of a film reader including the objective holder of this invention;

FIG. **2** is a top view of the adjustable focussing support in the holder of this invention;

FIG. **3** is a side view of the support of FIG. **2**; and

FIG. **4** is another side view of the support of FIG. **2**.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring firstly to FIG. **1** there is illustrated a housing **1** of a microfiche film reader having its front wall provided with a screen **4** of a ground glass plate upon which the projected picture is displayed. A control knob **2** on a control shaft **3** for sharp focussing projects beside the screen **4**.

A lateral wall of the housing **1** a portion of which is also illustrated in the drawing, is provided with means for guiding a film frame or casing **5** enclosing a transparent microfiche to be read. By means of nonillustrated levers the film casing is movable in two axial directions. An objective **6** mounted on a focussing support **7**, serves for the projection of the light beam passing through the transparent microfiche. The focussing support **7** includes a mounting base **8** which is fastened to a metal sheet **9** secured to the housing **1** of the optical apparatus.

For the sake of clarity it should be also mentioned that the projection is effected by a light beam transmitted from non-illustrated lamp and reflected by a reflecting mirror **10** through a light condenser **11** which directs a uniform light beam through the transparent image and through the objective **6**. Behind the objective **6** the light is again reflected by a reversing mirror **25** to another nonillustrated mirror from which the projected image is reflected on the screen **4**.

The essential part of the objective holder of this invention is the aforementioned focussing support **7** which is illustrated also in detail in FIGS. **2** to **4**. As seen from FIG. **2**, the focussing support **7** has two pairs of juxtaposed walls **14**, **14'** and **15**, **15'** forming together a parallelogram. Walls **14** and **14'** have a relatively large thickness whereas the other pair of walls **15** and **15'** are reduced in thickness and are therefore flexible. The edge of one rigid wall **14** is integral with a mounting base **18** forming therewith a substantially right angle. This base plate **8** as seen particularly from FIG. **4** is provided with two indentations or recesses **16** and **17** for receiving fastening screws by means of which the whole objective holder is secured to the housing of the microfiche reader. The outer surface of the opposite rigid wall **14'** is formed with a dove-tailed guide **18** for receiving the correspondingly shaped supporting plate **12** of the objective. An arresting member **19** is formed in the wall **14'** to arrest the objective plate **12** in its working position. The inner surface of the rigid wall **14'** is formed with an inwardly projecting block **20** including a control groove **21** extending parallel to the flexible walls **15** and **15'**.

Also, the inner surface of the rigid wall **14** is shaped with an inwardly directed block **22** extending in close proximity to the control groove **21** and defining a through bore **23** directed against the control groove **21** and serving as a bearing sleeve for control shaft **3**. The free end of the shaft **3** projects through the front wall of housing **1** and supports the control knob **2**.

Referring back to FIG. **1**, the inner end of shaft **3** has the form of an eccentric **24** which engages the control

groove **21**. By rotating the control knob **2** and thus the shaft **3**, the periphery of eccentric **24** displaces the block **20** and thus causes a swinging movement of the flexible walls **15** and **15'** and a corresponding movement of the rigid wall **14'** which is displaced parallel to the opposite rigid wall **14**. Due to the fact that flexible walls **15** and **15'** are integrally linked to the stationary rigid walls **14** and **14'**, the latter performs a rectilinear parallel movement which changes the distance of the objective **6** from the film casing **5**. The rigid walls as well as the effective flexible walls **15** and **15'** have the same lengths linked together at right angles. As a consequence, the resulting parallelogram ensures that the wall **14'** is axially displaced at a constant angle relative to the film in the casing.

As mentioned above, the whole focussing support **7** is produced as a single piece preferably by injection molding of a suitable plastic material.

It will be understood that each of the elements described above, or two or more together, may also find a useful application in other types of constructions differing from the types described above.

While the invention has been illustrated and described as embodied in a specific example of the objective holder, it is not intended to be limited to the details shown, since various modifications and structural changes may be made without departing in any way from the spirit of the present invention.

Without further analysis, the foregoing will so fully reveal the gist of the present invention that others can, by applying current knowledge, readily adapt it for various applications without omitting features that, from the standpoint of prior art, fairly constitute essential characteristics of the generic or specific aspects of this invention.

What is claimed as new and desired to be protected by Letters Patent is set forth in the appended claims:

1. An adjustable objective holder for use in a projecting device, comprising: a focussing support having two pairs of juxtaposed walls forming a parallelogram; one pair of said walls being rigid and the other pair of said walls being flexible; the outer surface of one of said rigid walls including means for mounting an objective thereon and the inner surface of said one rigid wall being formed with a control groove; the other rigid wall supporting for rotation a control shaft having an eccentric end portion, said eccentric portion engaging said control groove to swing said pair of flexible walls and thus to displace along a straight line said one rigid wall during the rotation of said shaft; and means for fixedly mounting said other rigid wall in said device.

2. The objective holder as defined in claim **1** wherein the inner surface of said other rigid wall is formed with a bearing block defining a through bore directed toward the control groove, at least a portion of said through bore forming the bearing sleeve for said control shaft and said bearing sleeve being located in close proximity to said control groove.

3. The objective holder as defined in claim **1** wherein said focussing support is made as a single piece of a plastic material shaped by an injection molding process.

4. The objective holder as defined in claim **1** wherein said mounting means on said outer surface of said one of said rigid walls is a dovetail guide for engaging a correspondingly shaped carrier plate for said objective.

5. The objective holder as defined in claim **4** wherein said dovetail guide includes an arresting member for locking the carrier plate for said objective in a fixed mounting position.

6. The objective holder as defined in claim **1** wherein said focussing support is made of an elastically deformable material for exerting a bias on said eccentric in any position of the latter.

7. The objective holder as defined in claim **1** wherein said means for fixedly mounting includes a mounting base integral with an edge portion of said other rigid wall.

* * * * *

United States Patent [19]

Yamazaki et al.

[11] **4,293,185**

[45] **Oct. 6, 1981**

[54] **OPTICAL CONVERSION ASSEMBLY FOR OBJECTIVE CAMERA LENSES**

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[73] Assignee: **Minolta Camera Kabushiki Kaisha**, Osaka, Japan

[21] Appl. No.: **106,444**

[22] Filed: **Dec. 26, 1979**

[30] **Foreign Application Priority Data**

Jan. 12, 1979 [JP] Japan ..... 54-3276[U]

[51] **Int. Cl.**[3] **G02B 21/00**

[52] **U.S. Cl.** **350/18**; 350/53

[58] **Field of Search** 350/18, 53, 410

[56] **References Cited**

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Primary Examiner—John K. Corbin
Assistant Examiner—Matthew W. Koren
Attorney, Agent, or Firm—Jackson, Jones & Price

[57] **ABSTRACT**

An optical conversion attachment assembly for objective camera lenses is provided to convert a lens into a monocular optical device. A camera exchangeable lens can be detachably mounted on the barrel of an optical attachment having an erecting prism and an ocular system to vary the diopter power. The optical attachment further provides a device for automatically contacting and holding the diaphragm of the camera exchange lens at a maximum aperture opening.

8 Claims, 2 Drawing Figures

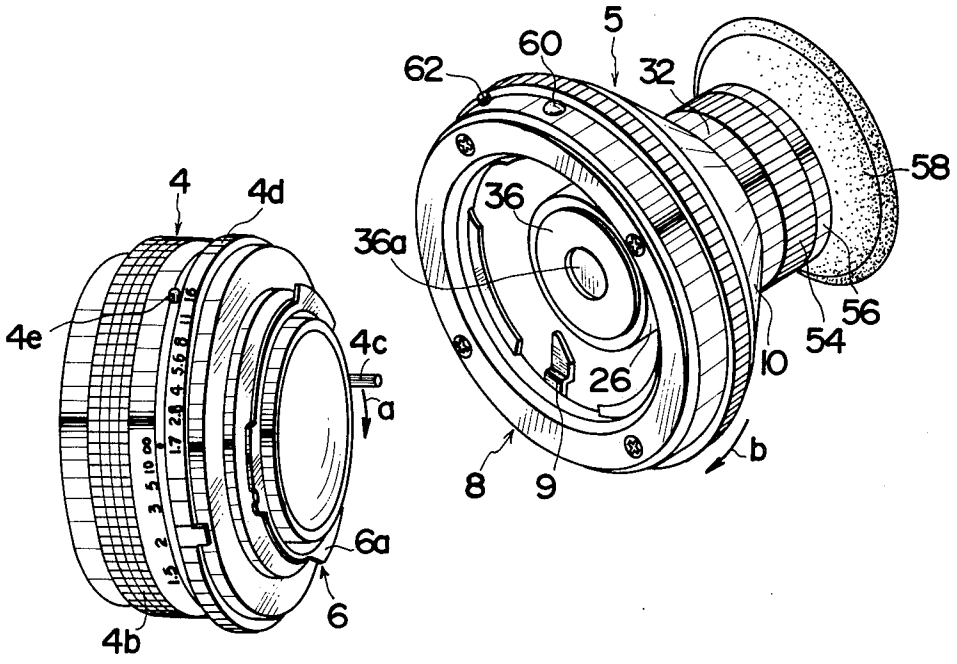
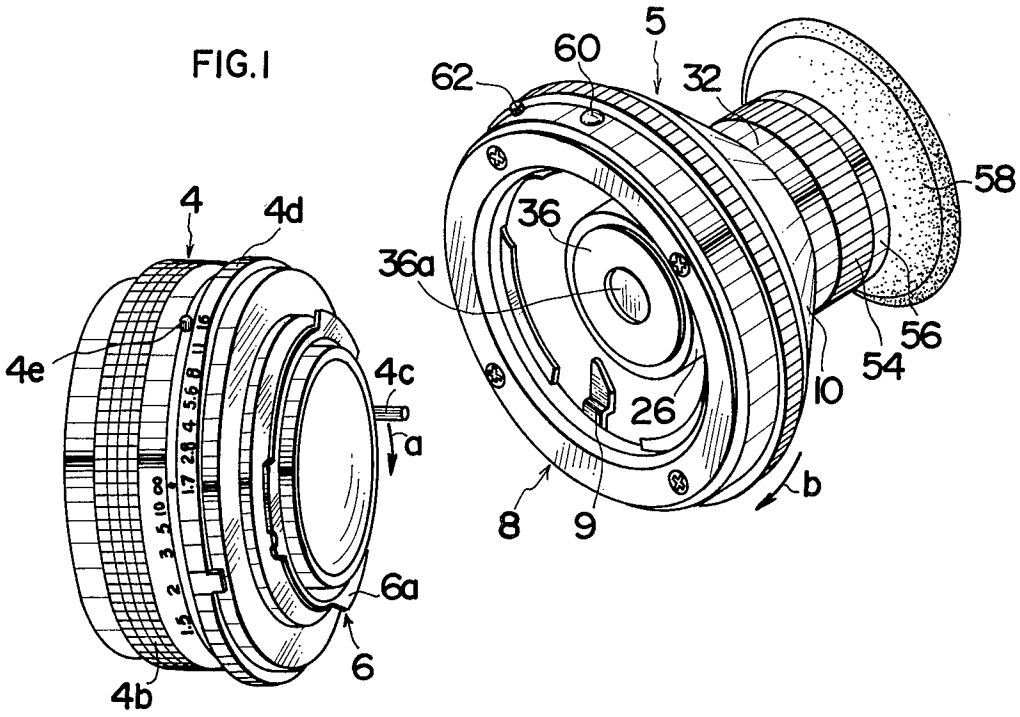


FIG.1


5
60
62
32
58
4
4d
36
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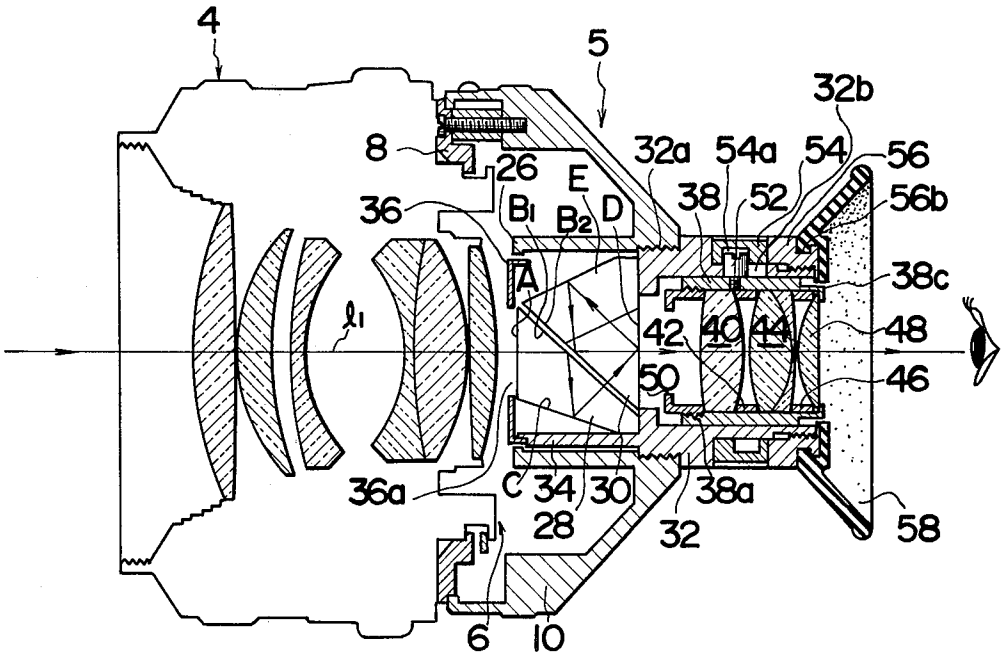
4e
4c
a
56
54
10
26
6a
6
b
8
9
4b

FIG.2


4
5
32b
8
26
32a
54a
54
56
E
38
52
56b
36
B1
B2
D
A
38c
l1
42
40
44
48
50
46
36a
C
34
30
38a
28
32
58
6
10

OPTICAL CONVERSION ASSEMBLY FOR OBJECTIVE CAMERA LENSES

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to an optical conversion assembly to convert exchangeable objective lenses of a camera into a monocular optical device such as a telescope, a microscope or a viewer.

2. Description of the Prior Art

The interchangeable lenses that are utilized on high quality still cameras such as 35 mm cameras and movie cameras have developed to a state wherein they have excellent resolving powers from the vicinity of the optical axis of the field of view to the outer circumference. These lenses are frequently coated to prevent reflection losses across a broad wavelength spectrum. The lenses provide highly accurate color reproduction with a minimum of reflection between the lens surfaces and minimum internal reflection in the lens barrel to eliminate any optical flare and ghost images. In many cases, the commercial cost of these wide angle, telephoto, and zoom lenses far exceeds the cost of the camera bodies.

Frequently, both amateur and professional photographers carry a number of exchangeable lenses with their camera to be prepared for various types of shots requiring the different lenses. These lenses can represent a substantial investment and to date have generally found no other substantial application other than being mounted on the camera. There is thus a need in the prior art to permit alternative utilization of these interchangeable lenses outside of the camera photography field.

Cited of general interest for its disclosure of a prism system in a telescope in U.S. Pat. No. 4,030,808.

SUMMARY OF THE INVENTION

A primary object of the present invention is to provide an optical attachment which is capable of converting exchangeable objective lenses of cameras into a useful monocular optical device, such as a telescope, a microscope or a viewer.

The optical attachment of the present invention includes a barrel housing having at one end a lens mounting means capable of interfacing with appropriate mounting means on a camera exchangeable lens such as a bayonet mounting arrangement. Means are provided on the optical attachment for automatically contacting and holding the diaphragm of the camera exchangeable lens in a maximum aperture opening. An ocular system is provided including movable lens to permit diopter power adjustment. Mounted within the barrel housing is a prism erecting system for rotating the transmitted image both about a vertical and horizontal axis to provide an erect viewing image.

The foregoing and other objects, features and advantages of the present invention will become more readily apparent from the following description of illustrated embodiments thereof taken in reference with respect to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** discloses an exploded perspective view of the combination of a camera objective lens and the optical conversation assembly of the present invention, and

FIG. **2** discloses a partially schematic cross-sectional view of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The following description is provided to enable any person skilled in the optical art to make and use the invention and sets forth the best mode contemplated by the inventors of carrying out their invention. Various modifications, however, will remain readily apparent to those skilled in the art, since the generic principles of the present invention have been defined herein specifically to provide an optical conversion assembly capable of being removably mounted on various camera objective lenses to permit their secondary use as a monocular optical device in a relatively economical manner.

The description will now be given of the preferred embodiment of the present invention according to the drawing.

Referring to FIG. **1**, an objective camera exchangeable lens **4** has a camera mounting means **6** which is well known per se, such as a known bayonet flange **6***a* used by the Minolta Camera Co. The exchangeable lens **4** is capable of being mounted on a camera body (not shown) by means of the camera mounting means **6**. Exchangeable lens **4** carries a diaphragm interlocking pin **4***c* which is biased in the direction of arrow (a) so as to stop down an internal diaphragm mechanism to a predetermined aperture size which can be preset by an external diaphragm setting ring member **4***d*. Diaphragm interlocking pin **4***c*, when forcibly moved in a direction opposite to that of arrow (a), increases the aperture size of the diaphragm mechanism, irrespective of the set position of diaphragm setting member **4***d*. Therefore, the diaphragm mechanism is maintained in its fully opened condition as long as diaphragm interlocking pin **4***c* is maintained at an extreme position in the direction opposite to that of arrow (a).

Provided at the front end of an optical conversion attachment assembly **5** is lens mounting means **8**, which is capable of direct coupling to the camera mounting means **6** of exchangeable lens **4**. The lens mounting means **8** firmly secures exchangeable lens **4** to optical assembly **5** to form a monocular optical device, such as a telescope or a microscope. The construction of lens mounting means **8** is identical to the known lens mounting means provided on a camera body for securing an exchangeable lens and includes spaced flange retainer members of a complementary shape and configuration.

When lens mounting means **8** of optical attachment **5** is coupled to camera mounting means **6** of exchangeable lens **4**, the optical attachment **5** is rotated in the direction of arrow (b), the exchangeable lens **4** and optical attachment **5** are firmly connected in place and can then be locked by a locking means (not shown) so that both may not be disconnected from each other. Provided in the vicinity of lens mounting means **8** of optical attachment **5** is a tongue member **9**, which automatically engages diaphragm interlocking pin **4***c* of exchangeable lens **4** when optical attachment **5** and exchangeable lens **4** are coupled to each other in the abovementioned manner so as to move diaphragm interlocking pin **4***c* in the direction opposite to that of arrow (a) and hold the aperture opening to a maximum nonadjustable position.

Referring now to FIG. **2**, internal cylinder **26** is formed integrally with external cylinder **10** and includes two prisms **28** and **30** that comprise a prism erecting system. These prisms are mounted with a slight gap

between their opposing surfaces, B1 and B2. The prisms **28** and **30** can be Schmidt or Pechan prisms having a light incident surface A and a light exiting surface D, both of which cross the optical axis l_1 at a substantially right angle (90°). Light incident on prism **28** from light incident surface A is reflected onto opposing surface B_1, then reflected on side surface C and transmitted through opposing surface B_1. The light is then incident upon surface B_2 of prism **30**. After being reflected on light exiting surface D and reflected on roof surface E, the light is reflected on opposing surface B_2 and is transmitted rearward through the light exiting surface D as a result of this prism system. The top and bottom of an image are inverted through these five reflections of light and the left and right of the image is also inverted by roof surface E of prism **30**. That is to say, the image passing through prisms **28** and **30** is inverted vertically and horizontally.

Semicircular cylindrical prism support member **34** is formed integrally with an ocular cylinder **32** which is located inside internal cylinder **26** of external cylinder **10** to support prisms **28** and **30**. In more detail, prisms **28** and **30** are fixed by a leaf spring (not shown) inside the prism support member **34** and they are further pressed against the front end of ocular cylinder **32** by holder **36** which is fixed on the tip of prism support member **34** so that they may not move along the optical axis, l. Holder **36** has a circular opening **36***a*, which is adjacent the rear surface of a lens system of exchangeable lens **4**. Ocular cylinder **32** is screw fastened through threads **32***a* at its front end to external cylinder **10**. Provided inside ocular cylinder **32** is a sliding internal cylinder **38**, which is slidable along the optical axis. Mounted inside sliding internal cylinder **38** are a lens **40**, cemented doublet **44** and lens **48** which are arranged in that order from the front at predetermined intervals set by spacers **42** and **46** to comprise the ocular system. Furthermore, ocular holding ring **50** is screwed through thread **38***a* to the front end of sliding internal cylinder **38**. Lens **40**, cemented doublet **44** and lens **48** making up the ocular system are fixed by ocular holding ring **50** as it presses against flange **38***c* formed at the other opening end of sliding internal cylinder **38**. Pin **52**, carried by sliding internal cylinder **38**, is fitted into cam groove **54***a* formed on the internal surface of diopter adjusting ring **54**. Pin **52** further extends through groove **32***b* formed on ocular cylinder **32** and extending elongated along the optical axis.

Diopter adjusting ring **54** is rotatably engaged with the circumference of ocular cylinder **32** and is restricted in axial movement by fixed ring **56** screwed to the rear end of ocular cylinder **32**. When diopter adjusting ring **54** is rotated, pin **52**, carried by sliding internal cylinder **38**, is forced by cam groove **54***a* and guided by groove **32***b* to shift along the optical axis. As a result, the sliding internal cylinder **38** and the ocular system consisting of lens **40**, cemented doublet **44** and lens **48** are moved, as a whole, along the optical axis for dioptric adjustment. Formed circumferentially on fixed ring **56** is an annular groove **56***b* which is fitted with a rubber ocular hood **58**.

Provided on the circumference of external cylinder **10** is an index **60** for use in mounting an exchangeable lens and a lock release button **62** for removing the exchangeable lens.

With the above construction, optical attachment **5** and exchangeable lens **4** can be matched so that the indices **60** and **4***e* may coincide with each other, and optical attachment **5** is rotated in the direction of arrow b to be firmly coupled with an exchangeable lens **4**. During this connection, the diaphragm interlocking pin **4***c* of exchangeable lens **4** is moved by tongue member **9** in the direction opposite to that of arrow (a), whereby the diaphragm mechanism of exchangeable lens **4** is maintained in its fully opened condition. Then, diopter adjustment is performed by rotating diopter adjusting ring **54**. While observing through the ocular section at the rear, distance setting ring **4***b* of exchangeable lens **4** is rotated, whereby the real image of an object erected vertically and horizontally appears at the rear of light projecting surface D of prism **30**. Looking at an object through the ocular, an enlarged image erected vertically and horizontally appears.

For example, when mounting an exchangeable lens of focal length 50 mm for use as a standard lens for 35 mm single lens reflex cameras, it is possible to provide an ocular system such as a telescope with 5X to 10X magnification. Furthermore, by mounting zoom lenses of focal length 100 mm to 200 mm on the optical attachment it is possible to provide telescopes with a higher magnification. Thus, even when different exchangeable lenses are used, the distance is constant from the mounting surface to the focal plane of various types of exchangeable lenses capable of mounting on a single type of camera. Real images transmitted through the exchangeable lenses are always in focus at the same position and can be observed by the same ocular. Therefore, the optical attachment can be used for a variety of exchangeable lenses and produces sharp images at all times with any type of exchangeable lenses.

Furthermore, when an intermediate ring or bellows is provided between an exchangeable lens and the optical attachment for closeups, the optical attachment can be used as a microscope of 20X to 100X magnification. Such a microscope, contrary to conventional ones, has a wide field of view and is capable of producing an erect image.

The use of the above described optical attachment makes it possible to observe the magnification and image formation of exchangeable lenses without using a camera. In this case, images are visible without being affected by a focal plane or the like of a camera, making it possible to easily see the difference of angle of views of exchangeable lenses and also to use the optical attachment as a viewer for comparing exchangeable lenses at camera shops. It should be understood that when the optical attachment is used in the above manner, a field-of-view frame corresponding to a field of an object to be photographed is provided in the vicinity of the focal plane of an exchangeable lens so as to obtain a clearer picture angle of the exchangeable lens. The prism erecting system of the above optical attachment is not limited only to the so-called Schmidt type, but may be of any prism systems, including the Porro, Abbe, Springer and Hensoldt type in which a light incident surface and a light projecting surface are substantially normal to the optical axis of a mounted exchangeable lens. In addition, the magnification of an ocular system is not limited to that mentioned above.

A strap mounted means and a tripod mounting means may be provided on the circumferences of the external cylinder **10** and ocular cylinder **32** to facilitate carrying and use.

The above optical attachment is not limited in application to exchangeable lenses for use in single lens reflex cameras. Any exchangeable lens for lens exchangeable cameras, regardless of whether it is a still or movie

camera, may be provided with an appropriate optical attachment having lens mounting means, a prism erecting system and a predetermined ocular section.

The optical attachment in accordance with the present invention comprises a lens mounting means for mounting an exchangeable lens, a prism erecting system having a light incident surface and a light projecting surface which are substantially on the optical axis of the exchangeable lens mounted on the lens mounting means. The prism system inverts the top, bottom, left and right of a real image through the exchangeable lens, and an ocular is provided at the rear of the prism erecting system. When used, the optical attachment is capable of converting an exchangeable lens for a camera such as an objective lens into a telescope, whereby a high performance telescope can be provided. Such a telesco pe is free to have varying magnifications by changing exchangeable lenses. With an intermediate or bellows for closeups provided between the optical attachment and an exchangeable lens, the optical attachment can further be used as a microscope. The microscope thus obtained is wide in field of view to produce high performance with erect images. In addition, such a telescope or a microscope may be used by looking at any desired object to be observed, resulting in great convenience of use. Yet, the optical attachment is compact, lightweight and very convenient to carry.

It is to be further understood that various modifications of the generic concepts of this invention are possible without departing from its spirit and accordingly the scope of the present invention should be determined solely from the following claims.

What is claimed is:

1. An optical attachment adapted for use with an objective camera exchangeable lens which includes a diaphragm interlocking member movable between a first position to maximize an aperture size of a diaphragm mechanism and a second position to minimize the aperture size, said diaphragm interlocking member being biased toward said second position, the optical attachment capable of providing a view of an object without the necessity of a camera body comprising:

lens mounting means on which said camera exchangeable lens can be detachably mounted, said lens mounting means having an axis capable of alignment with an optical axis of a camera exchangeable lens when mounted thereon;

a prism erecting system for rotating an image about vertical and horizontal axes, said prism erecting system provided on said axis and including a light entrance surface perpendicular to said axis and a light emitting surface in parallel with said light entrance surface;

retaining means for retaining said diaphragm interlocking member in its first position when said camera exchangeable lens is operatively connected, and

an occular system provided in the light path of the light emitted from said light emitting surface.

2. An optical attachment as set forth in claim 1 further comprising a dioptric adjusting assembly including means holding at least a part of said ocular system for axial movement thereof and externally accessible means interconnected to said part of ocular system for moving the same.

3. An optical attachment as set forth in claim 1 wherein said lens mounting means includes a plurality of flange retainer members of a complementary shape and configuration to lockingly interface with a bayonet flange.

4. An optical attachment as set forth in claim 1 wherein said prism erecting system is configured to position both the light entrance surface and the light emitting surface on a longitudinal axis substantially coincident with the optical axis.

5. An optical attachment as set forth in claim 1 wherein the ocular system includes a lens assembly capable of substantial magnification of the object image of the objective camera lens without substantial increase in the image aberrations to provide a telescope effect.

6. An optical attachment adapted for use with a camera exchangeable lens comprising:

lens mounting means on which said camera exchangeable lens can be detachably mounted, said lens mounting means having an axis capable of alignment with an optical axis of said camera exchangeable lens when mounted thereon and means for automatically contacting and holding a diaphragm of the camera exchangeable lens to a non-adjustable maximum aperture opening;

an ocular system having an optical axis in parallel with said axis of lens mounting means; and

a prism erecting system for inverting an image both in horizontal and vertical directions, said prism erecting system being provided between said lens mounting means and said ocular system and having an optical axis connected to said axis of lens mounting means and said optical axis of ocular system.

7. A combination of a camera objective exchangeable lens and an optical attachment device for use as a monocular optical device comprising:

a camera exchangeable lens with a diaphragm detachably mountable on a camera for use as an objective, said camera exchangeable lens having an optical axis and a diaphragm interlocking member movable between a first position to maximize an aperture size of a diaphragm mechanism and a second position to minimize the aperture size, said diaphragm interlocking member being biased toward said second position; and an optical attachment detachably mounted on said camera exchangeable lens, said optical attachment including an ocular system having an optical axis in parallel with said optical axis of said camera exchangeable lens and a prism erecting system for inverting an image both in horizontal and vertical directions, said prism erecting system being provided between said camera exchangeable lens and said ocular system and having an optical axis connected to said axis of both of said camera exchangeable lens and ocular system, said optical attachment includes retaining means for retaining said diaphragm interlocking member in its first position.

8. The device as set forth in claim 7, wherein said optical attachment further includes a dioptric adjusting device including means holding at least a part of said ocular system for axial movement thereof and externally accessible means interconnected to said part of ocular system for moving the same.

* * * * *

United States Patent [19]

Momiyama

[11] E **Re. 30,708**

[45] Reissued **Aug. 11, 1981**

[54] **TELEPHOTO OBJECTIVE**

[75] Inventor: **Kikuo Momiyama**, Yokohama, Japan

[73] Assignee: **Canon Kabushiki Kaisha**, Tokyo, Japan

[21] Appl. No.: **15,754**

[22] Filed: **Feb. 27, 1979**

Related U.S. Patent Documents

Reissue of:

[64] Patent No.: **4,045,128**
Issued: **Aug. 30, 1977**
Appl. No.: **570,958**
Filed: **Apr. 22, 1975**

[30] **Foreign Application Priority Data**

Apr. 25, 1974 [JP] Japan 49-46920
Jun. 28, 1974 [JP] Japan 49-74168

[51] **Int. Cl.**[3] **G02B 9/60**
[52] **U.S. Cl.** **350/465**; 350/255; 350/463
[58] **Field of Search** 350/214, 216, 255; 354/197

[56] **References Cited**

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2,503,789 4/1950 Wood et al. ..... 354/197 X
3,854,797 12/1974 Yokota 350/214

Primary Examiner—Paul A. Sacher
Attorney, Agent, or Firm—Toren, McGeady and Stanger

[57] **ABSTRACT**

A telephoto objective comprising a stationary convergent front lens group and a rear lens group which includes a lens member axially movable for focusing behind a front lens member which remains stationary during focusing, and an operating mechanism therefor. In order to achieve excellent stability of the various aberrations and particularly spherical aberration throughout the focusing range, compensation for the residual aberrations introduced by the front lens group is concentrated in the stationary front member of the rear lens group, while the movable rear member is configured to provide minimized variation of aberrations by constructing these two members as being divergent with their front surfaces convex to the object. In this particular arrangement, the movable member is moved toward the image plane as the objective is focused from the position for an object at infinity to the position for a close object.

25 Claims, 17 Drawing Figures

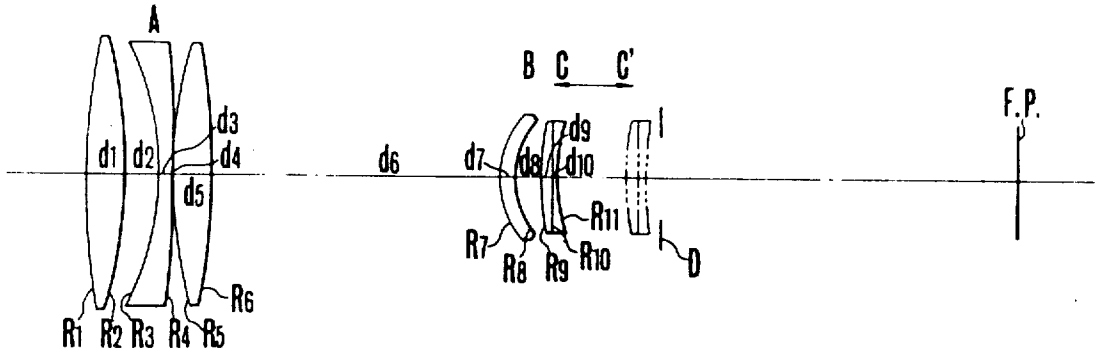
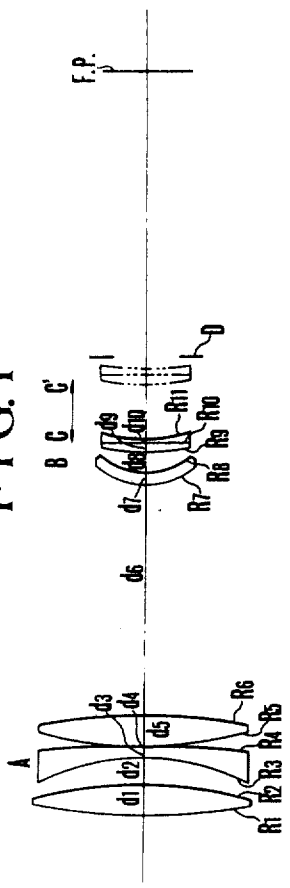


FIG. 1


F.P.
B C C'
D
A
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d1 d2 d3 d4 d5 d6 d7 d8 d9 d10

FIG. 2

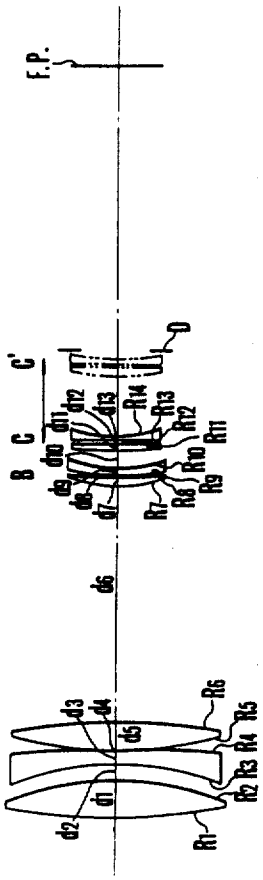
F.P.
B C C'
D
R1 R2 R3 R4 R5 R6 R7 R8 R9 R10 R11 R12 R13 R14
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FIG.3a FIG.3b FIG.3c

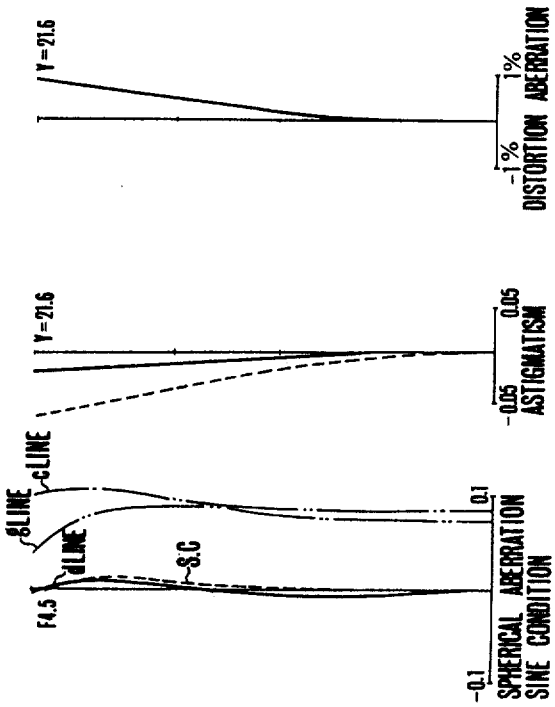
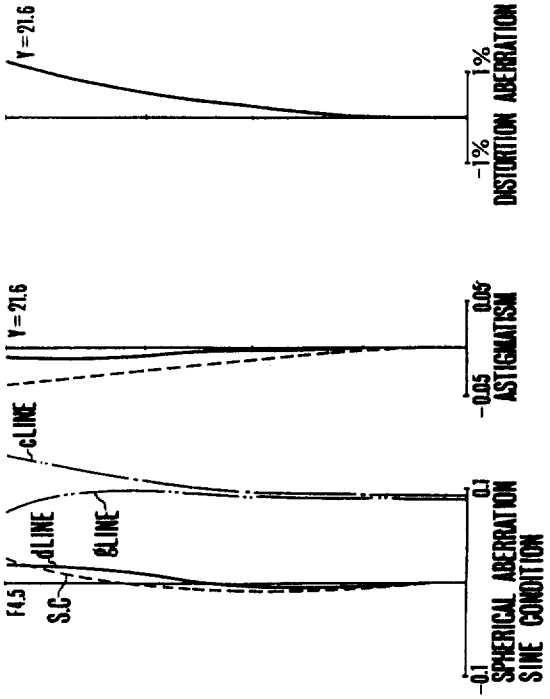


FIG.4a FIG.4b FIG.4c



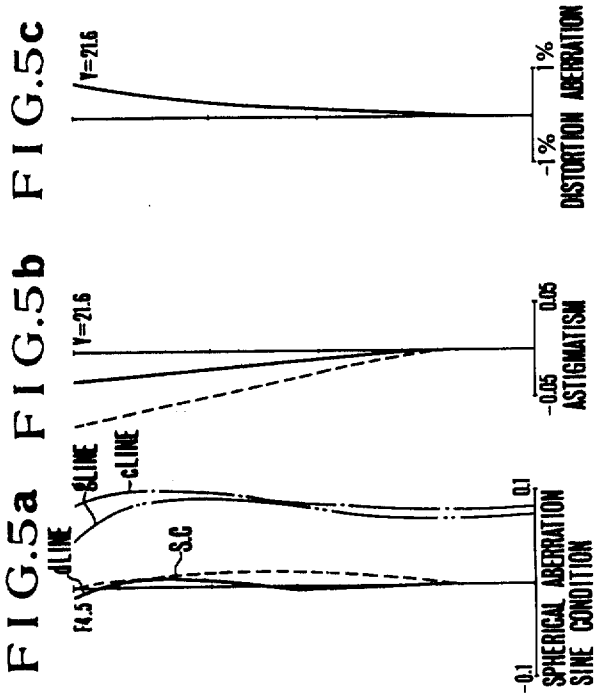


FIG.5a FIG.5b FIG.5c

FIG.6a FIG.6b FIG.6c

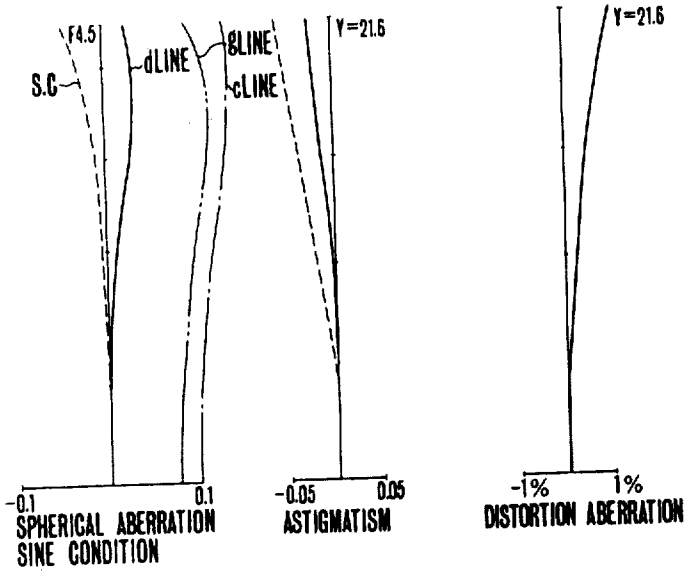


FIG.9

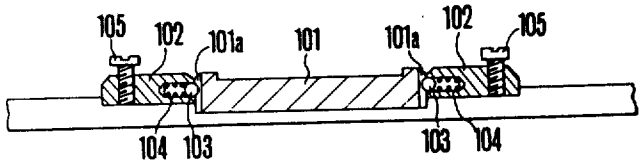


FIG.7

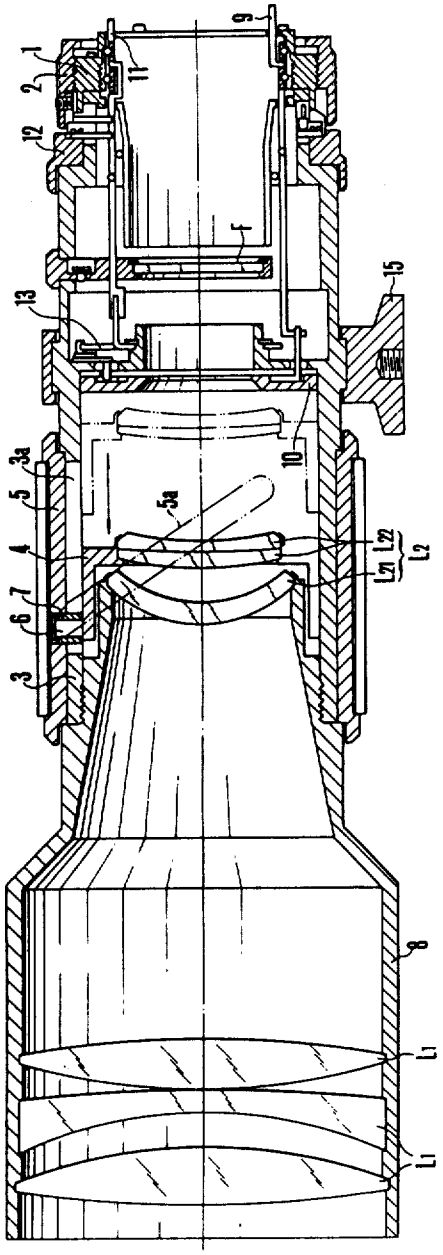
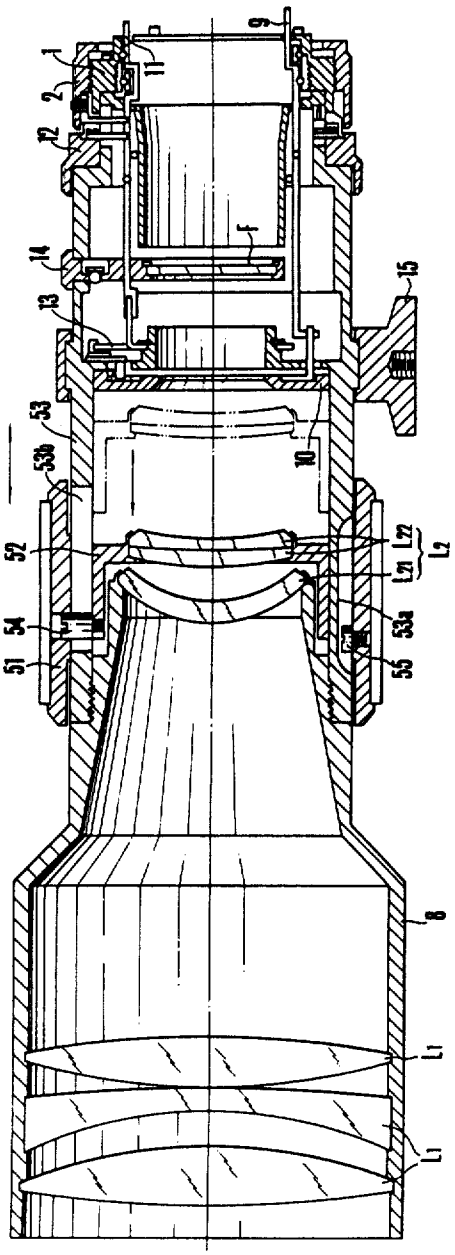


FIG.8



TELEPHOTO OBJECTIVE

Matter enclosed in heavy brackets [ ] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue.

BACKGROUND OF THE INVENTION

This invention relates to optical objectives for photographic devices, and more particularly to a telephoto objective comprising a stationary front lens group and a rear lens group which includes a member axially movable to focus while still maintaining improved stabilization of the aberrations throughout the focusing range.

In general, the focusing of an optical objective is effected by axially moving the objective bodily with reference to the image plane. But this may be otherwise achieved by axial movement of a part of the objective, for example, either the front, or the rear lens group thereof with reference to the other part which remains stationary during focusing. In telephoto objectives, if made bodily movable for focusing purposes, the amount of movement of the objective throughout the focusing range tends to increase, and this in turn calls for increases in the weight and bulk of the objective and the driving torque of its focusing mechanism as well as in the production cost thereof, thus it being made more difficult to keep the weight and bulk of the complete objective including its mechanical mounting and focusing mechanism within easily manageable proportion.

With a telephoto objective having the provision for focusing made at a rear part of the lens system, it is possible to minimize the movement of the focusing part and to employ a focusing mechanism of small size and weaker driving torque, because the focusing part comprises only a fraction of the weight and bulk of the complete objective, thereby giving an advantage of facilitating high-speed focus adjustment of the objective. Another advantage deriving from the selection of the rear lens group of the objective for employment as the movable part for focusing purposes is that the front lens group which is of a relatively large weight and bulk may be supported in fixedly secured relation with a camera body to minimize the probability of producing a jiggle or oscillation of the image at the focal plane by small accidental motions of the objective and camera assembly which is otherwise encountered particularly when the objective is telephoto in nature. However, this system has a disadvantage that variation of the aberration particularly variation of the spherical aberration due to the movement of the lens is large, and the image forming ability is low. Further, in order for an objective to embody an advantageously small overall length, a convergent lens group is usually selected for employment as the front part thereof in combination with a divergent rear lens group having design parameters determined so as to cancell out the residual spherical aberration introduced by the front lens group in a focusing position for an object at infinity. However, as the objective is focused from this position to a position for a close object, the axial separation between the front and rear lens groups is increased with decrease in the hight of incidence of an axial ray upon the rear lens group, so that occurrence of the positive spherical aberration is less, while varying the value of the spherical aberration to a remarkable extent. In this respect, it is well known that this arrangement is disadvantageous

for stabilization of the image aberrations throughout the focusing range.

SUMMARY OF THE INVENTION

The present invention has for a general object to provide the above-mentioned advantages in the case of a telephoto objective having the provision for focusing made at the rear part thereof, while still proving improved stabilization of the aberrations throughout the focusing range.

A concomitant object of the invention is to provide a focusing mechanism for use with an telephoto objective of the character described which assists in high-speed focus adjustment thereof.

In order to avoid the above defect in the focusing system by the movement of rear lens group, it is necessary to lessen the occurrence of the aberration particularly the spherical aberration in the rear lens group, but if the aberration is lessened in this way the spherical aberration of the whole lens system is remarkably undercorrection.

The telephoto objective of the invention is characterized in comprising a convergent front lens group and a rear lens group which includes a lens member axially movable to effect focusing in front of, or behind a lens member which remains stationary during focusing. This particular arrangement gives rise to the possibility of cancelling out the residual aberrations introduced by the convergent front lens group by suitable design of the stationary lens member of the rear lens group and gives high standard of stabilization of the various aberrations and particularly spherical aberration throughout the focusing range provided that the movable member is designed to give a good standard of stabilization of the aberrations throughout the focusing range.

Further, a good compromise has been achieved between the requirements of providing a large range of focusing adjustments with relatively small axial translations of the movable member of the rear lens group and of providing a distribution of powers between the stationary and movable parts of the objective which effects achievement of a high standard of aberration correction.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a diagrammatic view of an example of a telephoto objective according to an embodiment of the invention in two focusing positions.

FIG. **2** is a similar view of another example of the embodiment of the invention.

FIGS. **3a–3c** is a graphic representation of aberration achieved in the example of FIG. **1** when focused for an infinite object distance.

FIGS. **4a–4c** is a similar representation when focused for an object distance of 1,000 millimeters.

FIGS. **5a–5c** is a graphic representation of aberration achieved in the example of FIG. **2** when focused for an infinite object distance.

FIGS. **6a–6c** is a similar representation when focused for an object distance of 1,000 millimeters.

FIG. **7** is an axial sectional view of a barrel type mechanical mounting with a focusing mechanism adapted for use with the objective of the invention.

FIG. **8** is a similar view with a modification of the focusing mechanism.

FIG. 9 is a fragmentary sectional view of a focus-preselecting device in the focusing mechanism of FIGS. 7 or 8.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to FIGS. 1 and 2, there are shown two specific examples of a preferred embodiment of the invention as comprising a front lens group A which has a positive, power and remains stationary during focusing, and a rear lens group which has a negative power and is divided into two parts B and C, the rear part C being made axially movable to effect focusing to suit differing object distances, while the front part B remains stationary during focusing. The stationary part B consists of a negative meniscus singlet lens member in the instance of FIG. 1, or of a negative meniscus doublet lens member in the instance of FIG. 2, with the first refracting surface counting from the front convex to the front, and with the rearmost surface having a radius of curvature which is smallest among all of the surfaces of member B. The movable rear part C is constructed from a negative meniscus doublet lens member with the first surface convex to the front, and with the rearmost surface having a radius of curvature which is smallest among all the surfaces of member C. The absolute focal length of member B is larger than that of member C. A diaphragm D which is stationary is located behind movable member C at a distance to permit the entire range of focusing movement thereof.

As the objective of FIGS. 1 or 2 is focused from the position C marked in solid line for an object at infinity to the position C' marked in broken line for a close object, movable member C progressively approaches the focal plane FP through the space of a distance Δx as defined by the following formula

$$\Delta x = \frac{-2}{B\left(1+\sqrt{1-\frac{4A}{B^2}}\right)}$$

wherein

$$A = \frac{1}{F}\,\frac{1}{Fc}\left(\frac{S}{Ff}+1\right)$$

$$B = \frac{1}{Ff}\left(\frac{S_1}{Ff}+1\right)-\frac{1}{F}\left(\frac{S_1-O_1}{F}+1\right)$$

where

S_1 is the object distance as measuring from the vertex of the first refracting surface of the objective;

F is the focal length of the complete objective when focused for an infinitely distance object;

Ff is the focal length of the combined group A and member B;

Fc is the focal length of the movable member C; O_1 is the distance from the vertex of the first refractings surface to the primary principal point of the complete object; and

Δx when measured in a direction to the focal plane takes a plus sign.

In order to facilitate the solution of aberrational problems, it is preferred to specify the characteristics of the members B and C by the following relationships:

$$0.4F<|FC|<0.9F;Fc<0 \quad (1)$$

$$0.15F<Rc<0.25F \quad (2)$$

$$0.05<F(Fcv\cdot Vcv)+f/(Fcc\cdot Vcc)<0.05 \quad (3)$$

$$0.05F<Rb<0.15F \quad (4)$$

wherein

Rc is the radius of curvature of the rearmost surface of the member C;

Rb is the radius of curvature of the rearmost surface of the member B;

Fcv is the focal length of the positive lens element of the member C;

Vcv is the Abbe's number value for the material of the positive lens element of the member C

Fcc is the focal length of the negative lens element of the member C;

Vcc is the Abbe's number value for the material of the negative lens element of the member C.

Condition (1) assists toward achievement of a good compromise between the requirements of providing a large range of focusing adjustment with relatively small axial movement of the movable member C and of providing excellent stabilization of the aberrations throughout the focusing range. When the power of member C is otherwise increased, it is made rapidly more difficult to achieve the desired high standard of aberration correction although the axial translation of member C may be decreased to obtain an equivalent focusing effect. Conversely, the use of a lens member having a power smaller than that corresponding to the upper limit of condition (1) as the focusing member requires a focusing mechanism of increased size due to the increased axial translations of the focusing member.

Condition (2) assists in minimizing the residual aberrations and particularly spherical aberration introduced by the focusing member C to provide a good standard of stabilization of the aberrations throughout the focusing range.

Condition (3) assists in the stabilization with focusing of chromatic aberrations.

The use of a lens member having the parameters within the ranges specified above as the focusing member C results in somewhat under-corrections of the spherical aberration, coma and astigmatism of the complete objective. In order to preserve a good state of correction of the image aberrations, the stationary lens member B of the rear lens group must be designed according to condition (4) to provide correspondingly over-corrected values of the above-identified aberrations.

The specific examples of a telephoto objective of the invention as illustrated in FIGS. 1 and 2 may be constructed in accordance with the numerical data given in Tables 1 and 3 below respectively, in which R_1, R_2 . . . designate the radii of curvature of the individual surfaces of the objective counting from the front, the positive sign indicating that the surface is convex to the front and the negative sign that it is concave thereto, d_1, d_2 . . . designate the axial separations between successive refracting surfaces of the objective, N_1, N_2 . . . designate the refractive indices for the spectral d line of sodium of the materials from which the various lens elements of the objective are made, and V_1, V_2 . . . designate the Abbe numbers of the materials.

TABLE 1

Distance between surface R_1 and the focal plane: 80.01				
R_1 =	68.8306	d_1 = 3.625	N_1 = 1.48749	ν_1 = 70.1

TABLE 1-continued

Distance between surface R_1 and the focal plane: 80.01				
R_2 =	−32.7526	d_2 = 2.234		
R_3 =	−28.0632	d_3 = 1.250	N_2 = 1.80610	ν_2 = 40.9
R_4 =	−258.3399	d_4 = 0.125		
R_5 =	40.9645	d_5 = 3.250	N_3 = 1.48749	ν_3 = 70.1
R_6 =	−55.6211	d_6 = 25.005		
R_7 =	8.5369	d_7 = 1.250	N_4 = 1.58913	ν_4 = 61.1
R_8 =	7.6866	d_8 = variable		
R_9 =	36.3034	d_9 = 0.750	N_5 = 1.75520	ν_5 = 27.5
R_{10} =	108.9485	d_{10} = 0.625	N_6 = 1.71300	ν_6 = 53.9
R_{11} =	19.0641			

Object distance (from the focal plane)	Focal length of the complete objective	Variable axial air separation(d_8)
Infinity	100.00	2.250
−1.000	83.48	9.656

TABLE 2

Abberration Coefficients for Focussing setting at Infinity

sub-script numerals for the surfaces	I	II	III	P	V
1	0.6757	−0.5842	0.5051	0.4761	−0.8484
2	48.6504	−83.9162	144.7455	1.0006	−251.3948
3	−65.8017	111.7576	−189.8090	−1.5904	325.0728
4	−0.0012	0.0107	−0.0965	0.1727	−0.6818
5	3.6943	−3.9520	4.2277	0.8000	5.3786
6	13.3838	−24.0086	43.0677	0.5892	−78.3138
7	2.6172	−1.0971	0.4599	4.3427	−2.0133
8	−3.1924	1.1602	−0.4216	−4.8231	1.9061
9	−0.0808	0.4612	−2.6306	1.1852	8.2442
10	0.0483	−0.1003	0.2081	−0.0129	−0.4051
11	0.0711	0.1153	0.1871	−2.1833	−3.2381
Σ	0.0650	−0.1535	0.4434	−0.0430	−7.0508

In this table 2, I designates the spherical aberration coefficients; II designates the coma coefficients, III designates the astigmatism coefficients; P designates the Petzval sums, and V designates the distortion coefficients.

TABLE 3

Distance between surface R_1 and the focal plane: 81.05				
R_1 =	66.6001	d_1 = 3.625	N_1 = 1.48749	ν_1 = 70.1
R_2 =	−33.1516	d_2 = 2.089		
R_3 =	−28.6739	d_3 = 1.250	N_2 = 1.80610	ν_2 = 40.9
R_4 =	−316.5437	d_4 = 0.125		
R_5 =	41.3109	d_5 = 3.250	N_3 = 1.48749	ν_3 = 70.1
R_6 =	−57.4105	d_6 = 24.974		
R_7 =	12.8482	d_7 = 0.875	N_4 = 1.71300	ν_4 = 53.9
R_8 =	22.5379	d_8 = 0.125		
R_9 =	22.9059	d_9 = 0.500	N_5 = 1.57250	ν_5 = 57.7
R_{10} =	10.4573	d_{10} = variable		
R_{11} =	37.1996	d_{11} = 0.750	N_6 = 1.75520	ν_6 = 27.5
R_{12} =	96.1965	d_{12} = 0.125		
R_{13} =	86.0176	d_{13} = 0.625	N_7 = 1.71300	ν_7 = 53.9
R_{14} =	19.4620			

Object distance from the focal plane	Focal length of the complete objective	Variable axial air separation (d_{10})
Infinity	100.00	2.250
−1,000	83.73	10.208

TABLE 4

Aberration Coefficients when Focussed for Infinity

	I	II	III	P	V
1	0.7458	−0.6867	0.6323	0.4920	−1.0354
2	47.8640	−84.2475	148.2877	0.9885	−262.7476
3	−64.2813	111.5568	−193.6011	−1.5565	338.6858
4	−0.0004	0.0068	−0.1024	0.1409	−0.5765

TABLE 4-continued

Aberration Coefficients when Focussed for Infinity

	I	II	III	P	V
5	3.6287	−4.0041	4.4184	0.7933	−5.7510
6	12.5609	−23.0649	42.3527	0.5708	−78.8180
7	−0.3841	0.0296	−0.0022	3.2395	−0.2494
8	0.4545	−1.5903	5.5646	−1.8467	−13.0085
9	−0.4543	1.5283	−5.1408	1.5894	11.9458
10	−0.2681	0.0431	−0.0069	−3.4814	0.5608
11	−0.0696	0.4175	−2.5021	1.1566	8.0627
12	1.6256	−3.5645	7.8158	−0.4472	−16.1570
13	−1.4736	3.2945	−7.3652	0.4838	15.3839
14	0.0726	0.1110	0.1699	−2.1386	−3.0112
Σ	0.0205	−0.1703	0.5207	−0.0154	−6.7157

It will be appreciated from the foregoing description that, with a telephoto objective consisting of a convergent front lens group and a divergent rear lens group, the present invention provides a two part rear lens group, only one part of which is axially movable for focussing purposes, thereby giving rise to the possibility of achieving a high standard of aberration stabilization throughout the range of focussing movement. Therefore, by comparison with a conventional telephoto objective which is made bodily movable for focussing, or which has a front lens group movable for focussing, the objective of the invention is improved with respect to the focussing manupulation owing to the decreased weight and bulk of the complete objective, which will in turn reduce the probability of producing an oscilation of the image at the focal plane when it is used in association with a hand-held camera. On the other hand, by comparison with a conventional telephoto objective having a rear lens group which made bodily movable for focussing, the objective of the invention is remarkably improved with respect to the imaging performance owing to the stationary part of the rear lens group which is designed to provide improved stabilization of the various aberrations throughout the focussing range. It is to be noted that the present invention is not limited to use in the construction of three-component telephoto objective described and is useful to facilitate the design of the focussing member for any telephoto lens including additional lens components of almost zero powers located in front of, or behind the front part B, or behind the rear part C of the rear lens group, and that further assistance in achieving a higher standard of correction of the image aberrations can be obtained if an additional component which remains stationary during focussing is employed for arrangement between the front and rear lens groups.

Referring now to FIG. 7, there is shown a lens mount with a cam-operated focussing mechanism adapted for use with the telephoto objective of the character described, where L_1 and L_2 designate the front and rear lens groups of the objective respectively, and L_{21} and L_{22} designate the stationary front and movable rear parts of the rear lens groups L_2 respectively. This lens mount is connected to a single lens reflex camera, not shown, by an adapter **2** whose rear end constitutes a bayonet coupling engaging the camera housing. Rigidly connected to adapter **2** is a barrel **1** at one end thereof, the opposite end portion of which has a guide barrel **3** fixedly secured thereto and provided with a longitudinally elongated guiding slot **3a**. Mounted within guide barrel **3** is a slidable sleeve **4** carrying the movable lens member L_{22}. The sleeve **4** can be moved longitudinally but can not be rotated with reference to barrel **3**, as it is

prevented from rotating by a pin **6** outwardly radially extending from the slidable sleeve **4** and provided with a roller rotatable thereabout in the guiding slot **3a**. The roller **7** projects beyond the guiding slot **3a** and engages with a herical camming groove **5a** formed in the inner surface of a focus adjusting sleeve **5** which is rotatably mounted on guide barrel **3**. The parts, **3a**, **5**, **5a**, **6** and **7** constitutes the above mentioned camo perated focusing mechanism. Rigidly coupled to guide barrel **3** is a tubular extension **8** carrying the front lens group L_1 and the front part L_{21} of the rear lens group L_2 mounted therein in fixed relation to each other and to the extension **8**. The lens mount has a diaphgram device **10** mounted therein at a location behind the movable lens member L_{22}. The diaphragm device **10** is provided with a control lever **9**, and a presetting lever **11** cooperating with a diaphgram adjusting ring **12** rotatably mounted on barrel **1**. The control lever **9** serves to adjust the diaphragm device **10** to a preselected setting in response to an actuation of a camera release member. The presetting lever **11** serves to adjust the position of a diaphragm blade-operating cam member **13** in accordance with the preselected diaphragm value by the ring **12**, and also to transmit the diaphragm information to a diaphragm control mechanism not shown in the camera housing in response to a rotation of ring **12**. A filter being mounted in a filter holder **14** which is detachably mounted behind the diaphragm device **10** in the barrel **1**. The lens mount is further provided with a support member **15** having a nut formed therein for engagement with a bolt of a tripod not shown.

The operation of the focussing mechanism of FIG. **7** in connection with the diaphragm device **10** which constitutes a part of the exposure control apparatus of the camera. In order to make an exposure in the diaphragm preselection automatic exposure range, the operator turns the ring **12** to select a desired diaphragm value, thereby the position of the cam member **13** is adjusted through the presetting lever **11**. At the same time, the diaphragm information is introduced to the exposure control apparatus in the camera through the presetting lever **11**. On the other hand, when the camera is switched to the shutter preselection automatic exposure range, the position of the cam member **13** is adjusted in accordance with a computed diaphragm value through the presetting lever **11**.

In focussing the objective, the operator turns the rotary sleeve **5**, thereby the roller **7** is driven for movement along the guiding slot **3a** through the roller **7** and camming groove **5a** connection, causing axial translation of the slidable sleeve **4** with the lens member L_2 therein. What object the objective has been focussed for is recognizable either by the angular position of sleever **5**, or by looking through the viewfinder in which an image of the corresponding object is formed in sharpest focus. Next, the operator may depress the shutter release button not shown, thereby the diaphragm device **10** is first operated to the preselected setting through the control lever **9**, and thereafter the shutter mechanism is actuated to initiate an exposure.

The filter holder **14** is removably attached to the lens barrel so that various filters may be interchanged. When the filter is not used, it is desirable to use a transparent plate to adjust the optical path length.

FIG. **8** shows a modification of the focussing mechanism of FIG. **7** with employment of a longitudinally slidable focus-adjusting sleeve **51** in place of the rotary sleeve **5** of FIG. **7**. The sleeve **51** is fixedly connected to a slidable sleeve **52** carrying the movable lens member L_{22} through a pin **54** extending through a longitudinally elongated guiding slot **53b** provided in the guide barrel **53** corresponding to the guide barrel **3** of FIG. **7**. In order to define the range of possible focussing movements of the lens member L_{22}, there is provided a longitudinal groove **53a** formed in the outer surface of guide barrel **53** for engagement with a pin **55** internally radially extending from the focus adjusting sleeve **51**. In focussing the objective, the operator moves the external sleeve **51** to effect axial translation of the lens member L_{22}, as the internal sleeve **52** is guided through the pin **54** and guiding slot **53b** connection.

FIG. **9** shows a focussing position preselecting device particularly adapted for association with the focussing mechanism of FIG. **7**. The device comprises a pair of radially grooves recesses **101a** formed at the ends of a focus adjusting sleeve **101** corresponding to the sleeve **5** of FIG. **7** in longitudinal alignment with each other, a pair of click stop balls **103** which are biased by respective springs **104** in the opposite directions to each other for normal engagement with the respective recesses **101a**, and a pair of focus presetting rings **102** rotatably mounted on the guide barrel corresponding to the part **3** of FIG. **7**. The rings **102** each has a hole longitudinally bored therein for the mounting of ball **103** and spring **104**, and are provided with respective fasteners having knobs **105**. In operating the device, the rings **102** are turned as a unit to place the reaction points thereof in registry with a graduation representing a desired object distance for which the objective is to be focussed, and then are secured in position fixed to the guide barrel by means of the operated knobs **105**. With this arrangement, when the focus adjusting sleeve **101** is turned to a position where the recesses **101a** engage with balls **103**, the desired focussing effect is automatically obtained.

It will be appreciated form FIGS. **7**, **8** and **9** that the present invention provides a focussing mechanism of simple construction which may be incorporated in the lens mount for the telephoto objective of the character described at a location close to the center of the physical length of the complete objective including the lens mount and, in some cases, of the center of gravity of the objective and camera assembly. Such a central location of the focussing mechanism permits easy management procedures for high speed smooth focus adjustments of the objective, while holding the assembly by hand, and accordingly faciliates to prevent the production of an oscillation of the image at the film plane which would be otherwise introduced by the small accidental motions of the assembly owing to the difficult manupulation thereof and the necessity of large driving torque in operation of focussing mechanism. Furthermore, the constructions of the telephoto objective of the character described and the focussing mechanism therefor are advantageous for the provision of focussing down to a shorter object distance.

What is claimed is:

1. A telephoto objective of high speed adjustable focus comprising a front lens group which has a positive refracting power and remains stationary during focussing, and a rear lens group which is divided into two parts, of which one part is axially movable to effect focussing to suit differing object distances, wherein said movable part of said rear lens being located behind the other part which is stationary during focussing and wherein the characteristics of the various lens elements of said front and rear lens groups and their spatial rela-

tionships to each other are substantially of the proportions indicated by the numerical data in the following table, in which R designates the radii of curvature of the refracting surfaces identified by the corresponding subscript numerals and numbered from the front to the rear of the objective, the positive sign indicating that the surface is convex to the front and the negative sign that it is concave thereto, D designates the axial separations between successive refracting surfaces of the objective being numbered from the front to the rear; N designates the refractive indices for the spectral D line of sodium of the materials of the elements being numbered from the front to the rear; and ν designates the Abbe numbers of the materials:

Distance between surface R_1 and the focal plane: 80.01				
R_1 =	68.8306	d_1 = 3.625	N_1 = 1.48749	ν_1 = 70.1
R_2 =	−32.7526	d_2 = 2.234		
R_3 =	−28.0632	d_3 = 1.250	N_2 = 1.80610	ν_2 = 40.9
R_4 =	−258.3899	d_4 = 0.125		
R_5 =	40.9645	d_5 = 3.250	N_3 = 1.48749	ν_3 = 70.1
R_6 =	−55.6211	d_6 = 25.005		
R_7 =	8.5369	d_7 = 1.250	N_4 = 1.58913	ν_4 = 61.1
R_8 =	7.6866	d_8 = variable		
R_9 =	36.3034	d_9 = 0.750	N_5 = 1.75520	ν_5 = 27.5
R_{10} =	108.9485	d_{10} = 0.625	N_6 = 1.71300	ν_6 = 53.9
R_{11} =	19.0641			

Object distance from the focal plane	Focal length of the complete objective	Variable axial air separation (d_8)
Infinity	100.00	2.250
−1,000	83.48	9.656

2. A telephoto objective of high speed adjustable focus comprising a front lens group which has a positive refracting power and remains stationary during focussing, and a rear lens group which is divided into two parts of which one part is axially movable to effect focussing to suit differing object distances, wherein said movable part of said rear lens being located behind the other part which is stationary during focussing and wherein the characteristics of the various lens elements of said front and rear lens groups and their spatial relationships to each other are substantially of the proportions indicated by the numerical data in the following table:

Distance between surface R_1 and the focal plane: 81.05				
R_1 =	66.6001	d_1 = 3.625	N_1 = 1.48749	ν_1 = 70.1
R_2 =	−33.1516	d_2 = 2.089		
R_3 =	−28.6739	d_3 = 1.250	N_2 = 1.80610	ν_2 = 40.9
R_4 =	−316.5437	d_4 = 0.125		
R_5 =	41.3109	d_5 = 3.250	N_3 = 1.48749	ν_3 = 70.1
R_6 =	−57.4105	d_6 = 24.974		
R_7 =	12.8482	d_7 = 0.875	N_4 = 1.71300	ν_4 = 53.9
R_8 =	22.5379	d_8 = 0.125		
R_9 =	22.9059	d_9 = 0.500	N_5 = 1.57250	ν_5 = 57.7
R_{10} =	10.4573	d_{10} = variable		
R_{11} =	37.1996	d_{11} = 0.750	N_6 = 1.75520	ν_6 = 27.5
R_{12} =	96.1965	d_{12} = 0.125		
R_{13} =	86.0176	d_{13} = 0.625	N_7 = 1.71300	ν_7 = 53.9
R_{14} =	19.4620			

Object distance from the focal plane	Focal length of the complete objective	Variable axial air separation (d_{10})
Infinity	100.00	2.250
−1,000	93.73	10.208

3. A telephoto objective of high speed adjustable focus comprising:

a front lens group which has a positive refracting power and remains stationary during focussing; and

a rear lens group having a negative refracting power and composed of a stationary sub-group and at least one movable sub-group, said movable sub-group having a negative refracting power, a frontmost surface of which has a convex face toward the object, said movable sub-group being moved on the optical axis toward an image so as to cause the telephoto object to focus an object at a near distance from its focussing on an object at a far distance.

4. A telephoto objective according to claim 3, in which said stationary sub-group is arranged nearer the object than said movable sub-group.

5. A telephoto objective according to claim 3, in which said stationary sub-group has a negative refractory power and its frontmost surface is convex toward the object.

6. A telephoto objective according to claim 5, in which said stationary sub-group is a negative meniscus lens.

7. A telephoto objective according to claim 5, in which said stationary sub-group comprises a positive meniscus lens and a negative meniscus lens arranged in the written order.

8. A telephoto objective according to claim 3, wherein the absolute focal length of said stationary sub-group is larger than that of said movable sub-group.

9. A telephoto objective according to claim 8, in which said stationary sub-group comprises a positive meniscus lens and a negative meniscus lens arranged in the written order.

10. A telephoto objective according to claim 3, in which said front lens group comprises a positive lens, a negative lens and a positive lens.

11. A telephoto objective according to claim 10, in which said positive lenses is a biconvex lens, and said negative lens, is a negative meniscus lens having its concave face toward the object.

12. A telephoto objective of high speed adjustable focus comprising:

a primary lens group which comprises at least three lenses, has a positive refracting power and is stationary at a constant distance from the focal plane;

a middle lens group which is on the image side axially apart from said primary lens group and has a negative refracting power and front lens-surface of which group faces toward the object; and

a rearmost lens group which is first behind said middle lens group and has a negative refracting power, and comprises at least one positive lens and at least one negative lens, said rearmost lens group moving axially to the image side when refocussing is done from an object far from the object to an object near the object.

13. A telephoto objective according to claim 12, in which said primary lens group comprises a biconvex lens, a negative lens having the concave face toward the object and a positive lens arranged in the written order from the object side.

14. A telephoto objective according to claim 12, in which said middle lens group comprises a negative meniscus lens.

15. A telephoto objective according to claim 12, in which said rearmost lens group comprises a positive

meniscus lens and a negative lens arranged in the written order from the object side.

16. A telephoto objective of high speed adjustable focus comprising a front lens group which has a positive refracting power and remains stationary during focussing, and a rear lens group which is positioned on the image side axially apart from said front lens group and has a negative refracting power, said rear lens group being divided into two parts of which one part is axially movable to effect focussing to suit differing object distance, and the other part has a negative refracting power and stationary during focussing.

17. A telephoto objective according to claim **16**, wherein said movable part of said rear lens group is located behind the other part which is stationary during focussing.

18. A telephoto objective according to claim **16**, wherein said movable part of said rear lens group is located behind the other part which is stationary during focussing and composed of a plurality of lenses.

19. A telephoto objective according to claim **18**, wherein said movable lens part of said rear lens group has a rearmost surface concave to the rear, and said rearmost surface has a radius of curvature which is smallest among all the surfaces of said movable part.

20. A telephoto objective according to claim **16**, wherein said stationary part of said rear lens group has a frontmost surface convex to the front.

21. A telephoto objective according to claim **20**, wherein said stationary part has a rearmost surface concave to the rear, and said rearmost surface has a radius of curvature which is smallest among all the surfaces of the stationary part.

22. A telephoto objective according to claim **16**, wherein the movable part of said rear lens group has a negative refracting power, and the absolute focal length of the stationary part of said rear lens group is larger than that of said movable part, wherein said movable part is moved on the optical axis toward the image so as to cause the objective to focus an object at near distance from its focusing on an object at infinite distance.

23. A telephoto objective of high speed adjustable focus comprising: a front lens group which has a positive power and remains stationary during focusing, and a rear lens group which is positioned on the image side of said front lens group and has a negative power, said rear lens group consisting of at least one stationary sub-group and a movable sub-group, said movable sub-group having a negative power and being axially movable to focus, wherein the absolute focal length of said stationary sub-group is larger than that of said movable sub-group.

24. A telephoto objective according to claim 23, wherein the diameter of each component lens of said front lens group is larger than that of the rear lens.

25. A telephoto objective according to claim 23, wherein the movable sub-group includes a positive lens for compensating as spherical aberration of said movable sub-group and a negative lens.

* * * * *

United States Patent [19]

Yamaguchi

[11] **4,281,908**

[45] **Aug. 4, 1981**

[54] **TESSER TYPE OBJECTIVE LENS SYSTEM HAVING A REAR APERTURE STOP**

[75] Inventor: **Tamikazu Yamaguchi**, Sakai, Japan

[73] Assignee: **Minolta Camera Kabushiki Kaisha**, Osaka, Japan

[21] Appl. No.: **26,829**

[22] Filed: **Apr. 4, 1979**

[30] **Foreign Application Priority Data**

May 10, 1978 [JP] Japan 53/55856

[51] **Int. Cl.**[3] **G02B 9/20**

[52] **U.S. Cl.** **350/476**

[58] **Field of Search** 350/227, 476

[56] **References Cited**

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3,895,857	7/1975	Imai	350/227

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47-19387	6/1972	Japan	350/227
49-38620	4/1974	Japan .	
50-3163	1/1975	Japan .	
51-10092	4/1976	Japan .	

Primary Examiner—John K. Corbin
Assistant Examiner—Scott J. Sugarman
Attorney, Agent, or Firm—Jackson, Jones & Price

[57] **ABSTRACT**

An improved tesser type objective lens system having a rear aperture stop with a relatively wide field angle of about 60° and an F-number of about F 2.8 is provided. The thickness of the second negative lens in the lens system is increased relative to the total axial distance of the lens system which permits the reduction of the Petzval sum while maintaining a balance correction of spherical aberration and coma.

7 Claims, 18 Drawing Figures

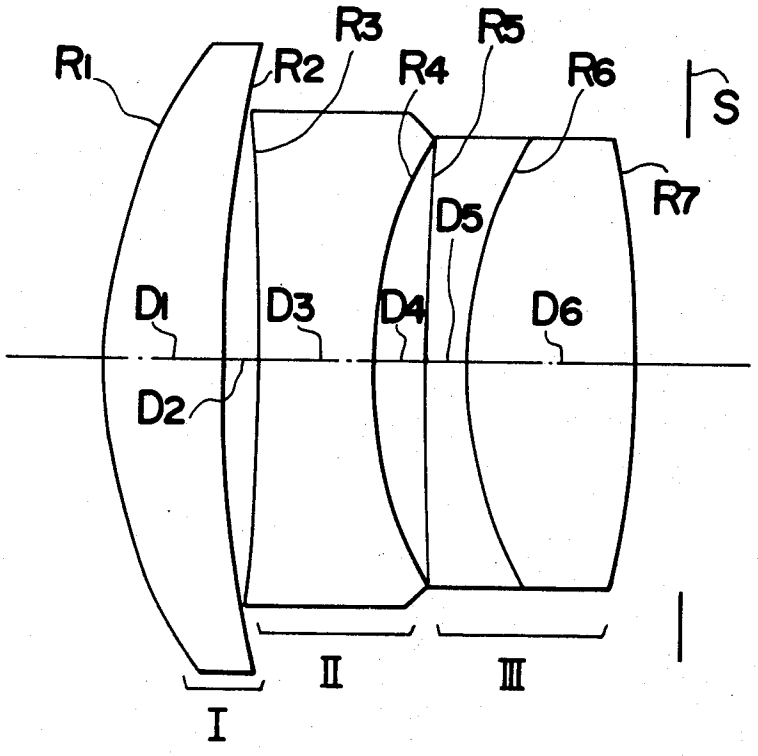


FIG.1

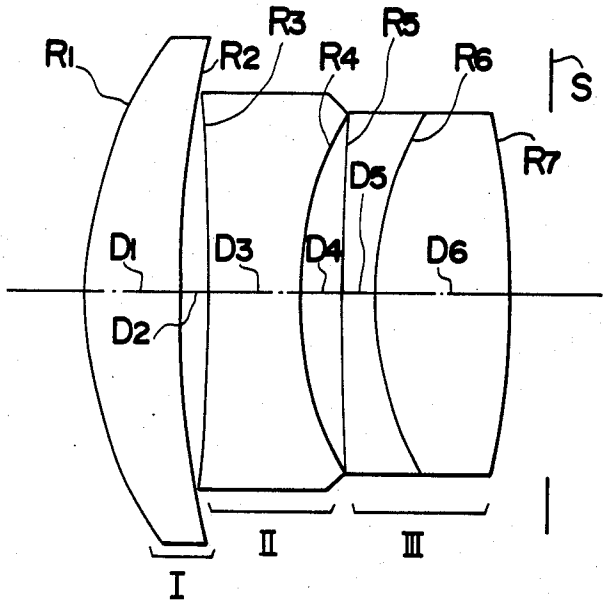
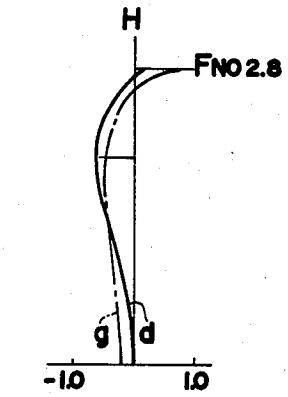
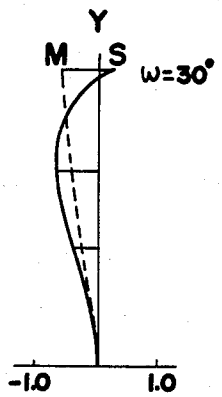


FIG.2a



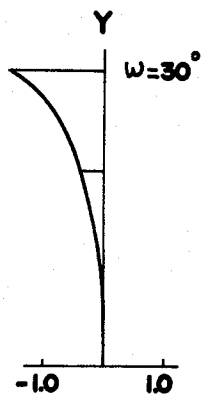
Spherical Aberration

FIG.2b



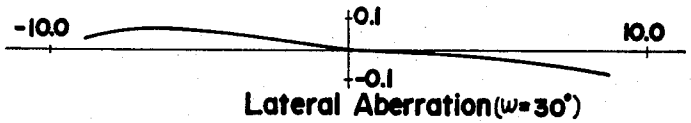
Astigmatism

FIG.2c



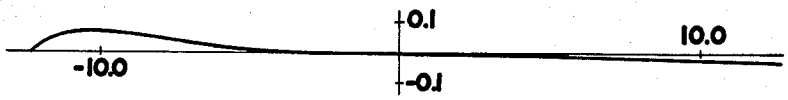
Distortion

FIG.2d



Lateral Aberration(ω=30°)

FIG.2e



Lateral Aberration(ω=19°)

FIG.3

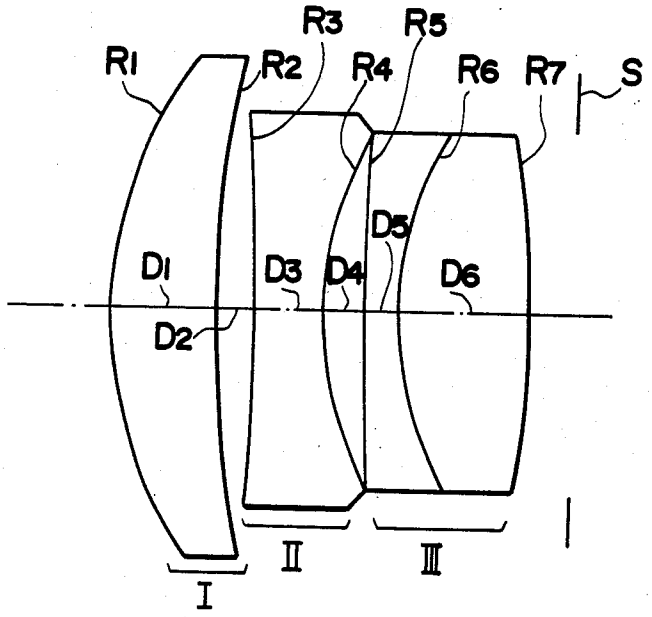


FIG.4a

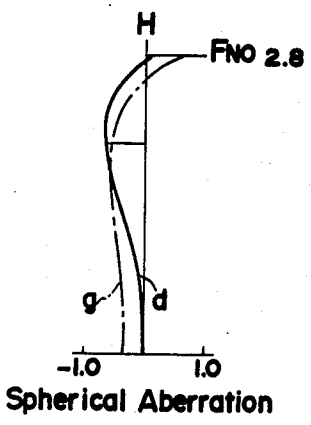


FIG.4b

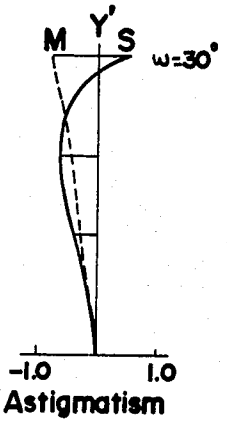


FIG.4c

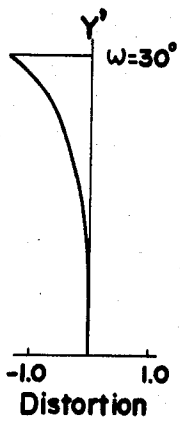


FIG.4d

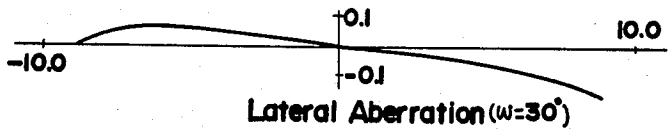


FIG.4e

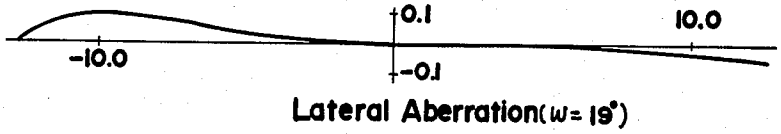


FIG.5

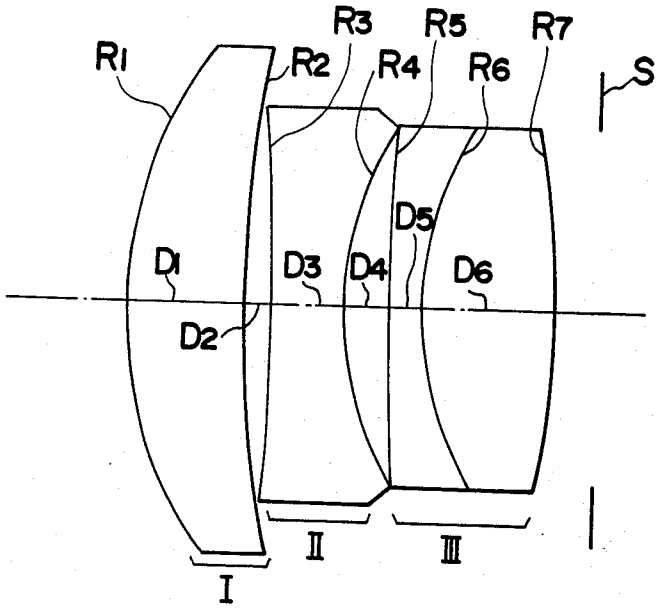
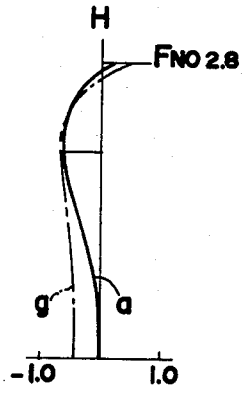
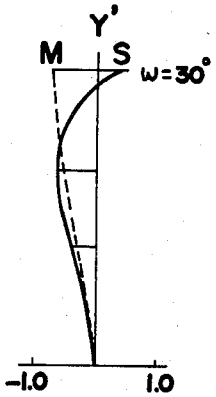


FIG.6a



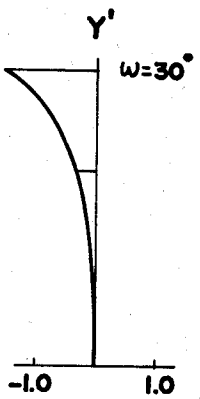
Spherical Aberration

FIG.6b



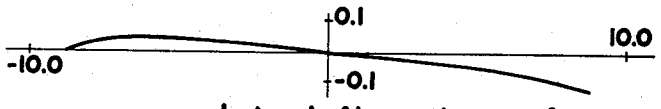
Astigmatism

FIG.6c



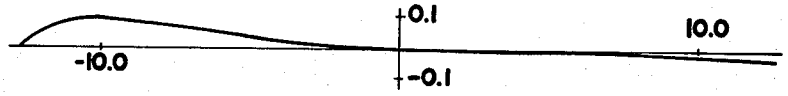
Distortion

FIG.6d



Lateral Aberration (ω=30°)

FIG.6e



Lateral Aberration(ω=19°)

TESSER TYPE OBJECTIVE LENS SYSTEM HAVING A REAR APERTURE STOP

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a tesser type lens system having an aperture stop located at the rear of the lens system and more particularly to a lens system of this type having a relatively wide field angle of about 60° and an F-number of about F. 2.8.

2. Description of the Prior Art

The prior art is quite familiar with various forms of tesser type lens systems having a rear aperture stop. These photographic objectives are frequently used in compact cameras, for example, to facilitate the incorporation of a shutter mechanism into the camera body. Numerous examples of prior art literature exist disclosing a tesser type lens system having an aperture stop located at the rear of the lens system so that the aperture stop can be controlled by a relatively simple mechanism. The prior art has recognized that it is difficult to effectively correct astigmatism and field curvature in the zonal area of the image if the field angle is desired to be increased to 60°.

Although numerous examples of prior art references indicate that this is a close art, there is still room for improvement in correcting abberations such as astigmatism, field curvature and coma in the zonal to marginal areas of the image.

Examples of relevant prior art can be found in U.S. Pat. No. 3,615,126 and U.S. Pat. No. 3,895,857. Additional tesser type objective lens systems having rear aperture stops are disclosed in Japanese Utility Model Publication No. 42-22354, Japanese Patent Publications Nos. 50-3163 and 51-10092 and Japanese Patent Application Laid-Open to Public Inspection No. 49-38620.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide an improved tesser type lens system having a rear aperture stop wherein aberrations associated with a field angle of approximately 60° can be favorably corrected.

The tesser type objective lens system includes from image to object side a first positive meniscus lens, a second negative lens, and a third positive doublet consisting of a positive element and a negative element cemented to the positive element on its image side. Finally an aperture stop is located at the image side of the doublet. This lens system fulfills the following conditions:

(1)	0.3	<	$D_3/(D_1 + D_2 + D_3)$	<0.45
(2)	0.05F	<	D_3	<0.08F
(3)	0.03F	<	D_4	<0.045F
(4)	−2.4F	<	R_3	<−1.6F
(5)	0.25F	<	R_6	<0.33F
(6)	0.13	<	N_4-N_3	<0.22
(7)	$(N_1 + N_4)/2 > 1.75$			

wherein:

F represents the focal length of the entire lens system;

D_i represents the i-th axial distance from the object side;

R_i represents the radius of curvature of the i-th surface from the object side; and

N_i represents the refractive index of the i-th glass material from the object side with respect to the ray of d-line.

The features of the present invention, which are believed to be novel, are set forth with particularity in the appended claims. The present invention, both as to its organization and manner of operation, together with further objects and advantages thereof, may be best understood by reference to the following description, taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** represents a cross sectional view of a first embodiment of the present invention;

FIGS. **2***a*, **2***b*, **2***c* and **2***e* represent graphic plots of various aberrations of the first embodiment;

FIG. **3** represents a cross sectional view of a second embodiment of the present invention;

FIGS. **4***a*, **4***b*, **4***c*, **4***d* and **4***e* represent graphic plots of various aberrations of the second embodiment;

FIG. **5** represents a cross sectional view of a third embodiment of the present invention; and

FIGS. **6***a*, **6***b*, **6***c*, **6***d* and **6***e* represent graphic plots of various aberrations of the third embodiment.

BRIEF DESCRIPTION OF THE PREFERRED EMBODIMENTS

The following description is provided to enable any person skilled in the optical art to make and use the invention and sets forth the best mode contemplated by the inventor for carrying out his invention. Various modifications however, will remain readily apparent to those skilled in the art, since the generic principles of the present invention have been defined herein specifically to provide an improved tesser type objective lens system having a rear aperture stop with favorable corrections of various higher order aberrations.

The derivation of the formulae and the relation set forth herein can be accomplished with the assistance of a computer. The present invention represents the parameters of a compromise balance of acceptable aberrations in a relatively easily manufactured and economical lens system for utilization, for example, with a camera.

Various examples of the present invention will hereinafter be described with reference to tabulated physical and optical characteristics in various Tables. The parameters of the lens elements of the present invention are listed in separate embodiments corresponding to the Figures which are illustrated diagrammatically. As usual, in conventional lens diagrams, the light is assumed to travel from left to right. The lenses are disclosed as assembled into three separate optical units. Both in the diagrams and in the Tables the radii of curvature of the lenses are indicated by R, with a subscript corresponding to the consecutive number of the lens element surfaces from object to image side.

In the Tables, a negative sign indicates the radii on centers of curvature lying on the object side of their vertices. In both the Figures and the Tables, the axial spacings are disclosed as, D, along the optical axis and include both the axial spacings between the lens elements and thickness of the lens elements.

All linear dimensions are given in absolute values and are given with reference to an equivalent focal length of unity. The Tables also provide with respect to each example, the intended relative aperture and the total field of view 2ω. Finally, the refractive index is designated, N, while the Abbe Number is designated ν.

FIGS. 1, 3 and 5 utilize lens elements of basically the same configuration with only the dimensions varying between each embodiment. Accordingly different reference numbers are not necessary and a diagram of each embodiment is conveniently located adjacent the aberration graphs for convenient reference to the lens designer.

With reference to FIGS. 1, 3 and 5 and in accordance with the present invention, a tesser type objective lens system having a rear aperture stop, S, comprises a first positive meniscus lens I convex to the object side; a second negative lens II located at the image side of the first positive meniscus lens I, and a third positive doublet III located at the image side of the second negative lens II. The third positive doublet consists of a positive element and a negative element cemented to the positive element by an intermediate cementing surface, R_6, convex to the object side. The aperture stop S is located at the image side of the third doublet III. The lens system of the present invention fulfills the following conditions:

(1)	0.3 <	$D_3/(D_1 + D_2 + D_3)$	<0.45
(2)	0.05F <	D_3	<0.08F
(3)	0.03F <	D_4	<0.045F
(4)	−2.4F <	R_3	<−1.6F
(5)	0.25F <	R_6	<0.33F
(6)	0.13 <	N_4-N_3	<0.22
(7)	$(N_1 + N_4)/2 > 1.75$		

wherein:

F represents the focal length of the entire lens system;

D_i represents the i-th axial distance from the object side;

R_i represents the radius of curvature of the i-th surface from the object side; and

N_i represents the refractive index of the i-th glass material from the object side with respect to the ray of d-line.

The following is an explanation of the purpose of the above seven parameters of the present invention. As noted in the description of the prior art, there has existed a general difficulty in effectively correcting astigmatism and field curvature in a tesser type lens system having a rear aperture. This problem existed because in a conventional design the Petzval sum could not be successfully reduced while at the same time maintaining a proper balance correction of spherical aberration and coma. In other words, the conventional design technique for reducing a Petzval sum by increasing the index of refraction for the positive lens elements in the lens system while reducing the index of refraction of the negative lens elements in the lens system would inevitably deteriorate the corrections of the spherical aberration and coma.

The present invention has adopted a novel design technique for reducing the Petzval sum while maintaining the corrections of spherical aberration and coma so that both astigmatism and field curvature as well as the spherical aberration and coma are correctly balanced.

In accordance with the present invention, this correction is achieved by increasing the thickness D_3 of the second negative lens II relative to the total axial distance, D1+D2+D3, to a greater degree than that suggested in a conventional tesser type lens design. By means of this relatively increased thickness of D3, the front surface R3 of the second negative lens II is located closer to the front surface R1 of the whole lens system. This allows the second negative lens II to utilize glass material of a relatively low refractive index to successfully reduce the Petzval sum, while the corrections of spherical aberration and coma can still be balanced. Conditions (1) and (2) relate to this particular design technique. In those cases wherein the lower limit of condition (1) or (2) is violated it will be difficult to desirably reduce the Petzval sum.

If the upper limit of these conditions are violated the chromatic aberration with respect to a shorter wavelength of light will be overcorrected in the zonal to marginal area of the image. Additionally if the upper limit of condition (2) is violated the lens design will fail to meet the criterion of a compact lens system which is necessary in commercially acceptable lenses. As a supplement to conditions (1) and (2), condition (7) is also utilized for reducing the Petzval sum, by requiring the refractive indices for the positive lens elements to be relatively high.

Conditions (3) through (6) are designed to insure the appropriate balance correction of coma in the zonial to marginal area of the image. By adherence to these conditions, it is possible to increase the absolute value of the radius of curvature R_3 of the front surface of the second negative lens II in accordance with the increase of its lens thickness D3. It is also possible to give the cemented surface R6 a suitably great refractive power by means of reducing the radius of curvature R6 and increasing the difference between the refractive indices N3 and N4 at both sides of the surface R6. Additionally, the airspace D4 between the second negative lens II and the third doublet III will be reduced. It has been found difficult to correct coma if any one of the following limits are violated, the upper limit of condition (3); both the upper and lower limits of condition (4); the upper limit of condition (5) and the lower limit of condition (6). The lower limit of condition (3) further defines a limit of a practical lens arrangement. Finally, it should be noted that an excessively large refractive power to the cementing surface R6 will result in causing an under correction of the meridonial field curvature if the lower limit of condition (5) or upper limit of condition (6) is violated.

Tables 1 through 3 show respectively 3 embodiments of the present invention. FIG. 1 corresponds to Table 1 while FIG. 2*a* discloses spherical aberration, FIG. 2*b* discloses astigmatism, FIG. 2*c* discloses distortion, and FIG. 2*d* discloses lateral aberration for a field angle of 30° while FIG. 2*e* discloses lateral aberration for a field angle of 19°. FIG. 3 corresponds to Table 2 with the aberrations being set forth in FIGS. 4*a* through 4*e*. FIG. 5 corresponds to Table 3 with the aberrations being set forth in FIGS. 6*a* through 6*e*.

TABLE 1

Embodiment 1

F = 100 1 : 2.8 2ω = 60°

	Radius of Curvature		Axial Distance		Refractive Index		Abbe Number
R_1	34.04	D_1	8.0	N_1	1.7885	ν_1	45.7
R_2	100.9	D_2	2.5				
R_3	−220.3	D_3	7.5	N_2	1.6727	ν_2	32.2
R_4	29.53	D_4	3.5				
R_5	203.0	D_5	3.0	N_3	1.6477	ν_3	33.9
R_6	28.3	D_6	11.0	N_4	1.805	ν_4	41.0
R_7	−86.43	S (Aperture Stop)					

TABLE 2

Embodiment 2

F = 100 1 : 2.8 2ω = 60°

	Radius of Curvature		Axial Distance		Refractive Index		Abbe Number
R_1	34.07	D_1	9.0	N_1	1.781	ν_1	44.5
R_2	101.5	D_2	3.5				
R_3	−184.6	D_3	5.5	N_2	1.7174	ν_2	29.4
R_4	30.6	D_4	3.5				
R_5	204.7	D_5	3.0	N_3	1.6727	ν_3	32.2
R_6	28.82	D_6	11.0	N_4	1.8340	ν_4	37.1
R_7	−79.9	S (Aperture Stop)					

TABLE 3

Embodiment 3

F = 100 1 : 2.8 2ω = 60°

	Radius of Curvature		Axial Distance		Refractive Index		Abbe Number
R_1	34.26	D_1	10.0	N_1	1.781	ν_1	44.5
R_2	103.1	D_2	2.4				
R_3	−194.1	D_3	6.0	N_2	1.683	ν_2	31.5
R_4	29.94	D_4	3.7				
R_5	218.0	D_5	3.0	N_3	1.6398	ν_3	34.6
R_6	29.65	D_6	11.0	N_4	1.805	ν_4	41.0
R_7	−81.78	S (Aperture Stop)					

It is to be further understood that various modifications of the generic concepts of this invention are possible without departing from its spirit and accordingly the scope of the present invention should be determined solely from the following claims.

What is claimed is:

1. An improved tesser type objective lens system having a rear aperture stop comprising:

a first positive meniscus lens convex to the object side;

a second negative lens located at the image side of the first positive meniscus lens;

a third positive doublet located at the image side of the second negative lens, the third positive doublet consisting of a positive element and a negative element cemented to the positive element by an intermediate cemented surface convex to the object side; and

an aperture stop located at the image side of the third doublet, wherein the lens system fulfills the following conditions:

0.3	<	$D_3/(D_1 + D_2 + D_3)$	<	0.45
0.05F	<	D_3	<	0.08F
0.03F	<	D_4	<	0.045F
−2.4F	<	R_3	<	−1.6F
0.25F	<	R_6	<	0.33F
0.13	<	N_4-N_3	<	0.22
		$(N_1 + N_4)/2 > 1.75$		

wherein:

F represents the focal length of the whole lens system;

D_i represents the i-th axial distance from the object side;

R_i represents the radius of curvature of the i-th surface from the object side; and

N_i represents the refractive index of the i-th glass material from the object side with respect to the ray of d-line.

2. An improved tesser lens system comprising the following design parameters:

F = 100 1 : 2.8 2ω = 60°

	Radius of Curvature		Axial Distance		Refractive Index		Abbe Number
R_1	34.04	D_1	8.0	N_1	1.7885	ν_1	45.7
R_2	100.9	D_2	2.5				
R_3	−220.3	D_3	7.5	N_2	1.6727	ν_2	32.2
R_4	29.53	D_4	3.5				
R_5	203.0	D_5	3.0	N_3	1.6477	ν_3	33.9
R_6	28.3	D_6	11.0	N_4	1.805	ν_4	41.0
R_7	−86.43	S (Aperture Stop)					

3. An improved tesser lens system comprising the following design parameters:

F = 100 1 : 2.8 2ω = 60°

	Radius of Curvature		Axial Distance		Refractive Index		Abbe Number
R_1	34.07	D_1	9.0	N_1	1.781	ν_1	44.5
R_2	101.5	D_2	3.5				
R_3	−184.6	D_3	5.5	N_2	1.7174	ν_2	29.4
R_4	30.6	D_4	3.5				
R_5	204.7	D_5	3.0	N_3	1.6727	ν_3	32.2
R_6	28.82	D_6	11.0	N_4	1.8340	ν_4	37.1
R_7	−79.9	S (Aperture Stop)					

4. An improved tesser lens system comprising the following design parameters:

F = 100 1 : 2.8 2ω = 60°

	Radius of Curvature		Axial Distance		Refractive Index		Abbe Number
R_1	34.26	D_1	10.0	N_1	1.781	ν_1	44.5
R_2	103.1	D_2	2.4				
R_3	−194.1	D_3	6.0	N_2	1.683	ν_2	31.5
R_4	29.94	D_4	3.7				
R_5	218.0	D_5	3.0	N_3	1.6398	ν_3	34.6
R_6	29.65	D_6	11.0	N_4	1.805	ν_4	41.0
R_7	−81.78	S (Aperture Stop)					

5. An improved tesser type objective lens system having a field angle of about 60° and a rear aperture stop comprising:

a first positive meniscus lens convex to the object side;

a second negative lens located at the image side of the first positive meniscus lens;

a third positive doublet located at the image side of the second negative lens, the third positive doublet consisting of a positive element and a negative element cemented to the positive element by an intermediate cemented surface convex to the object side; and

an aperture stop located at the image side of the third doublet, wherein the lens system fulfills the following conditions:

0.3	<	$D_3/(D_1 + D_2 + D_3)$	<	0.45
0.05F	<	D_3	<	0.08F
−2.4F	<	R_3	<	−1.6F
0.25F	<	R_6	<	0.33F
0.13	<	N_4-N_3	<	0.22

wherein:

F represents the focal length of the whole lens system;

D_i represents the i-th axial distance from the object side;

R_i represents the radius of curvature of the i-th surface from the object side; and

N_i represents the refractive index of the i-th glass material from the object side with respect to the ray of d-line.

6. The invention of claim 5 wherein the index of refraction of the second negative lens is approximately 1.7 or less.

7. An improved tesser type objective lens system having a field angle of approximately 60° and a rear aperture stop comprising from object to image side:

a first positive meniscus lens convex to the object side;

a relatively thick second negative lens with an index of refraction of approximately 1.7 or less, located at the image side of the first positive meniscus lens;

a third positive doublet located at the image side of the second negative lens, the third positive doublet consisting of a positive element and a negative element with an intermediate surface convex to the object side; and

an aperture stop located at the image side of the third doublet, wherein the lens system fulfills the following conditions to permit a reduction in the Petzval Sum below a conventional tesser value while still maintaining a balanced correction of spherical aberration, coma, astigmatism, and field curvature:

$$0.3 < \frac{D_3}{D_1 + D_2 + D_3} < 0.45$$

$$0.055F \leqq D_3 < 0.08F$$

wherein:

D_i represents the i-th axial distance of both air spaces and lens thicknesses and F represents the focal length of the entire lens system.

* * * * *

United States Patent [19]

Prochnow

[11] **4,280,762**

[45] **Jul. 28, 1981**

[54] **CAMERA HAVING AN INDEPENDENTLY FOCUSED RETRACTABLE OBJECTIVE LENS**

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[73] Assignee: **Rollei-Werke Franke & Heidecke GmbH & Co.**, Brunswick, Fed. Rep. of Germany

[21] Appl. No.: **100,358**

[22] Filed: **Dec. 5, 1979**

[30] **Foreign Application Priority Data**

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[51] **Int. Cl.**[3] **G03B 3/00**; G03B 17/04

[52] **U.S. Cl.** **354/187**; 354/198

[58] **Field of Search** 354/198, 195, 187-194

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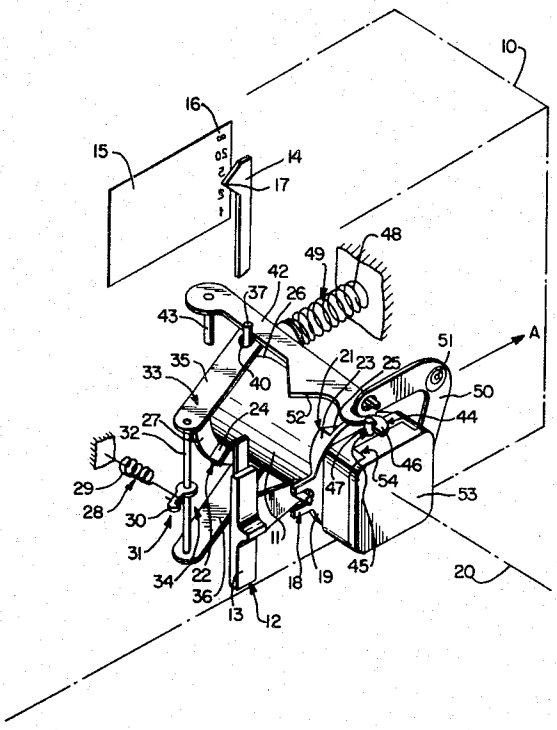
Primary Examiner—John Gonzales

Attorney, Agent, or Firm—Schwartz, Jeffery, Schwaab, Mack, Blumenthal & Koch

[57] **ABSTRACT**

Disclosed is a camera including a camera housing and an objective lens having an image axis. The objective lens for the camera is mounted in a tube which is movable between an extended exposure position and a retracted storage position. When the tube is in the extended exposure position, an annulus around the tube cooperates with a projection on the tube to set the precise extended position necessary to provide a sharply focused image on the camera film.

3 Claims, 2 Drawing Figures



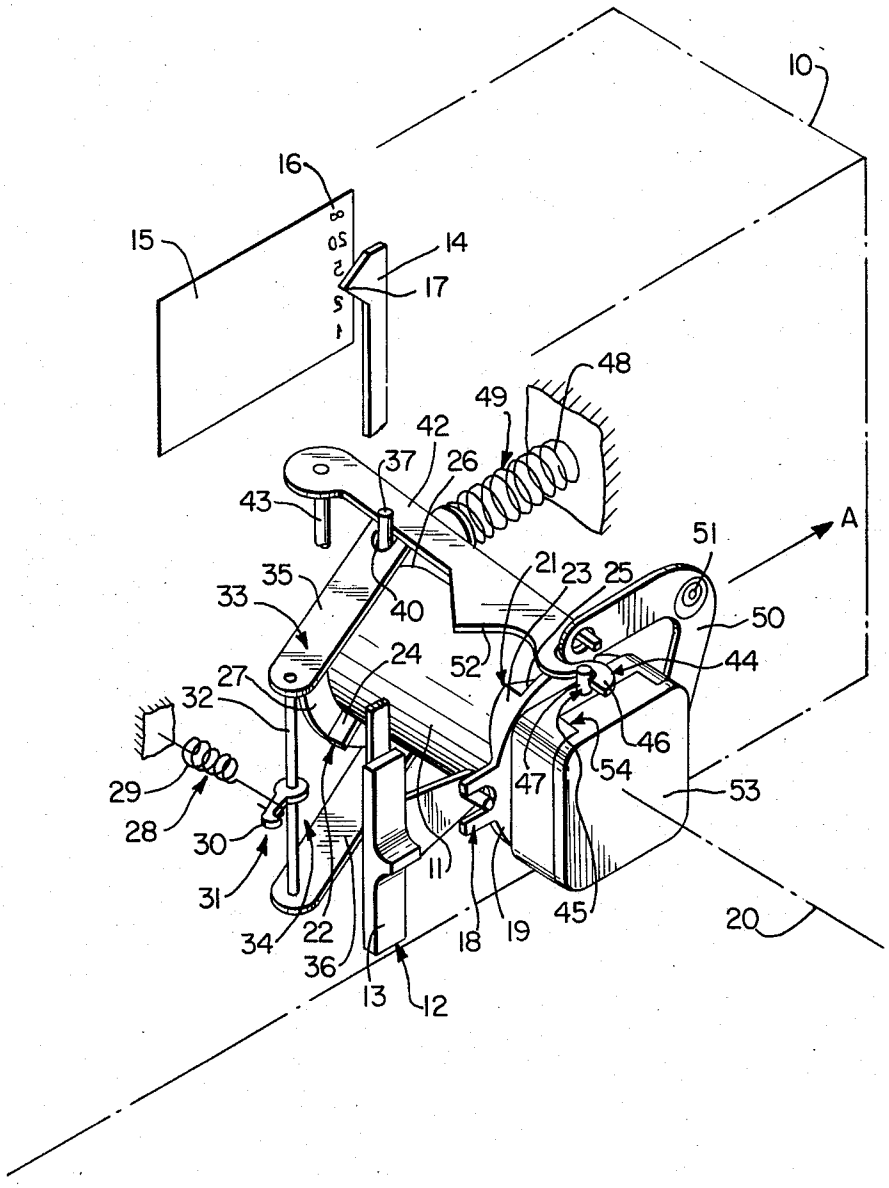

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FIG. 1

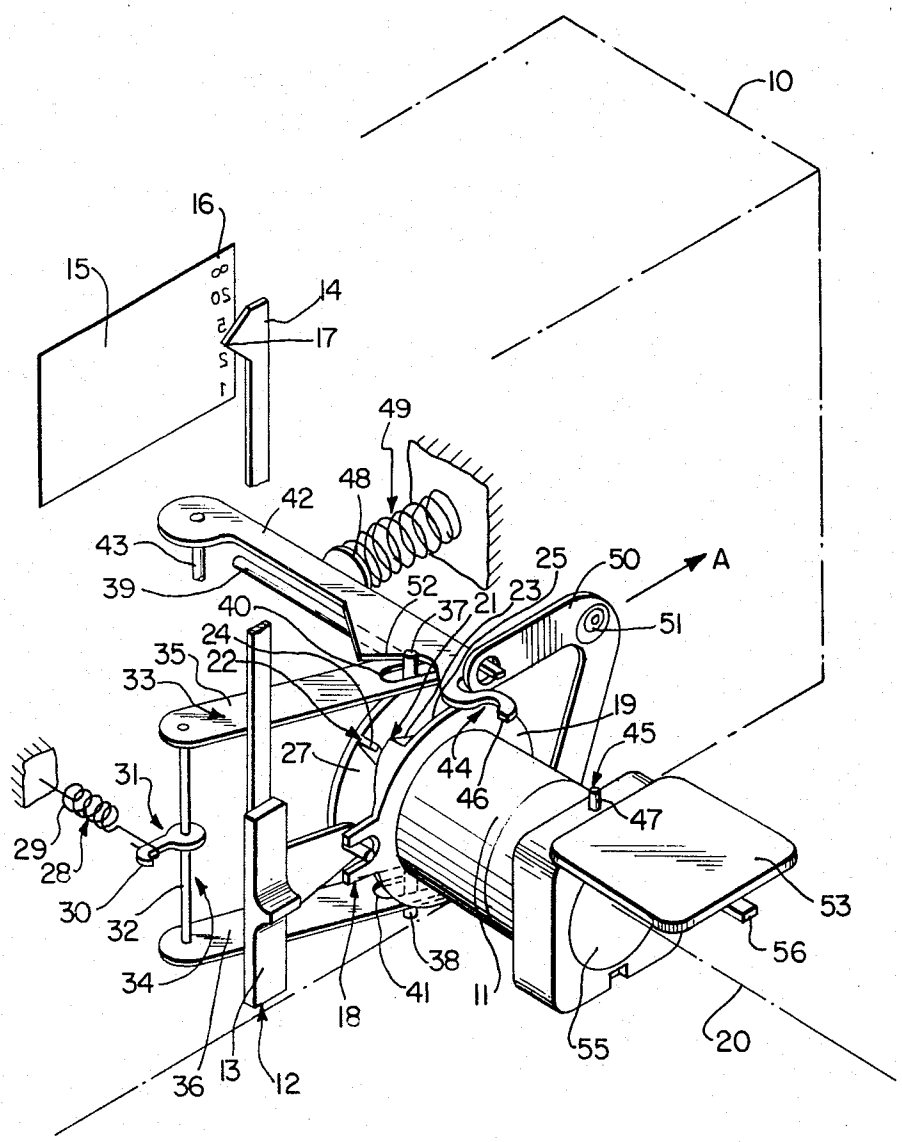
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FIG. 2

CAMERA HAVING AN INDEPENDENTLY FOCUSED RETRACTABLE OBJECTIVE LENS

BACKGROUND OF THE INVENTION

The invention generally concerns a photographic camera and particularly a miniature camera having a focusable objective lens.

In cameras of this type, the range setting device is arranged directly on the objective tube in the form of a rotating ring. This setting ring carries a range scale whereby the range number desired must be made to coincide with a marking stationarily arranged on the objective tube, in order to set the range desired. To set the range, the user of the camera is thus always forced to remove the camera from his eye and to set the range on the objective tube. This is extremely disadvantageous, because the observation of the object must be interrupted, when it is desired for example to continuously adjust the range to a moving object. Such a camera is poorly adapted for use in taking snapshots, because its handling is rather cumbersome. The modern requirements of a snapshot camera demamd as a minimum that an indication of range be provided in the viewfinder so that the necessary distance may be set and verified in the viewfinder without taking the camera from the eye, thus interrupting the observation of the object. The indication of a range set on the objective of the camera in a range indicating device in the viewfinder is, technically, extremely involved in a camera with an objective tube which slides in and out and thus is highly subject to problems, and as a result such a device has not been provided.

Another disadvantage of this known camera consists of the fact that the handling of the camera during the setting of the range is not of optimum ease. The diameter of the objective in such cameras having an objective tube capable of sliding in and out is mostly very small so that on the one hand the range scale is arranged in a highly crowded manner, which renders it difficult to read and on the other, the relatively small range setting annulus offers no easy grip that would facilitate handling.

SUMMARY OF THE INVENTION

It is thus an object of the present invention to provide a camera with an objective tube capable of sliding in and out, wherein the handling of the camera with respect to range setting is substantially improved. It is a further object of the present invention to provide an indication of the range selected in the viewfinder by simple means. It is a still further object to provide a camera which is simple in design and provides savings in production costs, while at the same time being sturdy and not susceptible to defects. An additional object is to provide a camera in which the accurate optical alignment of the objective lens in its exposure position is possible.

The above and other objects are achieved by providing a camera including a camera housing and an objective lens having an image axis. Additionally, means for manually setting the range of the camera and means for mounting the objective lens for movement, substantially parallel to the image axis, between an extended exposure position and the retracted storage position are provided. Furthermore, means for variably limiting axial movement of the mounting means in the extended position and means, responsive to the range setting means,

for varying the limiting means are also provided. Thus, the mounting means is movable between a retracted position and an extended position and whose extended position is adjusted by said limiting means which in concert with said varying means and in response to the range setting means, adjusts the axial position of the objective lens to ensure a properly focused image.

Further embodiments of the present invention comprise an indicator and a viewfinder reflecting the position of the range setting means and thus the focal distance of the objective lens. Additional embodiments include means for biasing the lens mounting means towards its extended exposure position in combination with means locking the mounting means in a retracted storage position. A further embodiment includes releasing means permitting said lens mounting means under the influence of the biasing means to move to its extended exposure position.

BRIEF DESCRIPTION OF THE DRAWINGS

A more complete appreciation of the invention and the attendant advantages thereof will be more clearly understood by reference to the following drawings wherein:

FIG. **1** is a front perspective view of one embodiment of the present invention with the lens tube in the storage position; and

FIG. **2** is a front perspective view of the embodiment of FIG. **1**, but in its extended exposure position.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

The range setting device arranged on the housing of the camera, according to the present invention, facilitates the setting of the range by the user of the camera because this range setting device may be designed independently of the diameter of the objective tube and arranged in an economically favorable manner on the camera housing. Beyond this, a device indicating the range in the viewfinder may be effectuated very simply in association with the range setting device arranged in the housing of the camera. Such a design is of the utmost simplicity. The range setting device arranged in the camera housing is particularly advantageous if a flash unit is additionally integrated with the housing. In such a case the range setter may also be able to perform simultaneous adjusting functions for the flash unit.

As a result of the measures taken in accordance with the invention, in spite of the removal of the range setting device from the objective tube and its arrangement on the housing of the camera, the transmission of the setting of the range from the range setting device to the objective is very simple from a design standpoint, sturdy and has low susceptibility to failure. Further, a significant optical advantage is achieved. By means of the present invention, complete adjustment of the objective lens takes place during the setting of the range and not, as in the case of the prior art camera, only during setting of the front lens. This substantially improves the imaging quality of the objective.

The measures taken in keeping with the invention make it further possible to set the range on a camera not ready for exposure, i.e. with the objective tube retracted into the camera housing. This is of particular advantage for cameras wherein the retracted objective tube is additionally covered in front. Such a capability represents a significant step to improve the camera in

the direction of a "rapid shot camera." The range may be set while the camera is still closed. The touch of a button is then sufficient to make the objective tube emerge. The exposure can then be triggered without wasting valuable time on the setting or resetting of the camera. In one embodiment, wedge-like projection on the setting annulus cooperates with at least one projection on the objective tube to effect transmission between the range setting device and the objective tube, that is overall simple in design, inexpensive to manufacture and sturdy.

In a further embodiment a slideout spring is prestressed in the retracted state of the objective tube such that the camera may be made ready for exposure very rapidly. The touch of a button on the corresponding locking element is sufficient to cause the objective tube to slide into its exposure position and to be frictionally arrested. All this may take place without a need for the user of the camera to remove his eye from the viewfinder and thus to interrupt his observation of the object. The preparation time of the camera for the actual performance of an exposure is thus extremely short.

A further embodiment includes a means for locking the objective tube in the camera housing that is simple and reliable and which, simultaneously, may be entrusted with additional functions.

In a further most advantageous embodiment, the satisfactory frictional stopping of the extended objective tube is obtained in its position of exposure, specifically in each of the different axial positions of the objective tube corresponding to the range setting. The objective tube and thus the objective is held securely in its optically correct position and cannot be deflected from this position by the accidental application of lateral pressure on the objective tube by the user of the camera.

In an additional embodiment a spring element secures a locking lever in place when the objective tube is retracted into the camera housing, and it effects the frictional arrest of the objective tube by means of the inclined edges of the locking lever, in the exposure position of the objective tube.

In a further embodiment, the locking of one of the two locking levers with a pin on the objective tube and the other locking lever with a pawl on the front cover which is hingedly mounted on the objective tube, permits the covering of the objective lens when the tube is in its retracted position. This front or objective cover automatically snaps into its open position, uncovering the objective, when the lock of the objective tube is released and the latter slides into its ready position under the pressure of the spring. Because the objective cover is arranged on the front side of the objective tube above the opening of the objective and, in the open position, stands out essentially at a right angle from the front side of the objective tube, the cover additionally performs the function of a sunshade. When converting the camera from its exposure ready position into its transport state, it is merely necessary to deflect the objective cover to the front side of the objective tube and to push the objective tube further into the camera housing by exerting additional pressure on the cover. When the objective tube arrives in its locking position, the locking levers automatically engage the objective tube and the cover and hold both, so that the objective tube is completely inserted in the camera housing and the objective protectively covered.

Referring now to the drawings wherein like reference characters designate like parts throughout the several views, FIGS. **1** and **2** illustrate a miniature camera designed for 35 mm film. It has a housing **10** indicated in the drawing by a dash-and-dot line and an objective tube **11** arranged in an axially displaceable manner. In the position ready for exposure of the camera, wherein photographic exposures may be effected, as in FIG. **2**, the objective tube **11** protrudes from the housing **10** and assumes its optically correct coordination with respect to the film placed in the window of the camera. When not in use, the objective tube may be inserted completely in the housing **10** as in FIG. **1**, so that the camera displays exclusively flat limiting surfaces without protruding parts that would interfere with the suitability for packing of the camera. In this so-called transport state of the camera, the latter is particularly compact and convenient and may be carried comfortably by the user.

In addition to the usual control knobs for the setting of the diaphragm and/or the exposure time and film sensitivity, the camera also has a range setting device **12**, arranged on the housing **10**. The range setting device **12** is designed in the form of a sliding key **13**, mounted transversely to the optical axis **20** in a longitudinally displaceable manner. A pointer **14** is rigidly connected with the range setting device. The pointer **14** serves to visually indicate the range set by means of the range setting device **12**. For this purpose, a distance scale **16** is arranged in the viewfinder **15** and the pointer **14** has a marker **17** correlated with the range scale **16** and following the displacement of the range setting device **12** while sliding along the range scale **16**.

The range setting device **12** is coupled with a setting annulus **19** by means of a pin and slot **18**. The setting annulus **19** is mounted in the housing **10** stationarily in the axial direction but rotatably around the optical axis **20** of the camera. On the setting annulus **19** and on the objective tube **11**, the adjusting elements **21** and **22**, respectively, are fixably mounted on their support, but in coordination with and displaceable relative to each other. The adjusting elements **21** and **22** rest in frictional contact against each other in the exposure position of the objective tube **11** (FIG. **2**) and determine the axial position of the objective tube **11** as a function of the rotating position of the setting annulus. The adjusting elements **21** and **22** are provided herein in the form of wedge-like protrusions **23** and noses **24**. The protrusions **23** are mounted on the setting annulus **19**, specifically on the rear side **25** of said annulus facing the inside of the housing, and have an axial depth increasing in the circumferential direction of the annulus **19**. The noses **24** coordinated with these protrusions **23** protrude from the circumference of the objective tube **11**, preferably at the rear end **26** of the tube or close to it.

The noses **24** are arranged on a flange **27** stationarily joined with the objective tube **11** and protruding over the objective tube **11**, and are radially aligned. The protrusions **23** and the noses **24** are distributed in a regular manner around the circumference of the setting annulus **19** and the flange **27**, respectively. In the exposure position of the objective tube **11**, depending on the rotational position of the setting annulus **19**, the noses **24** may contact the protrusions **23** at locations where they have different axial depths. As the result, the axial position of the objective tube **11** with respect to the image window can be changed. The actuation of the range setting device **12** thus alters the overall axial position of the objective tube **11** and therefore that of the objective lens held in the tube. With a suitable layout of the range

setting device 12 and the axial depth of wedge like protrusion 23, when a certain range is set by means of the sliding key 13 the objective tube 11 is positioned axially by means of the rotation of setting annulus 19. The range indicated by the pointer 14 in the viewfinder 15 is the distance necessary for the objective lens to reproduce sharply on film the object image of the camera.

The objective tube 11 is outwardly biased in the axial direction by an inwardly pulling spring 28, which is prestressed at least in the retracted state of the objective tube 11. In the present case, the spring 28 is provided in the form of a tension spring 29, engaging a lever arm 30 of a dual arm lever 31. The dual arm lever 31 is rotatable around the longitudinal axis of rotating axle 32 which is rotatably mounted in the housing 10 and engages with its other lever arm 33 the objective tube 11, specifically the flange 27. The lever arm 33 is here designed as a rocker arm, possessing two rocker arms 35 and 36, torsionally connected with the rotating axle 32. The tension spring 29 engages the lever arm 30 which is again torsionally connected with the rotating axle 32 and biases the rocker arm 34 in the outward direction of the objective tube.

The objective tube 11 carries on its flange 27, radially protruding and diametrically arranged pilot pins 37 and 38. The two pilot pins 37, 38 enter the guide slots 39 extending along the optical axis 20 (as seen in FIG. 2 where only the upper guide slot 39 is shown). By means of the pilot pins 37 and 38 and the guide slots 39, the objective tube 11 is guided satisfactorily in the axial direction. The two rocker arms 35 and 36 of the rocker 34, each have a slit 40 and 41, respectively, at their free ends, whereby they embrace the two pilot pins 37 and 38. This provides a hinged connection between the rocker 34 and the objective 11 so that the rocking motion of the rocker 34 is translated into an axial displacement of the objective tube 11.

In the housing 10 of the camera, a locking lever 42 is pivotably arranged about a rotation axle 43. An identical locking lever, again rotatable around the axle 43, is found on the underside of the objective tube 11, diametrically opposed to the upper locking lever 42. For reasons of clarity of the drawing, the lower locking lever is not shown. It is, however, identical with the upper locking lever 42 so that any reference to said upper locking lever 42 is equally valid for the lower locking lever. The locking lever 42 and the objective tube 11 both carry mutually coordinated and interlocking arresting elements 44 and 45, respectively, which engage each other in the retracted state of the objective tube 11, thus locking the objective tube in place in its retracted position with spring 28 under stress.

The arresting element 44 on the locking lever 42 is designed as arresting pawl 46 and the arresting element 45 on the objective tube 11 as a plunger pin 47. The plunger pin 47 is arranged on the front end of the objective tube 11. The locking lever 42 is prestressed by means of a spring element 49, provided in the form of a helical compression spring 48 so as to support the arresting action of the arresting elements 44 and 45. The locking lever 42 is coupled with manually actuated release element 50 carrying a slide knob 51, which protrudes form the front side of the camera housing 10 and may be displaced manually, in a direction transverse to the optical axis 20. Upon the displacement of the slide knob 51, the locking lever 42 is rotated against the force of the helical compression spring 48 and the arresting elements 44 and 45 are disengaged. The objective tube 11 is released. Under the effect of the spring 28 the rocker arm 34 urges the objective tube 11 into its exposure position.

The locking lever 42 has a bevelled edge 52 inclined at an acute angle to the optical axis 20. In the exposure position of the objective tube 11, i.e. with the objective tube 11 protruding from the housing 10, this bevelled edge 52 is resting in frictional contact against the pilot pin 37 and urges the objective tube 11 in the outward direction. Correspondingly, the lower locking lever is in frictional contact by means of a similar bevelled edge with the pilot pin 38. The frictional contact joining the bevelled edges 52 and the pilot pins 37 and 38, respectively, is effected by the helical compression spring 48. This application pressure of the helical compression spring may be dimensioned exactly and is nearly always constant, because the position of the locking lever 42 and thus the compression of the helical spring 48 is unchanging in almost all possible positions of the objective tube 11 along the optical axis 20.

On the front side of the objective tube 11 an objective lens cover 53 is pivotally mounted. The mounting point 54 of the cover 53 is located above the lens opening 55 of the objective tube 11. On its side opposite to the mounting point 54, the objective cover 53 carries an arresting projection 56 (FIG. 2). When the objective cover 53 is pressed onto the orifice 55 of the objective tube 11 (the position of FIG. 1), the arresting projection 56 is embraced by the pawl of the lower locking lever in the manner described hereinabove for the upper locking lever 47 and the plunger pin 47 on the upper side of the objective tube 11. When the objective cover 53 is in place on the objective tube 11 and the tube 11 retracted, the latter is held in position on the one hand by the engagement of the upper locking lever 42 with the plunger pin 47 and on the other hand by the engagement of the lower locking lever 42 with the arresting projection 56 of the objective cover, whereby the objective cover 53 is also held simultaneously in its position covering the objective lens.

The objective cover 53 is prestressed by means of a spring, not shown, so that, upon release, it automatically assumes the position shown in FIG. 2, thus essentially protruding at right angles from the front side of the objective tube 11. The objective cover 53 therey automatically uncovers the objective lens and simultaneously assumes a position wherein it acts as a sunshade.

In the transport state of the camera, i.e. when not in use (as in FIG. 1), the objective tube 11 is completely retracted into the housing 10 of the camera. The objective cover 53 is fixed onto the front side of the objective tube 11 and covers the lens opening 55 thereof and thus the objective lens in a protective manner. In this position, the objective tube 11 and the objective cover 53 is held in position by the two locking levers; of these, only the upper locking cover 42 is visible in the figures. The latter embraces with its pawl 46 the plunger pin 47 on the objective tube 11, while the lower locking lever with its similarly designed pawl grips the arresting protrusion 56 of the objective cover 53. The helical compression spring 48 maintains the secure locking of the objective tube 11 and the objective cover 53. In this position, the spring 28 is under stress.

The displacement of the sliding knob 51 of the release element 50 in the direction of the arrow A, pulls the two locking levers 42 in the direction of the arrow A. The upper locking lever pawl 46 and the plunger pin 47, and

the lower locking lever pawl and the arresting protrusion **56** are disengaged. The spring **28** urges the objective tube **11** by means of the rocker **34** out of the housing, until the protrusions **24** come to rest against the wedge-like protrusions **23**. Depending on the rotational position of the setting annulus **19**, corresponding to the range setting by means of the range setting device **12**, the objective tube **11** emerges, more or less, from the housing **10**. Simultaneously with the release of the lock between the arresting protrusion **56** and the lower locking lever, the objective cover **53** opens and assumes its position shown in FIG. **2**. Upon the release of the sliding knob **51**, the release element **50** and the upper and lower locking levers **42** return to the position shown in FIG. **2**. The upper locking lever **42** with its bevelled edge **52** thereby comes to rest against the pilot pin **37** and the lower locking lever correspondingly with its bevelled edge against the pilot pin **38**. The extended objective tube **11** is thus satisfactorily arrested and secured in its position of exposure.

In the example of embodiment described hereinabove, the objective cover **53** is designed so that it may be removed without difficulty from the objective tube **11**. This is achieved in the simplest manner by the suitable design of the mounting **54**. This makes it possible to mount further attachments in place of the objective cover **53** on the objective, particularly optical attachments. Thereby, for example, rapid changes between two focal lengths of the objective may be effected. During transportation, i.e., with the objective tube **11** retracted, such an adapter objective is securely fastened to the camera.

Although the invention has been described relative to a specific embodiment thereof, it is not so limited and many modifications and variations thereof will be readily apparent to those skilled in the art in light of the above teachings. It is, therefore, to be understood that, within the scope of the appended claims, the invention may be practiced otherwise than as specifically described.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. A camera including a camera housing and an objective lens having an image axis:

means for manually setting the focal range of said camera;

means for mounting said objective lens for movement substantially parallel to said image axis, between an extended exposure position and retracted storage position;

means for variably limiting axial movement of said mounting means in said extended position;

means, responsive to said range setting means, for varying said limiting means; and

means for releasably locking said mounting means in said storage position, said locking means comprising at least one locking lever pivotally mounted at one end with an arresting pawl on the other end and a plunger pin mounted on said mounting means such that in said storage position said pawl releasably engages said plunger pin preventing extention of said mounting means, said locking means further including means for releasing said plunger pin from engagement with said pawl, said releasing means comprising a release element internal to said camera housing, and connected to said locking means; and a manually actuated knob, external to said housing, for operating said release lever removing said locking means pawl from engagement with said plunger pin,

said camera further comprising an objective lens cover, pivotally mounted on said mounting means for movement between an open position and a closed position, said cover including an arresting projection, wherein said locking means comprises two locking levers disposed in diametrically opposing positions with respect to said mounting means, said one end of each of said levers pivotally mounted on a common pivoting axle and said arresting pawl of one of said locking levers releasably engages said plunger pin and said arresting pawl of the other of said locking levers releasably engages said arresting projection only when said cover is in said closed position and said mounting means is in said storage position.

2. The camera according to claim **1**, said camera including means for biasing said cover towards said open position, said cover in said open position being essentially parallel with said axis.

3. The camera according to claim **1**, said camera further including a viewfinder with a range scale and a pointer connected to said range setting means and extending into said viewfinder for indicating on said range scale the focal distance of said objective lens.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 4,281,762
DATED : August 4, 1981
INVENTOR(S) : James C. Hattemer

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Col. 3, line 24, "14" should be --41--.

Col. 4, line 28, "though" should be --through--.

Signed and Sealed this

First Day of December 1981

[SEAL]

Attest:

Attesting Officer

GERALD J. MOSSINGHOFF
Commissioner of Patents and Trademarks

UNITED STATES PATENT AND TRADEMARK OFFICE

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[SEAL]

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Attest:

GERALD J. MOSSINGHOFF

Attesting Officer

Commissioner of Patents and Trademarks

United States Patent [19]

Gross

[11] **4,274,725**

[45] **Jun. 23, 1981**

[54] **DEPTH OF FIELD OBJECTIVE**

[76] Inventor: **Walter O. Gross**, Lausanne, Switzerland

[21] Appl. No.: **868,707**

[22] Filed: **Jan. 11, 1978**

Related U.S. Application Data

[63] Continuation of Ser. No. 656,607, Feb. 12, 1976, abandoned.

[30] **Foreign Application Priority Data**

Mar. 13, 1975 [DE] Fed. Rep. of Germany 2510941

[51] **Int. Cl.**[3] **G03B 3/00**

[52] **U.S. Cl.** **354/196**

[58] **Field of Search** 354/195, 196, 198

[56] **References Cited**

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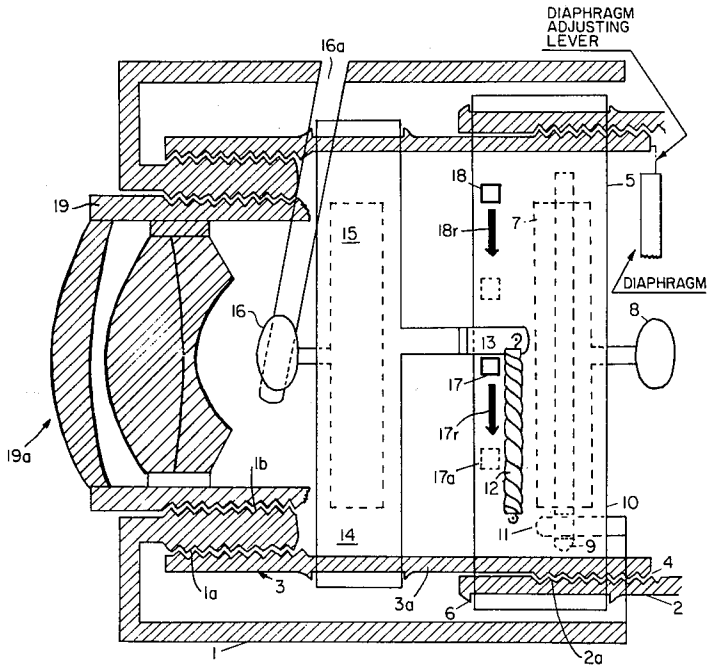
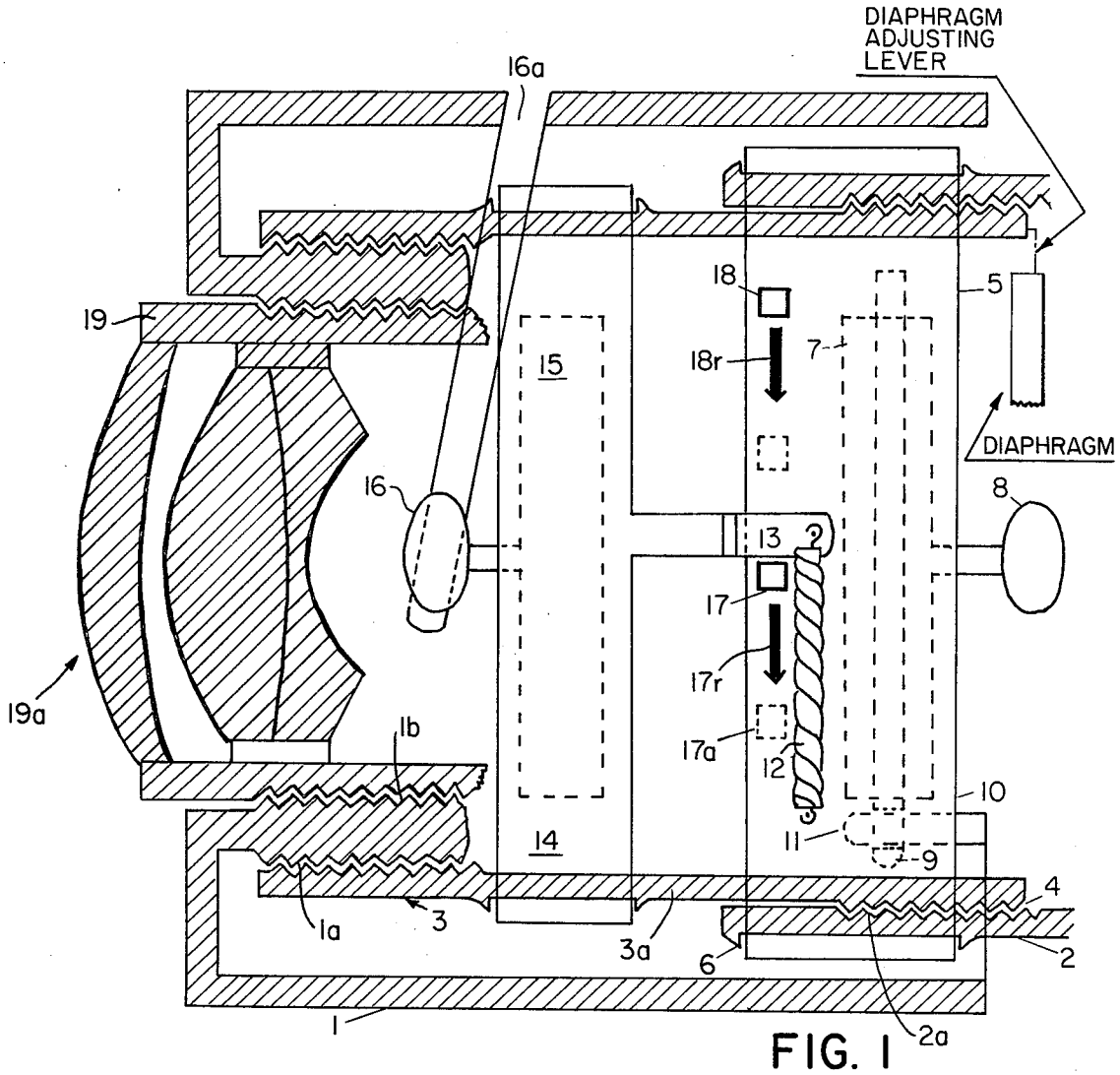
Primary Examiner—John Gonzales
Attorney, Agent, or Firm—Peter K. Kontler

[57] **ABSTRACT**

The present invention relates to an objective for still cameras and motion picture cameras into which the critical focusing values of the two boundary points of a selected depth of field range are fed without being examined, whereupon the lenses and the diaphragm are adjusted automatically for a sharp reproduction of the respective range.

7 Claims, 2 Drawing Figures

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ADJUSTING
LEVER
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19
18
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7
5
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DIAPHRAGM
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8
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17
17r
17a
12
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1b
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14
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1a
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3a
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2
1
2a

FIG. 1

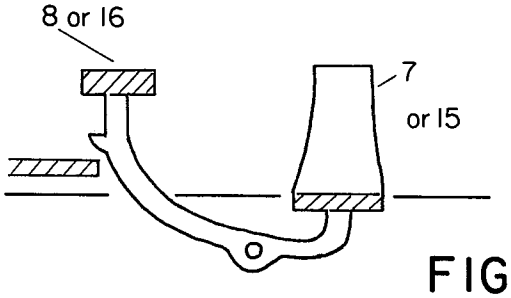
8 or 16
7
or 15

FIG. 2

DEPTH OF FIELD OBJECTIVE

This is a continuation, of application Ser. No. 656,607, filed Feb. 12, 1976, now abandoned.

BACKGROUND OF THE INVENTION

For a more accurate depth of field photography, the user of the camera normally relies on the depth of field scale. The operation involves the following six steps, one after the other: (a) Focusing one boundary point of the desired depth of field range. (b) Reading and memorizing the selected distance. (c) Focusing the other boundary point. (d) Reading and memorizing this second selected distance. (e) Rotating the focusing ring until the two memorized distances face the same stop numbers of the depth of field scale. (f) Adjusting the diaphragm in accordance with these stop numbers.

My Swiss Pat. No. 517,314 discloses a camera embodying a device which automatically performs the aforediscussed series of manipulations. No satisfactory construction of an objective which can carry out such manipulations is known as yet. However, the automatic exposure time device which is disclosed on page 3, lines 6 and 7 of the Swiss Patent has been incorporated in the meantime in at least 16 modern cameras. Moreover, there are many additional proposals relating to automated focusing aids. When photographing, only the selection of depth of field would still require manual adjustment including the four steps b, d, e and f during which the camera is not trained upon the subject or scene. Therefore, there exists a need for an objective which is capable of carrying out these manipulations in an automatic way.

OBJECTS AND SUMMARY OF THE INVENTION

An object of the present invention is to provide an objective of the type indicated hereinbefore, namely, an objective wherein the depth of field is automatically adjusted upon transmission of information pertaining to the two boundary points. Thus, instead of the aforesaid complex operations, the photographer is required to carry out only the two steps of determining the boundaries of the depth of field range. In other words, the photographer is still free to select the object even if focusing itself is automated.

Another object of the invention is to provide the objective with a device which can select the same depth of field position as is accomplished by the aforementioned six steps. This involves the movement of the lens mount to an intermediate position between the positions corresponding to the two focused boundary points and a corresponding adjustment of the diaphragm. During the step e, the lens system is shifted away from the position of focusing upon the second boundary point and, when the two distances denoting the selected boundary points face the same f/stop numbers of the depth of field scale, the lens system reaches precisely a position midway between the two boundary focus positions, as considered in the direction of the optical axis. Consequently, the step e involves moving the lens system exactly by half the distance it had to be advanced from focusing of the farthest boundary point to that of the nearest boundary point, or vice versa.

A further object of the invention is to provide a method and a device which automatically accomplish the aforediscussed forward and rearward movements of the lens system within an objective regardless of whether the information pertaining to the two boundary points is supplied manually (e.g., by depressing suitable keys) or automatically.

During the step f, that diaphragm aperture size is selected which is indicated by the two distances focused out on the depth of field scale. This aperture size has a specific relationship to the total focusing difference. When the stray circle diameter is based upon a specific millimeter fraction, the maximum focusing difference is defined by the distance which is indicated by the depth of field scale as converted torque between the pairs of the greatest f/stop numbers. Smaller f/stop numbers are associated with the correspondingly smaller focusing differences.

The present invention embraces all methods and devices which adjust the diaphragm automatically in accordance with the focusing differences within an objective in response to feeding of information by means of a key or in response to automatic feeding.

The shifting of the lens mount to a position midway between the positions assumed during focusing upon the two boundary points is derived from the movement which the objective had to carry out between the said positions. According to the invention, adjustment of the diaphragm is derived from the movement of the lens system.

BRIEF DESCRIPTION OF THE DRAWING

FIG. **1** is a schematic partly sectional view of an objective which embodies one form of the invention; and

FIG. **2** illustrates a detail in the objective of FIG. **1**.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

For the sake of simplicity, the device which embodies the invention will be described as though the farthest boundary point were focused first. However, the improved device can also operate in such a way that the nearest boundary point is focused first.

FIG. **1** is a section through the improved objective with certain parts shown in elevation. This is a modern objective in which, in a manner similar to that in the Nikkor-H Auto 1:1.8 f=35 mm No. 23 73 19 lens, a knurled focusing ring **1** can be rotated to move the tube **19** for the lenses of the optical system **19***a* forwardly by means of two equally steep threads **1***a* **1***b* in order to advance the lenses through a distance approximating twice its own advance. The rotary member or sleeve **3***a* in which the external thread **1***a* of the knurled ring **1** is guided is threadedly connected to the base **2** of the objective (as at **2***a*, **4**) in a manner known from conventional objectives. The base **2** is secured to the camera body, for instance by means of a slide lock. However, in the illustrated embodiment of the invention, this sleeve **3***a* is a composite body and the base **2** holds the sleeve **3***a* for the knurled ring **1** and optical elements or lenses of the system **19***a* (hereinafter called mount **3**) by means of the thread **2***a*. This thread **2***a* has the same slope as the two threads **1***a*, **1***b* of the knurled ring **1**. Upon completion of rotation in the direction indicated by the arrow **17***r* or **18***r*, the mount **3** is caused to perform a movement in a direction towards the camera housing through a distance which is exactly half the distance covered by the lenses if the angular movement of the tube **19** in the opposite direction amounts to the same number of degrees as that through which the knurled

ring 1 was rotated while causing the lenses to move forwardly. In order to insure that the angular movement which is carried out by the knurled ring 1 from focusing of the one boundary point to focusing of the other boundary point is converted into an equally large angular movement of the mount 3 with respect to the base 2 of the objective, discrete information storing rings 5 and 14 are mounted on the base 2 and on the mount 3, respectively. The ring 5 is mounted in a guide 6 on the base 2. It can be arrested by a lock 7 on the base 2 in response to depression of an actuating button 8. FIG. 2 illustrates the arresting means in detail. A springy strip 9 having a detent notch or recess 10 is provided on the ring 5 and is engaged by an arm 11 of the knurled ring 1. A resilient element in the form of a helical spring 12 is installed between the right-hand ring 5 and the ring 14. This spring is secured on the one hand to the ring 5 and on the other hand to an arm 13 of the second ring 14. The arm 13 has freedom of movement with respect to the ring 5 through a distance which is determined by two abutments 17 and 18 and corresponds exactly to the distance between the two outermost graduations of an imaginary depth of field scale. Moreover, this distance (which can subtend an arc of 55°) is identical with the extent of movement which is needed to adjust the diaphragm from the largest aperture (1.8) to the smallest aperture (22). A prerequisite for the correspondence of the angular movement of the mount 3 with the required diaphragm closure is the operation of the diaphragm adjusting lever in such a way that, in order to change the diameter of the diaphragm aperture from one diameter to a diameter one and a half times the one diameter, the lever is moved through identical angles. This is the case in modern objectives such as, for instance, the Nikkor-H Auto 1:1.8 f=35 mm. The ring 14 can be arrested by a locking device 15 which is actuated by depressing a button or key 16. In order to make it accessible from the outside, the key 16 extends through a slot 16*a* of the knurled ring 1. The manner in which the key 16 can initiate a locking action is shown in FIG. 2. The mount 3 is directly connected to the diaphragm adjusting lever and is held in the normal position with respect to the base 2. In the illustrated embodiment, the thread 4 between the rotary member 3*a* of the mount 3 and the base 2 is designed for easy movement with respect to the threads of the knurled ring 1. In order that, during return movement of the mount 3, the threads of the knurled ring 1 remain in their positions, they are designed for hard movement.

The operation of the illustrated embodiment of the invention is as follows: The selected depth of field is assumed to be between 15 m and 3 m from the camera and, upon the depth of field adjustment, the objects within this range shall be imaged on the negative with stray circles not exceeding 1/30 mm. By means of the knurled ring 1, the farthest point at 15 m is focused. During this movement, for instance, from the infinity, the ring 5 of the base 2 is carried along because the knurled ring 1 has its arm 11 engaged in the notch 10 of the strip 9. Moreover, the spring 12 pulls the ring 14 by way of the arm 13 so that the arm 13 engages the abutment 17. When the image of an object located at the distance of 15 m becomes sharp, the key 16 is depressed. This key is very close to the left forefinger which was used to rotate the ring 1 together with the thumb of the left hand. The ring 14 is thereby locked against the mount 3. By means of the knurled ring 1, an object at a distance of 3 m is now sighted. When the image of the object becomes sharp, the key 8 is depressed, also with the left forefinger, and the grip upon the knurled ring 1 is relaxed. This locks the ring 5 to the base 2, and secondly the arm 11 of the knurled ring is disengaged. Together with the ring 5, the abutment 17 has moved to the position 17*a*, this causing the spring 12 to store energy. As soon as this has occurred, a lock (not shown) which caused the mount 3 to engage the base 2 is released so that the parts 2 and 3 can move with respect to each other. The spring 12 pulls the mount 3 into the base 2 to the extent determined by the space which is allotted by the stop 17 in the position 17*a*. The mount 3 returns through about half the distance and the diaphragm which is coupled thereto is adjusted accordingly. The camera is ready to make an exposure. In another embodiment, the lock for the mount 3 is disengaged only when actuating the camera release. In such embodiment, a fully automatic diaphragm is superfluous since it remains open anyway until the camera release is actuated. Regardless of whether the one or the other embodiment is resorted to, several shots of the same depth of field can be made in response to repeated winding of film and actuation of the camera release. When another range is to be selected, the knurled ring 1 is returned in a direction towards the infinity. Its arm 11 soon enters the recess 10 of the strip 9 and thereby releases the lock 7 by way of a lever, not shown. The knurled ring 1 now again carries along the locking arrangement 7 on the ring 5. Shortly thereafter, the abutment 17 contacts the arm 13 as soon as it reaches the solid-line position of FIG. 1 whereby the ring 14 on the mount 3 is unlocked by means of a releasing lever, not shown. The ring 14 is now free to move again with the knurled ring 1, either in response to a push by the abutment 17 or in response to a pull by the spring 12, depending upon whether the ring 1 moves forwardly or backwards. Thus, the farthest point of another depth of field range can be focused out.

The objective can be designed to indicate that the selected range of the depth of field is too wide and to correct this by engagement against suitable abutments. The objective is also useful for exposures without any depth of field as well as for exposures with maximum sharpness outside of the point midway between the two boundary points. In the latter case, refocusing is necessary either by maintaining the mount 3 in engagement with the abutment or by providing a lock which locks the arm 13 when the arm contacts the abutment 17 in the position 17*a*.

The invention is claimed as follows:

1. A method of preparing a photographic camera for the making of exposures of objects within a selected depth of field range between two boundary points, comprising the steps of focusing the lens system of the objective upon one of said boundary points, including moving the lens system in the direction of the optical axis to a first position; storing in the objective information denoting said first position; focusing the lens system upon the other boundary point, including moving the lens system of the objective in the direction of the optical axis to a second position; storing in the objective information denoting said second position; and thereupon utilizing the stored information denoting said first and second positions to automatically shift the lens system to an exposure position substantially midway between said first and second positions.

2. A method as defined in claim 1, further comprising the step of adjusting the diaphragm of the photographic

camera in automatic response to shifting of the lens system to said exposure position so that the aperture size is a function of the exposure position of the lens system.

3. An objective for photographic cameras, comprising an optical system; means for focusing said optical system upon objects located at different distances from the objective, including means for moving said optical system in the direction of the optical axis; means in the objective for storing information pertaining to various positions of said optical system; means for actuating said information storing means; and means for automatically shifting said optical system to an exposure position substantially midway between spaced-apart first and second positions in each of which said information storing means was actuated so that the photographic camera embodying the objective is ready to make an exposure of objects located within the depth of field range bounded by points upon which said system was focused in said first and second positions thereof.

4. An objective as defined in claim 3, further comprising an adjustable diaphragm and means for adjusting said diaphragm in response to shifting of said optical system to said exposure position.

5. An objective as defined in claim 4, wherein said shifting means includes resilient means.

6. An objective as defined in claim 4, wherein said optical system comprises a rotary member and further comprising a base member supporting said rotary member, said information storing means including first and second rings respectively supported by said rotary member and said base member, each of said rings being rotatable relative to the associated member and said actuating means including arresting means for interrupting the rotary movements of said rings, said shifting means including means for turning said rotary member to the extent determined by relative angular positions of said rings upon interruption of the rotary movement thereof.

7. An objective as defined in claim 6, wherein said means for turning said rotary member includes a spring, one of said rings having an arm and the other of said rings having abutment means in the path of movement of said arm, said spring being arranged to move said arm against said abutment means or vice versa on disengagement of one of said arresting means.

* * * * *

United States Patent [19]

Tsujimoto

[11] **4,274,720**

[45] **Jun. 23, 1981**

[54] **AUTOMATIC FOCUS CONTROL DEVICE FOR OBJECTIVE LENS EXCHANGEABLE CAMERAS**

[75] Inventor: **Kayoshi Tsujimoto**, Osaka, Japan

[73] Assignee: **Minolta Camera Kabushiki Kaisha**, Osaka, Japan

[21] Appl. No.: **31,925**

[22] Filed: **Apr. 20, 1979**

[30] **Foreign Application Priority Data**

Apr. 21, 1978 [JP] Japan 53-47980

[51] **Int. Cl.**[3] **G03B 3/10**

[52] **U.S. Cl.** **354/25**; 354/195

[58] **Field of Search** 354/25, 43, 46, 195–197, 354/266, 286; 352/140; 358/227

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Primary Examiner—L. T. Hix
Assistant Examiner—William B. Perkey
Attorney, Agent, or Firm—Watson, Cole, Grindle & Watson

[57] **ABSTRACT**

In an automatic focusing system for a camera having an exchangeable lens, the camera body includes a control mechanism for controlling the focus of the exchangeable lens in accordance with an output of a photoelectric focus or distance detecting element. The control mechanism is interlocked by an intermediate elongated member with a lens displacing mechanism in the exchangeable lens, with the intermediate member extending within an aperture of the lens mount. The exchangeable lens may be of the type wherein a rear lens group is moveable for focusing.

6 Claims, 9 Drawing Figures

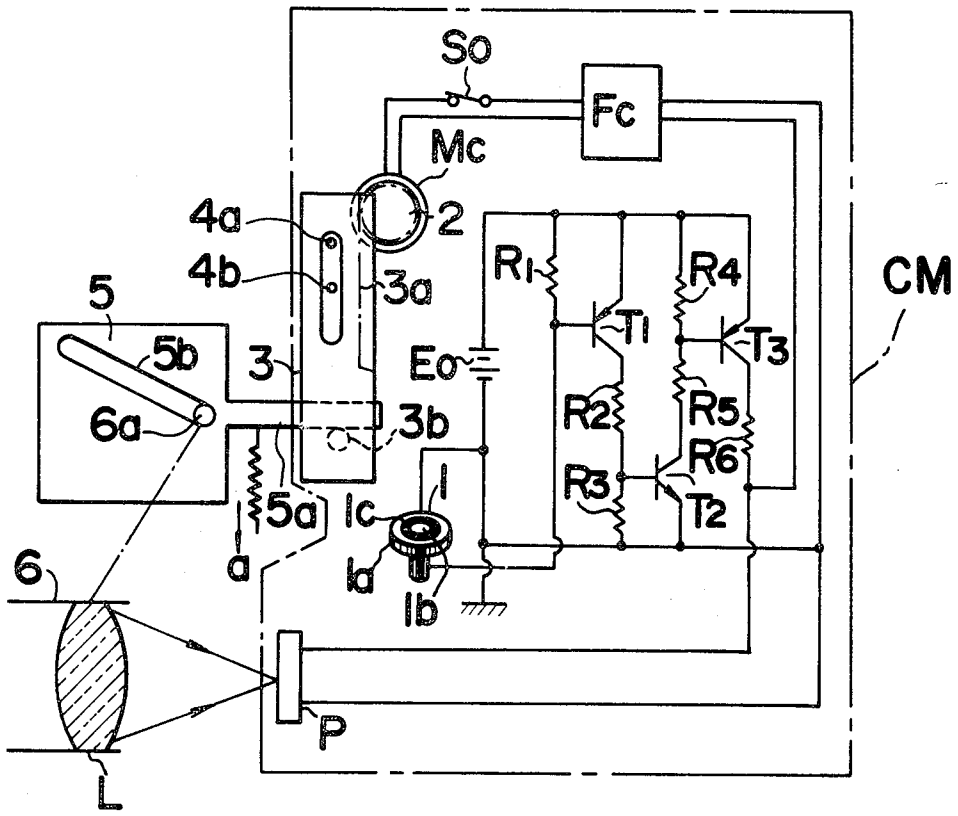


FIG.1

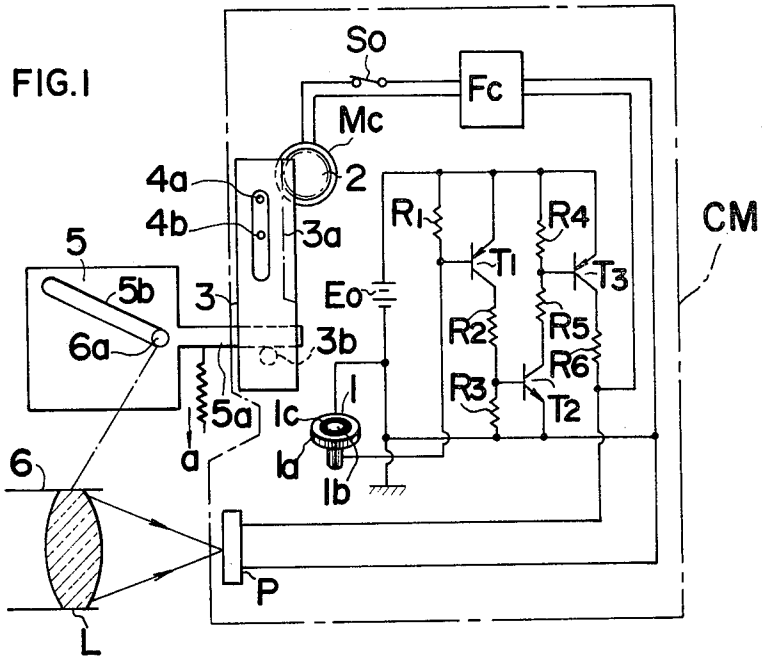


FIG.2

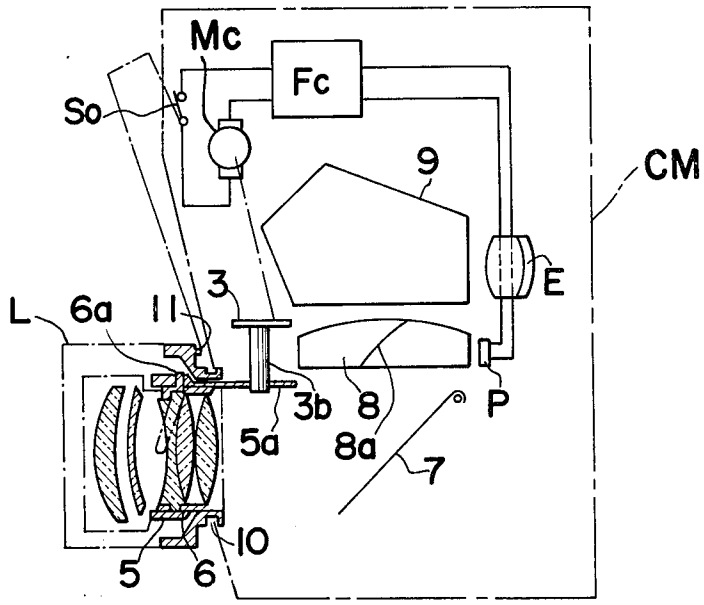
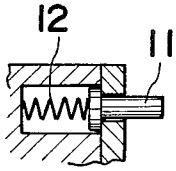


FIG.3



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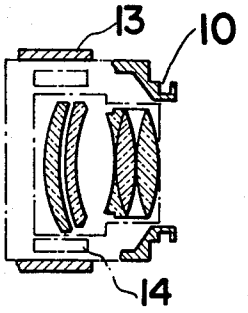


FIG.5

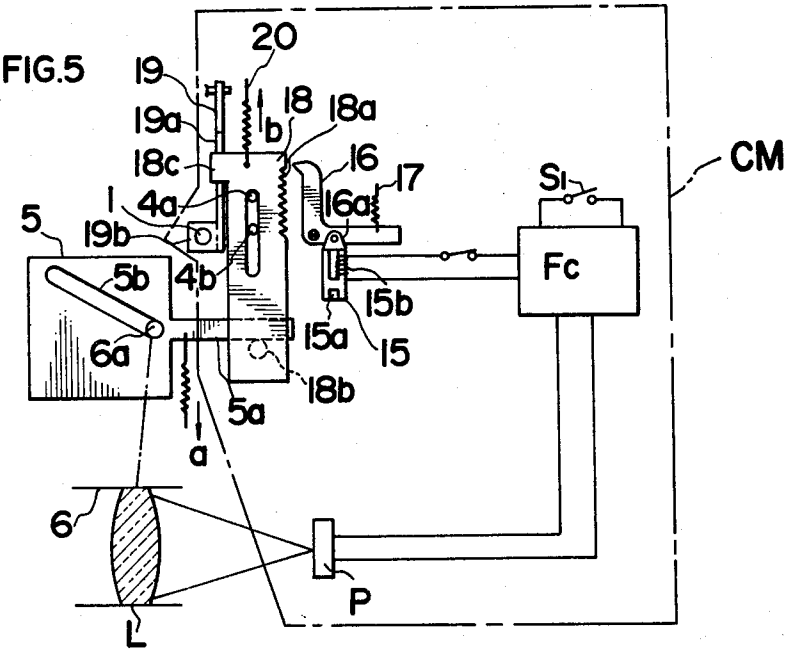


FIG.6

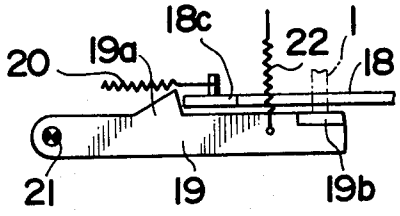


FIG.7

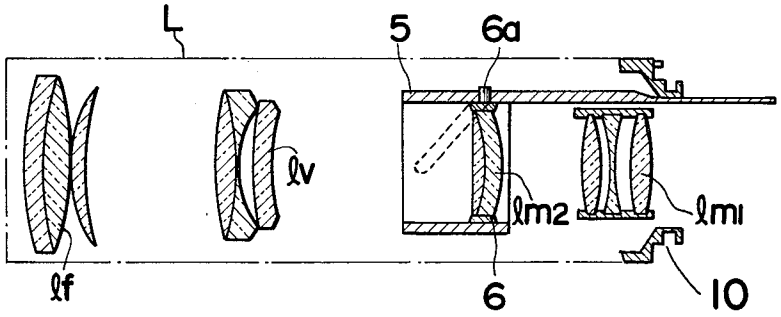


FIG.8

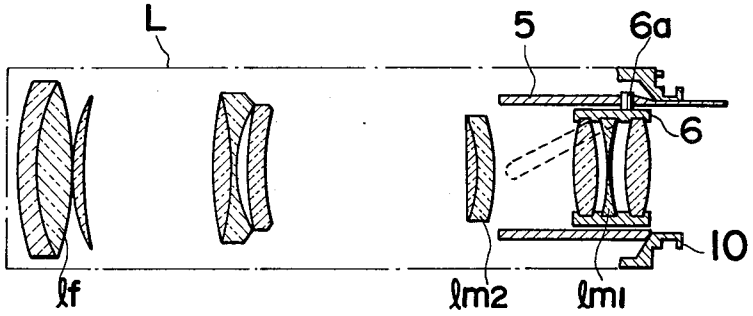
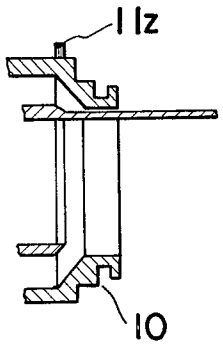


FIG.9



AUTOMATIC FOCUS CONTROL DEVICE FOR OBJECTIVE LENS EXCHANGEABLE CAMERAS

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to an automatic focusing or focus control device for use in a camera with which exchangeable objective lenses are selectively and detachably mounted, and more particularly it pertains to a coupling mechanism between a focus control mechanism in the camera and a lens driving mechanism in the exchangeable objective.

2. Description of Prior Art

An automatic focusing device for an objective lens exchangeable camera has been proposed by a Japanese Laid-Open Patent No. 48-53718. In the known device, however, an objective lens is axially displaced by a lens mount which supports an objective lens and is moved along the optical axis of the objective. Because of its arrangement, such device is applicable only to a specific type of objective in which focusing is made by the entire lens system being integrally moved. In addition, it is difficult for such device to avoid increases of its weight and size because the lens mount and a bearing or support for it must be made large and steady in order to displace a comparatively heavy objective in a predetermined incremental displacement range (which is generally large in may interchangeable lenses) without tilting the optical axis of the objective.

Further difficulties may be encountered when such an automatic focus device is to be associated with an objective which, as is common with single lens reflex cameras, has a so-called automatic diaphragm aperture control device wherein, in response to a shutter release operation, the diaphragm is stopped down to an aperture value manually preset or an aperture value to be automatically determined in accordance with scene brightness. For example, a coupling pin interlocking a diaphragm mechanism in the objective with a camera mechanism has to be made long enough to maintain the interconnection even when an objective mount is displaced fowardmost to a hyperfocal position. On the other hand, the coupling pin must not interfer with any mechansim inside the camera, e,g, a reflex mirror for a single-lens reflex camera when the objective is displaced rearmost to an infinity (focused position). Thus, the known mechanism imposes great restrictions on the mechanisms incorporated in a camera or provided between the camera and the objective, and restricts the variety of combinations between camera bodys and exchangeable lenses.

SUMMARY OF THE INVENTION

Accordingly, the primary object of the present invention is to provide an automatic focusing device which may be used for an objective lens exchangeable camera but which is free from the above mentioned disadvantages inherent to the prior art structure.

Another object of the present invention is to provide an improved coupling or interlocking mechanism for controlling focus of an exchangeable lens by a mechanism incorporated in a camera body.

Still another object of the present invention is to provide an automatic focusing device for use in an objective lens exchangeable camera which enables a wide variation of the combination of camera and exchangeable lens.

A further object of the present invention is to provide an automatic focus control device which controls focusing of an exchangeable lens without moving the whole structure of the exchangeable lens.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and other objects and features of the invention will appear more fully hereinafter from a consideration of the following description taken in connection with the accompanying drawing wherein exemplary embodiments are illustrated.

FIG. **1** is a schematic illustration of an embodiment of the present invention;

FIG. **2** shows schematically an optical system to be used with the device shown in FIG. **1**;

FIG. **3** is a partial enlarged sectional view of a switch operating pin of FIG. **2**;

FIG. **4** is a diagramatical sectional view of a manually focused exchangeable lens;

FIG. **5** is a schematic illustration of another embodiment of the present invention;

FIG. **6** is a side elavational view of a portion of the mechanism shown in FIG. **5**.

FIGS. **7** and **8** shows schematically exchangeable lenses to be used in the present invention.

FIG. **9** shows another embodiment of a switch operating pin.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

With reference to FIG. **1** showing a schematic diagram of a focus control mechanism according to an embodiment of the present invention, shutter release button **1** has on the top surface thereof a finger-touch responsive switch including electrodes **1***a* and **1***b* isolated by insulator **1***c*. Electrode **1***b* is connected through resistor **R1** to the positive electrode of battery Eo, and to the base of transistor **T1**, while electrode **1***a* is grounded to the camera body and connected to the negative electrode of battery Eo. To the collector of transistor **T1** are serially connected resistors **R2** and **R3** which constitute a voltage divider, with the node between resistors **R2** and **R3** connected to the base of amplifier transistor **T2**. Connected in series to the collector of transistor **T2** are resistors **R4** and **R5** for biasing the base of transistor **T3**. Transistor **T3** is used for energization, and its collector is connected through resistor **R6** to focus control circuit Fc. Light receiving element P detects the focusing condition of objective lens L, and it is located at a position optically equivalent to the film plane with respect to objective lens L. The output of light receiving element P is transferred to focus control circuit Fc. When objective lens L is in an out-of-focus condition, focus control circuit Fc operates to drive electric motor Mc.

When electric motor Me is driven, gear **2** rotates, causing slide plate **3** with tooth portion **3***a* to laterally move under the guide of pins **4***a* and **4***b* received in a slot of slide plate **3**. Pin **3***b* is spring-biased in the direction of arrow a, engaging coupling arm **5***a* of lens drive ring **5**. Coupling arm **5***a* is then moved laterally or rotationally inside a mount on the lens barrel, and at the same time inside the opening of an objective mount on camera body Cm, whereby the rotational position of lens drive ring **5** is determined in accordance with the position of slide plate **3**. Formed on lens drive ring **5** is

cam groove **5***b*, which in turn receives pin **6***a* interconnected with objective lens L. Thus rotation of the lens drive ring **5** moves lens frame **6** along the optical axis, which hold a lens group of objective lens L to be moved for focusing and when objective lens L is in focus, focus control circuit Fc stops electric motor Mc, whereby the movement of the lens group is stopped. FIG. **2** shows an optical system of the above mentioned embodiment in more detail as, for example, used in a single-lens reflex camera. Referring to FIG. **2**, light coming from a scene to be photographed and passing through objective lens L of standard focal length is reflected at reflex mirror **7** and introduced through condenser lens **8** and pentagonal prism **9** to eyepiece E, and at the same time is focused on light receiving element P by means of concave semi-transparent mirror **8***a* in condenser **8**. Thus, the light receiving surface of light receiving surface of light receiving element P is at the position optically equivalent to the focal plane (film plane). Objective lens L is mounted on camera body Cm with mount **10** of the lens coupled with the objective mount of the camera (not shown). Signal pin **11** is forced by spring **12** to project rearward, as shown in enlarged size in FIG. **3**, and when objective lens L is coupled to camera body, Cm signal pin **11** extends into the hole formed at a given place on camera body Cm to close power switch So. It should be noted that in case the objective L is coupled with camera body Cm through a bayonet type objective mount with which the coupling between object lens L and camera body Cm is secured by rotating objective lens L for a predetermined angle after their mounting and the objective mount have been fitted together, signal pin **11** remains pushed inside a lens barrel against the action of spring **12** until objective lens L is rotated into a predetermined angular position.

With objective lens L attached to camera Cm body, signal pin **11** closes power switch So, causing focus control circuit Fc to be operative. When the operator touches shutter release button **1** looking into a viewfinder through eyepiece E to aim at any desired object, transistor T1 turns on, causing power of battery Eo to be applied through output transistor T3 to focus control circuit Fc and light receiving element P. As a result, electric motor Mc is driven, causing lens frame **6** to be moved via coupling arm **5***a* for focusing. When objective lens L reaches focus condition, electric motor Mc is stopped and the movable lens group of objective lens L is set at a focusing position.

As shown in FIG. **4**, when a manual type objective lens, in which a lens group is displaced through helicoid **14** by manual rotation of a distance adjusting ring not shown without using a connecting arm and a signal pin, is attached to a camera having the focus control mechanism, power switch So is not closed by a signal pin, and focus control circuit Fc remains inoperative. In this case, manual focusing may be possible using a distance adjusting ring or manual focusing ring.

FIG. **5** shows another embodiment concerning a focus control mechanism, wherein the same reference symbols are used for the members corresponding to those of FIG. **1**, and description thereof is omitted. With reference to FIG. **5**, power switch S1 may be of a finger-touch responsive type or constructed such that it is closed at the early stage of a shutter release button depression. Electromagnetic member **15** has permanent magnet **15***a* which normally attracts armature **16***a* of stop lever **16**. When electromagnetic coil **15***b* is energized by an output from focus control circuit Fc, the magnetic force field of the permanent magnet is counterbalanced by the magnetic field caused in the coil **15***b*, allowing stop lever **16** to rotate counterclockwise under the action of spring **17**. Slide plate **18** corresponding to slide plate **3** in FIG. **1** has toothed or serrated portion **18***a* on its side with which claw **16***b* of stop lever **16** is engaged. Slide plate **18** is slidable laterally, i.e. vertically as viewed in FIG. **5** under the guide of guide pins **4***a* and **4***b*. Coupling pin **18***b* corresponds to the pin **3***b* in FIG. **1**. With the camera shutter being cocked, ear portion **18***c* engages triangular projection **19***a* of engaging lever **19**, to restrain slide plate **18** at a charging position against the action of spring **20**. Restraining lever **19** is pivoted on stud **21** and is urged by spring **22** in a counterclockwise direction, as viewed in the side elevational view in FIG. **6**. One side of triangular projection **19***a* opposite to the movement of slide plate **18** under the action of spring **20** has a steep incline, while the other side has a gentle incline so that projecting portion **18***c* of slide plate **18** may climb over triangular projection **19***a* when slide plate **18** is returned to its charging position by means of a mechanism (not shown) in response to a charging operation.

Furthermore, bent portion **19***b* of engaging lever **19** is located under shutter release button **1**, so that it may turn about stud **21** to disengage slide plate **18** from triangular projection **19***a* at a final stroke of shutter release button depression.

With the above arrangement, when shutter release button **1** is touched or lightly depressed, power switch S1 is closed, and with shutter release button **1** further depressed, bent portion **19***b* of engaging lever **19** is depressed down, causing slide plate **18** to be disengaged from its restrained condition and laterally moves under the action of spring **20**, whereby movable frame **6** of objective lens L is displaced along the optical axis of the camera objective for focusing. When light receiving element P detects the best focus condition, electromagnetic coil **15***b* of electromagnetic member **15** is energized by focus control circuit Fc, and stop lever **16** is rotated by spring **17** counterclockwise, with claw **16***a* engaging a tooth of slide plate **18**. As a result, movable frame **6** of objective lens L is stopped at a best focus position. Subsequently, the diaphragm stopped-down operation and mirror retraction are initiated in response to the rotation of stop lever **16**, and upon completion of the operations thereof, the shutter is released by means of a known mechanism (not shown).

FIGS. **7** and **8** show desirable types of objective lenses for use in the embodiments of the present invention. The objective lens shown in FIG. **7** is of a variable magnification lens type, as disclosed in Japanese Laid-Open Patent No. 50-92127, in which lens group lm2 of rear master lens groups lm1 and lm2 is moved for focusing while variator lens group lv is moved for focal length variations. As described earlier, displacement ring **5** has coupling arm **5***a*, and movable frame **6** holds movable master lens group lm2 and is provided with pin **6***a* received in a cam slot of ring **5**. This type of lens system can contain a number of lenses, and although it is long in overall length, a coupling mechanism for automatic focus control can be made simple. In addition, this lens system requires no mechanical compensation means for compensating for the change of focusing since focusing is made by an automatic focusing mechanism even as the focal distance is varied by moving variable magnification lens group lv. Furthermore, this type is advantageous in that the diameter of front lens

group lf may be made smaller in comparison with a conventional front lens group displacement focusing type.

The objective lens shown in FIG. 8 is a telephoto type lens in which focusing is made by moving one, e.g. lml of rear master lens groups lm1 and lm2 along the optical axis of the camera objective. The present invention can be easily applied to even a telephoto lens when it is of the above type. In FIG. 8, the same reference symbols are used for the members corresponding, in operation, to those of FIG. 7.

A slight modification of the above embodiment is shown in FIG. 9, wherein a signal pin a fixed on the outer circumference of a lens barrel at its rear end, and when an objective lens is rotated for a predetermined length relative to a camera body for the lens and camera body to be coupled with each other in position, power switch So may be closed by the signal pin. Needless to say, cameras to which the present invention is applicable are not limited to the single-lens reflex type, and they may be of a rangefinder type and other types as long as they are objective lens lens exchangeable cameras. As in the above embodiments, furthermore, coupling mechanisms between an objective lens and a camera body are not limited to the above depicted mechanism composed of an operating ring, a connecting arm and a slide plate, but any coupling member that functions like the connecting arm may be used as far as it can pass through the opening of a camera's objective mount when an objective lens and a camera body are coupled each other in position. For example, pinions or friction wheels may be provided at both ends of the connecting member for connection to a focus control mechanism in the camera body and a lens displacement mechanism in the objective lens.

What is claimed is:

1. An automatic focusing system for an objective lens exchangeable camera, comprising: an exchangeable lens having a lens group movable for focusing the lens; a fixed member with a mount for mounting said exchangeable lens on said camera, and a lens drive member movable relative to said fixed member for driving said lens group along the optical axis thereof, said mount including an aperture; a camera body including a movable member movable to any position corresponding to any position of said movable lens group, and means for determining the position of said movable member;/an intermediate member for interconnecting said movable member and said lens drive member upon coupling of said exchangeable lens with said camera body such that the position of said movable member determines the position of said movable lens group, said intermediate member being included in said exchangeable lens and extending through said aperture of said lens mount, said movable member including an abutting member abutting with said intermediate member from one direction to form one-directional engagement therewith; and

biasing means for abutting said intermediate member and said abutting member.

2. An automatic focusing system as claimed in claim 1 wherein said intermediate member includes an elongated member provided in said objective lens to move in the plane normal to the optical axis of said lens and extending in the direction of said optical axis.

3. An automatic focusing system as claimed in claim 2 further comprising a light receiving means for detecting the focus condition of said exchangeable lens and an electric circuit for controlling the position of said movable member in accordance with the output of said light receiving means, and said exchangeable lens further includes a signal means for enabling said electric circuit when said exchangeable lens is coupled with said camera body.

4. An automatic focusing system as claimed in claim 3 wherein said electric circuit includes a power switch and said signal means includes means for closing said power switch upon coupling of said exchangeable lens with said camera body.

5. An automatic focusing system as claimed in claim 4 further comprising means for actuating said power switch in response to a finger operated touch mechanism on the camera body.

6. An automatic focusing system as in claim 1 wherein said intermediate member is interconnected with said movable member upon coupling of said exchangeable lens with the camera body and further comprising cam means for transmitting movement of said intermediate member to said movable lens group such that the lateral position of said movable member determines the axial position of said movable lens group.

* * * * *

United States Patent [19]

Sonnet

[11] **4,273,415**

[45] **Jun. 16, 1981**

[54] **OPTICAL OBJECTIVE**

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[73] Assignee: **Jos. Schneider & Co., Optische Werke**, Bad Kreuznach, Fed. Rep. of Germany

[21] Appl. No.: **85,238**

[22] Filed: **Oct. 16, 1979**

[30] **Foreign Application Priority Data**

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[51] **Int. Cl.**[3] **G02B 9/60**

[52] **U.S. Cl.** **350/465**

[58] **Field of Search** 350/216

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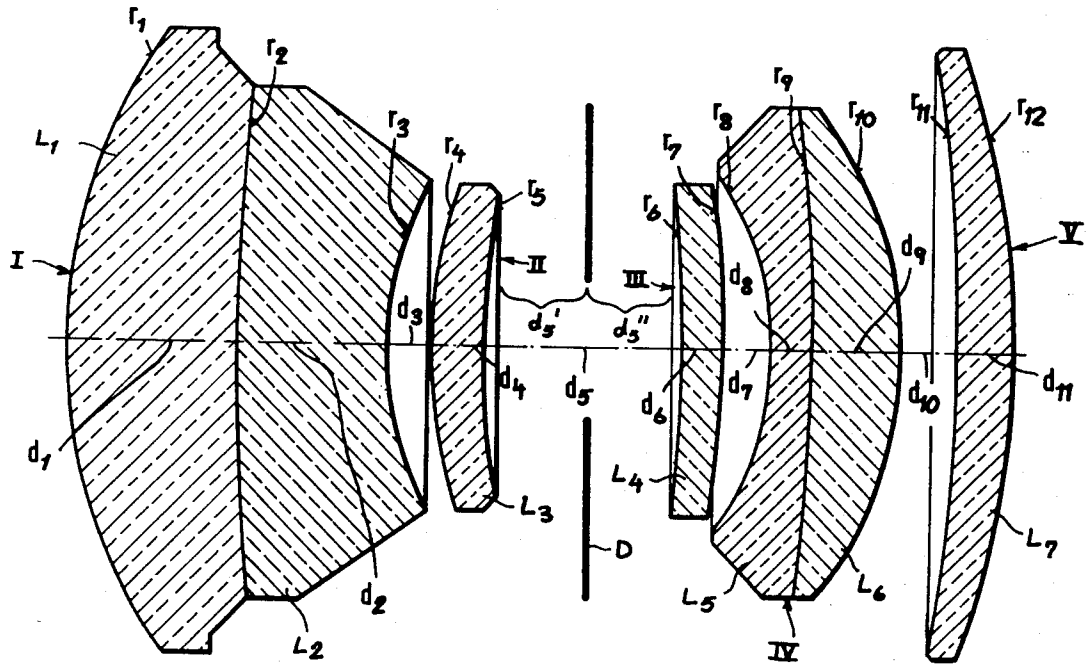
Primary Examiner—Paul A. Sacher

Attorney, Agent, or Firm—Karl F. Ross

[57] **ABSTRACT**

An optical objective, usable for reproduction as well as for photographic and cinematographic purposes, consists of five components—two on the object side and three on the image side of a diaphragm space—constituted by a total of seven meniscus-shaped lenses all of whose surfaces are concave toward the diaphragm space, the first object-side component and the middle image-side component being negatively refracting doublets. The objective is bodily movable for focusing purposes and its two object-side components are correlatedly axially shiftable to minimize aberrations over a wide range of magnification ratios.

6 Claims, 2 Drawing Figures



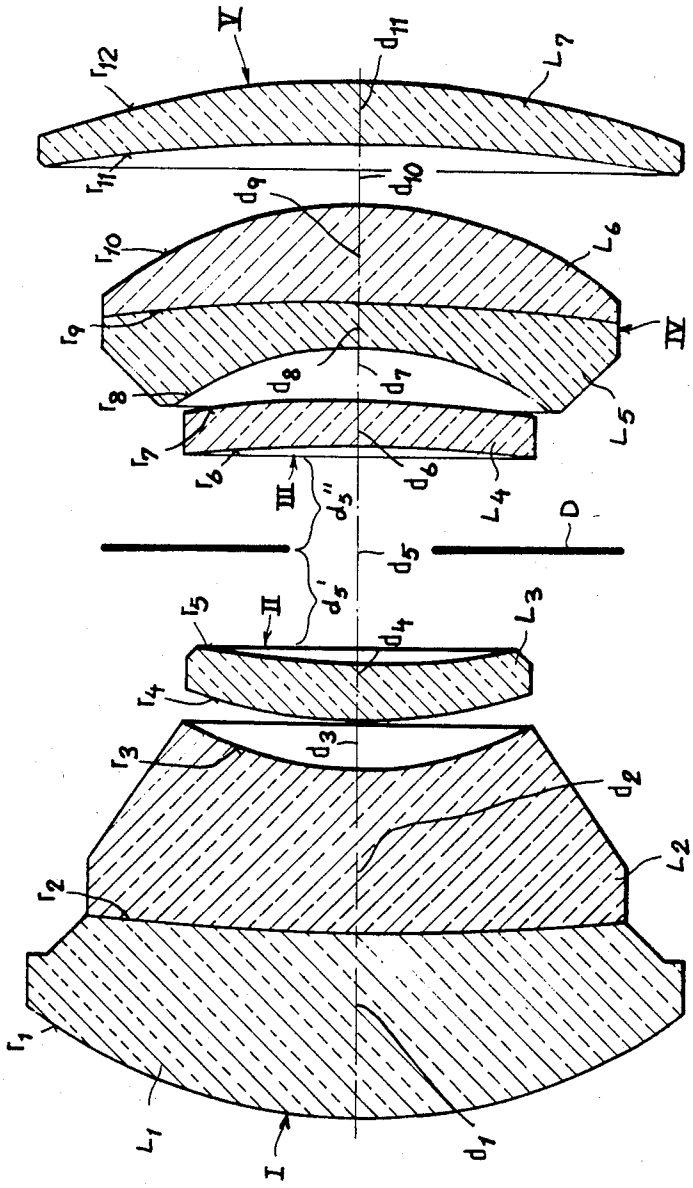

V
r12
d11
L7
r11
d10
d9
r10
L6
r9
IV
d8
d7
r8
L5
r7
r6
III
d6
L4
d5''
D
d5
d5'
r5
II
L3
d4
r4
d3
r3
d2
L2
r2
r1
L1
I
d1

FIG. 1

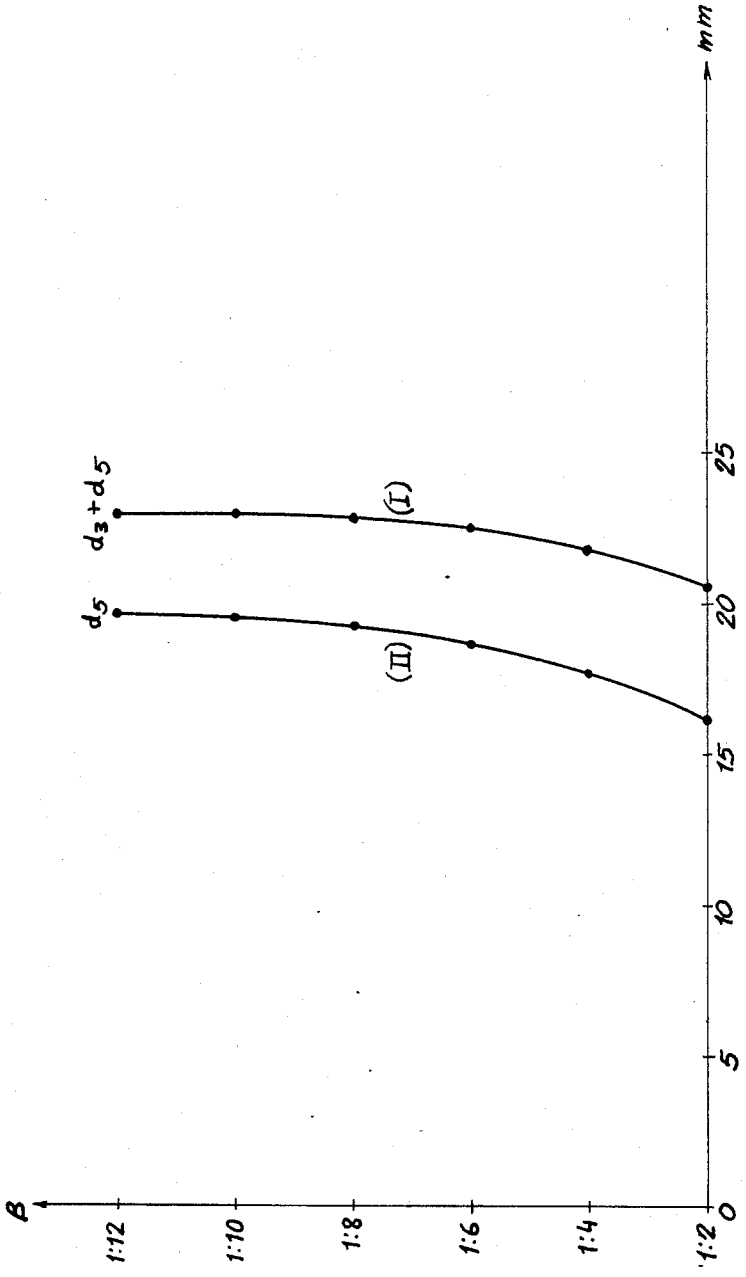


FIG. 2

OPTICAL OBJECTIVE

FIELD OF THE INVENTION

My present invention relates to an optical objective adapted to be used for reproduction of documents or the like as well as for photographic and cinematographic purposes.

BACKGROUND OF THE INVENTION

A known reproduction objective consists of two front components and three rear components separated by an intervening diaphragm space, i.e. a negatively refracting first component and a positively refracting second component on the object side and a positively refracting third component, a negatively refracting fourth component and a positively refracting fifth component on the image side of that space. The two negatively refracting components may be doublets, each composed of two lenses of opposite refractivity, while the others are singlets.

In such an objective it is important to provide satisfactory correction of optical abberrations over the entire field of view, at least for a particular magnification ratio with which it is to be used. When this ratio is subject to variation, the requirements become more stringent.

OBJECT OF THE INVENTION

The object of my present invention, therefore, is to provide an optical objective of this type which can be used over a wide range of magnification ratios with a relatively large aperture, preferably as high as 1:3.5.

SUMMUARY OF THE INVENTION

In accordance with one aspect of my present invention, the constituent lenses of a five-component objective as described above are so dimensioned that their individual focal lengths have absolute magnitudes which, progressing from the first to the fifth component, are related to one another in the ratio of substantially 7.5:1.1:2.7:9.7:1.6, each lens being bounded by spherically curved surfaces which are concave toward the diaphragm space. These individual focal lengths may also be expressed, in terms of the overall focal length F of the objective, by

$$f_I \approx -7.5F,\ f_{II} \approx +1.1F,\ f_{III} \approx +2.7F,\ f_{IV} \approx -9.7F,\ f_V \approx +1.6F.$$

I have found that such an objective, which is bodily movable for focusing purposes between the object plane and the image plane of a reproduction camera, is well corrected for a certain magnification ratio, e.g. of about 1:5, as determined by the positions of these planes in relation to the focal points of the objective. With other magnification ratios above and below this value, however, distortions are encountered which can be corrected, pursuant to a further feature of my invention, by axially shifting the first and second components at different rates but in a correlated manner. More particularly, these components are to be displaced codirectionally, with the first component moving more slowly than the second. Such correlated shifting, pursuant to my invention, could also be used in a differently dimensioned objective of this general type.

BRIEF DESCRIPTION OF THE DRAWING

The above and other features of my invention will now be described in detail with reference to the accompanying drawing in which:

FIG. 1 is a diagrammatic view of an objective embodying my invention; and

FIG. 2 is a graph showing the relative motion of the two front components of the objective with variations in the magnification ratio.

SPECIFIC DESCRIPTION

In FIG. 1 I have shown an objective consisting of five components I, II, III, IV and V. Component I is a negatively refracting doublet consisting of a positive lens L_1, with radii r_1, r_2 and thickness d_1, and of a negative lens L_2, with radii r_2, r_3 and thickness d_2. A limitedly variable air space d_3 separates this doublet from component II which is a single positive lens L_3 with radii r_4, r_5 and thickness d_4. Component III, separated from component II by a diaphragm space d_5 which is also limitedly variable, is a similar singlet L_4 with radii r_6, r_7 and thickness d_6. After a fixed air space d_7 there follows component IV which is also a negatively refracting doublet, consisting of a negative lens L_5 (radii r_8, r_9 and thickness d_8) cemented onto a positive lens L_6 (radii r_9, r_{10} and thickness d_9). A further fixed air space d_{10} lies between components IV and V, the latter being again a positive singlet with radii r_{11}, r_{12} and thickness d_{11}. The cemented surfaces r_2 and r_9 are only weakly refractive.

All lenses L_1–L_7 are menisci withe surfaces concave toward diaphragm space d_5 so that their radii have positive sign ahead of that space and negative sign beyond it. A diaphragm D within space d_5 is separated from lens L_3 by a distance d_5' and from lens L_4 by a distance $d_5'' = d_5 - d_5'$. Components I and II may be coupled together by a conventional camming sleeve, not shown, having guide grooves for correlatedly displacing them.

Based upon an overall focal length F of unity value, the radii r_1–r_{12} and the thicknesses and separations d_1–d_{11} of lenses L_1–L_7 have numerical values as given in the following Table A which also lists their refractive indices n_e and Abbé numbers ν_e together with their surface powers $\Delta n/r$.

TABLE A

Lenses	Radii	Thicknesses and Separations	n_e	ν_e	$\frac{\Delta n}{r}$
	$r_1 = +0.311$				$+2.01$
L_1		$d_1 = 0.110$	1.625	56.6	
	$r_2 = +7.784$				-0.005
L_2		$d_2 = 0.084$	1.584	40.6	
	$r_3 = +0.207$				-2.82
		$d_3 = 0.026$	(variable)		
	$r_4 = +0.311$				$+2.20$
L_3		$d_4 = 0.030$	1.685	47.9	
	$r_5 = +0.498$				-1.37
		$d_5 = 0.121$	(variable)		
	$r_6 = -0.912$				-0.75
L_4		$d_6 = 0.023$	1.685	47.9	
	$r_7 = -0.622$				$+1.10$
		$d_7 = 0.030$			
	$r_8 = -0.181$				-3.48
L_5		$d_8 = 0.026$	1.629	35.3	
	$r_9 = -1.243$				-0.03
L_6		$d_9 = 0.056$	1.670	48.1	
	$r_{10} = -0.230$				$+2.91$
		$d_{10} = 0.033$			
	$r_{11} = -1.095$				-0.57
L_7		$d_{11} = 0.033$	1.622	60.0	

TABLE A-continued

Lenses	Radii	Thicknesses and Separations	n_e	ν_e	$\frac{\Delta n}{r}$
	$r_{12} = -0.536$				$+1.16$

On the same basis the individual focal lengths f_I–f_V of components I–V have the numerical values of -7.5, $+1.1$, $+2.7$, -9.7 and $+1.6$, respectively. This objective has a relative aperture of 1:3.5 and, at maximum diaphragm opening, is very well corrected throughout its field of view with a magnification ratio which may range from 1:2 to 1:12, provided that fractional adjustments are made in the air spaces d_3 and d_5.

The following Table B gives the optimum values of spaces d_3 and d_5 for six different magnification ratios β in an objective as shown in FIG. 1. These spacings have also been graphically represented in FIG. 2 which clearly shows that components I and II shift codirectionally, with the former moving more slowly than the latter. The diaphragm D is separated from lens L_4 by a distance d_5'' of 0.061.

TABLE B

β	d_3	d_5	$d_3 + d_5$
1:12	0.021	0.130	0.151
1:10	0.022	0.129	0.151
1:8	0.023	0.127	0.150
1:6	0.025	0.124	0.149
1:4	0.027	0.117	0.144
1:2	0.030	0.106	0.136

The actual value of focal length F may be 150 mm. For the taking of photographic or cinematographic pictures with bodily shifting of the entire objective for focusing purposes, the components are advantageously left in the relative position given for $\beta = 1:12$. The values for d_3 and d_5 given in Table A are for $\beta = 1:5$; the overall shift of components I (d_3+d_5) and II (d_5) amounts to 0.009F and 0.015F, respectively.

I claim:

1. An optical objective consisting of a negatively refracting first component, a positively refracting second component, a positively refracting third components, a negatively refracting fourth component and a positively refracting fifth component, said second and third components being separated by a diaphragm space, said first and second components being coupled for correlated codirectional axial shifts at a relatively slow and a relatively fast rate, respectively, to minimize optical aberrations with different magnification ratios.

2. An optical objective consisting of a negatively refracting first component, a positively refracting second component, a positively refracting third component, a negatively refracting fourth component and a positively refracting fifth component, said components being constituted by meniscus-shaped lenses which are bounded by spherically curved surfaces all concave toward an intervening space separating said second and third components,

said first, second, third, fourth and fifth components having respective individual focal lengths whose absolute magnitudes are related to one another in the ratio of substantially 7.5:1.1:2.7:9.7:1.6.

3. An objective as defined in claim 1 or 2 wherein said first component is a doublet consisting of a positive lens L_1 and a negative lens L_2, said second and third components being single lenses L_3 and L_4, said fourth component being a doublet consisting of a negative lens L_5 and a positive lens L_6, said first component being a single lens L_7.

4. An objective as defined in claim 3 wherein said lenses L_1 to L_7 have radii r_1 to r_{12} and thicknesses and separations d_1 to d_{11} whose numerical values, based upon a value of unity for the overall focal length of the objective, together with their refractive indices n_e and their Abbe numbers ν_e are substantially as given in the following table:

lenses	radii	thicknesses and separations	n_e	ν_e
L_1	$r_1 = +0.31$			
		$d_1 = 0.11$	1.63	57
	$r_2 = +7.78$			
L_2		$d_2 = 0.08$	1.58	41
	$r_3 = +0.21$			
		$d_3 = 0.03$		
L_3	$r_4 = +0.31$			
		$d_4 = 0.03$	1.69	48
	$r_5 = +0.50$			
		$d_5 = 0.12$		
L_4	$r_6 = -0.91$			
		$d_6 = 0.02$	1.69	48
	$r_7 = -0.62$			
		$d_7 = 0.03$		
L_5	$r_8 = -0.18$			
		$d_8 = 0.03$	1.63	35
	$r_9 = -1.24$			
L_6		$d_9 = 0.06$	1.67	48
	$r_{10} = -0.23$			
		$d_{10} = 0.03$		
L_7	$r_{11} = -1.10$			
		$d_{11} = 0.03$	1.62	60
	$r_{12} = -0.54$			

5. An objective as defined in claim 2, usable for photographic reproductions, wherein said first and second components are coupled for correlated codirectional axial shifts at a relatively slow and a relatively fast rate, respectively, to minimize optical aberrations with different magnification ratios.

6. An objective as defined in claim 4 wherein said first and second components are correlatedly shiftable to vary their air spaces d_3 and d_5 in opposite senses by up to about 0.015 times said overall focal length.

* * * * *

United States Patent [19]

Fukuhara

[11] **4,266,865**

[45] **May 12, 1981**

[54] **DIAPHRAGM CORRECTING MEANS OF AN OBJECTIVE LENS MOUNTED ON A SINGLE LENS REFLEX CAMERA OF THE TTL FULL APERTURE EXPOSURE MEASUREMENT TYPE**

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[73] Assignee: **Nippon Kogaku K.K.**, Tokyo, Japan

[21] Appl. No.: **55,557**

[22] Filed: **Jul. 9, 1979**

[30] **Foreign Application Priority Data**

Jul. 26, 1978 [JP] Japan 53-101796

[51] **Int. Cl.**[3] **G03B 7/20**

[52] **U.S. Cl.** **354/46**

[58] **Field of Search** 354/40, 43, 46, 270, 354/271, 286

[56] **References Cited**

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Primary Examiner—L. T. Hix

Assistant Examiner—Thomas H. Tarcza

Attorney, Agent, or Firm—Fitzpatrick, Cella, Harper & Scinto

[57] **ABSTRACT**

In an objective lens removably mountable with respect to a camera housing and having a diaphragm member forming an aperture and diaphragm driving means displaceable to stop down the diaphragm member in a range over which the area of the aperture is from maximum to minimum, the housing having a metering circuit for measuring the light transmitted through the lens when the aperture is maximum, diaphragm correcting means are provided on at least one of the diaphragm driving means and the diaphragm member to impart a correction of the stop down step number corresponding to the difference between a theoretical metering output calculated from the open F-value of the lens and the brightness of an object and the actual metering output of the metering circuit, to the relation between the variation in area of the aperture and the displacement of the diaphragm driving means.

8 Claims, 6 Drawing Figures

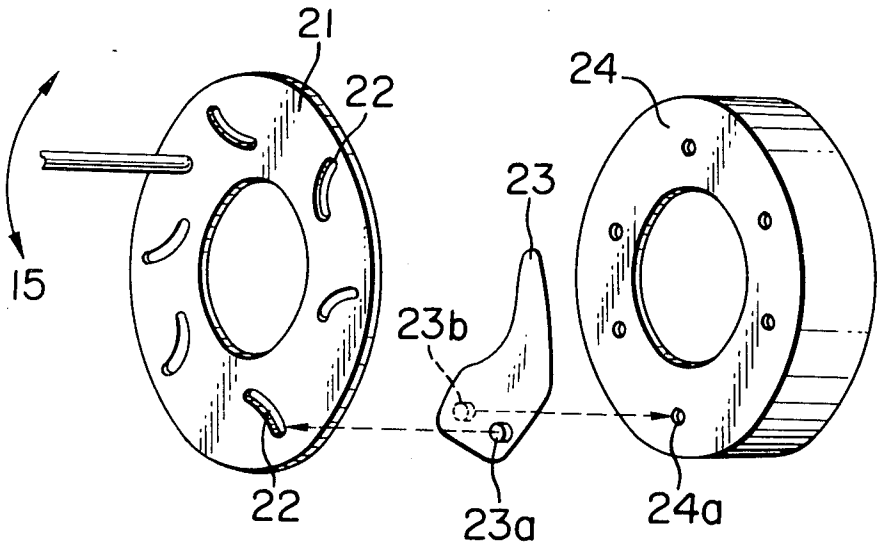


FIG. 1

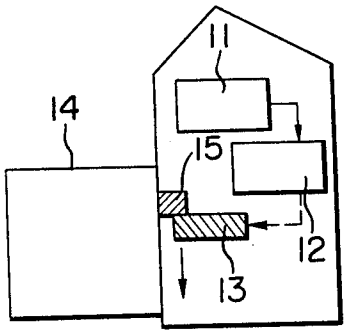


FIG. 2

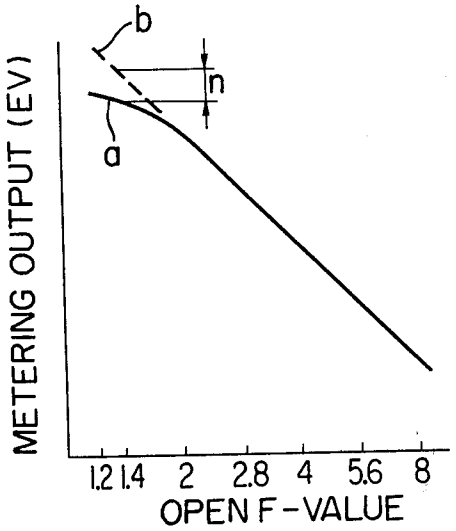


FIG. 3

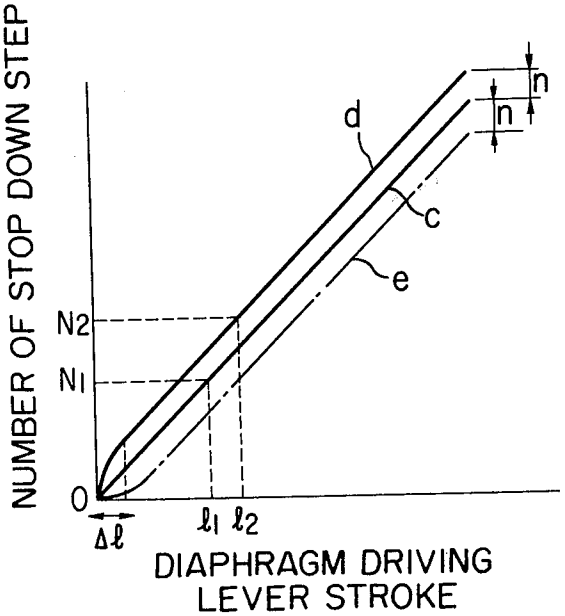


FIG. 4

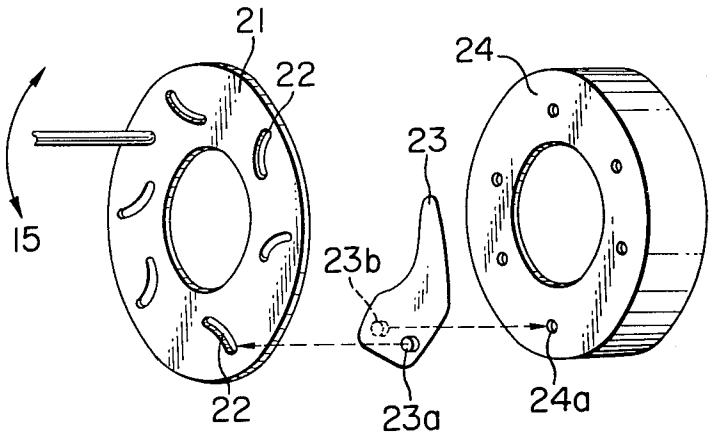


FIG. 5

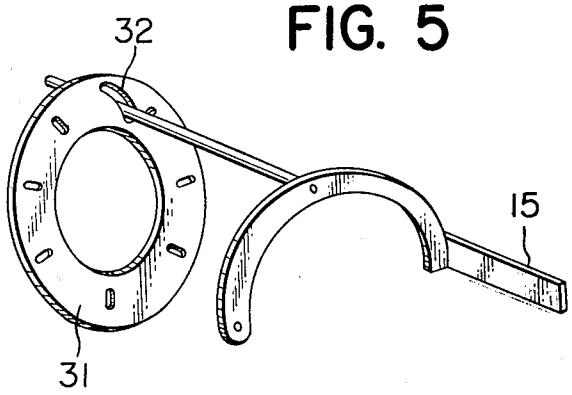
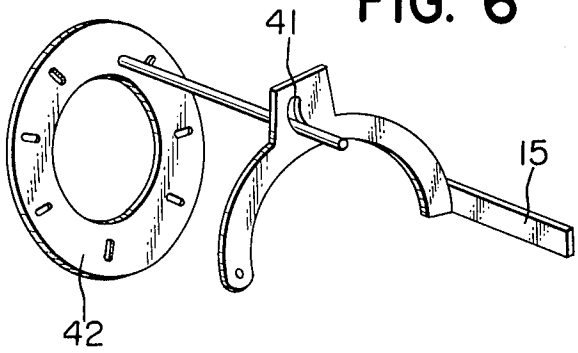


FIG. 6



DIAPHRAGM CORRECTING MEANS OF AN OBJECTIVE LENS MOUNTED ON A SINGLE LENS REFLEX CAMERA OF THE TTL FULL APERTURE EXPOSURE MEASUREMENT TYPE

BACKGROUND OF THE INVENTION

1. Field of The Invention

This invention relates to diaphragm correcting means of an objective lens mounted on a single lens reflex camera of the TTL full aperture exposure measurement type. The expression—full aperture exposure measurement—refers to a system for measuring the light transmitted through the objective lens when the lens aperture is fully opened.

2. Description of the Prior Art

In a single lens reflex camera of the TTL full aperture exposure measurement type wherein, for example, shutter speed priority automatic exposure control is effected, the preset diaphragm ring of the lens is set to a position in which a minimum aperture may be obtained to enable the stop-down of the diaphragm from its maximum aperture to its minimum aperture. Then, it is required to stop down the diaphragm from its maximum aperture to a proper aperture value determined by a preset shutter speed, film sensitivity, brightness of an object, etc. The metering output of a metering circuit included in the automatic exposure control circuit of TTL full aperture exposure measurement type of such a single lens reflex camera is substantially proportional to the area of the aperture formed by the diaphragm, but in lenses having a small open F-value such as F/1.2 or F/1.4, the aforementioned proportional relationship tends to become imprecise in the vicinity of the maximum aperture to thereby reduce the metering output. As the reason therefore, mention may be made of a reduction in the quantity of marginal light of the lens, and the characteristic of the construction of the metering optical system; for example, the fact that the greater the maximum aperture of the objective lens, the more difficult it is for a condenser lens of the metering optical system to condense the marginal light of the lens. In the case of the TTL full aperture exposure measurement, such imprecision of the mentioned proportional relationship appears directly as an exposure error. To correct such exposure error attributable to the open F-value of the lens, German Patent No. 1,258,727 discloses a technique in which a correcting cam is operatively associated with the preset diaphragm ring of the lens and an exposure meter needle is corrected and displaced by a lever following the correcting cam. This technique is effective in the case of an aperture priority system in which the photographer presets the aperture value and determines the diaphragm aperture by an aperture ring interlock member, but is not effective in the case of a shutter speed priority system in which a lever on the camera housing side determines the area of the aperture opening through a diaphragm driving lever on the lens side.

SUMMARY OF THE INVENTION

I have conceived and contribute by the present invention, correcting means for an objective lens adapted to be mounted on a single lens reflex camera of the TTL full aperture exposure measurement type which permit one to effect the aforementioned correction on the lens side without affecting the error of the metering output.

There has thus been outlined rather broadly the more important features of the invention in order that the detailed description thereof that follows may be better understood and in order that the present contribution to the art may be better appreciated. There are, of course, additional features of the invention that will be described hereinafter and which will form the subject of the claims appended hereto. Those skilled in the art will appreciate that the conception upon which this disclosure is based may readily be utilized as a basis for the designing of other structures for carrying out the several purposes of the invention. It is important, therefore, that the claims be regarded as including such equivalent constructions as do not depart from the spirit and scope of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

Specific embodiments of the invention have been chosen for purposes of illustration and description, and are shown in the accompanying drawings, forming a part of the specification wherein:

FIG. **1** shows a conceptual construction of a shutter priority type automatic exposure control camera;

FIG. **2** illustrates the relationship between the metering output of a metering circuit and the open F-value of each interchangeable lens;

FIG. **3** illustrates the relationship between the displacement of a diaphragm driving lever and the number of stop down steps; and

FIGS. **4**, **5**, and **6** illustrate embodiments which show the location whereat a correcting cam is installed.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. **1** shows a conceptual construction of a shutter speed priority type automatic exposure control camera wherein an automatic exposure control circuite **11**, including a metering circuit, measures the light transmitted through a lens when a diaphragm forms a maximum aperture, and produces an output corresponding to an aperture value determined by a preset shutter speed and film sensitivity. An aperture control mechanism **12**, in response to shutter release, displaces an interlock lever **13** from an initial position corresponding to said maximum aperture to a position corresponding to the output of the auotmatic exposure control circuit **11**. A diaphragm driving lever **15** connected to the diaphragm of a lens **14** is displaced following the interlock lever **13**, to stop down the aperture. The stop down is stopped at a position whereat the displacement of the interlock layer **13** is stopped. In this manner, the shutter speed priority automatic exposure control may be accomplished. Of course, the positional relationship between the interlock lever **13** and the diaphragm driving lever **15** is pre-adjusted so as to be convenient for the exposure control. FIG. **2** illustrates in a logarithmic graph the relationship between the metering output (EV display) of the metering circuit included in the automatic exposure control circuit **11** and the open F-value of each interchangeable lens when the object brightness and the set shutter speed and film sensitivity are constant. From the output characteristic curve *a* of FIG. **2** showing the actual metering output, it is seen that the metering output is not proportional to the area of the aperture opening in lenses having great open apertures such as lenses of F/1.2 or F/1.4. For example, in a lens having an open F-value of F/1.4, it is seen from the theoretical output characteristic curve *b* in which

the area of the aperture opening at the open F-value of each interchangeable lens is proportional to the metering output and from the output characteristic curve *a* showing the actual metering output that the actual metering output is lower than the theoretical metering output by *n* steps (N<1).

Such reduction in output by *n* steps is to be corrected. The correction will hereinafter be described in detail.

In FIG. **3**, *c* is the characteristic curve representing the stroke of the diaphragm driving lever and the number of steps of aperture value variation of a lens having an open F-value of F/2, namely, according to FIG. **2**, a lens in which the theoretical metering output is coincident with the actual metering output. The curve *d* is the characteristic curve representing the stroke of the diaphragm driving lever **15** and the number of steps of aperture value variation of a lens having an open F-value of F/1.4, namely, according to FIG. **2**, a lens in which the actual metering output is reduced by *nEV* from the theoretical metering output. As compared with *c*, *d* is such that the number of steps of aperture value variation at the same stroke is stopped down by the aforementioned *n* steps more in EV value from the vicinity of the open aperture to the minimum diaphragm aperture.

Now, assume that there is an object for which the aperture value F/4 is a proper exposure under a certain shutter speed. At this time, when full aperture expsoure measurement is effected through a lens having an open F-value of F/2, the interlock lever **13** is positioned by the automatic exposure control circuit **11** and the aperture control mechanism **12** so that the diaphragm driving lever **15** can be displaced by a stroke l_1 to stop down the aperture by $N_1=2$ is stopped down by two steps from the open aperture. Thus, the aperture is stopped down by two steps from the open F-value F/2 along the characteristic curve *c* and controlled to F/4. On the other hand, when full aperture exposure measurement is effected on the same object by the use of a lens having an open F-value of F/1.4, the automatic exposure control circuit **11** judges the number of stop down steps to be (3−n) steps and controls the interlock lever **13** through the aperture control mechanism **12** so that the diaphragm driving lever **15** can be displaced by a stroke l_2 to stop down the aperture by (3−n) steps from the open aperture. However, since the stroke of the diaphragm driving lever of the lens having an open F-value of F/1.4 is set as shown by the characteristic curve *d* of FIG. **3**, the actual number of the stop down steps is $N_2=(3-n)+m=3$ and after all, the aperture is stopped down by three steps from the open F-value of F/1.4 and controlled to F/4. Thus, proper exposure is obtained.

If the above-described correction is also made on other interchangeable lenses having great open apertures such as F/1.2, proper exposure control may be secured even for these interchangeable lenses. The stroke characteristic of FIG. **3** need not always be linear. Also, if the stroke characteristic of a lens having an open F-value of F/2 is such as indicated by *e*, the stroke characteristic of a lens of F/1.4 may of course be such as indicated by *c*. That is, design should only be made such that the difference in the number of stop down steps is *n* for the same stroke.

As shown in FIG. **3**, the difference in the number of stop down steps between the characteristic curve *d* and the characteristic curve *c* is small between the stroke O and Δ1 and the difference in the number of stop down steps approaches *n* from 0 as the stroke becomes Δ1 from 0. This is a measure taken because the aperture of each lens must be fully open or maximum in the position in which the aperture lever stroke is 0. Even if so constructed, the exposure error of the lens having the characteristic curve *d* can be suppressed to ½ to ⅓ step in the vicinity of the open or maximum aperture and so, there is no practical problem.

The number of stop down steps and the stroke characteristic of the diaphragm driving lever **15**, as described above, may be obtained by providing a correcting cam in the drive transmission path leading from the diaphragm driving lever **15** to the diaphragm. FIGS. **4** to **6** illustrate embodiments showing the location whereat the correcting cam is installed. In FIG. **4**, the correcting cam **22** is provided on a diaphragm driving ring **21** rotated by the diaphragm driving lever **15**. A diaphragm blade **23** has a pin **23***a* provided on the surface thereof adjacent to the diaphragm driving ring **21** fitted in the correcting cam **22** and a pin **23***b* provided on the back surface thereof and fitted in a hole **24***a* formed in a fixed ring **24**, and when the diaphragm driving ring **21** is rotated, the diaphragm blade **23** is controlled through the correcting cam **22** as shown by the characteristic curve *d* of FIG. **3**. The correcting cam **22** may be provided on the diaphragm balde **23** or the fixed ring **24**.

In FIG. **5**, the correcting cam **32** is provided on a diaphragm driving ring **31** and the rotation of the diaphragm driving ring **31** itself is controlled by the diaphragm driving lever **15**, as shown by the aforesaid characteristic curve *d*. In FIG. **6**, the correcting cam **41** is provided no the diaphragm driving lever **15** and a diaphragm driving ring **42** is rotated through the correcting cam **41**, whereby control is effected as shown by the characteristic curve *d*. The shape of the correcting cam **22**, **32** or **41** may be easily designed by those skilled in the art and need not be described in detail.

According to the present invention, as has hitherto been described, there is provided an objective lens in which aperture correcting means for imparting a correction of the stop down step number corresponding to the difference between the theoretical metering output calculated from the open F-value of the lens and the object brightness and the actual metering output, to the relationship between the displacement of the means for driving the diaphragm of the objective lens and the variation in area of the aperture opening, is provided on at least one of the diaphragm driving means and the diaphragm member. Therefore, if the objective lens provided with the correcting means is mounted on a single lens reflex camera of the TTL full aperture exposure measurement type, proper exposure may be obtained irrespective of the magnitude of the open F-value.

I believe that the construction and operation of my novel diaphragm connecting means of an objective lens mounted on a single lens reflex camera of the TTL full aperture exposure measurement type will now be understood and that the advantages thereof will be fully appreciated by those persons skilled in the art.

I claim:

1. In an objective lens removably mountable with respect to a single lens reflex camera housing, said lens having a diaphragm member forming an aperture, and diaphragm driving means displaceable to stop down said diaphragm member in a range over which the area of said aperture is from maximum to minimum, said

housing having a metering circuit for measuring the light transmitted through said lens when said aperture is maximum, the improvement comprising:

diaphragm correcting means provided on at least one of said diaphragm driving means and said diaphragm member to impart a correction of the stop down step number corresponding to the difference between a theoretical metering output calculated from the open F-value of said lens and the brightness of an object and the actual metering output of said metering circuit.

2. The objective lens according to claim **1**, wherein said camera has interlock means responsive, when said lens is mounted, to shutter release operation to displace the diaphragm driving means of said lens, and said diaphragm driving means includes a first member engaged with said interlock means, and a second member engaged with said first member and said diaphragm member.

3. The objective lens according to claim **2**, wherein said diaphragm correcting means is a cam provided at the portion of engagement between said second member and said diaphragm member.

4. The objective lens according to claim **2**, wherein said diaphragm correcting means is a cam provided at the portion of engagement between said first member and said second member.

5. In an objective lens removably mountable with respect to a single lens reflex camera housing, said lens having a diaphragm aperture control mechanism and said housing having a metering circuit for measuring the light transmitted through said lens when said diaphragm aperture is maximum, automatic exposure control means for calculating a proper diaphragm aperture based on output from the metering circuit and a member interlocking with the shutter release operation and a displaceable corresponding to output from said exposure control means,

the improvement wherein:

said aperture control mechanism includes diaphragm means for defining the diaphragm aperture, means for driving the diaphragm means from said maximum aperture to said proper aperture, the amount of displacement of said driving means being defined by the amount of displacement of said interlocking member, and means for transmitting driving force from said driving means to said diaphragm means, said force transmitting means comprising means for correcting the amount of displacement of said diaphragm means in correspondence with the difference between a theoretical metering output calculated from the open F-value of the lens and the brightness of an object and the actual metering output of said metering circuit.

6. The structure according to claim **5**, wherein the amount of correction by said correcting means is continuously increased from the maximum diaphragm aperture to a predetermined diaphragm aperture and is constant from the predetermined diaphragm aperture to the minimum aperture.

7. The structure according to claim **6**, wherein said driving force transmitting means includes a ring formed with a plurality of slots;

said diaphragm means includes pins engaging the respective slots, said ring being rotatable in association with the displacement of said diaphragm driving means so that said diaphragm means varies said diaphragm aperture through said pins; and

said correcting means is formed by a cam-shaped contour of each slot.

8. The structure according to claim **6**, wherein said driving force transmitting means includes a ring formed with a plurality of slots; said diaphragm means includes pins engaging the respective slots; said ring being rotatable in association with the displacement of said diaphragm driving means so that said diaphragm means varies said diaphragm aperture through said pins; and said correcting means includes a cam disposed between said diaphragm driving meand and said ring.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 4,266,865

DATED : May 12, 1981

INVENTOR(S) : TORU FUKUHARA

It is certified that error appears in the above—identified patent and that said Letters Patent is hereby corrected as shown below:

Column 2, line 37, "circuite" should be --circuit--; at line 56, "Fig. 2" should begin a new paragraph.

Column 3, line 34, delete "is stopped down by" after "N_1= 2; line 57, "The stroke" should begin a new paragraph.

Column 4, line 26, "balde" should be --blade--; line 33, "no" should be --on--.

Column 6, line 40, "meand" should be --means--.

Signed and Sealed this

Thirteenth Day of *October 1981*

[SEAL]

Attest:

Attesting Officer

GERALD J. MOSSINGHOFF

Commissioner of Patents and Trademarks

United States Patent [19]

Lermann et al.

[11] **4,258,998**

[45] **Mar. 31, 1981**

[54] **STILL CAMERA WITH AN OBJECTIVE WHICH CAN BE RETRACTED INTO THE CAMERA HOUSING FOR DIMENSIONAL COMPACTNESS**

[75] Inventors: **Peter Lermann**, Narring; **Dieter Engelsmann**, Unterhaching; **Dieter Maas**, Pöring; **Reinhard Nicko**, Munich, all of Fed. Rep. of Germany

[73] Assignee: **AGFA-Gevaert, A.G.**, Leverkusen, Fed. Rep. of Germany

[21] Appl. No.: **94,662**

[22] Filed: **Nov. 15, 1979**

[30] **Foreign Application Priority Data**

Nov. 17, 1978 [DE] Fed. Rep. of Germany 2849893

[51] **Int. Cl.**[3] **G03B 1/12**; G03B 13/02

[52] **U.S. Cl.** **354/173**; 354/195

[58] **Field of Search** 354/212–214, 354/187, 190, 286, 25, 173, 170, 195, 288, 202

[56] **References Cited**

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4,152,060	5/1979	Specht	354/195

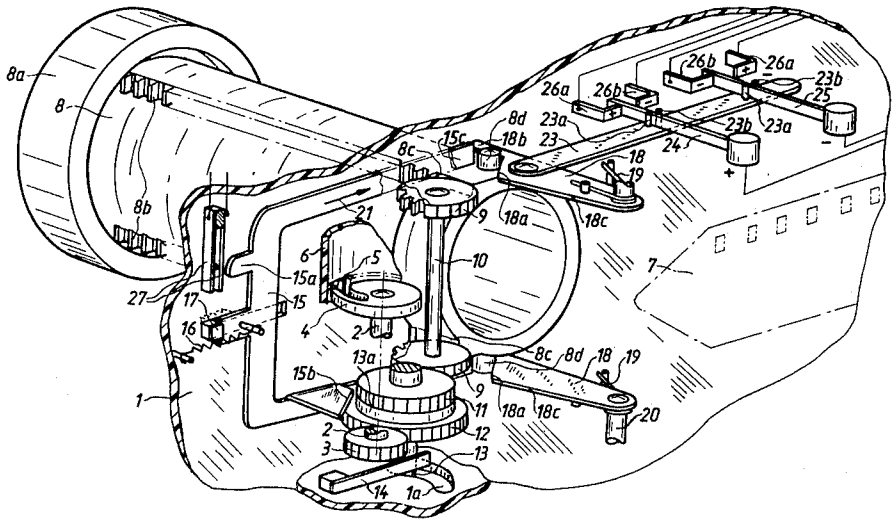
Primary Examiner—Donald A. Griffin

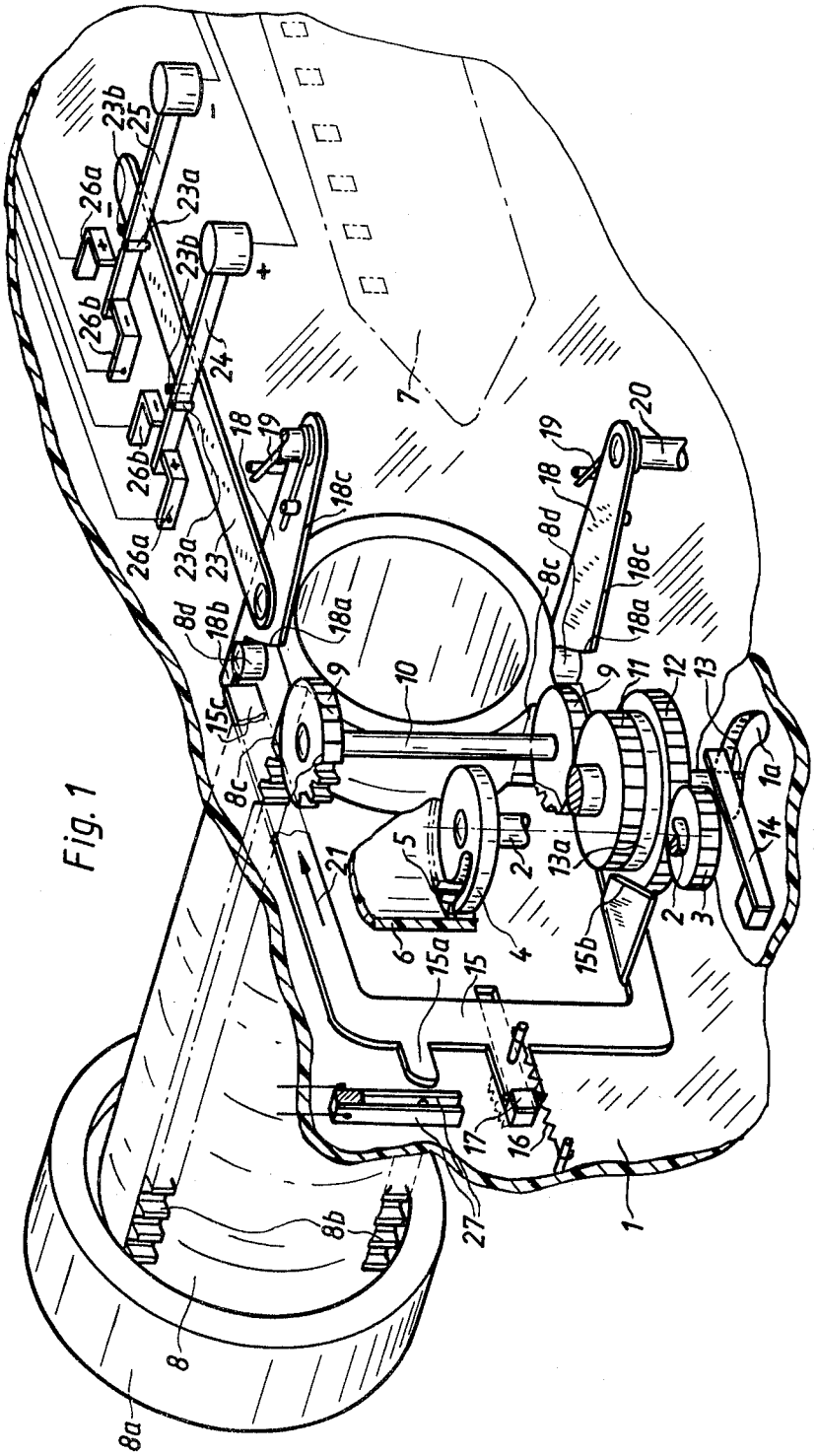
Attorney, Agent, or Firm—Michael J. Striker

[57] **ABSTRACT**

A camera has an objective which can be moved from an extended, operative position to an inoperative position retracted into the camera housing for dimensional compactness. The objective is driven by a motor from one to the other of those two positions and moved by hand back in the other direction, or is motor driven in both directions. The motor employed is the film transport motor anyway present. The objective is coupled to and decoupled from the drive motor in dependence upon the setting of a manual selector, so that the objective not be driven at improper times, and is preferably coupled and decoupled in automatic response to the setting of a manual selector used to implement other camera functions, so that extension and/or retraction of the camera objective occur automatically as a logical incident to the other camera functions selected by the user.

21 Claims, 6 Drawing Figures




23b
25
26a
23a
23b
26b
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18
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18c
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8d
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12
13
1a
14
15c
8c
21
5
2
13a
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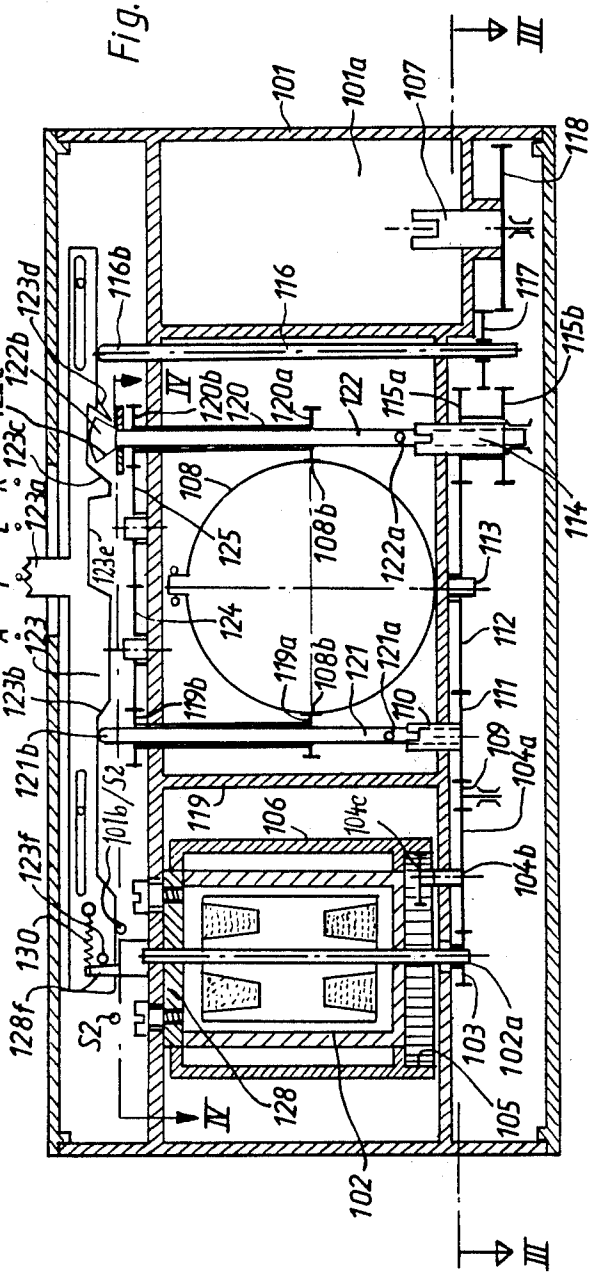
15a
15
4
15b
17
16
27
1
8b
8
8a

Fig. 1

Fig. 2


101
101a
107
III
118
116b
116
117
115b
123d
122b
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120a
122
115a
IV
108
108b
125
122a
114
113
123e
124
119a
108b
121
121a
112
123
123b
119b
110
111
121b
109
104a
101b/S2
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102a
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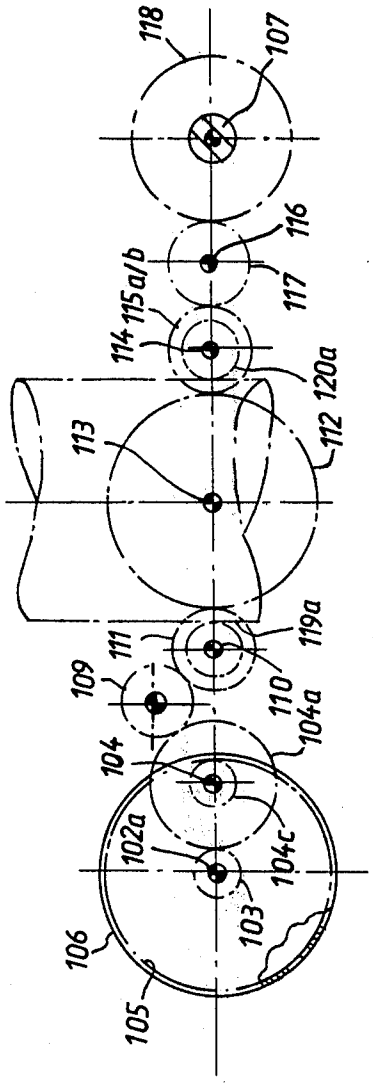
105
102
III

Fig. 3


118
107
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120a
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119a
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104a
104
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103
106
105

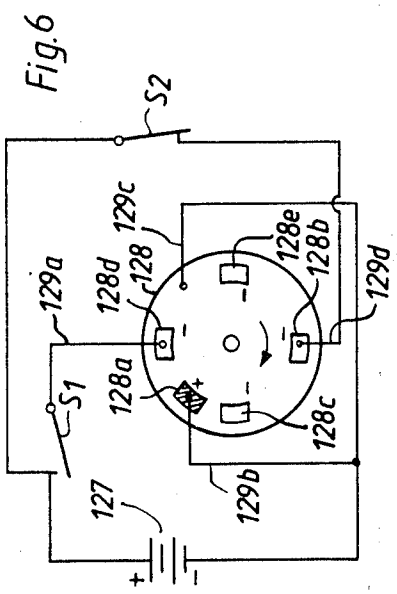
Fig.6
S2
129c
128d
128
128e
128b
129a
129d
128a
S1
128c
127
129b

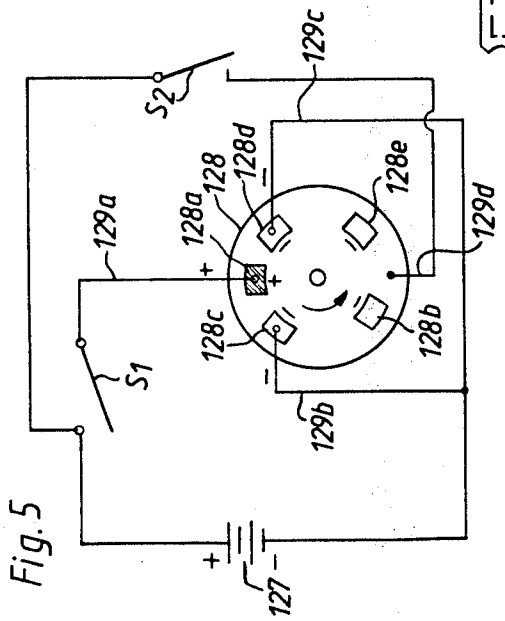
Fig.5
S2
129c
128d
128
128e
129a
128a
129d
S1
128c
128b
129b
127

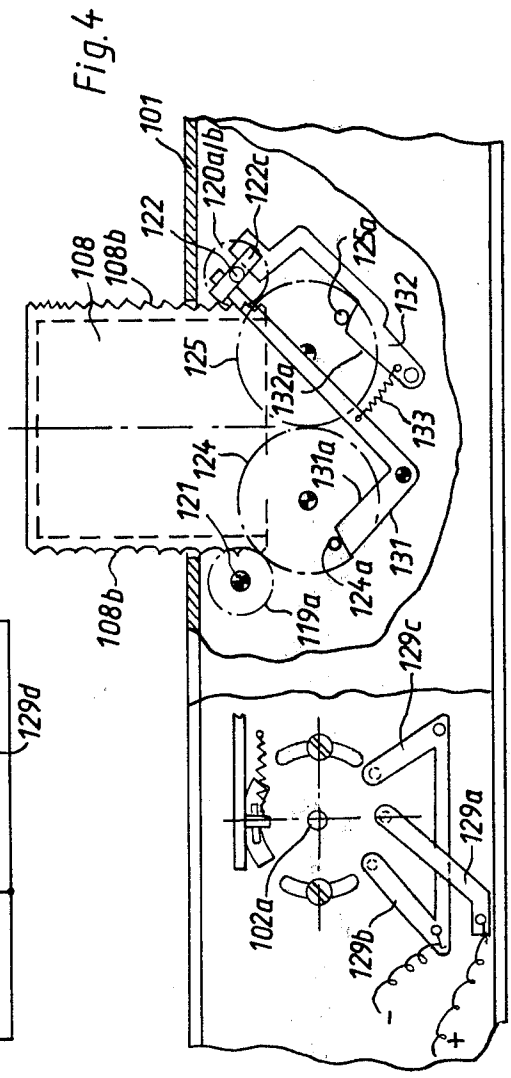
Fig.4
101
120a/b
122c
122
108
108b
125a
132
125
132a
133
124
131a
121
131
108b
119a
124a
129c
129a
102a
129b

STILL CAMERA WITH AN OBJECTIVE WHICH CAN BE RETRACTED INTO THE CAMERA HOUSING FOR DIMENSIONAL COMPACTNESS

BACKGROUND OF THE INVENTION

The present invention concerns photographic still camera of the type having an objective which can be moved from an extended, operative position in which it projects out from the camera housing to a retracted, inoperative position in which it is retracted into the camera housing for dimensional compactness of the camera, e.g., when the camera is being carried about and not in use.

With known cameras of this type the objective is moved between extended and retracted position by hand, the extended position into which the objective is manually brought generally being its infinite-subject-distance focal setting.

SUMMARY OF THE INVENTION

It is a main concept of the invention to provide a motorized system which implements motorized movement of the objective at least from its retracted to its extended position, and preferably also motorized movement of the objective back into its retracted position.

It is a further concept of the invention to power the movement of the objective between its retracted and extended positions by utilizing a drive motor already contained in the camera for other purposes, most typically the camera's film transport motor, or the camera's shutter-resetting motor.

The invention also contemplates various interlocks and automatic features, which will be best understood from the detailed description of presently preferred embodiments, below.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a perspective illustration of one embodiment of the present invention;

FIG. **2** depicts a second embodiment of the invention;

FIG. **3** is a section taken along line III—III of FIG. **2**;

FIG. **4** is a section on line IV—IV of FIG. **2**;

FIG. **5** depicts the rotary motor-direction switching mechanism of the embodiment of FIG. **2**, in the setting which it assumes for forwards film transport; and

FIG. **6** depicts the switching mechanism of FIG. **5**, in the setting which it assumes for causing the camera objective to be motor driven from extended, operative position to retracted, inoperative position.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

In FIG. **1**, numeral **1** denotes the housing of a still camera, the housing being shown mostly broken away. A non-illustrated reversible electric motor drives the shaft **2** of a pinion **3**. Also mounted on shaft **2**, for rotation therewith, is a springy pawl **4**. Pawl **4** is so oriented as to cooperate with the ratchet teeth of a ring of ratchet teeth or ratchet wheel **5**. Ratchet wheel **5** is connected with a film take-up spool **6**, or else with a rotation-imparting member which can be brought into rotation-imparting engagement with the take-up member internal to a film cassette. When the electric drive motor operates in its normal direction, so as to effect take-up of the film **7** (which is to say, clockwise in FIG. **1**), ratchet pawl **4** drives the ratchet wheel **5** and thereby effects film take-up. When the drive motor rotates in the opposite direction, the ratchet pawl **4** idles across the ratchet teeth of ratchet wheel **5**.

The camera **1** is provided with an objective **8** which can be retracted into the camera housing, for the sake of small overall camera dimensions when the camera is not in use, and which can be extended out of the camera housing into operative position when the camera is to be used. FIG. **1** depicts objective **8** in its extended, operative position, which here coincides with its infinite-subject-distance focal setting. If the objective **8** is to be set to shorter subject-distance settings, then this can be effected, for example, by manually rotating focus adjuster ring **8**, which rotation, in cooperation with non-illustrated means, serves to effect controlled partial retraction of the objective back into the camera. In the exemplary embodiment depicted in FIG. **1**, the objective **8** is motor-driven from its inoperative setting (in which it is fully retracted in the camera housing **1**) out to its fully extended setting, and then, when the camera is no longer to be used, is manually pushed back into the camera. In particularly, the (non-illustrated) drive motor which rotates shaft **2** and effects film transport is also used to drive the objective **8** out to its extended, operative position.

The outer surface of the objective housing is accordingly provided with two parallel rack portions **8***b*. As shown in FIG. **1**, the rear ends of the two racks **8***b*, i.e., the portions of the racks which are located internal to the camera housing, include untoothed or recessed portions **8***c*. Each of the two racks **8***b* is engaged by a respective gear **9**, both gears **9** being mounted on a shared shaft **10**. One of the two gears **9** is in engagement with a gear **11**. Gear **11** and a further gear **12** are mounted on a shared shaft **13**. Shaft **13** is movably mounted in a slot **1***a* of the housing structure **1** and is biased by weak spring **14**. Spring **14** urges **13** in a direction to bring the gear **12** into engagement with the gear **9**. The orientation of slot **1***a* relative to a line connecting the gear shafts **2** and **13** is such that, when the gear **3** is driven in the film take-up direction (clockwise in FIG. **1**), the interaction forces as between the gears **3** and **12** cause the gear **11** and its shaft **13** to be moved, against the force of biasing spring **14**, out of engagement with gear **9**. Conversely, when gear **3** is driven opposite the film take-up direction (i.e., is driven counterclockwise in FIG. **1**), not only does the ratchet detent idle across the teeth of ratchet wheel **5**, but additionally gear **11** is pressed into engagement with and drives gear **9**. Accordingly, when gear **3** is driven opposite to the film take-up direction, the gears **12**, **11** and **9** are driven, with gears **9**, in particular, rotating counterclockwise. As a result, when the motor starts in this direction, the objective **8** via its rack portions **8***b* is driven out of the camera housing **1** into its illustrated, extended position, the gears **9** idling once they are reached by the untoothed or recessed portions **8***c* of the racks **8***b*. In principle, it would be possible to make use of only a single rack **8***b* and a single rack drive gear **9**. However, it is preferred to use a pair of racks and a pair of drive gears, as shown, in order to prevent any tendency to impart to the objective **8** a downwards or upwards tilt.

In order to be able to switch over the transmission or the drive motor from its film-transport operation to its objective-drive action or so as to make possible pushing of the objective **8** into its retracted position in the camera housing, use is made in this embodiment of a slider **15** which extends and is mounted for movement in a

direction perpendicular to the optical axis of objective **8**. A spring **16** pulls slider **15** against an elastic stop member **17**. Slider **15** is provided with a switch-activating projection **15***a*, an inclined cam portion **15***b* and at least one control arm portion **15***c*.

The rear end of the housing of objective **8** is provided with a blocking portion **8***d*. When objective **8** is in its fully extended position, the blocking edge **18***a* of a blocking lever **18** snaps into place behind blocking potions **8***d* under the action of a biasing spring **19**, to prevent accidental pushing of the objective back into the camera housing. When the blocking lever **18** snaps into blocking position in this matter, it additionally switches off the drive motor. Here, too, use is preferably made of two blocking portions **8***d*, located at diametrally opposite portions of the objective housing, and two blocking levers **18** mounted on coaxial shafts **20**. The ends **18***b* of the blocking levers **18** are located in the paths of motion of the control arms **15***c*. Accordingly, when the slider **15** moves towards the objective **8**, i.e., rightwards in FIG. **1**, the control arms **15***c* push the ends **18***b* of the blocking levers away from the blocking portions **8**, the blocking levers **18***d* are swung away out of the path of motion of the blocking portions **8***d*, and the objective **8** can be manually pushed into its retracted position. The control edge **15***b* on slider **15** assures that the gears **9** do not interfere with the objective retraction and do not drive the ratchet pawl **4** in the film-transport direction. Slider **15** is moved in the direction of arrow **21**, against the force of spring **16**, by means of a (non-illustrated) manually shifted member located at the exterior of the camera housing, such member constituting an extension of or else being coupled to slider **15**. As slider **15** is moved in direction **21**, its cam portion **15***b* presses against an untoothed disk **13***a* on shaft **13**, displacing the latter in housing slot **1***a* by such a distance that gear **11** is moved out of engagement with gear **9**, so that as objective **8** is manually pushed into camera housing **1** the gears **9** idle, i.e., are passively driven by the racks **8***b*.

A control rod **23** is pivotally coupled, at **22**, to the upper blocking lever **18** and carries two pairs of control pins **23***a* and **23***b*. Each pair of control pins **23***a*, **23***b* confines a respective spring contact **24**, **25**, contacts **23** and **25** being respectively connected to the positive and to the negative terminal of the (non-illustrated) electric drive motor. Two stationary contacts **26**, both connected to the positive terminal of a (non-illustrated) battery, are each located to a respective first side of a respective one of the two contact springs **24**, **25**. Two stationary contacts **26***b*, both connected to the negative battery terminal, are each located to the respective other side of the respective contact spring **24** or **25**.

As already stated, in FIG. **1** the objective **8** is shown in its extended, operative position. After user activation of a (conventional and therefore non-illustrated) shutter released mechanism, the camera's shutter performs an exposure operation, and upon completion of the exposure operation a film-transport operation should next occur. Accordingly, in any appropriate, conventional manner, one or more (non-illustrated) motor-connect switches connected in circuit with the drive motor are closed, to permit motor energization, either by manual activation or else in automatic response to exposure completion. As shown in FIG. **1**, the positive terminal of the drive motor is presently connected, via spring contact **24** and its association contact **26***a*, to the positive battery terminal, whereas the negative drive motor terminal is presently connected, via spring contact **25** and its associate contact **26***b*, to the negative battery terminal. Accordingly, the motor is energized for rotation in the direction required for film take-up operation, and gear **3** is rotated clockwise. The initiation and termination of motor energization can be controlled by any of the various switching and/or transmission expedients so well known in the art, and accordingly, it is only the motor-direction control switches which are depicted in FIG. **1**.

Thus far, it has been explained how, with the objective **8** in extended position, a film transport operation is permitted to occur, and also how the objective **8** can be pushed by hand from its extended position back into its retracted position. Next to be explained is how the objective **8** is driven out from its retracted position to its illustrated, extended position. Slider **15** is moved by spring **16** opposite to direction **21** and compresses the elastic stop member **17**. Because the objective **8** is in retracted position, the edges **18***c* of the blocking levers **18** bear against the blocking portions **8***d* of the objective housing; accordingly, blocking levers **18** do not interfere with movement of the objective to extended position. With objective **8** not in fully extended position and levers **18** accordingly displaced somewhat clockwise, control slide **23** is displaced in the direction of arrow **21** by a distance such that the positive-terminal contact **24** of the motor engages the associated negative-battery-terminal contact **26***b*, whereas the negative-terminal contact **25** of the motor engages the associated positive-battery-terminal contact **26***a*, i.e., the settings opposite to those shown for film transport in FIG. **1**. When slider **15** is moved leftwards and compresses the elastic stop member **17**, the second (and illustrated one) of the aforementioned two, parallel-connected motor-energization switches, i.e., switch **27**, closes, so that the motor begin to turn and drive gear **3** counterclockwise. For this rotary direction, gear train **3**, **12**, **11**, **9** is engaged, and accordingly the gears **9** rotate counterclockwise and drive the objective **8**, via the racks **8***b*, into the illustrated extended position thereof. At the end of the extension movement of objective **8**, the blocking levers **18** snap into place, with their blocking edges **18***c* snapping into position behind the blocking portions **8***d* of the objective housing, thereafter preventing accidental depression or retraction of the objective **8**. Also, the control slide **23** is moved opposite to direction **21**, to set the motor direction back to the film-transport mode. The mode of operation causing the objective to move out to extended position has now been completed. When the user lets go of slider **15**, the elastic stop member **17**, acting as a compression spring, pushes the slider **15** a small distance rightward, i.e., back to the illustrated setting of slider **15**. If the motor does not come to an immediate stop as a result of the aforementioned direction-reversing action, the gears **9** can in any event idle in the untoothed portions **8***c* of the racks **8***b*.

Accordingly, in the embodiment of FIG. **1**, an electric film-transport motor drives the film take-up spool, or the like, through the intermediary of a coupling which transmits rotation to the take-up spool only when rotated in one of two rotary directions, and when the direction of the drive motor is reversed no film-transport action occurs and instead the camera's objective is driven out from retracted to extended position.

FIGS. **2**–**6** depict a modification of the FIG. **1** embodiment, in which the drive-motor rotation direction opposite to that which effects forward film transport is utilized to drive the camera objective out to extended

position but additionally to pull the camera objective back into retracted position and also to effect reverse or rewind transport of the film, especially in the case of miniature film in type-135 cartridges.

In FIGS. 2–6, the camera housing is denoted by **101**, the reversible electric drive motor by **102**, the motor output shaft by **102***a* and the motor drive pinion by **103**. Pinion **103** is engaged by a gear **104***a* mounted on a shaft **104**. Gear **104***a* is coupled to a film-transport gear **104***c* via a coupling **104***b* operative for transmitting rotation from pinion gear **104***a* to gear **104***c* only when drive pinion **103** is rotating in the direction associated with forward film transport. The film-transport gear **104***c* meshes with internal toothing **105** provided on a film take-up spool **106**. The drive motor **102** is located interiorly of and coaxial with the film take-up spool **106**. If the motor **102** turns counterclockwise, then the gears **104***c* and **105** and accordingly the take-up spool **106** turn clockwise, as a result of which the (non-illustrated) film will be pulled from the (non-illustrated) cartridge in film-supply compartment **101***a* and be taken up on the take-up spool **106**. To avoid pictorial complexity, there are omitted from these Figures the film-perforation-engaging sprocket wheel, the step-by-step transmission between motor **102** and such sprocket wheel, and the control means employed to activate the camera's shutter mechanism and to initiate and terminate the forward film transport operation, inasmuch as such mechanisms come in a variety of types all exceedingly familiar to persons skilled in the art. However, the rewind shaft **107**, which engages the (non-illustrated) film spool internal to the (non-illustrated) film-supply cartridge, is shown.

In FIGS. 2–6, as in FIG. **1**, in order to reduce the overall dimensions of the camera when it is not in use its objective can be retracted into the camera housing **101** and extended out to operative position when the camera is actually to be used. The housing of objective **108** is provided with two diametrally oppositely located rack portions **108***b*, located on a diameter of the objective housing which extends generally parallel to the film-transport direction.

The gear transmission for the motorized movement of the camera objective will now be described. Gear **104***a* meshes with a gear **109**, and the latter meshes with a gear **111** provided on a shaft **110**. Gear **111** engages a gear **112** mounted on a shaft **113**, the rotation axis of gear **112** intersecting the optical axis of the objective **108**, perpendicular thereto as shown. Gear **112** in turn meshes with a gear **115***a* provided on a shaft **114**. Shaft **114** also carries a further gear **115***b*, identical to gear **115***a* but axially spaced a small distance from the latter. A gear shaft **106**, mounted shiftable in the direction parallel to the longitudinal axis of take-up spool **106**, carries a further gear **117** so arranged that normally, i.e., during motor-powered forwards film transport, it is located axially intermediate the two gears **115***a*, **115***b*; however, if gear shaft **106** is displaced downwardly, then gear **117** comes into mesh with gear **115***b*, and also into mesh with a further gear **118** which is located at about the level of gear **115***b* and is connected to the film rewind shaft **107**, thereby establishing a complete power train from motor **102**, **103** to the rewind shaft **107**. The gear power train **103–118** is so designed that, when the motor **102** turns in the direction (clockwise) opposite to that for forward film transport, gear **118** turns counterclockwise, i.e., so as to drive the spool internal to a film-supply cartridge in the forward film-transport direction, with the shafts **110**, **114** likewise turning counterclockwise. The power train **103**, **118** can, as shown, be located beneath the objective **108** and the motor **102**.

The hollow shafts **119**, **120** are located to either side of objective **108** and extend parallel to the longitudinal axis of the film take-up spool **106**. The hollow shafts **119**, **120** carry respective pairs of identical gear **119***a*, **119***b* and **120***a*, **120***b*. The gears **119***a* and **120***a* mesh with respective ones of the two racks **108***b*. The hollow shafts **119**, **120** accommodate respective coupling shafts **121** and **122**. Each of coupling shafts **121**, **122** is axially shiftable within the interior of the respective hollow shaft **119**, **120** but is not rotatable relative to the respective hollow shaft. The ends of the coupling shafts **121**, **122** which face towards the shafts **110**, **114** are configured as coaxial shaft couplings **121***a* and **122***a*. The ends **121***b*, **122***b* of these coupling shafts located above the objective **108**, and also the shiftable shaft **116**, are passed by (non-illustrated) biasing springs upwards against a manual slider **123**. Located intermediate the two, identical gears **119**, **120***b* there are disposed two gears **124**, **125**, identical to each other, interengaged such that the two gears **119***b*, **120***b* rotate in opposite respective directions. The gear train **119***b*, **124**, **125**, **120***b* is advantageously disposed above the objective **108**, in the manner shown.

If drive motor **102** is set for rotation in such a direction that pinion **103** turns clockwise, and if the shaft **121** is in downwardly displaced setting and therefore in engagement with shaft **110**, then in the illustrated embodiment the other coupling shaft **122** is disengaged from shaft **114**, and the shaft **116** is in elevated setting so that gear **117** is disengaged from the gears **115***b* and **118**. If then the motor commences to turn, then due to the one-way coupling **104***b* no film-transport action occurs, and instead the gears **111**, **119***a*, **119***b* turn counterclockwise and accordingly the gear **120***a* clockwise. As a result, the objective **108** is driven out to the extended position shown in FIG. **4** via the rack portions **108***b*. In the other mode of operation, shaft **121** is disengaged as is also gear **117**, and shaft **122** is engaged with shaft **114**, shaft **122** being in its downwardly displaced position. As a result, gear **120***a* turns counterclockwise and gear **119***a* turns clockwise, and the objective **108** is then driven back into its retracted position retracted into the camera **1**. In a third mode of operation, shaft **116** is in its downwardly displaced position, both the coupling shafts **121**, **122** are in decoupled condition, and clockwise rotation of the motor drive pinion **103** effects reverse or rewind film transport via the gear **118**.

In order to be able to select from among these modes of operation, some sort of control means must be provided, and preferably including a manual selector member moved by the user of the camera. In the illustrated embodiment, the control means employed comprises the aforementioned slider **123**, the slider **123** having an arm **123***a* which projects out to the exterior of the camera to constitute the manual selector member. In the illustrated embodiment, the slider **123** is guided for sliding motion parallel to the film transport direction, by means of, for example, the illustrated pin-and-slot connections (no reference numeral). In FIG. **2**, slider **123** is in its setting F, for film transport, and the upper shaft ends **121***b*, **122***b* and **116***b* are located in recesses of the slider **123**, so that these shafts will not be pressed down into their downwardly displaced settings. As shown in FIG. **2**, to the right of the upper shaft end **121***b*

the slider 123 has a cam portion 123*b* with slanted ends, so that when slider 123 is shifted leftward into its setting A, the coupling shaft 121 come into engagement with the shaft 110, in which case the objective 108 is driven out to extended position. In FIG. 2, to the left of upper shaft end 122*b* the slider 123 has a cam portion 123*c* with a similar slanted end portion; the cam portion 123*c* is bent in such a configuration that it does not cooperate with upper shaft end 122*b* but instead only with upper shaft end 116*b*. Shown to the right of shaft end 122*b* is a further inclined camming portion 123*d* on slider 123; camming portion 123*d* is located a certain distance out of the way of shaft 116, so that it does not cooperate with shaft 116 but instead cooperates only with shaft end 122*b*. To the left of camming portion 123*c* is another recess 123*e*. If slider 123 is shifted rightwards from its film-transport setting F to its setting E, then shafts 121 and 116 are in their decoupled settings, whereas the camming portion 123*c* presses the shaft 122 into its setting engaged with the shaft 114; accordingly, in setting E of slider 123, the objective is pulled inwards into its retracted position. If slider 123 is shifted further rightward to setting R, then the upper shaft end 122 is located in recess 123*e*, whereas the camming portion 123*d* presses the shaft 116 downwards into its setting for a film-rewind operation.

In addition to the implementing operations described above, it is necessary that motor direction be controlled, here in dependence upon the setting of slider 123, suth that one motor direction is established for slider settings A, E and R and other motor direction for slider setting F. In order to achieve this in a simple way, in the illustrated embodiment the motor 102 is provided with a rotary switch 128 (see FIGS. 5 and 6) having a positive contact 128*a*, two negative contacts 128*c* and 128*d* each spaced 45° from the positive contact but located at opposite sides of the latter, and two further negative contacts 128*b* and 128*e* located to opposite sides of the positive contact and spaced therefrom by 125°. All these contacts 128*b*–128*e* are connected to the negative motor terminal and contact 128*a* to the positive motor terminal. Two switching circuits branch off from battery 217, one containing the switch S1 which serves to close the motor current path to effect forward film transport; this switch is, for example, in very familiar manner closed by an element of the camera's shutter mechanism upon completion of an exposure and then, for example, in equally familiar manner is reopened upon completion of a film-transport operation in response to the performance of one rotation of the camera's film-transport sprocket wheel. The second switching circuit which branches off from battery 127 contains the switch S2, which must be closed whenever the objective is to be driven out or retracted or when the film is to be rewound. The positive and negative terminals of battery 127 are connectable to various ones of these contacts 128*a*–128 via four stationary wipers 129*a*, 129*b*, 129*c*, 129*d*. The wipers 129*b* and 129*c* are connected in common to the negative terminal of battery 127, and are spaced apart 90°. Wiper 129*a* is located intermediate the two wipers 129*b*, 129*c* and is connected to the positive battery terminal. Wiper 129*d* is connected to the positive battery terminal, and is located diametrically opposite to wiper 129*a*. Rotary switch 128 is provided with a tab 128*f* (see FIG. 2). A tension spring 130 is at one end connected to tab 128*f* and at its other end is connected to a pin on slider 123. Spring 130 pulls tab 128*f* against a pin 123*f* on slider 123. When slider 123 is in the forward film-transport setting F, the rotary switch 128 occupies the setting depicted in FIG. 5, the motor 102 turns counterclockwise. If slider 123 is shifted to setting A, the pin 123*f* on slider 123 carries rotary switch 128 with it, turning the latter 45° to the left to the setting shown in FIG. 6. When switch S2 closes (switch S1 is shown open, because it is assumed for simplicity that no shutter triggering action has occurred), objective 108 is driven out to extended position, because motor 102 now turns in the direction opposite that for forward film transport. If slider 123 is shifted to setting E, rotary switch 128 follows slider pin 123*f* until it reaches a stationary stop member 101*b*, whereupon the rotary switch 128 will have reached a setting which is symmetrical (relative to contact 129*a*) to the setting shown in FIG. 6. In this setting too, the motor 102 turns in the direction opposite that in which it turns for forward film transport, so that when switch S2 is closed the objective 108 is pulled in to retracted position. If slider 123 is shifted further rightward to film-rewind setting R, then due to stationary stop member 101*b* the setting of rotary switch 128 just described, is maintained, and when switch S2 is closed the film rewind operation commences.

The switch S2, for driving the objective in and out and for film rewind, could be closed by a separate manually operated switch-control element on the exterior of the camera. However, it is more advantageous that it be closed in automatic response to the slider 123 assuming the settings for driving the objective and for film rewind. To this end, use can be made of two switches S2, connected in parallel to each other, one being formed by the stop member 101*b* and the other being formed by a further such switch located symmetrically relative to the first, considered with respect to rotary switch 128. The two parallel switches S2 are shown in FIG. 2, and when slider 123 is shifted into either setting A or setting E, one or the other of these two switches is closed, as the case may be, the tab 128*f* serving as the shared moving contact for this double switch arrangement.

In order that the objective 108, when it has been brought out to its extended, operative position, be secured against unintentional pushing of it back into the camera housing, the upper end 122*b* of shaft 122 is provided, as shown, with a conical portion 122*c*, against which two blocking levers 131, 132 are pressed by a biasing spring 133 (see FIG. 4). When the objective 108 is in its extended position, the blocking levers 131, 132 are located behind respective pins 124*a*, 125*a* provided on respective ones of the two gears 124, 125, and thereby prevent unintentional retraction of the objective 108. When slider 123 is shifted to setting E, the conical portion 122*c* presses these blocking levers 131, 132 out of the path of motion of the pins 124*a*, 125*a*, so that the objective 108 can then be pulled into retracted position in the camera 101 by means of the gears 119*a*, 120*a*.

It will be understood that a great variety of modifications of the foregoing are within the scope of the invention, although not illustrated herein. Thus, for example, the construction shown in FIG. 2 could be modified by omission of the gear train 116, 117, 118 for the film-rewind mode of operation, in the event no such mode of operation is needed, e.g., in the case of type-110 or -126 cassette films whose cassettes have not only a film supply compartment but a film take-up compartment as well. In such event, the motor 102, unlike the case shown in FIG. 2, of course could not be located in the

film take-up compartment of such cassette, but would instead need to be located at some other place, e.g., alongside the space which accommodates the cassette's take-up compartment. Likewise, instead of the rotary switch **128** described above, which implements motor-direction reversals in reliance upon the motor actually rotating to bring the moving contacts and stationary wipers of switch **128** into and out of engagement with each other, use could instead be made of a set of contacts forming three parallel switches, with the moving contact of such three switches being located in the path of motion of a respective one of the shiftable shafts **121**, **122** and **116**, so that these latter shafts close their associated switches as they respectively move into engagement with the shaft **110**, the shaft **114** and the gear **115***b*. Similarly, in the construction shown in FIG. **1**, the relationships could be reversed, with the objective **8** being motor-driven for its retracting movement, and being manually brought out to its extended, operative position, although such alternative is not presently preferred. As a further example of the various modifications which could be effected, instead of the racks provided on the objective housing or tube use could instead be made of an eccentric drive or a worm drive driven in two opposite directions by the camera's gear train.

It will be understood that each of the elements described above, or two or more together, may also find a useful application in other types of constructions and circuits differing from the types described above.

While the invention has been illustrated and described as embodied in preferred embodiments in which the extension and retraction of the camera objective is derived from the camera's film-transport motor, it is not intended to be limited to the details shown, since various modifications and structural changes may be made without departing in any way from the spirit of the present invention.

Without further analysis, the foregoing will so fully reveal the gist of the present invention that others can, by applying current knowledge, readily adapt it for various applications without omitting features that, from the standpoint of prior art, fairly constitute essential characteristics of the generic or specific aspects of this invention.

What is claimed as new and desired to be protected by Letters Patent is set forth in the appended claims:

1. In a photographic camera of the type having a camera housing and an objective including an objective housing and being mounted for movement between a retracted, inoperative position in which it is retracted into the camera housing for dimensional compactness of the camera and an extended, operative position in which it extends out from the camera, a drive mechanism for driving the objective from one to the other of said positions, the drive mechanism including an electric drive motor and transmission means coupled to the drive motor and to the objective and operative for transmitting motion to the latter from the former, the transmission means including two racks provided on the objective housing, two rack drive gears which engage respective ones of the two racks, and means transmitting motion from the drive motor to both rack drive gears simultaneously, the two racks and the two rack drive gears being so located and dimensioned that when the rack drive gears are driven by the drive motor they apply balanced drive forces to the objective housing.

2. In a photographic camera of the type having a camera housing and an objective mounted for movement between a retracted, inoperative position in which it is retracted into the camera housing for dimensional compactness of the camera and an extended, operative position in which it extends out from the camera, a drive mechanism for driving the objective from one to the other of said positions, the drive mechanism including a reversible rotary electric drive motor and transmission means coupled to the drive motor and to the objective and operative for transmitting motion to the latter from the former, the transmission means comprising at least one unidirectional transmission means operative for transmitting motion from the motor to the objective only when the motor rotates in one respective rotary direction, and the unidirectional transmission means comprising first and second gears, the first gear imparting motion to the objective, the second gear receiving motion from the drive motor, a further intermediate gear driven by the first gear and mounted for movement between a position engaging the second gear and a position not engaging the second gear and biasing means applying to the intermediate gear a biasing force biasing the intermediate gear towards said engaging position thereof, the direction in which the intermediate gear is movable between said positions thereof and the spatial locations of said first and second gears relative to said intermediate gear being such that when the first gear is driven by the drive motor in a first rotary direction the interaction force between said first and intermediate gears permits said biasing force to maintain said intermediate gear engaged with said second gear whereas when the first gear is driven by the drive motor in the opposite rotary direction the interaction force between the first and intermediate gears moves the intermediate gear out of engagement with the second gear against the action of said biasing force.

3. In a photographic camera of the type having a camera housing and an objective mounted for movement between a retracted, inoperative position in which it is retracted into the camera housing for dimensional compactness of the camera and an extended, operative position in which it extends out from the camera, a drive mechanism for driving the objective from one to the other of said positions, the drive mechanism including an electric drive motor and transmission means coupled to the drive motor and to the objective and operative for transmitting motion to the latter from the former, the transmission means including a disengageable coupling and manually activated means for engaging and disengaging the coupling.

4. The camera defined in claim **3**, the objective being provided with an objective housing, the transmission means comprising at least one rack on the objective, the rack extending parallel to the optical axis of the objective, and means engaging the rack and driven by the motor.

5. In a photographic camera of the type having a camera housing and an objective including an objective housing and being mounted for movement between a retracted, inoperative position in which it is retracted into the camera housing for dimensional compactness of the camera and an extended, operative position in which it extends out from the camera, a drive mechanism for driving the objective from one to the other of said positions, the drive mechanism including an electric drive motor and transmission means coupled to the drive motor and to the objective and operative for transmitting motion to the latter from the former, the transmission means being capable of deriving from the

motor either motion which drives the objective to extended position or to retracted position without a change of motor rotation direction and comprising two racks provided on the objective housing located diametrically opposite to each other, two rack drive gears meshing with respective ones of the two racks, two intermediate gears meshing with each other and each coupled to a respective one of the two rack drive gears, each of the two rack drive gears being provided on a respective gear shaft, two drive shafts to respective ones of which the two gear shafts can be coupled, two gears each provided on a respective one of the drive shafts and a further intermediate gear meshing with each of the two gears just mentioned, and manual means for causing one or the other of the two gear shafts to be coupled to the respective one of the two drive shafts.

6. The camera defined in claim **5**, furthermore including two coupling shafts each of which is axially shiftable between a coupling position in which it couples a respective one of the gear shafts to the respective drive shaft and an uncoupling position in which it decouples the respective one of the gear shafts from the respective drive shaft, the manual means comprising a manually operated slider provided with cam portions operative for axially shifting the coupling shafts.

7. The camera defined in claim **6**, the coupling shafts bearing against and being directly cammed by the cam portions.

8. In a photographic camera of the type having a camera housing an an objective mounted for movement between a retracted, inoperative position in which it is retracted into the camera housing for dimensional compactness of the camera and an extended, operative position in which it extends out from the camera, a drive mechanism for driving the objective from one to the other of said positions, the drive mechanism including an electric drive motor and transmission means coupled to the drive motor and to the objective and operative for transmitting motion to the latter from the former, the transmission means including disengageable coupling means coupling the drive motor to the objective.

9. The camera defined in claim **8**, the camera including means guiding photographic film from a supply compartment to a take-up compartment and take-up means rotatable in a predetermined direction for effecting film take-up, the disengageable coupling means comprising means engageable with the objective and with the take-up means.

10. The camera defined in claim **8**, the camera including means guiding photographic film from a supply compartment to a take-up compartment and rewind means rotatable in a predetermined direction for effecting film rewind, the disengageable coupling means comprising means engageable with the objective and with the rewind means.

11. The camera defined in claim **10**, the disengageable coupling means including rewind-action coupling means operable for coupling the rewind means to the objective so that both the rewind means and the objective be simultaneously driven by the drive motor.

12. The camera defined in claim **10**, the transmission including a gear driving the objective, the rewind-action coupling means comprising a gear mounted axially shiftable into and out of engagement with the gear driving the objective.

13. The camera defined in claim **12**, the gear of the rewind-action coupling means being provided on a gear shaft, furthermore including a manually operated slider having a cam portion which cooperates with the gear shaft for axially shifting the latter.

14. In a photographic camera of the type having a camera housing an an objective mounted for movement between a retracted, inoperative position in which it is retracted into the camera housing for dimensiona compactness of the camera and an extended, operative position in which it extends out from the camera, a drive mechanism for driving the objective from one to the other of said positions, the drive mechanism including an electric drive motor and transmission means coupled to the drive motor and to the objective and operative for transmitting motion to the latter from the former, the transmission means including disengageable coupling means capable of coupling the drive motor to the objective irrespective of the rotary direction of the drive motor.

15. In a photographic camera of the type having a camera housing and an objective mounted for movement between a retracted, inoperative position in which it is retracted into the camera housing for dimensional compactness of the camera and an extended, operative position in which it extends out from the camera, a drive mechanism for driving the objective from one to the other of said positions, the drive mechanism including a reversible electric drive motor, and transmission means coupled to the drive motor and to the objective and operative for transmitting motion to the latter from the former; take-up means rotatable in a predetermined direction for effecting film take-up; and a one-way coupling coupling the drive motor to the take-up means to rotate the latter in said predetermined direction when the drive motor rotates in one respective direction, the transmission means including disengageable coupling means for coupling the drive motor to the objective at least when the drive motor rotates in the opposite direction.

16. The camera defined in claim **15**, the transmission means furthermore including manual means for engaging and disengaging the disengageable coupling means, the drive motor being a reversible electric motor, and furthermore including electric motor-direction-reversing switches responsive to operation of said manual means.

17. In a photographic camera of the type having a camera housing and an objective mounted for movement between a retracted, inoperative position in which it is retracted into the camera housing for dimensional compactness of the camera and an extended, operative position in which it extends out from the camera, a drive mechanism for driving the objective from one to the other of said positions, the drive mechanism including an electric drive motor and transmission means coupled to the drive motor and to the objective and operative for transmitting motion to the latter from the former, the transmission means including disengageable coupling means for coupling the drive motor to the objective, the drive motor being a reversible electric motor, and furthermore including electric motor-direction-reversing switches responsive to operation of said manual means.

18. In a photographic camera of the type having a camera housing and an objective mounted for movement between a retracted, inoperative position in which it is retracted into the camera housing for dimensional compactness of the camera and an extended, operative position in which it extends out from the camera, a drive mechanism for driving the objective from one to

the other of said positions, the drive mechanism including an electric drive motor and transmission means coupled to the drive motor and to the objective and operative for transmitting motion to the latter from the former; film transport means operative for effecting forward film transport under the drive action of the drive motor when the latter is operated in a first direction; and two motor-direction control switches of which one is closed to cause the motor to rotate in said first direction and the other to cause the motor to rotate in the opposite second direction, the camera being of the type in which the first direction control switch is closed upon the completion of an exposure to initiate film transport and then reopens after completion of film transport, the transmission means including disengageable coupling means coupling the objective to the drive motor and manual means operable for disengaging and engaging the coupling means, the second motor direction control switch closing in response to at least one predetermined setting of said manual means.

19. In a photographic camera of the type having a camera housing and an objective mounted for movement between a retracted, inoperative position in which it is retracted into the camera housing for dimensional compactness of the camera and an extended, operative position in which it extends out from the camera, a drive mechanism for driving the objective from one to the other of said positions, the drive mechanism including an electric drive motor and transmission means coupled to the drive motor and to the objective and operative for transmitting motion to the latter from the former; a manually operated element having one setting which enables the objective to be moved out to extended position and another setting which enables the objective to be moved inward into retracted position; and blocking means operative when the manually operated element is in said one setting for preventing unintentional retraction of the objective.

20. The camera defined in claim **19**, the blocking means comprising a blocking element and biasing means causing the blocking element to move into a position preventing objective retraction when the manually operated element is in said one setting and means moving the blocking element out of said blocking position when the manually operated element is moved to the other setting thereof.

21. In a photographic camera of the type having a camera housing and an objective mounted for movement between a retracted, inoperative position in which it is retracted into the camera housing for dimensional compactness of the camera and an extended, operative position in which it extends out from the camera, a drive mechanism for driving the objective from one to the other of said positions, the drive mechanism including an electric drive motor and transmission means coupled to the drive motor and to the objective and operative for transmitting motion to the latter from the former; the transmission means including disengageable means disengageable for disengaging the objective from the drive motor; and manual means operable for disengaging the disengageable means and permitting the objective to be moved from one to the other of its positions by hand.

* * * * *

United States Patent [19]

House

[11] **4,255,023**

[45] **Mar. 10, 1981**

[54] **OBJECTIVE RETINAL RESPONSE RECORDER**

[76] Inventor: **Harold D. House,** Suite 1010, Kelly Prof. Bldg., 6565 S. Yale, Tulsa, Okla. 74136

[21] Appl. No.: **11,375**

[22] Filed: **Feb. 12, 1979**

[51] **Int. Cl.**[3] **A61B 3/06**

[52] **U.S. Cl.** **351/24;** 351/36

[58] **Field of Search** 351/24, 39, 23; 351/36

[56] **References Cited**

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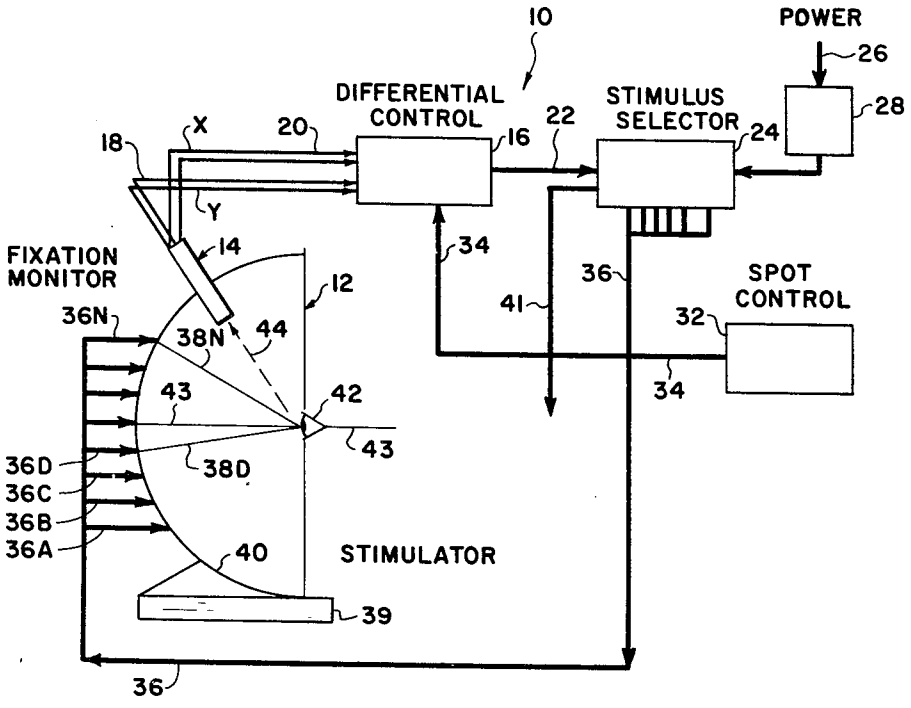
Primary Examiner—Paul A. Sacher

Attorney, Agent, or Firm—Head & Johnson

[57] **ABSTRACT**

A retinal response recorder that is fully automatic, comprises a light stimulator, with means for a patient to position his head, such that his eye is on the horizontal axis of the stimulator. Means are provided for selecting any one of the selected number of light beams directed from the stimulator to the eye of the patient at selected angular positions above and below the horizontal and left to right of the vertical plane through the axis of the stimulator. Appropriate electrodes are positioned on the skin surface of the patient to record electro-muscular potentials generated by the retina of the eye. Means are provided for a prearranged program of selection of stimulator spots. If the eye sees the spot of light a retinal response potential is generated and/or a visually evoked response is generated. These signals, one or both, go to amplifiers with selected filter characteristics, and then to a display-recorder apparatus, so that the magnitude of the response can be determined with regard to the specific position of the spot of light.

15 Claims, 9 Drawing Figures



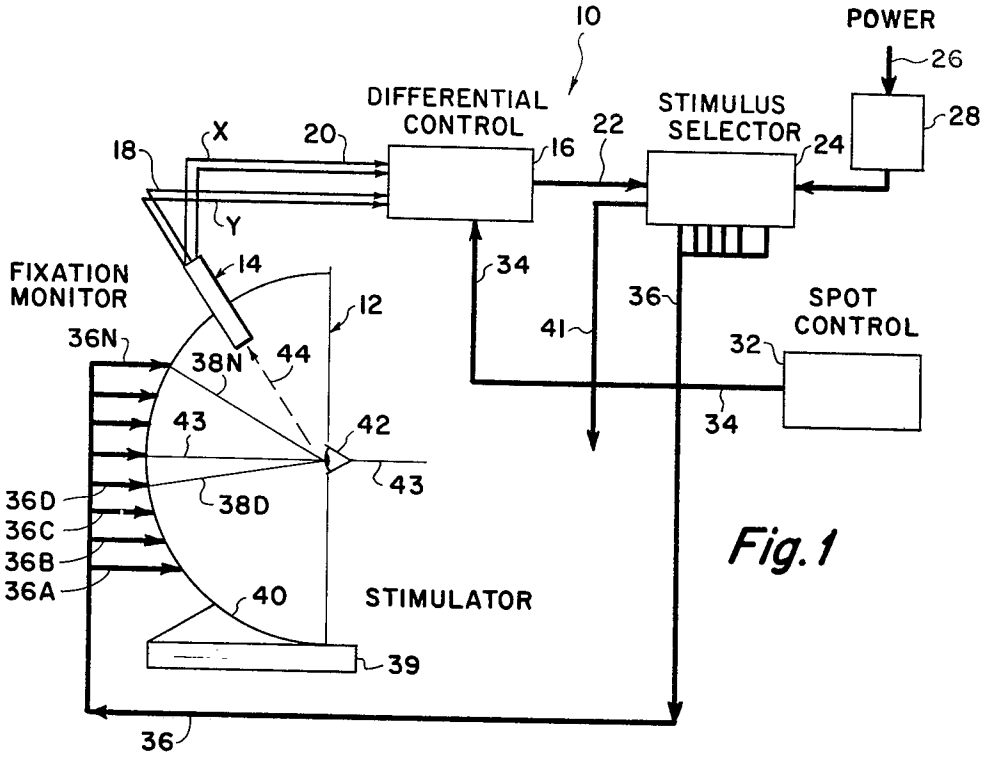


Fig. 1

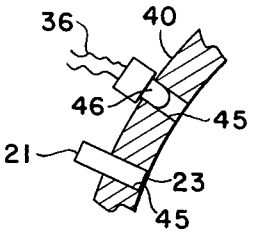


Fig. 1A

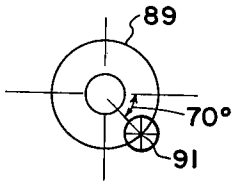


Fig. 1B

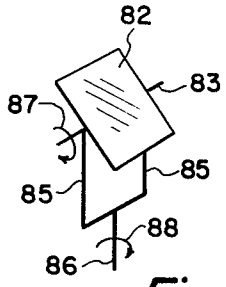


Fig. 4

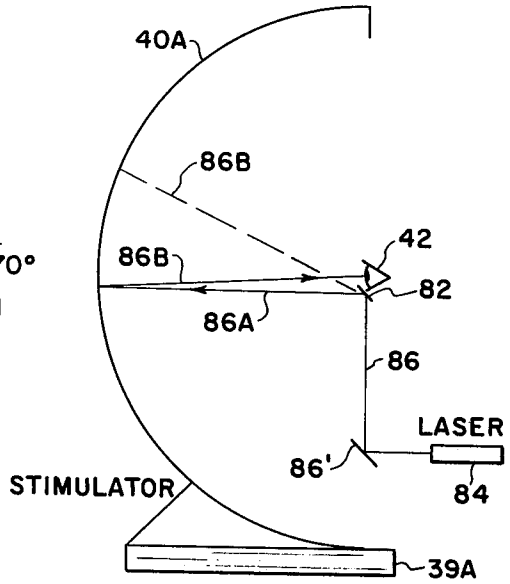


Fig. 3

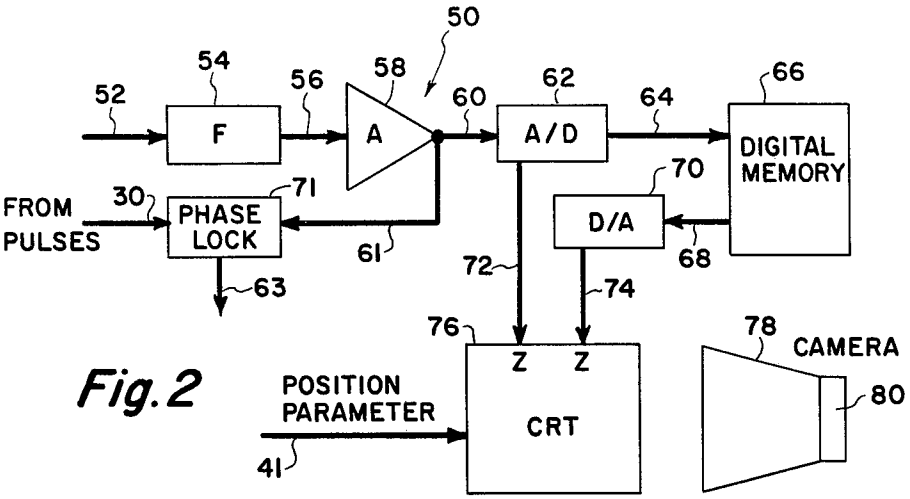


Fig. 2

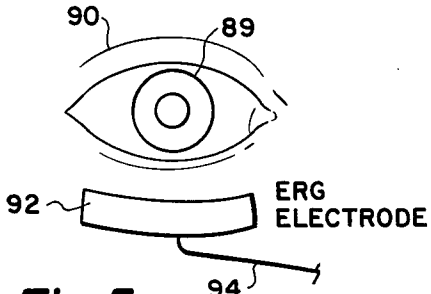


Fig. 5

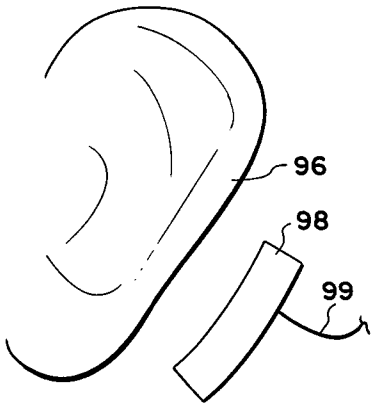


Fig. 6

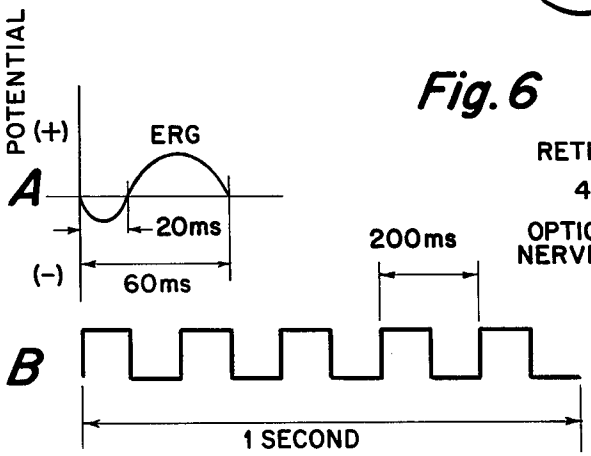


Fig. 7

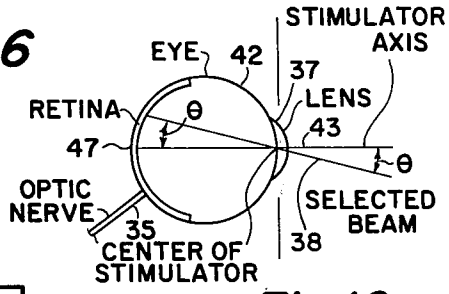


Fig. 1C

OBJECTIVE RETINAL RESPONSE RECORDER

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention lies in the field of study of the human eye. More particularly it concerns a process of determining the physiological condition of the retina of the eye, and of measuring the field of vision of the eye, by entirely objective automatic means irrespective of arbitrary eye movements of the patient.

2. Description of the Prior Art

In the prior art, ophthalmologists have routinely made measurements on the eyes of patients, such as determining the visual field by seating a patient before a blackened board and have a test person move a small whitened sphere along radial lines from the outer extreme of the board toward the central portion, in such a manner that the patient responds when he sees the spot, being cautioned to maintain the eye constantly fixed along the axis of the board. In other cases, semi-automatic stimulators have been used in which a plurality of small lamps are positioned at selected locations on a board or hemisphere. These lights are illuminated momentarily in selected succession and the patient indicates by closing a switch or pressing a button that he does or does not see the spot of light.

Also in the study of the visual process, research personnel have made measurements of the potential generated by the retina in response to a visual stimulus. These measurements have been made at various positions on the face and forehead of the patient by means of thin metal electrodes which are attached to the skin surface.

There are two particular types of potentials which are measured, namely, the electro-retinal potential and the visual evoked response.

These and other measurements can be made on the apparatus of this invention by the use of suitably placed electrodes, as are well known in the art.

SUMMARY OF THE INVENTION

It is the primary object of this invention to provide an electronic apparatus which is fully automatic, and on a prearranged program can provide any one of a plurality of separate light beams projected into the eye of the patient, at selected angles, with appropriate measurements being made of the visual evoked response (VER), and the electro-retinal potential (ERP), or other types of electrical measurements, which in one way or another may be responsive to the process of recognition by the eye and the brain of the optical stimuli.

It is a further object of this invention to provide means to digitize and make amplitude measurements on these potentials, and to display these potentials as a function of angular position of the stimulus spot with respect to the axis of the stimulator and to the axis of the eye so that a record may be made for future comparison.

These and other objects are realized and the limitations of the prior art are overcome in this invention by providing an apparatus which includes specific elements, including an optical spot stimulator, an eye fixation monitor, a spot control memory means which can produce a series of address locations which can be selected sequentially, or at random, to mark the location of successive light stimuli, In response to the output of the spot control memory, a selection is made in a stimulus selector of an individual electric lamp, or optical beam, at the selected angle with respect to the axis of the stimulator, and the optical axis of the eye of the patient.

By means of the eye fixation monitor and the crossed pairs of photocells, even though the eye of the patient may wander from the optical axis of the stimulator, the actual position of the eye in angular coordinates, or other incremental measurements, can be observed, and the selection of the beams from the stimulator can be modified so that the actual position of the beam in the stimulator is modified by the differential movement of the eye, as observed by the fixation monitor, so that the direction of passage of the light beam through the lens to the retina will be in the precisely desired direction. Several types of automatically positioned light beams will be described.

Means are provided to take the potentials observed on the electrodes attached to the surface of the skin, and to filter, amplify, determine the amplitude of the response, digitize the wave shape of the response if desired, and to display on a cathode ray tube or other display/record means at a position which corresponds to the angular or rectangular position of the beam of the stimulator. Conventional means are provided for placing a camera and camera hood, over the cathode ray tube, in order to record the positions of the spots, and some parameter of the response to the light, at those specific locations.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other objects and advantages of this invention and a better understanding of the principles and details of the invention will be evident from the following description taken in conjunction with the appended drawings in which:

FIG. **1** represents in block diagram form, one embodiment of an apparatus for stimulating the eye of a patient with a preselected sequence of angular beams.

FIGS. **1A**, **1B** and **1C** illustrate further details of the stimulator.

FIG. **2** illustrates in block diagram form the amplifying, processing, and display features of one embodiment of this invention.

FIG. **3** illustrates an alternative design of stimulator.

FIG. **4** illustrates a detail of FIG. **3**.

FIGS. **5** and **6** illustrate two methods of applying electrodes for measuring the evoked potentials.

FIG. **7** illustrates a manner in which the stimulated light beam can be modulated to provide an improved potential response curve for the ERG.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to the drawings and in particular to FIGS. **1**, **1A**, **1B** and **1C**, there is illustrated in FIG. **1C** a simple model of the eye indicated by the numeral **42**, with a lens **37** on the front of the eyeball and a retina **47** which covers a selected angular area of the back inside wall of the eye. An optic nerve **35** departs from the eyeball and the retina at a selected angle. The horizontal axis of the eye and of the stimulator is indicated by the numeral **43**. A selected stimulator light beam **38** is shown at an angle to the optical axis of the stimulator and of the eye.

In the testing of the retina it is important that the condition of the eye at each small area of the retina must be measured separately from each of the other areas.

Thus the eye must be held as closely as possible at a position so that the eye is on the axis of the stimulator, and the axis of the eye is directed constantly to the point of intersection of this axis and the wall of the stimulator. If the eye can be maintained in that position, then as different light beams are produced at known angles to the axis **43**, then the exact position of the inpingement of the light beam on the retina is also known and the response can be plotted as a function of the coordinates of the retina.

However, it is difficult for a patient to maintain the eye beam directed constantly at the axis of the stimulator, and there is a tendency for it to move up or down, or sideways, through some small angle. This variability of the position of the eye is determined by measurement on the eye, by means of a fixation monitor. The output reading of that monitor in terms of a voltage, which is a function of the angular movement of the eye away from axis **43** is then used to correct the selected position of the beam being generated by the stimulator, so that the point of impingement of the light beam on the retina will be the prescribed angle, that the beam would have reached if the eye had not wandered from the axis of the stimulator.

FIG. **1** illustrates schmetically the apparatus that produces the desired optical beams in a selected sequence. One type of stimulator is shown in FIG. **1**. This has a hemispherical shell, indicated generally by the numeral **12**, the spherical surface **40** is blackened inside, and has a plurality of small openings **45** (FIG. **1A**) through the wall, into which appropriate small lamps **46** can be inserted. The diameter of the hole and of the lamp is such that the angle subtended at the center of the hemisphere will be one second of arc. Thus the corresponding lighted area of the retina likewise will be one second of an arc, which has been selected as a standard unit area for examination of the retina.

There are a network of conductors **36A**, **36B**, **36C** . . . **36N** which are carried, and the lines **36**, from a stimulus selector **24**, which will be described in detail later. A spot control memory **32** comprises a paper tape reader, or equivalent memory source, such that by selecively moving from one address to another, the coordinates of the selected lamp attached to the wires **36** will be chosen by the stimulus selector **24**, in response to the address provided over leads **34** from the spot control memory. The selector **24** will switch in the proper lamp **36A** over the leads **36** so that a beam will then originate from the lamp, say **36D** for sample, to the eye **42** positioned on the axis **43** of the hemisphere **40**.

Appropriate means may be provided on the stimulator **40** such as resting the chin on an adjustable support, and holding the head in a specified position so that the beam which is relatively narrow in breadth, will pass through the center of the lens of the eye, at the proper angle, and on to the retina.

The fixation monitor **14** is a commercial device which comprises a microscope, which receives light from the eye over dashed line **44**, and magnifies the image of the eye. By means of two pairs of crossed photocells it can determine the movement of the eye, over a selected angular range. The output of the fixation monitor is provided by two pairs of leads **18** and **20** which represent, for example, the Y axis movement and the X axis movement of the eye relative to the axis **43** of the stimulator and of the eye.

The output of the spot control memory **32**, for any given address may be in any desired form. In one form it can be two voltages, an X voltage and a Y voltage. These go by lead **34** to a differential control **16**. There are means for adding to the X and Y values on line **34**, the X′ and Y′ values on lines **20** and **18**, in a proper algebraic manner, to provide an output signal on leads **22**, which provide the sum of the two values of $X+X'=X''$ and $Y+Y'=Y''$. This controls a stimulus selector to move or switch to another spot, such that the position of the image of the light spot on the retina will be at the true angular position X and Y desired.

Power for the output of the stimulator, that is, power to the lamps on leads **36**, is provided over leads **26**, and may for example go through a pulser switch **28**, and through leads **30** to the selector. The purpose of the pulser **28** is to provide a sequence of pulses such as shown for example in Part B of FIG. **7**, where a sequence of five or more square wave pulses of light are provided, each pulse of light say 100 milliseconds in duration, for example, and each space another 100 milliseconds. Thus the whole sequence may operate for a second or for several seconds. It is then possible to determine from the received signal what the component of signal there may be that has a periodicity, or frequency, equal to that of the imposed light pulsations. That portion of the signal picked up at the electrodes on the skin of the patient, which has this desired periodicity, can then be verified as a true signal, which is responsive to the light generated by the stimulator, and not a noise.

Referring now to FIG. **1A** there is shown a small portion of the wall **40** of the hemisphere stimulator, and a pair of openings **45** of selected diameter drilled through the wall. In one of them, a lamp **46** is inserted which is supplied with current by leads **36**. The diameter of the opening **45** is such that at the radius of the sphere **40**, is subtends at angle of 1°.

In FIG. **1B** is shown a portion of the eye in which the iris and the shaded portion of the eye, known as the limbus are shown. There is a circumferential line **89** marking the outer edge of the limbus against the white area of the eye. At a point on the perimeter **89** which is approximately 70° down from the horizontal the fixation monitor is focused with the cross-hairs, or crossed photocells **91** positioned with their axes horizontal and vertical. As they eye moves and the edge of the limbus **89** moves up or down or sideways, voltages will be generated in the photocells such that on the leads **18** and **20** they will represent the actual displacement in the X and Y directions with reference to the point **91**, the point of fixation of the monitor.

While there are many ways in which the stimulator can be built one of these has been shown in FIG. **1** which comprises a plurality of separate lamps, which are switched in, sequentially. These lamps are positioned in a grid, of selected design, either measured in angle radiating out from the axis, and angles of rotation between vertical and horizontal, for example, or they can be positioned in a selected rectangular grid of any desired spacing, for example.

Shown in FIGS. **3** and **4** is another embodiment in which the stimulator can be a hemisphere **40A**, as compared to the hemisphere **40** in FIG. **1**. At the position just below the eye, is a mirror **82** which receives light from a laser **84** of, selected intensity, which goes by way of mirror **86′** and beam **86**, to the mirror **82** and then by beam **86A** to the wall of the hemisphere **40A**, where it impinges upon a metal plug **21** (FIG. **1A**) inserted into the opening **45**. The front face **23** of the plug is a

brightly polished metal surface, which reflects the light backwardly to the eye **42** of the patient. In other words by rotating the mirror in azimuth and elevation, the light beam **86A** can be made to contact any one of the plurality of plugs **21**, at fixed desired locations in the shell **40A** and the light will then be reflected back to the eye at substantially the desired angle.

By referring to FIG. **4** there is shown schematically a type of small mirror **82** that has a horizontal axis **83** that can rotate in the direction of arrow **87**. The axis **83** is supported in a yoke with two upright arms **85** and a central vertical arm **86**, which is set in bearings (not shown) such that it can rotate the entire assembly in accordance with arrow **88**. Thus by driving the mirror and the yoke about the two axes **83** and **86**, by selected angular increments such as by step motors or servo motors, for example, in the well known manner, the beam can be positioned to any selected angle in azimuth or in elevation, with respect to the axis **43** of the hemisphere.

As previously stated, the apparatus consists of two essential parts. The first is an apparatus for producing a spot of light at a selected location on the wall of a hemisphere, for example, at selected angular location with respect to the axis of an eye positioned at the center of the hemisphere. This can be accomplished in many ways.

The feature that is very important in an automatic machine is to provide the fixation monitor **14** to provide adequate signs for the measurement of any deviation of the axis of the eye from the axis of the stimulator, so that the position of the light spot can be varied, such that with the known displacement of the eye the resultant angle of the image of the spot on the retina will be at the desired angular position, irrespective of how much the eye has drifted from its proper axial direction.

In order to make this apparatus fully objective and automatic it remains then to provide a means for generating a potential which is a function of the reception of the light spot signal to the retina, and to amplify and process this signal, to determine its validity, that is, to determine whether that signal is due to the light spot of the stimulator or is due to some other noise source, and so on. One way of determining the validity of the signal, as has been discussed, is by using a pulsating light spot and to search in the produced evoked response for that frequency of signal, and to display and record that particular component of the signal, the understanding being that any other electrical signal is a noise and should be disregarded.

Referring now to FIG. **2** there is shown one type of detecting and processing apparatus. This comprises an input lead **52** from one or another of a group of electrodes, which can be attached to the face and head of the patient. The purpose of amplifying and processing the signal, is to infer from the character of that potential, what the condition of the retina is, and what physiological problems may be present in the retina, the optic nerve or the brain for example. As will be explained in connection with FIGS. **5** and **6** there are a number of possible positions to place electrodes, and the potential of these electrodes will arrive on lead **52** from the electrode.

The received signal may pass through a filter **54** of selected band pass. The filter can of course be equivalent to a phase lock means **71** driven by the pulsing frequency of the current **28** that powers the light spot, or any other filtering apparatus. The filtered signal then goes by line **56** to a high-gain, low-noise amplifier **58**, of which a number of examples are available on the market. These would be the equivalent of electroencephalograph type amplifiers, and so on. The amplified output then may go to an analog to digital (A/D) converter **62**, where the particular wave shape of the evoked potential is digitized, and is stored in a digital memory **66**.

Reference is made to part A of FIG. **7** where there is shown a sample wave shape representing the electro-retinal potential, which occurs whenever a light is suddenly received on the retina. This wave form lasts about 60 milliseconds, and then drops to 0, and remains at 0 even though the light stimulus may still be on the eye. Such a wave form as this would be digitized, and of course its amplitude thereby determined, and its wave shape stored in the digital memory **66**. This can always be withdrawn from the memory over lead **68** to a digital-to-analog (D/A) converter **70**, and then over lead **74**, can be displayed on a cathode ray tube, as is well known in the art. Alternatively the potential brought in on lead **52** and after amplification delivered on lead **60**, can then be brought over lead **72** to the cathode ray tube. These would go to the Z axis of the tube in order to produce a spot of a selected brilliance, which would be some function of the observed voltage, for example, as might be the case for a visual evoked response measurement (VER) of the eye.

The cathode ray tube **76** would have input on leads **41** corresponding to the angular position of the light spot in the stimulus selector **24**, so that the spot which is presented on the cathode ray tube will be positioned at the coordinates X and Y in accordance with the precise angular position of the image of the spot on the retina of the patient.

The type of amplifying, filtering, processing and display apparatus illustrated in FIG. **2** is only by way of example, and other equivalent types of display can, of course, be utilized. The particular display apparatus also will vary with the type of coordinates of the stimulus light beams, whether generated by the lamps as in FIG. **1** or by the laser beam in FIG. **3**. Of course, if a different type of stimulator, with a plane board is used as the surface, then some combination of rectangular and polar coordinates may be required. As is well known, a camera **80** with a hood **78** placed over the cathode ray tube **76**, can be used for making a permanent record of the response of the eye at each of the stimulus positions.

Also shown in FIG. **2** is a lead **61** taken from the amplifier **58** and a corresponding lead **30** from the pulser **28** of FIG. **1**, to a phase lock device **71**, such that an output on lead **63** would indicate that the evoked response shows the pulsation frequency of the light stimulus provided, which would be verification that the measurement is a valid measurement of the eye.

In FIGS. **5** and **6** are shown two of many ways in which electrodes can be attached to the skin of the patient, on the face, forehead or scalp, in order to detect electrical potentials, which can be proven to be functions of the response of the retina, or optic nerve, or of the brain, in the processing of electrical signals from the retina. The ERG, or electro-retinal potential, it has been found, can be picked up readily by means of a thin metal plating on a flexible strip of plastic **92**, to which is attached a silver wire lead **94**, which goes to the line **52** of FIG. **2**. This strip **92** is attached to the skin surface by means of adhesive tape placed over it in a manner similar to that by which electrodes are attached to the scalp for purposes of EEG measurement, for example. They

are placed just below the lower lid of the eye **90** shown in FIG. **5**. They can be placed at other positions also.

The VER potential or visual evoked response potential, can be detected by means of a similar silvered plastic strip **98** FIG. **6**, which is positioned on the bony structure immediately behind the lower part of the ear. This potential is taken off by means of a silver wire **99**, for example, to lead **52**. The art of positioning these electrodes forms no part of this invention, and is well known in the art of medical testing.

Not shown but well known in the art is the manner in which electrodes may be attached to the scalp to indicate the response of certain areas of the brain, and in the same way that the ERG and VER potentials are utilized, the potential generated on the scalp electrodes can likewise be used for the same purpose.

Whereas, the present invention has been described in particular relation to the drawings attached hereto, other and further modifications apart from those shown or suggested herein may be made within the spirit and scope of the invention.

What is claimed is:

1. In an apparatus for making a non-manual, objective retinal response display, responsive to light stimulus to a human eye; an improved apparatus for providing a selected light stimulus, at selected positions relative to the retinal axis, comprising;

(a) stimulator means comprising means to supply, on command, a selected one, of a selected plurality of possible beams of light, each positioned so as to enter the lens of an eye of a patient positioned on the axis of said stimulator, at a difficult selected angle to the axis of said stimulator; and means to position the eye of a patient on the axis of said stimulator means;

(b) machine readable spot control memory means for storing in selected order each of the position parameters of said selected plurality of beams of light; and

(c) in which said selected beams of light are produced by means of small reflecting surfaces positioned at selected locations on the surface of said stimulator, and a focused beam of light reflected from a small mirror near the axis of said stimulator adapted to be rotated selectively about two perpendicular axes.

2. The apparatus as in claim **1** including display/record means for displaying the position parameters of said selected beam of light.

3. The apparatus as in claim **1** including;

(a) eye fixation monitor means, and means to direct the optical axis of said fixation monitor means to a selected point on said eye of said patient;

(b) output means from said fixation monitor means for providing;

(1) a first electrical signal responsive to the movement of said eye in the X direction;

(2) a second electrical signal responsive to the movement of said eye in the Y direction.

4. The apparatus as in claim **3** including differential positioning control means, responsive to said machine readable spot control memory means, for supplying to said selector means, a modified position parameter signal, comprising the sum of said recorded selected position parameter from said memory, plus said first and second electrical signals; whereby the actual angle of approach of said selected beam of light to the axis of said eye, will be the same as that which would be supplied by said selected position parameter, if the eye had not moved.

5. The apparatus as in claim **1** including means to modulate said selected one of said selected plurality of beams of light.

6. The apparatus as in claim **5** in which said modulation is amplitude modulation at a constant frequency; and including means to record said constant frequency.

7. The apparatus as in claim **5** in which said modulation is amplitude modulation at a variable frequency; and including means to record said variable frequency.

8. The apparatus as in claim **2** including:

(a) electrode means attached to the skin of said patient at a selected position; whereby a third electrical signal will be produced which is responsive to the passage of said selected beam of light to a selected portion of the retina of said eye of said patient; and

(b) means to utilize said third electrical signal.

9. The apparatus as in claim **8** in which said means to utilize includes means to determine the amplitude of said third electrical signal.

10. The apparatus as in claim **8** in which said means to utilize comprises means to digitize and store said third electrical signal.

11. The apparatus as in claim **8** in which said means to utilize comprises means to display/record said third signal in association with said position parameters of said selected beam of light.

12. The apparatus as in claim **8** in which said electrode means is attached to the skin below the lower lid of the eye; whereby said third electrical signal is the electro-retinogram (ERG) of the eye.

13. The apparatus as in claim **8** in which said electrode is attached to the skin behind the lower part of the ear; whereby said third electrical signal is the visual evoked response (VER) of the eye.

14. The apparatus as in claim **8** in which said electrode is attached to the scalp; whereby said third electrical signal is an EEG.

15. The apparatus as in claim **1** in which said focused beam of light comprises a laser beam of selected frequency.

* * * * *

NOOR2 OR 4,240,705

United States Patent [19]

Fujibayashi

[11] 4,240,705

[45] Dec. 23, 1980

[54] **FIVE ELEMENT PHOTOGRAPHIC OBJECTIVE**

[75] Inventor: **Kazuo Fujibayashi**, Yokohama, Japan

[73] Assignee: **Canon Kabushiki Kaisha**, Tokyo, Japan

[21] Appl. No.: **943,615**

[22] Filed: **Sep. 19, 1978**

[30] **Foreign Application Priority Data**

Sep. 22, 1977 [JP] Japan 52/114165

[51] **Int. Cl.**[3] **G02B 9/34**

[52] **U.S. Cl.** **350/220**

[58] **Field of Search** 350/220, 176

[56] **References Cited**

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1,888,156	11/1932	Brelicke	350/220
3,011,401	12/1961	Sandback	350/220 X

Primary Examiner—Paul A. Sacher

Attorney, Agent, or Firm—Toren, McGeady and Stanger

[57] **ABSTRACT**

An objective of the expanded Tessar type is disclosed. Five elements form four components of which the first counting from the front is positive and convex toward the front, the second is a bi-concave lens, the third is a positive doublet consisting of a negative lens element and a bi-convex lens element cemented together at their adjoining surfaces, and the fourth is a bi-convex lens. The objective fulfills the following conditions:

$$0.55 < \left| \frac{R_8}{R_9} \right| < 1.4, \text{ where } R_9 < 0 \quad (1)$$

$$D_4 < 0.056f \quad (2)$$

$$0.08 < N_1 - N_2 \quad (3)$$

$$0.16f < D_5 + D_6 < 0.21f \quad (4)$$

$$\frac{0.08}{f} \leqq \frac{N_4 - N_3}{R_6} < \frac{0.3}{f} \quad (5)$$

$$0.48f < |R_3| < 0.62f, \text{ where } R_3 < 0 \quad (6)$$

wherein f is the focal length of the entire lens system; Ri is the radius of curvature of the i-th surface counting from the front; Di is the axial thickness of the i-th glass or air lens element; and Ni is the refractive index of the material of the i-th lens element.

4 Claims, 12 Drawing Figures

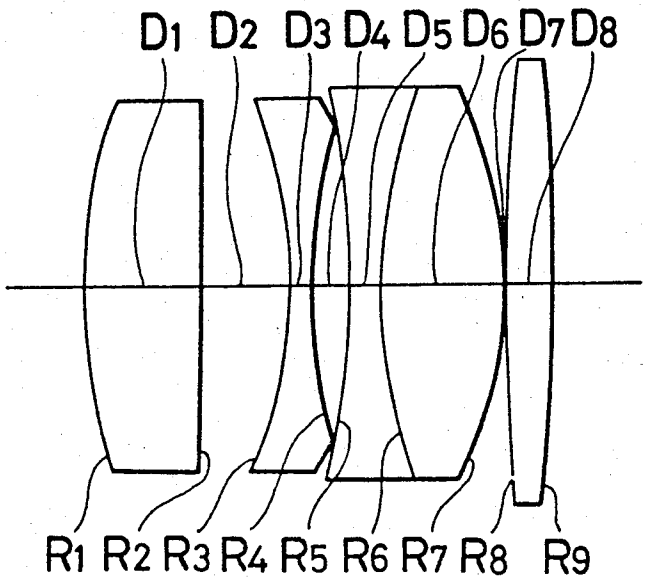


FIG.1

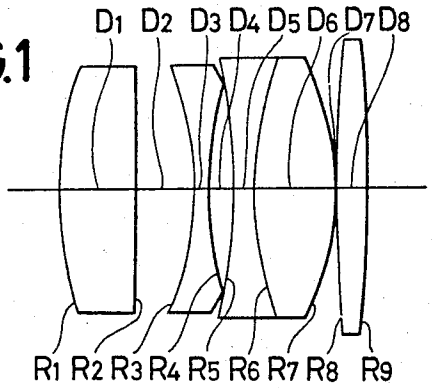


FIG.2

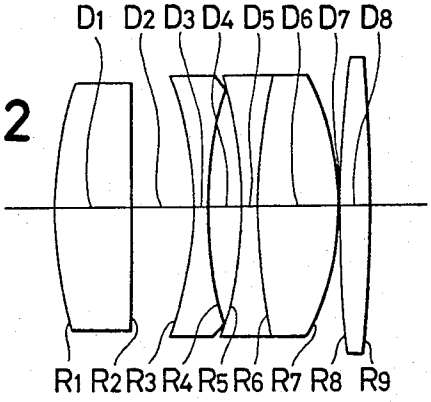


FIG.3

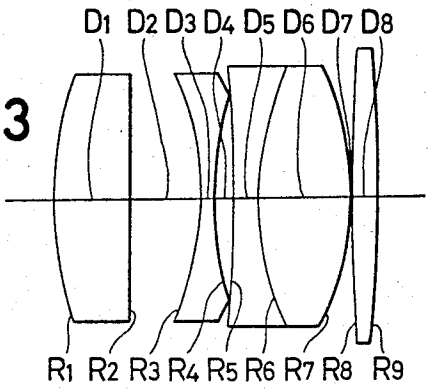


FIG.4A

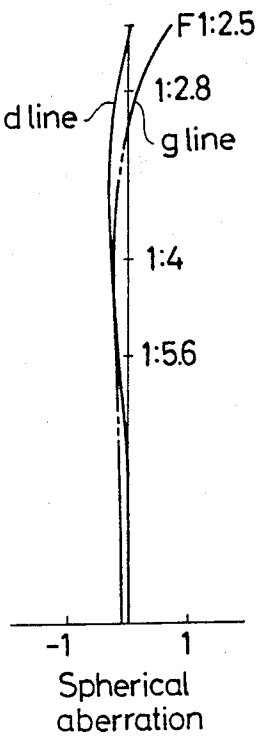


FIG.4B

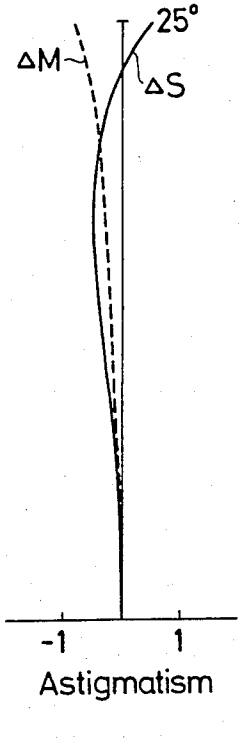


FIG.4C

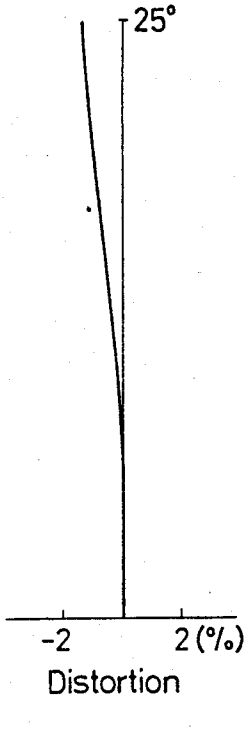


FIG.5A

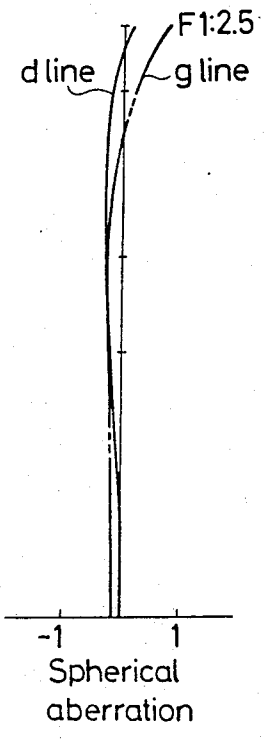


FIG.5B

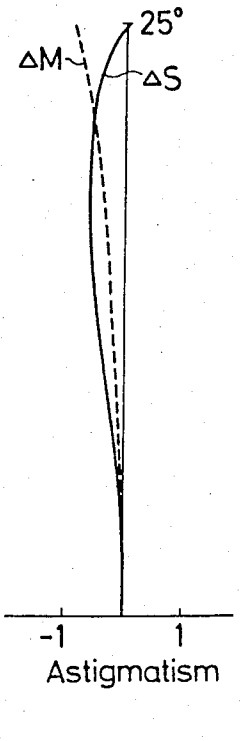


FIG.5C

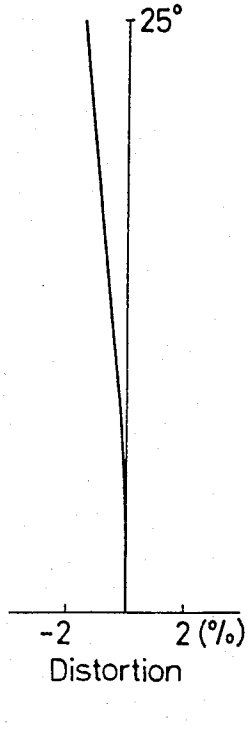
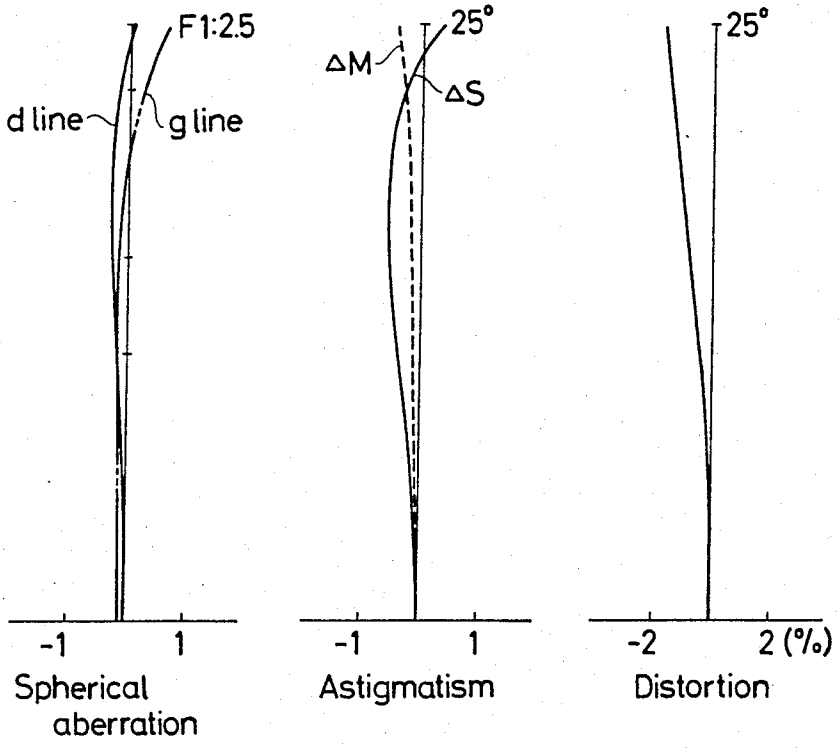


FIG.6A FIG.6B FIG.6C



FIVE ELEMENT PHOTOGRAPHIC OBJECTIVE

BACKGROUND OF THE INVENTION

This invention relates to photographic objectives and more particularly to objectives of standard or quasi-standard field angle.

Triplet objectives of the Tessar type, though widely having used in photographic devices tend to exhibit large longitudinal deviation from an ideal image field in the sagittal plane. At the same time, their astigmatism is quite large.

Various proposals for improving the aberrations of the Tessar type objectives have been made. One of these proposals, disclosed in U.S. Pat. No. 3,011,401 makes use of an additional lens element of bi-convex form positioned at the rear of the objective. With this Tessar type of objective system it is quite difficult to achieve a good compromise between the requirements of increasing the back focal length and of minimizing the various aberrations. Another proposed system is disclosed in Japanese Patent Application Laid-Open No.Sho 51-143326 where the additional lens element is in the form of a positive meniscus lens.

SUMMARY OF THE INVENTION

An object of the present invention is to provide an objective lens system of the expanded Tessar type having a standard or quasi-standard field angle.

Another object of the invention is to provide the objective lens system of the type described with a long back focal length suited for use with a single lens reflex camera, while simultaneously minimizing increases in dimensions of the entire system particularly in the axial direction.

A further object of the invention is to provide an improved objective lens system of the type described in which the positive supplemental lens at the rear of the Tessar type objective is utilized for facilitating flatness of the image field throughout an included angle of more than 50° and in which the image field curvature is corrected to a minimum and the astigmatism reduced by a front group of the Tessar type with a suitable arrangement and choice of glass materials.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an axial sectional view of a first embodiment of an objective lens system according to the present invention.

FIG. 2 is a similar view showing a second embodiment of the invention.

FIG. 3 is a similar view showing a third embodiment of the invention.

FIGS. 4A to 4C are graphic representations of spherical aberrations for the d line and g line of the sodium spectrum, astigmatism with the sagittal and meridional fans, and distortion of the lens of FIG. 1, respectively.

FIGS. 5A to 5C are similar representations concerning the lens of FIG. 2.

FIGS. 6A to 6C are similar representations concerning the lens of FIG. 3.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to FIGS. 1 to 3, the objective lens system of the present invention comprises a triplet objective of the Tessar type followed by a positive lens element in bi-convex form. The triplet comprises, from front to rear, a positive first lens with the front surface convex toward the front, a second lens of bi-concave configuration and a positive third lens which is a doublet consisting of a negative lens element and a bi-convex lens element cemented together at their adjoining surfaces.

The system of the invention fulfills the following requirements:

$$0.55 < \left| \frac{R_8}{R_9} \right| < 1.4, \text{ where } R_9 < 0 \quad (1)$$

$$D_4 < 0.056f \quad (2)$$

$$0.08 < N_1 - N_2 \quad (3)$$

$$0.16f < D_5 + D_6 < 0.21f \quad (4)$$

$$\frac{0.08}{f} \leqq \frac{N_4 - N_3}{R_6} < \frac{0.3}{f} \quad (5)$$

$$0.48f < |R_3| < 0.62f, \text{ where } R_3 < 0 \quad (6)$$

wherein f is the focal length of the entire system; R_8 and R_9 are the radii of curvature of the front and rear surfaces of the fifth or supplementary lens element respectively; D_4 is the axial air separation between the bi-concave lens and the doublet; N_1 and N_2 are the indices of refraction of glasses from which the first and second elements are made up; D_5 and D_6 are the axial thicknesses of the elements in the doublet respectively; N_3 and N_4 are the indices of refraction of the elements in the doublet; R_6 is the radius of curvature of the cemented surface; and R_3 is the radius of curvature of the front surface of the bi-concave lens element.

The requirement (1) represents the configuration of the surfaces of the rearmost positive lens element set forth to assist in bringing the image plane to a flatness in good balance. When the upper and lower limits of the range are violated, the image plane is over- and under-corrected at the marginal and intermediate zones respectively.

Statement (2) defines the axial air separation between the second and third components. This plays an important part in controlling halo produced in the sagittal light beam by the second component or bi-concave lens. When this limit is exceeded, the sagittal halo becomes extremely large.

The requirement (3) represents the difference between the refractive indices of the positive first and negative second lenses, which, when below 0.08, leads to substantial enlargement of the longitudinal deviations for the position of the sagittal image points.

Statement (4) defines the axial thickness of the doublet. This most seriously affects coma and astigmatism. When the upper limit is exceeded, the outward coma becomes extremely large. When the lower limit is exceeded, the substantial astigmatism appears in the picture field.

The requirement (5) represents the refractive power of the adjoining surfaces of the lenses of the doublet, and affects field curvature, astigmatism and coma aberration.

When the upper limit is exceeded, a large amount of coma is produced. When the lower limit is exceeded, good correction for field curvature and astigmatism becomes difficult to achieve.

The requirement (6) serves for minimizing the increase in dimensions of the system as the back focal length is increased while simultaneously achieving good correction of image field. When the lower limit is exceeded, large flare is produced. When the upper limit is exceeded, it becomes difficult to correct the image field while keeping the size of the system to a minimum.

Three examples of specific objective lens systems each having a large relative aperture of 1:2.5 with a total field angle of 50°, a back focal length of 0.8 f or more, and a total longitudinal length of less than 1.44 f measured from the front to the rear vertex can be constructed in accordance with the numerical data given in the following tables for the radii of curvature, R, the axial separations, D, between the successive surfaces along with the indices of refraction, Nd, for the d line of the sodium spectrum and the Abbe numbers, νd, for the various lens elements.

EXAMPLE 1

Focal length f = 100 F-number: 2.5 2ω = 50°				
	R	D	Nd	νd
1	66.915	12.98	$N_1 = 1.757$	$\nu_1 = 47.9$
2	−895.23	9.98		
3	−53.799	2.63	$N_2 = 1.62588$	$\nu_2 = 35.7$
4	68.239	4.05		
5	−93.639	3.94	$N_3 = 1.64769$	$\mu_3 = 33.8$
6	62.153	13.63	$N_4 = 1.7725$	$\nu_4 = 49.6$
7	−50.319	0.44		
8	301.84	5.19	$N_5 = 1.7859$	$\nu_5 = 44.2$
9	−301.84			

ΣD = 52.84
b.f = 87.32 (Back Focal Length)
$R_8/R_9 = -1$
$N_1 - N_2 = 0.131$
$D_5 + D_6 = 17.57$
$(N_4 - N_3)/R_6 = 0.0020$

3rd-order Aberration Coefficient					
	Spherical Aberration	Coma	Astigmatism	Petzval Sum	Distortion
1	0.811937	0.451674	0.251262	0.642166	0.497006
2	1.316481	−1.143061	0.992485	0.047999	−0.903421
3	−6.284365	2.295920	−0.838788	−0.713633	0.567159
4	−1.107707	−1.019213	−0.937789	−0.562622	−1.380545
5	0.010476	−0.028787	0.079107	−0.418680	0.933144
6	0.881258	0.531371	0.320400	0.068576	0.234540
7	3.892209	−0.580501	0.086579	0.863828	−0.141748
8	−0.016084	0.067833	−0.286087	0.145405	0.593325
9	1.096741	−0.56553	0.291637	0.145405	−0.225368
Total	0.600948	0.009682	−0.041194	0.218445	0.174094

EXAMPLE 2

Focal length f = 100 F-number: 2.5 2ω = 50°				
	R	D	Nd	νd
1	70.336	13	$N_1 = 1.804$	$\nu_1 = 46.6$
2	−1736.6	10.35		
3	−60.	2.67	$N_2 = 1.64769$	$\nu_2 = 33.8$
4	79.774	5.51		
5	−79.674	3	$N_3 = 1.68893$	$\nu_3 = 31.1$
6	100	13.69	$N_4 = 1.7725$	$\nu_4 = 49.6$
7	−50.551	0.44		
8	200	5.03	$N_5 = 1.8061$	$\nu_5 = 40.9$
9	−335.99			

ΣD = 53.69
b.f = 87.37
$R_8/R_9 = -0.595$
$N_1 - N_2 = 0.156$
$D_5 + D_6 = 16.69$
$(N_4 - N_3)/R_6 = 0.0008$

EXAMPLE 3

Focal length f = 100 F-number: 2.5 2ω = 50°				
	R	D	Nd	νd
1	70.989	12.96	$N_1 = 1.735$	$\nu_1 = 49.8$
2	−2734	12.04		
3	−50	2.67	$N_2 = 1.6398$	$\mu_2 = 34.5$
4	67.524	2.87		
5	−236.22	4.44	$N_3 = 1.62004$	$\nu_3 = 36.3$
6	53.333	15.56	$N_4 = 1.7725$	$\nu_4 = 49.6$
7	−51.493	0.44		
8	488.89	4.2	$N_5 = 1.7859$	$\nu_5 = 44.2$
9	−364.83			

ΣD = 55.18
b.f = 87.79
$R_8/R_9 = -1.34$
$N_1 - N_2 = 0.098$
$D_5 + D_6 = 20$
$(N_4 - N_3)/R_6 = 0.0029$

What is claimed is:

1. An objective lens system comprising, from front to rear, a positive first lens with the front surface convex toward the front, a bi-concave second lens, a positive third lens consisting of a negative element and a bi-convex lens element cemented together at their adjoining surface, and a bi-convex fourth lens, and fulfilling the following requirements:

$$0.595 \leqq |R_8| / |R_9| < 1.34, \text{ where } R_9 < 0 \quad (1)$$
$$0.0287f \leqq D_4 \leqq 0.0551f \quad (2)$$
$$0.095 \leqq N_1 - N_2 \leqq 0.156 \quad (3)$$
$$0.1669f \leqq D_5 + D_6 \leqq 0.20f \quad (4)$$
$$\frac{0.08}{f} \leqq \frac{N_4 - N_3}{R_6} \leqq \frac{0.29}{f} \quad (5)$$
$$0.5f \leqq |R_3| \leqq 0.53799f, \text{ where } R_3 < 0 \quad (6)$$

wherein f is the focal length of the entire lens system; Ri is the radius of curvature of the i-th surface counting from the front; Di is the i-th axial thickness or air separation; and Ni is the index of refraction of the i-th lens element.

2. An objective lens system according to claim 1, wherein the characteristics of the lens elements and their spatial relationship to each other are substantially as indicated below:

Focal length f = 100 F-number: 2.5 2ω = 50°				
	R	D	Nd	νd
1	66.915	12.98	$N_1 = 1.757$	$\nu_1 = 47.9$
2	−895.23	9.98		
3	−53.799	2.63	$N_2 = 1.62588$	$\nu_2 = 35.7$
4	68.239	4.05		
5	−93.639	3.94	$N_3 = 1.64769$	$\nu_3 = 33.8$
6	62.153	13.63	$N_4 = 1.7725$	$\nu_4 = 49.6$
7	−50.319	0.44		

-continued

	Focal length f = 100 F-number: 2.5 2ω = 50°			
	R	D	Nd	νd
8	301.84	5.19	$N_5 = 1.7859$	$\nu_5 = 44.2$
9	−301.84			

wherein R represents the radii of curvature of the lens surfaces; D represents the axial thicknesses or air separations; Nd represents the indices of refractions of the various lens elements; and νd represents the Abbe numbers of the lens elements.

3. An objective lens system according to claim **1**, wherein the characteristics of the lens elements and their spatial relationship to each other are substantially as indicated below:

	Focal length f = 100 F-number: 2.5 2ω = 50°			
	R	D	Nd	νd
1	70.336	13	$N_1 = 1.804$	$\nu_1 = 46.6$
2	−1736.6	10.35		
3	−60.	2.67	$N_2 = 1.64769$	$\nu_2 = 33.8$
4	79.774	5.51		
5	−79.674	3	$N_3 = 1.68893$	$\nu_3 = 31.1$
6	100	13.69	$N_4 = 1.7725$	$\nu_4 = 49.6$
7	−50.551	0.44		
8	200	5.03	$N_5 = 1.8061$	$\nu_5 = 40.9$

-continued

	Focal length f = 100 F-number: 2.5 2ω = 50°			
	R	D	Nd	νd
9	−335.99			

wherein R represents the radii of curvature of the lens surfaces; D represents the axial thicknesses or air separations; Nd represents the indices of refractions of the various lens elements; and νd represents the Abbe number of the lens elements.

4. An objective lens system according to claim **1**, wherein the characteristics of the lens elements and their spatial relationship to each other are substantially as indicated below:

	Focal length f = 100 F-number: 2.5 2ω = 50°			
	R	D	Nd	νd
1	70.989	12.96	$N_1 = 1.735$	$\nu_1 = 49.8$
2	−2734	12.04		
3	−50	2.67	$N_2 = 1.6398$	$\nu_2 = 34.5$
4	67.524	2.87		
5	−236.22	4.44	$N_3 = 1.62004$	$\nu_3 = 36.3$
6	53.333	15.56	$N_4 = 1.7725$	$\nu_4 = 49.6$
7	−51.493	0.44		
8	488.89	4.2	$N_5 = 1.7859$	$\nu_5 = 44.2$
9	−364.83			

wherein R represents the radii of curvature of the lens surfaces; D represents the axial thickness or air separations; Nd represents the indices of refractions of the various lens elements; and νd represents the Abbe numbers of the lens elements.

* * * * *

United States Patent [19]

Wagner

[11] **4,239,339**

[45] **Dec. 16, 1980**

[54] **VARIFOCAL OBJECTIVE FOR PHOTOGRAPHIC CAMERA**

[75] Inventor: **Werner Wagner,** Odernheim, Fed. Rep. of Germany

[73] Assignees: **Jos. Schneider GmbH & Co.; Optische Werke Kreuznach,** both of Bad Kreuznach, Fed. Rep. of Germany

[21] Appl. No.: **55,532**

[22] Filed: **Jul. 9, 1979**

[30] **Foreign Application Priority Data**

Jul. 10, 1978 [DE] Fed. Rep. of Germany 2830202

[51] **Int. Cl.**[3] **G02B 15/18**

[52] **U.S. Cl.** **350/184**

[58] **Field of Search** 350/184, 186, 176, 177

[56] **References Cited**

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Primary Examiner—Paul A. Sacher

Attorney, Agent, or Firm—Karl F. Ross

[57] **ABSTRACT**

The disclosed camera objective has a fixed rear lens group preceded by a four-component front group with negatively refracting second and third components which are axially shiftable between positively refracting first and fourth components to establish a minimum overall focal length F_{min} and a maximum overall focal length F_{max} with a ratio of about 1:2. The substantially stationary first component consists of a negative front lens (which may be limitedly shiftable for focusing purposes) followed by three positive lenses while the movable second component consists of two negative lenses followed by a positive lens; the movable third component and the fixed fourth component are constituted by a negative and a positive lens, respectively. The range of overall focal lengths, the image diagonal and the back-focal length of the objective as well as the individual focal lengths of the first and fourth components and of the rear lens group all lie between the absolute magnitudes of the individual focal lengths of the second and third components.

11 Claims, 4 Drawing Figures

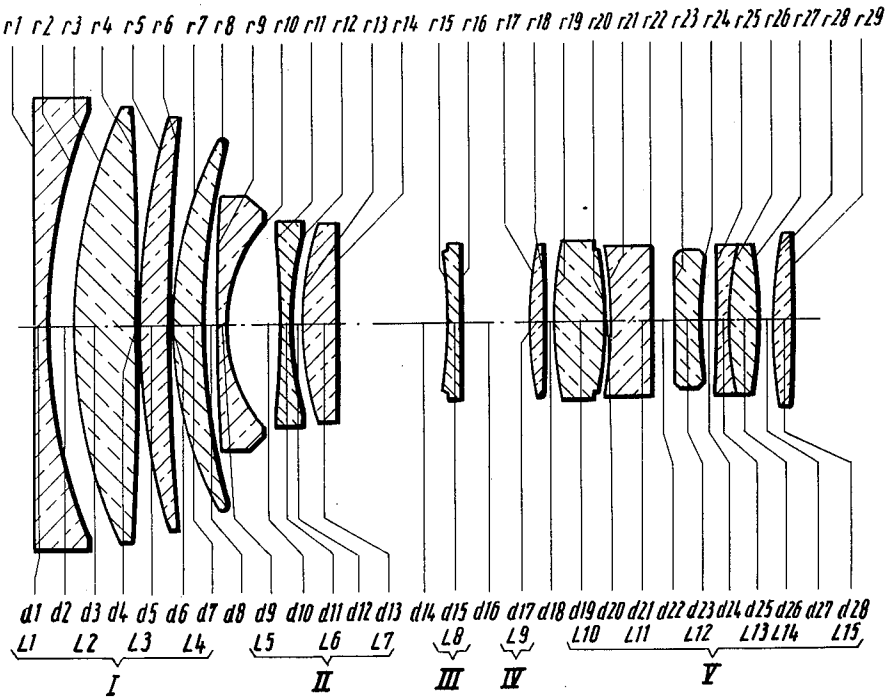
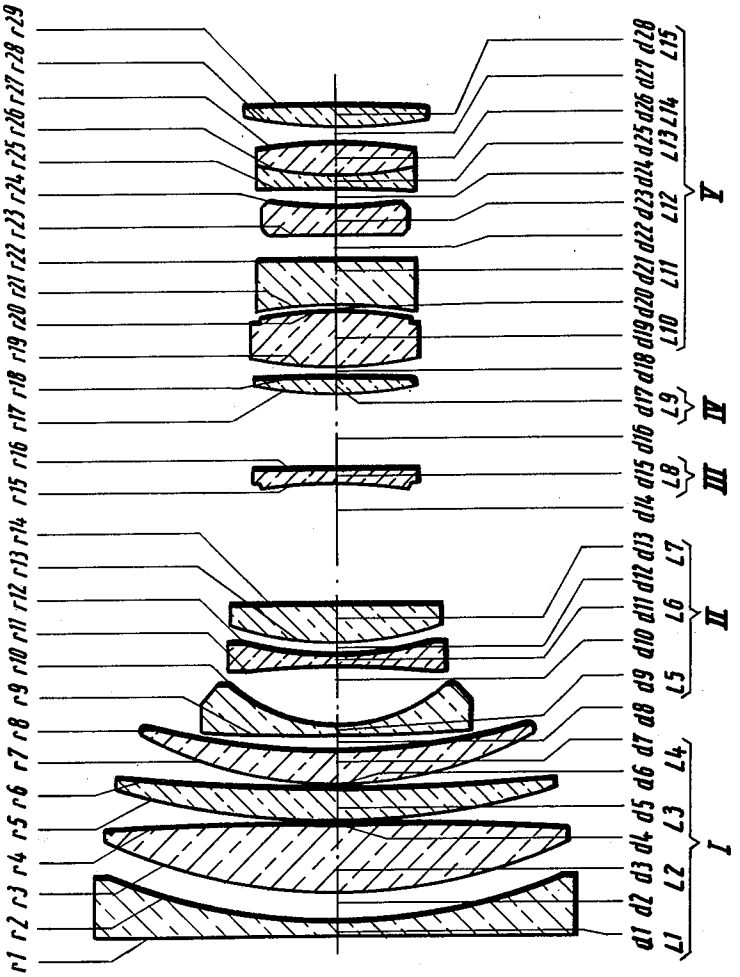


Fig.1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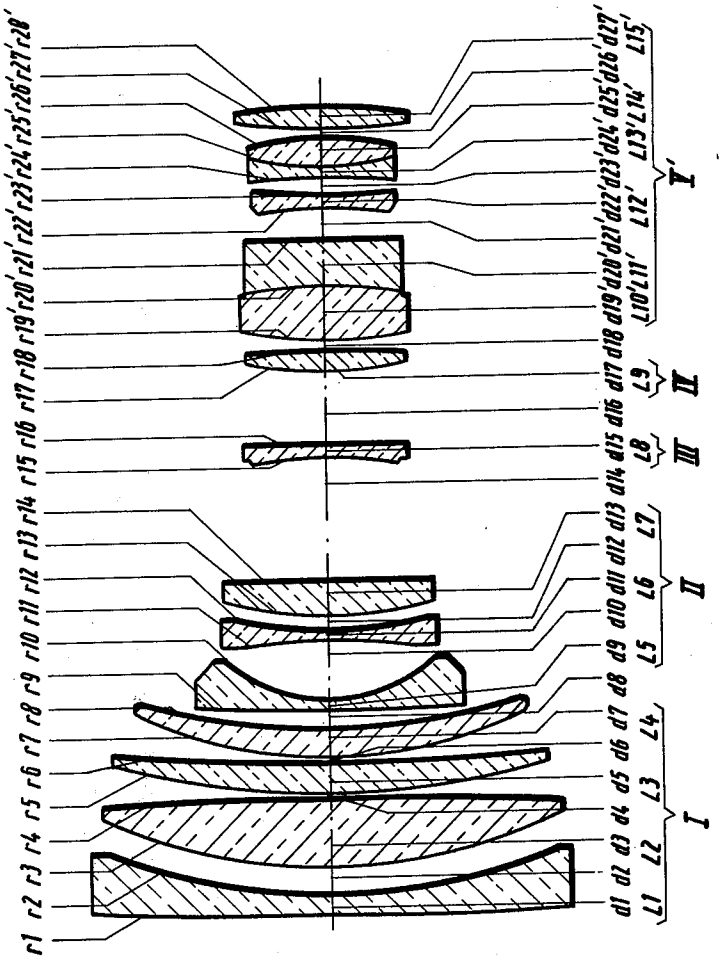
d1 d2 d3 d4 d5 d6 d7 d8 d9 d10 d11 d12 d13 d14 d15 d16 d17 d18 d19 d20 d21 d22 d23 d24 d25 d26 d27 d28
L1 L2 L3 L4 L5 L6 L7 L8 L9 L10 L11 L12 L13 L14 L15
I
II
III
IV
V

Fig. 2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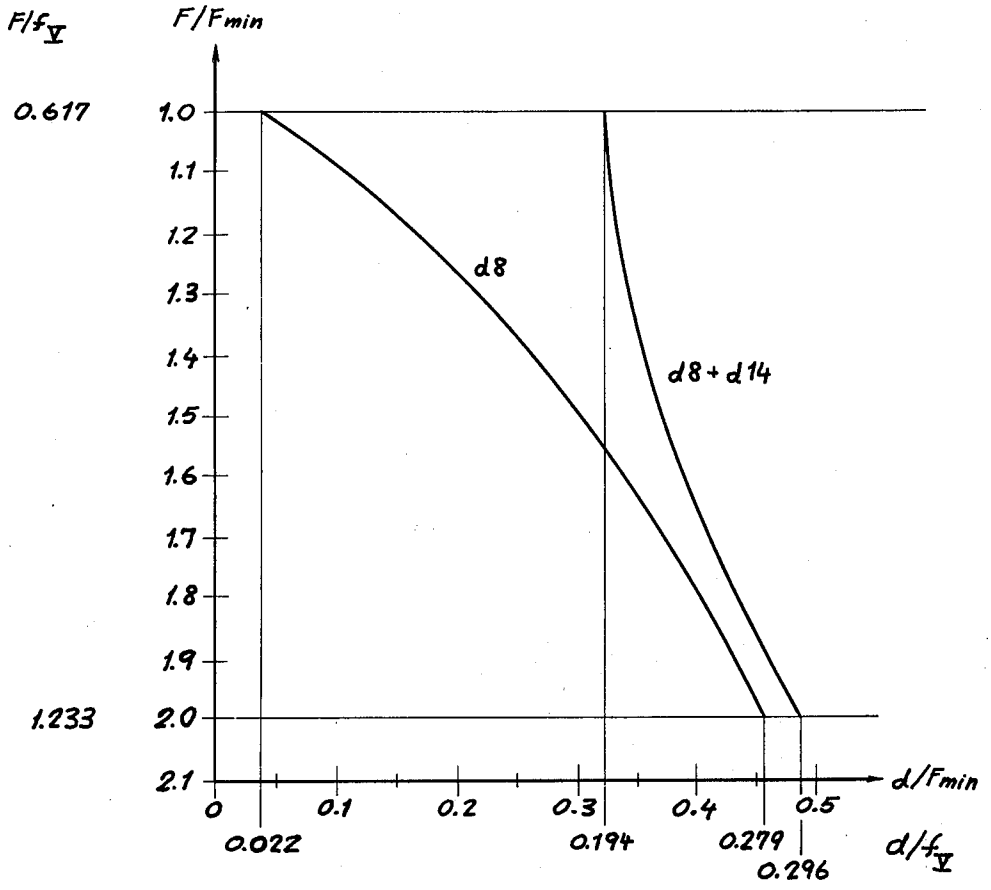
d1 d2 d3 d4 d5 d6 d7 d8 d9 d10 d11 d12 d13 d14 d15 d16 d17 d18 d19 d20 d21 d22 d23 d24 d25 d26 d27
L1 L2 L3 L4 I
L5 L6 L7 II
L8 III
L9 IV
L10 L11 L12 L13 L14 L15 V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F/Fmin
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1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
1.233
2.0
2.1
d8
d8 + d14
d/Fmin
0
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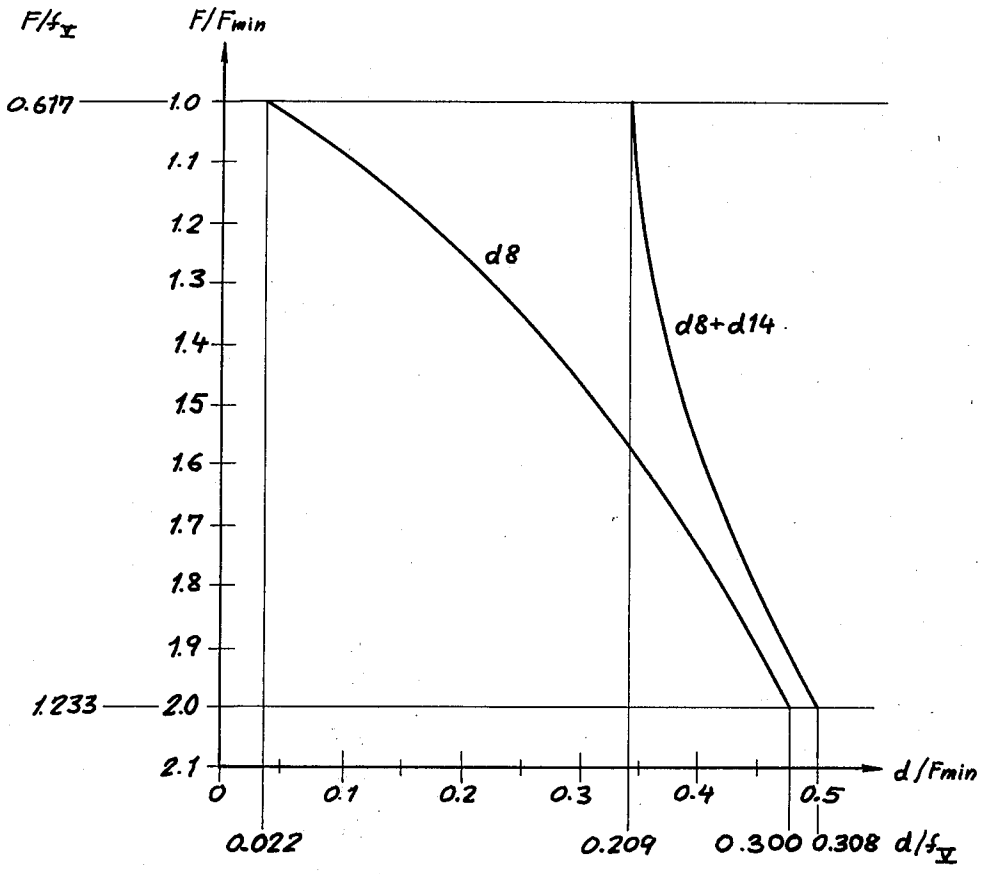
0.3
0.4
0.5
0.022
0.194
0.279
0.296
d/f_V

FIG. 3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1.6
1.7
1.8
1.9
1.233
2.0
2.1
d8
d8+d14
0
0.1
0.2
0.3
0.4
0.5
d/Fmin
0.022
0.209
0.300
0.308
d/fy

FIG. 4

VARIFOCAL OBJECTIVE FOR PHOTOGRAPHIC CAMERA

FIELD OF THE INVENTION

My present invention relates to an objective of the varifocal type for a photographic camera.

BACKGROUND OF THE INVENTION

Varifocal camera objectives of the type here envisaged are divided into a variable-focus front lens group and a fixed-focus rear lens group; the front group consists of four distinct components, namely a multilens first component of positive refractivity (considered stationary even though one or more of its lenses may be limitedly shiftable for focusing purposes), axially shiftable second and third components of negative refractivity, and a stationary positively refracting fourth component.

For certain cameras, such as those producing middle-sized still photographs of 60×60 mm or 45×60 mm, such objectives have hitherto been difficult to design in view of dimensional considerations imposing limitations upon total axial length and maximum lens diameter.

OBJECTS OF THE INVENTION

The general object of my present invention is to provide a varifocal objective of the type referred to which, with due regard to these dimensional restrictions, satisfies the requirements for good optical performance, simple construction and large relative aperture (preferably 1:4.5) with a focal-length ratio of about 2:1.

A more particular object is to provide a lens assembly for the purpose set forth whose minimum overall focal length, defining the wide-angle end of the varifocal range, is less than the image diagonal so as to provide a large field angle.

SUMMARY OF THE INVENTION

Let f_I, f_{II}, f_{III}, f_{IV} and f_V be the individual focal lengths of the four components I, II, III, IV of the adjustable front group and of the fixed rear group V, respectively. The absolute values of these individual focal lengths in my improved objective all are of the order of magnitude of the diagonal FD of the image projected upon a receiving surface, such as a film, positioned in a transverse plane separated by an invariable back-focal distance from the lat vertex of the rear lens group. The first component consists of a negative front lens **L1** followed by three positive lenses **L2**, **L3** and **L4**, while the second component consists of two negative lenses **L5**, **L6** followed by a positive lens **L7**; the third and fourth components respectively consist of a negative lens **L8** and a positive lens **L9**. I have found that, in order to realize the aforestated objects, the following requirements should be satisfied by the individual focal lengths f_I–f_{IV}, the radius **r2** of the rear surface of lens **L1**, the radius **r3** of the front surface of lens **L2**, the air spaces **d10** and **d12** respectively separating lens **L6** from lenses **L5** and **L7**, the radii **r10** and **r12** of the rear surfaces of lenses **L5** and **L6**, and the radius **r13** of the front surface of lens **L7**:

(1) $|f_I| \geqq FD$,
(2) $|f_{II}| \leqq FD$,
(3) $|f_{III}| \geqq FD$,
(4) $f_{IV} \leqq 0.5(|f_{II}| + f_{III}|)$,
(5) **r3**<**r2**,
(6) **d10**>2**d12**,
(7) **r13**<0.6(**r10**+**r12**).

Moreover, the stroke of the second component (i.e. the difference of its distances from the first component in the two limiting positions defining the wide-angle and the telephoto ends of the varifocal range) should be less than 0.6FD while the distances of the two movable components from each other in their two limiting positions should differ from each other by less than $0.5f_{II}$.

Relationships (1) through (4) establish the desired varifocal range. Relationship (5) minimizes the spherical zonal aberration in multilens component I. Relationships (6) and (7) help correct coma and astigmatism whereas the last two conditions lead to favorable dimensions for the total axial length and the lens diameters of the objective.

In the objective more particularly described hereinafter, not only the minimum and maximum overall focal length F_{min} and F_{max} but also the image diagonal FD and the individual focal lengths f_I, f_{IV} and f_V as well as the back-focal distance s′ lie between $|f_{II}|$ and $|f_{III}|$. Radius **r13**, moreover, lies roughly midway between radii **r10** and **r12**.

With each of the lenses **L1**,**L9** of the adjustable front group designed as a singlet, the objects of my invention are also satisfied if the front and rear surfaces of these lenses, identified by the radii **a1**–**a18**, have surface powers (n−1)/r—with r based on a value of unity for individual focal length f_V—within the following ranges:

(**r1**) +0.050 to +0.075
(**r2**) −0.820 to −0.940
(**r3**) +0.780 to +0.860
(**r4**) +0.060 to +0.080
(**r5**) +0.540 to +0.600
(**r6**) −0.160 to −0.200
(**r7**) +1.000 to +1.150
(**r8**) −0.560 to −0.650
(**r9**) +0.180 to +0.210
(**r10**) −2.800 to −3.100
(**r11**) −0.400 to −0.470
(**r12**) −1.050 to −1.250
(**r13**) +1.750 to +2.050
(**r14**) +0.040 to +0.050
(**r15**) −0.680 to −0.800
(**r16**) +0.020 to +0.030
(**r17**) +0.900 to +1.050
(**r18**) +0.270 to +0.330

Referred to the same value of f_V=1, the axial thickness of the lenses, their fixed separations and the main values of their variable separations are all equal to 0.1 or less.

BRIEF DESCRIPTION OF THE DRAWING

The above and other features of my invention will now be described in detail with reference to the accompanying drawing in which:

FIG. **1** diagrammatically illustrates a varifocal objective embodying my invention;

FIG. **2** is a view similar to FIG. **1**, showing a modified rear lens group;

FIG. **3** is a graph representing the displacement of the shiftable components of the front lens group having parameters substantially as given hereinafter in Tables I and II;

FIG. **4** is a set of graphs similar to FIG. **3** but relating to a front lens group having parameters substantially as given hereinafter in Table III.

SPECIFIC DESCRIPTION

In FIG. 1 I have shown a varifocal objective according to my invention with a front lens group consisting of a substantially stationary first component I of positive refractivity, an axially shiftable second component II of negative refractivity, a similarly shiftable third component III also of negative refractivity, and a positively refracting stationary fourth component IV; these components are followed by a fixed rear lens group V.

Component I consists of a negative front lens L1, with radii r1,r2 and thickness d1, separated by an air space d2 from three positive lenses L2 (radii r3, r4 and thickness d3), L3 (radii r5,r6 and thickness d5) and L4 (radii r7,r8 and thickness d7), the intervening air spaces being designated d4 and d6. Component II consists of a negative lens L5 (radii r9, r10 and thickness d9) separated by an air space d10 from a negative lens L6 (radii r11, r12 and thickness d11) which in turn is separated by an air space d12 from a positive lens L7 (radii r13, r14 and thickness d13). Component III is a single negative lens L8 with radii r15,r16 and thickness d15; component IV is a single positive lens L9 with radii r17,r18 and thickness d17. Rear group V consists of a positive lens L10 (radii r19, r20 and thickness d19) separated by an air space d18 from lens L9, a negative lens L11 (radii r21,r22 and thickness d21), another negative lens L12 (radii r23,r24 and thickness d23), a doublet formed from a negative lens L13 (radii r25,r26 and thickness d25) cemented onto a positive lens L14 (radii r26,r27 and thickness d26), and a final positive lens L15 (radii r28,r29 and thickness d28); the intervening air spaces have been designated d20, d22, d24 and d27.

Three variable air spaces d8, d14 and d16 exist between lenses L5/L6, L7/L8 and L8/L9. In the illustrated position, air space d8 has its minimum value while air space d14 and d16 are at a maximum; this corresponds to the wide-angle end of the varifocal range. The variations of spaces d8 and d14 throughout that range have been shown in FIGS. 3 and 4 for different sets of parameters tabulated hereinafter.

The objective shown in FIG. 2 differs from that of FIG. 1 only by the substitution of a modified rear lens group V' for group V. Group V' consists of a doublet formed from a positive lens L10 (radii r19', r20' and thickness d19') cemented onto a negative lens L11' (radii r20', r21' and thickness d20'), a negative lens L12' (radii r22', r23' and thickness d22'), another doublet formed from a negative lens L13' (radii r24', r25' and thickness d24') cemented onto a positive lens L14' (radii r25', r26' and thickness d25'), and a final positive lens L15' (radii r27', r28' and thickness d27'); the intervening air spaces have been designated d21', d23' and d26'.

Representative values for the radii r1–r18 and the thicknesses and separations d1–d17 of lenses L1–L9, based on a value of unity for the individual focal length f_V of lens group V or V', have been given in the following Tables I, II and III together with the refractive indices n_e and the Abbé numbers ν_e of these lenses as well as their surface powers $\Delta n/r$ (with $\Delta n = n_e - I$) and with r representing the respective radii r1–r18.

TABLE I

COMPONENTS	LENSES	RADII	THICKNESSES AND SEPARATIONS	n_e	ν_e	$\Delta n/r$
	L1	r1 = +14.05	d1 = 0.02	1.79	25.9	+0.056
		r2 = +0.87	d2 = 0.04			−0.910
	L2	r3 = +0.81	d3 = 0.09	1.69	54.5	+0.857
I		r4 = −9.44	d4 = 0.001			+0.074
	L3	r5 = +1.17	d5 = 0.05	1.69	54.5	+0.593
		r6 = +3.85	d6 = 0.001			−0.180
	L4	r7 = +0.61	d7 = 0.05	1.69	54.5	+1.138
		r8 = +1.11	d8 = 0.022–0.279			−0.625
	L5	r9 = +3.61	d9 = 0.02	1.72	47.7	+0.200
		r10 = +0.24	d10 = 0.08			−3.002
II	L6	r11 = −1.58	d11 = 0.02	1.72	47.7	−0.456
		r12 = +0.60	d12 = 0.02			−1.200
	L7	r13 = +0.40	d13 = 0.05	1.79	25.9	+1.980
		r14 = −16.88	d14 = 0.172–0.017			+0.047
III	L8	r15 = −0.64	d15 = 0.02	1.48	70.2	−0.764
		r16 = −18.85	d16 = 0.110–0.007			+0.026
IV	L9	r17 = +0.75	d17 = 0.02	1.74	44.5	+0.997
		r18 = −2.40				+0.312

The individual focal lengths are:

$f_I = +0.93$
$f_{II} = -0.45$
$f_{III} = -1.35$
$f_{IV} = +0.77$

TABLE II

COMPONENTS	LENSES	RADII	THICKNESSES AND SEPARATIONS	n_e	ν_e	$\Delta n/r$
	L1	r1 = +10.87	d1 = 0.02	1.79	25.9	+0.073
		r2 = +0.86	d2 = 0.04			−0.921
	L2	r3 = +0.81	d3 = 0.09	1.69	54.5	+0.857
I		r4 = −9.44	d4 = 0.001			+0.074
	L3	r5 = +1.18	d5 = 0.05	1.69	54.5	+0.588
		r6 = +3.55	d6 = 0.001			−0.195
	L4	r7 = +0.62	d7 = 0.05	1.69	54.5	+1.119
		r8 = +1.15	d8 = 0.022–0.280			−0.603
	L5	r9 = +3.61	d9 = 0.02	1.72	47.7	+0.200
		r10 = +0.24	d10 = 0.08			−3.002

TABLE II-continued

COMPONENTS	LENSES	RADII	THICKNESSES AND SEPARATIONS	n_e	ν_e	$\Delta n/r$
	L6	r11 = −1.58	d11 = 0.02	1.72	47.7	−0.456
II		r12 = +0.60	d12 = 0.02			−1.200
	L7	r13 = +0.40	d13 = 0.05	1.79	25.9	+1.980
		r14 = −16.88	d14 = 0.172–0.018			+0.047
III	L8	r15 = −0.64	d15 = 0.02	1.48	70.2	−0.764
		r16 = −18.85	d16 = 0.109–0.007			+0.026
IV	L9	r17 = +0.75	d17 = 0.02	1.74	44.5	+0.997
		r18 = −2.40				+0.312

The individual focal lengths are the same as in the case of Table I.

$f_{III} = -1.46$
$f_{IV} = +0.83$

TABLE III

COMPONENTS	LENSES	RADII	THICKNESSES AND SEPARATIONS	n_e	ν_e	$\Delta n/r$
	L1	r1 = +15.16	d1 = 0.03	1.79	25.9	+0.052
		r2 = +0.94	d2 = 0.05			−0.842
	L2	r3 = +0.88	d3 = 0.10	1.69	54.5	+0.789
		r4 = −10.18	d4 = 0.001			+0.068
I	L3	r5 = +1.27	d5 = 0.05	1.69	54.5	+0.546
		r6 = +4.15	d6 = 0.001			−0.167
	L4	r7 = +0.66	d7 = 0.05	1.69	54.5	+1.052
		r8 = +1.19	d8 = 0.022–0.300			−0.583
	L5	r9 = +3.90	d9 = 0.02	1.72	47.7	+0.185
		r10 = +0.25	d10 = 0.09			−2.882
		r11 = −1.71	d11 = 0.02	1.72	47.7	−0.421
II	L6					
		r12 = +0.65	d12 = 0.02			−1.108
	L7	r13 = +0.44	d13 = 0.05	1.79	25.9	+1.800
		r14 = −18.21	d14 = 0.187–0.019			+0.043
III	L8	r15 = −0.69	d15 = 0.02	1.48	70.2	−0.709
		r16 = −20.33	d16 = 0.118–0.008			+0.024
IV	L9	r17 = +0.81	d17 = 0.02	1.74	44.5	+0.923
		r18 = −2.59				+0.289

The individual focal lengths are:
$f_I = +1.0$

$f_{II} = -0.48$

Representative values for the lenses of group V (FIG. 1) are as follows:

TABLE IV

COMPONENT	LENSES	RADII	THICKNESSES AND SEPARATIONS	n_e	ν_e	$\Delta n/r$
	L10	r19 = +0.73	d18 = 0.01	1.72	50.2	+0.9861
		r20 = −0.70	d19 = 0.07			+1.0266
	L11	r21 = −0.51	d20 = 0.005	1.59	38.9	−1.1783
		r22 = −7.67	d21 = 0.06			+0.0780
V	L12	r23 = +2.65	d22 = 0.03	1.52	59.2	+0.1990
		r24 = +0.47	d23 = 0.04			−1.1055
	L13	r25 = −2.65	d24 = 0.02	1.81	25.2	−0.3057
		r26 = +0.39	d25 = 0.01			−0.7474
	L14	r27 = −0.46	d26 = 0.05	1.52	59.2	
			d27 = 0.01			+1.1381
	L15	r28 = +0.65	d28 = 0.03	1.50	56.2	+0.7726
		r29 = −6.33				+0.0794

Representative values for the lenses of group V' (FIG. 2) are as follows:

TABLE V

COMPONENT	LENSES	RADII	THICKNESSES AND SEPARATIONS	n_e	ν_e	$\Delta n/r$
	L10'	r19' = +0.68	d19' = 0.07	1.72	50.2	+1.0486
	L11'	r20' = −1.89	d20' = 0.07	1.59	38.9	+0.0655
		r21' = +12.57	d21' = 0.04			−0.0481
	L12'	r22' = −0.51	d22' = 0.01	1.52	59.2	−1.0254
		r23' = +1.24	d23' = 0.02			−0.4217
V'	L13'	r24' = −1.69	d24' = 0.01	1.81	25.2	−0.4797
	L14'	r25' = +0.38	d25' = 0.04	1.52	59.2	−0.7481

TABLE V-continued

COMPONENT	LENSES	RADII	THICKNESSES AND SEPARATIONS	n_e	ν_e	$\Delta n/r$
		r26' = −0.38	d26' = 0.01			+1.3624
	L15'	r27' = +0.93	d27' = 0.02	1.50	56.2	+0.5386
		r28' = −0.86				+0.5804

The lens assemblies for Tables I, II and III may be combined with either of the lens assemblies given in Tables IV and V to yield a varifocal objective having a relative aperture of 1:45 and a varifocal ratio of about 2:1.

More particularly, the objective represented by a combination of Tables I and IV has overall focal lengths $F_{min}=0.617$ and $F_{max}=1.233$; the same is true of the combinations of Table II with Table IV and Table III with Table V. The back-focal length s' varies slightly in these three instances, being 0.84 in the first, 0.88 in the second and 0.85 in the third case.

In FIGS. 3 and 4, where the left-hand curve represents the variable air space d8 and the right-hand curve represents the sum of air spaces d8 and d14 so as to show the actual positions of components II and III relative to component I, I have given the values of the overall focal length F (along the ordinate axis) in terms of the ratio F/F_{min} and also, for the limiting values F_{min} and F_{max}, in terms of the ratio F/f_V corresponding to the reference value used in the preceding Tables.

Similarly, the variable distances have been given (along the abscissa axis) in terms of d/F_{min} and also, for the limiting positions, in terms of d/f_V. It will be noted that the values given for distances d8 and d8+d14 in FIG. 3 correspond to those of Table I and closely approximate those of Table II; the values of FIG. 4 agree with those of Table III.

It will be apparent that some of the singlets L1–L9 of the varifocal group I–IV could be replaced by equivalent doublets with cemented surfaces, for better correction of chromatic aberrations, as is well known per se.

I claim:

1. In an optical objective with an adjustable front group and a fixed rear group, said front group consisting of a substantially stationary positive first component, an axially shiftable negative second component, an axially shiftable negative third component and a fixed positive fourth component, said second and third components having first limiting positions relatively close to said first component and remote from each other for establishing a minimum overall focal length F_{min} and having second limiting positions relatively remote from said first component and close to each other for establishing a maximum overall focal length F_{max}, the axial shifting of said second and third components between said first and second limiting positions thereof being correlated to project an image of an object upon a receiving surface in a plane separated from said rear group by an invariable back-focal distance,

the improvement wherein said first, second, third and fourth components and said rear group having respective individual focal lengths f_I, f_{II}, f_{III}, f_{IV}, f_V whose absolute values are of the order of magnitude of the diagonal FD of the projected image, said first component consisting of a negative front lens L1 followed by three positive lenses L2, L3, L4, said second component consisting of two negative lenses L5, L6 followed by a positive lens L7, said third component consisting of a negative lens L8, said fourth component consisting of a positive lens L9, said front lens L1 having a rear surface of radius r2, said lens L2 having a front surface of radius r3, said lens L6 being separated from lenses L5 and L7 by respective air spaces d10 and d12, said lenses L5 and L6 having rear surfaces of respective radii r10 and r12, said lens L7 having a front surface of radius r13, the following conditions being satisfied:

$f_I \geqq FD$,
$|f_{II}| \leqq FD$,
$|f_{III}| \geqq FD$,
$f_{IV} \leqq 0.5(|f_{II}|+|f_{III}|)$,
$r3 < r2$,
$d10 > 2d12$,
$r13 < 0.6(r10+r12)$,

the distances of said second component from said first component in said first and second limiting positions differing from each other by less than 0.6FD, the distances of said third component from said second component in said first and second limiting positions differing from each other by less than $0.5f_{II}$.

2. The improvement defined in claim 1 wherein the ratio of said overall focal lengths $F_{max}:F_{min}$ is substantially 2:1.

3. The improvement defined in claim 2 wherein said overall focal length F_{min} and F_{max}, said diagonal FD, said individual focal lengths f_I, f_{IV}, and f_V and said back-focal distance all lie between $|f_{II}|$ and $|f_{III}|$.

4. The improvement defined in claim 3 wherein $r10 < r13 < r12$.

5. The improvement defined in claim 4 wherein the surface radii r1 to r18 and the refractive indices n or the lenses L1 to L9 of said front group are so chosen, with reference to a value of unity for the individual focal length f_V of said rear group, as to have surface powers $(n-1)/r$ within the following ranges for the surfaces thereof defined by their respective radii:

(r1) +0.050 to +0.075
(r2) −0.820 to −0.940
(r3) +0.780 to +0.860
(r4) +0.060 to +0.080
(r5) +0.540 to +0.600
(r6) −0.160 to −0.200
(r7) +1.000 to +1.150
(r8) −0.560 to −0.650
(r9) +0.180 to +0.210
(r10) −2.800 to −3.100
(r11) −0.400 to −0.470
(r12) −1.050 to −1.250
(r13) +1.750 to +2.050
(r14) +0.040 to +0.050
(r15) −0.680 to −0.800
(r16) +0.020 to +0.030
(r17) +0.900 to +1.050
(r18) +0.270 to +0.330

6. The improvement defined in claim 5 wherein the thicknesses of said lenses L1 to L9, the fixed separations thereof and the mean values of their variable separations do not exceed substantially $0.1f_V$.

7. The improvement defined in claim 6 wherein the radii r1 to r18 and the thicknesses and separations d1 to d17 of said lenses L1 to L9, based upon said value of unity for f_V, their refractive indices n and their Abbé numbers ν have numerical values substantially as given in the following table:

LENSES	RADII	THICKNESSES AND SEPARATIONS	n	ν
L1	r1 = +14.1	d1 = 0.02	1.79	26
	r2 = +0.9	d2 = 0.04		
L2	r3 = +0.8	d3 = 0.09	1.69	55
	r4 = −9.4	d4 = 0.001		
L3	r5 = +1.2	d5 = 0.05	1.69	55
	r6 = +3.9	d6 = 0.001		
L4	r7 = +0.6	d7 = 0.05	1.69	55
	r8 = +1.1	d8 = 0.02–0.28		
L5	r9 = +3.6	d9 = 0.02	1.72	48
	r10 = +0.2	d10 = 0.08		
L6	r11 = −1.6	d11 = 0.02	1.72	48
	r12 = +0.6	d12 = 0.02		
L7	r13 = +0.4	d13 = 0.05	1.79	26
	r14 = −16.9	d14 = 0.17–0.02		
L8	r15 = −0.6	d15 = 0.02	1.48	70
	r16 = −18.9	d16 = 0.11–0.01		
L9	r17 = +0.8			
	r18 = −2.4	d17 = 0.02	1.74	45

8. The improvement defined in claim 6 wherein the radii r1 to r18 and the thicknesses and separations d1 to d17 of said lenses L1 to L9, based upon said value of unity for f_V, their refractive indices n and their Abbé numbers ν have numerical values substantially as given in the following table:

LENSES	RADII	THICKNESSES AND SEPARATIONS	n	ν
L1	r1 = +10.9	d1 = 0.02	1.79	26
	r2 = +0.9	d2 = 0.04		
L2	r3 = +0.8	d3 = 0.09	1.69	55
	r4 = −9.4	d4 = 0.001		
L3	r5 = +1.2	d5 = 0.05	1.69	55
	r6 = +3.6	d6 = 0.001		
L4	r7 = +0.6	d7 = 0.05	1.69	55
	r8 = +1.2	d8 = 0.02–0.28		
L5	r9 = +3.6	d9 = 0.02	1.72	48
	r10 = +0.2	d10 = 0.08		
L6	r11 = −1.6	d11 = 0.02	1.72	48
	r12 = +0.6	d12 = 0.02		
L7	r13 = +0.4	d13 = 0.05	1.79	26
	r14 = −16.9	d14 = 0.17–0.02		
L8	r15 = − 0.6	d15 = 0.02	1.48	70
	r16 = −18.9	d16 = 0.11–0.01		
L9	r17 = +0.8			
	r18 = −2.4	d17 = 0.02	1.74	45

9. The improvement defined in claim 6 wherein the radii r1 to r18 and the thicknesses and separations d1 to d17 of said lenses L1 to L9, based upon said value of unity for f_V, their refractive indices n and their Abbé numbers ν have numerical values substantially as given in the following table:

LENSES	RADII	THICKNESSES AND SEPARATIONS	n	ν
L1	r1 = +15.2	d1 = 0.03	1.79	26
	r2 = +0.9	d2 = 0.05		
L2	r3 = +0.9	d3 = 0.10	1.69	55
	r4 = −10.2	d4 = 0.001		
L3	r5 = +1.3	d5 = 0.05	1.69	55
	r6 = +4.2	d6 = 0.001		
L4	r7 = +0.7	d7 = 0.05	1.69	55
	r8 = +1.2	d8 = 0.02–0.30		
L5	r9 = +3.9	d9 = 0.02	1.72	48
	r10 = +0.3	d10 = 0.09		
L6	r11 = −1.7	d11 = 0.02	1.72	48
	r12 = +0.7	d12 = 0.02		
L7	r13 = +0.4	d13 = 0.05	1.79	26
	r14 = −18.2	d14 = 0.19–0.02		
L8	r15 = − 0.7	d15 = 0.02	1.48	70
	r16 = − 20.3	d16 = 0.12–0.01		
L9	r17 = +0.8			
	r18 = −2.6	d17 = 0.02	1.74	45

10. The improvement defined in claim 7, 8 or 9 wherein said rear group consists of a positive lens L10, two negative lenses L11 and L12, a negative lens L13 and a positive lens L14 cemented to each other, and a positive lens L15, the radii r19 to r29 and the thicknesses and separations d19 to d28 of said lenses L10 to L15, based upon said value of unity for f_V, their refractive indices n and their Abbé numbers ν having numerical values substantially as given in the following table:

LENSES	RADII	THICKNESSES AND SEPARATIONS	n	ν
L10	r19 = +0.7	d18 = 0.01	1.72	50
	r20 = −0.7	d19 = 0.07		
L11	r21 = −0.5	d20 = 0.01	1.59	39
	r22 = −7.7	d21 = 0.06		
L12	r23 = +2.7	d22 = 0.03	1.52	59
	r24 = +0.5	d23 = 0.04		
L13	r25 = −2.7	d24 = 0.02	1.81	25
	r26 = +0.4	d25 = 0.01		
L14		d26 = 0.05	1.52	59
	r27 = −0.5	d27 = 0.01		
L15	r28 = +0.7			
	r29 = −6.3	d28 = 0.03	1.50	56

11. The improvement defined in claim 7, 8 or 9 wherein said rear group consists of a positive lens L10′ and a negative lens L11′ cemented to each other, a negative lens L12′, a negative lens L13′ and a positive lens L14′ cemented to each other, and a positive lens L15′, the radii r19′ to r28′ and the thicknesses and separations d19′ to d27′ of said lenses L10′ to L15′, based upon said value of unity for f_V, their refractive indices n and their Abbé numbers ν having numerical values substantially as given in the following table:

LENSES	RADII	THICKNESSES AND SEPARATIONS	n	ν
L10′	r19′ = +0.7	d19′ = 0.07	1.72	50
L11′	r20′ = −1.9	d20′ = 0.07	1.59	39
	r21′ = +12.6	d21′ = 0.04		
L12′	r22′ = −0.5	d22′ = 0.01	1.52	59
	r23′ = +1.2	d23′ = 0.02		
L13′	r24′ = −1.7	d24′ = 0.01	1.81	25
L14′	r25′ = +0.4	d25′ = 0.04	1.52	59
	r26′ = −0.4	d26′ = 0.01		
L15′	r27′ = +0.9			
	r28′ = −0.9	d27′ = 0.02	1.50	56

* * * * *

E297A OR 4,235,519

United States
Fujibayashi

4,235,519
[45] Nov. 25, 1980

[54] COMPACT RETROFOCUS TYPE WIDE ANGLE OBJECTIVE

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[73] Assignee: Canon Kabushiki Kaisha, Tokyo, Japan

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[22] Filed: Apr. 12, 1979

[30] Foreign Application Priority Data

Apr. 17, 1978 [JP] Japan 53/45137

[51] Int. Cl.³ G02B 9/64
[52] U.S. Cl. 350/214
[58] Field of Search 350/214

[56] References Cited

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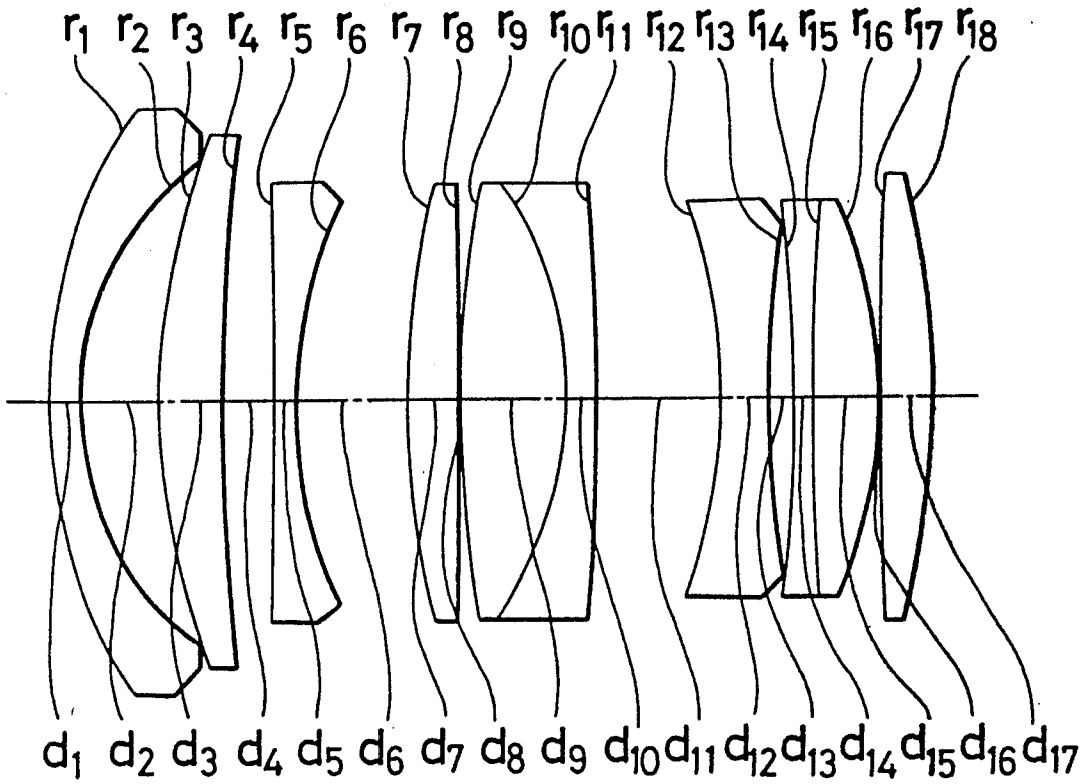
Primary Examiner—John K. Corbin
Assistant Examiner—Scott J. Sugarman
Attorney, Agent, or Firm—Toren, McGeady and Stanger

[57] ABSTRACT

The wide angle objective disclosed is composed of eight components. The first counting from the front is a negative meniscus lens of forward convexity. The second component is a positive lens with a front surface of strong positive power, and the third is a biconcave lens having a strong surface facing the rear. The fourth component is a positive lens with a front surface of strong positive power and the fifth is a doublet lens of positive power with its front surface convex toward the front and with its cemented surface of positive power convex torward the rear. The sixth component is a biconcave lens, the seventh is a positive doublet lens convex toward the rear and consisting of a negative lens element and a positive lens element cemented together at their adjoining surfaces, and the eighth is a positive lens with its rear surface being stronger in power than its front surface. In focusing the objective, as the entire lens system is axially moved as a whole relative to the image plane, the first and second components and moved as one fixed group and the third to eighth components as another fixed group are moved as another fixed group in differential relation to the first fixed group.

5 Claims, 16 Drawing Figures



No Dr

FIG.1

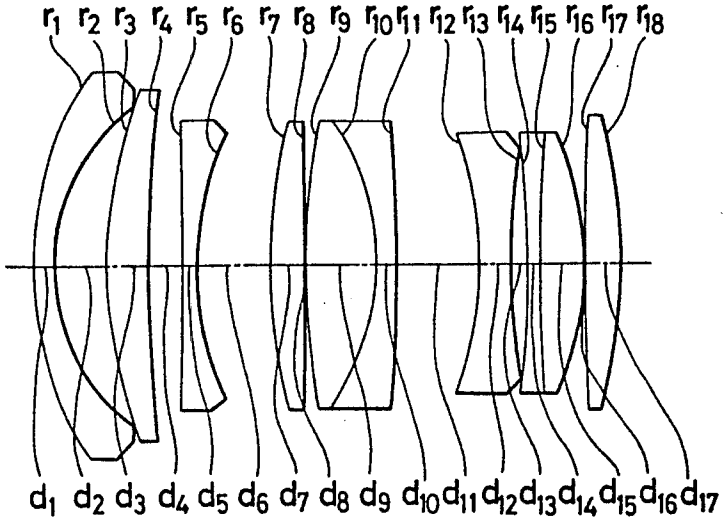

r1 r2 r3 r4 r5 r6 r7 r8 r9 r10 r11 r12 r13 r14 r15 r16 r17 r18
d1 d2 d3 d4 d5 d6 d7 d8 d9 d10 d11 d12 d13 d14 d15 d16 d17

FIG.2

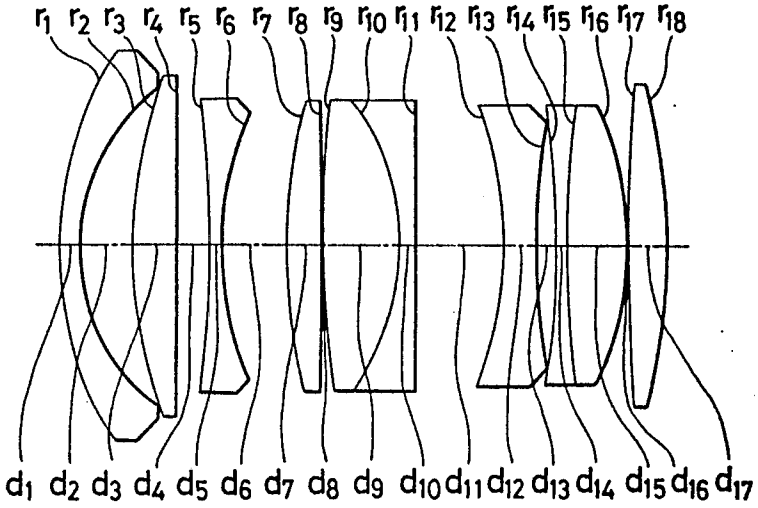

r1 r2 r3 r4 r5 r6 r7 r8 r9 r10 r11 r12 r13 r14 r15 r16 r17 r18
d1 d2 d3 d4 d5 d6 d7 d8 d9 d10 d11 d12 d13 d14 d15 d16 d17

FIG.3

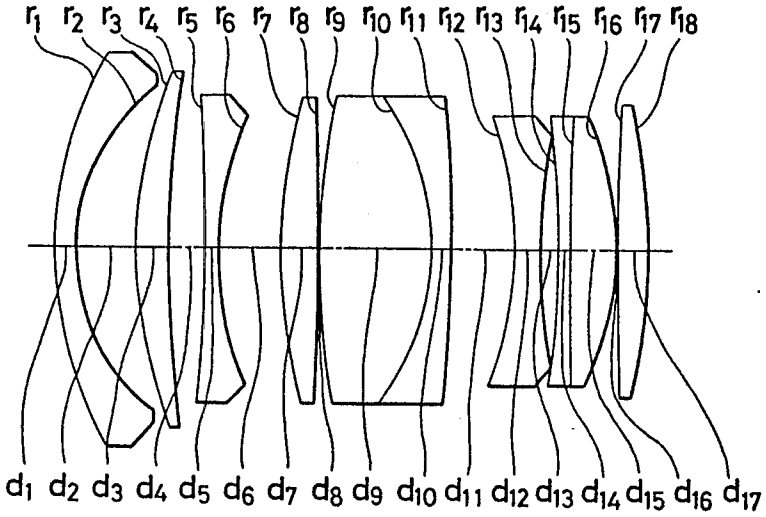


FIG.4A FIG.4B FIG.4C

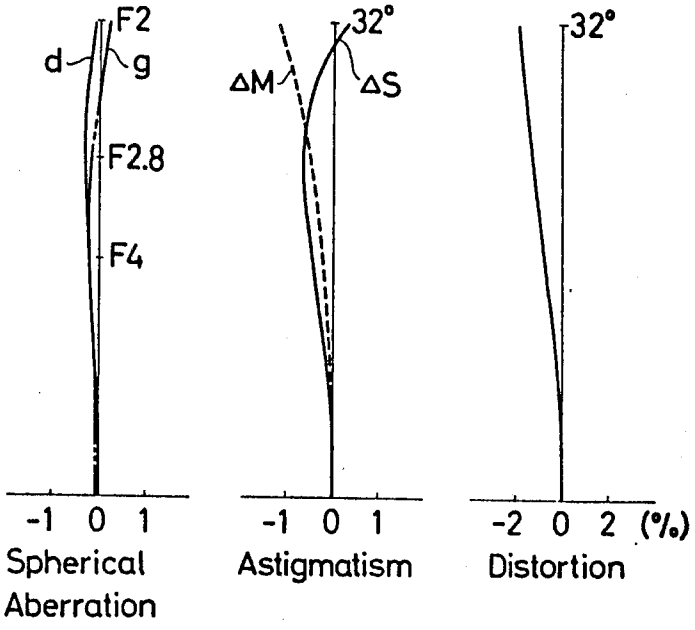


FIG.5A FIG.5B FIG.5C

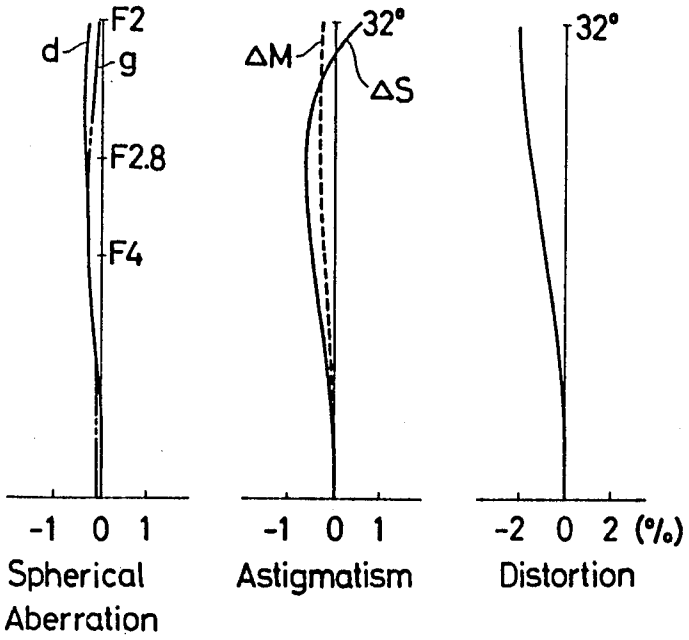


FIG.6A FIG.6B FIG.6C

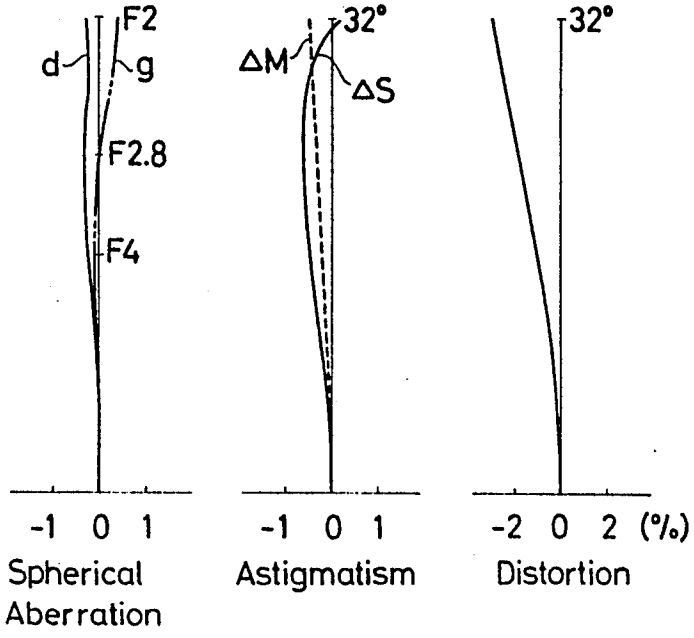


FIG.7A FIG.7B

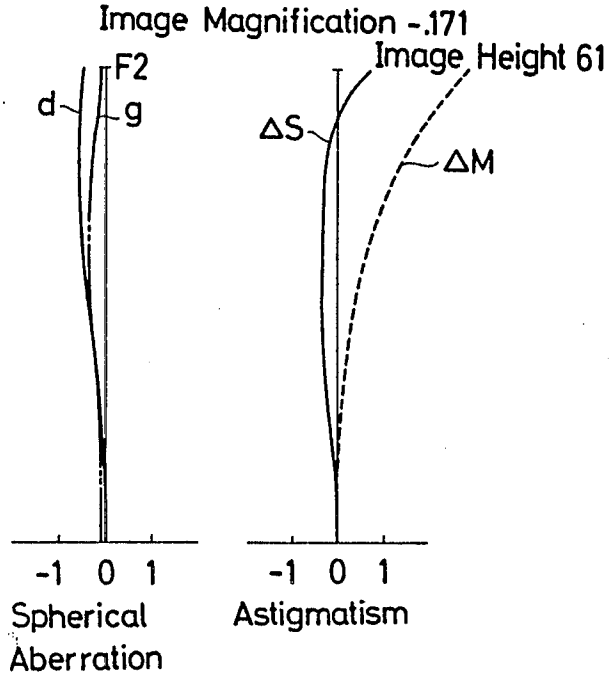
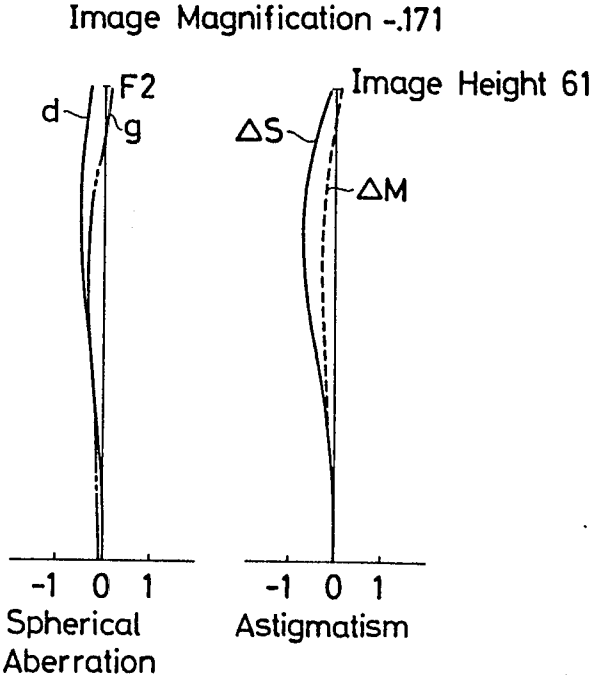


FIG.8A FIG.8B



COMPACT RETROFOCUS TYPE WIDE ANGLE OBJECTIVE

BACKGROUND OF THE INVENTION

This invention relates to retrofocus type objectives of long back focal length suited for use in single lens reflex cameras, and more particularly to retrofocus type wide angle objectives of minimized bulk and size.

The retrofocus type objective, because of its intent of lengthening the back focal length, uses a negative lens of strong power at the front. This produces the drawback of increasing the distortion, coma, halo of sagittal rays, and other abberrations. To minimize the bulk and size of the objective as in the present invention, the negative power of the front component is required to be stronger than that of the ordinary retrofocus type objective. Thus, the various aberrations tend to increase further. Particularly with an objective of large relative aperture, the halo of sagittal rays becomes serious, and good correction of the aberrations becomes difficult.

A wide variaty of retrofocus type objectives have already been developed. Examples of an objective comprising a negative front group, a positive middle group, a diaphragm, and a positive rear group, the front group including negative, positive and negative lenses, and the rear group including negative, positive, positive lenses, are shown in U.S. Pat. No. 3,736,049 and No. 3,982,823.

SUMMARY OF THE INVENTION

A first object of the present invention is to provide a compact retrofocus type objective.

A second object is to provide for a retrofocus type objective with an increased relative aperture.

A third object is to achieve good correction of the various aberrations.

The retrofocus type objective according to the present invention comprises, from front to rear, a negative first lens in the meniscus form of forward convexity, a positive second lens whose front surface is of strong positive power, a biconcave third lens whose surface strong in power faces the rear, a positive fourth lens whose front surface is stronger in power than its rear surface, a positive fifth lens in doublet form with its frontmost surface convex toward the front and with its cemented surface of positive power convex toward the rear, a biconcave sixth lens, a positive seventh lens in meniscus doublet form convex toward the rear and consisting of a negative lens element and a positive lens element cemented together at their adjoining surfaces, and a positive eighth lens whose rear surface is stronger in power than its front surface, and is characterized by fulfilling the following conditions:

$$\frac{0.33}{f} < \left|\frac{N_5 - N_6}{r_{10}}\right| < \frac{0.42}{f} \quad (1)$$

$$1.4 < \left|\frac{f_{5-6}}{f_{7-11}}\right| < 1.82 \quad (2)$$

$$0.4 < \frac{r_7}{r_9} < 0.64 \quad (3)$$

$$0.75 < \frac{d_6}{d_{11}} < 0.95 \quad (4)$$

$$20 < \nu_9 - \nu_8 < 28 \quad (5)$$

$$-0.1/f < 1/f_{1-4} < 0.15/f \quad (6)$$

where

f: the focal length of the entire system;

r_i: the radius of curvature of the i-th surface;

dj: the axial lens thickness or air separation between the j-th surface and the (j+1)th surface;

N_k: the index of refraction for the k-th lens element;

νl: the Abbe number for the l-th lens element; and

f_{m-n}: the overall focal length of the m-th to n-th surfaces.

These conditions have now been found to be effective for realization of a high performance retrofocus type photographic lens system having a back focal length of at least 1.02f and as large a relative aperture as F2 with the limitation of the bulk and size to 2.47f in the physical length and 0.9f in the diameter of the front lens member.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a sectional view of one embodiment of a retrofocus type objective according to the present invention.

FIG. 2 is a similar view showing another embodiment of the invention.

FIG. 3 is a similar view showing still another embodiment of the invention.

FIGS. 4A to 4C are graphs showing the spherical aberration, astigmatism and distortion of the objective of FIG. 1 respectively, when focused at infinity.

FIGS. 5A to 5C are similar graphs for the objective of FIG. 2.

FIGS. 6A to 6C are similar graphs for the objective of FIG. 3.

FIGS. 7A and 7B are graphs showing the spherical aberration and astigmatism of the objective of FIG. 1 when focused down to shorter object distances without variation of the lens separation between the first and second lens groups.

FIGS. 8A and 8B are similar graphs for the objective of FIG. 1 when the lens separation is varied during focusing.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The embodiments of the objectives represented in FIGS. 1 to 3 individually satisfy the above-defined conditions, each of which is explained below in detail.

In designing a wide angle objective for use in a single lens reflex camera, the shorter the total optical length of the objective, the stronger must be the negative power of the front part and the positive power of the rear part in order to assure the necessary back focal length. This intensifies the degree of curvature of the spherical aberration curve. Since the central bundle of light rays expands most widely in a space which the fifth lens component is intended to occupy, the curvature of the spherical aberration curve can be flattened to an acceptable degree by constructing the fifth component in the cemented form to satisfy condition (1). As the positive lens element is made from a glass material having a high index of refraction and the negative lens element from a glass material having a low index of refraction, this cemented lens contributes to correction of field curvature. In order to effect production of as little coma as possible, it is preferable to position the cemented surface adjacent the diaphragm. When the upper limit of condition (1) is exceeded, an unacceptable coma will be produced and deteriorate the image quality. When the lower limit is exceeded, the spherical aberration will be under-corrected, and the curvature of image field will also become large.

From a reason to be described later, since the composite system of the first and second components is

almost afocal, a large proportion of the negative power of the front part in the retrofocus type lens system must be concentrated only in the third component. This in turn causes the third component to produce very large distortion, coma and halo of sagittal rays. Particularly at the large relative aperture of F2, the halo of sagittal rays is very pronounced. In general it is advantageous to compensate for the halo of sagittal rays by those of the components at which the bundle size of sagittal rays is most widely expanded. To allow for this, conditions (2), (3) and (4) are set forth.

Condition (2) is a compromise between the requirements of lengthening the back focal length and shortening the total optical length and of well compensating for the halo of sagittal rays. In the latter connection, the powers of the fourth and fifth components must be strengthened to a moderate degree. When the lower limit of condition (2) is exceeded, though the back focal length becomes longer, the third component introduces too large a halo of sagittal rays to be properly corrected for by the fourth and fifth components. When the upper limit of condition (2) is exceeded, the assurance for the necessary back focal length becomes difficult, and very large coma and field curvature are produced.

Even if condition (2) is satisfied, an unbalanced power distribution over the fourth and fifth components will lead to the production of very large spherical aberration and coma. On this account, an optimum power distribution is set forth in condition (3) within a framework in which both components are positive lenses with their front surfaces convex toward the front and stronger in curvature than their rear surfaces. Under condition (3) the halo of sagittal rays can be effectively compensated for, while simultaneously suppressing the production of the other aberrations. When the upper limit of condition (3) is exceeded, the halo of sagittal rays will be insufficiently compensated for, and the spherical aberration will also be under-corrected. When the lower limit of condition (3) is exceeded, very large astigmatism and coma will be produced.

In effectively compensating for the halo of saggital rays, the arrangement of the fourth and fifth components is also important. When they are positioned in an air space between the third and sixth components at almost the center of the axial separation thereof, a good aberrational correction can be performed. This is condition (4). When the upper limit of condition (4) is exceeded, the diameter of an effective light bundle at the fourth and fifth components will become so large that very large spherical aberration is produced. The entire length is also increased so that one of the objects of the invention cannot be achieved. When the lower limit of condition (4) is exceeded, the axial separation between the third and fourth components will become so narrow that not only good correction of the halo of sagittal rays is difficult to perform. However, the back focal length is not lengthened.

Thus, the halo of sagittal rays introduced by the preceding components has been cancelled out by the suitable design of the fourth and fifth components.

The lateral chromatic aberration introduced by the preceding components is, however, not yet compensated for yet. Then, seventh component is constructed in the cemented form consisting of negative and positive lens elements for which the dispersive indices are controlled to differ greatly from each other in accordance with condition (5). When the upper limit of condition (5) is exceeded, over-correction of lateral chromatic aberration will result. When the lower limit of condition (5) is exceeded, it will be difficult to perform good correction.

On account of the large relative aperture, the front part tends to produce large aberrations. To avoid this, it is very effective for the first and second components to form a system nearly afocal. With the first component of negative power and the second component of positive power, such system assists in lengthening the back focal length while nevertheless permitting little distortion, astigmatism and coma be produced to. Then, condition (6) is set forth. When the upper limit of condition (6) is exceeded, it will become impossible to assure the sufficiently long back focal length. When the lower limit is exceeded, the back focal length can be advantageously lengthened, but very large distortion is produced.

Retrofocus type objectives generally exhibit the drawback that when they are focused upon shorter object distances, the astigmatic difference is greatly increased. It is particularly true that where the relative aperture is large, as the depth of focus is narrow, substantial deterioration of the image quality will be noted. To preserve high grade imaging performance even for objects at shorter distances, according to the present invention, whilst the entire system is axially moved forwards, the axial separation between the first group and the second group is narrowed, where the first group is composed of the first and second components and the second group is composed of the third to eighth component. Since the light bundle in this variable separation, namely, d_4 is made almost afocal based on the condition (6), the focal length of the entire system remains almost unchanged throughout the focusing range, and the variation with focusing of coma is limited to a minimum. How such focusing provision affects the imagery can be seen by comparison of FIGS. 7A–7B with FIGS. 8A–8B, where the object distance corresponds to an image magnification of −0.171, and the axial separation d_4 for that shorter object distance is different from that for object at infinity by 1.53.

The three specific objective lens systems can be constructed in accordance with the numerical data given below for the radii of curvature, r, of the lens surfaces, the axial lens thicknesses or air separations, d, along with the indices of refraction, Nd, for the spectral d line of sodium and the Abbe numbers, νd, for the spectral d line of sodium, for the various lens elements. The character f denotes the focal length of the entire system, b.f. the back focal length, L the total optical length and D the diameter of the front member.

EXAMPLE 1

Surface	F-number = 1:2		Image Angle 2ω = 64°	
No.	r	d	Nd	νd
1	80.127	5.07	1.60729	59.40
2	45.992	12.54	1	
3	97.715	10.21	1.72000	50.20
4	369.750	7.62	1	
5	−856.450	3.38	1.54869	45.60
6	71.127	17.65	1	
7	132.110	7.72	1.77250	49.60
8	9675.600	0.56	1	
9	219.290	16.88	1.80610	40.90
10	−56.941	4.44	1.59551	39.20
11	−608.610	19.38	1	
12	−88.811	7.80	1.72825	28.50
13	151.610	4.20	1	
14	−236.920	2.82	1.80518	25.40

-continued

Surface No.	F-number = 1:2 r	d	Image Angle 2ω = 64° Nd	νd
15	524.560	10.42	1.77250	49.60
16	−72.310	0.56	1	
17	1536.100	7.76	1.77250	49.60
18	−130.130		1	

f = 100.0, b.f. = 102.74, L = 241.75, D = 83.8,
$|(N_5-N_6)/r_{10}|$ = 0.00370 d_6/d_{11} = 0.910
$|f_{5\sim6}/f_{7\sim11}|$ = 1.61 $\nu_9-\nu_8$ = 24.2
r_7/r_9 = 0.603 $1/f_{1\sim4}$ = +0.00037

3rd-Order Aberration Coefficients

Surface No.	SA	CM	AS	PT	DS
1	0.4567	0.0761	0.0126	0.4714	0.0807
2	−5.6619	1.2240	−0.2646	−0.8214	0.2347
3	1.6266	0.1970	0.0238	0.4283	0.0547
4	−0.0025	−0.0093	−0.0336	−0.1131	−0.5297
5	−0.0012	0.0081	−0.0533	−0.0413	0.6219
6	−4.2497	−0.4236	−0.0422	−0.4980	−0.0538
7	2.6515	0.8386	0.2652	0.3298	0.1882
8	−0.0029	−0.0155	−0.0817	−0.0045	−0.4528
9	0.1278	0.1401	0.1536	0.2035	0.3915
10	3.4282	−1.0284	0.3085	0.1283	−0.1310
11	0.6277	−0.5858	0.5467	0.0613	−0.5674
12	−2.9116	1.2181	−0.5096	−0.4744	0.4117
13	−0.5043	−0.5661	−0.6355	−0.2778	−1.0254
14	0.0000	0.0042	0.2046	−0.1882	0.7982
15	−0.0135	−0.0151	−0.0169	−0.0019	−0.0211
16	1.9528	−0.4948	0.1254	0.6026	−0.1844
17	−0.0162	0.0528	−0.1725	0.0283	0.4707
18	2.8818	−0.6221	0.1343	0.3348	−0.1012
Total	0.3893	−0.0017	−0.0351	0.1676	0.1852

SA : Spherical Aberration
CM : Coma
AS : Astigmatism
PT : Petzval Sum
DS : Distortion

EXAMPLE 2

Surface No.	F-number = 1:2 r	d	Image Angle 2ω = 64° Nd	νd
1	82.079	5.07	1.60311	60.70
2	45.851	12.64	1	
3	107.720	9.92	1.69700	48.50
4	−4830.700	6.69	1	
5	−317.040	3.38	1.54869	45.60
6	77.090	15.41	1	
7	138.440	7.67	1.77250	49.60
8	−990.830	0.56	1	
9	330.460	17.67	1.80610	40.90
10	−54.417	4.45	1.58144	40.70
11	−1629.900	20.42	1	
12	−91.389	8.48	1.75520	27.50
13	175.110	3.89	1	
14	−217.940	2.82	1.75520	27.50
15	248.680	13.84	1.75700	47.90
16	−73.184	0.56	1	
17	529.010	9.03	1.77250	49.60
18	−144.071		1	

f = 100.0, b.f. = 102.81, L = 245.31,
D = 83.9
$|(N_5-N_6)/r_{10}|$ = 0.00413 d_6/d_{11} = 0.755
$|f_{5\sim6}/f_{7\sim11}|$ = 1.43 $\nu_9-\nu_8$ = 20.4
r_7/r_9 = 0.419 $f_{1\sim4}$ = +0.00142

3rd-Order Aberration Coefficients

Surface No.	SA	CM	AS	PT	DS
1	0.4243	0.0863	0.0175	0.4583	0.0968
2	−5.8650	1.1904	−0.2416	−0.8204	0.2155
3	1.4384	0.2402	0.0401	0.3812	0.0703
4	0.0027	−0.0171	0.1077	0.0085	−0.7316
5	−0.0352	0.0854	−0.2073	−0.1117	0.7742
6	−3.4449	−0.4708	−0.0643	−0.4595	−0.0716
7	2.1398	0.7495	0.2625	0.3147	0.2022
8	0.0000	−0.0001	0.0021	0.0439	−0.5198
9	0.0196	0.0407	0.0845	0.1350	0.4560
10	3.7790	−1.1475	0.3484	0.1445	−0.1497
11	0.3459	−0.4015	0.4661	0.0225	−0.5673
12	−2.3610	1.0598	−0.4757	−0.4707	0.4248
13	−0.4272	−0.5224	−0.6389	−0.2457	−1.0819
14	0.0000	0.0014	0.2029	−0.1974	0.7998
15	0.0016	0.0015	0.0014	0.0002	0.0015
16	1.7472	−0.4013	0.0921	0.5886	−0.1563
17	−0.0014	0.0142	−0.1356	0.0823	0.5076
18	2.5878	−0.5100	0.1005	0.3024	−0.0794
Total	0.3516	−0.0013	−0.0373	0.1771	0.1914

EXAMPLE 3

Surface No.	F-number = 1:2 r	d	Image Angle 2ω = 64° Nd	νd
1	84.454	5.07	1.60129	59.40
2	46.676	13.86	1	
3	103.080	7.73	1.72000	50.20
4	276.420	8.68	1	
5	−446.020	3.38	1.53172	48.90
6	79.609	14.68	1	
7	130.890	8.89	1.77250	49.60
8	−809.300	0.56	1	
9	211.680	25.94	1.80610	40.90
10	−57.195	4.45	1.61657	36.60
11	−486.000	15.77	1	
12	−87.415	6.58	1.71736	29.50
13	145.620	4.65	1	
14	−227.460	2.82	1.80518	25.40
15	823.080	10.56	1.75500	52.30
16	−70.518	0.56	1	
17	1034.700	7.22	1.77250	49.60
18	−145.000		1	

f = 100.0, b.f. = 105.02, L = 246.42
D = 86.1
$|(N_5-N_6)/r_{10}|$ = 0.00331 d_6/d_{11} = 0.931
$|f_{5\sim6}/f_{7\sim11}|$ = 1.8 $\nu_9-\nu_8$ = 26.9
r_7/r_9 = 0.618 $1/f_{1\sim4}$ = −0.00089

3rd-Order Aberration Coefficients

Surface No.	SA	CM	AS	PT	DS
1	0.3901	0.0783	0.0157	0.4473	0.0930
2	−5.6846	1.2779	−0.2872	−0.8094	0.2465
3	1.6059	0.2017	0.0253	0.4060	0.0542
4	−0.0343	−0.0554	−0.0893	−0.1514	−0.3880
5	0.0000	0.0004	−0.0027	−0.0778	0.5477
6	−4.4429	−0.3668	−0.0302	−0.4360	−0.0385
7	3.4135	0.8059	0.1902	0.3329	0.1235
8	0.0000	0.0015	−0.0278	0.0538	−0.4648
9	0.1145	0.1207	0.1274	0.2108	0.3568
10	3.1980	−0.9462	0.2799	0.1134	−0.1164
11	0.8466	−0.7187	0.6100	0.0784	−0.5844
12	−3.4863	1.4509	−0.6038	−0.4778	0.4501
13	−0.5338	−0.5534	−0.5737	−0.2868	−0.8921
14	0.0001	−0.0042	0.1786	−0.1960	0.7355
15	−0.0163	−0.0189	−0.0218	−0.0019	−0.0275
16	2.3245	−0.6044	0.1571	0.6099	−0.1994
17	−0.0156	0.0530	−0.1798	0.0421	0.4673
18	2.6848	−0.7344	0.2009	0.3005	−0.1371

-continued

Surface No.	3rd-Order Aberration Coefficients SA	CM	AS	PT	DS
Total	0.3640	−0.0121	−0.0311	0.1583	0.2261

What is claimed is:

1. A compact retrofocus type wide angle objective lens system comprising: from front to rear, a negative meniscus first lens convex toward the front, a positive second lens with its front surface having a strong positive power, a bi-concave third lens with its strong power surface facing the rear, a positive fourth lens with its front surface having a strong positive power, a positive cemented fifth lens with its cemented surface being convex toward the rear and having a positive power, and with its first surface being convex toward the front, a bi-concave sixth lens, a positive meniscus cemented seventh lens convex toward the rear, and a positive eighth lens with its strong power surface being faced toward the rear, and satisfying the following relationships:

$$\frac{0.33}{f} < \left| \frac{N_5 - N_6}{r_{10}} \right| < \frac{0.42}{f} \quad (1)$$

$$1.4 < \left| \frac{f_{5-6}}{f_{7-11}} \right| < 1.82 \quad (2)$$

$$0.4 < \frac{r_7}{r_9} < 0.64 \quad (3)$$

$$0.75 < \frac{d_6}{d_{11}} < 0.95 \quad (4)$$

$$20 < \nu_9 - \nu_8 < 28 \quad (5)$$

$$-0.1/f < 1/f_{1-4} < 0.15/f \quad (6)$$

where f is the focal length of the entire system; r_i is the radius of curvature of the i-th surface; d_j is the j-th axial lens thickness or air separation; N_k is the index of refraction of a material from which the k-th lens element is made; νl is the Abbe number of a material from which the l-th lens element is made; and f_{m-n} is the overall focal length of the m-th to n-th surfaces.

2. An objective lens system as described in claim 1, wherein said first and said second lenses are combined in fixed spatial relation as a group I, and said third to said eighth lenses are combined in fixed spatial relation as a group II, and wherein during focusing, whilst the entire system is axially moved relative to the film plane, said two groups I and II are axially moved in differential relation to each other.

3. An objective lens system as described in claim 1, and wherein said system has the following numerical data as related to a focal length of 100.

Surface No.	F-number = 1:2 r	d	Image Angle 2ω = 64° Nd	νd
1	80.127	5.07	1.60729	59.40
2	45.992	12.54	1	
3	97.715	10.21	1.72000	50.20
4	369.750	7.62	1	
5	−856.450	3.38	1.54869	45.60
6	71.127	17.65	1	
7	132.110	7.72	1.77250	49.60
8	9675.600	0.56	1	
9	219.290	16.88	1.80610	40.90
10	−56.941	4.44	1.59551	39.20
11	−608.610	19.38	1	
12	−88.811	7.80	1.72825	28.50
13	151.610	4.20	1	
14	−236.920	2.82	1.80518	25.40
15	524.560	10.42	1.77250	49.60
16	−72.310	0.56	1	
17	1536.100	7.76	1.77250	49.60
18	−130.130		1	

4. An objective lens system as described in claim 1, and wherein said system has the following numerical data as related to a focal length of 100.

Surface No.	F-number = 1:2 r	d	Image Angle 2ω = 64° Nd	νd
1	82.079	5.07	1.60311	60.70
2	45.851	12.64	1	
3	107.720	9.92	1.69700	48.50
4	−4830.700	6.69	1	
5	−317.040	3.38	1.54869	45.60
6	77.090	15.41	1	
7	138.440	7.67	1.77250	49.60
8	−990.830	0.56	1	
9	330.460	17.67	1.80610	40.90
10	−54.417	4.45	1.58144	40.70
11	−1629.900	20.42	1	
12	−91.389	8.48	1.75520	27.50
13	175.110	3.89	1	
14	−217.940	2.82	1.75520	27.50
15	248.680	13.84	1.75700	47.90
16	−73.184	0.56	1	
17	529.010	9.03	1.77250	49.60
18	−144.071		1	

5. An objective lens system as described in claim 1, and wherein said system has the following numerical data as related to a focal length of 100.

Surface No.	f-number 1:2 r	d	Image Angle 2ω = 64° Nd	νd
1	84.454	5.07	1.60129	59.40
2	46.676	13.86	1	
3	103.080	7.73	1.72000	50.20
4	276.420	8.68	1	
5	−446.020	3.38	1.53172	48.90
6	79.609	14.68	1	
7	130.890	8.89	1.77250	49.60
8	−809.300	0.56	1	
9	211.680	25.94	1.80610	40.90
10	−57.195	4.45	1.61659	36.60
11	−486.000	15.77	1	
12	−87.415	6.58	1.71736	29.50
13	145.620	4.65	1	
14	−227.460	2.82	1.80518	25.40
15	823.080	10.56	1.75500	52.30
16	−70.518	0.56	1	
17	1034.700	7.22	1.77250	49.60
18	−145.000		1	

* * * * *

United States Patent [19]

Bäab et al.

[11] **4,229,094**

[45] **Oct. 21, 1980**

[54] **CAMERA WITH TRANSVERSELY DISPLACEABLE OBJECTIVE**

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[73] Assignee: **Jos. Schneider GmbH & Co., Optische Werke Kreuznach,** Bad Kreuznach, Fed. Rep. of Germany

[21] Appl. No.: **2,743**

[22] Filed: **Jan. 11, 1979**

[30] **Foreign Application Priority Data**

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[51] **Int. Cl.**[2] **G03B 17/56**

[52] **U.S. Cl.** **354/286**

[58] **Field of Search** 354/286, 202, 232, 233, 354/272

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Primary Examiner—Donald A. Griffin
Attorney, Agent, or Firm—Karl F. Ross

[57] **ABSTRACT**

A camera housing carries an objective whose optical axis O is tiltable and/or transversely shiftable with respect to a reference line A passing centrally through an exposure window for adjusting the position of an object plane and/or eliminating perspective distortion with shots taken at certain angles. A presettable iris diaphragm and an adjoining shutter in the lens assembly of the objective are tripped, at the instant of exposure, by a deformable linkage in the shape of an articulated or flexible shaft extending generally parallel to the optical axis from the housing to the objective.

4 Claims, 3 Drawing Figures

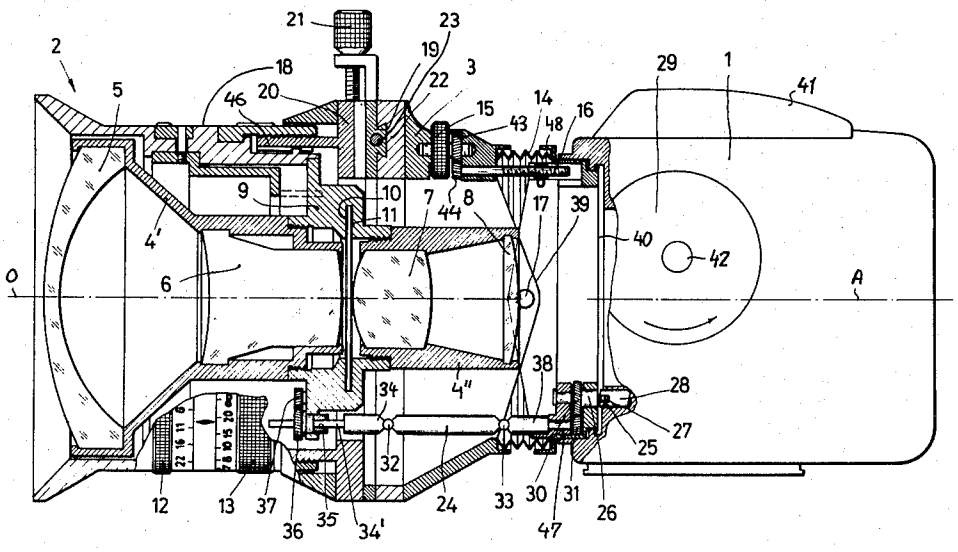
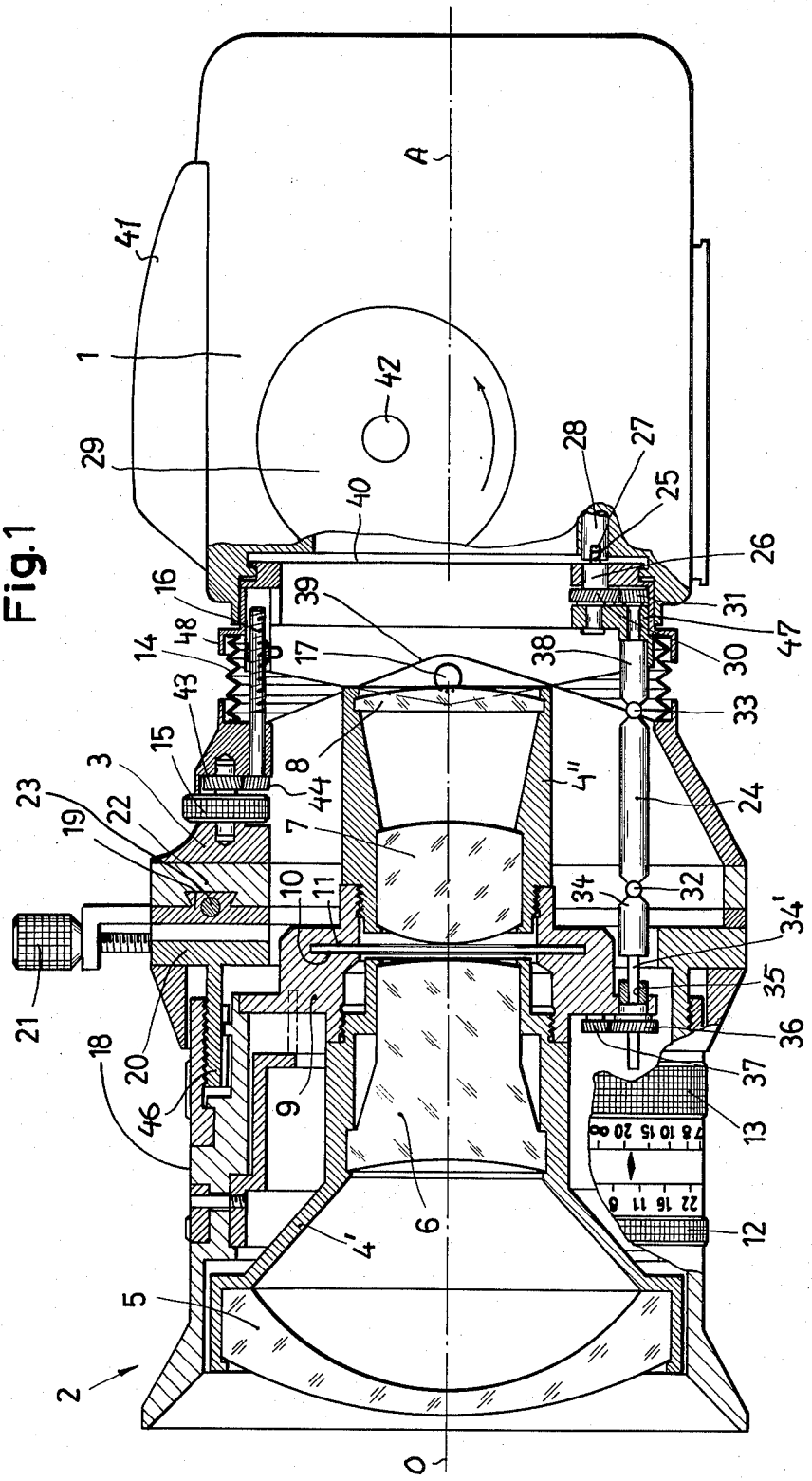


Fig.1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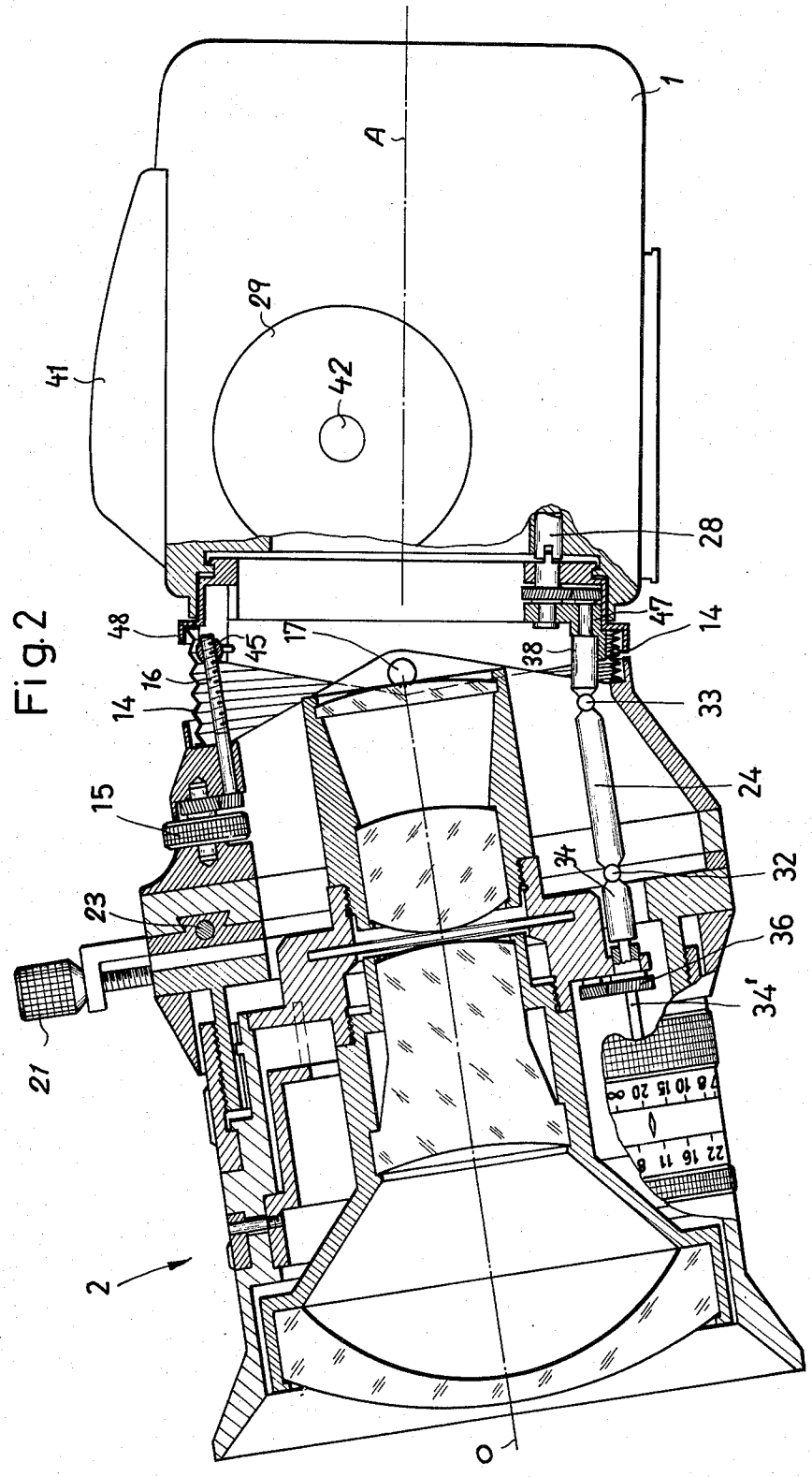
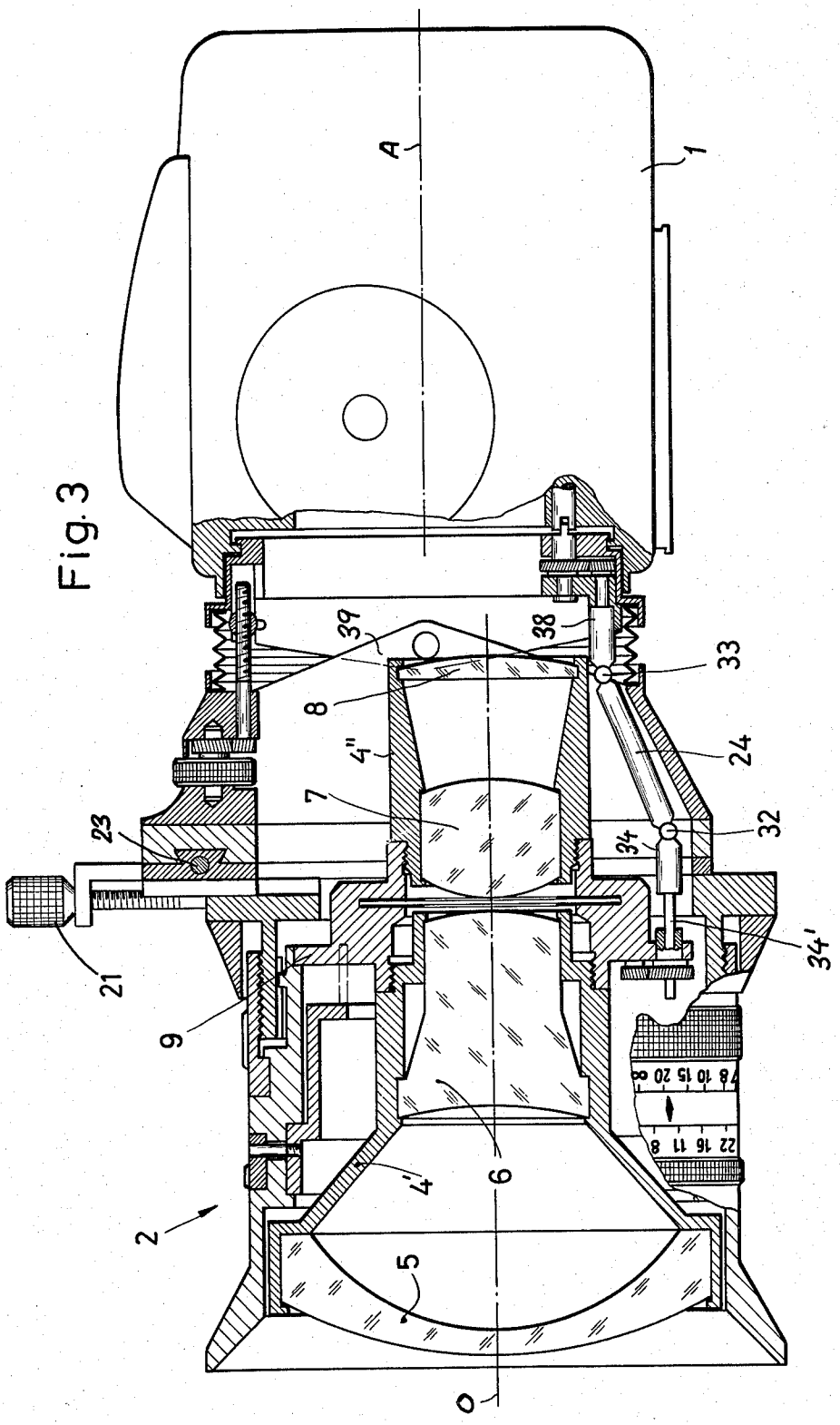


Fig. 2

Fig.3



CAMERA WITH TRANSVERSELY DISPLACEABLE OBJECTIVE

FIELD OF THE INVENTION

Our present invention relates to a photographic camera whose objective is transversely displaceable (i.e. tiltable and/or shiftable) for the purpose of adjusting the position of an object plane and/or eliminating perspective distortion.

BACKGROUND OF THE INVENTION

In a camera whose objective has a optical axis coinciding with a reference line perpendicular to the surface of a film or other photosensitive medium, generally at the center of an exposure window formed by the camera housing, the object plane lies parallel to the image plane constituted by the film surface. When the objective is tilted so that the optical axis includes an angle other than 90° with the image plane, the image and object planes as well as the diaphragm plane of the objective intersect (according to Scheimpflug's law) along a common line at a finite distance from the axis. Such a tilting can therefore be used to bring objects into sharp focus which do not all lie in a relatively narrow zone transverse to the field of view.

A parallel shifting of the objective from its normal position is useful for the purpose of suppressing perspective distortion, e.g. when it is desired to take pictures of a tall building.

Objectives capable of either or both types of transverse adjustment are already well known. In such camera, however, it is generally not possible to trip the shutter of the objective by operating a pushbutton or similar release means on the camera housing. The setting of the diaphragm to a preselected stop during the taking of a picture, from a wide-open position in which the diaphragm is placed for view-finding and focusing purposes, also requires manipulation of a trigger at the objective in lieu of the more convenient operation of a control element (usually coupled with the release button) on the housing.

OBJECT OF THE INVENTION

The object of our present invention is to facilitate, in a camera of the character described, the actuation of exposure-controlling means on the objective (such as a shutter possibly associated with a presettable diaphragm) with the aid of release means on the camera housing.

SUMMARY OF THE INVENTION

We realize this object, in accordance with our present invention, by the provision of a deformable linkage extending generally parallel to the optical axis from the release means on the housing to the exposure-controlling means on the objective.

Such a linkage, pursuant to a more particular feature of our invention, comprises a shaft which is rotatable upon operation of the release means and has extremities that are independently tiltable relatively to a central portion. While a flexible shaft may be used for this purpose, we prefer to employ an articulated one with two universal joints enabling a mutually parallel displacement of opposite shaft extremities as well as a relative tilting thereof.

BRIEF DESCRIPTION OF THE DRAWING

The above and other features of our invention will now be described in detail with reference to the accompanying drawing in which:

FIG. **1** is a side view, partly in axial section, of a camera embodying our invention;

FIG. **2** is a view similar to FIG. **1** but showing the camera objective tilted with respect to its housing; and

FIG. **3** is another view similar to FIG. **1** in which the objective has been transversely shifted from its normal position.

SPECIFIC DESCRIPTION

In FIG. **1** we have shown a camera with a housing **1** and a preferably exchangeable objective **2** having lens members **5**, **6**, **7**, **8** supported by front and rear lens mounts **4'**, **4''**. The two lens mounts are interconnected by an internally threaded ring **9** which is rigid with a front tube **18**. This tube is connected with an annular supporting body **3** through the intermediary of a pair of cross-slides constituted by three dovetailed members **19**, **20** and **22**, member **20** being an annular disk integral with a skirt **46** which is threaded into tube **18**. Members **19** and **20** are relatively slidable, in a vertical direction, under the control of a driver **21** including a knob whose stem is journaled in an extension of member **19** and threadedly engages member **20**. A similar driver **23** with a knob (not shown) and a threaded stem analogously coacts with members **19** and **22** for relatively displacing them in a horizontal direction. Thus, the lens-supporting tube **18** can be shifted in two dimensions with respect to body **3** which is pivoted to a coupling ring **48** by a pair of horizontally separated wings **39** (only one shown) for swinging in a vertical plane about respective pins **17**. A bellows **14** bridges the gap between housing **1** and objective body **3** in a lighttight manner; the camera-side end of the bellows is received within the ring **48** which is secured to the camera housing via the usual bayonet coupling.

The swinging of objective body **3** together with front tube **18** is manually controllable by a knurled wheel **15** which projects slightly from body **3** and is rigid with a gear **43** meshing with another gear **44** on a spindle **16** threadedly engaging a swivelable nut **45** (FIG. **2**) on a forward extension of coupling ring **48**.

Mounting ring **9** carries a conventional iris diaphragm **10** and a shutter **11** closely juxtaposed between lens members **6** and **7**. Diaphragm **10** is of the presettable type; in a manner known per se, it is held in a wide-open position during focusing and snaps into a preselected stop position just prior to the opening of the shutter **11**. The preliminary adjustment of the diaphragm is carried out with the aid of a presetting ring **12** while focusing is performed by a rotation of tube **18** via a ring **13** about its optical axis O, such rotation causing a relative axial shift between the lens support and the cylindrical skirt **46** threadedly engaged thereby.

The camera housing **1** carries a viewfinder **41**, illuminated through a nonillustrated reflex prism or mirror in line with the objective, and a release button **42**. A rotatable knob **29** on housing **1** serves for the advance of a film (not shown) whose photosensitive surface is perpendicular to a reference line A passing substantially midway through an exposure window at the front of the housing.

In accordance with our present invention, a displacement of release button **42** is transmitted to the dia-

phragm **10** and the shutter **11** by an articulated linkage including a shaft **24** extending generally parallel to optical axis O alongside the rear lens mount **4''**, thus outside the field of illumination. Shaft **24** has two extremities **34** and **38** connected with its central portion by a pair of universal joints **32** and **33** facilitating a relative tilting of these extremities (FIG. **2**) and/or a relative shifting thereof parallel to each other (FIG. **3**) under the control of wheel **15** and slide drivers **21, 23**. Rear extremity **38** is journaled in a bearing **47** fixedly secured to coupling ring **48** and is rotatably connected via a pair of meshing gears **30, 31** with a stub shaft **26**. Upon connection of objective **2** to housing **1** by its bayonet coupling, a tongue **25** on stub shaft **26** fits into a groove **27** of an extension shaft **28** which is drivingly connected with release button **42** so as to rotate upon depression of the latter. The front extremity **34** of shaft **24** terminates in a tongue **34'** slidably received by a transverse slot **35** (FIG. **3**) in the hub of a gear **36** which is journaled in mounting ring **9** and meshes with another gear **37** forming part of the otherwise nonillustrated, conventional shutter-trip mechanism. Thus, actuation of release button **42** causes the shaft **24** to rotate and to trip the shutter **11** along with the diaphragm **10**, placing that diaphragm in its preselected position while the picture is being taken. Button **42** may also retract the reflector of the viewfinder during the exposure.

In the normal position of FIG. **1**, optical axis O is aligned with reference line A so that the objective **2** is centered on the exposure window **40**. When it is desired to focus the camera on certain objects in a zone which is not parallel to the film plane, i.e. nonvertical in the case here assumed, the user operates the wheel **15** to adjust the objective to a tilted position such as that shown in FIG. **2**. When the object to be photographed requires an eccentric positioning of the objective to minimize perspective distortion, the user relatively shifts the dovetailed members **19, 20** and/or **19, 22** with the aid of driver **21** or **23**, e.g. as shown in FIG. **3**. The extent of these various adjustments, which may also be carried out concurrently, can be read on respective scales not shown.

The tongue **34'** of extremity **34** and the mating slot **35** of gear **36** form an extensible coupling which allows for changes in the effective length of the deformable linkage **24**. Thus, the position of FIG. **2** requires a deeper penetration of slot **35** by tongue **34'** whereas the position of FIG. **3** calls for a partial withdrawal of the tongue from the slot. These coupling elements, however, are so dimensioned as to remain interengaged in all operating positions, thus insuring positive torque transmission from pushbutton **42** to the shutter-trip mechanism. A similar effect is achievable if the tripartite link **24, 34, 38** is replaced by a continuous flexible shaft.

It will be apparent that such a linkage may also be used to control only the presettable diaphragm if the shutter is carried on the camera housing or on the coupling ring **48**, for example.

We claim:

1. In a camera comprising a housing with an exposure window and an objective secured to said housing for illuminating a photosensitive medium through said window, said objective being provided with exposure-controlling means and defining an optical axis normally aligned with a reference line passing substantially centrally through said window, adjustable mounting means securing said objective to said housing with freedom of disalignment of said optical axis from said reference line, and release means on said housing for initiating a picture-taking operation,

the combination therewith of a mechanical linkage extending generally parallel to said optical axis from said release means to said exposure-controlling means for actuating same upon operation of said release means, said linkage including a rotatable shaft having a central portion, a first extremity connected with said central portion on the side of said housing, and a second extremity connected with said central portion on the side of said objective, said extremities being independently tiltable relatively to said central portion.

2. The combination defined in claim **1** wherein said exposure-controlling means includes a drive member on said objective forming an extensible coupling with said second extremity.

3. The combination defined in claim **2** wherein said exposure-controlling means comprises a presettable diaphragm and a shutter disposed between two lens members forming part of said objective.

4. The combination defined in claim **1, 2** or **3** wherein said extremities are articulated to said central portion by a pair of universal joints.

* * * * *

United States Patent [19]

Kellner

[11] **4,226,518**

[45] **Oct. 7, 1980**

[54] **PHOTOGRAPHIC CAMERA HAVING LONG FOCAL LENGTH OBJECTIVE**

[76] Inventor: **Ferdinand Kellner**, Spittelmüllerstr. 6, 8940 Memmingen, Fed. Rep. of Germany

[21] Appl. No.: **38,119**

[22] Filed: **May 11, 1979**

[51] **Int. Cl.**[3] **G03B 17/48**; G03B 19/12; G03B 17/00

[52] **U.S. Cl.** **354/79**; 354/152; 354/293

[58] **Field of Search** 354/79, 219, 81, 224, 354/286, 150, 152, 155, 293; 114/340; 350/52

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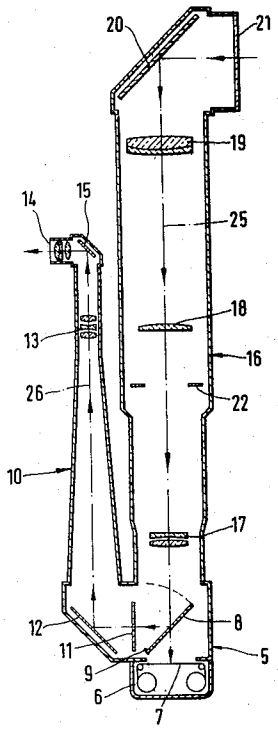
Primary Examiner—Donald A. Griffin
Attorney, Agent, or Firm—Holman & Stern

[57] **ABSTRACT**

In a photographic camera having a long focal length objective, both the objective and a tubular viewfinder extend vertically upwardly adjacent one another from the film carrying part of the camera which facilitates support of the camera in use. Preferably the objective and viewfinder are formed as a periscope arrangement with the light-admitting end of the objective being higher than the eyepiece of the viewfinder.

5 Claims, 2 Drawing Figures



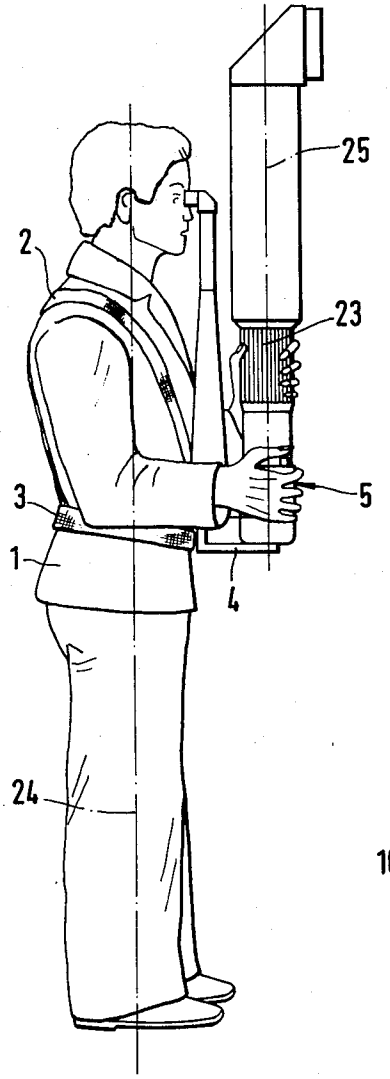
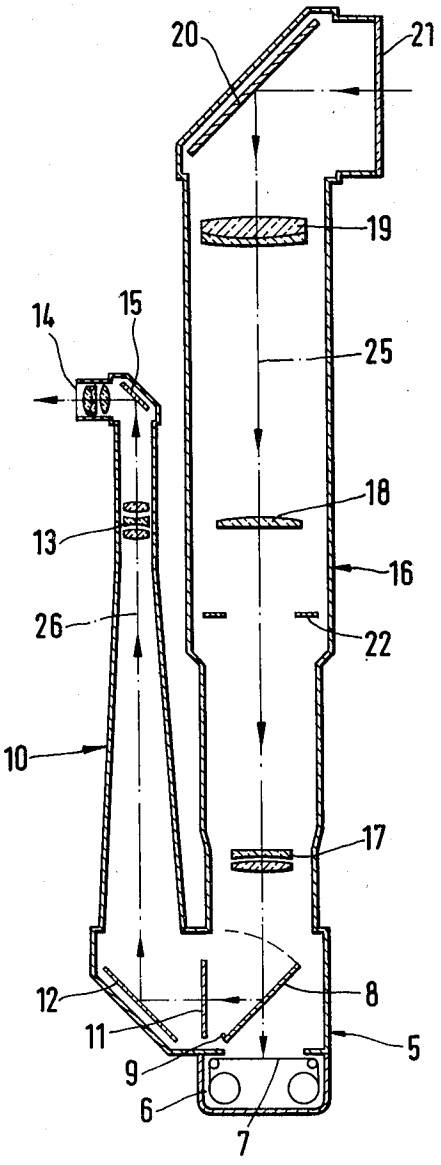


FIG. 1

FIG. 2



PHOTOGRAPHIC CAMERA HAVING LONG FOCAL LENGTH OBJECTIVE

BACKGROUND OF THE INVENTION

This invention relates to a photographic camera having a long focal length objective and a tubular viewfinder.

Photographic cameras with long focal length objectives are of considerable weight. In use, the unit comprising the objective and the camera must be held at eye level and directed towards the object which is being photographed. This holding at eye level in some cases must be maintained for a long time, since for example, in sports photography, the image must be captured at a very precise instant. The handling of a camera with a long focal length objective is therefore often fatiguing. At the same time, it is important that the objective and the camera be held very steady during release of the shutter.

Chest and shoulder braces are known by which the manipulation of such photographic assemblies is somewhat facilitated. However, since the center of gravity of the unit formed by the camera and the objective is located at some distance from the body of the photographer, where the apparatus extends horizontally from the photographer's eye, such supports are of limited effectiveness.

The additional use of a tripod is often not possible due to the local situation, and additionally, has the disadvantage that the mobility to direct the device at the object is reduced. In addition, a tripod is an extra load for the photographer if he wishes to change location.

There have been suggestions as to how to shorten the overall length of the objective lens assembly. This can be accomplished, for example, by the use of special optical systems in which the objective is in the form of a reflecting objective and/or the light path is deflected by means of a mirror or mirrors. The possible reduction in overall length by these techniques is however, limited. Furthermore, they have the disadvantage of increasing the diameter and weight of theobjective. They do not achieve a decrease in the burden on the photographer and moreover, such shortened objectives are also accompanied by optical disadvantages.

An object of this invention is to provide a photographic camera having a long focal length objective which as a result of its structure is less fatiguing on the photographer to handle than present designs. In particular, it is an object of the invention to provide a system or configuration which does not diminish the quality of the resulting photograph.

SUMMARY OF THE INVENTION

According to the invention, in photographic camera apparatus including a tubular objective of long focal length, the viewfinder is also in the form of a tube located next to the objective. In use, both the tubular objective and the viewfinder extend upwardly adjacent one another from the film carrying part of the apparatus and a light-deflecting mirror assembly is provided at the junction between the objective and the viewfinder for directing light from the light-admitting end of the objective to the viewfinder.

With this arrangement, the photographer does not have to hold the whole camera up to his eye or in front of his face while photographing but rather the camera can be held in a more comfortable position with its bulk situated below the photographer's eyes. Further, if the viewfinder is located next to the objective, the camera is in use in a position in front of the body of the photographer with the photographer looking down into the viewfinder and the optical axis of the objective assumes an essentially vertical position. The center of gravity of the device as a whole is relatively close to the photographer so that the resulting force moments are of low magnitude and can be easily managed by the photographer. This is of particular importance in a photographic session of lengthy duration.

An advantage which attaches to apparatus in accordance with the invention is the fact that light beams required for the photography are only reflected by a mirror which is in a location resulting in minimal effect on the image quality.

The additional cost occasioned by the construction of the viewfinder in the form of a tube is moderate.

The arrangement according to the invention makes it easy to bring the eyepiece of the viewfinder to eye level while the camera itself remains in a position which allows good support. The support of the camera can be facilitated, for example, by appropriate carrying straps in the form of a shoulder harness or body straps or even by the photographer wearing an item of clothing such as a vest or the like equipped with supporting means.

The viewfinder can be in the form of a telescope or in a further embodiment of the invention, it is proposed that the viewfinder be constructed in the form of a periscope. The result of the latter construction is that the photographer can maintain his normal head attitude in which he looks at the image in the viewfinder with one eye and may direct the other eye directly at the target. With a periscope viewfinder, as a rule, the light being passed is deflected by 90° twice, each time by a mirror assembly. While this may diminish the optical quality of the viewfinder image, the photograph itself is unaffected.

It is clear that the erect, normal body position in which the arms assume a position which can be maintained without fatigue, establishes conditions for a good photograph, since the danger of blurring resulting from unsteadiness is greatly reduced in this body position. Also, it is possible to maintain this body position for a relatively long time and thus to watch the object through the viewfinder for a long time as necessary for many photographs.

It is advantageous for the top part of the objective to project above the viewfinder. In the arrangement according to the invention, this results in the light-admitting end of the objective being at a height which for example, can extend over a crowd. This creates additional opportunities for picture taking under unfavorable external conditions.

The use of mirrors in photography is known as is the use of the above-mentioned type of mirror in the light-admitting end of the objective. The construction of the prior art devices have as their objects, for example, taking pictures "around a corner" or from a more or less concealed position, or by means of a kind of foxhole periscope or other periscope to establish a more favorable position for the entrance opening of the objective. The solution of a problem which would be comparable to that of the invention has not been attempted by these means.

In a preferred embodiment of the invention the objective has a light deflecting mirror at the light admitting

end with the light-admitting opening of the objective having an axis perpendicular to the general length of the tubular objective, i.e., with the axis of the opening being substantially parallel to the film plane.

DESCRIPTION OF DRAWINGS

FIG. **1** shows camera apparatus according to the invention with the objective and viewfinder in the positions in which they are used, and

FIG. **2** is a cross-sectional view of the apparatus.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENT

As shown in FIG. **1**, the photographer **1** carries for example, shoulder and hip straps **2** and **3**, to which a support element **4** is attached which serves to support the camera **5**. This camera comprises a viewfinder **10**, an objective **16**, and a film carrier in the form of a cassette **6** with a film **7** which in the arrangement shown is in the typical horizontal use position. A swinging mirror **8** is pivotal around a hinge **9** and a ground glass plate **11** is provided on which the image is viewed by means of the viewfinder.

The viewfinder, which is in the form of a periscope, has a mirror **12** at its lower end. It includes an optical system **13** and an eyepiece **14**. Deflecting mirror **15** is placed between the optical system and the eyepiece.

The entire viewfinder **10** can, if desired, be assembled as a unit which would include the mirror **12** and this unit may be removably attached to the camera. The viewfinder can also be integrally affixed to the camera and/or can have a telescopic i.e., collapsible construction in order to minimize the space requirement in the event of transport.

The objective of long focal length is designated **16** and comprises an optical system consisting of parts **17**, **18**, and **19**. At the upper end of the objective is a mirror **20** and a light-admitting opening **21** which is preferably covered with a transparent disc, not shown, in order to keep out contamination. The diaphragm of the objective is designated **22**.

The objective **16** has a focusing device which is not shown in detail and which for example is adjustable by means of a cylindrical tube **23**, FIG. **1**.

FIG. **1** makes clear the advantages of the invention. The camera with the objective and viewfinder is in such a position in front of the photographer **1** that the camera can be easily operated with one hand while the other hand operates the focusing device. The distance between the central plane **24** of the photographer and the optical axis **25** of the main part of the objective is relatively small so that the photographer basically need only support the weight of the device, i.e., he need not exert himself against substantial turning moments as when the objective is held horizontally. This is substantially facilitated by the straps **2** and **3**.

The optical axis **26** of the viewfinder is parallel to the optical axis **25** of the objective.

The invention can be modified in various ways although it is suggested that the embodiments according to the drawing affords the most satisfactory result. As an example of a modification, the viewfinder can be simplified such that the photographer looks down into it, with his head bent. This however, would have the disadvantage of an inconvenient and uncomfortable head position. Also in this case, the target object would not be easily followed with the free eye.

Deviations can be made from the exact parallel configuration of axes **25** and **26** without disadvantage, within limits, and in another variant of the invention the viewfinder can be located beside the objective so that the distances from the optical axes **25** and **26** to the central plane **24** are approximately equal.

In the embodiment shown in the drawings, the objective is longer than the telescopic viewfinder so that the opening **21** is displaced upwardly which affords the advantage of being able to photograph over a crowd. Good results may be achieved, however, if the lengths of the objective and the viewfinder are approximately the same.

The objective can be attached integrally and rigidly to the camera or this attachment can be accomplished removably as is provided by known means so that the objective as well as the viewfinder can be combined with whatever camera might be chosen.

For taking a photograph, the image on the ground glass screen **11** is viewed by a viewfinder in multiple magnification. For exposure, the mirror **8** is flipped away around hinge **9** so that the image can fall on the film **7**.

While only a single preferred embodiment of the invention has been described in detail, it will be appreciated that numerous modifications are possible within the scope of the invention as defined in the appended claims.

What I claimed is:

1. Portable photographic camera apparatus comprising a tubular objective of long focal length having a light-admitting end and a film carrier end, a tubular viewfinder having a junction with said objective between said film carrier end and said light-admitting end, said viewfinder being positioned adjacent said objective, said viewfinder and said objective having parallel longitudinal axes throughout most of their lengths, said viewfinder extending from said junction towards said one end of said objective and terminating in an eyepiece located longitudinally between said carrier end and said light-admitting end of said objective, and a light deflecting mirror means at the junction between said objective and said viewfinder for directing light rays from said light-admitting opening to said eyepiece.

2. The apparatus as defined in claim **1** wherein said viewfinder is detachable from said objective.

3. The apparatus as defined in claim **1** or **2** wherein said viewfinder is in the form of a periscope.

4. The apparatus of claim **1** including a light-admitting opening at said light-admitting end of the objective, said opening having an axis substantially perpendicular to the length of the objective and a further light deflecting mirror means at said light-admitting end for directing light from said opening towards said film carrier end.

5. The apparatus of claims **1**, **2** or **4** further comprising a support element secured to said film carrier end and strap means secured to said support element for supporting the camera on the body of a photographer.

* * * * *

United States Patent [19]

Rosner et al.

[11] **4,219,261**

[45] **Aug. 26, 1980**

[54] **PHOTOGRAPHIC CAMERA WITH A MEANS FOR COORDINATING AND INDICATING DEPTH OF FIELD FOCUSING AND OBJECTIVE SETTING VALUES**

[76] Inventors: **Ortwin Rosner**, Hiltenspergerstrasse 58, 8000 Munchen 40; **Karl-Peter Strauss**, Am Feuerteich 9, 3300 Braunschweig-Volkmarode, both of Fed. Rep. of Germany

[21] Appl. No.: **968,333**

[22] Filed: **Dec. 11, 1978**

[30] **Foreign Application Priority Data**

Dec. 12, 1977 [DE] Fed. Rep. of Germany 2755368

[51] **Int. Cl.**[2] **G03B 3/08**; G03B 17/18

[52] **U.S. Cl.** ..... **354/23 D**; 354/60 L; 354/196; 354/198

[58] **Field of Search** ..... 354/25, 195, 196, 23 D, 354/60 L, 198

[56] **References Cited**

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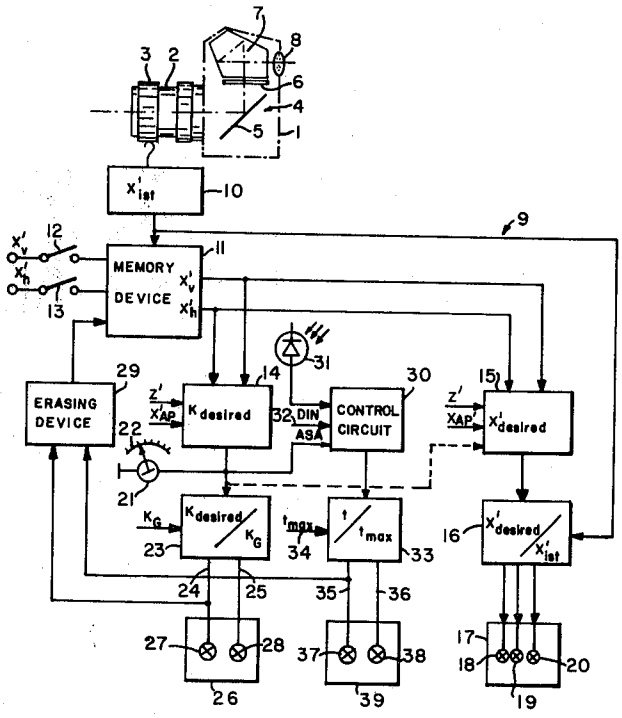
Primary Examiner—L. T. Hix
Assistant Examiner—William B. Perkey
Attorney, Agent, or Firm—Schwartz, Jeffery, Schwaab, Mack, Blumenthal & Koch

[57] **ABSTRACT**

A photographic camera having an objective, a viewfinder coupled to said objective and comprising means for converting the setting of the objective into electrical signal values, x'_{actual}, memory storage means for storing the electrical signal values, the memory storage means storing a first signal value, x_v', corresponding to the objective setting associated with a far point desired to be photographed, and for storing a second signal value, x_h', corresponding to the objective setting associated with a near point desired to be photographed, and calculator means connected to the memory storage means for automatically calculating a desired stop figure, $k_{desired}$, and a desired distance-setting value, $x'_{desired}$, associated with the first and second signal values.

16 Claims, 3 Drawing Figures



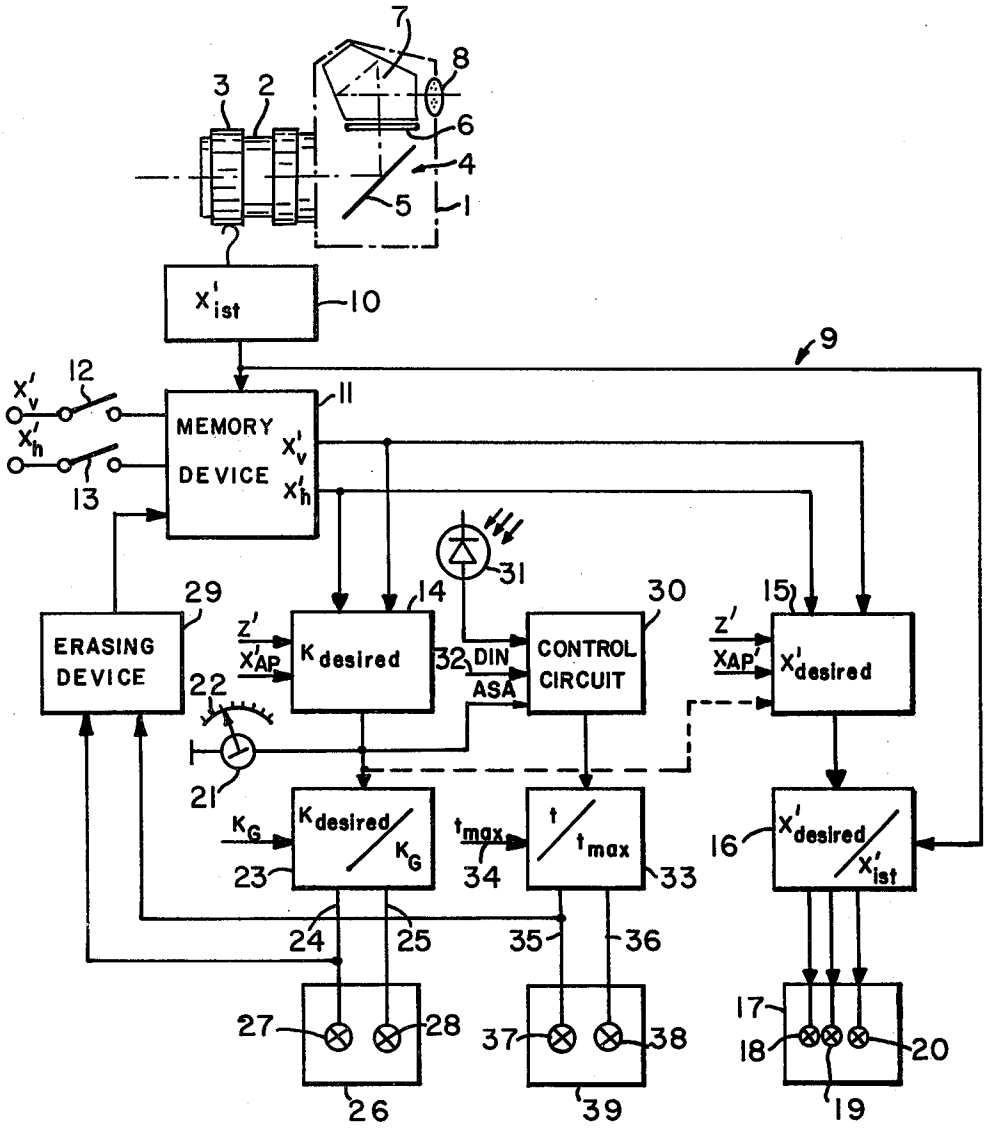

7
8
3
2
6
4
5
1
x'_{ist}
10
9
12
x'_v
x'_h
13
MEMORY DEVICE
11
31
29
14
30
15
ERASING DEVICE
Z'
X'_{AP}
$K_{desired}$
32
DIN
ASA
CONTROL CIRCUIT
$x'_{desired}$
22
21
K_G
$K_{desired}/K_G$
23
t_{max}
t/t_{max}
34
33
16
$x'_{desired}/x'_{ist}$
24
25
35
36
27
28
37
38
17
18
20
26
39
19

FIG. 1

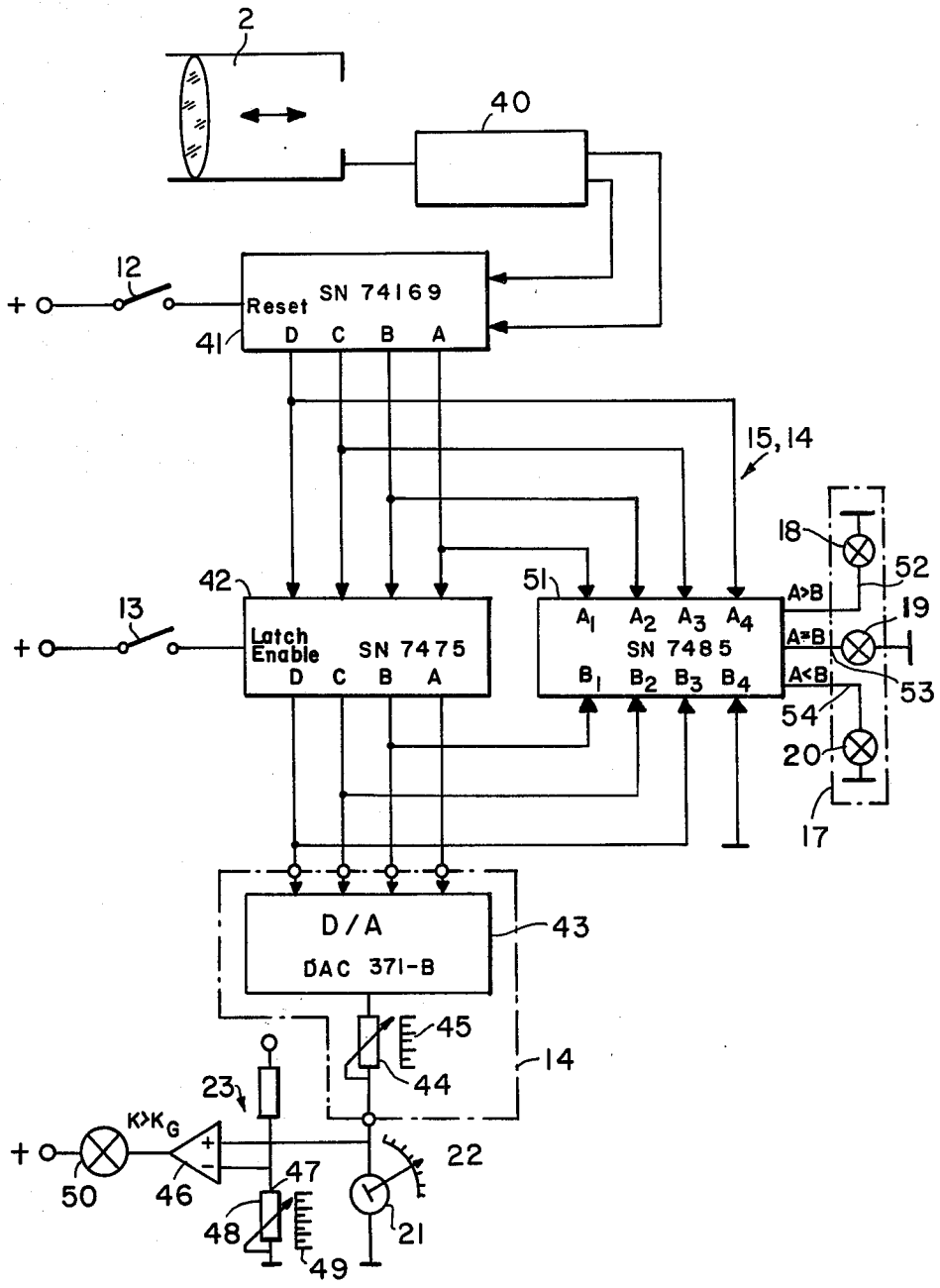

2
40
12
+
Reset
SN 74169
D C B A
41
15,14
18
52
42
51
A>B
19
13
+
Latch Enable
SN 7475
D C B A
A1 A2 A3 A4
SN 7485
B1 B2 B3 B4
A=B
A<B
53
54
20
17
D/A
DAC 371-B
43
45
14
44
23
K>KG
+
50
46
47
22
48
21
49

FIG. 2

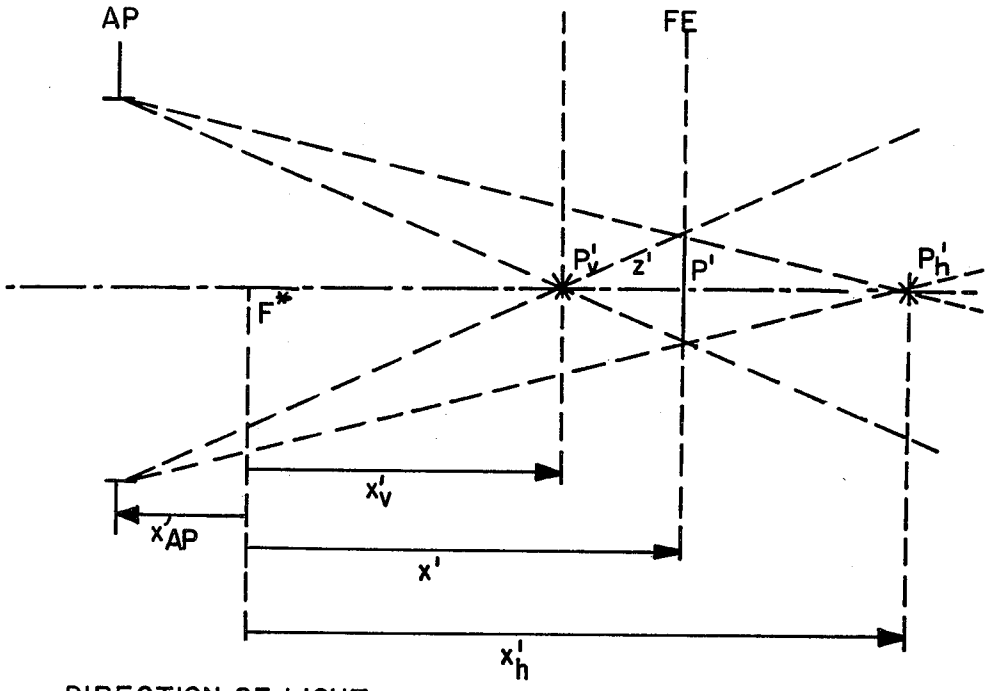


FIG. 3

REFERENCE MARKS IN FIG. 3

FE	FILM PLANE
AP	EXIT PUPIL
F*	FOCAL POINT
P_v'	IMAGE OF P_v
P_h'	IMAGE OF P_h
x_{AP}'	POSITION OF AP BASED ON F*
x'	POSITION OF FILM (COLLECTING, RECEING) PLANE BASED ON F*, OFTEN ALSO CALLED THE "EXTENSION LENGTH"
x_v', x_h'	POSITION OF IMAGES OF FORWARD OR REAR FOCAL PLANE
z'	DIAMETER OF THE PERMITTED CIRCLE OF DIVERGENCE IN THE IMAGE SPACE

PHOTOGRAPHIC CAMERA WITH A MEANS FOR COORDINATING AND INDICATING DEPTH OF FIELD FOCUSING AND OBJECTIVE SETTING VALUES

BACKGROUND OF THE INVENTION

The invention relates to a photographic or cinematic camera with an objective, a measuring view finder which is coupled to the objective, and a device for coordinating and indicating focal depth range and objective-setting values such as stop and distance. In a camera of this type, the measuring view finder which is coupled to the objective serves for sharply setting the sighted exposure object can also be equipped with a clearness indicator which considerably facilitates sharp focusing.

In one known camera of this type, a distance-setting ring which is provided with distance marks is rotatably arranged on the objective, which is adjustable on an index which is stationarily fixed to the objective. On both sides of the index are fixed in paris, marks for various stop figures. If a certain distance mark of the distance-setting ring coincides with the index, the stop figure marks which are located on both sides of the index, when compared with the other distance-setting marks of the objective-setting ring, indicate the so-called focal depth zone, i.e. the depth of the sharply reflected exposure (photographic) space, which is achieved with a selected stop figure. If, for example, in a camera with certain objective data, the 2 m distance mark is set on the index, the 1.5 m and 3 m distance marks face the two stop figure marks 8 and the distance marks 1.2 m and 6 m face the two stop figure marks 22. It is therefore indicated to the camera user, that with a distance setting of 2 m, the focal depth range which can be expected is from 1.5 m to 3 m with a stop figure 8, and is from 1.2 m to 6 m with a stop figure of 22.

This known device for the optically correct coordination of focal depth range and objective, setting values for stop and distance, which is usually known as a focal depth scale, can be used by the photographer to determine the desired depth of the exposure space which is desired for his motif and therefore the focal depth zone, but this process is very intricate, as no fewer than six time-consuming manipulations have to be mastered for this:

1. Focusing of the far point, that is, of the boundary point of the desired exposure space lying furthest removed from the camera;
2. Reading-off of the distance set on the distance-setting ring and noting of this distance figure;
3. Focusing of the near point and therefore of the boundary point of the desired exposure space situated nearest the camera;
4. Reading-off of the distance set thereby on the objective ring and noting of this distance figure;
5. Rotating of the distance-setting ring to a position where the two noted distance figures each face one pair of stop figure marks located on both sides of the index; and
6. Setting of the stop figure so found in the camera.

In this complicated process, the fact is really basically that the focal depth scale is not used in this way to determine the exact focal depth range, but in most cases serves merely to inform the camera user as to what focal depth can be expected with a set distance and stop. The photographer then estimates this stated focal depth range usually by comparison with the exposure object and judges whether the obtainable focal depth range is adequate for his motif or not.

The problem which therefore underlies the invention is to produce a camera of the type hereinbefore mentioned, with which the focal depth, and therefore the depth of the sharply reflected exposure space can be determined and fixed exactly with few manipulations, and in which the objective-setting values which are necessary for the desired focal depth range are made available rapidly and automatically without the photographer having to undertake time-consuming reflections and calculations. The assembly of the camera and the coordination device must be constructionally simple here, without complicated mechanical gearing, and be advantageous from a manufacturing technological point of view.

SUMMARY OF THE INVENTION

This problem is solved according to the present invention in a camera of the above-mentioned type, in that the device for coordinating and indicating focal depth range and objective-setting values has:
an Is value transmitter, which converts the distance objective-setting value into an electrical signal, a memory device connected to the Is value transmitter, for a first signal corresponding to the objective setting during focusing on a voluntarily selected far point and a second signal corresponding to the objective setting during focusing on a voluntarily selected near point, where the far and near point define the desired exposure space which is to be reflected within the focal depth range, a first calculator connected to the storage (memory) device, for determining the desired stop figure in dependence upon the stored signals, a second calculator connected to the memory device, for determining the desired distance-setting value of the objective in dependence upon the stored signals, a first comparator, which device reacts with coincidence and/or variation in the output signals of Is value transmitter and second calculator.

In the case of the camera according to the invention, the camera user merely needs to determine this focal depth range by focusing the far and near point which determines the focal depth range. Everything else is carried out automatically in the camera. The signals corresponding to the distance setting to the near point and the signals corresponding to the distance setting to the far point are stored in a memory device. From these stored signals, the first calculator calculates the stop figure which is necessary for this focal depth range, and the second calculator calculates the distance setting of the objective which is necessary for this range. The output signal, according to further specific embodiments of the invention, can either be optically, so that the photographer can set the read-off figure on the camera, or, for example, in the case of a camera with exposure time automatics—can be further processed directly for obtaining the exposure time. The output signal of the second calculator is conveyed to a comparator which is permanently connected to the Is value transmitter. The result of the comparison of the output signals of the second calculator and the Is value transmitter, which in each case represent the desired value of the distance setting and the actual value of the distance setting, can be read off by the photographer on the indicator device. The photographer need only actuate

the distance-setting ring until the indicator device signals to him by a stop signal that the exact distance has been set. The photographer must therefore carry out all the following operations:

1. Sharp setting (focusing) of the desired far point in the measuring viewfinder and pressing of the memory device button,
2. Sharp setting of the desired near point and pressing of the memory device button, and
3. Actuating of the distance-setting device until the indicator device delivers a stop signal.

These few manipulations for exact determination of the focal depth range and determination of the necessary objective-setting values can be carried out by the photographer without the camera being taken away from the eye. The stop signal of the indicator device advantageously appears in the camera viewfinder. As the photographer merely had to actuate the distance-setting device and a corresponding memory device button for this, this setting operation can be carried out very rapidly. The necessary few structural elements are all of an electronic nature and in normal commercial use. The electrical connection of such electronic components is unproblematical, so that the construction of the camera is altogether exceptionally advantageous from a manufacturing technology point of view.

One specific embodiment of the invention is distinguished by a second comparator which is connected to the output of the first calculator and which is fed with an electrical signal characterizing the largest stop figure of the objective, and has at least one first output, at which a signal occurs if the desired stop figure ascertained by the first calculator is larger than the largest stop figure of the objective. In this design of the invention, the camera recognizes when the stop figure which is necessary for a focal depth range is larger than the highest stop figure available in the objective and can therefore not be set. According to further specific embodiments of the invention, this result is signalled to the photographer either via an indicator device, so that with a new determinationof the focal depth range, he can reduce the latter, and/or is simultaneously conveyed to an erasing device which is thereby activated and erases the stored signals, so that the photographer is obliged to determine the focal depth range again.

According to a further specific embodiment of the invention, there is connected to the output of the first calculator, a known control circuit for the automatic determination of the exposure time in dependence upon the brightness of the object, sensitivity of the film and the stop.

In this way, the desired stop figure ascertained by the first calculator is used to ascertain the necessary exposure time.

According to a further specific embodiment of the invention, a third comparator which is connected to the output of the control circuit and which is charged with a signal corresponding to a predetermined maximum exposure time, and has at least one first output, at which an output signal occurs if the exposure time which is determined by the control circuit is longer than the predetermined exposure time. A fourth indicator device connected to the third comparator shows coincidence or variation in the two exposure times, so that the camera user, when the warning signal in the indicator device lights up, recognizes that the predetermined maximum exposure time has not been reached. He is again obliged to reduce the focal depth range in order to be able, with the given brightness of the object and the sensitivity of the film which is used, to take an exposure with a maximum predetermined exposure time, for example, 1/30 sec, for manual exposures.

In a further specific embodiment of the invention, the Is value transmitter for the distance objective-setting value is constructed as an incremental path transmitter which is connected to the inputs of a reversible digital counter, also known as an up/down counter, whose reset input is connected to a manually operable pulse switch. Such as incremental path transmitter produces, in known manner, impulses the number of which is proportional to a traveled path. This incremental path transmitter can be connected mechanically, for example, to the objective-setting ring, a distance-setting ring located in the camera body or to the movable part of the objective, so that in each case it comprehends the setting movement of this part. During focusing on the far point, the incremental path transmitter will deliver impulses to the digital counter and set it. By manual closing of the pulse switch, the digital counter is put back into its initial position. If focusing on the near point takes place, the incremental path transmitter delivers an appropriate number of impulses which are counted by the counter, so that after focusing on the near point has taken place, there occurs at the counter output a certain binary combination which represents a dimension of the depth of the exposure space and therefore of the difference in the distance from the far point to the near point. As the counter is constructed as a reversible digital counter, it is of no importance if, during focusing, the actual focal point is overrun several times in different directions.

According to a further specific embodiment of the invention, the memory device is constructed as a digital memory device (latch), whose inputs are connected to the outputs of the digital counter and whose latch-enable input is connected to a manually operable pulse switch. The binary combination which occurs at the outputs of the reversible digital counter as a result of the movement of the objective, is accepted in the memory device by manual closing of the pulse switch and occurs as a corresponding binary combination at the outputs of the memory device. If the pulse switch is opened again, the binary combination at the outputs of the digital counter or at the inputs of the memory device can be varied as desired, without the binary combination at the outputs of the memory device being affected thereby.

According to a further specific embodiment of the invention, the first calculator is composed of a digital analog converter whose digital inputs are connected to the outputs of the digital memory device and of a resistance whose first connection is connected to the analog output of the digital analog converter and whose second connection forms the output of the first calculator. The resistance value represents the input dimension of the permitted circle of divergence in the image space, which is necessary in order to calculate the desired stop figure according to an equation which has still to be explained. It is sufficient for qualitatively useful pictures if this divergence circle diameter is fixed at 50 μ.

According to a further specific embodiment of the invention, this resistance is adjustably constructed and has a settinf scale which is calibrated in diameter dimensions of the permitted circle of divergence of the object point which is reflected in the image (picture) plane. As a result of this, the photographer has the possibility of

varying the size of the diameter of the circle of divergence for certain photographic purposes.

According to a further specific embodiment of the invention, the second calculator and first comparator are combined into one structural unit which is composed of a digital comparator with two input series. The n bit inputs of the one input series are connected to the n bit outputs of the digital counter, the n-1 bit inputs of the second input series are connected to the 2 bit to n bit outputs of the digital memory device and the n bit input of the second input series is connected to zero potential. This simple construction of the second calculator in conjunction with the comparator can be achieved by an approximate calculation of the necessary desired distance setting with a predetermined focal depth range, which is not examined in greater detail in the specification. According to this calculation, the desired distance is half the difference in the distances of the far and near point. As a result of the aforedescribed construction of the second calculator and the comparator, the desired value transmitter must be adjusted until the counter state, i.e. the number of counting impulses comprehended in the counter, is half the impulses stored in the memory device. The first indicator device delivers a signal as soon as this state of the counter is reached, by which the exact distance setting of the objective within the predetermined focal depth range is given.

Further specific embodiments of the invention are represented in the claims, to which reference is expressly made herein.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention is explained in greater detail hereafter by reference to an exemplified embodiment which is represented in the drawing wherein:

FIG. **1** shows a block diagram of the fundamental construction of the camera according to the invention;

FIG. **2** shows the schematic diagram of one possible technical exemplified embodiment; and

FIG. **3** shows a graphic representation to explain the definition of the optical computational figures used in the specification.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

In the block diagram in FIG. **1**, the camera housing **1** is represented in dot-dash lines. The objective **2** is mounted on the front of the camera, which objective carries a rotatable setting ring **3** for distance-setting. In the camera housing **1** is provided a measuring viewfinder **4** which is constructed as a reflex viewfinder and is composed of a pivotable mirror **5**, a setting disc **6**, a pentaprism **7** and an eyepiece **8**. A clearness indicator, such as for example, a measuring wedge prism or microscreen, can be provided in the measuring viewfinder in order to facilitate sharp setting of the exposure object on the setting disc **6**.

The device **9** for optically correct coordination and indication of focal depth range and stop and distance objective-setting values has a series of structural elements which are described in greater detail hereafter.

An Is value transmitter **10**, which converts the objective-setting value for distance into an electrical signal is coupled in FIG. **1** to the setting ring **3** via a mechanical feeler. The mechanical feeler is responsive to the rotating movement of the setting ring and converts this rotation into corresponding electrical signals. The mechanical feeler of the Is value transmitter **10** can, however, be coupled to a distance-setting mechanism located in the camera housing **1** or directly to the adjustable lens mounting of the objective and in each case be responsive to the adjusting movements of these elements.

The output of the Is value transmitter **10** is connected to a memory device **11**, in which two signals can be stored either individually or in a mathematical combination. The storage of the signals takes place by closing the two memory device switches **12** and **13**, whereby in each case, the signal occurring at the output of the Is value transmitter **10** is accepted in the memory device **11**. If the objective **2** is focused on an optional far point by rotating the setting ring **3**, there occurs at the output of the Is value transmitter **10**, a signal x_v' which corresponds to this distance which signal, through temporary closing of the memory device switch **12**, is accepted in the memory device **11**. Similarly, when focusing an optional near point, there occurs at the output of the Is value transmitter **10**, a signal x_h', which corresponds to the distance of the near point and is accepted in the memory device when the memory device switch **13** is pressed. The desired depth of the exposure space which is to be sharply reflected is fixed by these two points and defined by the signals x_v' and x_h', which are stored in the memory device **11**. As is evident from the graphic representation in FIG. **3**, the signals x_v' and x_h' are a dimension for the spacing of the front or rear clearness plane from the focal point F^x of the objective.

The memory device **11** is connected to a first calculator **14** for determining the desired stop figure $k_{desired}$ in dependence upon the stored signals x_v' and x_h'. The desired stop figure is ascertained by the calculator in accordance with the following equation:

$$k = \frac{x_h' - x_v'}{2z'} \cdot \frac{1}{1 - \frac{x_h' + x_v'}{2x'_{AP}}} \tag{1}$$

where

x'_{AP} = the spacing of the exit pupil AP from the focal point F of the objective, and

z' = the diameter of the permitted circle of divergence in the film plane.

The graphic representation of the values x'_{AP} and z' can likewise be gathered from FIG. **3**. The value x'_{AP} is an objective constant and is introduced into the first calculator **14** as an input figure. In the case of varying objectives, it must be ensured that in each case the corresponding x'_{AP} value is introduced into the calculator. The z' value is essentially standardized, and in normal cameras reaches 50 μ. This z' value is likewise introduced as an input figure in the first calculator **14**. For special purposes it may be desirable for this z' value to be variable. In such cases a setting device must be provided for the z' value, said device being manually adjustable and connected at its output with the first computer **14**.

The memory device **11** is furthermore connected to a second calculator **15**, which determines the desired distance-setting value $x'_{desired}$ of the objective in dependence upon the stored signals x_v' and x_h' in accordance with the following equation:

$$x' = \frac{x_v' + x_h'}{2} \left[1 - \left(\frac{x_v' - x_h'}{x_v' + x_h'} \right) \frac{z' \cdot k}{x'_{AP}} \right] \tag{2}$$

In the graphic representation in FIG. 3, this desired distance-setting value represents the position of the film plane based on the focal point F of the objective, frequently also called the extension length. The values z' and x'_{AP} are likewise introduced into the second calculator **15** as input figures. In order to produce a simple construction of the calculator **15**, the output of the first calculator **14** can be connected to the input of the second calculator **15**—as represented in dotted lines in FIG. 1. In this case, the desired stop figure ascertained by the first calculator **14** from the values x_h', x_v', z' and x'_{AP} can be introduced into the second calculator **15**, so that the latter does not have to carry out the same computing operation again, which, as can easily be seen from the equations (1) and (2), would be the case if the second calculator **15** merely had to process the input figure x_v', x_h', z' and x'_{AP}.

To the output of the second calculator **15** is connected a first comparator **16**, which on the other hand is connected to the output of the Is value transmitter **10**. In this first comparator **16** there occurs a comparison of the desired distance-setting value $x'_{desired}$, ascertained by the second calculator **15**, with the actual Is distance-setting value x'_{actual} which is set on the objective. The result of this comparison is conveyed to a first indicator device **17**, which is connected to the first comparator **16**. This indicator device contains 3 indicator elements **18**, **19** and **20**, which are connected to the outputs of the first comparator **16** in such a way that the indicator element **18** reacts when $x'_{actual}<x'_{desired}$; the indicator element **19** reacts when $x'_{actual}=x'_{desired}$; and the indicator element **20** reacts when $x'_{actual}>x'_{desired}$. If the two indicator elements **18** and **20** are quenched by the preferably optical indicator elements **18**, **19** and **20**, and only the indicator element **18** lights up, the desired distance $x'_{desired}$ is set in the objective.

The output of the first calculator **14** is furthermore connected to a second indicator device **21**, which, in the exemplified embodiment in FIG. **1**, is constructed as a galvanometer. The indicator device has a scale **22** which is calibrated in stop figures, whereby the desired stop figure $k_{desired}$ ascertained by the first calculator **14** can be read off.

The output of the first calculator **14** is furthermore connected to a second comparator **23**, to which a signal denoting the maximum stop figure of the objective k_G is conveyed as an input figure. This maximum stop figure is an objective constant. In a camera with varying objectives, care must be taken that this respective objective constant is introduced into the second comparator **23**. The comparator **23** compares the desired stop figure $k_{desired}$ ascertained by the first calculator **14** with the maximum settable stop figure k_G of the objective. The second comparator **23** has two outputs. At the first output **24** there occurs a signal when $k_{desired}$ ascertained by the first calculator **14** on the basis of the predetermined focal depth range cannot be set with the objective. At the second output **25** of the second comparator **23** there occurs a signal when $k_{desired} \leqq k_G$. To both outputs **24** and **25** of the second comparator **23** is connected a third indicator device **26**, which has two indicator elements **27** and **28**, each of which are connected to one of the two outputs **24** and **25** of the second comparator **23**. The two indicator elements **27** and **28**, which preferably deliver an optical signal, react as soon as a signal occurs at one of the outputs **24** or **25** of the second comparator **23**. To the first output **24** of the second comparator **23** is connected an erasing device **29**, whose output is connected to the erasing input of the memory device **11**. As soon as a signal occurs at the output **24** of the second comparator **23**, the erasing device **29** is activated and the signals x_v' and x_h' are erased.

In the exemplified embodiment in FIG. **1**, the camera is constructed as a known so-called exposure time mechanism. To this end, it has a known control circuit **30** for automatic determination of the exposure time in dependence upon brightness of the object, film sensitivity and stop. The brightness of the object is measured by a photoelement **31** and introduced into the control circuit **30**. This film sensitivity is introduced into the control circuit **30** via a so-called DIN or ASA setter **32**. The input of the stop figure occurs by connecting the output of the first calculator **14** to the corresponding input of the control circuit **30**. From these introduced figures, the control circuit **30** ascertains in known manner the necessary exposure time t.

A third comparator **33** is connected, on the one hand, to the output of the control circuit **30**, and on the other hand, to a setter (not shown) on line **34** for an optionally predeterminable maximum exposure time t_{max}. Such a predetermined maximum exposure time is, for example, 1/30 sec., which constitutes the limit for manual exposures. The third comparator **33** compares the exposure time t ascertained by the control circuit with the predetermined maximum exposure time t_{max}, and delivers a signal at its first output **35** when $t>t_{max}$ and delivers a signal to its second output **36** when $t \leqq t_{max}$. Two indicator elements **37** and **38** of a fourth indicator device **39** are connected to the outputs **35** and **36** respectively, and react when a signal occurs at the respective outputs. The first output **35** of the third comparator **33** is connected to the erasing device **29**. As soon as a signal occurs at the first output **35**, the quenching device **29** is activated and the memory device **11** is quenced.

The mode of operation of the camera represented in the block wiring diagram in FIG. **1** is as follows:

The photographer must firstly determine his focal depth range. To this end, he focuses initially on a desired far point. For this purpose, he rotates the setting ring **3** until the far point is seen to be sharp in the measuring viewfinder **4**. A corresponding electrical signal occurs at the output of the Is value transmitter **10**. The photographer now actuates the memory device switch **12**, and the signal occurring at the output of the Is value transmiter **10** is received in the memory device as a memory device signal x_v'. The photographer now focuses in the same way on a desired near point. As soon as this point appears sharp in the measuring viewfinder **4**, the photographer presses the memory device switch **13**, and the signal occurring at the output of the Is value transmitter **10** is received in the memory device **11** as a memory device signal x_h'.

The first calculator **14** ascertains in accordance with equation (1) the desired stop figure $k_{desired}$, which the photographer can read off on the stop figure scale **22** of the second indicator device **21**. If the desired stop figure $k_{desired}$ ascertained by the calculator **14** is larger than the settable maximum stop figure of the objective, the indicator element **27** lights up and shows the photographer that the desired focal depth range cannot be obtained. Simultaneously, the erasing device **29** which erases the memory device **11** is activated, as the stored signals are zeroed. The photographer is obliged to determine his focal depth range again, that is to say, to reduce it. If the desired stop figure ascertained can be set on the camera

objective, the indicator element **28** of the third indicator device **26** lights up, and an OK signal is given to the photographer.

After the focal depth range has been determined, the photographer now has to set the necessary exact distance. This distance $x'_{desired}$ is ascertained by the second calculator **15** and conveyed to the first comparator **16**. The photographer now has to rotate the setting ring **3** until the two indicator elements **18** and **20** in the first indicator device **17** are erased and the indicator element **19** lights up. The two indicator elements **18** and **20** thereby give him, by appropriate illumination, an instruction as to whether he must move the setting ring in the direction of a larger or smaller distance.

If the camera is a manual camera, or if the camera operates manually by switching off the automatics which are usually provided, the photographer must adjust the stop figure $k_{desired}$ read off on the second indicator device on the stop figure setter of the camera, introduce a corresponding exposure time, and can therefore take the exposure. If the camera, as in the exemplified embodiment of FIG. **1**, is an exposure time automatic device, and if the automatics are switched on, the second indicator device **21** serves merely as additional information for the photographer. From the measured object brightness, the controlled film sensitivity, and the desired stop figure $k_{desired}$ which is ascertained by the first calculator **14**, the control circuit **30** ascertains the exposure time t in known manner. This exposure time t is compared in the third comparator **33** with a voluntarily predetermined maximum exposure time, for example, 1/30 sec., as a figure for manual exposure. If the exposure time t is larger than the introduced longest exposure time t_{max}, the indicator element **37** of the fourth indicator device **39** lights up and signals to the photographer that in view of the existing object brightness, an adequately lighted exposure is impossible with the desired focal depth range. At the same time, the erasing device **29** which erases the memory device signals present in the memory device is activated. The photographer is once again obliged to determine the focal depth range anew, and likewise reduce it. On the other hand, if the indicator element **38** of the fourth indicator device lights up, all the marginal conditions for an optimal photographic exposure are fulfilled, and the indicator element **39** likewise gives the photographer an OK signal. If, therefore, the indicator elements **29**, **38** and **19** light up, and the other indicator elements are dark, the photographer can actuate the release.

In order to be able to obtain such a construction of the camera of the invention in a technologically very simple manner, the first calculator **14** and the second calculator **15** are combined, so that they do not calculate the desired stop figure and the desired distance in accordance with the exact equations (1) and (2), but according to permitted proximity formulae which are adequate for practical requirements. Therefore, the desired stop figure is determined in the calculator **14** in accordance with:

$$k = \frac{x_h' - x_v'}{2z'} \tag{3}$$

and in the calculator **15** the desired distance in accordance with:

$$x' = \frac{x_v' + x_h'}{2} \tag{4}$$

In this case, the additional input of the x'_{AP} value into the two calculators **14** and **15** is unnecessary.

FIG. **2** shows an embodiment of the invention in which the calculators **14** and **15** for the stop and distance calculations take on a simple technological form.

The Is value transmitter **10** is here constructed as an incremental path transmitter **40**, which is responsive to the shifting movement of the objective **2** during the distance setting, and delivers a number of impulses corresponding to the extent of the shifting to a reversible digital counter **41**, as for example, an up/down counter. When the objective **2** is moved in the opposite direction, the incremental path transmitter **40** creates impulses of opposite polarity.

The reversible digital counter **41** is constructed as a forward/backward binary counter, such as is sold, for example, by Texas Instruments Model No. SN 74169. The two inputs for positive and negative counting impulses of the counter **41** are connected to the two outputs of the incremental path transmitter **40**. The reset input of the counter **41** is connected via the memory device switch **12** to a plus potential. The outputs of the digital counter **41** are connected to the inputs of a binary memeory device **42**. Such a memory device is likewise in normal commercial use and may be, for example, distributed by Texas Instruments Model No. SN 7475. The latch-enable input of the memory device **42** is connected via the second memory device swtich **13** to plus potential. Furthermore, a digital analog converter **43** is provided, whose digital inputs are connected to the corresponding outputs of the memory device **42**. Such a digital analog converter is similarly in normal commercial use and is, for example, sold by Hybrid Systems as an 8 bit digital analog converter Model No. DAC 371-8. To the analog output of the digital analog converter **43** is connected a resistance **44**, which is preferably adjustably constructed. Digital analog converter **43** and resistance **44** form the first calculator **14**, whose inputs are the digital inputs of the digital analog converter **43** and whose output is the free connection of the resistance **44**. The z' value, and therefore the permitted diameter of the circle of divergence in the film plane, is set with the resistance **44**. In addition, a scale **45** which is calibrated in diameter dimensions of the permitted circle of divergence can be provided on the resistance **44**.

The second indicator device **21**, as in FIG. **1**, is formed by a galvanometer which is connected to the output of the calculator **14** or to the resistance **44**. The second comparator **23** is a comparator **46**, whose non-inverting input is connected to the output of the calculator **14** or of the resistance. The inverting input of the comparator **46** is connected to a potential divider **47**, by which the maximum stop figure k_G of the respective objective **2** is set. For this purpose, there is fixed to the adjustable resistance **48** of the potential divider **47**, a scale **49** which is calibrated in stop figures. At the output of the comparator **46** is located a preferably optical indicator element **50**, which corresponds in mode of operation to the indicator element **27** in FIG. **1**. This indicator element **50** is connected to plus potential and lights up when the signal at the non-inverting input of the comparator **46** is larger than at the inverting input,

which means that the desired stop figure ascertained by the calculator **14** is larger than the largest settable stop figure of the objective.

As a result of the approximate determination of the desired distance in accordance with the approximate equation (4), the second calculator **15** and the comparator **16** can be combined into one unit and realized by a single structural element, that is to say, through a binary comparator **51**. Such a binary comparator is known and distributed by Texas Instruments as Model No. SN 7485. The binary comparator **51** has two input series, which are marked with A_1 to A_4 or B_1 to B_4. All the inputs A_1 to A_4 are connected to the outputs A to D of the binary counter **41**. Of the four inputs B_1 to B_4 of the binary comparator **51**, the first bit input B_1 is connected to the second bit output B of the memory device **42**, the second bit input B_2 is connected to the third bit output C, the third bit input B_3 to the fourth bit output Dof the memory device **42**, and the fourth bit input B_4 is connected to zero potential. The exemplified embodiment in FIG. **2** is fabricated from 4 bit modules. Naturally, a finer graduation of the distance measurement can be achieved by a multi-stage forward/backward binary counter **41**. If the binary counter **41** is an n staged counter with corresponding n bit outputs, the binary memory device **42** and the binary comparator **51** generally is connected such that the n bit inputs A_1 to A_n of the one input series are connected to the n bit outputs of the digital counter **41**, and such that the n-1 bit inputs B_1 to B_{n-1} of the second input series are each connected to the 2nd bit to n bit output of the binary memory device **42**, and that the n bit input B_n of the second input series is connected to zero potential. The binary comparator **51** has three outputs **52**, **53** and **54**, which are connected respectively to indicator elements **18**, **19** and **20** of the first indicator device **17**. At the first output **52** of the binary comparator **51** there occurs a signal as long as half the counter content of the binary counter **41** is larger than the memory device contents of the binary memory device **42**. A signal occurs at the second output **53** of the binary comparator **51** if the memory device contents of the binary memory device **42** and half the counter content of the binary counter **41** are identical, and a signal occurs at the third output **54** of the binary comparator **51** when the memory device content of the binary memory device **42** is smaller than half the counter contents of the binary counter **41**. As soon as a signal occurs at the putput **52–54** of the binary comparator **51**, the respective indicator elements **18–20** respectively is energized.

The mode of operation of the exemplified embodiment of the camera according to the invention is as follows:

As described with reference to FIG. **1**, the photographer has to focus the objective **2** on the far point by operating the distance-setting ring, and then close the memory device switch **12** for a short period. The forward/backward binary counter **41** is thereby set in its initial position via the reset input. The photographer now focuses on the near point. A corresponding number of impulses is conveyed to the counter **41**. As the counter **41** is a forward/backward counter, impulses are in each case counted up or down as would occur, for example, with repeated overrunning of the objective near the focusing point as the operator adjusts the objective to the near point focus. If the near point is focused, the counter contains a binary number which corresponds to the difference between the near point and far point, that is

$$\Delta x' = x_h' - x_v'. \tag{5}$$

By closing the memory device switch **13** for a short while, the information $\Delta x'$ is stored in the binary memory device **42**.

The content of the binary memory device **42** is converted by the digital analog converter **43** into an analog signal. The signal which corresponds to the z' value is set at the resistance **44**, so that at the output of the first calculator **14** (i.e. at the output of the resistance **44**) there occurs an analog signal which satisfies the equation

$$k = \Delta x'/2z'. \tag{6}$$

This analog signal is indicated by the galvanometer **21** on the stop figure scale **22**, and simultaneously conveyed to the comparator **46**. If this signal is larger than the maximum possible stop figure on the objective, the indicator element **50** lights up and the photographer must make his focal depth range smaller, whereby the aforedescribed procedure is repeated. If the analog signal at the output of the resistance **44** is smaller than or equal to the largest possible stop figure of the objective, the indicator element **50** shows no signal and the photographer knows that he has selected an acceptable focal depth range. Now he must also set the necessary desired distance exactly, for which he actuates the stop-setting ring until the indicator element **19** lights up and the indicator elements **18** and **20** are quenced. In this procedure, the necessary desired distance is calculated by the binary comparator in accordance with the following equation:

$$x' = x_v' + (\Delta x'/2). \tag{7}$$

As a result of the aforedescribed connection of the input series of the binary comparator **51** to the outputs of the binary counter **41** and of the binary memory device **42**, the 1 to n bits of the binary counter **41** are compared with the 2 to n+1 bits of the binary memory device **42**, whereby the n+1 bits is predetermined by zero potential. It thereby occurs that the second output **53** of the binary memory device **51** gives a signal when the counter content **41** amounts to half the memory device **42** content, so that the equation (7) is satisfied if it is borne in mind that the x_v' value is represented by the initial or zero position of the binary counter **41**.

The stop figure value indicated in the galvanometer **21** can be set on the stop setter of the camera. A corresponding exposure time control circuit **30** can likewise be connected to the output of the calculator **14** or to the output of the resistance **44**, as in FIG. **1**. As the latter is known per se, an additional representation and description of the exposure time control circuit is unnecessary.

What is claimed is:

1. A photographic camera having an objective, a viewfinder coupled to said objective and comprising:

(a) means for converting the setting of said objective into electrical signal values, x'_{actual},

(b) memory storage means for storing said electrical signal values, said memory storage means storing a first signal value, x_v', corresponding to the objective setting associated with a far point desired to be photographed, and for storing a second signal

value, x_h', corresponding to the objective setting associated with a near point desired to be photographed, and

(c) calculator means connected to said memory storage means for automatically calculating a desired stop figure, $k_{desired}$, and a desired distance-setting value, $x'_{desired}$, associated with said first and second signal values.

2. A photographic camera as recited in claim 1 further comprising means for indicating the desired stop figure, $k_{desired}$.

3. A photographic camera as recited in claim 1 further comprising first comparator means connected to said converting means and said calculator means for comparing the desired distance-setting value $x'_{desired}$ with the actual objective setting value, x'_{actual}, and means for indicating the equivalent of same.

4. A photographic camera as recited in claim 3 wherein said calculator means comprises a first calculator for calculating the desired stop figure, $k_{desired}$, and a second calculator for calculating the desired distance setting value $x'_{desired}$.

5. A photographic camera as recited in claim 4 further comprising means for indicating the desired stop figure, $k_{desired}$, said indicating means connected to said first calculator.

6. A photographic camera as recited in claim 5 further comprising second comparator means connected to said first calculator for comparing the desired stop figure $k_{desired}$ with a reference value corresponding to the largest stop figure for the camera objective, k_G, and means for providing an indication when $k_{desired} > k_G$.

7. A photographic camera as recited in claim 6 further comprising means for erasing said first and second signal values.

8. A photographic camera as recited in claim 7 wherein said erasing means is connected to said first calculator for erasing said first and second signal values, said erasing means operable when $k_{desired}$ is greater than k_G.

9. A photographic camera as recited in claim 6 further comprising means for providing an indication when $k_{desired} \leqq k_G$.

10. A photographic camera as recited in claim 1 further comprising a brightness control circuit connected to said calculator means for automatically determining exposure time, t, in response to film sensitivity, object brightness and the desired stop figure, $k_{desired}$.

11. A photographic camera as recited in claim 10 further comprising a comparator for comparing said exposure time, t, to a predetermined maximum exposure time, t_{max}, and means for indicating when $t > t_{max}$.

12. A photographic camera as recited in claim 11 further comprising means for indicating when $t \leqq t_{max}$.

13. A photographic camera as recited in claim 10 further comprising means for erasing said stored electrical signal values when $t > t_{max}$.

14. A photographic camera as recited in claim 1 wherein said means for converting the setting of the objective into electrical signal values comprises an incremental path transmitter.

15. A photographic camera as recited in claim 14 wherein said incremental path transmitter provides digital signals, and said camera further comprises a reversible digital counter providing digital signals to said memory storage device in response to said digital signals from said incremental path transmitter.

16. A photographic camera as recited in claim 14 wherein said calculator means comprises a digital-to-analog converter connected to said memory storage means and a variable resistor means connected to an output of said digital-to-analog converter.

* * * * *

United States

Göbl

4,217,033

Aug. 12, 1980

[54] **CAMERA OBJECTIVE OF VARIABLE FOCAL LENGTH**

[75] Inventor: **Irmgard Göbl**, Kitzbühel, Austria

[73] Assignees: **Karl Vockenhuber; Raimund Hauser**, both of Vienna, Austria

[21] Appl. No.: **918,399**

[22] Filed: **Jun. 23, 1978**

[30] **Foreign Application Priority Data**

Jun. 30, 1977 [AT] Austria 4653/77

[51] **Int. Cl.**[2] **G02B 15/18**

[52] **U.S. Cl.** **350/184**

[58] **Field of Search** 350/184, 186

[56] **References Cited**

U.S. PATENT DOCUMENTS

4,087,160 5/1978 Besenmatter 350/184

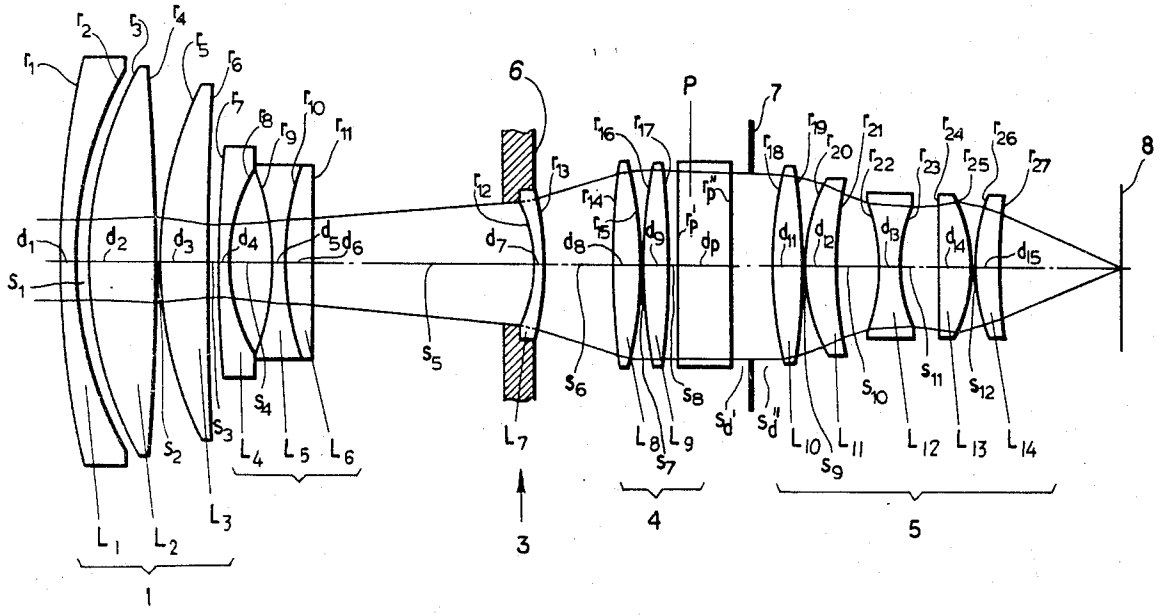
Primary Examiner—Conrad J. Clark

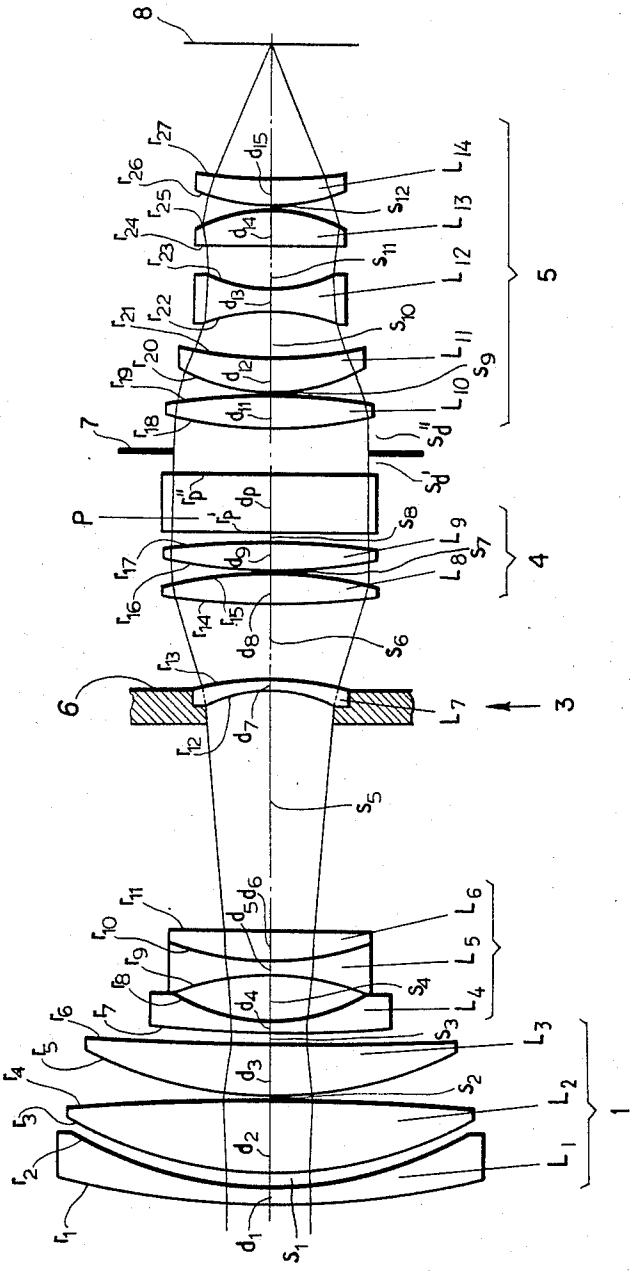
Attorney, Agent, or Firm—Montague & Ross

[57] **ABSTRACT**

A pancratic camera objective of varifocal ratio close to 5:1, and with a relative aperture varying between 1:1.2 in a wide-angle position and 1:1.5 in a telephoto position, has a pair of axially shiftable negative components bracketed by a pair of substantially fixed positive components. Its negative third component is more widely separated from its positive fourth component in the wide-angle position than in the telephoto position.

2 Claims, 1 Drawing Figure




8
r27
d15
L14
r26
s12
r25
L13
r24
d14
r23
s11
L12
d13
r21
r22
s10
r20
L11
r19
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s9
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d11
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sd''
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r1
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s1
5

CAMERA OBJECTIVE OF VARIABLE FOCAL LENGTH

FIELD OF THE INVENTION

My present invention relates to a pancratic camera objective of the general type described in commonly owned U.S. Pat. No. 4,087,160, including a varifocal forward lens group and a fixed-focus rear lens group centered on a common optical axis, the forward lens group consisting of a substantially axially fixed positive first component, axially shiftable negative second and third components, and an axially fixed fourth component. The first three components form a lens assembly of dispersive character; the third component approaches the fourth component more closely in a telephoto position of maximum overall focal length f_{max} than in a wide-angle position of minimum focal length f_{min} while having an inversion point at an intermediate position of overall focal length f_{med}.

BACKGROUND OF THE INVENTION

The prior patent referred to above discloses two specific embodiments, one of them with a varifocal ratio f_{max}/f_{min} approximately equal to 8, the other with a varifocal ratio of about 10. In the wide-angle position of the objective, its relative aperture is 1:1.2 according to the first embodiment and 1:1.8 according to the second one; the first system, accordingly, falls in the so-called XL (=existing light) class permitting—in a cinematographic camera—the taking of indoor motion pictures without additional illumination. The effective area of the third (negative) component of an objective as described in that patent is restricted to provide full illumination of the fourth (positive) component by axially incident light rays in the wide-angle position but less than full illumination in the telephoto position, thereby enabling a reduction in the lens diameters of the front component.

OBJECT OF THE INVENTION

The object of my present invention is to provide an objective of the general type described above which is of simpler construction, does not necessarily require a restriction of the effective area of the third component and has a relative aperture similar to that of the first embodiment disclosed in the prior patent, i.e. about 1:1.2 in the wide-angle position, while still affording a large varifocal ratio of approximately 5:1.

SUMMARY OF THE INVENTION

I realize this object, pursuant to my present invention, with a pancratic objective of only seven lens members (one of them a doublet) in its varifocal forward group, i.e. with a first component consisting of three singlets, having parameters substantially as given hereinafter.

BRIEF DESCRIPTION OF THE DRAWING

My invention will now be described in detail with reference to the accompanying drawing the sole FIGURE of which diagrammatically illustrates my improved pancratic objective.

SPECIFIC DESCRIPTION

In the drawing I have shown the wide-angle position of a pancratic objective according to my invention, including a varifocal forward lens group with components **1–4** and a rear lens group **5**. The substantially

stationary positive component **1** (which may be limitedly shiftable for focusing purposes) comprises a front lens in the form of a negative meniscus L_1 with radii r_1, r_2 and thickness d_1, two positive lenses L_2 (radii r_3, r_4 and thickness d_2) and L_3 (radii r_5, r_6 and thickness d_3) which intervening air spaces s_1 and s_2. A variable air space s_3 separates lens L_3 from the axially shiftable component **2** consisting of a singlet L_4 in the form of a negative meniscus (radii r_7, r_8 and thickness d_4) separated by an air space s_4 from a doublet consisting of lenses L_5 (radii r_9, r_{10} and thickness d_5) and L_6 (radii r_{10}, r_{11} and thickness d_6). Another variable air space s_5 lies between component **2** and component **3** which consists of a single lens L_7 in the form of a negative meniscus with radii r_{12}, r_{13} and thickness d_7. A third variable air space s_6 lies between component **3** and axially fixed component **4** which in this instance consists of two air-spaced biconvex lenses L_8 (radii r_{14}, r_{15} and thickness d_8) and L_9 (radii r_{16}, r_{17} and thickness d_9), the intervening air space having been designated s_7. The light path between components **3** and **4** is restricted by a mounting **6** for lens L_7, acting as an ancillary diaphragm.

A reflex prism P of thickness d_p, whose planar faces have been designated r_p' and r_p'', is separated by an air space s_8 from lens L_9 and by a diaphragm space $s_d'+s_d''$ from component **5**, the latter space containing an iris diaphragm **7**. Component **5** consists of five air-spaced singlets, namely a biconvex lens L_{10} (radii r_{18}, r_{19} and thickness d_{10}), a positive meniscus L_{11} (radii r_{20}, r_{21} and thickness d_{11}), a biconcave lens L_{12} (radii r_{22}, r_{23} and thickness d_{12}), a planoconvex lens L_{13} (radii r_{24}, r_{25} and thickness d_{13}) and another positive meniscus L_{14} (radii r_{26}, r_{27} and thickness d_{14}); the intervening air spaces have been designated s_9, s_{10}, s_{11} and s_{12}. The image plane of the objective has been shown at **8**.

In the following table I have given representative numerical values for the parameters r_1–r_{27}, d_1–d_{14} and s_1–s_{12} of the illustrated optical system, based upon a mean overall focal length $f_{med}=1$ in the extreme left-hand position of component **3**. The table also gives the refractive indices n_d and the Abbé numbers ν_d of the various lenses.

Lens	Radii	Thicknesses and Separations	n_d	ν_d
L_1	$r_1 = +6.626$			
	$r_2 = +2.734$	$d_1 = 0.139$	1.805	25.4
		$s_1 = 0.077$		
L_2	$r_3 = +2.734$			
	$r_4 = -21.705$	$d_2 = 0.499$	1.620	60.3
		$s_2 = 0.008$		
L_3	$r_5 = +2.806$			
	$r_6 = +18.186$	$d_3 = 0.333$	1.667	48.4
		$s_3 = 0.063\ f_{min}$ / $0.635\ f_{med}$ / $1.635\ f_{max}$		
L_4	$r_7 = +6.973$			
	$r_8 = +1.143$	$d_4 = 0.077$	1.713	53.8
		$s_4 = 0.317$		
L_5	$r_9 = -1.817$			
	$r_{10} = +1.817$	$d_5 = 0.077$	1.620	60.3
L_6	$r_{11} = \infty$	$d_6 = 0.213$	1.805	25.4
		$s_5 = 1.529\ f_{min}$ / $0.929\ f_{med}$ / $0.278\ f_{max}$		
	$r_{12} = -1.237$			

-continued

Lens	Radii	Thicknesses and Separations		n_d	ν_d
L_7	$r_{13} = -4.629$	$d_7 =$	0.077	1.744	44.8
		$s_6 =$	0.501 f_{min} 0.529 f_{med} 0.180 f_{max}		
L_8	$r_{14} = +6.802$ $r_{15} = -2.883$	$d_8 =$	0.213	1.620	60.3
		$s_7 =$	0.008		
L_9	$r_{16} = +4.703$ $r_{17} = -7.120$	$d_9 =$	0.170	1.620	60.3
		$s_8 =$	0.077		
P	$r_p' = \infty$ $r_p'' = \infty$	$d_p =$	0.387	1.517	64.2
		$s_d' + s_d'' =$	0.116 + 0.139		
L_{10}	$r_{18} = +2.294$ $r_{19} = -7.306$	$d_{10} =$	0.224	1.620	60.3
		s_9 ;32	0.008		
L_{11}	$r_{20} = +1.225$ $r_{21} = +2.660$	$d_{11} =$	0.221	1.620	60.3
		$s_{10} =$	0.310		
L_{12}	$r_{22} = +1.290$ $r_{23} = +1.290$	$d_{12} =$	0.166	1.847	23.8
		$s_{11} =$	0.252		
L_{13}	$r_{24} = +70.722$ $r_{25} = -0.947$	$d_{13} =$	0.255	1.713	53.8
		$s_{12} =$	0.008		
L_{14}	$r_{26} = +1.137$ $r_{27} = +4.420$	$d_{14} =$	0.174	1.620	60.3

The objective conforming to the foregoing table has a minimum focal length $f_{min}=0.666$, a median focal length $f_{med}=1$ and a maximum focal length $f_{max}=2.863$. Its relative aperture is 1:1.2 in the illustrated wide-angle position and 1:1.5 in the telephoto position at the opposite end of its varifocal range.

I claim:

1. In a camera objective of variable focal length including a varifocal foward lens group and a fixed-focus rear lens group centered on a common optical axis, said forward lens group consisting of a substantially axially fixed positive first component, an axially shiftable negative second component, an axially shiftable negative third component and an axially fixed fourth component, said second and third components being displaceable between a wide-angle position of minimum overall focal length and a telephoto position of maximum overall focal length with maintenance of an invarient image plane behind said rear lens group, said third component approaching said fourth component more closely in said telephoto position than in said wide-angle position, the combination of said first, second and third components being of dispersive character,

the improvement wherein said first component consists of lenses L_1, L_2 and L_3, said second component consists of lenses L_4, L_5 and L_6, said third component consists of a lens L_7 and said fourth component consists of lenses L_8 and L_9, said lenses having radii of curvature r_1–r_{17}, axial thicknesses d_1–d_9 and axial spacings s_1–s_7 whose numerical values, based on a numerical value of unity for an intermediate overall focal length, together with their refractive indices n_d and Abbé numbers ν_d are substantially as given in the following table:

				n_d	ν_d
L_1	$r_1 = +6.6$ $r_2 = +2.7$	$d_1 =$	0.14	1.81	25
		$s_1 =$	0.08		
L_2	$r_3 = +2.7$ $r_4 = -21.7$	$d_2 =$	0.50	1.62	60
		$s_2 =$	0.01		
L_3	$r_5 = +2.8$ $r_6 = +18.2$	$d_3 =$	0.33	1.67	48
		$s_3 =$	0.06 f_{min} 0.64 f_{med} 1.64 f_{max}		
L_4	$r_7 = +7.0$ $r_8 = +1.1$	$d_4 =$	0.08	1.71	54
		$s_4 =$	0.32		
L_5	$r_9 = -1.8$ $r_{10} = +1.8$	$d_5 =$	0.08	1.62	60
L_6	$r_{11} = \infty$	$d_6 =$	0.21	1.81	25
		$s_5 =$	1.53 f_{min} 0.93 f_{med} 0.28 f_{max}		
L_7	$r_{12} = -1.2$ $r_{13} = -4.6$	$d_7 =$	0.08	1.74	45
		$s_6 =$	0.50 f_{min} 0.53 f_{med} 0.18 f_{max}		
L_8	$r_{14} = +6.8$ $r_{15} = -2.9$	$d_8 =$	0.21	1.62	60
		$s_7 =$	0.01		
L_9	$r_{16} = +4.7$ $r_{17} = -7.1$	$d_9 =$	0.17	1.62	60

2. The improvement defined in claim 1 wherein said rear lens group consists of lenses L_{10}, L_{11}, L_{12}, L_{13} and L_{14} whose radii of curvature r_{18}–r_{27}, axial thicknesses d_{10}–d_{14}, axial spacings s_9–s_{12}, refractive indices n_d and Abbé numbers ν_d are substantially as given in the following table:

				n_d	ν_d
L_{10}	$r_{18} = +2.3$ $r_{19} = -7.3$	$d_{10} = 0.22$		1.62	60
		$s_9 = 0.01$			
L_{11}	$r_{20} = +1.2$ $r_{21} = +2.7$	d_{11} ' 0.22		1.60	60
		$s_{10} = 0.31$			
L_{12}	$r_{22} = +1.3$ $r_{23} = +1.3$	$d_{12} = 0.17$		1.85	24
		$s_{11} = 0.25$			
L_{13}	$r_{24} = +70.7$ $r_{25} = -0.9$	$d_{13} = 0.26$		1.71	54
		$s_{12} = 0.01$			
L_{14}	$r_{26} = +1.1$ $r_{27} = +4.4$	$d_{14} = 0.17$		1.62	60

* * * * *

OR 4,214,815 -464

United State

Shimokura

4,214,815

Jul. 29, 1980

[54] **SEMI-WIDE ANGLE OBJECTIVE LENS**

[75] Inventor: **Toshiko Shimokura**, Hachioji, Japan

[73] Assignee: **Konishiroku Photo Industry Co., Ltd.**, Tokyo, Japan

[21] Appl. No.: **913,018**

[22] Filed: **Jun. 6, 1978**

[30] **Foreign Application Priority Data**

Jun. 23, 1977 [JP] Japan 52-73881

[51] **Int. Cl.**[2] **G02B 9/60**; G02B 9/62

[52] **U.S. Cl.** **350/215**; 350/216

[58] **Field of Search** 350/216, 215, 176

[56] **References Cited**

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FOREIGN PATENT DOCUMENTS

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531115	12/1976	U.S.S.R.	350/216

Primary Examiner—Paul A. Sacher

Attorney, Agent, or Firm—Lane, Aitken, Ziems, Kice & Kananen

[57] **ABSTRACT**

A semi-wide angle objective lens in accordance with the present invention comprises five groups of six lens elements including a front group and a rear group in which the front group has a first group which includes a single positive meniscus lens L_1 with its convex surface directed toward the object side, a second group which includes a single negative meniscus lens L_2 with its convex surface directed toward the object side, and a third group which includes a single positive meniscus lens L_3 with its convex surface directed toward the object side; and in which the rear group has a fourth group which includes both a negative lens L_4 with its front concave surface having a large curvature directed toward the object side and a positive lens L_5 with its rear convex surface having a large curvature directed toward an image side with the fourth group lenses cemented together or arranged with an extremely small air space therebetween, and a fifth group which includes a positive lens L_6 characterized in that each of the following conditions is fulfilled:

$$1.4\,f < |f_2| < 2.0\,f \quad (1)$$

$$0.23\,f < r_4 < 0.33\,f \quad (2)$$

$$0.03\,f < d_4 < 0.08\,f \quad (3)$$

$$0.8 < r_4/r_5 < 1.0 \quad (4)$$

where,

f is the composite focal length of the entire lens system,

f_2 is the focal length of the lens L_2 of the second group ($f_2 < 0$),

r_4 is the radius of curvature of the rear surface of the lens L_2 of the second group,

d_4 is the axial air space between the lens L_2 of the second group and the lens L_3 of the third group, and

r_5 is the radius of curvature of the front surface of the lens L_3 of the third group.

7 Claims, 20 Drawing Figures

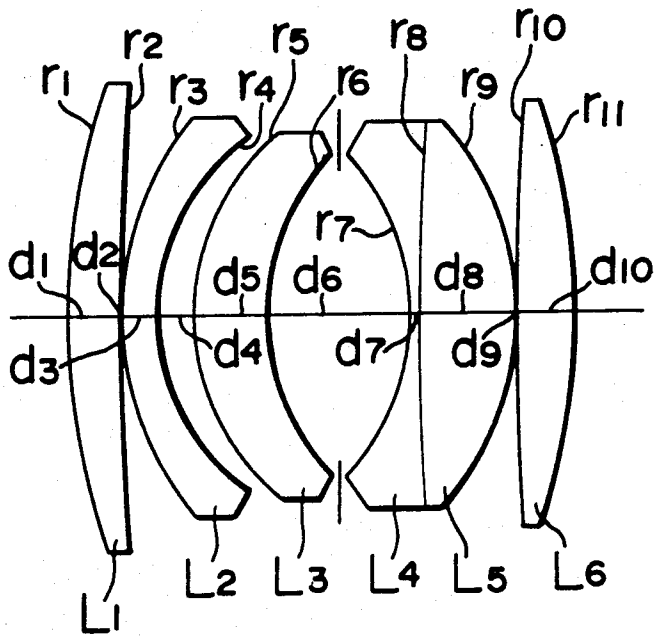
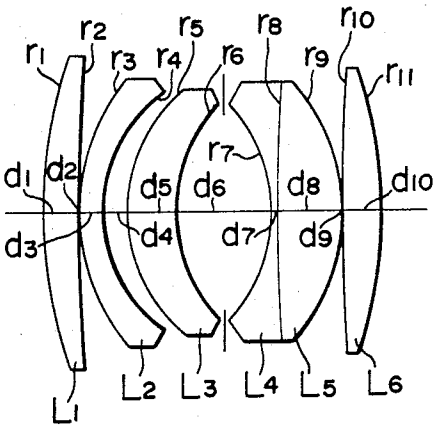


FIG. 1A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r8
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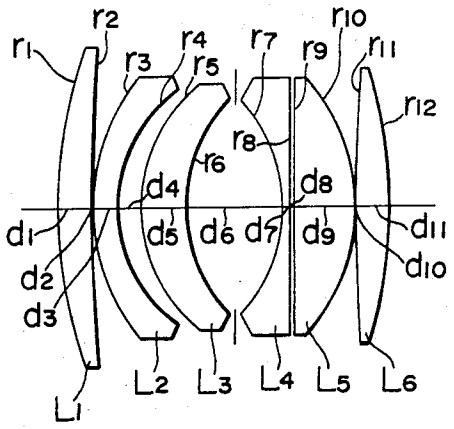
L1
L2
L3
L4
L5
L6

FIG. 1B


r1
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r10
r11
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d2
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d4
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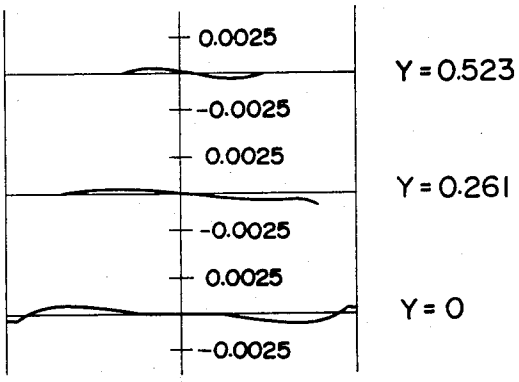
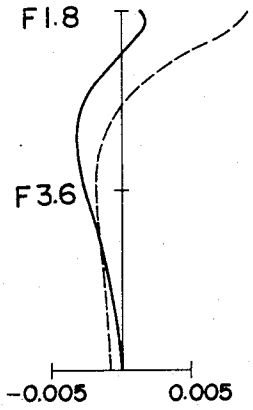
d10
d11
L1
L2
L3
L4
L5
L6

FIG. 2A

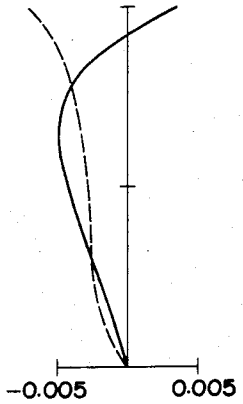


COMA



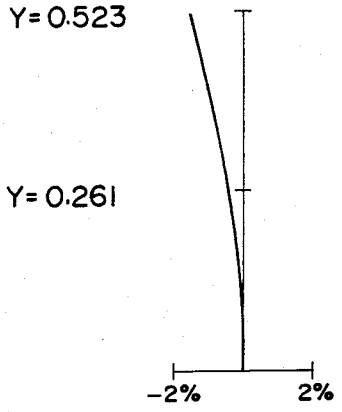
SPHERICAL ABERRATION

FIG. 2B



ASTIGMATISM

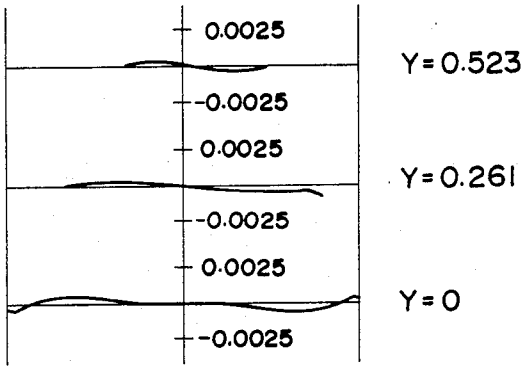
FIG. 2C



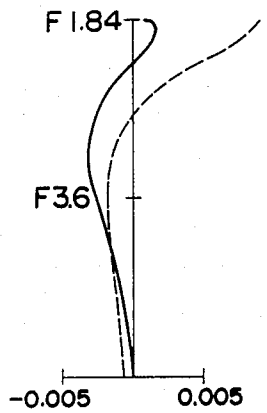
DISTORTION

FIG. 2D

FIG. 3A

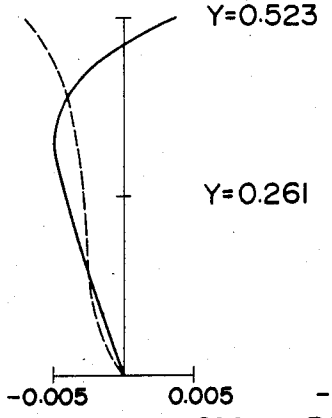


COMA



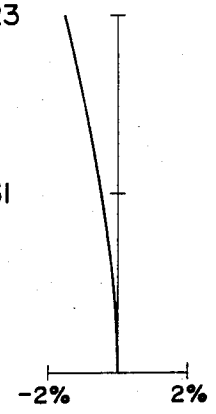
SPHERICAL ABERRATION

FIG. 3B



ASTIGMATISM

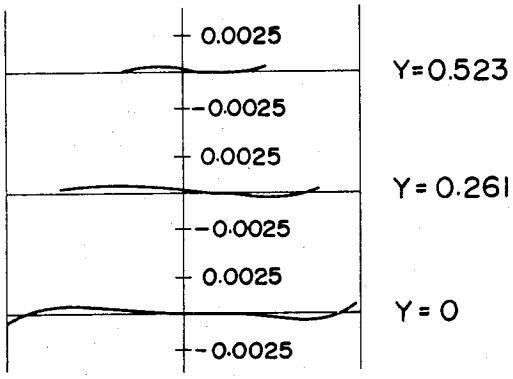
FIG. 3C



DISTORTION

FIG. 3D

FIG. 4A



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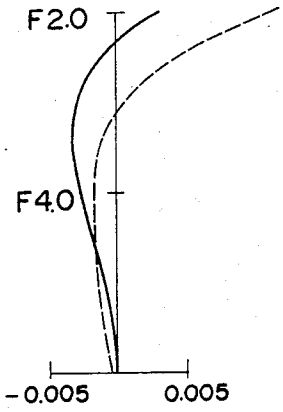
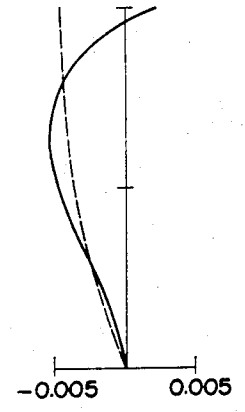


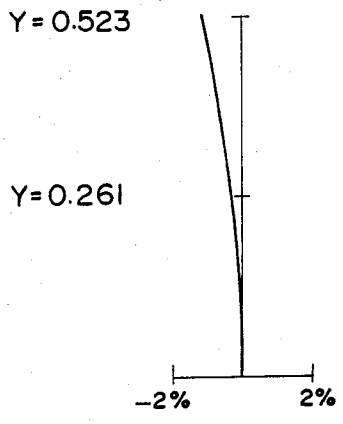
SPHERICAL ABERRATION

FIG. 4B



ASTIGMATISM

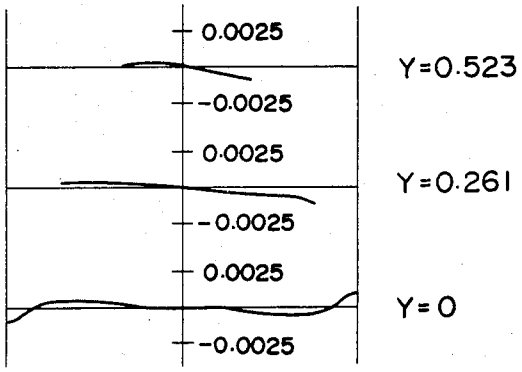
FIG. 4C



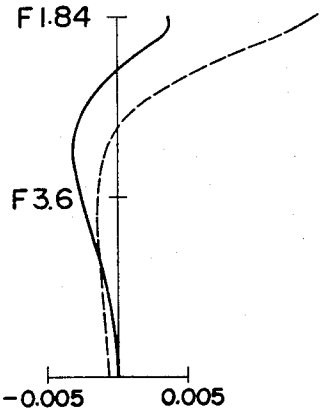
DISTORTION

FIG. 4D

FIG. 5A

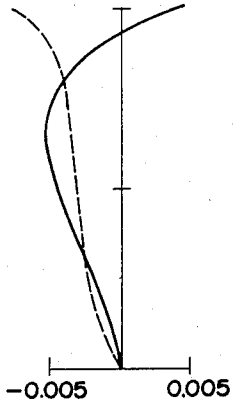


COMA



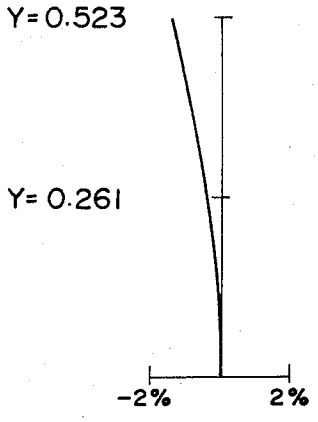
SPHERICAL ABERRATION

FIG. 5B



ASTIGMATISM

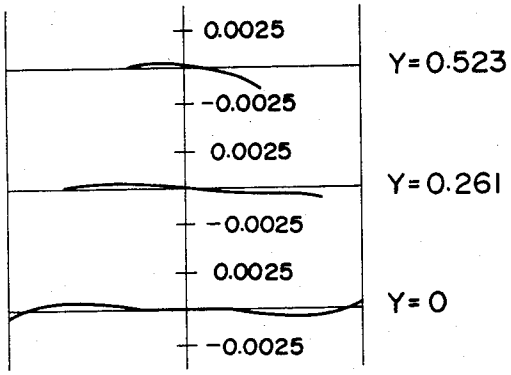
FIG. 5C



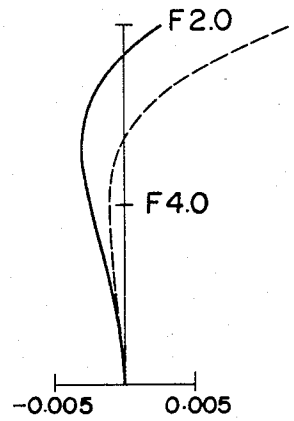
DISTORTION

FIG. 5D

FIG. 6A

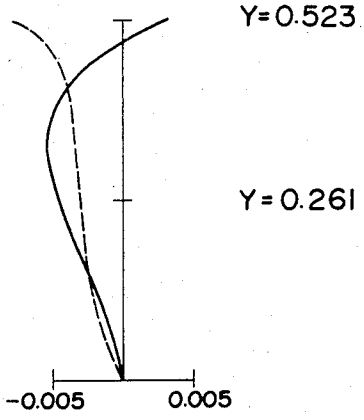


COMA



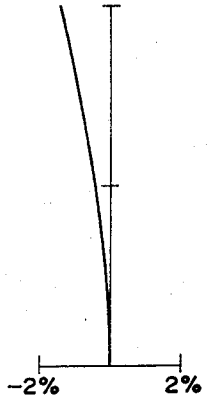
SPHERICAL ABERRATION

FIG. 6B



ASTIGMATISM

FIG. 6C



DISTORTION

FIG. 6D

SEMI-WIDE ANGLE OBJECTIVE LENS

BACKGROUND OF THE INVENTION

(1) Field of the Invention

This invention relates to an improved semiwide angle objective lens for use with single lens reflex cameras.

(2) Description of the Prior Art

In recent years, there has been an increasing trend towards compact size single lens reflex cameras and, along with this trend a requirement has developed for more compact and wider angle interchangeable lens. The shortest focal length of a standard lens for a 135 mm film format single lens reflex camera has been commonly chosen at 50 mm. However, lens shutter cameras have lenses with approximately equal to 40 mm are very popular. Thus, for SLR cameras, a semi-wide angle objective lens having a value of about f=40 mm has become a standard lens.

A desirable semi-wide angle objective lens having a compact size would have a preferred value of f=40 mm, an F number of F 2 to F 1.8 and a simple lens configuration of six lens elements or so. It has been extremely difficult to apply prior art lenses (e.g., Gaussian type six element lenses) for this purpose and keep the lens back focal length large enough for a single lens reflex camera and also provide a field angle up to about 56°.

The reason why it was so difficult is that keeping the back focal length f_B long requires a smaller setting of the positive power of the front group, resulting in an increased positive power of the rear group making it very difficult to correct residual aberrations with the positive lenses of the rear group.

Another reason for the above mentioned difficulty is that the requirement for a large aperture ranging from F 2 to F 1.8 results in a decreased power of refraction at each lens surface, which leads to difficulty correcting the curvature of the sagittal image surface, making it impossible to maintain a wide angle of view.

Further, even if an attempt is made to obtain a semi-wide angle objective lens by utilizing a lens system of a so-called retrofocus type e.g. a Gauss type or modified Tessar type in which a negative lens is added to the front lens element, the total length of the lens system is increased, or the front lens element is increased in size and the lens is no longer compact.

Because of the reasons mentioned above, it has been extremely difficult to provide a six lens element semi-wide angle objective lens of simple configuration having a large aperture and a compact size.

BRIEF SUMMARY OF THE INVENTION

It is an overall object of the present invention to provide a new and useful semi-wide angle objective lens for use with single lens reflex cameras.

It is further principal object of the present invention to provide a lens system for an extremely compact semi-wide angle objective lens having a simple configuration of five groups of six lens elements in which the back focal length f_B has a value of 0.85 times of the composite focal length f, an angle of view of 56°, an aperture range from F 2 to F 1.8 and in which all aberrations are well corrected.

The above and other objects of the present invention will be apparent from the following detailed description of a preferred embodiment of the present invention taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

The above description as well as further objects, features, and advantages of the present invention will be more fully understood by reference to the following description of a presently preferred but nonethless illustrative embodiment in accordance with the present invention, when taken in connection with the accompanying drawing, wherein

FIGS. 1A and 1B show a basic structural view of a semi-wide angle lens in accordance with the present invention with FIG. 1A showing an arrangement in which two lens elements in the fourth group are cemented together and with FIG. 1B showing an arrangement in which two lens elements in a similar fourth group are arranged with an extremely small air space being left therebetween.

FIGS. 2A, 2B, 2C, and 2D show, as labeled, the coma, spherical aberration, astigmatism, and distortion curves for a first embodiment having the basic construction shown in FIG. 1A;

FIGS. 3A, 3B, 3C, and 3D show, as labeled, the coma, spherical aberration, astigmatism, and distortion curves for a second embodiment having the basic construction shown in FIG. 1A;

FIGS. 4A, 4B, 4C, and 4D show, as labeled, the coma, spherical aberration, astigmatism, and distortion aberration curves for a third embodiment having the basic construction shown in FIG. 1A.

In each of these figures, the solid line in the spherical aberration curve shows the spherical aberration when d=line (a wave length: 587.56 mμ) is applied and the dotted line shows the spherical aberration when g-line (a wave length: 435.84 mμ) is applied. The solid line in the astigmatism shows a sagittal and the dotted line shows a meridional.

FIGS. 5A, 5B, 5C and 5D show, as labeled, the coma, spherical aberration, astigmatism, and distortion curves for a fourth embodiment having the basic construction shown in FIG. 1B; and

FIGS. 6 6B, 6C, and 6D show, as labeled, the coma spherical aberration, astigmatism, and distortion curves for a fifth embodiment in accordance with the basic construction shown in FIG. 1B.

In FIG. 1A,

L_1, L_2, L_3, . . . L_6: designates the lenses counted in sequence from the object side

r_1, r_2, r_3, . . . r_{11}: designates the radius of curvature of the lens surfaces measured in sequence from the object side,

d_1, d_3, d_5, d_7, d_8, d_{10}: designates the axial thickness of the lenses measured in sequence from the object side;

d_2, d_4, d_6, d_9: designates the axial air space between the lenses measured in sequence from the object side;

and in FIG. 1(B),

L_1, L_2, L_3, . . . L_6: designates the lenses counted in sequence from the object side

r_1, r_2, r_3, . . . r_{12}: designates the radius of curvature of the lenses surface measured in sequence from the object side

d_1, d_3, d_5, d_7, d_9, d_{11}: designates the axial thickness of the lens measured in sequence from the object side, and

d_2, d_4, d_6, d_8, d_{10}: designates the axial air space between the lenses measured in sequence from the object side

The solid line in the spherical aberration shows the spherical aberration when d-line (a wave length: 587.56 mμ) is applied and the dotted line shows the spherical aberration when g-line (a wave length: 435.84 mμ) is applied. The solid line in the astigmatism shows a sagittal and the dotted line shows a meridional.

DESCRIPTION OF THE PREFERRED EMBODIMENT

As apparent from the new type of lens shown in FIG. 1 A and B in which the arrangement of the front group of the Gauss type lens of five groups of six lens elements is changed by changing the arrangement of a positive lens, a positive lens and a negative lens to an arrangement of a positive lens, a negative lens and a positive lens, the present invention enables the provision of a lens system for an extremely compact and useful semi-wide angle lens having a back focal length f_B of about 0.85 times as that of a composite focal length f, an angle of view of 56°, and an aperture of F 2 to F 1.8 in which all aberrations are well corrected. A simple, common lens configuration of five groups of six lens elements, which has various problems when used as an interchangeable lens for single lens reflex cameras, may be improved upon by providing a lens system comprising five groups of six lens elements including a front group a rear group in which a first group includes a single positive meniscus lens L_1 having its convex surface directed toward a object side, the second group includes a single negative meniscus lens L_2 having its convex surface directed toward the object side, and a third group includes a single positive meniscus lens L_3 with its convex surface having a large curvature directed toward the object side and in which the rear group includes the fourth group which includes both a negative lens L_4 with its front concave surface having a large curvature directed toward the object side and a positive lens L_5 with its rear convex surface having a large curvature being directed toward the image side with the fourth group lenses cemented together or arranged with an extremely small air space therebetween and a fifth group includes a positive lens L_6 in which each of the following conditions are fulfilled.

$$1.4f < |f_2| < 2.0\ f \quad (1)$$

where,

f is the composite focal length of the entire lens system,

f_2 is the focal length of the lens L_2 of the second group;

$$0.23\ f < r_4 < 0.33\ f \quad (2)$$

where, r_4 is the radius of curvature of the rear surface of the lens L_2 of the second group;

$$0.03\ f < d_4 < 0.08\ f \quad (3)$$

where, d_4 is the axial air space between the lens L_2 of the second group and the lens L_3 of the third group; and

$$0.8 < r_4/r_5 < 1.0 \quad (4)$$

where, r_5 is the radius of curvature of the front surface of the lens L_3 of the third group

A technical background of the present invention and the meaning of several conditions are described in more detail as follows.

A new type of the lens in accordance with the present invention is made by replacing the arrangement of prior art Gauss-type lenses, which include five groups of six lens elements of which the front group includes a positive lens, a positive lens, and a negative lens, with an arrangement of a positive lens, a negative lens and a positive lens.

As mentioned in the description of the prior art, a semi-wide angle objective lens with the back focal length long enough for an interchangeable lens and with an aperture large enough for a standard lens is very difficult to provide with the prior art Gauss type or Tessar-type lens configurations.

To avoid the problems mentioned earlier, it is necessary to provide a lens which has a suitably large positive power in the front group as the prior art Gauss type lenses making a large aperture possible and which also has a suitably large emerging paraxial ray height at the end surface of the front group the prior art Tessar type lenses making a long back focal length possible; the new type of lens of the present invention satisfies these properties.

Namely, the suitably large power in the front group is made possible in the lens of the present invention by using the two positive lenses, one of which is located in the first position of the lens system, and one negative lens similar to the prior art Gauss-type lenses; thus keeping the power of the front group large and comparable to that of the Gauss-type lenses.

On the other hand, by changing the arrangement of the lenses in the front group from that of the Gauss-type lenses, which is a positive lens, a positive lens, and a negative lens, to the arrangement of a positive lens, a negative lens, and a positive lens, the type of lens of the present invention enables the attaining of a long back focal length.

Namely, the forward arrangement of the negative lens in the front group makes the emerging paraxial ray height at the end surface of the front group comparable to that of a Tessar type lens, and thus makes it possible for the total lens to have a long back focal length.

In view the arrangement described, major means for realizing a compact lens system having a superior aberration correction is expressed under the following conditions

$$1.4\ f < f_2 < 2.0\ f \quad (1)$$

$$0.23\ f < r_4 < 0.33\ f \quad (2)$$

$$0.03\ f < d_4 < 0.08\ f \quad (3)$$

$$0.8 < r_4/r_3 < 1.0 \quad (4)$$

Equation (1) shows a condition in which the negative lens arranged as the lens L_2 of the second group has a relatively large divergence action making it possible to obtain a required back focal length f_B without decreasing the composite power of the lenses of the front group when the single focal length is in the range indicated above.

Equation (2) shows a condition in which a substantially large radius of curvature r_4 of the lens surface of the meniscus lens L_2 of the second group directed toward the image side is provided, and a center of the curvature is approached toward the center of the lens in order to prevent a sagittal image surface from being curved, and then a space between the lens L_2 of the

second group and the lens L_3 of the third group is made small as indicated in the equation (3) to keep the size compact and also to keep the effect described below of a radius of curvature r_5 at the object side of the lens L_3 of the third group in reference to the equation (4). That is, these equations show the conditions to decrease the aberrations generated by the forward positioned negative lens, which aberrations are larger than those of the prior art arrangement of a positive lens, a negative lens and a negative lens, and thus provide a fast lens.

The reason for the above mentioned setting of the limitation values of each of the conditional equations are described as follows.

Negative power of the lens L_2 of the second group exceeding the lower limit of the equation (1) will necessarily increase the positive power of the lens L_3 of the third group and thus cause generation of an excessive aberration of each of the surfaces, making it impossible to provide a fast lens. In turn, negative power of the lens L_2 of the second group exceeding the upper limit of the equation (1) will decrease the diversive refractive power of the lens L_2 of the second group and thus it is impossible to obtain the required back focal length f_B.

Exceeding the lower limit of the equation (2) will make the negative refractive power excessive at the rear surface of the lens L_2 of the second group, and thus it will become impossible to correct the spherical aberration and coma, and further make it impossible to provide a fast lens. Conversely, exceeding the upper limit of the equation (2) will result in the center of curvature of the rear surface of the lens L_2 being moved farther away from the center of the total lens system decreasing the effect of correction of the sagittal image surface.

When the axial air space d_4 between the lens L_2 of the second group and the lens L_3 of the third group is small and exceeds the lower limit of equation (3), a positive refractive power at the front surface of lens L_3 decreases in reference to the equation (4), and then it becomes impossible to provide correction of the higher order spherical aberrations which may be generated in the negative lens L_2. To the contrary, when the axial air space d_4 exceeds the upper limit, a positive refractive power at the front surface of said lens L_3 increases, and thus it causes not only the tendency for the image surface to curve towards object side, but also the increase in size of the lens.

Equation (4) provides the relationship between the radii of curvature r_4 and r_5 with respect to a range of the axial air space d_4 given by the equation (3). When the value of r_4/r_5 exceeds the lower limit, it will cause an excessive negative refractive power in the front group, and, in a manner similar to the case in which the lower limit of the equation (3) is exceeded, and it is not possible to correct the spherical aberration and, further, it becomes impossible to provide a fast lens. When the upper limit is exceeded, it tends to increase the curvature of the image surface in the same manner as when the upper limit of the equation (3) is exceeded.

That is, under each of the conditions of the equations (1), (2), (3) and (4), it becomes possible to have the front group of the lens system satisfying the properties discussed earlier.

Thus, it is not necessary to have a large positive power in the rear group and thus the simple configuration of the prior art of only two positive lenses may be provided making it possible to correct aberrations easily while keeping the size of the lens compact and keeping the back focal length f_B sufficiently long enough. Further, in order to effect the correction of the aberration, it is preferable to provide the following conditions for the lenses of the rear group;

$$1.8 < n_6 \tag{5}$$

$$20 < \nu_5 - \nu_4 \tag{6}$$

where, n_6 is the refractive index of the glass of the lens L_6 of the fifth group with respect to d-line, ν_4 and ν_5 are Abbe numbers given by d-line of the component glass of the lenses L_4 and L_5 of the fourth group.

In order to keep the positive power born by the two positive lenses of the rear group as large as possible even if a positive power of the front group is made to be a relatively large value and a positive power of the rear group is not too high by fulfilling each of the above described conditions and further to keep a large aperture lens of the present invention, it is preferable to maintain the refractive indicies n of the two positive lenses as large as possible. However, it is required that the refractive index of the lens L_4 is large, the refractive index of the lens L_5 small, ν of the lens L_4 small, and the refractive index of the lens L_5 large in order to provide correction for the sagittal image surface in the fourth group and correction for the chromatic aberration and thus it is preferable to have a refractive index of n_6 as large as possible.

When it is less than the limit of the equation (5), it is impossible to provide proper corrections for the spherical aberration, distortion etc. in the lenses of the rear group. Along with this effect, the condition shown in the equation (6) is an essential condition of achromatism in the lenses L_4 and L_5 of the fourth group under such condition as a powerful achromatism in the lens L_6 of the fifth group may not be obtained and thus it becomes impossible to provide a chromatic correction in the rear group when it is less than the limitation.

Practical embodiments of the present invention will now be described herebelow.

EMBODIMENT 1

f = 1 F 1.8	$2\omega = 56°$	$f_B = 0.8464$	$\Sigma d = 0.7053$
$r_1 = 0.9951$	$d_1 = 0.0725$	$n_1 = 1.71300$	$\nu_1 = 53.9$
$r_2 = 3.9769$	$d_2 = 0.0024$		
$r_3 = 0.4274$	$d_3 = 0.0483$	$n_2 = 1.58144$	$\nu_2 = 40.7$
$r_4 = 0.2873$	$d_4 = 0.0531$		
$r_5 = 0.3052$	$d_5 = 0.0966$	$n_3 = 1.67003$	$\nu_3 = 47.3$
$r_6 = 0.3126$	$d_6 = 0.2029$		
$r_7 = -0.3341$	$d_7 = 0.0217$	$n_4 = 1.75520$	$\nu_4 = 27.5$
$r_8 = 38.9089$	$d_8 = 0.1329$	$n_5 = 1.67790$	$\nu_5 = 55.3$
$r_9 = -0.3966$	$d_9 = 0.0024$		
$r_{10} = 11.2319$	$d_{10} = 0.0725$	$n_6 = 1.88300$	$\nu_6 = 40.8$
$r_{11} = -0.9167$			

$f_2 = -1.725$

This is an embodiment of FIG. 1A, and where,

$r_1, r_2, \ldots r_{11}$ designates the radius of curvature of the lenses measured in sequence from the object side,

$d_1, d_3, d_5, d_7, d_8, d_{10}$ designates the axial thickness of the lenses measured in sequence from the object side,

d_2, d_4, d_6, d_9 designates the axial air spaces between the lenses measured in sequence from the object side,

$n_1, n_2, \ldots n_6$ designates the refractive index of the optical glass of the lenses with respect to the d-line measured in sequence from the object side, and

ν_1, ν_2, . . . designates the Abbe number of the optical glass of the lenses measured with respect to d-line in sequence from the object side.

Seidel's aberrations of Embodiment 1.

	S	C	A	P	D
1	0.2466	0.1487	0.0896	0.4183	0.3061
2	0.0259	−0.0982	0.3732	−0.1047	−1.0202
3	0.5778	0.1463	0.0371	0.8602	0.2273
4	−6.6261	−0.2376	−0.0085	−1.2799	−0.0462
5	5.6800	0.6946	0.0849	1.3146	0.1712
6	−1.6196	−0.6435	−0.2557	−1.2836	−0.6116
7	−3.4114	1.2462	−0.4553	−1.2878	0.6368
8	−0.0586	−0.0691	−0.0814	−0.0007	−0.0967
9	2.6149	−0.4894	0.0916	1.0187	−0.2078
10	−0.0001	0.0027	−0.0750	0.0418	0.9239
11	2.9679	−0.6796	0.1556	0.5116	−0.1528
Σ	0.3972	0.0211	−0.0438	0.2085	0.1300

Seidel's aberrations show the value when the distance of the object side is set to an infinite point and a diaphragm is set to a position of 0.101 rearward of the sixth lens surface, and the symbols in the table are as follows.
S: spherical aberration
C: coma
A: astigmatism
P: Petzval's condition
D: distortion
Σ: sum of each of the aberrations

EMBODIMENT 2

f = 1 F 1.84	2ω = 56°	f_B = 0.8443	Σd = 0.6940
r_1 = 0.9963	d_1 = 0.0724	n_1 = 1.71300	ν_1 = 53.9
r_2 = 3.9165	d_2 = 0.0024		
r_3 = 0.4165	d_3 = 0.0458	n_2 = 1.58144	ν_2 = 40.7
r_4 = 0.2851	d_4 = 0.0531		
r_5 = 0.3015	d_5 = 0.0965	n_3 = 1.67003	ν_3 = 47.3
r_6 = 0.3057	d_6 = 0.1978		
r_7 = −0.3287	d_7 = 0.0210	n_4 = 1.76182	ν_4 = 26.6
r_8 = 8.4698	d_8 = 0.1303	n_5 = 1.71300	ν_5 = 53.9
r_9 = −0.3998	d_9 = 0.0024		
r_{10} = 11.3076	d_{10} = 0.0724	n_6 = 1.83400	ν_6 = 37.2
r_{11} = −0.8810			

f_2 = −1.782

This is another embodiment of FIG. 1(A). Each of the symbols used herein is the same as that used in Embodiment 1.

Seidel's aberrations of Embodiment 2.

	S	C	A	P	D
1	0.2457	0.1500	0.0915	0.4178	0.3109
2	0.0243	−0.0944	0.3662	−0.1063	−1.0085
3	0.6707	0.1598	0.0381	0.8828	0.2194
4	−6.7190	−0.2515	−0.0094	−1.2897	−0.0486
5	5.8131	0.7110	0.0870	1.3307	0.1734
6	−1.7360	−0.6758	−0.2631	−1.3124	−0.6133
7	−3.5823	1.2938	−0.4672	−1.3155	0.6438
8	−0.0477	−0.0511	−0.0548	−0.0019	−0.0608
9	2.6768	−0.5298	0.1049	1.0412	−0.2268
10	−0.0003	0.0048	−0.0886	0.0402	0.8934
11	3.0449	−0.6941	0.1582	0.5162	−0.1537
Σ	0.3902	0.0226	−0.0373	0.2031	0.1291

Seidel's aberrations show the value when the distance of the object side is set to an infinite point and a diaphragm is set to a position of 0.099 rearward of the sixth lens surface, and the symbols in the table are as follows.
S: spherical aberration
C: coma
A: astigmatism
P: Petzval's condition
D: distortion
Σ: sum of each of the aberrations

EMBODIMENT 3

f = 1 F 2	2ω = 56°	f_B = 0.8518	Σd = 0.6359
r_1 = 0.9272	d_1 = 0.0689	n_1 = 1.71300	ν_1 = 53.9
r_2 = 3.3721	d_2 = 0.0024		
r_3 = 0.4119	d_3 = 0.0447	n_2 = 1.58144	ν_2 = 40.7
r_4 = 0.2803	d_4 = 0.0456		
r_5 = 0.2950	d_5 = 0.0864	n_3 = 1.67003	ν_3 = 47.3
r_6 = 0.3038	d_6 = 0.1816		
r_7 = 0.3076	d_7 = 0.0194	n_4 = 1.71736	ν_4 = 29.5
r_8 = 2.4272	d_8 = 0.1214	n_5 = 1.69680	ν_5 = 55.5
r_9 = 0.3800	d_9 = −0.0024		
r_{10} = −24.2718	d_{10} = 0.0631	n_6 = 1.83400	ν_6 = 37.2
r_{11} = −0.8295			

f_2 = −1.725

This is another embodiment of FIG. 1(A). Each of the symbols used herein is the same as that used in Embodiment 1.

Seidel's aberrations of Embodiment 3.

	S	C	A	P	D
1	0.3048	0.1765	0.1022	0.4489	0.3191
2	0.0224	−0.0905	0.3650	−0.1234	−0.9751
3	0.6404	0.1760	0.0484	0.8926	0.2586
4	−6.9706	−0.4731	−0.0321	−1.3115	−0.0912
5	6.1149	0.8681	0.1232	1.3601	0.2106
6	−1.7847	−0.7033	−0.2772	−1.3206	−0.6297
7	−4.5250	1.5041	−0.5000	−1.3580	0.6176
8	−0.0387	−0.0334	−0.0288	−0.0029	−0.0274
9	3.3309	0.6375	0.1220	1.0806	−0.2302
10	−0.0048	0.0257	−0.1366	−0.0187	0.8253
11	3.3502	−0.8033	0.1926	0.5482	−0.1776
Σ	0.4400	0.0092	−0.0213	0.1954	0.1000

Seidel's aberrations show the value when the distance of the object side is set to an infinite point and a diaphragm is set to a position of 0.091 rearward of the sixth lens surface, and the symbols in the table are as follows.
S: spherical aberration
C: coma
A: astigmatism
P: Petzval's condition
D: distortion
Σ: sum of each of the aberrations

EMBODIMENT 4

f = 1 F 1.84	2ω = 56°	f_B = 0.8434	Σd = 0.6775
r_1 = 0.9841	d_1 = 0.0700	n_1 = 1.71300	ν_1 = 53.9
r_2 = 3.8830	d_2 = 0.0024		
r_3 = 0.4285	d_3 = 0.0459	n_2 = 1.57845	ν_2 = 41.5
r_4 = 0.2865	d_4 = 0.0483		
r_5 = 0.3048	d_5 = 0.0954	n_3 = 1.67003	ν_3 = 47.3
r_6 = 0.3198	d_6 = 0.1981		
r_7 = −0.3290	d_7 = 0.0205	n_4 = 1.76180	ν_4 = 27.1
r_8 = 11.5942	d_8 = 0.0024		
r_9 = 24.1546	d_9 = 0.1292	n_5 = 1.71300	ν_5 = 53.9
r_{10} = −0.3871	d_{10} = 0.0024		
r_{11} = 5.6763	d_{11} = 0.0628	n_6 = 1.83400	ν_6 = 37.2
r_{12} = −1.0360			

f_2 = −1.695

This is an embodiment of FIG. 1(B), and where,

$r_1, r_2, \ldots r_{12}$ designates the radius of curvature of the lenses measured in sequence from the object side,

$d_1, d_3, d_5, d_7, d_9, d_{11}$ designates the axial thickness of the lenses measured in sequence from the object side,

$d_2, d_4, d_6, d_8, d_{10}$ designates the axial air spaces between the lenses measured in sequence from the object side,

$n_1, n_2, \ldots n_6$ designates the refractive index of the optical glass of the lenses with respect to the d-line measured in sequence from the object side, and

$\nu_1, \nu_2, \ldots \nu_6$ designates the Abbe number of the optical glass of the lenses measured with respect to d-line in sequence from the object side.

Seidel's aberrations of Embodiment 4.

	S	C	A	P	D
1	0.2549	0.1553	0.0946	0.4229	0.3152
2	0.0255	−0.0972	0.3705	−0.1072	−1.0030
3	0.5645	0.1531	0.0415	0.8552	0.2433
4	−6.8606	−0.3101	−0.0140	−1.2792	−0.0585
5	5.8792	0.7359	0.0921	1.3162	0.1763
6	−1.4179	−0.5926	−0.2476	−1.2544	−0.6277
7	−3.7501	1.3339	−0.4744	−1.3143	0.6362
8	−1.5504	−1.7222	−1.9131	−0.0373	−2.1667
9	1.4343	1.6240	1.8387	0.0172	2.1013
10	3.2868	−0.5480	0.0914	1.0751	−0.1945
11	−0.0002	0.0044	−0.1142	0.0801	0.8763
12	2.5109	−0.7102	0.2009	0.4389	−0.1810
Σ	0.3769	0.0263	−0.0338	0.2132	0.1173

Seidel's aberrations show the value when the distance of the object side is set to an infinite point and a diaphragm is set to a position of 0.099 rearward of the sixth lens surface, and the symbols in the table are as follows.

S: spherical aberration
C: coma
A: astigmatism
P: Petzval's condition
D: distortion
Σ: sum of each of the aberrations

EMBODIMENT 5

f = 1 F 2	2ω = 56°	f_B = 0.8538	Σd = 0.6389
r_1 = 0.9814	d_1 = 0.0685	n_1 = 1.71300	ν_1 = 53.9
r_2 = 3.7090	d_2 = 0.0024		
r_3 = 0.4053	d_3 = 0.0434	n_2 = 1.58144	ν_2 = 40.7
r_4 = 0.2796	d_4 = 0.0454		
r_5 = 0.2961	d_5 = 0.0869	n_3 = 1.67003	ν_3 = 47.3
r_6 = 0.3076	d_6 = 0.1834		
r_7 = −0.3132	d_7 = 0.0193	n_4 = 1.72825	ν_4 = 28.5
r_8 = 4.0871	d_8 = 0.0014		
r_9 = 4.4515	d_9 = 0.1219	n_5 = 1.69680	ν_5 = 55.5
r_{10} = −0.3747	d_{10} = 0.0024		
r_{11} = 16.6489	d_{11} = 0.0639	n_6 = 1.83400	ν_6 = 37.2
r_{12} = −0.9391			

f_2 = −1.776

This is another embodiment of FIG. 1(B). Each of the symbols used herein is the same as that used in Embodiment 4.

Seidel's aberrations of Embodiment 5.

	S	C	A	P	D
1	0.2560	0.1630	0.1038	0.4241	0.3363
2	0.0219	−0.0878	0.3526	−0.1122	−0.9655
3	0.7694	0.1963	0.0501	0.9072	0.2443
4	−7.2221	−0.4641	−0.0298	−1.3151	−0.0864
5	6.2365	0.8686	0.1210	1.3552	0.2056
6	−1.7196	−0.6840	−0.2721	−1.3041	−0.6270
7	−4.4021	1.4818	−0.4988	−1.3454	0.6208
8	−2.3472	−2.2302	−2.1190	−0.1031	−2.1113

-continued

Seidel's aberrations of Embodiment 5.

	S	C	A	P	D
9	2.2635	2.1663	2.0734	0.0923	2.0727
10	3.6913	−0.6397	0.1109	1.0960	−0.2092
11	−0.0023	0.0178	−0.1362	0.0273	0.8302
12	2.8765	−0.7851	0.2143	0.4842	−0.1906
Σ	0.4217	0.0032	−0.0299	0.2063	0.1198

Seidel's aberrations show the value when the distance of the object side is set to an infinite point and a diaphragm is set to a position of 0.092 rearward of the sixth lens surface, and the symbols in the table are as follows.

S: spherical aberration
C: coma
A: astigmatism
P: Petzval's condition
D: distortion
Σ: sum of each of the aberrations

What is claimed is:

1. A semi wide angle objective lens constituting of five groups of six lens elements formed a front group having the first group of a positive meniscus single lens L_1 with its convex surface directed toward the object side, the second group of a negative meniscus single lens L_2 with its convex surface directed toward the object side and the third group of a positive meniscus single lens L_3 with its convex surface directed toward the object side, and forming a rear group having the fourth group of a negative lens L_4 with its concave surface having a large curvature directed toward the object side and of a positive lens L_5 with its convex surface having a large curvature directed toward an image side which are arranged with a mutual contact condition therebetween, and the fifth group of a positive lens L_6 characterized in that each of the following conditions, i.e.

$$1.69f < |f_2| < 1.79f \quad (1)$$

$$0.27f < r_4 < 0.29f \quad (2)$$

$$0.045f < d_4 < 0.054f \quad (3)$$

$$0.94 < r_4/r_5 < 0.096 \quad (4)$$

where,

f: the composite focal length of the entire lens system

f_2: the single focal length of the lens L_2 of the second group

r_4: the radius of curvature of the rear surface of the lens L_2 of the second group

d_4: the axial air space between the lens L_2 of the second group and lens L_3 of the third group

r_5: the radius of curvature of the front surface of the lens L_3 of the third group

is fulfilled.

2. Semi wide angle objective lens for fulfilling the condition as set forth in claim 1 constructed according to the constructional data given herebelow:

f = 1 F 1.8	2ω = 56°	f_B = 0.8464	
r_1 = 0.9951	d_1 = 0.0725	n_1 = 1.71300	ν_1 = 53.9
r_2 = 3.9769	d_2 = 0.0024		
r_3 = 0.4274	d_3 = 0.0483	n_2 = 1.58144	ν_2 = 40.7
r_4 = 0.2873	d_4 = 0.0531		
r_5 = 0.3052	d_5 = 0.0966	n_3 = 1.67003	ν_3 = 47.3
r_6 = 0.3126	d_6 = 0.2029		

-continued

f = 1 F 1.8	2ω = 56°	f_B = 0.8464	
r_7 = −0.3341	d_7 = 0.0217	n_4 = 1.75520	ν_4 = 27.5
r_8 = 38.9089	d_8 = 0.1329	n_5 = 1.67790	ν_5 = 55.3
r_9 = −0.3966	d_9 = 0.0024		
r_{10} = 11.2319	d_{10} = 0.0725	n_6 = 1.88300	ν_6 = 40.8
r_{11} = −0.9167			

where,

$r_1,r_2, \ldots r_{11}$: the radius of curvature of the lens measured in sequence from the object side

$d_1,d_3,d_5,d_7,d_8,d_{10}$: the axial thickness of the lens measured in sequence from the object side

d_2,d_4,d_6,d_9: the axial air space between the lenses measured in sequence from the object side

$n_1,n_2, \ldots n_6$: the refractive index of the optical glass of the lens with respect to the d-line measured in sequence from the object side

$\nu_1,\nu_2, \ldots \nu_6$: Abbe number of the optical glass of the lens measured with respect to d-line in sequence from the object side.

3. Semi wide angle objective lens for fulfilling the condition as set forth in claim 1 constructed according to the constructional data given herebelow:

f = 1 F 1.84	2ω = 56°	f_B = 0.8443	
r_1 = 0.9963	d_1 = 0.0724	n_1 = 1.71300	ν_1 = 53.9
r_2 = 3.9165	d_2 = 0.0024		
r_3 = 0.4165	d_3 = 0.0458	n_2 = 1.58144	ν_2 = 40.7
r_4 = 0.2851	d_4 = 0.0531		
r_5 = 0.3015	d_5 = 0.0965	n_3 = 1.67003	ν_3 = 47.3
r_6 = 0.3057	d_6 = 0.1978		
r_7 = −0.3287	d_7 = 0.0210	n_4 = 1.76182	ν_4 = 26.6
r_8 = 8.4698	d_8 = 0.1303	n_5 = 1.71300	ν_5 = 53.9
r_9 = −0.3998	d_9 = 0.0024		
r_{10} = 11.3076	d_{10} = 0.0724	n_6 = 1.83400	ν_6 = 37.2
r_{11} = −0.8810			

where,

$r_1,r_2, \ldots r_{11}$: the radius of curvature of the lens measured in sequence from the object side

$d_1,d_3,d_5,d_7,d_8,d_{10}$: the axial thickness of the lens measured in sequence from the object side

d_2,d_4,d_6,d_9: the axial air space between the lenses measured in sequence from the object side

$n_1,n_2, \ldots n_6$: the refractive index of the optical glass of the lens with respect to the d-line measured in sequence from the object side

$\nu_1,\nu_2, \ldots \nu_6$: Abbe number of the optical glass of a lens measured with respect to d-line in sequence from the object side.

4. Semi wide angle objective lens for fulfilling the condition as set forth in claim 1 constructed according to the constructional data given herebelow:

f = 1 F 2	2ω = 56°	f_B = 0.8518	
r_1 = 0.9272	d_1 = 0.0689	n_1 = 1.71300	ν_1 = 53.9
r_2 = 3.3721	d_2 = 0.0024		
r_3 = 0.4119	d_3 = 0.0447	n_2 = 1.58144	ν_2 = 40.7
r_4 = 0.2803	d_4 = 0.0456		
r_5 = 0.2950	d_5 = 0.0864	n_3 = 1.67003	ν_3 = 47.3
r_6 = 0.3038	d_6 = 0.1816		
r_7 = −0.3076	d_7 = 0.0194	n_4 = 1.71736	ν_4 = 29.5
r_8 = 2.4272	d_8 = 0.1214	n_5 = 1.69680	ν_5 = 55.5
r_9 = −0.3800	d_9 = 0.0024		
r_{10} = −24.2718	d_{10} = 0.0631	n_6 = 1.83400	ν_6 = 37.2
r_{11} = −0.8295			

where,

$r_1,r_2, \ldots r_{11}$: the radius of curvature of the lens measured in sequence from the object side

$d_1,d_3,d_5,d_7,d_8,d_{10}$: the axial thickness of the lens measured in sequence from the object side

d_2,d_4,d_6,d_9: the axial air space between the lenses measured in sequence from the object side

$n_1,n_2, \ldots n_6$: the refractive index of the optical glass of the lens with respect to the d-line measured in sequence from the object side

$\nu_1,\nu_2, \ldots \nu_6$: Abbe number of the optical glass of the lens measured with respect to d-line in sequence from the object side.

5. Semi wide angle objective lens for fulfilling the condition as set forth in claim 1 constructed according to the constructional data given herebelow:

f = 1 F 1.84	2ω = 56°	f_B = 0.8434	
r_1 = 0.9841	d_1 = 0.0700	n_1 = 1.71300	ν_1 = 53.9
r_2 = 3.8830	d_2 = 0.0024		
r_3 = 0.4285	d_3 = 0.0459	n_2 = 1.57845	ν_2 = 41.5
r_4 = 0.2865	d_4 = 0.0483		
r_5 = 0.3048	d_5 = 0.0954	n_3 = 1.67003	ν_3 = 47.3
r_6 = 0.3198	d_6 = 0.1981		
r_7 = −0.3290	d_7 = 0.0205	n_4 = 1.76180	ν_4 = 27.1
r_8 = 11.5942	d_8 = 0.0024		
r_9 = 24.1546	d_9 = 0.1292	n_5 = 1.71300	ν_5 = 53.9
r_{10} = −0.3871	d_{10} = 0.0024		
r_{11} = 5.6763	d_{11} = 0.0628	n_6 = 1.83400	ν_6 = 37.2
r_{12} = −1.0360			

where,

$r_1,r_2, \ldots r_{12}$: the radius of curvature of the lens measured in sequence from the object side

$d_1,d_3,d_5,d_7,d_9,d_{11}$: the axial thickness of the lens measured in sequence from the object side

d_2,d_4,d_6,d_8,d_{10}: the axial air space between the lenses measured in sequence from the object side

$n_1,n_2, \ldots n_6$: the refractive index of the optical glass of the lens with respect to the d-line measured in sequence from the object side

$\nu_1,\nu_2, \ldots \nu_6$: Abbe number of the optical glass of the lens measured with respect to d-line in sequence from the object side.

6. Semi wide angle objective lens for fulfilling the condition as set forth in claim 1 constructed according to the constructional data given herebelow:

f =0 1 F 2	2ω = 56°	f_B = 0.8538	
r_1 = 0.9814	d_1 = 0.0685	n_1 = 1.71300	ν_1 = 53.9
r_2 = 3.7090	d_2 = 0.0024		
r_3 = 0.4053	d_3 = 0.0434	n_2 = 1.58144	ν_2 = 40.7
r_4 = 0.2796	d_4 = 0.0454		
r_5 = 0.2961	d_5 = 0.0869	n_3 = 1.67003	ν_3 = 47.3
r_6 = 0.3076	d_6 = 0.1834		
r_7 = −0.3132	d_7 = 0.0193	n_4 = 1.72825	ν_4 = 28.5
r_8 = 4.0871	d_8 = 0.0014		
r_9 = 4.4515	d_9 = 0.1219	n_5 = 1.69680	ν_5 = 55.5
r_{10} = −0.3747	d_{10} = 0.0024		
r_{11} = 16.6489	d_{11} = 0.0639	n_6 = 1.83400	ν_6 = 37.2
r_{12} = −0.9391			

where,

$r_1,r_2, \ldots r_{12}$: the radius of curvature of the lens measured in sequence from the object side

$d_1,d_3,d_5,d_7,d_9,d_{11}$: the axial thickness of the lens measured in sequence from the object side

d_2,d_4,d_6,d_8,d_{10}: the axial air space between the lenses measured in sequence from the object side

$n_1, n_2, \ldots n_6$: the refractive index of the optical glass of the lens with respect to the d-line measured in sequence from the object side

$\nu_1, \nu_2, \ldots \nu_6$: Abbe number of the optical glass of the lens measured with respect to d-line in sequence from the object side.

7. A semi wide angle objective lens constituting of five groups of six lens elements forming a front group having the first group of a positive meniscus single lens L_1 with its convex surface directed toward the object side, the second group of a negative meniscus single lens L_2 with its convex surface directed toward the object side and the third group of a positive meniscus single lens L_3 with its convex surface directed toward the object side, and forming a rear group having the fourth group of a negative lens L_4 with its concave surface having a large curvature directed toward the object side and of a positive lens L_5 with its convex surface having a large curvature directed toward an image side which are arranged with an extremely small air space therebetween, and the fifth group of a positive lens L_6 characterized in that each of the following conditions, i.e.

$$1.69f < |f_2| < 1.79f \quad (1)$$

$$0.27f < r_4 < 0.29f \quad (2)$$

$$0.045f < d_4 < 0.054f \quad (3)$$

$$0.94 < r_4/r_5 < 0.96 \quad (4)$$

where

f: the composite focal length of the entire lens system

f_2: the single focal length of the lens L_2 of the second group

r_4: the radius of curvature of the rear surface of the lens L_2 of the second group

d_4: the axial air space between the L_2 of the second group and lens L_3 of the third group

r_5: the radius of curvature of the front surface of the lens L_3 of the third group

is fulfilled.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 4,214,815

DATED : July 29, 1980

INVENTOR(S) : Toshiko Shimokura

It is certified that error appears in the above—identified patent and that said Letters Patent is hereby corrected as shown below:

Column 1, line 17, after "with" the letter -- f -- should have been inserted therefor.

Column 6, line 21, "n" should have read -- n --.

Column 10, line 45, "0.096" should read -- 0.96 --.

Signed and Sealed this

Twenty-fifth Day of *November 1980*

[SEAL]

Attest:

Attesting Officer

SIDNEY A. DIAMOND

Commissioner of Patents and Trademarks

United States Patent [19]

Kellner

[11] **4,213,686**

[45] **Jul. 22, 1980**

[54] **CLOSEUP FOCUSING MECHANISM FOR AN OBJECTIVE OF LONG FOCAL LENGTH**

[76] Inventor: **Ferdinand Kellner,** Spittelmüllerstr. 6, 8940 Memmingen, Fed. Rep. of Germany

[21] Appl. No.: **57,077**

[22] Filed: **Jul. 12, 1979**

[30] **Foreign Application Priority Data**

Jul. 25, 1978 [DE] Fed. Rep. of Germany 2832522

[51] **Int. Cl.**[2] **G03B 17/00;** G03B 13/02

[52] **U.S. Cl.** **354/195;** 354/286

[58] **Field of Search** 354/195, 196, 198, 200, 354/202, 286

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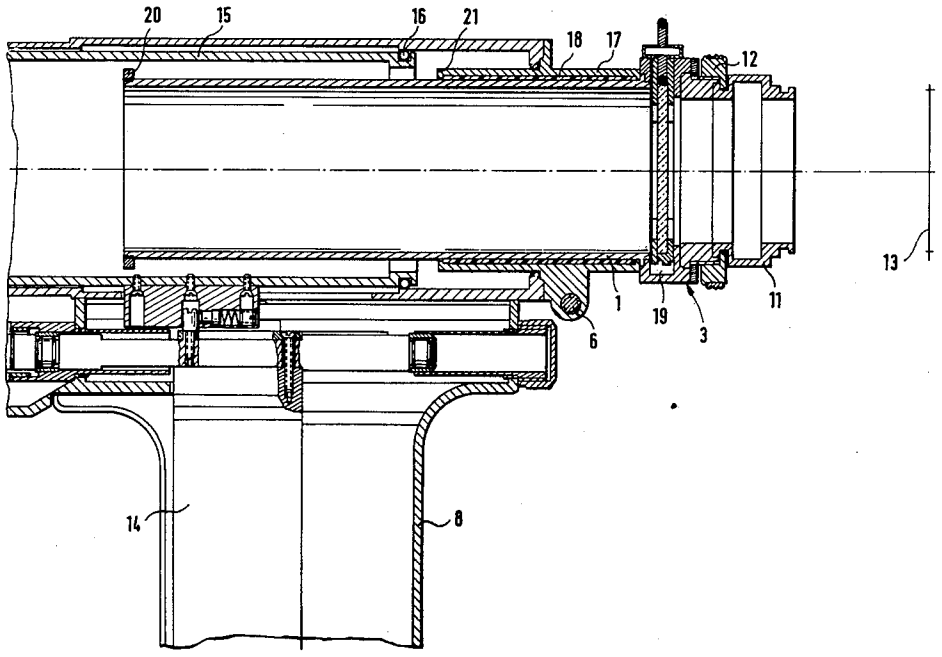
Primary Examiner—Donald A. Griffin

Attorney, Agent, or Firm—Holman & Stern

[57] **ABSTRACT**

In a closeup focusing mechanism for objectives of long focal length, a tube carried between the objective housing and a camera mounting means telescopes into and out of the objective housing. The camera mounting means carries an axially extending rod externally of the tube which is guided in a guide carried by the objective housing. Thus the tube does not rotate relative to the housing.

4 Claims, 5 Drawing Figures



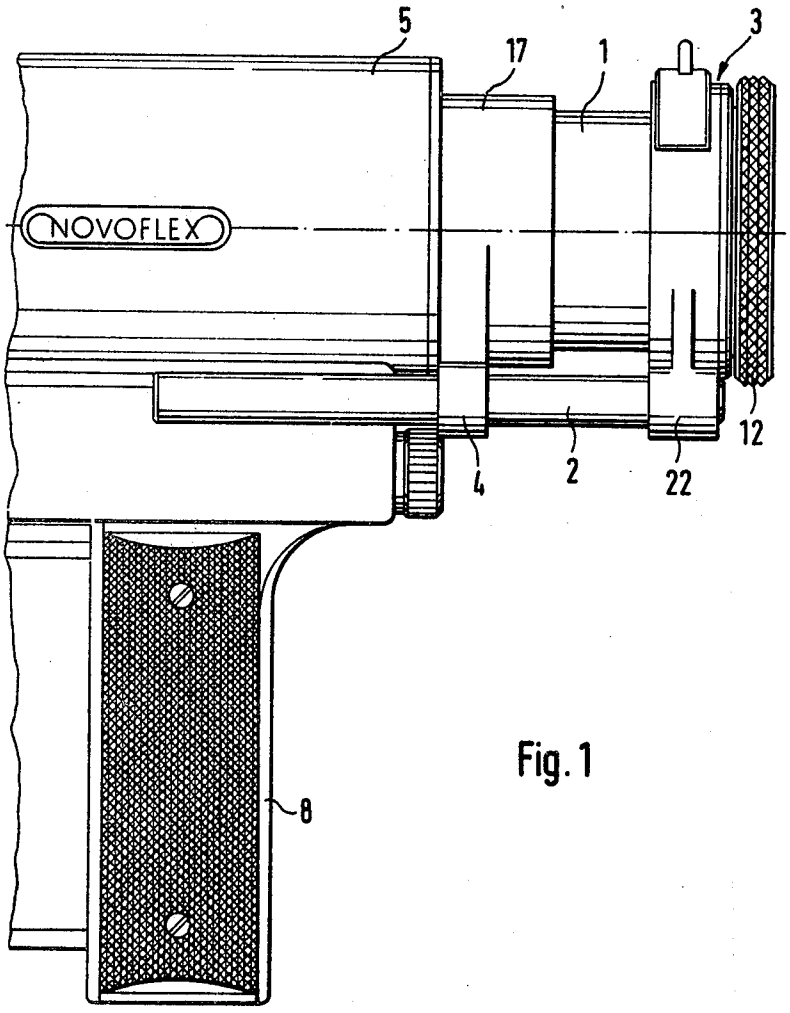


Fig. 1

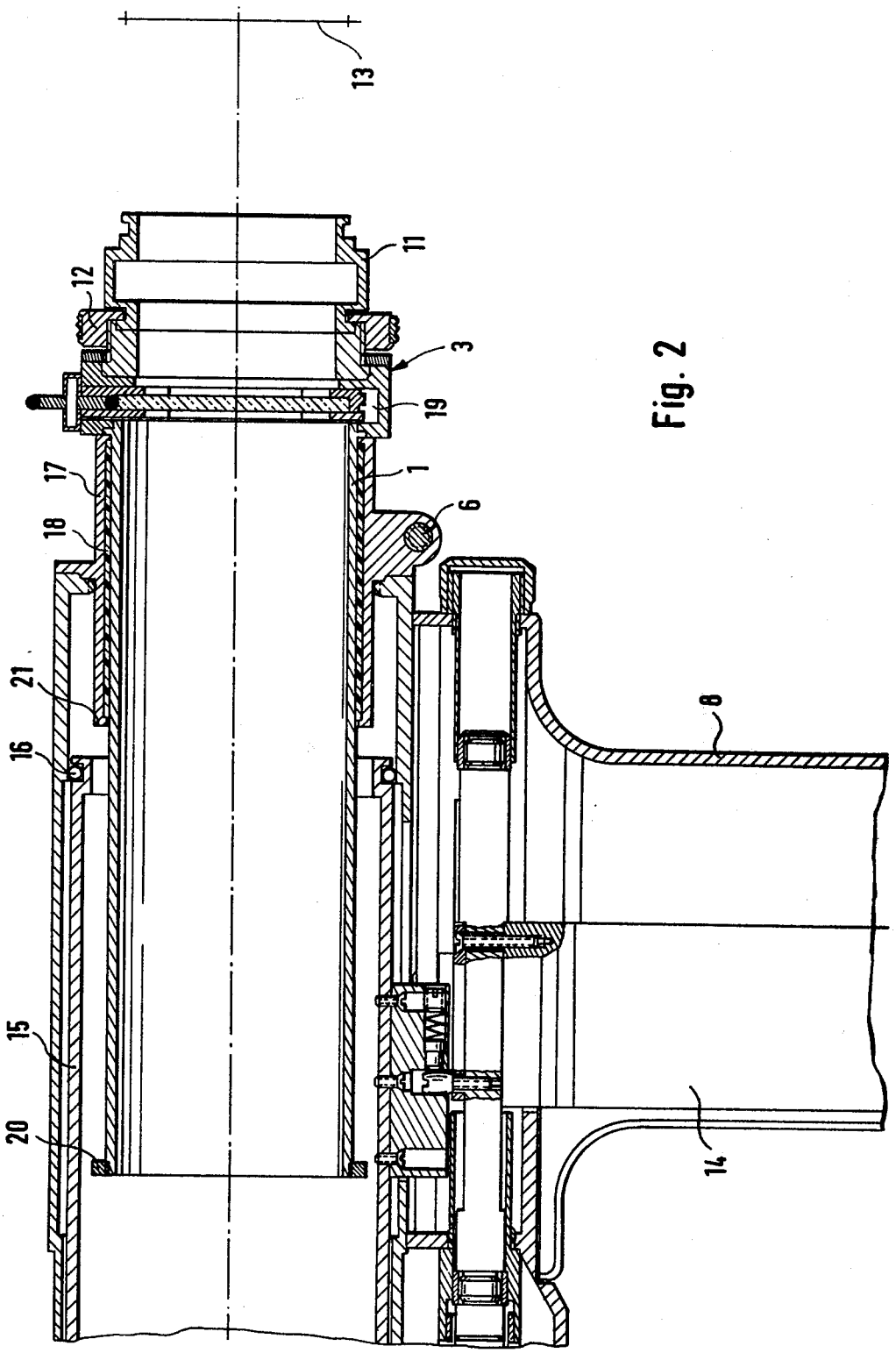


Fig. 2

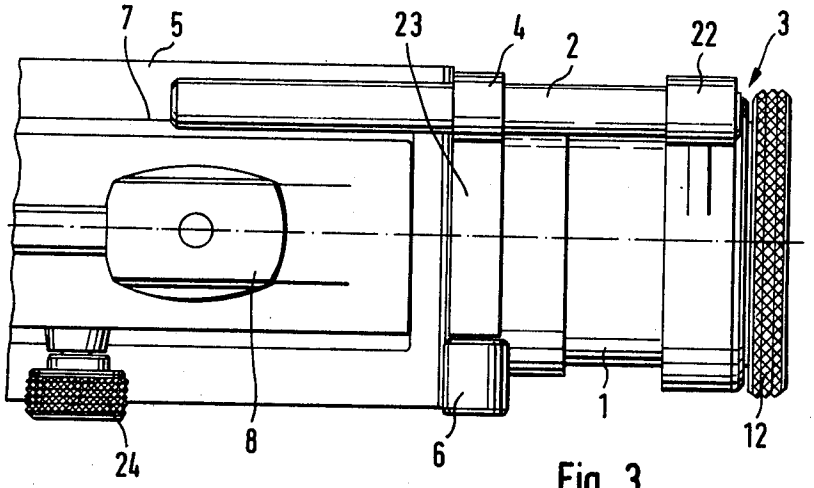


Fig. 3

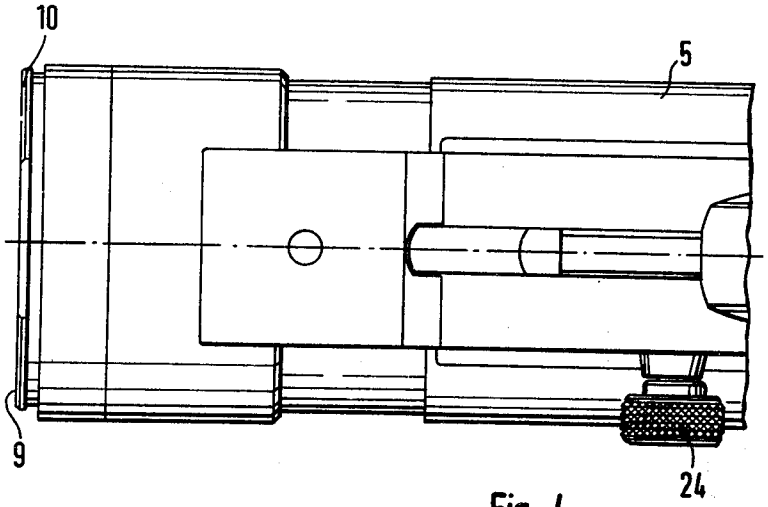


Fig. 4

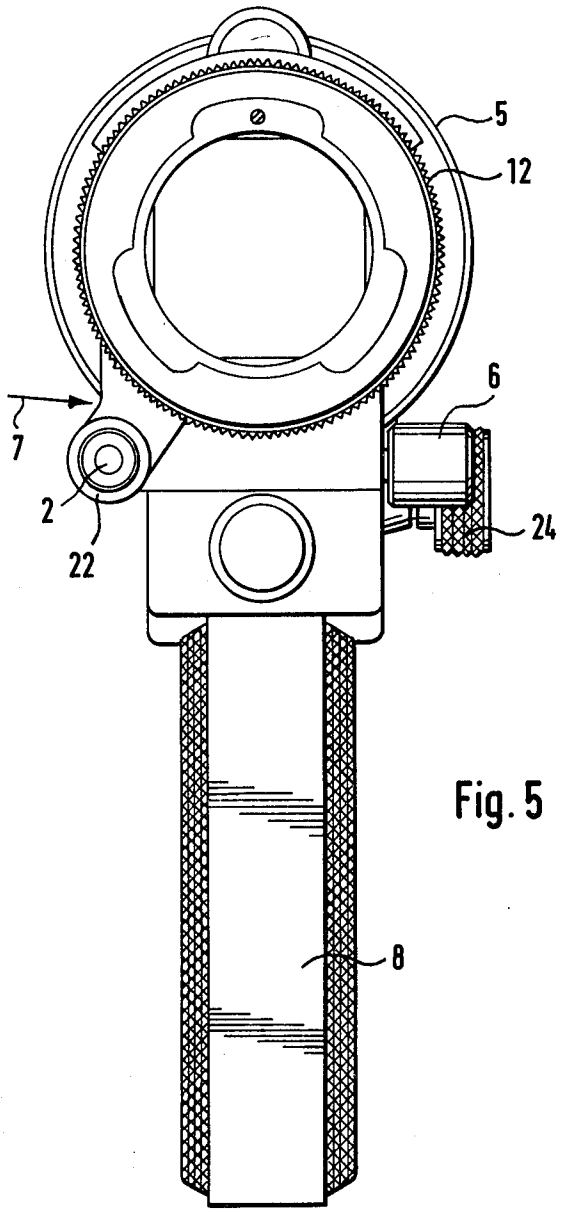


Fig. 5

CLOSEUP FOCUSING MECHANISM FOR AN OBJECTIVE OF LONG FOCAL LENGTH

BACKGROUND OF THE INVENTION

The invention concerns a camera closeup focusing mechanism for objectives of long focal length, comprising a tube between the objective housing and a mounting means for the camera, as well as anti-rotation means.

Telephoto objectives, objectives of long focal length, as a rule have focusing ranges of infinity to about 7 meters. However it is often desirable, when photographing birds and similar subjects, to be able to focus sharply at a distance of from two to three meters. This is achieved by inserting a closeup focusing mechanism between the objective housing and the mounting means for the camera.

The design of a closeup focusing mechanism in the form of a tube is already known. There is a certain minimum inner diameter which the tube must have, and should exceed, depending on the format and dimensions of the objective, in order to avoid underexposure of the border regions of the photograph.

At the same time the outer diameter of the tube imposes a limit on the dimensions of the objective and/or its fine-focusing mechanism. If the outer diameter of the tube is increased, all the dimensions of the objective must be modified. It is clear that the outer diameter of the tube is limited by these conditions

Known closeup focusing mechanisms use a tube which has the maximum possible thickness taking into account the above conditions. Grooves are machined into this tube in order to supply the required guiding means between the camera on the one side and the telephoto objective on the other.

Such guides or guide grooves are necessary in order to have means of transmitting rotational forces between the camera and the objective. This is a factor, for example, when the camera is being turned between vertical and horizontal formats, or in the attaching of the objective to the camera.

Cameras currently used for long-focal-length objectives, in particular, have substantial size and weight, typically with, for example, motorized film transports, etc. Also the weight of the telephoto objective itself is relatively high. The tube thus must form a connection between relatively heavy parts.

Since however the tube wall should be kept as thin as possible, the guide grooves in the tube must be kept small. The guides, grooves and the like are therefore subject to relatively high stresses. If the transmission and accommodation of these stresses is unsatisfactory, the guides can be overloaded, and there is danger of sudden or rapid wear. The useful life of the tube with guides therefore tends to be less than that of other parts of the camera or the telephoto objective.

An object of the present invention is to provide a closeup focusing mechanism for objectives with long focal lengths, which mechanism has a relatively high load-carrying capability and does not develop appreciable evidence of wear after long use. A further object of the invention is to provide a device which does not require an increase in the dimensions of the telephoto objective, particularly its diameter; but rather, such a closeup focusing mechanism should be usable with available telephoto objectives.

SUMMARY OF THE INVENTION

The present invention provides a closeup focusing mechanism for long-focal-length objectives, comprising a tube between the objective housing and the mounting means for the camera, which tube can be pushed or slid into and pulled out of the objective housing with prevention of rotation between the camera mounting means and the objective housing.

In accordance with the invention, it is proposed that the tube be manufactured from thin walled material, and that external to the tube there be a guide rod attached to the camera mounting means, which rod works in concert with a guide on the objective housing.

The invention employs a relatively thin walled tube but in an arrangement whereby it need not sustain any rotational stresses. It is therefore unnecessary to have grooves or other guide means on this tube. It is sufficient for the tube to be guided telescopically to ensure that the optical axis of the camera is directed in the direction of the optical axis of the telephoto objective. The forces involved in directing these parts can be transmitted by such a relatively thin walled tube substantially without damage or wear phenomena developing. One need only supply certain necessary elements, e.g., features of the camera mounting, or detent means, so as to prevent the tube from being pulled out of the objective housing. There is no particular problem in accommodating these parts with a thin walled tube of the type proposed. The invention thereby achieves a relatively large inner diameter for light beam passage without the diameter of the objective being increased.

The guide rod can be mounted so as not to affect the other parts of the objective, etc. The rod can for example be attached to the camera mount or mounting ring and work together with a guide on the objective housing. One guide rod suffices, since rotation is prevented by the combination of guide rod on one side and the tube on the other. The guide rod and guide are simple elements which can be manufactured at modest cost.

In its fixed position the guide rod is capable of bearing the entire stress of holding the assembly in place, thus substantially relieving the stress on the tube and its own telescoping guides, which contributes greatly to the operating life of the assembly.

It is further advantageous for the fixing of the guide rod to be effected by means of a set screw in the guide.

There is a wide choice of location of the guide rod. However, it is advantageous for the rod to be located in the angular section neighboring the attachment location of the holding grip or operating grip to the objective housing. In this way the guide rod fits into the outer contour of the telephoto objective and does not take up a great deal of additional space, which can become important when the apparatus is being carried or shipped. It is also important during use, where there are no projecting parts to interfere with manipulation.

It is further proposed that the set screw be on one side of the grip and the guide rod on the other, which yields a compact design.

BRIEF DESCRIPTION OF DRAWINGS

FIG. 1 is an elevation showing the rear part of a long-focal-length objective with a closeup focusing mechanism according to the invention;

FIG. 2 is a partial cross section of the above type of objective and closeup focusing mechanism;

FIG. 3 is a bottom view of the rear part of the objective of FIG. 1;

FIG. 4 shows the adjoining part of the objective of FIG. 3; and

FIG. 5 is a rear view of the objective of FIG. 1.

DESCRIPTION OF PREFERRED EMBODIMENT

The objective shown in the drawings is a piece which is constructed unitarily with objective housing 5. Another objective part attaches on at the front end 9 (see FIG. 4) of this first objective part, via bayonet mount 10, when the objective is in the operating mode. This front part of the objective is not shown further.

The associated camera is also omitted from the drawings. This camera can be attached, for example, on mounting ring 11, which is held by nut 12 to camera mount 3. The film plane of the camera is signified by 13 in FIG. 2.

The part of the objective shown in the drawing comprises basically the objective housing 5 which is rigidly connected to the grip 8. The tube 15 is moved in objective housing 5 for fine focusing by means of the movable part 14 of the grip. Tube 15 is supported in objective housing 5 by means of, for example, bearing 16. The guide tube 17 for tube 1 is attached at the rear end area of objective housing 5. A suitable coating 18 is provided on the inside of said guide tube 17 in order to ensure that tube 1 is easily slidable in guide tube 17.

The outer end of tube 1 supports the camera mount 3 and may be permanently joined to these parts. There may also be compartment 19 for filters or similar devices.

FIG. 2 shows the position in which tube 1 is fully slid into the objective housing 5. FIGS. 1 and 3 show a position where the tube is partly pulled out. A detent ring 20 is provided on the inner end of tube 1 to prevent undesired pulling out of said tube from the guide tube 17. At the maximum pulled-out position, detent 20 contacts the inner end 21 of guide tube 17.

A guide rod 2 is attached in a boss 22 on the camera mount 3. This guide rod is guided in guide 4 which is attached to guide tube 17. The arrangement places the guide rod in angular region 7 relative to grip 8 as attached to objective housing 5. A set screw 6, which is located on the other side of grip 8, is partially enclosed in part 23. It clamps by tightly engaging guide rod 2 in guide 4, at the desired extended position of tube 1. As seen clearly in FIG. 3, there is also an adjusting device 24 for fixing the fine-focusing setting of the objective.

What is claimed is:

1. A closeup focusing mechanism for a long-focal-length objective comprising an objective housing, means for mounting the objective to a camera, a tube between the objective housing and the camera mounting means, the tube being slidable into and out of the objective housing, a guide rod attached to the camera mounting means and extending towards the objective housing externally of the tube, and a guide for said rod on the objective housing.

2. A closeup focusing mechanism according to claim 1 including a set screw for fixing the guide rod in the guide.

3. A closeup focusing mechanism according to claim 2 and including an operating grip associated with said housing, said set screw being located on one side of said grip and said guide rod and guide being located on the other side of said grip.

4. A closeup focusing mechanism according to claim 1 or claim 2 including an operating grip associated with said housing and the guide rod being positioned adjacent the junction between said housing and said grip.

* * * * *

OR 4,211,472 465 ✓
X350-482 ✓

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Jul. 8, 1980

[54] **WIDE ANGLE OBJECTIVE LENS SYSTEM**

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[73] Assignee: **Minolta Camera Kabushiki Kaisha**, Sakai, Japan

[21] Appl. No.: **958,427**

[22] Filed: **Nov. 7, 1978**

[30] **Foreign Application Priority Data**

Nov. 16, 1977 [JP] Japan 52-138101

[51] **Int. Cl.**[2] **G02B 11/30**
[52] **U.S. Cl.** **350/216**
[58] **Field of Search** 350/215, 216

[56] **References Cited**

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3,132,199	5/1964	Zimmerman	350/216
3,492,064	1/1970	Hoogland	350/216
3,591,257	7/1971	Mandler	350/215
3,601,473	8/1971	Mandler	350/215

Primary Examiner—Conrad J. Clark
Attorney, Agent, or Firm—Jackson, Jones & Price

[57] **ABSTRACT**

A compact wide angle lens system for use in a camera having a range finder is provided. The lens system is of five-group, seven-element type comprising, consecutively from the object to the image side, a first lens group consisting of a negative meniscus single lens convex to the object side, a second lens group consisting of a positive doublet having a cementing surface concave to the object side, a third lens group consisting of a negative meniscus single lens concave to the object side, a fourth lens group consisting of a positive doublet, and a fifth lens group consisting of a negative meniscus single lens concave to the object side.

7 Claims, 16 Drawing Figures

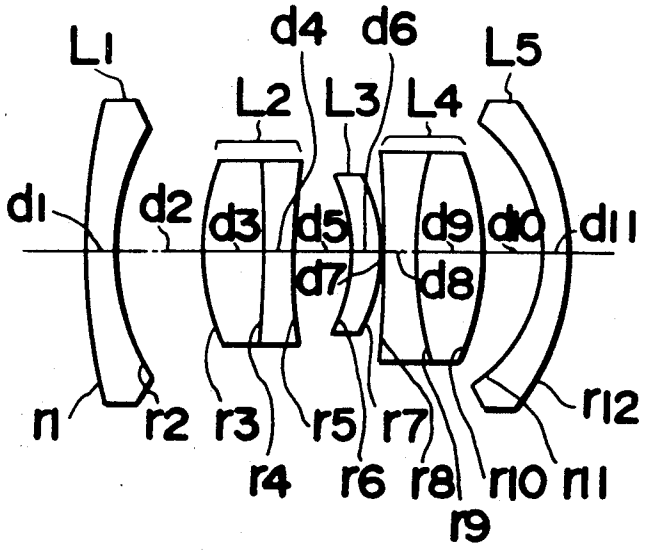


FIG.1

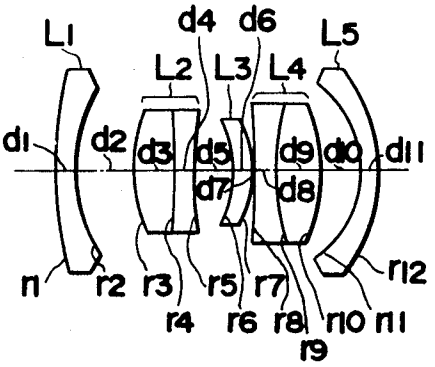
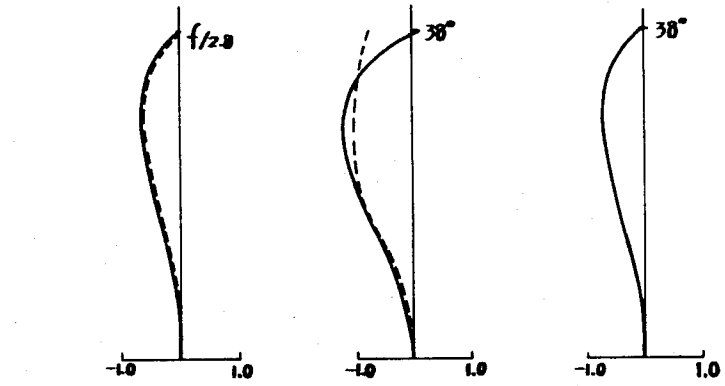


FIG.2a FIG.2b FIG.2c



——Spherical Aberration Astigmatism Distortion

----Sine Condition

FIG.3

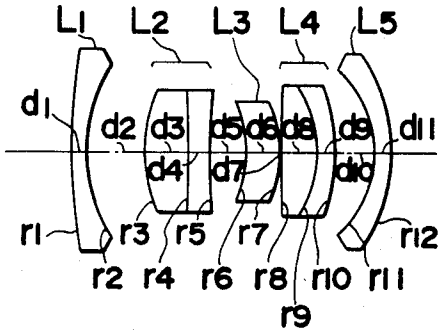


FIG.4a FIG.4b FIG.4c

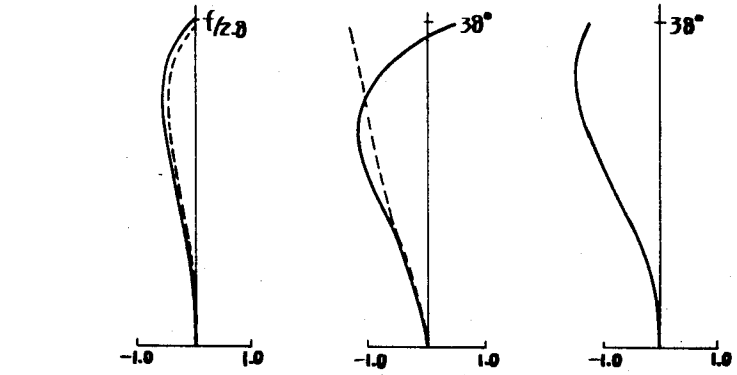


FIG.5

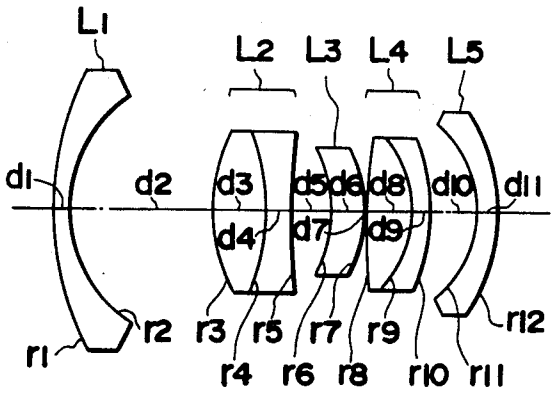


FIG.6a FIG.6b FIG.6c

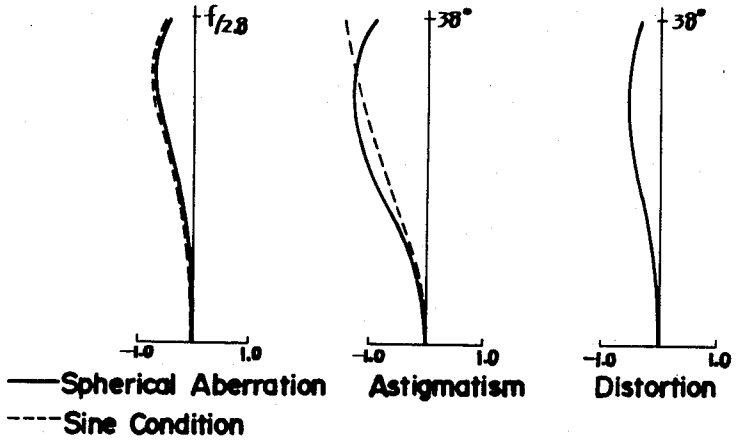


FIG.7

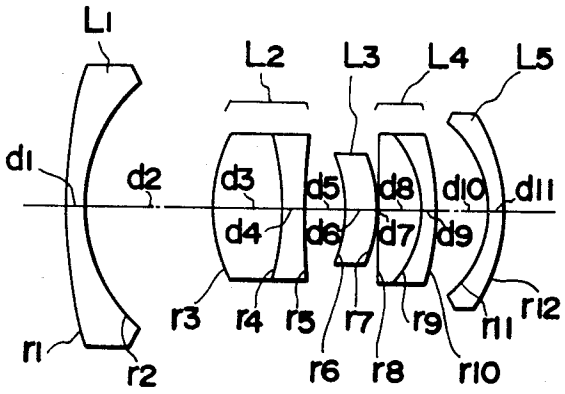
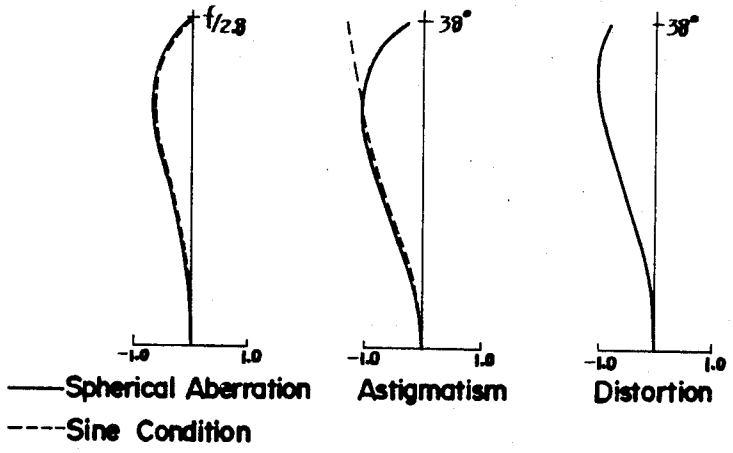


FIG.8a FIG.8b FHG.8c



WIDE ANGLE OBJECTIVE LENS SYSTEM

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a wide angle objective lens system for use in a camera having a range finder, and more particularly to a wide angle objective lens system of a type in which a lens component of positive refractive power is sandwiched in between a pair of outer lens components of negative refractive power.

2. Description of the Prior Art

Various wide angle objective lens systems of a type having a positive lens component sandwiched in between a pair of outer negative lens component have been suggested in the prior art such as that disclosed in the U.S. Pat. Nos. 3,132,199, 3,591,257 and 3,601,473.

There is still a demand in the prior art to provide a high quality wide angle objective lens system that can be economically manufactured. More particularly there is a demand to provide these features on a wide angle objective lens system having a compact size.

SUMMARY OF THE INVENTION

An object of the present invention is to provide a wide angle objective lens system of a type having a positive lens component sandwiched in between a pair of outer negative lens components in a compact size.

Another object of the present invention is to provide a wide angle objective lens system of the above mentioned type with an aperture ratio about 1/2.8, a field angle of about 76 degrees and a back focal distance of about 60 to 70 percent of the focal length of the system.

A still another object of the present invention is to provide an improved wide angle objective lens system for use in a camera having a range finder.

A further object of the present invention is to provide an improved wide angle objective lens system of the above mentioned type wherein the aberrations have been sufficiently corrected for commercial use.

The wide angle objective lens system of the present invention is of five-group, seven-element comprising, consecutively from the object to the image side, a first lens group consisting of a negative meniscus single lens convex to the object side, a second lens group consisting of a positive doublet having a cemented surface concave to the object side, a third lens group consisting of a negative meniscus single lens concave to the object side, a fourth lens group consisting of a positive doublet, and a fifth lens group consisting of a negative meniscus single lens concave to the object side, the system fulfilling the following conditions:

$0.70 < \phi_5/\phi_1 < 1.35$,

$0.15f < d_2 < 0.55f$,

$0.13 < N_2 - N_3 < 0.24$, and

$1.5f < r_5$.

The features of the present invention which are believed to be novel are set forth with particularity in the appended claims. The present invention, both as to its organization and manner of operation, together with further objects and advantages thereof, may best be understood by reference to the following description, taken in conjunction with the accompanying drawings.

DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic cross-sectional view of a first embodiment of the present invention;

FIGS. **2***a*, **2***b* and **2***c* are respectively graphical plots of the abberations of the first embodiment;

FIG. **3** is a schematic cross-sectional view of a second embodiment of the present invention;

FIGS. **4***a*, **4***b* and **4***c* are graphical plots of the abberations of the second embodiment;

FIG. **5** is a schematic cross-sectional view of a third embodiment of the present invention;

FIGS. **6***a*, **6***b* and **6***c* are graphical plots of the aberrations of the third embodiment;

FIG. **7** is a schematical cross-sectional view of the fourth embodiment of the present invention; and

FIGS. **8***a*, **8***b* and **8***c* are graphical plots of the aberrations of the fourth embodiment.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The following description is provided to enable any person skilled in the optical art to make and use the invention and sets forth the best modes contemplated by the inventor of carrying out his invention. Various modifications, however, will remain readily apparent to those skilled in the art, since the generic principles of the present invention have been defined herein specifically to provide a wide angle objective lens system of a type having a positive component sandwiched in between a pair of outer negative components in a compact size.

The present invention represents the parameters of a compromise balance of acceptable aberrations in wide angle objective lens system for utilization with a 35 mm camera having a range finder.

In the accompanying drawings which supplement the following tables, the lenses in accordance with the present invention are illustrated diagrammatically. As usual, in conventional lens diagrams, light is assumed to travel from left to right. The individual lens groups are designated by the letter L with a subscript number corresponding to the consecutive numbers of the lens groups from image to object side. The radii of curvature of the lenses are indicated by r, with a subscript corresponding to consecutive numbers of the lens elements. The axial distances, d, along the optical axis are set forth both in the tables and in the drawings and include both the axial spacings between the lens elements and the thickness of the lens elements. Finally, the refractive index, N, and Abbe number, ν, are provided in each of the tables. Since the specific lens parameters are provided herein to meet the requirements of a full disclosure adequate to convey the present invention to a lens designer, they should not be construed as limiting to any specific lens design as set forth in an individual embodiment.

Four specific embodiments of the present invention are disclosed respectively in FIGS. **1**, **3**, **5**, and **7**. Each of these wide angle objective lens systems is of five-group, seven-element comprising, consecutively from the object of the image side, a first lens group L_1 consisting of a negative meniscus single lens convex to the object side, a second lens group L_2 consisting of a positive doublet having a cemented surface r_4 concave to the object side, a third lens group L_3 consisting of a negative meniscus single lens concave to the object side, a fourth lens group L_4 consisting of a positive doublet,

and a fifth lens group L_5 consisting of a negative meniscus single lens concave to the object side.

The wide angle objective lens system fulfills the following conditions:

(1) $0.70<\phi_5/\phi_1<1.35$;

(2) $0.15f<d_2<0.55f$;

(3) $0.13<N_2-N_3<0.24$;

(4) $1.5f<r_5$

wherein ϕ_1 represents a refractive power of the first lens group; ϕ_5 represents a refractive power of the fifth lens group; d_2 represents an axial distance between the first and second lens groups; f represents the focal length of the whole lens system; N_2 and N_3 represent refractive indices of the object side and image side lens elements in the doublet of the second lens group, respectively; and r_5 represents a radius of curvature of the image side surface of the doublet of the second lens group.

The above mentioned condition (1) relates to a pair of outer lens groups L_1 and L_5 each having a negative refractive power, and defines a ratio of refractive power of the fifth lens group L_5 to that of first lens group L_1 for minimizing the various aberrations which would be increased when a wide angle lens system having a positive component sandwiched in between a pair of outer negative components is desired to be compact. In case that the ratio, ϕ_5/ϕ_1 increases beyond the upper limit, the field curvature may be difficult to be corrected because of an inevitably increased Petzval Sum although the desired compactness of the system would be attained. On the contrary, a bulkiness of the system may undesirably result if a well balanced aberration correction is sought with the ratio, ϕ_5/ϕ_1 below the lower limit.

Condition (2) is for balancing the corrections of astigmatism and coma. The value of d_2 below 0.55f is favorable to the compactness of the system desired. However, the balance of aberration correction may be broken and a necessary back focal distance of the system may be impossible to be attained in case d_2 is less than 0.15f.

Condition (3) means that the refractive power of the cemented surface r_4 in the second lens group L_2 is positive. This condition is for cancelling aberrations which are generated at the first lens group L_1 and for decreasing the Petzval Sum to improve the field curvature. If (N_2-N_3) excessively increases beyond the upper limit, the correction of spherical aberration may be insufficient although it would be possible to decrease the Petzval Sum. On the other hand, the correction of distortion and negative coma may be insufficient and the spherical aberration may be excessively corrected.

Condition (4) is for correcting spherical aberration and balancing corrections of astigmatism and coma, and has a relation to the third lens group L_3. If condition (4) is violated, astigmatism may be negatively biased to deteriorate the field curvature. To recover the desirable field curvature, the third lens group L_3 may be required to have an excessive negative refractive power, which results in an additional generation of spherical aberration. Thus, it may be difficult to increase an aperture ratio.

The following Tables 1 to 4 show the first to fourth embodiments of the present invention, respectively.

Table 1

Embodiment 1
$f = 100.0$ $F_{no} = 2.8$ $2\omega = 76°$

	Radius of Curvature	Axial Distance	Refractive Index	Abbe Number
L_1	$r_1 = 157.331$	$d_1 = 5.50$	$N_1 = 1.5346$	$\nu_1 = 43.4$
	$r_2 = 56.989$	$d_2 = 19.76$		
L_2	$r_3 = 50.896$	$d_3 = 15.02$	$N_2 = 1.7745$	$\nu_2 = 50.6$
	$r_4 = -173.616$	$d_4 = 5.75$	$N_3 = 1.6158$	$\nu_3 = 37.0$
	$r_5 = 170.107$	$d_5 = 13.61$		
L_3	$r_6 = -31.552$	$d_6 = 7.08$	$N_4 = 1.7043$	$\nu_4 = 36.3$
	$r_7 = -37.691$	$d_7 = 0.42$		
L_4	$r_8 = -450.753$	$d_8 = 6.23$	$N_5 = 1.8074$	$\nu_5 = 31.4$
	$r_9 = 64.408$	$d_9 = 16.48$	$N_6 = 1.7830$	$\nu_6 = 47.7$
	$r_{10} = -60.187$	$d_{10} = 14.02$		
L_5	$r_{11} = -33.494$	$d_{11} = 5.50$	$N_7 = 1.6169$	$\nu_7 = 36.3$
	$r_{12} = -58.576$			

Table 2

Embodiment 2
$f = 100.0$ $F_{no} = 2.8$ $2\omega = 76°$

	Radius of Curvature	Axial Distance	Refractive Index	Abbe Number
L_1	$r_1 = 191.417$	$d_1 = 5.50$	$N_1 = 1.5814$	$\nu_1 = 40.9$
	$r_2 = 58.286$	$d_2 = 20.23$		
L_2	$r_3 = 50.287$	$d_3 = 15.32$	$N_2 = 1.7725$	$\nu_2 = 50.1$
	$r_4 = -484.179$	$d_4 = 6.02$	$N_3 = 1.6129$	$\nu_3 = 37.0$
	$r_5 = 327.216$	$d_5 = 13.61$		
L_3	$r_6 = -35.164$	$d_6 = 12.00$	$N_4 = 1.6200$	$\nu_4 = 36.3$
	$r_7 = -42.542$	$d_7 = 0.42$		
L_4	$r_8 = -810.58$	$d_8 = 12.00$	$N_5 = 1.7810$	$\nu_5 = 44.8$
	$r_9 = -35.001$	$d_9 = 5.95$	$N_6 = 1.8052$	$\nu_6 = 25.2$
	$r_{10} = -70.196$	$d_{10} = 14.02$		
L_5	$r_{11} = -33.895$	$d_{11} = 5.50$	$N_7 = 1.6200$	$\nu_7 = 36.3$
	$r_{12} = -61.002$			

Table 3

Embodiment 3
$f = 100.0$ $F_{no} = 2.8$ $2\omega = 76°$

	Radius of Curvature	Axial Distance	Refractive Index	Abbe Number
L_1	$r_1 = 106.023$	$d_1 = 5.50$	$N_1 = 1.6200$	$\nu_1 = 36.3$
	$r_2 = 44.247$	$d_2 = 48.86$		
L_2	$r_3 = 56.604$	$d_3 = 19.00$	$N_2 = 1.7495$	$\nu_2 = 50.4$
	$r_4 = -74.197$	$d_4 = 8.00$	$N_3 = 1.5407$	$\nu_3 = 46.9$
	$r_5 = 271.409$	$d_5 = 14.00$		
L_3	$r_6 = -43.670$	$d_6 = 11.00$	$N_4 = 1.6200$	$\nu_4 = 36.3$
	$r_7 = -49.934$	$d_7 = 0.52$		

Table 3-continued

	Embodiment 3 f = 100.0 F_{no} = 2.8 2ω = 76°			
	Radius of Curvature	Axial Distance	Refractive Index	Abbe Number
	r_8 = 340.221			
		d_8 = 16.00	N_5 = 1.4875	ν_5 = 69.9
L_4	r_9 = −35.042			
		d_9 = 6.00	N_6 = 1.8052	ν_6 = 25.2
	r_{10} = −61.699			
		d_{10} = 17.00		
	r_{11} = −34.746			
L_5		d_{11} = 5.50	N_7 = 1.6200	ν_7 = 36.3
	r_{12} = −58.256			

Table 4

	Embodiment 4 f = 100.0 F_{no} = 2.8 2ω = 76°			
	Radius of Curvature	Axial Distance	Refractive Index	Abbe Number
	r_1 = 162.731			
L_1		d_1 = 5.50	N_1 = 1.5404	ν_1 = 51.0
	r_2 = 52.892			
		d_2 = 45.20		
	r_3 = 59.180			
		d_3 = 23.18	N_2 = 1.7725	ν_2 = 50.1
L_2	r_4 = −102.339			
		d_4 = 8.00	N_3 = 1.6129	ν_3 = 37.0
	r_5 = 321.316			
		d_5 = 14.00		
	r_6 = −43.340			
L_3		d_6 = 11.00	N_4 = 1.6200	ν_4 = 36.3
	r_7 = −51.046			
		d_7 = 0.52		
	r_8 = −753.97			
		d_8 = 14.00	N_5 = 1.7106	ν_5 = 43.2
L_4	r_9 = −34.327			
		d_9 = 6.00	N_6 = 1.8052	ν_6 = 25.2
	r_{10} = −75.827			
		d_{10} = 18.00		
	r_{11} = −34.832			
L_5		d_{11} = 5.50	N_7 = 1.6166	ν_7 = 36.7
	r_{12} = −54.510			

In the above tables the spherical aberration, sine condition, astigmatism and distortion are plotted for each of the four embodiments in respectively FIGS. **2**, **4**, **6**, and **8**.

By adhering to the parameters and design considerations set forth in the above specification, a lens designer in the optical field is capable of providing a wide angle objective lens system. While the parameters of the present invention can be found in the above examples, the examples should not be considered limiting but rather illustrative of the advantages of the present invention. Accordingly, the parameters of the present invention should be measured solely from the following claims.

What is claimed is:

1. A wide angle objective lens system of five-group, seven-elements comprising, consecutively from the object to the image side:

a first lens group consisting of a negative meniscus single lens convex to the object side;

a second lens group consisting of a positive doublet having a cemented surface concave to the object side;

a third lens group consisting of a negative meniscus single lens concave to the object side;

a fourth lens group consisting of a positive doublet; and

a fifth lens group consisting of a negative meniscus single lens concave to the object side.

2. The invention of claim **1**, wherein the wide angle objective lens system fulfills the following conditions:

$0.70 < \phi_5/\phi_1 < 1.35$;

$0.15f < d_2 < 0.55f$;

$0.13 < N_2\text{-}N_3 < 0.24$;

$1.5f < r_5$

wherein:

ϕ_1 represents a refractive power of the first lens group;

ϕ_5 represents a refractive power of the fifth lens group;

d_2 represents an axial distance between the first and second lens groups;

f represents the focal length of the whole lens system;

N_2 and N_3 represent refractive indices of the object side and image side lens elements in the doublet of the second lens group, respectively; and

r_5 represents a radius of curvature of the image side surface of the doublet of the second lens group.

3. A wide angle objective lens system comprising the following design parameters;

	f = 100.0 F_{no} = 2.8 2ω = 76°			
	Radius of Curvature	Axial Distance	Refractive Index	Abbe Number
	r_1 = 157.331			
L_1		d_1 = 5.50	N_1 = 1.5346	ν_1 = 43.4
	r_2 = 56.989			
		d_2 = 19.76		
	r_3 = 50.896			
		d_3 = 15.02	N_2 = 1.7745	ν_2 = 50.6
L_2	r_4 = −173.616			
		d_4 = 5.75	N_3 = 1.6158	ν_3 = 37.0
	r_5 = 170.107			
		d_5 = 13.61		
	r_6 = −31.552			
L_3		d_6 = 7.08	N_4 = 1.7043	ν_4 = 36.3
	r_7 = −37.691			
		d_7 = 0.42		
	r_8 = −450.753			
		d_8 = 6.23	N_5 = 1.8074	ν_5 = 31.4
L_4	r_9 = 64.408			
		d_9 = 16.48	N_6 = 1.7830	ν_6 = 47.7
	r_{10} = −60.187			
		d_{10} = 14.02		
	r_{11} = −33.494			
L_5		d_{11} = 5.50	N_7 = 1.6169	ν_7 = 36.3
	r_{12} = −58.576			

4. A wide angle objective lens system comprising the following design parameters;

	f = 100.0 F_{no} = 2.8 2ω = 76°			
	Radius of Curvature	Axial Distance	Refractive Index	Abbe Number
	r_1 = 191.417			
L_1		d_1 = 5.50	N_1 = 1.5814	ν_1 = 40.9
	r_2 = 58.286			
		d_2 = 20.23		
	r_3 = 50.287			
		d_3 = 15.32	N_2 = 1.7725	ν_2 = 50.1
L_2	r_4 = 484.179			
		d_4 = 6.02	N_3 = 1.6129	ν_3 = 37.0
	r_5 = 327.216			
		d_5 = 13.61		
	r_6 = −35.164			
L_3		d_6 = 12.00	N_4 = 1.6200	ν_4 = 36.3
	r_7 = −42.542			
		d_7 = 0.42		

-continued

	f = 100.0 F_{no} = 2.8 2ω = 76°			
	Radius of Curvature	Axial Distance	Refractive Index	Abbe Number
L_4	$r_8 = -810.58$	$d_8 = 12.00$	$N_5 = 1.7810$	$\nu_5 = 44.8$
	$r_9 = -35.001$	$d_9 = 5.95$	$N_6 = 1.8052$	$\nu_6 = 25.2$
	$r_{10} = -70.196$	$d_{10} = 14.02$		
L_5	$r_{11} = -33.895$	$d_{11} = 5.50$	$N_7 = 1.6200$	$\nu_7 = 36.3$
	$r_{12} = -61.002$			

5. A wide angle objective lens system comprising the following design parameters;

	f = 100.0 F_{no} = 2.8 2ω = 76°			
	Radius of Curvature	Axial Distance	Refractive Index	Abbe Number
L_1	$r_1 = 106.023$	$d_1 = 5.50$	$N_1 = 1.6200$	$\nu_1 = 36.3$
	$r_2 = 44.247$	$d_2 = 48.86$		
L_2	$r_3 = 56.604$	$d_3 = 19.00$	$N_2 = 1.7495$	$\nu_2 = 50.4$
	$r_4 = -74.197$	$d_4 = 8.00$	$N_3 = 1.5407$	$\nu_3 = 46.9$
	$r_5 = 271.409$	$d_5 = 14.00$		
L_3	$r_6 = -43.670$	$d_6 = 11.00$	$N_4 = 1.6200$	$\nu_4 = 36.3$
	$r_7 = -49.934$	$d_7 = 0.52$		
L_4	$r_8 = 340.221$	$d_8 = 16.00$	$N_5 = 1.4875$	$\nu_5 = 69.9$
	$r_9 = -35.042$	$d_9 = 6.00$	$N_6 = 1.8052$	$\nu_6 = 25.2$
	$r_{10} = -61.699$	$d_{10} = 17.00$		
L_5	$r_{11} = -34.746$	$d_{11} = 5.50$	$N_7 = 1.6200$	$\nu_7 = 36.3$
	$r_{12} = -58.256$			

6. A wide angle objective lens system comprising the following design parameters;

	f = 100.0 F_{no} = 2.8 2ω = 76°			
	Radius of Curvature	Axial Distance	Refractive Index	Abbe Number
L_1	$r_1 = 162.731$	$d_1 = 5.50$	$N_1 = 1.5404$	$\nu_1 = 51.0$
	$r_2 = 52.892$	$d_2 = 45.20$		
L_2	$r_3 = 59.180$	$d_3 = 23.18$	$N_2 = 1.7725$	$\nu_2 = 50.1$
	$r_4 = -102.339$	$d_4 = 8.00$	$N_3 = 1.6129$	$\nu_3 = 37.0$
	$r_5 = 321.316$	$d_5 = 14.00$		
L_3	$r_6 = -43.340$	$d_6 = 11.00$	$N_4 = 1.6200$	$\nu_1 = 36.3$
	$r_7 = -51.046$	$d_7 = 0.52$		
L_4	$r_8 = -753.97$	$d_8 = 14.00$	$N_5 = 1.7106$	$\nu_5 = 43.2$
	$r_9 = 34.327$	$d_9 = 6.00$	$N_6 = 1.8052$	$\nu_6 = 25.2$
	$r_{10} = -75.827$	$d_{10} = 18.00$		
L_5	$r_{11} = -34.832$	$d_{11} = 5.50$	$N_7 = 1.6166$	$\nu_7 = 36.7$
	$r_{12} = -54.150$			

7. A compact wide angle objective lens system comprising, consecutively from the object to the image side of the lens system;

a first negative lens;

a first positive doublet;

a second negative lens;

a second positive doublet, and

a third negative lens, wherein the wide angle objective lens system fulfills the following conditions:

$0.70 < \phi_5/\phi_1 < 1.35$;

$0.15f < d_2 < 0.55f$;

$0.13 < N_2 - N_3 < 0.24$;

$1.5f < r_5$

wherein:

$\phi 1$ represents a refractive power of the first negative lens;

$\phi 5$ represents a refractive power of the third negative lens;

d_2 represents an axial distance between the first lens and the first doublet;

f represents the focal length of the whole lens system;

N_2 and N_3 represent the refractive indices of the object side and image side lens elements in the first doublet respectively; and

r_5 represents a radius of curvature of the image side surface of the first doublet.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 4,211,472
DATED : July 8, 1980
INVENTOR(S) : Akiyoshi Nakamura

It is certified that error appears in the above—identified patent and that said Letters Patent is hereby corrected as shown below:

Column 4, line 24, delete "N_7= 1.6169" and

insert --N_7= 1.6169--.

Column 6, line 63 delete "r_4 =484.179" and

insert --r_4 =-484.179--.

Column 8, line 14, delete "ν_1= 36.3" and

insert --ν_4= 36.3--.

Column 8, line 17, delete "r_9= 34.327" and

insert --r_9=-34.327--.

Signed and Sealed this

Twenty-eighth Day of *October 1980*

[SEAL]

Attest:

Attesting Officer

SIDNEY A. DIAMOND

Commissioner of Patents and Trademarks

OR 4,206,973

United State

Ikemori

4,206,973

Jun. 10, 1980

[54] **RETROFOCUS TYPE WIDE-ANGLE OBJECTIVE**

[75] Inventor: **Keiji Ikemori**, Yokohama, Japan

[73] Assignee: **Canon Kabushiki Kaisha**, Tokyo, Japan

[21] Appl. No.: **931,255**

[22] Filed: **Aug. 4, 1978**

[30] **Foreign Application Priority Data**

Aug. 11, 1977 [JP] Japan 52-96442

[51] **Int. Cl.**[2] **G02B 9/64**

[52] **U.S. Cl.** **350/214**; 350/207

[58] **Field of Search** 350/214, 207, 176, 255

[56] **References Cited**

U.S. PATENT DOCUMENTS

3,877,795	4/1975	Yamashita	350/214
4,025,170	5/1977	Kamamura	350/214

Primary Examiner—Paul A. Sacher

Attorney, Agent, or Firm—Toren, McGeady and Stanger

[57] **ABSTRACT**

A retrofocus wide angle objective having an angle of view of at least 82° with a relative aperture of 1:2.8 and whose back focal distance is made longer than 1.4 times the focal length of the entire system. The objective comprises, from front to rear, a first lens of positive power in a forwardly convex meniscus form, a second negative meniscus lens, a third positive lens, a fourth negative lens, a fifth biconvex lens, a diaphragm, a sixth biconvex lens, a seventh biconcave lens, and eighth and ninth positive lenses. In such retrofocus objective with the positive meniscus lens arranged at the front, while the angle of view is maintained increased, the lens system is reduced in dimensions and is properly corrected in particular for distortion and astigmatism.

3 Claims, 24 Drawing Figures

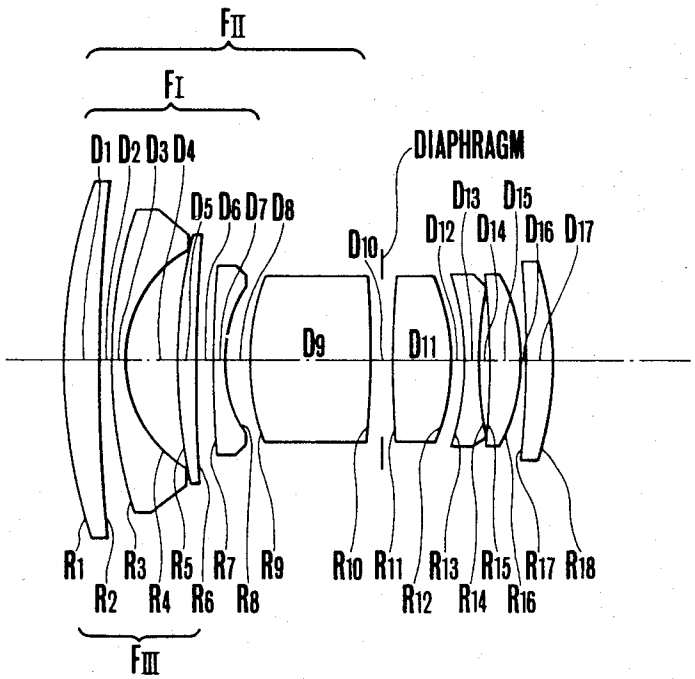


FIG. 1

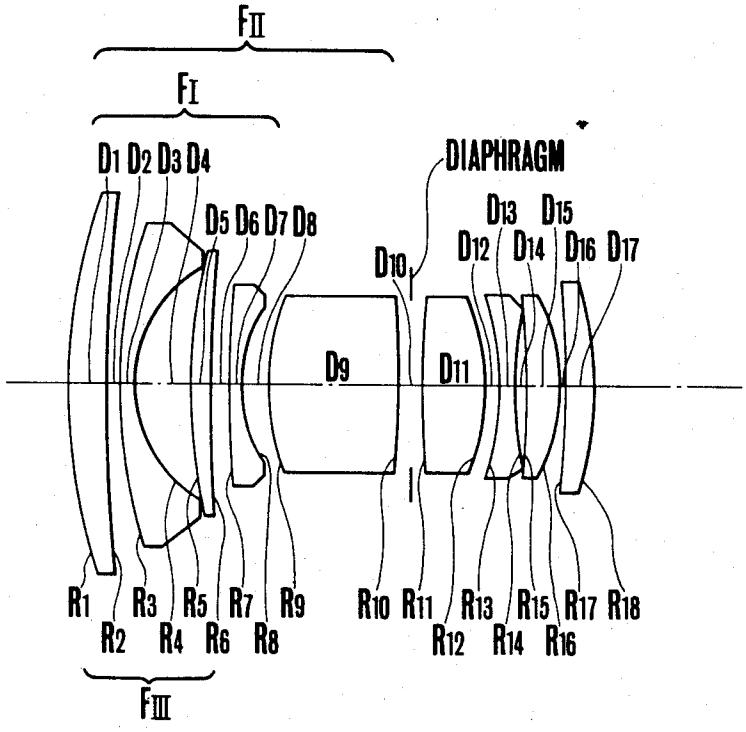

FII
FI
D1 D2 D3 D4
D5 D6 D7 D8
DIAPHRAGM
D10
D12
D13
D14
D15
D16
D17
D9
D11
R1
R2
R3
R4
R5
R6
R7
R8
R9
R10
R11
R12
R13
R14
R15
R16
R17
R18
FIII

FIG.2

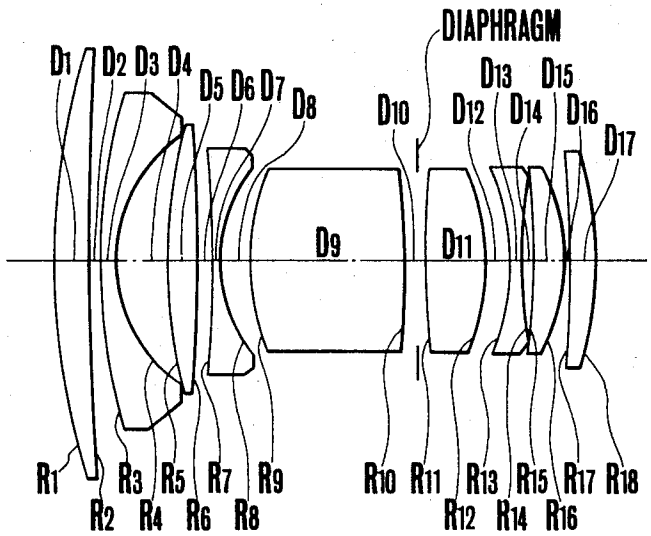

DIAPHRAGM
D1 D2 D3 D4 D5 D6 D7 D8 D9 D10 D11 D12 D13 D14 D15 D16 D17
R1 R2 R3 R4 R5 R6 R7 R8 R9 R10 R11 R12 R13 R14 R15 R16 R17 R18

FIG.3

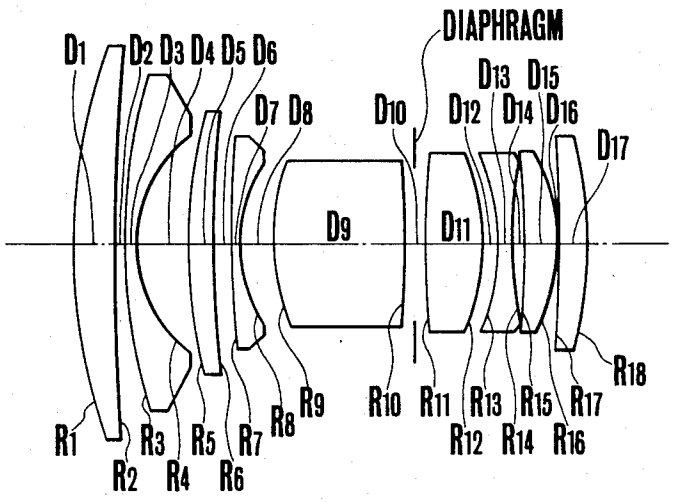

DIAPHRAGM
D1 D2 D3 D4 D5 D6 D7 D8 D9 D10 D11 D12 D13 D14 D15 D16 D17
R1 R2 R3 R4 R5 R6 R7 R8 R9 R10 R11 R12 R13 R14 R15 R16 R17 R18

FIG.4A FIG.4B FIG.4C FIG.4D

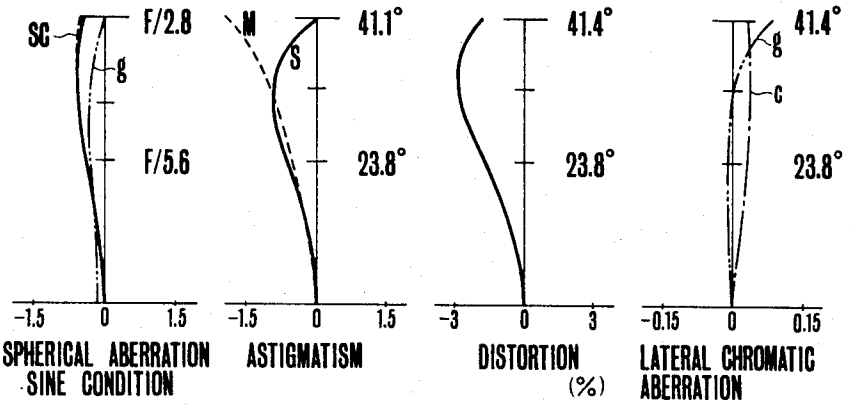


FIG.5A FIG.5B FIG.5C FIG.5D

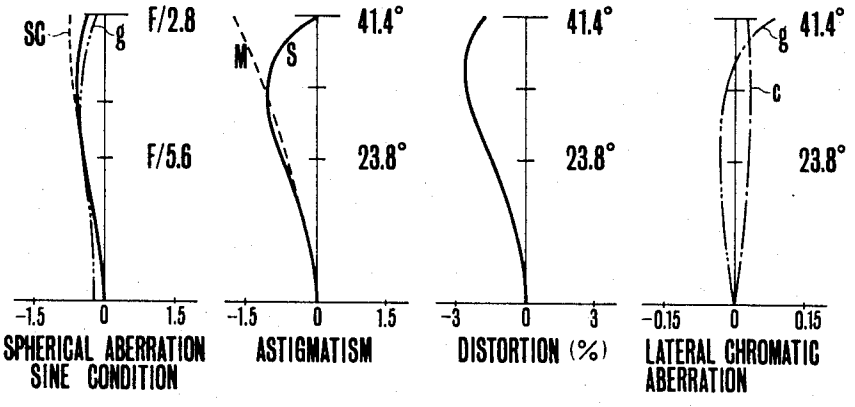


FIG.6A FIG.6B FIG.6C FIG.6D

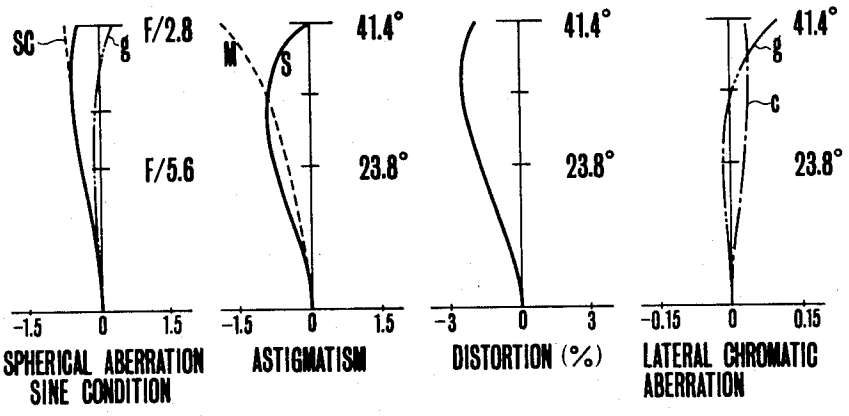


FIG.7A FIG.7B FIG.7C

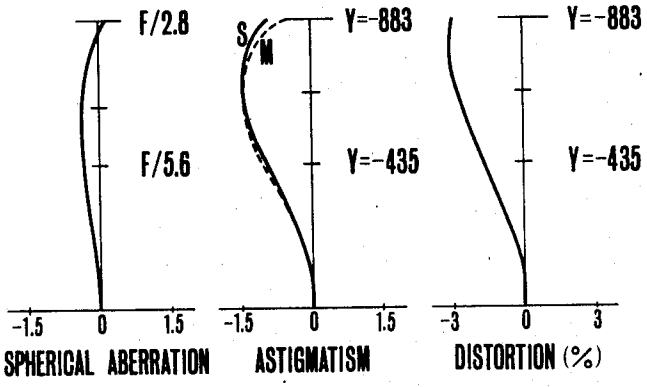


FIG.8A FIG.8B FIG.8C

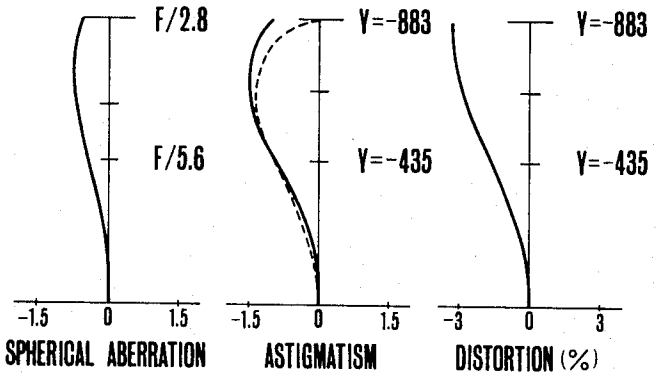
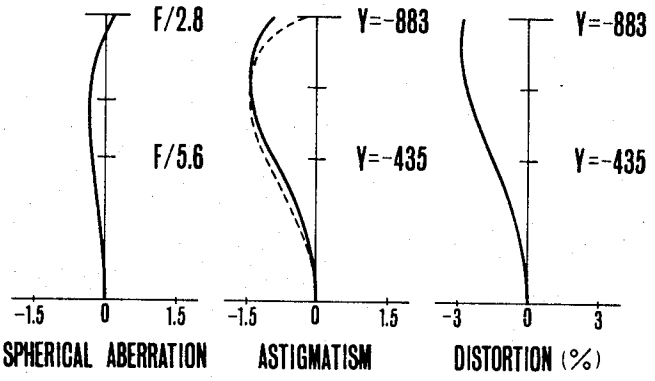


FIG.9A FIG.9B FIG.9C



RETROFOCUS TYPE WIDE-ANGLE OBJECTIVE

BACKGROUND OF THE INVENTION

This invention relates to retrofocus type photographic objectives, and more particularly to a compact retrofocus objective having a wide angular field coverage and a longer back focal distance than 1.4 times the focal length thereof.

Recent developments in interchangeable objectives for use in 35 m/m single lens reflex cameras are directed to compact designs, and this tendency is especially pronounced in the wide angle lens art. Because it allows a sufficiently long back focal distance, the retrofocus type has been widely accepted in designing such wide angle objectives. The employment of the retrofocus type, however, gives rise to many difficult problems of aberrational correction because of the asymmetrical lens arrangement.

Of the various aberrations, the distortion which is introduced by the divergent front lens group constitutes a most important subject for correction. According to the generally accepted proposal, a positive component is arranged in the front group of the lens system. With such construction and arrangement of the front lens group, however, the off-axial rays of light are strongly refracted by that positive component. Hence the other aberrations tend to be increased and the diameter of the front member must be increased to secure the equivalent angular field coverage.

As the dimensions of this type wide angle objective are reduced, therefore, these problems are made more difficult to solve, resulting in a less standard of correction of the aberrations. A high standard of aberrational correction has so far been realized by employing especial optical glasses in making the various lens elements. This leads to an increase in the production cost of objectives.

Attempts have been made to provide a compact retrofocus wide angle objective which has overcome the above mentioned drawbacks and which is well corrected for the various aberrations as in U.S. patent application Ser. No. 892,422 (Filed Mar. 31, 1978) assigned to the assignee of the present invention. Of the examples of the lens systems described therein, the fourth example nears the construction of the lens of the present invention. The lens in this example has an angle of view of 75°, and f-number of 1:2.0. The present invention provides a retrofocus type lens having a larger angle of view than that of the above mentioned cited example, while nevertheless maintaining the length of the entire lens system at minimum, and achieving good correction of the aberrations.

SUMMARY OF THE INVENTION

An object of the present invention is to provide a retrofocus type lens of reduced size and a large angle of view.

A second object of the present invention is to provide a retrofocus type lens having a back focal distance equal to or longer than 1.4 times the focal length thereof.

A third object of the present invention is to provide a retrofocus type lens which is well corrected for the various aberrations particularly distortion and astigmatism or lateral chromatic aberration simultaneously.

It is also an object of the present invention to prevent the image quality to be decreased when focusing is performed to suit for nearer objects.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a diagram of a first example of a specific compact retrofocus wide angle objective according to the present invention.

FIG. **2** is a diagram showing a second example of the present invention.

FIG. **3** is a diagram showing a third example of the present invention.

FIGS. **4A** to **4D** are graphic representations of the spherical aberration, astigmatism, distortion and lateral chromatic aberration of the lens of FIG. **1** with object at infinity.

FIGS. **5A** to **5D** and **6A** to **6D** are similar representations of the lenses of FIGS. **2** and **3** respectively.

FIGS. **7A** to **7C**, **8A** to **8C** and **9A** to **9C** are graphic representations of the spherical aberration, astigmatism and distortion of the lenses of FIGS. **1** to **3** respectively when focused at an object distance corresponding to a magnification of 1/10.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

In FIGS. **1** to **3** the lenses are identified by their dimensions D_x. FIGS. **1** to **3**, show an embodiment of a compact retrofocus wide angle objective according to the present invention including, from front to rear, a first lens D_1 of positive power in a forwardly convex meniscus form, a second negative meniscus lens D_3 of rearward concavity, a third positive lens D_5 and a fourth negative lens D_7, the image side curvature (radius R_6) of the third lens and the object side curvature (radius R_8) of the fourth lens being of the same sign and the combined refractive power of these four lenses being negative. The objective further includes a fifth biconvex lens D_9 having a strong front curvature R_9, that is, a smaller absolute value of the radius of curvature of the front surface than that of the radius R_{10} of curvature of the rear surface, a diaphragm, a sixth biconvex lens D_{11} having a strong rear curvature (radius R_{12}), a seventh biconcave lens D_{13} having a strong front curvature (radius R_{13}), and eighth and ninth positive lenses D_{15} and D_{17}. In the preferred embodiment of the present invention, the front surface of the third positive lens is convex toward the front, the rear surface of the fourth negative lens is concave toward the rear, and the eighth and ninth lenses are positive meniscus lenses of forward concavity. By employing the arrangement of the positive, negative, positive and negative lenses in this order from the front in combination with the above defined lens configurations, it is made possible to achieve simultaneous good correction of distortion and astigmatism which was considered in the prior art to be difficult to perform in good balance. Further, the location of the diaphragm in a space between the central or fifth lens D_9 and the sixth lens D_{11} is advantageously utilized to achieve the compactness of the lens system.

The objective of the present invention is characterized by fulfilling the following relationships:

$$0.5F \leqq |F_I| \leqq 0.75F,\ F_I < 0 \quad (1)$$

$$2.5F \leqq |F_{II}| \leqq 4.5F,\ F_{II} < 0 \quad (2)$$

$$0.29 \leqq (D9 + D11)/L \leqq 0.42 \quad (3)$$

$$\left| \frac{1}{R12} - \frac{1}{R13} \right| \leqq \frac{0.13}{F} \quad (4)$$

-continued

$0.02F \leqq D12 \leqq 0.1F$ (5)

$48 \leqq (\nu1, \nu4, \nu6) \leqq 63$ (6)

$30 \leqq (\nu2, \nu3) \leqq 41; 26 \leqq \nu5 \leqq 32$ (7)

wherein F is the focal length of the entire system; F_I is the composite focal length of the first four lenses; F_{II} is the composite focal length of the first five lenses; L is the total length of the lens system measured from the front surface of the first lens to the rear surface of the ninth lens; D9 is the axial thickness of the fifth lens; D11 is the axial thickness of the sixth lens; R12 is the radius of curvature of the rear surface of the sixth lens; R13 is the radius of curvature of the front surface of the seventh lens; D12 is the axial air separation between the sixth and seventh lenses; and $\nu1$, $\nu2$, $\nu3$, $\nu4$, $\nu5$ and $\nu6$ are the Abbe numbers of the first, second, third, fourth, fifth and sixth lenses respectively.

The fulfillment of the inequality (1) insures that a sufficiently long back focal length for adaptation to a single lens reflex camera is provided while the diameter of the front member of the lens system is maintained at minimum. In comparison with the conventional objective described in the aforesaid U.S. patent application Ser. No. 892,422, the absolute value of the composite focal length of the first four lenses is defined as shifted toward smaller values. This is because the objective of the present invention is provided with a larger angular field coverage of at least 82° than that of the conventional one, namely, 75°, and in order to provide such a large angular field coverage, it is necessary to increase the divergence of the first four lenses. But it is to be noted here that as $|F_I|$ is decreased, there is a higher possibility of producing higher order spherical aberration. On this account, according to the present invention, the F-number of the objective is increased from the cited reference so as to afford optimum aberrational correction. Moreover, the good correction of the aberrations for the marginal rays (rays at the large angle with optical axis), is facilitated by making use of a forwardly concave positive meniscus lens as a ninth component, since this lens form has no rapid refracting effect on the marginal rays. When the upper limit of the inequality (1) is exceeded, it is difficult to provide a sufficient back focal distance and to maintain the diameter of the front member at a minimum. When the lower limit is exceeded, extremely large higher order spherical aberration is produced. In the specific lens systems to be described later, the back focal length is made longer than 1.4 times the focal length.

The relationship (2) represents the focal length of a front lens group of all lens elements on the object side of the diaphragm. This focal length is required to be negative for the compactness of the lens system. As the angle of inclination of an oblique ray passing through an opening of the diaphragm aperture with the optical axis is smaller than that of incidence of that ray on the first surface of the lens system, the height of incidence of the most marginal ray (at the maximum angle with optical axis) on the first surface may correspondingly be decreased. Therefore, the diameter of the first member can be reduced along with those of the other four members in the front group. When the upper limit is exceeded, though the diameter of the front member may be decreased, the diameters of the following members must be increased to so large extent that the good correction of the aberrations particularly spherical aberration and coma is difficult to perform. Conversely when the lower limit is exceeded, the desired degree of compactness can not be assured so that the diameter of the front member and the physical length of the objective are simultaneously increased.

The relationship (3) represents a good compromise between the physical length of the objective and the diameter of the front member while still permitting distortion and astigmatism to be highly corrected. When the upper limit is exceeded, though the diameter of the front member may be reduced, the physical length of the objective becomes very long with increase in battel type distortion. When the lower limit is exceeded, the diameter of the front member is extremely increased with increase in higher order aberrations for the off-axial rays, and it becomes difficult to achieve simultaneous good correction of distortion and astigmatism.

The relationships (4) and (5) represent the form of an air lens between the sixth and seventh lenses which introduces higher-order aberrations into the system so that the spherical aberration and lateral aberration in the sagittal plane for the marginal rays at the full open aperture can be well compensated for. In other words, since the surfaces R12 and R13 are configured in almost concentric relation to the diaphragm, the meridional ray in the marginal zone is little susceptible to refraction, while the axial ray and the sagittal ray in the marginal zone are largely affected to compensate for the spherical aberration in an under-corrected sense at increasing rates as the size of diaphragm aperture is increased, and for the lateral aberration for the marginal rays in the sagittal plane in an under-corrected sense. When the values of $(1/R12 - 1/R13)$ and D12 are smaller than $-0.13/F$ and $0.02F$, respectively, the air lens hardly produces higher-order aberrations which compensate for the spherical aberration and for the lateral aberration for the marginal rays in the sagittal plane at the full open aperture toward moderate under-correction thereof. When the values of $(1/R12 - 1/R13)$ and D12 are larger than $0.13/F$ and $0.1F$ respectively, secondary and tertiary spherical aberrations are largely produced to result in extremely large under-correction of spherical aberration from the neighborhood of the optical axis. In addition thereto, the back focal distance becomes too short to cause mechanical interference between the objective lens and a tiltable mirror of the camera associated therewith.

The relationships (6) and (7) are the conditions for very good correction of lateral chromatic aberration, longitudinal chromatic aberration and chromatic spherical aberration. In other words, the first and second members are made up of glasses having Abbe numbers adjusted so as to contribute to under-corrected lateral chromatic aberrations with magnitudes as equal to each other as possible for the rays of inclination angles ranging from an intermediate angular field coverage to the maximum possible coverage at a short wave length, for example, that of g-line, while the third to sixth members are made up of glasses having Abbe numbers adjusted to contribute to over-corrected lateral chromatic aberrations (for g-line). As a result, the under-corrected residual of lateral chromatic aberration from the first and second members is cancelled out by the over-corrected one from the third to the sixth members.

The fourth member is made up of a glass having an Abbe number adjusted so as to produce as small longitudinal chromatic aberration and chromatic spherical aberration as possible, and the residual of such aberra-

tions introduced by the fourth member into the system is compensated for by adjusting the Abbe numbers of the third and fifth members.

Such selection of the glasses of the third, fourth and fifth members for adaptation to good simultaneous correction of lateral and longitudinal chromatic aberration and chromatic spherical aberration will lead to an occurrence of two different ideal values of Abbe number for each member. However these values do not deviate from each other so much as to be incapable of fulfilling the requirements (6) and (7), since a glass of low dispersion may be selected for employment in at least the positive first, negative fourth and positive lenses, and a glass of high dispersion in at least the negative second, positive third and positive fifth lenses. When the lower limit of the inequality (6) and the upper limit of the inequality (7) are simultaneously exceeded, it is no longer possible to achieve good correction of all lateral chromatic aberration, longitudinal chromatic aberration and chromatic spherical aberration. If the longitudinal chromatic aberration and chromatic spherical aberration are well corrected, the lateral chromatic aberration for g-line is under-corrected at the intermediate angles of view field, and is over-corrected at the largest angle. When the upper limit of (6) is exceeded, or when the lower limit of (7) is exceeded, the lateral chromatic aberration is well corrected, but instead the longitudinal chromatic aberration for g-line is extremely over-corrected, and the chromatic spherical aberration for g-line is extremely over-corrected in the neighborhood of the full open aperture. It is noted here that the glasses whose Abbe numbers fall in the ranges set forth in (6) and (7) are inexpensive and feasible for manufacturing techniques so that the production cost can be reduced.

In order to insure that the thus corrected aberrations are stabilized over the focusing range, it is desired to move the lens system as a whole toward the front as focusing is effected down to shorter object distances, while the axial air separation between the third and fourth members is decreased simultaneously and to fulfill the following requirements:

$$1.9F < |F_{III}| < 12F,\ F_{III} < 0 \quad (8)$$

$$1 < H7 < 1.2 \quad (9)$$

where R_{III} is the composite focal length of the first to third lenses, and H7 is the height of incidence on the front surface (R7) of the fourth lens of a paraxial ray which entered the system at an incident angle of zero (parallel to the optical axis) and at a height of 1 with object at infinity provided that the focal length of the entire system is 1.

As focusing is effected to suit shorter object distances, the forward axial movement of the lens system causes a tendency of producing extremely over-corrected astigmatism to appear. As is known in the art, such astigmatism can be compensated for by decreasing the axial air separation between the third and fourth members in synchronism with the forward axial movement of the entire lens system.

If such focusing provision is made without setting forth any condition, however, there will be a high possibility of deteriorating the other aberrations and particularly spherical aberration. The fulfillment of the requirements (8) and (9) insures that the astigmatism is maintained at a minimum without causing any large increase in the other aberrations.

With the first four lenses constituting a divergent group, as the diverging action of the fourth lens is prevented from becoming extremely strong, it is preferable to impart a negative power into the group of at least first three lenses. When the lower limit of (8) is exceeded, the spherical aberration becomes extremely over-corrected in close-up positions, and the astigmatism is varied considerably during focusing. Conversely when the upper limit is exceeded, the divergent refractive power of the fourth lens becomes too strong to increase the complexity of aberrational problem. Since the 3rd-order spherical aberration is proportional to the fourth power of incident height H, when H7 is larger than 1.2, extremely over-corrected spherical aberration is resulted in close up positions. When H7 is smaller than 1, the divergent refractive power of the fourth lens becomes too strong to unable the good correction of the aberrations by any simple method likewise as in the above.

Three examples of specific lens systems represented in FIGS. **1** to **3** can be constructed in accordance with the numerical data given in the following tables for the radii of curvature, **R1** to **R18**, the axial thickness and air separations, **D1** to **D17**, along with the indices of refraction, **N1** to **N9** and the Abbe numbers, ν**1** to ν**9** of the various lens elements. The minus values of the radii, R, indicate surfaces concave to the front. Each of the lens systems has a relative aperture of 1:2.8 and an angular field coverage of 82.9°.

EXAMPLE 1

Focal length F = 100			Back Focal Distance bf = 151.5				
R1	187.845	D1	14.98	N1	1.6031	ν1	60.7
R2	771.918	D2	0.61				
R3	166.237	D3	5.31	N2	1.62004	ν2	36.3
R4	44.714	D4	18.82				
R5	174.208	D5	7.55	N3	1.63636	ν3	35.4
R6	583.384	D6	variable				
R7	559.282	D7	3.27	N4	1.62299	ν4	58.2
R8	50.794	D8	10.				
R9	89.876	D9	44.33	N5	1.7552	ν5	27.5
R10	−392.261	D10	8.16				
R11	403.404	D11	21.63	N6	1.6935	ν6	53.2
R12	−76.404	D12	5.06				
R13	−83.343	D13	4.73	N7	1.80518	ν7	25.4
R14	159.769	D14	3.8				
R15	−320.816	D15	10.78	N8	1.6968	ν8	55.5
R16	−69.380	D16	0.61				
R17	−47.604	D17	8.65	N9	1.6968	ν9	55.5
R18	−126.982						

The values of the factors in the inequalities:-
$F_I = -0.591F$
$F_{II} = -3.098F$
$(D9 + D11)/L = 0.378$
$1/R12 - 1/R13 = -0.109/F$
$F_{III} = 2.308F$
$H7 = 1.123$

Lens Separation During Focusing

	D6
Infinity	6.12
Magnification 1/10	2.5

Surface No.	3rd-order Aberration Coefficients L	T	SA	CM	AS	PT	DS
1	0.004078	0.005058	0.035406	0.043911	0.054460	0.200278	O.315936
2	0.000889	−0.008142	0.001670	−0.015301	0.140165	−0.048737	−0.837497
3	0.004447	0.011230	−0.001563	−0.003948	−0.009971	0.230233	0.556293
4	−0.036546	0.004652	−7.144144	0.909352	−0.115748	−0.855949	0.123684
5	0.020439	0.007735	1.132722	0.428694	0.162245	0.223232	0.145889
6	−0.009674	−0.011518	−0.133782	−0.159270	−0.189615	−0.066661	−0.305102
7	0.005840	0.006871	0.142808	0.168018	0.197679	0.068633	0.313325
8	−0.036268	−0.000515	−27.298813	0.387600	−0.005503	−0.755702	−0.010808
9	0.083855	0.008527	19.151545	1.947380	0.198015	0.478732	0.068813
10	0.001404	−0.020592	−0.000409	0.005993	−0.087908	0.109688	−0.319490
11	0.009715	0.009825	0.209408	0.211773	0.214164	0.101513	0.319241
12	0.045740	−0.005584	20.136537	−2.458453	−0.300150	0.535975	−0.102082
13	−0.098393	0.012314	−16.560388	2.072584	−0.259390	−0.535185	0.099444
14	−0.056185	−0.030144	−3.221657	−1.728495	−0.927378	−0.279177	−0.647345
15	0.004757	0.009834	0.077787	0.160799	0.332400	−0.128003	0.422525
16	0.036401	−0.002950	8.254187	−0.668891	0.054205	0.591896	−0.052358
17	−0.010411	0.007355	−0.294687	0.208188	−0.147080	−0.091745	0.168723
18	0.030417	−0.003218	6.855397	−0.725271	0.076730	0.323396	−0.042332
Total	0.000503	0.000737	1.342025	0.009462	−0.012381	0.102417	0.216858

wherein
L: Lateral chromatic aberration;
T: Longitudinal chromatic aberration;
SA: Spherical aberration;
CM: Coma;
AS: Astigmatism;
PT: Petzval sum;
DS: Distortion

EXAMPLE 2

Focal length F = 100			Back Focal Distance bf = 147.6				
R1	233.696	D1	13.45	N1	1.65844	ν1	50.9
R2	962.989	D2	0.61				
R3	164.218	D3	5.31	N2	1.68893	ν2	31.1
R4	50.067	D4	15.95				
R5	140.4	D5	10.61	N3	1.68893	ν3	31.1
R6	−897.416	D6	variable				
R7	−452.406	D7	3.27	N4	1.65844	ν4	50.9
R8	48.627	D8	9.87				
R9	83.678	D9	53.37	N5	1.69895	ν5	30.1
R10	−313.835	D10	8.16				
R11	417.888	D11	18.85	N6	1.7725	ν6	49.6
R12	−84.507	D12	7.73				
R13	−80.807	D13	3.67	N7	1.80518	ν7	25.4
R14	175.545	D14	3.67				
R15	−250.479	D15	9.7	N8	1.6935	ν8	53.2
R16	−67.241	D16	0.61				
R17	−480.878	D17	8.27	N9	1.6935	ν9	53.2
R18	−128.052						

The values of the factors in the inequalities:-
$F_I = -0.584F$
$F_{II} = -2.951F$
$(D9 + D11)/L = 0.385$
$1/R12 - 1/R13 = 0.0542/F$
$F_{III} = -11.702F$
$H7 = 1.081$

Lens Separation during Focusing	D6
Infinity	4.49
Magnification 1/10	2.2

EXAMPLE 3

Focal Length F = 100			Back Focal Distance bf = 147.6				
R1	168.775	D1	16.33	N1	1.55963	ν1	61.2
R2	741.14	D2	0.61				
R3	172.106	D3	5.31	N2	1.59551	ν2	39.2
R4	43.912	D4	17.6				

-continued

R5	173.906	D5	8.16	N3	1.60342	ν3	38
R6	433.407	D6	variable				
R7	489.846	D7	3.27	N4	1.55963	ν4	61.2
R8	49.096	D8	10.8				
R9	85.318	D9	43.34	N5	1.71736	ν5	29.5
R10	−356.414	D10	8.16				
R11	476.96	D11	19.	N6	1.713	ν6	53.9
R12	−78.214	D12	4.29				
R13	−84.221	D13	4.9	N7	1.80518	ν7	25.4
R14	157.638	D14	4.01				
R15	−265.306	D15	10.28	N8	1.6968	ν8	55.5
R16	−68.231	D16	0.61				
R17	−560.154	D17	9.15	N9	1.6968	ν9	55.5
R18	−130.765						

The values of the factors in the inequalities:-
$F_I = -0.620F$
$F_{II} = -4.115F$
$(D9 + D11)/L = 0.343$
$1/R12-1/R13 = -0.0912/F$
$F_{III} = -2.132F$
$H7 = 1.108$

Lens Separation during Focusing	D6
Infinity	5.71
Magnification 1/10	2.1

What is claimed is:

1. A retrofocus type wide angle objective lens comprising, from front to rear, a first positive meniscus lens of forward convexity, a second negative meniscus lens of rearward concavity, a third positive lens, a fourth negative lens, the rear surface of said third positive lens and the front surface of said fourth negative lens having curvatures of the same sign, a fifth bi-convex lens with its front surface having a stronger curvature, a diaphragm, a sixth biconvex lens with its rear surface having a stronger curvature, a seventh biconcave lens with its front surface having a stronger curvature, and eighth and ninth positive meniscus lenses of foward concavity, said objective satisfying the following conditions:

$$0.5F \leqq |F_I| \leqq 0.75F,\ F_I<0 \quad (1)$$

$$2.5F \leqq |F_{II}| \leqq 4.5F,\ F_{II}<0 \quad (2)$$

$$0.29 \leqq (D9+D11)/L \leqq 0.42 \quad (3)$$

$$|1/R12-1/R13| \leqq 0.13/F \quad (4)$$

$$0.02F \leqq D12 \leqq 0.1F \quad (5)$$

wherein F is the focal length of the entire system; F_I is the composite focal length of the first to fourth lenses; F_{II} is the composite focal length of the first to fifth lenses; L is the length of the lens system from the front surface of the first lens to the rear surface of the ninth lens; **D9** is the axial thickness of the fifth lens; **D11** is the axial thickness of the sixth lens; **R12** is the radius of curvature of the rear surface of the sixth lens; **R13** is the radius of curvature of the front surface of the seventh lens; and **D12** is the axial air separation between the sixth and seventh lenses.

2. A retrofocus type wide angle objective lens according to claim **1**, satisfying the following conditions:

$$48 \leqq \nu 1 \leqq 63;\ 48 \leqq \nu 4 \leqq 63;\ 48 \leqq \nu 6 \leqq 63 \quad (6)$$

$$30 \leqq \nu 2 \leqq 41;\ 30 \leqq \nu 3 \leqq 41;\ 26 \leqq \nu 5 \leqq 32 \quad (7)$$

wherein $\nu 1$, $\nu 2$, $\nu 3$, $\nu 4$, $\nu 5$ and $\nu 6$ are the Abbe numbers of the first, second, third, fourth, fifth and sixth lenses respectively.

3. A retrofocus type wide angle objective lens according to claim **1**, wherein as focusing is effected down from infinity to shorter object distances, the lens system is moved forward as a whole, while the axial air separation between said third and said fourth lenses is simultaneously decreased, and satisfying the following conditions:

$$F_{III}<0,\ 1.9F \leqq |F_{III}| \leqq 12F \quad (8)$$

$$1 \leqq H7 \leqq 1.2 \quad (9)$$

wherein F_{III} is the composite focal length of the first to third lenses; and H7 is the height of incidence on the front surface of said fourth lens of a paraxial ray which entered the system at an incident angle of zero and at an incident height of 1 with object at infinity for the focal length of the entire system normalized to 1.

* * * * *

XR 4,200,377

United State
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4,200,377
Apr. 29, 1980

[54] **FOCUSING MECHANISM FOR CAMERA OBJECTIVE**

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[73] Assignee: **Jos. Schneider & Co., Optische Werke Kreuznach**, Bad Kreuznach, Fed. Rep. of Germany

[21] Appl. No.: **894,031**

[22] Filed: **Apr. 6, 1978**

[30] **Foreign Application Priority Data**

Apr. 7, 1977 [DE] Fed. Rep. of Germany 2715646

[51] **Int. Cl.**[2] **G02B 15/14**; G03B 3/00
[52] **U.S. Cl.** **354/195**; 350/187
[58] **Field of Search** 354/25, 195–199; 350/186, 187, 254, 255; 352/140; 353/76; 355/55

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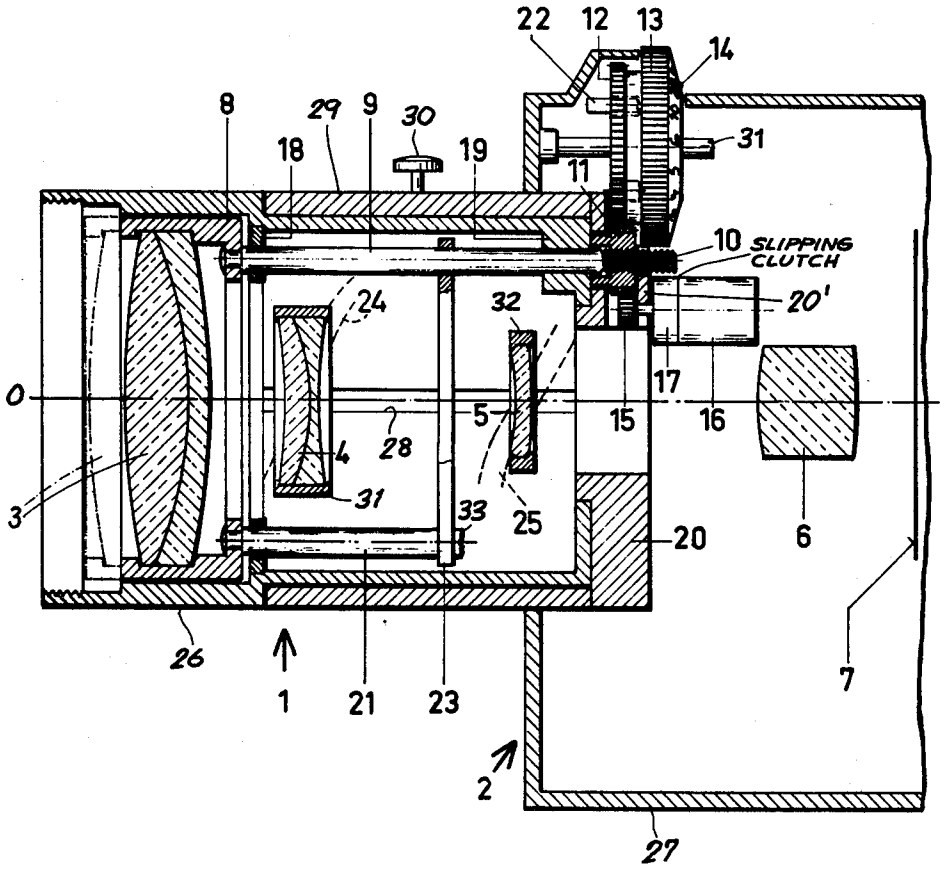
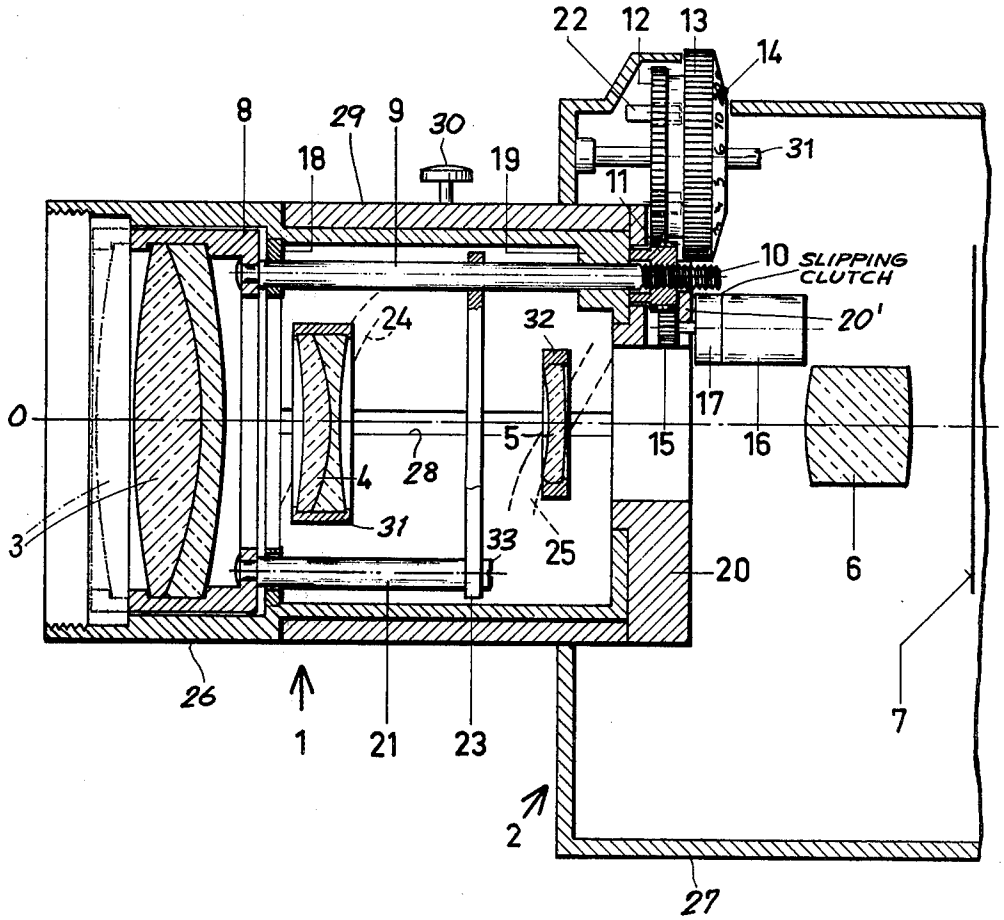
Primary Examiner—L. T. Hix
Assistant Examiner—Thomas H. Tarcza
Attorney, Agent, or Firm—Karl F. Ross

[57] **ABSTRACT**

A front component of a varifocal camera objective, axially shiftable for focusing purposes, is provided with a lens mount held by an axially extending guide rod which is slidably received in an inner annular flange and an end wall of a lens barrel. The guide rod has a rear extremity provided with male threads engaged by a drive nut held captive in the end wall, the nut being provided with outer gear teeth meshing on the one hand with a pinion, driven by a reversible electric motor via a slipping clutch, and on the other hand with a toothed wheel on the shaft of a milled setting wheel which projects from the camera housing. An ancillary rod, parallel to the driven guide rod but shorter than the latter, slides only in the annular flange and has its rear end gripped by a bracing ring also engaging the driven guide rod to form a cage.

6 Claims, 1 Drawing Figure

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FOCUSING MECHANISM FOR CAMERA OBJECTIVE

FIELD OF THE INVENTION

My present invention relates to a photographic or cinematographic camera whose objective includes one or more lenses that are axially shiftable for focusing purposes.

BACKGROUND OF THE INVENTION

Conventional cameras with focusable objectives are provided with an outer, axially fixed setting ring rotatably mounted on a lens barrel and provided with female threads engaging male threads of an inner guide ring which is held against rotation and is rigid with a lens mount supporting the shiftable lens or lenses, the latter usually constituting a front component of the objective. The two rings are centered on the objective axis and are therefore of a rather large diameter, resulting in considerable friction along their threaded contact surfaces. Moreover, the manual adjustment of a setting ring located forwardly of the camera body is inconvenient while automatic focusing with such an assembly is rather difficult.

In commonly owned U.S. Pat. No. 3,482,500 there has been disclosed a control mechanism for manual and automatic focusing in which a lens mount is supported by several axially extending guide rods, one of these rods having threads engaged by a nut which is integral with the shiftable lens mount. It has also been proposed to provide a shiftable lens support with an axially extending rack engaged by a rotatable worm; see German Pat. No. 1,101,801.

OBJECTS OF THE INVENTION

An object of my present invention is to provide a manually and/or automatically operable focusing mechanism for a photographic or cinematographic camera (this also includes television cameras) which has a reduced frictional resistance and can therefore be adjusted with little expenditure of energy.

Another object is to simplify the manipulation of such a focusing mechanism by allowing the positioning of a manually operable setting member on the camera body proper.

SUMMARY OF THE INVENTION

In accordance with my present invention, a guide rod fastened to a shiftable lens mount is slidably but nonrotatably held in stationary bearing means inside a lens barrel and extends rearwardly from that lens mount parallel to the optical axis of the objective, terminating in a threaded rear extremity within the camera housing which is engaged by a captive drive nut held in that housing against axial displacement. The nut is provided with external gear teeth in mesh with gear means forming part of the focusing mechanism. Advantageously, the gear means include a toothed wheel coaxial with a manually rotatable setting wheel projecting from the housing, the two wheels being positively coupled with each other and centered on an axis parallel to that of the objective, and further include a motor-driven pinion. The coupling between the pinion and its motor preferably comprises a slipping clutch to allow for manual setting without a decoupling of the motor; the slipping clutch also lets the motor continue its rotation when the lens mount is arrested in one of its limiting positions by a stop rigid with the two wheels.

BRIEF DESCRIPTION OF THE DRAWING

The above and other features of my invention will now be described in detail with reference to the accompanying drawing the sole FIGURE of which illustrates, somewhat diagrammatically and in axial section, a motion-picture camera with a varifocal objective focusable by a mechanism according to my invention.

SPECIFIC DESCRIPTION

The camera shown in the drawing comprises a varifocal or zoom-type objective, generally designated **1**, and a camera body, generally designated **2**. The objective **1** is provided with a lens barrel **26** which projects from the camera housing **27** and is centered on an optical axis **0**. Also centered on this axis are several lens members constituting a positively refracting front component **3**, two negatively refracting intermediate components **4, 5** and a stationary rear component **6**; the latter, disposed outside lens barrel **26** within housing **27**, consists of a plurality of lenses not illustrated individually.

As is well known per se, an axial shifting of the second component **4** changes the focal length of lens assembly **3 - 6** and must be accompanied by a compensatory displacement of the third component **5** in order to keep the image plane of the objective coincident with the sensitive surface of a film **7**. The concurrent shifting of components **4** and **5** is brought about by the rotation of a sleeve **29**, provided for this purpose with a knob **30**, which has camming grooves **24, 25** engaged by respective pins that pass through an axially extending slot **28** of the lens barrel **26** and are rigid with their respective lens mounts **31, 32**. The lens mounts are slidably supported by axially extending guide rods not shown.

Front component **3**, here shown as a compound lens, is provided with a lens mount **8** which is axially movable independently of lens mounts **31, 32** for focusing the objective upon an object to be photographed, either manully or automatically under the control of a conventional distance finder. Lens mount **8** is cantilevered on an axially extending guide rod **9** which is slidably and nonrotatably received in an inner annular flange **18** of lens barrel **26** as well as in a bearing block **19** forming part of a rear wall **20**. The extremity of guide rod **9** projecting rearwardly beyond the bearing block **19**, located within camera housing **27**, carries male threads **10** matingly engaged by a captive nut **11** which is held against axial displacement by the block **19** and by an extension **20'** of end wall **20**.

Nut **11** carries external gear teeth in mesh with a toothed wheel **12**, of larger diameter, which is rigid with a milled setting wheel **13** rotatable about a shaft **31** whose axis parallels the optical axis **0**. Setting wheel **13**, whose diameter—like that of wheel **12**—is considerably smaller than that of lens barrel **26**, partly projects through a lateral slot of camera housing **27** and carries a rearwardly facing distance scale **14** easily observable by the user. The manual rotation of wheels **12** and **13** is limited to less than a full revolution by a stud **22** projecting axially therefrom so as to come to rest on the periphery of end wall **20** in an infinity position and in a closeup position; the latter setting corresponds to a position of component **3** and lens mount **8** shown in dot-dash lines.

A reversible electric motor **16**, energizable (e.g. as described in commonly owned U.S. Pat. No. 3,165,044) from a nonillustrated power supply, is connected via a

slipping clutch **17** with the shaft of a pinion **15** also meshing with the gear teeth of nut **11**. The automatic displacement of nut **11** and lens mount **8** by motor **16**, under the control of the aforementioned distance finder for example, can thus be overridden by manipulation of setting ring **13** even if motor **16** is of the self-locking (e.g. stepping) type.

In order to hold the lens mount **8** against rotation, and to prevent jamming or canting, I provide that lens mount with an ancillary guide rod **21** also slidable in flange **18** but terminating short of end wall **20**. The two parallel rods **9** and **21** are fixedly interconnected, inside lens barrel **26**, by a bracing ring **23** fastened to the rear end of rod **21** by a screw **33** and frictionally fitted onto an intermediate portion of the driven guide rod **9**. It will be observed that ring **23** lies between the cam tracks **24** and **25** of components **4** and **5** so as not to interfere with their displacement by sleeve **29**. Such a precaution, however, will not be necessary if the shifting of these components for zooming purposes is controlled by a camming sleeve of smaller diameter lodged inside ring **23**. In either case, lens mount **8** forms with the two diametrically opposite rods **9** and **21** as well as ring **23** a rigid cage insuring precise axial movement of component **3** upon rotation of drive nut **7**.

The relocation of the manual focusing means **13**, **14** from the vicinity of the front end of the objective, pursuant to conventional practice, to a position on the camera housing **27**, according to my invention, leaves that front end free for the emplacement of various attachments such as supplemental lenses, filters or lens hoods without interfering with incident light rays.

With pinion **15** of smaller diameter than nut **11**, a favorable transmission ratio exists between motor **16** and guide rod **9** so that the frictional resistance encountered by the motor is small, its energy consumption is low and precise focusing is possible, e.g. under the control of an electronic comparator measuring contrasts between adjacent image points against a locally generated reference parameter. Other known distance meters usable for automatic focusing control operate with emitters of infrared radiation or radar pulses and corresponding receivers on the camera.

It will be apparent that more than a single component of an objective—possibly the entire lens assembly thereof—can be axially shifted for focusing purposes by the mechanism according to my invention.

I claim:

1. In a camera provided with a housing and an objective projecting forwardly from said housing, said objective including a lens barrel centered on an optical axis and a plurality of lenses in said lens barrel, at least one of said lenses being provided with an axially shiftable lens mount,

the combination therewith of:

stationary bearing means in said lens barrel;

a guide rod slidably and nonrotatably held in said bearing means, said guide rod being fastened to said lens mount and extending rearwardly therefrom parallel to said optical axis while terminating in a threaded rear extremity within said housing;

a rotatable captive drive nut matingly engaging said extremity, said nut being provided with external gear teeth and being held against axial displacement in said housing;

focusing means for rotating said nut to shift said lens mount along with said lenses, said focusing means including a setting wheel on an ancillary shaft parallel to said optical axis, said setting wheel projecting from said housing for manual rotation; and

a spur gear on said ancillary shaft rigid with said setting wheel and in mesh with the gear teeth of said nut.

2. The combination defined in claim **1** wherein said focusing means further comprises a reversible motor and a pinion coupled with said motor via a slipping clutch, said pinion meshing with said gear teeth.

3. The combination defined in claim **2**, further comprising stop means rigid with said setting wheel for limiting the rotation thereof to less than a full revolution.

4. The combination defined in claim **1** or **2**, further comprising an ancillary rod parallel to said guide rod and shorter than the latter, said bearing means including an internal annular flange on said lens barrel close to said lens mount, said ancillary rod being slidably guided in said flange.

5. The combination defined in claim **4**, further comprising annular bracing means centered on said optical axis rigidly connecting the rear end of said ancillar rod with an intermediate portion of said guide rod.

6. The combination defined in claim **5** wherein said one of said lenses is part of a front component of the objective, said lenses further formina a pair of additional components axially shiftable independently of said front component to vary the focal length of the objective, said annular bracing means being disposed between the paths of displacement of said additional components.

* * * * *

OR 4,196,970

United States
Macher et al.

4,196,970
Apr. 8, 1980

[54] **OPTICAL OBJECTIVE WITH EXTENDED VARIFOCAL RANGE**

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[73] Assignee: **Jos. Schneider & Co. Optische Werke,** Bad Kreuznach, Fed. Rep. of Germany

[21] Appl. No.: **857,190**

[22] Filed: **Dec. 2, 1977**

[30] **Foreign Application Priority Data**

Dec. 4, 1976 [DE] Fed. Rep. of Germany 2655116

[51] **Int. Cl.**[2] **G02B 15/18;** G02B 7/10
[52] **U.S. Cl.** **350/187;** 350/184
[58] **Field of Search** 350/187, 184, 186

[56] **References Cited**

U.S. PATENT DOCUMENTS

3,773,402	11/1973	Gela et al.	350/184
4,078,857	3/1978	Kantner et al.	350/187
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Primary Examiner—Jon W. Henry
Attorney, Agent, or Firm—Karl F. Ross

[57] **ABSTRACT**

An objective of a photographic or cinematographic camera has an adjustable four-component front lens group and a fixed rear lens group. Axial displacement of the movable second and third components of the front group establishes a normal varifocal range in which the overall focal length varies between a minimum value f_{min} and a maximum value f_{max} having a ratio of 1:6. In the presence of a front attachment with a negatively refracting additional lens member, further shifting of the two movable components establishes an extended wide-angle range with focal lengths smaller than f_{min}; similarly, in the presence of a front attachment with a positively refracting additional lens member the two movable components are shiftable to establish an extended telephoto range with focal lengths greater than f_{max}. Between the normal and wide-angle ranges the third component is also shiftable, without attachment, to focus in a macro range.

8 Claims, 3 Drawing Figures

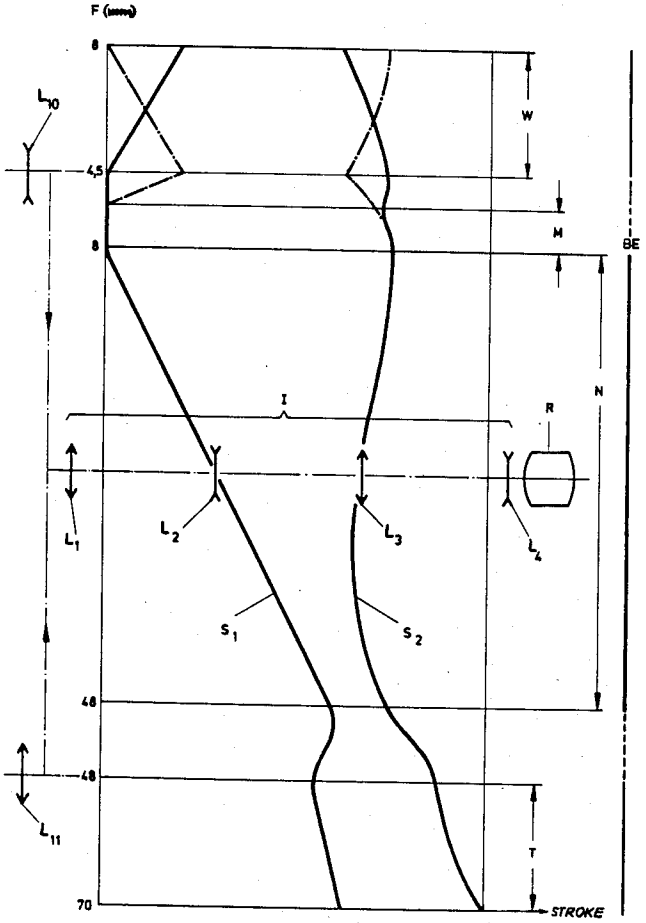


Fig. 1

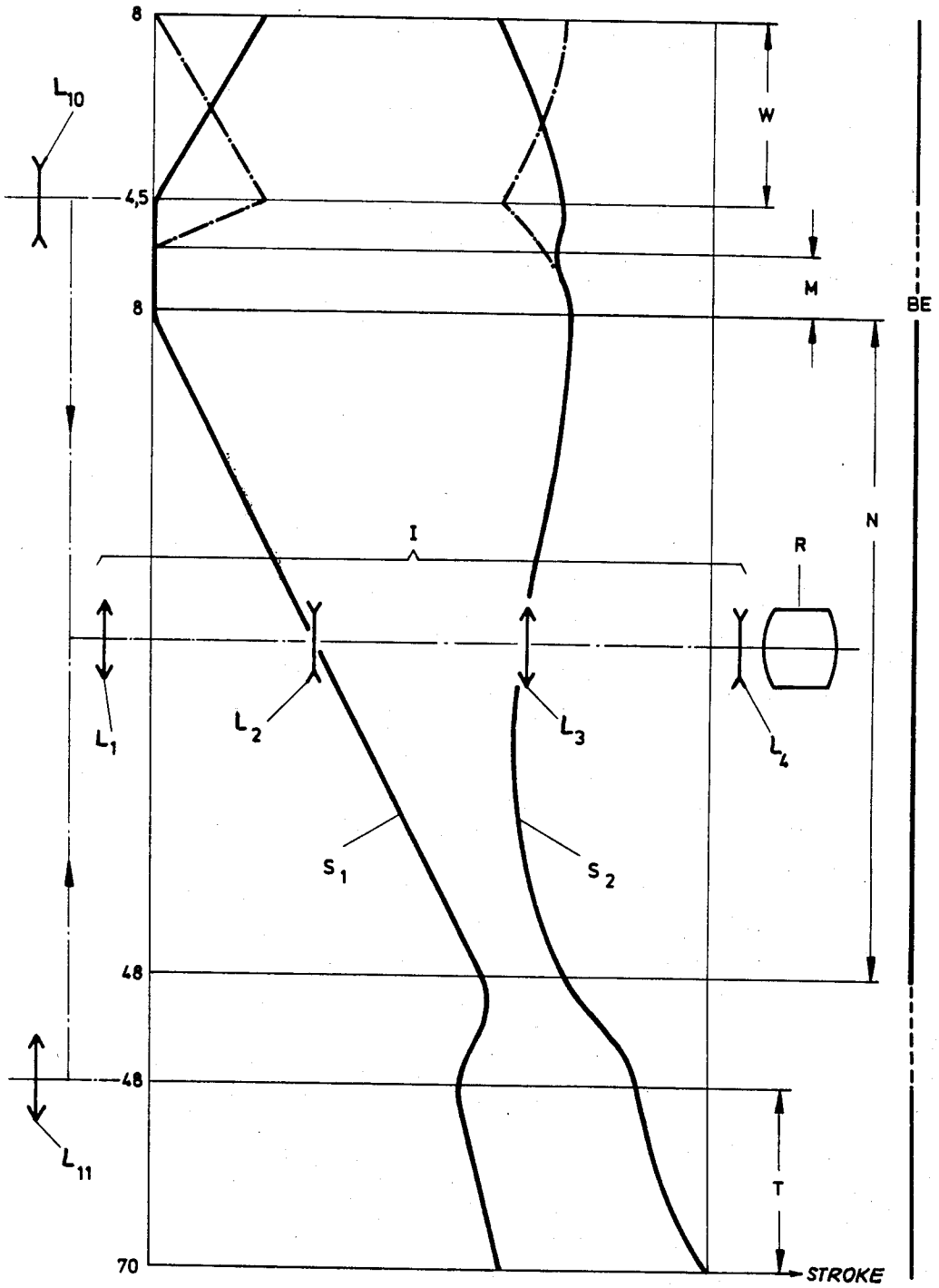


Fig. 2

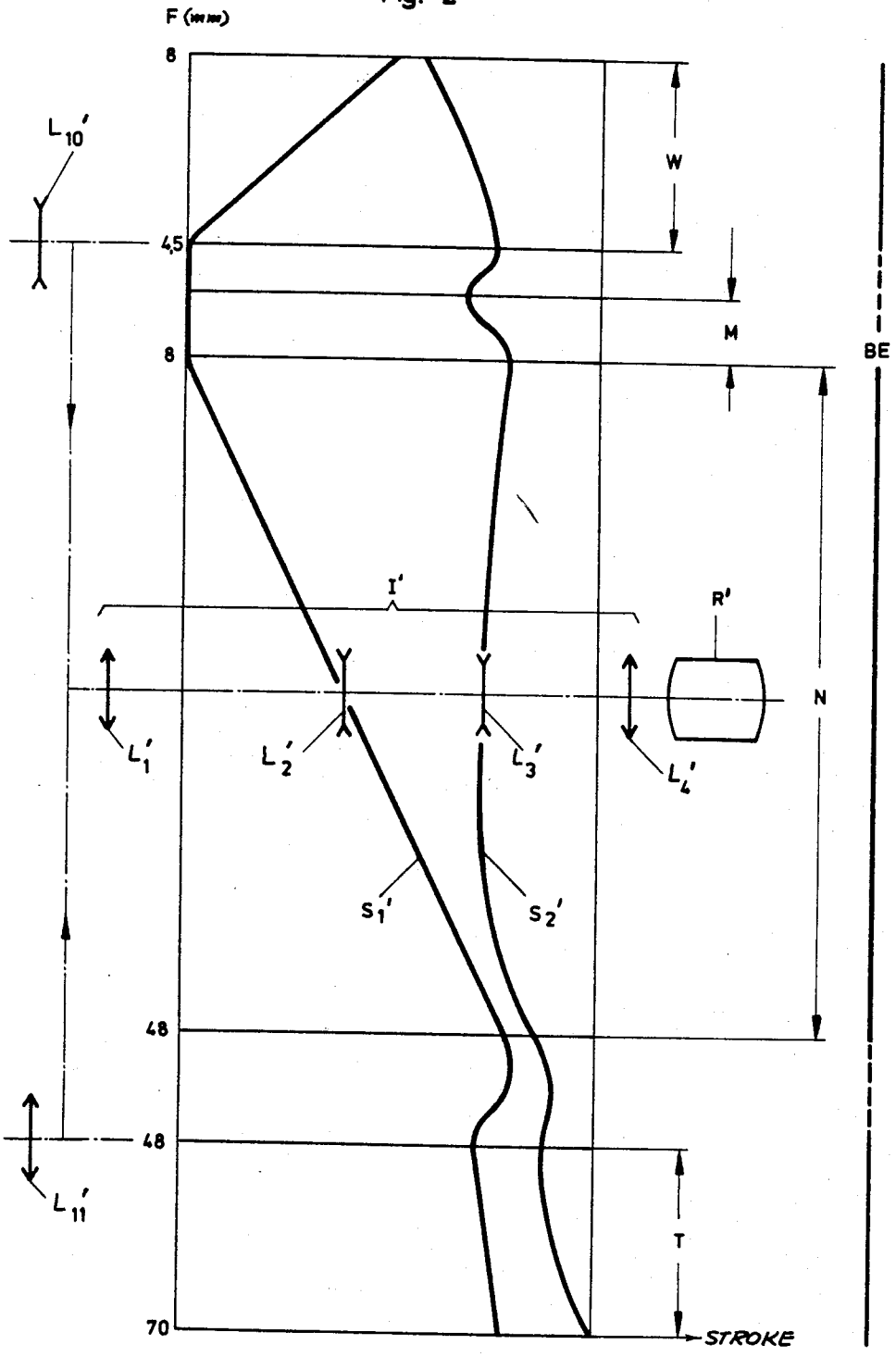
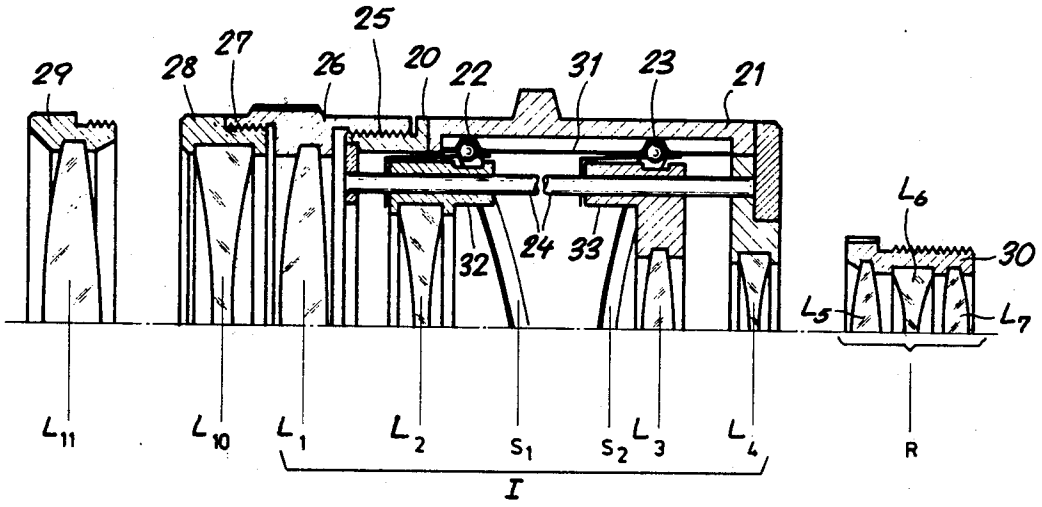


Fig. 3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L6
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L1
L2
S1
S2
L3
L4
R
I

OPTICAL OBJECTIVE WITH EXTENDED VARIFOCAL RANGE

FIELD OF THE INVENTION

Our present invention relates to an optical objective with adjustable overall focal length, comprising a lens assembly with two axially shiftable components which can be concurrently but independently displaced by manual or automatic control means between a lower and an upper limit of a varifocal range.

BACKGROUND OF THE INVENTION

Conventional varifocal objectives of this type can be fitted with various attachments to extend their ratio of maximum and minimum overall focal lengths, either beyond the wide-angle end or beyond the telephoto end of their normal operating range. Such an extension of the normal range can also be effected by an exchange or an interposition of lens members, e.g. with the aid of a revolving carrier or turret. These attachments are, generally, somewhat unhandy, especially when it is desired to shift the operating range toward the shorter focal lengths since the resulting increase in the object-side field angle requires lenses of larger diameter at the front of the objective. Thus, a conventional wide-angle attachment includes a large negative front lens followed by several lenses or lens combinations air-spaced therefrom. The effect of such an attachment is to multiply the numerical values of the overall focal length in the various positions of the shiftable components by a factor smaller than unity, with the law of relative displacement of these components remaining unchanged; on the telephoto side the multiplication factor has a value greater than unity.

OBJECT OF THE INVENTION

The object of our present invention is to provide simple, inexpensive and easily manipulable means for extending the normal operating range of such a varifocal objective beyond its wide-angle and/or its telephoto limit.

SUMMARY OF THE INVENTION

We realize this object, pursuant to our present invention, by the provision of supplemental lens means positionable in front of the varifocal lens assembly whenever that assembly arrives at a limit of its normal range, the associated control means being operable to establish an adjoining ancillary range by axially displacing both shiftable components of the assembly in the presence of the supplemental lens means to increase the ratio of maximum and minimum overal focal lengths while maintaining the same fixed image plane throughout the normal range and the ancillary range or ranges.

Generally, the normal operating range will be separated from each ancillary range, established in accordance with our invention, by an intervening range in which the image plane is not stationary and which is of no further interest as far as the range extension is concerned, except at the wide-angle end where that intervening range may be used to focus the lens assembly upon nearby objects in a so-called macro range.

Advantageously, the camming sleeve serving for the axial displacement of the two shiftable components of our improved lens assembly has guide tracks (e.g. grooves) of which the first one—controlling the movement of the object-side shiftable component—has a constant slope within the normal operating range, as is usual in varifocal objectives. In the ancillary range or ranges according to our invention, the same guide track preferably also has a constant slope which, however, is different from its slope in the normal range and may in fact be of opposite sign. The law of motion of the image-side shiftable component, serving to maintain the constancy of the image plane, is therefore also different in the several ranges.

BRIEF DESCRIPTION OF THE DRAWING

The above and other features of our invention will now be described in detail with reference to the accompanying drawing in which:

FIG. 1 is a developed view of the guide tracks of two axially shiftable components of a varifocal objective according to our invention;

FIG. 2 is a diagram similar to that of FIG. 1, illustrating a modification; and

FIG. 3 is an axial sectional view of the upper half of an objective conforming to the diagram of FIG. 1.

SPECIFIC DESCRIPTION

Reference will first be made to FIG. 3 in which we have shown a largely conventional objective of a photographic or cinematographic camera with a lens assembly including a varifocal front group I and a fixed-focus rear group or relay component R. Front group I consists of four components here shown for the sake of simplicity as single lenses L_1, L_2, L_3 and L_4. This lens group is of the general type described in commonly owned U.S. Pat. No. 3,451,743, with two axially shiftable components L_2 and L_3 of negative and positive refractivity, respectively; the first or front component L_1 is of positive refractivity whereas the fourth component L_4 is negatively refracting.

Front group I is mounted in a camera housing **20** centered on the optical axis of the objective, a sleeve **21** being rotatable about that axis to displace the second and third components L_2, L_3 whose lens mounts **32** and **33** carry balls **22** and **23** engaging in camming grooves S_1, S_2 of a cylindrical sheet **31** secured to that sleeve. Lens mounts **32** and **33** are slidably guided on axially extending rods **24** (only one shown); see commonly owned U.S. Pat. No. 3,931,629 for further details. A ring **26** threadedly engages the housing **20** at **25** and holds the front lens L_1 which is thus limitedly axially shiftable for focusing the objective in the normal varifocal range. Rear group R, consisting of a positive lens L_5, a negative lens L_6 and another positive lens L_7, is seated in a lens mount **30** rigid with housing **20**.

Focusing ring **26** has a flange **27** threadedly accommodating either of two attachments **28**, **29** which carry supplemental lenses L_{10} and L_{11} of negative and positive refractivity, respectively. These attachments are alternatively emplaceable on ring **26**, in line with lens assembly L_1–L_7, when the shiftable components L_2 and L_3 of group I have arrived at a respective end of a normal operating range N as shown in FIG. 1. In the embodiment represented there, the overall focal length F of the objective changes from a minimum value of 8 mm at the wide-angle end of range N to a maximum value of 48 mm at the telephoto end of that range, thus providing a varifocal ratio $F_{max}:F_{min}=6:1$.

An image plane BE remains constant throughout range N. At the wide-angle end of F=8 mm, however, component L_3 may be further displaced while compo-

nent L_2 remains stationary to bring about a sharp reduction in the overall focal length concurrently with a shifting of the image plane whereby the objective is focusable upon nearby objects as is well known per se. This so-called macro range has been designated M and is characterized by a shift of component L_3 toward the left, i.e. to the object side of the system; in principle, macro focusing is also possible by a shift of component L_2 while holding component L_3 stationary.

The guide track S_2 of component L_3 is so shaped that component L_3, upon further rotation of the control sleeve **21** of FIG. **3**, is shifted partly back to the right after reaching the extreme macro position. At this point, which represents one of the boundaries of an adjoining wide-angle range W, the negative supplemental lens L_{10} is placed in front of component L_1 to realign the image plane BE with the position it had in the normal range N. Lens L_{10} may have a power of about -10 to -20 diopters corresponding to an individual focal length of -50 to -100 mm.

It will be understood that the addition of this negative supplemental lens L_{10} results in a slight increase of the overall focal length from the low value, substantially less than 8 mm, it assumed on account of the forward shift of component L_3. The new focal length at the end of the extended wide-angle range W is 4.5 mm and represents the lowest value attainable with this system for focusing upon infinity. Further rotation of camming sleeve **21** moves the two lenses L_2 and L_3 toward each other to increase the focal length until it again reaches the value $F=8$ mm it had at the wide-angle end of the normal varifocal range N.

At the opposite end of that varifocal range, i.e. in a position of $F=48$ mm, further rotation of the camming sleeve separates the two shiftable lenses L_2 and L_3 within an intervening range of instability of image plane BE (the progressively increasing overall focal length) until they reach a position where the addition of the positively refracting supplemental lens L_{11} re-establishes the value of $F=48$ mm while restoring the image plane to its normal position. From that point on the tracks S_1, S_2 again diverge, letting the lenses L_2 and L_3 separate in an extended telephoto range T whose other boundary represents an overall focal length $F=70$ mm.

Thus, the overall focal length F is continuously variable from a lowest value of 4.5 mm to a highest value of 70 mm which corresponds to an extended varifocal ratio of about 15.5:1.

Lens L_{11} may have a power of about 0.5 to 5 diopters corresponding to an individual focal length of 200 to 2,000 mm. The maximum stroke of lens L_2 is about 65 mm, that of lens L_3 being about 37 mm.

Naturally, the bulge in track S_2 establishing an extreme macro position can be omitted if focusing in the macro range is not required. It is evidently also possible to displace the lenses L_2 and L_3 from the extreme macro position directly into the position shown at the top of FIG. **1** in which $F=8$ mm in the presence of lens L_{10}, the additional range from 8 mm to 4.5 mm being then traversed upon further rotation of sleeve **21** as indicated in dot-dash lines.

FIG. **2** shows a modified objective with components L_1', L_2', L_3', L_4', R' and supplemental lenses L_{10}', L_{11}'. In this system the two shiftable components L_2', L_3' of the varifocal group I' are both negative while the stationary (or substantially stationary) components L_1' and L_4' are positive, e.g. as shown in commonly owned U.S. Pat. No. 3,273,457, 3,442,573 or 3,457,003. Guide tracks S_1' and S_2' are shaped generally similarly to tracks S_1 and S_2 of FIG. **1**. The maximum strokes of components L_2' and L_3' are about 60 and 32 mm, respectively. Again, an extreme macro position beyond the wide-angle end of the normal range N could be skipped, with or without inversion of the extended range W as described above.

The displacement of the shiftable components in the manner illustrated in FIGS. **1** and **2** could also be brought about automatically with digital control, e.g. as described in commonly owned U.S. Pat. No. 4,008,951. The law of displacement may be prerecorded on a data carrier such as a glass rod or a perforated tape. With manual control, the various operating ranges N, W and T could be indicated to the user by distinctive coloring, for example; a control member such as sleeve **21** could be indexable at the boundaries of these several ranges, e.g. by means of a ball check, to alert the user to the need for emplacing or removing a supplemental lens.

The supplemental lenses L_{10}, L_{11} or L_{10}', L_{11}' may be given an aspherical curvature for improved optical performance.

Whereas focusing upon objects at distances closer than infinity is accomplished in the normal range N by the axial displacement of front lens L_1 or L_1', such focusing can be carried out in the two extended ranges W and T by a shifting of either or both components L_2, L_3 or L_2', L_3' in a manner moving the image plane BE out of its normal position.

We claim:

1. In an optical objective of adjustable overall focal length, with a lens assembly including two axially shiftable components and control means coupled with said shiftable components for concurrently displacing same to vary said overall focal length between a lower value and an upper value defining a wide-angle end and a telephoto end of a normal varifocal range,

the combination therewith of supplemental lens means positionable in front of said lens assembly upon arrival at a limit of said normal range, said control means being operable to establish an adjoining ancillary range by axially displacing both said shiftable components in the presence of said supplemental lens means to increase the ratio of maximum and minimum overall focal lengths beyond the ratio of said upper and lower values, with maintenance of a fixed image plane throughout both said normal range and said ancillary range;

said supplemental lens means including negative lens means and positive lens means alternatively positionable in front of said lens assembly at said wide-angle end and at said telephoto end, respectively, said shiftable components being concurrently displaceable by said control means to establish an ancillary wide-angle range in the presence of said negative lens means and an ancillary telephoto range in the presence of said positive lens means.

2. The combination defined in claim **1** wherein at least one of said shiftable components is displaceable by said control means in a zone between said normal range and said wide range ancillary range to focus said lens assembly upon objects in a macro range.

3. The combination defined in claim **1** wherein said lens assembly includes a variable four-component front group and a fixed rear group, said shiftable components being a second and a third component of said front group.

4. The combination defined in claim 3 wherein said front group includes a first component shiftable independently of said second and third components, further comprising focusing means coupled with said first component for displacing same.

5. The combination defined in claim 3 wherein said control means comprises a camming sleeve with guide tracks for said second and third components, the guide track for said second component having a constant slope in said normal range and a different constant slope in said ancillary telephoto range.

6. The combination defined in claim 5 wherein the guide track for said second component has slopes of opposite sign in said normal and ancillary wide-angle ranges and has infinite slope in an intervening range.

7. In an optical objective of adjustable overall focal length, comprising a lens assembly which includes a fixed rear group and a variable four-component front group with axially shiftable second and third components, said assembly being provided with control means coupled with said shiftable components for concurrently displacing same to vary said overall focal length between a lower value and an upper value defining a wide-angle end and a telephoto end of a normal varifocal range,

the combination therewith of supplemental lens means positionable in front of said lens assembly upon arrival at a limit of said normal range, said control means being operable to establish an adjoining ancillary range by axially displacing both said shiftable components in the presence of said supplemental lens means to increase the ratio of maximum and minimum overall focal lengths beyond the ratio of said upper and lower values, with maintenance of a fixed image plane throughout both said normal range and said ancillary range;

said control means comprising a camming sleeve with guide tracks for said second and third components, the guide track for said second component having constant slopes of the same sign but different magnitudes in said normal and ancillary ranges and having a slope of opposite sign in an intervening range.

8. The combination defined in claim 7 wherein said ancillary range is separated by said intervening range from the telephoto end of said normal range.

* * * * *

United Sta[illegible] 7 [11] 4,188,092
Momiyama [45] Feb. 12, 1980

[54] RETROFOCUS TYPE WIDE-ANGLE OBJECTIVE LENS

[75] Inventor: **Kikuo Momiyama**, Yokohama, Japan

[73] Assignee: **Canon Kabushiki Kaisha**, Tokyo, Japan

[21] Appl. No.: **892,422**

[22] Filed: **Mar. 31, 1978**

[30] **Foreign Application Priority Data**

Apr. 5, 1977 [JP] Japan 52/38690

[51] **Int. Cl.**[2] **G02B 9/64**
[52] **U.S. Cl.** **350/214**; 350/207
[58] **Field of Search** 350/214, 176, 207

[56] **References Cited**

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3,973,832	8/1976	Ogura et al.	350/214
4,025,168	5/1977	Sugiyama	350/207 X

Primary Examiner—Paul A. Sacher
Attorney, Agent, or Firm—Toren, McGeady and Stanger

[57] **ABSTRACT**

A retrofocus type lens having an angle of view at least 75° and F number 1:2.0. The lens includes a first lens group of a divergent type, a second lens group of a convergent type and a third lens group of a convergent type. The first lens group includes in the order stated a positive meniscus lens, a negative meniscus lens, a positive meniscus lens and a negative meniscus lens. The second lens group includes a positive lens which is either a single lens or consists of a positive lens and a negative lens cemented to each other and with a front convex face directed toward an object to be photographed. The third lens group includes a positive lens having a rear convex face directed toward an image of the object, a biconcave lens with its front surface radius smaller than its rear surface radius, a positive meniscus lens with a convex surface facing the image and a positive lens. The biconcave lens and the positive meniscus lens are respectively replaceable with cemented doublet lenses. The lens system is characterized in that the first lens group includes meniscus lenses arranged in the order of positive, negative, positive and negative lenses, and particularly in that the third positive meniscus lens serves effectively to correct chromatic distortion aberration and chromatic coma aberration.

5 Claims, 20 Drawing Figures

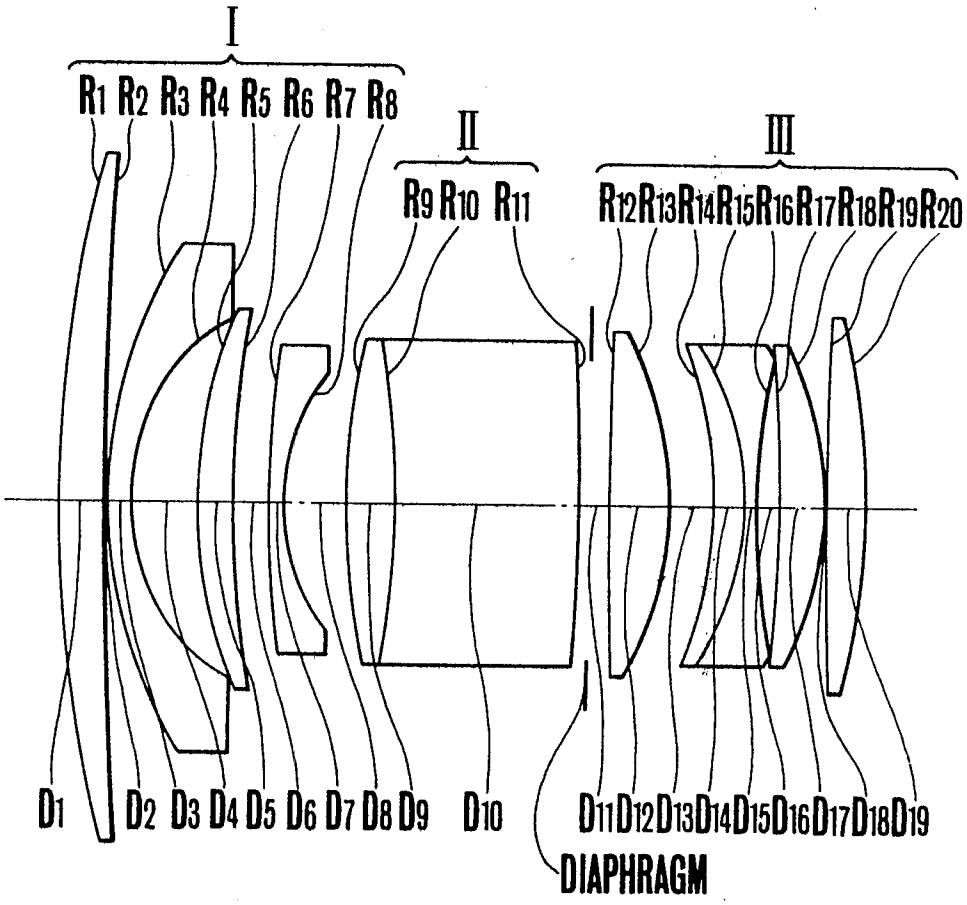
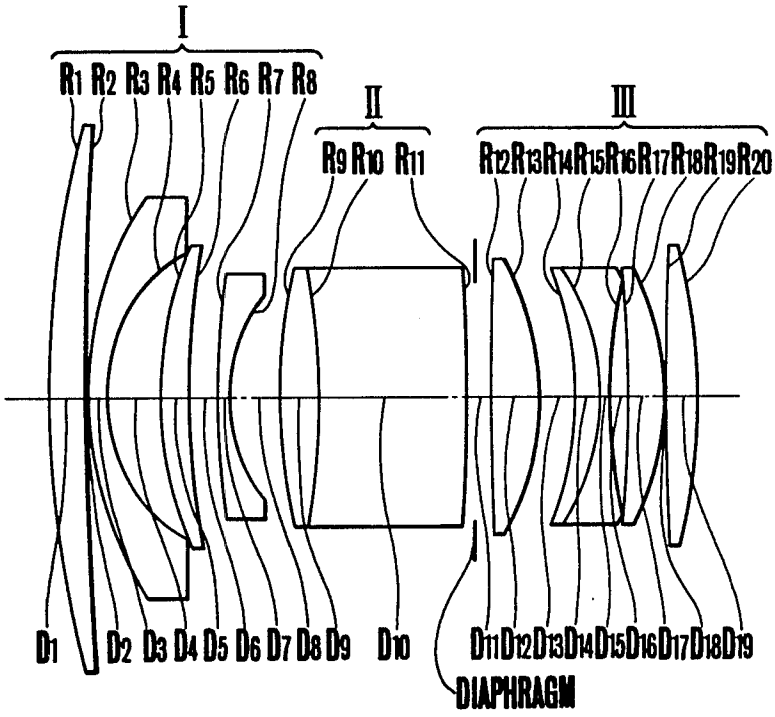


FIG. 1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III
R1 R2 R3 R4 R5 R6 R7 R8
R9 R10 R11
R12 R13 R14 R15 R16 R17 R18 R19 R20
D1 D2 D3 D4 D5 D6 D7 D8 D9 D10 D11 D12 D13 D14 D15 D16 D17 D18 D19
DIAPHRAGM

FIG.2A FIG.2B FIG.2C

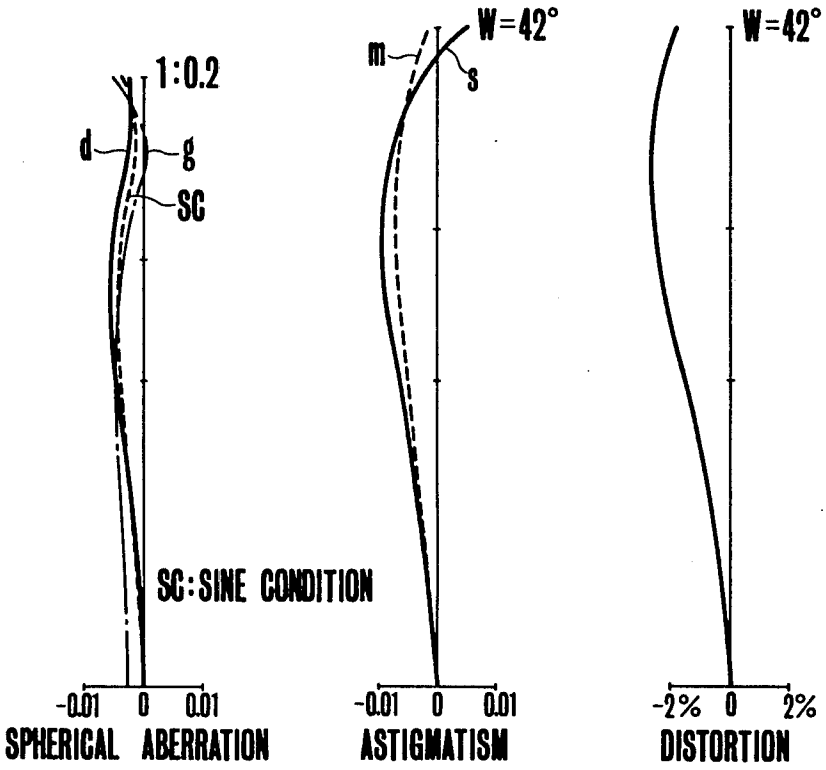


FIG.2D

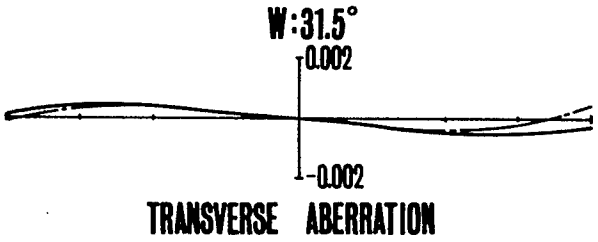


FIG.3

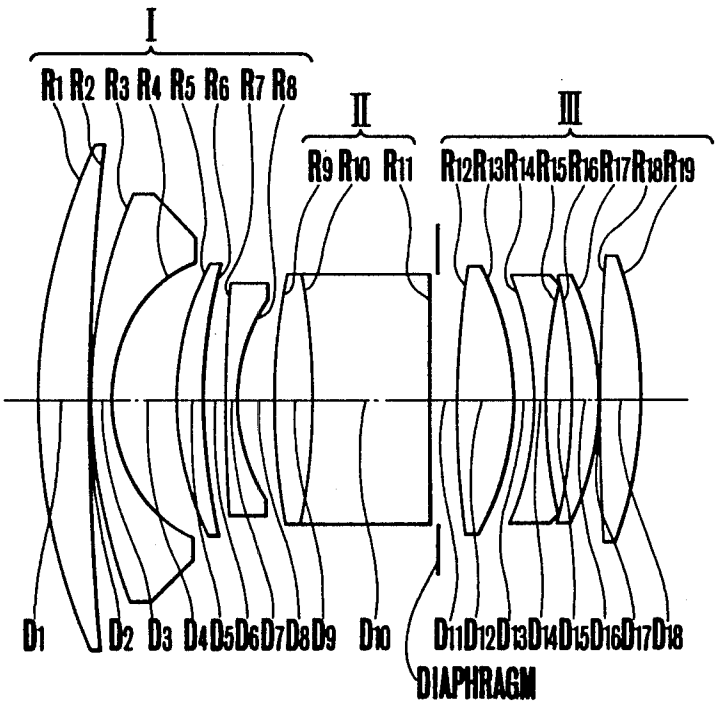

I
II
III
R1 R2 R3 R4 R5 R6 R7 R8
R9 R10 R11
R12 R13 R14 R15 R16 R17 R18 R19
D1 D2 D3 D4 D5 D6 D7 D8 D9 D10 D11 D12 D13 D14 D15 D16 D17 D18
DIAPHRAGM

FIG.4A FIG.4B FIG.4C

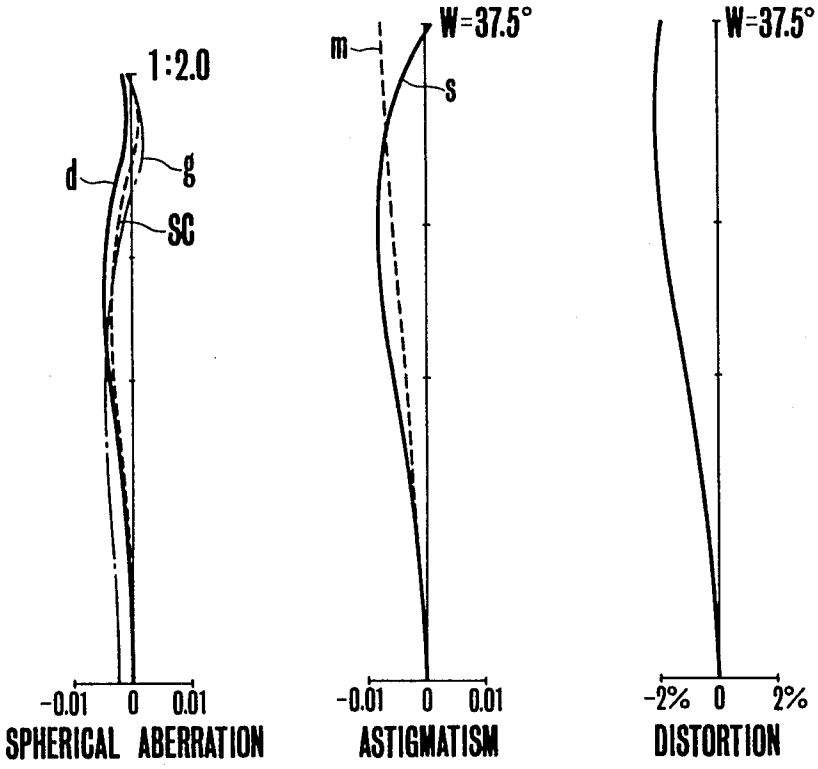


FIG.4D

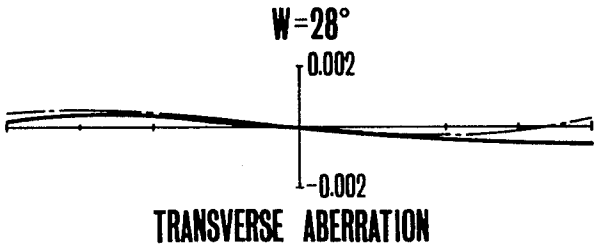
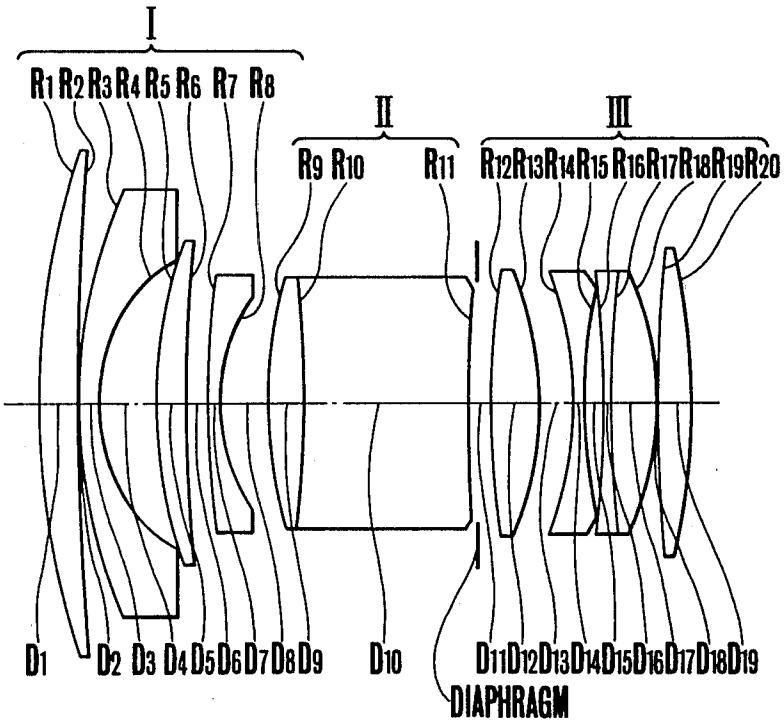


FIG.5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II
III
R1 R2 R3 R4 R5 R6 R7 R8
R9 R10 R11
R12 R13 R14 R15 R16 R17 R18 R19 R20
D1 D2 D3 D4 D5 D6 D7 D8 D9 D10 D11 D12 D13 D14 D15 D16 D17 D18 D19
DIAPHRAGM

FIG.6A FIG.6B FIG.6C

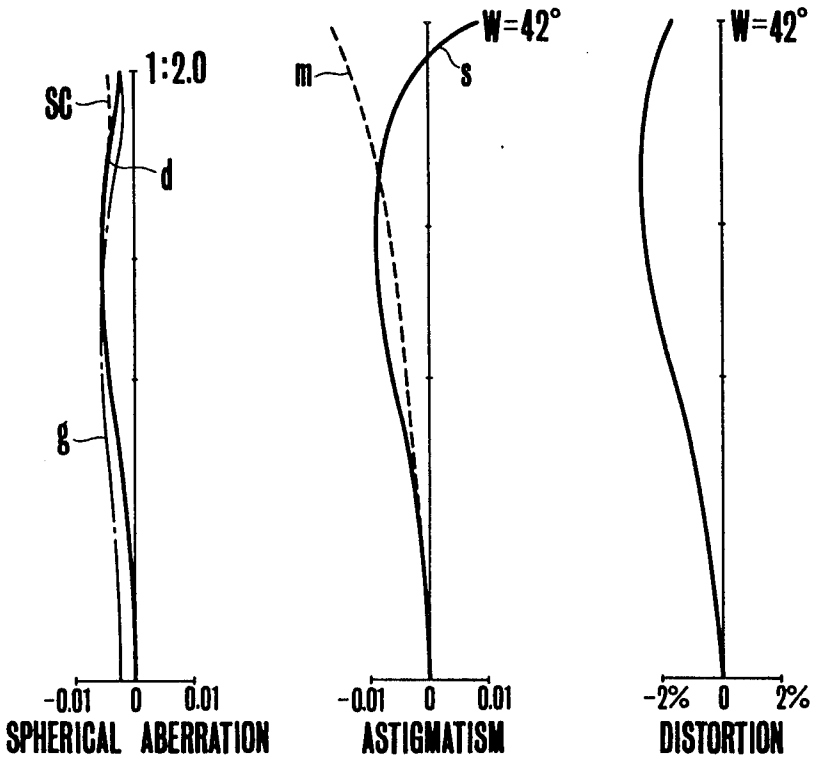


FIG.6D

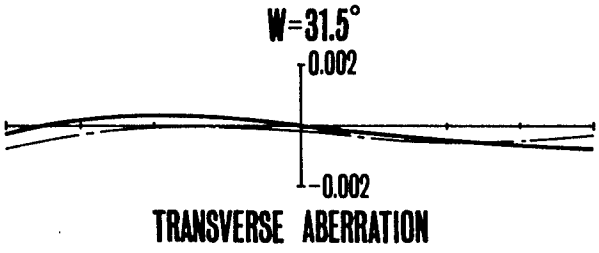


FIG.7

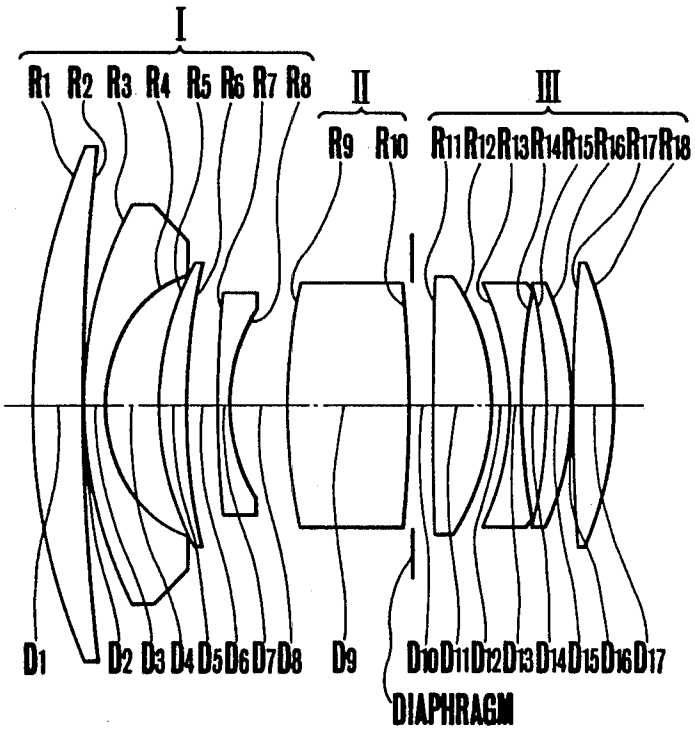

I
II
III
R1 R2 R3 R4 R5 R6 R7 R8
R9 R10
R11 R12 R13 R14 R15 R16 R17 R18
D1 D2 D3 D4 D5 D6 D7 D8
D9
D10 D11 D12 D13 D14 D15 D16 D17
DIAPHRAGM

FIG.8A FIG.8B FIG.8C

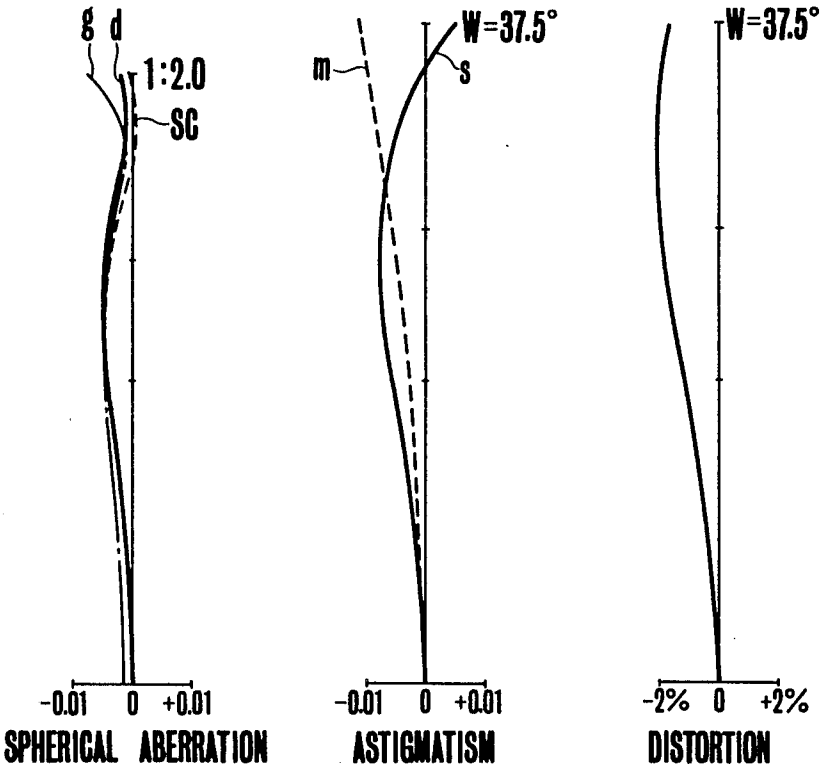
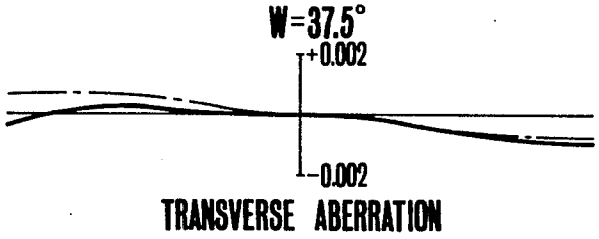


FIG.8D



RETROFOCUS TYPE WIDE-ANGLE OBJECTIVE LENS

BACKGROUND OF THE INVENTION

This invention relates to a large-aperture, wide-angle photographic lens and particularly to a lens system having a short total length.

A strong desire on the part of users of single lens reflex cameras has recently prompted attempts to construct wide-angle or ultra-wide-angle lenses which are more compact and yet have larger apertures than hitherto available Wide-angle lenses for single lens reflex cameras generally utilize a so called retrofocus arrangement. A characteristic of this type of photographic lens is that the symmetry of the lens is impaired when the lens permits a long back focal distance. This makes it difficult to correct aberrations in such lenses. The difficulty tends to increase as the lens construction incorporates a wider angle of view, a larger aperture and a smaller size.

The most difficult problem in reducing the size of a retrofocus type wide-angle lens lies in correcting the distortion in the divergent lens group at the object end of the lens. Such aberration can be effectively corrected by including a positive lens in the divergent lens group. The typical lens arrangements in such a divergent lens group include the following two: In one lens arrangement, a negative lens is disposed at the object end of the lens arrangement and a positive lens positioned behind the negative lens. In the other lens arrangement, a positive lens is disposed in one position and a negative lens arranged behind the positive lens. Because the incident height and the incident angle of light rays relative to the optical axis of the positive lens that acts to correct distortion are great, the corrective action can be made more effectively with a positive lens disposed on the object end. Hence the positive lens disposed at the object end avoids one problem, namely that the total length can not be shortened for effective correction of aberration. However, such a lens arrangement has the following disadvantages: The rays of light outside of an optical axis are excessively bent by the positive lens at the object end. This tends to increase astigmatism, comatic aberration, chromatic distortion aberration or chromatic coma aberration. Moreover, because it is necessary to increase the diameter of the first lens in view of the excessive inward bending of the rays of light, the front lens diameter tends to become greater than other lenses of the same angle of view.

An example of a retrofocus type lens with a positive lens disposed at the object end is disclosed in U.S. Pat. No. 3,877,795. Such a known lens arrangement, however, requires a plurality of negative meniscus lenses behind a positive meniscus lens. Further, the positive lens to be disposed next to the negative meniscus lenses is either a biconvex lens or a positive meniscus lens directing its convexed face toward an image of the object being photographed.

SUMMARY OF THE INVENTION

It is an object of this invention to provide a retrofocus type lens system having a wider angie of view with a larger aperture.

It is another object of this invention to provide a retrofocus type lens system which prevents the diameter of a lens on the object end of the lens system from increasing and which corrects various aberrations in spite of the shortness of its total length.

In accordance with this invention, a retrofocus type lens comprises a negative first lens group at the object end thereof, a positive second lens group and a positive third lens group. From the object end, the first lens group is composed of a positive meniscus lens with a convex surface facing the object to be photographed, then a negative meniscus lens with a convex surface facing the object, then a positive meniscus lens with a convex surface directed toward the object and then a negative meniscus lens with a convex face to the object. The second lens group is either composed of a positive cemented doublet lens consisting of a positive lens and a negative lens or is composed of a positive single lens. The third lens group is composed of seven lenses in the order of a positive lens having a face of a greater curvature on the object side, either a positive-and-negative cemented biconcave lens having a face of a greater curvature directed to an image of the object being photographed or a single biconcave lens, and either a positive-and-negative cemented positive meniscus lens having a convex face on the image end or a single positive meniscus lens and a positive lens. A diaphragm is disposed between the second and third lens groups.

According to a feature of the invention the first lens group is composed of a positive lens, a negative lens, another positive lens and another negative lens, each of these lenses being a single lens and each of them being in a meniscus shape with a convex surface of each facing the object end of the lens system. The first lens group is particularly characterized by the employment of a meniscus lens as the positive lens arranged third from the front to ensure effective correction of chromatic distortion aberration and chromatic coma aberration. It is another feature of the invention that, in the third lens group, an air lens is interposed in between the positive first lens and the biconcave second lens. The air lens has a negative meniscus shape with a convex surface facing an image of the object being photographed to ensure effective correction of spherical aberration and various aberrations that take place outside of the optical axis. The whole lens system may be either composed of single lenses only, as hereinafter will be shown as embodiment example in FIG. 7, or may be formed using cemented doublet lenses as will also be shown as other examples.

The above and further objects and novel features of the invention will more fully appear from the following detailed description taken in connection with the accompanying drawings in which:

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a sectional view showing a lens system representing Embodiment Example 1 of this invention.

FIGS. 2A–2D are illustrations showing various aberrations of Example 1.

FIG. 3 is a sectional view showing a lens system representing Embodiment Example 2 of the invention.

FIGS. 4A–4D are illustrations showing various aberrations of Example 2.

FIG. 5 is a sectional view showing a lens system representing embodiment Example 3 of the invention.

FIGS. 6A–6D are illustrations showing various aberrations of Example 3.

FIG. 7 is a sectional view showing a lens system representing embodiment Example 4 of the invention.

FIGS. 8A–8D are illustrations showing various aberrations of Example 4.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

The lens arrangement of the invention as already described in the foregoing permits increase in lens aperture and reduction in lens size. For improved performance, however, it is preferable to add the following conditions to the lens arrangement already described:

(1) $0.8f < |fI| < 1.5f$—provided that $fI < 0$
(2) $1.5f < |fI, II| < 6.0f$—provided that FI, II, < 0
(3) $f1 > f3$
(4) $|f2| > |f4|$—provided that $f2 < 0$ and $f4 < 0$
(5) $\nu 1 > \nu 3$
(6) $0.32f < DII < 0.72f$

In the above conditions,

f: Focal length of the total lens system
FI: Focal length of the first lens group
FI, II: Focal length of the first and second lens groups
f1: Focal length of the positive meniscus lens of the first lens group.
f2: Focal length of the negative meniscus lens of the first lens group disposed in the 2nd place from the front of the first lens group.
f3: Focal length of the positive meniscus lens of the first lens group disposed in 3rd place from the front of the first lens group
f4: Focal length of the negative meniscus lens of the first lens group disposed in 4th place from the front of the first lens group.
$\nu 1$: Abbe number of the positive meniscus lens of the first lens group disposed in 1st place in the first lens group
$\nu 3$: Abbe number of the positive meniscus lens of the first lens group disposed in 3rd place in the first lens group
DII: Lens thickness on the axis of the positive lens of the second lens group

Of the above conditions, the conditions (1) and (2) determine the allocation of the basic refracting power of the lens system of the present invention. The condition (1) is necessary for ensuring a sufficient long back focal length for a lens usable in a single lens reflex camera and is required for keeping the front lens diameter small. If the upper limit value of this formula $0.8f < |fI| < 1.5f$ is exceeded, it would be difficult to obtain a sufficiently long back focal length and to hold the front lens diameter to a small value. On the other hand, if the lower limit value is further lowered, the positive spherical aberration including the high aberration which takes place at the first lens group increases. This makes it difficult to have a large lens aperture.

Conditions (2) is required for keeping the front lens diameter small by making the refracting power of the lens portions from the first lens face to the diaphragm relatively strong and divergent. If the upper limit value of the condition $1.5f < |fI, II| < 6$ is exceeded, the front lens diameter tends to increase. On the other hand, if the lower limit value of the condition is not reached, the positive refracting power of the third lens group must be made stronger. The stronger positive refracting power results in an increase in the negative spherical aberration in the third lens group and this makes a large lens aperture difficult.

It is a novel feature of the present invention that the first lens group is composed of, as already mentioned in the foregoing, a positive lens, a negative lens, another positive lens and another negative lens each having a meniscus shape and, in addition to that, the conditions (3) and (4) are applied to the lens arrangement under the condition (1). In other words, the rays of light impinging upon the first lens group outside of the optical axis are refracted by each lens and their incident height is gradually lowered. The refracting power is arranged to increase as the incident height gradually decreases in such a manner as to correct distortion by naturally refracting the rays of light outside of the optical axis. This arrangement ensures satisfactory correction of the various aberrations which take place outside of the optical axis. Thus, with these conditions satisfied, improvement can be effectively attained in the correction of astigmatism and comatic aberration.

The condition (5) is required for lessening chromatic distoration aberration and chromatic coma distortion at the positive lenses disposed in the first lens group. The condition defines the Abbe number of the positive third lens from the front and at which the incident height incident angle of off-axial rays is smaller than those of the positive lens disposed in the first place. Because of the smaller Abbe number in condition (5), chromatic aberration on the optical axis and magnification chromatic aberration are corrected for improvement in the correction of chromatic distortion aberration and chromatic coma aberration. Also, because the positive third lens from the front is formed into a meniscus shape, chromatic distortion aberration and chromatic coma aberration occur to a relatively lesser degree at this lens even when a glass material of high dispersion (or a small Abbe number) is used for this lens.

In accordance with the condition (6), the lens thickness of the positive lens of the second lens group is made relatively thick. This arrangement makes it possible to satisfactorily correct curvature of field and astigmatism. If the lower limit value of the condition $0.32f < DII < 0.72f$ is not reached, the curvature of field and astigmatism increase while, if the upper limit value thereof is exceeded, the front lens diameter tends to increase. Therefore, deviation from this condition is not desirable.

Further, for higher performance of the lens system, it is preferable to impose the following conditions upon the third lens group:

(7) $0.75 < (Ra/Rb) < 0.95$
(8) $0.7f < |Ra| < 1.2f$—provided that $Ra < 0$, i.e. convex face is directed toward the object.
(9) $1.7 < \overline{NIII}$

In the above conditions

Ra: Radius of curvature of the face on the object side of the positive lens disposed in the 1st place in the third lens group
Rb: Radius of curvature of the face on the object side of the biconcave lens of the third lens group
NIII: Mean value of refractive indexes of the materials of all positive lenses included in the third lens group

It is a novel feature of the third lens group that, with lenses arranged in order of positive lens, negative lens, positive lens and another positive lens, the aforementioned conditions (7) and (8) are imposed upon an air lens interposed between the first positive lens and the negative lens next disposed in such a way as to give the air lens a positive refracting power. The air lens is formed into a relatively strong meniscus shape with its convexed side disposed toward the image end. This arrangement makes it possible to obtain satisfactory

conditions in terms of spherical aberration and various aberrations that take place outside of the optical axis.

The condition (7) defines a range of the ratios of radius of curvature of one side to the other of the air lens. If the lower limit value of the condition $0.75<(-Ra/Rb)<0.95$ not reach, the spherical aberration tends to be insufficiently corrected while the comatic aberration tends to be excessively corrected when the air lens is formed in a strong miniscus shape. On the other hand, if the upper limit value of the condition (7) is exceeded, the reverse tendency arises. In both cases, deviation from condition (7) makes it difficult to achieve a lens system with a large aperture.

Condition (8) is required so that the radius of curvature of the front of the air lens lies within the optimum range for correction of aberrations under the condition (7). If the lower limit value of the condition (8) $0.7f<|Ra|<1.2f$ is not exceeded, a negative high spherical aberration would take place in this part. This is not desirable. Then, if the upper limit value of this condition is exceeded, correction of comatic aberrations would become insufficient. Hence deviation from the condition (8) is disadvantageous for correction of curvature of field and astigmatism.

Condition (9) is required to make the refracting power of the positive lenses in the third lens group relatively high for reducing the spherical aberration and the curvature of field in the third lens group. Deviation from this condition is disadvantageous for satisfactory correction of spherical aberration and the curvature of field. Also, the value of $\overline{NIII}$ is normally less than 1.9. Examples of preferred embodiments the present invention are given in the following values. In Example 1, $f=24$, $F1=2.0$ and $\omega=42°$. In Example 2, $f=28$, $F1=2.0$ and $\omega=37.5°$. In Example 3, $f=24$, $F1=2.0$ and $\omega=42°$. In Example 4, $f=28$, $F1=2.0$ and $\omega=37.5°$. In these examples, the values are converted into $f=1$; R represents radius of curvature; D represents spacing between lenses; Nd represents a refractive index for a ray d; and νd represents an Abbe number for the ray d.

Moreoever, for the purpose of preventing degradation of images of nearby objects, the following examples of embodiments employ a method of correcting aberrations by expanding the distance between faces R6 and R7 when the whole lens system is drawn out forward for focusing on such objects.

Example 1

Face No.	R	D	Nd	νd
1	3.4178	0.1346	1.58913	61.1
2	14.7626	0.0082		
3	1.2691	0.0612	1.68893	31.1
4	0.5642	0.1892		
5	1.3099	0.0979	1.59551	39.2
6	2.8093	0.0938		
7	2.6138	0.0408	1.58913	61.1
8	0.5419	0.1744		
9	1.8876	0.1306	1.80518	25.4
10	−2.9555	0.5203	1.62041	60.3
11	−6.9175	0.0816		
12	19.2176	0.1714	1.804	46.6
13	−0.9078	0.1212		
14	−1.1481	0.0857	1.6968	55.5
15	−0.7869	0.0408	1.80518	25.4
16	2.0960	0.0551		
17	−4.8410	0.1265	1.6968	55.5
18	−0.9381	0.0061		
19	11.8518	0.1102	1.7725	49.6

-continued

Example 1

Face No.	R	D	Nd	νd
20	−2.0774			

$\Sigma D = 2.2496$

Example 2

Face No.	R	D	Nd	νd
1	1.7125	0.1509	1.58913	61.1
2	7.2659	0.0070		
3	1.4893	0.0526	1.54869	45.6
4	0.4495	0.1937		
5	0.8255	0.0842	1.8061	40.9
6	1.6042	0.0681		
7	4.2025	0.0351	1.59551	39.2
8	0.5165	0.1084		
9	1.9171	0.1158	1.80518	25.4
10	−1.8670	0.3538	1.54869	45.6
11	∞	0.0772		
12	2.6999	0.1719	1.7725	49.6
13	−0.7704	0.0616		
14	−0.9343	0.0351	1.80518	25.4
15	1.5313	0.0766		
16	−1.6006	0.0807	1.6968	55.5
17	−0.8102	0.0053		
18	8.2287	0.1193	1.6968	55.5
19	−1.1918			

$\Sigma D = 1.7973$

Example 3

Face No.	R	D	Nd	νd
1	2.5255	0.1385	1.60311	60.7
2	12.0690	0.0081		
3	1.7340	0.0611	1.64769	33.8
4	0.5646	0.2034		
5	1.7074	0.0977	1.51742	52.3
6	5.5931	0.0774		
7	3.6731	0.0407	1.60311	60.7
8	0.6413	0.1589		
9	1.4160	0.1222	1.80518	25.4
10	−4.4086	0.5701	1.60311	60.7
11	5.0857	0.0815		
12	2.8280	0.1711	1.804	46.6
13	−1.0858	0.1173		
14	−1.1667	0.0391	1.80518	25.4
15	1.8444	0.054		
16	−5.5811	0.0407	1.80518	25.4
17	4.0765	0.1581	1.6968	55.5
18	−0.9331	0.0061		
19	6.3838	0.1100	1.7725	49.6
20	−2.3104			

$\Sigma D = 2.2564$

Example 4

Face No.	R	D	Nd	νd
1	1.9079	0.1509	1.6935	53.2
2	6.6761	0.0070		
3	1.2535	0.0526	1.53172	48.9
4	0.4221	0.1601		
5	0.8363	0.0842	1.8061	40.9
6	1.6640	0.0940		
7	3.5789	0.0351	1.58921	41.1
8	0.5181	0.1686		
9	1.5972	0.3611	1.80518	25.4
10	−4.6263	0.0772		
11	36.1202	0.1719	1.7725	49.6
12	−0.7118	0.0558		
13	−0.7948	0.0351	1.80518	25.4
14	1.7791	0.0714		
15	−1.5582	0.0807	1.6968	55.5
16	−0.8083	0.0053		
17	8.4093	0.1193	1.6968	55.5

-continued

Example 4

Face No.	R	D	Nd	νd
18	−1.0326			

ΣD = 1.7303

Aberration Coefficients of Example 1:

Face No.	I	II	III	P	V
1	0.0058	0.0152	0.0396	0.1084	0.3854
2	0.0003	−0.0045	0.0721	−0.0251	−0.7545
3	0.0410	0.0353	0.0304	0.3213	0.3028
4	−3.4521	0.7258	−0.1526	−0.7228	0.1840
5	0.8975	0.2039	0.0463	0.2848	0.0752
6	−0.0989	−0.1061	−0.1137	−0.1328	−0.2642
7	0.1171	0.1216	0.1263	0.1417	0.2784
8	−12.8269	0.5760	−0.0259	−0.6839	0.0319
9	4.3994	0.9086	0.1876	0.2362	0.0875
10	−0.0007	0.0028	−0.0122	0.0214	−0.0393
11	−0.0117	−0.0397	−0.1347	0.0553	−0.2689
12	0.1149	0.1540	0.2064	0.0232	0.3077
13	14.0525	−2.2901	0.3732	0.4908	−0.1408
14	−7.6215	1.3777	−0.2490	−0.3576	0.1097
15	−1.0424	0.0726	−0.0051	−0.0449	0.0035
16	−1.3389	−0.9363	−0.6548	−0.2127	−0.6067
17	0.0356	0.0926	0.2410	−0.0848	0.4066
18	3.6939	−0.4358	0.0514	0.4376	−0.0577
19	−0.0139	0.0398	−0.1137	0.03676	0.2200
20	3.8359	−0.5523	0.0795	0.2097	−0.0416
Σ	0.7867	−0.0391	−0.0078	0.1026	0.2188

I : Spherical aberration
II : Comatic aberration
III : Astigmatism
P : Petzval's sum
V : Distortion

Aberration Coefficients of Example 2

Face No.	I	II	III	P	V
1	0.0464	0.0437	0.0410	0.2165	0.2420
2	0.0022	−0.0186	0.1578	−0.0510	−0.9058
3	−0.0009	−0.0019	−0.0039	0.2379	0.4773
4	−5.1746	1.1778	−0.2681	−0.7882	0.2404
5	2.3155	0.2231	0.0215	0.5407	0.0542
6	−0.0782	−0.0848	−0.0919	−0.2782	−0.4010
7	0.0053	0.0174	0.0577	0.0888	0.4857
8	−10.4518	−0.1750	−0.0029	−0.7226	−0.0121
9	2.7316	0.8750	0.2803	0.2327	0.1643
10	0.0013	−0.0021	0.0036	0.0491	−0.0894
11	−0.0543	−0.1016	−0.1898	0.	−0.3548
12	0.4276	0.3794	0.3367	0.1614	0.4419
13	14.6903	−2.4298	0.4019	0.5657	−0.1600
14	−9.8520	1.8126	−0.3335	−0.4774	0.1492
15	−0.9443	−0.7577	−0.6080	−0.2913	−0.7216
16	0.0146	−0.0306	0.0638	−0.2566	0.4025
17	1.9134	−0.4121	0.0888	0.5068	−0.1283
18	0.	−0.0011	−0.393	0.0499	0.3678
19	5.0984	−0.5391	0.0570	0.3446	−0.0425

-continued

Aberration Coefficients of Example 2

Face No.	I	II	III	P	V
Σ	0.6904	−0.0254	−0.0273	0.1288	0.2098

Aberration Coefficients of Example 3

Face No.	I	II	III	P	V
1	0.0348	0.0400	0.0461	0.2146	0.3002
2	0.0018	−0.0173	0.1629	−0.0613	−0.9574
3	0.0059	0.0081	0.0112	0.2769	0.3986
4	−5.7083	1.3324	−0.3110	−0.8224	0.2645
5	2.0502	0.2187	0.0233	0.5336	0.594
6	−0.0599	−0.0726	−0.0879	−0.2682	−0.4314
7	0.0063	0.0194	0.0599	0.1035	0.5036
8	−8.9145	−0.4398	−0.0217	−0.7156	−0.0363
9	2.9700	1.0408	0.3647	0.2792	0.2256
10	−0.0005	0.0052	−0.0470	0.0964	−0.4455
11	0.0076	0.0286	0.1065	0.0120	0.4415
12	14.9082	−2.4032	0.3873	0.6123	−0.1611
13	−11.1977	1.8699	−0.3122	−0.5611	0.1458
14	−0.9638	−0.7995	−0.6631	−0.2507	−0.7580
15	0.0133	−0.0385	0.1110	−0.2635	0.4392
16	1.3884	−0.3452	0.0859	0.5080	−0.1477
17	0.0004	0.0029	0.0182	0.0488	0.4112
18	6.2053	0.4688	0.0354	0.3977	−0.0327
Σ	0.7476	−0.0187	−0.0302	0.1403	0.2195

Aberration Coefficients of Example 4

Face No.	I	II	III	P	V
1	0.0145	0.0248	0.0424	0.1489	0.3267
2	0.0011	0.0113	0.1149	−0.0311	−0.8482
3	0.0019	0.0040	0.0080	0.2266	0.4724
4	−3.5841	0.7717	−0.1661	−0.6961	0.1856
5	0.6523	0.2078	0.0662	0.1997	0.0847
6	−0.0637	0.0877	−0.1206	−0.0609	−0.2496
7	0.1133	0.1239	0.1354	0.1024	0.2601
8	−10.6222	0.3468	−0.0113	−0.5866	0.0195
9	5.9740	0.8099	0.1098	0.3150	0.0575
10	−0.0001	0.0013	−0.0101	0.0158	−0.0439
11	−0.4252	−0.3400	−0.2718	−0.0739	−0.2765
12	0.9278	0.5893	0.3743	0.1575	0.3379
13	9.1012	−1.8667	0.3828	0.4104	−0.1627
14	−6.7447	1.3467	−0.2689	−0.3823	0.1300
15	−1.4995	−0.9970	−0.6629	−0.2418	−0.6016
16	0.0517	0.1191	0.2742	−0.0799	0.4474
17	−0.1353	−0.0883	−0.0576	−0.0086	−0.0433
18	3.5191	−0.4224	0.0507	0.4401	−0.0589
19	−0.0013	0.0113	−0.0967	0.0682	0.2420
20	3.4205	−0.5512	0.0888	0.1886	−0.0447
Σ	0.7012	−0.0078	−0.0182	0.1120	0.2346

Conditions	Ex. 1	Ex. 2	Ex. 3	Ex. 4
$0.8f < \lvert f1 \rvert < 1.5f$	0.8471f	0.9452f	0.8463f	1.0144f
$1.5f < \lvert f1\ II \rvert < 6.0f$	1.8923f	2.3889f	1.7972f	5.5402f
$f1 > f3$	7.516 > 4.02	3.765 > 2.013	5.267 > 4.709	3.803 > 1.995
$\lvert f2 \rvert > \lvert f4 \rvert$	1.529 > 1.169	1.195 > 0.992	1.320 > 1.295	1.234 > 1.033
$\nu 1 > \nu 3$				
$0.32f < DII < 0.72f$	0.6509f	0.4696f	0.6923f	0.3611f
$0.75 < \frac{Ra}{Rb} < 0.95$	0.7907	0.8246	0.9307	0.8956
$0.7f < \lvert Ra \rvert < 1.2f$	0.9078f	0.7704f	1.0858f	0.7118f
$1.7 < \overline{NIII}$	1.7425	1.7220	1.75776	1.7220

What is claimed is:

1. A retrofocus type wide-angle objective lens comprising:

a divergent first lens group including in the indicated order a first positive meniscus lens having a convex face directed toward an object to be photographed, a second negative meniscus lens having a convex face directed toward the object, a third positive meniscus lens having a convex face directed toward the object and a fourth negative meniscus lens also having a convex face directed toward the object;

a convergent second lens group behind the first lens group and coaxial therewith and including a positive lens having a convex front lens face directed toward the object;

a convergent third lens group behind the second lens group and coaxial therewith and including in the indicated order a positive lens having a convex rear lens face directed toward an image of the object being photographed, a biconcave lens, a positive meniscus lens directing a convexed face to the image and a positive lens; and

a diaphragm disposed between the second and third lens groups.

2. A wide-angle objective lens according to claim 1, wherein the positive lens of said second lens group includes positive and negative lenses cemented to each other.

3. A wide-angle objective lens according to claim 1, wherein the biconcave lens of said third lens group includes positive and negative lenses cemented to each other.

4. A wide-angle objective lens according to claim 1, wherein the positive meniscus lens of said third lens group includes positive and negative lenses cemented to each other.

5. A lens as in claim 1, wherein the distance between the third positive meniscus lens and the fourth negative meniscus lens changes during focusing.

* * * * *

OR 4,183,625

SEARCH ROOM

United State [19] 4,183,625

Tsunashima [45] Jan. 15, 1980

[54] WIDE-ANGLE PHOTOGRAPHIC OBJECTIVE

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[51] Int. Cl.[2] G02B 13/04

[52] U.S. Cl. 350/207; 350/214

[58] Field of Search 350/214, 207

[56] References Cited

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Primary Examiner—Conrad J. Clark

Attorney, Agent, or Firm—Shapiro and Shapiro

[57] ABSTRACT

A wide-angle photographic objective comprises, in the order from the object side, a positive meniscus lens convex to the object side, a negative meniscus lens convex to the object side, a negative meniscus lens convex to the object side, a positive lens, a negative meniscus lens convex to the object side, a positive lens, a meniscus lens convex to the image side and comprising a biconcave lens and a biconvex lens cemented together, a meniscus lens convex to the image side and comprising a biconcave lens and a biconvex lens cemented together, and a positive lens.

8 Claims, 4 Drawing Figures

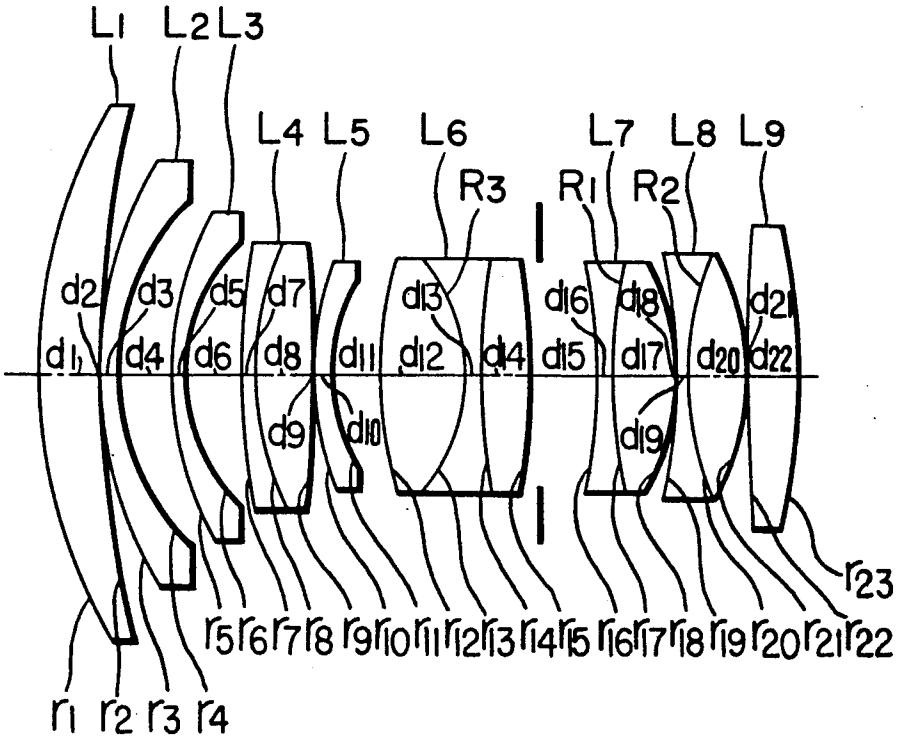


FIG. 1

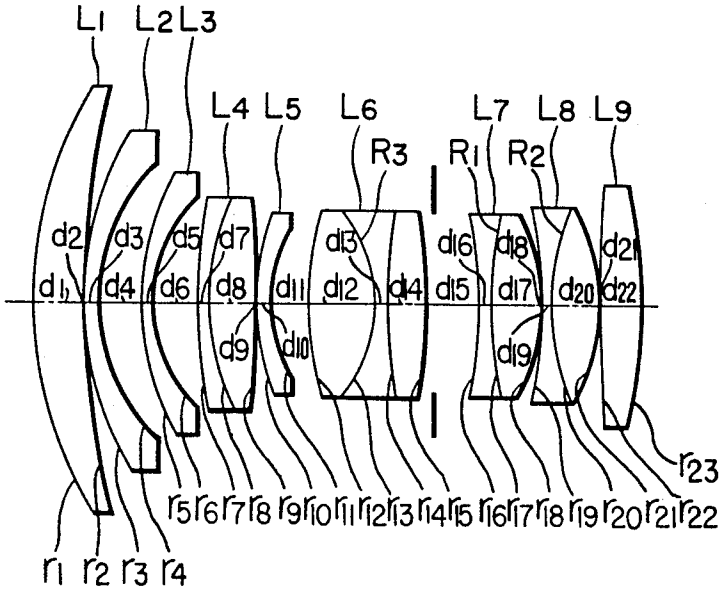


FIG. 2A

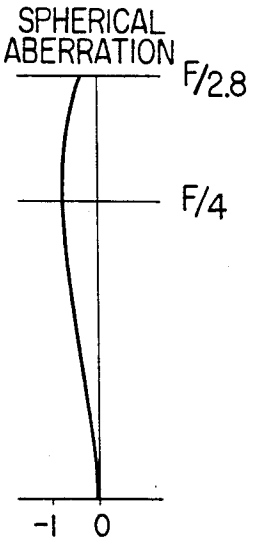


FIG. 2B

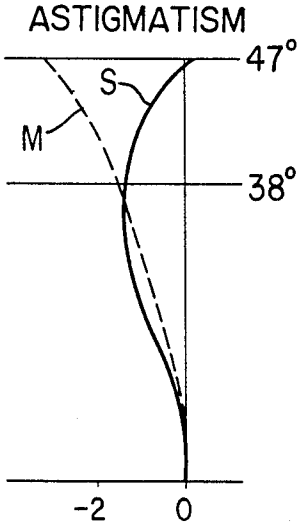
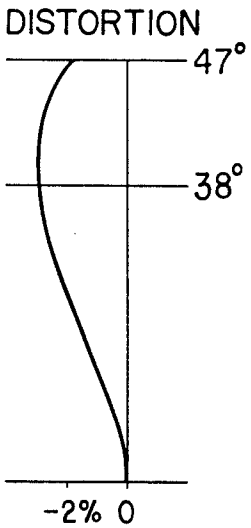


FIG. 2C



WIDE-ANGLE PHOTOGRAPHIC OBJECTIVE

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to an inverted telephoto lens type or a retrofocus type wide-angle photographic objective.

2. Description of the Prior Art

In single lens reflex cameras there is a demand for lenses of small size and of camera bodies which are compact. Nevertheless, it has also become desirable to increase the relative aperture while covering a wider angle of view in order to increase the versatility of the photographic objectives. The attainment of such lenses has been difficult because of the problems encountered in the correction of the aberrations.

SUMMARY OF THE INVENTION

The primary object of the present invention is to provide a wide-angle photographic objective which affords small size coupled with large relative aperture, wide angle of view and good correction of the aberrations.

The wide-angle photographic objective according to the present invention is small in size while having an angle of view of 94° and a relative aperture of 1:2.8. More particularly, for use as the objective for a 35 mm single lens reflex camera, the filter diameter of the forward lens may be even smaller, on the order of 52 mm.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates a lens construction according to the invention;

FIGS. 2A, 2B and 2C are graphs illustrating the spherical aberration, astigmatism and distortion of the third embodiment of the invention, the values of the various aberrations being for an objective where f=100 mm.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The wide-angle photographic objective as shown in FIG. 1 comprises nine components. In the order from the object side, the objective comprises a first component L1 which is a positive meniscus lens convex to the object side, a second component L2 which is a negative meniscus lens convex to the object side, a third component L3 which is a negative meniscus lens also convex to the object side, a fourth component L4 which is a positive lens, a fifth component L5 which is a negative meniscus lens convex to the object side, a sixth component L6 which is a positive lens, a seventh component L7 which is a meniscus lens convex to the image side and comprising a biconcave lens and a biconvex cemented together, an eighth component L8 which is a meniscus lens also convex to the image side and comprising a biconcave lens and a biconvex lens cemented together, and a ninth component L9 which is a positive lens. Adjacent components are disposed with a predetermined air space therebetween, and a diaphragm is disposed between the sixth component L6 and the seventh component L7. The significant features of the photographic objective of the invention reside in the lens components subsequent to the diaphragm, particularly the seventh component which is a meniscus lens convex to the image side and comprising a concave and a convex lens cemented together, and the eighth component which is a meniscus lens similar in construction to the seventh component.

In greater detail and in accordance with the preferred form of the invention, when the curvature radius of that surface of a certain one of the lens components which faces the object side is Rf and the curvature radius of that surface of the same component which faces the image side is Rr, the shape factor (SF), if introduced as a value representing the shape of such lens component, is defined as $SF=(R_r+R_f)/(R_r-R_f)$. For the seventh and the eighth component each comprising a concave and a convex lens cemented together, let SF_1 and SF_2 designate the shape values, respectively, let N_{1n} and N_{2n} designate the refractive indices of the glass materials of the concave lenses forming the respective two components, and let N_{1p} and N_{2p} designate the refractive indices of the glass materials of the biconvex lenses forming the respective two components. Also, let R_1 and R_2 designate the curvature radii of the cemented surfaces of the respective two lens components, and f the total focal length of the entire system.

Then, these significant features or conditions may be expressed as follows:

$$-5.0<SF_1<-2.5 \quad (1)$$

$$-3.5<SF_2<-1.3 \quad (2)$$

$$N_{1n}>N_{1p} \quad (3)$$

$$0.7f<R_1 \quad (4)$$

$$N_{2n}>N_{2p} \quad (5)$$

$$0.6f<R_2<2f \quad (6)$$

Usually, reduction in size of a lens system necessarily results in the aggravation of various aberrations. However, by adopting a lens construction which includes the above-described conditions in the portion subsequent to the diaphragm space, it is now possible to adequately correct the various aberrations created in the portion of the lens system disposed forwardly of the diaphragm and to arrange the forward lens group more compactly than has heretofore been accomplished.

Each of the aforementioned conditions will hereinafter be discussed in detail. Conditions (1) and (2) define the shapes of the seventh component L7 and the eighth component L8 each comprising a doublet. Outside the ranges of these conditions, coma will be aggravated to induce curvature of the image plane; also, unbalanced coma will result from the image height. If the upper limits of these conditions are exceeded, distortion will be under-corrected, and while this might be corrected by increasing the center thickness or the air space of a particular lens component without affecting the other aberrations, the result is loss of compactness for the lens system.

Conditions (3) and (4) define the refractive indices of the glass materials on the opposite sides of the cemented surface of the seventh component L7 and the radius of curvature of this cemented surface. Condition (3) is essential because to depart therefrom will cause coma to be aggravated. It is usually the tendency of a cemented surface that as the difference in its refractive index is greater, the curvature radius of the cemented surface is greater to make the aberrations easier to correct. If selection of a glass material having a great difference in

refractive index is allowed for the cemented surface of this component, it will be possible to provide a construction in which the curvature radius is infinitely great. On the other hand, if the difference in refractive index is small, the curvature radius of the cemented surface must be small.

Conditions (5) and (6) are similar in significance to conditions (3) and (4) but concerned with the eighth component L8 which comprises a doublet. Condition (5), like condition (3), also is essential in order that the cemented surface of this component may be effective. The above-described relationship between the cemented surface and the refractive indices holds true in this case as well. This component greatly affects coma and distortion in particular and plays an important role in the correction of these aberrations, imposing even stricter conditions than the seventh component. If the lower limit of condition (6) is exceeded, coma will be aggravated while distortion will be over-corrected. If the upper limit of this condition is exceeded, the symmetry of coma will be destroyed and distortion will be under-corrected. In any case, these aberrations may not be maintained well corrected by any other component.

By satisfying the above-described construction and conditions, there is achieved a wide-angle photographic objective having an angle of view of 94° and a relative aperture 1:2.8 and yet smaller in size than heretofore.

In a wide-angle photographic objective according to the present invention, it is further preferred that the following conditions be satisfied to enable the correction of aberrations in the entire system to be accomplished with greater ease. More specifically, the sixth component L6 is a triplet lens comprising, in the order from the object side, a positive lens, a negative lens and a positive lens. Preferably, the following conditions are satisfied:

$$N_{3p} > N_{3n} \quad (7)$$

$$-0.4f < R_3 < -0.8f \quad (8),$$

where N_{3p} represents the refractive index of the glass material forming the positive lens nearer the object side, N_{3n} the refractive index of the glass material forming the negative lens, and R_3 the curvature radius of the cemented surface of these two lenses.

Condition (7) is desirable to make the role of this component more effective, and condition (8) is particularly effective to correct spherical aberration and coma under the restriction of condition (7). Outside condition (8), spherical aberration cannot be maintained well and asymmetry of coma will be created. Of the two cemented surfaces of this component, the one between the positive lens nearer the image side and the negative lens is intended only for the correction of chromatic aberration and will be unnecessary if chromatic aberration can be sufficiently corrected by substituting a doublet for one of any other component.

The lens system of the invention enables the correction of aberration for close-up photography. This is accomplished by causing the lens groups behind the diaphragm to be moved as a unit in a direction to reduce the diaphragm space when the entire lens system is moved axially in accordance with a desired photographing magnification, thereby correcting for the curvature of the image plane during the short distance photography.

Numerical data of some embodiments of the present invention will be shown below, with the understanding that $r_1, r_2, r_3, \ldots, r_{23}$ represent the curvature radii of the successive lens surfaces in the order from the object side, $d_1, d_2, d_3, \ldots, d_{22}$ represent the center thicknesses or the air spaces between the respective lenses, $nd_1, nd_2, nd_3, \ldots, nd_{14}$ represent the refractive indices of the glass materials forming the respective lenses, and $\nu d_1, \nu d_2, \nu d_3, \ldots, \nu d_{14}$ represent the Abbe numbers of such glass materials.

EMBODIMENT 1

Total focal length f=100mm Relative aperature 1:2.8
Angle of view $2\omega = 94°$

r_1=	170.588	d_1=	18.63	nd_1=1.60327	νd_1=60.7
r_2=	377.203	d_2=	0.49		
r_3=	145.875	d_3=	4.41	nd_2=1.80518	νd_2=25.5
r_4=	62.500	d_4=	17.16		
r_5=	107.843	d_5=	3.92	nd_3=1.78797	νd_3=47.5
r_6=	61.520	d_6=	20.59		
r_7=	369.304	d_7=	4.41	nd_4=1.80186	νd_4=44.4
r_8=	107.843	d_8=	19.61	nd_5=1.53246	νd_5=46.0
r_9=	−606.387	d_9=	0.49		
r_{10}=	134.804	d_{10}=	3.92	nd_6=1.74443	νd_6=49.4
r_{11}=	63.461	d_{11}=	16.67		
r_{12}=	128.412	d_{12}=	29.90	nd_7=1.74950	νd_7=35.0
r_{13}=	−61.765	d_{13}=	3.92	nd_8=1.48749	νd_8=70.0
r_{14}=	147.059	d_{14}=	10.73	nd_9=1.74077	νd_9=27.7
r_{15}=	−2237.872	d_{15}=	25.49		
r_{16}=	−196.078	d_{16}=	4.41	nd_{10}=1.79504	νd_{10}=28.4
r_{17}=	205.882	d_{17}=	19.61	nd_{11}=1.51680	νd_{11}=64.2
r_{18}=	−100.000	d_{18}=	0.49		
r_{19}=	−237.142	d_{19}=	3.92	nd_{12}=1.80537	νd_{12}=25.5
r_{20}=	99.020	d_{20}=	21.08	nh_{13}=1.51680	νd_{13}=64.2
r_{21}=	−91.313	d_{21}=	0.49		
r_{22}=	2450.980	d_{22}=	15.69	nd_{14}=1.51823	νd_{14}=59.0
r_{23}=	−145.800				

EMBODIMENT 2

	Total focal length f=100mm Relative aperture 1:2.8 Angle of view 2ω = 94°			
r_1=	166.667	d_1= 19.12	n_1=1.60327	νd_1=60.7
r_2=	355.034	d_2= 0.49		
r_3=	147.059	d_3= 4.90	n_2=1.80454	νd_2=39.5
r_4=	59.804	d_4= 17.16		
r_5=	102.941	d_5= 3.92	n_2=1.80454	νd_2=39.5
r_6=	60.294	d_6= 19.61		
r_7=	352.446	d_7= 4.41	n_4=1.80186	νd_4=44.4
r_8=	96.314	d_8= 19.61	n_5=1.59507	νd_5=35.6
r_9=	−606.387	d_9= 0.49		
r_{10}=	121.569	d_{10}= 3.92	n_6=1.77279	νd_6=49.4
r_{11}=	63.725	d_{11}= 16.67		
r_{12}=	137.760	d_{12}= 29.90	n_7=1.77279	νd_7=49.4
r_{13}=	−56.618	d_{13}= 3.92	n_8=1.52000	νd_8=70.1
r_{14}=	281.863	d_{14}= 12.25	n_9 =1.74077	νd_9=27.7
r_{15}=	−755.642	d_{15}= 25.98		
r_{16}=	−196.275	d_{16}= 4.41	n_{10}=1.79668	νd_{10}=45.4
r_{17}=	230.392	d_{17}= 19.61	n_{11}=1.51714	νd_{11}=64.2
r_{18}=	−101.407	d_{13}= 0.49		
r_{19}=	−235.294	d_{19}= 3.92	n_{12}=1.80537	νd_{12}=25.5
r_{20}=	105.779	d_{20}= 22.06	n_{13}=1.50153	νd_{13}=56.5
r_{21}=	−89.706	d_{21}= 0.49		
r_{22}=	1960.784	d_{22}= 15.69	n_{14}=1058913	νd_{14}=61.2
r_{23}=	−169.466			

EMBODIMENT 3

	Total focal length f=100mm Relative aperture 1:2.8 Angle of view 2ω = 94°			
r_1=	173.824	d_1= 13.63	n_1=1.60311	νd_1=60.7
r_2=	406.863	d_2= 0.49		
r_3=	147.794	d_3= 4.41	n_2=1.79877	νd_2=44.3
r_4=	62.500	d_4= 17.16		
r_5=	107.843	d_5= 3.92	n_3=1.78797	νd_3=47.5
r_6=	56.373	d_6= 20.59		
r_7=	267.745	d_7= 4.41	n_4=1.79877	νd_4=44.3
r_8=	107.843	d_8= 19.61	n_5=1.53256	νd_5=46.0
r_9=	−606.387	d_9= 0.49		
r_{10}=	116.667	d_{10}= 3.92	n_6=1.73350	νd_6=51.0
r_{11}=	61.814	d_{11}= 17.16		
r_{12}=	136.569	d_{12}= 29.90	n_7=1.74400	νd_7=45.0
r_{13}=	−53.922	d_{13}= 3.92	n_8=1.51680	νd_8=64.2
r_{14}=	294.118	d_{14}= 10.78	n_9=1.62588	νd_9=35.6
r_{15}=	−357.059	d_{15}= 25.98		
r_{16}=	−195.108	d_{16}= 4.41	n_{10}=1.78797	νd_{10}=47.5
r_{17}=	215.608	d_{17}= 19.61	n_{11}=1.51680	νd_{11}=64.2
r_{18}=	−100.000	d_{18}= 0.49		
r_{19}=	−237.142	d_{19}= 3.92	n_{12}=1.80518	νd_{12}=25.5
r_{20}=	104.588	d_{20}= 21.08	n_{13}=1.50137	νd_{13}=56.5
r_{21}=	−90.907	d_{21}= 0.49		
r_{22}=	4411.765	d_{22}= 15.69	n_{14}=1.62299	νd_{14}=58.1
r_{22}=	−177.897			

The lens construction of each embodiment has been described previously and typically may be represented by the lens construction of the first embodiment which is shown in FIG. 1. To illustrate the aberrations in the wide-angle photographic objective of the present invention, FIGS. 2A, 2B and 2C illustrate the various aberrations for the third embodiment. It will be seen that the photographic objective of the present invention is small in size while having an angle of view of 94° and a relative aperture of 1:2.8 and yet maintains good conditions of aberrations.

It is believed that the advantages and improved results afforded by the wide angle photographic objectives of the invention will be apparent from the foregoing detailed description of preferred embodiments thereof. Various modifications and changes may be made without departing from the spirit and scope of the invention as sought to be defined in the following claims.

I claim:

1. A wide-angle photographic objective comprising, in the order from the object side:
- a first component which is a positive meniscus lens convex to the object side;
- a second component which is a negative meniscus lens convex to the object side;
- a third component which is a negative meniscus lens convex to the object side;
- a fourth component which is a positive lens;
- a fifth component which is a negative meniscus lens convex to the object side;
- a sixth component which is a positive lens;
- a seventh component which is a meniscus lens convex to the image side and comprising a biconcave lens and a biconvex lens cemented together;
- an eighth component which is a meniscus lens convex to the image side and comprising a biconcave lens and a biconvex lens cemented together; and

a ninth component which is a positive lens.

2. A wide-angle photographic objective according to claim 1, wherein said sixth component has at least one cemented surface of a positive and a negative lens, said cemented surface being convex to the image side.

3. A wide-angle photographicobjective according to claim 1, wherein the numerical values of the radii r_1 to r_{23} and of the thickness and separations d_1 to d_{22}, the refractive indices nd and the Abbe numbers νd of the respective components are substantially as follows:

Total focal length f=100mm Relative aperature 1:2.8
Angle of view $2\omega = 94°$

r_1=	170.588	d_1=	18.63	nd_1=1.60327	νd_1=60.7
r_2=	377.203	d_2=	0.49		
r_3=	145.875	d_3=	4.41	nd_2=1.80518	νd_2=25.5
r_4=	62.500	d_4=	17.16		
r_5=	107.843	d_5=	3.92	nd_3=1.78797	νd_3=47.5
r_6=	61.520	d_6=	20.59		
r_7=	369.304	d_7=	4.41	nd_4=1.80186	νd_4=44.4
r_8=	107.843	d_8=	19.61	nd_5=1.53246	νd_5=46.0
r_9=	−606.387	d_9=	0.49		
r_{10}=	134.804	d_{10}=	3.92	nd_6=1.74443	νd_6=49.4
r_{11}=	63.461	d_{11}=	16.67		
r_{12}=	128.412	d_{12}=	29.90	nd_7=1.74950	νd_7=35.0
r_{13}=	−61.765	d_{13}=	3.92	nd_8=1.48749	νd_8=70.0
r_{14}=	147.059	d_{14}=	10.78	nd_9=1.74077	νd_9=27.7
r_{15}=	−2237.872	d_{15}=	25.49		
r_{16}=	−196.078	d_{16}=	4.41	nd_{10}=1.79504	νd_{10}=28.4
r_{17}=	205.882	d_{17}=	19.51	nd_{11}=1.51680	νd_{11}=54.2
r_{18}=	−100.000	d_{18}=	0.49		
r_{19}=	−237.142	d_{19}=	3.92	nd_{12}=1.80537	νd_{12}=25.5
r_{20}=	99.020	d_{20}=	21.08	nd_{13}=1.51580	νd_{13}=64.2
r_{21}=	−91.313	d_{21}=	0.49		
r_{22}=	2450.980	d_{22}=	15.69	nd_{14}=1.51823	νd_{14}=59.0
r_{23}=	−145.800				

4. A wide-angle photographic objective according to claim 1, wherein the numerical values of the radii r_1 to r_{23} and of the thicknesses and separations d_1 to d_{22}, the refractive indices nd and the Abbe numbers νd of the respective components are substantially as follows:

Total focal length f-100mm Relative aperture 1:2.8
Angle of view $2\omega = 94°$

r_1=	166.667	d_1=	19.12	n_1=	1.60327	νd_1=60.7
r_2=	355.034	d_2=	0.49			
r_3=	147.059	d_3=	4.90	n_2=	1.80454	νd_2=39.5
r_4=	59.804	d_4=	17.16			
r_5=	102.941	d_5=	3.92	n_3=	1.80454	νd_3=39.5
r_6=	60.294	d_6=	19.61			
r_7=	352.446	d_7=	4.41	n_4=	1.80186	νd_4=44.4
r_8=	96.314	d_8=	19.61	n_5=	1.59507	νd_5=35.6
r_9=	−606.387	d_9 =	0.49			
r_{10}=	121.569	d_{10}=	3.92	n_6=	1.77279	νd_6=49.4
r_{11}=	63.725	d_{11}=	16.67			
r_{12}=	137.760	d_{12}=	29.90	n_7=	1.77279	νd_7=49.4
r_{13}=	−56.618	d_{13} =	3.92	n_8=	1.52000	νd_8=70.1
r_{14}=	281.863	d_{14}=	12.25	n=	1.74077	νd_9=27.7
r_{15}=	−755.642	d_{15}=	25.98			
r_{16}=	−196.275	d_{16}=	4.41	n_{10}=	1.79668	νd_{10}=45.4
r_{17}=	230.392	d_{17}=	19.61	n_{11}=	1.51714	νd_{11}=64.2
r_{18}=	−101.407	d_{18}=	0.49			
r_{19}=	−235.294	d_{19}=	3.92	n_{12}=	1.80537	νd_{12}=25.5
r_{20}=	105.779	d_{20}=	22.06	n_{13}=	1.50153	νd_{13}=56.5
r_{21}=	−89.706	d_{21}=	0.49			
r_{22}=	1960.784	d_{22}=	15.69	n_{14}=	1.58913	νd_{14}=61.2
r_{23}=	−169.466					

5. A wide-angle photographic objective according to claim 1, wherein the numerical values of the radii r_1 to r_{23} and of the thicknesses and separations d_1 to d_{22}, the refractive indices nd and the Abbe numbers νd of the respective components are substantially as follows

Total focal length f=100mm Relative aperture 1:2.8
Angle of view $2\omega = 94°$

r_1=	173.824	d_1=	18.63	n_1=1.60311	νd_1=60.7
r_2=	406.863	d_2=	0.49		
r_3=	147.794	d_3=	4.41	n_2 =1.79877	νd_2 =44.3
r_4=	62.500	d_4=	17.16		
r_5=	107.843	d_5=	3.92	n_3=1.78797	νd_3=47.5
r_6=	56.373	d_6=	20.59		
r_7=	267.745	d_7=	4.41	n_4=1.79877	νd_4=44.3
r_8=	107.843	d_8=	19.61	n_5=1.53256	νd_5=46.0
r_9=	−606.387	d_9=	0.49		
r_{10}=	116.667	d_{10}=	3.92	n_6=1.73350	νd_6=51.0
r_{11}=	61.814	d_{11}=	17.16		
r_{12}=	136,569	d_{13}=	29.90	n_7=1.74400	νd_7=45.0
r_{13}=	−54.922	d_{13}=	3.92	n_8=1.51680	νd_8=64.2
r_{14}=	294.118	d_{14}=	10.78	n_9 =1.62588	νd_9=35.6
r_{15}=	−357.059	d_{15}=	25.98		
r_{16}=	−195.108	d_{16}=	4.41	n_{10}=1.78797	νd_{10}=47.5
r_{17}=	215.608	d_{17}=	19.61	n_{11}=1.51680	νd_{11}=64.2
r_{18}=	−100.000	d_{18}=	0.49		
r_{19}=	−237.142	d_{19}=	3.92	n_{12}=1.80518	νd_{12}=25.5
r_{20}=	104.588	d_{20}=	21.08	n_{13}=1.50137	νd_{13}=56.5
r_{21}=	−90.907	d_{21}=	0.49		
r_{22}=	4411.765	d_{22}=	15.69	n_{14}=1.62299	νd_{14}=58.1
r_{23}=	−177.897				

6. In a wide-angle photographic objective comprising a diaphragm, a front lens group positioned at the object side and a rear lens group positioned at the image side, the diaphragm being interposed between said lens groups, the improvement wherein the front lens group comprises a positive meniscus component having its surface convex to the object side, at least two negative meniscus lens components having their surfaces convex to the object side and at least one positive lens component, and wherein the rear lens group consists of, in the order from the object side, two meniscus lens components each having their surfaces convex to the image side and comprising a biconcave and a biconvex lens cemented together, and one position lens component.

7. A wide-angle photographic objective according to claim 6, wherein the front lens group comprises, in the order from the object side:

a first component which is a positive meniscus lens convex to the object side;

a second component which is a negative meniscus lens convex to the object side;
a third component which is a negative meniscus lens convex to the object side;
a fourth component which is a positive lens;
a fifth component which is a negative meniscus lens convex to the object side; and
a sixth component which is a positive lens.

8. A wide-angle photographic objective according to claim 7, wherein in the rear lens group said meniscus lens components each having their surfaces convex to the image side and comprising a biconcave lens and a biconvex lens cemented together constitute the seventh and eighth components; and the positive lens constitutes the ninth component.

* * * * *

United States Patent [19]

Bauer

[11] **4,182,565**

[45] **Jan. 8, 1980**

[54] **LIGHT-RAY DEVIATOR FOR CAMERA OBJECTIVE**

[75] Inventor: **Klaus Bauer**, Bad Kreuznach, Fed. Rep. of Germany

[73] Assignee: **Jos. Schneider & Co.**, Bad Kreuznach, Fed. Rep. of Germany

[21] Appl. No.: **902,161**

[22] Filed: **May 2, 1978**

[30] **Foreign Application Priority Data**

May 17, 1977 [DE] Fed. Rep. of Germany 2722787

[51] **Int. Cl.**[2] **G02B 1/00**; G02B 1/10; G03B 13/06

[52] **U.S. Cl.** ..... **354/224**; 354/225; 350/276 SL

[58] **Field of Search** ..... 354/224, 225, 201, 166, 354/154, 155, 296; 350/276 SL, 282

[56] **References Cited**

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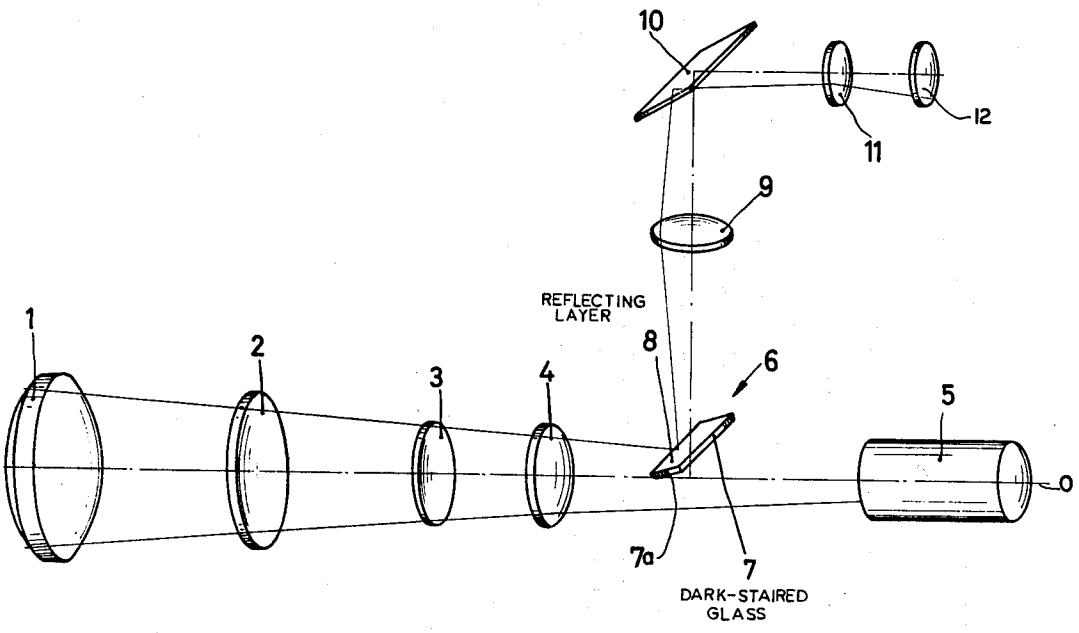
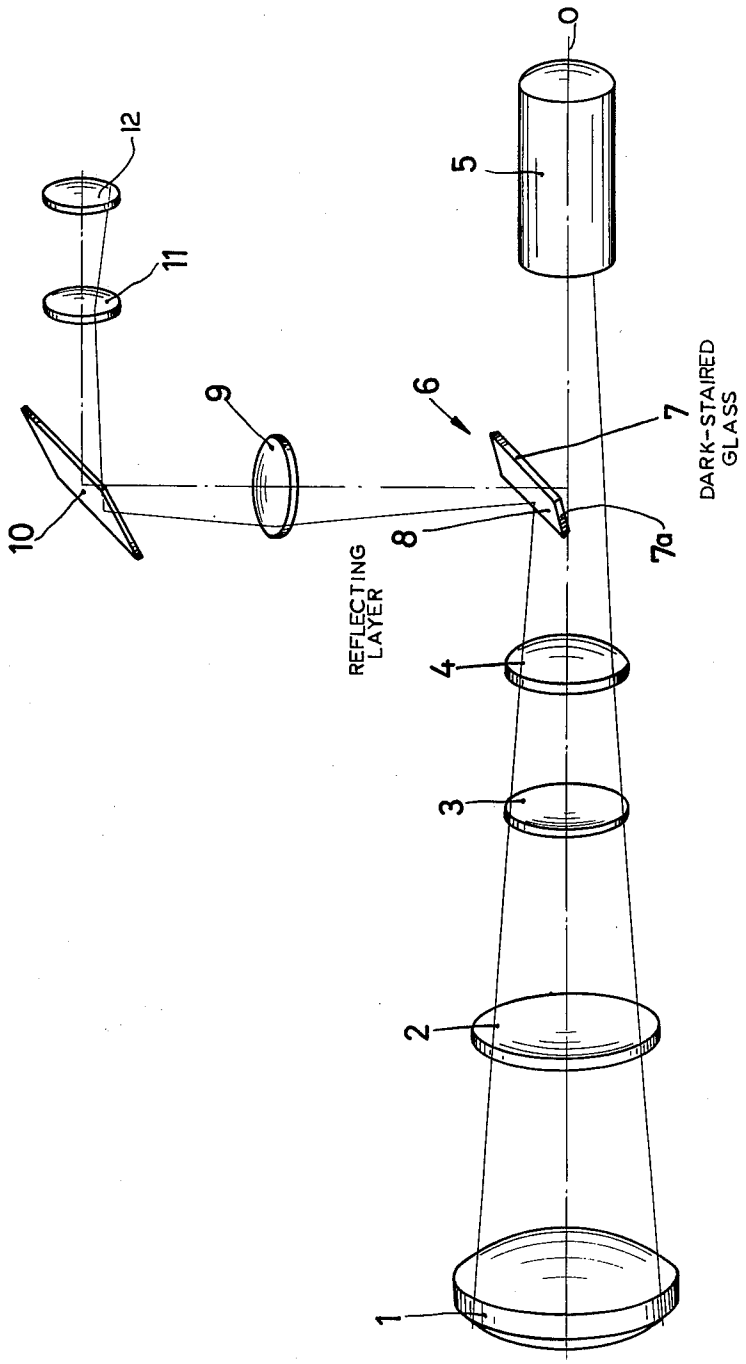
Primary Examiner—John Gonzales
Assistant Examiner—Shelley Wade
Attorney, Agent, or Firm—Karl F. Ross

[57] **ABSTRACT**

A viewfinder system of a photographic or cinematographic camera, provided with a varifocal objective, is illuminated by light deviators including a fully reflective mirror intercepting part of the light rays passing from the fourth to the final component of the objective. The mirror has a body of dark-stained glass, designed to prevent spurious reflections at the edges, and is coated on its front surface with a reflective layer produced by vapor deposition.

3 Claims, 1 Drawing Figure




0
5
12
11
9
6
7
DARK-STAIRED GLASS
10
8
7a
REFLECTING LAYER
4
3
2
1

LIGHT-RAY DEVIATOR FOR CAMERA OBJECTIVE

FIELD OF THE INVENTION

My present invention relates to a photographic or cinematographic camera equipped with a viewfinder system of the type wherein some of the light rays traversing certain lens members of the main objective are deviated to an eyepiece of the finder.

BACKGROUND OF THE INVENTION

The deviation of some of the incident rays for viewfinding purposes can be carried out either by a semitransparent reflector intercepting the entire beam, as formed for example by a pair of cemented prisms, or by a small fully reflective mirror interposed in the path of only some of the rays. The latter solution is often preferred for economic reasons.

Conventional mirrors of the fully reflective type have lateral edges which, on being struck at a glancing angle by incident rays not directly intercepted, may give rise to objectionable reflections. To avoid this problem, it has been customary to blacken the mirror edges by coating them with a lacquer or the like.

OBJECT OF THE INVENTION

The object of my present invention is to provide an improved mirror for the purpose set forth which need not be subjected to such a blackening procedure.

SUMMARY OF THE INVENTION

I have found, in accordance with the present invention, that disturbing reflections from the lateral edges of an interposed mirror can be avoided if the body of that mirror is made of dark-stained glass. The front surface of this body, facing the incident rays, is covered by a fully reflective layer which may be applied thereto by vapor deposition, for example.

BRIEF DESCRIPTION OF THE DRAWING

The above and other features of the invention will now be described in detail with reference to the accompanying drawing the sole FIGURE of which diagrammatically shows a camera objective equipped with a viewfinder system according to my invention.

SPECIFIC DESCRIPTION

The objective shown in the drawing is of a conventional zoom type with a varifocal front group **1–4** and a fixed-focus rear or relay group **5** whose several lenses have not been illusrated individually. The varifocal group consists of a positive front component **1**, two negative and axially shiftable intermediate components **2, 3** and a stationary positive component **4**, all represented diagrammatically by single lenses. The optical axis of the objective has been indicated at **0**.

In accordance with my invention, a part of the incoming beam is diverted in a direction generally perpendicular to axis **0** by a reflector **6** comprising a prismatic body **7** of dark-stained glass coated with a reflecting layer **8** on its forward surface confronting the incident rays. Mirror **6**, which may be disposed just ahead of a nonillustrated iris diaphragm, is entirely located on one side of axis **0** so as to intercept only a fraction of the bundle of light rays originating at any point of an object to be photographed. The deflected rays pass through a finder objective **9** and are redirected into an axial position by another mirror **10** so as to traverse a pair of lenses **11, 12**, the latter constituting the eyepiece of the finder. It will be noted than an edge *7a* of mirror body **7** transverse to its reflecting front surface **8** is positioned to intercept some of the incident light rays. The dark color of the body and therefore of edge *7a* prevents the latter from reflecting any of these intercepted light rays.

My improved reflector **6** can be produced at low cost without giving rise to objectionable reflection phenomena within the objective **1–5**.

I claim:

1. In a camera provided with a multilens objective centered on an optical axis, a viewfinder eyepiece offset from said axis, and ray-deviating means for diverting to said eyepiece part of the light traversing said objective, the improvement wherein said ray-deviating means includes a fully reflecting mirror inserted between two lens members of said objective, said mirror having a body of nonreflective dark-stained glass covered with a reflective layer on a surface confronting the incident light rays, said body further having a lateral edge transverse to said surface positioned to intercept some of said light rays but prevented by the dark color of the body from reflecting the intercepted light rays.

2. The improvement defined in claim **1** wherein said mirror is entirely positioned on one side of said axis.

3. The improvement defined in claim **1** or **2** wherein said objective comprises a varifocal front group and a fixed-focus rear group, said mirror being disposed between said groups.

* * * * *

United States
Freudenschuss et al

4,179,191
Dec. 18, 1979

[54] **ADJUSTING MECHANISM FOR OPTICAL OBJECTIVE WITH LOST-MOTION ZONE**

[75] Inventors: **Otto Freudenschuss; Eduard Keznickl; Gottfried Patels,** all of Vienna, Austria

[73] Assignees: **Karl Vockenhuber; Raimund Hauser,** both of Vienna, Austria

[21] Appl. No.: **851,353**

[22] Filed: **Nov. 14, 1977**

[30] **Foreign Application Priority Data**

Nov. 15, 1976 [AT] Austria 8469/76

[51] **Int. Cl.**[2] **G02B 7/10;** G02B 15/14; G02B 15/10

[52] **U.S. Cl.** **350/187;** 350/255

[58] **Field of Search** 350/187, 186, 184, 255

[56] **References Cited**

U.S. PATENT DOCUMENTS

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Primary Examiner—Jon W. Henry
Attorney, Agent, or Firm—Montague & Ross

[57] **ABSTRACT**

In order to establish a predetermined position of focusing or focal-length adjustment for an optical objective, a mechanism for the axial shifting of one or more lens members has a lost-motion zone in its operating range in which a continuing displacement of a control element does not change the focal length and/or distance of the objective. The halting of the lens shift (or, possibly, a compensatory displacement of an otherwise stationary lens member) can be brought about mechanically, with the aid of suitably shaped cam tracks, or electromechanically, via analog or binary position sensors. Arrival of the adjusting mechanism in the lost-motion zone may be signaled to the user by a detent, by a change in frictional resistance, or by a visual or acoustical indicator.

14 Claims, 13 Drawing Figures

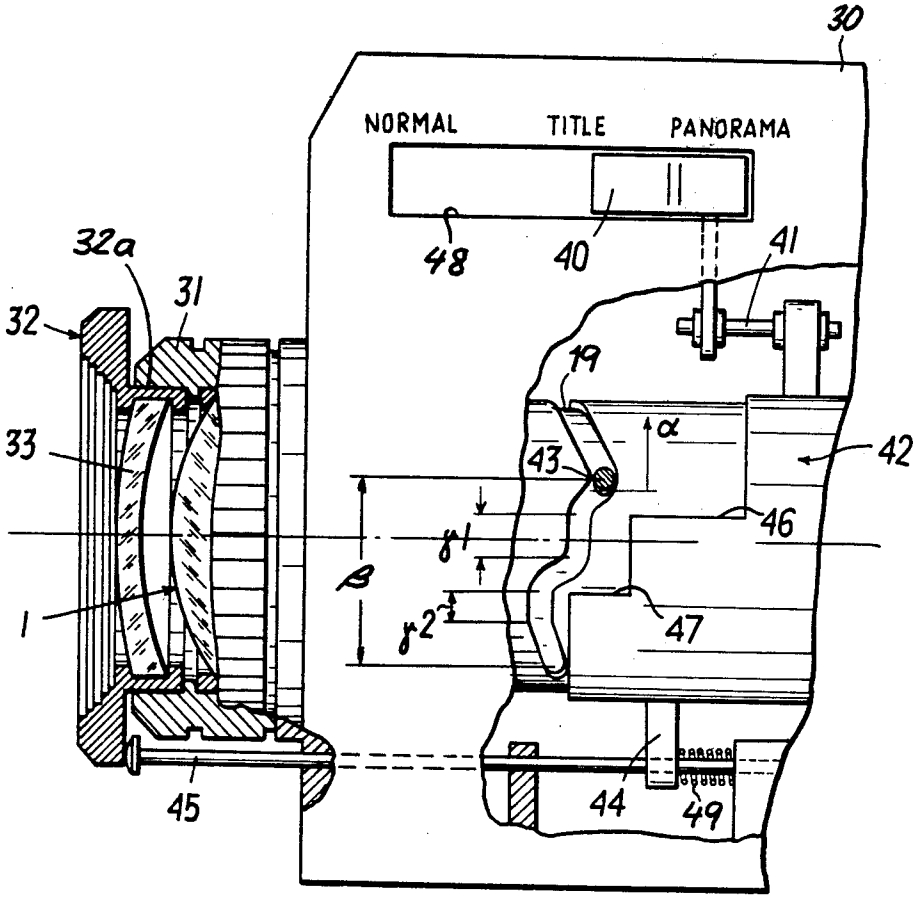


FIG. 1

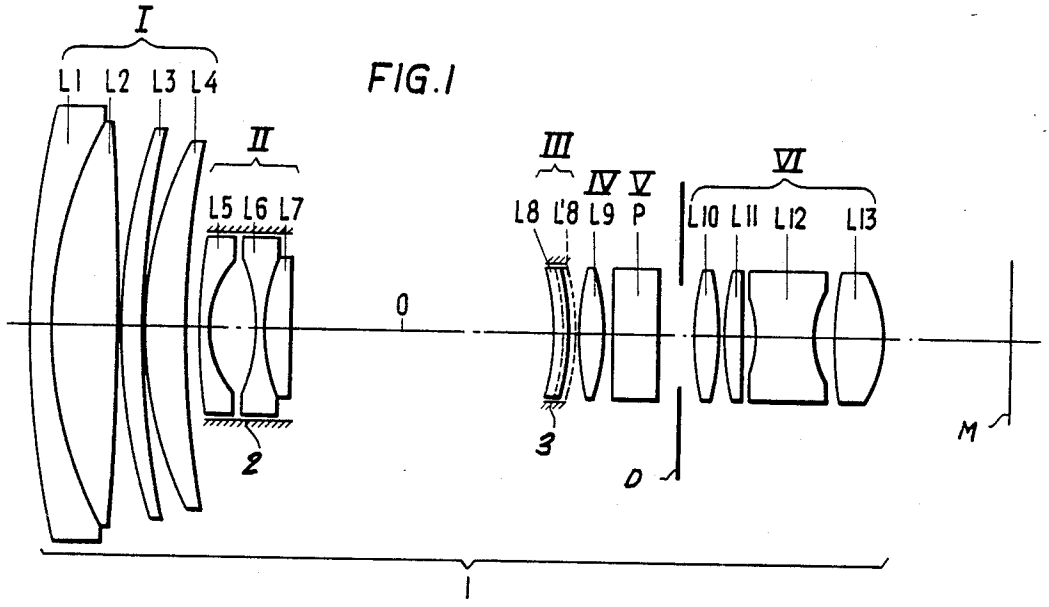


FIG. 2

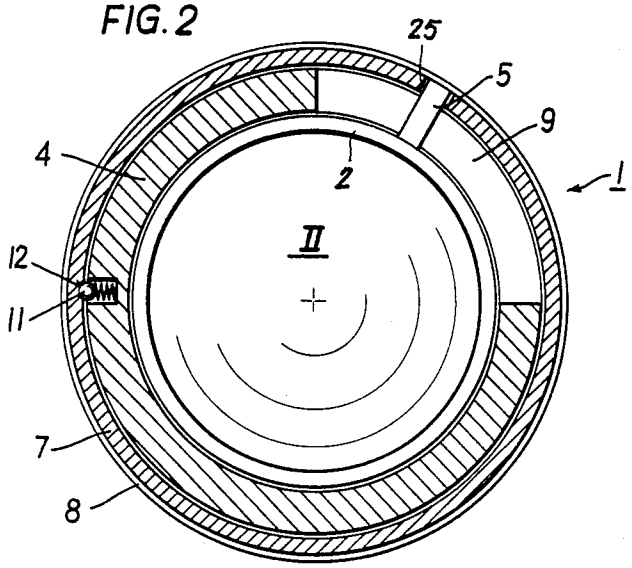


FIG. 3

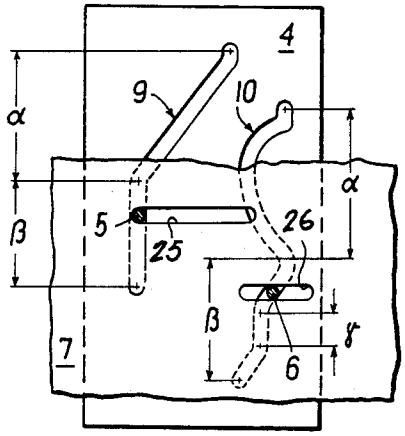


FIG. 4

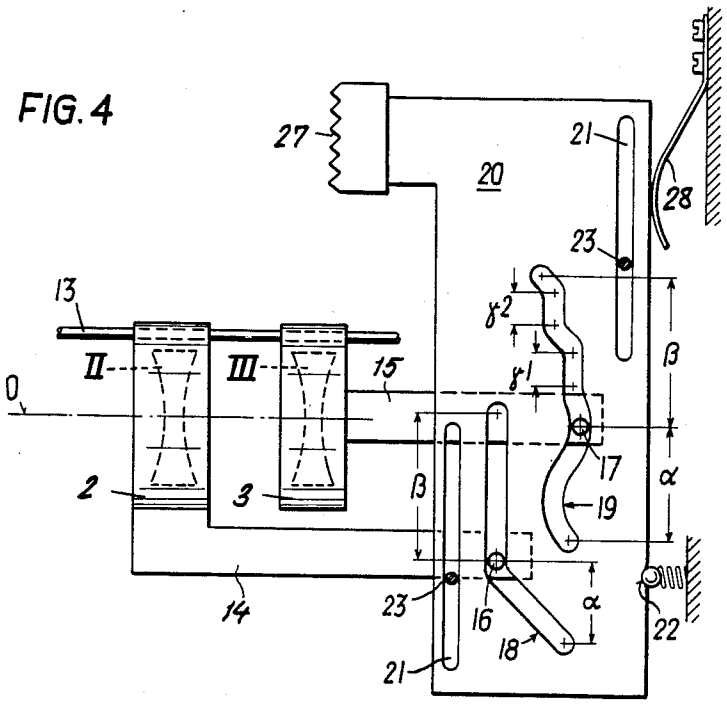


FIG. 5A

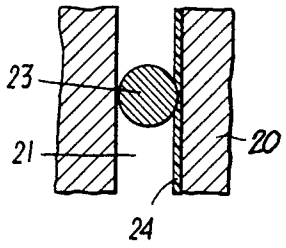


FIG. 5B

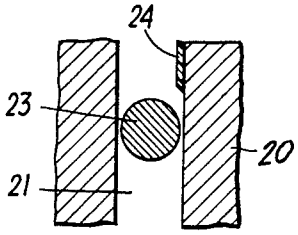


FIG. 8

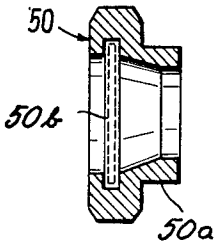


FIG. 9A

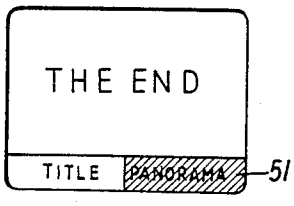


FIG. 9B

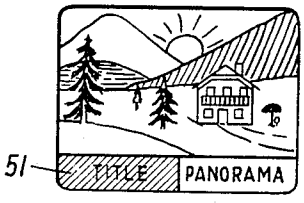
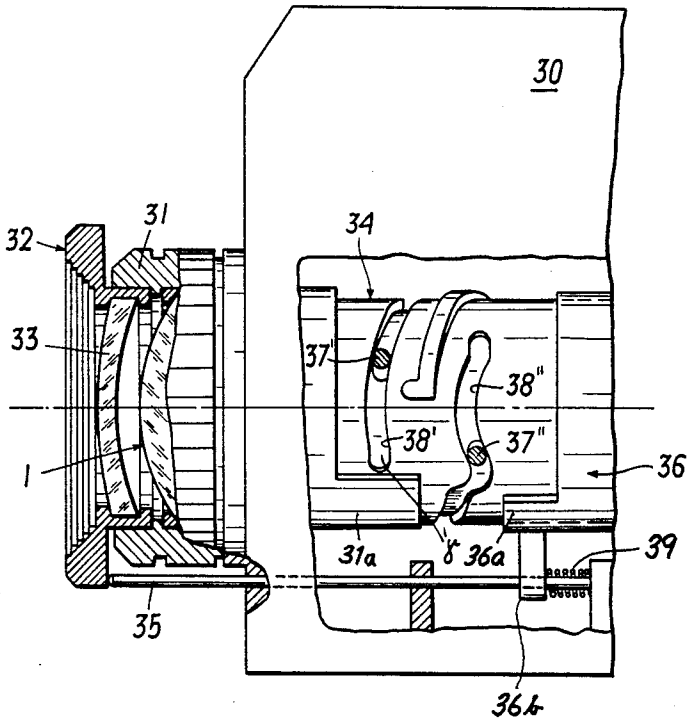


FIG.6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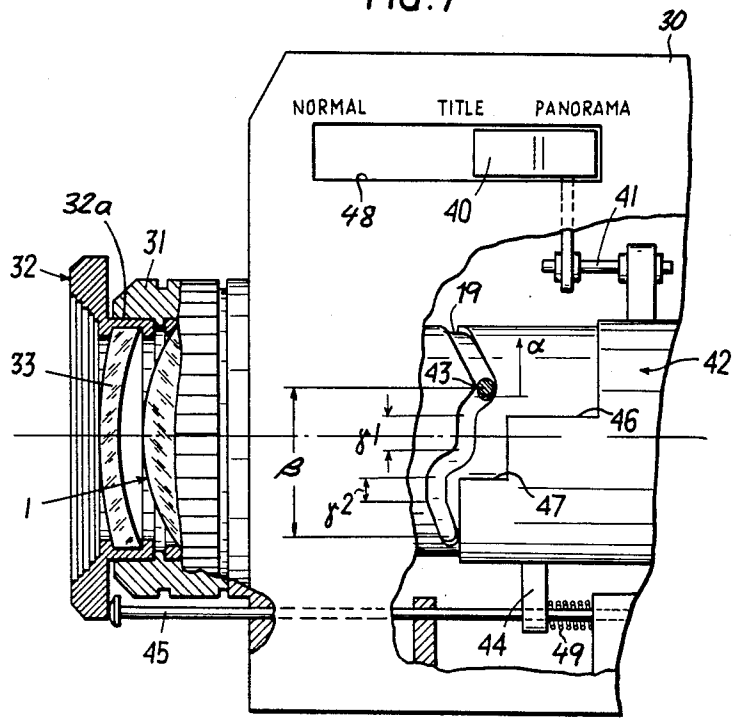
31
32
34
33
37'
38"
38'
37"
36
1
31a
δ
36a
39
35
36b

FIG.7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NORMAL
TITLE
PANORAMA
48
40
41
32a
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32
19
α
42
33
43
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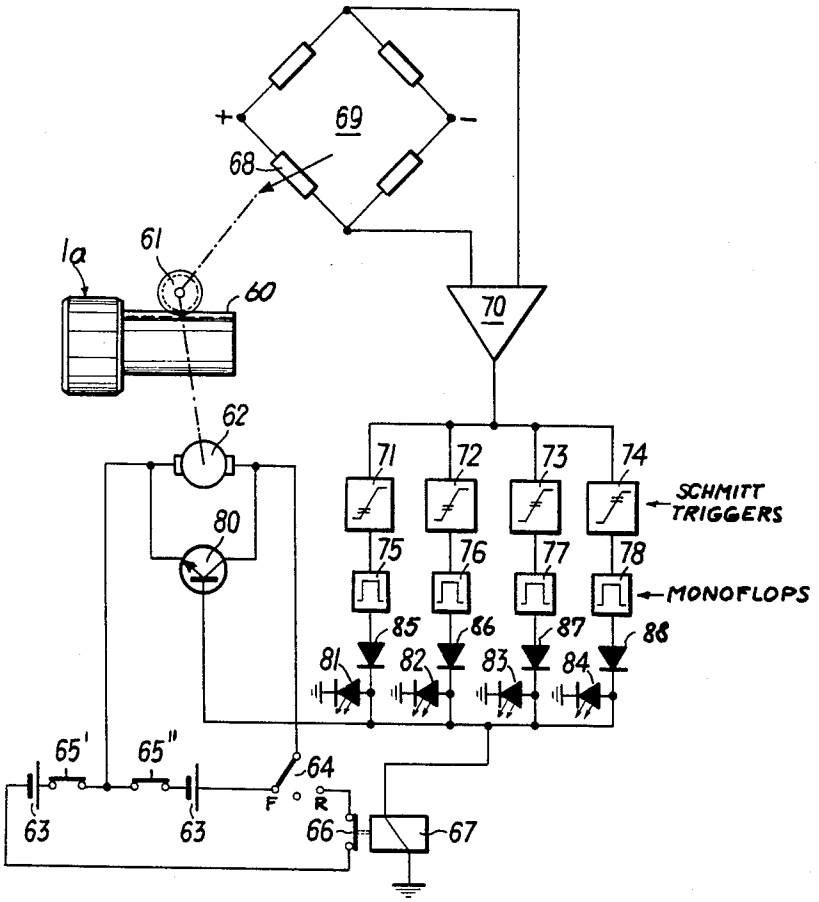
δ1
B
δ2
47
1
45
44
49

FIG.10


69
68
61
1a
60
70
62
71
72
73
74
SCHMITT TRIGGERS
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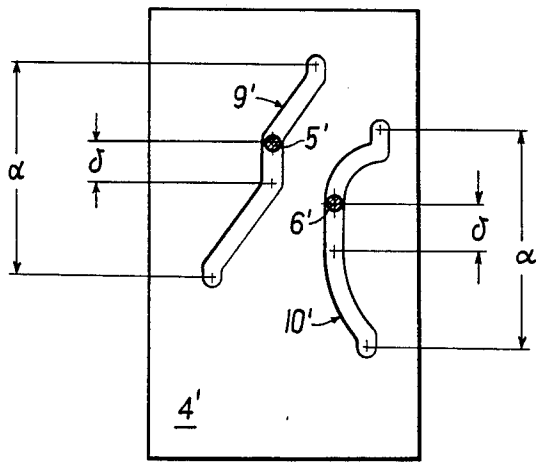
75
76
77
78
MONOFLOPS
85
86
87
88
81
82
83
84
65'
65"
64
F
R
63
63
66
67

FIG.11


9'
5'
α
δ
6'
δ
α
10'
4'

ADJUSTING MECHANISM FOR OPTICAL OBJECTIVE WITH LOST-MOTION ZONE

FIELD OF THE INVENTION

Our present invention relates to a mechanism for adjusting an optical objective, for a camera or a projector, by shifting one or more lens members thereof along its optical axis to vary a parameter such as focusing distance or focal length.

BACKGROUND OF THE INVENTION

In conventional objectives, sharp focusing upon an object to be photographed is carried out by shifting or rotating a control element operatively coupled with a movable lens member whereby the latter is axially displaced. This lens member is often a front component of the objective, or part of such component, especially for focusing at normal distances between infinity and the so-called macro range generally defined as lying between the image-ratio limits of 1:10 and 1:1. To facilitate the taking of close-up pictures in this macro range, especially with a pancratic or varifocal objective having two fixed positive components and two movable negative components, one of these movable components (generally the second one) may be shifted while the other is held stationary; see, for example, commonly owned U.S. Pat. application Ser. No. 747,207 filed Dec. 3, 1976 by Walter Besenmatter et al, now U.S. Pat. No. 4,087,160.

With normal front-lens focusing, the usual distance scale engraved on a lens barrel will provide a sufficiently accurate reading inasmuch as—given a tolerable blur circle in the image plane—the objective will have a depth of field allowing minor positional deviations. With focusing in the macro range by the displacement of a more rearwardly located lens member, however, precise setting of that lens member becomes critical since the position of the object plane changes significantly even upon the slightest shifting of that member. To help the user find the proper setting for the taking of pictures in a predetermined object plane, e.g. for producing titles with an amateur motion-picture camera, it has heretofore been the practice to provide stops or detents (e.g. ball checks) indexing the control element in the correct position. The emplacement of the detent on the objective housing, however, involves unavoidable manufacturing tolerances which are difficult to compensate; such arrangements, therefore, are costly and of limited reliability.

Similar problems arise with conventional devices for indexing the shiftable components of a varifocal objective in a preselected position of focal-length adjustment.

OBJECT OF THE INVENTION

The object of our present invention, therefore, is to provide simple means for establishing a desired focusing or focal-length setting in an effortless manner and with a high degree of optical precision.

SUMMARY OF THE INVENTION

We realize this object, in accordance with our present invention, by operatively coupling one or more shiftable lens members with manual or automatic control means therefor via intermittently effective drive means holding the lens member or members stationary throughout at least one lost-motion zone which extends over a fraction of the range of adjustment of the control means.

There are several ways in which this temporary immobilization of a shiftable lens member can be achieved. One possibility is the physical decoupling of that lens member from its control element as it passes through the lost-motion zone; this, however, may allow the decoupled lens member to change its position spontaneously unless means are provided for holding it in place. Another solution would be the use of a special transmission, such as a crank drive or a Geneva gear. Where the shiftable lens member is displaced by an electric motor, its energizing circuit may be temporarily interrupted in response to a signal from an analog-type or digital position sensor, possibly with intervention of a microprocessor.

A particularly simple and advantageous mechanical solution utilizes a stationary or movable cam carrier, having at least one dwell of zero pitch (i.e., an edge portion parallel to the direction of motion), as part of the intermittently affective drive means. Such a cam carrier may be a slotted or grooved cylinder or plate of the type used in conventional varifocal objectives to shift the two movable components independently of each other. In that instance, the cam carrier according to our invention has a first and a second guide track engaged by respective cam followers rigid with the two movable components, these guide tracks having zero-pitch dwells concurrently engaged by their associated cam followers so that both components are held stationary simultaneously. The zero-pitch dwell of one guide track, generally the one for the first movable component, may be substantially longer than the corresponding dwell of the other guide track in order to define a focusing subrange adjoining a varifocal subrange, the zero-pitch dwell of the other guide track being engaged by its cam follower over only a fraction of that focusing subrange to define the lost-motion zone. In some instances we may provide more than one lost-motion zone in this subrange.

According to another feature of our invention, the arrival of the cam carrier in the lost-motion zone is indicated to the user by special position-sensing means preferably of the tactile type, such a coacting indexing formations on the cam carrier and on an adjoining surface (which could be part of the control element). Since the cam carrier may move relatively to the adjoining surface over considerable distance without changing the objective setting, a precise positioning of these indexing formations is no longer required. By the same token, a change in frictional resistance may signal that the desired focusing position (or focal-length setting) has been reached. Visual or audible indicators may also be used, especially with electromechanical control of the lens shift.

BRIEF DESCRIPTION OF THE DRAWING

The above and other features of our invention will now be described in detail with reference to the accompanying drawing in which:

FIG. 1 diagrammatically shows a varifocal objective, of well-known type, adjustable in conformity with our invention;

FIG. 2 is a cross-sectional view of the objective, drawn to a larger scale and showing a control ring and a camming sleeve included in its adjusting mechanism;

FIG. 3 is a developed view of the camming sleeve and part of the control ring of FIG. 2;

FIG. 4 is a diagrammatic developed view of a modified adjusting mechanism;

FIGS. 5A and 5B are enlarged detail views of part of the mechanism of FIG. 4 in two different positions;

FIG. 6 is a side-elevational view (parts broken away) of a camera objective embodying our invention;

FIG. 7 is a view similar to FIG. 6, showing a modification;

FIG. 8 is an axial sectional view, drawn to a smaller scale, of a front atachment for the objective of FIG. 7;

FIGS. 9A and 9B show different images appearing in a viewfinder of the camera of FIG. 7 in certain operating positions;

FIG. 10 is a circuit diagram of an electromechanical system for adjusting an objective in accordance with our invention; and

FIG. 11 is a developed view of a modified camming sleeve for the objective of FIG. 1.

SPECIFIC DESCRIPTION

In FIG. 1 we have shown a pancratic objective, generally designated 1, with a varifocal front group consisting of four components I–IV, a component V constituted by a reflex prism P, a diaphragm D, and a fixed-focus rear group VI. The image plane of objective 1 is shown at M.

Front component I is axially fixed and positively refracting, consisting of three lens members L1/L2, L3 and L4. Component II is shiftable along optical axis O and consists of two lens members L5, L6/L7 held in a lens mount 2. Component III is a single lens L8 of negative refractivity held in an axially shiftable lens mount 3. Component IV is an axially fixed positively refracting lens L9. Rear group VI is composed of four single lenses L10, L11, L12 and L13.

For adjustment of the focal length, with maintenance of a constant image plane M, components II and III are separately shifted as is well known per se. With lens L8 in the position L'8 illustrated in dotted lines, the objective shown in FIG. 1 is at the wide-angle end of its varifocal range. A shift of lens L8 into the solid-line position focuses the objective onto nearby objects for the taking of close-ups.

Lens mounts 2 and 3 carry cam-follower pins 5 and 6 which, as shown in FIGS. 2 and 3, traverse respective guide slots 9 and 10 of a camming sleeve 4 rigid with the otherwise non-illustrated objective housing or lens barrel. The pins 5 and 6 further engage in respective slots 25 and 26 of a control ring 7, axially fixed but rotatable about axis 0, for entrainment thereby. Manual rotation of ring 7 is facilitated by a knurled periphery 8.

The guide track 9 for component II has a constant-slope section of angular extent α, defining a varifocal subrange, and an adjoining dwell of zero pitch, i.e. a section located in a plane transverse to the optical axis, of angular extent β defining a focusing subrange (at close-up distances). The guide track 10 for component III is of varying slope throughout the entire range $\alpha+\beta$, except for a short zero-pitch dwell of angular extent γ corresponding to a minor fraction of subrange β. Curve section γ defines a lost-motion zone since neither of these components moves during its engagement with pin 6, the other pin 5 simultaneously engaging the transverse section of curve 9. Thus, rotation of control ring 7 through the angle γ does not cause any change in either the focal length or the position of the object plane of objective 1. This situation is indicated to the user by the engagement of a ball check 11 on sleeve 4 in a notch 12 on ring 7; the angular position of the ball check, within an arc of length γ, is not critical since it does not affect the setting of the objective.

Whereas in FIGS. 2 and 3 the cam member 4 is stationary and the lens mounts 2, 3 rotate about axis 0 during adjustment, the reverse arrangement is possible as illustrated in FIG. 4. Here the two lens mounts are traversed by an axially extending guide rod 13, preventing their rotation, and are provided with extensions 14 and 15 carrying pins 16 and 17 engaging in respective slots 18 and 19 of a transversely shiftable cam plate 20. This plate, provided with a knurled control knob 27 to facilitate its displacement, has a pair of parallel guide slots 21 engaged by fixed pins 23 on the objective housing; any play in these slots is eliminated by the pressure of a ball check 22 and of a leaf spring 28 upon a longitudinal edge of plate 20, ball check 22 engaging in a notch of that edge in the illustrated position which represents the transition between varifocal subrange α and focusing subrange β. Plate 20 is also representative of the developed peripheral surface of an annular cam member, similar to ring 7 of FIGS. 2 and 3, centered on axis 0. Curve 19 has two mutually separated zero-pitch dwells at $\gamma 1$ and $\gamma 2$ within section γ.

Although plate 20 could be provided with two further notches engageable by ball check 22 in the two lost-motion positions, i.e., with pin 17 received in the transverse stretch $\gamma 1$ or $\gamma 2$ of curve 19, we have shown in FIGS. 5A and 5B an alternate way of signaling to the user the arrival of component III in a desired focusing position. Thus, either or both slots 21 may be lined with a friction layer 24 in contact with pin 23 anywhere except along stretch $\gamma 1$ or $\gamma 2$, as seen in FIG. 5A; the manual displacement of plate 20 by the user, therefore, encounters a significant resistance. In the two zero-pitch zones the layer 24 is omitted, as seen in FIG. 5B, so that shifting is noticeably easier (albeit ineffectual). The thickness of layer 24 is taken into account in the shaping of curve 19, the additional play being eliminated by the biasing elements 22 and 28; the precise locations of the gaps of layer 24, however, are not critical for the reason already explained.

In FIG. 6 we have shown a motion-picture camera equipped with a lens-adjusting mechanism according to our invention. The camera body, partly illustrated at 30, carries a lens housing with a rotatable front ring 31 which accommodates an attachment 32 comprising a dispersive lens 33 positionable in front of the varifocal objective 1. A camming sleeve 34 has grooves 38', 38'', with zero-pitch dwells again indicated at γ, engaged by respective follower pins 37', 37'' which are entrainable by horizontal slots in a non-illustrated extension of ring 31. A nonrotatable blocking sleeve 36 is axially slidable on camming sleeve 34 and has a ledge 36*a* which normally is held by a spring 39 against a fixed portion 31*a* of the lens housing, overlying the section γ of curve 38'' and preventing the displacement of the shiftable lens members into the lost-motion zone defined by that section within the focusing subrange β (cf. FIG. 3). A push rod 35 rigid with a lug 36*b* of sleeve 36, engaged by spring 39, projects in that normal position beyond front ring 31 so as to be repressible into its illustrated position by the attachment 32 upon emplacement thereof in line with objective 1. Lens 33 forms a virtual intermediate image of an object in a plane located forwardly (i.e., to the left) of that lens, e.g. in its focal plane if the object is situated at infinity. For an extreme wide-angle or panoramic effect, therefore, the objective 1 can be fo-

cused in its lost-motion position on that forward plane after section γ of curve 38'' has been uncovered by repression of the rod 35 which acts as a feeler for the presence of attachment 32.

FIG. 7 shows a similar arrangement in which, however, the interplay of a front attachment with a focusing control is reversed in that an emplacement of the attachment is possible only after a selector has been preset to permit focusing upon a predetermined object distance at close range. A slider 40, shiftable in a slot 48 of camera body 30, is connected by a linkage 41 with an axially displaceable blocking sleeve 42 having two axially and angularly staggered ledges 46 and 47. In a slider position designated NORMAL, designed for the taking of pictures beyond the macro range, ledge 46 cuts across cam groove 19 (here shown inverted with reference to FIG. 4) just above its dwell γ1 so as to allow focusing in only a part of the macro range. In another slider position, designated TITLE, ledge 46 unblocks the dwell γ1 yet ledge 47 still inhibits the shifting of the movable lens members into the position defined by dwell γ2. The latter position can be attained upon moving the slider 40 into a third position, designated PANORAMA, in which sleeve 42 is fully withdrawn from the path of a cam-follower pin 43 traversing the groove 19. A push rod 45, rigid with a lug 44 of sleeve 42, normally projects beyond front ring 31 so as to prevent the emplacement of any attachment thereon.

Besides the panoramic-lens attachment 32, shown emplaced in FIG. 7, another attachment 50 illustrated in FIG. 8 can be used with this camera. A comparison of the two attachments 32 and 50 (the latter being drawn to a much smaller scale) will show that attachment 50 has an axially extending neck 50*a* whose length substantially exceeds that of a corresponding neck 32*a* of attachment 32. Attachment 50, holding a title carrier 50*b*, can therefore be fitted into front ring 31 in the intermediate position of slider 40 in which the rod 45 projects farther to the left than in the extreme right-hand position of the slider, illustrated in FIG. 7. Thus, the intermediate slider position allows the filming of titles upon entrainment of pin 43 (by rotation of control ring 31) to dwell γ1 whereas the right-hand position permits the taking of panoramic views, with the aid of lens 33, upon further entrainment of the cam follower to dwell γ2.

The position of slider 40 can also be indicated directly to the user by a coupling of linkage 41 with a shutter 51, FIGS. 9A and 9B, located in the light path of a viewfinder of the camera 30. In the intermediate slider position, as shown in FIG. 9A, the shutter obstructs a legend reading PANORAMA but uncovers another legend reading TITLE. In the right-hand slider position, as shown in FIG. 9B, the reverse is the case. In the left-hand slider position labeled NORMAL in FIG. 7, both legends are obscured. The shutter 51 could be mechanically operated but might also be represented by a pair of electro-optical light-control elements such as Kerr cells.

We shall now describe, with reference to FIG. 10, an electromechanical system for establishing a number of lost-motion zones in a range of displacement of an axially shiftable lens mount 1*a* for a component of a focusable objective, e.g. its front member. Lens mount 1*a* is here shown provided with an extension which bears a rack 60 meshing with a pinion 61, the latter being coupled with a reversible electric motor 62 whose energizing circuit includes a pair of batteries 63, two limit switches 65', 65'', a reversing switch 64 and a break contact 66 of a relay 67. A resistance bridge 69 has one arm formed by a potentiometer 68 whose slider is coupled with pinion 61. One bridge diagonal is connected across power supply 63 whereas its other diagonal is connected across the inputs of a differential amplifier 70. From a balanced or nearly balanced state in one limiting position of lens mount 1*a*, bridge 69 is progressively unbalanced upon a shifting of the lens mount to the other end of the adjustment range so as to develop progressively higher voltages in the output of amplifier 70.

Four threshold circuits 71–74, such as Schmitt triggers, are connected in parallel across this amplifier output and work into respective one-shot pulse generators, such as monoflops, 75–78. These trigger stages are connected in parallel, via respective diodes 85–88, to the winding of relay 67 as well as to the base of a transistor 80 shunting the motor 62. Each monoflop, when in its off-normal condition, also energizes a respective visual indicator such as a light-emitting diode 81–84.

With switch 64 in either of its two operative positions, i.e., "forward" (F) or "reverse" (R), motor 62 drives the pinion 61 to change the position of the object plane of the objective within its macro range. At a first predetermined point in that range, the output voltage of amplifier 70 is sufficient to trip the Schmitt trigger 71 whereupon monoflop 75 generates a pulse which actuates the relay 67 to break the motor circuit; the simultaneous saturation of shunt transistor 80 effectively cuts off the motor 62 (and could also operate a nonillustrated brake). The duration of this pulse is long enough to allow the user to open the switch 64 if the system is to remain in that position for an extended period.

In an analogous manner, trigger stages 72, 73 and 74 successively go into action upon the attainment of progressively higher voltage thresholds by the output of amplifier 70. The particular threshold, and therefore the specific stop position, is inidicated to the user by the respective LED 81–84 which could be positioned in line with the viewfinder of the camera. Audible signals could also be produced, if desired, by sound generators in the outputs of monoflaps 75–78. The interruption of the lens shift, taking place while control switch 64 is held closed, may be considered a lost-motion operation.

The four stop positions established by trigger stages 71–74 could be so chosen that the first two lie in the macro range (e.g. at locations defined by the dwell γ1 and γ2 of FIGS. 4 and 7), the third one lies in an intermediate range (e.g. at a distance suitable for snapshots) and the fourth markings focusing at infinity. Furthermore, pinion 61 could be coupled with a control element such as ring 7 (FIGS. 2 and 3) or plate 30 (FIG. 4) to provide varifocal adjustment, as described above, with or without focusing control in the macro range. Also, a digital mode can be substituted for the analog mode of operation described above, with the use of a stepping motor to drive the pinion 61 and with replacement of Schmitt triggers 71–74 by binary pulse counters stepped by the source of driving pulses for that motor. In either instance the stop positions may be preprogrammed with the aid of servo drives for the establishment of selected voltage thresholds or pulse counts.

In FIG. 11 we have illustrated a modified camming member 4' (either a sleeve or a plate) with curves 9' and 10' engaged by respective cam-follower pins 5' and 6', these curves having zero-pitch dwells δ in an intermediate section of varifocal range α. The lost-motion zone defined by these dwells δ may represent a middle posi-

tion of the varifocal group I–IV (FIG. 1) in which the magnification ratio of that group has a value of unity.

The front component I (or its first lens member LI/L2) of a varifocal objective 1 as shown in FIG. 1, whose negative components are shiftable by means of cam drives as described with reference to FIGS. 1–7 and 11, could be conventionally adjustable for focusing at normal range. Such cam drives, however, could also be used (like the electromechanical drive system of FIG. 10) for the intermittent shifting of a front lens or component with stop positions indexed by lost-motion zones.

The position-feeling or emplacement-blocking mechanism of FIGS. 6 and 7 is not part of our invention, except in combination with attachments 32 and 50; such a mechanism has been disclosed and claimed in application Ser. No. 711,835 filed Aug. 5, 1976 by Kurt Bohm et al. and assigned to a company affiliated with the assignee of our present application, now U.S. Pat. No. 4,110,005.

We claim:

1. An optical system comprising:

a varifocal objective including lens means axially shiftable over a predetermined range of displacement including a first subrange for varying the focal length of the objective and a second subrange for varying the position of an object plane thereof;

control means adjustable over a predetermined operating range corresponding to said range of displacement; and

drive means operatively linking said control means with said lens means, said drive means positively connecting said control means with said lens means throughout said operating range except for at least one lost-motion zone coinciding with a predetermined position of said lens means in said second subrange in which said object plane lies at a certain close distance from the objective.

2. The system defined in claim 1 wherein said shiftable lens means comprises a first and a second component respectively displaceable by separate portions of said drive means, said portions being operative to immobilize said first component throughout said second subrange during axial shifting of said lost-motion zone.

3. The system defined in claim 1, further comprising position-sensing means coupled with said control means for indicating the arrival thereof at said lost-motion zone.

4. The system defined in claim 1 wherein said intermittently effective drive means comprises a cam carrier having at least one dwell of zero pitch.

5. The system defined in claim 4 wherein said shiftable lens means comprises a first and a second component, said cam carrier forming a first and a second guide track engaged by respective cam followers on said first and second components, said guide tracks having zero-pitch dwells concurrently engaged by their respective cam followers.

6. The system defined in claim 5 wherein the zero-pitch dwell of said first guide track defines a focusing subrange of said operating range corresponding to said second subrange and adjoining a varifocal subrange of said operating range corresponding to said first subrange, the zero-pitch dwell of said second guide track being engaged by its cam follower over only a fraction of said focusing subrange.

7. The system defined in claim 6 wherein the objective is part of a camera provided with an attachment positionable in front of said objective for the taking of pictures in a position of engagement of said cam followers with said zero-pitch dwells.

8. The system defined in claim 7 wherein the camera is provided with inhibiting means normally blocking a displacement of said control means into said focusing subrange, said inhibiting means being deactivable by said attachment upon emplacement thereof on said camera.

9. The system defined in claim 7 wherein the camera is provided with selector means for optionally blocking and unblocking a displacement of said control means into said focusing subrange, said selector means having an extension preventing the emplacement of said attachment on said camera in a blocking position.

10. The system defined in claim 9 wherein said second guide track has two zero-pitch dwells in a first and a second part of said focusing subrange, the camera being provided with a second attachment emplaceable thereon in said second part of said focusing subrange, said selector means having an intermediate position blocking access to only said second part of said focusing subrange while preventing emplacement of said second attachment only.

11. The system defined in claim 4, further comprising position-sensing means on said cam carrier and on an adjoining surface for indicating the arrival of said control means in said lost-motion zone.

12. The system defined in claim 11 wherein said position-sensing means comprises a pair of indexing formations on said cam carrier and on said adjoining surface.

13. The system defined in claim 11 wherein said position-sensing means comprises a pair of mating formations on said cam carrier and on said adjoining surface, one of said formations being a guide slot, the other of said formations being a projection received in said guide slot, the latter being provided with a friction layer engageable by said projection, said friction layer being omitted at a location corresponding to said lost-motion zone.

14. In an optical objective provided with axially shiftable lens means and with control means for varying an optical parameter of the objective, said control means being operatively coupled with said shiftable lens means for axially displacing same within a predetermined adjustment range,

the improvement wherein the coupling between said control means and said shiftable lens means comprises intermittently effective drive means holding said shiftable lens means stationary throughout at least one lost-motion zone extending over a fraction of said adjustment range, said drive means including a cam carrier having at least one dwell of zero pitch,

further comprising position-sensing means on said cam carrier and on an adjoining surface for indicating the arrival of said control means in said lost-motion zone, said position-sensing means including a pair of mating formations on said cam carrier and on said adjoining surface, one of said formations being a guide slot, the other of said formations being a projection received in said guide slot, the latter being provided with a friction layer engageable by said projection, said friction layer being omitted at a location corresponding to said lost-motion zone.

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Dec. 4, 1979

[54] **OPHTHALMOSCOPIC SYSTEM WITH A WIDE ANGLE OBJECTIVE LENS**

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[73] Assignee: **Canon Kabushiki Kaisha**, Tokyo, Japan

[21] Appl. No.: **797,636**

[22] Filed: **May 17, 1977**

[30] **Foreign Application Priority Data**

May 19, 1976 [JP] Japan 51-57466

[51] **Int. Cl.**[2] **A61B 3/14**

[52] **U.S. Cl.** **351/7**; 350/189; 351/16; 354/62

[58] **Field of Search** 351/7, 6, 16; 350/189; 354/62

[56] **References Cited**

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Primary Examiner—Paul A. Sacher
Attorney, Agent, or Firm—Toren, McGeady and Stanger

[57] **ABSTRACT**

The wide angle ophthalmoscopic system disclosed includes an objective lens group having a forward direction toward an eye to be examined and having at least one meniscus lens and a positive lens. The meniscus lens includes a front concave forward surface and constitutes substantially an aplanatic lens having an aplanatic point to be situated in the front part of an eye to be examined. A converging lens group in the system is positioned behind the objective lens group. An illuminating system has at least one light source and light transmitting arrangement for directing light in the forward direction. An observing optical system is optically aligned with the objective lens group for transmitting images formed by the objective lens group.

11 Claims, 10 Drawing Figures

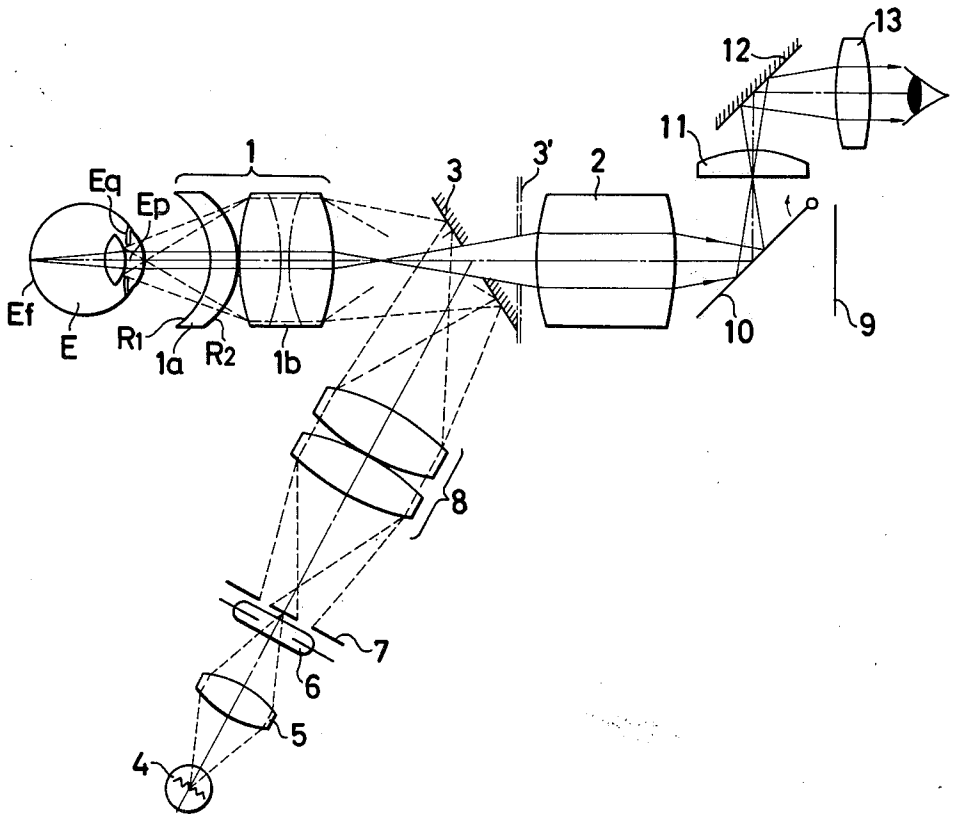


FIG.3

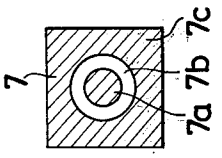


FIG.2

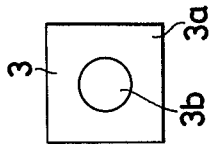


FIG.1

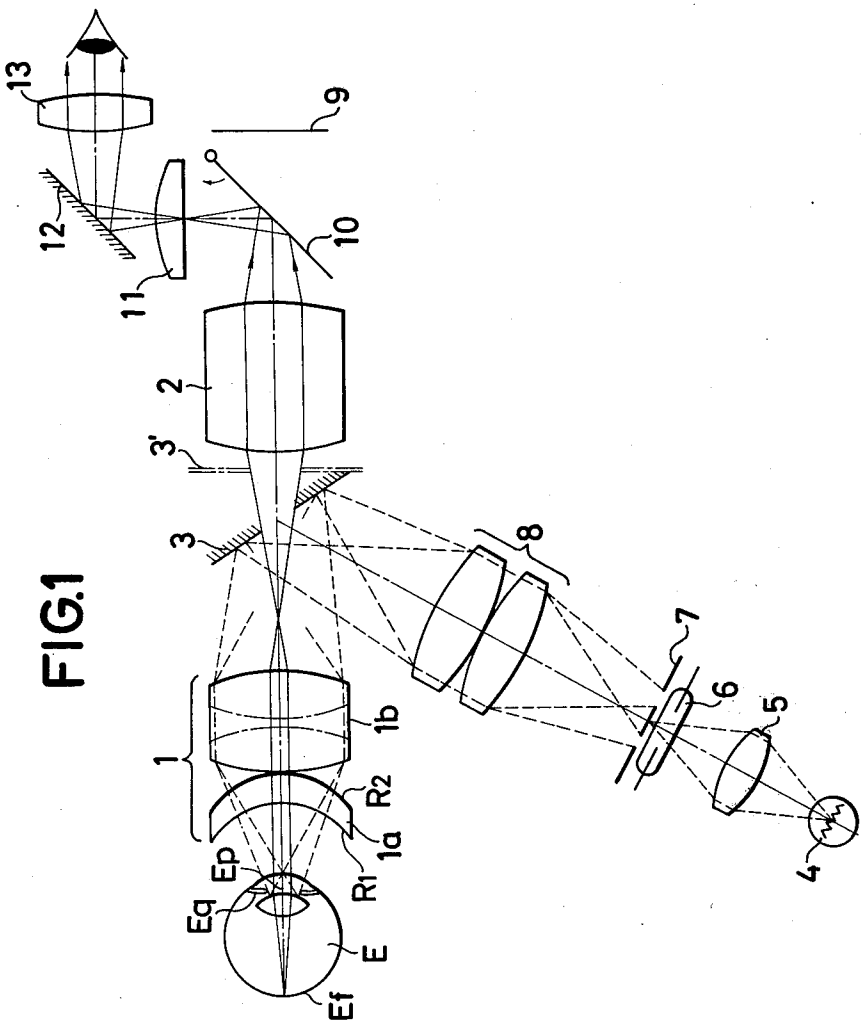


FIG.4

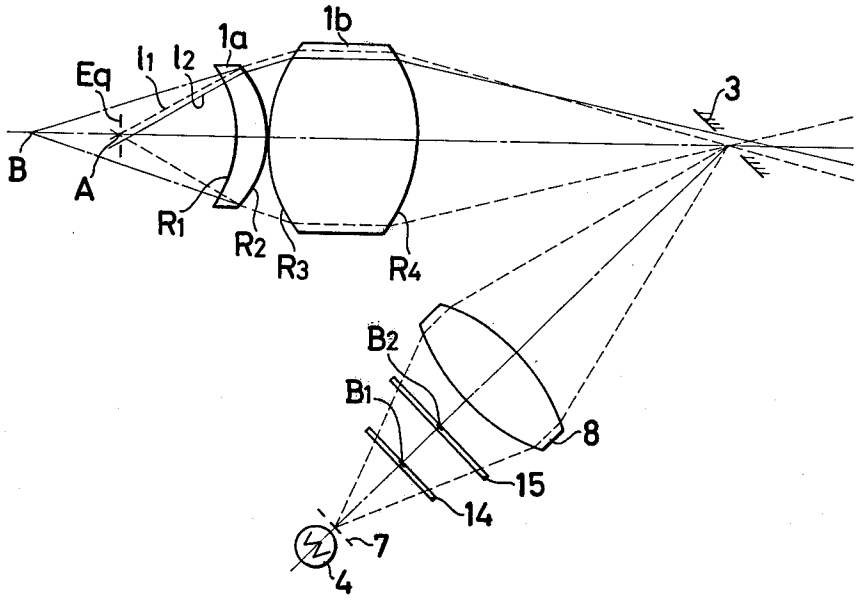


FIG.5

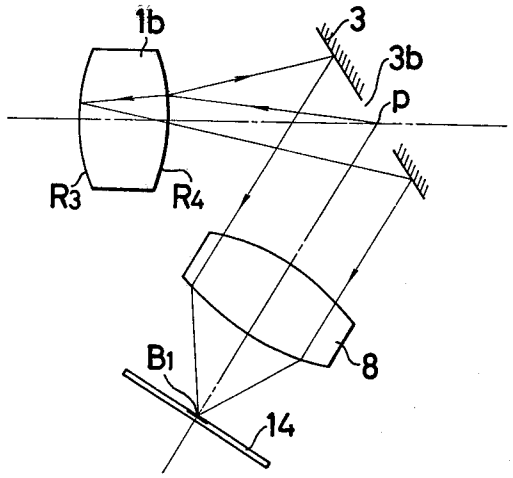


FIG.6

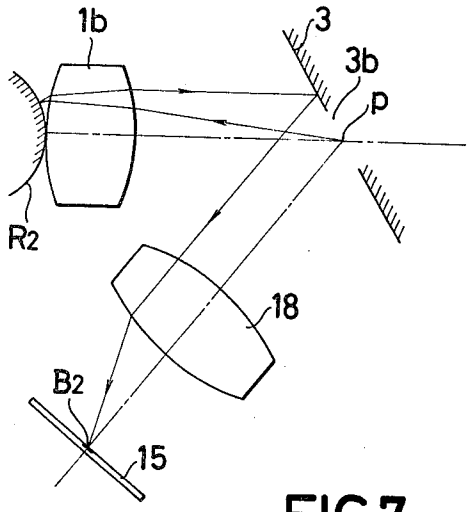


FIG.7

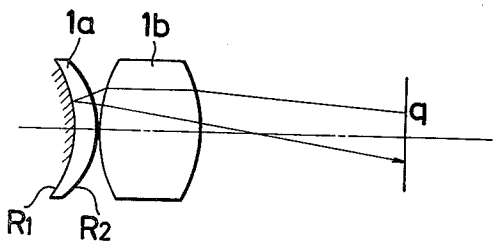


FIG.8

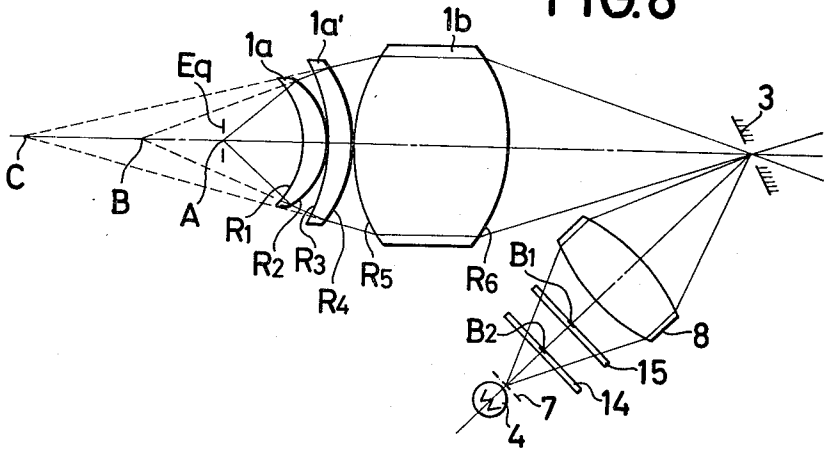


FIG.9

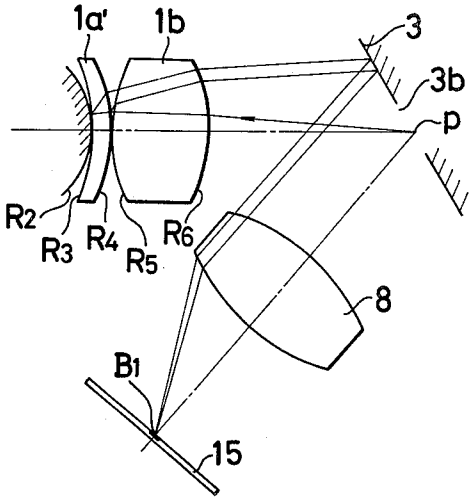
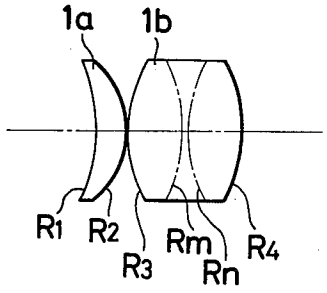


FIG.10



OPHTHALMOSCOPIC SYSTEM WITH A WIDE ANGLE OBJECTIVE LENS

BACKGROUND OF THE INVENTION

This invention relates to ophthalmoscopes and ophthalmoscopic cameras, and more particularly to improvements of an objective lens for use in such ophthalmoscope or ophthalmoscopic camera.

Most of the ophthalmoscopic cameras which have found wide acceptance are designed to have an objective lens comprised of a positive meniscus lens convex toward an eye to be examined with limitation of its view angle to about 30 degrees. To increase the image angle up to about 45 degrees, it is known to make use of a biconvex lens as the objective lens. It has also been proposed by the present applicant to construct the objective lens from a positive meniscus lens concave toward an eye to be examined and a positive meniscus lens concave toward an image thereof as described in U.S. Pat. No. 3,914,032.

With the objective lens having an increased view angle, it is desired to reduce astigmatism. Incorporation of an apertured mirror as arranged between the objective lens and an image forming lens to reflect the illuminating light rays from a light source in the direction of the optical axis of the eye leads to a further requirement of increasing the relative aperture of the objective lens, while still minimizing spherical aberration and coma thereof. As the objective lens is positioned in the path of the illuminating light rays, there is some possibility of producing disturbing light reflection due to the light rays reflected from the surfaces of the objective lens to the film plane.

SUMMARY OF THE INVENTION

The present invention has for its general object to provide an ophthalmoscopic system with an objective lens having an increased angle of view without causing production of unduly large aberrations. Whilst the conventional objective lens described in U.S. Pat. No. 3,914,032 has an angle of view not exceeding 45 degrees, two specific embodiments of the present invention to be described later are to provide for view angles of 60 degrees and 80 degrees. According to the present invention, the achievement of such a large increase in the angle of view is realized by designing at least one positive meniscus lens element of concavity toward an eye to be examined in the objective lens to aplanatic configuration, or likewise configuration to an aplanatic lens element. In this connection, it should be noted that the positive meniscus lens shown in U.S. Pat. No. 3,914,032 is designed not so much complicated but to the simple positive meniscus lens configuration known in the art.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic sectional view of one embodiment of an ophthalmoscopic system according to the present invention.

FIGS. **2** and **3** are plan views of an apertured illuminating mirror and a ring-shaped diaphragm usable in the system of FIG. **1**.

FIG. **4** is a fragmentary sectional view of the system of FIG. **1**.

FIG. **5** is a diagram of geometry considered in defining the location of a black spot for freedom from disturbing light reflections according to the prior art.

FIGS. **6** and **7** are similar views showing a method of eliminating the disturbing light reflections from the objective lens according to the present invention.

FIG. **8** is a fragmentary schematic sectional view of another embodiment of an ophthalmoscopic system according to the present invention.

FIG. **9** is a diagram of geometry considered in defining the location of a black spot for freedom from disturbing light reflections from the objective lens of FIG. **8**.

FIG. **10** is a block diagram of the objective lens of the present invention in which the biconvex lens comprises a plurality of elements cemented together.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to FIGS. **1** to **7** and first to FIG. **1**, there is shown one embodiment of an ophthalmoscopic system according to the present invention including an objective lens group **1** and an image-forming lens group **2** aligned along a common optical axis of an eye E so that an image of the ocular fundus Ef to be examined is either to be formed at a film plane **9** with a tiltable mirror **10** set in its non-viewing position, or to be viewed through a field lens **11**, a reflection mirror **12** and an eye-piece **13**, as the tiltable mirror **10** is set in the illustrated position.

Positioned in an air space between the objective lens group **1** and the image-forming lens group **2** is an illuminating mirror **3** inclined to the optical axis of the eye E and reflecting the illuminating light rays from an illuminating optical arrangement in the direction of the optical axis of the eye E. The illuminating mirror **3** contains a central aperture **3***b* for the passage of image forming rays, in known manner as shown in FIG. **2**, with the remaining area **3***a* being fully mirrored. The illuminating optical arrangement is disposed with its optical axis declined from the optical axis of the eye E and comprises a tungsten lamp **4** as a first light source extending transversely to the optical axis, a condenser lens **5**, a strobotube **6** as a second light source extending transversely to the optical axis, a ring-shaped diaphragm **7** positioned adjacent the strobotube **6** and in conjugate relation to the first light source or tungsten lamp **4** with respect to the condenser lens **5**, and a relay lens **8** arranged so that the ring-shaped diaphragm **7** is conjugate to the apertured illuminating mirror **3** with respect to the relay lens **8**. The details of the ring-shaped diaphragm are shown in FIG. **3**, wherein a central obscuring diaphragm element **7***a* and an apertured diaphragm element **7***c* are concentrically disposed on a single transparent substrate not shown with the resulting opening being of a ring-shape so that an outer annular zone of a pupil Ep of an iris Eq in the eye E is illuminated, as the apertured mirror **3** is almost conjugate to the pupil Ep with respect to the objective lens group **1**. Although the apertured mirror **3** serves as a diaphragm for the image forming rays, a diaphragm may be used as located at **3'**.

The objective lens group **1** comprises a positive meniscus lens **1***a* concave toward the eye E and a biconvex lens **1***b* which may be in the form of a singlet but preferably of a cemented triplet of achromatism. The image-forming lens group **2** comprises a plurality of singlets. According to the present invention, while the front surface R_1 of the positive meniscus lens **1***a* is a spherical

surface with its center of curvature being coincident with the center A of the pupil Ep (see FIG. 4), the rear surface R_2 is configured to an aplanatic surface relative to the center A of the pupil Ep. Letting S denote the axial separation between the pupil center A and a point at which the surface R_2 intersects the optical axis, and S' the axial separation between that point and an aplanatically conjugate point which is designated by B in FIG. 4, then we have $S'/S=n$, wherein n is the index of refraction of the material from which the positive meniscus lens is made. With this lens configuration, there is no spherical aberration and no coma from the front and rear surfaces R_1 and R_2 and also no astigmatism from the rear surface R_2, provided that the object point is located in coincidence with the pupil center A. To facilitate aberrational correction in the extended range of view angles, it is preferred that the rear surface R_4 of the biconvex lens **1***b* is made aspherical as known in the art. For a further increase in the view angle, the both surfaces of the biconvex lens **1***b* are formed to aspherical surfaces.

Another advantage deriving from the employment of the aplanatic lens **1***a* is that, as a ray of light l_1 emanating from the pupil center A is not subjected to refraction at the front surface R_1 and is refracted by the rear surface R_2 as if it emanate from the aplanatically conjugate point B, the angle of inclination of the incident light ray on the front surface R_3 of the biconvex lens can be gradually decreased.

As the objective lens group constitutes part of a photographic optical system with its diaphragm coinciding with the iris Eq, a light ray l_1 passing through the opening of the iris Eq at the center thereof becomes a principal light ray. And a bundle of light rays including ones l_1 and l_2 as marginal rays contributes as a part to the image forming rays which are projected by (image-forming) lens the group **2** onto the film plane **9**. In this case, the front surface R_1 does not produce any coma and astigmatism, because the diaphragm is located at the center of curvature of the front surface R_1. It will be understood from the above that a large increase in the view angle of the ophthalmoscopic system can be achieved by designing the positive meniscus lens **1***a* in the form of an aplanatic lens, or likewise lens having a similar function to that of the aplanatic lens, while nevertheless preserving a high level of aberrational correction over the extended range of view angles.

A specific example of the objective lens group having only one positive meniscus lens as shown in FIG. 4 with a view angle of 60 degrees may be constructed in accordance with the numerical data given in Table 1 below. In the table, the radii of curvature, R, and the axial thicknesses and separations, D, numbered consecutively from front to rear are given along with the corresponding indices of refraction for the spectral D line of sodium and the Abbe numbers for the various lens elements. The minum values of the radii, R, indicate surfaces concave toward front.

Table 1

f = 100 (mm)	2ω = 60° (view angle) F 1 : 1		
R_1 = −96.05			
	D_1 = 24.01	Nd = 1.617	Vd = 62.8
R_2 = −74.19			
	D_2 = 0.1		
R_3 = 124.87			
	D_3 = 124.87	Nd = 1.617	Vd = 62.8
R_4 = −124.87	(aspherical)		

As the objective lens group **1** is illuminated, some of the illuminating light rays are reflected from the lens surfaces in the group **1** to the central hole **3***b* of the illuminating mirror **3** which must be kept free from disturbing incident light as the hole **3***b* serves for the passage of image forming rays. It is known to eliminate disturbing light reflections on the surfaces R_3 and R_4 of the biconvex lens element in the group **1** by making use of a black spot B_1 arranged at a point between the light source and the relay lens **8** coaxially on the optical axis of the illuminating optical arrangement as shown in FIG. **5**. This is also disclosed in U.S. Patent application Ser. No. 658,874 now U.S. Pat. No. 4,098,549 assigned to the assignee of the present invention. The location and size of the black spot B_1 are defined as follows. A light ray emerging from a point P on the plane of the illuminating mirror **3** in the area of the hole **3***b* is either reflected from, or refracted by the rear surface R_4 of the biconvex lens **1***b* to the mirror **3**, or to the front surface R_3 respectively. The reflected ray from the mirror **3** is converged by the relay lens **8**, while the refracted ray after successive reflections from the front surface R_3 and from the mirror **3** is also converged by the same relay lens **8**. The convergence points for the reflected and refracted rays can be brought into coincidence with each other by suitable selection of the radii of curvature of the front and rear surfaces R_3 and R_4 and the axial thickness of the lens **1***b*. In practice, the black spot B_1 may be formed on a transparent plate **14**.

FIG. **6** shows a method of determining the location and size of an additional black spot B_2 for eliminating disturbing light reflections on the rear surface R_2 of the positive meniscus lens **1***a*. In this case, the black spot B_2 is conjugate to the hole **3***b* of the illuminating mirror **3** with respect to a particular optical arrangement consisting of the aplanatic surface R_2, the biconvex lens **1***b*, the reflecting surface **3***a* of the illuminating mirror **3** and the relay lens **8**, as an ideal light ray emerging from the point P is passed through the biconvex lens **1***b* to the aplanatic surface R_2, then reflected therefrom to the biconvex lens **1***b*, then goes after passage therethrough to the mirror surface **3***a* and is then reflected therefrom to the relay lens **8** by which it is converged to the black spot B_2 formed on a transparent plate **15**.

In the case of disturbing light reflections on the front surface R_1 of the positive meniscus lens **1***a*, there is no possibility of its entrance into the hole **3***b* of the illuminating mirror **3**, because, as has been explained in connection with FIGS. **1** and **2**, the center of curvature of the front surface R_1 coincides with the center of the eye-pupil, and the rear surface R_2 is made aplanatic for freedom from aberrations even at wide angles of view. When the front surface R_1 is regarded as a mirror surface, therefore, an ideal light ray emerging from an optional point, q, on the mirror **3** which is conjugate to the eye-pupil is converged to a point symmetrical to the point, q, with respect to the optical axis, as shown in FIG. **7**.

According to the present invention, therefore, the two black spots B_1 and B_2 on the respective transparent plates **14** and **15** are employed as arranged in an air space between the light source **4** and the relay lens **8** and extending transversely to the optical axis of the illuminating optical arrangement as shown in FIG. **4** for the purpose of eliminating disturbing light reflections on the objective lens group **1**.

FIG. **8** shows another embodiment of the present invention in which two positive meniscus lenses **1***a* and

1a' are employed as arranged nearer an eye to be examined than a biconvex lens 1b. These two positive meniscus lenses 1a and 1a' are so configured that the front surface R_1 of the front positive meniscus lens 1a has a center of curvature coincident with the center A of an eye-pupil, and the rear surface R_2 is aplanatic with its aplanatically conjugate point at B, and that the front surface R_3 of the second positive meniscus lens 1a' has a center of curvature coincident with the point B, and the rear surface R_4 is aplanatic with an aplanatically conjugate point to the point B being at C. In other words, the first and second positive meniscus lenses 1a and 1a' form an aplanatic broken-contact doublet to the center of the eye-pupil, so that there is no spherical aberration and no coma for the object point at the pupil center A. Further, the surfaces R_2 and R_4 produce no astigmatism. When this objective lens is used for photography, the surfaces R_1 and R_3 produce no coma and no astigmatism provided that the iris position corresponds to the diaphragm position.

A specific example of the objective lens corresponding to that shown in FIG. 8 may be constructed in accordance with the numerical data given in Table 2 below. The various symbols in the table have the meanings described in connection with Table 1.

Table 2

f = 100 (mm)	2ω = 80°	F 1 : 0.78	
R_1 = −83.54			
	D_1 = 22.28	Nd = 1.617	Vd = 62.8
R_2 = −65.39			
	D_2 = 0.1		
R_3 = −171.39			
	D_3 = 22.28	Nd = 1.617	Vd = 62.8
R_4 = −119.67			
	D_4 = 0.1		
R_5 = 150.38			
	D_5 = 150.38	Nd = 1.617	Vd = 62.8
R_6 = −150.38	(aspherical)		

The disturbing light reflections on the objective lens of FIG. 8 are also possible with two black spotted plates 14 and 15. In other words, those on the surfaces R_5 and R_6 of the biconvex lens 1b are eliminated by the method shown in FIG. 5, and those on the front surfaces R_1 and R_3 of the first and second positive meniscus lenses 1a and 1a' are removed for the reasons explained in connection with FIG. 7. The elimination of those on the rear surfaces R_2 and R_4 will next be explained by reference to FIG. 9.

For the surface R_4, situation is similar to that shown in FIG. 6. On the other hand, a light ray coming from the point P through the biconvex lens 1b and the second positive meniscus lens 1a' is reflected from the surface R_2 and therefrom directed through the second positive meniscus lens 1a' and the biconvex lens 1b to the mirror 3 by which it is reflected to the relay lens, finally reaching a convergence point. This point can be brought into coincidence with that for the surface R_4 at the black spot B_1 by suitable selection of either the axial thickness of the second positive meniscus lens 1a', or the axial air separation between the surfaces R_2 and R_3, or between the surfaces R_4 and R_5. The size of the black spot B_1 is dependent upon an image of the hole 3b formed on the plate 15 by a particular optical system between the illuminating mirror 3 and the black spotted plate 15 in the path of disturbing incident light. As a single black spot is adopted for elimination of reflexes from two separate reflecting surfaces, it is of course required that a larger size of black spot be selected from two different ones.

If the biconvex lens 1b is constructed in the form of a cemented triplet as shown in FIG. 10, disturbing light reflections on the cemented surfaces Rm and Rn must be taken into account. In this case, those on the surface Rm is simultaneously eliminated with those on the surface R_2 in a manner similar to that shown in connection with the surfaces R_3 and R_4 of FIG. 9. The surface Rn may be designed in relation to the surfaces R_3 and R_4 for elimination of reflection. The number of black spots necessary to eliminate disturbing light reflections is equal to that of the lens surfaces in the objective lens group 1 with exclusion of those shown in FIG. 7. As has been noted above, however, this number can be largely reduced not only by suitable selection of the lens thicknesses and/or axial air separations, but also by adjusting the size of each black spot to a somewhat larger level than the theoretical one.

It will be seen from the foregoing that the present invention provides an ophthalmoscopic system with a remarkably increased angle of view without causing production of unduly large aberrations over the extended view angle range. The positive lens located on the image side of the aplanatic lens is formed to biconvex configuration, thereby giving an additional advantage of increasing design flexibility for power distribution and aberrational correction, as both of the entrance and exit surfaces of the eye convex lens act in converging manner. A furthermore advantage of the invention is to facilitate elimination of disturbing light reflections.

What is claimed is:

1. An ophthalmoscopic system provided with a wide angle objective lens comprising;
   - an objective lens group opposed to a human eye and including at least one meniscus lens and positive lens, and said meniscus lens having a front surface concave to the human eye and being substantially an aplanatic lens having an aplanatic point, the aplanatic point being situated in the front part of the human eye;
   - a converging lens group positioned in rear of said objective lens group;
   - an illuminating system having at least one light source and light transmitting means, and the light emergent section of this system being directed toward the human eye; and
   - an observing optical system having said objective lens group and image transmitting means.

2. An ophthalmoscopic system as described in claim 1, wherein said objective lens group consists of a positive meniscus lens and a biconvex lens.

3. An ophthalmoscopic system as described in claim 1, wherein said objective lens group consists of two positive meniscus lenses and a biconvex lens.

4. An ophthalmoscopic system as described in claim 1, wherein said light transmitting means has reflecting means and a plurality of lenses, and said reflecting means is positioned between the human eye and said converging lens group.

5. An ophthalmoscopic system as described in claim 1, wherein said light transmitting means has a mirror and lens means, an aperture stop is arranged between the reflecting plane of the mirror and said converging lens group, and a light obscuring spot is arranged in conjugate relation to the aperture of said stop with respect to said positive lens, the aplanatic surface serv-

ing as a mirror surface, said positive lens, said reflecting plane and lens means.

6. An ophthalmoscopic system provided with a wide angle objective lens comprising;

at least one positive aplanatic meniscus lens concave to a human eye, a biconvex lens arranged adjacent and in rear of said positive meniscus lens, followed by an image forming lens group, and followed by a photographic film;

an apertured mirror arranged between said biconvex lens and said image forming group;

a relay lens and a light-impermeable spot between a photographic light source and the apertured mirror, said light-impermeable spot and the aperture opening of said apertured mirror as well as said biconvex lens being conjugate in respect of the rear surface of said positive aplanatic meniscus lens with said biconvex lens and the mirror portion of said apertured mirror and said relay lens.

7. A wide angle opthalmoscopic system for examining an eye comprising:

an objective lens group having a forward direction toward an eye to be examined, said group having at least one meniscus lens and a positive lens, said meniscus lens having a front concave forward surface, said meniscus lens being substantially an aplanatic lens having an aplanatic point to be situated in the front part of an eye to be examined;

a converging lens group positioned behind said objective lens group;

an illuminating system having at least one light source and light transmitting means for directing light in the forward direction; and

an observing optical system optically aligned with said objective lens group for transmitting images formed by said objective lens group.

8. A system as in claim 7, wherein said objective lens group consists of a positive meniscus lens and a biconvex lens.

9. A system as in claim 7, wherein said objective lens group consists of two positive meniscus lenses and a biconvex lens.

10. A system as in claim 7, wherein said light transmitting means includes reflecting means and a plurality of lenses, said reflecting means being positioned between the converging lens group and the objective lens group.

11. A system as in claim 7, wherein said light transmitting means has lens means and a mirror with a reflecting plane, an aperture stop between the reflecting plane of the mirror and said converging lens group, and a light obscuring spot in conjugate relation to the aperture of said stop with respect to said positive lens, said aplanatic surface serving as a mirror surface, said positive lens, said reflecting plane and said lens means.

* * * * *

OR 4,176,914

United Stat
Fujibayashi

1] 4,176,914
5] Dec. 4, 1979

[54] **COMPACT RETROFOCUS WIDE ANGLE OBJECTIVE**

[75] Inventor: **Kazuo Fujibayashi**, Yokohama, Japan

[73] Assignee: **Canon Kabushiki Kaisha**, Tokyo, Japan

[21] Appl. No.: **906,852**

[22] Filed: **May 17, 1978**

[30] **Foreign Application Priority Data**

May 26, 1977 [JP] Japan 52-61467

[51] **Int. Cl.**[2] **G02B 9/64**
[52] **U.S. Cl.** **350/214**; 350/176
[58] **Field of Search** 350/214, 176

[56] **References Cited**

U.S. PATENT DOCUMENTS

3,874,770	4/1975	Shimizu	350/214
4,046,459	9/1977	Kawamura	350/214

Primary Examiner—Paul A. Sacher
Attorney, Agent, or Firm—Toren, McGeady and Stanger

[57] **ABSTRACT**

A wide angle objective lens with an angular field coverage of 76° and a relative aperture of 1:2.8, comprising seven members of which the first and second (counting from the front) are negative meniscuses of forward convexity, the third is positive with the front surface more strongly curved than the rear one and convex toward the front, the fourth is bi-convex, the fifth is bi-concave, and the sixth and seventh are positive meniscuses of rearward convexity. This lens is shortened in the longitudinal direction and the diameter of the first member is smaller. By the shortening of the dimensions of the lens, it is increasing in the halo due to the sagittal rays. In order to diminish the increased halo it is restricted optimumly the reduced air space between the second and fourth members which affects the incident height of the marginal ray on the fourth member.

1 Claim, 2 Drawing Figures

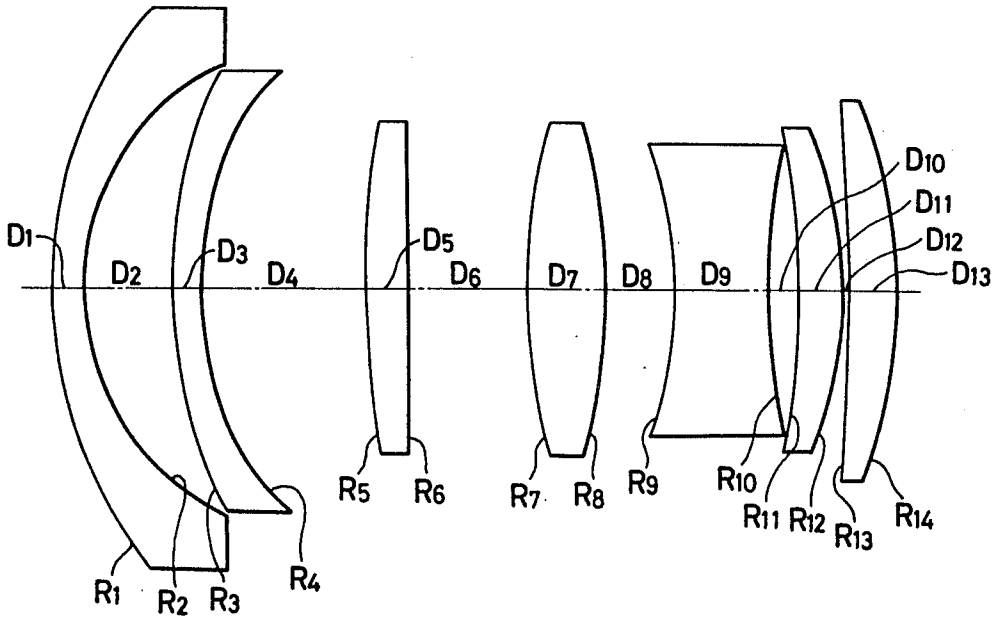
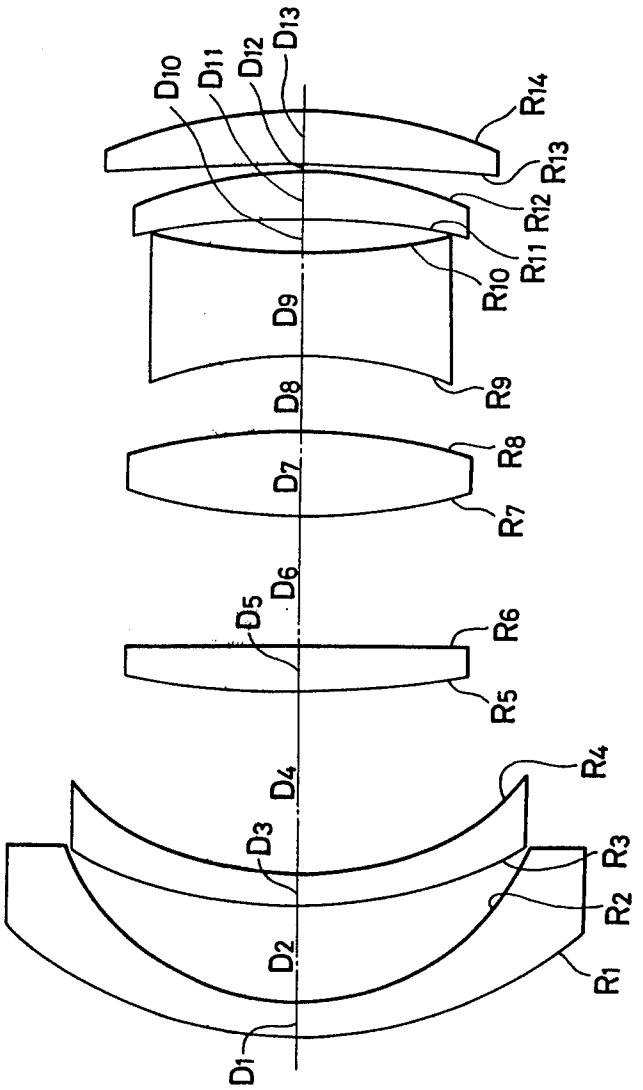


FIG.1


D10
D11
D12
D13
R14
R13
R12
R11
R10
D9
R9
D8
R8
D7
R7
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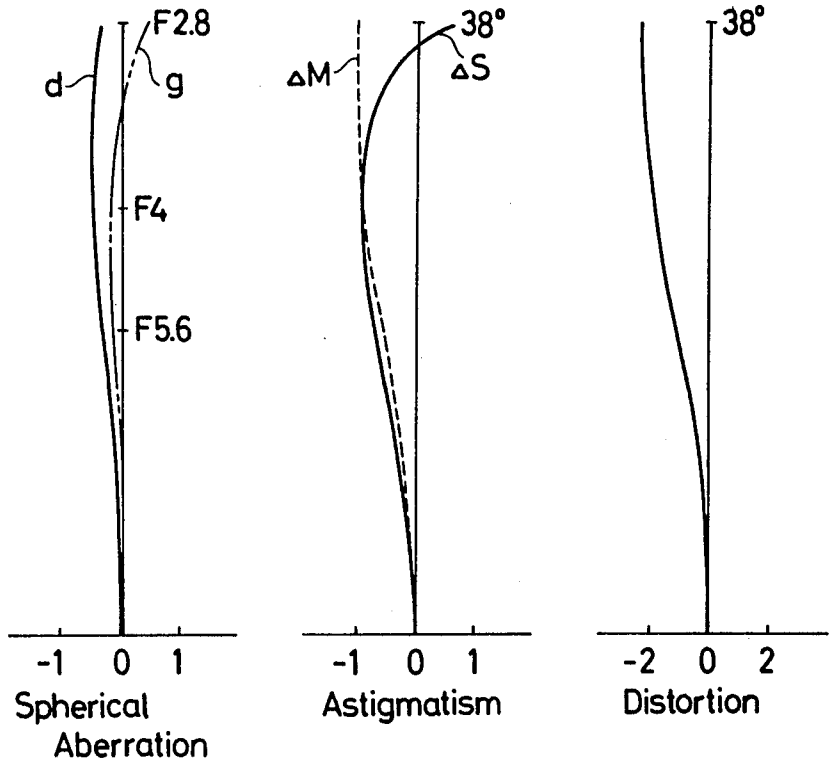
D5
R6
R5
R4
D4
D3
R3
R2
D2
R1
D1

FIG.2


F2.8
d
g
F4
F5.6
-1 0 1
Spherical Aberration
ΔM
38°
ΔS
-1 0 1
Astigmatism
38°
-2 0 2
Distortion

COMPACT RETROFOCUS WIDE ANGLE OBJECTIVE

This invention relates to photographic objectives, and more particularly to a wide angle objective having a long back focus suited for use in a single lens reflex camera.

Wide angle objectives when in the retrofocus type, though being advantageous for an increase in the back focal length, tend to give rise to a very difficult aberrational problem for distortion, coma and particularly halo due to the sagittal rays because of the requirement of employing a strongly divergent lens members at the front part. To avoid a considerable drop in image quality, therefore, the conventional design features are that the suitable arrangement of the lens members that follow the front member is combined with the simultaneous elongation of the complete objective in the longitudinal direction to reduce the absolute amount of aberrations ascribable to the individual lens members, and that the number of lens members in the complete objective is increased to facilitate correction of aberrations.

A retrofocus wide angle objective lens which is well corrected for the various aberrations has been proposed in U.S. Pat. No. 4,046,459 assigned to the assignee of the present invention. With this lens when shortened by 10% in the longitudinal length and at the same time in the diameter of the front member, however, it has been found that the halo due to the sagittal rays becomes serious. The use of special and expensive glass materials in making the lens elements is effective to improve the image quality, but will lead to an increase in the production cost.

Accordingly, the present invention aims at affording optimum correction for the various aberrations including halo due to the sagittal rays by making the lens arrangement appropriately selected.

For this purpose, two negative meniscus lens members are arranged in the foremost section of the objective, and are spaced from each other by as close a distance as is needed to achieve a minimization of the size of the objective in the total length and in the diameter of the front members. In such compact objective, the two negative meniscus lens members tend to produce remarkable halo of the sagittal rays which can be balanced out by the suitable design of the following lens members.

FIG. 1 is cross-sectional view of a preferred embodiment of the present invention.

FIG. 2 is aberrations diagram of the lens of FIG. 1.

One example of a specific wide angle objective lens of the present invention is represented in the drawing with FIG. 1 showing a lens block diagram wherein the first and second negative meniscus lens members (counting from the front) are convex toward the front and followed by a third lens member of positive power, in this instance, of bi-convexity as near as plano-convexity, a fourth lens member of bi-convexity, a fifth lens member of bi-concavity, a sixth lens member of rearwardly convex meniscus form, and a seventh lens member of positive power, in this instance, of rearwardly convex meniscus form. A diaphragm is positioned in a space between the third and fourth lens members.

The data of the objective represented in FIG. 1 refer to a total focal length of 100, a relative aperture of 1:2.8 and an angular field of 76°, and are given in Table 1 for the radii of curvature, R, the axial thicknesses of the lens elements or the axial separations between the lens elements, D, along with the corresponding indices of refraction, Nd, for the spectral D line of sodium and the Abbe numbers, || d, for the lens elements.

Table 1

f = 100 F 1 : 2.8 2ω = 76°

Surface No.	R	D	Nd	νd
1	79.151	5.79	1.60311	60.7
2	44.593	14.21	1	
3	85.091	4.56	1.60311	60.7
4	54.902	27.54	1	
5	184.03	7.09	1.69895	30.1
6	−7813.7	19.86	1	
7	120.79	12.35	1.7725	49.6
8	−107.45	11.33	1	
9	−86.095	15.79	1.80518	25.4
10	113.87	5.09	1	
11	−131.19	7.47	1.713	53.9
12	−65.814	0.7	1	
13	−479.44	8.14	1.7725	49.6
14	−96.351		1	

ΣD = 139.92
b.f = 127.3 (back-focus)

The values of 3rd-order aberration coefficients of the objective of FIG. 1 are compiled in Table 2 for lateral chromatic aberration L, longitudinal chromatic aberration T, spherical aberration SA, coma CM, astigmatism AS, Petzval sum PT and distortion DS. The spherical aberration, astigmatism and distortion of the objective of FIG. 1 are graphically represented in FIG. 2.

Table 2

Surface No.	L	T	SA	CM	AS	PT	DS
1	0.009683	0.002599	0.473995	0.127241	0.034157	0.475556	0.136829
2	−0.020377	0.002234	−6.186963	0.678250	−0.074354	−0.844094	0.100685
3	0.014408	0.002666	2.114452	0.391310	0.072417	0.442358	0.095267
4	−0.022932	−0.000305	−8.845863	−0.117759	−0.001568	−0.685598	−0.009148
5	0.039077	0.013206	2.911235	0.983846	0.332489	0.223667	0.187952
6	−0.010239	−0.016902	−0.071260	−0.117633	−0.194183	0.005268	−0.311852
7	0.025201	0.011208	2.215402	0.985291	0.438204	0.360999	0.355442
8	0.041691	−0.009076	13.670529	−2.976118	0.647910	0.405817	−0.229400
9	−0.081376	0.014070	−13.700771	2.368811	−0.409558	−0.518345	0.160431
10	−0.043716	−0.030729	−1.865837	−1.311551	−0.921928	−0.391911	−0.923536
11	−0.004672	0.008612	0.024141	−0.044499	0.082025	−0.317436	0.433931
12	0.025822	−0.003505	3.378902	−0.458648	0.062256	0.632759	−0.094340
13	−0.006267	0.009460	−0.049145	0.074183	−0.111977	−0.090950	0.306312
14	0.032356	−0.002291	6.894154	−0.488230	0.034576	0.452565	−0.034498
Sum	−0.001342	0.001246	0.962971	0.094493	−0.009533	0.150653	0.174074

What is claimed is:

1. A retrofocus wide angle objective lens comprising seven lenses arranged on a common optical axis and of which the first and second counting from the front are negative meniscus lenses convex toward the front, the third is a positive lens convex toward the front, the fourth is a bi-convex lens, the fifth is a bi-concave lens,

and the sixth and the seventh are positive meniscus lenses convex toward the rear, said system being characterized by the following numerical values for the radii of curvature, R, the axial thicknesses or the axial separations, D, the refractive indices, Nd, and the Abbe numbers, νd:

Surface No.	R	D	Nd	νd
1	79.151	5.79	1.60311	60.7
2	44.593	14.21	1	
3	85.091	4.56	1.60311	60.7
4	54.902	27.54	1	
5	184.03	7.09	1.69895	30.1
6	−7813.7	19.86	1	
7	120.79	12.35	1.7725	49.6
8	−107.45	11.33	1	
9	−86.095	15.79	1.80518	25.4
10	113.87	5.09	1	
11	−131.19	7.47	1.713	53.9
12	−65.814	0.7	1	
13	−479.44	8.14	1.7725	49.6
14	−96.351		1	

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XR 4,174,153

T 4064T
X4069C
X 4076R
X 4077W

United States]

Laurent

4,174,153

Nov. 13, 1979

[54] **VARIFOCAL OBJECTIVE WITH FOCAL LENGTH ADJUSTMENT**

[75] Inventor: **François Laurent**, Yverdon, Switzerland

[73] Assignee: **Bolex International SA**, Ste-Croix, Switzerland

[21] Appl. No.: **851,352**

[22] Filed: **Nov. 14, 1977**

[30] **Foreign Application Priority Data**

Nov. 15, 1976 [AT] Austria 8501/76

[51] **Int. Cl.**[2] **G02B 15/10**; G02B 15/16

[52] **U.S. Cl.** **350/184**; 350/176; 350/183; 350/191; 350/192; 354/295

[58] **Field of Search** 350/184, 186, 176, 191, 350/192, 183

[56] **References Cited**

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2634941 2/1977 Fed. Rep. of Germany 350/184
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Primary Examiner—Paul A. Sacher
Attorney, Agent, or Firm—Montague & Ross

[57] **ABSTRACT**

A varifocal camera objective is adjusted in its telephoto position, by an axial shift of one of its movable components or by the insertion of a negative lens member, to extend its overall focal length with consequent increase in its back-focal length, that increase being compensated by the emplacement of a supplemental positive lens member in first or second position. If the movement of the shiftable component is controlled by a cam track, the axial displacement thereof beyond the varifocal range may be normally blocked and may be unblocked only when a feeler detects the presence of the supplemental positive lens member. A similar feeler mechanism may be used to prevent the emplacement of an attachment bearing such a supplemental lens member unless the shiftable component is enabled to move into its off-normal position. A focal-length-increasing negative lens member may be carried on an eccentric disk for selective interposition into the path of incident light rays just ahead of a reflex prism. The supplemental positive lens member may have an aspherical surface approximating a paraboloid of revolution.

28 Claims, 18 Drawing Figures

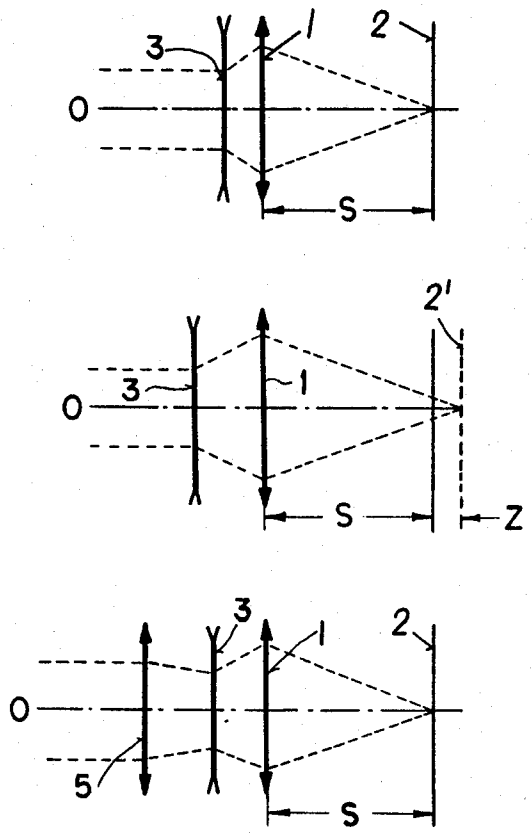


FIG.1A

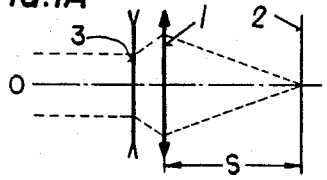


FIG.2A

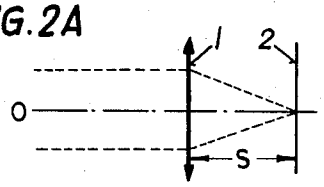


FIG.1B

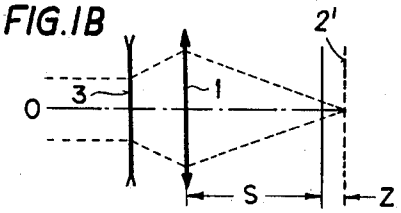


FIG.2B

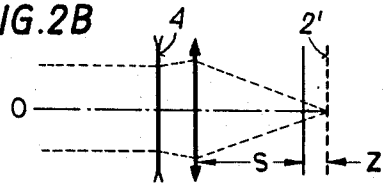


FIG.1C

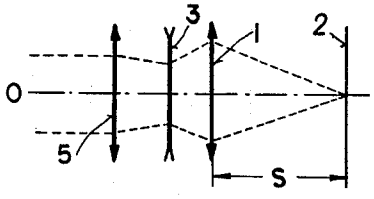


FIG.2C

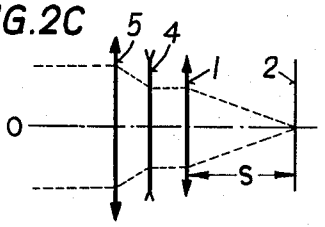


FIG.3

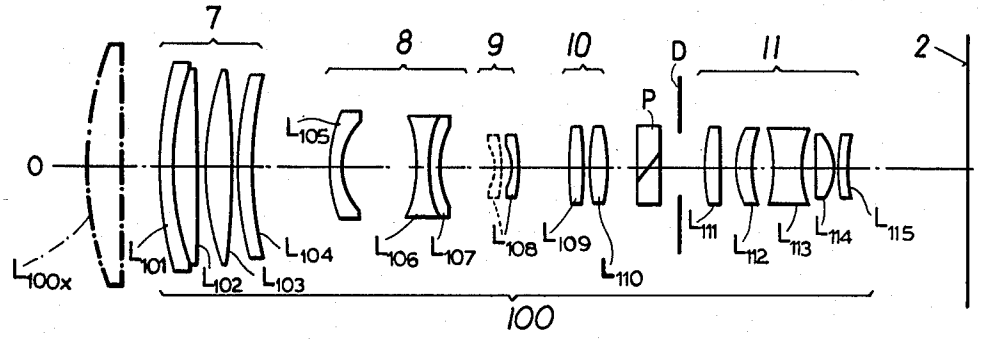


FIG.4

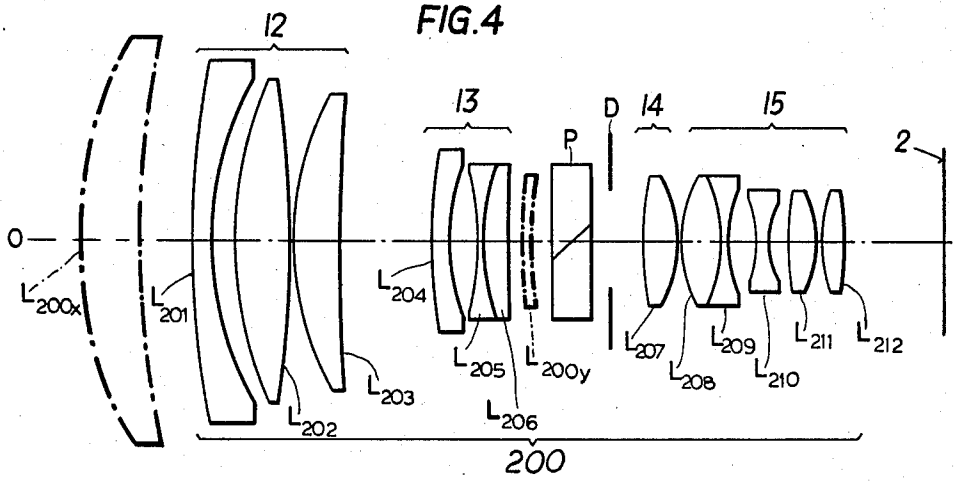


FIG. 5

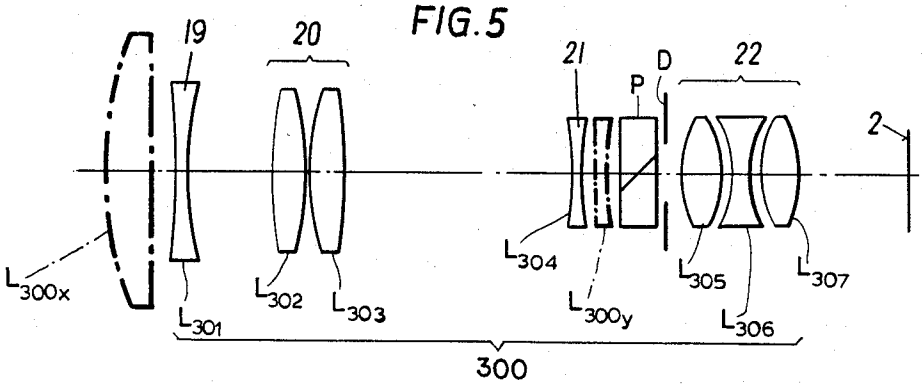


FIG. 6

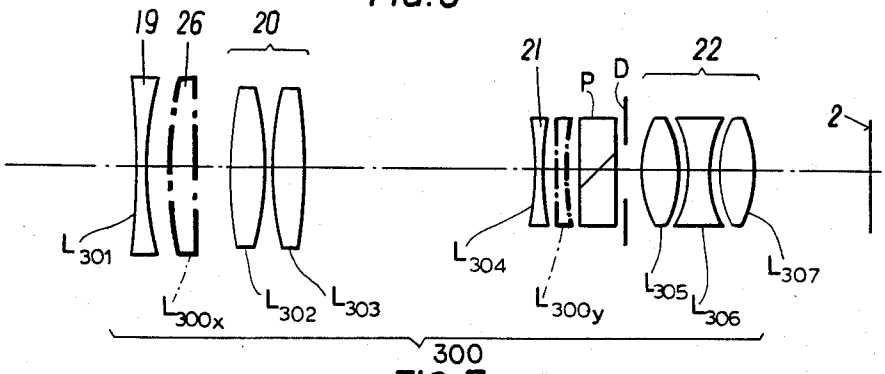


FIG. 7

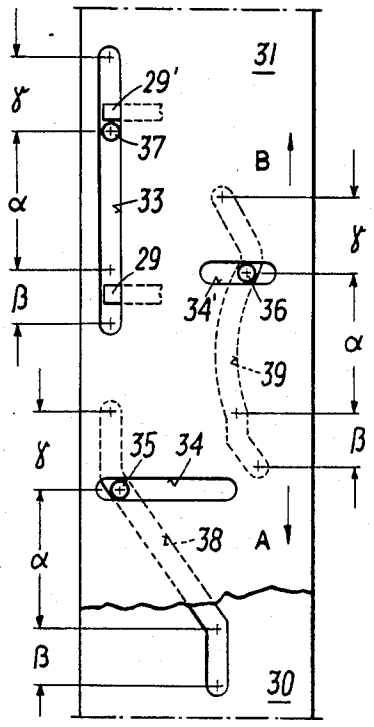


FIG. 8

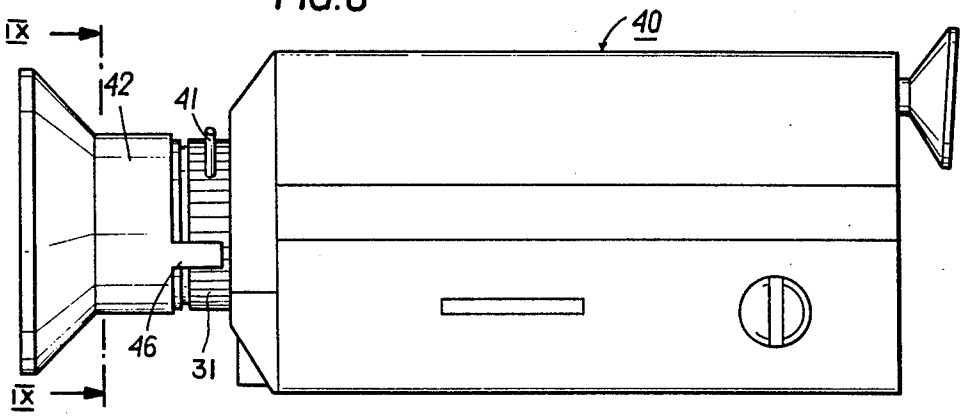


FIG. 11

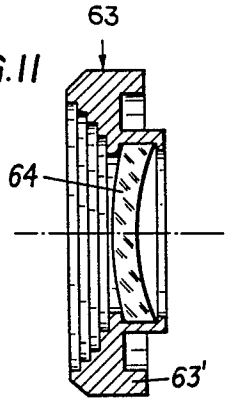


FIG. 9

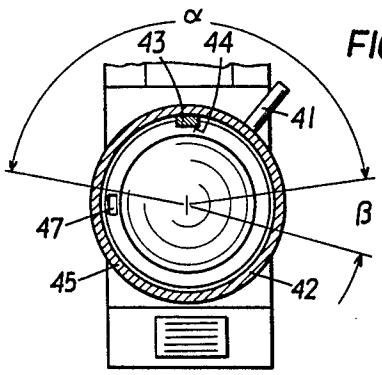


FIG. 10

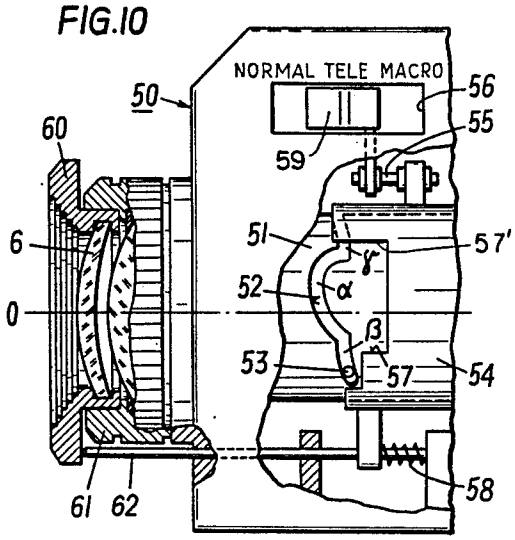


FIG. 12

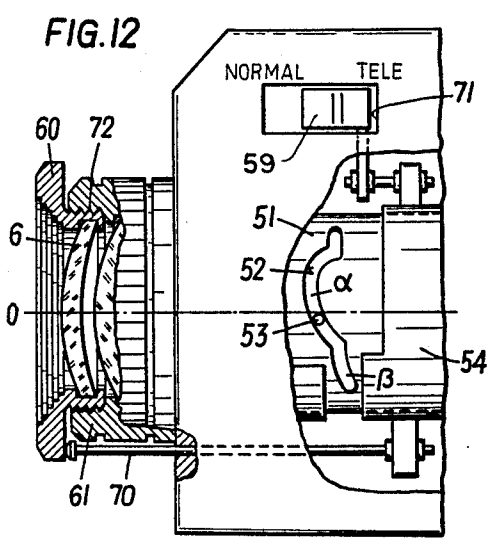


FIG. 13

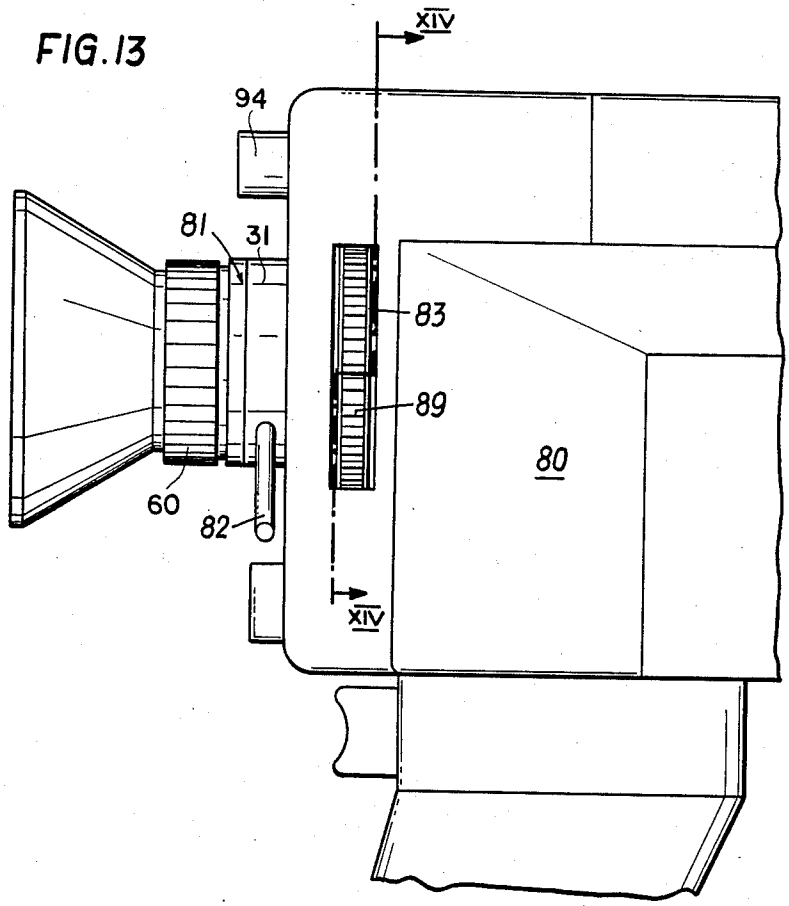
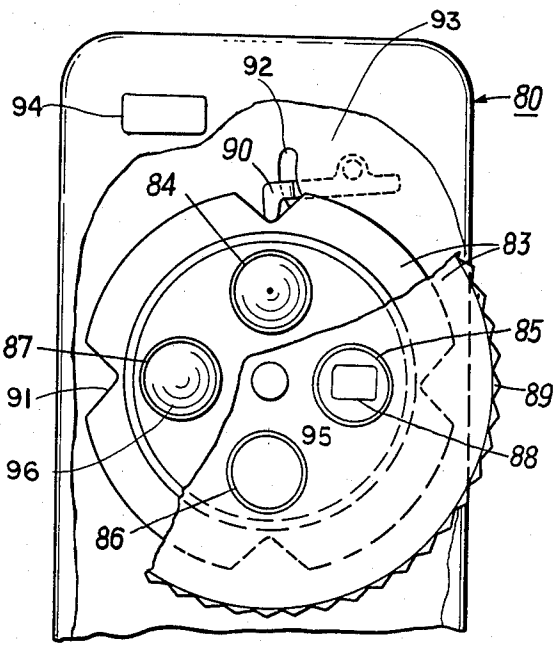

XIV
94
81
31
83
89
80
60
82
XIV

FIG. 14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VARIFOCAL OBJECTIVE WITH FOCAL LENGTH ADJUSTMENT

FIELD OF THE INVENTION

My present invention relates to an optical objective including a positively refracting lens assembly, as used in photographic and cinematographic cameras, which is adapted to focus incident rays from remote objects upon a receiving surface (e.g. a sensitive film) in line with an image plane located rearwardly of that lens assembly.

BACKGROUND OF THE INVENTION

The usual photographic and cinematographic objective can be sharply focused upon objects in a normal range between infinity and a so-called macro range, the latter being generally defined as lying between the image-ratio limits of 1:10 and 1:1. In the case of varifocal or pancratic objectives, in which the image plane does not shift between a telephoto position and a wide-angle position brought about by the concurrent axial displacement of two movable components, focusing within the macro range can be achieved by axially shifting one of these movable components beyond the position occupied by it at the wide-angle end of the varifocal range; see, for example, U.S. Pat. No. 3,891,304. Moreover, as proposed in commonly owned application Ser. No. 711,835 filed by me jointly with two others on Aug. 5, 1976, now U.S. Pat. No. 4,110,005 the angle of view can be further increased with the aid of a front attachment to be emplaced on the optical axis, such an attachment being of compact design so that its presence does not significantly extend the overall physical length of the objective.

At the opposite or telephoto end of the varifocal range, however, no such simple attachments have heretofore been available for the purpose of further extending the overall focal length of the system to increase its image scale. In order to operate in such an extended telephoto range, telescope-type front attachments of considerable axial length had to be used. The presence of such a device not only complicates handling of the camera but also tends to destabilize same, thereby aggravating the risk of blurring which commonly exists to a greater or lesser extent in any objective of large focal length.

OBJECTS OF THE INVENTION

The general object of my present invention, accordingly, is to provide simple means for modifying an objective of standard optical quality to facilitate the taking of telephoto pictures with an image scale greater than that normally obtainable.

A more particular object is to provide means for adapting a convex varifocal or pancratic objective to the taking of such telephoto pictures.

SUMMARY OF THE INVENTION

In accordance with my present invention, a multilens optical objective is provided with focal-length-increasing means effective to enlarge the image scale thereof, with consequent rearward displacement of the image plane from its normal position in line with a receiving surface, and a positively refracting supplemental lens member which is emplaceable on the optical axis in line with the lens assembly of the objective for restoring the image plane to its normal position by shortening the back-focal length of the system.

There are two basic ways of increasing the focal length of such an objective, namely by the shifting of one of its lens members or by the interposition of a negatively refracting ancillary lens member in its ray path. With a pancratic objective including a varifocal lens group, either of these measures is preferably carried out in the telephoto position. Thus, by holding one of the shiftable components stationary and further displacing the other shiftable component, I can achieve the desired increase in overall focal length together with an unwanted increase in back-focal length which is to be compensated with the aid of the supplemental lens member of positive refractivity. Alternatively, however, the negatively refracting ancillary lens member may be introduced between certain elements of the lens assembly, preferably on the image side of both shiftable components, without further axial displacement.

In optical systems used with xerographic copying machines, in which an object plane and an image plane are separated by a fixed distance, it has already been proposed to change the image scale or magnification ratio by axially shifting a main lens group and selectively interposing a supplemental lens in the light path thereof; see, for example, U.S. Pat. No. 3,600,066. In the normal position of the main lens group, without any supplemental lens, that system has a magnification ratio of 1:1. In order to reduce this ratio, the main group is shifted with insertion of a supplemental lens whereby the overall focal length of the system is decreased. In contradistinction thereto, my present invention seeks to increase rather than to reduce the overall focal length of an objective.

According to a more particular feature of my invention, the supplemental lens member is to be emplaced either at the very front of the lens assembly or in second position, i.e. just behind a front component which may constitute one of the axially shiftable members of a varifocal lens group. In some instances, it will be desirable to provide this supplemental lens member with an aspherical surface for better correction of aberrations due to the shifting of another component beyond the telephoto position or the insertion of an ancillary negative lens member. Such an aspherical surface may approximate a paraboloid of rotation, as more fully described hereinafter; under less exacting conditions, however, that surface may conform to the paraboloid itself or even to its osculating sphere.

Since correct focusing in the extended telephoto range requires both the enlargement of the overall focal length and the emplacement of the supplemental positive lens member, means may be provided for preventing the inadvertent omission of one of these steps by the user which could result in the spoiling of a picture or even of an entire film. For this purpose, the mechanism designed to shift one of the movable components of the varifocal lens group beyond the telephoto position may be blocked in the absence of a front attachment carrying the supplemental lens member; alternatively, the emplacement of such a front attachment may be prevented unless the shiftable component is enabled to move into its off-normal position.

If the focal-length-increasing means includes a mechanism for interposing a negatively refracting lens member as described above, that mechanism advantageously comprises a disk-shaped lens carrier rotatable about an axis parallel to that of the objective and provided with

a plurality of peripherally spaced cutouts, one of these cutouts containing the ancillary lens member. A similar arrangement may be used for the selective emplacement of the positively refracting supplemental lens member, especially when that member is to be inserted in some intermediate position.

BRIEF DESCRIPTION OF THE DRAWING

The above and other features of my invention will now be described in detail with reference to the accompanying drawing in which:

FIGS. 1A, 1B and 1C diagrammatically illustrate one of the aspects of my present invention, involving the axial shifting of a lens member for focal-length-increasing purposes;

FIGS. 2A, 2B and 2C illustrate, in a similar diagrammatic way, another aspect of my invention involving the interposition of an ancillary lens member for the same purpose;

FIG. 2 shows a camera objective embodying the principles described with reference to FIGS. 1A–1C;

FIG. 4 shows a camera objective embodying the principles described with reference to FIGS. 2A–2C;

FIG. 5 shows another camera objective according to my invention, operable according to the principles of either FIGS. 1A–1C or FIGS. 2A–2C;

FIG. 6 shows a camera objective similar to that of FIG. 5, representing a modification;

FIG. 7 shows a cam member adapted to be used with the system of FIG. 3;

FIG. 8 is an elevational view of a camera equipped with such a system;

FIG. 9 is a cross-sectional view taken on the line IX—IX of FIG. 8;

FIG. 10 is a side-elevational view (parts broken away) of the front part of a camera equipped with an objective of the type shown in FIG. 3, including a removable front attachment;

FIG. 11 is an axial sectional view of an alternate attachment for the camera shown in FIG. 10;

FIG. 12 is a view similar to FIG. 10, illustrating a modification;

FIG. 13 is a side-elevational view of the front part of a camera equipped with an objective of the type shown in FIG. 4; and

FIG. 14 is a fragmentary cross-sectional view of the camera shown in FIG. 13, taken generally on line XIV—XIV thereof.

SPECIFIC DESCRIPTION

FIG. 1A diagrammatically illustrates a multilens objective, represented in simplified fashion by a positive lens 1 and a negative lens 3, focused on infinity. The incident parallel light rays converge on an image plane 2 which in a camera would lie at the sensitized surface of a film or plate. The optical axis has been indicated at 0.

In FIG. 1B the negative lens 3 has been shown axially shifted to the left, i.e. toward the object side of the system. This shift causes an increase in the overall focal length of the objective and, with it, of its back-focal length s defined as the distance between its last lens vortex—that of member 1—and its image plane. The latter, therefore, has shifted to the right by a distance z to a position 2'.

A supplemental positive lens 5 has been positioned in FIG. 1C forwardly of the lens assembly 1,3. The presence of lens 5 shortens the back-focal length s by the amount z, thus restoring the image plane to the position 2 of FIG. 1A, without reducing the overall focal length to its original value.

Although the shiftable member 3 of FIGS. 1A–1C is shown as a negatively refracting lens, there are also multilens systems—such as the one of FIG. 5 described hereinafter—in which a similar focal-length-increasing effect can be achieved by the leftward displacement of a positive lens member or component.

In FIG. 2A I have shown a similar multilens objective here represented simply by a single positive lens 1 again having an image plane 2. The addition of an ancillary lens 4, of negative refractivity, shifts that image plane to a more distant position 2', FIG. 2B, as the back-focal length s of the system increases to s+z along with its overall focal length. Here, too, the emplacement of a supplemental positive lens 5 in front of the basic objective 1 restores the image plane to its normal position 2 while preserving an increased overall focal length.

FIG. 3 depicts a complete camera objective according to my invention including a basic objective 100 and a supplemental, positive lens L_{100x} selectively emplaceable in front thereof. Objective 100 consists of a varifocal front group with components 7, 8, 9, 10 and a fixed-focus rear group 11. Front component 7, which is positively refracting and stationary except for focusing purposes, consists of three air-spaced positive lens members, namely a doublet L_{101}, L_{102} and two singlets L_{103}, L_{104}. The second, negatively refracting component is axially shiftable and consists of a negative singlet L_{105} air-spaced from a biconcave doublet L_{106}, L_{107}. The third, also axially shiftable component 9 consists of a single negative lens L_{108} here illustrated in two alternative positions, the one shown in dotted lines representing the conventional telephoto position while the other one (solid lines) indicates the extra shift given to this member for extending the telephoto range with simultaneously use of supplemental lens L_{100x}. Component 10, fixed and positively refracting, consists of two air-spaced biconvex lenses L_{109}, L_{110}. There follows an air space, occupied by a reflex prism P and a diaphragm D, separating the varifocal group 7–10 from the fixed-focus group 11; the latter consists of five air-spaced singlets, namely two positive lenses L_{111}, L_{112}, a negative lens L_{113} and two further positive lens L_{114}, L_{115}.

In Table A, below, I have given representative numerical values in linear units (e.g. millimeters) for the radii r of the lenses shown in FIG. 3 as well as their thicknesses and separations d, together with their refractive indices n_d and Abbé numbers ν_d. In the wide-angle position, the system has a minimum focal length $f_{min}=7$; its maximum focal length in the telephoto position, without lens L_{100x} and with lens L_{108} in its dotted-line position, is $f_{max}=56$. With lens L_{108} shifted to its full-line position and lens L_{100x} in place, that focal length changes to $f_{ext}=80$. The image plane 2 retains its position in all instances, with a back-focal length s=13.546. In this and the following tables, items pertaining to the extended telephoto position according to my invention have been placed in parentheses.

TABLE A

	r	d		n_d	ν_d
	(+740.000)				
(L_{100x})		(3.000)		(1.517)	(64.17)
	(∞)				
		(1.000)	air space		
	+180.615				
L_{101}		2.400		1.805	25.43
	+48.094				
L_{102}		5.650		1.607	59.46
	+242.533				
		0.100	air space		
	+55.800				
L_{103}		5.900		1.620	60.33
	−1034.500				
		0.100	air space		
	+39.960				
L_{104}		3.900		1.744	44.77
	+81.340				
		f_{min} 1.160	variable		
		f_{max} 27.801	air		
		(f_{ext} 27.801)	space		
	+126.360				
L_{105}		1.200		1.691	54.71
	+13.872				
		5.150	air space		
	−33.159				
L_{106}		1.000		1.620	60.33
	+18.364				
L_{107}		3.100		1.805	25.43
	+84.000				
		f_{min} 23.915	variable		
		f_{max} 2.959	air		
		(f_{ext} 8.044)	space		
	−15.981				
L_{108}		1.000		1.744	44.77
	−59.820				
		f_{min} 12.503	variable		
		f_{max} 6.818	air		
		(f_{ext} 1.733)	space		
	+108.104				
L_{109}		3.383		1.620	60.33
	−45.822				
		0.123			
	+74.746				
L_{110}		2.706		1.620	60.33
	−113.160				
		1.230			
	∞				
P		6.150		1.517	64.17
	∞				
		1.845	diaphragm		
D	—		space		
	+36.455	2.214			
L_{111}		3.505		1.620	60.33
	−116.115				
		0.123	air space		
	+19.468				
L_{112}		3.506		1.620	60.33
	+42.280				
		4.920	air space		
	−20.498				
L_{113}		2.645		1.847	23.83
	+20.498				
		3.998	air space		
	+1124.045				
L_{114}		4.059		1.713	53.83
	−15.055				
		0.123	air space		
	+18.079				
L_{115}		2.768		1.620	60.33
	+69.946				

It will be noted that the air space between lenses L_{110} and L_{111}, accommodating the prism P and the diaphragm D, equals 11.439 units.

It may be mentioned that the emplacement of lens L_{100x} accompanied by an axial shift of lens L_{108} is also possible with the first variable air space (between lenses L_{104} and L_{105}) smaller than in the telephoto position, though the increase in overall focal length will then not be as great.

FIG. 4 illustrates the application of my invention to an objective **200** of the type disclosed in U.S. Pat. No. 3,937,562, comprising a shiftable positive component **12**, a shiftable negative component **13** and a fixed positive component **14** followed by a fixed-focus rear group

15. Components 12 consists of a negative lens L_{201} and two positive lenses L_{202}, L_{203}; component 13 is formed from a negative singlet L_{204} and a negative doublet L_{205}, L_{206} whereas component 14 is a single biconvex lens L_{207}. Rear group 15 is composed of a positive doublet L_{208},L_{209}, a negative singlet L_{210} and two positive singlets L_{211}, L_{212}. Prism P and diaphragm D are here inserted between components 13 and 14, this diagragm space also accommodating in the telephoto position an ancillary planoconcave lens L_{200y} whose interposition is accompanied by the placement of a supplemental, positive lens member L_{200x} in front of objective 200 whereby the overall focal length of the system is further increased without dislocation of image plane 2. Naturally, members L_{200x} and L_{200y} need not be single lenses, as shown; this also applies to member L_{100x} of the preceding embodiment and to analogous members of subsequent Figures.

In the following Table B I have given representative numerical values for the radii r, thicknesses and separations d, refractive indices n_d and Abbé numbers ν_d for the lenses shown in FIG. 4. The overall focal length of this system changes from $f_{min}=7.5$ to $f_{max}=22$ in the varifocal range and increases to $f_{ext}=34$ in the presence of lenses L_{200x} and L_{200y}. The system has a back-focal length s=9.298.

TABLE B

	r		d		n_d	ν_d
	−97.000					
L_{200x}			3.000		1.492	54.67
	∞					
			4.000	air space		
	−88.381					
L_{201}			1.950		1.805	25.43
	−32.209					
			3.200	air space		
	−42.597					
L_{202}			6.000		1.603	60.60
	−387.159					
			0.100	air space		
	−28.656					
			6.950		1.651	55.89
L_{203}						
	−913.857					
		f_{min}	0.510	variable		
		f_{max}	14.430	air		
		(f_{ext}	14.430)	space		
	−508.015					
L_{204}			1.000		1.713	53.83
	−12.563					
			3.250	air space		
	−47.668					
L_{205}			1.000		1.640	60.10
	−14.773					
L_{206}			2.800		1.847	23.83
	−53.225					
			3.000			
	(∞)			f_{min} 20.530		
(L_{200y})			(1.000)	f_{max} 7.000	(1.517)	(64.17)
	(−27.000)			variable		
				air space		
			(3.000)			
	∞					
P			5.000		1.517	64.17
	∞					
			1.800	diaphragm		
D	—					
			1.430	space		
	−36.362					
L_{207}			2.700		1.717	47.98
	−45.739					
			0.100	air space		
	−12.644					
L_{208}			5.500		1.657	36.73
	−19.780					
			2.200		1.805	25.43
L_{209}	−26.779					
			1.100	air space		
	−27.135					
			3.300		1.847	23.83
L_{210}	−13.397					
			2.000	air space		
	−67.244					
			3.000		1.713	53.83
L_{211}	−13.501					
			0.100			
	−12.103					
L_{212}			3.000		1.604	60.10
	−508.015					

In this case the prism P and the diaphragm D lie in a variable air space separating components 13 and 14 of

the varifocal group, the length of this space changing from 28.760 for f_{min} to 15.230 for f_{max}.

The objective **300** of FIG. **5** is generally similar to that of FIG. **4**, except that its shiftable front component **19** is a biconcave singlet L_{301} and its likewise shiftable second component **20** consists of two positive singlets L_{302}, L_{303} while a fixed third component **21** is another biconcave singlet L_{304}. This varifocal group is separated from a fixed-focus group **22** by an air space containing prism P and diaphragm D. As before, a supplemental positive lens L_{300x} and an ancillary negative lens L_{300y} can be used to extend the overall focal length of the system beyond its varifocal range, the former being positioned in front of lens L_{301} while the latter is inserted between lens L_{304} and prism P in the diaphragm space. Group **22** consists of a positive singlet L_{305}, a negative singlet L_{306} and another positive singlet L_{307}.

Representative numerical values for radii r, thicknesses and separations d, refractive indices n_d and Abbe numbers ν_d are given in Table C, below, for a system whose overall focal length ranges from $f_{min}=10.6$ to $f_{max}=27.0$ without lenses L_{300x}, L_{300y}, the focal length increasing to $f_{ext}=37.0$ in the presence of these additional lenses.

TABLE C

	r	d		n_d	ν_d
	(+20.000)				
(L_{300x})		(2.000)		(1.492)	(54.67)
	(+23.780)				
		(7.000)	air space		
	−160.000				
L_{301}		1.500		1.782	37.09
	+35.700				
		f_{min} 41.961 f_{max} 10.054 (f_{ext} 10.054)	variable air space		
	+508.000				
L_{302}		4.000		1.492	54.67
	−33.600				
		0.100	air space		
	+31.000				
L_{303}		4.000		1.492	54.67
	−155.600				
		f_{min} 2.150 f_{max} 26.380 (f_{ext} 26.380)	variable air space		
	−52.760				
L_{304}		1.000		1.492	54.67
	+31.700				
		(2.000)	air space		
	(∞)				
(L_{300y})		(1.000)		(1.492)	(54.67)
	(+48.137)				
		(2.000)	air space		
	∞				
P		5.000		1.569	56.13
	∞				
		1.800	diaphragm space		
D	—				
		2.500			
	+10.980				
L_{305}		4.300		1.720	50.41
	−87.360				
		0.940	air space		
	−22.200				
L_{306}		4.770		1.728	28.41
	+8.300				
		1.480	air space		
	+16.200				
L_{307}		2.900		1.720	50.41
	−16.200				

Here the air space between the vertical and fixed-focus lens groups **19–21** and **22**, of length 14.300, accommodates the ancillary lens L_{300y} together with prism P and diaphragm D.

In a refinement of the system given in Table C, the front surface of lens L_{300x} is made aspherical according to the formula

$$x = \frac{y^2}{R(1+\sqrt{1-y^2/R^2})} - k \cdot y^4$$

where x is the distance of any point on that surface from a reference plane transverse to axis O passing through the left-hand vertex of the lens, y is the distance of the point from the axis, R is the radius of an osculating sphere and k is a constant on the order of $1/R^4$. Within an area centered on the axis for which $y<<R$ we can write $x \approx y^2/R$ which is the formula for a paraboloid of rotation. With $R=20$ (corresponding to the radius for the first lens surface given in Table C), k may have a value of $5.5 \cdot 10^{-6}$.

The objective **300** of FIG. **5** can also be adjusted to an extreme telephoto position by the technique described with reference to FIGS. **1A–1C**, without use of the ancillary lens L_{300y} but with a further axial shifting of component **20** toward the object side, i.e. to the left, accompanied by the emplacement of lens L_{300x}. In this instance, lens L_{301} is substantially stationary while lens L_{304} is shiftable. The parameters of such a system are

given in the following Table D; the overall focal length changes from $f_{min}=10.41$ to $f_{max}=29.16$ in the varifocal range and is increased to $f_{ext}=34.00$ by the adjustment according to my invention. The back-focal length is s=11.700.

TABLE D

	r	d			n_d	ν_d
	(+380.000)					
(L_{300x})		(2.000)			(1.492)	(54.67)
	(∞)					
		(3.000)		air space		
	−106.100					
L_{301}		1.700			1.744	44.77
	+37.000					
		f_{min}	40.254	variable		
		f_{max}	4.976	air space		
		(f_{ext}	3.469)			
	+450.000					
L_{302}		3.400			1.517	64.17
	−34.700					
		0.100		air space		
	+25.530					
L_{303}		4.200			1.517	64.17
	−450.000					
		f_{min}	1.122	variable		
		f_{max}	24.849	air space		
		(f_{ext}	26.356)			
	−54.410					
L_{304}		1.000			1.623	58.06
	+38.000					
		f_{min}	1.181	variable		
		f_{max}	12.732	air space		
		(f_{ext}	12.732)			
	∞					
P		5.000			1.517	64.17
	∞					
		1.800		diaphragm		
D	—			space		
		3.500				
	+12.350					
L_{305}		3.400			1.782	37.09
	<24.020					
		0.850		air space		
	−15.000					
L_{306}		6.250			1.805	25.43
	+9.500					
		0.900		air space		
	+18.280					
L_{307}		3.200			1.691	54.71
	−13.020					

In the foregoing table the last variable air space is measured between lens L_{304} and prism P. Since the position of the prism is not critical (in fact, it might be omitted), that space could also be measured between lenses L_{304} and L_{305} if the latter lens—like lens L_{207} in FIG. 4—is considered part of the varifocal group, i.e. 11.481 for f_{min} and 24.032 for f_{max} and f_{ext}.

In FIG. 6 I have shown the same objective **300** as in FIG. 5, with insertion of ancillary lens L_{300y} but with supplemental lens L_{300x} positioned between components **19** and **20** rather than forwardly thereof. The corresponding parameters are given in Table E, below, for a system whose overall focal length normally varies between $f_{min}=10.6$ and $f_{max}=26.9$ but can be increased to $f_{ext}=34.5$ by the addition of these extra lenses. In this instance, too, the optical properties in the extreme telephoto positions can be further improved by using an aspherical front surface for lens L_{300x} according to the formula given in connection with Table C, or at least a paraboloidal approximation thereof. Elements P, D and L_{305}–L_{307} have the same dimensions and spacings as in Table C, with a back-focal length s=12.906.

TABLE E

	r	d			n_d	ν_d
	−160.000					
L_{301}		1.500			1.782	37.09
	+35.700					
		(4.000)				
	(+20.000)					
(L_{300x})		(1.500)		f_{min} 41.961 f_{max} 10.050 variable	(1.492)	(54.67)
	(+24.700)					
		(4.500)		air space		
	+508.000					
L_{302}		4.000			1.492	54.67
	−33.600					
		0.100		air space		
	+31.000					
L_{303}		4.000			1.492	54.67
	−155.600					

TABLE E-continued

	r	d		n_d	ν_d
		f_{min} 2.154 f_{max} 26.380 (f_{ext} 26.380)	variable air space		
	−52.760				
L_{304}		1.000		1.492	54.67
	+31.700				
		(2.000)	air space		
	(∞)				
(L_{300y})		(1.000)		(1.492)	(54.67)
	(+48.000)				
		(2.000)	air space		
	∞				
P		5.000		1.569	56.13
	∞				
		1.800	diaphragm space		
D	—				
		2.500			
	10.980				
L_{305}		4.300		1.720	50.41
	−87.360				
		0.940	air space		
	−22.200				
L_{306}		4.770		1.728	28.41
	+8.300				
		1.480	air space		
	+16.200				
L_{307}		2.900		1.720	50.41
	−16.200				

The axial shifting of the movable components of any of the aforedescribed objectives can be brought about in the well-known manner with the aid of rotatable or slidable cam members. FIG. 7 shows, in developed view, a camming sleeve **30** coaxial with a control ring **31**, the latter being provided with axially extending guide slots **34**, **34'** traversed by pins **35** and **36** which are rigid with the lens mounts for the shiftable components, e.g. those designated **8** and **9** in FIG. 3. Pins **35** and **36** also pass through respective camming slots **38** and **39** in sleeve **30** which bring about their independent axial displacement upon relative rotation of members **30** and **31**.

The camming slots **38** and **39** are seen to be divided into three sections corresponding to respective operating zones α, β and γ. Zone α represents the normal varifocal range in which slot **38** has a constant slope or pitch angle for a linear shifting of component **8**. In zones β and γ, the slot **38** has zero pitch so that no further displacement of component **8** occurs even though component **9** continues to move under the control of slot **39**. It will be noted that this slot is so shaped as to shift component **9** toward the right, i.e. from its dotted-line position to its full-line position as seen in FIG. **3**, upon rotation of ring **31** past the telephoto end of the varifocal range as indicated by an arrow A. A shift of component **9** in the opposite direction, i.e. toward the left, takes place in zone γ under the control of slot **39** as the ring **31** is rotated in a reverse sense past the wide-angle end of the varifocal range as indicated by an arrow B; this latter displacement serves for the focusing of the objective in the macro range as discussed above.

In FIG. 7 I have also schematically indicated the provision of retractable stops **29**, **29'** for blocking the transition frame from zone α to either of the other two zones under certain conditions, e.g. as more fully described hereinafter with reference to FIGS. **10–12**. Stops **29** and **29'** are shown to coact with a pin **37** on sleeve **30** extending into a guide slot **33** of ring **31**.

FIGS. **8** and **9** illustrate a motion-picture camera **40** of conventional construction equipped with an objective of the type shown in FIG. **3**, for example, whose focal length is adjustable within the normal varifocal limits as well as into an extended telephoto range in which the camera is to be fitted with a front attachment **42** carrying a supplemental lens member of positive refractivity. A manually operable handle **41** on control ring **31** (cf. FIG. 7) can be swung, upon the release of a nonillustrated detent, through a large arc corresponding to zone α and a smaller arc corresponding to zone β as seen in FIG. **9**; an opposite swing into the zone γ discussed with reference to FIG. 7 may also be allowed. Attachment **42**, holding for example the lens L_{100x} of FIG. **3**, has a lug **43** fitting into a groove **44** of the objective housing **45**. Another such groove **47**, differing in size and location from groove **44**, is engageable by a lug of a similar attachment carrying a negative lens to be used in the marco range upon shifting of component **9** to a position in zone γ, such an attachment having been illustrated in FIG. **11** discussed hereinafter. Thus, either type of attachment occupies a characteristic position when mounted on the objective housing.

Attachment **42** further has a projection **46** extending into the path of handle **41** to form an abutment which defines the correct position of component **9** for the particular supplemental lens carried by it. This insures a correct positioning of the image plane if the camera can be selectively fitted with a variety of telephoto attachments. The same applies, of course, to wide-angle attachments usable in the marco range.

FIG. **10** illustrates a camera **50** having a camming sleeve **51** with a slot **52** generally similar to the slot **39** of FIG. 7, the slot being again divided into three sections corresponding to respective zones α, β and γ. A nonrotatable blocking sleeve **54** is positively connected with a slide **59** which moves within a slot **56** between three positions respectively labeled "NORMAL," "TELE" and "MARCRO." In position "NORMAL," the objective can be used only within its varifocal range as the extremities of slot **52** are overlain by respective ledges **57** and **57'** of sleeve **54**, thus preventing the cam-follower pin **53** of component **9** (FIG. **3**) from moving

into either the extended telephoto zone β or the macro zone γ. In slider position "TELE" the lower part of slot **52** is uncovered, allowing operation in the extended telephoto zone, whereas in position "MACRO" the upper slot extremity is also accessible to facilitate the taking of closeups.

A push rod **62** rigid with sleeve **54** projects forwardly under pressure of a spring **58** which tends to hold the sleeve in its position "NORMAL," the rod **62** extending past the objective housing **61** as long as no attachment is mounted thereon.

If a telephoto attachment **60** with a positive lens **6** is secured to the objective housing, the presence of this attachment is sensed by the rod **62** which represses the sleeve **54** into its position "TELE" and indicates this fact to the user with the aid of slider **59**. Another attachment **63**, shown in FIG. **11**, carries a negative lens **64** for the taking of closeups; attachment **63** has a peripheral flange **63'** which partly embraces the objective housing **61** and represses the sensing rod **62** still further to the right, thus moving the slider **59** into the position "MACRO" and fully unblocking the camming slot **52**.

FIG. **12** shows a similar camera whose camming slot **52**, however, lacks the extension labeled γ in FIG. **10**. Slider **59**, accordingly, is manually shiftable only between positions "NORMAL" and "TELE" within a slot **71**, with selective blocking or unblocking of slot extension β. Sleeve **54** is indexable in position "NORMAL" or is urged into that position by a strong biasing spring (not shown) so that a push rod **70** rigid therewith prevents the emplacement of an attachment **60** on the objective housing **61** in that position. Thus, the user must first shift the sider **59** to the position "TELE" before the attachment can be used. In FIG. **12** the attachment **60** and the objective housing **61** are shown provided with complementary threads facilitating the emplacement of lens member **6** which may correspond to lens L_{100x} of FIG. **3**.

In FIGS. **13** and **14** I have shown a camera **80** in which an ancillary lens member **17**, which may be the lens L_{200y} of FIG. **4**, is interposable in the lens assembly of a varifocal objective whose housing **81** can be fitted with an attachment **60** or **63** as shown in FIGS. **10–12**. A control ring **31** on the objective housing is rotatable by a handle **82**.

The camera body has a lateral aperture through which a disk **83**, provided with knurled rim **89**, projects for manual rotation about a shaft **95** offset from the optical axis O. Disk **83** has four angularly equispaced circular cutouts **84–87** and is provided with as many peripheral notches **91** engageable by a detent **90** for releasable indexing in any position in which one of these cutouts is in line with the optical axis. Detent **90**, passing through a slot **92** in a partition **93** of the camera housing, may be biased by a nonillustrated spring into engagement with notches **91**. The camera is further provided with a viewfinder **94** and other conventional devices.

Besides the negatively refracting ancillary lens **17**, lodged in cutout **84**, there may also be provided a positively refracting ancillary lens **96** for interposition in the taking of closeups with the aid of a negative supplemental lens **64** as shown in FIG. **11**. Lens **96** is shown mounted in cutout **87** whereas cutout **85** holds a toroidal lens **88** for the taking of anamorphotic pictures. Cutout **86** is empty and is aligned with axis O during normal focusing in the varifocal range.

Although my invention has been particularly described in its application to varifocal or pancratic objectives, its teachings are also applicable to objectives of fixed focus. Aside from being useful in photography, the invention could be readily adapted to the enlargement of scenes viewed through a telescope. A device similar to slider **59** of FIG. **10**, indicating the adjustment of the objective to the extended telephoto range, may also serve to alert the user to the desirability of placing the camera on a tripod or other suitable support.

The position-feeling or emplacement-blocking mechanism of FIGS. **10** and **12** is of the general type disclosed and claimed, for use with wide-angle attachments, in the aforementioned copending application Ser. No. 711,835 now U.S. Pat. No. 4,110,005.

I claim:

1. In an optical objective including a positively refracting lens assembly centered on an optical axis and adapted to focus incident rays from remote objects upon a receiving surface in line with an image plane located rearwardly of said lens assembly, the combination therewith of focal-length-increasing means for enlarging the image scale of said lens assembly, with consequent rearward displacement of said image plane from a normal position, and a positively refracting supplemental lens member emplaceable on said axis in line with said lens assembly for restoring said image plane to said normal position thereof.

2. The combination defined in claim **1** wherein said focal-length-increasing means comprises an axially shiftable member of said lens assembly and mechanism for axially displacing said axially shiftable member.

3. The combination defined in claim **2** wherein said lens assembly includes a varifocal lens group with two axially shiftable components for selectively establishing a wide-angle position and a telephoto position between which said image plane remains fixed, said axially shiftable member being one of said components.

4. The combination defined in claim **3** wherein said supplemental lens member is emplaceable on the side of said axially shiftable member remote from said image plane.

5. The combination defined in claim **4** wherein the objective is part of a camera provided with an objective housing, said supplemental lens member being part of a front attachment emplaceable on said objective housing.

6. The combination defined in claim **5** wherein the camera is provided with inhibiting means normally blocking a displacement of said one of said components by said mechanism beyond said telephoto position, said inhibiting means being deactivable by said attachment upon emplacement thereof on said objective housing.

7. The combination defined in claim **5** wherein the camera is provided with selector means for optionally blocking and unblocking a displacement of said one of said components by said mechanism beyond said telephoto position, said selector means having an extension preventing the emplacement of said attachment on said camera in a blocking position.

8. The combination defined in claim **5** wherein said supplemental lens member L_{100x} and the lenses L_{101}–L_{110} of said varifocal lens group have radii of curvature r, axial thickness and separations d, refractive indices n_d and Abbé numbers ν_d substantially as given in the following table:

	r	d		n_d	ν_d
	(+740.0)				
(L_{100x})		(3.0)		(1.52)	(64)
	(∞)				
		(1.0)	air space		
	+180.6				
L_{101}		2.4		1.81	25
	+48.1				
L_{102}		5.7		1.61	59
	+242.5				
		0.1	air space		
	+55.8				
L_{103}		5.9		1.62	60
	−1,034.5				
		0.1	air space		
	+40.0				
L_{104}		3.9		1.74	45
	+81.3				
		f_{min} 1.2 f_{max} 27.8 (f_{ext} 27.8)	variable air space		
	+126.4				
L_{105}		1.2		1.69	55
	+13.9				
		5.2	air space		
	−33.2				
L_{106}		1.0		1.62	60
	+18.4				
L_{107}		3.1		1.81	25
	+84.0				
		f_{min} 23.9 f_{max} 3.0 (f_{ext} 8.0)	variable air space		
	−16.0				
L_{108}		1.0		1.74	45
	−59.8				
		f_{min} 12.5 f_{max} 6.8 (f_{ext} 1.7)	variable air space		
	+108.1				
L_{109}		3.4		1.62	60
	−45.8				
		0.1	air space		
	+74.7				
L_{110}		2.7		1.62	60
	−113.2				

9. The combination defined in claim 8 wherein said lens assembly further comprises a fixed-focus lens group on the image side of said varifocal lens group, the lenses L_{111}–L_{115} of said fixed-focus lens group having radii of curvature r, axial thicknesses and separations d, refractive indices n_d and Abbé numbers ν_d substantially as given in the following table:

	r	d	n_d	ν_d
	+36.5			
L_{111}		3.5	1.62	60
	−116.1			
		0.1	air space	
	+19.5			
L_{112}		3.5	1.62	60
	+42.3			
		4.9	air space	
	−20.5			
L_{113}		2.6	1.85	24
	+20.5			
		4.0	air space	

-continued

	r	d	n_d	ν_d
	+1124.0			
L_{114}		4.1	1.71	54
	−15.1			
		0.1	air space	
	+18.1			
L_{115}		2.8	1.62	60
	+69.9			

10. The combination defined in claim 4 wherein said one of said components is of positive refractivity and is shiftable by said mechanism away from said image plane.

11. The combination defined in claim 10 wherein said supplemental front lens L_{300x} and the lenses L_{301}–L_{304} of said varifocal lens group have radii of curvature r, axial thicknesses and separations d, refractive indices n_d and Abbé numbers ν_d substantially as given in the following table:

	r	d	n_d	ν_d
	(+380.0)			
(L_{300x})		(2.0)	(1.49)	(55)
	(∞)			
		(3.0)	air space	
	−106.1			

-continued

	r	d	n_d	ν_d
L_{301}		1.7	1.74	45
	+ 37.0			
		f_{min} 40.3 f_{max} 5.0 (f_{ext} 3.5)	variable air space	
	+450.0			
L_{302}		3.4	1.52	64
	− 34.7			
		0.1	air space	
	+ 25.5			
L_{303}		4.2	1.52	64
	−450.0			
		f_{min} 1.1 f_{max} 24.8 (f_{ext} 26.4)	variable air space	
	− 54.4			
L_{304}		1.0	1.62	58
	+ 38.0			

12. The combination defined in claim 10 wherein said lens assembly further comprises a fixed-focus lens group on the image side of said varifocal lens group, the lenses L_{305}–L_{307} of said fixed-focus lens group having radii of curvature r, axial thicknesses and separations d, refractive indices n_d and Abbé numbers ν_d substantially as given in the following table:

	r	d	n_d	ν_d
	+12.4			
L_{305}		3.4	1.78	37
	−24.0			
		0.9	air space	
	−15.0			
L_{306}		6.3	1.81	25
	+9.5			
		0.9	air space	
	+18.3			
L_{307}		3.2	1.69	55
	−13.0			

13. The combination defined in claim 1 wherein said focal-length-increasing means comprises an ancillary negatively refracting lens member interposable in said lens assembly, on the image side of said supplemental lens member, and mechanism for selectively interposing said ancillary lens member.

14. The combination defined in claim 13 wherein said lens assembly includes a varifocal lens group with two axially shiftable components for selectively establishing a wide-angle position and a telephoto position between which said image plane remains fixed, said ancillary lens member being insertable by said mechanism in said telephoto position on the image side of said shiftable components.

15. The combination defined in claim 14 wherein said mechanism comprises a lens carrier rotatable about an axis parallel to said optical axis.

16. The combination defined in claim 15 wherein said lens carrier is a disk with a plurality of peripherally spaced cutouts, one of said cutouts being provided with said ancillary lens member.

17. The combination defined in claim 16, further comprising indexing means for arresting said disk in a position of alignment of any of said apertures with said lens assembly.

18. The combination defined in claim 14 wherein said supplemental lens member is emplaceable on the object side of said shiftable components.

19. The combination defined in claim 18 wherein said supplemental lens member has an aspherical surface approximating a paraboloid of rotation.

20. The combination defined in claim 19 wherein said aspherical surface is defined by the formula

$$x = \frac{y^2}{R(1+\sqrt{1-y^2/R^2})} - k \cdot y^4$$

where x is the distance from a reference plane transverse to said axis, y is the distance from said axis and R is the radius of an oscilating sphere, k being a constant on the order of $1/R^4$.

21. The combination defined in claim 18 wherein said supplemental lens member L_{200x}, said ancillary lens member L_{200y} and the lenses L_{201}–L_{205} of said varifocal lens group have radii of curvature r, axial thicknesses and separations d, refractive indices n_d and Abbé numbers ν_d substantially as given in the following table:

	r	d	n_d	ν_d
	(+97.0)			
(L_{200x})		(3.0)	(1.49)	(55)
	(∞)			
		(4.0)	air space	
	+88.4			
L_{201}		2.0	1.81	25
	+32.2			
		3.2	air space	
	+42.6			
L_{202}		6.0	1.60	61
	−387.2			
		0.1	air space	
	+28.7			

-continued

	r	d		n_d	ν_d
L_{203}		7.0		1.65	56
	−913.9				
		f_{min} 0.5 f_{max} 14.4 (f_{ext} 14.4)	variable air space		
	+508.0				
L_{204}		1.0		1.71	54
	+12.6				
		3.3	air space		
	−47.7				
L_{205}		1.0		1.64	60
	+14.8				
L_{206}		2.8		1.85	24
	+53.2				
		(3.0)			
	(∞)				
(L_{200y})		(1.0)	f_{min} 28.8 f_{max} 15.2 variable	(1.52)	(64)
	(+27.0)				
		(11.2)	air space		
	+36.4				
L_{207}		2.7		1.72	48
	−45.7				

22. The combination defined in claim 21 wherein said lens assembly further comprises a fixed-focus lens group on the image side of said varifocal lens group, the lenses L_{207}–L_{212} of said fixed-focus lens group having radii of curvature r, axial thicknesses and separations d, refractive indices n_d and Abbé numbers ν_d substantially as given in the following table:

	r	d	n_d	νd
	+12.6			
L_{208}		5.5	1.66	37
	−19.8			
L_{209}		2.2	1.81	25
	+26.8			
		1.1	air space	
	−27.1			
L_{210}		3.3	1.85	24
	+13.4			
		2.0	air space	
	+67.2			
L_{211}		3.0	1.71	54
	−13.5			
		1.0	air space	
	+12.1			
L_{212}		3.0	1.60	60
	−508.0			

23. The combination defined in claim 18 wherein said supplemental lens member L_{300x}, said ancillary lens member L_{300y} and the lenses L_{301}–L_{304} of said varifocal lens group have radii of curvature r, axial thicknesses and separations d, refractive indices n_d and Abbé numbers ν_d substantially as given in the following table:

	r	d	n_d	νd
	(+20.0)			
(L_{300x})		(2.0)	(1.49)	(55)
	(+23.8)			
		(7.0)	air space	
	−160.0			
L_{301}		1.5	1.78	37
	+35.7			
		f_{min} 42.0 f_{max} 10.1 (f_{ext} 10.1)	variable air space	
	+508.0			
L_{302}		4.0	1.49	55
	−33.6			
		0.1	air space	
	+31.0			
L_{303}		4.0	1.49	55
	−1.55.6			
		f_{min} 2.2 f_{max} 26.4 (f_{ext} 26.4)	variable air space	
	−52.8			
L_{304}		1.0	1.49	55
	+31.7			
		(2.0)	air space	
	(∞)			
(L_{300y})		(1.0)	(1.49)	(55)
	(+48.0)			

24. The combination defined in claim 23 wherein said supplemental lens member L_{300x} has an aspherical front surface substantially defined by the formula

and separations d, refractive indices n_d and Abbé numbers ν_d substantially as given in the following table:

	r	d		n_d	ν_d
	−160.0				
L_{301}		1.5		1.78	37
	+35.7				
		(4.0)			
	(+20.0)		f_{min} 42.0		
(L_{300x})		(1.5)	f_{max} 10.1	(1.49)	(55)
	(+24.7)		variable		
		(4.6)	air space		
	+508.0				
L_{302}		4.0		1.49	55
	−33.6				
		0.1	air space		
	+31.0				
L_{303}		4.0		1.49	55
	−155.6				
		f_{min} 2.2	variable		
		f_{max} 26.4	air space		
		(f_{ext} 26.4)			
	−52.8				
L_{304}		1.0		1.49	55
	+31.7				
		2.0	air space		
	(∞)			(1.49)	(55)
(L_{300y})		(1.0)			
	(+48.0)				

$$x = \frac{y^2}{20(1+\sqrt{1-y^2/400})} - 5.5 \cdot 10^{-6}y^4$$

where x is the distance from a reference plane transverse to said axis and y is the distance from said axis.

25. The combination defined in claim **23** wherein said lens assembly further comprises a fixed-focus lens group on the image side of said varifocal lens group, the lenses L_{305}–L_{307} of said fixed-focus lens group having radii of curvature r, axial thickness and separations d, refractive indices n_d and Abbé numbers substantially as given in the following table:

	r	d	n_d	ν_d
	+11.0			
L_{305}		4.3	1.72	50
	−87.4			
		0.9	air space	
	−22.2			
L_{306}		4.8	1.73	28
	+8.3			
		1.5	air space	
	+16.2			
L_{307}		2.9	1.72	50
	−16.2			

26. The combination defined in claim **18** wherein said supplemental lens member L_{300x}, said ancillary lens member L_{300y} and the lenses L_{301}–L_{304} of said varifocal lens group have radii of curvature r, axial thicknesses

27. The combination defined in claim **26** wherein said supplemental lens member L_{300x} has an aspherical front surface substantially defined by the formula

$$x = \frac{y^2}{20(1+\sqrt{1-y^2/400})} - 5.5 \cdot 10^{-6}y^4$$

where x is the distance from a reference plane transverse to said axis and y is the distance from said axis.

28. The combination defined in claim **26** wherein said lens assembly further comprises a fixed-focus lens group on the image side of said varifocal lens group, the lenses L_{305}–L_{307} of said fixed-focus lens group having radii of curvature r, axial thicknesses and separations d, refractive indices n_d and Abbé numbers ν_d substantially as given in the following table:

	r	d	n_d	ν_d
	+11.0			
L_{305}		4.3	1.72	50
	−37.4			
		0.9	air space	
	−22.2			
L_{306}		4.8	1.73	28
	+8.3			
		1.5	air space	
	+16.2			
L_{307}		2.9	1.72	50
	−16.2			

* * * * *

OR 4,168,884

United State
Tesch

4,168,884
Sep. 25, 1979

[54] **VARIFOCAL OBJECTIVE WITH MECHANISM FOR CLOSEUP FOCUSING**

[75] Inventor: **Karl Tesch**, Bad Kreuznach, Fed. Rep. of Germany

[73] Assignee: **Jos. Schneider & Co. Optische Werke Kreuznach**, Bad Kreuznach, Fed. Rep. of Germany

[21] Appl. No.: **902,160**

[22] Filed: **May 2, 1978**

[30] **Foreign Application Priority Data**

May 25, 1977 [DE] Fed. Rep. of Germany 2723540

[51] **Int. Cl.**[2] **G02B 15/18**; G02B 7/10
[52] **U.S. Cl.** **350/187**; 350/255
[58] **Field of Search** 350/187, 186

[56] **References Cited**

U.S. PATENT DOCUMENTS

3,613,544	10/1971	Plihal et al.	350/187
3,655,271	4/1972	Suzuki	350/187
3,659,921	5/1972	Hirose et al.	350/186
3,661,445	5/1972	Someya	350/186
3,884,555	5/1975	Suwa et al.	350/187
4,054,372	10/1977	Schröeder	350/187

Primary Examiner—Jon W. Henry
Attorney, Agent, or Firm—Karl F. Ross

[57] **ABSTRACT**

A varifocal objective with a front component, axially shiftable for focusing purposes, and with a second and third component, axially displaceable by camming grooves in a control sleeve for changing the focal length, is provided with a coupling ring centered on the objective axis which is axially entrained by the lens mount of the front component. During normal operation, the coupling ring is indexed in a disengagement position. When the front component is in its infinity position and the control sleeve has cammed the second and third components into their wide-angle position, the coupling ring is manually rotatable into an engagement position in which it links the lens mount of the first component with that of the third component for joint axial shifting into a macro range by the focusing drive; such shifting is facilitated by an axial slot in the control sleeve preventing rotation of the latter in that range.

7 Claims, 3 Drawing Figures

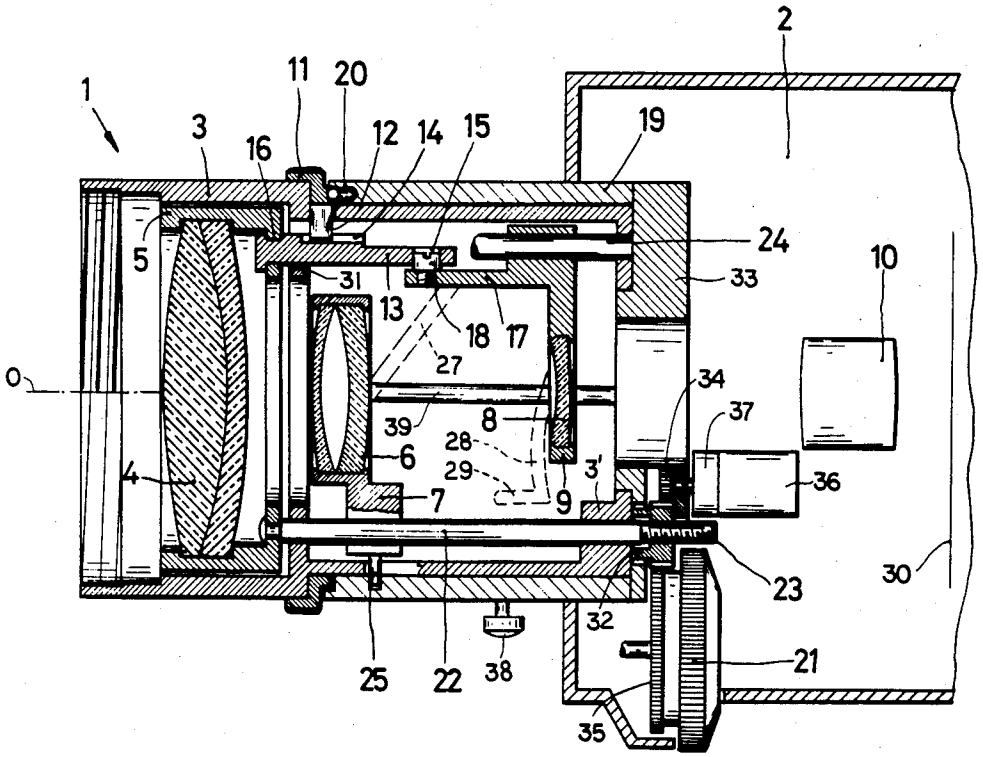


Fig.1

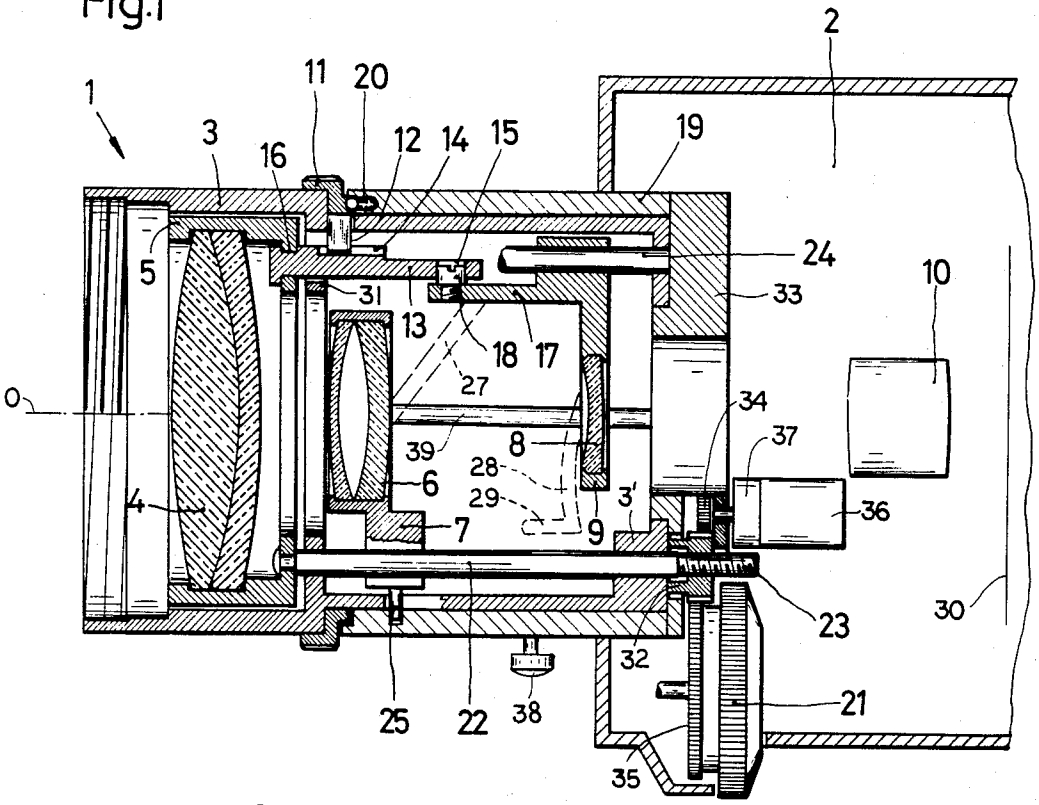


Fig.2

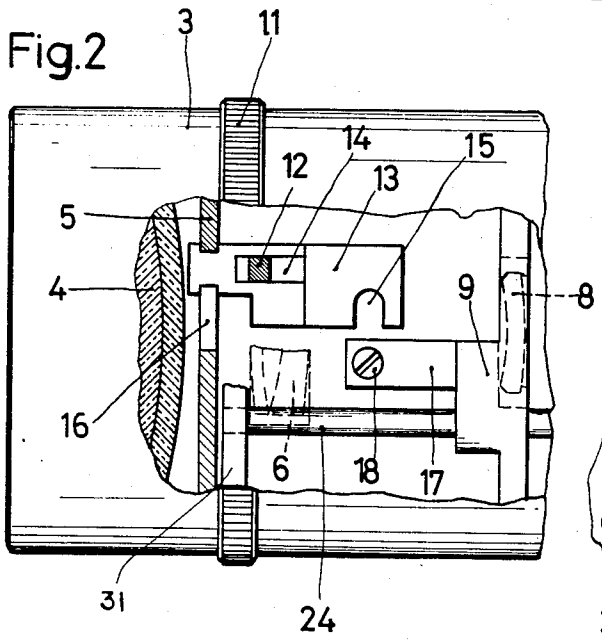
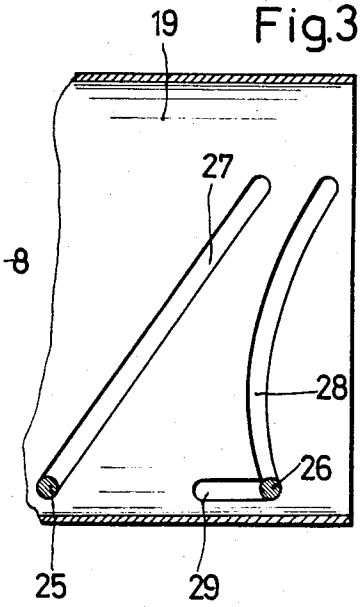


Fig.3



VARIFOCAL OBJECTIVE WITH MECHANISM FOR CLOSEUP FOCUSING

FIELD OF THE INVENTION

My present invention relates to a varifocal or zoom-type objective for a photographic or cinematographic camera in which an axial shift of an objective component, normally serving as a compensator to maintain a constant image-plane position during changes in focal length, facilitates the taking of closeup pictures in a macro range.

BACKGROUND OF THE INVENTION

Varifocal objectives of this type are well known per se, e.g. from U.S. Pat. Nos. 3,655,271 and 3,891,304. Reference in this connection may also be made to German printed specifications Nos. 2,023,804 and 2,029,254 as well as German published applications Nos. 2,634,941 and 2,634,964.

The term "macro range" encompasses distances closer than a normal focusing range, usually within limits giving image scales between 1:10 and 1:1. Whereas normal zooming involves the simultaneous displacement of the aforementioned compensator component (generally the third component as counted from the front or object side) and of the immediately preceding variator component (commonly the second one), the shift into the macro range is ordinarily carried out by the compensator component alone. The first or front component, considered stationary for the purpose of changing the overall focal length, is limitedly axially shiftable for focusing in both the normal and macro ranges.

OBJECT OF THE INVENTION

The object of my present invention is to provide a simple mechanism for enabling an axial shifting of the third or compensator component of a varifocal lens group, independently of the associated second or variator component, to facilitate the projection of images from objects closer than the normal focusing range upon the plane of a receiving surface such as that of a photosensitive film.

SUMMARY OF THE INVENTION

I realize this object, in accordance with my present invention, by the provision of a coupling element—preferably a milled ring—projecting outwardly from a lens barrel in which at least the first three components of a varifocal objective are located, this coupling element being manually rotatable about the objective axis between two alternate positions. A link member inside the lens barrel is connected with the coupling element for joint rotation therewith and is further connected with the first lens mount, carrying the front component of the objective, for axial entrainment thereby. This link member and the third lens mount, carrying the compensator component, are provided with complementary formations which are disengaged from each other in one of the aforementioned alternate positions but are aligned with each other in predetermined positions of a setting means serving for focusing and a camming means serving for focallength adjustment. Upon such alignment, a rotation of the coupling element into its alternate position interengages the complementary formations of the link member and of the third lens mount to facilitate a joint axial shifting of the front and compensator components into the macro range under the control of the aforementioned setting means.

BRIEF DESCRIPTION OF THE DRAWING

The above and other features of my invention will now be described in detail with reference to the accompanying drawing in which:

FIG. 1 is an axial sectional view of a cinematographic camera provided with an objective embodying my invention;

FIG. 2 is a fragmentary top view, with parts broken away, of the objective shown in FIG. 1; and

FIG. 3 is an axial sectional view of part of a camming sleeve used on the objective.

SPECIFIC DESCRIPTION

The camera shown in the drawing comprises a varifocal or zoom-type objective, generally designated **1**, and a camera body or housing **2**. The objective **1** is provided with a lens barrel **3** which projects from the camera housing **2** and is centered on an optical axis O. Also centered on this axis are several lens members constituting a positively refracting front component **4**, two negatively refracting intermediate components **6**, **8** and a stationary rear component **10**. The latter, disposed outside lens barrel **3** within housing **2**, consists of a plurality of lenses not illustrated individually.

Components **6** and **8** are provided with respective lens mounts **5**, **7** and **9** which are individually displaceable along axis O. The shifting of lens mount **5** for focusing purposes is carried out by a mechanism similar to that disclosed and claimed in commonly owned U.S. patent application Ser. No. 894,031 filed Apr. 6, 1978 by Karl-Heinz Holderbaum. The focusing mechanism comprises an axially extending guide rod **22** which is slidably and nonrotatably received in an inner annular flange **3'** of lens barrel **3** and terminates inside housing **2** in a rear extremity **23** carrying male threads matingly engaged by a captive nut **32**. This nut, held against axial displacement by the flange **3'** and an end wall **33**, carries external gear teeth in mesh with a pinion **34** and with a toothed wheel **35**. Pinion **34** can be driven by a reversible motor **36**, via a slipping clutch **37**, whereas wheel **35** is rigid with a milled setting wheel **21** which is rotatable about an axis parallel to optical axis O. Setting wheel **21** may be provided with two distance scales relating to a normal focusing range and to a macro range, respectively. Motor **36** is energizable from a nonillustrated power supply, e.g. as described in commonly owned U.S. Pat. No. 3,165,044.

As disclosed in the above-identified Holderbaum application, lens mount **5** can be stabilized with the aid of an additional and preferably shorter guide rod not shown.

Lens mounts **7** and **9**, carrying the variator component **6** and the compensator component **8**, are displaceable in a manner well known per se by the rotation of a sleeve **19**, provided for this purpose with a knob **38**, which has camming grooves **27** and **28** engaged by respective pins **25** and **26** (see FIG. **3**) on these lens mounts, the cam-follower pins passing through an axially extending slot **39** of lens barrel **3**. Lens mounts **7** and **9** are slidably supported on axially extending guide rods including the rod **22** and at least one other rod **24**.

In accordance with my present invention, a milled coupling ring **11** projects outwardly from an annular groove in lens barrel **3** just ahead of camming sleeve **19**.

A lug 12 rigid with ring 11 extends inwardly through an arcuate slot in the lens barrel and engages in an axially extending slot 14 of a link member 13 whose front end is received in an arcuate cutout 16 of lens mount 5 centered on axis O. Link member 13 is peripherally displaceable inside cutout 16 between a normal angular position, shown in FIG. 2, and an alternate position in which a recess 15 on a rear part of that member is engaged by a stud 18 on a forward extension 17 of lens mount 9. A rotation of ring 11 into this alternate position is evidently not possible unless link member 13 and extension 17 are aligned with each other as illustrated in FIG. 2. Such alignment occurs when the camming sleeve 19 is in its limiting position at the wide-angle end of the varifocal range, with pins 25 and 26 lying at the lower ends of their cam tracks 27 and 28 as viewed in FIG. 3, and when setting wheel 21 has retracted the lens mount 5 into its extreme right-hand position to focus the objective on the distal end of the normal range, generally infinity.

If, under these circumstances, coupling ring 11 is rotated into its alternate position to interengage the complementary formations 15 and 18 of member 13 and lens mount 9, rotation of wheel 21 results in a joint axial displacement of objective components 4 and 8. Such displacement is facilitated by the provision of a spur 29 extending from the lower end of the rear of cam track 28, the entry of pin 26 into that spur preventing any rotation of camming sleeve 19. The forward shifting of compoents 4 and 8 by means of setting wheel 21 focuses the objective upon objects in the macro range whose images are thereby projected upon a film plane 30.

Ring 11 is yieldably retained in its alternate or coupling position by indexing means here shown as a ball check 20 lodged in camming sleeve 19. Thus, rotation of sleeve 19 from the position of FIG. 3 in the direction of the larger focal lengths automatically decouples the link member 13 from lens mount 9.

Although the manual control of lens mount 5 by a setting wheel 21 on the camera body 2 is very convenient, the illustrated arrangement could be modified to replace the wheel 21 by a focusing ring on the forward end of the lens barrel as disclosed and claimed in commonly owned U.S. patent application Ser. No. 896,588 filed 14 Apr. 1978 by Paul Himmelsbach.

I claim:

1. In a camera comprising a housing, a lens barrel projecting from said housing, said lens barrel being centered on an optical axis, and an objective centered on said axis, said objective including a front component held in a first lens mount, a variator component held in a second lens mount and a compensator component held in a third lens mount, said lens mounts being axially shiftable in said lens barrel, camming means operatively coupled with said second and third lens mount for axially shifting same to change the focal length of the objective between a wide-angle end and a telephoto end of a varifocal range while keeping an image plane of the objective coincident with a receiving surface, and setting means independent of said camming means coupled with said first lens mount for axially shifting same to project upon said receiving surface the images of objects located at different distances from the camera within a normal focusing range,

the combination therewith of a coupling element projecting outwardly from said lens barrel for manual rotation about said axis between two alternate positions, and a link member in said lens barrel connected with said element for joint rotation and with said first lens mount for axial entrainment thereby, said link member and said third lens mount being provided with complementary formations disengaged from each other in one of said alternate positions but aligned with each other in predetermined positions of said setting means and said camming means for enabling interengagement of said formations upon a rotation of said element into the other alternate position thereof, such interengagement facilitating a joint axial shifting of said front and compensator components into a macro range under the control of said setting means to project upon said receiving surface the images of objects closer than said normal focusing range.

2. The combination defined in claim 1 wherein said element is a ring held in said lens barrel against axial movement.

3. The combination defined in claim 2 wherein said first lens mount is provided with an arcuate cutout centered on said axis, said link member having a front end projecting into said cutout with freedom of peripheral displacement relative to said first lens mount, said link member further having an axial slot engaged by an inward projection of said ring.

4. The combination defined in claim 1 or 3 wherein said camming means comprises a rotatable sleeve centered on said axis and provided with front and rear tracks respectively engaged by cam followers on said second and third lens mounts, said rear track having an axially extending spur enabling the axial shifting of said third lens mount by said setting means in a predetermined position of said sleeve while locking the latter against rotation in said macro range.

5. The combination in claim 4 wherein said predetermined positions of said setting means are at a distal end of said normal focusing range and at said wide-angle end of the varifocal range, respectively.

6. The combination defined in claim 4 wherein said element and said sleeve adjoin each other and are provided with indexing means yieldably connecting said element in said other alternate position with said sleeve in said predetermined position thereof.

7. The combination defined in claim 1 wherein said setting means comprises a guide rod extending axially rearwardly from said first lens mount, said guide rod terminating in a threaded extremity within said housing, a captive nut in said housing meshing with said extremity, and drive means for rotating said nut.

* * * * *

OR 4,165,916

United States Patent [19]
Nakamura

[11] 4,165,916
[45] Aug. 28, 1979

[54] **OBJECTIVE LENS SYSTEM WITH CLOSE OBJECT FOCUSING ABERRATION CORRECTION**

[75] Inventor: **Akiyoshi Nakamura**, Sakai, Japan

[73] Assignee: **Minolta Camera Kabushiki Kaisha**, Osaka, Japan

[21] Appl. No.: **815,376**

[22] Filed: **Jul. 13, 1977**

[30] **Foreign Application Priority Data**

Jul. 16, 1976 [JP] Japan 51/85244

[51] **Int. Cl.**[2] **G02B 9/62**; G02B 9/60
[52] **U.S. Cl.** **350/215**; 350/209; 350/210; 350/216
[58] **Field of Search** 350/215, 207, 209, 210, 350/255, 216

[56] **References Cited**

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3,883,228	5/1975	Betensky	350/215 X

FOREIGN PATENT DOCUMENTS

2364469 9/1974 Fed. Rep. of Germany 350/216

Primary Examiner—Paul A. Sacher
Attorney, Agent, or Firm—Jackson, Jones & Price

[57] **ABSTRACT**

An objective lens system, for example of a Gauss or Tessar type is provided having the capability of adequately correcting aberrations even when the lens system is focussed at a relatively close object. The lens system is adaptable for use in cameras and comprises a first lens group including an aperture stop and a second lens group positioned on the image side of the first lens group. The second lens group includes a first lens sub-group of positive refracting power and a second lens sub-group of negative refractive power. The air spaces provided between the first lens group and the first lens sub-group and also between the first lens sub-group and the second lens sub-group are varied to compensate for changes in aberrations resulting from focussing at a relatively close object. More specifically, the first air space is increased while the second air space is decreased when the object distance of the lens system is decreased.

14 Claims, 56 Drawing Figures

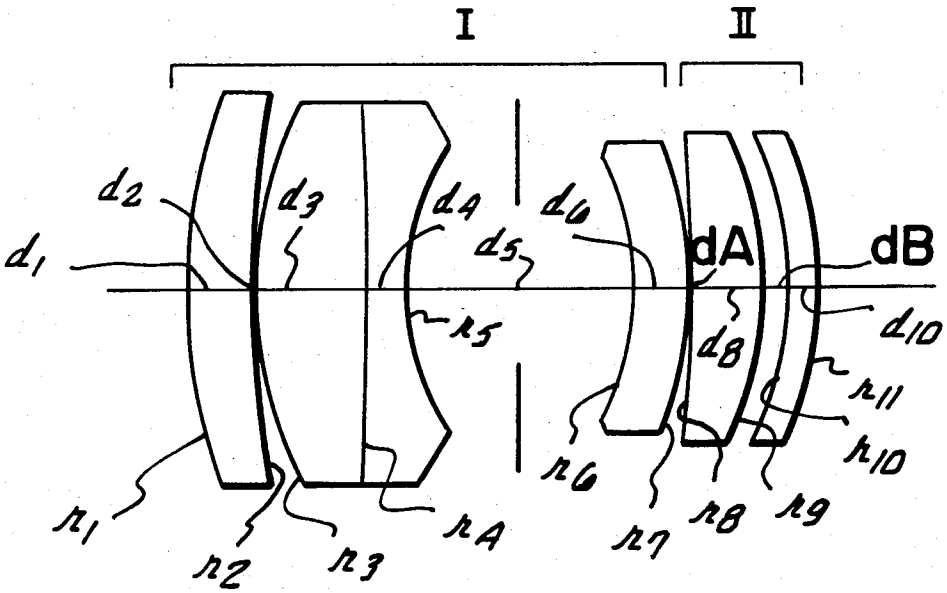


FIG.1

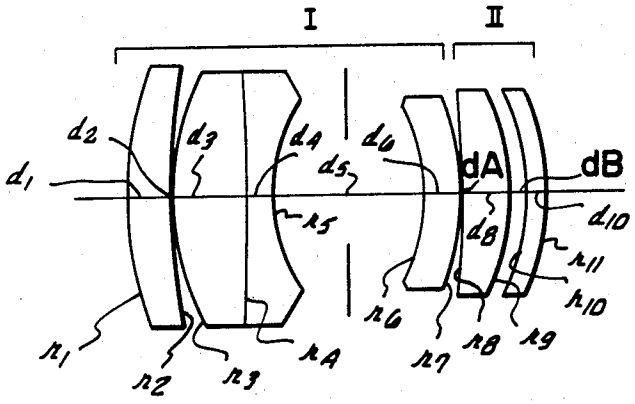
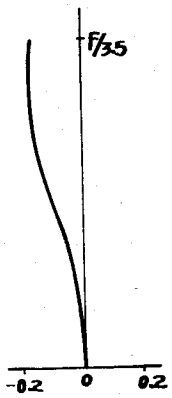
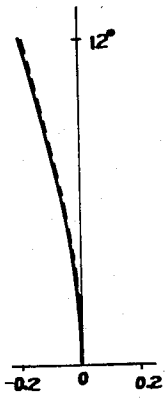


FIG.2a



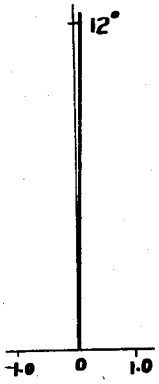
Spherical Aberration

FIG.2b



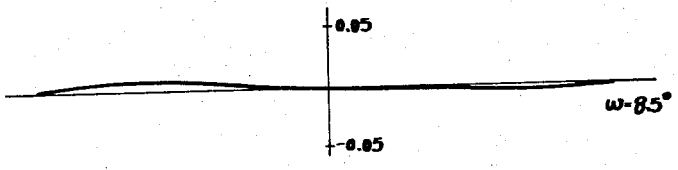
Astigmatism

FIG.2c



Distortion

FIG.2d



Coma

FIG.3

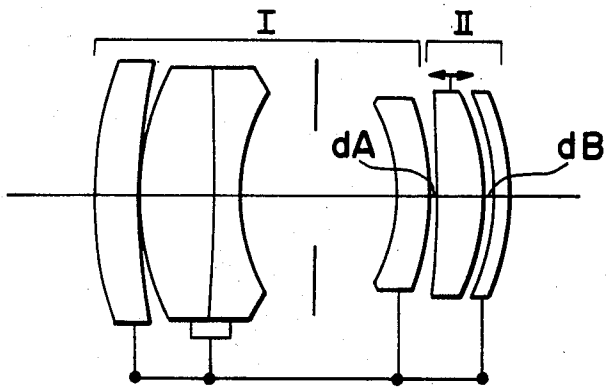
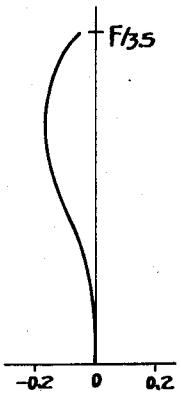
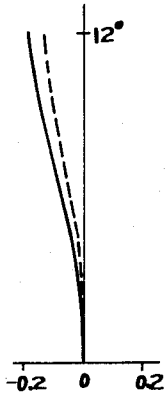


FIG.4a



Spherical Aberration

FIG.4b

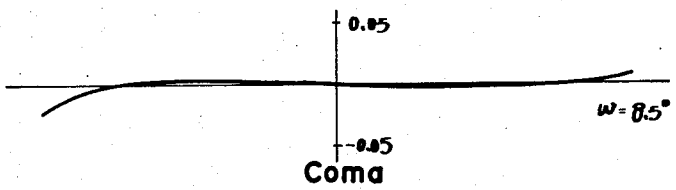


Astigmatism

FIG.4c

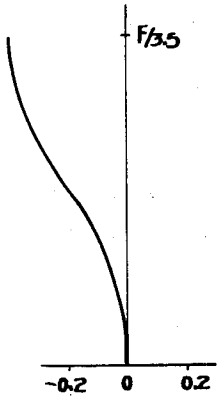
Distortion

FIG.4d



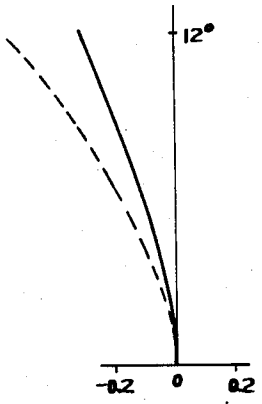
Coma

FIG.5a



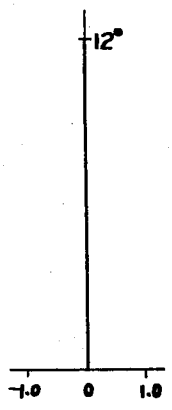
Spherical Aberration

FIG.5b



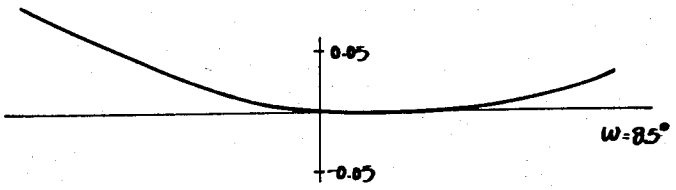
Astigmatism

FIG.5c



Distortion

FIG.5d



Coma

FIG.6

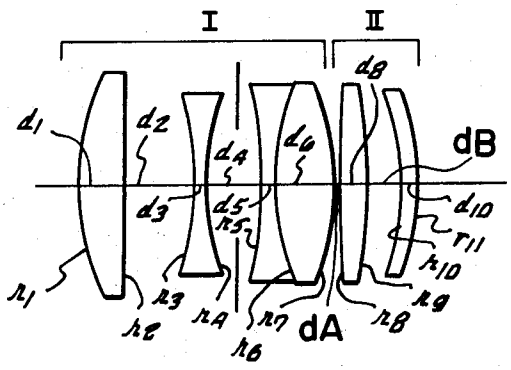
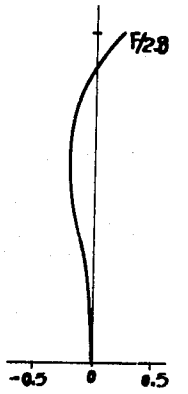
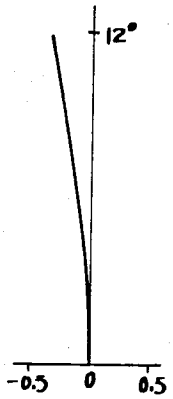


FIG.7a



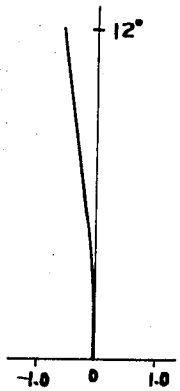
Spherical Aberration

FIG.7b



Astigmatism

FIG.7c



Distortion

FIG.7d

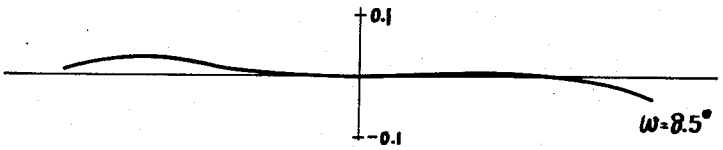


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FIG.8

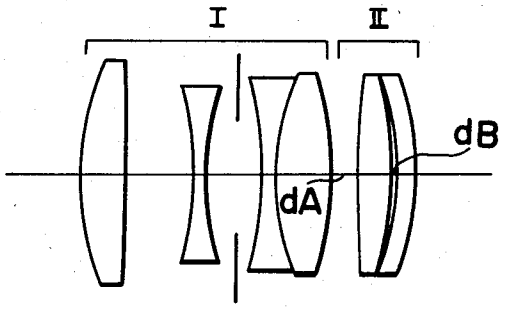
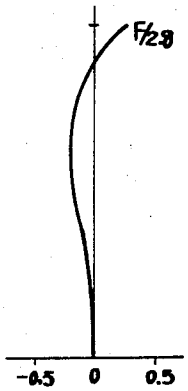
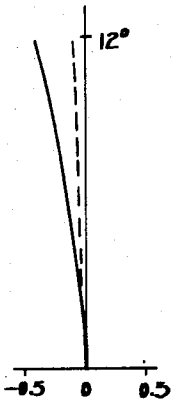


FIG.9a



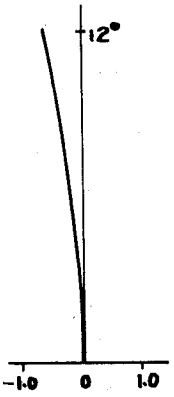
Spherical Aberration

FIG.9b



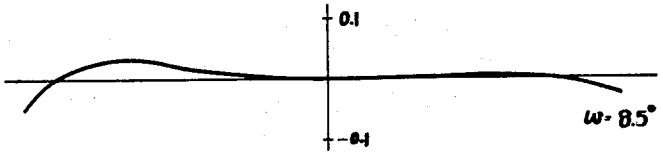
Astigmatism

FIG.9c



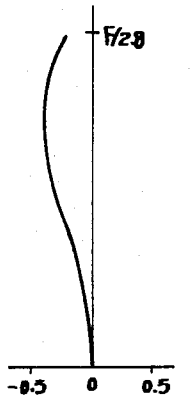
Distortion

FIG.9d



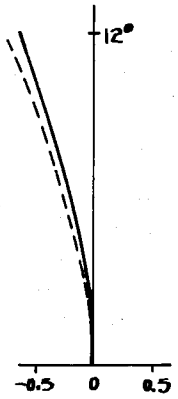
Coma

FIG.10a



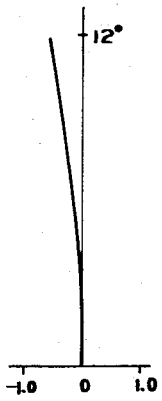
Spherical Aberration

FIG.10b



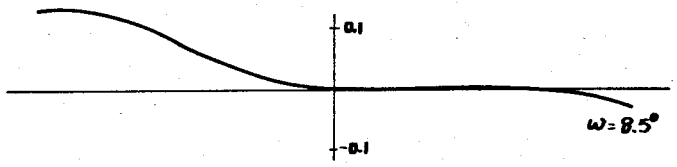
Astigmatism

FIG.10c



Distortion

FIG.10d



Coma

FIG.11

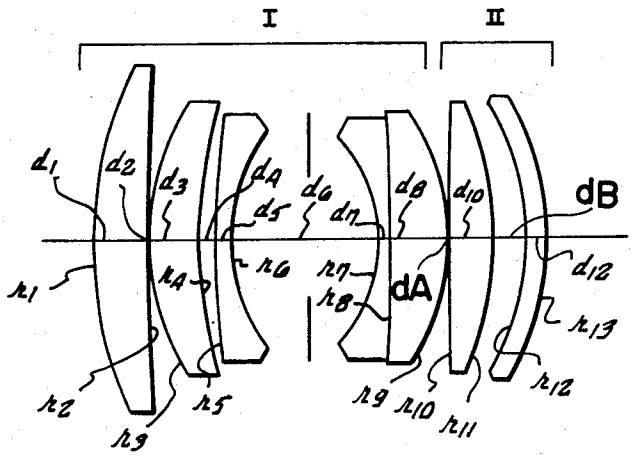
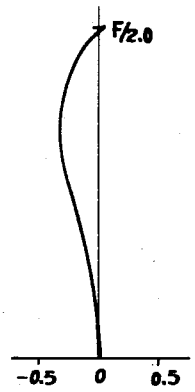
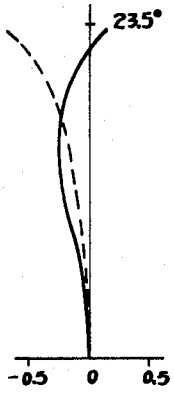


FIG.12a



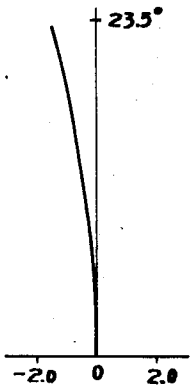
Spherical Aberration

FIG.12b



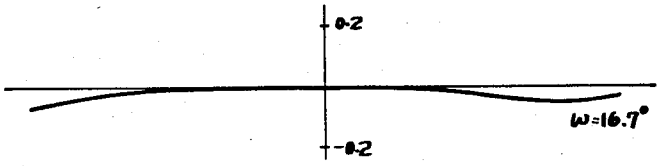
Astigmatism

FIG.12c



Distortion

FIG.12d



Coma

FIG.13

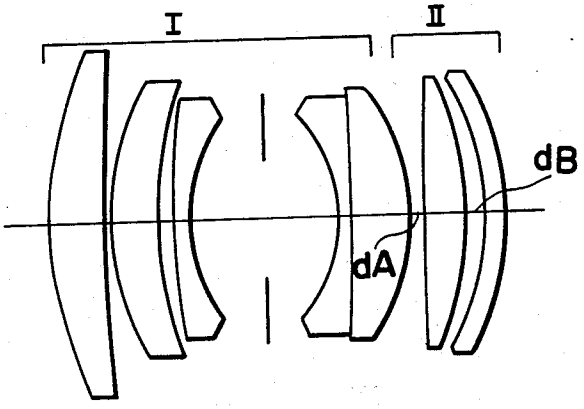
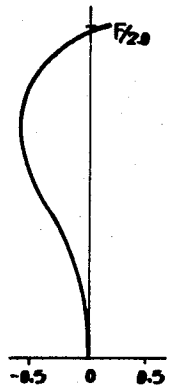
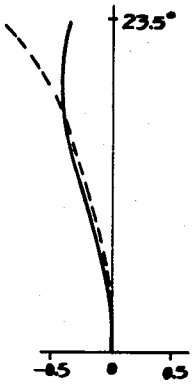


FIG.14a



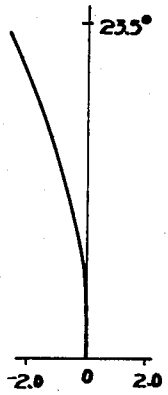
Spherical Aberration

FIG.14b



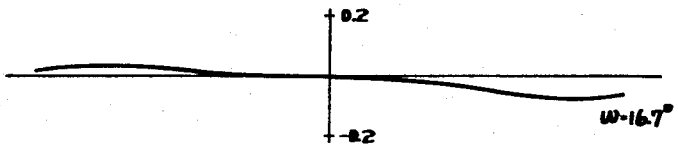
Astigmatism

FIG.14c



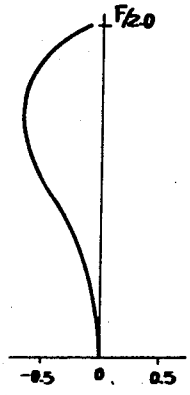
Distortion

FIG.14d



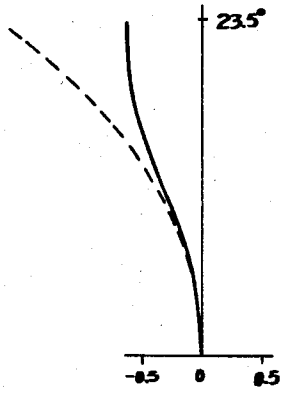
Coma

FIG.15a



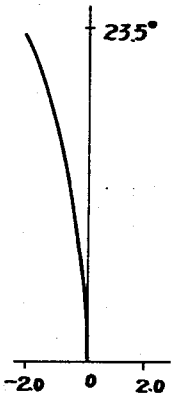
Spherical Aberration

FIG.15b



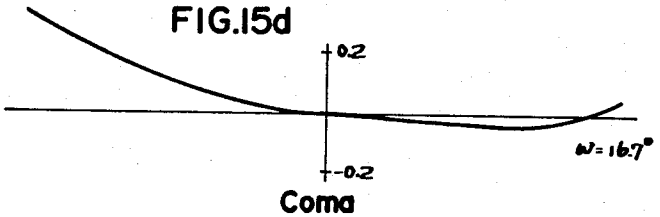
Astigmatism

FIG.15c



Distortion

FIG.15d



Coma

FIG.16

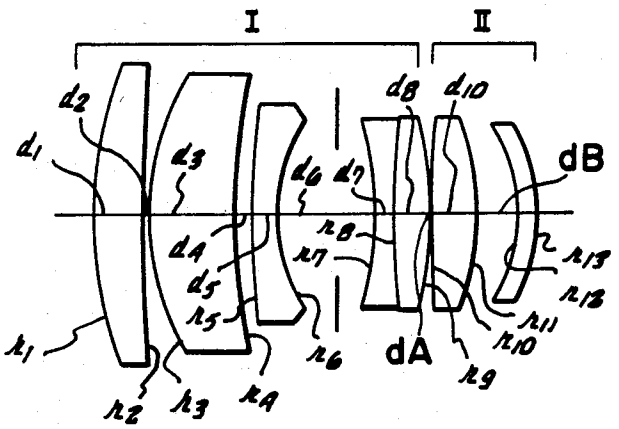
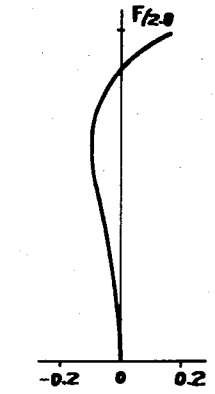
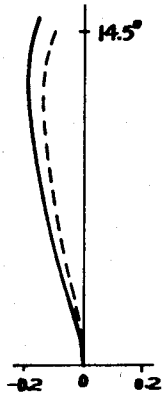


FIG.17a



Spherical Aberration

FIG.17b

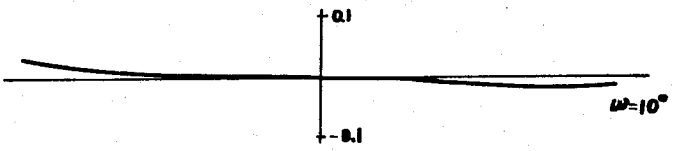


Astigmatism

FIG.17c

Distortion

FIG.17d



Coma

FIG.18

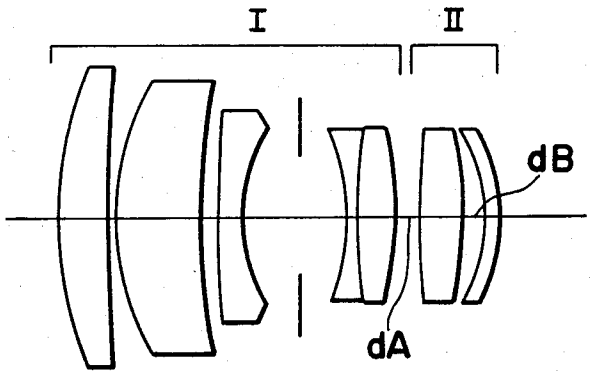
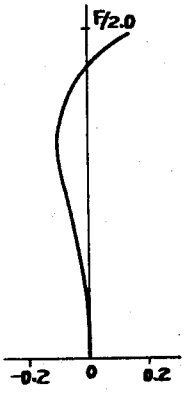
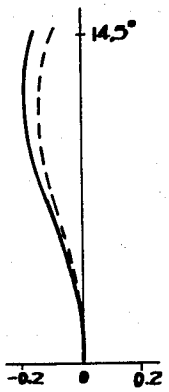


FIG.19a



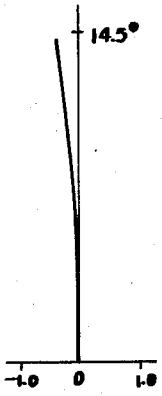
Spherical Aberration

FIG.19b



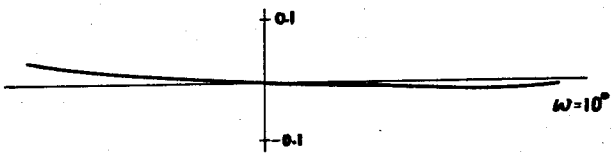
Astigmatism

FIG.19c



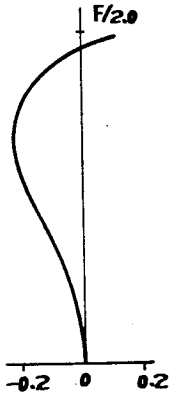
Distortion

FIG.19d



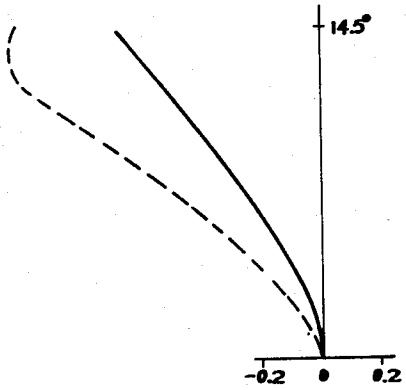
Coma

FIG.20a



Spherical Aberration

FIG.20b

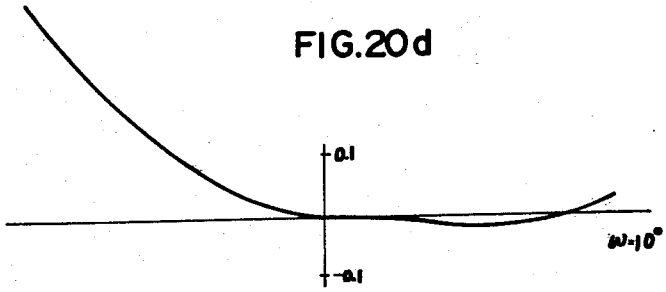


Astigmatism

FIG.20c

Distortion

FIG.20d



Coma

OBJECTIVE LENS SYSTEM WITH CLOSE OBJECT FOCUSING ABERRATION CORRECTION

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to a photographic camera objective lens system, for example of the Gauss or Tessar type having a tendency to increase various aberrations when the photographic object is relatively close to the lens system, and more particularly to such an objective lens system which incorporates means for compensating aberrations when focussing at a close object.

2. Brief Description of the Prior Art

The prior art is familiar with the aberration problems that are created when it is desired to utilize a lens system for focussing at relatively close objects. For example, a lens system is known wherein an air space behind a diaphragm in the lens system is provided before a positive overall refractive power lens group. This air space is varied in coordination with focussing to compensate for any changes in aberrations. The axial rays passing through this air space are convergent. Thus, by widening this air space the height of the axial rays relative to the optical axis that are incident on the positive lens group can be reduced to accordingly reduce the refraction of the axial rays by the positive lens group and thereby compensate for spherical aberrations. Additionally, the height of the off-axial rays incident on the same positive lens group will also be varied to compensate for astigmatism and coma. An example of such an optical design approach to compensate for these aberrations is disclosed in U.S. Pat. No. 3,815,974.

However, a design problem exists, in that the convergent axial rays in the variable air space become divergent when the object distance becomes sufficiently close. Accordingly, when photographing an object at a relatively close distance a point will be reached in which it is no longer possible to obtain an effective compensation for spherical aberration. If this focussing range is sought to be increased by maintaining the convergence of the axial rays in the variable air space, the lens group at the object side of the variable air space must be provided with a considerably strong positive refractive power. The provision of this power distribution in the lens system, however, would create problems and would not provide a desirable design solution.

Another patent of general interest for its disclosure of various air spaces in a photocopier application can be found in U.S. Pat. No. 3,883,228.

The prior art is still seeking an optical design to optimize the correction of aberrations when focussing at close distances within a commercial priced lens system for the average photographer.

SUMMARY OF THE INVENTION

An object of the present invention is to overcome the compensation problems associated with focussing on an object at a relatively close distance, while at the same time providing a lens system that is capable of providing a balanced compensation for spherical aberration, astigmatism and coma.

Accordingly, an objective lens system for cameras and the like with a close focussing capability is provided having a first lens group which includes an aperture stop. On the image side of the first lens group, a second lens group is positioned and defines with the first lens group a first air space. The second lens group can be subdivided into a first lens sub-group of positive refractive power and a second lens sub-group of negative refractive power. The first and second lens sub-groups are spaced from each other to form a second air space.

Compensation for aberrations is provided by a compensation means which can increase the relative first air space displacement of the first lens group and the first lens sub-group when the object distance of the lens system is decreased during focussing at a close object. While, at the same time, the compensation means can decrease the second air space between the first and second lens sub-groups. The compensation means thereby provides adequate compensation for aberrations resulting from focussing at a close object.

Any variation in the focal length f, of the lens system resulting from variations in the axial air spaces, dA and dB, if any, are maintained with ± 3 percent of the focal length of the lens system while focussed at infinity.

The features of the present invention which are believed to be novel are set forth with particularity in the appended claims. The present invention, both as to its organization, and manner of operation, together with further objects and advantages thereof, may be best understood by reference to the following description, taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic cross-sectional view of a first embodiment of the present invention focussed at infinity;

FIGS. **2***a*, **2***b*, **2***c* and **2***d* disclose respectively the spherical aberration, astigmatism, distortion and coma for the lens system of FIG. **1**;

FIG. **3** is a schematic cross-sectional view of FIG. **1** focussed at an object distance corresponding to a magnification of 0.25;

FIGS. **4***a*, **4***b*, **4***c* and **4***d* respectively show the spherical aberration, astigmatism, distortion and coma for the lens system of FIG. **3**;

FIGS. **5***a*, **5***b*, **5***c* and **5***d* disclose the respective aberration curves resulting when the lens system of FIG. **1** has been shifted to a magnification of 0.25 without varying the variable air spaces;

FIG. **6** discloses a schematic cross-sectional view of a second embodiment of the present invention focussed at infinity;

FIGS. **7***a*, **7***b*, **7***c* and **7***d* show respectively the spherical aberration, astigmatism, distortion and coma of the lens system of FIG. **6**;

FIG. **8** shows the lens system of FIG. **6** focussed at an object distance corresponding to a magnification of 0.25;

FIGS. **9***a*, **9***b*, **9***c* and **9***d* show respectively the spherical aberration, astigmatism, distortion and coma of the lens system of FIG. **8**;

FIGS. **10***a*, **10***b*, **10***c* and **10***d*, are the respective aberration curves for the lens system of FIG. **6** focussed at an object distance corresponding to a magnification of 0.25 without varying the variable air spaces;

FIG. **11** shows a schematic cross-sectional view of a third embodiment of the present invention focussed at infinity;

FIGS. **12***a*, **12***b*, **12***c* and **12***d* show the resulting aberration curves for the embodiment of FIG. **11** when focussed at infinity;

FIG. **13** is a schematic view of FIG. **11** focussed to an object distance corresponding to a magnification of 0.25;

FIGS. **14***a*, **14***b*, **14***c* and **14***d* show the resulting aberration curves for the lens system of FIG. **13**;

FIGS. **15***a*, **15***b*, **15***c* and **15***d* are the aberration curves for the embodiment of FIG. **11** when the lens groups have been shifted to a magnification of 0.25 without varying the variable air spaces;

FIG. **16** shows a schematic cross-sectional view of a fourth embodiment of the present invention focussed at infinity;

FIGS. **17***a*, **17***b*, **17***c* and **17***d*, show the various aberration cirves for the lens system of FIG. **16** when focussed at infinity;

FIG. **18** shows the lens system of FIG. **16** focussed to an object distance corresponding to a magnification of 0.25;

FIGS. **19***a*, **19***b*, **19***c* and **19***d* show the resulting aberration curves for FIG. **18**; and

FIGS. **20***a*, **20***b*, **20***c* and **20***d* show the resulting aberration curves for the embodiment of FIG. **16** when the lens group has been shifted to a magnification of 0.25 without varying the variable air spaces.

BRIEF DESCRIPTION OF THE PREFERRED EMBODIMENTS

The following description is provided to enable any person skilled in the optical art to make and use the invention and sets forth the best modes contemplated by the inventor of carrying out his invention. Various modifications, however, will remain readily apparent to those skilled in the art, since the generic principles of the present invention has been defined herein specifically to provide an objective lens system with close focussing capabilities.

The derivation of the values and their relationships as set forth in the tables, hereinafter, can be accomplished with the assistance of a computer. The present invention represents the parameters of a compromised balance of acceptable aberrations in an objective lens system for utilization, for example, with a camera.

In the accompanying drawings, which supplement the tables, the lenses in accordance with the present invention, are illustrated diagrammatically using reference symbols which indicate groups of lenses. As usual, in conventional lens diagrams, the light is assumed to travel from left to right, the radii of curvature of the lens are indicated by, r, with a subscript corresponding to consecutive surfaces of the lens elements and the axial spacings, d, along the optical axis are also indicated with a consecutive subscript. In the tables, the minus signs indicate surfaces concave toward the object side, while the surfaces without a sign are convex toward the object side. The value of the axial spacing symbol, d, includes both the axial spacing between the lens elements and the thickness of the lens elements. The axial spacings between the lens elements are positioned accordingly relative to the radii in the tables while the thicknesses are designated accordingly between the radii. Zero axial spacing indicates lens elements cemented to each other. All other axial spacings greater than zero refer to air spacings.

All linear dimensions are given in absolute values and are given with reference to the equivalent focal length of unity. The tables also provide with respect to each example, the intended relative aperture, the total angle of view, 2ω, and the back focal length, S, with reference to an object at infinity.

Referring specifically to FIG. **1**, a first embodiment of the present invention is schematically disclosed with the lens elements therein positioned for photographing at infinity.

A first lens group (I) can have either a positive or negative overall refractive power and includes a diaphragm or aperture stop. A second lens group (II) is axially displaced from the first lens group and has a positive overall refractive power. The resulting air space, dA, between the first lens group and the second lens group can be varied in association with focussing. Taking into account the appropriate design considerations, the height of the off-axial rays incident on the second lens group off the optical axis, can be varied to correct for astigmatism and coma.

The second lens group (II) comprises a positive lens and a negative meniscus lens respectively from object to image side and includes a second air space, dB, between these two lenses. The second air space has a cross-sectional configuration of a meniscus air lens with its concave side facing the diaphragm. By varying this second air space, dB, the distance of the intersection or incidence of the convergent axial rays, emergent from the positive lens, and off-set from the optical axis can be varied on the negative meniscus lens. Thus, when dB is narrowed, the height from the optical axis of the axial rays incident on the negative meniscus lens is increased so that the negative refractive power of the negative meniscus lens exerts a greater influence on the axial rays to positively displace the spherical aberration. In this arrangement, the axial rays in the air space, dA, need not be convergent, however, if the rays are convergent in the air space, dA, the spherical aberration can also be corrected in the same manner associated with the displacement or variation of the air space dB.

Because the air space of air lens, dB, has a configuration of a meniscus lens with its concave side facing the diaphragm, any variation in the axial spacing of dB, produces substantially no astigmatism. Therefore, the present inventor has discovered that by shifting the lens system for photographing a close object with magnification in the range of 0.25, a satisfactory aberration condition can always be maintained by increasing the air space, dA, especially to correct for astigmatism and coma. Further, by decreasing the air space, dB, it is possible to correct the spherical aberration.

FIGS. **2***a*, **2***b*, **2***c* and **2***d* show various aberration curves for respectively spherical aberration, astigmatism, distortion and coma when the lens system of FIG. **1** is focused at infinity.

The schematic cross-sectional view of the lens system of FIG. **3** discloses the lens system of FIG. **1** shifted to focus on a close object so that the magnification is $\beta=0.25$. As can be seen from FIG. **3**, the positive lens of the second lens group has been shifted toward the image side relative to the entire system when compared with FIG. **1** to thereby increase the air space dA, and decrease the air space dB. This shifting produces the desirable intersection or incidence of the convergent axial rays to thereby adequately compensate for the various aberrations. This compensation can be seen in the graphs of FIGS. **4***a*, **4***b*, **4***c* and **4***d*. In this arrangement, the air space dA=0.012 and the air space dB=0.011 with a lens system focal length f=1.002.

Simply for comparison sake, FIGS. **5***a*, **5***b*, **5***c* and **5***d* show aberration curves that have been plotted to dis-

close the situation that occurs when the lens system of Table 1 has been shifted to a magnification of $\beta=0.25$ without varying the air spaces dA and dB.

TABLE 1

f=1.0 FNo.=3.5 2ω=24° Back Focal Length S=0.69

Radius of Curvature		Axial Distance	Refractive Index	Abbe Number
r_1 = 0.452		d_1 = 0.048	N_1 = 1.7755	ν_1 = 37.9
r_2 = 0.788		d_2 = 0.003		
r_3 = 0.293		d_3 = 0.082	N_2 = 1.6779	ν_2 = 55.5
r_4 = −16.234		d_4 = 0.028	N_3 = 1.6545	ν_3 = 33.9
r_5 = 0.201		d_5 = 0.174		
r_6 = −0.223		d_6 = 0.04	N_4 = 1.6815	ν_4 = 36.8
r_7 = −0.348		d_7 = 0.003	(dA:Variable)	
r_8 = −1.916		d_8 = 0.05	N_5 = 1.6589	ν_5 = 56.5
r_9 = −0.282		d_9 = 0.02	(dB:Variable)	
r_{10} = −0.271		d_{10} = 0.02	N_6 = 1.6583	ν_6 = 57.4
r_{11} = −0.329				

A second embodiment of the present invention is disclosed in FIG. **6**. The purpose of the air spacing and its effect on the incident axial rays are the same as described with respect to the first embodiment and, therefore, it is not necessary to repeat this description. The aberration curves for the second embodiment, focussed at infinity, are shown respectively in FIGS. **7***a*, **7***b*, **7***c* and **7***d*.

FIG. **8** discloses the second embodiment with the lens system focussed at a relatively close distance, magnification $\beta=0.25$, dA=0.048 and dB=0.013 with a focal length, f=1.009. The resultant aberration curves for this close focus position are shown respectively in FIGS. **9***a*, **9***b*, **9***c* and **9***d*. FIGS. **10***a*, **10***b*, **10***c* and **10***d* are the respective aberration curves produced when the lens system of FIG. **6** has been shifted for close focussing, $\beta=0.25$ (without varying the air spaces dA and dB).

TABLE 2

f=1.0 FNo.=2.8 2ω=24° Back Focal Length S=0.81

Radius of Curvature		Axial Distance	Refractive Index	Abbe Number
r_1 = 0.484		d_1 = 0.072	N_1 = 1.6661	ν_1 = 47.9
r_2 = −6.382		d_2 = 0.114		
r_3 = −0.638		d_3 = 0.024	N_2 = 1.6741	ν_2 = 31.9
r_4 = 0.465		d_4 = 0.092		
r_5 = −0.794		d_5 = 0.024	N_3 = 1.5821	ν_3 = 42.0
r_6 = 0.383		d_6 = 0.096	N_4 = 1.658	ν_4 = 51.4
r_7 = −0.552		d_7 = 0.011	(dA:Variable)	
r_8 = 3.105		d_8 = 0.05	N_5 = 1.6661	ν_5 = 47.9
r_9 = −0.776		d_9 = 0.05	(dB:Variable)	
r_{10} = −0.456		d_{10} = 0.03	N_6 = 1.6661	ν_6 = 47.9
r_{11} = −0.491				

A third embodiment of the present invention is shown in a schematic view as FIG. **11** with the lens system focussed at infinity. The resultant aberration curves for this mode of operation is shown respectively in FIGS. **12***a*, **12***b*, **12***c* and **12***d*.

FIG. **13** shows the lens system of FIG. **11** focused at a close distance, $\beta=0.25$, wherein dA=0.025 and dB=0.038. In this particular lens design, the focal length, f=1.000 can be maintained. The aberration curves for this close focussing arrangement is shown respectively in FIGS. **14***a*, **14***b*, **14***c* and **14***d*. Again, for comparison, aberration curves were derived as disclosed in FIGS. **15***a*, **15***b*, **15***c* and **15***d* for the lens system of FIG. **11** shifted for close focusing, $\beta=0.25$ without varying the air spaces dA and dB in accordance with the teachings of the present invention to minimize the aberrations.

TABLE 3

f=1.0 FNo.=2 2ω=47° Back Focal Length S=0.71

Radius of Curvature		Axial Distance	Refractive Index	Abbe Number
r_1 = 0.666		d_1 = 0.093	N_1 = 1.6935	ν_1 = 50.3
r_2 = 5.009		d_2 = 0.004		
r_3 = 0.433		d_3 = 0.084	N_2 = 1.6700	ν_2 = 47.1
r_4 = 0.695		d_4 = 0.025		
r_5 = 1.400		d_5 = 0.027	N_3 = 1.6545	ν_3 = 33.9
r_6 = 0.293		d_6 = 0.248		
r_7 = −0.273		d_7 = 0.024	N_4 = 1.6477	ν_4 = 33.9
r_8 = −3.777		d_8 = 0.097	N_5 = 1.6779	ν_5 = 55.5
r_9 = −0.367		d_9 = 0.003	(dA:Variable)	
r_{10} = 8.963		d_{10} = 0.07	N_6 = 1.6935	ν_6 = 51.9
r_{11} = −0.577		d_{11} = 0.06	(dB:Variable)	
r_{12} = −0.423		d_{12} = 0.03	N_7 = 1.6975	ν_7 = 58.3
r_{13} = −0.454				

Finally, a fourth embodiment of the present invention is disclosed in FIG. **16** focussed at infinity. The corresponding aberration curves for this mode of focussing operation are disclosed respectively in FIGS. **17***a*, **17***b*, **17***c* and **17***d*.

FIG. **18** shows the fourth embodiment of FIG. **16** with the lens elements positioned for close focusing. The magnification is $\beta=0.25$ and air space distances are dA=0.043 and dB=0.029 with a focal length f=1.009. The aberration curves set forth in FIGS. **19***a*, **19***b*, **19***c* and **19***d*, respectively disclose resulting aberrations with this close focusing position. FIGS. **20***a*, **20***b*, **20***c* and **20***d* set forth the aberration curves for simply comparison of the lens system of FIG. **16** shifted for a magnification $\beta=0.25$ without varying the air spaces dA and dB.

TABLE 4

f=1.0 FNo.=2 2ω=29° Back Focal Length S=0.51

Radius of Curvature		Axial Distance	Refractive Index	Abbe Number
r_1 = 0.708		d_1 = 0.085	N_1 = 1.7495	ν_1 = 50.4
r_2 = 3.767		d_2 = 0.007		
r_3 = 0.443		d_3 = 0.144	N_2 = 1.7495	ν_2 = 50.4
r_4 = 0.899		d_4 = 0.03		

TABLE 4-continued

f=1.0 FNo.=2 2ω=29° Back Focal Length S=0.51

Radius of Curvature		Axial Distance	Refractive Index	Abbe Number
r5 =	1.985			
		d5 = 0.04	N3 = 1.733	ν3 = 28.1
r6 =	0.270			
		d6 = 1.172		
r7 =	−0.415			
		d7 = 0.025	N4 = 1.6645	ν4 = 35.7
r8 =	0.997			
		d8 = 0.065	N5 = 1.6779	ν5 = 55.5
r9 =	−0.633			
		d9 = 0.0015	(dA:Variable)	
r10 =	2.313			
		d10 = 0.075	N6 = 1.7106	ν6 = 43.2
r11 =	−0.541			
		d11 = 0.07	(dB:Variable)	
r12 =	−0.296			
		d12 = 0.03	N7 = 1.7106	ν7 = 43.2
r13 =	−0.315			

The values in each of the above Tables 1 through 4 are representative of their corresponding lens systems focussed at infinity.

As can be readily appreciated in veiw of the above description, the present invention utilizes a second lens group comprising, object to image side, a positive lens, a negative meniscus lens with the interposition of a variable air space, dB, therebetween so that spherical aberration may be compensated by taking advantage of the convergence of the axial rays in this variable air space. It should be realized, that the axial rays entering this variable air space dB, need not necessarily be convergent and dA, may be relied upon mainly for the correction of astigmatism and coma. By the specific selection of the aboveidentified lens elements, and their manipulation relative to the air spaces, it is possible to obtain a well-balanced correction for spherical aberration, astigmatism and coma while extending the range of photography to closer distances in the order of a magnification $\beta=0.25$. This is accomplished without placing an excessive design burden on the power of the first lens group. Thus, relatively easily assembled lens system compatible to conventional lens barrels can be produced. The advantages of the present invention are particularly valuable in increasing the relative object distance range for photography in an economical manner while still providing satisfactory aberration compensations to insure a high-quality lens system.

As can be readily appreciated, it is possible to deviate from the above embodiments of the present invention and will be readily understood by those skilled in the art that the invention is capable of many modifications and improvements within the scope and spirit thereof. Accordingly, it will be understood that the invention is not to be limited by the specific disclosed embodiment but only by the scope and spirit of the appended claims.

What is claimed is:

1. An objective lens system for cameras with a close focusing capability comprising;

a first lens group including an aperture stop;

a second lens group of an overall positive refractive power spaced from the image side of the first lens group to form a first air space, the second lens group consisting of a first lens sub-group of positive refractive power having an image side convex surface and a second lens sub-group of negative refractive power having an object side concave surface and an image side convex surface, the first and second lens sub-groups being spaced from each other to form a second air space, and

compensation means for increasing the relative first air space displacement of the first lens group and the first lens sub-group when the object distance of the lens system is decreased during focusing and decreasing the relative second air space between the first and second lens sub-groups to compensate for aberrations resulting from focusing on a close object.

2. The invention of claim 1, wherein the first lens sub-group consists of a single positive lens having an image side convex surface and the second sub-group consists of a negative meniscus single lens convex to the image side.

3. The invention of claim 2, wherein the first lens group has an image side convex surface.

4. The invention of claim 3, wherein the positive lens of the first lens sub-group has an object side concave surface.

5. The invention of claim 3, wherein the positive lens of the first sub-group has an object side convex surface.

6. The invention of claim 2, wherein the first lens group comprises, from the object to the image side, a positive meniscus lens convex to the object side, a first negative meniscus lens convex to the object side, an aperture stop and a second negative meniscus lens convex to the image side, the first negative meniscus lens consists of a positive lens element and a negative lens element cemented to the positive lens element at the image side thereof.

7. The invention of claim 6, wherein the positive meniscus lens of the first lens group consists of a single lens element and the second negative meniscus lens consists of a single lens element.

8. The invention of claim 2, wherein the first lens group comprises, from the object to the image side, a first positive lens, a biconcave lens, an aperture stop and a second positive lens.

9. The invention of claim 8, wherein one of the positive lenses of the first lens group consists of a cemented doublet and each of the other lenses of the first lens group consists respectively of a single lens element.

10. The invention of claim 2, wherein the first lens group comprises, from the object to the image side, a first positive meniscus lens convex to the object side, a second positive meniscus lens convex to the object side, a first negative meniscus lens convex to the object side, an aperture stop and a second negative meniscus lens convex to the image side.

11. The invention of claim 10, wherein the second negative meniscus consists of a negative lens element and a positive lens element cemented to the negative lens element at the image side thereof and each of the other respective lens elements of the first lens group consists of a single lens.

12. The invention of claim 1, wherein the position of the second lens sub-group is fixed relatively to the first lens group and the first lens sub-group is movable relatively to both the first lens group and the second sub-group for varying the first and second air spaces.

13. An objective lens system comprising a design parameter of approximately the values set forth within the following specification:

f=1.0 FNo.=2ω=47° Back Focal Length S=0.71

Radius of Curvature	Axial Distance	Refractive Index	Abbe Number
r_1 = 0.666			
	d_1 = 0.093	N_1 = 1.6935	ν_1 = 50.3
r_2 = 5.009			
	d_2 = 0.004		
r_3 = 0.433			
	d_3 = 0.084	N_2 = 1.6700	ν_2 = 47.1
r_4 = 0.695			
	d_4 = 0.025		
r_5 = 1.400			
	d_5 = 0.027	N_3 = 1.6545	ν_3 = 33.9
r_6 = 0.293			
	d_6 = 0.248		
r_7 = −0.273			
	d_7 = 0.024	N_4 = 1.6477	ν_4 = 33.9
r_8 = −3.777			
	d_8 = 0.097	N_5 = 1.6779	ν_5 = 55.5
r_9 = −0.367			
	d_9 = 0.003	(dA:Variable)	
r_{10} = 8.963			
	d_{10} = 0.07	N_6 = 1.6935	ν_6 = 51.9
r_{11} = −0.577			
	d_{11} = 0.06	(dB:Variable)	
r_{12} = −0.423			
	d_{12} = 0.03	N_7 = 1.6975	ν_7 = 48.3

-continued

f=1.0 FNo.=2ω=47° Back Focal Length S=0.71

Radius of Curvature	Axial Distance	Refractive Index	Abbe Number
r_{13} = −0.454			

wherein dA and dB refer to intralens air spaces.

14. A close focusing objective lens system for cameras comprising:

a first lens group including an aperture stop, and

a positive refractive power second lens group adjacent to the first lens group at the image side thereof, the second lens group consists of a first lens element of a positive refractive power having an image side surface convex to the image side and a second lens element of a negative refractive power adjacent to the image side of the first lens element and having a concave object side surface and a convex image side surface, a first variable air space is formed between the first lens group and the first lens element which is increased as the object distance of the lens system is decreased, while a second variable air space is formed between the first lens element and the second lens element which is decreased as the object distance of the lens system is decreased, the variation in the respective first and second air spaces providing compensation for changes in aberrations resulting from focusing to a close object.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 4,165,916

DATED : August 28, 1979

INVENTOR(S) : AKIYOSHI NAKAMURA

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

In Column 6, line 40 delete "58.3" and insert --48.3--.

In Column 9, line 2 delete "f=1.0FNo.=2ω=47°" and insert --f=1.0 FNo.=2 2ω=47°--.

Signed and Sealed this

First Day of April 1980

[SEAL]

Attest:

SIDNEY A. DIAMOND

Attesting Officer

Commissioner of Patents and Trademarks

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United Stat

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[11] **4,162,827**

[45] **Jul. 31, 1979**

[54] **WIDE ANGLE OBJECTIVE FOR OPHTHALMOSCOPIC INSTRUMENT**

[75] Inventor: **Yuji Ito,** Chigasaki, Japan

[73] Assignee: **Canon Kabushiki Kaisha,** Tokyo, Japan

[21] Appl. No.: **802,877**

[22] Filed: **Jun. 2, 1977**

[30] **Foreign Application Priority Data**

Jun. 9, 1976 [JP] Japan 51/67521

[51] **Int. Cl.**[2] **A61B 3/14**

[52] **U.S. Cl.** **351/7;** 350/234; 351/13; 351/16; 354/62

[58] **Field of Search** 351/7, 13, 16, 6; 354/62; 350/234

[56] **References Cited**

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Primary Examiner—Paul A. Sacher

Attorney, Agent, or Firm—Toren, McGeady and Stanger

[57] **ABSTRACT**

An ophthalmoscopic camera with an achromatic objective arranged on a common optical axis of an image forming lens in front of a photographic film and adapted to project a ring-shaped bundle of illuminating light rays onto the cornea of an eye to be photographed as the illuminating light rays come from a light source through a relay lens after reflection from an apertured mirror positioned between the objective and the image forming lens at an angle with the optical axis thereof. For an increase in the angle of view, the objective is constructed in the form of a biconvex triplet consisting of a forwardly convex negative meniscus lens, an equiconvex lens and a rearwardly convex negative meniscus lens with its four refracting surfaces so configured and so separated that a beam of image forming rays passing through a central aperture of the illuminating mirror to the film can be made free from disturbing light reflections from these four lens surfaces by use of a single black spot positioned at a point between the light source and the mirror in coaxial relation thereto.

7 Claims, 3 Drawing Figures

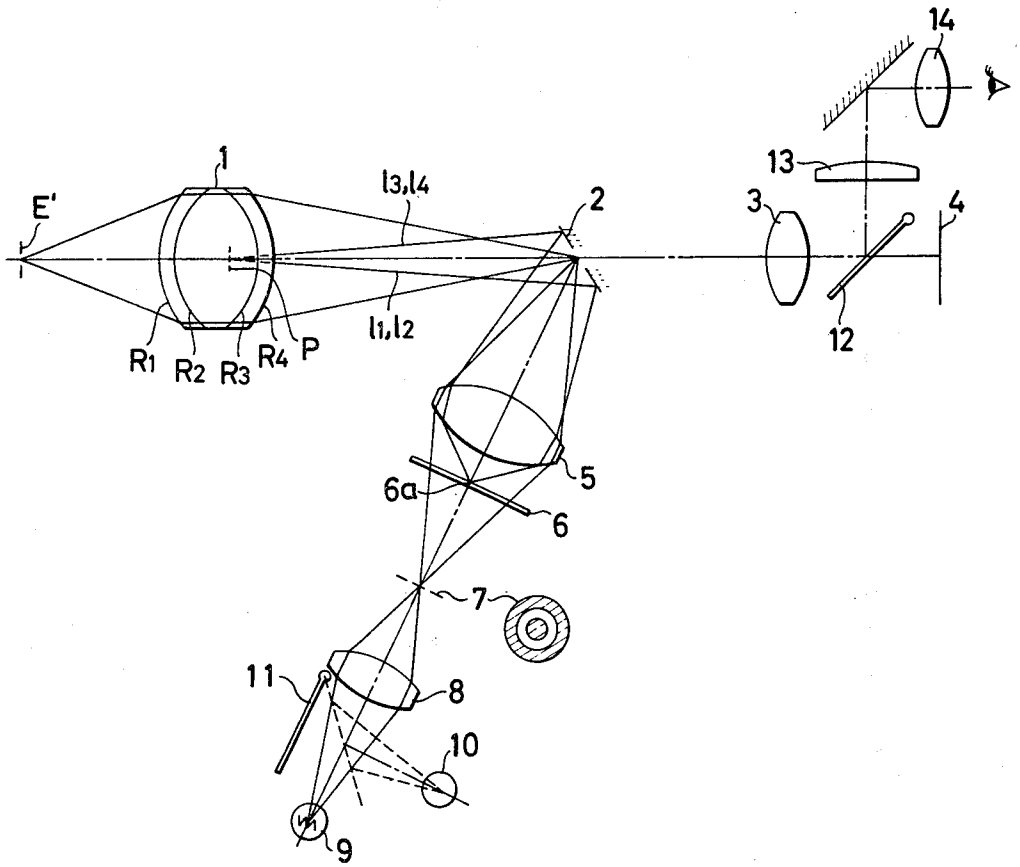


FIG. 1

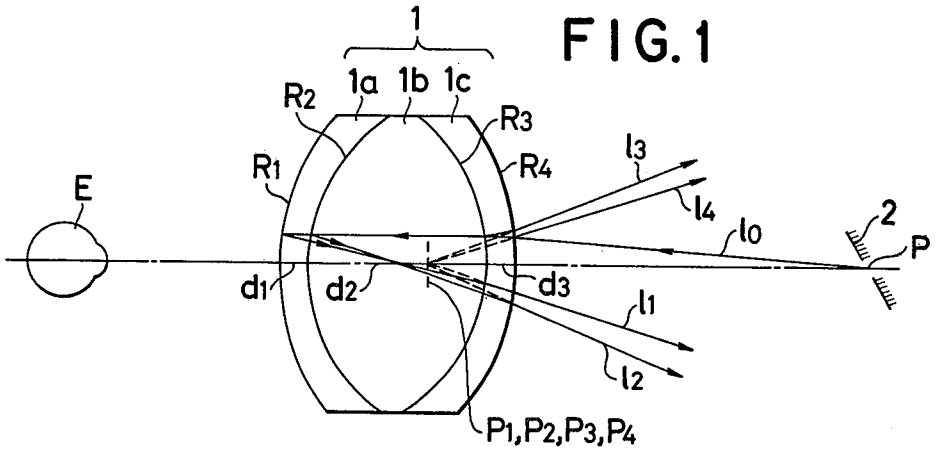


FIG. 2

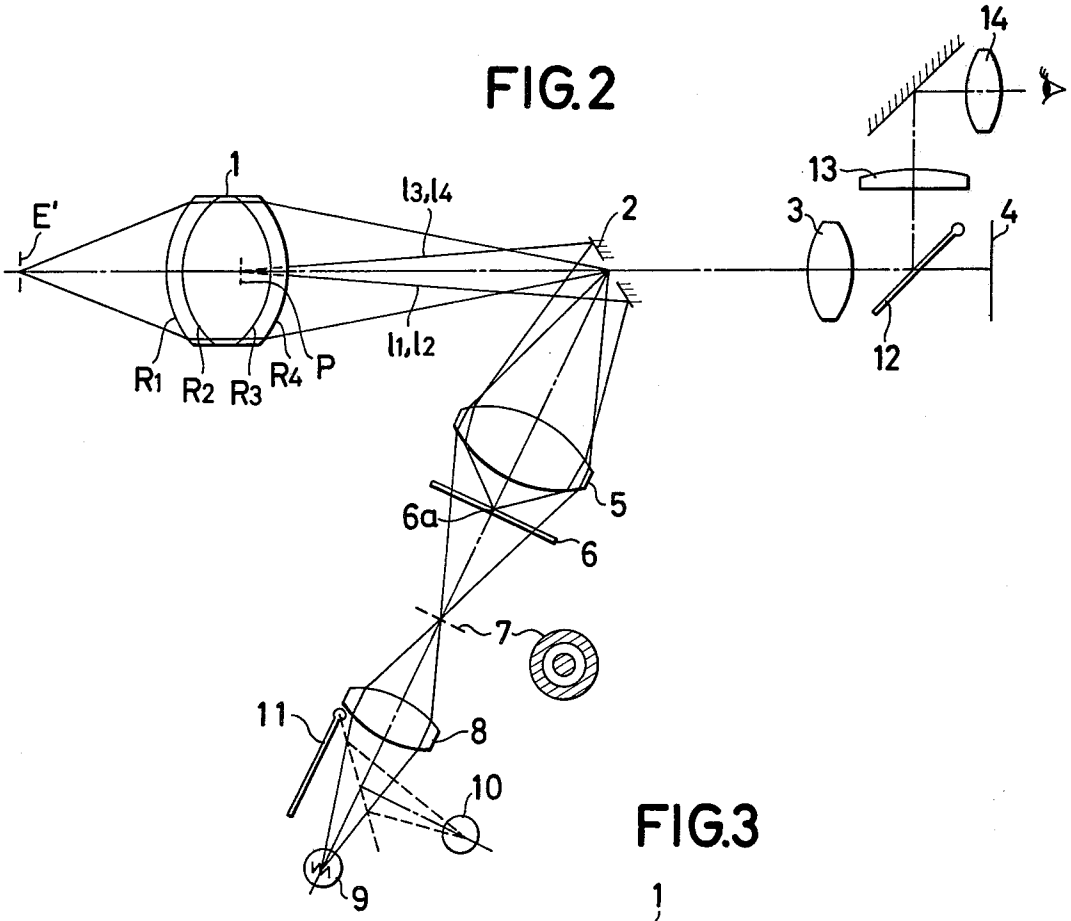
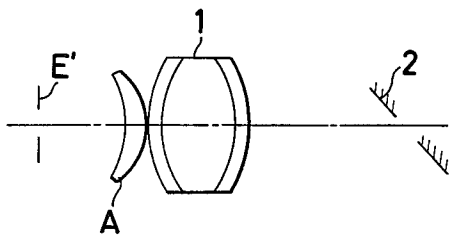


FIG. 3



WIDE ANGLE OBJECTIVE FOR OPHTHALMOSCOPIC INSTRUMENT

BACKGROUND OF THE INVENTION

This invention relates to ophthalmoscopic instruments, and more particularly to a wide angle achromatic photographic objective for use in such ophthalmoscopic instruments.

In conventional ophthalmoscopes and eye-fundus cameras, a large proportion of the objectives are formed as a positive meniscus lens convex toward an object (human eye). With this type objective, however, the angle of view has to be limited to about 30 degrees or less, or otherwise a substantially lowered picture quality will be resulted.

To increase the angle of view up to about 45 degrees, the objective preferably takes a biconvex form. When a chromatic correction is required, the biconvex objective is generally designed to have a cemented surface or surfaces. This gives rise to introduction of disturbing reflections from the cemented surface or surfaces.

SUMMARY OF THE INVENTION

A primary object of the present invention is to increase the angle of view of an achromatic photographic objective for use in an ophthalmoscopic instrument.

A secondary object is to provide a wide angle achromatic objective with the cemented surfaces formed therein to a configuration suitable for eliminating the undesirable light reflected from the cemented surfaces as the illuminating light rays are projected through the objective to the cornea of an eye to be examined.

According to the present invention, the objective is constructed in the form of a triplet consisting of, in the direction in which the image forming rays enter, a negative meniscus lens convex toward the eye, a biconvex lens, and a negative meniscus lens concave toward the eye. By employing the biconvex form for the central constituent lens in the triplet, it is made possible to eliminate all the disturbing light reflections from the cemented surfaces as well as from the front and rear surfaces by limiting the necessary number of light obscuring spots to only one as arranged in the path of illuminating light rays.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram of one embodiment of an achromatic photographic objective according to the present invention with geometrical illustration of the effect on elimination of the disturbing reflections from the various surfaces thereof.

FIG. 2 is a schematic sectional view of an ophthalmoscopic camera with the objective of FIG. 1.

FIG. 3 is a lens block diagram showing an example of modification of the objective.

DESCRIPTION OF THE PREFERRED EMBODIMENT

In FIGS. 1 and 2 and especially FIG. 2, there is shown an ophthalmoscopic camera for photographing the fundus of an eye E with its pupil indicated at E'. The camera includes an achromatic photographic objective 1 and an image-forming lens 3 arranged along a common optical axis in starting from the object end in front of a photographic film 4. Positioned between the objective 1 and the image forming lens 3 is an apertured mirror 2 inclined at an angle to the optical axis with an aperture disposed at its center coincident to the optical axis. The mirror 2 constitutes part of an illuminating optical arrangement which further includes a relay lens 5 adapted to produce an image of a ring-shaped patch 7 on the mirror 2, a condenser lens 8 positioned behind the path 7 in optically alined relation thereto for selectively forming an image of either one of two light sources, namely, a filament coil of an incandescent lamp 9 and an arc of a flash-tube 10 on the path 7. A mirror 11 in the illuminating optical arrangement is pivotable between an illustrated position where the incandescent lamp 9 is selected for visual observation of the ocular fundus through a viewfinder optical system, and a position indicated by a dashed line where the flash-tube 10 is selected for the exposure of the film 4. The viewfinder optical system comprises a reflex mirror 12 movable between a viewing position illustrated and a non-viewing position, a field lens 13, and an eye-piece 14. When the mirror 12 is in the viewing position, a final image of the ocular fundus is formed on the field lens 13 and can, therefore, be viewed by an eye of an observer looking through the eye-piece 14. It is to be noted here that instead of using the eye-piece 14 a collective lens may be used in combination with a pick-up tube with its image receiving surface being position in coincidence with the focal plane of the collective lens, so that an image of the ocular fundus is displayed on the Braun tube.

With this illuminating optical arrangement, it is possible to illuminate an annular zone of the pupil E' while the central portion remains unilluminated, as the objective 1 is adapted to project a final image of the ring-shaped patch 7 on the plane of the pupil E'. The image forming rays reflected from the retina and emerging from the pupil E' are collected by the objective 1 to form an intermediate image of the retina in front of the illuminating mirror 2. The size of the aperture of the illuminating mirror 2 is adjusted so that only that portion of the emergent rays from the pupil E' which passes through the unilluminated central portion thereof is allowed to pass through the aperture of the illuminating mirror 2. That portion is then focused by the image forming lens 3 on the film 4, provided that the mirror 12 is in the non-viewing position. An image of the fundus of the eye E is thus recorded on the film 4.

The illuminating light rays are incident on the front and rear surfaces R_1 and R_4 respectively in a direction opposite to that of the image forming rays. Hence a certain fraction of the illuminating rays is reflected from the rear surface R_4 so they diverge, and an additional fraction is reflected from the front surface R_1 so they converge. Both serve as disturbing incident light on the film 4. It is known that such disturbing light reflections can be eliminated, as, for example, disclosed in Japanese Patent Application Publication No. Sho 44-8406 and No. Sho 47-44645. However, no care has been taken of the disturbing reflections from the cemented surface or surfaces in the achromatic objective.

FIG. 1 shows one embodiment of the photographic objective according to the present invention the lens is constructed in the form of an achromatic triplet 1 consisting of a negative meniscus lens 1*a* convex toward the eye E to be photographed, a biconvex lens 1*b*, in this instance, equiconvex lens, and a negative meniscus lens 1*c* concave toward the eye E cemented at their adjoining surfaces. The material of the two negative meniscus lenses 1*a* and 1*c* has a higher index of refraction and a

lower Abbe number than those of the material of the positive lens **1***b*.

In order to produce a beam of image forming light rays free from disturbing incident light rays between the objective **1** and the illuminating mirror **2**, specific requirements are set forth as follows. Assuming now that a light ray, l_0, emanating from a point P on the central plane of the aperture of the illuminating mirror **2** impinges on the objective **1**, four different virtual image points P_1, P_2, P_3 and P_4 are formed at different positions within the body of the objective by respective reflected rays, l_1, l_2, l_3, and l_4, from the respective surfaces R_1, R_2, R_3 and R_4 after the necessary successive refractions at the incident surfaces. In order to eliminate the four reflected rays, therefore, it is necessary to provide four black spots in the illuminating optical arrangement at respective positions conjugate to those of the virtual image points P_1 to P_4. If the positions of these four black spots deviate from one another to a large extent, the possibility arises of a lack of uniformity of illumination over the entire area of the fundus of the eye E. This would happen even when two of the image points, namely, P_1 and P_4 are made to coincide with each other by means known in the art.

According to the present invention, the four surfaces R_1 to R_4 are oriented in the same direction in each pair of adjacent surfaces, that is, in the front pair of surfaces R_1 and R_2, and the rear pair of surfaces R_3 and R_4, so as to bring the image points P_1 and P_4 into coincidence at a point, and the image point P_2 and P_3 into coincidence at that point. Thus the number of black spots necessary can be reduced to only one. Also provided for is the proper adjustment of the size of the spot. In the latter connection, it is to be noted that the size of the black spot can be minimized when the magnitudes of the virtual images points P_1 and P_4 of the spot are made equal to each other. To achieve this, it is required that the radii of curvature of the surfaces, R_1 and R_4 and the axial thicknesses of the constituent lenses, d_1, d_2 and d_3, must fulfill the following relationships:

$$|R_1| = |R_4| = d_1 + d_2 + d_3 \quad (1)$$

$$|R_2| = |R_3| = d_2 \quad (2)$$

$$d_1 = d_3 \quad (3)$$

Referring again to FIG. **2**, there is shown an example of arrangement and construction of a single black spot. This single black spot **6***a* is provided on a transparent plate **6** located between the relay lens **5** and the ring-shaped patch **7** at a point conjugate to that point at which the four image points P_1 to P_4 coincide with one another with respect to the combination of the illuminating aperture mirror **2** and the relay lens **5**. The size of the black spot **6***a* is found to be determined by the size of the aperture of the mirror and the magnifying power of the relay lens **5**. Because the magnitudes of the virtual images P_2 and P_3 are usually smaller than those of the virtual images P_1 and P_4, the size of the black spot **6***a* depends upon the latter images. Further, it is not necessary to establish the exact coincidence of the positions of the virtual images, because a small deviation therefrom can be compensated for by a small increase in the size of the spot.

An example of a specific achromatic triplet may be constructed in accordance with the numerical data given in the following table for the radii, R_1 to R_4, the lens thicknesses, d_1 to d_3, along with the corresponding indices of refraction, nd_1 to nd_3, for the spectral D line of sodium, and the Abbe numbers, Vd_1 to Vd_3, of the various lenses. The minus values of the radii, R_3 and R_4, indicate surfaces concave toward the image forming incident light. Instead of using the spherical surface as R_4, an aspheric surface may be used. In this case, the standard spherical surface for the aspheric surface applies to the relationships.

Focal length	f = 100	Angle of view	2ω = 45°
$R_1 = 95.70$			
	$d_1 = 9.57$	$nd_1 = 1.7552$	$Vd_1 = 27.5$
$R_2 = 76.56$			
	$d_2 = 76.56$	$nd_2 = 1.6170$	$Vd_2 = 62.8$
$R_3 = -76.56$			
	$d_3 = 9.57$	$nd_3 = 1.7552$	$Vd_3 = 27.5$
$R_4 = -95.70$			

As shown in FIG. **3**, the photographic objective of the present invention may include an aplanatic lens A as has already been proposed in a U.S. patent application Ser. No. 797,636 assigned to the assignee of the present invention. If so, the aplanatic lens A must be positioned in front of the triplet **1** of FIGS. **1** and **2** with the center of curvature of the front surface of lens A being in coincidence with the center of the aperture of the pupil E'. The rear surface of the lens A is an aplanatic surface.

What is claimed is:

1. An opthalmoscopic optical instrument having a wide angle of view of an object comprising;

objective lens means having a positive refractive power and including a triplet cemented lens consisting of a negative meniscus lens convex toward the object, a biconvex lens and a negative meniscus lens concave toward the object; said triplet cemented lens having outer lens surfaces and cemented surfaces

an image forming lens for re-imaging an image formed by said objective lens means; and

an illuminating system having at least one light source for illumination of the object, apertured mirror for directing the illuminating light rays toward the object, and optical means for transmitting the light rays emanating from said light source to said apertured mirror, said apertured mirror being positioned on the object end of said image forming lens group; said apertured mirror being positioned between said objective lens means and said image forming lens; masking means positioned between said light source and said apertured mirror for substantially eliminating reflection from the outer lens surfaces and cemented surfaces of said triplet cemented lens; light-detecting means positioned on the image end of said image forming lens and light directing means positioned between said image forming lens group and said light-detecting means to direct the imaging light to an observing system for observation of an image of the object.

2. An ophthalmoscopic optical instrument according to claim **1**, wherein said negative meniscus lens, biconvex lens, and negative meniscus lens are cemented together in the order stated.

3. An ophthalmoscopic optical instrument according to claim **2**, wherein the radius of curvature of each of the outer two negative meniscus lenses is substantially equal to the sum of the axial thicknesses of the two negative meniscus lenses and the biconvex lens, and

each radii of curvature of the surfaces of the biconvex lens is equal to the axial thickness of the biconvex lens.

4. An ophthalmoscopic optical instrument according to claim 1, wherein said optical means comprises a condenser lens group and a relay lens group.

5. An ophthalmoscopic optical instrument having a wide angle of view of an object comprising:

objective lens means having a positive refractive power and including a triplet cemented lens, said triplet cemented lens having a negative meniscus lens convex toward the object, a biconvex lens and a negative meniscus lens concave toward the object in the order mentioned;

an image forming lens for re-imaging an image formed by said objective lens means;

an illuminating system including at least one light source for illumination of the object, beam-reflecting means for directing the illuminating beam toward said objective lens means, and optical means for transmitting the beam emanating from said light source to said beam-reflecting means, said beam-reflecting means being positioned on the object end of said image forming lens; and

masking means positioned between said light source and said beam reflecting means for preventing the reflection of light at the lens surfaces of said triplet cemented lens;

the respective radii of outer surface of said triplet cemented lens being substantially equal to the compound axial thickness of said triplet cemented lens and the respective radii of the surfaces of said biconvex lens being substantially equal to the axial thickness of said biconvex lens.

6. An ophthalmoscopic optical instrument in accordance with claim 5, wherein one of the outer surfaces of said triplet cemented lens is aspherical.

7. An ophthalmoscopic optical instrument having a wide angle of view of an eye to be inspected comprising:

objective lens means having a positive refractive power and including at least one aplanatic meniscus lens concave toward the eye and a triplet cemented lens, said triplet cemented lens including a negative meniscus lens convex toward the eye,

a biconvex lens and a negative meniscus lens concave toward the object and arranged in sequence from the object,

an image forming lens for re-imaging an image formed by said objective lens means,

an illuminating system including at least one light source for illumination of the eye, beam-reflecting means for directing the illuminating beam toward said objective lens means, optical means for transmitting the beam emanating from said light source to said beam-reflecting and a masking means for preventing the reflection of light at the lens surfaces of said triplet cemented lens, said beam-reflecting means being positioned between said objective lens means and said image forming lens,

the center of curvature of the front surface of said aplanatic meniscus lens substantially coinciding with the center of the pupil of the eye to be inspected.

* * * * *

XR 4,161,756

United States Patent [19]

Thomas

[11] **4,161,756**

[45] **Jul. 17, 1979**

[54] **CONTROL SYSTEM FOR VARIFOCAL OBJECTIVE**

[75] Inventor: **Otto Thomas**, Bad Kreuznach, Fed. Rep. of Germany

[73] Assignee: **Jos. Schneider & Co. Optische Werke**, Bad Kreuznach, Fed. Rep. of Germany

[21] Appl. No.: **801,017**

[22] Filed: **May 26, 1977**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 778,933, Mar. 18, 1977, abandoned.

[30] **Foreign Application Priority Data**

Mar. 19, 1976 [DE] Fed. Rep. of Germany 2611639

[51] **Int. Cl.**[2] **G02B 7/11**; G02B 15/14

[52] **U.S. Cl.** **358/225**; 350/44; 350/187; 352/140; 358/227

[58] **Field of Search** 358/225, 227; 352/140; 350/41, 44, 42, 43, 184, 186, 187

[56] **References Cited**

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2546455 4/1976 Fed. Rep. of Germany.

Primary Examiner—Robert L. Richardson
Attorney, Agent, or Firm—Karl F. Ross

[57] **ABSTRACT**

The correlated positions of two axially shiftable components of a varifocal objective, i.e., a variator and a compensator, throughout a zoom range are stored in a memory from which they can be read out to control respective drives during a zooming operation. The readout rate is determined by a speed selector which sets a frequency for the pulsing of a control unit that scans successive memory addresses. The memory may also contain data for focusing control, either through axial adjustment of a front component of the objective or through modification of the positional correlation of the two shiftable components, as well as for an adjustment of a diaphragm with changes in the overall focal length.

10 Claims, 6 Drawing Figures

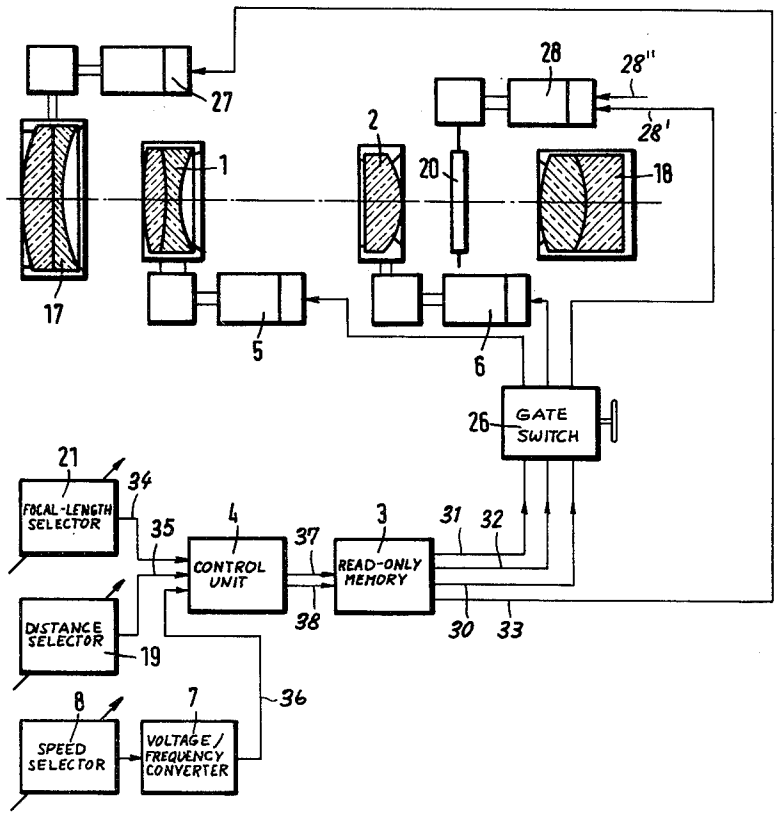
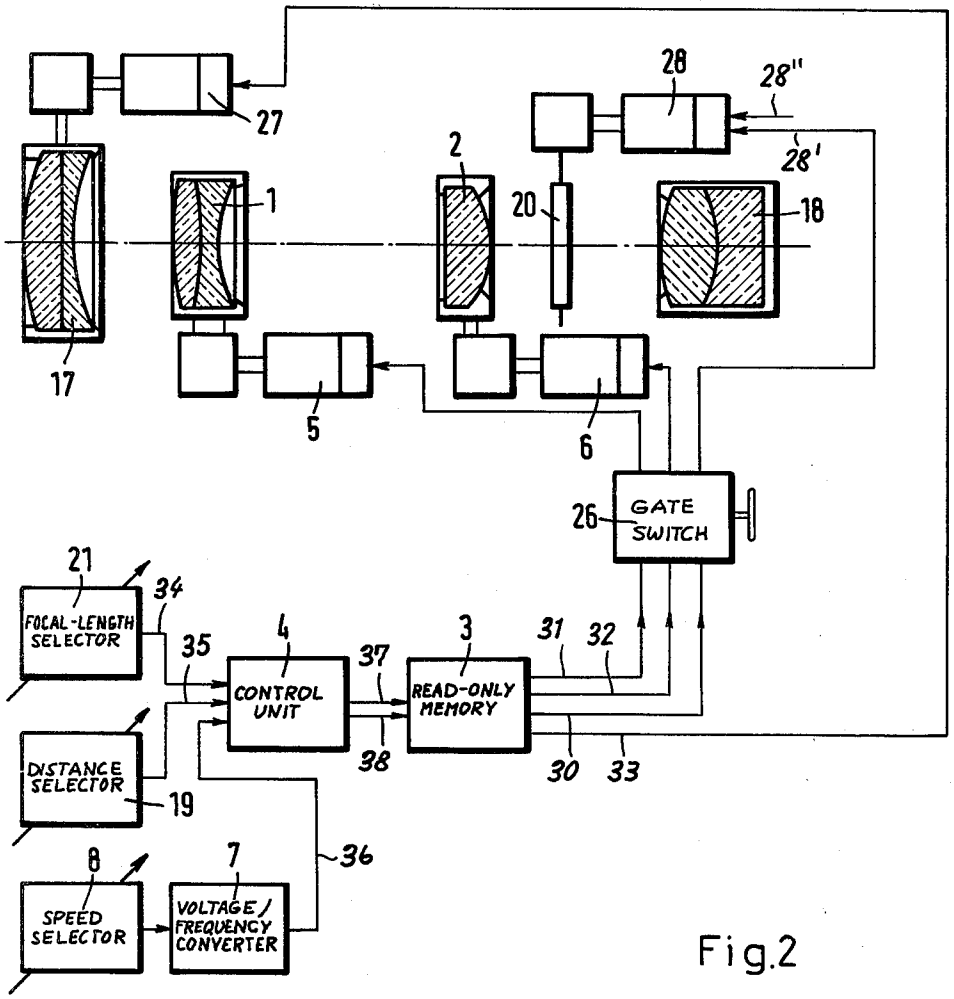


Fig.1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28'
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1
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18
17
5
6
26
GATE SWITCH
21
FOCAL-LENGTH SELECTOR
34
35
4
CONTROL UNIT
37
38
3
READ-ONLY MEMORY
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32
30
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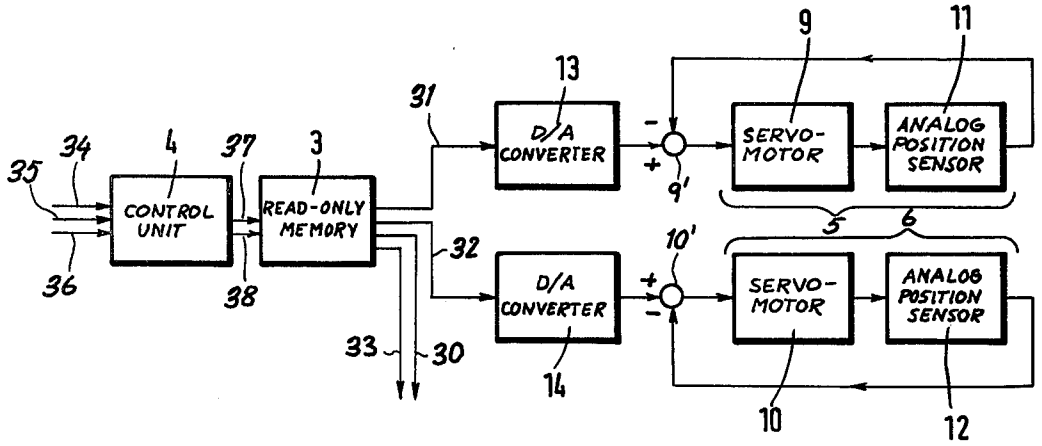
DISTANCE SELECTOR
19
8
SPEED SELECTOR
7
VOLTAGE / FREQUENCY CONVERTER
36

Fig.2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38
3
READ-ONLY MEMORY
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32
33
30
13
D/A CONVERTER
14
D/A CONVERTER
9
9'
10'
SERVO-MOTOR
10
SERVO-MOTOR
11
ANALOG POSITION SENSOR
12
ANALOG POSITION SENSOR
5
6

Fig.3

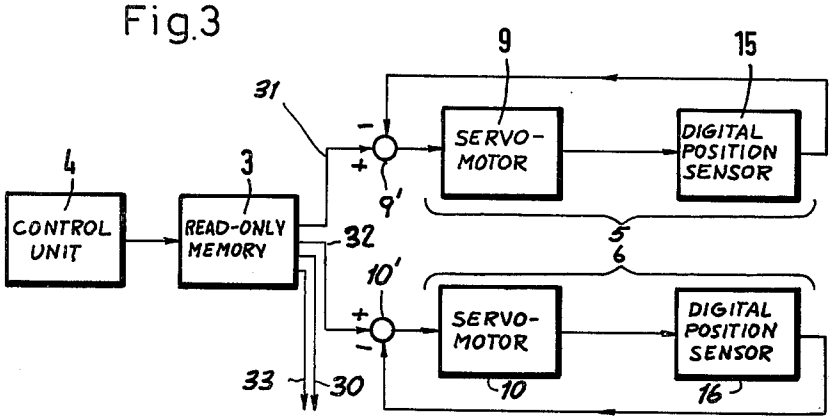
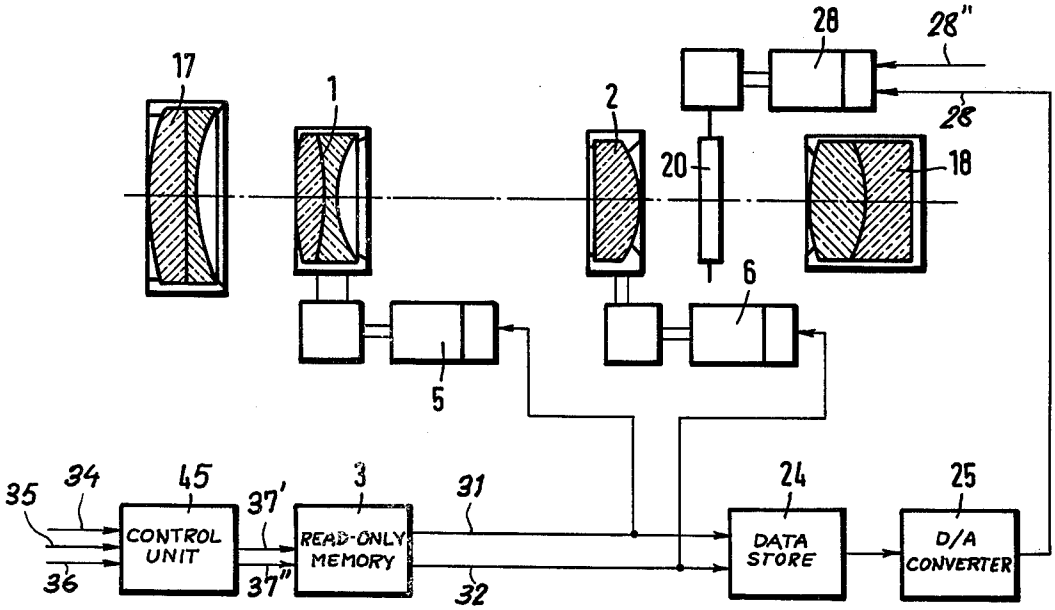


Fig.4



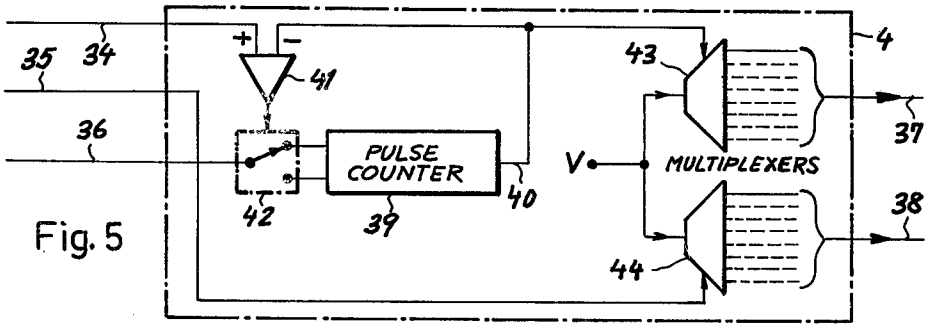
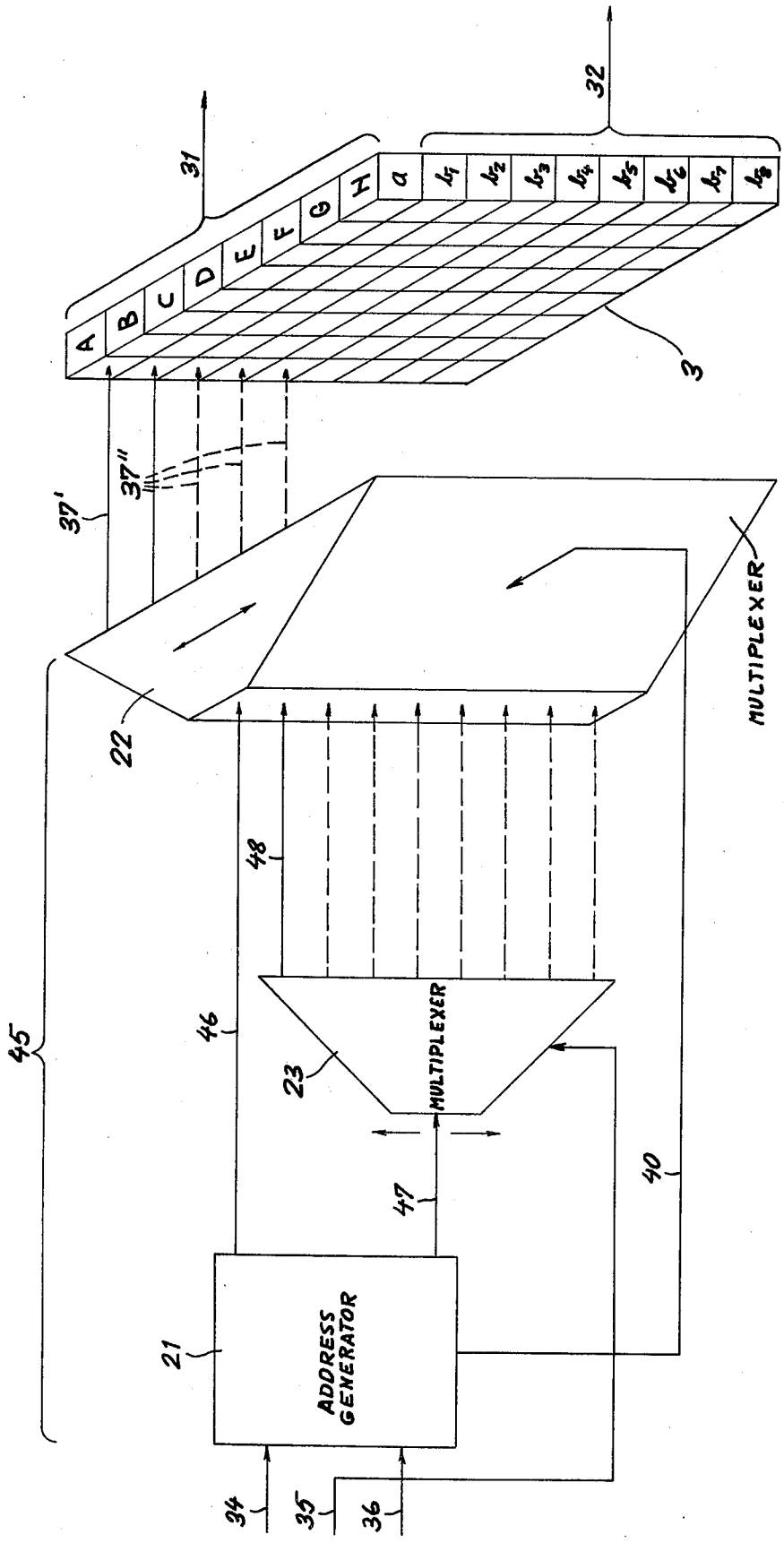


Fig. 5


32
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A
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C
D
E
F
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H
a
3
37''
37'
MULTIPLEXER
22
48
46
45
23
MULTIPLEXER
47
40
21
ADDRESS GENERATOR
34
35
36

FIG. 6

CONTROL SYSTEM FOR VARIFOCAL OBJECTIVE

CROSS-REFERENCE TO RELATED APPLICATION

This is a continuation-in-part of my application Ser. No. 778,933 filed 18, Mar. 1977 and now abandoned.

FIELD OF THE INVENTION

My present invention relates to a system for the control of a varifocal or zoom objective in an optical system such as a photographic, cinematographic or television camera or a copier.

BACKGROUND OF THE INVENTION

Conventional varifocal objectives comprise several (usually four) components of which two, generally the second and the third one, are axially shiftable to vary the overall focal length. The first of these axially shiftable components, termed a variator, determines that overall focal length whereas the second one, termed a compensator, maintains the position of the image plane constant throughout the zoom range. Thus, the positions of these shiftable and usually negatively refracting components are correlated in a predetermined manner according to a nonlinear law of relative displacement. Frequently, the objective also has a (usually positively refracting) front component which is limitedly axially adjustable, or includes an axially adjustable lens member, for focusing purposes. Alternatively, focusing (i.e. a change in the object distance) can also be carried out by modifying the relative position of the axially shiftable components used for zooming, yet this is more complicated since the extent of the supplemental shift required for focusing varies with the selected overall focal length.

In commonly owned U.S. Pat. No. 4,008,951 there has been disclosed a control mechanism in which the position of the second shiftable component, i.e., the compensator, is changed in response to stepping pulses generated upon the displacement of the first shiftable component, i.e., the variator, to maintain the requisite positional correlation of the two components.

A somewhat similar system has been described in German published specification No. 2,410,744 and corresponding U.S. Pat. No. 4,043,642 wherein the variator and the compensator are provided with respective position sensors working into a computer which sends corrective signals to the compensator drive for establishing the proper correlation. The operation of the computer may be modified to focus the objective upon an object located at a certain distance therefrom. The intervention of a computer in the positioning of the compensator introduces a certain delay into the adjustment of the compensator, thereby limiting the speed of the zooming operation. This delay, and the complexity of the computer, is aggravated if focusing is to be performed by modifying the positional correlation of the two shiftable components.

OBJECTS OF THE INVENTION

The general object of my present invention, therefore, is to provide a simplified control system for the purpose set forth.

Another object is to provide a control system which can be realized at moderate cost but whose sophistication can be increased at will for greater precision and/or a larger number of adjustment positions.

SUMMARY OF THE INVENTION

In accordance with my present invention, the correlated positional data for the two axially shiftable zooming components of a varifocal objective are stored in a memory from which sequences thereof are concurrently read out to respective drive means with the aid of control means having input connections to a source of zooming signals and, advantageously, also to a source of focusing signals. The focusing signals may be fed to a separate drive for another component of the objective, such as a front lens, or may be used to switch the readout among different sets of correlated positional data stored in the memory. The data read out from the memory can also be used, pursuant to a further feature of my invention, for the adjustment of a diaphragm in order to take into account the variations in luminosity occurring along the zoom range.

BRIEF DESCRIPTION OF THE DRAWING

The above and other features of my present invention will now be described in detail with reference to the accompanying drawing in which:

FIG. **1** is a diagrammatic overall view of an optical zooming system according to my invention;

FIG. **2** is a block diagram of an assembly of the control and drive units forming part of the system of FIG. **1**;

FIG. **3** is a block diagram similar to FIG. **2**, illustrating a modification;

FIG. **4** is a view similar to FIG. **1** of another optical zooming system according to the invention;

FIG. **5** shows details of a control unit included in the system of FIGS. **1–3**; and

FIG. **6** shows details of a control unit and a memory included in the system of FIG. **4**.

Specific Description

In FIG. **1** I have illustrated a conventional varifocal objective with a positive front component **17**, an axially shiftable negative component or variator **1**, an axially shiftable negative component or compensator **2**, and a fixed positive rear component **18** which may be part of a larger group of fixed lens members not further illustrated. An iris diaphragm **20** is inserted between components **2** and **18**.

Shiftable components **1** and **2** are provided with respective electromechanical driving units **5** and **6**; a similar driving unit **27** serves for a limited axial adjustment of front component **17** in order to focus the objective upon objects at different distances from component **17**. Driving units **27**, **5** and **6** are individually energizable by setting voltages appearing on output leads **33**, **31** and **32** of a read-only memory **3** which can be preprogrammed or selectively masked to provide a predetermined correlation between the voltages appearing at any one time on leads **31** and **32**. Diaphragm **20** is adjustable by a driving unit **28** energizable by memory **3** via another output lead **30**. Memory **3** is addressed by a control unit **4** to which signals are fed on respective input leads **34**, **35** and **36** from a focal-length selector **21**, a distance selector **19** and a speed selector **8** which may be manually operated. The selectors may be potentiometers producing variable d-c voltages; in the case of speed selector **8**, that d-c voltage is fed to a voltage/frequency

converter 7 emitting a train of stepping pulses of variable repetition frequency or cadence.

The voltage on lead **34** establishes the position within the zoom range to which the objective is to be adjusted at a speed determined by the cadence of the stepping pulses on lead **36**. Independently thereof, the voltage on lead **35** gives the displacement of front component **17** in order to focus the objective upon a desired object. Focal length, object distance and zooming speed may be indicated by suitable markings on the corresponding selectors.

Control unit **4** has two outputs **37** and **38** respectively addressing the zooming section and the focusing section of memory **3**. Output leads **30**, **31** and **32** extend from the zooming section whereas lead **33** originates at the focusing section. Leads **30–32** pass through a gate switch **26** which can be manually opened, upon attainment of a desired overall focal length, to halt the shifting of components **1** and **2** as well as the concomitant adjustment of diaphragm **20** regardless of the actual setting of selector **21**. Lead **30** terminates at an input **28'** of diaphragm drive **28** which also has another input **28''** for changing the diaphragm aperture; input **28''** may be energized manually, or automatically from a photometer. The setting signals from the two inputs are added electrically or mechanically, e.g. via a differential gearing.

As shown in FIG. **2**, the variator drive **5** and the compensator drive **6** comprise respective servomotors **9** and **10** provided with position sensors **11** and **12** which in this instance are of the analog type. The output signals of sensors **11** and **12** are fed back to the inputs of the associated servomotors by way of respective differential amplifiers **9'** and **10'** also receiving the signals on leads **31** and **32**, read out in digital form from memory **3**, via respective digital/analog converters **13**, **14**. Thus, the two servomotors operate in a forward or reverse direction until their input signals match the feedback signals from the position sensors. The driving units **27** and **28** for front component **17** and diaphragm **20**, not shown in FIG. **2**, may be similarly constituted.

In FIG. **3** the servomotors **9** and **10** work into digital position sensors **15** and **16**, thus obviating the need for digital/analog converters **13** and **14**.

The system of FIG. **4** differs from that of FIG. **1** in that the front component **17** of the varifocal objective is axially fixed and focusing is carried out by a supplemental shift of compensator **2** through a modification of the setting signals read out to driving unit **6** from memory **3**. A modified control unit **45** is used for this purpose to address the memory **3**, in response to selector signals on leads **34–36**, via connections **37'** and **37''** commanding the readout of certain positional data stored in the memory. Output leads **31** and **32** have branches addressing a further data store **24** for the readout of digital setting signals into a digital/analog converter **25** working into the input **28'** of diaphragm drive **28**.

Reference will now be made to FIG. **5** for details of the control unit **4** shown in FIGS. **1–3**. That unit comprises a reversible pulse counter **39** which receives the stepping pulses on input lead **36** and energizes an output lead **40** with a voltage proportional to its count. Leads **34** and **40** extend to respective inputs of a comparator **41** whose output directs the incoming stepping pulses, via an electronic switch **42**, to a forward-counting or a backward-counting input of counter **39** depending on the relative polarity of the voltages on these leads. When the two voltages are equal, counter **39** is stopped.

The output voltage of the counter is also applied to a switching input of a multiplexer **43** for directing a reading voltage V to any one of a number of leads forming part of a multiple which constitutes the output **37** of unit **4**. Another multiplexer **44** is switched by the setting signal on lead **35** to energize one of several leads in a multiple constituting the other output **38**. Each lead of multiple **37** has three branches terminating at homologous address inputs of respective sections of memory **3**, i.e., a first section delivering the setting voltage for driving unit **5** on lead **31**, a second section delivering the setting voltage for driving unit **6** on lead **32** and a third section delivering the setting voltage for driving unit **28** on lead **30**. The leads of multiple **38** extend to respective address inputs of a fourth memory section from which the setting voltages from driving unit **27** are read out on lead **33**. Thus, with gate switch **26** (FIG. **1**) closed, a given signal voltage on lead **34** will establish the selected focal-length setting and a corresponding diaphragm adjustment in successive increments determined by the stepping pulses on lead **36** whose cadence may be so chosen, for example, that the entire zoom range is traversed in a time period varying from 1 second to 10 minutes.

FIG. **6** shows a possible layout of the modified control unit **45** of FIG. **4** together with that of memory **3** which in this instance is divided into a multiplicity of cells forming an orthogonal array with columns A–H and rows a, b_1–b_8; the number of columns or rows in the array can of course be different from that shown. The cells of the top row a contain the positional data for variator **1**, to be read out on lead **31**; the cells of any one row b_1–b_8 contain the positional data, applicable to a given object distance, for compensator **2** which are to be read out on lead **32**.

An address generator **21** in unit **45**, which may comprise the pulse counter **39**, the comparator **41** and the electronic switch **42** of FIG. **5**, has its output lead **40** connected to a switching input of a multiplexer **22** having output multiples **37'** and **37''**, only one lead of multiple **37'** and a few leads of multiple **37''** having been shown for the sake of clarity. Reading voltage appearing on an output lead **46** of address generator **21** is fed to multiplexer **22** in order to address one of the cells of top row a of memory **3** as selected by the voltage on lead **40**. Another output lead **47** of address generator **21** applies reading voltage to a second multiplexer **23** whose output multiple **48** scans the rows b_1–b_8 of memory **3**, under the control of focusing voltage on lead **35**, through the intermediary of multiplexer **22**. Thus, if multiplexer **22** receives on lead **40** a voltage corresponding to column A of memory **3**, cell A/a will be addressed by the illustrated lead **37'** together with one of the other cells in column A, depending on which of the illustrated leads **37''** is energized in response to the voltage on lead **35**. If the energization of lead **40** changes, two memory cells in another column will be jointly addressed to set the variator **1** and the compensator **2** in a correlated manner determined by the selected focal length and object distance.

For the sake of low cost and high dependability, the several memory cells are preferably designed as semiconductors.

I claim:

1. In an optical zooming system wherein a varifocal objective has a plurality of components including an axially shiftable variator for changing its focal length

and an axially shiftable compensator for maintaining a constant image plane, the combination therewith of:

first drive means for axially shifting said variator;

second drive means for axially shifting said compensator;

memory means storing correlated positional data for said variator and said compensator;

a source of zooming signals; and

control means connected to said memory means and to said source for concurrently reading out respective sequences of said correlated positional data to said first and second drive means in response to said zooming signals whereby said variator and said compensator are axially shifted between different positions in a zoom range.

2. The combination defined in claim **1** wherein said control means includes a generator of stepping signals establishing a variable readout rate for said positional data to facilitate selection of different zooming speeds.

3. The combination defined in claim **2** wherein said generator comprises a voltage/frequency converter.

4. The combination defined in claim **1** wherein said objective is provided with focusing means for displacing another component thereof in response to distance data stored in said memory means, further comprising a source of focusing signals connected to said control means for the readout of said distance data to said focusing means.

5. The combination defined in claim **1** wherein said objective is provided with a diaphragm and with adjusting means for changing the diaphragm aperture, said memory means having an output connected to said adjusting means for automatically modifying said diaphragm aperture concurrently with a shifting of said variator and said compensator.

6. The combination defined in claim **1** wherein said control means is provided with separate inputs respectively connected to said source of zooming signals and to a source of focusing signals, said memory means containing different sets of correlated positional data selectable by said focusing signals for readout in response to said zooming signals.

7. The combination defined in claim **1** wherein said first and second drive means comprise each a servomotor coupled with the respective shiftable component, a sensor determining the instantaneous position of said respective component and feedback means for signaling said instantaneous position to said servomotor.

8. The combination defined in claim **7** wherein said positional data are stored in said memory means in digital form, said sensor being an emitter of digital signals.

9. The combination defined in claim **7** wherein said positional data are stored in said memory means in digital form, further comprising digital/analog conversion means inserted between said memory means and said servomotor, said sensor being an emitter of analog signals.

10. The combination defined in claim **1**, further comprising switch means inserted between said memory means and said first and second drive means for halting the shifting of said variator and said compensator independently of said zooming signals.

* * * * *

United States Patent [19]

Christy et al.

[11] **4,160,263**

[45] **Jul. 3, 1979**

[54] **DUAL OR MULTIPLE OBJECTIVE VIDEO MICROSCOPE FOR SUPERIMPOSING SPACED IMAGES**

[75] Inventors: **Harold Christy**, Phoenix; **Robert R. Bernham**, Apache Junction, both of Ariz.

[73] Assignee: **George R. Cogar**, Frankfort, N.Y.

[21] Appl. No.: **905,576**

[22] Filed: **May 15, 1978**

[51] **Int. Cl.**[2] **H04N 9/02**

[52] **U.S. Cl.** **358/1**; 358/93; 358/101; 358/107

[58] **Field of Search** 358/1, 41, 56, 88, 93, 358/101, 107, 209, 225, 226

[56] **References Cited**

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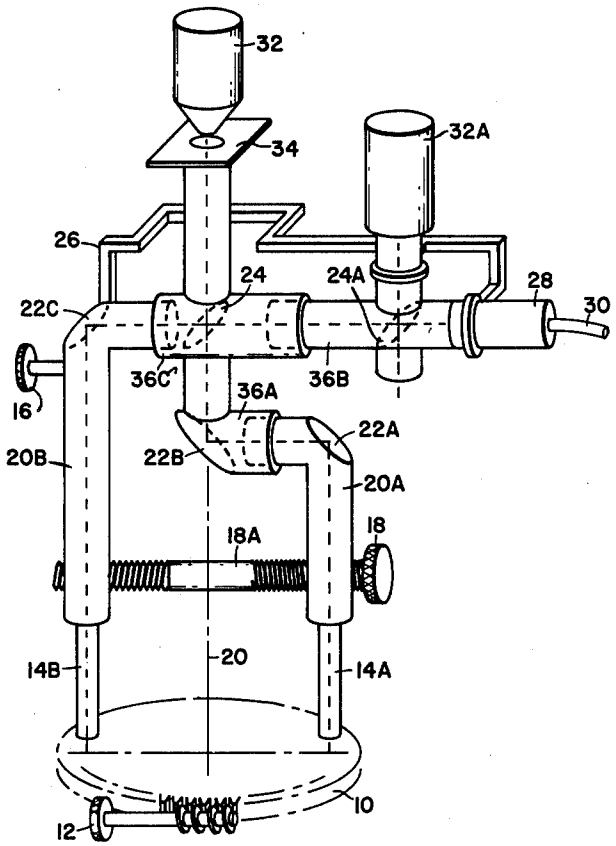
4,042,960	8/1977	Wooding, Jr.	358/101

Primary Examiner—Richard Murray
Attorney, Agent, or Firm—Harry M. Weiss

[57] **ABSTRACT**

This disclosure relates to a video microscope with wide potential range of magnification powers, including but not limited to from 10× to 1000× whose separate images originating from multiple objective lenses are combined on a half-silvered mirror and focused into a vidicon camera tube to produce a two dimensional composite image. Separation of the multiple objective lenses can be adjusted with a preloaded right-hand/left-hand lead screw arrangement without defocusing the image from either lens system. A third image such as a cross hair, grid pattern or graticule can be introduced via a light source which is projected on a silicon semiconductor wafer or other subjects through the objective lenses and in turn reflects as a composite image onto the face plate of the vidicon camera tube. The third projected image permits measurement of areas and linear dimensions of the subjects viewed. Digital null reference electronic techniques in the video output also is disclosed for auto correlation of images using servo controls. Selective deletion of scanning lines on a CRT viewing screen also provides a convenient means of measuring the vertical dimensions of subject matter being viewed, where the magnification in use in the system is accurately known. The viewed subjects are displayed on the cathode-ray tube (CRT) screen in a true relationship without image inversion, reversal or left-right ambiguity. Means are also disclosed for projecting an electronically generated image or laser beam onto the subject matter being viewed for optical printing or altering (i.e. trimming) the subject.

30 Claims, 4 Drawing Figures



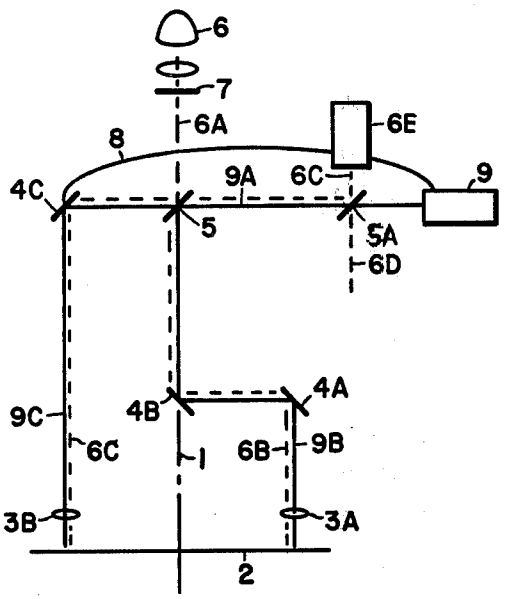

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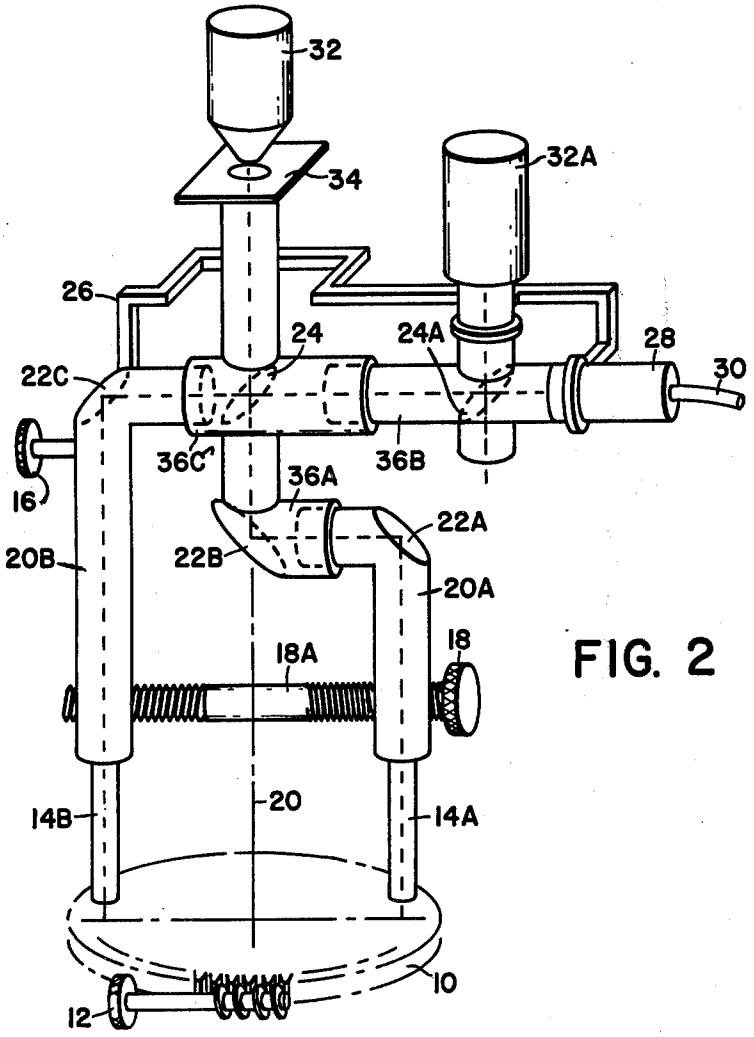
FIG. 1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14B
14A
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12

FIG. 2

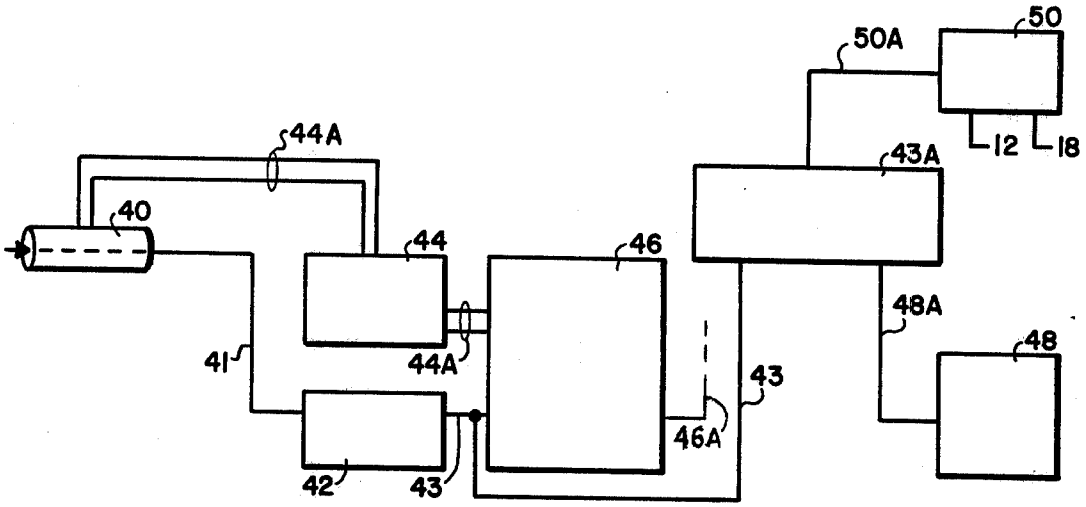
50
50A
12
18
44A
43A
40
44
46
48A
48
41
44A
43
46A
42
43

FIG. 3A

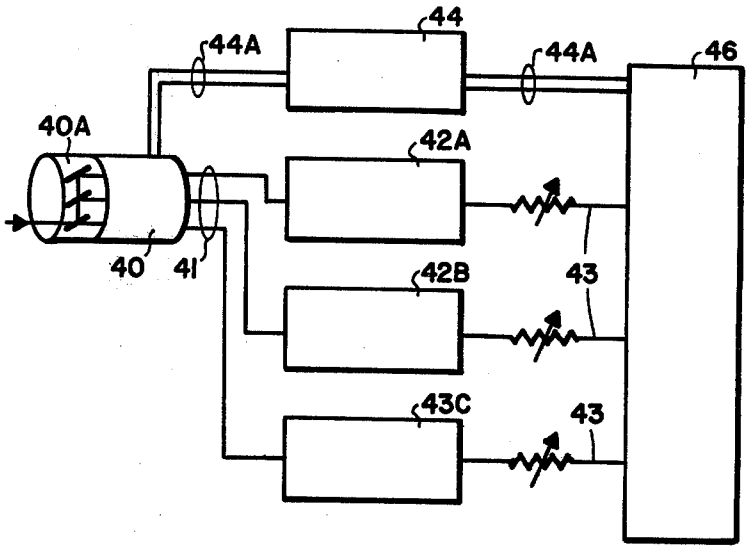
44
44A
44A
46
40A
42A
40
41
42B
43
43C
43

FIG. 3B

DUAL OR MULTIPLE OBJECTIVE VIDEO MICROSCOPE FOR SUPERIMPOSING SPACED IMAGES

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates generally to video systems, and more particularly, relates to video microscopes for comparing objects or images which can, for example, be used for aligning and locating the kerf between integrated circuit or discrete device chips formed in a silicon wafer.

2. Background of the Prior Art

In the past, fabrication of integrated circuit or discrete device chips from a single semiconductor wafer required the necessary step of separating the integrated circuit chips or, as the case may be, the discrete device chips. This separation step usually was known as a "sink and break" operation. In some cases a slurry saw was used to separate the chips without a sinking operation.

Several types of optical alignment systems are being used for positioning silicon wafers under a high speed diamond saw generally used for scribing circuit wafers. These prior art systems are all derivations of the binocular comparison microscope which was designed to superimpose two nearly identical images in registration for the purpose of examining image differences, if any.

Optical projection rather than viewing systems have been developed to reduce operator fatigue caused by the need to observe the work area through binocular eyepieces for extended periods. It should be observed that optical projection requires large aperture objective lenses, a high intensity light source and a complex arrangement of lenses and a projection screen which usually required a basic redesign of the work unit such as the alignment or processing machine.

There is also a limit to the intensity of visible and accompanying infrared light which can be projected onto work objects such as silicon wafers without risk of modifying their characteristics. Thus, optical projection systems designed for semiconductor wafer alignment usually have to be viewed in subdued light.

Accordingly, a need existed for a simplified object viewing or processing arrangement or a silicon wafer alignment system which provides a bright, sharp image from a comparatively low intensity light source and which can be easily incorporated into a wafer scoring or other micro viewing machine without extensive modifications. A need also existed for a projection system where the reproduced image of the viewed subject could be located to best serve the operator's requirements and where the reproduced image can be repeated at a supervisory position or elsewhere as often as desired.

SUMMARY OF THE INVENTION

Accordingly, it is an objective of this invention to provide an improved apparatus and method for comparing objects.

It is another object of this invention to provide an improved means of accurately aligning the margins or kerf areas between integrated circuits or discrete components on a silicon wafer for further processing by the scoring or scribing saw.

It is another object of this invention to provide an improved apparatus and method for providing alignment information of two or more superimposed images on a bright viewing screen of convenient size at a location which best serves the needs of the operator.

It is a further object of this invention to provide a means of laterally positioning two or more objective lenses over an object such as a silicon wafer or any focal plane surface with backlashfree differential screw controllers.

It is a still further object of this invention to provide an apparatus which has means to fix any objective lens of a multiple lens system over a point on the object's focal plane surface and move other objective lenses to desired points on the object's viewing plane with a simple screw controller mechanism.

It is still another object of this invention to provide an optical system with sufficient depth of focus to accommodate limited vertical variations in an essentially flat image and with inherent mechanical stability to produce a two dimensional image and to make refocusing and/or readjustment unnecessary during normal usage.

It is a still further object of this invention to provide an optical system which keeps the optical path length between viewing plane and a vidicon face plate constant between the outer and inner limits of the objective lenses regardless of whether multiple lenses are moved simultaneously, or only one objective lens is moved with respect to the other objective lenses.

It is a still further object of this invention to provide an optical system which facilitates projection of an accurately ruled grid pattern or linear scale on the focal plane surface of an object which will permit measurement of areas and linear dimensions of objects.

It is still another object of this invention to take advantage of the bilateral nature of optical transmission paths which will permit substitution of a small commercially available mini-CRT for a small commercially available vidicon and permit projection of two or more micro images on a focal plane surface, thus permitting a video microscope to be used as a micro printer for exposing silicon wafers or other light sensitive material or objects.

Alternatively, by installing an additional image splitter in series with the vidicon optical input, it is another objective of this invention to project the image from the mini-CRT onto the focal plane surface while viewing the result on the vidicon output screen.

It is a still further object of this invention to use the unused half of an image splitter to project another image from the subject plane surface or some other image source onto a vidicon face plate.

It is still another object of this invention to utilize, as an alternate to the mini-CRT projector of an optical system, a medium powered YIG or Niobium invisible output laser which can, for example, be used in a trimming operation.

The foregoing, and other objects, features, and advantages of the invention will be apparent from the following, more particular description of the preferred embodiment of the invention, as illustrated in the accompanying drawing.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a schematic diagram of the optical path through the dual or multiple objective video microscope of this invention from the right and left objective lens to the vidicon tube and from the light source to the illuminated area on each side of the object's turntable.

FIG. 2 is a simplified elevational, perspective view (with parts broken away) of the video microscope

showing mechanical construction and mechanisms for adjusting spacing of the objective lenses up and down movement for focusing and the viewing plane turntable adjustment.

FIGS. 3A and 3B depict block diagrams of electronic functions used for projection (black and white FIG. 3A, color FIG. 3B) of the dual or multiple optical input to the vidicon tube.

Referring to the schematic diagram of the optical paths shown in FIG. 1, the image on the right side of centerline 1, which is the centerline of a silicon wafer (not shown), turntable 2, passes through an objective lens 3A thence to a plane mirror 4A, to plane mirror 4B and to a half-silvered image-splitting mirror 5 which reflects the right side image from lens 3A into a vidicon tube 9. This path is shown by line 9B/9A.

The image on the left side of the centerline 1 is brought into focus from the wafer turntable 2 by objective lens 3B. The image then goes to plane mirror 4C, reflected through half-silvered mirror 5 to the vidicon tube 9. The optical path for the left image is shown by line 9C/9A.

A light source with condensing lens 6 is installed on the microscope centerline 1. The parallel beams from light source and lens system 6 go through the half-silvered mirror 5 to the plane mirror 4B, then to the plane mirror 4A, through the right side objective lens 3A to illuminate an area equal to the field of vision of the right microscope image. The path of the light source and lens system 6 to the right-hand image is shown by line 6A/6B. The image-splitting properties of the half-silvered mirror 5 reflect light from the combined light source and lens system 6 to mirror 4C, thence to the objective lens 3B which illuminates the field on the left-hand side of the video microscope. The path from the combined light source and lens system 6 to the left-hand image is shown by line 6A/6C.

A line grid, linear scale, cross-hair or secondary image can be projected simultaneously on the right and left side of the wafer turntable 2 by introducing a prepared slide at 7, below the condensing lens combined with light source 6. The projected image from the slide 7 is reflected in focus via optical paths 9C and 9B to 9A and to the vidicon tube 9.

A rigid mechanical linkage couples the vidicon tube 9 to the mirror 4C is indicated by reference numeral 8. The purpose of the rigid mechanical linkage 8 is to keep the optical path length uniform from the wafer turntable 2 through the objective lenses 3A and 3B to the vidicon tube 9 throughout lateral adjustment of the objective lenses 3A and 3B from their inner and outer limits of spacing from the centerline 1. The location of the centerline 1 and the position of the image-splitting mirror 5 and the combined light source and lens 6 is unchanged by adjustment of the objective separation lead screw (not shown in FIG. 1) which moves the objective lenses 3A and 3B laterally.

The optical path lengths shown schematically in FIG. 1 shows that, if the objective lens 3B is moved farther from the centerline 1, the optical path from the image-splitting mirror 5 and the plane mirror 4C is increased. If at the same time, the objective lens 3A is moved farther from the centerline 1, the optical path length from the plane mirror 4A to the plane mirror 4B is increased. This increase in optical path length to the objective lenses 3A and 3B is compensated by the rigid coupling of vidicon tube 9 through the linkage 8 to the mirror 4C. Thus, a lengthening of the optical paths to the mirror 4C, and to the mirror 4B to the mirror 4A is compensated by a shortening of the optical path from the stationary image-splitting mirror 5 to the moving vidicon tube 9. A secondary image splitting mirror may be installed as shown at 5A of FIG. 1. This secondary mirror 5A is also connected to the linkage 8. A mini-CRT or laser unit is installed as shown at 6E in FIG. 1 and is also connected to the linkage 8. The CRT or laser output from the unit 6 goes alone path 6C to the secondary mirror 5A where it is reflected to the main image splitter 5 of FIG. 1. The laser output from the unit 6B (FIG. 1) or 32A (FIG. 2) can be used, for example, to trim thick or thin film resistors located on the table 2 (FIG. 1) or table 10 (FIG. 2). The lower side of the secondary image-splitter mirror 5A may be used to feed a fifth image into the vidicon 9 via the optical path shown at 6 of FIG. 1. This fifth image would come from a third objective lens (not shown). Similarly, if desired, additional objective lenses can be added with corresponding additional image splitters.

FIG. 2 is a perspective, elevational view (with parts broken away) of the image comparison video microscope. Not shown are mounting arrangements which would be used to support the video microscope.

For example, a silicon wafer (not shown) requiring alignment for scribing is mounted on turntable 10 of FIG. 2 which is designed for angular rotation by worm and wheel adjustment mechanism 12. Objective lenses 14A and 14B (or part of the entire video microscope) are focused by a rack and pinion arrangement (not shown) using a control or adjustment wheel 16 which moves the complete microscope unit up and down with reference to the focal plane surface of the turntable 10. Differential movement of the dual objective lenses 14A and 14B to equal distances from the video microscope centerline 20 is accomplished with control or adjustment wheel 18 which turns a RH/LH combined thread lead screw 18A. Not shown are the use of spring loaded nuts on the back of the microscope tubes 20A and 20B which removes backlash while driving the microscope tubes 20A and 20B simultaneously toward and away from the centerline 20. While the embodiment of FIG. 2 shows the use of two microscope tubes and driving mechanism therefor, it should be understood that more than two microscope tubes can be utilized with associated driving mechanisms. Plane mirrors which reflect the images from the objective lenses 14A and 14B to a half-silvered image-splitting mirror 24 are shown at 22A, 22B and 22C. If desirable, redesign of the video microscope can be accomplished so that the objective lens 14A and 14B is fixed with the other lens being movable. Linkage 26 of FIG. 2 (corresponding to linkage 8 of FIG. 1) couples movement of the video microscope tube 20B to vidicon tube 28. A cable for transmitting the video signal to a video amplifier 42 (see FIG. 3A) and for transmitting scanning frequencies from a time base generator 44 (see FIG. 3A) to the vidicon tube 28 is shown at 30.

The light source and condensing lens required to illuminate the video microscope subject matter under the objective lenses 14A and 14B is shown by reference numerals 32 (corresponds to reference numeral 6 of FIG. 1). A slide mounting platform which may be used for introducing a third image into the system is shown at 34 (corresponds to reference numeral 7 of FIG. 1). Slip joints which exclude external light but allow lateral motion of the microscope tubes 20A and 20B to and from the centerline 20 are shown at 36A, 36B and 36C.

A secondary image-splitting mirror is shown at **24A** of FIG. 2. This splitter **24A** provides the means of introducing the output of a mini-CRT or laser unit **32A** into the image system terminating at the objective lenses **14A** and **14B**. The unused lower part of the splitter mirror **24A** provides an optical channel for introducing a fifth image to the vidicon tube **28**, if so desired.

Construction and Operation

The optical path length from the objective lens **14A** of FIG. 2 or objective lens **3A** (FIG. 1) to the image-splitting mirror (**5** in FIG. 1 and **24** in FIG. 2) must agree very closely with the optical path length from the objective lens **3B** to the mirror **5** (FIG. 1) or from the objective lens **14B** to the mirror **24** of FIG. 2. Control **16** in FIG. 2 moves the video microscope with reference to the viewing plane located in the turntable **10** thus focusing the right and left images together.

With respect to FIG. 1, the reflected images from the objective lenses **3A** and **3B** to the mirror **5** should be perpendicular to the plane of the wafer table **2** at all settings of the differential lead screw controlled by knob **18** (see FIG. 2). This means that the image centerline in the viewing tubes **20A** and **20B** must remain exactly parallel to all settings of the lead screw controlled by knob **18**. The angles of the plane mirrors **22A**, **22B** and **22C** must be set to 45 degrees within one or two seconds of an arc. If desired, optically finished prisms can be used as an alternative to the plane mirrors shown at **22A**, **22B** and **22C**. The planes of the 90 degree parts of the prism must be set exactly perpendicular to the image centerlines coming through the tubes **20A** and **20B**. These mechanical and optical requirements are to insure perfect registration of the right and left images at all settings of the lead screw controlled by the knob **18** and to prevent double imaging which would interfere with the azimuth setting capability of the video microscope of this invention.

The centerline of the video microscope (**1** in FIG. 1 and **20** in FIG. 2) must be exactly positioned over the center of the wafer turntable (**2** in FIG. 1 and **10** in FIG. 2). This requirement is to prevent undesired movement of the images when the turntable is rotated by the control mechanism **12**.

Other operational applications of the video microscope of this invention may include comparisons of individual circuits or devices on a chip or inspection of circuits or devices for visible defects. The dual or multiple image video microscope of this invention may also have application potential in ballistics comparisons, forensics or biological studies. Further operational applications of the video microscope of this invention may include usage of projected images from the mini-CRT (**6B** of FIG. 1 or **32** of FIG. 2) as an optical printer on a sensitized medium or to compare an electronically generated image with existing subjects or objects on the focal plane of the table **2** (FIG. 1) or **10** (FIG. 2). This electronically generated image technique could be used to reinforce, regenerate or correct an existing image. A driving source for the mini-CRT may be from the main cathode-ray tube (CRT) viewing unit via cable **46A** in FIG. 3, although alternate sources of electronically generated images, such as from unit **48** in FIG. 3, can be provided. As noted above, more than three directly viewed images can be accommodated by adding additional image splitters, objective lenses and associated supporting elements.

If magnification greater than 1200 power is desired, reproduced detail can be improved by operation of the video amplifier **42** (FIG. 3A) and time base generator **44** (FIG. 3A) at 1050 lines per frame at 15 frames per second instead of the conventional 525 lines per frame at 30 frames per second.

If operational applications would be enhanced by color reproduction, the video microscope of this invention can be adapted to color through usage of the three-channel red, green, blue "RGB" system as shown in FIG. 3B.

Functional Electronic Block Diagram

FIG. 3A is a simplified electronic block diagram showing the technique for processing the output of, for example, a 0.6 inch electrostatically scanned vidicon camera tube **40** and presenting the viewing results on a 12" to 20" (diagonal) monitor cathode-ray tube (CRT) **46**. The vidicon camera tube **40** drives the video amplifier **42** using a low capacity cable **41** (**30** in FIG. 2). For high definition reproduction, the video amplifier **42** should have a response to 8 Mhz. The output of the video amplifier **42** is connected to the CRT reproduction unit **46** via cable **43**. Synchronized line and frame scanning signals are generated by the time base generator **44** which drives the vidicon camera tube **40** and the CRT reproduction unit **46** through cables **44A**. If the subjects being viewed are motionless, or relatively so, it would be possible to operate the vidicon unit **40** with a lower frame frequency and a higher line frequency and thus obtain higher definition.

For additional flexibility for the video microscope, the cable **43** also can be used to drive a digitizer unit **43A** which could be used if it was necessary for the video microscope to be used in an automatic image comparison mode. The digitizer **43A** also receives a signal on cable **48A** from unit **48** which is either an actual stored image or an electronically generated image. Cable **50A** feeds a null reference comparator **50** which generates servo signals to drive controls or knobs **12** and **18** (see FIG. 2). Within specified limits, a servoed version of the video microscope of this invention will seek out and match images stored in image storage unit **48**. Video images from the microscope system may be transferred to any other system or viewing apparatus.

If it is desirable or necessary that the dual or multiple objective video microscope produce images in color, it is possible to accomplish this object with electronics shown in the block diagram in FIG. 3B. The vidicon camera arrangement **40** shown in FIG. 3B preferably consists of three 0.6 inch electrostatically scanned stacked vidicon tubes. The incoming visual signal going into the camera **40** is split into three color components with a dichroic mirror assembly shown in outline form by reference numeral **40A**. The input visual signal emerges from the three vidicons as red, green and blue (RGB) signals which are individually amplified by three video amplifiers **42A**, **42B** and **42C** which are driven by three cables **41** from the vidicon unit **40**.

The RGB output of the video amplifiers **42A**, **42B**, **42C** is fed to the CRT reproduction unit **46** through three cables **43**, which include voltage adjustment resistors, to permit setting of the white level and adjustment of color values.

The CRT reproduction unit **46** may incorporate a three-gun color tube or any of the single gun color tubes. As shown in FIG. 3B, the time base generator **44**

drives the vidicon assembly 40 and the CRT reproduction unit 46 through cables 44A.

While the invention has been particularly shown and described in reference to the preferred embodiment thereof, it will be understood by those skilled in the art that changes in the form and details may be made therein without departing from the spirit and scope of the invention.

We claim:

1. An optical vidicon apparatus comprising, in combination, multiple objective lenses, a vidicon optically coupled to said multiple objective lenses, display means coupled to said vidicon to display images received by said vidicon, means for moving at least one of said multiple objective lenses toward and away from at least another of said multiple objective lenses, and means for maintaining the length of the optical path between said one of said multiple objective lenses and said vidicon substantially equal to the length of the optical path between said other multiple objective lenses and said vidicon.

2. An optical vidicon apparatus in accordance with claim 1 wherein said multiple objective lenses comprising two objective lenses, said display means comprising a CRT.

3. An optical vidicon apparatus in accordance with claim 1 wherein said means for moving at least one of said multiple objective lenses toward and away from at least another of said multiple objective lenses comprising means for moving both said one and said other of said multiple objective lenses toward and away from each other.

4. An optical vidicon apparatus in accordance with claim 3 wherein said multiple objective lenses comprising two objective lenses, said display means comprising a CRT.

5. An optical vidicon apparatus in accordance with claim 1 wherein said means for maintaining the length of the optical path between said one of said multiple objective lenses and said vidicon substantially equal to the length of the optical path between said other multiple objective lenses and said vidicon comprising reflecting means located in the optical paths for transmitting the images of objects to said vidicon.

6. An optical vidicon apparatus in accordance with claim 5 wherein said means for maintaining the length of the optical path between said one of said multiple objective lenses and said vidicon substantially equal to the length of the optical path between said other multiple objective lenses and said vidicon further comprising at least one image-splitting means for splitting images received from said multiple objective lenses.

7. An optical vidicon apparatus in accordance with claim 6 wherein said at least one image-splitting means comprising a half-silvered mirror.

8. An optical vidicon apparatus in accordance with claim 7 including light source means optically coupled to said multiple objective lenses for projecting a source of light through said multiple objective lenses onto objects viewed by said multiple objective lenses.

9. An optical vidicon apparatus in accordance with claim 8 wherein said light source means comprising a source of light and a condensing lens coupled to said source of light.

10. An optical vidicon apparatus in accordance with claim 7 including CRT means optically coupled to said multiple objective lenses for projecting an image back through said multiple objective lenses.

11. An optical vidicon apparatus in accordance with claim 7 including laser means optically coupled to said multiple objective lenses for projecting a laser beam back through said multiple objective lenses.

12. An optical vidicon apparatus in accordance with claim 1 including light source means optically coupled to said multiple objective lenses for projecting a source of light through said multiple objective lenses onto objects viewed by said multiple objective lenses.

13. An optical vidicon apparatus in accordance with claim 12 wherein said light source means comprising a source of light and a condensing lens coupled to said source of light.

14. An optical vidicon apparatus in accordance with claim 12 including CRT means optically coupled to said multiple objective lenses for projecting an image back through said multiple objective lenses.

15. An optical vidicon apparatus in accordance with claim 12 including laser means optically coupled to said multiple objective lenses for projecting a laser beam back through said multiple objective lenses.

16. An optical vidicon apparatus in accordance with claim 1 including CRT means optically coupled to said multiple objective lenses for projecting an image back through said multiple objective lenses.

17. An optical vidicon apparatus in accordance with claim 1 including laser means optically coupled to said multiple objective lenses for projecting a laser beam back through said multiple objective lenses.

18. An optical vidicon apparatus in accordance with claim 1 including fixed image means coupled to said light source means for projecting a fixed image back through said multiple objective lenses.

19. An optical vidicon apparatus in accordance with claim 1 wherein said vidicon having means for permitting images viewed by said vidicon received from said multiple objective lenses to be viewed in color.

20. An optical vidicon apparatus in accordance with claim 1 including means coupled to said moving means for the autocorrelation of images viewed by said multiple objective lenses.

21. A method for superimposing and comparing spaced images comprising the steps of:

moving at least one of a multiple of objective lenses toward and away from at least another of the multiple objective lenses;

viewing the multiple images received from the multiple objective lenses with a vidicon;

visually displaying the images received by the vidicon; and

maintaining the length of the optical path between the said one of the multiple objective lenses and the vidicon to be substantially equal to the length of the optical path between said other of the multiple objective lenses and the vidicon.

22. A method in accordance with claim 21 wherein said multiple objective lenses being two.

23. A method in accordance with claim 21 including the steps of illuminating using a light source objects viewed by multiple objective lenses.

24. A method in accordance with claim 23 including the steps of projecting a static image between the light source and the multiple objective lenses to provide a measurement or comparison image.

25. A method in accordance with claim 23 including the step of visually displaying in color the images received from the vidicon.

26. A method in accordance with claim 23 including the step of autocorrelating images viewed by the multiple objective lenses to control the positioning of the multiple objective lenses.

27. A method in accordance with claim 21 including the step of projecting an electronically generated image back through the multiple objective images.

28. A method in accordance with claim 21 including the step of projecting a laser beam back through the multiple objective lenses.

29. A method in accordance with claim 21 including the step of visually displaying in color the images received from the vidicon.

30. A method in accordance with claim 21 including the step of autocorrelating images viewed by the multiple objective lenses to control the positioning of the multiple objective lenses.

* * * * *

United States Patent [19]

Holle et al.

[11] **4,117,325**

[45] **Sep. 26, 1978**

[54] **OPTICAL OBJECTIVE FOCUS INDICATOR AND DISPLAY**

[75] Inventors: **Werner Holle**, Wetzlar; **Walter Bletz**, Braunfels, both of Germany

[73] Assignee: **Ernst Leitz Wetzlar GmbH**, Wetzlar, Germany

[21] Appl. No.: **845,666**

[22] Filed: **Oct. 26, 1977**

Related U.S. Application Data

[63] Continuation of Ser. No. 711,462, Aug. 5, 1976, abandoned.

[30] **Foreign Application Priority Data**

Aug. 22, 1975 [DE] Fed. Rep. of Germany 2537482

[51] **Int. Cl.**[2] **H01J 39/12**; G01J 1/42

[52] **U.S. Cl.** ..... **250/209**; 354/25; 354/60 L; 356/4; 356/227; 250/201; 250/204

[58] **Field of Search** ..... 250/201, 204, 209; 356/4, 125, 126, 227; 354/60 L, 25, 31

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Primary Examiner—Alfred E. Smith
Assistant Examiner—Charles F. Roberts
Attorney, Agent, or Firm—Gilbert L. Wells

[57] **ABSTRACT**

Apparatus for indicating and displaying the focus of an optical objective and particularly a photographic camera. An image of the object is projected by means of the objective onto a scanning disk or plate where the light rays are divided into two separate light beams originating from two different areas of the exit pupil of the objective. Two photoelectric detectors are provided behind said scanning disk with one of said light beams impinging on one detector. Each detector delivers an electrical signal, the phase difference between these signals being a measure of the degree of focus of the objective. For indicating said degree of focus two LED's (Light Emitting Diodes) are provided which are so coupled that for focus (phase difference = null) they are equally luminous and that for lack of focus they indicate the direction of the image offset from the focusing plane and approximately also the magnitude of this offset on account of their special coupling and their change in luminosity which is independent of object brightness.

1 Claim, 4 Drawing Figures

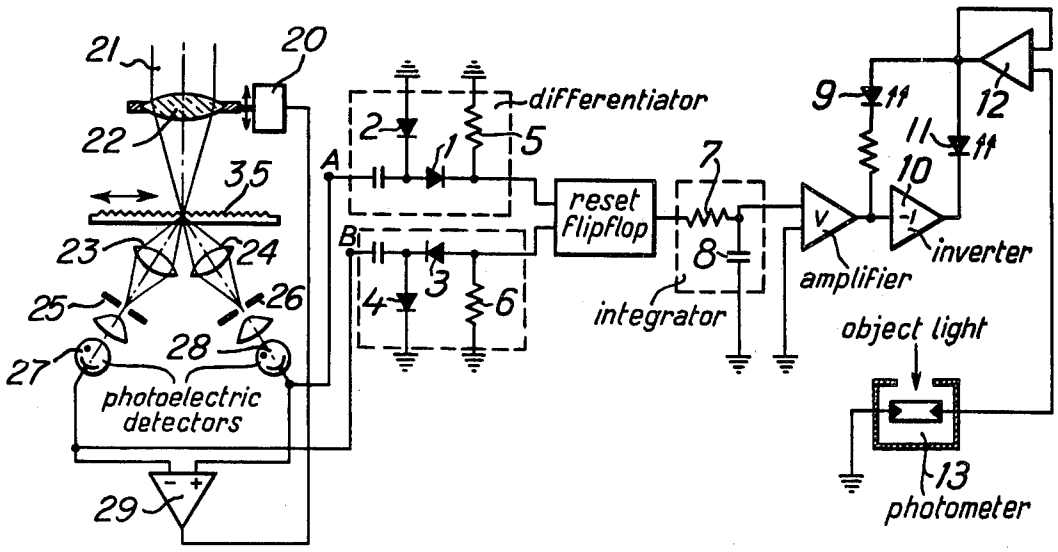


Fig. 1

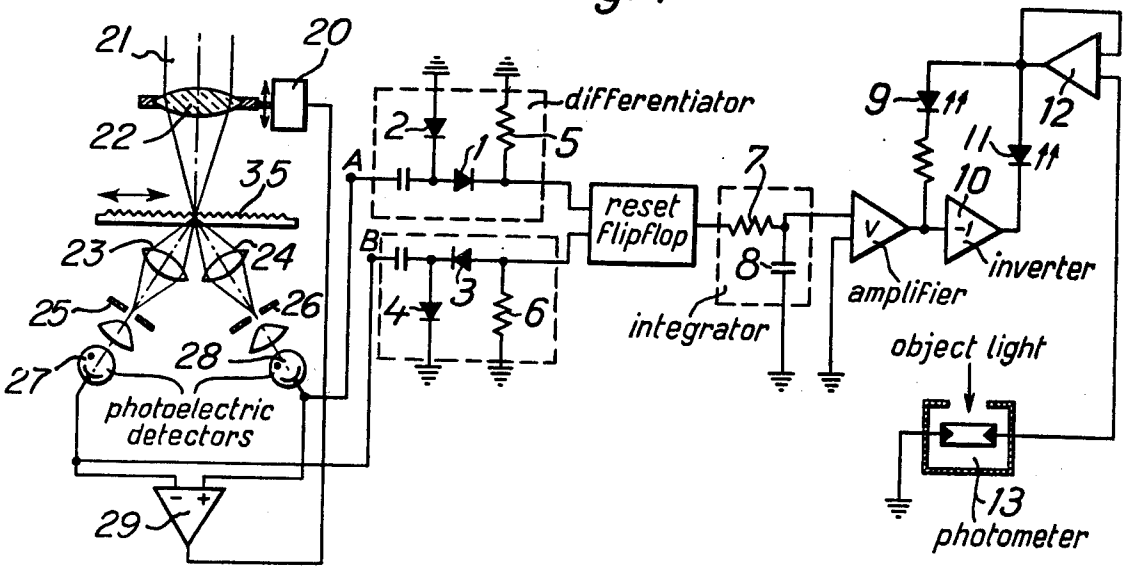


Fig. 2

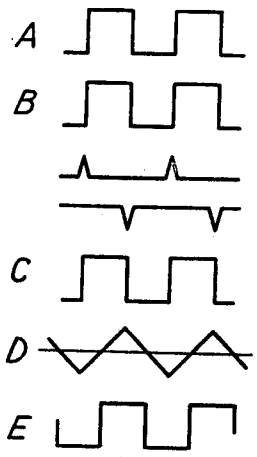


Fig. 3

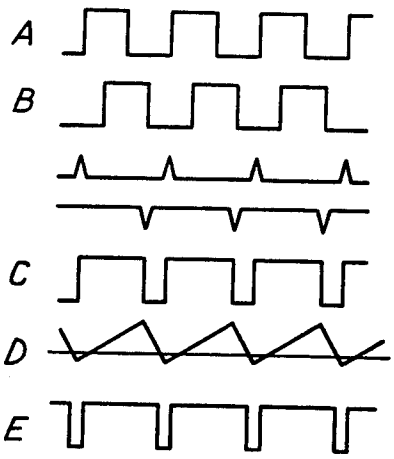
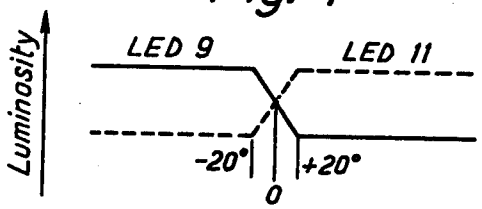


Fig. 4



OPTICAL OBJECTIVE FOCUS INDICATOR AND DISPLAY

The present application is a continuation of application Ser. No. 711,462 filed Aug. 5, 1976 and now abandoned.

BACKGROUND OF THE INVENTION

The present invention relates to apparatus for indicating and displaying the focus of an objective, in particular that of a photographic camera.

It is known to the prior art, as regards focusing of objectives, to project an image of the object onto a scanning disk or plate located in one image plane of the objective. This disk or plate comprises a grating being moved normal to its grating lines. The light rays impinging on this grating are split into two separate light beams which originate from different areas of the exit pupil of the objective. Two photoelectric detectors are provided behind the scanning disk or plate, each of which delivers one electrical signal, the phase difference between the two signals representing a measure of the focus or lack of focus of the objective.

It is known to use a phase difference signal to control a servo motor displacing the objective by means of gearing into one direction or the other until the phase difference is null, that is, until the objective is focused on the object.

However, the objectives to be displaced frequently are fairly heavy, so that their displacement requires significant power and a strong motor is required, which in turn often is packaged only with difficulty in optical instruments. This is especially the case for camera objectives having long focal lengths.

The state of the art of scanning disks and gratings in combination with photoelectric detectors therebehind for measuring the focus of objectives may be ascertained by reference to U.S. Pat. Nos. 3,781,110 and 3,833,299 the disclosures of which are incorporated herein. The state of the art of the circuitry for auotomatic comparison of two beam photoelectric radiation may be ascertained by reference to U.S. Pat. No. 3,255,355, the disclosure of which is incorporated herein.

Having the above limitations in mind, it has been proposed therefore to make use of a simple control in lieu of a closed loop, that is, to provide semi-automatic focus instead of a fully automatic one, the objective being adjusted manually and a special focus indicator being provided.

Conceivably such a focusing display might be a simple measuring unit requiring displacing the objective until a given pointer position is reached. Such a measurement unit however will be disadvantageous if the light conditions for the object are poor, that is, when the object is fairly dark, because there would be difficulties in reading the pointer position.

SUMMARY OF THE INVENTION

Having the above in mind, it is an object of the present invention to have a focus display which would be largely independent of the object's brightness or illumination.

The present invention achieves this objective by providing a focus display consisting of a photo scale of two LEDs (Light Emitting Diodes) which are so powered as to be equally luminous for full focus (phase difference = 0). These LEDs because of their special circuitry ascertain the direction of the offset of the image from the focusing plane by their changes in luminosity independent of the object brightness when there is defocusing, and furthermore approximately also the amount of this offset.

Such a focusing display is independent of the object brightness whenever the luminosity of the LEDs of the photo scale depends only on the phase difference of the signals supplied by the photodetectors. If there is zero phase difference, both LEDs will be of an even and median luminosity. But if there is a phase difference, one of the LEDs will be brighter than the other, this difference in luminosity depending only on the phase difference and being independent of the object brightness.

However, in order to prevent any swamping of the view finder, it is desirable to adapt the median luminosity of the LEDs to the brightness of the view finder, that is, the LEDs are the more luminous the brighter the object, and the less luminous the lower the object brightness.

To make such allowance, it is further proposed to couple the two LEDs so that their median luminosity varies with object brightness.

When the display system of the present invention is used to indicate objective focus in a photographic camera, then preferably the two LEDs should be mounted approximately at the center of the view finder, and in particular so that they are visible at the edge of the part of the image field being evaluated.

BRIEF DESCRIPTION OF THE DRAWING

Further objects and features of the present invention may be ascertained by reference to the accompanying drawings wherein:

FIG. **1** is a schematic circuit drawing of one embodiment of the present invention;

FIG. **2** is a graphical representation of the signal processing in the circuit of FIG. **1** when the object is in focus;

FIG. **3** is a graphical representation of the signal processing of FIG. **1** when the objective is out of focus; and

FIG. **4** is a graphical representation of the luminosity angle relationship of the two LEDs.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The circuit shown in FIG. **1** is provided with two inputs A and B fed with square wave pulses from photoelectric detectors. These pulse trains are in phase for focus. Each input A and B is followed by a differentiator consisting of two diodes **1,2** and **3,4** and one resistance **5,6**.

A reset flip-flop RSFF is connected to the outputs of the differentiators, its own output being connected to an integrator in the form of an RC-circuit **7,8**. The integrator is followed by an amplifier V or high gain. The first LED **9** connects to the output of amplifier V, which is followed by an inverter **10**, the output of the latter being connected to the second LED **11**.

The other two terminals of LEDs **9** and **11** are jointly connected to the output of voltage follower **12** which is fed with its potential from photometer **13**. The last part of the circuit, that is the voltage follower in combination with light or photometer **13** is used to adjust the

median luminosity of LEDs **9** and **11** to the particular object brightness.

Reference numeral **21** designates a light bundle coming from an object to be measured. An objective **22** images the object in the plane of grating **35**. As a result of the relative movement between the grating **35** and the image, which may be generated stochastically by movements or vibrations of the user of the rangefinder, a time-variable signal of maximum amplitude occurs at the output of the push-pull amplifier **29** in the condition of sharp focusing. Diaphragms **25** and **26** have here, in connection with the objectives **23** and **24**, the purpose of defining the detection directions of the photoelectric detectors **27** and **28** in single valued manner so as to be unambiguous. The image sharpness is regulated by means of regulator **20** and objective **22**.

The circuit operates as follows:

The square wave pulses from the photodetectors are applied to inputs A and B, as shown in FIG. **2**, for zero phase shift. Differentiation in differentiators **1,2,5** generates pulses from wave train A following transition into Plus, whereas pulses are generated from wave train B by means of differentiators **3,4,6** when transiting into Minus. These pulses control the reset flip-flop RSFF, which for the assumed phase difference of zero of FIG. **2** delivers at its output a square wave train C with a keying ratio of 1:1.

This square wave train is applied to the RC circuit **7,8** (= integrator), which delivers an output in the form of a saw tooth wave D which, for focus — that is, for zero phase difference between the square wave trains at inputs A and B evenly fluctuates about the null point. Amplifier V again shapes curve D into a square wave E of 1:1 keying ratio. In this manner both LEDs **9** and **11** are controlled, furthermore making use of inverter **10**. Because of the 1:1 keying ratio of the square wave train E, the LEDs are equally luminous when focus has been obtained (i.e., when the phase difference between the square wave trains at inputs A and B is zero).

FIG. **3** on the other hand shows the signal-time relationship for the objective out of focus. In this case there is phase difference between the square waves at inputs A and B, which is proportional to defocusing.

Therefore the pulses delivered by differentiators **1,2,5** and **3,4,6** are not equally spaced upon comparison of the two pulse trains. In turn this causes keying ratio deviating from 1:1 in the square wave C at the output of the reset flip-flop RSFF. Then saw-tooth wave D no longer evenly fluctuates about the null point, but is offset to one side, and the square wave E after amplifier V therefore also deviates from 1:1 in its keying ratio. The end result is that the currents applied to LEDs **9** and **11** are unequal and these LEDs are of unequal luminosities, thereby displaying lack of focus.

The combination of the RC circuit **7,8** and amplifier V allows increasing the keying ratio of wave train E with respect to C, that is, to increase the discrimination slope.

FIG. **4** shows the luminosity of the two LEDs **9** and **11** as a function of the phase difference between the two square waves applied at inputs A and B. It is seen that for zero phase difference, the two LEDs are equally luminous. If however there is minus phase difference, the luminosity of LED **11** decreases while that of LED **9** increases. A boundary value is reached for a phase difference of about $-20°$, beyond which LED **11** is completely dark while LED **9** shines at constant and maximum brightness. When the phase difference is Plus, mirror-image relationships are obtained, so that beyond a phase difference of about $+20°$, LED **9** is dark while LED **11** shines with maximum luminosity.

The photo or light meter denoted by **13** is assumed to deliver a potential increasing with illumination. The potential applied to the LED is so controlled by means of that potential passing through the voltage follower and when appropriate through non-linear resistances that the LEDs are less luminous for lesser ambient brightness.

We claim:

1. In an apparatus comprising an optical objective, a scanning disk or a scanning plate and first and second photoelectric detectors all located along optical axes for indicating the focus of said optical objective which projects an image of an object onto said scanning disk or scanning plate for pupil division of the image into imaging beams, and projection of said imaging beams onto said photoelectric detectors, each of which generates an electrical impulse where a phase difference between said pulses is a measure of the degree of said focus of the objective, the improvement comprising first and second differentiators connected respectively to said first and second photoelectric detectors, a reset flip-flop having first and second input terminals connected respectively to said first and second differentiators and an output terminal, an integrator connected to said output terminal, an amplifier connected to said integrator, a first and a second light emitting diode, said first light emitting diode connected to said amplifier and said second light emitting diode connected to an inverter connected to said amplifier, a voltage follower connected to said first and second light emitting diodes, and means for photoelectrically measuring the object brightness, said means connected to said voltage follower for adjusting the median luminosity of said light emitting diodes in dependence on the object brightness.

* * * * *

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Schütz et al. 5] Aug. 29, 1978

[54] **COUPLING MECHANISM FOR THE ALTERNATE MANUAL AND AUTOMATIC ADJUSTMENT OF A VARIFOCAL OBJECTIVE**

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[73] Assignee: **Jos. Schneider & Co. Optische Werke Kreuznach,** Bad Kreuznach, Fed. Rep. of Germany

[21] Appl. No.: **789,228**

[22] Filed: **Apr. 20, 1977**

[30] **Foreign Application Priority Data**

Apr. 21, 1976 [DE] Fed. Rep. of Germany 2617464

[51] **Int. Cl.**[2] **G02B 7/10;** G03B 3/02
[52] **U.S. Cl.** **354/195;** 350/75; 350/187
[58] **Field of Search** 352/140; 350/40, 75, 350/247, 76, 254, 255, 257, 187, 184; 354/195, 289

[56] **References Cited**

U.S. PATENT DOCUMENTS

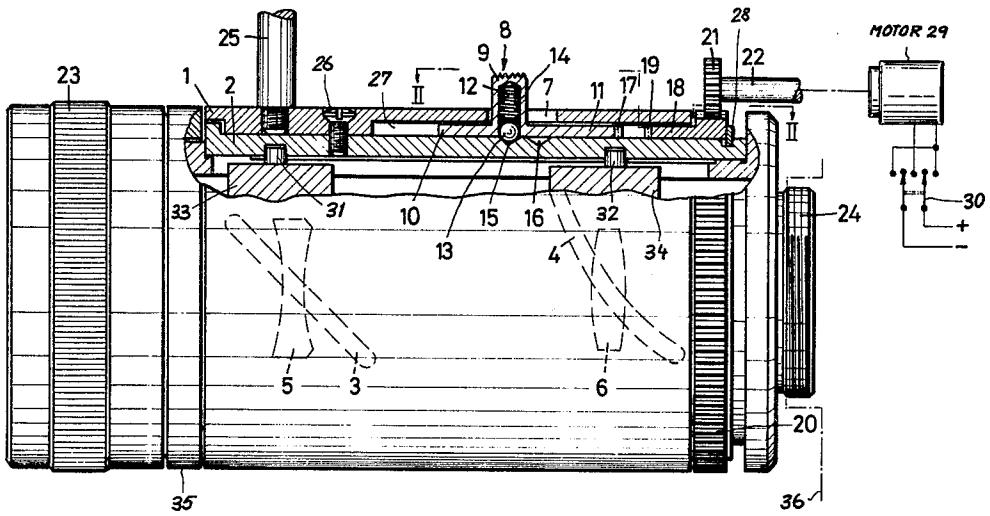
3,095,794	7/1963	Raab	350/75
3,224,351	12/1965	Strasser	350/76
3,582,188	6/1971	Rau et al.	350/187 X
4,057,327	11/1977	Kumazawa	354/195 X

Primary Examiner—Donald A. Griffin
Attorney, Agent, or Firm—Karl F. Ross

[57] **ABSTRACT**

A camming sleeve for the adjustment of the shiftable components of a varifocal objective is fixed to a surrounding coaxial control ring having a slot traversed by a knob which is rigid with a slider received in a recess between the control ring and the sleeve. The slider, which is indexable in two different axial positions, has a toothed edge engageable in one of these positions with a toothed face of a coupling ring, permanently connected via a step-down transmission with a reversible drive motor, which in the other slider position is freely rotatable on the camming sleeve so that the latter can be manually displaced by means of a handle rigid therewith.

4 Claims, 2 Drawing Figures



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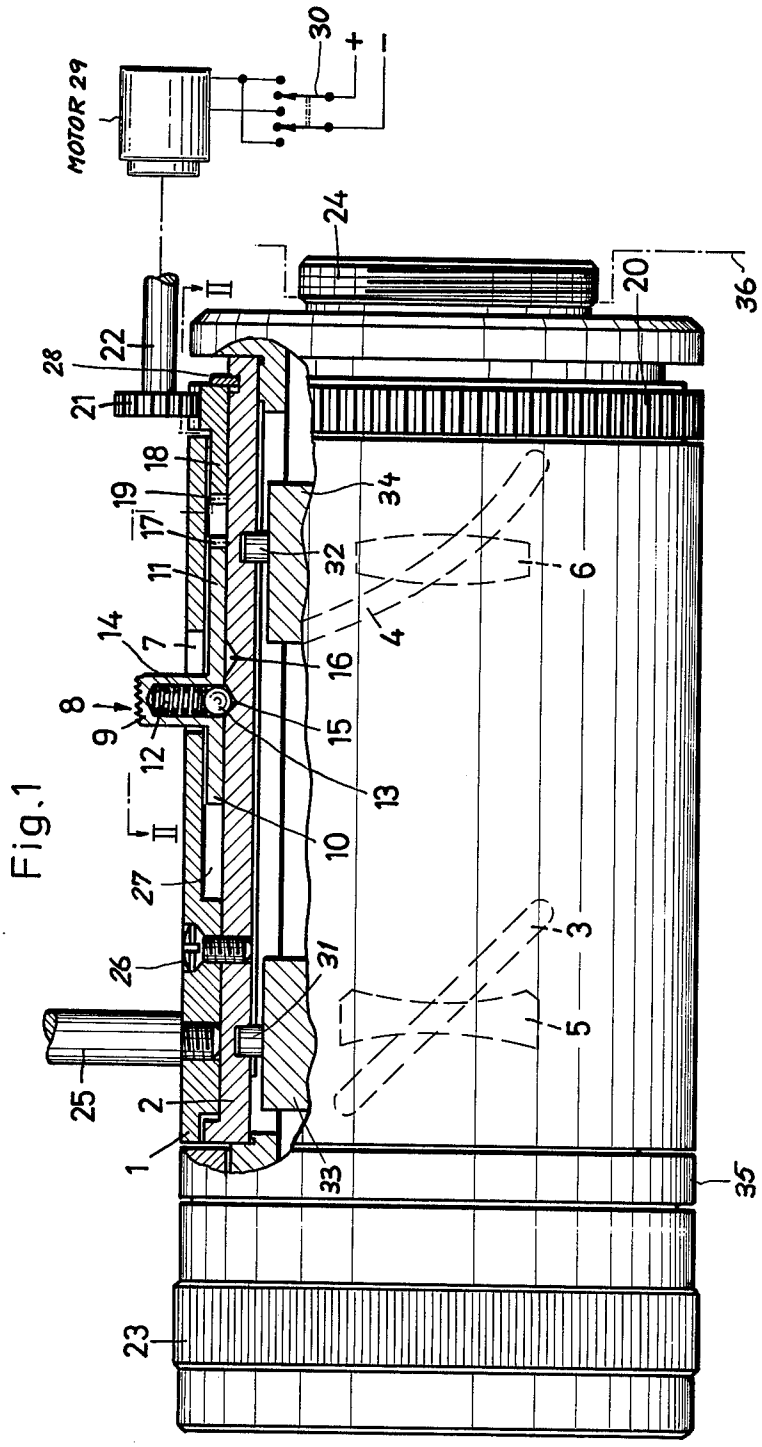
MOTOR 29
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Fig. 1

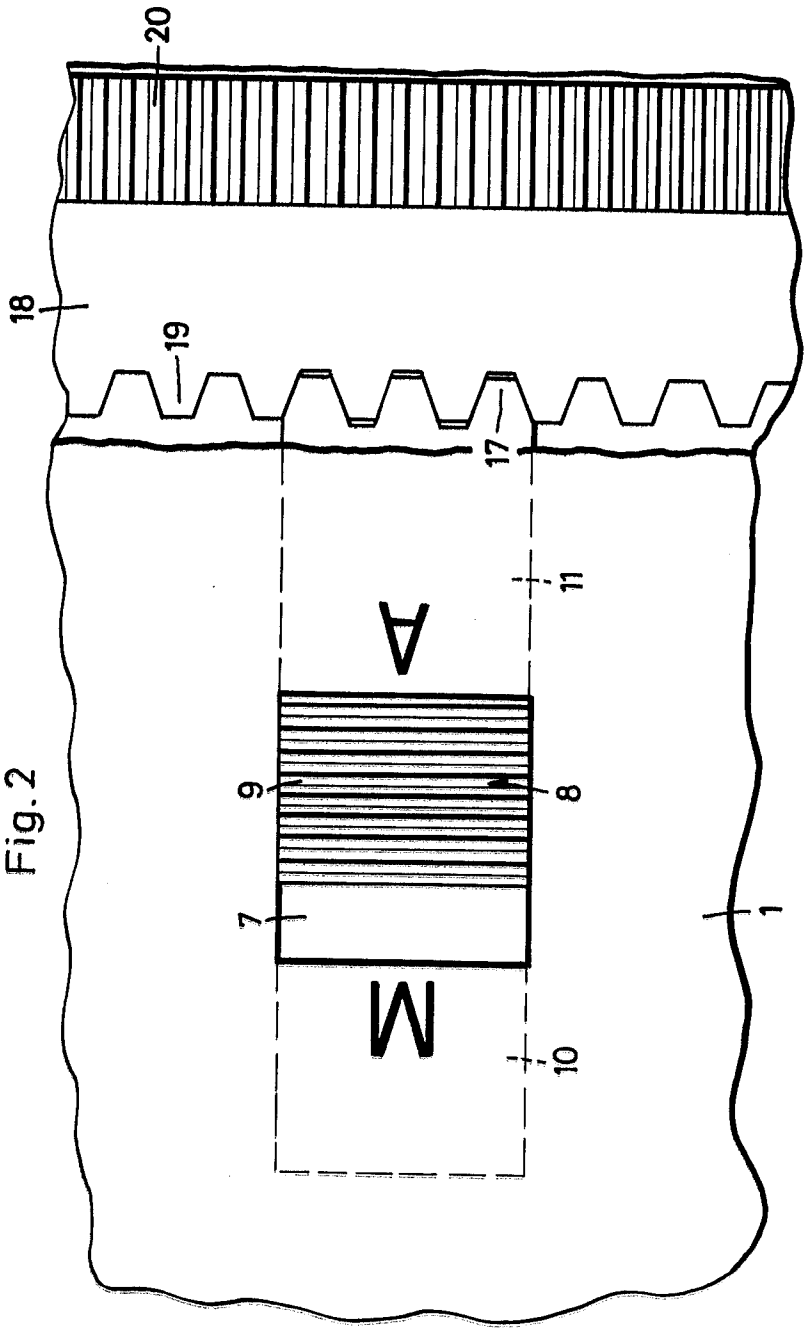

Fig. 2

COUPLING MECHANISM FOR THE ALTERNATE MANUAL AND AUTOMATIC ADJUSTMENT OF A VARIFOCAL OBJECTIVE

FIELD OF THE INVENTION

Our present invention relates to a photographic, cinematographic or television camera with a varifocal objective whose axially shiftable components can be adjusted either manually or automatically with the air of a rotatable camming sleeve centered on the objective axis.

BACKGROUND OF THE INVENTION

In commonly owned U.S. Pat. No. 3,095,794 there has been described a camera of this type in which a handle is shiftable in an objective housing between a "manual" position and an "automatic" position; a camming sleeve for the adjustment of the overall focal length is coupled with a reversible drive motor in the "automatic" position and is decoupled from that motor in the "manual" position in which the sleeve can be rotated by the handle. In a later U.S. Pat. No. 3,224,351, a rotary knob can be similarly shifted on an objective housing for selective manual or automatic adjustment. In both these instances the manual/automatic selector, i.e. the handle or knob, is decoupled from the sleeve in the "automatic" position and therefore does not participate in its rotation by the motor; thus, the selector position is not related to focal length and a separate indicator must be provided to inform the user of the position last reached by the camming sleeve.

German Pat. No. 2,345,078 describes a varifocal objective or zoom lens in which the drive motor rotates the camming sleeve through a gear train, acting as a step-down transmission, and can be decoupled therefrom by the separation of two gears of that train. Upon such decoupling, the sleeve can be manually rotated by a lever or the like not illustrated in that German patent. Since the manual adjustment entails the entrainment of several meshing gears of the step-down transmission, the user must overcome an added frictional resistance. Also, because of the unavoidable play of the gear teeth, a false impression of a defective mechanism may be created.

OBJECT OF THE INVENTION

The object of our present invention, therefore, is to provide means in such a camera for the selective changeover from manual to automatic adjustment or vice versa anywhere within the varifocal range and with a minimum of encumbrance in the manual position.

SUMMARY OF THE INVENTION

In accordance with our present invention, a control ring surrounding the camming sleeve is partly separated from that sleeve by an intervening clearance communicating with an axially extending slot of that ring. A slider axially displaceable in the clearance, provided with indexing means for yieldably representing manual and automatic operation, has an extension which passes outwardly through the slot of the ring to form a knob or other element manipulable by the user. A coupling ring coaxial with the camming sleeve has a toothed face confronting a toothed edge of the slider which is engageable with that toothed face in the "automatic" position but is disenaged therefrom in the "manual" position. In the "automatic" position, the sleeve is reversibly rotatable by drive means operatively connected with the coupling ring, advantageously through step-down transmission including a pinion in permanent mesh with a set of gear teeth on this ring. In the "manual" position, such rotation can be performed by a handle on the control ring.

BRIEF DESCRIPTION OF THE DRAWING

The above and other features of our invention will now be described in detail with reference to the accompanying drawing in which:

FIG. 1 is a side-elevational view, partly in section, of a lens mounting for a camera embodying our invention; and

FIG. 2 is a fragmentary top view taken on the line II — II of FIG. 1 and drawn to a larger scale.

SPECIFIC DESCRIPTION

In FIG. 1 we have shown a varifocal or zoom objective comprising a control ring **1** that is manually rotatable, with the aid of a handle **25**, about the objective axis and coaxially surrounds a sleeve **2** with which it is rigidly connected by screws **26** (only one shown). Sleeve **2** is formed with a pair of camming grooves **3** and **4** engaged by pins **31** and **32** on respective lens mounts **33** and **34** which are axially shiftable therein and carry components **5** and **6** of the objective designed to vary its overall focal length. A short, axially extending slot **7** in ring **1** communicates with a clearance **27** existing between that ring and the carrying sleeve **2**, that clearance being here formed by a recess in the inner peripheral surface of the ring. A slider **8** has a knob **9** projecting outwardly through slot **7** and is guided by front and rear legs **10** and **11** integral therewith, these legs being received in clearance **27**. As shown in FIG. **2**, knob **9** is shiftable within slot **7** between a forward position marked M (for "manual") and a rear position marked A (for "automatic"); two depressions **15** and **16** in the outer surface of sleeve **2** coact with detent in a bore **14** of knob **9**, i.e. a ball check **13** loaded by a spring **12**, for yieldably arresting the slider **8** in either of these positions. Depressions **15** and **16** could be small dimples but may also be in the form of parallel peripheral grooves.

Leg **11** of slider **8** has a toothed edge **17** which, in "automatic" position A, engages a confronting toothed face **19** of a coupling ring **18** coaxially surrounding the rear end of sleeve **2** on which ring **18** is freely rotatable, being held against rearward displacement by a jump ring **28**. Coupling ring **18** has a set of peripheral gear teeth **20** in permanent mesh with a pinion **21** whose shaft **22** can be reversibly driven by a motor **29**. A manual switch **30** in the energizing circuit of that motor has two operating positions for forward and reverse rotation, respectively.

Rings **1** and **18** as well as sleeve **2** are carried on a lens barrel **35** which is also provided with the usual setting ring **23** for focusing purposes. A rear flange **24** on lens barrel **35** allows the latter to be removably secured to a camera housing **36** indicated only diagrammatically.

As will be readily apparent, an indexing of slider **8** in its "automatic" position A allows the focal length of the objective to be reduced or increased by the zoom drive **20 – 22, 29** under the control of three-position switch **30**; ring **1**, handle **25** and slider **8** participate in the rotation of camming sleeve **2**. In the "manual" position M, handle **25** allows the assembly **1, 2, 8** to be rotated without entrainment of ring **18** or pinion **21**. The established focal length can be ascertained in either case by the

angular position of handle **25** as read, for example, on a stationary scale engraved on lens barrel **35**.

In principle, the clearance **27** could also be formed by a recess in the outer surface of sleeve **2**. Moreover, the ball check **12, 13** or equivalent indexing means could be located elsewhere in the assembly, though the illustrated arrangement is particularly advantageous for its compactness.

The use of a coupling ring **18** (whose diameter substantially equals that of lens barrel **35**) as part of a step-down transmission between motor **29** and sleeve **2** eliminates the need for a multistage gear train of the type shown in the aforementioned German Pat. No. 2,345,078.

We claim:

1. In a camera provided with a varifocal objective having components shiftable along an optical axis with the aid of a camming sleeve centered on said axis,

the combination therewith of:

a control ring surrounding said sleeve, said control ring being partly separated from said sleeve by an intervening clearance and having an axially extending slot communicating with said clearance;

a slider axially displaceable in said clearance and provided with indexing means for yieldably arresting it in either of two axially spaced positions, said slider having an extension passing outwardly through said slot for manipulation by a user;

a coupling ring coaxial with said sleeve having a toothed surface confronting said slider, the latter having a toothed edge engageable with said toothed face in one of said positions but disengaged therefrom in the other of said positions; and

automatic drive means operatively connected with said coupling ring for reversibly rotating said sleeve through the intermediary of said slider in said one of said positions, said control ring being provided with handle means enabling manual rotation of said sleeve in said other of said positions.

2. The combination defined in claim **1** wherein said coupling ring is rotatably mounted on said sleeve.

3. The combination defined in claim **1** wherein said automatic drive means comprises a reversible motor connected with said coupling ring through a step-down transmission including a pinion in permanent mesh with a set of gear teeth on said coupling ring.

4. The combination defined in claim **1** wherein said extension is a knob provided with a bore open toward said sleeve, said indexing means comprising a ball check in said bore engageable with coacting formations on said sleeve.

* * * * *

United States Patent [19]

Uesugi et al.

[11] **4,110,008**

[45] **Aug. 29, 1978**

[54] **CUSHIONED OBJECTIVE LENS**

[75] Inventors: **Kyozo Uesugi**, Izumi; **Tsuneyo Metabi**; **Ryuzo Hachiken**, both of Sakai, Japan

[73] Assignee: **Minolta Camera Kabushiki Kaisha**, Osaka, Japan

[21] Appl. No.: **770,959**

[22] Filed: **Feb. 22, 1977**

[30] **Foreign Application Priority Data**

Mar. 2, 1976 [JP] Japan 51-22806

[51] **Int. Cl.**[2] **G02B 7/02**

[52] **U.S. Cl.** **350/255**; 354/195; 354/286

[58] **Field of Search** 350/187, 252, 255, 257; 354/286, 195

[56] **References Cited**

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3,329,075	7/1967	Padelt	350/255
3,594,068	7/1971	Kirstein	350/187 X
3,944,340	3/1976	Hashimoto	350/187 X

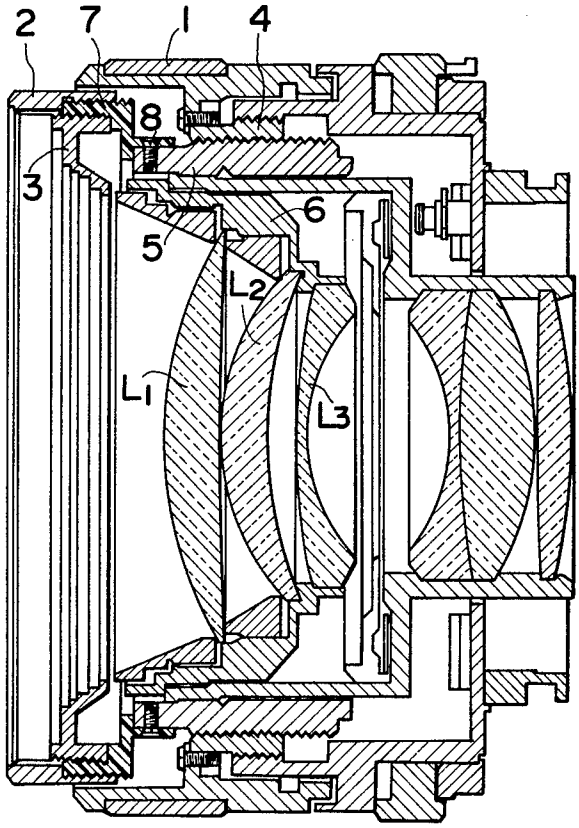
Primary Examiner—F. L. Evans

Attorney, Agent, or Firm—Wolder, Gross & Yavner

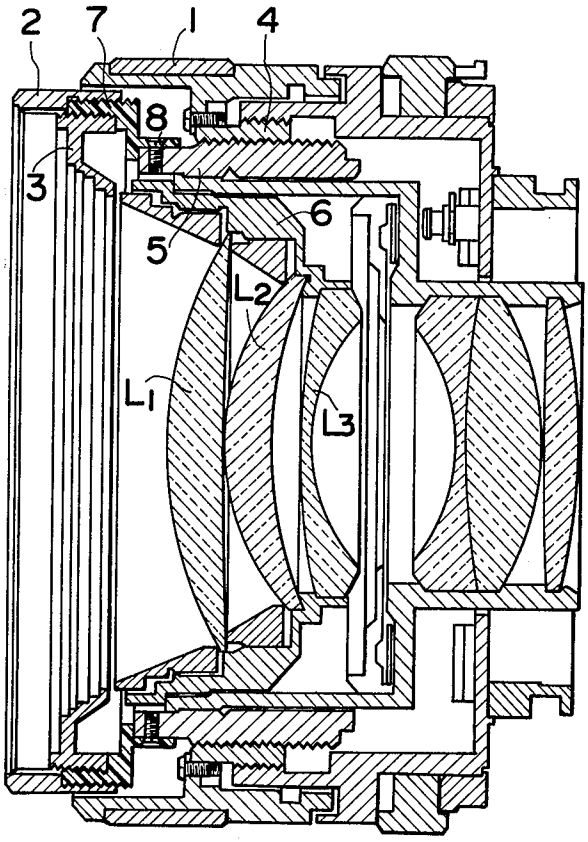
[57] **ABSTRACT**

A buffer or cushion made of a plastic material is interposed between an external device exposed to the exterior of a lens barrel and an internal mechanism within the barrel of a lens to absorb any impact applied to the external device and transmitted toward the internal mechanism and the lens unit. The external device may include an ornament ring and a barrel head sleeve and the internal mechanism may include sleeves for shifting the lens unit and members for holding the lens unit.

13 Claims, 1 Drawing Figure



Figure



CUSHIONED OBJECTIVE LENS

BACKGROUND OF THE INVENTION

The present invention relates generally to improvements in optical devices and it relates particularly to an improved shock-proof lens barrel assembly.

In general, the conventional lens barrel is constructed of metal members of high rigidity, such as the operating ring which is exposed to the exterior of the lens barrel, the focussing means constituting an internal mechanism, one or more lens holding rings and the like. In addition, these members are directly interfitted or intercoupled providing a rigid assembly and construction. As a consequence, when a lens barrel is inadvertently struck by another article, or falls on the floor, then an impact is directly transmitted from an external member of the lens barrel to the internal mechanism, thus impairing the desired and proper functioning of the focussing mechanism or the optical system, or damaging the same. Once the damage occurs, then the function of the device as an optical instrument is diminished or lost and its repair, if possible, leads to an expenditure of much time and effort and is generally highly expensive.

SUMMARY OF THE INVENTION

It is accordingly an object of the present invention to provide a lens device such as an objective lens which will not suffer from loss of the desired and proper functioning of any internal mechanism and lens unit and damage thereto due to an impact applied to an external component of the lens device.

Another object of the present invention is to provide an improved lens barrel with a buffer or cushion of simple and rugged construction and of low manufacturing cost.

To accomplish the above objects, a lens barrel of the present invention includes a buffer or cushion interposed between an external component or bumper exposed to the exterior thereof and an internal mechanism disposed between a lens unit and the external component. With this construction, any impact exerted on the external component is absorbed by the buffer and weakened or highly attenuated when transmitted to the internal mechanism. As a result, there will be little or no danger of a strong impact being imparted to the internal mechanism and the lens unit, and thus these latter will not lose their desired or proper functioning nor will they be damaged.

The buffer is advantageously formed of a plastic or synthetic organic polymeric resin material which is in general less rigid and more flexible than a metallic material. Such a buffer of a plastic material can be manufactured by molding at low cost and will be simple in its construction and application.

In accordance with a preferred embodiment of the present invention, the buffer is advantageously made of a synthetic polymeric resin of high flexibility. The external component includes an ornament ring disposed in front of the lens unit and a barrel head sleeve disposed at a forwardmost portion of the lens barrel, the ornamental ring and barrel head sleeve being most liable to receive any impact among the members exposed to the exterior of the lens barrel. However, the external bumper component may include an operating member such as a focussing ring. Furthermore, the internal mechanism in the embodiment includes sleeves for shifting the lens units for focussing and members for holding the lens units.

Furthermore, parts of the external and internal mechanisms may be made of a plastic material as part of the buffer or cushion. That is, the buffer may include as a part thereof, a part of the external and/or internal mechanisms. With such a construction, the number of members is reduced, which results in lower manufacturing cost of the lens barrel.

The above and other objects and features of the present invention will be more apparent from the following description taken in connection with the accompanying drawing.

BRIEF DESCRIPTION OF THE DRAWING

The single FIGURE is a medial longitudinal cross-sectional view of a lens barrel according to an embodiment of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to the drawing which illustrates a preferred embodiment of the present invention in the form of an exchangeable objective lens for use in a single lens reflex camera, the reference number **1** designates a focussing operating ring, a barrel head sleeve **2** having a threaded portion for use in securing attachments thereto and **3**, an ornament ring on which are marked the nomenclature of the lens and the like. The members **1**, **2**, and **3** are exposed to the exterior of the lens barrel. The internal mechanism of the objective lens includes focussing means composed of an outer helicoid sleeve **4** and an inner helicoid sleeve **5**, and a holding ring or collar **6** for holding lens groups **L1**, **L2** and **L3**. The outer helicoid sleeve **4** is integral and rotatable with focussing operating ring **1** and is fitted on the inner helicoid sleeve **5** by means of a helicoid thread. Lens holding ring **6** moves lens groups **L1**, **L2**, and **L3** as a unit along the optical axis, in response to the shifting of the inner helicoid sleeve **5** along the optical axis. Shown at **7** is buffer or cushion ring made of a synthetic resin of high flexibility and ring **7** threadingly engages the lens head ring **2** as well as the ornamental ring **3**, and is secured to inner helicoid sleeve **5** by means of a screw **8**.

With the aforesaid arrangement, in the event that an impact is applied to the barrel head sleeve **2** which is most likely to be subjected to an impact, then the impact is neutralized by means of buffer ring **7** by absorbtion and attenuation thereof, to a desired degree, so that inner helicoid sleeve **5** will not be adversely affected. Likewise, in case an impact is applied to ornament ring **3** from front of the lens barrel, the buffer ring **7** will absorb and attenuate the impact. As a result, there is little or no danger of a strong impact being imparted to and acting on inner helicoid sleeve **5** nor on the lens holding ring **6**, and thus these members or lenses will not lose their functions nor be damaged.

This embodiment provides a cushion or buffer member for the lens and the internal mechanism, which are most likely to be subjected to an impact. Alternatively, a buffer member may be provided between focussing operating ring **1** and the outer helicoid sleeve **4**. The ornament ring **3** or the inner helicoid sleeve in most cases are made of a metal of a high rigidity, but one or both of these members may be molded integrally with buffer ring **7** by using a synthetic resin, with an accompanying saving in manufacturing cost. In the embodi-

ment described, buffer ring 7, barrel head sleeve 2, and ornament ring 3 need not necessarily be threadingly interfitted, but may be simply fitted without using a threaded section.

The principle incorporated in the structure of the present invention may be applied to zoom lens barrels as well as to lens barrels of cameras of the types other than a single lens reflex camera.

While there have been described and illustrated preferred embodiments of the present invention, it is apparent that numerous alterations, additions and omissions may be made without departing from the spirit thereof.

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We claim:

1. A lens device comprising:

a lens barrel;

a lens unit disposed within said lens barrel;

an external component including a barrel head sleeve disposed at a forwardmost portion of said lens barrel and exposed to the exterior of said lens barrel so as to receive an impact applied from the front of said lens barrel;

an internal mechanism disposed between said lens unit and said external component; and

a buffer coupled to and interposed between said barrel head sleeve and said internal mechanism.

2. A lens device as defined in claim 1, wherein said buffer is made of a plastic material.

3. A lens device as defined in claim 2, wherein said buffer is made of a synthetic resin of high flexibility.

4. A lens device as defined in claim 2, wherein said external component includes an ornament ring disposed in front of said lens unit and coupled to said buffer.

5. A lens device as defined in claim 2, wherein said internal mechanism includes means for shifting said lens unit.

6. A lens device as defined in claim 2, wherein said internal mechanism includes means for holding said lens unit.

7. A lens device as defined in claim 2, wherein said external component includes a portion made of a plastic material and said buffer has said portion as a part thereof.

8. A lens device as defined in claim 2, wherein said internal mechanism includes a portion made of a plastic material and said buffer has said portion as a part thereof.

9. A lens device as defined in claim 5, wherein said barrel head sleeve is axially movable relative to said lens barrel, said lens unit shifting means includes a movable sleeve which is axially movable relative to said lens barrel for shifting said lens unit, and said buffer has a front end coupled to said barrel head sleeve and a rear end coupled to said movable sleeve.

10. A lens device as defined in claim 9, wherein said lens barrel includes a focussing ring accessible for actuating said lens unit shifting means such that said movable sleeve is axially moved relative to said lens barrel.

11. An objective lens comprising:

a lens barrel;

a lens unit disposed within said lens barrel;

an adjusting mechanism disposed within said lens barrel and supporting said lens unit;

a bumper component projecting axially forwardly of said adjusting mechanism and said lens barrel so as to be directly exposed to impact, applied externally of said lens barrel; and

an impact attenuating cushion member disposed between and intercoupling said adjusting mechanism and said bumper component.

12. The objective lens of claim 11 wherein said bumper member comprises a ring.

13. The objective lens of claim 12 wherein said bumper ring is formed of metal and said cushion member comprises a ring formed of a synthetic polymeric resin coaxial with and directly joined to said bumper ring.

* * * * *

OR 4,110,005

United State

Bohm et al.

1] **4,110,005**

5] **Aug. 29, 1978**

[54] **WIDE-ANGLE ATTACHMENT FOR VARIFOCAL OBJECTIVE**

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[73] Assignee: **Bolex International SA**, Ste-Croix, Switzerland

[21] Appl. No.: **711,835**

[22] Filed: **Aug. 5, 1976**

[30] **Foreign Application Priority Data**

Aug. 6, 1975 [AT] Austria 6079/75

[51] **Int. Cl.**[2] **G02B 15/18**; G02B 7/02

[52] **U.S. Cl.** **350/184**; 350/187; 350/257; 354/295

[58] **Field of Search** 350/257, 187, 184, 186; 354/295, 296

[56] **References Cited**

U.S. PATENT DOCUMENTS

2,559,844	7/1951	Bennett	350/202
3,891,304	6/1975	Muszumanski et al.	350/184
3,997,245	12/1976	Uesugi	350/187

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Primary Examiner—Conrad J. Clark

Attorney, Agent, or Firm—Montague & Ross

[57] **ABSTRACT**

A varifocal object selectively focusable upon a normal range of object distances and a substantially shorter macro range can be supplemented by a negative component of one or more lenses whose focal length is less than the depth of the macro range and which forms a virtual image of a nearby object on the object plane of the objective when the latter is adjusted to a predetermined closeup position. A correlating linkage between a seat for the supplemental component and a control member designed to establish the closeup position serves to index the control member in that position or to prevent the emplacement of the supplemental component if the objective is in a different position.

8 Claims, 11 Drawing Figures

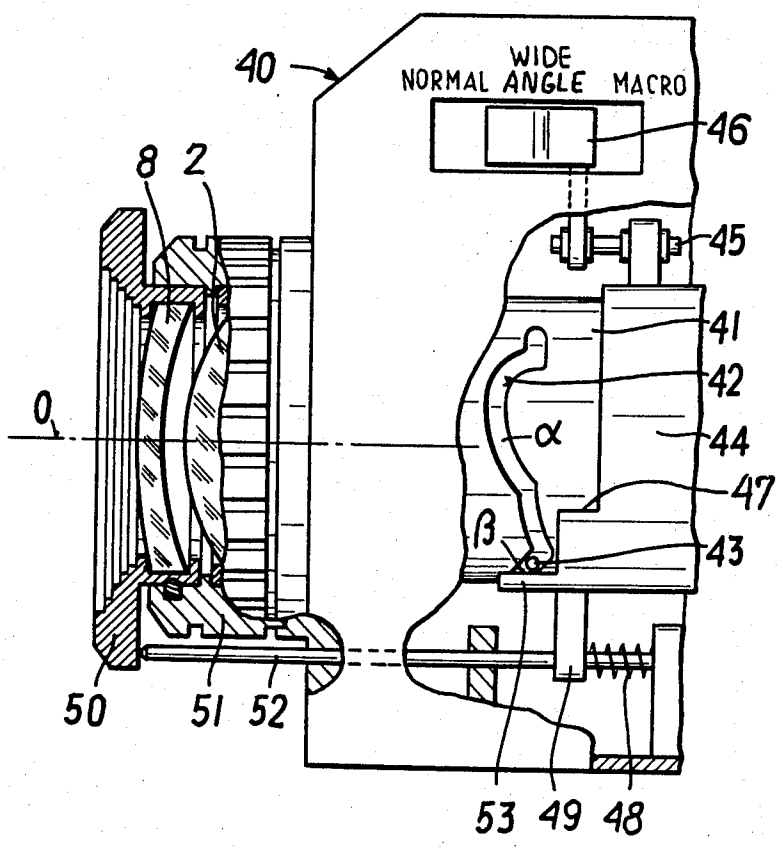


FIG. 1

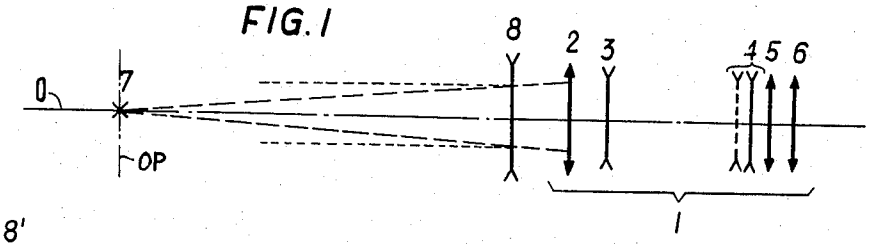


FIG. 2

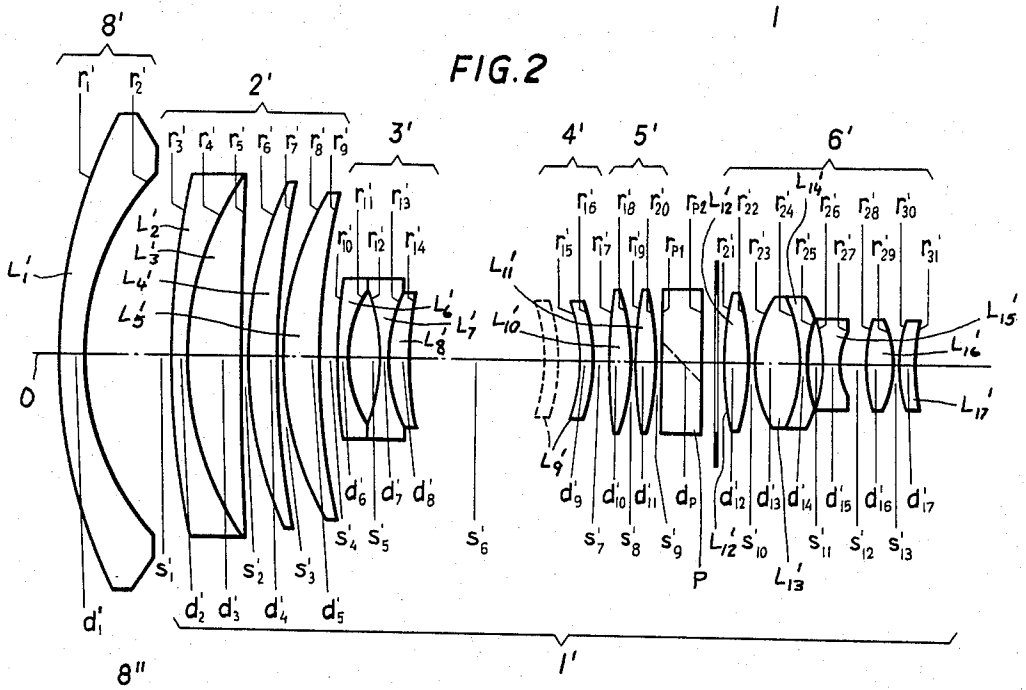
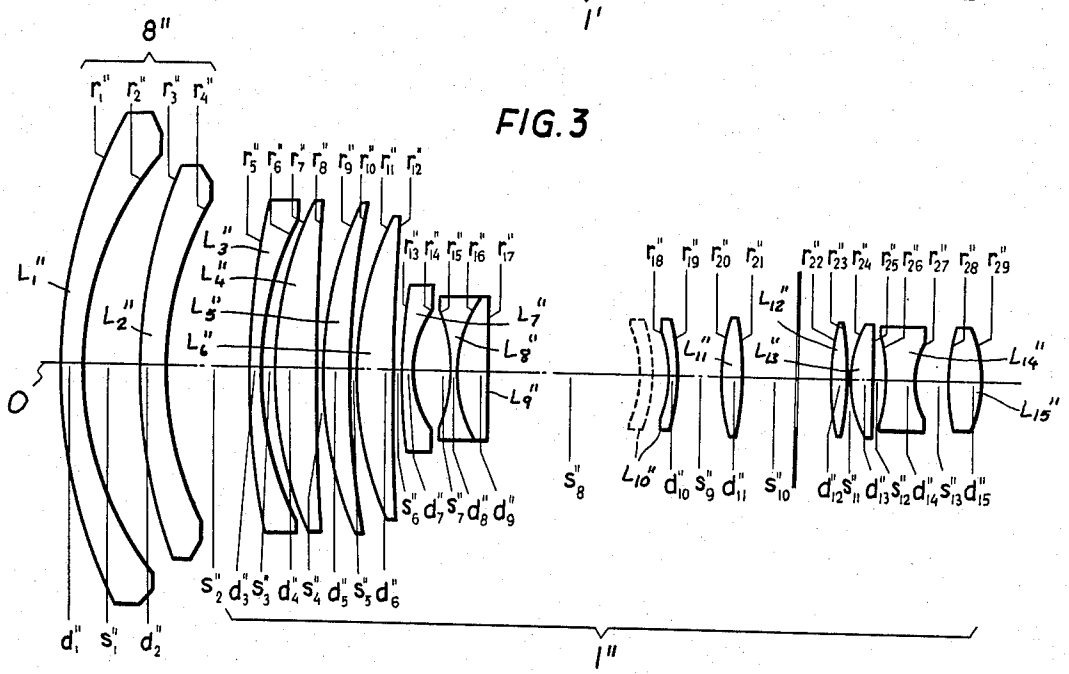


FIG. 3



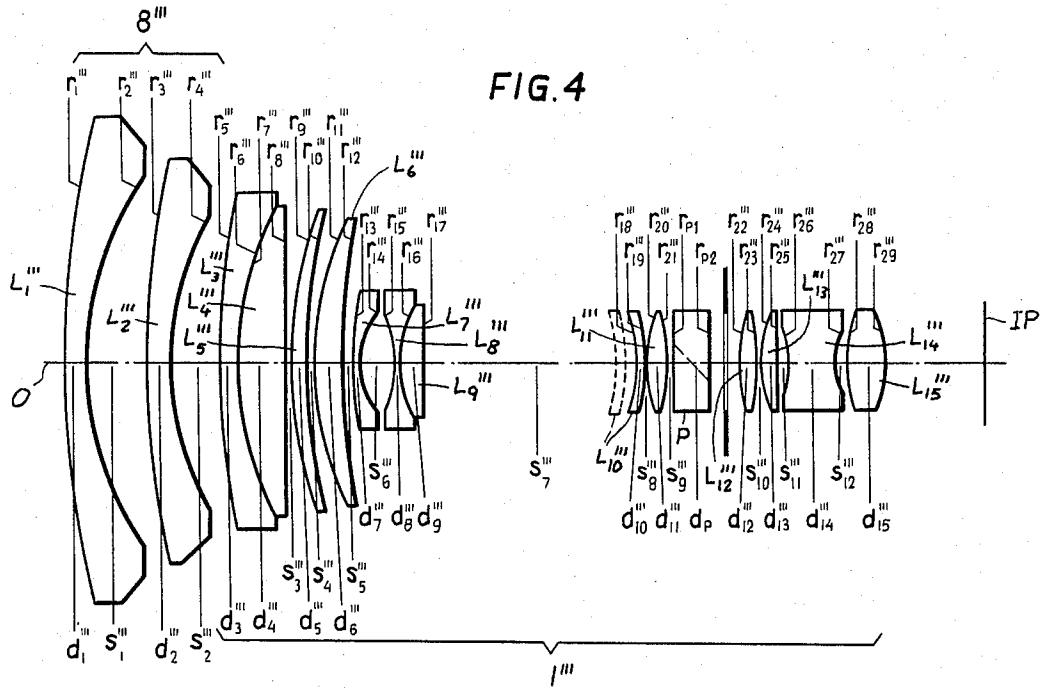


FIG. 4

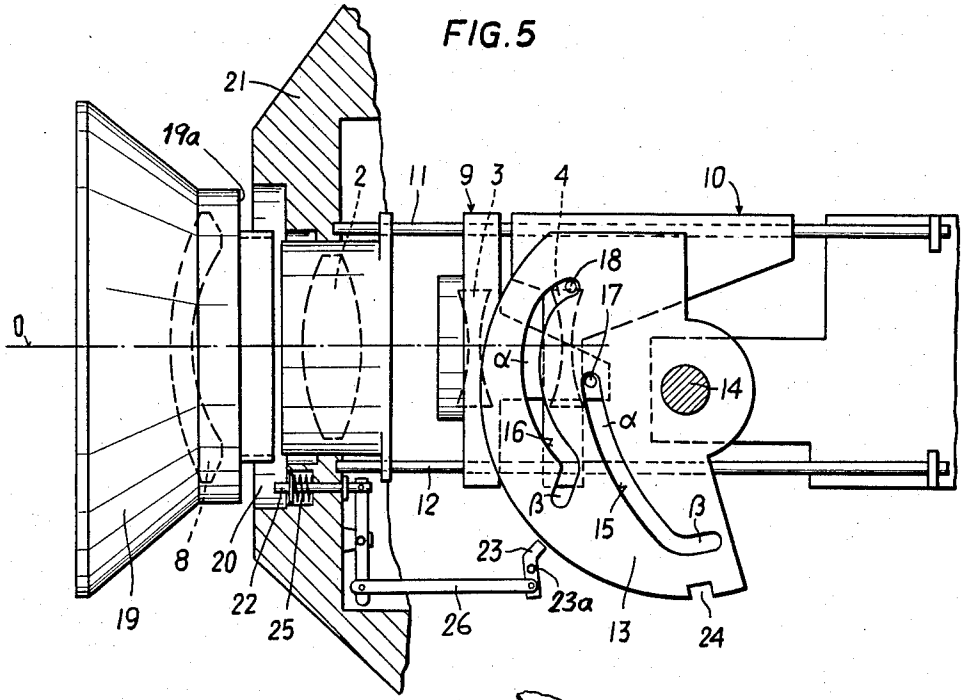


FIG. 5

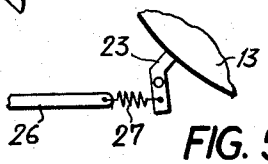


FIG. 5A

FIG.6A

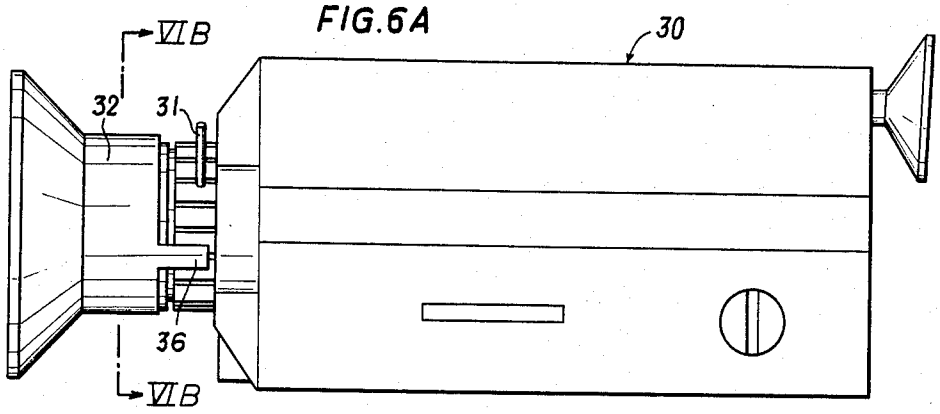


FIG.6B

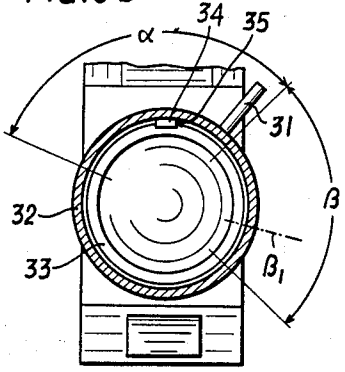


FIG.9

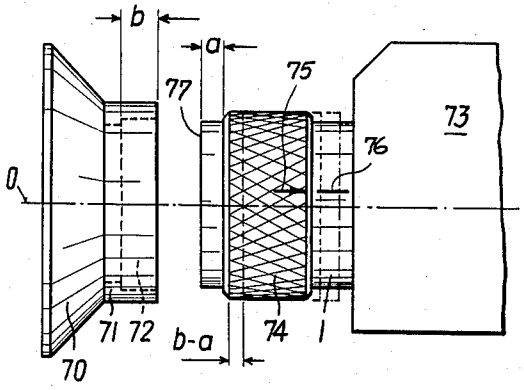


FIG.7

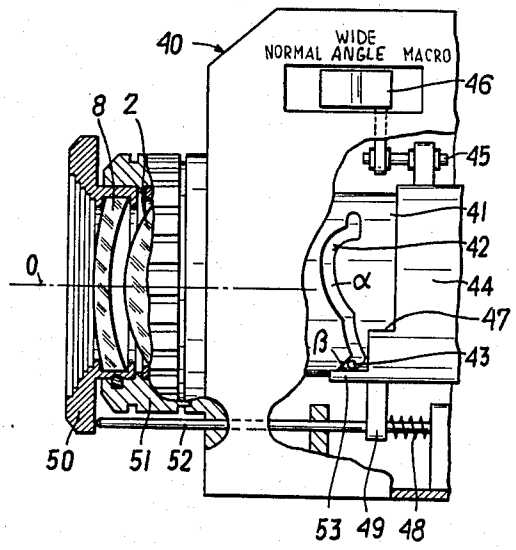
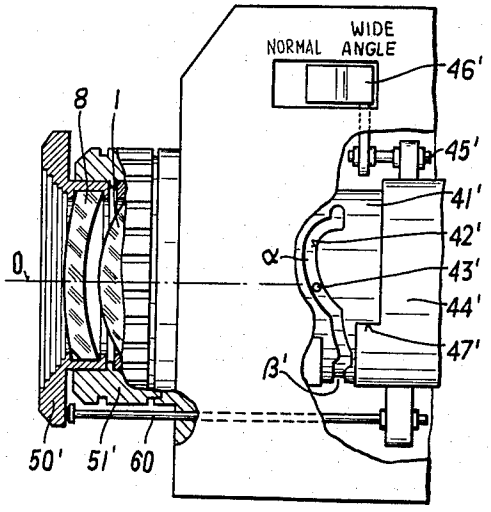


FIG.8



WIDE-ANGLE ATTACHMENT FOR VARIFOCAL OBJECTIVE

FIELD OF THE INVENTION

Our present invention relates to an optical system of the varifocal type for a camera or other instruments such as microscopes or photographic copiers.

BACKGROUND OF THE INVENTION

In an objective of the pancratic type, more often referred to as a varifocal or zoom objective, it is known to provide two axially shiftable components, usually preceded by a stationary front component, whose displacement changes the overall focal length of the system while holding its image plane constant. Within a normal zoom range, the object plane lies at infinity or at a lesser distance that may be chosen by slightly displacing, for example, all or part of the stationary front component. This normal range is limited at one end by a telephoto position, in which the overall focal length has its maximum value f_{max}, and at the other end by a wide-angle position, the overall focal length then having a minimum value f_{min}.

As has been shown in U.S. Pat. No. 3,773,402, it is possible to reduce the effective focal length beyond that limiting value by a further shifting of one or both of the two axially movable components with concurrent displacement of the object plane, correlated with the stationary image plane, toward the objective. This enables the taking of closeup pictures of wide-angle format within the macro range which may be defined as one giving image scales between 1:10 and 1:1. Reference in this connection may also be made to U.S. Pat. No. 3,891,304. The transition from the normal range to the macro range is generally characterized by a reversal of the relative shift of the two movable components.

Alternatively, a foreshortening of the overall focal length with concurrent reduction in object distance can also be achieved — abeit less conveniently — by moving a normally withdrawn additional lens member into the path of the light rays within the varifocal objective.

In practice, conventional objectives of this type have overall focal lengths whose lower limit f_{min} in the normal range is not less than about 7 mm. This restricts the extent to which a camera so equipped can be used by, for example, an amateur photographer interested in taking indoor pictures.

OBJECTS OF THE INVENTION

The general object of our invention is to provide simple means in an optical system of the type discussed for allowing selective reduction of the effective focal length to a value enabling the taking of pictures of very wide angle at close range.

A more particular object is to provide an objective of this kind whose effective minimum focal length can be as low as 3 mm or less.

SUMMARY OF THE INVENTION

We realize these objects, in accordance with our present invention, by providing supplemental lens means of negative refractivity selectively insertable between the varifocal objective and an object to be imaged on a wide-angle scale, the supplemental lens means having a focal length which is less than the depth of the macro range. The varifocal objective includes movable lens means displaceable by a control member in order to shift the object plane from a normal range to a substantially shorter closeup or macro range, as defined above. A sensor responsive to the position of the supplemental and/or the movable lens means serves to correlate the establishment of a working position for the supplemental lens means with a displacement of the movable lens means into a predetermined focusing position in which the object plane lies at a distance from the objective at which virtual images of objects within the closeup range can be formed by the supplemental lens means.

The term "depth of the closeup (or macro) range" can be defined as the distance between the limit of that range proximal to the normal range and the varifocal objective itself, more particularly its object-side principal point.

The supplemental lens means may be an attachment consisting of one or more air-spaced lens members of negative refractivity, preferably meniscus-shaped with forwardly facing convex surfaces. Two or more lens members of this nature, preferably of similar optical parameters, could be used individually or jointly to provide different wide-angle effects.

Such a component will form a reduced, virtual, intermediate image of an object in a plane lying between itself and its own front-focal point. If that virtual-image plane coincides — within the focal-depth limits of the objective — with the object plane selected by adjustment of the control member, the object will be sharply reproduced on the fixed image plane of the varifocal system.

In the simplest case, the sensor may be a visual indicator operatively coupled with the movable lens means for alerting the user to the fact that the object plane has been shifted into the desired position within the macro range. Such an operative coupling need not include a physical connection but may be effected optically, as by light rays traversing the movable lenses and reaching a viewfinder equipped with a conventional focus indicator such as an image-splitting viewer or a ground-glass plate.

In a more sophisticated system, pursuant to another feature of our invention, the sensor forms part of a correlating linkage between a seat for the supplemental component and the control member used for adjusting the varifocal objective to the macro range. Such a linkage may either index the control member in the predetermined focusing position or prevent the emplacement of the wide-angle attachment in its seat as long as that focusing position is not established.

BRIEF DESCRIPTION OF THE DRAWING

The above and other features of our invention will now be described in detail with reference to the accompanying drawing in which:

FIG. 1 diagrammatically shows the layout of an optical system embodying our invention;

FIGS. 2, 3 and 4 are detail views of the components of the system of FIG. 1 according to three different embodiments;

FIG. 5 is a fragmentary side view, partly in axial section, of a lens mounting for a system according to our invention provided with a position sensor;

FIG. 5A is a detail view relating to a modification of the position sensor of FIG. 5;

FIG. 6A is a side view of a camera equipped with another position sensor according to our invention;

FIG. 6B is a cross-sectional view taken on the line VIB—VIB of FIG. 6A;

FIGS. 7 and 8 are views similar to FIG. 5, illustrating further types of position sensors; and

FIG. 9 is part of a side view similar to FIG. 6A, showing another modification.

SPECIFIC DESCRIPTION

In FIG. 1 we have represented by thin-lens symbols the several components of a conventional varifocal objective 1 along with a supplemental component or front attachment B. Objective 1 comprises a fixed positive front component 2, two axially movable negative components 3, 4, another axially fixed positive component 5 and a positive rear lens group 6 separated from components 2–5 by a diaphragm space. Components 3 and 4 are simultaneously shiftable along optical axis O, at different rates and/or in different directions, to vary the overall focal length of objective 1 with maintenance of a constant image plane (indicated at IP in FIG. 4) as is well known per se. At the wide-angle end of the normal varifocal range, component 4 can be further displaced from its full-line position to its dotted-line position for the purpose of establishing an object plane OP in the macro range intersecting the axis O at a point 7, e.g. as described in the two above-identified U.S. patents.

Attachment 8 does not form part of the varifocal objective but can be selectively positioned in front thereof, pursuant to our present invention, for the purpose of increasing the angle of view in the macro range. The focal length of this attachment is less than the depth of the macro range as discussed above, its front-focal point preferably lying near the point 7 on axis O. With objective 1 focused upon plane OP, by a suitable positioning of component 4, a virtual image of a nearby object to be photographed is formed by attachment 8 in that plane whence the incident rays strike the front component 2 of objective 1 at angles giving a wide field of view.

In FIGS. 2–4 we have shown representative embodiments of the system of FIG. 1 including varifocal objectives 1′, 1″, 1‴ and attachments 8′, 8″, 8‴. It should be understood, however, that these attachments may be interchanged among the illustrated systems and that they could also be used with other varifocal objectives known per se, e.g. as given hereinafter with reference to Table D.

In FIG. 2 the attachment 8′ is a single negative meniscus L_1'. The positive first component 2′ of objective 1′ consists of a compound lens member L_2', L_3' and two further lenses L_4' and L_5' air-spaced therefrom. The axially shiftable negative second component 3′ consists of a singlet L_6' and a doublet L_7', L_8'. The axially shiftable negative third component 4′ is a single negative meniscus L_9'. The fixed positive fifth component 5′ consists of two biconvex lenses L_{10}' and L_{11}'. A reflex prism P and a diaphragm separate this latter component from the fixed-focus rear lens group 6′ consisting of a positive singlet L_{12}', a positive doublet L_{13}', L_{14}', a negative singlet L_{15}' and two positive singlets L_{16}' and L_{17}'.

Illustrative numerical values for the radii of curvature r_1'–r_{31}' and axial thicknesses d_1'–d_{17}' of all these lenses, their axial separations s_1'–s_{13}', their refractive indices n_d and their Abbé numbers ν_d are given in the following Table:

TABLE A

			n_d	ν_d
L_1'	$r_1' = +2.33$ $r_2' = 1.14$	$d_1' = 0.12$	1.805	25.4
		$s_1' = 0.34$		
L_2'	$r_3' = +9.929$	$d_2' = 0.10$	1.805	25.4
L_3'	$r_4' = +2.044$ $r_5' = \infty$	$d_3' = 0.38$	1.606	43.9
		$s_2' = 0.01$		
L_4'	$r_6' = +2.482$ $r_7' = +7.189$	$d_4' = 0.21$	1.620	60.3
		$s_3' = 0.01$		
L_5'	$r_8' = +1.947$ $r_9' = +8.453$	$d_5' = 0.28$	1.691	54.7
		$s_4' = \begin{cases} 0.038\ f_{min} \\ 0.763\ f_{med} \\ 1.097\ f_{max} \end{cases}$		
L_6'	$r_{10}' = +6.210$ $r_{11}' = +0.629$	$d_6' = 0.05$	1.691	54.7
		$s_5' = 0.21$		
L_7'	$r_{12}' = -1.112$	$d_7' = 0.05$	1.620	60.3
L_8'	$r_{13}' = +0.888$ $r_{14}' = +5.048$	$d_8' = 0.14$	1.805	25.4
		$s_6' = \begin{cases} 1.204\ f_{min} \\ 0.368\ f_{med} \\ 0.145\ f_{max} \end{cases}$		
L_9'	$r_{15}' = -0.782$ $r_{16}' = -1.899$	$d_9' = 0.05$	1.744	44.8
		$s_7' = \begin{cases} 0.024\ f_{min} \\ 0.135\ f_{med} \\ 0.024\ f_{max} \end{cases}$		
L_{10}'	$r_{17}' = \infty$ $r_{18}' = -1.131$	$d_{10}' = 0.14$	1.620	60.3
		$s_8' = 0.01$		
L_{11}'	$r_{19}' = +2.659$ $r_{20}' = -4.235$	$d_{11}' = 0.12$	1.620	60.3
		$s_9' = 0.04$		
P	$r_{p1} = \infty$ $r_{p2} = \infty$	$d_p = 0.25$	1.517	64.2
		diaphragm space 0.09 + 0.05		
L_{12}'	$r_{21}' = +3.948$ $r_{22}' = -2.475$	$d_{12}' = 0.16$	1.720	50.4
		$s_{10}' = 0.01$		
L_{13}'	$r_{23}' = +0.676$	$d_{13}' = 0.30$	1.664	35.8
L_{14}'	$r_{24}' = -0.835$ $r_{25}' = +2.399$	$d_{14}' = 0.05$	1.805	25.4
		$s_{11}' = 0.07$		
L_{15}'	$r_{26}' = -1.295$ $r_{27}' = +0.522$	$d_{15}' = 0.11$	1.847	23.8
		$s_{12}' = 0.19$		
L_{16}'	$r_{28}' = +2.482$ $r_{29}' = -0.576$	$d_{16}' = 0.17$	1.713	53.8
		$s_{13}' = 0.01$		
L_{17}'	$r_{30}' = +0.700$ $r_{31}' = +1.440$	$d_{17}' = 0.12$	1.641	60.1

The numerical values for the radii, axial thicknesses, separations and focal lengths in the foregoing and following tables are based upon a value of unity for the median overall focal length f_{med} of the varifocal objective 1′ without the attachment 8′. The focal lengths f_{max} and f_{min} have the numerical values 1.91 and 0.40, respectively. Thus, the objective has a varifocal ratio of almost 5:1; its relative aperture is 1:1.2.

The combination of varifocal objective 1′ and attachment 8′ in the macro-range focusing position has an overall focal length of 0.22 and an image angle of 90°.

The prism P, of thickness d_p and with planar faces r_{p1}, r_{p2}, deflects some of the incident rays to a nonillustrated viewfinder which may serve as a position sensor for the

focusing lens L_9' in the macro range, as mentioned above.

In the embodiment of FIG. 3 the attachment 8'' is shown to comprise two air-spaced negative menisci L_1'' and L_2'' with identical front radii r_1'', r_3'' and with identical rear radii r_2'', r_4''; the axial thicknesses and other parameters of these two lenses are also the same, as will be apparent from the illustrative numerical values given below. These two lenses are advantageously mounted for individual interposition in the path of incident rays so that either one or both of these lenses can be utilized to provide different field angles and magnification ratios.

The several components of objective 1'' are generally similar to those of objective 1' (FIG. 2), except that lenses L_3'', L_4'' of the front member are air-spaced rather than cemented, the fourth component consists only of one positive lens L_{11}'', the second member of the rear group is a singlet L_{13}'' and the weakly refractive final positive lens L_{17}' has been omitted. A prism P, not shown in FIG. 3, could of course also be inserted into the diaphragm space of objective 1''.

The magnitudes of the radii r_1''–r_{29}'', thicknesses d_1''–d_{15}'' and separations s_1''–s_{13}'' of lenses L_1–L_{15}'', are refractive indices n_d and their Abbe numbers ν_d are listed in the following Table:

TABLE B

				n_d	ν_d
L_1''	$r_1'' = +2.14$		$d_1'' = 0.13$	1.805	25.4
	$r_2'' = +1.47$		$s_1'' = 0.26$		
L_2''	$r_3'' = +2.14$		$d_2'' = 0.13$	1.805	25.4
	$r_4'' = +1.47$		$s_2'' = 0.36$		
L_3''	$r_5'' = +6.308$		$d_3'' = 0.07$	1.805	25.4
	$r_6'' = +1.976$		$s_3'' = 0.06$		
L_4''	$r_7'' = +2.082$		$d_4'' = 0.26$	1.620	60.3
	$r_8'' = \infty$		$s_4'' = 0.01$		
L_5''	$r_9'' = +2.341$		$d_5'' = 0.15$	1.623	58.1
	$r_{10}'' = +4.961$		$s_5'' = 0.01$		
L_6''	$r_{11}'' = +1.805$		$d_6'' = 0.22$	1.623	58.1
	$r_{12}'' = +12.664$	$s_6'' =$	0.04 f_{min} 0.69 f_{med} 1.03 f_{max}		
L_7''	$r_{13}'' = +5.981$		$d_7'' = 0.05$	1.658	50.9
	$r_{14}'' = +0.567$		$s_7'' = 0.16$		
L_8''	$r_{15}'' = -1.086$		$d_8'' = 0.05$	1.669	57.4
L_9''	$r_{16}'' = +0.652$		$d_9'' = 0.15$	1.805	25.4
	$r_{17}'' = +7.039$	$s_8'' =$	1.09 f_{min} 0.32 f_{med} 0.14 f_{max}		
L_{10}''	$r_{18}'' = -0.639$		$d_{10}'' = 0.05$	1.624	47.0
	$r_{19}'' = -1.288$	$s_9'' =$	0.10 f_{min} 0.22 f_{med} 0.06 f_{max}		
L_{11}''	$r_{20}'' = +1.097$		$d_{11}'' = 0.10$	1.691	54.7
	$r_{21}'' = -3.661$		$s_{10}'' = 0.46$		
L_{12}''	$r_{22}'' = +2.052$		$d_{12}'' = 0.10$	1.620	60.3
	$r_{23}'' = -2.052$		$s_{11}'' = 0.01$		
L_{13}''	$r_{24}'' = +0.686$		$d_{13}'' = 0.13$	1.717	48.0
	$r_{25}'' = +26.527$		$s_{12}'' = 0.04$		
L_{14}''	$r_{26}'' = -0.848$		$d_{14}'' = 0.16$	1.785	26.1
	$r_{27}'' = +0.535$		$s_{13}'' = 0.18$		
L_{15}''	$r_{28}'' = +1.614$		$d_{15}'' = 0.19$	1.720	50.4
	$r_{29}'' = -0.639$				

Attachment 8'' has an individual focal length of 3.11. The overall focal length of objective 1'' (without the attachment) varies between values

$f_{max} = 2.03$

$f_{med} = 1$

$f_{min} = 0.43.$

This corresponds again to a varifocal ratio of nearly 5:1; the relative aperture is 1:1.9. The objective 1'' has the advantage of small loss of luminosity toward the image periphery as compared with similar objectives of the prior art.

The combined system 1'' + 8'' again has an overall focal length of 0.22 in the macro-range focusing position and an image angle of 90°.

The wide-angle attachment 8''' of FIG. 4 consists also of two optically identical negative menisci L_1''', L_2''' which could be used individually or in combination. The objective 1''' has a compound front member L_3''', L_4''' and is otherwise similar to objective 1'' of FIG. 3.

Illustrative numerical values for the parameters r_1'''–r_{29}''', d_1'''–d_{15}''', s_1'''–s_{12}''', n_d and ν_d of its lenses L_1'''–L_{15}''' are listed in the following Table:

TABLE C

			n_d	ν_d
L_1'''	$r_1''' = +5.64$	$d_1''' = 0.10$	1.805	25.4
	$r_2''' = +1.35$	$s_1''' = 0.29$		
L_2'''	$r_3''' = +5.64$	$d_2''' = 0.10$	1.805	25.4
	$r_4''' = +1.35$	$s_2''' = 0.21$		
L_3'''	$r_5''' = +5.279$	$d_3''' = 0.084$	1.805	25.4
	$r_6''' = +1.670$			
L_4'''	$r_7''' = +1.670$	$d_4''' = 0.276$	1.620	60.3
	$r_8''' = \infty$	$s_3''' = 0.004$		
L_5'''	$r_9''' = +2.339$	$d_5''' = 0.100$	1.658	50.9
	$r_{10}''' = +4.191$	$s_4''' = 0.004$		
L_6'''	$r_{11}''' = +1.583$	$d_6''' = 0.221$	1.658	50.9
	$r_{12}''' = +7.391$	$s_5''' = \begin{cases} 0.029\ f_{min} \\ 0.821\ f_{med} \\ 1.112\ f_{max} \end{cases}$		
L_7'''	$r_{13}''' = +5.201$	$d_7''' = 0.038$	1.691	54.7
	$r_{14}''' = +0.459$	$s_6''' = 0.153$		
L_8'''	$r_{15}''' = -0.877$	$d_8''' = 0.038$	1.669	57.4
L_9'''	$r_{16}''' = +0.639$	$d_9''' = 0.113$	1.805	25.4
	$r_{17}''' = +7.187$	$s_7''' = \begin{cases} 1.198\ f_{min} \\ 0.249\ f_{med} \\ 0.114\ f_{max} \end{cases}$		
L_{10}'''	$r_{18}''' = -0.576$	$d_{10}''' = 0.042$	1.624	47.0
	$r_{19}''' = -1.459$	$s_8''' = \begin{cases} 0.016\ f_{min} \\ 0.172\ f_{med} \\ 0.016\ f_{max} \end{cases}$		
L_{11}'''	$r_{20}''' = +1.055$	$d_{11}''' = 0.102$	1.689	49.5
	$r_{21}''' = -1.682$	$s_9''' = 0.038$		
P	$r_{p1} = \infty$	$d_p = 0.209$	1.517	64.2
	$r_{p2} = \infty$			
L_{12}'''	$r_{22}''' = +1.785$	$d_{12}''' = 0.088$	1.620	60.3
	$r_{23}''' = -1.785$	$s_{10}''' = 0.004$		
L_{13}'''	$r_{24}''' = +0.614$	$d_{13}''' = 0.109$	1.717	48.0
	$r_{25}''' = +15.718$	$s_{11}''' = 0.031$		
L_{14}'''	$r_{26}''' = 0.826$	$d_{14}''' = 0.251$	1.785	26.1
	$r_{27}''' = +0.468$	$s_{12}''' = 0.107$		
L_{15}'''	$r_{28}''' = +0.967$	$d_{15}''' = 0.163$	1.720	50.4
	$r_{29}''' = -0.618$			

diaphragm space = 0.034 + 0.104

The overall focal length of objective 1''' (without attachment 8''') varies as follows:

$f_{max} = 2.219$
$f_{med} = 1$
$f_{min} = 0.299.$

This corresponds to a varifocal ratio of nearly 8:1. The objective has a relative aperture of 1:1.8. In combination with attachment 8''', whose individual focal length measures 1.033, it has an image angle of approximately 180° so as to give a "fish-eye" semipanoramic view. The focal length of the combination is 0.11.

In a practical realization, the median focal length f_{med} measured 19.134 mm. This corresponds to an overall focal length of 2.1 mm for the system illustrated in FIG. 4.

An attachment consisting of one or more lenses such as the one shown in FIG. 2, but of reduced power for better correction of aberrations, could be substituted for component 8''' in FIG. 4. Such a lens could have, for example, a front radius $r_1 = +2.18$, a rear radius $r_2 = +1.25$, a thickness $d = 0.18$, a refractive index $n_d =$

1.517 and an Abbé number $\nu_d = 62.2$. Its distance from lens L_3''' may be $s_2''' = 0.40$.

Another varifocal objective to be used with any of the herein disclosed front attachments has the same structure as objective **1'''** of FIG. **4** with the following parameters known per se from Austrian patent No. 325,325:

TABLE D

			n_d	ν_d
L_3'''	$r_5''' = +5.279$ $r_6''' = +1.670$	$d_3''' = 0.084$	1.805	25.4
L_4'''	$r_7''' = +1.670$ $r_8''' = \infty$	$d_4''' = 0.276$	1.620	60.3
		$s_3''' = 0.004$		
L_5'''	$r_9''' = +2.339$ $r_{10}''' = +4.292$	$d_5''' = 0.109$	1.658	5.9
		$s_4''' = 0.004$		
L_6'''	$r_{11}''' = +1.597$ $r_{12}''' = +7.433$	$d_6''' = 0.213$	1.658	50.9
		$s_5''' = \begin{cases} 0.034\ f_{min} \\ 0.826\ f_{med} \\ 1.117\ f_{max} \end{cases}$		
L_7'''	$r_{13}''' = +5.201$ $r_{14}''' = +0.439$	$d_7''' = 0.038$	1.691	54.7
		$s_6''' = 0.171$		
L_8'''	$r_{15}''' = -0.749$ $r_{16}''' = +0.638$	$d_8''' = 0.038$	1.620	60.3
L_9'''	$r_{17}''' = +13.065$	$d_9''' = 0.113$	1.805	25.4
		$s_7''' = \begin{cases} 1.173\ f_{min} \\ 0.224\ f_{med} \\ 0.089\ f_{max} \end{cases}$		
L_{10}'''	$r_{18}''' = -0.727$ $r_{19}''' = -1.845$	$d_{10}''' = 0.042$	1.784	43.9
		$s_8''' = \begin{cases} 0.019\ f_{min} \\ 0.175\ f_{med} \\ 0.020\ f_{max} \end{cases}$		
L_{11}'''	$r_{20}''' = +1.173$ $r_{21}''' = -1.462$	$d_{11}''' = 0.100$	1.691	54.7
		$s_9''' = 0.038$		
P	$r_{p1} = \infty$ $r_{p2} = \infty$	$d_p = 0.209$	1.517	64.2
		diaphragm space = 0.075 + 0.084		
L_{12}'''	$r_{22}''' = +1.833$ $r_{23}''' = -2.661$	$d_{12}''' = 0.088$	1.744	44.8
		$s_{10}''' = 0.021$		
L_{13}'''	$r_{24}''' = +0.620$ $r_{25}''' = \infty$	$d_{13}''' = 0.100$	1.744	44.8
		$s_{11}''' = 0.031$		
L_{14}'''	$r_{26}''' = -0.826$ $r_{27}''' = +0.481$	$d_{14}''' = 0.292$	1.847	23.8
		$s_{12}''' = 0.050$		
L_{15}'''	$r_{28}''' = +1.481$ $r_{29}''' = -0.479$	$d_{15}''' = 0.196$	1.735	41.6

This objective has a relative aperture of 1:1.8 and focal lengths $f_{max} = 2.232$, $f_{med} = 1.006$, $f_{min} = 0.301$.

In FIG. **5** we have shown lens mounts **9** and **10** for the shiftable members **3** and **4**, these lens mounts being slidable along rods **11** and **12** paralleling the optical axis O of the objective. A cam disk **13**, rotatable by a nonillustrated zoom-control member on a shaft **14** transverse to the axis, has two slots **15** and **16** in which pins **17** and **18** on lens mounts **9** and **10** are guided. Sections α of these slots serve for the adjustment of the focal length within the normal range as discussed above; the illustrated limiting position of disk **13** corresponds to the maximum focal length f_{max}. At the opposite end of the range the slots **15** and **16** are provided with extensions β by which the two components **3** and **4** are shifted away from each other in the macro range.

A lens holder **19**, carrying the front attachment **8**, is receivable in a socket **20** of a camera housing illustrated in part at **21**. Upon such emplacement of holder **19**, a shoulder **19a** thereof bears upon a position sensor in the form of a pin **22** whose free end is urged into the socket **20** by a spring **25**. Pin **22** forms part of a linkage **26** articulated to a detent **23** which has a fixed pivot at **23a** and faces the periphery of cam disk **13**. Unless a notch **24** in that periphery confronts the detent **23**, pin **22** cannot be repressed and prevents the emplacement of holder **19** in the working position of attachment **8**. Notch **24** is an indexing formation which registers with detent **23** only when the pins **17** and **18** engage the macro sections β of slots **15** and **16**.

As shown in FIG. **5A**, detent **23** may be coupled with linkage **26** through another spring **27**, weaker than spring **25**, which allows the lens holder **19** to be operatively positioned whereby spring **27** is stressed to bias the detent toward the periphery of disk **13**, causing it to fall into the notch **24** and to lock the disk **13** in the desired focusing position within the macro range. The objective in this case advantageously includes a visual indicator designed to alert the user to the fact that the objective is still out of focus, e.g. a view-finder of the focus-indicating type referred to above and served by a reflex prism to the rear of the shiftable lenses as shown in FIGS. **2** and **4**. Such an indicator could also be a pair of marks **75**, **76** on a control member **74** of the objective housing as shown in FIG. **9**.

In FIGS. **6A** and **6B** we have illustrated a camera **30** with a setting lever **31** swingable about the objective axis for varying the focal length. The normal and macro ranges of the swing have again been designated α and β, respectively. A lens holder **32**, carrying the wide-angle front attachment, has an extension **36** which projects into the path of lever **31** to stop it in the correct focusing position within the macro range as indicated at β_1. The correct angular alignment of holder **32** and camera **30** is insured by a key **34** on the holder engaging in a keyway **35** on the camera body.

Reference may be made to U.S. Pat. No. 3,613,544 for a description of a focusing mechanism using such a swingable control member.

In FIG. **7** we have shown a camera **40** provided with a fitting **51** for receiving an attachment **50** which carries a supplemental component **8**. A rod **52** slidable in the camera housing is rigid with a lug **49** on a stepped sleeve **44** surrounding a lens barrel **41** with camming slots for the movable lens members, only a slot **42** controlling the second negative component **4** (FIG. **1**) being visible. Slot **42** is again subdivided into a section α for the normal range and an extension β for the macro range. A mode-selector switch **46** is coupled with sleeve **44** in order to interpose a step **47** of this sleeve into the path of a pin **43** guided by slot **42** when that switch is in its left-hand position, thereby preventing an adjustment of the objective beyond the normal range. Upon insertion of attachment **8**, **50**, rod **52** is repressed against the force of a spring **48** so as to shift the sleeve **44** to the right, thereby enabling a continuing displacement pin **43** to be moved into a position within the macro range in which that pin comes to rest against another step **53** of sleeve **44**. This axial shift of the sleeve entrains the mode-selector switch **46** into its midposition labeled "wide angle." The switch can also be manually moved into a right-hand position in which the step **53** is withdrawn from

the path of pin 43 to enable free adjustment of the objective (in the absence of attachment 8, 50) within the macro range. A suitable latch, not shown, preferably arrests the sleeve in the last-mentioned position against the force of spring 48.

FIG. 8 shows an arrangement similar to that of FIG. 7 in which analogous elements have been designated by the same numerals with the addition of a prime mark (′). Switch 46′ here has only its "normal" and "wide angle" positions, sleeve 44′ being provided with only a single step 47′. A rod 60, replacing the spring-loaded rod 52 of FIG. 7, positively prevents the emplacement of lens holder 50′ as long as the mode-selector switch 46′ holds the sleeve 44′ in its "normal" position in which the guide pin 43′ for the axially shiftable lens 4 is prevented from entering the extension β' of slot 42′. Thus, the user must first adjust the switch 46′ to "wide angle" before being able to fit the holder 50′ to the camera. It should be noted that slot section β' lies in a plane transverse to the axis so as to define the desired focusing position no matter how far the pin 43′ is moved past the junction of slot sections α and β'.

A lens holder 70 shown in FIG. 9 has a flange 71 with an internal recess 72 fitting onto a neck 77 of a lens mount rigid with a camera 73, this neck carrying the aforementioned control member 74 in the form of a ring which can be rotated for adjustment of the focal length and axially slid for the shifting of an objective component in the macro range. A non-illustrated spring biases the control ring 74 into the position shown in full lines in which normal-range adjustment by rotation is possible; the ring can be slid to the right, into its dotted-line position, only upon alignment of the two marks 75, 76. The width a of the free end of neck 77 is less than the depth b of recess 72 whereby the ring 74 is automatically shifted into the proper focusing position if the marks 75 and 76 register with each other. If not, the lens holder 70 cannot be emplaced. Naturally, this lens holder must be able to engage the neck 77 with sufficient friction to resist the force of the aforementioned spring unless suitable retaining means such as a bayonet coupling are provided therefor.

The various correlating linkages described above could also be used to indicate or bring about the movement of an additional lens from an off-axial position into line with the normal components of the varifocal objective, in order to establish the desired macro position, or to prevent the fitting of a wide-angle attachment to the objective housing as long as that additional lens is withdrawn.

We claim:

1. In a camera including a housing, a varifocal objective in said housing provided with movable lens means and with a control element for displacing said movable lens means from a normal operating range into a macro position, and supplemental lens means emplaceable on a seat formed by said housing in line with said objective for focusing same on nearby objects in a closeup range upon displacement of said movable lens means into said macro position,

the combination therewith of blocking means normally extending into the path of said control element for preventing the displacement of said movable lens means into said macro position, and a contact member on said housing coupled with said blocking means and engageable by said supplemental lens means upon emplacement thereof on said seat for removing said blocking means from the path of said control element.

2. The combination defined in claim 1 wherein said housing includes a lens barrel provided with a peripheral camming slot, said control element being a pin traversing said camming slot, said blocking means comprising a sleeve axially movable along said lens barrel, said sleeve having an edge extending across said camming slot in a normal axial position thereof.

3. The combination defined in claim 2, further comprising spring means urging said sleeve into said normal axial position, said contact member being a rod axially projecting from said sleeve toward said seat.

4. In a camera including a housing, a varifocal objective in said housing provided with movable lens means and with a control element for displacing said movable lens means from a normal operating range into a macro position, and supplemental lens means emplaceable on a seat formed by said housing in line with said objective for focusing same on nearby objects in a closeup range upon displacement of said movable lens means into said macro position,

the combination therewith of a contact member on said housing engageable by said supplemental lens means upon emplacement thereof on said seat for displacement toward said control element to arrest the latter in a position of adjustment corresponding to said macro position of said movable lens means, said contact member being provided with a resiliently biased extension bearing on said control element upon such displacement by said supplemental lens means, said control element having an indexing formation coacting with said extension in said position of adjustment.

5. The combination defined in claim 4 wherein said control element comprises a cam disk provided with a peripheral notch constituting said indexing formation.

6. The combination defined in claim 4 wherein said contact member is part of an articulated linkage.

7. In a camera including a housing, a lens barrel in said housing centered on an optical axis and provided with at least one peripheral camming slot, a varifocal objective in said hosuing including axially movable lens means, control means for displacing said movable lens means to vary the focal length of said objective, said control means including a pin traversing said camming slot, and supplemental lens means emplaceable on a seat formed by said housing in line with said objective for focusing same on nearby objects in a closeup range upon displacement of said pin into an extension of said camming slot with entrainment of said movable lens means into a macro position,

the combination therewith of a sleeve axially movable along said lens barrel, said sleeve having an edge extending in a normal axial position thereof across said camming slot for blocking the movement of said pin into said extension, and a contact member rigid with said sleeve extending into said seat in said normal axial position for preventing the emplacement of said supplemental lens means until the removal of said sleeve to an alternate position enabling the establishment of said macro position.

8. The combination defined in claim 7 wherein said contact member is a rod axially projecting from said sleeve toward said seat.

* * * * *

United States Patent [19]

Yamazaki et al.

[11] **4,104,663**

[45] **Aug. 1, 1978**

[54] **MULTIPLE OBJECTIVE LENS CAMERA**

[75] Inventors: **Yasuo Yamazaki**, Kawachinagano; **Taizo Kawaguchi**, Amagasaki; **Kazuo Kimura**, Sakai, all of Japan

[73] Assignee: **Minolta Camera Kabushiki Kaisha**, Osaka, Japan

[21] Appl. No.: **790,220**

[22] Filed: **Apr. 25, 1977**

[30] **Foreign Application Priority Data**

May 12, 1976 [JP] Japan 51-53251

[51] **Int. Cl.**[2] **G03B 3/00**; G03B 13/02

[52] **U.S. Cl.** **354/197**; 354/219

[58] **Field of Search** 354/202, 275, 200, 221, 354/197, 199, 219

[56] **References Cited**

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Primary Examiner—Donald A. Griffin

Attorney, Agent, or Firm—Wolder, Gross & Yavner

[57] **ABSTRACT**

A compact camera contains a plurality of objective lenses which are selectively alternatively advanced by external manipulation into registry with the camera photographing optical axis to vary the image magnification. A view finder optical system is provided which includes a lens member which is movable into and out of registry with the view finder optical system to vary the viewer field to correspond to the field of the operative objective lens. A lens storage space is provided between the laterally spaced view finder and photographing optical axis, one of the objective lenses when retracted occupies the storage space and when this lens is advanced to the photographic optical axis it may be replaced in the storage space by the retracted view finder lens member.

12 Claims, 13 Drawing Figures

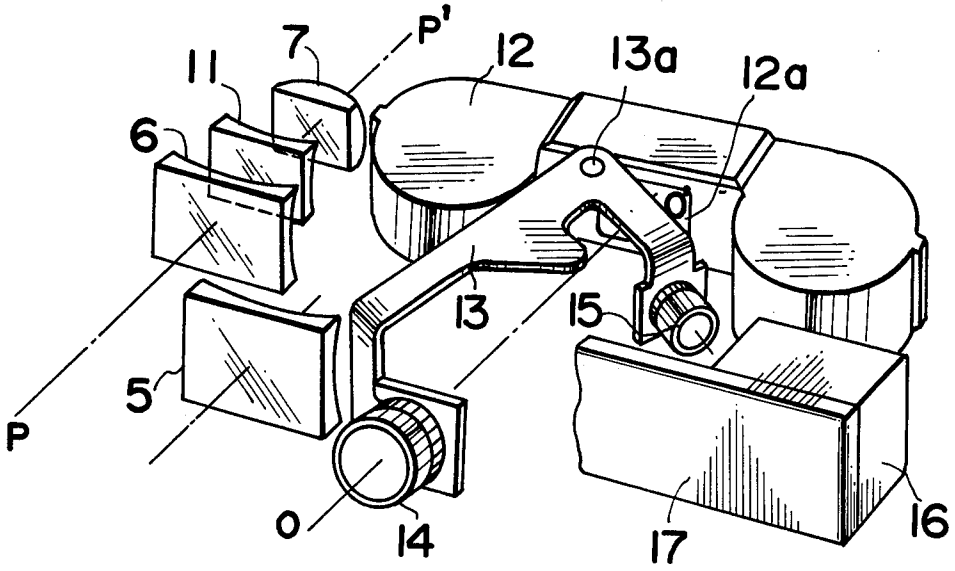

FIG. 1 Prior Art

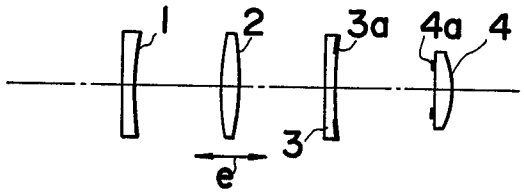

FIG. 2A

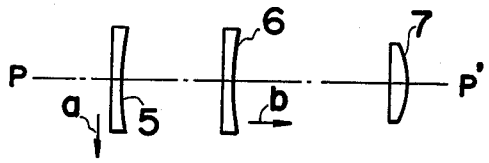

FIG. 2B

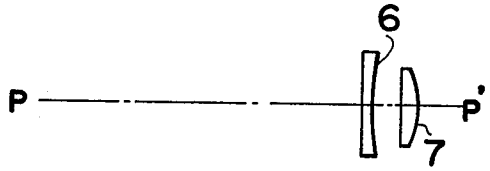

FIG. 3A

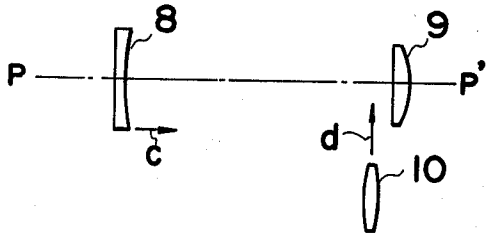

FIG. 3B

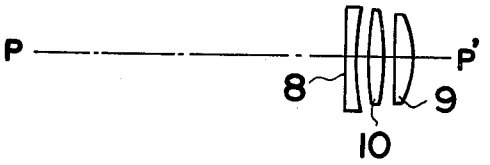

FIG. 4

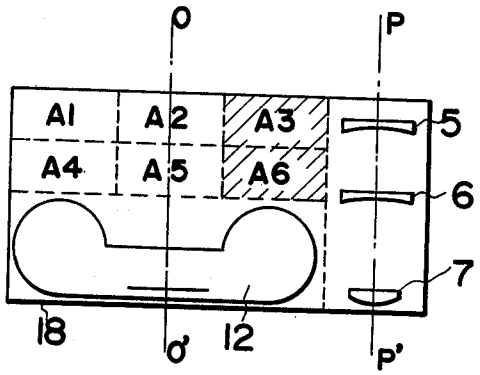

FIG.5A

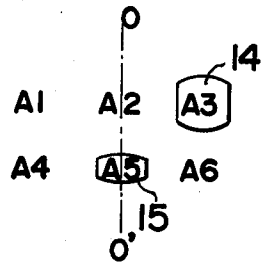

FIG.5B

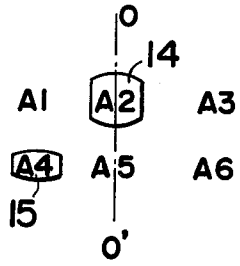

FIG.6A

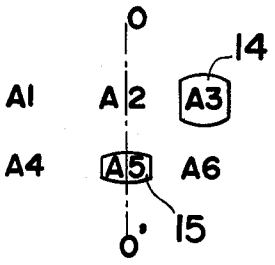

FIG.6B

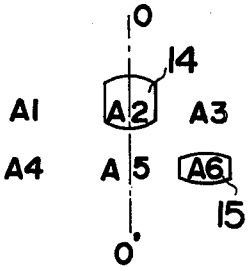

FIG.7

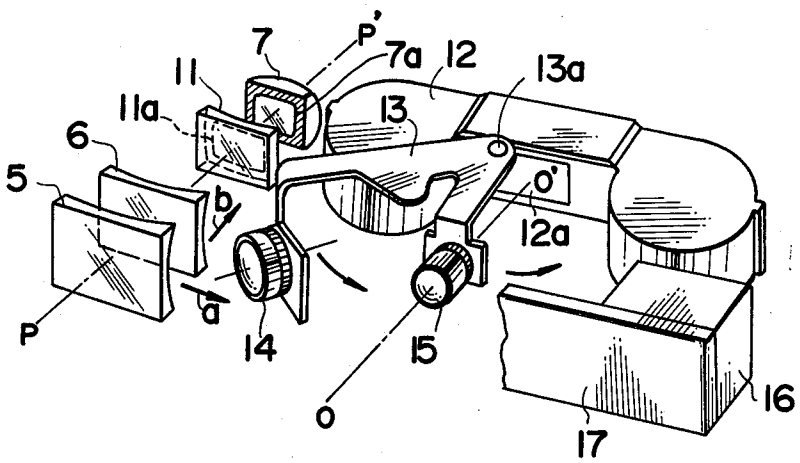

FIG.8

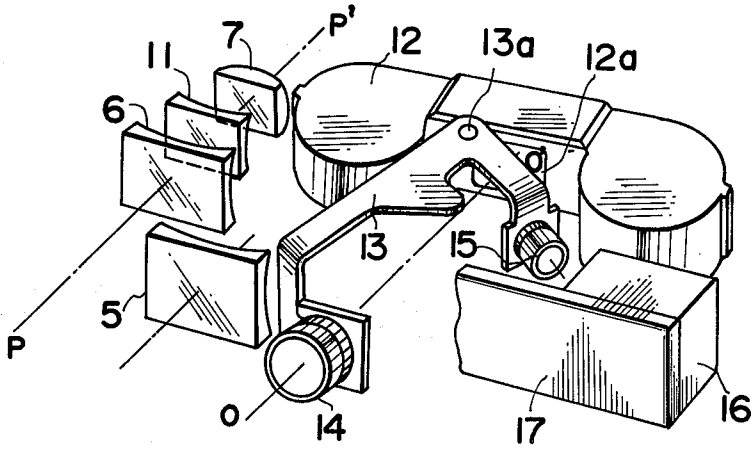
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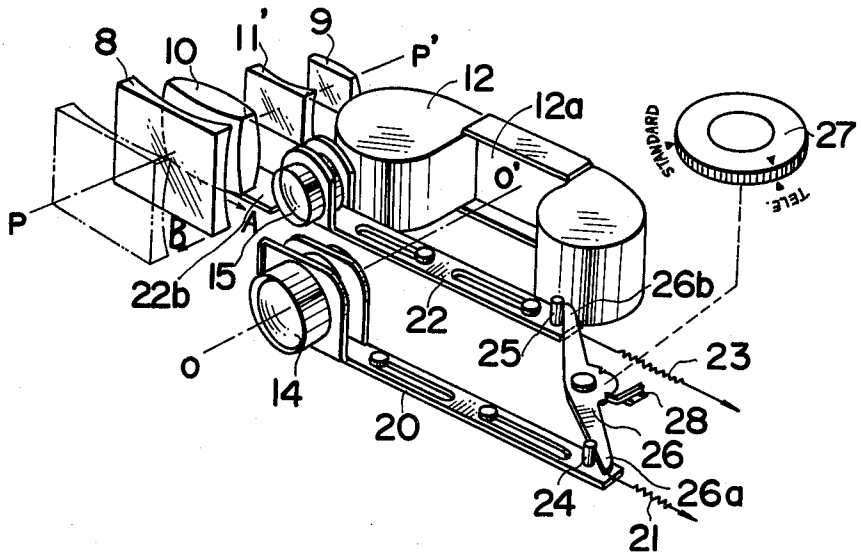
FIG.9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MULTIPLE OBJECTIVE LENS CAMERA

BACKGROUND OF THE INVENTION

The present invention relates generally to improvements in cameras and it relates particularly to an improved compact camera self-containing a plurality of objective lenses which are selectively alternatively transferred between displaced and operative positions and a view finder whose field is varied in accordance with the power of the operatively positioned objective lens.

With a camera of the type, in which the power of magnification of the picture-taking or objective lens system is varied by selectively moving two or more objective lenses built or self-retained in the camera into or out of the picture-taking or photographing optical path, it has been necessary to change the picture-taking field or range indicated within the associated view finder in conformity with the selected magnification of the picture-taking lens system.

Mechanisms proposed for changing the picture-taking range indicated within the finder may be classified into two types in which:

(1) The size of a view frame within the finder is changed, while maintaining the magnification of the image in the finder constant, thereby indicating the picture-taking field of the operative picture-taking lens system; and

(2) The magnification of the image in the finder is varied while maintaining the size of the view frame in a finder constant.

According to the first mechanism, the size of the view limiting frame consisting of an Albada finder system alone may be varied, without varying the magnification of the image in the finder, and hence the construction may be simplified. However, in case a picture-taking lens system is changed from a standard lens to a telephoto lens, the size of the view frame of the finder is reduced, and in addition, the finder image is reduced in size, because an object in general is located at a great distance, with the result that detailed observation of the object becomes difficult.

In contrast thereto, the second mechanism is devoid of the aforesaid shortcoming and provides advantages over the first mechanism. However, a complicated structure is required for varying the magnification of the image in the finder, with the resulting increase in the size of the finder as well as in the manufacturing cost.

Moreover, a mechanism has been proposed in which a zoom lens system is employed as a finder optical system for varying the magnification of the image in the field of view of the finder, providing the basic optical system as shown in FIG. **1** of the drawing herein. More particularly, the finder optical system proposed includes an inverse Galilean finder system consisting of a concave objective lens **1** and a convex movable lens **2**, a concave lens **3** for use in an Albada finder, and an eye-piece **4**, so that the magnification of the image in the finder may be varied by moving the convex movable lens **2** along the system optical axis in the direction of arrows e. In addition, as is well known, the size of the view limiting frame is so arranged as to be maintained constant by means of an optical image frame **4***a* formed on the object side of eye piece **4**, and mirror surface **3***a* which is formed on the image side of concave Albada lens **3** and shown by a thick line.

In general, important fundamental problems in the finder system are whether or not an optimum magnification is achieved for an image, and how far the image of an object is viewed, when observed in the finder, i.e., a dioptric power problem.

However, with the finder lens system as shown in FIG. **1**, when the image magnification of the finder remains substantially unchanged, i.e., in a range lower than 1.5, variation in magnification will not lead to a marked variation in dioptric power, thus providing desired practicability in actual application. However, when the finder magnification is increased to over 1.5, in response to a variation in the magnification of the picture-taking lens, then the variation in the dioptric power will exceed **1** diopter, so that in case the magnification exceeds **2**, then the view in the finder becomes hard to recognize, and in addition, marked distortion of the field results, thus failing to provide the desired practicability for a short-sighted photographer who suffers from an insufficient adjusting capability of the eyes.

This may be attributed to the fact that part of the lenses constituting the finder optical system is moved only along the optical axis of a finder, so that compensation for aberration cannot be positively achieved.

SUMMARY OF THE INVENTION

It is a principal object of the present invention to provide an improved camera for effecting variation in magnification by transferring one of two or more picture-taking or objective lenses built or self-contained in a camera body into or out of the photographing or picture-taking optical path, in which there is provided a finder capable of varying the magnification of the object image in the finder, with the size of the view finder limiting frame maintained constant, and yet with the dioptric power being maintained unchanged.

It is another object of the present invention to provide a camera of a compact size, in which a given space within the camera body may be alternately utilized as a common retracting position both for part of lenses in the finder optical system, which may be so arranged as to move into or out of the finder optical path, and for the movable picture-taking lenses which are self-contained in the camera body.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a side-elevational view showing one example of a prior art finder optical system in which the magnification of the finder image may be varied;

FIG. **2** is a side elevational view showing one example of a finder optical system in which an Albada system is obviated according to the present invention, the aforesaid finder optical system being capable of varying the image magnification without changing the dioptric power, and in which FIG. **2**(A) illustrates the condition of standard magnification, and FIG. **2**(B) illustrates the condition of a telephoto magnification;

FIG. **3** is a side elevational view of a finder optical system in which an Albada system is obviated according to another embodiment of the present invention, in which FIG. **3**(A) illustrates the case of a standard magnification, and FIG. **3**(B) illustrates the condition of a telephoto magnification;

FIG. **4** is a top plan view of a camera of a small size, showing the spaces alloted within the camera and in which the magnification may be varied;

FIG. **5** is a top plan view showing one example of the detailed arrangement of the picture-taking lenses posi-

tioned within the space shown in FIG. 4, in which FIG. 5(A) illustrates a standard picture-taking condition, and FIG. 5(B) illustrates a telephoto picture-taking condition;

FIG. 6 is a top plan view showing one example of the arrangement of the picture-taking lenses positioned in the space shown in FIG. 4, in which FIG. 6(A) illustrates a standard picture-taking condition, and FIG. 6(B) illustrates a telephoto picture-taking condition;

FIG. 7 is a perspective view showing an essential part of one embodiment of the present invention in a standard picture-taking condition;

FIG. 8 is a perspective view of the essential part of the camera shown in FIG. 7 in a telephoto picture-taking condition; and

FIG. 9 is a perspective view of another embodiment of the present invention shown in a telephoto picture-taking condition.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to FIGS. 2 to 8 which illustrate preferred embodiments of the present invention, FIGS. 2(A) and (B) show one embodiment of a finder optical system according to the present invention, in which FIG. 2(A) illustrates the condition of standard magnification, while FIG. 2(B) illustrates the condition of telephoto magnification, although an Albada system is not shown. For standard magnification, concave lens 5, concave lens 6 and convex lens 7 in a lens system are consecutively arranged in this order from the front or object side along the finder optical axis P–P', as shown in FIG. 2(A). For shifting from a standard magnification to a telephoto magnification, the concave lens 5 is transversely retracted in the direction of arrow *a* from the optical axis P–P', while concave lens 6 is moved toward the face of convex lens 7 in the direction of arrow *b* along its optical axis, as shown in FIG. 2(B).

FIG. 3 shows another embodiment of a finder optical system. For standard magnification, front concave lens 8 and successive convex lens 9 are arranged in a lens system as shown in FIG. 3(A). For shifting from standard magnification to telephoto magnification, concave lens 8 is moved in the direction of arrow *c* towards the face of convex lens 9, while convex lens 10 which has been retracted from the optical axis P–P' for standard magnification is moved into the optical axis P–P' in the direction of the arrow *d*, as shown in FIG. 3(B).

In either case, concave lens 6 or lens 8 should be moved along the optical axis P–P', while lens 5 or lens 10 should be moved into or out of the optical axis P–P'. Thus there is required a space, into which lens 5 or lens 10 is to be moved when retracted from the finder optical axis P–P'.

Further, FIG. 4 shows a small-size or compact camera of a flat cubic shape, into which a film cartridge may be loaded. This camera has a picture-taking lens system consisting of two or more lenses having different magnifications and effects the magnification by selectively moving one of the picture-taking or objective lenses onto the picture taking optical axis O–O'. The respective components of the camera are arranged as shown in FIG. 4 for reducing the size of the camera. As shown in FIG. 4 a film cartridge 12 is removably loaded in a predetermined position within the camera case 18, and thus the position of the picture-taking optical axis and focal or image plane is determined. Position sidewise of camera case 18 is a finder optical system P–P' consisting of lenses 5, 6, 7 and the like. Depending on the desired magnification of the picture-taking lens system, either one of standard objective lens system 15 and telephoto objective lens system 14 is positioned in either one of spaces A2 and A5 on the optical axis O–O' of a camera. The above condition is shown as a block diagram in FIGS. 5(A) and (B) or FIG. 6(A) or (B).

FIG. 5(A) shows the case of a standard picture-taking lens system, in which standard objective lens system 15 is positioned in a space A5 on the picture-taking optical axis O–O' of a camera. In this respect, assume that telephoto objective lens system 14 is positioned in a space A3 off the picture-taking optical axis O–O', then spaces A1, A2, A4, A6 are not occupied by a lens system. When telephoto objective lens system 14 is moved into the space A2 on the picture-taking optical axis O–O', as shown in FIG. 5(B), standard objective lens system 15 retracts into the space A4, while the spaces A1, A3, A5, A6 are not occupied by a lens system. In either case of FIGS. 5(A) (B), the spaces which are not occupied by an objective lens system remain to be A1, A6. Assume that the space A1 is allotted for a space for locating a shutter operating mechanism therein, while the space A6 is allotted for locating other camera mechanisms therein. When telephoto objective lens system 14 is moved into the space A2 on the picture-taking optical axis O–O', the space A3 on the side of the finder optical axis P–P' becomes empty. This empty space A3 may be used as a storage space for concave lens 5, when retracting from the finder optical axis P–P' in the direction of arrow *a*, as shown in FIG. 2(A), upon shifting from standard magnification to telephoto magnification in a finder optical system.

In FIG. 6(A), standard objective lens system 15 is located in the space A5 on the picture-taking optical axis O–O', telephoto objective lens system 14 is located in the space A3 offset from and out of registry with the optical axis O–O', and spaces A1, A2, A4, A6 are unoccupied by a picture-taking lens system. In the telephoto picture-taking condition as shown in FIG. 6(B), however, the telephoto objective lens system 14 is moved into the space A2 on the picture-taking optical axis O–O', and standard objective lens system 15 is moved from the space A5 on the optical axis O–O' into the space A6, while the spaces A1, A3, A4 A5 are unoccupied by a picture-taking lens system. As has been described earlier, a shutter operating mechanism and other camera mechanisms are located in the spaces A1, A6 which are not occupied by either of the objective lenses.

The space A6 which has remained empty as illustrated in FIG. 6(A) may be allotted as a space, into which convex lens 10 is retracted from the finder optical system in the direction opposite to the direction of arrow *d* in the finder optical system for the standard picture-taking condition, as shown in FIG. 3. As a result, a space into which convex lens 10 is retracted need not be additionally provided.

FIGS. 7 and 8 show one embodiment of the present invention, in which there is provided a camera as shown in FIG. 5, incorporating a finder lens system shown in FIG. 2.

Referring to FIG. 7 which shows the standard picture-taking condition, concave lens 5, concave lens 6, Albada lens 11 having a concave surface facing the eyepiece lens 7, and convex eyepiece lens 7 are consecutively located in this order from the front or object side on the finder optical axis, while optical image frame 7*a*

is formed on the surface of the eyepiece on the object side, and reflecting surface **11***a* is provided on the concave surface of Albada lens **11**.

On the other hand, objective lenses for the camera, i.e., standard objective lens **15** and telephoto objective lens **14** are mounted on respective arms of a V-shaped lever **13** which is pivoted to a camera body by means of a shaft **13***a* in a manner to be rotatable through a limited predetermined angle. Shown at **12** is film cartridge which is to be loaded in a predetermined position in the camera body, and film cartridge **12** is provided with an exposure window **12***a*. Shutter member **17** is operated by means of a shutter operating member **16** occupying the space A1 as shown in FIG. **5**.

In a standard picture-taking condition, the V-shaped lever **13** assumes a first position by turning in a clockwise direction from its home position, and the standard objective lens **15** is thus located on the picture-taking optical axis O–O′ passing through the center of exposure window **12***a* which lies in the camera focal plane and intersecting exposure window **12***a* at a right angle, and positioned in the space A5. In contrast thereto, telephoto objective lens **14** is positioned in the space A3 off the picture-taking optical axis.

For shifting or transferring from a standard picture-taking condition to a telephoto picture-taking condition as shown in FIG. **8**, V-shaped lever **13** is rotated in the direction of the arrow as shown in FIG. **7** in the counterclockwise direction, thereby shifting telephoto objective lens **14** from the space A3 to the second position in the space A2 on the picture-taking optical axis O–O′. At this time, standard objective lens **15** is moved from the space A5 on the optical axis O–O′ to the space A4 offset from the optical axis O–O′.

On the other hand, it is necessary for the finder optical system P–P′ that concave lens **5** be moved away from the optical axis in the direction *a* and concave lens **6** be moved along the optical axis P–P′ in an arrow direction *b* for varying the magnification of the finder image of the view finder in response to the selection of the objective lenses. At this time, telephoto objective lens **14** which has occupied the space A3 in the standard picture-taking condition is moved into the space A2, so that the space A3 becomes empty, and as a result concave lens **5** may retract into the space A3 as shown in FIG. **8**. Accordingly, a space, into which concave lens **5** retracts, should not be additionally provided thus contributing to a reduction in the size of the camera.

As is apparent from the foregoing description, when the magnification of a finder optical system is varied, part of the lenses in the optical system may be not only retracted from the optical path but also moved along its optical axis, without changing its dioptric power. In addition, the aforesaid part of lenses in the finder optical system may be moved into a space, from which an objective lens has been moved from its retracting position to the position on the optical path for varying a magnification, so that a space into which part of the finder optical system is to retract, should not be additionally provided thereby permitting efficient utilization of the space within the camera body.

FIG. **9** shows another embodiment of the present invention, in which there is provided a camera shown in FIG. **6**, incorporating the finder lens system as shown in FIG. **3**.

In FIG. **9** showing a telephoto picture-taking condition, concave lens **8** and convex lens **10** are positioned on the axis P–P′ of the finder optical system from the object side, as shown in FIG. **3**, followed by Albada lens **11**′ having a concave surface facing the eyepiece lens **9**, and the rear convex eyepiece lens **9** consecutively in this order, while as in FIG. **7**, an optical image frame and a reflecting surface (not shown) are provided on the surface of convex eyepiece lens **9** on the object side as well as on the concave surface of Albada lens **11**′ respectively.

Telephoto objective lens **14** is mounted on a first slide plate **20** which is slidingly movable over a predetermined range in a direction perpendicular to the picture-taking optical axis, by means of know pin-slot coupling or the like. First slide plate **20** is spring-loaded by a tension spring **21** provided between the slide plate **20** and a stationary portion of the camera in a manner that telephoto objective lens **14** held by one end thereof is urged to a position on the picture-taking optical path. On the other hand, standard objective lens **15** is mounted on second slide plate **22** which is slidably movable over a predetermined range in the direction parallel with first slide plate **20** and is urged to a position on the picture-taking optical path by means of a tension spring **23** provided between the second slide plate **22** and a stationary portion of the camera body. Meanwhile, one end **22***b* of second slide plate **22** extends up to a finder mechanism for supporting convex lens **10** in the finder optical system, in a manner that convex lens **10** is moved into or from the finder optical path in response to the movement of standard objective lens **15**. Pins **24**, **25** are carried by first and second slide plates **20**, **22**. Shown at **26** is a control lever coupled to and cooperating with a switching dial **27** provided on the outer surface (not shown) of the camera body, while both arm portions **26***a*, **26***b* of control lever **26** engage pins **24**, **25** at all times. Shown at **28** is a click spring for locking control lever **26** in a given rotational position by releasably engaging respective notches in the central section of lever **26**. Shown at **12** is a film cartridge loaded in a predetermined position within the camera body, as has been described earlier, and the film cartridge is equipped with an exposure opening **12***a*.

As shown in FIG. **9**, in the telephoto picture-taking condition, control lever **26** is in the rotational position which has been assumed by lever **26** when rotated through a predetermined angle in the counterclockwise direction so that first slide plate **20** is located in the position effected by the spring **21** and second slide plate **22** is urged by arm **26***b* in the direction opposite to the biasing direction of spring **23**. Accordingly, the telephoto objective lens **14** occupies the space A5 of FIG. **6** on the picture-taking optical axis O–O′ passing through the center of exposure opening **12***a* and perpendicularly incident on the opening **12***a*. In contrast thereto, standard objective lens **15** remains in the space A3 offset from the picture-taking optical axis O–O′.

For shifting from the above condition to the standard picture-taking condition, switching dial **27** is rotated from a TELE position to a STANDARD position, by returning the switching dial externally of the camera. Clockwise rotation of control lever **26** then causes first slide plate **20** to be moved in the direction opposite to the biasing direction of spring **21**, while causing second slide plate **22** to be moved to a position drawn by spring **23**. As a result, telephoto objective lens **14** is retracted from the space A2 on the optical axis O–O′ to the space A3 offset from the optical axis, while standard objective lens **14** is moved from the space A6 into the space A5 on the picture-taking optical axis O–O′, (FIG. **6**(a)).

On the other hand, in the finder optical system P–P', concave lens **8** is moved by known means along the optical axis P–P' in the direction of arrow B in response to the selection of objective lenses, while concave lens **10** mounted on second slide plate **22** is moved in the direction of arrow A. At this time, the space **A6** within the camera body becomes empty due to the removal of standard objective lens **15** therefrom, so that convex lens **10** may retract into the space **A6**, which is empty. Accordingly, the space **A6** may be used as a common retracting space both for standard objective lens **15** and for convex lens **10** in the finder system, thus dispensing with an additional space for convex lens **10** to retract with the resulting reduction in size of a camera.

When the camera shown in FIG. **6** is employed as the space **A3** into which telephoto objective lens **14** is retracted at the time of standard picture-taking becomes empty, such space **A3** may be used as a retracting space for part of the lenses in the finder optical system. This permits the use of the finder optical system as shown in FIG. **2**.

While there has been described and illustrated preferred embodiments of the present invention, it is apparent that numerous alterations, omissions and additions may be made without departing from the spirit thereof.

We claim:

1. A camera comprising:

a body having a lens storage space and a photographic optical axis perpendicularly incident on a focal plane in said body;

a plurality of objective lenses located in said body and selectively transferrable between advanced and retracted positions respectively in and out of registry with said optical axis for varying the camera image magnification;

a finder optical system proximate said storage space and including a field varying lens member transferrable between advanced and retracted positions respectively in and out of registry with said finder optical system, said lens member in its retracted position occupying said lens storage space; and

operating means for selectively advancing and retracting a first of said objective lenses, said first objective lens in its retracted position occupying said storage space and in its advanced position being out of said storage space and permitting the occupation thereof by said lens member.

2. A camera as set forth in claim **1**, wherein said objective lenses include a standard objective lens for use in photographing at a predetermined magnification, and a telephoto objective lens for use in photographing at a magnification higher than that of said standard objective lens.

3. A camera as set forth in claim **2**, wherein the optical axis of said finder optical system and the photographic optical axis are located in a common plane perpendicular to said focal plane and said standard objective lens and said telephoto objective lens are movable with the optical axes thereof maintained along said plane.

4. A camera as set forth in claim **3**, wherein said finder optical system comprises an inverse Galilean type finder and includes an Albada optical element positioned to form a view-limiting frame delineating a picture-taking range.

5. A camera as set forth in claim **4**, wherein at least said telephoto objective lens is movable from its retracted position in said storage space in the vicinity of said finder optical path to its advanced position, and said lens member comprises a concave lens which occupies said storage space when in retracted position from the finder optical path, said storage space being the space which has been occupied by the retracted telephoto objective lens before moving to is advanced position.

6. A camera as set forth in claim **5**, wherein said operating means includes a V-shaped lever including two arms one of which holds said telephoto objective lens and the other of which holds said standard objective lens, said lever being swingable through a predetermined angle so as to selectively transfer said lenses between their advanced and retracted positions.

7. A camera as set forth in claim **5**, wherein said operating means comprises a first slide plate slidably movable over a given range and supporting said telephoto objective lens for movement therewith between its retracted position occupying said storage space in the vicinity of said finder optical path and its advanced position; a second slidably movable slide plate supporting said standard objective lens for movement therewith between its retracted position and its advanced position; and an externally operable control member for moving said first and second slide plates to selectively advance said telephoto objective lens and said standard objective lens into registry with said photographic optical axis.

8. A camera as set forth in claim **4**, wherein said standard objective lens is movable from its retracted position in said storage space in the vicinity of said finder optical path to its advanced position, and said lens member comprises a convex lens which may enter said storage space from which said standard objective lens has advanced into registry with said camera body optical axis.

9. A camera as set forth in claim **8** wherein said operating means comprises a first slide plate supporting said telephoto objective lens and slidably movable with said telephoto objective lens over a given range between its retracted position and its advanced position; a second slide plate slidably movable over a given range and supporting said standard objective lens for movement therewith between its retracted position in said storage space in the vicinity of said finder optical path and its advanced position; and an externally operable control member for moving said first and second slide plates for selectively moving said telephoto objective lens and said standard objective lens to their advanced positions.

10. A camera comprising:

a camera body having a lens storage space and a photographic image optical axis;

a plurality of objective lenses selectively movable between respective advanced positions in registry with said photographic image optical axis and transversely offset from said photographic image optical axis, a first of said objective lenses in its retracted position occupying said lens storage space;

a view finder optical system including a lens member movable between an advanced position in registry with the optical axis of said view finder optical system and a retracted position occupying said lens storage space transversely offset from said view finder optical system to vary the field of view of said view finder; and

means for selectively alternatively transferring said objective lenses to their respective advanced posi-

tions, said storage space being empty of said first objective lens when said first objective lens is in its advanced position to permit the retraction of said view finder lens member into said storage space.

11. The camera of claim 10 wherein the optical axes of said view finder optical system and the camera photographic axis are laterally spaced and said storage space is disposed between said axes.

12. The camera of claim 11 including means for advancing and retracting said view finder lens member with the retraction and advance respectively of said first objective lens.

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[11] **4,101,202**

[45] **Jul. 18, 1978**

[54] **VARIFOCAL CAMERA OBJECTIVE WITH ADJUSTMENT-RANGE SELECTION**

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[30] **Foreign Application Priority Data**

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[51] **Int. Cl.**[2] **G02B 15/18**

[52] **U.S. Cl.** **350/187**

[58] **Field of Search** 350/187

[56] **References Cited**

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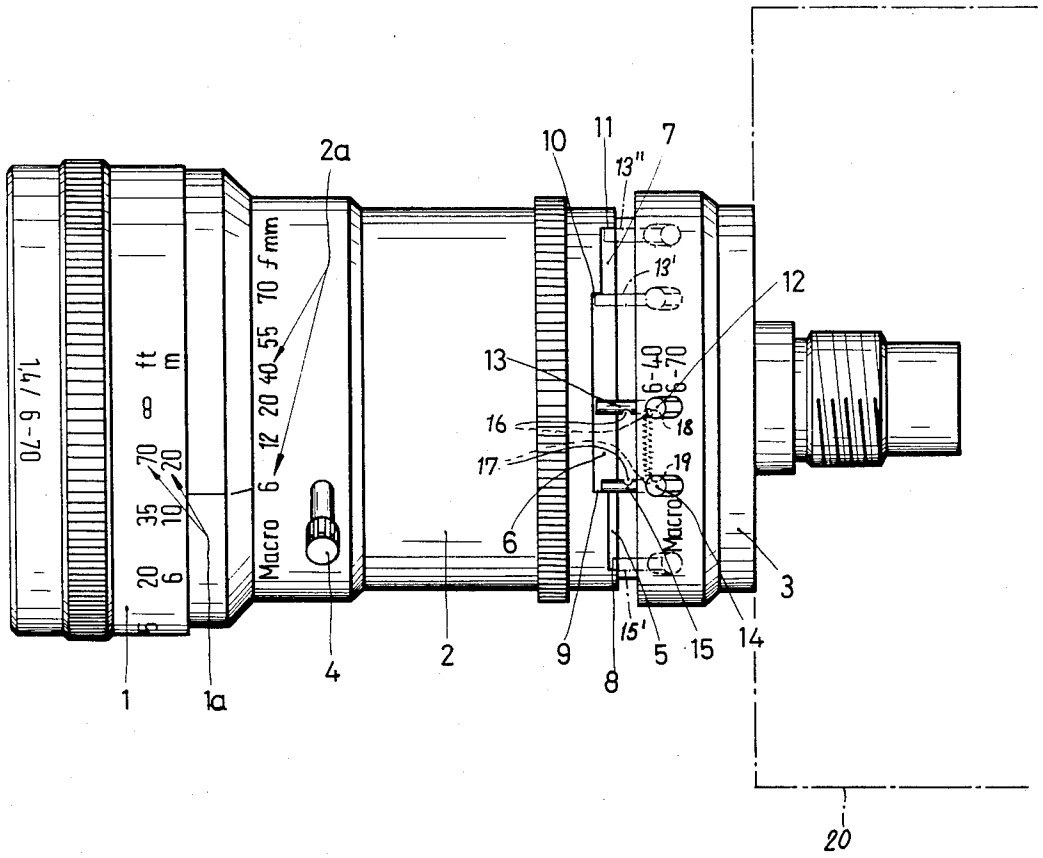
Primary Examiner—Paul A. Sacher

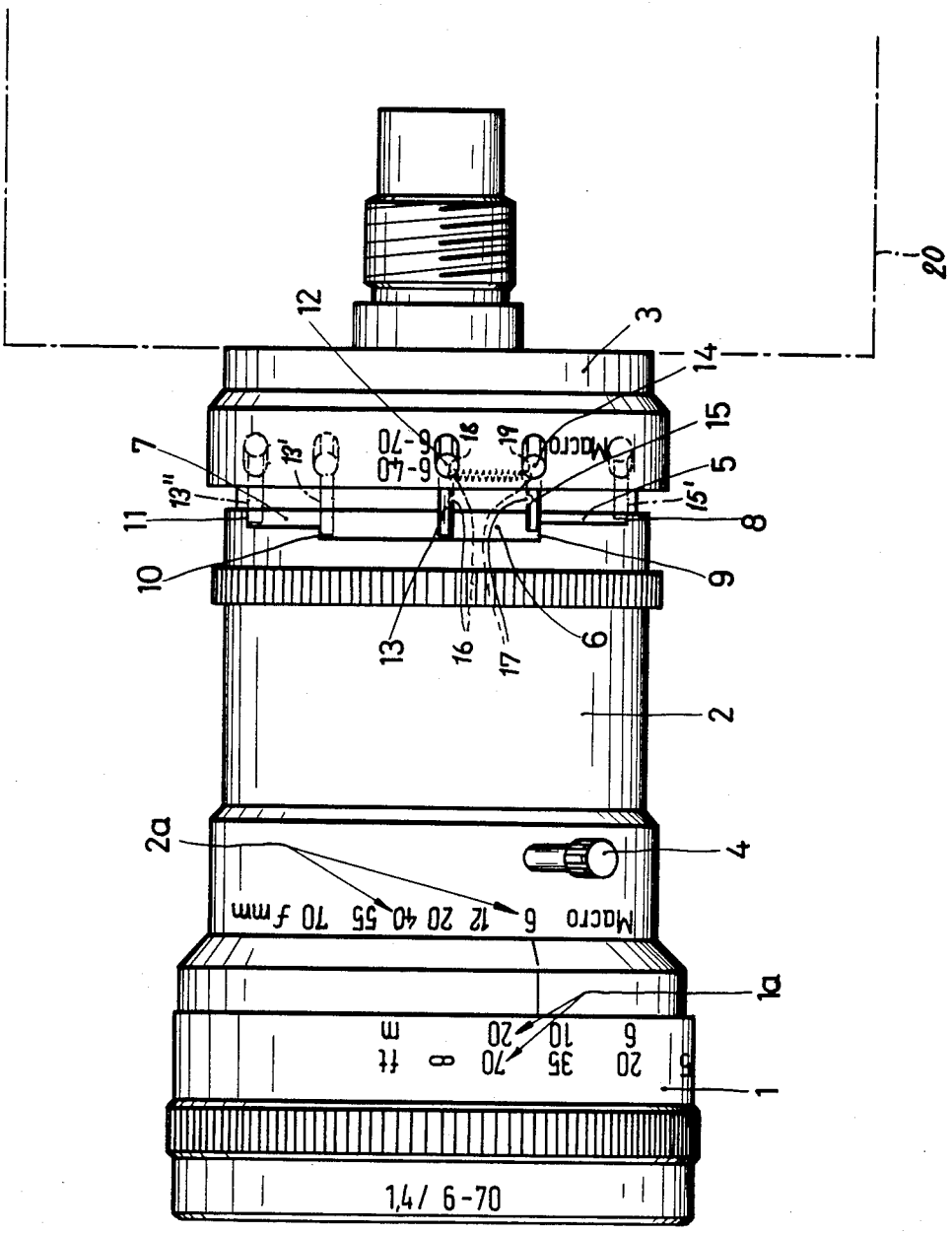
Attorney, Agent, or Firm—Karl F. Ross

[57] **ABSTRACT**

A varifocal camera objective, having a rotatable control ring for adjustment to a desired focal length in a zoom range and to a closeup position in a macro range, is provided with a pair of independently settable stop members for selectively limiting the adjustability to less than the entire zoom range and for optionally excluding the macro range. The stop members coact with edges of a stepped recess in a rim of the control ring and are each indexable in an advanced and in a retracted position.

4 Claims, 1 Drawing Figure

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VARIFOCAL CAMERA OBJECTIVE WITH ADJUSTMENT-RANGE SELECTION

FIELD OF THE INVENTION

My present invention relates to a photographic or cinematographic camera equipped with a varifocal or zoom objective and with displaceable control means, such as a ring rotatable about the objective axis, for selecting a desired focal length within the zoom range as well as for focusing the camera upon a nearby object in a so-called macro range.

BACKGROUND OF THE INVENTION

The well-known varifocal objectives have a pair of axially shiftable components whose displacement with the aid of a camming ring changes the overall focal length from a maximum value in a telephoto position to a minimum value in a wide-angle position. It is also known to design the camming mechanism in such a way that further rotation of the ring beyond the wideangle position will move only one of these shiftable components to displace the previously stationary image plane so as to permit the taking of closeups in the macro range which is usually defined as encompassing image ratios between **1:10** and **1:1**.

While it is convenient to have a single control element available for both zooming and closeups, it is frequently desirable to prevent an accidental overshooting of the zoom range when the object or scene to be filmed or photographed is distant from the camera. Furthermore, working near the telephoto end of the zoom range generally requires a steadier support for the camera in order to prevent objectionable blurring, making it desirable to limit the extent of the varifocal adjustment when no tripod or the like is available. It is also known to provide varifocal objectives with diaphragms which automatically increase the relative aperture with changes in the focal length, e.g. from a midposition of the zoom range to the telephoto position. In this case, again, it may be undesirable under certain lighting conditions to move beyond the position where the relative aperture begins to grow larger.

It has already been proposed (see German Pat. No. 1,169,280) to provide a zoom-type camera with a stop which arrests a camming ring in an intermediate position unless the user makes a special effort to deactivate that stop. This mode of operation requires a higher degree of alertness on the part of an operator wishing to utilize the full zoom range.

OBJECT OF THE INVENTION

It is, therefore, the object of my present invention to provide means in such a photographic or cinematographic camera for enabling the operator to select beforehand the extent of the range of adjustment he wants to use, thereby allowing him to concentrate entirely on the normal tasks of focusing and zooming without paying special attention to the self-imposed range limitations.

SUMMARY OF THE INVENTION

I realize this object, in accordance with my present invention, by the provision of first and second stop means selectively settable independently of each other to coact with a camming ring or other control means for blocking movement thereof from the wide-angle position to the telephoto position beyond a predetermined intermediate position and away from the telephoto position past the wide-angle position, respectively.

BRIEF DESCRIPTION OF THE DRAWING

The above and other features of my invention will now be described in detail with reference to the accompanying drawing, the sole FIGURE of which shows a varifocal camera objective embodying the present improvement.

SPECIFIC DESCRIPTION

The drawing shows, diagrammatically, a camera **20** having a rear lens mount **3** fixedly secured thereto, this lens mount carrying a nonillustrated fixed-focus lens group supplemented by a varifocal front attachment of conventional type disposed within a housing. Rotatably mounted on this housing is a focusing ring **1** with a distance scale **1***a*, graduated in meters and feet, and a control ring **2** provided with a handle **4**, carrying a focal-length scale **2***a* graduated in millimeters. In the illustrated embodiment, the zoom range extends from a wide-angle position with $f = 6$ mm to a telephoto position with $f = 70$ mm. Scale **2***a* also indicates, adjacent the lower limit of the zoom range, a macro range to which the objective can be adjusted by an upward movement of knob **4** beyond the illustrated wide-angle position.

In accordance with my present invention, control ring **2** has an annular end face proximal to lens mount **3** which is formed with a stepped recess **6**. The deepest part of this recess is bounded by edges **9** and **10**, a shallower extension **7** of the recess terminating at an edge **11**. On its opposite side the recess **6** has a still shallower extension **5** bounded by an edge **8**.

Two stop members **13** and **15** in the form of axially extending pins are lodged in lens mount **3** and are provided with actuating knobs **12** and **14** received in slots of that lens mount in order to facilitate a shifting of these pins between an advanced position at left and a retracted position at right. The pins can be indexed in either of their positions by respective spring-loaded ball checks **18** and **19** engaging in notches **16** of pin **13** and notches **17** of pin **15**. With pin **13** in its advanced position, as illustrated in full lines, the zoom range is curtailed to end in the 40-mm position in which the pin comes to rest against edge **10** as indicated in phantom lines at **13'**. With pin **15** advanced, as also shown in full lines, the upward movement of handle **4** is stopped in the wide-angle position in which this pin abuts the edge **9**. Retraction of pin **13** opens up the full zoom range from 6 to 70 mm, the pin engaging the edge **11** in the telephoto position as indicated in phantom line at **13''**. The macro range is available upon retraction of pin **15** which then engages the edge **8** as indicated in phantom lines at **15'**. Recess edges **8** and **11** could also be replaced by lugs projecting from ring **2** toward lens mount **3**.

Obviously, the peripheral separation of pins **13** and **15** along the recessed end face of ring **2** must be at least equal to the angular extent of the macro range if the end of that range is to be determined in the aforedescribed manner by the coaction of pin **15** with edge **8**. With edge **9** higher than edge **10**, however, the macro range could also be limited by contact between edge **9** and pin **13** in either its advanced or its retracted position. In either case, the two stop pins **13** and **15** allow a preliminary selection to be made among four different working modes, namely:

(a) full zoom plus macro range,

(b) curtailed zoom plus macro range,
(c) full zoom without macro range,
(d) curtailed zoom without macro range.

With the objective focused on the macro range, the advance of pin **15** is prevented by the bottom of recess extension **5**. Similarly, pin **13** cannot be advanced in the upper part of the zoom range in which it confronts recess extension **7**.

While the embodiment described above is designed for manual adjustment of ring **2**, it will be apparent that the same range limitations can be selectively imposed if the ring is electrically driven by a reversible motor through the intermediary of a friction clutch, e.g. as described in commonly owned U.S. Pat. Nos. 3,165,044, 3,656,422 and 3,682,072.

I claim

1. In a camera having a varifocal objective provided with control means displaceable between a telephoto position and a wide-angle position for adjusting the focal length of the objective in a zoom range, said control means being further displaceable beyond said wide-angle position for focusing the objective upon nearby objects in a macro range, the combination therewith of:

first stop means coupled with said objective and selectively settable to coact with said control means for blocking movement thereof from said wide-angle position toward said telephoto position beyond a predetermined intermediate position; and

second stop means coupled with said objective and selectively settable independently of said first stop means to coact with said control means for blocking movement thereof away from said telephoto position past said wide-angle position.

2. The combination defined in claim **1** wherein said control means comprises a manually rotatable ring centered on the objective axis, said first and second stop means comprising a pair of axially shiftable members engageable with abutments on said ring.

3. The combination defined in claim **2** wherein said ring has an annular end face provided with a stepped recess with edges constituting said abutments, said members are peripherally spaced along said ring face within the bounds of said recess.

4. The combination defined in claim **2** wherein said members are provided with indexing means for alternate retention in an advanced position and in a retracted position.

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SR

OR 4,099,849

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Lawson et al.

4,099,849

Jul. 11, 1978

[54] **WIDE ANGLE OBJECTIVE**

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[73] Assignee: **Vivitar Corporation**, Santa Monica, Calif.

[21] Appl. No.: **492,403**

[22] Filed: **Jul. 29, 1974**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 392,118, Aug. 27, 1973, abandoned.

[51] **Int. Cl.**[2] **G02B 9/64**

[52] **U.S. Cl.** **350/214**

[58] **Field of Search** 350/214

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Attorney, Agent, or Firm—DeLio and Montgomery

[57] **ABSTRACT**

This disclosure relates to a Wide Angle Lens of the retrofocus type having a new lens group arrangement which comprises from the object end to the image end a first negative group, a second negative group in the form of a meniscus having a concave image side surface, a third positive group having a convex object side surface, a fourth positive group having a convex image side surface, a fifth negative group, and a sixth positive group having convex image and object side surfaces.

33 Claims, 12 Drawing Figures

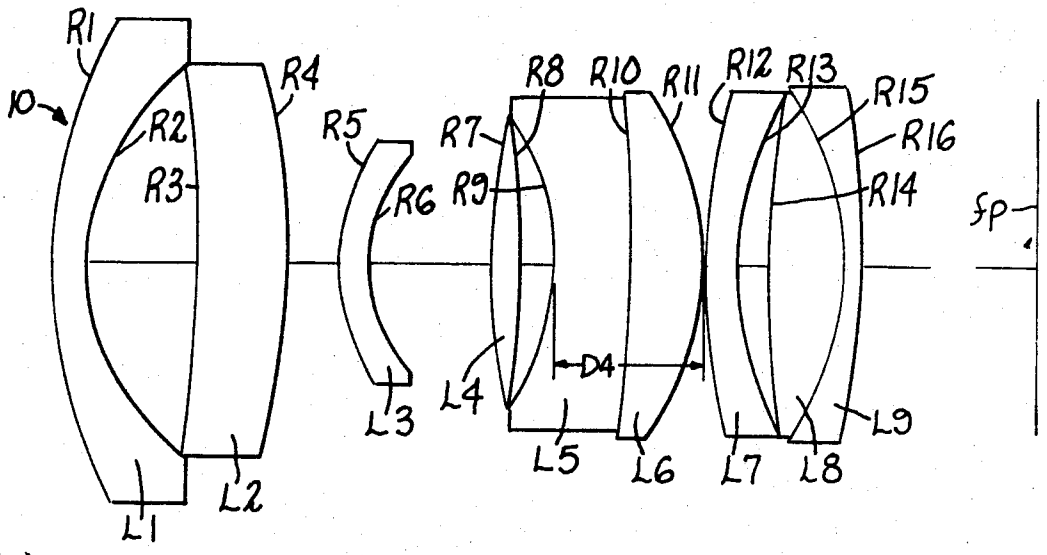


Fig. 1.

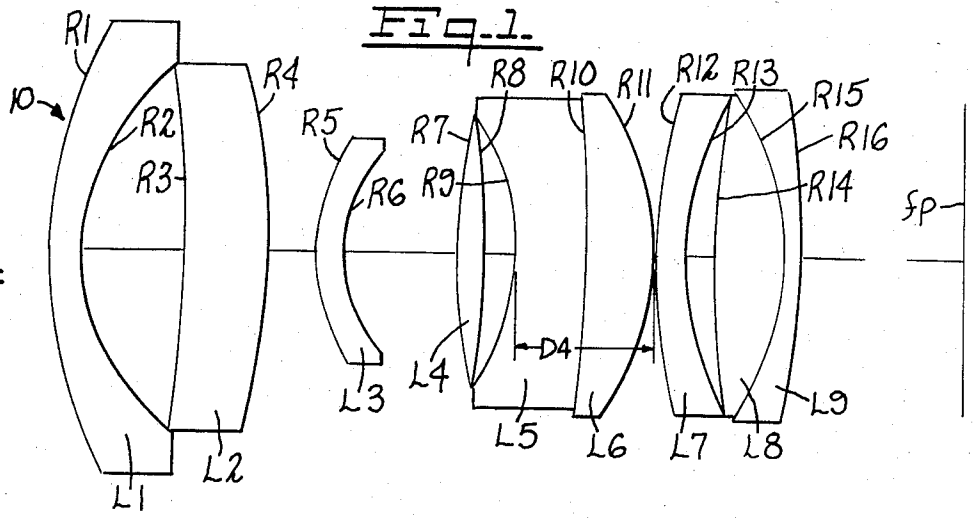
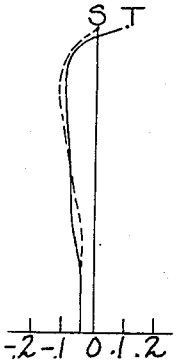


Fig. 4.



28mm. f/2.0

Fig. 2.

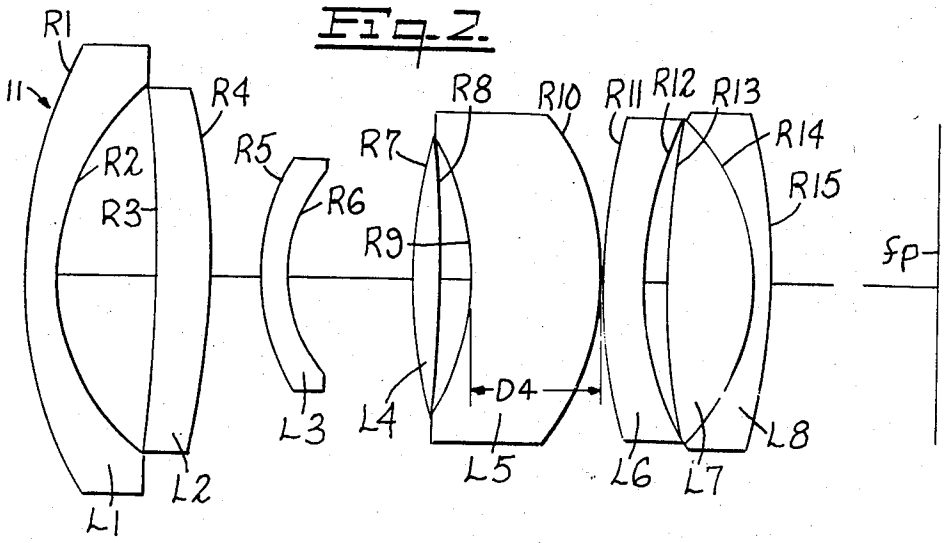
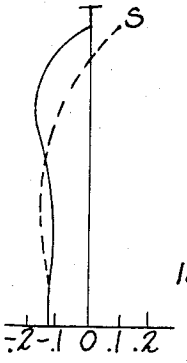


Fig. 5.



28mm f/2.0

Fig. 3.

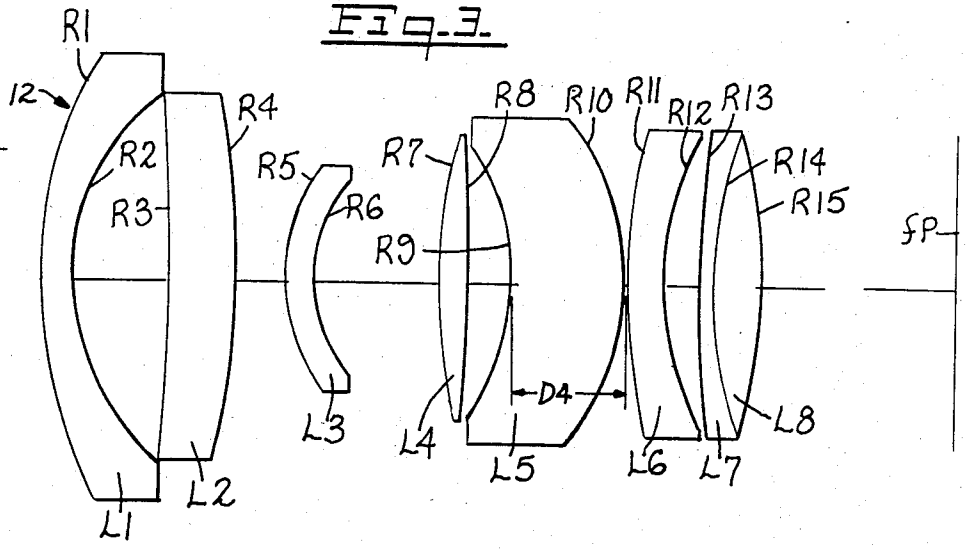


Fig. 7.

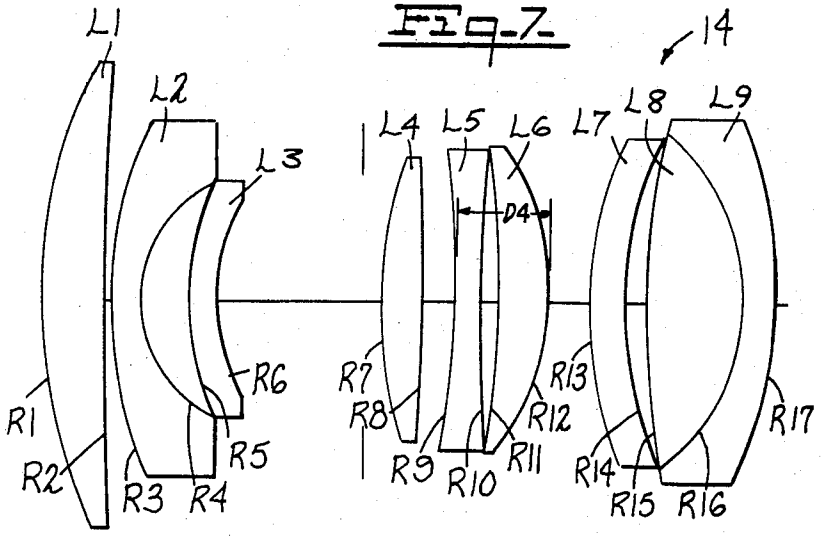


Fig. 6.

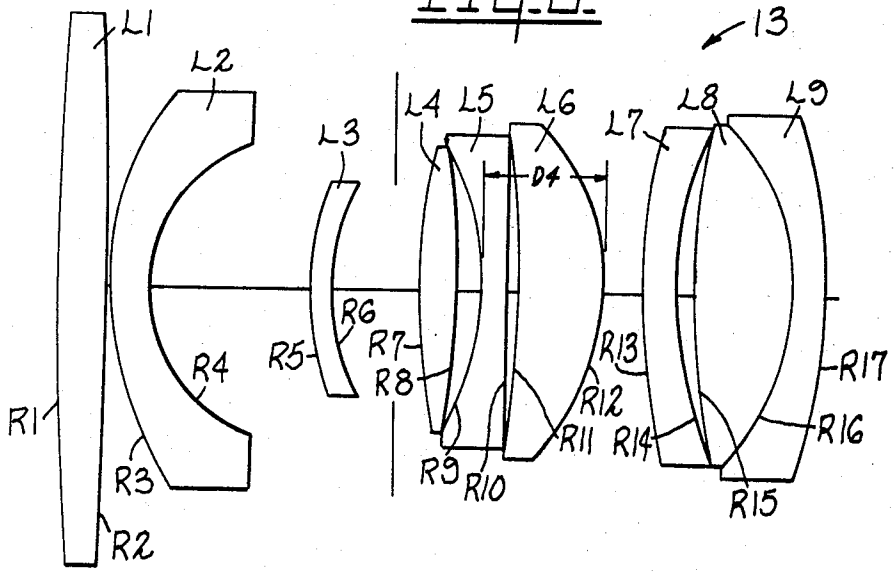


Fig. 11.

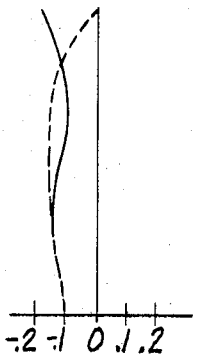


Fig. 12.

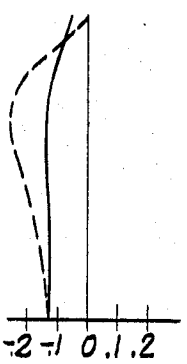


Fig. 8.

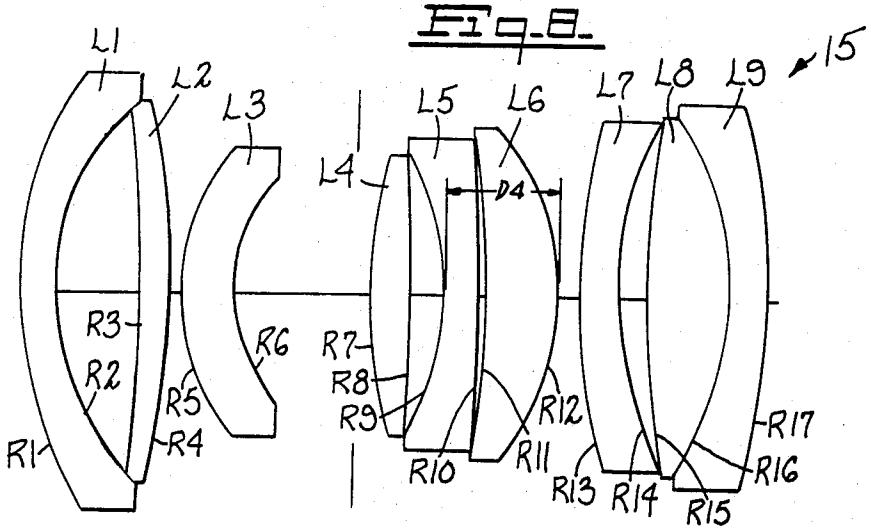


Fig. 9.

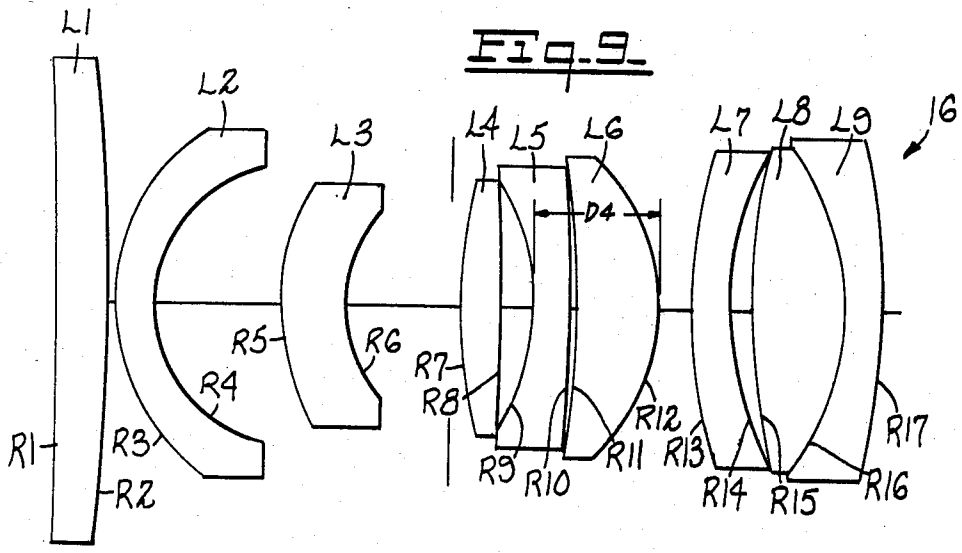
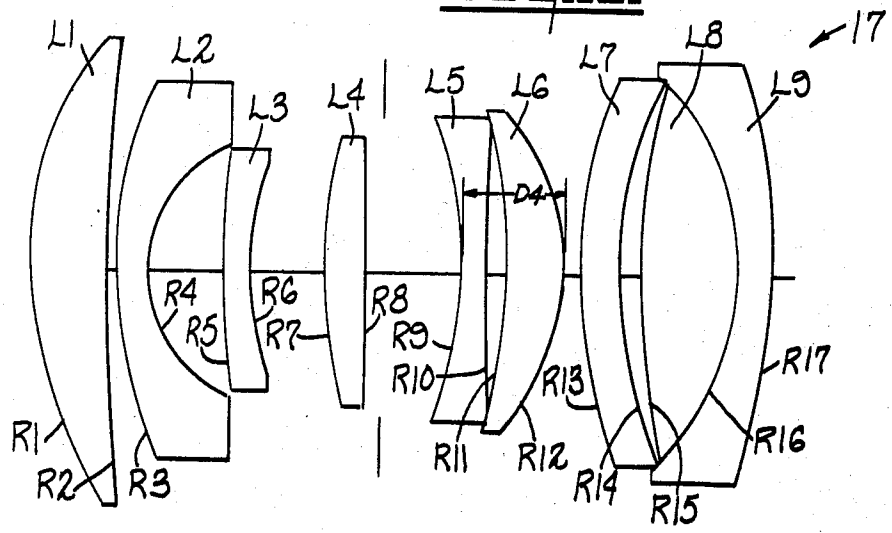


Fig. 10.



WIDE ANGLE OBJECTIVE

This application is a continuation-in-part of co-pending application Ser. No. 392,118 filed Aug. 27, 1973, now abandoned.

This invention relates to lenses, and more particularly to those known as wide angle lenses of the retrofocus type.

Wide angle lenses may be defined as those in which the diameter of the film or image frame of the camera with which the lens is used is substantially equal to or greater than the equivalent focal length of the lens. Moderately wide angle rectrofocus objectives covering field angles of approximately 80° have been known for many years. Typically these lenses have been large in length and diameter resulting in considerable manufacturing expense and a lack of portability. In order to reduce the size, it is necessary to increase the lens element powers which normally increase the lens surface aberration contributions. When wide angle objectives of reduced size configuration are constricted to relative apertures of *f*/2.8, the need to correct large aperture dependence aberrations is apparent; however, when relative apertures of approximately *f*/2.0 or greater are desired, the amount of zonal spherical aberration and aperture dependent coma is considerably increased. Moreover, due to the large lens element powers, the amount of field curvature of third order and greater becomes excessive. Even though the aperture dependent aberrations may be well corrected, the zonal field curvature and astigmatism will severely limit resolution.

The present invention provides a new and improved lens configuration for wide angle objectives through the employment of a new lens grouping arrangement which minimizes the lens element powers in order to obtain the necessary back focal distance and front vertex distance as required to be useful in single lens reflex cameras. The minimization of the lens group powers decreases the surface contributions to distortion and various aberrations.

Briefly stated, a wide angle lens embodying the invention comprises a first lens group from the object end to the image end which is afocal, a second diverging group, third and fourth converging groups, a fifth diverging group and a sixth converging group. The lens groups and elements, and particularly the fourth group, have relative powers and configurations to achieve the objects of the invention, as hereinafter more specifically pointed out.

An object of this invention is to provide a new and improved wide angle lens of the retrofocus type.

Another object of this invention is to provide a lens of the type described of large relative aperture with minimized field curvature and astigmatism.

A further object of this invention is the provision of a lens of the type described having the capability of focusing to very close object distance without introduction of unacceptable field curvature and astigmatism.

The features of the invention which are believed to be novel are particularly pointed out and distinctly claimed in the concluding portion of this specification. However, the invention both as to its organization and operation, together with further objects and advantages thereof, may best be appreciated by reference to the following detailed description taken in conjunction with the drawings, wherein:

FIGS. **1** – **3** are side elevations of lens embodying the invention;

FIGS. **4** and **5** are curves illustrating the improved performance of the lens of FIG. **1**;

FIGS. **6** – **10** are side elevations of additional lens embodying the invention; and

FIGS. **11** and **12** are curves illustrating the improved performance of the lens of FIG. **8**.

In all lens designs, the elemental groupings and spacings thereof are chosen to minimize aberrations and distortion of the overall lens and generally provide a true image of an object. The lens groupings are chosen to provide a lens of given field angle or equivalent focal length for a specified image quality. Therefore, the contribution of each lens group or element in multi-element lens is incapable of precise definition inasmuch as all lens configurations are selected in view of the others to provide the desired result.

The objects of the present invention are achieved by the provision of a new grouping of lens elements as hereinafter described.

A lens embodying the invention as disclosed comprises six lens groups from the object end to the image end as follows:

I. A two element group of negative power.
II. A meniscus of negative power.
III. A positive element having a convex front surface.
IV. A positive element or doublet having a concave front surface and a convex rear surface.
V. A meniscus of negative power, and
VI. A positive doublet.

A first lens **10** embodying the invention is set forth in FIG. **1**, and comprises nine lens elements **L1** - **L9**, arranged in six lens groups. The surfaces of the elements **L1** – **L9** are defined in radii **R1** – **R16** as shown. The first group viewed from the object end to the image end comprises elements **L1** and **L2** which are, as a combination, afocal with respect to the equivalent focal length (EFL) of the overall lens. The second group II is comprised of a meniscus **L3** of negative power (diverging). The third group III is comprised of a biconvex element **L4** of positive power (converging). The fourth group IV is comprised of a contacting doublet **L5** and **L6** of positive power (converging). The fifth group V is comprised of a negative meniscus (diverging) and the sixth group VI is a contacting doublet of positive power (diverging). This lens is defined by the data set forth in Table I.

A second lens **11** embodying the invention is set forth in FIG. **2** and comprises lens elements **L1** – **L8**, arranged in six groups of the same relative powers as the lens of FIG. **1**. Lens **11** differs from lens **10** primarily in that Group IV comprises a single element **L5**, but which is still of positive power (converging). Lens **11** is defined by the data set forth in Table II.

Another lens **12** is shown in FIG. **3** and comprises the six group I – VI of the same relative power as lens **11**, having eight elements **L1** – **L8**. The lens surfaces are defined on radii **R1** – **R15** as shown. Lens **12** differs from lens **11** primarily in that Group VI, elements **L7** and **L8**, is comprised of a meniscus and a contacting bi-convex element in that order, rather than vice-versa, as lens **11**. Lens **12** is defined by the data as set forth in Table III.

In the tables the index of refraction is denoted as N_d and the dispersion as referenced by the Abbe number is denoted by V_d.

Table I sets forth data on lens 10 of FIG. 1 scaled to an EFL of 28.7mm for a 24 × 36mm image frame, and having a relative aperture of F/1.9.

TABLE I

FIG. 1

Lens		Radius	Axial Distance Between Surfaces	N_d	V_d
	R1	38.387mm			
L1			2.435mm	1.5168	64.2
	R2	18.755			
			8.5083		
	R3	−119.389			
L2			7.167	1.7995	42.3
	R4	−52.877			
			4.72–0.20		
	R5	18.178			
L3			2.180	1.5831	59.5
	R6	12.456			
			9.369		
	R7	49.0379			
L4			2.159	1.8306	36.5
	R8	−123.776			
			2.581		
	R9	−22.141			
L5			6.000	1.7470	27.5
	R10	−109.562			
L6			5.774	1.7620	40.3
	R11	−21.131			
			0.135		
	R12	55.725			
L7			2.454	1.8467	23.8
	R13	26.386			
			2.239		
	R14	76.751			
L8			6.000	1.8042	46.5
	R15	−22.374			
L9			1.500	1.8052	25.5
	R16	−54.363			

BFL = 38.8mm

The aperture stop is located 8.4mm after L3.

The spacing between elements L2 and L3 varies from 0.20mm to 4.72mm for focusing from infinity to 178.4mm. Elements L3 – L9 move in fixed relation as a group during focusing travel.

Table II sets forth data on lens 11 of FIG. 2 scaled to an EFL of 28.7mm for a 24 × 36mm image frame, and having a relative aperture of F/2.0.

TABLE II

FIG. 2

Lens		Radius	Axial Distance Between Surfaces	N_d	V_d
	R1	38.570mm			
L1			2.435mm	1.5168	64.2
	R2	19.187			
			8.508		
	R3	−118.121			
L2			4.797	1.7995	42.3
	R4	−53.498			
			4.000–0.25		
	R5	18.556			
L3			2.180	1.5831	59.5
	R6	12.336			
			10.615		
	R7	50.120			
L4			2.159	1.8306	36.5
	R8	−160.5232			
			2.581		
	R9	−22.590			
L5			10.883	1.7600	47.5
	R10	−21.050			
			0.135		
	R11	51.8954			
L6			3.257	1.8467	23.8
	R12	26.298			
			2.239		
	R13	77.064			
L7			7.000	1.8042	46.5
	R14	−18.570			
L8			1.500	1.8052	25.5
	R15	−51.214			

BFL = 39.0mm

The aperture stop is located 9.55mm behind L3 Elements L3 – L8 move in fixed relation as a group for focusing while L1 and L2 are stationary. The spacing between elements L2 and L3 varies from 0.25mm to 4.00mm for focusing from infinity to 178mm.

Table III sets forth data on lens 12 of FIG. 3 scaled to an EFL of 28.7mm for a 24×36mm image frame and having a relative aperture of F/2.0.

TABLE III

FIG. 3

Lens		Radius	Axial Distance Between Surfaces	N_d	V_d
	R1	39.897mm			
L1			2.435mm	1.520	65.6
	R2	19.832			
			8.500		
	R3	−111.180			
L2			5.835	1.802	47.5
	R4	−55.111			
			4.000–0.25		
	R5	17.557			
L3			2.180	1.807	44.3
	R6	2.193			
			10.789		
	R7	47.013			
L4			2.433	1.833	41.8
	R8	−138.976			
			3.390		
	R9	−23.286			
L5			9.700	1.837	51.9
	R10	−21.573			
			0.135		
	R11	51.904			
L6			3.324	1.848	23.4
	R12	26.009			
			2.682		
	R13	85.346			
L7			1.000	1.848	23.4
	R14	31.429			
L8			4.000	1.776	50.6
	R15	−43.746			

BFL = 39.9mm

The aperture stop is located 10.79mm behind L3. The spacing between elements L2 and L3 varies between 0.25mm and 4.00mm for focusing from inifinity to 178mm. Elements L3 – L8 move in fixed relation as a group for focusing while L1 and L2 are stationary.

In the examples of Tables I - III, all lens have a rated EFL of 28mm and a rated equivalent aperture of F/1.9, as scaled to a film or image frame size of 24 × 36mm. The lenses may, of course, be scaled to other image frame sizes, and EFL's.

FIGS. 4 and 5 exemplify plots of image height versus focal plane shift for the lens of FIG. 1, and a known wide angle lens scaled to 28mm EFL and a stated relative aperture of F/2.0, respectively, as shown in U.S. Pat. No. 3,736,049. Comparisons were made at a magnification of M = −0.025 for a half image height of 20mm, for both sagittal S and tangential T rays.

The curves of FIG. 4 are relatively close together evidencing essential elimination of astigmatism. The curves of FIG. 4 have less deviation from the vertical, and are generally flatter than those of FIG. 5, to evidence a substantial reduction in field curvature.

The lenses of Tables I, II and III are designed for the first group elements L1 and L2 to be stationary while the rear elements are shifted in fixed relation as a group for focusing, as disclosed and claimed in the copending application of John A. Lawson, Ser. No. 492,413, filed July 29, 1974.

However, the lens Groups may also be arranged to move differentially as in the conventional wide angle objectives. For example, the entire objective may be shifted for focusing, while the fourth and fifth lens Groups move differentially in a well known manner. Also, the lens may be arranged to move only Groups V and VI for focusing, as disclosed and claimed in U.S. Pat. No. 3,975,090.

Further examples of lenses embodying the invention are set forth in FIGS. 6 – 10, and Tables IV – IX. In all

of the examples, Group IV is an air spaced doublet L5, L6.

Table IV sets forth data on the lens 13 of FIG. 6 as scaled to an EFL of 28.5mm for a 24 × 36mm image plane, and having a relative aperture of F/1.9.

TABLE IV

		FIG. 6			
Lens		Radius(mm)	Axial Distance Between Surfaces(mm)	N_d	V_d
L1	R1	155.101	4.160	1.562	58.52
	R2	−541.744	.300		
L2	R3	29.242	3.000	1.487	70.4
	R4	13.031	12.759		
L3	R5	22.898	2.000	1.800	42.3
	R6	15.520	8.692		
L4	R7	48.249	3.200	1.785	25.7
	R8	−70.561	1.967		
L5	R9	−24.204	2.164	1.805	25.5
	R10	−1430.264	.844		
L6	R11	−94.529	5.504	1.800	42.3
	R12	−19.767	3.550–1.028		
L7	R13	45.215	2.580	1.847	23.8
	R14	29.179	1.700		
L8	R15	70.687	8.00	1.743	49.2
L9	R16	−19.969	2.700	1.847	23.8
	R17	−44.577			

The aperture stop is located 7.18mm after L3. The BFL varies from 39.68mm to 44.34mm as the lens is focused from infinity to an object distance of 174.7mm. All lens elements move for focusing and the space between Groups IV and V moves differentially as shown.

Table V sets forth data on a lens 14 substantially as shown in FIG. 7 scaled to an EFL of 28.6mm for a 24 × 36mm frame size and a relative aperture of F/1.9.

TABLE V

		FIG. 7			
Lens		Radius(mm)	Axial Distance Between Surfaces(mm)	N_d	V_d
L1	R1	42.160	5.700	1.487	70.4
	R2	384.104	.300		
L2	R3	35.935	2.800	1.487	70.4
	R4	11.488	4.032		
L3	R5	26.721	2.000	1.517	64.2
	R6	15.510	14.343		
L4	R7	39.692	3.200	1.689	31.2
	R8	925.392	2.973		
L5	R9	−76.847	2.164	1.847	23.8
	R10	97.091	1.750		
L6	R11	−75.162	4.549	1.800	42.3
	R12	−21.352	4.098–.100		
L7	R13	37.634	2.700	1.722	29.2
	R14	32.248	2.000		
L8	R15	70.613	8.400	1.641	59.8
L9	R16	−18.940	2.700	1.805	25.5
	R17	−42.358			

The aperture stop is located 12.3mm after L3. The BFL varies from 39.2mm to 43.2mm as the lens is focused from infinity to an object distance of 203mm. Groups I–IV are stationary while Groups V and VI (elements L7–L9) move in fixed relation for focusing.

Table VI sets forth data on lens 15 of FIG. 8 scaled to an EFL of 35.0mm for a 24 × 36mm image frame, and a relative aperture of F/2.0.

TABLE VI

		FIG. 8			
Lens		Radius(mm)	Axial Distance Between Surfaces(mm)	N_d	V_d
L1	R1	31.195	2.998	1.517	64.2
	R2	20.569	7.074		
L2	R3	−96.642	2.829	1.785	25.7
	R4	−58.277	0.726		
L3	R5	18.356	4.321	1.723	38.0
	R6	12.649	11.925		
L4	R7	53.996	2.800	1.831	36.5
	R8	−172.838	3.000		
L5	R9	−22.950	2.695	1.741	27.8
	R10	−276.177	0.720		
L6	R11	−76.849	6.081	1.757	47.7
	R12	−19.800	2.000–0.20		
L7	R13	51.599	3.000	1.847	23.8
	R14	31.353	2.332		
L8	R15	82.914	7.000	1.800	42.3
L9	R16	−25.647	3.00		
	R17	−57.034		1.805	25.5

BFL = 40.5

The aperture stop is located 10.73mm after element L3. The space between Groups IV and V varies as shown for close focus compensation at a linear rate as the lens focuses to 230.1mm. The entire lens also shifts for focusing.

Table 7 sets forth data on lens 16 of FIG. 9 scaled to an EFL of 35.0mm for a 24 × 36mm image frame, and a relative aperture of F/1.9.

TABLE VII

		FIG. 9			
Lens		Radius	Axial Distance Between Surfaces	N_d	V_d
L1	R1	1598.84mm	4.160mm	1.750	35.0
	R2	−175.71	.300		
L2	R3	22.57	2.985	1.487	70.4
	R4	13.99	9.079		
L3	R5	23.40	5.005	1.700	47.8
	R6	15.49	8.869		
L4	R7	58.80	3.200	1.831	36.5
	R8	−100.28	2.385		
L5	R9	−24.54	2.358	1.741	27.8
	R10	−845.99	6.80		
L6	R11	−102.81	6.778	1.757	47.7
	R12	−19.97			

TABLE VII-continued

FIG. 9

Lens		Radius	Axial Distance Between Surfaces	N_d	V_d
			0.91–3.66		
L7	R13	58.83			
			3.000	1.847	23.8
	R14	32.65			
			1.700		
	R15	65.28			
L8			7.300	1.800	42.3
	R16	−27.00			
L9			0	1.805	25.5
	R17	−79.24			

BFL = 39.48 – 45.28mm as lens is focused from infinity to 221.3mm. The aperture stop is located 7.54mm after element L3. The BFL varies from 39.48mm to 45.28mm as the lens is focused from infinity to 221.3mm. The spacing between Groups IV and V also varies as shown.

221.3

Table VIII sets forth data on lens 17 of FIG. 10 scaled to an EFL of 35.0mm for a 24 × 36mm image frame, and a relative aperture of F/1.9.

TABLE VIII

FIG. 10

Lens		Radius(mm)	Axial Distance Between Surfaces(mm)	N_d	N_d
	R1	30.600			
L1			7.000	1.487	70.4
	R2	170.290			
			.300		
	R3	34.231			
L2			2.985	1.487	70.4
	R4	11.567			
			6.000		
	R5	67.235			
L3			2.000	1.569	56.0
	R6	25.201			
			6.171		
	R7	46.077			
L4			3.200	1.806	40.7
	R8	−644.608			
			7.931		
	R9	−34.424			
L5			2.358	1.762	26.6
	R10	−829.911			
			1.350		
	R11	−47.763			
L6			4.832		
	R12	−19.289		1.757	47.7
			4.70–.10		
	R13	41.514			
L7			3.000	1.667	33.1
	R14	35.544			
			1.900		
	R15	64.725			
L8			8.000	1.717	48.0
	R16	−22.414			
L9			2.700	1.805	25.5
	R17	−56.648			

The BFL varies from 39.56mm to 44.16mm as the lens is focused from infinity to 258mm, and the spacing between Groups IV and V varies as shown. The aperture stop is located 1.59mm behind element L4.

Table IX sets forth data on a lens substantially as shown in FIG. 7 scaled to an EFL of 28.5mm for a 24 × 36mm frame size and a relative aperture of F/1.9.

TABLE IX

FIG. 7

Lens		Radius(mm)	Axial Distance Between Surfaces(mm)	N_d	V_d
	R1	54.600			
L1			5.700	1.487	70.4
	R2	937.48			
			.300		
	R3		28.640		
L2			2.800	1.487	70.4
	R4	11.392			
			4.474		
	R5	28.640			
L3			2.000	1.517	64.2
	R6	15.990			
			13.502		
	R7	41.450			
L4			3.200	1.689	31.2
	R8	840.70			

TABLE IX-continued

FIG. 7

Lens		Radius(mm)	Axial Distance Between Surfaces(mm)	N_d	V_d
			3.342		
L5	R9	−70.750			
			2.164	1.805	25.5
	R10	106.030			
			1.900		
	R11	−71.649			
L6			4.549	1.804	46.5
	R12	−21.220			
			4.098–.10		
	R13	48.140			
L7			2.700	1.741	27.8
	R14	35.430			
			1.212		
	R15	53.960			
L8			9.159	1.639	55.5
	R16	−20.430			
L9			2.700	1.805	25.5
	R17	−44.190			

The aperture stop is located 11.5mm behind L3, Groups V and VI move from a BFL of 39.2mm to 43.2mm for focusing from infinity to 203mm while Groups I – IV are fixed with respect to the film plane.

FIGS. 11 and 12 exemplify further comparison of the focal plane shift of the lens of FIG. 8 and the lens of the previously mentioned patent at a magnification of M = −0.025 for a half image height of 20mm, for both sagittal S and tangential T rays.

The curves of FIG. 11 are relatively close together evidencing substantially less astigmatism than FIG. 12. The curves of FIG. 11, particularly in the saggital have less deviation from the vertical, evidencing reduction in field curvature.

As previously mentioned, the contribution of each lens group to an overall lens is incapable of precise definition since properties of one or more elements and groups serve the same function and are complimenting and supplementing each other. However, in the new lens form described, Group IV is designed to provide certain contributions to the overall lens.

Group IV provides a substantial correction for the Petzval sum of the lens. The axial spacing of the front and rear surfaces contributes to correction of field curvature convex toward the object. Additionally, it provides positive power required to shorten the EFL of the overall lens while maintaining the required back focal length (BFL) to make the lens of the retrofocus type. The EFL of Group IV (F_4) should have the following relation to the EFL of the overall lens (F_o).

$$2.5\ F_o \leqq F_4 \leqq 6.5\ F_o$$

The foregoing is a critical relation, and other preferred relationships exist which do not have the same criticality. The radius R_{44} of the rear surface is less than F_o, or

$$F_o > R_{44}$$

This relationship contributes to correction for distortion. The axial separation D_4 between front and rear surfaces is a substantial percentage of the EFL of the lens and preferably is in the range of

$$0.4\ F_o \geqq D_4 \geqq 0.20\ F_o$$

Additionally, to maintain the desired power contribution the combined EFL of Groups III and IV (F_{34}) is preferably

$$2.0\ F \geqq F_{34} \geqq 1.0\ F_o$$

As shown Group IV may be a single element or a doublet, either cemented or air spaced. It might also be defined in three elements. The front surface of Group III, L4, is convex. However, the rear surface may be other than convex depending on the design.

Groups V and VI are of positive power of a magnitude determined by the power of the other elements but in the preferred designs have an EFL (F_{56})

$$4.0 \geqq F_{56} \geqq 1.0$$

while the EFL (F_6) of Group VI is

$$2.0 > F_6 \geqq 1.0$$

Group III is of positive power to supplement the positive power of Group IV and preferably has an EFL (F_3) range

$$2.5 \geqq F_3 \geqq 1.2F_o$$

The ranges set forth above may be better appreciated in consideration with Table X which tabulates the ratio of the EFL of each group and combinations thereof to the overall EFL of the lens.

TABLE X

	RATIO OF EFL OF LENS GROUPS TO EFL OF LENS								
TABLE	GROUP I	GROUP II	GROUP III	GROUP IV	GROUP V	GROUP VI	GROUPS V & VI	GROUPS I - IV	GROUPS III & IV
I	−11.541	−2.740	1.472	3.299	−2.124	1.4139	3.610	1.502	1.261
II	−10.770	−2.514	1.598	3.492	−2.307	1.373	3.030	1.730	1.332
III	−9.415	−2.105	1.478	3.410	−2.276	1.394	3.251	1.688	1.249
IV	−2.602	−2.391	1.285	5.325	−3.647	1.492	2.413	2.414	1.249
V	−2.282	−2.656	2.088	3.132	−13.743	1.854	2.178	3.202	1.446
VI	−15.020	−2.345	1.414	4.604	−2.866	1.250	2.103	2.172	1.312
VII	−3.718	−2.472	1.279	3.342	−3.061	1.324	2.279	2.094	1.121
VIII	−2.799	−2.052	1.518	3.732	−13.175	1.381	1.574	4.829	1.313
IX	−2.429	−2.589	2.200	2.952	−6.933	1.662	2.179	3.190	1.459

The lenses disclosed may be focused on an object as close as 6.25 EFL's or less than seven inches in the case of the lens of Table IV. In the case of the lens of Table I, the lens is focused to 6.37 EFL or 7.02 inches with minimal astigmatism and field curvature, as exemplified in FIG. 4.

Table XI exemplifies the close focusing capability of the various lens disclosed.

TABLE XI

LENS		CLOSE FOCUS DISTANCE (FD)		$FD/_{EFL}$
TABLE	I	178mm	7.02 in.	6.20
	II	178	7.02	6.20
	III	178	7.02	6.20
	IV	175	6.91	6.14
	V	203	7.99	7.12
	VI	230	9.06	6.57
	VII	221	8.70	6.31
	VIII	258	10.20	7.37
	IX	203	7.99	7.12

It may thus be seen that the objects of the invention set forth above as well as those made apparent are efficiently attained. The invention provides a new wide-angle lens of the retrofocus type having a large relative aperture which will focus to an object distance of less than seven EFL's with minimal astigmatism and field curvature.

While preferred embodiments of the invention have been set forth for purposes of disclosure, other embodiments and modification to the disclosed embodiment of the invention may be derived by others skilled in the art. Accordingly, the appended claims are intended to cover all embodiments and applications of the invention and reversals thereof which do not depart from the spirit and scope of the invention.

What is claimed is:

1. A lens of the retrofocus type which comprises a plurality of lens elements arranged in six groups along a common optical axis from the object end to the image end as follows: a first group of negative power including positive and negative lens element, a second negative group in the form of a meniscus having a concave image side surface, a third positive group having a convex object side surface, a fourth positive group having a concave object side surface and convex image side surface, a fifth negative group consisting of a meniscus having a convex object side surface, and a sixth positive group consisting of a biconvex doublet.

2. The lens of claim 1 further defined by

$$6.5\ F_o \geqq F_4 \geqq 2.5F_o$$

where F_o is the equivalent focal length of the overall lens, and F_4 is the equivalent focal length of the fourth group.

3. The lens of claim 1 further defined by

$$1.5\ F_o \geqq F_{34} \geqq 1.0\ F_o$$

where F_{34} is the combined equivalent focal length of the third and fourth groups, and F_o is the equivalent focal length of the overall lens.

4. The lens of claim 1 further defined in that the first surface of said fourth group is concave and the distance D_4 between the first and last surface thereof is

$$0.45\ F_o \geqq D_4 \geqq 0.20\ F_o$$

where F_o is the equivalent focal length of the overall lens.

5. The lens of claim 1 further defined by

$$2.0\ F_o \geqq F_6 \geqq 1.0\ F_o$$

where F_o is the equivalent focal length of the overall lens and F_6 is the equivalent focal length of the sixth group.

6. The lens of claim 1 further defined by

$$2.5\ F_o \geqq F_3 \geqq 1.2\ F_o$$

where F_3 is the equivalent focal length of said third group, and F_o is the equivalent focal length of the overall lens.

7. The lens of claim 1 further defined by

$$5.5\ F_o \geqq F_4 \geqq 2.5\ F_o$$

where F_4 is the equivalent focal length of said fourth group and F_o is the equivalent focal length of the overall lens.

8. The lens of claim 1 defined by substantially the following data as scaled to an equivalent focal length of 28.7mm.

Lens		Radius	Axial Distance Between Surfaces	N_d	V_d
	R1	38.387mm			
L1			2.435mm	1.5168	64.2
	R2	18.755			
			8.5083		
	R3	−119.389			
L2			7.167	1.7995	42.3
	R4	−52.877			
			4.72–0.20		
	R5	18.178			
L3			2.180	1.5831	59.5
	R6	12.456			
			9.369		
	R7	49.0379			
L4			2.159	1.8306	36.5
	R8	−123.776			
			2.581		
	R9	−22.141			
L5			6.000	1.7470	27.5
	R10	−109.562			
L6			5.774	1.7620	40.3
	R11	−21.131			
			0.135		
	R12	55.725			
L7			2.454	1.8467	23.8
	R13	26.386			
			2.239		
	R14	76.751			
L8			6.000	1.8042	46.5
	R15	−22.374			
L9			1.500	1.8052	25.5
	R16	−54.363			

where L1–L9 are successive lens elements arranged in six groups, L1, L2; L3; L4; L5, L6, L7; and L8, L9; R1–R16 are the radii of curvature of the successive lens surfaces according to sequence of the surfaces in the overall lens, N_d and V_d are the indexes of refraction and Abbe Numbers, respectively, of the elements L1–L9.

9. The lens of claim 1 defined substantially by the following data as scaled to an equivalent focal length of 28.7mm.

Lens		Radius	Axial Distance Between Surfaces	N_d	V_d
	R1	38.570mm			
L1			2.435mm	1.5168	64.2
	R2	19.187			
			8.508		
	R3	−118.121			
L2			4.797	1.7995	42.3
	R4	−53.498			
			4.000–0.25		
	R5	18.556			
L3			2.180	1.5831	59.5
	R6	12.336			
			10.615		
	R7	50.120			
L4			2.159	1.8306	36.5
	R8	−160.5232			
			2.581		
	R9	−22.590			
L5			10.883	1.7600	47.5
	R10	−21.050			
			0.135		
	R11	51.8954			
L6			3.257	1.8467	23.8
	R12	26.298			
			2.239		
	R13	77.064			
L7			7.000	1.8042	46.5
	R14	−18.570			
L8			1.500	1.8052	25.5
	R15	−51.214			

where L1–L8 are successive lens elements arranged in six groups L1, L2; L3; L4; L5; L6; L7, L8; R1–R15 are the radii of curvature of the successive lens surfaces according to the sequence of the surfaces in the overall lens, N_d and V_d are the indexes of refraction and Abbe numbers, respectively, of the elements L1–L8.

10. The lens of claim 1 defined substantially by the following data as scaled to an equivalent focal length of 28.7mm.

Lens		Radius	Axial Distance Between Surfaces	N_d	V_d
	R1	39.897mm			
L1			2.435mm	1.520	65.6
	R2	19.832			
			8.500		
	R3	−111.180			
L2			5.835	1.802	47.5
	R4	−55.111			
			4.000–0.25		
	R5	17.557			
L3			2.180	1.807	44.3
	R6	12.193			
			10.789		
	R7	47.013			
L4			2.433	1.833	41.8
	R8	−138.976			
			3.390		
	R9	−23.286			
L5			9.700	1.837	51.9
	R10	−21.573			
			0.135		
	R11	51.904			
L6			3.324	1.848	23.4
	R12	26.009			
			2.682		
	R13	85.346			
L7			1.000	1.848	23.4
	R14	31.429			
L8			4.000	1.776	50.6
	R15	−43.746			

where L1–L8 are successive lens elements arranged in six groups, L1, L2; L3; L4; L5; L6; L7, L8; R1–R15 are the radii of curvature of the successive lens surfaces according to the sequence of the surfaces in the overall lens, N_d and V_d are the indexes of refraction and Abbe numbers, respectively, of the elements L1–L8.

11. The lens of claim 1 defined substantially by the following data as scaled to an equivalent focal length of 28.5mm.

Lens		Radius(mm)	Axial Distance Between Surfaces(mm)	N_d	V_d
	R1	155.101			
L1			4.160	1.562	58.52
	R2	−541.744			
			.300		
	R3	29.242			
L2			3.000	1.487	70.4
	R4	13.031			
			12.759		
	R5	22.898			
L3			2.000	1.800	42.3
	R6	15.520			
			8.692		
	R7	48.249			
L4			3.200	1.785	25.7
	R8	−70.561			
			1.967		
	R9	−24.204			
L5			2.164	1.805	25.5

-continued

Lens		Radius(mm)	Axial Distance Between Surfaces(mm)	N_d	V_d
	R10	−1430.264			
			.844		
	R11	−94.529			
L6			5.504	1.800	42.3
	R12	−19.767			
			3.550–1.028		
	R13	45.215			
L7			2.580	1.847	23.8
	R14	29.179			
			1.700		
	R15	70.687			
L8			8.00	1.743	49.2
	R16	−19.969			
L9			2.700	1.847	23.8
	R17	−44.577			

where L1–L9 are successive lens elements arranged in six groups, L1,L2; L3; L4; L5,L6; L7; L8,L9; R1–R17 are the radii of curvature of the successive lens surfaces according to sequence of the surfaces in the overall lens, N_d and V_d are the indexes of refraction and Abbe Numbers, respectively, of the elements L1–L9.

12. The lens of claim 1 defined substantially by the following data as scaled to an equivalent focal length of 28.6mm.

Lens		Radius(mm)	Axial Distance Between Surfaces(mm)	N_d	V_d
	R1	42.160			
L1			5.700	1.487	70.4
	R2	384.104			
			.300		
	R3	35.935			
L2			2.800	1.487	70.4
	R4	11.488			
			4.032		
	R5	26.721			
L3			2.000	1,517	64.2
	R6	15.510			
			14.343		
	R7	39.692			
L4			3.200	1.689	31.2
	R8	925.392			
			2.973		
	R9	−76.847			
L5			2.164	1.847	23.8
	R10	97.091			
			1.750		
	R11	−75.162			
L6			4.549	1.800	42.3
	R12	−21.352			
			4.098–.100		
	R13	37.634			
L7			2.700	1.722	29.2
	R14	32.248			
			2.000		
	R15	70.613			
L8			8.400	1.641	59.8
	R16	−18.940			
L9			2.700	1.805	25.5
	R17	−42.358			

where L1–L9 are successive lens elements arranged in six groups, L1,L2; L3; L4; L5,L6; L7; L8,L9; R1–R17 are the radii of curvature of the successive lens surfaces according to sequence of the surfaces in the overall lens, N_d and V_d are the indexes of refraction and Abbe Numbers, respectively, of the elements L1–L9.

13. The lens of claim 1 defined substantially by the following data as scaled to an equivalent focal length of 35.0mm.

Lens		Radius(mm)	Axial Distance Between Surfaces(mm)	N_d	V_d
	R1	31.195			

-continued

Lens		Radius(mm)	Axial Distance Between Surfaces(mm)	N_d	V_d
L1			2.998	1.517	64.2
	R2	20.569			
			7.074		
	R3	−96.642			
L2			2.829	1.785	25.7
	R4	−58.277			
			0.726		
	R5	18.356			
L3			4.321	1.723	38.0
	R6	12.649			
			11.925		
	R7	53.996			
L4			2.800	1.831	36.5
	R8	−172.838			
			3.000		
	R9	−22.950			
L5			2.695	1.741	27.8
	R10	−276.177			
			0.720		
	R11	−76.849			
L6			6.081	1.757	47.7
	R12	−19.800			
			2.000–0.20		
	R13	51.599			
L7			3.000	1.847	23.8
	R14	31.353			
			2.332		
	R15	82.914			
L8			7.000	1.800	42.3
	R16	−25.647			
L9			3.000		
	R17	−57.034		1.805	25.5

where L1–L9 are successive lens elements arranged in six groups, L1,L2; L3; L4; L5,L6; L7; L8,L9; R1–R17 are the radii of curvature of the successive lens surfaces according to sequence of the surfaces in the overall lens, N_d and V_d are the indexes of refraction and Abbe Numbers, respectively, of the elements L1–L9.

14. The lens of claim 1 defined substantially by the following data as scaled to an equivalent focal length of 35.0mm.

Lens		Radius	Axial Distance Between Surfaces	N_d	V_d
	R1	598.84mm			
L1			4.160mm	1.750	35.0
	R2	−175.71			
			.300		
	R3	22.57			
L2			2.985	1.487	70.4
	R4	13.99			
			9.079		
	R5	23.40			
L3			5.005	1.700	47.8
	R6	15.49			
			8.869		
	R7	58.80			
L4			3.200	1.831	36.5
	R8	−100.28			
			2.385		
	R9	−24.54			
L5			2.358	1.741	27.8
	R10	−845.99			
			.680		
	R11	−102.81			
L6			6.778	1.757	47.7
	R12	−19.97			
			0.91–3.66		
	R13	58.83			
L7			3.000	1.847	23.8
	R14	32.65			
			1.700		
	R15	65.28			
L8			7.300	1.800	42.3
	R16	−27.00			
L9			0	1.805	25.5
	R17	−79.24			

where L1–L9 are successive lens elements arranged in six groups, L1,L2; L3; L4; L5,L6; L7; L8,L 9;

R1–R17 are the radii of curvature of the successive lens surfaces according to sequence of the surfaces in the overall lens, N_d and V_d are the indexes of refraction and Abbe Numbers, respectively, of the elements L1–L9.

15. The lens of claim 1 defined substantially by the following data as scaled to an equivalent focal length of 35.0mm.

Lens		Radius(mm)	Axial Distance Between Surfaces(mm)	N_d	V_d
	R_1	30.600			
L1			7.000	1.487	70.4
	R2	170.290			
			.300		
	R3	34.231			
L2			2.985	1.487	70.4
	R4	11.567			
			6.000		
	R5	67.235			
L3			2.000	1.569	56.0
	R6	25.201			
			6.171		
	R7	46.077			
L4			3.200	1.806	40.7
	R8	−644.608			
			7.931		
	R9	−34.424			
L5			2.358	1.762	26.6
	R10	−829.911			
			1.350		
	R11	−47.763			
L6			4.832		
	R12	−19.289		1.757	47.7
			4.70–.10		
	R13	41.514			
L7			3.000	1.667	33.1
	R14	35.544			
			1.900		
	R15	64.725			
L8			8.000	1.717	48.0
	R16	−22.414			
L9			2.700	1.805	25.5
	R17	−56.648			

where L1–L9 are successive lens elements arranged in six groups, L1,L2; L3; L4; L5, L6; L7; L8,L9; R1–R17 are the radii of curvature of the successive lens surfaces according to sequence of the surfaces in the overall lens, N_d and V_d are the indexes of refraction and Abbe Numbers, respectively, of the elements L1–L9.

16. The lens of claim 1 defined substantially by the following data as scaled to an equivalent focal length of 28.5mm.

Lens		Radius(mm)	Axial Distance Between Surfaces(mm)	N_d	V_d
	R1	54.600			
L1			5.700	1.487	70.4
	R2	937.48			
			.300		
	R3	28.640			
L2			2.800	1.487	70.4
	R4	11.392			
			4.474		
	R5	28.640			
L3			2.000	1.517	64.2
	R6	15.990			
			13.502		
	R7	41.450			
L4			3.200	1.689	31.2
	R8	840.70			
			3.342		
	R9	−70.750			
L5			2.164	1.805	25.5
	R10	106.030			
			1.900		
	R11	−71.649			
L6			4.549	1.804	46.5
	R12	−21.220			
			4.098–.10		
	R13	48.140			
L7			2.700	1.741	27.8

-continued

Lens		Radius(mm)	Axial Distance Between Surfaces(mm)	N_d	V_d
	R14	35.430			
			1.212		
	R15	53.960			
L8			9.159	1.639	55.5
	R16	−20.430			
L9			2.700	1.805	25.5
	R17	−44.190			

where L1–L9 are successive lens elements arranged in six groups, L1,L2; L3; L4; L5,L6; L7; L8,L9; R1–R17 are the radii of curvature of the successive lens surfaces according to sequence of the surfaces in the overall lens, N_d and V_d are the indexes of refraction and Abbe Numbers, respectively, of the elements L1–L9.

17. the lens of claim 1 further defined by

$$1.5\ F_o \geqq F_{34} \geqq 1.0\ F_o$$

where F_{34} is the combined equivalent focal length of the third and fourth groups, and F_o is the equivalent focal length of the overall lens.

18. The lens of claim 2 further defined in that the axial distance D_4 between the first and last surface of said fourth group is

$$0.45\ F_o \geqq D_4 \geqq 0.20\ F_o$$

where F_o is the equivalent focal length of the overall lens.

19. The lens of claim 2 further defined by

$$2.5\ F_o \geqq F_3 \geqq 1.2\ F_o$$

where F_3 is the equivalent focal length of said third group, and F_o is the equivalent focal length of the overall lens.

20. The lens of claim 2 further defined by

$$2.0\ F_o \geqq F_6 \geqq 1.0\ F_o$$

where F_o is the equivalent focal length of the overall lens and F_6 is the equivalent focal length of the sixth group.

21. The lens of claim 1 further defined by

$$6.5\ F_o \geqq F_4 \geqq 2.5\ F_o \text{ and}$$

$$1.5\ F_o \geqq F_{34} \geqq 1.0\ F_o$$

where F_4 is the equivalent focal length of said fourth group, F_{34} is the combined equivalent focal length of said third and fourth groups and F_o is the equivalent focal length of the overall lens.

22. A retrofocus lens consisting of nine elements and from the object side comprising a first two element group including a positive and a negative lens element of overall negative power, a third element in the form of a negative meniscus having a convex object side surface, a fourth positive element having a convex object side surface, fifth and sixth elements, said fifth element having a concave object side surface and said sixth element having a convex image side surface, said fifth and sixth elements being of overall positive power, a seventh element in the form of a negative meniscus having a convex object side surface, and eighth and

ninth elements cemented together and being overall bi-convex.

23. The lens of claim 22 further defined by

$$1.5\ F_o \geqq F_{34} \geqq 1.0\ F_o$$

where F_{34} is the combined equivalent focal length of the third and fourth groups, and F_o is the equivalent focal length of the overall lens.

24. The lens of claim 22 further defined in that the axial distance D_4 between the first and last surface of said fourth group is

$$0.45\ F_o \geqq D_4 \geqq 0.20\ F_o$$

where F_o is the equivalent focal length of the overall lens.

25. The lens of claim 22 further defined by

$$2.5\ F_o \geqq F_3 \geqq 1.2\ F_o$$

where F_3 is the equivalent focal length of said third group, and F_o is the equivalent focal length of the overall lens.

26. The lens of claim 22 further defined by

$$2.0\ F_o \geqq F_6 \geqq 1.0\ F_o$$

where F_o is the equivalent focal length of the overall lens and F_6 is the equivalent focal length of the sixth group.

27. A retrofocus lens consisting of eight elements and from the object side comprising a first two element group including a positive and negative lens element of overall negative power, a third element in the form of a negative meniscus having a convex object side surface, a fourth positive element having a convex object side surface, a fifth positive element having a concave object side surface and a convex image side surface, a sixth element in the form of a negative meniscus having a convex object side surface, and seventh and eighth elements cemented together and being overall bi-convex.

28. A lens of the retrofocus type which comprises from the object end a first group of a positive and a negative element of overall negative power, a second group of negative power in the form of a meniscus having a concave image side, a third group of positive power having a convex object side surface, a fourth positive group comprising two elements and having a concave object side and a convex image side, a fifth group and a sixth group, said fifth group consisting of a negative meniscus having a convex object side surface, said sixth group consisting of a biconvex doublet.

29. The lens of claim 28 further defined by

$$1.5\ F_o \geqq F_{34} \geqq 1.0\ F_o$$

where F_{34} is the combined equivalent focal length of the third and fourth groups, and F_o is the equivalent focal length of the overall lens.

30. The lens of claim 28 further defined in that the axial distance D_4 between the first and last surface of said fourth group is

$$0.45\ F_o \geqq D_4 \geqq 0.20\ F_o$$

where F_o is the equivalent focal length of the overall lens.

31. The lens of claim 28 further defined by

$$2.5\ F_o \geqq F_3 \geqq 1.2\ F_o$$

where F_3 is the equivalent focal length of said third group, and F_o is the equivalent focal length of the overall lens.

32. The lens of claim 28 further defined by

$$2.0\ F_o \geqq F_6 \geqq 1.0\ F_o$$

where F_o is the equivalent focal length of the overall lens and F_6 is the equivalent focal length of the sixth group.

33. The lens of claim 28 further defined by

$$1.5\ F_o \geqq F_{34} \geqq 1.0\ F_o$$

$$0.45\ F_o \geqq D_4 \geqq 0.20\ F_o$$

$$2.5\ F_o \geqq F_3 \geqq 1.2\ F_o$$

$$2.0\ F_o \geqq F_6 \geqq 1.0\ F_o$$

where

F_o is the equivalent focal length of the overall lens,

F_{34} is the combined equivalent focal length of the third and fourth groups,

D_4 is the axial distance between the front and rear surfaces of the fourth group,

F_3 is the equivalent focal length of the third group, and

F_6 is the equivalent focal length of the sixth group.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 4,099,849

DATED : July 11, 1978

INVENTOR(S) : John A. Lawson et al

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 4, line 58, after "July 29, 1974" insert --, now U. S. Patent 3,975,090--.

Column 7, line 15, delete "221.3".

Column 7, Table IX, under the heading "Axial Distance Between Surfaces (mm)" delete "28.640" and insert "28.640" under the heading "Radius (mm)", same line.

Column 10, line 5, before "positive" insert --a--.

Column 13, claim 12, under "N_d" "1,517" should read --1.517--.

Column 14, claim 14, under "Radius", "598.84mm" should read --1598.84mm--.

Column 16, line 1 of claim 17, "claim 1" should read --claim 2--.

Column 17, line 3 of claim 27, before "negative" insert --a--.

Signed and Sealed this

Sixth Day of *February 1979*

[SEAL]

Attest:

RUTH C. MASON
Attesting Officer

DONALD W. BANNER
Commissioner of Patents and Trademarks

United States Patent [19]

Rehn

[11] **4,095,247**

[45] **June 13, 1978**

[54] **INTERCHANGEABLE OBJECTIVE FOR CAMERAS**

[75] Inventor: **Heinz Rehn**, Braunschweig, Germany

[73] Assignee: **Rollei-Werke Franke & Heidecke**, Braunschweig, Germany

[21] Appl. No.: **746,224**

[22] Filed: **Nov. 30, 1976**

[30] **Foreign Application Priority Data**

Dec. 17, 1975 Germany 2556771

[51] **Int. Cl.**[2] **G03B 7/20**; G03B 9/02; G03B 17/00

[52] **U.S. Cl.** **354/286**; 354/46; 354/272

[58] **Field of Search** 354/286, 196, 46, 270, 354/272

[56] **References Cited**

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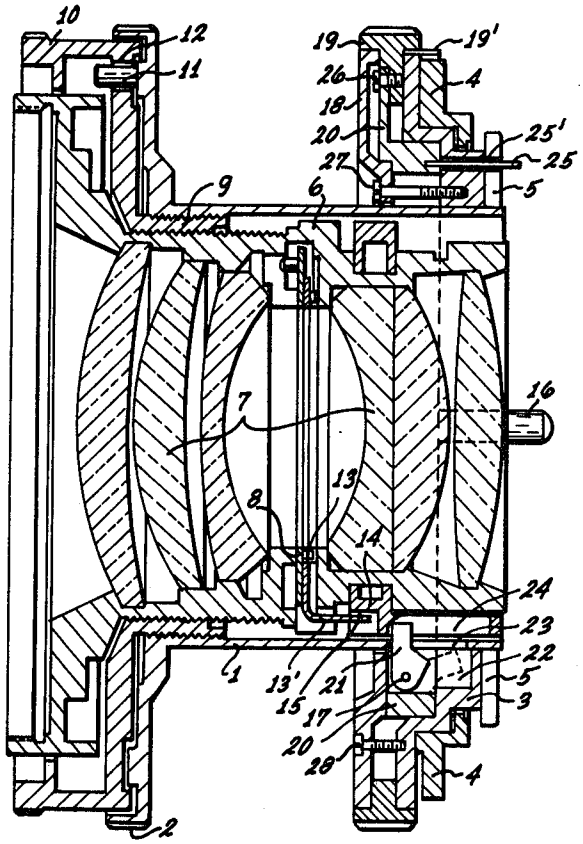
Primary Examiner—Donald A. Griffin
Attorney, Agent, or Firm—Ralf H. Siegemund

[57] **ABSTRACT**

An interchangeable objective for a camera to provide diaphragm control. The objective has an objective tube and a lens mounting axially movable in the tube. A bayonet ring is provided for connecting the objective tube to a camera. Further means are provided for axially moving said objective tube within the bayonet ring to bring said tube into and out of the camera housing and for engaging said tube into the bayonet ring in the position ready for exposure. A diaphragm adjustment ring is rotatably mounted on the bayonet ring, and a diaphragm control ring rotatably disposed on the lens mounting transmits the adjustment of the adjustment ring upon the diaphragm. A coupling element on the adjustment ring is disengageable from and capable of being engaged into the diaphragm control ring.

4 Claims, 3 Drawing Figures



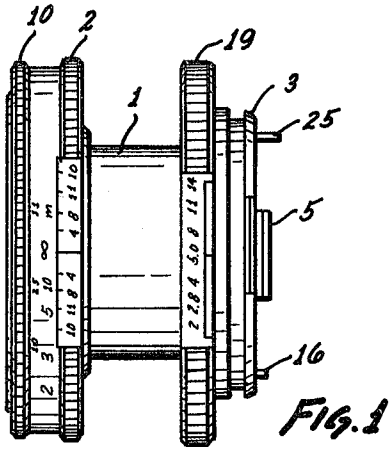


Fig. 1

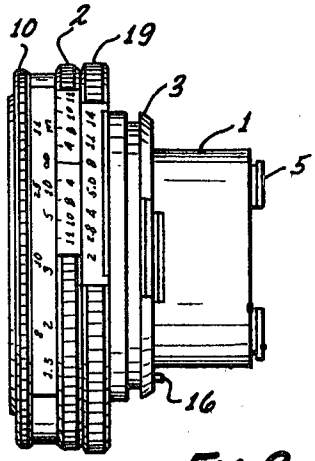


Fig. 2

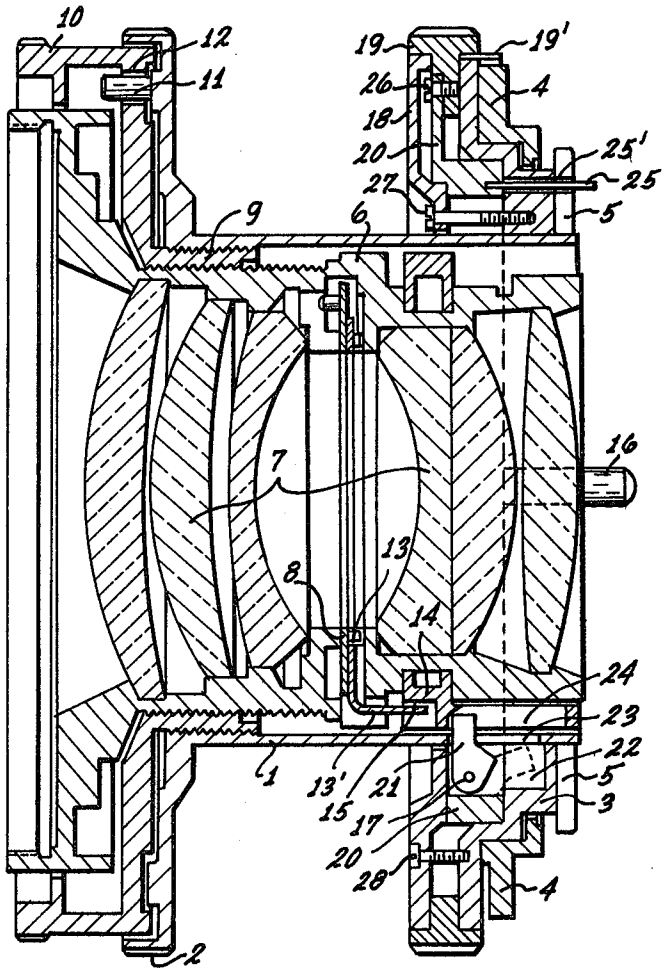


Fig. 3

INTERCHANGEABLE OBJECTIVE FOR CAMERAS

BACKGROUND OF THE INVENTION

The present invention relates to interchangeable objectives for cameras of the type having an objective tube and a lens mounting axially displaceable thereon so that the diaphragm may be adjusted after the objective has been inserted.

Objectives for cameras of the type referred to above are known. These known objectives are focussed by axial displacement of the lens in the objective tube. A knurled ring is arranged at the objective tube for turning, and a worm gear translates the turning motion into an axial displacement of the lens mounting in the objective tube. The objective may be focussed and the diaphragm may be adjusted, e.g. by means of a diaphragm adjustment ring, even when the objective has been removed from the camera. Also, the objective tube carrying the lens with the diaphragm, the knurled ring and the diaphragm adjustment ring may be moved at will within the bayonet ring of the objective regardless of whether the objective is mounted at the camera bayonet mounting or not.

Cameras are known having an exposure metering or exposure control system which require coupling with the objective diaphragm. In this case, it is conventional practice to provide the diaphragm adjustment ring with a plunger extending from the objective in direction to the camera or with a pin which can be swivelled. Such a plunger or pin engage a coupling element in the camera to couple the diaphragm with the exposure metering or control system when the objective is introduced and locked to the camera. The coupling must be coordinated with the introduction or removal of the objective that the coupling elements and plungers or pins clearly cooperate in a form-locking and positive-drive position.

SUMMARY OF THE INVENTION

It is accordingly an object of the present invention to provide a reliable connection or coupling of an interchangeable objective to a camera.

It is another object of the present invention to improve interchangeable objectives having a tube for holding the objective proper, a diaphragm and a bayonet connection.

It is a particular object of the present invention to improve the construction of interchangeable objectives not only having a lens which moves axially for focusing - inclusively its diaphragm - but being also displaceable with its objective tube over a larger distance without requiring long and complicated transmission devices or rods.

In accordance with the present invention, a diaphragm adjustment ring is rotatably mounted on the bayonet ring of the objective. The adjustment ring carries a coupling element which may be disengaged from or engaged with a diaphragm control ring being rotatably mounted on a lens mounting of the objective. The diaphragm control ring adjusts the diaphragm. Hence, the diaphragm adjustment ring is spatially fixedly mounted with respect to the objective bayonet ring. Therefore, the known simple coupling with the coupling portions of the camera for transmitting or controlling the diaphragm may be retained.

Preferably, the coupling element is comprised of a lever that turns about a tangential axis at the diaphragm adjustment ring. The lever may be selectively turned into the path of an axial projection of the diaphragm control ring or be moved into a cutout of the objective bayonet ring.

Further in accordance with the invention, an opening may be provided at the objective tube for this lever which is so limited in its axial direction that it permits passage of the lever only in the exposure position of the objective tube. When the objective tube is introduced it displaces the lever outwardly and hence locks the diaphragm adjustment ring at the objective bayonet ring. Accordingly, the diaphragm adjustment ring will function for adjustment of the diaphragm only when the tube has been pulled out. Vice versa, removal of the objective from the camera is possible only when the objective tube has been pushed in. Furthermore, the diaphragm adjustment ring has a double function in that it serves on the one hand as diaphragm adjustment ring proper, and on the other hand as actuating ring or handle for connecting the objective to the camera or removing it therefrom.

According to a further extension of the invention, the cutout of the objective bayonet ring is correlated to a predetermined position of the diaphragm adjustment ring, preferably corresponding to the largest opening of the objective diaphragm in such a manner that the lever may drop into the cutout only in this position. Thus, the diaphragm adjustment ring and diaphragm control ring may disengage only then, and the coupling of diaphragm adjustment ring with the bayonet ring and the introduction of the objective tube into the camera housing is likewise possible only in this position.

DESCRIPTION OF THE DRAWINGS

While the specification concludes with claims particularly pointing out and distinctly claiming the subject matter which is regarded as the invention, it is believed that the invention, the objects and features of the invention and further objects, features and advantages thereof will be better understood from the following description taken in connection with the accompanying drawings, in which:

FIG. **1** is a side elevational view of the interchangeable objective of the invention, the objective tube being pulled out;

FIG. **2** is a side elevational view corresponding to that of FIG. **1** with the objective tube pushed in; and

FIG. **3** is a longitudinal section of the entire objective and a camera bayonet mounting corresponding to the position of FIG. **1**.

Referring now to the drawings, there is illustrated an objective tube **1** having a frontal flange with a knurled ring **2** which serves as a handle. Tube **1** is axially slidably mounted in an objective bayonet ring **3**. The objective bayonet ring **3** can be inserted into bayonet mounting **4** shown in FIG. **3**, mounting **4** pertaining to the camera housing. The tube **1** carries also a bayonet ring **5** which faces the camera and serves as an axial stop. When the tube is in the pulled out position and ready for exposure, bayonet ring **5** can be inserted and locked into the objective bayonet ring **3**. The objective tube **1** is locked in the position ready for exposure as shown in FIG. **3**.

A lens mounting **6** with a lens system **7** and a diaphragm of iris **8** is provided in tube **1**. A worm gear that is disposed in a sleeve **9** having inner and outer threads guides the lens mount. The adjustment knurled ring **10** of the sleeve **9** is turned to move the lens **7** in an axial

direction for purposes of focussing. Turning of ring **10** or of the sleeve **9** is limited to an adjustment range by a pin **11** mounted on the knurled ring **2** of the tube **1** and by an arcuate slot **12** of the adjustment knurled ring **10**.

The diaphragm **8** is arranged within the lens system in a known manner. The blade or lamella drive ring **13** is adjusted by a follower lever **13'** being connected thereto. Lever **13'** is controlled by a diaphragm control ring **14** by means of its radial cam track **15**. The diaphragm control ring **14** is rotatably mounted on the lens mounting **6**. A diaphragm adjustment ring **20** is, in turn, rotatably mounted between the objective bayonet ring **3** and a bayonet ring housing **18**, the latter being connected with the objective bayonet ring **3** by screws **27** and **28**.

Ring **20** is connected to knurled ring **19** by a screw **26**. This knurled ring **19** will be gripped by the user for manipulating ring **20**. Ring **19** covers partially the diaphragm scale **19'** disposed at the upper portion of the objective bayonet ring **3**. A lever **21** is mounted at the diaphragm adjustment ring **20** for turning about a tangential axis **17**. The objective bayonet ring **3** is provided with an axial cutout **22** into which the lever **21** may be pushed as shown in dotted lines at **21'**. This requires, of course, that lever **21** and cutout **22** are in alignment with each other. On the other hand, an opening **23** is provided in the tube **1** and is traversed by the lever **21**, whereby the lever **21** projects into the interior of the tube. Insertion of lever **21** into cutout **22** occurs when tube **1** is pushed into the camera. As lever **21** is inserted in cutout **22**, the diaphragm adjustment ring **20**, or respectively the knurled ring **19**, is locked to the objective bayonet ring **3**. This opening **23** extends over that portion of the circumference of the tube which corresponds to the region of adjustment of the diaphragm. The axial length of the opening **23** is selected, at least in one place, so that lever **21** can only pass through this opening when the tube has been pulled out or extended.

The cutout **22** of the objective bayonet ring **3** and the position of the tube opening **23** having the greates axial length for the insertion of the lever **21**, are arranged so that they permit the introduction of the lever only for one very particular position of the diaphragm adjustment ring corresponding to a particular predetermined position of the diaphragm; this corresponds preferably to the largest adjustable diaphragm opening.

The diaphragm control ring **14** carries an axial extension **24** which, for example, is constructed to have the configuration of a fork into which the lever **21** may move through the opening **23** of the tube **1** due to the action of a spring not illustrated. The diaphragm adjustment ring **20** and the diaphragm control ring **14** are coupled in this manner. The axial length of the extension **24** depends upon the greatest axial movement of the lens mounting **6** during focussing.

Since the extension **24** is constructed as a fork, lever **21** provides a rigid coupling between the diaphragm **8** and the diaphragm adjustment ring **20** or its knurled ring **19**. By means of a tappet **25** which extends rearwardly from the diaphragm adjustment ring **20** through the arcuate slot **25'**, a rigid connection is provided to the exposure and diaphragm control at the camera in the conventional manner.

For cameras having a measurement with open diaphragm and wherein the diaphragm is closed only and moved to the correct aperture value when the shutter is released, the extension **24** is preferably not arranged as a fork but should be provided as a simple stop. As the shutter is released in this case the diaphragm **8** is closed in the known manner by means of a diaphragm plunger **16** and against the action of a spring or under the action of a spring; that is the diaphragm control ring **14** is turned until closure movement of the diaphragm is stopped by the stop **24** intercepting lever **21**. In this known camera the diaphragm is again fully opened after exposure, independently of the diaphragm value previously adjusted on the scale **19'**. In this case, the most favorable solution for the position of the cutout **22** for the lever **21** for the adjustment of the diaphragm adjustment ring **19** corresponds to the largest opening of the diaphragm at scale **19'**.

The position of the objective as illustrated in FIG. 3 shows the objective attached to the camera and ready for exposure; focussing is accomplished by turning the knurled ring **10**, while the diaphragm is adjusted by turning the ring **19**. After adjustment of the diaphragm to the above mentioned, predetermined aperture value, the tube **1** may be disengaged by means of the handle **2** at the bayonet ring **3** and may be pushed into the camera housing. While the tube is pushed in, the lever **21** is displaced into the cutout **22** of the bayonet ring **3**. Thus, the diaphragm adjustment ring **20** is now locked to the objective bayonet ring **3** so that the objective can be disengaged by means of the knurled handle **19** from the camera bayonet ring **4** and removed from the camera.

In the opposite case, when the objective has been removed from the camera or the tube had been pushed in the camera housing, adjustment of the diaphragm is not possible. The diaphragm **8** or the diaphragm blade drive **13** is disengaged from the diaphragm adjustment ring when the objective tube is pushed in. However, the diaphragm retains this position without the necessity of an additional locking device because an adjustment of the diaphragm is not possible without engaging the interior of the objective. The only possibility is to manually operate the plunger **16**. This, however, will not result in any damage because the plunger is returned to its rest position by the action of a spring.

The invention is not limited to the embodiments described above but all changes and modifications thereof not constituting departures from the spirit and scope of the invention are intended to be included.

I claim:

1. Interchangeable objective for a camera to provide diaphragm control, said objective comprising:

(a) an objective tube; a lens mounting being disposed in and axially movable in said objective tube;

(b) a lens or lens system and a diaphragm mounted in said lens mounting;

(c) a bayonet ring for connecting said objective tube to the camera, said objective tube being axially movably disposed in the bayonet ring for purposes of inserting the tube into the camera and pulling the tube out of the camera;

(d) releasable means for engaging said objective tube with the bayonet ring in a position ready for exposure after the tube has been pulled out of the camera and for disengaging the tube from the ring for pushing the tube into the ring and the camera;

(e) a diaphragm adjustment ring being rotatably mounted on said bayonet ring;

(f) a diaphragm control ring for transmitting the adjustment of said adjustment ring upon the diaphragm, said control ring being rotatably disposed on said lens mounting; and

(g) a coupling element being movably disposed on said diaphragm adjustment ring and capable of being engaged with and disengaged from the diaphragm control ring, respectively, when the objective tube has a pulled out and an inserted position.

2. Objective as defined in claim **1**, wherein said coupling element includes a lever for turning about a tangential axis on said diaphragm adjustment ring, a cutout on said bayonet ring, an axial projection on said diaphragm control ring, said lever being capable for selective turning into the path of said axial projection of said control ring and into said cutout of said bayonet ring.

3. Objective as defined in claim **2** wherein an opening is provided in said objective tube for the passage of said lever, said opening being limited in an axial direction in such a manner that the passage of said lever is only permitted when said objective tube is in a position ready for taking exposures, and said opening displacing said lever during the insertion of said objective tube into the camera outwardly into said cutout of said bayonet ring.

4. Objective as defined in claim **2** wherein said cutout of said bayonet ring is coordinated with a predetermined position of said diaphragm adjustment ring so that it permits the passage of said lever and therefore the insertion of said objective tube into the camera only in said predetermined position.

* * * * *

United Stat

Besenmatter et a

1] **4,087,160**

·5] **May 2, 1978**

[54] **CAMERA OBJECTIVE OF VARIABLE FOCAL LENGTH**

[75] Inventors: **Walter Besenmatter; Trude Muszumanski,** both of Vienna; **Irmgard Wendisch,** Trumau, all of Austria

[73] Assignees: **Karl Vockenhuber; Raimund Hauser,** both of Vienna, Austria

[21] Appl. No.: **747,207**

[22] Filed: **Dec. 3, 1976**

[30] **Foreign Application Priority Data**

Dec. 5, 1975 Austria 9297/75

[51] **Int. Cl.**[2] **G02B 15/18**

[52] **U.S. Cl.** **350/184;** 350/207

[58] **Field of Search** 350/184, 207

[56] **References Cited**

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3,918,798	11/1975	Takano	350/207

Primary Examiner—Conrad J. Clark
Attorney, Agent, or Firm—Montague & Ross

[57] **ABSTRACT**

A varifocal forward lens group of a camera objective, with a pair of axially shiftable negative components bracketed by a pair of substantially fixed positive components, has its negative third component more widely separated from its positive fourth component in a wide-angle position of minimum overall focal length than in a telephoto position of maximum overall focal length. The effective diameter of that third component is just large enough to let a bundle of axially incident light rays fully illuminate the fourth component in the wide-angle position, with less than full illumination in the telephoto position. The positive first component is also just large enough to provide full illumination of the effective area of the third component by axial rays in the telephoto position.

8 Claims, 9 Drawing Figures

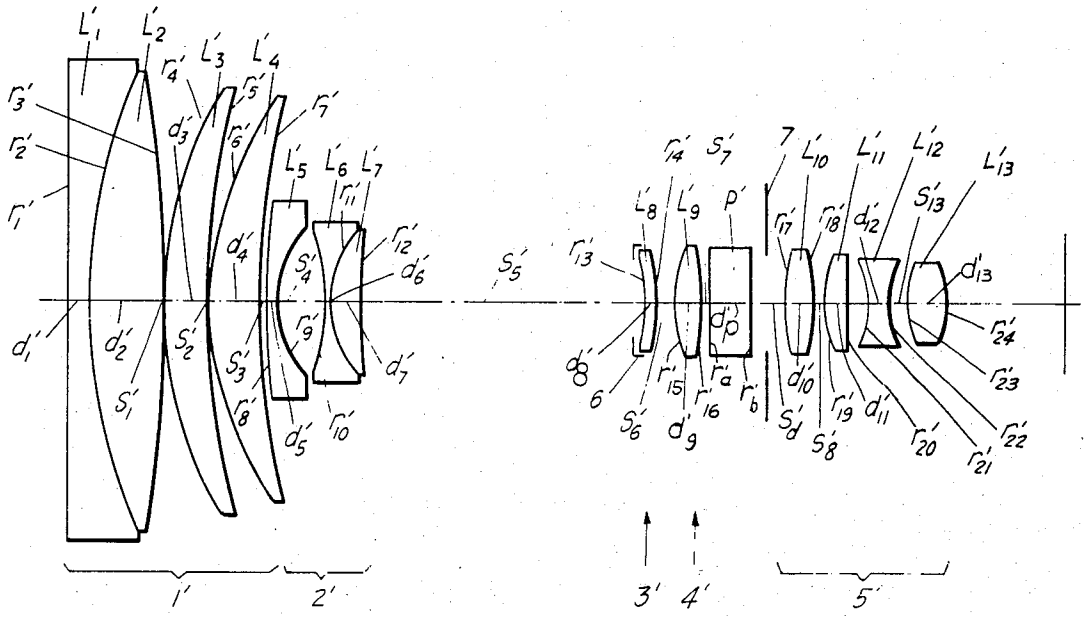
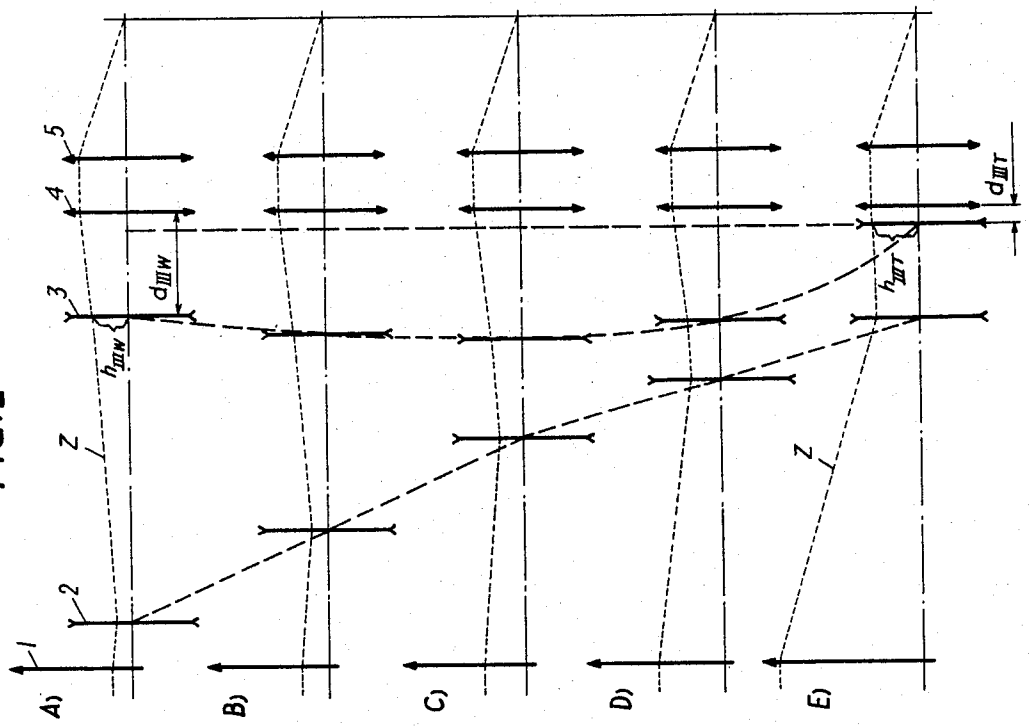


FIG. 2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B)
C)
D)
E)
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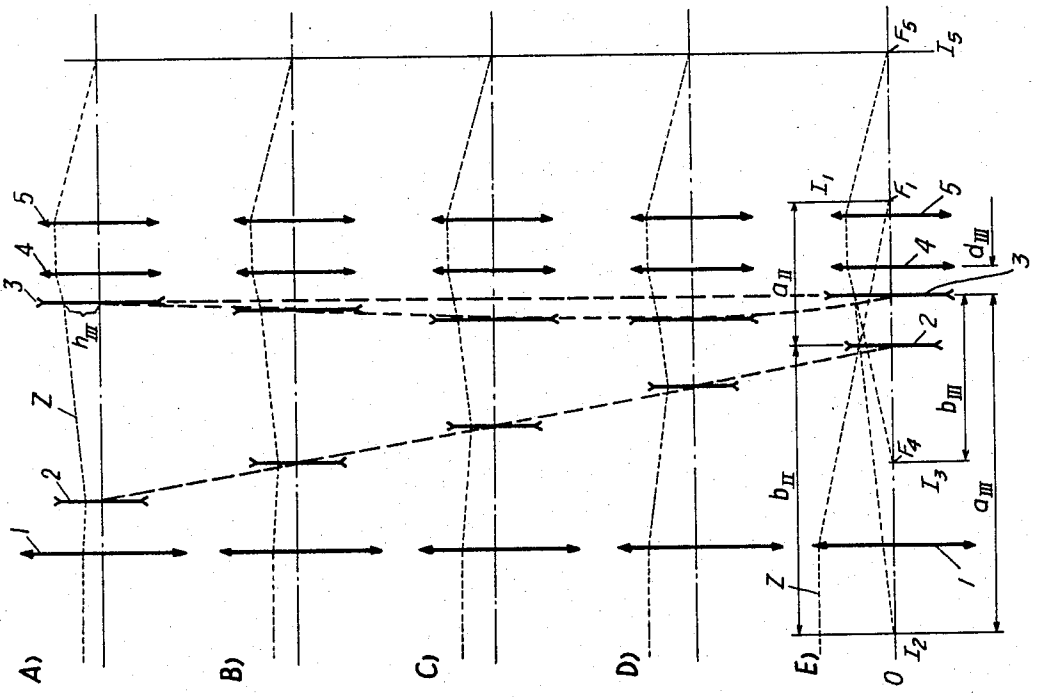
3
4
5
$h_{III w}$
$d_{III w}$
$h_{III r}$
$d_{III r}$

FIG. 1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I_2
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F_4
F_5
0

FIG.3

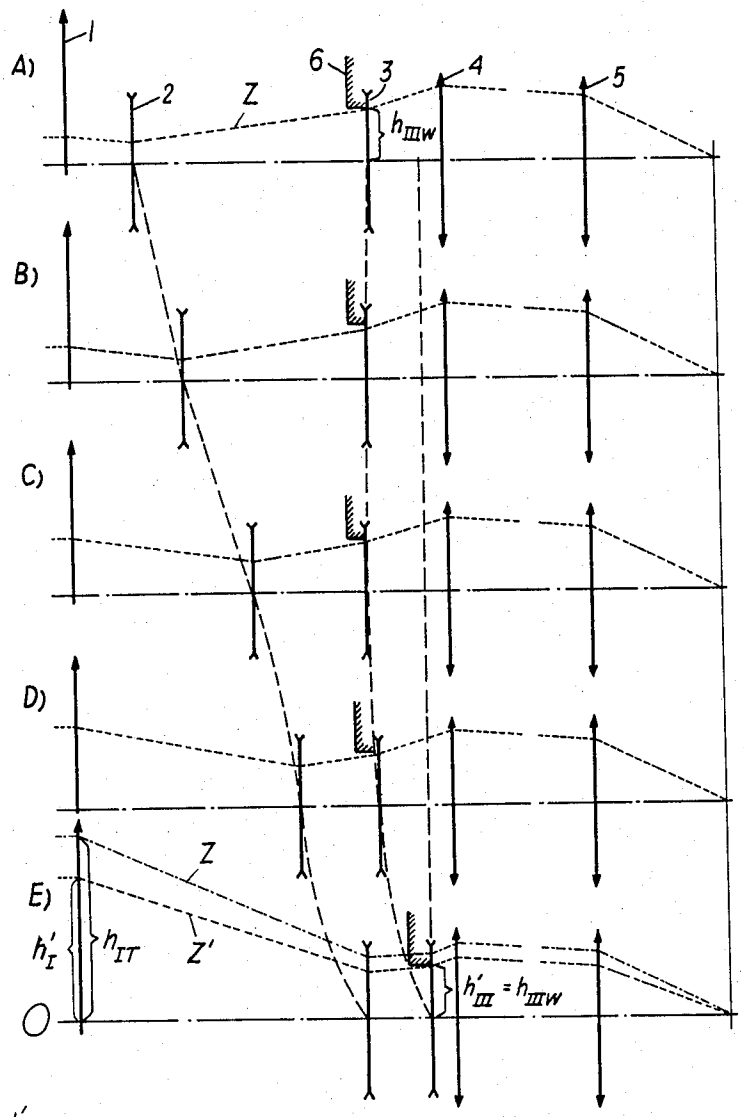


FIG.5

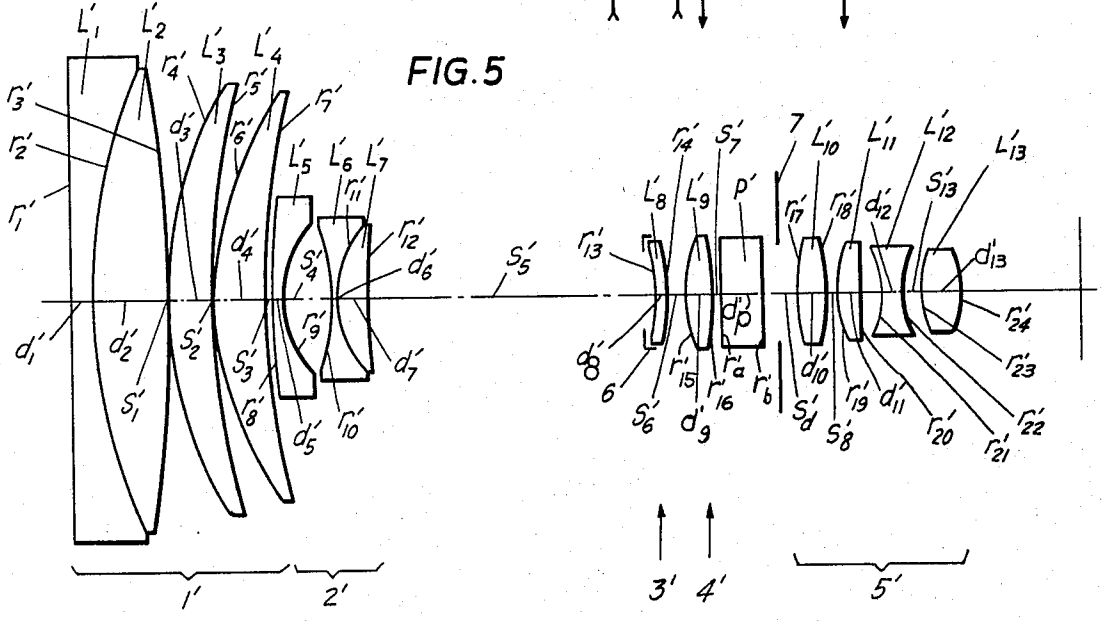


FIG.4A

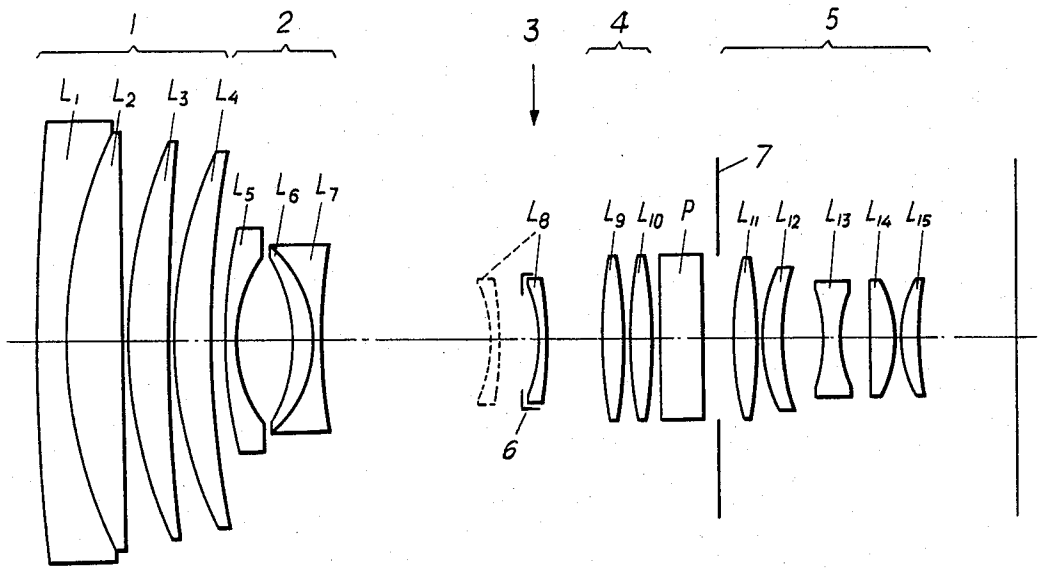


FIG.4B

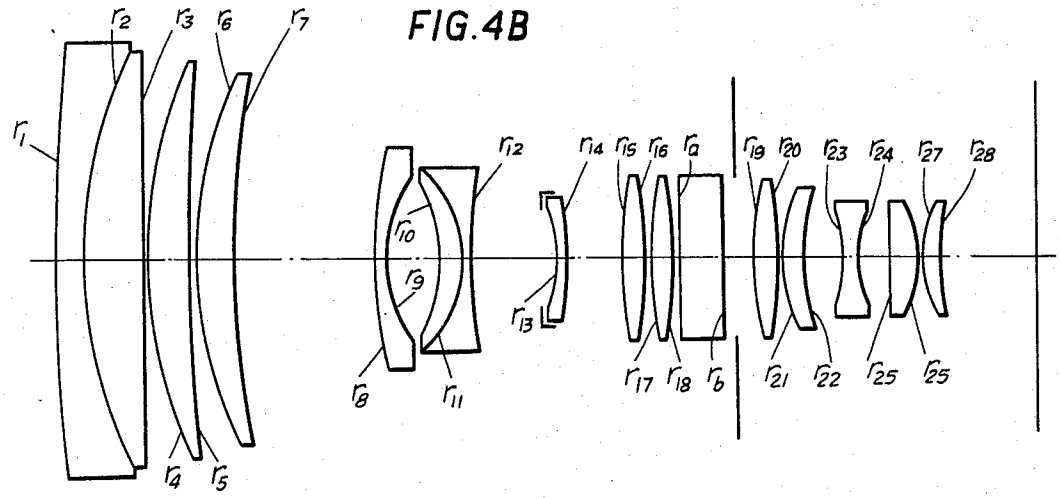
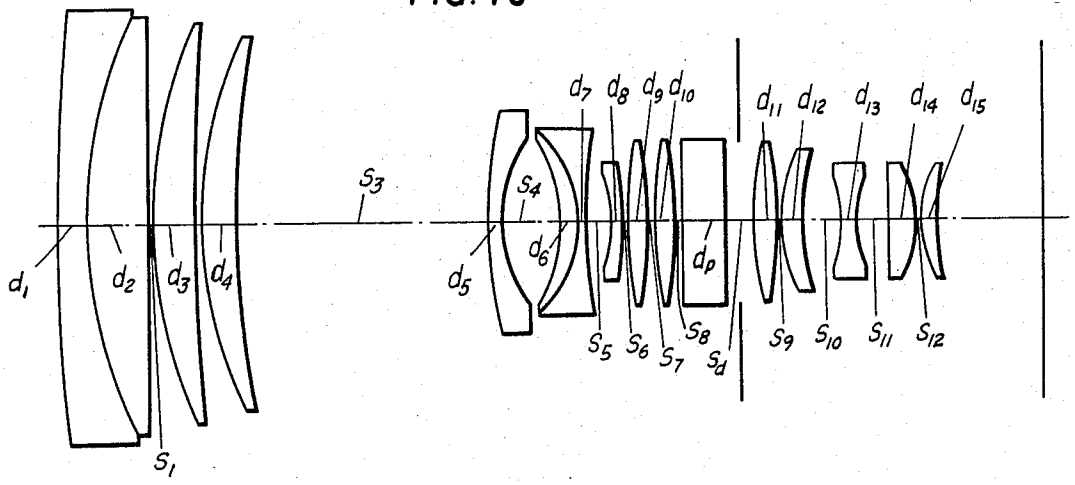
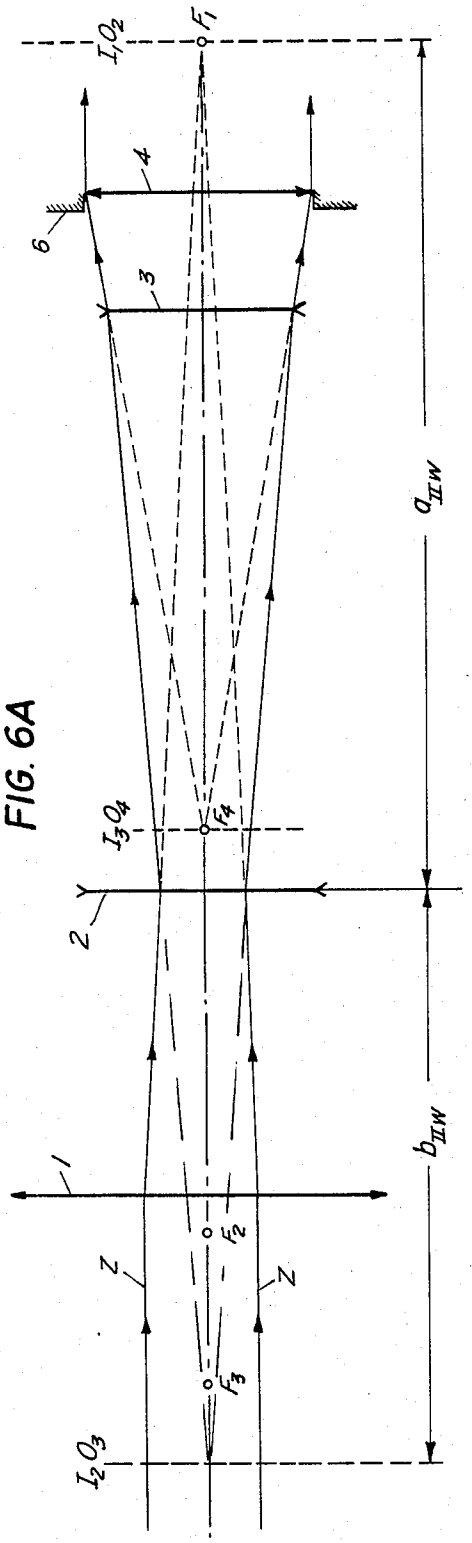


FIG.4C

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F_1
4
6
3
a_{IIW}
I_3O_4
F_4
2
b_{IIW}
1
F_2
Z
Z
F_3
I_2O_3

FIG. 6A

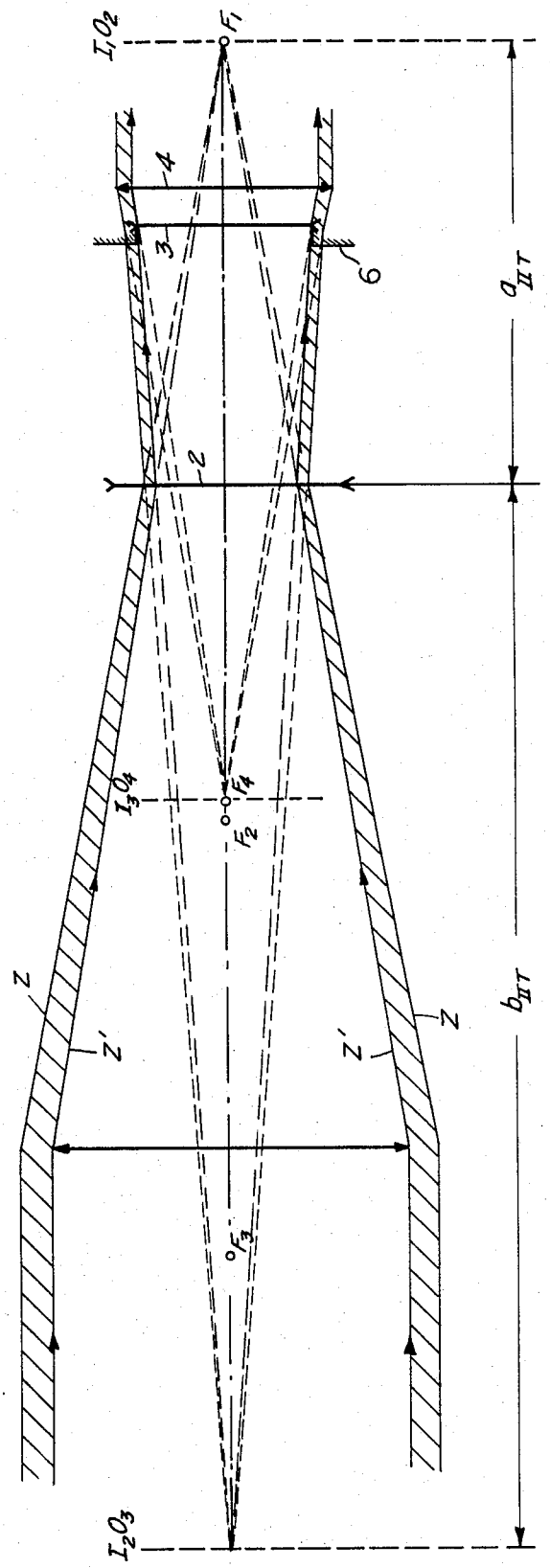

I_1O_2
F_1
4
3
6
a_{IIT}
2
I_3O_4
F_4
F_2
Z
Z'
Z'
Z
b_{IIT}
F_3
I_2O_3

FIG. 6B

CAMERA OBJECTIVE OF VARIABLE FOCAL LENGTH

FIELD OF THE INVENTION

Our present invention relates to a camera objective of the pancratic type, having a variable focal length, in which a four-component varifocal forward lens group is coaxially juxtaposed with a fixed-focus rear lens group.

BACKGROUND OF THE INVENTION

In such objectives it is customary to assemble the varifocal front group from two axially shiftable components of negative refractivity bracketed by two positively refracting components whose axial position is substantially fixed (allowance being made for a limited axial adjustability, for focusing purposes, of especially the first component or at least a front lens forming part thereof). A typical varifocal or pancratic objective of this description has been disclosed in U.S. Pat. No. 3,433,559 and in our copending application Ser. No. 713,224 filed Aug. 10, 1976.

There are certain relationships in such a system between their optical qualities, such as relative aperture and varifocal ratio, and their structural parameters including front-lens diameter and total axial length. These relationships are well understood in the art; reference may be made, by way of example, to Austrian Pat. No. 317,576.

It is generally convenient to design the varifocal front group as an afocal system in order to allow interposition of ancillary elements, such as a shutter, a diaphragm and a reflex prism, in a field of parallel rays between the two groups. Since the fourth component of the front group is positively refracting, the combination of the three preceding components must be of dispersive character so that axially incident rays diverge from the axis between the third and fourth components. The extent of this divergence increases, of course, in proportion to the axial separation of the two components; an axial ray bundle fully illuminating the stationary fourth component passes, therefore, through a smaller portion of the third component when the latter is in a forward position than when it lies close to the fourth component.

Systems are known (e.g. from Austrian Pat. Nos. 317,576 and 316,891) in which the axial movement of the third component, designed to keep constant the image plane of the objective during changes of the overall focal length, follows a substantially symmetrical course as the second component is shifted rearwardly from a wide-angle position of minimum focal length f_{min} to a telephoto position of maximum focal length f_{max}. In such a case, the third component moves forwardly during a changeover from f_{min} to an intermediate focal length f_{med} and then recedes at about the same rate during a changeover from f_{med} to f_{max}, being substantially equidistant from the fourth component in the two limiting positions of the varifocal range.

Alternatively, e.g. as known from French Pat. No. 1,459,076 and German published Specification No. 2,164,937, the motion of the third component may be an unsymmetrical function of the displacement of the second component, so chosen that the third component approaches the fourth component more closely in the telephoto position (f_{max}) than in the wide-angle position (f_{min}).

OBJECT OF THE INVENTION

The object of our present invention is to provide a more compact varifocal objective of the type specified in which the lens diameters, especially that of the front lens, can be significantly reduced with only a minor loss of illumination in certain positions of adjustment.

SUMMARY OF THE INVENTION

In accordance with our present invention, the first three components of a varifocal forward lens group as defined above have lens diameters sufficient for full illumination of the fourth component by axially incident light rays in the wide-angle position, in which the third and fourth components are relatively widely separated, with such dimensioning of the third component as to make its effective area sufficient for full illumination of the fourth component by axially incident light rays in the wide-angle position, yet with restriction of that bundle of light rays in the telephoto position to less than full illumination of the fourth component.

Thus, taking advantage of the aforedescribed unsymmetrical law of displacement in which the third and fourth components are far apart with the overall focal length $f = f_{min}$ but are closely spaced with $f = f_{max}$, we provide a maximum aperture ratio in the wide-angle position and a slightly reduced aperture ratio in the telephoto position in which a small loss of luminosity at the center of the image (e.g. on the order of one diaphragm stop) can be readily tolerated. This minor restriction of the relative aperture of the objective at the telephoto end of the varifocal range allows a considerable reduction in the diameter of the front lens which can thus be manufactured much more inexpensively and accommodated in a camera housing of correspondingly decreased dimensions. The lowering of the aperture ratio at large overall focal lengths has the incidental advantage of an increased depth of field in the telephoto position.

According to another feature of our invention, the effective area of the third component is circumscribed by an ancillary diaphragm carried thereon, preferably at the forward face of a constituent lens of that component. The ancillary diaphragm may be part of the lens mount for that component.

BRIEF DESCRIPTION OF THE DRAWING

The above and other features of our invention will now be described in detail with reference to the accompanying drawing in which:

FIG. 1 is a schematic view of a conventional pancratic objective with a symmetrical law of displacement for the third component, shown in five different positions;

FIG. 2 is a view similar to FIG. 1 but showing, again in five different positions, a pancratic objective with an asymmetrical law of displacement to which our invention is applicable;

FIG. 3 shows the objective of FIG. 2 provided with an ancillary diaphragm reducing its entrance pupil in the telephoto position;

FIGS. 4A, 4B, and 4C are more detailed presentations of an objective of the type shown in FIGS. 2 and 3, illustrated in its wide-angle, intermediate and telephoto positions, respectively;

FIG. 5 is a view similar to FIG. 4A, showing another objective according to our invention in its wide-angle position; and

FIGS. 6A and 6B are more detailed diagrammatic views of the objective of FIG. 3 in its wide-angle and telephoto positions, respectively.

SPECIFIC DESCRIPTION

The conventional pancratic or zoom objective shown in FIG. 1, which may be designed for a camera of the Super-8 type, has a varifocal front attachment consisting of a substantially stationary positive front component 1, two axially shiftable negative components 2 and 3, and a fixed positive component 4; this attachment is coaxially juxaposed with a fixed-focus rear lens group or basic lens system 5. At Z we have shown a limiting ray of an axially incident light bundle focused on a point F_5 which is a focal point of component 5 inasmuch the group 1 – 4 is considered to be afocal. Point F_5 lies on an image plane I_5 whose position is unaffected by the correlated axial displacement of components 2 and 3. Components 1 – 5 have all been represented as thin lenses.

In graph A of FIG. 1, which illustrates the wide-angle position of minimum focal length, component 2 is at extreme left while component 3 is closely spaced from component 4. With component 2 moving progressively toward the right into the telephoto position illustrated in graph E, component 3 is shifted first to the left (graphs B and C), then begins to move back to the right (graph D) and ends up at its original small spacing from component 4 (graph E).

As further shown in graph E of FIG. 1, the limiting ray Z is refracted by component 1 toward its focal point F_1 located in an image plane I_1 of that component, is intercepted by component 2 so as to seem to originate at an image plane I_2, is further refracted by component I_3 which increases its divergence from the optical axis to make its apparent origin in an image plane I_3 coincide with the focal point F_4 of component 4, and then passes parallel to the axis to component 5 (the image plane of component 4 being thus at infinity).

The object distance of component 2, between that component and image plane I_1, has been designated a_{II}; the corresponding image distance between that component and plane I_2 is designated b_{II}. In an analogous manner we have designated by a_{III} the object distance of component 3 (measured from plane I_2) and by b_{III} the image distance of component 3 (extending to plane I_2). With the generally symmetrical law of displacement of component 3 the system satisfies the relationships

$$a_{IIW} = -b_{IIT}$$

and

$$b_{IIW} = -a_{IIT}$$

where the subscripts W and T indicate the wide-angle position of FIG. 1 (A) and the telephoto position of FIG. 1 (E), respectively. In the middle position of FIG. 1 (C), we have

$$a_{IIM} = -b_{IIM}.$$

The magnification ratio β_{II} of the second component 2 in the wide-angle position is the reciprocal of that in the telephoto position, i.e.

$$\beta_{IIW} = 1/\beta_{IIT}.$$

In the middle position of FIG. 1 (C), with $f = f_{med}$, we find

$$\beta_{IIM} = -1.$$

For the third component 3 we have

$$a_{IIIW} = a_{IIIT},$$

$$b_{IIIW} = b_{IIIT},$$

$$\beta_{IIIW} = \beta_{IIIT}.$$

If the position of the limiting ray Z is determined by the diameter of component 4, then the effective area of component 3 varies inversely with its distance d_{III} from component 4. The radius of this effective area has been indicated at h_{III} in FIG. 1(A) and is the same in the wide-angle and telephoto positions. The relative aperture B_{III} of component 3 can thus be expressed by

$$B_{III} = f_{III}/2h_{III}$$

where f_{III} is the individual focal length of this component. It follows that, in the system of FIG. 1,

$$B_{IIIW} = B_{IIIT}.$$

In the system of FIG. 2 the separation d_{IIIW} between components 3 and 4 in the wide-angle position, graph A, substantially exceeds the corresponding spacing d_{IIIT} in the telephoto position of graph E. With zooming from the position of FIG. 2 (A) to that of FIG. 2 (E), component 3 moves forward into the position of FIG. 2 (B) and reaches its most advanced point in the intermediate position of FIG. 2 (C). In that position we again have the relationships

$$a_{IIM} = -b_{IIM}$$

and

$$\beta_{IIM} = -1.$$

With further increases in the overall focal length, component 3 recedes into the position of FIG. 2 (D) before reaching its final position closest to component 4 according to FIG. 2 (B).

Instead of the equations relating to the system parameters of FIG. 1, we now have the following inequalities:

$$a_{IIW} < -b_{IIT},$$

$$-b_{IIW} > a_{IIT},$$

$$d_{IIIW} < d_{IIIT},$$

$$B_{IIIW} < B_{IIIT}.$$

The final inequality results from the fact that, owing to the close spacing of components 3 and 4 in the telephoto position, radius h_{IIIT} is significantly larger than the corresponding radius h_{IIIW} in the wide-angle position.

In accordance with our present invention, and as shown in FIG. 3, the effective radius h_{III} is limited in the telephoto position (graph E) to the value h_{IIIW} which it assumes in the wide-angle position (graph A). This limitation is here brought about by the provision of an ancillary diaphragm 6 fastened to the front face of component 3, the presence of this diaphragm being without

effect upon the width of the axially incident light bundle in the positions of graphs B and C in which the spacing of component 3 from component 4 exceeds that of graph A. In FIG. 3(D) the axial separation of these components is slightly less than in graph A so that diaphragm 6 begins to restrict the effective diameter of component 3, thereby reducing the entrance pupil of the objective. In FIG. 3(E) this restriction results in a limiting ray Z' traversing the front component 1 at a point whose distance h'_I from the axis is substantially less than the corresponding distance h_{IT} of ray Z. Thus, the diameter of component 1 can be materially reduced without significantly restricting the brightness of the image except in positions at or close to the telephoto end of the varifocal range.

The ancillary diaphragm 6 may be part of the lens mounting of component 3. Even if that diaphragm were omitted, the reduction of the diameter of the front component would have an equivalent effect on the axially incident ray bundle.

The relationships briefly discussed above will be better understood from a reference to FIGS. 6A and 6B in which the focal points of positive component 1, negative components 2, 3 and positive component 4 have been indicated at F_1, F_2, F_3 and F_4. An axially incident bundle of parallel light rays, with limiting rays Z, impinges upon component 1 and converges toward its focal point F_1 whose image plane I_1 also constitutes the object plane O_2 of component 2. The light bundle intercepted by the latter component appears to originate at an image plane I_2 which is also the object plane O_3 of component 3. The relative positions of components 2 and 3 are so chosen that the image plane I_3 of component 3, also constituting the object plane O_4 of component 4, always passes through the focal point F_4 whereby the light bundle is focused on infinity after leaving the lens group 1 - 4.

In view of the afocality of this lens group, focal point F_4 constitutes the vertex of a light cone whose base has a diameter equal to that of component 4. As component 3 approaches component 4, its own effective diameter must increase if it is to pass all the rays of this light cone that can be collected by component 4 in the wide-angle position of FIG. 6A. The incident cylindrical light bundle corresponding to this cone fills only a limited central zone of front component 1. In the telephoto position of FIG. 6B, however, component 1 must have a large diameter in order to allow full illumination of component 4. By making the effective diameter of component 3 in the telephoto position equal to that in the wide-angle position, we can substantially reduce the diameter of component 1 with only a minor diminution of the total quantity of incident light as indicated by the hatched areas in FIG. 6B.

In FIGS. 4A, 4B and 4C we have shown the wide-angle position, the middle position and the telephoto position of a representative objective conforming to the one indicated diagrammatically in FIGS. 1, 2 and 3. Component 1 comprises a front lens member in the form of a doublet consisting of a negative meniscus L_1 with radii r_1, r_2 and thickness d_1 cemented onto a nearly planoconvex lens L_2 with radii r_2, r_3 and thickness d_2. Component 1 further includes two positive lenses L_3 (radii r_4, r_5 and thickness d_3) and L_4 (radii r_6, r_7 and thickness d_4) with intervening air spaces s_1 and s_2. A variable air space s_3 separates lens L_4 from the axially shiftable component 2 consisting of a singlet L_5 in the form of a negative meniscus (radii r_8, r_9 and thickness d_5) separated by an air space s_4 from a doublet consisting of lenses L_6 (radii r_{10}, r_{11} and thickness d_6) and L_7 (radii r_{11}, r_{12} and thickness d_7). Another variable air space s_5 lies between component 2 and component 3 which consists of a single lens L_8 in the form of a negative meniscus with radii r_{13}, r_{14} and thickness d_8. In dotted lines we have illustrated an alternate position of component 3 designed to facilitate, in a manner known per se, the taking of pictures in a so-called macro range with image ratios between 1: −10 and 1: −1. A third variable air space s_6 lies between component 3 and axially fixed component 4 which in this instance consists of two air-spaced biconvex lenses L_9 (radii r_{15}, r_{16} and thickness d_9) and L_{10} (radii r_{17}, r_{18} and thickness d_{10}), the intervening air space having been designated s_7.

A reflex prism P of thickness d_p, whose planar faces have been designated r_a and r_b, is separated by an air space s_8 from lens L_{10} and by a diaphragm space s_d from component 5, the latter space containing an iris diaphragm 7 distinct from the invariable ancillary diaphragm 6 on face r_{13} on lens L_8. Component 5 consists of five air-spaced singlets, namely a biconvex lens L_{11} (radii r_{19}, r_{20} and thickness d_{11}), a positive meniscus L_{12} (radii r_{21}, r_{22} and thickness d_{12}), a biconcave lens L_{13} (radii r_{23}, r_{24} and thickness d_{13}), a planoconvex lens L_{14} (radii r_{25}, r_{26} and thickness d_{14}) and another positive meniscus L_{15} (radii r_{27}, r_{28} and thickness d_{15}); the intervening air spaces have been designated s_9, s_{10}, s_{11} and s_{12}.

In the following Table A we have given representative numerical values for the parameters $r_1 - r_{28}$, $d_1 - d_{15}$ and $s_1 - s_{12}$ of the optical system of FIGS. 4A - 4C, based upon a mean overall focal length $f_{med} = 1$ in the middle position of FIG. 4B. The Table also gives the refractive indices n_d and the Abbe number ν_d of the various lenses.

TABLE A

Lens	Radii	Thicknesses and Separations	n_d	ν_d	Diameter
L_1	$r_1 = +21.871$				
		$d_1 = 0.15$	1.805	25.4	
L_2	$r_2 = +3.172$				
		$d_2 = 0.46$	1.607	59.5	
	$r_3 = -262.556$				
		$s_1 = 0.01$			
L_3	$r_4 = +3.740$				
		$d_3 = 0.32$	1.689	49.5	
	$r_5 = +30.344$				
		$s_2 = 0.01$			
L_4	$r_6 = +3.047$				
		$d_4 = 0.29$	1.744	44.8	
	$r_7 = +8.896$				
		$s_3 = \begin{cases} 0.061 & \dots f_{min} \\ 0.951 & \dots f_{med} \\ 1.773 & \dots f_{max} \end{cases}$			
L_5	$r_8 = +5.897$				
		$d_5 = 0.08$	1.691	54.7	

TABLE A-continued

Lens	Radii		Thicknesses and Separations		n_d	ν_d	Diameter
	r_9	= +	1.020				
				$s_4 = 0.39$			
L_6	r_{10}	= −	1.317				
				$d_6 = 0.15$	1.847	23.8	
L_7	r_{11}	= −	0.954				
				$d_7 = 0.06$	1.569	63.1	
	r_{12}	= +	6.800				
				$s_5 = \begin{cases} 1.540 & \dots f_{min} \\ 0.575 & \dots f_{med} \\ 0.184 & \dots f_{max} \end{cases}$			
L_8	r_{13}	= −	1.018				
				$d_8 = 0.06$	1.744	44.8	$D_{8eff} = 0.78$
	r_{14}	= −	3.854				
				$s_6 = \begin{cases} 0.416 & \dots f_{min} \\ 0.490 & \dots f_{med} \\ 0.059 & \dots f_{max} \end{cases}$			
L_9	r_{15}	= +	5.601				
				$d_9 = 0.17$	1.620	60.3	$D_9eff = 1.11$
	r_{16}	= −	2.361				
				$s_7 = 0.01$			
L_{10}	r_{17}	' +	3.879				
				$d_{10} = 0.14$	1.620	60.3	
	r_{18}	= −	5.870				
				$s_8 = 0.06$			
P	r_a	=	∞				
				$d_p = 0.32$	1.517	64.2	
	r_b	=	∞				
				$s_d = 0.21$			
L_{11}	r_{19}	= +	1.752				
				$d_{11} = 0.18$	1.620	60.3	
	r_{20}	= −	6.856				
				$s_9 = 0.01$			
L_{12}	r_{21}	= +	1.015				
				$d_{12} = 0.18$	1.620	60.3	
	r_{22}	= +	2.066				
				$s_{10} = 0.25$			
L_{13}	r_{23}	= −	1.059				
				$d_{13} = 0.14$	1.847	23.8	
	r_{24}	= +	1.059				
				$s_{11} = 0.21$			
L_{14}	r_{25}	=	∞				
				$d_{14} = 0.21$	1.713	53.8	
	r_{26}	= −	0.772				
				$s_{12} = 0.01$			
L_{15}	r_{27}	= +	0.953				
				$d_{15} = 0.14$	1.620	60.3	
	r_{28}	= +	4.297				

This system has a minimum focal length $f_{min} = 0.46$, a maximum focal length $f_{max} = 3.44$, a relative aperture varying between 1: 1.2 (in the wide-angle position) and 1 : 1.5 (in the telephoto position), and an image diagonal $2y' = 0.47$. As indicated in the Table, the effective diameter D_{8eff} of lens L_8 has the numerical value 0.78. Thus, the objective has a varifocal ratio $f_{max} : f_{min}$ of about 8 : 1, with $f_{min} \approx 2y'$. The reduced diameter of front component **1**, realized by a decrease of the relative aperture in the telephoto position, amounts to about 85% of the diameter that would be required for full illumination of component **4** in that position.

FIG. **5** shows another embodiment of our invention in the wide-angle position. Its front component **1'** comprises a positive doublet consisting of lenses L'_1 (radii r'_1, r'_2 and thickness d'_1) and L'_2 (radii r'_2, r'_3 and thickness d'_2) closely followed by two positive menisci L'_3 (radii r'_4, r'_5 and thickness d'_3) and L'_4 (radii r'_6, r'_7 and thickness d'_4), the intervening air spaces s'_1 and s'_2 being practically zero. A variable air space s'_3 separates component **1'** from component **2'** which again consists of two lens members, i.e. a singlet L'_5 (radii r'_8, r'_9 and thickness d'_5) and a doublet made up of lenses L'_6 (radii r'_{10}, r'_{11} and thickness d'_6) and L'_7 (radii r'_{11}, r'_{12} and thickness d'_7). After another variable air space s'_5 there follows the third component **3'**, again consisting of a single negative meniscus L'_8 (radii r'_{15}, r'_{16} and thickness d'_8), separated by a third variable air space s'_6 from the fourth component **4'** which in this instance is a single biconvex lens L'_9 (radii r'_{15}, r'_{16} and thickness d'_9). A reflex prism **P'**, of thickness d'_p and with planar faces r'_a, r'_b, is separated from lens L'_9 by an air space s'_7 and from the rear component **5'** by a diaphragm space s'_d.

Component **5'** consists here of four singlets, namely a positive lens L'_{10} (radii r'_{17}, r'_{18} and thickness d'_{10}), a positive lens L'_{11} (radii r'_{19}, r'_{20} and thickness d'_{11}), a negative lens L'_{12} (radii r'_{21}, r'_{22} and thickness d'_{12}) and a positive lens L'_{13} (radii r'_{23}, r'_{24} and thickness d'_{13}); the intervening air spaces have been designated s'_8, s'_9 and s'_{10}.

Representative numerical values for parameters $r'_1 - r'_{24}$, $d'_1 - d'_{13}$ and $s'_1 - s'_{10}$, again based on a mean focal length $f_{med} = 1$, are given together with refractive indices n_d and Abbe numbers ν_d in the following Table B.

TABLE B

Lens	Radii		Thicknesses and Separations		n_d	ν_d	Diameter
L'_1	r'_1	= +	123.127				
				$d'_1 = 0.11$	1.805	25.4	
L'_2	r'_2	= +	2.801				
				$d'_2 = 0.43$	1.620	60.3	
	r'_3	= −	5.218				
				$s'_1 = 0$			

TABLE B-continued

Lens	Radii		Thicknesses and Separations	n_d	ν_d	Diameter
L'_3	r'_4	$=+$ 2.308				
	r'_5	$=+$ 4.175	$d'_3 = 0.17$	1.622	53.2	
			$s'_2 = 0$			
L'_4	r'_6	$=+$ 1.643				
	r'_7	$=+$ 3.972	$d'_4 = 0.24$	1.643	48.0	
			$s'_3 = \begin{cases} 0.031 & \dots f_{min} \\ 0.994 & \dots f_{med} \\ 1.373 & \dots f_{max} \end{cases}$			
L'_5	r'_8	$=+$ 4.332				
	r'_9	$=+$ 0.473	$d'_5 = 0.04$	1.691	54.7	
			$s'_4 = 0.23$			
L'_6	r'_{10}	$=-$ 1.128				
	r'_{11}	$=+$ 0.626	$d'_6 = 0.04$	1.620	60.3	
L'_7	r'_{12}	$=+$ 3.189	$d'_7 = 0.15$	1.805	25.4	
			$s'_5 = \begin{cases} 1.402 & \dots f_{min} \\ 0.258 & \dots f_{med} \\ 0.155 & \dots f_{max} \end{cases}$			
L'_8	r'_{13}	$=-$ 0.990				
	r'_{14}	$=-$ 3.946	$d'_8 = 0.01$	1.788	47.4	$D'_{8eff} = 0.47$
			$s'_6 = \begin{cases} 0.122 & \dots f_{min} \\ 0.303 & \dots f_{med} \\ 0.028 & \dots f_{max} \end{cases}$			
L'_9	r'_{15}	$=+$ 0.982				
	r'_{16}	$=-$ 3.593	$d'_9 = 0.10$	1.682	48.2	D'_{9eff}=0.57
			$s'_7 = 0.04$			
P'	r'_a	$=$ ∞				
	r'_b	$=$ ∞	$d'_p = 0.22$	1.517	64.2	
			$s'_d = 0.17$			
L'_{10}	r'_{17}	$=+$ 1.885				
	r'_{18}	$=-$ 2.897	$d'_{10} = 0.09$	1.744	44.8	
			$s'_8 = 0.02$			
L'_{11}	r'_{19}	$=+$ 0.653				
	r'_{20}	$=$ ∞	$d'_{11} = 0.11$	1.744	44.8	
			$s'_9 = 0.03$			
L'_{12}	r'_{21}	$=-$ 0.869				
	r'_{22}	$=+$ 0.506	$d'_{12} = 0.31$	1.847	23.8	
			s'_{10} 0.05			
L'_{13}	r'_{23}	$=+$ 1.404				
	r'_{24}	$=-$ 0.533	$d'_{13} = 0.21$	1.735	41.6	

This system has a minimum focal length $f_{min} = 0.27$ and a maximum focal length $f_{max} = 2.78$. Its relative aperture ranges from 1 : 1.8 (in the wide-angle position) to 1 : 2 (in the telephoto position); its image diagonal is $2y' = 0.31$. The effective diameter of lens L'_8, given in the Table, is $D'_{8eff} = 0.47$. The minimum focal length f_{min} falls here short of the image diagonal $2y'$ by more than 10%. The objective of Table B is not as fast as that of Table A but has a higher varifocal ratio, slightly exceeding 10 : 1.

In practice, the reduction of the diameter of the front component **1** cannot be carried quite as far as diagrammatically illustrated in FIG. **6B** because of the adverse effect this would have on nonaxially incident light bundles. Hence, component **3** and diaphragm **6** are chosen to determine the relative aperture of the system throughout its varifocal range.

We claim:

1. In a camera objective of variable focal length including a varifocal forward lens group and a fixed-focus rear lens group centered on a common optical axis, said forward lens group consisting of a substantially axially fixed positive first component, an axially shiftable negative second component, an axially shiftable negative third component and an axially fixed fourth component, said second and third components being displaceable between a wide-angle position of minimum overall focal length and a telephoto position of maximum overall focal length with maintenance of an invariant image plane behind said rear lens group, said third component approaching said fourth component more closely in said telephoto position than in said wide-angle position, the combination of said first, second and third components being of dispersive character, the improvement wherein said first, second and third components have lens diameters sufficient for full illumination of said fourth component by axially incident light rays in said wide-angle position but wherein said third component has an effective area sufficient for full illumination of said fourth component by a bundle of axially incident light rays in said wide-angle position but restricting said bundle to less than full illumination of said fourth component in said telephoto position.

2. The improvement defined in claim **1** wherein said third component is provided with diaphragm means circumscribing said effective area.

3. The improvement defined in claim **2** wherein said diaphragm means is carried on a front face of a constituent lens of said third component.

4. The improvement defined in claim **2** wherein said diaphragm means forms part of a lens mount for said third component.

5. The improvement defined in claim **1** wherein said first component consists of four lenses L_1, L_2, L_3 and L_4,

said second component consists of lenses L_5, L_6 and L_7, said third component consists of a lens L_8 and said fourth component consists of lenses L_9 and L_{10}, said lenses having radii of curvature $r_1 - r_{18}$, axial thicknesses $d_1 - d_{10}$ and axial spacings $s_1 - s_7$ whose numerical values, based upon a numerical value of unity for an intermediate overall focal length, together with their refractive indices n_d and Abbe numbers ν_d are substantially as given in the following table:

		n_d	ν_d
$r_1 = +\ 21.9$			
	$d_1 = 0.15$	1.81	25
$r_2 = +\ 3.2$			
	$d_2 = 0.46$	1.61	60
$r_3 = -\ 262.6$			
	$s_1 = 0.01$		
$r_4 = +\ 3.7$			
	$d_3 = 0.32$	1.69	50
$r_5 = +\ 30.3$			
	$s_2 = 0.01$		
$r_6 = +\ 3.0$			
	$d_4 = 0.29$	1.74	45
$r_7 = +\ 8.9$			
	$s_3 = \begin{cases} 0.06 \ldots f_{min} \\ 0.95 \ldots f_{med} \\ 1.77 \ldots f_{max} \end{cases}$		
$r_8 = +\ 5.9$			
	$d_5 = 0.08$	1.69	55
$r_9 = +\ 1.0$			
	$s_4 = 0.39$		
$r_{10} = -\ 1.3$			
	$d_6 = 0.15$	1.85	24
$r_{11} = -\ 1.0$			
	$d_7 = 0.06$	1.57	63
$r_{12} = +\ 6.8$			
	$s_5 = \begin{cases} 1.54 \ldots f_{min} \\ 0.58 \ldots f_{med} \\ 0.18 \ldots f_{max} \end{cases}$		
$r_{13} = -\ 1.0$			
	$d_8 = 0.06$	1.74	45
$r_{14} = -\ 3.9$			
	$s_6 = \begin{cases} 0.42 \ldots f_{min} \\ 0.49 \ldots f_{md} \\ 0.06 \ldots f_{max} \end{cases}$		
$r_{15} = +\ 5.6$			
	$d_9 = 0.17$	1.62	60
$r_{16} = -\ 2.4$			
	$s_7 = 0.01$		
$r_{17} = +\ 3.9$			
	$d_{10} = 0.14$	1.62	60
$r_{18} = -\ 5.9$			

6. The improvement defined in claim 5 wherein the effective diameter of lens L_8 has a numerical value of substantially 0.78.

7. The improvement defined in claim 1 wherein said first component consists of four lenses L'_1, L'_2, L'_3 and L'_4, said second component consists of lenses L'_5, L'_6 and L'_7, said third component consists of a lens L'_8 and said fourth component consists of a lens L'_9, said lenses having radii of curvature $r'_1 - r'_{16}$, axial thicknesses $d'_1 - d'_9$ and axial spacings $s'_1 - s'_6$ whose numerical values, based upon a numerical value of unity for an intermediate overall focal length, together with their refractive indices n_d and Abbe numbers ν_d are substantially as given in the following table:

		n_d	ν_d
$r'_1 = +\ 123.1$			
	$d'_1 = 0.11$	1.81	25
$r'_2 = +\ 2.8$			
	$d'_2 = 0.43$	1.62	60
$r'_3 = -\ 5.2$			
	$s'_1 = 0$		
$r'_4 = +\ 2.3$			
	$d'_3 = 0.17$	1.62	53
$r'_5 = +\ 4.2$			
	$s'_2 = 0$		
$r'_6 = +\ 1.6$			
	$d'_4 = 0.24$	1.64	48
$r'_7 = +\ 4.0$			
	$s'_3 = \begin{cases} 0.03 \ldots f_{min} \\ 0.99 \ldots f_{med} \\ 1.37 \ldots f_{max} \end{cases}$		
$r'_8 = +\ 4.3$			
	$d'_5 = 0.04$	1.69	55
$r'_9 = +\ 0.5$			
	$s'_4 = 0.23$		
$r'_{10} = -\ 1.1$			
	$d'_6 = 0.04$	1.62	60
$r'_{11} = +\ 0.6$			
	$d'_7 = 0.15$	1.81	25
$r'_{12} = +\ 3.2$			
	$s'_5 = \begin{cases} 1.40 \ldots f_{min} \\ 0.26 \ldots f_{med} \\ 0.16 \ldots f_{max} \end{cases}$		
$r'_{13} = -\ 1.0$			
	$d'_8 = 0.01$	1.79	47
$r'_{14} = -\ 4.0$			
	$s'_6 = \begin{cases} 0.12 \ldots f_{min} \\ 0.30 \ldots f_{med} \\ 0.03 \ldots f_{max} \end{cases}$		
$r'_{15} = +\ 1.0$			
	$d'_9 = 0.10$	1.68	48
$r'_{16} = -\ 3.6$			

8. The improvement defined in claim 7 wherein the effective diameter of lens L'_8 has a numerical value of substantially 0.47.

* * * * *

United States Patent [19]

Baab et al.

[11] **4,081,811**

[45] **Mar. 28, 1978**

[54] DIAPHRAGM PRESELECTOR FOR CAMERA OBJECTIVE

[75] Inventors: **Albert Baab; Paul Himmelsbach,** both of Bad Kreuznach, Germany

[73] Assignee: **Jos. Schneider & Co., Optische Werke Kreuznach,** Bad Kreuznach, Germany

[21] Appl. No.: **769,204**

[22] Filed: **Feb. 16, 1977**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 752,833, Dec. 21, 1976.

[30] **Foreign Application Priority Data**

Dec. 22, 1975 Germany 2557855

[51] **Int. Cl.**[2] **G03B 9/02**

[52] **U.S. Cl.** **354/272;** 354/274

[58] **Field of Search** 354/270, 272, 274

[56] **References Cited**

U.S. PATENT DOCUMENTS

3,715,965 2/1973 Alfredsson 354/274

Primary Examiner—John Gonzales

Attorney, Agent, or Firm—Karl F. Ross

[57] **ABSTRACT**

An iris diaphragm of a reflex camera, spring-biased into a wide-open position, is settable to a preselectable stop position via a linkage including a cam follower on an integral extension of a resilient swing ring oscillatable about an off-axial fulcrum. The cam follower coacts with a cam disk which is manually rotated against the force of a restoring spring during a windup operation and, upon subsequent release, displaces the cam follower and the swing ring which entrains the setting ring of the diaphragm through a yieldable coupling to the selected stop position and restores it to the wide-open position in the course of a revolution. During windup, a beveled flank on the high dwell of the cam disk axially displaces the extension of the swing ring which is thereby made ineffectual and prevented from reducing the diaphragm aperture.

9 Claims, 5 Drawing Figures

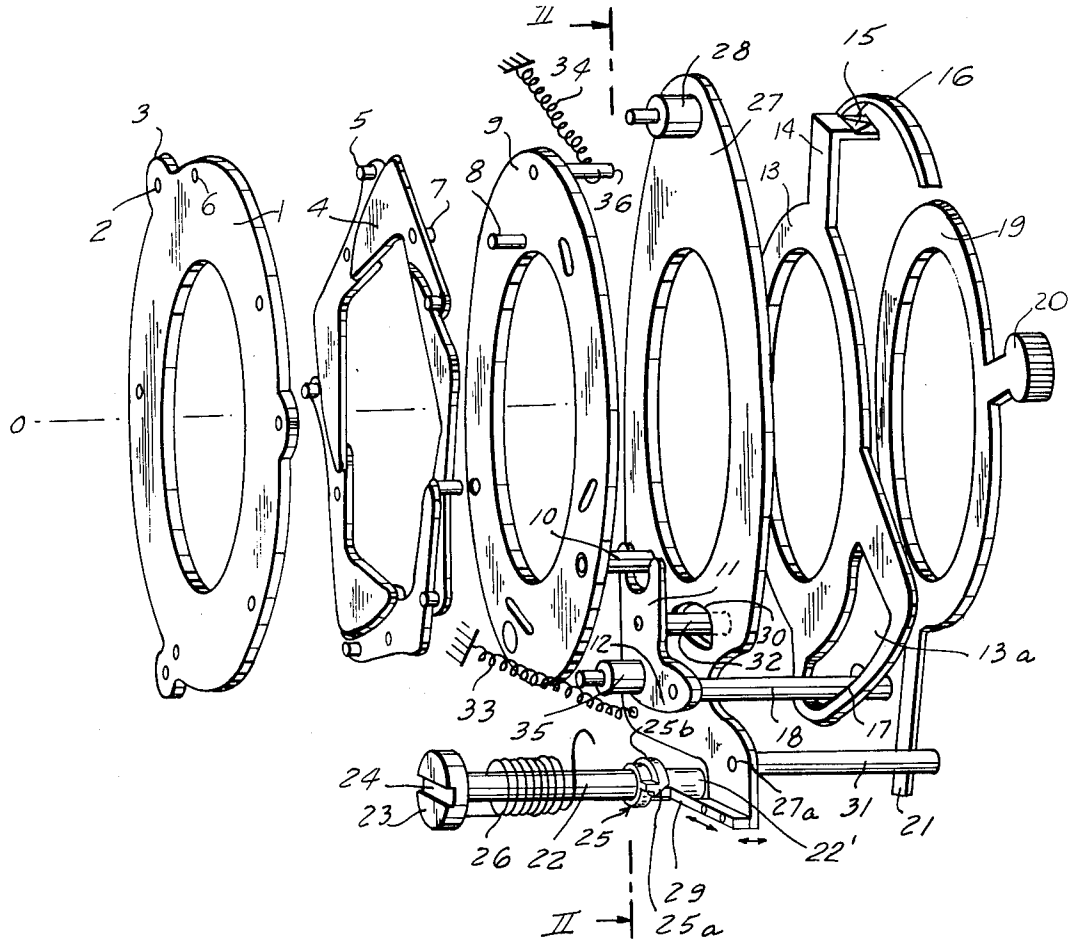
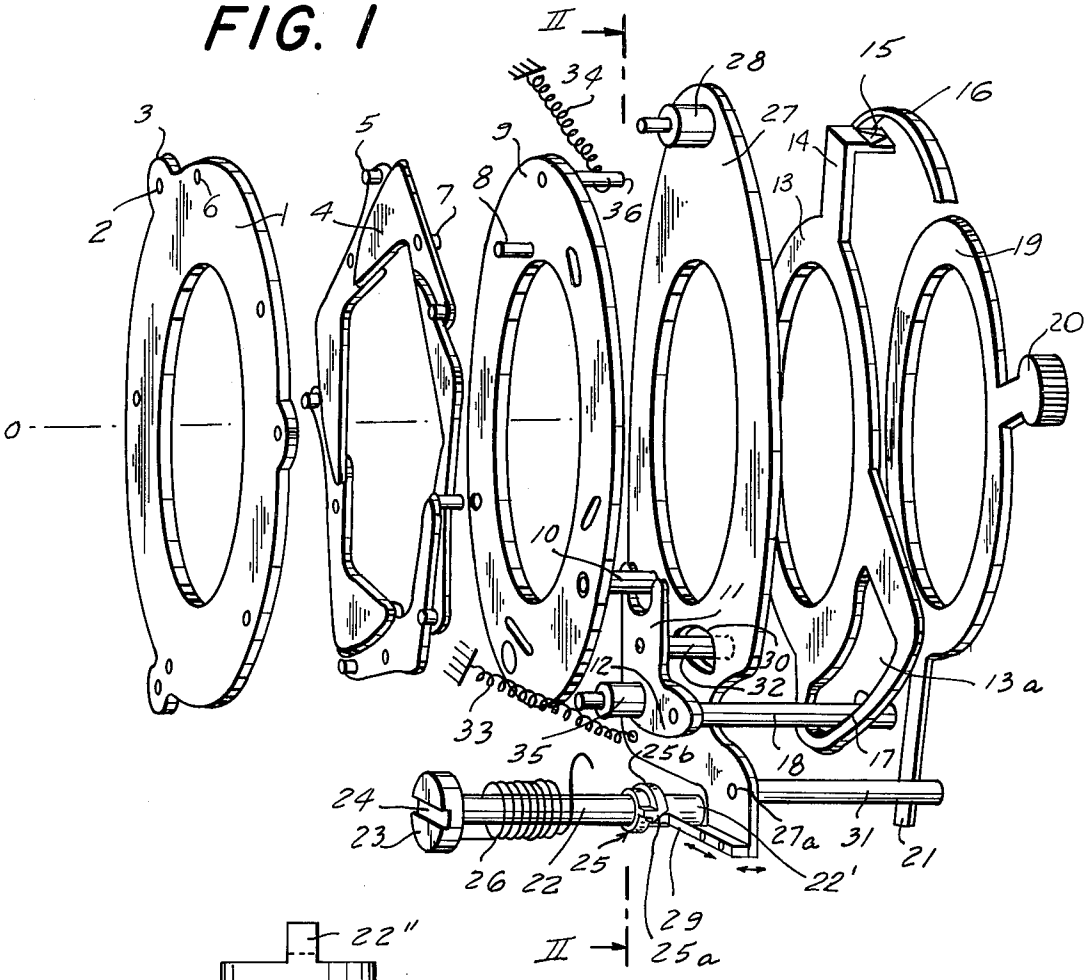


FIG. 1



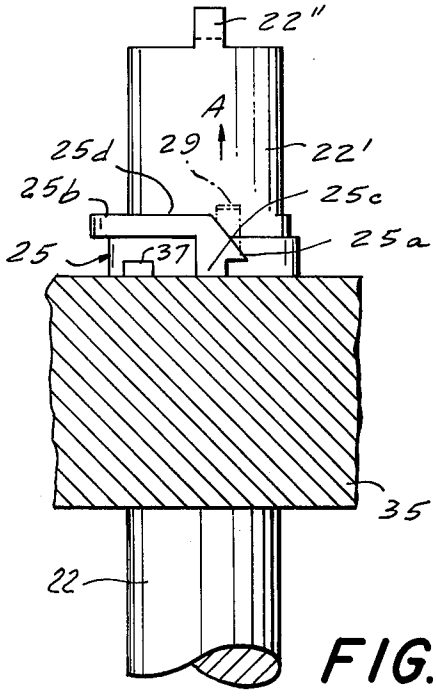


FIG. 5

FIG. 4

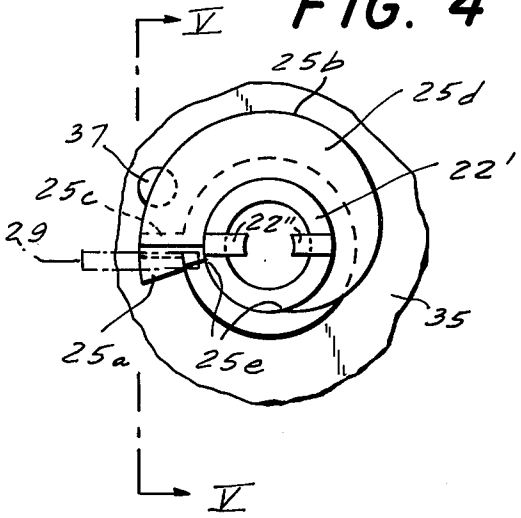


FIG. 2

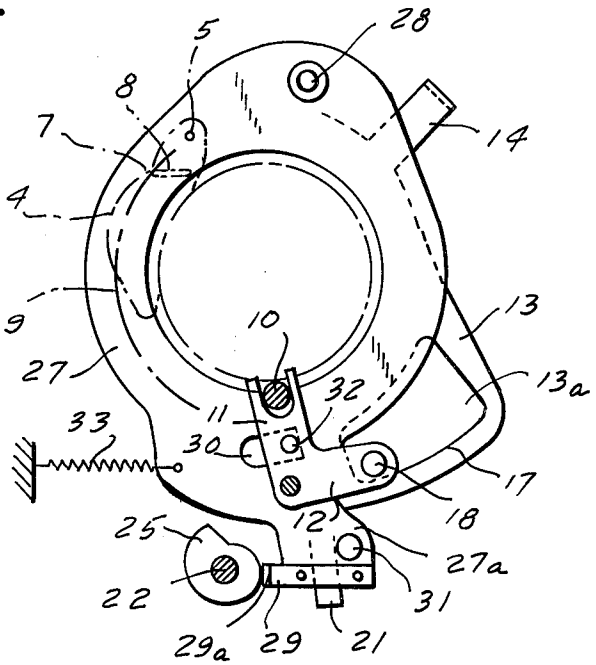

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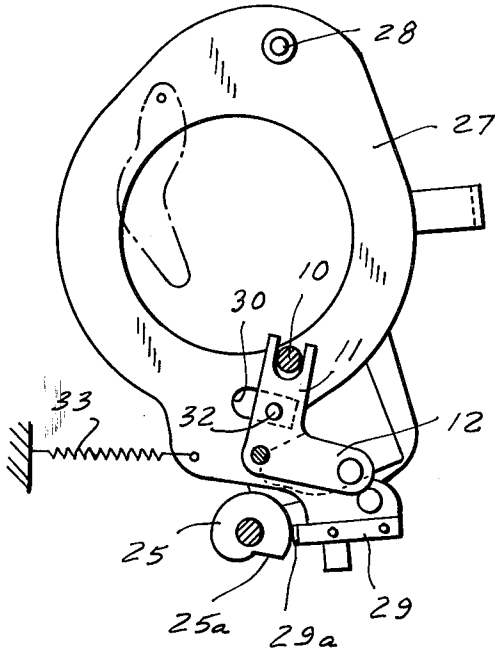
FIG. 3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DIAPHRAGM PRESELECTOR FOR CAMERA OBJECTIVE

CROSS-REFERENCE TO RELATED APPLICATION

This is a continuation-in-part of our copending application Ser. No. 752,833 filed Dec. 21, 1976.

FIELD OF THE INVENTION

Our present invention relates to an iris diaphragm for a camera equipped with a reflex-type viewfinder

BACKGROUND OF THE INVENTION

In such cameras, especially in those provided with interchangeable objectives in which the reflex mirror must be disposed behind an iris diaphragm, it is known to provide a preselector which is adjustable to a desired stop position, the diaphragm being normally biased into its wide-open position from which is it briefly displaced into the preselected position just before the tripping of a shutter by a release button or the like. This enables the operator to use full illumination when sighting and focusing upon an object to be photographed.

Such cameras are generally equipped with a windup handle which is manually operated to advance the film, cock the shutter and possibly carry out additional functions such as reactivating the viewfinder after its disablement upon the previous exposure. With the subsequent actuation of the shutter release, by which a control member coupled with the handle is returned to its original position by a restoring spring, the motion of this control member can be utilized to displace the iris diaphragm into its selected stop position and back to its wide-open position in timed relationship with the opening and closure of the shutter. Such an arrangement, which does not use the windup stroke itself for diaphragm control, has been disclosed in German Pat. No. 2,062,230. That system comprises a cam disk executing a full forward rotation during the windup stroke and a full reverse rotation during the return stroke, a coacting cam follower being connected with the setting ring of the diaphragm through a linkage including a yieldable coupling. The linkage further comprises a relatively complicated system of levers and springs designated to facilitate the escapement of the cam follower during the next windup stroke without entrainment of the setting ring.

OBJECT OF THE INVENTION

The object of our present invention is to provide an improved preselecting mechanism of this character which is of simplified construction and has a reduced number of relatively movable parts.

SUMMARY OF THE INVENTION

In accordance with our present improvement, the linkage between the cam follower and the setting ring of the iris diaphragm comprises a swingable member having a fulcrum offset from the diaphragm axis (which is also the axis of the associated objective), the cam follower being rigid with a resilient extremity of this member which lies substantially diametrically opposite the fulcrum with reference to that axis. The cam disk and the cam follower are provided with coating surfaces serving for the axial deflection of the cam follower, and thereby of the extremity of the swingable member on which it is supported, at the beginning of each windup stroke whereby the cam follower is disaligned for the remainder of that stroke from a radially effective ramp surface of the disk normally engaged by it; thus, the aforementioned camming surfaces form part of a unidirectionally effective escapement mechanism which deactivates the setting control during windup. An abutment coacting with the axially deflected extremity facilitates realignment of the cam follower with the ramp surface at the end of each windup stroke; this abutment preferably forms a contact surface on the cam disk engageable by the cam follower itself.

In a preferred embodiment of our invention, the swingable member comprises an oscillating ring substantially centered on the diaphragm axis at least in the wide-open position in which the cam follower engages a low dwell on the coating ramp surface, the aforementioned extremity being an extension of this ring.

BRIEF DESCRIPTION OF THE DRAWING

The above and other features of our invention will now be described in detail with reference to the accompanying drawing in which:

FIG. **1** is an exploded perspective view of an iris diaphragm and an associated preselecting mechanism according to our invention;

FIG. **2** is an axial view of part of the assembly, taken on the line II—II of FIG. **1**;

FIG. **3** is a view similar to FIG. **2**, showing an alternate position;

FIG. **4** is a detail view, drawn to a larger scale, of a camming mechanism included in the assembly of FIGS. **1–3**; and

FIG. **5** is a cross-sectional view taken on the line V—V of FIG. **4**.

SPECIFIC DESCRIPTION

In order to facilitate a comparison between the system of the aforementioned German Pat. No. 2,062,230 and our present improvement, the same reference numerals have been used wherever practical. The illustrated assembly comprises a mounting ring **1** of an iris diaphragm having lugs **3** with holes **2** for pins **5** of a set of iris leaves **4** having other pins **7** receivable in inclined guide slots **8** of a setting ring **9** rotatable with reference to ring **1** about a common axis **0**. A preselecting ring **13**, centered on the same axis, carries a lug **14** with a pointer **15** co-operating with a stationary diaphragm scale **16**. Ring **13** has a cutout **13***a* with an edge **17**, not centered on the diaphragm axis, engageable by a pin **18** on an arm **12** of a bell-crank lever having a fixed fulcrum **35**. A second arm **11** of this lever has a bifurcate end engaging a stud **10** which is rigid with setting ring **9**. Another stud **36** on ring **9** is connected to a coil spring **34** which is anchored to the objective housing and tends to rotate the ring **9** counterclockwise (as viewed in FIGS. **2** and **3**) into a wide-open position in which the iris leaves **4** are fully withdrawn as shown in FIGS. **1** and **2**. With pointer **15** confronting a selected mark on scale **16**, the curvature of edge **17** determines a point beyond which the ring **9** will not be able to rotate clockwise against the force of spring **34**.

In accordance with our present invention, an oscillating ring **27** of resilient sheet material (e.g. punched from a metallic or plastic foil) is swingable about a fixed fulcrum **28** on one side of the objective axis **0**, i.e. at the top as shown in FIGS. **1–3**, and is provided at its opposite side (thus at the bottom) with an integral extension **27***a* rigidly connected with a cam follower **29**. The

latter coacts with a cam disk **25** on a shaft **22** having a coupling head **23** provided with a slot **24** through which it is linked with a nonillustrated control element, such as a shaft of a pinion driven through approximately **360°** upon the displacement of a windup handle coupled with a gear or rack in mesh with that pinion. A restoring spring **26** is tensioned during a clockwise windup stroke after which the shaft **22** and the disk **25** are latched in the position of FIG. **2**, with the cam follower **29** urged by a spring **33** against a low dwell of the disk. A pin **32** on lever arm **12** passes through a slot **30** of swing ring **27** and is normally held against the right-hand end of that slot (as viewed in FIGS. **2** and **3**) by the spring **34** acting through ring **9** and stud **10**; pin **32** and slot **30** thus constitute a yieldable lost-motion coupling between setting ring **9** and cam follower **29**. Shaft **22** is journaled in a housing wall **35**, omitted for the sake of clarity in FIG. **1** but shown in FIGS. **4** and **5**. An extension **22'** of this shaft beyond cam disk **25** ends in a pair of lugs **22''** by which it may be coupled to an unidirectional film-transport mechanism.

Upon the tripping of the shutter release, the nonillustrated control element coupled with shaft **22** is unlatched whereupon spring **26** rotates the shaft and cam disk **25** counterclockwise as viewed in FIGS. **2** and **3**. Cam follower **29**, riding on a ramp surface **25*b*** of disk **25**, is progressively displaced toward the right and eventually comes to rest on the high dwell of the cam after about half a revolution. At or before this point, depending upon the setting of preselector ring **13**, pin **18** contacts the edge **17** of that ring so that setting ring **9** is no longer entrained and iris leaves **4** occupy the selected position as diagrammatically illustrated for one of these leaves in FIG. **3**. Next, the nonillustrated camera shutter is briefly opened with stoppage of the rotation of shaft **22**, if necessary, to expose the film. Thereafter, as cam disk **25** continues its rotation beyond the position of FIG. **3** into substantially its starting position shown in FIG. **1**, as determined by the engagement of a web **25*c*** with a fixed stop **37** on housing wall **36**, cam follower **29** drops back onto the low dwell of disk **25** and restores the setting ring to normal, thereby returning the diaphragm to its wide-open position shown in FIG. **2**. Swing ring **27** also reverts to its normal position centered on axis **0**.

During the next windup stroke, which is clockwise in FIGS. **2** and **3** but counterclockwise in FIG. **4**, a beveled flank **25*a*** extending from the high dwell of cam disk **25** to its low dwell coacts with an oppositely beveled facet **29*a*** of cam follower **29** whereby extension **27*a*** of swing ring **27** is resiliently deflected in an axial direction indicated by an arrow A in FIG. **5**. The resiliency of ring **9** and the force of spring **33** now combine to hold the cam follower **29** against a face **25*d*** of cam disk **25** as well as against a contact surface constituted by the periphery of shaft extension **22'** which thus acts as an abutment limiting the displacement of ring extension **27*a*** of spring **33**. At the end of the windup stroke, with stop **37** contacted by the opposite side of web **25*c***, cam follower **29** confronts a zone **25*e*** of disk **25** in which the ramp surface **25*b*** is flush with the contact surface of shaft extension **22'** so that the cam follower is able to snap back into alignment with the coacting ramp surface to re-establish the initial starting position in which the associated control element is relatched. Thus, the assembly shown in FIGS. **4** and **5** constitutes a unidirectionally effective escapement mechanism as discussed above.

As in the prior German patent already referred to, an ancillary ring **19** also centered on axis **0** is provided with a handle **20** by which it may be rotated to reduce the diaphragm aperture independently of the shutter release within the limits set by preselector **13**, **14**. Ring **19** has an extension **21** engaging a pin **31** on ring extension **27*a*** whereby counterclockwise rotation of ring **19** separates the cam follower **29** from cam disk **25** within the limits established by curve **17** of ring **13**.

The compact preselection mechanism according to our invention links the setting ring **9** and the cam follower **29** through the intermediary of only two relatively movable members forming a lost-motion coupling therebetween, i.e. the oscillating ring **27** and the bell-crank lever **11**, **12** establishing a positive connection between ring **9** and pin **32**; there is no need for a biasing spring acting upon that lever. This minimizes the risk of malfunction due to spring fatigue or similar mechanical failures.

We claim:

1. In a reflex camera having an iris diaphragm centered on an optical axis and provided with a setting ring rotatable about said axis, biasing means engaging said settable ring for urging same into a wide-open diaphragm position, preselector means adjustable to a desired stop position, a spring-loaded cam disk manually rotatable in one direction against its spring force during a windup stroke and rotatable by its spring force in the opposite direction during a picture-taking operation, cam-follower means coacting with a radially effective ramp surface of said cam disk, and a linkage including a yieldable lost-motion coupling between said cam-follower means and said setting ring engageable with said preselector means for entraining said setting ring into the desired stop position,

the improvement wherein said linkage comprises a swingable resilient member having a fulcrum offset from said axis, said cam-follower means being rigid with an extremity of said member substantially diametrically opposite said fulcrum with reference to said axis, said cam disk and said cam-follower means being provided with coacting surfaces for axially deflecting said extremity at the beginning of each windup stroke with consequent disalignment of said cam-follower means and said ramp surface for the remainder of said windup stroke.

2. The improvement defined in claim **1** wherein said member is an oscillatable ring substantially centered on said axis in said wide-open position.

3. The improvement defined in claim **2** wherein said yieldable coupling includes a pin positively connected with said setting ring and urged by said biasing means against an edge of a slot in said oscillatable ring traversed by said pin.

4. The improvement defined in claim **1** wherein said ramp surface has a low dwell engaged by said cam-follower means in said wide-open position and a high dwell engaged by said cam-follower means at an intermediate point of said windup stroke, said high dwell being separated from said low dwell by a beveled flank forming one of said coacting surfaces.

5. The improvement defined in claim **4**, further comprising abutment means positioned for coaction with the axially deflected extremity of said member to enable a realignment of said cam-follower means with said ramp surface at the end of said windup stroke.

6. The improvement defined in claim **5** wherein said abutment means is rigid with said cam disk and forms a contact surface engageable by said cam-follower means.

7. The improvement defined in claim **6**, further comprising stationary stop means for arresting said cam disk at the end of said windup stroke in starting position in which said cam-follower means confronts a portion of said contact surface substantially flush with said ramp surface whereby said realignment is facilitated.

8. The improvement defined in claim **7** wherein said cam disk is provided with a shaft, said abutment means being part of said shaft.

9. The improvement defined in claim **1**, further comprising ancillary diaphragm-adjusting means linked with said extremity.

* * * * *

United States Patent [19]

Baab et al.

[11] **4,079,401**

[45] **Mar. 14, 1978**

[54] **DIAPHRAGM PRESELECTOR FOR CAMERA OBJECTIVE**

[75] Inventors: **Albert Baab; Paul Himmelsbach,** both of Bad Kreuznach, Germany

[73] Assignee: **Jos. Schneider & Co. Optische Werke Kreuznach,** Bad Kreuznach, Germany

[21] Appl. No.: **752,833**

[22] Filed: **Dec. 21, 1976**

[30] **Foreign Application Priority Data**

Dec. 22, 1975 Germany 2557855

[51] **Int. Cl.**[2] **G03B 9/02**

[52] **U.S. Cl.** **354/272;** 354/274

[58] **Field of Search** 354/272, 270, 274

[56] **References Cited**

U.S. PATENT DOCUMENTS

3,715,965 2/1973 Alfredsson 354/274

Primary Examiner—John Gonzales
Attorney, Agent, or Firm—Karl F. Ross

[57] **ABSTRACT**

An iris diaphragm of a reflex camera, spring-biased into a wide-open position, is settable to a preselectable stop position via a linkage including a cam follower on a swing ring oscillatable about an off-axial fulcrum. The cam follower coacts with a cam disk which is manually rotated against the force of a restoring spring during a windup operation and, upon subsequent release, displaces the cam follower and the swing ring which entrains the setting ring of the diaphragm through a yieldable coupling to the selected stop position and restores it to the wide-open position in the course of a revolution. During windup, a beveled flank on the high dwell of the cam disk oscillates the swing ring and entrains the setting ring for another brief but ineffectual reduction in the diaphragm aperture.

5 Claims, 3 Drawing Figures

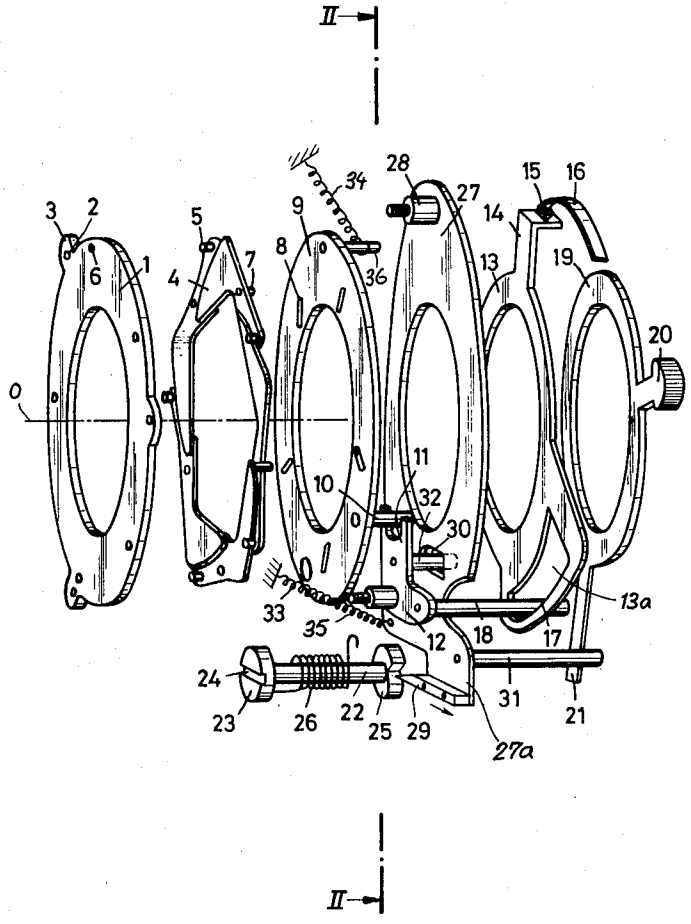

Fig. 1

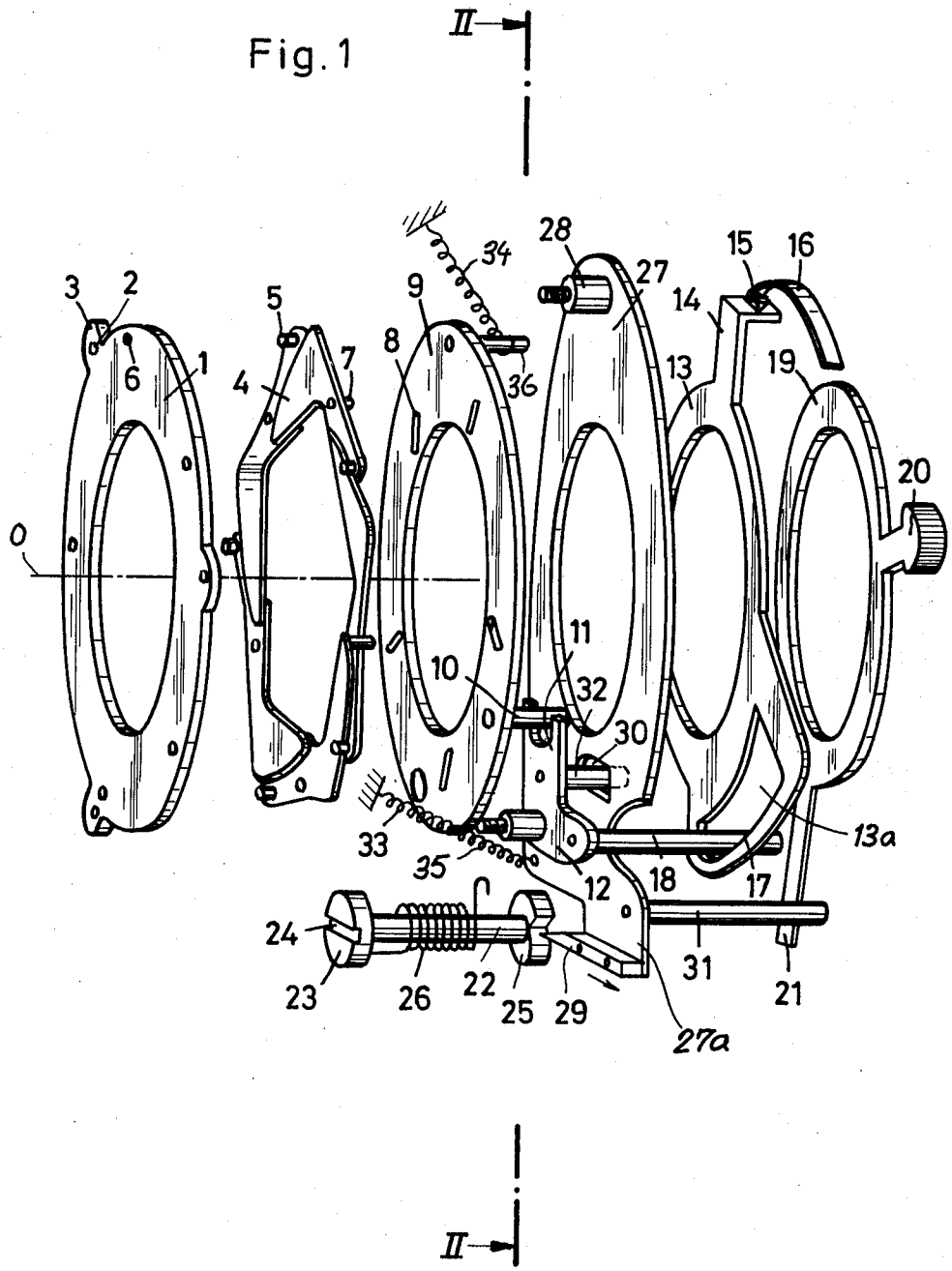
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Fig. 2

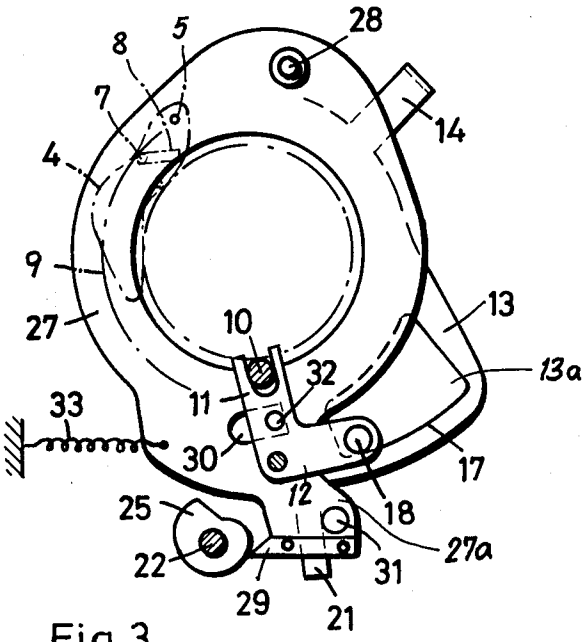
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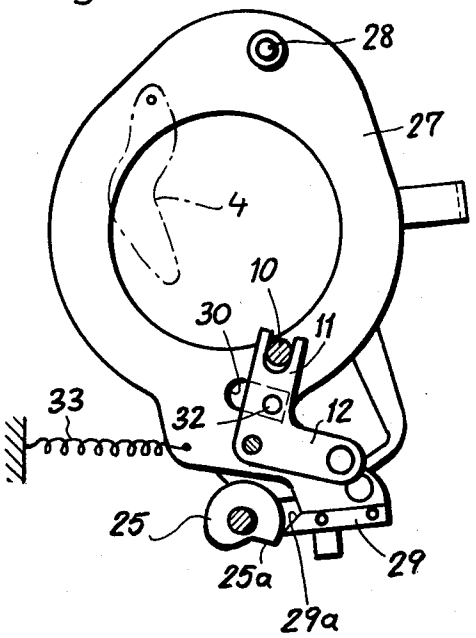
Fig. 3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DIAPHRAGM PRESELECTOR FOR CAMERA OBJECTIVE

FIELD OF THE INVENTION

Our present invention relates to an iris diaphragm for a camera equipped with a reflex-type viewfinder.

BACKGROUND OF THE INVENTION

In such cameras, especially in those provided with interchangeable objectives in which the reflex mirror must be disposed behind an iris diaphragm, it is known to provide a preselector which is adjustable to a desired stop position, the diaphragm being normally biased into its wide-open position from which it is briefly displaced into the preselected position just before the tripping of a shutter by a release button or the like. This enables the operator to use full illumination when sighting and focusing upon an object to be photographed.

Such cameras are generally equipped with a windup handle which is manually operated to advance the film, cock the shutter and possibly carry out additional functions such as reactivating the viewfinder after its disablement upon the previous exposure. With the subsequent actuation of the shutter release, by which a control member coupled with the handle is returned to its original position by a restoring spring, the motion of this control member can be utilized to displace the iris diaphragm into its selected stop position and back to its wide-open position in timed relationship with the opening and closure of the shutter. Such an arrangement, which does not use the windup stroke itself for diaphragm control, has been disclosed in German Pat. No. 2,062,230. That system comprises a cam disk executing a full forward rotation during the windup stroke and a full reverse rotation during the return stroke, a coacting cam follower being connected with the setting ring of the diaphragm through a linkage including a yieldable coupling. The linkage further comprises a relatively complicated system of levers and springs designated to facilitate the escapement of the cam follower during the next windup stroke without entrainment of the setting ring.

OBJECT OF THE INVENTION

The object of our present invention is to provide an improved preselecting mechanism of this character which is of simplified construction and has a reduced number of relatively movable parts.

SUMMARY OF THE INVENTION

In accordance with our present improvement, the linkage between the cam follower and the setting ring of the iris diaphragm comprises a swingable member having a fulcrum offset from the diaphragm axis (which is also the axis of the associated objective), the cam follower being rigid with an extremity of this member which lies substantially diametrically opposite the fulcrum with reference to that axis.

In a preferred embodiment of our invention, the swingable member comprises an oscillating ring substantially centered on the diaphragm axis at least in the wide-open position in which the cam follower engages a low dwell of the coacting cam disk, the aforementioned extremity being an extension of this ring.

BRIEF DESCRIPTION OF THE DRAWING

The above and other features of our invention will now be described in detail with reference to the accompanying drawing in which:

FIG. **1** is an exploded perspective view of an iris diaphragm and an associated preselecting mechanism according to our invention;

FIG. **2** is an axial view of part of the assembly, taken on the line II—II of FIG. **1**; and

FIG. **3** is a view similar to FIG. **2**, showing an alternate position.

SPECIFIC DESCRIPTION

In order to facilitate a comparison between the system of the aforementioned German Pat. No. 2,062,230 and our present improvement, the same reference numerals have been used wherever practical. The illustrated assembly comprises a mounting ring **1** of an iris diaphragm having lugs **3** with holes **2** for pins **5** of a set of iris leaves **4** having other pins **7** receivable in inclined guide slots **8** of a setting ring **9** rotatable with reference to ring **1** about a common axis O. A preselecting ring **13**, centered on the same axis, carries a lug **14** with a pointer **15** co-operating with a stationary diaphragm scale **16**. Ring **13** has a cutout **13***a* with an edge **17**, not centered on the diaphragm axis, engageable by a pin **18** on an arm **12** of a bell-crank lever having a fixed fulcrum **35**. A second arm **11** of this lever has a bifurcate end engaging a stud **10** which is rigid with setting ring **9**. Another stud **36** on ring **9** is connected to a coil spring **34** which is anchored to the objective housing and tends to rotate the ring **9** counterclockwise (as viewed in FIGS. **2** and **3**) into a wide-open position in which the iris leaves **4** are fully withdrawn as shown in FIGS. **1** and **2**. With pointer **15** confronting a selected mark on scale **16**, the curvature of edge **17** determines a point beyond which the ring **9** will not be able to rotate clockwise against the force of spring **34**.

In accordance with our present invention, an oscillating ring **27** is swingable about a fixed fulcrum **28** on one side of the objective axis O, i.e. at the top as shown in the drawing, and is provided at its opposite side (thus at the bottom) with an extension **27***a* rigidly connected with a cam follower **29**. The latter coacts with a cam disk **25** on a shaft **22** having a coupling head **23** provided with a slot **24** through which it is linked with a nonillustrated control element, such as a shaft of a pinion driven through approximately 360° upon the displacement of a windup handle coupled with a gear or rack in mesh with that pinion. A restoring spring **26** is tensioned during a clockwise windup stroke after which the shaft **22** and the disk **25** are latched in the position of FIG. **2**, with the cam follower **29** urged by a spring **33** against a low dwell of the disk. A pin **32** on lever arm **12** passes through a slot **30** of ring **27** and is normally held against the right-hand end of that slot (as viewed in FIGS. **2** and **3**) by the spring **34** acting through ring **9** and stud **10**; pin **32** and slot **30** thus constitute a yieldable lost-motion coupling between setting ring **9** and cam follower **29**.

Upon the tripping of the shutter release, the nonillustrated control element coupled with shaft **22** is unlatched whereupon spring **26** rotates the shaft and cam disk **25** counterclockwise. Cam follower **29**, riding on the surface of disk **25**, is progressively displaced toward the right and eventually comes to rest on the high dwell of the cam after about half a revolution. At or before

this point, depending upon the setting of preselector ring **13**, pin **18** contacts the edge **17** of that ring so that setting ring **9** is no longer entrained and iris leaves **4** occupy the selected position as diagrammatically illustrated for one of these leaves in FIG. **3**. Next, the nonillustrated camera shutter is briefly opened with stoppage of the return rotation of shaft **22**, if necessary, to expose the film. Thereafter, as cam disk **25** continues its rotation beyond the position of FIG. **3** into substantially its starting position in FIG. **1**, cam followr **29** drops back onto the low dwell of disk **25** and restores the setting ring to normal, thereby returning the diaphragm to its wide-open position shown in FIG. **2**. Swing ring **27** also reverts to its normal position centered on axis O.

During the next windup stroke, a beveled flank **25***a* extending from the high dwell of cam disk **25** to its low dwell coacts with an oppositely beveled edge **29***a* of cam follower **29** whereby setting ring **9** is again briefly rotated into and out of its preselected position; since the viewfinder is generally not used at this time, and may even be obstructed by the control mechanism, this brief reduction in the illumination of the reflex mirror is of no consequence.

As in the prior German patent referred to above, an ancillary ring **19** also centered on axis O is provided with a handle **20** by which it may be rotated to reduce the diaphragm aperture independently of the shutter release within the limits set by preselector **13**, **14**. Ring **19** has an extension **21** engaging a pin **31** on ring extension **27***a* whereby counterclockwise rotation of ring **19** separates the cam follower **29** from cam disk **25** within the limits established by curve **17** of ring **13**.

The compact preselection mechanism according to our invention links the setting ring **9** and the cam follower **29** through the intermediary of only two relatively movable members forming a lost-motion coupling therebetween, i.e. the oscillating ring **27** and the bell-crank lever **11**, **12** establishing a positive connection between ring **9** and pin **32**; there is no need for a biasing spring acting upon that lever. This minimizes the risk of malfunction due to spring fatigue or similar mechanical failures.

We claim:

1. In a reflex camera having an iris diaphragm centered on an optical axis and provided with a setting ring rotatable about said axis, biasing means engaging said settable ring for urging same into a wide-open diaphragm position, preselector means adjustable to a desired stop position, a spring-loaded cam disk manually rotatable in one direction against its spring force during a windup stroke and rotatable by its spring force in the opposite direction during a picture-taking operation, cam-follower means coacting with said cam disk, and a linkage including a yieldable lost-motion coupling between said cam-follower means and said setting ring engageable with said preselector means for entraining said setting ring into the desired stop position,

the improvement wherein said linkage comprises a swingable member having a fulcrum offset from said axis, said cam-follower means being rigid with an extremity of said member substantially diametrically opposite said fulcrum with reference to said axis.

2. The improvement defined in claim **1** wherein said member is an oscillatable ring substantially centered on said axis in said wide-open position.

3. The improvement defined in claim **2** wherein said yieldable coupling includes a pin positively connected with said setting ring and urged by said biasing means against an edge of a slot in said oscillatable ring traversed by said pin.

4. The improvement defined in claim **1** wherein said cam disk has a low dwell engaged by said cam-follower means in said wide-open position and a high dwell engaged by said cam-follower means at an intermediate point of a windup stroke, said high dwell being separated from said low dwell by a beveled flank momentarily repressing said cam-follower means during the windup stroke with subsequent re-establishment of the wide-open position at the end of said stroke.

5. The improvement defined in claim **1**, further comprising ancillary diaphragm-adjusting means linked with said extremity.

* * * * *

United States Patent [19]

Ross

[11] **4,072,396**

[45] **Feb. 7, 1978**

[54] **FOCUSSING OBJECTIVE MECHANISM FOR TELESCOPIC RIFLE SIGHTS**

[75] Inventor: **Cecil Jack Ross**, El Paso, Tex.

[73] Assignee: **W. R. Weaver**, El Paso, Tex.

[21] Appl. No.: **594,904**

[22] Filed: **July 10, 1975**

[51] **Int. Cl.**[2] **G02B 7/04**

[52] **U.S. Cl.** **350/46**; 350/255

[58] **Field of Search** ..... 350/46, 47, 10, 41, 350/44, 187, 255; 354/195; 74/567, 569; 192/93 A

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3,336,831	8/1967	Unertl	350/46 X
3,431,052	3/1969	Jacknau	354/195 X
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3,516,736	6/1970	Weaver	350/255

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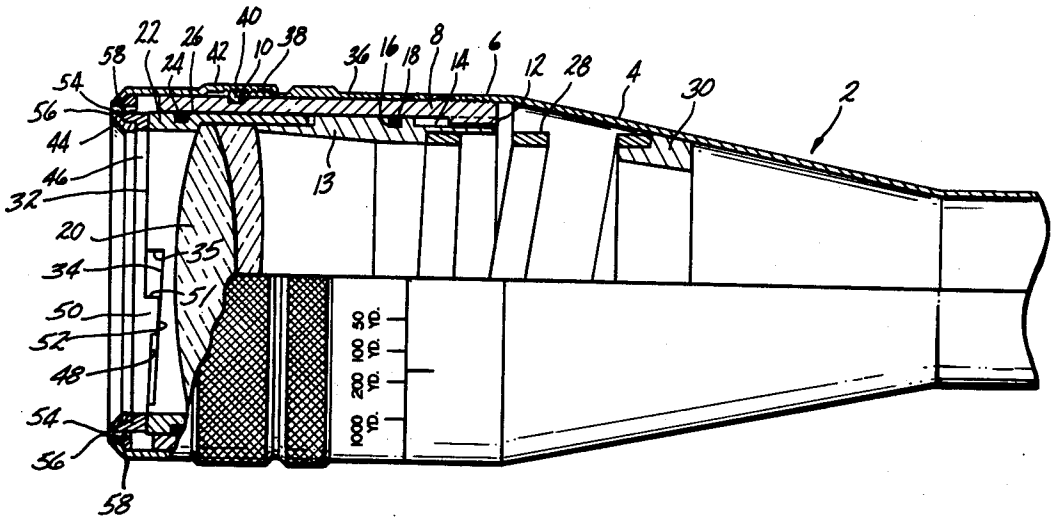
Primary Examiner—David H. Rubin

Attorney, Agent, or Firm—William W. Jones; Paul J. Lerner

[57] **ABSTRACT**

A mechanism for focussing the objective lens assembly of a variable power telescopic rifle sight. A rotatable cam ring is used in conjunction with a coil spring which urges the lens assembly against the cam ring. A lens retainer portion of the lens assembly adjacent to the cam ring has formed thereon a camming ramp which is complimentary to a camming surface formed on the cam ring.

5 Claims, 3 Drawing Figures



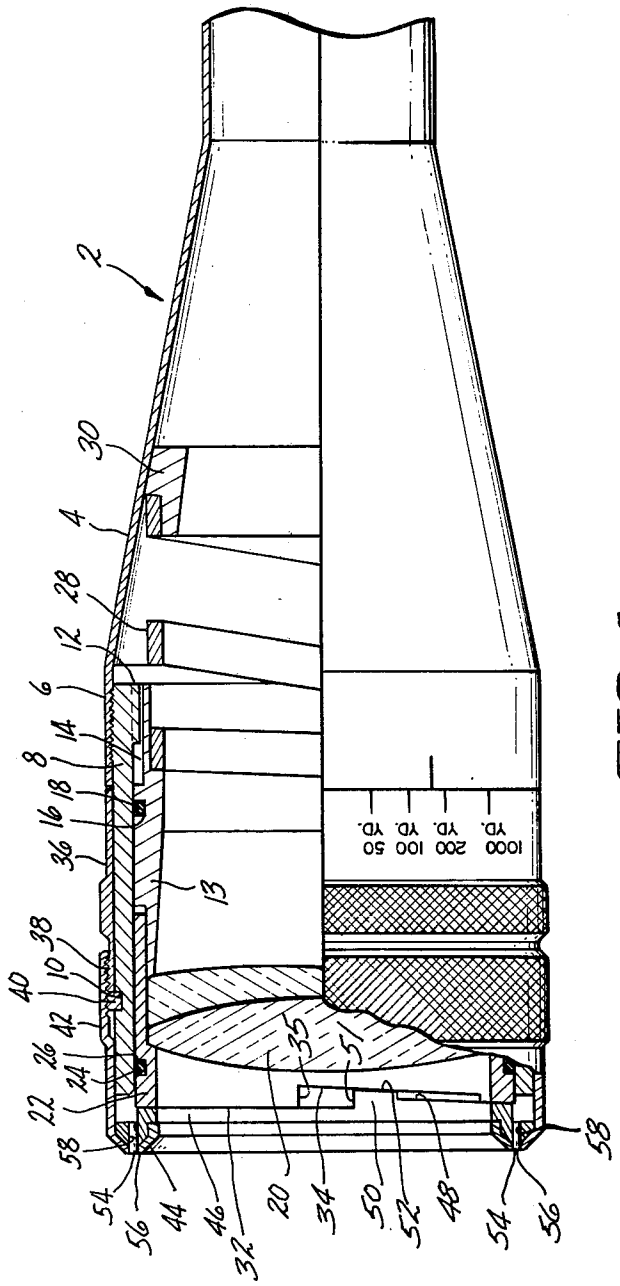


FIG-1

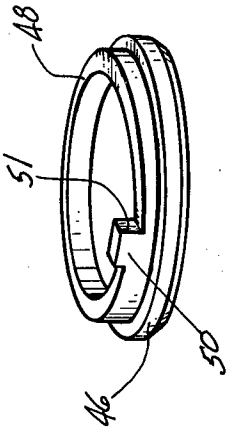


FIG-3

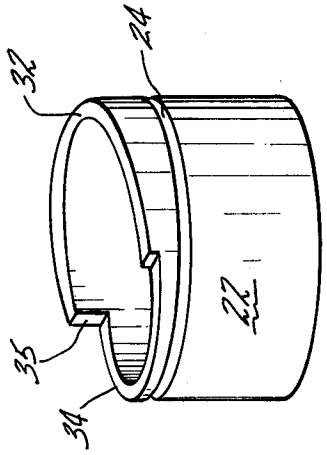


FIG-2

FOCUSSING OBJECTIVE MECHANISM FOR TELESCOPIC RIFLE SIGHTS

This invention relates to a mechanism used to focus the objective lens of a telescopic rifle sight. More particularly, the mechanism of this invention utilizes a rotatable cam ring and coil spring combination to move the objective lens cell for focussing, rather than a pin and cam slot or threaded collar.

The use of an objective lens which can be focussed on objects which are different distances from the viewer is an old concept in the optical instrument art. Such focussing arrangements can be preset as to distance so as to give a clear image as, for example, with a camera. They can also be used on other optical instruments, such as range finders, rifle scopes, and the like to bring a viewed object into focus, thereby determining the range or distance of the viewed object from the viewer from a vernier disposed on the instrument.

Optical instruments such as rifle scopes which have been equipped with focussing objective lens mechanisms have, for the most part, employed a pin and cam slot mechanism for moving the objective lens assembly during focussing. U.S. Pat. No. 3,336,831, issued Aug. 22, 1967 to J. Unertl, Jr. discloses a pin and cam slot focussing arrangement which is typical of the prior art. Another focussing arrangement disclosed in the prior art involves the use of a threaded end cap which, by reason of its threads, can be turned and moved longitudinally along the scope barrel. The threaded end cap bears against an objective lens cell assembly which is spring-biased and which follows the end cap for focussing. This structure is shown in U.S. Pat. No. 3,516,736, issued June 23, 1970 to W. R. Weaver.

The focussing assemblies for objective lenses which are found in the prior art have proved generally functional, but have presented problems relating to their ability to repeat proper focus at the predetermined ranges. These problems arise from wear on the pin and cam slot, and the presence of some degree of backlash when the focussing ring is rotated in opposite directions. The problem of wear and fouling of scope barrel threads also is found in connection with the threaded cap focussing system described above. The wearing problem is magnified in the prior art systems mainly because of the minimum surface contact area between the cam surface and the cam follower.

The focussing system of this invention involves the use of a rotating cam ring having a profiled cam surface in the form of an inclined ramp on one of its faces. The objective lens holder is formed with a similar or matching cam surface taking the form of an inclined ramp on one of its faces. The matching cam ramps are held in face-to-face contact by a coil spring engaging the objective lens assembly thus providing maximum area contact between the cam ring and the lens assembly. This maximum area contact provides for increased repeatability of focus at predetermined ranges and greatly reduces the deteriorating effects of wear on the several components of the system. The coil spring eliminates the problem of backlash found in the prior art camtype focussing systems.

It is, therefore, an object of this invention to provide an objective lens focussing system for a riflescope, which focussing system produces repeatable focussing on a target at different predetermined ranges.

It is a further object of this invention to provide a focussing system of the character described wherein minimum wear of the system components is encountered.

It is yet another object of this invention to provide a focussing system of the character described wherein backlash is minimized during focussing and re-focussing.

These and other objects and advantages of the focussing system of this invention will become more readily apparent to those skilled in the art from the following detailed description of an embodiment of the invention taken in conjunction with the accompanying drawings, in which:

FIG. **1** is an axial sectional view of the objective end of a riflescope formed in accordance with the invention;

FIG. **2** is a perspective view of the front objective lens cell part of FIG. **1** showing the cam ramp end thereof; and

FIG. **3** is a perspective view of the cam ring showing the cam ramp surface thereon.

Referring now to the drawings, there is shown in FIG. **1** the objective end portion of a telescopic rifle sight employing the objective lens focussing assembly of this invention. The barrel of the scope is denoted generally by the numeral **2** and includes an outwardly tapering portion **4** and an enlarged internally threaded terminal portion **6**. A tubular scope barrel extension **8** is threaded into the scope barrel terminal **6**. The extension **8** includes an external groove **10** and a longitudinally extending inwardly projecting key **12**.

Inside of the extension there is mounted an objective lens assembly which includes a rear tubular lens cell **13** having a longitudinally extending external slot **14** in which the extension key **12** is disposed. The rear lens cell includes an external groove **16** in which is mounted a gas-sealing O-ring **18**. The objective lens assembly also includes an objective lens doublet **20** and a forward tubular lens cell **22** which telescopes over the rear lens cell **12** and which includes an external groove **24** in which is mounted a gas-sealing O-ring **26**. A coil spring **28** is mounted within the scope barrel **2** and engages a fixed spring seat **30** on one end and the rear objective lens cell **12** on the other end. Thus the objective lens assembly is biased forwardly by the spring **28**. The forward end **32** of the front lens cell **22** takes the form of a helix of predetermined pitch. The helical lens cell end **32** also includes a slot **34** the bottom wall of which is also formed with the predetermined helical pitch.

An annular graduated collar **36** is mounted on the exterior of the barrel extension **8** and includes a forward externally threaded end **38**. The collar **36** is held on the extension **8** against forward movement with respect thereto by a snap-type retaining ring **40** which is mounted in the extension groove **10**. An annular shroud **42** is threaded onto the collar **36** and includes an inwardly turned U-shaped forward end part **44** which serves to retain a cam ring **46** in place forward of the front lens cell **22**. the cam ring **46** is formed with a rear end **48** which takes the form of a helix having the same predetermined pitch as the forward end **32** of the front objective lens cell **22**. The rear end **48** of the cam ring **46** is formed with a rearwardly projecting lug **50** which has a top wall **52** formed with the same predetermined helical pitch as the bottom wall of the front lens cell groove **34**.

While it is preferred to provide the entire ends **32** and **48** of the front lens cell **22** and cam ring **46** respectively,

as well as the bottom wall of the slot **34** and top wall **52** of the lub **50** with the helical pitch so as to maximize the area of contact of the cam actuator, it will be appreciated that only the top wall **52** of the lub **50** and the bottom wall of the slot **34** could be helically pitched, or alternatively, only the remainder of the ends **32** and **48** of the lens cell **22** and cam ring **46** could be pitched to provide the necessary camming action. It will also be appreciated that the lug **50** and slot **34** combine to limit the extent of rotational movement in both directions of the cam ring **46** with respect to the objective lens assembly.

A pair of pins **54** are inserted into aligned holes **56** and **58** drilled in the shroud **42** and cam ring **46** respectively to secure the shroud **42** and cam ring **46** together for concurrent rotation.

The device is assembled as follows. The graduated collar **36** is mounted on the barrel extension **8** and is retained thereon by the retainer ring **40**. Cement is applied to the internal threads of the scope barrel **2** and the barrel extension **8** is screwed into the barrel **2** to a depth that allows no loose linear movement of the graduated collar **36** but permits rotational movement thereof. The cement is then cured and must be free of gas leaks. The objective lens **20** is then cemented inside of the front lens cell **22** and the rear lens cell **13** is then cemented inside of the front lens cell **22**. The cement is cured and must be free of gas leaks. The O-rings **18** and **26** are then positioned on the outside of the objective lens assembly. The cam ring **46** is placed inside of the shroud **42** and both are then placed on an assembly arbor fixture for future adjustment. The coil spring **28** and spring seat **30** are then assembled to the objective lens assembly and then inserted into the scope barrel - barrel extension sub-assembly with the key **12** being inserted into the key slot **14** and the spring **28** is compressed after the spring seat **30** comes into contact with the tapered portion **4** of the scope barrel **2**. The fully compressed spring and lens assembly is held in place temporarily with the barrel and barrel extension by a test fixture. The shroud and cam ring sub-assembly is then moved into place over the barrel extension and then screwed fully onto the threads of the graduated collar **36**.

From FIG. **1**, it will be noted that a vernier scale is formed on the graduated collar **36** and an indicator mark is formed on the enlarged portion **6** of the scope barrel **2**. The partially assembled device is then mounted on a fixture and sighted in on an object which is a known, fixed distnce from the sighting fixture, for example 50 yards away. The proper distance graduation, in this instance, the "50 Yd." graduation is then rotated into alignment with the indicator mark stamped on the scope barrel and the graduated collar **36** is held fixed in this position. The adjustor then looks through the scope at the fixed range target and rotates the shroud **42** in a clockwise direction on its threads. This rotates the cam ring lug **50** until its longest side wall **51** contacts the longest side wall **35** of the front lens cell groove **34**, which is the builtin "low range" stop for the cam ring **46**. The cam ring **46** will then stop rotating but clockwise unscrewing of the shroud **42** is continued resulting in forward axial movement of the objective lens assembly resulting from pressure thereon by the spring **28**. The unscrewing action of the shroud **42** is continued until the scope focuses on the fixed range (50 yd.) target. The scope is then removed from the focussing fixture and cement is applied to the threads of the shroud **42** and graduated collar **36**, which cement is allowed to cure securing the shroud **42** to the collar **36** so that the two will thereafter rotate together. The holes **56–58** are then drilled in the shroud **42** and cam ring **46** and the pins **54** are inserted therein to lock the shroud **42** and cam ring **46** together for concurrent rotation. Assembly is then complete.

It will be readily appreciated that the mating helical cam surfaces on the cam ring and objective lens cell assembly will result in rotational movement of the graduated collar, shroud and cam ring (which rotate together as a unit) being translated into longitudinal movement of the objective lens assembly, aided by the coil spring. This longitudinal movement of the objective lens assembly results in focussing of the scope at predetermined different distances, which are marked on the graduated collar. The use of matched helical cam surfaces on the cam ring and lens cell provides maximum contact area for the focussing mechanism which results in a minimum of wear, and also permits the cam ring and lens cells to be made of molded plastic material, if desired. The coil spring acting in concert with the cam surfaces reduces focussing backlash to a minimum and increases the accuracy of the device. The use of a projecting lug and slot combination in the mating cam surfaces provides convenient high and low range focus stops for the device.

Since many changes and variations of the disclosed embodiment of the invention may be made without departing from the inventive concept, it is not intended to limit the invention otherwise than as required by the appended claims.

What is claimed is:

1. A focussing objective mechanism for a telescopic gun sight comprising in combination:

a. a sight barrel;

b. an objective lens assembly mounted in said barrel for axial reciprocal movement therein, said lens assembly having one end wall thereof formed with a predetermined helical pitch extending for substantially the entire duration of said one end wall;

c. a ring rotatably mounted on said barrel but fixed against axial movement thereon, said ring being adjacent to said lens assembly and having an end surface facing said lens assembly end wall, substantially the entire duration of said end surface which faces said lens assembly end wall being formed with the same predetermined helical pitch as said lens assembly end wall; and

d. spring means engaging said lens assembly to bias said end wall into engagement with said ring end surface.

2. The mechanism of claim **1**, wherein one of said end wall and said end surface is formed with a slot having a bottom wall formed with said predetermined helical pitch, and the other of said end wall and said end surface is formed with a projecting lug having an end wall formed with said predetermined helical pitch, said lug being disposed in said slot, and said slot and said lug having respective side walls forming stops governing the degree of rotation which said ring can undergo.

3. A focussing objective mechanism for a telescopic gun sight comprising in combination:

a. a sight barrel;

b. an objective lens assembly mounted in said barrel for axial reciprocal movement therein, said lens assembly having one end wall thereof formed with a predetermined helical pitch over substantially its entire extent, said end wall including a slot having

a bottom wall formed with said predetermined helical pitch, and said slot having side walls;

c. a ring rotatably mounted on said barrel but fixed against axial movement thereon, said ring being adjacent to said lens assembly and having an end surface formed with said predetermined helical pitch throughout substantially its entire extent, said end surface facing said lens assembly end wall, and said end surface including a projecting lug disposed within the confines of said slot and having an end wall formed with said predetermined helical pitch and side walls, the respective slot and lug side walls forming stops defining the rotational arc through which said ring can be turned; and

d. spring means biasing said lens assembly toward said ring to urge said lens assembly end wall into face-to-face contact with said ring end surface.

4. A focussing objective mechanism for a telescopic gun sight comprising in combination:

a. means forming a sight barrel;

b. an objective lens assembly mounted in said sight barrel for reciprocal axial sliding movement therein, said lens assembly including one end wall formed with a predetermined helical pitch;

c. means fixing said lens assembly against rotational movement in said sight barrel;

d. a focussing collar mounted on said sight barrel for rotational movement thereon, said collar having one end thereof which is threaded;

e. means for preventing said collar from moving axially of said sight barrel;

f. a shroud screwed onto said collar;

g. a camming ring carried by said shroud, said camming ring having an end surface facing said lens assembly end wall, said end surface being formed with the same predetermined helical pitch;

h. spring means engaging said lens assembly to bias said end wall thereof into face-to-face contact with said end surface of said camming ring;

i. means securing said camming ring to said shroud; and

j. means securing said shroud to said collar to prevent said shroud from being unscrewed from said collar and to enable said collar, said shroud and said camming ring to be concurrently rotated to focus said lens assembly at a plurality of different distances from the sight.

5. The mechanism of claim 4, further comprising cooperating slot means and lug means formed on said contacting end wall and end surface of said lens assembly and camming ring, said lug means being disposed in said slot means to form rotational stops for the focussing mechanism.

* * * * *

UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 4,072,396 Dated February 7, 1978

Inventor(s) Cecil Jack Ross

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Col. 3, line 2: "lub" should read --lug--.

Col. 3, line 4: "lub" should read --lug--.

Col. 3, line 49: "distnce" should read --distance--.

Col. 3, line 59: "builtin" should read --built-in--.

Signed and Sealed this

Eleventh Day of *November 1980*

[SEAL]

Attest:

SIDNEY A. DIAMOND

Attesting Officer *Commissioner of Patents and Trademarks*

United States Patent [19]

Lange

[11] **4,070,686**

[45] **Jan. 24, 1978**

[54] **CAMERA WITH ADJUSTABLE OBJECTIVE**

[75] Inventor: **Karl-Heinz Lange**, Bunde, Germany

[73] Assignee: **Balda-Werke Photographische Gerate & Kunststoff GmbH. & Co. KG**, Bunde, Germany

[21] Appl. No.: **752,340**

[22] Filed: **Dec. 20, 1976**

[30] **Foreign Application Priority Data**

July 17, 1976 Germany 2632370
Aug. 16, 1976 Germany 2636795

[51] **Int. Cl.**[2] **G03B 3/00**; G03B 13/02

[52] **U.S. Cl.** **354/195**; 354/221; 354/354

[58] **Field of Search** 354/195, 174, 198, 199, 354/219, 221, 222, 275, 289, 288, 354

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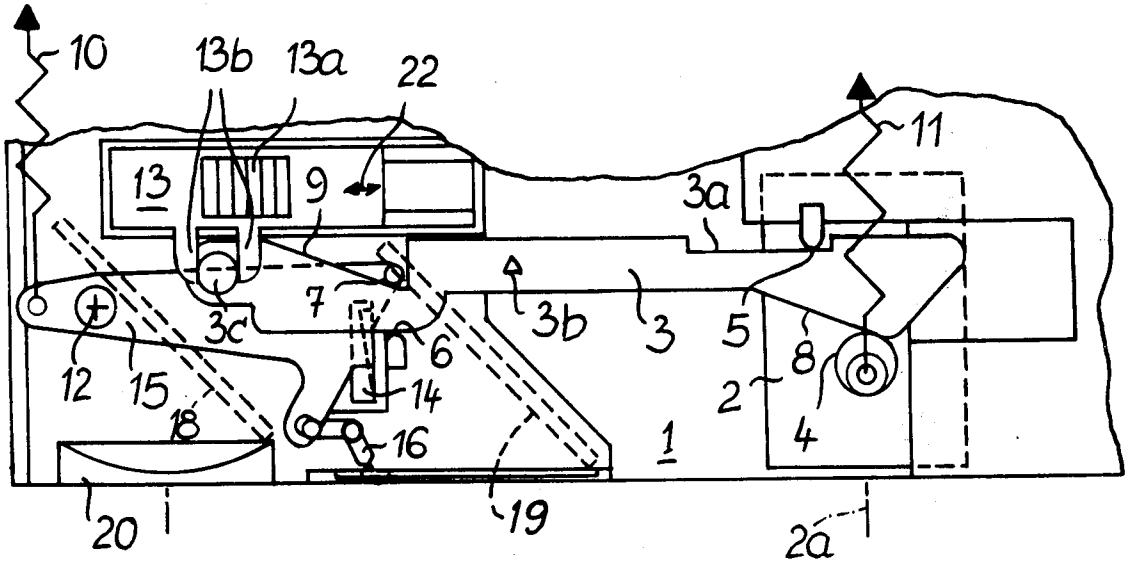
Primary Examiner—Richard A. Wintercorn

Attorney, Agent, or Firm—Blum, Moscovitz, Friedman & Kaplan

[57] **ABSTRACT**

A camera is provided with an objective supported by a housing of the camera for movement along its optical axis. A movable member is guided by the camera housing for movement transversely with respect to the optical axis, and this movable member has a pair of inclined surfaces. These inclined surfaces are inclined both with respect to the optical axis and with respect to the direction of movement of the movable member. A pair of pressing members respectively press against the inclined surfaces of the movable member, a pair of springs acting on the pair of pressing members for urging them against the inclined surfaces, respectively, so that the latter surfaces are slidable with respect to the pressing members engaging the same. One of these pressing members is fixed to the objective so that when the movable member is moved transversely with respect to the optical axis this one pressing member in cooperation with the inclined surface engaging the same will bring about adjustment of the objective along its optical axis. The arrangement of the pair of inclined surfaces of the movable member is such that at all times, irrespective of the position of the movable member, the spring-pressed pressing members provide equal and opposite forces in the direction of movement of the movable member.

6 Claims, 3 Drawing Figures



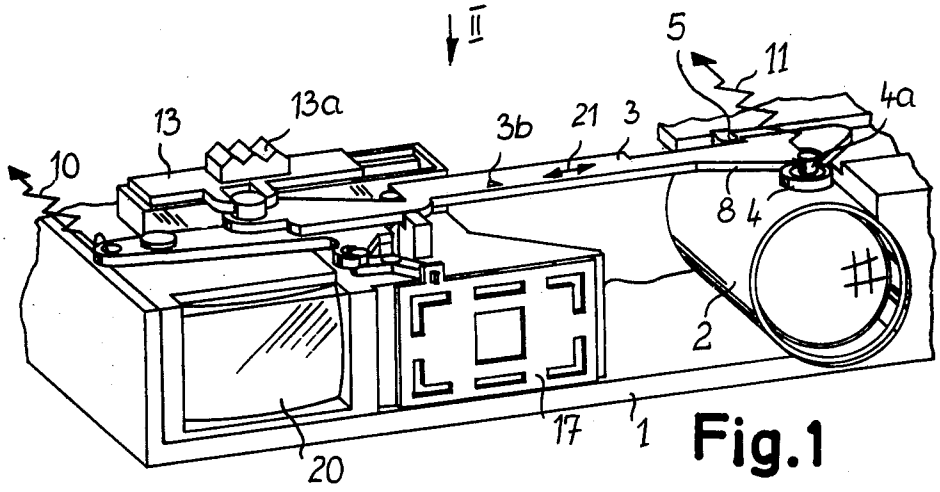


Fig.1

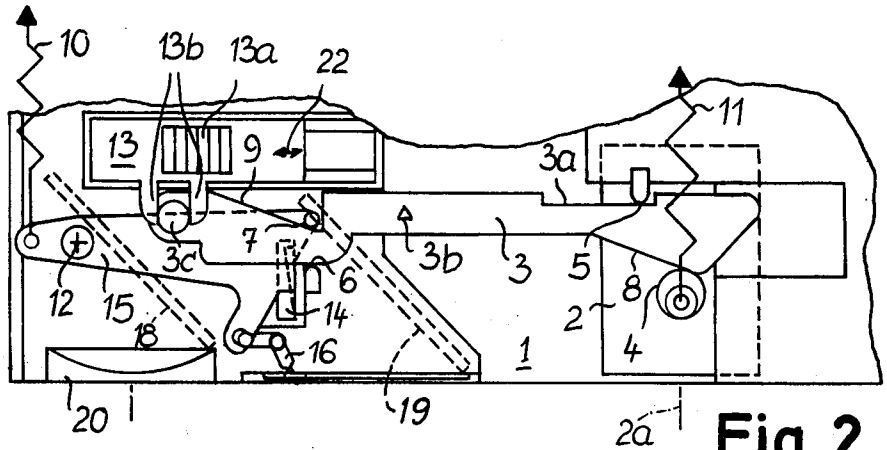
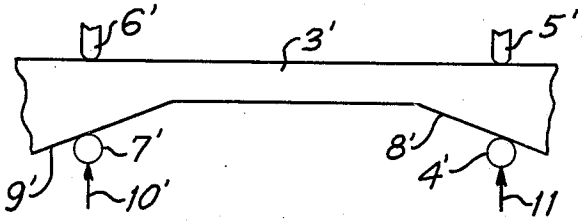


Fig. 2

Fig. 3



CAMERA WITH ADJUSTABLE OBJECTIVE

BACKGROUND OF THE INVENTION

The present invention relates to cameras.

In particular, the present invention relates to cameras having adjustable objectives.

The present invention relates to that type of device according to which an objective can be moved along its optical axis without play upon movement of an adjusting member which extends transversely with respect to the optical axis and which can be moved with respect to the objective, this movable adjusting member having an inclined surface engaged by a member which is fixed to the objective and which is urged against the inclined surface by a spring.

With a known construction of the above type the pressure with which the member fixed to the objective acts against the inclined surface of the transversely movable member can be resolved into a pair of vectors, one of which acts in the direction of the optical axis and the other of which is perpendicular thereto. The component of this force which is perpendicular to the optical axis seeks to overcome the frictional forces which are encountered and to return the movable objective-adjusting member toward a position where this movable adjusting member is free of forces acting on the same. Such movement is prevented by mounting the movable member in such a way that it is difficult to move so as to assure the presence of sufficiently great forces of friction to hold the movable member in its adjusted position. This requirement of a relatively great friction for the member which is moved to adjust the objective has a considerable disadvantage in that the adjustment of this movable member under certain circumstances can only be carried out in a non-uniform manner because the so-called stick-slip effect is encountered. In other words this movable member in a conventional construction does not slide smoothly and instead tends at one time to stick and then at another time to slip easily, rendering it difficult to provide a precise adjustment of the objective.

SUMMARY OF THE INVENTION

A primary object of the present invention is to provide a construction which will avoid the above drawbacks.

In particular, it is an object of the present invention to provide a structure which is capable of moving an objective smoothly and uniformly back and forth along its optical axis while also providing a smooth uniform movement for the movable member which adjusts the objective.

Also, it is an object of the present invention to provide a construction according to which this movable member which adjusts the objective is at all times acted upon by forces which are substantially in equilibrium.

Thus, it is an object of the present invention to provide for a camera objective the possibility of play-free movement thereof completely without any possibility of sudden, jerking movements, especially by providing at the member which adjusts the objective equal and opposite forces which cancel each other.

It is also an object of the present invention to provide a construction which can achieve the above advantages irrespective of whether the objective-adjusting member is in the region of a central position thereof or in the region of one of its end positions.

Furthermore, it is an object of the present invention to provide a construction according to which part of the structure of the invention can be combined with other camera structure such as, for example, range-finder structure, paralax-compensating structure, or automatic flash-control structure.

According to the invention the camera has an objective means which is provided with an optical axis and which is guided for movement along its optical axis by a housing means of the camera, this housing means also guiding a movable means for movement transversely with respect to the optical axis. A pair of inclined surface means are connected to and form part of the movable means and a pair of pressing means respectively press against and slidably engage the pair of inclined surface means. A pair of spring means cooperate with the pair of pressing means for pressing the latter against the pair of inclined surface means. One of the pressing means is fixed with the objective means so that when the movable means is moved transversely of the optical axis one of the inclined surface means cooperates with the pressing means fixed to the objective means for adjusting the objective along its optical axis. The pair of inclined surface means cooperate with the pressing means for providing at all positions of the movable means equal and opposite forces in the direction of movement of the movable means, so that the latter is maintained in equilibrium at all of its positions.

BRIEF DESCRIPTION OF DRAWINGS

The invention is illustrated by way of example in the accompanying drawings which form part of this application and in which:

FIG. 1 is a schematic fragmentary perspective illustration of part of a camera provided with the structure of the invention;

FIG. 2 is a fragmentary schematic top plan view of the structure of FIG. 1 as seen in the direction of the arrow II of FIG. 1; and

FIG. 3 is a schematic illustration of another embodiment of the invention.

DESCRIPTION OF PREFERRED EMBODIMENTS

Referring to FIGS. 1 and 2, the camera illustrated therein includes a housing means 1 which carries an objective means 2 and which guides the objective means for movement along its optical axis 2*a*. The objective means 2 carries a pressing means 4 in the form of a circular member which is eccentrically mounted for angular adjustment so as to have its eccentricity adjusted in a known way, this pressing means 4 being formed with an opening through which a pin 4*a* extends, this pin 4*a* being fixed to and projecting from the objective means 2. A spring means 11 is operatively connected with the pin 4*a*, this spring being fixed distant from the pin 4*a* to a stationary part of the housing 1, so that the spring means 11 acts on the pressing means 4, 4*a* to urge the objective means 2 rearwardly along its optical axis. Through the spring means 11 the pressing means 4, 4*a* is urged against an inclined surface means 8 which forms part of a movable means 3 which is guided by the housing means 1 for movement, as shown by the double-headed arrow 21, in opposite directions transversely with respect to the optical axis. Thus, the movable means 3 is guided by the housing means 1 for movement in a direction parallel to the film plane and perpendicular with respect to the optical axis 2*a*. For the pur-

pose of guiding the movable means **3** the housing means **1** carries a stationary bearing member **5** which has a convex end surface engaging a longitudinal side surface **3***a* of the movable means **3**, this side surface **3***a* being formed by the inner surface of a notch which is formed along the rear longitudinal edge of the transversely movable objective-adjusting means **3**. Thus the member **5** forms a bearing member for the movable means **3** and has a substantially line-contact therewith.

The movable means **3** has a longitudinal side surface opposed to the side surface **3***a* and engaged by a second bearing member **6** fixedly carried by the housing means **1**, and forming a part thereof, this bearing member **6** also having a convex surface engaging a longitudinal side surface of the member **3** so as to have a substantially line-contact therewith. At the side of member **3** which is opposite from the bearing member **6**, the member **3** has a second inclined surface means **9** which it will be noted is inclined in the same direction as the inclined surface means **8**. A pressing means **7** presses against the inclined surface means **9**, this pressing means **7** being in the form of a pin carried by a lever **15** which is supported for turning movement about a stationary pivot pin **12** carried by the camera housing **1**, and through the lever **15** a spring means **10** acts on the pressing means **7** to urge the latter into engagement with the inclined surface means **9**. This spring means **10** is fixed distant from the lever **15** to a stationary part of the housing **1**. Thus, the pair of pressing means **4** and **7** are respectively urged by the pair of spring means **11** and **10** against the pair of inclined surface means **8** and **9** so as to press against the same, while the pair of inclined surface means **8** and **9** are respectively slidable with respect to the pair of pressing means **4** and **7**.

The camera housing **1** carries a manually shiftable member **13** having a portion **13***a* capable of being conveniently engaged by the operator. This member **13** can be moved back and forth by the operator on suitable guides in the directions indicated by the double-headed arrow **22**. This manually shiftable member **13** has a pair of fingers **13***b* defining between themselves a space which receives a pin **3***c* which is fixed to and projects upwardly from the transversely movable means **3**. Thus, when the operator moves the member **13** by engaging the portion **13***a* thereof, in the direction indicated by the arrow **22**, the movable means **3** is moved by engagement of one or the other of the fingers **13***b* with the pin **3***c*, so that in this way the movable means **3** is moved to the right or left, as viewed in FIGS. **1** and **2**. Thus, the member **13** receives the force exerted by the operator and transmits this force only in one or the other of the directions indicated by the double-headed arrow **22**, so that only horizontal forces are transmitted from the member **13** to the movable means **3**.

Of course, the movable means **3** is urged against the bearing member **5** by the spring-pressed pin **4**, and since the pin **4** is out of line with the bearing member **5** it seeks to turn the member **3** about the member **5** in a counterclockwise direction, as viewed in FIG. **2**, thus pressing the movable means **3** against the guide member **6**. This force with which the movable means **3** is urged against the bearing member **6** by way of the action of members **4** and **5** is augmented by the force of the spring **10** acting on the pin or pressing member **7**. Thus this member **7** also seeks to press the member **3** against both of the bearing members **5** and **6**.

As a result of the force provided at the pressing means **4** by way of the spring **11**, this pressing means **4** cooperates with the inclined surface means **8** to tend to urge the movable means **3** toward the right, as viewed in FIGS. **1** and **2**. However, the spring **10** acts through the lever **15**, swingable on the pivot pin **12**, to provide at the pressing means **7** on the inclined surface means **9** a force which urges the movable means **3** toward the left, as viewed in FIGS. **1** and **2**. Because the pair of inclined surface means **8** and **9** have the same inclination, being parallel to each other, by suitable selection of the spring forces, the components of force which are opposite to each other and which are perpendicular to the optical axis **2***a* are equal to each other. Thus, the movable means **3** will be in equilibrium in all of its positions.

In the example illustrated the lever **15** is operatively connected with a wedge-shaped lens **14** utilized for range-finder purposes. Moreover, the lever **15** acts through a lever **16** on a framing member **17** which has openings shaped as shown in FIG. **1** to provide in a known way in the field of the viewfinder an image of the frame in which the viewed image will be photographed. The viewfinder lens **20** is also shown in FIGS. **1** and **2** as well as the mirror or reflector **19** and the semi-transparent reflector or mirror **18**.

It will be noted that the movable means **3** carries an index **3***b*. This index is movable along an unillustrated scale indicating the distance between the object to be photographed and the camera.

Of course, certain variations are possible. Thus there is schematically shown in FIG. **3** an embodiment according to which the movable means **3'** corresponding to the means **3** has one longitudinal side surface engaging a pair of bearing members **5'** and **6'** respectively corresponding to the bearing members **5** and **6**. At its opposite longitudinal side surface the movable means **3'** of FIG. **3** is provided with a pair of inclined surface means **8'** and **9'** which it will be noted are oppositely inclined. The pair of pressing means **4'** and **7'**, corresponding respectively to the pair of pressing means **4** and **7**, press against the pair of inclined surface means **8'** and **9'**. FIG. **3** schematically illustrates a spring means **10'** acting on the pressing means **7'** for urging the latter against the inclined surface means **9'** as well as a spring means **11'** acting on the pin means **4'** for urging the latter against the inclined surface means **8'**. Of course, the pin means **4'** of FIG. **3** is fixed to the objective while the pin means **7'** can be carried by a swingable lever which is acted upon by a spring in the same way as in FIG. **2**. Thus it will be seen that the embodiment of FIG. **3** also can achieve the results of the invention inasmuch as the forces with which the members **7'** and **4'** are urged against the inclined surfaces **9'** and **8'** can be resolved into components which include components directed respectively to the left and right as viewed in FIG. **3**, the arrangement being such that these latter oppositely directed components are equal to each other at all times, thus achieving in this way the results set forth above.

It is thus apparent that with the structure of the invention it is possible to achieve for the objective a smooth movement free of any play. With the known construction having only one inclined surface and only one spring urging a pin into engagement with this one inclined surface, the force required to adjust the objective will vary with different adjusting directions. In one direction of adjustment it is necessary to tension the spring as well as to overcome the forces of friction. In the opposite direction of adjustment the force stored in

the spring will itself contribute to overcoming the friction force, so that uniformity in both directions of adjustment cannot be achieved with a conventional construction, whereas such uniformity is indeed achieved with the structure of the invention.

Thus, in contrast with the above conventional construction, with the structure of the invention the movable means is in all of its positions in a condition of equilibrium. The same force is required to move the movable means in one direction as in the opposite direction. Moreover the magnitude of the adjusting force remains practically the same at all positions of adjustment. It is immaterial whether the movable means **3** is at a central position or at the region of one of its end positions.

Of course, it is of advantage to utilize the lever **15** not only for transmitting the spring force of the spring **10** to the pressing means **7** but also to actuate other components such as those utilized in connection with range-finding, parallax compensation, or operation of a component such as the diaphragm of a flash device.

What is claimed is:

1. In a camera, objective means having an optical axis, housing means guiding said objective means for movement along said optical axis thereof, movable means guided by said housing means transversely with respect to said optical axis, a pair of inclined surface means connected with and forming part of said movable means and each being inclined both with respect to the direction of movement of said movable means and with respect to said optical axis, a pair of pressing means respectively pressing against and slidably engaging said pair of inclined surface means, one of said pressing means being fixed to said objective means, and a pair of spring means respectively connected operatively with said pair of pressing means for respectively urging the latter against said pair of inclined surface means, said movable means when moved transversely with respect to said optical axis acting through one of said inclined surface means on said one pressing means which is fixed to said objective means for moving the latter along said optical axis, and said pair of inclined surface means respectively cooperating with said pair of pressing means for providing at all positions of said movable means equal and opposite forces in the direction of movement of said movable means.

2. The combination of claim **1** and wherein, for guiding said movable means, said housing means carries a pair of bearing members which are stationary with respect to said housing means and with respect to said movable means, said movable means slidably engaging said bearing members to be guided thereby.

3. The combination of claim **2** and wherein said movable means is of an elongated configuration and in its longitudinal direction extends transversely with respect to said optical axis, said movable means having a pair of opposed longitudinal side surfaces, and said pair of bearing members respectively engaging said pair of opposed longitudinal side surfaces of said movable means, said pair of inclined surface means being inclined in the same direction and also being respectively situated in the region of said opposed longitudinal side surfaces of said movable means.

4. The combination of claim **2** and wherein said movable means is of an elongated configuration and in its longitudinal direction extends transversely with respect to said optical axis, said movable means having a pair of opposed longitudinal side surfaces, and said pair of bearing members both engaging one of said longitudinal side surfaces of said movable means, said pair of inclined surface means respectively being oppositely inclined and both being situated at the region of the other of said longitudinal side surfaces of said movable means.

5. The combination of claim **1** and wherein a lever is swingably carried by said housing means, said lever carrying the other of said pressing means.

6. The combination of claim **5** and wherein said lever forms part of said spring means which acts on said other pressing means, the latter spring means including a spring connected directly to said lever for acting through the latter on said other pressing means.

* * * * *

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[11] 4,063,801
[45] Dec. 20, 1977

[54] **TELEPHOTO TYPE OBJECTIVE**

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[73] Assignee: **Canon Kabushiki Kaisha**, Tokyo, Japan

[21] Appl. No.: **708,302**

[22] Filed: **July 26, 1976**

[30] **Foreign Application Priority Data**

Aug. 5, 1975 Japan 50-95119

[51] **Int. Cl.²** **G02B 9/60**
[52] **U.S. Cl.** **350/216**
[58] **Field of Search** 350/214, 216, 255; 354/197

[56] **References Cited**

U.S. PATENT DOCUMENTS

2,503,789	4/1950	Wood et al.	350/255
3,854,797	12/1974	Yokota	350/214

Primary Examiner—Paul A. Sacher
Attorney, Agent, or Firm—Toren, McGeady and Stanger

[57] **ABSTRACT**

A telephoto type objective comprising a front lens group and a rear lens group axially spaced apart from each other. The front lens group has a positive refracting power and which remains stationary during focusing. The rear lens group has a negative refracting power and is comprised of two movable lens members for focusing. When the two movable lens members are moved along the optical axis toward an image plane, the telephoto type objective is caused to focus an object at a near distance from its focusing on an object at a far distance with the resulting amount of movement of the rear lens member being larger than that of movement of the front movable lens group.

13 Claims, 18 Drawing Figures

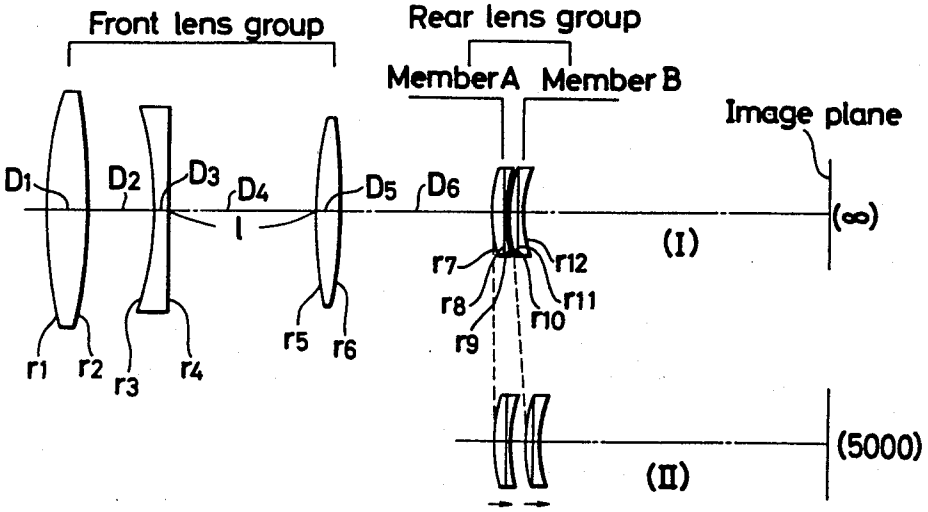
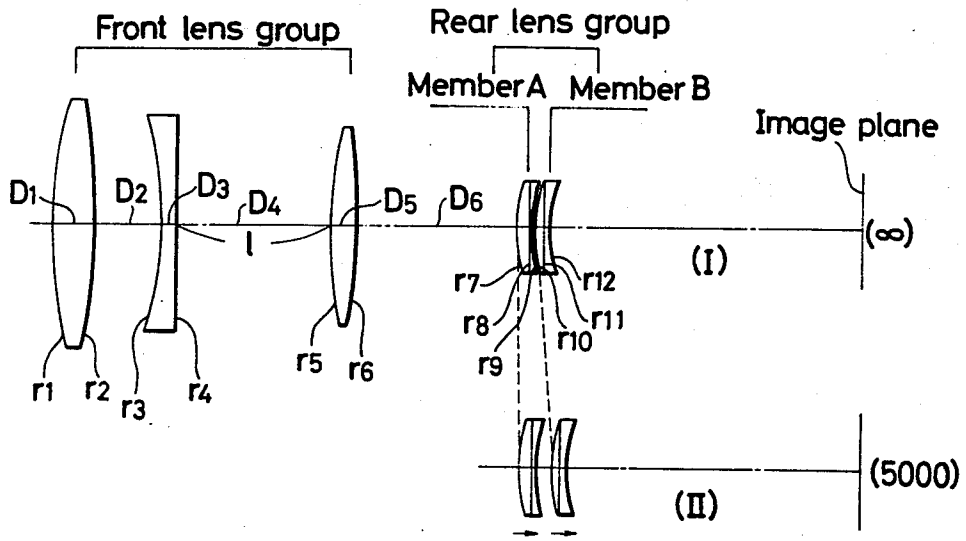


FIG. 1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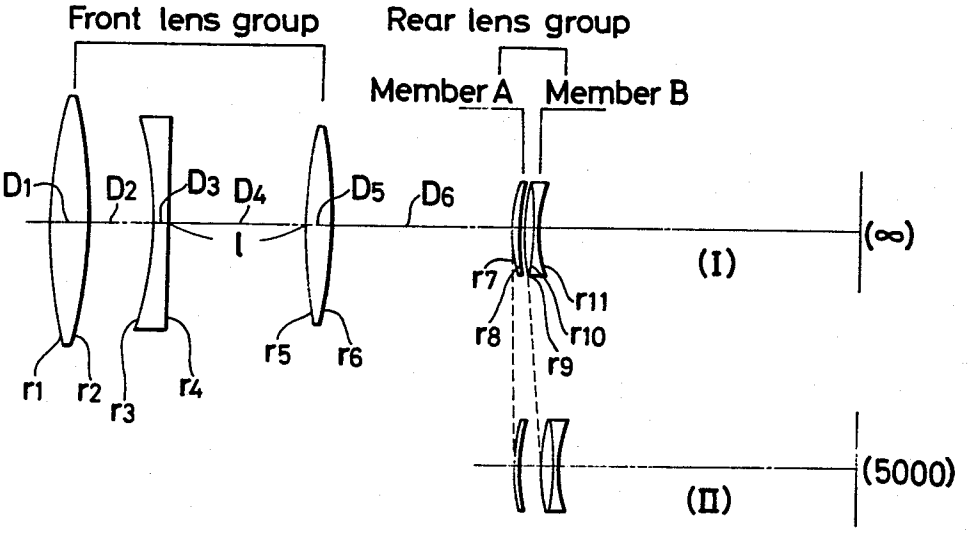
Rear lens group
Member A
Member B
Image plane
D1
D2
D3
D4
D5
D6
l
(∞)
(I)
r1
r2
r3
r4
r5
r6
r7
r8
r9
r10
r11
r12
(5000)
(II)

FIG. 3


Front lens group
Rear lens group
Member A
Member B
D1
D2
D3
D4
D5
D6
l
(∞)
(I)
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r3
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r5
r6
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r8
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r11
(5000)
(II)

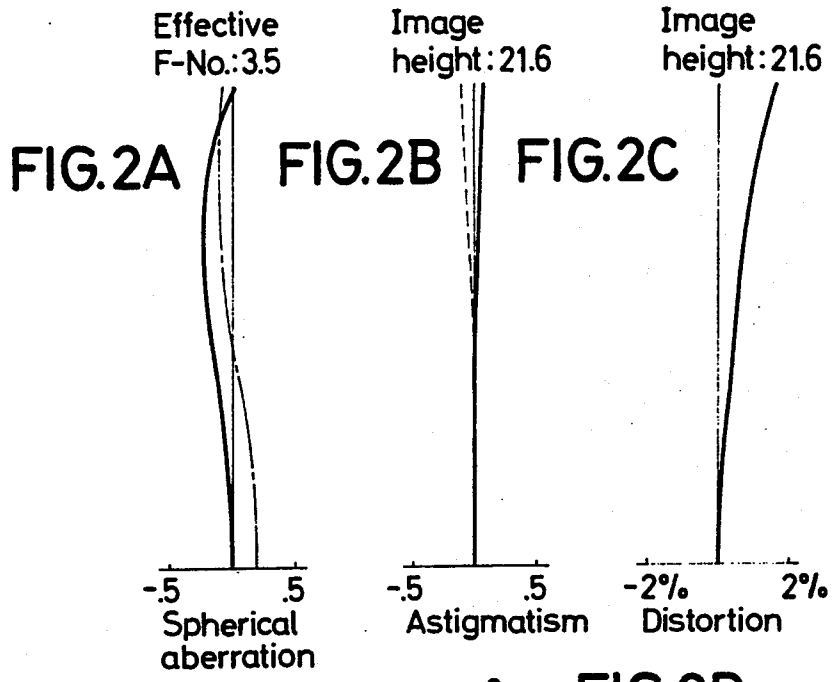

FIG.2A FIG.2B FIG.2C

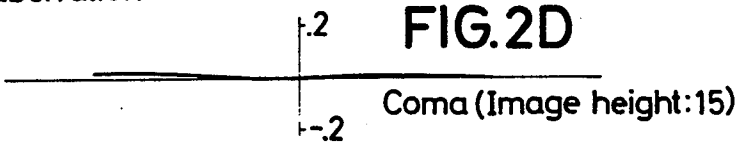

FIG.2D

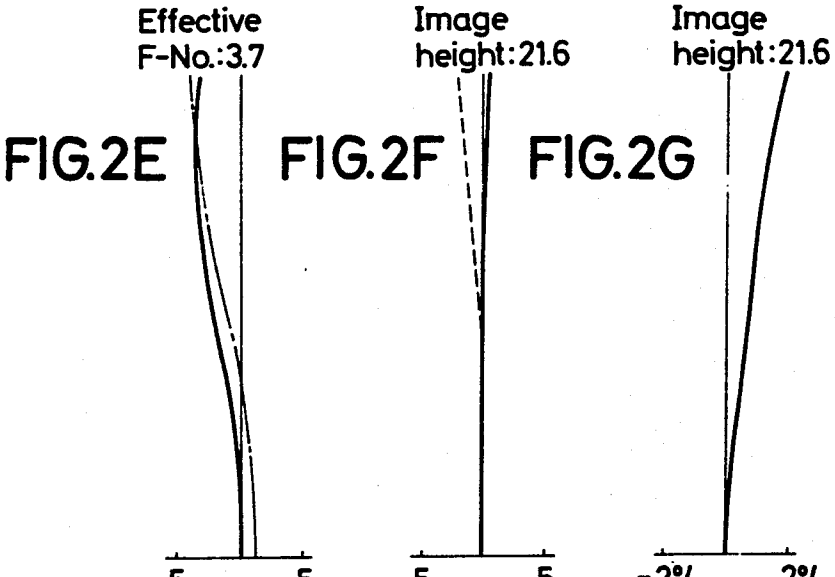

FIG.2E FIG.2F FIG.2G

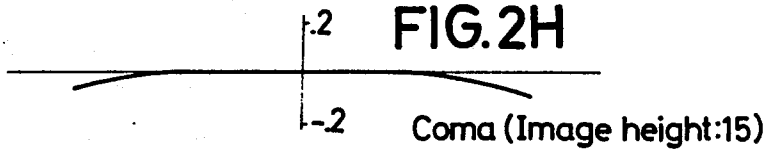

FIG.2H

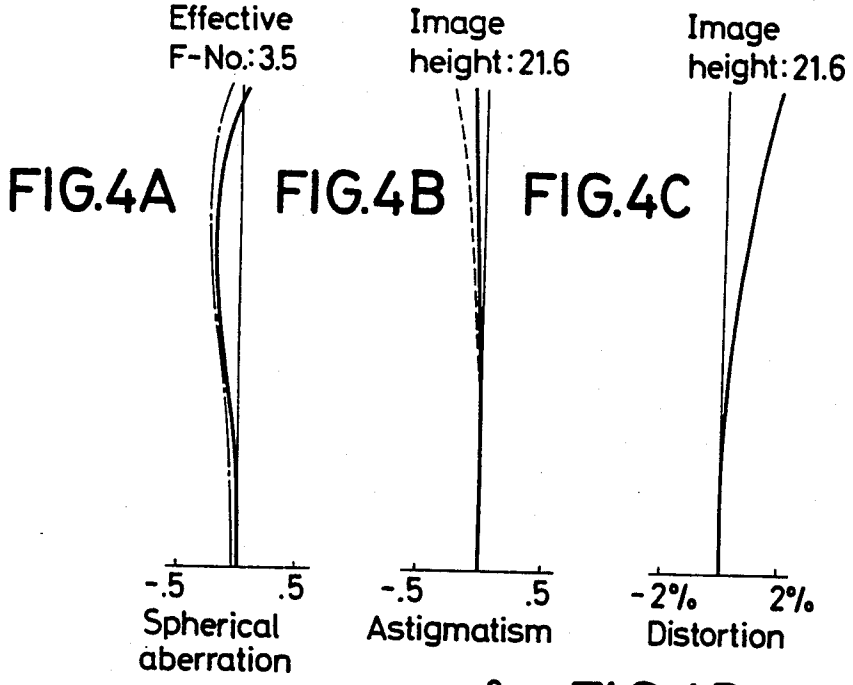

FIG.4A FIG.4B FIG.4C

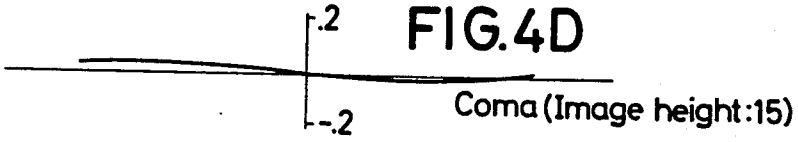

FIG.4D

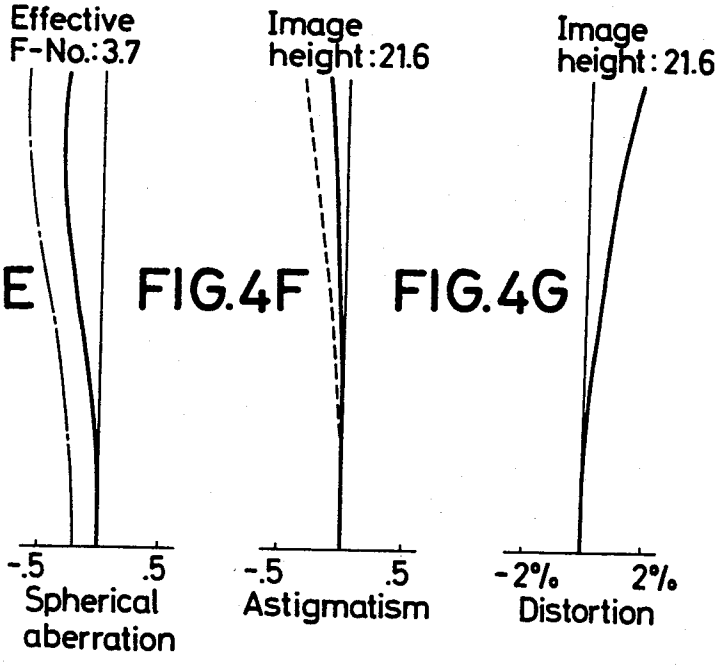

FIG.4E FIG.4F FIG.4G

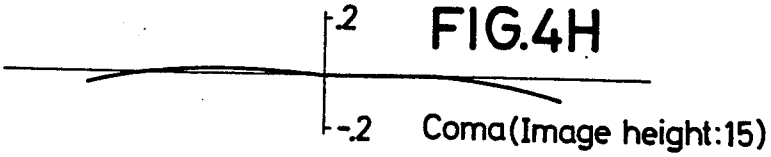

FIG.4H

TELEPHOTO TYPE OBJECTIVE

BACKGROUND OF THE INVENTION

This invention relates to a telephoto type objective comprising a front lens group and a rear lens group which includes at least two members movable for focusing.

It is known to provide a symmetrical lens or triplet lens of which the rearmost lens element is movable for focusing, as disclosed in U.S. Pat. Nos. 2,503,789 and 3,020,804. In these patents, however, no account is taken of the fact that the image quality will be deteriorated when only one lens element is moved for focusing.

It is also known to provide a telephoto lens composed of convergent front and divergent rear lens groups, both of which are made movable as a unit for focusing purposes. In the course of development of new types of telephoto lens, however, it is considered possible to achieve the focusing by moving either the front lens group or the rear lens group.

If the telephoto lens is made bodily movable for focusing, as the amount of axial movement of the entire lens system through the focusing range is far larger than that of axial movement of the ordinary lens, and the weight and bulk of the telephoto lens are relatively large, it is proven that the focusing mechanism such as those employing helicoid structure requires not only large constructional dimensions with high production cost thereof but also a large driving torque with difficult management thereof.

In the case of focusing provision made at the rear lens group, it is possible to minimize the dimensions of the focusing mechanism with improved management thereof. Another advantage of this type telephoto lens is that the front lens group may be supported in fixedly secured relation to a camera body as the physical length between the front lens vertex and the image plane within the camera housing is maintained constant, thereby minimizing the probability of producing a jiggle or oscillation of the image at the focal plane by small accidental motion of the lens-and-camera assembly which is otherwise encountered particularly when the objective lens of the camera is telephoto in nature. With this type of telephoto lens, however, it is made more difficult to prevent deterioration of image quality resulting from variation of aberrations with focusing.

This difficulty can be overcome by employing an additional lens member arranged to be movable along with the focusing member to compensate for variation of aberrations caused by the focusing member. An example of such method is described in U.S. Pat. No. 3,854,797 assigned to the same assignee as the patent application, in which the rear lens group is divided into at least two sub-groups of which the image side one has a negative refracting power and is arranged to be moved toward the rear as the entire lens system is focused for shorter object distances, and another subgroup on the object side which has a strong divergent surface and is arranged to be moved toward the front in the same focusing as above. This arrangement, however, leads to an increase in the diameter of the front sub-group, or otherwise those of the axial rays which are to pass through the marginal portion of the rear sub-group are blocked by the lens cell holding the front sub-group when the entire system is focused for shorter object distances.

SUMMARY OF THE INVENTION

Accordingly, it is a primary object of the present invention to provide a new type of focusing lens arrangement which, though requiring no undue increase in the diameter of the front lens sub-group, will avoid the eclipse or shading which would occur when the front and rear lens sub-groups of the rear lens group are arranged to move in the opposite directions to each other for focusing purposes.

Thus, it is an object of the invention to provide a telephoto type objective which, while maintaining a high standard of aberration correction throughout the entire focusing range, is also capable of avoiding any undue increase in the diameter of the focusing members as well as in the complexity of the focusing mechanism.

To achieve this, the telephoto type objective of the invention is constructed as comprising a stationary front lens group and a rear lens group which includes at least two movable members arranged to be moved in the same direction with variation of the axial separation therebetween, for example, toward the image plane when the objective is focused for shorter object distances. In this case, the prerequisite is that the amount of axial movement of the member adapted to the focusing purpose be larger than that of axial movement of the member adapted to the compensation for variation of aberrations. On this account, these movable lens members are arranged so that when the objective is infinitely focused, the axial separation between the members is minimum, and also in such a manner as to be moved toward the image plane in differential relation as the object distance is decreased.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram of an embodiment of the telephoto type objective according to the present invention in two different focusing positions designated I and II with object at infinity and at a distance of 5 meters respectively.

FIG. 2 is aberration curves of FIG. 1 embodiment, wherein FIGS. 2A to 2D show various aberrations occurring when the objective is focused for object at infinity, and FIGS. 2E to 2H show various aberrations occurring when focused for object at a distance of 5 meters.

FIG. 3 is a block diagram of another embodiment of the telephoto type objective according to the present invention in two different focusing positions I and II with object at infinity and at a distance of 5 meters respectively.

FIG. 4 is aberration curves of FIG. 3 embodiment, wherein FIGS. 4A to 4D show various aberrations occurring when the objective is focused for object at infinity, and FIGS. 4E to 4H show various aberrations occurring when focused for object at a distance of 5 meters.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to FIG. 1, a preferred embodiment of a telephoto type objective is shown comprising a stationary front lens group having a positive refracting power and a rear lens group having a negative refracting power and comprised of two achromatic doublets A and B having positive and negative refracting powers respectively. The doublets A and B are arranged in this order with respect to incident light to be moved from

their positions I to their positions II when the object distance is changed in focusing from infinity to 5 meters. The rear doublet B is adapted to effect the focusing, and therefore will be hereinafter referred to as "focusing member B", while the front doublet A is adapted to compensate for aberration variation caused by the movement of focusing member B, and therefore will be hereinafter referred to as "compensating member A".

For facilitating the achievement of good stabilization of aberrations throughout the focusing range, it is preferred that focusing member B is configured with the strongest diverging surface of rearward concavity. If otherwise configured with the strongest diverging surface of forward concavity, remarkable spherical aberrations are produced at the close focusing region. The aforesaid preferred condition when satisfied, however, leads to the production of inward coma and positive astigmatism. In order to facilitate the compensation for these aberrations, it is preferred that compensating member A is configured with the strongest converging surface of forward convexity.

In practice, the following relationships must be satisfied to assist the achievement of a high standard of aberration correction which is a further object of the invention.

$$Sa < Sb \tag{1}$$

$$0.8f < fa < 2f \tag{2}$$

$$1.6 < (Ra/Rb) < 1.8 \tag{3}$$

$$Vb_1 - Vb_2 > 8 \tag{4}$$

wherein Sa and Sb are the amounts of axial movement of the members A and B respectively, f is the focal length of the entire lens system, fa is the focal length of the member A, Ra is the radius of curvature of the strongest converging surface in the member A, Rb is the radius of curvature of the strongest diverging surface in the member B, Vb_1 is the mean value of the Abbe numbers of the positive lens elements in the member B, and Vb_2 is the mean value of the Abbe numbers of the negative lens elements in the member B.

The function of each of the above relationships will be explained below.

The type of objective of the invention is characterized in that when the object distance is changed in focusing from infinity to a close range, the movable members A and B are moved in the same direction toward the image plane, while permitting the compensation for variation of aberrations with focusing. For this reason, inequality (1) must be satisfied.

The positive lens member A is adapted to have a function of compensating for spherical aberrations, but results in an adverse effect on the focusing function. On this account, inequality (2) is set forth. When the upper limit is violated, the spherical aberrations are under-corrected in the short distance region, while when the lower limit is violated, the amount of movement of the focusing member B is increased to such an extent that fabricating difficulties are introduced to the focusing mechanism as incorporated in the lens barrel.

As excessive movement of the compensating member A causes serious increase in variation of spherical aberrations, inequality (1) is also effective in avoiding remarkable under-correction of spherical aberrations.

In equality (3) is set forth for achieving the minimization of variation of coma under the conditions of inequalities (1) and (2). When the upper limit is violated, unacceptable inward coma is produced in the short distance region, while the lower limit is violated, under-correction of shperical aberrations are resulted in the short distance region.

In order to achieve good stabilization of chromatic aberrations over the focusing range, it is required to employ positive and negative lens elements in constructing the focusing member B, and further that these elements satisfy inequality (4). If not so, variation of chromatic aberrations becomes excessive. In the practical embodiments of FIGS. 1 and 3, the focusing member B is shown as constructed from only one positive and only one negative lens elements, but it may be constructed from two or more lens elements in the same sign.

The telephoto type objective of the invention having a rear lens group R characterized by the above described relationships makes it more difficult as compared with the known type telephoto lens to perform correction of spherical aberration due to the divergent lens elements. On this account, the front lens group F must be well corrected in itself for various aberrations, thereby creating a difficult problem of correcting coma. In order to provide for the objective of the invention a large relative aperture, therefore, it is desired to set forth specific requirements for construction and arrangement of the various elements of the front lens groups F.

Thus, in the preferred embodiments of FIGS. 1 and 3, the front lens group F is constructed in the form of the so-called Taylor triplet, namely, a positive lens member, a negative lens member and a positive lens member arranged in this order from the front to increase the capabilities of correcting chromatic aberrations as well as other various aberrations, and is characterized by the following relationships:

$$-0.95 < (R_1R_2) < -0.8 \tag{5}$$

$$-0.45f < R_3 < -0.38 \tag{6}$$

$$0.15f < l < 0.2f \tag{7}$$

wherein R_1 and R_2 are the radii of curvature of the front and rear surfaces of the first lens member counting from the front, R_3 is the radius of curvature of the front surface of the second lens member, and l is the axial separation between the second and third lens members.

When the upper limit of inequality (5) and the lower limit of inequality (6) are violated, coma is deteriorated, while when the lower limit of (5) and the upper limit of (6) are violated, spherical aberration is deteriorated.

In order to minimize variation of astigmatism with focusing at the widest aperture, it is required to satisfy inequality (7). When the upper limit is violated, spherical aberration becomes large at the intermediate height region of light incidence, while when the lower limit is violated, unacceptable negative astigmatism is produced.

The two embodiments of the telephoto type objective of the invention represented in FIGS. 1 and 3 may be constructed in accordance with the numerical data given in Tables 1 and 3 respectively, in which the radii of curvature, R, and the axial separations between the successive surfaces, D, along with the indices of refraction Nd for the spectral D line of sodium and the Abbe numbers Vd for the various lens elements are all expressed with the corresponding numbers counted from

the front to the rear. The minus values of the radii, R, indicate surfaces concave toward the front. The aberration coefficients of the telephoto type objective of FIGS. 1 and 3 with object at infinity are given in Tables 2 and 4 respectively, in which L: axial chromatic aberration; T: lateral chromatic aberration; LS: axial chromatic aberration of pupil; Sa: spherical aberration; CM: coma, AS astigmatism; PT: Petzval sum; and DS: distortion. Aberration correction attained in the objective according to the data of Table 1 when focused for object at infinity or at a distance of 5 meters measured from the image plane is shown respectively in FIG. 2A or 2E for spherical aberration and sine condition, FIG. 2B or 2F for astigmatism, FIG. 2C or 2G for distortion, and FIG. 2D or 2H for coma. In the case of the objective according to Table 3, aberration correction for object at infinity or at a 5 meters distance is shown respectively in FIG. 4A or 3E for spherical aberration and sine condition, FIG. 4B or 4F for astigmatism, FIG. 4C or 4G for distortion and FIG. 4D or 4H for coma.

Table 1

f = 278.6 – 251.4 f-number: F/3.5 Image angle: 4.4°

Lens		Number	R	D	Nd	Vd
Front lens group		1	173.019	14.05	1.61800	63.4
		2	−202.393	23.17		
		3	−114.403	5.2	1.73000	31.2
		4	3480.006	51.78		
		5	183.248	7.78	1.61800	63.4
		6	−231.576	Variable		
Rear lens group	Member A fa = 316	7	65.632	4.0	1.70000	55.2
		8	595.390	1.0	1.65000	33.4
		9	84.857	Variable		
		10	100.459	3.0	1.73500	33.0
	Member B fb = −103.4	11	−176.924	1.0	1.69350	53.3
		12	39.579			

Overall focal length, lens separation and back focal length during focusing

Object distance	f	D_6	D_9	BK
Infinity	278.6	52.56	1.22	104.98
−5000	251.4	54.06	6.09	98.6

Table 2

	Aberration coefficients with infinitely distant object							
	L	T	LS	SA	OM	AS	PT	DS
1	0.011936	−0.014750	0.027390	0.985071	−1.217335	1.504364	0.614925	−2.618984
2	0.022649	−0.048743	0.088944	13.860509	−29.829110	64.195031	0.525680	−139.285017
3	−0.054744	0.111720	−0.192133	−20.141722	41.104509	−83.884616	−1.027417	173.285452
4	0.003619	−0.023737	0.040438	0.010216	−0.067009	0.439533	−0.033776	−2.661499
5	0.004637	0.000919	−0.001287	0.038411	0.007613	0.001509	0.580600	0.115375
6	0.013445	−0.025830	0.035380	5.277607	−10.139274	19.479450	0.459433	−38.306342
7	0.001193	0.008378	−0.006596	−0.021553	−0.151343	−1.062726	1.747587	4.809078
8	−0.006314	0.010639	−0.007884	0.156096	−0.263017	0.443174	−0.008340	−0.732681
9	0.004097	−0.018261	0.013298	0.165924	−0.739533	3.296129	−1.293150	−8.927366
10	−0.005911	0.020766	−0.014568	−0.336010	1.180493	−4.147383	1.174641	10.444028
11	0.010343	−0.013836	0.009146	0.314419	−0.420573	0.562569	0.022237	−0.782250
12	−0.005991	−0.005749	0.003716	0.010243	0.009828	0.009430	−2.882052	−2.756358
Σ	−0.001041	0.001516	−0.004156	0.319209	−0.524750	0.836464	−0.119631	−7.416563

Table 3

f = 276.06 – 250.8 f-number: F/3.5 Image angle: 4.4°

Lens		Number	R	D	Nd	Vd
Front lens group		1	184.499	11.16	1.61800	63.4
		2	−201.838	23.15		
		3	−114.3	5.2	1.73000	31.4
		4	3543.068	46.49		
		5	182.695	7.88	1.61800	63.4
		6	−229.238	Variable		
Rear lens group	Member A fa = 484.1	7	69.773	1.72	1.72342	50.0
		8	86.229	Variable		
	Member B fb = −131.1	9	84.282	3.0	1.73500	42.7
		10	−319.319	1.0	1.69350	53.3
		11	41.236			

Overall focal length, lens separations and back focal length during focusing

Object distance	f	D_6	D_8	BK
Infinity	276.06	59.72	1.17	108.6
−5000	250.8	61.72	7.3	100.5

Table 4

Aberration Coefficients with infinitely distant object

	L	T	LS	SA	CM	AS	PT	DS
1	0.011093	−0.010401	0.016703	0.790771	−0.741427	0.695162	0.571500	−1.187622
2	0.022355	−0.042742	0.067549	13.003398	−24.862664	47.537733	0.522404	−91.891600
3	−0.54379	0.097759	−0.144385	−19.368552	34.819600	−62.596548	−1.019132	114.364381
4	0.002530	−0.021142	0.030890	0.003663	−0.030607	0.255726	−0.032877	−1.861947
5	0.005533	0.000762	−0.000917	0.093707	0.012914	0.001780	0.577141	0.079781
6	0.014109	−0.023965	0.028111	5.529942	−9.392662	15.953531	0.459963	−27.878486
7	0.000795	0.010154	−0.005343	−0.007899	−0.100885	−1.288467	1.660788	4.755130
8	0.002013	−0.011592	0.005872	0.074118	−0.426807	2.457760	−1.343827	−6.414564
9	−0.002332	0.013773	−0.006646	−0.071236	0.420770	−2.485354	1.387566	6.484278
10	0.004122	−0.004861	0.002163	0.238417	−0.281153	0.331548	0.012211	−0.405376
11	−0.006178	−0.006956	0.003000	0.015388	0.017326	0.019508	−2.741488	−3.064837
E	−0.000339	0.000790	−0.003002	0.301716	−0.565595	0.882379	0.054250	−7.020862

What is claimed is:

1. A telephoto type objective comprising:

a front lens group having a positive refracting power and which remains stationary during focusing, said front lens group being comprised of a plurality of lens members, and

a rear lens group having a negative refracting power and positioned on the image side of said front lens group in axial alignment therewith, said rear lens group including at least two movable lens members arranged to be moved in the same direction along the common optical axis toward the image plane when the object distance is changed in focusing from infinitely distant object to close object with the resulting speed of movement of the front one of said two movable lens members being different from that speed of movement of the rear one.

2. A telephoto type objective according to claim 1, wherein said front lens member of said rear lens group moves at a slower speed than said rear lens member.

3. A telephoto type objective according to claim 2, wherein said rear movable lens member has at least one positive lens element and at least one negative lens element.

4. A telephoto type objective according to claim 2, wherein said front movable lens member has a front lens surface convex toward the front.

5. A telephoto type objective according to claim 1, wherein said front movable lens member of said rear lens group has a positive refracting power, and said rear movable lens member has a negative refracting power.

6. A telephoto type objective according to claim 5, wherein said front movable lens member has a plurality of surfaces including a strongest converging surface convex toward the front, and said rear movable lens member has a plurality of surfaces including a strongest diverging surface concave toward the rear, and wherein the focusing is effected with the resulting speed of movement of said front movable lens member being slower than that of movement of said rear movable lens member.

7. A telephoto type objective according to claim 6, wherein the mean value of the Abbe numbers of the positive lens elements in said rear movable lens member is larger than the mean value of the Abbe numbers of the negative lens elements therein.

8. A telephoto type objective according to claim 1, wherein said front lens group is comprised of a positive lens, a negative lens and a positive lens arranged in this order.

9. A telephoto type objective comprising:

a primary lens group having a positive refracting power and which remains stationary during focusing, said primary lens group being comprised of a plurality of lens member, and

two movable sub-groups positioned on the image side of said primary lens group in axial alignment therewith to be movable for focusing in such a manner that the image side one of said two sub-groups moves at a faster speed than the object side sub-group.

10. A telephoto type objective according to claim 9, wherein said image side sub-group has a negative refracting power, and said object side sub-group has a positive refracting power.

11. A telephoto type objective according to claim 9, wherein said image side sub-group has at least one positive and at least one negative lenses, and said object side sub-group is meniscus-shaped.

12. A telephoto type objective according to claim 9, wherein the axial separation between said primary lens group and said object side sub-group is larger than that between said two sub-groups.

13. A telephoto type objective according to claim 9, wherein said primary lens group is comprised of a positive lens, a negative lens and a positive lens arranged in this order.

* * * * *

United States Patent [19]

Jernigan

[11] **4,059,348**

[45] **Nov. 22, 1977**

[54] **OBJECTIVE PLOTTING OF VISUAL FIELDS BY EYE MOVEMENT MONITORING**

[75] Inventor: **Marvin E. Jernigan**, Weston, Mass.

[73] Assignee: **Narco Scientific Industries, Inc.**, Fort Washington, Pa.

[21] Appl. No.: **707,373**

[22] Filed: **July 21, 1976**

Related U.S. Application Data

[62] Division of Ser. No. 505,339, Sept. 12, 1974, Pat. No. 3,984,156.

[51] **Int. Cl.**[2] **A61B 3/02**

[52] **U.S. Cl.** **351/30**; 351/7; 351/23; 353/94

[58] **Field of Search** 351/30, 31, 23, 39, 351/17, 7, 24; 353/94, 98

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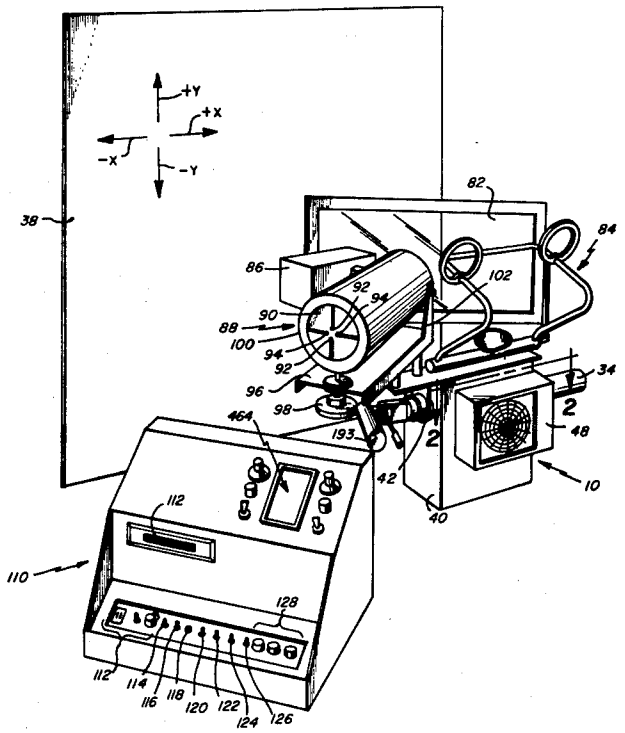
Primary Examiner—Paul A. Sacher

Attorney, Agent, or Firm—Wolf, Greenfield & Sacks

[57] **ABSTRACT**

An apparatus for measuring and evaluating a subject's visual field presents a target image, consisting of a spot of light, at a series of selected locations within the subject's visual field. Means are provided to monitor his resulting eye movement and positions in response to each target presentation. A projection apparatus presents the target images at various locations and in a programmed sequence. The apparatus also includes means for making a photographic plot of those presented targets which the subject has seen or missed, as desired. Determination of whether subject has seen or missed a particular target is evaluated by logic systems which discriminate between eye movement and positions displaying characteristics indicative of whether the subject has seen or missed the target. The logic discriminates between blinks, hunting eye movements and other characteristic positions and movements which are indicative of the subject having seen the target. Means also are provided to enable selective coarse or fine mapping of selected regions of the subject's visual field.

11 Claims, 23 Drawing Figures



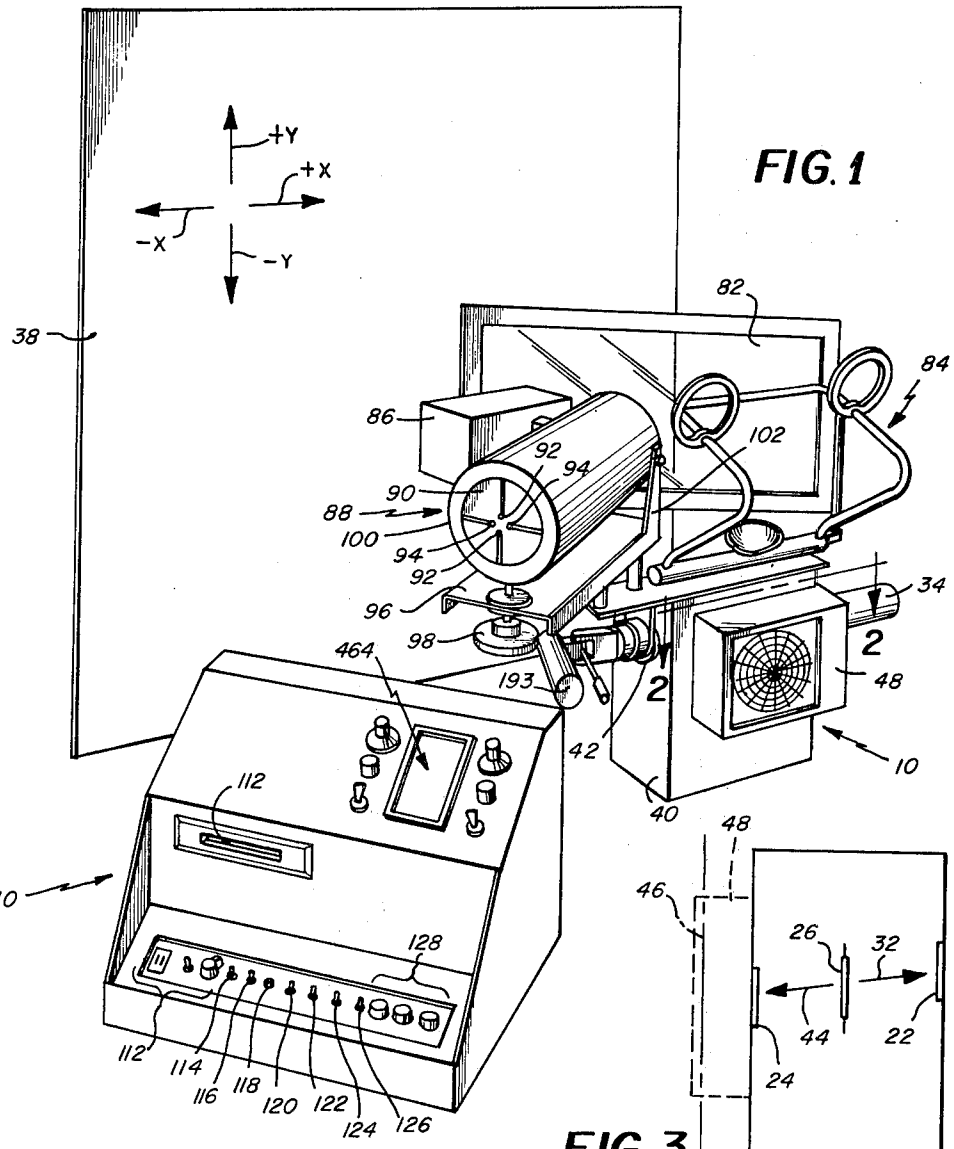


FIG. 1

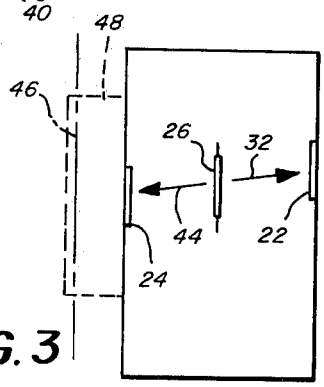


FIG. 3

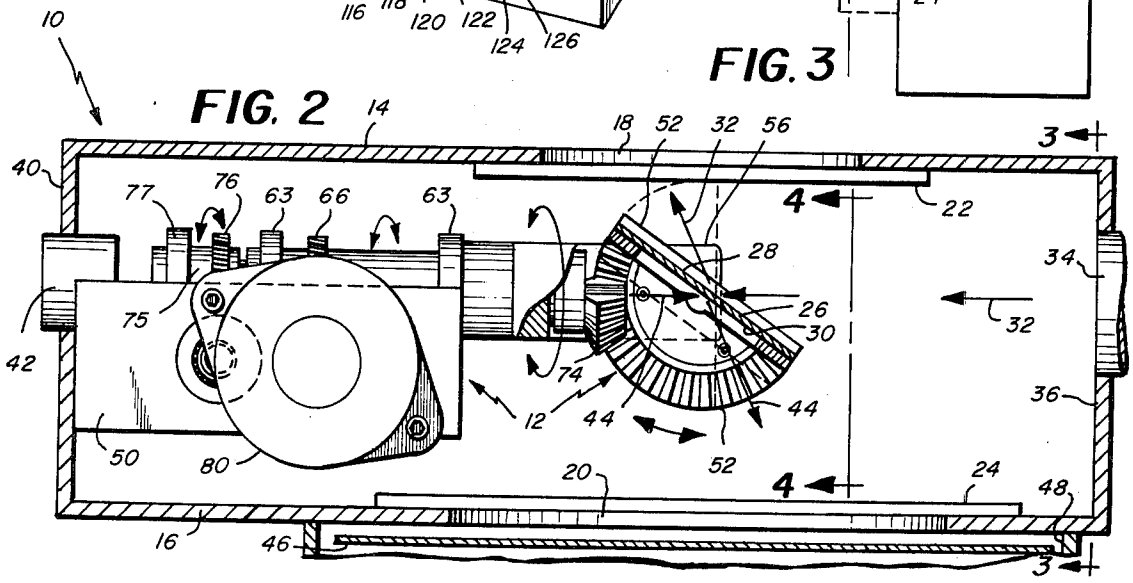


FIG. 2

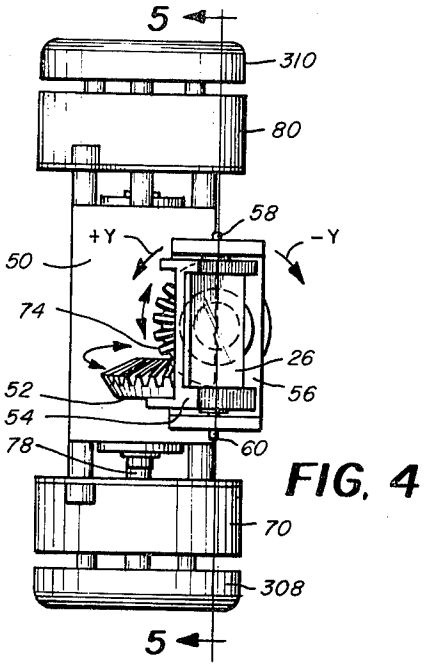


FIG. 4

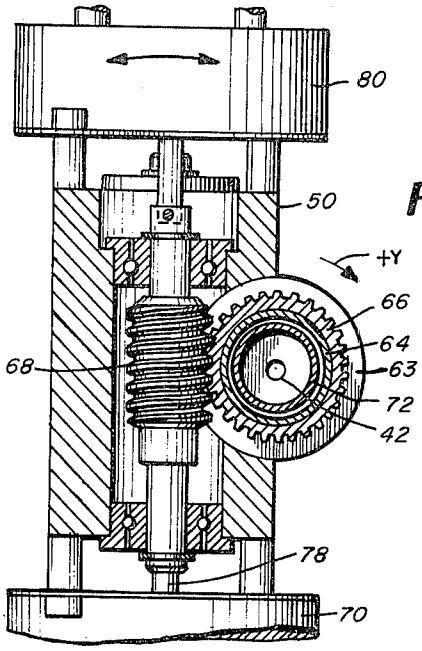


FIG. 6

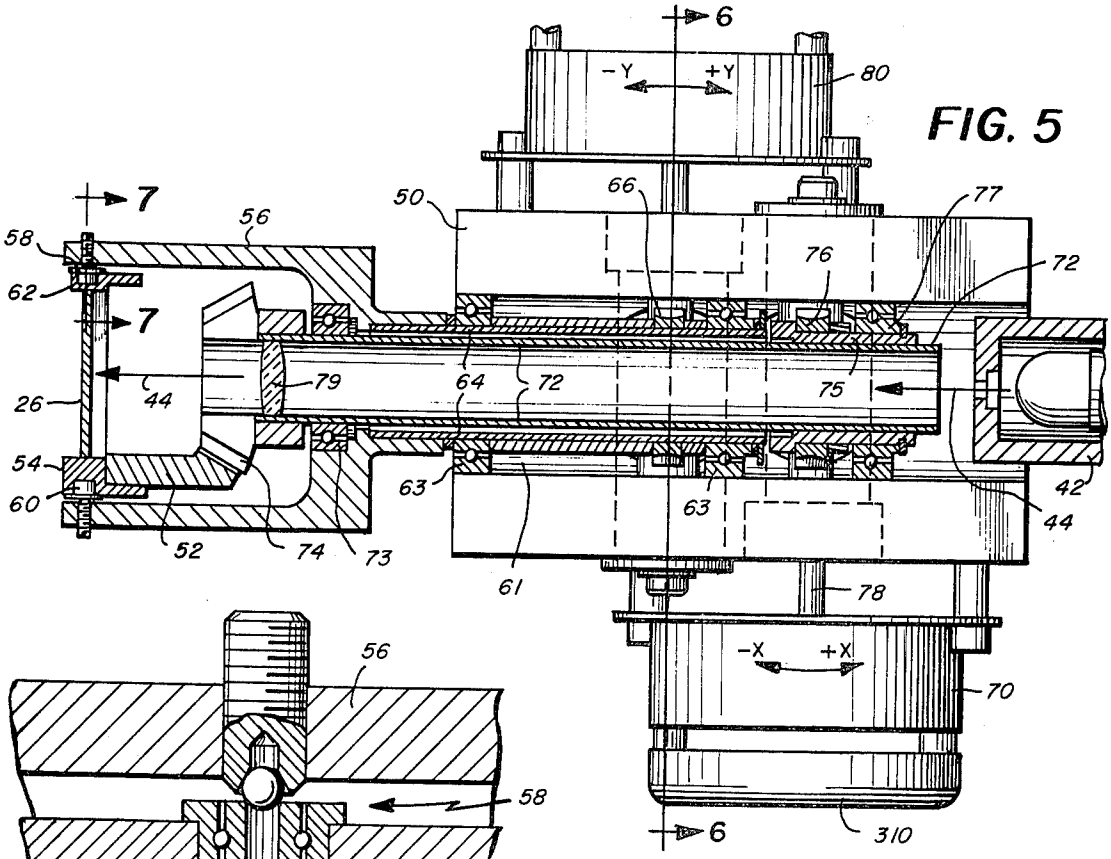


FIG. 5

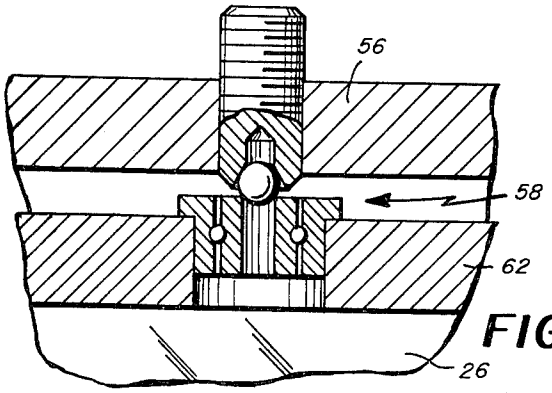


FIG. 7

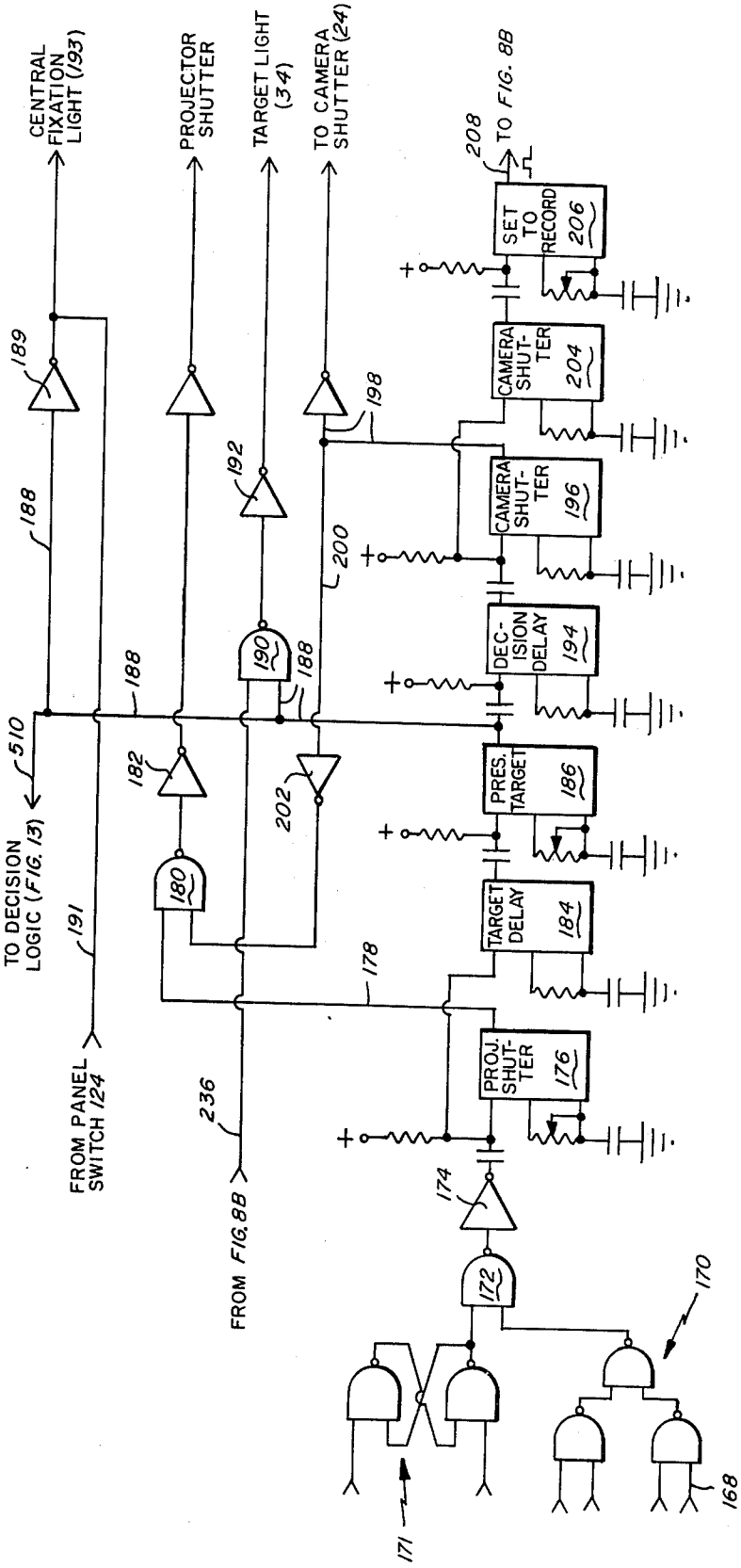

CENTRAL FIXATION LIGHT (193)
PROJECTOR SHUTTER
TARGET LIGHT (34)
TO CAMERA SHUTTER (24)
208
TO FIG. 8B
SET TO RECORD 206
CAMERA SHUTTER 204
CAMERA SHUTTER 196
DECISION DELAY 194
PRES. TARGET 186
TARGET DELAY 184
PROJ. SHUTTER 176
189
188
192
198
200
190
182
202
180
178
174
172
170
168
171
510
TO DECISION LOGIC (FIG. 13)
191
FROM PANEL SWITCH 124
236
FROM FIG. 8B

FIG. 8A

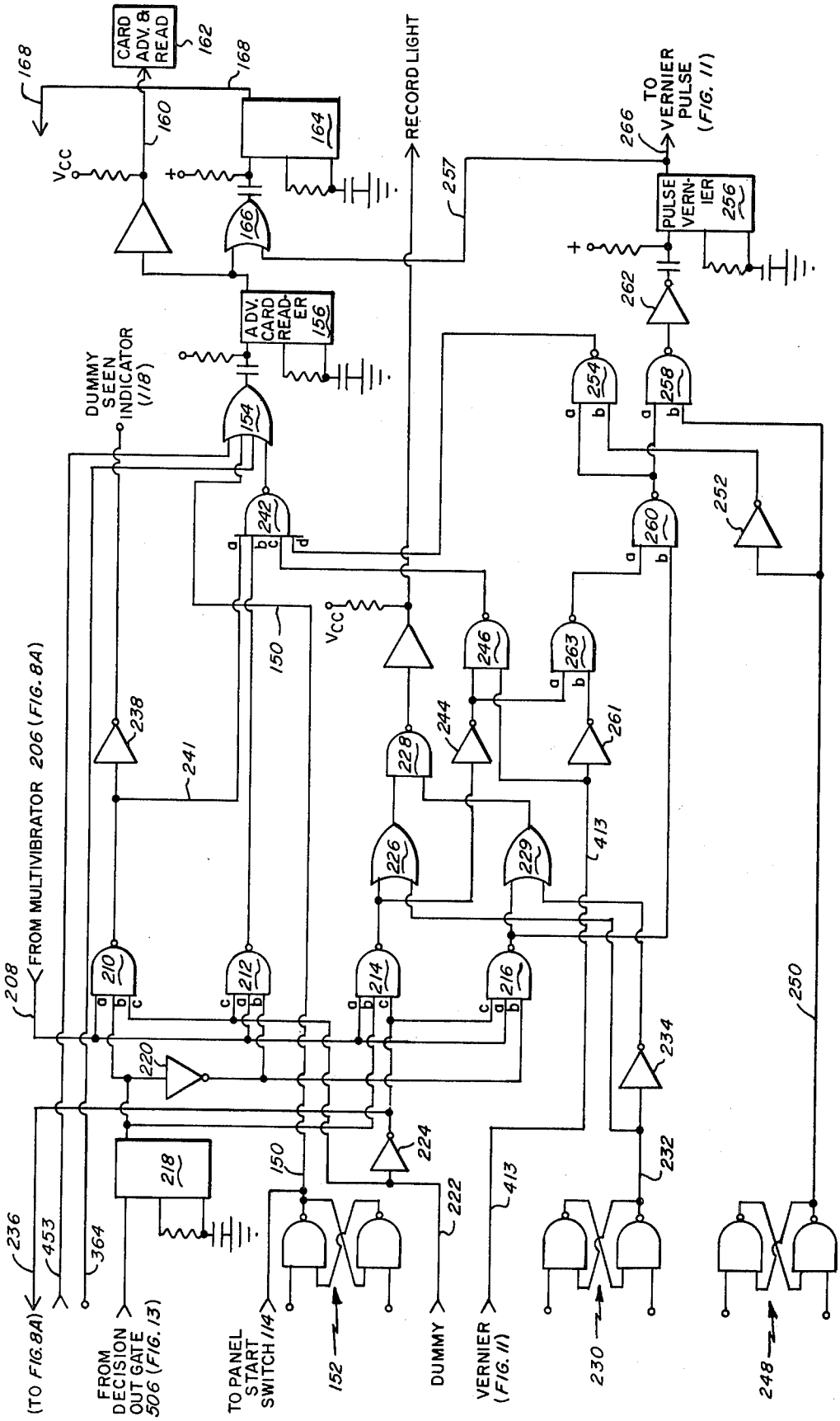

CARD ADV. & READ
162
168
164
RECORD LIGHT
TO VERNIER PULSE (FIG. 11)
266
PULSE VERNIER 256
257
ADV. CARD READER 156
DUMMY SEEN INDICATOR (118)
154
166
160
Vcc
262
254
258
252
260
242
246
263
150
238
241
228
244
261
226
229
413
FROM MULTIVIBRATOR 206 (FIG. 8A)
208
210
212
214
216
220
234
250
218
224
232
222
236
453
364
(TO FIG. 8A)
FROM DECISION OUT GATE 506 (FIG. 13)
TO PANEL START SWITCH 114
152
DUMMY
VERNIER (FIG. 11)
230
248

FIG. 8B

FIG. 9

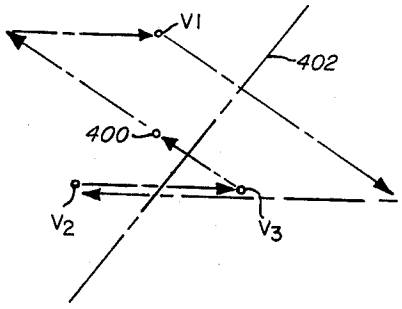


FIG. 9A

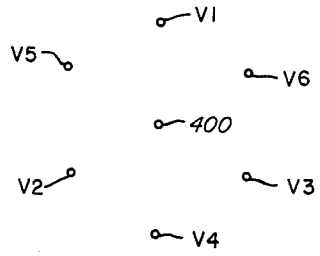


FIG. 12A

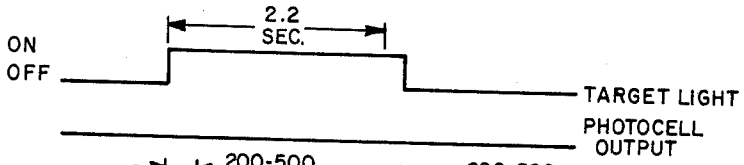


FIG. 12B

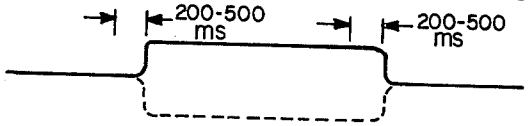


FIG. 12C

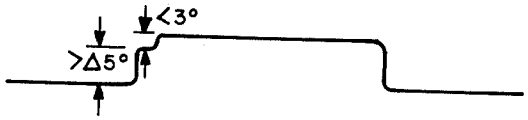


FIG. 12D

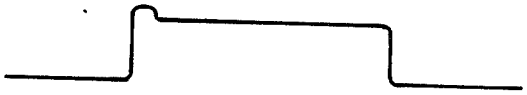


FIG. 12E

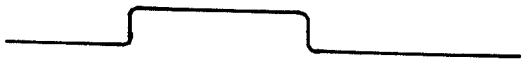


FIG. 12F

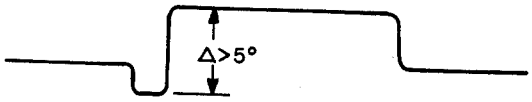


FIG. 12G

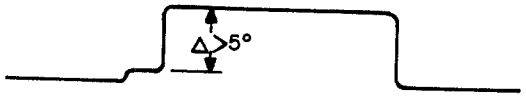


FIG. 12H

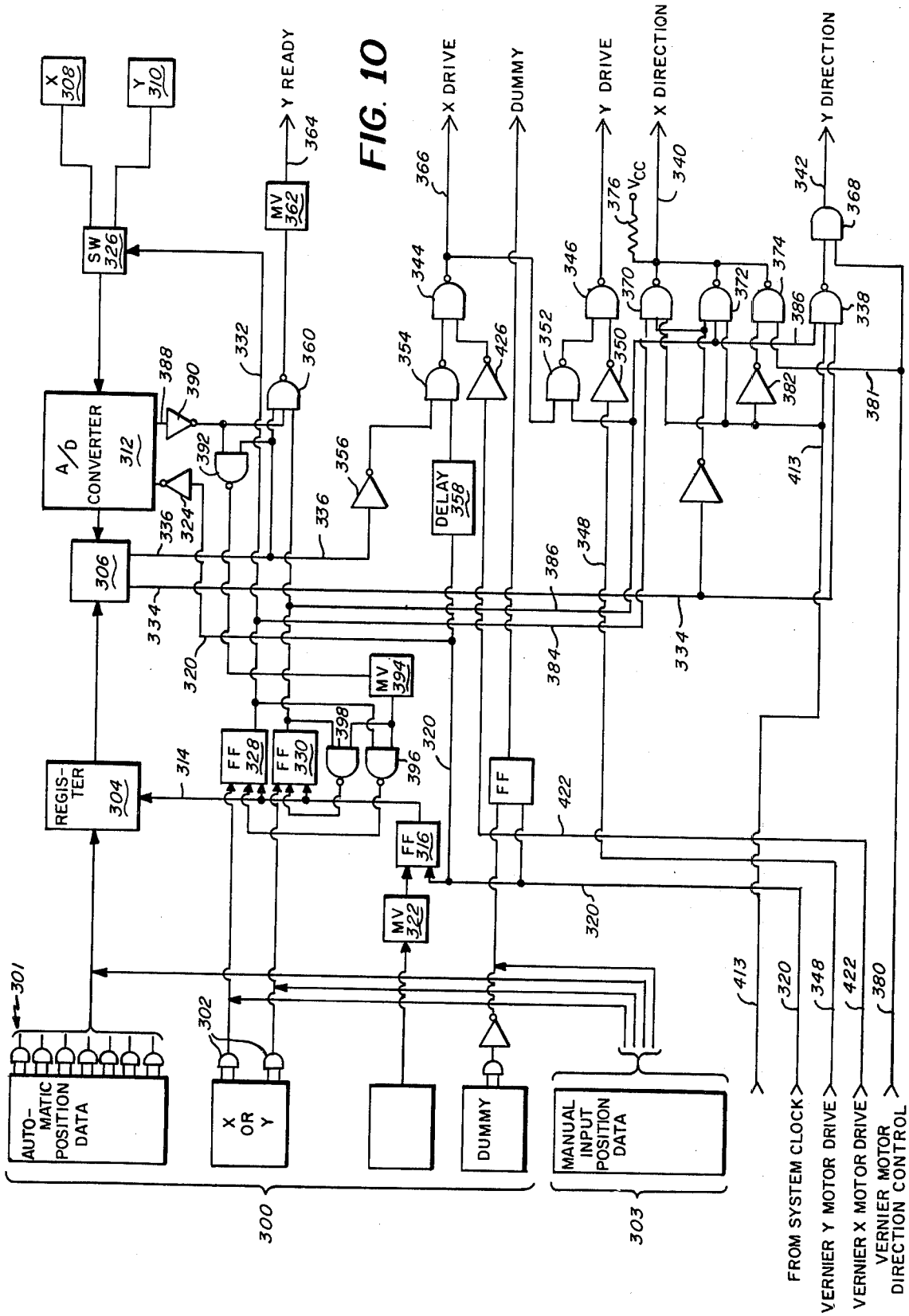

X 308
Y 310
Y READY 364
X DRIVE 366
DUMMY
Y DRIVE
X DIRECTION
Y DIRECTION 342
SW 326
MV 362
A/D CONVERTER 312
DELAY 358
REGIS-TER 304
306
FF 328
FF 330
FF 316
FF
MV 394
MV 322
V_{CC} 376
340
368
338
AUTO-MATIC POSITION DATA
X OR Y
DUMMY
MANUAL INPUT POSITION DATA
300
303
FROM SYSTEM CLOCK
VERNIER Y MOTOR DRIVE
VERNIER X MOTOR DRIVE
VERNIER MOTOR DIRECTION CONTROL

FIG. 10

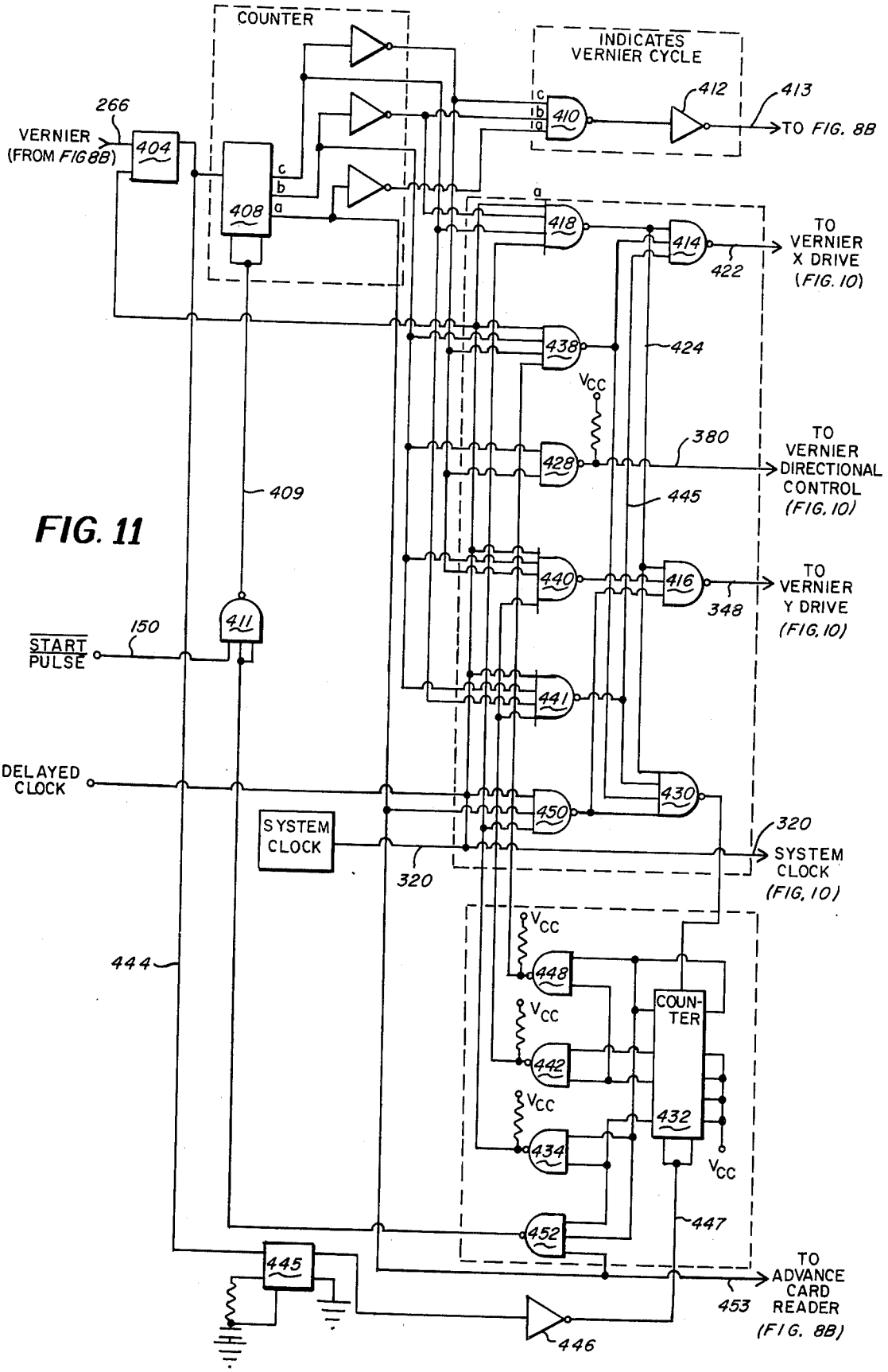

COUNTER
INDICATES VERNIER CYCLE
266
VERNIER (FROM FIG 8B)
404
408
c
b
a
410
412
413
TO FIG. 8B
418
414
422
TO VERNIER X DRIVE (FIG. 10)
438
424
Vcc
428
380
TO VERNIER DIRECTIONAL CONTROL (FIG. 10)
409
445
440
416
348
TO VERNIER Y DRIVE (FIG. 10)
411
150
START PULSE
441
DELAYED CLOCK
430
450
320
SYSTEM CLOCK (FIG. 10)
SYSTEM CLOCK
320
444
448
442
434
COUN-TER
432
447
452
445
446
453
TO ADVANCE CARD READER (FIG. 8B)

FIG. 11

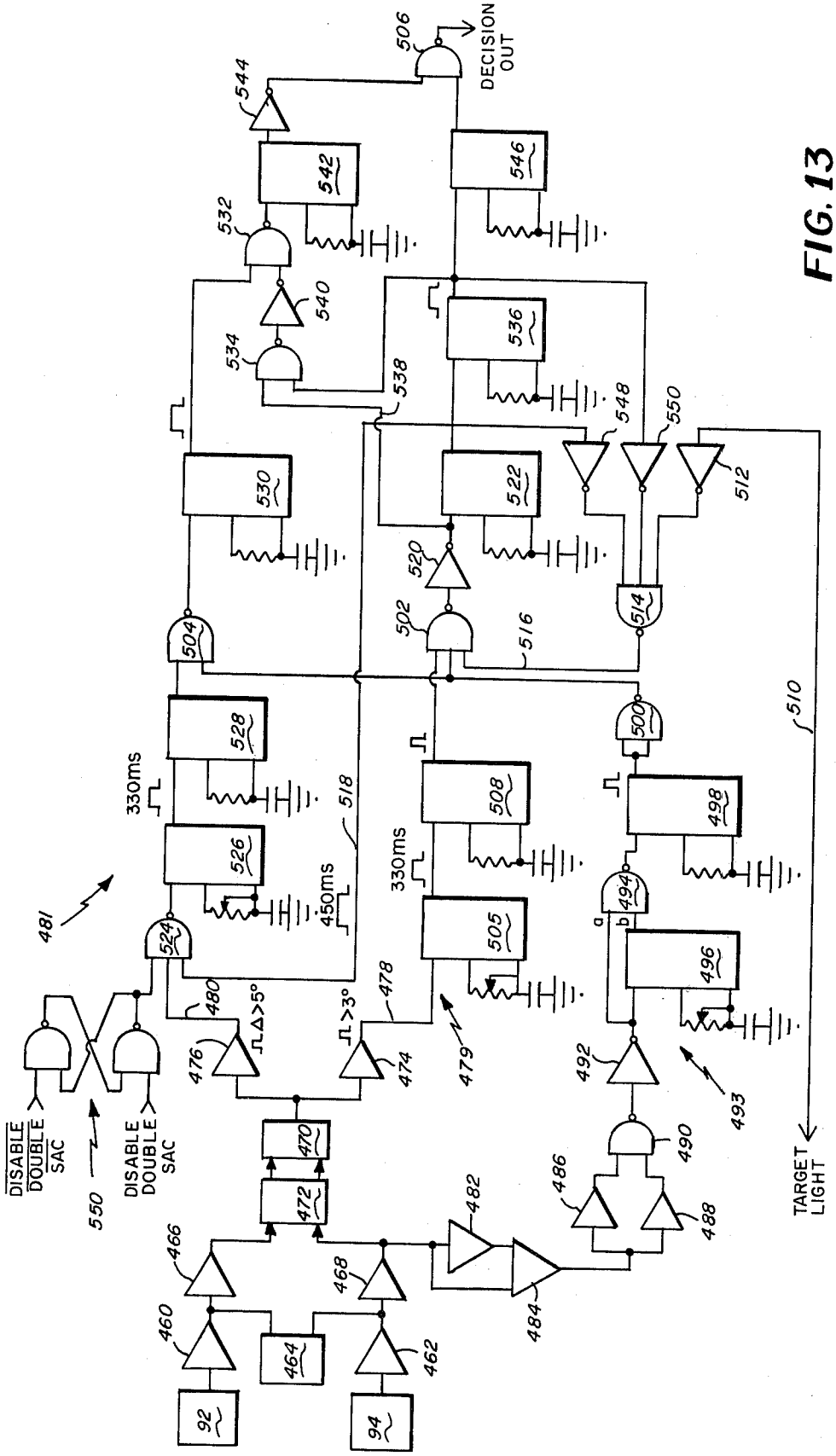
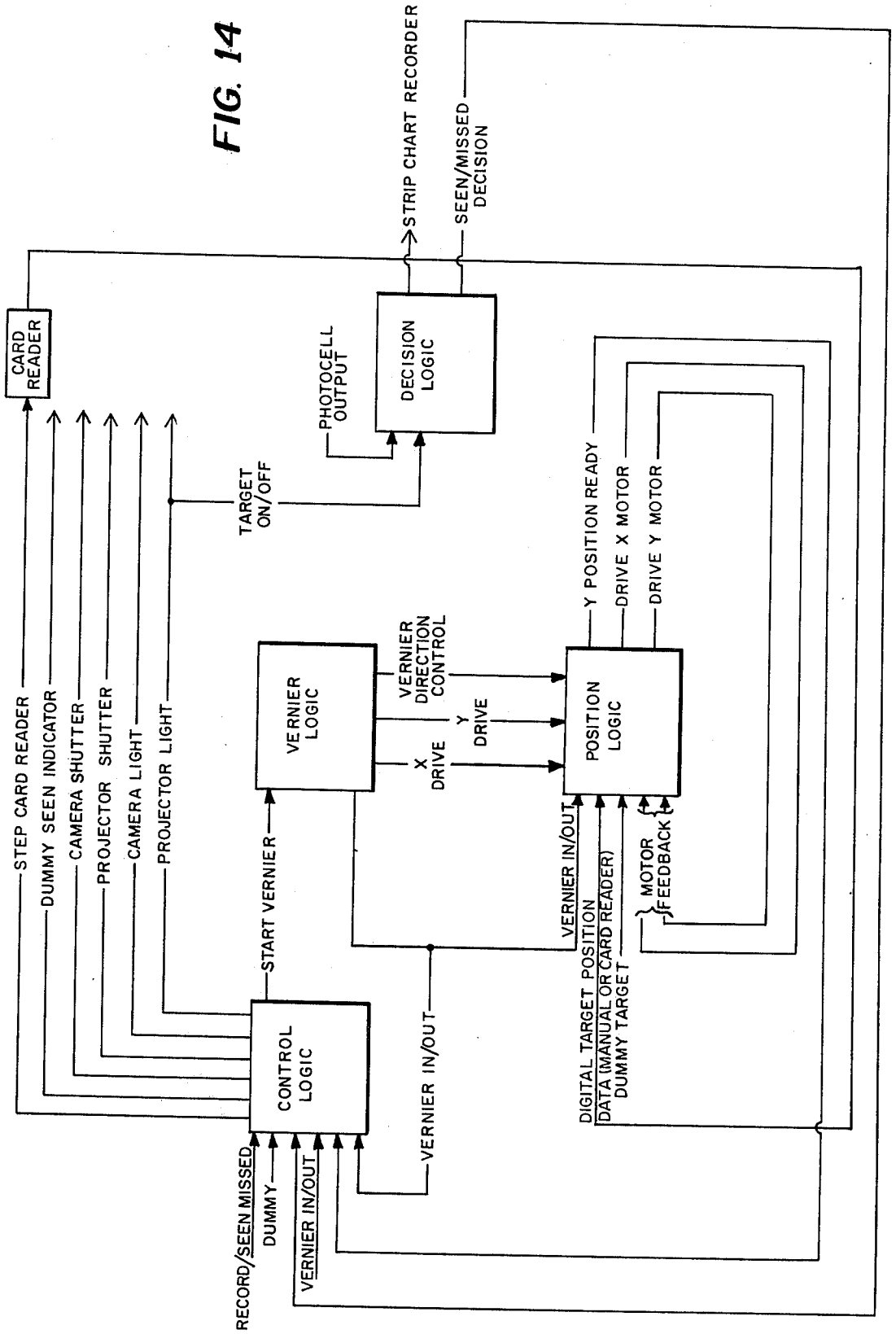

DECISION OUT
TARGET LIGHT
DISABLE DOUBLE SAC
DISABLE DOUBLE SAC
330ms
450ms
330ms
Δ>5°
>3°
481
550
92
94

FIG. 13

FIG. 14


STRIP CHART RECORDER
SEEN/MISSED DECISION
CARD READER
DECISION LOGIC
PHOTOCELL OUTPUT
TARGET ON/OFF
Y POSITION READY
DRIVE X MOTOR
DRIVE Y MOTOR
VERNIER LOGIC
VERNIER DIRECTION CONTROL
Y DRIVE
X DRIVE
POSITION LOGIC
STEP CARD READER
DUMMY SEEN INDICATOR
CAMERA SHUTTER
PROJECTOR SHUTTER
CAMERA LIGHT
PROJECTOR LIGHT
START VERNIER
VERNIER IN/OUT
MOTOR FEEDBACK
DIGITAL TARGET POSITION DATA (MANUAL OR CARD READER) DUMMY TARGET
CONTROL LOGIC
VERNIER IN/OUT
RECORD/SEEN MISSED
DUMMY
VERNIER IN/OUT

OBJECTIVE PLOTTING OF VISUAL FIELDS BY EYE MOVEMENT MONITORING

This is a division of application Ser. No. 505,339, filed Sept. 12, 1974 now U.S. Pat. No. 3,984,156.

BACKGROUND OF THE INVENTION

Measurement of one's visual field is important for a variety of reasons including the diagnosis of glaucoma as well as other human visual system diseases or impairments. In general, the prior techniques for determining one's visual field and any blind spots have been quite slow and tedious and require a definite subjective response from the person being tested in order to determine whether he has sighted the target at a particular location in his visual field. Additionally, the previously employed tests require administration by one having relatively high degree of skill such as an ophthalmic technician, optometrist or ophthalmologist. For example, in the most common type of visual field test, a hand held target such as a small disc at the end of a wand, is moved about the subject's visual field by the examiner while the subject fixates on a central point. During movement of the hand held target through the subject's field, the examiner asks the subject repeatedly whether he can see the movable target as it is passing from location to location. The examiner may plot, manually, the location of each point which is seen by the subject, or alternatively, he may plot those locations which the subject is unable to see, and which, therefore, define his blind spot.

In order to overcome the uncertainties and difficulties in the foregoing testing techniques some attempts have been made to automate partly the foregoing visual field test, such as employing an arrangement for automatically presenting a series of targets to the subject. Although these devices are somewhat faster than the completely manual test described above, they still are relatively slow and require that the subject respond consciously and intentionally when he sees the target. For example, the response may be verbal or may be indicated by the subjective manipulation of a lever or a button.

Also among the primary difficulties in obtaining fast and accurate plots of the subject's visual field is that the examiner must be assured that the subject's line of sight is directed toward a central fixation point or other known reference point before the target is presented to him. In some instances this may be quite difficult when problems of communication exist between the subject and the examiner as, for example, when testing the young, the aged, or persons whose native language is different than that of the examiner. Furthermore, any such difficulties render efficient and accurate testing still more complicated because it may confuse the results of the test.

A further difficulty in conducting visual field tests with prior techniques is that an indication by the subject that he has seen the target may be the result of hunting eye movements in which, he did not at first actually see the target but moved his eyes about slightly, in a searching motion, and then having seen the target, then moved his eyes directly to it. The present invention employs means for discriminating between such hunting movements and movements in which the presented target was initially seen by the subject.

It is among the primary objects of the invention to provide an apparatus for determining a subject's visual field which avoids the foregoing and other difficulties.

SUMMARY OF THE INVENTION

The invention takes advantage of the natural voluntary or involuntary eye movements which result when a target is presented suddenly to a subject within his visual field. Measurement of the eye movement or change in eye position in response to presentation of the target is employed to determine whether the subject has seen the target. The eye movements may be detected and monitored by a technique described in U.S. Pat. No. 3,473,868 in which the direction and magnitude of the eye movements are translated into electrical signals. Electronic logic means are provided for discriminating between signals which represent eye movements characteristic of the subject having actually seen the target from other types of eye movements such as blinks, hunting or searching movements or the like which produce electrical impulses unrelated to the subject's actual initial detection of the target image. The logic means includes a decision logic circuit which evaluates whether the subject actually visually detected the target by reference to the number and magnitude of the subject's eye movements within an extended time interval which includes the interval during which the target image is presented and a short period thereafter.

The invention employs a target image projector which develops a narrow collimated light beam and directs the beam sequentially toward selected locations on a screen which is within the subject's expected visual field. The position of the intermittent light beam and target image on the screen is determined by reflecting the beam, from its source, off one surface of a double faced mirror toward the screen. The attitude of the mirror is controllable to selectively direct the beam in the desired direction by stepping motors which are positioned in accordance with preprogrammed digital information. The location of the target imge on the screen, as presented to the subject, may be recorded permanently and automatically on photographic film incorporated into the projector. In the preferred embodiment, the photographic film is of the Polaroid type which enables immediate inspection after the test has been completed. The photographic recording is made by employing a second light beam which is reflected off the opposite face of the controlled mirror toward the photographic film. The second, reflected beam is directed along the same axis as the first projection beam, but from the opposite direction and impinges on the film at a location which is dependent on the angle of incidence of the beam to the mirror which corresponds to the direction of the light beam which impinges on the target screen. Shutters are provided in association with each of the first and second light beams, the first shutter being employed to control the timing and duration of presentation of the target light and the second shutter means being employed to expose the photographic film to the second beam. In another mode of operation only those points which are not observed are photographically recorded to provide a plot of the subject's blind spot or spots. The second shutter is controlled automatically in response to the logic circuitry which evaluates whether the subject has seen or missed a particular target.

The stepping motor arrangement for changing the attitude of the mirror also enables the device to be pro-

grammed to present a sequence of targets on the screen in close proximity to each other rather than more widely spaced locations about the screen. This enables more precise plotting and evaluation of an area of the subject's blind spot or spots after the more coarse presentation of the target spots has indicated the general location of the blind spot or spots. The device may be operated in a mode in which the more precise evaluation is effected automatically when a subject has missed a presented target.

It is among the primary objects of the invention to provide an improved technique for determining and plotting a subject's visual field.

Another object of the invention is to provide an improved technique in which the subject's response to a series of targets presented at various locations in his visual field is determined objectively without subjective response on his part.

A further object of the invention is to provide an arrangement for making a permanent record of the subject's visual field.

Still another object of the invention is to provide an improved technique for plotting and measuring a subject's visual field without requiring that the test be administered by highly skilled personnel.

Another object of the invention is to provide an improved technique by which eye movements characteristic of a subject's actual sighting of a target presented within his visual field may be discriminated from other types of eye movements automatically.

DESCRIPTION OF THE DRAWINGS

The foregoing and other objects and advantages of the invention will be understood more fully from the following further description thereof, with reference to the accompanying drawings wherein:

FIG. **1** is an illustration of the invention set up in readiness for use;

FIG. **2** is a sectional plan illustration of the mirror positioning mechanism as seen from line **2—2** of FIG. **1** and showing portions of the mechanism broken away;

FIG. **3** is a sectional elevation as seen along the line **3—3** of FIG. **2**;

FIG. **4** is a side elevation of the mirror positioning mechanism as seen along the line **4—4** of FIG. **2**;

FIG. **5** is a sectional view of the mirror positioning mechanism as seen along the line **5—5** of FIG. **4**;

FIG. **6** is a sectional elevation of the mirror positioning mechanism as seen along the line **6—6** of FIG. **5**;

FIG. **7** is an enlarged illustration of the low friction bearing by which the mirror is mounted;

FIG. **8A** and **8B** illustrate a schematic of the control logic electronics of the invention;

FIG. **9** is an illustration of the relative locations of the vernier target images with respect to each other and to the location of the primary target image on the presentation screen;

FIG. **9A** is an illustration of an alternative configuration of vernier target locations;

FIG. **10** is a schematic illustration of the electronic logic circuitry for controlling the positioning of the mirror mechanism;

FIG. **11** is a schematic illustration of the electronic logic system for controlling presentation of the vernier target images;

FIG. **12A** is a DC plot of a subject's response when an actually presented target has been missed;

FIG. **12B** is a DC plot of an ideal "target seen" response;

FIGS. **12C** and **12D** are DC plots of a three saccade response in which the subject initially detected the target but required a minor correctional saccade to focus directly on the target;

FIG. **12E** is a DC plot of a subject's response where the target was detected but where his eyes returned to the central fixation point before the target light was switched off;

FIGS. **12F** and **12G** are DC plots of the subject's eye movement where he did not see the target image and moved his eyes to hunt or search for the target;

FIG. **12H** is a DC plot representative of a blink;

FIG. **13** is a schematic diagram of the decision logic circuitry; and

FIG. **14** is a block diagram illustrating diagrammatically the relationship between the various functions of the logic circuits.

DESCRIPTION OF THE PREFERRED EMBODIMENT

FIGS. **1-3** shows generally the apparatus employed in the invention which includes a projector-camera housing **10** in which is mounted the mirror mechanism **12**. The housing **10** includes a front wall **14** and a rear wall **16**, having apertures **18, 20** respectively which can be opened or closed by a projection shutter **22** and film shutter **24**. The mirror mechanism **12** includes a double faced mirror **26** having a front face **28** and a rear face **30**. The mirror **26** is arranged so that it will reflect the light beam **32** from a projection light **34**, mounted to a sidewall **36** of the housing, **10** through the projection shutter **22** and onto the projection screen **38**. The opposite sidewall **40** of the housing **10** supports a second light source **42** which directs a beam of light **44** toward the rear face **30** of the mirror **26** along the same axis as that of the light beam from the projection light **34**. The beam from the second light source **42** is reflected from the mirror surface **30** in a direction which is opposite that of the reflected projection beam **32** from the front face **28** of the mirror **26**. The recording light beam **44** is directed toward a film plane, indicated diagrammatically at **46** and disposed at the rear of the housing **10** by any of a variety of well-known film holding devices **48**. The double faced mirror **26** thus directs the projection beam **32** to a selected location on the screen and simultaneously directs the recording beam **44** (when it is operated) to a corresponding location in the film plane **46**, as controlled by the attitude of the mirror **26**.

The mirror **26** is mounted for adjustable movement by the mirror mechanism **12**. The mirror mechanism is mounted to a support block **50** which is secured to the interior of the housing **10**. As shown more fully in FIGS. **2-7**, the mirror mechanism **12** includes a driven bevel gear segment **52**. The mirror **26** is secured to and across the diameter of gear **52** by a bracket **54** and lies in a plane perpendicular to that of the gear **52**. The mirror **26** and gear **52** are supported for rotation in unison about the central axis of the gear **52** by means of a yoke **56** having a low friction bearing **58** which supports the upper edge of the mirror, by bracket **62**, and a low friction bearing **60** which supports the opposite face of the gear **52**, by bracket **54**, to enable the mirror **26** and gear **52** to rotate in unison about a common axis defined by the bearings **58, 60**. The yoke **56** is mounted for rotation about a horizontal axis to rotate the mirror **26** and gear **52** bodily about that horizontal axis. To this

end the yoke **56** is secured to the end of an outer cylinder **64** which is mounted for rotation to the block **50** by bearings **63**. The cylinder **64** has a gear **66** secured thereto which is rotated by a worm gear **68** which is driven, in turn, by a stepping motor **80** mounted to the block **50**. The mirror **26** and gear **52** are rotatable with respect to the yoke **56** by means of an inner cylinder **72** which extends through and is rotatable within the outer cylinder **64**. One end of the inner cylinder **72** extends into and is supported at the yoke by bearing **73** and has a bevel gear **74** secured thereto which meshes with driven bevel gear **52**. The opposite end of the inner cylinder **72** extends outwardly beyond the end of the outer cylinder **64** and has a collar **75** secured thereto. The collar **75**, in turn, is rotatably mounted to the block **50** by bearing **77**. The inner cylinder **64** is driven by a gear **76** secured thereto which is driven by the worm gear as described above. The worm gear is secured to shaft **78** of stepping motor **70**. The stepping motors **70**, **80** of the mirror mechanism **12** are operated by the position logic system which, in turn, is controlled by the digital information on the program card or the vernier positioning system to orient the mirror **26** to present the target image at any desired location within the subject's visual field and also direct the recording light beam (when operated) to a corresponding location in the film plane. The second light source **42** is mounted to a sidewall of the housing in alignment with the axis of rotation of the innerwall and outer cylinders **72**, **64**. The inner cylinder **72** is hollow along its length to enable the light beam from the second light source to impinge on and be reflected by the mirror **26**.

For convenience in the further description herein, the mirror axis of rotation extending through the bearings **58**, **60** will be referred to as the "X" axis and the axis of rotation of the mirror by means of the yoke **56** will be considered as the "Y" axis. Similarly, step motor **70** will be referred to as the "X" step motor and step motor **80** will be referred to as the "Y" step motor.

In order to monitor the position and eye movements of the subject during the test, the device may include a partially reflective plate **82** mounted above and forwardly of the housing **10** so as to be directly in front of the subject's view when his head is properly placed in the head rest and chin support **84**. Plate **82** is adapted to enable the subject to view the screen **38** and is disposed at an angle to his general line of sight to enable a light source **86**, preferably infrared, to reflect from the plate **82** and illuminate the subject's eyes. The image from the subject's eyes is, in turn, reflected from the plate **82** toward an imaging arrangement **88** which includes a ground glass screen **90** on which the reflected image of the subject's eye may be focused, employing the technique described in the aforementioned U.S. patent. As described in that patent a pair of vertically spaced photoelectric cells **92** and horizontally spaced photoelectric cells **94** are located on or adjacent the screen **90** and are aligned with selected regions of the image of the subject's eye on the screen **90**. Variations in the output signals from the photocells **42**, **94** are dependent on the direction and magnitude of the subject's eye movements and their signals are processed in the logic circuitry as described more fully herein. Imaging arrangement **88** preferably is mounted for adjustment to the housing **10** to facilitate initial alignment of the photocells **92**, **94** with the subject's eye image on the screen **90**. This may include a bracket **96** pivoted for horizontal movement to the housing **10** and a vertical elevation screw **98** carried by the bracket **96** and in engagement with the end of the barrel **100**, the other end of the barrel **100** being pivoted to the bracket at trunnions **102**.

GENERAL DESCRIPTON OF OPERATION

The invention employs a number of electronic logic systems which are interrelated as shown diagrammatically in FIG. **14**. The primary logic systems include a control logic circuit, a positioning logic circuit, a decision logic circuit and a vernier logic circuit. A typical cycle might begin by an output from the control logic circuit to step a card reader and read the card bearing digital information corresponding to an intended location of the target image. The digital information is fed into the position logic circuitry which controls the mirror positioning mechanism **12** and positions the mirror in the intended attitude. In the embodiment of the invention described, digital data is included in the card for the positions of each of the X and Y motors with the Y motor being positioned first and then the X motor. When the Y motor has been driven to its intended position, a "Y position ready" signal is fed into the control logic to cause the card reader to advance to the next column of X positioning information on the digital information card. This is fed into the position logic and the X motor is driven to its intended position. During the stepping of the motors **70**, **80** the position of the X or Y step motor being driven is fed back to the position logic circuit for comparison with the intended position corresponding to the digital positioning input. The control logic includes means for delaying operation of the other elements of the invention during positioning of the mirror. After that delay has elapsed and the mirror has been positioned the control logic resumes operation to open the projector shutter and turn on the projector light to present the target image on the projection screen while simultaneously turning off the central, reference fixation target light. The target image will be located at a predetermined angular distance, within approximately 40°, from the central reference fixation target. The position and movement of the subject's eyes, during and slightly after presentation of the target image, is monitored by the photocells **92**, **94** and their output is fed into the decision logic which evaluates whether the subject has seen or missed the presented target. The seen/missed decision from the decision logic is fed back into the control logic and, depending on whether the manual inputs to the control logic were set to record seen or missed targets, the control logic will operate the camera shutter and the camera light to make, or not to make, a photographic plot of that target image.

Means are also incorporated in the invention for checking the subject's cooperation in the test by enabling "dummy" targets (those in which there is no target presented) to be "presented" to the subject. In the event that the output from the photocells indicates eye movement indicating that the subject did "see" the dummy target, the control logic causes a "dummy seen" indicator light on the operator's control panel to turn on thus advising the operator of the subject's uncooperativeness.

It should be noted that the shutter mechanisms are opened and closed whether a real target or a dummy target is presented. This is desirable when the shutter mechanism selected makes audible operating sounds which might be heard by the subject. By operating the

shutters for each mode the subject cannot tell audibly whether the target is real or a dummy.

The invention also includes means for evaluating the subject's visual field closely about the region in which he missed an actually presented target. For this purpose the vernier logic circuit may be employed. The vernier logic circuit is set into operation when the control logic receives a signal from the decision logic indicating that the subject missed an actual target. When the vernier logic circuit is initiated, the control logic is disabled from operating the card reading mechanism and the positioning of the mirror, to present the vernier target images, is controlled entirely by the vernier logic circuit. When the vernier target images have been presented the vernier logic causes the position logic to return the mirror to the attitude which it was in before the vernier sequence and the positioning logic is then enabled to be responsive to the digital positioning information from the card reader. The control logic causes the card reader to be advanced to the next informational word corresponding to the next intended target location and the sequence is begun anew.

The electronic logic systems may be housed conveniently in a control module **110** which houses the card advancing and reading mechanism which includes an exposed slot **112** to receive the card. The module **110** may also house a strip chart recorder **464** to provide a supplemental record of subject's eye test. The module **110** also includes a control panel which includes a manual target positioning means **112**, a start switch **114**, a stop switch **116**, a "dummy seen" indicator light **118**, a record seen/missed selector switch **120**, a vernier in/out switch **122**, a manually controllable switch **124** for turning the reference fixation target on or off, a "disable double saccade" switch **126** and a number of intensity controls **128** for the target light, recording light and reference fixation light.

DESCRIPTION OF CONTROL LOGIC

FIGS. **8A** and **8B** show the circuitry controlling and coordinating the operation of the machine. The sequence of operation is begun by applying a pulse to line **150** through flip-flop **152** and through OR gate **154** to trigger monostable multivibrator **156**. When first starting the sequence of operation the starting pulse may be applied to line **150** through manual start switch **114**. Succeeding pulses are applied to line **150** through flip-flop **152** which is operated in a manner described herein. The high output pulse from multivibrator **156** is amplified and fed through line **160** to initiate operation of a card advancing and reading device **162** which may be of any of a variety of commercially available designs. It should be noted that while the present embodiment of the invention is described as employing digital programming information in the form of a machine readable card, other information, storage and reading techniques may be employed such as tape or the like as is well known in the art. The pulse from multivibrator **156** is also applied to multivibrator **164** through OR gate **166**. Multivibrator **164** has a delay constant (will remain at a high output) sufficient to delay presentation of the target image long enough to enable the card advancing and reading mechanism **162** to position the card so that its digital information may be read as well as to provide sufficient delay for the stepping motors of mirror mechanism **12** to position the mirror, as for example, a delay of approximately one second. The output from multivibrator **164** also is directed through line **168** to a gating circuit **170** (FIG. **8A**) which has an AND function. The output from gate circuit **170** is fed through NAND gate **172** and inverter **174** to apply a high input to monostable multivibrator **176**. The other inputs to the gating circuit **170** are from the positioning logic circuitry, described below, which is effective to apply a high input to gating circuit **170** when the mirror has been positioned in accordance with the digital information on the input card, as described herein. With the mirror properly positioned, monostable multivibrator **176** is triggered and its output is directed, through line **178** to actuate the driving mechanism for the projection shutter **22** to open the projection shutter. In the embodiment shown this may be achieved by applying the output from the multivibrator **176** to the input of an enabled NAND gate **180**, inverting the low output from gate **180** to a high state through inverter **182** and applying the high pulse to the shutter mechanism to open the shutter. Multivibrator **176** has a time delay sufficient to maintain the projection shutter open while the target light is being presented. For example, the delay may be of the order of 2.75 seconds.

It is desirable to delay the operation of the target light until the projection shutter **22** has been opened fully. To this end simultaneously with actuation of monostable multivibrator **176**, the pulsed output from inverter **174** is also applied to monostable multivibrator **184** which has a delay constant of the order of 55 milliseconds, depending on the time required to open the shutter fully. The high output pulse from multivibrator **184** is fed into monostable multivibrator **186** which, in turn, controls operation of the target light. The output from multivibrator **186** causes the target light **34** to turn on through line **188** to NAND gate **190** and inverter **192** to the switch mechanism (not shown) for the target light. Gate **190** is normally enabled because of the normally high state of line **236** as will be described. Multivibrator **186** has a delay constant sufficient to remain in a high output state and present the target image for a predetermined time interval long enough to afford the subject a sufficient opportunity to detect and respond to the target. By way of example, a delay constant of the order of 2.2 seconds would be typical. It is desirable to switch the central reference fixation target light **193** off when the target image is presented. This may be accomplished automatically by connecting line **188** through an inverter **189** to the central fixation light. When multivibrator **186** switches high to present the target light, the output from inverter **189** switches low to extinguish the central fixation light **193**. When multivibrator **186** returns to its stable state, turning off target light **134**, the output from inverter **189** will return to its high state to re-present the central reference fixation target. In an alternative mode of operation the central fixation light **193** may be maintained on at all times, including the time in which the target is presented, by line **191** which is connected to the panel switch **124**.

The subject's eye movements and positions are monitored during an extended time interval which includes the predetermined time interval of the presentation of the target image. As described, the output from the photocells **92, 94** is evaluated by the decision logic circuitry to determine whether the subject actually visually detected the target image. In order to provide ample opportunity for the decision logic to perform its function the output from multivibrator **186** is applied concurrently to monostable multivibrator **194** which has a delay constant sufficient for the subject's eye posi-

tions and movements to be monitored by the photocells **92, 94** and the resulting signals processed through the decision logic circuitry. The delay constant of multivibrator **194** preferably is somewhat longer than the time constant of multivibrator **186** to enable the decision logic to evaluate eye movements after the target image has been extinguished, for the full extended time interval. The delay may be, for example, of the order of three seconds. This is desirable because the subject's eyes may move after the target light has been extinguished, as when returning his vision to the central fixation point as described herein.

When the decision logic has evaluated whether a subject actually visually detected the presented target image, it then remains for the photographic recording system to make, or not make, a photographic plot of the target image location, as determined by the mode of operation which the examiner has selected. To this end as multivibrator **194** returns to its stable, low output state, the pulse triggers multivibrator **196**, and the output of multivibrator **196** is directed through line **198** to the camera shutter mechanism to open the camera shutter **24**. At the same time, the output from multivibrator **196** is directed through line **200** through inverter **202** to apply a low signal at NAND gate **180** which will insure that the projector shutter is closed. This precludes ambient light from reaching the film plane as might occur if the projection shutter **22** remained opened at the same time as the camera shutter. Simultaneously with the actuation of multivibrator **196**, the output from multivibrator **194** is applied to monostable multivibrator **204** which is effective to delay further sequencing of the photographic recording functions until the camera shutter **24** is open fully. The delay will depend on the characteristics of the shutter mechanism and may for example, be of the order of 55 milliseconds. It may be noted that monostable multivibrator **196** has a time delay constant sufficient for the logic and control circuits to "decide" whether or not to make a photographic plot of the relative location of the target image as described below. By way of example, the delay may be of the order of 1.2 seconds. When the camera shutter **24** has been opened fully, the return to its stable, low output state of multivibrator **204** triggers multivibrator **206**. Multivibrator **206** sets the control logic circuitry in readiness to cause a photographic record of the position of the target to be made, depending on whether the target light was actually presented, whether it was a "dummy" in which case no target would have been presented, whether the subject "saw" or "missed" the target or dummy and whether the intended mode of operation, as controlled by a suitable selector switch on the panel of the control box, is set to record "seen" or "missed" points.

As shown in FIGS. **8A** and **8B** the output from multivibrator **206** is directed through line **208** to one of the inputs "*a*" of each of the NAND gates **210, 212, 214, 216**. Each of gates **210, 212, 214** and **216** also has an input "*b*" which is controlled by the decision output front the decision logic circuitry. As described more fully herein, the output from the decision logic circuitry is a signal which is indicative of whether the subject's eye positions and movements where characteristic of his having "seen" the target. As shown in FIG. **8B** the output from the decision logic circuitry is applied to monostable multivibrator **218** and the output from multivibrator **218** is directly connected to input "*b*" of each of NAND gates **210** and **214.** The output from multivibrator **218** is also connected, through inverter **220** to input "*b*" of each of NAND gates **212** and **216**. Each of the gates **210, 212, 214, 216** also includes an input "*c*", as through line **222**, which controls gates **210, 212, 214, 216** in the event that a "dummy" target was presented. The state of line **222** may indicate a "dummy" either by a manual dummy presentation switch on the control panel or from appropriate digital information programmed into the card. Line **222** is connected directly to input "*c*" of each of the NAND gates **210, 212** and is applied, in an inverted form, through inverter **224** to input "*c*" of each of the NAND gates **214, 216**.

Gates **210, 212** are effective to detect, respectively, whether a dummy signal was "seen" or whether it was "missed", as it should have been. Gates **214, 216** discriminate between actually presented targets which were "seen" or "missed". For example, assuming that an actually presented target was seen and that the manually controlled panel switch (which controls the output of flip-flop arrangement **230**), to selectively record points seen or points missed, is in the "record seen" configuration. Where the target was actually presented, line **222** is at a low state which applies low inputs to terminals "*c*" of gates **210** and **212** and high inputs to terminals "*c*" of gates **214, 216**. Inputs "*a*" of each of gates **210, 212, 214, 216** are high at this time, from the output of multivibrator **206** through line **208**. A target which was actually seen will result in an output pulse from the decision logic to pulse multivibrator **218**. This will result in a high input to terminal "*b*" of NAND gate **214** and a low input to terminal "*b*" of NAND gate **216**. The resulting high output of gate **214** is passed through OR gate **226** and the high output from OR gate **226** is applied to NAND gate **228**. The other input to NAND gate **228** is high because of its connection to the output of OR gate **229**, which was high because of the high output from NAND gate **216**. This results in a pulse at the output from NAND gate **228** which triggers the recording light source. Had the subject under test missed the presented target, input "*a*" to NAND gate **216** would have remained in its inverted high state thus maintaining its output low which, through OR gate **229**, would maintain NAND gate **228** in its previous state. The result would be no output pulse from NAND gate **228** and the record light source would not be triggered.

If it is desired to record the missed targets, thus providing a photographic plot of only the missed points, the panel controlled record seen/missed selector **230** may be set manually to switch the state at line **232** from high to low which sets one of the input terminals of NAND gate **228** at a high state through inverter **234** and OR gate **229**. The low state of line **232** is applied directly to one of the inputs to OR gate **226**. When the presented target is missed, there will be no pulse from multivibrator **218** and its output will remain low, resulting in a high output from gate **216** which, through OR gate **226**, will generate a low output pulse from NAND gate **228**, thus triggering the recording light source and making a photographic plot of that missed point. If, however, the target is seen, the output pulse from multivibrator **218** will be applied to input "*b*" of NAND gate **214** which will switch gate **156** to a low output state with a corresponding low output state from OR gate **226**. NAND gate **228** will not be triggered and no photographic recording will be made.

In those instances where it is desired to spot check the subject's response by providing a "dummy" target, the state of line **222** may be changed from low to high either by a manually operable switch on the face of the control

panel or by preprogrammed digital instruction on the program card. In either event, when the state of line **222** is switched to high, the high state is applied to inputs "*c*" of NAND gates **210, 212**, respectively. Inputs "*a*" of gates **210, 212** are also at a high state. Gates **214, 216** are disabled from operating the recording light during this mode of operation by means of the low output of the inverter **224**. The low output from inverter **224** also is applied, through line **236** to an input of NAND gate **190**, thus disabling gate **190** (FIG. 8A) and precluding operation of the target light.

When a "dummy target" is presented and "missed" input "*b*" to gate **210** will be low, resulting in a high output from gate **210** which, is inverted through inverter **238**. The output from inverter **238** is employed to control the operation of an indicator light **240** on the panel which, when lit, indicates that the subject moved his eyes when there was no target presented. Here, however, where the "dummy target" was missed, the output from inverter is low and the indicator **240** is not lit. The "dummy missed" indication also results in a high input at terminal "*b*" of gate **212**, thus switching the output of gate **212** to a low state which, in turn, is applied at the input terminal "*b*" of NAND gate **242**. This maintains a high output state from gate **242** which is passed through OR gate **154** and is employed to actuate multivibrator **156**, to step the card reading mechanism and begin a new cycle of operation.

Where the dummy target has been "seen" the high output from multivibrator **218** is applied to input terminal "*b*" of gate **210** resulting in a low output from that gate. This actuates the "dummy seen" indicator light on the panel which advises the operator that the subject is moving his eyes in a search for the target or is otherwise being uncooperative in the test. It also switches AND gate **242** through line **241** to pulse multivibrator **156** and advance the card reading mechanism.

After the foregoing arrangement has completed its cycle of evaluating whether the subject detected or missed a real or dummy target and a photographic plot of the seen or missed points has been made, the card reader is sequenced to its next position to read the next column of digital information from the preprogrammed card and begin a new cycle of operation.

When the target image is presented, the inputs to terminals "*c*" of gates **210, 212** will be low resulting in a high output from these gates into NAND gate **242**. If the real target was seen the low output from gate **214** will be inverted at inverter **244** and the resulting high signal will be applied to an input of NAND gate **246**. In most instances (except as described below in connection with operation of the vernier logic circuitry) the other input to gate **246** will also be at a high state, resulting in a low output from gate **246** which applied into terminal "*c*" of gate **242** thus causing a high output pulse to be applied to multivibrator **156** through OR gate **154** to advance the card reader and begin a new cycle as described above.

Where an actually presented target has been missed (assuming that the device is not being operated in its vernier mode) gate **242** is switched by switching its input "*d*" low. This results from the low output of NAND gate **254** when an actual target has been missed. Input "*b*" to gate **254** is set high when not operating in vernier (as will be described). Input "*a*" to gate **254** is controlled by the output from gate **260**. NAND gate **260**, in turn, has one input "*a*" set high when not operating in the vernier mode through the high state in line **413** which is inverted, at inverter **261** to a low output state which, in turn, is applied to input "*b*" of gate **263** maintaining the output of gate **263** high which is applied to input "*a*" of NAND gate **260**. When an actual target has been missed, output of gate **216** switches low resulting in a high output pulse from NAND gate **260** which switches gate **254** low and in turn switches NAND gate **242**.

As will be described more fully with regard to the vernier logic circuitry, when in the vernier mode, a series of targets are presented in a programmed sequence which is incorporated into the logic circuitry itself and is not embodied in the preprogrammed digital input information. For this reason, the card reading and stepping mechanism must be disabled while the vernier sequence is being performed. Whether the vernier cycle is to be employed in a given test is controlled manually by the operator at a switch at the control panel. Once the switch has been set by the operator, the vernier circuit will operate automatically in response to a subject having missed a real target and the card reading mechanism will be disabled. The card reading mechanism is disabled by maintaining a low output from gate **242**. Inputs "*a*" and "*b*" of gate **242** are maintained at a high state when the target image is actually presented and missed. This results from the high output of gate **246** which, in turn, results from the low output of inverter **244** which, in turn, results from the high output of gate **214** when an actual target has been missed. Input "*d*" of gate **242** also is maintained at a high state when an actual target is missed and when operating in the vernier mode. To this end, the manual vernier switch operates a flip-flop **248** which, when the vernier is "in", is at a high output state. The high state from flip-flop **248** is applied to line **250** and is inverted through inverter **252** and the resulting low state is applied to input "*b*" of NAND gate **254**. The resulting high output from gate **254** is applied at input "*d*" of gate **242** thus disabling that gate. After the device operation of the vernier mode, inputs "*c*" and "*d*" to gate **242** are maintained at a high state, thus maintaining the card stepping and reading mechanism **162** disabled throughout the vernier operation, which results from line **413** being switched to a low state. This maintains the output from gate **246** into input "*c*" of gate **242** high. The output from gate **254**, which is applied to input "*b*" of gate **242** also is maintained high as a result of the low output from inverter **252** which occurs when operating in the "vernier in" mode.

With the card advancing and reading mechanism disabled the presentation of the vernier target images is initiated by an output pulse from monostable multivibrator **256** as will be described more fully herein. The input to multivibrator **256** is dependent on whether the device is being operated in a "vernier in" mode and also whether a real target has been missed. When operating in the "vernier in" mode, the high state in line **250** is fed into input "*b*" of NAND gate **258** to enable that gate. When an actually presented target is missed, the output from gate **216** switches low which, in turn, switches the output from NAND gate **260** high thus switching gate **258** to its low output state. This is inverted at inverter **262** and the resulting pulse is employed to trigger multivibrator **256** and pulse line **266** to begin the functioning of the vernier control logic as will be described.

Should it be desired to stop the machine at any time this may be done by operating panel stop switch **116**

which controls a flip-flop **171** to the disable gate **172** and preclude further sequencing of the control logic.

DESCRIPTION OF POSITIONING LOGIC

The circuitry for controlling the position of the mirror **26** includes means for both manually and automatically feeding digital information into the machine regarding the desired attitude of the mirror and/or whether a particular target is to be a real or dummy target. The mirror positioning logic receives inputs, selectively, from the vernier control circuitry as well as from the programmed digital information card or tape. As mentioned above, when operating in the vernier mode the sequential positioning of the mirror is a function of the circuitry incorporated into the vernier circuit itself. However, when the position of the mirror is to be controlled by the digital information on the program card or tape, a separate input to the positioning logic is employed. For this purpose, and as shown in FIG. **10**, the card reader indicated generally at **300** includes a plurality of output gates **301** which are set to a state corresponding to the information read by the card reader and which corresponds to the target coordinates. This data is transferred to a seven bit register **304** which stores the digital information regarding the particular coordinates of the intended target location. The register **304** feeds a comparator **306**. The comparator **306** also receives feedback input corresponding to the actual position of the X and Y stepping motors **70, 80** at any given time. To this end, step motors include follower potentiometers **308, 310** which step with the motors **70, 80** and are employed to feed back, in analog form, a signal corresponding to the position of their respective step motors **70, 80**. The analog information is fed through an analog-to-digital converter **312** and the output from the A/D converter is fed into the comparator **306**. As will be described below, the X and Y step motors **70, 80** are driven by the output pulses from a system clock in incremental steps which, in cooperation with the gearing selected, will cause the target image on the screen to shift one degree (1°). The output from comparator **306** is employed to terminate driving of the step motors when they have reached a position corresponding to that which was fed into register **304** in digital form.

It may be noted that in the described embodiment of the invention the digital information for a particular intended mirror position is stored on a conventional card having rows and columns of digital data and in a manner in which each column has information relating to either the X or Y position. Whether a particular seven bit digital word read by the target coordinate portion of the card reader relates to an X or Y coordinates is so identified by a bit in the column being read. Thus, card reader **300** also includes a section including output gates **302** which are set, alternatively, to a high or low state depending whether the information which relates to X or Y coordinates. It may be noted that the invention also includes manual means for positioning the target location, indicated generally at **303** and having controls at the control panel.

When operating automatically the card reader will first read a data column relating to the intended position of one of the step motors (the Y motor) and then, after that function has been carried out, the card reader will be advanced to read the next column and carry out the positioning instructions with regard to the other step motor (the X motor).

When a column of digital information is read at reader **300** or fed in at manual input **302**, it is entered into the register **304** when the register **304** is pulsed through line **314**. Line **314**, in turn, carries the output from flip-flop **316** which, in turn, is pulsed by the system clock **318** through line **320**, flip-flop **316** having been previously set by multivibrator **322**. The starting pulse from the system clock **318** is also applied, through inverter **324** to A/D converter **312** to initiate its operation. The A/D converter **312** is selectively fed with analog information from either of the following pots **308, 310** as controlled by a switch **326**. The position of switch **326** is in turn controlled by the digital input information which also includes in each column data indicative of whether the particular column or manual input relates to positioning of X motor **80** or Y motor **90**. The "X" or "Y" motor identification data is applied to a pair of flip-flops **328, 330**. Digital information indicating a column of "X" information relating to the intended position of motor **80** will actuate X flip-flop **328** which, through line **332** operates switch **326** to connect the A/D converter **312** to the "X" motor follower pot **308**. In the absence of an output pulse from X flip-flop **328**, switch **326** will normally be in a position which connects the output from the "Y" follower pot **310** to the A/D converter **312**.

The direction in which the step motors **70, 80** are driven is controlled by output **334** of comparator **306**. Comparator output **334** controls the state of lines **340** and **342** which are connected to the X and Y step motors **80, 90**, respectively to switch the polarity of each motor in accordance with the desired drive direction. Thus, comparator output **334** is low at all times except when the digital information in register **304** is greater than that indicated by the output A/D coverter **312**. The number of incremental steps which the motors **70, 80** are driven is controlled by comparator output **336** which, in turn, controls the outputs of NAND gates **344** and **346** respectively. Gates **344** and **346** are connected to the motors to drive them one increment for each output pulse. Output **336** of comparator **306** remains low at all times except when the outputs from storage register **304** and A/D converter **312** are equal, in which case comparator **306** produces a high output pulse in line **336**.

Assuming that the digital input data in register **304** relates to a Y position coordinate, switch **326** will direct the feedback of analog motor position information from the Y follower pot **310** to the A/D converter **312**. This will be compared at comparator **306** with the position data in register **304** which will be entered into the register **304** in response to the output pulse from flip-flop **316**, the A/D converter **312** being simultaneously pulsed through line **320** to begin its operation. When the "Y" information in register **304** is greater than the output from A/D converter **312**, the output **334** from comparator **306** will be high, which will result in a low pulse from NAND gate **338**. The other inputs to gate **338** also are high, line **413** being high when the system is not operating in vernier and line **386** being pulsed high in response to switching of Y flip-flop **330** as is the case when the digital data relates to "Y" positioning information. The low output from gate **338** is employed to maintain the polarity of the drive pulse applied to Y step motor **80** to drive it in one direction as will be described. Conversely, if the digital position information in register **304** is not greater than the output from A/D converter **312**, output **334** from comparator **306** will switch

low which, in turn, will switch the output of gate **338** to high, thus reversing the polarity of the pulse applied to Y step motor **80** and, therefore, reversing its direction of rotation.

The number of drive pulses received by the Y step motor **80** from the system clock is controlled by NAND gate **346**. One input to gate **346** is a function of whether the machine is in a vernier sequence, and, when not, line **348** is low which, when inverted through inverter **350**, is applied as a high input to gate **346**. The other input to gate **346** is controlled by NAND gates **352, 344** and **354**. As long as the outputs from register **304** and A/D converter **312** are not equal, line **336** will be at a low state which, when inverted through inverter **346** will apply a high input to gate **354**. The other input to gate **354** is pulsed high by the system clock **318**, through line **320** and through a delay circuit **358** to cause a low output from gate **354**. This, in turn, results in a high output from gate **344** which produces a low output from gate **352**. The low output of gate **352** results in a high output pulse from gate **346** to drive the Y step motor **80** one increment. Delay circuit **358** is of conventional design and permits the analog feedback information from the follower pots **308, 310** to be fed through A/D converter **312** and converted to digital information usable in the circuit.

In the foregoing manner a high output pulse will result from gate **346** each time the clock **316** pulses to step the Y motor **90** until the information in register **304** is equal to the output from A/D converter **312**. When that occurs, the output **336** will switch to a high state, switching NAND gate **344** to a low output and thus terminating further stepping of the Y step motor **80**. In addition, when line **336** is pulsed to its high state, this pulse is applied to NAND gate **360** which then switches low, triggering monostable multivibrator **362**. The output pulse from multivibrator **362** is connected through line **364** to multivibrator **156** of the control circuitry to step the card reader to the next column of digital information which will bear data corresponding to the other (X) coordinate of the intended target image.

It may be noted that when the Y step motor **80** is stepped to its intended position in response to each high output pulse from gate **344**, that high output pulse also is directed through line **366** to the X step motor **70** to drive it simultaneously with the Y motor **80**. This mode of operation is employed because of the special construction of the mirror positioning mechanism shown in FIGS. **2–7**. The construction of that mechanism is such that operation of the Y step motor **80** alone will cause the yoke **56** to rotate which will move the mirror **26** to a position in which the reflected light beam would shift horizontally as well as vertically on the target screen. For example, rotation of the Y step motor **80** in a direction indicated by the arrow +Y in FIGS. **5** and **6** would cause the yoke to rotate in the direction indicated by the arrow +Y in FIG. **4**. Because the surface of the mirror lies at an angle to the axis of rotation of the yoke, rotation of the yoke in the +Y direction will also cause the mirror to pivot to an attitude to cause the target image to be shifted not only in the +Y direction but also to the left in a −X direction on the projection screen **38** as indicated by the corresponding ±X, ±Y arrows in FIGS. **1** and **2**. By simultaneously operating the X step motor **70** in a direction opposite to that which is caused by the Y step motor (here +X), the X component of Y step motor movement can be compensated for. The positioning logic circuitry is arranged so that if the Y step motor **80** is driven a direction to shift the target location up (+Y) and to the left (−X) the X motor **70** is also driven in a direction which will shift the target image to the right (+X). As will be described, a high output in line **340** will switch the polarity of the X step motor **70** to shift the target image to the left (−X) and a high output in line **342** is effective to switch the Y step motor **80** to shift the target image up (+Y) and to the left (−X), the outputs at lines **340** and **342** would be opposite when the mirror is being positioned to a Y coordinate. The opposite polarity at lines **340, 342** will cause the X step motor **70** to be driven in a +X or −X direction which is opposite to that component of the −Y or +Y direction of the mirror movement which would cause shifting of the target image along an X direction as the yoke is rotated.

The polarity of the pulse applied to Y step motor **80** is controlled by AND gate **368** and the polarity of the pulse applied to X step motor **70** is controlled by NAND gates **370, 372, 374**. The outputs from NAND gates **370, 372, 374** are connected in common to a termination resistor **376** which provides an OR function for that combination of gates. When not operating in the vernier mode, line **413**, which is connected to the vernier control circuitry in a manner described below, is at a high state. The high state of line **413** is inverted at inverter **382** and the resultant low state is applied to gate **374** thus maintaining its output high at all times when the system is not in vernier and the mirror attitude is being determined by the digital input data. The high state of line **413** is also applied to an input of each of gates **370, 372** to enable them to be switched to high or low outputs depending on the state of the other inputs to those gates as will be described below. The high state at line **413**, when not in the vernier mode, is also applied to an input of AND gate **368** which enables that gate to be switched, depending on the output from NAND gate **338**. Switching of gates **370, 372** and **368** are dependent on the output **334** from comparator **306** and on whether the mirror mechanism **12** is being positioned to a Y coordinate or an X coordinate. When positioning the mirror to a Y coordinate and assuming that the output **334** from comparator **306** is high, all the inputs to gate **338** will be high, switching the output of gate **338** low to maintain a low output from gate **368** to set the polarity of the Y step motor **80** in a direction which will shift the target image down (−Y) and to the right (+X). The X step motor **70** is driven in a compensating direction (−X), to shift the target image to the left, because the high state at line **334** will result in a high output from each of NAND gates **370** and **372**. Conversely, if the intended Y coordinate were such that the state of line **334** was low, the output from NAND gate **338** would be high, thus switching AND gate **368** high and directing the Y step motor thus switching AND gate **368** high and directing the Y step motor **80** to shift the target image up (+Y) and to the left (−X). The X step motor **70** would be driven in a compensating direction (+X), to shift the target image to the right, by a low output in line **340** which results from all high inputs to NAND gate **72**, switching its output low with a resultant low signal at line **340**.

After the mirror has been shifted to the new Y coordinate and the card reader as been advanced as a result of the pulse in line **364**, the next columm on the card will include data relating to "X" positioning information and will trigger flip-flop **330**. This switches switch **326** to connect A/D converter **312** with the X follower

pot **308**. In the manner similar to that described above, the gates **370, 372** and **374** result in an output at line **340** which is dependent on comparator output **334**. However, when processing X positioning information the high output from flip-flop **328** is applied through lines **384** to an input of gate **370**. A second input to gate **370** is maintained high by line **413**. The output of gate **370** this depends on the input **334** from comparator **306**. Gate **372** which, during the positioning of "X" data, has a low input from Y flip-flop **330** will remain in a high output state at all times as will gate **338** which is also connected through line **386** to the output from Y flip-flop **330**. Thus, when the output from comparator **306**, in line **334**, is high, the outputs from each of the gates **370, 372, 374** will be high which will direct the X step motor **70** to shift the target image to the left (−X). When the comparator output **334** is low, however, all the inputs to gate **370** will be high, switching its output low and resulting in a low state in line **340** which sets the polarity of the X step motor **70** to shift the target image to the right (+X).

With the polarity for the X step motor **70** set, regular pulses from the system clock will result in high output pulses from gate **344**. When the feedback from the X step motor **70** indicates that the motor **70** has reached the intended position, the output from comparator **306** at line **336**, switches high which will switch the output of gate **344** low thus terminating further stepping of the X step motor **70**. It should be noted that when the mirror **26** is being positioned with respect to X coordinate information, the Y step motor **80** is disabled because of the low output from gate **346**. This results from high input to gate **346** from inverter **350** (when not operating in vernier) and a high input to gate **346** from gate **352**. The output from gate **352** is maintained high during the X coordinate positioning because of the low input to that gate by line **386** from Y flip-flop **330** which has a low output state during the processing of X coordinate information.

Where a dummy target is to be presented neither of the X or Y flip-flops **328, 330** are actuated and the positioning system remains inactive.

It may be noted that X and Y flip-flops **348, 330** are self-resetting. When the A/D converter **312** has cycled, its "busy" output at line **388** switches low which, when inverted through inverter **390** switches gate **392** which, in turn, actuates multivibrator **394**. The output from multivibrator **394** operates gates **396, 398** which are effective to reset the Y flip-flop **330** and X flip-flop **332**, respectively.

The foregoing description of the positioning control has related to its operation when the system is not within a vernier cycle. When in a vernier cycle the number and direction of steps for each stepper motor is controlled entirely and independently by the vernier control circuitry.

DESCRIPTION OF VERNIER LOGIC

As mentioned above when it is desired to examine more closely the regions of the subject's visual field about actually presented targets which were missed by the subject, the panel switch **122** is set to the "vernier in" mode of operation. This enables automatic operation of the vernier cycle in response to the subject having missed an actual target and disables the card reading and advancing system until the vernier target presentation has been completed. When operating in the "vernier in" mode, a signal from the decision logic indicating that the subject has missed a real target image will cause automatic actuation of the vernier control logic to automatically present a plurality of target images in a predetermined array and sequence and in close proximity to and surrounding the location of the target image which was missed. FIG. **9A** shows the relative location of the vernier target images with respect to the primary target image which was missed. In the preferred embodiment, three vernier targets are presented in a triangular configuration about the primary target image location located at **400** in FIG. **9**. The first of the three vernier points to be presented in the sequence **V1** is located 1° directly above the primary target location **400**. After vernier image **V1** has been presented and the subject's eye position and movements evaluated the vernier control circuitry causes the mirror to be repositioned to present vernier point **V2** which is also spaced 1° from primary target location **400** but below and to the left of location **400** as indicated. The procedure of evaluating the subject's eye movements with respect to vernier target image **V2** is performed and the vernier control logic then causes repositioning of the mirror to present vernier target image **V3**. Vernier image **V3** is spaced 1° from the primary target image **400** and is downwardly and to the right of that location to define the triangular spacing of the three vernier points **V1, V2, V3**.

By presenting a plurality of vernier targets in sequence, fine mapping of the subject'visual field about the region of a missed point is achieved and may show a general boundary line of the subject'scotoma. For example, if the vernier presentation indicates that the subject missed vernier points **V1** and **V2** but saw vernier point **V3**, this would indicate that the boundary line of the particular scotoma in question would extend somewhere between vernier point **V3** and a line drawn between vernier points **V1** and **V2** as indicated in phantom by the line **402** in FIG. **9**. If the subject missed all three of the vernier targets **V1, V2** and **V3** this would indicate that the boundary of the scotoma was somewhere outside all of the vernier points. Conversely, if the subject saw all three vernier points this might indicate that the scotoma is quite small and is located closely about the primary target image location **400**. It may be noted that while the illustrative embodiment of the invention shows a vernier pattern of only three points, a more fine mapping of the scotoma boundary could be achieved by employing more than three vernier points, as suggested in FIG. **9A** in which there are six vernier points presented which would provide still further fine mapping of the scotomic boundary. However, three vernier points are adequate for most testing purposes.

The vernier sequence is begun in response to a missed target by an output pulse from multivibrator **256** (FIG. **8B**) which is applied to pulse flip-flop **404** (FIG. **11**) through line **266**. The other input to flip-flop **404** is synchronously controlled by the system clock **318** to produce an output pulse from flip-flop **404** synchronously with the timing of the vernier system as controlled by the system clock. The output pulse from flip-flop **404** is fed into a three bit digital counter **408** having both positive and inverted outputs. It may be noted that counter **408** is rezeroed through line **409** at the beginning of each operational sequence by its connection to line **150** through gate **411**. The inverted outputs are connected to the three inputs of NAND gate **410**, the output of which is connected to line **413** of the

control logic and position logic circuits described above. Thus, where the system is not operating in vernier or, if an in vernier and a target was seen, there is no output pulse from multivibrator **256** and the flip-flop **404** remains in the low output state. As a result each of the three counter outputs *a, b, c* will be at a low state (000) which, when inverted and fed into NAND gate **410** will result in a low output which may be inverted through inverter **412** to a high state which is applied to line **413**. As described above, when line **413** is high gates **246** and **254** are disabled and cannot control switching of gate **242**.

When a target is missed the first vernier pulse from multivibrator **256** is applied to flip-flop **404**. The counter **408** switches to a (001) digital state which results in input "*a*" to gate **410** being switched low. This results in a high output from gate **410** which is inverted to a low state through inverter **412** to switch line **413** to a low state. As described above, when line **413** is switched low, gate **246** is switched to produce a high output which further precludes operation of the step card reader multivibrator **156** during the vernier sequence. Similarly, because the panel switch and flip-flop **248** is set to the vernier position, the output from gate **254** is high. In addition, line **413** is connected to an input of each of NAND gates **370**. **372** and **338** of the position logic (FIG. **10**) to maintain their high outputs and disabling them from switching to low output during the vernier cycle. The high output from NAND gate **338** enables AND gate **368** to be controlled directly by the vernier circuitry through line **380** as will be described below. Line **380** is also connected through line **381** to an input of gate **374** to control its output in response to the vernier circuit. It should be noted that the other input to NAND gate **374** is enabled by a high signal from an inverted input, through inverter **382** from line **413**. It may be noted that during operation of a vernier cycle one of the inputs "*a*", "*b*" or "*c*" to gate **410** will be low, which maintains the low state in line **413**.

When counter **408** has received its first pulse from flip-flop **404** and has been switched to a (001) digital configuration the X and Y step motors **70, 80** are driven to a position which will orient the mirror **26** to reflect the light target at the first vernier position V1 which, in the illustrative embodiment, is 1° above the location of the missed target **400**. This requires the Y step motor **80** to be advanced to move the mirror to reposition the image one step upwardly (+Y) and to the left (−X) and the X motor **70** to compensate one step to the right (+X). The number of pulses applied to the step motors is controlled by switching X NAND gate **414** and Y NAND gate **416** to develop output pulses in response to and for the desired number of output pulses from the system clock **318**. For example, with the counter **408** set to a (001) output all but input terminal "*a*" of NAND gate **418** will be high. When the system clock **316** pulses input "*a*", through line **420**, the output from gate **418** will be switched to low which will result in an output pulse from X NAND gate **414** and, through line **424**, a high output pulse from gate **416**. The output of gate **414** is connected through line **422** to the position logic circuit. As shown in FIG. **10**, a high output in line **422** will be inverted to low at inverter **426** and that low signal switches the output of gate **344** high to pulse the X step motor **70**. The high output from gate **416** is connected through line **348**, through inverter **350** (FIG. **10**) to pulse NAND gate **346** high and drive the Y step motor **80** one increment.

The direction in which each of the step motors is driven for the first vernier point is controlled by the state of line **380**. Line **380** is connected to the output of NAND gate **428** and its state is dependent on the output from counter **408**. When counter **408** receives its first pulse to begin positioning of the first vernier point the input to gate **428** from output "*b*" of counter **408** will be low thus maintaining line **380** at a high state. This, in turn, results in a high output pulse from gate **368** to direct the Y step motor to drive the mirror in a +Y, −X direction (up and to the left as seen on the screen) and results also in switching of gate **374** resulting in a low output which will direct the X step motor **70** to drive the mirror in a compensating +X direction to shift the target image location to the right.

The output pulse from gate **418** also is applied to NAND gate **430** which, in turn, drives a two-bit counter **432**. When the output from gate **418** switches low in response to termination of the clock pulse, output from NAND gate **430** switches high, pulsing counter **432**. The output from counter **432** switches NAND gate **434** so that its resultant low output will be applied to an input of gate **418** through line **436** thus switching gate **418** back to its high output state which, in turn, switches vernier control gates **414, 416** back to their low output state and terminates the positioning of the mirror at the first vernier point. With the mirror having been positioned to the first vernier point V1 within the delay of multivibrator **164**, the resetting of multivibrator **164** to its low output state pulses gating circuit **170** through line **168** (FIG. **8A**) to control the projection shutter, projection light, the camera shutter, record light in the same manner and sequence described previously. The subject's response to the presentation of the first vernier point V1 is monitored by the photocells **92, 94** and the decision logic circuitry determines whether the subject saw or missed the first vernier point. Depending on whether the photographic recording system is set to record seen/record missed points, a photographic plot of the subject's response to the presentation of the first vernier target image may be recorded. Whether the subject saw or missed the first vernier point, after his response has been evaluated multivibrator **256** is then pulsed to continue the vernier sequence. This results from the output pulse from gate **258** each time either of gates **214** or **216** are switched. It should be noted that each time counter **408** is advanced from the output from flip-flop **404**, counter **432** is reset to a (00) state through line **444**, flip-flop **445**, inverter **446** and line **447**.

The foregoing sequence of automatically entering into the vernier mode and positioning the mirror to direct the target image to the first vernier location all takes place within the delay constant of multivibrator **164** which may be of the order of slightly over one second.

After the first vernier target image V1 has been presented, and it has been determined whether the subject has seen or missed it, and whether the response should be photographed, the second vernier point is presented. As can be seen from FIG. **9**, this requires movement of the Y step motor **80** to shift the target image two increments downwardly (−Y) and to the right (+X) and three incremental steps of the X step motor to the left (−X). When multivibrator **256** is again pulsed to cause the output from flip-flop **404** to advance counter **408** to the next digital state (010), the output from counter **408**

switches NAND gates **438, 428, 440** to each produce low output pulses which, in turn, switches X and Y gates **414, 416** to produce high output pulses synchronously with system clock **316**. The switching of NAND gate **328** produces a low pulse in line **380** which is effective to reverse the polarity of the pulses applied to the step motors thus reversing the direction of the X and Y step motors. By switching the state of line **380** low, the output from AND gate **368** will switch low causing the of the X and Y step motors. By switching the state of line **380** low, the output from AND gate **368** will switch low causing the polarity of the drive pulses which are directed to the Y step motor to shift the target image location downwardly (−Y) and to the right (+X). The low pulse in line **380** also is applied through line **381** to gate **374** switching its output high which, in combination with the high outputs from gates **370** and **372** result in a high state in line **340** which will direct the X step motor **70** to shift the target image location to the left (−X). The X and Y motors are pulsed in the manner described above with counter **432** being advanced for each pulse from the system clock. When the counter **432** has been pulsed twice and advanced to a **(10)** digital state NAND gate **442** switches from its high state to produce a low output pulse which is applied to an input of gate **440** thus switching that gate to a high output which in turn switches gate **416** low and terminates further operation of the Y step motor **80** after two incremental steps. The X drive gate **414**, however, is driven one more time until counter **432** registers the third digital state **(11)** which causes NAND gate **448** to switch to a low output, causing a high output from gate **438** which, in turn, disables X gate **414** to terminate operation of the X step motor **70**. The target is then presented at the second vernier point V2 and the decision and control logic run through their respective sequences as described above. It may be noted that when presenting the second vernier target the operation of multivibrator **164** is controlled by the output of multivibrator **256** through line **257** and not by multivibrator **156** which is disabled during vernier operation.

In order then to present the third vernier point it may be seen (FIG. **9**) that the mirror must be moved to shift the target image location two increment to the right (+X). In the illustrative emebodiment this requires operation of the X step motor alone. Thus, when the counter **408** has been pulsed to its next digital state **(011)** gate **428** will switch to a high output again reversing the polarity of the pulse which is applied to the step motors through line **380**. The Y drive gate **416** remains in a low output state as all of its inputs are high. X drive gate **414** is switched through line **445** to produce a high output pulse as the output from gate **441** switches to low in response to all high inputs to gate **441**, thus stepping the X motor. When counter **432** has been pulsed twice, the output from gate **442** switches to low, the switching gate **441** to a high output which switches X drive gate **414** low and terminates further stepping of the X drive motor. With the mirror positioned to show the third vernier point, the third vernier target image is presented and the control and decision logic perform their respective functions.

After the three vernier points have been presented, it then remains for the mirror to be repositioned to the location of the original target image which was missed and which initiated the vernier sequence. This, in turn, requires that the Y motor be stepped one increment up (+Y) and to the left (−X) while the X motor is maintained inoperative. When counter **408** is pulsed, for the fourth time, and is advanced to the **(100)** state, the inputs to X gate **414** remain high thus maintaining X step motor inoperative. The Y drive gate **416**, however, is switched to a high output state because of the low input in response to the low input from fate **450**. Gate **450** is switched to a low output by reason of the high input to it from counter **408**. After NAND gate **430** has pulsed counter **432** to indicate one pulse, NAND gate **452** is switched high and, through line **454** resets counter **408** to its initial digital state **(000)**. Resetting of counter **408** to the **(000)** digital state, returns line **413** to a high state. The **(100)** state of counter **408** also causes gate **453** to be pulsed and which passes through OR gate **154** switches multivibrator **156** to advance the card reader and resume the presentation of the primary targets.

DESCRIPTION OF THE DECISION LOGIC

The position and movement of the subject's eyes are monitored by the eye imaging techniques described in U.S. Pat. Nos. 3,583,794 and 3,689,135 in which the image of the subject's eye is projected onto a screen and in which photocells **92, 94** are located on the screen to be responsive to the position and movement of the eye image. The vertically spaced photocells **92** detects variations in the vertical position of the subject's eye (including movements of the eye lid) and the horizontally spaced photocells **94** detects changes in the subject's horizontal eye position. The outputs from the horizontal and vertical photocell pairs results in a single which is indicative of both magnitude and direction of the subject's eye movement. The decision logic circuitry is designed to discriminate between photocell outputs which are characteristic of the subject having actually seen or missed the presented target, hunting eye movements and blinks.

FIG. **12A** is a DC representation illustrating the relationship between the presentation of the target image and a subject's target missed response as indicated by the output from the photocells. Where the subject's eye does not move during presentation of the target there is no change in output from the photocells.

FIG. **12B** illustrates an ideal response in which the subject has actually seen the target image. Typically, there will be a slight delay from the time in which the target is presented to the time in which the subject's eyes actually move and the response may be delayed, for example 200–500, milliseconds. Also, when the slighted target image is turned off a similar delay will occur in the subject's returning his eyes to the central fixation target. It may be noted that the photocell output may be positive or negative depending on the direction of movement of the subject's eyes. As will be described in connection with the decision logic circuitry, the direction of eye movement is not critical in the particular embodiment shown, the magnitude being the primary consideration.

FIG. **12C** illustrates the photocell output in a situation where the subject has sighted the target but was unable to control his eye movement to direct it precisely to the target image in a single saccade. The photocell output indicates a first substantial eye movement to the general vicinity of the presented target image and a second, minor correctional movement. For example, the first sccade may be of the order of 5° or more, depending on how far the target image is from the central fixation point and the second correctional saccade may be of the order of 3° or less. FIG. **12C** shows a minor

correctional saccade in the same direction as the first saccade and FIG. 12D shows a minor correctional saccade in an at least partly reversed direction. Both responses indicate an actually seen target.

FIG. 12E shows a further response which is indicative of the subject having actually seen the target. This response may be considered as an "early return" in which the subject returned his eyes to the central fixation position before the target light was extinguished. This response also is considered as an actually seen target.

FIG. 12F illustrates a hunting or searching eye movement in which the difference in magnitude of the photocell outputs between the first and second saccades is substantial, for example, of the order of more than 5°. This may result from a first saccade in a direction which is away from the location of the target image, as shown in FIG. 12F or may result from an eye movement shown in FIG. 12G in which, while the searching saccade and second saccade are in the same general direction, the second saccade is substantial, of the order of more than 5°.

FIG. 12H shows a typical output from the vertically spaced photocells which results from a blink. The duration of a typical blink is of the order of 30–50 milliseconds and results in a relatively short duration pulse. Of course, a blink may occur at any time, whether the target is being presented or not.

The decision logic circuitry is effective first to determine whether an output from the photocells is the result of a blink. If so, the remaining portions of the decision logic are disabled from further evaluating that photocell output.

As shown in FIG. **13** the outputs from the horizontal and vertical photocell pairs are amplified at amplifiers **460, 462** respectively. The amplified signals may be coupled to a strip chart recorder **464** if desired to provide a permanent charted D.C. record of the subject's eye movements. The outputs from amplifiers **460, 462** are fed through buffer amplifiers **466, 468** and these signals are coupled to an absolute value adder **470** through AC couple **472**. Where the amplified signals from the photocell pairs are DC, the AC couple is effective to overcome the effect of any long term drift which might be inherent in the system as well as to overcome the effect of any slight head shift of the subject during the test. The absolute value adder insures that a positive output from one pair of photocells will not be negated by a negative output from the other pair of photocells but, instead, results in an output which is the sum of the magnitude of the photocell outputs regardless of their sense. The output from absolute value adder **470** is coupled to a first sense amplifier **474** and also to a second sense amplifier **476**. Sense amplifier **474** is selected so that it will pulse line **478** when the amplitude of the input to amplifier **474** corresponds to an eye movement of more than a first predetermined magnitude, for example, 3°. Sense amplifier **476** is effective to produce an output pulse in line **480** in response to an input from adder **470** having an amplitude corresponding to a change in the direction of eye movement of more than a second predetermined magnitude, for example, 5°. **The outputs at lines** 478 **and** 480 **are employed in the decision logic circuitry to discriminate between the various saccadic movements illustrated in FIGS.** 12A-12H **in a manner described below.**

The decision logic includes three channels including a primary saccade detection channel **479**, a secondary saccade detection channel **481** and a link detection channel **493**. Each signal resulting from the output of either or both of the photocell pairs **92, 94** is applied to each of the three channels simultaneously. If the photocell output was the result of a blink the blink detection channel **493** disables the primary and secondary channels **479, 481** from further operation thus disregarding the effect of the blink. If the resulting signal from the photocells **92, 94** was caused by a genuine saccade this is detected by the primary channel **479** which, in turn, is connected to the secondary channel **481** to enable the secondary channel to thereafter detect existence of a second saccade within a predetermined time interval after the first saccade. The output from the first channel is also connected to an output decision gate **506** (as will be described) in a manner which causes that gate to be enabled at a fixed, predetermined time interval after the detection of the first saccade. The state of the other input to decision out gate **506** is dependent on whether the primary and secondary channels **479, 481** have detected the existence of only two or more saccades and the timed relationship of the saccades with respect to the presentation of the target image as well as their magnitude.

More particularly in order to discriminate blinks from other eye movements, the signal from the vertical photocells is connected through buffer amplifier **468** to a sample and hold circuit **482** and also to a comparator **484**, the output from the sample and hold circuit **482** also being fed into comparator **484**. Comparator **484**, in turn, drives a pair of sense amplifiers **486, 488** which produce an output pulse when the output from the comparator is positive and negative respectfully. When an output signal results from the photocells, the decision logic circuit first evaluates whether the output was the result of a blink. If so, the decision logic circuitry is disabled and there is no change in its output. The blink detection circuitry includes a NAND gate **490** having its inputs fed by sense amplifiers **485, 488**. The output from NAND gate **490** is inverted at inverter **492**. The inputs to NAND gate **474** are normally high which results in a normally high output from inverter **492**. The output from inverter **492** thus may be switched by any change of state to either input to gate **490** resulting from a pulse from either of sense amplifiers **486, 488**. The output from the inverter **492** is connected directly to an input of NAND gate **494** and also to the other input of gate **494** through a multivibrator **496** having a delay constant of, for example, approximately **330** milliseconds. When either input to NAND gate **490** is low as a result of a signal from the vertical photocells input of gate **494** will remain low, to preclude switching of gate **494** while monostable multivibrator **496** will switch to a high output state.

If the triggering input to NAND gate **490** was the result of a blink, which typically lasts between 30–50-milliseconds, the low output of inverter **492** and input "*a*" of gate **494** will switch back to high before multivibrator **496** has returned to its low output state. The all high inputs switch gate **494** to a low output which triggers monostable multivibrator **498**, switching it to a high output state and switching the output of NAND gate **500** to low. A low state at the output of NAND gate **500** indicates the presence of a blink and disables NAND gate **502** and **504** which, in turn, precludes any change in output of the decision out gate **506** as will be apparent from the further following description. If, on the other hand, the input to NAND gate **490** was the

result of a genuine saccade in which the subject's eye remain fixated for considerably more than 30–50 milliseconds, the direct input to gate **494** will remain low at all times during and after the delay of multivibrator **496** thus leaving gate **94** unactuated and maintaining the output from gate **500** in its normally high state which, in turn, maintains the inputs to gates **502, 504** high and in an enabled state.

If the blink detection channel **493** has detected that the input pulse was the result of a genuine saccade, the remaining primary and secondary channels **479, 481** evaluate whether the saccade was the result of the subject's actual perception of the target image or whether it was the result of "hunting" of searching eye movements. When an added pulse from one or both pairs of photocells is fed into sense amplifiers **474, 476** those amplifiers, respectively, evaluate whether the saccade (here the first saccade) was of a magnitude of more than 3° and whether the saccade was a change in eye movement of more than 5°. For example, assuming that a target was presented and was seen, the subject's eye movement of more than 3° results in an input pulse to monostable multivibrator **505** switching its output high. Multivibrator **505** has a 330 delay function and serves to delay further operation of the portions of the primary channel **479** for a time sufficient to enable the blink detection channel **493** to evaluate whether the pulse resulted from an eye movement or a blink. When multivibrator **505** switches back to its low, stable state, that actuates monostable multivibrator **508** switching its output momentarily to a high state. If the target light was on at the time of the saccade then all three inputs to NAND gate **502** are switched to high. This is accomplished by applying a pulse in line **510** indicating that the target light is on and passing it through inverter **512** and NAND gate **514** to produce a high pulse at input of gate **502**, thus enabling that gate as long as the target light is on. It may be noted that while the first saccade may have been of a magnitude which would have also switched the output from sense amplifier **476** to a high state, gate **524** is, at that time, in a disabled state because of the low input, through line **518** from the monostable multivibrator **522** as will be described.

In order to evaluate whether the first saccade was the first of a series of eye movements indicating true perception of the target or whether it was a "hunting" saccade, the decision logic awaits subsequent signals from the photocells to determine whether only a second saccade follows or whether both a second and third saccade follows. Also, where there are three saccades, their relative magnitudes must be evaluated to discriminate between hunting movements (FIGS. **12F, 12G**) and acceptable correctional movements (FIGS. **12C, 12D**). As described above, saccadic movements of less than a predetermined magnitude for example, 3°, are considered to be mere correctional movements. Thus, a pulse resulting from photocells **92, 94** which corresponds to an eye movement of less than 3° will be isolated from the primary and secondary channel, **479, 481** by the sense amplifiers **474, 476** respectively. There being no signal applied to the primary and secondary channels, an eye movement of less than 3° has the same effect as if there had been no eye movement at all thus completely disregarding mere correctional movements.

As indicated at FIGS. **12A–12B**, where there has been a first saccade there will always be a second saccade. The second saccade may result from the subject's returning his eyes to the central fixation target (FIGS. **12B, 12E**) in which case the second saccade is a final saccade indicating that the subject actually saw the target. However, the second saccade may have been the result of the first time that the subject actually saw the target, in which case the second saccade would be only an intermediate saccade which would indicate that the first saccade would have been a hunting or searching movement (FIGS. **12F, 12G**). In order to discriminate between these saccadic movements the invention employs a technique in which the subject's eyes are monitored to detect the existence and magnitude of at least three saccades in which the intermediate saccade or saccades was more than 5° which would indicate that the first saccade was a hunting movement and that the subject did not actually see the presented target.

The foregoing functions are enabled by the switching of gate **502** to a low output state which is the case when the first saccade is not a blink, as described above. The low output from gate **502** is inverted to a high state through inverter **520** and that pulse is applied to monostable multivibrator **522**. Multivibrator **522** is switched to its high output state when the output from multivibrator **508** returns to its low state after generating its short pulse. When multivibrator **522** is switched, its high output is applied to the input of NAND gate **524** which enables that gate and, consequently, the secondary channel **481** to be actuated when the remaining low input of gate **524** receives a high pulse from sense amplifier **476**. Multivibrator **522** has a time delay which will maintain its high output state, thus maintaining the secondary channel **481** in an enabled state for a time sufficient to include that in which a second, intermediate saccade would be made. For example, the delay of multivibrator **522** may be of the order to 450 milliseconds. Thus, if the photocells **92, 94** produce a signal indicating a saccade which was a change of more than 5° and during the enabled interval of secondary channel **481**, gate **524** will be actuated to switch its output low to low thus actuating blink delay monostable multivibrator **526** which also has time delay constant of **330** milliseconds. This enables the blink detection logic to again evaluate whether the second input signal to gate **524** was the result of a blink or a genuine second saccade. If a blink, the low output at gate **500** of the blink detection logic is applied to an input of gate **504** thus disabling that gate and the secondary channel **481**. However, if the signal was not a blink gate **504** will be enabled. When multivibrator **526** switches back to low state, after its **330** millisecond delay, and that pulse triggers monostable multivibrator **528** to produce a short output pulse switching gate **504** low which triggers monostable multivibrator **530** switching its output high. This high output is applied to an input of NAND gate **532** which enables that gate. Multivibrator **530** has a delay constant sufficient to maintain gate **532** in an enabled state for an extended interval ending shortly after the target light has been extinguished. By way of example the delay may be of the order of 2.75 seconds. As described below the other input to gate **533** depends on whether or not there was a third saccade which, in turn, controls the output of gate **532** and the input to decision out gate **506**.

The detection of a third saccade is effected by the primary channel **479**. After the **450** millisecond delay of multivibrator **522**, its output switches low which switches multivibrator **536** to a high output state. This, in turn, enables one of the inputs to gate **534**. Multivibrator **536** has a delay constant which also extends

beyond the time that the target lights is extinguished in order to be able to detect return eye movements which often occur after the extinguishment of the target light. It may be noted that multivibrator **530** has a delay slightly longer than multivibrator **536** so that gate **532** may remain enabled and be switchable in the event that gate **534** is switched. If a third pulse is emitted from the photocells, it will, as in the case for each such pulse, be directed to the sense amplifiers **474, 476** as well as to the blink detection circuitry. Multivibrator **505** delays functioning of the primary channel **479** stages until the blink detection channel **493** has an opportunity to evaluate whether the photocell output was the result of a saccade or a blink. Assuming that it was not a blink and that a third saccade was made by the subject, the signal resulting from the third saccade switches the output from inverter **520** high which is applied through lines **538** to the other input of gate **534** switching its output low which, is inverted at inverter **540** and is fed as high pulse into an input of NAND gate **532**. This results in a low output from gate **532** which switches multivibrator **542** to produce a high output which is inverted at inverter **544** and is fed into decision out gate **506**. This will not switch multivibrator **164** in the control logic and its output will remain low thus indicating a "missed target".

When there is no third saccade during the delay of multivibrator **536**, this indicates that the second saccade was in fact a final saccade to the central fixation point and was thus an actually seen target. When there is no third saccade the input to decision out gate **506** from inverter **544** is high thus enabling that gate. When multivibrator **536** switches back to its low stable output this switches multivibrator **546** and the high output pulse from multivibrator **546** switches decision out gate **506** to a low output which, in turn, actuates multivibrator **164** and indicates a target seen.

In some mass testing situations it may be desirable to make a more coarse test, for example, to detect only whether the subject responded at all to presentation of the target image. This may be accomplished by disabling the second channel **481** so that the output from inverter **544** will remain high at all times thus maintaining decision out gate **506** enabled continuously. Any non-blinking eye movement during presentation of the target image will result, ultimately, in a pulse from multivibrator **546** which will switch decision out gate **506** low indicating a response by the subject during presentation of the target image. While this mode of operation does not discriminate between hunting eye movements and true perceptions, it does not give a rapid more coarse testing procedure. The second channel may be disabled by switch **126** on the control panel which switches flip-flop **550** to enable or disable gate **524** as desired.

When the subject has actually perceived the target and makes a "normal" response (FIG. **12B**) his eyes will fixate on it as long as it is presented (approximately 2.2 seconds). In this event there will be no detected eye movement during the **450** milliseconds that the multivibrator **522** is in its high state. Thus, even though gate **522** is in readiness to be actuated in response to sensed eye movement during the **450** millisecond interval, there is no movement and the input to gate **532** remains low. When the subject's eyes do not return to the reference fixation target shortly after the target light has been extinguished from the subject's view the pulse resulting from that saccade, which is channeled to gate **502** causes multivibrator **522** to be pulsed. The high output from multivibrator **522** is inconsequential at this time because the multivibrator **536** already is in its high state. When the multivibrator **536** switches back to its low state multivibrator **546** is pulsed to apply a high input to decision out gate **506**. The other input of the deecision out gate **506** is also high at this time because as multivibrator **536** was switched to its low state, gate **534** switched to a high state which is inverted to low through inverter **540** which maintains gate **532** at a high state thus precluding actuation of multivibrator **542** whose normally low output is inverted at **544** to a high state which is applied to the decision out gate **506**. The resulting low pulse from gate **506** is applied through line **470** to the control logic as previously described.

As described previously, there may be some instances in which the subject has perceived the target but returns his gaze to the general region of the central fixation target before the target light has been extinguished. Such early return is detected by the foregoing decision logic as a perceived target. Here, the subject's eye movement usually will be after the **450** millisecond delay of multivibrator **522** but before multivibrator **536** has switched back to its low state. This has the same effect as a "seen" response described above.

In order to insure that gate **502** is enabled through line **516** during the extended time interval which includes the interval during which the target is actually presented and a short time thereafter, the output from multivibrator **522** is connected through inverter **548** to an input of gate **514** and the output from multivibrator **536** is connected through inverter **550** to the other input of gate **514** thus insuring a high state in line **516** at all times during operation of the decision logic.

The foregoing mode of operation of the decision logic may be considered as employing a technique in which the extended time interval during which the subject's eye positions and movements are monitored may be considered as divided into successive portions in which each portion begins with eye movement. The number and duration of each such portion of the extended time interval will, of course, depend on the time in which the subject moves his eyes. In addition, an initial segment of each portion of the extended time interval is employed to evaluate whether the particular eye movement was a blink, in which case the eye movement is disregarded as described above.

It should be understood that the foregoing description of the invention is intended merely to the illustrate thereof and that other modifications and embodiments of the invention may be apparent to those skilled in the art without departing from its spirit.

Having thus described the invention what I desire to claim and secure by Letters Patent is:

1. An apparatus for presenting a target image at various selected locations within a subject's visual field comprising:

a light source adapted to emit a beam of light;

a mirror:

means mounting said mirror with respect to said light source to reflect said beam, said means mounting said mirror being constructed and arranged to enable said mirror to be oriented in various selected attitudes with respect to said beam of light to selectively reflect said beam of light to said various locations;

electrically operable drive means connected to said means for mounting said mirror to effect said movement thereof;

circuit means having its output connected to said drive means for operating said drive means;

said circuit means including storage register means for storing digital information corresponding to a selected intended position of said drive means:

feedback means operatively associated with said drive means for developing a signal corresponding to the position of said drive means;

said circuit means including a comparator having inputs from each of said storage register means and said feedback means;

said circuit means including means responsive to the output of said comparator to operate said drive means when said input to said comparator are unequal thereby to move said mirror toward a selected attitude and for thereafter terminating operation of said drive means when said inputs to said comparator are equal.

2. An apparatus as defined in claim **1** wherein said drive means comprises a reversible step motor constructed and arranged as to be driven a selected angular increment in response to a pulse applied thereto, the polarity of the pulse applied thereto determining the direction in which said step motor is driven;

said circuit means including means responsive to the sense of said output from said comparator for controlling the polarity of the signal applied to said step motor thereby to control the direction of drive of said step motor.

3. An apparatus as defined in claim **1** further comprising:

said mirror being mounted for rotational movement about each of a pair of perpendicular axis;

said drive means including a pair of step motors, each connected to said mirror mounting means to effect rotation of said mirror about said axes;

said storage register means being constructed and arranged to receive digital information corresponding to an intended position of one of said step motors;

means for selectively connecting the feedback means associated with one of said step motors to said comparator to correspond with the step motor with which said digital information in said storage register means corresponds to, whereby said selected step motor may be driven to the position corresponding to that represented by the digital information in said storage register means; and

means responsive to positioning of said step motor to said intended position for resetting said storage register means with digital information corresponding to the intended position position of the other of said step motors and for switching said feedback means to said comparator means into connection with the other of said step motors whereby the other of said step motors may be advanced to its intended position corresponding to that represented by said reset digital information whereby said step motors may be positioned sequentially.

4. An apparatus as defined in claim **3** further comprising:

said mirror mounting means being constructed and arranged so that one of said axes is rotatable about the other of said axes whereby, when one of said step motors is operated it will cause the mirror to rotate simultaneously about both of said axes;

means for operating that step motor which controls rotation of said mirror about the other of said axes to drive said step motor in a direction opposite to that which is caused by operation of said first mentioned step motor.

5. An apparatus as defined in claim **1** further comprising:

control means for operating said light source;

means for applying digital information to said storage register means to set said storage register means;

said control means including means for delaying operation of said light source for a predetermined time interval sufficient to enable said drive means to move said mirror to a selected attitude.

6. An apparatus as defined in claim **1** further comprising:

means for monitoring the subject's eye positions and movements;

means for detecting those of the subject's eye positions and movements which display at least one characteristic indicative of whether the subject actually visually detected said presented target image;

circuit means responsive to the detection, by said detection means, of the subject's having failed to visually detect said presented target, for disabling the input from said storage register means to said comparator means, said second circuit including means connected to said drive means to move said mirror to an attitude which may direct said light beam to a predetermined location within the subject's visual field and with respect to the location of said first presented target image.

7. An apparatus for presenting a target image to a subject and for recording the position of said target image comprising:

a housing having front and rear walls;

projection shutter means mounted to said front wall;

camera shutter means mounted to said rear wall.

a double faced mirror mounted within said housing between said projection shutter means and said camera shutter means;

projection light means supported within the housing and located with respect to said mirror to direct a first narrow beam of light along an axis toward one surface of said mirror and to reflect said first beam toward said projection shutter;

recording light means supported in said housing on the other side thereof for directing a second narrow beam of light along said axis and toward the opposite surface of said mirror to enable said second beam to be reflected toward said camera shutter means and in a direction which is opposite to that at which said light beam is reflected from said one surface of said mirror;

film mounting means disposed on said rear wall and on the other side of said camera shutter means;

means for orienting said mirror in selected attitudes thereby to vary the direction of each of said reflected first and second beams;

means for operating said projection light means and said recording light means independently of each other; and

means for operating each of said projection shutter means and camera shutter means.

8. An apparatus as defined in claim 7 further comprising:

means for delaying operation of said projection light means until after said projection shutter has opened fully.

9. An apparatus as defined in claim 8 further comprising:

means for precluding operation of said projection light means after said projection shutter has opened thereby to preclude presentation of an actual target image but without varying the character of audible sound from the operation of said projection shutter means.

10. An apparatus as defined in claim 8 further comprising:

means for delaying operation of said recording light until said camera shutter has opened fully;

means delaying opening of said camera shutter until said projection shutter has closed fully.

11. An apparatus as defined in claim 8 further comprising:

means for operating said camera shutter after each operation of said projection shutter means; and

means for selectively enabling or disabling operation of said recording light source independently of operation of said camera shutter means.

* * * * *

OR 4,054,372

United State
Schröeder

X4071N

1] 4,054,372
5] Oct. 18, 1977

[54] **FOCUSING MECHANISM FOR VARIFOCAL OBJECTIVE**

[75] Inventor: **Wolfgang Schröeder**, Bad Kreuznach, Germany

[73] Assignee: **Jos. Schneider & Co. Optische Werke Kreuznach**, Bad Kreuznach, Germany

[21] Appl. No.: **709,324**

[22] Filed: **July 28, 1976**

[30] **Foreign Application Priority Data**

July 29, 1975 Germany 2533825

[51] **Int. Cl.²** **G02B 15/18**
[52] **U.S. Cl.** **350/186;** 350/187
[58] **Field of Search** 350/184, 186, 187

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Primary Examiner—Paul A. Sacher
Attorney, Agent, or Firm—Karl F. Ross

[57] **ABSTRACT**

A varifocal objective with a four-component front lens group, including axially shiftable second and third components, is provided with a focusing mechanism for the joint displacement of these second and third components as well as a further lens member relatively to the axially fixed first component, that further lens member being either the fourth component of the front lens group or part of an otherwise fixed rear lens group. In the case of an afocal front lens group the last three components thereof are displaced in unison by the focusing mechanism. The lens shifts can be co-ordinated by electric servomotors under the control of stored data.

8 Claims, 8 Drawing Figures

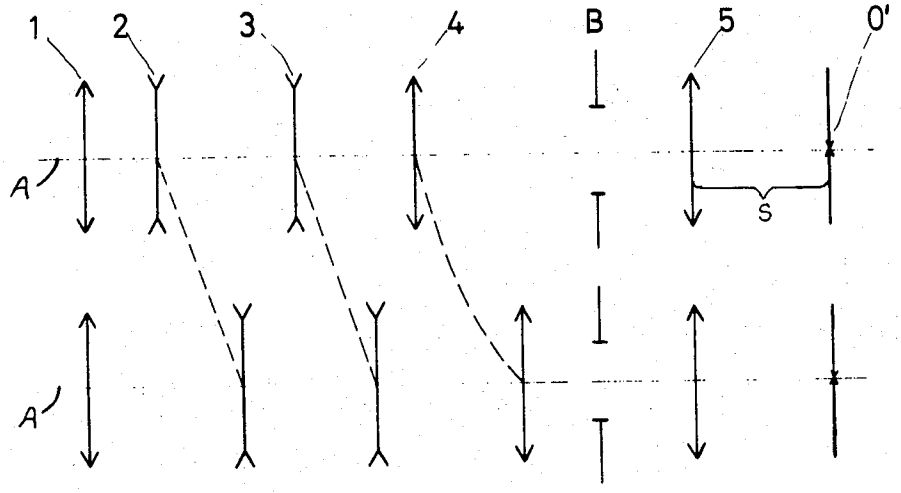


Fig.1

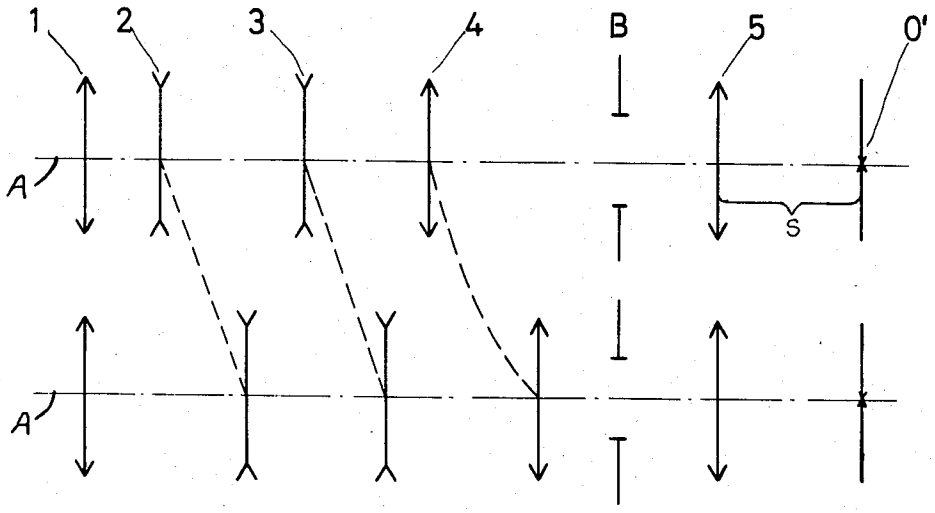


Fig.2

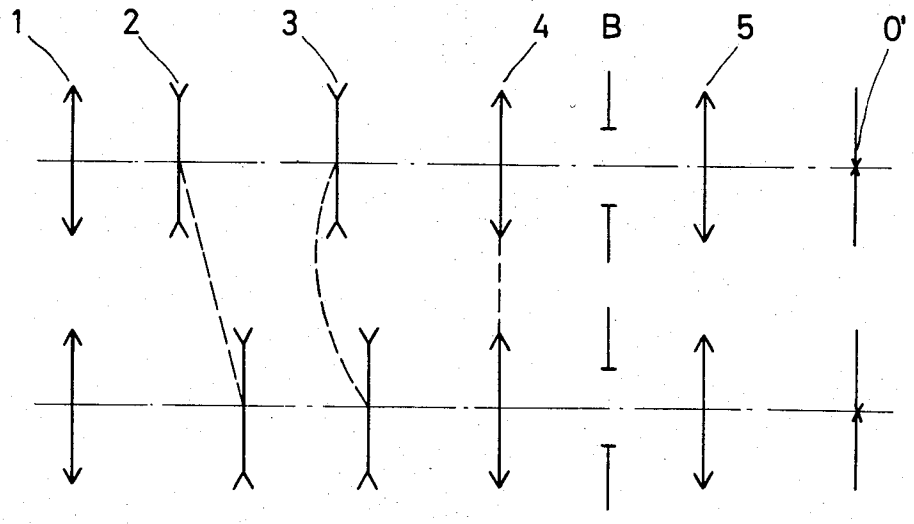
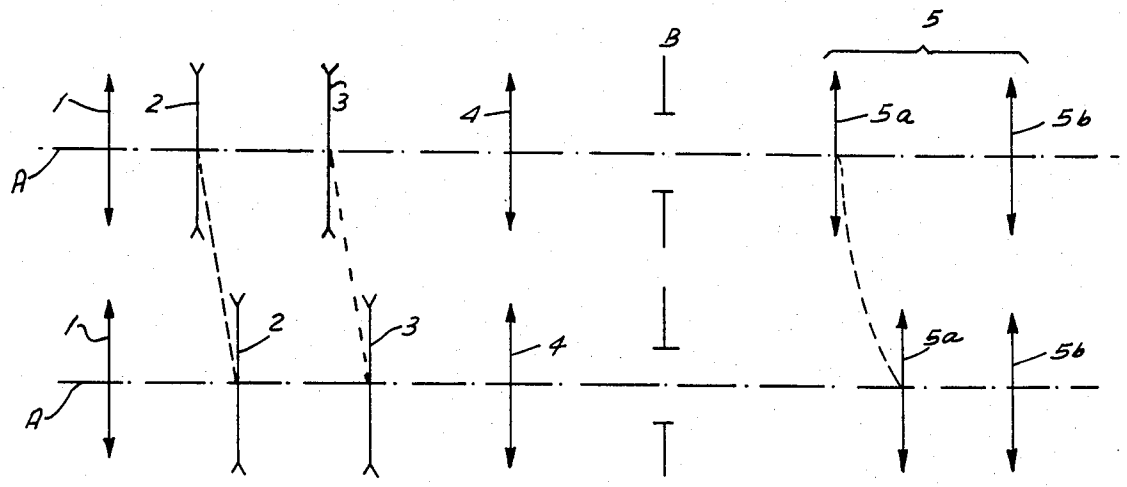


FIG. 1a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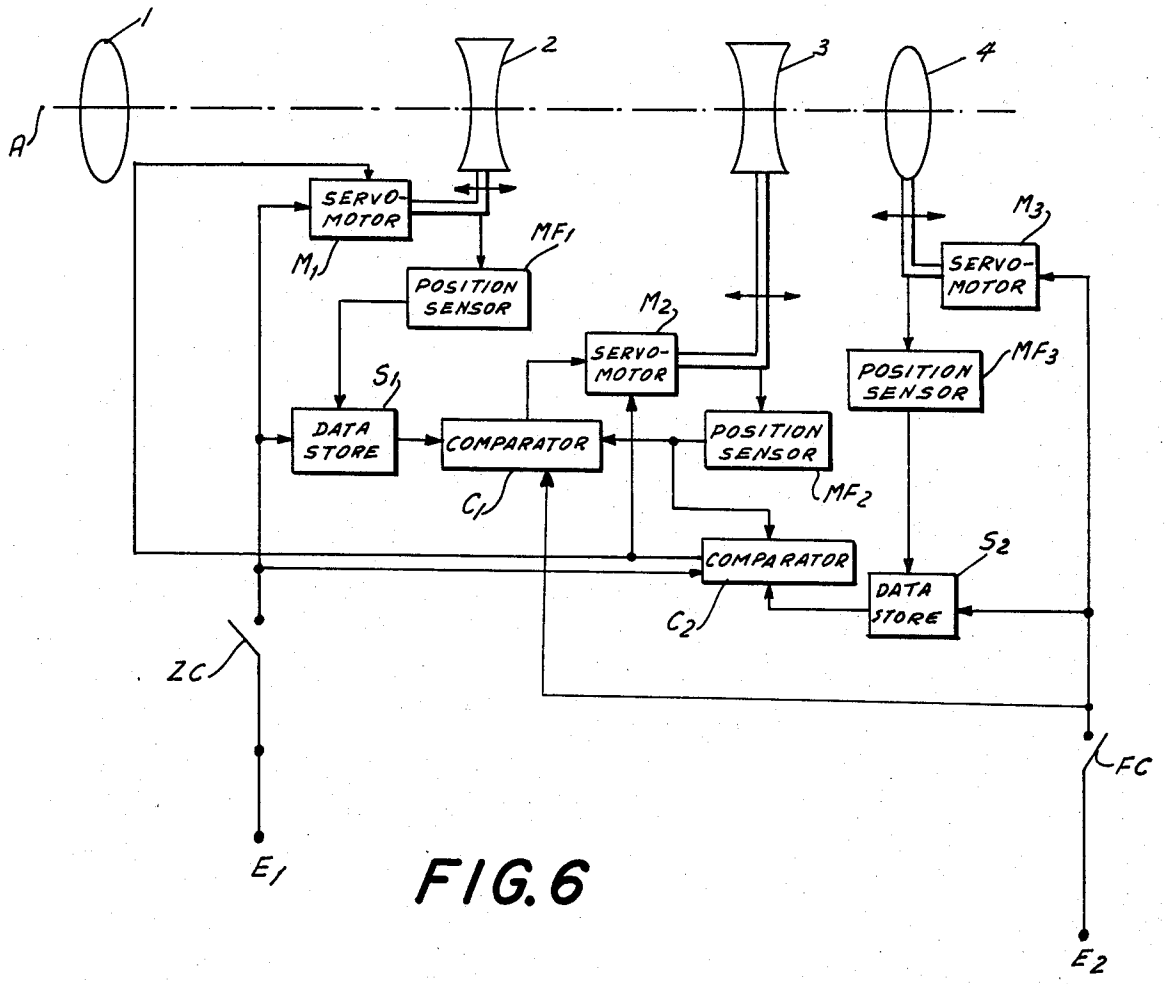
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S1
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COMPARATOR
C1
M2
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POSITION SENSOR
MF2
M3
SERVO-MOTOR
POSITION SENSOR
MF3
COMPARATOR
C2
S2
DATA STORE
ZC
E1
FC
E2

FIG. 6

Fig. 3

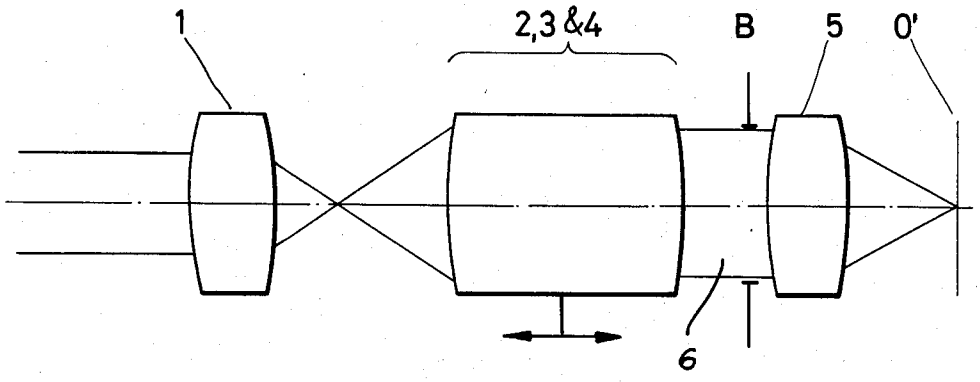


Fig.3a

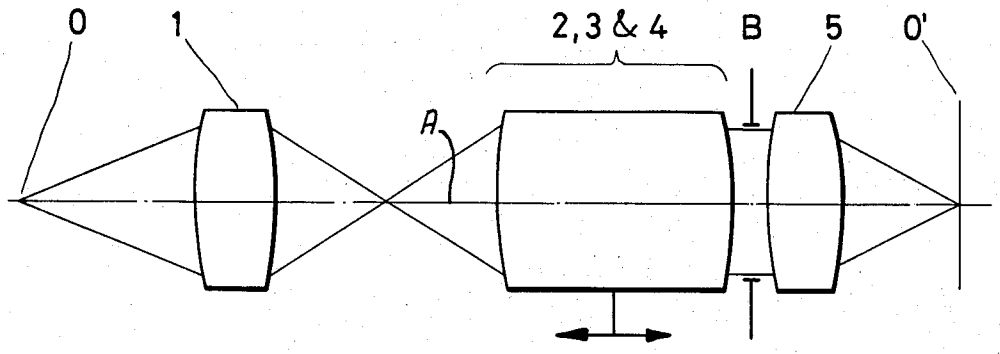
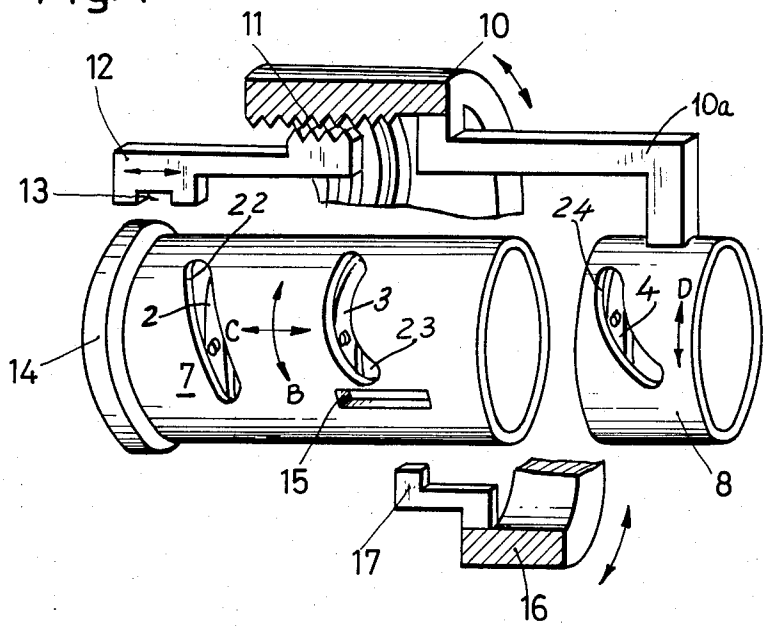


Fig.4


11
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10a
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D
C
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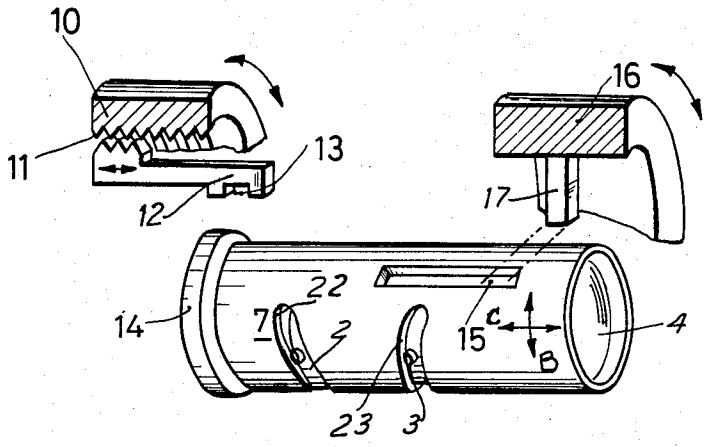
Fig.5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FOCUSING MECHANISM FOR VARIFOCAL OBJECTIVE

FIELD OF THE INVENTION

My present invention relates to a focusable varifocal objective.

BACKGROUND OF THE INVENTION

Conventional varifocal objectives usually comprise an adjustable front group and a fixed rear group of coaxial lens members, the front group being constituted by an object-side first component considered stationary for the purpose of focal-length adjustment, axially shiftable second and third components, and an axially fixed fourth component. The first and fourth components are usually of positive refractivity whereas the shiftable second and third components are negatively refracting. The third component, sometimes termed compensator, moves in a manner designed to keep the image plane of the objective stationary during displacement of the second component or variator. Reference in this connection may be made, for example, to commonly owned U.S. Pat. No. 3,827,786 in the name of Karl Macher.

For focusing purposes, the quasi-stationary first component (or just a front lens thereof) is limitedly axially displaceable to an extent which does not significantly alter the selected overall focal length but shifts the rear focal plane of the objective relatively to the image plane. This axial displaceability of the first component or at least its front lens increases the physical axial length of the objective and also tends to cut off slanting incident rays, thus causing vignetting, unless the front lens is correspondingly enlarged. The presence of a large mobile front lens, however, makes the correction of aberrations more difficult; moreover, in a camera equipped with servofocusing the motor is burdened by the weight of this front lens. Finally, the air volume trapped behind the front lens within the camera housing impedes its movements unless fairly large vent openings are provided which, however, could make the optical system sensitive to atmospheric conditions.

OBJECT OF THE INVENTION

The object of my present invention, therefore, is to provide a focusing system for a varifocal objective which obviates the aforestated drawbacks without materially changing the selected focal-length setting.

SUMMARY OF THE INVENTION

I realize this object, in accordance with my present invention, by the provision of focusing means operatively coupled with the second and third components of the varifocal front group for jointly shifting same to vary the distance at which objects can be sharply focused on the image plane, the focusing means also being operatively coupled with a lens member disposed on the image side of the third component for axially shifting that lens member concurrently with the second and third components to maintain the preselected focal length of the objective. The joint shifting of the second and third components is, of course, independent of their separate shifting by the zooming means designed to vary that overall focal length.

The lens member chosen for the compensatory focusing displacement may be the normally fixed fourth component (or part thereof) of the varifocal front group but could also be one of the constituents of the normally fixed rear group, especially the first — usually positive — lens member of the latter group.

The zooming and focusing shifts of these various lens members can be carried out mechanically, as by means of lens barrels provided with the usual camming grooves or slots, or electronically with the aid of data stores and position sensors controlling the operation of the respective servomotors.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and other features of my invention will now be described in detail with reference to the accompanying drawing in which:

FIG. **1** is a diagram schematically illustrating the focusing displacement of certain components in a five-component varifocal objective according to the invention;

FIG. **1***a* is a similar diagram relating to a modified varifocal objective;

FIG. **2** is a diagram similar to FIG. **1**, schematically illustrating the zooming displacement of certain components of the objective represented in FIG. **1**;

FIG. **3** diagrammatically illustrates an objective with an afocal front group focused upon infinity;

FIG. **3***a* is a view similar to FIG. **3**, showing the objective focused upon a finite object distance;

FIG. **4** is an exploded isometric side view of a zooming and focusing mechanism for an objective of the type represented by the diagrams of FIGS. **1** and **1***a*;

FIG. **5** is a similar view of a zooming and focusing mechanism for an objective of the type shown in FIGS. **3** and **3***a*; and

FIG. **6** is a block diagram of an electronic zooming and focusing circuit for use with an objective as represented in FIGS. **1** and **1***a*.

SPECIFIC DESCRIPTION

In FIGS. **1**, **1***a* and **2** the several objective components have been illustrated schematically as thin lenses even though at least some of these components will generally consist of more than one lens. In all embodiments described hereinafter, the objective comprises an axially fixed positive first component **1**, an axially shiftable negative second component **2**, an axially shiftable third component **3**, a positive fourth component **4** and a positive rear component **5** usually constituted by a multilens group. A diaphragm B is inserted between front group **1–4** and rear group **5**.

The conventional focal-length adjustment, schematically illustrated in FIG. **2**, involves only the negative components **2** and **3**, with component **3** moving first forwardly and then rearwardly while component **2** is shifted toward the rear from a position of minimum focal length to a position of maximum focal length (top and bottom graphs in FIG. **2**). During this displacement along the optical axis A, the position of the image plane O' remains fixed.

In FIG. **1** I have shown how, from the starting position similar to that illustrated in the upper graph of FIG. **2**, the two negative components **2** and **3** are jointly displaced at the same rate toward the rear with reference to the axially fixed first positive component **1**. As far as these three components **1–3** are concerned, such a displacement is equivalent to a forward shifting of the first component as is conventionally done for focusing purposes. In the present instance, however, such a movement — if unaccompanied by a compensatory adjustment of some other lens member — could not

bring about the desired shift of the secondary focal point of the system with reference to the image plane O' without significantly altering the preselected focal length. Thus, a compensatory movement is simultaneously imparted to component **4** at a rate nonlinearly related to that of components **2** and **3** whereby the overall focal length is kept constant on passing from the position of the upper graph to that of the lower graph with focusing of the objective upon closer objects.

Let us consider, by way of example, a conventional varifocal objective with a back-focal length *s* (FIG. **1**) of **12** mm having a relative aperture of 1:2.1 and an overall focal length variable between f_{min} = 20 mm and f_{max} = 300 mm by a shifting of its negative components **2** and **3** in the manner indicated in FIG. **2**. The following values represent the focusing displacement of lens members **2** and **3** on the one hand and lens member **4** on the other hand from the position shown in the upper graph of FIG. **1** to that shown in the lower graph.

TABLE

Rightward shift of components 2 and 3 (mm)	Rightward shift of component 4 (mm)	Focusing distance (meters)
0	0	∞
5	5.93	4.42
10	11.94	2.46
15	18.06	1.81
20	24.30	1.48

As illustrated in FIG. **1***a*, the lens member undergoing a compensatory shifting need not be the component **4** of the front group but could be a positive lens **5***a* (preferably the one nearest the diaphragm space) forming part of rear group **5**, that group also comprising one or more axially fixed lenses **5***b*.

If lens members **2–4** are designed to complement the front member **1** to an afocal system, there will be a field of parallel rays **6** in the diaphragm space between the varifocal front group **1–4** and the rear group **5**. In that instance the spacing between components **4** and **5** becomes noncritical whereby the three movable members **2–4** can be shifted as a unit, relatively to components **1** and **5**, between the position shown in FIG. **3** (with focus on infinity) and the closeup position of FIG. **3***a* in which the objective is focused on a nearby object. An intermediate image is formed in both positions (and in all intervening ones) between components **1** and **2**. The amount of shift required for focusing purposes depends on the individual focal length of component **1** and corresponds to that conventionally imparted to the front lens, yet in the present instance no increase occurs in the total axial length of the objective.

Reference will now be made to FIG. **4** showing a lens barrel **7** centered on the optical axis of the system, this lens barrel being provided with conventional camming slots **22** and **23** for displacing the lens members **2** and **3** in the manner indicated in FIG. **2** upon rotation of that barrel about its axis (arrow B). Such rotation can be brought about by a zooming mechanism including a setting ring **16** from which an arm **17** extends into a slot **15** or lens barrel **7**. This lens barrel is also axially reciprocable (arrow C) with the aid of a focusing ring **10** having threads **11** meshing with a rack **12**, a bifurcated extremity **13** of this rack straddling an annular flange **14** of the lens barrel; rack **12** is guided for movement parallel to the barrel axis by mounting means not shown. An arm **10***a* extending from focusing ring **10** is rigid with another, shorter lens barrel **8** surrounding the positive lens member **4** which is guided therein by a camming slot **24**. All these lens members are, of course, held against rotation by conventional means such as stops engaging the pins which traverse the camming slots **22–24**.

A change in the overall focal length (zoom effect) with the aid of ring **16** does not affect the lens member **4** since only the lens barrel **7** rotates in one or the other sense as indicated by arrow B. On the other hand, a rotation of focusing ring **10** causes this lens barrel to slide axially, as indicated by arrow C, together with lens members **2** and **3** while lens barrel **8** rotates (arrow D) and axially shifts the lens member **4**. Thus, the mechanism of FIG. **4** brings about the lens displacements diagrammatically shown in FIGS. **1** and **2**.

In FIG. **5**, in which lens members **2–4** are assumed to be part of an afocal group as described with reference to FIGS. **3** and **3***a*, component **4** is fixedly held in lens barrel **7** which is rotatable and slidable in the aforedescribed manner under the control of rings **16** and **10**, respectively. A rotation of the lens barrel under the control of zooming ring **16** has no effect upon the axial position of component **4** whereas an axial shift under the control of focusing eing **10** displaces all three lens members concurrently.

In FIG. **6** I have shown an electronic control system for shifting the components **2, 3** and **4** without a slotted lens barrel. A zooming-control switch ZC, when closed, connects a voltage source E_1 to a reversible servomotor M_1 for axially shifting the negative lens member **2**; switch ZC actually has two working positions for energizing the motor M_1 in one sense or the other, e.g. as described in commonly owned U.S. Pat. No. 3,165,044 in the name of Paul Himmelsbach. A motion feeler or position sensor MF_1, coupled with lens member **2**, reports the position of that lens member to a data store S_1 such as a read-only memory which is activated upon closure of switch ZC to deliver a signal representative of the corresponding zooming position of lens member **3** to one input of a comparator C_1 also having another input connected to a position sensor MF_2 which is coupled with lens member **3**. Comparator C_1 thereupon energizes a servomotor M_2 which displaces the lens member **3** until its position conforms to that of lens member **2** in accordance with the schematic showing of FIG. **2**. The position information available from sensor MF_2 is also fed to a comparator C_2 which, however, is inhibited at this time by a blocking voltage on another lead from switch ZC.

A third servomotor M_3, controlling the displacement of lens member **4**, is unaffected by closure of switch ZC but is energizable from a voltage source E_2, in one sense or the other, by a similarly constructed focusing-control switch FC which also activates a data store S_2 receiving the output of a position sensor MF_3 coupled with lens members **4**.

Data store S_2 works into comparator C_2 which, with comparator C_1 blocked upon closure of switch FC, controls the two servomotors M_1 and M_2 to correlate the position of lens members **2** and **3** with that of lens member **4** as indicated schematically in FIG. **1**.

If lens group **1–4** is afocal, as discussed with reference to FIGS. **3** and **3***a*, data store S_2 will be omitted along with comparator C_2 and position sensor MF_3; servomotors M_1, M_2 and M_3 are then energizable in parallel from source E_2 through the closed switch FC.

The provision of a fixed front lens, made possible by the present improvement, allows the camera to be

equipped with stable holders for filter and lens attachments as well as devices for the insertion of film titles or the like. The normally unavoidable decentering effect due to rotation of the front lens for focusing purposes is eliminated.

I claim:

1. In a varifocal objective comprising a plurality of coaxial lens members constituting an axially fixed object-side first component, an axially shiftable second component following said first component, an axially shiftable third component following said second component, a fourth component following said third component and an image-side fifth component following said fourth component, the combination therewith of:

zooming means operatively coupled with said second and third components for axially shifting same at different rates to selectively vary the overall focal length of the objective while maintaining a stationary image plane beyond said further lens members; and

focusing means operatively coupled with said second and third components for jointly shifting same to vary the distance at which objects can be sharply focused on said image plane, one of said lens members disposed on the image side of said third component being axially shiftable and operatively coupled with said focusing means for displacement thereby concurrently with said second and third components to maintain the selected overall focal length.

2. The combination defined in claim **1** wherein said second and third components are mounted in a first lens barrel provided with camming slots for the axial shifting thereof and coupled with said zooming means for rotation thereby, said one of said lens members being mounted in a second lens barrel provided with a camming slot for the axial shifting thereof, said focusing means being directly connected with said second lens barrel for rotating same and being threadedly coupled with said first lens barrel for axially displacing the latter.

3. The combination defined in claim **1** wherein said one of said lens members constitutes said fourth component.

4. The combination defined in claim **3** wherein said second, third and fourth components complement said first component to an afocal group, said focusing means maintaining said second, third and fourth components at an invariable relative distance selected by said zooming means.

5. The combination defined in claim **4** wherein said second, third and fourth components are mounted in a common lens barrel provided with camming slots for the axial displacement of said second and third components, said lens barrel being coupled with said zooming means for rotation thereby and with said focusing means for axial displacement thereby, said second, third and fourth components complementing said first component to an afocal group.

6. The combination defined in claim **1** wherein said one of said lens members is a part of said fifth component.

7. The combination defined in claim **1**, further comprising a pair of servomotors for respectively shifting said second and third components and a further servomotor for shifting said one of said lens members, said zooming means including a first control circuit for the energization of said pair of servomotors, said focusing means including a second control circuit for the energization of all said servomotors.

8. The combination defined in claim **7** wherein said first control circuit includes a position sensor of one of the axially shiftable components and a data store addressable by said position sensor for determining the displacement of the other axially shiftable component.

* * * * *

OR 4,046,459

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4,046,459

Sept. 6, 1977

[54] **RETROFOCUS WIDE ANGLE OBJECTIVE LENS SYSTEM**

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[22] Filed: **Aug. 26, 1975**

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Sept. 4, 1974 Japan 49-101709

[51] **Int. Cl.**[2] **G02B 13/04**

[52] **U.S. Cl.** **350/214**

[58] **Field of Search** 350/214

[56] **References Cited**

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[57] **ABSTRACT**

A retrofocus wide angle objective lens system of seven air-spaced lenses, the first and second lenses, counting in the order of the entrant light beam, being negative meniscus lenses of forward convexity, the third lens being a positive lens, the fourth lens being a bi-convex lens, the fifth lens being a bi-concave lens, and the sixth and seventh lenses being positive lenses. The third and fourth lenses are separated by a large axial air space, and the third lens has a larger diameter than the fourth lens.

8 Claims, 12 Drawing Figures

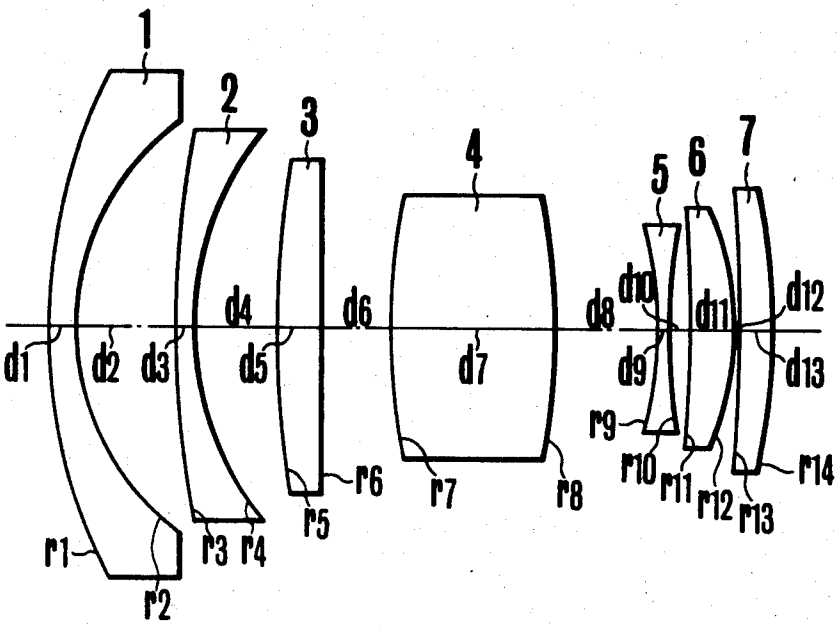


FIG.1

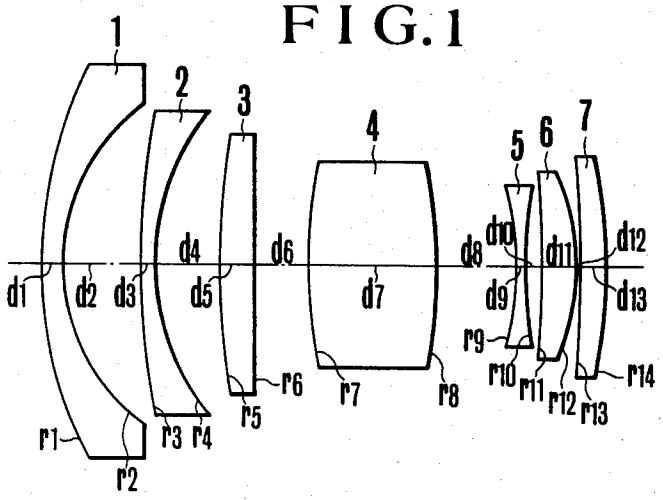


FIG.2 FIG.3 FIG.4

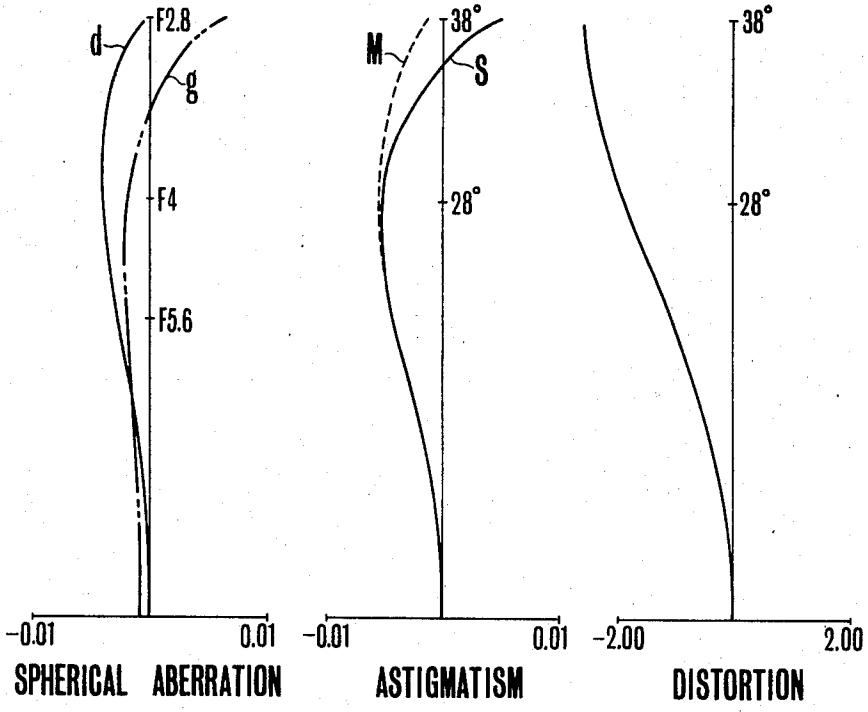


FIG.5

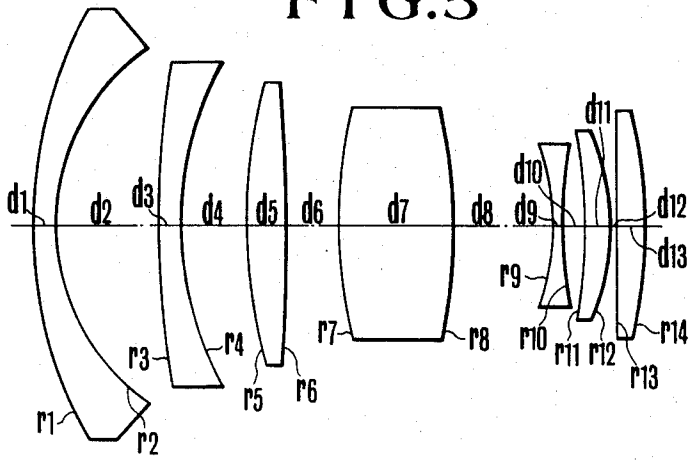


FIG.6 FIG.7 FIG.8

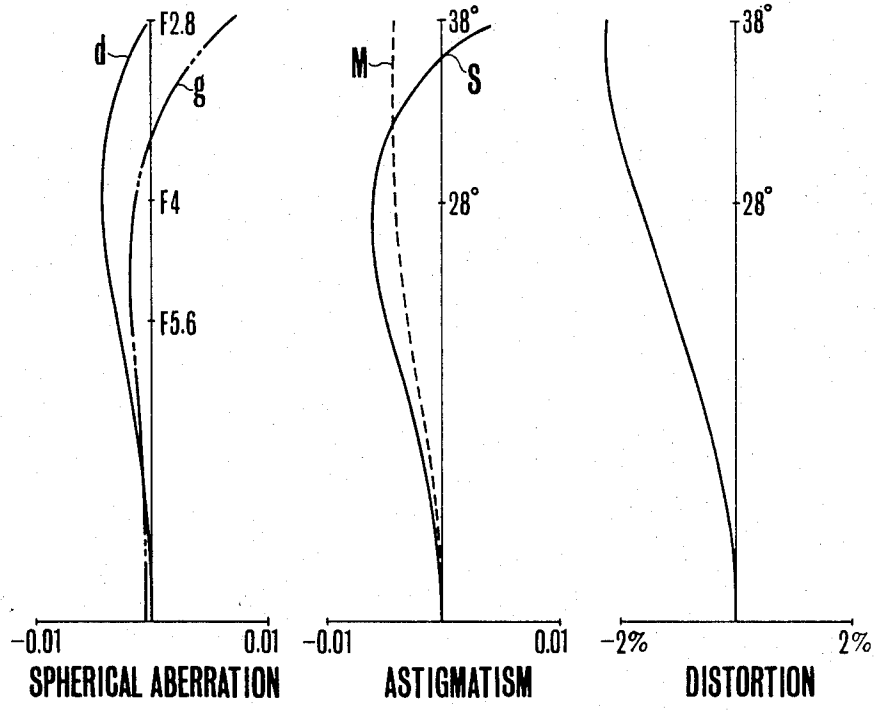


FIG.9

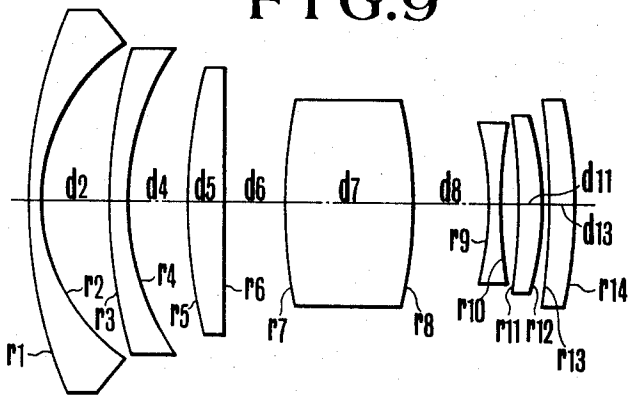
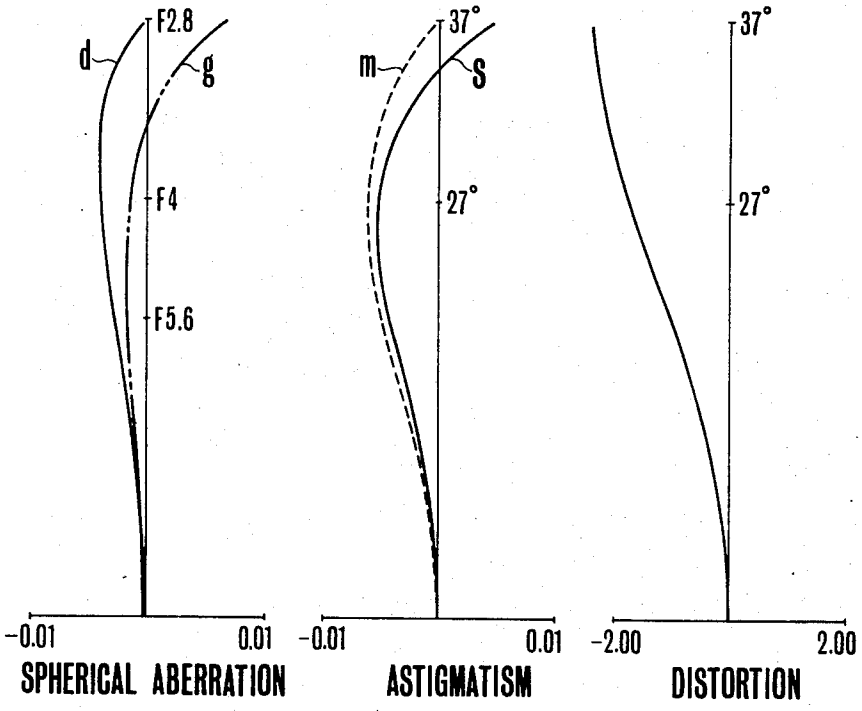


FIG.10 FIG.11 FIG.12



RETROFOCUS WIDE ANGLE OBJECTIVE LENS SYSTEM

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to a compact retrofocus wide angle objective lens system of a long back-focal length adapted for use with a single lens reflex camera.

2. Description of the Prior Art

In general, retrofocus objective lenses are configured to have a negatively refracting front lens assembly and a positively refracting rear lens assembly for the purpose of facilitating increase in the back-focal length thereof. This type of retrofocus objectives has been characterized by the difficulty of achieving a good standard of aberration correction because of the asymmetric configuration of the complete lens system. Further, in this type of objective, an increase in the overall physical length resulting from, for example, decreasing the number of lens components constituting the complete lens system, or the diameter of the front lens component, makes it more difficult to compensate for various aberrations.

SUMMARY OF THE INVENTION

The general object of the present invention is to provide an improved retrofocus lens system of the above-described character yielding a back focal length as high as 1.28 times the overall focal length of the complete system with as small as seven air-spaced lens components and having a relative aperture 1 : 2.8 with a field angle of at least 75° with limitation of the overall length of the lens system to less than 1.83 times the overall focal length thereof, while nevertheless achieving a very high standard of correction of various aberrations otherwise encountered by limitation of the overall dimensions of the lens system to such a minimum.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is an axial sectional view of a retrofocus wide angle objective lens according to one embodiment of the invention.

FIGS. **2, 3** and **4** are curves of the spherical aberration, astigmatism and distortion respectively for the lens of FIG. **1.**

FIG. **5** is an axial sectional view of a lens according to a second embodiment of the invention.

FIGS. **6, 7** and **8** are curves of the spherical aberration, astigmatism and distortion respectively for the lens of FIG. **5.**

FIG. **9** is an axial sectional view of a lens according to a third embodiment of the invention.

FIGS. **10, 11** and **12** are curves of the spherical aberration, astigmatism and distortion respectively for the lens of FIG. **9.**

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

As shown in FIGS. **1, 5** and **9,** a retrofocus wide angle objective lens system of the present invention is characterized in comprising seven optically aligned lens elements, the first and second lens elements counting in the order of the entrant light beam being negative meniscus singlet lenses of forward convexity, the third lens element being a positive singlet lens, the fourth lens element being a bi-convex singlet lens, the fifth lens element being a bi-concave singlet lens, and the sixth and seventh lens elements being positive singlet lenses. If desired, the fourth, fifth and sixth lenses may be individual cemented lenses. For facilitating minimization of the overall dimensions of the lens system, the third and fourth lens elements are separated by a large axial air space as will be described in more detail later, and, accordingly, the diameter of the third lens element is considerably larger than that of the fourth lens element.

A conventionally well-accepted technique for reducing the bulk and size of a complete objective lens is to increase the powers of the individual lens components with decrease in axial air spaces between the successive lens components. When this technique is employed in designing such retrofocus objectives as comprising a divergent front lens assembly and a convergent rear lens assembly, an important problem arising therein is to compensate residual aberrations introduced by the front lens assembly in a manner to achieve a high standard of correction of the image aberrations without involving any great increase in the overall dimensions of the complete objective.

The present invention provides a retrofocus wide angle objective lens with seven lens elements of which the first and second lens elements constitute a divergent front lens assembly and with limitation of the overall dimensions of the complete objective to a minimum by utilizing the above mentioned size reduction technique, whereas residual spherical aberration and field curvature introduced by the front lens assembly are well compensated for. As is known in the art, good compensation for residual aberration is more effectively made at a lens located nearer the lens which contributes to the lens system the residual aberrations. For this reason, the third lens element following the divergent front lens assembly to compensate residual aberrations introduced thereby is required to be located as near to the second lens element as possible. It is desirable to separate the third and fourth lens elements from each other by an axial air space d_6 larger than the axial thickness d_5 of the third lens element, as the second and lens elements are separated from each other by a small axial space.

While the above mentioned feature is generally applicable to any retrofocus objective lens comprising divergent front and convergent rear lens assemblies, the objective is characterized, for purposes of assisting towards improvement of various aberrations otherwise encountered with such size limitation by the following features in combination:

a. $0.6 < d_6/d_4 < 1.0$
b. $0.68f < \gamma_4 < 0.9f$
c. $7.0f < |\gamma_6|$
d. $N_3 > 1.72$; $V_3 < 40$
e. $0.95f < |\gamma_8| < 1.5f$; $\gamma_8 < 0$

wherein f is the overall focal length of the complete objective; d_4 and d_6 are the axial air separations between the second and third lens elements and between the third and fourth lens elements respectively; γ_4, γ_6 and γ_8 are the radii of curvature of the rear refracting surfaces of the second, third and fourth lens elements respectively; and N_3 and V_3 are the refractive index and Abbe number of a glass respectively from which the third lens element is made.

Condition (a) is a compromise between the requirements of limiting to a minimum the dimensions of the complete objective both in the axial and in the radial directions, and of compensating the residual spherical aberration and field curvature introduced by the first

and second lens elements to a modest degree under the situation that the third lens element is located as far from the fourth lens element as possible for the purpose of effecting the limitation of the dimensions. When the lower limit namely, 0.6 is violated, residual spherical aberration and field curvature ascribable to the third lens element become so serious that various residual aberrations ascribable to the first and second lens elements can not be compensated for with the result of a low standard of correction of the image aberrations. When the upper limit, namely, 1.0 is violated, the diverging function of the first and second lens elements is weakened by the converging function of the third lens element. Consequently, the diverging powers of the first and second lens elements must be increased, or otherwise the desired back focal length could not be retained. As the powers of the first and second lens elements are increased, various aberrations ascribable thereto are increased in a non-linear manner to such values as cannot be balanced out by the suitable design of the remaining lens elements.

Condition (b) assists in adjusting the balance in this respect. When the lower limit is violated, this refracting surface γ_4 produces large aberrations which can not be balanced out by the suitable design of the remaining lens elements. When the upper limit, namely, 0.94 is violated, residual aberration ascribable to this surface is decreased with decrease in the diverging effect. In order to obtain an equivalent diverging effect, therefore, the axial air separation d_4 between the second and third lens elements must be increased with sacrificing an increase in the size of the complete objective and permitting an adverse effect on the balance of the nature described above.

Conditions (c) and (d) are concerned particularly with lateral chromatic aberration correction. When the absolute value of the radius of curvature of the rear surface γ_6 of the third lens element is smaller than $7.0f$, the lateral chromatic aberration is over-corrected when $\gamma_6 < 0$, and is under-corrected when $\gamma_6 > 0$. Condition (d) facilitates correction of lateral chromatic aberration along with spherical aberration and field curvature.

Condition (e) assists towards correction of spherical aberration, coma and distortion. When the lower limit, namely $0.95f$ is violated, the rear surface of the fourth lens element contributes to the system large aberration with the result of over-compensated coma and distortion. When the upper limit, namely, $1.5f$ is violated, effective compensation cannot be made because of the production of small aberration. Particularly in the spherical aberration and distortion, under-compensation will be resulted. In other words, condition (e) provides a compromise in respect of the good balance of the image aberrations.

According to a further feature of the present invention, the objective may be constructed from a forwardly convex lens as the third lens element of positive power either independently of or in combination with a rearwardly convex lens as the seventh lens element of positive power. In addition to this feature, the objective is characterized in that the axial thickness d_9 of the fifth lens element is related to the axial air separation d_{10} between the fifth and sixth lens elements as $d_9 < d_{10}$.

Numerical date for three preferred embodiments of the retrofocus wide angle objective lens system according to the present invention are given in Tables 1, 3 and 5 in which γ_1, γ_2 . . . designate the radii of curvature of the individual surfaces counting from the front, the negative sign indicating that the surface is concave to the front; d_1, d_2 . . . designate the axial thicknesses or air separations between the successive two surfaces; N_1, N_2 . . . designate the refractive indices for the sodium d-line of the spectrum of the materials from which the various elements of the objective are made; and ν_1, ν_2 . . . designate the Abbe numbers of the corresponding materials. Seidel aberration coefficients for the lens systems of Tables 1, 3 and 5 are given in Tables 2, 4 and 6 respectively, in which SA designates the spherical aberration coefficients for the individual surfaces; CM designates the coma coefficients; AS designates the astigmatism coefficients; PT designates the Petzval sums; and DS designates the distortion coefficients.

Table 1

(for Fig.1)

f = 1; F 2.8; $\omega = 38°$

γ_1 =	1.1726	d_1 =	0.0632	N_1 =	1.61117	ν_1 =	55.9
γ_2	0.5675	d_2	0.2290				
γ_3	1.9078	d_3	0.0526	N_2	1.56965	ν_2	49.4
γ_4	0.6840	d_4	0.1909				
γ_5	1.8065	d_5	0.1053	N_3	1.74950	ν_3	35.2
γ_6	13.2025	d_6	0.1510				
γ_7	1.1998	d_7	0.4009	N_4	1.71300	ν_4	53.9
γ_8	−1.3263	d_8	0.2315				
γ_9	−0.7066	d_9	0.0351	N_5	1.76182	ν_5	26.6
γ_{10}	1.7226	d_{10}	0.0386				
γ_{11}	−3.0411	d_{11}	0.1088	N_6	1.7725	ν_6	49.7
γ_{12}	−0.6435	d_{12}	0.0070				
γ_{13}	−4.6120	d_{13}	0.0912	N_7	1.7725	ν_7	49.7
γ_{14}	−1.2212						

Σd = 1.7050 Back focal length = 1.2807

$\frac{d_6}{d_4}$ = 0.7910

Table 2

Surface No.	SA	CM	AS	PT	DS
1	0.146035	0.072971	0.036463	0.323504	0.179870
2	−3.675033	0.665763	−0.120608	−0.668456	0.142946
3	0.613187	0.242821	0.096157	0.190228	0.113408
4	−8.755002	0.570447	−0.037168	−0.530591	0.036993
5	4.305823	0.614058	0.087572	0.237154	0.046309
6	−0.365293	−0.270320	−0.200039	−0.032449	−0.172043
7	3.713808	0.791168	0.168546	0.346934	0.109815
8	5.199990	−2.024604	0.788275	0.313842	−0.429107
9	8.839787	1.945718	−0.428270	−0.611967	0.228966
10	−2.044805	−1.356149	−0.899421	−0.251018	−0.762990
11	0.108422	0.219507	0.444402	−0.143312	0.609570
12	5.819640	−0.823215	0.116448	0.677296	−0.112279
13	−0.209745	0.198654	−0.188150	−0.094499	0.267704
14	5.050752	−0.844388	0.141166	0.356891	−0.083265
Total	1.067991	0.002431	0.005370	0.113556	0.175897

Table 3

(for Fig. 5)

f = 1 F 2.8 ω = 38°

γ_1 =	1.3064	d_1 =	0.0632	N_1 =	1.61117	ν_1 =	55.9
γ_2	0.6109	d_2	0.3152				
γ_3	3.7622	d_3	0.0526	N_2	1.60729	ν_2	49.3
γ_4	0.7757	d_4	0.2100				
γ_5	1.7619	d_5	0.1053	N_3	1.72342	ν_3	38.0
γ_6	−9.1853	d_6	0.1500				
γ_7	1.0840	d_7	0.3627	N_4	1.60311	ν_4	60.7
γ_8	−1.3336	d_8	0.2910				
γ_9	−0.6365	d_9	0.0351	N_5	1.74077	ν_5	27.8
γ_{10}	1.8877	d_{10}	0.0491				
γ_{11}	−2.5630	d_{11}	0.0947	N_6	1.69350	ν_6	53.3
γ_{12}	−0.6112	d_{12}	0.0070				
γ_{13}	−26.827	d_{13}	0.0912	N_7	1.69350	ν_7	53.3
γ_{14}	−1.1736						

Σ d = 1.8271 Back focal length = 1.2807

$\frac{d_6}{d_4}$ = 0.714

Table 4

Surface No.	SA	CM	AS	PT	DS
1	0.105587	0.059938	0.034024	0.290356	0.184139
2	−3.066142	0.670053	−0.146429	−0.620868	0.167679
3	0.295980	0.192558	0.125274	0.100422	0.146833
4	−9.455414	0.709214	−0.053195	−0.487021	0.040519
5	5.935596	0.492389	0.040846	0.238226	0.023150
6	−0.066984	−0.105458	−0.166028	0.045696	−0.189446
7	3.871075	0.642769	0.106728	0.347024	0.075343
8	5.370527	−2.129211	0.844152	0.282080	−0.446509
9	−10.436956	2.066115	−0.409011	−0.668528	0.213311
10	−1.922981	−1.311824	−0.894904	−0.225415	−0.764202
11	0.079507	0.181560	0.414605	−0.159764	0.581946
12	5.156481	−0.705360	0.096487	0.669966	−0.104844
13	−0.026222	0.057400	−0.125648	−0.015263	0.308455
14	5.125056	−0.776300	0.117587	0.348893	−0.070659
Total	0.965109	0.043842	−0.015511	0.145805	0.165657

Table 5

(for Fig. 9)

f = 1 F 2.8 ω = 37°

γ_1 =	1.1756	d_1 =	0.0421	N_1 =	1.61117	ν_1 =	55.9
γ_2	0.5588	d_2	0.2132				
γ_3	1.9760	d_3	0.0351	N_2	1.56965	ν_2	49.4
γ_4	0.6857	d_4	0.1855				
γ_5	1.8555	d_5	0.1053	N_3	1.83400	ν_3	37.2
γ_6	19.7733	d_6	0.1810				
γ_7	1.2309	d_7	0.3879	N_4	1.71300	ν_4	53.9
γ_8	−1.3096	d_8	0.2258				
γ_9	−0.7213	d_9	0.0351	N_5	1.76182	ν_5	26.6
γ_{10}	1.6736	d_{10}	0.0421				
γ_{11}	2.7127	d_{11}	0.0877	N_6	1.77250	ν_6	49.7
γ_{12}	−0.6361	d_{12}	0.0070				
γ_{13}	−3.6831	d_{13}	0.0877	N_7	1.77250	ν_7	49.7
γ_{14}	−1.1511						

Σd = 1.6355 Back focal length = 1.2807

Table 5-continued

(for Fig. 9)

f = 1 F 2.8 ω = 37°

$\frac{d_6}{d_4}$ = 0.9757

Table 6

Surface No.	SA	CM	AS	PT	DS
1	0.144897	0.077862	0.041840	0.322662	0.195868
2	−4.045723	0.710444	−0.124757	−0.678829	0.141113
3	0.638314	0.250461	0.098276	0.183665	0.110628
4	−9.173934	0.685262	−0.051187	−0.529290	0.043360
5	4.655788	0.600873	0.077548	0.245076	0.041638
6	−0.297485	−0.244292	−0.200610	−0.022998	−0.183625
7	3.425532	0.764424	0.170585	0.338162	0.113529
8	5.714320	−2.166275	0.821226	0.317817	−0.431807
9	−9.155042	2.047703	−0.458008	−0.599468	0.236525
10	−2.005424	−1.309790	−0.855454	−0.258371	−0.727466
11	0.066322	0.162210	0.396732	−0.160663	0.577376
12	5.980070	−0.913598	0.139574	0.685112	−0.125990
13	−0.272288	0.232108	−0.197858	−0.118330	0.269530
14	5.459993	−0.930889	0.158710	0.378608	−0.091609
Total	1.135339	−0.036496	0.016616	0.103153	0.169071

What is claimed is:

1. A retrofocus wide angle objective lens system comprising seven axially aligned lenses including, in the order of the entrant light beam:

negative meniscus first and second lenses of forward convexity;

a positive third lens;

a bi-convex fourth lens;

a bi-concave fifth lens; and

positive sixth and seventh lenses; and

wherein axial air space between said third lens and said fourth lens is larger than the axial thickness of said third lens, said third lens having a diameter larger than the fourth lens.

2. A retrofocus wide angle objective lens system according to claim **1**, wherein said third lens of positive power has a front surface convex to the front.

3. A retrofocus wide angle objective lens system according to claim **2**, wherein said seventh lens is a positive meniscus lens of rearward convexity.

4. A retrofocus wide angle objective lens system according to claim **3**, wherein said fifth lens has an axial thickness smaller than the axial air space between said fifth and sixth lenses.

5. A retrofocus wide angle objective lens system according to claim **1**, wherein

a. $0.6 < d_6/d_4 < 1.0$

b. $0.68f < \gamma_4 < 0.9f$

c. $7.0f < |\gamma_6|$

d. $N_3 > 1.72$; $V_3 < 40$

e. $0.95f < |\gamma_8| < 1.5f$; $\gamma_8 < 0$

wherein f is the overall focal length of the complete objective lens system; d_4 and d_6 are the axial air separations between said second and third lenses and between said third and fourth lenses respectively; γ_4, γ_6 and γ_8 are the radii of curvature of the rear refracting surfaces of said second, third and fourth lenses respectively; and N_3 and V_3 are the refractive index and Abbe number of a glass respectively from which said third lens is made.

6. A retrofocus wide angle objective lens system having the following characteristics of the various lens elements thereof with their spatial relationships from each other as related to a focal length of unity:

f = 1; F 2.8; $\omega = 38°$

Surface radius		Axial thickness and separation		Refractive index		Abbe number	
γ_1 =	1.1726	d_1 =	0.0632	N_1 =	1.61117	ν_1 =	55.9
γ_2	0.5675	d_2	0.2290				
γ_3	1.9078	d_3	0.0526	N_2	1.56965	ν_2	49.4
γ_4	0.6840	d_4	0.1909				
γ_5	1.8065	d_5	0.1053	N_5	1.74950	ν_3	35.2
γ_6	13.2025	d_6	0.1510				
γ_7	1.1998	d_7	0.4009	N_4	1.71300	ν_4	53.9
γ_8	−1.3263	d_8	0.2315				
γ_9	−0.7066	d_9	0.0351	N_5	1.76182	ν_5	26.6
γ_{10}	1.7226	d_{10}	0.0386				
γ_{11}	−3.0411	d_{11}	0.1088	N_6	1.7725	ν_6	49.7
γ_{12}	−0.6435	d_{12}	0.0070				
γ_{13}	−4.6120	d_{13}	0.0912	N_7	1.7725	ν_7	49.7
γ_{14}	−1.2212						

$\Sigma d = 1.7050$ Back focal length = 1.2807

$$\frac{d_6}{d_4} = 0.7910$$

7. A retrofocus wide angle objective lens system having the following characteristics of the various lens elements thereof with their spatial relationships from each other as related to a focal length of unity:

f = 1 F 2.8 $\omega = 38°$

Surface radius		Axial thickness and separation		Refractive index		Abbe number	
γ_1 =	1.3064	d_1 =	0.0632	N_1 =	1.61117	ν_1 =	55.9
γ_2	0.6109	d_2	0.3152				
γ_3	3.7622	d_3	0.0526	N_2	1.60729	ν_2	49.3
γ_4	0.7757	d_4	0.2100				
γ_5	1.7619	d_5	0.1053	N_3	1.72342	ν_3	38.0
γ_6	−9.1853	d_6	0.1500				
γ_7	1.0840	d_7	0.3627	N_4	1.60311	ν_4	60.7
γ_8	−1.3336	d_8	0.2910				
γ_9	−0.6365	d_9	0.0351	N_5	1.74077	ν_5	27.8
γ_{10}	1.8877	d_{10}	0.0491				
γ_{11}	−2.5630	d_{11}	0.0947	N_6	1.69350	ν_6	53.3
γ_{12}	−0.6112	d_{12}	0.0070				
γ_{13}	−26.827	d_{13}	0.0912	N_7	1.69350	ν_7	53.3
γ_{14}	−1.1736						

$\Sigma d = 1.8271$ Back focal length = 1.2807

$$\frac{d_6}{d_4} = 0.714$$

8. A retrofocus wide angle objective lens system having the following characteristics of the various lens elements thereof with their spatial relationships from each other as related to a focal length of unity:

f = 1 F 2.8 $\omega = 37°$

Surface radius		Axial thickness and separation		Refractive index		Abbe number	
γ_1 =	1.1756	d_1 =	0.0421	N_1 =	1.61117	ν_1 =	55.9
γ_2	0.5588	d_2	0.2132				
γ_3	1.9760	d_3	0.0351	N_2	1.56965	ν_2	49.4
γ_4	0.6857	d_4	0.1855				
γ_5	1.8555	d_5	0.1053	N_3	1.83400	ν_3	37.2
γ_6	19.7733	d_6	0.1810				
γ_7	1.2309	d_7	0.3879	N_4	1.71300	ν_4	53.9
γ_8	−1.3096	d_8	0.2258				
γ_9	−0.7213	d_9	0.0351	N_5	1.76182	ν_5	26.6
γ_{10}	1.6736	d_{10}	0.0421				
γ_{11}	2.7127	d_{11}	0.0877	N_6	1.77250	ν_6	49.7
γ_{12}	−0.6361	d_{12}	0.0070				
γ_{13}	−3.6831	d_{13}	0.0877	N_7	1.77250	ν_7	49.7
γ_{14}	−1.1511						

$\Sigma d = 1.6355$ Back focal length = 1.2807

$$\frac{d_6}{d_4} = 0.9757$$

* * * * *

OR 4,045,128

United Stat
Momiyama

[11] 4,045,128
[45] Aug. 30, 1977

[54] **TELEPHOTO OBJECTIVE**

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[73] Assignee: **Canon Kabushiki Kaisha**, Tokyo, Japan

[21] Appl. No.: **570,958**

[22] Filed: **Apr. 22, 1975**

[30] **Foreign Application Priority Data**

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June 28, 1974 Japan 49-74168

[51] **Int. Cl.**[2] **G02B 9/60**
[52] **U.S. Cl.** **350/216**; 350/214; 350/255
[58] **Field of Search** 350/214, 216, 255; 354/197

[56] **References Cited**

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Primary Examiner—Paul A. Sacher
Attorney, Agent, or Firm—Toren, McGeady and Stanger

[57] **ABSTRACT**

A telephoto objective comprising a stationary convergent front lens group and a rear lens group which includes a lens member axially movable for focusing behind a front lens member which remains stationary during focusing, and an operating mechanism therefor. In order to achieve excellent stability of the various aberrations and particularly spherical aberration throughout the focusing range, compensation for the residual aberrations introduced by the front lens group is concentrated in the stationary front member of the rear lens group, while the movable rear member is configured to provide minimized variation of aberrations by constructing these two members as being divergent with their front surfaces convex to the object. In this particular arrangement, the movable member is moved toward the image plane as the objective is focused from the position for an object at infinity to the position for a close object.

22 Claims, 17 Drawing Figures

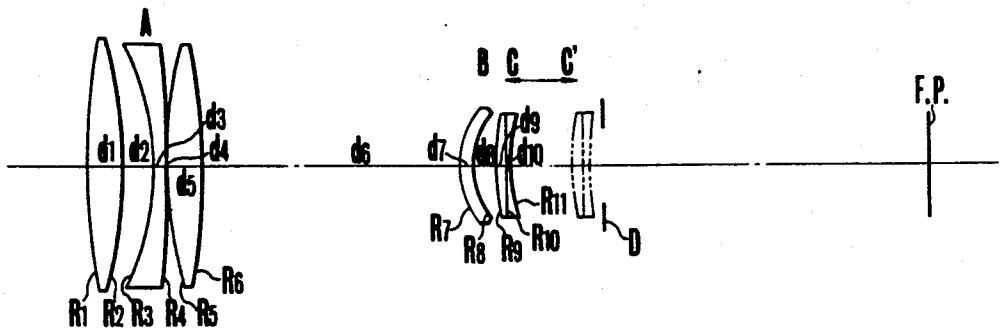


FIG. 1

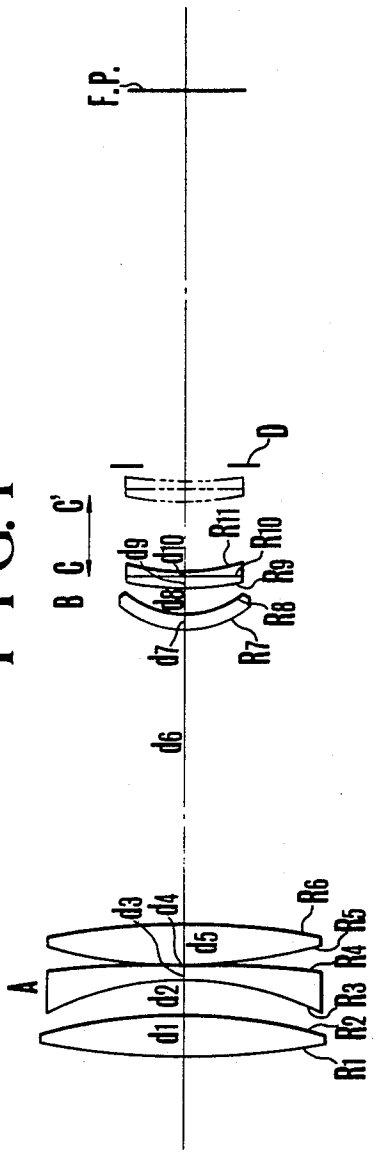

F.P.
B C C'
D
d9
d10
R11
R10
R9
d8
R8
d7
R7
d6
d3
d4
R6
R5
A
d5
R4
d2
R3
d1
R2
R1

FIG. 2

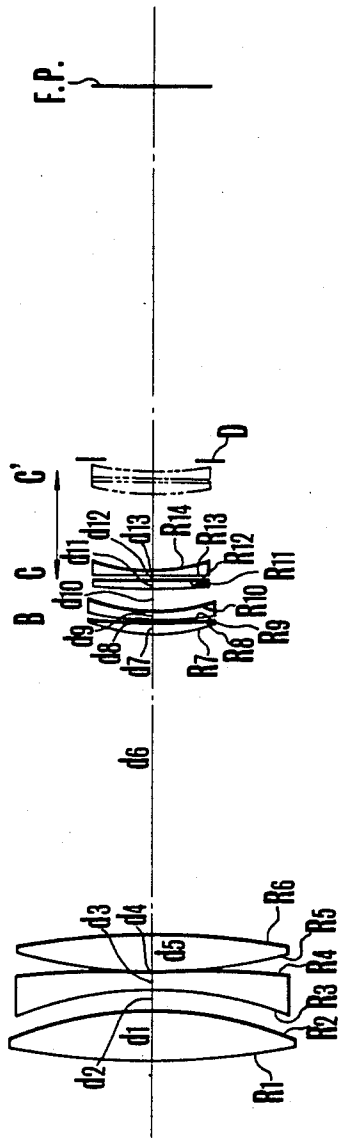

F.P.
B C C'
D
d12
d13
R14
R13
d11
R12
R11
d10
d9
R10
d8
R9
d7
R7
R8
d6
d3
d4
R6
R5
d5
R4
d1
R3
d2
R2
R1

FIG.3a FIG.3b FIG.3c

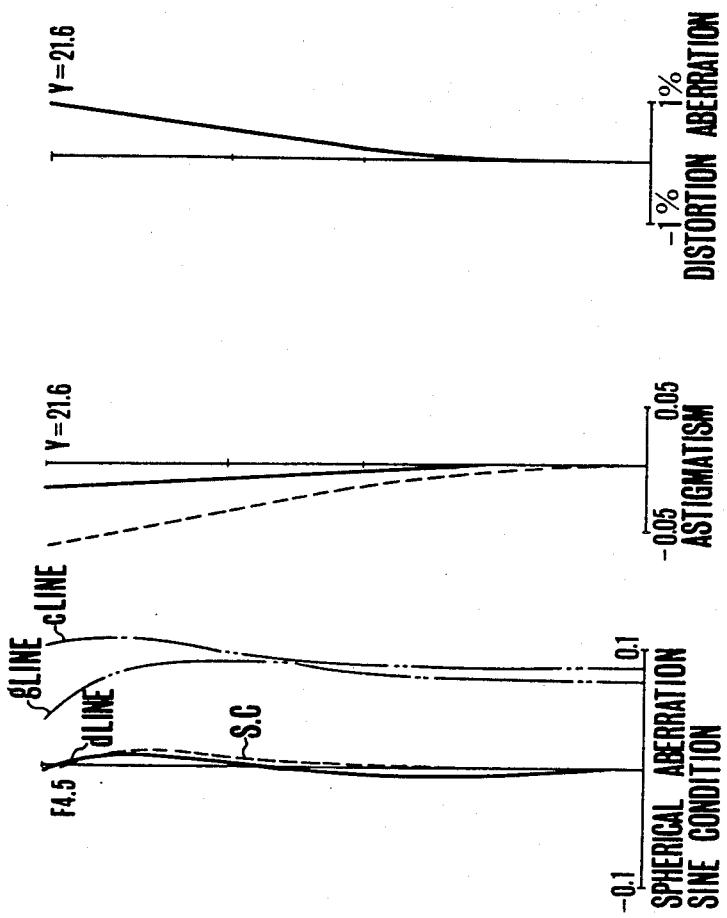
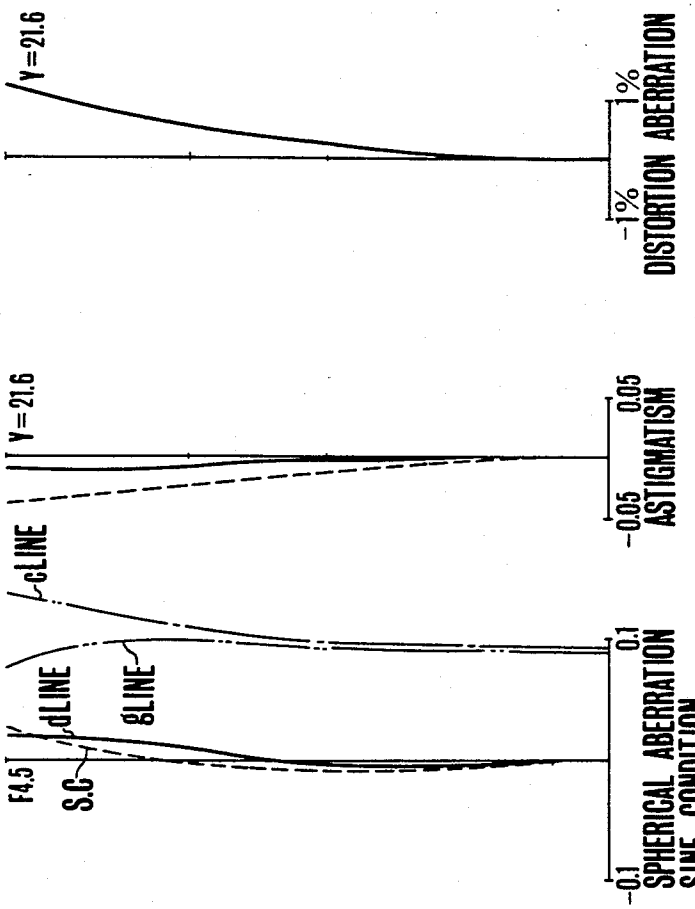


FIG.4a FIG.4b FIG.4c



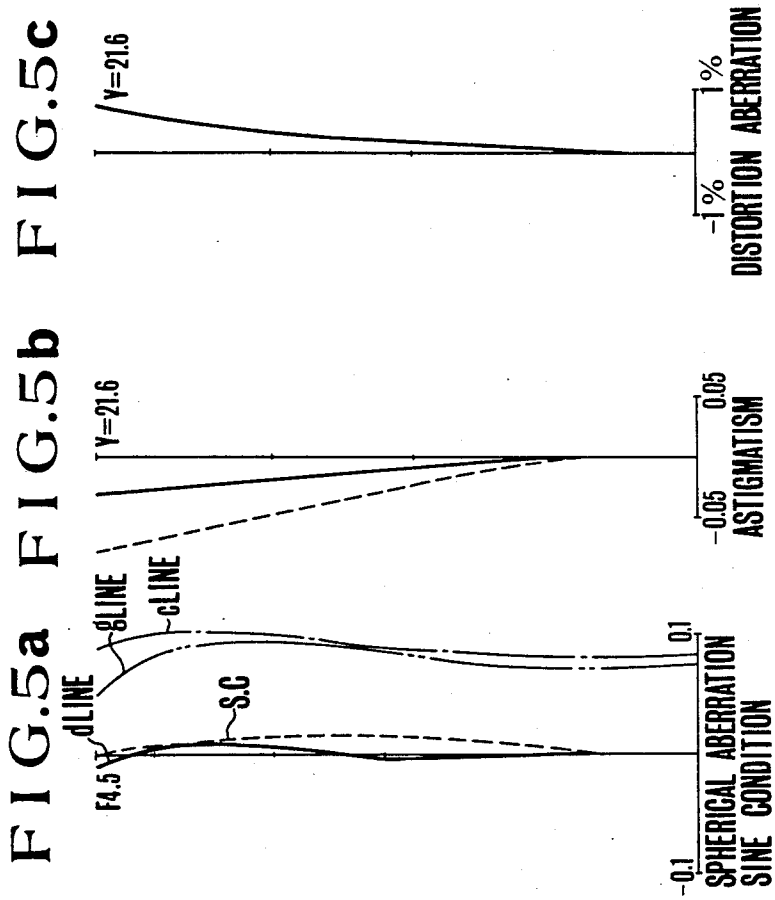


FIG.5a FIG.5b FIG.5c

FIG.6a FIG.6b FIG.6c

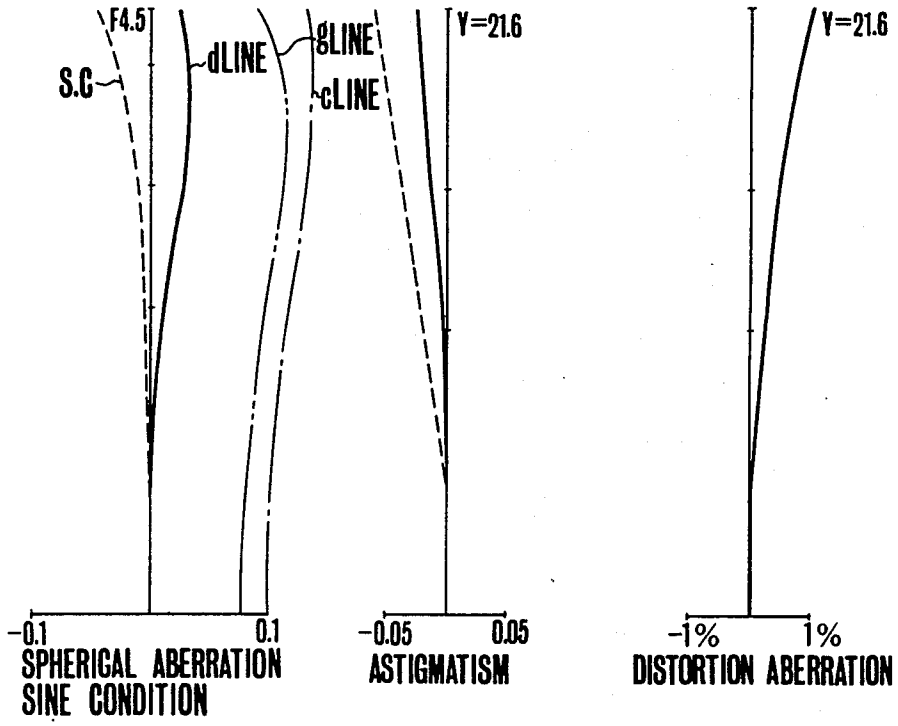


FIG.9

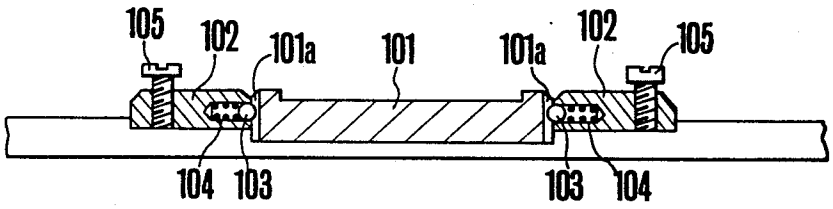


FIG.7

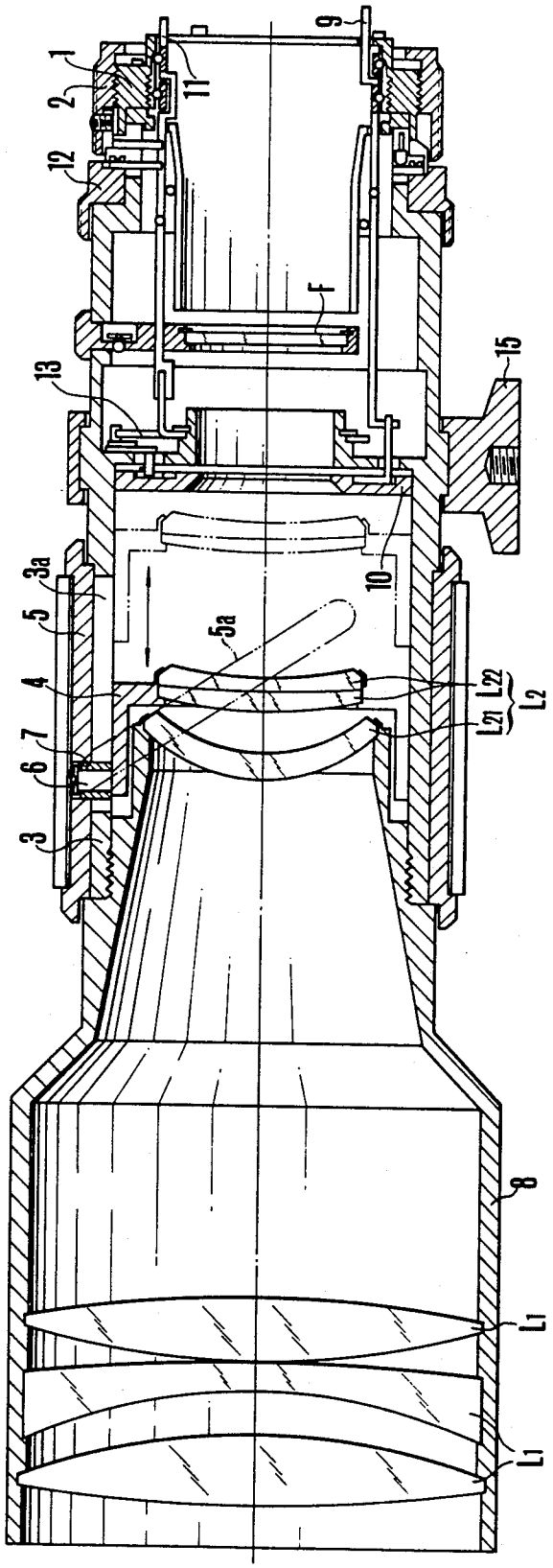
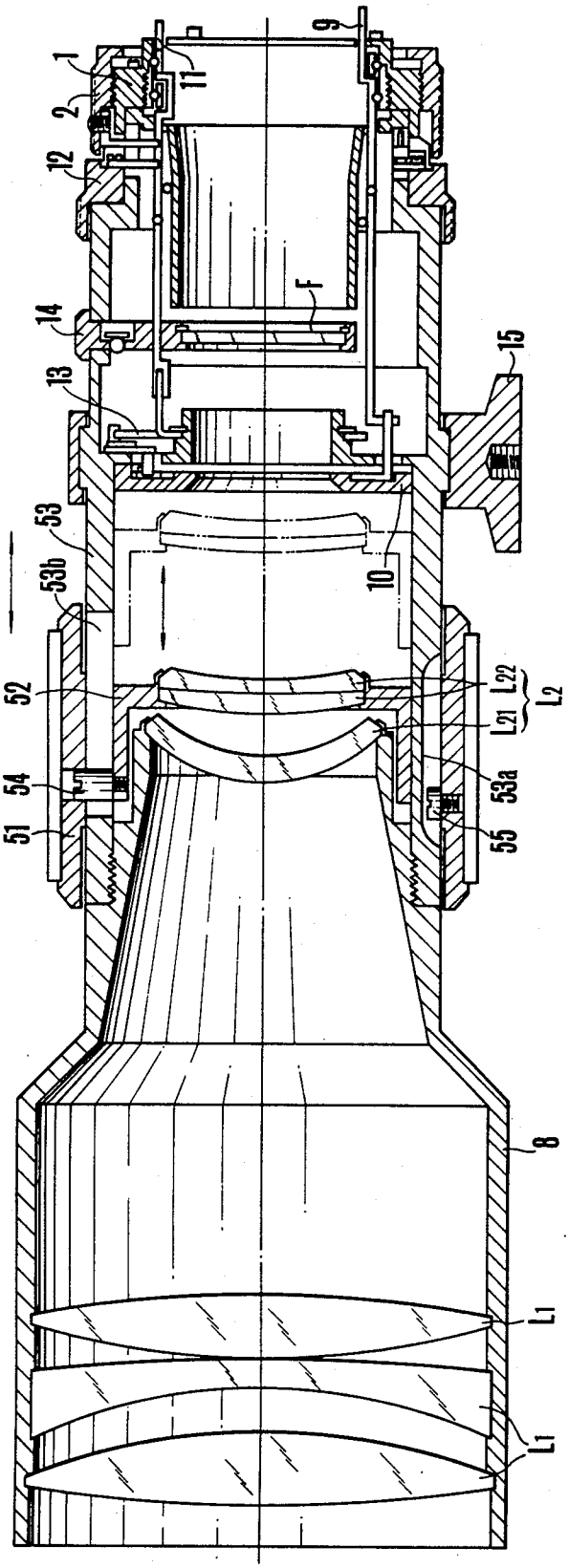


FIG.8



TELEPHOTO OBJECTIVE

BACKGROUND OF THE INVENTION

This invention relates to optical objectives for photographic devices, and more particularly to a telephoto objective comprising a stationary front lens group and a rear lens group which includes a member axially movable to focus while still maintaining improved stabilization of the aberrations throughout the focusing range.

In general, the focusing of an optical objective is effected by axially moving the objective bodily with reference to the image plane. But this may be otherwise achieved by axial movement of a part of the objective, for example, either the front, or the rear lens group thereof with reference to the other part which remains stationary during focusing. In telephoto objectives, if made bodily movable for focusing purposes, the amount of movement of the objective throughout the focusing range tends to increase, and this in turn calls for increases in the weight and bulk of the objective and the driving torque of its focusing mechanism as well as in the production cost thereof, thus it being made more difficult to keep the weight and bulk of the complete objective including its mechanical mounting and focusing mechanism within easily manageable proportion.

With a telephoto objective having the provision for focusing made at a rear part of the lens system, it is possible to minimize the movement of the focusing part and to employ a focusing mechanism of small size and weaker driving torque, because the focusing part comprises only a fraction of the weight and bulk of the complete objective, thereby giving an advantage of facilitating high-speed focus adjustment of the objective. Another advantage deriving from the selection of the rear lens group of the objective for employment as the movable part for focusing purposes is that the front lens group which is of a relatively large weight and bulk may be supported in fixedly secured relation with a camera body to minimize the probability of producing a jiggle or oscillation of the image at the focal plane by small accidental motions of the objective and camera assembly which is otherwise encountered particularly when the objective is telephoto in nature. However, this system has a disadvantage that variation of the aberration particularly variation of the spherical aberration due to the movement of the lens is large, and the image forming ability is low. Further, in order for an objective to embody an advantageously small overall length, a convergent lens group is usually selected for employment as the front part thereof in combination with a divergent rear lens group having design parameters determined so as to cancell out the residual spherical aberration introduced by the front lens group in a focusing position for an object at infinity. However, as the objective is focused from this position to a position for a close object, the axial separation between the front and rear lens groups is increased with decrease in the hight of incidence of an axial ray upon the rear lens group, so that occurrence of the positive spherical aberration is less, while varying the value of the spherical aberration to a remarkable extent. In this respect, it is well known that this arrangement is disadvantageous for stabilization of the image aberrations throughout the focusing range.

SUMMARY OF THE INVENTION

The present invention has for a general object to provide the above-mentioned advantages in the case of a telephoto objective having the provision for focusing made at the rear part thereof, while still proving improved stabilization of the aberrations throughout the focusing range.

A concomitant object of the invention is to provide a focusing mechanism for use with an telephoto objective of the character described which assists in high-speed focus adjustment thereof.

In order to avoid the above defect in the focusing system by the movement of rear lens group, it is necessary to lessen the occurrence of the aberration particularly the spherical aberration in the rear lens group, but if the aberration is lessened in this way the spherical aberration of the whole lens system is remarkably undercorrection.

The telephoto objective of the invention is characterized in comprising a convergent front lens group and a rear lens group which includes a lens member axially movable to effect focusing in front of, or behind a lens member which remains stationary during focusing. This particular arrangement gives rise to the possibility of cancelling out the residual aberrations introduced by the convergent front lens group by suitable design of the stationary lens member of the rear lens group and gives high standard of stabilization of the various aberrations and particularly spherical aberration throughout the focusing range provided that the movable member is designed to give a good standard of stabilization of the aberrations throughout the focusing range.

Further, a good compromise has been achieved between the requirements of providing a large range of focusing adjustments with relatively small axial translations of the movable member of the rear lens group and of providing a distribution of powers between the stationary and movable parts of the objective which effects achievement of a high standard of aberration correction.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a diagrammatic view of an example of a telephoto objective according to an embodiment of the invention in two focusing positions.

FIG. 2 is a similar view of another example of the embodiment of the invention.

FIGS. 3*a*–3*c*is a graphic representation of aberration achieved in the example of FIG. 1 when focused for an infinite object distance.

FIGS. 4*a*–4*c*is a similar representation when focused for an object distance of 1,000 millimeters.

FIGS. 5*a*–5*c*is a graphic representation of aberration achieved in the example of FIG. 2 when focused for an infinite object distance.

FIGS. 6*a*–6*c* is a similar representation when focused for an object distance of 1,000 millimeters.

FIG. 7 is an axial sectional view of a barrel type mechanical mounting with a focusing mechanism adapted for use with the objective of the invention.

FIG. 8 is a similar view with a modification of the focusing mechanism.

FIG. 9 is a fragmentary sectional view of a focus-preselecting device in the focusing mechanism of FIGS. 7 or 8.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to FIGS. **1** and **2**, there are shown two specific examples of a preferred embodiment of the invention as comprising a front lens group A which has a positive, power and remains stationary during focusing, and a rear lens group which has a negative power and is divided into two parts B and C, the rear part C being made axially movable to effect focusing to suit differing object distances, while the front part B remains stationary during focusing. The stationary part B consists of a negative meniscus singlet lens member in the instance of FIG. **1**, or of a negative meniscus doublet lens member in the instance of FIG. **2**, with the first refracting surface counting from the front convex to the front, and with the rearmost surface having a radius of curvature which is smallest among all of the surfaces of member B. The movable rear part C is constructed from a negative meniscus doublet lens member with the first surface convex to the front, and with the rearmost surface having a radius of curvature which is smallest among all the surfaces of member C. The absolute focal length of member B is larger than that of member C. A diaphragm D which is stationary is located behind movable member C at a distance to permit the entire range of focusing movement thereof.

As the objective of FIGS. **1** or **2** is focused from the position C marked in solid line for an object at infinity to the position C' marked in broken line for a close object, movable member C progressively approaches the focal plane FP through the space of a distance Δx as defined by the following formula

$$\Delta x = \frac{-2}{B\left(1+\sqrt{1-\frac{4A}{B^2}}\right)}$$

wherein

$$A = \frac{1}{F}\ \frac{1}{Fc}\left(\frac{S}{Ff}+1\right)$$

$$B = \frac{1}{Ff}\left(\frac{S_1}{Ff}+1\right)-\frac{1}{F}\left(\frac{S_1-O_1}{F}+1\right)$$

where

S_1 is the object distance as measuring from the vertex of the first refracting surface of the objective;

F is the focal length of the complete objective when focused for an infinitely distance object;

Ff is the focal length of the combined group A and member B;

Fc is the focal length of the movable member C; O_1 is the distance from the vertex of the first refractings surface to the primary principal point of the complete object; and

Δx when measured in a direction to the focal plane takes a plus sign.

In order to facilitate the solution of aberrational problems, it is preferred to specify the characteristics of the members B and C by the following relationships:

$$0.4F < |FC| < 0.9F;\ Fc < 0 \quad (1)$$
$$0.15F < Rc < 0.25F \quad (2)$$
$$0.05 < F(Fcv \cdot Vcv) + f/(Fcc \cdot Vcc) < 0.05 \quad (3)$$
$$0.05F < Rb < 0.15F \quad (4)$$

wherein

Rc is the radius of curvature of the rearmost surface of the member C;

Rb is the radius of curvature of the rearmost surface of the member B;

Fcv is the focal length of the positive lens element of the member C;

Vcv is the Abbe's number value for the material of the positive lens element of the member C

Fcc is the focal length of the negative lens element of the member C;

Vcc is the Abbe's number value for the material of the negative lens element of the member C.

Condition (1) assists toward achievement of a good compromise between the requirements of providing a large range of focusing adjustment with relatively small axial movement of the movable member C and of providing excellent stabilization of the aberrations throughout the focusing range. When the power of member C is otherwise increased, it is made rapidly more difficult to achieve the desired high standard of aberration correction although the axial translation of member C may be decreased to obtain an equivalent focusing effect. Conversely, the use of a lens member having a power smaller than that corresponding to the upper limit of condition (1) as the focusing member requires a focusing mechanism of increased size due to the increased axial translations of the focusing member.

Condition (2) assists in minimizing the residual aberrations and particularly spherical aberration introduced by the focusing member C to provide a good standard of stabilization of the aberrations throughout the focusing range.

Condition (3) assists in the stabilization with focusing of chromatic aberrations.

The use of a lens member having the parameters within the ranges specified above as the focusing member C results in somewhat under-corrections of the spherical aberration, coma and astigmatism of the complete objective. In order to preserve a good state of correction of the image aberrations, the stationary lens member B of the rear lens group must be designed according to condition (4) to provide correspondingly over-corrected values of the above-identified aberrations.

The specific examples of a telephoto objective of the invention as illustrated in FIGS. **1** and **2** may be constructed in accordance with the numerical data given in Tables **1** and **3** below respectively, in which R_1, R_2... designate the radii of curvature of the individual surfaces of the objective counting from the front, the positive sign indicating that the surface is convex to the front and the negative sign that it is concave thereto, d_1, d_2... designate the axial separations between successive refracting surfaces of the objective, N_1, N_2... designate the refractive indices for the spectral d line of sodium of the materials from which the various lens elements of the objective are made, and V_1, V_2... designate the Abbe numbers of the materials.

Table 1

Distance between surface R_1 and the focal plane: 80.01

R_1 =	68.8306	d_1 = 3.625	N_1 = 1.48749	ν_1 = 70.1
R_2 =	−32.7526	d_2 = 2.234		
R_3 =	−28.0632	d_3 = 1.250	N_2 = 1.80610	ν_2 = 40.9
R_4 =	−258.3399	d_4 = 0.125		
R_5 =	40.9645	d_5 = 3.250	N_3 = 1.48749	ν_3 = 70.1
R_6 =	−55.6211	d_6 = 25.005		
R_7 =	8.5369	d_7 = 1.250	N_4 = 1.58913	ν_4 = 61.1
R_8 =	7.6866	d_8 = variable		
R_9 =	36.3034	d_9 = 0.750	N_5 = 1.75520	ν_5 = 27.5
R_{10} =	108.9485	d_{10} = 0.625	N_6 = 1.71300	ν_6 = 53.9
R_{11} =	19.0641			

Object distance	Focal length of the	Variable axial air

Table 1-continued

(from the focal plane)	complete objective	separation(d_8)
Infinity	100.00	2.250
−1,000	83.48	9.656

Table 2

subscript numerals for the surfaces	Aberration Coefficients for Focussing setting at Infinity I	II	III	P	V
1	0.6757	−0.5842	0.5051	0.4761	−0.8484
2	48.6504	−83.9162	144.7455	1.0006	−251.3948
3	−65.8017	111.7576	−189.8090	−1.5904	325.0728
4	−0.0012	0.0107	−0.0965	0.1727	−0.6818
5	3.6943	−3.9520	4.2277	0.8000	−5.3786
6	13.3838	−24.0086	43.0677	0.5892	−78.3138
7	2.6172	−1.0971	0.4599	4.3427	−2.0133
8	−3.1924	1.1602	−0.4216	−4.8231	1.9061
9	−0.0808	0.4612	−2.6306	1.1852	8.2442
10	0.0483	−0.1003	0.2081	−0.0129	−0.4051
11	0.0711	0.1153	0.1871	−2.1833	−3.2381
Σ	0.0650	−0.1535	0.4434	−0.0430	−7.0508

In this table 2, I designates the spherical aberration coefficients; II designates the coma coefficients, III designates the astigmatism coefficients; P designates the Petzval sums, and V designates the distortion coefficients.

Table 3

Distance between surface R_1 and the focal plane: 81.05

R_1 =	66.6001	d_1 = 3.625	N_1 = 1.48749	ν_1 = 70.1
R_2 =	−33.1516	d_2 = 2.089		
R_3 =	−28.6739	d_3 = 1.250	N_2 = 1.80610	ν_2 = 40.9
R_4 =	−316.5437	d_4 = 0.125		
R_5 =	41.3109	d_5 = 3.250	N_3 = 1.48749	ν_3 = 70.1
R_6 =	−57.4105	d_6 = 24.974		
R_7 =	12.8482	d_7 = 0.875	N_4 = 1.71300	ν_4 = 53.9
R_8 =	22.5379	d_8 = 0.125		
R_9 =	22.9059	d_9 = 0.500	N_5 = 1.57250	ν_5 = 57.7
R_{10} =	10.4573	d_{10} = variable		
R_{11} =	37.1996	d_{11} = 0.750	N_6 = 1.75520	ν_6 = 27.5
R_{12} =	96.1965	d_{12} = 0.125		
R_{13} =	86.0176	d_{13} = 0.625	N_7 = 1.71300	ν_7 = 53.9
R_{14} =	19.4620			

Object distance from the focal plane	Focal length of the complete objective	Variable axial air separation (d_{10})
Infinity	100.00	2.250
−1,000	83.73	10.208

Table 4

	Aberration Coefficients when Focussed for Infinity I	II	III	P	V
1	0.7458	−0.6867	0.6323	0.4920	−1.0354
2	47.8640	−84.2475	148.2877	0.9885	−262.7476
3	−64.2813	111.5568	−193.6011	−1.5565	338.6858
4	−0.0004	0.0068	−0.1024	0.1409	−0.5765
5	3.6287	−4.0041	4.4184	0.7933	−5.7510
6	12.5609	−23.0649	42.3527	0.5708	−78.8180
7	−0.3841	0.0296	−0.0022	3.2395	−0.2494
8	0.4545	−1.5903	5.5646	−1.8467	−13.0085
9	−0.4543	1.5283	−5.1408	1.5894	11.9458
10	−0.2681	0.0431	−0.0069	−3.4814	0.5608
11	−0.0696	0.4175	−2.5021	1.1566	8.0627
12	1.6256	−3.5645	7.8158	−0.4472	−16.1570
13	−1.4736	3.2945	−7.3652	0.4838	15.3839
14	0.0726	0.1110	0.1699	−2.1386	−3.0112
Σ	0.0205	−0.1703	0.5207	−0.0154	−6.7157

It will be appreciated from the foregoing description that, with a telephoto objective consisting of a convergent front lens group and a divergent rear lens group, the present invention provides a two part rear lens group, only one part of which is axially movable for focussing purposes, thereby giving rise to the possibility of achieving a high standard of aberration stabilization throughout the range of focussing movement. Therefore, by comparison with a conventional telephoto objective which is made bodily movable for focussing, or which has a front lens group movable for focussing, the objective of the invention is improved with respect to the focussing manupulation owing to the decreased weight and bulk of the complete objective, which will in turn reduce the probability of producing an oscilation of the image at the focal plane when it is used in association with a hand-held camera. On the other hand, by comparison with a conventional telephoto objective having a rear lens group which made bodily movable for focussing, the objective of the invention is remarkably improved with respect to the imaging performance owing to the stationary part of the rear lens group which is designed to provide improved stabilization of the various aberrations throughout the focussing range. It is to be noted that the present invention is not limited to use in the construction of three-component telephoto objective described and is useful to facilitate the design of the focussing member for any telephoto lens including additional lens components of almost zero powers located in front of, or behind the front part B, or behind the rear part C of the rear lens group, and that further assistance in achieving a higher standard of correction of the image aberrations can be obtained if an additional component which remains stationary during focussing is employed for arrangement between the front and rear lens groups.

Referring now to FIG. 7, there is shown a lens mount with a cam-operated focussing mechanism adapted for use with the telephoto objective of the character described, where L_1 and L_2 designate the front and rear lens groups of the objective respectively, and L_{21} and L_{22} designate the stationary front and movable rear parts of the rear lens group L_2 respectively. This lens mount is connected to a single lens reflex camera, not shown, by an adapter 2 whose rear end constitutes a bayonet coupling engaging the camera housing. Rigidly connected to adapter 2 is a barrel 1 at one end thereof, the opposite end portion of which has a guide barrel 3 fixedly secured thereto and provided with a longitudinally elongated guiding slot 3*a*. Mounted within guide barrel 3 is a slidable sleeve 4 carrying the movable lens member L_{22}. The sleeve 4 can be moved longitudinally but can not be rotated with reference to barrel 3, as it is prevented from rotating by a pin 6 outwardly radially extending from the slidable sleeve 4 and provided with a roller rotatable thereabout in the guiding slot 3*a*. The roller 7 projects beyond the guiding slot 3*a* and engages with a herical camming groove 5*a* formed in the inner surface of a focus adjusting sleeve 5 which is rotatably mounted on guide barrel 3. The parts, 3*a*, 5, 5*a*, 6 and 7

constitutes the above mentioned camo perated focusing mechanism. Rigidly coupled to guide barrel **3** is a tubular extension **8** carrying the front lens group L_1 and the front part L_{21} of the rear lens group L_2 mounted therein in fixed relation to each other and to the extension **8.** The lens mount has a diaphgram device **10** mounted therein at a location behind the movable lens member L_{22}. The diaphragm device **10** is provided with a control lever **9,** and a presetting lever **11** cooperating with a diaphgram adjusting ring **12** rotatably mounted on barrel **1.** The control lever **9** serves to adjust the diaphragm device **10** to a preselected setting in response to an actuation of a camera release member. The presetting lever **11** serves to adjust the position of a diaphragm blade-operating cam member **13** in accordance with the preselected diaphragm value by the ring **12,** and also to transmit the diaphragm information to a diaphragm control mechanism not shown in the camera housing in response to a rotation of ring **12.** A filter being mounted in a filter holder **14** which is detachably mounted behind the diaphragm device **10** in the barrel **1.** The lens mount is further provided with a support member **15** having a nut formed therein for engagement with a bolt of a tripod not shown.

The operation of the focussing mechanism of FIG. **7** in connection with the diaphragm device **10** which constitutes a part of the exposure control apparatus of the camera. In order to make an exposure in the diaphragm preselection automatic exposure range, the operator turns the ring **12** to select a desired diaphragm value, thereby the position of the cam member **13** is adjusted through the presetting lever **11.** At the same time, the diaphragm information is introduced to the exposure control apparatus in the camera through the presetting lever **11.** On the other hand, when the camera is switched to the shutter preselection automatic exposure range, the position of the cam member **13** is adjusted in accordance with a computed diaphragm value through the presetting lever **11.**

In focussing the objective, the operator turns the rotary sleeve **5,** thereby the roller **7** is driven for movement along the guiding slot **3***a* through the roller **7** and camming groove **5***a* connection, causing axial translation of the slidable sleeve **4** with the lens member L_2 therein. What object the objective has been focussed for is recognizable either by the angular position of sleever **5,** or by looking through the viewfinder in which an image of the corresponding object is formed in sharpest focus. Next, the operator may depress the shutter release button not shown, thereby the diaphragm device **10** is first operated to the preselected setting through the control lever **9,** and thereafter the shutter mechanism is actuated to initiate an exposure.

The filter holder **14** is removably attached to the lens barrel so that various filters may be interchanged. When the filter is not used, it is desirable to use a transparent plate to adjust the optical path length.

FIG. **8** shows a modification of the focussing mechanism of FIG. **7** with employment of a longitudinally slidable focus-adjusting sleeve **51** in place of the rotary sleeve **5** of FIG. **7.** The sleeve **51** is fixedly connected to a slidable sleeve **52** carrying the movable lens member L_{22} through a pin **54** extending through a longitudinally elongated guiding slot **53***b* provided in the guide barrel **53** corresponding to the guide barrel **3** of FIG. **7.** In order to define the range of possible focussing movements of the lens member L_{22}, there is provided a longitudinal groove **53***a* formed in the outer surface of guide barrel **53** for engagement with a pin **55** internally radially extending from the focus adjusting sleeve **51.** In focussing the objective, the operator moves the external sleeve **51** to effect axial translation of the lens member L_{22}, as the internal sleeve **52** is guided through the pin **54** and guiding slot **53***b* connection.

FIG. **9** shows a focussing position preselecting device particularly adapted for association with the focussing mechanism of FIG. **7.** The device comprises a pair of radially grooved recesses **101***a* formed at the ends of a focus adjusting sleeve **101** corresponding to the sleeve **5** of FIG. **7** in longitudinal alignment with each other, a pair of click stop balls **103** which are biased by respective springs **104** in the opposite directions to each other for normal engagement with the respective recesses **101***a,* and a pair of focus presetting rings **102** rotatably mounted on the guide barrel corresponding to the part **3** of FIG. **7.** The rings **102** each has a hole longitudinally bored therein for the mounting of ball **103** and spring **104,** and are provided with respective fasteners having knobs **105.** In operating the device, the rings **102** are turned as a unit to place the reaction points thereof in registry with a graduation representing a desired object distance for which the objective is to be focussed, and then are secured in position fixed to the guide barrel by means of the operated knobs **105.** With this arrangement, when the focus adjusting sleeve **101** is turned to a position where the recesses **101***a* engage with balls **103,** the desired focussing effect is automatically obtained.

It will be appreciated form FIGS. **7, 8** and **9** that the present invention provides a focussing mechanism of simple construction which may be incorporated in the lens mount for the telephoto objective of the character described at a location close to the center of the physical length of the complete objective including the lens mount and, in some cases, of the center of gravity of the objective and camera assembly. Such a central location of the focussing mechanism permits easy management procedures for high speed smooth focus adjustments of the objective, while holding the assembly by hand, and accordingly faciliates to prevent the production of an oscillation of the image at the film plane which would be otherwise introduced by the small accidental motions of the assembly owing to the difficult manupulation thereof and the necessity of large driving torque in operation of focussing mechanism. Furthermore, the constructions of the telephoto objective of the character described and the focussing mechanism therefor are advantageous for the provision of focussing down to a shorter object distance.

What is claimed is:

1. A telephoto objective of high speed adjustable focus comprising a front lens group which has a positive refracting power and remains stationary during focussing, and a rear lens group which is divided into two parts, of which one part is axially movable to effect focussing to suit differing object distances, wherein said movable part of said rear lens being located behind the other part which is stationary during focussing and wherein the characteristics of the various lens elements of said front and rear lens groups and their spatial relationships to each other are substantially of the proportions indicated by the numerical data in the following table, in which R designates the radii of curvature of the refracting surfaces identified by the corresponding subscript numerals and numbered from the front to the rear of the objective, the positive sign indicating that the surface is convex to the front and the negative sign that

it is concave thereto, D designates the axial separations between successive refracting surfaces of the objective being numbered from the front to the rear; N designates the refractive indices for the spectral D line of sodium of the materials of the elements being numbered from the front to the rear; and ν designates the Abbe numbers of the materials:

Distance between surface R_1 and the focal plane: 80.01				
R_1 =	68.8306	d_1 = 3.625	N_1 = 1.48749	ν_1 = 70.1
R_2 =	−32.7526	d_2 = 2.234		
R_3 =	−28.0632	d_3 = 1.250	N_2 = 1.80610	ν_2 = 40.9
R_4 =	−258.3899	d_4 = 0.125		
R_5 =	40.9645	d_5 = 3.250	N_3 = 1.48749	ν_3 = 70.1
R_6 =	−55.6211	d_6 = 25.005		
R_7 =	8.5369	d_7 = 1.250	N_4 = 1.58913	ν_4 = 61.1
R_8 =	7.6866	d_8 = variable		
R_9 =	36.3034	d_9 = 0.750	N_5 = 1.75520	ν_5 = 27.5
R_{10} =	108.9485	d_{10} = 0.625	N_6 = 1.71300	ν_6 = 53.9
R_{11} =	19.0641			

Object distance from the focal plane	Focal length of the complete objective	Variable axial air separation(d_8)
Infinity	100.00	2.250
−1,000	83.48	9.656

2. A telephoto objective of high speed adjustable focus comprising a front lens group which has a positive refracting power and remains stationary during focussing, and a rear lens group which is divided into two parts of which one part is axially movable to effect focussing to suit differing object distances, wherein said movable part of said rear lens being located behind the other part which is stationary during focussing and wherein the characteristics of the various lens elements of said front and rear lens groups and their spatial relationships to each other are substantially of the proportions indicated by the numerical data in the following table:

Distance between surface R_1 and the focal plane: 81.05				
R_1 =	66.6001	d_1 = 3.625	N_1 = 1.48749	ν_1 = 70.1
R_2 =	−33.1516	d_2 = 2.089		
R_3 =	−28.6739	d_3 = 1.250	N_2 = 1.80610	ν_2 = 40.9
R_4 =	−316.5437	d_4 = 0.125		
R_5 =	41.3109	d_5 = 3.250	N_3 = 1.48749	ν_3 = 70.1
R_6 =	−57.4105	d_6 = 24.974		
R_7 =	12.8482	d_7 = 0.875	N_4 = 1.71300	ν_4 = 53.9
R_8 =	22.5379	d_8 = 0.125		
R_9 =	22.9059	d_9 = 0.500	N_5 = 1.57250	ν_5 = 57.7
R_{10} =	10.4573	d_{10} = variable		
R_{11} =	37.1996	d_{11} = 0.750	N_6 = 1.75520	ν_6 = 27.5
R_{12} =	96.1965	d_{12} = 0.125		
R_{13} =	86.0176	d_{13} = 0.625	N_7 = 1.71300	ν_7 = 53.9
R_{14} =	19.4620			

Object distance from the focal plane	Focal length of the complete objective	Variable axial air separation (d_{10})
Infinity	100.00	2.250
−1,000	93.73	10.208

3. A telephoto objective of high speed adjustable focus comprising:

a front lens group which has a positive refracting power and remains stationary during focussing; and

a rear lens group having a negative refracting power and composed of a stationary sub-group and at least one movable sub-group, said movable sub-group having a negative refracting power, a frontmost surface of which has a convex face toward the object, said movable sub-group being moved on the optical axis toward an image so as to cause the telephoto object to focus an object at a near distance from its focussing on an object at a far distance.

4. A telephoto objective according to claim 3, in which said stationary sub-group is arranged nearer the object than said movable sub-group.

5. A telephoto objective according to claim 3, in which said stationary sub-group has a negative refractory power and its frontmost surface is convex toward the object.

6. A telephoto objective according to claim 5, in which said stationary sub-group is a negative meniscus lens.

7. A telephoto objective according to claim 5, in which said stationary sub-group comprises a positive meniscus lens and a negative meniscus lens arranged in the written order.

8. A telephoto objective according to claim 3, wherein the absolute focal length of said stationary sub-group is larger than that of said movable sub-group.

9. A telephoto objective according to claim 8, in which said stationary sub-group comprises a positive meniscus lens and a negative meniscus lens arranged in the written order.

10. A telephoto objective according to claim 3, in which said front lens group comprises a positive lens, a negative lens and a positive lens.

11. A telephoto objective according to claim 10, in which said positive lenses is a biconvex lens, and said negative lens, is a negative meniscus lens having its concave face toward the object.

12. A telephoto objective of high speed adjustable focus comprising:

a primary lens group which comprises at least three lenses, has a positive refracting power and is stationary at a constant distance from the focal plane;

a middle lens group which is on the image side axially apart from said primary lens group and has a negative refracting power and front lens-surface of which group faces toward the object; and

a rearmost lens group which is first behind said middle lens group and has a negative refracting power, and comprises at least one positive lens and at least one negative lens, said rearmost lens group moving axially to the image side when refocussing is done from an object far from the object to an object near the object.

13. A telephoto objective according to claim 12, in which said primary lens group comprises a biconvex lens, a negative lens having the concave face toward the object and a positive lens arranged in the written order from the object side.

14. A telephoto objective according to claim 12, in which said middle lens group comprises a negative meniscus lens.

15. A telephoto objective according to claim 12, in which said rearmost lens group comprises a positive meniscus lens and a negative lens arranged in the written order from the object side.

16. A telephoto objective of high speed adjustable focus comprising a front lens group which has a positive refracting power and remains stationary during focussing, and a rear lens group which is positioned on the image side axially apart from said front lens group and has a negative refracting power, said rear lens group being divided into two parts of which one part is axially movable to effect focussing to suit differing object distance, and the other part has a negative refracting power and stationary during focussing.

17. A telephoto objective according to claim 16, wherein said movable part of said rear lens group is

located behind the other part which is stationary during focussing.

18. A telephoto objective according to claim 16, wherein said movable part of said rear lens group is located behind the other part which is stationary during focussing and composed of a plurality of lenses.

19. A telephoto objective according to claim 18, wherein said movable lens part of said rear lens group has a rearmost surface concave to the rear, and said rearmost surface has a radius of curvature which is smallest among all the surfaces of said movable part.

20. A telephoto objective according to claim 16, wherein said stationary part of said rear lens group has a frontmost surface convex to the front.

21. A telephoto objective according to claim 20, wherein said stationary part has a rearmost surface concave to the rear, and said rearmost surface has a radius of curvature which is smallest among all the surfaces of the stationary part.

22. A telephoto objective according to claim 16, wherein the movable part of said rear lens group has a negative refracting power, and the absolute focal length of the stationary part of said rear lens group is larger than that of said movable part, wherein said movable part is moved on the optical axis toward the image so as to cause the objective to focus an object at near distance from its focusing on an object at infinite distance.

* * * * *

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Momiyama

[11] 4,037,935
[45] July 26, 1977

[54] HIGH-SPEED ADJUSTABLE FOCUS TELEPHOTO OBJECTIVE LENS

[75] Inventor: **Kikuo Momiyama**, Yokohama, Japan

[73] Assignee: **Canon Kabushiki Kaisha**, Tokyo, Japan

[21] Appl. No.: **610,338**

[22] Filed: **Sept. 4, 1975**

[30] **Foreign Application Priority Data**

Sept. 11, 1974 Japan 49-104736

[51] **Int. Cl.²** **G02B 13/02**

[52] **U.S. Cl.** **350/176**; 350/216; 350/220

[58] **Field of Search** 350/176, 220, 214, 212, 350/216

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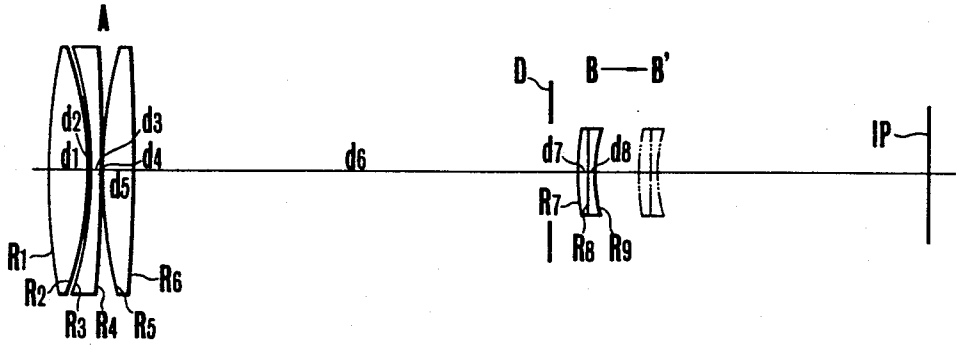
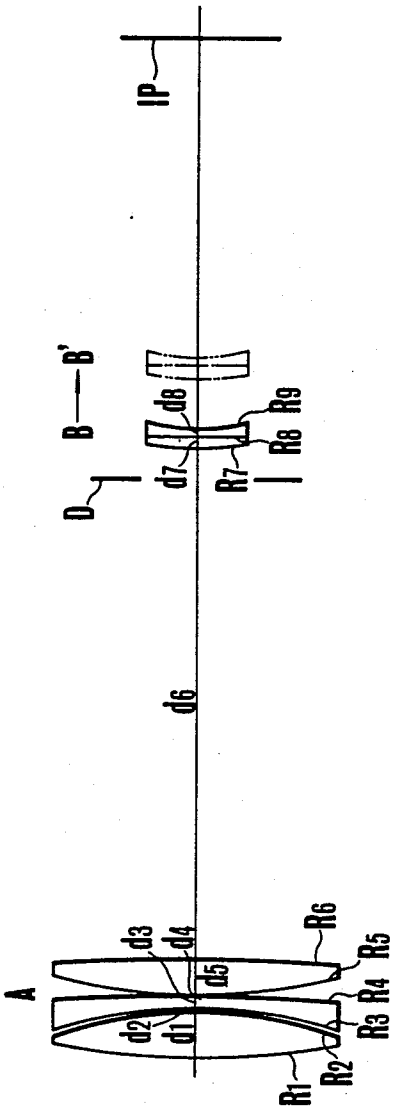
Primary Examiner—John K. Corbin
Assistant Examiner—Conrad Clark
Attorney, Agent, or Firm—Toren, McGeady and Stanger

[57] **ABSTRACT**

A telephoto objective lens comprising a normally stationary front lens group having a positive power and a rear lens group having a negative power axially movable for focusing, the front lens group including at least two positive members and at least one negative member, and the rear lens group including at least one positive member and at least one negative member. The rear lens group has a negative meniscus configuration as a whole with the first refracting surface counting from the front being convex to the front and with the rearmost surface being concave to the rear. As the objective lens is focused from the position for an object at infinity to the position for a close object, only the rear lens group is moved toward the image plane.

11 Claims, 22 Drawing Figures

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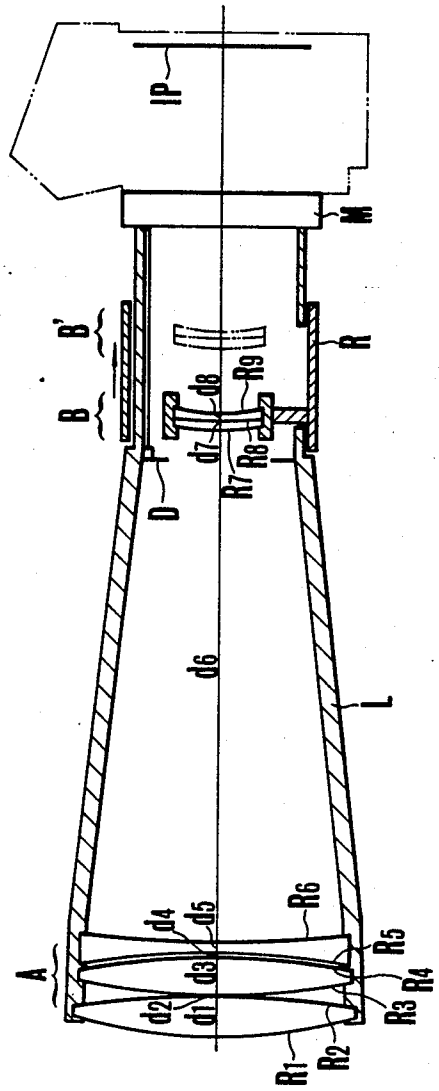
B—B'
d8
R9
R8
d7
R7
D
d6
A
d3
d4
R6
R5
d5
R4
d2
d1
R3
R2
R1

FIG.1


IP
M
B
B'
R
d8
R9
d7
R8
R7
D
d6
L
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d5
R6
R5
d3
R4
d2
d1
R3
R2
R1

FIG.2

FIG.3

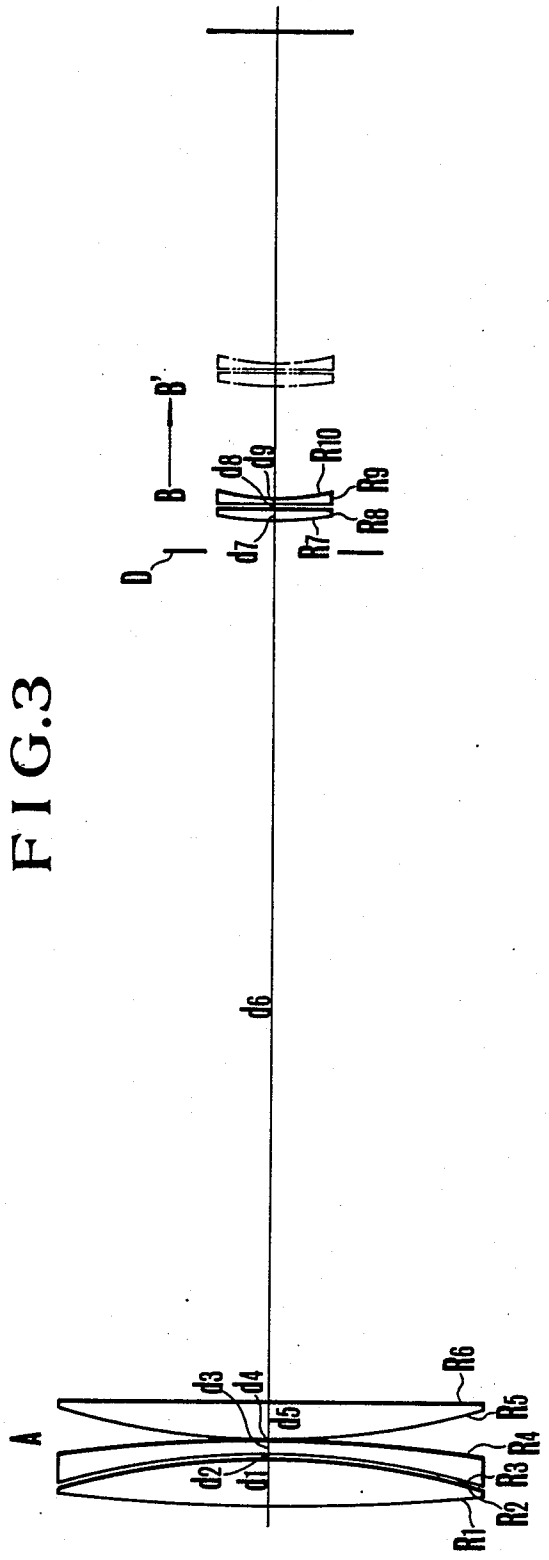


FIG.4 FIG.5 FIG.6

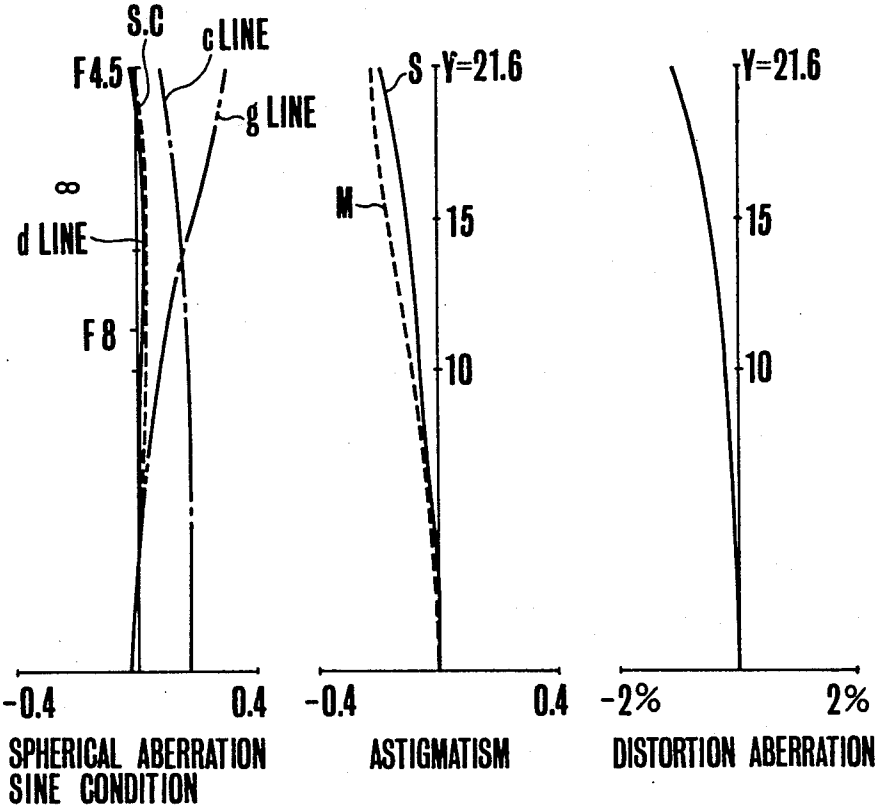


FIG.7

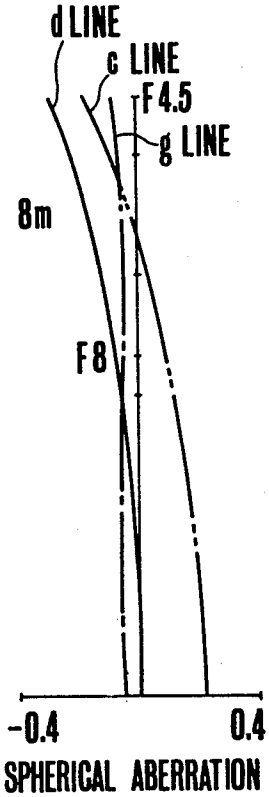


FIG.8

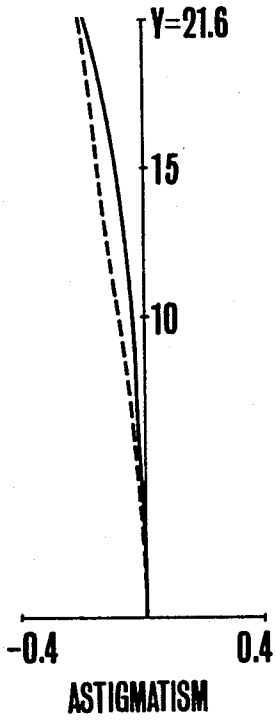


FIG.9

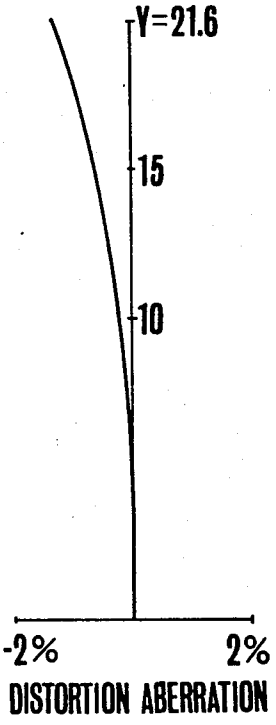


FIG.10 FIG.11 FIG.12

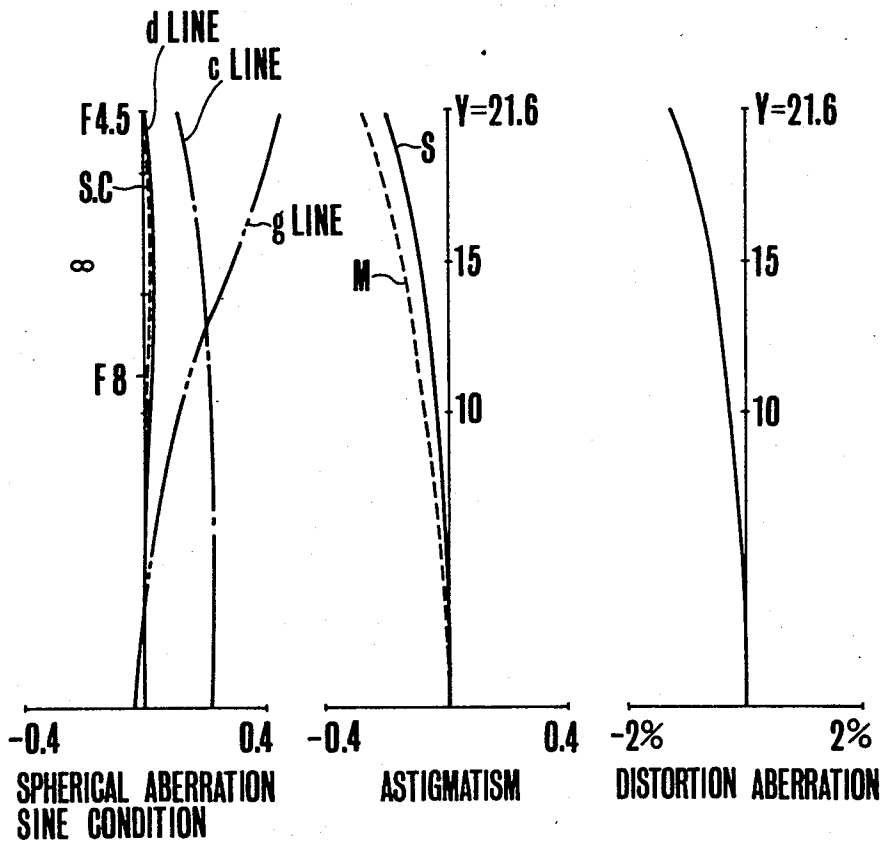


FIG. 13 FIG. 14 FIG. 15

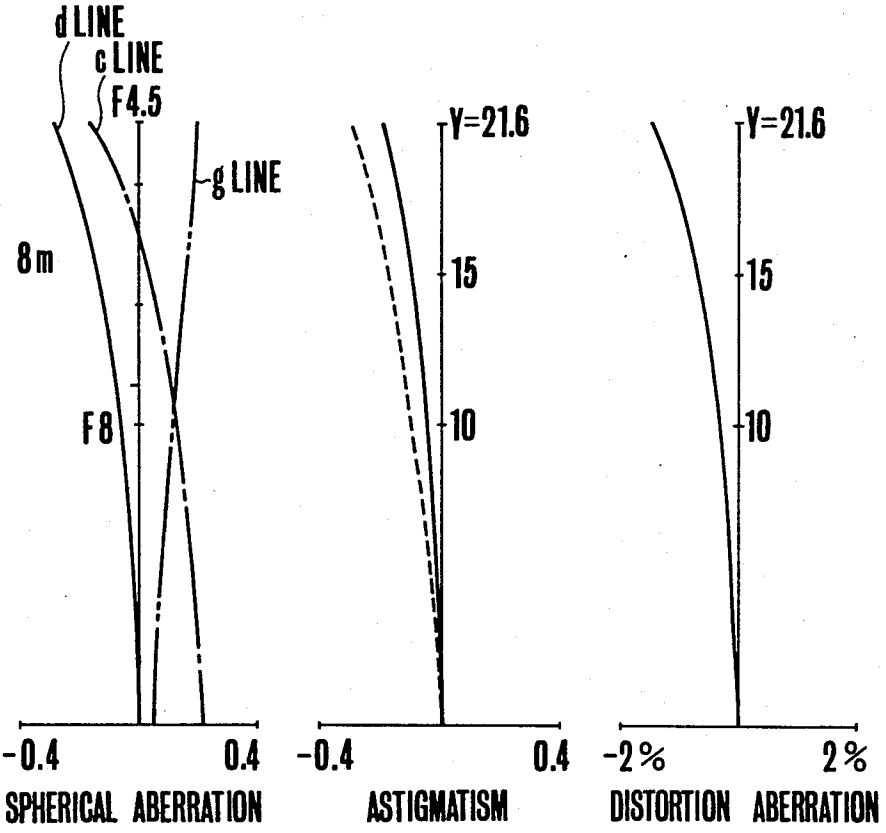


FIG.16 FIG.17 FIG.18

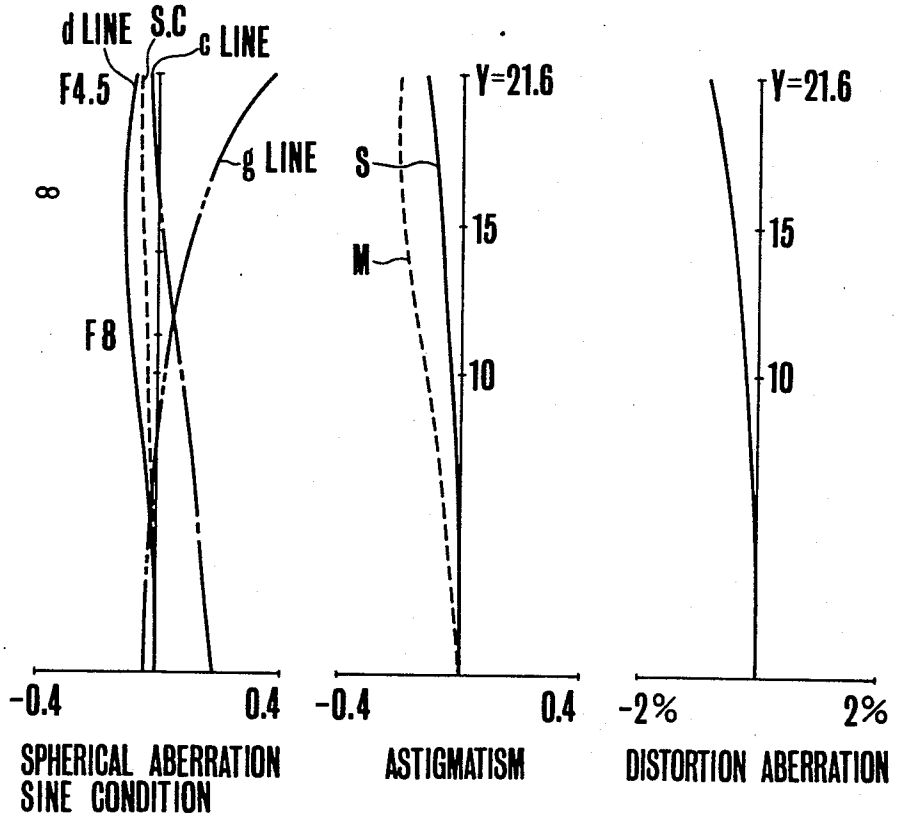


FIG.19 FIG.20 FIG.21

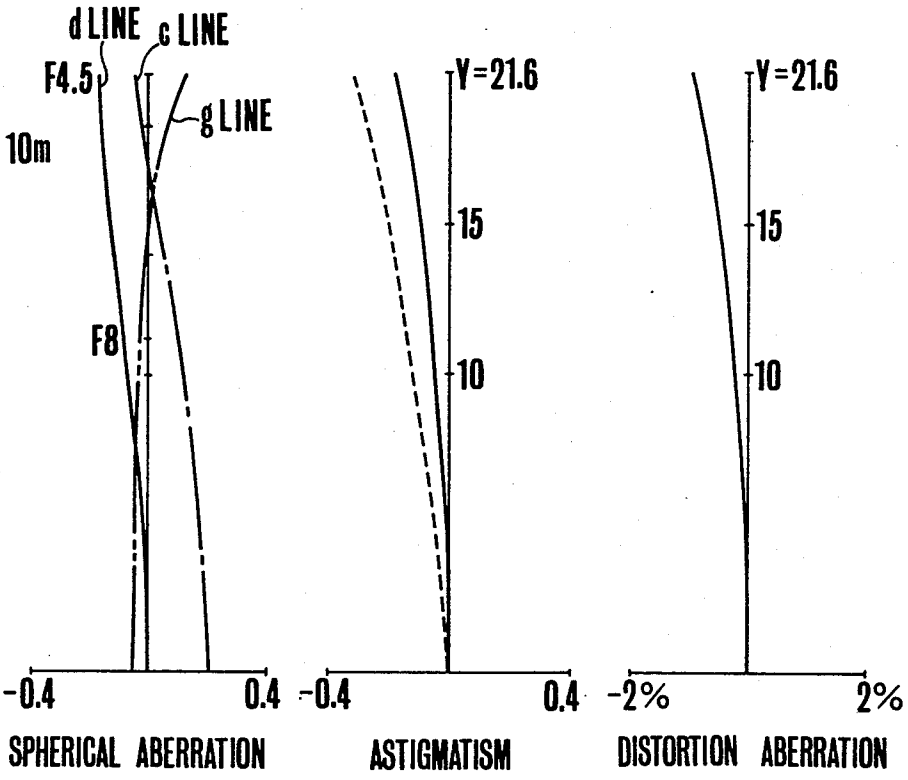
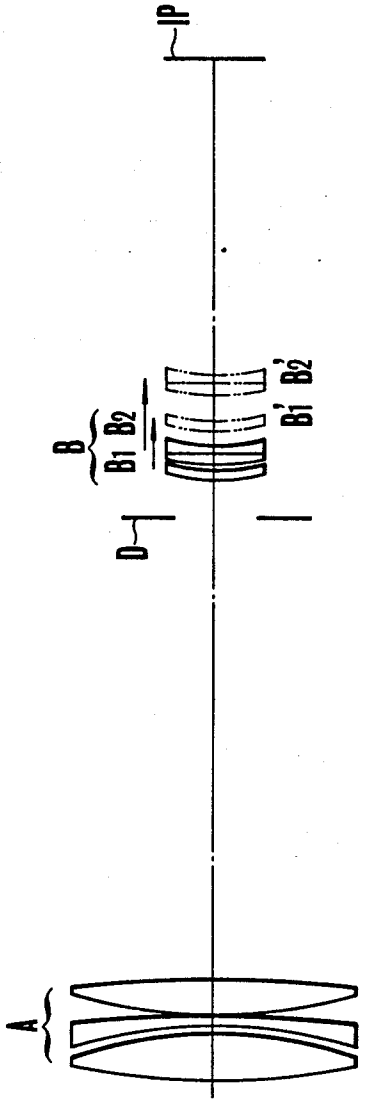


FIG.22



HIGH-SPEED ADJUSTABLE FOCUS TELEPHOTO OBJECTIVE LENS

BACKGROUND OF THE INVENTION

This invention relates to optical objectives, and more particularly, to a telephoto objective having a stationary front lens group of positive power and a rear lens group of negative power movable for focusing.

Although most optical objectives are bodily movable for focusing purposes, the focusing can be otherwise achieved by axial movement of either the front or the rear lens group of the optical objective.

In telephoto objectives, if made bodily movable for focusing, the amount of axial movement of the objective throughout the entire focusing range tends to increase, and this, in turn, calls for increases in the weight and bulk of the objective and the driving torque of its focusing mechanism such as those including helicoid structure as well as in the production cost thereof, thereby it being made more difficult to keep the weight and bulk of the complete objective including its mechanical mounting and focusing mechanism within easily manageable proportions.

In the case of a telephoto objective of the type in which the provision for focusing is made at a rear lens group thereof, it is possible to minimize the amount of focusing movement and further to reduce the size and cost of the focusing mechanism therefor, because of the relatively small weight and bulk of the rear lens group, which in turn results in a reduction of the driving torque which would be otherwise necessary for the focusing thereof. This provides an advantage of facilitating high-speed focus adjustment of the objective. Another advantage of this type telephoto objective is that the front lens group which is of a relatively large weight and bulk may be supported in fixedly secured relation with a camera body to minimize the probability of producing a jiggle or oscillation of the image at the focal plane by small accidental motions of the objective and camera assembly which is otherwise encountered, particularly when the objective is telephoto in nature. This type of telephoto objective is, however, susceptible to large variation of aberrations and particularly spherical aberration during focusing, and consequently high grade imagery cannot be preserved throughout. This is particularly true when the objective is constructed as comprising a front lens group which has a positive power and a rear lens group which has a negative power for the purpose of minimizing the overall length of the objective. In the objective of such construction, the front lens group produces a negative spherical aberration, while the rear lens group produces a positive spherical aberration, whereby the best balance between them is usually effected at a focusing position for an object at infinity. As the objective is focused from the infinity distant position to a close distance position, however, the height of incidence of an axial ray upon the rear lens group is decreased causing the rear lens group to contribute a decreased positive spherical aberration to the whole lens system. As a result, the image spherical aberration is remarkably undercorrected.

SUMMARY OF THE INVENTION

The present invention has for the general object to provide a telephoto objective lens having a rear lens group movable for focusing purposes and which is well corrected for high grade imaging performance throughout the entire focusing range.

To achieve this, the rear lens group is corrected for aberrations to a large extent, with a construction such that the rear lens group has a negative power, and the strongest convergent surface among the surfaces in this group is convex to the front, and the strongest divergent surface which is located on the image side of the strongest convergent surface is concave to the rear. By the term "strong" as herein used, it is meant that the radius of curvature of the surface is small. For the purpose of better understanding this, reference to FIG. 1 may be had wherein a surface designated by R_7 corresponds to the convergent surface, and a surface designated by R_9 corresponds to the divergent surface. With this rear lens group, it is impossible to provide a decreased variation of positive spherical aberration during focusing, as the difference between the maximum and minimum spherical aberrations occurring at different heights of incidence of an axial ray on the rear lens group depending upon the extent to which the rear lens group is corrected for spherical aberration.

On the other hand, the front lens group is corrected for spherical aberration by itself with resulting further decreased image spherical aberration of the complete telephoto objective. For this purpose, it is preferred to construct the front lens group from at least two positive lenses and at least one negative lens. For facilitating chromatic aberration correction, it is preferred to construct the rear lens group from at least one positive lens and at least one negative lens.

The above and other features of the present invention will be described in greater detail with reference to the accompanying drawings in which:

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an axial sectional view of a telephoto objective according to one embodiment of the present invention.

FIG. 2 is an axial sectional view of another embodiment of the invention shown as mounted in a lens barrel with a focusing mechanism for a single lens reflex camera.

FIG. 3 is an axial sectional view of still another embodiment of the invention.

FIGS. 4, 5 and 6 are aberration curves of the objective of FIG. 1 occurring in a focusing position for an object at infinity.

FIG. 7, FIG. 8 and FIG. 9 are aberration curves of the objective of FIG. 1 occurring in a focusing position for a close object at a distance of 8 meters.

FIGS. 10, 11 and 12 are aberration curves of the objective of FIG. 2 occurring in a focusing position for an object at infinity.

FIGS. 13, 14 and 15 are aberration curves of the objective of FIG. 2 occurring in a focusing position for an object distance of 8 meters.

FIGS. 16, 17 and 18 are aberration curves of the objective of FIG. 3 occurring in a focusing position for an object at infinity.

FIGS. 19, 20 amd 21 are aberration curves of the objective of FIG. 3 occurring in a focusing position for an object at a distance of 12 meters.

FIG. 22 is an axial sectional view of a telephoto objective of a type different from the above showing the effectiveness of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to FIGS. 1, 2 and 3, there are shown three embodiments of the present invention each providing a telephoto objective adapted for use with a photographic camera and which comprises a normally stationary front lens group of positive power designated by A and a rear lens group of negative power designated by B moveable for focusing purposes. The front lens group A consists of two positive lens elements and one negative lens element. The rear lens group B consists of two lens elements which are either cemented together at their adjoining surfaces as shown in FIGS. 1 and 2, or air-spaced from each other as shown in FIG. 3, and is substantially configured to a negative meniscus lens as a whole, with the first refracting surface counting from the front being convex to the front, and with the rearmost refracting surface being concave to the rear, whereby the radii of curvature of the first and rearmost surfaces are smaller than that of the cemented surface, or those of the confronting surfaces thereof.

In focusing the telephoto objective from an object at infinity to a close object at a distance of 8 or 12 meters, the rear lens group B is moved behind a diaphragm D from a position marked in solid lines to a position marked by dashed lines by means, for example, including a slidable focusing ring R associated with a lens barrel L which is assembled with a camera body at a fitting ring M as shown in FIG. 2. The amount of focusing movement ΔX of the rear lens group B may be expressed by the following formulae

$$\Delta X = \frac{-2}{K\left(1 + \sqrt{1 - \frac{4J}{K^2}}\right)}$$

$$K \equiv \frac{1}{F} \cdot \frac{1}{Fb}\left(\frac{S_1}{Fa} + 1\right)$$

$$J \equiv \frac{1}{Fa}\left(\frac{S_1}{Fa} + 1\right) - \frac{1}{F}\left(\frac{S_1 - O_1}{F} + 1\right)$$

wherein S_1 is the object distance as measured from the vertex of the first refracting surface of the objective; F is the focal length of the complete objective occurring when focused at infinity; Fa is the focal length of the front lens group; Fb is the focal length of the rear lens group; and O_1 is the interval between the primary principal point of the complete objective focused at infinity and the vertex of the first refracting surface of the objective, the value of ΔX taking a plus sign when measuring the movement amount in the direction from the front to the rear.

In order to facilitate the solution of aberrational problems, it is preferred that the rear lens group and its lens components satisfy the following relationships:

$$0.4F < |Fb| < 0.9F,\ Fb < 0 \qquad \text{(a)}$$

$$3.5 < \frac{Rc + Rv}{Rc - Rv} < 8 \qquad \text{(b)}$$

$$-0.05 < \frac{F}{Fp \cdot Vp} + \frac{F}{Fn \cdot Vn} < 0.05 \qquad \text{(c)}$$

wherein F is the focal length of the complete objective when focused at infinity; Fb is the focal length of the rear lens group; Rv is the radius of curvature of a strong convex surface of the rear lens group; Rc is the radius of curvature of a strong concave surface of the rear lens group; Fp and Vp are the overall focal length and mean Abbe number of positive lens or lenses comprising the rear lens group respectively; and Fn and Vn are the overall focal length and mean Abbe number of negative lens or lenses comprising the rear lens group, respectively.

Condition (a) assists towards achievement of a good compromise between the requirements of providing a large range of focusing adjustments with relatively small axial translation of the rear lens group B and of providing the possibility of achieving a high standard of stabilization of the aberrations throughout the entire focusing range. Although the amount of axial translation of the rear lens group can further be decreased by decreasing the absolute focal length $|Fb|$ of the rear lens group from the lower limit 0.4F, it is made more difficult to compensate the variation with focusing of aberrations. Conversely, the use of a lens group having an absolute focal length longer than the upper limit 0.9F as the rear lens group requires a focusing mechanism of increased size due to the increased axial translation of the rear lens group.

In compensating for variation with focusing of aberrations, it is required that various residual aberrations and particularly spherical aberration ascribable to the rear lens group must be decreased. For this reason, the rear lens group must be designed to have a concave meniscus configuration directed rearwardly toward the image plane, as satisfying condition (*b*). When the upper limit of condition (*b*) is violated, residual spherical aberration ascribable to the rear lens group is objectionably increased with resulting increased variation of aberration during focusing. When the lower limit is violated, a difficult problem arises in balancing residual aberrations of the complete objective throughout the entire focusing range.

For stabilization with focusing of chromatic aberrations, it is preferred to correct the rear lens group for achromatizm to a modest degree as defined by condition (*c*).

Three examples of embodiments of the invention represented in FIGS. 1, 2 and 3 may be constructed in accordance with the numerical data given in Tables 1, 3 and 5 below respectively, in which R_1, R_2 . . . designate the radii of curvature of the individual surfaces counting from the front, the negative sign indicating that the surface is concave to the front; d_1, d_2 . . . designate the axial lens thicknesses of the individual elements, or air separations between the components of the objective; N_1, N_2 . . . . and V_1, V_2 . . . respectively designate the refractive indices for the sodium d-line of the spectrum and the Abbe numbers of the materials of which the various elements of the objective are made, and in addition the variation of an axial air separation between the front and rear lens group during focusing. The aberration coefficients of the objectives of FIGS. 1, 3 and 5 are given in Tables 2, 4 and 6 respectively, in which I: Spherical aberration; II: Coma; III: Astigmatism; P: Petzval sum; and V: Distortion as related to object at infinity.

EXAMPLE I

Table 1

(for FIG. 1)

Total focal length f = 400 F-number: 4.5

R_1 =	269.35	d_1 =	15.0	N_1 =	1.43387	V_1 =	95.2

Table 1-continued

(for FIG. 1)

R_2 =	−167.16	d_2 =	0.57				
R_3 =	−175.34	d_3 =	5.	N_2 =	1.8061	V_2 =	40.9
R_4 =	−582.43	d_4 =	0.5				
R_5 =	221.05	d_5 =	11.0	N_3 =	1.48749	V_3 =	70.1
R_6 =	−1181.46	d_6 =	vari-able				
R_7 =	78.47	d_7 =	4.	N_4 =	1.70154	V_4 =	41.1
R_8 =	612.19	d_8 =	2.5	N_5 =	1.713	V_5 =	53.9
R_9 =	54.91						

Lens separation during focusing

Object distance from image plane	d_6	f
Infinity	170.66	400
8 meters	192.69	359.5

Table 2

Surface No.	I	II	III	P	V
1	0.691	−0.328	0.156	0.449	−0.287
2	21.450	−29.497	40.562	0.724	−56.773
3	−25.505	35.242	−48.695	−1.018	68.691
4	0.511	−1.052	2.164	0.306	−5.083
5	0.312	−0.114	0.042	0.593	−0.234
6	2.514	−4.243	7.163	0.110	−12.278
7	−0.021	−0.178	−1.516	2.101	4.959
8	−0.020	0.021	−0.023	0.002	0.021
9	0.051	0.132	0.340	−3.032	−6.903
Σ	−0.015	−0.018	0.194	0.237	−7.888

EXAMPLE II

TABLE 3

(for FIG. 2)

Total focal length f = 400–356.5 F-number : 4.5

R_1 =	174.03	d_1 =	13.0	N_1 =	1.43387	V_1 =	95.2
R_2 =	−599.39	d_2 =	0.5				
R_3 =	224.05	d_3 =	12.5	N_2 =	1.48749	V_2 =	70.1
R_4 =	−252.26	d_4 =	1.08				
R_5 =	−261.06	d_5 =	5.	N_3 =	1.8061	V_3 =	40.9
R_6 =	892.27	d_6 =	vari-able				
R_7 =	69.67	d_7 =	3.	N_4 =	1.7552	V_4 =	27.5
R_8 =	97.92	d_8 =	2.5	N_5 =	1.7725	V_5 =	49.7
R_9 =	51.80						

Lens separation during focusing

Object distance from image plane	d_6	f
Infinity	169.7	400
8 meters	195.7	356.5

Table 4

Surface No.	I	II	III	P	V
1	2.562	−2.146	1.797	0.695	−2.088
2	2.902	−5.163	9.185	0.201	−16.698
3	−0.066	−0.064	−0.062	0.585	0.507
4	32.868	−48.426	1.348	0.519	−105.886
5	−39.041	57.621	−85.041	−0.683	126.519
6	0.734	−1.722	4.036	−0.200	−8.991
7	−0.037	−0.241	−1.547	2.470	5.911
8	−0.000	0.005	−0.030	0.022	0.045
9	0.057	0.156	0.425	−3.365	−7.996
Σ	−0.020	0.018	0.111	0.245	−8.677

EXAMPLE III

Table 5

(for FIG. 3)

Total focal length f = 600–509.7 F-number = 4.5

R_1 =	751.56	d_1 =	16.	N_1 =	1.43387	V_1 =	95.2
R_2 =	−241.19	d_2 =	0.5				
R_3 =	−246.4	d_3 =	5.	N_2 =	1.8061	V_2 =	40.9
R_4 =	−517.34	d_4 =	0.5				
R_5 =	270.97	d_5 =	12.	N_3 =	1.43387	V_3 =	95.2
R_6 =	−3511.86	d_6 =	vari-able				
R_7 =	106.09	d_7 =	4.	N_4 =	1.72342	V_4 =	38.0
R_8 =	463.13	d_8 =	0.5				
R_9 =	399.18	d_9 =	2.5	N_5 =	1.6935	V_5 =	53.3
R_{10} =	67.67						

Lens separation during focusing

Object distance from image plane	d_6	f
Infinity	294.2	600
10 meters	336.0	509.7

Table 6

Surface No.	I	II	III	P	V
1	0.107	−0.044	0.018	0.241	−0.106
2	18.801	−35.793	68.142	0.752	−131.160
3	−23.078	44.008	−83.922	−1.086	162.109
4	1.358	−3.095	7.075	0.517	−17.359
5	0.835	−0.902	0.974	0.670	−1.777
6	1.908	−4.327	9.809	0.051	−22.354
7	−0.002	−0.072	−2.096	2.373	7.980
8	1.475	−2.458	4.096	−0.543	−5.919
9	−1.350	2.323	−3.999	0.615	5.823
10	0.042	0.141	0.472	−3.630	−10.575
Σ	0.093	−0.220	0.571	−0.038	−13.340

The present invention is particularly concerned with the rear lens group provided to facilitate focusing with improved stabilization of the image aberrations. In this respect, the rear lens group B is capable of variation and can be split into two parts, for example, two negative meniscus members B_1 and B_2, as shown in FIG. 22, which are moved for focusing purposes in differential relation to each other and with reference to the front lens group, thereby giving an advantage of improving the state of correction of the image aberrations. This aberration corrected method is usually called "floating".

The basic construction of telephoto objective lens described is applicable with substantially equivalent result to another type of telephoto objective having a meniscus lens member of almost zero power with its convex surface rearwardly directed to the image plane, such meniscus lens being positioned just in front of or behind the moveable rear lens group without substantially affecting the aberrations.

What is claimed is:

1. A high-speed focus adjustable telephoto objective lens, comprising:

a fixed lens group which has a positive refracting power and has at least one negative lens, said fixed lens group further being fixed at a position separated from the image surface by a prescribed length,

a movable lens group, which has a negative refracting power and has at least one positive element lens and at least one negative element lens, wherein the front surfaces contacting air of these element lenses have their convex planes facing toward an object and the rear faces thereof contacting air have their concave planes facing toward an image, said movable lens group being located at an object side on an axis being separated from said fixed lens group, and the diameters of the element lenses within the movable lens group being smaller than the diameters of the lenses within the fixed lens group,

whereby said movable lens group is shifted toward an object as said telephoto lens is refocused from an object at far distance to an object at close distance.

2. A high-speed focus adjustable telephoto objective lens, comprising:

a front lens group which has a positive refracting power and consists of a plurality of lenses, said front lens group further being fixed at a position having a prescribed distance from the image surface of said objective lens, and

a rear lens group which has a negative refracting power and has at least one positive lens and at least one negative lens, wherein the frontmost lens surface within this group has its convex plane facing an object side and has a radius of curvature being smaller than that of said frontmost lens surface,

whereby as said objective lens is focused from an object at infinity to an object at a close distance, said rear lens group is moved rearwardly toward the image surface along an optical axis of said objective, and the amount of shifting ΔX of said rear lens is as follows:

$$\Delta X = \frac{-2}{K\left(1 + \sqrt{1 - \frac{4J}{K^2}}\right)}$$

$$K \equiv \frac{1}{F} \cdot \frac{1}{Fb}\left(\frac{S_1}{Fa} + 1\right)$$

$$J \equiv \frac{1}{Fa}\left(\frac{S_1}{Fa} + 1\right) - \frac{1}{F}\left(\frac{S_1 - O_1}{F} + 1\right)$$

wherein S_1 is the object distance as measured from the vertex of the first refracting surface of the objective; F is the focal length of the complete objective occurring when focused at infinity; Fa is the focal length of the front lens group; Fb is the focal length of the rear lens group; and O_1 is the interval between the primary principal point of the complete objective focused at infinity and the vertex of the first refracting surface of the objective, the value of ΔX taking a plus sign when measuring the movement amount in the direction from the front to the rear.

3. A high-speed focus adjustable telephoto objective lens according to claim 2, wherein said front lens group has a bi-convex lens, a negative meniscus lens of forward concavity and a positive lens of forward convexity arranged in this order from the front, and said rear lens group has a positive lens of forward convexity and a negative lens of rearward concavity arranged in this order from the front.

4. A high-speed focus adjustable telephoto objective lens according to claim 3, wherein said positive and negative lenses in said rear lens group are cemented together at their adjoining surfaces.

5. A high-speed focus adjustable telephoto objective lens according to claim 2, wherein said front lens group has two bi-convex lenses and a negative lens of forward concavity arranged in this order from the front, and said rear lens group has a positive lens of forward convexity and a negative lens of rearward concavity arranged in this order from the front.

6. A high-speed focus adjustable telephoto objective lens according to claim 5, wherein said positive and negative lenses in said rear lens group are cemented together at their adjoining surfaces.

7. A telephoto objective lens according to claim 2, in which said negative element lens of said movable lens group is located at a position closer to an image than the positive element lens of said movable lens group.

8. A telephoto objective lens according to claim 2, in which the positive element lens of said movable lens group and the negative element lens of the same are cemented together.

9. A high-speed focus adjustable telephoto objective lens with the various elements thereof having the characteristics and their spatial relationships to each other which are substantially of the proportions indicated by the numerical data in the following table:

Total focal length f = 400					F-number : 4.5		
R_1 =	269.35	d_1 =	15.0	N_1 =	1.43387	V_1 =	95.2
R_2 =	−167.16	d_2 =	0.57				
R_3 =	−175.34	d_3 =	5.	N_2 =	1.8061	V_2 =	40.9
R_4 =	−582.43	d_4 =	0.5				
R_5 =	221.05	d_5 =	11.0	N_3 =	1.48749	V_3 =	70.1
R_6 =	−1181.46	d_6 =	variable				
R_7 =	78.47	d_7 =	4.	N_4 =	1.70154	V_4 =	41.1
R_8 =	612.19	d_8 =	2.5	N_5 =	1.713	V_5 =	53.9
R_9 =	54.91						

Lens separation during focusing

Object distance from image plane	d_6	f
Infinity	170.66	400
8 meters	192.69	359.5

in which the radii of curvature R of each element surface are given with the respective surfaces being numbered from front to rear and being identified by the respective numeral subscripts, the axial separations d between successive surfaces are given with the respective numeral subscripts counting from front to rear, and the refractive indices N for the sodium d-line of the spectrum and Abbe numbers V of the materials of which the various elements are made are given with the respective numeral subscripts successively from front to rear.

10. A high-speed focus adjustable telephoto objective lens with the various elements thereof having the characteristics and their spatial relationships to each other which are substantially of the proportions indicated by the numerical data in the following table:

Total focal length f = 400–356.5					F-number : 4.5		
R_1 =	174.03	d_1 =	13.0	N_1 =	1.43387	V_1 =	95.2
R_2 =	−599.39	d_2 =	0.5				
R_3 =	224.05	d_3 =	12.5	N_2 =	1.48749	V_2 =	70.1
R_4 =	−252.26	d_4 =	1.08				
R_5 =	−261.06	d_5 =	5.	N_3 =	1.8061	V_3 =	40.9
R_6 =	892.27	d_6 =	variable				
R_7 =	69.67	d_7 =	3.	N_4 =	1.7552	V_4 =	27.5
R_8 =	97.92	d_8 =	2.5	N_5 =	1.7725	V_5 =	49.7
R_9 =	51.80						

Lens separation during focusing

Object distance from image plane	d_6	f
Infinity	169.7	400
8 meters	195.7	356.5

11. A high-speed focus adjustable telephoto objective lens with the various elements thereof having the characteristics and their spatial relationships to each other which are substantially of the proportions indicated by the numerical data in the following table:

Total focal length f = 600–509.7					F-number = 4.5		
R_1 =	751.56	d_1 =	16.	N_1 =	1.43387	V_1 =	95.2
R_2 =	−241.19	d_2 =	0.5				
R_3 =	−246.4	d_3 =	5.	N_2 =	1.8061	V_2 =	40.9
R_4 =	−517.34	d_4 =	0.5				
R_5 =	270.97	d_5 =	12.	N_3 =	1.43387	V_3 =	95.2

-continued

R_6 =	−3511.86	d_6 =	variable				
R_7 =	106.09	d_7 =	4.	N_4 =	1.72342	V_4 =	38.0
R_8 =	463.13	d_8 =	0.5				
R_9 =	399.18	d_9 =	2.5	N_5 =	1.6935	V_5 =	53.3
R_{10} =	67.67						

-continued

Lens separation during focusing

Object distance from image plane	d_6	f
Infinity	294.2	600
10 meters	336.0	509.7

* * * * *

OR 4,025,170

United Stat

Kawamura

[11] **4,025,170**

[45] **May 24, 1977**

[54] **RETRO-FOCUS TYPE WIDE ANGLE OBJECTIVE LENS**

[75] Inventor: **Naoto Kawamura**, Inagi, Japan

[73] Assignee: **Canon Kabushiki Kaisha**, Tokyo, Japan

[22] Filed: **Oct. 10, 1975**

[21] Appl. No.: **621,595**

[30] **Foreign Application Priority Data**

Oct. 21, 1974 Japan 49-121141

[52] **U.S. Cl.** **350/214**

[51] **Int. Cl.²** **G02B 13/04**

[58] **Field of Search** 350/214, 215, 216, 220

[56] **References Cited**

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Primary Examiner—John K. Corbin
Assistant Examiner—Conrad Clark
Attorney, Agent, or Firm—Toren, McGeady and Stanger

[57] **ABSTRACT**

A retrofocus type wide angle objective lens comprising a negative lens group N and a positive lens group P having a diaphragm therein arranged in this order from the object side, said negative lens group N being constructed from a divergent front lens group F and a rear lens group R. When the lens is focused to a close object, only the rear lens group R located in the divergent light bundle from said front lens group F is moved in a different manner from that in which the other lens groups are moved in unison to effect good correction of aberrations in close photography.

12 Claims, 30 Drawing Figures

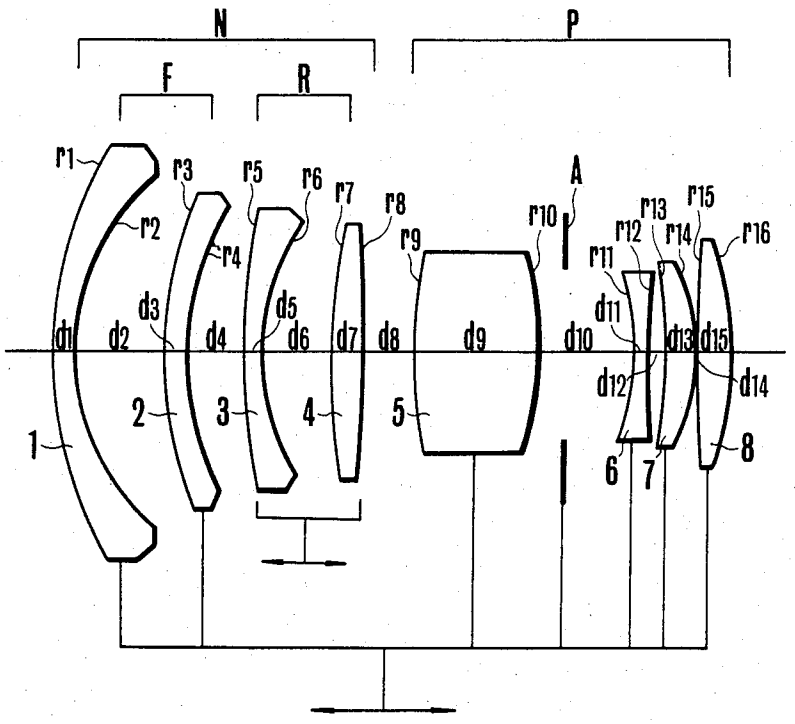

FIG.1

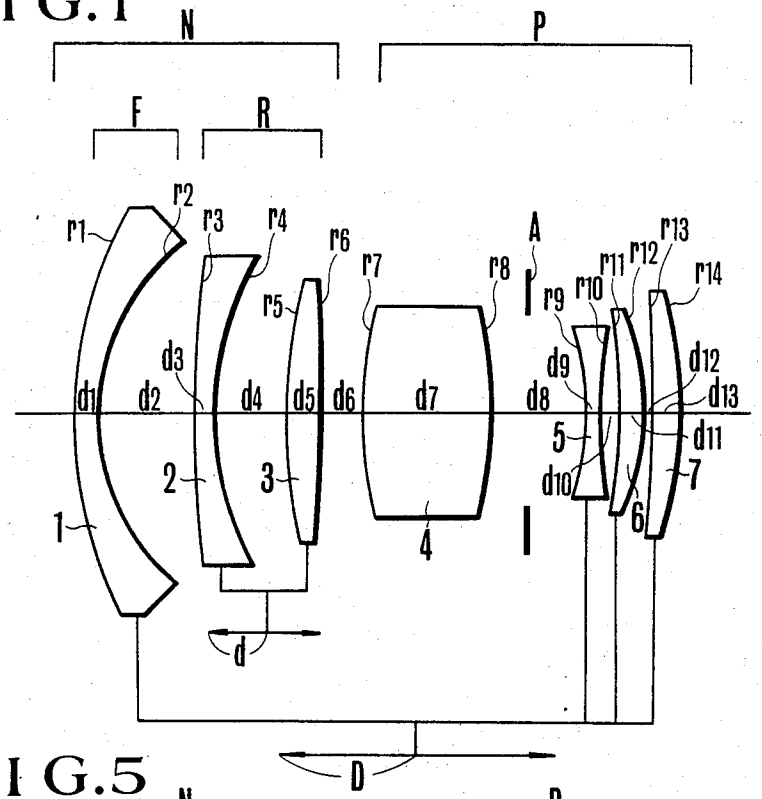
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FIG.5

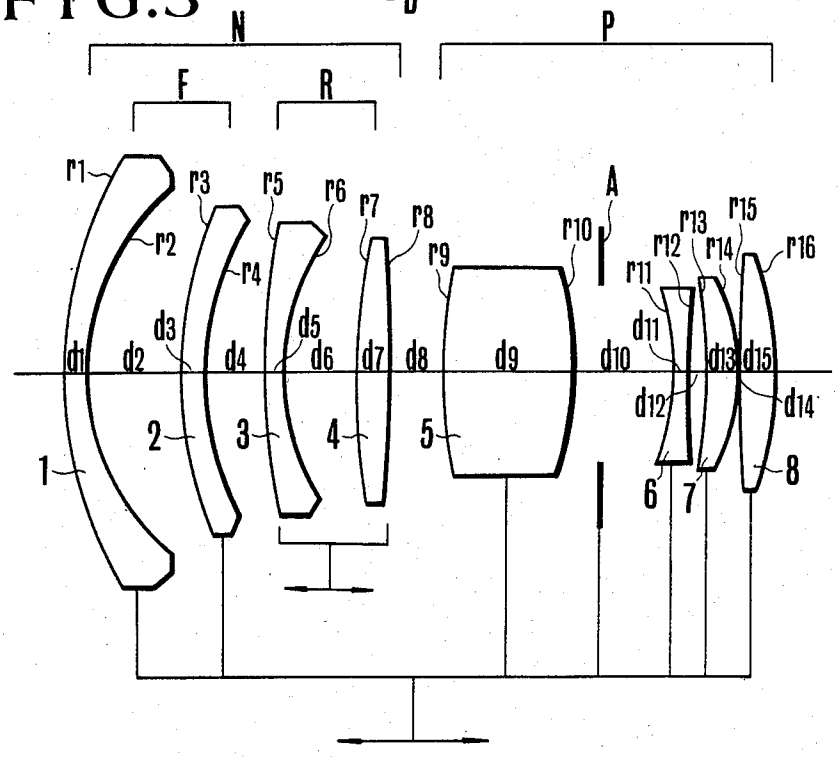
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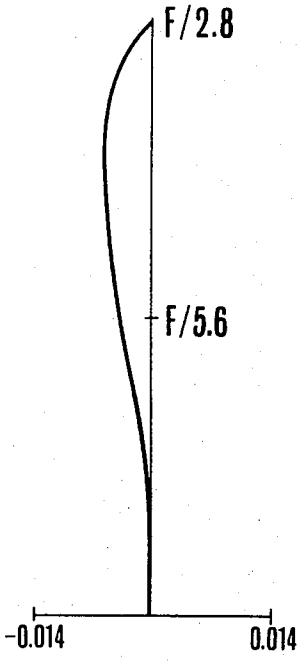
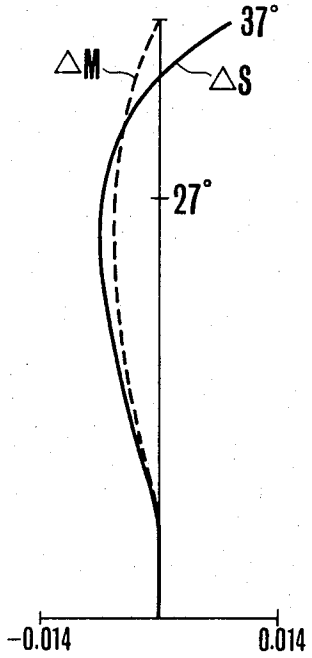
FIG.2A



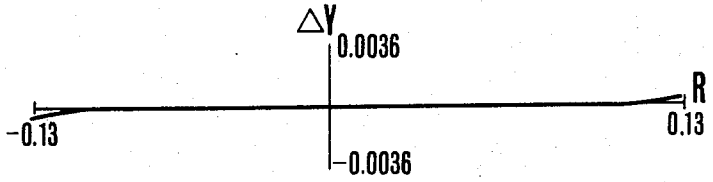
SPHERICAL ABERRATION

FIG.2B



ASTIGMATISM

FIG.2c



LATERAL ABERRATION (W = 37°)

FIG.3A

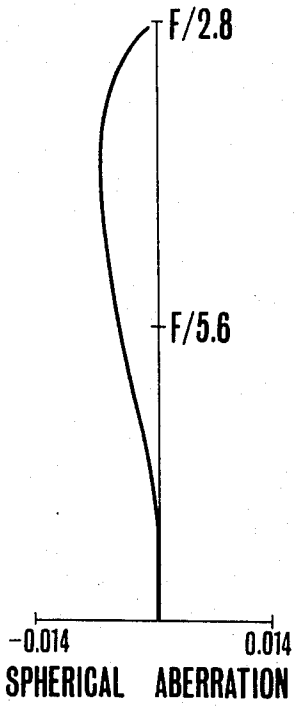


FIG.3B

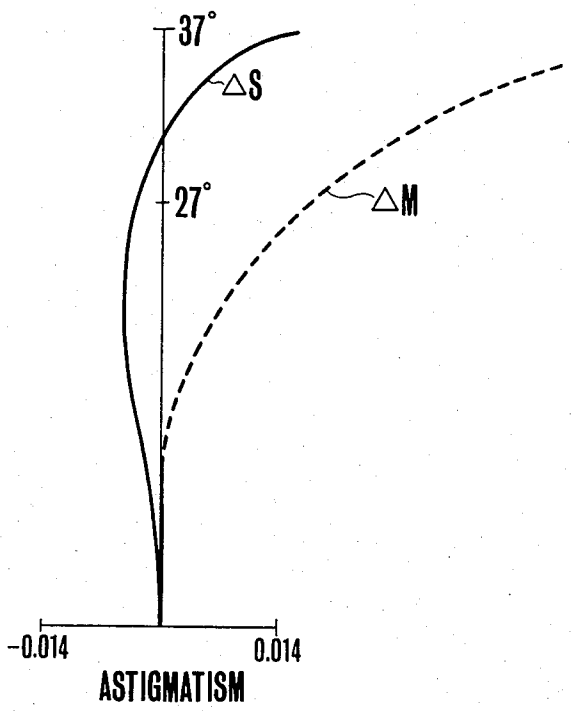


FIG.3c

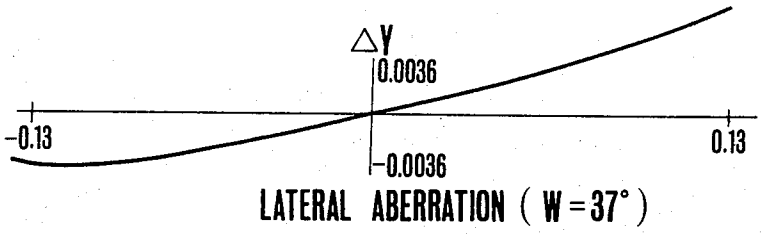


FIG.4A

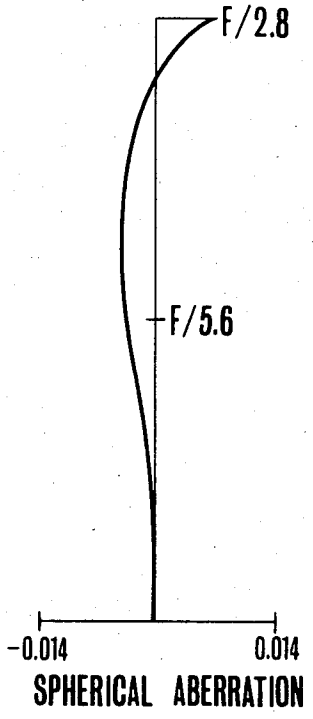


FIG.4B

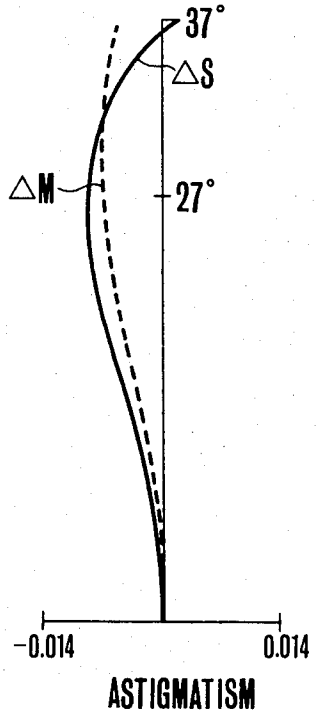


FIG.4c

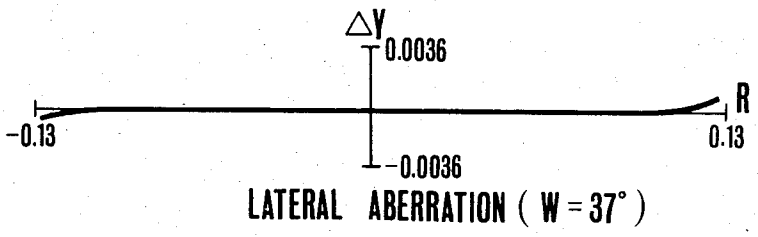
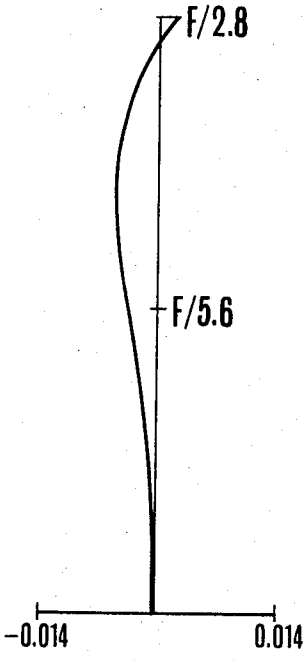
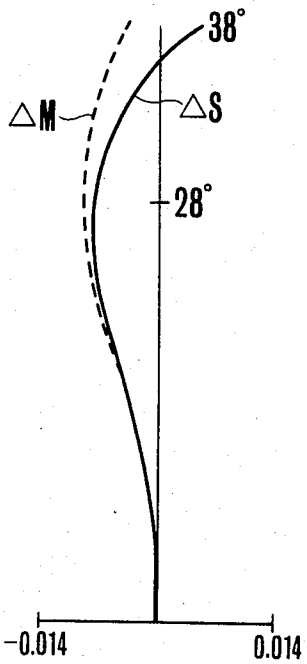


FIG.6A



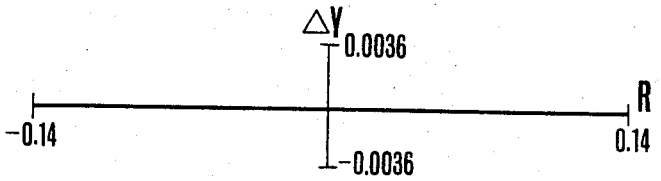
SPHERICAL ABERRATION

FIG.6B



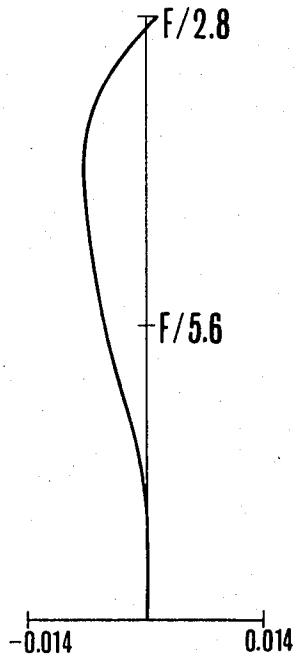
ASTIGMATISM

FIG.6c



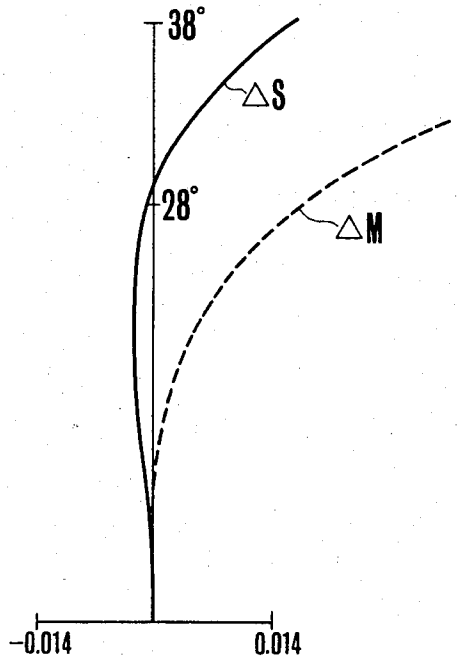
LATERAL ABERRATION (W=38°)

FIG.7A



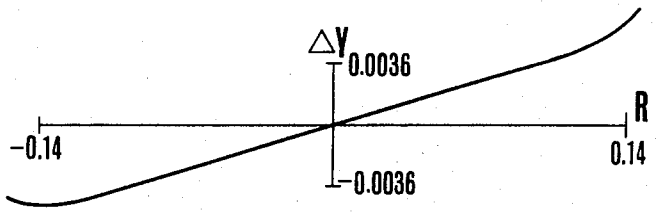
SPHERICAL ABERRATION

FIG.7B



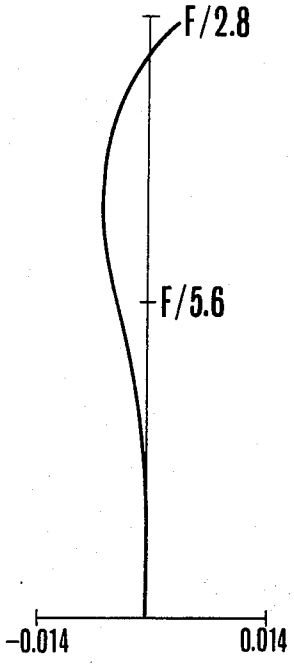
ASTIGMATISM

FIG.7c



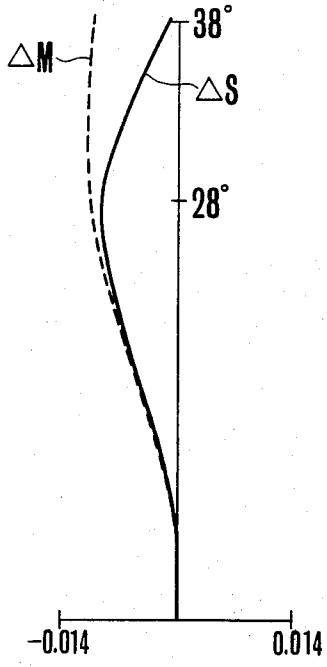
LATERAL ABERRATION (W = 38°)

FIG.8A



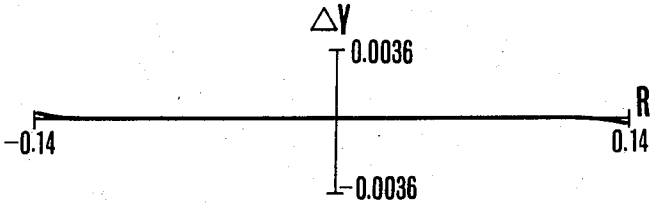
SPHERICAL ABERRATION

FIG.8B



ASTIGMATISM

FIG.8c



LATERAL ABERRATION (W = 38°)

FIG.9

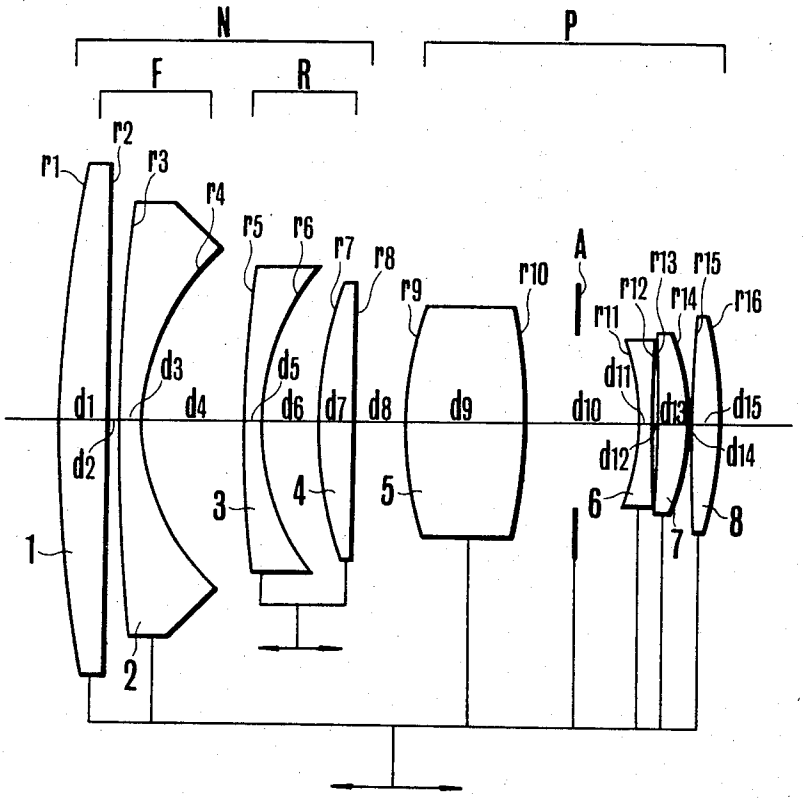

N
P
F
R
r1
r2
r3
r4
r5
r6
r7
r8
r9
r10
A
r11
r12
r13
r14
r15
r16
d1
d2
d3
d4
d5
d6
d7
d8
d9
d10
d11
d12
d13
d14
d15
1
2
3
4
5
6
7
8

FIG.10A FIG.10B

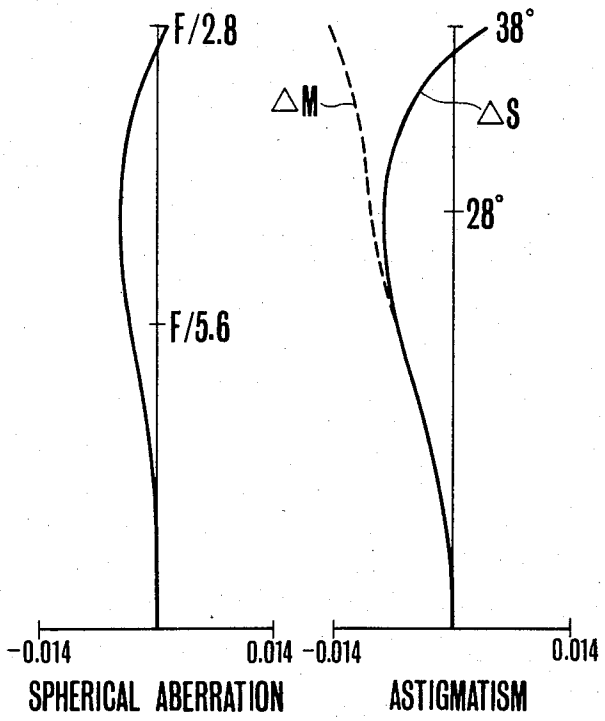


FIG.10C

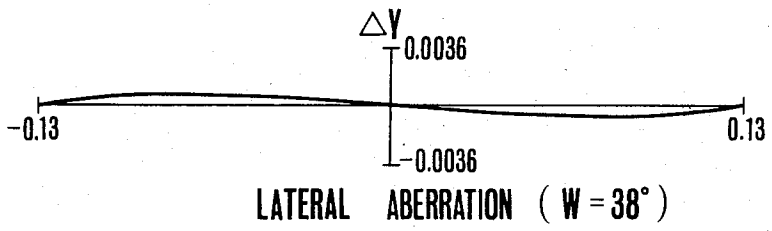


FIG.11A FIG.11B

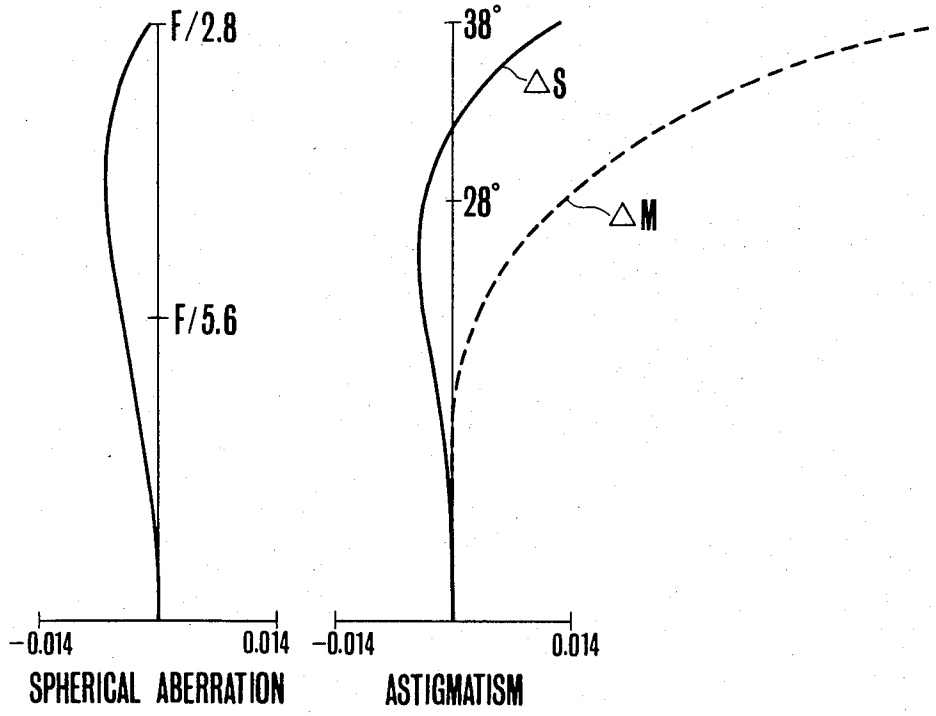


FIG.11c

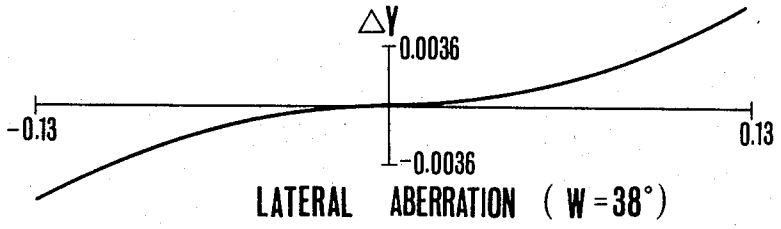


FIG.12A FIG.12B

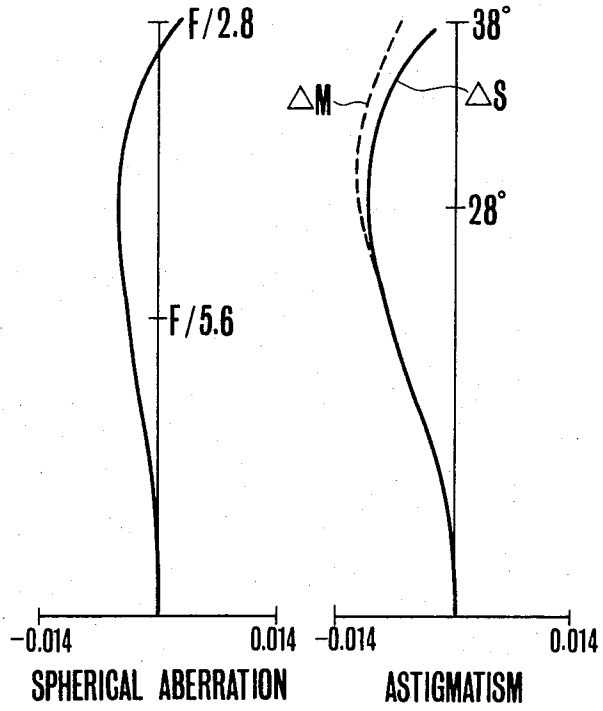
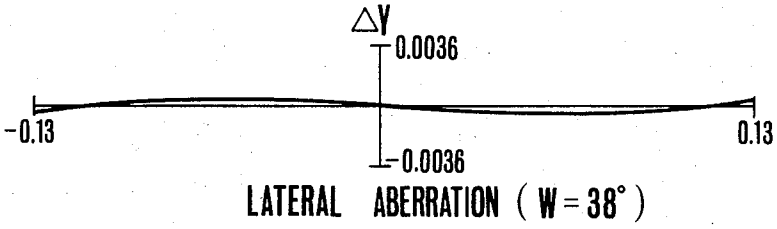


FIG.12C



RETRO-FOCUS TYPE WIDE ANGLE OBJECTIVE LENS

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to a retrofocus type wide angle objective lens in which aberrations are prevented from deteriorating even in short distance photography.

2. Description of the Prior Art

In general, the aberrational state of an optical lens varies with object distance. Ordinary photographic lenses are corrected for aberrations at infinity so that the closer the object position is with the photographing lens, the larger the aberrations become with the result that the picture quality on the film deteriorates.

This phenomenon is especially remarkable in optical systems of longitudinal asymmetry with respect to the diaphragm thereof and it has been a very serious problem in retrofocus type lenses as the field angle is large.

In general, the retrofocus type lens when focused to a cloe object produces spherical aberration, coma, astigmatism and curvature of field to a remarkable extent. Therefore, various techniques of correcting aberrations at short distances have been proposed.

However, most of these proposals are subjected to a limitation such that air spaces in which axial rays are parallel or substantially parallel with the optical axis be varied. This limitation is laid down for the purpose of producing to bad influence on the spherical aberration and back focus.

Although this method is effective for correction of astigmatism and curvature of field, generally speaking, it is difficult to effect good correction of coma. This is because the space defined as having parallel rays is not always coincidence with a space suitable for use in correction of coma, and because the degree of freedom is not sufficient so that it is difficult to obtain the space with parallel rays usuable for aberration correction. Even in this method, it is usual that the performance of the lens for close photography is not always satisfactory as compared with the performance for infinite photography.

SUMMARY OF THE INVENTION

The present invention has for the general object to improve the above mentioned difficult points and to provide a method of compensating deterioration of the image quality of an object at a short distance in a retrofocus type wide angle objective lens.

According to the present invention, the various aberrations and particularly coma of a retrofocus type lens are corrected from deterioration thereof in short distance photography by moving a lens group consisting of a negative lens and a positive lens in the lens system in a divergent light bundle which inevitably exists in the retrofocus type lens, thereby the image quality of an object at a short distance is improved to as a high standard as that of an object at infinity.

In a retrofocus wide angle objective lens of the present invention, therefore, there is provided a lens group having one or more negative lens or lenses and a positive lens arranged in this order from the object side in a divergent light bundle on the object side with respect to a diaphragm thereof to be moved when focusing in response to variation of object distance. In more detail, a retrofocus wide angle objective lens of its aberrations being prevented from deteriorating when making short distance photography is constructed from a lens group N having a negative refractive power and a lens group P, with a diaphragm provided therein, having a positive refractive power. Further, the above mentioned lens group N consists of a front lens group having a negative refractive power and a rear lens group, and the above mentioned rear lens group consists of, from the object side, at least one concave lens and one convex lens, the rear lens group being placed in a divergent light bundle from the front lens group. When the entire lens system is moved outwards in short distance photography, the amount of movement of the above mentioned front lens group and lens group P being moved in unison with each other is different from the amount of movement of the above mentioned rear lens group. Letting f_R be the focal length of the above mentioned rear lens, f the focal length of the entire lens system, and ω the semi-angle of field, we have $|f_R| > 0.1\omega f$. By satisfaction of this formula, it is made possible to preserve aberrations almost equivalent to those occurring when photographing an infinitely distant object.

The rear lens group constructed in accordance with the present invention comprises, from the object side, one or more negative lens or lenses and one positive lens, whereby it is preferred that the shape of the negative lens is meniscus, and the positive lens is a convex lens having a strong surface faced toward the object side. The term "strong" means that the radius of curvature is smaller.

Further, the front lens group is a divergent lens group constructed from a concave lens or lenses alone, or a divergent lens group containing at most one convex lens as located at the frontmost position.

And located just before the object side of the rear lens group is always the convex lens of the front lens group.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a lens block diagram showing a first embodiment of the present invention.

FIG. **2A**, FIG. **2B** and FIG. **2C** are various aberration curves of the optical system of FIG. **1** occurring when the object distance is infinite.

FIG. **3A**, FIG. **3B** and FIG. **3C** are various aberration curves of the optical system of FIG. **1** occurring at a magnification of −0.134 when the rear lens group R is moved in unison with the front lens group F and lens group P.

FIG. **4A**, FIG. **4B** and FIG. **4C** are various aberration curves of the optical system of FIG. **1** occurring at a magnification of −0.134 when the rear lens group R is moved with a different amount of movement from that movement of the front lens group F and lens group P.

FIG. **5** is a lens block diagram showing a second embodiment of the present invention.

FIG. **6A**, FIG. **6B** and FIG. **6C** are various aberration curves of the optical system of FIG. **5** when the object distanct is infinite.

FIG. **7A**, FIG. **7B** and FIG. **7C** are various aberration curves of the optical system of FIG. **5** at a magnification of −0.134 when the rear lens group R is moved in unison with the front lens group F and lens group P.

FIG. **8A**, FIG. **8B** and FIG. **8C** are various aberration curves of the optical system of FIG. **5** at a magnification of −0.134 when the rear lens group R is moved with a different amount of movement thereof from that of movement of the front lens group F and lens group P.

FIG. 9 is a lens block diagram showing a third embodiment of the present invention.

FIG. 10A, FIG. 10B and FIG. 10C are various aberration curves of the optical system of FIG. 9 when the object distance is infinite.

FIG. 11A, FIG. 11B and FIG. 11C are various aberration curves of the optical system of FIG. 9 at a magnification of −0.134 when the rear lens group R is moved in unison with the front lens group F and lens group P.

FIG. 12A, FIG. 12B and FIG. 12C are various aberration curves of the optical system of FIG. 9 at a magnification of −0.134 when the rear lens group R is moved with a different amount of movement thereof from that of movement of the front lens group F and lens group P.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENT

FIG. 1 is a lens block diaphragm showing the first embodiment of the present invention. In FIG. 1, lenses 1, 2 and 3 constitute a negative lens group N, and lenses 4, 5, 6 and 7 constitute a positive lens group P, the lens group N being divided into a front lens group (1) F having a negative refractive power and a rear lens group (2, 3) R. The lens group P and front lens group 1, 4, 5, 6 and 7 are secured in fixed relation with each other. On the other hand, the negative meniscus lens 2 and the positive lens 3 constituting the rear lens group R and positioned in a divergent light bundle emanating from the front lens group F are secured as a unit independently of the other lens groups. A is a diaphragm.

When the lens system is focused to an object at a short distance, it is moved as a whole toward the object, but the amount of movement, d, of the lenses (2, 3) is smaller than the amount of movement D of the lenses (1, 4, 5, 6, 7). As a result, the axial separation $d2$ between the lens 1 and the lens 2 is increased with decrease in the object distance, and the axial separation $d6$ between the lens 3 and lens 4 is decreased.

In the following, the reason why the aberration deterioration can be prevented by moving the rear lens group R, with the negative and positive lenses thereof arranged in this order, in the divergent light bundle considerably far away from the diaphragm A will be explained. In order to explain the correction principle, it is assumed that a parallel plane surface plate is inserted into the divergent light bundle in the lens system, and that the lens system is corrected for aberrations together with the parallel plane surface plate inserted therein. In such a lens system, a slight axial movement of the parallel plane surface plate does not cause variation of aberrations. In the case where this parallel plane surface plate is divided into a convex lens and a concave lens, while the combined lens resembling in shape the parallel plane surface plate and an appropriate air space is given between said convex and concave lenses, however, the axial movement of such a plate causes variation of aberrations, because higher order aberrations are apt to occur at a surface having a curvature. In the retrofocus type objective lens, therefore correction of spherical aberration, coma, astigmatism and curvature of field which are the more liable to collapse as the object distance becomes the smaller is made possible by designing the lens system so as to satisfy certain conditions for this portion.

The above-mentioned condition formula $|f_R| > 0.1\omega f$: when $|f_R|$ exceeds this range, aberration correction at short distances can not be effected. In other words, when the absolute value of the focal length of the rear lens group exceeds $0.1\omega f$, certain aberrations which are caused to deteriorate by focusing to a short distance can be well corrected on the one hand, but the other aberrations are produced out of balance to more than correction values on the other hand, so that as a whole it is impossible to preserve the aberration state occurring when the object is at infinity.

For example, when spherical aberration is corrected, the curvature of field and astigmatism are produced. Conversely, when the curvature of field and astigmatism are intended to be corrected, the spherical aberration is largely produced, thus it being made difficult to correct all the aberrations completely.

However, it is convenient from the standpoint of aberration correction at short distances that the value of $|f_R|$ is generally large, because the movement of the lens group is made in the divergent light bundle. However, there are many cases where it is better to positively use the movable lens portion in performing aberration correction for an object at infinity based on the lens configuration of the entire system and the power distribution. In that time, by satisfying the above mentioned condition formula, the character at short distances are also corrected.

As another meaning of the condition formula, when this condition formula is violated, the back focus and F-number vary at short distances. In other words, by satisfying this formula it is made possible to reduce variation of the back focus and F-number and to correct aberrations at short distances.

The reason why ω is included as a variable in the condition formula is that the larger the angle of field, the severer the correction of image surface is. In order that aberrations at short distances are corrected while maintaining balance of the overall aberrations, it is necessary to increase the lower limit of $|f_R|$.

In such a manner as the above, the performance at short distances can be corrected to as high as the performance an infinity. As a explanation of the effectiveness of this method, mention may be made of the degree of freedom such that there are two variable air spaces in the lens system. Further, based on the fact that the movable portion of the lens system is comprised of a negative lens and a positive lens, it can be pointed out that the coma aberrations are cancelled by the mutual lenses to result in almost no production of coma aberration even at short distances.

This reason will be explained theoretically. Letting II be the aberration coefficient of coma at infinit object position, III the aberration coefficient of astigmatism, and IV the aberration coefficient of sagittal curvature of field according to Matsui's notation, and letting δ the parameter of movement of the object, the coefficient IIo of coma in parameter δ for the case where the focusing is performed by moving the entire lens system in unison can be expressed as follows:

$$\mathrm{II}o = (1/K^2)\,[\mathrm{II} - \delta(2\mathrm{III} + \mathrm{IV} + \bar{\alpha}') + (\text{the terms of the higher powers of } \delta)]$$

wherein K is the parameter of object movement; and $\bar{\alpha}'$ is the quantity representing the inclination angle of a pupil-paraxial ray exiting from the rearmost surface.

For $\delta << 1$, neglecting the terms of the higher powers of IIo and replacing IV by II + P (wherein P is the petzval sum), we have

$$IIo = (1/K^2)\,[II - \delta(3III + P + \bar{\alpha}')]$$

On the other hand, $3III + P + \bar{\alpha}' \neq 0$ generally holds. It is, therefore, to be understood that the value of II varies with object distance.

For example, in the first embodiment shown in FIG. 1, the magnitude of II at the state of object infinity is 0.05, but it is decreased to −0.01 at a magnification of −0.134. For this reason, the balance of aberrations breakes with production of outward coma.

By moving the rear lens group, however, the coefficient of coma is shifted to (+) side, taking 0.01. Therefore, inward coma is produced. Taking into account the amounts of 5th order aberrations, we see that the coma aberration is reduced to zero as a whole.

Further, the rear lens group is constructed by combining a negative lens with a positive lens so that the absolute value of the overall focal length of this portion is longer than the focal length of the entire system, thus the refractive power being weak. Therefore, the deterioration of image quality by the eccentricity (parallel and inclination) of this movable portion is small.

Also the strength against the eccentricity can be said from the fact that the rear lens group is arranged on the object side of the diaphragm and in the divergent light bundle apart from the diaphragm.

In other words, beyond the positive lens group which is usually located on the object side of the diaphragm in the retrofocus type lens is located further on the object side the rear lens group, so that the distance from the center of the diaphragm to the lens is long. Therefore, this distance can be made close to the curvature of lens and therefore the influence due to the eccentricity becomes very dull, so that the image quality can be secured even from the eccentricity.

Further, even when the lens system is incorporated in a lens barrel which is made complicate by the mounting of a diaphragm mechanism linkable with the camera body, there is an advantage that the mechanism design of the lens barrel is easy and the overall size is minimized, because the rear lens group is positioned in the front part of the lens barrel as compared with the diaphragm rear or neighborhood which makes the lens barrel complicate. Also, the rear lens group has a negative lens and positive lens arranged in order so that there is a merit that the inclination of a light bundle entering the negative lens and the inclination of a light bundle exiting from the positive lens can be brought close to each other.

Next, the values of various dimensions of the first embodiment according to FIG. 1, of the second embodiment according to FIG. 1, of the second embodiment according to FIG. 5 and of the third embodiment according to FIG. 9 are given below.

First embodiment (FIG. 1) f = 1, F_{NO} = 2.8, ω = 37°

r_1 =	1.3064	d_1 = 0.0632	N_1 = 1.61117	V_1 = 55.9
r_2 =	0.6109	*d_2 = 0.3152		
r_3 =	3.7622	d_3 = 0.0526	N_2 = 1.60729	V_2 = 49.3
r_4 =	0.7757	d_4 = 0.2100		
r_5 =	1.7619	d_5 = 0.1053	N_3 = 1.72342	V_3 = 38.0
r_6 =	−9.1853	*d_6 = 0.1500		
r_7 =	1.0840	d_7 = 0.3627	N_4 = 1.60311	V_4 = 60.7
r_8 =	−1.3336	d_8 = 0.2910		
r_9 =	−0.6365	d_9 = 0.0351	N_5 = 1.74077	V_5 = 27.8
r_{10} =	1.8877	d_{10} = 0.0491		
r_{11} =	−2.5630	d_{11} = 0.0947	N_6 = 1.69350	V_6 = 53.3
r_{12} =	−0.6112	d_{12} = 0.0070		
r_{13} =	−26.8270	d_{13} = 0.0912	N_7 = 1.69350	V_7 = 53.3
r_{14} =	−1.1736			

*is a variable space

The length from the first surface to the rearmost surface = 1.8271

Back focus = **1.2807**

$|f_R|$ = 15.06

At a magnification of −0.134 :

d_2 = 0.3854

d_6 = 0.0798

wherein *ri* is the radii of curvature of lenses, *di* is the thicknesses of lenses or separations between the surfaces; *Ni* is the indicies of refraction; and *Vi* is the Abbe's number.

Second embodiment (FIG. 5) f = 1, F_{NO} = 2.8, ω = 37°

r_1 =	1.23155	d_1 = 0.06316	N_1 = 1.61117	V_1 = 55.9
r_2 =	0.70388	d_2 = 0.28121		
r_3 =	1.50662	d_3 = 0.05263	N_2 = 1.61117	V_2 = 55.9
r_4 =	0.92380	*d_4 = 0.20631		
r_5 =	2.98847	d_5 = 0.05263	N_3 = 1.60729	V_3 = 49.3
r_6 =	0.81910	d_6 = 0.19952		
r_7 =	1.65922	d_7 = 0.10526	N_4 = 1.72342	V_4 = 38.0
r_8 =	−10.16219	*d_8 = 1.12219		
r_9 =	1.08565	d_9 = 0.38597	N_5 = 1.60311	V_5 + 60.7
r_{10} =	−1.46681	d_{10} = 0.29961		
r_{11} =	−0.63435	d_{11} = 0.03509	N_6 = 1.74077	V_6 = 27.8
r_{12} =	2.01901	d_{12} = 0.04912		
r_{13} =	−2.67331	d_{13} = 0.09474	N_7 = 1.69350	V_7 = 53.3
r_{14} =	−0.59919	d_{14} = 0.00702		
r_{15} =	85.43513	d_{15} = 0.09123	N_8 = 1.69350	V_8 = 53.3
r_{16} =	−1.33708			

*is a variable space

The length from the first surface to the rearmost surface = 2.0457

Back focus = 1.3133

$|f_R|$ = 40.4

At a magnification of −0.134:

d_4 = 0.24120

d_6 = 0.08710

In the second embodiment, only lens **3** and lens **4** are movable independently of the other lenses.

Third embodiment (FIG. 9) f = 1, F_{NO} = 2.8, ω = 38°

r_1 =	3.8596	d_1 = 0.14035	N_1 = 1.60311	V_1 = 60.7
r_2 =	∞	d_2 = 0.03494		
r_3 =	7.5094	d_3 = 0.06316	N_2 = 1.60729	V_2 = 49.3
r_4 =	0.6628	*d_4 = 0.30565		
r_5 =	4.0216	d_5 = 0.05263	N_3 = 1.60729	V_3 = 49.3
r_6 =	0.7421	d_6 = 0.16742		
r_7 =	1.2428	d_7 = 0.10526	N_4 = 1.72342	V_4 = 38.0
r_8 =	−30.6430	*d_8 = 0.15683		
r_9 =	1.0579	d_9 = 0.36140	N_5 = 1.60311	V_5 = 60.7
r_{10} =	−1.5508	d_{10} = 0.33634		
r_{11} =	−0.6291	d_{11} = 0.03509	N_6 = 1.74077	V_6 = 27.8
r_{12} =	1.9835	d_{12} = 0.01856		
r_{13} =	−2.8834	d_{13} = 0.09474	N_7 = 1.69350	V_7 = 53.3
r_{14} =	−0.6405	d_{14} = 0.00702		
r_{15} =	25.9050	d_{15} = 0.09123	N_8 = 1.69350	V_8 = 53.3
r_{16} =	−1.0729			

*is a variable space

The length from the first surface to the rearmost surface = 1.9706

Back focus = 1.2807

$|f_R|$ = 150.49

At a magnification of −0.134:

d_4 = 0.36881

d_8 = 0.09368

In the third embodiment, lens **3** and lens **4** are movable independently of the other lenses.

What is claimed is:

1. A retro-focus wide-angle objective lens corrected for short distance photography, comprising:

a first lens group N at the object end and having a negative refractive power,

a second lens group P closer to the image end and having a positive refractive power, said first lens group N including a front lens group having a negative refractive power and a rear lens group, said front lens group producing a divergent light bundle,

said rear lens group being located in the divergent light bundle from the front lens group, said rear lens group having a negative lens toward the object and a first positive lens,

said second lens group P including a front positive lens facing said first positive lens of said rear lens group and a diaphragm disposed toward the image end of said front positive lens,

said first and second lens groups N and P being movable toward the object for short distance photography, said front lens group and said second lens group P being movable in unison with each other at a rate different from the rate of said rear lens group.

2. A lens as in claim **1**, wherein said front lens group of said first lens group N includes a negative lens adjacent said rear lens group.

3. A lens as in claim **2**, wherein said rear lens group includes a negative meniscus lens concave to the image, said rear lens group having a biconvex lens with one surface more convex than a second surface, said one surface being directed toward the object end.

4. A lens as in claim **2**, wherein said front lens group consists of a single negative meniscus lens concave to the image.

5. A lens as in claim **2**, wherein said front lens group consists of two negative meniscus lenses concave to the image.

6. A retrofocus wide-angle objective lens corrected for short distance photography, comprising

a pair of adjoining negative lenses with a first variable air space therebetween,

a pair of adjoining positive lenses with a second variable air space therebetween, said negative lenses being disposed toward an object end and said positive lenses toward an image end of the objective lens,

said lens toward the image end of said second variable air space forming at least a portion of a positive lens group having a positive refractive power, said lens toward the object end of said first variable air space forming at least a portion of a front lens group having a negative refractive power and said lenses between the variable air spaces forming a rear lens group,

a diaphragm in said positive lens group disposed toward the image end of said positive lens facing the second variable air space,

all of said lenses being movable toward the object for short distance photography, the rate of movement of said front lens group and said positive lens group being equal and in unison and being different from the rate of movement of said rear lens group.

7. A lens as in claim **6**, wherein said first variable air space is larger and said second variable air space is smaller during photography of an object at an infinite distance as compared with the air spaces during close-up photography.

8. A retrofocus wide-angle objective lens corrected for short distance photography, comprising:

a first lens group and a second lens group and a third lens group in order from an object end to an image end,

said first lens group having a divergent power, said second lens group including a negative group having at least one negative meniscus lens concave to the image, and one positive lens closer to the image end than the negative group,

said third lens group having convergent power and having a positive lens toward the object end,

a diaphragm incorporated into said third lens group closer to the image end than said front positive lens,

means for moving the first and third lens groups and maintaining a constant space therebetween, means for moving the second lens group at a rate different from that of said first lens group during short distance photography.

9. A lens as in claim **8**, wherein said first lens group has a negative lens adjacent to said second lens group.

10. A lens as in claim **9**, wherein said one positive lens of said second lens group is a double convex lens having two convex surfaces, one convex surface being more convex than the other of the convex surfaces and facing the object end.

11. A lens as in claim **8**, wherein said first lens group consists of a single negative meniscus lens concave to the image.

12. A lens as in claim **8**, wherein said first lens group consists of two negative meniscus lenses concave to the image.

* * * * *

OR 4,025,169

United Stat

Fischer et al.

[11] **4,025,169**

[45] **May 24, 1977**

[54] **HIGH SPEED WIDE ANGLE OBJECTIVE LENS SYSTEM**

[75] Inventors: **Helmut Fischer**, Oberkochen; **Erhard Glatzel**; **Walter Jahn**, both of Heidenheim (Brenz); **Heinz Zajadatz**, Essingen, all of Germany

[73] Assignee: **Carl Zeiss-Stiftung**, Oberkochen, Germany

[22] Filed: **Mar. 29, 1976**

[21] Appl. No.: **671,129**

[30] **Foreign Application Priority Data**

Mar. 29, 1975 Germany 2514081

[52] **U.S. Cl.** **350/212**; 350/214

[51] **Int. Cl.²** **G02B 13/04**

[58] **Field of Search** 350/212, 214, 215

[56] **References Cited**

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Primary Examiner—John K. Corbin
Assistant Examiner—Conrad Clark
Attorney, Agent, or Firm—Stonebraker, Shepard & Stephens

[57] **ABSTRACT**

An extremely high speed wide angle objective lens system, wherein a reducing Newtonian finder telescope is arranged in front of an objective lens group which produces a real image on an image plane. Rules or conditions are stated, and several specific examples are given. In many of the examples, the back focus distance is relatively large, thus making the lens system suitable for use with a mirror reflex camera where room is needed for swinging the reflex mirror.

25 Claims, 15 Drawing Figures

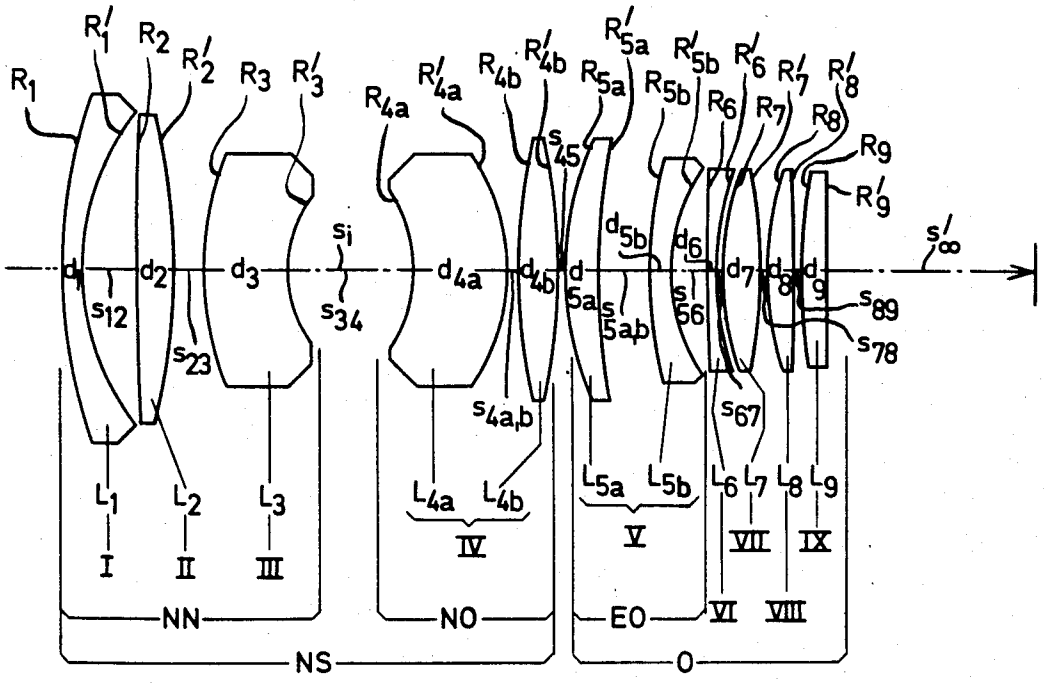
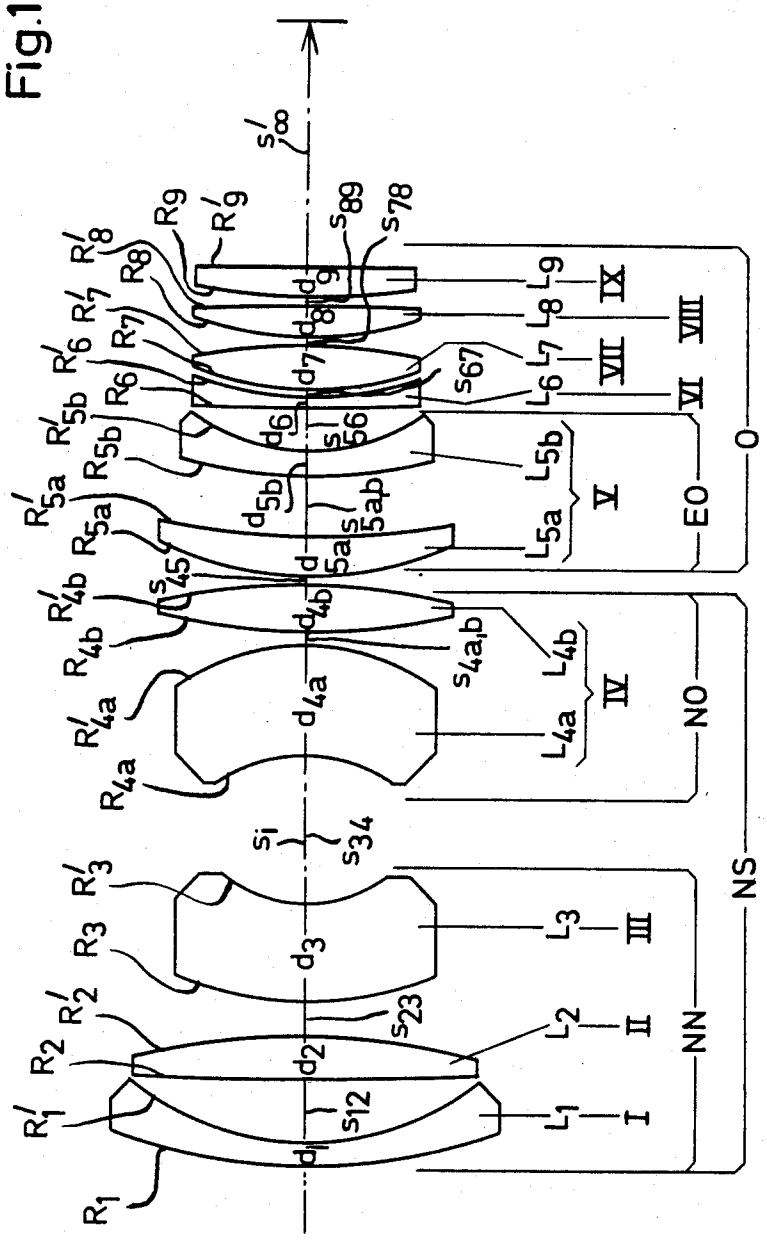


Fig.1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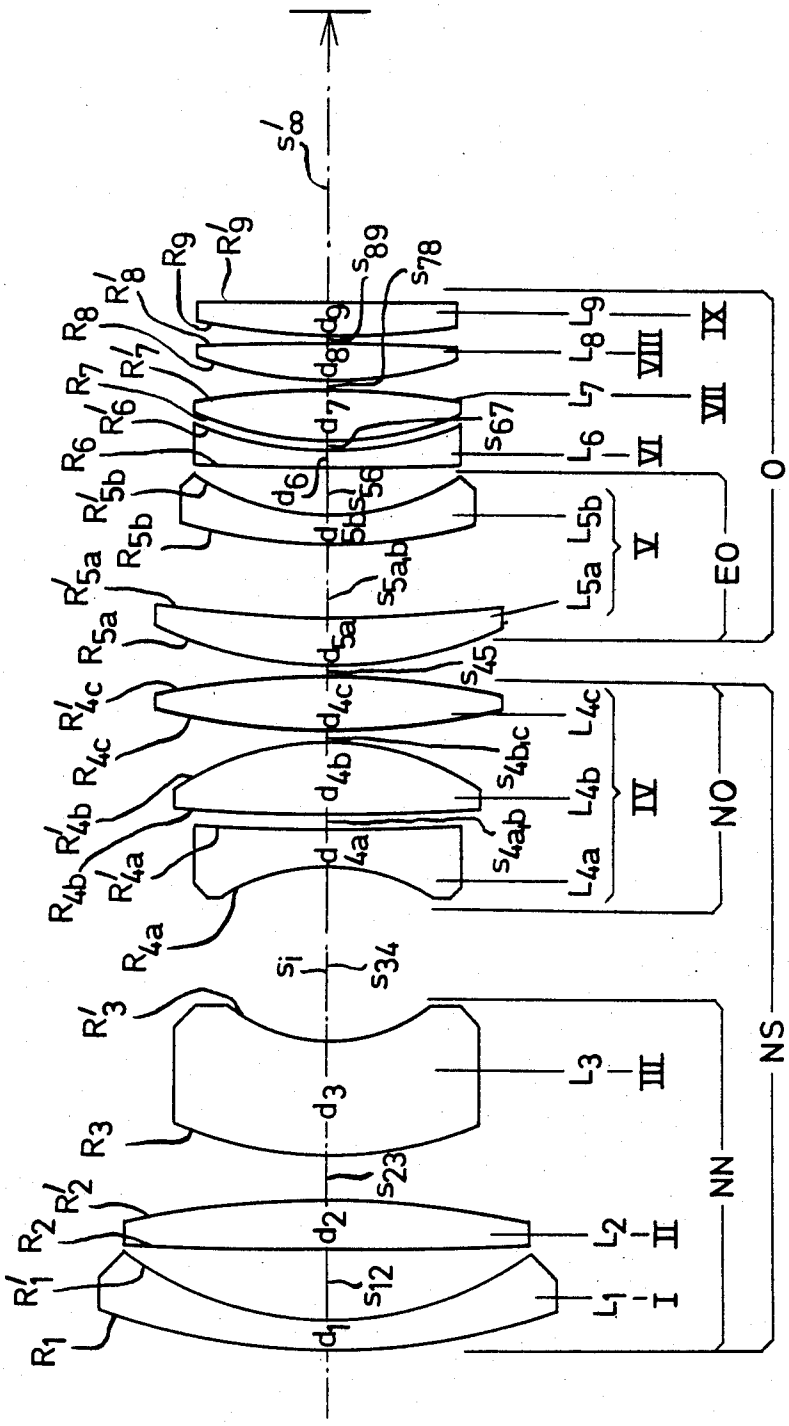
s89
s78
R'8
R8
R'7
R7
R'6
R6
R'5b
R5b
R'5a
R5a
R'4b
R4b
R'4a
R4a
si
s34
R'3
R3
R'2
R2
R'1
R1
d9
d8
d7
d6
d5b
d5a
d45
d4b
d4a
d3
d2
d1
s67
s56
s5ab
s45
s4a,b
s23
s12
L9
L8
L7
L6
L5b
L5a
L4b
L4a
L3
L2
L1
IX
VIII
VII
VI
V
IV
III
II
I
O
EO
NO
NS
NN

Fig.2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R9
s89
s78
R'8
R8
R'7
R7
R'6
R6
s67
R'5b
R5b
d6
s56
d5b
s5ab
R'5a
R5a
d5a
s45
R'4c
R4c
d4c
s4bc
R'4b
R4b
d4b
s4ab
R'4a
R4a
d4a
si
s34
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R3
d3
s23
R'2
R2
d2
R'1
R1
s12
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L9
L8
L7
L6
L5b
L5a
L4c
L4b
L4a
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II
I
O
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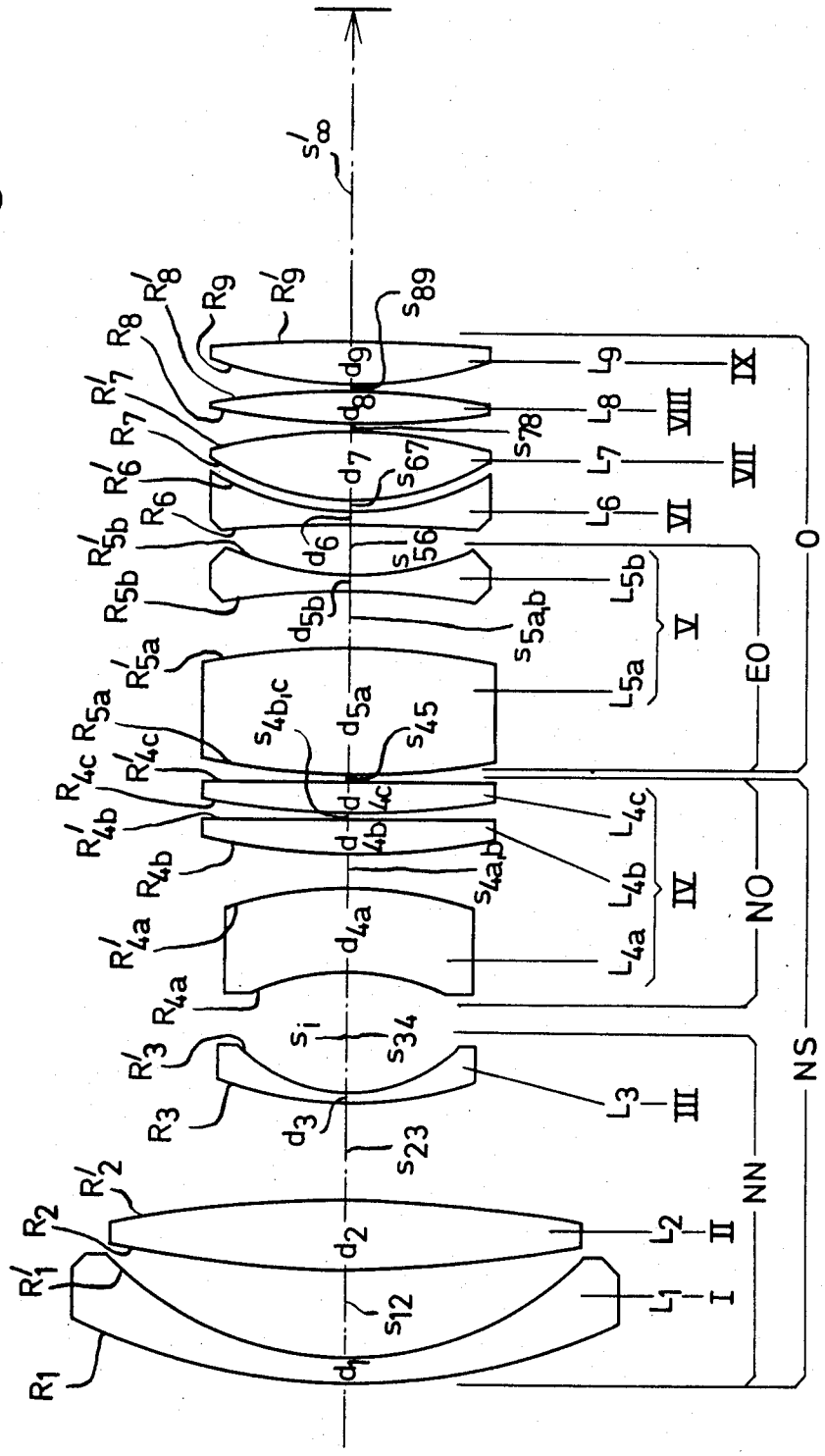
NS
NN

Fig.3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L8
VIII
s78
R7
d7
s67
L7
VII
R'6
R6
L6
VI
R'5b
d6
s56
R5b
L5b
d5b
s5a,b
V
R'5a
L5a
R5a
s4b,c
d5a
s45
EO
R4c
R'4c
d4c
L4c
R'4b
d4b
L4b
R4b
s4a,b
IV
R'4a
d4a
L4a
R4a
NO
si
s34
R'3
L3
R3
III
d3
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L2
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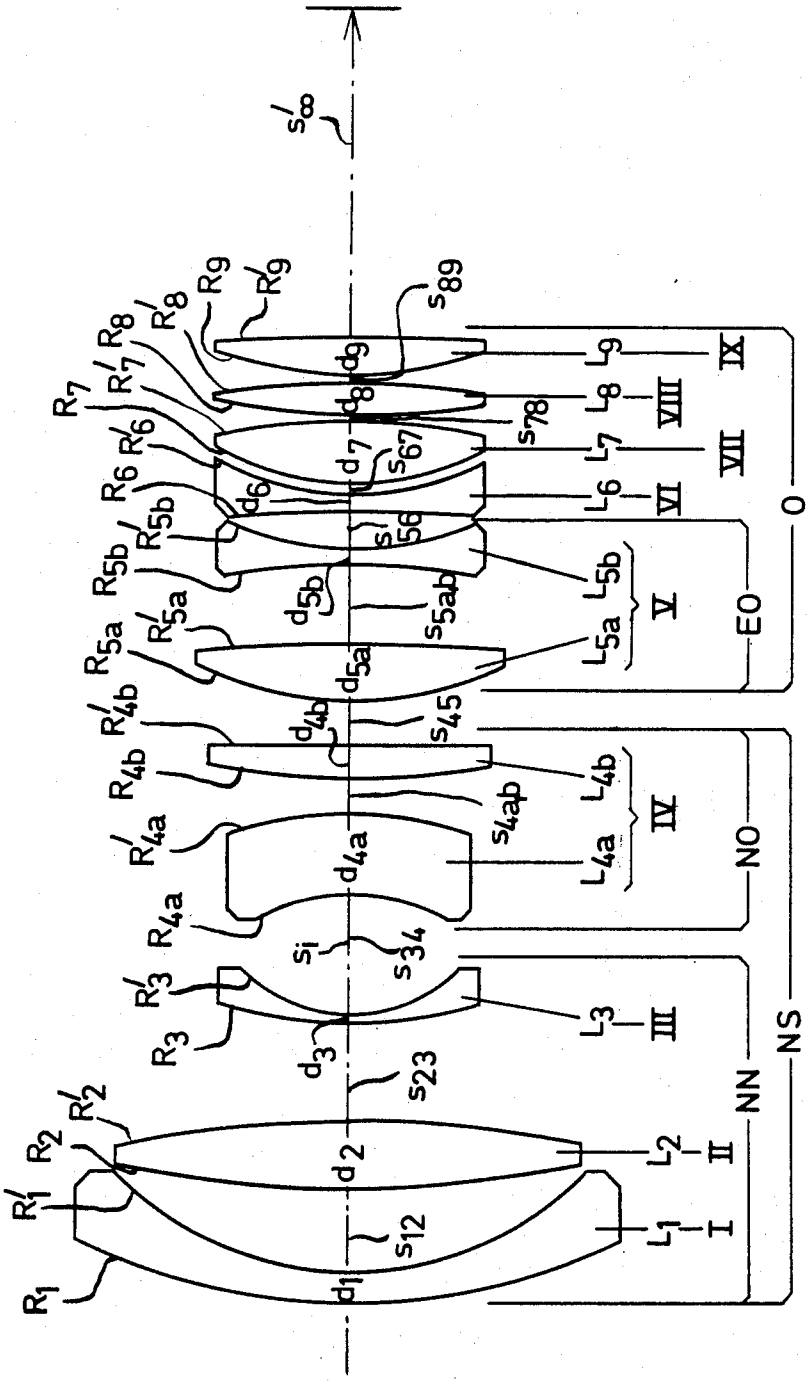
I
s12
R1
d1
NS
O

Fig. 4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R'5a
R4b
R'4b
R4a
R'4a
R3
R'3
R2
R'2
R1
d9
d8
d7
d6
d5b
d5a
d4b
d4a
si
d3
d2
d1
s78
s67
s56
s5ab
s45
s4ab
s34
s23
s12
L9
L8
L7
L6
L5b
L5a
L4b
L4a
L3
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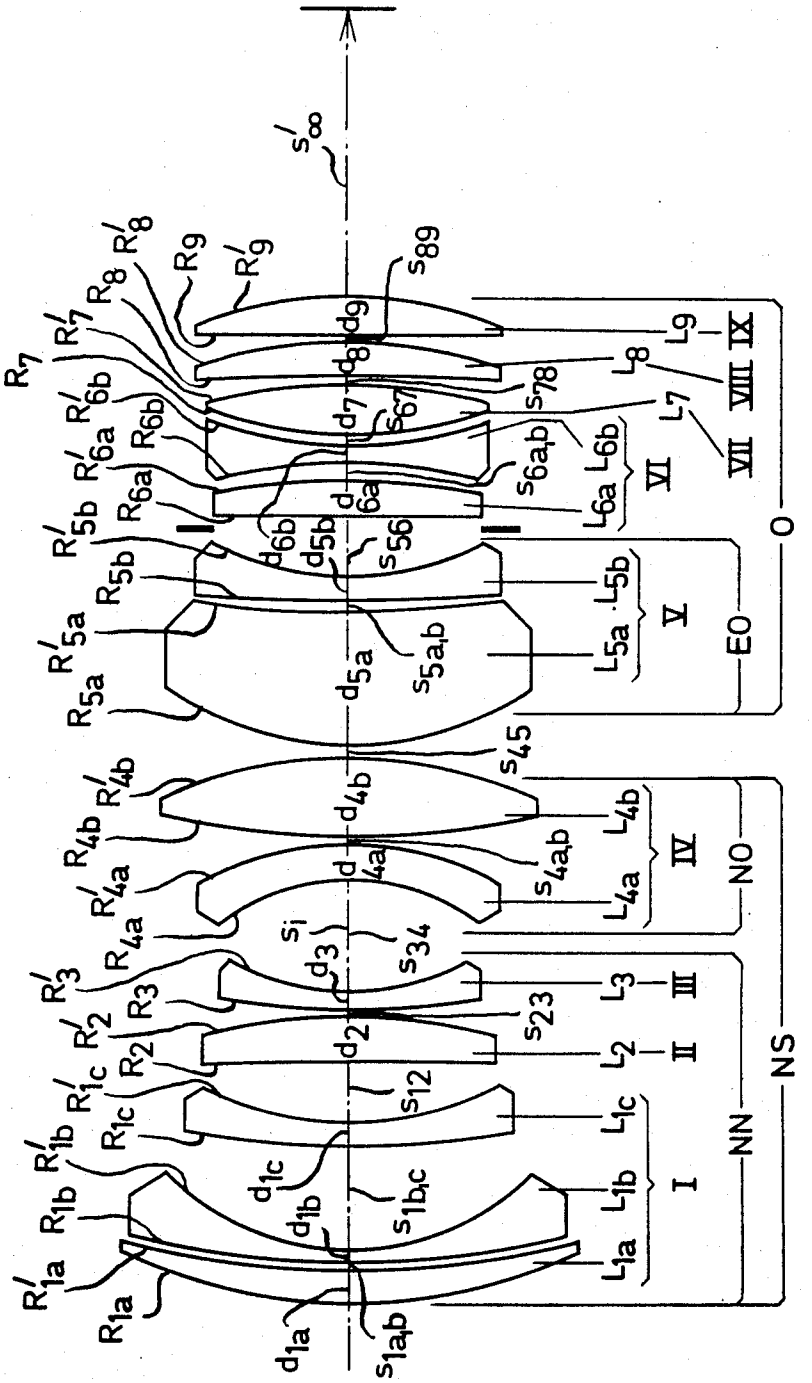
L1
IX
VIII
VII
VI
V
IV
III
II
I
O
EO
NO
NN
NS

Fig.5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R'6a
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R'5b
R5a
R'5a
R4b
R'4b
R4a
R'4a
R3
R'3
R2
R'2
R1c
R'1c
R1b
R'1b
R1a
R'1a
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s78
s67
s6a,b
s56
s5a,b
s45
s4a,b
s34
s23
s12
s1b,c
s1a,b
d9
d8
d7
d6b
d6a
d5b
d5a
d4b
d4a
di
d3
d2
d1c
d1b
d1a
L9
L8
L7
L6b
L6a
L5b
L5a
L4b
L4a
L3
L2
L1c
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VIII
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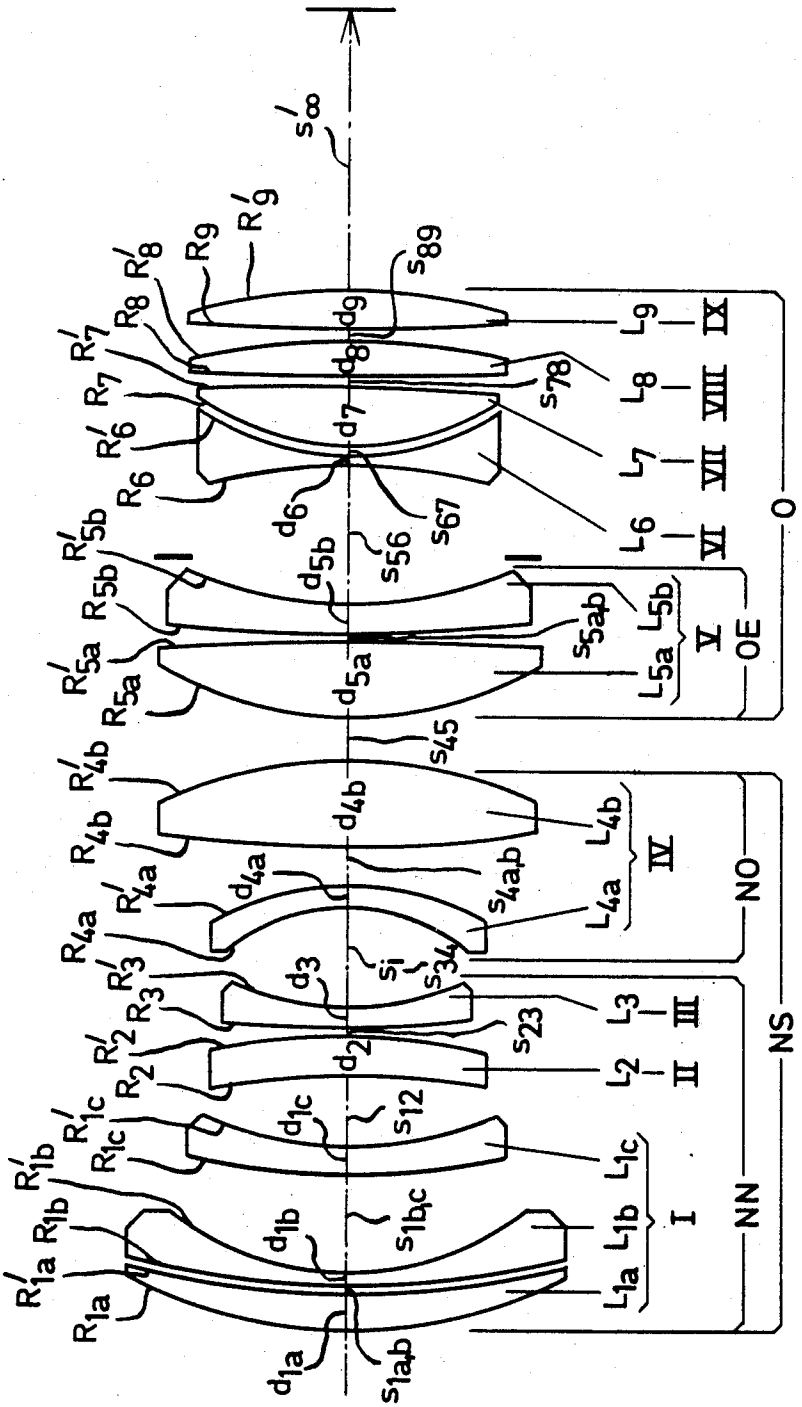
II
I
O
EO
NO
NN
NS

Fig.6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L9
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R6
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L7
VII
d6
s67
L6
VI
O
R'5b
R5b
s56
d5b
s5ab
L5b
L5a
V
OE
R'5a
R5a
d5a
s45
R'4b
R4b
d4b
L4b
IV
R'4a
R4a
d4a
s4ab
L4a
NO
R'3
R3
d3
si
s34
L3
III
R'2
R2
d2
s23
L2
II
R'1c
R1c
d1c
s12
L1c
R'1b
R1b
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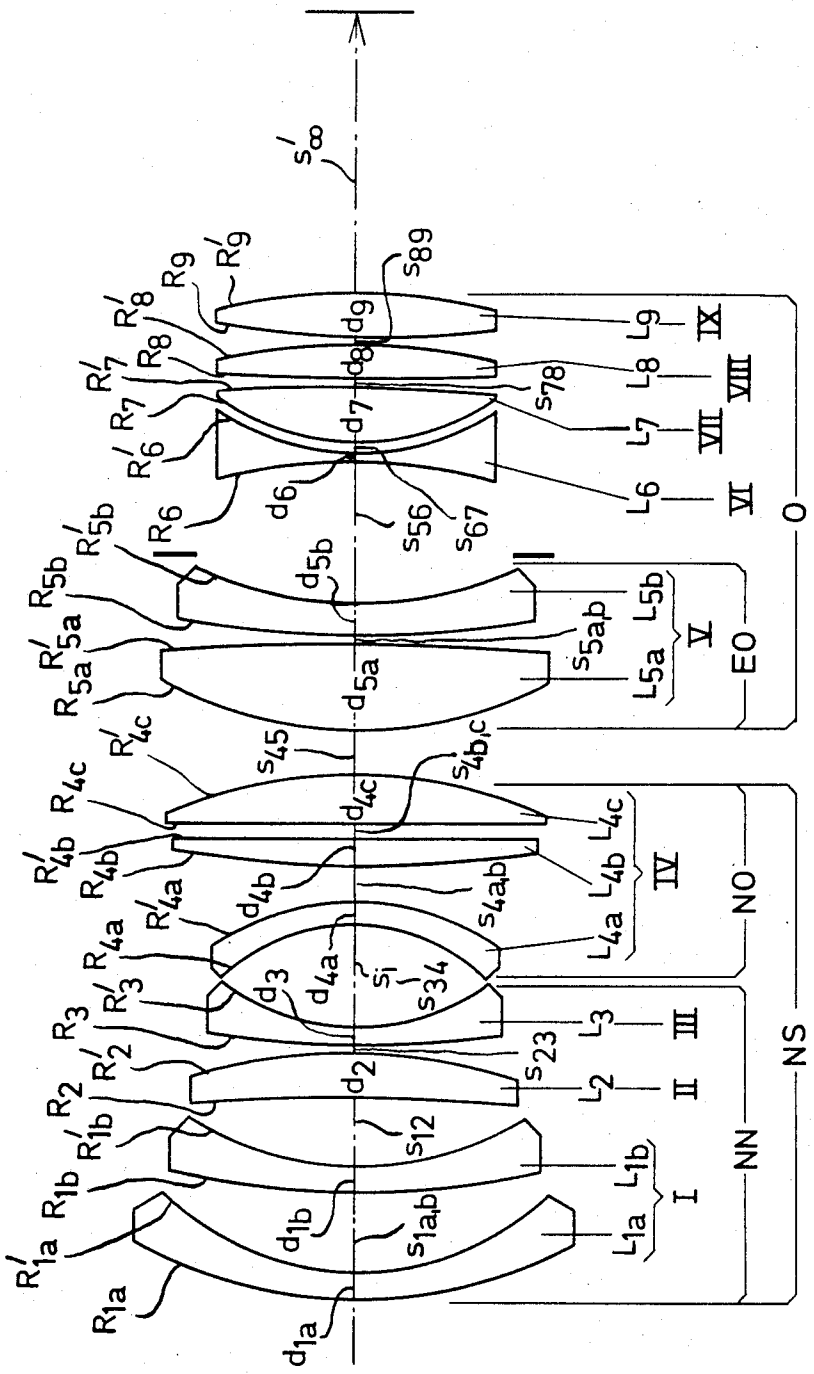
s1a1b

Fig.7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R'8 R8 d9 L9 IX
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R'6 R6 s78 d7 L7 VII
d6 L6 VI
s56 s67
R'5b R5b d5b
R5b R'5a R5a d5a s5ab L5b L5a V EO O
R'4c R4c s45 s'4b,c d4c L4c
R'4b R4b d4b s4ab L4b IV NO
R'4a R4a d4a si s34 L4a
R'3 R3 d3 L3 III
R'2 R2 d2 s23 L2 II
R'1b R1b s12 L1b
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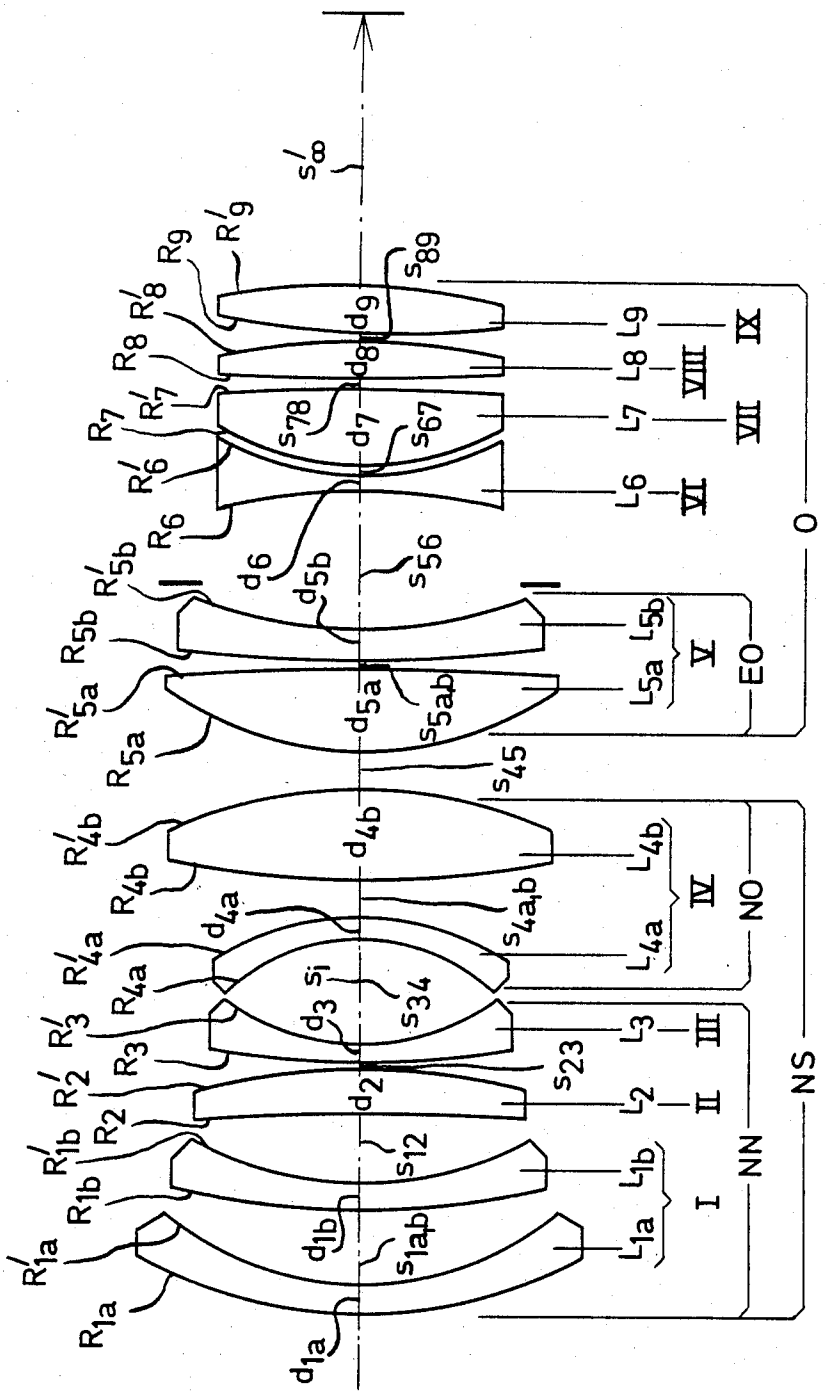
d1a

Fig.8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R'7
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L2
II
R'1b
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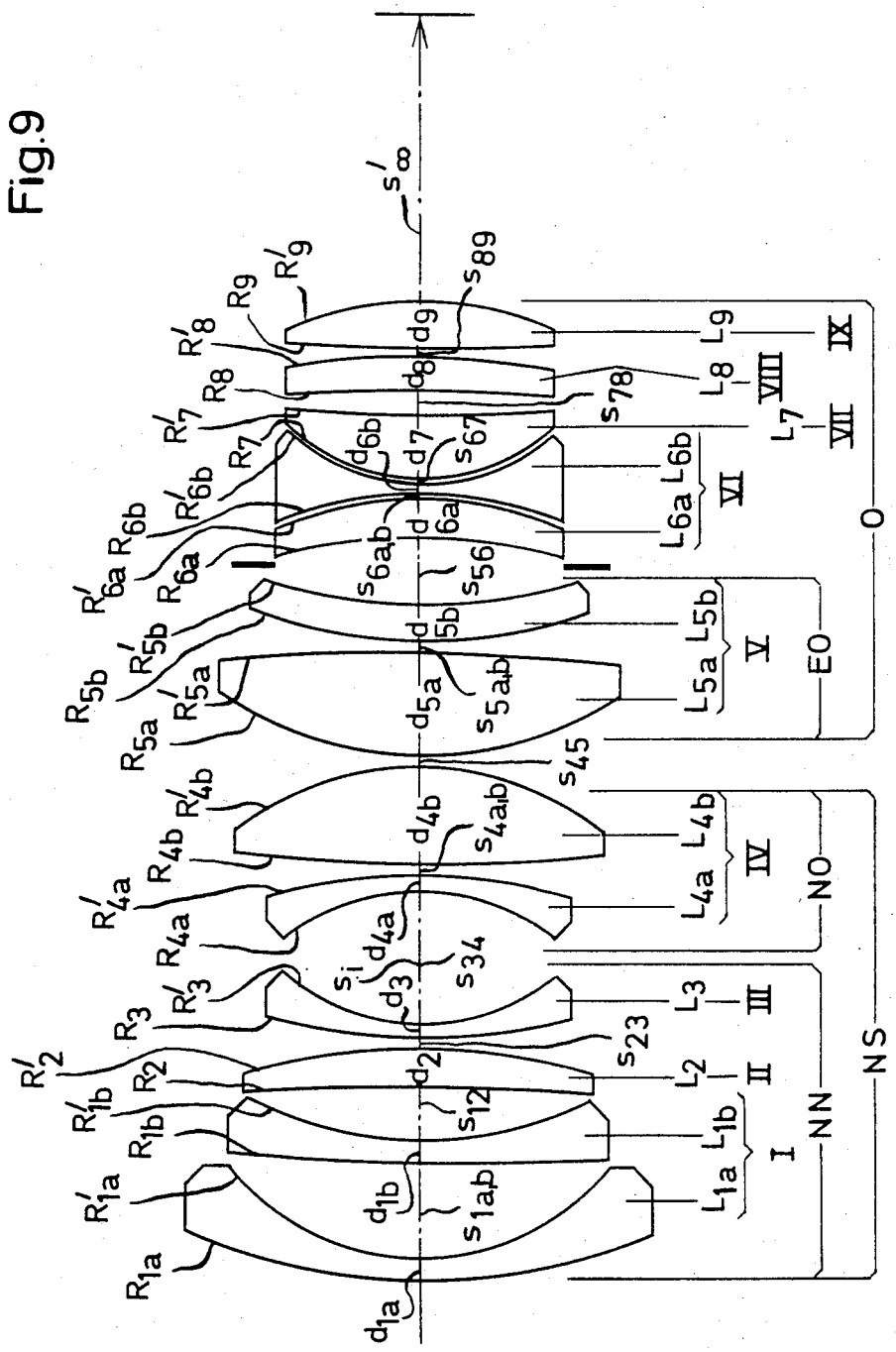
NS
d1a

Fig.9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d2
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d4a
d4b
d5a
d
5b
d6a
d6ab
d6b
d7
d8
d9
s12
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s23
s34
si
s45
s5ab
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L4b
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L6b
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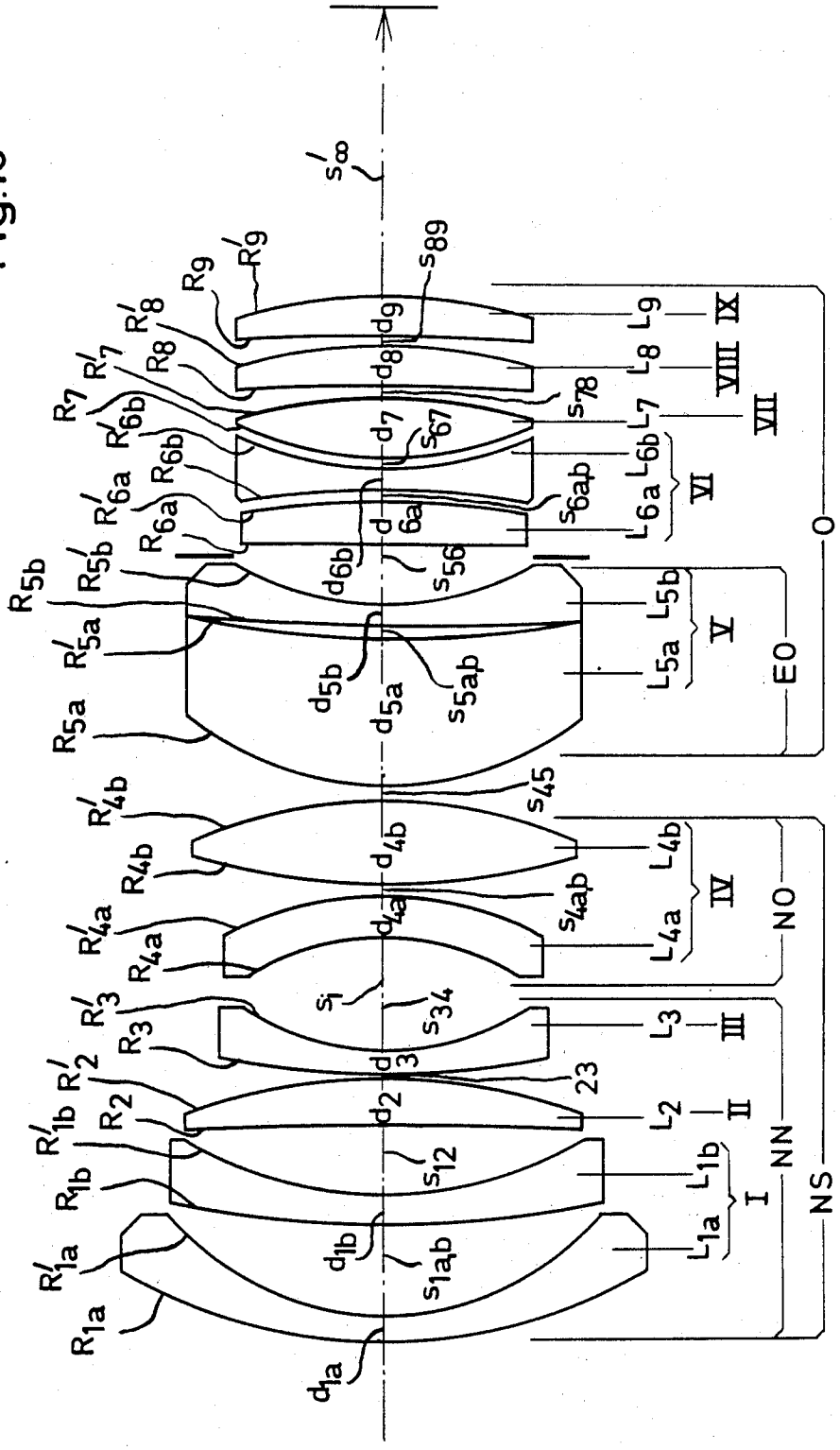
Fig.10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d7
s67
L7
VII
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R6b
L6b
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s6ab
L6a
VI
d6a
d6b
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R'5a
R5a
d5b
d5a
s5ab
L5a
V
EO
O
s45
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L4b
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d4a
L4a
IV
NO
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s34
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R3
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III
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23
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R2
d2
L2
II
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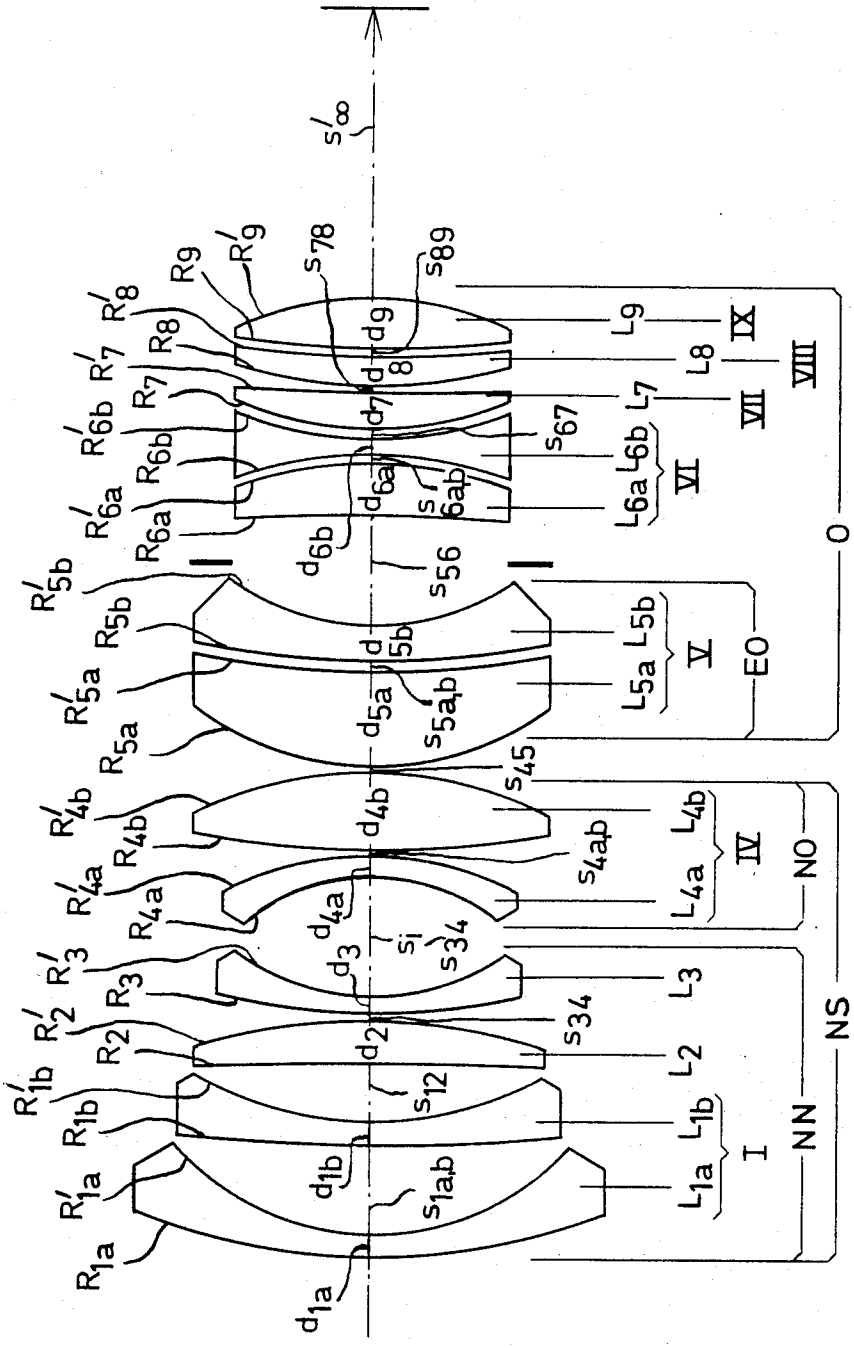
d1a

Fig.11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d4b
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d5a
s5ab
d
5b
s56
d6b
d6a
s6ab
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s67
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L6b
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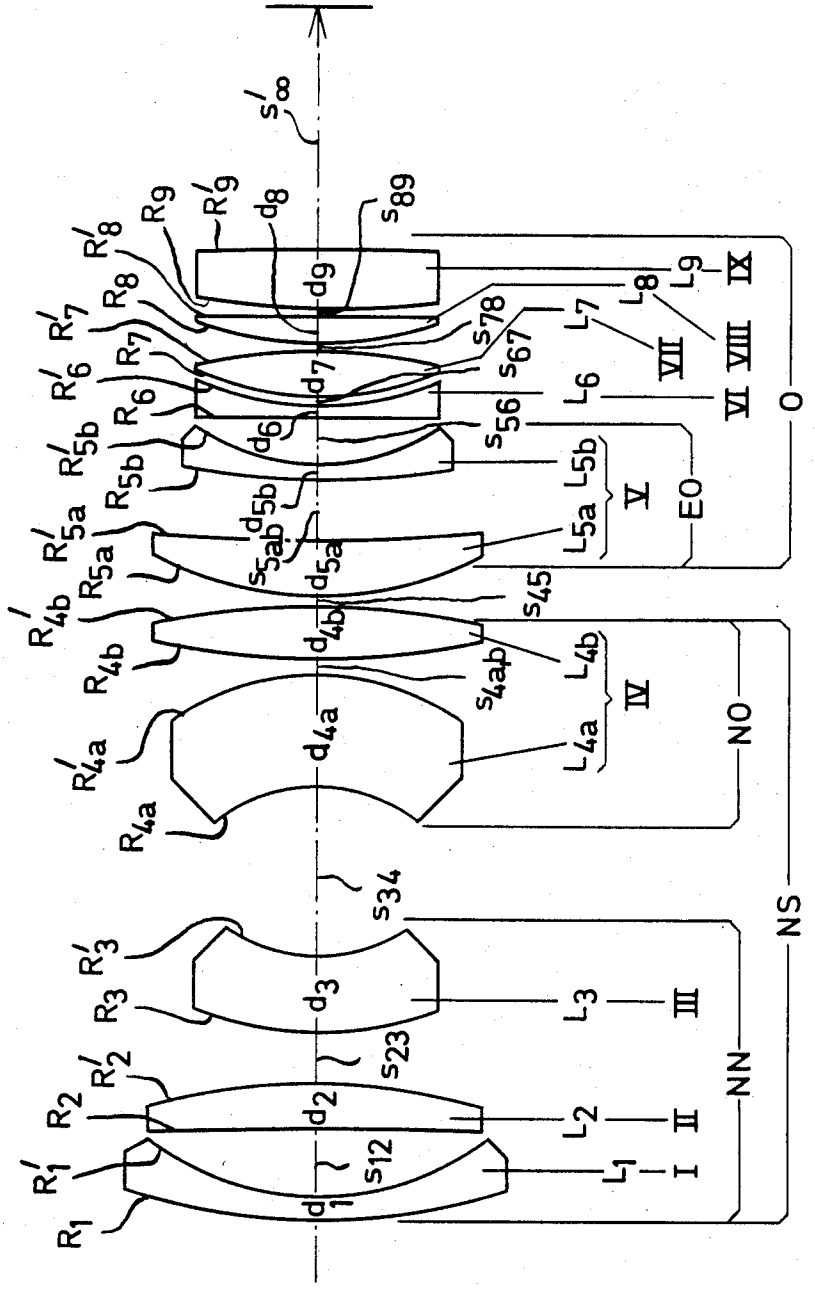
Fig.12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R8
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L9
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VIII
s67
VII
R'6
R6
d7
L6
VI
s56
O
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R5b
d6
L5b
R5a
d5b
L5a
V
EO
R'5a
s5ab
d5a
s45
R'4b
R4b
d4b
L4b
s4ab
IV
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R4a
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L4a
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d3
L3
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R1
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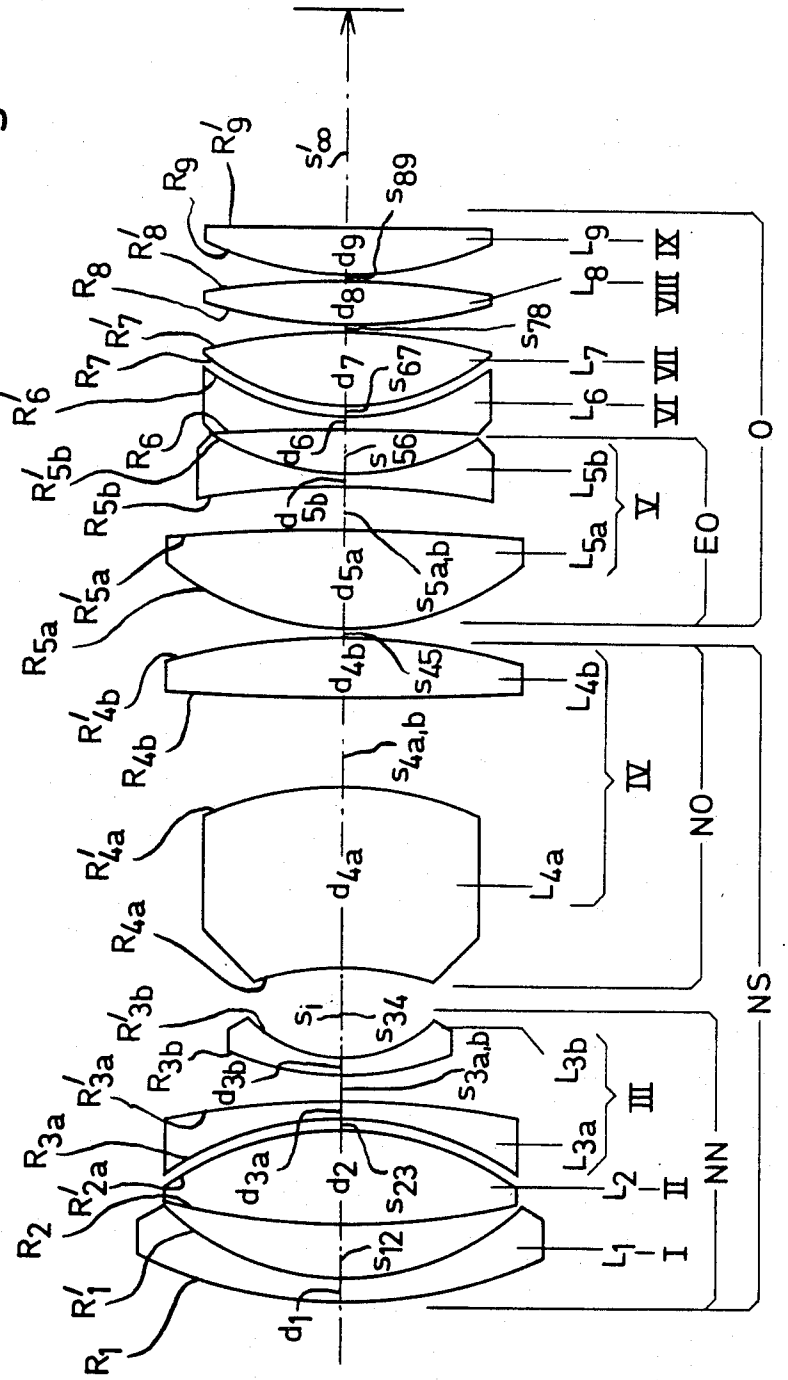
L1
I
NS

Fig.13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d7
s67
L7
L6
VII
VI
R'6
R6
d6
s56
R'5b
R5b
d5b
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V
O
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R5a
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s45
L4b
IV
NO
s4a,b
R'4a
R4a
d4a
L4a
NS
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R3a
d3b
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III
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R2
s12
L1
I
R'1
R1
d1

Fig. 14

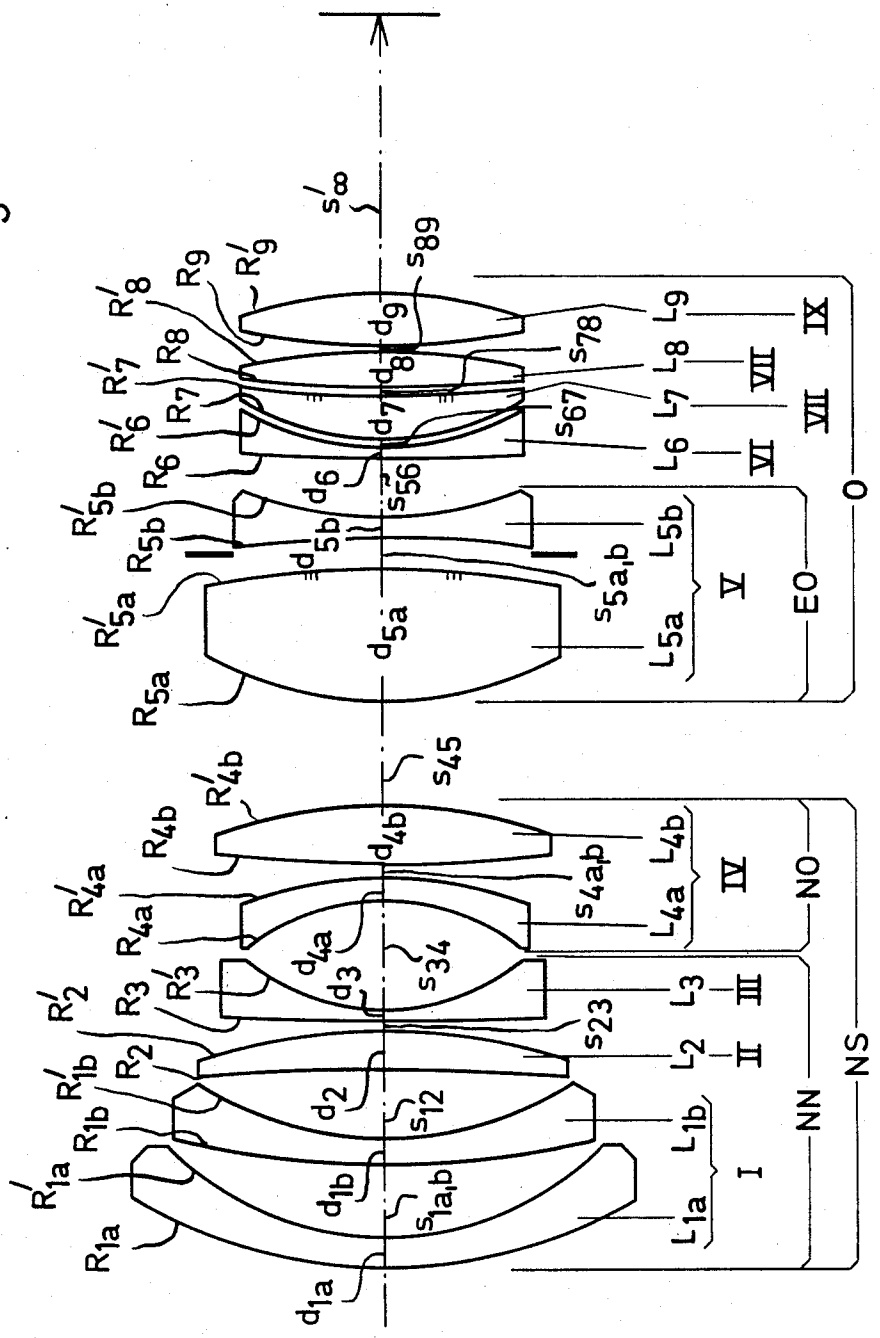
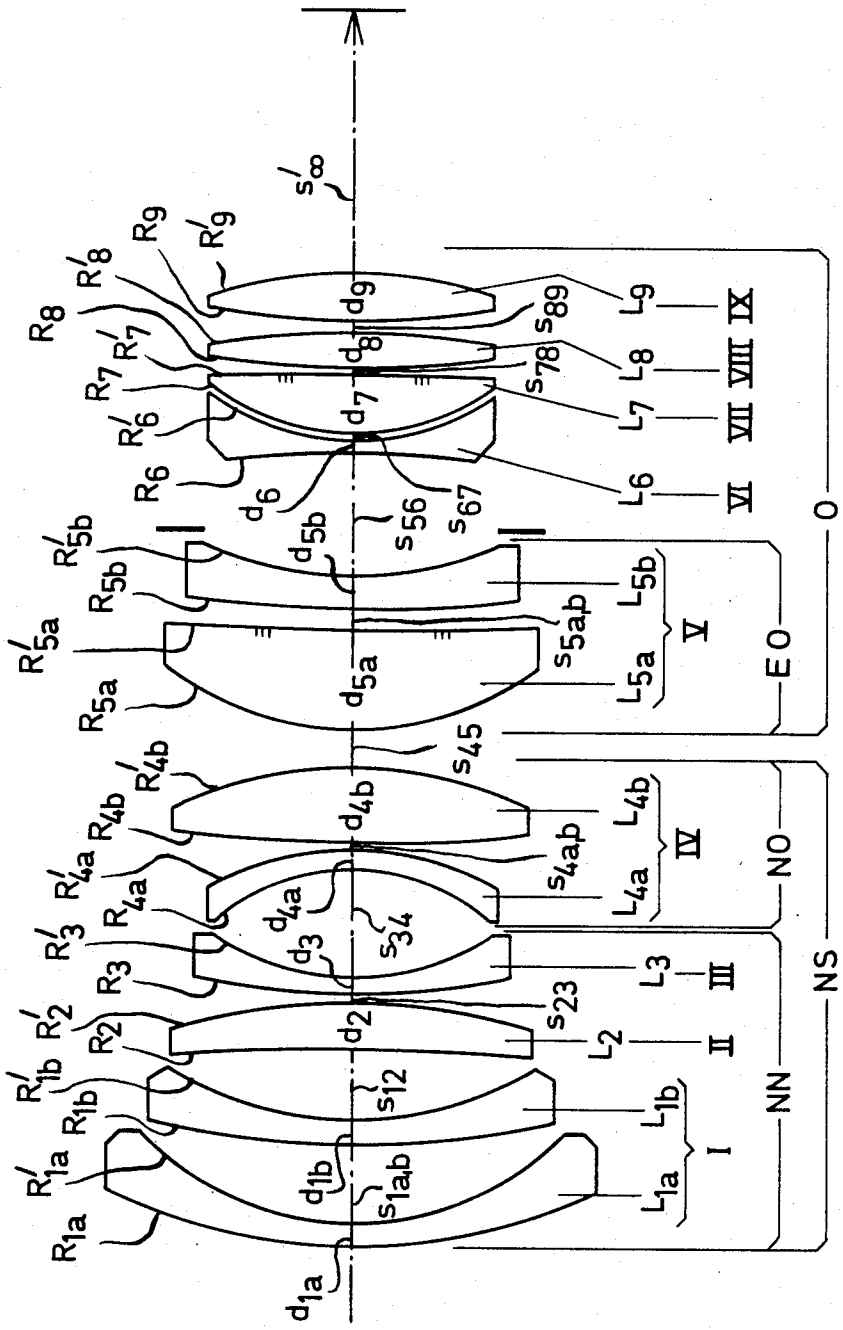

s'8
s89
R'9
R9
R'8
R8
R'7
R7
R'6
R6
R'5b
R5b
R'5a
R5a
d9
d8
d7
d6
d5b
d5a
s78
s67
s56
s5a,b
L9
L8
L7
L6
L5b
L5a
IX
VIII
VII
VI
V
O
EO
s45
R'4b
R4b
R'4a
R4a
R'3
R3
R'2
R2
R'1b
R1b
R'1a
R1a
d4b
d4a
d3
d2
d1b
d1a
s4a,b
s34
s23
s12
s1a,b
L4b
L4a
L3
L2
L1b
L1a
IV
III
II
I
NO
NN
NS

Fig. 15


s'∞
R9
R'9
R'8
R8
R7
R'7
R'6
R6
R'5b
R5b
R'5a
R5a
R'4b
R4b
R'4a
R4a
R'3
R3
R'2
R2
R'1b
R1b
R'1a
R1a
d1a
d1b
d2
d3
d4a
d4b
d5a
d5b
d6
d7
d8
d9
s12
s1a,b
s23
s34
s4a,b
s45
s5a,b
s56
s67
s78
s89
L1a
L1b
L2
L3
L4a
L4b
L5a
L5b
L6
L7
L8
L9
I
II
III
IV
V
VI
VII
VIII
IX
NN
NS
NO
EO
O

HIGH SPEED WIDE ANGLE OBJECTIVE LENS SYSTEM

BACKGROUND OF THE INVENTION

This invention relates to objectives such as used on cameras or other optical equipment, for forming a real image on photographic film or other suitable receiving surface. The object of the invention is to produce what may be regarded as a new species of extremely high speed wide angle objective, with relatively long back focus so that there is ample space for swinging a reflex mirror if it is desired to use the objective with a single lens reflex camera. A high quality image is produced, with a usable diameter of the entrance pupil which is greater than 0.73 times the equivalent focal length of the entire lens system.

Reference is made to German Pat. Nos. 1,187,393, published on 18, Feb. 1965, and 1,250,153, published on 14 Sept. 1967, both granted for inventions of Erhard Glatzel, one of the joint inventors of the present U.S. application. The present invention may be regarded as an improvement on the lenses disclosed in these German patents.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a lens diagram illustrating the general features of one embodiment of the present invention; and FIGS. 2–15 are similar lens diagrams illustrating other embodiments.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The objective lens system of the present invention (sometimes referred to herein, for brevity, merely as a "lens" or an "objective") may be described in general as a composite structure having a rear section or group or member similar in general to an ordinary conventional objective, these parts being collectively identified in the accompanying lens diagrams by the letter O. In front of this rear group or objective portion of the complete system, there is placed a plurality of components constituting, in effect, a Newtonian finder objective, designated as a whole in the lens diagrams by the letters NS. This Newtonian section NS, in turn, may be regarded as having two groups or members, a front group NN of diverging or negative optical power, and behind it a converging or positive ocular group NO.

The light from a distant object is front of the lens enters first the diverging group NN and passes through it, then entering and passing through the converging ocular group NO, and then enters the main objective group O in a bundle of rays approximately parallel to the optical axis, although possibly slightly diverging or slightly converging when the rays reach the first surface of the objective group O. In designing a lens of this special type with which the present invention deals, it is found that, especially when a lens of very high speed and wide angular field of view is desired, certain rules or conditions or limits of relationship of the parts to each other should be observed in order to obtain a high quality image free of troublesome aberrations. These conditions or limits, compliance with which is found to be highly desirable, may be briefly stated as follows:

1. The focal length of the diverging group NN at the front of the Newtonian finder telescope section is not less than 0.106 times and not more than 0.690 times the focal length of the converging ocular group NO of the Newtonian telescope section NS. This feature or condition gives assurance that, on account of the reducing effect of this relationship, the beam or rays entering the system from the distant object can, on account of the diverging action of this Newtonian or reverse Galilean telescope system, enter the main objective O with from 1.53 to 2.73 times the bundle heights and thus with from 2.3 to 7.45 times the bundle cross sectional areas entering from the object side. On the other hand, due to the limitation in downward direction of the reduction scale, there is no need to have excessively strong collecting refractive powers in the main objective group or member O which produces the real image, and which would lead to an increase in the aberrations of higher order both in the central field and in the lateral image field. This possible disadvantage can be successively eliminated when the relationship of the group NN to the group NO is within the limits just mentioned.

2. This diverging group NN has at least three components, one of which, at or near the front of this group, is a negative component having a rear surface bounded by air and concave toward the rear of the system, another of which is a positive component located behind the negative component just mentioned, and a third one of which is another negative component located behind the positive component and having a rear surface concave toward the rear and constituting the rearmost surface of this diverging group NN.

3. The converging ocular group NO should be spaced rearwardly from the diverging group NN sufficiently to provide between them an air lens of diverging action having a paraxial surface refractive power sum (ϕ_t) which has a negative numerical value not less than 0.948 times and not more than 1.808 times the equivalent refractive power (Φ) of the entire lens system.

4. In contrast to the conventional Newtonian telescopic finder system, which usually has only a single element ocular portion, the ocular group NO according to the present invention has a plurality of components spaced axially from each other to provide an air lens of collecting action followed by a positive components, such air lens acting to provide, for a middle bundle of rays, a strongly divergent ray path bent by the positive component to a ray path differing only slightly from a paraxial course, that is bent to a course which may be slightly divergent or slightly convergent, if not exactly parallel to the optical axis. Thus the lens designer operating in accordance with the teaching of the present invention is not forced to design the Newtonian system NS to produce a strictly telecentric course of the rays from the rear surface of the Newtonian system to the entrance of the objective group O, but it is entirely possible to design the part NS so that the rays enter the part O with a slight convergence or divergence, when this may be desirable for the sake of fine correction of the entire system. This freedom of choice to produce slight convergence or divergence at this point would result in only an insignificant dioptric effect on the fundamental properties of the main objective O and/or the back focus of the entire objective system.

5. The main objective group or portion O should have a paraxial intrinsic focal length (f_O) which is not less than 1.53 times and not more than 2.73 times the equivalent focal length (F) of the entire lens system. The importance of this design rule or condition will be understood when it is borne in mind that if the stated upper limit is exceeded, the difficulties in obtaining a

high relative aperture increased progressively in an undesirable manner, while if the lower limit is violated, this would read to an increase in the aberrations of higher order. These undesirable consequences are successfully eliminated by following the design rules or conditions above set forth, thereby giving the optical designer great freedom in the arrangement of many lens details, as may be readily noted by observing the details of the specific examples given below, and noting, in comparing one example with another, how many of these details can be varied.

The new lens system of the present invention can be provided in a particularly advantageous manner with one or two aspherically shaped lens surfaces, in order to carry out specific correction processes by means of the aspherical surfaces. Thus the possibility is established of maintaining a large number of the individual lens elements free of specifically these partial effects of the correction process, as for instance for utilization of the reduction of aberrations of a higher order. It will be noted from some of the examples that the aspherical surfaces can be introduced with great advantage not only in the main objective assembly or group (O) which produces the real image, but also, in a manner both effective and surprising, in the Newtonian system assembly (NS).

It may be mentioned here that when considering the various limits or ranges of variable factors as mentioned above, it is customary to allow a tolerance of less or minus 5%.

The various examples of the following tables illustrate that many of the components can be formed either as single individual lens elements, or as doublets or other split components formed of a plurality of individual lens elements. Frequently, but not necessarily, the neighboring radii of curvature are made the same both in size and in sign, so that they may be cemented if desired. It may be pointed out in this connection that the lens diagrams which illustrate various embodiments of the invention are to be regarded as "exploded" view, with adjacent lens surfaces slightly separated from each other for the sake of clarity of illustration, even though in the data tables it may be indicated that there is zero spacing, denoting a cemented surface.

In the data tables, all linear measurements such as radii, thicknesses, and spacings are not given as absolute dimensions, but rather are stated as proportions of the equivalent focal length (F) of the entire objective lens system, which is considered as unity. That is, F = 1.00000. The individual lens elements are indicated by the letter L with a subscript corresponding to the number of the individual lens element as numbered consecutively from front to rear, except that in some instances two or more related lens elements are given the same numerical subscript followed by a letter of the alphabet to distinguish one from another.

The notations or symbols used in the data tables and also in the lens diagrams are in accordance with the notations and symbols often used in many lens patents, and will be well understood by those skilled in the art. For instance, the radii of curvature of the front surface and the rear surface of each element are indicated by R and R', respectively, with a subscript indicating the number of that particular element. Positive values of R or R' indicates surfaces convex toward the front of the lens, and negative values indicates surfaces concave toward the front, in accordance with customary usage. The end of the lens toward the distant object or longer conjugate is referred to for convenience as the front, and the end toward the image (that is, toward the camera, if the lens system is used on a photographic camera) is referred to for convenience as the rear of the lens. The light is assumed, in accordance with conventional lens patent practice, to enter from the front, and to pass through the lens from left to right.

The axial thicknesses of individual lens elements are indicated in the tables by the letter d with a subscript identifying the particular element. Axial spacings between elements are indicated by the letter s likewise with a subscript, but in the case of these spacings, the subscript refers to the identifying number of the lens in front of and the lens behind the space is question. Zero spacing indicates elements cemented to each other. All spacings greater than zero refer to air spacings. The lens elements or groups of elements which may be regarded or submembers are indicated by Roman numerals.

The index of refraction is indicated by n with a subscript identifying the lens element, in some of the tables. In other tables, the indices of refraction are given in a column headed n_d for the sake of compactness when the data also include the Abbe number or dispersive index, stated in an adjacent column headed v_d. When an objective is designed for use in only a very narrow spectral range, the refractive index refers specifically to this narrow range. If the lens system is to be used over a wide spectral range, as for example in color photography, then instead of monochromatic image error correction, achromatism should be brought out over the wider spectral range required. For this purpose, in known manner, the glasses used in the elements are to be chosen so that the color dispersion of the glasses used serves to eliminate the chromatic deviations or errors due to the wavelengths which enter into consideration.

During the course of development of this invention it was found, by way of confirmation, that upon the development of the so-called preforms or initial forms of the objectives, and then during the course of the following technical rough development to produce a rough form in known manner with the first correction normally customary in the Seidel range (third order), the use of one of the standard refractive indices can take place in a routine manner. A convenient index to use for this purpose is the index of refraction for the yellow d-line of the helium spectrum, with a wavelength of 5876 Angstrom units. Data for this wavelength are customarily shown in many commercial catalogues of manufacturers of optical glasses.

In the heading of each data table there is indicated the figure number of the particular lens diagram which is intended to illustrate the specific example in the table. In this connection it should be borne in mind that the lens diagrams are not intended to be drawn strictly to scale, but are intended merely to furnish a quick visual indication of the general characteristics of the particular specific example. Thus a single lens diagrams is sufficient to illustrate two or more specific examples which are of the same general configuration but which may differ somewhat from each other in thicknesses, spacings, curvatures, or other factors.

The specific example tables also indicate, in each case, the relative aperture for which the particular example is intended, expressed as a conventional f number, and the angular field of view, expressed in degrees, and the back focus from the axial vertex of the

last lens element to the focal plane (for an object at infinity) expressed in proportion to the equivalent focal length (F) of the entire objective lens system. The heading of each table also indicates the diameter of the entrance pupil, expressed in proportion to the equivalent focal length (F) of the entire system, and the refractive power of the entire Newtonian finder telescope system NS expressed in proportion to the refractive power (ϕ) of the entire object lens system as a whole.

The first five examples relate to embodiments of the invention which are developed with only spherical surfaces. Then, in examples 6–15, data are given for ten additional embodiments of extremely high image-forming ability, which are provided with aspherical surfaces. As already indicated, the lens system of the present invention is particularly suitable and advantageous for introduction of aspherical surfaces to provide a very high quality of image.

In these examples, the possible breaking down of lens components by splitting into a plurality of individual elements is shown both by the data in the tables, and pictorially in the lens diagrams, both for the negative group NN and for the ocular group NO of the Newtonian finder telescope NS. Possible splitting of components within the main objective part O which forms the real image, is also indicated both pictorially and by the data in the tables.

A few comments on some of the specific examples will be given, before turning to the actual data tables themselves. In example 1 (illustrated by the diagram in FIG. 1). there is given a compilation of data for a preform of a lens system according to the invention, intended for a relative aperture of f/1.35 and a total field angle of 52°, in which the Newtonian finder telescope (NS) is constructed in the simplest fashion from a three part Newtonian negative or diverging group (NN) and a two part Newtonian ocular (NO), the entire objective being provided with a monochromatic precorrection in the Seidel range of third order.

Example 2 (FIG. 2) shows an embodiment in which the Newtonian occular (NO) has a total of three individual elements, in which a doublet of diverging action which is concave toward the front is split into two individual elements of opposite sign of power. This is followed by a biconvex lens element. In order to illustrate the wide possibilities of development opened up by the new principle of design, this biconvex lens element is shown as an equal sided or equiconvex lens, constituting the last element of the Newtonian finder telescope (NS) at the rear end thereof. This embodiment of the invention is contemplated for an angular field of view of 53° and a relative aperture of $f/1.33$ and a corresponding entrance pupil diameter of 0.752 F. It is monochromatically precorrected in the region of the third order. The back focus, for an object at infinity, is somewhat greater than 1.40 F, thus allowing room for installing this lens system in mirror reflex cameras currently on the market.

In contrast to this, the structure in example 3 (illustrated in FIG. 3) has the collecting component of the Newtonian ocular (NO) split into two individual lens elements with refractive power of the same sign, so that the lens designer working in accordance therewith is shown, based on these data, this specific development within the scope of the present invention. This practical example is intended for a total field angle of 60° and an entrance pupil diameter of 0.769° F, corresponding to a relative aperture of f/1.30. It is monochromatically precorrected in the third order Seidel range, since there is here concerned an extremely high speed lens system for the recording of substantially monochromatic signals which lie within a very narrow spectral range.

The same is also true of all those examples which give only the refractive indices of the glasses without mention of the Abbe numbers or dispersive indices. On the other hand, examples 4 and 5 are embodiments designed for forming an image of multi-color objects within the visible spectrum, and accordingly the types of glasses used are characterized by giving both the refractive indices and the Abbe numbers, which assure achromatization over the required broad spectral range of visible light.

The same method is also taken as a basis for the following examples, which are equipped with aspherical surfaces for further correction of aberrations and enhancement of image quality. In examples 6 and 13, only one aspherical surface has been introduced into the system. In examples 7–12 as well as examples 14 and 15, two aspherical surfaces are provided in each example.

In order to prove the broad scope of use which is opened up so successfully for practical use by the new principle of design and its concrete rules of technical action, it is shown by way of demonstration in the following data tables that such aspherical surfaces can be arranged either in the Newtonian finder telescope portion or section (NS) of the system, or in the main objective portion or section (O) which produces the real image, or in both of such sections. Likewise, aspherical surfaces can be used either in the entrance part (EO) of the main objective (O), or in the rear portion of this main objective (O), or in both.

The aspherical development of a deformed surface is determined by the known camber expression:

$$P = c_1.H^3 + c_2.H^4 + c_3.H^8 + c_4.H^8 + c_5.H^{10},$$

wherein H is the height of the perpendicular to the axis at its specific place of surface penetration. The values of the coefficients c for each individual example including an aspherical surface are given at the end of the appropriate data table. It is also shown by the data that two or more neighboring surfaces can be combined to form pairs of cemented surfaces in the main objective part (O).

It should be emphasized that the previously mentioned characteristic enlargement (V_{NS}) as known applies strictly to the region of Gaussian dioptrics only when the paraxial rays from the Newtonian finder telescope (NS) and therefore also from the Newtonian ocular (NO) emerge "telecentrally," and thus have an infinitely long image distance at this place. In practice, as in certain telescopes or Galilean glasses, the course of such rays will frequently not be precisely telecentric, but will emerge from the telescope system with a back focus which is numerically very long. It is known to the optical designer to use the reciprocal of such an accidentally occurring very long back focus with reversed sign of the power for the arithmetical compensation for the determination of the strict paraxial enlargement (V_{NS}) in the same way as is customary in the case of a practical telescope system, to bring about the precise telecentric ray path on the side of the eye of the observer, simply by accurate focusing adjustment of the ocular. The corresponding above treatment of the ar-

ithmetical determination of the strict value of the paraxial enlargement of the finder telescope part is also indicated for the new objectives of the present invention, whenever no ocular adjustment is provided between the diverging objective (NN) and the collecting ocular (NO) and the internal spacing distance between them (s_i) is thus constant.

In the case of objective lens systems for installation, for example, in motion picture cameras, these fast objectives of the present invention may be given relatively extremely long structural length, for additional reduction of aberrations of higher order. Furthermore it may be desirable to provide these objectives with a very long back focus, for example in order to facilitate the mechanical arrangement of fixed or movable deflection elements between the last lens element and the image plane. Examples 16–20 indicate that, in accordance with the present invention, it is possible to produce such systems with entrance pupil diameters which can be increased to more than 0.95 times the equivalent focal length (F) of the entire objective.

Example 1 (FIG. 1)
F = 1.00000 f/1.34 $2\omega_o = 52°$ $s'_\infty = +1.4095$ F
Diameter of entrance pupil = 0.746 F $\Phi_{NS} = +0.0537\ \Phi$

Lens	Radii	Thicknesses and spacings	N		
I L_1	$R_1 = +3.3100$	$d_1 = 0.14600$	$n_1 = 1.639$		
	$R'_1 = +1.6700$	$s_{12} = 0.34600$			
II L_2	$R_2 = +40.000$	$d_2 = 0.23700$	$n_2 = 1.673$	NN	
	$R'_2 = -4.5350$	$s_{23} = 0.20140$			
III L_3	$R_3 = +1.9710$	$d_3 = 0.53380$	$n_3 = 1.744$		NS
	$R'_3 = +0.7735$	$s_i = s_{34} = 0.83250$			
IV L_{4a}	$R_{4a} = -0.9192$	$d_{4a} = 0.61260$	$n_{4a} = 1.623$		
	$R'_{4a} = -1.35568$	$s_{4a,b} = 0.06850$		NO	
IV L_{4b}	$R_{4b} = +4.0000$	$d_{4b} = 0.26642$	$n_{4b} = 1.623$		
	$R'_{4b} = -4.0000$	$s_{45} = 0.00638$			
V L_{5a}	$R_{5a} = +1.7310$	$d_{5a} = 0.25246$	$n_{5a} = 1.658$		
	$R'_{5a} = +5.42638$	$s_{5a,b} = 0.33569$		EO	
V L_{5b}	$R_{5b} = +\ 2.3605$	$d_{5b} = 0.14605$	$n_{5b} = 1.785$		
	$R'_{5b} = +1.1830$	$s_{56} = 0.21823$			
VI L_6	$R_6 = +11.5687$	$d_6 = 0.09232$	$n_6 = 1.805$		
	$R'_6 = +1.4258$	$s_{67} = 0$			O
VII L_7	$R_7 = +1.4258$	$d_7 = 0.30382$	$n_7 = 1.488$		
	$R'_7 = -3.06946$	$s_{78} = 0.00336$			
VIII L_8	$R_8 = +1.8595$	$d_8 = 0.19465$	$n_8 = 1.658$		
	$R'_8 = -12.0749$	$s_{89} = 0.00336$			
IX L_9	$R_9 = +4.10615$	$d_9 = 0.16280$	$n_9 = 1.623$		
	$R'_9 = +47.4162$				

Example 2 (FIG. 2)
F = 1.00000 f/1.33 $2\omega_o = 52°$ $s'_\infty = +1.4095$ F
Diameter of entrance pupil = 0.752 F $\Phi_{NS} = +0.0537\ \Phi$

Lens	Radii	Thicknesses and spacings	N	
I L_1	$R_1 = +3.31000$	$d_1 = 0.14600$	$n_1 = 1.6390$	
	$R'_1 = +1.67000$	$s_{12} = 0.34600$		
II L_2	$R_2 = +40.0000$	$d_2 = 0.23700$	$n_2 = 1.6730$	NN
	$R'_2 = -4.53500$			

-continued

Example 2 (FIG. 2)
F = 1.00000 f/1.33 $2\omega_a = 52°$ $s'_\infty = +1.4095$ F
Diameter of entrance pupil = 0.752 F $\Phi_{NS} = +0.0537$ Φ

Lens	Radii	Thicknesses and spacings	N		
		$s_{23} = 0.20140$			
III L_3	$R_3 = +1.97100$	$d_3 = 0.53380$	$n_3 = 1.7440$		
	$R'_3 = +0.77350$	$s_f = s_{34} = 0.83250$			NS
IV L_{4a}	$R_{4a} = -0.91920$	$d_{4a} = 0.16230$	$n_{4a} = 1.6230$		
	$R'_{4a} = +10.2000$	$s_{4a,b} = 0.0685003$			
L_{4b}	$R_{4b} = +9.38050$	$d_{4b} = 0.334851$	$n_{4b} = 1.6204$	NO	
	$R'_{4b} = -1.3728209$	$s_{4b,c} = 0.0685002$			
L_{4c}	$R_{4c} = +4.00000$	$d_{4c} = 0.26642$	$n_{4c} = 1.6230$		
	$R'_{4c} = -4.00000$	$s_{45} = 0.006380$			
V L_{5a}	$R_{5a} = +1.73100$	$d_{5a} = 0.25246$	$n_{5a} = 1.6580$		
	$R'_{5a} = +5.42638$	$s_{5a,b} = 0.33569$		EO	
L_{5b}	$R_{5b} = +2.36050$	$d_{5b} = 0.14605$	$n_{5b} = 1.7850$		
	$R'_{5b} = +1.18300$	$s_{56} = 0.21823$			
VI L_6	$R_6 = +11.56870$	$d_6 = 0.09232$	$n_6 = 1.8050$		
	$R'_6 = +1.42580$	$s_{67} = 0$			O
VII L_7	$R_7 = +1.42580$	$d_7 = 0.30382$	$n_7 = 1.4880$		
	$R'_7 = -3.06946$	$s_{78} = 0.00336$			
VIII L_8	$R_8 = +1.85950$	$d_8 = 0.19465$	$n_8 = 1.6580$		
	$R'_8 = -12.07490$	$s_{89} = 0.00336$			
IX L_9	$R_9 = +4.10615$	$d_9 = 0.16280$	$n_9 = 1.6230$		
	$R'_9 = -47.4162$				

Example 3 (FIG. 3)
F = 1.00000 f/1.33 $2\omega_a = 61°$ $s'_\infty = +1.5959$ F
Diameter of entrance pupil = 0.752 F $\Phi_{NS} = 0$ (telezentr.)

Lens	Radii	Thicknesses and spacings	N		
I L_1	$R_1 = +3.25586$	$d_1 = 0.139391$	$n_1 = 1.62299$		
	$R'_1 = +1.69156$	$s_{12} = 0.412113$			
II L_2	$R_2 = +5.78979$	$d_2 = 0.343428$	$n_2 = 1.64250$	NN	
	$R'_2 = -5.87383$	$s_{33} = 0.460597$			
III L_3	$R_3 = +1.99604$	$d_3 = 0.056565$	$n_3 = 1.74400$		
	$R'_3 = +0.80039$	$s_f = s_{34} = 0.569686$			NS
IV L_{4a}	$R_{4a} = -1.25941$	$d_{4a} = 0.428275$	$n_{4a} = 1.62004$		
	$R'_{4a} = -1.92550$	$s_{4a,b} = 0.149492$			
L_{4b}	$R_{4b} = +3.78696$	$d_{4b} = 0.164250$	$n_{4b} = 1.64250$	NO	
	$R'_{4b} = \text{plan}$	$s_{4b,c} = 0.010000$			
L_{4c}	$R_{4c} = +4.050827$	$d_{4c} = 0.178470$	$n_{4c} = 1.78470$		
	$R'_{4c} = \text{plan}$	$s_{45} = 0.020000$			

-continued

Example 3 (FIG. 3)
F = 1.00000 f/1.33 $2\omega_e = 61°$ $s'_m = +1.5959$ F
Diameter of entrance pupil = 0.752 F $\Phi_{NS} = 0$ (telezentr.)

Lens	Radii	Thicknesses and spacings	N		
V L_{5a}	$R_{5a} = +4.183696$	$d_{5a} = 0.624055$	$n_{5a} = 1.78600$		
	$R'_{5a} = -4.183696$	$s_{5a,b} = 0.267900$		EO	
L_{5b}	$R_{5b} = -4.050827$	$d_{5b} = 0.080000$	$n_{5b} = 1.80518$		
	$R'_{5b} = +1.500270$	CS = $s_{56} = 0.249073$			
VI L_6	$R_6 = -8.417200$	$d_6 = 0.0646458$	$n_6 = 1.78470$		
	$R'_6 = +1.16357$	$s_{67} = 0$			O
VII L_7	$R_7 = +1.16357$	$d_7 = 0.410093$	$n_7 = 1.71300$		
	$R'_7 = -2.47696$	$s_{78} = 0.004040$			
VIII L_8	$R_8 = +3.84187$	$d_8 = 0.191916$	$n_8 = 1.64250$		
	$R'_8 = -3.95403$	$s_{89} = 0.004040$			
IX L_9	$R_9 = +1.96752$	$d_9 = 0.212117$	$n_9 = 1.56384$		
	$R'_9 = -7.94652$				

Example 4 (FIG. 1)
F = 1.00000 f/1.29 $2\omega_e = 53.5°$ $s'_m = +1.4095$ F
Diameter of entrance pupil = 0.775 F $\Phi_{NS} = +0.102023$ Φ

Lens	Radii	Thicknesses and spacings	n_d/ν_d		Bez.
I L_1	$R_1 = +3.30888$	$d_1 = 0.146023$	1.63854/55.38		
	$R'_1 = +1.67033$	$s_{12} = 0.345755$			
II L_2	$R_2 = +39.89615$	$d_2 = 0.236994$	1.67270/32.20	NN	
	$R'_2 = -4.54148$	$s_{23} = 0.201411$			
III L_3	$R_3 = +1.97097$	$d_3 = 0.533739$	1.74400/44.77		
	$R'_3 = +0.77345$	$s_i = s_{34} = 0.832498$			NS
IV L_{4a}	$R_{4a} = -0.91924$	$d_{4a} = 0.612625$	1.62299/58.06		
	$R'_{4a} = -1.35576$	$s_{4a,b} = 0.068815$		NO	
L_{4b}	$R_{4b} = +3.82110$	$d_{4b} = 0.281975$	1.62299/58.06		
	$R'_{4b} = -3.60727$	$s_{45} = 0.003357$			
V L_{5a}	$R_{5a} = +1.73153$	$d_{5a} = 0.238336$	1.65844/50.88		
	$R'_{5a} = +4.47636$	$s_{5a,b} = 0.335685$		EO	
L_{5b}	$R_{5b} = +2.35943$	$d_{5b} = 0.146023$	1.78470/26.08		
	$R'_{5b} = +1.18252$	CS = $s_{56} = 0.218195$			
VI L_6	$R_6 = +11.57274$	$d_6 = 0.092313$	1.80518/25.43		
	$R'_6 = +1.42579$	$s_{67} = 0$		O	
VII L_7	$R_7 = +1.42579$	$d_7 = 0.302116$	1.48749/70.45		
	$R'_7 = -3.05708$	$s_{78} = 0.003357$			
VIII L_8	$R_8 = +1.86073$	$d_8 = 0.194697$	1.65844/50.88		
	$R'_8 = -12.08331$	$s_{89} = 0.003357$			

-continued

Example 4 (FIG. 1)
F = 1.00000 f/1.29 $2\omega_o = 53.5°$ $s'_o = +1.4095$ F
Diameter of entrance pupil = 0.775 F $\Phi_{NS} = +0.102023\ \Phi$

Lens	Radii	Thicknesses and spacings	n_d/ν_d	Bez.
IX L_9	$R_9 = +4.10610$ $R'_9 = -47.41549$	$d_9 = 0.162807$	1.62299/58.06	

Example 5 (FIG. 4)
F = 1.00000 f/1.3 $2\omega_o = 61.5°$ $s'_o = +1.59591$ F
Diameter of entrance pupil = 0.769 F $\Phi_{NS} = -0.3467\ \Phi$

Lens	Radii	Thicknesses and spacings	n_d/ν_d		Bez.
I L_1	$R_1 = +3.25586$ $R'_1 = +1.69156$	$d_1 = 0.139391$ $s_{12} = 0.412113$	1.62299/58.06		
II L_2	$R_2 = +5.78979$ $R'_2 = -5.87383$	$d_2 = 0.343428$ $s_{23} = 0.460597$	1.64250/57.94	NN	
III L_3	$R_3 = +1.99604$ $R'_3 = +0.80039$	$d_3 = 0.056565$ $s_i = s_{34} = 0.569686$	1.74400/44.77		NS
IV L_{4a}	$R_{4a} = -1.25941$ $R'_{4a} = -1.92550$	$d_{4a} = 0.428275$ $s_{4a,b} = 0.149492$	1.62004/36.37	NO	
IV L_{4b}	$R_{4b} = +3.78696$ $R'_{4b} = +117.1978$	$d_{4b} = 0.175754$ $s_{45} = 0.218178$	1.64250/57.94		
V L_{5a}	$R_{5a} = +1.70381$ $R'_{5a} = -9.44427$	$d_{5a} = 0.298984$ $s_{5a,b} = 0.391104$	1.78470/26.08	EO	
V L_{5b}	$R_{5b} = -4.56597$ $R'_{5b} = +1.47541$	$d_{5b} = 0.076766$ $CS = s_{56} = 0.183835$	1.80518/25.43		
VI L_6	$R_6 = -8.41722$ $R'_6 = +1.16357$	$d_6 = 0.064645$ $s_{67} = 0$	1.78470/26.08		O
VII L_7	$R_7 = +1.16357$ $R'_7 = -2.47696$	$d_7 = 0.410093$ $s_{78} = 0.004040$	1.71300/53.85		
VIII L_8	$R_8 = +3.84187$ $R'_8 = -3.95403$	$d_8 = 0.191916$ $s_{89} = 0.004040$	1.64250/57.94		
IX L_9	$R_9 = +1.96752$ $R'_9 = -7.94652$	$d_9 = 0.212117$	1.56384/60.82		

Example 6 (FIG. 5)
F = 1.00000 f/1.37 $2\omega_o = 70°$ $s'_o = +1.37816$
Diameter of entrance pupil = 0.730 F $\Phi_{NS} = +0.1190\ \Phi$

Lens	Radii	Thicknesses and spacings	N
I L_{1a}	$R_{1a} = +2.600$ $R'_{1a} = +4.220$	$d_{1a} = 0.162$ $s_{1a,b} = 0.030$	$n_{1a} = 1.620$
I L_{1b}	$R_{1b} = +4.220$ $R'_{1b} = +1.305$	$d_{1b} = 0.078$	$n_{1b} = 1.630$

-continued

Example 6 (FIG. 5)

$F = 1.00000$ f/1.37 $2\omega_o = 70°$ $s'_m = +1.37816$
Diameter of entrance pupil = 0.730 F $\Phi_{NS} = +0.1190\ \Phi$

	Lens	Radii	Thicknesses and spacings	N		
			$s_{1b,c} = 0.499$			
	L_{1c}	$R_{1c} = +6.200$	$d_{1c} = 0.090$	$n_{1c} = 1.620$	NN	
		$R'_{1c} = +1.630$	$s_{12} = 0.294$			
II	L_2	$R_2 = -36.01$	$d_2 = 0.232$	$n_2 = 1.670$		NS
		$R'_2 = -2.790$	$s_{23} = 0.003$			
III	L_3	$R_3 = +3.760$	$d_3 = 0.0908$	$n_3 = 1.713$		
		$R'_3 = +1.180$	$s_f = s_{34} = 0.534$			
IV	L_{4a}	$R_{4a} = -1.110$	$d_{4a} = 0.186$	$n_{4a} = 1.740$		
		$R'_{4a} = -1.490$	$s_{4a,b} = 0.010$		NO	
	L_{4b}	$R_{4b} = +4.220$	$d_{4b} = 0.411$	$n_{4b} = 1.730$		
		$R'_{4b} = -2.030$	$s_{45} = 0.013$			
V	L_{5a}	$R_{5a} = +1.437$	$d_{5a} = 0.667$	$n_{5a} = 1.744$		
		$R'_{5a} = +4.917$	$s_{5a,b} = 0.052$		EO	
	L_{5b}	$R_{5b} = +12.55$	$d_{5b} = 0.105$	$n_{5b} = 1.756$		
		$R'_{5b} = +1.342$	$CS = s_{56} = 0.320$			
VI	L_{6a}	$R_{6a} = \pm$plan	$d_{6a} = 0.157$	$n_{6a} = 1.548$		
		$R'_{6a} = -3.119$	$s_{6a,b} = 0.079$			
	L_{6b}	$R_{6b} = -2.837$	$d_{6b} = 0.075$	$n_{6b} = 1.805$		O
		$R'_{6b} = +1.691$	$s_{67} = 0$			
VII	L_7	$R_7 = +1.691$	$d_7 = 0.320$	$n_7 = 1.510$		
		$R'_7 = -2.068$	$s_{78} = 0.004$			
VIII	L_8	$R_8 = -21.43$	$d_8 = 0.172$	$n_8 = 1.713$		
		$R'_8 = -2.470$	$s_{89} = 0.004$			
IX	L_9	$R_9 = -29.95$	$d_9 = 0.175$	$n_9 = 1.713$		
		$R'_9 = -1.932329$				

Aspherical surface R_{6a} with: $c_1 = c_4 = c_5 = 0$, $c_2 = -1.984\ 1448 \cdot 10^{-1}$, $c_3 = -2.189\ 7588 \cdot 10^{-2}$.

Example 7 (FIG. 6)

$F = 1.00000$ f/1.35 $2\omega_o = 61°$ $s'_m = +1.38483$ F
Diameter of entrance pupil = 0.741 F $\Phi_{NS} = +0.0297\ \Phi$

	Lens	Radii	Thickness and spacings	N		
I	L_{1a}	$R_{1a} = +2.3500$	$d_{1a} = 0.900$	$n_{1a} = 1.620$		
		$R'_{1a} = +8.4100$	$s_{1a,b} = 0.0100$			
	L_{1b}	$R_{1b} = +8.4100$	$d_{1b} = 0.0500$	$n_{1b} = 1.625$		
		$R'_{1b} = +1.4000$	$s_{1b,c} = 0.3613$			
	L_{1c}	$R_{1c} = +4.2100$	$d_{1c} = 0.0800$	$n_{1c} = 1.625$	NN	
		$R'_{1c} = +1.7800$	$s_{12} = 0.3205$			
II	L_2	$R_2 = -8.4100$	$d_2 = 0.2109$	$n_2 = 1.670$		
		$R'_2 = -2.8100$	$s_{23} = 0.0197$			NS

-continued

Example 7 (FIG. 6)
F = 1.00000 f/1.35 $2\omega_o = 61°$ $s'_m = +1.38483$ F
Diameter of entrance pupil = 0.741 F $\Phi_{NS} = +0.0297\ \Phi$

	Lens	Radii	Thickness and spacings	N		
III	L_3	$R_3 = +5.8900$	$d_3 = 0.0880$	$n_3 = 1.713$		
		$R'_3 = +1.1080$	$s_f = s_{34} = 0.4850$			
IV	L_{4a}	$R_{4a} = -0.9906$	$d_{4a} = 0.1189$	$n_{4a} = 1.662$		
		$R'_{4a} = -1.2803$	$s_{4a,b} = 0.1647$		NO	
	L_{4b}	$R_{4b} = +4.8876$	$d_{4b} = 0.4167$	$n_{4b} = 1.788$		
		$R'_{4b} = -2.2904$	$s_{45} = 0.2058$			
0						
V	L_{5a}	$R_{5a} = +1.8900$	$d_{5a} = 0.3710$	$n_{5a} = 1.744$		
		$R'_{5a} = -13.203$	$s_{5a,b} = 0.0097$		EO	
	L_{5b}	$R_{5b} = +5.6822$	$d_{5b} = 0.1554$	$n_{5b} = 1.794$		
		$R'_{5b} = +2.1055$	$CS = s_{56} = 0.6609$			
VI	L_6	$R_6 = -3.1200$	$d_6 = 0.0650$	$n_6 = 1.805$		
		$R'_6 = +1.1784$	$s_{67} = 0$			O
VII	L_7	$R_7 = +1.1784$	$d_7 = 0.3148$	$n_7 = 1.510$		
		$R'_7 = -6.0511$	$s_{78} = 0.0044$			
VIII	L_8	$R_8 = +10.250$	$d_8 = 0.1697$	$n_8 = 1.721$		
		$R'_8 = -3.4884$	$s_{89} = 0.0044$			
IX	L_9	$R_9 = +5.1200$	$d_9 = 0.1960$	$n_9 = 1.787$		
		$R'_9 = -2.543163$				

Aspherical surfaces: R_{4b} with $c_1 = (2 \cdot R_{4b})^{-1}$, $c_2 = -1.390\ 4948 \cdot 10^{-2}$, $c_3 = -1.532\ 5255 \cdot 10^{-3}$, $c_4 = c_5 = 0$
R_9 with $c_1 = (2 \cdot R_9)^{-1}$, $c_2 = -4.405\ 4084 \cdot 10^{-2}$, $c_3 = c_4 = c_5 = 0$.

Example 8 (FIG. 7)
F = 1.00000 f/1.33 $2\omega_o = 62°$ $s'_m = +1.38445$ F
Diameter of entrance pupil = 0.752 F $\Phi_{NS} = +0.0300\ \Phi$

	Lens	Radii	Thicknesses and spacings	N		
I	L_{1a}	$R_{1a} = +2.3360$	$d_{1a} = 0.1309$	$n_{1a} = 1.623$		
		$R'_{1a} = +1.4320$	$s_{1a,b} = 0.3686$			
	L_{1b}	$R_{1b} = +4.2120$	$d_{1b} = 0.1366$	$n_{1b} = 1.624$		
		$R'_{1b} = +1.7280$	$s_{12} = 0.3222$		NN	
II	L_2	$R_2 = -9.3050$	$d_2 = 0.2140$	$n_2 = 1.641$		
		$R'_2 = -2.8230$	$s_{23} = 0.0196$			
III	L_3	$R_3 = +5.8930$	$d_3 = 0.0878$	$n_3 = 1.713$		
		$R'_3 = +1.1080$	$s_f = s_{34} = 0.4851$			NS
IV	L_{4a}	$R_{4a} = -0.9890$	$d_{4a} = 0.1188$	$n_{4a} = 1.661$		
		$R'_{4a} = -1.2780$	$s_{4a,b} = 0.1647$			
	L_{4b}	$R_{4b} = +4.8870$	$d_{4b} = 0.1160$	$n_{4b} = 1.788$	NO	
		$R'_{4b} = \pm$plan	$s_{4b,c} = 0.06819$			
	L_{4c}	$R_{4c} = \pm$plan	$d_{4c} = 0.1788$	$n_{4c} = 1.788$		
		$R'_{4c} = -2.2900$	$s_{45} = 0.18821$			

-continued

Example 8 (FIG. 7)

F = 1.00000 f/1.33. $2\omega_a = 62°$ $s'_a = +1.38445$ F
Diameter of entrance pupil = 0.752 F $\Phi_{NS} = +0.0300\ \Phi$

Lens	Radii	Thicknesses and spacings	N		
V L_{5a}	$R_{5a} = +1.8900$	$d_{5a} = 0.3710$	$n_{5a} = 1.744$		
	$R'_{5a} = -13.200$	$s_{5a,b} = 0.0096$		EO	
L_{5b}	$R_{5b} = +5.6820$	$d_{5b} = 0.1554$	$n_{5b} = 1.795$		
	$R'_{5b} = +2.1050$	$CS = s_{56} = 0.6610$			
VI L_6	$R_6 = -3.1210$	$d_6 = 0.0648$	$n_6 = 1.805$		
	$R'_6 = +1.1790$	$s_{67} = 0$			O
VII L_7	$R_7 = +1.1790$	$d_7 = 0.3147$	$n_7 = 1.510$		
	$R'_7 = -6.0500$	$s_{78} = 0.0044$			
VIII L_8	$R_8 = +9.3050$	$d_8 = 0.1500$	$n_8 = 1.720$		
	$R'_8 = -3.6060$	$s_{89} = 0.0052$			
IX L_9	$R_9 = +5.12012$	$d_9 = 0.1960$	$n_9 = 1.788$		
	$R'_9 = -2.54700$				

Aspherical surfaces: R_{5b} with $c_1 = (2 \cdot R_{5b})^{-1}$, $c_2 = -1.390\ 4948 \cdot 10^{-2}$, $c_3 = -1.532\ 5255 \cdot 10^{-3}$, $c_4 = c_5 = 0$
R_9 with $c_1 = (2 \cdot R_9)^{-1}$, $c_2 = -4.405\ 4084 \cdot 10^{-2}$, $c_3 = c_4 = c_5 = 0$.

Example 9 (FIG. 8)

F = 1.00000 f/1.30 $2\omega_a = 62°$ $s'_a = +1.38442$ F
Diameter of entrance pupil = 0.769 F $\Phi_{NS} = 0$ (telezent.)

Lens	Radii	Thicknesses and spacings	N		
I L_{1a}	$R_{1a} = +2.3250$	$d_{1a} = 0.1300$	$n_{1a} = 1.620$		
	$R'_{1a} = +1.4200$	$s_{1a,b} = 0.3685$			
L_{1b}	$R_{1b} = +4.2000$	$d_{1b} = 0.1367$	$n_{1b} = 1.625$		
	$R'_{1b} = +1.8000$	$s_{12} = 0.3322$		NN	
II L_2	$R_2 = -8.0000$	$d_2 = 0.2140$	$n_2 = 1.670$		
	$R'_2 = -3.0000$	$s_{23} = 0.0200$			NS
III L_3	$R_3 = +6.0000$	$d_3 = 0.0880$	$n_3 = 1.713$		
	$R'_3 = +1.1080$	$s_1 = s_{34} = 0.4781$			
IV L_{4a}	$R_{4a} = -1.0000$	$d_{4a} = 0.1200$	$n_{4a} = 1.670$		
	$R'_{4a} = -1.3000$	$s_{4a,b} = 0.1650$		NO	
L_{4b}	$R_{4b} = +4.5000$	$d_{4b} = 0.4113$	$n_{4b} = 1.788$		
	$R'_{4b} = -2.4290$	$s_{45} = 0.2060$			
V L_{5a}	$R_{5a} = +1.8300$	$d_{5a} = 0.3833$	$n_{5a} = 1.744$		
	$R'_{5a} = -13.150$	$s_{5a,b} = 0.0100$		EO	
L_{5b}	$R_{5b} = +5.6800$	$d_{5b} = 0.1550$	$n_{5b} = 1.795$		
	$R'_{5b} = +2.1070$	$CS = s_{56} = 0.6610$			
VI L_6	$R_6 = -3.1200$	$d_6 = 0.0620$	$n_6 = 1.805$		
	$R'_6 = +1.3000$	$s_{67} = 0$			O
VII L_7	$R_7 = +1.3000$	$d_7 = 0.4247$	$n_7 = 1.520$		

-continued

Example 9 (FIG. 8)

$F = 1.00000$ f/1.30 $2\omega_e = 62°$ $s'_m = +1.38442$ F
Diameter of entrance pupil = 0.769 F $\Phi_{NS} = 0$ (telezent.)

Lens	Radii	Thicknesses and spacings	N
	$R'_7 = -9.6900$	$s_{78} = 0.0044$	
VIII L_8	$R_8 = +9.6900$	$d_8 = 0.1695$	$n_8 = 1.720$
	$R'_8 = -3.5500$	$s_{89} = 0.0040$	
IX L_9	$R_9 = +5.1200$	$d_9 = 0.19597$	$n_9 = 1.788$
	$R'_9 = -2.5472$		

Aspherical surfaces: R_{4b} with $c_1 = (2 \cdot R_{4b})^{-1}$, $c_2 = -1.390\ 4948 \cdot 10^{-2}$, $c_3 = -1.532\ 5255 \cdot 10^{-3}$, $c_4 = c_5 = 0$
R_9 with $c_1 = (2 \cdot R_9)^{-1}$, $c_2 = -4.405\ 4084 \cdot 10^{-2}$, $c_3 = c_4 = c_5 = O$.

Example 10 (FIG. 14)

$F = 1.00000$ f/1.27 $2\omega_e = 63°$ $s'_m = +1.37988$ F
Diameter of entrance pupil = 0.787 F $\Phi_{NS} = -0.0599\ \Phi$

Lens	Radii	Thicknesses and spacings	N		
I L_{1a}	$R_{1a} = +2.47176$	$d_{1a} = 0.130780$	$n_{1a} = 1.62299$		
	$R'_{1a} = +1.43597$	$s_{1a,b} = 0.379206$			
L_{1b}	$R_{1b} = +5.06090$	$d_{1b} = 0.119586$	$n_{1b} = 1.57376$		
	$R'_{1b} = +1.67312$	$s_{12} = 0.327155$		NN	
II L_2	$R_2 = -12.2972$	$d_2 = 0.204174$	$n_2 = 1.68628$		
	$R'_2 = -2.65889$	$s_{23} = 0.006045$			NS
III L_3	$R_3 = +19.9265$	$d_3 = 0.079438$	$n_3 = 1.48787$		
	$R'_3 = +1.03249$	$s_1 = s_{34} = 0.513494$			
IV L_{4a}	$R_{4a} = -1.06224$	$d_{4a} = 0.143429$	$n_{4a} = 1.66526$		
	$R'_{4a} = -1.51053$	$s_{4a,b} = 0.006604$		NO	
L_{4b}	$R_{4b} = +4.80894$	$d_{4b} = 0.310924$	$n_{4b} = 1.75862$		
	$R'_{4b} = -2.33692$	$s_{45} = 0.486479$			
V L_{5a}	$R_{5a} = +1.78534$	$d_{5a} = 0.632408$	$n_{5a} = 1.74400$		
	$R'_{5a} = -4.53844$	$s_{5a,b} = 0.140780$		EO	
L_{5b}	$R_{5b} = -5.04251$	$d_{5b} = 0.104960$	$n_{5b} = 1.80975$		
	$R'_{5b} = +1.92364$	$CS = s_{5a} = 0.278537$			
VI L_6	$R_6 = +19.36343$	$d_6 = 0.075558$	$n_6 = 1.80518$		
	$R'_6 = +1.31773$	$s_{67} = 0$			O
VII L_7	$R_7 = +1.31773$	$d_7 = 0.208427$	$n_7 = 1.51009$		
	$R'_7 = +7.64015$	$s_{78} = 0.018470$			
VIII L_8	$R_8 = +6.67422$	$d_8 = 0.165331$	$n_8 = 1.71300$		
	$R'_8 = -3.70201$	$s_{89} = 0.004403$			
IX L_9	$R_9 = +4.36936$	$d_9 = 0.216561$	$n_9 = 1.78581$		
	$R'_9 = -2.11985$				

Aspherical surfaces: R'_{5a} with $c_1 = (2 \cdot R'_{5a})^{-1}$, $c_2 = +3.155\ 8520 \cdot 10^{-2}$, $c_3 = -1.093\ 4658 \cdot 10^{-2}$, $c_4 = c_5 = 0$,
R'_7 with $c_1 = (2 \cdot R'_7)^{-1}$, $c_2 = +7.743\ 2718 \cdot 10^{-2}$, $c_3 = c_4 = c_5 = 0$.

Example 11 (FIG. 15)
F = 1.00000 f/1.27 $2\omega_0 = 71°$ $s'_m = +1.38267$ F
Diameter of entrance pupil = 0.787 F $\Phi_{NS} = -0.0905\ \Phi$

	Lens	Radii	Thicknesses and spacings	N		
I	L_{1a}	$R_{1a} = +2.74796$				
		$R'_{1a} = +1.38529$	$d_{1a} = 0.113696$	$n_{1a} = 1.62299$		
			$s_{1a,b} = 0.396517$			
	L_{1b}	$R_{1b} = 4.72779$				
		$R'_{1b} = +1.62153$	$d_{1b} = 0.113050$	$n_{1b} = 1.63282$		
			$s_{12} = 0.336512$		NN	
II	L_2	$R_2 = -9.76130$				
		$R'_2 = -2.55659$	$d_2 = 0.251728$	$n_2 = 1.70223$		
			$s_{23} = 0.003873$			NS
III	L_3	$R_3 = +5.24780$				
		$R'_3 = +1.14502$	$d_3 = 0.075885$	$n_3 = 1.59282$		
			$s_f = s_{34} = 0.496877$			
IV	L_{4a}	$R_{4a} = -1.08216$				
		$R'_{4a} = -1.64005$	$d_{4a} = 0.108446$	$n_{4a} = 1.73174$		
			$s_{4a,b} = 0.031053$		NO	
	L_{4b}	$R_{4b} = +8.23292$				
		$R'_{4b} = -1.87001$	$d_{4b} = 0.379461$	$n_{4b} = 1.75711$		
			$s_{45} = 0.176652$			
V	L_{5a}	$R_{5a} = +1.56677$				
		$R'_{5a} = +233.608$	$d_{5a} = 0.465503$	$n_{5a} = 1.74400$		
			$s_{5a,b} = 0.079057$		EO	
	L_{5b}	$R_{5b} = +6.15175$				
		$R'_{5b} = +1.70231$	$d_{5b} = 0.156555$	$n_{5b} = 1.71941$		
			$CS = s_{5a} = 0.596110$			
VI	L_6	$R_6 = -5.99853$				
		$R'_6 = +1.11299$	$d_6 = 0.089333$	$n_6 = 1.80518$		
			$s_{67} = 0$			O
VII	L_7	$R_7 = +1.11299$				
		$R'_7 = -27.8242$	$d_7 = 0.286056$	$n_7 = 1.51009$		
			$s_{78} = 0.003799$			
VIII	L_8	$R_8 = +5.38523$				
		$R'_8 = -3.54530$	$d_8 = 0.167282$	$n_8 = 1.71360$		
			$s_{89} = 0.003731$			
IX	L_9	$R_9 = +5.52585$				
		$R'_9 = -2.37677$	$d_9 = 0.189790$	$n_9 = 1.78730$		

Aspherical surfaces: R'_{5a} with $c_1 = (2 \cdot R'_{5a})^{-1}$, $c_2 = +2.816\ 6962 \cdot 10^{-2}$, $c_3 = -7.553\ 0319 \cdot 10^{-3}$, $c_4 = c_5 = 0$, R'_7 with $c_1 = (2 \cdot R'_7)^{-1}$, $c_2 = +6.553\ 3496 \cdot 10^{-2}$, $c_3 = c_4 = c_5 = 0$.

Example 12 (Fig. 9)
F = 1.00000 f/1.25 $2\omega_0 = 78°$ $s'_m = +1.37450$ F
Diameter of entrance pupil = 0.800 F $\Phi_{NS} = 0.2405\ \Phi$

	Lens	Radii	Thicknesses and spacings	N		
I	L_{1a}	$R_{1a} = +3.06439$				
		$R'_{1a} = +1.23750$	$d_{1a} = 0.102379$	$n_{1a} = 1.62299$		
			$s_{1a,b} = 0.440991$			
	L_{1b}	$R_{1b} = +10.38196$				
		$R'_{1b} = +2.10356$	$d_{1b} = 0.125732$	$n_{1b} = 1.66846$		
			$s_{12} = 0.262269$		NN	
II	L_2	$R_2 = -9.76062$				
		$R'_2 = -2.47073$	$d_2 = 0.201702$	$n_2 = 1.74555$		
			$s_{23} = 0.005522$			NS
III	L_3	$R_3 = +2.54629$				
		$R'_3 = +1.11281$	$d_3 = 0.084891$	$n_3 = 1.54834$		
			$s_f = s_{34} = 0.620145$			

-continued

Example 12 (Fig. 9)

F = 1.00000 f/1.25 $2\omega_o = 78°$ $s'_m = +1.37450$ F
Diameter of entrance pupil = 0.800 F $\Phi_{NS} = 0.2405\ \Phi$

	Lens	Radii	Thicknesses and spacings	N		
IV	L_{4a}	$R_{4a} = -1.18498$	$d_{4a} = 0.107960$	$n_{4a} = 1.65843$		
		$R'_{4a} = -2.07360$	$s_{4a,b} = 0.016611$		NO	
	L_{4b}	$R_{4b} = +7.38277$	$d_{4b} = 0.494227$	$n_{4b} = 1.45818$		
		$R'_{4b} = -1.49120$	$s_{45} = 0.003862$			
V	L_{5a}	$R_{5a} = +1.71860$	$d_{5a} = 0.524953$	$n_{5a} = 1.74400$		
		$R'_{5a} = -8.79790$	$s_{5a,b} = 0.042897 = s_{IN}$		EO	
	L_{5b}	$R_{5b} = +2.52240$	$d_{5b} = 0.164345$	$n_{5b} = 1.59810$		
		$R'_{5b} = +2.42654$	$CS = s_{56} = 0.345369$			
VI	L_{6a}	$R_{6a} = -2.26150$	$d_{6a} = 0.212701$	$n_{6a} = 1.62109$		
		$R'_{6a} = -1.87031$	$s_{6a,b} = 0$			
	L_{6b}	$R_{6b} = -1.87031$	$d_{6b} = 0.067369$	$n_{6b} = 1.80518$	O	
		$R'_{6b} = +0.99891$	$s_{67} = 0$			
VII	L_7	$R_7 = +0.99891$	$d_7 = 0.280335$	$n_7 = 1.62059$		
		$R'_7 = +7.52353$	$s_{78} = 0.141992$			
VIII	L_8	$R_8 = -12.94667$	$d_8 = 0.167916$	$n_8 = 1.74400$		
		$R'_8 = -3.21190$	$s_{89} = 0.015969$			
IX	L_9	$R_9 = +7.02160$	$d_9 = 0.239763$	$n_9 = 1.78742$		
		$R'_9 = -1.72219$				

Aspherical surfaces : R'_7 with $c_1 = (2 \cdot R'_7)^{-1}$, $c_2 = +1.137\ 5238 \cdot 10^{-1}$, $c_3 = -9.1802926 \cdot 10^{-2}$, $c_4 = c_5 = 0$,
R_8 with $c_1 = (2 \cdot R_8)^{-1}$, $c_2 = -4.471\ 3009 \cdot 10^{-2}$, $c_3 = -6.452\ 3482 \cdot 10^{-2}$, $c_4 = c_5 = 0$.

Example 13 (FIG. 10)

F = 1.00000 f/1.25 $2\omega_o = 78°$ $s'_m = +1.37760$ F
Diameter of entrance pupil = 0.800 F $\Phi_{NS} = -0.1180\ \Phi$

	Lens	Radii	Thicknesses and spacings	N		
I	L_{1a}	$R_{1a} = +2.59200$	$d_{1a} = 0.117052$	$n_{1a} = 1.62299$		
		$R'_{1a} = +1.32769$	$s_{1a,b} = 0.418691$			
	L_{1b}	$R_{1b} = +6.22602$	$d_{1b} = 0.117974$	$n_{1b} = 1.62354$		
		$R'_{1b} = +1.63444$	$s_{12} = 0.288116$		NN	
II	L_2	$R_2 = -36.16198$	$d_2 = 0.232183$	$n_2 = 1.66946$		
		$R'_2 = -2.78970$	$s_{23} = 0.004672$			NS
III	L_3	$R_3 = +3.77575$	$d_3 = 0.089881$	$n_3 = 1.71321$		
		$R'_3 = +1.17608$	$s_i = s_{34} = 0.531844$			
IV	L_{4a}	$R_{4a} = -1.11123$	$d_{4a} = 0.186795$	$n_{4a} = 1.73764$		
		$R'_{4a} = -1.49128$	$s_{4a,b} = 0.009011$		NO	
	L_{4b}	$R_{4b} = +4.21870$	$d_{4b} = 0.411960$	$n_{4b} = 1.73270$		
		$R'_{4b} = -2.04042$	$s_{45} = 0.013735$			
V	L_{5a}	$R_{5a} = +1.43571$	$d_{5a} = 0.667893$	$n_{5a} = 1.74400$		
		$R'_{5a} = +4.91662$	$s_{5a,b} = 0.051485 = s_{IN}$		EO	
	L_{5b}	$R_{5b} = +12.54440$	$d_{5b} = 0.104870$	$n_{5b} = 1.75644$		
		$R'_{5b} = +1.34195$	$CS = s_{56} = 0.322004$			
VI	L_{6a}	$R_{6a} = \pm$plan	$d_{6a} = 0.156762$	$n_{6a} = 1.54814$		
		$R'_{6a} = -3.11895$	$s_{6a,b} = 0.079336$			O
		$R_{6b} = -2.84169$				

-continued

Example 13 (FIG. 10)

F = 1.00000 f/1.25 $2\omega_o = 78°$ $s'_m = +1.37760$ F
Diameter of entrance pupil = 0.800 F $\Phi_{NS} = -0.1180\ \Phi$

Lens	Radii	Thicknesses and spacings	N
L_{6b}		$d_{6b} = 0.074429$	$n_{6b} = 1.80518$
	$R'_{6b} = +1.69106$		
		$s_{67} = 0$	
	$R_7 = +1.69106$		
VII L_7		$d_7 = 0.320337$	$n_7 = 1.51009$
	$R'_7 = -2.06825$		
		$s_{78} = 0.003780$	
	$R_8 = -21.43097$		
VIII L_8		$d_8 = 0.171855$	$n_8 = 1.71328$
	$R'_8 = -2.47440$		
		$s_{89} = 0.004522$	
	$R_9 = -30.57726$		
IX L_9		$d_9 = 0.176090$	$n_9 = 1.71368$
	$R'_9 = -1.93341$		

Aspherical surface R_{6a} with $c_1 = c_2 = c_3 = 0$, $c_4 = -1.984\ 1317 \cdot 10^{-1}$, $c_5 = -2.189\ 7347 \cdot 10^{-2}$

Example 14 (FIG. 8)

F = 1.00000 f/1.25 $2\omega_o = 74°$ $s'_m = +1.37634$ F
Diameter of entrance pupil = 0.800 F $\Phi_{NS} = -0.0105\ \Phi$

Lens	Radii	Thicknesses and spacings	n_d/ν_d	Bez.
	$R_{1a} = +3.47226$			
I L_{1a}		$d_{1a} = 0.110822$	1.62299/58.06	
	$R'_{1a} = +1.39191$			
		$s_{1a,b} = 0.386569$		
	$R_{1b} = +7.23358$			
I L_{1b}		$d_{1b} = 0.113060$	1.74400/44.77	
	$R'_{1b} = +1.74031$			
		$s_{12} = 0.314181$		NN
	$R_2 = -9.78625$			
II L_2		$d_2 = 0.201867$	1.80518/25.43	
	$R'_2 = -2.49382$			
		$s_{23} = 0.004851$		NS
	$R_3 = +2.08322$			
III L_3		$d_3 = 0.097762$	1.71300/53.85	
	$R'_3 = +1.14642$			
		$s_f = s_{34} = 0.667914$		
	$R_{4a} = -1.27713$			
IV L_{4a}		$d_{4a} = 0.117911$	1.72830/28.68	
	$R'_{4a} = -2.00964$			
		$s_{4a,b} = 0.009328$		NO
	$R_{4b} = +5.82914$			
IV L_{4b}		$d_{4b} = 0.554481$	1.57250/57.60	
	$R'_{4b} = -1.59620$			
		$s_{4b} = 0.005970$		
	$R_{5a} = +1.42266$			
V L_{5a}		$d_{5a} = 0.493286$	1.74400/44.77	
	$R'_{5a} = +26.75841$			
		$s_{5a,b} = 0.070896 = s_{IN}$		EO
	$R_{5b} = +2.94259$			
V L_{5b}		$d_{5b} = 0.107090$	1.75520/27.58	
	$R'_{5b} = +1.34296$			
		$CS = s_{56} = 0.531346$		
	$R_6 = -2.51162$			
VI L_6		$d_6 = 0.144031$	1.80518/25.43	
	$R'_6 = +1.16310$			
		$s_{67} = 0$		O
	$R_7 = +1.16310$			
VII L_7		$d_7 = 0.304106$	1.53996/59.73	
	$R'_7 = -9.12969$			
		$s_{78} = 0.016791$		
	$R_8 = +20.38444$			
VIII L_8		$d_8 = 0.162314$	1.74400/44.77	
	$R'_8 = -4.00969$			
		$s_{89} = 0.003731$		
	$R_9 = +6.35608$			
IX L_9		$d_9 = 0.228733$	1.78831/47.37	
	$R'_9 = -1.83008$			

Aspherical surfaces: R'_{5a} with $c_1 = (2 \cdot R'_{5a})^{-1}$, $c_2 = +3.864\ 7311 \cdot 10^{-2}$, $c_3 = -6.078\ 3773 \cdot 10^{-3}$, $c_4 = c_5 = 0$, R'_7 with $c_1 = (2 \cdot R'_7)^{-1}$, $c_2 = +1.177\ 2204 \cdot 10^{-1}$, $c_3 = +6.739\ 1168 \cdot 10^{-2}$, $c_4 = c_5 = 0$.

Example 15 (FIG. 11)

F = 1.00000 f/1.25 $2\omega_e = 78°$ $s'_m = +1.37384$ F

Diameter of entrance pupil = 0.800 F $\Phi_{NS} = +0.622\ \Phi$

	Lens	Radii	Thicknesses and spacings	n_d/ν_d		Bez.
I	L_{1a}	$R_{1a} = +3.42199$	$d_{1a} = 0.104456$	1.62299/58.06		
		$R'_{1a} = +1.33320$	$s_{1a,b} = 0.415587$			
	L_{1b}	$R_{1b} = +8.84707$	$d_{1b} = 0.124974$	1.62299/58.06		
		$R'_{1b} = +1.92420$	$s_{12} = 0.269348$		NN	
II	L_2	$R_2 = -14.22209$	$d_2 = 0.211897$	1.71736/29.52		
		$R'_2 = -2.47531$	$s_{23} = 0.011192$			NS
III	L_3	$R_3 = +3.11656$	$d_3 = 0.090653$	1.74400/44.77		
		$R'_3 = +1.21412$	$s_i = s_{34} = 0.562944$			
IV	L_{4a}	$R_{4a} = -1.06668$	$d_{4a} = 0.111544$	1.76180/26.95		
		$R'_{4a} = -1.38211$	$s_{4a,b} = 0.003731$		NO	
	L_{4b}	$R_{4b} = +5.66302$	$d_{4b} = 0.393949$	1.67790/55.20		
		$R'_{4b} = -1.76505$	$s_{45} = 0.007088$			
V	L_{5a}	$R_{5a} = +1.46325$	$d_{5a} = 0.503628$	1.74400/44.77		
		$R'_{5a} = +5.66302$	$s_{5a,b} = 0$		EO	
	L_{5b}	$R_{5b} = +5.66302$	$d_{5b} = 0.185410$	1..62004/36.37		
		$R'_{5b} = +1.30473$	$CS = s_{56} = 0.520789$			
VI	L_{6a}	$R_{6a} = -8.11401$	$d_{6a} = 0.253306$	1.63854/55.38		
		$R'_{6a} = -2.28707$	$s_{6a,b} = 0$			
	L_{6b}	$R_{6b} = -2.28707$	$d_{6b} = 0.133182$	1.80518/25.43		O
		$R'_{6b} = +1.38211$	$s_{67} = 0$			
VII	L_7	$R_7 = +1.38211$	$d_7 = 0.207047$	1.58913/61.24		
		$R'_7 = +11.79684$	$s_{78} = 0.003731$			
VIII	L_8	$R_8 = +2.49330$	$d_8 = 0.176456$	1.78831/47.37		
		$R'_8 = +17.30998$	$s_{89} = 0.017907$			
IX	L_9	$R_9 = +6.82834$	$d_9 = 0.239503$	1.78831/47.37		
		$R'_9 = -1.65421$				

Aspherical surfaces: : R_{6a} with $c_1 = (2 \cdot R_{6a})^{-1}$, $c_2 = +3.388\ 7542 \cdot 10^{-3}$, $c_3 = +7.045\ 4329 \cdot 10^{-4}$, $c_4 = +2.543\ 9721 \cdot 10^{-4}$, $c_5 = e$.

R'_8 with $c_1 = (2 \cdot R'_8)^{-1}$, $c_2 = +1{,}175\ 3002 \cdot 10^{-1}$, $c_3 = -1.076\ 9779 \cdot 10^{-2}$, $c_4 = c_5 = 0$.

Example 16 (FIG. 12)

F = 1.00000 f/1.03 $2\omega_e = 50°$ $s'_m = +1.6723$ F

Diameter of entrance pupil = 0.970 F $\Phi_{NS} = -0.12570\ \Phi$

	Lens	Radii	Thicknesses and spacings	N		
I	L_1	$R_1 = +3.12540$	$d_1 = 0.225586$	$n_1 = 1.69766$		
		$R'_1 = +1.67740$	$s_{12} = 0.283246$			
II	L_2	$R_2 = +4.72183$	$d_2 = 0.804452$	$n_2 = 1.74855$	NN	
		$R'_2 = -6.03608$	$s_{23} = 0.202643$			
III	L_3	$R_3 = +2.30430$	$d_3 = 0.151272$	$n_3 = 1.78831$		NS
		$R'_3 = +0.92630$	$s_i = s_{34} = 0.651910$			
IV	L_{4a}	$R_{4a} = -1.42395$	$d_{4a} = 1.110675$	$n_{4a} = 1.58725$		
		$R'_{4a} = -2.48132$	$s_{4a,b} = 0.557327$		NO	
	L_{4b}	$R_{4b} = +34.75847$	$d_{4b} = 0.333179$	$n_{4b} = 1.58324$		
		$R'_{4b} = -4.49128$	$s_{45} = 0.005920$			

-continued

Example 16 (FIG. 12)

F = 1.00000 f/1.03 $2\omega_o = 50°$ $s'_m = +1.6723$ F
Diameter of entrance pupil = 0.970 F $\Phi_{NS} = -0.12570\ \Phi$

Lens	Radii	Thicknesses and spacings	N		
V L_{5a}	$R_{5a} = +2.21649$	$d_{5a} = 0.818633$	$n_{5a} = 1.66838$		
V L_{5a}	$R'_{5a} = -15.46901$	$s_{5a,b} = 0.257125$		EO	
V L_{5b}	$R_{5b} = -40.83014$	$d_{5b} = 0.145921$	$n_{5b} = 1.71241$		
V L_{5b}	$R'_{5b} = +1.58895$	$s_{56} = 0.322577$			
VI L_6	$R_6 = -23.68569$	$d_6 = 0.107960$	$n_6 = 1.80518$		
VI L_6	$R'_6 = +1.86230$	$s_{67} = 0$		O	
VII L_7	$R_7 = +1.86230$	$d_7 = 0.664753$	$n_7 = 1.65750$		
VII L_7	$R'_7 = -5.57027$	$s_{78} = 0.003278$			
VIII L_8	$R_8 = +4.03129$	$d_8 = 0.315353$	$n_8 = 1.71228$		
VIII L_8	$R'_8 = -6.81727$	$s_{89} = 0.001973$			
IX L_9	$R_9 = +2.15163$	$d_9 = 0.360637$	$n_9 = 1.70904$		
IX L_9	$R'_9 = \pm$plan				

Aspherical surface: R_{4b} with $c_1 = (2 \cdot R_{4b})^{-1}$, $c_2 = +3.018\ 9030 \cdot 10^{-4}$, $c_3 = c_4 = c_5 = 0$.

Example 17 (FIG. 1)

F = 1.00000 f/1.03 $2\omega_o = 50°$ $s'_m = +1.6703$ F
Diameter of entrance pupil = 0.970 F $\Phi_{NS} = +0.07058\ \Phi$

Lens	Radii	Thicknesses and spacings	N		
I L_1	$R_1 = +3.37508$	$d_1 = 0.156624$	$n_1 = 1.67758$		
I L_1	$R'_1 = +1.81527$	$s_{12} = 0.229605$			
II L_2	$R_2 = +5.13335$	$d_2 = 0.251159$	$n_2 = 1.70684$	NN	
II L_2	$R'_2 = -7.48648$	$s_{23} = 0.540079$			
III L_3	$R_3 = +3.09067$	$d_3 = 0.104627$	$n_3 = 1.78831$		NS
III L_3	$R'_3 = +0.98321$	$s_1 = s_{34} = 1.108094$			
IV L_{4a}	$R_{4a} = -1.05451$	$d_{4a} = 1.006475$	$n_{4a} = 1.60156$		
IV L_{4a}	$R'_{4a} = -1.89550$	$s_{4a,b} = 0.046315$		NO	
IV L_{4b}	$R_{4b} = +7.53207$	$d_{4b} = 0.493897$	$n_{4b} = 1.64987$		
IV L_{4b}	$R'_{4b} = -3.57956$	$s_{45} = 0.003475$			
V L_{5a}	$R_{5a} = +2.22790$	$d_{5a} = 0.464257$	$n_{5a} = 1.57938$		
V L_{5a}	$R'_{5a} = +8.61454$	$s_{5a,b} = 0.346597$		EO	
V L_{5b}	$R_{5b} = +4.03619$	$d_{5b} = 0.144828$	$n_{5b} = 1.80797$		
V L_{5b}	$R'_{5b} = +1.76905$	$s_{56} = 0.327984$			
VI L_6	$R_6 = +25.48305$	$d_6 = 0.118495$	$n_6 = 1.80518$		
VI L_6	$R'_6 = +1.85408$	$s_{67} = 0$			O
VII L_7	$R_7 = +1.85408$	$d_7 = 0.543889$	$n_7 = 1.49541$		
VII L_7	$R'_7 = -4.65393$	$s_{78} = 0.002205$			
VIII L_8	$R_8 = +3.29999$	$d_8 = 0.266631$	$n_8 = 1.69932$		
VIII L_8	$R'_8 = +139.3801$	$s_{89} = 0.002272$			
IX L_9	$R_9 = +2.08234$	$d_9 = 0.382252$	$n_9 = 1.60202$		
IX L_9	$R'_9 = \pm$plan				

Aspherical surface: R_{4b} with $c_1 = (2 \cdot R_{4b})^{-1}$, $c_2 = -1.868\ 2513 \cdot 10^{-3}$, $c_3 = c_4 = c_5 = 0$.

Example 18 (FIG. 13)
F = 1.00000 f/1.03 $2\omega_o = 60°$ $s'_o = +1.5725$ F
Diameter of entrance pupil = 0.970 F ΦNS = −0.09231 Φ

Lens	Radii	Thicknesses and spacings	N		
I L_1	$R_1 = +3.17554$				
	$R'_1 = +1.72019$	$d_1 = 0.147782$	$n_1 = 1.74400$		
		$s_{12} = 0.373225$			
II L_2	$R_2 = +5.39546$				
	$R'_2 = -1.82276$	$d_2 = 0.683184$	$n_2 = 1.74400$		
		$s_{23} = 0$		NN	
III L_{3a}	$R_{3a} = -1.82276$				
	$R'_{3a} = -6.47118$	$d_{3a} = 0.132500$	$n_{3a} = 1.72293$		
		$s_{3a,b} = 0.186613$			NS
L_{3b}	$R_{3b} = +2.19333$				
	$R'_{3b} = +0.96524$	$d_{3b} = 0.114355$	$n_{3b} = 1.78831$		
		$s_4 = s_{34} = 0.615604$			
IV L_{4a}	$R_{4a} = -1.51067$				
	$R'_{4a} = -2.27995$	$d_{4a} = 1.206328$	$n_{4a} = 1.56770$		
		$s_{4a,b} = 0.589354$		NO	
L_{4b}	$R_{4b} = +76.89089$				
	$R'_{4b} = -4.93095$	$d_{4b} = 0.378144$	$n_{4b} = 1.58215$		
		$s_{45} = 0.054395$			
V L_{5a}	$R_{5a} = +1.94227$				
	$R'_{5a} = -13.11638$	$d_{5a} = 0.672095$	$n_{5a} = 1.76302$		
		$s_{5a,b} = 0.276209$		EO	
L_{5b}	$R_{5b} = -6.06972$				
	$R'_{5b} = +1.73584$	$d_{5b} = 0.092661$	$n_{5b} = 1.84666$		
		$s_{56} = 0.300766$			
VI L_6	$R_6 = -17.50515$				
	$R'_6 = +1.63509$	$d_6 = 0.090040$	$n_6 = 1.81003$		
		$s_{67} = 0$		O	
VII L_7	$R_7 = +1.63509$				
	$R'_7 = -3.44805$	$d_7 = 0.575886$	$n_7 = 1.68714$		
		$s_{78} = 0.002056$			
VIII L_8	$R_8 = +3.83796$				
	$R'_8 = -7.65103$	$d_8 = 0.271290$	$n_8 = 1.69782$		
		$s_{89} = 0.002540$			
IX L_9	$R_9 = +2.20451$				
	$R'_9 = \pm$plan	$d_9 = 0.291411$	$n_9 = 1.62890$		

Example 19 (FIG. 12)
F = 1.00000 f/1.30 $2\omega_o = 53.5°$ $s'_o = 1.37352$ F
Diameter of entrance pupil = 0.770 F ΦNS = + 0.11921 Φ

Lens	Radii	Thicknesses and spacings	n_d/ν_d		Bez.
I L_1	$R_1 = +3.38273$				
	$R'_1 = +1.61177$	$d_1 = 0.139963$	1.63854/55.38		
		$s_{12} = 0.370064$			
II L_2	$R_2 = -52.57847$				
	$R'_2 = -4.06399$	$d_2 = 0.244159$	1.67270/32.20	NN	
		$s_{23} = 0.301373$			
III L_3	$R_3 = +1.98189$				
	$R'_3 = +0.83213$	$d_3 = 0.406607$	1.74400/44.77		NS
		$s_4 = s_{34} = 0.954689$			
IV L_{4a}	$R_{4a} = -1.00073$				
	$R'_a = -1.38657$	$d_{4a} = 0.643115$	1.62299/58.06		
		$s_{4a,b} = 0.088154$		NO	
L_{4b}	$R_{4b} = +4.65051$				
	$R'_{4b} = -3.79456$	$d_{4b} = 0.300803$	1.62299/58.06		
		$s_{45} = 0.001678$			
V L_{5a}	$R_{5a} = +1.71929$				
	$R'_{5a} = +7.69345$	$d_{5a} = 0.334326$	1.70181/41.02		
		$s_{5a,b} = 0.341608$		EO	
L_{5b}	$R_{5b} = +5.24069$				
	$R'_{5b} = +1.26146$	$d_{5b} = 0.093388$	1.80518/25.43		

-continued

Example 19 (FIG. 12)
F = 1.00000 f/1.30 $2\omega_0 = 53.5°$ $s'_o = 1.37352$ F
Diameter of entrance pupil = 0.770 F $\Phi NS = +0.11921\ \Phi$

Lens	Radii	Thicknesses and spacings	n_d/ν_d	Bez.
		$s_{56} = 0.211105$		
VI L_6	$R_6 = +7.85137$	$d_6 = 0.108288$	1.80518/25.43	
	$R'_6 = +1.57841$			
		$s_{67} = 0$		O
	$R_7 = +1.57841$			
VII L_7		$d_7 = 0.319259$	1.48749/70.45	
	$R'_7 = -2.70741$			
		$s_{78} = 0.001678$		
	$R_8 = +1.87531$			
VIII L_8		$d_8 = 0.181039$	1.65844/50.88	
	$R'_8 = +300.6715$			
		$s_{89} = 0.001678$		
	$R_9 = +4.84509$			
IX L_9		$d_9 = 0.326071$	1.62299/58.06	
	$R'_9 = -23.38907$			

Example 20 (FIG. 4)
F = 1.00000 f/1.30 $2\omega_0 = 60° s'_o = +1.53252$ F
Diameter of entrance pupil = 0.770 F $\Phi_{NS} = -0.30684\ \Phi$

Lens	Radii	Thicknesses and spacings	n_d/ν_d	Bez.
	$R_1 = +2.81910$			
I L_1		$d_1 = 0.138164$	1.62299/58.06	
	$R'_1 = +1.60408$			
		$s_{12} = 0.398024$		
	$R_2 = +4.87862$			
II L_2		$d_2 = 0.332861$	1.64250/57.94	NN
	$R'_2 = -6.62313$			
		$s_{23} = 0.336934$		
	$R_3 = +2.25473$			
III L_3		$d_3 = 0.141277$	1.74400/44.77	NS
	$R'_3 = +0.79371$			
		$s_i = s_{34} = 0.543265$		
	$R_{4a} = -1.38496$			
IV L_{4a}		$d_{4a} = 0.529119$	1.62004/36.37	
	$R'_{4a} = -2.72430$			
		$s_{4a,b} = 0.038339$		NO
	$R_{4b} = +10.56737$			
IV L_{4b}		$d_{4b} = 0.178584$	1.64250/57.94	
	$R'_{4b} = -3.64117$			
		$s_{45} = 0.2654594$		
	$R_{5a} = +1.59675$			
V L_{5a}		$d_{5a} = 0.285969$	1.78470/26.08	
	$R'_{5a} = -56.84085$			
		$s_{5a,b} = 0.408633$		EO
	$R_{5b} = -10.07983$			
V L_{5b}		$d_{5b} = 0.074812$	1.80518/25.43	
	$R'_{5b} = +1.33822$			
		$s_{56} = 0.204165$		
	$R_6 = -9.53618$			
VI L_6		$d_6 = 0.068505$	1.78470/26.08	
	$R'_6 = +1.18245$			
		$s_{67} = 0$		
	$R_7 = +1.18245$			
VII L_7		$d_7 = 0.396121$	1.71300/53.85	
	$R'_7 = -2.53940$			
		$s_{78} = 0.002016$		
	$R_8 = +2.68615$			
VIII L_8		$d_8 = 0.209613$	1.64250/57.94	
	$R'_8 = -4.65915$			
		$s_{89} = 0.002016$		
	$R_9 = +2.33476$			
IX L_9		$d_9 = 0.184984$	1.56384/60.82	
	$R'_9 = -7.91351$			

It should be mentioned that in the specific examples which include aspherical surfaces, the value given in the data table for the radius of the aspherical surface refers to the vertex radius of the surface in question, at the axial vertex point at the place of passage of the optical axis.

In order to show the breadth of use of the new principle of design in accordance with the present invention, numerical values for certain partial features of the various examples are given in the following tables I and II. The numerical values given in these tables are the rounded-off results of a multi-place computation by digital electronics. In each case the values are stated with respect to the total equivalent focal length (F) considered as unity, of the entire objective lens system as a whole, or with respect to the total refractive power (Φ) of the entire system. Of course the refractive power is the reciprocal of the focal length, as well understood in the art.

From the numerical values of the individual focal length (f_{NN}) of the Newtonian negative component (NN) on the one hand, and the air lens refractive power (ϕ_l) of the air lens between this group and the following ocular group (NO) on the other hand, it can easily be noted by comparing these two numerical values, with due consideration to their common negative sign, that in fact a very strong divergent ray path prevails within the Newtonian ocular (NO) for the central bundles of rays, which accordingly also continues into the lateral area of the image.

In the last vertical column of table II, there is an indication of which claim or claims, among the first five claims, is intended to relate to the particular example in question. This provides a good view of some of the relationships of different examples to each other, and of the intended scope of the claims which are expressed in general language, as distinguished from claims containing specific tabular data.

Table I

Example	f_{NN}	ϕ_l	$\Phi_{NO} = f_{NO}^{-1}$	$\lvert V_{NS} \rvert$
1	−1.94003 F	−1.63962 Φ	+0.29023 Φ	0.56305
2	−1.94003 F	−1.63962 Φ	+0.29026 Φ	0.56311
3	−1.99610 F	−1.42187 Φ	+0.28782 Φ	0.57453
4	−1.94002 F	−1.63965 Φ	+0.32014 Φ	0.62108
5	−1.99610 F	−1.42187 Φ	+0.06034 Φ	0.12044
6	−1.28338 F	−1.27090 Φ	+0.43228 Φ	0.55478
7	−1.21413 F	−1.31178 Φ	+0.40979 Φ	0.49754
8	−1.21448 F	−1.31185 Φ	+0.40298 Φ	0.48941
9	−1.19776 F	−1.31350 Φ	+0.40018 Φ	0.47932
10	−1.38831 F	−1.09880 Φ	+0.34656 Φ	0.48113
11	−1.32780 F	−1.19392 Φ	+0.32003 Φ	0.42493
12	−1.54644 F	−1.04840 Φ	+0.17432 Φ	0.26957
13	−1.27863 F	−1.27023 Φ	+0.43308 Φ	0.55375
14	−1.51227 F	−1.19220 Φ	+0.29330 Φ	0.44354
15	−1.34987 F	−1.32697 Φ	+0.38991 Φ	0.52633
16	−2.69614 F	−1.26344 Φ	+0.09262 Φ	0.24970
17	−2.21420 F	−1.37224 Φ	+0.22742 Φ	0.50356
18	−2.69800 F	−1.19249 Φ	+0.11249 Φ	0.30349
19	−1.90198 F	−1.51662 Φ	+0.30772 Φ	0.58528
20	−1.95996 F	−1.38506 Φ	+0.08906 Φ	0.17456

Table II

Example	ϕ_{IN}	f_O	Claim Nr.
1	+0.21130 Φ	+2.06031 F	2
2	+0.21130 Φ	+2.06031 F	2 and 4
3	−0.01090 Φ	+1.74056 F	1 and 4
4	+0.18549 Φ	+2.11270 F	2
5	−0.09326 Φ	+1.68117 F	1
6	−0.09092 Φ	+2.14998 F	1,3,5
7	+0.19608 Φ	+2.10051 F	2,3,5
8	+0.19628 Φ	+2.13695 F	2 to 5
9	+0.19654 Φ	+2.08629 F	2,3,5
10	+0.00335 Φ	+1.88436 F	1,3,5
11	+0.11634 Φ	+2.01931 F	1,3,5
12	+0.32168 Φ	+2.05755 F	2,3,5
13	−0.09102 Φ	+2.14887 F	1,3,5
14	+0.22884 Φ	+2.20934 F	2,3,5
15	−0.02189 Φ	+2.09041 F	1,3,5
16	+0.02576 Φ	+2.14883 F	1 and 5
17	+0.13293 Φ	+2.46367 F	1 and 5
18	−0.08132 Φ	+2.16950 F	1
19	+0.06242 Φ	+2.33563 F	1
20	−0.06608 Φ	+1.68190 F	1

What is claimed is:

1. An extremely high speed wide angle objective lens system for forming an image of a distant object in front of said system on an image plane in rear of said system, said lens system comprising in succession from front to rear

1. a diverging group (NN) composed of a plurality of components,

2. a converging ocular group (NO), and

3. a main objective group (O) serving to form a real image on said image plane in rear of said main objective group,

said diverging group (NN) and said converging ocular group (NO) together forming a Newtonian finder telescope (NS) in the nature of a reverse Galilean telescope, said groups being so formed and dimensioned and so related to each other that

4. the focal length of said diverging group (NN) is not less than 0.106 and not more than 0.690 times the focal length of said converging ocular group (NO), and

5. said diverging group (NN) has at least three components,

i. of which is a negative component having a rear surface which is bounded by air and which is concave toward the rear,

ii. another of which is a positive component located behind said negative component, and

iii. another of which is a negative component located behind said positive component and having a rear surface which is concave toward the rear and which constitutes the rearmost surface of said diverging group (NN),

iv. there being an air lens of diverging action between said first mentioned negative component and said positive component, and an air lens of converging action between said positive component and said other negative component,

6. said converging ocular group (NO) is spaced rearwardly from said diverging group (NN) to provide between them an air lens of diverging action having a paraxial surface refractive power sum (ϕ_l) which in negative numerical value is not less than 0.948 and not more than 1.808 times the equivalent refractive power (Φ) of the entire lens system,

7. said converging ocular group (NO) has a plurality of components spaced axially from each other to provide an air lens of collecting action followed by a positive component, such air lens acting to provide, for a middle bundle of rays, a strongly divergent ray path bent by said positive component to a ray path differing only slightly from a paraxial course,

8. said main objective group (O) has a plurality of components receiving rays from said converging ocular group (NO) and transmitting them to produce a real image on said image plane, and

9. said main objective group (O) has a paraxial focal length which is not less than 1.53 and not more than 2.73 times the equivalent focal length of the entire lens system.

2. A lens system as defined in claim 1, wherein said main objective group (O) has an entrance component (EO) at the forward end of said group (O), said entrance component having two adjacent lens elements having an inner neighboring pair of surfaces (IN) which have a collecting surface power sum (ϕ_{IN}) not less than 0.167 nor more than 0.357 times the equivalent refractive power (Φ) of the entire lens system.

3. A lens system as defined in claim 1, wherein the forward one of said three components of said first diverging group (NN) comprises at least two negative lens elements separated by an air space shaped to provide an air lens of diverging action, through which light rays entering the front of the lens system must pass before entering the next succeeding one of said three components of said diverging group (NN).

4. A lens system as defined in claim 1, wherein said converging ocular group (NO) includes a component split into two adjacent individual lens elements.

spacings being expressed in proportion to the equivalent focal length of the entire system, which is considered as unity:

I L_1	$R_1 = +3.3100$	$d_1 = 0.14600$	$n_1 = 1.639$		
	$R'_1 = +1.6700$	$s_{12} = 0.34600$			
II L_2	$R_2 = +40.000$	$d_2 = 0.23700$	$n_2 = 1.673$	NN	
	$R'_2 = -4.5350$	$s_{23} = 0.20140$			
III L_3	$R_3 = +1.9710$	$d_3 = 0.53380$	$n_3 = 1.744$	NS	
	$R'_3 = +0.7735$	$s_1 = s_{34} = 0.83250$			
IV L_{4a}	$R_{4a} = -0.9192$	$d_{4a} = 0.61260$	$n_{4a} = 1.623$		
	$R'_{4a} = -1.35568$	$s_{4a,b} = 0.06850$		NO	
IV L_{4b}	$R_{4b} = +4.0000$	$d_{4b} = 0.26642$	$n_{4b} = 1.623$		
	$R'_{4b} = -4.0000$	$s_{45} = 0.00638$			
V L_{5a}	$R_{5a} = +1.7310$	$d_{5a} = 0.25246$	$n_{5a} = 1.658$		
	$R'_{5a} = +5.42638$	$s_{5a,b} = 0.33569$		EO	
V L_{5b}	$R_{5b} = +2.3605$	$d_{5b} = 0.14605$	$n_{5b} = 1.785$		
	$R'_{5b} = +1.1830$	$s_{56} = 0.21823$			
VI L_6	$R_6 = +11.5687$	$d_6 = 0.09232$	$n_6 = 1.805$		
	$R'_6 = +1.4258$	$s_{67} = 0$			O
VII L_7	$R_7 = +1.4258$	$d_7 = 0.30382$	$n_7 = 1.488$		
	$R'_7 = -3.06946$	$s_{78} = 0.00336$			
VIII L_8	$R_8 = +1.8595$	$d_8 = 0.19465$	$n_8 = 1.658$		
	$R'_8 = -12.0749$	$s_{89} = 0.00336$			
IX L_9	$R_9 = +4.10615$	$d_9 = 0.16280$	$n_9 = 1.623$		
	$R'_9 = -47.4162.$				

5. A lens system as defined in claim 1, wherein at least one individual lens element of the entire lens system has a surface shaped aspherically.

6. A lens system as defined in claim 1, wherein the characteristics of the components of the system and their spatial relationship to each other are substantially in the proportions indicated by the data in the following table, all linear dimensions of radii, thicknesses, and

7. A lens system as defined in claim 1, wherein the characteristis of the components of the system and their spatial relationship to each other are substantially in the proportions indicated by the data in the following table, all linear dimensions of radii, thicknesses, and spacings being expressed in proportion to the equivalent focal length of the entire system, which is considered as unity:

I L_1	$R_1 = +3.31000$	$d_1 = 0.14600$	$n_1 = 1.6390$		
	$R'_1 = +1.67000$	$s_{12} = 0.34600$			
II L_2	$R_2 = +40.0000$	$d_2 = 0.23700$	$n_2 = 1.6730$	NN	
	$R'_2 = -4.53500$	$s_{23} = 0.20140$			
III L_3	$R_3 = +1.97100$	$d_3 = 0.53380$	$n_3 = 1.7440$		
	$R'_3 = +0.77350$	$s_1 = s_{34} = 0.83250$			NS
IV L_{4a}	$R_{4a} = -0.91920$	$d_{4a} = 0.16230$	$n_{4a} = 1.6230$		
	$R'_{4a} = +10.2000$	$s_{4a,b} = 0.0685003$			
IV L_{4b}	$R_{4b} = +9.38050$	$d_{4b} = 0.334851$	$n_{4b} = 1.6204$	NO	
	$R'_{4b} = -1.3728209$				

-continued

		$s_{4b,c} = 0.0685002$		
L_{4c}	$R_{4c} = +4.00000$ $R'_{4c} = -4.00000$	$d_{4c} = 0.26642$ $s_{4b} = 0.006380$	$n_{4c} = 1.6230$	
V L_{5a}	$R_{5a} = +1.73100$ $R'_{5a} = 5.42638$	$d_{5a} = 0.25246$ $s_{5a,b} = 0.33569$	$n_{5a} = 1.6580$	EO
V L_{5b}	$R_{5b} = +2.36050$ $R'_{5b} = +1.18300$	$d_{5b} = 0.14605$ $s_{5a} = 0.21823$	$n_{5b} = 1.7850$	
VI L_6	$R_6 = +11.56870$ $R'_6 = +1.42580$	$d_6 = 0.09232$ $s_{67} = 0$	$n_6 = 1.8050$	O
VII L_7	$R_7 = +1.42580$ $R'_7 = -3.06946$	$d_7 = 0.30382$ $s_{78} = 0.00336$	$n_7 = 1.4880$	
VIII L_8	$R_8 = 1.85950$ $R'_8 = -12.07490$	$d_8 = 0.19465$ $s_{89} = 0.00336$	$n_8 = 1.6580$	
IX L_9	$R_9 = +4.10615$ $R'_9 = -47.4162.$	$d_9 = 0.16280$	$n_9 = 1.6230$	

8. A lens system as defined in claim 1, wherein the characteristics of the components of the system and their spatial relationship to each other are substantially in the proportions indicated by the data in the following table, all linear dimensions of radii, thicknesses, and spacings being expressed in proportion to the equivalent focal length of the entire system, which is considered as unity:

I L_1	$R_1 = +3.25586$ $R'_1 = +1.69156$	$d_1 = 0.139391$ $s_{12} = 0.412113$	$n_1 = 1.62299$	
II L_2	$R_2 = +5.78979$ $R'_2 = -5.87383$	$d_2 = 0.343428$ $s_{23} = 0.460597$	$n_2 = 1.64250$	NN
III L_3	$R_3 = +1.99604$ $R'_3 = +0.80039$	$d_3 = 0.056565$ $s_4 = s_{34} = 0.569686$	$n_3 = 1.74400$	NS
IV L_{4a}	$R_{4a} = -1.25941$ $R'_{4a} = -1.92550$	$d_{4a} = 0.428275$ $s_{4a,b} = 0.149492$	$n_{4a} = 1.62004$	
IV L_{4b}	$R_{4b} = +3.78696$ $R'_{4b} = \text{plan}$	$d_{4b} = 0.164250$ $s_{4b,c} = 0.010000$	$n_{4b} = 1.64250$	NO
IV L_{4c}	$R_{4c} = +4.050827$ $R'_{4c} = \text{plan}$	$d_{4c} = 0.178470$ $s_{45} = 0.020000$	$n_{4c} = 1.78470$	
V L_{5a}	$R_{5a} = +4.183696$ $R'_{5a} = -4.183696$	$d_{5a} = 0.624055$ $s_{5a,b} = 0.267900$	$n_{5a} = 1.78600$	EO
V L_{5b}	$R_{5b} = -4.050827$ $R'_{5b} = +1.500270$	$d_{5b} = 0.080000$ $CS = s_{56} = 0.249073$	$n_{5b} = 1.80518$	
VI L_6	$R_6 = -8.417200$ $R'_6 = +1.16357$	$d_6 = 0.0646458$ $s_{67} = 0$	$n_6 = 1.78470$	O
VII L_7	$R_7 = +1.16357$ $R'_7 = -2.47696$	$d_7 = 0.410093$ $s_{78} = 0.004040$	$n_7 = 1.71300$	
VIII L_8	$R_8 = +3.84187$ $R'_8 = -3.95403$	$d_8 = 0.191916$	$n_8 = 1.64250$	

-continued

		$s_{89} = 0.004040$		
IX L_9	$R_9 = +1.96752$ $R'_9 = 7.94652.$	$d_9 = 0.212117$	$n_9 = 1.56384$	

9. A lens system as defined in claim 1, wherein the characteristis of the components of the system and their spatial relationship to each other are substantially in the proportions indicated by the data in the following table, all linear dimensions of radii, thicknesses, and spacings being expressed in proportion to the equivalent focal length of the entire system, which is considered as unity:

I L_1	$R_1 = +3.30888$ $R'_1 = +1.67033$	$d_1 = 0.146023$ $s_{12} = 0.345755$	1.63854/55.38		
II L_2	$R_2 = +39.89615$ $R'_2 = -4.54148$	$d_2 = 0.236994$ $s_{23} = 0.201411$	1.67270/32.20	NN	
III L_3	$R_3 = +1.97097$ $R'_3 = 0.77345$	$d_3 = 0.533739$ $s_1 = s_{34} = 0.832498$	1.74400/44.77		NS
IV L_{4a}	$R_{4a} = -0.91924$ $R'_{4a} = -1.35576$	$d_{4a} = 0.612625$ $s_{4a,b} = 0.068815$	1.62299/58.06	NO	
IV L_{4b}	$R_{4b} = +3.82110$ $R'_{4b} = -3.60727$	$d_{4b} = 0.281975$ $s_{45} = 0.003357$	1.62299/58.06		
V L_{5a}	$R_{5a} = +1.73153$ $R'_{5a} = +4.47636$	$d_{5a} = 0.238336$ $s_{5a,b} = 0.335685$	1.65844/50.88	EO	
V L_{5b}	$R_{5b} = 2.35943$ $R'_{5b} = +1.18252$	$d_{5b} = 0.146023$ $CS = s_{56} = 0.218195$	1.78470/26.08		
VI L_6	$R_6 = +11.57274$ $R'_6 = +1.42579$	$d_6 = 0.092313$ $s_{67} = 0$	1.80518/25.43	O	
VII L_7	$R_7 = +1.42579$ $R'_7 = -3.05708$	$d_7 = 0.302116$ $s_{78} = 0.003357$	1.48749/70.45		
VIII L_8	$R_8 = +1.86073$ $R'_8 = -12.08331$	$d_8 = 0.194697$ $s_{89} = 0.003357$	1.65844/50.88		
IX L_9	$R_9 = +4.10610$ $R'_9 = -47.41549.$	$d_9 = 0.162807$	1.62299/58.06		

10. A lens system as defined in claim 1, wherein the characteristics of the components of the system and their spatial relationship to each other are substantially in the proportions indicated by the data in the following table, all linear dimensions of radii, thicknesses, and spacings being expressed in proportion to the equivalent focal length of the entire system, which is considered as unity:

I L_1	$R_1 = +3.25586$ $R'_1 = +1.69156$	$d_1 = 0.139391$ $s_{12} = 0.412113$	1.62299/58.06		
II L_2	$R_2 = +5.78979$ $R'_2 = -5.87383$	$d_2 = 0.343428$ $s_{23} = 0.460597$	1.64250/57.94	NN	
III L_3	$R_3 = +1.99604$ $R'_3 = +0.80039$	$d_3 = 0.056565$ $s_1 = s_{34} = 0.569686$	1.74400/44.77	NS	
	$R_{4a} = 1.25941$				

-continued

IV L_{4a}	$R'_{4a} = -1.92550$	$d_{4a} = 0.428275$	1.62004/36.37	
		$s_{4a,b} = 0.149492$		NO
L_{4b}	$R_{4b} = +3.78696$	$d_{4b} = 0.175754$	1.64250/57.94	
	$R'_{4b} = +117.1978$	$s_{45} = 0.218178$		
V L_{5a}	$R_{5a} = +1.70381$	$d_{5a} = 0.298984$	1.78470/26.08	
	$R'_{5a} = -9.44427$	$s_{5a,b} = 0.391104$		EO
L_{5b}	$R_{5b} = -4.56597$	$d_{5b} = 0.076766$	1.80518/25.43	
	$R'_{5b} = +1.47541$	$CS = s_{56} = 0.183835$		
VI L_6	$R_6 = -8.41722$	$d_6 = 0.064645$	1.78470/26.08	
	$R'_6 = +1.16357$	$s_{67} = 0$		O
VII L_7	$R_7 = +1.16357$	$d_7 = 0.410093$	1.71300/53.85	
	$R'_7 = -2.47696$	$s_{78} = 0.004040$		
VIII L_8	$R_8 = +3.84187$	$d_8 = 0.191916$	1.64250/57.94	
	$R'_8 = -3.95403$	$s_{89} = 0.004040$		
IX L_9	$R_9 = +1.96752$	$d_9 = 0.212117$	1.56384/60.82	
	$R'_9 = -7.94652$			

11. A lens system as defined in claim 1, wherein the characteristics of the components of the system and their spatial relationship to each other are substantially in the proportions indicated by the data in the following table, all linear dimensions of radii, thicknesses, and spacings being expressed in proportion to the equivalent focal length of the entire system, which is considered as unity:

I L_{1a}	$R_{1a} = +2.600$	$d_{1a} = 0.162$	$n_{1a} = 1.620$	
	$R'_{1a} = +4.220$	$s_{1a,b} = 0.030$		
L_{1b}	$R_{1b} = +4.220$	$d_{1b} = 0.078$	$n_{1b} = 1.630$	
	$R'_{1b} = +1.305$	$s_{1b,c} = 0.499$		
L_{1c}	$R_{1c} = +6.200$	$d_{1c} = 0.090$	$n_{1c} = 1.620$	NN
	$R'_{1c} = +1.630$	$s_{12} = 0.294$		
II L_2	$R_2 = -36.01$	$d_2 = 0.232$	$n_2 = 1.670$	NS
	$R'_2 = -2.790$	$s_{23} = 0.003$		
III L_3	$R_3 = +3.760$	$d_3 = 0.0908$	$n_3 = 1.713$	
	$R'_3 = +1.180$	$s_4 = s_{34} = 0.534$		
IV L_{4a}	$R_{4a} = -1.110$	$d_{4a} = 0.186$	$n_{4a} = 1.740$	
	$R'_{4a} = -1.490$	$s_{4a,b} = 0.010$		NO
L_{4b}	$R_{4b} = +4.220$	$d_{4b} = 0.411$	$n_{4b} = 1.730$	
	$R'_{4b} = -2.030$	$s_{45} = 0.013$		
V L_{5a}	$R_{5a} = 1.437$	$d_{5a} = 0.667$	$n_{5a} = 1.744$	
	$R'_{5a} = +4.917$	$s_{5a,b} = 0.052$		EO
L_{5b}	$R_{5b} = +12.55$	$d_{5b} = 0.105$	$n_{5b} = 1.756$	
	$R'_{5b} = +1.342$	$CS = s_{56} = 0.320$		
VI L_{6a}	$R_{6a} = \pm$plan	$d_{6a} = 0.157$	$n_{6a} = 1.548$	
	$R'_{6a} = -3.119$	$s_{6a,b} = 0.079$		
L_{6b}	$R_{6b} = -2.837$	$d_{6b} = 0.075$	$n_{6b} = 1.805$	O

-continued

	$R'_{6b} = +1.691$	$s_{67} = 0$	
VII L_7	$R_7 = +1.691$ $R'_7 = -2.068$	$d_7 = 0.320$ $s_{78} = 0.004$	$n_7 = 1.510$
VIII L_8	$R_8 = -21.43$ $R'_8 = 2.470$	$d_8 = 0.172$ $s_{89} = 0.004$	$n_8 = 1.713$
IX L_9	$R_9 = -29.95$ $R'_9 = -1.932329$	$d_9 = 0.175$	$n_9 = 1.713$

Aspherical surface R_{6a} with: $c_1 = c_4 = c_5 = 0$, $c_2 = -1.984\,1448 \cdot 10^{-1}$, $c_3 = -2.189\,7588 \cdot 10^{-2}$.

12. A lens system as defined in claim **1**, wherein the characteristics of the components of the system and their spatial relationship to each other are substantially in the proportions indicated by the data in the following table, all linear dimensions of radii, thicknesses, and spacings being expressed in proportion to the equivalent focal length of the entire system, which is considered as unity:

I L_{1a}	$R_{1a} = +2.3500$ $R'_{1a} = +8.4100$	$d_{1a} = 0.0900$ $s_{1a,b} = 0.0100$	$n_{1a} = 1.620$	
I L_{1b}	$R_{1b} = +8.4100$ $R'_{1b} = +1.4000$	$d_{1b} = 0.0500$ $s_{1b,c} = 0.3613$	$N_{1b} = 1.625$	
I L_{1c}	$R_{1c} = +4.2100$ $R_{1c} = +1.7800$	$d_{1c} = 0.0800$ $s_{12} = 0.3205$	$n_{1c} = 1.625$	NN
II L_2	$R_2 = -8.4100$ $R'_2 = -2.8100$	$d_2 = 0.2109$ $s_{23} = 0.0197$	$n_2 = 1.670$	NS
III L_3	$R_3 = +5.8900$ $R'_3 = +1.1080$	$d_3 = 0.0880$ $s_f = s_{34} = 0.4850$	$n_3 = 1.713$	
IV L_{4a}	$R_{4a} = -0.9906$ $R'_{4a} = -1.2803$	$d_{4a} = 0.1189$ $s_{4a,b} = 0.1647$	$n_{4a} = 1.662$	NO
IV L_{4b}	$R_{4b} = +4.8876$ $R'_{4b} = -2.2904$	$d_{4b} = 0.4167$ $s_{45} = 0.2058$	$n_{4b} = 1.788$	
V L_{5a}	$R_{5a} = +1.8900$ $R'_{5a} = -13.203$	$d_{5a} = 0.3710$ $s_{5a,b} = 0.0097$	$n_{5a} = 1.744$	EO
V L_{5b}	$R_{5b} = +5.6822$ $R'_{5b} = +2.1055$	$d_{5b} = 0.1554$ $CS = s_{56} = 0.6609$	$n_{5b} = 1.794$	
VI L_6	$R_6 = -3.1200$ $R'_6 = +1.1784$	$d_6 = 0.0650$ $s_{67} = 0$	$n_6 = 1.805$	O
VII L_7	$R_7 = +1.1784$ $R'_7 = -6.0511$	$d_7 = 0.3148$ $s_{78} = 0.0044$	$n_7 = 1.510$	
VIII L_8	$R_8 = +10.250$ $R'_8 = -3.4884$	$d_8 = 0.1697$ $s_{89} = 0.0044$	$n_8 = 1.721$	
IX L_9	$R_9 = +5.1200$ $R'_9 = -2.543163$	$d_9 = 0.1960$	$n_9 = 1.787$	

Aspherical surfaces: R_{4b} with $c_1 = (2 \cdot R_{4b})^{-1}$, $c_2 = -1.390\,4948 \cdot 10^{-2}$, $c_3 = -1.532\,5255 \cdot 10^{-3}$, $c_4 = c_5 = 0$
R_9 with $c_1 = (2 \cdot R_9)^{-1}$, $c_2 = -4.405\,4084 \cdot 10^{-2}$, $c_3 = c_4 = c_5 = 0$.

13. A lens system as defined in claim **1**, wherein the characteristics of the components of the system and their spatial relationship to each other are substantially

in the proportions indicated by the data in the following table, all linear dimensions of radii, thicknesses, and spacings being expressed in proportion to the equivalent focal length of the entire system, which is considered as unity:

I L_{1a}	$R_{1a} = +2.3360$	$d_{1a} = 0.1309$	$n_{1a} = 1.623$		
	$R'_{1a} = +1.4320$	$s_{1a,b} = 0.3686$			
L_{1b}	$R_{1b} = +4.2120$	$d_{1b} = 0.1366$	$n_{1b} = 1.624$		
	$R'_{1b} = +1.7280$	$s_{12} = 0.3222$		NN	
II L_2	$R_2 = -9.3050$	$d_2 = 0.2140$	$n_2 = 1.641$		
	$R'_2 = -2.8230$	$s_{23} = 0.0196$			
III L_3	$R_3 = +5.8930$	$d_3 = 0.0878$	$n_3 = 1.713$		
	$R'_3 = +1.1080$	$s_f = s_{34} = 0.4851$			NS
IV L_{4a}	$R_{4a} = -0.9890$	$d_{4a} = 0.1188$	$n_{4a} = 1.661$		
	$R'_{4a} = -1.2780$	$s_{4a,b} = 0.1647$			
L_{4b}	$R_{4b} = +4.8870$	$d_{4b} = 0.1160$	$n_{4b} = 1.788$	NO	
	$R'_{4b} = \pm$plan	$s_{4b,c} = 0.06819$			
L_{4c}	$R_{4c} = \pm$plan	$d_{4c} = 0.1788$	$n_{4c} = 1.788$		
	$R'_{4c} = -2.2900$	$s_{45} = 0.18821$			
V L_{5a}	$R_{5a} = +1.8900$	$d_{5a} = 0.3710$	$n_{5a} = 1.744$		
	$R'_{5a} = -13.200$	$s_{5a,b} = 0.0096$		EO	
L_{5b}	$R_{5b} = +5.6820$	$d_{5b} = 0.1554$	$n_{5b} = 1.795$		
	$R'_{5b} = +2.1050$	$CS = s_{56} = 0.6610$			
VI L_6	$R_6 = -3.1210$	$d_6 = 0.0648$	$n_6 = 1.805$		
	$R'_6 = +1.1790$	$s_{67} = 0$			O
VII L_7	$R_7 = +1.1790$	$d_7 = 0.3147$	$n_7 = 1.510$		
	$R'_7 = -6.0500$	$s_{78} = 0.0044$			
VIII L_8	$R_8 = +9.3050$	$d_8 = 0.1500$	$n_8 = 1.720$		
	$R'_8 = -3.6060$	$s_{89} = 0.0052$			
IX L_9	$R_9 = +5.12012$	$d_9 = 0.1960$	$n_9 = 1.788$		
	$R'_9 = -2.54700$				

Aspherical surfaces: R_{4b} with $c_1 = (2 \cdot R_{4b})^{-1}$, $c_2 = -1.390\,4948 \cdot 10^{-2}$, $c_3 = -1.532\,5255 \cdot 10^{-3}$, $c_4 = c_5 = 0$
R_9 with $c_1 = (2 \cdot R_9)^{-1}$, $c_2 = -4.405\,4084 \cdot 10^{-2}$, $c_3 = c_4 = c_5 = 0$.

14. A lens system as defined in claim **1**, wherein the characteristics of the components of the system and their spatial relationship to each other are substantially in the proportions indicated by the data in the following table, all linear dimensions of radii, thicknesses, and spacings being expressed in proportion to the equivalent focal length of the entire system, which is considered as unity:

I L_{1a}	$R_{1a} = +2.3250$	$d_{1a} = 0.1300$	$n_{1a} = 1.620$		
	$R'_{1a} = +1.4200$	$s_{1a,b} = 0.3685$			
L_{1b}	$R_{1b} = +4.2000$	$d_{1b} = 0.1367$	$n_{1b} = 1.625$		
	$R'_{1b} = +1.8000$	$s_{12} = 0.3322$		NN	
II L_2	$R_2 = -8.0000$	$d_2 = 0.2140$	$n_2 = 1.670$		
	$R'_2 = -3.0000$	$s_{23} = 0.0200$			NS
III L_3	$R_3 = +6.0000$	$d_3 = 0.0880$	$n_3 = 1.713$		
	$R'_3 = +1.1080$	$s_f = s_{34} = 0.4781$			

-continued

IV L_{4a}	$R_{4a} = -1.0000$	$d_{4a} = 0.1200$	$n_{4a} = 1.670$	
	$R'_{4a} = -1.3000$	$s_{4a,b} = 0.1650$		NO
L_{4b}	$R_{4b} = +4.5000$	$d_{4b} = 0.4113$	$n_{4b} = 1.788$	
	$R'_{4b} = -2.4290$	$s_{45} = 0.2060$		
V L_{5a}	$R_{5a} = +1.8300$	$d_{5a} = 0.3833$	$n_{5a} = 1.744$	
	$R'_{5a} = -13.150$	$s_{5a,b} = 0.0100$		EO
L_{5b}	$R_{5b} = +5.6800$	$d_{5b} = 0.1550$	$n_{5b} = 1.795$	
	$R'_{5b} = +2.1070$	$CS = s_{56} = 0.6610$		
VI L_6	$R_6 = -3.1200$	$d_6 = 0.0620$	$n_6 = 1.805$	
	$R'_6 = +1.3000$	$s_{67} = 0$		O
VII L_7	$R_7 = +1.3000$	$d_7 = 0.4247$	$n_7 = 1.520$	
	$R'_7 = -9.6900$	$s_{78} = 0.0044$		
VIII L_8	$R_8 = +9.6900$	$d_8 = 0.1695$	$n_8 = 1.720$	
	$R'_8 = -3.5500$	$s_{89} = 0.0040$		
IX L_9	$R_9 = +5.1200$	$d_9 = 0.19597$	$n_9 = 1.788$	
	$R'_9 = -2.5472$			

Aspherical surfaces: R_{4b} with $c_1 = (2 \cdot R_{4b})^{-1}$, $c_2 = -1.390\,4948 \cdot 10^{-2}$, $c_3 = -1.532\,5255 \cdot 10^{-2}$, $c_4 = c_5 = 0$
R_9 with $c_1 = (2 \cdot 9)^{-1}$, $c_2 = -4.405\,4084 \cdot 10^{-2}$, $c_3 = c_4 = c_5 = 0$.

15. A lens system as defined in claim 1, wherein the characteristics of the components of the system and their spatial relationship to each other are substantially in the proportions indicated by the data in the following table, all linear dimensions of radii, thicknesses, and spacings being expressed in proportion to the equivalent focal length of the entire system, which is considered as unity:

I L_{1a}	$R_{1a} = +2.47176$	$d_{1a} + 0.130780$	$n_{1a} = 1.62299$		
	$R'_{1a} = +1.43597$	$s_{1a,b} = 0.379206$			
L_{1b}	$R_{1b} = +5.06090$	$d_{1b} = 0.119586$	$n_{1b} = 1.57376$		
	$R'_{1b} = +1.67312$	$s_{12} = 0.327155$		NN	
II L_2	$R_2 = -12.2972$	$d_2 = 0.204174$	$n_2 = 1.68628$		
	$R'_2 = -2.65889$	$s_{23} = 0.006045$			NS
III L_3	$R_3 = +19.9265$	$d_3 = 0.079438$	$n_3 = 1.48787$		
	$R'_3 = +1.03249$	$s_1 = s_{34} = 0.513494$			
IV L_{4a}	$R_{4a} = -1.06224$	$d_{4a} = 0.143429$	$n_{4a} = 1.66526$		
	$R'_{4a} = -1.51053$	$s_{4a,b} = 0.006604$		NO	
L_{4b}	$R_{4b} = +4.80894$	$d_{4b} = 0.310924$	$n_{4b} = 1.75862$		
	$R'_{4b} = -2.33692$	$s_{45} = 0.486479$			
V L_{5a}	$R_{5a} = +1.78534$	$d_{5a} = 0.632408$	$n_{5a} = 1.74400$		
	$R'_{5a} = -4.53844$	$s_{5a,b} = 0.140780$		EO	
L_{5b}	$R_{5b} = 5.04251$	$d_{5b} = 0.104960$	$n_{5b} = 1.80975$		
	$R'_{5b} = +1.92364$	$CS = s_{56} = 0.278537$			
VI L_6	$R_6 = +19.36343$	$d_6 = 0.075558$	$n_6 = 1.80518$		
	$R'_6 = +1.31773$	$s_{67} = 0$			O
VII L_7	$R_7 = +1.31773$	$d_7 = 0.208427$	$n_7 = 1.51009$		
	$R'_7 = +7.64015$				

-continued

		$s_{78} = 0.018470$		
VIII L_8	$R_8 = +6.67422$ $R'_8 = -3.70201$	$d_8 = 0.165331$ $s_{89} = 0.004403$	$n_8 = 1.71300$	
IX L_9	$R_9 = +4.36936$ $R'_9 = -2.11985$	$d_9 = 0.216561$	$n_9 = 1.78581$	

Aspherical surfaces; R'_{8a} with $c_1 = (2 \cdot R'_{8a})^{-1}$, $c_2 = +3.155\,8520 \cdot 10^{-2}$, $c_3 = -1.093\,4658 \cdot 10^{-2}$, $c_4 = c_5 = 0$, R'_7 with $c_1 = (2 \cdot R_7)^{-1}$, $c_2 = +7.743\,2718 \cdot 10^{-2}$, $c_3 = c_4 = c_5 = 0$.

16. A lens system as defined in claim 1, wherein the characteristics of the components of the system and their spatial relationship to each other are substantially in the proportions indicated by the data in the following table, all linear dimensions of radii, thicknesses, and spacings being expressed in proportion to the equivalent focal length of the entire system, which is considered as unity:

I L_{1a}	$R_{1a} = +2.74796$ $R'_{1a} = +1.38529$	$d_{1a} = 0.113696$	$n_{1a} = 1.62299$		
I L_{1b}	$R_{1b} = +4.72779$ $R'_{1b} = +1.62153$	$s_{1a,b} = 0.369517$ $d_{1b} = 0.113050$ $s_{12} = 0.336512$	$n_{1b} = 1.63281$	NN	
II L_2	$R_2 = -9.76130$ $R'_2 = -2.55659$	$d_2 = 0.251728$ $s_{23} = 0.003873$	$n_2 = 1.70223$		NS
III L_3	$R_3 = +5.24780$ $R'_3 = +1.14502$	$d_3 = 0.075885$ $s_1 = s_{34} = 0.496877$	$n_3 = 1.59282$		
IV L_{4a}	$R_{4a} = -1.08216$ $R'_{4a} = -1.64005$	$d_{4a} = 0.108446$ $s_{4a,b} = 0.031053$	$n_{4a} = 1.73174$	NO	
IV L_{4b}	$R_{4b} = +8.23292$ $R'_{4b} = -1.87001$	$d_{4b} = 0.379461$ $s_{45} = 0.176652$	$n_{4b} = 1.75711$		
V L_{5a}	$R_{5a} = +1.56677$ $R'_{5a} = +233.608$	$d_{5a} = 0.465503$ $s_{5a,b} = 0.079057$	$n_{5a} = 1.74400$	EO	
V L_{5b}	$R_{5b} = +6.15175$ $R'_{5b} = +1.70231$	$d_{5b} = 0.156555$ $CS = s_{56} = 0.596110$	$n_{5b} = 1.71941$		
VI L_6	$R_6 = -5.99853$ $R'_6 = +1.11299$	$d_6 = 0.089333$ $s_{67} = 0$	$n_6 = 1.80518$	O	
VII L_7	$R_7 = +1.11299$ $R'_7 = -27.8242$	$d_7 = 0.286056$ $s_{78} = 0.003799$	$n_7 = 1.51009$		
VIII L_8	$R_8 = +5.38523$ $R'_8 = -3.54530$	$d_8 = 0.167282$ $s_{89} = 0.003731$	$n_8 = 1.71360$		
IX L_9	$R_9 = +5.52585$ $R'_9 = -2.37677$	$d_9 = 0.189790$	$n_9 = 1.78730$		

Aspherical surfaces: R'_{8a} with $c_1 = (2 \cdot R'_{8a})^{-1}$, $c_2 = +2.816\,6962 \cdot 10^{-2}$, $c_3 = -7.553\,0319 \cdot 10^{-3}$, $c_4 = c_5 = 0$, R'_7 with $c_1 = (2 \cdot R'_7)^{-1}$, $c_2 = +6.553\,3496 \cdot 10^{-2}$, $c_3 = c_4 = c_5 = 0$.

17. A lens system as defined in claim 1, wherein the characteristics of the components of the system and their spatial relationship to each other are substantially in the proportions indicated by the data in the following table, all linear dimensions of radii, thicknesses, and spacings being expressed in proportion to the equivalent focal length of the entire system, which is considered as unity:

L_{1a}	$R_{1a} = +3.06439$	$d_{1a} = 0.102379$	$n_{1a} = 1.62299$

-continued

I L_{1a}	$R'_{1a} = +1.23750$	$s_{1a,b} = 0.440991$			
L_{1b}	$R_{1b} = +10.38196$	$d_{1b} = 0.125732$	$n_{1b} = 1.66846$		
	$R'_{1b} = +2.10356$	$s_{12} = 0.262269$		NN	
II L_2	$R_2 = -9.76062$	$d_2 = 0.201702$	$n_2 = 1.74555$		
	$R'_2 = -2.47073$	$s_{23} = 0.005522$			NS
III L_3	$R_3 = +2.54629$	$d_3 = 0.084891$	$n_3 = 1.54834$		
	$R'_3 = +1.11281$	$s_i = s_{34} = 0.620145$			
IV L_{4a}	$R_{4a} = -1.18498$	$d_{4a} = 0.107960$	$n_{4a} = 1.65843$		
	$R'_{4a} = -2.07360$	$s_{4a,b} = 0.016611$		NO	
L_{4b}	$R_{4b} = +7.38277$	$d_{4b} = 0.494227$	$n_{4b} = 1.45818$		
	$R'_{4b} = -1.49120$	$s_{45} = 0.003862$			
V L_{5a}	$R_{5a} = +1.71860$	$d_{5a} = 0.524953$	$n_{5a} = 1.74400$		
	$R'_{5a} = -8.79790$	$s_{5a,b} = 0.042897 = s_{IN}$		EO	
L_{5b}	$R_{5b} = +2.52240$	$d_{5b} = 0.164345$	$n_{5b} = 1.59810$		
	$R'_{5b} = +2.42654$	$CS = s_{5a} = 0.345369$			
VI L_{6a}	$R_{6a} = -2.26150$	$d_{6a} = 0.212701$	$n_{6a} = 1.62109$		
	$R'_{6a} = -1.87031$	$s_{6a,b} = 0$			
L_{6b}	$R_{6b} = -1.87031$ $R'_{6b} = +0.99891$	$d_{6b} = 0.067369$	$n_{6b} = 1.80518$	O	
		$s_{67} = 0$			
VII L_7	$R_7 = +0.99891$	$d_7 = 0.280335$	$n_7 = 1.62059$		
	$R'_7 = +7.52353$	$s_{78} = 0.141992$			
VIII L_8	$R_8 = -12.94667$	$d_8 = 0.167916$	$n_8 = 1.74400$		
	$R'_8 = -3.21190$	$s_{89} = 0.015969$			
IX L_9	$R_9 = +7.02160$	$d_9 = 0.239763$	$n_9 = 1.78742$		
	$R'_9 = -1.72219$				

Aspherical surfaces: R'_7 with $c_1 = (2 \cdot R'_7)^{-1}$, $c_2 = +1.137\,5238 \cdot 10^{-1}$, $c_3 = -9.1802926 \cdot 10^{-2}$, $c_4 = c_5 = 0$, R_8 with $c_1 = (2 \cdot R_8)^{-1}$, $c_2 = -4.471\,3009 \cdot 10^{-2}$, $c_3 = -6.452\,3482 \cdot 10^{-2}$, $c_4 = c_5 = 0$.

18. A lens system as defined in claim **1**, wherein the characteristics of the components of the system and their spatial relationship to each other are substantially in the proportions indicated by the data in the following table, all linear dimensions of radii, thicknesses, and spacings being expressed in proportion to the equivalent focal length of the entire system, which is considered as unity:

I L_{1a}	$R_{1a} = +2.59200$	$d_{1a} = 0.117052$	$n_{1a} = 1.62299$		
	$R'_{1a} = +1.32769$	$s_{1a,b} = 0.418691$			
L_{1b}	$R_{1b} = +6.22602$	$d_{1b} = 0.117974$	$n_{1b} = 1.62354$		
	$R'_{1b} = +1.63444$	$s_{12} = 0.288116$		NN	
II L_2	$R_2 = -36.16198$	$d_2 = 0.232183$	$n_2 = 1.66946$		
	$R'_2 = -2.78970$	$s_{23} = 0.004672$			NS
III L_3	$R_3 = +3.77575$	$d_3 = 0.089881$	$n_3 = 1.71321$		
	$R'_3 = +1.17608$	$s_i = s_{34} = 0.531844$			
IV L_{4a}	$R_{4a} = -1.11123$	$d_{4a} = 0.186795$	$n_{4a} = 1.73764$		
	$R'_{4a} = -1.49128$	$s_{4a,b} = 0.009011$		NO	
	$R_{4b} = +4.21870$				

-continued

L_{4b}	$R'_{4b} = -2.04042$	$d_{4b} = 0.411960$	$n_{4b} = 1.73270$	
		$s_{4b} = 0.013735$		
V L_{5a}	$R_{5a} = +1.43571$	$d_{5a} = 0.667893$	$n_{5a} = 1.74400$	
	$R'_{5a} = +4.91662$	$s_{5a,b} = 0.051485 = s_{IN}$		EO
L_{5b}	$R_{5b} = +12.54440$	$d_{5b} = 0.104870$	$n_{5b} = 1.75644$	
	$R'_{5b} = +1.34195$	$CS = s_{56} = 0.322004$		
VI L_{6a}	$R_{6a} = \pm$plan	$d_{6a} = 0.156762$	$n_{6a} = 1.54814$	
	$R'_{6a} = -3.11895$	$s_{6a,b} = 0.079336$		O
L_{6b}	$R_{6b} = -2.84169$	$d_{6b} = 0.074429$	$n_{6b} = 1.80518$	
	$R'_{6b} = +1.69106$	$s_{67} = 0$		
VII L_7	$R_7 = +1.69106$	$d_7 = 0.320337$	$n_7 = 1.51009$	
	$R'_7 = -2.06825$	$s_{78} = 0.003780$		
VIII L_8	$R_8 = -21.43097$	$d_8 = 0.171855$	$n_8 = 1.71328$	
	$R'_8 = -2.47440$	$s_{89} = 0.004522$		
IX L_9	$R_9 = -30.57726$	$d_9 = 0.176090$	$n_9 = 1.71368$	
	$R'_9 = -1.93341$			

Aspherical surface R_{6a} with $c_1 = c_4 = c_5 = 0$, $c_2 = -1.984\ 1317 \cdot 10^{-1}$, $c_3 = -2.189\ 7347 \cdot 10^{-2}$.

19. A lens system as defined in claim **1**, wherein the characteristis of the components of the system and their spatial relationship to each other are substantially in the proportions indicated by the data in the following table, all linear dimensions of radii, thicknesses, and spacings being expressed in proportion to the equivalent focal length of the entire system, which is considered as unity:

I L_{1a}	$R_{1a} = +3.47226$	$d_{1a} = 0.110822$	1.62299/58.06	
	$R'_{1a} = +1.39191$	$s_{1a,b} = 0.386569$		
L_{1b}	$R_{1b} = +7.23358$	$d_{1b} = 0.113060$	1.74400/44.77	
	$R'_{1b} = +1.74031$	$s_{12} = 0.314181$		NN
II L_2	$R_2 = -9.78625$	$d_2 = 0.201867$	1.80518/25.43	
	$R'_2 = -2.49382$	$s_{23} = 0.004851$		NS
III L_3	$R_3 = +2.08322$	$d_3 = 0.097762$	1.71300/53.85	
	$R'_3 = +1.14642$	$s_I = s_{34} = 0.667914$		
IV L_{4a}	$R_{4a} = -1.27713$	$d_{4a} = 0.117911$	1.72830/28.68	
	$R'_{4a} = -2.00964$	$s_{4a,b} = 0.009328$		NO
L_{4b}	$R_{4b} = +5.82914$	$d_{4b} = 0.554481$	1.57250/57.60	
	$R'_{4b} = -1.59620$	$s_{45} = 0.005970$		
V L_{5a}	$R_{5a} = +1.42266$	$d_{5a} = 0.493286$	1.74400/44.77	
	$R'_{5a} = +26.75841$	$s_{5a,b} = 0.070896 = s_{IN}$		EO
L_{5b}	$R_{5b} = +2.94259$	$d_{5b} = 0.107090$	1.75520/27.58	
	$R'_{5b} = +1.34296$	$CS = s_{56} = 0.531346$		
VI L_6	$R_6 = -2.51162$	$d_6 = 0.144031$	1.80518/25.43	
	$R'_6 = +1.16310$	$s_{67} = 0$		O
VII L_7	$R_7 = +1.16310$	$d_7 = 0.304106$	1.53996/59.73	
	$R'_7 = -9.12969$	$s_{78} = 0.016791$		

-continued

VIII L_8	$R_8 = +20.38444$ $R'_8 = -4.00969$	$d_8 = 0.162314$ $s_{89} = 0.003731$	1.74400/44.77		
IX L_9	$R_9 = +6.35608$ $R'_9 = -1.83008$	$d_9 = 0.228733$	1.78831/47.37		

Aspherical surfaces: R'_{5a} with $c_1 = (2 \cdot R'_{5a})^{-1}$, $c_2 = +3.864\ 7311 \cdot 10^{-3}$, $c_3 = -6.078\ 3773 \cdot 10^{-3}$, $c_4 = c_5 = 0$, R'_7 with $c_1 = (2 \cdot R'_7)^{-1}$, $c_2 = +1.177\ 2204 \cdot 10^{-1}$, $c_3 = +6.739\ 1168 \cdot 10^{-3}$, $c_4 = c_5 = 0$.

20. A lens system as defined in claim **1**, wherein the characteristics of the components of the system and their spatial relationship to each other are substantially in the proportions indicated by the data in the following table, all linear dimensions of radii, thicknesses, and spacings being expressed in proportion to the equivalent focal length of the entire system, which is considered as unity:

21. A lens system as defined in claim **1**, wherein the characteristics of the components of the system and their spatial relationship to each other are substantially in the proportions indicated by the data in the following table, all linear dimensions of radii, thicknesses, and spacings being expressed in proportion to the equivalent focal length of the entire system, which is considered as unity:

I L_{1a}	$R_{1a} = +3.42199$ $R'_{1a} = +1.33320$	$d_{1a} = 0.104456$ $s_{1a,b} = 0.415587$	1.62299/58.06		
I L_{1b}	$R_{1b} = +8.84707$ $R'_{1b} = +1.92420$	$d_{1b} = 0.124974$ $s_{12} = 0.269348$	1.62299/58.06	NN	
II L_2	$R_2 = -14.22209$ $R'_2 = -2.47531$	$d_2 = 0.211897$ $s_{23} = 0.011192$	1.71736/29.52		NS
III L_3	$R_3 = +3.11656$ $R'_3 = +1.21412$	$d_3 = 0.090653$ $s_1 = s_{34} = 0.562944$	1.74400/44.77		
IV L_{4a}	$R_{4a} = -1.06668$ $R'_{4a} = -1.38211$	$d_{4a} = 0.111544$ $s_{4a,b} = 0.003731$	1.76180/26.95	NO	
IV L_{4b}	$R_{4b} = +5.66302$ $R'_{4b} = -1.76505$	$d_{4b} = 0.393949$ $s_{45} = 0.007088$	1.67790/55.20		
V L_{5a}	$R_{5a} = +1.46325$ $R'_{5a} = +5.66302$	$d_{5a} = 0.503628$ $s_{5a,b} = 0$	1.74400/44.77	EO	
V L_{5b}	$R_{5b} = +5.66302$ $R'_{5b} = +1.30473$	$d_{5b} = 0.185410$ $CS = s_{56} = 0.520789$	1.62004/36.37		
VI L_{6a}	$R_{6a} = -8.11401$ $R'_{6a} = -2.28707$	$d_{6a} = 0.253306$ $s_{6a,b} = 0$	1.63854/55.38		
VI L_{6b}	$R_{6b} = -2.28707$ $R'_{6b} = +1.38211$	$d_{6b} = 0.133182$ $s_{67} = 0$	1.80518/25.43	O	
VII L_7	$R_7 = +1.38211$ $R'_7 = +11.79684$	$d_7 = 0.207047$ $s_{78} = 0.003731$	1.58913/61.24		
VIII L_8	$R_8 = +2.49330$ $R'_8 = +17.30998$	$d_8 = 0.176456$ $s_{89} = 0.017907$	1.78831/47.37		
IX L_9	$R_9 = +6.82834$ $R'_9 = -1.65421$	$d_9 = 0.239503$	1.78831/47.37		

Aspherical surfaces: R_{6a} with $c_1 = (2 \cdot R_{6a})^{-1}$, $c_2 = +3.388\ 7542 \cdot 10^{-3}$, $c_3 = +7.045\ 4329 \cdot 10^{-4}$, $c_4 = +2.543\ 9721 \cdot 10^{-4}$, $c_5 = 0$,
R'_8 with $c_1 = (2 \cdot R'_8)^{-1}$, $c_2 = +1,175\ 3002 \cdot 10^{-1}$, $c_3 = -1.076\ 9779 \cdot 10^{-2}$, $c_4 = c_5 = 0$.

I L_1	$R_1 = +3.12540$	$d_1 = 0.225586$	$n_1 = 1.69766$		
	$R'_1 = +1.67740$	$s_{12} = 0.283246$			
II L_2	$R_2 = +4.72183$	$d_2 = 0.804452$	$n_2 = 1.74855$	NN	
	$R'_2 = -6.03608$	$s_{23} = 0.202643$			
III L_3	$R_3 = +2.30430$	$d_3 = 0.151272$	$n_3 = 1.78831$		NS
	$R'_3 = +0.92630$	$s_f = s_{34} = 0.651910$			
IV L_{4a}	$R_{4a} = -1.42395$	$d_{4a} = 1.110675$	$n_{4a} = 1.58725$		
	$R'_{4a} = -2.48132$	$s_{4a,b} = 0.557327$		NO	
L_{4b}	$R_{4b} = +34.75847$	$d_{4b} = 0.333179$	$n_{4b} = 1.58324$		
	$R'_{4b} = -4.49128$	$s_{4b} = 0.005920$			
V L_{5a}	$R_{5a} = +2.21649$	$d_{5a} = 0.818633$	$n_{5a} = 1.66838$		
	$R'_{5a} = -15.46901$	$s_{5a,b} = 0.257125$		EO	
L_{5b}	$R_{5b} = -40.83014$	$d_{5b} = 0.145921$	$n_{5b} = 1.71241$		
	$R'_{5b} = +1.58895$	$s_{5a} = 0.322577$			
VI L_6	$R_6 = -23.68569$	$d_6 = 0.107960$	$n_6 = 1.80518$		
	$R'_6 = +1.86230$	$s_{67} = 0$			O
VII L_7	$R_7 = +1.86230$	$d_7 = 0.664753$	$n_7 = 1.65750$		
	$R'_7 = -5.57027$	$s_{78} = 0.003278$			
VIII L_8	$R_8 = +4.03129$	$d_8 = 0.315353$	$n_8 = 1.71228$		
	$R'_8 = -6.81727$	$s_{89} = 0.001973$			
IX L_9	$R_9 = +2.15163$	$d_9 = 0.360637$	$n_9 = 1.70904$		
	$R'_9 = \pm$plan				

Aspherical surface: R_{4b} with $c_1 = (2 \cdot R_{4b})^{-1}$, $c_2 = +3.018\,9030 \cdot 10^{-4}$, $c_3 = c_4 = c_5 = 0$.

22. A lens system as defined in claim 1, wherein the characteristics of the components of the system and their spatial relationship to each other are substantially in the proportions indicated by the data in the following table, all linear dimensions of radii, thicknesses, and spacings being expressed in proportion to the equivalent focal length of the entire system, which is considered as unity:

I L_1	$R_1 = +3.37508$	$d_1 = 0.156624$	$n_1 = 1.67758$		
	$R'_1 = +1.81527$	$s_{12} = 0.229605$			
II L_2	$R_2 = +5.13335$	$d_2 = 0.251159$	$n_2 = 1.70684$	NN	
	$R'_2 = -7.48648$	$s_{23} = 0.540079$			
III L_3	$R_3 = +3.09067$	$d_3 = 0.104627$	$n_3 = 1.78831$		NS
	$R'_3 = +0.98321$	$s_f = s_{34} = 1.108094$			
IV L_{4a}	$R_{4a} = -1.05451$	$d_{4a} = 1.006475$	$n_{4a} = 1.60156$		
	$R'_{4a} = -1.89550$	$s_{4a,b} = 0.046315$		NO	
L_{4b}	$R_{4b} = +7.53207$	$d_{4b} = 0.493897$	$n_{4b} = 1.64987$		
	$R'_{4b} = -3.57956$	$s_{4b} = 0.003475$			
V L_{5a}	$R_{5a} = +2.22790$	$d_{5a} = 0.464257$	$n_{5a} = 1.57938$		
	$R'_{5a} = +8.61454$	$s_{5a,b} = 0.346597$		EO	
L_{5b}	$R_{5b} = +4.03619$	$d_{5b} = 0.144828$	$n_{5b} = 1.80797$		

-continued

	$R'_{5b} = +1.76905$	$s_{56} = 0.327984$		
VI L_6	$R_6 = +25.48305$ $R'_6 = +1.85408$	$d_6 = 0.118495$ $s_{67} = 0$	$n_6 = 1.80518$	O
VII L_7	$R_7 = +1.85408$ $R'_7 = -4.65393$	$d_7 = 0.543889$ $s_{78} = 0.002205$	$n_7 = 1.49541$	
VIII L_8	$R_8 = +3.29999$ $R'_8 = +139.3801$	$d_8 = 0.266631$ $s_{89} = 0.002272$	$n_8 = 1.69932$	
IX L_9	$R_9 = +2.08234$ $R'_9 = \pm$ plan	$d_9 = 0.382252$	$n_9 = 1.60202$	

Asperical surface R_{4b} with $c_1 = (2 \cdot R_{4b})^{-1}$, $c_2 = -1.868\ 2513 \cdot 10^{-3}$, $c_3 = c_4 = 0$.

23. A lens system as defined in claim 1, wherein the characteristics of the components of the system and their spatial relationship to each other are substantially in the proportions indicated by the data in the following table, all linear dimensions of radii, thicknesses, and spacings being expressed in proportion to the equivalent focal length of the entire system, which is considered as unity:

I L_1	$R_1 = +3.17554$ $R'_1 = +1.72019$	$d_1 = 0.147782$ $s_{12} = 0.373225$	$n_1 = 1.74400$		
II L_2	$R_2 = +5.39546$ $R'_2 = -1.82276$	$d_2 = 0.683184$ $s_{23} = 0$	$n_2 = 1.74400$	NN	
III L_{3a}	$R_{3a} = -1.82276$ $R'_{3a} = -6.47118$	$d_{3a} = 0.132500$ $s_{3a,b} = 0.186613$	$n_{3a} = 1.72293$		NS
III L_{3b}	$R_{3b} = +2.19333$ $R'_{3b} = +0.96524$	$d_{3b} = 0.114355$ $s_1 = s_{34} = 0.61504$	$n_{3b} = 1.78831$		
IV L_{4a}	$R_{4a} = -1.51067$ $R'_{4a} = -2.27995$	$d_{4a} = 1.206328$ $s_{4a,b} = 0.589354$	$n_{4a} = 1.56770$	NO	
IV L_{4b}	$R_{4b} = +76.89089$ $R'_{4b} = -4.93095$	$d_{4bb} = 0.378144$ $s_{45} = 0.054395$	$n_{4b} = 1.58215$		
V L_{5a}	$R_{5a} = +1.94227$ $R'_{5a} = -13.11638$	$d_{5a} = 0.672095$ $s_{5a,b} = 0.276209$	$n_{5a} = 1.76302$	EO	
V L_{5b}	$R_{5b} = -6.06972$ $R'_{5b} = +1.73584$	$d_{5b} = 0.092661$ $s_{56} = 0.300766$	$n_{5b} = 1.84666$		
VI L_6	$R_6 = -17.50515$ $R'_6 = +1.63509$	$d_6 = 0.090040$ $s_{67} = 0$	$n_6 = 1.81003$		O
VII L_7	$R_7 = +1.63509$ $R'_7 = -3.44805$	$d_7 = 0.575886$ $s_{78} = 0.002056$	$n_7 = 1.68714$		
VIII L_8	$R_8 = +3.83796$ $R'_8 = -7.65103$	$d_8 = 0.271290$ $s_{89} = 0.002540$	$n_8 = 1.69782$		
IX L_9	$R_9 = +2.20451$ $R'_9 = \pm$plan	$d_9 = 0.291411$	$n_9 = 1.62890$		

24. A lens system as defined in claim 1, wherein the characteristics of the components of the system and their spatial relationship to each other are substantially in the proportions indicated by the data in the following

table, all linear dimensions of radii, thicknesses, and spacings being expressed in proportion to the equivalent focal length of the entire system, which is considered as unity:

I L_1	$R_1 = +3.38273$ $R'_1 = +1.61177$	$d_1 = 0.139963$ $s_{12} = 0.370064$	1.63854/55.38	
II L_2	$R_2 = -52.57847$ $R'_2 = -4.06399$	$d_2 = 0.244159$ $s_{23} = 0.301373$	1.67270/32.20	NN
III L_3	$R_3 = -1.98189$ $R'_3 = +0.83213$	$d_3 = 0.406607$ $s_1 = s_{34} = 0.954689$	1.74400/44.77	NS
IV L_{4a}	$R_{4a} = -1.00073$ $R'_{4a} = -1.38657$	$d_{4a} = 0.643115$ $s_{4a,b} = 0.088154$	1.62299/58.06	NO
IV L_{4b}	$R_{4b} = +4.65051$ $R'_{4b} = -3.79456$	$d_{4b} = 0.300803$ $s_{45} = 0.001678$	1.62299/58.06	
V L_{5a}	$R_{5a} = +1.71929$ $R'_{5a} = +7.69345$	$d_{5a} = 0.334326$ $s_{5a,b} = 0.341608$	1.70181/41.02	EO
V L_{5b}	$R_{5b} = +5.24069$ $R'_{5b} = +1.26146$	$d_{5b} = 0.093388$ $s_{56} = 0.211105$	1.80518/25.43	
VI L_6	$R_6 = +7.85137$ $R'_6 = +1.57841$	$d_6 = 0.108288$ $s_{67} = 0$	1.80518/25.43	O
VII L_7	$R_7 = +1.57841$ $R'_7 = -2.70741$	$d_7 = 0.319259$ $s_{78} = 0.001678$	1.48749/70.45	
VIII L_8	$R_8 = +1.87531$ $R'_8 = +300.6715$	$d_8 = 0.181039$ $s_{89} = 0.001678$	1.65844/50.88	
IX L_9	$R_9 = +4.84509$ $R'_9 = -23.3890$	$d_9 = 0.326071$	1.62299/58.06	

25. A lens system as defined in claim **1**, wherein the characteristics of the components of the system and their spatial relationship to each other are substantially in the proportions indicated by the data in the following table, all linear dimensions of radii, thicknesses, and spacings being expressed in proportion to the equivalent focal length of the entire system, which is considered as unity:

I L_1	$R_1 = +2.81910$ $R'_1 = +1.60408$	$d_1 = 0.138164$ $s_{12} = 0.398024$	1.62299/58.06	
II L_2	$R_2 = +4.87862$ $R'_2 = -6.62313$	$d_2 = 0.332861$ $s_{23} = 0.336934$	1.64250/57.94	NN
III L_3	$R_3 = +2.25473$ $R'_3 = +0.79371$	$d_3 = 0.141277$ $s_1 = s_{34} = 0.543265$	1.74400/44.77	NS
IV L_{4a}	$R_{4a} = -1.38496$ $R'_{4a} = -2.72430$	$d_{4a} = 0.529119$ $s_{4a,b} = 0.038339$	1.62004/36.37	NO
IV L_{4b}	$R_{4b} = +10.56737$ $R'_{4b} = -3.64117$	$d_{4b} = 0.178584$ $s_{45} = 0.264594$	1.64250/57.94	
V L_{5a}	$R_{5a} = +1.59675$ $R'_{5a} = -56.84085$	$d_{5a} = 0.285969$ $s_{5a,b} = 0.408633$	1.78470/26.08	EO

-continued

L_{5b}	$R_{5b} = -10.07983$ $R'_{5b} = +1.33822$	$d_{5b} = 0.074812$ $s_{56} = 0.204165$	1.80518/25.43	
VI L_6	$R_6 = -9.53618$ $R'_6 = +1.18245$	$d_6 = 0.068505$ $s_{67} = O$	1.78470/26.08	O
VII L_7	$R_7 = +1.18245$ $R'_7 = -2.53940$	$d_7 = 0.396121$ $s_{78} = 0.002016$	1.71300/53.85	
VIII L_8	$R_8 = +1.68615$ $R'_8 = -4.65915$	$d_8 = 0.209613$ $s_{89} = 0.002016$	1.64250/57.94	
IX L_9	$R_9 = +2.33476$ $R'_9 = -7.91351$	$d_9 = 0.184984$	1.56384/60.82	

* * * * *

United States Patent [19]

Deml et al.

[11] **4,009,386**

[45] **Feb. 22, 1977**

[54] **METHOD AND ARRANGEMENT FOR AUTOMATICALLY FOCUSSING AN OBJECTIVE ONTO A SUBJECT, USING AUTOCOLLIMATION**

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[21] Appl. No.: **619,396**

[30] **Foreign Application Priority Data**

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[52] **U.S. Cl.** **250/201**; 354/25

[51] **Int. Cl.²** **G01J 1/20**

[58] **Field of Search** ..... 250/201, 202, 203, 234 R, 250/237 G; 356/4, 5; 354/25

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Primary Examiner—David C. Nelms

Attorney, Agent, or Firm—Michael J. Striker

[57] **ABSTRACT**

An optical apparatus is provided with an objective and an autocollimation lens having a position and orientation bearing a known relationship to the position and orientation of the objective. A grating has alternating transmissive and non-transmissive portions. The grating is so positioned relative to the autocollimation path of the autocollimation lens that the latter projects an image of the grating onto the subject, and the image of the grating on the subject is projected back onto the grating. A photoelectric detector derives from the light projected back onto the grating an electrical signal indicative of the degree of focus of the objective. The setting of the objective is controlled in dependence upon the electrical signal.

18 Claims, 5 Drawing Figures

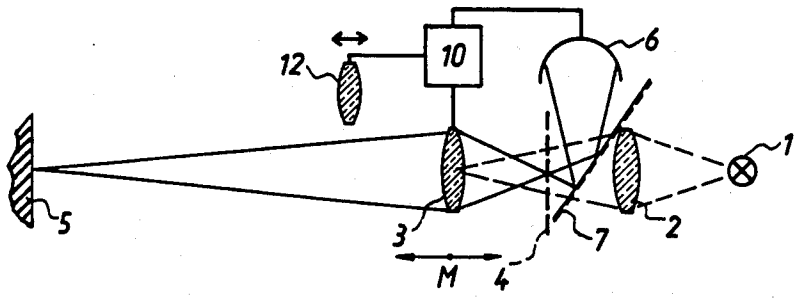

Fig.1

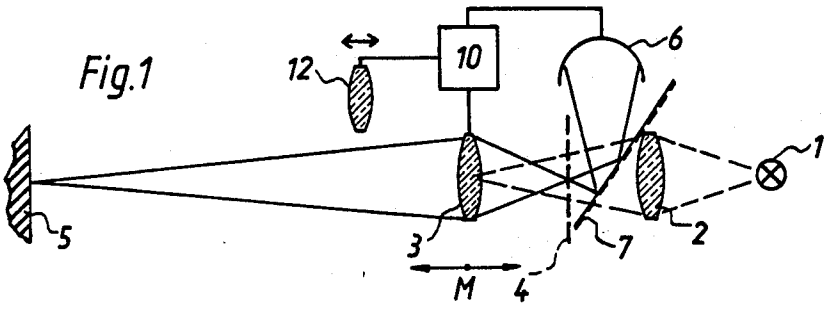

Fig.2

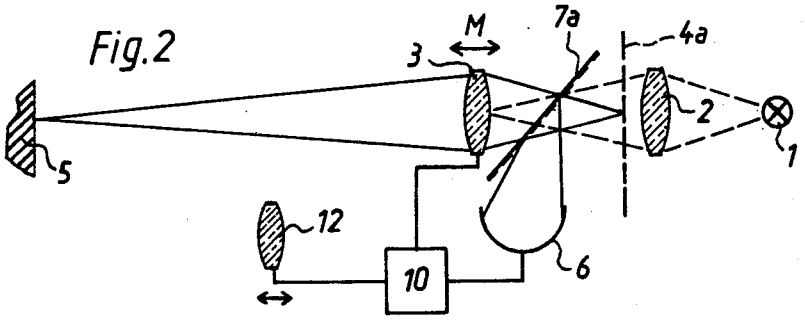

Fig.3

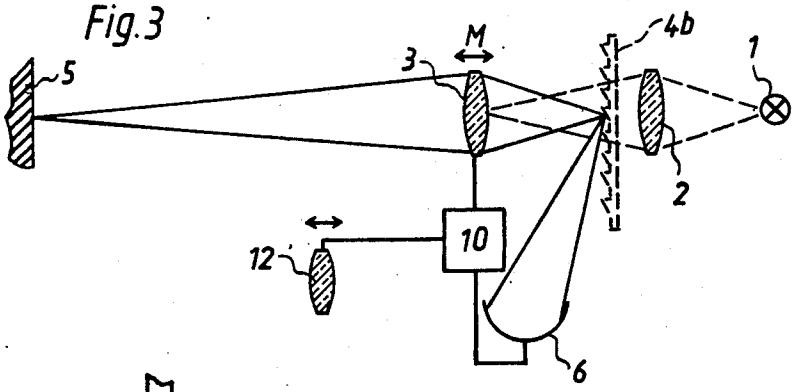

Fig.3a

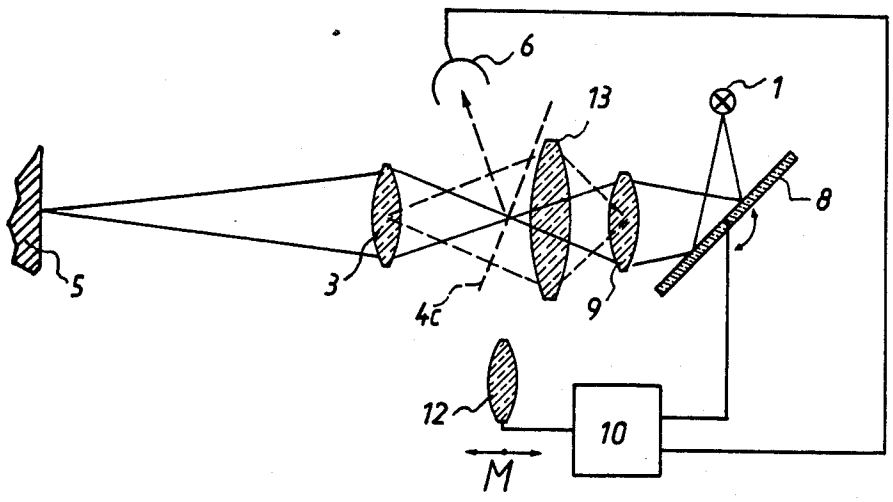

Fig.4

METHOD AND ARRANGEMENT FOR AUTOMATICALLY FOCUSSING AN OBJECTIVE ONTO A SUBJECT, USING AUTOCOLLIMATION

BACKGROUND OF THE INVENTION

The invention relates to a method and arrangement for automatically focussing an objective onto a subject or test object. More particularly, the invention relates to automatic focussing expedients involving autocollimation and the use of gratings for generating an electrical signal which can be used to control the operation of means for automatically adjusting the setting of the objective.

It has been many times proposed (for example in Federal Republic of Germany published patent application DT-OS **1,908,687**) to use gratings or rasters located in the autocollimation beam path of a camera objective or autocollimation objective. Specifically, these known expedients have involved the projection of the image of one grating onto the subject or test object. Then the image, on the subject, of the first grating is projected, using autocollimation, onto the second grating. The extent to which the image of the first grating registers with the second grating is detected photoelectrically, by detecting the intensity of the light projected onto the second grating, and an electrical signal is generated for controlling electromechanical means for effecting proper or optimal focussing of the objective.

The known proposals for effecting automatic focussing in this way have not, to our knowledge, met with any practical success. The reason for this, at least in part, is that the use of two discrete gratings or rasters is relatively complicated and expensive, because they must be properly adjusted relative to each other and kept properly adjusted with very great precision.

SUMMARY OF THE INVENTION

It is a general object of the invention to provide a method and arrangement for effecting automatic focussing of an objective in which use can be made of only a single grating or raster in the autocollimation path of the objective or separate autocollimation lens.

According to the most general concept of the present invention, this object is achieved by projecting the image of the light-transmitting portions of the grating onto the subject or test object, and then projecting such image on the subject back along the autocollimation path onto the selfsame grating.

In this way, it becomes possible to dispense altogether with the second grating, obviating the necessity for the complicated and difficult fine adjustment of the relative positions of the two gratings.

The invention also embraces a number of particular concepts concerning the disposition of components of an optical system to effect the above-mentioned action in a variety of ways. However, these will best be understood from the description, below, of preferred embodiments.

The novel features which are considered as characteristic for the invention are set forth in particular in the appended claims. The invention itself, however, both as to its construction and its method of operation, together with additional objects and advantages thereof, will be best understood from the following description of specific embodiments when read in connection with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** depicts a first embodiment of the invention in which the grating employed in a transmission-absorption grating;

FIG. **2** depicts a second embodiment of the invention in which the grating employed is a transmission-reflection in which the grating employed is a transmission-reflection grating;

FIG. **3** depicts a third embodiment of the invention in which the grating employed is comprises of alternating first and second portions, with the first portions being transmissive and the second portions being inclined reflecting surface portions;

FIG. **3***a* is an enlarged-scale view of a portion of the grating of FIG. **3**; and

FIG. **4** depicts a fourth embodiment of the invention in which the grating employed is a transmission-reflection grating arranged at an angle relative to the autocollimation path.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

In the embodiment of FIG. **1**, a source **1** of modulated light transmits light through a condenser **2** through an inclined semitransmissive mirror **7** towards an absorptiontransmission grating **4**. The grating **4** is comprises of light-transmissive portions which alternate with nontransmissive portions. The light passing leftwards through the transmissive portions of grating **4** is projected by an autocollimation objective **3** onto the subject or test object **5**, to form on the subject **5** an image of the transmissive portions of the grating **4**. The light from the image on the subject **5** is reflected back towards the autocollimation objective **3**, which in turn projects the light image on the subject **5** back onto the grating **4**. The back-reflected light passing through the transmissive portions of grating **4** impinges upon the front surface of semitransmissive mirror **7** and is deflected out of the autocollimation path towards a photoelectric detector **6** operative for generating a signal whose value is indicative of the intensity of received light.

The electrical signal generated by the photoelectric detector **6** serves as a control signal applied to means **10** for adjusting the settings of the autocollimation objective **3** and of an associated camera objective **12**. The autocollimation objective **3** can be shifted in the directions indicated by the double-headed arrow **M**, and the adjusting means **10** also effects corresponding shifting adjustment of the camera objective **12**.

The construction of the adjusting means **10** does not as such form part of the present invention. However, by way of example, the adjusting means **10** can be comprised of a positioning motor activatable by the user of the camera to move the autocollimation objective **3** and accordingly the camera objective **12** through their entire range of distance settings. During the performance of this range of movement, the value of the photoelectric signal applied to adjusting means **10** will change. The adjusting means **10** can include a resettable circuit for detecting and registering an extreme value of the light-indicating signal. Thereafter, the adjusting means **10** causes the autocollimation objective **3** and the camera objective **12** to be moved once more through their entire range of distance settings. However, during the movement, as soon as the value of the light-indicating signal reaches the extreme value regis-

tered during the preceding cycle of movement, the adjusting motor stops, so that the autocollimation objective 3 and camera objective 12 will assume and maintain the position corresponding to the extreme value of the light-indicating signal. These positions are assumed to correspond to proper, or at least optimal, focus. It will be understood that the manner of operation of the adjusting means 10 just explained could be principle be different.

In the embodiment of FIG. 1 the splitting of the light beam does not occur until after the light, during its return trip, passes through the transmissive portions of the grating 4 a second time. In this embodiment, the extreme value to which the adjusting means 10 responds will be the maximum light intensity value as indicated by the maximum photocurrent.

It will be understood that the adjusting means 10 can adjust the distance settings of autocollimation objective 3 and of camera objective 12 in two separate but simultaneous actions, or else adjust the setting of only one of the objectives, with the other objective being connected, via a suitably designed linkage, to assume predetermined settings pre-correlated with the settings of the first objective.

In the embodiment of FIG. 2, the grating 4*a* is a transmission-reflection grating. It is comprised of alternating transmissive and non-transmissive portions. The non-transmissive portions, at the side of the grating facing towards the subject or test object 5, are mirrored so as to be reflecting.

In the embodiment of FIG. 2, the modulated light from source 1 is projected by condenser 2 through the transmissive portions of grating 4*a*, and through a semitransmissive mirror 7*a* towards an autocollimation objective 3 which projects an image of the transmissive portions of the grating 4*a* onto the surface of the subject or test object 5. At the same time, the autocollimation objective 3 projects an image of the light image on subject 5 back through semitransmissive mirro 7*a* onto the grating 4*a*. It will be noted that in the embodiments of both FIGS. 1 and 2 the grating is located in the back focal plane of the autocollimation objective 3. The light projected back onto the grating 4*a* is reflected off the reflecting grating portions towards the back side of semitransmissive mirror 7*a*, and from there is reflected towards the photoelectric detector 6. The signal generated by photoelectric detector 6 is utilized to control the adjusting means 10 in the manner described with respect to FIG. 1. In the embodiment of FIG. 2, however, the objectives 3 and 12 are automatically stopped in positions corresponding to minimum light intensity and minimum value of the photocurrent.

In the embodiment of FIG. 3, the grating 4*b* employed is comprised of alternating first and second portions. The first portions are simple transmissive portions. The second portions have inclined mirrored surfaces each making an angle with respect to the general plane of the grating 4*b*. The grating 4*b* of FIG. 3 is depicted, on a larger scale and in somewhat greater detail, in FIG. 3*a*. The use of a grating 4*b* having the illustrated inclined reflecting surfaces makes unnecessary the use of the separate semitransmissive mirrors 7 and 7*a* of FIGS. 1 and 2.

IN the embodiment of FIG. 3, modulated light from source 1 is projected by condenser 2 through the transmissive portions of grating 4*b* towards the autocollimation objective 3. The autocollimation objective 3 projects an image of the transmissive portion of the grating 4*b* onto the surface of subject or test object 5. At the same, the autocollimation objective 3 projects an image of light image on subject 5 back towards the surface of grating 4*b*. The part of the back-reflected light incident upon the reflecting inclined surface portions of grating 4*b* are deflected out of the autocollimation path towards the photoelectric detector 6. In other respects, the automatic focussing is performed as explained with reference to FIGS. 1 and 2.

In the embodiment of FIG. 4, use is made of a transmission-reflection grating 4*c* comprised of alternating transmissive and non-transmissive portions, with the non-transmissive portions being reflecting at the side of the grating4*c* facing towards the subject or test object 5. In FIG. 4, the light source 1 is not lined up with the optical axis of the autocollimation objective 3. Instead, the light source 1 cooperates with a pivotally mounted mirror 8 which deflects light from source 1 towards a cylindrical lens 9 to effect a linewise or strip-formed illumination of the grating 4*c*. The angle of inclination of grating 4*c* relative to the optical axis of autocollimation objective 3 is no selected that, during each period of movement of the pivotal mirror 8, the system goes through its whole range of distance settings. However, if the autocollimation objective 3 has a short focal lenght, which is usually the case, there may not be space enough in the lens arrangement to allow the deflection of a sufficient amount of light out of the autocollimation path and towards the photodetector 6. With this in mind, use is preferably made of the type of grating depicted in FIGS. 3 and 3*a*, to increase the angle of deflection of the back-reflected light, and use is furthermore preferably made of a field lens 13 whch serves, in a per se conventional manner, to increase the intensity of the light.

The arrangement of FIG. 4 operates somewhat differently from the arrangements of FIGS. 1–3. In FIGS. 1–3, the autocollimation objective 3 and the camera objective 12 were both moves through their whole range of distance settings and then stopped at the setting corresponding to an extreme value of the photocurrent generated by photodetector 6. In FIG. 4, however, the autocollimation objective 3 is not moved during the automatic focussing operation. Instead, the setting of the camera objective 12 is correlated with the angular position of the pivoting mirror 8. During a first or test run-through, the adjusting means 10 moves the camera objective 12 through its entire range of distance settings while simultaneously moving the pivotaing mirror 8 through its entire range of pivotal movement. For example, the camera objective 12 and the pivoting mirror 8 can be connected by a suitably designed linkage. A circuit in the adjusting means 10 registers an extreme value of the photocurrent generated during this period of movement. The cycle of movement is then repeated, and the pivoting mirror 8 and camera objective 12 are stopped when they reach a position corresponding to the extreme photocurrent value registered during the preceding cycle of movement. In this embodiment, the extreme value in question will be a photocurrent minimum.

In the foregoing embodiments, use has been made of an autocollimation objective 3 discrete from the camera objective 12. However, it is also within the scope of the invention to utilize the camera objective itself to project the image of the light-transmissive grating portions back onto the grating.

It will be understood that each of the elements described above, or two or more together, may also find a useful application in other types of constructions and arrangements, differing from the types described above.

While the invention has been illustrated and described as embodied in an automatic focussing arrangement making use of separate camera and autocollimation objectives, it is not intended to be limited to the details shown, since various modifications and structural changes may be made without departing in any way from the spirit of the present invention.

Without further analysis, the foregoing will so fully reveal the gist of the present invention that others can be applying current knowledge readily adapt if for various applications without omitting features that, from the standpoint of prior art, fairly constitute essential characteristics of the generic or specific aspects of this invention.

What is clamed as new and desired to be protected by Letters Patent is set forth in the appended claims.

1. A method for automatically focussing onto a subject the objective of an optical apparatus provided with autocollimation lens means having a position bearing a predetermined relationship to the position of the objective, comprising the steps of so positioning a grating relative to the autocollimation path of the autocollimation lens means as to cause the latter to project an image of the grating onto the subject and to cause the image of the grating on the subject to be projected back onto the grating and into steady register with the grating structure to an extent dependent upon the degree of focus of the objective; using photoelectric means to derive from the light projected back onto the grating an electrical signal indicative of the extent to which the image of the grating projected back onto the grating is in steady register with the grating structure and accordingly indicative of the degree of focus of the objective; and controlling the operation of means for adjusting the setting of the objective by applying the electrical signal to such means.

2. The method defined in claim **1**, wherein the step of positioning the grating comprises using a absorption-transmission grating having alternating transparent and non-transparent portions and positioning the grating in the region of the focal plane of the autocollimation lens means at that side of the autocollimation lens means which faces away from the subject and intermediate the autocollimation lens means and semitransmissive mirror arranged intermediate the autocollimation lens means and a light source in such a manner that light from the light source is transmitted through the semitransmissive mirror and through the absorption-transmission grating, projected by the autocollimation lens means onto the subject, reflected back from the subject and projected back onto and through the grating onto the semitransmissive mirror, and reflected off the semitransmissive mirror to the photoelectric means.

3. The method defined in claim **1**, wherein the step of positioning the grating comprises using a transmission-reflection grating having alternating transmissive and reflecting portions and positioning the grating in the region of the focal plane of the autocollimation lens means at that side of the autocollimation lens means which faces away from the subject and intermediate a light source and a semitransmissive mirror arranged between the grating and the autocollimation lens means in such a manner that light from the light source is transmissive grating portions and through the semitransparent mirror towards the autocollimation lens means and projected by the latter onto the subject, reflected back from the subject projected back through the semitransmissive mirror onto the reflecting grating portions, reflected from the reflecting grating portions onto the semitransmissive mirror, and reflected from the semitransmissive mirror onto the photoelectric means.

4. The method defined in claim **1**, wherein the step of positioning the grating comprises using a grating having alternating first and second portions, the first portions being transmissive portions and the second portions being inclined reflecting portions lying in respective planes each oriented at an angle to the general plane of the grating, and positioning the grating in the region of the focal plane of the autocollimation lens means intermediate the latter and a light source with the inclined reflecting portions facing towards the subject and in such a manner that light from the light source is transmitted through the transmissive portions of the grating towards the autocollimation lens means, projected by the latter onto the subject, reflected back from the subject towards the autocollimation lens means, projected by the latter onto the grating, and reflected off the inclined reflecting portions of the grating onto the photoelectric means.

5. The method defined in claim **1**, wherein the step of positioning the grating comprises using a transmission-reflection grating having alternating transmissive and reflecting portions, positioning the grating in the region of the focal plane of the autocollimation lens means but inclined relative to the optical axis of the autocollimation lens means, projecting light through the grating using a light source and a pivotable mirror which receives light from the light source and reflects the received light towards the grating so that the light from the source passes through the grating, is projected by the autocollimation lens means onto the subject, is reflected back from the subject and projected by the autocollimation lens means onto the grating, and reflected off the reflecting grating portions at an angle to the optical axis of the autocollimation lens means and towards the photoelectric means, wherein the step of using photoelectric means to derive an electrical signal comprises pivoting the pivotable mirror until the electrical signal assumes a value indicative of a certain degree of focus.

6. A method for automatically focusing the objective of an optical apparatus onto a subject using autocollimation, comprising the steps of so positioning a grating relative to the autocollimation path of the objective as to cause the latter to project an image of the grating onto the subject and to cause the image of the grating on the subject to be projected back onto the grating and into steady register with the grating structure to an extent dependent upon the degree of focus of the objective; using photoelectric means to derive from the light projected back onto the grating an electrical signal indicative of the extent to which the image of the grating projected back onto the grating is in steady register with the grating structure and accordingly indicative of the degree of focus of the objective; and controlling the operation of means for adjusting the setting of the objective by applying the electrical signal to such means.

7. The method defined in claim **6**, wherein the step of positioning the grating comprises using an absorption-

transmission grating having alternating transparent and nontransparent portions and positioning the grating in the region of the focal plane of the objective at that side of the objective which faces away from the subject and intermediate the objective and a semitransmissive mirror arranged intermediate the objective and a light source in such a manner that light from the light source is transmitted through the semitransmissive mirror and through the adsorption-transmission grating, projected by the objective onto the subject, reflected back from the subject and projected back onto and through the grating ont the semitransmissive mirror, and reflected off the semitransmissive to the photoelectric means.

8. The method defined in claim **6,** wherein the step of positioning the grating comprises using a transmission-reflection grating having alternating transmissive and reflecting portions and positioning the grating in the region of the focal plane of the objective at that side of the objective which faces away from the subject and intermediate a light source and a semitransmissive mirror arranged between the grating and the objective in such a manner that light from the light source is transmitted through the transmissive grating portions and through the semitransparent mirror towards the objective and projected by the latter onto the subject, reflected back from the subject projected back through the semitransmissive mirror onto the reflecting grating portions, reflected from the the reflecting grating portions onto the semitransmissive mirror, and reflected from the semitransmissive mirror onto the photoelectric means.

9. The method defined in claim **6,** wherein the step of positioning the grating comprises using a grating having alternating first and second portions, the first portions being transmissive portions and the second portions being inclined reflecting portions lying in respective planes each oriented at an angle to the general plane of the grating in the region of the focal plane of the objective intermediate the latter and a light source with the inclined reflecting portions facing towards the subject and in such a manner that light from the light source is transmitted through the transmissive portions of the grating towards the objective, projected by the latter onto the subject, reflected back from the subject towards the objective, projected by the latter onto the grating, and reflected off the inclined reflecting portions of the grating towards the photoelectric means.

10. In an optical apparatus having an objective, an arrangement for automatically focussing the objective onto a subject, comprising, in combination, autocollimation lens means having a position and orientation bearing a predetermined relationship to the position and orientation of the objective; a light source located to that side of the autocollimation lens means which faces away from the subject; a grating having alternating transmissive and non-transmissive portions, the grating being located intermediate the light source and the autocollimation lens means and so positioned that an illuminated image of the grating is projected by the autocollimation lens means onto the subject, reflected back from the subject towards the autocollimation lens means and projected back onto the grating and into steady register with the grating structure to an extent dependent upon the degree of focus of the objective; photoelectric means operative for deriving from the light projected back onto the grating an electrical signal indicative of the extent to which the image of the grating projected back onto the grating is in steady register with the grating structure and accordingly indicative of the degree of focus of the objective; and adjusting means operative for adjusting the setting of the objective in dependence upon the electrical signal.

11. The apparatus defined in claim **10,** where in the grating is a transmission-absorption grating having alternating transmissive and absorptive portions, and further including a semitransmissive mirror located intermediate the grating and the light source and having a position and orientation such that light from the image of the grating on the subject reflected back onto the grating passes through the transmissive portions of the grating to the semitransmissive mirror and is reflected off the latter to the photoelectric means.

12. The apparatus defined in claim **10,** wherein the grating is a tranmission-reflection grating having alternating transmissive and reflecting portions, and further including a semitransmissive mirror located intermediate the grating and the autocollimation lens means and having a position and orientation such that light from the image of the grating on the subject reflected back towards the autocollimation lens means is projected by the latter through the semitransmissive mirror onto the grating towards the semitransmissive mirror, and reflected off the latter towards the photoelectric means.

13. The apparatus defined in claim **10,** wherein the grating is a grating having alternating first and second portions, the first portions being transmissive portions and the second portions being inclined reflecting portions lying in respective planes each oriented at an angle to the general plane of the grating, the grating being so positioned and oriented relative to the autocollimation path of the autocollimation lens means and relative to the photoelectric means that light from the image of the grating on the subject reflected back onto the grating is reflected off the inclined reflecting portions of the grating towards the photoelectric means.

14. The apparatus defined in claim **10,** wherein the grating is a transmissive-reflection grating having alternating transmissive and reflecting portions, the grating being located in the region of the focal plane of the autocollimation lens means but inclined relative to the optical axis of the autocollimation lens means, the position and orientation of the grating being such that light from the image of the grating on the subject reflected back onto the grating is reflected off the reflecting portions of the grating towards the photoelectric means, and further including a pivotally mounted mirror between the grating and the light source, and said adjusting means for adjusting the setting of the objective in dependence upon the electrical signal comprising means for adjusting the setting of the objective in dependence upon both the electrical signal and the angular position of the pivotally mounted mirror.

15. In an optical apparatus having an objective, an arragement for automatically focussing the objective onto a subject using the effect of autocollimation comprising, in combination, a light source located to that side of the objective which faces away from the subject; a grating having alternating transmissive and non-transmissive portions, the grating being located intermediate the light source and the objective and so positioned that an illuminated image of the grating is projected by the objective onto the subject, reflected back from the subject towards the objective and projected back onto the grating and into steady register with the grating structure to an extent dependent upon the degree of focus of the objective; photoelectric means operative

for deriving from the light projected back onto the grating an electrical signal indicative of the extent to which the image of the grating projected back onto the grating is in steady register with the grating structure and accordingly indicative of the degree of focus of the objective; and adjusting means operative for adjusting the setting of the objective in dependence upon the electrical signal.

16. The apparatus defined in claim **15**, wherein the grating is a transmission-absorption grating having alternating transmissive and absorptive portions, and further including a semitransmissive mirror located intermediate the grating and the light source and having a position and orientation such that light from the image of the grating on the subject reflected back onto the grating passes through the transmissive portions of the grating to the semitransmissive mirror and is reflected off the latter to the photoelectric means.

17. The apparatus defined in claim **15**, wherein the grating is a transmission-reflection grating having alternating transmissive and reflecting portions, and further

including a semitransmissive mirror located intermediate the grating and the objective and having a position and orientation such that light from the image of the grating on the subject reflected back towards the objective is projected by the latter through the semitransmissive mirror onto the grating, reflected off the reflecting portions of the grating towards the semitransmissive mirror and reflected off the latter towards the photoelectric means.

18. The apparatus defined in claim **15**, wherein the grating is a grating having alternating first and second portions, the first portions being transmissive portions and the second portions being inclined reflecting portions lying in respective planes each oriented at an angle to the general plane of the grating, the grating being so positioned and oriented relative to the autocollimation path of the objective and relative to the photoelectric means that light from the image of the grating on the subject reflected back onto the grating is reflected off the inclined reflecting portions of the grating towards the photoelectric means.

* * * * *

United States Patent [19]

Collet

[11] **4,005,263**

[45] **Jan. 25, 1977**

[54] **DEVICE FOR ADJUSTING THE DISTANCE BETWEEN THE OBJECTIVE AND THE PICK-UP TUBE IN A TELEVISION CAMERA**

[75] Inventor: **Pierre Jacques Collet,** Louviers, France

[73] Assignee: **U.S. Philips Corporation,** New York, N.Y.

[22] Filed: **Jan. 2, 1976**

[21] Appl. No.: **646,023**

[30] **Foreign Application Priority Data**

Jan. 14, 1975 France 75.00955

[52] **U.S. Cl.** **358/227;** 358/41

[51] **Int. Cl.²** **H04N 5/26**

[58] **Field of Search** 178/7.92, 7.1; 354/195, 354/286; 358/41, 42

[56] **References Cited**

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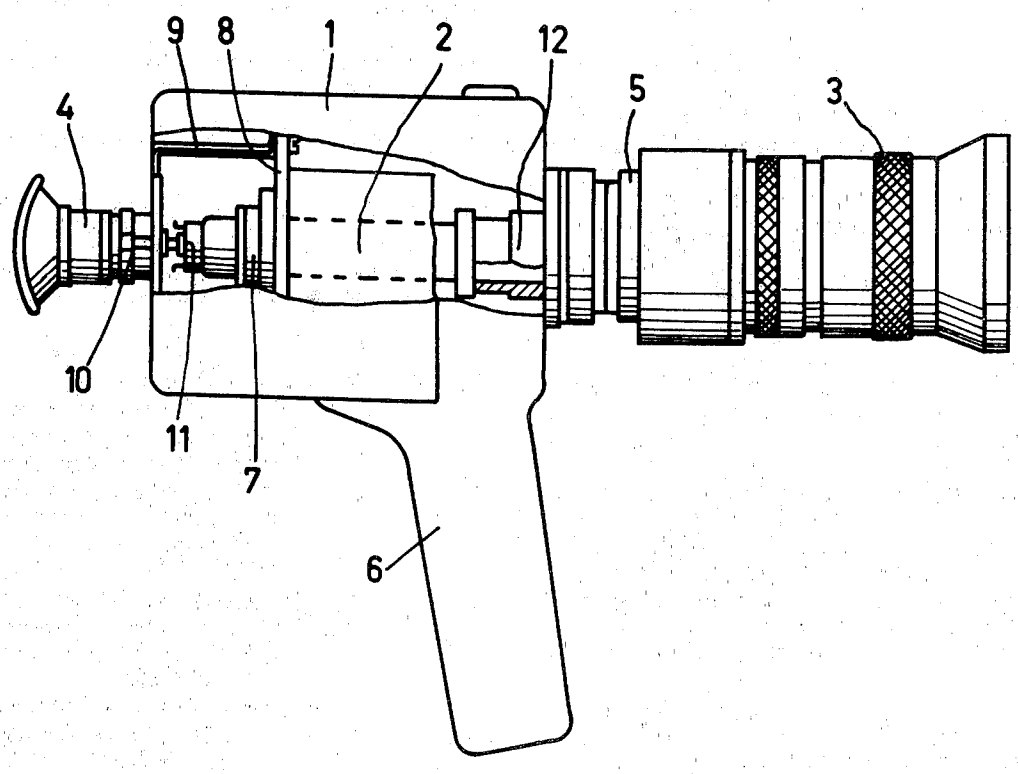
Primary Examiner—Benedict V. Safourek
Assistant Examiner—Edward L. Coles
Attorney, Agent, or Firm—Frank R. Trifari; David R. Treacy

[57] **ABSTRACT**

An adjusting device for a television camera consists of a resilient tubular member which is arranged between the window of the pick-up tube and the objective and which is compressed when an adjusting member acts on the neck of the tube. The deformation of the tubular member enables accurate distance adjustment without it being necessary to rotate the objective or the housing.

10 Claims, 3 Drawing Figures



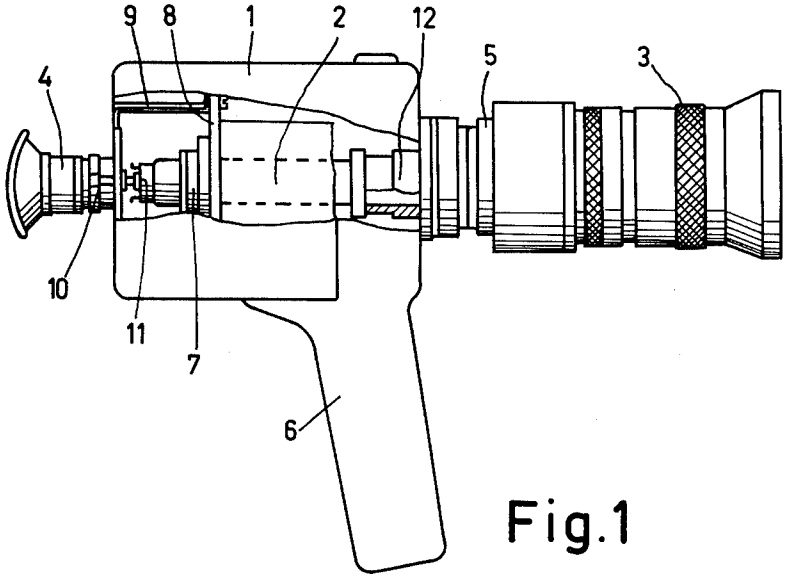


Fig.1

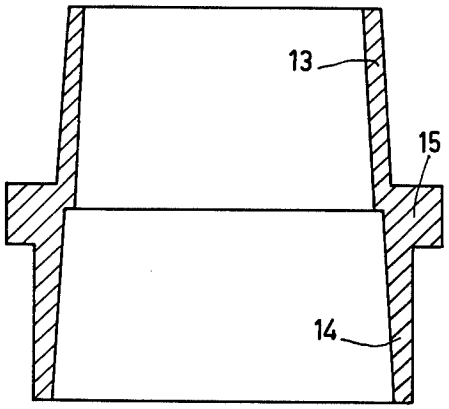


Fig.2

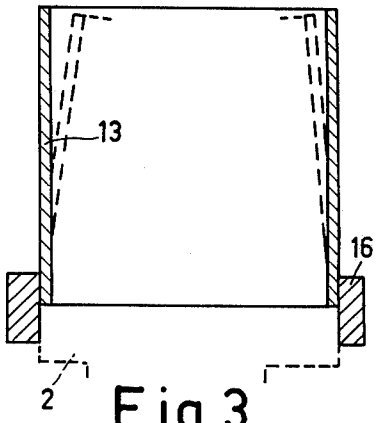


Fig.3

DEVICE FOR ADJUSTING THE DISTANCE BETWEEN THE OBJECTIVE AND THE PICK-UP TUBE IN A TELEVISION CAMERA

The invention relates to a television camera comprising an objective, a pick-up tube and a device for adjusting a distance between the objective and the pick-up tube, the said device comprising a displacement mechanism, including a return mechanism, for the longitudinal displacement of the pick-up tube.

It is known to adjust the position of the objective with respect to the target of the pick-up tube in television cameras by screwing an objective holder until an optimum focussed image is obtained. The devices used consists of a threaded holder wherein the objective is mounted. The threaded holder usually comprises a blocking member, for example, in the form of an adjusting screw.

An adjustment problem occurs if the objective comprises a reflex view-finder which does not permit the rotation of the objective. In that case mechanical "prepositioning" must be performed, and the adjustment must be completed by a very restricted rotation of the objective. This final adjustment preferably does not amount to more than one-eighth revolution of the objective and is smaller as the distance between the viewfinder and the housing of the camera is smaller.

The invention has for its object to facilitate this adjustment by utilising a rigidly arranged objective and an axially displaceable pick-up tube.

A device for adjusting the distance between the objective and the pick-up tube in a television camera of the kind set forth according to the invention is characterized in that the displacement mechanism comprises a fixed ring which at least partly enclosed the pick-up tube, an abutment piece and an adjusting member, the abutment piece being arranged between the said adjusting member and the pick-up tube, the return mechanism comprising a resilient member which is arranged between the rigidly arranged objective and the movably arranged pick-up tube.

The return mechanism is mounted in a tubular element, the ends of which cooperate with circular edges formed on the objective holder and on the window of the pick-up tube. The movable mechanism comprises retaining means which, in a preferred embodiment, include a ring which grips the edge of the objective and/or of the tube.

The length of the return mechanism in the rest position is slightly larger than the final adjusting distance between the objective and the window of the pick-up tube.

The abutment piece is a component which can be secured, for example, to the pumping stem of the pick-up tube.

The tubular resilient element is made of plastic material.

The invention will be described in detail hereinafter with reference to the drawing.

FIG. 1 is a partial sectional view of a television camera comprising the device in accordance with the invention.

FIGS. 2 and 3 show embodiments of resilient members for an adjusting mechanism in accordance with the invention.

A television camera as shown in FIG. **1**, comprises a housing **1** which accommodates electronic circuits for operating a pick-up tube **2** and for the output of image signals. The housing **1** has connected to it an objective **3** and a reflex view finder **4**. The objective comprises a diaphragm **5**. The housing furthermore comprises a grip **6** which also serves for the passage of connection cables. The adjusting mechanism for the longitudinal displacement of the pick-up tube comprises a ring **7** wherein at least part of the pick-up tube is slid. This ring is fixed with respect to the camera housing by a supporting member **8** which is secured to the chassis of the housing, for example, by transverse connections **9**. A displacement member **10**, in this case consisting of a screw which cooperates with a nut or a thread in the chassis, enables displacement of the pick-up tube in the longitudinal direction via an abutment piece **11**. For accurate adjustment, it is necessary that the pick-up tube can remain in permanent contact with the displacement member; to this end, a return mechanism **12** is arranged between the pick-up tube **2** and the objective **3** or an element which forms part of the objective and which occupies a fixed position with respect thereto in the longitudinal direction such as, for example, the diaphragm **5**. In this preferred embodiment the return mechanism comprises a cylindrical resilient member.

In a further preferred embodiment, the cylindrical component has a thin or corrugated wall which enables deformation in the longitudinal direction. On its end this member can comprise portions having a larger thickness, so that the support by the round edges of the objective and the tube is enhanced. FIG. **2** is a sectional view of a preferred embodiment of such a cylindrical member, consisting of two portions, one of which is conical and fits, for example, on an objective having a diameter which is smaller than that of the window of the tube and which is contacted by a substantially cylindrical second portion **14**. The tubular member is provided on its outer surface with a ring **15** whereto a supporting member can be coupled which is secured either to the tube or to the objective. Due to the use of such a tubular member, decentring during assembly, when no pressure is yet exerted, is avoided.

FIG. **3** shows a further embodiment of a retaining means. A ring **16**, arranged on an end of a resilient cylinder, has an inner diameter which is adapted to the pick-up tube **2** or to that of a ring of the objective holder. A broken line indicates that the resilient cylinder can also have a conical shape. The cylinder can also be of a double construction, a conical or non-conical cylinder then being situated one on each side of the ring.

The resilient member is preferably of a plastic material by moulding.

The abutment piece **11** (FIG. **1**) is formed by a component of plastic material which is connected to the pumping stem of the pick-up tube or which is secured on the jacket of the pick-up tube.

The adjusting device is mounted, for example, as follows: a tubular member is secured against the objective, is arranged on the end of the pick-up tube or is accommodated in the supporting member, after which the pick-up tube is slid into the ring of the supporting member of the pick-up tube and is so pressed that the resilient member presses against the window as well as against the objective; subsequently, the abutment piece is positioned and is clamped lightly against the tube by the screw. The length of the resilient member is chosen such that adjustment is possible over a distance which is smaller than this length. The distance between the

window and the target of the pick-up tube is rather exactly defined, which enables determination of the maximum length of the resilient member.

Adjustment is effected by tightening the screw, thus compressing the resilient member; when the adjusting point has been passed, the resilient member will tend to retain the original height when the screw is turned in the opposite direction, thus pushing back the pick-up tube, the pick-up tube, the abutment piece and the displacement member then constantly being maintained on contact with each other. Blocking is effected in known manner, for example, by the clamping of a ring or by blocking by means of a screw. The resilient member offers the additional advantage that it constitutes a dust-tight chamber between objective and window of the pick-up tube.

What is claimed is

1. A television camera comprising an objective, a pick-up tube and a device for adjusting a distance between the objective and the pick-up tube, the said device comprising a displacement mechanism, including a return mechanism, for the longitudinal displacement of the pick-up tube, characterized in that the displacement mechanism comprises a fixed ring which at least partly encloses the pick-up tube, an abutment piece, and an adjusting member, the abutment piece being arranged between the said adjusting member and the pick-up tube, the return mechanism comprising a resilient member which is arranged between the rigidly arranged objective and the movably arranged pick-up tube.

2. A television camera as claimed in claim **1,** characterized in that the resilient member which forms part of the return mechanism consists of a deformable tubular component.

3. A television camera as claimed in claim **2,** characterized in that the tubular component comprises portions on its ends which can be coupled to circular edges of the objective and of the window of the pick-up tube.

4. A television camera as claimed in claim **3,** characterized in that the portions situated on the ends of the tubular component are formed by edges of the tubular component.

5. A television camera as claimed in characterized in that the tubular component is made of plastic material.

6. A television camera tube as claimed in claim **1** characterized in that return mechanism comprises retaining means.

7. A television camera as claimed in claim **6,** characterized in that the retaining means are formed by a ring.

8. A television camera as claimed in claim **6,** characterized in that the said retaining means are formed by at least one of the ends which grips the edge of the objective and/or the tube.

9. A television camera as claimed in claim **1,** characterized in that the length of the return mechanism in the rest position is slightly larger than the final adjusting distance between the objective and the window of the tube.

10. A television camera as claimed in claim **1,** characterized in that the abutment piece is a component which can be mounted on the sleeve of the tube.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 4,005,263

DATED : January 25, 1977

INVENTOR(S) : PIERRE JACQUES COLLET

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Col. 4, line 13, after "as claimed in" insert --claim 2--

Signed and Sealed this

Twelfth Day of April 1977

[SEAL]

Attest:

RUTH C. MASON
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents and Trademarks

SR
OR 3,999,840
x4074C

United States
Momiyama

11] 3,999,840
45] Dec. 28, 1976

[54] **WIDE ANGLE OBJECTIVE HAVING A NON-SPHERICAL SURFACE**

[75] Inventor: **Kikuo Momiyama**, Chofu, Japan

[73] Assignee: **Canon Kabushiki Kaisha**, Tokyo, Japan

[22] Filed: **July 15, 1974**

[21] Appl. No.: **488,733**

[30] **Foreign Application Priority Data**

Aug. 1, 1973 Japan 48-86485

[52] **U.S. Cl.** **350/214**; 350/189

[51] **Int. Cl.**[2] **G02B 9/64**; G02B 13/04; G02B 13/18

[58] **Field of Search** 350/189, 214

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Primary Examiner—John K. Corbin
Assistant Examiner—Conrad Clark
Attorney, Agent, or Firm—Toren, McGeady and Stanger

[57] **ABSTRACT**

A retrofocus wide angle objective with the backfocal length being at least two times the overall focal length, comprising in optical alignment, a plurality of negative meniscus lenses of forward convexities, a positive lens, a negative meniscus lens of forward convexity, a biconvex lens, a negative lens, a positive doublet lens and a positive lens, and the first surface counting from the front being configured in a non-spherical form such that the curvature increases with distance from the optical axis. This non-spherical surface compensates for barrel distortion and negative coma which are introduced by the object-side negative meniscus lenses into the lens system.

3 Claims, 15 Drawing Figures

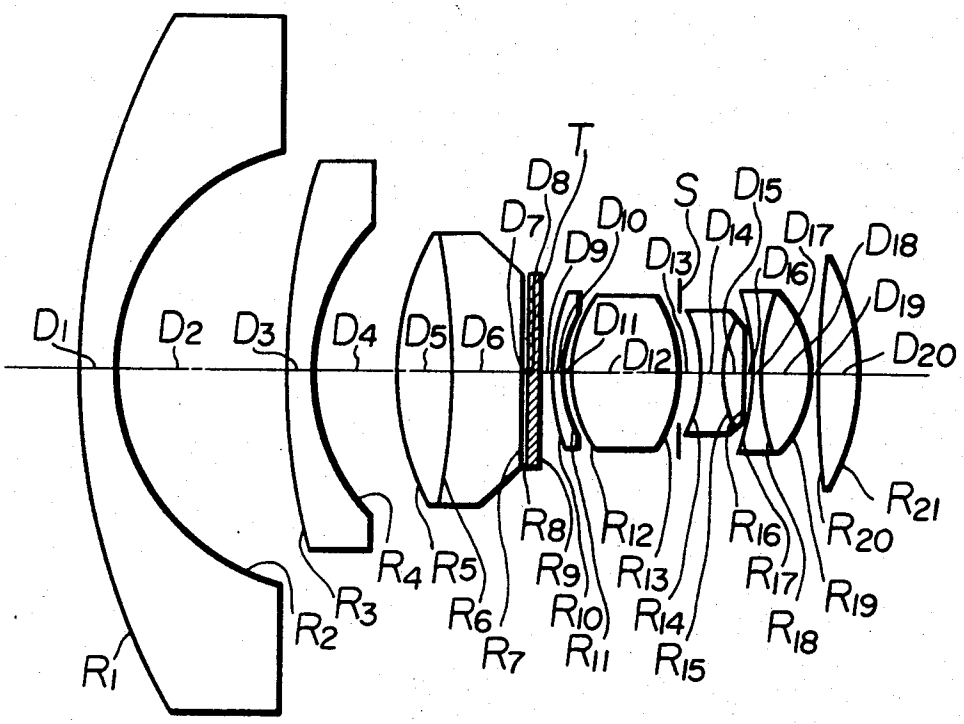


FIG. 1

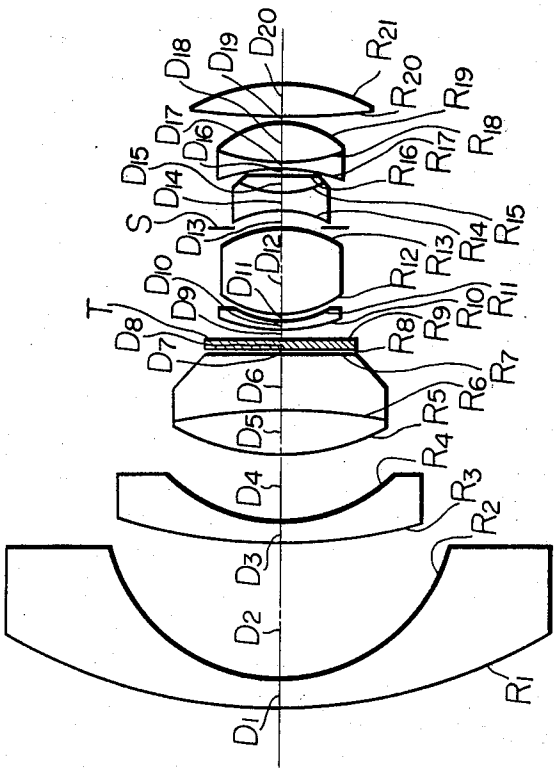
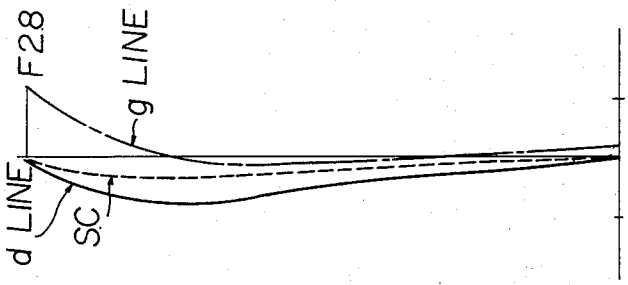
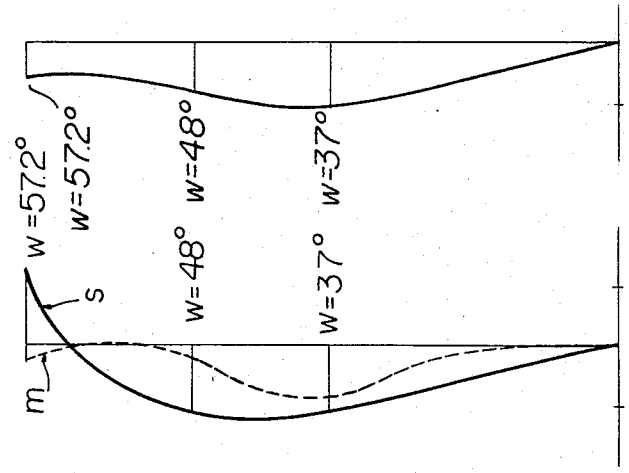


FIG. 2A



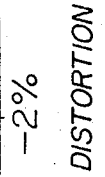
SPHERICAL ABERRATION
SINE CONDITION

FIG. 2B



ASTIGMATISM

FIG. 2C



DISTORTION

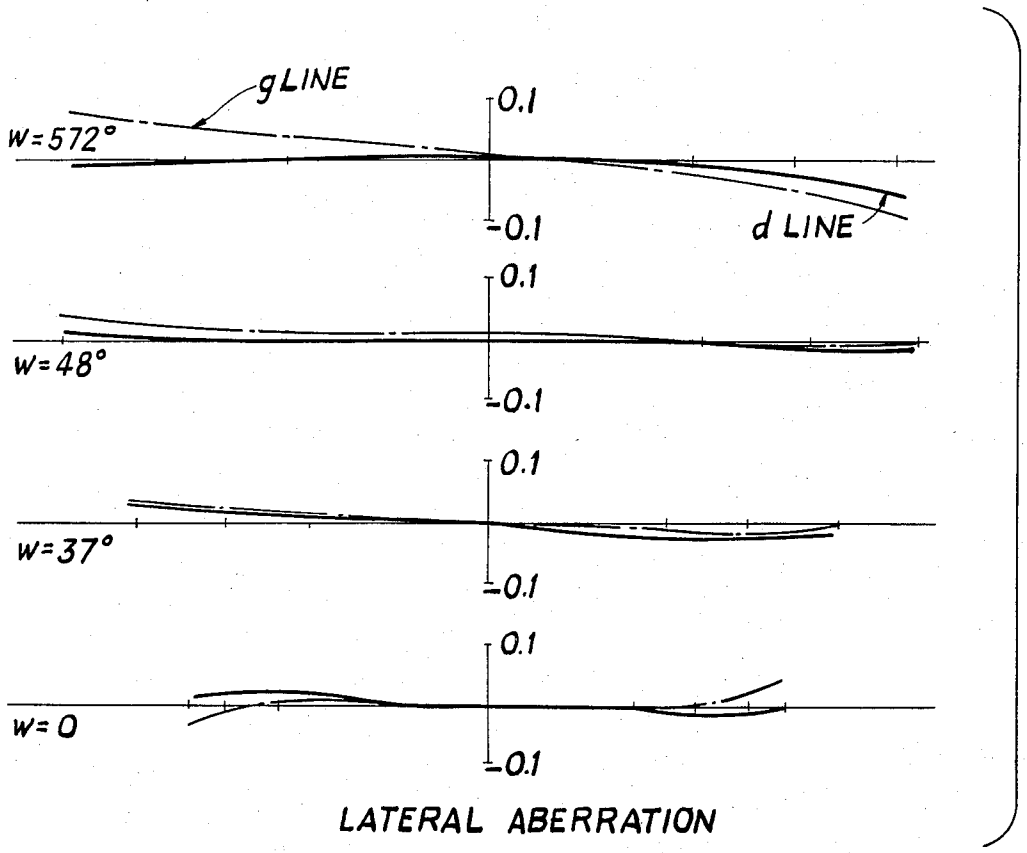
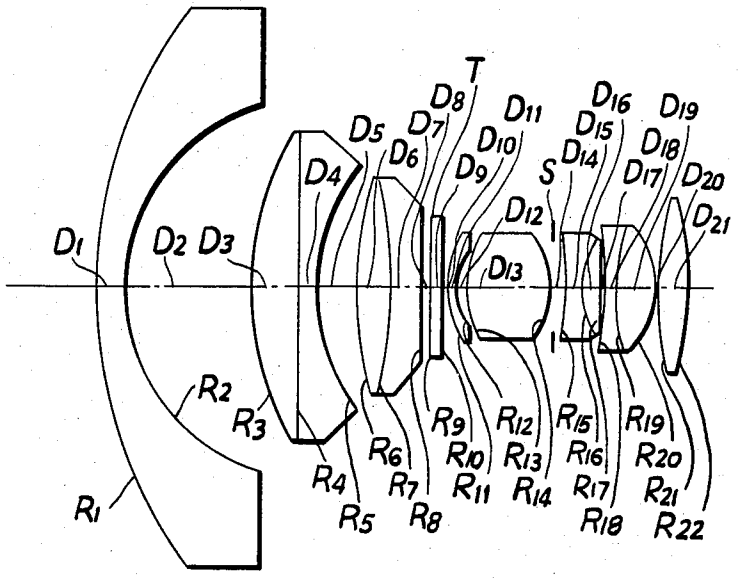

g LINE
d LINE
w=572°
w=48°
w=37°
w=0
0.1
-0.1
LATERAL ABERRATION

FIG. 2D


T
S
D1
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D21
R1
R2
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R5
R6
R7
R8
R9
R10
R11
R12
R13
R14
R15
R16
R17
R18
R19
R20
R21
R22

FIG. 3

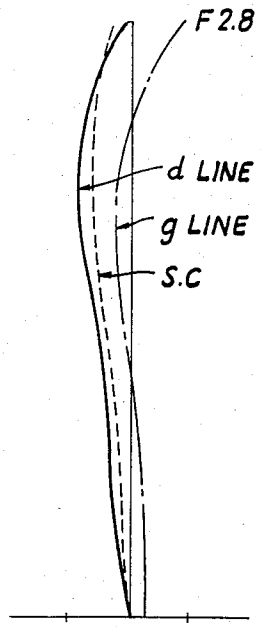


FIG. 4A

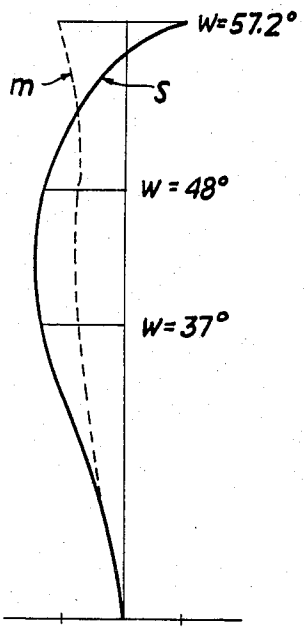


FIG. 4B

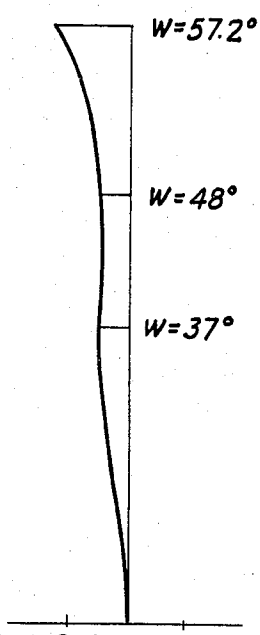


FIG. 4C

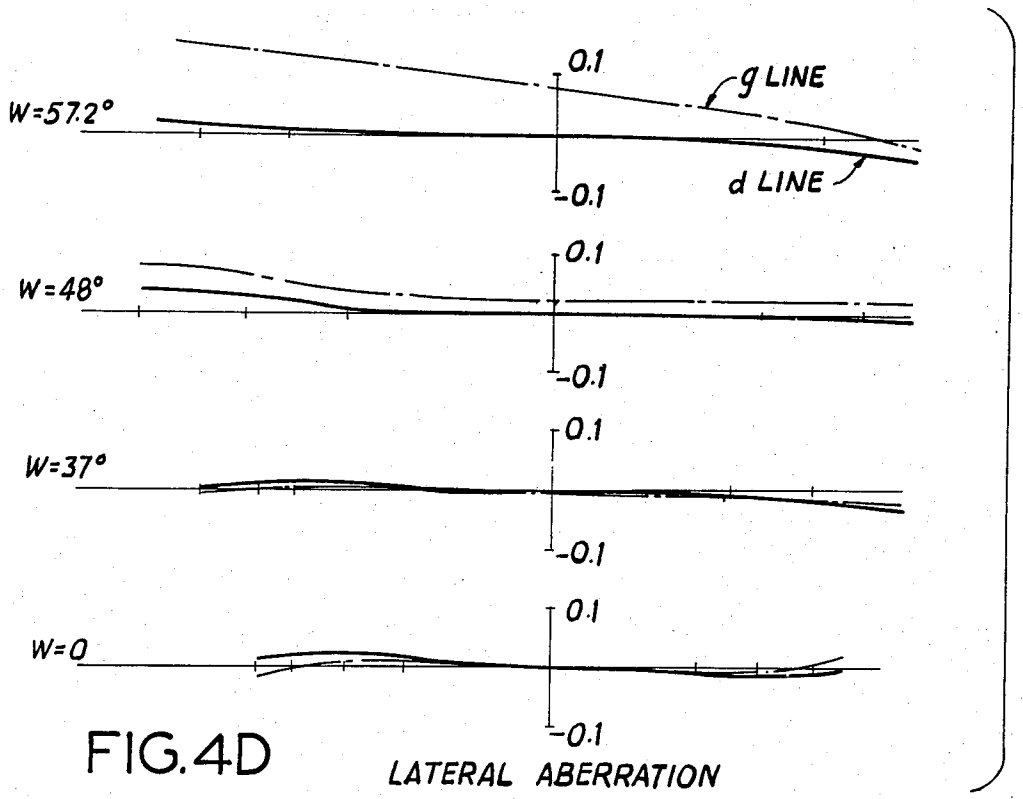


FIG. 4D

FIG. 6A

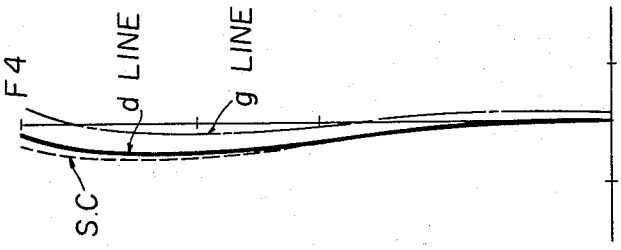


FIG. 6B

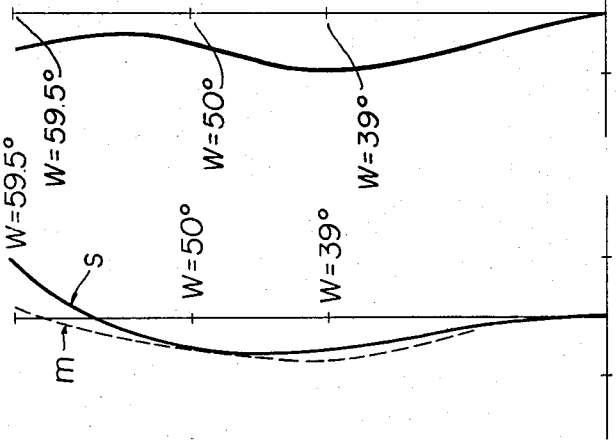


FIG. 6C

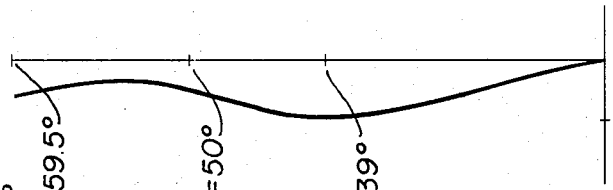
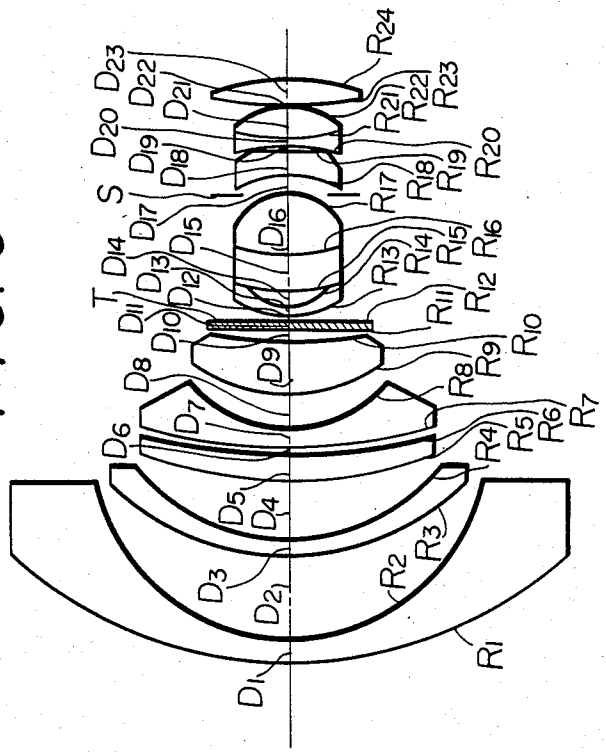


FIG. 5



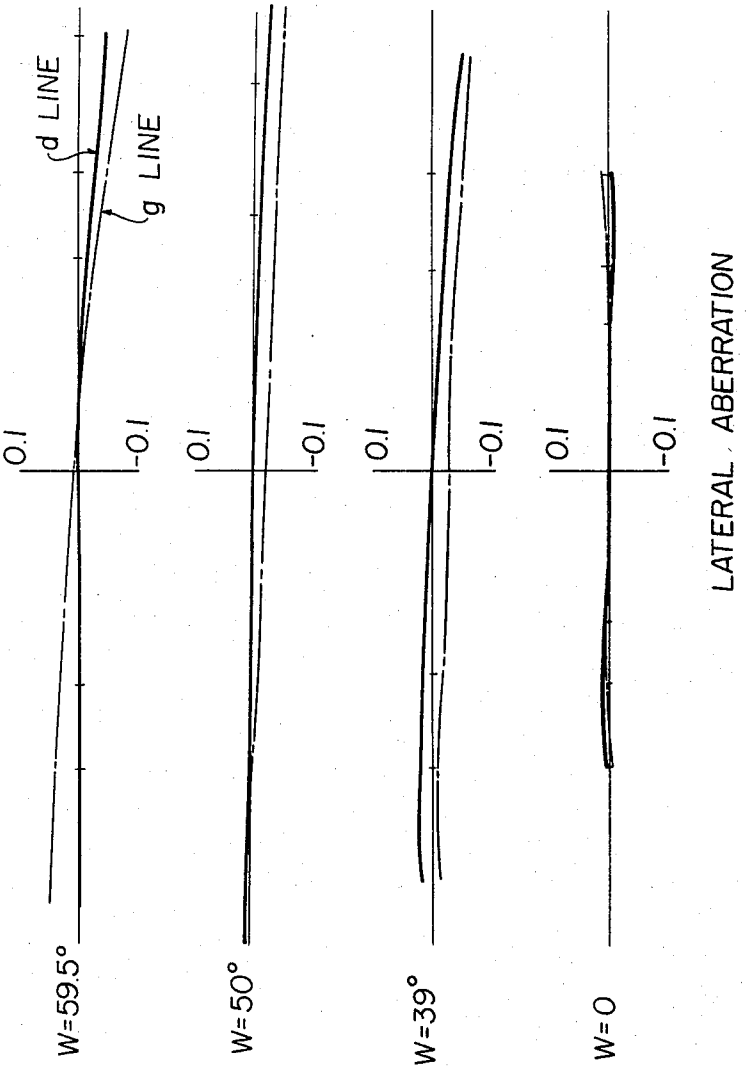


FIG. 6D

WIDE ANGLE OBJECTIVE HAVING A NON-SPHERICAL SURFACE

BACKGROUND OF THE INVENTION

This invention relates to a wide angle objective for a single lens reflex camera.

Objectives for single lens reflex cameras are required to have a back focal length sufficiently long to permit for the quick return operation of the mirror mechanism. In single lens reflex cameras of 35mm format type, it is necessary that this distance be at least 36mm. Wide angle objectives for such single lens reflex cameras are constructed in the form of retrofocus lens in which concave lenses are arranged in the object-side of the lens system for the purpose of meeting the aforementioned requirement. These concave lenses contribute an increase in the back focal length to the lens system, but they have adverse effects on the correction of aberrations, because of the asymmetry of lens configuration of the resulting lens system with respect to the center thereof. Particularly barrel distortion and negative coma which are produced by the object-side concave lenses are more difficult to be corrected in high degree over the entire field. As the field angle of the objective increases, or as the overall focal length is decreased, it is necessary to increase the retro ratio, or the ratio of the back focal length to the overall focal length. As a result, the asymmetry of the lens configuration is intensified which complicates the correction of the aforementioned aberrations. Particularly with wide angle objectives which operate with a retro ratio of more than two, it is impossible to preserve a high standard imagery with respect to the aforementioned aberrations so long as all of the refracting surfaces in the lens system are spherical.

SUMMARY OF THE INVENTION

The present invention has for the primary object to provide a wide angle objective which operates with a retro ratio of more than two and of which the first surface counting from the front is configured in a non-spherical form such that the curvature is increased with distance from the optical axis by the use of which the barrel distortion and negative coma produced by the object-side negative meniscus lenses are corrected.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a diagrammatic view of an objective optical system according to Example **1** of the present invention.

FIGS. **2A, 2B, 2C** and **2D** are curves illustrating various aberrations of the optical system of FIG. **1.**

FIG. **3** is a diagrammatic view of an objective optical system according to Example **2** of the present invention.

FIGS. **4A, 4B, 4C** and **4D** are curves illustrating various aberrations of the optical system of FIG. **2.**

FIG. **5** is a diagrammatic view of an objective optical system according to Example 3 of the present invention.

FIGS. **6A, 6B, 6C** and **6D** are curves illustrating various aberrations of the optical system of FIG. **5.**

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Aberration correction of an optical lens system is facilitated by the provision of a non-spherical surface. For the most effective correction of the aforementioned distortion and coma aberrations by the non-spherical surface, it is preferred to arrange the non-spherical surface in a position where an extra-axial oblique pencil of light rays passes across it at a longest distance from the optical axis. This is because oblique aberrations are susceptible to the surface of higher incident height and because the axial aberrations are influenced by the surface to a smaller extent. For this reason, in the retrofocus objective in which an oblique pencil of light cuts across the first surface at a point extremely farther from the optical axis than the other surfaces. Therefore, if the most effective correction of aberrations is to be effected, the non-spherical surface is used in the place of the first surface.

On the other hand, as shown in FIGS. **1, 3** and **5,** the objective optical system in accordance with the present invention is constructed as comprising eight optically aligned lens members. A first member counting from the front comprises one or two negative meniscus lenses of forward convexities. A second member comprises a negative meniscus lens component of forward convexity which is in the form of either a singlet, or a doublet composed of a positive lens and a negative lens cemented together at their adjoining surfaces, or, if desired, it may be composed of a positive meniscus lens and a negative meniscus lens spaced apart from each other at a minute air space. A third member comprises a positive lens component with the front surface having a smaller radius of convex curvature which is in the form of either a singlet or doublet of a bi-convex lens and a negative lens cemented together. A fourth member is a negative meniscus lens of forward convexity. A fifth member comprises a bi-convex lens component which is in the form of either a singlet or a doublet composed of a positive meniscus lens and a bi-convex lens cemented together. A sixth member comprises a negative lens component of forward concavity which is in the form of either a singlet or a doublet composed of a bi-convex lens and a convex lens cemented together. A seventh member is a positive meniscus doublet of forward concavity composed of a bi-concave lens and a bi-convex lens cemented together. An eighth member is a bi-convex lens. A diaphragm is located between the fifth and sixth members.

Further, the retrofocus objective of the construction described above has the first surface which is configured in a non-spherical form represented by the general formula

$$X = \frac{Y^2}{R_1 - R_1\sqrt{1 - \left(\frac{r}{R_1}\right)^2}} + BY^4 + CY^6 + DY^8 + EY^{10} + \ldots .$$

wherein

X : The abscissa taken along the direction of incoming light on the optical axis.

Y : the ordinate perpendicular to the abscissa

R_1: the radius of curvature of the first non-spherical surface at the vertex, being characterized in that

$$\frac{0.0005}{f^3} < B < \frac{0.1}{f^3}$$

wherein f is the overall focal length of the system.

This non-spherical surface is in such a form that the curvature is increased with distance from the optical axis. Particularly by defining the non-spherical coefficient of the fourth order term as $0.0005/f^3 < B < 0.1/f^3$, the aforementioned aberrations which are introduced by the object-side concave lenses into the lens system can be well compensated for. When the lower limit is violated, the correction of the aforesaid aberrations is more difficult to accomplish. When the upper limit is violated, the correction of astigmatism and higher order aberrations are more difficult to accomplish.

The relationship set out above facilitates the correction of various aberrations of the retrofocus wide angle objective. As far as the best lens design is concerned, the high degree of correction is obtainable by the use of certain relationships set out in detail below. The relationships are particularly concerned with the negative meniscus lens of the fourth member arranged in rear of the plurality of negative meniscus lenses and a positive lens, the bi-convex lens of the fifth member arranged just in front of the diaphragm and the positive cemented meniscus lens of the seventh member arranged beyond the sixth member rearwardly from the diaphragm.

$$0.7 < |R_s| < 2.0\ R_s < 0 \quad (1)$$

wherein R_s is the radius of curvature of the rear surface of the fifth member, or of the surface just in front of the diaphragm.

$$\overline{Na} < \overline{Nb} \quad (2)$$

wherein $\overline{Na}$ is the average value of the refractive indices of all the positive lens elements in the objective, and $\overline{Nb}$ is the average value of the refractive indices of all the negative lens elements in the objective.

$$1.65 < N_{IV} < 2.0 \quad (3)$$

wherein N_{IV} is the refractive index of the fourth member, or in general, of the negative lens arranged in front of the positive lens just in front of the diaphragm.

$$0.2 < (N_{VIIb} - N_{VIIa}) < 0.5 \quad (4)$$

wherein N_{VIIIa} is the refractive index of the positive lens in the seventh member, or in general, the cemented lens component in the rear of the negative lens component just in rear of the diaphragm, and N_{VIIb} is the refractive index of the negative lens in the same lens component.

These relationships have the following meanings. Relationship (1): In order to effect a good state of correction of coma aberrations it is necessary that the surface just in front of the diaphragm is of relatively strong convex curvature to produce a positive coma which is balanced with the negative coma introduced into the system by the object-side concave lenses. When the upper limit is violated, a good state of correction of coma is made difficult. When the lower limit is violated, spherical aberrations and astigmatism deteriorate. For a severer condition, the upper limit may be defined as 1.7.

Relationship (2) facilitates the compensation for over-correction of curvature of field which becomes serious in the retrofocus wide angle objective. By selecting all the concave lenses having an average refractive index higher than the average refractive index of all the convex lenses, the Petzval sum is prevented from being over-corrected and the curvature of field is reduced.

Relationship (3) cooperates with relationship (2) to reduce the positive spherical aberrations as well as field curvature of the fourth member by selecting a particularly high refractive index glass for employment in the fourth member of particularly strong curvature.

Relationship (4): as the refractive index of the negative lens in the seventh member is comparatively higher than that of the positive lens thereof, a diverging action is imparted to the cemented surface at the adjoining lens surfaces of the doublet composed of these negative and positive lenses so as to influence in a desirable manner the correction of extra-axial aberrations. This correction operates effectively with the marginal portions of the image so that a good state of correction of field curvature, coma and distortion is preserved over the entire field. For severer conditions, the lower limit may be defined as 0.25.

Three examples of a specific wide angle objective optical system may be constructed in accordance with the numerical data given in Tables 1 through 12 below with respect to the characteristics of the various elements of the lens system and their spatial relationships to each other, non-spherical surface factors and aberration coefficients. As is evident from the aberration curves in FIG. 2, a lens system constructed according to the specified numerical data in Table 1 is well corrected for various aberrations. The various symbols in the tables have the following meaning.

R: the radii of curvature of the respective lens elements

D: the axial thicknesses of the respective lens elements and axial air spaces between the successive lens elements

Nd: the refractive indices for the d line of the sodium spectrum of the respective material glasses

T: an interchangeable filter

S: a diaphragm.

* the radius of curvature of the non-spherical surface at the vertex on the optical axis.

Example 1:

f = 14.300
FNo = 2.8
$2\omega = 114.2°$

Table 1

No.	R	D	Nd	νd
1	258.12900*	5.00000	1.60311	60.7
2	29.28800	22.65400		
3	78.02500	2.50000	1.77250	49.6
4	24.55600	12.42500		
5	43.10800	7.00000	1.72151	29.2
6	78.36300	8.74400	1.62041	60.3
7	∞	1.50000		
8	∞	1.80000	1.51633	64.1
9 (T)	∞	0.50000		
10	24.56600	1.50000	1.77250	49.6
11	13.65000	1.50000		
12	18.16500	14.64000	1.48749	70.1
13	−19.15600	3.00000		
14	−18.53300	2.50000	1.62041	60.3

Table 1-continued

No.	R	D	Nd	νd
15	15.85200	3.00000	1.72151	29.2
16	−303.07100	1.00000		
17	−33.46500	1.00000	1.92286	20.9
18	29.20100	7.00000	1.48749	70.1
19	−15.92400	0.10000		
20	82.10500	5.80000	1.77250	49.6
21	−35.13000			

ΣD = 103.16300
b, f = 36.497

Table 2

Configuration of the non-spherical surface	
Y	X
0.	0.
2.00000	0.00780
4.00000	0.03189
6.00000	0.07426
8.00000	0.13818
10.00000	0.22805
12.00000	0.34931
14.00000	0.50824
16.00000	0.71177
18.00000	0.96733
20.00000	1.28269
22.00000	1.66578
24.00000	2.12471
26.00000	2.66780
28.00000	3.30377
30.00000	4.04215
32.00000	4.89395
34.00000	5.87262
36.00000	6.99547
38.00000	8.28552
40.00000	9.77407
42.00000	11.50391
44.00000	13.53344

TABLE 3

Non-spherical surface coefficients
$B = 3.5235 \times 10^{-6}$
$C = -9.7912 \times 10^{-10}$
$D = 2.0882 \times 10^{-13}$
$E = 2.6494 \times 10^{-17}$

Table 4

	Aberration coefficients				
No.	I	II	III	P	V
1	0.0497	−0.1034	0.2279	0.0208	0.0390
2	−0.1493	0.0774	−0.0401	−0.1837	0.1161
3	0.0895	0.0578	0.0373	0.0799	0.0757
4	−2.1807	0.4734	−0.1028	−0.2538	0.0774
5	2.3207	−0.0329	0.0005	0.1390	−0.0020
6	0.0021	−0.0030	0.0042	0.0066	−0.0153
7	−0.0070	−0.0172	−0.0423	0	−0.1040
8	0.0065	0.0159	0.0390	0	0.0958
9	−0.0065	−0.0160	−0.0392	0	−0.0964
10	1.9469	0.2739	0.0385	0.2537	0.0411
11	−24.8080	0.3994	−0.0064	−0.4566	0.0075
12	14.1201	0.3550	0.0089	0.2580	0.0067
13	10.8293	−2.0166	0.3755	0.2446	−0.1155
14	−10.3206	1.6653	−0.2687	−0.2954	0.0910
15	1.8608	0.3714	0.0741	0.0327	0.0213
16	0.0012	−0.0044	0.0167	0.0198	−0.1380
17	−0.4540	0.1801	−0.0715	−0.2051	0.1097
18	−6.4304	−1.7416	−0.4717	−0.0745	−0.1479
19	5.3082	−0.0418	0.0003	0.2943	−0.0023
20	0.2039	0.1645	0.1327	0.0759	0.1683
21	9.9433	0.1216	0.0015	0.1774	0.0022
Σ	2.3258	0.1790	−0.0855	0.1337	0.2303

EXAMPLE 2:

$f = 14.3$
FNo = 2.8
$2\omega = 114.20°$

Table 5

No.	R	D	Nd	νd
1	141.395*	5.000	1.60311	60.7
2	31.477	22.770		
3	61.359	6.000	1.72151	29.2
4	936.733	2.500	1.77250	49.6
5	27.667	8.466		
6	80.973	5.000	1.80518	25.4
7	−88.739	5.958	1.64328	47.9
8	∞	1.500		
9	∞	1.800	1.51633	64.1
10 } T	∞	0.500		
11	20.662	1.000	1.77250	49.6
12	9.627	3.000		
13	16.950	13.432	1.48749	70.1
14	−14.296	3.000		
15	−28.095	2.870	1.62041	60.3
16	21.179	2.500	1.72151	29.2
17	89.099	1.000		
18	−36.119	1.000	1.84666	23.9
19	28.905	7.000	1.48749	70.1
20	−16.098	0.100		
21	66.585	5.800	1.77250	49.6
22	−41.712			

ΣD = 100.196
b, f = 3.6500

Table 6

Configuration of the non-spherical surface	
Y	X
0.	0.
2.00000	0.01419
4.00000	0.05723
6.00000	0.13060
8.00000	0.23665
10.00000	0.37861
12.00000	0.56040
14.00000	0.78661
16.00000	1.06233
18.00000	1.39305
20.00000	1.78461
22.00000	2.24313
24.00000	2.77508
26.00000	3.38734
28.00000	4.08744
30.00000	4.88381
32.00000	5.78628
34.00000	6.80659
36.00000	7.95916
38.00000	9.26191
40.00000	10.73736
42.00000	12.41376

Table 6-continued

Configuration of the non-spherical surface	
Y	X
44.00000	14.32645

TABLE 7

Non-spherical surface coefficients
$B = 2.5263 \times 10^{-6}$
$C = 7.4595 \times 10^{-10}$
$D = 2.6068 \times 10^{-13}$
$E = -1.5147 \times 10^{-17}$

Table 8

	Aberration coefficients				
	I	II	III	P	V
1	0.0359	−0.0823	0.2125	0.0380	−0.0794
2	−0.0995	0.0596	−0.0357	−0.1709	0.1238
3	0.0754	0.0413	0.0226	0.0977	0.0659
4	0.0000	0.0000	0.0001	0.0003	0.0107
5	−0.9640	0.0798	−0.0066	−0.2253	0.0192
6	0.4378	0.1454	0.0483	0.0788	0.0422
7	−0.0001	0.0004	−0.0013	0.0088	−0.0247
8	−0.0147	−0.0315	−0.0674	0.	−0.1443
9	0.0134	0.0286	0.0613	0.	0.1314
10	−0.0135	−0.0290	−0.0620	0.	−0.1328
11	1.8097	0.3042	0.0511	0.3016	0.0593
12	−41.1144	2.2059	−0.1184	−0.6474	0.0411
13	20.1014	0.4642	0.0107	0.2765	0.0066
14	18.3026	−2.7499	0.4132	0.3278	−0.1113
15	−4.6836	1.0416	−0.2316	−0.1949	0.0949
16	0.6534	0.1635	0.0409	0.0245	0.0164
17	−0.0810	−0.0855	−0.0903	−0.0673	−0.1663
18	−0.1521	0.0794	−0.0415	−0.1815	0.1164
19	−5.7558	−1.5051	−0.3936	−0.0647	−0.1198
20	5.8615	−0.0601	0.0006	0.2911	−0.0030
21	0.2578	0.1870	0.1357	0.0936	0.1664
22	8.0483	−0.1011	0.0013	0.1494	−0.0019
Σ	2.7184	0.1564	−0.0500	0.1362	0.1105

EXAMPLE 3:

$f = 13.0$
FNo = 4.0
$2\omega = 119°$

Table 9

No.	R	D	Nd	νd
1	147.341*	4.000	1.64000	60.2
2	32.584	13.145		
3	41.808	3.000	1.64000	60.2
4	31.301	10.825		
5	76.838	5.000	1.80518	25.4
6	154.018	0.200		
7	101.770	2.500	1.77250	49.6
8	20.599	5.525		
9	25.164	9.624	1.75520	27.5
10	152.475	1.500		
11 } T	∞	1.800	1.51633	64.1
12 }	∞	0.500		
13	14.142	1.000	1.88300	41.0
14	7.486	3.000		
15	26.776	5.891	1.75520	27.5
16	43.727	7.000	1.51633	64.1
17	−10.620	2.500		
18	−25.398	4.788	1.75520	27.5
19	−915.785	1.000		
20	−24.503	1.000	1.88300	41.0

Table 9-continued

No.	R	D	Nd	νd
21	36.421	5.000	1.48749	70.1
22	−13.504	0.100		
23	62.000	4.500	1.77250	49.6
24	−37.307			

ΣD = 93.398
b, f = 36.500

Table 10

Configuration of the non-spherical surface	
Y	X
0.	0.
2.00000	0.01361
4.00000	0.05490
6.00000	0.12523
8.00000	0.22689
10.00000	0.36309
12.00000	0.53800
14.00000	0.75669
16.00000	1.02513
18.00000	1.35012
20.00000	1.73919
22.00000	2.20046
24.00000	2.74257
26.00000	3.37461
28.00000	4.10610
30.00000	4.94735
32.00000	5.90993
34.00000	7.00783
36.00000	8.25921
38.00000	9.68926
40.00000	11.33427
42.00000	13.24758
44.00000	15.50770

TABLE 11

Non-spherical surface coefficients
$B = 2.31920 \times 10^{-6}$
$C = 1.95593 \times 10^{-10}$
$D = -3.74324 \times 10^{-13}$
$E = 1.44546 \times 10^{-16}$

Table 12

	Aberration coefficients				
No.	I	II	III	P	V
1	0.0263	−0.0611	0.1631	0.0344	0.0646
2	−0.0750	0.0373	−0.0186	−0.1557	0.0868
3	0.0802	0.0113	0.0016	0.1213	0.0173

Table 12-continued

	Aberration coefficients				
No.	I	II	III	P	V
4	−0.1999	0.0283	−0.0040	−0.1621	0.0235
5	0.0922	0.0586	0.0372	0.0755	0.0716
6	−0.0197	−0.0334	−0.0567	−0.0376	−0.1601
7	0.0312	0.0405	0.0526	0.0557	0.1406
8	−2.8060	0.4420	−0.0696	−0.2750	0.0543
9	3.3812	−0.2150	0.0137	0.2223	−0.0150
10	−0.0275	−0.0409	−0.0608	−0.0367	−0.1449
11	0.0049	0.0150	0.0459	0.	0.1405
12	−0.0049	−0.0151	−0.0463	0.	−0.1417
13	3.2757	0.3301	0.0333	0.4310	0.0468
14	−61.4426	3.6433	−0.2160	−0.8143	0.0611
15	14.3464	1.0856	0.0821	0.2089	0.0220
16	−1.0162	−0.1811	−0.0323	−0.0267	−0.0105
17	44.0612	−4.7455	0.5111	0.4168	−0.0999
18	−8.1225	1.4860	−0.2718	−0.2202	0.0900
19	−0.0003	−0.0026	−0.0212	0.0061	−0.1214
20	−0.8646	0.2371	−0.0650	−0.2488	0.0861
21	−7.2559	−1.6397	−0.3706	−0.0504	−0.0951
22	8.8625	−0.1625	0.0030	0.3155	−0.0058
23	0.5642	0.3102	0.1706	0.0914	0.1440
24	10.1347	−0.3495	0.0121	0.1519	−0.0057
Σ	3.0255	0.2788	−0.1068	0.1033	2.2491

What is claimed is:

1. A wide angle objective optical system comprising a lens system wherein the first surface of the system is configured in a non-spherical form and is represented by the formula

$$X = \frac{Y^2}{R_1 - R_1\sqrt{1-\left(\frac{Y}{R_1}\right)^2}} + BY^4 + CY^6 + DY^8 + EY^{10}$$

wherein

X : the abscissa taken along the optical axis in the direction of incoming light,

Y : the ordinate perpendicular to the abscissa,

R_1 : the radius of curvature of the non-spherical surface at the vertex of the optical axis and wherein the optical elements have the following data:

$f = 14.300$

$FN_o = 2.8$

$2\omega = 114.2°$

No.	R	D	Nd	νd
1	258.12900*	5.00000	1.60311	60.7
2	29.28800	22.65400		
3	78.02500	2.50000	1.77250	49.6
4	24.55600	12.42500		
5	43.10800	7.00000	1.72151	29.2
6	78.36300	8.74400	1.62041	60.3
7	∞	1.50000		
8 } T	∞	1.80000	1.51633	64.1
9 } T	∞	0.50000		
10	24.56600	1.50000	1.77250	49.6
11	13.65000	1.50000		
12	18.16500	14.64000	1.48749	70.1
13	−19.15600	3.00000		
14	−18.53300	2.50000	1.62041	60.3
15	15.85200	3.00000	1.72151	29.2
16	−303.07100	1.00000		
17	−33.46500	1.00000	1.92286	20.9
18	29.20100	7.00000	1.48749	70.1
19	−15.92400	0.10000		
20	82.10500	5.80000	1.77250	49.6
21	−35.13000			

$\Sigma_D = 103.16300$

b,f = 36,497

R : the radii of curvature of the respective lens elements;

D : the axial thicknesses of the respective lens elements and axial air spaces between the successive lens elements;

Nd : the refractive indices for the *d* line of the sodium spectrum of the respective material glasses;

T : an interchangeable filter;

S : a diaphragm;

* the radius of curvature of the non-spherical surface at the vertex on the optical axis;

and wherein the non-spherical surface has a configuration as indicated by the following relationship between X and Y:

Y	K
0.	0.
2.00000	0.00780
4.00000	0.03189
6.00000	0.07426
8.00000	0.13818
10.00000	0.22805
12.00000	0.34931
14.00000	0.50824
16.00000	0.71177
18.00000	0.96733
20.00000	1.28269
22.00000	1.66578
24.00000	2.12471
26.00000	2.66780
28.00000	3.30377
30.00000	4.04215
32.00000	4.89395
34.00000	5.87262
36.00000	6.99547
38.00000	8.28552
40.00000	9.77407
42.00000	11.50391
44.00000	13.53344

2. A wide angle objective optical system comprising a lens system wherein the first surface of the system is configured in a non-spherical form and is represented by the formula

$$X = \frac{Y^2}{R_1 - R_1\sqrt{1 - \left(\frac{Y}{R_1}\right)^2}} + BY^4 + CY^6 + DY^8 + EY^{10}$$

wherein

X : the abscissa taken along the optical axis in the direction of incoming light,

Y : the ordinate perpendicular to the abscissa,

R_1 : the radius of curvature of the non-spherical surface at the vertex of the optical axis and wherein the optical elements have the following data:

$f = 14.3$

$FN_o = 2.8$

$2\omega = 114.20°$

No.	R	D	Nd	νd
1	141.395*	5.000	1.60311	60.7
2	31.477	22.770		
3	61.359	6.000	1.72151	29.2
4	936.733	2.500	1.77250	49.6
5	27.667	8.466		
6	80.973	5.000	1.80518	25.4
7	−88.739	5.958	1.64328	47.9
8	∞	1.500		
9 } T	∞	1.800	1.51633	64.1
10 } T	∞	0.500		
11	20.662	1.000	1.77250	49.6
12	9.627	3.000		
13	16.950	13.432	1.48749	70.1
14	−14.296	3.000		
15	−28.095	2.870	1.62041	60.3
16	21.179	2.500	1.72151	29.2
17	89.099	1.000		
18	−36.119	1.000	1.84666	23.9
19	28.905	7.000	1.48749	70.1
20	−16.098	0.100		
21	66.585	5.800	1.77250	49.6
22	−41.712			

ΣD = 100.196

b, f = 3.6500

wherein the symbols have the following meaning:

R : the radii of curvature of the respective lens elements;

D : the axial thicknesses of the respective lens elements and axial air spaces between the successive lens elements;

Nd : the refractive indices for the *d* line of the sodium spectrum of the respective material glasses;

T : an interchangeable filter;

S : a diaphragm;

* the radius of curvature of the non-spherical surface at the vertex on the optical axis;

and wherein the non-spherical surface has a configuration as indicated by the following relationship between X and Y:

Y	X
0.	0.
2.00000	0.01419
4.00000	0.5723
6.00000	0.13060
8.00000	0.23665
10.00000	0.37861
12.00000	0.56040
14.00000	0.78661
16.00000	1.06233
18.00000	1.39305
20.00000	1.78461
22.00000	2.24313
24.00000	2.77508
26.00000	3.38734

-continued

Y	X
28.00000	4.08744
30.00000	4.88381
32.00000	5.78628
34.00000	6.80659
36.00000	7.95916
38.00000	9.26191
40.00000	10.73736
42.00000	12.41376
44.00000	14.32645

3. A wide angle objective optical system comprising a lens system wherein the first surface of the system is configured in a non-spherical form and is represented by the formula

$$X = \frac{Y^2}{R_1 - R_1\sqrt{1 - \left(\frac{Y}{R_1}\right)^2}} + BY^4 + CY^6 + DY^8 + EY^{10}$$

wherein

X : the abscissa taken along the optical axis in the direction of incoming light,

Y : the ordinate perpendicular to the abscissa,

R_1 : the radius of curvature of the non-spherical surface at the vertex of the optical axis and wherein the optical elements have the following data:

$f = 13.0$

FNo = 4.0

$2\omega = 119°$

No.	R	D	Nd	νd
1	147.341*	4.000	1.64000	60.2
2	32.584	13.145		
3	41.808	3.000	1.64000	60.2
4	31.301	10.825		
5	76.838	5.000	1.80518	25.4
6	154.018	0.200		
7	101.770	2.500	1.77250	49.6
8	20.599	5.525		
9	25.164	9.624	1.75520	27.5
10	152.475	1.500		
11 } T	∞	1.800	1.51633	64.1
12 } T	∞	0.500		
13	14.142	1.000	1.88300	41.0
14	7.486	3.000		
15	26.776	5.891	1.75520	27.5
16	43.727	7.000	1.51633	64.1
17	−10.620	2.500		
18	−25.398	4.788	1.75520	27.5
19	−915.785	1.000		
20	−24.503	1.000	1.88300	41.0
21	36.421	5.000	1.48749	70.1
22	−13.504	0.100		
23	62.000	4.500	1.77250	49.6
24	−37.307			

ΣD = 93.398

b, f = 36.500

wherein the symbols have the following meaning:

R : the radii of curvature of the respective lens elements;

D : the axial thicknesses of the respective lens elements and axial air spaces between the successive lens elements;

Nd : the refractive indices for the *d* line of the sodium spectrum of the respective material glasses;

T : an interchangeable filter;

S : a diaphragm;

* the radius of curvature of the non-spherical surface at the vertex on the optical axis;

and wherein the non-spherical surface has a configuration as indicated by the following relationship between X and Y:

Y	X
0.	0.
2.00000	0.01361
4.00000	0.05490
6.00000	0.12523
8.00000	0.22689
10.00000	0.36309
12.00000	0.53800

-continued

Y	X
14.00000	0.75669
16.00000	1.02513
18.00000	1.35012
20.00000	1.73919
22.00000	2.20046
24.00000	2.74257
26.00000	3.37461
28.00000	4.10610
30.00000	4.94735
32.00000	5.90993
34.00000	7.00783
36.00000	8.25921
38.00000	9.68926
40.00000	11.33427
42.00000	13.24758
44.00000	15.50770

* * * * *

OR 3,994,576 +D

United States P... 3,994,576
Glatzel et al. [45] Nov. 30, 1976

[54] **OBJECTIVE LENS SYSTEM WITH FIVE ELEMENTS**

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[22] Filed: **Apr. 17, 1975**

[21] Appl. No.: **569,014**

[30] **Foreign Application Priority Data**

Apr. 20, 1974 Germany 2419140

[52] **U.S. Cl.** **350/223**; 350/176
[51] **Int. Cl.²** **G02B 9/34**
[58] **Field of Search** 350/223, 176

[56] **References Cited**

UNITED STATES PATENTS

3,390,936 7/1968 Price ..... 350/223 X

FOREIGN PATENTS OR APPLICATIONS

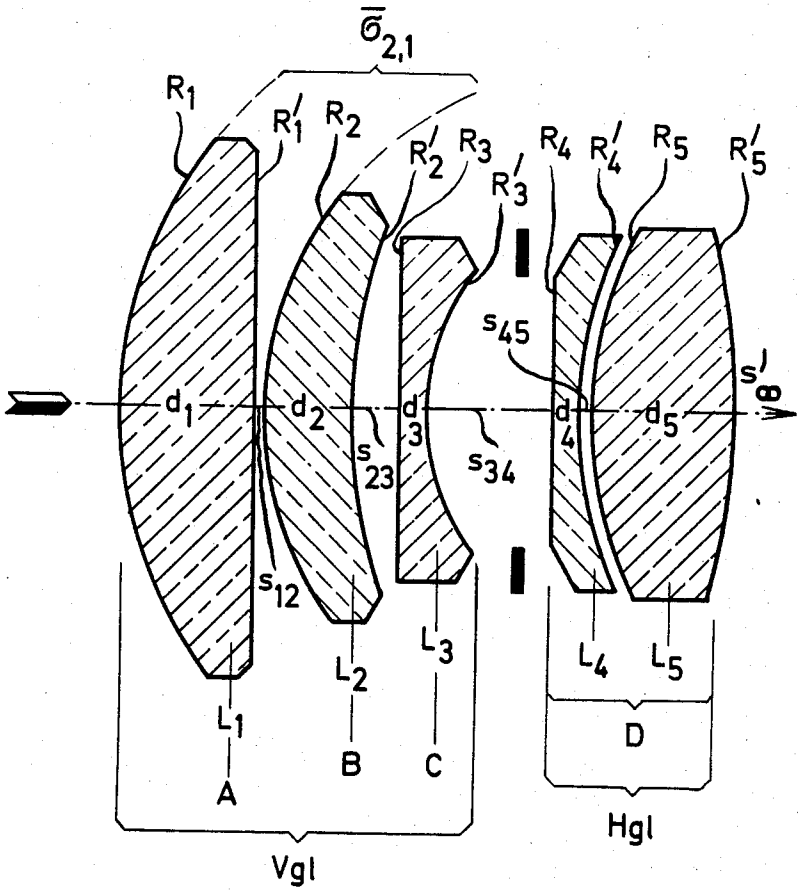
1,190,216 4/1965 Germany 350/223
46-26670 2/1968 Japan 350/223

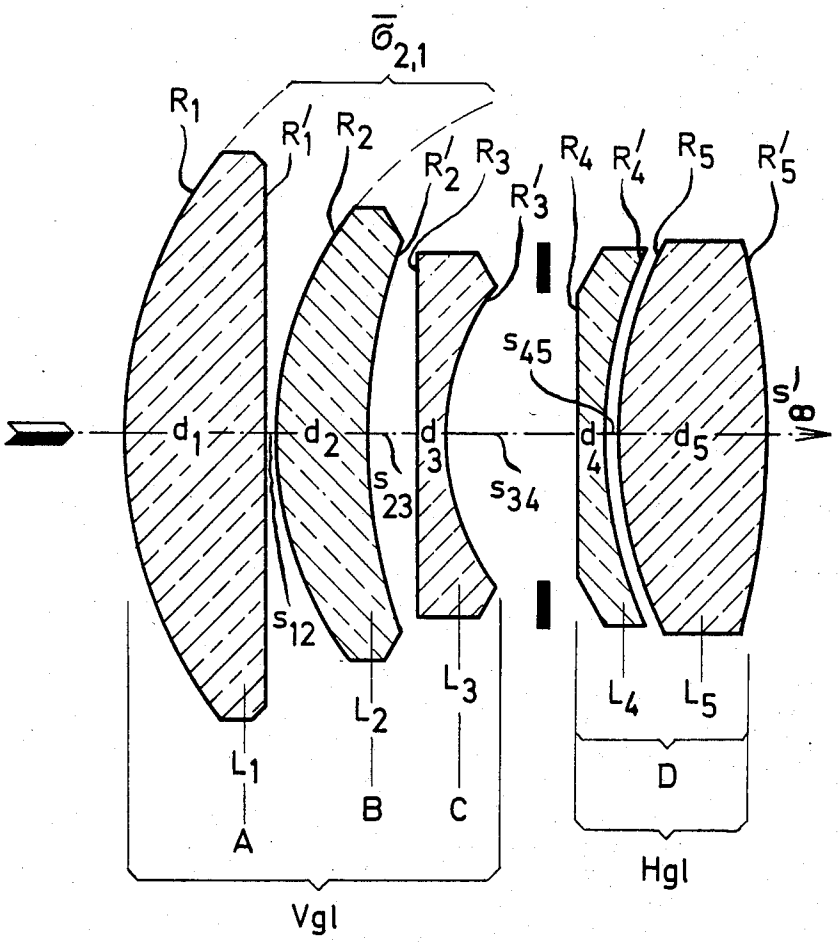
Primary Examiner—Paul A. Sacher
Attorney, Agent, or Firm—Stonebraker, Shepard & Stephens

[57] **ABSTRACT**

An objective of the expanded Tessar type, having five elements constituting four components (two of the elements being cemented to each other to form one component), all of the components being air spaced from each other. The front two components (in the direction from the object or long conjugate side toward the image or short conjugate side) are both positive. Numerical limits or ranges are given, for certain designated features of the lens system. If a lens of this type is so designed that the designated features fall within the specified ranges, improved results are attained.

15 Claims, 1 Drawing Figure




$\overline{\sigma}_{2,1}$
R_1
R_1'
R_2
R_2'
R_3
R_3'
R_4
R_4'
R_5
R_5'
s_{45}
s_{BI}'
d_1
d_2
d_3
d_4
d_5
s_{23}
s_{34}
s_{12}
L_1
L_2
L_3
L_4
L_5
A
B
C
D
Vgl
Hgl

OBJECTIVE LENS SYSTEM WITH FIVE ELEMENTS

BACKGROUND OF THE INVENTION

This invention relates to an objective lens system of what may be called the expanded Tessar type, which type is disclosed, for example, in U.S. Pat. No. 2,105,799. The lens has a front member, designated in the drawing and in the examples as Vgl (standing for the German word Vorderglied) and a rear member designated as Hgl (standing for the German word Hinterglied). The front member is made up of three individually air spaced lens elements, and the rear member is a doublet consisting of two lens elements of opposite sign of power, cemented to each other to constitute a single component. A diaphragm space is provided between the front member and the rear member. The neighboring cemented surfaces of this doublet constituting the rear member constitute a collecting cement surface. In the front member, the front element is an unequal-sided collecting element, followed at a small finite air spacing by a positive meniscus which is convex toward the front and concave toward the rear, this meniscus being followed, in turn, by an unequal-sided negative lens which has its most strongly curved surface in the form of a surface concave toward the rear. A dispersing air lens is formed between the rear surface of the second element and the front surface of the negative lens constituting the third element.

SUMMARY OF THE INVENTION

In a five element objective of the expanded Tessar type, a valuable increase in the picture taking quality of the lens is achieved if, in order to keep the proportion of primary abberrations small, the first pair of collecting lenses into which the rays of light enter from the remote object are both made of glass having a refractive index (for the d-line of the helium spectrum, wavelength 5876 Angstrom units) is greater than 1.6454. The use of such glass for the first two elements fundamentally provides assurance that, from the very start, the refractive index proportional values of these glasses in the aberration coefficients of third order are in the desirable range of less than 2.55 for the coefficient $n/(n-1)$, and less than 6.50 for the coefficient $n^2/(n-1)^2$. These coefficients are respectively referred to hereafter as x' and x''. The importance of keeping these values of x' and x'' less than 2.55 and 6.50, respectively, can be seen from the well known work by I. C. Gardner, "Application of the algebraic abberration equations to optical design," published as U.S. Bureau of Standards Scientific Paper No. 550, 1927, particularly equation 24 on page 95, and appendix 4, page 201, value column 4.

Values within these limits are known in the art from German patent 1,190,216, but have not been generally recognized in the art as being important, as will be seen from Table I below, which shows these values of the refractive indices for the first two elements of a lens of this same general type, according to typical prior patents, and the resulting coefficient values x' and x'', and shows in comparison thereto the corresponding values for the examples of the present invention.

According to the present invention, a lens system of this general type above described should have certain other features or physical characteristics not found in the prior art, which give greatly improved results, when these additional features are within the values or limits stated, the lens otherwise being of the kind described above. These additional features or conditions which are highly desirable, according to the present invention, are the following, which may be regarded as rules of design for the front pair of collecting lenses.

Feature (a). The front radii R_1 and R_2, respectively of the front positive lens elements L_1 and L_2, respectively, which are both of convex curvature toward the front, are so dimensioned with such curvature with respect to each other that the reciprocal of Gardner's curvature index is within the range or limits of + 0.109 and − 0.275. For further explanation of the Gardner curvature index, see the above cited work by Gardner. The reciprocal of the curvature index for these first two lens elements may be written as $\overline{\sigma}_{2,1}$, which is the quotient of the difference in radii $R_2 - R_1$ divided by the sum of these radii $R_2 + R_1$.

Feature (b_1). The relative distribution of the proportional portions of the Petzval picture curvature between the front lens element L_1 and the following positive meniscus element L_2 is so dimensioned that the difference in the Petzval curvature portions $\dot{B} - \dot{A}$ is within the limits or range of $+0.124\,\Phi$ and $-0.599\,\Phi$, wherein Φ represents the equivalent refractive power of entire lens system. The Petzval curvature portion B is the refractive power of the second lens element divided by the index of refraction of the glass used for this lens, that is, $\dot{B} = \phi_2 : n_2$. Similarly, the Petzval curvature portion $\dot{A} = \phi_1 : n_1$. That is, in each case the Petzval curvature portion of a lens element is the corresponding lens power divided by the corresponding index of refraction.

Feature (b_2). The quotient $(\overline{\psi}\,\dot{B}\dot{A})$ of the difference of the above Petzval curvature portions $(\dot{B} - \dot{A})$ of these two front collecting lenses divided by the sum $(\dot{B} + \dot{A})$ of these two Petzval curvature portions is within the limits or range of + 0.089 and − 0.625. In this connection, one may note the recognized theory that the lens power ϕ_x for a lens of either glass or air of any order x is equal to the sum of the two associated surface powers $\phi_x + \phi_x'$, in which connection each surface power means $\phi_x = (n_x' - n_x) : R_x$.

BRIEF DESCRIPTION OF THE DRAWING

The single FIGURE of the drawing is a schematic exploded diagram indicating the general configuration of the lens according to the present invention, and is not necessarily drawn to scale, as it is intended to be a schematic representation of all of the various specific embodiments here disclosed, even though the embodiments may differ from each other somewhat in specific dimensions of radii, thicknesses, and spacings.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

As stated above, in connection with feature *a*, an important feature of the invention is the design of the lens system in such a way that the Gardner curvature index is within the limits above stated. Within the stated limits, it may be either positive or negative. Those skilled in the art will immediately recognize, from what has been said above, that if the Gardner curvature index is to be positive, then the front surface R_1 of the first lens element L_1 must be of greater curvature (that is, of less radius) than the front surface R_2 of the positive meniscus lens element L_2. Similarly, if it is

desired to have a negative value for the Gardner curvature index, then the front surface R_1 must be of lesser or weaker curvature (i.e., greater radius) than the surface R_2 of the second lens element. If the radii of curvature of the front faces of the first two lense elements are exactly equal, then the Gardner curvature index will be zero.

By dimensioning the lens components to achieve a Gardner curvature index within the limits above specified for feature *a*, a particularly excellent balancing of the dioptric effect on the course of the zonal abberations in the finitely opened parts of the beam of light can be established for the first time for the central and middle region of image field. If the above stated upper limit of a positive value of the Gardner curvature index is exceeded, this would lead to enlargement of the longitudinal aberration deviation in the zonal inner region. If the Gardner curvature index range above stated is exceeded in the negative direction, this would lead to an increase of aberration in the region of the beam cross section close to the edge.

By utilizing also the above stated rule or feature b_1 with respect to the Petzval curvature, in conjunction with feature *a*, it is possible to achieve a particularly suitable stretching of the residual image curvature over the extended field of view by dimensioning the lens to comply with feature b_1 and at the same time to comply with feature *a*, there is obtained a dioptric action which is both surprising and very excellent, on the course of the image curvature over the entire useful field of view. Dimensioning the two positive lens components L_1 and L_2 at the front of the lens system (these components also being designated, in the diagram and elsewhere, as components $\underset{\cdot}{A}$ and $\underset{\cdot}{B}$) in such a way as to comply with the above stated rule b_1 relating to the Petzval image curvature, one achieves for the first time a previously unknown balancing out of the Petzval coefficients to increase the quality of the picture image in a practical manner of carrying out the technical embodiment. Within the range stated for this rule, if one achieves a Petzval coefficient of zero, then we have the coefficient $\underset{\cdot}{B}$ exactly equal to the coefficient $\underset{\cdot}{A}$, since the two have the same sign. Such a value of zero is achieved in example 1 given below, as will be observed from Table II.

The extremely great increase in picture quality achieved by dimensioning the lens system to comply simultaneously with the two rules or features *a* and b_1 in a lens system of the expanded Tessar type initially identified above, will be clearly evident to those skilled in the art, after reading the present disclosure, particularly with reference to the widened field of view. It is very important that in the pair of collecting lenses at the front of the objective, the front lens L_1 is at a substantially larger distance from the corresponding position of the entrance pupil EP than the positive meniscus L_2 which follows this front lens L_1. For this reason not only do the collecting front surfaces R_1 and R_2 of these two collecting lenses act toward producing extremely different beam path lengths up to the stop or diaphragm, but furthermore in this connection the lens coefficients of the Petzval image curvature (and therefore $\underset{\cdot}{A}$ on the one hand and $\underset{\cdot}{B}$ on the other hand) also have the particular importance of their position within the course of the beam in their influence on the shape of the two astigmatic image shells and the astigmatism has the angle-corresponding difference in each case between the sagittal and the tangential image point in the lateral course of these image shells. The above mentioned position of the entrance pupil refers to the image of the diaphragm produced by the lens elements in front of the diaphragm, considered in a direction forwardly (opposite to the direction of incoming light) from the location of the stop of diaphragm.

In order to make clear in particular this previously generally insufficiently known optical event even for the zonal astigmatic beam course, it may be stated here, under permissible simplification, that in the concrete case of example 3 given below, the front surface vertex of the surface R_1 is at a distance of + 0.5062 F from the image associated with it of the axial base point of the stop or diaphragm, while the axial vertex point of the front surface R_2 of the positive meniscus is at a distance from the corresponding image of the location of the stop of only + 0.2531 F. (F represents the equivalent focal length of the entire lens system.) Therefore this comparison difference for the front lens L_1 with respect to that of the positive meniscus L_2, is practically exactly twice as great as in the case of the latter, since the quotient of these two comparative values of the associated pupil positions is 1.99991, and thus the beam path lengths, referred to the location of the pupil, of the oblique beams is practically in the ratio of 2:1, for these two characteristic collecting surfaces.

The feature or rule of construction b_1 teaches in detail that in its positive range of positions, the dimensioning of the positive meniscus in accordance with the power of refraction and collection of the glass, is to be chosen such that its lens coefficient of the Petzval image curvature $\underset{\cdot}{B}$ is less than + 0.124Φ greater than the partial coefficient $\underset{\cdot}{A}$ of the front lens L_1. Thus an advantageous relaxation, so important for the obtaining of the advance or improvement, is assured in practice. On the other hand, in the negative range of positions of this feature or rule b_1 the Petzval lens coefficient $\underset{\cdot}{A}$ is greater than the coefficient $\underset{\cdot}{B}$ of the positive meniscus, and in accordance with the inventive concept, is to be dimensioned in such a manner that its negative numerical value is within the limits or range from zero to − 0.599Φ as compared with the numerical value $\underset{\cdot}{B}$ meniscus the lens coefficient of the menicus L_2, in order to make certain that the beams coming from the object and passing through the pair of collecting lenses are not already imparted by the first element L_1 an intolerably high image curvature partial coefficient, which would lead to a rise in zonal aberration of the lateral image shells and thus counteract the intended increase in performance.

Furthermore in accordance with the invention, in order to insure that, without any possibility of doubt, the distribution of the lens partial coefficients of the Petzval image curvature on the two front lens elements L_1 and L_2 will be advantageous, it is desirable that the lens components be so dimensioned that they fulfill also a third rule or condition stated above as feature b_2. This third feature is related to the second feature b_1 but is somewhat different therefrom. It relates, as already mentioned above when it was initially stated, to the reciprocal of the image curvature distribution number as the quotient of the difference $\underset{\cdot}{B}-\underset{\cdot}{A}$ divided by the sum $\underset{\cdot}{B}+\underset{\cdot}{A}$. As already stated above, if this distribution number is positive, it should be within the limits or range of + 0.089 and zero, and if negative it should be within the limits or range of − 0.625 and zero.

These three rules or features *a* and b_1 and b_2 in their entirety (that is, considering all three rules simultaneously) unequivocally set forth the principle of con-

struction of an objective according to the present invention. It should be recognized, of course, that the numerical limits above stated are subject to the usual tolerance of plus or minus 5%, as customary in the optical design field when stating numerical values or ranges. Also it should be recognized that we are here talking about improvements in a lens system of the extended or expanded Tessar type identified or defined near the beginning of this specification. The herein stated rules or features for improving performance of lens systems of the expanded Tessar type do not necessarily apply to lenses of other types.

From the analysis of the above stated features or rules of construction and a careful consideration of the other information given in this disclosure, it will be apparent to a person skilled in this art, that in agreement with recognized teaching, there is not only a definite redundance provided by following the subsidiary condition b_2 for the second main feature b_1 but at the same time there is also established a framework of dimensioning which at the same time permits the maintaining of the astigmatism small in the edge portions of the extended lateral field of view. The extreme optical importance for the total picture performance is in this connection now obvious (as a result of the present disclosure) to the person skilled in the art when he bears in mind, in accordance with the recognized but frequently disregarded teaching, that the Petzval theorem is of importance for the image curvature if and only if the the beam combination is punctiform even laterally of the axis. This teaching is stated in the standard reference work "Theorie und Geschichte des Photographischen Objektivs" (Theory and History of Photographic Objectives) by M. von Rohr, published by Julius Springer, Berlin, 1899, page 359, lines 31–34. The expression "punctiform" means that there is concerned a focusing with astigmatism-free combining of the image in the lateral parts of the field of view.

The present new principle of construction with its requirement that all three of the rules or features above stated be simultaneously satisfied, in the very specific type of expanded Tessar lens initially identified, has been fully confirmed in the course of extensive investigations. This principle importantly and surprisingly establishes an advance in the art, and the investigations also show at the same time that before these rules of construction were recognized, it was impossible to realize in practice a great improvement in the picture performance. Before the making of the present invention and the recognition of the importance of simultaneously fulfilling the above stated rules or features, it was at most conceivable to obtain very small and unsubstantial improvements for a certain course of aberration, only by tolerating an extremely detrimental or injurious increase in the aberrations of higher order for the predominant majority of other aberrations in or outside of the central parts of the image. The analysis of the present invention and of the consequences of its dioptric effect make it possible clearly to see that the aberration-free beam courses coming from the object within the pair of collecting lenses arranged at the front of the overall system is to be subjected only to very specifically measured portions of aberrations during its passage through this pair of collecting lenses L_1 and L_2, since the lens components following these lenses in the direction toward the shorter conjugate or image, otherwise cannot lead to a proper compensation of image aberrations. Hence as a practically necessary consequence, there are disturbing residual aberrations which oppose the desired improvement in the image, and also, if extreme types of glass are used, unavoidable aberrations of higher order which greatly impair the combining of the image, if one does not design the lens in accordance with the inventive principles here disclosed.

There have been previous proposals for increasing the picture performance of the five lens objective of the expanded Tessar type with which the present invention deals. One of these proposals, that disclosed in U.S. Pat. No. 2,105,799 and the corresponding British patent 476,349, has become known to a wide group of experts, particularly by the publication in the supplement by K. Michel to the "Handbuch der wissenschaftlichen und angewandten Photographie" (Handbook of scientific and applied photography) published by Springer, Vienna, 1943, page 28, FIG. 22. The description given therein of the variation of the aberration in the central part of the image (FIG. 22*a*) shows the extremely large zonal defects of spherical aberration (solid line curve) and deviation from the sine condition (dashed line curve) which clearly confirm the above statements. Such defects may have been entirely acceptable for the state of the art at that time, but are no longer acceptable at the present time, when a higher quality of performance is demanded. FIG. 22*b* of the above cited publication shows the astigmatic image-point deviations for the position of the sagittal image points (solid line curve) as well as for the tangential image points (dashed line curve).

From this information given in the publication just cited, it can be seen that even with an inclination of the main beam of 20° the astigmatism reaches the critical limit of 1.0% of the equivalent focal length, increasing in the case of an inclination of the beam of 25.5° to 2.09%, and thus exceeding the permissible amount which modern photographic technique specifies for the existence of an image combining which is considered to be good according to today's standards.

With a knowledge of the present disclosure of the new principle of construction and its optical importance, a comparative analysis readily shows the man skilled in the art that not only are the detailed statements in connection with the present patent application fully confirmed, but that, in addition, this older form of construction of five-lens expansions of the Tessar type must necessarily have such an aberration-affected beam combination of finitely opened and finitely inclined beam bundles that the comparative numerical values in the case of this older objective lie far outside the characteristic framework and the combination of features in accordance with the present invention. The present invention enables this specific type of five-lens partially cemented objective to be designed by using the rules or features herein stated, in a manner which is very simple for such an important increase in picture performance.

In the following data tables, **14** specific examples of lens systems according to the present invention are given. In all of these examples, all linear measurements such as radii, thicknesses, and spacings are stated as proportions of the equivalent focal length (F) of the entire objective or lens system, which is considered as unity. That is, $F = 1.0000$. The individual lens elements are indicated, both in the example tables and in the schematic drawing, by the letter L with a subscript corresponding to the number of the individual lens

element as numbered consecutively from front to rear, that is, from 1 to 5. The lens components are indicated by capital letters A through D, the first three lens elements being regarded as individual components, while lens elements **4** and **5**, being cemented to each other, are regarded as a single component D. For convenience of illustration, the elements L_4 and L_5 are shown in the diagram as being slightly separated from each other, but actually they are cemented to each other as shown by the designation of zero spacing at this point, in all of the tables of specific examples.

The radii of curvature of the front surface and the rear surface of each element are indicated by R and R', respectively, with a subscript indicating the number of that particular element. Positive values of R or R' indicates surfaces convex toward the front of the lens, and negative values indicate surfaces concave toward the front, in accordance with customary usage. The end of the lens toward the distant object or longer conjugate is referred to for convenience as the front, and the end toward the image (that is, toward the camera, if the lens is used on a photographic camera) is referred to for convenience as the rear of the lens. The light is assumed, in accordance with conventional lens patent practice, to enter from the front, and to pass through the lens from left to right as indicated by the arrow in the lens diagram.

Axial thicknesses of individual elements are indicated in the tables by the letter *d* with a subscript referring to the identifying number of the particular lens element. Spacings between the elements are indicated by the letter *s* with a subscript corresponding to the identifying number of the lens element in front of the space and lens element behind the space. For example, s_{12} indicates the space between element **1** and element **2**, and s_{23} indicates the space between element **2** and element **3**, and so on. Zero spacing indicates elements cemented to each other. All spacings greater than zero refer to air spacings. In all examples, the space s_{34} between element **3** and element **4** is considered the central space (CS) in which the stop or diaphragm is to be located.

The index of refraction of the glass used for each element is shown either by the symbol *n* with a subscript referring to the individual lens element, or by data in a column headed n_d, the latter being used for the sake of compactness when the data also includes the Abbe number or dispersive index, in a column headed ν_d. When an objective is designed for use in only a very narrow spectral range, the refractive index refers specifically to this narrow range. If the lens is to be used over a wide spectral range, as for example in taking color photographs, then instead of monochromatic image-error correction, an achromatism should be brought about over the wider spectral range required. For this purpose, in known manner, the glasses are to be chosen so that the color dispersion of the glasses used, defined by their corresponding ν value or Abbe number, serves to eliminate the chromatic deviations or errors due to the wavelengths which enter into consideration.

During the course of making this invention it was found, by way of confirmation, that upon the development of the so-called initial forms or preforms of the objective, and then in the course of the subsequent technical rough shaping (rough form) in known manner with the first correction normally customary in the Seidel range (third order) the use of one of the standard indices of refraction can take place in a purely routine manner. A convenient index to use for this purpose is the index of refraction for the yellow d-line of the helium spectrum, with a wavelength of 5876 Angstrom units. Data for this wavelength is customarily shown in many commercial catalogues of manufacturers of optical glasses.

In addition to the values of the linear dimensions and the characteristics of the glass, the example tables also indicate, at the top of each table, the intended relative aperture, the total field angle designated as numeral $2w_o$ provided for, as well as the resultant back focus s_{oo}'.

The first four examples relate to preforms in accordance with the invention which are provided in the region of the third order with monochromatic precorrection, the indices of refraction used in these examples being based on the above mentioned wavelength of 5876 Angstrom units.

The fact that the invention provides a truly novel principle of construction is made clear not only by the scope of use both with respect to relative aperture and with respect to angular extent of the image field, but also by the fact the front element in its three-lens overall combination can be developed either with a negative paraxial power of its own (examples 6, 8, 9, and 10) or with a positive power (examples 1, 2, 4, 5, 7, 11, 12, 13, and 14) or with a completely free power or refraction and therefore with an intrinsic power of 0 (example 3) provided that the new rules of construction in accordance with the invention are satisfied.

Example 1

F = 1.00000 f/2.9 $2\omega_o = 50°$			' = + 0.6341 F
	$R_1 = +0.39000$		
A L_1		$d_1 = 0.09000$	$n_1 = 1.6810$
	$R_1' = +0.91453$		
		$s_{12} = 0.00140$	
	$R_2 = +0.35150$		
B L_2		$d_2 = 0.07000$	$n_2 = 1.7200$ Vgl.
	$R_2' = +0.70339$		
		$s_{23} = 0.02844$	
	$R_3 = +2.35386$		
C L_3		$d_3 = 0.02055$	$n_3 = 1.7850$
	$R_3' = +0.25217$		
		$CS = s_{34} = 0.10163$	
	$R_4 = +2.50017$		
D L_4		$d_4 = 0.028999$	$n_4 = 1.6380$
	$R_4' = +0.32000$		
		$s_{45} = 0$	Hgl.
	$R_5 = +0.32000$		
L_5		$d_5 = 0.115965$	$n_5 = 1.7440$
	$R_5' = -1.13500$		

Example 2

F = 1.00000 f/2.7 $2\omega_o = 53°$ $s_{\infty}' = +0.6341$ F

A	L_1	$R_1 = +0.3910$			
		$R_1' = +0.8200$	$d_1 = 0.08620$	$n_1 = 1.717$	
			$s_{12} = 0.00250$		
B	L_2	$R_2 = +0.3450$			
		$R_2' = +0.7450$	$d_2 = 0.07060$	$n_2 = 1.717$	Vgl.
			$s_{23} = 0.02750$		
C	L_3	$R_3 = +2.5000$			
		$R_3' = +0.2485$	$d_3 = 0.02050$	$n_3 = 1.785$	
			$CS = s_{34} = 0.100020$		
D	L_4	$R_4 = +2.5000$			
		$R_4' = +0.3200$	$d_4 = 0.02900$	$n_4 = 1.638$	
			$s_{45} = 0$		Hgl.
	L_5	$R_5 = +0.3200$			
		$R_5' = -1.1350$	$d_5 = 0.116025$	$n_5 = 1.744$	

Example 3

F = 1.00000 f/2.3 $2\omega_o = 43°$ $s_{\infty}' = +0.6383$ F

A	L_1	$R_1 = +0.4440$			
		$R_1' = +1.9000$	$d_1 = 0.08700$	$n_1 = 1.6780$	
			$s_{12} = 0.00180$		
B	L_2	$R_2 = +0.4530$			
		$R_2' = +0.5700$	$d_2 = 0.06850$	$n_2 = 1.7440$	Vgl.
			$s_{23} = 0.05250$		
C	L_3	$R_3 = -7.2440$			
		$R_3' = +0.3076$	$d_3 = 0.06677$	$n_3 = 1.7280$	
			$CS = s_{34} = 0.12000$		
D	L_4	$R_4 = +1.7160$			
		$R_4' = +0.3900$	$d_4 = 0.02440$	$n_4 = 1.5810$	
			$s_{45} = 0$		Hgl.
	L_5	$R_5 = +0.3900$			
		$R_5' = -0.9530$	$d_5 = 0.08090$	$n_5 = 1.7440$	

Example 4

F = 1.00000 f/1.6 $2\omega_o = 33°$ $s_{\infty}' = +0.3890$ F

A	L_1	$R_1 = +0.576$			
		$R_1' = +3.580$	$d_1 = 0.1915$	$n_1 = 1.734$	
			$s_{12} = 0.0027$		
B	L_2	$R_2 = +0.454$			
		$R_2' = +0.684$	$d_2 = 0.1207$	$n_2 = 1.788$	Vgl.
			$s_{23} = 0.0600$		
C	L_3	$R_3 = +8.180$			
		$R_3' = +0.295$	$d_3 = 0.0375$	$n_3 = 1.847$	
			$CS = s_{34} = 0.1702$		
D	L_4	$R_4 = +1.900$			
		$R_4' = +0.516$	$d_4 = 0.0375$	$n_4 = 1.500$	
			$s_{45} = 0$		Hgl.
	L_5	$R_5 = +0.516$			
		$R_5' = -1.033$	$d_5 = 0.206996$	$n_5 = 1.784$	

Example 5

F = 1.00000 f/3.5 $2\omega_o = 52°$ $s_{\infty}' = +0.6751$ F

				n_d / ν_d	
A	L_1	$R_1 = +0.34480$			
		$R_1' = +0.68793$	$d_1 = 0.070785$	1.67790/55.20	
			$s_{12} = 0.002441$		
B	L_2	$R_2 = +0.31175$			
		$R_2' = +0.65413$	$d_2 = 0.062974$	1.67790/55.20	Vgl.
			$s_{23} = 0.028070$		
C	L_3	$R_3 = +2.38868$			
		$R_3' = +0.22715$	$d_3 = 0.014645$	1.72151/29.25	

Example 5-continued

F = 1.00000 f/3.5 $2\omega_o = 52°$ $s\infty' = +0.6751$ F

			CS = $s_{34} = 0.096414$		
		$R_4 = +1.69108$	$d_4 = 0.017574$	1.68900/49.46	
D	L_4	$R_4' = +0.24946$	$s_{45} = 0$		Hgl.
D	L_5	$R_5 = +0.24946$	$d_5 = 0.059801$	1.74400/44.77	
		$R_5' = -1.27733$			

Example 6

F = 1.00000 f/2.9 $2\omega_o = 51°$ $s\infty' = +0.6988$ F

				n_d / ν_d	
A	L_1	$R_1 = +0.35015$	$d_1 = 0.069804$	1.71700/47.99	
		$R_1' = +0.90521$	$s_{12} = 0.001225$		
B	L_2	$R_2 = +0.42220$	$d_2 = 0.042862$	1.71700/47.99	Vgl.
		$R_2' = +0.59635$	$s_{23} = 0.027187$		
C	L_3	$R_3 = +57.93723$	$d_3 = 0.051434$	1.72830/28.68	
		$R_3' = +0.26829$	CS = $s_{34} = 0.062456$		
		$R_4 = +2.74182$	$d_4 = 0.044699$	1.54814/45.75	
D	L_4	$R_4' = +0.35520$	$s_{45} = 0$		Hgl.
D	L_5	$R_5 = +0.35520$	$d_5 = 0.105930$	1.74400/44.77	
		$R_5' = -0.93837$			

Example 7

F = 1.00000 f/2.9 $2\omega_o' = 53.8°$ $s\infty' = +0.6341$ F

				n_d / ν_d	
A	L_1	$R_1 = +0.39063$	$d_1 = 0.086215$	1.71700/47.99	
		$R_1' = +0.81969$	$s_{12} = 0.002395$		
B	L_2	$R_2 = +0.34563$	$d_2 = 0.070649$	1.71700/47.99	Vgl.
		$R_2' = +0.74651$	$s_{23} = 0.027541$		
C	L_3	$R_3 = +2.31031$	$d_3 = 0.020356$	1.78472/25.76	
		$R_3' = +0.24823$	CS = $s_{34} = 0.100585$		
		$R_4 = +2.76560$	$d_4 = 0.020356$	1.63854/55.38	
D	L_4	$R_4' = +0.31936$	$s_{45} = 0$		Hgl.
D	L_5	$R_5 = +0.31936$	$d_5 = 0.116151$	1.74400/44.77	
		$R_5' = -1.13309$			

Example 8

F = 1.00000 f/2.4 $2\omega_o = 54°$ $s\infty' = +0.6649$ F

				n_d / ν_d	
A	L_1	$R_1 = +0.37875$	$d_1 = 0.094919$	1.67790/55.20	
		$R_1' = +0.72387$	$s_{12} = 0.002373$		
B	L_2	$R_2 = +0.42194$	$d_2 = 0.070477$	1.80279/46.76	Vgl.
		$R_2' = +0.64054$	$s_{23} = 0.040340$		
C	L_3	$R_3 = -9.72419$	$d_3 = 0.024916$	1.76180/26.95	
		$R_3' = +0.29449$			

Example 8-continued

F = 1.00000 f/2.4 $2\omega_o = 54°$ $s_{\infty}' = +0.6649$ F

		CS = $s_{34} = 0.053392$		
D	L_4	$R_4 = +1.62057$	$d_4 = 0.018984$	1.46450/65.70
		$R_4' = +0.40696$	$s_{45} = 0$	Hgl.
	L_5	$R_5 = +0.40696$	$d_5 = 0.129327$	1.74400/44.77
		$R_5' = -0.97225$		

Example 9

F = 1.00000 f/2.5 $2\omega_o = 41°$ $s_{\infty}' = +0.6473$ F

				n_d / ν_d	
A	L_1	$R_1 = +0.44587$	$d_1 = 0.113794$	1.67790/55.20	
		$R_1' = +2.79332$	$s_{12} = 0.001737$		
B	L_2	$R_2 = +0.50391$	$d_2 = 0.061675$	1.74400/44.77	Vgl.
		$R_2' = +0.68174$	$s_{23} = 0.069493$		
C	L_3	$R_3 = -1.66399$	$d_3 = 0.035615$	1.76180/26.95	
		$R_3' = +0.32724$	CS = $s_{34} = 0.109451$		
D	L_4	$R_4 = +4.12005$	$d_4 = 0.030403$	1.52341/51.47	
		$R_4' = +0.50391$	$s_{45} = 0$		Hgl.
	L_5	$R_5 = +0.50391$	$d_5 = 0.074705$	1.74400/44.77	
		$R_5' = -0.68174$			

Example 10

F = 1.00000 f/2.5 $2\omega_o = 41°$ $s_{\infty}' = +0.6381$ F

				n_d / ν_d	
A	L_1	$R_1 = +0.44382$	$d_1 = 0.087078$	1.67790/55.20	
		$R_1' = +1.89875$	$s_{12} = 0.001742$		
B	L_2	$R_2 = +0.45343$	$d_2 = 0.068791$	1.74400/44.77	Vgl.
		$R_2' = +0.57095$	$s_{23} = 0.052247$		
C	L_3	$R_3 = -7.13672$	$d_3 = 0.067921$	1.72825/28.41	
		$R_3' = +0.30524$	CS = $s_{34} = 0.118774$		
D	L_4	$R_4 = +1.64413$	$d_4 = 0.024382$	1.58144/40.86	
		$R_4' = +0.38986$	$s_{45} = 0$		Hgl.
	L_5	$R_5 = +0.38986$	$d_5 = 0.081853$	1.74400/44.77	
		$R_5' = -0.95159$			

Example 11

F = 1.00000 f/1.4 $2\omega_o = 32.5°$ $s_{\infty}' = +0.3890$ F

				n_d / ν_d	
A	L_1	$R_1 = +0.57562$	$d_1 = 0.191482$	1.73350/51.65	
		$R_1' = +3.58024$	$s_{12} = 0.002659$		
B	L_2	$R_2 = +0.45392$	$d_2 = 0.120740$	1.78831/47.37	Vgl.
		$R_2' = +0.68418$	$s_{23} = 0.060104$		
C	L_3	$R_3 = +8.30927$	$d_3 = 0.037233$	1.84666/23.82	
		$R_3' = +0.29478$	CS = $s_{34} = 0.170207$		
D	L_4	$R_4 = +1.90083$	$d_4 = 0.037233$	1.50013/61.44	
		$R_4' = +0.51680$	$s_{45} = 0$		Hgl
	L_5	$R_5 = +0.51680$	$d_5 = 0.207439$	1.78427/41.30	
		$R_5' = -1.03119$			

Example 12

F = 1.00000 f/1.4 $2\omega_o = 33°$ $s_{\infty}' = +0.3640$ F

				n_d / ν_d	
A	L_1	$R_1 = +0.59523$			
		$R_1' = +5.78329$	$d_1 = 0.206663$	1.71300/53.85	
			$s_{12} = 0.002691$		
B	L_2	$R_2 = +0.45297$			
		$R_2' = +0.67747$	$d_2 = 0.142081$	1.78831/47.37	Vgl.
			$s_{23} = 0.043055$		
C	L_3	$R_3 = +6.87377$			
		$R_3' = +0.29826$	$d_3 = 0.037673$	1.84666/23.82	
			$CS = s_{34} = 0.153383$		
D	L_4	$R_4 = +1.85545$			
		$R_4' = +0.55003$	$d_4 = 0.061891$	1.50013/61.44	
			$s_{45} = 0$		Hgl.
	L_5	$R_5 = +0.55003$			
		$R_5' = -1.12126$	$d_5 = 0.207202$	1.78427/41.30	

Example 13

F = 1.00000 f/1.2 $2\omega_o = 33°$ $s_{\infty}' = +0.2895$ F

				n_d / ν_d	
A	L_1	$R_1 = +0.85142$			
		$R_1' = +5.64969$	$d_1 = 0.221864$	1.78831/47.37	
			$s_{12} = 0.005411$		
B	L_2	$R_2 = +0.51816$			
		$R_2' = +1.18551$	$d_2 = 0.189396$	1.78831/47.37	Vgl.
			$s_{23} = 0.021645$		
C	L_3	$R_3 = +2.56026$			
		$R_3' = +0.29990$	$d_3 = 0.140694$	1.91761/21.51	
			$CS = s_{34} = 0.156928$		
D	L_4	$R_4 = +2.13866$			
		$R_4' = +0.44236$	$d_4 = 0.035174$	1.52341/51.47	
			$s_{45} = 0$		Hgl.
	L_5	$R_5 = +0.44236$			
		$R_5' = -1.31143$	$d_5 = 0.216453$	1.80801/40.75	

Example 14

F = 1.00000 f/1.3 $2\omega_o = 18°$ $s_{\infty}' = +0.3420$ F

				n_d / ν_d	
A	L_1	$R_1 = +0.65893$			
		$R_1' = -11.97527$	$d_1 = 0.230703$	1.71300/53.85	
			$s_{12} = 0.004837$		
B	L_2	$R_2 = +0.51229$			
		$R_2' = +0.95812$	$d_2 = 0.125750$	1.78831/47.37	Vgl.
			$s_{23} = 0.048365$		
C	L_3	$R_3 = -4.24885$			
		$R_3' = +0.30077$	$d_3 = 0.106404$	1.84666/23.82	
			$CS = s_{34} = 0.154769$		
D	L_4	$R_4 = +54.26597$			
		$R_4' = +0.55848$	$d_4 = 0.096731$	1.51009/63.52	
			$s_{45} = 0$		Hgl.
	L_5	$R_5 = +0.55848$			
		$R_5' = -0.67818$	$d_5 = 0.162024$	1.78831/47.37	

The specific examples given above show the wide scope for practical use of the new principles of construction herein disclosed, with respect to a range of relative apertures from *f*/3.5 (example 5) to *f*/1.2 (example 13) with various useful angular fields which,

depending on the purpose of use, may cover an angle from about 18° (example 14) to about 54° (example 8).

The great importance of the new features or rules of construction herein disclosed, in obtaining improved imageforming performance in five-lens objectives of the expanded Tessar type herein discussed, is shown particularly impressively by a comparison of the data of the preforms indicated with the construction data for the precisely corrected objectives. Reference may be had in this connection to such a data comparison between example 2 on the one hand and example 7 on the other hand. Furthermore, from a comparison of the data of example 3 with the data of example 10, and from a comparison of the data of example 4 with the data of example 11, it can be clearly noted what slight variations within the scope of the new principles of design need only be still effected to arrive from a simplified form of construction to an extremely precisely corrected embodiment, by following the inventive concepts in accordance with the design rules or features here disclosed.

It may also be pointed out that examples 12 and 13 are particularly useful for photographing signals by means of photoelectronic picture tubes. For this purpose, both examples 12 and 13 are corrected with due consideration of the action of a selected filter plate (SF) as well as an emulsion support plate (TP), the latter having its rear surface coinciding with the image then directly adjacent the photoelectronic recording layer. In example 12, the filter plate (SF) is developed with flat parallel surfaces arranged at a distance of 0.107637 F axially from the last lens vertex R'_5. This plate has an axial thickness d_{SF} of 0.080728 F. The emulsion plate (TP) has a thickness d_{TP} of 0.064582 F, following at a distance of 0.15905 F behind the filter plate. Both plates are made of the same type of glass, having an index of refraction of 1.51680, and an Abbe dispersion index of 64.12.

In example 13, both plates are of the same type of glass used in example 12, but the spacing and thicknesses are somewhat different. The distance of the first plate behind the vertex of the last lens surface is 0.108226 F, the thickness of this plate is 0.081170 F, the distance from the rear surface of this plate to the front surface of the emulsion support plate is 0.083876 F, and the thickness of the emulsion support plate is 0.064936 F.

The following tables I and II give data useful in comparing various features of the lenses according to examples 1–14 with each other and in comparing them with typical constructions of the prior art. Table I gives numerical values, for comparison purposes, of the indices of refraction of the glass of the first two lens elements, indicated in the respective columns headed n_1 and n_2, and the values of the coefficients calculated therefrom, explained near the beginning of this specification and identified there as x' and x'', in the columns with those respective headings. These respective numerical values are given for all of the 14 specific examples embodying the present invention, at the bottom portion of Table I, and are also given, in the top portion of Table I, for certain selected typical lenses of the prior art. The first line, under the prior art section, gives the calculated values for British patent 476,349. The second and third lines give the calculated values for examples 1 and 2, respectively, of German gebrauchsmuster 1,882,723, while the fourth and last line of the prior art section of this table, gives the calculated values for the lens disclosed in German patent 1,190,216.

In Table II, the numerical values are given, for the same prior art patents and for the 14 specific examples of the present invention, with respect to the three special features of the present invention, in the respective columns headed (*a*) and (b_1) and (b_2), corresponding to the designation of these special features of the present invention in the above discussion.

In stating limits or ranges for the various features of the invention, in the claims or elsewhere, it should be borne in mind that ranges are subject to a tolerance of plus or minus 5%, as customary in the optical field.

Table 1

Objective	The generic concept					
	n_1	x'	x''	n_2	x'	x''
The prior art						
Brit. Pat. 476.349	1.5890	2.69779	7.27809	1.63750	2.56863	6.59785
Dt.GM 1.882.723/1	1.62041	2.61184	6.82169	1.62041	2.61184	6.82169
1.882.723/2	1.62041	2.61184	6.82169	1.62041	2.61184	6.82169
Dt.Pat. 1.190.216	1.6910	2.44718	5.98868	1.6910	2.44718	5.98868
The invention						
Ex. 1	1.6810	2.46843	6.09314	1.7200	2.38889	5.70679
2	1.7170	2.39470	5.73459	1.7170	2.39470	5.73459
3	1.6780	2.47493	6.12526	1.7440	2.34409	5.49474
4	1.7340	2.36240	5.58092	1.7880	2.26904	5.14852
5	1.6779	2.47514	6.12634	1.6779	2.47514	6.12634
6	1.7170	2.39470	5.73459	1.7170	2.39470	5.73459
7	1.7170	2.39470	5.73459	1.7170	2.39470	5.73459
8	1.6779	2.47514	6.12634	1.80279	2.24566	5.04297
9	1.6779	2.47514	6.12634	1.7440	2.34409	5.49474
10	1.6779	2.47514	6.12634	1.7440	2.34409	5.49474
11	1.7335	2.36333	5.58531	1.78830	2.26855	5.14633
12	1.7130	2.40252	5.77212	1.78831	2.26854	5.14626
13	1.78831	2.26854	5.14626	1.78831	2.26854	5.14626
14	1.7130	2.40252	5.77212	1.78831	2.26854	5.14626

Table II

Objective	Values of features		
	(a) $\overline{\sigma}_{2,1}$	(b_1) B - A	(b_2) $\overline{\psi}_{BA}$
The prior art			
Brit.Pat. 476.349	+0.1129	−0.62741 Φ	−0.54540
Dt.GM 1.892.723/1	−0.3525	+0.18496 Φ	+0.22512
1.882.723/2	−0.3535	+0.18999 Φ	+0.23250

Table II-continued

Objective	Values of features (a) $\bar{\sigma}_{2,1}$	(b1) B - A	(b2) $\bar{\psi}_{BA}$
Dt.Pat. 1.190.216	−0.2930	+0.25193 Φ	+0.23202
The invention			
Ex. 1	−0.0519	0	0
Ex. 2	−0.0625	+0.09113 Φ	+0.07540
Ex. 3	+0.0100	−0.50407 Φ	−0.56594
Ex. 4	−0.0844	−0.29024 Φ	−0.30776
Ex. 5	−0.0503	+0.09027 Φ	+0.07128
Ex. 6	+0.0932	−0.44247 Φ	−0.43374
Ex. 7	−0.0611	+0.08924 Φ	+0.07385
Ex. 8	+0.0539	−0.14841 Φ	−0.17083
Ex. 9	+0.0611	−0.54067 Φ	−0.55039
Ex. 10	+0.0107	−0.50389 Φ	−0.56540
Ex. 11	−0.1182	−0.29008 Φ	−0.30737
Ex. 12	−0.1357	−0.30518 Φ	−0.32145
Ex. 13	−0.2433	+0.03918 Φ	+0.04265
Ex. 14	−0.1252	−0.26603 Φ	−0.24937

What is claimed is:

1. An objective of five lens elements, divided into a front member of three elements all air spaced from each other, and a rear member of two lens elements cemented to each other to form a single component, the two elements of said rear member being of opposite sign of power and the neighboring surfaces thereof forming a collecting cement surface;

the front lens element of said front member being a collecting lens having unequal front and rear surfaces;

the second lens element being a positive meniscus concave toward the rear and slightly air spaced rearwardly from said front element;

the third lens element being separated from the second element by a dispersing air space, said third element being a negative lens having unequal front and rear surfaces and having its rear surface concave toward the rear and having its rear surface more strongly curved than its front surface;

said front element and said second element both being formed of glass having an index of refraction for the yellow d-line of the helium spectrum which is within the range limits of 1.6454 and 1.80279;

said objective being characterized by the presence of all of the following features:

a. the respective radii of the front surfaces of said front element and said second element are so related to each other that the reciprocal of the Gardner curvature index for those two surfaces is within the range limits of + 0.094 and − 0.244;

b_1. said front element and said second element are so dimensioned relative to each other that the difference of the Petzval curvature portion of the second element minus the Petzval curvature portion of the front element is within the range limits of + 0.092 Φ and − 0.541 Φ; and

b_2. the quotient of said difference of the Petzval curvature portion of the second element minus that of the front element divided by the sum of said Petzval curvature portions of the front and second elements is within the range limits of + 0.076 and − 0.566;

said reciprocal of said Gardner curvature index being determined as the quotient of the radius of the front surface of said second element minus the radius of the front surface of said front element, divided by the sum of the two radii; and

said Petzval curvature portion of each of said front and second elements being determined as the quotient of the power of the respective lens element divided by the index of refraction of the glass of which the respective element is made.

2. An objective as defined in claim **1**, wherein the characteristics of the lens elements and their spatial relationship to each other are substantially as indicated below:

F = 1.00000 f/2.9 $2\omega o = 50°$ $s\infty' = +0.6341$ F

		$R_1 = +0.39000$		
A	L_1		$d_1 = 0.09000$	$n_1 = 1.6810$
		$R_1' = +0.91453$		
			$s_{12} = 0.00140$	
		$R_2 = +0.35150$		
B	L_2		$d_2 = 0.07000$	$n_2 = 1.7200$ Vgl.
		$R_2' = +0.70339$		
			$s_{23} = 0.02844$	
		$R_3 = +2.35386$		
C	L_3		$d_3 = 0.02055$	$n_3 = 1.7850$
		$R_3' = +0.25217$		
			$CS = s_{34} = 0.10163$	
		$R_4 = +2.50017$		
	L_4		$d_4 = 0.028999$	$n_4 = 1.6380$
D		$R_4' = +0.32000$		
			$s_{45} = 0$	Hgl.
		$R_5 = +0.32000$		
	L_5		$d_5 = 0.115965$	$n_5 = 1.7440$
		$R_5' = -1.13500$		

all linear dimensions being expressed in proportion to the equivalent focal length of the entire lens system considered as unity, the symbols having the meanings explained in the foregoing specification.

3. An objective as defined in claim **1**, wherein the characteristics of the lens elements and their spatial relationship to each other are substantially as indicated below:

		F = 1.00000 f/2.7 $2\omega o = 53°$ $s_\infty' = +0.6341$ F		
A	L_1	$R_1 = +0.3910$ $R_1' = +0.8200$	$d_1 = 0.08620$	$n_1 = 1.717$
			$s_{12} = 0.00250$	
B	L_2	$R_2 = +0.3450$ $R_2' = +0.7450$	$d_2 = 0.07060$	$n_2 = 1.717$ Vgl.
			$s_{23} = 0.02750$	
C	L_3	$R_3 = +2.5000$ $R_3' = +0.2485$	$d_3 = 0.02050$	$n_3 = 1.785$
			$CS = s_{34} = 0.100020$	
D	L_4	$R_4 = +2.5000$ $R_4' = +0.3200$	$d_4 = 0.02900$	$n_4 = 1.638$
			$s_{45} = 0$	Hgl.
	L_5	$R_5 = +0.3200$ $R_5' = -1.1350$	$d_5 = 0.116025$	$n_5 = 1.744$

all linear dimensions being expressed in proportion to the equivalent focal length of the entire lens system considered as unity, the symbols having the meanings explained in the forgoing specification.

5. An objective as defined in claim **1**, wherein the characteristics of the lens elements and their spatial relationship to each other are substantially as indicated below:

		F = 1.00000 f/1.6 $2\omega o = 33°$ $s_\infty' = 0.3890$ F		
A	L_1	$R_1 = +0.576$ $R_1' = +3.580$	$d_1 = 0.1915$	$n_1 = 1.734$
			$s_{12} = 0.0027$	
B	L_2	$R_2 = +0.454$ $R_2' = +0.684$	$d_2 = 0.1207$	$n_2 = 1.788$ Vgl.
			$s_{23} = 0.0600$	
C	L_3	$R_3 = +8.180$ $R_3' = +0.295$	$d_3 = 0.0375$	$n_3 = 1.847$
			$CS = s_{34} = 0.1702$	
D	L_4	$R_4 = +1.900$ $R_4' = +0.516$	$d_4 = 0.0375$	$n_4 = 1.500$
			$s_{45} = 0$	Hgl.
	L_5	$R_5 = +0.516$ $R_5' = -1.033$	$d_5 = 0.206996$	$n_5 = 1.784$

4. An objective as defined in claim **1**, wherein the characteristics of the lens elements and their spatial relationship to each other are substantially as indicated below:

		F = 1.00000 f/2.3 $2\omega o = 43°$ $a_\infty' = +0.6383$ F		
A	L_1	$R_1 = +0.4440$ $R_1' = +1.9000$	$d_1 = 0.08700$	$n_1 = 1.6780$
			$s_{12} = 0.00180$	
B	L_2	$R_2 = +0.4530$ $R_2' = +0.5700$	$d_2 = 0.06850$	$n_2 = 1.7440$ Vgl.
			$s_{23} = 0.05250$	
C	L_3	$R_3 = -7.2440$ $R_3' = +0.3076$	$d_3 = 0.06677$	$n_3 = 1.7280$
			$CS = s_{34} = 0.12000$	
D	L_4	$R_4 = +1.7160$ $R_4' = +0.3900$	$d_4 = 0.02440$	$n_4 = 1.5810$
			$s_{45} = 0$	Hgl.
	L_5	$R_5 = +0.3900$ $R_5' = -0.9530$	$d_5 = 0.08090$	$n_5 = 1.7440$

all linear dimensions being expressed in proportion to the equivalent focal length of the entire lens system considered as unity, the symbols having the meanings explained in the foregoing specification.

6. An objective as defined in claim **1**, wherein the characteristics of the lens elements and their spatial relationship to each other are substantially as indicated below:

		F = 1.00000 f/3.5 2ωo = 52° $s_{\infty}' = +0.6751$ F		n_d/ν_d	
A	L_1	$R_1 = +0.34480$			
		$R_1' = +0.68793$	$d_1 = 0.070785$	1.67790/55.20	
			$s_{12} = 0.002441$		
B	L_2	$R_2 = +0.31175$			
		$R_2' = +0.65413$	$d_2 = 0.062974$	1.67790/55.20	Vgl.
			$s_{23} = 0.028070$		
C	L_3	$R_3 = +2.38868$			
		$R_3' = +0.22715$	$d_3 = 0.014645$	1.72151/29.25	
			CS = $s_{34} = 0.096414$		
D	L_4	$R_4 = +1.69108$			
		$R_4' = +0.24946$	$d_4 = 0.017574$	1.68900/49.46	
			$s_{45} = 0$		Hgl.
	L_5	$R_5 = +0.24946$			
		$R_5' = -1.27733$	$d_5 = 0.059801$	1.74400/44.77	

all linear dimensions being expressed in proportion to the equivalent focal length of the entire lens system considered as unity, the symbols having the meanings explained in the foregoing specification.

7. An objective as defined in claim **1**, wherein the characteristics of the lens elements and their spatial relationship to each other are substantially as indicated below:

		F = 1.00000 f/2.9 2ωo = 53.5° $s_{\infty}' = +0.6341$ F		n_d/ν_d	
A	L_1	$R_1 = +0.39063$			
		$R_1' = +0.81969$	$d_1 = 0.086215$	1.71700/47.99	
			$s_{12} = 0.002395$		
B	L_2	$R_2 = +0.34563$			
		$R_2' = +0.74651$	$d_2 = 0.070649$	1.71700/47.99	Vgl.
			$s_{23} = 0.027541$		
C	L_3	$R_3 = +2.31031$			
		$R_3' = +0.24823$	$d_3 = 0.020356$	1.78472/25.76	
			CS = $s_{34} = 0.100585$		
D	L_4	$R_4 = +2.76560$			
		$R_4' = +0.31936$	$d_4 = 0.020356$	1.63854/55.38	
			$s_{45} = 0$		Hgl.
	L_5	$R_5 = +0.31936$			
		$R_5' = -1.13309$	$d_5 = 0.116151$	1.74400/44.77	

relationship to each other are substantially as indicated below:

all linear dimensions being expressed in proportion to the equivalent focal length of the entire lens system considered as unity, the symbols having the meanings explained in the foregoing specification.

8. An objective as defined in claim **1**, wherein the characteristics of the lens elements and their spatial relationship to each other are substantially as indicated below:

		F = 1.00000 f/2.9 2ωo = 51° $s_{\infty}' = +0.6988$ F		n_d/ν_d	
A	L_1	$R_1 = +0.35015$			
		$R_1' = +0.90521$	$d_1 = 0.069804$	1.71700/47.99	
			$s_{12} = 0.001225$		
B	L_2	$R_2 = +0.42220$			
		$R_2' = +0.59635$	$d_2 = 0.042862$	1.71700/47.99	Vgl.
			$s_{23} = 0.027187$		
C	L_3	$R_3 = +57.93723$			
		$R_3' = +0.26829$	$d_3 = 0.051434$	1.72830/28.68	
			CS = $s_{34} = 0.062456$		
D	L_4	$R_4 = +2.74182$			
		$R_4' = +0.35520$	$d_4 = 0.044699$	1.54814/45.75	
			$s_{45} = 0$		Hgl.
	L_5	$R_5 = +0.35520$			
		$R_5' = -0.93837$	$d_5 = 0.105930$	1.74400/44.77	

all linear dimensions being expressed in proportion to the equivalent focal length of the entire lens system considered as unity, the symbols having the meanings explained in the foregoing specification.

9. An objective as defined in claim **1**, wherein the characteristics of the lens elements and their spatial relationship to each other are substantially as indicated below:

F = 1.00000 f/2.5 $2\omega o = 41°$ $s_{a'} = +0.6473$ F

				η_d / ν_d	
A	L_1	$R_1 = +0.44587$	$d_1 = 0.113794$	1.67790/55.20	
		$R_1' = +2.79332$			
			$s_{12} = 0.001737$		
B	L_2	$R_2 = +0.50391$	$d_2 = 0.061675$	1.74400/44.77	Vgl.
		$R_2' = +0.68174$			
			$s_{23} = 0.069493$		
C	L_3	$R_3 = -1.66399$	$d_3 = 0.035615$	1.76180/26.95	
		$R_3' = +0.32724$			
			$CS = s_{34} = 0.109451$		
D	L_4	$R_4 = +4.12005$	$d_4 = 0.030403$	1.52341/51.47	
		$R_4' = +0.50391$			
			$s_{45} = 0$		Hgl.
	L_5	$R_5 = +0.50391$	$d_5 = 0.074705$	1.74400/44.77	
		$R_5' = -0.68174$			

relationship to each other are substantially as indicated below:

all linear dimensions being expressed in proportion to the equivalent focal length of the entire lens system considered as unity, the symbols having the meanings explained in the foregoing specification.

F = 1.00000 f/2.4 $2\omega o = 54°$ $s_{a'} = +0.6649$ F

				η_d / ν_d	
A	L_1	$R_1 = +0.37875$	$d_1 = 0.094919$	1.67790/55.20	
		$R_1' = +0.72387$			
			$s_{12} = 0.002373$		
B	L_2	$R_2 = +0.42194$	$d_2 = 0.070477$	1.80279/46.76	Vgl.
		$R_2' = +0.64054$			
			$s_{23} = 0.040340$		
C	L_3	$R_3 = -9.72419$	$d_3 = 0.024916$	1.76180/26.95	
		$R_3' = +0.29449$			
			$CS = s_{34} = 0.053392$		
D	L_4	$R_4 = +1.62057$	$d_4 = 0.018984$	1.46450/65.70	
		$R_4' = +0.40696$			
			$s_{45} = 0$		Hgl.
	L_5	$R_5 = +0.40696$			
		$d_5 = 0.129327$	1.74400/44.77		
		$R_5' = -0.97225$			

all linear dimensions being expressed in proportion to the equivalent focal length of the entire lens system considered as unity, the symbols having the meanings explained in the forgoing specification.

10. An objective as defined in claim **1**, wherein the characteristics of the lens elements and their spatial relationship to each other are substantially as indicated below:

F = 1.00000 f/2.5 $2\omega o = 41°$ $s_{a'} = +0.6381$ F

				η_d / ν_d	
A	L_1	$R_1 = +0.44382$	$d_1 = 0.087078$	1.67790/55.20	
		$R_1' = +1.89875$			
			$s_{12} = 0.001742$		
B	L_2	$R_2 = +0.45343$	$d_2 = 0.068791$	1.74400/44.77	Vgl.
		$R_2' = +0.57095$			
			$s_{23} = 0.052247$		
C	L_3	$R_3 = -7.13672$	$d_3 = 0.067921$	1.72825/28.41	
		$R_3' = +0.30524$			
			$CS = s_{34} = 0.118774$		
D	L_4	$R_4 = +1.64413$	$d_4 = 0.024382$	1.58144/40.86	
		$R_4' = +0.38986$			
			$s_{45} = 0$		Hgl.
	L_5	$R_5 = +0.38986$	$d_5 = 0.081853$	1.74400/44.77	
		$R_5' = -0.95159$			

all linear dimensions being expressed in proportion to the equivalent focal length of the entire lens system considered as unity, the symbols having the meanings explained in the foregoing specification.

13. An objective as defined in claim **1**, wherein the characteristics of the lens elements and their spatial relationship to each other are substantially as indicated below:

		F = 1.00000 f/1.4 $2\omega o = 33°$ $s_{\infty}' = +0.3640$ F		η_d / ν_d	
A	L_1	$R_1 = +0.59523$	$d_1 = 0.206663$	1.71300/53.85	
		$R_1' = +5.78329$	$s_{12} = 0.002691$		
B	L_2	$R_2 = +0.45297$	$d_2 = 0.142081$	1.78831/47.37	Vgl.
		$R_2' = +0.67747$	$s_{23} = 0.043055$		
C	L_3	$R_3 = +6.87377$	$d_3 = 0.037673$	1.84666/23.82	
		$R_3' = +0.29826$	$CS = s_{34} = 0.153383$		
D	L_4	$R_4 = +1.85545$	$d_4 = 0.061891$	1.50013/61.44	
		$R_4' = +0.55003$	$s_{45} = 0$		Hgl.
	L_5	$R_5 = +0.55003$	$d_5 = 0.207202$	1.78427/41.30	
		$R_5' = 0 - 1.12126$			

12. An objective as defined in claim **1**, wherein the characteristics of the lens elements and their spatial relationship to each other are substantially as indicated below:

		F = 1.00000 f/1.4 $2\omega o = 32.5°$ $s_{\infty}' = +0.3890$ F		η_d / ν_d	
A	L_1	$R_1 = +0.57562$	$d_1 = 0.191482$	1.73350/51.65	
		$R_1' = +3.58024$	$s_{12} = 0.002659$		
B	L_2	$R_2 = +0.45392$	$d_2 = 0.120740$	1.78831/47.37	Vgl.
		$R_2' = +0.68418$	$s_{23} = 0.060104$		
C	L_3	$R_3 = +8.30927$	$d_3 = 0.037233$	1.84666/23.82	
		$R_3' = +0.29478$	$CS = s_{34} = 0.170207$		
D	L_4	$R_4 = +1.90083$	$d_4 = 0.037233$	1.50013/61.44	
		$R_4' = +0.51680$	$s_{45} = 0$		Hgl.
	L_5	$R_5 = +0.51680$	$d_5 = 0.207439$	1.78427/41.30	
		$R_5' = -1.03119$			

all linear dimensions being expressed in proportion to the equivalent focal length of the entire lens system considered as unity, the symbols having the meanings explained in the foregoing specification.

14. An objective as defined in claim **1**, wherein the characteristics of the lens elements and their spatial relationship to each other are substantially as indicated below:

		F = 1.00000 f/1.2 $2\omega o = 33°$ $s_{\infty}' = +0.2895$ F		η_d / ν_d	
A	L_1	$R_1 = +0.85142$	$d_1 = 0.221864$	1.78831/47.37	
		$R_1' = +5.64969$	$s_{12} = 0.005411$		
B	L_2	$R_2 = +0.51816$	$d_2 = 0.189396$	1.78831/47.37	Vgl.
		$R_2' = +1.18551$	$s_{23} = 0.021645$		
C	L_3	$R_3 = +2.56026$	$d_3 = 0.140694$	1.91761/21.51	
		$R_3 40 = +0.29990$	$CS = s_{34} = 0.156928$		
D	L_4	$R_4 = +2.13866$	$d_4 = 0.035174$	1.52341/51.47	
		$R_4' = +0.44236$	$s_{45} = 0$		Hgl.
	L_5	$R_5 = +0.44236$	$d_5 = 0.216453$	1.80801/40.75	
		$R_5' = -1.31143$			

all linear dimensions being expressed in proportion to the equivalent focal length of the entire lens system

relationship to each other are substantially as indicated below:

		F = 1.00000 f/1.3 $2\omega o = 18°$ $s_{\infty}' = +0.3420$ F		η_d / ν_d	
A	L_1	$R_1 = +0.65893$	$d_1 = 0.230703$	1.71300/53.85	
		$R_1' = -11.97527$	$s_{12} = 0.004837$		
B	L_2	$R_2 = +0.51229$	$d_2 = 0.125750$	1.78831/47.37	Vgl.
		$R_2' = +0.95812$	$s_{23} = 0.048365$		
C	L_3	$R_3 = -4.24885$	$d_3 = 0.106404$	1.84666/23.82	
		$R_3' = +0.30077$	$CS = s_{34} = 0.154769$		
D	L_4	$R_4 = +54.26597$	$d_4 = 0.096731$	1.51009/63.52	
		$R_4' = +0.55848$	$s_{45} = 0$		Hgl.
	L_5	$R_5 = +0.55848$	$d_5 = 0.162024$	1.78831/47.37	
		$R_5' = -0.67818$			

considered as unity, the symbols having the meanings explained in the foregoing specification.

15. An objective as defined in claim **1**, wherein the characteristics of the lens elements and their spatial

all linear dimensions being expressed in proportion to the equivalent focal length of the entire lens system considered as unity, the symbols having the meanings explained in the foregoing specification.

* * * * *

United States Patent [19]

Schulz et al.

[11] **3,994,558**

[45] **Nov. 30, 1976**

[54] **BINOCULAR MICROSCOPE WITH IMPROVED MONOCULAR PHOTOGRAPHIC AND MEASURING CAPABILITY USING MOVABLE OBJECTIVE**

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[73] Assignee: **Wild Heerbrugg Aktiengesellschaft**, Heerbrugg, Switzerland

[22] Filed: **June 23, 1975**

[21] Appl. No.: **589,183**

[30] **Foreign Application Priority Data**

July 4, 1974 Switzerland 9153/74

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[51] **Int. Cl.²** **G02B 21/20;** G02B 7/02

[58] **Field of Search** 350/36, 35, 45, 19, 350/39, 38, 37, 247, 44; 354/79

[56] **References Cited**

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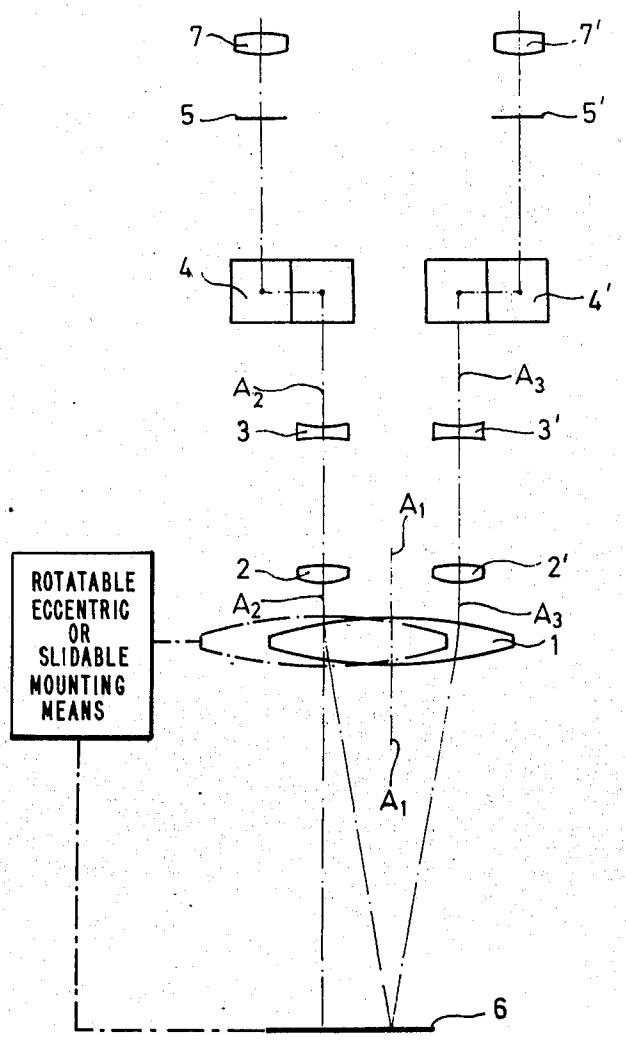
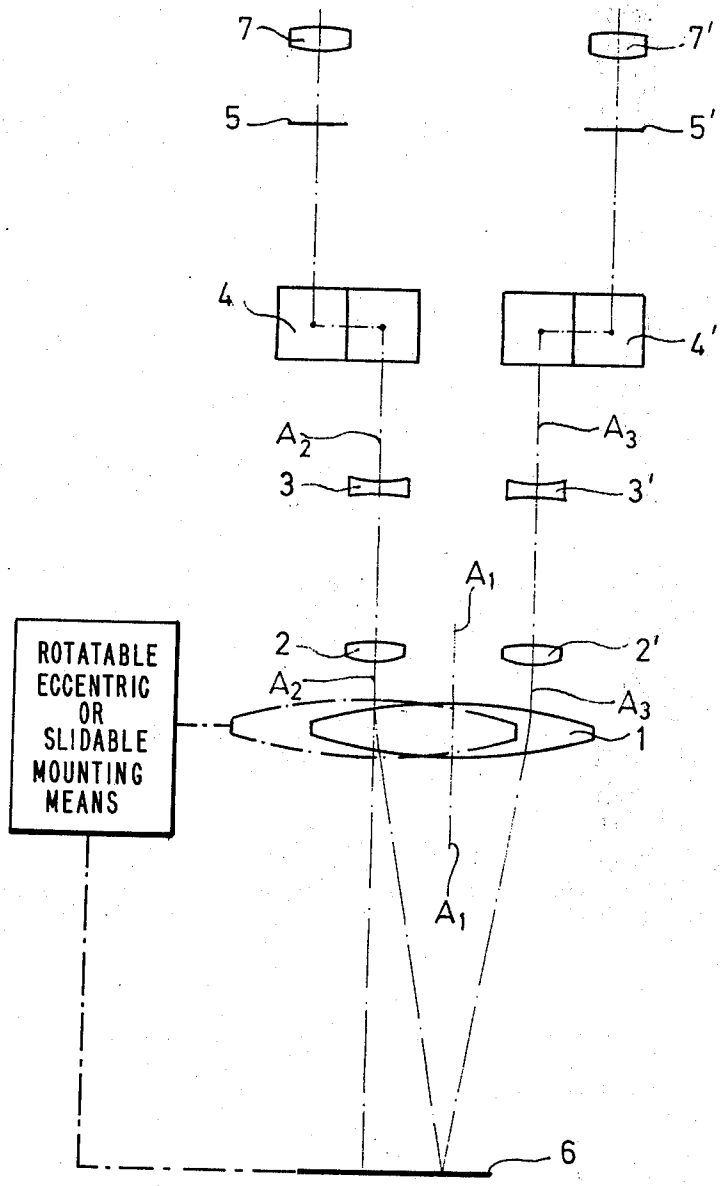
Primary Examiner—John K. Corbin
Assistant Examiner—Jon W. Henry
Attorney, Agent, or Firm—William R. Woodward

[57] **ABSTRACT**

The main objective of the microscope is shifted from the stereoscopic viewing position to a position in which its optic axis coincides with the optic axis of one of the twin variable magnification optical systems used for stereoscopic viewing. This shifted position provides better resolution for photography and measurement and reduces the correction requirements on the main objective. The shift of the objective is coordinated with a shift of the object under observation or a countershift of the upper part of the microscope in order to maintain the same field of view of the object.

5 Claims, 1 Drawing Figure




7
7'
5
5'
4
4'
A2
A3
3
3'
A1
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A2
A3
1
ROTATABLE ECCENTRIC OR SLIDABLE MOUNTING MEANS
A1
6

BINOCULAR MICROSCOPE WITH IMPROVED MONOCULAR PHOTOGRAPHIC AND MEASURING CAPABILITY USING MOVABLE OBJECTIVE

This invention relates to a stereomicroscope of the kind in which a main objective is used with a twin variable magnification binocular system.

Stereomicroscopes of this type are known. In these instruments the direction of view through the main objective to the object under observation in the object plane uses eccentric rays through the objective falling obliquely on the object. Only in this way does the observer have the possibility of obtaining a spatial impression of the observed object. In order to obtain monocular individual photographs of the objects observed, supplementary camera attachments are used.

Stereomicroscopes are frequently used for measurements, blood counts and similar determinations.

A disadvantage of these known stereomicros lies in the fact that the direction of viewing passes eccentrically through the main objective and falls obliquely on the object to be measured or photographed. For this reason, the photographs obtained are seriously deteriorated. Measuring errors arise in the measurement of distances as the result of parallax and of oblique projection. For this reason, stereomicroscopes have been used only for measuring tasks of low accuracy requirements.

In order to avoid this disadvantage, it has already been proposed that in the variable magnification system used with the objective, a triplet of identical variable magnification systems should be used instead of the usual twin systems, the third being the central system between the two used for binocular viewing that is rotationally symmetrical with the main objective. Since in modern stereo microscopes variable magnification is generally carried out in continuous fashion with so-called zoom objectives, great design and manufacture costs are involved in the provision of the optical and mechanical components of the variable magnification system. For these reasons the proposed solution of providing a triplicate magnification system has not worked out in practice.

It is an object of the present invention so to improve a stereomicroscope that for measuring and for photography, the principal ray from the object observed coming perpendicularly through the main objective will come within the scope of the variable magnification optical system.

SUBJECT MATTER OF THE PRESENT INVENTION

Briefly, means are provided to change the relative position of the main objective with regard to at least one of the twin variable magnification optical systems in a stero microscope, so that the optical axis of the main objective can be brought into alignment with the optical axis of one of the two twin variable magnigication systems. This is preferably done by moving the main objective relative to the casing of the twin variable magnification optical systems, and that may be done in coordination with a shift of the object under observation to prevent too great a change of the field of view between stereo viewing and photography.

The invention is further described by way of example with reference to the annexed drawing in which the single FIGURE is a diagram of the optical system of a stereomicroscope according to the present invention.

The main objective is designated **1** in the drawing. Above the main objective **1** are twin variable magnification optical systems consisting respectively of the lenses **2, 3** and **2',3'**. These twin optical systems geometrically subdivide the rays entering through the main objective and respectively lead the two ray bundles through erecting prisms **4** and **4'** to intermediate image planes **5** and **5'** respectively. As the result of the provision of the erecting prisms **4** and **4'**, monocular images that are unreversed laterally and vertically of the object under observation lying in the object plane **6** are produced. Eyepieces **7** and **7'** serve for viewing the projected monocular images in the intermediate image planes **5** and **5'** respectively. By means of a mechanical arrangement symbolically shown by the dashed line **10,** the position of the main objective **1** can be so changed that its optical axis A_1—A_1 coincides with one of the optical axes of the respective twin variable magnification systems, in the example shown the axis A_2—A_2 which is the optical axis of the system comprising the lenses **2** and **3.** When the main objective **1** is shifted to that position, which is shown with a dot-dash line in the FIGURE, the central or principal ray from the object plane **6** through the main objective is a ray that also goes perpendicularly through the center of the lenses **2** and **3,** which is to say that the optic axes of the lenses **1, 2** and **3** coincide.

The mechanical arrangement for changing the position of the main objective can be a mounting that can be slid in a guide by half the distance between the optical axes A_2—A_2 and A_3—A_3 of the respective twin optical systems **2, 3** and **2',3'**. It is also possible to mount the main objective **1** in a rotatable eccentric mounting **11** that can be rotated by 180° relative to the casing of the twin optical systems, in which case the spacing between the optical axis A_1—A_1 of the main objective and the axis of rotation of its mounting amounts to half the spacing between A_1—A_1, and one of the respective optical axes of the twin variable magnification optical systems.

It is not absolutely necessary to change the position of the main objective in the instrument. It is also conceivable that the position of the main objective should remain unchanged and that the position of one or both of the twin variable magnification optical systems could be changed.

A substantial advantage of the invention lies in the fact that when a photographic camera is mounted either on the tubus of the microscope or between the tubus and the variable magnification system, perfect monocular individual photographs can be made. A further advantage lies in the fact that no errors arise through parallax or oblique projection when measurements are made when the microscope of the present invention is in its measuring and photographing configuration.

For visual observation, the requirements for the main objective are not as exacting as for measurements and for photography. For this reason, there is a further advantage in the invention that lower requirements are set for the correction of the main objective if photography is always done with the principal rays passing perpendicularly through the center of the main objective. This results in considerable cheapening of the manufacture of the optical elements of the microscope.

When the position of the main objective is changed, a different field of view (different picture section) of an object in the object plane is projected on the intermediate image plane (the image plane **5** in the example illustrated). In order to correct for this change, the object is simply moved by the same length in the same direction as the main objective, as indicated by the dashed line **10** in the FIGURE, or else the upper portion of the stereomicroscope is shifted by the same distance but in the opposite direction.

The provision of a mechanical linkage to produce simultaneously a change of position of the main objective and a correction movement of the object or of the binocular microscope upper portion by coupling the two movements so that both functions can be accomplished by actuating a single operating lever in order to convert the microscope from the binocular viewing position to the photographing and measuring position can be so readily devised that it need not be further described here.

We claim:

1. A stereomicroscope comprising a main objective and twin variable magnification optical systems arranged for stereoscopic viewing through said main objective and further comprising means for producing relative displacement of said main objective and at least one of said twin optical means with respect to each other between a monocular viewing position in which the optical axis (A_1—A_1) of said main objective (**1**) is coincident with the optical axis (A_2—A_2) of one (**2, 3**) of said twin optical systems to minimize errors of parallox and oblique projection and a stereoscopic viewing position in which said optical axis (A_1—A_1) of said main objective (**1**) is equidistant between the optical axes (A_2—A_2, A_3—A_3) of said twin optical systems (**2,3; 2',3'**).

2. A stereomicroscope as defined in claim **1,** in which said means for producing relative displacement is constituted by means for moving said main objective relative to said twin optical systems.

3. A stereomicroscope as defined in claim **2,** in which said main objective is mounted on a sliding carriage and said sliding carriage is laterally movable in a guide fixed in the casing of the twin variable magnification optical means.

4. A stereomicroscope as defined in claim **2,** in which said main objective is eccentrically mounted in a rotatable mounting located in front of the variable magnification twin optical means.

5. A stereomicroscope as defined in claim **2,** in which means are also provided for movement of the object under observation in coordination with the operation of said means for moving said main objective.

* * * * *

United States Patent [19]

Jernigan

[11] **3,984,156**

[45] **Oct. 5, 1976**

[54] **OBJECTIVE PLOTTING OF VISUAL FIELDS BY EYE MOVEMENT MONITORING**

[75] Inventor: **Marvin E. Jernigan,** Weston, Mass.

[73] Assignee: **Narco Scientific Industries, Inc.,** Fort Washington, Pa.

[22] Filed: **Sept. 12, 1974**

[21] Appl. No.: **505,339**

[52] **U.S. Cl.** **351/6;** 351/39

[51] **Int. Cl.²** **A61B 3/10**

[58] **Field of Search** 351/6, 17, 23, 24, 39, 351/7

[56] **References Cited**

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Primary Examiner—Paul A. Sacher

Attorney, Agent, or Firm—Wolf, Greenfield & Sacks

[57] **ABSTRACT**

An apparatus for measuring and evaluating a subject's visual field presents a target image, consisting of a spot of light, at a series of selected locations within the subject's visual field. Means are provided to monitor his resulting eye movement and positions in response to each target presentation. A projection apparatus presents the target images at various locations and in a programmed sequence. The apparatus also includes means for making a photographic plot of those presented targets which the subject has seen or missed, as desired. Determination of whether subject has seen or missed a particular target is evaluated by logic systems which discriminate between eye movement and positions displaying characteristics indicative of whether the subject has seen or missed the target. The logic discriminates between blinks, hunting eye movements and other characteristic positions and movements which are indicative of the subject having seen the target. Means also are provided to enable selective coarse or fine mapping of selected regions of the subject's visual field.

22 Claims, 23 Drawing Figures

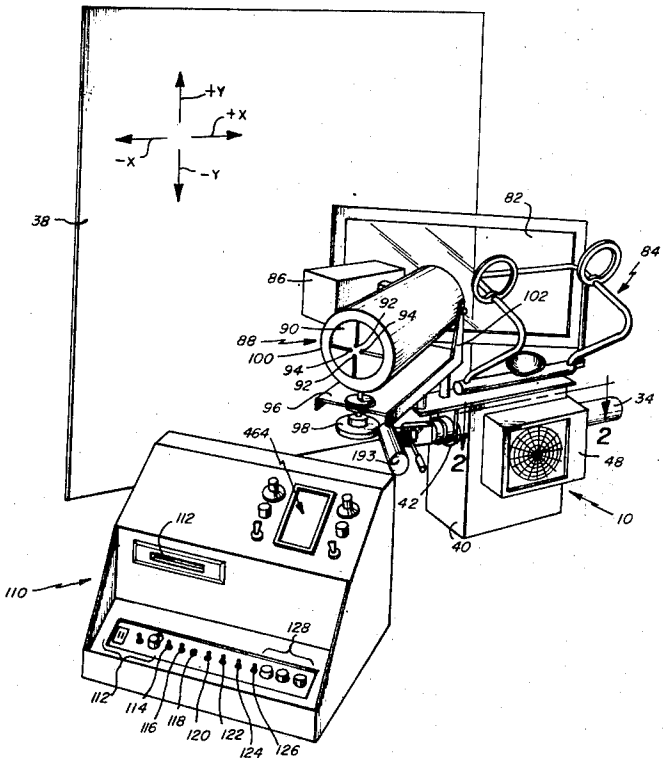


FIG. 1

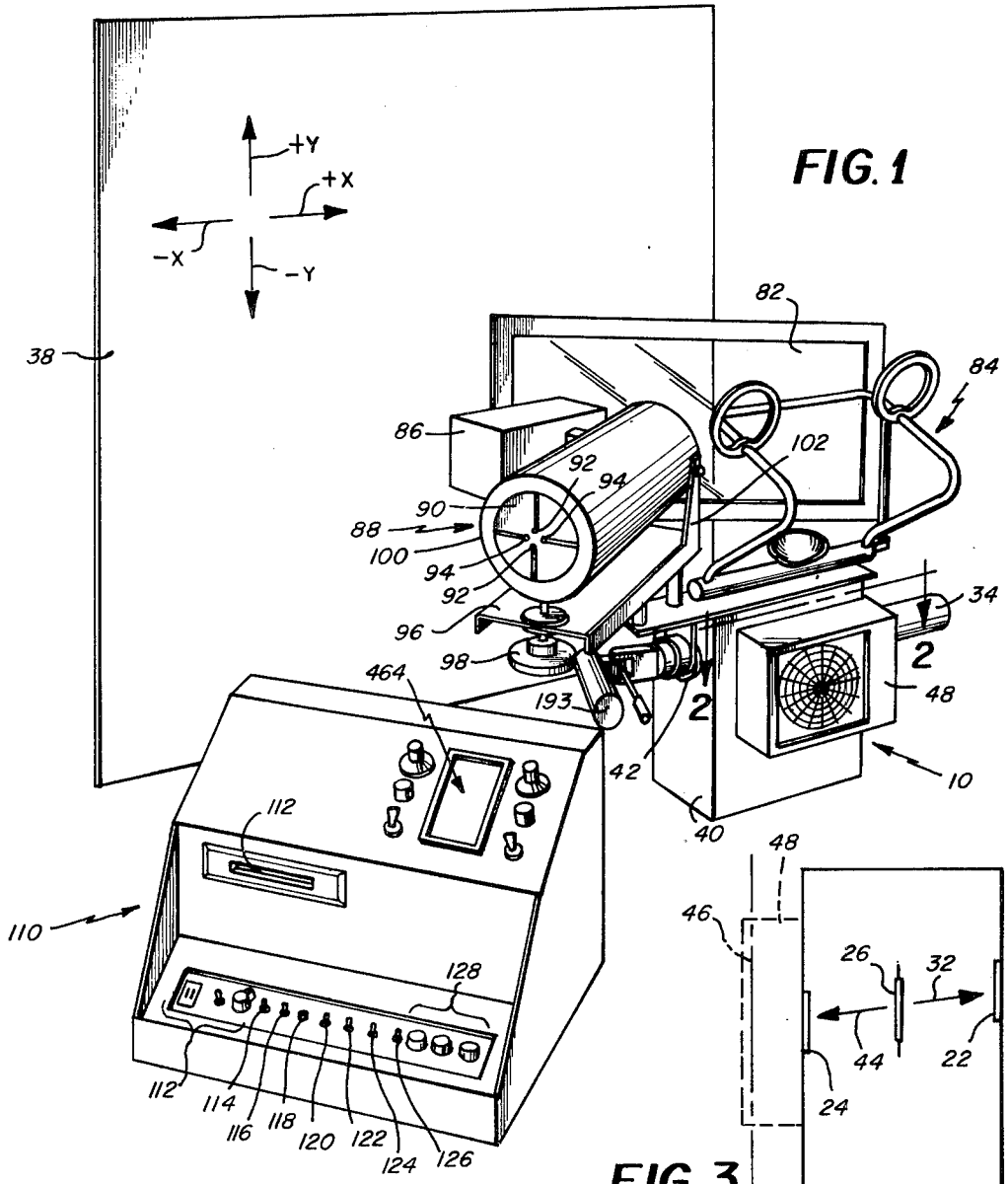
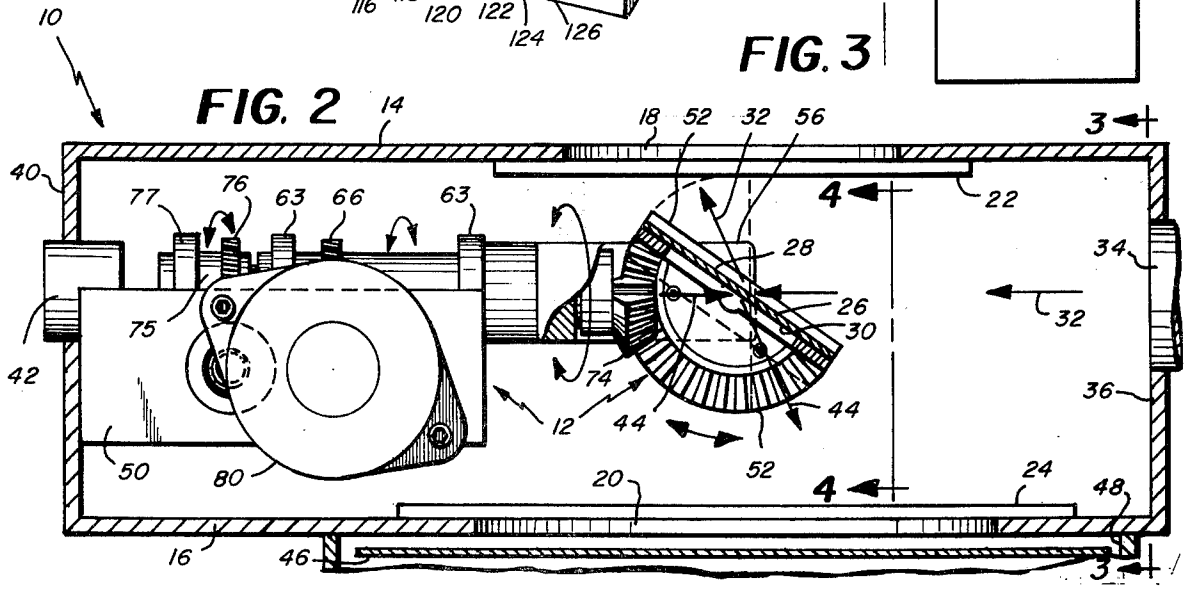


FIG. 3

FIG. 2



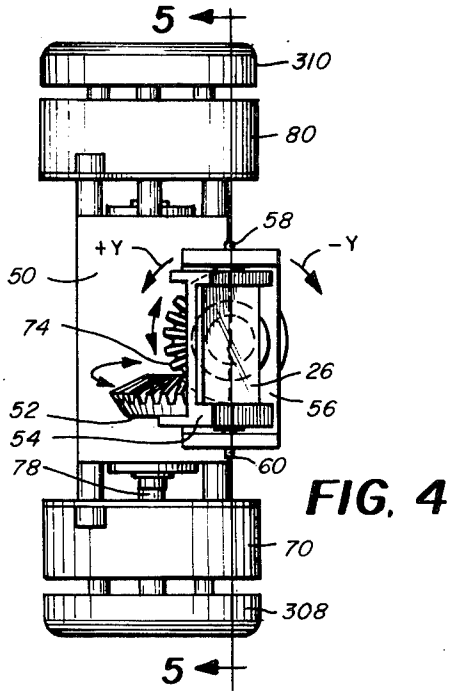


FIG. 4

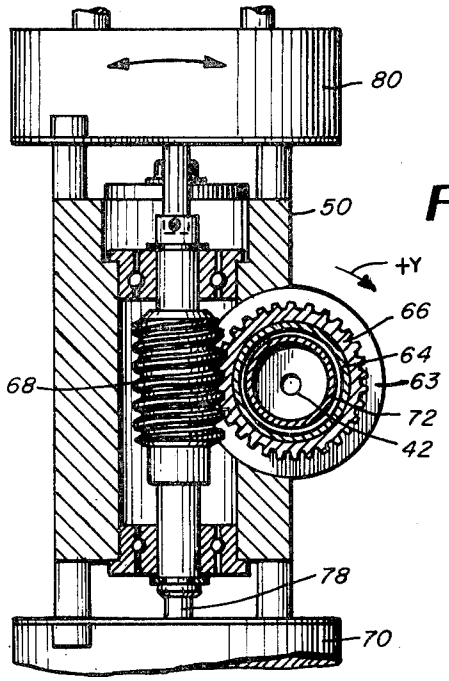


FIG. 6

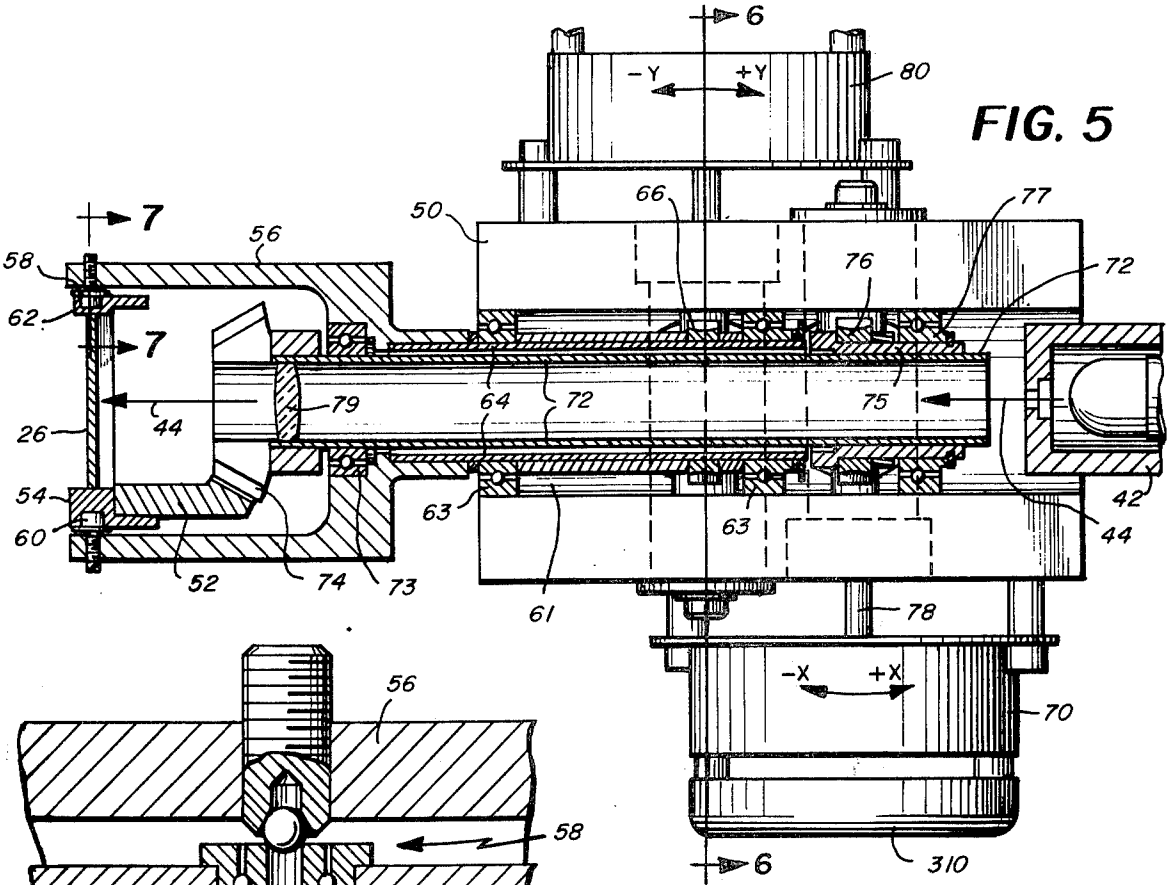


FIG. 5

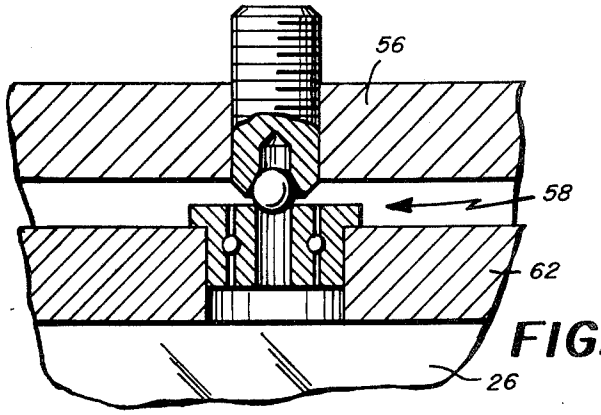


FIG. 7

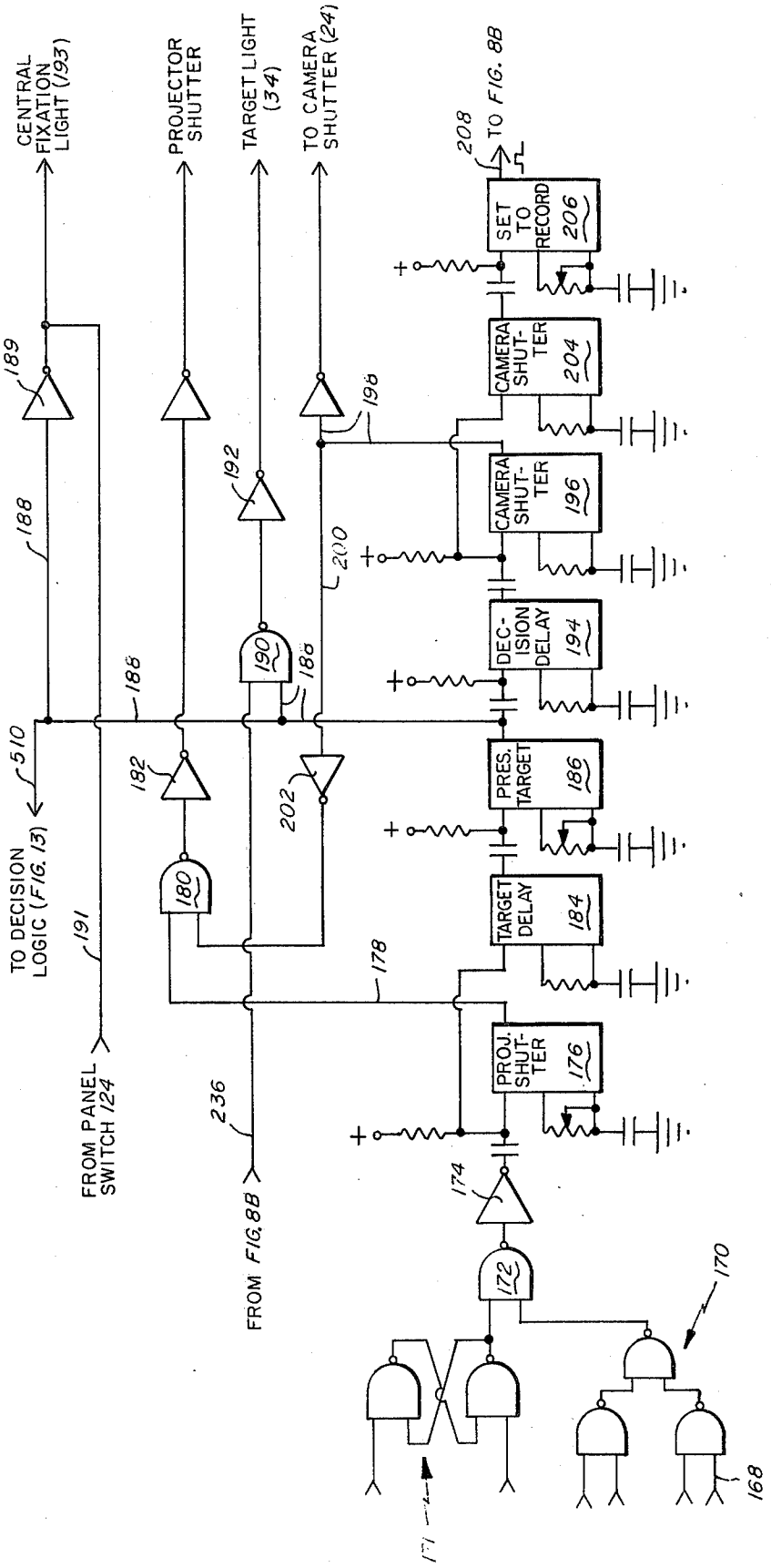

CENTRAL FIXATION LIGHT (193)
PROJECTOR SHUTTER
TARGET LIGHT (34)
TO CAMERA SHUTTER (24)
208
TO FIG. 8B
SET TO RECORD 206
CAMERA SHUT-TER 204
CAMERA SHUT-TER 196
DEC-ISION DELAY 194
PRES. TARGET 186
TARGET DELAY 184
PROJ. SHUT-TER 176
189
188
192
198
210
190
186
180
182
202
510
TO DECISION LOGIC (FIG. 13)
191
FROM PANEL SWITCH 124
236
FROM FIG. 8B
178
174
172
170
168
171

FIG. 8A

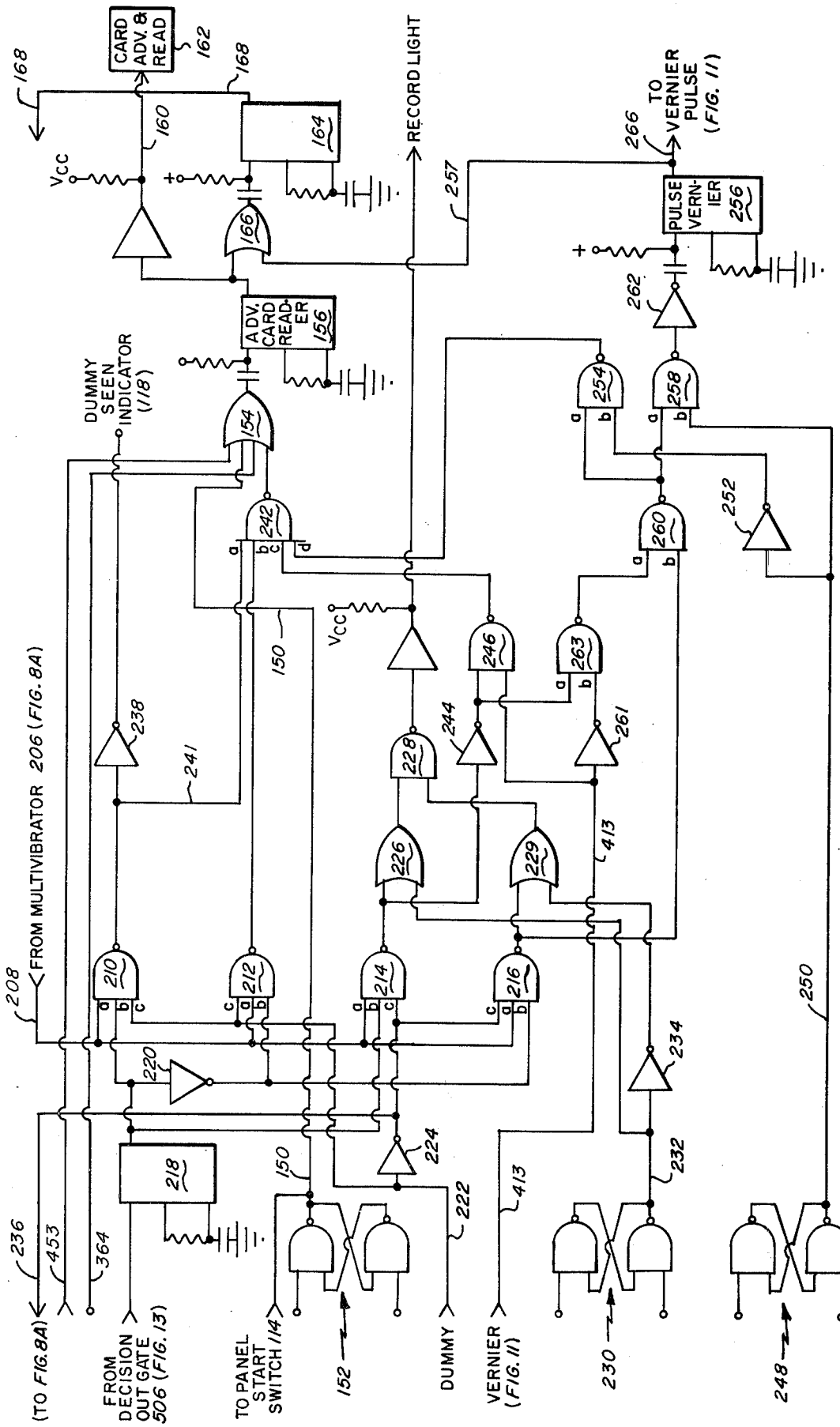

CARD ADV. & READ
162
168
160
164
RECORD LIGHT
257
266
TO VERNIER PULSE (FIG. 11)
PULSE VERNIER 256
166
ADV. CARD READER 156
DUMMY SEEN INDICATOR (118)
154
242
254
258
262
252
260
263
246
150
VCC
238
241
228
244
261
226
229
413
FROM MULTIVIBRATOR 206 (FIG. 8A)
208
210
212
214
216
220
234
250
218
224
232
222
236
453
364
(TO FIG. 8A)
FROM DECISION OUT GATE 506 (FIG. 13)
TO PANEL START SWITCH 114
152
DUMMY
VERNIER (FIG. 11)
230
248

FIG. 8B

FIG. 9

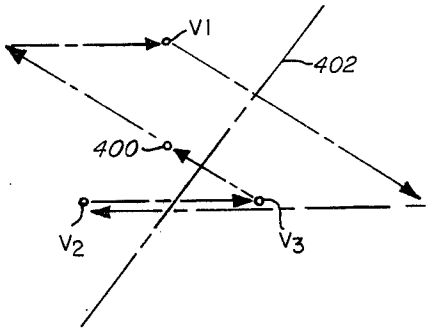


FIG. 9A

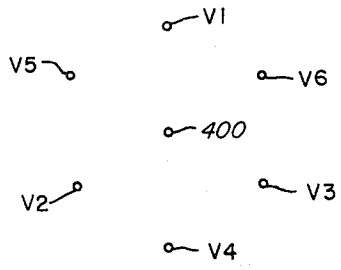


FIG. 12A

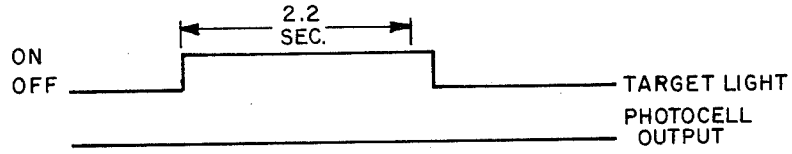


FIG. 12B

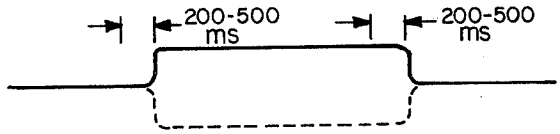


FIG. 12C

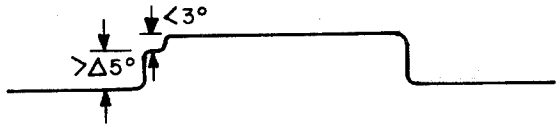


FIG. 12D

FIG. 12E

FIG. 12F

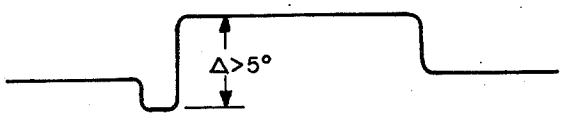


FIG. 12G

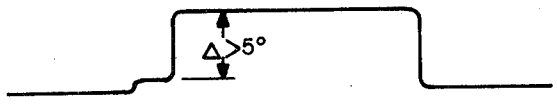
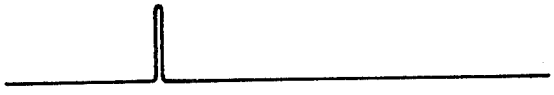


FIG. 12H



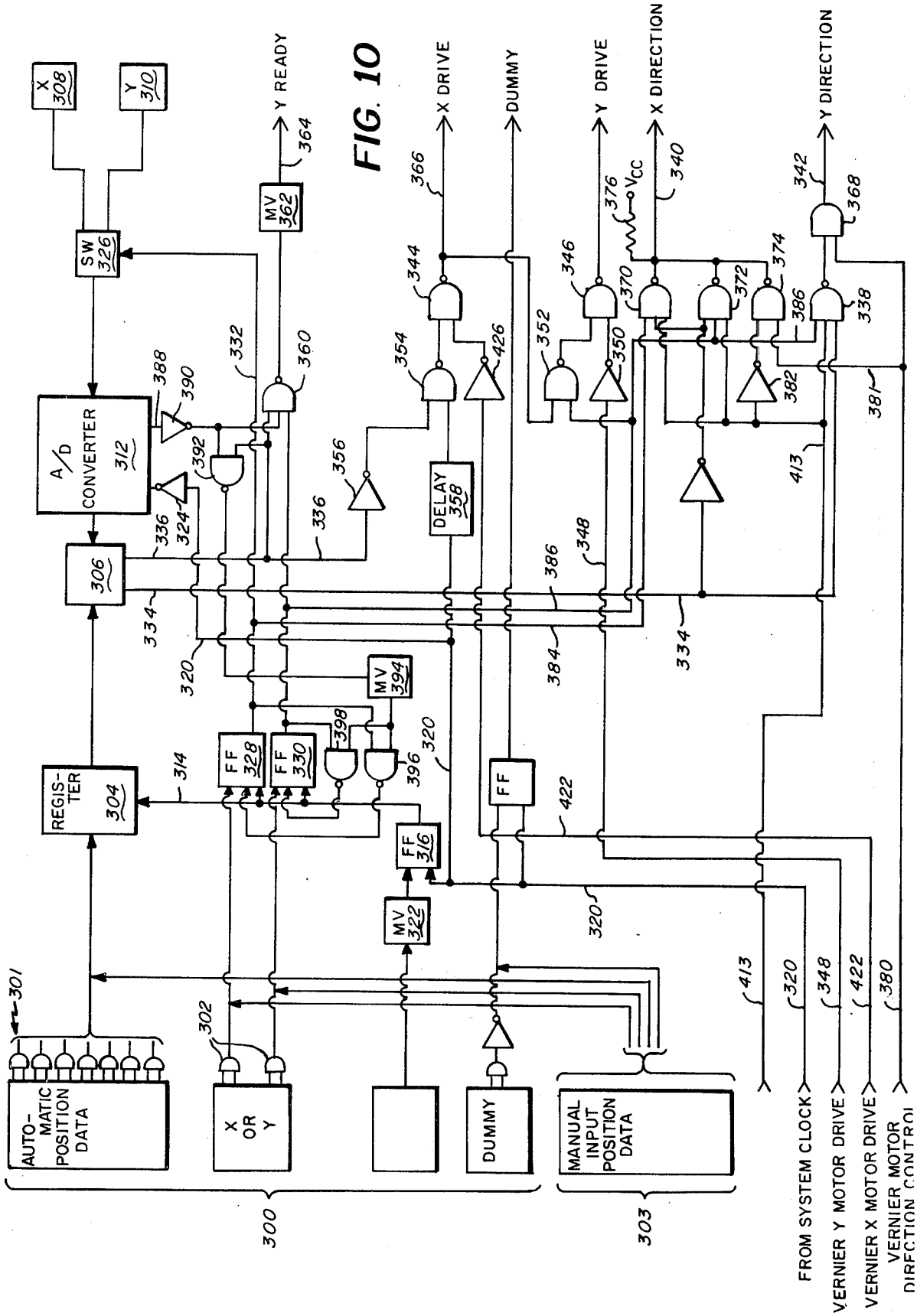

X 308
Y 310
SW 326
A/D CONVERTER 312
306
REGIS-TER 304
314
FF 328
FF 330
FF 316
MV 322
MV 362
MV 394
Y READY
364
X DRIVE
DUMMY
Y DRIVE
X DIRECTION
Y DIRECTION
DELAY 358
FF
AUTO-MATIC POSITION DATA
X OR Y
DUMMY
MANUAL INPUT POSITION DATA
300
303
FROM SYSTEM CLOCK
VERNIER Y MOTOR DRIVE
VERNIER X MOTOR DRIVE
VERNIER MOTOR DIRECTION CONTROL

FIG. 10

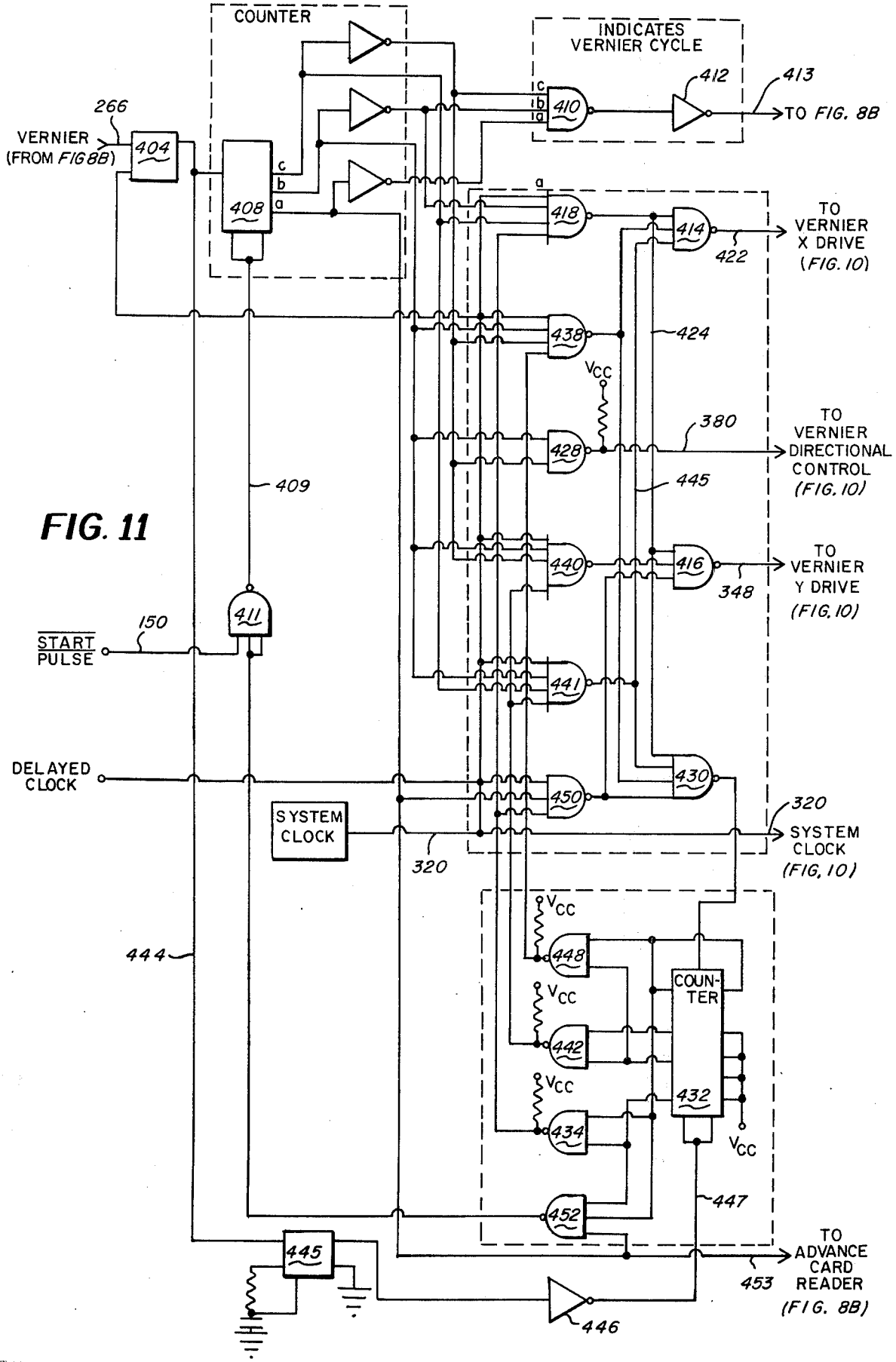

COUNTER
INDICATES VERNIER CYCLE
266
VERNIER (FROM FIG 8B)
404
408
410
412
413
TO FIG. 8B
418
414
422
TO VERNIER X DRIVE (FIG. 10)
438
424
Vcc
428
380
TO VERNIER DIRECTIONAL CONTROL (FIG. 10)
445
409
440
416
348
TO VERNIER Y DRIVE (FIG. 10)
411
150
START PULSE
441
DELAYED CLOCK
430
450
320
SYSTEM CLOCK
SYSTEM CLOCK (FIG. 10)
444
448
442
COUN-TER
432
434
447
452
445
446
453
TO ADVANCE CARD READER (FIG. 8B)

FIG. 11

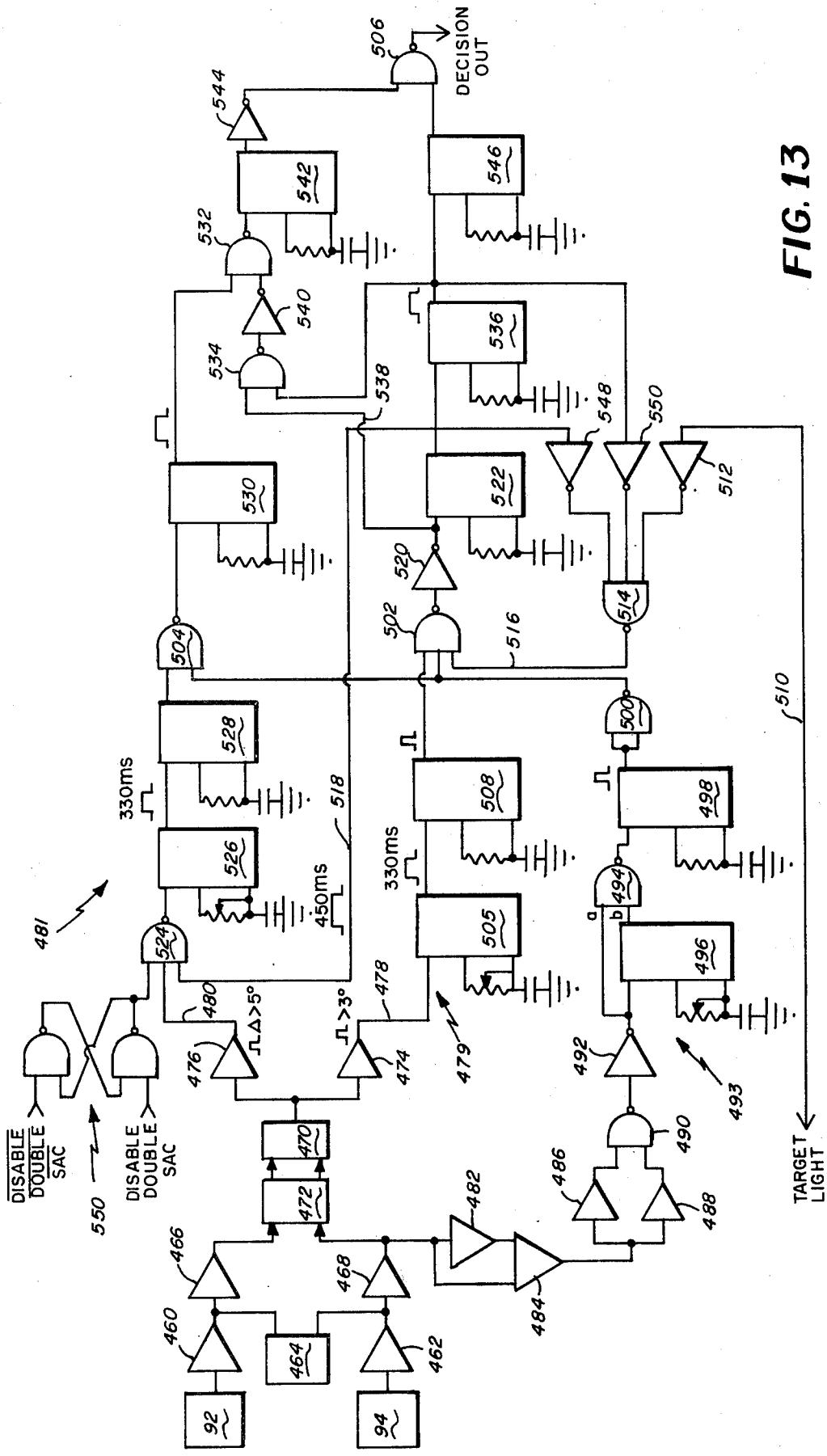
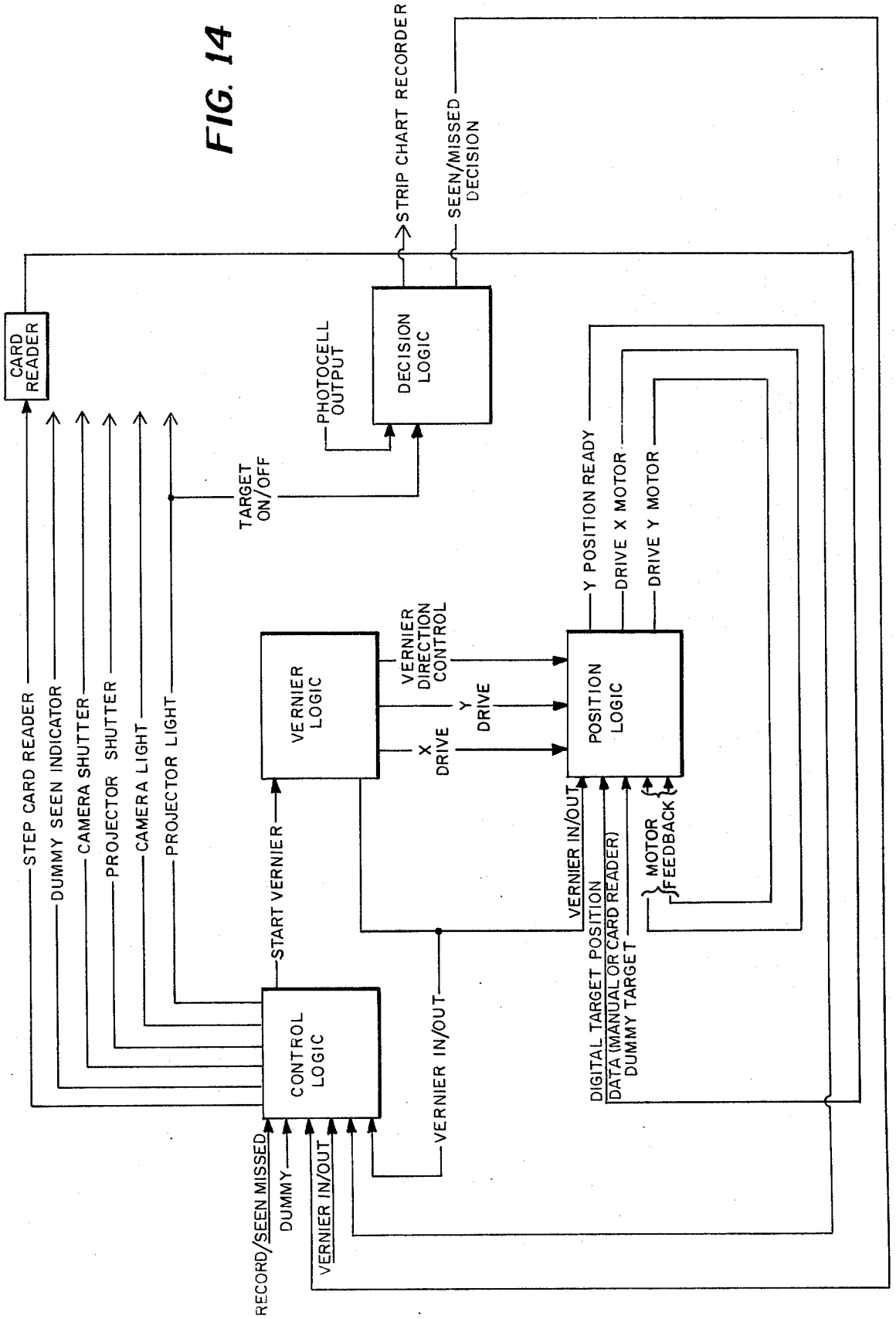

DECISION OUT
TARGET LIGHT
DISABLE DOUBLE SAC
DISABLE DOUBLE SAC
330ms
330ms
450ms
Δ>5°
>3°
481
479
493
550

FIG. 13

FIG. 14


STRIP CHART RECORDER
SEEN/MISSED DECISION
CARD READER
PHOTOCELL OUTPUT
DECISION LOGIC
TARGET ON/OFF
Y POSITION READY
DRIVE X MOTOR
DRIVE Y MOTOR
VERNIER DIRECTION CONTROL
VERNIER LOGIC
Y DRIVE
X DRIVE
POSITION LOGIC
STEP CARD READER
DUMMY SEEN INDICATOR
CAMERA SHUTTER
PROJECTOR SHUTTER
CAMERA LIGHT
PROJECTOR LIGHT
START VERNIER
VERNIER IN/OUT
MOTOR FEEDBACK
CONTROL LOGIC
DIGITAL TARGET POSITION DATA (MANUAL OR CARD READER) DUMMY TARGET
VERNIER IN/OUT
RECORD/SEEN MISSED
DUMMY
VERNIER IN/OUT

OBJECTIVE PLOTTING OF VISUAL FIELDS BY EYE MOVEMENT MONITORING

BACKGROUND OF THE INVENTION

Measurement of one's visual field is important for a variety of reasons including the diagnosis of glaucoma as well as other human visual system diseases or impairments. In general, the prior techniques for determining one's visual field and any blind spots have been quite slow and tedious and require a definite subjective response from the person being tested in order to determine whether he has sighted the target at a particular location in his visual field. Additionally, the previously employed tests require administration by one having relatively high degree of skill such as an ophthalmic technician, optometrist or ophthalomologist. For example, in the most common type of visual field test, a hand held target such as a small disc at the end of a wand, is moved about the subject's visual field by the examiner while the subject fixates on a central point. During movement of the hand held target through the subject's field, the examiner asks the subject repeatedly whether he can see the movable target as it is passing from location to location. The examiner may plot, manually, the location of each point which is seen by the subject, or alternatively, he may plot those locations which the subject is unable to see, and which, therefore, define his blind spot.

In order to overcome the uncertainties and difficulties in the foregoing testing techniques some attempts have been made to automate partly the foregoing visual field test, such as employing an arrangement for automatically presenting a series of targets to the subject. Although these devices are somewhat faster than the completely manual test described above, they still are relatively slow and require that the subject respond consciously and intentionally when he sees the target. For example, the response may be verbal or may be indicated by the subjective manipulation of a lever or a button.

Also among the primary difficulties in obtaining fast and accurate plots of the subject's visual field is that the examiner must be assured that the subject's line of sight is directed toward a central fixation point or other known reference point before the target is presented to him. In some instances this may be quite difficult when problems of communication exist between the subject and the examiner as, for example, when testing the young, the aged, or persons whose native language is different than that of the examiner. Furthermore, any such difficulties render efficient and accurate testing still more complicated because it may confuse the results of the test.

A further difficulty in conducting visual field tests with prior techniques is that an indication by the subject that he has seen the target may be the result of hunting eye movements in which, he did not at first actually see the target but moved his eyes about slightly, in a searching motion, and then having seen the target, then moved his eyes directly to it. The present invention employs means for discriminating between such hunting movements and movements in which the presented target was initially seen by the subject.

It is among the primary objects of the invention to provide an apparatus for determining a subject's visual field which avoids the foregoing and other difficulties.

SUMMARY OF THE INVENTION

The invention takes advantage of the natural voluntary or involuntary eye movements which results when a target is presented suddenly to a subject within his visual field. Measurement of the eye movement or change in eye position in response to presentation of the target is employed to determine whether the subject has seen the target. The eye movements may be detected and monitored by a technique described in U.S. Pat. No. 3,473,868 in which the direction and magnitude of the eye movements are translated into electrical signals. Electronic logic means are provided for discriminating between signals which represent eye movements characteristic of the subject having actually seen the target from other types of eye movements such as blinks, hunting or searching movements or the like which produce electrical impulses unrelated to the subject's actual initial detection of the target image. The logic means includes a decision logic circuit which evaluates whether the subject actually visually detected the target by reference to the number and magnitude of the subject's eye movements within an extended time interval which includes the interval during which the target image is presented and a short period thereafter.

The invention employs a target image projector which develops a narrow collimated light beam and directs the beam sequentially toward selected locations on a screen which is within the subject's expected visual field. The position of the intermittent light beam and target image on the screen is determined by reflecting the beam, from its source, off one surface of a double faced mirror toward the screen. The attitude of the mirror is controllable to selectively direct the beam in the desired direction by stepping motors which are positioned in accordance with preprogrammed digital information. The location of the target image on the screen, as presented to the subject, may be recorded permanently and automatically on photographic film incorporated into the projector. In the preferred embodiment, the photographic film is of the Polaroid type which enables immediate inspection after the test has been completed. The photographic recording is made by employing a second light beam which is reflected off the opposite face of the controlled mirror toward the photographic film. The second, reflected beam is directed along the same axis as the first projection beam, but from the opposite direction and impinges on the film at a location which is dependent on the angle of incidence of the beam to the mirror which corresponds to the direction of the light beam which impinges on the target screen. Shutters are provided in association with each of the first and second light beams, the first shutter being employed to control the timing and duration of presentation of the target light and the second shutter means being employed to expose the photographic film to the second beam. In another mode of operation only those points which are not observed are photographically recorded to provide a plot of the subject's blind spot or spots. The second shutter is controlled automatically in response to the logic circuitry which evaluates whether the subject has seen or missed a particular target.

The stepping motor arrangement for changing the attitude of the mirror also enables the device to be programmed to present a sequence of targets on the screen in close proximity to each other rather than more widely spaced locations about the screen. This

enables more precise plotting and evaluation of an area of the subject's blind spot or spots after the more coarse presentation of the target spots has indicated the general location of the blind spot or spots. The device may be operated in a mode in which the more precise evaluation is effected automatically when a subject has missed a presented target.

It is among the primary objects of the invention to provide an improved technique for determining and plotting a subject's visual field.

Another object of the invention is to provide an improved technique in which the subject's response to a series of targets presented at various locations in his visual field is determined objectively without subjective response on his part.

A further object of the invention is to provide an arrangement for making a permanent record of the subject's visual field.

Still another object of the invention is to provide an improved technique for plotting and measuring a subject's visual field without requiring that the test be administered by highly skilled personnel.

Another object of the invention is to provide an improved technique by which eye movements characteristic of a subject's actual sighting of a target presented within his visual field may be discriminated from other types of eye movements automatically.

DESCRIPTION OF THE DRAWINGS

The foregoing and other objects and advantages of the invention will be understood more fully from the following further description thereof, with reference to the accompanying drawings wherein:

FIG. **1** is an illustration of the invention set up in readiness for use;

FIG. **2** is a sectional plan illustration of the mirror positioning mechanism as seen from line **2—2** of FIG. **1** and showing portions of the mechanism broken away;

FIG. **3** is a sectional elevation as seen along the line **3—3** of FIG. **2**;

FIG. **4** is a side elevation of the mirror positioning mechanism as seen along the line **4—4** of FIG. **2**;

FIG. **5** is a sectional view of the mirror positioning mechanism as seen along the line **5—5** of FIG. **4**;

FIG. **6** is a sectional elevation of the mirror positioning mechanism as seen along the line **6—6** of FIG. **5**;

FIG. **7** is an enlarged illustration of the low friction bearing by which the mirror is mounted;

FIG. **8A** and **8B** illustrate a schematic of the control logic electronics of the invention;

FIG. **9** is an illustration of the relative locations of the vernier target images with respect to each other and to the location of the primary target image on the presentation screen;

FIG. **9A** is an illustration of an alternative configuration of vernier target locations;

FIG. **10** is a schematic illustration of the electronic logic circuitry for controlling the positioning of the mirror mechanism;

FIG. **11** is a schematic illustration of the electronic logic system for controlling presentation of the vernier target images;

FIG. **12A** is a DC plot of a subject's response when an actually presented target has been missed;

FIG. **12B** is a DC plot of an ideal "target seen" response;

FIGS. **12C** and **12D** are DC plots of a three saccade response in which the subject initially detected the target but required a minor correctional saccade to focus directly on the target;

FIG. **12E** is a DC plot of a subject's response where the target was detected but where his eyes returned to the central fixation point before the target light was switched off;

FIGS. **12F** and **12G** are DC plots of the subject's eye movement where he did not see the target image and moved his eyes to hunt or search for the target;

FIG. **12H** is a DC plot representative of a blink;

FIG. **13** is a schematic diagram of the decision logic circuitry; and

FIG. **14** is a block diagram illustrating diagrammatically the relationship between the various functions of the logic circuits.

DESCRIPTION OF THE PREFERRED EMBODIMENT

FIGS. **1–3** shows generally the apparatus employed in the invention which includes a projector-camera housing **10** in which is mounted the mirror mechanism **12.** The housing **10** includes a front wall **14** and a rear wall **16,** having apertures **18, 20** respectively which can be opened or closed by a projection shutter **22** and film shutter **24.** The mirror mechanism **12** includes a double faced mirror **26** having a front face **28** and a rear face **30.** The mirror **26** is arranged so that it will reflect the light beam **32** from a projection light **34,** mounted to a sidewall **36** of the housing, **10** through the projection shutter **22** and onto the projection screen **38.** The opposite sidewall **40** of the housing **10** supports a second light source **42** which directs a beam of light **44** toward the rear face **30** of the mirror **26** along the same axis as that of the light beam from the projection light **34.** The beam from the second light source **42** is reflected from the mirror surface **30** in a direction which is opposite that of the reflected projection beam **32** from the front face **28** of the mirror **26.** The recording light beam **44** is directed toward a film plane, indicated diagrammatically at **46** and disposed at the rear of the housing **10** by any of a variety of well-known film holding devices **48.** The double faced mirror **26** thus directs the projection beam **32** to a selected location on the screen and simultaneously directs the recording beam **44** (when it is operated) to a corresponding location in the film plane **46,** as controlled by the attitude of the mirror **26.**

The mirror **26** is mounted for adjustable movement by the mirror mechanism **12.** The mirror mechanism is mounted to a support block **50** which is secured to the interior of the housing **10.** As shown more fully in FIGS. **2–7,** the mirror mechanism **12** includes a driven bevel gear segment **52.** The mirror **26** is secured to and across the diameter of gear **52** by a bracket **54** and lies in a plane perpendicular to that of the gear **52.** The mirror **26** and gear **52** are supported for rotation in unison about the central axis of the gear **52** by means of a yoke **56** having a low friction bearing **58** which supports the upper edge of the mirror, by bracket **62,** and a low friction bearing **60** which supports the opposite face of the gear **52,** by bracket **54,** to enable the mirror **26** and gear **52** to rotate in unison about a common axis defined by the bearings **58, 60.** The yoke **56** is mounted for rotation about a horizontal axis to rotate the mirror **26** and gear **52** bodily about that horizontal axis. To this end the yoke **56** is secured to the end of an outer cylinder **64** which is mounted for rotation to the block **50** by bearings **63.** The cylinder **64** has a gear **66** secured thereto which is rotated by a worm gear **68** which

is driven, in turn, by a stepping motor **80** mounted to the block **50.** The mirror **26** and gear **52** are rotatable with respect to the yoke **56** by means of an inner cylinder **72** which extends through and is rotatable within the outer cylinder **64.** One end of the inner cylinder **72** extends into and is supported at the yoke by bearing **73** and has a bevel gear **74** secured thereto which meshes with driven bevel gear **52.** The opposite end of the inner cylinder **72** extends outwardly beyond the end of the outer cylinder **64** and has a collar **75** secured thereto. The collar **75,** in turn, is rotatably mounted to the block **50** by bearing **77.** The inner cylinder **64** is driven by a gear **76** secured thereto which is driven by the worm gear as described above. The worm gear is secured to shaft **78** of stepping motor **70.** The stepping motors **70, 80** of the mirror mechanism **12** are operated by the position logic system which, in turn, is controlled by the digital information on the program card or the vernier positioning system to orient the mirror **26** to present the target image at any desired location within the subject's visual field and also direct the recording light beam (when operated) to a corresponding location in the film plane. The second light source **42** is mounted to a sidewall of the housing in alignment with the axis of rotation of the inner and outer cylinders **72, 64.** The inner cylinder **72** is hollow along its length to enable the light beam from the second light source to impinge on and be reflected by the mirror **26.**

For convenience in the further description herein, the mirror axis of rotation extending through the bearings **58, 60** will be referred to as the X axis and the axis of rotation of the mirror by means of the yoke **56** will be considered as the Y axis. Similarly, step motor **70** will be referred to as the X step motor and step motor **80** will be referred to as the Y step motor.

In order to monitor the position and eye movements of the subject during the test, the device may include a partially reflective plate **82** mounted above and forwardly of the housing **10** so as to be directly in front of the subject's view when his head is properly placed in the head rest and chin support **84.** Plate **82** is adapted to enable the subject to view the screen **38** and is disposed at an angle to his general line of sight to enable a light source **86,** preferably infrared, to reflect from the plate **82** and illuminate the subject's eyes. The image from the subject's eyes is, in turn, reflected from the plate **82** toward an imaging arrangement **88** which includes a ground glass screen **90** on which the reflected image of the subject's eye may be focused, employing the technique described in the aforementioned U.S. patent. As described in that patent a pair of vertically spaced photoelectric cells **92** and horizontally spaced photoelectric cells **94** are located on or adjacent the screen **90** and are aligned with selected regions of the image of the subject's eye on the screen **90.** Variations in the output signals from the photocells **92, 94** are dependent on the direction and magnitude of the subject's eye movements and their signals are processed in the logic circuitry as described more fully herein. Imaging arrangement **88** preferably is mounted for adjustment to the housing **10** to facilitate initial alignment of the photocells **92, 94** with the subject's eye image on the screen **90.** This may include a bracket **96** pivoted for horizontal movement to the housing **10** and a vertical elevation screw **98** carried by the bracket **96** and in engagement with the end of the barrel **100,** the other end of the barrel **100** being pivoted to the bracket at trunnions **102.**

GENERAL DESCRIPTION OF OPERATION

The invention employs a number of electronic logic systems which are interrelated as shown diagrammatically in FIG. **14.** The primary logic systems include a control logic circuit, a positioning logic circuit, a decision logic circuit and a vernier logic circuit. A typical cycle might begin by an output from the control logic circuit to step a card reader and read the card bearing digital information corresponding to an intended location of the target image. The digital information is fed into the position logic circuitry which controls the mirror positioning mechanism **12** and positions the mirror in the intended attitude. In the embodiment of the invention described, digital data is included in the card for the positions of each of the X and Y motors with the Y motor being positioned first and then the X motor. When the Y motor has been driven to its intended position, a "Y position ready" signal is fed into the control logic to cause the card reader to advance to the next column of X positioning information on the digital information card. This is fed into the position logic and the X motor is driven to its intended position. During the stepping of the motors **70, 80** the position of the X or Y step motor being driven is fed back to the position logic circuit for comparison with the intended position corresponding to the digital positioning input. The control logic includes means for delaying operation of the other elements of the invention during positioning of the mirror. After that delay has elapsed and the mirror has been positioned the control logic resumes operation to open the projector shutter and turn on the projector light to present the target image on the projection screen while simultaneously turning off the central, reference fixation target light. The target image will be located at a predetermined angular distance, within approximately 40°, from the central reference fixation target. The position and movement of the subject's eyes, during and slightly after presentation of the target image, is monitored by the photocells **92, 94** and their output is fed into the decision logic which evaluates whether the subject has seen or missed the presented target. The seen/missed decision from the decision logic is fed back into the control logic and, depending on whether the manual inputs to the control logic were set to record seen or missed targets, the control logic will operate the camera shutter and the camera light to make, or not to make, a photographic plot of that target image.

Means are also incorporated in the invention for checking the subject's cooperation in the test by enabling "dummy" targets (those in which there is no target presented) to be "presented" to the subject. In the event that the output from the photocells indicates eye movement indicating that the subject did "see" the dummy target, the control logic causes a "dummy seen" indicator light on the operator's control panel to turn on thus advising the operator of the subject's uncooperativeness.

It should be noted that the shutter mechanisms are opened and closed whether a real target or a dummy target is presented. This is desirable when the shutter mechanism selected makes audible operating sounds which might be heard by the subject. By operating the shutters for each mode the subject cannot tell audibly whether the target is real or a dummy.

The invention also includes means for evaluating the subject's visual field closely about the region in which

he missed an actually presented target. For this purpose the vernier logic circuit may be employed. The vernier logic circuit is set into operation when the control logic receives a signal from the decision logic indicating that the subject missed an actual target. When the vernier logic circuit is initiated, the control logic is disabled from operating the card reading mechanism and the positioning of the mirror, to present the vernier target images, is controlled entirely by the vernier logic circuit. When the vernier target images have been presented the vernier logic causes the position logic to return the mirror to the attitude which it was in before the vernier sequence and the positioning logic is then enabled to be responsive to the digital positioning information from the card reader. The control logic causes the card reader to be advanced to the next informational word corresponding to the next intended target location and the sequence is begun anew.

The electronic logic systems may be housed conveniently in a control module **110** which houses the card advancing and reading mechanism which includes an exposed slot **112** to receive the card. The module **110** may also house a strip chart recorder **464** to provide a supplemental record of subject's eye test. The module **110** also includes a control panel which includes a manual target positioning means **112,** a start switch **114,** a stop switch **116,** a "dummy seen" indicator light **118,** a record seen/missed selector switch **120,** a vernier in/out switch **122,** a manually controllable switch **124** for turning the reference fixation target on or off, a "disable double saccade" switch **126** and a number of intensity controls **128** for the target light, recording light and reference fixation light.

DESCRIPTION OF CONTROL LOGIC

FIGS. **8A** and **8B** show the circuitry controlling and coordinating the operation of the machine. The sequence of operation is begun by applying a pulse to line **150** through flip-flop **152** and through OR gate **154** to trigger monostable multivibrator **156.** When first starting the sequence of operation the starting pulse may be applied to line **150** through manual start switch **114.** Succeeding pulses are applied to line **150** through flip-flop **152** which is operated in a manner described herein. The high output pulse from multivibrator **156** is amplified and fed through line **160** to initiate operation of a card advancing and reading device **162** which may be of any of a variety of commercially available designs. It should be noted that while the present embodiment of the invention is described as employing digital programming information in the form of a machine readable card, other information, storage and reading techniques may be employed such as tape or the like as is well known in the art. The pulse from multivibrator **156** is also applied to multivibrator **164** through OR gate **166.** Multivibrator **164** has a delay constant (will remain at a high output) sufficient to delay presentation of the target image long enough to enable the card advancing and reading mechanism **162** to position the card so that its digital information may be read as well as to provide sufficient delay for the stepping motors of mirror mechanism **12** to position the mirror, as for example, a delay of approximately 1 second. The output from multivibrator **164** also is directed through line **168** to a gating circuit **170** (FIG. **8A**) which has an AND function. The output from gate circuit **170** is fed through NAND gate **172** and inverter **174** to apply a high input to monostable multivibrator **176.** The other inputs to the gating circuit **170** are from the positioning logic circuitry, described below, which is effective to apply a high input to gating circuit **170** when the mirror has been positioned in accordance with the digital information on the input card, as described herein. With the mirror properly positioned, monostable multivibrator **176** is triggered and its output is directed, through line **178** to actuate the driving mechanism for the projection shutter **22** to open the projection shutter. In the embodiment shown this may be achieved by applying the output from the multivibrator **176** to the input of an enabled NAND gate **180,** inverting the low output from gate **180** to a high state through inverter **182** and applying the high pulse to the shutter mechanism to open the shutter. Multivibrator **176** has a time delay sufficient to maintain the projection shutter open while the target light is being presented. For example, the delay may be of the order of 2.75 seconds.

It is desirable to delay the operation of the target light until the projection shutter **22** has been opened fully. To this end simultaneously with actuation of monostable multivibrator **176,** the pulsed output from inverter **174** is also applied to monostable multivibrator **184** which has a delay constant of the order of 55 milliseconds, depending on the time required to open the shutter fully. The high output pulse from multivibrator **184** is fed into monostable multivibrator **186** which, in turn, controls operation of the target light. The output from multivibrator **186** causes the target light **34** to turn on through line **188** to NAND gate **190** and inverter **192** to the switch mechanism (not shown) for the target light. Gate **190** is normally enabled because of the normally high state of line **236** as will be described. Multivibrator **186** has a delay constant sufficient to remain in a high output state and present the target image for a predetermined time interval long enough to afford the subject a sufficient opportunity to detect and respond to the target. By way of example, a delay constant of the order of 2.2 seconds would be typical. It is desirable to switch the central reference fixation target light **193** off when the target image is presented. This may be accomplished automatically by connecting line **188** through an inverter **189** to the central fixation light. When multivibrator **186** switches high to present the target light, the output from inverter **189** switches low to extinguish the central fixation light **193.** When multivibrator **186** returns to its stable state, turning off target light **134,** the output from inverter **189** will return to its high state to re-present the central reference fixation target. In an alternative mode of operation the central fixation light **193** may be maintained on at all times, including the time in which the target is presented, by line **191** which is connected to the panel switch **124.**

The subject's eye movements and positions are monitored during an extended time interval which includes the predetermined time interval of the presentation of the target image. As described, the output from the photocells **92, 94** is evaluated by the decision logic circuitry to determine whether the subject actually visually detected the target image. In order to provide ample opportunity for the decision to perform its function the output from multivibrator **186** is applied concurrently to monostable multivibrator **194** which has a delay constant sufficient for the subject's eye positions and movements to be monitored by the photocells **92, 94** and the resulting signals processed through the decision logic circuitry. The delay constant of multivibrator

194 preferably is somewhat longer than the time constant of multivibrator 186 to enable the decision logic to evaluate eye movements after the target image has been extinguished, for the full extended time interval. The delay may be, for example, of the order of 3 1 seconds. **This is desirable because the subject's eyes may move after the target light has been extinguished, as when returning his vision to the central fixation point as described herein.**

When the decision logic has evaluated whether a subject actually visually detected the presented target image, it then remains for the photographic recording system to make, or not make, a photographic plot of the target image location, as determined by the mode of operation which the examiner has selected. To this end as multivibrator 194 returns to its stable, low output state, the pulse triggers multivibrator 196, and the output of multivibrator 196 is directed through line 198 to the camera shutter mechanism to open the camera shutter 24. At the same time, the output from multivibrator 196 is directed through line 200 through inverter 202 to apply a low signal at NAND gate 180 which will insure that the projector shutter is closed. This precludes ambient light from reaching the film plane as might occur if the projection shutter 22 remained opened at the same time as the camera shutter. Simultaneously with the actuation of multivibrator 196, the output from multivibrator 194 is applied to monostable multivibrator 204 which is effective to delay further sequencing of the photographic recording functions until the camera shutter 24 is open fully. The delay will depend on the characteristics of the shutter mechanism and may for example, be of the order of 55 milliseconds. It may be noted that monostable multivibrator 196 has a time delay constant sufficient for the logic and control circuits to "decide" whether or not to make a photographic plot of the relative location of the target image as described below. By way of example, the delay may be of the order of 1.2 seconds. When the camera shutter 24 has been opened fully, the return to its stable, low output state of multivibrator 204 triggers multivibrator 206. Multivibrator 206 sets the control logic circuitry in readiness to cause a photographic record of the position of the target to be made, depending on whether the target light was actually presented, whether it was a "dummy" in which case no target would have been presented, whether the subject "saw" or "missed" the target or dummy and whether the intended mode of operation, as controlled by a suitable selector switch on the panel of the control box, is set to record "seen" or "missed" points.

As shown in FIGS. 8A and 8B the output from multivibrator 206 is directed through line 208 to one of the inputs *a* of each of the NAND gates 210, 212, 214, 216. Each of gates 210, 212, 214 and 216 also has an input *b* which is controlled by the decision output from the decision logic circuitry. As described more fully herein, the output from the decision logic circuitry is a signal which is indicative of whether the subject's eye positions and movements where characteristic of his having "seen" the target. As shown in FIG. 8B the output from the decision logic circuitry is applied to monostable multivibrator 218 and the output from multivibrator 218 is directly connected to input *b* of each of NAND gates 210 and 214. The output from multivibrator 218 is also connected, through inverter 220 to input *b* of each of NAND gates 212 and 216. Each of the gates 210, 212, 214, 216 also includes an input *c*, as through line 222, which controls gates 210, 212, 214, 216 in the event that a "dummy" target was presented. The state of line 222 may indicate a "dummy" either by a manual dummy presentation switch on the control panel or from appropriate digital information programmed into the card. Line 222 is connected directly to input *c* of each of the NAND gates 210, 212 and is applied, in an inverted form, through inverter 224 to input *c* of each of the NAND gates 214, 216.

Gates 210, 212 are effective to detect, respectively, whether a dummy signal was "seen" or whether it was "missed," as it should have been. Gates 214, 216 discriminate between actually presented targets which are "seen" or "missed." For example, assuming that an actually presented target was seen and that the manually controlled panel switch (which controls the output of flip-flop arrangement 230), to selectively record points seen or points missed, is in the "record seen" configuration. Where the target was actually presented, line 222 is at a low state which applies low inputs to terminals *c* of gates 210 and 212 and high inputs to terminals *c* of gates 214, 216. Inputs *a* of each of gates 210, 212, 214, 216 are high at this time, from the output of multivibrator 206 through line 208. A target which was actually seen will result in an output pulse from the decision logic to pulse multivibrator 218. This will result in a high input to terminal *b* of NAND gate 214 and a low input to terminal *b* of NAND gate 216. The resulting high output of gate 214 is passed through OR gate 226 and the high output from OR gate 226 is applied to NAND gate 228. The other input to NAND gate 228 is high because of its connection to the output of OR gate 229, which was high because of the high output from NAND gate 216. This results in a pulse at the output from NAND gate 228 which triggers the recording light source. Had the subject under test missed the presented target, input *a* to NAND gate 216 would have remained in its inverted high state thus maintaining its output low which, through OR gate 229, would maintain NAND gate 228 in its previous state. The result would be no output pulse from NAND gate 228 and the record light source would not be triggered.

If it is desired to record the missed targets, thus providing a photographic plot of only the missed points, the panel controlled record seen/missed selector 230 may be set manually to switch the state at line 232 from high to low which sets one of the input terminals of NAND gate 228 at a high state through inverter 234 and OR gate 229. The low state of line 232 is applied directly to one of the inputs to OR gate 226. When the presented target is missed, there will be no pulse from multivibrator 218 and its output will remain low, resulting in a high output from gate 216 which, through OR gate 226, will generate a low output pulse from NAND gate 228, thus triggering the recording light source and making a photographic plot of that missed point. If, however, the target is seen, the output pulse from multivibrator 218 will be applied to input *b* of NAND gate 214 which will switch gate 214 to a low output state with a corresponding low output state from OR gate 226. NAND gate 228 will not be triggered and no photographic recording will be made.

In those instances where it is desired to spot check the subject's response by providing a "dummy" target, the state of line 222 may be changed from low to high either by a manually operable switch on the face of the control panel or by preprogrammed digital instruction on the program card. In either event, when the state of

line 222 is switched to high, the high state is applied to inputs *c* of NAND gates 210, 212, respectively. Inputs *a* of gates 210, 212 are also at a high state. Gates 214, 216 are disabled from operating the recording light during this mode of operation by means of the low output of the inverter 224. The low output from inverter 224 also is applied, through line 236 to an input of NAND gate 190, thus disabling gate 190 (FIG. 8A) and precluding operation of the target light.

When a "dummy target" is presented and "missed" input *b* to gate 210 will be low, resulting in a high output from gate 210 which, is inverted through inverter 238. The output from inverter 238 is employed to control the operation of an indicator light 240 on the panel which, when lit, indicates that the subject moved his eyes when there was no target presented. Here, however, where the "dummy target" was missed, the output from inverter is low and the indicator 240 is not lit. The "dummy missed" indication also results in a high input at terminal *b* of gate 212, thus switching the output of gate 212 to a low state which, in turn, is applied at the input terminal *b* of NAND gate 242. This generates a high output state from gate 242 which is passed through OR gate 154 and is employed to actuate multivibrator 156, to step the card reading mechanism and begin a new cycle of operation.

Where the dummy target has been "seen" the high output from multivibrator 218 is applied to input terminal *b* of gate 210 resulting in a low output from that gate. This actuates the "dummy seen" indicator light on the panel which advises the operator that the subject is moved his eyes in a search for the target or is otherwise being uncooperative in the test. It also switches AND gate 242 through line 241 to pulse multivibrator 156 and advance the card reading mechanism.

After the foregoing arrangement has completed its cycle of evaluating whether the subject detected or missed a real or dummy target and a photographic plot of the seen or missed points has been made, the card reader is sequenced to its next position to read the next column of digital information from the preprogrammed card and begin a new cycle of operation.

When the target image is presented, the inputs to terminals *c* of gates 210, 212 will be low resulting in a high output from these gates into NAND gate 242. If the real target was seen the low output from gate 214 will be inverted at inverter 244 and the resulting high signal will be applied to an input of NAND gate 246. In most instances (except as described below in connection with operation of the vernier logic circuitry) the other input to gate 246 will also be at a high state, resulting in a low output from gate 246 which applied to terminal *c* of gate 242 thus causing a high output pulse to be applied to multivibrator 156 through OR gate 154 to advance the card reader and begin a new cycle is described above.

Where an actually presented target has been missed (assuming that the device is not being operated in its vernier mode) gate 242 is switched by switching its input *d* low. This results from the low output of NAND gate 254 when an actual target has been missed. Input *b* to gate 254 is set high when not operating in vernier (as will be described). Input *a* to gate 254 is controlled by the output from gate 260. NAND gate 260, in turn, has one input *a* set high when not operating in the vernier mode through the high state in line 413 which is inverted, at inverter 261 to a low output state which, in turn, is applied to input *b* of gate 263 maintaining the output of gate 263 high which is applied to input *a* of NAND gate 260. When an actual target has been missed, output of gate 216 switches low resulting in a high output pulse from NAND gate 260 which switches gate 254 low and in turn switches NAND gate 242.

As will be described more fully with regard to the vernier logic circuitry, when in the vernier mode, a series of targets are presented in a programmed sequence which is incorporated into the logic circuitry itself and is not embodied in the preprogrammed digital input information. For this reason, the card reading and stepping mechanism must be disabled while the vernier sequence is being performed. Whether the vernier cycle is to be employed in a given test is controlled manually by the operator at a switch at the control panel. Once the switch has been set by the operator, the vernier circuit will operate automatically in response to a subject having missed a real target and the card reading mechanism will be disabled. The card reading mechanism is disabled by maintaining a low output from gate 242. Inputs *a* and *b* of gate 242 are maintained at a high state when the target image is actually presented and missed. This results from the high output of gate 246 which, in turn, results from the low output of inverter 244 which, in turn, results from the high output of gate 214 when an actual target has been missed. Input *d* of gate 242 also is maintained at a high state when an actual target is missed and when operating in the vernier mode. To this end, the manual vernier switch operates a flip-flop 248 which, when the vernier is "in", is at a high output state. The high state from flip-flop 248 is applied to line 250 and is inverted through inverter 252 and the resulting low state is applied to input *b* of NAND gate 254. The resulting high output from gate 254 is applied at input *d* of gate 242 thus disabling that gate. After the device begins operation of the vernier mode, inputs *c* and *d* to gate 242 are maintained at a high state, thus maintaining the card stepping and reading mechanism 162 disabled throughout the vernier operation, which results from line 413 being switched to a low state. This maintains the output from gate 246 into input *c* of gate 242 high. The output from gate 254, which is applied to input *d* of gate 242 also is maintained high as a result of the low output from inverter 252 which occurs when operating in the "vernier in" mode.

With the card advancing and reading mechanism disabled the presentation of the vernier target images is initiated by an output pulse from monostable multivibrator 256 as will be described more fully herein. The input to multivibrator 256 is dependent on whether the device is being operated in a "vernier in" mode and also whether a real target has been missed. When operating in the "vernier in" mode, the high state in line 250 is fed into input *b* of NAND gate 258 to enable that gate. When an actually presented target is missed, the output from gate 216 switches low which, in turn, switches the output from NAND gate 260 high thus switching gate 258 to its low output state. This is inverted at inverter 262 and the resulting pulse is employed to trigger multivibrator 256 and pulse line 266 to begin the functioning of the vernier control logic as will be described.

Should it be desired to stop the machine at any time this may be done by operating panel stop switch 116 which controls a flip-flop 171 to the disable gate 172 and preclude further sequencing of the control logic.

DESCRIPTION OF POSITIONING LOGIC

The circuitry for controlling the position of the mirror **26** includes means for both manually and automatically feeding digital information into the machine regarding the desired attitude of the mirror and/or whether a particular target is to be a real or dummy target. The mirror positioning logic receives inputs, selectively, from the vernier control circuitry as well as from the programmed digital information card or tape. As mentioned above, when operating in the vernier mode the sequential positioning of the mirror is a function of the circuitry incorporated into the vernier circuit itself. However, when the position of the mirror is to be controlled by the digital information on the program card or tape, a separate input to the positioning logic is employed. For this purpose, and as shown in FIG. **10,** the card reader indicated generally at **300** includes a plurality of output gates **301** which are set to a state corresponding to the information read by the card reader and which corresponds to the target coordinates. This data is transferred to a seven bit register **304** which stores the digital information regarding the particular coordinates of the intended target location. The register **304** feeds a comparator **306.** The comparator **306** also receives feedback input corresponding to the actual position of the X and Y stepping motors **70, 80** at any given time. To this end, step motors include follower potentiometers **308, 310** which step with the motors **70, 80** and are employed to feed back, in analog form, a signal corresponding to the position of their respective step motors **70, 80.** The analog information is fed through an analog-to-digital converter **312** and the output from the A/D converter is fed into the comparator **306.** As will be described below, the X and Y step motors **70, 80** are driven by the output pulses from a system clock in incremental steps which, in cooperation with the gearing selected, will cause the target image on the screen to shift 1°. The output from comparator **306** is employed to terminate driving of the step motors when they have reached a position corresponding to that which was fed into register **304** in digital form.

It may be noted that in the described embodiment of the invention the digital information for a particular intended mirror position is stored on a conventional card having rows and columns of digital data and in a manner in which each column has information relating to either the X or Y position. Whether a particular seven bit digital word read by the target coordinate portion of the card reader relates to an X or Y coordinates is so identified by a bit in the column being read. Thus, card reader **300** also includes a section including output gates **302** which are set, alternatively, to a high or low state depending whether the information which relates to X or Y coordinates. It may be noted that the invention also includes manual means for positioning the target location, indicated generally at **303** and having controls at the control panel.

When operating automatically the card reader will first read a data column relating to the intended position of one of the step motors (the Y motor) and then, after that function has been carried out, the card reader will be advanced to read the next column and carry out the positioning instructions with regard to the other step motor (the X motor).

When a column of digital information is read at reader **300** or fed in at manual input **302,** it is entered into the register **304** when the register **304** is pulsed through line **314.** Line **314,** in turn, carries the output from flip-flop **316** which, in turn, is pulsed by the system clock **318** through line **320,** flip-flop **316** having been previously set by multivibrator **322.** The starting pulse from the system clock **318** is also applied, through inverter **324** to A/D converter **312** to initiate its operation. The A/D converter **312** is selectively fed with analog information from either of the follower pots **308, 310** as controlled by a switch **326.** The position of switch **326** is in turn controlled by the digital input information which also includes in each column data indicative of whether the particular column or manual input relates to positioning of X motor **80** or Y motor **90.** The "X or Y" motor identification data is applied to a pair of flip-flops **328, 330.** Digital information indicating a column of X information indicating a column of X information relating to the intended position of motor **80** will actuate X flip-flop **328** which, through line **332** operates switch **326** to connect the A/D converter **312** to the X motor follower pot **308.** In the absence of an output pulse from X flip-flop **328,** switch **326** will normally be in a position which connects the output from the Y follower pot **310** to the A/D converter **312.**

The direction in which the step motors **70, 80** are driven is controlled by output **334** of comparator **306.** Comparator output **334** controls the state of lines **340** and **342** which are connected to the X and Y step motors **80, 90,** respectively to switch the polarity of each motor in accordance with the desired drive direction. Thus, comparator output **334** is low at all times except when the digital information in register **304** is greater than that indicated by the output A/D converter **312.** The number of incremental steps which the motors **70, 80** are driven is controlled by comparator output **336** which, in turn, controls the outputs of NAND gates **344** and **346** respectively. Gates **344** and **346** are connected to the motors to drive them one increment for each output pulse. Output **336** of comparator **306** remains low at all times except when the outputs from storage register **304** and A/D converter **312** are equal, in which case comparator **306** produces a high output pulse in line **336.**

Assuming that the digital input data in register **304** relates to a Y position coordinate, switch **326** will direct the feedback of analog motor position information from the Y follower pot **310** to the A/D converter **312.** This will be compared at comparator **306** with the position data in register **304** which will be entered into the register **304** in response to the output pulse from flip-flop **316,** the A/D converter **312** being simultaneously pulsed through line **320** to begin its operation. When the Y information in register **304** if greater than the output from A/D converter **312,** the output **334** from comparator **306** will be high, which will result in a low pulse from NAND gate **338.** The other inputs to gate **338** also are high, line **413** being high when the system is not operating in vernier and line **386** being pulsed high in response to switching of Y flip-flop **330** as is the case when the digital data relates to Y positioning information. The low output from gate **338** is employed to maintain the polarity of the drive pulse applied to Y step motor **80** to drive it in one direction as will be described. Conversely, if the digital positin information in register **304** is not greater than the output from A/D converter **312,** output **334** from comparator **306** will switch low which, in turn, will switch the out-

put of gate **338** to high, thus reversing the polarity of the pulse applied to Y step motor **80** and, therefore, reversing its direction of rotation.

The number of drive pulses received by the Y step motor **80** from the system clock is controlled by NAND gate **346.** One input to gate **346** is a function of whether the machine is in a vernier sequence, and, when not, line **348** is low which, when inverted through inverter **350,** is applied as a high input to gate **346.** The other input to gate **346** is controlled by NAND gates **352, 344** and **354.** As long as the outputs from register **304** and A/D converter **312** are not equal, line **336** will be at a low state which, when inverted through inverter **346** will apply a high input to gate **354.** The other input to gate **354** is pulsed high by the system clock **318,** through line **320** and through a delay circuit **358** to cause a low output from gate **354.** This, in turn, results in a high output from gate **344** which produces a low output from gate **352.** The low output of gate **352** results in a high output pulse from gate **346** to drive the Y step motor **80** one increment. Delay circuit **358** is of conventional design and permits the analog feedback information from the follower pots **308, 310** to be fed through A/D converter **312** and converted to digital information usable in the circuit.

In the foregoing manner a high output pulse will result from gate **346** each time the clock **316** pulses to step the Y motor **90** until the information in register **304** is equal to the output from A/D converter **312.** When that occurs, the output **336** will switch to a high state, switching NAND gate **344** to a low output and thus terminating further stepping of the Y step motor **80.** In addition, when line **336** is pulsed to its high state, this pulse is applied to NAND gate **360** which then switches low, triggering monostable multivibrator **362.** The output pulse from multivibrator **362** is connected through line **364** to multivibrator **156** of the control circuitry to step the card reader to the next column of digital information which will bear data corresponding to the other (X) coordinate of the intended target image.

It may be noted that when the Y step motor **80** is stepped to its intended position in response to each high output pulse from gate **344,** that high output pulse also is directed through line **366** to the X step motor **70** to drive it simultaneously with the Y motor **80.** This mode of operation is employed because of the special construction of the mirror positioning mechanism shown in FIGS. **2–7.** The construction of that mechanism is such that operation of the Y step motor **80** alone will cause the yoke **56** to rotate which will move the mirror **26** to a position in which the reflected light beam would shift horizontally as well as vertically on the target screen. For example, rotation of the Y step motor **80** in a direction indicated by the arrow +Y in FIG. **5** and **6** would cause the yoke to rotate in the direction indicated by the arrow +Y in FIG. **4.** Because the surface of the mirror lies at an angle to the axis of rotation of the yoke, rotation of the yoke in the +Y direction will also cause the mirror to pivot to an attitude to cause the target image to be shifted not only in the +Y direction but also to the left in a −X direction on the projection screen **38** as indicated by the corresponding ±X, ±Y arrows in FIGS. **1** and **2.** By simultaneously operating the X step motor **70** in a direction opposite to that which is caused by the Y step motor (here +X), the X component of Y step motor movement can be compensated for. The positioning logic circuitry is arranged so that if the Y step motor **80** is driven a direction to shift the target location up (+Y) and to the left (−X) and the X motor **70** is also driven in a direction which will shift the target image to the right (+X). As will be described, a high output in line **340** will switch the polarity of the X step motor **70** to shift the target image to the left (−X) and a high output in line **342** is effective to switch the Y step motor **80** to shift the target image up (+Y) and to the left (−X), the outputs at lines **340** and **342** would be opposite when the mirror is being positioned to a Y coordinate. The opposite polarity in lines **340, 342** will cause the X step motor **70** to be driven in a +X or −X direction which is opposite to that component of the −Y or +Y direction of the mirror movement which would cause shifting of the target image along an X direction as the yoke is rotated.

The polarity of the pulse applied to Y step motor **80** is controlled by AND gate **368** and the polarity of the pulse applied to X step motor **70** is controlled by NAND gates **370, 372, 374.** The outputs from NAND gates **370, 372, 374** are connected in common to a termination resistor **376** which provides an OR function for that combination of gates. When not operating in the vernier mode, line **413,** which is connected to the vernier control circuitry in a manner described below, is at a high state. The high state of line **413** is inverted at inverter **382** and the resultant low state is applied to gate **374** thus maintaining its output high at times when the system is not in vernier and the mirror attitude is being determined by the digital input data. The high state of line **413** is also applied to an input of each of gates **370, 372** to enable them to be switched to high or low outputs depending on the state of the other inputs to those gates as will be described below. The high state at line **413,** when not in the vernier mode, is also applied to an input of AND gate **368** which enables the gate to be switched, depending on the output from NAND gate **338.** Switching of gates **370, 372** and **368** are dependent on the output **334** from comparator **306** and on whether the mirror mechanism **12** is being positioned to a Y coordinate or an X coordinate. When positioning the mirror to a Y coordinate and assuming that the output **334** from comparator **306** is high, all the inputs to gate **338** will be high, switching the output of gate **338** low to maintain a low output from gate **368** to set the polarity of the Y step motor **80** in a direction which will shift the target image down (−Y) and to the right (+X). The X step motor **70** is driven in a compensating direction (−X), to shift the target image to the left, because the high state at line **334** will result in a high output from each of NAND gates **370** and **372.** Conversely, if the intended Y coordinate were such that the state of line **334** was low, the output from NAND gate **338** would be high, thus switching AND gate **368** high and directing the Y step motor **80** to shift the target image up (+Y) and to the left (−X). The X step motor **70** would be driven in a compensating direction (+X), to shift the target image to the right, by a low output in line **340** which results from all high inputs to NAND gate **372,** switching its output low with a resultant low signal at line **340.**

After the mirror has been shifted to the new Y coordinate and the card reader has been advanced as a result of the pulse in line **364,** the next column on the card will include data relating to X positioning information and will trigger flip-flop **330.** This switches switch **326** to connect A/D converter **312** with the X follower

pot 308. In the manner similar to that described above, the gates 370, 372 and 374 result in an output at line 340 which is dependent on comparator output 334. However, when processing X positioning information the high output from flip-flop 328 is applied through lines 384 to an input of gate 370. A second input to gate 370 is maintained high by line 413. The output of gate 370 thus depends on the input 334 from comparator 306. Gate 372, which, during the positioning of X data, has a low input from Y flip-flop 330 will remain in a high output state at all times as will gate 338 which is also connected through line 386 to the otuput from Y flip-flop 330. Thus, when the output from comparator 306, in line 334, is high, the outputs from each of the gates 370, 372, 374 will be high which will direct the X step motor 70 to shift the target image to the left (−X). When the comparator output 334 is low, however, all the inputs to gate 370 will be high, switching its output low and resulting in a low state in line 340 which sets the polarity of the X step motor 70 to shift the target image to the right (+X).

With the polarity for the X step motor 70 set, regular pulses from the system clock will result in high output pulses from gate 344. When the feedback from the X step motor 70 indicates that the motor 70 has reached the intended position, the output from comparator 306 at line 336, switches high which will switch the output of gate 344 low thus terminating further stepping of the X step motor 70. It should be noted that when the mirror 26 is being positioned with respect to X coordinate information, the Y step motor 80 is disabled because of the low output from gate 346. This results from high input to gate 346 from inverter 350 (when not operating in vernier) and a high input to gate 346 from gate 352. The output from gate 352 is maintained high during the X coordinate positioning because of the low input to that gate by line 386 from Y flip-flop 330 which has a low output state during the processing of X coordinate information.

Where a dummy target is to be presented neither of the X or Y flip-flops 328, 330 are actuated and the positioning system remains inactive.

It may be noted that X and Y flip-flops 328, 330 are self-resetting. When the A/D converter 312 has cycled, its "busy" output at line 388 switches low which, when inverted through inverter 390 switches gate 392 which, in turn, actuates multivibrator 394. The output from multivibrator 394 operates gates 396, 398 which are effective to reset the Y flip-flop 330 and X flip-flop 332, respectively.

The foregoing description of the positioning control has related to its operation when the system is not within a vernier cycle. When in a vernier cycle the number and direction of steps for each stepper motor is controlled entirely and independently by the vernier control circuitry.

DESCRIPTION OF VERNIER LOGIC

As mentioned above when it is desired to examine more closely the regions of the subject's visual field about actually presented targets which were missed by the subject, the panel switch 122 is set to the "vernier in" mode of operation. This enables automatic operation of the vernier cycle in response to the subject having missed an actual target and disables the card reading and advancing system until the vernier target presentation has been completed. When operating in the "vernier in" mode, a signal from the decision logic indicating that the subject has missed a real target image will cause automatic actuation of the vernier control logic to automatically present a plurality of target images in a predetermined array and sequence and in close proximity to and surrounding the location of the target image which is missed. FIG. 9A shows the relative location of the vernier target images with respect to the primary target image which was missed. In the preferred embodiment, three vernier targets are presented in a triangular configuration about the primary target image location located at 400 in FIG. 9. The first of the three vernier points to be presented in the sequence V1 is located 1° directly above the primary target location 400. After vernier image V1 has been presented and the subject's eye position and movements evaluated, the vernier control circuitry causes the mirror to be repositioned to present vernier point V2 which is also spaced 1° from primary target location 400 but below and to the left of location 400 as indicated. The procedure of evaluating the subject's eye movements with respect to vernier target image V2 is performed and the vernier control logic then causes repositioning of the mirror to present vernier target image V3. Vernier image V3 is spaced 1° from the primary target image 400 and is downwardly and to the right of that location to define the triangular spacing of the three vernier points V1, V2 V3.

By presenting a plurality of vernier targets in sequence, fine mapping of the subject's visual field about the region of a missed point is achieved and may show a general boundary line of the subject's scotoma. For example, if the vernier presentation indicates that the subject missed vernier points V1 and V2 but saw vernier point V3, this would indicate that the boundary line of the particular scotoma in question would extend somewhere between vernier point V3 and a line drawn between vernier points V1 and V2 is indicated by phantom by the line 402 in FIG. 9. If the subject missed all three of the vernier targets V1, V2 and V3 this would indicate that the boundary of the scotoma was somewhere outside all of the vernier points. Conversely, if the subject saw all three vernier points this might indicate that the scotoma is quite small and is located closely about the primary target image location 400. It may be noted that while the illustrative embodiment of the invention shows a vernier pattern of only three points, a more fine mapping of the scotoma boundary could be achieved by employing more than three vernier points, as suggested in FIG. 9A in which there are six vernier points presented which would provide still further fine mapping of the scotomic boundary. However, three vernier points are adequate for most testing purpose.

The vernier sequence is begun in response to a missed target by an output pulse from multivibrator 256 (FIG. 8B) which is applied to pulse flip-flop 404 (FIG. 11) through line 266. The other input to flip-flop 404 is synchronously controlled by the system clock 318 to produce an output pulse from flip-flop 404 synchronously with the timing of the vernier system as controlled by the system clock. The output pulse from flip-flop 404 is fed into a three bit digital counter 408 having both positive and inverted outputs. It may be noted that counter 408 is rezeroed through line 409 at the beginning of each operational sequence by its connection to line 150 through gate 411. The inverted outputs are connected to the three inputs of NAND gate 410, the output of which is connected to line 413

of the control logic and position logic circuits described above. Thus, where the system is not operating in vernier or, if in vernier and a target was seen, there is no output pulse from multivibrator **256** and the flip-flop **404** remains in the low output state. As a result each of the three counter outputs *a*, *b*, *c* will be at a low state (**000**) which, when inverted and fed into NAND gate **410** will result in a low output which may be inverted through inverter **412** to a high state which is applied to line **413.** As described above, when line **413** is high gates **246** and **254** are disabled and cannot control switching of gate **242.**

When a target is missed the first vernier pulse from multivibrator **256** is applied to flip-flop **404.** The counter **408** switches to a (**001**) digital state which results in input *a* to gate **410** being switched low. This results in a high output from gate **410** which is inverted to a low state through inverter **412** to switch line **413** to a low state. As described above, when line **413** is switched low, gate **246** is switched to produce a high output which further precludes operation of the step card reader multivibrator **156** during the vernier sequence. Similarly, because the panel switch and flip-flop **248** is set to the vernier position, the output from gate **254** is high. In addition, line **413** is connected to an input of each of NAND gates **370, 372** and **338** of the position logic (FIG. **10**) to maintain their high outputs and disabling them from switching to low output during the vernier cycle. The high output from NAND gate **338** enables AND gate **368** to be controlled directly by the vernier circuitry through line **380** as will be described below. Line **380** is also connected through line **381** to an input of gate **374** to control its output in response to the vernier circuit. It should be noted that the other input to NAND gate **374** is enabled by high signal from an inverted input, through inverter **382** from line **413.** It may be noted that during operation of a vernier cycle one of the inputs *a*, *b* or *c* to gate **410** will be low, which maintains the low state in line **413.**

When counter **408** has received its first pulse from flip-flop **404** and has been switched to a (**001**) digital configuration the X and Y steps motors **70, 80** are driven to a position which will orient the mirror **26** to reflect the light target at the first vernier position V1 which, in the illustrative embodiment, is 1° above the location of the missed target **400.** This requires the Y step motor **80** to be advanced to move the mirror to reposition the image one step upwardly (+Y) and to the left (−X) and the X motor **70** to compensate one step to the right (+X). The number of pulses applied to the step motors is controlled by switching X NAND gate **414** and Y NAND gate **416** to develop output pulses in response to and for the desired number of output pulses from the system clock **318.** For example, with the counter **408** set to a (**001**) output all but input terminal *a* of NAND gate **418** will be high. When the system clock **316** pulses input *a*, through line **420,** the output from gate **418** will be switched to low which will result in an output pulse from X NAND gate **414** and, through line **424,** a high output pulse from gate **416.** The output of gate **414** is connected through line **422** to the position logic circuit. As shown in FIG. **10,** a high output in line **422** will be inverted to low at inverter **426** and that low signal switches the output of gate **344** high to pulse the X step motor **70.** The high output from gate **416** is connected through line **348,** through inverter **350** (FIG. **10**) to pulse NAND gate **346** high and drive the Y step motor **80** one increment.

The direction in which each of the step motors is driven for the first vernier point is controlled by the state of line **380.** Line **380** is connected to the output of NAND gate **428** and its state is dependent on the output from counter **408.** When counter **408** receives its first pulse to begin positioning of the first vernier point the input to gate **428** from output *b* of counter **408** will be low thus maintaining line **380** at a high state. This, in turn, results in a high output pulse from gate **368** to direct the Y step motor to drive the mirror in a +Y, −X direction (up and to the left as seen on the screen) and results also in switching of gate **374** resulting in a low output which will direct the X step motor **70** to drive the mirror in a compensating +X direction to shift the target image location to the right.

The output pulse from gate **418** also is applied to NAND gate **430** which, in turn, drives a two-bit counter **432.** When the output from gate **418** switches low in response to termination of the clock pulse, output from NAND gate **430** switches high, pulsing counter **432.** The output from counter **432** switches NAND gate **434** so that its resultant low output will be applied to an input of gate **418** through line **436** thus switching gate **418** back to its high output state which, in turn, switches vernier control gates **414, 416** back to their low output state and terminates the positioning of the mirror at the first vernier point. With the mirror having been positioned to the first vernier point V1 within the delay of multivibrator **164,** the resetting of multivibrator **164** to its low output state pulses gating circuit **170** through line **168** (FIG. **8A**) to control the projection shutter, projection light, the camera shutter, record light in the same manner and sequence described previously. The subject's response to the presentation of the first vernier point V1 is monitored by the photocells **92, 94** and the decision logic circuitry determines whether the subject saw or missed the first vernier point. Depending on whether the photographic recording system is set to record seen/record missed points, a photographic plot of the subject's response to the presentation of the first vernier target image may be recorded. Whether the subject saw or missed the first vernier point, after his response has been evaluated multivibrator **256** is then pulsed to continue the vernier sequence. This results from the output pulse from gate **258** each time either of gates **214** or **216** are switched. It should be noted that each time counter **408** is advanced from the output from flip-flop **404,** counter **432** is reset to a (**00**) state through line **44,** flip-flop **445,** inverter **446** and line **447.**

The foregoing sequence of automatically entering into the vernier mode and positioning the mirror to direct the target image to the first vernier location all takes place within the delay constant of multivibrator **164** which may be of the order of slightly over one second.

After the first vernier target image V1 has been presented, and it has been determined whether the subject has seen or missed it, and whether the response should be photographed, the second vernier point is presented. As can be seen from FIG. **9,** this requires movement of the Y step motor **80** to shift the target image two increments downwardly (−Y) and to the right (+X) and three incremental steps of the X step motor to the left (−X). When multivibrator **256** is again pulsed to cause the output from flip-flop **404** to advance counter **408** to the next digital state (**010**), the output from counter **408** switches NAND gates **438,**

428, 440 to each produce low output pulses which, in turn, switches X and Y gates 414, 416 to produce high output pulses synchronously with system clock 316. The switching of NAND gate 328 produces a low pulse in line 380 which is effective to reverse the polarity of the pulses applied to the step motors thus reversing the direction of the X and Y step motors. By switching the state of line 380 low, the output from AND gate 368 will switch low causing the polarity of the drive pulses which are directed to the Y step motor to shift the target image location downwardly (−Y) and to the right (+X). The low pulse in line 380 also is applied through line 381 to gate 374 switching its output high which, in combination with the high outputs from gates 370 and 372 result in a high state in line 340 which will direct the X step motor 70 to shift the target image location to the left (−X). The X and Y motors are pulsed in the manner described above with counter 432 being advanced for each pulse from the system clock. When the counter 432 has been pulsed twice and advanced to a (10) digital state NAND gate 442 switches from its high state to produce a low output pulse which is applied to an input of gate 440 thus switching that gate to a high output which in turn switches gate 416 low and terminates further operation of the Y step motor 80 after two incremental steps. The X drive gate 414, however, is driven one more time until counter 432 registers the third digital state (11) which causes NAND gate 448 to switch to a low output, causing a high output from gate 438 which, in turn, disables X gate 414 to terminate operation of the X step motor 70. The target is then presented at the second vernier point V2 and the decision and control logic run through their respective sequences as described above. It may be noted that when presenting the second vernier target the operation of multivibrator 164 is controlled by the output of multivibrator 256 through line 257 and not by multivibrator 156 which is disabled during vernier operation.

In order then to present the third vernier point it may be seen (FIG. 9) that the mirror must be moved to shift the target image location two increments to the right (+X). In the illustrative embodiment this requires operation of the X step motor alone. Thus, when the counter 408 has been pulsed to its next digital state (011) gate 428 will switch to a high output again reversing the polarity of the pulse which is applied to the step motors through line 380. The Y drive gate 416 remains in a low output state as all of its inputs are high. X drive gate 414 is switched through line 445 to produce a high output pulse as the output from gate 441 switches to low in response to all high inputs to gate 441, thus stepping the X motor. When counter 432 has been pulsed twice, the output from gate 442 switches to low, thus switching gate 441 to a high output which switches X drive gate 414 low and terminates further stepping of the X drive motor. With the mirror positioned to show the third vernier point, the third vernier target image is presented and the control and decision logic perform their respective functions.

After the three vernier points have been presented, it then remains for the mirror to be repositioned to the location of the original target image which was missed and which initiated the vernier sequence. This, in turn, requires that the Y motor be stepped one increment up (+Y) and to the left (−X) while the X motor is maintained inoperative. When counter 408 is pulsed, for the fourth time, and is advanced to the (100) state, the inputs to X gate 414 remain high thus maintaining X step motor inoperative. The Y drive gate 416, however, switching to a high output state because of the low input in response to the low input from fate 450. Gate 450 is switched to a low output by reason of the high input to it from counter 408. After NAND gate 430 has pulsed counter 432 to indicate one pulse, NAND gate 452 is switched high and, through line 454 resets counter 408 to its initial digital state (000). Resetting of counter 408 to the (000) digital state, returns line 413 to a high state. The (100) state of counter 408 also causes gate 453 to be pulsed and which passes through OR gate 154 switches multivibrator 156 to advance the card reader and resume the presentation of the primary targets.

DESCRIPTION OF THE DECISION LOGIC

The position and movement of the subject's eyes are monitored by the eye imaging techniques described in U.S. Pat. Nos. 3,583,794 and 3,689,135 in which the image of the subject's eye is projected onto a screen and in which photocells 92, 94 are located on the screen to be responsive to the position and movement of the eye image. The vertically spaced photocells 92 detect variations in the vertical position of the subject's eye (including movements of the eye lid) and the horizontally spaced photocells 94 detect changes in the subject's horizontal eye position. The outputs from the horizontal and vertical photocell pairs result in a signal which is indicative of both magnitude and direction of the subject's eye movement. The decision logic circuitry is designed to discriminate between photocell outputs which are characteristic of the subject having actually seen or missed the presented target, hunting eye movements and blinks.

FIG. 12A is a DC representation illustrating the relationship between the presentation of the target image and a subject's target missed response as indicated by the output from the photocells. Where the subject's eye does not move during presentation of the target there is no change in output from the photocells.

FIG. 12B illustrates an ideal response in which the subject has actually seen the target image. Typically, there will be a slight delay from the time in which the target is presented to the time in which the subject's eyes actually move and the response may be delayed, for example 200–500, milliseconds. Also, when the sighted target image is turned off a similar delay will occur in the subject's returning his eyes to the central fixation target. It may be noted that the photocell output may be positive or negative depending on the direction of movement of the subject's eyes. As will be described in connection with the decision logic circuitry, the direction of eye movement is not critical in the particular embodiment shown, the magnitude being the primary consideration.

FIG. 12C illustrates the photocell output in a situation where the subject has sighted the target but was unable to control his eye movement to direct it precisely to the target image in a single saccade. The photocell output indicates a first substantial eye movement to the general vicinity of the presented target image and a second, minor correctional movement. For example, the first saccade may be of the order of 5° or more, depending on how far the target image is from the central fixation point and the second correctional saccade may be of the order of 3° or less. FIG. 12C shows a minor correctional saccade in the same direc-

tion as the first saccade and FIG. **12D** shows a minor correctional saccade in an at least partly reversed direction. Both responses indicate an actually seen target.

FIG. **12E** shows a further response which is indicative of the subject having actually seen the target. This response may be considered as an "early return" in which the subject returned his eyes to the central fixation position before the target light was extinguished. This response also is considered as an actually seen target.

FIG. **12F** illustrates a hunting or searching eye movement in which the difference in magnitude of the photocell outputs between the first and second saccades is substantial, for example, of the order of more than 5°. This may result from a first saccade in a direction which is away from the location of the target image, as shown in FIG. **12F** or may result from an eye movement shown in FIG. **12G** in which, while the searching saccade and second saccade are in the same general direction, the second saccade is substantial, of the order of more than 5°.

FIGS. **12H** shows a typical output from the vertically spaced photocells which results from a blink. The duration of a typical blink is of the order of 30–50 milliseconds and results in a relatively short duration pulse. Of course, a blink may occur at any time, whether the target is being presented or not.

The decision logic circuitry is effective first to determine whether an output from the photocells is the result of a blink. If so, the remaining portions of the decision logic are disabled from further evaluating that photocell output.

As shown in FIG. **13** the outputs from the horizontal and vertical photocell pairs are amplified at amplifiers **460, 462** respectively. The amplified signals may be coupled to a strip chart recorder **464** if desired to provide a permanent charted D.C. record of the subject's eye movements. The outputs from amplifiers **460, 462** are fed through buffer amplifiers **466, 468** and these signals are coupled to an absolute value adder **470** through AC couple **472.** Where the amplified signals from the photocell pairs are DC, the AC couple is effective to overcome the effect of any long term drift which might be inherent in the system as well as to overcome the effect of any slight head shift of the subject during the test. The absolute value adder insures that a positive output from one pair of photocells will not be negated by a negative output from the other pair of photocells but, instead, results in an output which is the sum of the magnitude of the photocell outputs regardless of their sense. The output from absolute value adder **470** is coupled to a first sense amplifier **474** and also to a second sense amplifier **476.** Sense amplifier **474** is selected so that it will pulse line **478** when the amplitude of the input to amplifier **474** corresponds to an eye movement of more than a first predetermined magnitude, for example, 3°. Sense amplifier **476** is effective to produce an output pulse in line **480** in response to an input from adder **470** having an amplitude corresponding to a change in the direction of eye movement of more than a second predetermined magnitude, for example, 5°.The outputs at lines **478** and **480** are employed in the decision logic circuitry to discriminate between the various saccadic movements illustrated in FIGS. **12A–12H** in a manner described below.

The decision logic includes three channels including a primary saccade detection channel **479,** a secondary saccade detection channel **481** and a blink detection channel **493.** Each signal resulting from the output of either or both of the photocell pairs **92, 94** is applied to each of the three channels simultaneously. If the photocell output was the result of a blink the blink detection channel **493** disables the primary and secondary channels **479, 481** from further operation thus disregarding the effect of the blink. If the resulting signal from the photocells **92, 94** was caused by a genuine saccade this is detected by the primary channel **479** which, in turn, is connected to the secondary channel **481** to enable the secondary channel to thereafter detect existence of a second saccade within a predetermined time interval after the first saccade. The output from the first channel is also connected to an output decision gate **506** (as will be described) in a manner which causes that gate to be enabled at a fixed, predetermined time interval after the detection of the first saccade. The state of the other input to decision out gate **506** is dependent on whether the primary and secondary channels **479, 481** have detected the existence of only two or more saccades and the timed relationship of the saccades with respect to the presentation of the target image as well as their magnitude.

More particularly in order to discriminate blinks from other eye movements, the signal from the vertical photocells is connected through buffer amplifier **468** to a sample and hold circuit **482** and also to a comparator **484,** the output from the sample and hold circuit **482** also being fed into comparator **484.** Comparator **484,** in turn, drives a pair of sense amplifiers **486, 488** which produce an output pulse when the output from the comparator is positive and negative respectfully. When an output signal results from the photocells, the decision logic circuit first evaluates whether the output was the result of a blink. If so, the decision logic circuitry is disabled and there is no change in its output. The blink detection circuitry includes a NAND gate **490** having its inputs fed by sense amplifiers **485, 488.** The output from NAND gate **490** is inverted at inverter **492.** The inputs to NAND gate **474** are normally high which results in a normally high output from inverter **492.** The output from inverter **492** thus may be switched by any change of state to either input to gate **490** resuling from a pulse from either of sense amplifiers **486, 488.** The output from the inverter **492** is connected directly to an input of NAND gate **494** and also to the other input of gate **494** through a multivibrator **496** having a delay constant of, for example, approximately 330 milliseconds. When either input to NAND gate **490** is low as a result of a signal from the vertical photocells input of gate **494** will remain low, to preclude switching of gate **494** while monostable multivibrator **496** will switch to a high output state.

If the triggering input to NAND gate **490** was the result of a blink, which typically lasts between 30–50 milliseconds, the low output of inverter **492** and input *a* of gate **494** will switch back to high before multivibrator **496** has returned to its low output state. The all high inputs switch gate **494** to a low output which triggers monostable multivibrator **498,** switching it to a high output state and switching the output of NAND gate **500** to low. A low state at the output of NAND gate **500** indicates the presence of a blink and disabled NAND gates **502** and **504** which, in turn, precludes any change in output of the decision out gate **506** as will be

apparent from the further following description. If, on the other hand, the input to NAND gate **490** was the result of a genuine saccade in which the subject's eye remain fixated for considerably more than 30–50 milliseconds, the direct input to gate **494** will remain low at all times during and after the delay of multivibrator **496** thus leaving gate **94** unactuated and maintaining the output from gate **500** in its normally high state which, in turn, maintains the inputs to gates **502, 504** high and in an enabled state.

If the blink detection channel **493** has detected that the input pulse was the reset of aa genuine saccade, the remaining primary and secondary channels **479, 481** evaluate whether the saccade was the result of the subject's actual perception of the target image or whether it was the result of "hunting" or searching eye movements. When an added pulse from one or both pairs of photocells is fed into sense amplifiers **474, 476** those amplifiers, respectively, evaluate whether the saccade (here the first saccade) was of a magnitude of more than 3° and whether the saccade was a change in eye movement of more than 5°. For example, assuming that a target was presented and was seen, the subject's eye movement of more than 3° results in an input pulse to monostable multivibrator **505** switching its output high. Multivibrator **505** has a 330 millisecond delay function and serves to delay further operation of the portions of the primary channel **479** for a time sufficient to enable the blink detection channel **493** to evaluate whether the pulse resulted from an eye movement or a blink. When multivibrator **505** switches back to its low, stable state, that actuates monostable multivibrator **508** switching its output momentarily to a high state. If the target light was on at the time of the saccade then all three inputs to NAND gate **502** are switched to high. This is accomplished by applying a pulse in line **510** indicating that the target light is on and passing it through inverter **512** and NAND gate **514** to produce a high pulse at input of gate **502,** thus enabling that gate as long as the target light is on. It may be noted that while the first saccade may have been of a magnitude which would have also switched the output from sense amplifier **476** to a high state, gate **524** is, at that time, in a disabled state because of the low input, through line **518** from the monostable multivibrator **522** as will be described.

In order to evaluate whether the first saccade was the first of a series of eye movements indicating true perception of the target or whether it was a "hunting" saccade, the decision logic awaits subsequent signals from the photocells to determine whether only a second saccade follows or whether both a second and third saccade follows. Also, where there are three saccades, their relative magnitudes must be evaluated to discriminate between hunting movements (FIGS. **12F, 12G**) and acceptable correctional movements (FIGS. **12C, 12D**). As described above, saccadic movements of less than a predetermined magnitude for example 3°, are considered to be mere correctional movements. Thus, a pulse resulting from photocells **92, 94** which corresponds to an eye movement of less than 3° will be isolated from the primary and secondary channel, **479, 481** by the sense amplifiers **474, 476** respectively. There being no signal applied to the primary and secondary channels, an eye movement of less than 3° has the same effect as if there had been no eye movement at all thus completely disregarding mere correctional movements.

As indicated at FIGS. **12A–12G,** where there has been a first saccade there will always be a second saccade. The second saccade may result from the subject's returning his eyes to the central fixation target (FIGS. **12B, 12E**) in which case the second saccade is a final saccade indicating that the subject actually saw the target. However, the second saccade may have been the result of the first time that the subject actually saw the target, in which case the second saccade would be only an intermediate saccade which would indicate that the first saccade would have been a hunting or searching movement (FIGS. **12F, 12G**). In order to discriminate between these saccadic movements the invention employs a technique in which the subject's eyes are monitored to detect the existence and magnitude of at least three saccades in which the intermediate saccade or saccades was more than 5° which would indicate that the first saccade was a hunting movement and that the subject did not actually see the presented target.

The foregoing functions are enabled by the switching of gate **502** to a low output state which is the case when the first saccade is not a blink, as described above. The low output from gate **502** is inverted to a high state through inverter **520** and that pulse is applied to monostable multivibrator **522.** Multivibrator **522** is switched to its high output state when the output from multivibrator **508** retuns to its low state after generating its short pulse. When multivibrator **522** is switched, its high output is applied to the input of NAND gate **524** which enables that gate and, consequently, the secondary channel **481** to be actuated when the remaining low input of gate **524** receives a high pulse from sense amplifier **476.** Multivibrator **522** has a time delay which will maintain its high output state, thus maintaining the secondary channel **481** in an enabled state for a time sufficient to include that in which a second, intermediate saccade would be made. For example, the delay of multivibrator **522** may be of the order to 450 milliseconds. Thus, if the photocells **92, 94** produce a signal indicating a saccade which was a change of more than 5° and during the enabled interval of secondary channel **481,** gate **524** will be actuated to switch its output low to low thus actuating blink delay monostable multivibrator **526** which also has a time delay constant of 330 milliseconds. This enables the block detection logic to again evaluate whether the second input signal to gate **524** was the result of a blink or a genuine second saccade. If a blink, the low output at gate **500** of the blink detection logic is applied to an input of gate **504** thus disabling that gate and the secondary channel **481.** However, if the signal was not a blink gate **504** will be enabled. When multivibrator **526** switches back to low state, after its 330 millisecond delay, and that pulse triggers monostable multivibrator **528** to produce a short output pulse switching gate **504** low which triggers monostable multivibrator **530** switching its output high. This high output is applied to an input of NAND gate **532** which enables that gate. Multivibrator **530** has a delay constant sufficient to maintain gate **532** in an enabled state for an extended interval ending shortly after the target light has been extinguished. By way of example the delay may be of the order of 2.75 seconds. As described below the other input to gate **533** depends on whether or not there was a third saccade which, in turn, controls the output of gate **532** and the input to decision out gate **506.**

The detection of a third saccade is effected by the primary channel **479.** After the 450 millisecond delay

of multivibrator **522,** its output switches low which switchs multivibrator **536** to a high output state. This, in turn, enables one of the inputs to gate **534.** Multivibrator **536** has a delay constant which also extends beyond the time that the target lights is extinguished in order to be able to detect return eye movements which often occur after the extinguishment of the target light. It may be noted that multivibrator **530** has a delay slightly longer than multivibrator **536** so that gate **532** may remain enabled and be switchable in the event that gate **534** is switched. If a third pulse is emitted from the photocells, it will, as is the case for each such pulse, be directed to the sense amplifiers **474, 476** as well as to the blink detection circuitry. Multivibrator **505** delays functioning of the primary channel **479** stages until the blink detection channel **493** has an opportunity to evaluate whether the photocell output was the result of a saccade or a blink. Assuming that it was not a blink and that a third saccade was made by the subject, the signal resulting from the third saccade switches the output from inverter **520** high which is applied through line **538** to the other input of gate **534** switching its output low which, is inverted at inverter **540** and is fed as high pulse into an input of NAND gate **532.** This results in a low output from gate **532** which switches multivibrator **542** to produce a high output which is inverted at inverter **544** and is fed into decision out gate **506.** This will not switch and its **164** in the control logic andits output will remain low thus indicating a "missed target."

When there is no third saccade during the delay of multivibrator **536,** this indicates that the second saccade was in fact a final saccade to the central fixation point and was thus an actually seen target. When there is no third saccade the input to decision out gate **506** from inverter **544** is high thus enabling that gate. When multivibrator **536** switches back to its low stable output state this switches multivibrator **546** and the high output pulse from multivibrator **546** switches decision out gate **506** to a low output which, in turn, actuates multivibrator **164** and indicates a target seen.

In some mass testing situations it may be desirable to make a more coarse test, for example, to detect only whether the subject responded at all to presentation of the target image. This may be accomplished by disabling the second channel **481** so that the output from inverter **544** will remain high at all times thus maintaining decision out gate **506** enabled continuously. Any non-blinking eye movement during presentation of the target image will result, ultimately, in a pulse from multivibrator **546** which will switch decision out gate **506** low indicating a response by the subject during presentation of the target image. While this mode of operation does not discriminate between hunting eye movements and true perceptions, it does give a rapid more coarse testing procedure. The second channel may be disabled by switch **126** on the control panel which switches flip-flop **550** to enable or disable gate **524** as desired.

When the subject has actually perceived the target and makes a "normal" response (FIG. **12B**) his eyes will fixate on it as long as it is presented (approximately 2.2 seconds). In this event there will be no detected eye movement during the 450 milliseconds that the multivibrator **522** is in its high state. Thus, even though gate **522** is in readiness to be actuated in response to sensed eye movement during the 450 millisecond interval, there is no movement and the input to gate **532** remains low. When the subject's eyes do return to the reference fixation target shortly after the target light has been extinguished from the subject's view the pulse resulting from the saccade, which is channeled to gate **502** causes multivibrator **522** to be pulsed. The high output from multivibrator **522** is inconsequential at this time because multivibrator **536** already is in its high state. When the multivibrator **536** switches back to its low state multivibrator **546** is pulsed to apply a high input to decision out gate **506.** The other input of the decision out gate **506** is also high at this time because as multivibrator **536** was switched to its low state, gate **534** switched to a high state which is inverted to low through inverter **540** which maintains gate **532** at a high state thus precluding actuation of multivibrator **542** whose normally low output is inverted at **544** to a high state which is applied to the decision out gate **506.** The resulting low pulse from gate **506** is applied through line **470** to the control logic as previously described. As described previously, there may be some instances in which the subject has perceived the target but returns his gaze to the general region of the central fixation target before the target light has been extinguished. Such early return is detected by the foregoing decision logic as a perceived target. Here, the subject's eye movement usually will be after the 450 millisecond delay of multivibrator **522** but before multivibrator **536** has switched back to its low state. This has the same effect as a "seen" response described above.

In order to insure that gate **502** is enabled through line **516** during the extended time interval which includes the interval during which the target is actually presented and a short time thereafter, the output from multivibrator **522** is connected through inverter **548** to an input of gate **514** and the output from multivibrator **536** is connected through inverter **550** to the other input of gate **514** thus insuring a high state in line **516** at all times during operation of the decision logic.

The foregoing mode of operation of the decision logic may be considered as employing a technique in which the extended time interval during which the subject's eye positions and movements are monitored may be considered as divided into successive portions in which each portion begins with eye movement. The number and duration of each such portion of the extended time interval will, of course, depend on the time in which the subject moves his eyes. In addition, an initial segment of each portion of the extended time interval is employed to evaluate whether the particular eye movement was a blink, in which case the eye movement is disregarded as described above.

It should be understood that the foregoing description of the invention is intended merely to be illustrative thereof and that other modifications and embodiments of the invention may be apparent to those skilled in the art without departing from its spirit.

Having thus described the invention what I desire to claim and secure by Letters Patent is:

1. A method of objectively testing the visual field of a subject:

providing reference fixation target within the subject's visual field;

thereafter presenting a target image to said subject, at a selected location within the subject's visual field and at a selected angular distance from said reference target, said target image being presented for a determined time interval;

monitoring the position and movement of the subject's eye at least during an extended time interval which includes and which extends beyond said predetermined time interval; and

determining whether the subject actually visually detected the presented target image by electronically detecting the number and magnitude of the subject's eye movements during said extended time interval.

2. A method as defined in claim **1** wherein said step of determining whether the subject actually visually detected the presented target image comprises, at least in part:

detecting, within said extended time interval, those of the subject's eye movements having at least three saccades and in which the magnitude of an intermediate of said saccades is more than a predetermined magnitude thereby indicating a hunting eye movement and a missed target.

3. A method as defined in claim **2** wherein said predetermined magnitude comprises approximately 3°.

4. A method as defined in claim **1** wherein said step of determining whether the subject actually visually detected the presented target image comprises, at least in part:

detecting, within said extended time interval, those of the subject's eye movements having at least three saccades and in which the magnitude of the first of said saccades does not differ from said selected angular distance by more than a predetermined magnitude and in which the magnitude of an intermediate of said saccades is no more than a predetermined angle.

5. A method as defined in claim **1** wherein said step of determining whether the subject actually visually detected the presented target image comprises, at least in part:

detecting, within said extended time interval, those of the subject's eye movements having only two saccades, each of which is of a magnitude substantially equal to said selected angular distance.

6. A method as defined in claim **1** wherein said step of determining whether the subject actually visually detected the presented target image comprises:

detecting, within a first portion of said extended time interval, the existence of an initial saccade of a magnitude greater than a first predetermined magnitude;

detecting, within a second portion of said extended time interval, the existence of a subsequent saccade of a magnitude greater than a second predetermined magnitude;

detecting, within a third portion of said extended time interval, the existence of a subsequent saccade of a magnitude greater than said first predetermined magnitude; and

discriminating between those groups of saccadic movements which include said second saccade and those which do not.

7. A method as defined in claim **6** further comprising:

detecting within a first segment of each of said portions of said extended time interval, the existence of double eye movements having a short duration characteristic of a blink; and

discriminating between said saccadic movements and said blink movements.

8. An apparatus for objectively testing the visual field of a subject comprising:

means for presenting a reference fixation target within the subject's visual field;

means for presenting a target image to the subject at a selected location within the subject's visual field at a selected angular distance from said reference target and for a predetermined time interval;

means for monitoring the position and movement of the subject's eye at least during an extended time interval which includes and which extends beyond said predetermined time interval, said monitoring means being constructed and arranged to provide an electrical output signal of an amplitude corresponding to the magnitude of movement of the subject's eye; and

circuit means having an input connected to the output of said monitoring means and having an input from said target image presentation means for determining whether the subject actually visually detected a presented target image by electronically detecting the number and magnitude of the subject's eye movements during said extended time interval.

9. An apparatus as defined in claim **8** wherein said circuit means comprises, at least in part:

means for detecting, within said extended time interval, groups of at least three output signals from said monitoring means and in which the amplitude of an intermediate of said signals is more than a predetermined amount.

10. An apparatus as defined in claim **9** wherein said predetermined amplitude corresponds to a subject's eye movement of approximately 3°.

11. An apparatus as defined in claim **8** wherein said circuit means comprises, at least in part:

means for detecting, within said extended time interval, groups of at least three output signals from said monitoring means and in which the amplitude of the first of said signals corresponds to an eye movement which does not differ from said selected angular distance by more than a predetermined amount and in which the amplitude of the succeeding of said signals is no greater than that which would correspond to an eye movement which is no more than said predetermined amount.

12. An apparatus as defined in claim **8** wherein said circuit means comprises, at least in part:

means for detecting, within said extended time interval, the existence of only two output signals from said monitoring means, each of said two output signals being of an amplitude which corresponds to an eye movement of a magnitude substantially equal to said selected angular distance.

13. An apparatus as defined in claim **8** wherein said circuit means comprises:

a primary channel having an output connected to an output gate, said primary channel being constructed and arranged to apply a pulse to said output gate and in response to an input signal to said primary channel and at the end of said extended time interval;

said monitoring means including an output connected to the input to said primary channel;

said primary channel including, at its input, means for enabling only those of the output signals from said monitoring means which have an amplitude more than that which corresponds to a predetermined magnitude of eye movement to be applied to the input of said primary channel;

means for enabling said output gate, at least at the end of said extended time interval; and

whereby an eye movement of a magnitude at least equal to said predetermined magnitude will switch the output of said output gate at the end of said extended time interval.

14. An apparatus as defined in claim **8** wherein said circuit means further comprises:

a primary channel having an output connected to an output gate, said primary channel being constructed and arranged to apply a pulse to said output gate in response to an input signal to said primary channel and at the end of said extended time interval;

said monitoring means including a first output connected to the input to said primary channel;

said primary channel including, at its input, means for enabling only those of the output signals from monitoring means which have an amplutude of more than that which corresponds to a predetermined magnitude of eye movement to be applied to the input to said primary channel;

a second channel having an output connected to said output gate, said second channel being constructed and arranged to disable said output gate in response to an input signal to said second channel;

said monitoring means including a second output connected to the input to said second channel;

said second channel including, at its input, means for enabling only those of the output signals from said monitoring means which have amplitude more than that which corresponds to a second predetermined magnitude of eye movement, which second predetermined magnitude is greater than said first predetermined magnitude, to be applied to the input of said second channel;

means responsive to an initial signal to said primary channel for enabling said second channel for a predetermined time interval after said first signal; and

means connecting said primary and second channels for reenabling said output gate in response to a third signal applied to said primary channel within said extended time interval.

15. An apparatus as defined in claim **14** further comprising:

means for manually and independently disabling said second channel whereby said circuit means will be responsive solely to the first and said eye movements.

16. An apparatus as defined in claim **14** further comprising:

a third channel having an input connected to an output from said monitoring means, said third channel having an output connected to said primary channel for selectively enabling or disabling said primary channel;

said third channel being constructed and arranged to disable said primary channel in response to a pulse signal from said monitoring means in which said signal has a period of up to approximately 50 milliseconds and being characteristic of a blink; and

said primary and second channels including means for delaying operation of said channels until after said third channel has selectively enabled or disabled said primary channel.

17. A method for determining the visual field of a subject comprises:

providing a reference fixation target within the subject's visual field;

thereafter presenting a target image to the subject at a location spaced from said reference fixation target but within his expected visual field;

electronically determining whether the subject actually visually detected said presented target image; and

in response to an indication that the subject did not actually visually detect said presented target image, thereafter automatically and sequentially presenting a plurality of individual secondary target images, each of said secondary target images being presented at equally spaced locations with respect to the location of said first presented target image, and determining, by electronic detection of the eye movements of the subject, which of said secondary targets were actually seen.

18. A method as defined in claim **17** wherein said sequentially presentation of said secondary target images includes presentation of at least three such images disposed in a generally triangular pattern surrounding the location of said first presented target.

19. A method as defined in claim **18** wherein said secondary target images are each spaced approximately 1° from the location of the first presented target image.

20. An apparatus for determining the visual field of the subject comprising:

means for displaying a reference fixation target within the subject's expected visual field;

means for presenting a target image to the subject within his expected visual field and at a location spaced from that of said reference fixation target;

means for monitoring the subject's eye positions and movements;

means for detecting those of the subject's eye positions and movements which display at least one characteristic indicative of whether the subject actually visually detected said presented target image;

means responsive to detection by said detection means of the subject's having failed to visually detect an actually presented target for thereafter sequentially presenting a plurality of individual, secondary target images, each of said secondary target images being presented at equally spaced locations with respect to the location of said first presented target image; and said means for monitoring the subject's eye positions and movements including means for electronically monitoring the subject's position and eye movements for each of said presented secondary target image to determine whether said subject actually visually detected said secondary target images.

21. An apparatus as defined in claim **20** further comprising:

said means for presenting said target image including means for directing a beam of light toward a surface within the subject's expected visual field;

directional control means for varying the direction of said beam to enable a plurality of target images to be presented at various locations;

digital input information means constructed and arranged to receive digital information corresponding to selected locations of said target image and being operatively associated with said directional

control means to sequentially position the direction of said beam to said selected locations;

means for monitoring the subject's eye positions and movements in response to presentation of said target images and for detecting and discriminating between those of the presented targets which the subject has actually visually detected and those which he has not;

means responsive to detection of the subject's having failed to actually visually detect a presented target for disabling said operative association between said digital input information means and said directional control means; and

means for thereafter sequentially presenting a plurality of individual secondary target images at equally spaced locations with respect to the location of said target image which the subject failed to actually visually detect, and including secondary target positioning means operatively associated with said directional control means for controlling the direction of said light beam independently of said digital input information means.

22. An apparatus as defined in claim **21** further comprising:

said secondary target positioning means including means for operating said directional control means to reposition the location of said target image to the position within the subject's visual field in which said last target image was presented, after completion of the presentation of said individual secondary target images; and

means for disabling said operative association between said secondary target positioning means and said directional control means and for reestablishing the operative association between said digital input information means and said directional control means.

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OR 3,982,823

United States
Momiyama et al

[11] 3,982,823
[45] Sept. 28, 1976

[54] **RETROFOCUS WIDE-ANGLE OBJECTIVE LENS SYSTEM OF LARGE RELATIVE APERTURE**

[75] Inventors: **Kikuo Momiyama**, Chofo; **Yujiro Agari**, Tokyo, both of Japan

[73] Assignee: **Canon Kabushiki Kaisha**, Tokyo, Japan

[22] Filed: **June 13, 1975**

[21] Appl. No.: **586,550**

Related U.S. Application Data

[63] Continuation of Ser. No. 387,038, Aug. 9, 1973, abandoned.

[30] **Foreign Application Priority Data**

Aug. 23, 1972 Japan 47-84315

[52] **U.S. Cl.** **350/214**; 350/176; 350/207

[51] **Int. Cl.**[2] **G02B 9/64**

[58] **Field of Search** 350/176, 207, 214

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Primary Examiner—Paul A. Sacher
Attorney, Agent, or Firm—Toren, McGeady and Stanger

[57] **ABSTRACT**

A retrofocus wide-angle objective lens having a range of at least 75° with a large relative aperture and which is corrected for various aberrations and particularly curvature of field at the outer portions of the viewing field.

3 Claims, 4 Drawing Figures

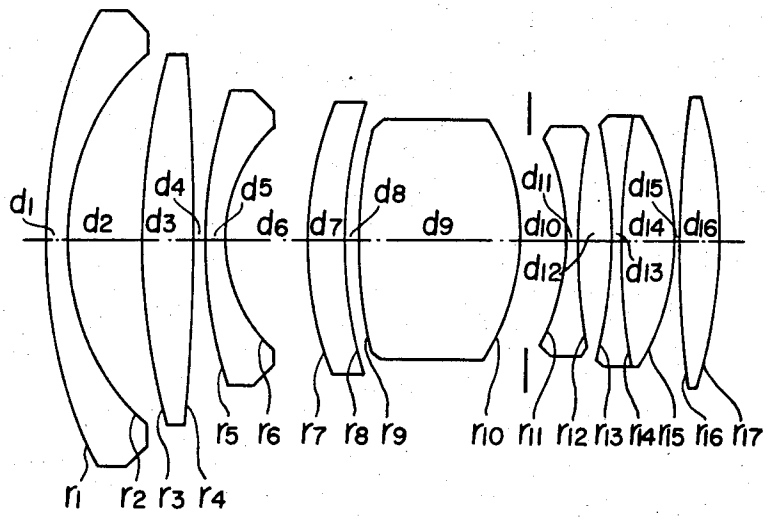

FIG. 1

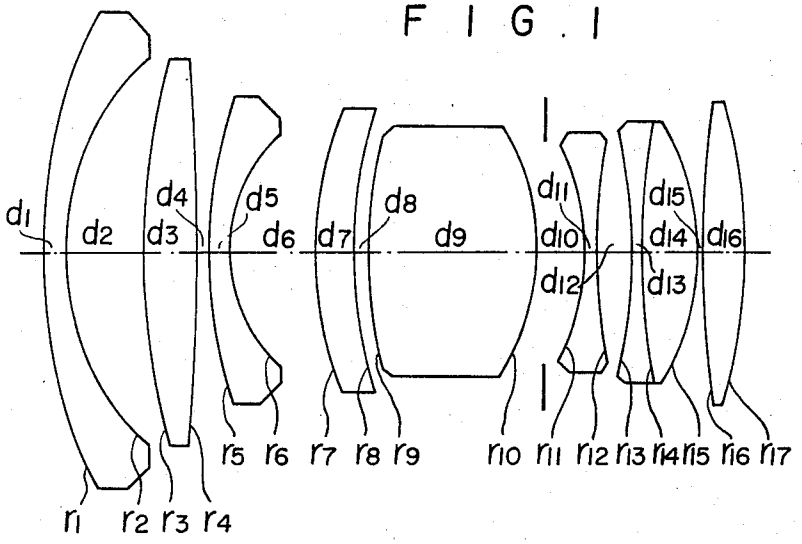
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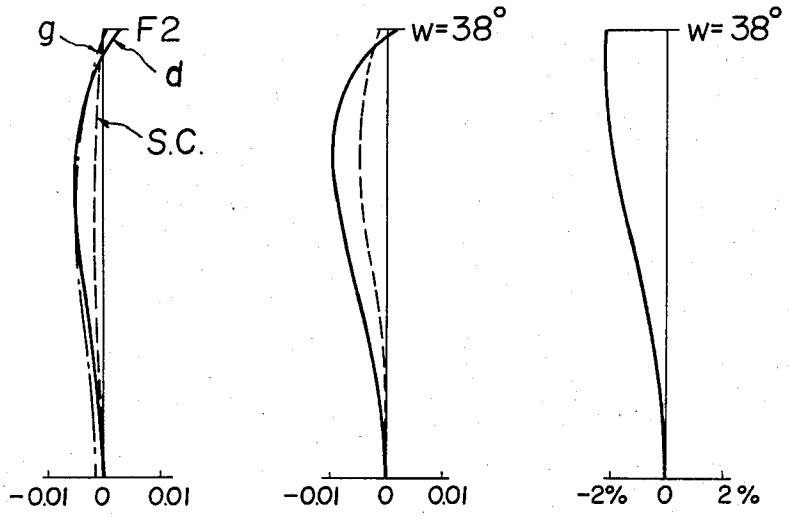
FIG. 2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0
2%

FIG. 3

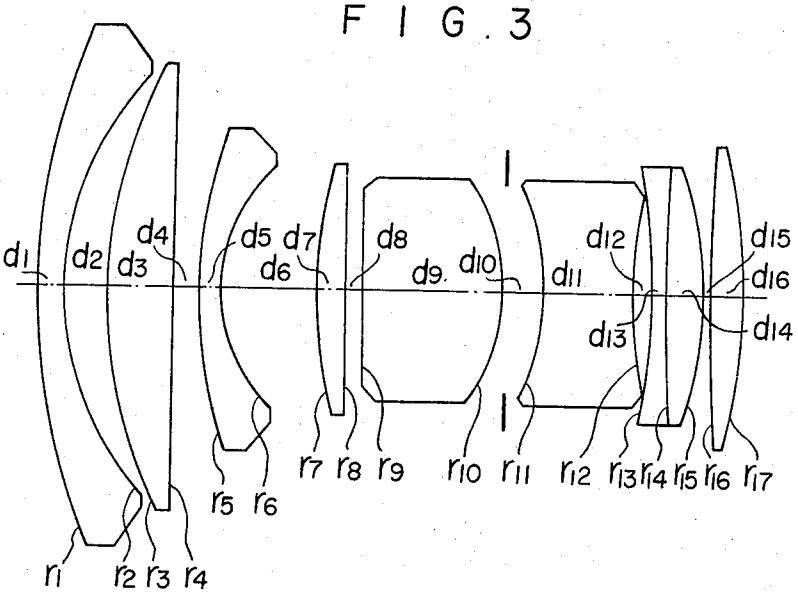
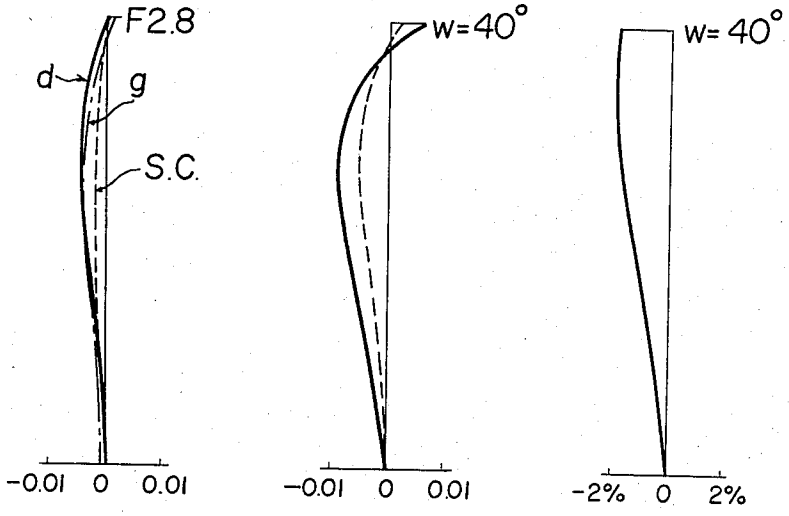

d1
d2
d3
d4
d5
d6
d7
d8
d9
d10
d11
d12
d13
d14
d15
d16
r1
r2
r3
r4
r5
r6
r7
r8
r9
r10
r11
r12
r13
r14
r15
r16
r17

FIG. 4


F2.8
d
g
S.C.
-0.01
0
0.01
w=40°
-0.01
0
0.01
w= 40°
-2%
0
2%

RETROFOCUS WIDE-ANGLE OBJECTIVE LENS SYSTEM OF LARGE RELATIVE APERTURE

This is a continuation of application Ser. No. 387,038 filed Aug. 9, 1973, now abandoned.

DETAILED DESCRIPTIION OF THE INVENTION

This invention relates to a retrofocus ultrawide-angle camera objective which has a relative aperture of less than 2.8 in F-number with an field angle of at least 75°, and which also is so designed that the back focus length is sufficient long to permit the quick-return pivoting operation of the reflecting mirror incorporated in a single lens reflex camera.

In retrofocus wide-angle objectives of the conventional type, it is often unavoidable that the curvature of field at the lateral or outer portions of the viewing field is over-corrected with the result of a considerable drop in image sharpness at the edge regions of the image. Particularly when this known construction is modified so as to provide a furthermore increased relative aperture and simultaneously a short total length, the resulting drawback is so intensified as to abandon its use.

Accordingly, the present invention has for a general object to provide an optical objective system designed so as to have a wide-angle of field and compact structure while nevertheless being well corrected for various aberrations.

Further objects and advantages will become apparent during the course of the following description with reference to the accompanying drawings in which:

FIG. 1 is a diagrammatic view of one example of a practical wide-angle objective in accordance with the present invention.

FIG. 2 is a graphic representation of spherical aberrations, sine condition, astigmatism and distortion in the corrected objective shown in FIG. 1.

FIG. 3 is a diagrammatic view of a further example of a practical wide-angle objective in accordance with the present invention.

FIG. 4 is a graphic representation of spherical aberrations, sine condition, astigmatism and distortion in the corrected objective shown in FIG. 3.

Now referring to FIGS. 1 and 3, in order to accomplish the foresaid object, the lens system constructed in accordance with the present invention comprises eight optically aligned lens components, of which the first component designated by Roman character I counting from the front is a concave meniscus lens of rearward concavity, component II is a convex lens, component III is a concave meniscus lens of rearward concavity, component IV is a concave lens of which the strongly curved surface, or the surface with a smaller radius of curvature than that of the other faces toward the object, component V is a convex lens of strong rearward convexity, component VI is a double concave lens, components VII is a convex meniscus doublet consisting of a concave lens and a convex lens cemented together, and component VIII is a double convex lens, and having a diaphragm interposed between components V and VI.

In the eight-component lens system, the symbols for lens parameters denote the following:

f: The equivalent focal length of the entire system

r: The radii of curvature of the individual refracting surfaces

d: The axial separations between the retracting surfaces

N: The refractive indices of the individual lens glasses

ν: The Abbe number of the individual lens glasses

Thus, the wide-angle objective of the present invention is characterized by good aberration correction effected by satisfying the following conditions in combination:

$$0.35f < d_7 + d_8 + d_9 < 0.8f \quad (1)$$

$$0.5 \left| r_{13} \right| / r_{12} < 2.0 \; ; \; r_{13} < 0 \quad (2)$$

$$0.03f < d_{12} < 0.13f \quad (3)$$

$$1.73 < \frac{N_8 + N_9}{2} \quad (4)$$

$$\nu_4 < 35.0 \quad (5)$$

$$2.0 < \nu_6 - \nu_7 < 20.0 \quad (6)$$

The meanings of the above specified conditions and their limit values will be explained herebelow.

Condition (1) defines the limits for permitting the design of an objective so as to cover a wide-angular field of view and simultaneously shorten the total length while still maintaining a good state of correction for field curvature at the outer regions of the viewing field. As the deviation down from the lower limit increases, the field curvature at the outer portions rapidly increases to result in a strong over-correction, whilst as the upper limit is exceeded, the total length increases with an increase in the diameter of the front lens assembly so that the bulk of the complete lens system cannot be minimized in good proportion.

Condition (2) has an effect on the optical performance of an air lens intervening between components VI and VII. As far as the lens system of the type described is concerned, the provision of the air lens is effective for the correction of distortion ascribable to the concave lenses on the object side of the air lens, but this effect is remarkably reduced, as the relative aperture of the lens system increases. In order to secure the effect sufficiently even in a greatly increased relative aperture range, condition (2) is required. When the upper limit is exceeded, or when r_{12} is far smaller than the absolute value of r_{13}, spherical aberrations increase. When the lower limit is violated, or when r_{12} is far longer than the absolute value of r_{13}, the correction for negative distortion is difficult to be achieved. From the standpoint of severer lens design specification, it is desirable for $\left| r_{13} \right| / r_{12}$ to lie between 0.7 and 1.5.

Condition (3) provides the adjustment of the axial thickness of the air lens in order to compensate residual distortion and astigmatism resulting from the dependence of aberration correction for completeness upon not only conditions (2) but also the balancing with other elements of the objective. When the upper limit is violated, a remarkable under-correction of distortion is effected. When the lower limit is violated, a remarkable under-correction of astigmatism is effected.

Condition (4) is concerned with a range in the effective reduction of field curvature at the intermediate portions under the above-mentioned condtions (1), (2) and (3) and it is also effective for the purpose of facilitating the correction of spherical aberrations ascribable to the convex lenses of components VII and VIII. When

the limit is violated, it is impossible to secure these effects.

As far as the lens system of the type described, the correction of chromatic aberrations is achieved usually by virtue of the choice of lowly dispersive glasses for the concave lenses arranged on the object side of the diaphragm and highly dispersive glasses for the convex lenses arranged thereon. However, the use of such convex lenses causes color coma and color distortion to be strongly over-corrected.

Condition (5) prevents such over-corrections of color aberrations. Inasmuch as condition (5) is satisfied, due correction for chromatic aberrations can be achieved by increasing the dispersive power of component IV and decreasing the dispersive power of component V while avoiding increases in color coma and color distortion ascribable to the strong rearward convexity of the component V. When ν_4 is increased from the specified limit value, ν_5 must be decreased for the maintenance of the equivalent chromatic aberration correction, or otherwise color coma and color distortion increase. The practical upper limits of conditions (4) and (5) depend on the characteristics of available glasses, whereby it is preferred that $(N_8 + N_9)/2$ and ν_4 are deviated from the above-specified limit values as much as possible.

Condition (6) works effectively on the correction for color coma and color distortion ascribable to the lens components arranged on the image side of the diaphragm. When the lower limit is violated, color coma and color distortion ascribable to the front surface of the air lens formed between components VI and VII in accordance with conditions (2) and (3) increase. When the upper limit is violated, color astigmatism ascribable to the rear surface of the air lens increases.

By satisfying the above-specified conditions, the retrofocus wide-angle objective can be constructed as represented by the numerical data in Table 1 or Table 3 for the radii of curvature of the individual refracting surfaces, r_1 to r_{17}, the negative sign indicating that the surface is concave to the front, the axial thickness of the individual elements, or the axial air separation between the components, d_1 to d_{16} along with the corresponding refractive indices, N_1 to N_9 and the Abbe numbers ν_1 to ν_9 of which the individual lens elements are made. The numerical data of the first practical example in Table 1 are related to the lens system of FIG. **1**. The aberration curves of the corrected lens system shown in FIG. **1** are illustrated in FIG. **2***a*, **2***b* and **2***c*. The numerical data of the second practical example in Table 3 are related to the lens system of FIG. **3**, and its aberration curves are illustrated in FIGS. **4***a*, **4***b* and **4***c*.

As far as the present invention is concerned, the permissible limit of variation for the parameters of the lens system from the values stated in respect of each of the two examples, are ±5% for the inverse number of the radius of curvature ($1/r$), ±5% for the thickness or separation (d), ±0.03 for the refractive index, and ±5% for the dispersive power ($1/\nu$).

Table 1

f = 1		F 2.0		2ω = 76°
r_1 = 1.7090				
	d_1 = 0.0707	N_1 = 1.64328		ν_1 = 47.85
r_2 = 0.8800				
	d_2 = 0.2743			
r_3 = 2.5246				
	d_3 = 0.1646	N_2 = 1.58913		ν_2 = 61.11
r_4 = −9.0518				
	d_4 = 0.0661			
r_5 = 1.3704				
	d_5 = 0.0536	N_3 = 1.65100		ν_3 = 56.15
r_6 = 0.4995				
	d_6 = 0.2571			
r_7 = 1.1928				
	d_7 = 0.0821	N_4 = 1.75520		ν_4 = 27.51
r_8 = 3.4759				
	d_8 = 0.0357			
r_9 = 3.6293				
	d_9 = 0.6179	N_5 = 1.67790		ν_5 = 55.33
r_{10} = −0.8696				
	d_{10} = 0.1536			
r_{11} = −0.8850				
	d_{11} = 0.0611	N_6 = 1.62004		ν_6 = 36.25
r_{12} = 1.5573				
	d_{12} = 0.1036			
r_{13} = −1.4292				
	d_{13} = 0.0357	N_7 = 1.80518		ν_7 = 25.43
r_{14} = 2.0409				
	d_{14} = 0.1654	N_8 = 1.77250		ν_8 = 49.57
r_{15} = −0.7961				
	d_{15} = 0.0036			
r_{16} = −3.2359				
	d_{16} = 0.1361	N_9 = 1.77250		ν_9 = 49.57
r_{17} = −2.3112				
Back focus = 1.3346				

Table 2

No.	Aberration Coefficients in Example 1 I	II	III	P	V
1	0.0477	0.0376	0.0296	0.2291	0.2039
2	−1.0121	0.1834	−0.0332	−0.4448	0.0867
3	0.1958	0.1149	0.0675	0.1468	0.1258
4	0.0002	−0.0016	0.0161	0.0410	−0.5569
5	0.1465	0.0957	0.0625	0.2877	0.2287
6	−10.7936	1.5168	−0.2131	−0.7893	0.1409
7	4.5474	0.5541	0.0675	0.3607	0.0522
8	−0.2371	−0.1907	−0.1534	−0.1238	−0.2229
9	0.2206	0.1837	0.1529	0.1113	0.2200
10	8.5241	−2.5711	0.7755	0.4646	−0.3740
11	−5.9891	1.6225	−0.4395	−0.4325	0.2362
12	−0.6955	−0.5679	−0.4637	−0.2458	−0.5794
13	0.0154	−0.0223	0.0323	−0.3121	0.4059
14	−0.1189	−0.0646	−0.0350	−0.0050	−0.0217
15	3.0533	−0.3932	0.0506	0.5475	−0.0770
16	−0.0027	−0.0104	−0.0404	0.1347	0.3646
17	2.7356	−0.5173	0.0978	0.1886	−0.0542
Σ	0.6376	−0.0304	−0.0261	0.1587	0.1786

Table 3

f = 1		F 2.8		2ω = 80°
r_1 = 1.4927				
	d_1 = 0.0563	N_1 = 1.66672		ν_1 = 48.32
r_2 = 0.7418				
	d_2 = 0.1336			
r_3 = 1.4464				
	d_3 = 0.1542	N_2 = 1.62041		ν_2 = 60.27
r_4 = 27.1473				
	d_4 = 0.0704			
r_5 = 1.1989				
	d_5 = 0.0423	N_3 = 1.67790		ν_3 = 55.33
r_6 = 0.4236				
	d_6 = 0.2714			
r_7 = 1.2905				
	d_7 = 0.0648	N_4 = 1.80518		ν_4 = 25.43
r_8 = 34.2692				
	d_8 = 0.0423			
r_9 = 24.0238				
	d_9 = 0.3358	N_5 = 1.58913		ν_5 = 61.11
r_{10} = −0.7445				
	d_{10} = 0.1070			
r_{11} = −0.9866				
	d_{11} = 0.2268	N_6 = 1.67270		ν_6 = 32.10
r_{12} = 1.6820				
	d_{12} = 0.0507			
r_{13} = −1.1886				
	d_{13} = 0.0338	N_7 = 1.80518		ν_7 = 25.43
r_{14} = −3.9876				
	d_{14} = 0.1183	N_8 = 1.77250		ν_8 = 49.57
r_{15} = −0.7141				
	d_{15} = 0.0042			
r_{16} = 8.6313				
	d_{16} = 0.0901	N_9 = 1.77250		ν_9 = 49.57

Table 3-continued

f = 1	F 2.8	2ω = 80°
r_{17} = −1.4720		
Back focus = 1.4460		

Table 4

No.	Aberration Coefficients in Example 2 I	II	III	P	V
1	0.0722	0.0569	0.0448	0.2680	0.2466
2	−1.8412	0.1753	−0.0167	−0.5392	0.0529
3	0.6206	0.1775	0.0508	0.2647	0.0902
4	−0.0001	−0.0009	−0.0166	−0.0141	−0.5401
5	0.1792	0.1245	0.0864	0.3370	0.2940
6	−16.0951	1.3993	−0.1217	−0.9537	0.0935
7	5.7642	1.3557	00.2238	0.3456	0.1122
8	−0.0273	−0.0606	−0.1348	−0.0130	−0.3284
9	0.0273	0.0575	0.1212	0.0154	0.2878
10	9.8713	−2.6717	0.7231	0.4979	−0.3305
11	−5.3357	1.6095	−0.4855	−0.4076	0.2694
12	−1.2512	−0.8855	−0.6267	−0.2391	−0.6127
13	0.0458	−0.0531	0.0615	−0.3753	0.3635
14	−0.1180	−0.0620	−0.0326	−0.0026	−0.0185
15	3.9041	−0.4442	0.0505	0.6103	−0.0752
16	−0.002	−0.0020	−0.0238	0.0505	0.3165
17	5.2503	−0.6196	0.0731	0.2963	−0.0436
Σ	1.0664	−0.0635	−0.0230	0.1412	0.1777

What is claimed is:

1. A retrofocus wide-angle objective lens system with large relative aperture comprising eight optically aligned lens components of which the first component is a concave meniscus lens of rearward concavity, the second component is a convex lens, the third component is a concave meniscus lens of rearward concavity, the fourth component is a convex lens of strong forward convexity, the fifth component is a convex lens of strong rearward convexity, the sixth component is a bi-concave lens, the seventh component is a convex meniscus doublet consisting of a concave lens and a convex lens cemented together and the eighth component is a bi-convex lens, and having a diaphragm interposed between the fifth and sixth components, and said objective lens system being characterized by the following relationships in combination:

$$0.4f<d_7+d_8+d_9<0.75f \quad (1)$$

$$0.68 < \frac{|r_{13}|}{r_{12}} < 1.75,\ r_{13} < 0 \quad (2)$$

$$0.05f<d_{12}<0.105f \quad (3)$$

$$1.73<(N_8+N_9)/2 \quad (4)$$

$$\nu_4<35 \quad (5)$$

$$2.5<\nu_6-\nu_7<17 \quad (6)$$

wherein f is the equivalent focal length of the entire lens system, d_7 is the axial thickness of the fourth component, d_8 is the axial air separation between the fourth and fifth components, d_9 is the axial thickness of the fifth component, r_{12} is the radius of curvature of the rear refracting surface of the sixth component, r_{13} is the radius of curvature of the front refracting surface of the seventh component, d_{12} is the axial air separation between the sixth and seventh components, N_8 is the refractive index of the convex lens of the seventh doublet lens component for the sodium d-line of the spectrum, N_9 is the refractive index of the eighth convex lens component for the sodium d-line of the spectrum, ν_4 is the Abbe number of the fourth convex lens component, ν_6 is the Abbe number of the sixth bi-concave lens component, and ν_7 is the Abbe number of the concave lens of the seventh doublet lens component.

2. A retrofocus wide-angle objective lens system with large relative aperture comprising eight optically aligned lens components of which the first component is a concave meniscus lens of rearward concavity, the second component is a convex lens, the third component is a concave meniscus lens of rearward concavity, the fourth component is a convex lens of strong forward convexity, the fifth component is a convex lens of strong rearward convexity, the sixth component is a bi-concave lens, the seventh component is a convex meniscus doublet consisting of a concave lens and a convex lens cemented together and the eighth component is a bi-convex lens, and having a diaphragm interposed between the fifth and sixth components, and said objective lens system being characterized by the following relationships in combination:

$$0.35f < d_7 + d_8 + d_9 < 0.8f \quad (1)$$

$$0.5 < \frac{|r_{13}|}{r_{12}} < 2.0 \ ;\ r_{13} < 0 \quad (2)$$

$$0.03f < d_{12} < 0.13f \quad (3)$$

$$1.73 < \frac{N_8 + N_9}{2} \quad (4)$$

$$\nu_4 < 35.0 \quad (5)$$

$$2.0 < \nu_6 - \nu_7 < 20.0 \quad (6)$$

wherein f is the equivalent focal length of the entire lens system, d_7 is the axial thickness of the fourth component, d_8 is the axial air separation between the fourth and fifth components, d_9 is the axial thickness of the fifth component, r_{12} is the radius of curvature of the rear refracting surface of the sixth component, r_{13} is the radius of curvature of the front refracting surface of the seventh component, d_{12} is the axial air separation between the sixth and seventh components, N_8 is the refractive index of the convex lens of the seventh doublet lens component for the sodium d-line of the spectrum, N_9 is the refractive index of the eighth convex lens component for the sodium d-line of the spectrum, ν_4 is the Abbe number of the fourth convex lens component, ν_6 is the Abbe number of the sixth bi-concave lens component, and ν_7 is the Abbe number of the convex lens of the seventh doublet lens component, the characteristics of the various lenses of the components and their special relationships to each other being of the proportions indicated by the numerical data in the following table,

f = 1			F 2.0		2 = 76°
r_1 = 1.7090					
	d_1 = 0.0707	N_1 = 1.64328		ν_1 = 47.85	
r_1 = 0.8800					
	d_2 = 0.2743				
r_3 = 2.5246					
	d_3 = 0.1646	N_2 = 1.58913		ν_2 = 61.11	
r_4 = −9.0518					
	d_4 = 0.0661				
r_5 = 1.3704					
	d_5 = 0.0536	N_3 = 1.65100		ν_3 = 56.15	

-continued

f = 1			F 2.0			2ω = 76°
r_6	=	0.4995				
			d_6 = 0.2571			
r_7	=	1.1928				
			d_7 = 0.0821	N_4 = 1.75520		ν_4 = 27.51
r_8	=	3.4759				
			d_8 = 0.0357			
r_9	=	3.6293				
			d_9 = 0.6179	N_5 = 1.67790		ν_5 = 55.33
r_{10}	=	−0.8696				
			d_{10} = 0.1536			
r_{11}	=	−0.8850				
			d_{11} = .0611	N_6 = 1.62004		ν_6 = 36.25
r_{12}	=	1.5573				
			d_{12} = 0.1036			
r_{13}	=	−1.4292				
			d_{13} = 0.0357	N_7 = 1.80518		ν_7 = 25.43
r_{14}	=	2.0409				
			d_{14} = 0.1654	N_8 = 1.77250		ν_8 = 49.57
r_{15}	=	−0.7961				
			d_{15} = 0.0036			
r_{16}	=	3.2359				
			d_{16} = 0.1361	N_9 = 1.77250		ν_9 = 49.57
r_{17}	=	−2.3112				

Back focus = 1.3346.

3. A retrofocus wide-angle objective lens system with large relative aperture comprising eight optically aligned lens components of which the first component is a concave meniscus lens of rearward concavity, the second component is a convex lens, the third component is a concave meniscus lens of rearward concavity, the fourth component is a convex lens of strong forward convexity, the fifth component is a convex lens of strong rearward convexity, the sixth component is a bi-concave lens, the seventh component is a convex meniscus doublet consisting of a concave lens and a convex lens cemented together and the eighth component is a bi-convex lens, and having a diaphragm interposed between the fifth and sixth components, and said objective lens system being characterized by the following relationships in combination:

$$0.35f < d_7 + d_8 + d_9 < 0.8f \quad (1)$$

$$0.5 < \frac{|r_{13}|}{r_{12}} < 2.0 \quad ; \quad r_{13} < 0 \quad (2)$$

$$0.03f < d_{12} < 0.13f \quad (3)$$

$$1.73 < \frac{N_8 + N_9}{2} \quad (4)$$

$$\nu_4 < 35.0 \quad (5)$$

$$2.0 < \nu_6 - \nu_7 < 20.0 \quad (6)$$

wherein f is the equivalent focal length of the entire lens system, d_7 is the axial thickness of the fourth component, d_8 is the axial air separation between the fourth and fifth components, d_9 is the axial thickness of the fifth component, r_{12} is the radius of curvature of the rear refracting surface of the sixth component, r_{13} is the radius of curvature of the front refracting surface of the seventh component, d_{12} is the axial air separation between the sixth and seventh components, N_8 is the refractive index of the convex lens of the seventh doublet lens component for the sodium d-line of the spectrum, N_9 is the refractive index of the eighth convex lens component for the sodium d-line of the spectrum, ν_4 is the Abbe number of the fourth convex lens component, ν_6 is the Abbe number of the sixth bi-concave lens component, and ν_7 is the Abbe number of the concave lens of the seventh doublet lens component, the characteristics of the various lenses of the components and their special relationships to each other being of the proportions indicated by the numerical data in the following table,

f = 1			F 2.8			2ω = 80°
r_1	=	1.4927				
			d_1 = 0.0563	N_1 = 1.66672		ν_1 = 48.32
r_2	=	0.7418				
			d_2 = 0.1336			
r_3	=	1.4464				
			d_3 = 0.1542	N_2 = 1.62041		ν_2 = 60.27
r_4	=	27.1473				
			d_4 = 0.0704			
r_5	=	1.1989				
			d_5 = 0.0423	N_3 = 1.67790		ν_3 = 55.33
r_6	=	0.4236				
			d_6 = 0.2714			
r_7	=	1.2905				
			d_7 = 0.0648	N_4 = 1.80518		ν_4 = 25.43
r_8	=	34.2692				
			d_8 = 0.0423			
r_9	=	24.0238				
			d_9 = 0.3358	N_5 = 1.58913		ν_5 = 61.11
r_{10}	=	−0.7445				
			d_{10} = 0.1070			
r_{11}	=	−0.9866				
			d_{11} = 0.2268	N_6 = 1.67270		ν_6 = 32.10
r_{12}	=	1.6820				
			d_{12} = 0.0507			
r_{13}	=	−1.1886				
			d_{13} = 0.0338	N_7 = 1.80518		ν_7 = 25.43
r_{14}	=	−3.9876				
			d_{14} = 0.1183	N_8 = 1.77250		ν_8 = 49.57
r_{15}	=	−0.7141				
			d_{15} = 0.0042			
r_{16}	=	8.6313				
			d_{16} = 0.0901	N_9 = 1.77250		ν_9 = 49.57
r_{17}	=	−1.4720				

Back focus = 1.4460.

* * * * *

OR 3,975,090

United State

Lawson

[11] **3,975,090**

[45] **Aug. 17, 1976**

[54] **WIDE ANGLE OBJECTIVE**

[75] Inventor: **John A. Lawson,** Scarborough, Canada

[73] Assignee: **Optigon Research & Development Corporation,** Santa Monica, Calif.

[22] Filed: **July 29, 1974**

[21] Appl. No.: **492,413**

Related U.S. Application Data

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[52] **U.S. Cl.** **350/214;** 350/176; 350/255

[51] **Int. Cl.²** **G02B 9/64;** G02B 7/10

[58] **Field of Search** 350/214, 255, 176

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Primary Examiner—Paul A. Sacher

Attorney, Agent, or Firm—DeLio and Montgomery

[57] **ABSTRACT**

A wide angle lens of the retrofocus type comprising six lens groups in front and rear groupings. The rear grouping is movable forward while the front grouping is stationary to focus the lens to within ten equivalent focal lengths of the lens.

12 Claims, 4 Drawing Figures

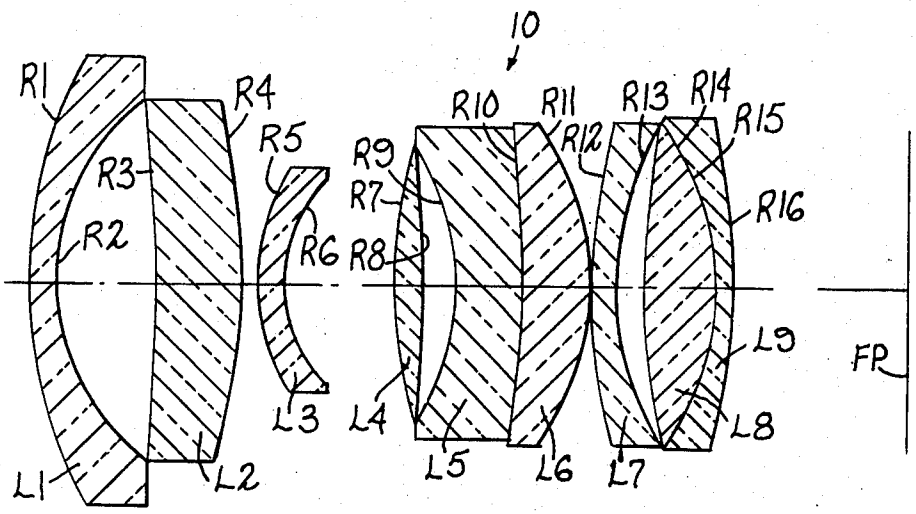


Fig. 1

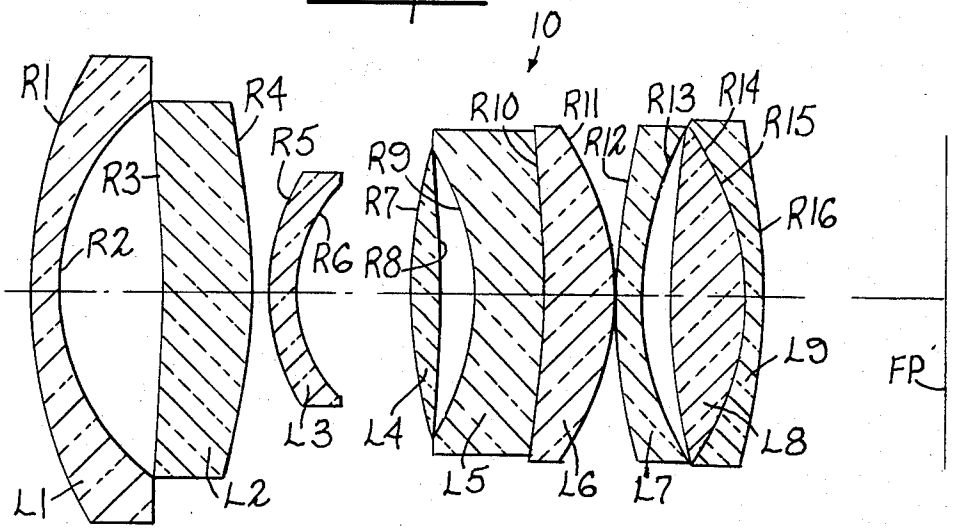
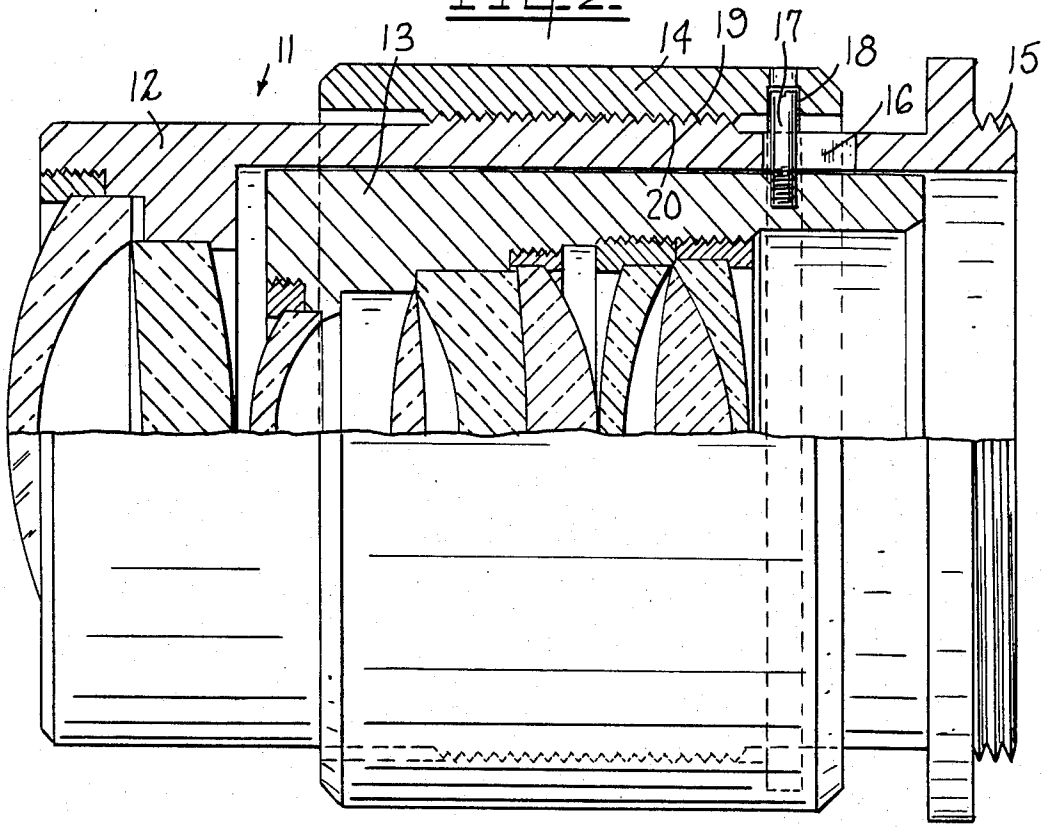

10
R1
R2
R3
R4
R5
R6
R7
R8
R9
R10
R11
R12
R13
R14
R15
R16
L1
L2
L3
L4
L5
L6
L7
L8
L9
FP

Fig. 2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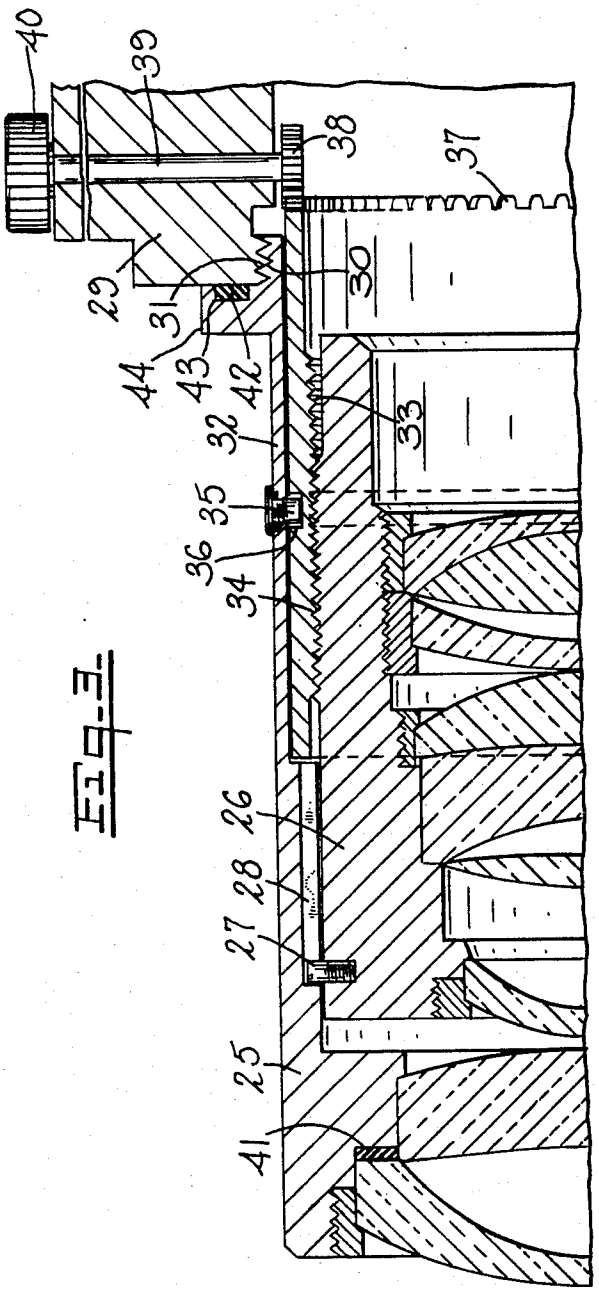
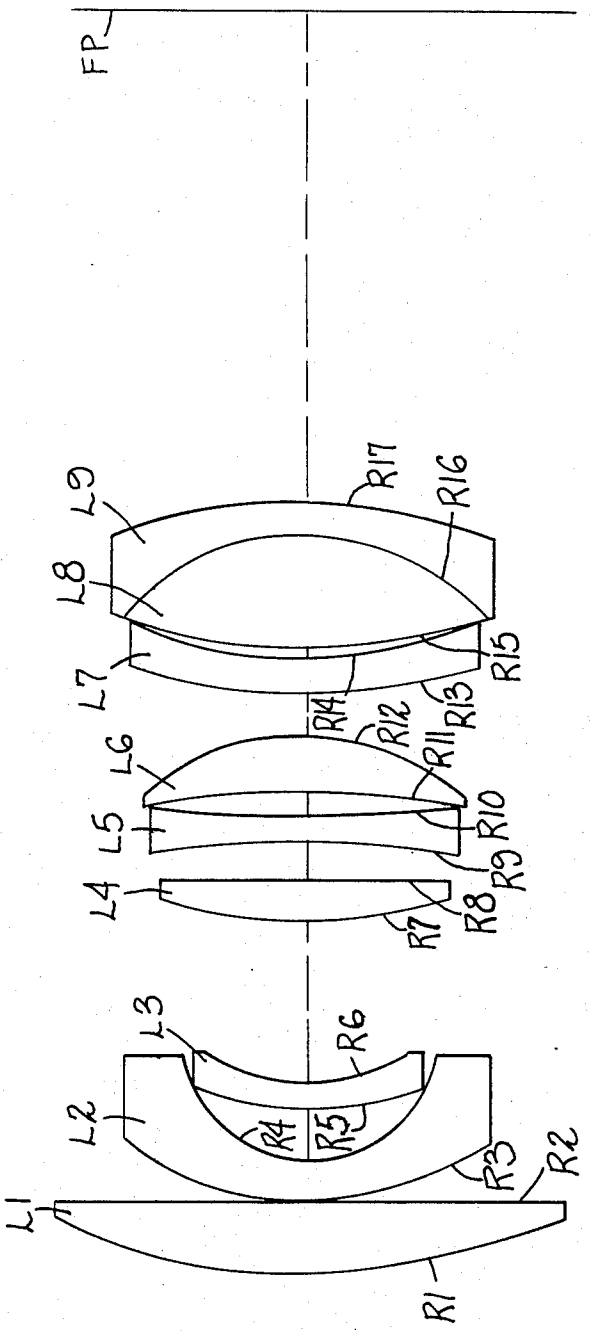


Fig. 3

Fig. 4.


FP
L9
R17
R16
L8
L7
R15
R14
R12
R13
L6
R11
L5
R10
R9
L4
R8
R7
L3
R6
L2
R4
R5
R3
R2
L1
R1

WIDE ANGLE OBJECTIVE

This application is a continuation-in-part of application Ser. No. 392,120, filed Aug. 27, 1973, now abandoned.

This invention relates to lenses and more particularly to those known as wide angle lenses.

Wide angle lenses may be defined as those in which the diameter of the film frame with which the camera is used is substantially equal to or greater than the effective focal length of the lens. Generally, wide angle objectives and particularly those of the retrofocus type are well corrected for ordinary aberrations for only one magnification. Wide angle lens of the retrofocus type are generally used with single lens reflex cameras and have a back focal length (BFL) greater than the equivalent focal length (EFL). This is generally dictated by design considerations which must permit room for the viewing mirror behind the last lens element.

Where the lens is designed for close focusing applications, the magnification will change slightly and such objectives then have considerably degraded performance due to the introduction of astigmatism, coma and other aberrations. One technique often employed to compensate for this change of aberration is to change an axial separation between lens elements as a function of focusing distance independent of focusing travel of the overall lens. While this technique has theoretical merit and can often be used to produce satisfactory results over a large range of focusing distances, the power of the lens elements for this type of objective is often large, and together with the nature of the lens element aberration contributions, the group of elements moving independent of the focusing travel is often very sensitive to deviations in mechanical centration. The resulting image is thus often degraded due to decentration more than to the effects of astigmatism, the dominant aberration due to focusing.

Accordingly, the present invention provides a new and improved wide angle lens of the retrofocus type which corrects the aberrations generally encountered in close focusing, decreases or eliminates the sensitivity to decentration resulting from focusing motion of the lens elements, and may also provide a lens barrel in which the length is not elongated during focusing. This construction may be quite useful in environments potentially damaging to the lens.

Briefly stated, the invention in one form thereof comprises a lens utilizing a front grouping of elements which are fixed in location with respect to the image plane and are generally afocal. The remaining lens elements move as a unit for focusing. since the front element grouping in combination is nearly afocal, the sensitivity to decentration resulting from the focusing motion is considerably reduced. With the proper selection of lens elements the effect of focusing the rearward group is merely to provide a constant correction for astigmatism.

An object of this invention is to provide a new and improved wide angle lens of the retrofocus type.

Another object of this invention is to provide a wide angle lens of the retrofocus type which can be focused very close distances without degradation of the image.

A further object of this invention is to provide a wide angle lens in which the front vertex distance of the lens does not change during focusing.

The features of the invention which are believed to be novel are particularly pointed out and distinctly claimed in the concluding portion of this specification. However, the invention both as to its organization and operation, together with further objects and advantages thereof, may best be appreciated by reference to the following detailed description taken in conjunction with the drawings, wherein:

FIG. 1 is a representation of elements of a first lens embodying the invention;

FIG. 2 is a side elevation, partially in half section of a lens utilizing the elements of FIG. 1;

FIG. 3 is a side elevation, partially in half section of another lens utilizing the invention; and

FIG. 4 is a representation of another lens embodying the invention.

Reference is now made to FIG. 1 which exemplifies a wide angle lens of the retrofocus type adapted to be utilized with a 35 millimeter camera (24 millimeter × 36 millimeter frame size) and which has a relative aperture of f/1.9 and an equivalent focal length (EFL) of 28 millimeters.

The lens **10** comprises elements L1 – L9 having surfaces defined by radii R1 – R16 as shown. The aperture is placed between elements L3 and L4. Elements L1 and L2 form a first group which is fixed in relation to a lens housing and, hence, the film plane FP. The elements L3 – L9 are held in fixed relation to each other but move axially for focusing.

The lens of FIG. 1 comprises from the object end a first negative group L1, L2; a second negative group L3 in the form of a meniscus having a convex object side surface; a third positive group L4 having a convex object side surface; a fourth positive group L5, L6 having a convex image side surface; a fifth negative group L7; and a sixth positive group L8, L9 having convex object and image side surfaces.

The lens of FIG. 1 for the frame size specified is defined substantially by the data of Table I, as scaled to an equivalent focal length of 28.7mm;

TABLE I

Lens		Radius	Axial Distance Between Surfaces	N d	V d
	R1	38.387mm			
L1			2.435mm	1.5168	64.2
	R2	18.755			
			8.5083		
	R3	−119.389			
L2			7.167	1.7995	42.3
	R4	−52.877			
			4.00		
	R5	18.178			
L3			2.180	1.5831	59.5
	R6	12.456			
			9.369		
	R7	49.0379			
L4			2.159	1.8306	36.5
	R8	−123.776			
			2.581		
	R9	−22.141			
L5			6.000	1.7470	27.5
	R10	−109.562			
L6			5.774	1.7620	40.3
	R11	−21.131			
			0.135		
	R12	55.725			
L7			2.454	1.8467	23.8
	R13	26.386			
			2.239		
	R14	76.751			
L8			6.000	1.8042	46.5
	R15	−22.374			
L9			1.500	1.8052	25.5
	R16	−54.363			

TABLE I-continued

Lens	Radius	Axial Distance Between Surfaces	N d	V d
		41.687		

Film Plane

EFL = 28.7mm

The aperture stop is located between elements L3 and L4. The focal length of elements L1 and L2 is −329.5mm, or nearly twelve times the EFL of the lens. The spacing between elements L2 and L3 varies from 0.20mm to 4.72mm for focusing from infinity to 178.4mm. N_d is the index of refraction and V_d is the Abbe number.

The lens disclosed may, of course, be scaled for other image frame sizes and EFL.

FIG. **2** exemplifies the lens **10** of FIG. **1** in a lens mount **11** which includes a lens barrel or housing **12,** a lens mount **13,** and a focusing ring **14.** Barrel **12** is provided with a camera mount in the form of threads **15,** and has a longitudinal slot **16** defined therein. A pin **17** is received in mount **13** and extends through slot **16** into barrel **12** into an annular groove **18** in ring **14.** Ring **14** has internal threads **19** engaging mating external threads **20** on barrel **12.** As ring **14** is rotated, pin **17** in slot **16** inhibits rotation of mount **13,** and axial movement is imparted to mount **13** for focusing travel.

FIG. **3** exemplifies a sealed lens construction, where there is no change in the front vertex distance of the lens during focusing. The first group comprising elements L1 and L2 is fixed in a lens barrel on housing **25,** a movable lens mount **26** carrying a pin **27** therein which extends into an internal axially directed slot **28** in barrel **25.** The image end of the barrel **25** is adapted to be coupled to a camera body **29** as by means of threads **30,** mating with mounting threads **31** of the camera body. A focusing sleeve **32** is disposed within barrel **25,** and has internal threads **33** engaging external threads **34** on mount **26.** A pin **35** carried by barrel **25** extends into an annular groove **36** in sleeve **26** and prevents axial motion thereof. A gear **37** is defined on the end of sleeve **26,** and meshes with a pinion **38** on a shaft **39** journaled in body **29.** A focusing knob **40** is coupled to shaft **39.**

To focus the lens, knob **40** is rotated imparting rotational movement to pinion **38** and sleeve **37.** As sleeve **32** rotates, mount **26** travels axially in barrel **25** over the focusing range of the lens.

The barrel **25** has a continuous uninterrupted outer surface with the exception of an aperture for pin **35,** which may be suitably sealed. A seal **41** may be provided between the rear side of lens element L1 and barrel **35.** Also a seal **42** may be provided in an annular groove **43** in mounting flange **44** on barrel **25.**

This construction provides a sealed lens which may be utilized in underwater applications without the necessity of placing the camera body and lens in a sealed container.

Table II sets forth data of another lens embodying the invention as scaled to an equivalent focal length of 35mm for a 24 × 36mm frame size, and with a relative aperture of F/1.9. The lens of Table II is exemplified in FIG. **4.**

TABLE II

Lens		Radius(mm)	Axial Distance Between Surfaces(mm)	N_d	N_d
L1	R_1	30.600	7.000	1.487	70.4
	R_2	170.290	.300		
	R_3	34.231	2.985	1.487	70.4
L2	R_4	11.567	6.000		
	R_5	67.235	2.000	1.569	56.0
L3	R_6	25.201	6.171		
	R_7	46.077	3.200	1.806	40.7
L4	R_8	−644.608	7.931		
	R_9	−34.424	2.358	1.762	26.6
L5	R_{10}	−829.911	1.350		
	R_{11}	−47.763	4.832		
L6	R_{12}	−19.289	4.70–.10	1.757	47.7
	R_{13}	41.514	3.000	1.667	33.1
L7	R_{14}	35.544	1.900		
	R_{15}	64.725	8.000	1.717	48.0
L8	R_{16}	−22.414	2.700	1.805	25.5
L9	R_{17}	−56.648			

The BFL varies from 39.56mm to 44.16mm as the lens is focused from infinity to 258mm, and the spacing between Groups IV and V varies as shown. The aperture stop is located 1.59mm behind element L4. Groups I-IV are fixed with respect to the film plane.

In this arrangement only the grouping of elements L7, L8 and L9 move while the grouping of elements L1 – L6 as shown in FIG. **4** are stationary in the lens housing. There is thus no change in the front vertex distance and the lens barrel may be completely sealed.

Table III exemplifies a lens also as represented in FIG. **4** as scaled for a 28.5mm equivalent focal length for a 24 × 36mm image frame in which the grouping elements L7, L8 and L9 move relative to the image frame while the grouping of elements L1 – L6 are in fixed relation to the image frame and there is no change in the front vertex distance of the lens when focused as close as 203mm or 7.25 EFL's.

TABLE III

Lens		Radius(mm)	Axial Distance Between Surfaces(mm)	N_d	V_d
L1	R_1	54.600	5.700	1.487	70.4
	R_2	937.48	.300		
L2	R_3	28.640	2.800	1.487	70.4
	R_4	11.392	4.474		
L3	R_5	28.640	2.000	1.517	64.2
	R_6	15.990	13.502		
L4	R_7	41.450	3.200	1.689	31.2
	R_8	840.70	3.342		
L5	R_9	−70.750	2.164	1.805	25.5
	R_{10}	106.030	1.900		
L6	R_{11}	−71.649	4.549	1.804	46.5
	R_{12}	−21.220	4.098 –.10		
L7	R_{13}	48.140	2.700	1.741	27.8
	R_{14}	35.430	1.212		
L8	R_{15}	53.960	9.159	1.639	55.5

TABLE III-continued

Lens		Radius(mm)	Axial Distance Between Surfaces(mm)	N_d	V_d
L9	R_{16}	−20.430	2.700	1.805	25.5
	R_{17}	−44.190			

The aperture stop is located 11.5mm behind L3. Groups V and VI move from a BFL of 39.2mm to 43.2mm for focusing from infinity to 203mm while Groups I –IV are fixed with respect to the film plane.

The lens groupings of the lenses are set forth in Table IV.

TABLE IV

Lens		Stationary Grouping	Movable Grouping
Table	I	L1 , L2	L3 – L9
	II	L1 – L6	L7 – L9
	III	L1 – L6	L7 – L9

The absolute value of the EFL (F_s) of the stationary grouping is is substantially greater than the EFL (F_o) of the overall lens, the EFL of the stationary grouping being at least three times the focal length of the overall lens or

$$| F_s | \geq 3F_o$$

It is preferred that the following relations are maintained:

$$3.7\ F_o \geq F_{56} \geq 1.5\ F_o$$

where F_o is the EFL of the lens and F_{56} is the combined equivalent focal length of Groups V and VI, and

$$1.5\ F_o \geq F_{34} \geq 1.0\ F_o$$

where F_{34} is the combined equivalent focal length of Groups III and IV.

The disclosed lens have the following relationships:

LENS	F_s/F_o	F_{56}/F_o	F_{34}/F_o	Focuses To	
Table I	−11.54	3.61	1.26	$6.20F_o$	(7.01")
Table II	4.89	1.57	1.31	$7.12F_o$	(10.15")
Table III	3.19	2.18	1.46	$7.25F_o$	(7.99")

It is possible to focus even closer by moving the overall lens after the movable grouping has reached the end of its travel. This is merely a conjugate shift, which is accomplished after the primary focusing movement.

For example the lens of Table III can be arranged so that after L7–L9 move forward from an object distance of infinity to an object distance 209mm (8.23 EFL) through 3.9mm of forward travel, the entire lens may be moved 1.3mm to focus to an object distance 149.7mm or 5.89 EFL. This may easily be accomplished mechanically by making movement of the overall lens responsive to the moving group reaching the end of its close focusing travel.

The described arrangements provide wide angle lens of the retrofocus type which give excellent image quality while focusing to less than 10 EFL's from the front element and capable of focusing within 8 EFL's while maintaining a relatively small front vertex distance.

It may thus be seen that the objects of the invention set forth as well as those made apparent from the foregoing description are efficiently attained. While preferred embodiments of the invention have been set forth for purposes of disclosure, modification to the disclosed embodiments of the invention as well as other embodiments thereof may occur to those skilled in the art. Accordingly, the appended claims are intended to cover all embodiments of the invention and modifications to the disclosed embodiments which do not depart from the spirit and scope of the invention.

What is claimed is:

1. A wide angle lens of the retrofocus type comprising a housing, said housing having means for detachable mounting to a camera, a plurality of lens groups in said housing comprising from the object end to the image end, a first negative group, a second negative group in the form of a meniscus having a convex object side surface, a third positive group having a convex object side surface, a fourth positive group having a convex image side surface, a fifth negative group, and a sixth positive group having convex image and object side surfaces, said lens groups arranged in said housing in first and second groupings, said first grouping including said first group and mounted in said housing in fixed relation thereto, said second grouping residing on the image side of said first grouping and being of positive overall power, means for moving said second grouping with all groups therein in said housing in fixed relation to each other toward said first grouping while said first grouping remains stationary in said housing to focus said lens to within ten equivalent focal lengths of said lens.

2. The lens of claim **1** wherein said second grouping comprises said second, third, fourth, fifth and sixth groups.

3. The lens of claim **1** wherein said second grouping comprises said fifth and sixth groups.

4. The lens of claim **1** wherein

$$1.5\ F_o \geq F_{34} \geq 1.2\ F_o$$

where F_{34} is the combined equivalent focal length of the third and fourth groups and F_o is the equivalent focal length of the overall lens.

5. The lens of claim **1** wherein

$$3.7\ F_o \geq F_{56} \geq 1.5\ F_o$$

where F_{56} is the combined equivalent focal length of the fifth and sixth groups and F_o is the equivalent focal length of the overall lens.

6. The lens of claim **1** defined substantially by the following data where the elements L1 and L2 comprise said first grouping:

Lens		Radius(mm)	Axial Distance Between Surfaces(mm)	N_d	V_d
	R1	38.387mm			
L1			2.435mm	1.5168	64.2
	R2	18.755			
			8.5083		
	R3	−119.389			
L2			7.167	1.7995	42.3
	R4	−52.877			
			4.00		
	R5	18.178			
L3			2.180	1.5831	59.5
	R6	12.456			
			9.369		
	R7	49.0379			
L4			2.159	1.8306	36.5
	R8	−123.776			
			2.581		

-continued

Lens		Radius(mm)	Axial Distance Between Surfaces(mm)	N_d	V_d
	R9	−22.141			
L5			6.000	1.7470	27.5
	R10	−109.562			
L6			5.774	1.7620	40.3
	R11	−21.131			
			0.135		
	R12	55.725			
L7			2.454	1.8467	23.8
	R13	26.386			
			2.239		
	R14	76.751			
L8			6.000	1.8042	46.5
	R15	−22.374			
L9			1.500	1.8052	25.5
	R16	−54.363			

where L1—L9 are lens elements from the object to the image end, R1–R16 are the radii of the surfaces of the lens elements, N_d is the index of refraction and V_d is the Abbe number of elements L1–L9.

7. The lens of claim **1** defined substantially by the following data:

Lens		Radius(mm)	Axial Distance Between Surfaces(mm)	N_d	N_d
	R_1	30.600			
L1			7.000	1.487	70.4
	R_2	170.290			
			.300		
	R_3	34.231			
L2			2.985	1.487	70.4
	R_4	11.567			
			6.000		
	R_5	67.235			
L3			2.000	1.569	56.0
	R_6	25.201			
			6.171		
	R_7	46.077			
L4			3.200	1.806	40.7
	R_8	−644.608			
			7.931		
	R_9	−34.424			
L5			2.358	1.762	26.6
	R_{10}	−829.911			
			1.350		
	R_{11}	−47.763			
L6			4.832		
	R_{12}	−19.289		1.757	47.7
			4.70 – .10		
	R_{13}	41.514			
L7			3.000	1.667	33.1
	R_{14}	35.544			
			1.900		
	R_{15}	64.725			
L8			8.000	1.717	48.0
	R_{16}	−22.414			
L9			2.700	1.805	25.5
	R_{17}	−56.648			

where L1–L9 are lens elements from the object to the image end, R1–R17 are the radii of the surfaces of the lens elements, N_d is the index of refraction and V_d is the Abbe number of elements L1–L9.

8. The lens of claim **1** defined substantially by the following data:

Lens		Radius(mm)	Axial Distance Between Surfaces(mm)	N_d	V_d
	R_1	54.600			
L1			5.700	1.487	70.4
	R_2	937.48			
			.300		
	R_3	28.640			
L2			2.800	1.487	70.4
	R_4	11.392			
			4.474		
	R_5	28.640			
L3			2.000	1.517	64.2
	R_6	15.990			
			13.502		
	R_7	41.450			
L4			3.200	1.689	31.2
	R_8	840.70			
			3.342		
	R_9	−70.750			
L5			2.164	1.805	25.5
	R_{10}	106.030			
			1.900		
	R_{11}	−71.649			
L6			4.549	1.804	46.5
	R_{12}	−21.220			
			4.098 – .10		
	R_{13}	48.140			
L7			2.700	1.741	27.8
	R_{14}	35.430			
			1.212		
	R_{15}	53.960			
L8			9.159	1.639	55.5
	R_{16}	−20.430			
L9			2.700	1.805	25.5
	R_{17}	−44.190			

where L1–L9 are lens elements from the object to the image end, R1–R17 are the radii of the surfaces of the lens elements, N_d is the index of refraction and V_d is the Abbe number of elements L1–L9.

9. A wide angle lens of the retrofocus type comprising from the object end a first negative group, a second negative group in the form of a meniscus, a third positive group having a convex object side surface, a fourth positive group having a convex image side surface, a fifth negative group in the form of a meniscus having a concave image side surface, a sixth positive group having convex object and image side surfaces, said lens groups arranged in front and rear groupings with said rear grouping of positive power, said rear grouping being movable forwardly a predetermined distance toward said front grouping while said front grouping is held stationary to focus said lens to within ten equivalent focal lengths of the first element of said lens, said front and rear groups being movable toward an object in fixed relation after said predetermined movement of said rear grouping.

10. The lens of claim **9** wherein said second grouping comprises said fifth and sixth groups.

11. The lens of claim **9** wherein

$$1.5\ F_o \geqq F_{34} \geqq 1.2\ F_o$$

where F_{34} is the combined equivalent focal length of the third and fourth groups and F_o is the equivalent focal length of the overall lens.

12. The lens of claim **10** wherein

$$3.7\ F_o \geqq F_{56} \geqq 1.5\ F_o$$

where F_{56} is the combined equivalent focal length of the fifth and sixth groups and F_o is the equivalent focal length of the overall lens.

* * * * *

United Sta
Reinsch et al.

[11] 3,969,018
[45] July 13, 1976

[54] **OBJECTIVE SYSTEM WITH ZOOM LENS FOR PHOTOGRAPHIC APPARATUS**

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[73] Assignee: **Robert Bosch G.m.b.H.**, Stuttgart, Germany

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[21] Appl. No.: **505,601**

[30] **Foreign Application Priority Data**

Sept. 17, 1973 Germany 2346758

[52] **U.S. Cl.** **350/187**
[51] **Int. Cl.²** **G02B 15/00**
[58] **Field of Search** 350/187

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Primary Examiner—John K. Corbin
Assistant Examiner—Conrad Clark
Attorney, Agent, or Firm—Michael J. Striker

[57] **ABSTRACT**

An objective system for motion picture cameras wherein a zoom lens is installed in a barrel and the barrel is surrounded by two ring-shaped selectors. The rear selector is rotatable to change the focal length of the lens by moving the optical elements of the rear group of optical elements of the lens with and relative to each other in the direction of the optical axis. The front selector is rotatable within a first angle to focus the image of a subject which is located at a distance of 5 ft. or more from the barrel, and within a second angle to focus the image of a subject prior to the making of close-up shots. The front selector moves the optical elements of the front group of optical elements of the lens during rotation within the first angle and the optical elements of the second group during rotation within the second angle. The focussing for close-up shots can be made after the focal length of the lens is reduced to a minimum value.

11 Claims, 2 Drawing Figures

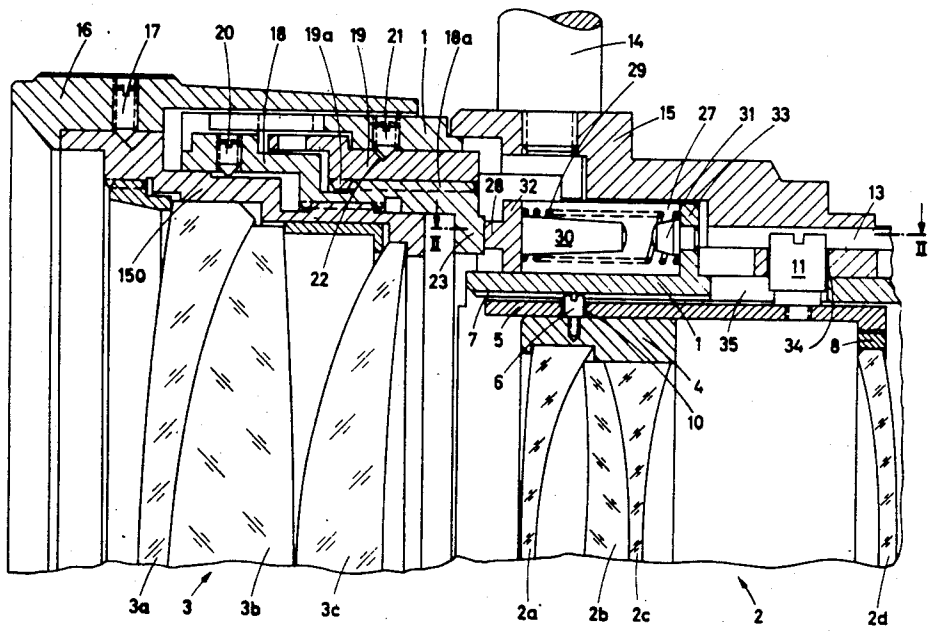


Fig. 1

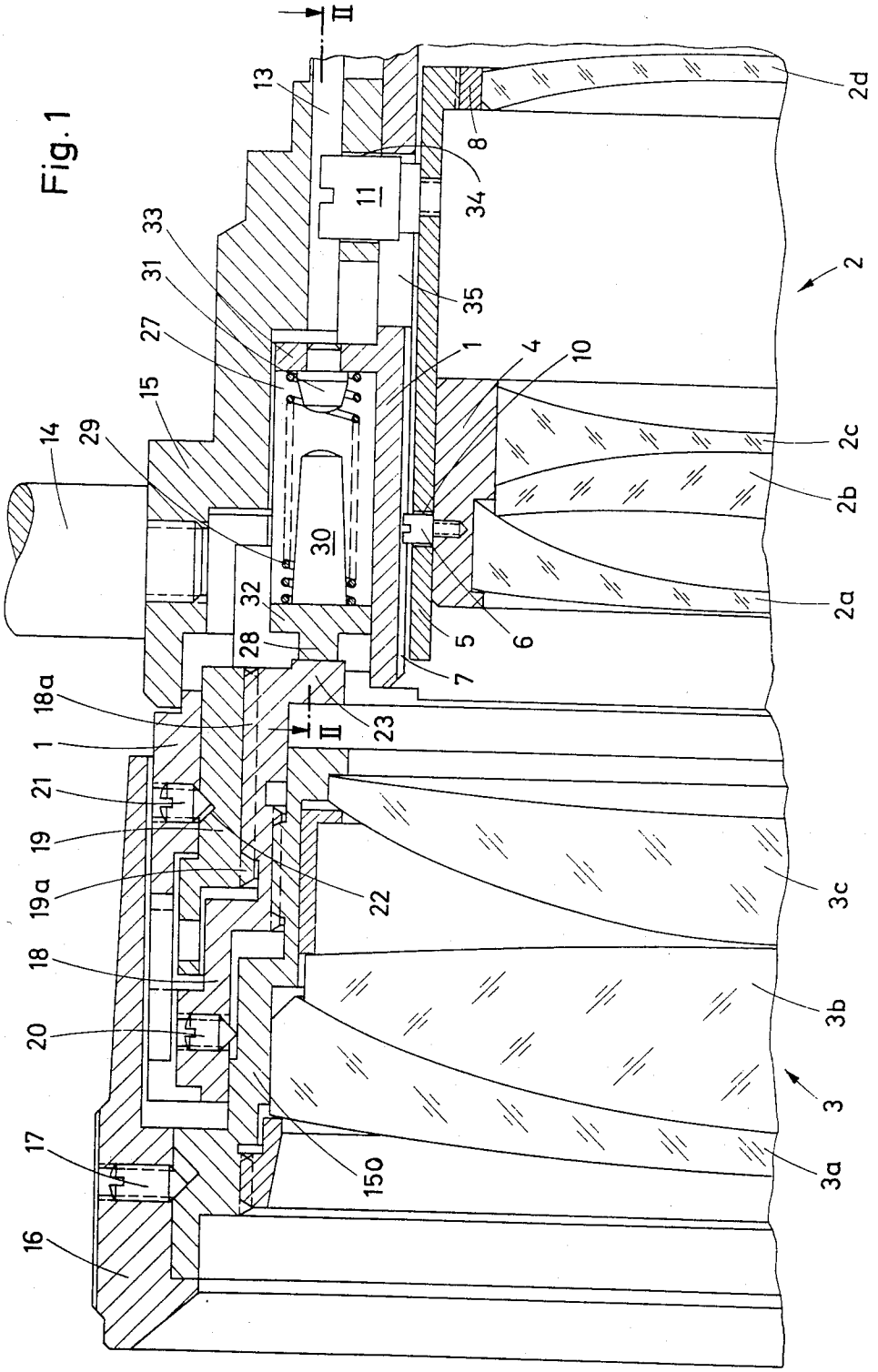
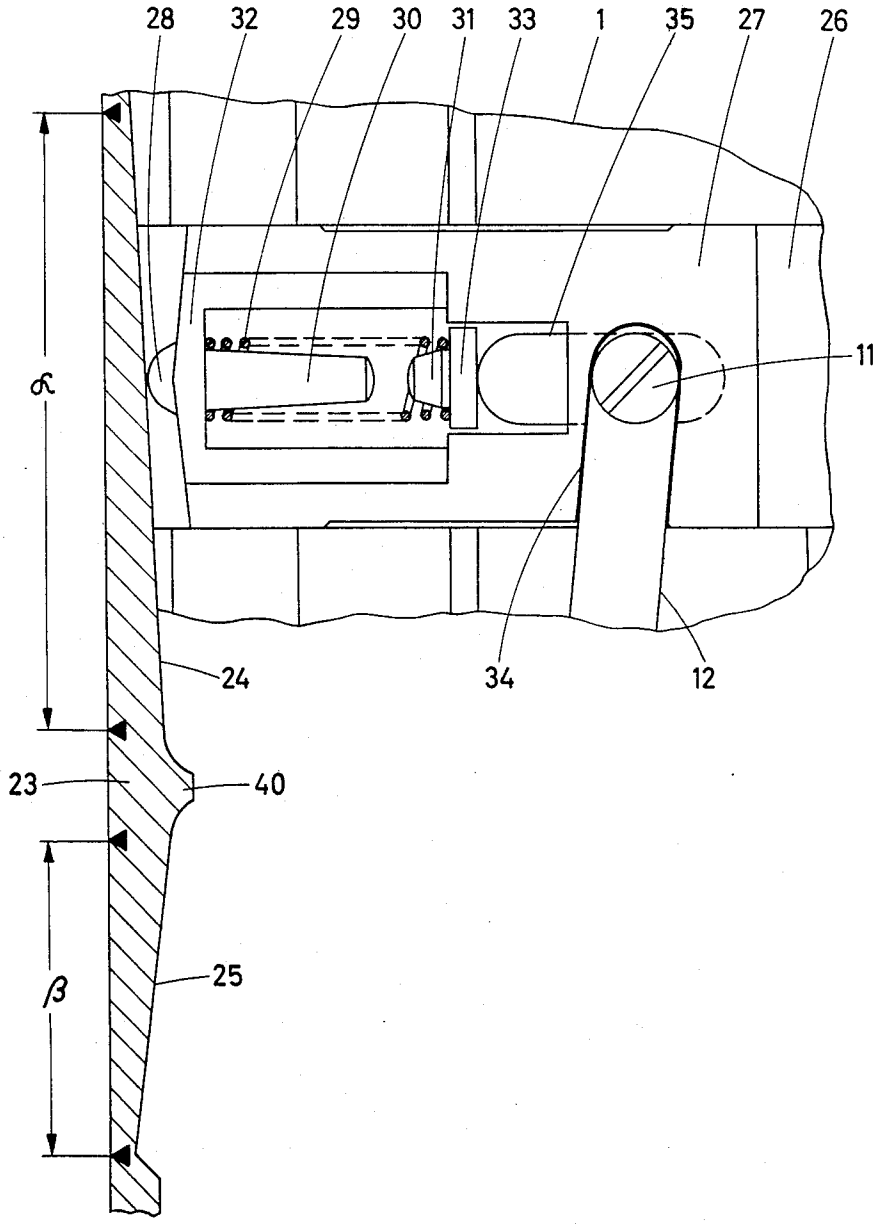

II
13
2d
8
34
11
33
31
35
2
27
1
4
10
15
2c
14
29
2b
30
32
2a
28
5
6
7
18a
II
23
1
21
19
19a
22
3c
18
3b
20
3
17
150
3a
16

Fig. 2



OBJECTIVE SYSTEM WITH ZOOM LENS FOR PHOTOGRAPHIC APPARATUS

BACKGROUND OF THE INVENTION

The present invention relates to objectives or objective systems for photograhic apparatus, and more particularly to improvements in objectives which comprise variable-focus or zoom lenses. Still more particularly, the invention relates to objectives having variable-focus lenses and means for focussing during the making of exposures at close range or at a greater distance (including infinity) from the subject. As used in the specification and claims, the expression "objective" or "objective system" is intended to denote a picture taking lens (preferably a zoom lens), a tubular barrel or mount for the lens, and means for moving selected optical elements of the lens with respect to the barrel in the direction of the optical axis.

In certain presently known objectives with variable-focus lenses, the focussing of the image of a subject which is close to the lens is effected by actuating a first selector and the focussing of the image of a subject which is located at a larger distance from the lens (e.g., at a distance exceeding 1.5 meters) is effected by actuating a second selector. In an objective having a pancratic lens, the first selector (for focussing prior to the making of close-up shots) can also serve as a means for changing the focal length of the lens. The provision of two discrete selectors (one of which enables the user to focus at close range and the other of which allows for focussing at a greater distance from the subject) is likely to confuse an inexperienced photographer. Thus, the photographer must be on the alert to distinguish between focussing for close-up shots and focussing for normal shots. The likelihood of confusion is increased due to that fact that one of the selectors performs a dual function, namely focussing at close range and changing the focal length of the lens. Thus, a novice or an unskilled amateur will make many unsatisfactory exposures or will miss many unique shots because the first selector is mistakenly actuated to focus at a normal distance from the subject, the second selector is actuated by mistake to change the focal length, or the first selector is actuated in a wrong direction for the purpose of focussing at close range.

SUMMARY OF THE INVENTION

An object of the invention is to provide a novel and improved objective with variable-focus lens wherein a single selector serves for focussing the image of a subject at close range or at a greater distance from the camera.

Another object of the invention is to provide an objective which comprises a zoom lens and wherein the manipulation of means for changing the focal length and for focussing at any desired distance from the subject is simpler and less confusing to the user than in heretofore known objectives.

A further object of the invention is to provide novel and improved means for shifting the optical elements of a zoom lens in the objective of a motion picture camera.

An additional object of the invention is to provide a novel and improved operative connection between the focussing means and the means for changing the focal length of a zoom lens.

The invention is embodied in an objective system for photographic apparatus, especially motion picture cameras, which comprises a tubular mount or barrel, a picture taking lens (preferably a variable-focus lens) having a plurality of optical elements disposed in and movable axially of the barrel to thereby focus the image of a subject, selector means (e.g., a ring-shaped member which is rotatable on the barrel), and means for connecting the selector means with the plurality of optical elements so as to move selected optical elements axially in response to movement of the selector means with respect to the barrel. The selector means is movable between a first plurality of positions to thereby move at least one first optical element (e.g., the front group of optical elements of the lens) during focussing of the image of a subject which is located within a range of greater first distances from the barrel (e.g., within a range of distances from about 5 ft. to infinity), and the selector means is movable beyond the first plurality of positions to any one of a second plurality of positions to thereby move at least one second optical element (e.g., a rear group of optical elements of the lens) during focussing of the image of a subject which is located within a range of shorter second distances (e.g., not exceeding 5 ft.) from the barrel. Such shorter second distances correspond to the making of close-up shots.

The connecting means preferably comprises a cam which serves to effect axial movements of the second optical element while the selector means moves between the second plurality of positions.

The objective system preferably further comprises second selector means (e.g., a ring-shaped member which surrounds and is rotatable on the barrel behind the first selector means) and means for connecting the second selector means with selected optical elements of the lens (preferably with the aforementioned rear group of optical elements). The second selector means is movable with respect to the barrel to thereby move at least one optical element of the lens (e.g., the aforementioned second optical element) axially of the barrel and to thus change the focal length of the lens. The arrangement is preferably such that the first mentioned selector means can focus the image of a subject for the making of a close-up shot when the focal length of the lens is reduced to a minimum value.

The novel features which are considered as characteristic of the invention are set forth in particular in the appended claims. The improved objective system itself, however, both as to its construction and its mode of operation, together with additional features and advantages thereof, will be best understood upon perusal of the following detailed description of certain specific embodiments with reference to the accompanying drawing.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a fragmentary axial sectional view of an objective system with zoom lens which embodies the invention; and

FIG. 2 is a fragmentary sectional view substantially as seen in the direction of arrows from the line II—II of FIG. 1.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The drawing shows an objective which comprises a tubular barrel or mount 1 assumed to be rigidly secured

to the housing or body of a photographic apparatus, not shown. The barrel **1** contains a variable-focus picture taking lens or zoom lens having two groups **2** and **3** of optical elements. The rear group or variator system **2** is movable axially in the barrel **1** in order to adjust the focal length of the lens as well as for focussing prior to the making of close-up shots. The front group **3** is movable axially in the barrel **1** for the purpose of focussing in the normal range of distances from the subject. The group **2** comprises four optical elements **2***a*, **2***b*, **2***c*, **2***d* and the group **3** comprises three optical elements **3***a*, **3***b*, **3***c*.

The elements **2***a*–**2***c* of the rear group **2** are fixedly mounted in a ring **4** which is axially movable in a sleeve **5**. The latter is rotatable in the barrel **1** to thereby effect a movement of the ring **4** and optical elements **2***a*–**2***c* in the direction of the optical axis of the picture taking lens. The ring **4** receives motion from a follower here shown as a screw **6** whose head extends through a cam slot **10** in the sleeve **5** and into a longitudinally extending guide groove **7** in the internal surface of the barrel **1**. The rearmost optical element **2***d* of the group **2** is mounted in a discrete ring **8** which is fixedly mounted in the sleeve **5**. A second follower **11** is threadedly connected with and extends radially outwardly from the sleeve **5** in the region between the rings **4** and **8**; this follower extends through and outwardly beyond a cam slot **12** (FIG. **2**) of the barrel **1** so that its outermost portion extends into a longitudinally extending internal guide groove **13** of an annular focal length selector **15**. The latter is rotatable on the barrel **1** and has a radially outwardly extending handle **14**. When the user of the photographic apparatus rotates the selector **15** through the medium of the handle **14**, the cam slots **10** and **12** cause the rings **4**, **8** and the optical elements **2***a*–**2***d* of the group **2** to move in the direction of the optical axis of the lens in accordance with a predetermined pattern which is calculated to establish desirable optical characteristics of the lens. The optical element **2***d* rotates with the sleeve **5** but the optical elements **2***a*–**2***c* merely move in the axial direction of the barrel **1** because the outer end portion of the follower **6** extends into the groove **7**. The shortest focal length is selected when the followers **6**, **11** assume the illustrated positions, i.e., when the ring **4** is located at a maximum distance from the ring **8**.

The optical elements **3***a*–**3***c* of the front group **3** are installed in a ring **150** which is movable axially of the barrel **1** in response to manual rotation of a second annular selector **16**. The latter surrounds and extends forwardly of the barrel **1** and is separably but rigidly affixed to the ring **150** by one or more screws **17** or analogous fasteners. FIG. **1** further shows two intermediate rings **18** and **19** which are installed between the ring **150** and the selector **16**. The inner intermediate ring **18** is threadedly connected to the ring **150** and is non-rotatably secured thereto in a selected axial position by a screw **20**. The outer intermediate ring **19** is axially adjustably connected with the barrel **1** by a screw **21**. The rings **18** and **19** are respectively provided with mating external and internal threads **18***a*, **19***a*. When the ring **19** is being adjusted axially of the barrel **1**, it transmits motion to the rings **18**, **150** and to the selector **16**. Such adjustment is effected by rotating the screw **21** which is received in a tapped radial bore of the barrel **1** and has a conical inner end portion extending into a conical socket or recess **22** in the periphery of the ring **19**. If the screw **21** is rotated to move toward the optical axis of the lens the rings **18**, **19**, **150** and the selector **16** will move rearwardly. The screw **21** further serves as a means for non-rotatably connecting the ring **19** to the barrel **1**.

The rear end portion of the inner intermediate ring **18** has an inwardly extending annular portion **23** which includes two cams **24** and **25** (see FIG. **2**) facing the ring **4** for the optical elements **2***a*–**2***c*. The cam **24** or **25** is engaged by a motion transmitting slide **27** which is movable in parallelism with the optical axis in ways **26** provided therefor in the barrel **1**. The front end portion **28** of the slide **27** has a semicylindrical shape and abuts against the cam **24** or **25** under the bias of a helical spring **29**. The latter surrounds a stud **30** of the slide **27** and a stud **31** in the barrel **1**. The foremost convolution of the spring **29** bears against a crosshead **32** which forms part of the slide **27** and is disposed between the end portion **28** and stud **30**. The rearmost convolution of the spring **29** bears against a retainer **33** which is a bracket forming part of the barrel **1** and carrying the stud **31**.

FIG. **2** shows that the slide **27** has a cutout or slot **34** which extends substantially transversely of the ways **26** and can receive the head of the follower **11**. The width of the slot **34** equals or approximates the width of the cam slot **12** in the barrel **1**. In the illustrated axial position of the slide **27**, the slot **34** is in exact register with the cam slot **12**, i.e., the follower **11** can enter the slot **34** as soon as the sleeve **5** assumes that axial position which corresponds to the shortest focal length of the lens.

The barrel **1** is formed with an internal groove **35** which extends in parallelism with the optical axis and communicates with the cam slot **12**. The groove **35** permits axial movements of the group **2** for the purpose of focussing prior to the making of a close-up shot when the focal length of the lens has been reduced to a minimum value. Thus, the follower **11** can move in the groove **35** when the sleeve **5** assumes the position shown in FIG. **1**. The distance between the optical elements **2***a*–**2***c* on the one hand and the optical element **2***d* on the other hand (i.e., between the rings **4** and **8**) remains unchanged when the follower **11** extends into and moves in the groove **35** of the barrel **1**. The sleeve **5** is then movable by the selector **16** while the latter causes the cam **25** of the annular portion **23** of the intermediate ring **18** to move with respect to the slide **27**. The annular portion **23** can reach the front end portion **28** of the slide **27** subsequent to an angular displacement through the angle alpha (focussing prior to the making of shots at close range), i.e., the cam **25** can engage the slide **27** only after the ring **18** has been rotated beyond the plurality of angular positions (angle alpha) in which the slide **27** bears against the cam **24**. The plurality of angular positions of the selector **16** in which the cam **25** engages the slide **27** is shown at beta. The inclination of the cam **25** is selected in such a way that the spring **29** is free to expand and to move the slide **27** forwardly when the cam **25** engages the end portion **28** and the ring **18** is rotated in a direction to move the cam **24** away from the slide **27**. The slide **27** then causes the group **2** to move toward the group **3** because the surface bounding the slot **34** moves the follower **11** forwardly and the latter is free to slide in the longitudinally extending groove **35** of the barrel **1**. The forward movement of the group **2** toward the group **3** is a composite movement including a first movement which is caused by the spring **29** (the latter

urges the slide **27** forwardly while the end portion **28** engages the cam **25** and the cam **25** moves upwardly, as viewed in FIG. **2**) and a second movement which is caused by the inner intermediate ring **18** (the latter moves forwardly because its threads **18***a* mesh with the threads **19***a* of the ring **19** which is fixed to the barrel **1**). The ring **18** is rotated by the selector **16** through the medium of the ring **150**, and the ring **19** causes the ring **18** to move forwardly when the cams **24**, **25** move upwardly, as viewed in FIG. **2**.

The inclination of the cam **24** is identical to the pitch of the threads **18***a*, **19***a*. Therefore, the axial position of the slide **27** remains unchanged when its end portion **28** tracks the cam **24** while the selector **16** rotates the ring **18** and its annular portion **23**. This insures that the follower **11** can enter the slot **34** of the slide **27** when the sleeve **5** is moved to the axial position of FIG. **1** (shortest focal length of the lens).

During assembly of the objective, the rings **150**, **18** and **19** are threadedly connected to each other and inserted into the barrel **1** in such a way that the end portion **28** of the slide **27** abuts against the cam **24** of the annular portion **23** at the rear end of the ring **18**. Thus, the ring **18** can assume the angular position which is shown in FIG. **2**. The screw **21** is thereupon rotated in a direction to introduce its conical inner end portion into the socket **22** and to adjust the axial position of the rings **18**, **19**, **150** in such a way that the slot **34** of the slide **27** is in exact register with the cam **12**. As the screw **21** moves radially inwardly, its conical end portion slides along the right-hand side of the conical surface bounding the socket **22** so that the rings **18**, **19**, **150** move rearwardly against the opposition of the spring **29**, i.e., the spring **29** permanently urges the surface surrounding the socket **22** against the screw **21**. The exact axial position of the ring **150** and group **3** can be selected thereafter by loosening the screw **20**, by rotating the ring **150** through the medium of the selector **16** (the ring **150** meshes with the ring **18**), and by thereupon tightening the screw **20**.

The operation:

If the user of the camera wishes to focus for the purpose of making normal exposures (i.e., other than close-up shots), the selector **16** is rotated to move the ring **18** within the angle alpha so that the slide **27** engages the cam **24**. For example, such angular adjustment of the ring **18** enables the user to focus the image of a subject which is located at a distance between 1.5 meters and infinity. As a result of the just mentioned rotation of the selector **16**, the ring **18** moves axially of the barrel **1** because it rotates with the selector **16** (it receives torque via screw **17**, ring **150** and screw **20**) and because its threads **18***a* mesh with the threads **19***a* of the ring **19** which is secured to the barrel **1** by the screw **21**. The end portion **28** of the slide **27** bears against the cam **24** under the action of the spring **29** but the axial position of the sleeve **5** (and hence of the group **2**) remains unchanged because the slope of the cam **24** is identical with the pitch of threads **18***a*, **19***a*.

If the user wishes to change the focal length of the picture taking lens, the selector **15** is rotated by moving the handle **14** about the barrel **1**. The selector **15** rotates the sleeve **5** through the medium of the follower **11** (because the latter extends into the longitudinally extending groove **13** of the selector **15**) whereby the follower **11** travels in the cam slot **12** and moves the sleeve **5** in the barrel **1** through a relatively short distance, as considered in the direction of the optical axis. As the sleeve **5** turns with the selector **15**, the follower **6** slides in the cam slot **10** and causes the ring **4** to move axially of the sleeve. The cam slot **10** causes the ring **4** and the optical elements **2***a*–**2***c* to approach the ring **8** and optical element **2***d* while the focal length increases.

In order to focus prior to the making of close-up shots, the focal length of the lens must be reduced to the minimum value, i.e., the selector **15** must be rotated in a direction to increase the distance between the rings **4**, **8** to the maximum value shown in FIGS. **1** and **2**, whereby the slot **34** of the slide **27** registers with the cam slot **12**. The follower **11** has entered the slot **34** and its outermost portion extends into the groove **35** of the barrel **1**. Thus, the slide **27** can move the sleeve **5** lengthwise (through the medium of the follower **11** and the surface surrounding the slot **34**) whereby the follower **11** slides in the groove **35**. Ths slide **27** moves lengthwise in response to rotation of the selector **16** and ring **18** beyond that plurality of angular positions (angle alpha) in which the ring **18** focuses prior to the making of exposures at a distance from the subject which exceeds 1.5 meters. In order to enable the user to detect or sense the movement of the ring **18** beyond the angular positions for normal focussing (angle alpha), the cams **24**, **25** of the annular portion **23** are separated from each other by a pronounced protuberance or lobe **40** (FIG. **2**) which must be caused to bypass the slide **27** before the latter can engage the cam **25**. Thus, the focussing is always effected by rotating the selector **16** whereby, in order to focus prior to the making of close-up shots, the user must rotate the selector **16** beyond that range of angular positions (angle alpha) which are provided for focussing at a distance between 1.5 meters and infinity in order to move the selector **16** to one of a second plurality of angular positions (angle beta) which are provided for focussing at a close range. When the selector **16** is rotated in a direction to move the lobe **40** beyond the end portion of the slide **27**, the latter begins to move forwardly under the action of the spring **29** because the cam **25** slopes forwardly as considered in the circumferential direction of the annular portion **23** (and assuming that the selector **16** moves the ring **18** and annular portion **23** upwardly, as viewed in FIG. **2**). The sleeve **5** shares the lengthwise movement of the slide **27** in the ways **26** but the distance between the rings **4** and **8** remains unchanged because the sleeve **5** does not rotate about the optical axis. Thus, the optical element **2***d* is separated from the optical elements **2***a*–**2***c* by a (maximum) distance, which corresponds to the minimum focal length of the lens, whenever the slide **27** engages the cam **25**.

An important advantage of the improved objective is that a single selector **16** can be manipulated to focus at any distance of the subject from the photographic apparatus. Thus, the user need not actuate different selectors for the same purpose (focussing); all the user has to know is that focussing at close range must be preceded by the selection of a predetermined focal length, and the focal length is changed by manipulating one and the same selector **15**. As mentioned above, such simplification of the manipulation of a relatively complex objective is especially important when the photographic apparatus embodying the improved objective is used by a novice or an inexperienced amateur photographer. However, the simplification of manipulation of the objective is equally beneficial to professionals or skilled amateur photographers.

Without further analysis, the foregoing will so fully reveal the gist of the present invention that others can, by applying current knowledge, readily adapt it for various applications without omitting features which fairly constitute essential characteristics of the generic and specific aspects of our contribution to the art and, therefore, such adaptations should and are intended to be comprehended within the meaning and range of equivalence of the claims.

What is claimed as new and desired to be protected by Letters Patent is set forth in the appended claims:

1. In an objective system for photographic apparatus, a combination comprising a barrel; a variable-focus picture-taking lens having a plurality of optical elements disposed in and movable axially of said barrel to thereby focus the image of a subject; a focus selector element movably mounted on said barrel; first connecting means for connecting said selector element with said plurality of optical elements so as to move selected optical elements axially in response to movement of said selector element relative to said barrel, said selector element being displaceable between a first plurality of positions to thereby move at least one first optical element of said plurality of optical elements through the medium of said connecting means during normal focusing of the image of a subject which is located within a range of first distances from the barrel, and said selector element being displaceable beyond said first plurality of positions to any one of a second plurality of positions to thereby move at least one second optical element of said plurality of optical elements through the medium of said connecting means during close-up focussing of the image of a subject which is located within a range of shorter second distances from the barrel such as correspond to the making of close-up shots, said connecting means comprising a cam, a motion transmitting member engaging said cam and operatively connected with said second optical element in each of said plurality of second positions of said selector element, and means for biasing said motion transmitting member against said cam, said motion transmitting member including a slide which is reciprocable in said barrel in parallelism with the optical axis of said lens; selector means and second connecting means for connecting said selector means with said second optical element, said selector means being movable with respect to said barrel to thereby move said second optical element axially and to thus change the focal length of said lens, said second connecting means comprising a second cam in said barrel and a follower operatively connected with said first optical element, tracking said second cam and rotatable by said selector means, said barrel further having a longitudinally extending groove and said slide having a slot into which said follower extends in a predetermined axial position of said second optical element, said follower further extending into said groove in response to movement of said second optical element to said predetermined axial position whereby said slide can move said second optical element axially in response to movement of said selector element between said second plurality of positions, said first connecting means comprising a third cam which is engaged by said slide in each of said plurality of first positions of said selector element, the slope of said third cam being such that the axial position of said second optical element remains unchanged while said selector element moves between said plurality of first positions, said first connecting means further comprising a ring which surrounds said first optical element and is rotatably and axially movably mounted in said barrel, said first mentioned and third cams being provided on said ring, and said ring comprising a protuberance disposed between said first mentioned and third cams and over which said slide rides against the opposition of said biasing means during movement of said selector element beyond said plurality of first positions; and means for confining said selector element to a single type of movement with respect to said barrel both during its displacement between said first plurality of positions and during its displacement between said second plurality of positions.

2. A combination as defined in claim **1,** wherein said connecting means further comprises means for connecting said ring to said selector element so that said ring moves axially of said barrel at least while said selector element moves between said first plurality of positions, said first optical element being mounted in and being movable with said ring and said additional cam being rigid with said ring.

3. A combination as defined in claim **2,** further comprising means for adjusting the axial position of said ring with respect to said barrel.

4. A combination as defined in claim **2,** wherein said ring has a first set of threads and further comprising a second set of threads supported by said barrel and meshing with said first set of threads, said selector element being rotatable with said ring relative to said barrel to thereby rotate said ring and said first optical element while moving between said first plurality of positions whereby said threads move said ring and said first optical element axially.

5. A combination as defined in claim **4,** wherein said confining means comprises a second ring normally rigid with said barrel, said first set of threads constituting external threads on said first mentioned ring and said second set of threads constituting internal threads of said second ring.

6. A combination as defined in claim **1,** further comprising selector means, and means for connecting said selector means with selected optical elements of said lens, said selector means being movable with respect to said barrel to thereby move at least one of said optical elements axially of said barrel through the medium of said last mentioned connecting means and to thus change the focal length of said lens.

7. A combination as defined in claim **6,** wherein said one optical element is said second optical element and said last mentioned connecting means comprises a device for moving said one optical element to a predetermined axial position corresponding to a predetermined focal length of said lens, said one optical element being movable axially by said first mentioned connecting means from said predetermined axial position in response to movement of said selector element between said second plurality of positions.

8. A combination as defined in claim **7,** wherein said last mentioned connecting means further comprises a sleeve surrounding said one optical element and being rotatable and axially movable in said barrel, a cam on said barrel, and a follower constituting said device, said follower being connected with said sleeve and tracking said cam in response to rotation of said sleeve by said selector means.

9. A combination as defined in claim **8,** wherein said barrel has a longitudinally extending groove into which said follower extends in said predetermined axial posi-

tion of said one optical element, said motion transmitting member moving said follower in said groove in response to movement of said selector element between said plurality of second positions.

10. A combination as defined in claim **9**, wherein the focal length of said lens is reduced to a minimum value in said predetermined axial position of said one optical element.

11. In an objective system for photographic apparatus, a combination comprising a barrel; a variable-focus picture-taking lens having a plurality of optical elements disposed in and movable axially of said barrel to thereby focus the image of a subject; a focus selector element movably mounted on said barrel; connecting means for connecting said selector element with said plurality of optical elements so as to move selected optical elements axially in response to movement of said selector element relative to said barrel, said selector element being displaceable between a first plurality of positions to thereby move at least one first optical element of said plurality of optical elements through the medium of said connecting means during normal focusing of the image of a subject which is located within a range of first distances from the barrel, and said selector element being displaceable beyond said first plurality of positions to any one of a second plurality of positions to thereby move at least one second optical element of said plurality of optical elements through the medium of said connecting means during close-up focussing of the image of a subject which is located within a range of shorter second distances from the barrel such as correspond to the making of close-up shots, said connecting means comprising a cam, a motion transmitting member engaging said cam and operatively connected with said second optical element in each of said plurality of second positions of said selector element, said motion transmitting member including a slide which is reciprocable in said barrel in parallelism with the optical axis of said lens means for biasing said motion-transmitting member against said cam, an additional cam which is engaged by said slide in each of said plurality of first positions of said selector element and having a slope which is such that the axial position of said second optical element remains unchanged while said selector element moves between said plurality of first positions, a ring which surrounds said first optical element and is rotatably and axially movably mounted in said barrel, said cams being provided on said ring, and said ring comprising a protuberance disposed between said first cams and over which said slide rides against the opposition of said biasing means during movement of said selector element beyond said plurality of first positions; and means for confining said selector element to a single type of movement with respect to said barrel both during its displacement between said first plurality of positions and during its displacement between said second plurality of positions.

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De Jager

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[45] **July 6, 1976**

[54] THREE ELEMENT OBJECTIVE LENS

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[73] Assignee: **Eastman Kodak Company**, Rochester, N.Y.

[22] Filed: **Nov. 5, 1974**

[21] Appl. No.: **521,227**

[52] **U.S. Cl.** **350/226;** 350/189

[51] **Int. Cl.²** **G02B 9/14;** G02B 3/04

[58] **Field of Search** 350/226, 189

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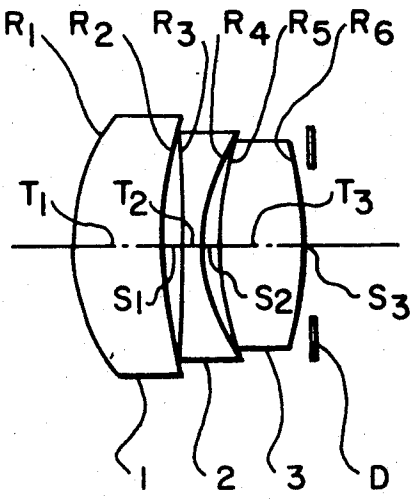
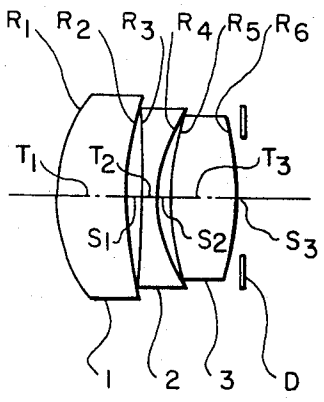
Primary Examiner—John K. Corbin
Assistant Examiner—Conrad Clark
Attorney, Agent, or Firm—J. A. Morrow

[57] **ABSTRACT**

An objective lens comprising a front positive meniscus element, a middle negative biconcave element and a rear positive biconvex element. Improved optical performance at a relative aperture of f/1.70 is achieved by the incorporation of an asphere on the rear surfaces of the first and second elements.

2 Claims, 1 Drawing Figure




R1
R2
R3
R4
R5
R6
T1
T2
T3
S1
S2
S3
1
2
3
D

THREE ELEMENT OBJECTIVE LENS

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to photographic objective lenses and in particular to such lenses that comprise three air spaced elements.

2. Description of the Prior Art

Triplet lenses for use in photographic apparatus are well known and have been used for many years. Moreover, high relative aperture lenses have also been in use for many years in the photographic industry. However, with the advent of available light photography, the use of high relative aperture lenses has spread to photographic apparatus designed to be mass produced for the amateur market. The price of such lenses then becomes of great concern and the relatively complex, well corrected, high relative aperture lenses known in the art are too costly.

Another trend in the photographic industry is toward compact designs to provide convenience in storage, handling and transportation. Large, complex lenses represent a sizable percentage of the camera's volume and place a lower limit on the size of the photographic apparatus. A reduction in the number of elements in a lens will generally aid in reducing the size and cost of the lenses to be incorporated in the photographic apparatus.

SUMMARY OF THE INVENTION

In accordance with the present invention, there is provided a three element air spaced objective lens comprising a front positive meniscus element, a middle negative biconcave element and a rear positive biconvex element, with a diaphragm positioned to the rear of the lens. Good optical performance is achieved by incorporation of an asphere on the rear surfaces of the first two elements of the lens, and by the use of glass having a very high index of refraction for all three elements.

BRIEF DESCRIPTION OF THE DRAWING

In the detailed description of the preferred embodiment of the invention presented below, reference is made to the accompanying drawing which is a diagrammatic axial cross-section of a lens according to the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

For all purposes of describing or claiming of the invention, the term lens will be used to describe the complete lens and not the elements thereof. In the drawing, the elements are numbered from left to right with Arabic numerals. In each of the examples, the elements, indices of refraction N, Abbe numbers V, radii of curvature R, thicknesses T and air spaces S are numbered to correspond with the drawing. The indices of refraction are for the 0.5876 micron helium d line of the spectrum. The Abbe numbers are calculated utilizing this d line index and, as the dispersion, the index difference between the 0.4861 micron hydrogen F line and the 0.6563 micron hydrogen C line. Radii of curvature having centers of curvature to the right of the surface are considered positive; those with centers of curvature to the left of the surface are considered negative.

In all embodiments of the invention as illustrated in the drawing, the lens comprises three air spaced elements. Element 1 is a front positive meniscus element. Element 2 is a middle negative biconcave element. Element 3 is a rear positive biconvex element. D is a diaphragm.

The use of aspheric surfaces in a lens design provides additional parameters for correction of aberrations. Incorporation of an aspheric surface is particularly useful in a high relative aperture lens, because it permits a better correction of spherical aberration than is otherwise obtainable. In the design of the present invention, the improved spherical aberration correction and the reduction of other aberrations, along with the high relative aperture, are achieved by the use of aspheres on surfaces 2 and 4 of the lens.

A general aspheric surface may be described by the following equation:

$$x = \frac{Cy^2}{1 + \sqrt{1 - (1 + K)C^2y^2}} + Dy^4$$

This equation describes a surface in terms of its surface sag x at a semi-aperture distance y from the axis of the lens. The constat C is the vertex curvature, that is, the surface curvature at the vertex of the lens, equal to the reciprocal of the vertex radius of curvature R. The constant K is the conic constant and is defined by the equation $K = -e^2$ where e is the eccentricity of the surface. Certain values of K describe conic sections or surfaces of revolution about the optical axis of the lens. The coefficient D determined the first term of higher order aspheric sag of the surface and is selected to achieve the higher order corrections that are desired. Terms higher than the quartic in the equation for x may also be included, if desired.

Lenses may be made according to this invention by following the specification in the preferred embodiment presented below:

EXAMPLE I

Element	N	V	Radius mm	Thickness or Separation mm
			R_1=13.506	
1	2.01940	34.21		T_1=6.000
			R_2=Asphere	
				S_1=1.210
			R_3=−185.19	
2	1.90893	19.31		T_2=1.200
			R_4=Asphere	
				S_2=1.340
			R_5=25.258	
3	2.01940	34.21		T_3=6.000
			R_6=−25.258	
				S_3=.500

Example I is an all glass triplet objective which is characterized by a relative aperture of f/1.70, with an effective focal length of 25.00 and a semifield angle of 23.70°. The lens is relatively compact with a total length of 15.750mm. In order to achieve the high relative aperture and good optical quality, aspheric surfaces have been incorporated on the rear surfaces of Elements 1 and 2. The asphere on Surface 2 represents a higher order correction to a spherical surface whereas the asphere on Surface 4 represents a hyperboloid of revolution around the optical axis. The re-

spective coefficients for defining the two aspheres are given in the following table:

Table I

Surface	R=1/C	K	D
2	36.338	0	0.12283×10^{-3}
4	9.4853	−1.6218	0

The invention has been described in detail with particular reference to a preferred embodiment thereof, but it will be understood that variations and modifications can be effected within the spirit and scope of the invention.

I claim:

1. A three element objective lens comprising, from front to rear, a positive meniscus element, a negative biconcave element and a positive biconvex element, each of said elements being formed of a glass having an index of refraction in excess of 1.90 and said lens including an aspheric surface on the rear surfaces of said positive meniscus element and said negative biconcave element, said aspheric surfaces being represented by the following formula and parameters:

$$x = \frac{Cy^2}{1 + \sqrt{1 - (1 + K)C^2y^2}} + Dy^4$$

Surface	R=1/C	K	D
2	36.338	0	0.12283×10^{-3}
4	9.4853	−1.6218	0

wherein x is the sag of the aspheric surface from a plane reference surface at a radial distance y from the axis of the lens, C is equal to the reciprocal of the vertex radius of curvature R and K is the conic constant.

2. A three element objective lens comprising, from front to rear, a positive meniscus element, a negative biconcave element and a positive biconvex element, each of said elements being formed of a glass having an index of refraction in excess of 1.90 and said lens including an aspheric surface on the rear surfaces of said positive meniscus element and said negative biconcave element, said lens having a focal length of 25.00mm when constructed according to the parameters in the following table:

Element	N	V	Radius mm	Thickness or Separation mm
			R_1=13.506	
1	2.01940	34.21		T_1=6.000
			R_2=Asphere	
			R_3=−185.19	S_1=1.210
2	1.90893	19.31		T_2=1.200
			R_4=Asphere	
			R_5=25.258	S_2=1.340
3	2.01940	34.21		T_3=6.000
			R_6=−25.258	
				S_3=.500

wherein, from front to rear, the elements are numbered from 1 to 3, the corresponding indices of refraction, N, and Abbe' numbers, V, are listed for each of the lens elements, the radii are numbered from R_1 to R_6, the thicknesses are numbered from T_1 to T_3 and the air spaces are numbered from S_1 to S_3, and wherein R_2 and R_4 represent the radius of curvature at the vertex of aspheric surfaces defined by the following formula and parameters:

$$x = \frac{Cy^2}{1 + \sqrt{1 - (1 + K)C^2y^2}} + Dy^4$$

Surface	R=1/C	K	D
2	36.338	0	0.12283×10^{-3}
4	9.4853	−1.6218	0

wherein x is the sag of the aspheric surface from a plane reference surface at a radial distance y from the axis of the lens, C is equal to the reciprocal of the vertex radius R and K is the conic constant.

* * * * *

United States Patent [19]

Sekida

[11] **3,961,347**

[45] **June 1, 1976**

[54] **INTERCHANGEABLE OBJECTIVE LENS DIAPHRAGM EXPOSURE CONTROL COUPLING MECHANISM**

[75] Inventor: **Minoru Sekida,** Sakai, Japan

[73] Assignee: **Minolta Camera Kabushiki Kaisha,** Osaka, Japan

[22] Filed: **Jan. 23, 1975**

[21] Appl. No.: **543,571**

[30] **Foreign Application Priority Data**

Feb. 5, 1974 Japan 49-14089

[52] **U.S. Cl.** **354/272;** 354/46

[51] **Int. Cl.²** **G03B 9/02;** G03B 7/20

[58] **Field of Search** ..... 354/40, 46, 270, 272, 354/38, 50, 51, 60 R

[56] **References Cited**

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Primary Examiner—L. T. Hix
Assistant Examiner—James LaBarre
Attorney, Agent, or Firm—Wolder & Gross

[57] **ABSTRACT**

A mechanism for transmitting the position of a diaphragm ring of a camera interchangeable lens to an exposure control device in the camera interchangeable viewer, a mechanism is mounted on the housing and includes a fixed gear, a mounting arm swingable about the fixed gear and having a sector shaped outer end which supports a rotatable gear which is coupled to the fixed gear by an idler gear carried by the mounting arm. A connector arm has one end connected to and moveable and rotatable with the rotatable gear, and is provided at its outer end with a coupling pin which separably engages a coupling element carried by the diaphragm ring. A flexible line extends from the outer end of the mounting arm along the periphery of the arm sector shaped end to the exposure control device and is spring loaded. The fixed and rotatable gears may be replaced by pulleys coupled by a flexible belt. The end of the connector arm traverses a circular path corresponding to that of the diaphragm ring coupling element.

11 Claims, 7 Drawing Figures

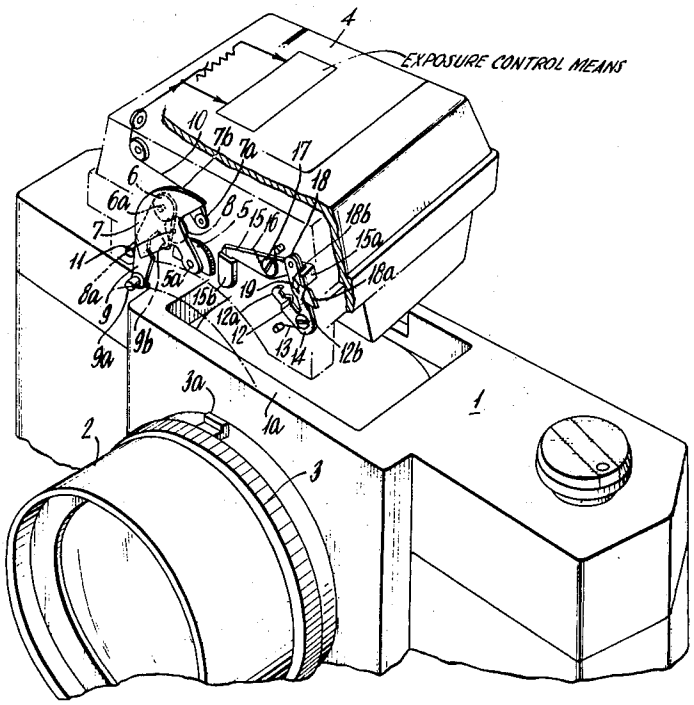


FIG. 1.

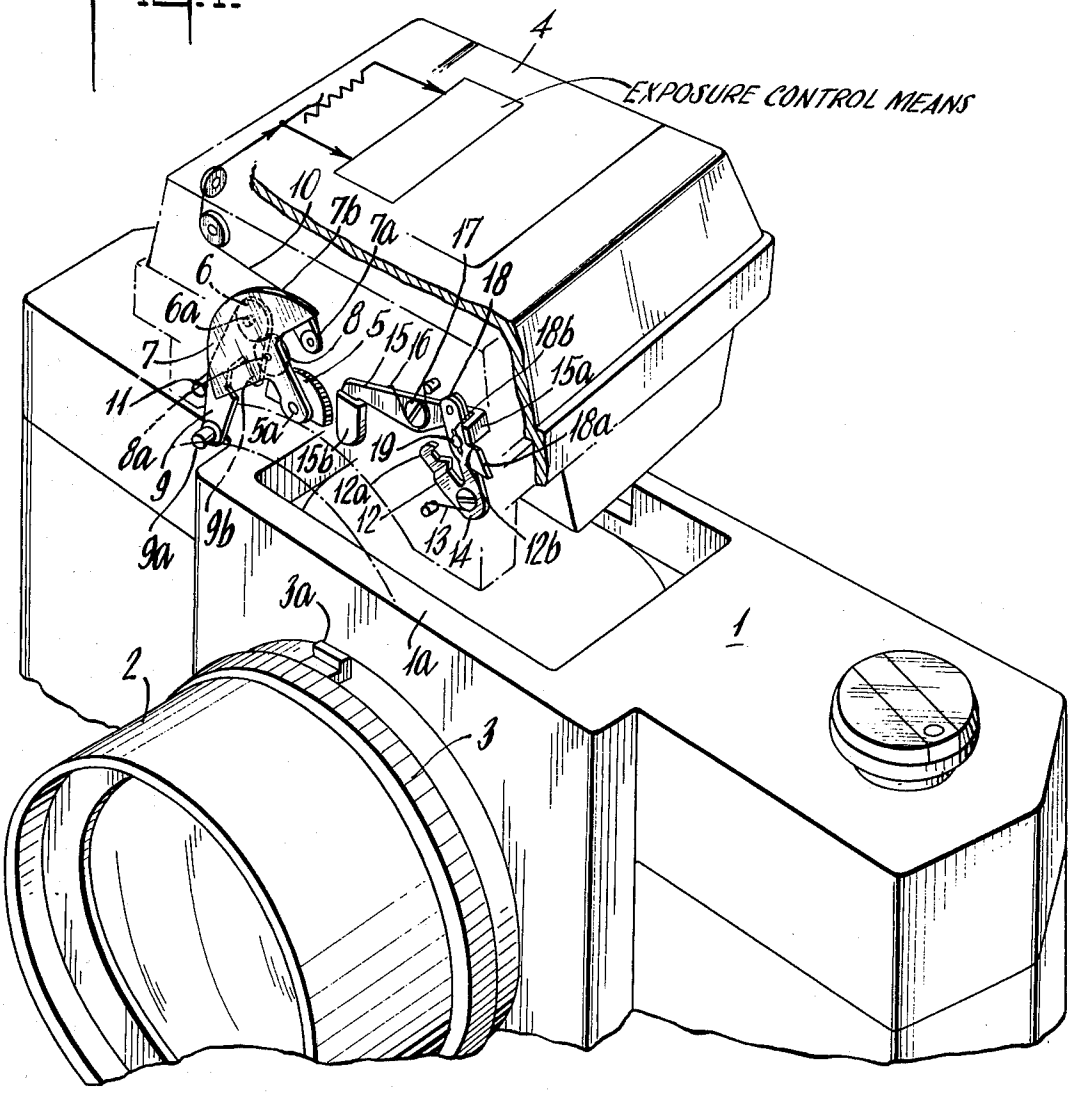
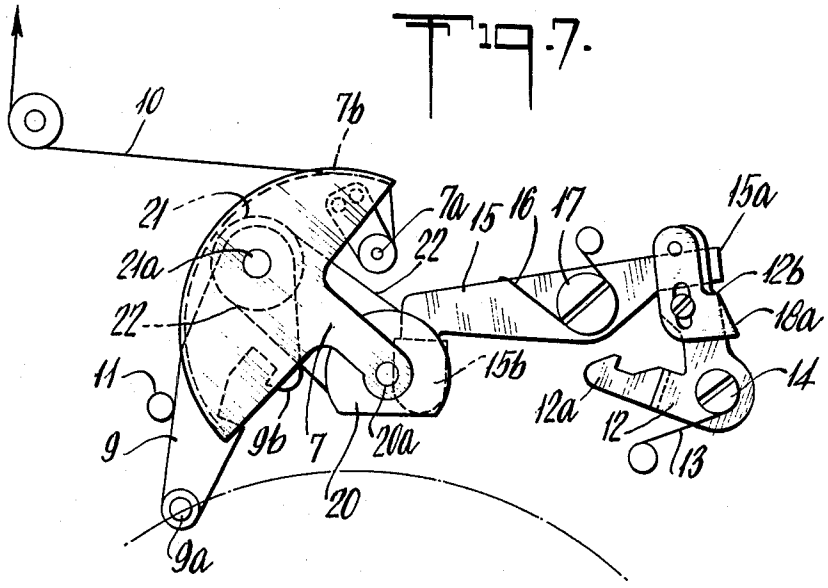

4
EXPOSURE CONTROL MEANS
10
7b
7a
17
18
6
6a
8
5
15
16
18b
15a
7
11
5a
18a
8a
9
15b
19
12a
12
13
14
12b
9a
9b
3a
1a
1
2
3

FIG. 7.


10
7b
21
7a
15
16
17
15a
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22
12b
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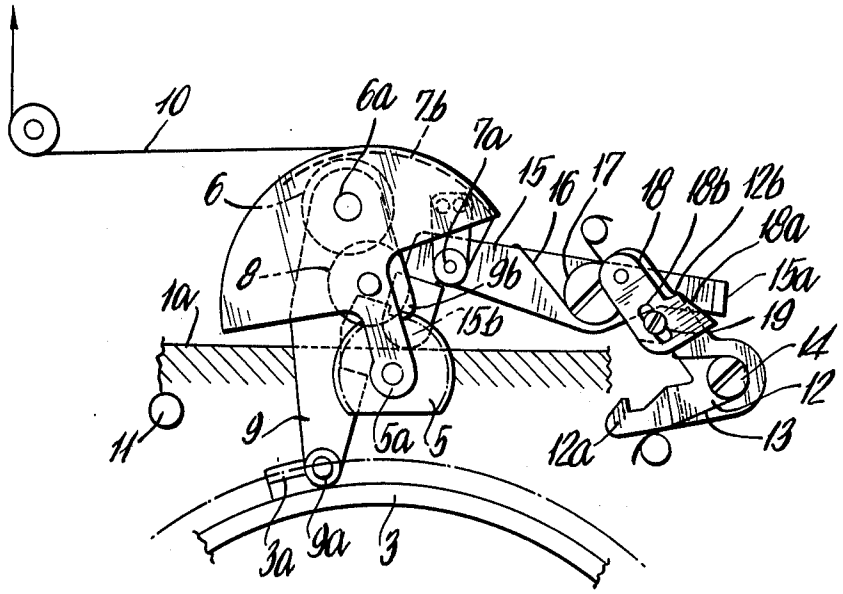
12
9
9b
7
20a
13
20
9a

Fig. 2.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9a
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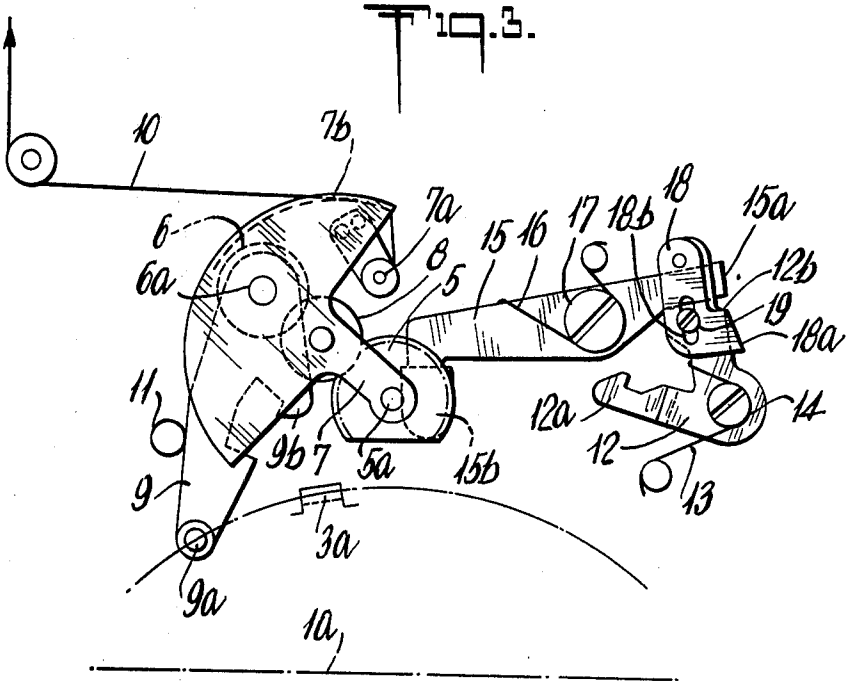
Fig. 3.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9b
7
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15b
12
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13
3a
9a
1a

Fig.4.

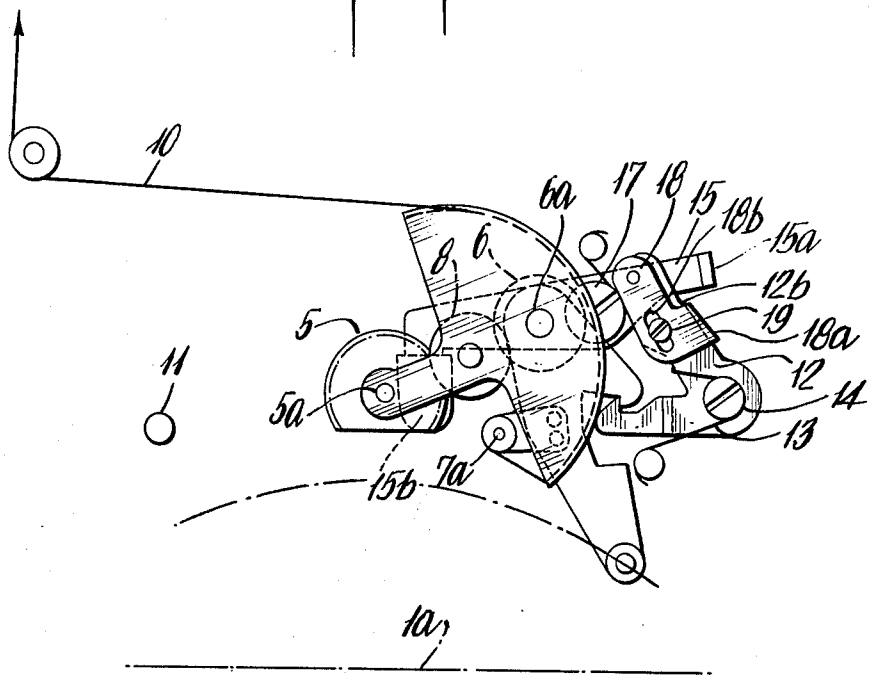


Fig.5.

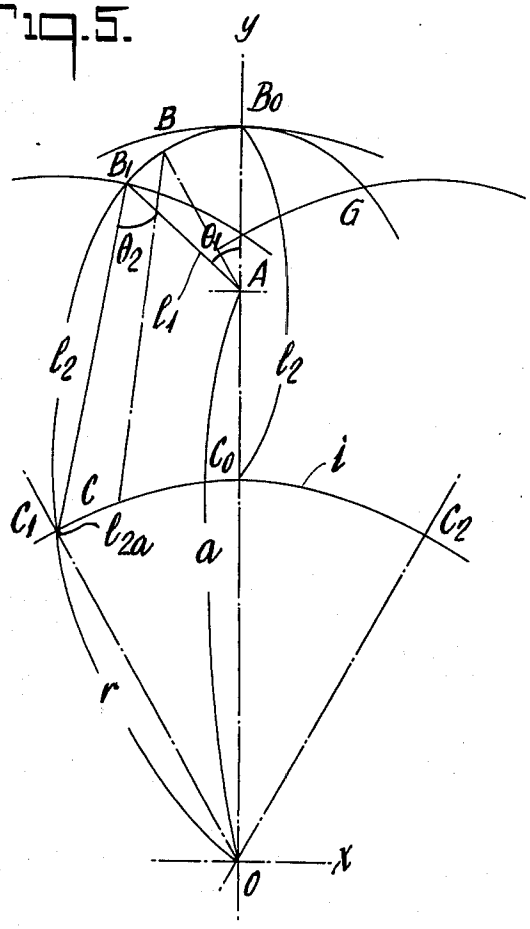
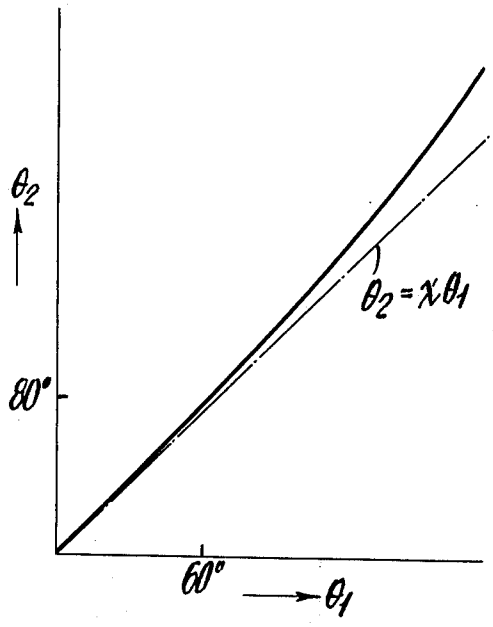


Fig.6.



INTERCHANGEABLE OBJECTIVE LENS DIAPHRAGM EXPOSURE CONTROL COUPLING MECHANISM

BACKGROUND OF THE INVENTION

The present invention relates to improvements in diaphragm coupling or interlock devices for use in an interchangeable lens type camera, by which the aperture value set by the lens diaphragm setting member which operates to preset the diaphragm aperture in the interchangeable lens, is transmitted to an exposure control mechanism located in the camera body.

Among the known interlocking devices of the present type is one which is provided with a coupling element secured to a diaphragm setting ring which is rotatable relative to the interchangeable objective lens barrel, and a pantograph mechanism which may be interlocked with the coupling element, or one which is provided with a pin engageable with the coupling element and an arcuate rail concentric with the center of rotation of the coupling element.

However, both the pantograph mechanism and the arcuate rail occupy considerable space, and thus considerably increase the size and bulk of the camera. In addition, great difficulties are encountered in the connection of an exposure control mechanism which is mounted in a finder casing removable from a camera body. Furthermore, the pin engaged with the rail has to slidingly rotate relative to the camera body or relative to the finder casing on the camera body, so that a smooth rotation in association with the movement of the diaphragm setting ring is not achieved.

SUMMARY OF THE INVENTION

It is a principal object of the present invention to provide a diaphragm interlocking or coupling device for use in an interchangeable lens type camera, in which a connecting member moves in accordance with the extent of displacement of the diaphragm setting member of an interchangeable lens and the displacement of the connecting member is transmitted as an aperture value to an exposure control mechanism.

It is another object of the present invention to provide a diaphragm interlocking device for use in a lens interchangeable type camera, in which a connecting member which is connectable with the diaphragm setting member of an interchangeable objective lens is secured to a revolving member which revolves around a fixed member and rotates about its own axis, thereby reducing the space occupied by the diaphragm interlocking mechanism housed in the camera body, contributing to a compact camera size and affording a smooth operation of the diaphragm interlocking device.

It is a further object of the present invention to provide a diaphragm interlocking device for use in an interchangeable objective lens type camera, in which, even if the diaphragm interlocking device is provided within an interchangeable pentaprism viewer removeable from the camera body, the extent of manipulation of the diaphragm setting member may be positively transmitted to an exposure control means.

The above and other objects and features of the present invention may be readily attained in a diaphragm interlocking device of the type described, which comprises a fixed member provided on the body of a camera, a revolving member which revolves around the fixed member and rotates on its own axis, a connecting member secured to the revolving member and connectable with a diaphragm setting member of an interchangeable lens, and means for transmitting the displacement of the connecting member to an exposure control means.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a perspective view, partly broken away, of the essential parts of one embodiment of the present invention;

FIG. **2** is a front elevational view of the coupling mechanism of the embodiment of FIG. **1**, showing the interchangeable lens and the finder casing properly mounted on the body of the camera;

FIG. **3** is a front view of the coupling mechanism, showing the finder casing removed from the camera body;

FIG. **4** is a front view of the coupling mechanism, showing the condition of the mechanism set for properly mounting the finder casing to the camera body;

FIG. **5** is a diagram illustrating the operation of the coupling mechanism;

FIG. **6** is a diagram showing the relationship between an angle θ_1 and an angle θ_2; and

FIG. **7** is a front view of another embodiment of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to the drawings, particularly FIGS. **1** to **4** thereof which illustrate a preferred embodiment of the present invention, the reference numeral **1** generally designates a camera body which is provided with an objective lens barrel **2** interchangeably mounted thereon and a finder casing **4** removeably mounted on the camera body in communication with the objective lens.

When the interchangeable objective lens **2** and the finder casing **4** are properly mounted on the camera body **1**, a coupler element or pawl **3***a* affixed to a diaphragm setting ring **3**, which is rotatable relative to the lens barrel, is engageable with an engaging or coupling pin **9***a* located on a connecting member **9** which will be hereinafter described, the connecting member **9** being disposed within the finder casing **4**.

A fixed or stationary gear **5** is rigidly mounted on the finder casing **4** and is substantially housed therein. A rotatable gear **6** is drive coupled by way of an idle gear **8** to the fixed gear **5**. A sector member or arm **7** is pivoted to a pivot **5***a* which is mounted at the center of the fixed gear **5**. The revolving gear **6** and idle gear **8** are both pivoted to the sector arm **7** by means of a pivot **6***a* and a pivot **8***a*, respectively. Accordingly, when the revolving gear **6** revolves together with the sector arm **7** around the fixed gear **5**, the gear **6** rotates on its axis **6***a*. The gear ratio of the gear **6** to the fixed gear **5** is set to a ratio which will be hereinafter described.

A flexible wire or line **10** has one end thereof secured to the sector arm **7** by means of a fastening piece **7***a* and extends along a cam groove **7***b* formed in the peripheral portion of the sector arm **7**, the other end of the line **10** being connected to an exposure control means which is provided within the finder casing. The line **10** is normally pulled in a direction toward the exposure control means, thereby resiliently loading or biasing the sector arm **7** so as to rotate in the counterclockwise direction.

A connecting arm or member **9** is secured at one end to the revolving gear **6** and is formed with an engaging pawl **9***b* at one edge thereof and is provided at its opposite end with an engaging pin **9***a* engageable with the coupler pawl **3***a*.

With the coupler pawl **3***a* in engagement with the engaging pin **9***a*, when the diaphragm setting ring **3** is rotated in the clockwise direction, then the coupler pawl **3***a* urges the engaging pin **9***a* in the same direction. This causes gear **6** to rotate on its axis in the counter-clockwise direction, so that it revolves in the clockwise direction around the fixed gear **5** by way of the idle gear **8,** and the sector arm **7** rotates in the clockwise direction about the pivot **5***a* to pull the wire **10** opposite to the direction in which the wire is spring drawn. On the other hand, when the diaphragm setting ring is rotated in the counter-clockwise direction, then the tendency of the wire to be pulled under the spring influence rotates the sector arm **7** in the counter-clockwise direction, so that the gear **6** revolves about gear **5** in the counter-clockwise direction, but rotates in the clockwise direction on its own axis, and the engaging pin **9***a* follows the coupler pawl **3***a*. As is clear from the foregoing, the clockwise and counter-clockwise rotations of the setting ring **3** draws the wire **10** against the spring pull thereon and pays out the wire **10,** respectively, thereby transmitting diaphragm aperture information to the exposure control means.

A pin **11** serves as a stop which limits the clockwise rotation of the connecting member **9** due to the spring influence on wire **10** when the engaging pin **9***a* is disengaged from the coupler pawl **3***a*.

For transmitting the aforesaid operation to the exposure control means irrespective of the aperture value set by the setting ring **3,** it is necessary that the coupler pawl **3***a* and the engaging pin **9***a* maintain an engaging relationship, independently of the position of the revolving gear **6.** Furthermore, for maintaining the aforesaid relationship, it is necessary that a predetermined gear ratio be maintained between the fixed gear **5** and the revolving gear **6,** as has been earlier set forth.

Now, a more detailed description will be given of the aforesaid gear ratio relationship, by referring to FIGS. **5** and **6.** In FIG. **5,** the point O represents the center of rotation of the coupler pawl **3***a*, and the coupler pawl **3***a* follows an arc *i* having a radius *r* (OC_1, OC, OC_0, OC_2) about the center O; the pivot **5***a* of the fixed gear **5** is shown at point A; the revolving radius of the revolving gear **6** has a length l_1 (AB_1, AB, AB_0); the distance between the pivot **6***a* on the connecting member **9** and the engaging pin **9***a* is represented as a length l_2 (B_1C_1, BC, B_0C_0); the revolving angle of the revolving gear **6** is represented as an angle θ_1, i.e., the rotational angle of the sector arm **7;** the rotating angle of the revolving gear **6** on its axis is represented as an angle θ_2; and the distance from the center of rotation to the pivot **5***a* of the fixed O **5** is represented as a length *a*.

Still referring to FIG. **5,** suppose a four joint link consisting of four link members $\overline{OA}$ (*a*), $\overline{AB}$ (l_1), $\overline{BC}$ (l_2), $\overline{CO}$ (*r*), then

$$a + l_1 = l_2 + r$$

wherein the link member $\overline{OA}$ is a fixed link member, assume the point O which is the original point of the coordinates, fixed link $\overline{OA}$ which is represented by the y axis, and the intersection B_0 of the link $\overline{AB}$ with the *y* axis, and

$$< BAB_0 = \theta_1$$

$$< ABC = \theta_2,$$

then the point C (X_c, Y_c) is given as follows:

$$X_c = l_1 \sin \theta_1 + l_2 \sin (\theta_2 - \theta_1) \quad (1)$$

$$Y_c = d + l_1 \cos \theta_1 - l_2 \cos (\theta_2 - \theta_1)$$

Thus,

$$\gamma^2 = X_c^2 + Y_c^2 = d^2 + l^2 + l_2^2 + Zdl_1, \cos \theta_1 - Zl_1 l_2 \cos \theta_2 - 2dl_2 \cos (\theta_2 - \theta_1) \quad (2)$$

When the relationship between θ_1 and θ_2 is determined by selecting *r*, *a*, l_1, l_2 at suitable values, the relationship shown by the solid line in FIG. **6** may be obtained. As is clear from FIG. **6,** if the angle θ_1, remains within a certain angular range, the aforesaid relationship approximates the following linear relationship:

$$\theta_2 = \lambda\theta_1$$

This demonstrates that, even if the aforesaid four joint link is devoid of the link member $\overline{OC}$, the tip C_{BC} of the arm $\overline{BC}$ will describe an arc approximately the arc described by the tip C_{OC} of the link member $\overline{OC}$, if the relationship $\theta_2 = \lambda\theta_1$ is maintained. This further indicates that, for defining the arc described by the coupler pawl **3***a* commensurate with the diaphragm setting as being an arc C_1C_2 within a given rotational angle as well as for causing the engaging pin **9***a* of the connecting member **9** to move within the locus approximating the aforesaid arc C_1C_2, the gear ratio Z1/Z2 of the fixed gear **5** to the revolving gear **6** should be $\lambda = \theta_2/\theta_1$, i.e., $\lambda = \theta_2/\theta_1 = Z_1/Z_2$,

In addition to the aforesaid relationship, since the interchangeable lens **2** and finder casing **4** are both removeable from the camera body **1,** when the interchangeable lens **2** and finder casing **4** are both mounted on the camera body **1,** the relationship between the coupler pawl **3***a* and the engaging pin **9***a* should be such that the pin **9***a* engages the righthand portion of the coupler pawl **3***a*, as shown in FIG. **2.** Conversely, when the relationship of the both members are reversed as shown in FIG. **3,** then there results a failure to transmit an aperture value set by the diaphragm setting ring **3** to the exposure control means by means of the wire **10.** To avoid the aforesaid failure, the present embodiment permits proper mounting of the finder casing **4** on the camera body **1** in the case as shown in FIG. **3.**

Specifically, an angular locking lever **12** is pivoted at its elbow on the finder casing by means of a shaft **14** and loaded by means of a spring **13** so as to be biased to rotate in the clockwise direction. The locking lever **12** has formed on one arm a locking pawl **12***a* which is engageable with an engaging hook **9***b* and on its other arm with a shoulder portion **12***b*. A guide screw **19** is positioned on the locking pawl **12.**

An adjusting member **18** is provided with a guide groove **18***b*, with which the guide screw **19** is engaged, and the adjusting member **18** is rigidly fixed, with its position being adjusted in the lengthwise direction. The adjusting member **18** is formed with a slope **18***a* positioned on the same side of the pivot **14** as the shoulder portion **12***b*.

A selecting lever **15** is pivoted on the finder casing by means of a pivot **17** and is loaded by a spring **16** so as to be biased to rotate in the counter-clockwise direction. The selecting lever **15** has formed on one arm a bent piece which is engageable with the shoulder portion **12***b*, and a projecting portion **15***b* projects downwards from the other arm thereof.

As shown in FIG. **3**, the bent piece in engagement with the shoulder portion **12***b* stops the clockwise rotation of the selecting lever **15** against the action of the spring **16**. On the other hand, as shown in FIG. **4**, when the aforesaid engagement is released, then the selecting lever **15** is allowed to rotate in the clockwise direction. However, when the selecting lever **15** is rotated in the clockwise direction against the action of the spring **16**, then the bent piece **15***a* will engage the slope **18***a*, thereby rotating the locking lever **12** in the counter-clockwise direction against the action of the spring **13**.

Shown at **1***a* is a base plate which is provided within the camera body **1** and adapted to engage the aforesaid projecting portion **15***b*, when the finder casing **4** is mounted on the camera body **1**.

As shown in FIG. **3**, when the finder casing **4** is to be mounted on the camera body **1**, with the bent piece **15***a* in engagement with the shoulder portion **12***b*, then the projecting portion **15***b* will abut the base plate **1***a* so that the clockwise rotation of the selecting lever **15** is interrupted. Thus, the finder casing is prevented from being mounted on the camera body **1**.

When the connecting member **9** is rotated in the counter-clockwise direction against the spring loaded pull of the wire **10**, and hence the sector arm **7** is rotated in the clockwise direction manually, then the engaging pawl **9***b* will engage the locking pawl **12***a* at its final step of the rotation, so that the locking lever **12** is rotated in the counter-clockwise direction against the action of the spring **13**, and the shoulder portion **12***b* will be retracted from the bent piece **15***a*, and thus the engagement of both will be released. As a result, when the projecting portion **15***b* abuts the base plate **1***a*, with the finder casing **4** being mounted on the camera body **1**, then the selecting lever **15** is rotated in the clockwise direction, and the projecting portion **15***b* is moved upwards, so that the finder casing **4** may be properly mounted on the camera body **1**. The bent piece **15***a* which rotates in the clockwise direction will engage the slope **18***a* to thereby advance the same so that the engaging pawl **9***b* is disengaged from the locking pawl **12***a*. Accordingly, the connecting member **9** is rotated in the clockwise direction under the pulling force of the wire **10**, while its engaging pin **9***a* engages the righthand portion of the coupler pawl **3***a*, as shown in FIG. **2**.

The aforesaid arrangement completely prevents the finder casing **4** from being mounted on the camera body **1** in a manner that the engaging pin **3***a* is positioned on the lefthand side of the coupler pawl **3***a*, as shown in FIG. **3**.

FIG. **7** shows another embodiment of the present invention in which the gear meshing arrangement of the first embodiment is replaced by a fixed pulley **20** and a belt **22** trained therearound, and about a revolving member **21** which rotates about the center pivot **20***a* of the fixed member **20**. Specifically, the pulley **20** which is affixed to the finder casing takes over the place of and defines the fixed member. In addition, there is provided a sector arm **7** which is identical to that shown in the first embodiment and which is rotatable about the center pivot. Furthermore, the manner in which the wire **10** is secured to the fastening metal piece **7***a* of the sector arm **7** is the same as that in the first embodiment. The pulley **21** serving as a revolving member is pivoted on the sector arm **7** by means of a pivot **21***a*. Journalled on the pivot **21***a* is a connecting member **9** which rotates integrally with the revolving pulley **21**. A belt **22** is trained around the revolving pulley **21** and fixed pulley **20**, so that the revolving pulley **21** may be revolved about the pivot **20***a* around the fixed pulley **20** and rotates on its own axis. The other structural details of the present arrangement are the same as those shown in the first embodiment.

In the last described embodiment as well, when the interchangeable lens **2** and the finder casing **4** are properly mounted on the camera body **1**, the engaging pin **9***a* of the connecting member **9** should maintain the engaging relationship with the righthand portion of the coupler pawl **3***a*. In this case, the following relationship may be obtained. $\lambda = \theta_2/\theta_1 = Z/Z_2$ at the gear ration of Z_1/Z_2 of the fixed gear **5** to the revolving gear **5** in the first embodiment, and number of teeth $Z = D/m$, thus

$$\lambda = \theta_2/\theta_1 = Z_1/Z_2 = D_1/D_2,$$

wherein $D = a$ diameter, m= module, $D_1 = a$ diameter of the fixed pulley **20**, and $D_2 = a$ diameter of the revolving pulley **21**.

In other words, even if the fixed gear is replaced by the fixed pulley and the revolving gear is replaced by the revolving pulley, there remains no difference in principle. Thus, it suffices that a specific relationship between the both only be maintained when replacing the gear ratio λ in the first embodiment with the diameter ratio.

While in the aforesaid embodiments there is shown a pentaprism view of the interchangeable type, even if the viewer is of a fixed type, the extent of manipulation of the diaphragm setting member may positively be transmitted to the exposure control means. In addition, the present invention is not intended to limit the arrangement as far as such compensation is effected during the time in which the extent of rotation of the diaphragm setting member is transmitted to the final exposure control means.

While there have been described and illustrated preferred embodiments of the present invention, it is apparent that numerous alterations, omissions and additions may be made without departing from the spirit thereof.

I claim:

1. A lens interchangeable type camera including a camera body, an objective lens interchangeably mounted on said camera body and having a rotatable diaphragm ring, and a finder housing, comprising:

an exposure control means;

a fixed member disposed in said camera;

a revolving member rotatable around said fixed member through an interlocking means and rotatable about its own axis;

a connecting member having one end connected to and rotatable with said revolving member and its other end connectable with said diaphragm ring and moveably interlocking with the movement of said diaphragm ring for moving said diaphragm ring;

a transmitting means for transmitting the movement of said revolving member to said exposure control means; and

an arm member rotatably pivoted at one end to said fixed member, said revolving member being pivoted to said arm member.

2. The camera as set forth in claim **1** wherein said arm member includes a sector shaped section, a peripheral portion of said sector shaped section defining a cam forming part of said transmitting means.

3. The camera as set forth in claim **1** including a shaft rotatably mounting said revolving member and said connecting member to said arm member.

4. The camera as set forth in claim **1** wherein said finder housing is interchangeable, and said exposure control means, said fixed member, said revolving member, said connecting member and said transmitting means are disposed in said finder housing.

5. The camera as set forth in claim **1** wherein said fixed member and said revolving member comprise a fixed gear and a revolving gear respectively, and said interlocking means comprises an interlocking gear meshed with said fixed gear and said revolving gear.

6. The camera as set forth in claim **1** wherein said fixed member and said revolving member comprise a fixed pulley and revolving pulley respectively, and said interlocking means comprises a belt trained around said fixed pulley and revolving pulley.

7. In a camera including an interchangeable objective lens having a diaphragm control ring and an adjustable exposure control device, a mechanism for transmitting the angular position of said diaphragm control ring to said exposure control device comprising a first gear rotatable about a first axis thereof and swingable about a second axis parallel to and offset from said first axis, means including a second gear coaxial with said second axis and a mounting arm swingable about said second axis and rotatably supporting said first gear and means drive coupling said first gear to said second gear for rotating said first gear about its first axis in response to its swinging about said second axis, a connector arm having one end connected to said first gear and being rotatable and moveable therewith and an opposite end coupled to and moveable with said diaphragm control ring and motion transmission means connecting said first gear to said exposure control device.

8. A lens interchangeable type camera including a camera body, an objective lens interchangeably mounted on said camera body and having a rotatable diaphragm with a coupler pawl, and a finder housing, comprising,

an exposure control means;

a fixed gear disposed in said camera;

a revolving gear rotatable around said fixed gear and revolvable about its own axis, and an interlocking gear intercoupling said fixed and revolving gears;

a connecting member having one end connected to said revolving gear and being moveable with said revolving gear and its other end connectable with said coupler pawl of said diaphragm ring and moveably interlocking with the movement of said diaphragm ring for moving said revolving gear;

a mounting arm swingable about said fixed gear and rotatably supporting said revolving gear and interlocking gear; and

a transmitting means for transmitting the movement of said revolving gear to said exposure control means.

9. The camera of claim **8** wherein said mounting arm includes a sector shaped section, a peripheral portion of said sector shaped section defining a cam forming part of said transmitting means.

10. The camera of claim **8** including a shaft rotatably mounting said revolving gear and said connecting member to said connecting arm.

11. The camera of claim **8** wherein said finder housing is interchangeable, and said exposure control means, said fixed gear, said revolving gear said connecting member and said transmitting means are disposed in said finder housing.

* * * * *

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Reinsch et al.

[11] 3,957,355
[45] May 18, 1976

[54] **OBJECTIVE SYSTEM WITH ZOOM LENS FOR MOTION PICTURE CAMERAS**

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[73] Assignee: **Robert Bosch G.m.b.H.**, Stuttgart, Germany

[22] Filed: **Nov. 18, 1974**

[21] Appl. No.: **524,930**

[30] **Foreign Application Priority Data**

Nov. 23, 1973 Germany 2358345

[52] **U.S. Cl.** **350/187;** 350/255
[51] **Int. Cl.²** **G02B 15/18;** G02B 7/10
[58] **Field of Search** 350/187, 255

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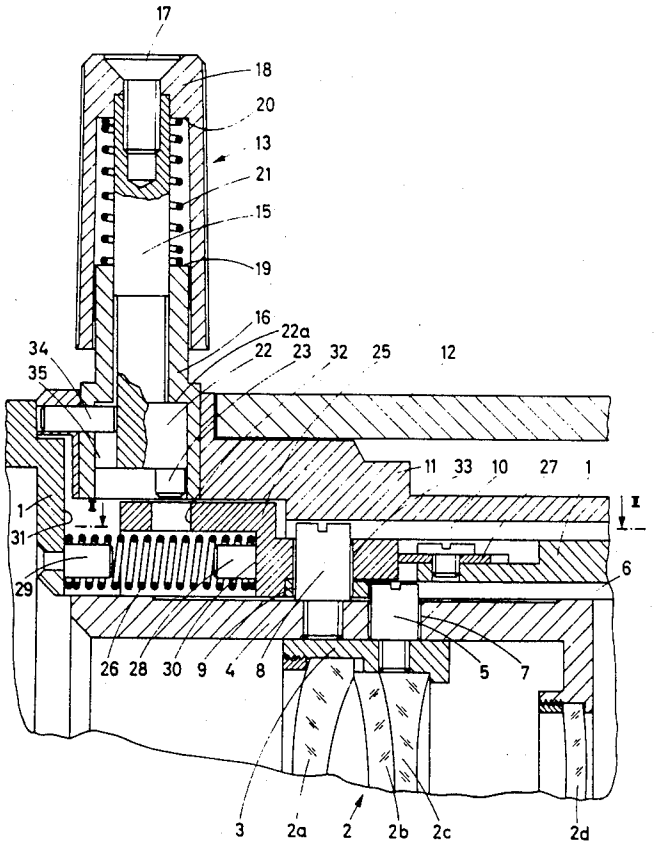
Primary Examiner—Paul A. Sacher
Attorney, Agent, or Firm—Michael J. Striker

[57] **ABSTRACT**

An objective system for motion picture cameras wherein the focal length of a zoom lens is variable by rotating a ring-shaped selector about the optical axis through the medium of a radially extending handle, and focussing prior to the making of exposures at close range is effected by rotating the handle about its own axis. Prior to rotation of the handle about its axis, the selector must be moved to an angular position corresponding to the shortest focal length of the lens and the handle is thereupon depressed radially inwardly against the opposition of a spring so that an eccentric pin at its inner end enters a socket in a slide which is reciprocable in the lens barrel and is coupled to a sleeve for the optical elements of the lens by means of a follower which also serves to couple the sleeve to the selector. The handle can be depressed in a single angular position and can be moved outwardly to become disengaged from the slide only after it reassumes the single angular position. The selector may be completely or nearly completely concealed in the interior of a tubular extension of the front wall of the camera body.

16 Claims, 2 Drawing Figures



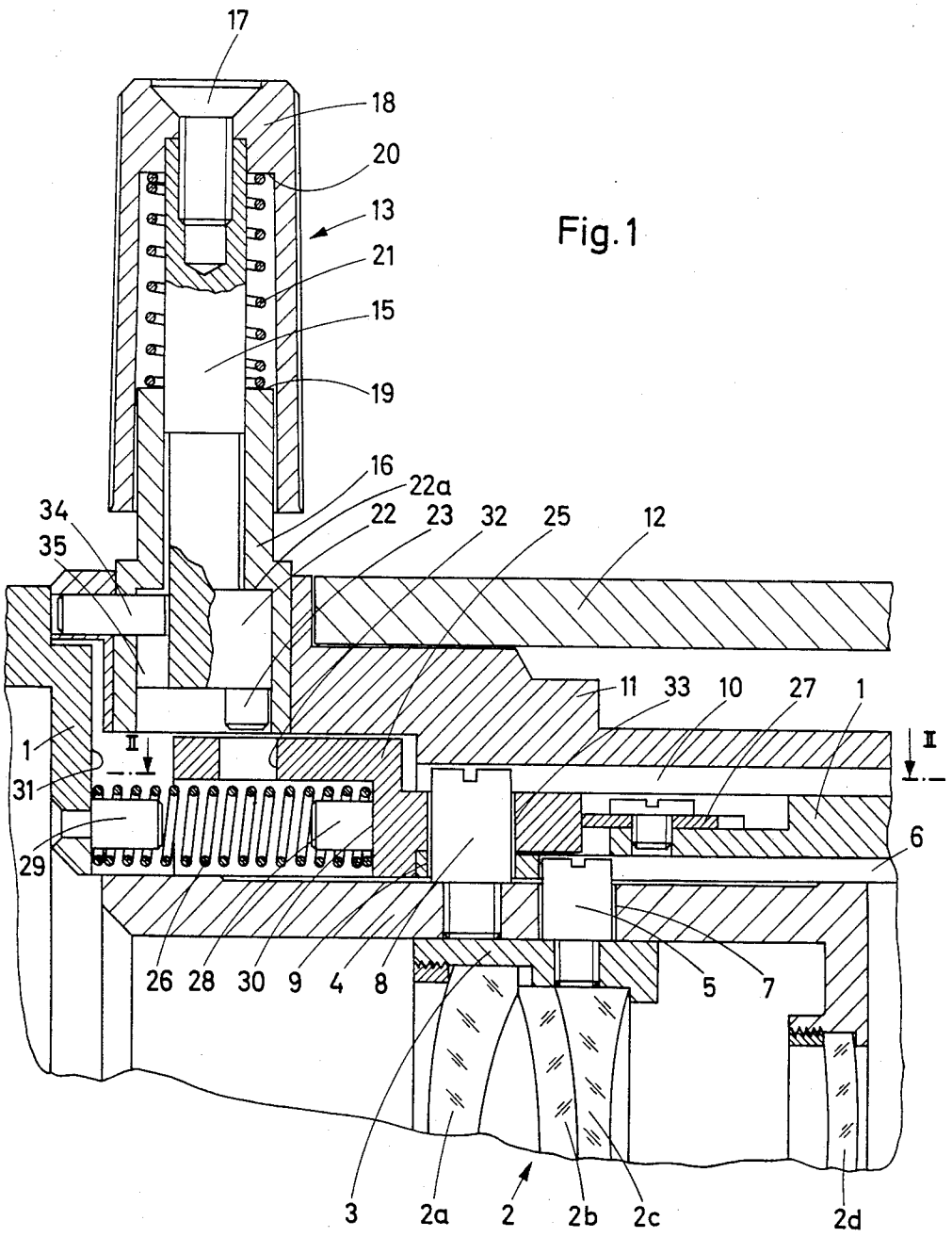

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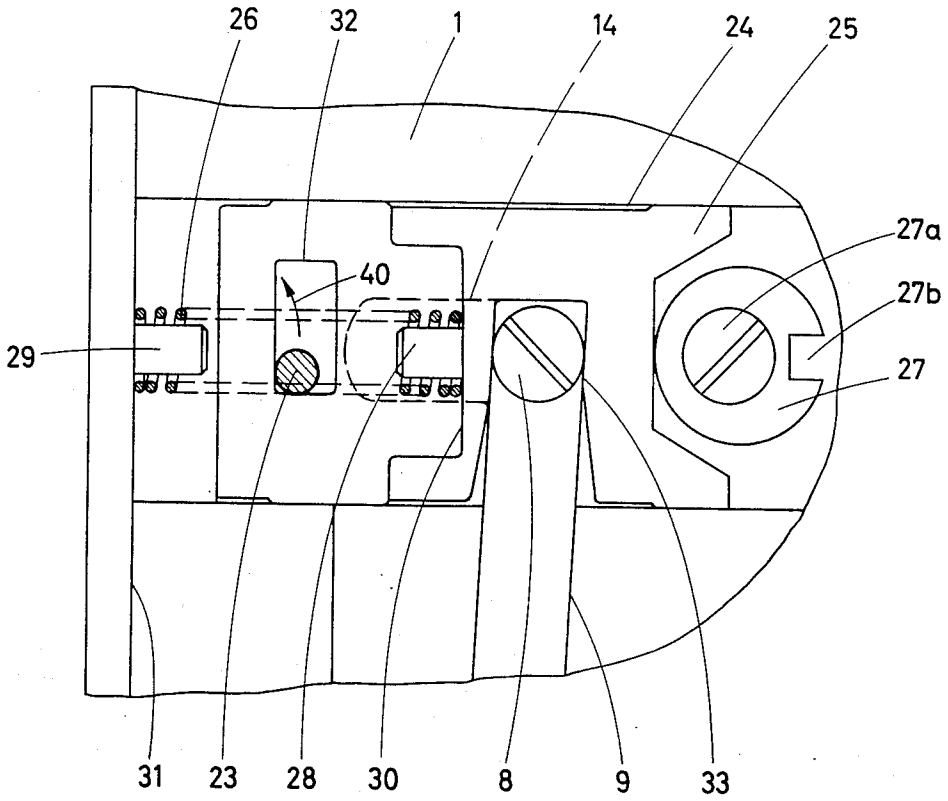
Fig.1

Fig. 2



OBJECTIVE SYSTEM WITH ZOOM LENS FOR MOTION PICTURE CAMERAS

CROSS-REFERENCE TO RELATED APPLICATION

Certain features of our objective system are disclosed in the commonly owned copending application Ser. No. 505,601 filed Sept. 12, 1974 by Reinsch and Körner.

BACKGROUND OF THE INVENTION

The present invention relates to objective systems for photographic apparatus, and more particularly to improvements in objective systems which comprise variable-focus or zoom lenses. Still more particularly, the invention relates to objective systems having variable-focus lenses and means for focussing during the making of exposures at close range or at a greater distance (including infinity) from the subject. As used in the specification and claims, the term "objective system" is intended to denote a variable-focus lens, a tubular barrel or mount for the lens, and means for moving selected optical elements of the lens with respect to the barrel in the direction of the optical axis.

It is already known to provide an objective system for use in motion picture cameras with a variable-focus lens and with a rotary ring-shaped selector which can be displaced by means of a radially extending handle. When the handle is moved in a direction to rotate about the optical axis, the selector changes the focal length of the lens. In order to enable the selector to allow for focussing at close range, the handle is moved in the direction of the optical axis whereby such movement of the handle does not influence the positions of the optical elements but merely serves to disengage the selector from a further ring-shaped member which is connected with the optical elements of the lens. When the axial movement of the selector with the handle **1** is completed, the selector is rotated again to thereby focus prior to the making of exposures at close range. Such rotation causes a predetermined axial adjustment of certain optical elements of the lens.

It is further known to provide an objective system which includes a variable-focus lens with a selector which is rotatably and axially movably mounted on the barrel for the optical elements. When the selector is rotated in one axial position, it changes the focal length of the lens. Rotation of the selector in another axial position results in focussing prior to the making of exposures at close range.

Each of the just described prior solutions employs a single selector which must be rotated for the purpose of changing the focal length as well as for the purpose of focussing at close range. As a rule, the selector must be provided with a relatively wide annular knurled portion so that it may be readily gripped and conveniently manipulated by the user prior to and/or during picture taking. This is not possible when the selector is relatively small (e.g., if the manufacturer wishes to reduce the overall dimensions of the photographic apparatus) and/or when the selector is partly or nearly fully concealed in a forwardly extending part (e.g., a sleeve) of the camera body. In such instances, the selector is invariably provided with a radially extending handle which replaces the aforementioned knurled portion and enables the user to move the selector axially and/or about the axis of the lens.

SUMMARY OF THE INVENTION

An object of the invention is to provide an objective system for photographic apparatus, especially for motion picture cameras, wherein the optical elements of the variable-focus lens can be moved by novel and improved means which facilitates convenient manipulation even if the diameter of the selector (which forms part of such moving means) is very small and/or if the selector is fully or nearly fully concealed in the body of the photographic apparatus.

Another object of the invention is to provide the objective system with a versatile handle which facilitates the shifting of selected optical elements of the variable-focus lens with and/or relative to the selector.

A further object of the invention is to provide the objective system with novel and improved means for moving selected optical elements of the variable-focus lens for the purpose of focussing prior to the making of exposures at close range.

An additional object of the invention is to provide novel and improved motion transmitting connections between the handle for a ring-shaped selector and the optical elements of the variable-focus lens in the objective system of a motion picture camera. The objective system of the present invention comprises a tubular barrel, a variable-focus picture taking lens having a variator system including a plurality of optical elements disposed in the barrel one behind the other and being movable axially of the barrel to thereby focus the image of a subject (preferably at close range) and to change the focal length of the lens, and novel and improved means for moving the optical elements. Such moving means includes a handle which extends outwardly (preferably radially outwardly) from the barrel and is movable in a first direction about the optical axis of the lens (i.e., about the barrel) and in a different second direction (preferably about an axis extending radially of the barrel), first motion transmitting means for moving the optical elements in response to movement of the handle in the first direction to thereby change the focal length of the lens, and second motion transmitting means for moving the optical elements in response to movement of the handle in the second direction to thereby focus the image of a subject.

The first motion transmitting means may comprise a ring-shaped selector which comprises a sleeve or an analogous carrier or holder for the handle, a sleeve which is mounted in the barrel and surrounds the optical elements of the lens, and means (e.g., a follower) for connecting the selector with the sleeve. The second motion transmitting means preferably comprises a slide which is reciprocable in parallelism with the optical axis in guide means provided therefor in the barrel, a coupling which can connect the slide to the handle in response to movement of the handle substantially radially of the barrel from a first to a second position, and means for connecting the slide to the aforementioned sleeve in the barrel. Such connecting means may constitute the aforementioned follower which couples the sleeve to the slide in a predetermined angular position of the selector.

The novel features which are considered as characteristic of the invention are set forth in particular in the appended claims. The improved objective system itself, however, both as to its construction and its mode of operation, together with additional features and advantages thereof, will be best understood upon perusal of

the following detailed description of certain specific embodiments with reference to the accompanying drawing.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a fragmentary axial sectional view of an objective system with zoom lens and a handle which embodies the invention; and

FIG. 2 is a fragmentary view substantially as seen in the direction of arrows from the line II—II of FIG. 1.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. 1 shows an objective system which comprises a tubular barrel or mount 1 fixedly mounted in the body of a motion picture camera. The barrel 1 contains a variable-focus picture taking lens or zoom lens having two groups of optical elements including a front group (not shown) and a rear group or variator system 2 including four discrete optical elements 2*a*, 2*b*, 2*c* and 2*d*. The optical elements 2*a*–2*d* of the group 2 are disposed one behind the other, as considered in the direction of the optical axis, and are movable axially of the barrel 1 in order to adjust the focal length of the lens as well as for the purpose of focussing prior to the making of close-up shots. The front group of optical elements is shown at 3 in the copending application Ser. No. 505,601. Such front group can be moved axially by rotating the selector 16 of Ser. NO. 505,601 which selector is coupled to the ring 150 of Ser. No. 505,601. The threads of the ring 150 of Ser. No. 505,601 mesh directly with the barrel 1 of our objective system. Thus, the intermediate rings 18 and 19 of Ser. No. 505,601 can be omitted. Reference may also be had to U.S. Pat. No. 3,259,044 to MacMillin et al. which discloses a suitable adjusting device for the front group of optical elements in a variable-focus lens.

The optical elements 2*a*–2*c* are fixedly mounted in a ring 3 which is axially movably installed in a sleeve 4. The sleeve 4 is rotatable in the barrel 1 to thereby effect a movement of the ring 3 and optical elements 2*a*–2*c* in the direction of the optical axis of the picture taking lens. The ring 3 receives motion from a follower here shown as a screw 5 whose head extends through a cam slot 7 in the sleeve 4 and into a longitudinally extending guide groove 6 in the internal surface of the barrel 1. The rearmost optical element 2*d* of the variator system 2 is mounted directly in the rearmost portion of the sleeve 4. The sleeve 4 is further threadedly secured to a connecting means or follower 8 which extends radially outwardly in the region of the optical elements 2*b*, 2*c* so that its outermost portion projects into and is movable lengthwise of an internal groove 10 of a ring-shaped motion-transmitting selector 11. The selector 11 is rotatably mounted on the barrel 1 and its internal groove 10 is parallel to the optical axis of the lens. An intermediate portion of the follower 8 extends through an arcuate cam slot 9 of the barrel 1. The major portion of the selector 11 is confined in a tubular extension or sleeve 12 of the front wall (not shown) of the camera body. The means for rotating the selector 11 about the barrel 1 comprises a novel handle 13 which extends radially outwardly at the front end of the extension 12.

When the handle 13 is grasped by hand and is caused to rotate the selector 11 about the barrel 1, i.e., about the optical axis, the cam slots 7 and 9 cause the ring 3 and the optical elements 2*a*–2*d* of the variator system 2 to move in the direction of the optical axis in accordance with a predetermined pattern which is calculated to establish desirable optical characteristics of the lens. The optical element 2*d* rotates with the sleeve 4 but the optical elements 2*a*–2*c* merely move in the axial direction of the barrel 1 because the outer end portion of the follower 5 extends into the groove 6. The shortest focal length is selected when the followers 5 and 8 assume the illustrated positions, namely when the ring 3 (with the optical elements 2*a*–2*c*) is located at a maximum distance from the optical element 2*d*.

The barrel 1 is formed with an internal groove 14 (FIG. 2) which extends in parallelism with the optical axis and communicates with the cam slot 9. The groove 14 permits axial movements of the variator system 2 for the purpose of focussing prior to the making of close-up shots when the focal length of the lens has been reduced to a minimum value. The follower 8 is then in register with the slot 14 (as shown in FIG. 2) so that the sleeve 4 can be moved forwardly. During such movement of the sleeve 4 (i.e., when the follower 8 moves in the groove 14 of the barrel 1), the distance between the optical elements 2*a*–2*c* and 2*d* remains unchanged. The just described movement of the sleeve 4 is effected by rotating the handle 13 about its own axis. In addition, the handle 13 is movable axially, i.e., radially of the extension 12, selector 11 and barrel 1, between a first or extended position and a second or depressed position.

The handle 13 comprises a shaft 15 which is rotatably and axially movably mounted in a sleeve-like guide or carrier 16 of the selector 11. The outer end portion of the shaft 15 has a tapped bore for the shank of a screw 17 serving as a means for fastening the shaft 15 to a cupped handgrip portion 18 which surrounds the carrier 16. The outer end face 19 of the carrier 16 constitutes a retainer for the inner end convolution of a helical spring 21 which bears against an annular internal shoulder 20 of the handgrip portion 18 and serves to urge the shaft 15 to the extended position, i.e., away from the extension 12. The extended positions of the shaft 15 and handgrip portion 18 are shown in FIG. 1.

The inner end portion 22 of the shaft 15 has a larger diameter and constitutes a cylindrical plunger which is rotatable and axially movable in a counterbore at the inner end of the carrier 16. The inner end face of the plunger 22 has an eccentric projection or pin 23 which constitutes a first coupling means and can be introduced into a complementary second coupling means here shown as a socket or aperture 32 provided in a motion transmitting slide 25. The projection or pin 23 can enter the socket 32 in response to deformation of the spring 21. The slide 25 can transmit motion from the handle 13 (and more particularly from the shaft 15 and handgrip portion 18) to the optical elements 2*a*–2*d* of the variator system 2.

As shown in FIG. 2, the slide 25 is reciprocable in a guide groove 24 which is machined into the internal surface of the barrel 1 and is parallel to the optical axis of the lens. This slide is located inwardly of the groove 14 and is biased rearwardly (i.e., in a direction to the right, as viewed in FIG. 1 or 2) by a helical spring 26 which reacts against the foremost portion of the barrel 1; this foremost portion of the barrel has a radially extending surface 31 against which the foremost convolution of the spring 26 abuts. Furthermore, the surface 31 is formed with a projection or post 29 which is surrounded by the foremost convolutions of the spring

26. The rearmost convolutions of the spring 26 surround a similar projection or post 28 extending forwardly from a crosshead 30 of the slide 25. The spring 26 urges the slide 25 to a predetermined starting position in which the rear end of the slide abuts against an adjusting device here shown as a disk 27 which is eccentrically mounted on the shank of a screw 27*a* secured to the barrel 1. The angular position of the adjusting disk 27 (and hence the starting position of the slide 25 in the groove 24) can be changed by inserting a suitable tool into a peripheral notch 27*b* of the disk 27 and by thereupon turning the disk about the axis of the screw 27*a*. The slide 25 normally abuts against the disk 27 under the action of the spring 26; however, it can be moved forwardly and away from the disk 27 when the pin 23 of the plunger 22 extends into the socket 32 and the handgrip portion 18 is rotated about its axis to thereby displace the pin 23 through the medium of the shaft 15.

The socket 32 has a substantially rectangular shape and extends circumferentially of the barrel 1. The slide 25 is further formed with an open-ended slot 33 which can receive the follower 8. The width of the slot 33 approximates the width of the cam slot 9 in the barrel 1 and slightly exceeds the diameter of the follower 8. When the slide 25 assumes the starting position shown in FIG. 2, the slot 33 is in exact register with the slot 9, i.e., the follower 8 can enter the slot 33 as soon as the variator system 2 assumes the position of FIG. 1 which corresponds to the shortest focal length of the lens. The follower 8 thereupon moves forwardly in response to forward movement of the slide 25, i.e., in response to depression and subsequent rotation of the hand-grip portion 18 about the axis of the shaft 15.

The selector 11 has a blocking pin 34 which is parallel to the axis of the barrel 1 and extends through the carrier 16 and into a peripheral groove 35 of the plunger 22. The groove 35 is parallel to the axis of the shaft 15.

When the handgrip portion 18 is in the extended position of FIG. 1, the blocking pin 34 extends into the radially outermost portion of the groove 35 and holds the plunger 22, shaft 15 and handgrip portion 18 against rotation about the axis of the shaft 15. However, if the operator depresses the handgrip portion 18 to stress the spring 21, the outer end of the groove 35 moves inwardly beyond the blocking pin 34 so that the handgrip portion 18 is free to rotate about the axis of the shaft 15. At the same time, the pin 23 enters the socket 32 of the slide 25 so that rotation of the handgrip portion 18 entails a lengthwise movement of the slide 25 in the guide groove 24. If the handgrip portion 18 is turned only slightly from the angular position shown in FIG. 1 (while the pin 23 extends into the socket 32, the blocking pin 34 engages the outer end face or shoulder 22*a* of the plunger 22 and automatically holds the handgrip portion 18 in the depressed position against the opposition of the spring 21. Thus, the handgrip portion 18 is free to return to the extended position of FIG. 1 only when the shaft 15 and its plunger 22 assume the predetermined angular position of FIG. 1 in which the groove 34 can receive the blocking pin 34.

The operation is as follows:

If the user of the motion picture camera wishes to change the focal length of the lens, the selector 11 is rotated, preferably by way of the handle 13. Such angular movement of the selector 11 and of its internal groove 10 causes the follower 8 to move about the optical axis and to move the sleeve 4. An intermediate portion of the follower 8 travels in the cam slot 9 of the barrel 1 whereby the follower 8 causes the sleeve 4 to move axially. Also, as the sleeve 4 rotates in response to rotation of the selector 11, the cam slot 7 moves relative to the follower 5 whereby the latter moves the ring 3 and the optical elements 2*a*–2*c* in the direction of the optical axis. The configuration of the cam slot 7 is such that the optical elements 2*a*–2*c* move away from the optical element 2*d* while the user reduces the focal length of the lens.

In order to focus for the making of close-up shots, the user must reduce the focal length of the lens to the minimum value in a first step, i.e., the follower 8 must enter the slot 33 of the slide 25 and must be in register with the internal groove 14 of the barrel 1. The user thereupon depresses the handgrip portion 18 against the opposition of the spring 21 so that the groove 35 moves inwardly beyond the blocking pin 34 of the selector 11 and the pin 23 penetrates into the socket 32 of the slide 25. The user then rotates the handgrip portion 18 about the axis of the shaft 15 whereby the pin 23 causes the slide 25 to move in the guide groove 24 toward the post 29 on the foremost portion of the barrel 1. The direction in which the handgrip portion 18 can rotate the shaft 15 and its plunger 22 in order to move the slide 25 forwardly is indicated by the arrow 40 (FIG. 2). The slide 25 entrains the follower 8 which in turn entrains the sleeve 4, the follower 5 and ring 3, i.e., the optical elements 2*a*–2*d* are moved forwardly as a unit because the angular position of the sleeve 4 remains unchanged. Thus, the distance between the optical elements 2*a*–2*c* and optical element 2*d* remains unchanged while the slide 25 moves away from the adjusting disk 27. The just described lengthwise movement of the slide 25 results in focussing for the making of close-up shots. The user can release the handgrip portion 18 in the selected angular position (proper focussing for the making of close-up shots) because the friction between moving parts suffices to prevent accidental changes in angular position of the shaft 15 and its plunger 22. The handgrip portion 18 remains in the depressed position because the blocking pin 34 engages the outer end face or shoulder 22*a* of the plunger 22 and the plunger thereby bears against the pin 34 under the action of the spring 21. Such engagement between the plunger 22 and blocking pin 34 suffices to prevent unintentional angular displacements of the handle 18 under the action of the spring 26 which tends to move the slide 25 back into abutment with the disk 27.

If the camera is thereupon to make one or more normal exposures, the user rotates the handgrip portion 18 back to the angular position of FIG. 1 whereby the spring 21 expands and moves the plunger 22 radially outwardly so that the groove 35 receives the blocking pin 34. The pin 23 is withdrawn from the socket 32 whereby the spring 29 automatically returns the slide 25 into abutment with the adjusting disk 27. The focal length of the lens can be increased by rotating the selector 11 about the barrel 1.

The groove 35 is preferably located substantially diametrically opposite the pin 23. Thus, the pin 23 must be located in the rearmost position (as considered in the direction of the optical axis) in order to enter the socket 32 while the slide 25 abuts against the disk 27.

An advantage of the blocking means including the pin 34 and the plunger 22 with its groove 35 and shoul-

der 22*a*, and of the spring 21 is that such parts reduce the likelihood of improper manipulation of the means for moving the optical elements 2*a*–2*d*. Thus, the pin 34 prevents rotation (movement in the second direction) of the handgrip portion 18 about the axis of the shaft 15 when the handle 13 dwells in the extended position of FIG. 1 or in any other position except in the fully depressed position. Also, the pin 34 automatically blocks the movement of the handle 13 from the depressed position except when the handle assumes that angular position (with respect to the axis of the shaft 15) in which the pin 34 is in register with the groove 35 of the plunger 22. Thus, the optical elements 2*a*–2*d* automatically assume those positions which correspond to the shortest focal length of the lens when the slide 25 can be engaged by or disengaged from the pin 23 of the handle 13.

Without further analysis, the foregoing will so fully reveal the gist of the present invention that others can, by applying current knowledge, readily adapt it for various applications without omitting features which fairly constitute essential characteristics of the generic and specific aspects of our contribution to the art and, therefore, such adaptations should and are intended to be comprehended within the meaning and range of equivalence of the claims.

What is claimed as new and desired to be protected by Letters Patent is set forth in the appended claims.

We claim:

1. In an objective system for photographic apparatus, a combination comprising a tubular barrel; a variable-focus picture taking lens having a variator system including a plurality of optical elements disposed in said barrel one behind the other and being movable axially of said barrel to thereby change the focal length of said lens and to focus the image of a subject; and means for moving said optical elements, including a handle extending outwardly from said barrel and being movable in a first direction substantially circumferentially of said barrel and in a different second direction, first motion transmitting means for moving said optical elements in response to movement of said handle in said first direction to thereby change the focal length of said lens, and second motion transmitting means for moving said optical elements in response to movement of said handle in said second direction to thereby focus the image of a subject, said handle being further movable substantially radially of said barrel between first and second positions, said handle and said second motion transmitting means comprising complementary first and second coupling means which are engaged with each other only in one of said positions of said handle to move said second motion transmitting means in response to movement of said handle in said second direction while said handle assumes said one position.

2. A combination as defined in claim 1, wherein said handle has an axis which extends substantially radially of said barrel and said movement in said second direction constitutes a rotary movement about said axis.

3. A combination as defined in claim 1, further comprising means for biasing said handle to the other of said positions.

4. A combination as defined in claim 1, wherein said second motion transmitting means further comprises a slide which is reciprocable in parallelism with the axis of said barrel and said second coupling means comprises a socket in said slide, said first coupling means comprising a projection which enters said socket in response to movement of said handle to said one position.

5. A combination as defined in claim 4, wherein said barrel has guide means for said slide and further comprising means for biasing said slide to a predetermined position from which said slide is shifted in response to movement of said handle in said second direction in said one position of said handle.

6. A combination as defined in claim 4, wherein said handle has an axis extending substantially radially of said barrel and said movement in said second direction constitutes an angular movement about said last mentioned axis, said projection being laterally offset with respect to said last mentioned axis.

7. A combination as defined in claim 6, wherein said first motion transmitting means comprises a hollow carrier and said handle further comprises a shaft which is reciprocable in said carrier between said first and second positions and is rotatable in said carrier about said last mentioned axis, and a handgrip portion rigid with said shaft and surrounding said carrier.

8. A combination as defined in claim 7, further comprising means for biasing said handle to the other of said positions, including a spring reacting against said carrier and bearing against said handgrip portion.

9. A combination as defined in claim 1, further comprising means for blocking the movement of said handle in said second direction in response to movement of said handle from said one position.

10. A combination as defined in claim 1, wherein said second movement is an angular movement about an axis extending sbstantially radially of said barrel and further comprising means for blocking the movement of said handle from said one position thereof except in a single angular position of said handle.

11. A combination as defined in claim 10, wherein said blocking means comprises a device which also blocks the angular movement of said handle in response to movement of said handle from said one position.

12. A combination as defined in claim 11, further comprising means for biasing said handle to said other position, said blocking means comprising a groove provided in said handle and extending in parallelism with said axis, an annular shoulder provided on said handle at one end of said groove, and a pin provided on said first motion transmitting means and extending into said groove except in said one position of said handle, said pin engaging said shoulder in said one position of said handle and when said handle is rotated from said predetermined angular position, said biasing means storing energy in response to movement of said handle from said other to said one position to thereupon bias said shoulder against said pin in said one position of said handle and to return said handle to said other position when said handle assumes said single predetermined angular position so that said pin can reeneter said groove.

13. A combination as defined in claim 12, wherein said handle further comprises a plunger and said groove is provided in the periphery of said plunger, said plunger having an end face which constitutes said shoulder.

14. A combination as defined in claim 1, wherein said first motion transmitting means comprises a ring-shaped selector surrounding said barrel and being rotatable by said handle about the axis of said barrel.

15. A combination as defined in claim 14, wherein said lens further comprises a sleeve for said optical elements and said first motion transmitting means further comprises means for connecting said sleeve to said selector.

16. A combination as defined in claim 15, wherein said means for connecting said sleeve to said selector is connected to said second motion transmitting means in a predetermined angular position of said selector.

* * * * *

United States Patent [19]

Lang

[11] **3,953,863**

[45] **Apr. 27, 1976**

[54] **METHOD AND APPARATUS FOR FOCUSING AN OBJECTIVE**

[75] Inventor: **Karl Lang**, Atzbach, Germany

[73] Assignee: **Ernst Leitz G.m.b.H.**

[22] Filed: **Nov. 27, 1973**

[21] Appl. No.: **419,282**

[30] **Foreign Application Priority Data**

Dec. 11, 1972 Germany 2260474

[52] **U.S. Cl.** **354/25**; 352/140

[51] **Int. Cl.**[2] **G03B 3/10**

[58] **Field of Search** 354/25, 162, 163, 165, 354/166, 4; 352/140; 353/101; 356/122

[56] **References Cited**

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Primary Examiner—L. T. Hix
Assistant Examiner—E. M. O'Connor
Attorney, Agent, or Firm—Gilbert L. Wells

[57] **ABSTRACT**

In a method for focusing a reproducing objective, such as may be used for measuring distances, wherein multiplication of the image of the entrance pupil is achieved by image-splitting optical elements mounted in the plane of the object image, the improvement comprising:

projecting the light fluxes from different parts of the pupil image plane on separate sets or groups of photoelectric receivers, deriving a signal from the comparison of the output signals from these receiver groups and using this signal as a criterion for focusing as a function of magnitude and sign. Apparatus for performing the method includes a grid of prisms or pyramids, and a beam splitter for directing light through two separate photoelectric receiver masks.

6 Claims, 7 Drawing Figures

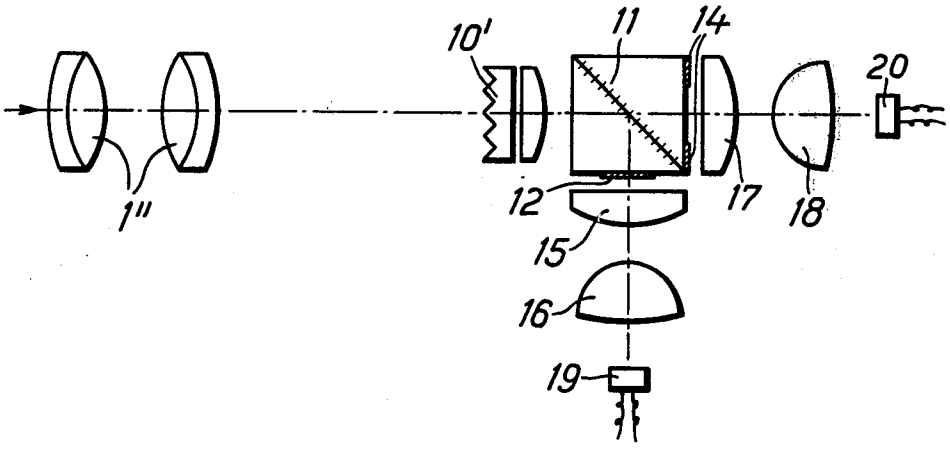


Fig. 1

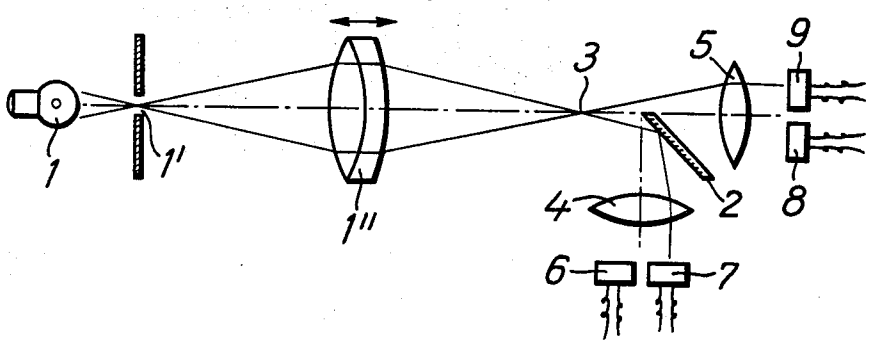


Fig. 2

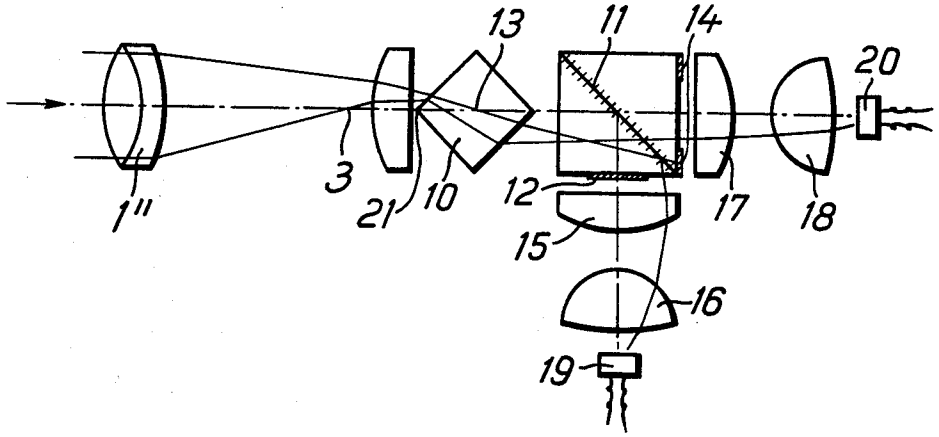


Fig. 3

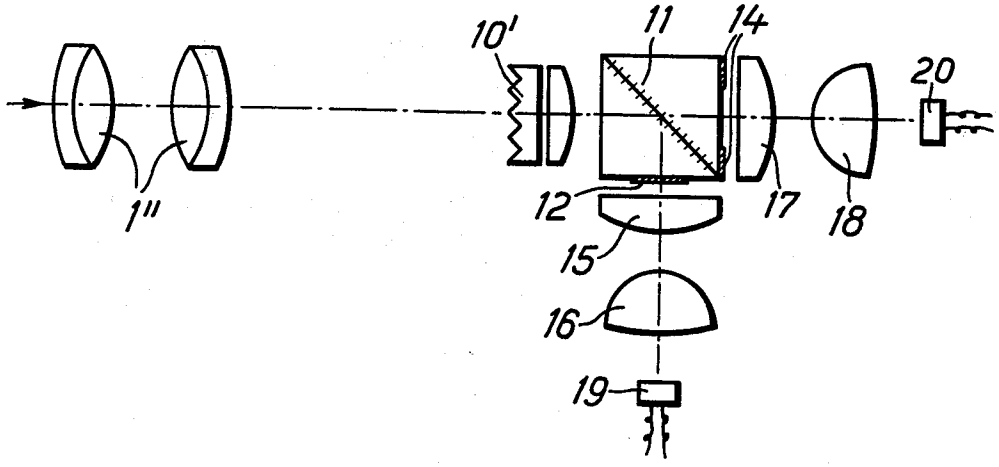


Fig. 4

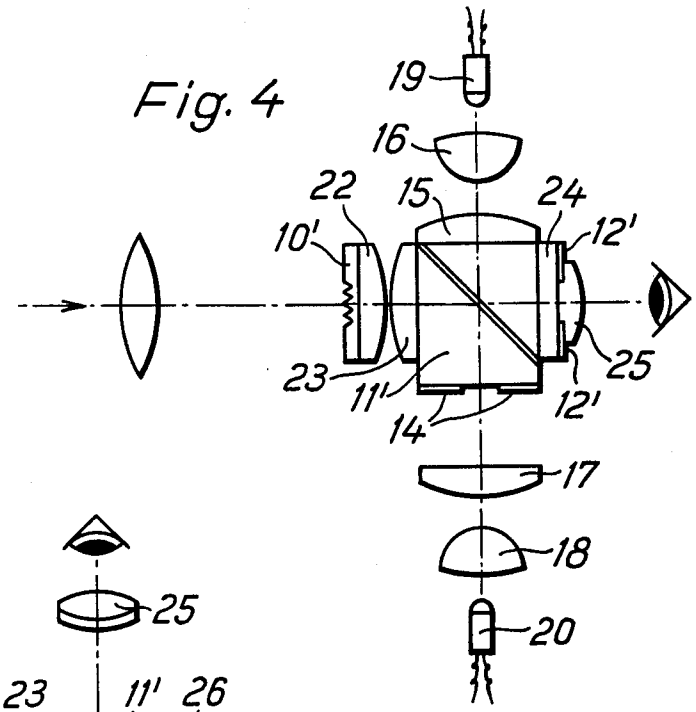


Fig. 5

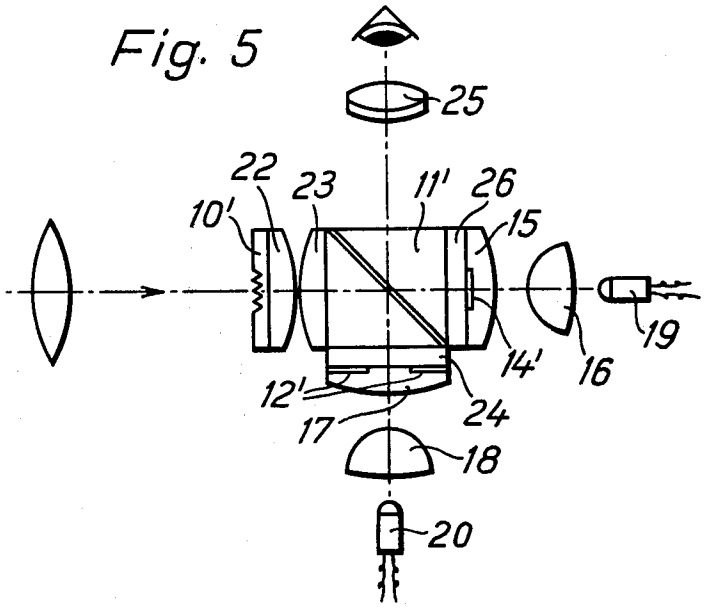


Fig. 6

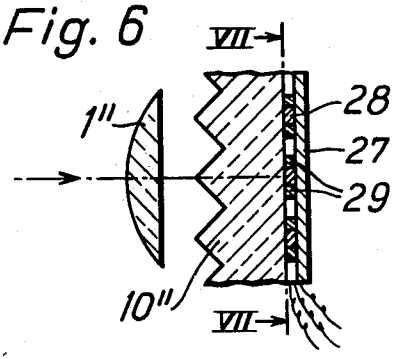
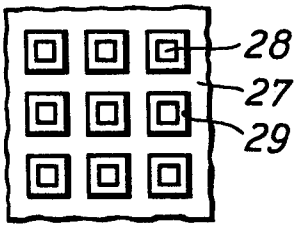


Fig. 7



METHOD AND APPARATUS FOR FOCUSING AN OBJECTIVE

CROSS REFERENCE TO A RELATED APPLICATION

Applicant claims priority under 35 U.S.C. 119 for application Ser. No. P 22 60 474.6, filed Dec. 11, 1972 in the Patent Office of the Federal Republic of Germany.

BACKGROUND OF THE INVENTION

The invention relates to a method for focusing a reproducing objective, for instance for distance measurements, wherein multiplication of the image of the entrance pupil or iris is achieved by means of image splitting optical elements located in the plane of the object image.

The state of the art of follow up systems for focusing the slide in a slide projector may be ascertained by reference to U.S. Pat. Nos. 3,399,595 and 3,517,992, and the follow up systems are useful in focusing the objective of the present invention. The disclosures of these patents are incorporated herein.

With regard to photographic cameras, it is known to mount pyramidal grids or rasters on the pane of the viewer for the purpose of focusing the objective or for visual assessment of the same. For each direction of surface inclination of the trilateral or quadrilateral pyramid, there will be a laterally shifted reproduction of the objective pupil, provided a lens reproducing the object pupil is mounted in the vicinity of the grid plane. The observing (ocular) puil covers part of the domain of the overlapping pupil images. However, since the ocular pupil is of a different relative position in each of the pupil images, many object images shifted by parallax and corresponding in number to that of the pupil images will occur when the focusing plane is moved out of the screen plane. Errors in camera objective setting therefore are noted by the fuzzy, fringy nature of the transitions in image contrasts.

Under such conditions, it becomes difficult to subjectively assess focus, especially if there is great depth of field of the reproduction through the camera objective.

SUMMARY OF THE INVENTION

The object of the present invention therefore is to create a method for focusing a reproducing objective such as is used in photographic cameras and the like, wherein there will not be the above-described difficulty relating to known visual-subjective methods, which will not require accurate objective setting at the edges of the images, and which will allow the use of automatic objective setting devices.

The object of the present invention is achieved by applying light fluxes from different parts of the pupil plane to separate photoelectric receiver groups and deriving a signal from the latter to serve as a criterion for focus as a function of magnitude and sign.

Advantageous systems for implementing the method of the present invention are also disclosed herein.

The special advantage of the novel method of the present invention consists in its many faceted applicability. If electronic automatic control is dispensed with, the novel devices of the invention may also be used as an improved, visual, static display. The setting criterion in this instance is the equality in brightness of two test fields.

BRIEF DESCRIPTION OF THE DRAWINGS

The new method and the corresponding devices and systems are best described by reference to the appended drawings, wherein:

FIG. 1 shows schematically an embodiment of the elements of the present invention for focusing an objective;

FIG. 2 shows schematically another embodiment of the elements of the present invention for focusing an objective;

FIG. 3 shows schematically still another embodiment of the elements of the present invention for focusing an objective using a beam splitter;

FIG. 4 shows schematically yet another embodiment of the elements of the present invention for focusing an objective having an arrangement for the visual observation of a pupil sector near the axis;

FIG. 5 shows schematically an embodiment of the elements of the present invention having reflecting pupil stops, a polarizing beam splitter and two quarter-wave plates;

FIG. 6 is a side view of a prism useful in the present invention having a photoelectric differential receiver; and

FIG. 7 is a detailed showing of the differential receiver of FIG. 6 along the line VII—VII.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

As shown in FIG. **1**, a light source **1** illuminates a narrow light slit **1'** normal to the plane of the drawing. Light slit **1'** is reproduced in the region of a dividing mirror **2** by means of an objective **1''**, for instance at location **3**. The parts of the split beam are applied by means of condensing lenses (**4, 5**) mounted downstream dividing mirror **2** to two photoelectric receiver sets **6, 7** and **8,9**. Shifting objective **1''** along the optical axis allows the displacement of the image location **3** of slit **1'** in front of and behind dividing mirror **2.**

If location **3,** as shown, lies in front of dividing mirror **2,** then receivers **7** and **9** will be illuminated, while receivers **6** and **8** will not be. When the image location **3** is moved beyond mirror **2,** illumination passes to the photoelectric receivers **6** and **8.** The change in signal at the outputs of the receiver sets **6, 7** and **8, 9** occurring when the location of focusing is passing the front edge of mirror **2** therefore is a criterion for the focusing of the slit image.

Such a change in signal will also be obtained from the arrangement of FIG. **2.** A luminous object, not shown, is to be focused by means of objective **1''** which is followed by a prism **10** having its front edge **21** as well as its rear edge aligned to the optical axis of said objective. A beam splitting prism **11** is located behind prism **10,** the exit surfaces of prism **11** being provided with two complementary stops **12, 14** for blocking light fluxes passing the device close to the axis and away from the axis respectively. The rays leaving beam splitter **11** and passing through lenses **15, 16** and **17, 18** are collected respectively at photoelectric receivers **19** and **20.**

The method of operation of the arrangement described so far is as follows:

If the object is focused in front of edge **21** of prism **10,** for instance at location **3,** the refracting power of prism **10** is concentrating the image of the entrance pupil reproduced by objective **1''** close to the optical

axis. Therefore, only receiver **20** will be illuminated as light fluxes emitted from said image and deflected by the splitting surface of beam splitting prism **11** will be blocked by stop **12**, while light fluxes penetrating beam splitter **11** will pass stop **14**.

Yet if the object is focused behind edge **21**, for instance at location **13**, the image of the entrance pupil is formed away from the optical axis as a result of the refracting power of prism **10**, thus causing the illumination of receiver **19** only as light fluxes deflected by beam splitter **11** will pass stop **12** but will be blocked by stop **14** after penetrating prism **11**. Therefore, the image position with respect to the edge **21** of prism **10** is shown by the ratio of the photoelectric receiver outputs. Exact focus signified by coincidence of edge **21** and the focus of objective **1''** is represented by equality of signals.

As regards the arrangement of FIG. **3**, prism **10** of FIG. **2** is replaced by a grid of prisms **10'**. The remaining components are denoted by the same reference numerals and operate as in FIG. **2**. The grid of prisms **10'** may also be replaced by a grid of pyramids of known kind. Stops **12, 14** must be adapted to the grid geometry.

The arrangement of FIG. **4** differs from that of FIG. **3** in being provided with a polarizing beam splitter **11'**. The object, not shown, is reproduced in the region of the grid plate **10'**. Collecting optical elements project the light passing through the grid plate to the polarizing splitter **11'**. Stop **12'**, corresponding to stop **12** of FIG. **3**, in this instance is made reflecting and separated from splitter **11'** by means of a quarter-wave plate **24**, so that the reflected light rays far from the axis are projected on the photoelectric receiver **19** by means of lenses **15, 16**. Ocular **25** is located behind stop **12'**, allowing visual observation of the rays being transmitted. Components **14, 17, 18, 20** are analogous to those of FIG. **3**.

In the arrangement of FIG. **5**, both stops **12'** and **14'** are reflecting and separated from the polarizing splitter **11'** by quarter-wave plates **24, 26** so that the light rays away from the axis reflected at stop **12'** and the paraxial rays reflected at stop **14'** reach via the ocular **25** an observer's eye. The ray portions passing the stops **12', 14'** reach the photoelectric receivers **19, 20** as in FIG. **3**.

In the variation of the invention shown in FIG. **6**, splitting of the light beams onto different photoelectric receivers is achieved by designing these receivers proper as a photoelectric differential receiver group **27**, as shown in detail in FIG. **7**. This group is mounted in the rear of the grid of pyramids **10''** at a spacing corresponding to the deviation angle of this pyramid grid **10''** and to the aperture of objective **1''**. The receiver group **27** is so designed that its subdivision corresponds to that of grid **10''** and that the limited field of one set of receivers **28** is located behind each peak of a grid element, while the adjacent receiver elements are combined into a group or set of receivers **29** for the rays more removed from the peaks. Equality of signal at the receiver outputs here to is the criterion for focusing the object image on the grid plate **10''**.

The arrangement shown in FIGS. **6** and **7** is particularly well suited for photographic cameras.

Following focusing adjustment, the distance between object and adjustment component may be read off, for instance from a suitable scale on the objective setting.

I claim:

1. A method for focusing an objective of an object projecting light fluxes consisting of said objective having an entrance pupil receiving said light fluxes and reproducing the image of said entrance pupil at an image plane, splitting optical elements mounted in the range of said image plane for achieving multiplication of said image of said entrance pupil, selecting from said light fluxes predetermined ones passing through different parts of said entrance pupil, applying said fluxes to first and second photoelectric receiver means for generating output signals corresponding to said light fluxes passing through said different pupil parts, comparing said signals of said receiver means, deriving a signal from said comparison, and using said signal for focusing said objective according to magnitude and sign of said signal.

2. The method of claim **1**, further consisting of separating said image plane into two planes of spatially different location by means of a beam splitter (**11**), said different planes corresponding to said photoelectric receiver means.

3. A system comprising an objective with an optical axis and an entrance pupil, said objective being adjustable for focusing an object image in a plane along said optical axis, ray splitting optical elements mounted in said image plane selecting light fluxes from different parts of said entrance pupil, first and second photoelectric receiver means receiving said light fluxes from said different part of said entrance pupil and generating output signals depending on the amount of light received, means for comparing said output signals and generating a comparison signal and means responsive to said comparison signal for focusing said objective according to magnitude and sign of said comparison signal.

4. The system of claim **3**, further comprising a beam splitter (**11**) located along said optical axis producing together with a field lens and said ray splitting optical elements on respectively each exit surface of the splitter, two spatially separate double images of said entrance pupil in spatially separate planes corresponding to said first and second photoelectric receiver means, said two spatially separate double images having first and second separate axes, first and second stops **12, 14** located along said first and second separate axes at said double images, said stops being matched to the geometrical form of said image splitting elements and having apertures corresponding respectively to the paraxial part of said entrance pupil and to the complementary part of said entrance pupil, and one objective and one condensing lens each located along said first and second separate double image axes for collimating the light fluxes passing said apertures onto said receiver means.

5. The system of claim **3**, wherein said ray splitting optical elements comprise a grid of pyramids (**10''**) mounted in said plane of the image of the object.

6. The system of claim **3**, wherein said ray splitting optical elements comprise a grid of prisms (**10'**) mounted in said plane of the image of the object.

* * * * *

OR 3,944,339 T

United States T4091D

Momiyama

[11] **3,944,339**

[45] **Mar. 16, 1976**

[54] **LARGE APERTURE PHOTOGRAPHIC OBJECTIVE**

[75] Inventor: **Kikuo Momiyama**, Chofu, Japan

[73] Assignee: **Canon Kabushiki Kaisha**, Tokyo, Japan

[22] Filed: **July 3, 1974**

[21] Appl. No.: **485,555**

[30] **Foreign Application Priority Data**

July 7, 1973 Japan 48-76162

[52] **U.S. Cl.** **350/220**; 350/206

[51] **Int. Cl.²** **G02B 9/34**

[58] **Field of Search** 350/220, 206

[56] **References Cited**

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Primary Examiner—John K. Corbin

Attorney, Agent, or Firm—Toren, McGeady and Stanger

[57] **ABSTRACT**

A photographic objective lens system for adaption with a diaphragm located in front of the entire system. The lens system comprises positive front and rear lenses and a negative intermediate lens in optical alignment with each other. The front lens is in the form of a positive meniscus doublet composed of a double convex lens and double concave lens cemented together at their adjoining surfaces. The intermediate lens is a double concave singlet. The rear lens consists of a positive meniscus front singlet of rearward convexity and a positive meniscus rear singlet of forward convexity. This objective is so designed as to have a relative aperture of at most two in F-number and a field angle as wide as 44° while nevertheless preserving an excellent state of correction of various aberrations.

4 Claims, 8 Drawing Figures

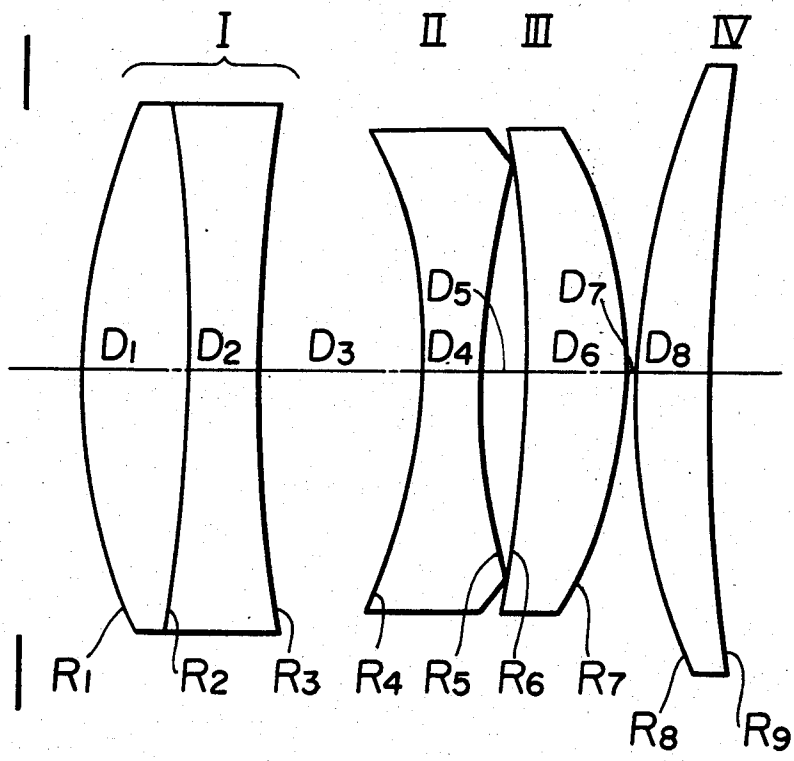


FIG. 1

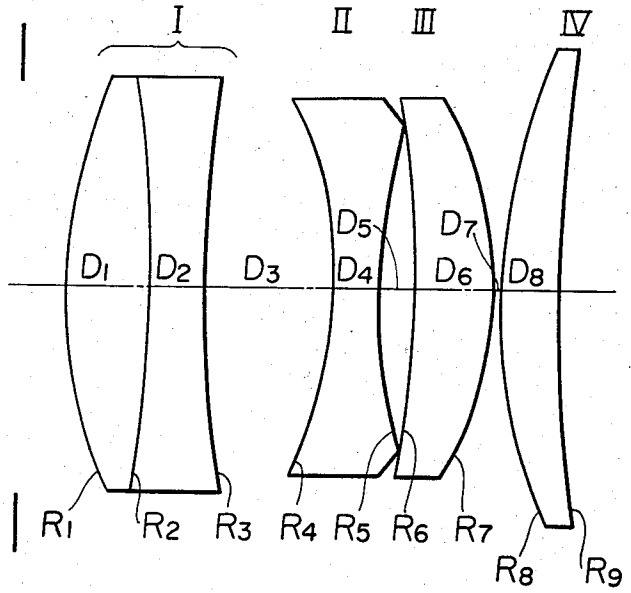


FIG. 2A FIG. 2B FIG. 2C

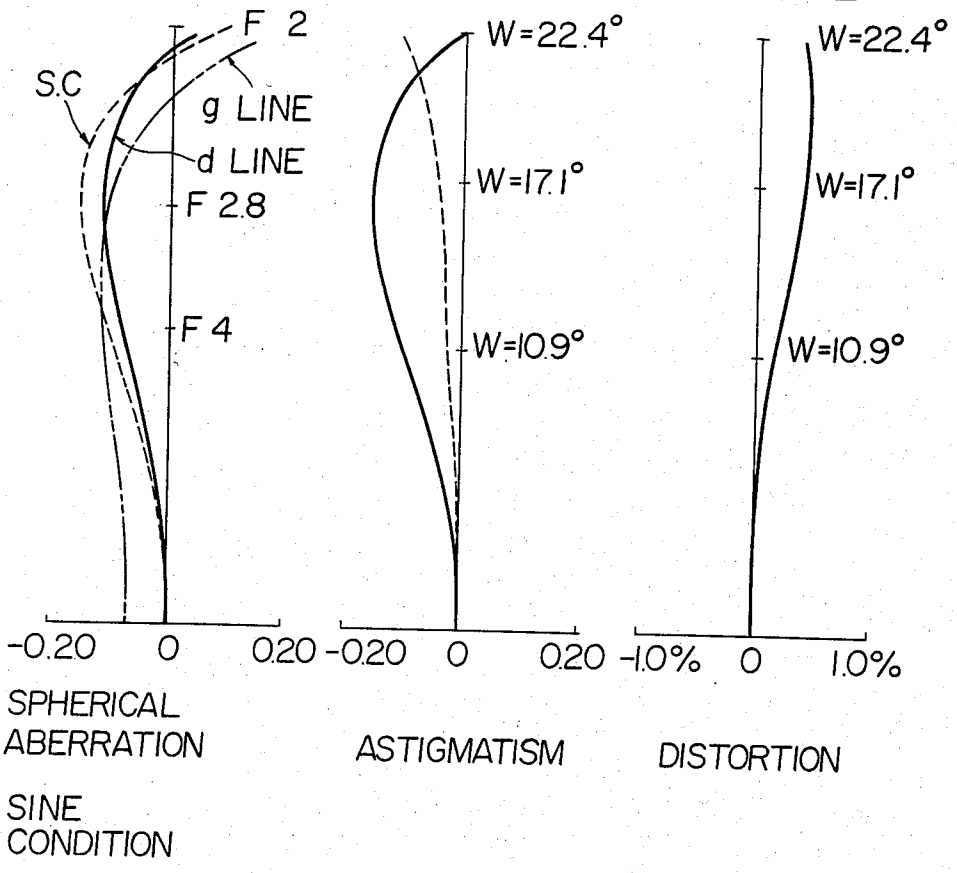


FIG. 3

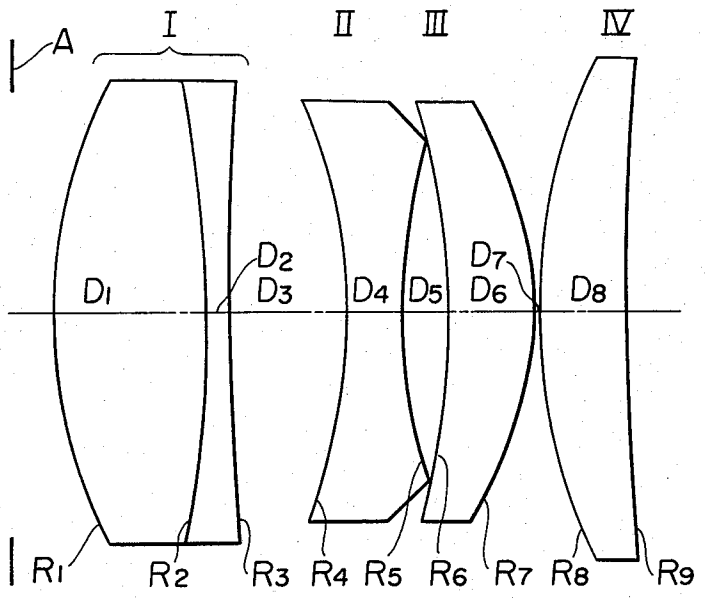


FIG. 4A

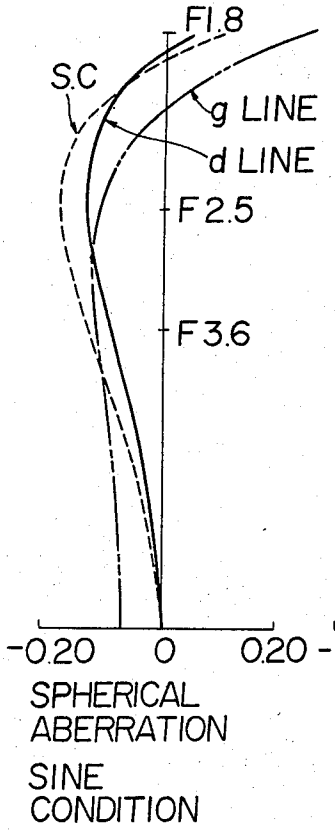


FIG. 4B

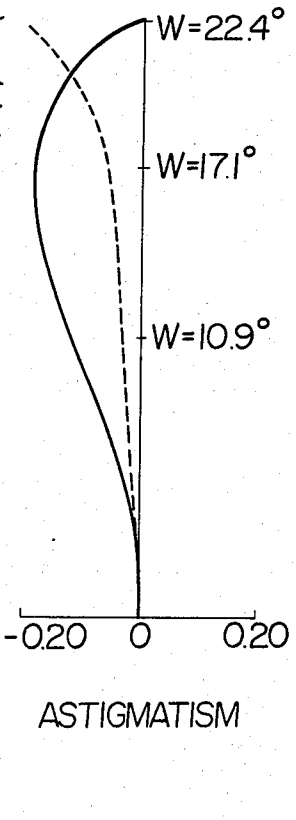
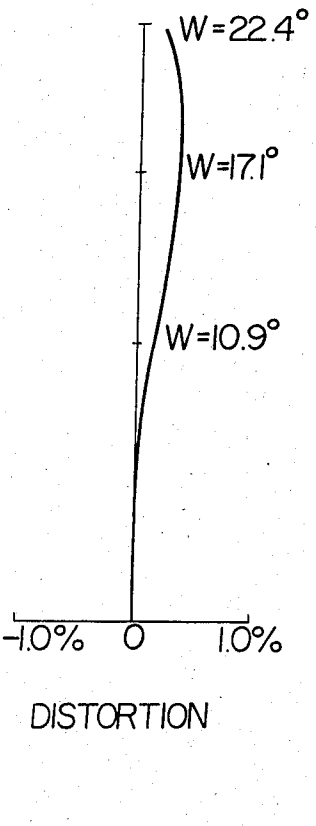


FIG. 4C



LARGE APERTURE PHOTOGRAPHIC OBJECTIVE

BACKGROUND OF THE INVENTION

This invention relates to photographic objective lens systems having a relative aperture of at least *f*/2.0 and field angle as wide as 44°, and more particularly to a photographic objective lens system adapted for use with a diaphragm located outwardly of the entire lens system while nevertheless an excellent state of correction of the image aberrations is preserved even in such situation.

The commonly known photographic objective lens systems are designed so that the diaphragm is located within an air space of the lens system, and, therefore, the entrance and exit pupils lie inside of the lens system. In some special photography, however, it is required for the objective lens to have a pupil lying outwardly thereof. For example, with specially designed cameras, it is desired because of the arrangement and construction of the mechanism thereof to position the shutter, diaphragm and the like in front of the objective lens. In this case, there is required the front diaphragm type of objective lens.

SUMMARY OF THE INVENTION

The lens design parameters of such an objective lens system are seriously limited in the possibility of establishing certain relationships because of the high tendency of producing various aberrations, so that a high degree of correction of the image aberrations are considerably difficult to accomplish. Particularly with an objective lens having an abnormally large relative aperture compared to an ordinary objective, such a difficulty is remarkably intensified. The present invention is adapted to overcome the above-mentioned problem. Accordingly, the object of the invention is to provide a photographic objective lens system having a large relative aperture along with an excellent state of correction of the image aberrations.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a diagrammatic view of an objective lens system according to a preferred embodiment of the present invention.

FIGS. **2A, 2B** and **2C** are curves illustrating various aberrations of the lens of FIG. **1.**

FIG. **3** is a diagrammatic view of an objective lens system according to another preferred embodiment of the present invention.

FIGS. **4A, 4B** and **4C** are curves illustrating various aberrations of the lens of FIG. **3.**

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to FIGS. **1** and **3,** the objective lens system according to the present invention is illustrated as comprising four optically aligned lens components with five lens elements. Character A indicates a diaphragm position. The first component I is in the form of a positive meniscus doublet composed of a double convex lens element and a double concave lens element which has a first refracting surface R1 of a convex curvature forwardly directed toward the object side. The second component II is a double concave singlet which has a front surface R4 of stronger concave curvature, or having a smaller radius of concave curvature than that of the rear surface thereof and is rearwardly spaced in an axial distance D3 from Component I. The third component III is a positive meniscus singlet which has a rear surface R7 of convex curvature rearwardly directd toward the image plane, and is spaced in an axial distance D5 from Component II. The fourth component IV is a positive convex singlet which has a front surface R8 of stronger convex curvature or having a smaller radius of convex curvature forwardly directed toward the object side. The adjacent surfaces R7 and R8 of Components III and IV are characterized in that the surface R8 of Component IV is flatter than the surface R7 of Component III. Further, the axial distance from the first surface R1 of Component I to the first surface R4 of Component II or the sum of the axial thicknesses D1 and D2 of the front and rear lens elements of Component I and the axial separation D3 between Components I and II is longer than the axial distance from the second surface of Component II to the second surface of Component III, or the sum of the axial separation D5 between Components II and III and the axial thickness D6 of Component III. The arrangement and construction of the components of the lens system according to the present invention may be considered to be of modified triplet type from the standpoint of the basic lens design, for which the rear lens component of the triplet type objective is formed by two convex lenses. By the provision of the two convex lenses in the rear lens component it is made possible to decrease the refractive powers of each surface with decrease in residual spherical aberrations. However, these two convex lenses, namely, Components III and IV, are spaced apart from the diaphragm at so long distance that extra-axial pencils of rays pass practically through the marginal portions thereof to cause the production of extra-axial image aberrations. In order to minimize such image aberrations, the relationship between the adjacent surfaces of Components III and IV is set forth as $R7 < R8$. Component II of a concave lens plays a roll of cancelling various residual aberrations of the positive lens of Component I. As far as the extraaxial aberration correction is concerned, it is preferred to place component II near Component III. From this point of view, the relationship $D1 + D2 + D3 > D5 + D6$ is herein set forth. To impart a refractive power of a predetermined magnitude to Component II, the front surface R4 rather than the rear surface R5 is provided with a smaller radius of curvature, thereby contributing a large proportion of the refractive power to Component II, or otherwise residual aberrations are deteriorated as the incident angles of extra-axial pencils of rays impinging upon the rear surface R5 increases. Under the condition that $D1 + D2 + D3 < D5 + D6$, the axial separation between Components I and II is relatively long. In order to effect a high degree of correction of chromatic aberrations under such situation, Component I is constructed in the form of a doublet of lens elements cemented together at their adjoining surfaces. The present invention in its broader aspects has been described with respect to the optical constructional principle. In the practice of the present invention, however, good image quality can be obtained by the use of certain relationships set out in more detail below which define the limits for an optimum lens design.

$$(1)\ 0.55f < \Sigma D > 0.9f$$

$$(2)\ 1.70 < \bar{N}_{convex}$$

$$(3)\ 1.4 < \frac{R_8}{|R_7|} < 2.5;\ R7<0$$

$$(4)\ 0.12f < (D1 + D2 + D3) - (D5 + D6) < 0.3f$$

$$(5)\ 0.6f < R5 < 1.2f$$

$$(6)\ 0.005 < \left(\frac{1}{V_2} - \frac{1}{V_1} \right) < 0.020$$

wherein f is the overall focal length of the entire lens system; ΣD is the total physical length of the entire lens system; R5, R7 and R8 are the radii of curvature of the fifth, seventh and eighth refracting surfaces counting from the front respectively; D1, D2, D3, D5 and D6 are the first, second, third, fifth and sixth axial distances between successive refracting surfaces respectively; $\overline{N}_{convex}$ is the mean value of the refractive indices of materials of which all the convex lens element are made; and V1 and V2 are the Abbe numbers of the convex and concave lens elements respectively constituting said first component.

As the pupil of an objective of front diaphragm type lies outwardly of the lens system, the diameter of the rear lens is unavoidably increased and a high degree of correction of extra-axial aberrations is more difficult to accomplish. These problems may be neglected when designing objectives of the type having, though large relative aperture, a small field angle, and objectives of the type having, though relatively wide field angle, a small relative aperture. On the other hand, as an objective has a large relative aperture of at least $f/2.0$ and field angle as great as 44° as in the present invention, the solution of aberrational problems is made complicated.

Relationship (1): The diameter of the rear lens may be decreased with decrease in the total length of the complete objective. As the total length is shortened, however, the refractive powers of each lens element are necessarily strengthened to thereby make it difficult to correct particularly spherical aberrations, so that an objective having a large relative aperture is hardly obtainable. Relationship (1) is set out for the purposes of facilitating the minimization of the diameter of the rear lens of a large aperture objective adapted for use with a diaphragm located in front of the objective while permitting the objective to have a field angle of as great as 44°. When the upper limit of relationship (1) is violated, the required diameter of the rear lens is increased so that a difficulty is created in assembling the resultant objective with a given camera body. When the lower limit is violated, the solution of aberrational problems can not be facilitated even by the use of relationships to be subsequently described.

Relationship (2): Spherical aberrations and the Petzval sum tend to over-correction when the total length of the complete objective is restricted in the range defined by relationship (1). For this reason, a relatively high refractive indices of glasses have to be selected for employment in the convex lens elements. For facilitating a high standard correction of spherical aberrations and the Petzval sum with an objective having a large aperture of more than $f/2.0$, it is necessary that the mean value of the refractive indices of all the convex lens elements satisfies at least relationship (2). The upper limit of relationship (2) is not given, but it may be the presently available maximum refractive index of glass.

Relationship (3): The reason why the surfaces R7 and R8 of strong convex curvature of Components III and IV are particularly selected for subject to relationship (3) is to define the surfaces R7 and R8 of such configurations that extra-axial aberrations and particularly coma aberration are minimized. When the lower limit is violated, coma aberration is intensified. When the upper limit is violated, the spherical aberrations are intensified.

Relationship (4): When the lower limit is violated, a high degree of correction of extra-axial aberrations are more difficult to accomplish and the diameter of the rear lens is increased. When the upper limit is violated, spherical aberrations are deteriorated.

Relationship (5): A preferable balance of astigmatism is effected with the rear surface R5 of controlled curvature of the concave lens of Component II. When the upper limit is violated, under-correction of astigmatism results. When the lower limit is violated, over-correction of astigmatism results.

Relationship (6): determines the range of acceptable differences between the dispersive indices of the convex and concave lens elements of Component I, When the lower limited is violated, the concave lens of Component II has to compensate for chromatic aberrations to so large extent that when longitudinal chromatic aberrations are over-corrected, lateral chromatic aberrations are caused to result in over-correction. When the upper limit is violated, the situation is reversed. Thus, in any case, good states of correction of longitudinal chromatic aberrations as well as lateral chromatic aberrations can not be effected simultaneously.

Two examples of a specific objective of the present invention may be constructed in accordance with the numerical data given in Tables 1 and 2 below wherein;

- R: the radii of curvature of each lens surface with the respective refracting surfaces being numbered from the front to the rear of the objective and being identified respectively by a subscript numeral for each R
- D: the axial spacings between successive refracting surfaces with each D being identified by its numerical subscript successively from front to rear
- N: the refractive indices of each lens element for the spectral D line of sodium with each N being identified by its numerical subscript successively from front to rear
- V: the dispersive indices of each lens element with each V being identified by its numerical subscript successively from front to rear.

Table 1 (FIG. 1)

Example 1:		
$f = 26.0$	F - number = 2.0	$2\omega = 44.7°$
$R_1 = 15.445$		
$D_1 = 3.0$	$N_1 = 1.77250$	$V_1 = 49.6$
$R_2 = -44.635$		
$D_2 = 1.85$	$N_2 = 1.64769$	$V_2 = 33.8$
$R_3 = 45.846$		
$D_3 = 4.23$		
$R_4 = -15.233$		
$D_4 = 1.63$	$N_3 = 1.68893$	$V_3 = 31.1$
$R_5 = 21.407$		
$D_5 = 1.2$		
$R_6 = -33.113$		
$D_6 = 2.73$	$N_4 = 1.77250$	$V_4 = 49.6$
$R_7 = -12.198$		
$D_7 = 0.15$		
$R_8 = 20.022$		
$D_8 = 2.1$	$N_5 = 1.77250$	$V_5 = 49.6$
$R_9 = 66.210$		

Table 1 (FIG. 1)-continued

Example 1:
Σ D = 16.89

Table 2

Aberration Coefficient					
No.	I	II	III	P	V
1	1.1725	0.7642	0.4981	0.7336	0.8029
2	0.4133	−0.1479	0.0529	0.0249	−0.0278
3	0.1509	−0.2833	0.5316	−0.2229	−0.5794
4	−3.2651	0.6392	−0.1222	−0.6961	0.1608
5	−0.3557	−0.6543	−1.2038	−0.4954	−3.1261
6	0.0029	−0.0169	0.0987	−0.3422	1.4213
7	2.1506	0.1903	0.0168	0.9288	0.0837
8	−0.0147	−0.0533	−0.1932	0.5659	1.3506
9	0.2249	−0.2592	0.2987	−0.1711	−0.1471
Σ	0.4797	0.1788	−0.0252	0.3255	−0.0612

Table 3 (FIG. 3)

Example 2 :		
f = 26.0	F-number = 1.8	2 ω = 44.7°
R_1 = 16.333		
D_1 = 5.0	N_1 = 1.78590	V_1 = 44.2
R_2 = −43.284		
D_2 = 1.0	N_2 = 1.75520	V_2 = 27.5
R_3 = 123.054		
D_3 = 3.88		
R_4 = −18.019		
D_4 = 1.97	N_3 = 1.75520	V_3 = 27.5
R_5 = 20.840		
D_5 = 1.4		
R_6 = −26.607		
D_6 = 3.1	N_4 = 1.77250	V_4 = 49.6
R_7 = −12.558		
D_7 = 0.1		
R_8 = 21.232		
D_8 = 3.0	N_5 = 1.78590	V_5 = 44.2
R_9 = 119.791		
Σ D = 19.45		

Table 4

Aberration Coefficients					
No.	I	II	III	P	V
1	0.9940	0.6818	0.4676	0.7005	0.8012
2	0.0782	−0.0272	0.0095	0.0059	−0.0053
3	0.5532	−0.5732	0.5938	−0.0909	−0.5210
4	−2.9460	0.6899	−0.1616	−0.6208	0.1832
5	−0.2299	−0.4792	−0.9990	−0.5368	−3.2019
6	−0.0022	0.0060	−0.0165	−0.4259	1.2114
7	1.6650	0.1720	0.0178	0.9023	0.0950
8	−0.0109	−0.0443	−0.1802	0.5389	1.4583
9	0.3084	−0.2547	0.2103	−0.0955	−0.0948
Σ	0.4099	0.1711	−0.0584	0.3777	−0.0740

FIGS. 2A, 2B and 2C are graphic representations of corrections attained for various aberrations in the above-mentioned Examples 1 and 2 respectively. It will be appreciated that by the use of four lens components with five lens elements, high quality objectives of the front diaphragm type are economically produced which have a relative aperture of at least *f*/2.0 while nevertheless preserving a good state of correction of aberrations.

The numerical values of relationships (1) – (6) in Examples 1 and 2 are given in Table 5 below.

Table 5

	Example 1	Example 2
(1)	0.65f	0.748f
(2)	1.7725	1.7814
(3)	1.641	1.691
(4)	0.198f	0.207f
(5)	0.823f	0.802f
(6)	0.0094	0.0137

Relationships (1) – (6) may be modified as follows without causing appreciable deteriolation of aberrations from the states shown in FIGS. 2 and 4.

(1') $0.55f < \Sigma D < 0.8f$

(2') $1.7 < \bar{N}_{convex}$

(3') $1.6 < \frac{R8}{|R7|} < 1.75$

(4') $0.15f < (D1+D2+D3) - (D5+D6) < 0.25f$

(5') $0.7f < R5 < 0.95f$

(6') $0.005 < \left(\frac{1}{\nu 2} - \frac{1}{\nu 1} \right) < 0.018$

What is claimed is:

1. A large aperture photographic objective lens system adapted for use with a diaphragm located forwardly thereof, said objective comprising in order from the object side:

a first positive meniscus doublet lens component which is convex toward the object side and is composed of a double convex lens and a double concave lens cemented together at their adjoining surfaces;

a second double concave single lens component a strong concave curvature directed forwardly toward the object side and being rearwardly spaced from said first component;

a third positive meniscus singlet lens component which is convex toward the image side and lying substantially in edge contact with said second component; and

a fourth convex singlet lens component having a refracting surface of strong convex curvature directed toward the object side and being spaced from said third component; said refracting surface of strong convex curvature of the fourth component being flatter than the adjacent surface of said third component; and the axial length from the first surface of said first component to the first surface of said second component being longer than the axial length from the second surface of said second component to the second surface of said third component.

2. A large aperture photographic objective as described in claim 1, wherein said fourth component has a second surface of concave curvature rearwardly directed toward the image side.

3. A large aperture photographic objective lens system for use with a diaphragm located forwardly thereof, said objective comprising in order from the object side:

a first positive meniscus doublet lens component which is convex toward the object side and is composed of a double convex lens and a double con-

cave lens cemented together at their adjoining surfaces;

a second double concave single lens component having a strong concave curvature directed forwardly toward the object side and being rearwardly spaced from said first component;

a third positive meniscus singlet lens component which is convex toward the image side and lying substantially in edge contact with said second component; and

a fourth convex singlet lens component having a refracting surface of strong convex curvature directed toward the object side and being spaced from said third component,

said fourth component also having a second surface of concave curvature rearwardly directed toward the image side;

said refracting surface of strong convex curvature of the fourth component being flatter than the adjacent surface of said third component; and the axial length from the first surface of said first component to the first surface of said second component being longer than the axial length from the second surface of said second component to the second surface of said third component, wherein the characteristics of the various lenses of the four lens components and their spatial relationships to each otehr being substantially of the proportions indicated by the numerical data in the following table

The focal length of the entire system f = 26.0
F-number = 2.0
The field angle 2ω = 44.7°

$R_1 = 15.445$		
$D_1 = 3.0$	$N_1 = 1.77250$	$V_1 = 49.6$
$R_2 = -44.635$		
$D_2 = 1.85$	$N_2 = 1.64769$	$V_2 = 33.8$
$R_3 = 45.846$		
$D_3 = 4.23$		
$R_4 = -15.233$		
$D_4 = 1.63$	$N_3 = 1.68893$	$V_3 = 31.1$
$R_5 = 21.407$		
$D_5 = 1.2$		
$R_6 = -33.113$		
$D_6 = 2.73$	$N_4 = 1.77250$	$V_4 = 49.6$
$R_7 = -12.198$		
$D_7 = 0.15$		
$R_8 = 20.022$		
$D_8 = 2.1$	$N_5 = 1.77250$	$V_5 = 49.6$
$R_9 = 66.210$		
$\Sigma D = 16.89$		

wherein R denotes the radii of curvature of each lens surface with the respective refracting surfaces being numbered from front to rear and being identified respectively by a subscript numeral for each R; D denotes the axial spacings between successive refracting surfaces with each D being identified by its numerical subscript successively from front to rear; N denotes the refractive indices of each lens for the spectral D line of sodium with each N being identified by its numerical subscript successively from front to rear; and V denotes the dispersive indices of each lens with each V being identified by its numerical subscript successively from front to rear.

4. A large aperture photographic objective lens system for use with a diaphragm located forwardly thereof, said objective comprising in order from the object side:

a first positive meniscus doublet lens component which is convex toward the object side and is composed of a double convex lens and a double concave lens cemented together at their adjoining surfaces;

a second double concave single lens component having a strong concave curvature directed forwardly toward the object side and being rearwardly spaced from said first component;

a third positive meniscus singlet lens component which is convex toward the image side and lying substantially in edge contact with said second component; and

a fourth convex singlet lens component having a refracting surface of strong convex curvature directed toward the object side and being spaced from said third component, said fourth component also having a second surface of concave curvature rearwardly directed toward the image side; said refracting surface of strong convex curvature of the fourth component being flatter than the adjacent surface of said third component; and the axial length from the first surface of said first component to the first surface of said second component being longer than the axial length from the second surface of said second component to the second surface of said third component, wherein the characteristics of the various lenses of the four lens components and their spatial relationships to each other being substantially of the proportions indicated by the numerical data in the following table

The focal length of the entire system f = 26.0
F-number = 1.8 The field angle 2ω = 44.7°

$R_1 = 16.333$		
$D_1 = 5.0$	$N_1 = 1.78590$	$V_1 = 44.2$
$R_2 = -43.284$		
$D_2 = 1.0$	$N_2 = 1.75520$	$V_2 = 27.5$
$R_3 = 123.054$		
$D_3 = 3.88$		
$R_4 = -18.019$		
$D_4 = 1.97$	$N_3 = 1.75520$	$V_3 = 27.5$
$R_5 = 20.840$		
$D_5 = 1.4$		
$R_6 = -26.607$		
$D_6 = 3.1$	$N_4 = 1.77250$	$V_4 = 49.6$
$R_7 = -12.558$		
$D_7 = 0.1$		
$R_8 = 21.232$		
$D_8 = 3.0$	$N_5 = 1.78590$	$V_5 = 44.2$
$R_9 = 119.791$		
$\Sigma D = 19.45$		

wherein R denotes the radii of curvature of each lens surface with the respective refracting surfaces being numbered from front to rear and being identified respectively by a subscript numeral for each R; D denotes the axial spacings between successive refracting surfaces with each D being identified by its numerical subscript successively from front to rear; N denotes the refractive indices of each lens for the spectral D line of sodium with each N being identified by its numerical subscript successively from front to rear; and V denotes the dispersive indices of each lens with each V being identified by its numerical subscript successively from front to rear.

* * * * *

OR 3,938,882

United States P:

Oishi

3,938,882

Feb. 17, 1976

[54] **HIGH NUMERICAL APERTURE INTERMEDIATE WIDE ANGLE OBJECTIVE**

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[73] Assignee: **Asahi Kogyo Kabushiki Kaisha,** Tokyo, Japan

[22] Filed: **Sept. 20, 1974**

[21] Appl. No.: **507,743**

[30] **Foreign Application Priority Data**

Sept. 27, 1973 Japan 48-108715

[52] **U.S. Cl.** **350/214;** 350/176

[51] **Int. Cl.²** **G02B 9/64**

[58] **Field of Search** 350/214, 176

[56] **References Cited**

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Primary Examiner—John K. Corbin

Attorney, Agent, or Firm—Christie, Parker & Hale

[57] **ABSTRACT**

A 7 group 8 lens photographic objective lens which corrects for aberration.

3 Claims, 6 Drawing Figures

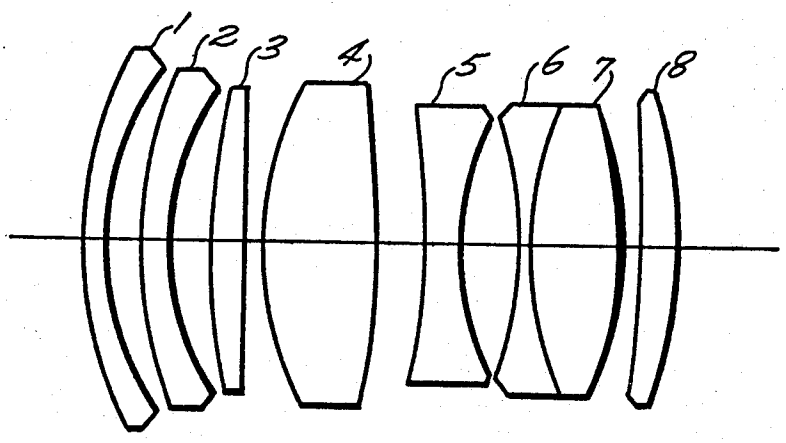

Fig 1

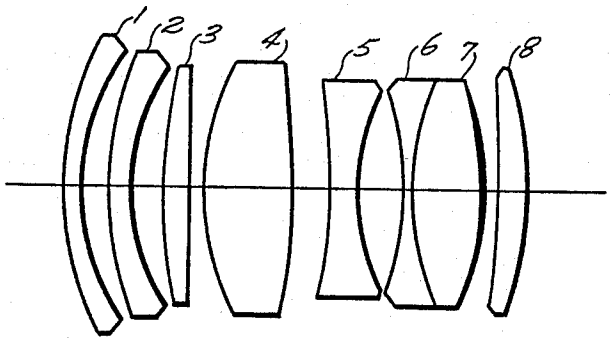
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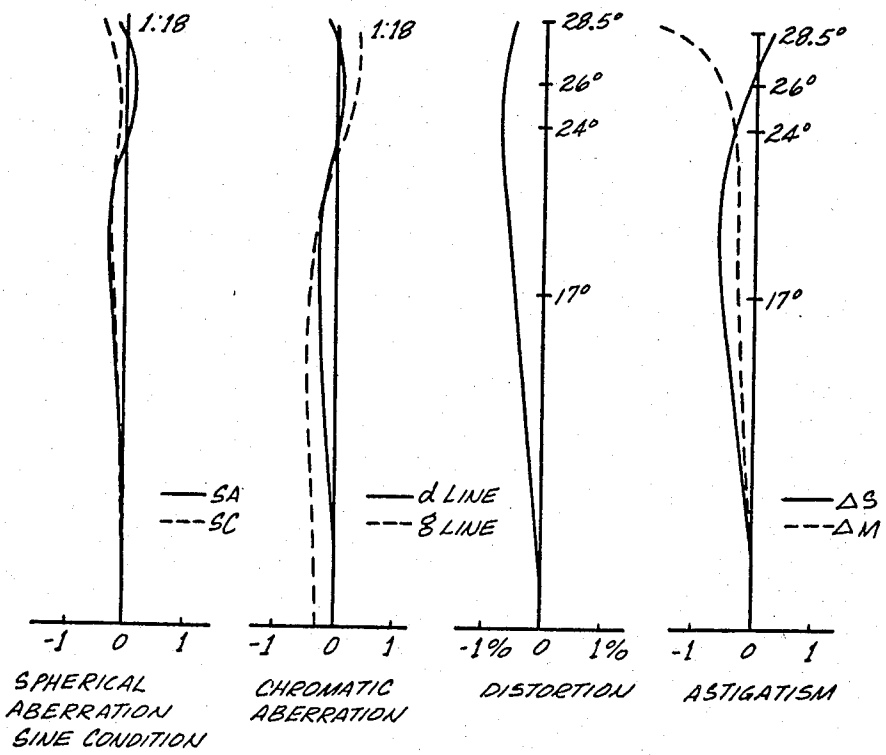
Fig 2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26°
24°
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26°
24°
17°
ΔS
ΔM
-1 0 1
ASTIGATISM

Fig - 3

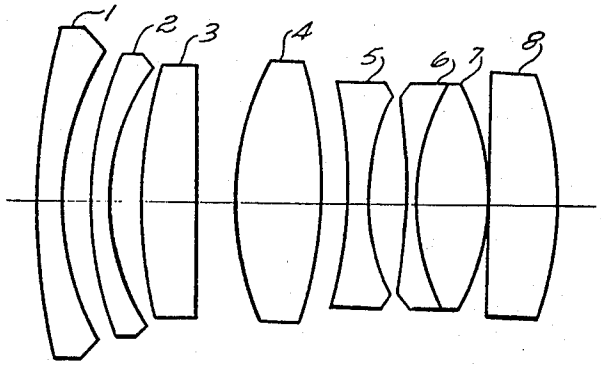
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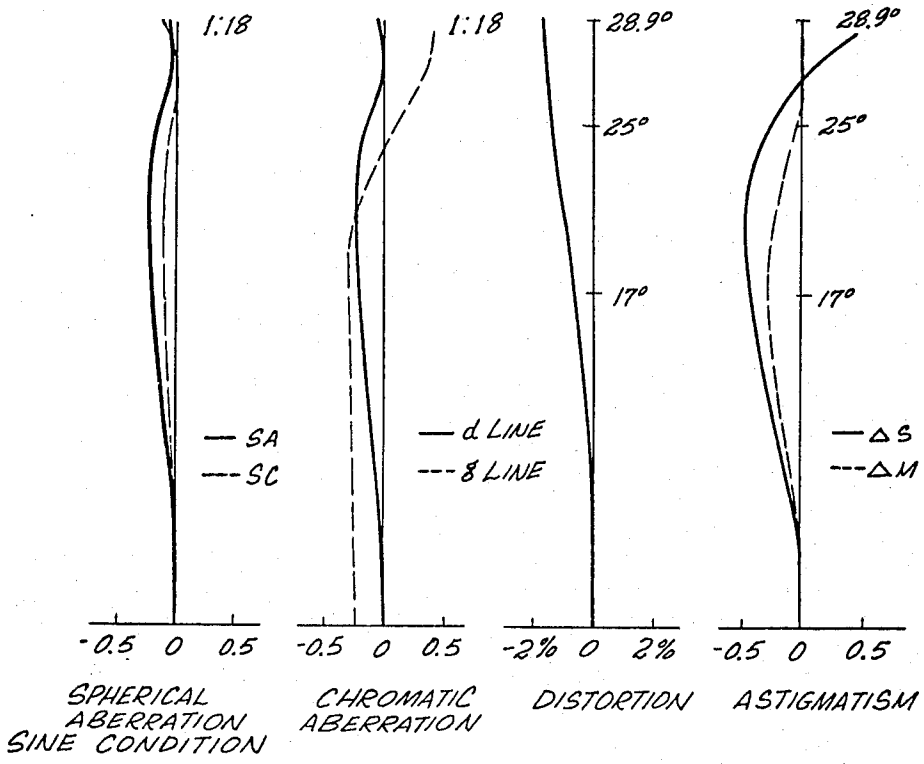
Fig - 4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--- g LINE
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ASTIGMATISM

Fig - 5

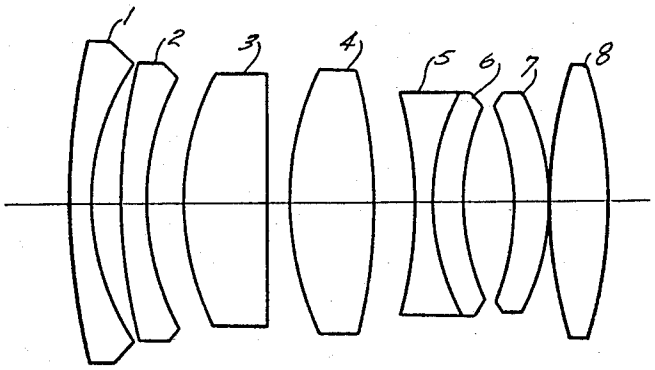
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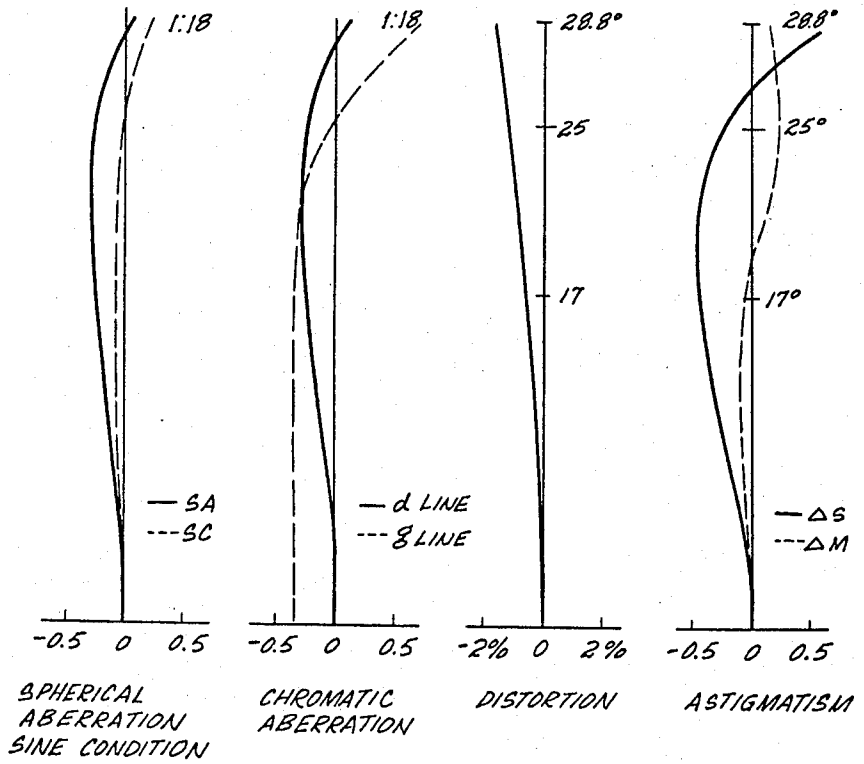
Fig - 6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CHROMATIC ABERRATION
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25
17
-2% 0 2%
DISTORTION
28.8°
25°
17°
— ΔS
---ΔM
-0.5 0 0.5
ASTIGMATISM

HIGH NUMERICAL APERTURE INTERMEDIATE WIDE ANGLE OBJECTIVE

BACKGROUND OF THE INVENTION

The present invention relates to a high numerical aperture intermediate wide angle lens system of image angle ranging from 55° to 60°, which is small in size and suitable for use in a single lens reflex camera as a retro focus type objective.

SUMMARY OF THE INVENTION

The present invention involves high numerical aperture intermediate wide angle objective lens system whose aberration is corrected to a high degree of excellence and which is a retro focus lens system consisting of a 7 group 8 lens system characterized in that the image angle is 55° or greater and which satisfies the following conditions:

$$F / 1.4 < |F_{1.2}| < F / 0.8 \ , \ F_{1.2} < 0 \qquad 1$$

$$F / 1.4 < |F_{1.2.3.4}| < F / 0.9 \qquad 2$$

$$0.8 < \frac{(d_1 + d_2 + d_3 + \cdots + d_6 + d_7)}{(d_8 + d_9 + d_{10} + \cdots + d_{13} + d_{14})} < 1.3 \qquad (3)$$

$$1.1 < (\nu_1 + \nu_2) / (\nu_3 + \nu_4) < 1.6 \qquad 4$$

where;

F:	is the resultant focal length of the whole optical system;
$F_{1.2...i}$:	is the resultant focal length of the first to the i-th lenses;
n_i:	is the d-line index of refraction of the i-th lens;
ν_i:	is the Abbe's number of the i-th lens;
r_k:	is the radius of curvature of the k-th surface;
d_j:	is the j-th lens spacing or lens thickness.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows the lens system of example 1;

FIG. 2 shows graphs of the aberration curves of example 1;

FIG. 3 shows the lens system of example 2;

FIG. 4 shows graphs of the aberration curves of example 2;

FIG. 5 shows the lens system of example 3; and

FIG. 6 shows graphs of the aberration curves of example 3.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The first and the second lenses 1 and 2 are of negative meniscus type whose concave surfaces are directed to the image side; the third and the fourth lenses 3 and 4 are of positive type and are positioned opposite to the fifth lens with a diaphragm (not shown) positioned therebetween. The fifth lens 5 is of negative type. In example 3 (FIG. 5), the fifth lens 5 and the sixth lens 6 are cemented together. In examples 1 and 2, the sixth lens 6 is of negative type and is cemented to the seventh lens 7. In all examples, the seventh and eighth lenses 7 and 8 are of positive type. Each example is of 7 group 8 lens structure.

In the conditions indicated below, the characters denote as follows:

F:	is the resultant focal length of the whole optical system;
$F_{1.2...i}$:	is the resultant focal length of the first to the i-th lenses;
n_i:	is the d-line index of refraction of the i-th lens;
ν_i:	is the Abbe's number of the i-th lens;
r_k:	is the radius of curvature of the k-th surface;
d_j:	is the j-th lens spacing or lens thickness.

In accordance with the present invention, the optical system is characterized with the following conditions:

$$F / 1.4 < |F_{1.2}| < F / 0.8 \ , \ F_{1.2} < 0 \qquad 1$$

$$F / 1.4 < |F_{1.2.3.4}| < F / 0.9 \qquad 2$$

$$0.8 < \frac{(d_1 + d_2 + d_3 + d_4 + d_5 + d_6 + d_7)}{(d_8 + d_9 + d_{10} + d_{11} + d_{12} + d_{13} + d_{14})} < 1.3 \qquad (3)$$

$$1.1 < (\nu_1 + \nu_2) / (\nu_3 + \nu_4) < 1.6 \qquad 4$$

Condition 1 indicates the power of the front group negative lenses of the retro focus lens system. Naturally, for small size, it is necessary to increase the power of the negative lenses and diminish the spacing. However, if the negative value of the focal length $F_{1.2}$ is too much smaller than $F / 1.4$, the desired result is obtained but aberration is aggravated and it is difficult to compensate for aberration at the rear lens group. If focal length $F_{1.2}$ is greater than $F / 0.8$, miniaturization of the lens system is not likely to be attained. Under this condition, steps must be taken to obtain greater back focus at the rear lens group, and also corresponding steps must be taken for correction of aberration.

Conditions 2, with relation to the condition 4, indicate steps for compensation of chromatic aberration, and is, naturally, for correcting aberrations caused under the condition 1. If the focal length $F_{1.2.3.4}$ is smaller than $F / 1.4$, the desired chromatic aberration can be advantageously corrected, but this is apt to cause decrease of Petzval sum or decrease of the radius of curvature of each surface, and especially variation of coma aberration. Furthermore, this will disadvantageously prevent increase in the value of back focus determined by the focal length $F_{1.2}$. On the other hand, a focal length value which is greater than $F / 0.9$ is advantageous for Petzval sum, but this will naturally cause a limitation such that for correction of chromatic aberration, a very small value of Abbe's number ν must be utilized. Thus, condition 2 is most advantageous.

Condition 3 is necessary for miniaturization and also for keeping balance between the front lens group and the rear lens group. If the value of the condition 3 ratio is smaller than the left side value, miniaturization is advantageously attained, but a far greater power combination is required at the front lens group and this will naturally cause failure of condition 1 and disadvantage in correction. In order to retain vignetting light, in relation to coma aberration, certain steps are taken such as increasing the diameter of the rear lens group, but this causes a failure in balance between the front lens group and the rear lens group. Further, difficulty is caused in correction of aberration. This requires such undesirables as increasing the number of lenses used or impossibility in retaining numerical aperture. On the other hand, if condition 3 is greater than 1.3, for the admission of the proper amount of light into the diaphragm aperture, the front lens group must be made greater in size. This is contra to the object of miniaturization and is therefore undesirable.

Condition 4 is closely related with condition 2 and determines the value of Abbe's number ν which is necessary for correction of chromatic aberration. If $(\nu_1 +$

$\nu_2) / (\nu_3 + \nu_4)$ is smaller than 1.1, correction of chromatic aberration up to the fourth lens is not sufficient and particularly too much of the transverse chromatic aberration may be produced. This requires that special steps should be taken at the rear lens group which is undesirable for correction of aberrations. On the other hand, if the last mentioned value of ratio is greater than 1.6, it is feared that correction of chromatic aberration up to the fourth lens would be too little, and this is undesirable for overall balance of chromatic aberration.

The data for the examples and the Seidel's coefficients of the examples are as follows:

Example 1

Radius of Curvature in m m		Lens Spacing in m m		n_i / ν_i
r_1	92.500	d_1	3.95	1.51633 / 64.1
r_2	57.275	d_2	9.52	
r_3	132.250	d_3	5.32	1.69350 / 53.3
r_4	55.875	d_4	9.42	
r_5	167.500	d_5	7.50	1.83400 / 37.2
r_6	1537.500	d_6	2.50	
r_7	68.313	d_7	26.50	1.78590 / 44.2
r_8	−178.523	d_8	9.27	
r_9	−149.500	d_9	9.00	1.76182 / 26.6
r_{10}	68.250	d_{10}	9.67	
r_{11}	−159.375	d_{11}	5.00	1.74077 / 27.8
r_{12}	80.750	d_{12}	19.20	1.80610 / 40.8
r_{13}	−79.500	d_{13}	3.75	
r_{14}	−951.448	d_{14}	8.75	1.78590 / 44.2
r_{15}	−111.275			

F = 100.0
$F_{1,2}$ = 95.13
$F_{1,2,3,4}$ = 83.54

Seidel's Coefficients

Lens Surface	S_1	S_2	S_3	S_4	S_5
	0.284	0.131	0.061	0.368	0.198
2	−2.375	−0.138	−0.008	−0.595	−0.035
3	0.493	0.272	0.151	0.310	0.255
4	−9.272	−0.324	−0.011	−0.733	−0.026
5	2.942	0.879	0.263	0.271	0.160
6	−0.187	−0.225	−0.270	−0.030	−0.360
7	4.454	0.977	0.214	0.637	0.187
8	3.146	−1.869	1.111	0.247	−0.806
9	−2.925	1.608	−0.884	−0.289	0.645
10	−1.069	−0.892	−0.743	−0.634	−1.148
11	0.003	−0.010	0.034	−0.267	0.771
12	0.264	0.175	0.116	0.026	0.094
13	1.593	−0.366	0.084	0.561	−0.148
14	−0.074	0.120	−0.193	−0.046	0.386
15	3.029	−0.261	0.023	0.395	−0.036
SUM	0.306	0.078	−0.054	0.223	0.134

Example 2

Radius of Curvature in m m		Lens Spacing in m m		n_i / ν_i
r_1	175.400	d_1	6.90	1.53172 / 48.9
r_2	73.563	d_2	9.42	
r_3	128.468	d_3	3.00	1.54072 / 47.2
r_4	56.023	d_4	10.95	
r_5	168.280	d_5	15.37	1.83400 / 37.2
r_6	−3453.988	d_6	8.27	
r_7	71.325	d_7	23.82	1.79952 / 42.3
r_8	−246.250	d_8	9.05	
r_9	−195.000	d_9	6.25	1.72825 / 28.5
r_{10}	58.013	d_{10}	10.25	
r_{11}	−176.700	d_{11}	3.75	1.69895 / 30.1
r_{12}	70.078	d_{12}	18.85	1.78590 / 44.2
r_{13}	−79.025	d_{13}	0.25	
r_{14}	996.250	d_{14}	18.80	1.65830 / 53.4

-continued

Example 2

Radius of Curvature in m m		Lens Spacing in m m	n_i / ν_i
r_{15}	−155.585		

F = 100.0
$F_{1,2}$ = 103.37
$F_{1,2,3,4}$ = 76.42

Seidel's Coefficients

Lens Surface	S_1	S_2	S_3	S_4	S_5
	0.042	0.052	0.063	0.198	0.321
2	−1.634	−0.162	−0.016	−0.472	−0.049
3	0.628	0.264	0.111	0.273	0.162
4	−7.842	0.147	−0.003	−0.627	0.012
5	2.577	0.686	0.183	0.270	0.121
6	−0.036	−0.082	−0.186	0.013	−0.393
7	−3.425	0.878	0.225	0.623	0.217
8	3.292	−1.920	1.119	0.181	−0.758
9	−3.040	1.651	−0.897	−0.216	0.604
10	−1.488	−1.040	−0.727	−0.727	−1.016
11	−0.000	0.000	−0.000	−0.233	0.699
12	0.433	0.258	0.154	0.041	0.116
13	2.211	−0.480	0.104	0.557	−0.144
14	−0.063	0.121	−0.233	0.040	0.373
15	1.834	−0.388	0.082	0.255	−0.071
SUM	0.339	−0.015	−0.020	0.177	0.194

Example 3

Radius of Curvature in m m		Lens Spacing in m m		n_i / ν_i
r_1	217.623	d_1	6.17	1.49782 / 66.8
r_2	69.596	d_2	9.20	
r_3	234.650	d_3	4.75	1.51454 / 54.7
r_4	64.373	d_4	12.02	
r_5	108.900	d_5	23.57	1.83400 / 37.2
r_6	−34888.149	d_6	6.52	
r_7	91.838	d_7	21.75	1.78800 / 47.5
r_8	−269.731	d_8	12.27	
r_9	−215.345	d_9	5.00	1.84666 / 23.9
r_{10}	57.528	d_{10}	9.77	1.78800 / 47.5
r_{11}	79.998	d_{11}	13.67	
r_{12}	−87.823	d_{12}	10.60	1.77250 / 49.6
r_{13}	−62.057	d_{13}	0.25	
r_{14}	182.638	d_{14}	14.45	1.81600 / 46.8
r_{15}	−229.152			

F = 100.0
$F_{1,2}$ = 92.05
$F_{1,2,3,4}$ = 85.04

Seidel's Coefficients

Lens Surface	S_1	S_2	S_3	S_4	S_5
1	0.022	0.047	0.102	0.153	0.554
2	−2.087	−1.194	−0.683	−0.478	−0.664
3	0.324	0.383	0.452	0.145	0.705
4	−7.452	−3.837	−1.976	−0.528	−1.289
5	5.660	3.694	2.411	0.418	1.846
6	−0.005	−0.025	−0.125	0.001	−0.612
7	1.232	1.165	1.102	0.480	1.496
8	2.528	−0.212	0.018	0.163	−0.015
9	−2.383	0.094	−0.004	−0.213	0.009
10	−0.066	−0.074	−0.082	−0.031	−0.126
11	−0.630	−0.970	−1.496	−0.551	−3.155
12	−0.093	0.035	−0.014	−0.496	0.194
13	1.778	0.654	0.240	0.702	0.346
14	−0.002	−0.010	−0.041	0.246	0.853
15	1.473	0.372	0.094	0.196	0.073
SUM	0.299	0.122	−0.000	0.208	0.217

In the foregoing examples, the number of the lens surfaces and the radius of curvature are taken from the left hand side of the figures.

What is claimed is:

1. An intermediate wide angle retro focus objective lens system comprising a 7 group, 8 element lens wherein the lens elements have the following characteristics:

	Radius of Curvature in m m		Lens spacing in m m	n_i / ν_i
r_1	92.500	d_1	3.95	1.51633 / 64.1
r_2	57.275	d_2	9.52	
r_3	132.250	d_3	5.32	1.69350 / 53.3
r_4	55.875	d_4	9.42	
r_5	167.500	d_5	7.50	1.83400 / 37.2
r_6	1537.500	d_6	2.50	
r_7	68.313	d_7	26.50	1.78590 / 44.2
r_8	−178.523	d_8	9.27	
r_9	−149.500	d_9	9.00	1.76182 / 26.6
r_{10}	68.250	d_{10}	9.67	
r_{11}	−159.375	d_{11}	5.00	1.74077 / 27.8
r_{12}	80.750	d_{12}	19.20	1.806610 / 40.8
r_{13}	−79.500	d_{13}	3.75	
r_{14}	−951.448	d_{14}	8.75	1.78590 / 44.2
r_{15}	−111.275			

F = 100.0
$F_{1.2}$ = 95.13
$F_{1.2.3.4}$ = 83.54.

Seidel's Coefficients

Lens Surface	S_1	S_2	S_3	S_4	S_5
1	0.284	0.131	0.061	0.368	0.198
2	−2.375	−0.138	−0.008	−0.595	−0.035
3	0.493	0.272	0.151	0.310	0.255
4	−9.272	−0.324	−0.011	−0.733	−0.026
5	2.942	0.879	0.263	0.271	0.160
6	−0.187	−0.225	−0.270	−0.030	−0.360
7	4.454	0.977	0.214	0.637	0.187
8	3.146	−1.869	1.111	0.247	−0.806
9	−2.925	1.608	−0.884	−0.289	0.645
10	−1.069	−0.892	−0.743	−0.634	−1.148
11	0.003	−0.010	0.034	−0.267	0.771
12	0.264	0.175	0.116	0.026	0.094
13	1.593	−0.366	0.084	0.561	−0.148
14	−0.074	0.120	−0.193	−0.046	0.386
15	3.029	−0.261	0.023	0.395	−0.036
SUM	0.306	0.078	−0.054	0.223	0.134

Wherein the lenses are numbered from 1 to 8 from the object side, and lenses 5 and 6 form doublets; and wherein

F: is the resultant focal length of the whole optical system;
$F_{1.2....i}$: is the resultant focal length of the first to the i-th lenses;
n_i: is the d-line index of refraction of the i-th lens;
ν_i: is the Abbe's number of the i-th lens;
r_k: is the radius of curvature of the k-th surface; and
d_j: is the j-th lens spacing or lens thickness.

2. An intermediate wide angle retro focus objective lens system comprising a 7 group, 8 element lens wherein the lens elements have the following characteristics:

	Radius of Curvature in m m		Lens Spacing in m m	n_i / ν_i
r_1	175.400	d_1	6.90	1.53172 / 48.9
r_2	73.563	d_2	9.42	
r_3	128.468	d_3	3.00	1.54072 / 47.2
r_4	56.023	d_4	10.95	
r_5	168.280	d_5	15.37	1.83400 / 37.2
r_6	−3453.988	d_6	8.27	
r_7	71.325	d_7	23.82	1.79952 / 42.3
r_8	−246.250	d_8	9.05	
r_9	−195.000	d_9	6.25	1.72825 / 28.5
r_{10}	58.013	d_{10}	10.25	
r_{11}	−176.700	d_{11}	3.75	1.69895 / 30.1
r_{12}	70.078	d_{12}	18.85	1.78590 / 44.2
r_{13}	−79.025	d_{13}	0.25	
r_{14}	996.250	d_{14}	18.80	1.65830 / 53.4
r_{15}	−155.585			

F = 100.0
$F_{1.2}$ = 103.37
$F_{1.2.3.4}$ = 76.42.

Seidel'3 Coefficients

Lens Surface	S_1	S_2	S_3	S_4	S_5
1	0.042	0.052	0.063	0.198	0.321
2	−1.634	−0.162	−0.016	−0.472	−0.049
3	0.628	0.264	0.111	0.273	0.162
4	−7.842	0.147	−0.003	−0.627	0.012
5	2.577	0.686	0.183	0.270	0.121
6	−0.036	−0.082	−0.186	0.013	−0.393
7	−3.425	0.878	0.225	0.623	0.217
8	3.292	−1.920	1.119	0.181	−0.758
9	−3.040	1.651	−0.897	−0.216	0.604
10	−1.488	−1.040	−0.727	−0.727	−1.016
11	−0.000	0.000	−0.000	−0.233	0.699
12	0.433	0.258	0.154	0.041	0.116
13	2.211	−0.480	0.104	0.557	−0.144
14	−0.063	0.121	−0.233	0.040	0.373
15	1.834	−0.388	0.082	0.255	−0.071
SUM	0.339	−0.015	−0.020	0.177	0.194

Wherein the lenses are numbered from 1 to 8 from object side, and lenses 6 and 7 form doublets; and wherein

F: is the resultant focal length of the whole optical system;
$F_{1.2....i}$: is the resultant focal length of the first to the i-th lenses;
n_i: is the d-line index of refraction of the i-th lens;
ν_i: is the Abbe's number of the i-th lens;
r_k: is the radius of curvature of the k-th surface; and
d_j: is the j-th lens spacing or lens thickness.

3. An intermediate wide angle retro focus objective lens system comprising a 7 group, 8 element lens wherein the lens elements have the following characteristics:

	Radius of Curvature in m m		Lens Spacing in m m	n_i / ν_i
r_1	217.623	d_1	6.17	1.49782 / 66.8
r_2	69.596	d_2	9.20	
r_3	234.650	d_3	4.75	1.51454 / 54.7
r_4	64.373	d_4	12.02	
r_5	108.900	d_5	23.57	1.83400 / 37.2
r_6	−34888.149	d_6	6.52	
r_7	91.838	d_7	21.75	1.78800 / 47.5
r_8	−269.731	d_8	12.27	
r_9	−215.345	d_9	5.00	1.84666 / 23.9
r_{10}	57.528	d_{10}	9.77	1.78800 / 47.5
r_{11}	79.998	d_{11}	13.67	
r_{12}	−87.823	d_{12}	10.60	1.77250 / 49.6
r_{13}	−62.057	d_{13}	0.25	
r_{14}	182.638	d_{14}	14.45	1.81600 / 46.8
r_{15}	−229.152			

F = 100.0
$F_{1.2}$ = 92.05
$F_{1.2.3.4}$ = 85.04.

Seidel's Coefficients

Lens Surface	S_1	S_2	S_3	S_4	S_5
1	0.022	0.047	0.102	0.153	0.554

-continued

Seidel's Coefficients

Lens Surface	S_1	S_2	S_3	S_4	S_5
2	−2.087	−1.194	−0.683	−0.478	−0.664
3	0.324	0.383	0.452	0.145	0.705
4	−7.452	−3.837	−1.976	−0.528	−1.289
5	5.660	3.694	2.411	0.418	1.846
6	−0.005	−0.025	−0.125	0.001	−0.612
7	1.232	1.165	1.102	0.480	1.496
8	2.528	−0.212	0.018	0.163	−0.015
9	−2.383	0.094	−0.004	−0.213	0.009
10	−0.066	−0.074	−0.082	−0.031	−0.126
11	−0.630	−0.970	−1.496	−0.551	−3.155
12	−0.093	0.035	−0.014	−0.496	0.194
13	1.778	0.654	0.240	0.702	0.346
14	−0.002	−0.010	0.041	0.246	0.853
15	1.473	0.372	0.094	0.196	0.073

-continued

Seidel's Coefficients

Lens Surface	S_1	S_2	S_3	S_4	S_5
SUM	0.299	0.122	−0.000	0.208	0.217

Wherein the lenses are numbered from **1** to **8** from the object side, and lenses **6** and **7** form doublets; and wherein

F: is the resultant focal length of the whole optical system;

$F_{1,2,\ldots,i}$: is the resultant focal length of the first to the i-th lenses;

n_i: is the d-line index of refraction of the i-th lens;

ν_i: is the Abbe's number of the i-th lens;

r_k: is the radius of curvature of the k-th surface; and

d_j: is the j-th lens spacing or lens thickness.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 3,938,882
DATED : Feb. 17, 1976
INVENTOR(S) : Michiro Oishi

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

page 1, Assignee should read

-- Asahi Kogaku Kogyo Kabushiki Kaisha --

Col. 1, lines 20-26, the example numbers "1" "2" "4" should be parenthesized;

col. 2, lines 10-16, the example numbers "1" "2" "4" should be parenthesized;

col. 3, line 32, "$F_{1.2}$" should be -- $|F_{1.2}|$ --

line 40, insert the numeral -- 1 -- under "Lens Surface"

col. 4, line 7, "$F_{1.2}$" should be -- $|F_{1.2}|$ --

line 14, insert the numeral -- 1 -- under "Lens Surface"

line 44, "$F_{1.2}$" should be -- $|F_{1.2}|$ --

col. 5, line 16, "1.806610" should be -- 1.80610 --
line 20, "$F_{1.2}$" should be -- $|F_{1.2}|$ --

col. 6, line 8, "$F_{1.2}$" should be -- $|F_{1.2}|$ --

line 13, "Seidel'3" should be -- Seidel's --
line 62, "$F_{1.2}$" should be -- $|F_{1.2}|$ --

Signed and Sealed this

first Day of June 1976

[SEAL]

Attest:

RUTH C. MASON
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents and Trademarks

OR 3,936,153

United St:
Ogura

[11] 3,936,153
[45] Feb. 3, 1976

[54] **RETROFOCUS TYPE OBJECTIVE LENS SYSTEM**

[75] Inventor: **Toshinobu Ogura**, Tondabayashi, Japan

[73] Assignee: **Minolta Camera Kabushiki Kaisha**, Osaka, Japan

[22] Filed: **Mar. 11, 1974**

[21] Appl. No.: **450,249**

[30] **Foreign Application Priority Data**

Mar. 12, 1973 Japan 48-27978

[52] **U.S. Cl.** **350/216**
[51] **Int. Cl.²** **G02B 9/60**
[58] **Field of Search** 350/216

[56] **References Cited**

UNITED STATES PATENTS

3,731,989 5/1973 Shimizu 350/216

Primary Examiner—John K. Corbin
Attorney, Agent, or Firm—Wolder & Gross

[57] **ABSTRACT**

A retrofocus type objective lens system consists of five lenses, from the object side, a front first lens, a biconvex second lens, a biconcave third lens, a positive meniscus fourth lens having a rear convex surface, and a positive fifth lens, the system satisfying the following conditions:

a. $d_4 > d_5 + d_6 + d_7 + d_8 + d_9$
b. $0.7d_4 < d_3 < 1.3d_4$
c. $-0.5 < r3/r4 < -0.1$
d. $N_1 < N_3$
e. $d_2 > 0.2f$

wherein r_j is the radius of curvature of the jth lens surface, designated sequentially from the object side: d_j is the axial distance between the jth and the $j+1$ lens surfaces; N_i is the refractive index of the ith lens; and f is the focal length of the entire lens system.

3 Claims, 7 Drawing Figures

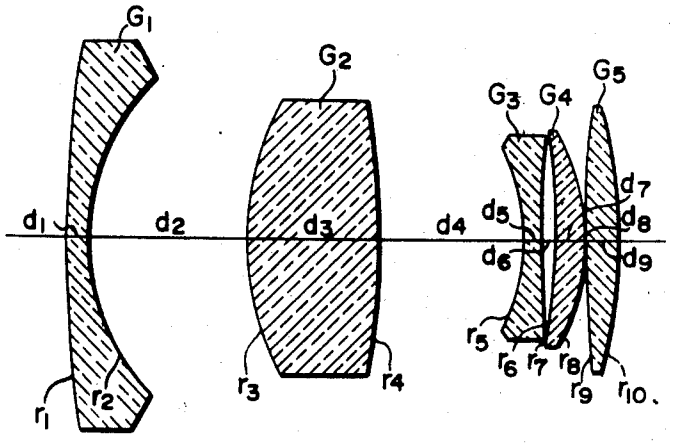


FIG. 1

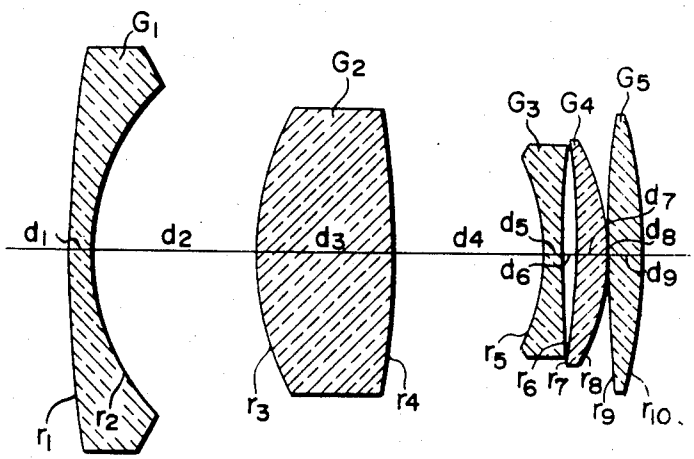


FIG. 2a

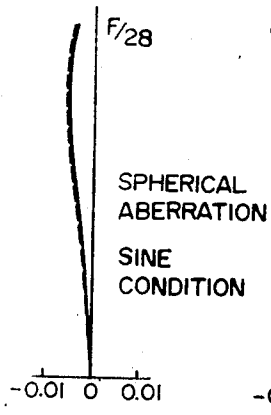


FIG. 2b

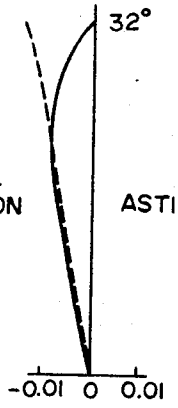


FIG. 2c

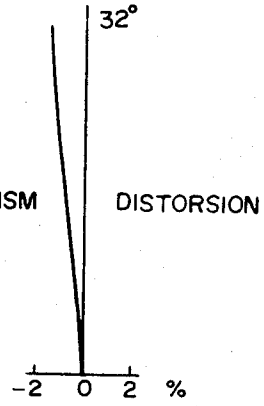


FIG. 3a

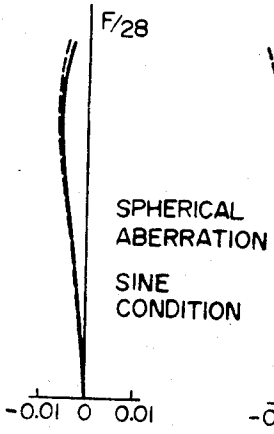


FIG. 3b

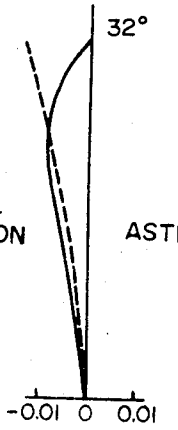
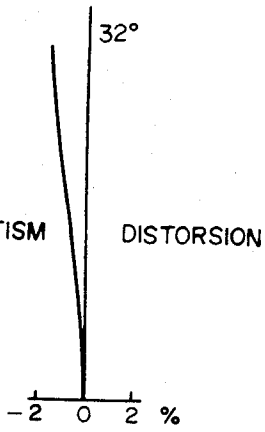


FIG. 3c



RETROFOCUS TYPE OBJECTIVE LENS SYSTEM

BACKGROUND OF THE INVENTION

The present invention relates generally to a retrofocus type objective lens system, and more particularly to a retrofocus type objective lens system for use in a single lens reflex camera having a backfocus longer than 0.9 times the focal length of the entire lens system.

A known retrofocus type lens for use in a single reflex camera incorporates a divergent lens ahead of the entire lens system and a convergent lens in the rear half portion thereof overcoming the divergency of the aforesaid lens system, for the purpose of obtaining a long backfocus. An attempt to achieve better compensation for the aberration of the entire lens system results in a complicated construction of the lenses. The objective lenses of the retrofocus type of this kind consists of five lenses and are known as the simplest construction of lenses, i.e., consisting from the object side, a first negative lens, a second positive lens, a third negative lens, a fourth positive lens and a fifth positive lens.

According to the present invention, there is provided a small size and light weight objective lens system having an image forming capability at least equal to or better than that of the conventional retrofocus type lens system which consists of six or seven lenses, by providing an improved lens arrangement and dimensional relationship of the retrofocus type lens system consisting of five components defining five lenses.

OBJECT OF THE INVENTION

It is an object of the present invention to provide a retrofocus type objective lens system whose backfocus is longer than 0.9 times as long as the focal length (f) of the entire lens system and in which aberration is well compensated, said system consisting of five components defining five lenses.

It is another object of the invention to provide a retrofocus type objective lens system whose backfocus is longer than 0.9 times as long as the focal length of the entire lens system and which is adapted for use as an interchangeable lens in a single reflex camera having a field angle of over 64° and being light in weight, said system consisting of five components, five lenses.

These and other objects and features of the present invention will be apparent from the reading of the following description in conjunction with the accompanying drawings, which set forth embodiments of the invention.

SUMMARY OF THE INVENTION

It has been found that the above and related objects of the invention may be readily attained in a retrofocus type objective lens system of five groups, five lenses consisting, from the object side, of a negative meniscus first lens having a convex surface facing the front or object side, a second lens having convex surfaces on both sides, a third lens having concave surfaces on both sides, a positive meniscus fourth lens having a convex surface facing the rear or image side and a fifth positive lens, said system satisfying the following conditions:

a. $d_4 > d_5 + d_6 + d_7 + d_8 + d_9$

b. $0.7d_4 < d_3 < 1.3d_4$

c. $-0.5 < r3/r4 < -0.1$

d. $N_1 < N_3$

e. $d_2 > 0.2f$

wherein $r1, r2, r3, r4 \ldots r10$ are the radii of curvatures of the lens refracting surfaces arranged sequentially from the object side; $d_1, d_2 \ldots d_9$ are the axial lengths between the refracting surfaces arranged sequentially from the object side; $N_1, N_2 \ldots N_5$ are the refractive indexes of the lenses arranged sequentially from the object side; and f is focal length of the entire lens system.

Since the objective lens system according to the present invention is of a retrofocus type, it is required that a divergent lens be disposed at the forward side of the lens system. According to the present invention, a single negative first lens placed closest to the object side is used as the aforesaid divergent lens, while a biconvex second lens follows this single meniscus negative lens and possesses an axial position and configuration as defined in the conditions (a), (b), (c), thereby providing a retrofocus type objective lens system having the least number of lenses, yet possessing effective aberration compensation.

More particularly, following the condition (a) the biconvex second lens is placed at a considerably greater air distance $d4$ apart from the lenses subsequent to the third lens inclusive, while the second lens is located somewhat ahead of the center of the entire lens system and has a relatively greater thickness as defined in the condition (b), thereby functioning to effectively compensate for coma aberration, distortion aberration and lateral chromatic aberration which are created by the first lens.

In addition to the aforesaid feature, the condition (c) permits proper compensation for coma aberration by means of the second lens and the minimization of spherical aberration a highly satisfactory degree, while the condition (d) provides a small Petzval sum and good image surface characteristic, while preventing the development of a halo component for improving the image contrast. Furthermore, the condition (e) presents a backfocus longer than 0.9 times the focal length of the entire lens system.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a longitudinal medial sectional view of a retrofocus lens system embodying the present invention;

FIG. 2*a*, 2*b* and 2*c* are graphs illustrating the aberration characteristics of a specific example of the lens system of FIG. 1; and

FIGS. 3*a*, 3*b* and 3*c* are graphs similar to those of FIGS. 2*a*, 2*b* and 2*c* of another specific example of the lens system.

DESCRIPTION OF THE INVENTION

Referring now to FIG. 1, the improved retrofocus type objective lens system consists of five consecutively designated lenses; a front or object side first lens G_1 which is a negative meniscus lens with a rear concave face, a biconvex second lens G_2, a biconcave third lens G_3, a positive meniscus fourth lens G_4 with a rear convex face and a positive fifth lens G_5. The following Table 1 sets forth the specific dimensions and parameters of a lens system embodying the present invention in which r_j is the radius of curvature of the jth lens surface which surfaces are successively designated from the front to the rear; d_j is the axial distance between the jth lens surface and the $j+1$ surface, N_i is the refractive index of the ith lens; and V_i is the Abbe's number of the ith lens, the values of r_j and d_j being

based on the focal length f of the lens system being equal to 1 :

TABLE I

f = 1.0 1:2.8 radius of curvature	field angle 2ω = 64° length on axis	refractive index	backfocus s' = 1.06 Abbe's number
r1 = 2.3437	d1 = 0.0441	N1 = 1.5714	v1 = 53.0
r2 = 0.4709	d2 = 0.3538		
r3 = 0.6206	d3 = 0.28	N2 = 1.6583	v2 = 58.5
r4 = −1.8643	d4 = 0.3182		
r5 = −0.4012	d5 = 0.0379	N3 = 1.6889	v3 = 31.2
r6 = 2.3930	d6 = 0.0283		
r7 = −1.4595	d7 = 0.067	N4 = 1.7200	v4 = 50.3
r8 = −0.4496	d8 = 0.0029		
r9 = 2.4019	d9 = 0.068	N5 = 1.6204	v5 = 60.3
r10 = −1.1931			

In the aforesaid specific embodiment, $d4=0.3182$

$d_5 + d_6 + d_7 + d_8 + d_9 = 0.0379 + 0.0283 + 0.067 + 0.0029 + 0.068$ $d_5 + d_6 + d_7 + d_8 + d_9 = 0.2041$

thus satisfying the condition (a) $d_4 > d_5 + d_6 + d_7 + d_8 + d_9$. In addition, $d_3 = 0.28$, $d_4 = 0.3182$.

d3/d4 = 1.136

thus satisfying the condition (b) $0.7d_4 < d_3 < 1.3d_4$ Furthermore,

r3/r4 = 0.6206/−1.8643 ≈ −0.333

thus satisfying the condition

(c) **−0.5 < r3/r4 < −0.1**

$N_1=1.5714 < N_3 = 1.6583$

thus satisfying the conditions that $N_1<N_3$ Furthermore, $d_2=0.3538 > 0.2$ thus satisfying the condition that $d_2 > 0.2f$.

Seidel's coefficient at each refracting surface in the objective lens system of the aforesaid first embodiment as specified in Table I are set forth in the following Table II:

TABLE II

surface	spherical aberration	coma	astigmatism	Petzval sum	distortion
1	0.0179	0.0328	0.0601	0.1551	0.3940
2	−9.9235	1.5625	−0.2463	−0.7721	0.1604
3	14.5162	0.3321	0.0076	0.6397	0.0148
4	2.2703	−1.4168	0.8842	0.2129	−0.6847
5	−12.48240	2.0868	−0.3488	−1.0167	0.2283
6	−1.67585	−1.4327	−1.2249	−0.1704	−1.1930
7	0.0690	0.2028	0.5957	−0.2868	0.9074
8	4.9718	−0.6484	0.0845	0.9311	−0.1324
9	0.0000	0.0002	0.0007	0.1594	0.5695
10	3.1335	−0.7222	0.1664	0.3209	−0.1123
Σ	0.8972	−0.0018	−0.0205	0.1730	0.1521

The excellent optical properties and aberration compensation of the lens system set forth in Table I are illustrated in the graphs shown in FIGS. 2*a*, 2*b* and 2*c*.

A second specific embodiment of a retrofocus type objective lens system in accordance with the present invention is shown in the following Table III in which the designations are similar to those of the first specific embodiment.

TABLE III

f=1.0 1:2.8 radius of curvature	field angle 2ω=64° thickness on axis	refractive index	backfocus s'=1.06 Abbe's number
r1 = 2.5414			
r2 = 0.4915	d1 = 0.0469	N1 = 1.5725	v1 = 57.5
r3 = 0.6600	d2 = 0.3284		
r4 =−1.8698	d3 = 0.3345	N2 = 1.6968	v2 = 55.6
r5 =−0.4287	d4 = 0.2722		
r6 = 2.1911	d5 = 0.0428	N3 = 1.7006	v3 = 30.1
r7 =−1.9373	d6 = 0.0376		
r8 =−0.4795	d7 = 0.067	N4 = 1.7495	v4 = 50.1
r9 = 4.3712	d8 = 0.0029		
r10=−1.1652	d9 = 0.068	N5 = 1.6214	v5 = 61.3

In the last embodiment, as well,

$d_5 + d_6 + d_7 + d_8 + d_9 = 0.0428 + 0.0376 + 0.067 + 0.0029 + 0.068$ $d_5 + d_6 + d_7 + d_8 + d_9 = 0.2183 < 0.2722 = d_4$

thus satisfying the condition (a). Furthermore,

$$\frac{d3}{d4} = 1.232$$

thus satisfying the condition (b). Furthermore,

$$\frac{r3}{r4} = \frac{0.6600}{-1.8698} = -0.353$$

thus satisfying the condition (c). Still further, $N_1 = 1.5725 < N_3 = 1.7006$ thus satisfying the condition (d). Additionally, $d_2 = 0.3284 > 0.2$ thus satisfying the condition (e).

Seidel's coefficients at the respective refracting surfaces of the aforesaid second embodiment set forth in Table III are shown in the following Table IV :

TABLE IV

surface	spherical aberration	coma	astigmatism	Petzval sum	distortion
1	0.0141	0.02858	0.0577	0.1432	0.4069
2	−8.8585	1.2967	−0.1898	−0.7407	0.1362
3	11.8527	0.3852	0.0125	0.6221	0.0206
4	2.1255	−1.3671	0.8793	0.2196	−0.7068
5	−10.9140	2.2181	−0.4508	−0.9608	0.2869
6	−1.6166	−1.3646	−1.1518	−0.1880	−1.1310
7	0.1295	0.2877	0.6391	−0.2211	0.9286
8	5.1230	−0.7390	0.1066	0.8935	−0.1442
9	−0.0001	0.0040	−0.1058	0.0876	0.4808
10	3.2265	−0.7520	0.1753	0.3289	−0.1175
Σ	1.0820	−0.0026	−0.0275	0.1843	0.1604

The excellent optical properties and aberration compensation of the lens system set forth in Table III are illustrated in the graphs shown in FIGS. 3*a*, 3*b* and 3*c*.

The aforesaid condition (a) affords to the second lens G2 the function of positively compensating for coma, distortion, etc. which are created due to the first lens G1 of the single divergent system. If the air spacing d4 between the second lens G2 and the third lens G3 is added to the value exceeding the upper or lower limit value of the condition (a), there will result an abrupt decrease in the compensating function, whereby there will be imposed a limitation on the refractive index of the first lens or the selection of the thickness of the lens so as to decrease coma or distortion.

In addition, since coma and the like are compensated for by means of lenses subsequent to the third lens, the freedom in the configuration of the lenses subsequent to the third lens will be lost or the number of those lenses has to be increased.

The condition (b) defines the thickness of the second lens G2 to a desired range with respect to the aforesaid air spacing *d4*, whereby the combined or multiplicated actions of the functions of the second lens G2 according to the condition (b) and the function of the second lens G2 according to the aforesaid condition (a) may well compensate for aberrations.

If the thickness d3 of the second lens G2 is smaller than that of the lower limit of the condition (b), then there will be an abrupt increase in the lateral chromatic aberration at the corner portions of the image surface, while the balance of coma will be lost over the entire surface of the image, thereby losing the sphero achromatic characteristic. On the other hand, if the thickness *d3* exceeds the upper limit, then there will remain a negative distortion which will not allow for its compensation.

The condition (c) defines the relationship of the radii of curvatures *r3* and *r4* of the second lens having convex surfaces on both sides, thereby optimizing the compensating function for coma, of the second lens G2, while maintaining minimized spherical aberration created due to the second lens G2. In other words, if the upper limit is exceeded, the spherical aberration produced thereby may not be compensated for by the third lens G3. If the lower limit is exceeded, then external coma is produced due to the second lens G2 as well as the third lens G3. However, this coma may not be compensated for by the other three lenses.

The condition (d) defines the relationship of the refractive indexes of the first lens G1 and the third lens G3, to thereby minimize the Petzval sum of the entire lens system, with the attendant good image surface. If the aforesaid condition (d) is not followed, there will result an increase in the halo component, although the Petzval sum may be reduced, thus impairing the contrast of the image materially, such that the performance of the entire lens system will be lowered at the time of the diaphragm being released.

The condition (e) defines an air spacing between the first lens G1 and the second lens G2, thereby limiting the second lens so as not to be over-biased forwardly. This condition (e) maintains the backfocus longer than 0.9 times as long as the focal length '*f*' of the entire lens system. If this condition is not followed, then there will be created considerable internal coma in the lens system, thus failing to meet practical application standards.

It should be appreciated that the present invention is by no means limited to the aforesaid two embodiments, but presents a retrofocus type objective lens system of five components, five lenses, which consists of a first lens of a negative meniscus, a second lens having convex surfaces on its both sides, a third lens having concave surfaces on its both sides, a fourth lens of a positive meniscus and having its convex surface facing the image side, and a fifth positive lens, and which system satisfies the aforesaid conditions (a) to (e), thereby presenting a long backfocus and being well compensated for the various aberrations.

It will be understood that the above description is merely illustrative of preferred embodiments of the invention. Additional modifications and improvements utilizing the discoveries of the present invention can be readily anticipated by those skilled in the art from the present disclosure, and such modifications and improvements may fairly be presumed to be within the scope and purview of the invention as defined by the claims that follow.

I claim:

1. A retrofocus objective lens system comprising a negative meniscus front first lens having a concave rear face, a biconvex second lens, a biconcave third lens, a positive meniscus fourth lens with a convex rear face, and a positive fifth lens, said lens system satisfying the following conditions:

$$1.6\,(d_5 + d_6 + d_7 + d_8 + d_9) > d_4 > d_5 + d_6 + d_7 + d_8 + d_9 \quad 0.7d_4 < d_3 < 1.3d_4$$

$$-0.5 < \frac{r3}{r4} < -0.1$$

wherein r_j is the radius of curvature of the jth lens face successively designated from the front lens face, and d_j is the axial distance between the jth and the $j+1$ lens faces of the lens system.

2. A retrofocus type objective lens as set forth in claim **1**, wherein the arrangement and construction of the five lenses are as follows:

f=1.0 1:2.8 radius of curvature	field angle 2ω=64° length on axis	refractive index	backfocus s'=1.06 Abbe's number
r1 = 2.3437			
r2 = 0.4709	d1 = 0.0441	N1 = 1.5714	v1 = 53.0
r3 = 0.6206	d2 = 0.3538		
r4 = −1.8643	d3 = 0.28	N2 = 1.6583	v2 = 58.5
r5 = −0.4012	d4 = 0.3182		
r6 = 2.3930	d5 = 0.0379	N3 = 1.6889	v3 = 31.2
r7 = −1.4595	d6 = 0.0283		
r8 = −0.4496	d7 = 0.067	N4 = 1.7200	v4 = 50.3
r9 = 2.4019	d8 = 0.0029		
r10 = −1.1931	d9 = 0.068	N5 = 1.6204	v5 = 60.3

wherein Vi is the Abbe's number of the ith lens.

3. A retrofocus type objective lens system set forth in claim **1**, wherein the arrangement and construction of the five lenses are as follows.

f=1.0 1:2.8 radius of curvature	field angle 2ω=64° length on axis	refractive index	backfocus s'=1.06 Abbe's number
r1 = 2.5414			
r2 = 0.4915	d1 = 0.0469	N1 = 1.5725	v1 = 57.5
r3 = 0.6600	d2 = 0.3284		
r4 = −1.8698	d3 = 0.3345	N2 = 1.6968	v2 = 55.6
r5 = −0.4287	d4 = 0.2722		
r6 = 2.1911	d5 = 0.0428	N3 = 1.7006	v3 = 30.1
r7 = −1.9373	d6 = 0.0376		
r8 = −0.4795	d7 = 0.067	N4 = 1.7495	v4 = 50.1
r9 = 4.3712	d8 = 0.0029		
r10 = −1.1652	d9 = 0.068	N5 = 1.6214	v5 = 61.3

Wherein Vi is the Abbe's number of the ith lens.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 3,936,153

DATED : February 3, 1976

INVENTOR(S) : Toshinobu Ogura

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Claim 1, lines 7 and 8: Delete and substitute the following:

--1.6 $(d_5+d_6+d_7+d_8+d_9) > d_4 > d_5+d_6+d_7+d_8+d_9$

$0.7d_4 < d_3 < 1.3d_4$--

Signed and Sealed this

eighth Day of June 1976

[SEAL]

Attest:

RUTH C. MASON
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents and Trademarks